SAN ANTONIO
RIVER AUTHORITY
Leaders in Watershed Solutions

Natural Channel Design Protocol

San Antonio, Texas Region




V.1

MAY 2013

Prepared By:

W. H. Harman, K.L. Tweedy, W.S. Hunt, J. Calmbacher, T. Norton, K. Van Stell, and C.H. Kaiser. 2012. Natural Channel Design Protocol, v1. San Antonio River Authority, San Antonio, TX.

Acknowledgements:

This natural channel design protocol was a cumulative effort put forth by many individuals with an array of expertise all focusing on one goal, to provide a Standard Operating Procedure and Standard of Care criteria for performing natural channel design projects for the San Antonio Region. Special thanks to the SARA initiative to provide invaluable review, comments, and input for the Stream Restoration Program. Thanks to the efforts of the SARA Stream Team for facilitating the progress and support of this natural channel design protocol. Without the generous help of these individuals, the progress and completion of this design criteria manual would not have been possible.

Prepared in Cooperation with:

San Antonio River Authority
100 East Guenther Street
San Antonio, Texas 78283

Prepared By:

Michael Baker Jr., Inc.
17721 Rogers Ranch Parkway, Suite 250
San Antonio, Texas 78258

And

Stream Mechanics
5645 Normanshire Drive
Raleigh, North Carolina 27606

**Photos on cover are from the East Salitrillo Stream Restoration Pilot Project located on the Judson High School campus in Converse, Texas. Construction was completed in March 2011.*

Table of Contents

List of Tables

List of Figures

Appendices

GLOSSARY

Aggrade/Aggradation: The raising of the streambed elevation due to sediment deposition, which can cause an increase in width/depth ratio and a corresponding decrease in channel capacity.

Alluvial: A general term for all deposits laid down by present-day rivers, especially during floods.

Bankfull Discharge: Represents a breakpoint between processes of channel formation and floodplain development. Bankfull discharge is the flow that fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain.

Bedform: A shape of the surface feature on the bottom of a stream that is formed by the flow of water and the movement of bed material. Examples include riffles, runs, pools, and glides.

Bioengineering: A broad category of stabilization techniques using living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment as an alternative treatment to traditional hardening approaches.

Confluence: The point at which one stream flows into another stream.

Degrade/Degradation: The lowering of the local base level of streams through the process of excess bed scour and channel incision.

Denitrification: A chemical process in which nitrates in the soil are reduced to molecular nitrogen that is released into the atmosphere.

Dimension: The representative cross-sectional shape and area of a stream channel.

Entrenchment: The vertical containment of a stream in the valley bottom.

Ephemeral Stream: A stream that only flows during and immediately after a rain event and is not connected to the water table.

Floodplain: The area adjacent to a stream that is subject to periodic flooding when the stream overtops its banks.

Floodprone Area: The area of inundation associated with the elevation that is twice the maximum bankfull depth. Floodprone area is not referring to a specific frequency such as the 100-year storm event).

Flow Regime: A range of stream flows having similar bedforms, flow resistance, and means of transporting sediment.

Fluvial Geomorphology: The processes in which water shapes landforms.

Functional Lift: The improved performance of a stream function after restoration compared to its performance before restoration.

Geomorphology: A branch of geology that studies surface features and landforms, including the forces and processes that create them.

Glide: A transitional area between a pool and a riffle, which is the only bedform that slopes uphill as one moves downstream. It is a common spawning area for many fish species.

Headcut: An erosional feature where an abrupt vertical drop in the streambed occurs. This sudden change in elevation can indicate that the bed is unstable.

Headwaters: A source or area from which the water in a stream originates. Also, the upper regions of a watershed.

Hydraulic Geometry: Developed by Leopold and Maddock in 1953; relationships that predict dependent variables such as channel width, depth, velocity, and suspended load as a function of the independent variable of discharge.

Hydraulic Analysis: Evaluations of how water behaves in the channel, particularly flood levels, shear stress, velocity, and stream power.

Hydrology Analysis: Evaluations of how much water is produced by the watershed via rainfall/runoff relationship.

Hydrophysiographic: Geographic regions that have similar rainfall and runoff relationships.

Incised/Incision: The process of lowering a streambed through headcuts or other mechanisms. An incised stream is disconnected from the adjacent floodplain.

Inner Berm: A depositional feature that is typically found at a stage of about one half the bankfull depth. It is most prominent in stream systems where sand makes up a significant portion of the bedload.

Intermittent Stream: A stream that only flows for part of the year.

Knickpoint: Abrupt, steep changes in the stream profile.

Meander Belt Width: The width of the full lateral extent of the bankfull channel measured perpendicular to the fall line of the valley.

Meander Wavelength: The longitudinal distance parallel with the fall line of the valley between the apex of two sequential meanders.

Nutrient Cycling: A repeated pathway of a particular nutrient or element from the environment through one or more organisms and back to the environment. Examples include the carbon cycle, the nitrogen cycle, and the phosphorus cycle.

Organic Processing: The movement of organic matter and energy from the producer level through various consumer levels which comprise a food chain.

Pattern: A measurement of the stream's plan features, including radius of curvature, meander wavelength, meander belt width, stream length, and valley length. Patterns can be generally described as straight, braided, meandering, or anastomosed.

Profile: A longitudinal profile is created by measuring and plotting elevations of the channel bed, water surface, bankfull, and low bank height. Profile points are surveyed at prescribed intervals and at significant breaks in slope such as the head of a riffle or the head of a pool and can be used to assess changes in river slope compared to valley slope, which affect sediment transport, stream competence, and the balance of energy.

Perennial Stream: A stream that flows for most or all of the year.

Pool: An area of a stream characterized by scour and slow current and a depth significantly greater than riffle areas.

Radius of Curvature: A measurement of 'tightness' of an individual meander bend that is negatively correlated with sinuosity. Measeured from the center of the bankfull channel to the intersection point of two lines that perpendiculary bisect the tangent lines of each curve departure point.

Reference Reach: A stable stream that is well connected to its floodplain and has reached an evolutionary end point. Reference reaches are used to gather information regarding stable stream conditions during the natural channel design process.

Regional Curves: Developed by Dunne and Leopold in 1978; relate dependent variables such as cross-sectional area, width, depth, and discharge as a function of the independent variable of drainage area.

Riffle: An area of a stream characterized by fast current and shallow depth. Riffles are the natural grade control feature for the stream.

Riparian Corridor Management: A management approach that considers community interests and property owner rights along a waterway and its associated buffers in order to protect and improve the resource values.

Riparian Buffer: A vegetative interface between land and waterway that acts as a biofilter by reducing pollutant runoff, erosion, and sedimentation.

Run: A transitional area of a stream between an upstream riffle and a downstream pool characterized by a rapid, non-turbulent flow.

Sinuosity: The curvature or meander of a stream, generally measured as stream length divided by valley length.

Step-Pool: A vertical drop formed by boulders, bedrock, or woody material that serves as grade control in higher gradient streams.

Stream Channel: A flowing body of water within a bed and banks that acts as a conduit for the water cycle.

Stream Length: The distance measured along the thalweg of the channel.

Stream Morphology: A stable combination of stream alignment, profile, and cross-section that work together to dissipate stream energy while providing a diverse aquatic and riparian habitat.

Terrace: A remnant or abandoned floodplain feature created by a lowering in a stream's base level.

Thalweg: A line that represents the deepest point in a channel along the entire streambed or "valley way."

Valley Length: Linear distance of the stream valley.

Water Cycle: Also known as the hydrologic cycle; describes the continuous movement of water on, above, and below the surface of the earth.

Watershed: A watershed is the geographic area through which water flows across the land and drains into a common body of water such as a stream, river, lake, or ocean. Usually synonymous with "Drainage Area" and "Basin."

LIST OF ACRONYMS

A	Area
BANCS	Bank Assessment for Non-Point Source Consequences of Sediment
BEHI	Bank Erosion Hazard Index
BFW	Bankfull Width
BH	Bank Height
BHR	Bank Height Ratio
BKF	Bankfull
BMP	Best Management Practice
CAD	Computer Aided Design
CL	Channel Length
CLOMR	Conditional Letter of Map Revision
COGO	Coordinate Geometry
CWA	Clean Water Act
D	Depth
$\mathbf{d_{bkf}}$,$\mathbf{D_{bkf}}$	Mean Bankfull Depth
ER	Entrenchment Ratio
FEMA	Federal Emergency Management Agency
FPW	Floodprone Area Width
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
K	Sinuosity
LID	Low Impact Development
$\mathbf{L_m}$	Linear Meander Length
LOMR	Letter of Map Revision
MCW	Maximum Corridor Width

MWR	Meander Width Ratio
MS4s	Municipal Separate Storm Sewers
NCD	Natural Channel Design
NBS	Near Bank Stress
NOI	Notice of Intent
NOT	Notice of Termination
NRCS	Natural Resource Conservation Service
P-P	Pool to Pool Spacing
PI	Point of Intersection
P_L	Pool Length
Q	Discharge
R_c	Radius of Curvature
RFP	Request for Proposals
RFQ	Request for Qualifications
S	Average Water Surface Slope
SARA	San Antonio River Authority
SAWS	San Antonio Water System
SOP	Standard Operating Procedure
SH	Step Height
SL	Step Length
S_{glide}	Glide Slope
S_{pool}	Pool Slope
S_{rif}	Riffle Slope
S_{run}	Run Slope
SWPPP	Stormwater Pollution Prevention Plan
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
τ_{ci}	Critical dimensionless shear stress
TPDES	Texas Pollution Discharge Elimination System
TXRAM	Texas Rapid Assessment Method
u	Mean Velocity
V	Velocity
W	Width
W_{blt}	Belt Width
W_{fpa}	Flood Prone Area Width
USACE	United States Army Corps of Engineers
USGS	United States Geological Service
USEPA	United States Environmental Protection Agency
VL	Valley Length
VS	Valley Slope

1.0 INTRODUCTION

1.1 Purpose of Document

The purpose of this manual is to provide a Standard Operating Procedure (SOP) and Standard of Care criteria guidance for performing natural channel design projects in the San Antonio Region. The manual is intended for the engineering community, San Antonio River Authority (SARA) staff, and all public and private entities within the SARA four county jurisdiction of Bexar, Wilson, Karnes and Goliad counties engaged in such projects.

Goals presented in this manual for incorporating natural channel design into projects include:

- Creating geomorphically stable conditions for appropriate stream reaches;
- Improving and restoring hydrologic connections between the streams and their floodplains;
- Improving aquatic and terrestrial habitat;
- Improving water quality by establishing buffers for nutrient removal from runoff, and by stabilizing stream banks to reduce bank erosion and sediment contribution to stream flows;
- Improving in-stream habitat by providing a more diverse bedform with riffles and pools, creating deeper pools and areas of water re-aeration, providing woody debris for habitat and, reducing bank erosion; and
- Providing storage within a floodplain to retain and attenuate flood flows.

It is important to note that natural channel design is only one technique that is often used in stream restoration projects, but is also implemented in projects where restoration of ecosystem habitat is not the primary goal, such as flood control projects. Projects that implement restoration and natural channel design techniques are typically part of a holistic, multi-objective plan to improve water quality, restore riparian communities, provide recreation opportunities, and address flooding concerns. Storm water best management practices (BMPs), Low Impact Development (LID) measures, habitat creation, re-vegetation of stream banks, preservation of natural communities, and trail systems are often incorporated into the project design to meet these multiple objectives. Often, projects implementing natural channel design techniques will do so to address USACE permitting requirements and minimize impacts.

Additionally, not all projects may be suitable for a natural channel design approach. Project constraints may preclude a pure natural channel design approach, particularly in urban settings. However, natural channel design elements may still potentially be incorporated into designs. Project goals and constraints must be carefully considered when using the approaches presented in this SOP.

This SOP is a living document that will be updated based on lessons learned from completed projects, and as applied research is completed and progresses. The sections that follow provide guidance and criteria for developing and performing regional curves, reference reach surveys, geomorphic assessments, and incorporating natural channel design methods and in-stream structures into projects within SARA's four county jurisdiction of Bexar, Wilson, Karnes, and Goliad counties.

2.0 STANDARD CONTRACT PROCEDURES

Contracts for natural channel design projects will follow standard contractual procedures for typical engineering design projects. Refer to the contracting agency's contract coordinator for agency specific contract requirements. However, consultants will also be required to demonstrate that the project team has sufficient project experience and specialized training specifically related to stream restoration, natural channel design and fluvial geomorphology.

2.1 Request for Statement of Qualification

In response to Requests for Qualifications (RFQ), the project team will be required to demonstrate and provide at a minimum:

- Photographs and reports of similar completed natural channel design projects;
- References for similar past projects; and
- Experienced and qualified person(s) assigned to work on the project with 5 years of relevant project experience and Rosgen Level IV certification of completion or comparable training such as SARA provided training or a MS in Fluvial Geomorphology; or 10 years relevant project experience without Rosgen Level IV certification or MS in Fluvial Geomorphology.

3.0 WATERSHED ASSESSMENT

Watershed assessments range from simple office-based data collection efforts using geographic information systems (GIS) to intensive field data collection efforts. For this SOP, the purpose of the assessment is to broadly determine how the upstream watershed has affected the project reach, and may affect the project reach in the future. Parameters to be addressed include: drainage area, percent impervious cover, land use, and hydrology. Data collection, data sources, and methods used to analyze the data shall be described in the watershed assessment section of the natural channel design report (see Chapter 10).

The project drainage area must be carefully estimated and provided. Many of the hydrologic, hydraulic, and geomorphic equations and relationships used in the natural channel design process are expressed as functions of drainage area. For example, regional hydraulic geometry curves ("regional curves") are charts that estimate channel dimensions (e.g., bankfull width, mean depth, and cross-sectional area) as a function of drainage area. It is impossible to review design elements without knowing the drainage area.

The percent impervious cover is used to determine if the project reach will be classified as an urban or rural watershed. Urban and rural watersheds have different hydrologic characteristics; these differences must be considered by the designer. Typically, watersheds with impervious cover greater than 15% are considered urban.

A watershed with rapidly changing land uses is one of the most challenging settings for a stream restoration project because the design will need to accommodate future conditions. Therefore, it is important to know the current land use as well as the future build-out potential. If a watershed is currently rural, but is becoming urbanized, the design should take these changes into account. A key element to take into consideration when performing a watershed assessment in the San Antonio region and surrounding Texas Hill Country is water table loss.

Each project must take into consideration water table loss and incorporate design elements to retain water on site with oxbows and onsite wetland features, as practical for a given site. Other elements that must be evaluated during the watershed assessment includes review and analysis of soils and geology, topography (basin relief, basin shape, valley type), and flow regime including drainage characteristics (length of open stream channel, storm water infrastructure).

The watershed assessment task often includes hydrologic calculations to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year discharges. These calculations are used to quantify channel hydraulics and to complete a flood study, if one is required. If the Federal Emergency Management Agency (FEMA) or the local floodplain manager does not require a flood study, complex watershed hydrologic calculations may not be necessary, especially if the watershed has a gage station or is undeveloped. In these cases, discharges may be obtained directly from gage records or estimated from U.S. Geological Service (USGS) regression equations, regional curves, or Manning's equation and cross-section geometry from the project channel. For information on Manning's equation refer to *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling* (SARA, 2005) and white paper, *Process to Obtain Peak Discharge Data and Update or Modify Hydrology Models* (SARA, 2007).

4.0 REGIONAL CURVES

4.1 Background

Regional curves relate bankfull channel dimensions (i.e., width, depth and cross-sectional area) and discharge to watershed drainage area. These curves, and their associated regression equations, are developed to assist practitioners in identifying the bankfull stage in ungaged watersheds and estimating the bankfull discharge and dimensions for river studies and natural channel designs. In the San Antonio region, this tool can also be used as an aid in designing the pilot or low flow channel within flood control projects. Regional curves should only be applied where the project reach has the same hydrophysiographic characteristics as the reaches that were used to generate the curve. A detailed discussion of how to use regional curves for creating the channel dimension design is provided in Chapter 8 of this document. Additionally, see Chapter 9 for using regional curves to size the pilot channel.

Regional curves are based on channel forming discharge theory, which states that one unique flow can yield the same channel morphology as the full range of flows. Inglis (1947) stated that at this discharge, equilibrium is most closely approached and the tendency to change is least. This condition may be regarded as the integrated effect of all varying conditions over a long period of time. Channel forming discharge theory is often described as dominant discharge, effective discharge, and the bankfull discharge (Knighton, 1998). Dominant discharge is simply a synonym for channel forming discharge theory. Effective discharge is the product of the flow duration curve and the sediment transport rating curve. Therefore, it is the discharge that moves the most sediment over time (Wolman and Miller, 1960). Bankfull discharge fills a stream channel to the elevation of the active floodplain, thereby delineating the break between channel forming or sediment transport processes and depositional features on a floodplain (Dunne and Leopold, 1978; FISRWG, 1998). Since the bankfull discharge leaves a geomorphic indicator, it has become the method used most often to describe channel forming discharge theory and is the method that will be used in the San Antonio region.

Regional curves evolved from earlier studies of hydraulic geometry. Stream channel hydraulic geometry analysis was first developed by Leopold and Maddock (1953) and related the dependent variables of stream width, depth, velocity, and total suspended sediment load as a function of discharge. These relationships were developed for a single cross-section (at-a-station) and across many stations along a reach (downstream) (Meligliano, 1997). Practical applications of bankfull hydraulic geometry relations led to the development of regional curves by Dunne and Leopold (1978) and others (Harman et al., 1999; Dutnell, 2000; Harman et al., 2000; Castro and Jackson, 2001; Doll et al., 2002; McCandless and Everett, 2002; Cinotto, 2003; McCandless, 2003a; McCandless, 2003b; Miller and Davis, 2003; Sweet and Geratz, 2003; Dudley, 2004; Metcalf, 2004; Chaplin, 2005; Keaton et al., 2005; Mulvihill et al., 2005).

Various studies have addressed the role of bankfull discharge in creating the form of the channel (Wolman and Leopold, 1957; Nixon, 1959; Schumm, 1960; Kilpatrick and Barnes, 1964; Williams, 1978; and Knighton, 1998). Despite major variations in climate and precipitation/runoff relationships across the United States, the hydraulic properties of flowing water and its influence on sediment transport and therefore channel forming processes are very similar (Bull and Kirby, 2002). Cooke et al., (1993) showed that the exponent of regression equations used to describe at-a-station hydraulic geometry were very similar between perennial and ephemeral rivers. Their research also showed that exponent sets plotted on a tri-axial graph overlapped between dryland and humid channels. As regional curves are being developed for the San Antonio region and drier areas of the Southwest, the exponent of the regression equations are very similar to exponents from eastern (humid) U.S. curves.

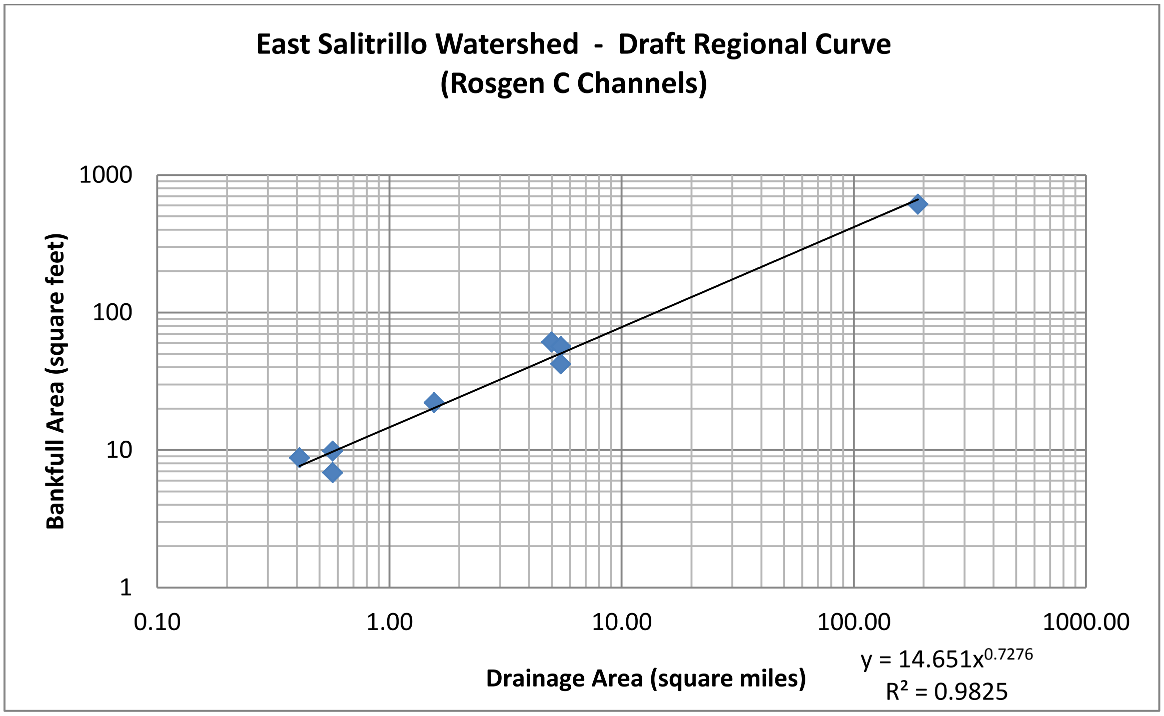
Gage station analyses throughout the United States have shown that the average return interval for the bankfull discharge is approximately 1.5 years, which equates to a 66.7 percent annual exceedence probability (Dunne and Leopold, 1978). Leopold et al. (1995) described floodplains which had a bankfull return interval closer to one year in Colorado, United Kingdom and other locations. Similar bankfull return intervals were discovered in coastal plain streams of Georgia, Maryland, and North Carolina (GDOT, 2003; McCandless 2003b; Sweet and Geratz, 2003) as well as in the southwestern United States in Arizona, Utah and New Mexico (Moody and Yard, 2003). Generally, it is more common to see bankfull return intervals between 1 and 1.5 years than closer to 2 years. In cases where watersheds have experienced rapid urbanization without stormwater controls, bankfull intervals may even be found to be less than the 1 to 1.5 year return interval. For this reason, engineers and practitioners using this SOP should use available regional curves to predict the bankfull discharge rather than using the 2-year discharge as an approximation.

4.2 Draft Watershed-Specific Regional Curves

Regional curves are currently being developed for the entire San Antonio region by SARA. More specifically, regional curves are being developed to correspond with the hydrophysiographic regions provided by USGS in the *Regional Equations for Estimation of Peak-Streamflow Frequency for Natural Basins in Texas* (Asquith et al., 1997). Maps showing the hydrophysiographic regions are provided in Appendix A. Additional information and regional curve updates can be obtained through SARA (see Contact information in Appendix B).

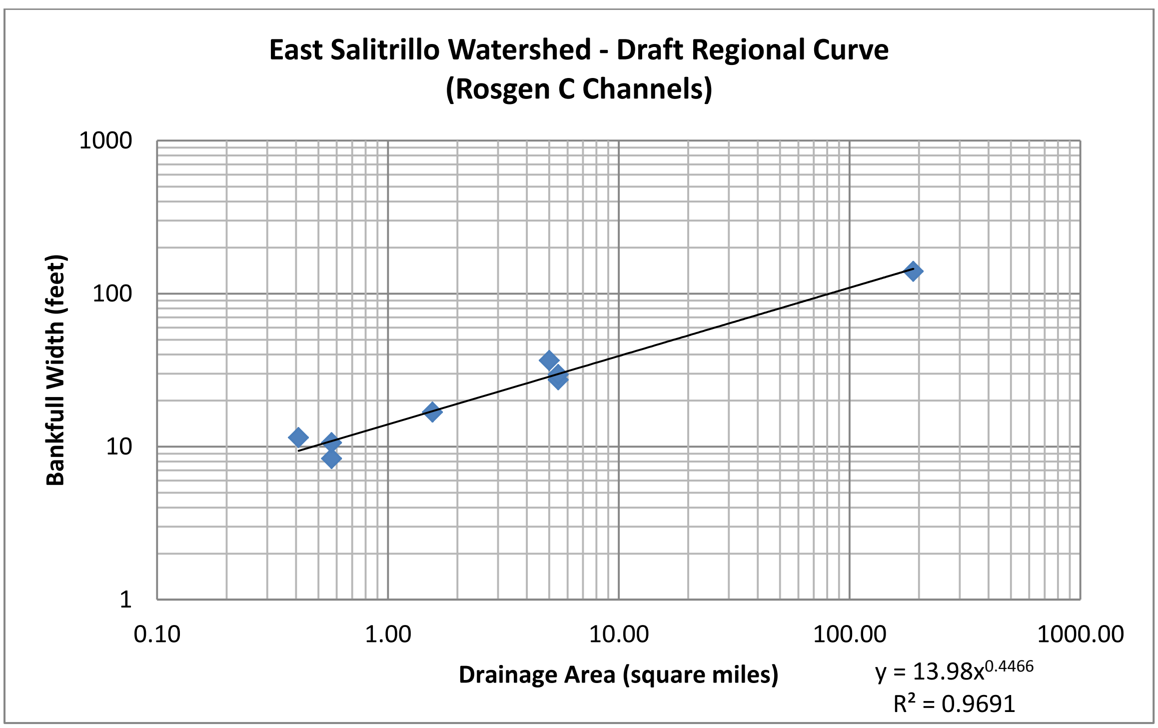
A watershed-specific regional curve was developed for a demonstration project in the East Salitrillo Watershed. These curves are available below (**Figure 1**, **Figure 2**, **Figure 3**, and **Figure 4**), but should only be used for projects that are in or near the East Salitrillo Watershed.

Figure 1: East Salitrillo Watershed – Draft Regional Curve (Bankfull Area vs Drainage Area)



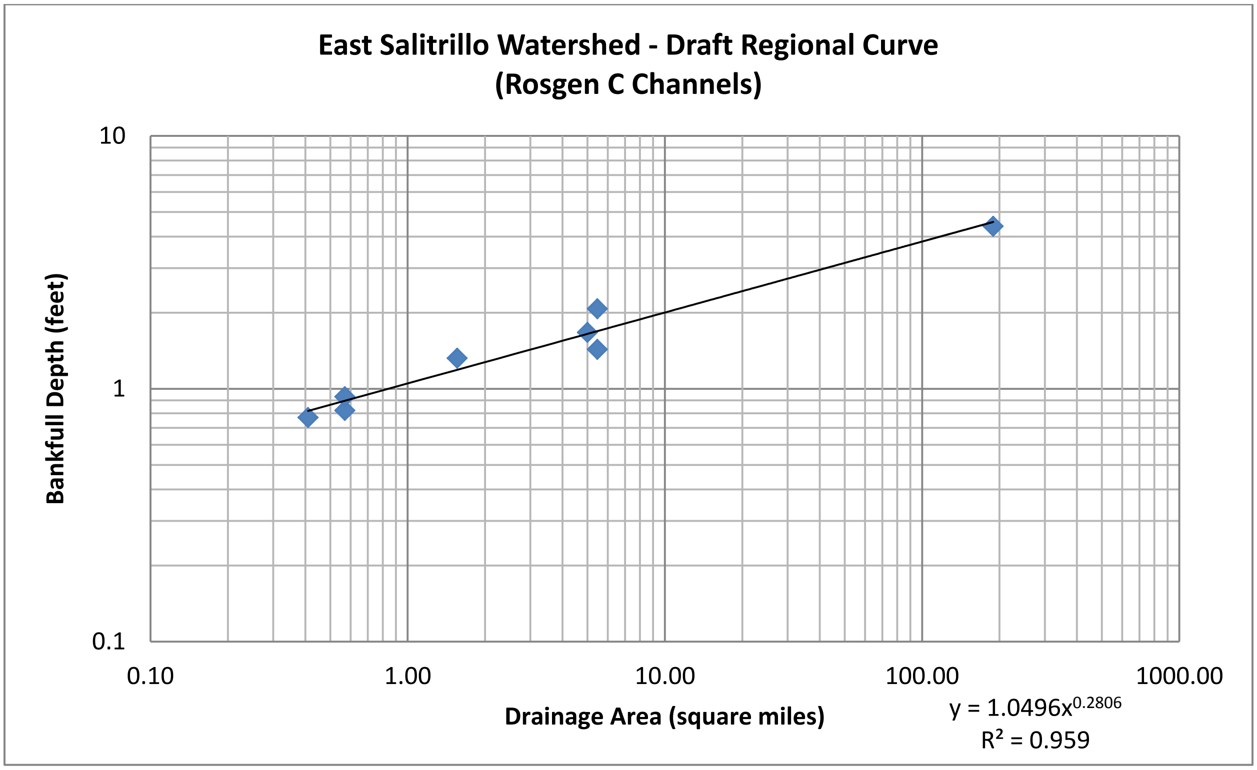
Source: SARA, 2010

Figure 2: East Salitrillo Watershed – Draft Regional Curve (Bankfull Width vs Drainage Area)

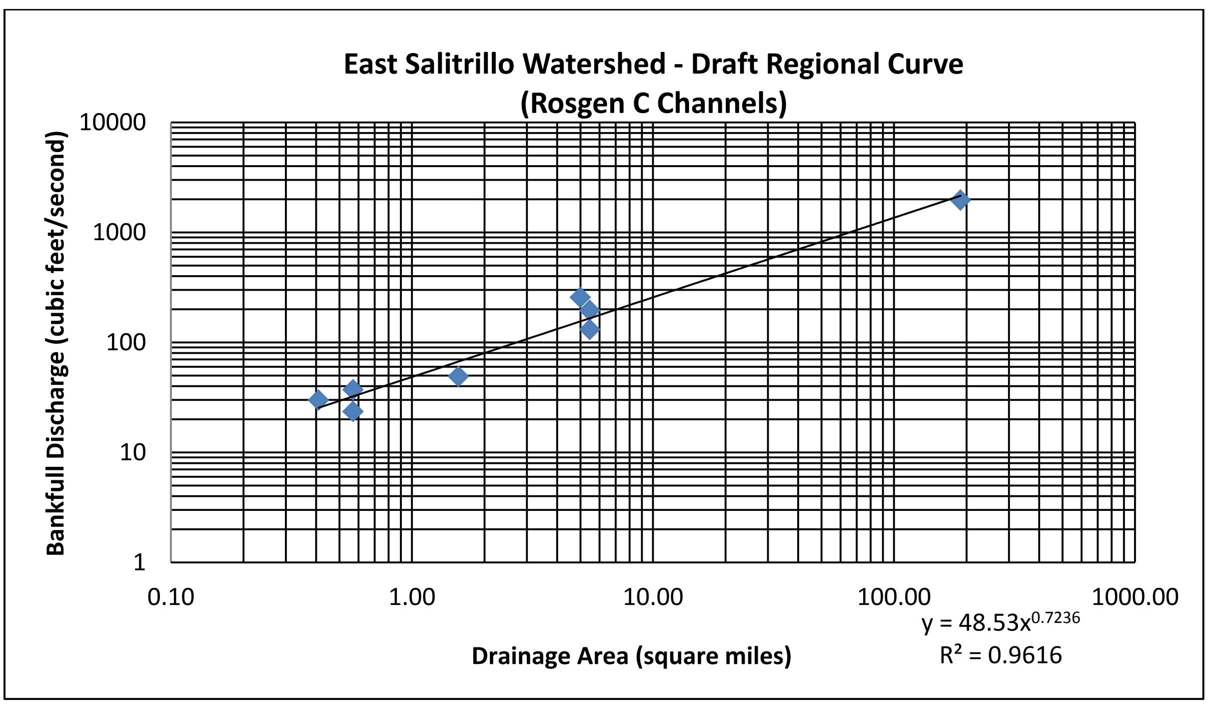


Source: SARA, 2010

Figure 3: East Salitrillo Watershed – Draft Regional Curve (Bankfull Depth vs Drainage Area)



Source: SARA, 2010**Figure 4: East Salitrillo Watershed – Draft Regional Curve (Bankfull Discharge vs. Drainage Area)**



Source: SARA, 2010

4.3 How to Develop Watershed-Specific Regional Curves

For projects that do not have a regional curve that represents the project hydrophysiographic region, practitioners will need to develop a watershed-specific regional curve (like the ones shown above) before completing a geomorphic assessment or natural channel design. Gage stations are preferred over ungaged streams as long as the gage station stream reach is not incised and has a drainage area that is in the same or adjacent log cycle as the project reach. Gage stations are often located on bridge or culvert crossings, frequently creating unnatural or unstable geomorphic conditions. Therefore, riffle cross sections, which are used to calculate bankfull area, width, and mean depth, should be surveyed upstream or downstream of the gage in a more natural, stable section of the study reach.

It is acceptable to use stable riffles from reference reach quality streams that are not incised and are in the same hydrophysiographic region as the project site. Regardless of the source (gaged or ungaged), the sites used to create the regional curve should bracket the project reach, meaning that some points should be smaller than the project reach drainage area and some larger. Generally, eight or more points are needed to create a reliable watershed specific regional curve.

A detailed checklist for creating a watershed-specific regional curve is provided in Appendix C. However, the key criteria for selecting sites, performing the field survey, and creating the curves are provided below.

Developing Watershed-Specific Regional Curves:

1. Determine the drainage area for the project stream, i.e., the proposed restoration reach.

2. Look for stable riffle cross sections within, upstream, and downstream of the project reach. Also search for stable riffles in nearby watersheds.

3. A riffle is stable if it meets the following requirements. These requirements apply to riffles within the same watershed as the project reach and sites in other watersheds.

   A. Bank height ratio less than 1.2, preferably 1.0.

   B. The cross section must be free to adjust, meaning that it can't have a bedrock bed and banks or stabilization structures like rip rap. Some bedrock in the channel bed is okay, especially if bed material is also present.

   C. Similar rainfall/runoff relationship as project reach (for sites outside of project watershed).

   D. Similar bed material and bank vegetation as project reach.

   E. Same stream type as proposed project design.

4. Survey 6 to 8 project reaches. Refer to Harrelson et al. (1994) for guidance on surveying techniques.

   A. Measure/calculate cross sectional area, width, and mean depth.

   B. Measure the average channel slope.

   C. Determine the drainage area.

   D. Determine bed material grain size distribution for gravel-bed streams.

   E. Estimate discharge using Manning's equation or similar method.

5. Plot regional curves and regression lines.

A. Plot bankfull cross sectional area, width, mean depth, and discharge versus drainage area using a log-log scale. Refer to **Figures 1-4** above as examples.

B. Apply a power function regression equation to each data set and show the equation and coefficient of determination on the graph.

Rosgen (2006) also shows a method for developing regional curves; however, this method focuses on gage stations. A review of the watershed-specific regional curve approach shown above and in Appendix C along with Rosgen (2006) is encouraged to provide a thorough understanding of the regional curve development process.

5.0 BASE MAP SURVEY

It is critical that an adequate base map survey is conducted for each project. The base map is a topographic map, usually with one foot contour lines, that also includes the existing channel alignment, utilities, large trees, roads, property boundaries, and other constraints. This information forms the existing condition mapping that is provided in the project plan sheets (Chapter 12). Typically, base maps are produced using a Total Station survey instrument that records northing, easting, and elevation coordinates for survey points. This data set is imported into a software program that analyzes the coordinate geometry (COGO). From there, the data set is imported into Computer Aided Design (CAD) software, where the base map is developed and used for the design. For complex projects, especially urban projects, the base map should be tied to real world, state plane coordinates. The base map may also be used to record stability and geomorphic assessment results, such as the location of eroding stream banks, headcuts, and cross-sections. The base map CAD drawing is required to follow the contracting agency's electronic data standards (similar to SARA CAD Data Standards).

6.0 GEOMORPHIC ASSESSMENTS

Geomorphic assessments are completed prior to beginning the stream restoration design. These assessments evaluate the current state of the stream and its departure from the potential stable state that is suitable for its watershed and valley conditions. In addition, the geomorphic assessment will:

- Identify the type of stream instability (e.g. vertical instability, lateral instability)
- Identify the extent of the stream impairment (e.g. localized, widespread)
- Identify the cause(s) of the stream impairment
- Present the bankfull characteristics and discharge for the project site
- Discuss the bankfull determination and validation process and results

The geomorphic assessment will have a thorough discussion of bankfull and its validation. The accurate identification of bankfull is critical to assessing a stream and preparing a design. It is used to classify the stream, evaluate its current condition, and its departure from its potential stable state. The validation of bankfull is often a comparison to a bankfull regional curve; however, a more intensive validation may be required for more complex sites.

The sections that follow describe the fundamental components of geomorphic assessments, but are not meant to be an exhaustive list of the procedures that are available for assessment purposes. For complex projects, a higher level of assessment may be needed to fully examine the causes of impairment and prepare a restoration plan. The reader is referred to Rosgen (2006) for more detailed information on geomorphic assessment procedures.

6.1 Preparing for a Geomorphic Assessment

Proper preparation is important to ensure efficient and accurate completion of geomorphic assessment tasks. Specific preparation steps are provided in the sections below.

6.1.1 Office Preparation

Office preparation begins with collecting basic information about the project site that will be needed during the field assessments. It is often helpful to view aerial photographs (such as those available through Google Earth or similar resource) of the project site and its watershed prior to visiting the project site. As discussed previously, aerials can be obtained for each of the four counties under SARA jurisdiction from the appropriate county GIS department. Characteristics to note are area land uses, the level of development in the watershed, and project constraints.

Field maps of the project site should be prepared in the office. Typical maps are a USGS topographic quadrangle for the project and its watershed, and aerial photographs of the site. The watershed for the project reach should be delineated in square miles. In some situations, project specific topographic mapping or local community topographic data may be available prior to geomorphic assessments being prepared. This mapping, along with the aerial photographs of the site, is used for marking field observations and general locations of cross-section surveys and bed material samples.

6.1.2 Basic Field Procedures

Basic field procedures for geomorphic assessment of stream reaches have been described thoroughly by Harrelson et al. (1994). This publication describes geomorphic assessment methods for use with reference reach surveys; however, the surveying and data collection methods described are generally the same when conducting these assessments on degraded stream reaches targeted for restoration. The sections below describe considerations to be made when conducting these assessments on degraded reaches that may differ from the survey methods describes by Harrelson et al. (1994).

6.1.3 Site Sketch

A site sketch is prepared in the field to record details of the study reach and notes about the site. Information typically provided on site maps includes, but is not limited to:

- Location of benchmarks
- Direction of stream flow
- North arrow
- Map scale
- Valley cross-section sketch
- Terrace location and heights
- Location of trees, rocks, debris and other features

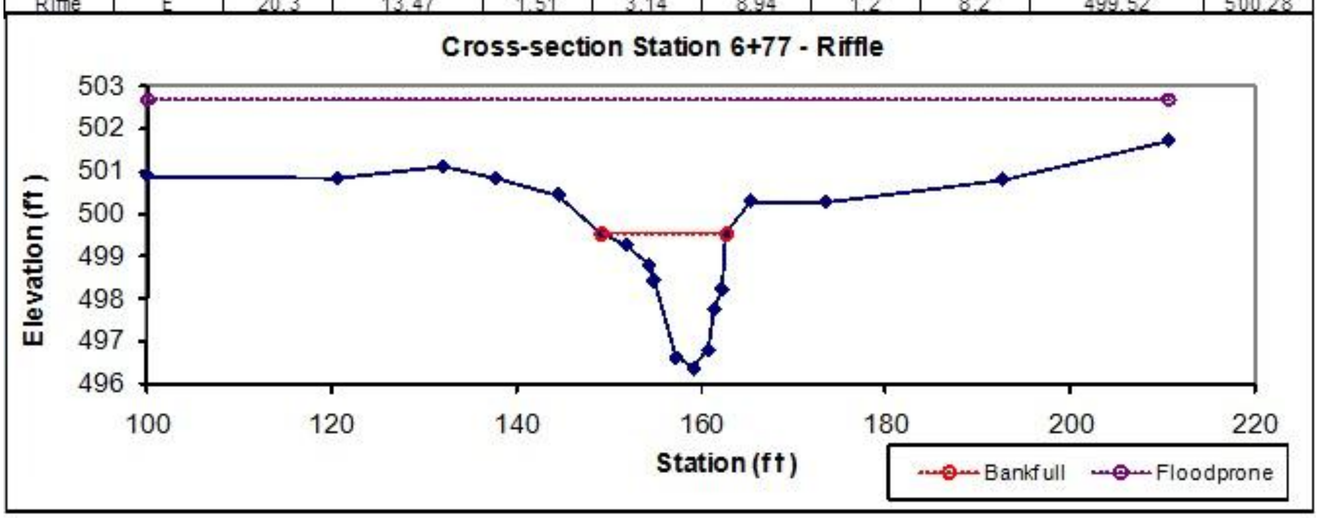
- Pool/riffle sequences
- Gravel and sand bars
- Cross-section locations
- Longitudinal profile alignment and stationing
- Stream pattern measurements (meander lengths, radii, etc.)

6.1.4 Cross-section Surveys

Cross-section surveys are conducted at riffle and pool locations to determine channel cross-sectional geometry. The data collected are used to develop the same ratios that are calculated for reference reaches (see Chapter 7), to provide a means of quantifying the degree of departure from reference conditions. Such parameters include bankfull cross-sectional area (BKF Area), depth (BKF Depth), width (BKF Width), entrenchment ratio (ER), and bankfull discharge estimates. On degraded reaches that will be stabilized, monumented cross-sections as described by Harrelson et al. (1994) are not needed if resurvey of the cross-sections in the future is not planned. Cross-sections for bankfull determinations should be made at the most stable riffle sections of the reach. For degraded sites that are highly unstable, a stable riffle section may not be available, and consistent field indicators of bankfull discharge may be difficult to identify. In these situations, bankfull stage estimates should be made up and/or downstream of the degraded reach where the stream is more stable and bankfull indicators can be reliably identified, if available. In addition, other methods for confirming the bankfull discharge will be used, as described in Section 6.2 of this document. Example data from a cross-section survey are provided in **Figure 5** below.

Figure 5: Example cross-section survey plot and bankfull parameters.

Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Riffle	E	20.3	13.47	1.51	3.14	8.94	1.2	8.2	499.52	500.28

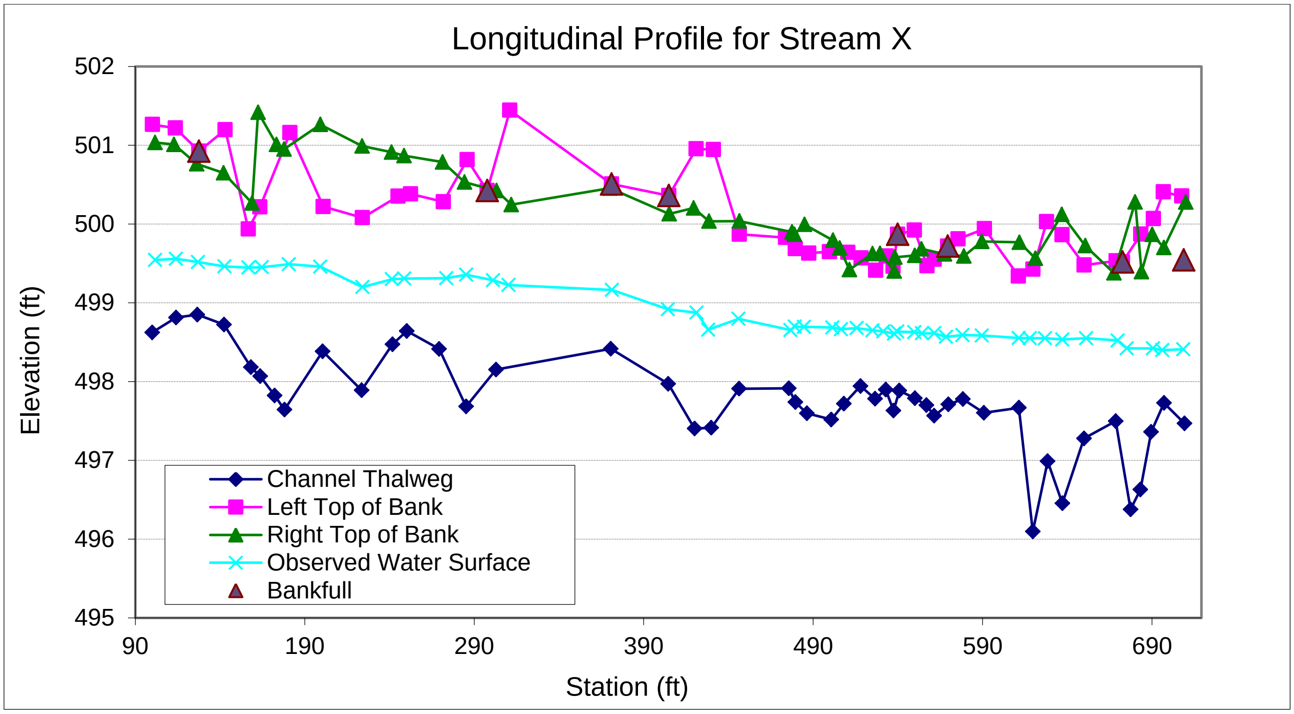


6.1.4.1 **Longitudinal Profiles**

In the Bexar County region, ephemeral channels are common and it is likely that a degraded reach identified for restoration may be dry during the geomorphic assessment phase. Normally, stream slope is measured as the difference in water surface elevation between two ends of a surveyed reach. For dry channels, slope is calculated from the head of one riffle feature to the head of another riffle feature. This measurement should closely approximate the water surface slope under flowing conditions. Generally, the change in bed elevation should be made over a distance of 20 times the bankfull width, as long as the reach slope is consistent with no defined knickpoints. However, the required length can be adjusted as needed, especially for larger drainage areas, and as long as the data collected captures prominent bed features and accurately reflects the channel slope.

A longitudinal profile is created by measuring and plotting elevations of the channel bed, water surface, bankfull, and low bank height or tops of bank. Profile points are surveyed at prescribed intervals and at significant breaks in slope, such as the head of a riffle or pool. This profile can be used to assess changes in river slope compared to valley slope, which affect sediment transport, stream competence, and the balance of energy. For example, the removal of large woody debris may decrease the step/pool spacing in a high gradient stream and result in excess energy and subsequent channel degradation. Refer to **Figure 6** for an example longitudinal profile.

Figure 6: Example longitudinal profile.



Profile measurements are used to develop ratios like those developed for reference reaches (see Chapter 7) to assess the degree of departure from reference conditions.

6.1.4.2 Stream Pattern

Field measurements relating to stream pattern are the linear meander length (L_m), radius of curvature (R_c), and belt width (W_{blt}). The data collected are used to develop the same ratios that are calculated for reference reaches (see Chapter 7). These data are compared to reference reach ratios for similar stream types to assess the degree of departure from reference conditions.

Not all streams have pattern. Straight reaches with very low sinuosity will not have meander bends and associated variables. In these cases, belt width (W_{blt}) will be very near bankfull width.

6.1.4.3 Bed Material Sampling

Gravel and Cobble Bed Systems

Harrelson et al. (1994) provides detailed methods for performing a pebble count to determine size fractions of the streambed and bank materials, primarily used for stream classification. Rosgen's stream classification methodology (Rosgen, 1996) uses the median particle size as part of a Level II classification. The determination is made by performing a pebble count of 100 samples, which includes 10 stations across each of 10 cross-sections, along the reach to be classified. The locations of the 10 cross-sections are stratified by the percentage of riffles and pools along the reach. For example, if the reach is approximately 60% riffles and 40% pools by length, then 6 pebble count cross-sections are conducted in riffles, and 4 pebble count cross-sections are conducted in pools. Upon determination of the median particle size for the reach, the Level II classification is designated as a number that follows the lettered stream type determined in the Level I classification.

1 = Bedrock

2 = Boulder (> 256 mm)

3 = Cobble (64 – 256 mm)

4 = Gravel (2 – 64 mm)

5 = Sand (0.062 – 2 mm)

6 = Silt/Clay (< 0.062 mm)

Therefore, a "C4" stream type is a "C" type channel that has a median particle size in the gravel size fraction.

Bunte and Abt (2001) provide detailed methods for the sampling of streambed material in wadeable gravel and cobble bed streams. Their methods for sampling the armor and sub-armor layers of the streambed should be used to develop bed material size distributions for these layers. A sample of armor and sub-armor should be collected and sieved from two representative riffle locations within the project reach. Use of a barrel sampler as described by Bunte and Abt (2001) is recommended for this task. In addition, if well-formed point bar features are evident for the reach, an armor and sub-armor sample should be taken from the lower half of the point bar and sieved to determine particle size distributions for both the armor and sub-armor layers. This information will be used later in the design phase of the project for sediment transport calculations.

Sand Bed Systems

For sand bed systems (< 2 mm particle size), a pebble count is not required to classify the stream system. However, bulk sand samples can be collected and sieved from representative riffle/ripple areas to determine grain size distributions for use in sediment transport capacity calculations.

Sediment transport capacity in sand bed systems is most often conducted using numerical modeling software that calculates stream power and shear stresses at design flows. Two examples include the hydraulic design and sediment transport capacity functions included with HEC-RAS, and the SAM hydraulic design package for channels, both developed by and available from the US Army Corps of Engineers. Users should refer to the model literature and users guides to determine the sediment and particle distribution data required for each model.

6.2 Bankfull Discharge Determination

There are three primary methods for evaluating bankfull discharge; 1) use of field indicators to predict bankfull stage, 2) use of regional curve information, and 3) use of hydraulic modeling programs to estimate the bankfull discharge. Methods 1 and 2 typically provide better estimations of bankfull than method 3. However, it is best to use all three methods described below to estimate bankfull discharge, to provide the maximum confidence in the final estimate.

6.2.1 Field Indicators of Bankfull Stage and Area

The bankfull discharge often leaves a visual indicator that can be used to predict the bankfull stage. For unincised streams that have access to their floodplains, bankfull is at or near the top of the streambank. If the stream has incised due to changes in the watershed or streamside vegetation, the bankfull stage may be indicated by a small, depositional bench or scour line on the stream bank (Harman et al., 1999); in this case, the top of the bank, which was formerly the floodplain, is called a terrace. Rosgen (2006) provides more detailed information on evaluating and using field indicators of bankfull stage.

Specific steps in the identification of bankfull stage are provided below:

- Identify the most consistent bankfull indicators along the reach that were obviously formed by the stream, such as a point bar or lateral bar. Bankfull is usually the back of this feature, unless sediment supply is high; in that case, the bar may flatten, and bankfull will be the front of the feature at the break in slope. If such features are not apparent in the stream, and the adjacent floodplain shows indications of frequent flooding, then bankfull stage may be the top of the streambank.
- Measure the difference in height between the water surface and the bankfull indicator; for example, the indicator may be 2.2 feet above water surface. Bankfull stage corresponds to a flow depth. It should not vary by more than approximately 10 – 15% throughout the reach, unless a tributary enters the reach and increases the size of the watershed or the reach has large step-pool formations causing abrupt changes in bed elevation.
- Look for bankfull indicators at a stable riffle. If a bankfull indicator is not present at this riffle, use the height measured in the previous step to estimate the indicator; for example, measure 2.2 feet above water surface, and place a flag in both the right and left banks.
- Survey the stable riffle cross-section to calculate the cross-sectional area of the channel at the bankfull stage.

- At this point, the user should compare the bankfull cross-sectional area estimate with regional curve information (see Using Regional Curves to Estimate Bankfull Discharge section below) if that information is available. If the measured cross-sectional area is not a close fit to the regional curve information, look for other bankfull indicators, and test them. If there are no other indicators, look for reasons to explain the difference between the two cross-sectional areas; for example, if the cross-sectional area of the stable riffle is lower than the regional curve area, look for upstream impoundments, wetlands, or a mature forested watershed. If the cross-sectional area is higher than the regional curve area, look for stormwater drains, parking lots, or signs of channelization.

It is important to perform the bankfull verification at a stable riffle, using indicators from depositional features. The cross-sectional area will change with decreasing stability. In some streams, bankfull indicators will not be present due to recent incision or maintenance. In such cases, it is important to verify bankfull through other means (see Section 6.2.3).

6.2.2 Using Hydraulic Models to Estimate Bankfull Discharge

Hydraulic models, such as HEC-RAS, that can predict flow stage and hydraulic properties given a discharge and topographic information for the stream channel, can be used to confirm field indicators of bankfull stage. Proper use of these models requires detailed topographic information for the stream reach in question, which is usually developed from field-based surveys (see Chapter 5 Base map Survey). To determine the appropriate level of detail for these surveys, the user should refer to the guidance documents and manuals for their specific model. Often there are existing hydraulic models developed for other uses, such as FEMA flood studies, but it should be noted that the resolution of the channel geometry and cross-section spacing is usually insufficient for use in estimation of bankfull parameters. Therefore, geometry data from these models are generally not recommended for use in estimating bankfull parameters for detail natural channel design purposes without further refinement of the models.

Within the one-dimensional hydraulic modeling program HEC-RAS, channel geometry and watershed hydrology data are required to conduct a bankfull analysis. The geometry is gathered from field data collection and should include both cross-section and channel slope information. If bankfull indicators are poor or appear inconsistent, it is desirable to have multiple cross-sections and respective bankfull field calls to input into this exercise. The hydrologic data are obtained from long-term gage data, USGS regression equations, regional curves, and/or other reliable sources. At a minimum, the user must know the drainage area for the use of regression equations and regional curves. For cases involving the use of regression equations, a plot of flow data versus flow frequency (1/return interval) can be developed and a power function equation fit to the data. The power function equation can be used to develop estimates of the T-year return interval event with frequency equal to 1/T. Bankfull flow typically has a return interval between 1 to 1.5 years, so it is appropriate to test flows with frequencies in this range against field calls. The user is cautioned that the best fit curve often fits poorly to the data at the extreme low end of the curve. The user may elect to hand-fit a point to serve as a reference from which to conduct a comparison to field indicators.

The user can now build a HEC-RAS model and input the hydrology that has been developed. In the absence of more detailed information, the boundary condition can be set to normal depth. The geometry options are as follows, depending on the data available:

- Plot one cross-section and copy it up or downstream, adjusting the elevation of the copied section in accordance with the channel slope.
- Plot two or more cross-sections on the same vertical datum and at known distances from one another.
- Plot two cross-sections on the same vertical datum with known profile in between. Interpolate one or more times (depending on the variability in the profile) between the two cross-sections to get an interpolated geometry and adjust the interpolated cross-section to coincide with the known profile.

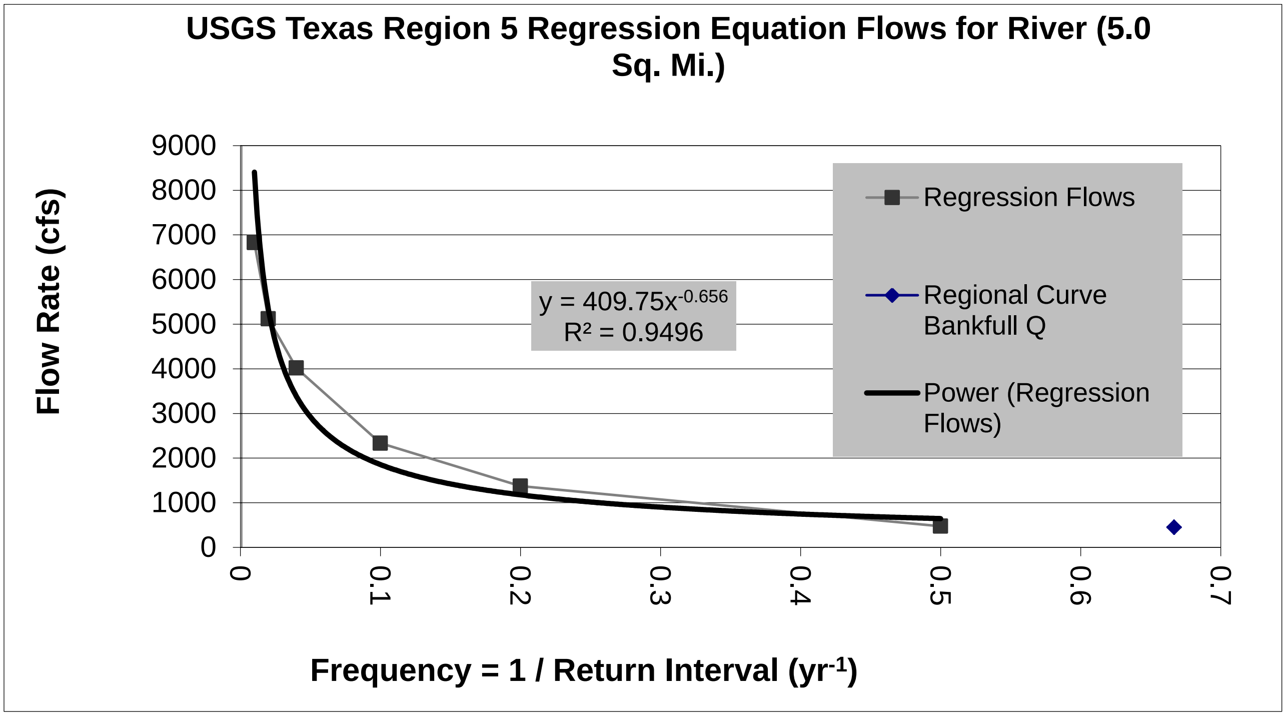
After running the model, the user should use the cross-section viewer and/or the profile viewer to help assess the flow that is best fit to the selected field indicators. The user should give more weight to better indicators and less weight to more subjective indicators. Additionally, for this method to be valid, the user must consider factors outside of the analysis reach that could influence water surface profiles at the cross-sections being observed. As with other modeling efforts, the user should test the model sensitivity to Manning's "n" and other input parameters in order to assess how robust the test is.

Example: The USGS has developed the following flow estimate equations for the Region 5 San Antonio area of Texas (Asquith, 1996). For drainage areas (A) less than 32 square miles, and slope (SL) in feet per mile:

$$Q_2=159A^{0.680}$$
$$Q_5=396A^{0.773}$$
$$Q_{10}=624A^{0.820}$$
$$Q_{25}=997A^{0.866}$$
$$Q_{50}=278A^{0.973}SL^{0.360}$$
$$Q_{100}=295A^{1.01}SL^{0.405}$$

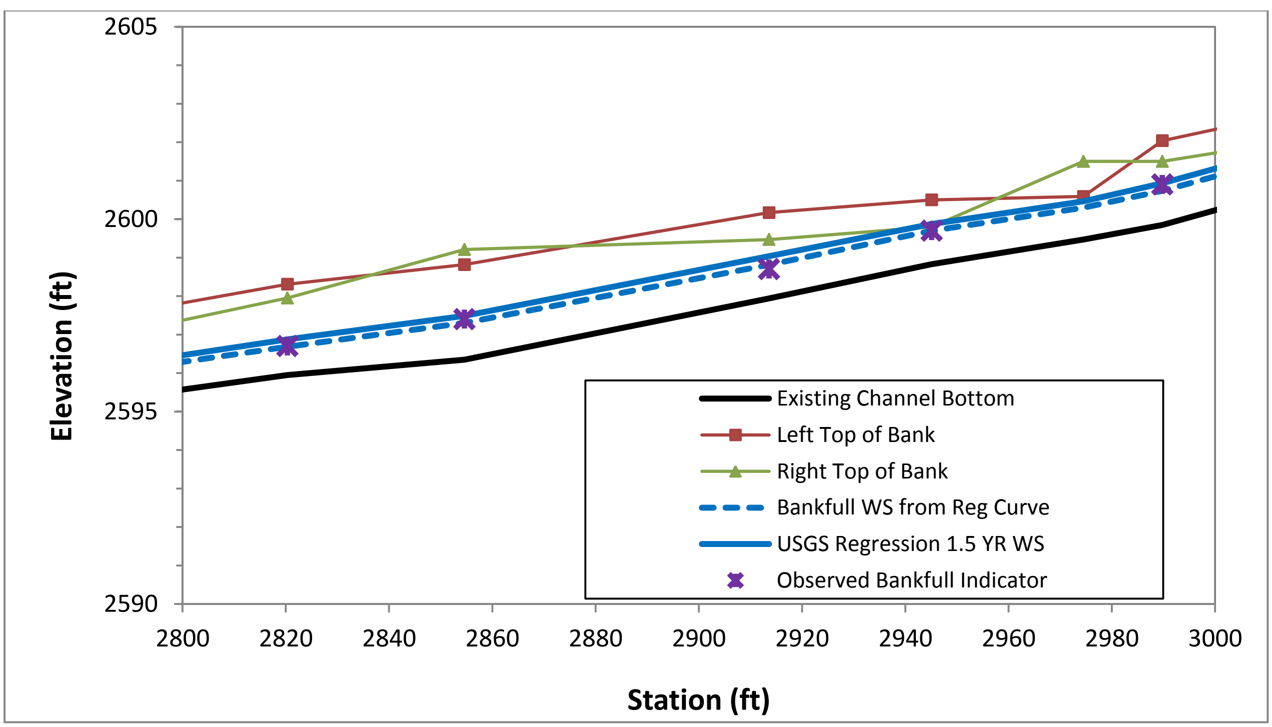
Consider the hypothetical case for a given stream in Texas Region 5, drainage area 5.0 square miles, and channel slope 0.008 ft/ft (SL=42.24). **Figure 7** below can be developed, and the equation of the best fit power function can be plotted. In addition, it is appropriate to plot the regional curve flow when a regional curve is available (by inputting a typical return interval of 1 to 1.5 years). Using this information, an estimate of flows with return periods of 1 and 1.5 years can be developed and input into the HEC-RAS model to predict bankfull stage and assess observed indicators. **Figure 8** shows an example of HEC-RAS output profiles with observed bankfull indicators plotted for comparison. The data indicate that the observed bankfull indicators match well with the water surface profile predicted from the regional curve for bankfull discharge.

Figure 7: USGS Texas Region 5 Regression Equation



Note: Example of extrapolating low return period flows from USGS flow estimate equations.

Figure 8: Comparison to Observed Bankfull Indicators with HEC-RAS Water Surface Profile Simulations.



6.3 Stream Classification

In the Rosgen stream classification method (Rosgen, 1994; Rosgen, 1996), cross-sections are surveyed at riffles for the purpose of stream classification. **Figure 10** shows the Rosgen Stream Classification Key for natural rivers (Rosgen 1994, 1996). Values for entrenchment ratio and width/depth ratio, along with sinuosity and slope, are used to perform a Level I classification of the stream. The entrenchment ratio (ER) is calculated by dividing the flood-prone width (width measured at twice the maximum bankfull depth) by the bankfull width. The width/depth ratio (w/d ratio) is calculated by dividing bankfull width by the mean bankfull depth. **Figure 10** shows examples of the channel dimension measurements used in the Rosgen Stream Classification System. For more detailed information on the Rosgen stream classification method, the reader is referred to Rosgen (1994, 1996).

Finally, the numbers that coincide with each bed material classification are used as part of the Level II classification (see Section 6.1.4.3). For example, a Rosgen “E3” stream type is a narrow and deep, cobble-dominated channel, with access to a floodplain that is greater than two times its bankfull width.

Figure 9: Classification Key for Natural Rivers (Rosgen, 1996)

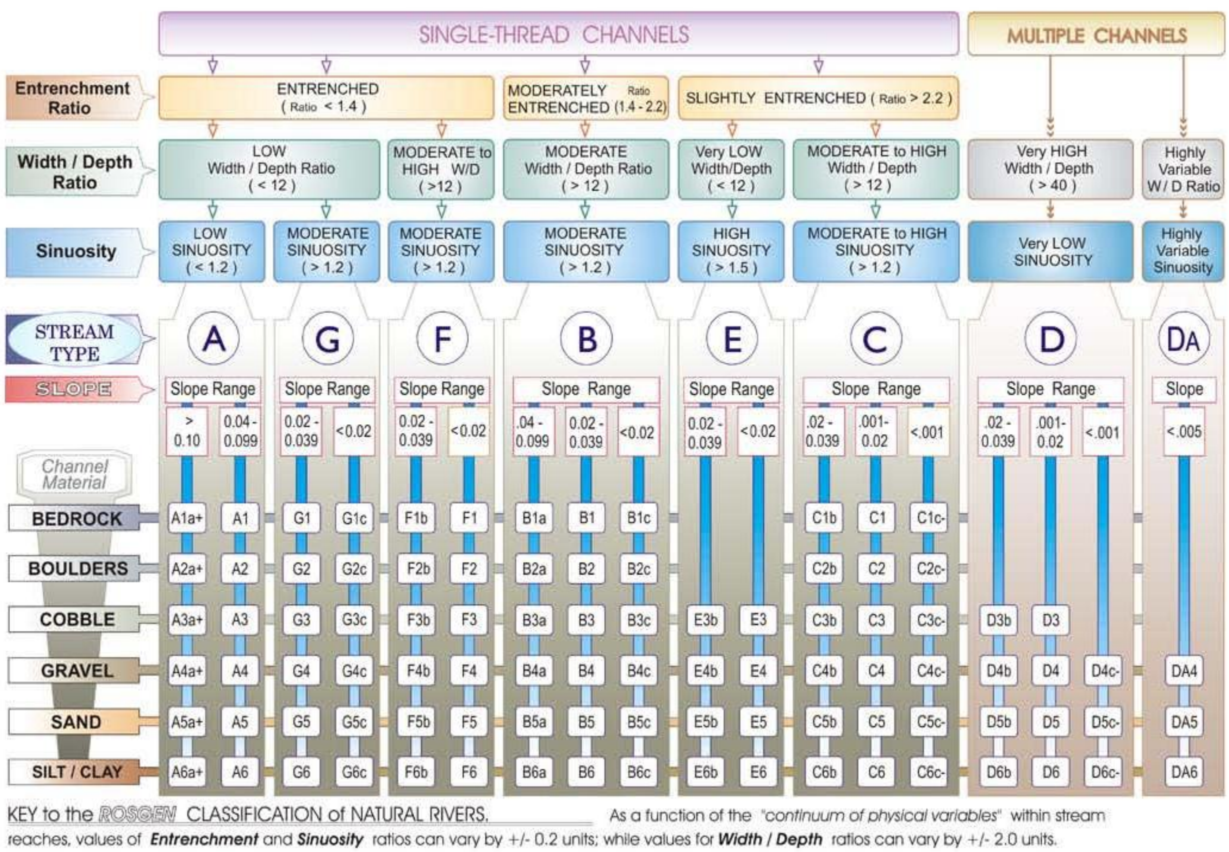
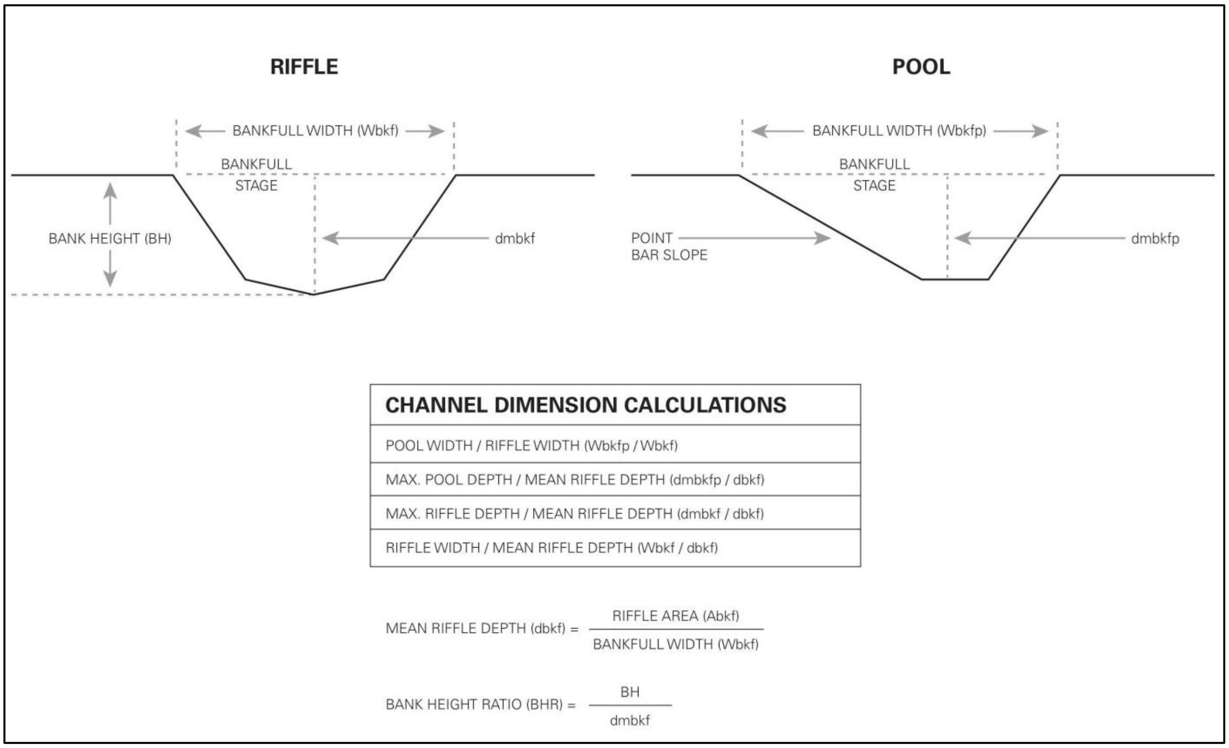


Figure 10: Channel Dimension Measurements & Ratios



Source: Reprinted with permission from Stream Mechanics.

6.4 Vertical Stability

Geomorphic assessments of channel condition must include assessments of vertical stability, which quantify the degree to which a stream is incised and connected to its floodplain. Vertical stability is assessed through measurement and observation of bank height ratios, entrenchment ratios, sediment transport competency and capacity, and visual observations.

6.4.1 **Bank Height Ratios**

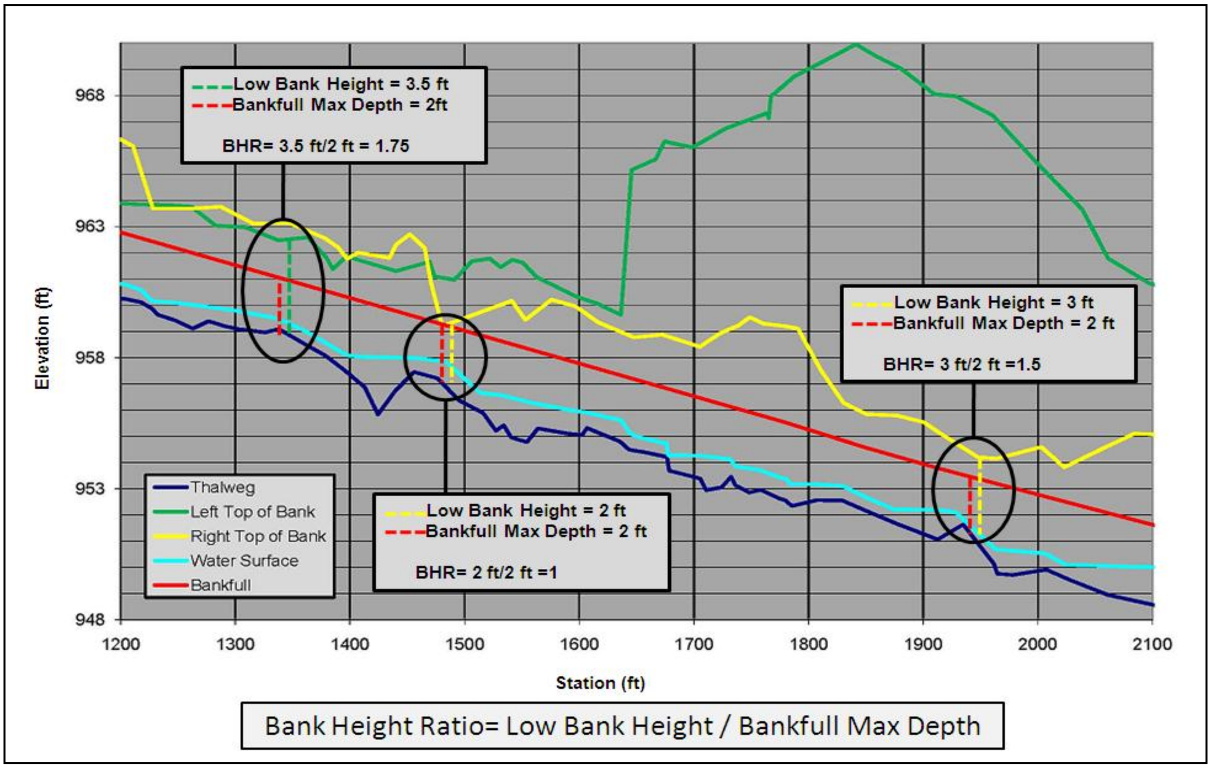
Bank height ratios are measured in the field to assess the degree of channel incision. The bank height ratio is measured as the ratio of the lowest bank height divided by a maximum bankfull depth. **Table 1** shows the relationship between bank height ratio (BHR) and vertical stability developed by Rosgen (2001), and **Figure 11** illustrates the method for calculating BHR.

Table 1: Conversion of Bank Height Ratio (Degree of Incision) to Adjective Rankings of Stability

Adjective Stability Rating	Bank Height Ratio
Stable (low risk of degradation)	1.0 – 1.05
Moderately unstable	1.06 – 1.3
Unstable (high risk of degradation)	1.3 – 1.5
Highly unstable	> 1.5

Source: Rosgen, 2001

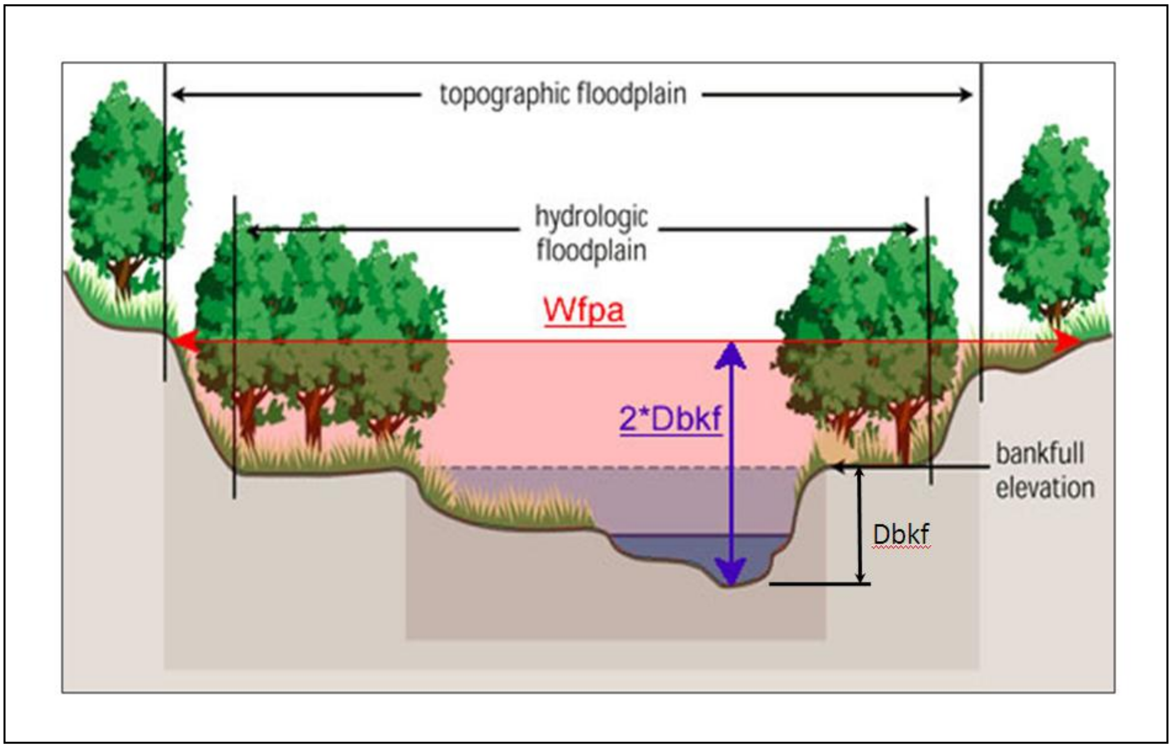
Figure 11: Method for Calculating Bank Height Ratio (BHR).



6.4.2 Entrenchment Ratios

Entrenchment is the degree of vertical confinement of a river channel within its valley. Entrenchment ratio is a computed index value, which is used to describe the level of entrenchment and is calculated as the width of the flood prone area at an elevation twice the maximum bankfull depth, divided by the bankfull width. If the entrenchment ratio is less than 1.4 (+/- 0.2), the stream is considered entrenched (Rosgen, 1996). The method for calculating entrenchment ratio is illustrated in **Figure 12.**

Figure 12: Method for Calculating Entrenchment Ratio.



Source: Endreny, 2003 and FISRWG, 1998

6.4.3 Sediment Transport Competency and Capacity

The ability of a stream to transport its total sediment load can be assessed through two primary measures: sediment transport competency and sediment transport capacity. Competency is a stream's ability to move particles of a given size and is a measurement of force, often expressed as units of pounds per square foot (lbs/ft^2). Sediment transport capacity is a stream's ability to move a quantity of sediment and is a measurement of stream power, often expressed as units of watts per square meter (w/m^2). Assessing a stream's transport competency and capacity allows for quantifying the stream's ability to moves its sediment load. If competency and capacity are higher than necessary, degradation and incision of the stream are likely unless there is some form of vertical control, such as a bedrock knick-point. If competency and capacity are lower than necessary, aggradation of the channel is likely.

Methods for assessing sediment transport competency and capacity are provided in Section 8.6 of this document. The methods described in Section 8.6 are provided to assess sediment transport in design channels; however, the same procedures can be used to evaluate sediment transport processes in degraded channels prior to restoration.

6.4.4 Visual Observations

Visual observations from the channel are also helpful in assessing vertical stability. Active headcuts (abrupt drops in water surface over a feature that is being eroded) are an obvious sign of vertical instability, as they indicate that the channel is still actively downcutting. A lack of depositional bed features, such as bars and gravel riffles, can indicate stream energies that are moving all sediment through the system, often resulting in further channel downcutting and incision. Hanging outfall pipes, headwalls, and undercut trees are indicators that the channel has incised in the past and may be continuing.

If hard bedrock outcrops are evident along the channel, further incision of the channel is unlikely.

Visual observations of heavy sediment deposition, and braided channel forms through recent deposition are indications that the channel may be aggrading (i.e. filling with sediment such that the bed elevation is rising over time). This condition occurs when the sediment supply from upstream is too large for the stream to transport, or sediment transport capacity is too low. Aggrading channels often lack the sorting of particle grains in the bed that stable channel exhibit; therefore, the bed materials may feel loose and easy to excavate or disturb by hand or by using one's foot.

6.5 Lateral Stability

Lateral stability assessments are performed to evaluate the integrity of the streambanks along the reach. Lateral instability is a common cause of stream impairment, resulting in excess sediment to downstream waters and loss of property as the stream channel migrates laterally. Two primary methods are used for assessing lateral stability: aerial photographs, and the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen, 2006)..

6.5.3 Aerial Photographs

Historic aerial photographs can be used to determine the degree to which a stream has migrated over time. By overlaying aerial images and measuring changes in channel position over time, estimates of migration and sediment loss rates can be developed. Historic aerials can often provide clues to the cause of lateral instability and bank erosion. For example, a review of historic aerials may indicate that a stream exhibited little tendency to migrate until the riparian buffer was cleared and all vegetation along the banks was removed, resulting in subsequent unstable stream banks and active meander migration.

6.5.4 Estimating Bank Erosion Potential

The BANCS model uses two bank erosion estimating methods, the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) (Rosgen, 2006). The BEHI method is used to evaluate the potential for erosion along a length of stream bank with similar characteristics. The methodology involves assessing seven contributing variables that affect bank erodibility: bank height/bankfull depth ratio, root depth/bank height ratio, root density, bank angle, surface protection, bank material, and stratification of bank material. After field assessments of these parameters, index values are determined and an overall value (from very low to extreme) for bank erodibility is assigned to the reach.

The Near Bank Stress (NBS) method (Rosgen, 2006) is used to evaluate the disproportionate stresses that are placed on the near-bank regions of the stream bank, estimating the amount of stress (hydraulic force) placed on the bank that promotes erosion. The method provides seven available ways to estimate near-bank stress, based on the geometry of the channel and/or physical measurements of stress and velocity. One or more of the methods are used to calculate an appropriate NBS value (very low – extreme) for a section of stream bank.

The values of BEHI and NBS together can be used to predict an annual stream bank erosion rate from erosion rate curves (Rosgen, 2006). The user is cautioned that the curves developed by Rosgen were developed for the Colorado and Yellowstone areas; therefore, the erosion rates predicted may not be accurate for other regions with different climatic and geologic conditions. However, the predicted rates are useful as an estimate and for providing relative comparisons between different streams and stream reaches in an area. Rosgen (2006) provides more detailed information regarding the use of the BEHI and NBS methods, and their use for predicting stream bank erosion rates.

The BEHI/NBS methods are performed along the entire project reach to 1) estimate the amount of sediment being lost along the project reach on a yearly basis, and 2) to provide a means for assessing the effectiveness of the restoration practices, by comparing pre-restoration erosion estimates with estimates or actual field measurements conducted after the restoration.

6.6 Bedform Diversity

Proper bedform diversity is critical to many of the aquatic organisms that live in streams. Organisms have evolved for pools, riffles, coarse sediments, and fine sediments. Without proper bedform diversity, ecological diversity is negatively affected.

A longitudinal profile, as described in Section 6.1.4.1, is required to assess bedform diversity along a stream reach.

The longitudinal profile can be used to estimate the percentage of riffles and pools along a reach, and when compared with reference conditions, provides a means of quantifying the departure of the stream from reference conditions. In the same way, facet (e.g., riffle, run, pool) slopes of each individual feature can be compared with reference reach values to assess the level of degradation.

6.6.1 Gravel Bed Streams

Meandering gravel bed streams in alluvial valleys have sequences of riffles and pools that maintain channel slope and bed stability. The riffle is a bed feature composed of gravel or larger-size particles. During low-flow periods, the water depth at a riffle is relatively shallow, and the slope is steeper than the average slope of the channel. At low flows, water moves faster over riffles, providing oxygen to the stream. Riffles control the streambed elevation and are usually found entering and exiting meander bends. The inside of the meander bend is a depositional feature called a point bar, which also helps maintain channel form (Knighton, 1998). Pools are typically located on the outside bends of meanders, between riffles. Pools have a near flat slope and are deeper than the average depth of the channel. At low flows, pools are depositional features, and riffles are scour features.

At high flows, the water surface becomes more uniform; i.e., the water surface slope at the riffles decreases, and the water surface slope at the pools increases. The increase in pool slope coupled with the greater water depth at the pools causes an increase in shear stress at the bed elevation. The opposite is true at riffles. With a relative increase in shear stress, pools scour. The relative decrease in shear stress at riffles results in bed material depositing at these features during the falling limb of the hydrograph.

6.6.2 Sand Bed Streams

While gravel bed streams have riffle/pool sequences with riffles composed of gravel-size particles, sand bed channels are characterized by median bed material sizes less than 2 millimeters (Bunte and Abt, 2001). Bed material features called ripples, dunes, planebeds, and antidunes characterize the sand bedform. Although sand bed streams do not, technically, have riffles, the term is often used to describe the crossover reach between pools. The term “riffle” may be used in this manual to mean the same as “crossover section.”

Pools in sand bed channels are most often formed around a structure that provides scour, such as fallen trees, logs, or debris jams. These structures promote convergence of flows around their edges, resulting in higher flow velocities that keep the areas scoured and deeper. Unlike gravel bed systems, sand bed channels do not typically form deep pools around meander bends unless there is also some type of structure in the bed to promote scour.

6.7 Channel Evolution

A common sequence of physical adjustments has been observed in many streams following disturbance. This adjustment process is often referred to as channel evolution. Disturbance can result from channelization, increased runoff due to build-out in the watershed, removal of streamside vegetation, and other changes that negatively affect stream stability. All of these disturbances occur in both urban and rural environments. Several models have been used to describe this process of physical adjustment for a stream. The Simon (1989) Channel Evolution Model characterizes evolution in six steps:

I. sinuous, pre-modified,

II. channelized,

III. degradation,

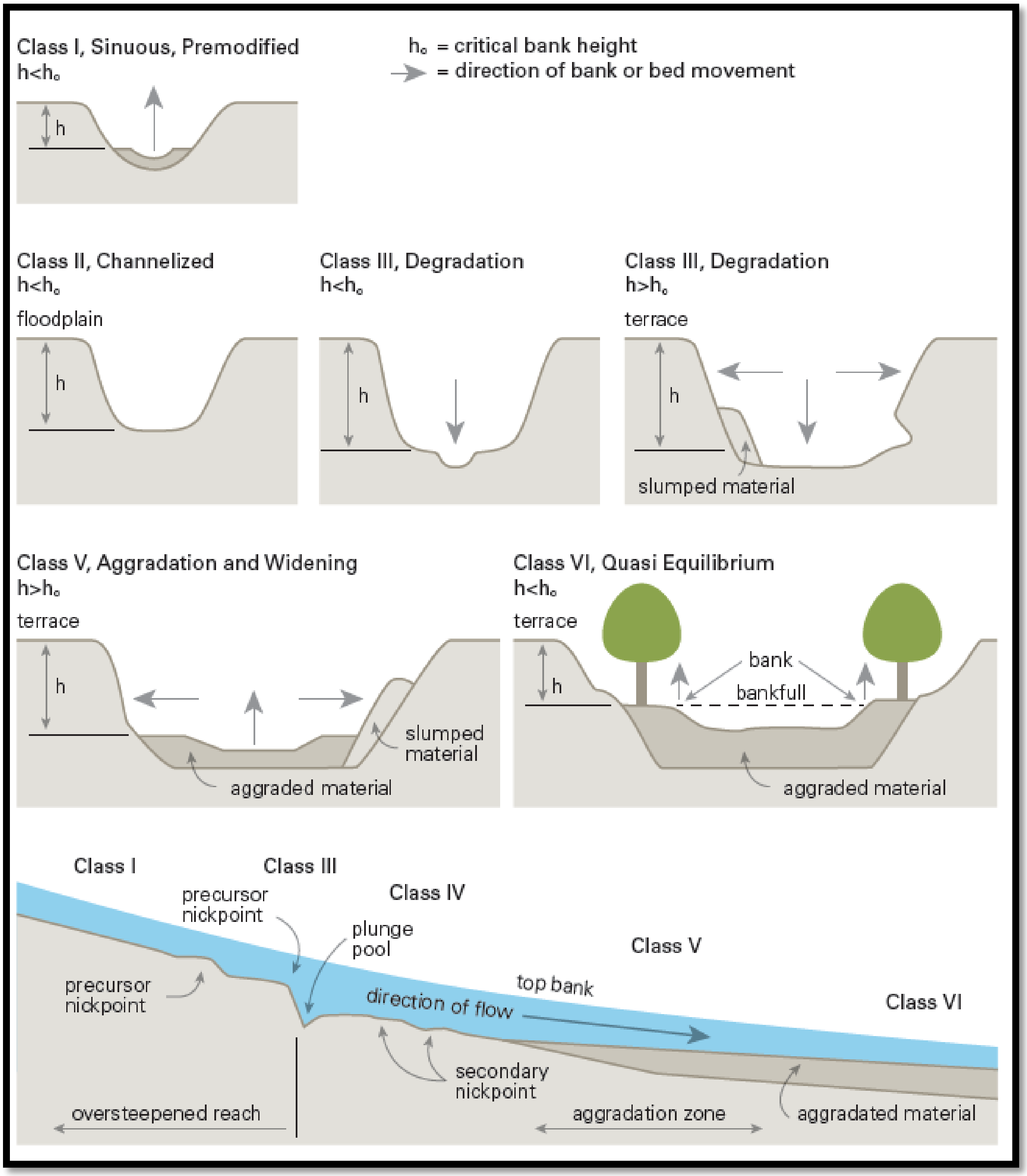
IV. degradation and widening,

V. aggradation and widening, and

VI. quasi-equilibrium.

Figure 13 illustrates the six steps of the Simon Channel Evolution Model.

Figure 13: Simon Channel Evolution Model

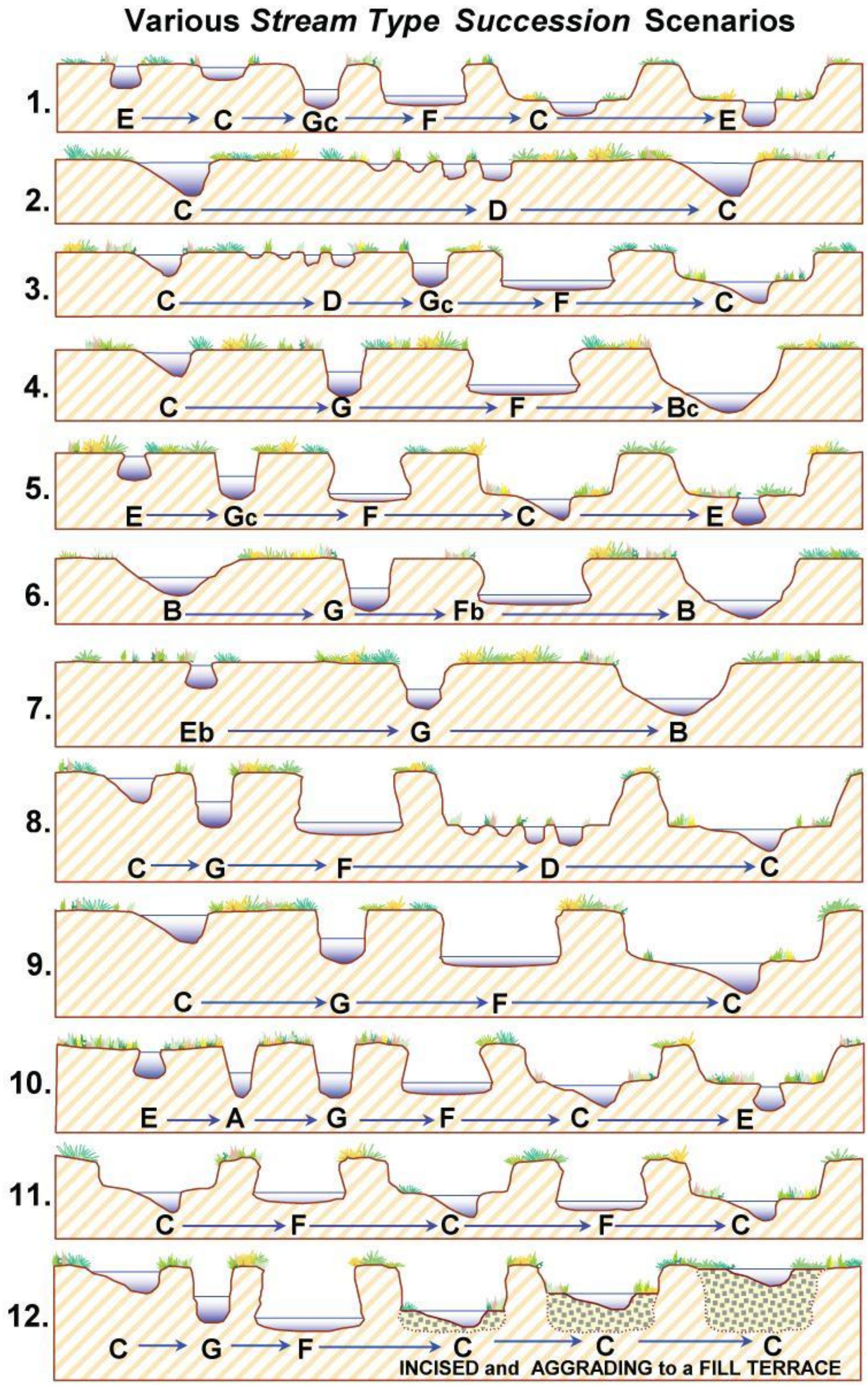


Source: Adapted from FISRWG (1998) and Simon (1989)

The channel evolution process is initiated once a stable, well-vegetated stream that interacts frequently with its floodplain is disturbed. This kind of disturbance commonly causes increased in-stream power that causes degradation, often referred to as channel incision (Lane, 1955). Incision eventually leads to over-steepening of the banks, and when critical bank heights are exceeded, the banks begin to fail, and mass wasting of soil and rock leads to channel widening. Incision and widening continue moving upstream in the form of a head-cut. Eventually, the mass wasting slows, and the stream begins to aggrade. A new, low-flow channel begins to form in the sediment deposits. By the end of the evolutionary process, a stable stream with dimension, pattern, and profile similar to those of undisturbed channels forms in the deposited alluvium. The new channel is at a lower elevation than its original form, with a new floodplain constructed of alluvial material (FISRWG, 1998).

The concept of channel evolution has also been described in terms of changes in Rosgen stream classification. Rosgen (2006) recognizes 12 scenarios by which a stable stream form is disturbed and subsequently evolves back to a stable stream type. These scenarios are based on observed changes from actual streams and represent a wide range of time spans, from several months to numerous years to complete the evolutionary steps shown in **Figure 14**.

Figure 14: Various Stream Type Succession Scenarios



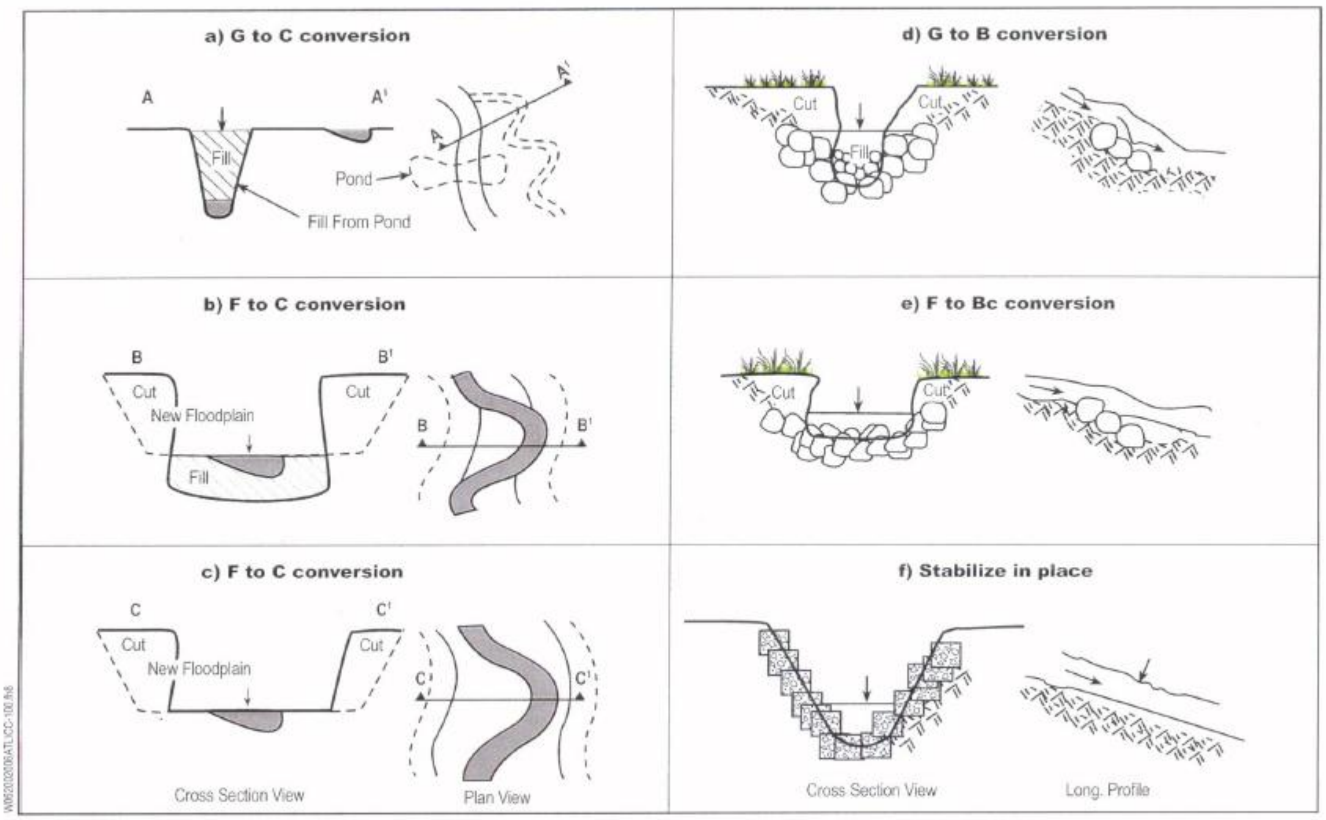
Source: Wildland Hydrology

6.8 Restoration Potential

Determining the restoration potential of a site combines the findings of the geomorphic assessments, the project goals, and the site constraints. The findings of the geomorphic assessments indicate how far the existing stream channel deviates from a stable, functional condition. Project goals will typically include providing long-term stability, reduced erosion rates, and improved ecological and water quality functions; however, goals will vary depending on the project. Likewise, site constraints will vary widely depending on the project, but may include utilities, structures, sensitive habitats to be protected, and available funding.

Since most degraded channels tend to be incised, a priority system for the restoration of incised streams, developed and used by Rosgen (1997), considers a range of options to provide the best level of stream restoration possible for a given setting. Though incised streams can occur naturally in certain landforms, they are often the product of disturbance. Characteristics of incised streams include high, steep stream banks; poor or absent in-stream or riparian habitat; increased erosion and sedimentation; and low sinuosity. Complete restoration, in which the incised channel's grade is raised so that an abandoned floodplain terrace is reclaimed, is the ideal, overriding objective of stream restoration; however, such an objective may be impractical when homes, roadways, utilities, or other structures have encroached upon the abandoned floodplain. **Figure 15** illustrates various restoration/stabilization options for incised channels within the framework of the Rosgen priority system. This priority system is discussed further in Section 8.2.

Figure 15: Restoration Priorities for Incised Channels



Source: Rosgen, David L., "A Geomorphological Approach to Restoration of Incised Rivers," *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*, 1997

Restoration Priorities for Incised Channels

7.0 GEOMORPHIC REFERENCE REACH SURVEYS

7.1 Role and Importance of Reference Reach Surveys

For the purposes of this manual, a geomorphic reference reach (referred to as reference reach previously and for the remainder of this document) is a segment of stream channel that is stable and supports high-level functions that are appropriate for its watershed and valley morphology. A reference reach moves the sediment and water generated by its watershed while maintaining dimension, pattern and profile without aggrading or degrading over time. The reach must be connected with its floodplain, such that flows larger than bankfull spread onto an active floodplain, and should exhibit a wide riparian buffer of native species appropriate for stream valleys in the region.

Reference reach surveys are field assessments conducted to quantitatively document the condition of the reference reach. Such surveys generally include measurements of stream pattern, cross-sectional dimensions at various bed features, and longitudinal profile measurements to evaluate channel and bed feature depths and slopes. Depending on the objectives of the project and location of the reference reach in relation to the project, reference reach surveys can also include assessments of bed materials, in-stream habitats, vegetation communities, water quality parameters, and aquatic life.

There are three main uses of the reference reach survey: a benchmark for evaluating morphological impairment, an aid in natural channel design, and post-restoration evaluation. A description of each is provided below.

1) By representing the stable, natural form of a stream, reference reaches serve as a benchmark for evaluating the degree of impairment.

   Reference reaches represent stable and highly functioning stream channels from a hydrologic, hydraulic, and geomorphic perspective. Therefore, data collected from reference reaches provide a standard against which lower quality streams can be compared. For example, collected data may indicate that reference reaches for a certain valley type have width-depth ratios ranging from 6 to 10. Impaired streams that are experiencing significant bank erosion and widening would likely exhibit higher width-depth ratios, with the degree of departure from the reference condition being indicative of the level of impairment. Similarly, impaired streams that are actively incising would likely exhibit lower width-depth ratios with corresponding increases to the bank height ratio. Such comparisons to reference conditions can be used to assess vertical and lateral stability, floodplain connectivity, bank erodibility, and bedform diversity.

2) As an aid in the natural channel design process.

   Reference reach data play an important role in the natural channel design process, as discussed in detail in Chapter 8. Reference reach data represent the stable channel condition that is to be achieved through the restoration design. As discussed in Chapter 8, it is not always appropriate to use reference data as the design condition, but restoration designs will ideally be completed in a way that will allow the stream to evolve towards reference conditions over time.

3) To evaluate post-restoration success.

   Similar to the discussion above, reference reach data provide a means of assessing restoration performance. Over time, the restoration reach should begin to exhibit stability and functions similar to the reference reach.

One of the most important tasks in natural channel design is the development of the design criteria. Design criteria provide the numerical guidelines for designing channel dimension, pattern, and profile. These criteria should come from a number of sources including reference reach surveys, modeling, and results of monitoring studies. If using reference reach data, it is best to use a composite database rather than one reference reach site. There is not a set number of reference reaches required to have a composite data set; however, it is generally best to have as many as possible. Sites selected for a composite data set should meet the requirements provided in Section 7.2 Site Selection. SARA is currently developing a reference reach survey database, which is described in Section 7.5 (check the SARA website http://www.sara-tx.org/ for periodic updates to the reference reach database). Further details concerning natural channel design criteria can be found in Chapter 8.

7.1.1 Reference Reach Considerations

The user of this manual should review the following considerations when evaluating the needs and uses of reference reach surveys on a particular project.

1) Reference reach surveys may not be required for all projects.

   Reference reach data are generally developed to assist in the design of full channel restorations and relocations, where parameters that define channel dimension, pattern, and profile are needed. Designs that involve channel realignment or relocation include changes to channel geometry and will benefit from the use of reference reach information. For projects that do not involve changes to channel geometry, reference reach surveys may not be necessary. For example, minor bank stabilization projects would not require a reference reach survey to develop stabilization designs.

   It should also be noted that if sufficient reference reach data are already available for a given stream type, additional reference reach surveys may not be necessary. This is particularly true if the available reference reach data have been used to develop successful restoration designs that are performing well.

2) Use of reference reach data in projects with constraints.

   To perform full restoration of a Rosgen C or E stream type, a wide floodplain and riparian buffer area are required. These projects tend to occur in less constrained locations, such as rural areas, where the design approach is not limited by site constraints. In more constrained areas, often a more practical approach is to enhance the functions of the existing stream. For enhancement approaches, reference reach data that describes channel pattern become less critical to the design effort, and such data are not required. Reference reach data for proper riffle and pool dimensions and channel profile are still required.

3) SARA will be developing a reference reach database.

   The goals of the reference reach database development are to provide design criteria data for natural channel design, to aid in the development of regional curves, and to provide data for comparison to post-restoration monitoring data.

   Designers must submit all reference reach surveys to SARA for QA/QC prior to use in the design process, and for inclusion in the SARA reference reach database.

7.2 Site Selection

Identifying an appropriate site for a reference reach is imperative and requires diligence and time spent “in the field” assessing potential sites. Reference reaches will be hardest to locate in areas that have been intensively modified for agriculture and/or development. In these areas, most stream channels have been modified and may be periodically maintained for drainage and flood control. Hey (2006) shows that, unlike regional curves, reference reaches do not need to come from the same hydrophysiographic region as the project site. Therefore, it is important to look in different regions if a reference cannot be found near the project. However, it should be noted that only channel pattern and profile ratios (listed in Sections 7.4.2 and 7.4.3) can be used for design purposes where a project site is located in a different hydrophysiographic region than the reference reach. Channel dimensions and hydrology must come from the same hydrophysiographic region as the project site.

In general, reference reaches should meet the criteria outlined below:

- Stable dimension, pattern, and profile
  - Single-thread channel
  - Bank height ratio less than 1.2, preferably 1.0
  - Stable banks – aggregate BEHI score of Low. However, some ephemeral channels may naturally have erosion rates that are higher. The appropriate BEHI category is unknown for ephemeral channels.
  - Natural features such as point bars may be present, but without excessive bar development, like mid-channel or transverse bars.
- Same stream type as the proposed design reach after restoration (i.e. C4, E5, etc.)
- Same valley type and approximate slope as study reach
- Same bed material as study reach (i.e. sand, gravel, cobble, bedrock, etc.)
- Exhibit the conditions above for a stream length of at least two full meander wavelengths, or 20 bankfull widths.
- Same type of bank vegetation as the proposed restoration site.

In order to select an appropriate reference reach, several tools are used in support of the identification process:

- <u>US Geological Survey Quadrangle Maps</u> – Quadrangle maps can be used to identify streams of a particular watershed size, valley type, and slope. Quadrangle maps also provide general information on watershed conditions and land-use, although these data should be checked against other more recent data sources (such as aerial photographs), since quadrangle maps are not updated very frequently.
- <u>Aerial Photographs</u> – Aerial photographs can be very useful in identifying potential reference reaches, and in further evaluating reference reaches identified by other maps, such as from a USGS quadrangle map. In the SARA four county jurisdiction, aerial photographs are available on-line, through county GIS-sites, regional planning websites, or public websites such as Google Earth. Please refer to the county specific website or contact the Information Technology group for each county to obtain aerials for each specific project. These photos are often of high quality, allowing the examination of stream size, length, pattern, riparian buffers, and watershed conditions. Evaluating multiple aerial photographs over time can provide additional support regarding stream stability by documenting stream dimension and pattern before and after flood events (Rosgen, 1998).
- <u>Windshield Surveys</u> – Many reference reach sites have been identified by simply driving and looking at streams at roadway stream crossings. Ensure that landowner permission to access the stream is obtained before entering private property.
- <u>Discussions with Local Residents</u> – Landowners and local residents are often very familiar with their land and the land that is nearby. These resources can often be used to identify streams that are in good condition and may potentially serve as a reference reach.
- <u>Looking Upstream and Downstream of the Project Reach</u> – When available, this is one of the best sources for reference reach data, because the reference reach and impaired reach targeted for restoration share the same climatic, topographic, and watershed conditions. As with windshield

surveys, ensure that landowner permission to access the stream is obtained before entering private property.

In urban environments, it is often difficult to identify true reference reach sites that meet the criteria above. Often, urban streams have been highly modified, either by direct manipulation or through modified hydrology from increased impervious surface runoff. While it is often difficult to identify a stable urban reference reach, it is not uncommon to find short segments of stable urban channel that can be used to evaluate stable bankfull dimensions. Such a stream segment is ideally located just upstream or downstream of the study reach, allowing for direct correlations to proper bankfull dimensions for the design. If the urban design allows for the full restoration of stream pattern and profile, these parameters are best taken from rural reference reaches and scaled to the appropriate size using the bankfull dimension determined from the urban reference segment.

Finding an applicable reach can be a time consuming process and a thorough investigation should be completed to ensure a suitable reference reach is located.

7.3 Methods for Completing Reference Reach Surveys

A reference reach survey consists of a detailed survey of channel dimension, pattern, profile, and stream bed materials. The survey may also include additional assessments such as in-stream habitats, vegetation communities, water quality parameters, and aquatic life. Based on the reference survey of channel dimension, pattern, and profile, the morphological parameters and ratios that describe the reference condition can be developed.

In general, the following survey points will be required along the reference reach so that the necessary calculations and ratios can be developed:

- Endpoints of flood-prone area (see **Figure 10**)
- Top of bank
- Breaks in slope along the cross-section and profile
- Terrace locations
- Bankfull indicators
    - Height of depositional features
    - Change in vegetation
    - Slope or topographic breaks along the bank
    - Change in the particle size of bank material
    - Undercuts in the bank (generally at a slightly lower elevation than bankfull stage)
    - Stain lines
- Thalweg (deepest point in the channel bed). Thalweg points are collected at the head of each feature (riffle, run, pool, and glide) and at the deepest part of the pool. Some studies also include the deepest part of the riffle, run, and glide as well.
- Water surface elevations at each thalweg point taken at the head of the feature. Do not collect a water surface point at the thalweg location for the deepest part of the feature.

All points surveyed will have a label associated with the point, generally an abbreviation for the type of point. For example, a left bank elevation point is labeled as LB and a right edge of water point as REW. For a standard list of stream survey labels, see Appendix D. Harrelson et al. (1994) provide additional information concerning basic surveying techniques for reference reach studies.

When conducting the reference survey, the vertical datum that was used must be noted. At minimum, a length of stream equal to at least two full meander wavelengths or 20 bankfull widths will be measured as a longitudinal profile. It is also essential to record locations and features through a photographic log, being careful to document where each photograph was taken (Harrelson et al., 1994).

The reference reach survey, as well as the resulting calculations, can be divided into three main components: channel dimension survey (cross-sections), pattern survey, and profile survey. In addition to the surveying, the stream bed materials and, in some cases, the vegetation communities are documented. Each of these components of the reference reach survey is described in the sections that follow.

7.3.1 Channel Dimension Survey (Cross-section)

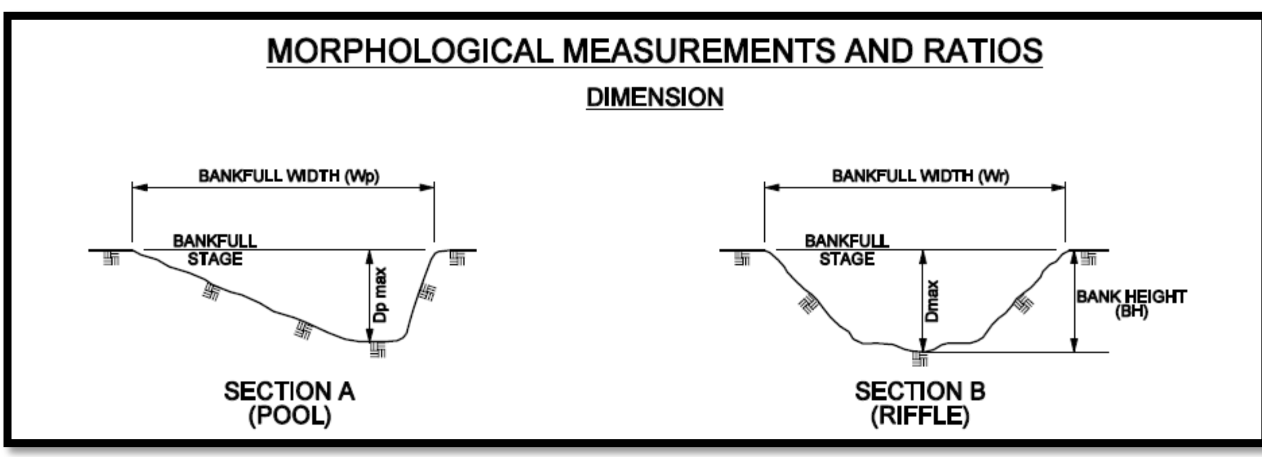
At least two riffle and one pool cross-sections are to be surveyed. For perennial streams with a drainage area greater than 5 square miles, a glide and run cross-section should also be completed. Points are taken at each break in slope along the cross-section, including the top of bank, bankfull, inner berm (if present), edge of channel, water surface, and thalweg. Outside channel points are taken at breaks in slope, flood-prone area limits, and top of terrace. A piece of rebar can be used as a marker for cross-section end points, if permitted by the landowner, and if future re-surveys are anticipated.

The measurements and calculations to be taken relating to channel dimension at each feature cross-section (riffle, pool, run, and glide) are as follows:

- Maximum Depth (D_{max})
- Width (W)
- Area (A)
- Mean Depth (D_{bkf})

Maximum depth (D_{max}) and bankfull width (W) measurements are illustrated in **Figure 16** along with information on measurement locations.

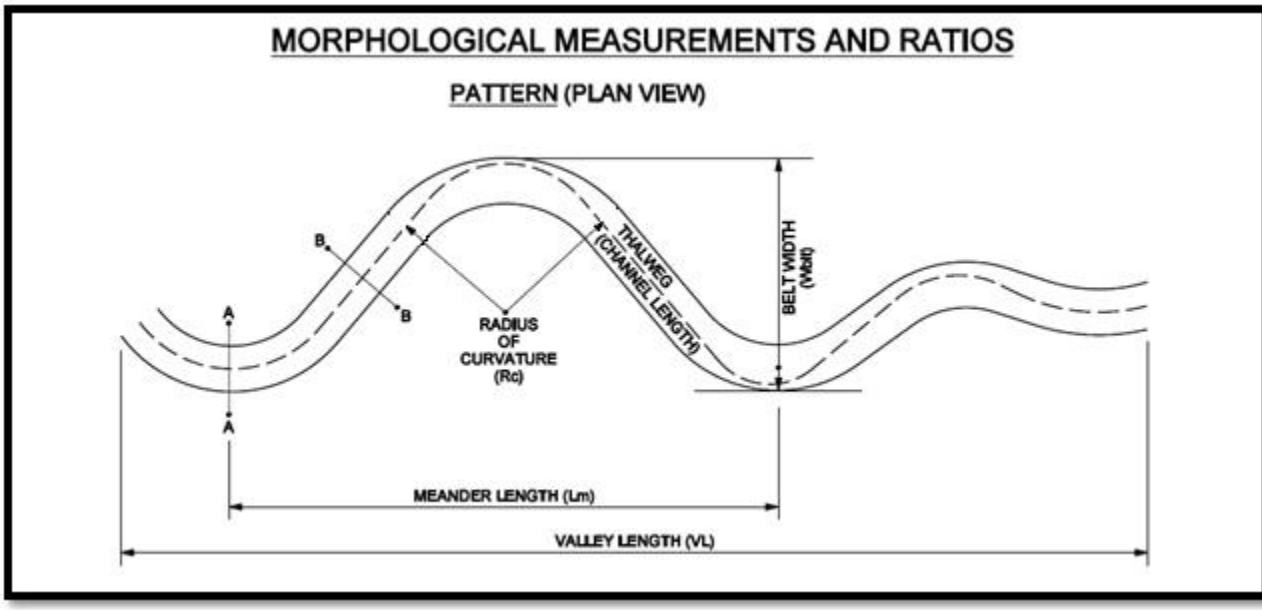
Figure 16: Morphological Measurements and Ratios – Dimension



7.3.2 Channel Pattern Survey

As shown in **Figure 17**, important measurements relating to the stream pattern are the linear meander length (L_m), radius of curvature (R_c), and belt width (W_{blt}). **Figure 17** presents the starting and ending locations of these measurements. Linear meander length (L_m) is the straight line distance between the apex of two right or two left meander bends. Radius of curvature (R_c) is the radius of a meander bend, measured to the center of bankfull channel. Belt width (W_{blt}) is the parallel distance between the outside of two sequential meander bends, measured from outside stream bank to outside stream bank.

Figure 17: Morphological Measurements and Ratios - Pattern



7.3.3 Channel Profile Survey

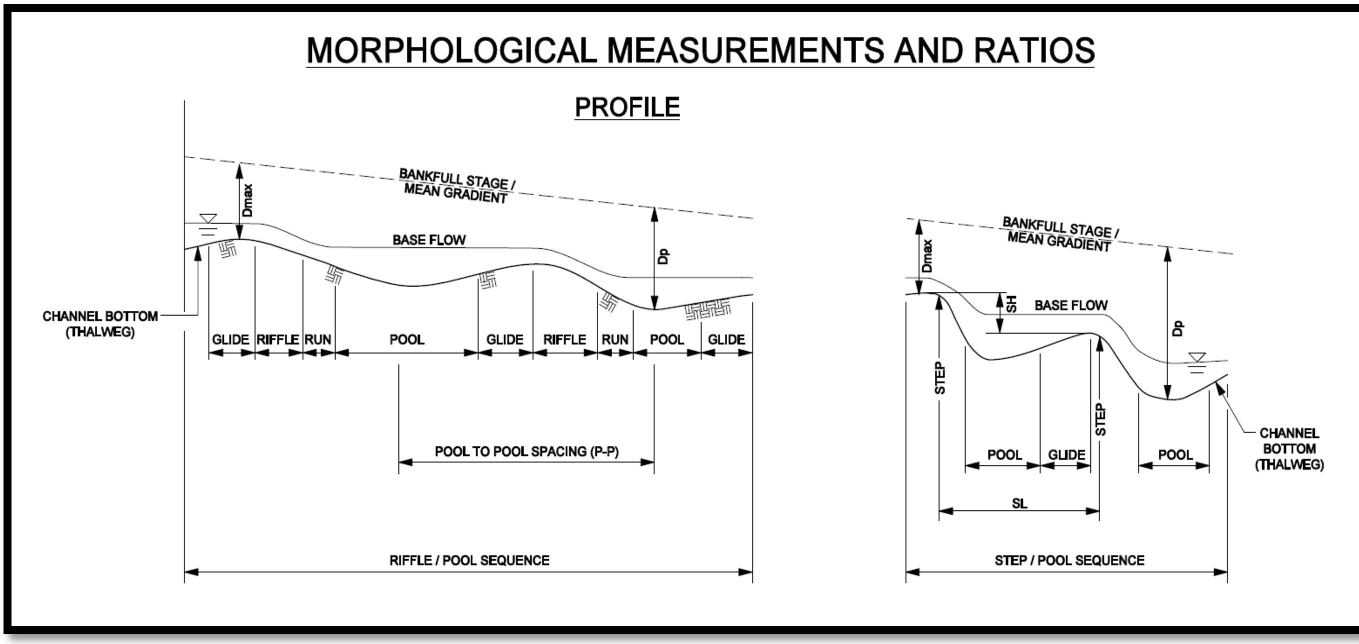
The length of the channel profile survey shall be at least two full meander wavelengths or 20 times the channel width at bankfull. This length will be sufficient to pick up multiple sets of riffle, run, pool, and glide features in order to determine their corresponding spacing. The slope of the channel is determined through the survey of the thalweg elevations along the reach.

Key measurements relating to the channel profile include:

- Valley Slope (VS)
- Average Water Surface Slope (S) (average thalweg slope if surveying a dry channel)
- Riffle Slope (S_{rif})
- Pool Slope (S_{pool})
- Pool to Pool Spacing (P-P)
- Pool Length (PL)
- Run Slope (S_{run})
- Glide Slope (S_{glide})
- Step Height (SH)
- Step Length (SL)

Figure 18 illustrates the distance measurements and presents the appropriate locations to obtain these values. Facet slopes (riffles, pools, runs, and glides) are measured as the slope of the water surface over the feature at base flow conditions. Riffles exhibit the steepest facet slopes, followed by runs, glides, and pools in order of decreasing slope.

Figure 18: Morphological Measurements and Ratios - Profile



7.3.4 **Bed Materials**

Bed material along the reference reach is documented using the pebble count procedure as described by Harrleson et al. (1994). A reach-wide pebble count of at least 100 particles is conducted to classify the stream bed material using the Rosgen (1996) methodology. For classification purposes, bed material sampling should occur across the entire bankfull channel, including bank areas that are lower than the bankfull stage. See Section 6.1.4.3 for more information on bed material sampling for stream classification.

7.3.5 **Vegetation Communities**

If a reference reach location contains native vegetation that is appropriate for the landscape and stream system, vegetation components shall be documented for the purpose of providing a reference for vegetation communities to be established at the restoration site. A reference quality vegetative community should have climax species and/or healthy vegetation that are representative of a mature riparian system. Documentation should include recording the species present, their densities, and approximate age class. Vegetation recorded should include canopy, sub-canopy, shrub, and herbaceous species. For recordation purposes, example recording worksheets are provided in Appendix E.

7.4 Reference Survey Calculations and Ratios

The measurements and data obtained in the field survey of the reference reach are used to develop dimensionless ratios based on bankfull parameters such as width or depth. For example, the Radius of Curvature Ratio is calculated by dividing the Radius of Curvature measurement (R_c) by the Riffle Bankfull Width (W_r). By developing dimensionless ratios for reference reaches, values for different sized reference reaches may be compared and used to develop typical ratio ranges for comparison with impaired reaches. The dimensionless reference reach ratios also aid in natural channel design: by knowing the bankfull width, depth, and area of an impaired study reach, stable design parameters can be estimated by multiplying the study reach bankfull values by the reference reach dimensionless ratios.

7.4.1 Channel Dimension (Cross-section) Calculations

Channel dimension calculations based on measurements shown in **Figure 16** are listed below. The mean velocity and discharges can be estimated using Manning's equations, HEC-RAS, or an actual flow measurement.

- Mean Pool Depth / Mean Riffle Depth (D_p / D_{bkf})
  (Mean depths are calculated by dividing the bankfull cross-sectional area by the bankfull width. They do not represent a physical feature.)
- Pool Width / Riffle Width (W_p / W_r)
- Pool Area / Riffle Area (A_p / A_r)
- Maximum Pool Depth / Mean Riffle Depth (D_{pmax} / D_{bkf})
- Lowest Bank Height / Maximum Riffle Depth (BH_{low} / D_{max})
- Maximum Riffle Depth / Mean Riffle Depth (D_{max} / D_{bkf})
- Riffle Width / Mean Riffle Depth (W_r / D_{bkf})
- Run Depth / Mean Riffle Depth (D_m / D_{bkf})
- Glide Depth / Mean Riffle Depth (D_{gl} / D_{bkf})
- Estimated Mean Velocity (u) at Bankfull Stage
- Estimated Discharge (Q) at Bankfull Stage

7.4.2 Channel Pattern Calculations

Channel pattern calculations based on measurements shown in **Figure 17** are listed below.

- Radius of Curvature / Riffle Width (R_c / W_r)
- Meander Length / Riffle Width (L_m / W_r)
- Meander Width Ratio (MWR) = Belt Width / Riffle Width (W_{blt} / W_r)
- Sinuosity (K) = Channel Length / Valley Length

7.4.3 Channel Profile Calculations

Channel profile calculations based on measurements shown in **Figure 18** are listed below.

- Riffle Slope / Average Water Surface Slope (S_{rif} / S)
- Pool Slope / Average Water Surface Slope (S_{pool} / S)
- Run Slope / Average Water Surface Slope (S_{run} / S)
- Glide Slope / Average Water Surface Slope (S_{glide} / S)
- Pool Length / Riffle Width (PL / W_r)
- Pool to Pool Spacing / Riffle Width (P-P / W_r)

7.4.4 Common Reference Reach Ratios

Harman and Starr (2011) provide common reference reach ratios for a variety of stream types in Appendix F of their document. In the absence of local data, this data set may be used as a comparison against a single reference reach, i.e., a draft composite data set. Please note that these values were developed primarily from reference reach streams in the southeastern US, and are provided as typical ratio ranges. Actual measured ratios may vary from these ranges, depending on channel slope, geography, topography, vegetation densities, and climatic conditions.

7.5 SARA Survey Database

SARA is currently developing a reference reach database that will include data collected by SARA, their consultants, and other partners. As this database develops, more details will be included in this section concerning the specific type of information required for database entry. Currently, the Rosgen reference reach worksheet 5-4 should be filled out and submitted for database use. The Rosgen worksheet 5-4 can be found in Appendix E.

8.0 NATURAL CHANNEL DESIGN METHODS

A stable stream moves and stores the sediment and water generated by its watershed while maintaining its geometry without aggrading or degrading. A successful project will provide increased habitat and stable channel plan and profile. Channel stability doesn't mean that there won't be adjustments to channel geometry after restoration construction. Rather, a restored channel will continue to adjust its form to provide a higher level of aquatic functionality, ultimately meeting the quality of the reference condition. To achieve this, it is usually necessary to involve a variety of specialists including biologists, hydrologists, and engineers who understand the components of natural channel design.

8.1 Developing Function- Based Assessments and Design Goals

Natural channel design seeks to restore stream functions in a logical order, recognizing that higher level functions are supported by lower level functions. Harman et al. (2012) provides a framework for developing function-based assessments and setting goals and objectives based on the potential for functional lift. The framework is based on the Streams Function Pyramid which is shown in **Figure 19**. The Stream Functions Pyramid Framework is shown in **Figure 20**. Chapter 4 of Harman et al. (2012) provides a detailed description of the Stream Functions Pyramid Framework. Chapter 11

Harman et al. (2012) describes how to apply the framework including steps and examples for developing function-based assessments and setting goals and objectives. Forms are provided in the document for showing functional lift. Practitioners are encouraged to use this resource to determine the baseline function-based condition of a project reach, as an aid in predicting restoration potential and for predicting and evaluating functional lift. Once a function-based assessment has been completed, design goals and objectives should be developed. The goals should state why the project is being completed and what functions will be restored. The objectives should state how the functions will be restored, relating restoration activities to function-based parameters from the framework.

Fischenich (2006) reports that a common goal of stream restoration is to restore stream habitat. However, he points out that habitat has the least effect on the other functions and is affected by the most functions. The Stream Functions Pyramid can be used by practitioners to establish goals that are more specific than restoring habitat. It can also be used to identify and think through the underlying, supporting functions that would need to be addressed to achieve a desired result.

Restoring habitat as a goal is too broad. One could ask, “Habitat for whom?” Most of the planet provides habitat for something, so a goal like this does not communicate why the project is needed or what it hopes to accomplish. A better goal would be to restore habitat for a specific species of concern, e.g. a native fish species. Of course, this goal should come after some form of functional assessment has been completed to determine that their habitat is in need of restoration and that the watershed can support the species of interest if the reach is restored. The Pyramid framework can assist with this process by helping the restoration team think through the underlying functions that are needed to support the species of interest. First, it must be acknowledged that restoring a fish species is a Level 5 function, it relates to the life history of an aquatic organism. So, the team would “enter” the Pyramid at Level 5. If they enter at Level 5, there must be supporting functions in Levels 1-4. Now, the team must identify those functions and function-based parameters. Again, this is not a cookbook, and the Pyramid does not automatically prescribe the supporting functions. This is a thought process that requires qualified professionals to be able to identify the appropriate parameters. For example, the first question might be, “what are the Level 4 function-based parameters that are needed to support the species of interest?” The answer might include appropriate “temperate and oxygen regulation.” Water quality must also be sufficient to support fish populations, which could be affected by lower level functions at a reach scale, as well as the health of the upstream watershed. Using the temperate and oxygen regulation as an example to further explore how the Pyramid can be used, the team might ask, “how do we achieve the proper temperature and oxygen regulation? What are the supporting function-based parameters?” The answer is found in Level 3.

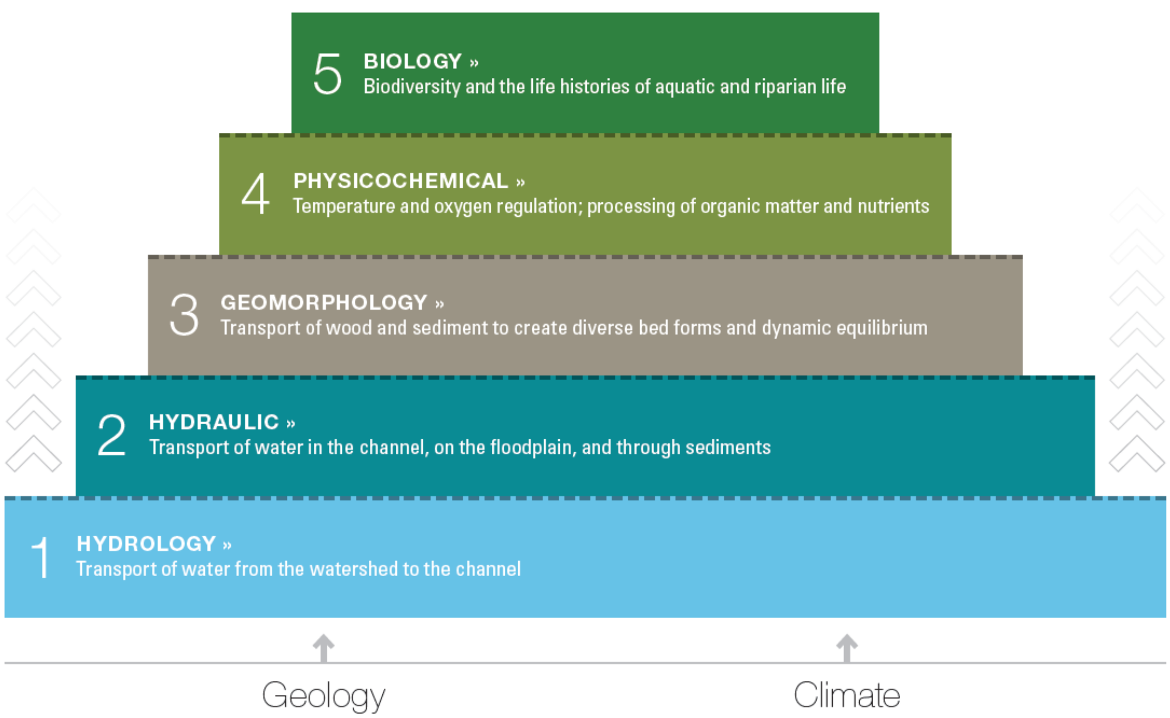
Geomorphology function-based parameters like bank migration/lateral stability, bed form diversity, and riparian vegetation affect temperature and oxygen regulation. This is a critical understanding, because these parameters can be manipulated as part of the design to change oxygen and temperature regulation. For example, the channel form can be changed to create riffles and deep pools, banks can be stabilized, and the riparian corridor can be planted. The Level 4 parameter of oxygen and temperature regulation cannot be directly manipulated; rather, changes at level 3 are made to affect changes at level 4.

The thought process continues. The team can now ask, “What Hydraulic (Level 2) function-based parameters are needed to support bank migration/lateral stability, bed form diversity, and riparian vegetation?” In this case, all of the Level 2 function-based parameters (floodplain connectivity, flow dynamics, and groundwater/surface water exchange are important to support the identified Level 3 functions as well as Level 4 functions. Floodplain connectivity minimizes the amount of energy and force within the channel banks by dissipating flood energy on a floodplain or floodprone area. However, the appropriate amount of energy is maintained in the channel to support the creation of appropriate bed forms, e.g. riffles and pools. Floodplain connectivity also affects flow dynamics and groundwater/surface water interaction, which helps create healthy hyporheic zones that can regulate water temperature and support macroinvertebrate populations, among other benefits. Floodplain connectivity is also a function-based parameter that can be directly modified by a restoration team and if often considered the most important restoration activity because it supports Level 2-5 functions.

Finally, the team can ask, "What Level 1 function-based parameters are needed to support the higher level function-based parameters listed above?" These function-based parameters support functions from Level 1 through Level 5. Level 1 function-based parameters, including channel forming discharge, precipitation/runoff, and flow duration, are important to restoring fish populations. The channel forming discharge is used to determine how large the channel should be and is directly used to determine floodplain connectivity. Runoff is a watershed calculation and may or may not be modified based on the size of the watershed, property control, and condition. Flow duration is typically determined by watershed conditions, but can be moderately improved by some restoration activities. It is important to evaluate these Level 1 parameters to make sure that the Hydrology can support the project goals. And of course, if the underlying geology or climate regime does not support the species of interest, the project should not be attempted.

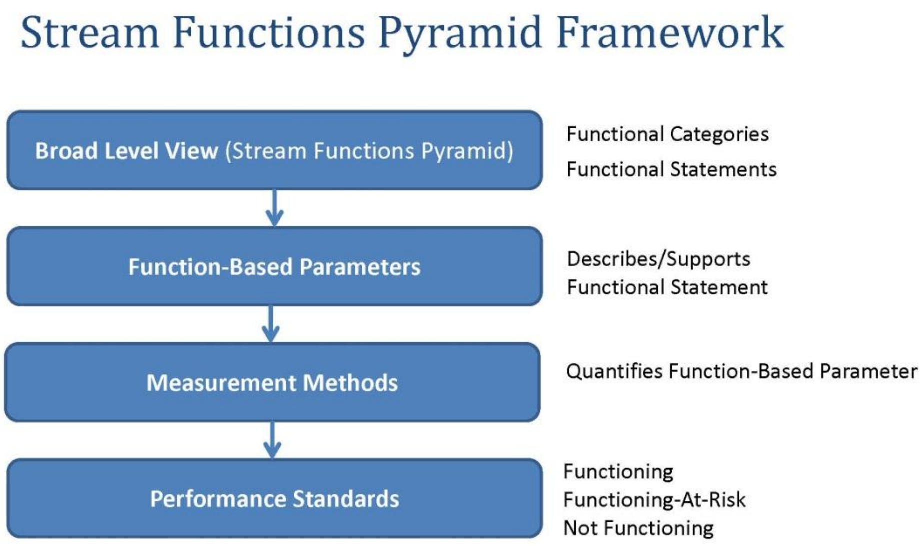
This is a simple example of how the Pyramid can be used as a process for developing and thinking through reach scale project goals. Other function-based parameters could be identified, but questions about the supporting functions would be the same. And there are certainly many other goals that could be considered. For example, improving water quality is another common goal. Like habitat, this goal could be improved by being more specific. What water quality issues are being addressed; temperature and oxygen, nutrients, conductivity, pH, etc.? The answer to this question will help the restoration team identify the supporting functions required to make this improvement and to determine if restoration activities that change function-based parameters are needed or should things outside of the Pyramid be addressed, e.g. stormwater best management practices.

Figure 19: Stream Functions Pyramid – Overview



Source: Reprinted with permission from Stream Mechanics

Figure 20: Stream Functions Pyramid Framework



Source: Reprinted with permission from Stream Mechanics

8.2 Restoration Alternatives for Incised Streams

Incised channels are good candidates for stream restoration projects. Stream incision can occur naturally in certain landforms, but more often it is the product of human disturbance. Characteristics of incised streams include high, steep stream banks; poor or absent in-stream or riparian habitat; increased erosion and sedimentation; and low sinuosity for streams in alluvial valleys. Complete restoration, in which the grade of the incised channel is raised so that an abandoned floodplain terrace is reclaimed, often provides the highest level of functional lift. Raising the bed, however, may be impractical when homes, roadways, utilities, or other structures have encroached upon the abandoned floodplain. A priority system for the restoration of incised streams, developed by Rosgen (1997), considers a range of options to provide the best level of stream restoration possible for a given setting.

Figure 21,

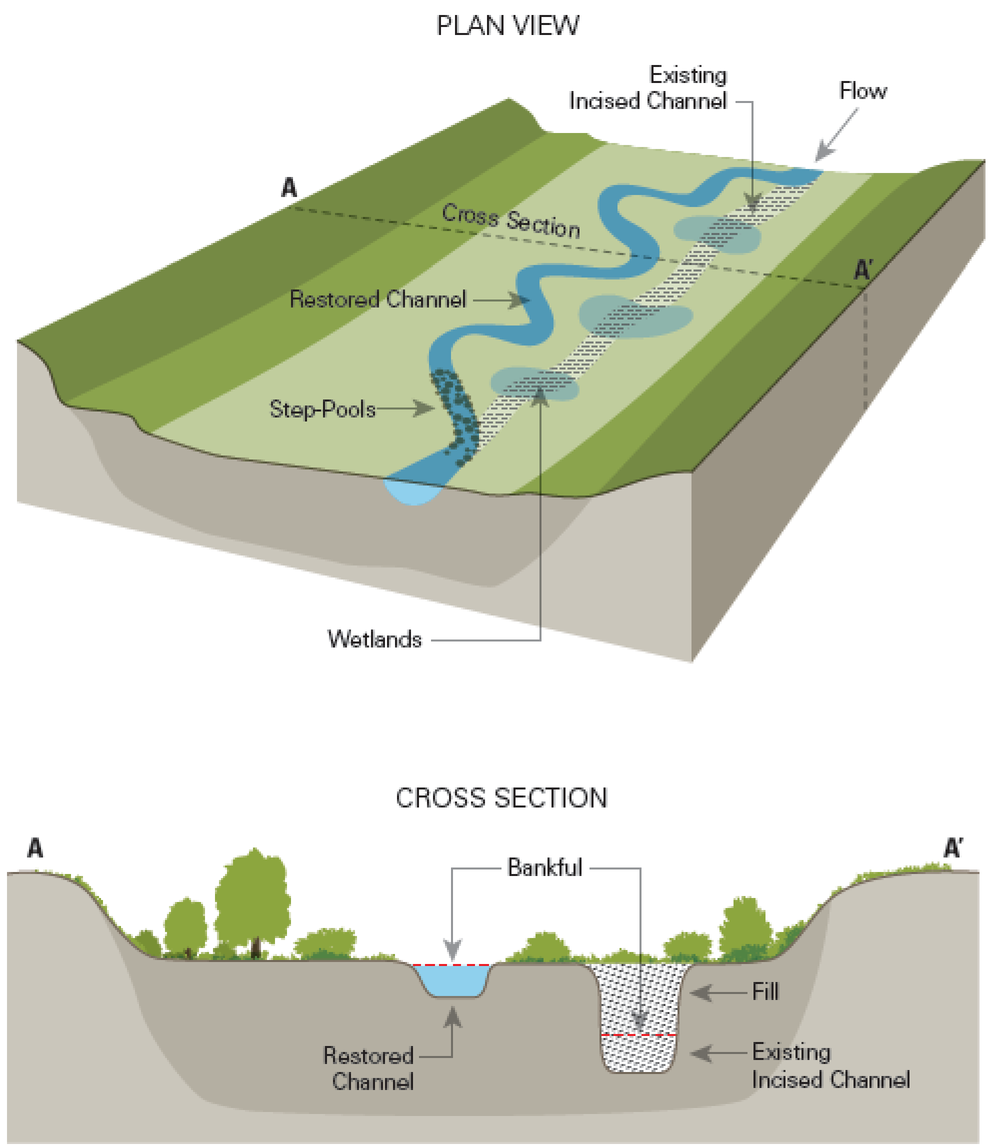
Figure 22, and

Figure 23 illustrate various restoration/stabilization options for incised channels within the framework of the Rosgen priority system.

Generally:

- Priority 1 – Re-establishes the channel on a previous floodplain (i.e., raises channel elevation); restores a new channel to achieve the dimension, pattern, and profile characteristic of a stable stream for the particular valley type; and fills or isolates the existing incised channel. This option requires that the upstream start point of the project not be incised.

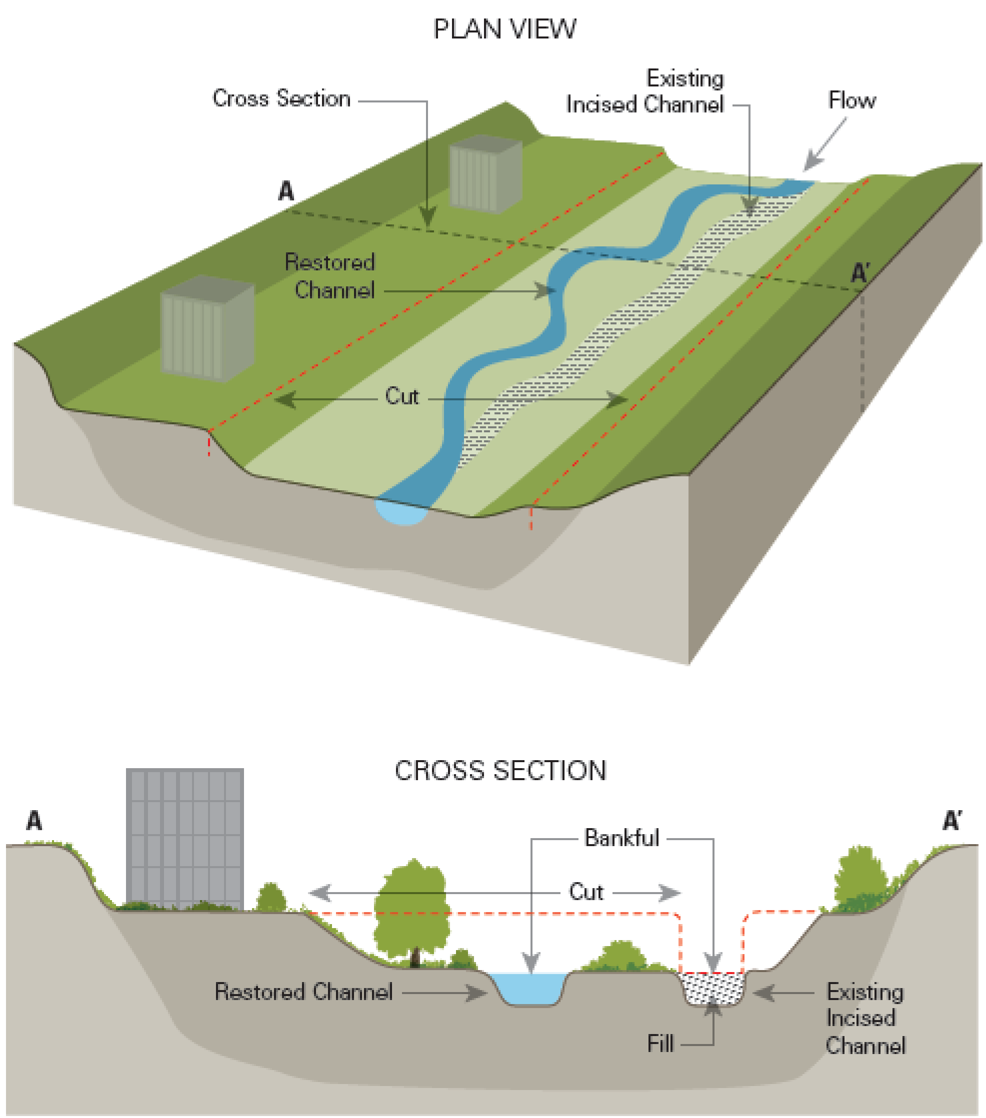
Figure 21: Priority 1 Restoration



Source: Reprinted with permission from Stream Mechanics. Adapted from Rosgen (1997)

- Priority 2 – Establishes a new floodplain at the existing bankfull elevation (i.e., excavates a new floodplain); restores the channel to achieve the dimension, pattern, and profile characteristic of a stable stream for the particular valley type; and fills or isolates the existing incised channel.

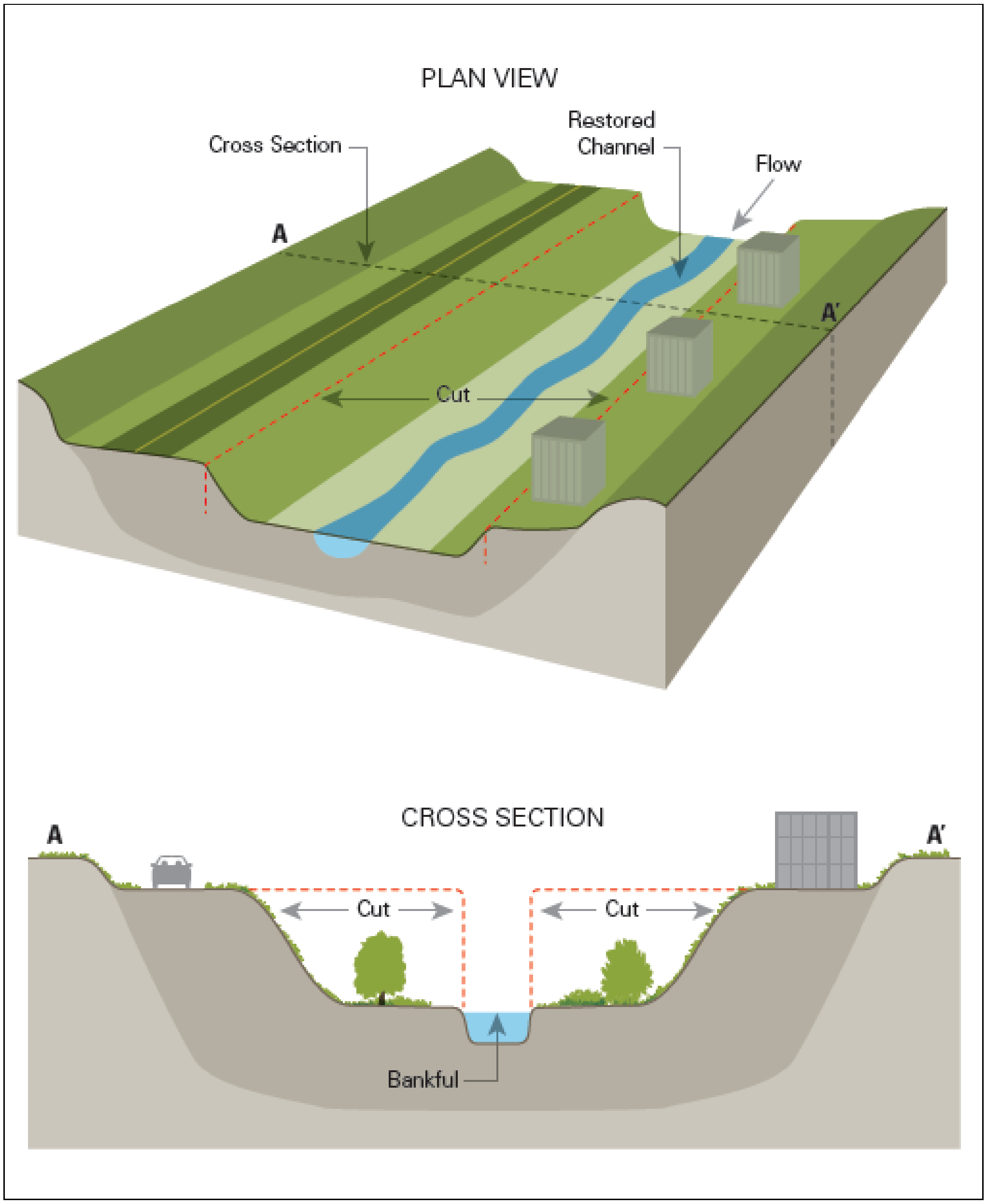
Figure 22: Priority 2 Restoration



Source: Reprinted with permission from Stream Mechanics. Adapted from Rosgen (1997)

- Priority 3 – Converts a straight channel to a different stream type while leaving the existing channel in place, by excavating bankfull benches at the existing bankfull elevation. Effectively, the valley for the stream is made more bowl-shaped. This approach uses in-stream structures to dissipate energy through a step/pool channel type.

Figure 23: Priority 3 Restoration



Source: Reprinted with permission from Stream Mechanics. Adapted from Rosgen (1997)

- Priority 4 – Stabilizes the channel in place, using in-stream structures and bioengineering to decrease streambed and stream bank erosion. This approach is typically used in highly-constrained environments.

8.3 Develop Preliminary Design

Once project constraints have been analyzed and the level of the potential restoration is known, a preliminary design can be developed. The preliminary design equates to a 30% design plan submission. The primary purpose is to provide a proposed channel alignment to the landowners and stakeholders to allow them to gain a better understanding of the proposed design. The landowners and stakeholders are able to review the preliminary design and either approve it or request modifications. If any aspect of the preliminary design is unacceptable to the landowners or stakeholders, modifications can be made at the early stage of design. This avoids costly and time-consuming redesign that would occur at the final design stages. In some cases, it may be beneficial to include more than one alignment so that the landowners and stakeholders can decide which design they prefer.

A meandering channel can only be accomplished if there is sufficient room to implement a sustainable pattern. To determine if a meandering channel can be designed within the limits of a drainage project, measure the width along the project corridor that is available to construct the channel. Is the area free of constraints and can it be disturbed as part of the construction? If the available width of the work area is at least five times the width of the design riffle, there is sufficient room to design and construct a meandering stream channel.

The preliminary design alignment should include the centerline and bankfull width (i.e. top of bank lines). Bankfull cross-sections for a typical riffle and typical pool should be provided. Larger streams may also include typical cross-sections for runs and glides. The typical cross-sections should show the shape of the channel and, at a minimum, the bankfull width, bottom width, maximum depth, and bank slopes.

At the preliminary design stage, the channel width can be obtained from the regional curve data. The belt width, wavelength, and radius of curvature can be taken from appropriate reference reaches. The design of the profile should be sufficient to determine the level of restoration (Priority 1, 2, or 3). Further detailed analysis of design ratios will be completed at the later design phases. It is not necessary for the preliminary plans to include any in-stream structures or a planting plan. Easement and/or construction limits may be appropriate for inclusion at this stage in design, depending on the requirements of the project and stakeholders.

8.4 Developing Final Design Criteria

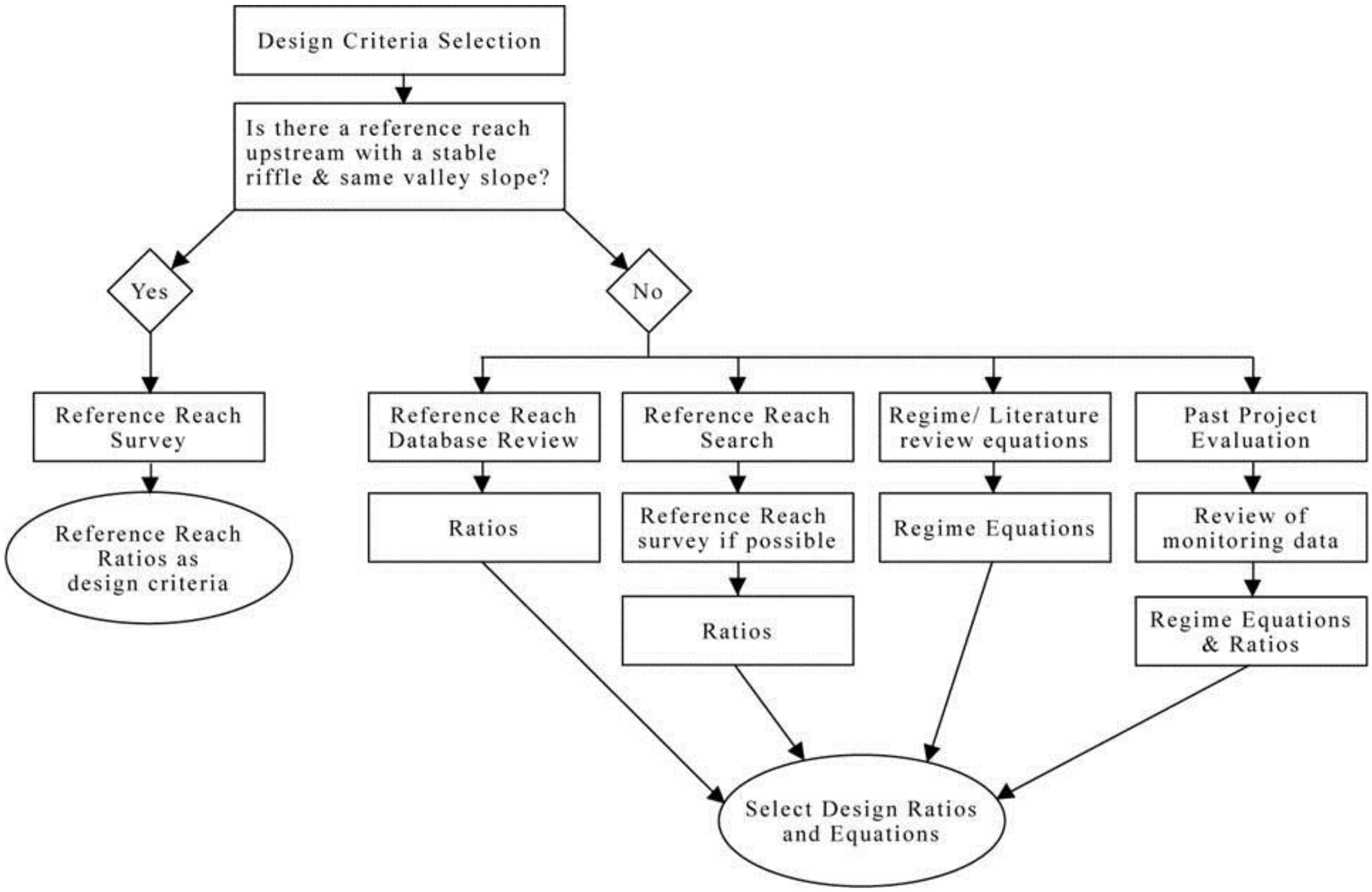
The development of design criteria is one of the most important tasks in a natural channel design. Design criteria provide the numerical guidelines for designing channel dimension, pattern, and profile and should be developed in concert with the design goals, constraints, and restoration potential. Design goals establish the reason for pursuing a natural channel design project and should be based on improving specific stream functions as described in Section 8.1. The constraints establish the level that functions may or may not be restored. For example, upstream impairments may not provide sufficient base flow or water quality to improve fish species diversity or abundance; however, a reduction in streambank erosion may be achievable. With a clear understanding of the goals, constraints, and the existing geomorphic condition, the restoration potential can be determined. High level restoration may include re-connecting a meandering stream to a previous floodplain (current terrace) and establishing a wide riparian corridor. More constrained, typically urban, environments may require a straighter channel that focuses on dissipating energy through a step-pool channel form. This approach can still improve channel stability and bedform diversity. Once these project elements are known, the design criteria are developed for the new stream type. Different criteria will be used depending on the restoration potential (e.g. design criteria for a C/E stream type are different than for a B stream type).

This section describes the basic design steps for completing a natural channel design but is not to be used as a comprehensive design methodology. Design criteria can and should come from a number of different sources. Lessons learned from past project evaluations should play a major role in making final design criteria decisions. Ultimately, professional judgment is required to select the final criteria, which is why design experience is critically important. Please see the Rosgen Geomorphic Channel Design methodology as described in Chapter 11 of the Natural Resources Conservation Service (NRCS) handbook: Part 654 – Stream Restoration Design (2007) for detailed design methods.

Basic design criteria guidelines are provided below. These guidelines are provided as a general overview of how to prepare a natural channel design. However, additional techniques and analyses may be required based on specific project requirements. The designer is responsible for knowing when and how to apply the appropriate design criteria methods.

Figure 24 presents a flow chart that will lead the designer through the standard steps of developing the design criteria. A description of this process follows.

Figure 24: Design Criteria Selection Flow Chart



8.4.1 Reference Reaches

Reference streams are stable reaches that provide data and information useful to the natural channel design process, as described in Chapter 7. Reference reach ratios that describe and quantify the reference reach dimension (cross-section), pattern (alignment), and profile (slope) provide guidelines for stable ratios to be used in the design process. However, the designer should be cautioned that using reference reach ratios without consideration for how newly constructed stream reaches differ from mature reference reaches will likely lead to stability problems on projects.

Reference reaches are difficult to find in many parts of the United States that have experienced urban and suburban growth. Many reaches are found to be located near constraints where the stream pattern is not free to form without influence from these constraints. As a result, the stream pattern ratios may not be suitable for design projects. It is imperative that the designer does not rely solely on the data from reference reaches to develop their design criteria. Reference reach survey calculations (ratios) should be compared to other methods, including analytical models (Copeland et al., 2001), regime equations (Hey, 2006), and empirical relationships. It is always best to use a composite database rather than one reference reach site. SARA is currently developing a reference reach survey database for the San Antonio Basin, which is described in Section 7.5 of this document, and will be monitoring restored stream sites over time to evaluate project performance and aid in future designs.

The following ratios should typically be modified to account for the lack of vegetation following construction. A comparison of typical reference reach reaches and suggested changes, shown as design criteria, are provided in in Appendix F of Harman and Starr (2011).

- Minimum width to depth ratio (W/D) is increased to provide a wider design channel and reduce the stresses placed on stream banks until vegetation can become established. Caution: The W/D ratio should not be increased to a point where aggradation occurs or the bottom width is wider than reference conditions.
- Radius of curvature ratios (R_c/W_{bkf}) are also increased to reduce stresses placed on the outside of the meander bend, so outside banks remain stable while vegetation becomes established.
- Maximum riffle slope ratio (S_{rif}/S_{chan}) is decreased from typical reference conditions. Newly constructed stream beds lack the sorting of bed substrate and armor layer that naturally develop is streams over time with subsequent flooding events. Steeper riffles can be designed, but may require a constructed riffle of larger bed material or other structure to provide grade control.
- Pool width ratios (W_{pool}/W_{bkf}) are increased above what is common in reference reaches. This is a more conservative approach, reducing stresses placed on the outside meander bend and allowing a point bar to form over time.

8.4.2 Lessons Learned through Monitoring

Completed natural channel design projects that have performed well over several seasons and large storm events can and should be used as design references when available. Past monitoring experience has shown that completed projects should be evaluated soon after construction since this is the time period when the project cannot rely on vegetation to provide stability. If the channel is stable after a floodplain event without vegetation, there is a high likelihood of long term success.

Previous experience is extremely valuable in developing design criteria and has shown that when evaluating the pattern of C/E stream types:

- Meander width ratio should not be less than 3.0 to 3.5
- Pool to pool spacing ratio should not be less than 3.0
- Riffle angles should typically range from 30 to 75 degrees off the fall line to the valley, but can be higher for low slope valleys.
- Radius of curvature ratios should not be less than 2.0 without significant bank protection.

When the above criteria are violated, the results are often damaging. Riffle angles over 75 degrees to the fall of the valley may result in erosion near the downstream end of the meander bend, and/or increased potential for cut-offs to form across point bars and resulting instability. When the meander width, pool to pool spacing, and/or radius of curvature ratios are less than the suggested values provided here, meander pool formation on the outside of bends will be negatively affected, providing increased potential for channel instability and erosion due to increased stream energy (Harman and Starr, 2011).

8.4.3 Regime and Analytical Equations

There are a variety of regime and analytical equations available to designers to provide additional guidance and cross-checks for design criteria developed from reference reach information. It should be noted that currently there are no regime or analytical based methods that can be used to fully develop a natural channel design. Rather, these methods can be used to provide additional insight and confidence in the design criteria ranges developed from reference reaches and past project experience. They can be used to test a natural channel design for potential areas of instability. Several publications that discuss the use of regime equations and analytical models are provided in the list below.

- Copeland, R. R, D. N. McComas, C. R. Thorne, P. J. Soar, M. M. Jonas, and J. B. Fripp. *Hydraulic Design of Stream Restoration Projects*. September 2001. Coastal and Hydraulics Laboratory; ERDC/CHL TR-01-28.
- Hey, R. D. *Fluvial Gemorphology Methodolgy for Natural Stable Channel Design*. April 2006. Journal of American Water Resources Association.
- Federal Interagency Stream Restoration Working Group (FISRWG). 1998. *Stream Corridor Restoration: Principles, Processes and Practices.* National Technical Information Service. Springfield, VA.

8.5 Natural Channel Design

The subsections that follow provide detailed steps for developing the channel geometry components of a natural channel design. The sections are organized in the order that they should be completed when going through the design process, and describe the steps involved with designing the channel dimension, pattern and profile. The following steps outline the design calculation procedures based on the procedure described in Chapter 11 of the NRCS National Engineering Handbook, Part 654 – Stream Restoration Design.

8.5.1 Design Channel Dimension

Channel dimensions consist of cross-section widths, depths, and areas. The cross-section should be sized to carry no more than the bankfull discharge. Flows larger than bankfull should be transported on a floodplain (in alluvial valleys) or a flood-prone area (in colluvial valleys). A low flow channel should also be sized to maintain baseflow depths. Designing the riffle cross-section is one of the most important aspects of the design. If it is improperly designed, the pattern and profile will be wrong as well, as these are sized based on the designed channel width.

Step 1. Determine the design riffle bankfull cross-sectional area. Use the regional curve, stable riffle from the project reach, watershed build-out scenarios, and reference reach information (see above discussion about design criteria).

Step 2. Select a bankfull W/D ratio using reference reach information, stable riffles from the project reach, type of bank vegetation, and type of bed and bank material.

Step 3. Calculate the riffle bankfull width as Wbkf = $\sqrt{A_{bkf} * W / D}$

Step 4. Calculate the bankfull mean riffle depth as dbkf = Abkf / Wbkf

Step 5. Calculate the bankfull max riffle depth as Dmax = dbkf * ($Dmax_{ref}$ / $dbkf_{ref}$). The subscript *ref* means that these values are from the reference reach / design criteria analysis.

Step 6. Calculate the bankfull pool cross-sectional area as APbkf = Abkf * ($APbkf_{ref}$ / $Abkf_{ref}$)

Step 7. Calculate the bankfull pool width as WPbkf = Wbkf * ($WPbkf_{ref}$ / $Wbkf_{ref}$)

Step 8. Calculate the bankfull pool mean depth as dPbkf = $APbkf_{ref}$ / $WPbkf_{ref}$

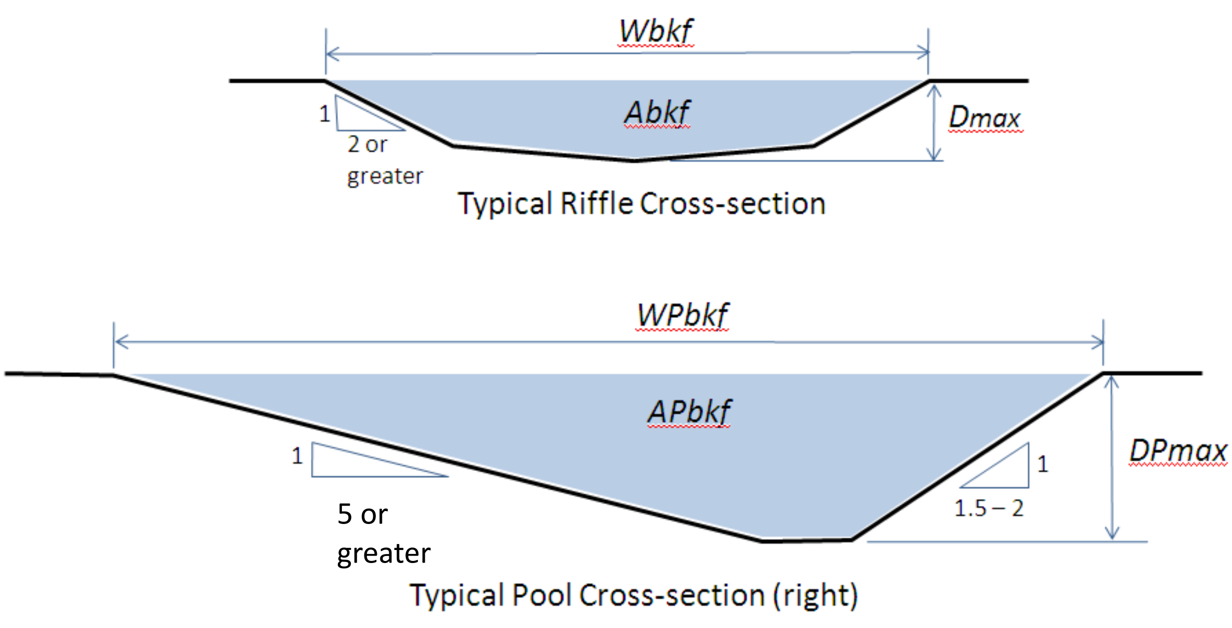
Step 9. Calculate the bankfull max pool depth as DPmax = dbkf * ($DPmax_{ref}$ / $dbkf_{ref}$)

Step 10. Calculate the bankfull W/D for the pool

Step 11. This same approach can be used for the run and glide.

A trapezoidal channel shape, with a concaved bottom, is used for the riffle sections of the design channel. In meandering channels, pools develop within the meander bends and form cross-section shapes that are skewed with the deepest part of the pool being toward the outside of the bend. Once the design dimensions for the riffle and pool sections have been determined using the steps outlined above, the cross-section design can be developed as illustrated in **Figure 25**. On newly constructed stream channels, bank side slopes should not exceed 2:1 and the banks should be protected with erosion control matting. Steeper banks in the pools are possible with the use of additional provisions for stabilization (bioengineering, in-stream structures, etc.). When developing design drawings and constructing the project, smooth transitions must be provided between the riffle sections and pool sections of the channel.

Figure 25: Typical Design Shape for Channel Cross-section Design.

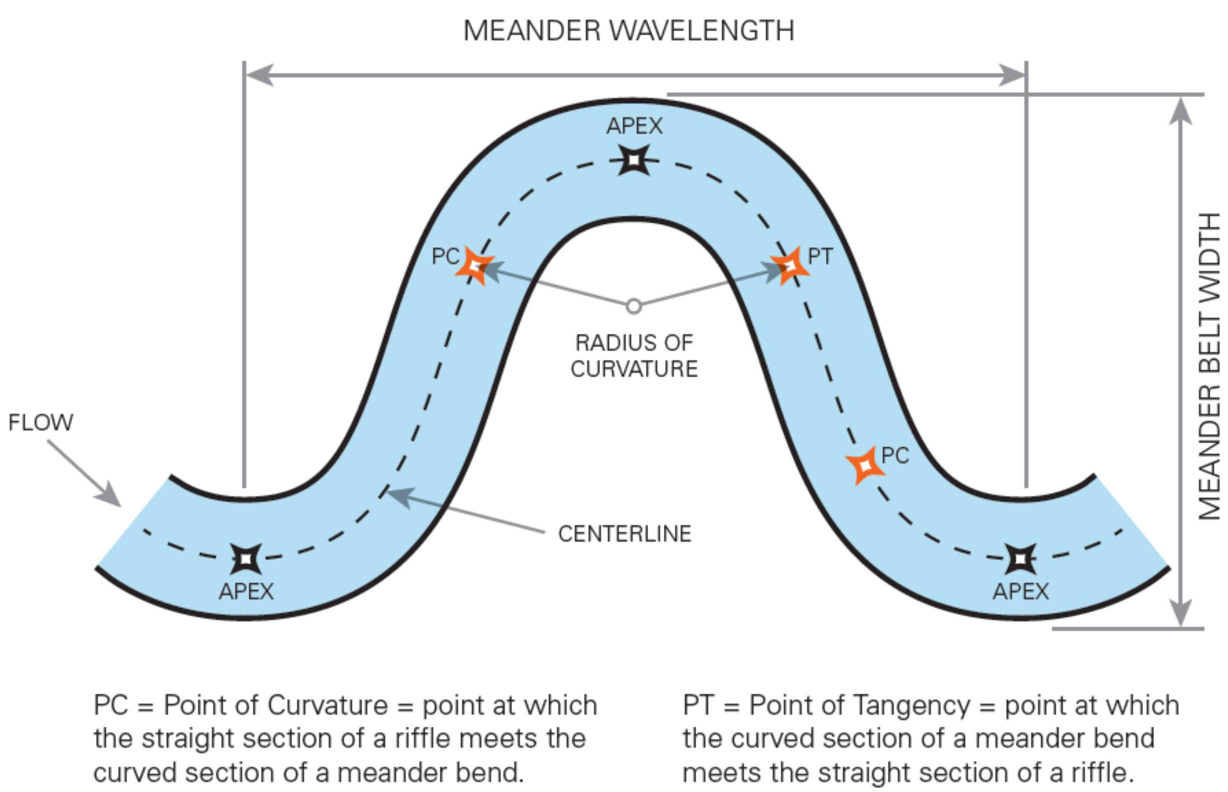


8.5.2 **Design the Channel Pattern**

Channel pattern is the shape of the stream channel as viewed from above. Meandering stream systems form an “S” shaped pattern, or a sine-generated curve, and form in lower gradient streams (less than 2% slope) with alluvial deposits and without constrained floodplains. Step-pool channels tend to be straighter and typically form in steep and/or confined valleys. Ephemeral channels, and some intermittent channels, generally lack a meandering pattern, forming flow paths that tend to follow the fall of the valley. Development of a meandering channel form for designs of high gradient (> 2% slope) or ephemeral streams should be avoided. Additionally, lateral constraints may preclude a meandering stream pattern, particularly in urban settings. Section 9.2 provides further discussion of site selection and proper design in confined systems.

Channel pattern can be defined by four parameters: meander wavelength, meander belt width, radius of curvature, and sinuosity. Meander wavelength is the straight distance between the apexes of two adjacent meander bends. Meander belt width is the straight line distance between the outside edges of two consecutive meanders. Radius of curvature is the radius of the meander bend measured from the approximate center of the channel. Sinuosity is a measure of the degree of meandering and is calculated as the distance between two points along the longitudinal length of the stream, divided by the straight line distance between the two points. Sinuosity can also be calculated as the valley slope divided by the channel slope. The higher the sinuosity, the more the stream meanders. Meander belt width, wavelength, and radius of curvature parameters are illustrated in **Figure 26**.

Figure 26: Parameters that Describe Channel Pattern



Source: Adapted from Rosgen (2006)

For meandering streams (typically found in valleys with a slope less than 2%), the following design ratios are provided as a guide for developing appropriate stream pattern. These ratios have been developed from reference stream sites and past project experience. Design ranges are provided in Harman and Starr (2011) and may be used as a starting point for pattern design.

When developing the design stream pattern, the design should seek to keep the channel as far away as practical from stormwater outfalls, to allow greater retention time and buffer distances between outfalls and the stream channel. Riffle sections should be designed to always angle down-valley, avoiding meander bends that turn up-valley. When the channels must tie-in with piped sections of stream, either at the upstream or downstream ends of the design reach, design a riffle section in line with the pipe or culvert avoiding meander bends going into or coming out of these constricted conveyances. Riffle lengths for these sections will vary based on velocity vectors and access of floodwater to the floodplain. Velocity vectors upstream of the pipe should be oriented in the direction of the pipe. Downstream, the riffle should continue until floodwaters can be spread onto the floodplain. A plunge pool should be designed immediately downstream of the pipe to provide energy dissipation.

The following steps outline the design calculation procedures for channel pattern:

Step 1. Calculate the Meander Wavelength as $Lm = Wbkf * (Lm_{ref} / Wbkf_{ref})$

Step 2. Calculate the Radius of Curvature as $Rc = Wbkf * (Rc_{ref} / Wbkf_{ref})$

Step 3. Calculate the Belt Width as Wblt = Wbkf * MWR. The suggested minimum MWR is 3.5. The maximum is dependent on the range of stable ratios from reference reaches,valley width and lateral constraints at the project site.

Step 4. Calculate the Pool to Pool Spacing as $PP = Wbkf * (PP_{ref} / Wbkf_{ref})$

Step 5. Layout the channel on the base map and aerial photograph if possible keeping in mind project constraints, upstream and downstream tie in points, vegetation, etc.

Step 6. Develop a baseline stationing for the new channel alignment, starting at the upstream beginning of the project. The stationing should follow the channel centerline.

Step 7. Measure the length of the new channel (CL).

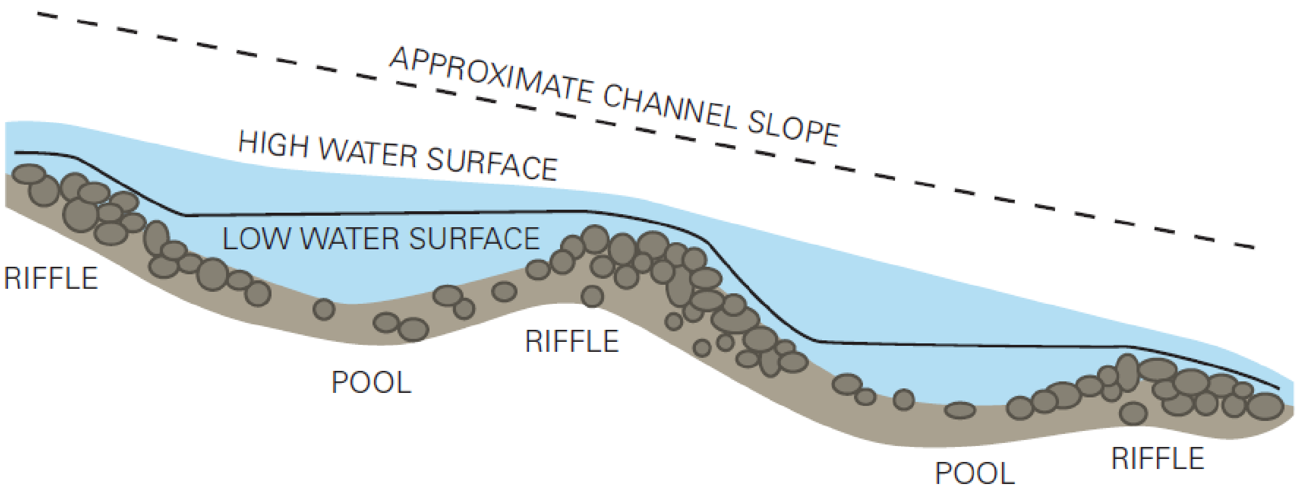
Step 8. Measure the valley length (VL).

Step 9. Calculate the new channel sinuosity as K = CL / VL

8.5.3 Design the Channel Profile

Channel profile is a cross-section view taken longitudinally through a stream channel and provides slope information about the channel as well as the depths of bed features, e.g., riffles and pools (**Figure 27**). To develop a design profile, a channel alignment must first be developed as stated in Section 8.3. Once the pattern has been developed, a profile along the existing ground topography is generated, which is typically performed in a CAD program. A longitudinal stationing line is drawn along the center of the channel. Once the stationing line has been developed, a profile is cut along the alignment and through the existing topographic data for the site. Any controlled elevation points along the proposed layout, such as culvert inverts, bedrock outcrops, utility crossings, etc., should be accurately represented and elevations verified before beginning to develop the design profile.

Figure 27: Channel Profile



Source: Adapted from Knighton (1998)

For sites where the land surface is relatively flat and even along the design reach, the average slope of the stream can be approximated by the elevation change over the land divided by the length of the longitudinal stationing (stream length). An approximate channel slope line can now be developed by connecting the beginning and ending point elevations. The beginning and end points are located where the new channel ties into the existing channel, e.g. an upstream culvert and downstream existing channel bed. If there are other points of controlled elevation along the reach, the approximate slope line must be drawn to intercept these points as well, e.g. a water or sewer crossing. For the remaining stream length, the riffle bed elevation is determined by subtracting Dmax from the approximate bankfull / top of bank slope line along the reach. After completing this step, a general channel bed elevation profile for the design reach has been developed.

The next step in designing the channel profile is to incorporate pools. To simplify the process, assume that pools begin and end at the inflection points of meander bends and that the deepest part of the pool is in the apex of the meander bend **Figure 26**. Also, assume that the pool slopes evenly from the inflection points down to the deepest part of the pool at the apex of the bend. At each bend apex along the longitudinal profile, determine the design elevation of the bottom of the pool by subtracting the design pool depth from the approximate bankfull / top of bank slope line between the beginning and end points of the reach.

The following steps outline the design calculation procedures for channel profile:

Step 1. Calculate the new average channel slope as S = valley slope / K

Step 2. Calculate the riffle slope as $Srif = S * (Srif_{ref} / S_{ref})$

Step 3. Calculate the pool slope as $Spool = S * (Spool_{ref} / S_{ref})$

Step 4. Calculate the run slope as $Srun = S * (Srun_{ref} / S_{ref})$

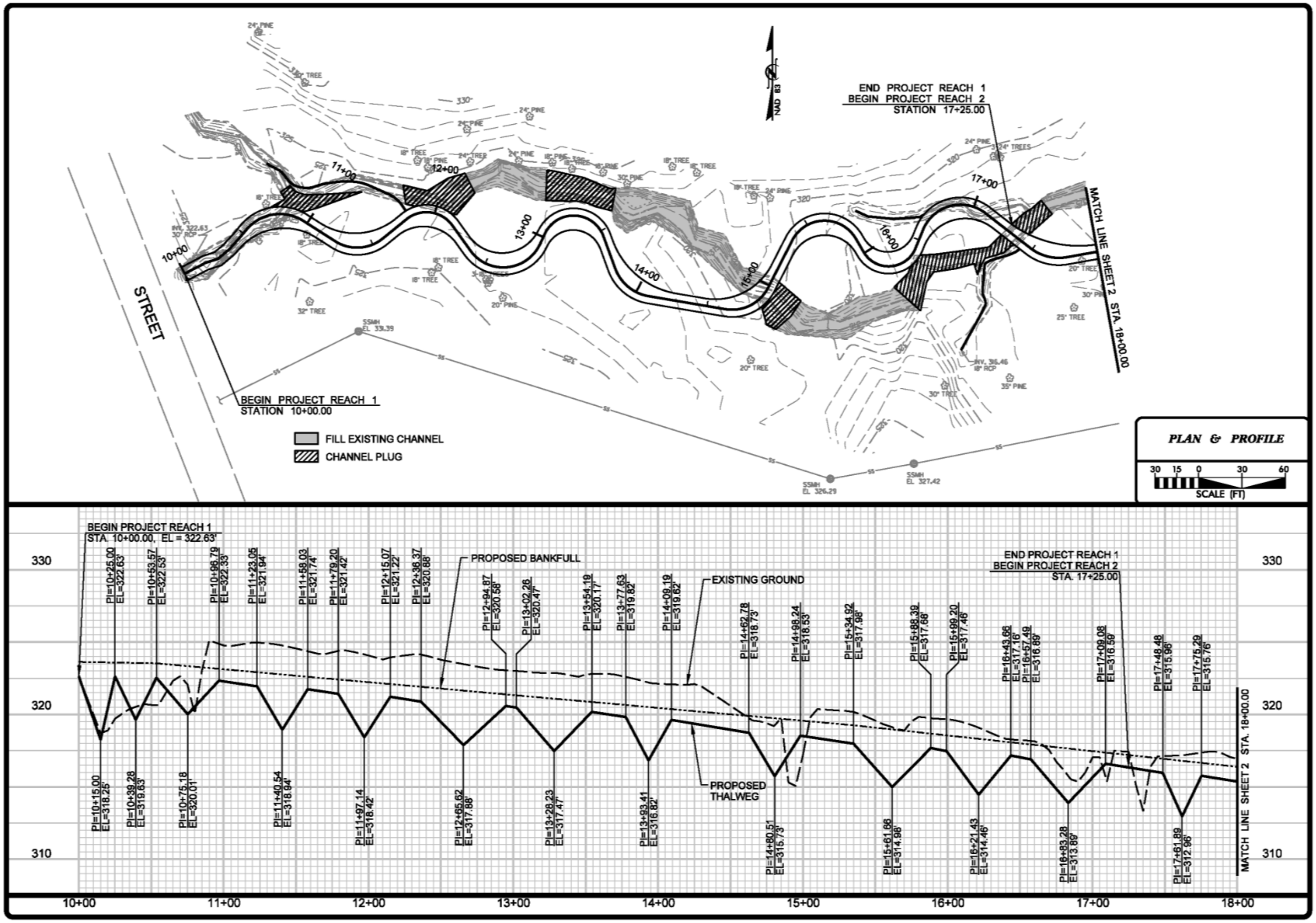
Step 5. Calculate the glide slope as $Sglide = S * (Sglide_{ref} / S_{ref})$

Step 6. Design new profile by cutting along the design channel baseline. At a minimum, design the riffles and pools. Note: It is recommended that the sediment transport check be run first (Section 8.6) to determine if riffles are affected by the sediment transport analysis.

The design steps described above are applicable to sites that have an even topography and a relatively uniform valley slope of no more than 0.5 percent. If site topography is uneven, profile slopes may vary along the design and/or extra grading may be required during the construction of the site to ensure proper channel slope and cross-sectional dimensions.

Figure 28 presents typical plan and profile views of a proposed natural channel design, which should be submitted by the consultant.

Figure 28: Example Design Plan and Profile



8.6 Sediment Transport Analysis

Most projects will require some form of sediment transport analysis, at least to determine if sediment transport calculations are necessary. A sediment transport analysis is one of the more complex components of a natural channel design. These analyses address questions about the ability of the stream to transport sediment particles of a certain size (competency) and load (capacity). The type and distribution of the bed material governs the complexity of the analyses, i.e., bed material composed of all sand requires fewer analyses than cobble, gravel, and sand mixtures. Rosgen (2006) provides an overview of sediment transport in Chapter 2.

Projects with a low sediment supply from the upstream watershed may not require sediment transport calculations and may not require a design that transports sediment. For example, a stream with a highly impervious watershed that has been developed for many years may have a minimal sediment supply. And a small rural headwater channel may benefit more (from a functional lift perspective) from a stream/wetland complex design. However, some level of sediment transport analysis is required to determine if sediment is being supplied to the project reach, either from within the channel or from uplands. In addition, hydraulic forces should be assessed for the design to ensure that the bed won't become degradational or aggradational. Bed degradation (incision) can occur without sediment supply if the design has excessive shear stress or stream power.

General instructions for completing a sediment transport competency analysis in gravel bed streams is provided below. Sediment transport competency analysis is used as an aid in designing channel depth (riffle) and slope in gravel/cobble bed streams.

Step 1. Calculate the bankfull discharge for the riffle section using the regional curve, Manning's equation, or other models.

Step 2. Calculate the bankfull mean velocity as V = Q/A. Compare to hydraulic geometry relationships from gage station surveys or local regional curves.

Step 3. Complete competency analysis for gravel bed streams. Refer to the Sediment Transport Competency Procedures below, Section 8.6.4.

Step 4. Compare the critical depth to the design mean riffle depth (d_{bkf}). If the critical depth is sufficiently larger than the design depth, then there is potential for aggradation. If the critical depth is sufficiently smaller than the design depth, then there is potential for degradation. If degradation is a concern, increase the design W/D ratio and re-run the design. If aggradation is the concern, decrease the W/D ratio and re-run the design. If adjustments in the W/D ratio do not work, then the channel sinuosity will have to be adjusted to increase or decrease slope as needed.

Step 5. As a separate check, compute the boundary shear stress of the design riffle as shown in the Sediment Transport Competency Procedures below, Section 8.6.4.

Step 6. Complete a capacity analysis. See Sediment Transport Capacity Section (8.6.5).

8.6.1 Sediment Transport Competency and Capacity

Stream restoration projects that are designed to transport sediment must be tested to ensure that the new channel dimensions create a stream that has the ability to move its sediment load without aggrading or degrading over long periods of time. The ability of the stream to transport its total sediment load can be understood through two measures: sediment transport competency and sediment transport capacity. Competency is a stream's ability to move particles of a given size and is a measurement of force, often expressed as units of pounds per square foot (lbs/ft^2). Sediment transport capacity is a stream's ability to move a quantity of sediment and is a measurement of stream power, often expressed as units of watts/square meter. Sediment transport capacity is also calculated as a sediment transport rating curve, which provides an estimate of the quantity of total sediment load transported through a cross-section per unit of time. The curve is provided as a sediment transport rate in pounds per second (lbs/sec) versus discharge or stream power.

The total sediment load transported through a cross-section can be divided by type of movement into bedload and suspended load fractions. Bedload is generally composed of larger particles, such as coarse sand, gravels, and cobbles, which are transported by rolling, sliding, or hopping (saltating) along the bed. Suspended load is normally composed of fine sand, silt, and clay particles transported in the water column.

8.6.2 Competency Analysis for Gravel Bed Streams

Median substrate size has an important influence on the mobility of particles in streambeds. Critical dimensionless shear stress (τ_{ci}) is the measure of force required to initiate general movement of particles in a bed of a given composition. At shear stresses exceeding this critical value, essentially all grain sizes are transported at rates in proportion to their presence in the bed (Wohl, 2000). Competency can be calculated for gravel bed stream reaches using surface and subsurface particle samples from a stable, representative riffle in the reach (Andrews, 1983). Critical dimensionless shear stress is calculated as follows (Rosgen, 2001):

a) Calculate the ratio d_{50}/ds_{50}

where: d_{50} = median diameter of the riffle bed (from 100 count in riffle or pavement sample)
ds_{50} = median diameter of the bar sample (or subpavement)

If the ratio d_{50}/ds_{50} is between the values of 3.0 and 7.0, then calculate the critical dimensionless shear stress using Equation 1.

$$\tau_{ci} = 0.0834(d_{50}/ds_{50})^{-0.872} \qquad \textbf{(Equation 1)}$$

b) If the ratio d_{50}/ds_{50} is not between the values of 3.0 and 7.0, then calculate the ratio of D_i/d_{50}

where: D_i = largest particle from the bar sample (or subpavement)
d_{50} = median diameter of the riffle bed (from 100 count in the riffle or pavement sample)

If the ratio D_i/d_{50} is between the values of 1.3 and 3.0, then calculate the critical dimensionless shear stress using Equation 2.

$$\tau_{ci} = 0.0384(D_i/d_{50})^{-0.887} \qquad \textbf{(Equation 2)}$$

8.6.3 Required Depth and Slope Analysis

The aggradation analysis is based on calculations of the required depth and slope needed to transport large sediment particles, in this case defined as the largest particle of the riffle subpavement sample.

Required depth can be compared with the existing/design mean riffle depth, and required slope can be compared to the existing and design slopes to verify that the stream has sufficient competency to move large particles (and thus prevent thalweg aggradation). The required depth and slope are calculated by:

$$d_r = \frac{1.65\tau_{ci}D_i}{S_e}$$ **(Equation 3)**

$$s_r = \frac{1.65\tau_{ci}D_i}{d_e}$$ **(Equation 4)**

where: d_r = required bankfull mean depth (ft)
d_e= design bankfull mean depth (ft)
1.65 = sediment density (submerged specific weight)
= density of sediment (2.65) – density of water (1.0)
τ_{ci} = critical dimensionless shear stress
D_i = largest particle from bar sample (or subpavement) (ft)
s_r = required bankfull water surface slope (ft/ft)
S_e = design bankfull water surface slope (ft/ft)

The aggradation analysis is used to assess both existing and design conditions; for example, if the calculated value for the existing critical depth is significantly larger than the measured maximum bankfull depth, this indicates that the stream is aggrading. Alternately, if the proposed design depth significantly differs from the calculated critical depth, and the analysis is deemed appropriate for the site conditions, the design dimensions should be revised accordingly.

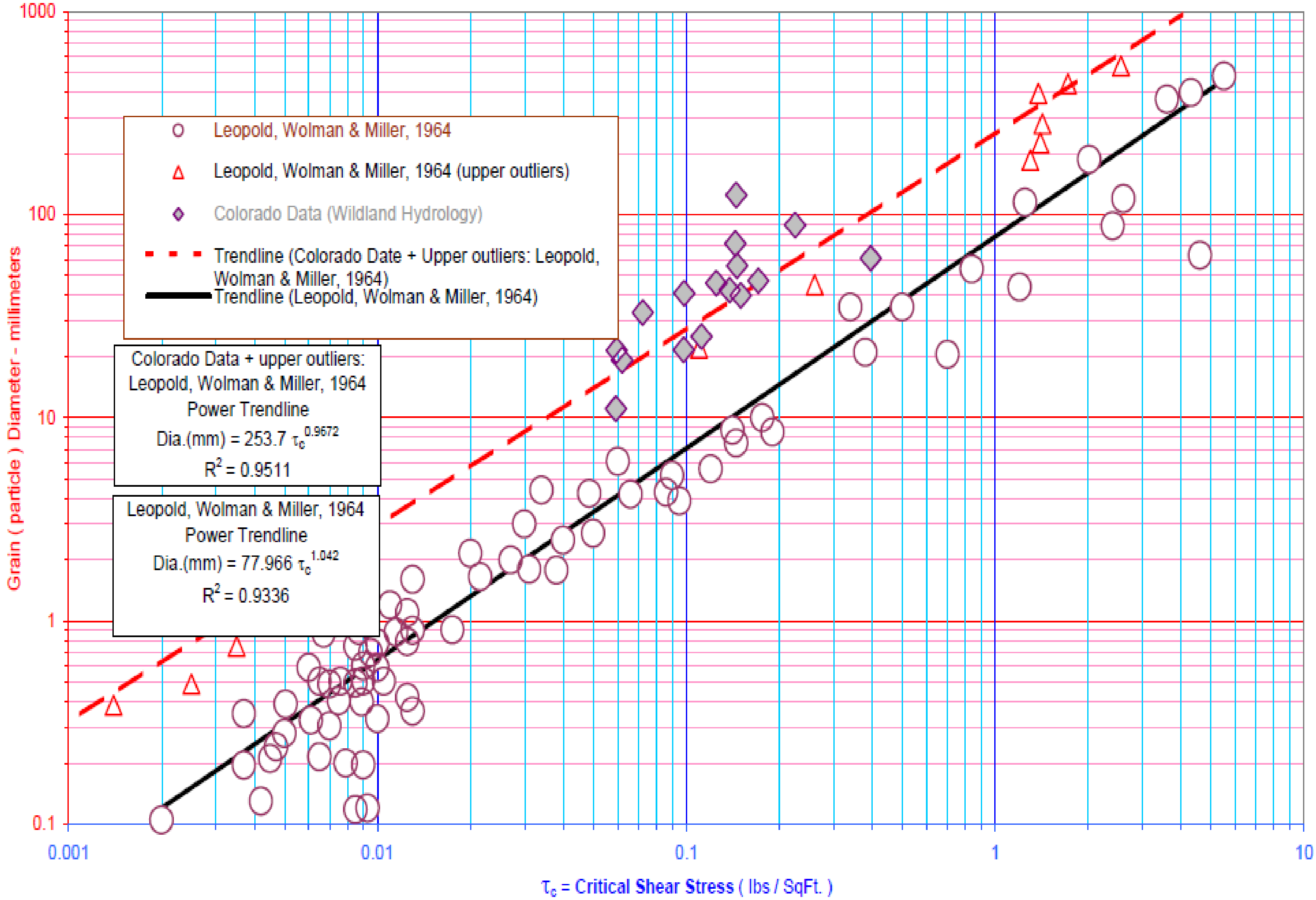
8.6.4 Competency Analysis for Gravel Bed Streams Using a Modified Shields Curve

Rosgen (2006) provides a complement to the above required depth and slope calculations, by using the boundary shear stress from the design riffle cross-section and comparing it to the Coloradocurve on **Figure 29** or a locally developed curve. Rosgen (2006) recommends using this method if the ratios in Equations 1 and 2 are not within the range suggested. The curve is used to predict the grain sizes that will become mobile for the calculated shear stress. Based on measured bedload data, Rosgen (2006) recommends that the modified Shields curve (lower curve of **Figure 30**) not be used, especially within the range of 0.05 to 1.5 lbs/ft^2. A few points above this range on the modified Shields curve were used in the development of the CO curve as shown by the red triangles. The shear stress placed on the sediment particles is the force that entrains and moves the particles, given by:

$$\tau = \gamma R s$$ **(Equation 5)**

where: τ = shear stress (lb/ft^2)
γ = specific gravity of water (62.4 lb/ft^3)
R = hydraulic radius (ft)
s = average channel slope (ft/ft)

Figure 29: Critical Shear Stress Curve (USEPA Watershed Assessment of River Stability & Sediment Supply)



8.6.5 Sediment Transport Capacity

For fine-grained streambeds, sediment transport capacity is much more important than competency. Sediment transport capacity refers to the stream's ability to move a mass of sediment past a cross-section per unit of time in pounds/second or tons/year. Sediment transport capacity can be assessed directly using actual monitored data from bankfull events if a sediment transport rating curve has been developed for the project site. Since this curve development is extremely difficult, other empirical relationships are used to assess sediment transport capacity. The most common estimate of channel capacity is by calculating stream power. Stream power is not a direct measure of capacity in terms of providing a rate of transport per unit time; however, it does imply the ability of the stream to move a load. Stream power can be calculated a number of ways, but the most common is the following:

$$w = \gamma QS/W_{bkf} \qquad \textbf{(Equation 6)}$$

where: w = mean stream power (W/m^2)
γ = specific weight of water 9,810 N/m^3); $\gamma = \rho g$, where ρ is the density of the water-sediment mixture (1,000 kg/m^3) and g is the acceleration due to gravity 9.81 m/s^2)
Q = bankfull discharge (m^3/s)
S = design channel slope (m/m)
Wbkf = bankfull channel width (m)

Note: 1 ft-lb/sec/ft^2 = 14.56 W/m^2

Equation 6 does not provide a sediment transport rating curve; however, it does describe the stream's ability to accomplish work, i.e., move sediment. Calculated stream power values are compared to reference and published values. If deviations from known stable values for similar stream types and slopes are observed, the design should be reassessed to confirm that sediment will be adequately transported through the system without containing excess energy in the channel. Supplemental resources include the Copeland Stability Curve, sediment transport modeling using the HEC-RAS modeling program (versions 4.0 and later), and the hydraulic design package SAM.

8.6.6 Stabilizing Streambanks

Establishing vegetation on streambanks is a critical component to natural channel design. Newly constructed streambanks are susceptible to erosion while vegetation is establishing; therefore, steps must be taken to provide immediate bank protection at the completion of the project, to allow time for vegetation to become rooted and dense. Appendix I presents a list of native plants compiled by SARA for use in local natural channel design projects. The designer should seek to establish permanent vegetation on the project streambanks as quickly as possible following the completion of the restoration project. A number of bank stabilization practices that are commonly used in natural channel design are listed below with a brief description of their appropriate use. More detailed information on the use of in-stream structures and bioengineering is provided in Chapter 11.

- Erosion Control Matting: Textile fabrics and matting are commonly applied to constructed and bare streambanks to provide initial surface protection while vegetation is establishing. There are a wide variety of fabrics available, ranging from those that provide minimal protection for a short period of time to those that are rated for high velocity, high shear stress applications and are designed to last for many years. The discussion that follows provides an overview of considerations to be made when selecting the appropriate erosion control matting.

  Erosion control matting for natural channel design projects should be completely biodegradable, with an expected life that will provide protection long enough for vegetation to become established. Matting made of coconut (coir) material and cotton fabrics generally provide good protection for most natural channel design projects. Designers should consult the matting manufacturers' specifications to compare permissible velocities and shear stresses with those calculated for the design channels. Follow the manufacturer's recommendations for proper installation techniques.

Selected matting products must allow for penetration of moisture and enough porous space to allow vegetation to grow up through the matting. Newly constructed streambanks should be smooth and free of roots and debris, providing good contact between the matting to be applied and the soil surface. Temporary seeding, permanent seeding and a light layer of straw mulch shall be applied to the newly constructed banks prior to applying erosion control matting. Ensure good contact with applied seeding by first hand-raking the banks to loosen the soil surface and then applying a thin layer of soil over the applied seeding prior to application of straw mulch and matting.

Provide smooth transitions between areas that are matted and areas that are not. Matting edges shall be trenched into the bank a minimum of 6 inches and staked heavily to prevent edges from becoming loose during flow events.

- Bioengineering: Bioengineering consists of the application of live, woody plant material cuttings to streambanks to provide for rapid establishment of woody species and dense root mass. Live cuttings are taken from native woody plant species that will root when placed in contact with moist soil, and include such plant families as willows (*Salix* spp.), cottonwoods (*Populus* spp.), certain dogwood species (*Cornus* spp.), and a variety of other depending on the region.

  There are a wide variety of bioengineering practices and techniques for their use and application. See Chapter 11 for more information.

- In-stream Structures: In-stream structures are used in natural channel design projects for a variety of reasons, and often streambank stability is an objective. Some structures, such as vanes and deflectors, provide streambank stability by turning the water's energy away from the banks, promoting scour of the streambed and reducing stresses placed on streambanks. Other structures, such as root wads and toe-wood, provide protection by absorbing and deflecting energies directed at streambanks. For more information on in-stream structures for streambank stability, see Chapter 11.

Streams in certain areas (especially arid regions) do not support growth of streambank vegetation. In these types of areas, other bank protection/stabilization measure should be used.

8.6.7 Erosion and Sedimentation Control

General Requirements

Erosion and sedimentation at construction sites within SARA's four county jurisdiction must comply with all regulations mandated by the state through the Texas Commission on Environmental Quality (TCEQ). Construction sites that discharge stormwater associated with construction activity are covered under the Texas Pollution Discharge Elimination System (TPDES) General Permit Number TXR150000.

The TPDES General Permit describes the necessary practices to obtain permit coverage, to comply with permit coverage during construction, the required elements to include in a Stormwater Pollution

Prevention Plan (SWPPP), erosion and sedimentation control best management practices (BMPs) to use during construction, monitoring requirements, post construction stabilization measures, and how to terminate coverage. BMPs include temporary and permanent vegetation establishment efforts, silt fencing, and storm drain inlet protection. Coverage is based on construction size. Sites under five acres are considered small sites and receive automatic permit coverage. Sites with disturbed areas greater than five acres have a more involved application process and termination process. Large sites must file a Notice of Intent (NOI) and pay a fee to receive permit coverage. The SWPPP and erosion and sedimentation control BMPs should be in place before construction and permit coverage begins. The TCEQ Website provides the most current information regarding SWPPP requirements and should be utilized to confirm existing requirements prior to the start of construction.

A SWPPP is a living document that must be maintained on site during construction. The SWPPP should identify all of the disturbed areas on site and all of the potential pollutants on site, and describe the ways these materials will be kept out of stormwater runoff. The SWPPP must also contain inspection forms completed at least every 30 days until the Notice of Termination (NOT) is filed with the TCEQ. Changes to the site, BMP modifications and maintenance schedule, employee training records, potential pollutant inventories, and completed inspection forms should all be maintained on site as part of the SWPPP and are subject to review by TCEQ inspectors.

Sites located within the Edwards Aquifer Recharge Zone or the Edward's Aquifer Contributing Zone within Bexar County are required to prepare an Edwards Aquifer Protection Plan and comply with additional notification requirements included in the TPDES General Permit.

Cities and counties within SARA's jurisdiction may be categorized as Municipal Separate Storm Sewers (MS4s) and have additional erosion and sedimentation control requirements. For example, projects located in unincorporated Bexar County must submit an application, site plans, and an application fee to the Bexar County Environmental Services for additional permit coverage within the Bexar County MS4. Sites within Bexar County are also subject to inspection by Bexar County Environmental Services.

Project sites within the City of San Antonio are also required to comply with city ordinance 94002, which makes sites open to inspection by employees of the San Antonio Water System (SAWS). No additional reporting requirements or fees are associated with compliance of this ordinance.

Other counties and cities with SARA's jurisdiction may have their own MS4, notification requirements, and associated fees. A determination of jurisdiction and reporting requirements should be made before construction begins on any project.

Specific Stream Restoration Practices

Correctly designed and constructed stream restoration projects significantly reduce erosion and sedimentation as they result in streams that mimic naturally occurring, stable channels. These projects can therefore be viewed as significant erosion and sedimentation control practices on their own. Stream restoration construction is often a sensitive subject with regard to erosion and sedimentation control. Significant disturbance to the same waterways that erosion and sedimentation control laws and regulations are intended to protect is required in order to construct stream restoration projects. Stream practitioners understand that this disturbance is temporary and necessary to prevent long term erosion and sedimentation issues. The erosion and sedimentation generated during stream restoration construction projects is generally very small in comparison to that generated by the same stream reach in the long term if left untreated. Specific stream restoration practices proven to consistently reduce erosion and sedimentation during construction are discussed below.

Utilizing well designed plans and contract documents

Well developed erosion and sedimentation control plans and contract documents lay the ground work for good stream restoration construction practices. Erosion and sedimentation control is no exception. Plans and technical specifications that include all the necessary erosion and sedimentation control practices and devices, their locations, intended uses, maintenance procedures and requirements insure that practices and devices are installed, utilized, and maintained as intended. Thorough contract documents insure that the contractor is held liable for the same.

Regular Inspection and Maintenance

Regular inspection and maintenance of all erosion and sedimentation control practices and devices is vital. This insures that each device and practice is in working order at all times.

Working "In the Dry" or "In the Wet"

Stream restoration projects can be constructed "in the dry" (with base flow pumped around the work area, or "in the wet" (with construction taking place without base flow being pumped around the work area). Typically, streams with very large drainage areas are constructed in the wet, as pump-around and diversion operations are not financially feasible to conduct for such streams, and the amount of sediment disturbed relative to the flow is smaller. Likewise, streams with very small drainage areas are typically constructed in the dry. Permitting requirements should always be considered when determining which method is chosen. Pump-around operations are typically set up by isolating the work area with temporary dams at both the upstream and downstream ends. The extents of the various work limits are typically identified on the erosion and sedimentation control plans and on the construction sequence. A pump with sufficient capacity to divert base flow is set up above the upstream dam and the base flow is pumped around the work area to a location downstream of the downstream dam and discharged to some type of energy dissipater, typically a rip rap apron. Under ideal conditions, such flow diversion can be done under gravity flow conditions, without the need or expense of a pump. This flow is clean and therefore does not cause any additional erosion or sedimentation to the receiving waters. An additional pump(s) is also utilized to de-water the work area between the dams. The discharge from this pump(s) is normally run through some type of filter system, such as a sediment bag, before being discharged to the downstream channel.

Working In the Stream Channel or From the Stream Banks

Stream restoration projects can be constructed with the construction equipment working from the top of the stream banks or from working within the stream channel, or a combination of both. Typically, streams with very large drainage areas are constructed predominantly with the construction equipment working from within the stream channel. Likewise, streams with very small drainage areas are typically constructed with the construction equipment working from the top of the stream bank(s). Permitting requirements should always be considered when determining which method is chosen. Construction access and protection of existing riparian vegetation should also be considered when determining which method is best.

Developing and Following a Construction Sequence

The construction sequence should be carefully developed to consider and specify all phases of construction. The construction sequence typically begins with mobilization, includes the establishment of erosion and sedimentation control measures, moves through the various phases of construction, includes all site planting, site clean-up, and ends with demobilization. Often it is a good idea to include mandatory phase inspection in the construction sequence in order to insure that the contractor completes critical phasing before moving on to later phases, thereby minimizing erosion and sedimentation. The following is an example of a typical construction sequence:

- Prior to beginning any land disturbing activities, permit notification and approval must be granted from the proper local, state and national regulatory agencies.
- The Contractor shall notify the local One-Call system at least 48 hours before any excavation begins to identify utility locations.
- The Contractor shall install silt fence and safety fence before storing equipment and materials in staging areas as shown on the plans.
- The Contractor shall prepare stabilized construction entrance(s) as indicated on the plans and install any signage and safety devices necessary to maintain and protect traffic through areas of construction. The Contractor shall mobilize equipment and materials to the site using the specified construction entrances and is responsible for maintaining access throughout all construction activities.
- The Contractor shall only utilize the haul roads and temporary stream crossings as shown on the plans. Construction traffic shall be restricted to the area denoted as limits of disturbance/temporary construction easement as shown on the plans and after inspection and approval by the Engineer.
- Flag tree protection areas prior to construction activities and before clearing and grubbing begins.
- The Contractor shall clear and grub an area adequate to access the stream and perform channel work and floodplain bench grading operations, in accordance with the plans. Materials not suitable for construction shall be stockpiled within the designated areas and hauled offsite to a specified location approved by the Owner.
- Any work within the active stream shall be conducted during base (or lower) flow conditions. In general, the Contractor shall work from upstream to downstream and in-stream structures shall be installed using a pump-around or flow diversion measures. Bank protection includes transplants, brush mattresses, geolifts, and/or seeding with matting. Silt fence shall be placed between stockpiles and the existing channel as shown on the plans.
- The Contractor will begin construction by excavating floodplain bench areas as directed on the plans. Excavated material not suitable for backfill, bank stabilization or structure installation should be stockpiled in areas shown on the plans. In areas where excavation depths exceed 10 inches, topsoil shall be stockpiled and placed back over these areas to a minimum depth of 10 inches to achieve design grades and create a soil base for vegetation establishment.
- Immediately upon completion of bank grading, the slopes will be reseeded and matted with the specified erosion control matting. The Contractor shall not disturb any area larger than they can completely stabilize in one day. All disturbed stream banks must be stabilized by the end of each day.

- Upon completion of the channel work and bank stabilization, all disturbed areas including staging areas and haul roads, shall be seeded and mulched. Permanent seed mixtures and temporary seed shall be applied to all disturbed areas as shown on the vegetation selection. Temporary seeding shall be conducted in all areas susceptible to erosion (i.e. disturbed ditch banks, steep slopes, and spoil areas) such that ground cover is established quickly.
- The Contractor shall remove temporary stream crossings and erosion and sedimentation control measures. All waste material must be removed from the project site to a specified location approved by the Owner.
- The Contractor shall plant woody vegetation, live stakes, and conduct any remaining temporary and/or permanent seeding at the appropriate time of the year and as described in the planting details and specifications.
- The Contractor shall ensure that the site is free of trash and leftover materials prior to demobilization of equipment from the site. Upon completion of all construction activities, the area is to be restored to a condition equal to or better than found prior to undertaking work.

9.0 NATURAL CHANNEL DESIGN WITHIN FLOOD CONTROL CHANNELS

9.1 Project Constraints

Chapter 8 provides guidance on natural channel design methods, establishing design goals, and alternatives for incised streams. However, applying restoration and natural channel design techniques within urban flood control channels often presents unique challenges. Project constraints drive the applicability and appropriateness of using natural channel design techniques and in some cases, natural channel design may not be feasible. Project constraints include physical constraints such as corridor width, geology (bedrock), utility crossings, etc. But the project goals and objectives often create constraints that could preclude natural channel design from the onset. For example, traditionally, flood control projects aim to remove the maximum number of structures from the 100-year floodplain by maximizing the 100-year flood conveyance channel without considering geomorphic or environmental impacts to the stream. Generally, the reduction of the 100-year water surface elevation is the most valued objective and therefore given the most weight when evaluating project objectives. Unless other objectives are equally or closely valued, such as sediment transport (which impacts to long-term channel maintenance), water quality and riparian habitat, natural channel design is likely not a viable option for a project. Careful review of the project objectives is the first step in determining the maximum stream function potential of a project reach.

Generally, urban flood conveyance corridors have already been altered to some degree, from completely channelized streams that convey the 100-year flow, to streams where development has occurred in the floodplain fringe but the stream channel is still relatively natural. The existing condition of the corridor, along with the project objectives, will determine the maximum stream function potential that can be expected from a proposed flood control project. Section 8.1 describes in detail the basic functions of natural stream systems and the relationships between these functions. **Figure 19**, the Stream Functions Pyramid describes the hierarchy of natural stream functions. The pyramid demonstrates the dependence of the higher level functions on the functions below. It is important to clearly understand what levels of stream function can be improved and/or what levels of stream function will potentially be lost for a given proposed project.

For example, a stream that has a stable natural channel with development in the floodplain fringe will most likely have higher level stream functions under existing conditions, i.e., intact aquatic and riparian life. A project that reduces flood risk and damage to structures in the floodplain fringe by modifying the stream channel would alter the foundational stream functions (hydrology and/or hydraulics) and could result in the loss of the existing higher level functions. The proposed project may meet the flood control objective, but with negative environmental, aesthetic, and long-term maintenance implications. This scenario presents an opportunity to preserve the stable natural stream section to minimize the negative impacts while meeting the flood control objectives through methods other than channel modification, such as flood-proofing of structures or buy-out of flood prone properties.

In the case where the existing stream channel is not channelized but is degraded and unstable, higher level stream functions may not be exhibited, depending on the degree of degradation. This scenario presents an opportunity to improve stream functions using a natural channel design approach where physical constraints allow.

In the case where a stream has been completely channelized and/or hardened, a natural channel design approach is likely precluded unless the project goals and objectives call for restoration of a natural stream system. Such a project would inherently include buy-outs to provide a corridor that can support a stable natural stream system.

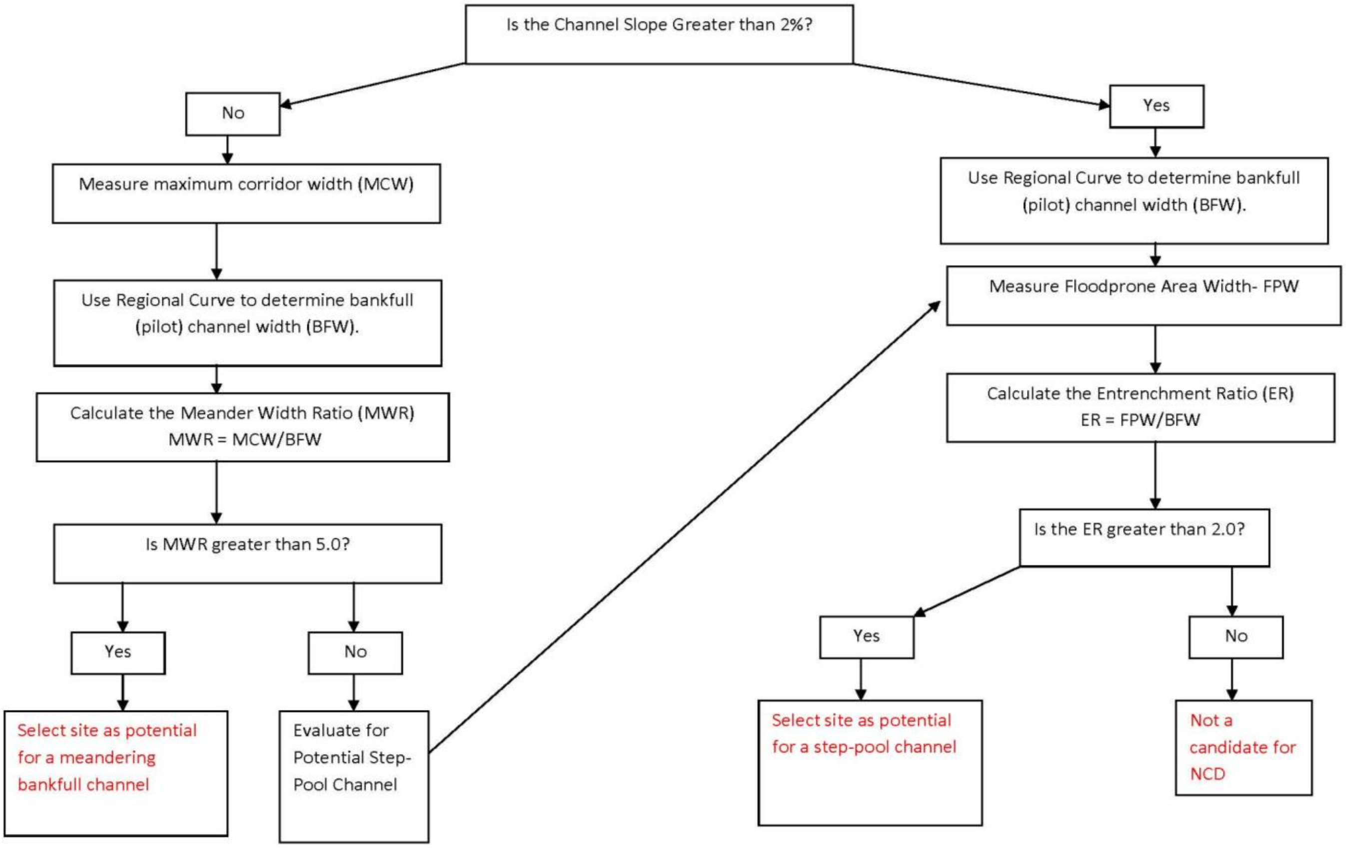
Again, the project goals and objectives will set the level of stream function that can be expected from a given project and determine the feasibility of a natural channel design approach.

9.2 Site Selection and Proper Design

As stated in Section 9.1, project constraints will determine if natural channel design is feasible for a given site. Valley type and channel slope will determine the proper design approach. Usually flood control corridors allow for a Priority 2 or Priority 3 restoration approach as described in Section 8.2. Previous experience has shown that streams with channel slope of 2% and greater should not be designed to have a meandering pattern but may be able to use a step-pool channel design.

Figure 30 provides a flow chart for providing site selection criteria for potential use of natural channel design techniques in a flood control project.

Figure 30: Site Selection Criteria for Potential Use of Natural Channel Design Techniques in a Flood Control Project

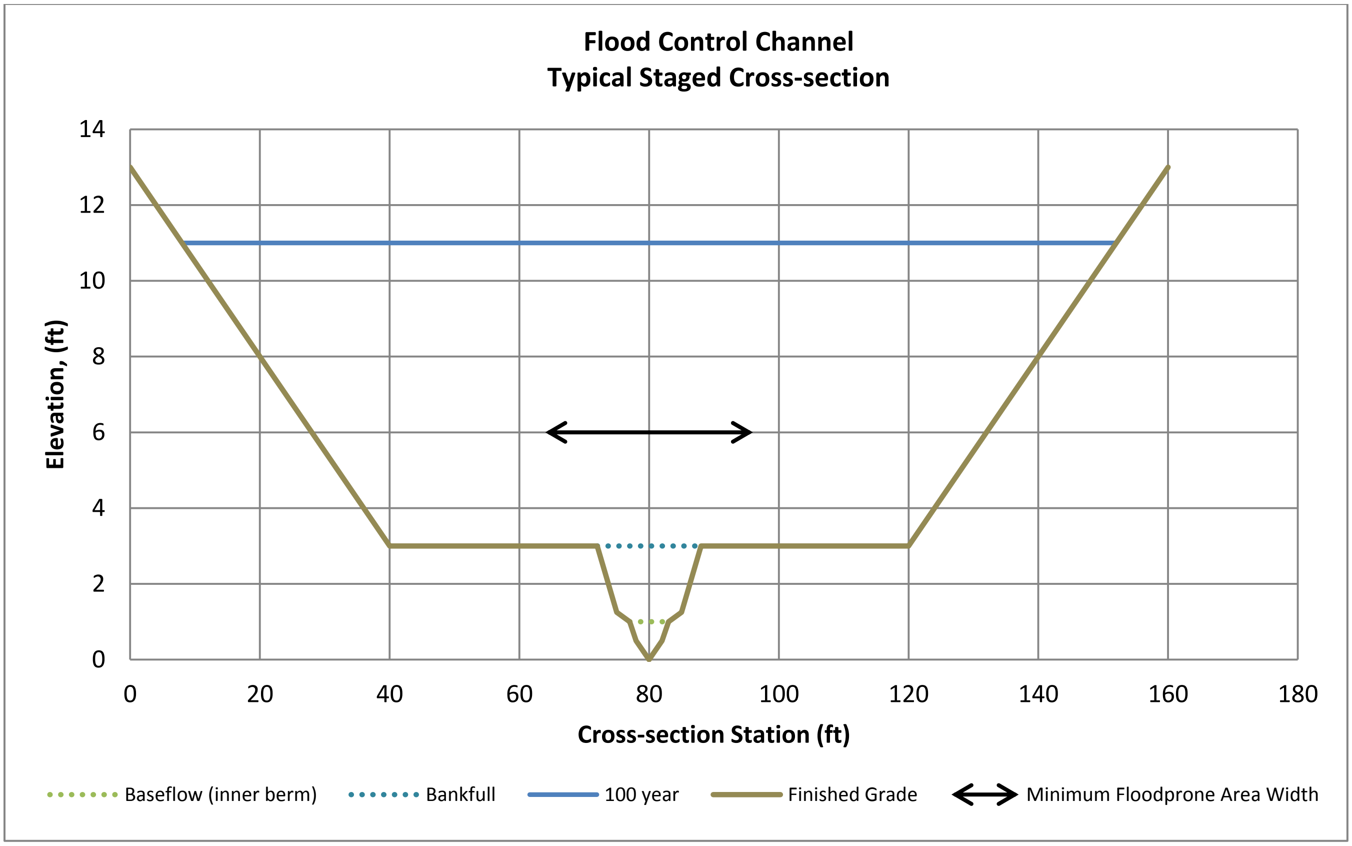


The first step is to look at the channel and valley slope. If the channel slope is less than 2%, a meandering pattern may be possible given that the meander width ratio (MWR) is greater than 5.0 following the steps on the left side of the flow chart. If the (MWR) is less than 5.0, a step-pool design may still be feasible if the Entrenchment Ratio (ER) is greater than 2.0 (following the step on the right side of the flow chart). Additionally, if the slope is greater than 2%, a step-pool design may be possible given an Entrenchment Ratio greater than 2.0. A detailed guide for using this flow chart is located in Appendix F.

9.3 Bankfull Pilot Channel

The cross-section for flood control channels is typically trapezoidal and conveys all design storms, such as the 10-year through the 100-year flood events. Sometimes a pilot channel is designed to convey more frequent flows, typically up to the 2-year flood event. When using a natural channel design approach, a multi-stage cross-section is designed where a pilot channel is sized as a bankfull channel, the floodprone area width is sized to maintain an Entrenchment Ratio greater than 2, and larger flood events up to the 100-year are conveyed within the overall cross-section that includes the floodplain. Additional stages can be designed to convey other design flows, such as baseflow within an inner berm section. **Figure 31** shows a typical staged cross-section for flood control channels.

Figure 31: Typical Staged Cross-section for Flood Control Channel



Refer to Chapter 8 for development of bankfull channel design parameters and inner berm features.

10.0 NATURAL CHANNEL DESIGN REPORT STANDARDS

A natural channel design report is required for each project. The report will provide background information and documentation for the design approach that includes discussion on the watershed, existing stream condition, design criteria selection and design parameters. Harman and Starr (2011) include a Natural Channel Design Review Checklist in Appendix A of their document. This checklist provides a list of detailed items that are typically included in a natural channel design report and plans. Appendix G provides a template for the natural channel design report and required sections, as well as a copy of the NCD Review Checklist.

11.0 IN-STREAM-STRUCTURES AND BIOENGINEERING

11.1 Overview and Purpose

In-stream structures are commonly utilized in the natural channel design process to provide grade control, stream bank protection (lateral stability), and improved in-stream habitat (bed form diversity). In-stream structures are typically constructed from natural materials, predominantly large rock and wood. The rock materials used for in-stream structures range from gravel to boulders, while the wood materials are comprised of trees, including the root balls (or root wads), tree trunks (or boles), as well as the smaller materials from branches and tree tops. In-stream structures constructed from logs are typically limited to those applications where the wood materials remain permanently saturated such that those materials do not rot and deteriorate prematurely. In some situations, natural materials used for the construction of in-stream structures can be harvested on-site during the construction process. For example, trees removed during the clearing and grubbing phase of construction can often be "recycled" into an in-stream structure. Many in-stream structures can be built completely out of wood or rock materials, or a combination of both, depending on the availability of materials, the intended function of the given structure, the desired appearance, or other project specific factors.

Bioengineering refers to a family of practices that use manufactured support materials and fabrics, soil materials, live plant cuttings, and vegetation to stabilize streambanks. Bioengineering practices seek to provide initial stability and support through the use of manufactured, often biodegradable, materials that allow for the quick establishment of deep rooted vegetation along treated streambanks. Live, dormant plant cuttings are installed using native species that propagate well from cut stems placed in contact with soil. By using cuttings, woody species with deep roots are established quickly, providing long-term stability to the treated areas.

In-stream structure and bioengineering selection, placement, and design occur after the geometry design (channel dimension, pattern, and profile) is completed. Design guidance is provided below for a variety of in-stream structures. The guidance is stratified by their primary use (e.g., grade control, lateral stability, and bed form diversity). Example detail drawings are provided in Appendix H. Additional information regarding in-stream structures for the cross-vane, W-weir, and J-hook in-stream structures are provided by Rosgen (2001). Addition information regarding the use of bioengineering practices is provided by NRCS (2007).

11.2 In-stream Grade Control Structures

Certain types of in-stream structures can be utilized to provide grade control in order to prevent the stream from eroding vertically downward, often referred to as down-cutting or incising. Grade control is provided naturally in stream systems by stable riffles, bedrock outcrops, and sometimes root masses associated with woody vegetation. In-stream structures intended to provide grade control are thus carefully designed and constructed to mimic these natural features. Providing adequate long-term grade control is essential to the success of natural channel design projects. Without adequate grade control, channel incision can occur, followed by over-steepening of stream banks and accelerated stream bank erosion. These processes can cause severe loss of land and riparian habitat, along with significant degradation of the remaining riparian areas. In-stream habitat is also negatively affected by the extreme sediment supply from such processes. These effects occur mainly when sediment is carried downstream and fills in pools and voids between bed substrate that are necessary for aquatic life. In addition, the sediment can also carry nutrients and pollutants, which may degrade water quality downstream of the area of instability. Examples of in-stream structures that are used to provide grade control include constructed riffles, step pools, cross-vanes, and grade control j-hook vanes. Each of these structures is described in the sections that follow.

11.2.1 Constructed Riffles

Description

A constructed riffle is created by placing coarse bed material (gravel, cobble, and small boulders) in the stream at specific riffle locations along the profile. The purpose of this structure is to provide initial and/or permanent grade control and establish riffle habitat within the restored channel, prior to the natural establishment of an armored streambed. Constructed riffles function in a similar way as natural riffles; the gravel and cobble surfaces and interstitial spaces are crucial to the life cycles of many aquatic macroinvertebrate species. From a stability standpoint, riffles establish the overall grade for a stream reach and maintain the low water surface slopes of the upstream pools.

Figure 32: Constructed Riffle during Construction and Post-Construction

Constructed riffle during construction   Constructed Riffle two months after construction

Application

Constructed riffles can be used to provide grade control in any riffle/pool stream system. Because constructed riffles are normally constructed of coarse gravel materials, they are not often used in sand bed stream systems when providing and maintaining completely natural appearance is vital. Typically, constructed riffles are used to provide grade control for smaller streams, e.g. streams with a drainage area less than 5 to 10 square miles. Other appropriate applications for constructed riffles include:

- Urban stream reaches with high shear stress and low sediment supply. In these situations, constructed riffles are built from large enough rock that the base of the riffle will not move during storm events, since bed material supply is not sufficient to build riffles naturally.
- Newly constructed channels with bi-modal distribution of bank and bed sediments. Constructed riffles provide initial stability to hold channel grade until a natural armor layer can develop.
- Streams in which coarser riffles are desired for habitat improvement. Riffle gradation can be controlled by the size of rock used to construct the riffle.   Steeper riffles with coarser bed material may be desirable for improved dissolved oxygen after construction.

- Encouraging groundwater and surface water interaction. Because of the gradation of stone used in constructed riffles, water can pass back and forth between the surface water in the channel and the groundwater below the streambed.
- To provide a more conservative design and account for uncertainty in vertical stability / sediment transport calculations. The potential for channel degradation is usually higher than the potential for aggradation. Constructed riffles provide additional confidence that the restored channel will not degrade over time.

Placement

Constructed riffles are used in typical riffle locations, such as between meander bends and especially in areas of new channel construction where natural bed sorting is not established. Constructed riffles are rarely needed at every riffle location, but should be used near the beginning and end of the reach, as well as critical locations throughout the reach to prevent head-cutting.

Design Considerations

An example detail for constructed riffles is included in Appendix H. Additional design considerations for constructed riffles include:

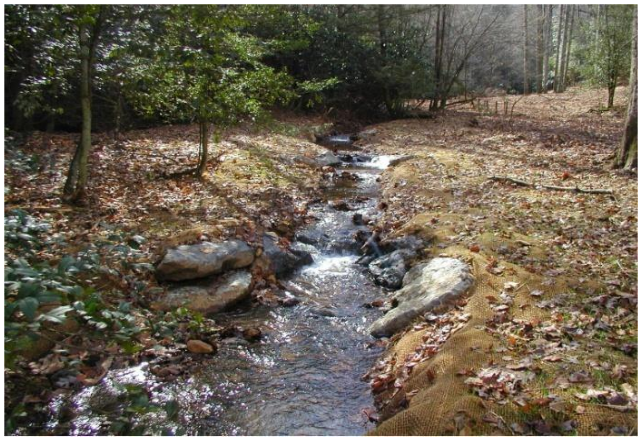
- Size, depth, and gradation of rock used in the constructed riffle should be based on shear stress and sediment transport analyses. The detail provided in Appendix H is provided as an example.
- Using boulder clusters at the head of the constructed riffle to maintain a flat water surface slope over the upstream pool.
- Small boulders and large cobble can be used sparingly throughout the length of the riffle. This increases riffle complexity and provides additional stability. However, care should be taken to not over armor the riffle with large particles.

11.2.2 Step Pools

Description

Step pools are used to provide grade control and bed form diversity. Step pools are constructed by installing abutting courses of footer and header rocks in a formation of cascading or stepped, alternating pools with stepped sills in between. The sills are installed at the same elevation as the streambed, but should not be installed such that they back up water in the channel like a weir. Step pool structures should be constructed out of large boulders and not riprap. The pools depth will depend on the configuration of the structure, flow velocity and gradient, and bed material of the stream.

Figure 33: Examples of Step Pool Sequences



Example Step Pool Sequence

Example Step Pool Sequence

Application

Step pools are utilized most for stream systems in colluvial valleys and in valleys with slopes greater than 2 percent. Normally, use of step pool structures is limited to stream systems with confined settings where sinuosity is less than 1.2 and in drainage areas less than 3 square miles. Step pool structures can be used in very small streams and even ephemeral channels with the same goal of providing grade control and improving bed form diversity. Step pool structures can be used for outlet protection in conjunction with stormwater outfall channels where the bed elevation drops more than one foot to the bed elevation of the receiving channel. Step pools are also commonly used as floodplain interceptors to intercept concentrated floodplain flows from swales, ditches, low points, oxbow pond or vernal pool drains, etc. and to drain such flow to the restored channel in a stable and natural manner.

Placement

Step pools are located based on pool-to-pool spacing ratios. Lower (closer together) spacing is used for steep gradient streams and higher (farther apart) spacing is used for lower gradient streams. When used for outlet protection and as floodplain interceptors, step pools are located to intercept the primary flow and transition that flow to the outlet elevation.

Design Considerations

An example detail for step pools is included in Appendix H. Additional design considerations for constructed step pools include:

- Step pool design and placement is an integral component of the overall longitudinal profile design for steeper channels. The height of each step and the spacing between steps are used to set the overall profile.
- The downstream header rock(s) for a given step pool should be placed at an elevation to protect the upstream footer rock(s) in steeper channels and in newly constructed channels.
- When fish passage is a concern, step height should be minimized to the extent practical. Absolute step height limits will depend on the fish species in question, and the designer should

consult available research. Pool depth and length below each step are also important factors for fish passage.

11.2.3 Cross-vanes

Description

Cross-vanes are used to provide grade control, keep flow energies centered in the channel, and protect the adjacent stream banks. A cross-vane consists of two rock vanes joined by a center structure installed perpendicular to the direction of flow. This center structure sets the invert elevation of the streambed.

Due to the increased flow velocity and gradient, scour pools form downstream of cross-vanes. Pool depth will depend on the configuration of the structure, flow velocity and gradient, and bed material of the stream. For many fish species, these pools form areas of refuge due to increased water depth, and prime feeding areas as food items are washed into the pool from the riffle or step directly upstream.

Figure 34: Cross-vane Examples

Example Cross-vane

Application

Cross-vanes can be used to provide grade control in practically any stream system. Cross-vanes are also used to create pools in streams with low slope and long riffle sections, to improve bed form diversity. Cross-vanes are best utilized as step pool structures in streams with drainage areas greater than 5 square miles. Cross-vanes are best suited for use in gravel bed streams, because the gravel substrate helps to seal the voids between the larger rocks.

Placement

Cross-vanes are placed within long riffles to improve bed form diversity. Cross-vanes can be placed at the tails of pools if used as a step to provide grade control and set the water surface elevation of the upstream pool. Cross-vanes can also be used in riffle areas where the stream is overly wide, to promote settling of sediment along the channel edges and narrowing of the channel. Cross-vanes can also be utilized immediately upstream of bridges to concentrate flow to the middle of the stream, away from the bridge piers. In steep gradient streams, cross-vanes can be used as steps to provide grade control, or as components of a step pool channel design.

Design Considerations

An example detail for cross-vanes is included in Appendix H. Additional design considerations for constructed cross-vanes include:

- Filter fabric, typically non-woven geotextile, should be used if the stream bed material is predominantly gravel or smaller size fraction, to ensure sealing of voids between boulders.
- For narrower streams (less than 20 feet), the width of the center of the structure (weir) should be set at 1/3 of the stream bottom width instead of 1/3 of the bankfull width.
- The arm angle should be measured from the upstream edge of each boulder.

11.2.4 Grade Control J-Hook Vanes

Description

Grade control j-hook vanes are utilized to provide grade control and protect the stream banks.   These vanes may be constructed out of logs or rock boulders. The structure arms turn water away from the banks and re-direct flow energies toward the center of the channel. In addition to providing stability to stream banks, grade control j-hook vanes also promote pool scour and provide structure within the pool habitat. Grade control j-hooks have two to three boulders placed in a hook shape at the upstream end of the vane. The primary difference between regular j-hooks and grade control j-hooks is the way that the "hook" part of the structure is constructed. Regular j-hooks are constructed to have gaps between the header boulders in the hook to promote flow convergence. Grade control j-hooks do not have gaps between the header boulders in the hook and also have a boulder sill built from the outside of the hook over to the opposite bank such that the structure can serve as a grade control feature. Grade control j-hooks still promote scour in the downstream pool, thus providing habitat benefit.

Figure 35: Grade Control J-Hook Vane Examples

Grade control j-hook during construction — Grade control j-hook out of log/boulder mix

Application

Grade control j-hook vanes are utilized in the same scenarios as regular j-hook vanes (see **Figure 38** below), but where additional grade control is desired. Grade control j-hook vanes are used to provide grade control at meander bends where the opposite arm (inside of the meander bend) of a cross-vane would need to be built shorter and at a lower angle. For this reason, grade control j-hook vanes are sometimes referred to as offset cross-vanes. Grade control j-hook vanes hold the grade of the upstream riffle.

Placement

Grade control J-hook vanes are most often located in meander bends just downstream of the point where the stream flow intercepts the bank at acute angles.

Design Considerations

An example detail for grade control j-hook vanes is included in Appendix H. Additional design considerations for grade control j-hook vanes include:

- Filter fabric, typically non-woven geotextile, should be used if the stream bed material is predominantly gravel or smaller size fraction, to ensure sealing of voids between boulders.
- The arm angle should be measured from the upstream edge of each boulder

11.3 In-stream Lateral Stability Structures

Laterally stable streams resist unnatural or abnormal rates of horizontal migration. Lateral stability is directly related to stream bank stability. When stream banks are not naturally "armored" or protected by woody vegetation, lateral instability often occurs. Various in-stream structures can work to provide critical bank protection by re-directing stream flow away from the stream bank or by simply armoring the stream bank. These structures provide stability until a mature riparian buffer can be established. Similar to grade control structures, lateral stability structures are carefully designed and constructed to mimic natural features. Providing adequate reach-wide lateral stability until the mature stream bank and floodplain vegetation can establish is essential to the success of natural channel design projects. The protection afforded by lateral stability structures prevents accelerated stream bank erosion and associated loss of land and riparian habitat, protecting both the project reach and downstream reaches from water quality degradation.

A variety of in-stream structures can be used to provide lateral stability. These structures include root wads, log vanes, toe-wood structures, j-hook vanes, and rock vanes. Example detail drawings are provided in Appendix H. There is flexibility in selecting methods that provide lateral stability. The decision to use one technique over another should be based on the risk of bank erosion and the relative cost. The risk of erosion increases with increasing drainage area, increasing percent impervious cover, and the erodibility of bank particles. The table below (**Table 2)** provides guidance on selecting an in-stream structure bank stabilization practice based on the structure's ability to provide bank stability and cost.

Table 2: Guidance for Selecting an In-stream Bank Stabilization Practice

In-Stream Structure	Relative Strength to Provide Bank Protection	Relative Cost
Root Wads	High	Low to High depending on on-site availability (on-site = low)
Log Vanes	Moderate	Low to Moderate depending on on-site availability (on-site = low)
J-hook and Rock Vanes	Moderate	Moderate to High

11.3.1 Root Wads

Description

Root wads are in-stream structures that provide increased lateral stability by armoring the stream banks, and work particularly well in small streams. Root wads are the root masses or root balls of live trees dug out of the ground with the trunk of the tree still intact. Root wads function by deflecting energy away from the stream banks, thus preventing erosive forces from acting on the stream banks themselves. Root wads can also provide improved in-stream habitat by promoting scour near the outside of a meander bend, in close proximity to the cover and structure supplied by the root wads.

Figure 36: Example of Root Wads

Example root wad in meander bend

Application

Root wads are used primarily in small streams with drainage areas less than 5 square miles to provide lateral stability. Root wads can be utilized in larger stream systems, but such application is more for habitat improvement. Utilizing root wads is preferable when trees can be harvested onsite in conjunction with clearing operations. Cover logs can be installed with root wads to increase in-stream cover and structure, improving the habitat value offered by the root wads.

Placement

Root wads are installed along the toe of the stream bank at the outside of meander bends in locations where the stream flow velocity vectors directly impact the stream banks. Root wads can also be installed in other locations where flow is focused directly at stream banks, such as bank areas positioned opposite of tributaries or outlet pipes. The number and arrangement of the root wads required to protect a meander bend depends upon the size and configuration of the meander bend as well as the size of the root wads. Root wads can also be used in conjunction with other in-stream structures such as log vanes.

Design Considerations

An example detail for root wads is included in Appendix H. Additional design considerations for root wads include:

- Care must be taken to avoid erosion of the bank areas around and above the installed root wads. There are three primary methods to protect against this type of erosion:
    1. Place dense vegetation transplants above the root wads to provide immediate living root mass to the bank;
    2. Install bioengineering practices, such as brush layers or geolifts, on the stream bank above the root wads; and
    3. Reduce the slope of the upper bank above the root wads and construct a wide (5 – 10 feet), shallow (0.5 – 1.0 foot high) berm along the top of bank to prevent flood waters and runoff from flowing down around the installed root wads. Erosion control matting is then applied to the upper bank above the root wads and to the constructed berm. Live stakes are installed in the applied matting to provide additional long-term stability.
- Adjacent root wads should be installed so that they butt against each other, avoiding gaps and voids between root wads that can erode.

11.3.2 Log Vanes

Description

Log vanes can be constructed completely out of log materials, or a combination of both log and boulder materials. Log vanes are typically utilized along outer meander bends, areas where flow direction changes abruptly, and areas where pool habitat for fish species is desirable. Location, vane length, angle, and slope are all considered and designed for the specific site conditions. Log vanes function by intercepting stream flow and redirecting that flow away from the stream bank and towards the center of the channel, reducing the erosive force of water on the banks. Log vanes also improve in-stream habitat by creating scour pools and providing oxygen and cover.

Figure 37: Example of Log Vane during Construction and Post-Construction

Installation of log vane during construction. Completed log vane and root wad structure.

Application

Log vanes are used where stream banks are less than 3 feet high and shear stresses placed on stream banks are low to moderate. Log vanes should not be used along stream banks that are highly vulnerable to erosion. Log vanes should only be used in perennial streams where the logs are under water and saturated at all times to avoid premature deterioration.

Placement

Log vanes are best used to provide lateral stability on the outside of a meander bend. Vanes should be placed so that they intercept flow velocity vectors just downstream of the point where the stream flow strikes the stream bank.

Design Considerations

An example detail for log vanes is included in Appendix H. Additional design considerations for log vanes include:

- Filter fabric, typically non-woven geotextile, should be used to ensure sealing of voids between logs.
- Ensure that the arm slopes are low, with arms tying into the banks at no higher than ½ bankfull stage.
- Log vanes are often secured to the stream bank using root wad(s) and/or transplants. Logs are secured to the stream bed with large rocks, or by burying the log to a sufficient depth.

11.3.3 J-Hook and Rock Vanes

Description

J-hook and rock vanes may be constructed out of logs or rock boulders. The structure arm turns water away from the banks and re-directs flow energies toward the center of the channel. Both structures provide stability to stream banks; however, j-hook vanes also promote pool scour and provide structure within the pool habitat. J-hooks are rock vane structures that have two to three boulders placed in a hook shape at the upstream end of the vane. The boulders are placed with gaps between them to promote flow convergence through the rocks and increased scour of the downstream pool. Due to the increased scour depths and additional structure that is added to the pool, J-hooks are primarily used to enhance pool habitat for fish species. The boulders that cause flow convergence also create current breaks and holding areas along feeding lanes. The boulders tend to trap leaf packs and small woody debris that are used as a food source for macroinvertebrate species.

Figure 38: Examples of J-Hook and Rock Vanes

Example J-Hook and Rock Vanes

Application

J-hook and rock vanes are used in meandering stream systems in alluvial valleys. Rock vanes are best suited for use in streams having drainage areas greater than 2 square miles, while J-hook vanes are best suited for use in streams having drainage areas greater than 5 square miles. J-hook and rock vanes are very useful for helping to stabilize stream banks with severe erosion.

Placement

J-hook and rock vanes are most often located in meander bends just downstream of the point where the stream flow intercepts the bank at acute angles. Both vane structures can be used at the beginning and end of pools.

Design Considerations

An example detail for j-hook vanes is included in Appendix H. Additional design considerations for J-hook and rock vanes include:

- Filter fabric, typically non-woven geotextile, should be used if the stream bed material is predominantly gravel or smaller size fraction, to ensure sealing of voids between boulders.
- J-hooks provide greater habitat diversity than rock vanes, particularly for fish. If improved aquatic habitats are not a design goal of the project (i.e. highly polluted waters with little to no fish communities), rock vanes should be used instead of J-hooks.

- Care should be taken to avoid placing the last boulder in the "hook" of the J-hook too close to the opposite stream bank from the vane arm. This can cause scour and erosion on the opposite bank near the boulder. In narrower streams, reduce the number of boulders used to form the "hook", to avoid this condition.

11.3.4 Toe Wood Structures

Description

Toe wood structures may be constructed using a combination of native materials such as logs, branches, brush, live cuttings, sods mats, transplants, and soil. The structure helps ensure long-term stability against eroding banks and provides a more natural appearance than hard armoring. Toe wood can be a cost-effective solution for bank protection while restoring channel dimensions and floodplain connection. In addition to providing stream bank stability, toe wood structures enhance aquatic and terrestrial habitat within the pool area by establishing a source of detritus and large woody debris.

Figure 39: Installation of Toe Wood Structures

Installation of toe wood, during construction.

Toe wood after growing season.

Application

Toe wood structures are used in meandering stream systems in alluvial valleys. They can be applied to stream systems with a broad range of geomorphic settings and drainage area sizes, but should only be used in perennial streams such that the toe wood is submerged and saturated at all times to avoid premature deterioration. Toe wood structures are very useful for helping to stabilize stream banks with severe erosion or unstable cut banks.

Placement

Toe wood structures are most often located around outer meander bends to intercept flow energies applied to the outer stream banks. Toe wood can be used from the beginning of a meander pool to the end, and is positioned on the lower 1/3 to 1/2 of the bank. The upper bank contains live cuttings in combination with sod mats, live stakes, transplants, or geolifts to cover the toe wood up to the bankfull stage.

Design Considerations

An example detail for a toe wood structure with a geolift is included in Appendix H. There are multiple options to covering the toe wood that can depend on available materials, cost, channel dimension, and site conditions.

11.4 Bed Form Diversity Structures

Bed form diversity is defined as the variation in depth and character of the streambed. Bed forms include riffles, runs, pools, and glides. For this document, riffles are defined as straight sections of the channel with shallow depths. Runs are transitional features between the upstream riffle and the downstream pool. Pools are deep areas created by scour that have slopes that are much less than the reach average slope. Glides are transitional features between the upstream pool and the downstream riffle, and are the only bed feature that slopes uphill in a down valley direction.

Bed form diversity is primarily achieved by re-establishing pattern in alluvial streams. Riffles form in the straight sections and pools form in the meander bends. For straight channels (sinuosity less than 1.2) and colluvial streams, bed form diversity is achieved through a step pool channel morphology. In both cases, in-stream structures can be used to further diversify the bed by creating more depth variability and complexity. The added complexity is primarily achieved by adding more wood or structure to the channel. Double wing deflectors, single wing deflectors, and large wood debris cover logs are structures that are commonly used to provide additional bed form diversity.

11.4.1 **Double Wing Deflectors**

Description

Double wing deflectors are used to provide enhanced bedform diversity. Double wing deflectors are constructed by installing matching “wing-shaped” boulder sills, one on each side of the stream, centered about the thalweg. Each sill extends out from the stream bank, runs parallel to the stream bank in the downstream direction, and then returns to tie in to the stream bank. The narrow area between the boulder sills creates and maintains a well-defined, narrowed low flow channel. The flow convergence created by the structure also creates controlled areas of bed scour immediately downstream of the deflector.

Figure 40: Examples of Double Wing Deflectors

Example of double wing deflectors

Application

Double wing deflectors are typically utilized in larger size streams, e.g. larger than 5 square miles. They are best employed in gravel bed stream systems with moderately stable to stable stream banks. Double wing deflectors are commonly used in the repair of over-widened stream reaches where the goal is to narrow the low flow channel. They are also very useful structures to use in flood control channels to create an inner berm feature if adequate sediment supply exists. Double wing deflectors are also used to protect bridges and large culverts that have divided cells, aiding in deflecting flows to those divided cells.

Placement

Double wing deflectors are typically placed in long straight stream reaches. When used to repair over-widened channels, they are installed where mid-channel bars have been removed. In these cases, the double wing deflectors are installed to prevent the reoccurrence of the mid-channel bars. For the described bridge and culvert protection applications, double wing deflectors are placed immediately upstream of bridges and large culvert structures as needed for proper flow deflection.

Design Considerations

An example detail for double wing deflectors is included in Appendix H. Additional design considerations for double wing deflectors include:

- Filter fabric, typically non-woven geotextile, should be used if the stream bed material is predominantly gravel or smaller size fraction, to ensure sealing of voids between boulders.
- Double wing deflectors are best utilized on larger stream systems.

11.4.2 Single Wing Deflectors

Description

Like double wing deflectors, single wing deflectors are used to provide enhanced bedform diversity. Single wing deflectors are constructed in the same manner as double wing deflectors, but only include one boulder sill on one side of the stream channel. The alignment and construction of the sill is the same as described for the double wing deflector. The narrowed area between the boulder sill and the opposite stream bank helps maintain a better defined, narrowed low flow channel.

Application

Single wing deflectors are typically utilized in larger size streams, e.g. larger than 5 square miles. They are best employed in gravel bed stream systems with moderately stable to stable stream banks. Single wing deflectors are used rather than double wing deflectors in situations where the stream needs to be narrowed to promote a better defined low flow channel, but one stream bank is very stable in its existing condition (the bank opposite the proposed single deflector), and the amount of narrowing desired is not as great.

Placement

Single wing deflectors are typically placed in straight to gently curving stream reaches. They can be placed in locations to move the location of the thalweg and promote a more well-defined low flow channel, or in channel sections that are overly wide to promote narrowing.

Design Considerations

An example detail for a single wing deflector is included in Appendix H. Additional design considerations for single wing deflectors include:

- Filter fabric, typically non-woven geotextile, should be used if the stream bed material is predominantly gravel or smaller size fraction, to ensure sealing of voids between boulders.
- In some instances, single wing deflectors can be used in conjunction with a different bank stabilization practice on the opposite bank, such as a rock vane, root wads, or bioengineering approach.
- Single wings are typically used to narrow the channel where a double wing would cause too much constriction.

11.4.3 Large Woody Debris Cover Logs

Description

A cover log is placed in the channel to provide cover and enhanced habitat in the pool area. The log is buried into the outside bank of the meander bend; the opposite end extends through the deepest part of the pool and may be buried in the inside of the meander bend, in the bottom of the point bar. The placement of the cover log near the bottom of the bank slope on the outside of the bend encourages scour in the pool, provides cover and ambush locations for fish species, and provides additional shade. Cover logs are often used in conjunction with other structures, such as vanes and root wads, to provide additional structure in the pool.

Figure 41: Example of Large Woody Debris Cover Logs

Example of large woody debris cover log in a pool.

Application

Cover logs can be used in any sized stream where the introduction of large woody debris is appropriate. Cover logs are typically used in conjunction with those in-stream structures that are installed along the outside of meander bends at pools.

Placement

Cover logs are placed between root wads and also integrated into the construction of rock vanes, cross-vanes, and both types of j-hook vanes. Placement is within pool areas, and generally the logs are anchored into the outside of a meander bend. Logs are installed below the baseflow water level to keep the logs saturated and prevent scour on the adjacent bank.

Design Considerations

An example detail for large woody debris cover logs is included in Appendix H. Additional design considerations for cover log include:

- Specify cover logs in circumstances where improved fish habitat is a project goal.
- Cover logs are effective at catching smaller debris such as limbs and leaves. In urban environments with significant amounts of trash that enter the waterway, cover logs will also collect trash and may cause aesthetic concerns.

11.5 Bioengineering

Bioengineering methods are used to provide lateral stability. Bioengineering can be implemented as a stand-alone practice, or in combination with in-stream structures. Within the context of natural channel design, bioengineering is simply defined as the specialized use of plant materials to stabilize stream bank soils. Bioengineering provides stabilization through the accelerated establishment of vegetation along the stream banks. The vegetation growing out of the stream banks acts like flexible armoring against erosive stream flow, and the associated root mass growing into the stream banks adds "structural reinforcement" by holding the stream bank soils together. Examples of common bioengineering techniques include brush mattresses, brush layers, live stakes, geolifts, fascines, transplants, and erosion control matting.

Beyond stabilizing the stream banks, the use of bioengineering provides many other benefits. These benefits include adding biomass to the stream system, stream shading, quicker vegetation establishment, lower costs for establishing vegetation by utilizing native and/or local materials, improved aesthetics, improved riparian and in-steam habitat, increased infiltration, and increased sediment deposition.

The main component common to all appropriate bioengineering techniques is native species vegetation. Species selection is important, as not all species are well suited for use in bioengineering practices. In some situations, the native species vegetation can be harvested on-site during construction. This vegetation can typically be harvested from areas of the project site that are to be restored, abandoned, cleared, or otherwise be impacted during the construction process. Such potential should always be considered during the planning and design phases of stream restoration projects. Consult local biologists, botanists, forestry professionals, or other qualified practitioners to determine which species are suitable for use in bioengineering practices.

A detailed overview of bioengineering, entitled "Streambank Soil Bioengineering," is included as Technical Supplement 14I, in Part 654 Stream Restoration Design, National Engineering Handbook by the NRCS. Refer to this detailed source of information for more information on the use of bioengineering practices. Some of the most commonly used bioengineering practices associated with natural channel design are briefly described below. Example details for these practices are provided in Appendix H for reference.

It should be noted that in the semi-arid climate of the San Antonio region, irrigation may be required for a period of time following construction to achieve acceptable growth of bioengineering and vegetative practices.

The decision to use one bioengineering technique over another should be based on the erosion protection that the technique provides and the relative cost. The table below (**Table 3**) provides guidance on selecting common bioengineering practices based on the relative strength that the practice provides and the relative cost.

Table 3: Guidance for Selecting a Bioengineering Bank Stabilization Practice

Bioengineering Method	Relative Strength to Provide Bank Protection	Relative Cost
Brush Mattress	Moderate	Moderate to High
Brush Layers	Moderate	Moderate to High
Live Stakes	Low	Low
Geolifts	High	High
Fascines	Moderate	Moderate
Transplants	High	Low (Must come from on-site)
Erosion Control Matting	Low to Moderate	Low to Moderate

11.5.1 Brush Mattresses & Brush Layers

Brush mattresses are placed on bank slopes for stream bank protection. Layers of live, woody cuttings are wired or tied together and staked into the bank. The woody cuttings are then covered by a fine layer of soil. The plant materials quickly sprout during the growing season and form a dense root mat across the treated area, securing the soil and reducing the potential for erosion. Within one to two years, a dense stand of vegetation can be established that, in addition to improving bank stability, provides shade and a source of organic debris to the stream system. Deep root systems often develop along the waterline of the channel, offering another source of organic matter and a food source to certain macroinvertebrate species, as well as cover and ambush areas for fish species. Brush mattresses are typically placed along the outer meander bends, areas where bank sloping is constrained, and areas susceptible to high velocity flows.

Brush layers are very similar to brush mattresses, except that they are placed on the top of bank instead of on the bank slopes for stream bank protection. Brush layers are therefore used in conjunction with other bank protection structures or measures such as vanes or root wads, as brush layers do not provide immediate protection of the toe of bank..

11.5.2 Live Stakes

Live stakes are live cuttings, typically dormant season, from native species woody plants that are directly planted into the stream banks. Some species are better suited than others for use as live stakes, with willows and some dogwood species typically performing the best. Live stakes can often be harvested on site, particularly with proper planning during both the design and construction phases. They should be harvested from live, healthy, vigorous, well-rooted plants. Proper handling and storage of live stake material is also vital. Live stakes are normally installed in areas of higher stress, such as along the outside of meander bends, but can also be installed anywhere along the stream channel where accelerated vegetation growth is desired. They are usually installed through the erosion control matting, directly into the restored stream bank. Each live stake is installed approximately two feet into the ground, with not more than one foot exposed above the ground. The intent is to install them as deep as possible and as close to the water table as possible. Live stakes are thus installed within the limits of the bankfull channel and are installed by pushing or hammering them into the stream banks. Live stakes provide all of the advantages associated with establishing riparian vegetation at relatively low cost and are most commonly using in conjunction with other in-stream structures, and not as a stand-alone measure.

11.5.3 **Geolifts**

Geolifts are a bioengineering measure used to stabilize stream banks. Geolifts are most commonly used along the outside of stream meander bends. They are basically a series of large overlapping soil "burritos," or lifts, constructed using coir fiber erosion control matting and native soils. Often, live cutting materials from specific woody native species plants are planted in the layers between the lifts. A stone toe base is typically installed to provide protection at the toe of the stream bank and to provide a foundation for the geolifts. The geolifts are installed on top of the stone base to comprise the entire restored stream bank up to the bankfull channel elevation. Geolifts can be used to effectively stabilize restored stream banks for all sizes of streams simply by varying the number of lifts required to form the stream bank.

11.5.4 **Fascines**

Fascines are bundles of long live cuttings, typically dormant season, from native species woody plants that are planted to help stabilize the stream banks. Some species are better suited than others for use as fascines, with willows and some dogwood species typically performing the best. Fascines can often be harvested on site, particularly with proper planning during both the design and construction phases. They should be harvested from live, healthy, vigorous, well-rooted plants. Proper handling and storage of fascine materials is also vital. Fascines are normally installed in areas of higher stress, such as along the outside of meander bends, but can also be installed anywhere along the stream channel where accelerated vegetation growth is desired. They are usually installed laterally along the toe of the stream bank or at elevations within the bankfull channel and securely staked in trenches, with their tops being exposed just above the ground. Fascines provide all of the advantages associated with establishing riparian vegetation at relatively low cost and are most commonly used in conjunction with other in-stream structures, and not as a stand-alone measure.

11.5.5 **Transplants**

Transplants are used to increase lateral stability by providing instant living root mass within the stream bank. They are living native plants that are excavated and replanted on site and are typically harvested from areas of the project site that are to be restored, abandoned, cleared, or otherwise be impacted during the construction process. These areas include the existing stream banks, existing flood plain, haul roads, staging and stockpile areas, etc. Native plants that are suited to stream bank areas and can be successfully harvested and replanted along the restored stream banks may be good candidates for transplanting, understanding that some species transplant better than others. Consult local biologists, botanists, forestry professionals, or other qualified practitioners to determine which species are suitable for transplanting. Because transplants are harvested from areas where the existing vegetation would be impacted or removed as a result of construction, transplanting tends to be a relatively inexpensive way to help prevent lateral instability, while also salvaging and recycling on-site materials.

Transplants are harvested with the root ball and the surrounding soil intact and are quickly re-planted along the stream banks and the flood plain to avoid drying out the roots. They can be planted as a stand-alone measure to provide stream bank protection, or installed in conjunction with other in-stream structures, such a log vanes and root wads, where they are typically planted at the interface where the in-stream structure ties into the stream bank. Transplants have mature root systems that re-establish in their new location, much quicker than the smaller commercially grown or harvested planting stock typically used for stream bank planting. This accelerated rate of vegetation establishment allows the root system from the transplants to help hold the stream bank together and help prevent stream bank erosion. Transplants also significantly contribute to in-stream habitat as they provide a permanent source of shading and contribute organic material to the stream system.

11.5.6 Erosion Control Matting

Coir (coconut) fiber matting is the type of erosion control matting most commonly used to stabilize restored stream banks. This type of erosion control matting is available in many different styles and weights. The most common used for stream bank restoration is the 700-gram matting. This erosion control matting is fabricated from 100 percent coir twine woven into a high strength blanket. Erosion control matting is installed on all of the newly constructed stream banks, from the toe or edge of water, up to the top of the stream bank or bankfull elevation. After the proposed stream channel construction is complete, temporary and permanent seed, fertilizer and other soil amendments, and mulch are applied. The erosion control matting is then immediately installed on top to hold everything in place. The matting is secured in place using specified wood or metal stakes. Both the temporary and permanent vegetation germinate faster and grow more vigorously when installed with mulch under the erosion control matting. Erosion control matting is installed along all of the restored stream banks as described. A possible exception is that sometimes the point bars on the inside of the meander bends are not matted, as these are depositional features and therefore not typically subject to erosion.

12.0 PLAN SHEETS

12.1 Overview and Purpose

Natural channel designs are typically shown on a set of plans and described by technical specifications that are developed under the responsible charge of and certified by a professional engineer. These plans are thus an important part of the natural channel design process as they are used to communicate the project design to the various stakeholders including the project owner, contractor, the regulatory and permitting agencies, as well as the public. Plans are used in nearly every phase of natural channel design projects, from the conceptual phase all the way through the monitoring phases. Plans are used to apply for and obtain regulatory permits, to bid projects, for project construction, and for project monitoring. For the purposes of this document, the term “plans” shall refer to complete or final plan sets that have been developed to the bidding and/or construction phase, sometimes referred to as “final” or “construction” plans.

The plans, in conjunction with sound, complete technical specifications, typically form the bid documents and later, the construction contract documents (when paired up with the actual construction contract (see Chapter 13.0 for more about technical specifications), which together serve as the legal documents that govern both the bidding and construction processes. It is therefore vital that plan sets are comprehensive, accurate, and that they completely and concisely define, depict, and convey all aspects of the proposed design.

Plan sets for natural channel design projects are typically comprised of numerous types of sheets including:

- Title sheets
- Legend sheets
- General notes sheets
- Construction sequence sheets
- Typical sections sheets
- Details sheets
- Alignment data sheets
- Profile data sheets
- Structure tables sheets
- Planting tables sheets
- Seeding tables sheets
- Plan and profile sheets
- Erosion and sedimentation control plan sheets
- Planting plan sheets
- Proposed cross-section sheets

The following sections detail the minimum content and format requirements for plan sets for natural channel design projects. The designer should obtain specific requirements and standards for plan set development (i.e., sheet breakdown and sequencing) from the appropriate contracting agency (e.g. COSA, Bexar County, SARA).

12.2 Title Sheets

The title sheet shall show the correct project name, number and description. The project description shall include the location of the project. A clearly legible scaled project vicinity map shall also be included on the title sheet. The title sheet shall show a plan view index of sheets with match lines, including a north arrow. An index of the entire plan set should also be included on the title sheet. The address and logo for both the project owner and designer shall be shown on the title sheet. Consistent title blocks should be used for all sheets in the plan set, including the title sheet. The title block should include the designer's address and contact information, the project name and number, and the sheet name and number. Each sheet should also have a revision block that includes corresponding spaces for various revisions, associated dates, and designer initials. The revision block can be imbedded in the title block. Each sheet in the plan set should also be marked appropriately to indicate the status of the plan set. Examples include "Preliminary Drawings - Do Not Use for Construction," "Issued for Construction," etc.

12.3 Legend Sheets

Symbols depicting all of the items included on the plan view sheets (plans and erosion and sedimentation control plans) should be included on the legend sheet. The designer should ensure that all symbology depicted on the plan view sheets matches and is consistent with that shown in the legend.

12.4 General Notes Sheets

General notes applicable to the project shall be included on the general notes sheet. The general notes are typically standard notes that are applicable to natural channel design permitting and construction requirements.

12.5 Construction Sequence Sheets

A construction sequence covering all phases of construction shall be included. The construction sequence typically begins with mobilization, includes construction survey staking, the establishment of erosion and sedimentation control measures, moves through the various phases of construction, includes site planting and fencing, site clean-up, and ends with demobilization. Often it is a good idea to include mandatory phase inspection in the construction sequence in order to einsure that the contractor completes critical phasing before moving on to later phases. This can help to insure that applicable permitting requirements are satisfied.

12.6 Typical Section Sheets

The typical sections should show a typical view of the proposed stream dimensions. Typical sections should be included for both riffles and pools, at a minimum. The typical sections should be shown relative to the existing ground such that the proposed restoration type is clearly demonstrated (example: benching proposed for Priority Level 2 projects or filling of channels and raising of existing stream bed to conduct Priority Level 1 projects). This will also illustrate the areas of cut and fill for the project. The typical sections should be categorized by station ranges or limits or project reaches. Typical sections should be shown to scale and should include the section type (pool or riffle), the proposed bankfull cross-sectional area, width, and depth, the incremental widths and depths of the proposed bankfull channel, the cut/fill return slopes labeled at X:1, and the bankfull bench widths. The designer should ensure that the entire project length is covered by the typical section(s) and that the typical section stationing agrees with the plan and profile.

12.7 Details Sheets

Details should be included for all of the proposed project components including all erosion and sedimentation control measures, in-stream structures, bank stabilization measures, bioengineering practices, and all other applicable devices and products.

12.8 Alignment Data Sheets

Alignment data sheets are used to provide all of the horizontal alignment data to describe the proposed horizontal alignment of the stream. These data include the stationing of the horizontal curves, the horizontal curve and tangent lengths, the chord and tangent bearings, the chord lengths, the delta angles and the horizontal curve radii. The horizontal curve information should be complete and presented in a logical format such that the contractor can easily use it to lay out the proposed stream alignment during construction.

12.9 Profile Data Sheets

Similar to the alignment data sheets, the profile data sheets are used to provide all of the profile data to describe the proposed vertical elevations of the stream; specifically, the streambed and bankfull elevations for each of the proposed bed features (riffles, runs, maximum pools depth, and glides). The proposed profile information should include the station, thalweg elevation, and bankfull elevation for each proposed bed feature.

12.10 Structure Table Sheets

The structure table sheets provide the in-stream structure data in tabular format for easy reference during construction. It is helpful to number each in-stream structure on the plan-view drawings and then include those structure numbers in the structure tables. This promotes easier identification as well as data management (structure elevations, locations, types, etc.) during construction. The structure tables should also include the structure type, station, and the proposed thalweg and bankfull elevations. It is also very helpful to provide "blanks" for recording actual constructed elevations such that they can be filled in and accounted for during construction.

12.11 Planting Table and Seeding Table Sheets

The planting table and seeding table sheets specify the placement and type of vegetation to be implemented into the design in tabular form. These tables may include a combination of temporary and permanent seeding materials, container materials, bare root materials, live cuttings and live stakes.

Planting tables are used to specify the type and species and corresponding planting zones for the native vegetation. In addition, other project specific plants such as large specimen trees should be included. Both the scientific and common names for each plant should be specified. An example plant list for a project in the San Antonio region can be found in Appendix I. Acreages and descriptions should also be provided for each planting zone.

Seeding tables provide the same information as planting tables, except for the herbaceous vegetation to be established by seeding. The seeding table should therefore also specify the type and species and corresponding planting zones for both the temporary and permanent herbaceous vegetation seed. Both the scientific and common names for each plant should be specified. Acreages and descriptions should also be provided for each planting zone.

12.12 Plan and Profile Sheets

Plan sheets should be developed using an appropriate base map. It is critical that the project include an adequate base map (see Chapter 5). A USGS 1:24,000 quadrangle is not a sufficient plan view sheet for design purposes, especially for projects that include new channel alignments and utility relocations. The plan sheet may be used to record stability and geomorphic assessment results, e.g. location of eroding stream banks, headcuts, and cross-sections. The proposed channel alignment with stationing should be shown on the plan view sheet. This alignment is important because the profile and cross-section design developed with CAD software use the alignment stationing as a reference. In other words, the bulk of the design is linked to the alignment. The plan view sheets should also include survey control point locations and descriptions. An accurate north arrow should be included on all plan-view sheets. Each sheet should be drawn to scale and the correct scale shown on each sheet, preferably as a bar scale such that the sheets can be re-sized via photocopying without "distorting" the scale. The beginning and ending of the construction for each of the project stream reaches should be clearly labeled, including the northing and easting. The plans should also clearly indicate the proposed thalweg, bankfull channel limits, proposed grades using either proposed contours or spot elevations, proposed construction limits, proposed limits of disturbance, all easement and/or property boundaries, stream crossings, culverts, and proposed in-stream structures with numbers. Existing site features including roads, paths, utilities, woods or tree lines, and large individual trees, should be clearly shown. The plan view sheets should be developed to have sheet numbers, reach labels, stationing and match lines and labels.

The proposed profile is important because it establishes the overall grade for the proposed channel. It also shows feature slopes for riffles and pools. The existing ground elevation and the bankfull elevations are shown both on the profile. This information shows if the proposed channel has access to a floodplain at flows greater than the bankfull stage for the entire length of the project. If it does not, the design will likely include the excavation of a floodplain or bankfull bench. The profile view should also include the beginning and ending of the construction for each of the project stream reaches with labels, including the northing and easting to match the plan view. The major bed features should be labeled on the profile with the Point of Inflection (PI) station and elevation. The proposed average bankfull slopes and slope breaks (PI station and elevation) should be labeled on the profile as well. The profile should also be drawn to scale and the correct scale shown on each sheet, preferably as a bar scale such that the sheets can be re-sized via photocopying without "distorting" the scale. Any stream reach confluences should be shown and be labeled on the profile with equalities using the PI station and elevation and northing and easting as well. Culvert and bridges, both existing and proposed, should be shown on the profile.

12.13 Erosion and Sedimentation Control Plan Sheets

The erosion and sedimentation control plan sheets show basically the same information as the regular plan view sheet, but specific to erosion and sedimentation control. The additional features to be shown on the erosion and sedimentation control plans sheets include standard erosion and sedimentation control notes, haul roads and staging areas, utility avoidance notes, construction entrances, construction phase break limits, and pump-around limits. All erosion and sedimentation control measures, including silt fences, check dams, pump-around operations, gravel construction entrances, tree protection fence, etc. should also be shown. An erosion and sedimentation control overview plan sheet is also helpful to provide an "overview" of the project for items such as site access, staging and stockpiling, haul road, construction phase breaks, etc.

12.14 Planting Plan Sheets

The planting plan sheets show basically the same information as the regular plan view sheet, but specific to project planting. The primary additional feature shown on the planting plans sheets includes the proposed planting zones clearly delimited. Any specific planting notes should also be included on this plan.

12.15 Proposed Cross-section Sheets

Proposed dimensions are shown on the detailed cross-sections at some regular stationing interval (example: every 50 feet). Each cross-section should be labeled with the corresponding project reach and stationing. The proposed cross-sections should be overlaid with the existing ground, so that areas of cut and fill are clearly depicted. The bankfull stage should be clearly identified so that the reviewer can tell that the bankfull stage corresponds with the top of the stream bank. The cross-sections should extend far enough across the valley so that the adjacent floodplain width, and hence the flood-prone width, can be determined such that the entrenchment ratio is clearly depicted.

13.0 TECHNICAL SPECIFICATIONS

Technical specifications describe in detail what is shown in the set of plans. The technical specifications can be considered the "written instructions" that go along with the plan set. Like the plans, the technical specifications are an important part of the natural channel design process as they are used to communicate specific detailed information about the project design to the various stakeholders including the project owner, designer, contractor, the regulatory and permitting agencies, as well as the public. The technical specifications are typically developed during the permitting phase of the project as they are used to apply for and obtain regulatory permits, to bid projects and for project construction. For the purposes of this document, the term "plans" shall refer to complete or final construction drawing plan sets that have been developed to the bidding and/or construction phase, sometimes referred to as "final" or "construction" version of the construction drawings.

As noted in Chapter 12 above, the plans, in conjunction with sound, complete technical specifications, typically form the bid documents and later, the construction contract documents (when paired up with the actual construction contract), which together serve as the legal documents that govern both the bidding and construction processes. It is therefore vital that technical specifications be comprehensive, accurate, and that they completely and concisely define, depict, and convey all aspects of the proposed design.

The technical specifications describe and define all of the technical components required to implement each of the various work items associated with the project construction. The work items include more broad categories such as:

- Constructon Survey
- Mobilization and Demobilization
- Erosion and Sedimenation Control Measures
- Coir Fiber Matting
- Clearing and Grubbing
- Earthwork
- In-stream Strucutres
- Temporary and Permanent Seeding
- Translplanted Vegetation
- Live Staking
- Bare-root Vegetation

Each of these work items would typically serve as an individual section in the set of technical specifications for a project. Each of these individual sections would be further sub-divided and organized into various technical components specific to that work item. Examples of these technical components include:

- Description
- Method and Materials
- Method of Measurement and Payment

A technical specification should be developed for each of the work items associated with project construction as noted above. Technical specifications can be organized and presented in various formats ranging from detailed outlines to paragraph or narrative form. Technical specifications can also be organized as special provisions to amend or complement a standard or accepted set of master technical specifications, such as those utilized by a Department of Transportation or government agency. Standard technical specifications can be carefully developed, much like standard details, such that they are truly standardized, and thus can be re-used from project to project with minimal edits. Several technical specification software programs are available commercially that simplify the development and management of technical specifications, particularly standardized sets.

An example set of technical specifications for the in-stream structures and bioengineering practices are presented in Appendix J.

14.0 PERMITS

Section 404 of the Clean Water Act (CWA) authorizes the USACE to regulate dredging or discharge of fill material into Waters of the U.S., including wetlands. As part of the USACE approval process, the state environmental agency (TCEQ) must certify, pursuant to Section 401 of the CWA, that the permitted action will comply with the applicable state water quality standards. All practices within the City of San Antonio, Bexar County, and SARA jurisdiction are performed in compliance with appropriate federal, state, and local environmental rules, laws, regulations, and permits as required when working in or modifying wetlands and waters of the U.S. or any maintained facilities. With an ever-increasing rate of development in San Antonio and the surrounding areas, direct and indirect impacts to streams and tributaries are inevitable. Development and subsequent impacts to any aquatic resources would require coordination with the USACE and other permitting agencies. A wetland delineation and/or jurisdictional determination must be performed in accordance with the USACE Wetlands Delineation Manual (1987 Manual) and appropriate Regional Supplement. For the San Antonio region, either the Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Great Plains Region (Version 2.0) (2010; Great Plains Supplement) or the Gulf Coast Regional Supplement are applicable USACE supplements would be used, depending on location of project.

Additionally, a Storm Water Pollution Prevention Plan (SWPPP) must be prepared for construction projects in accordance with the TPDES Construction Stormwater Permit (TXR150000) under Section 402 of the Clean Water Act and Chapter 26 of the Texas Water Code. A Notice of Intent should be prepared and submitted to the TCEQ for projects in which disturbance exceeds 5 acres. The SWPPP should also be coordinated with any local floodplain administrator or local environmental quality compliance representative such as city or county inspectors.

Coordination must be performed with the project specific local jurisdiction to determine allowable floodplain impacts. A Conditional Letter of Map Revision (CLOMR) and post-construction Letter of Map Revision (LOMR) may be required to changes to the base flood boundaries. Restoration projects will most likely cause change to the base flood boundaries based on stream or tributary pattern being altered. All environmental components in regards to preparing a CLOMR and/or LOMR must be adhered and submitted in the review process in accordance with San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling (SARA, 2005).

As always, during the permitting and environmental review phase of a project, it is important to review county, local, and city ordinances for any additional permits required that are project specific. Additionally, coordination and review of Impaired Waters, soils impacts, Natural and Scenic Rivers, Threatened and Endangered Species, NHPA Section 106 review and Texas Antiquities Act must be performed and coordinated as appropriate.

15.0 CONSTRUCTION OBSERVATION AND INSPECTION SERVICES

There are well established rules and regulations related to the responsibilities of the design professional and the construction contractor. In general, the design professional is responsible for creating design plans and specifications and the contractor is responsible for the construction means and methods necessary to build the project per the design plans and specifications. The owner, such as the San Antonio River Authority, City, or County government will provide the construction contract. The designer and contractor should refer to these contracts for specific requirements and obligations.

Stream restoration projects in the San Antonio area will typically be part of a standard contracting process Stream restoration project are not good candidates for design build type projects due to the comprehensive watershed assessment and field data collection required to develop appropriate design criteria However, because stream restoration using natural channel design techniques is fairly new to the San Antonio region, there is currently a lack of experience in the local contracting community. Therefore, the designer will be more involved during the construction phase than typical channel projects, such as flood conveyance projects. These additional services will be provided under construction observation and/or inspection tasks.

Construction observation or evaluation is simply observing construction on-site, as it progresses, to make certain that the project is constructed as designed and permitted. The work is observed or evaluated to determine whether it will comply with the requirements of the contract documents when completed. If deficiencies are seen, they are reported to the owner and contractor in writing so they can be corrected. These are general observations or evaluations, not inspections of the work. However, the designer can answer questions about the intent of the design or to assist in clarifying design ambiguities. This will be a critical element during the construction of the first few projects for any given contractor.

Construction inspection is different than construction observation in terms of review intensity / level of effort. A construction inspection will require more time on-site and quantitative measurements to determine if the completed construction is within the tolerances set forth in the design plans and specifications.

The contents of this manual clearly demonstrate that developing a sound natural channel design for a given project is a complex process involving multiple disciplines. Such designs can quickly be put at significant risk of failure if the project is not constructed as designed. Construction observation and inspection are thus vital to the success of all natural channel design projects, helping to properly implement projects such that the desired functional uplift is achieved.

The amount of time the design professional needs to spend at the project site actively observing or inspecting construction depends on several factors. These factors include:

- Project complexity
- Project site conditions
- Contractor experience and ability
- Owner requirements
- Contractual requirements

Typically, the design professional spends at least one to two days per week at the site providing construction observation services. It is not uncommon for the observer to spend several days per week at the site, particularly at the beginning of construction or for projects with more complex designs or site constraints, or with less experienced contractors. These requirements are normally dynamic and are determined by the design professional and owner based on construction progress. Construction observation duties that should be considered for stream restoration projects include:

- Verifying that site conditions have not changed significantly since the project design was completed
- Identifying and marking transplant vegetation
- Identifying and marking exotic/non-native vegetation to be treated/removed
- Verifying that sedimentation and erosion control measures are installed correctly before proceeding with construction
- Verifying that project construction complies with permitting requirements
- Observing that project construction complies with the design plans and construction documents
- Making minor design adjustments in the field to adapt to on-site conditions
- Preparing punch lists of deficient or incomplete work
- Effectively communicating with the contractor and owner through site visit reports.

Examples of construction inspection services include:

- Verifying construction staking is correct
- Providing stakeout services for in-stream structures (strongly recommended for new projects and inexperienced contractors)
- Measuring channel dimensions and in-stream structures to determine if they comply with the plans and specifications.

The contractor is responsible for construction means and methods, including:

- Ensuring that the project in constructed in accordance with the proposed design
- Ensuring that all permitting requirements are satisfied during all phases of construction
- Ensuring that all applicable health and safety requirements are satisfied during all phases of construction

16.0 AS-BUILT SURVEYS

As-built surveys are post construction surveys used to document the completed construction and as a baseline for future monitoring. These surveys document locations and elevations for top of bank, thalweg, water surface, inverts of structures, permanent cross-section pins, vegetation transplant locations, locations of vegetation monitoring plots and instrumentation (e.g. wells, gauges), photo point locations, new berms or roads constructed, and any other significant site features that were constructed.

The as-built survey should be performed in accordance current electronic drawing standards as well as SARA MicroStation and CAD standards as previously defined. At the completion of work, the contractor should conduct a complete site survey, performed to a level of detail that will allow the as-built stream channel dimension, planform, and profile, as well as floodplain elevations, to be verified against the proposed design. The contractor should produce as-built plans indicating the following surveyed features:

- Channel alignment (based on thalweg)
- Left and right top of bank
- Left and right toe of bank
- Longitudinal profile
- Limits of disturbance (LOD)
- In-stream structures
- Elevation contour lines within the LOD in increments of one foot
- Limits of gradingKey floodplain break points (e.g., top and toe of terraces, benches and levees)
- Boundaries for wetland areas
- Boundaries for other areas labeled as sensitive (e.g., graves, protected species, etc.)
- Boundaries of surface water features (e.g. vernal pools, ponds, stormwater BMPs)
- Permanent crossings
- Fencing
- Locations of utility lines within the disturbance areas verified prior to construction
- Surveyed benchmarks (e.g. permanent monuments, property boundaries)
- Other features or critical design elements flagged by the construction manager, designer, or owner.

The contractor should also show the location of representative cross-sections for post-construction monitoring at locations determined by the designer. The cross-section locations should be clearly marked by the designer in the field and on the working plans. The number of cross-sections for each project may vary depending on permit conditions and monitoring requirements.

All structures should be surveyed in location and elevation. The longitudinal profile survey should include elevations of the channel bed, water surface, and low bank height. Profile points are typically surveyed at prescribed intervals and at significant breaks in slope, such as the head of a riffle or pool.

The final as-built should clearly indicate any deviations between the design and construction. As-builts are usually submitted to the designer after all grading activities have been completed and no later than 60 days after the project completion.

17.0 MAINTENANCE

Each project will have site specific maintenance considerations. A maintenance plan will be prepared as part of the natural channel design report for each project site, and will address both short-term and long-term maintenance items. Maintenance plans should include such aspects as inspections, repairs, replacement, and warranties. The Contractor is typically responsible for coordinating maintenance activities for a specific project area for one year following installation of the project (the warranty period). Example tasks to be considered in the first year following installation for the successful establishment of a project site include:

- Initial inspections for the first 6 months following construction. The site should be inspected at least twice after storm events that exceed 0.5 inch of rainfall.
- Bare or eroding areas in the project area should be re-seeded to ensure they are immediately stabilized with grass cover.
- Fertilization may be needed for initial plantings.
- Watering may be needed once per week during the first 2 months and then as needed during the first growing season, depending on rainfall. Under drought or unusual site conditions, watering may be needed for longer periods of time to ensure proper vegetation establishment. Minimum quantities of water should coincide with plant specific needs.
- Since plant stock may die off in the first year, construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction. The typical thresholds below which replacement is required are 90% survival of plant material and planted trees during the first growing season. In later years, the project’s defined success criteria for vegetation will dictate whether replanting is necessary.

Long-term maintenance considerations may include items such as those listed below:

- Allowing for site access in the future to address maintenance needs
- Inspection schedules
- Addressing severe storm damage
- Control of invasive and/or exotic vegetation
- Control of animal activity that may damage planted vegetation or site stability (i.e. beavers, voles, etc.)
- Vandalism and/or unauthorized site access

18.0 MONITORING AND EVALUATION

Monitoring natural channel design projects is a useful way to evaluate project performance as it relates to specific goals and objectives outlined in the project design. A monitoring plan should be developed to determine whether these goals and objectives have been achieved, in order to validate the effectiveness of the project and identify trends, or necessary corrective actions, through the adaptive management process.

Various site assessments and monitoring activities are often conducted to document the pre- and post-restoration conditions. Proper and consistent data collection methods allow a designer to observe, measure, and quantify changes in stream functions involving hydrology and hydraulics, geomorphology, vegetation, water quality, and biotic communities (i.e. fish, amphibians, and macroinvertebrates). Examples of these functions and their respective parameters and measurement methods are discussed in Chapter 8.

Determinations of project success are proposed during the design plan phase and approved by stakeholders and/or regulatory agencies during the permit approval process. The type and extent of monitoring activities can be modified based on site specific goals and objectives, individual permit requirements, site/watershed conditions, and physical locations (i.e., urban vs. rural setting, climate, etc.). The monitoring activities and data compiled are typically summarized in annual or biennial Monitoring Report to document the results.

18.1 Monitoring Methodologies

A common goal when monitoring a natural channel design project is to demonstrate that the restoration activities create a stable functioning stream channel. To ensure that channel stability has been achieved, physical inspections are conducted using a variety of qualitative and quantitative measures. Inspections data are then compared to data and photographs collected prior to restoration and/or during the monitoring previous years. Reports are submitted to the necessary parties (SARA, USACE, etc.) by the end of each monitoring year and include data for each inspection as well as an evaluation and discussion of the results.

The following equipment can be used to complete basic monitoring:

- Half-size set of as-built plan sheets
- Approved monitoring data sheets
- High resolution digital camera
- Survey equipment
- 50’ tape measure
- Field survey book
- Flagging tape, pin flags and/or reference stakes

18.2 General Monitoring Procedures and Requirements

A qualified or knowledgeable field inspector must walk the entire length of the project with the as-built plans noting any areas of concern. Using a monitoring data sheet, the inspector should describe, in detail, the problem area(s) and take adequate photographs to document the concern and if necessary, provide a recommendation for corrective action. Specific metrics and resolution alternatives should be tabulated in the Monitoring Report.

Inspections should be conducted at least once per year. More frequent inspections may be necessary if stability concerns have previously been noted, or there have been frequent/intense storm events. An inspection may be necessary immediately following a significant storm event (bankfull or higher) if it occurs soon after completion of the project and, before bank vegetation has been established in accordance with the plans and specifications.

Vertical Instability - Any indication of incision or headcutting should be noted and immediate corrective action recommended. As-built plans will provide the design and construction bankfull depth at riffles. This depth will be verified upon inspection and should not deviate from the post-construction depth by a factor greater than 1.3 or other approved metric. A subsequent longitudinal profile survey may not be required during routine stability monitoring, unless negative changes have been identified.

Lateral Instability - Any observation of changes in meander geometry such as channel widening, channel migration, or lateral erosion should be noted with recommended corrective action. For most projects, it is preferred that the channel develops some degree of narrowing and adjustment through depositional processes during the first few years as vegetation becomes established.

Structural Integrity - In-stream structures are specifically designed to reduce bank shear stresses, maintain a stable plan and profile, and provide habitat. Any indication of structure failure such as undermining of structures, erosion between structures and the bank, piping, etc. should be noted along with an immediate corrective action. It should also be noted if structure instability is considered insignificant and is not likely to result in further instability. Such areas should be monitored closely in subsequent monitoring years.

Vegetation Viability – For many natural channel design projects, native buffer vegetation along the channel bank and riparian corridor is critical to the stability of the stream. Any indication that vegetation planting is not establishing in accordance with the approved plans and specifications should be noted and recommendations made for corrective action. This includes an overabundance of vegetation within the bankfull channel such as on riffles that may cause bank instability.

Monitoring Stations - Cross-sectional surveys, reference photographs, and visual evaluations should be completed to measure and compare changes in channel geometry over the course of the monitoring period. The monitoring stations are installed in locations determined by the designer after construction is completed and shown on the as-built plans. They typically include representative cross-sections riffle and pool feature.

The number of cross-sections for each project may vary depending on permit conditions and monitoring requirements.

Each permanent cross-section is marked on both banks with permanent pins to establish the exact transect used. A common benchmark should be used for cross-sections and consistently used to facilitate easy comparison of year-to-year data. Additioanlly, bank pins may be added to monitor bank erosion. The cross-section survey will include points measured at breaks in slope, including top of bank, bankfull, inner berm, edge of water, and thalweg, if the features are present. There should be only minor changes in the monitored cross-section (dimension) over the monitoring period. If changes do take place they should be evaluated to determine if they represent a movement toward a more unstable condition (e.g., down-cutting or erosion, increased bank height ratio) or a movement toward increased stability (e.g., settling, vegetative changes, deposition along the banks, decrease in width/depth ratio).

Visual Assessments - Photographs may be taken at representative in-stream structures, grade control features, or at the permanent cross-section locations along the stream. Photographers should make every effort to consistently maintain the same area in each photo over time. Photographs will be taken looking upstream and downstream in order to document site conditions and to evaluate channel aggradation or degradation, bank erosion, success of riparian vegetation, and effectiveness of erosion control measures.

Additional photographs may be taken to document any problematic areas or special areas of interest such as in-stream habitat improvements, unique native vegetation or volunteer species, debris/ wrack lines, and wildlife observations. Photographs may be labeled with the name of the site, the photo station number, the photograph orientation, the date and time of the photograph, the name of the person taking the photographs, and/or a brief description of the photograph subject.

18.3 Performance Standards and Success Criteria

For natural channel design projects that provide compensatory mitigation within the SARA's four county jurisdiction, a more robust post-construction monitoring plan may be required in order to meet performance standards for determining a project's success. Both the USACE-Fort Worth District and the interim USACE-Galveston District SOPs state that providers must submit compensatory mitigation monitoring plan reports in accordance with the Final Rule (33 CFR 332.6) and Regulatory Guidance Letter 08-03: Minimum Monitoring Requirements for Compensatory Mitigation Projects. The monitoring plans should include at a minimum an annual monitoring assessment and report of the site until the compensatory mitigation project has met its objectives and no additional reports are required. See Appendix K for USACE monitoring templates, mitigation SOP, and other monitoring guidance information.

Stream monitoring - Per the USACE-Fort Worth District monitoring guidance document, stream monitoring requirements typically include annual inspections of stream reaches to document stream stability parameters for dimension, pattern, and profile. Prior to requesting a credit release, measurement data sheets must demonstrate stable conditions. Selected cross-sections should be representative of the bedform (riffle or pool).

Monitoring of stream channel restoration/streambank stabilization and stream relocation projects should include collection of initial baseline information or references reach data on physical parameters in streams before mitigation is implemented and monitoring of these physical parameters annually for at least five years. Physical parameters to be measured include stream pattern, profile, and dimension metrics at locations within the restored reach. Bed material samples will be collected in gravel bed streams to document substrate material. Site photographs of cross-sections, taken from bench-marked reference sites, will also be required.

Vegetation monitoring - Monitoring of planted riparian buffer vegetation and enhancement should include collection of baseline information on any existing vegetation in the buffer before mitigation is implemented and annually for at least five years after site implementation. The minimum information collected annually should include vegetation present, species composition, density, and survival rates for planted stems and vegetation.

Water Quality – Additional requirements may also include water quality sampling to document the pre- and post-restoration conditions and follow the TCEQ Surface Water Quality Standards protocol (TCEQ, 2012). Baseline and post-restoration water quality variables such as fecal coliform, dissolved oxygen, nutrient levels, chlorophyll-A can be assessed throughout the monitoring period to demonstrate an improvement in water quality or that the site is not increasing levels of impairment. Fish and aquatic macroinvertebrates sampling may also be conducted to document the pre- and post-restoration conditions and follow the TCEQ Surface Water Quality Monitoring (SWQM) protocol (TCEQ, 2012). Baseline and post-restoration indices such as the Index of Biotic integrity (IBI) can be assessed throughout the monitoring period to demonstrate that the stream is supporting the designated aquatic life use as defined in the plan.

While water quality parameters may be of interest to the project stakeholders and regulatory agencies, caution should be used in attempting to tie specific success criteria to water quality standards. Water quality within a stream reach is highly influenced by the upstream watershed, which will often be outside the limits of the project. Therefore, water quality improvements may not be feasible without watershed level efforts, which may be beyond the scope of the natural channel design project. Further monitoring guidance and assessment methods, such as the Texas Rapid Assessment Method (TXRAM) (USACE, 2010), are also being considered by the USACE to measure stream conditions and predict the maximum ecological lift potential in order to evaluate success over time. Although the TXRAM scoring method does not quantify specific ecologic functions, it does compare existing conditions with the post-restoration to identify functional lift/loss potential for determining mitigation credit/debit scenarios. The method may become a useful tool for comparing restoration alternatives and incorporating into a mitigation monitoring plan on a case-by case basis to meet specific regulatory requirements related streams functional processes (physical, chemical, biological components) and overall health.

The USACE-Galveston District has initiated an interim Stream Condition Assessment tool (USACE, 2013) to establish a tiered process for determining stream condition and functions, assessing stream impact, and determining compensation requirements. However, at the time of this report, the interim SOP does not provide specific guidance or monitoring requirements that can be used to develop a monitoring plan.

18.4 Contingency Plans and Remedial Actions

In the event that the site or a specific component of the site fails to achieve the defined success criteria or project goals, the designer or mitigation provider should work with the owner to develop necessary adaptive management plans and/or implement appropriate corrective actions for the site in coordination with SARA, USACE, TCEQ, and other stakeholders and agencies. Corrective action required should be implemented to achieve the success criteria specified in the project design and monitoring plan, and should include a work schedule and monitoring criteria that consider physical (exotic vegetation, beaver dams) and climatic conditions (droughts/floods, long-term hydrology), as well as documenting any significant changes within the watershed.

19.0 REFERENCES

Asquith, William H., Slade, Jr., Raymond M. Regional Equations for Estimation of Peak-Streamflow Frequency for Natural Basins in Texas. USGS WRIR 96-4307. http://pubs.usgs.gov/wri/wri964307/pdf/wri4307.pdf

Bull, W.B., 1979. Threshold of critical power in Streams. Geological Society of American Bulletin 90:453-464.

Bunte, K. and S. Abt, 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-74, 428 p.

Castro, J.M. and P.L. Jackson, 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA. Journal of the American Water Resources Association 37(5):1249-1262.

Chaplin, J.J., 2005. Development of Regional Curves Relating Bankfull-Channel Geometry and Discharge to Drainage Area for Streams in Pennsylvania and Selected Areas of Maryland. U.S. Geological Survey Water-Resources Investigation Report 2005-5147, 34p.

Cinotto, P.J., 2003. Development of Regional Curves of Bankfull-Channel Geometry and Discharge for Streams in Non-Urban, Piedmont Physiographic Province, Pennsylvania and Maryland. U.S. Geological Survey Investigation Report 03-4014, 27p.

CoStat, 2004. CoStat version 6.2. CoHort Software, Monterey, California.

Copeland, R.R, D.N. McComas, C.R. Thorne, P.J. Soar, M.M. Jones, and J.B. Fripp. 2001. Hydraulic Design of Stream Restoration Projects. United States Army Corps of Engineers (USACOE), Washington, D.C. ERDC/CHL TR-01-28.

http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA400662&Location=U2&doc=GetTRDoc.pdf

Doll, B.A., D.E. Wise-Frederick, C.M. Buckner, S.D. Wilkerson, W.A. Harman, R.E. Smith, and J. Spooner, 2002. Hydraulic Geometry Relationships for Urban Streams throughout the Piedmont of North Carolina. Journal of the American Water Resources Association 38: 641-651.

Doll, B.A., G.L. Grabow, K.R. Hall, J. Halley, W.A. Harman, G.D. Jennings and D.E. Wise. 2003. Stream Restoration: A Natural Channel Design Handbook. NC Stream Restoration Institute, NC State University. 128 pp. http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf

Dudley, R.W., 2004. Hydraulic-Geometry Relations for Rivers in Coastal and Central Maine. U.S. Geological Survey Water-Resources Investigation Report 2004-5042, 30p.

Dunne, T., and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman Co., San Francisco, California.

Dutnell, R.C., 2000. Development of Bankfull Discharge and Channel Geometry Relationships for Natural Channel Design in Oklahoma Using a Fluvial Geomorphic Approach. Master's Thesis, University of Oklahoma, Norman, Oklahoma.

Eng, Christopher K., Conor C. Shea, Richard R. Starr and Sandra L. Davis. Natural Channel Design Protocols for Baltimore City, Maryland. 2009. U.S. Fish & Wildlife Service, Annapolis, MD. CBFO-S09-03

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. *Stream Corridor Restoration: Principles, Processes and Practices.* National Technical Information Service. Springfield, VA.

FISRWG (Federal Interagency Stream Restoration Working Group), 1998. Stream Corridor Restoration: Principles, Processes, and Practices. Government Printing Office Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653, ISBN-0-934213-59-3.

GDOT (Georgia Department of Transportation), 2004. Final Report: Regional Curve Development for the Coastal Plain of Georgia. Buck Engineering, Cary, NC.

Gerbert, W.A., D.J. Graczyk, and W.R. Krug, 1987. Average Annual Runoff in the United States, 1951-1980. U.S. Geologic Survey Hydrologic Atlas, HA-710, Reston, VA.

Harman, W.R., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012. *A Function-Based Framework for Stream Assessment and Restoration Projects.* US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division. Washignton, D.C. EPA 843-K-12-006.

Harman, William A. and Richard Starr. 2011. *Natural Channel Design Review Checklist*. US Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD and US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division. Washignton, D.C. EPA 843-B-12-005.Harman, W.A. 2000. Finding Bankfull Stage in North Carolina Streams. River Course Fact Sheet Series Number 3. NC Cooperative Extension Service. NC State University. Raleigh, NC.

Harman, W.A., G.D. Jennings, J.M. Patterson, D.R. Clinton, L.O. Slate, A.G. Jessup, J.R. Everhart, and R.E. Smith, 1999. Bankfull Hydraulic Geometry Relationships for North Carolina Streams. In: Wildland Hydrology Proceedings, Darren S. Olsen and John P. Potyondy (Editors). AWRA TPS-99-3, pp. 401-408.

Harman, W.A., D.E. Wise, M.A. Walker, R. Morris, M.A. Cantrell, M. Clemmons, G.D. Jennings, D. Clinton, and J. Patterson, 2000. Bankfull Regional Curves for North Carolina Mountain Streams. In: Water Resources in Extreme Environments Proceedings, D. L. Kane (Editor). AWRA TPS-00-1, pp.185-190.

Hey, R.D. 2006. Fluvial Geomorphological Methodology for Natural Stable Channel Design. *Journal of American Water Resources Association*. April 2006. Vol. 42, No. 2. pp. 357-374. AWRA Paper No. 02094. http://www.awra.org/jawra/papers/J02094.html

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245, Fort Collins, Colorado.

Inglis, C.C., 1947. Meanders and their Bearing on River Training. Institution of Civil Engineers, Maritime and Waterways Engineering Division, Paper No. 7, 54 p.; 61 p.

Johnson, P.A., and T.M. Heil, 1996. Uncertainty in Estimating Bankfull Conditions. Journal of the American Water Resources Association 32(6):1283-1292.

Keaton, J.N., T. Messinger, and E.J. Doheny, 2005. Development and Analysis of Regional Curves for Streams in the Non-Urban Valley and Ridge Physiographic Province, Maryland, Virginia, and West Virginia. U.S. Geological Survey Water-Resources Investigation Report 2005-5076, 116p.

Keystone Stream Team. Guidelines for Natural Stream Channel Design for Pennsylvania Waterways. April 2002.

Kilpatrick, F.A., and H.H. Barnes Jr., 1964. Channel Geometry of Piedmont Streams as Related to Frequency of Floods. U.S. Geological Survey Professional Paper 422-E, Washington, DC.

Knighton, D., 1998. Fluvial Forms and Processes. Rutledge, Chapman, and Hall, Inc., New York, NY.

Lane, E.W. 1955. *Design of stable channels*. Transactions of the American Society of Civil Engineers. Paper No. 2776. 1234-1279.

Leopold, L.B., and T. Maddock, 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. U.S. Geologic Survey Professional Paper 252, 57 p.

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, Mass.

Leopold, L.B., M.G. Wolman, and J.P. Miller, 1995. Fluvial Processes in Geomorphology. Dover Publications, Inc., New York, New York, 522 p.

Lichvar, R.W., and J.S. Wakeley. 2004. Review of ordinary high water mark indicators for delineating arid stream in the southwestern United States. ERDC TR-04-1. Hanover, NH: U.S. Army Engineer Research and Development Center.

Manning, R., 1891. On the Flow of Water in Open Channels and Pipes. Transactions of the Institution of Civil Engineers of Ireland 20:161-207.

McCandless, T.L. and R.A., Everett, 2002. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Piedmont Hydrologic Region. U.S. Fish and Wildlife Service Technical Report CBFO-S02-01, Annapolis, Maryland.

McCandless, T.L, 2003a. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Allegheny Plateau and the Valley and Ridge Hydrologic Regions. U.S. Fish and Wildlife Service Technical Report CBFO-S03-01, Annapolis, Maryland.

McCandless, T.L., 2003b. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Coastal Plain Hydrologic Region. U.S. Fish and Wildlife Service Technical Report CBFO-S03-02, Annapolis, Maryland.

Metcalf, C.K., 2004. Regional Channel Characteristics for Maintaining Natural Fluvial Geomorphology in Florida Streams. U.S. Fish and Wildlife Service Technical Report, Panama City, Florida.

Merigliano, M.F., 1997. Hydraulic Geometry and Stream Channel Behavior: An Uncertain Link. Journal of the American Water Resources Association 33(6):1327-1336.

Miller, S.J. and D. Davis, 2003. Optimizing Catskill Mountain Regional Bankfull Discharge and Hydraulic Geometry Relationships. In: International Congress on Watershed Management for Water Supply Systems Proceedings, Max J. Pfeffer, Daniel J. Van Abs, and Kenneth N. Brooks (Editors). AWRA TPS-03-2.

Miller, J.H. and K.S. Robinson, 1995. A regional perspective of the physiographic provinces of the southeastern United States. In: Eight Biennial Southern Silvaculture Research Conference Proceedings, M. Boyd Edwards (Editor). U. S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC, General Technical Report SRS-1, pp. 581-591.

Moody, T., M. Wirtanen, and S.N. Yard. 2003. Regional Relationships for Bankfull Stage in Natural Channel of the Arid Southwest, Natural Channel Design, Inc. Flagstaff, AZ. http://naturalchanneldesign.com/NCD%20Reports.htm

Mulvihill, C.I., A.G. Ernst, and B.P. Baldigo, 2006. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 6 in the Southern Tier of New York. U.S. Geological Survey Water-Resources Investigation Report 2004-5100, 42p.

Nanson, G.C. and J.C. Croke, 1992. A Genetic Classification of Floodplains. Geomorphology 4:459-486.

Nanson, G.C. and A.D. Knighton, 1996. Anabranching Rivers: Their Cause, Character and Classification. Earth Surface Processes and Landforms 21:217-239.

Nixon, M., 1959. A Study of Bankfull Discharges of Rivers in England and Wales. In: Institution of Civil Engineers Proceedings, 12(2):157-174.

NRCS. 2007. Part 654 – Stream Restoration Design. USDA, Natural Resources Conservation Service. H.210.NEH.654. http://policy.nrcs.usda.gov/index.aspx

NRCS. 2007. National Engineering Handbook, Part 654, Technical Supplement 14I, *Streambank Soil Bioengineering*. http://directives.sc.egov.usda.gov/17818.wba

Rosgen, D.L., 1994. A Classification of Natural Rivers. Catena 22:169-199.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology Inc., Pagosa Springs, Colorado.

Rosgen, D.L. 1997. *A geomorphological approach to restoration of incised rivers*. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision. S.S.Y.Wang, E.J. Langendoen, and F.D. Shields, Jr., Eds. 12-22.

Rosgen, D.L. 2001. *A stream channel stability assessment methodology*. Proceedings of the Federal Interagency Sediment Conference. Reno, NV. March, 2001.

Rosen, D. L. *The Cross-Vane, W-Weir and J-Hook Vane Structures...Their Description, Design and Application for Stream Stabilization and River Restoration*. Updated from the Paper Published by ASCE Conference, Reno, NV, August, 2001 (http://www.wildlandhydrology.com/assets/The_Cross_Vane_W-Weir_and_J-Hook_Structures_Paper_Updated_2006.pdf)

Rosgen, D.L. 2006. A Watershed Assessment for River Stability and Sediment Supply (WARSSS). Wildland Hydrology Books, Fort Collins, CO. http://www.epa.gov/warsss/

Rosgen, D.L. 1998. The Reference Reach – A Blueprint for Natural Channel Design (Draft). ASCE Conference on River Restoration, Denver, CO. March, 1998. ASCE. Reston, VA. http://www.wildlandhydrology.com/assets/The_Reference_Reach_II.pdf

SAS Institute, 2007. SAS Version 9.1.3. User's Guide. SAS Institute, Inc., Cary, North Carolina.

San Antonio River Authority, 2007. Process to Obtain Peak Discharge Data and Update or Modify Hydrology Models.

San Antonio River Authority, 2005. San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling.

Schumann, R.R, 1989. Morphology of Red Creek, Wyoming, an Arid-Region Anastomosing Channel System. Earth Surface Process and Landforms 14:277-288.

Schumm, S.A, 1960. The Shape of Alluvial Channels in Relation to Sediment Type. U.S. Geological Survey Professional Paper 352-B, pp. 17-30.

Simon, A. 1989. *A model of channel response in disturbed alluvial channels*. Earth Surface Processes and Landforms 14(1): 11-26.

Sweet, W.V. and J.W. Geratz, 2003. Bankfull Hydraulic Geometry Relationships and Recurrence Intervals for the North Carolina's Coastal Plain. Journal of the American Water Resources Association 39(4):861-871.

TCEQ (Texas Commission on Environmental Quality). 2012. Stormwater Permits. (http://www.tceq.texas.gov/permitting/stormwater/)

USACE. 1987. Corps of Engineers Wetlands Delineation Manual. Wetlands Research Program Technical Report Y-87-1.

USACE. 2005. Regulatory Guidance Letter No. 05-05.

USACE. 2008 Regulatory Guidance Letter No. 08-02.

USACE. 2008 Regulatory Guidance Letter No. 08-03.

USACE. 2010 The Texas Rapid Assessment Method (TXRAM), Wetlands and Streams Modules

, Version 1.0. Final Draft.

USACE. 2013 Special Public Notice: 2013 Stream Condition Assesment.

USACE. 2010 Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Great Plains Region (Version 2).

USACE. 2008 Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Gulf Coast Regional Supplement.

USGS (U. S. Geological Survey), 1969. Techniques of Water-Resources Investigations of the United States Geological Survey: Discharge Measurements at Gaging Stations. Book 3, Chapter A8, Washington, DC.

USGS (U. S. Geological Survey), 1982. Guidelines for Determining Flood Flow Frequency. Interagency Advisory Committee on Water Data, Bulletin No. 17B of the Hydrology Subcommittee, Reston, VA.

Williams, G.P., 1978. Bankfull Discharge of Rivers. Water Resources Research 14(6):1141-1154.

Wolman, M.G. and L.B. Leopold, 1957. River Floodplains: Some Observations on their Formation. U.S. Geological Survey Professional Paper 282-C, Washington, DC.

Wolman, M.G. and J.P. Miller, 1960. Magnitude and Frequency of Forces in Geomorphic Processes. Journal of Geology 68:54-74.

APPENDIX A

APPENDIX B

SARA CONTACT

LeeAnne Lutz, P.E.
llutz@sara-tx.org
Direct 210-302-3206
Main 210-227-1373
Toll Free 1-866-345-7272

San Antonio River Authority
100 East Guenther St.
P.O. Box 839980
San Antonio, Texas 78283-9980
http://www.sara-tx.org/

Stream Restoration Website:
http://www.sara-tx.org/major_initiatives/stream_team/what_is_stream_restoration.php

APPENDIX C

Gage Station Survey for the Development of Regional Curves
Survey Checklist

Office Data

Obtain the following information for each gage site prior to field survey.

1. Benchmark / reference mark data from USGS.
2. Lat/long coordinates.
3. Driving directions.
4. Drainage area for gage from USGS.
5. Percent impervious cover for watershed.
6. Description of flow regulation structures and potential impact on gage.
7. Annual runoff in cfs/sq mi from USGS.
8. Type of gage, i.e. continuous or peak from USGS.
9. Log Pearson Type III Distribution results for gage from USGS.

Field Supplies

1. Total Station 9TS), tripod and data Logger
2. Key Codes for Stream Works software
3. 2 Rods and prisms
4. Pocket Rod
5. Hand Level
6. 50' Tape
7. 300' Tape
8. Pin Flags (3 different colors)
9. Gravelometer
10. Waders
11. Field Book
12. Pebble Count forms
13. BEHI / NBS Forms and Guides
14. Large scale aerial photograph of the project reach
15. Digital Camera
16. Bottomless 5-gal bucket

Survey Steps

A. <u>**Bankfull, Inner Berm, and Terrace Identification**</u>

1. Walk upstream and downstream of gage station looking for bankfull indicators. Start with indicators on depositional features. Measure the difference between the indicator and the water surface with hand level and pocket rod.
2. Flag the bankfull indicator for the entire reach length, approximately 20 times the bankfull width.
3. If present, flag the inner berm and terrace feature with different color flags. Flag all indicators at a place where the feature will be surveyed.
4. Record the gage plate reading at the bankfull stage.

B. <u>**Select Riffle and Pool for Cross Section Survey**</u>

1. Within the study reach find a stable riffle with a Bank Height Ratio less than 1.2. Look for riffles where the thalweg is near the center of the channel.
2. Survey the riffle starting from the left terrace and moving to the right (looking downstream). Survey all breaks in slope including the terrace, top of bank, bankfull, inner berm, edge of channel and thalweg.
3. Survey at least one stable riffle, two can be surveyed if the stream type changes or there is another significant change.
4. Survey one pool at the deepest point in a meander bend.
5. Note: the elevations should be tied to the gage datum. Horizontal control can be assumed or set with a GPS.

C. **Perform Longitudinal Survey**

1. Perform a longitudinal profile that is 20 times the bankfull width. Survey the following points at the head of each riffle, run, pool, and glide: thalweg, water surface, inner berm, bankfull, top of bank, and terrace. Note: only survey the inner berm, bankfull, or terrace feature if it has been flagged.
2. Survey the thalweg in the deepest part of the pool.
3. Survey the gage plate reading at the bankfull stage.

D. **Collect Bed Material Samples (Gravel Bed Streams)**

1. Perform a reach-wide pebble count for Rosgen Stream Classification Purposes.
2. At the riffle cross section, collect a pavement sample using the Zig Zag pebble count method.

3. Collect a subpavement or bar sample based on field conditions.

E. Collect Bed Material Samples (Sand Bed Streams)

1. Uuse sand card.

F. Streambank Erosion Estimates Using the BANCS Model

1. Estimate BEHI and NBS scores for the entire reach length and locate the estimates on a large scale aerial photo.
2. Note: The crew could do this at a later date and locate the estimates on a base map created from the TS survey.

G. Photographs

1. Take photos of each cross section looking downstream.
2. Take photo of each bank that represents a BEHI/NBS category.
3. Take photo of gage station and gage plate.
4. Take photos of other points of interest.

APPENDIX D

APPENDIX – Survey Key Codes

Refer to scope of work first but this sheet is intended to demonstrate how survey shots should be recorded. Key codes listed below are preferred for ease of data processing with in-house software.

Cross Section:

X# LPN – begin labeling cross sections from left to right using 'X#' prefix on all shots

X# RPN – end of cross section on right terrace/floodplain

TWG – thalweg (deepest part of channel cross section – not necessarily centerline)

LCH – left channel (bottom edge of channel, or toe of channel bank) / RCH – right channel

LTB – left top of bank (of main channel) / RTB – right top of bank

CLD – center line ditch

LTD – left top of ditch / LTD – right top of ditch

WSF – water surface (if present)

GSN – ground shot natural

LTR – left top of terrace / RTR – right top of terrace

TBM – temporary bench mark

CP – Control point

Longitudinal Profile:

The thalweg, edge of channel, and top of bank shots should be recorded as breaklines. Ditches are infrequent tributaries to the main channel.

Please shoot all breaks in slope to pick up straight sections, pools (Pc, A, Pt), and major drops over 6 inches.

TWG HOR – thalweg head of riffle

TWG HOP – thalweg head of pool

TWG MXP – thalweg max pool

A1 – breakline for a repeating feature such as a toe of slope

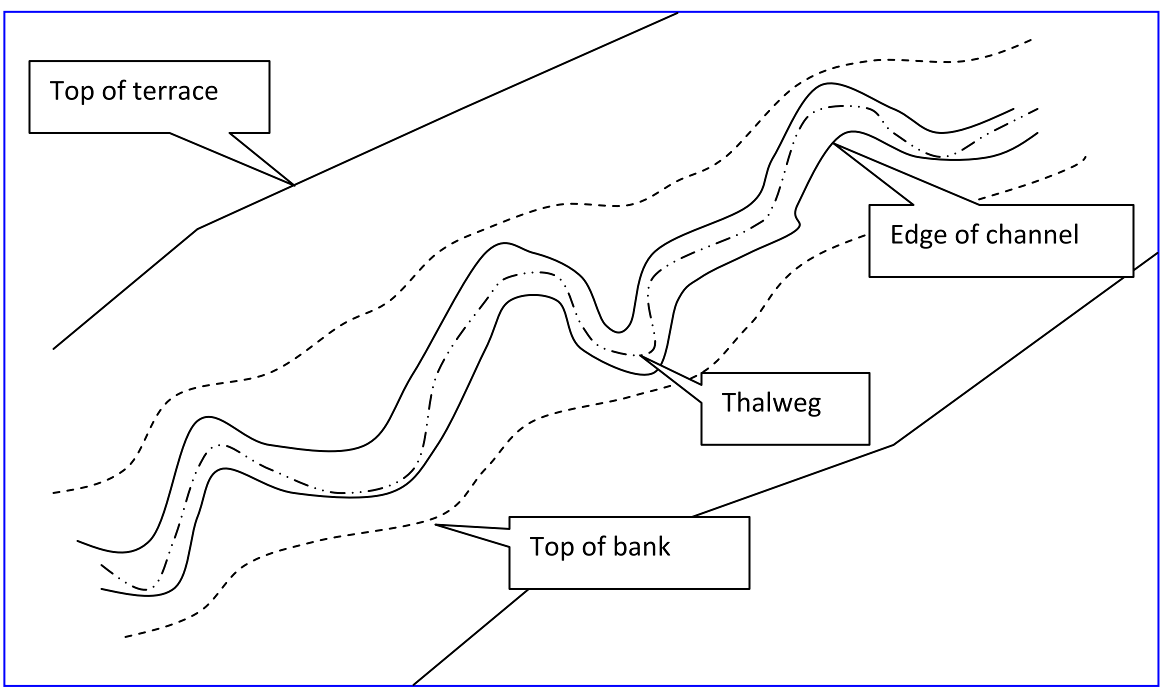
A2 – breakline for another feature such as edge of valley (top of terrace)

A1 needs to tie in to something so we know where it stops (A1/A2)

Other features can use different letters, such as B1. So if another feature started within 500 feet of A1 it should not be called A1 (otherwise, we might try to connect them).

It's not important what breaklines are called as long as they're consistent

Topography shots will be used to create a DTM with 1-foot contours.



APPENDIX E

Worksheet 2-4 (Part 1). Morphological relations and dimensionless ratios of a river reach site (Rosgen, 2006b; Rosgen Silvey, 2007).

Stream:		Location:	
Observers:	Date:	Valley Type:	Stream Type:

River Reach Dimension Summary Data…..1

Riffle Dimensions*, **, ***

Riffle Dimensions*, **, ***	Mean	Min	Max		Riffle Dimensions & Dimensionless Ratios****	Mean	Min	Max
Riffle Width (W_{bkf})				ft	Riffle Cross-Sectional Area (A_{bkf}) (ft^2)			
Riffle Mean Depth (d_{bkf})				ft	Riffle Width/Depth Ratio (W_{bkf} / d_{bkf})			
Riffle Maximum Depth (d_{max})				ft	Riffle Max Depth to Riffle Mean Depth (d_{max} / d_{bkf})			
Width of Flood-Prone Area (W_{fpa})				ft	Entrenchment Ratio (W_{fpa} / W_{bkf})			
Riffle Inner Berm Width (W_{ib})				ft	Riffle Inner Berm Width to Riffle Width (W_{ib} / W_{bkf})			
Riffle Inner Berm Depth (d_{ib})				ft	Riffle Inner Berm Depth to Mean Depth (d_{ib} / d_{bkf})			
Riffle Inner Berm Area (A_{ib})				ft^2	Riffle Inner Berm Area to Riffle Area (A_{ib} / A_{bkf})			
Riffle Inner Berm W/D Ratio (W_{ib} / d_{ib})								

Pool Dimensions*, **, ***

Pool Dimensions*, **, ***	Mean	Min	Max		Pool Dimensions & Dimensionless Ratios****	Mean	Min	Max
Pool Width (W_{bkfp})				ft	Pool Width to Riffle Width (W_{bkfp} / W_{bkf})			
Pool Mean Depth (d_{bkfp})				ft	Pool Mean Depth to Riffle Mean Depth (d_{bkfp} / d_{bkf})			
Pool Cross-Sectional Area (A_{bkfp})				ft	Pool Area to Riffle Area (A_{bkfp} / A_{bkf})			
Pool Maximum Depth (d_{maxp})				ft	Pool Max Depth to Riffle Mean Depth (d_{maxp} / d_{bkf})			
Pool Inner Berm Width (W_{ibp})				ft	Pool Inner Berm Width to Pool Width (W_{ibp} / W_{bkfp})			
Pool Inner Berm Depth (d_{ibp})				ft	Pool Inner Berm Depth to Pool Depth (d_{ibp} / d_{bkfp})			
Pool Inner Berm Area (A_{ibp})				ft^2	Pool Inner Berm Area to Pool Area (A_{ibp} / A_{bkfp})			
Point Bar Slope (S_{pb})				ft/ft	Pool Inner Berm Width/Depth Ratio (W_{ibp} / d_{ibp})			

Run Dimensions*

Run Dimensions*	Mean	Min	Max		Run Dimensionless Ratios****	Mean	Min	Max
Run Width (W_{bkfr})				ft	Run Width to Riffle Width (W_{bkfr} / W_{bkf})			
Run Mean Depth (d_{bkfr})				ft	Run Mean Depth to Riffle Mean Depth (d_{bkfr} / d_{bkf})			
Run Cross-Sectional Area (A_{bkfr})				ft	Run Area to Riffle Area (A_{bkfr} / A_{bkf})			
Run Maximum Depth (d_{maxr})				ft	Run Max Depth to Riffle Mean Depth (d_{maxr} / d_{bkf})			
Run Width/Depth Ratio (W_{bkfr} / d_{bkfr})				ft				

Glide Dimensions*

Glide Dimensions*	Mean	Min	Max		Glide Dimensions & Dimensionless Ratios****	Mean	Min	Max
Glide Width (W_{bkfg})				ft	Glide Width to Riffle Width (W_{bkfg} / W_{bkf})			
Glide Mean Depth (d_{bkfg})				ft	Glide Mean Depth to Riffle Mean Depth (d_{bkfg} / d_{bkf})			
Glide Cross-Sectional Area (A_{bkfg})				ft	Glide Area to Riffle Area (A_{bkfg} / A_{bkf})			
Glide Maximum Depth (d_{maxg})				ft	Glide Max Depth to Riffle Mean Depth (d_{maxg} / d_{bkf})			
Glide Width/Depth Ratio (W_{bkfg} / d_{bkfg})				ft/ft	Glide Inner Berm Width/Depth Ratio (W_{ibg} / d_{ibg})			
Glide Inner Berm Width (W_{ibg})				ft	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})			
Glide Inner Berm Depth (d_{ibg})				ft	Glide Inner Berm Depth to Glide Depth (d_{ibg} / d_{bkfg})			
Glide Inner Berm Area (A_{ibg})				ft^2	Glide Inner Berm Area to Glide Area (A_{ibg} / A_{bkfg})			

Step**

Step Dimensions**	Mean	Min	Max		Step Dimensionless Ratios****	Mean	Min	Max
Step Width (W_{bkfs})				ft	Step Width to Riffle Width (W_{bkfs} / W_{bkf})			
Step Mean Depth (d_{bkfs})				ft	Step Mean Depth to Riffle Mean Depth (d_{bkfs} / d_{bkf})			
Step Cross-Sectional Area (A_{bkfs})				ft	Step Area to Riffle Area (A_{bkfs} / A_{bkf})			
Step Maximum Depth (d_{maxs})				ft	Step Max Depth to Riffle Mean Depth (d_{maxs} / d_{bkf})			
Step Width/Depth Ratio (W_{bkfs} / d_{bkfs})				ft/ft				

*Riffle–Pool system (i.e., C, E, F stream types) bed features include riffles, runs, pools and glides.

**Step–Pool system (i.e., A, B, G stream types) bed features include riffles, rapids, chutes, pools and steps (note: include rapids and chutes in riffle category).

***Convergence-Divergence system (i.e., D stream types) bed features include riffles and pools; cross-sections taken at riffles for classification purposes.

Worksheet 6-5 (Part 1). Morphological relations and dimensionless ratios of a river reach site (Rosgen, 2006; Rosgen Silvey, 2009).

Stream:		Location:	
Observers:	Date:	Valley Type:	Stream Type:

River Reach Summary Data…..2

Hydraulics

Streamflow: Estimated Mean Velocity at Bankfull Stage ($\bar{u}_{bkf}$)		ft/sec	Estimation Method	
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})		cfs	Drainage Area	mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Linear Wavelength (λ)				ft	Linear Wavelength to Riffle Width (λ / W_{bkf})			
Stream Meander Length (L_m)				ft	Stream Meander Length Ratio (L_m / W_{bkf})			
Radius of Curvature (R_c)				ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})			
Belt Width (W_{blt})				ft	Meander Width Ratio (W_{blt} / W_{bkf})			
Arc Length (L_a)				ft	Arc Length to Riffle Width (L_a / W_{bkf})			
Riffle Length (L_r)				ft	Riffle Length to Riffle Width (L_r / W_{bkf})			
Individual Pool Length (L_p)				ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})			
Pool to Pool Spacing (P_s)				ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})			

Channel Profile

Valley Slope (S_{val})		ft/ft	Average Water Surface Slope (S)		ft/ft	Sinuosity (S_{val} / S)	
Stream Length (SL)		ft	Valley Length (VL)		ft	Sinuosity (SL / VL)	
Low Bank Height (LBH) start		ft	Max Bankfull Depth (d_{max}) start		ft	Bank-Height Ratio (BHR) (LBH / d_{max}) start	
end		ft	end		ft	end	

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})				ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)			
Run Slope (S_{run})				ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)			
Pool Slope (S_p)				ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)			
Glide Slope (S_g)				ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)			
Step Slope (S_s)				ft/ft	Step Slope to Average Water Surface Slope (S_s / S)			

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{max})				ft	Max Riffle Depth to Mean Riffle Depth (d_{max} / d_{bkf})			
Max Run Depth (d_{maxr})				ft	Max Run Depth to Mean Riffle Depth (d_{maxr} / d_{bkf})			
Max Pool Depth (d_{maxp})				ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})			
Max Glide Depth (d_{maxg})				ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})			
Max Step Depth (d_{maxs})				ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})			

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay				D_{16}					mm
% Sand				D_{35}					mm
% Gravel				D_{50}					mm
% Cobble				D_{84}					mm
% Boulder				D_{95}					mm
% Bedrock				D_{100}					mm

[a] Min, max & mean depths are measured from Thalweg to bankfull at mid-point of feature for riffles and runs, the deepest part of pools, & at the tail-out of glides.

[b] Composite sample of riffles and pools within the designated reach. [c] Active bed of a riffle. [d] Height of roughness feature above bed.

RIPARIAN LINE INTERCEPT DATA FORM

Page ___ of ___

Contract #:___________________________ Contract name:_________________________________

Stream:_________________________ Date: _____________ Evaluation crew:________________

Drainage:____

Transect #:________ Transect length:_________Start Point:______________________________

Streambank: (*Left* or *Right*) **Direction:** *(Upstream* or *Downstream)*

0-3 ft height class			**3-15 ft. height class**			**>15 ft. height class**			**Comments**
Start	End	Species	Start	End	Species	Start	End	Species	(Record location of other transects/plots)
Distance			Distance			Distance			

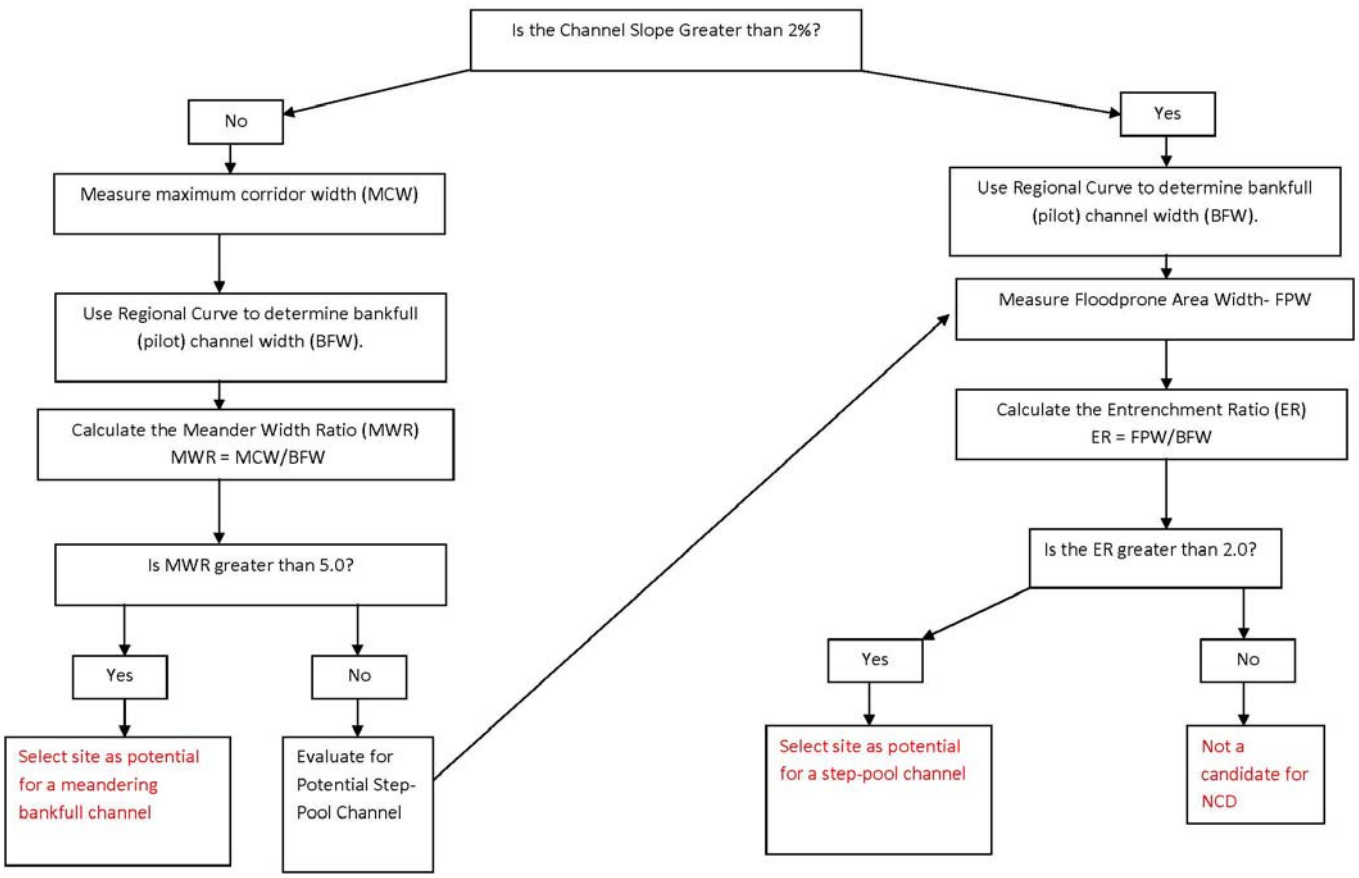
Species Codes

			BRRS = Barren soil
			HERB = Herbaceous
			LITT = Litter
			REST = Restoration Structure
			WOOD = Wood
			ROCK = Rock
			OTST = Other structure

APPENDIX F

Site Selection Criteria for Potential Use of Natural Channel Design (NCD) Techniques for Urban Drainage and Flood Conveyance Corridors

This flow chart is a planning tool to aid in site selection for the potential use of NCD techniques in urban drainage and flood conveyance corridors. This example uses the East Salitrillo Watershed Draft Regional Curves. Regional curves are being developed for different watersheds in the San Antonio area. Contact SARA for information regarding regional curves for project specific watershed.



Measurement Notes

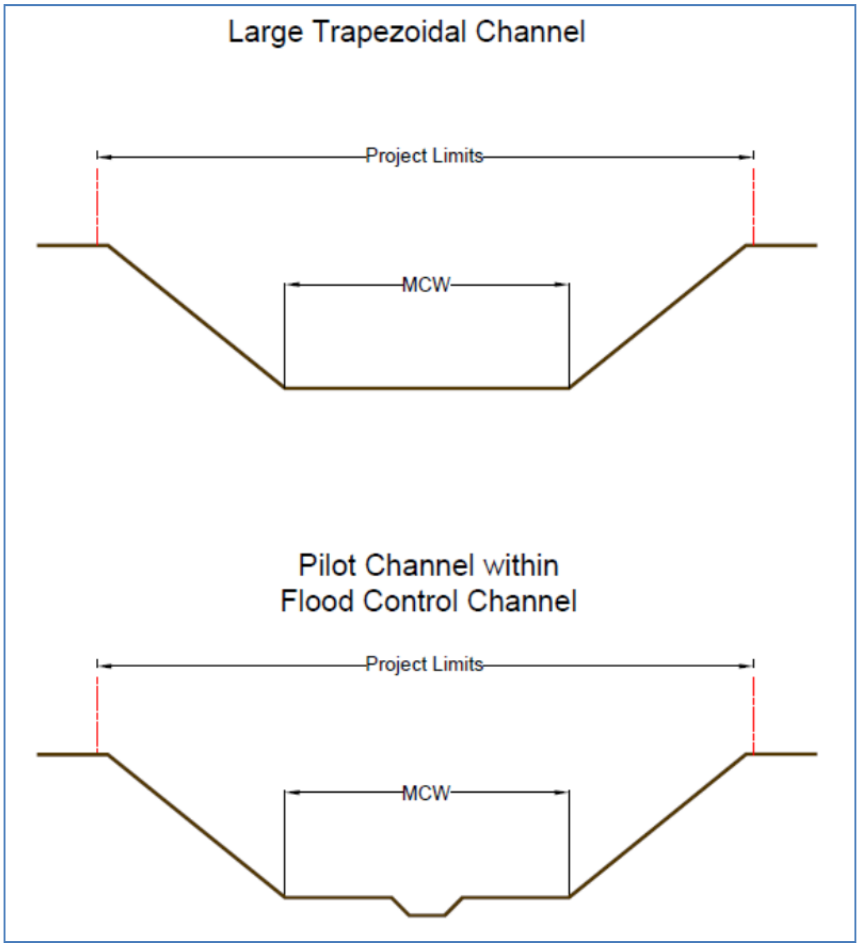
Channel Slope

Estimate the reach wide channel slope by using the slope of the energy grade of the 2-year discharge.

Maximum Corridor Width (MCW)

Measure the width from bottom edge of flood control channel as shown below in Figure 1. Corridor width is measured perpendicular to the valley length.

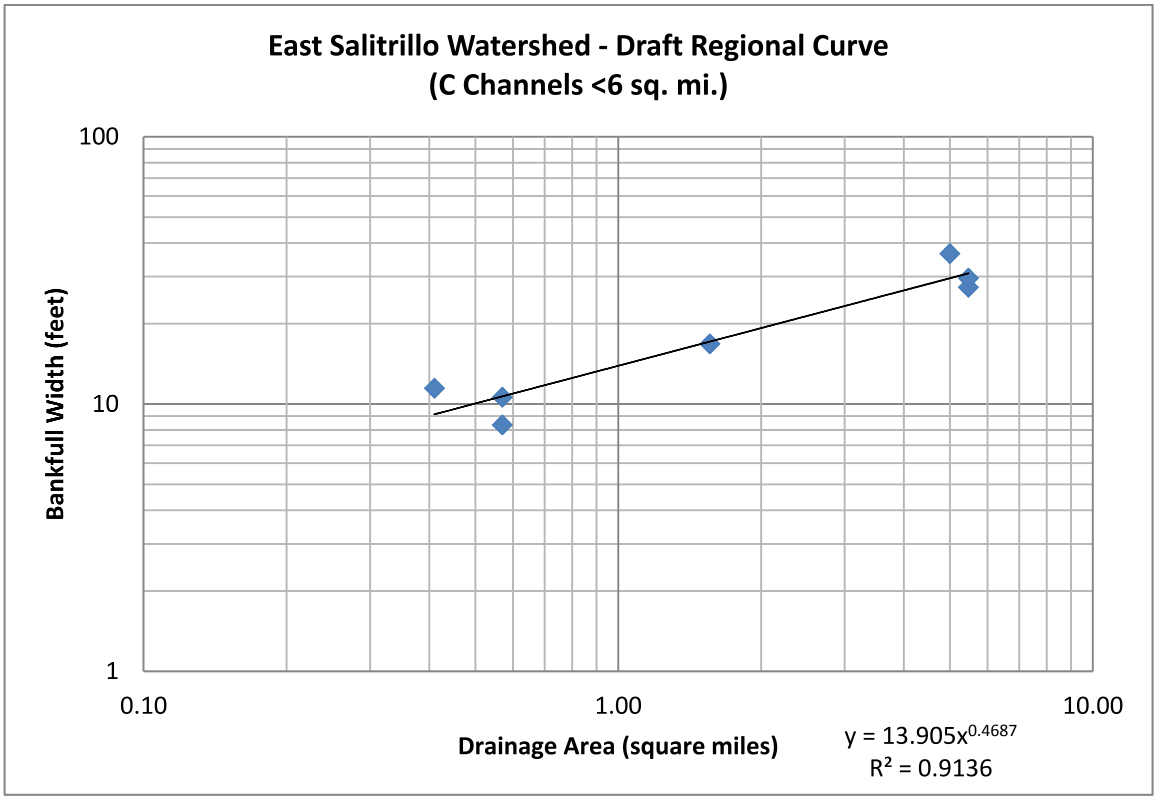
Figure 1 – Maximum Corridor Width Measurement



Bankfull Width (BFW)

Use the Regional Curve below (Figure 2) to determine the Bankfull Channel Width (BFW).

Figure 2 East Salitrillo Watershed – Draft Regional Curve (Drainage Area vs Bankfull Width).



Floodprone Area Width (FPW)

Complete the following steps to calculate the floodprone area width.

1. Select a representative cross section for the study reach. The cross section should be in a riffle (straight section) and not in a pool.
2. Use the Regional Curve below in Figure 3 to determine the Bankfull Mean Depth.
3. Calculate the Floodprone Depth by multiplying the Bankfull Mean Depth by 2.0.
4. At the representative cross section, measure the Floodprone Area Width at the Floodprone Depth elevation. Refer to Figure 4 below.

Figure 3. East Salitrillo Watershed - Draft Regional Curve (Drainage Area vs Bankfull Depth)

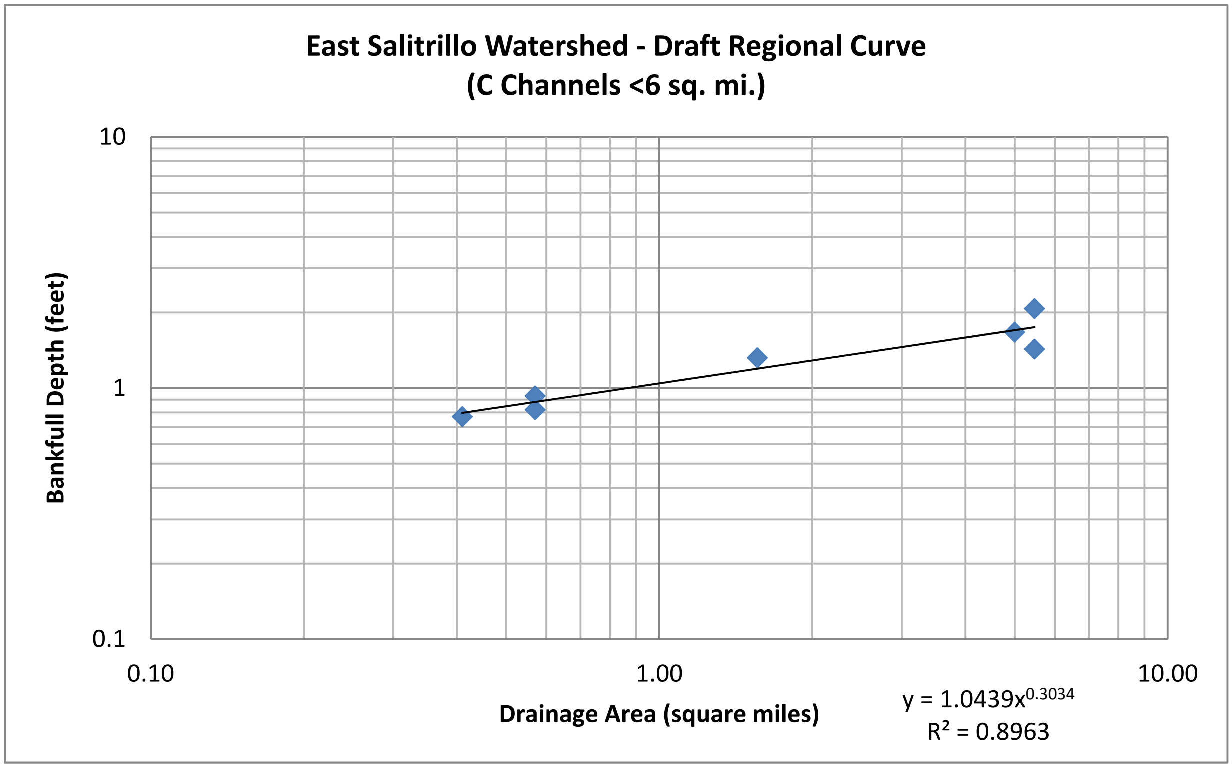
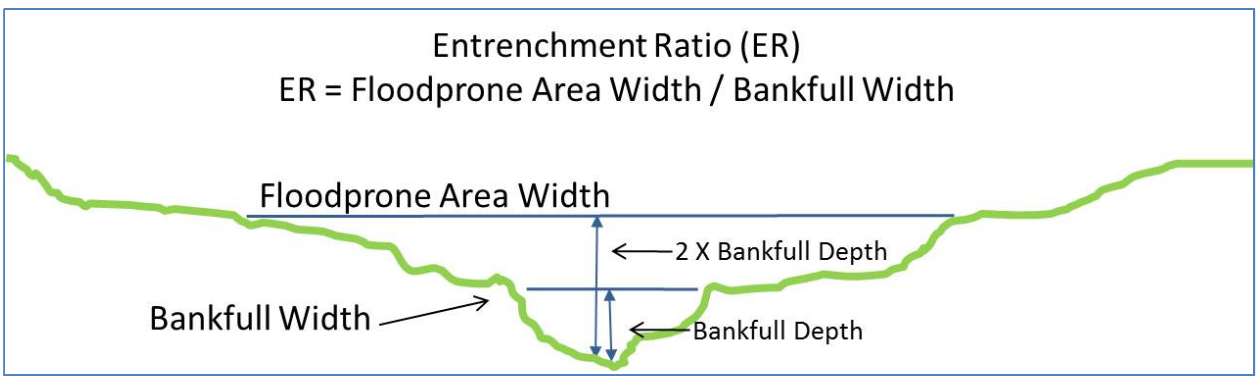


Figure 4 - Floodprone Area Width and ER Calculation



Results

The flow chart will yield one of three possible results: potential for a meandering stream, potential for a step-pool channel, or not appropriate for a natural channel design solution. Create a legend that differentiates between the three outcomes and show the result on an appropriate report figure. For example, a reach that has the potential for a meandering stream could be highlighted in yellow. Create an ID for each segment and show the following on a table that accompanies the map: ID, outcome/result, reach length, ER, and MWR.

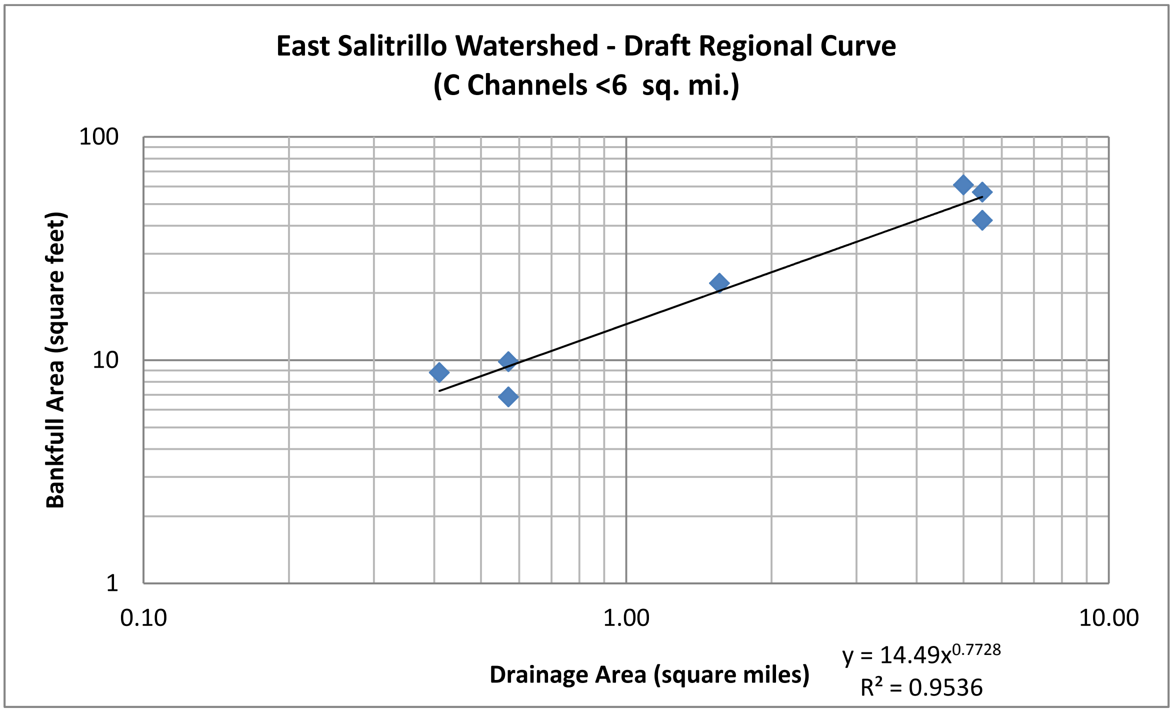
<u>Optional Additional Analyses</u>

Earthwork

Rough earthwork estimates can be made for the bankfull channel using the following criteria.

1. Determine the bankfull cross sectional area using Figure 5.
2. Determine Channel Length as follows:
    a. For step pool option use a straight line down the fall line of the valley.
    b. For the meandering channel option, multiply the straight channel length by 1.3.

Figure 5. East Salitrillo Watershed - Draft Regional Curve (Drainage Area vs Bankfull Area)



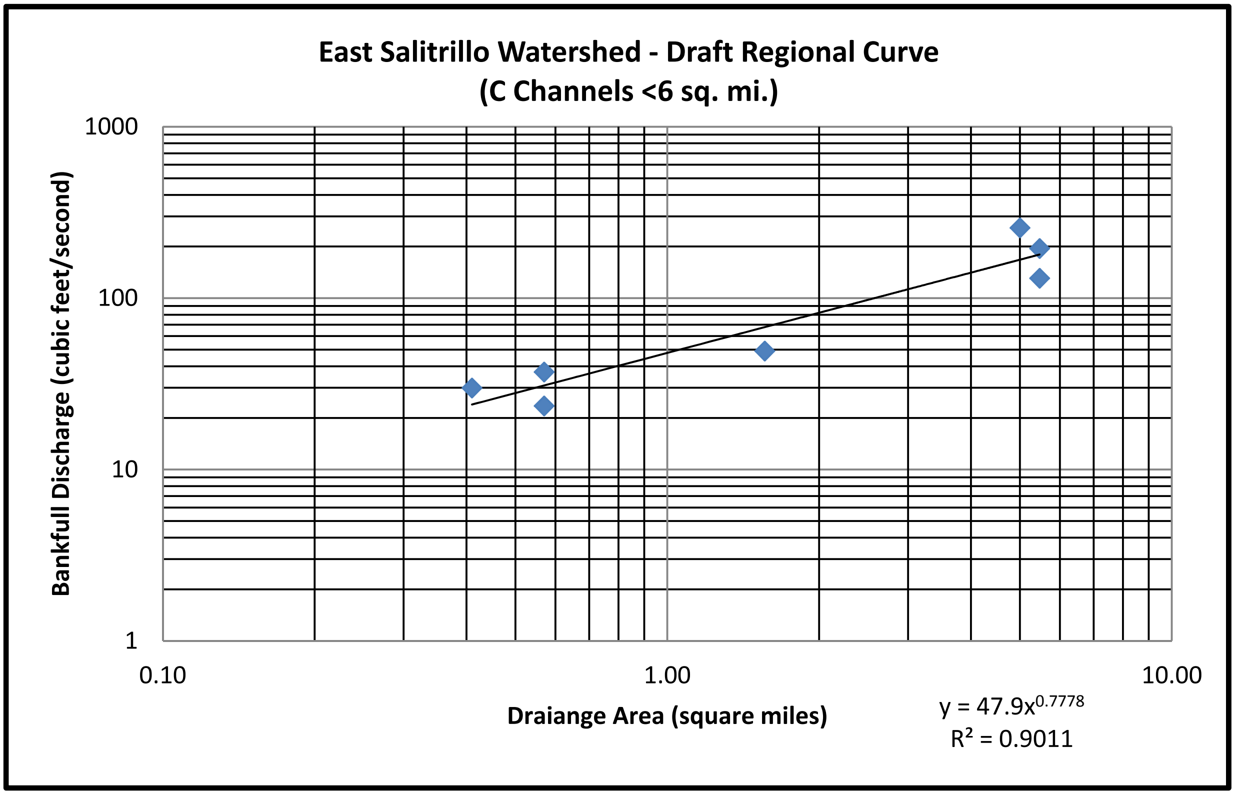
In-Stream Structures

Concrete weirs should not be used for the natural channel design options. Instead, cross vanes should be used to provide grade control in the step-pool option and constructed riffles should be used in the meandering channel option. Bank protection and habitat structures should also be included. Bank protection measures may include erosion control matting, bioengineering, rock vanes, and root wads. The specific application of these structures will vary based on the stream size. However, constructed riffles will generally be placed in the cross over sections (riffles) and the cross vanes will be spaced every 1 to 3 times the bankfull width for step-pool channels above 2% slope and 3 to 6 times the bankfull width for slopes less than 2%.

Bankfull Discharge

A Regional Curve for the bankfull discharge is provided below in Figure 6. The discharge could be added to the HEC RAS model if desired.

Figure 5. East Salitrillo Watershed - Draft Regional Curve (Drainage Area vs Bankfull Discharge)



APPENDIX G

Appendix - Natural Channel Design Report Standards

The Natural Channel Design Report will include, at a minimum, the following sections:

1. Introduction and Background
   This section will include discussion relating to:
   - Project description
   - Background information
   - Clearly defined goals and objectives of the project

2. Watershed Characterization
   This section will include discussion and relevancy of:
   - Watershed Delineation
   - Physiography, Geology and Soils
   - Land Use and Development Trends
   - Endangered/Threatened Species
   - Cultural Resources

3. Existing Stream Condition
   This section will include discussion relating to:
   - Hydraulic and geomorphic process assessment
   - Existing Data Collection
   - Bankfull Verification
   - Bankfull Discharge and Gage Station Surveys
   - Sediment Transport

4. Project Design
   This section will include discussion relating to:
   - Design Criteria Selection
   - Design Parameters

5. References
   Supporting documentation attached as appendices will include:
   - Maps and Relevant Exhibits
   - Existing Site Data and Calculations
   - Reference Reach Data
   - Site Photos

Natural Channel Design Review Checklist

Project Design Checklist **Reviewer:** ______________________
Date: ______________________

Project: ______________________
Engineer: ______________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
1.0 Watershed and Geomorphic Assessment				
1.1 Watershed Assessment				
1.1a Was the watershed assessment methodology described?				
1.1b Was the project drainage area provided?				
1.1c Was the percent impervious cover for the watershed provided?				
1.1d Was the current land use described along with future conditions?				
1.1e Were watershed hydrology calculations performed?				
1.2 Basemapping				
1.2a Does the project include basemapping?				
1.3 Hydraulic Assessment				
1.3a Was a hydraulic assessment completed?				
1.3b Was stream velocity, shear stress and stream power shown in relation to stage and discharge?				
1.4 Bankfull Verification				
1.4a Were bankfull verification analyses completed?				
1.4b Were USGS gages or regional curves used to validate bankfull discharge and area?				
1.4c If a regional curve was used, were the curve data representative of the project data?				
1.4d If gages or regional curves were not available, were other methods, such as hydrology and hydraulic models used?				
1.5 Project Reach Geomorphic Assessment				
1.5a Was the geomorphic assessment methodology described?				
1.5b Were vertical and lateral stability analyses completed?				
1.5c Was it shown whether the instability was localized or system-wide?				
1.5d Was the cause-and-effect relationship of the instability identified?				
1.5e Was the channel evolution predicted?				
1.5f Were constraints identified that would inhibit restoration?				
1.5g Should this stream reach be a restoration project?				
1.5h Overall Geomorphic Assessment Comment(s)				

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ____________________
Date: ____________________

Project: ____________________
Engineer: ____________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
2.0 Preliminary Design				
2.1 Goals and Restoration Potential				
2.1a Does the project have clear goals and objectives?				
2.1b Was the restoration potential based on the assessment data provided?				
2.1c Was a restoration strategy developed and explained based on the restoration potential?				
2.2 Design Criteria				
2.2a Were design criteria provided and explained?				
2.2b Were multiple methods used to prepare design criteria?				
2.2c Are the design criteria appropriate given the site conditions and restoration potential?				
2.3 Conceptual Design				
2.3a Was the conceptual channel alignment provided and developed within the design criteria?				
2.3b Were typical bankfull cross sections provided and developed within the design criteria?				
2.3c Were typical drawings of in-stream structures provided and their use and location explained?				
2.3d Was a draft planting plan provided?				
2.3e Overall Conceptual Design Comment(s)				
3.0 Final Design				
3.1 Natural Channel Design				
3.1a Was a proposed channel alignment provided and developed within the design criteria?				
3.1b Were proposed channel dimensions provided and developed within the design criteria?				
3.1c Do the proposed channel dimensions show the adjacent floodplain or flood prone area?				
3.1d Was a proposed channel profile provided and developed within the design criteria?				
3.1e Were specifications for materials and construction procedures provided and explained for the project (i.e., in-stream structures and erosion control measures)?				

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ______________________
Date: ______________________

Project: ______________________
Engineer: ______________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
3.2 Sediment Transport				
3.2a Was a sediment transport analysis necessary?				
3.2b If necessary, was the type of sediment transport analysis explained?				
3.2c Were graphs or relationships created that show shear stress, velocity and stream power as a function of stage or discharge?				
3.2d Did sediment transport capacity analysis show that the stream bed would not aggrade or degrade over time?				
3.2e Did sediment transport competency analysis show what particle sizes would be transported with a bankfull discharge?				
3.2f For gravel/cobble bed streams, does the proposed design move particles that are larger than the D100 of the stream bed?				
3.3 In-Stream Structures				
3.3a Based on the assessment and design, were in-stream structures necessary for lateral stability?				
3.3b Based on the assessment and design, were in-stream structures needed for vertical stability?				
3.3c If needed, was the reason for their location and use explained?				
3.3d Will the in-stream structures provide the intended stability?				
3.3e Were detail drawings provided for each type of in-stream structure?				
3.4 Vegetation Design				
3.4a Was a vegetation design provided?				
3.4b Does the design address the use of permanent vegetation for long term stability?				
3.4c Overall Final Design Comment(s)				

Natural Channel Design Review Checklist

Project Design Checklist

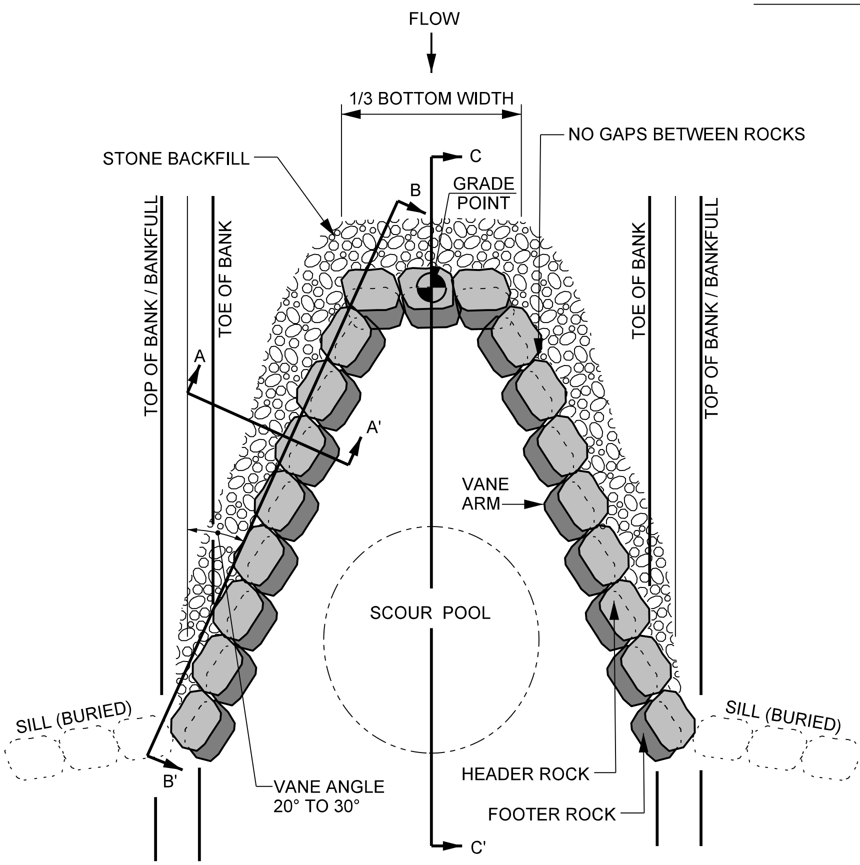
Reviewer: ____________________
Date: ____________________

Project: ____________________
Engineer: ____________________

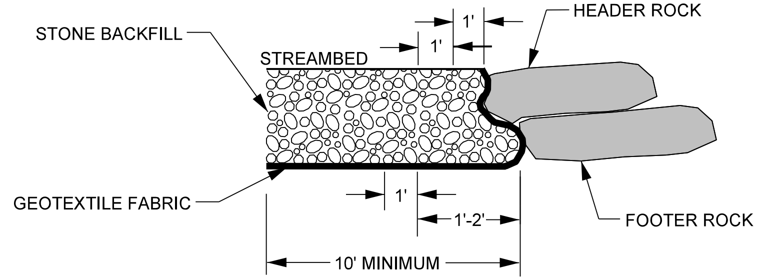
Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
4.0 Maintenance and Monitoring Plans				
4.1 Maintenance Plan				
4.1a Was a maintenance plan provided?				
4.1b Does it clearly state when maintenance will be required and if so, is it quantifiable?				
4.1c Does it clearly state how erosion will be addressed and by whom?				
4.2 Monitoring Plan				
4.2a Was a monitoring plan provided?				
4.2b Does it state who is required to conduct the monitoring?				
4.2c Does it have measurable performance standards?				
4.2d Is monitoring required for at least 3 years?				
5.0 Overall Design Review				
5.0a Does the design address the project goals and objectives?				
5.0b Are there any design components that are missing or could adversely affect the success of the project?				
5.0c Does the project have a high potential for success?				

APPENDIX H

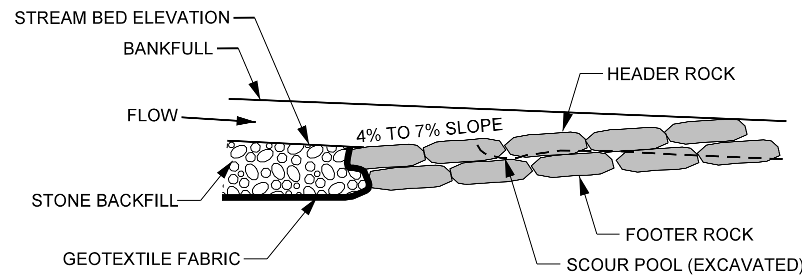
ROCK CROSS VANE



PLAN VIEW



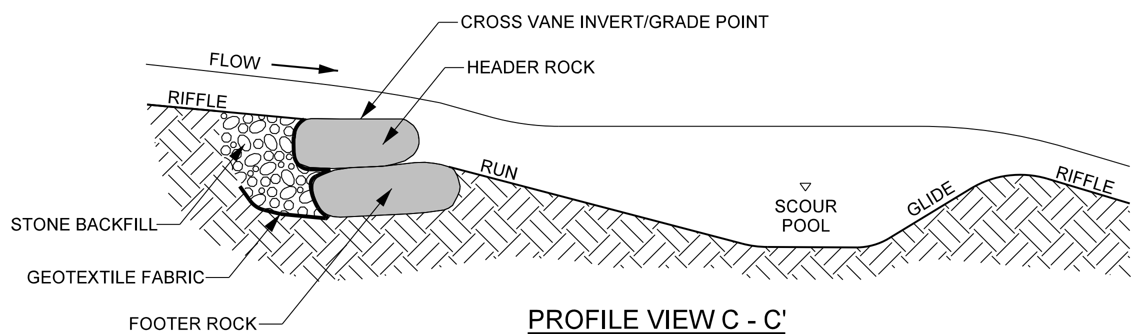
SECTION A - A'



PROFILE VIEW B - B'
VANE ARM

NOTES FOR ALL VANE STRUCTURES:

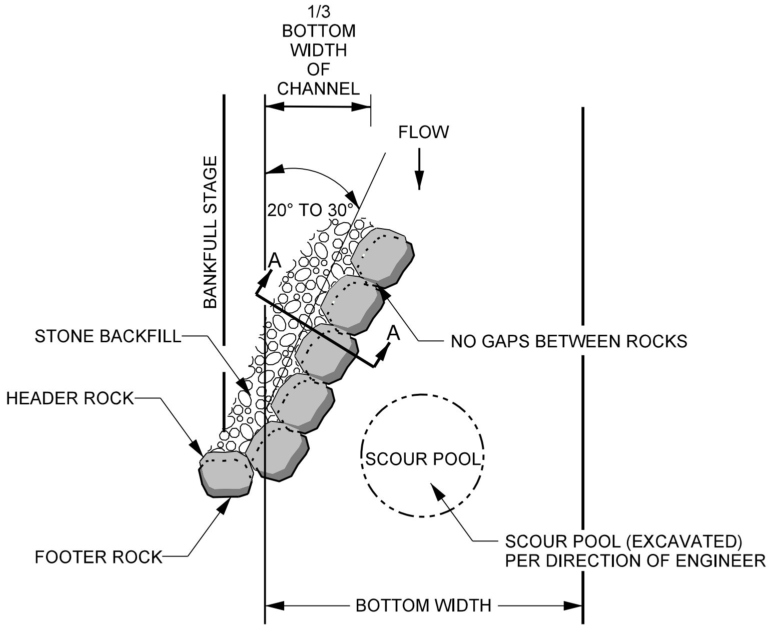
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.



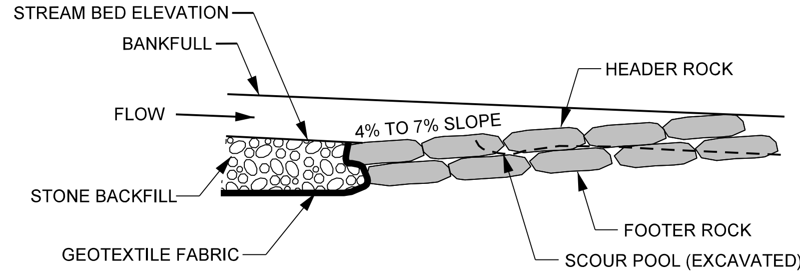
PROFILE VIEW C - C'

ROCK CROSS VANE

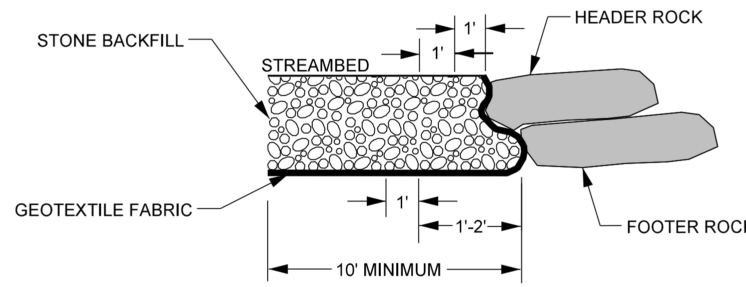
ROCK VANE



PLAN VIEW



PROFILE VIEW



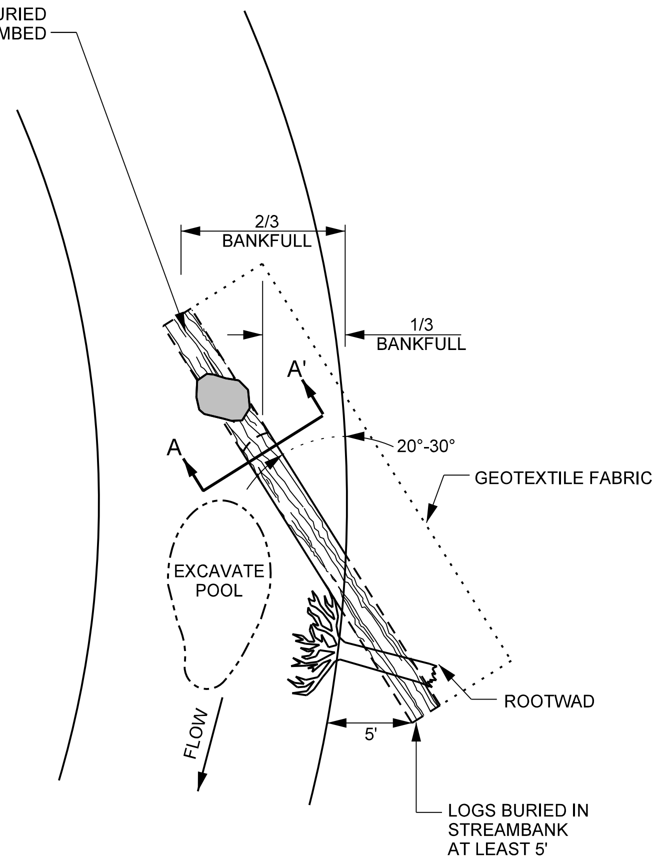
SECTION A - A

NOTES FOR ALL VANE STRUCTURES:

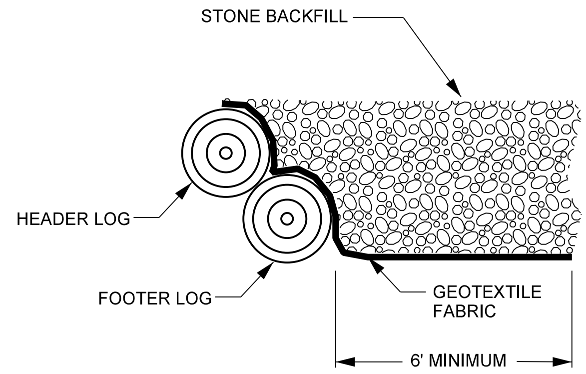
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.
8. START SLOPE AT 2/3 TO 1 TIMES THE BANKFULL STAGE.

ROCK VANE

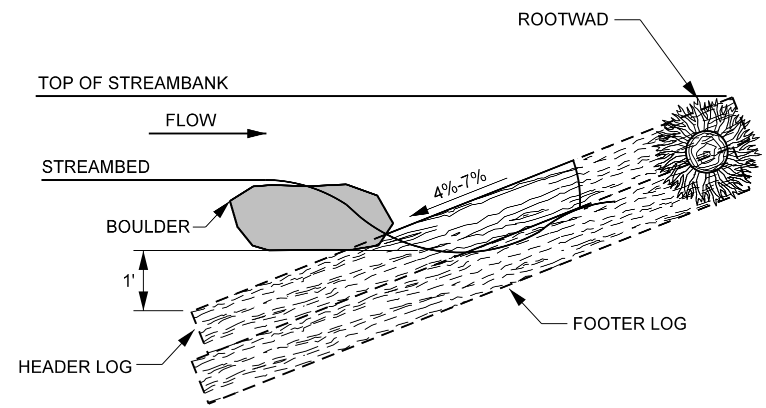
LOG VANE



PLAN VIEW



SECTION A - A'



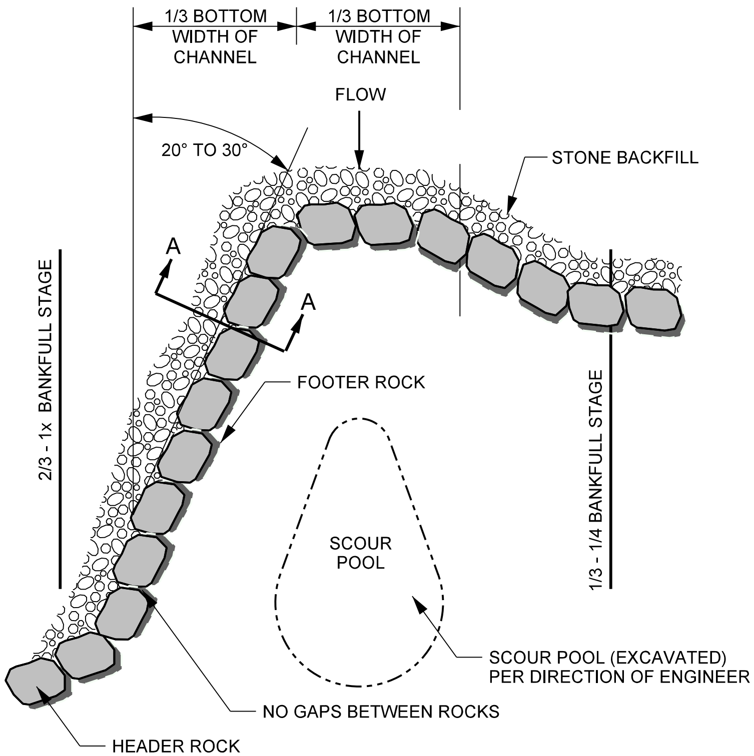
PROFILE VIEW

NOTES:

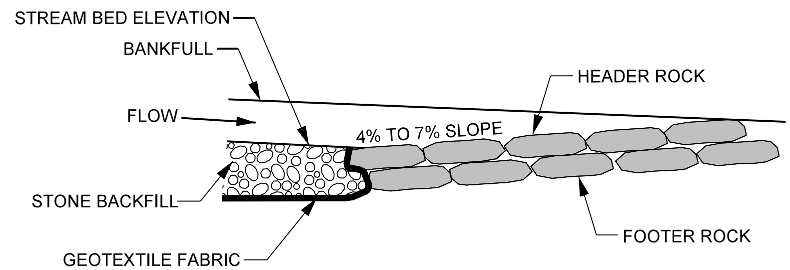
1. LOGS SHOULD BE AT LEAST 10" IN DIAMETER, RELATIVELY STRAIGHT, HARDWOOD, AND RECENTLY HARVESTED.
2. BOULDERS MUST BE OF SUFFICIENT SIZE TO ANCHOR LOGS.
3. SOIL SHOULD BE COMPACTED WELL AROUND BURIED PORTIONS OF LOGS.
4. ROOTWADS SHOULD BE PLACED BENEATH THE HEADER LOG AND PLACED SO THAT IT LOCKS THE HEADER LOG INTO THE BANK. SEE ROOTWAD DETAIL.
5. BOULDER SHOULD BE PLACED ON TOP OF HEADER LOG FOR ANCHORING.
6. GEOTEXTILE FABRIC SHOULD BE NAILED TO THE LOG BELOW THE BACKFILL.
7. TRANSPLANTS CAN BE USED INSTEAD OF ROOTWADS, PER DIRECTION OF ENGINEER.

LOG VANE

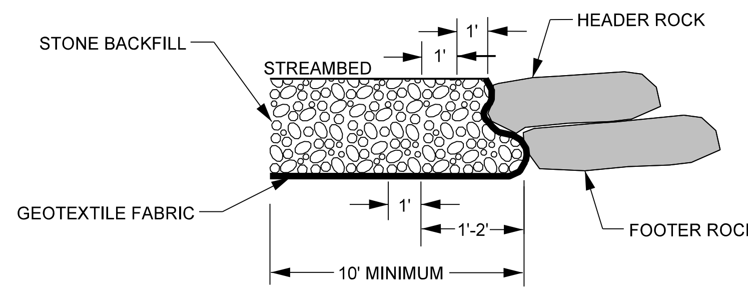
GRADE CONTROL J-HOOK VANE



PLAN VIEW



PROFILE VIEW



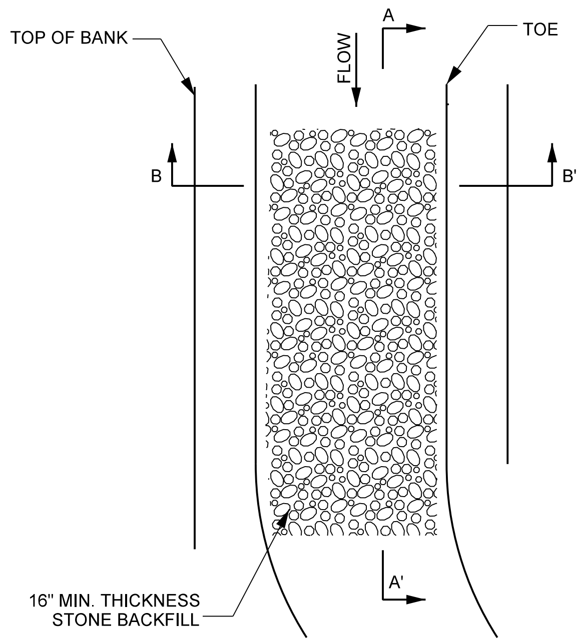
SECTION A - A

NOTES FOR ALL VANE STRUCTURES:

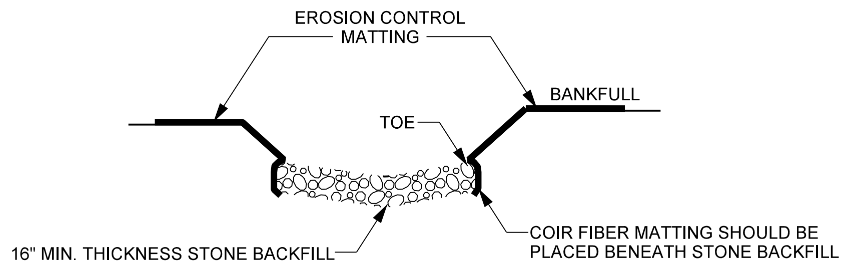
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.

GRADE CONTROL J-HOOK VANE

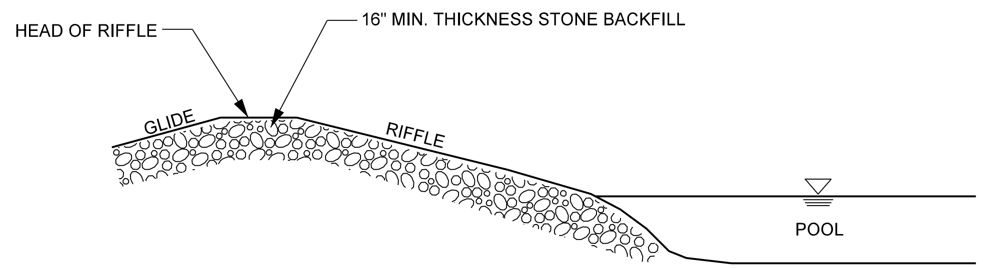
CONSTRUCTED RIFFLE



PLAN VIEW



SECTION B - B'



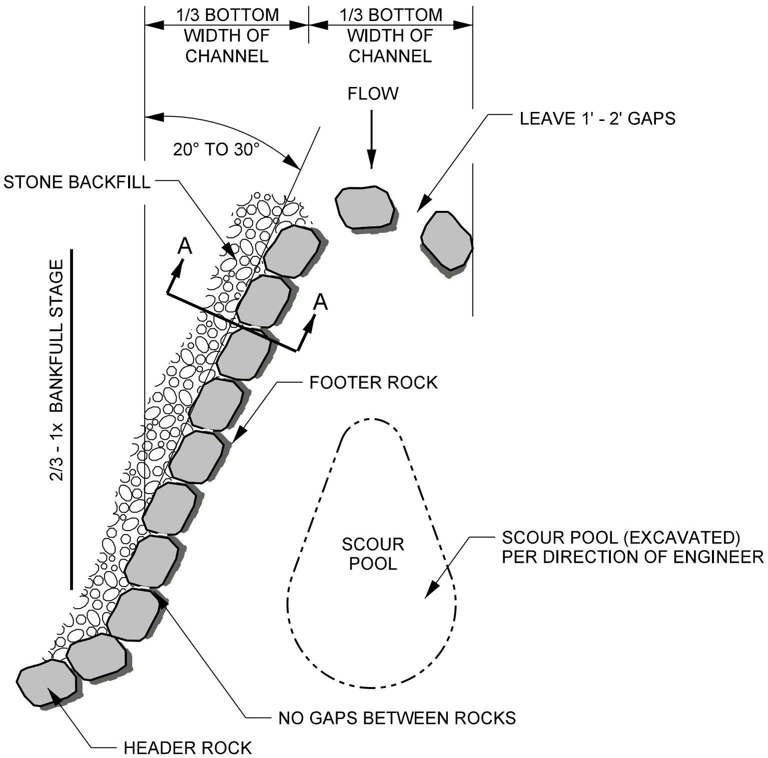
PROFILE A - A'

NOTES:

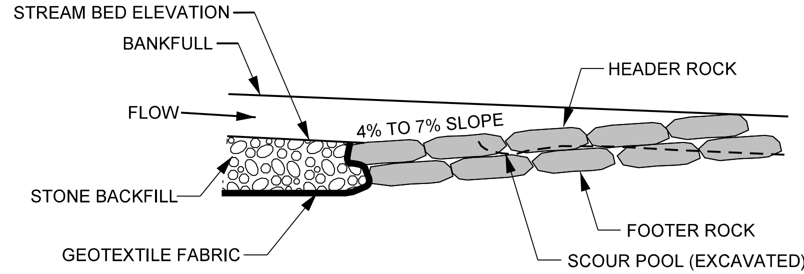
1. DIG A TRENCH BELOW THE BED FOR THE STONE BACKFILL.
2. FILL TRENCH WITH STONE BACKFILL.

CONSTRUCTED RIFFLE

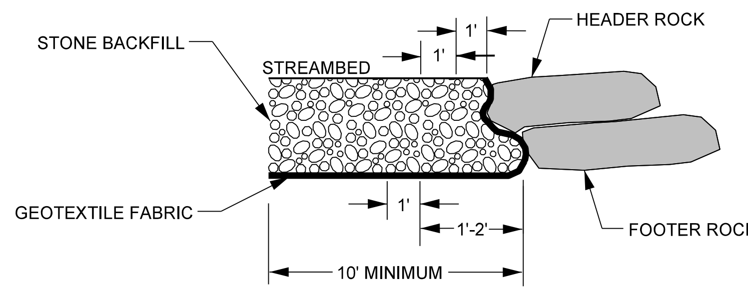
J-HOOK VANE



PLAN VIEW



PROFILE VIEW



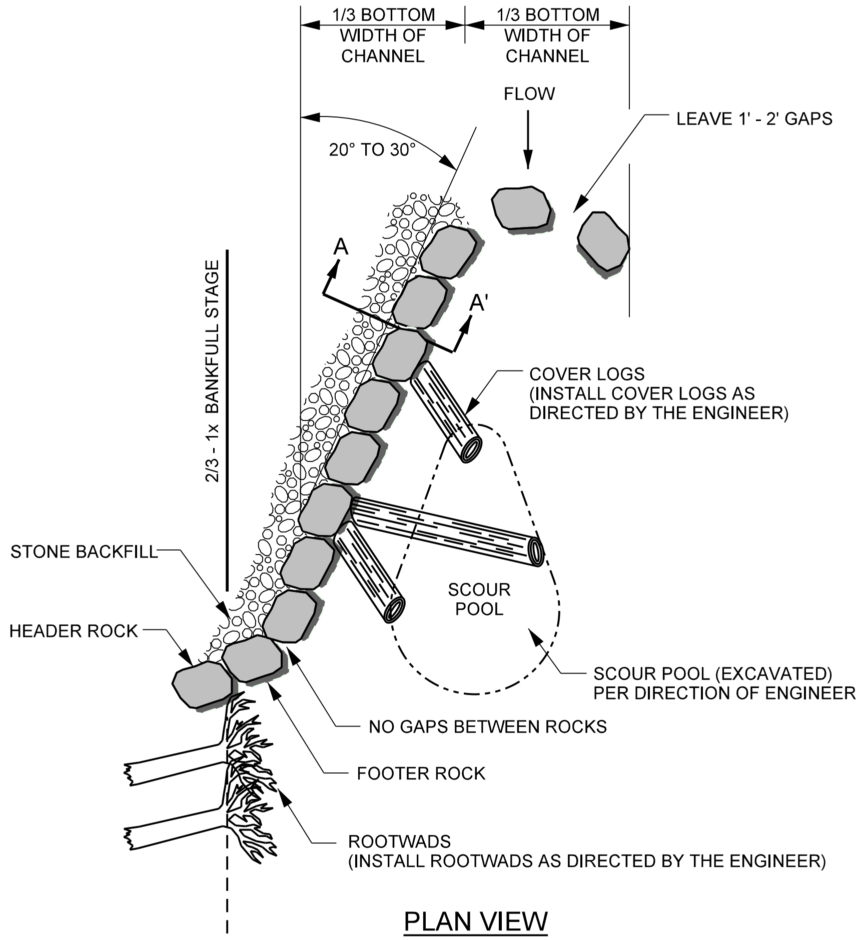
SECTION A - A

NOTES FOR ALL VANE STRUCTURES:

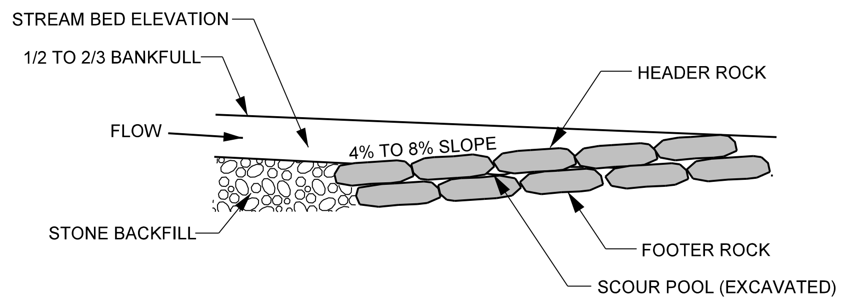
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.

J-HOOK VANE

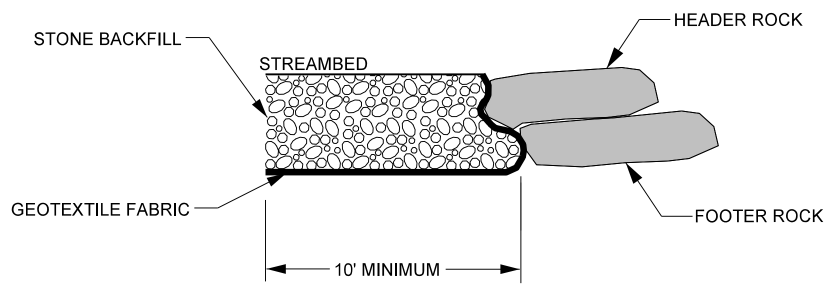
J-HOOK VANE WITH COVER LOG



PLAN VIEW



PROFILE VIEW



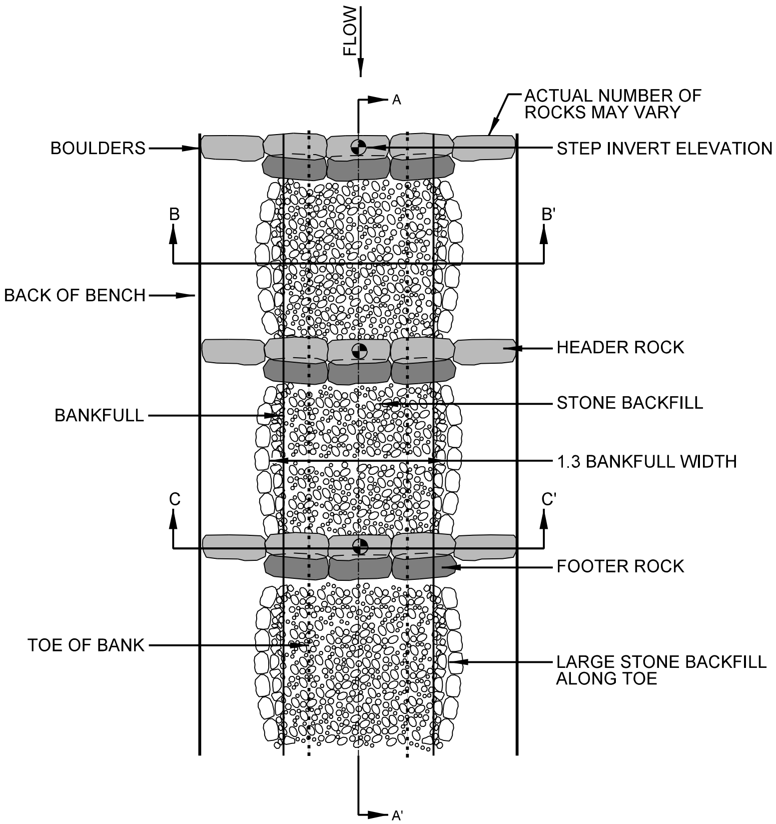
SECTION A - A'

NOTES FOR ALL J-HOOK STRUCTURES:

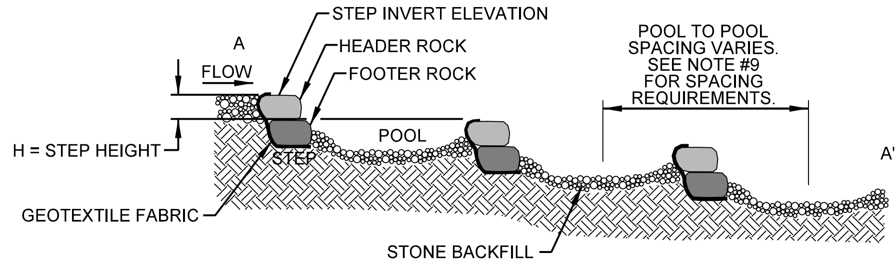
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.

J-HOOK VANE W/ COVER LOG

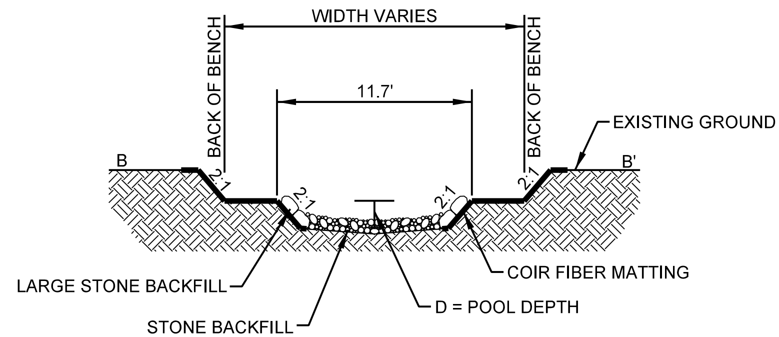
STEP POOL CHANNEL



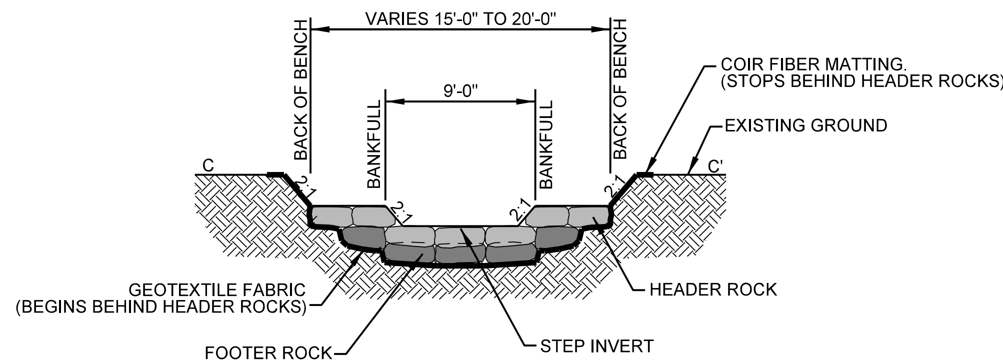
PLAN VIEW



PROFILE VIEW A-A'



POOL CROSS SECTION B-B'



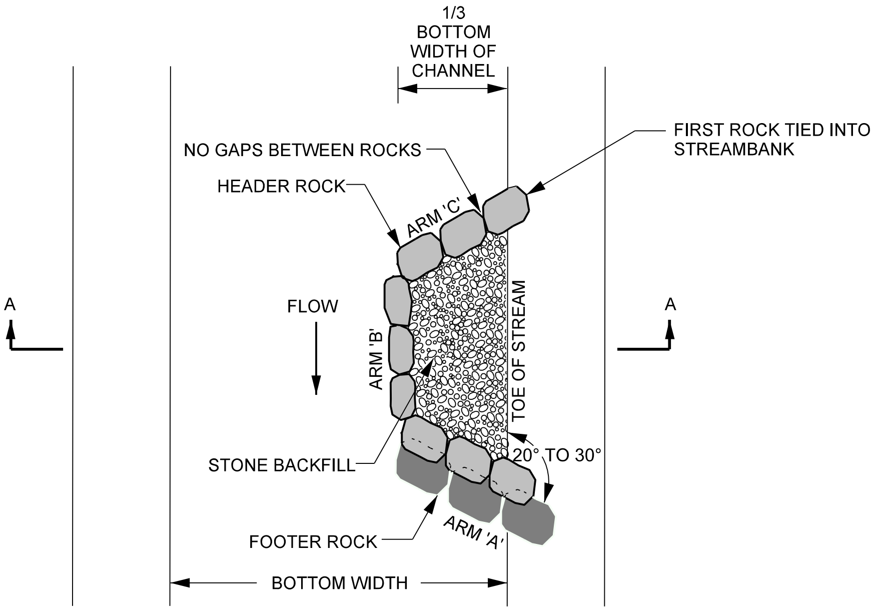
POOL CROSS SECTION C-C'

NOTES:

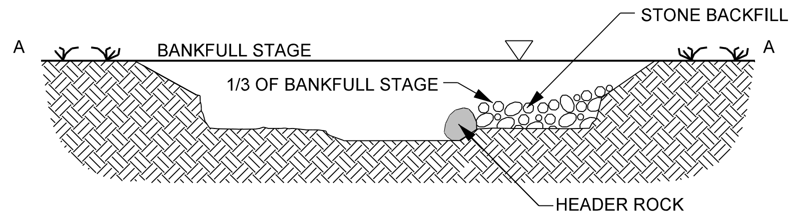
1. FOOTER ROCKS SHALL BE INSTALLED SUCH THAT 1/4 TO 1/3 OF THE LENGTH IS DOWNSTREAM OF THE HEADER ROCKS.
2. SOIL SHALL BE WELL COMPACTED AROUND BURIED PORTION OF FOOTER ROCKS WITH BUCKET OF TRACK HOE.
3. INSTALL GEOTEXTILE FILTER FABRIC UNDERNEATH FOOTER ROCKS.
4. UNDERCUT POOL BED ELEVATION 8 INCHES TO ALLOW FOR LAYER OF STONE.
5. INSTALL COIR FIBER MATTING ALONG COMPLETED BANKS SUCH THAT THE COIR FIBER MATTING AT THE TOE OF THE BANK EXTENDS DOWN TO THE UNDERCUT ELEVATION.
6. INSTALL LARGE STONE BACKFILL ALONG SIDE SLOPES.
7. FINAL CHANNEL BED SHAPE SHOULD BE ROUNDED, COMPACTED, AND CONCAVE, WITH THE ELEVATION OF THE BED APPROXIMATELY 0.5 FT DEEPER IN THE CENTER THAN AT THE EDGES.
8. STEP HEIGHT (H) SHALL NOT EXCEED 0.8 FT.
9. IN GENERAL, POOL TO POOL SPACING SHALL BE NO LESS THAN AND NO GREATER THAN AS SPECIFIED BY ENGINEER BASED ON EXISTING CONDITIONS SUCH AS SLOPE AND SUITABLE FILL MATERIAL. CONSTRUCTED RIFFLES MAY BE SUBSTITUTED IN AREAS WHERE EXISTING SLOPES EXCEED 10% AS DETERMINED IN THE FIELD BY THE ENGINEER.

STEP POOL CHANNEL

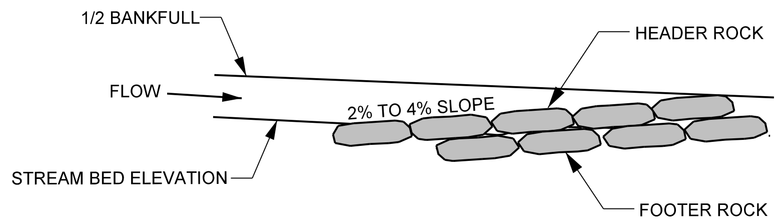
SINGLE WING DEFLECTOR



PLAN VIEW



SECTION A - A



ARM 'A' PROFILE VIEW

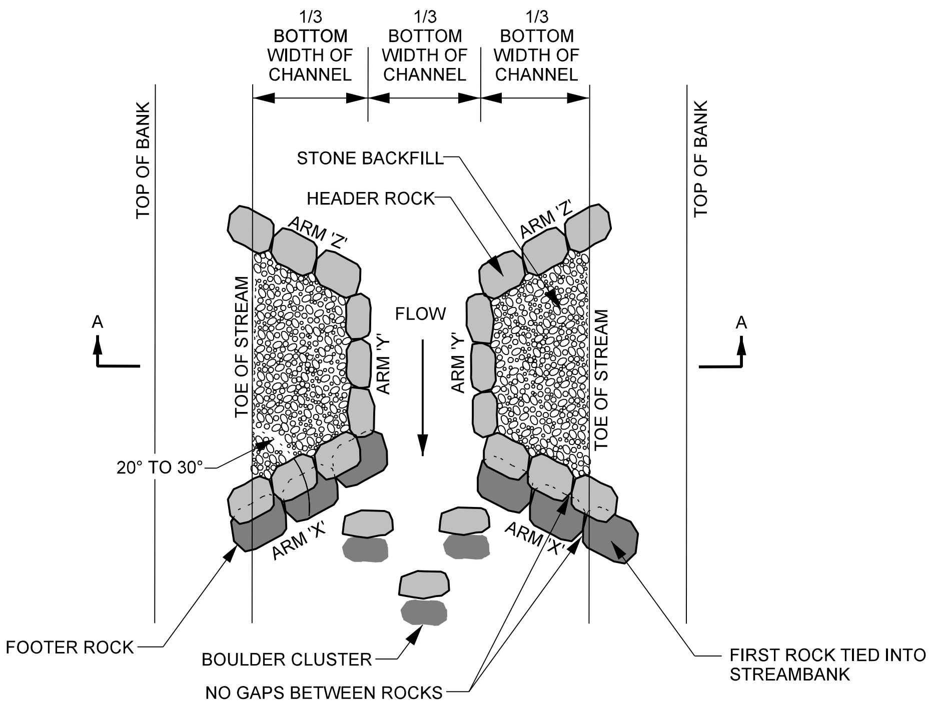
NOTE: NO SLOPE FOR ARMS B & C

NOTES:

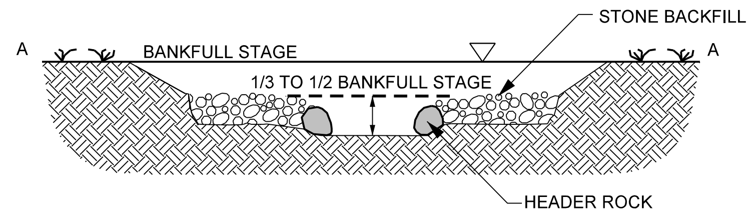
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.

SINGLE WING DEFLECTOR

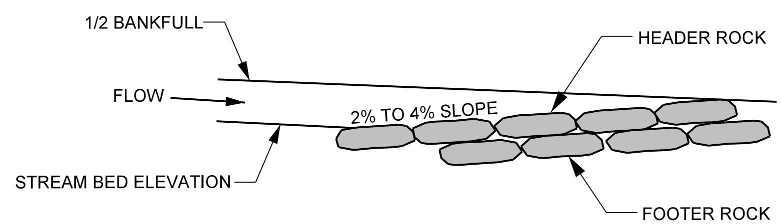
DOUBLE WING DEFLECTOR



PLAN VIEW



SECTION A - A



ARM 'X' PROFILE VIEW

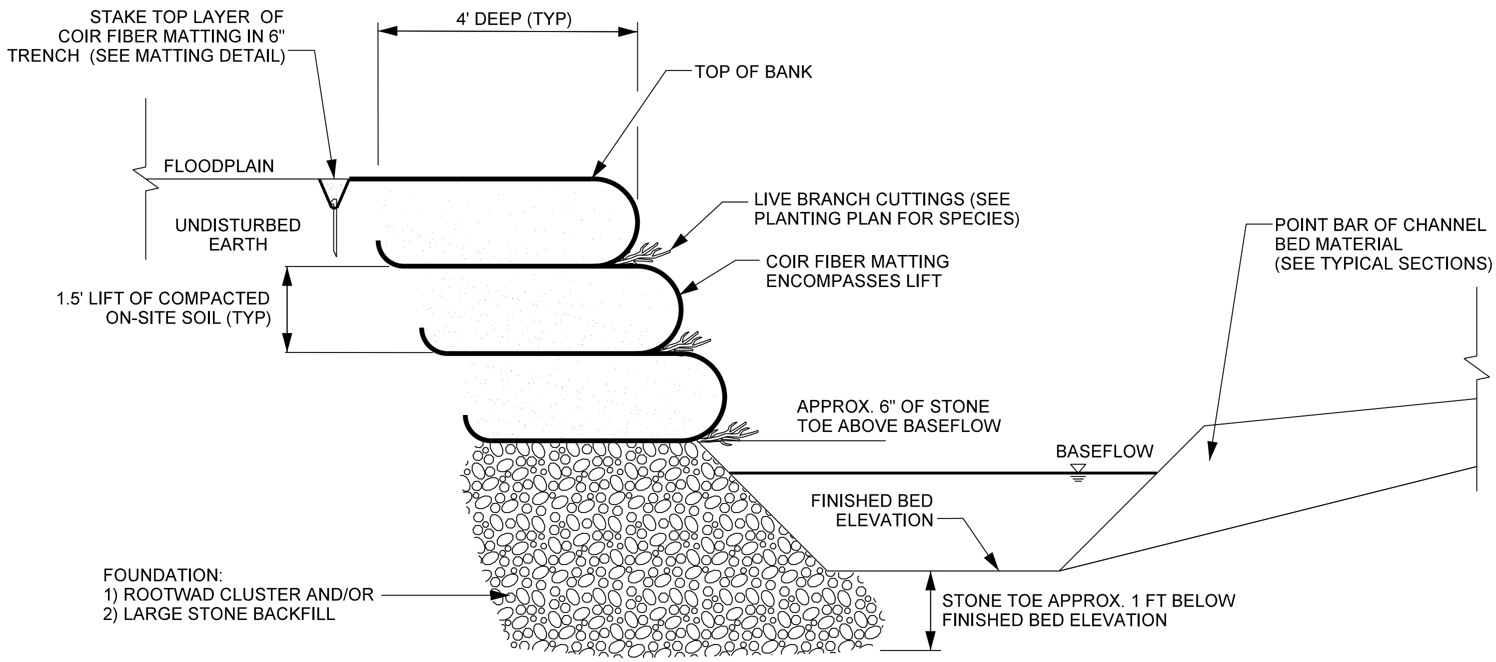
NOTE: NO SLOPE FOR ARMS Y & Z

NOTES:

1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. START AT BANK AND PLACE FOOTER ROCKS FIRST AND THEN HEADER (TOP) ROCK.
4. CONTINUE WITH STRUCTURE, FOLLOWING ANGLE AND SLOPE SPECIFICATIONS.
5. AN EXTRA ROCK CAN BE PLACED IN SCOUR POOL FOR HABITAT IMPROVEMENT.
6. USE HAND PLACED STONE TO FILL GAPS ON UPSTREAM SIDE OF HEADER AND FOOTER ROCKS.
7. AFTER ALL STONE BACKFILL HAS BEEN PLACED, FILL IN THE UPSTREAM SIDE OF THE STRUCTURE WITH ON-SITE ALLUVIUM TO THE ELEVATION OF THE TOP OF THE HEADER ROCK.

DOUBLE WING DEFLECTOR

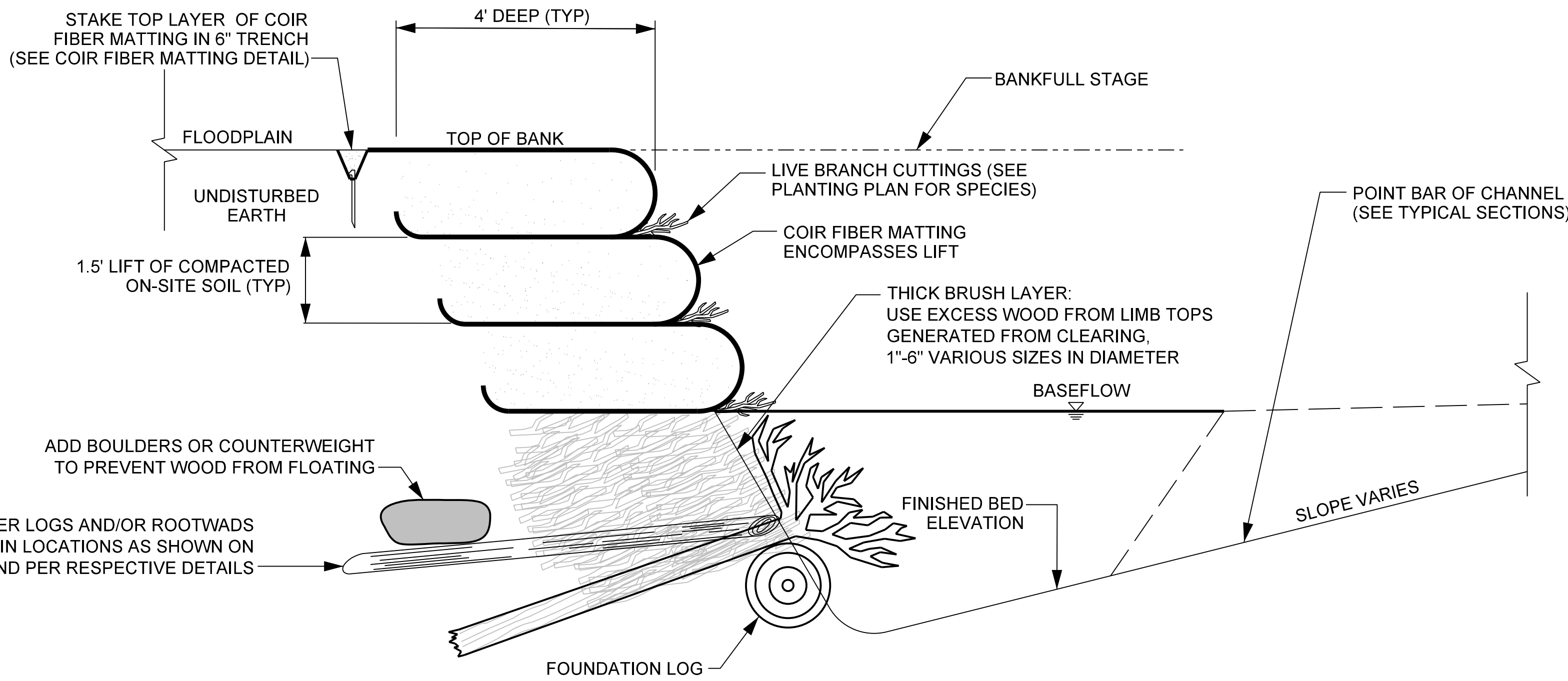
GEOLIFT



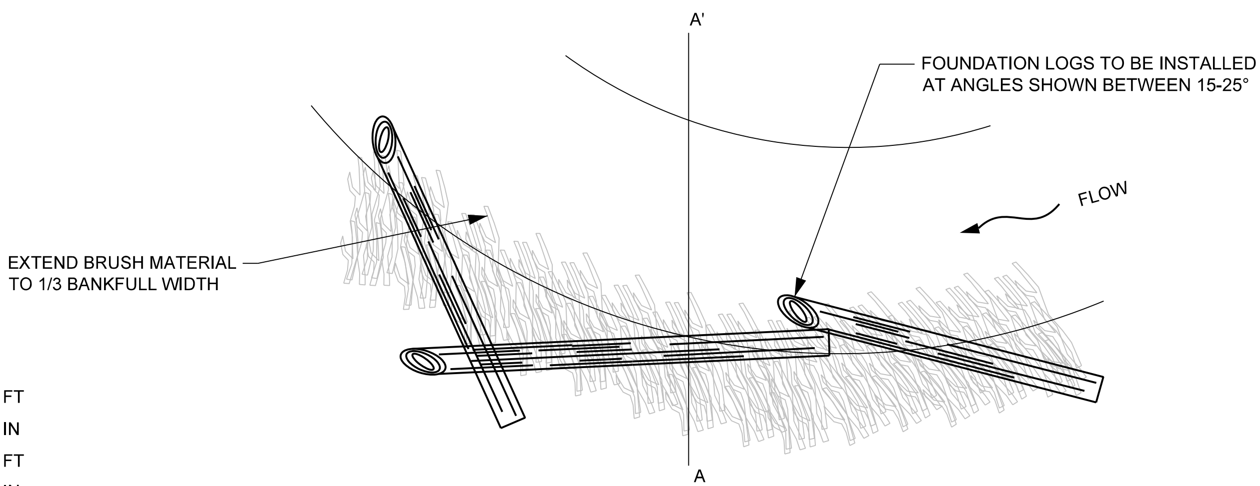
NOTES:
1. WHEN GEOLIFTS ARE BUILT ABOVE ROOTWAD CLUSTER, USE LARGE STONE BACKFILL BEHIND ROOT MASS TO BUILT FOUNDATION.

GEOLIFT

TOE WOOD WITH GEOLIFT



SECTION VIEW



PLAN VIEW

PROJECT SPECIFIC SPECS

POOL WATER DEPTH ___________ FT

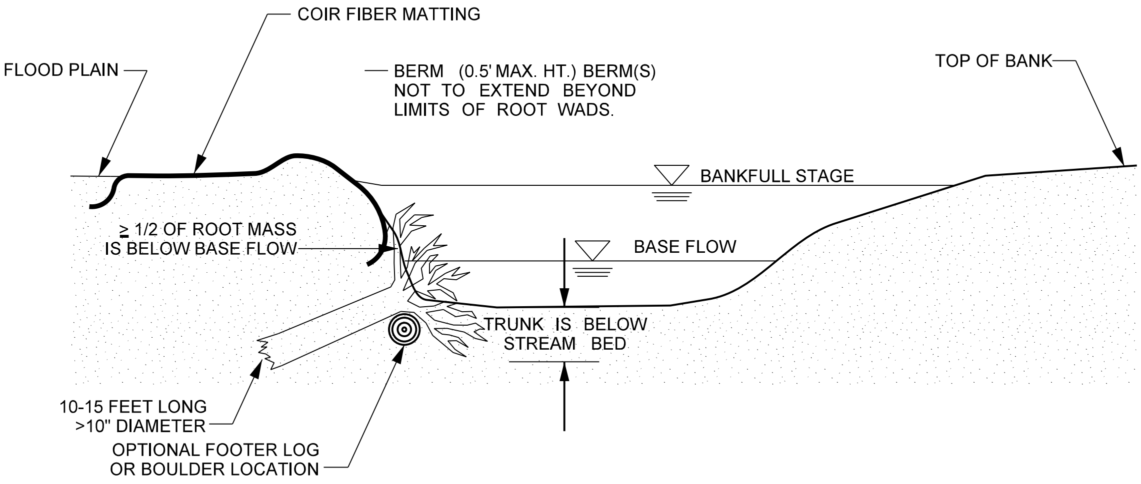
FOUNDATION HEIGHT ___________ IN

FOUNDATION WIDTH ___________ FT

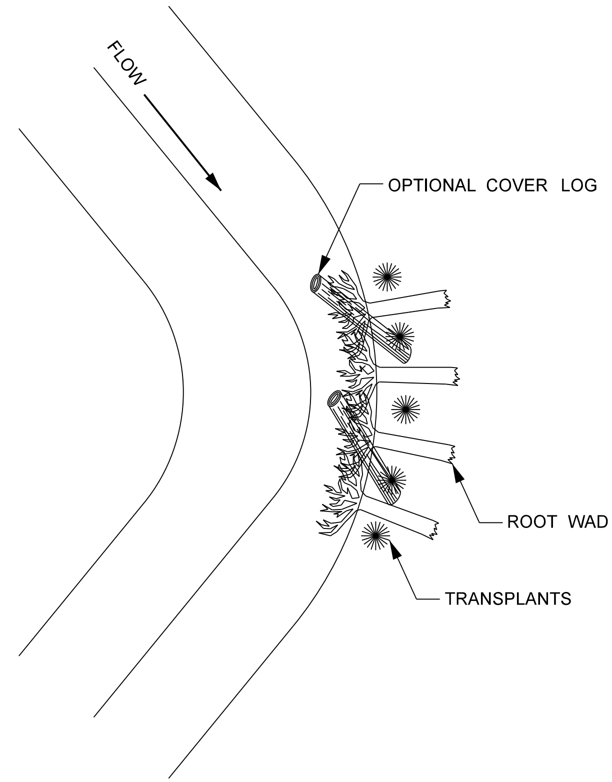
BRUSH THICKNESS ___________ IN

TOE WOOD WITH GEOLIFT

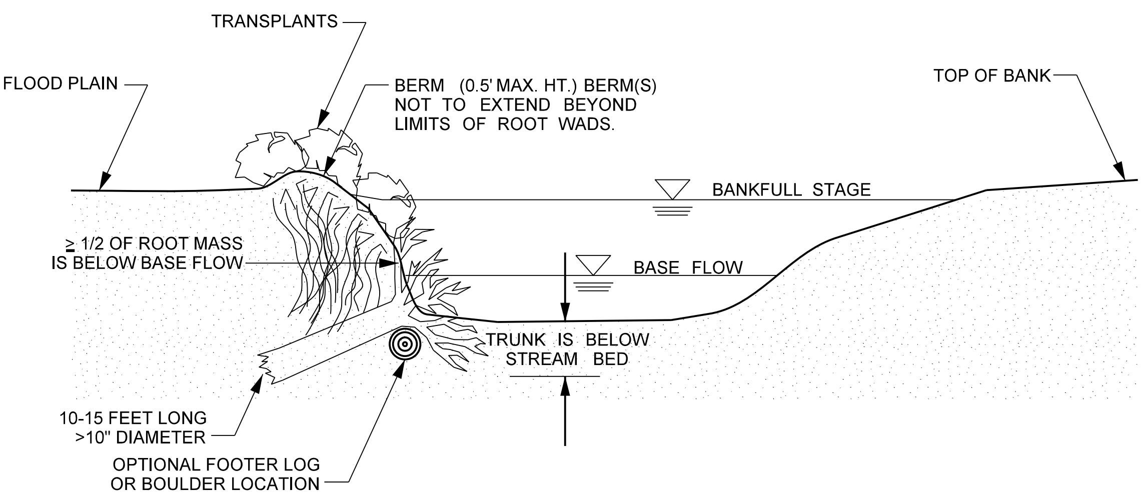
ROOT WADS WITHOUT TRANSPLANTS
CROSS SECTION VIEW
NTS



PLAN VIEW
NTS



ROOT WADS WITH TRANSPLANTS
CROSS SECTION VIEW
NTS



NOTES:

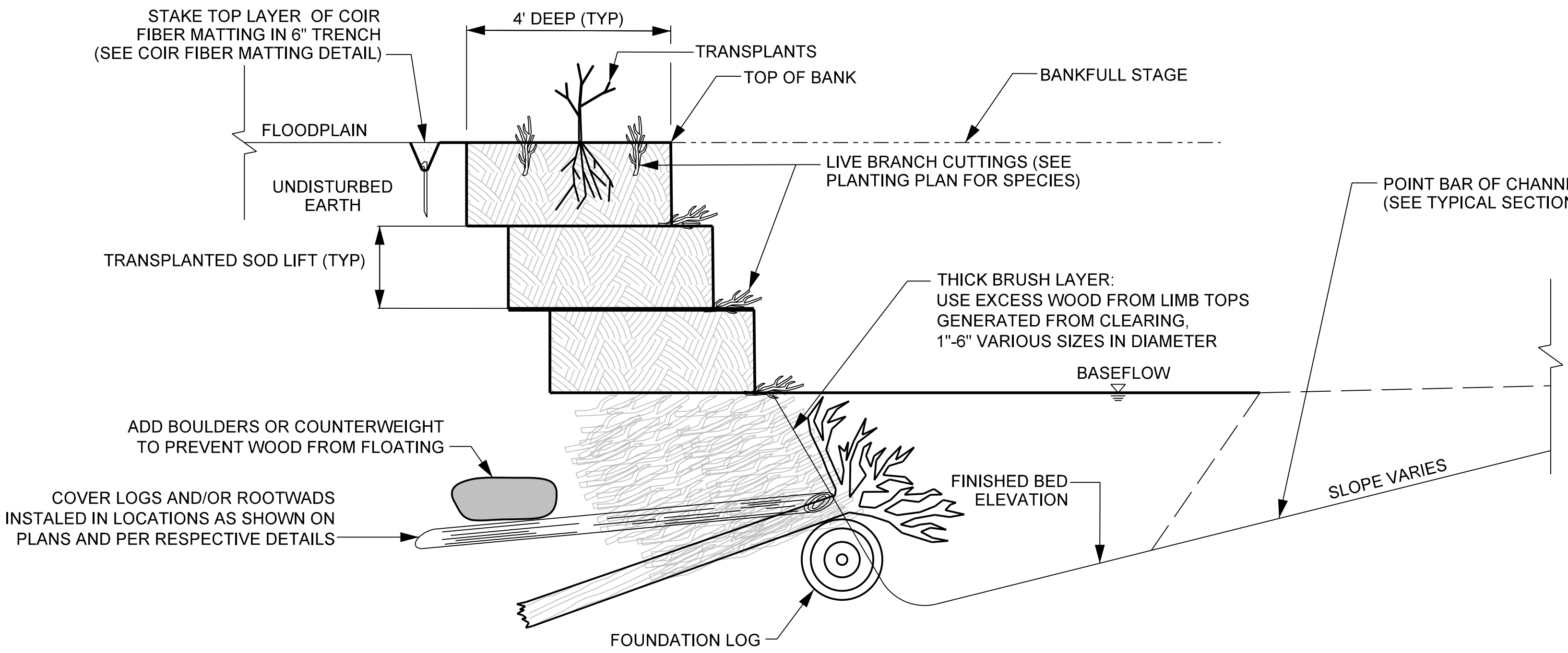
TRENCHING METHOD:
IF THE ROOT WAD CANNOT BE DRIVEN INTO THE BANK OR THE BANK NEEDS TO BE RECONSTRUCTED, THE TRENCHING METHOD SHOULD BE USED. THIS METHOD REQUIRES THAT A TRENCH BE EXCAVATED FOR THE LOG PORTION OF THE ROOT WAD. IN THIS CASE, A FOOTER LOG SHOULD BE INSTALLED UNDERNEATH THE ROOT WAD IN A TRENCH EXCAVATED PARALLEL TO THE BANK AND WELL BELOW THE STREAMBED. ONE-THIRD OF THE ROOT WAD SHOULD REMAIN BELOW NORMAL BASE FLOW CONDITIONS.

NOTES:

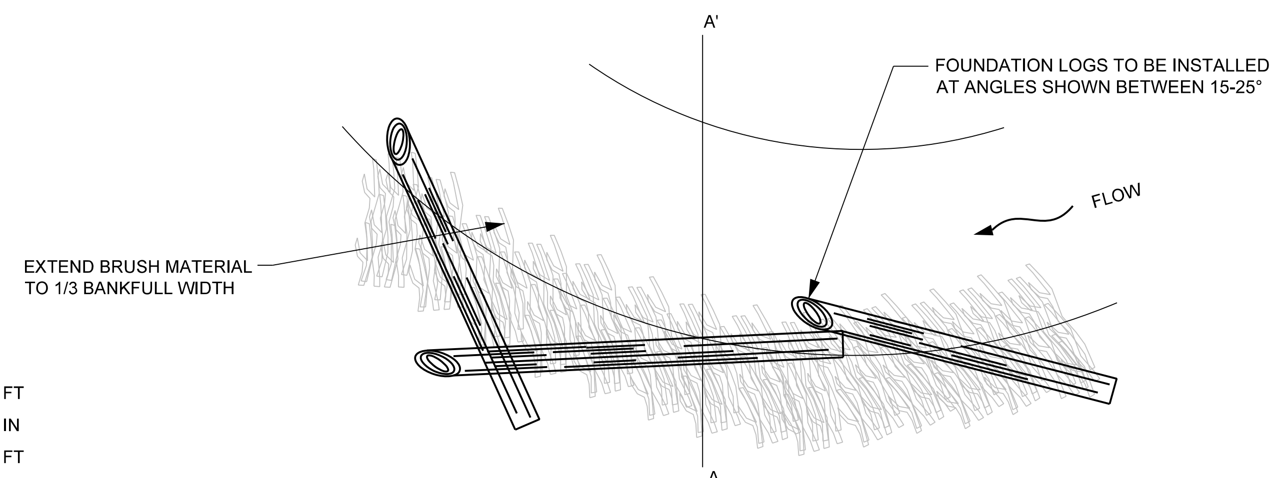
DRIVE POINT METHOD:
SHARPEN THE END OF THE LOG WITH A CHAINSAW BEFORE "DRIVING" IT INTO THE BANK. ORIENT ROOT WADS AS SHOWN, DEFLECTING THE WATER AWAY FROM THE BANK. A TRANSPLANT SHOULD BE PLACED ON THE DOWNSTREAM SIDE OF THE ROOT WAD IF A BACK EDDY IS FORMED BY THE ROOT WAD.

ROOT WADS

TOE WOOD WITH SOD AND TRANSPLANTS



SECTION VIEW



PROJECT SPECIFIC SPECS

POOL WATER DEPTH ________ FT

FOUNDATION HEIGHT ________ IN

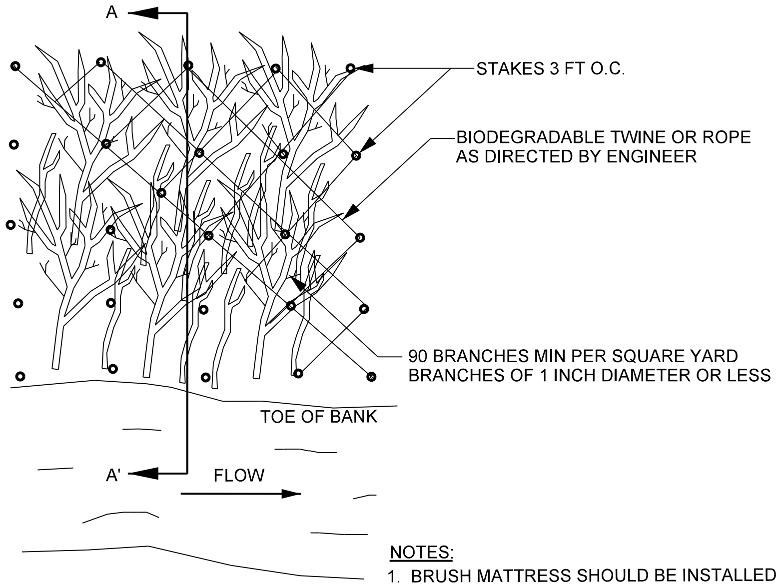
FOUNDATION WIDTH ________ FT

BRUSH THICKNESS ________ IN

PLAN VIEW

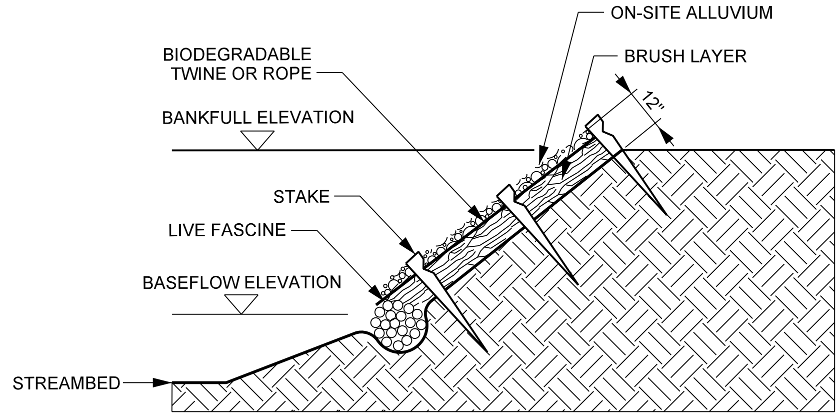
TOE WOOD WITH SOD AND TRANSPLANTS

BRUSH MATTRESS



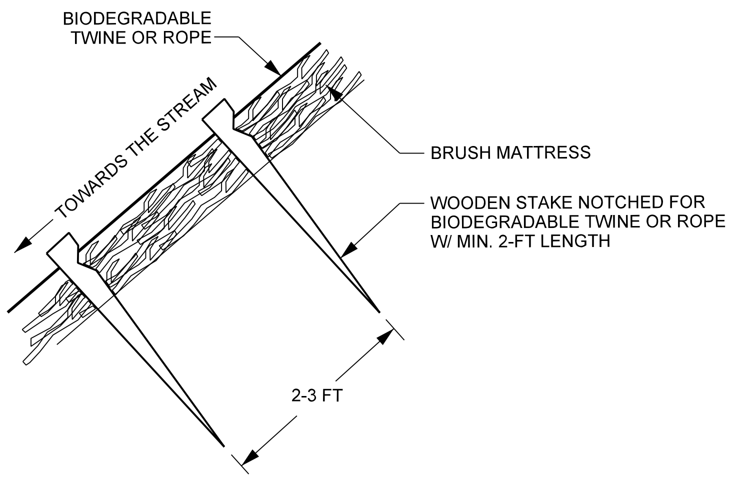
PLAN VIEW

NOTES:
1. BRUSH MATTRESS SHOULD BE INSTALLED DURING VEGETATION DORMANCY.
2. ONLY USE SPECIES SPECIFIED FOR LIVE STAKES.
3. BACKFILL 3" OF ON-SITE ALLUVIUM OVER BRUSH LAYER.

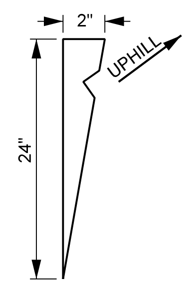


NOTES:
1. CREATE 12" DEEP TRENCH.
2. STAKE AND SECURE BRUSH LAYER INTO TRENCH.
3. BACK FILL 3" OF ON-SITE ALLUVIUM OVER BRUSH LAYER.

CROSS SECTION A-A'



STAKE SPACING DETAIL

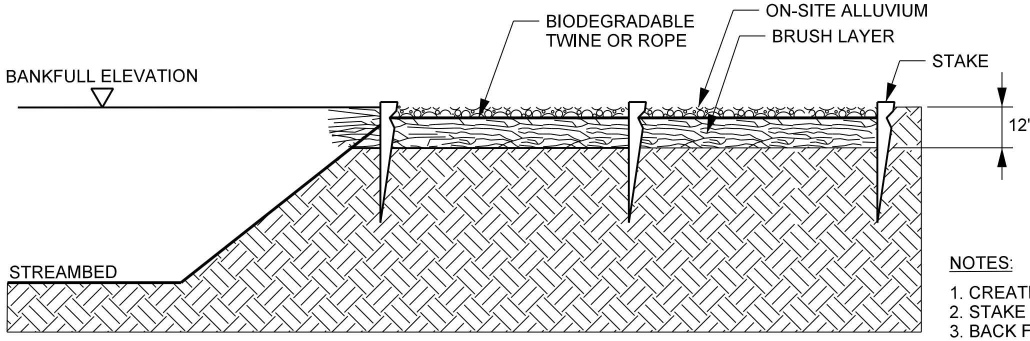


TYPICAL STAKE

NOTES:
1. BOARD FOR STAKE SHOULD BE 2" x 4" x 24".
2. SAW DIAGONALLY TO PRODUCE 2 DEAD STOUT STAKES.

BRUSH MATTRESS

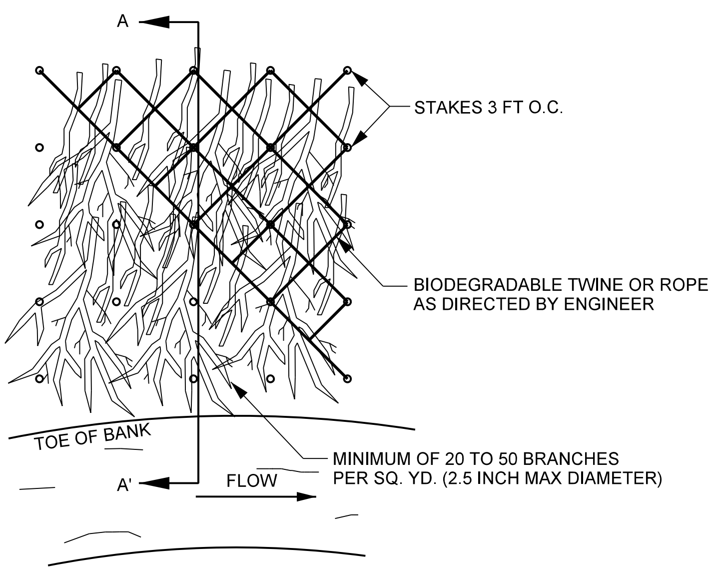
BRUSH LAYER



NOTES:

1. CREATE 12" DEEP TRENCH
2. STAKE AND SECURE BRUSH LAYER INTO TRENCH.
3. BACK FILL 3" OF ON-SITE ALLUVIUM OVER BRUSH LAYER.

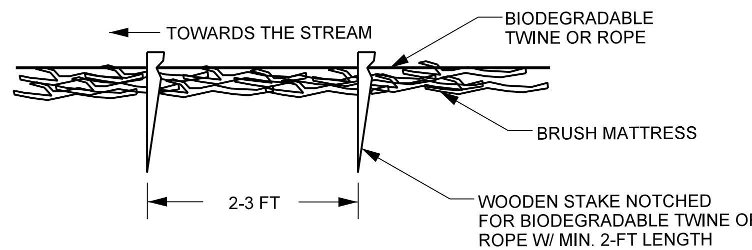
CROSS SECTION A - A'



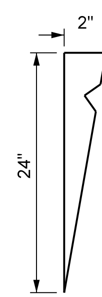
PLAN VIEW

NOTES:

1. BRUSH MATTRESS SHOULD BE INSTALLED DURING VEGETATION DORMANCY.
2. ONLY USE SPECIES SPECIFIED FOR LIVE STAKES.
3. BACKFILL 3" OF ON-SITE ALLUVIUM OVER BRUSH LAYER.



STAKE SPACING DETAIL



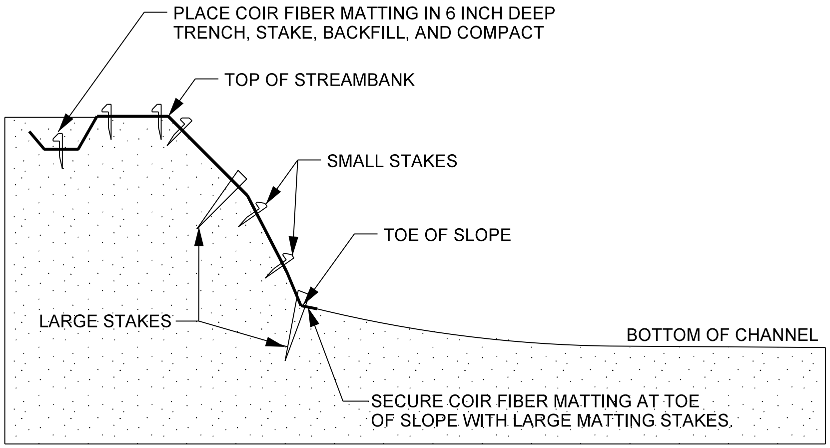
NOTES:

1. BOARD FOR STAKE SHOULD BE 2" X 4" X 24".
2. SAW DIAGONALLY TO PRODUCE 2 DEAD STOUT STAKES.

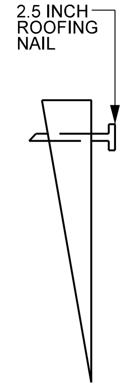
TYPICAL STAKE

BRUSH LAYER

COIR FIBER MATTING

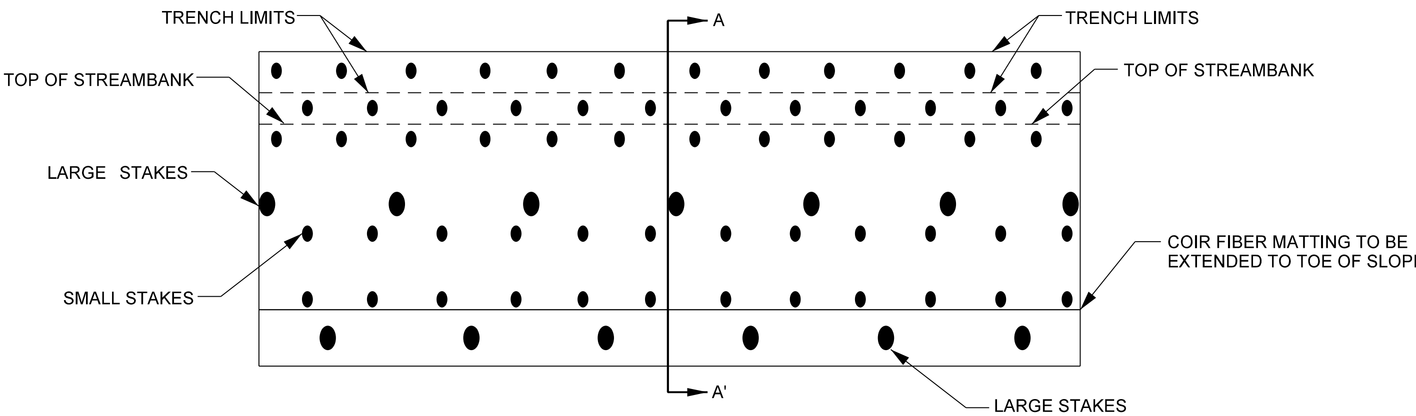


SECTION A - A'

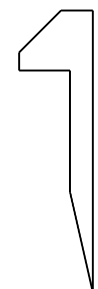


TYPICAL LARGE MATTING STAKE

LEG LENGTH	17.00 IN (43.18 CM) (TAPERED TO POINT)
WIDTH	1.5 IN (3.81 CM)
THICKNESS	1.5 IN (3.81 CM)



PLAN VIEW



TYPICAL SMALL MATTING STAKE

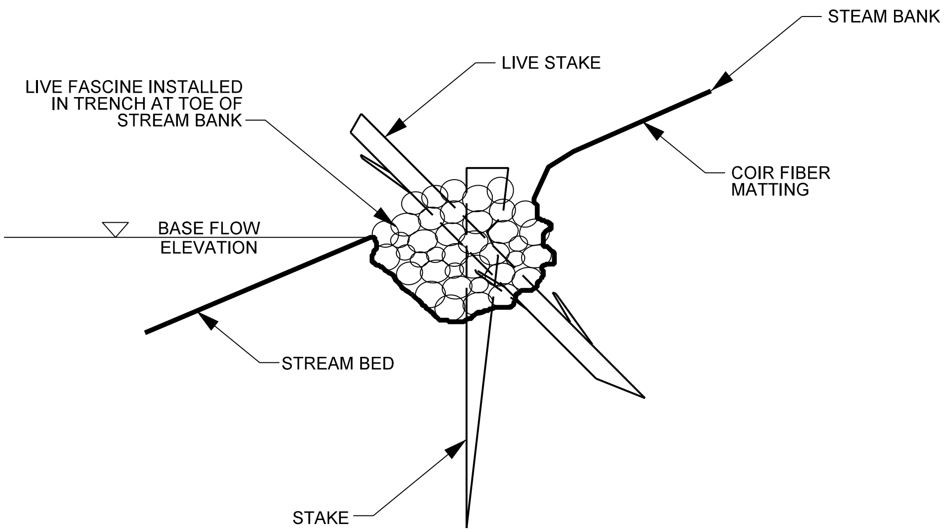
LEG LENGTH	11.00 IN (27.94 CM)
HEAD WIDTH	1.25 IN (3.18 CM)
HEAD THICKNESS	0.40 IN (1.02 CM)
LEG WIDTH	0.60 IN (1.52 CM) (TAPERED TO POINT)
LEG THICKNESS	0.40 IN (1.02 CM)
TOTAL LENGTH	12.00 IN (30.48 CM)

NOTES:

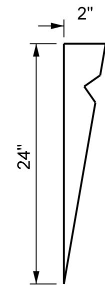
1. BANKS SHOULD BE SEEDED PRIOR TO PLACEMENT OF MATTING.
2. LARGE STAKES SHOULD NOT BE SPACED FURTHER THAN 18" APART.
3. PLACE LARGE STAKES ALONG ALL SEAMS, IN THE CENTER OF BANK, AND TOE OF SLOPE.

COIR FIBER MATTING

LIVE FASCINE



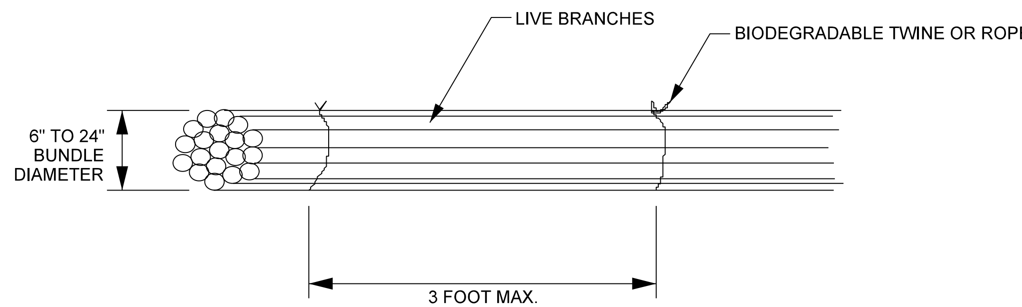
SECTION VIEW



NOTES:

1. BOARD FOR STAKE SHOULD BE 2" X 4" X 24".
2. SAW DIAGONALLY TO PRODUCE 2 DEAD STOUT STAKES.

TYPICAL STAKE

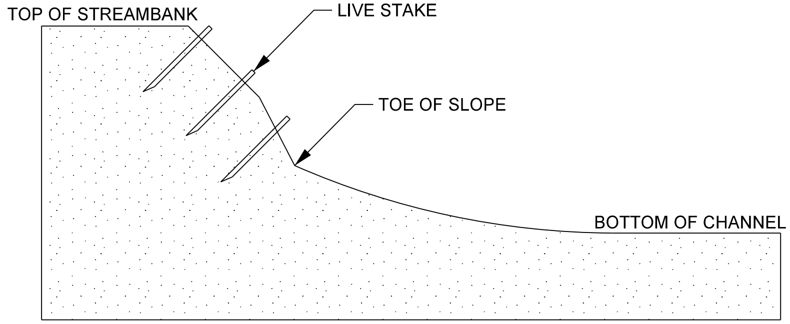


NOTES:

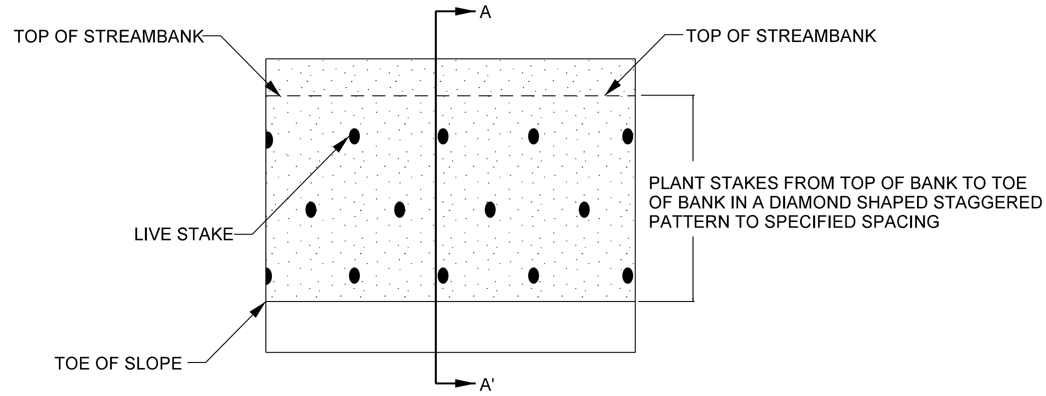
1. LIVE BRANCHES SHOULD BE 1/2 TO 2 INCHES IN DIAMETER.
2. STAGGER ORIENTATION OF CUTTINGS TO CREATE UNIFORM BUNDLE 5-20 FEET LONG AND VARY BASAL ENDS.
3. TRENCH DEPTH 2/3 DIAMETER OF BUNDLE.
3. WASH SOIL INTO TRENCHES TO BACKFILL AND CREATE GOOD SOIL CONTACT.
4. SECURE BUNDLE TIGHTLY WITH BIODEGRADABLE TWINE.
5. ANCHOR FASCINE IN TRENCH WITH STAKES ON 3 FOOT MAX. SPACING. DRIVE STAKE VERTICALLY THROUGH CENTER OF FASCINE AND SECURE BUNDLE TO STAKE WITH BIODEGRADABLE ROPE OR TWINE.
6. PROVIDE ADDITIONAL FASCINE ANCHORING BY DRIVING LARGE LIVE STAKES THROUGH FASCINE ON 3 FOOT MAX. CENTERS.

LIVE FASCINE

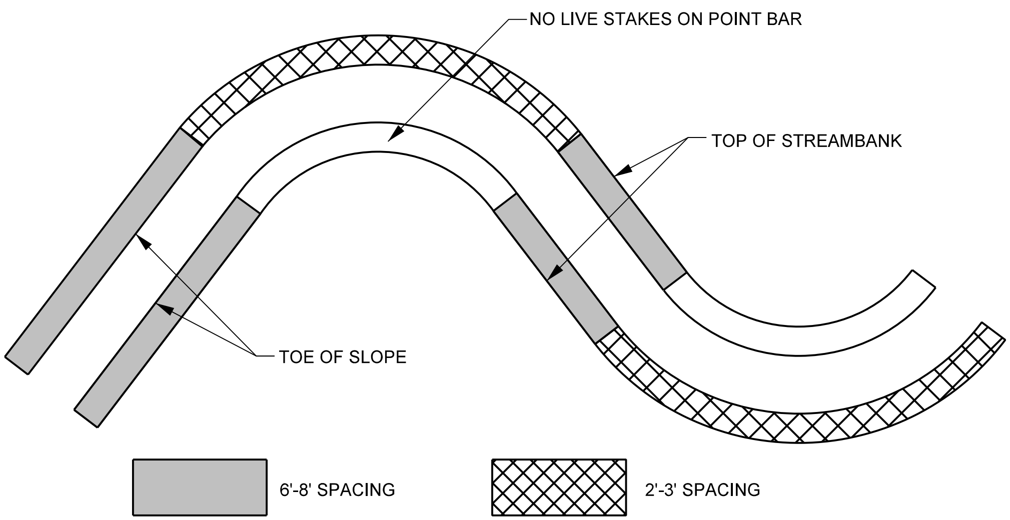
LIVE STAKING



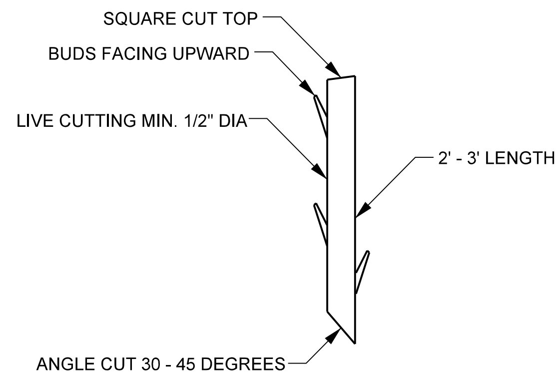
SECTION A - A'



PLAN VIEW



LIVE STAKE SPACING PLAN VIEW



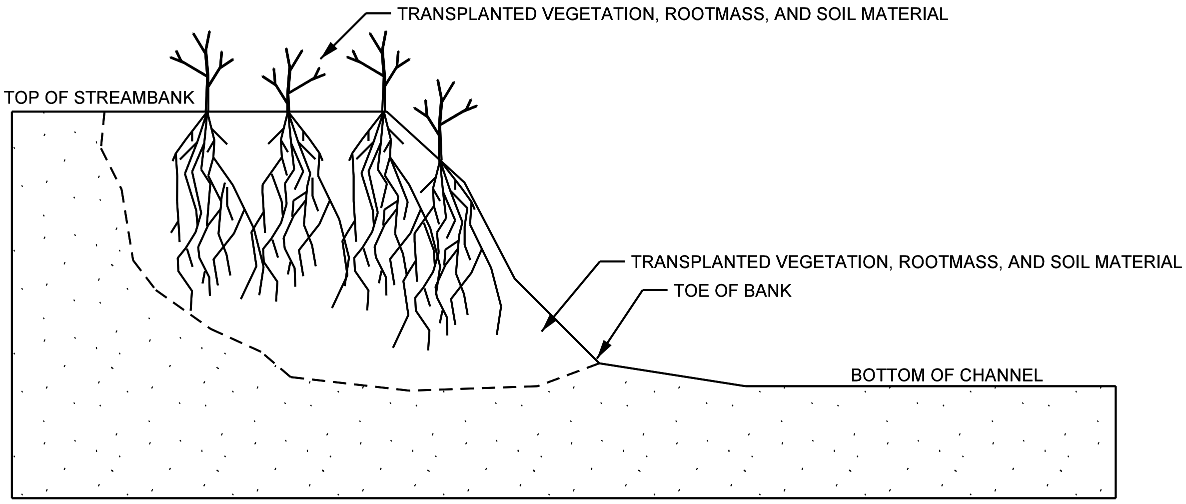
LIVE STAKE DETAIL

NOTES:

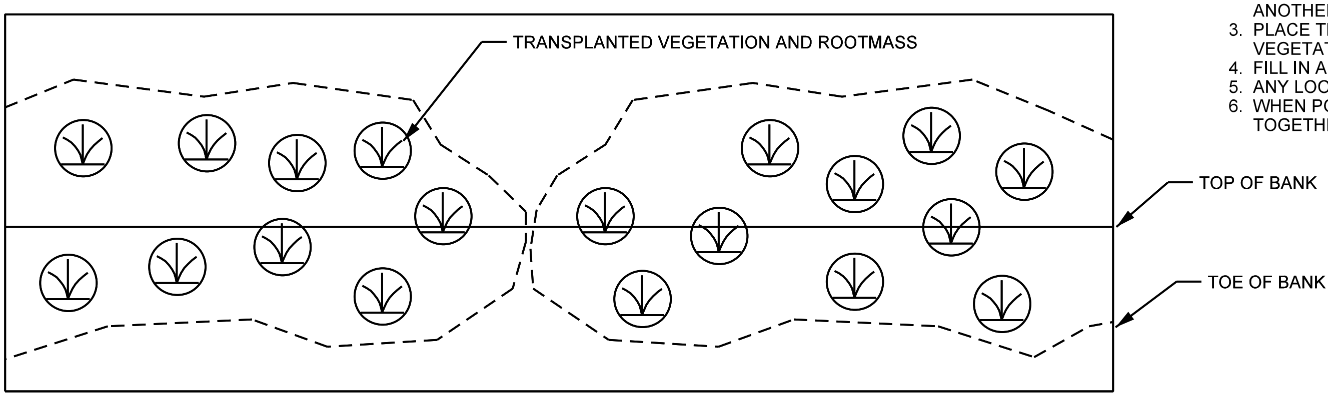
1. STAKES SHOULD BE CUT AND INSTALLED ON THE SAME DAY.
2. DO NOT INSTALL STAKES THAT HAVE BEEN SPLIT.
3. STAKES MUST BE INSTALLED WITH BUDS POINTING UPWARDS.
4. STAKES SHOULD BE INSTALLED PERPENDICULAR TO BANK.
5. STAKES SHOULD BE 1/2 TO 2 INCHES IN DIAMETER AND 2 TO 3 FT LONG.
6. STAKES SHOULD BE INSTALLED LEAVING 1/5 OF STAKE ABOVE GROUND.

LIVE STAKING

TRANSPLANTED VEGETATION



CROSS SECTION VIEW



PLAN VIEW

NOTES:

1. EXCAVATE A HOLE IN THE BANK TO BE STABILIZED THAT WILL ACCOMMODATE THE SIZE OF TRANSPLANT TO BE PLACED. BEGIN EXCAVATION AT THE TOE OF THE BANK.
2. EXCAVATE THE ENTIRE ROOT MASS AND AS MUCH ADDITIONAL SOIL MATERIAL AS POSSIBLE. IF ENTIRE ROOT MASS CAN NOT BE EXCAVATED AT ONCE, THE TRANSPLANT IS TOO LARGE AND ANOTHER SHOULD BE SELECTED.
3. PLACE TRANSPLANT IN THE BANK TO BE STABILIZED SO THAT VEGETATION IS ORIENTATED VERTICALLY.
4. FILL IN ANY HOLES AROUND THE TRANSPLANT AND COMPACT.
5. ANY LOOSE SOIL LEFT IN THE STREAM SHOULD BE REMOVED.
6. WHEN POSSIBLE, PLACE MULTIPLE TRANSPLANTS CLOSE TOGETHER SUCH THAT THEY TOUCH.

TRANSPLANTED VEGETATION

APPENDIX I

Native Plant Lists

Prepared by the San Antonio River Authority

This native plant guide was created to assist in plant selection based on the key parameters that affect the suitability of a plant to a particular site including site moisture, sun exposure and soil type. The native species included in this guide are naturally adapted to local conditions, but a plant is not necessarily suitable for all sites simply because it is native to the area. When plants are matched to the specific site conditions that they are most adapted to, they stand a better chance of surviving and thriving to their greatest abilities over time.

Existing native plant species of a site can provide a great foundation for plant selection, and an inventory of native plant species present is highly recommended. These plants have most likely undergone many disturbances and climatic conditions over time and are therefore well suited to persist over the long term. Protection of individual native plants or native plant communities during site development can provide significant ecological benefits for a site and should be considered. Salvaging and relocating native plants that would otherwise be destroyed by development is another option that can add benefit to a site. Regardless of the approaches taken, using appropriate native plants in the landscape is a smart choice for any site.

Although native plants can survive the often fluctuating climatic conditions experienced in Bexar County, they require care in order to become successfully established. In particular, they will likely require supplemental water unless sufficient rainfall occurs for some period immediately following installation as all plants typically do. The appropriate period of time will depend on the species chosen, the type of plant material used (e.g. live root, seed, container stock), and the particular climate conditions at the time of planting. Once established, native plants are better able to withstand local conditions including drought, high temperatures, and periodic freezes. If placed in an appropriate site, they require little care over the long term, provide habitat for native animals, aid in the conservation of our local species biodiversity, and provide beauty to the landscape.

Additionally, a list of undesirable plants has also been provided and should be avoided.

Native Plants for the San Antonio River Basin

Prepared by San Antonio River Authority

Native Forbs for the San Antonio Area - Prepared by San Antonio River Authority

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height (Feet)	Duration
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand		
Amblyolepis setigera	Huisache daisy			X	X	X	X		X		X	X	0-1	Annual
Argemone albiflora	White prickleypoppy			X	X	X	X		X	X	X	X	2-4	Annual
Asclepias tuberosa	Butterflyweed			X	X	X	X			X	X	X	1-2	Perennial
Bacopa monnieri	Water hyssop	X	X	X		X	X			X	X	X	0.5-1	Perennial
Calyptocarpus vialis	Straggler daisy			X	X	X	X	X	X	X	X	X	0.5-1	Perennial
Callirhoe involucrata	Winecup			X	X	X	X		X	X	X	X	1	Perennial
Cassia/Chamaecrista fasciculata	Partridge pea			X	X	X	X			X	X	X	1-3	Annual
Castilleja coccinea	Indian paintbrush			X		X				X	X	X	0.5-1.5	Annual, Biennial
Centaurea americana	American basketflower		X	X		X				X	X	X	2-5	Annual
Commelina erecta	Widow's tears				X		X				X	X	0.5-1.5	Perennial
Cooperia pedunculata	Hill Country rain lily			X		X			X	X	X	X	0-1	Perennial
Coreopsis basilis	Golden wave			X	X	X	X					X	0.5-1.5	Annual
Coreopsis lanceolata	Lanceleaf coreopsis, Tickseed			X	X	X	X	X		X	X	X	1-2.5	Perennial
Coreopsis tinctoria	Plains coreopsis			X	X	X	X			X	X	X	1-2	Annual
Corydalis aurea	Scrambled eggs			X		X				X	X	X	0.5-1	Annual
Dalea candida	White prairie clover			X	X	X			X	X	X	X	1-2	Perennial
Dalea purpurea	Purple prairie clover			X	X	X			X	X	X	X	1-3	Perennial
Desmanthus illinoensis	Illinois bundleflower			X		X	X		X	X	X	X	1-3	Perennial
Dracopis amplexicaulis	Clasping leaf coneflower			X		X	X			X	X	X	1-2	Annual
Echinacea purpurea	Purple coneflower			X	X	X	X			X	X	X	2-5	Perennial
Engelmannia peristenia	Engelmann's daisy, cutleaf daisy			X	X		X	X	X	X	X	X	1-3	Perennial
Gaillardia pulchella	Indian blanket			X	X	X	X			X	X	X	1-2	Annual
Gaura Lindheimeri	White guara			X	X	X	X		X	X	X	X	2-5	Perennial
Gaura suffulta	Bee blossom, wild honeysuckle			X		X					X	X	0-3	Annual
Glandularia bipinnatifida	Purple prairie verbena		X	X			X		X	X	X	X	0-1	Perennial
Helianthus annuus	Annual sunflower			X	X	X	X		X	X	X	X	2-8	Annual
Helianthus maximiliani	Maximilian sunflower			X		X	X			X	X	X	4-6	Perennial
Hydrocotyle umbellata	Money plant, water pennywort		X	X		X	X	X		X	X	X	0-1	Perennial
Ipomopsis rubra	Standing cypress				X	X	X				X	X	2-4	Perennial
Justicia americana	American water-willow	X	X	X		X	X	X		X	X	X	1-3	Perennial
Liatris mucronata	Gayfeather				X	X	X		X	X	X	X	1-3	Perennial
Lupinus texensis	Texas bluebonnet			X	X	X			X	X	X	X	0.5-1.5	Annual
Monarda citriodora	Horsemint			X	X	X	X			X	X	X	1-3	Annual
Oenothera jamesii	River primrose		X			X			X	X	X	X	3-6	Biennial
Oenothera speciosa	Pink evening primrose			X	X	X	X		X	X	X	X	1-2	Perennial
Oxalis drummondii	Drummond's woodsorrel			X	X	X	X					X	0-1	Perennial
Drummond's woodsorrel	Yellow Wood-sorrel				X	X			X	X	X	X	0-1	Perennial
Penstemum cobaea	Foxglove			X	X	X	X		X	X	X	X	1-1.5	Perennial
Phacelia congesta	Blue curls			X	X	X	X	X		X	X	X	1-3	Annual, Biennial
Phlox drummondii	Drummond phlox			X		X	X					X	0.5-1.5	Annual
Phyla nodiflora	Frogfruit		X	X	X	X	X	X		X	X	X	0.5	Perennial
Physostegia intermedia	Obedient plant		X	X		X	X	X		X	X	X	3-6	Perennial
Pontederia cordata	Pickerelweed	X	X			X	X			X	X	X	1-3	Perennial
Ratibida columnifera	Mexican hat			X	X	X	X		X	X	X	X	1-3	Perennial
Rivina humilis	Pigeonberry			X			X		X	X	X	X	1-3	Perennial
Rudbeckia hirta	Black-Eyed Susan			X	X	X	X			X	X	X	1-3	Annual
Ruellia nudiflora	Wild petunia			X	X	X	X	X				X	1-3	Perennial
Sagittaria latifolia	Broadleaf arrowhead	X				X	X		X	X	X		1-3	Perennial
Salvia azurea	Pitcher sage			X	X	X	X		X	X	X	X	2-6	Perennial
Salvia coccinea	Scarlet sage			X		X	X		X	X	X	X	0.5-2	Perennial
Salvia farinacea	Mealy blue sage				X	X	X		X	X	X	X	1-3	Perennial
Senna lindheimeriana	Lindheimers senna				X	X	X		X	X	X	X	3-6	Perennial
Simsia calva	Bush sunflower				X	X			X				1-3	Perennial
Thelesperma filifolium	Greenthread				X	X						X	1-3	Annual
Verbena bipinnatifida	Prairie verbena			X	X	X	X		X	X	X	X	0.5-1	Perennial
Verbena halei	Texas vervain				X	X				X	X	X	1-3	Perennial
Verbesina encelioides	Cowpen Daisy				X	X			X	X	X	X	1-3	Annual
Wedelia texana	Zexmenia			X	X	X	X		X	X	X	X	1-3	Perennial

*** S** = shallow water; **W** = wet/saturated soil; **M** = moderate/moist soil; **D** = dry soil

Native Grasses, Sedges & Rushes for the San Antonio Area - Prepared by San Antonio River Authority

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height (Feet)	Duration
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand		
Andropogon gerardii	Big bluestem			X		X	X		X	X	X	X	4-8	Perennial
Andropogon glomeratus	Bushy bluestem		X	X		X				X	X	X	2-5	Perennial
Aristida purpurea	Purple threeawn				X	X				X	X	X	1-1.5	Annual
Bothriochloa barbinodis	Cane Bluestem			X	X	X			X	X	X	X	1-3	Perennial
Bouteloua curtipendula	Sideoats grama			X	X	X	X			X	X	X	1-3	Perennial
Bouteloua dactyloides	Buffalograss				X	X			X	X	X		0-1	Perennial
Bouteloua hirsuta	Hairy grama				X		X		X	X	X	X	0.5-1.5	Perennial
Bouteloua rigidiseta	Texas grama				X	X				X	X	X	0.5-1	Perennial
Chasmanthium latifolium	Inland Sea Oats			X			X	X		X	X		1-4	Perennial
Chloris ciliata	Fringed windmillgrass			X			X				X	X	1-3	Perennial
Chloris cucullata	Hooded windmillgrass			X			X				X	X	0.5-2	Perennial
Eleocharis acicularis	Needle spikerush		X	X		X				X	X		0.5	Annual, Perennial
Eleocharis quadrangulata	Squarestem spikerush	X	X			X				X	X		1.5-4	Perennial
Eleocharis tenuis	Slender spikerush		X	X		X				X	X	X	1-3	Perennial
Equisetum hyemale	Scouring rush		X	X		X	X	X		X	X		1-3	Perennial
Elymus canadensis	Canada Wildrye, Prairie Wildrye			X	X	X	X		X	X	X	X	2-4	Perennial
Eragrostis trichodes	Sand lovegrass			X	X		X				X	X	3	Perennial
Eriochloa sericea	Texas cupgrass			X	X	X	X		X	X	X	X	1-2	Perennial
Leptochloa dubia	Green sprangletop			X	X	X	X		X	X	X	X	2-3	Perennial
Panicum obtusum	Vine mesquite			X	X		X				X	X	2	Perennial
Panicum virgatum	Switchgrass		X	X	X	X	X		X	X	X	X	3-6	Perennial
Pascopyrum smithii	Western wheatgrass			X	X	X	X		X	X	X	X	1-2.5	Perennial
Setaria leucopila	Plains Bristlegrass				X	X				X		X	3-6	Perennial
Schoenoplectus/Scirpus tabernaemontani	Softstemm bulrush		X			X				X	X		3-6	Perennial
Schizachyrium scoparium	Little bluestem			X	X	X	X		X	X	X	X	1.5-2	Perennial
Sorghastrum nutans	Indiangrass			X	X	X	X		X	X	X	X	3-6	Perennial
Tridens flavus	Purpletop			X		X	X		X	X	X	X	2-6	Perennial
Tripsacum dactyloides	Eastern gamagrass		X	X			X			X	X	X	3-6	Perennial

* **S** = shallow water; **W** = wet/saturated soil; **M** = moderate/moist soil; **D** = dry soil

Native Trees, Shrubs, Subshrubs & Vines for the San Antonio Area - Prepared by San Antonio River Authority

Scientific Name	Common Name	Moisture*				Exposure			Soil				Height (Feet)
		S	W	M	D	Sun	Partial	Shade	Caliche	Clay	Loam	Sand	
Acacia berlandieri	Guajillo				X	X	X		X	X	X	X	3-15
Acacia Farnesiana	Huisache				X	X			X	X	X	X	15-25
Acacia rigidula	Black brush acacia, Catclaw acacia				X	X	X		X	X	X	X	5-15
Acer Negundo	Box Elder			X		X	X			X	X	X	35-50
Ampelopsis arborea	Peppervine			X		X	X			X	X	X	30-40
Baccharis neglecta	False Willow				X		X				X	X	6-12
Campsis Radicans	Trumpet Creeper			X	X	X			X	X	X	X	25-35
Capsicum annuum	Chile pequin			X		X	X	X		X	X		1-3
Carya illinoinesis	Pecan			X		X			X	X	X	X	70-100
Celtis laevigata	Sugar Hackberry, Sugarberry				X		X		X	X	X	X	60-80
Cephalanthus occidentalis	Buttonbush		X	X			X	X		X	X	X	6-12
Cercis canadensis var. texensis	Texas redbud				X	X	X			X	X	X	10-20
Clematis drummondii	Old man's beard			X	X		X			X	X	X	3-6
Cocculus carolinus	Carolina snailseed, Moonseed			X			X			X	X	X	3-15
Desmanthus illinoensis	Illinois bundleflower			X		X			X		X		1-3
Ehretia anacua	Anacua				X	X	X			X	X	X	36-72
Fraxinus velutina	Arizona ash				X	X			X		X		36-72
Juglans nigra	Black walnut			X		X	X			X	X	X	72-100
Lantana urticoides (L. horrida)	Texas lantana				X	X	X		X	X	X	X	2-6
Leucophyllum frutescens	Texas sage				X	X	X		X	X	X	X	2-8
Ludwigia octovalvis	Narrow-leaf Water Primrose			X		X	X			X	X		3-6
Malvaviscus arboreus var. drummondii	Turk's cap			X	X		X	X		X	X	X	3-6
Merremia dissecta	Alamo vine			X	X	X	X		X	X	X	X	6-12
Morus rubra	Red mulberry			X	X	X	X	X		X	X	X	12-36
Parkinsonia aculeata	Retama			X	X	X			X	X	X	X	12-36
Parthenocissus quinquefolia	Virginia creeper			X		X	X	X	X	X	X	X	12-36
Passiflora foetida	Corona de Cristo, Downy passionflower				X	X	X				X	X	3-6
Platanus occidentalis	American sycamore			X		X	X	X		X	X	X	75-100
Populus deltoides	Cottonwood		X	X	X	X	X	X		X	X	X	12-36
Prosopis glandulosa	Honey mesquite				X	X			X	X	X	X	12-36
Prunus mexicana	Mexican plum			X	X	X	X			X	X	X	12-36
Quercus macrocarpa	Bur oak		X	X	X	X	X	X	X	X	X	X	36-100
Sabal minor	Dwarf palmetto			X	X	X	X	X		X	X	X	3-6
Salix nigra	Black Willow		X	X		X	X	X		X	X	X	36-72
Sambucus nigra ssp. Canadensis	Common elderberry		X				X		X	X	X	X	6-12
Taxodium distichum	Bald cypress			X		X	X			X	X	X	36-72
Ulmus americana	American elm			X		X	X			X	X	X	72-100
Ulmus crassifolia	Cedar elm			X			X		X	X	X	X	36-72
Ungnadia speciosa	Mexican buckeye				X		X		X	X	X	X	12-36
Vitis mustangensis	Mustang grape				X		X			X	X	X	36-72

*** S** = shallow water; **W** = wet/saturated soil; **M** = moderate/moist soil; **D** = dry soil

NON-NATIVE PROBLEMATIC PLANTS AND RECOMMENDED ALTERNATIVES for the San Antonio Area - Prepared by San Antonio River Authority

NON-NATIVE PROBLEMATIC PLANTS		COMMENTS	NATIVE ALTERNATIVE PLANTS
Common Name	**Scientific Name**		
Chaste tree	Vitex agnus-castus	This small tree has beautiful flowers and is drought tolerant but it invades riparian areas, re-seeds readily, spreads aggressively and is difficult to control. This species is often promoted in our region because many people are currently unaware of the problems that it creates in natural areas.	Wild olive (Cordia boissieri) – multi-trunked shrub or small tree; grows up to 25 ft tall; large, showy white flowers bloom throughout the year; can survive freezes except extreme situations where it will die back to the ground but often re-sprout
			Red buckeye (Aesculus pavia) – attractive shrub to small tree; grows to 20 ft tall; showy, spike-like clusters of deep red flowers; grows best in sandy soil; drops leaves at the end of summer
Chinaberry	Melia azedarach	This tree has attractive flowers but readily invades many different habitats and spreads aggressively.	Western Soapberry (Sapindus saponaria var. drummondii) – attractive small to medium tree; grows up to 30 ft tall; fast growing; tolerates poor soils; often suckers and forms groves
			Carolina buckthorn ((Rhamnus caroliniana) - large shrub to small tree; grows up to 25 ft tall; shade and sun tolerant; tolerates variety of site conditions
Chinese tallow	Triadica sebifera	This fast-growing tree has attractive fall foliage but readily invades many different habitats and spreads aggressively.	Sycamore (Platanus occidentalis) – drought tolerant tree that grows quickly and can grow in difficult sites; grows up tp 100 ft tall; bark can be an attractive feature
			Texas red oak (Quercus buckleyi) - small to medium tree; grows up to 20 ft tall; beautiful fall foliage; moderate to fast growth rate
Elephant ears	Alocasia species, Colocasia species	This widely available plant prefers the water's edge and is known to invade streams and other natural riparian areas.	Pickerelweed (Pontederia cordata) – aquatic perennial with blue hyacinth-like flowers that bloom through the summer
			Arrowhead (Sagittaria latifolia) – aquatic emergent perennial with arrowhead shaped leaves; flowers have showy white petals
Giant cane, Georgia cane	Arundo donax	This very tall member of the grass family forms dense stands along waterways and is very difficult to control.	Yaupon holly (Ilex vomitoria) – typically a multi-trunked shrub or small tree, grows 12-25 ft tall; tolerates drought & poor drainage; can form a good hedge when densely planted
Golden Bamboo	Phyllostachys aurea	This very tall member of the grass family is commonly used as a hedge, but it is extremely difficult to contain and spreads readily in all directions.	Yaupon holly (Ilex vomitoria) – typically a multi-trunked shrub or small tree, grows 12-25 ft tall; tolerates drought & poor drainage; can form a good hedge when densely planted
Mexican petunia	Ruellia brittoniana	This well-known landscape plant is drought tolerant but readily invades streambanks and other riparian areas. It is very difficult to control.	Pickerelweed (Pontederia cordata) – aquatic perennial with blue hyacinth-like flowers that bloom through the summer
			Blue curls (Phacelia congesta) – leafy annual or biennial which grows 1-3 ft tall; numerous purple to lavender-blue, bell-shaped flowers, in coiled clusters which uncurl as the buds develop; usually found in large colonies
Nandina, Sacred bamboo	Nandina domestica	This common landscape plant has attractive fall foliage and berries but is known to invade woodlands and other natural areas.	Barbados cherry, Wild crapemyrtle (Malpighia glabra) – this shrub (3-6 feet tall); attractive pink flowers April to October followed by large, bright red fruit; can form a good hedge when densely planted
Privet	Ligustrum species	Multiple species exist and are readily available in the nursery trade. This species is known to aggressively invade woodlands and other natural areas.	Blackhaw (Viburnum prunifolium) – shrub or small tree 12-15 ft tall, sometimes growing to 30 ft; white flower clusters followed by yellow berries turning blue-black; attractive, dark-green foliage becomes reddish-purple in fall
			Texas mountain-laurel (Sophora secundiflora) – usually a multi-trunked shrub or small tree; grows up to 30 ft tall; dense, dark green evergreen foliage; fragrant and showy bluish-lavender flowers in drooping clusters

APPENDIX J

COIR FIBER MATTING TECHNICAL SPECIFICATIONS

Description

Coir Fiber Matting will be used as erosion control matting will consist of coir fiber matting to be installed in locations specified in the plans. Locations will primarily be on newly restored streambanks. Other areas may also require the placement of coir fiber matting as shown on the plans or as directed by the Engineer.

Methods and Materials

The Coir Fiber Matting shall be amachine-produced mat conform to the following specifications:

Matrix	100% Coconut Fiber
Weight	20 oz/SY
Tensile Strength	1348 x 626 lb/ft minimum
Elongation	34% x 38%
Open Area (measured)	50%
Max Flow Velocity	11 ft/sec
Size	6.6 x 164 ft (120 SY)
“C” Factor	0.002

Property	**Test Method**	**Typical**
Thickness	ASTM D5199/ECTC	0.30 in minimum
Resiliency	ECTC Guidelines	85%
Mass per Unit Area	ASTM D5261	10.72 oz/SY
Water Absorption	ASTM D1117/ECTC	155%
Swell	ECTC Guidelines	40%
Stiffness/Flexibility	ASTM D1388/ECTC	0.11 oz-in
Light Penetration	ECTC Guidelines	16.40%
MD Tensile Strength	ASTM D5035	342.00 lbs/ft
MD Elongation	ASTM D5035	7.60%
TD Tensile Strength	ASTM D5035	222.00 lbs/ft
TD Elongation	ASTM D5035	11.1%

Small Matting Stakes - Small matting stakes shall be made from hardwood not less than 12 inch length with a notch cut 1 inch from the top. These stakes shall be used to stake the matting along the slopes and spaced approximately one (1) foot apart.

Large Matting Stakes - Large matting stakes shall be hardwood stakes to be used to secure the matting at the toe of slope, seams and in the center of the matting. The large wooden stakes shall have a minimum 1.5-inch by 1.5-inch cross-section and shall taper to a point, and shall be a minimum length of two (2) feet. These stakes shall have a 2.5 inch galvanized roofing nail driven through the square end of the stake so that 0.5 inches of nail is extruding from both sides of the stake. The nail is to be installed in the large stakes so the matting will not slide past the exposed end of the stake. Large stakes shall be spaced a minimum of 18 inches apart.

Provide a smooth soil surface free from stones, clods, or debris that will prevent the contact of the matting with the soil. Place the matting immediately upon final grading. Take care to preserve the required line, grade, and cross section of the area covered. Apply fertilizer, temporary and permanent seed, mulch and lime prior to installing matting.

Unroll the matting and apply without stretching such that it will lie smoothly but loosely on the soil surface. Bury the top slope end of each piece of matting in a narrow trench at least 6 inches deep and tamp firmly. Where one roll of matting ends and a second roll begins, overlap the end of the upper roll over the buried end of the second roll so there is a 6 inch overlap. Construct check trenches at least 12 inches deep every 50 feet longitudinally along the edges of the matting, or as directed by the Engineer. Fold over and bury matting to the full depth of the trench, close and tamp firmly. Overlap matting at least 6 inches where 2 or more widths of matting are installed side by side.

Place large stakes across the matting at ends, junctions, and check trenches approximately 1 foot apart.

Place large stakes along the toe and down the center of each strip of matting 36 inches apart. Place stakes along all lapped edges 1 foot apart. Refer to details in the plan sheets.

The Engineer may require adjustments in the trenching or staking requirements to fit individual site conditions.

Method of Measurement and Payment:

Coir Fiber Matting: **Square Yard (SY) installed**

IN-STREAM STRUCTURES TECHNICAL SPECIFICATIONS

Description

The work covered by this section consists of the construction of in-stream structures to stabilize streambanks and improve aquatic habitats and bedform diversity. The quantity of in-stream structures to be constructed will be affected by actual conditions that occur during the construction of the project. The type and quantity of structures may be increased or decreased at the direction of the Engineer. Such variations in quantity will not be considered as alterations in the details of construction or a change in the character of the work.

Methods and Materials

Geotextile Fabric - Work under this section consists of furnishing all labor, materials, equipment, supplies, supervision and tools, and performing all work necessary for installation of geotextile fabric used as “filter fabric” as shown on the plans.

Geotextile fabric shall be non-woven geotextile fabric (also referred to as "filter fabric" herein and on the plans) shall be Type 2 non-woven, stabilized to provide resistance to ultra-violet degradation and meet the following specifications for flow rates, strength, and permeability:

Property	Test Method	Minimum Specifications	
		English	Metric
Weight	ASTM D3776	8.0 oz/yd	248.03 g/m
Grab Tensile	ASTM D4632	200.0 lb	90.72 kg
Puncture	ASTM D4833	130.0 lb	58.97 kg
Flow Rate	ASTM D4491	80.0 gal/min	0.47 l/s/sm
Permittivity	ASTM D4491	1.5 l/sec	
UV Resistance	ASTM D4355	70%	

Nails - Nails used for fastening the geotextile fabric to the log sills shall be plastic cap galvanized or aluminum roofing nails of sufficient length to securely fasten the fabric to the logs.

Stone - The work covered by this section consists of furnishing, stockpiling, placing and maintaining an approved stone to be utilized to construct in-stream structures and for use in other practices specified herein and/or as directed by the Engineer. This work includes all labor, materials, equipment, supplies, supervision, tools, etc. necessary for the installation of stone as shown on the plans.

Stone shall consist of blasted granite quarry stone stockpiled on-site and approved by the Engineer. It shall be composed of clean, tough, durable fragments free from fines, organic matter and deleterious substances. The stone shall be sound, tough, dense, resistant to the action of air and water, and suitable in all other respects for the purpose intended. Gravel sized stone shall be composed of clean, tough, durable fragments free from fines, organic matter and deleterious substances. The stone shall be native to the area and of approved color.

All stone shall meet the approval of the Engineer. The size of an individual stone particle will be determined by measuring its long dimension.

CLASS	**REQUIRED STONE SIZE (INCHES)**		
	MINIMUM	AVERAGE	MAXIMUM
GRAVEL (Washed Stone #57)	0.25	0.5	1.5
CLASS A	2	4	6
CLASS B	5	8	12
CLASS II	6	10	14
BOULDERS (Length" X Width" X Height")	varies	varies	varies

No more than 5.0% of the material furnished can be less than the minimum size specified. No more than 10.0% of the material can exceed the maximum size specified. The Contractor shall place stone in locations shown on the plans or as directed by the Engineer, to the thickness, widths, and lengths as shown on the plans and described in the specifications and details, or directed by the Engineer.

All stone shall be placed in accordance with the plans, neatly and uniformly, and shall meet the approval of the Engineer.

Stone backfill shall be composed of a well-graded mix of on-site alluvium, if available, and if approved by the Engineer. Otherwise, a well-graded mix of Class A, Class B and Washed Stone #57 shall be used. Appropriate on-site alluvium consists of a naturally occurring mix of cobble, gravel and sand, with the cobble and gravel sized materials dominating the mix. Appropriate on-site alluvium is preferred over quarried rock for stone backfill. All of the suitable on-site alluvium shall be exhausted at the direction of the Engineer prior to using quarried rock. Stone backfill may contain small amounts of fine aggregate, but may not contain soil materials.

Large stone backfill shall be composed of a well-graded mix of larger on-site alluvium, if available, and if approved by the Engineer. Otherwise, a well-graded mix of Class A, Class B and Class II Stone shall be used. Appropriate larger on-site alluvium consists of a naturally occurring mix of large cobble and large gravel, with the large cobble sized materials dominating the mix. Appropriate on-site alluvium is preferred over quarried rock for stone backfill. All of the suitable on-site alluvium shall be exhausted at the direction of the Engineer prior to using quarried rock. Stone backfill may not contain soil materials.

Header rocks and footer rocks shall be boulder sized stone.

The Contractor shall arrange for Engineer to observe and approve stone at its source prior to delivery to the project site. The scheduling of the delivery of stone should be carefully coordinated to ensure that adequate supplies of both are on site at all times such that construction progress is not delayed. Contractor is responsible for making all necessary arrangements with the source of supply in order to insure an adequate supply of stone such that the work will not be unnecessarily delayed due to insufficient supply of such materials on site. Delivery of a large excess of stone is discouraged, as Contractor shall be responsible for disposal of all stone not incorporated into the project as directed by Engineer. Contractor shall not be granted an extension of time or extra compensation due to delay caused by supply, delivery, or provision of, or sampling, testing, approval or disapproval of stone under the requirements of these specifications.

All stone shall be safely delivered, stockpiled, stored, and handled such that at no times the stockpiles are unstable or subject to collapse, rolling, or other movement that might pose threat to the safety of those in the vicinity of such stockpiles.

Stone should not be delivered, stockpiled, or otherwise handled when weather or site conditions are such that equipment delivering or handling the stone causes excessive rutting, pumping, erosion or other damage to the soils, site construction entrances, haul roads, or staging and stockpile areas.

Logs and Root Wads - Logs and root wads for in-stream structure construction will be harvested on-site and only native hardwood species will be utilized. On-site root wads will be selected by the Engineer. The tree shall have been alive when recently removed from the ground. Logs shall be cut approximately 15 to 20 feet in length based on the channel dimensions as shown on the construction documents and as directed by the Engineer. Root wads shall consist of the root mass and at least 8 feet of trunk. Tree basal diameter shall be a minimum of 10 inches. Root mass shall be dense and at least 2 feet in diameter. All branches and limbs shall be pruned to and completely removed from the surface of the log and shall have all of the original bark intact except for that removed during the course of normal harvesting, handling, and installation activities. The ends of all logs and root wads shall have the ends cut off square and blunt.

The supply of native hardwood trees removed from the project site that meet the proper specifications as outlined here, shall be exhausted for the construction of in-stream structures prior to using such logs from an off-site source. Once this requirement is satisfied, specified logs obtained from off site may be utilized as required to supplement those obtained on site for the purpose of constructing in-stream structures.

Weather Limitations - Proceed with installations only when existing weather conditions permit to be performed according to manufactures' written instructions and warranty requirements.

Field Measurements and Surveys - Verify each in-stream structure type, size, orientation, location, and elevation by field measurements and surveying prior to and during installations.

Contractor shall:

- Verify the suitability of substrates where the in-stream structures are to be installed.
- Verify with Engineer that the in-stream structures are at the location and grade indicated on the plans and profiles.
- Verify that all materials, including stone, logs, geotextile fabric, nails, coir fiber matting and stakes, temporary and permanent seed, all specified soil amendments, and mulching, are on site prior to beginning the construction of any in-stream structures.
- Identify and quantify, where feasible, the existing materials at the project site, if any prior to beginning construction, as well as throughout construction, including stone, logs, and/or root wads, that meet the requirements specified above and are otherwise suitable for use in the construction of in-stream structures.
- Use an excavator with a hydraulic thumb for the installation of the in-stream structures. The excavator and all appurtenances shall be of sufficient size and condition to perform the work.

Header and footer rocks shall be hand selected for each in-stream structure to provide the best possible fit as directed by Engineer.

Footer rocks shall be placed at the bottom and downstream side of the trench toward the thalweg (deepest portion) of the channel and shall abut one another. Footer rocks shall be firmly embedded into the stream bottom substrate.

Each in-stream structure is to be installed such that the top of the header rock or log at the center of the channel is at an elevation equal to the proposed thalweg elevation for the station where that given in-stream structure is located, unless otherwise directed by Engineer. Header rocks shall be placed directly on the footer rocks and fit snugly against each other. The header rocks shall be set back from their supporting footer rocks such that water flowing over the top of the header rock splashes down onto the top of the exposed supporting footer rocks. The intent of this arrangement is to prevent scour at the toe of the footers. Care should be taken when placing header rocks such that the seams between the header rocks do not line up with the seams between the footer rocks.

If the bedrock is present in the area of installation, footer rocks shall still be required unless approval for elimination of footer rocks is obtained from Engineer. For example, where bedrock is friable and weathered and can be trenched with the excavator, footer rocks will be required. In areas where bedrock is resistant and blasting would be required, Engineer shall determine whether or not to eliminate footer rocks.

In the event where installation of the structure arm may damage tree roots, excavation shall be minimized. This may include reducing the length of the structure arm or eliminating trenching for footer rocks or stone. This decision shall be field determined and as directed by Engineer.

All in-stream structures shall be constructed such that there are no gaps between the rocks except for the j-hook vanes. Gaps between the header and footer rocks in the "J" section for j-hook vanes are desired and should be installed at the direction of the Engineer. Gaps between the only the header rocks in the "J" section of the for grade control j-hook vanes are desired and should be installed at the direction of the Engineer.

All in-stream structures shall have sills securely installed where they tie into the proposed streambank to prevent the possibility of water diverting around the structure's arm(s).

At the direction of the Engineer, Contractor shall hand place small rocks or stones along the upstream face a structure to plug (chink) the voids between the rocks or logs prior to placing the geotextile fabric and stone backfill.

The installation of geotextile fabric shall always occur on the upstream side of a structure to create a "sealed" structure. This will prevent sediment loss and stream flow through the header and/or footer rocks that could otherwise compromise the structure. The installation of geotextile fabric shall be in accordance with the following procedures:

- For rock structures, the fabric shall be placed a minimum of 8 inches along the top of the header rock, down the upstream face of the structure to below the footer rocks and upstream a minimum of 10 feet. After placement of the fabric, the trench behind the header and footer rocks can be backfilled with stone backfill. Care shall be taken to secure the fabric in place during the placement of the stone backfill in order to prevent the fabric from being pulled out of position by the weight of the stone backfill.
- For log structures, the geotextile fabric is secured to the log using roofing nails spaced evenly along the log, no further than 12-inches apart along the horizontal with a minimum of two rows opposite each other. After secure placement of the fabric, the trench behind the logs can be backfilled. Care shall be taken to secure the fabric in place during the placement of the stone backfill in order to prevent the fabric from being pulled out of position by the weight of the stone backfill.

Stone backfill shall be placed a minimum of ten feet upstream of the header and footer rocks and logs. The stone backfill shall be placed to the proposed invert elevation shown on the Construction Drawings.

All disturbed or fill materials shall be compacted to a density comparable to the adjacent, undisturbed material unless otherwise directed by Engineer. The preferred location for sod and other vegetation transplants shall be planted where the in-stream structures interface with the newly constructed streambanks, unless otherwise directed by Engineer.

Rock Vane

1.Rock vanes are used for streambank protection and in-stream habitat.

2.The rock vane shall be constructed by installing abutting courses of footer and header rock to form a straight arm in plan view. The arm shall be constructed at the outside of the meander bend in the outside third of the bottom width of the channel. The arm shall be constructed such that adjoining rocks in the arm slopes evenly upward from the elevations of the proposed streambed, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambank at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope. The vane arm shall be constructed such that it is angled 20 to 30 degrees from the stream bank towards the middle third of the bottom width of the channel, where the arm connects to the streambed.

3.The structures shall be constructed by first installing footer rocks on the channel bed under the footprint of the entire structure to establish a sound foundation on which to install header rocks. The footer rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks starting at the channel bed, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 4-7% to the end header rock resting at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope.

5.Adjacent to the outermost header rock, a rock sill shall be constructed where each vane arm ties into the proposed streambank at the bankfull elevation (or lower if directed by Engineer as described above) to prevent higher stream flows from cutting into the streambank and washing around the arm. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The voids in the structure shall be filled as described above.

7.The geotextile fabric shall be installed as described above.

8. The structure shall be backfilled with stone as described above.

Rock Cross Vane

1.Rock cross vanes shall be used for grade control, streambank protection, and in-stream habitat.

2.The rock cross vane shall be constructed by installing abutting courses of footer and header rock in a “U” formation in plan view. The header and footer rocks in the middle third of the bottom width of the channel shall be installed perpendicular the flow, to form an invert with the top of the header rock installed at the same elevation as the proposed streambed. The header and footer rocks in the left and right thirds of the bottom width of the channel shall be installed to form symmetrical arms that tie into the header invert. These arms shall be constructed such that adjoining rocks in the arms slope evenly upward from the elevation of the proposed streambed at the header invert, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambanks at the bankfull elevation. At the direction of Engineer, the structure arms may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slopes. Each arm of the vane shall be constructed such that it is angled 20 to 30 degrees from the stream bank towards the middle third of the bankfull channel, where the arms connect to the header invert. Contractor shall install an abutting course of rock footers and headers perpendicular to flow to create a sill at the widest point between the vane arms (at the downstream end of the vane). This sill shall be installed at the proposed bankfull elevation.

3.The structures shall be constructed by first installing footer rocks on the channel bed under the footprint of the entire structure to establish a sound foundation on which to install header rocks. The footer rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 4-7% to the end header rock resting at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope.

5.Adjacent to the outermost header rock, a rock sill shall be constructed where each vane arm ties into the proposed streambank at the bankfull elevation (or lower if directed by Engineer as described above) to prevent higher stream flows from cutting into the streambank and washing around the arm. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The voids in the structure shall be filled as described above.

7.The geotextile fabric shall be installed as described above.

8.The structure shall be backfilled with stone as described above.

Constructed Riffle

1.Constructed riffles are used for grade control and in-stream habitat.

2.The constructed riffle shall be installed at proposed riffle locations at the proposed streambed elevation as shown on the plans and profiles. The structure shall be constructed by first excavating the stream bed to the required depth of at least 16 inches.

3.Stone backfill shall be placed in the constructed riffles a minimum of 16 inches deep to form the riffle bed material. Care shall be given to ensure that the thalweg is in the center of the channel and not against the toe along the entire length of the constructed riffle.

Log Vane

1.Log vanes are used for streambank protection and in-stream habitat.

2.The log vane shall be constructed by installing parallel footer and header logs to form a straight arm in plain view. The arm shall be constructed at the outside of the meander bend in the outside third of the bottom width of the channel. The arm shall be constructed such that the log arm slopes evenly upward from the elevations of the proposed streambed, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambank at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope. The vane arm shall be constructed such that it is angled 20 to 30 degrees from the stream bank towards the middle third of the bottom width of the channel, where the arm connects to the streambed.

3.The structures shall be constructed by first installing a footer log on the channel bed under the footprint of the entire structure to establish a sound foundation on which to install the header log. The footer log shall be installed so that the header log overhangs the footer log toward the center of the channel to create a habitat pocket. The footer log shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer logs, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids between the logs and installation of the geotextile fabric and stone backfill. The footer log shall be buried below the streambed and into the streambank a minimum of 6 feet.

4.The header log shall be placed on top of the footer log at a slope of approximately 4-7% from the channel bed to the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope.

5.A boulder of suitable size and weight shall be set on top of the header log at the stream bed elevation to help anchor the log into the streambed. If the header log cannot be buried into the streambank a minimum of 6 feet, then boulders can be used to create a sill adjacent to the end of the header log where the vane arm ties into the proposed streambank at the bankfull elevation (or lower if directed by Engineer as described above) to prevent higher stream flows from cutting into the streambank and washing around the arm. This sill shall be constructed perpendicular from the streambank to extend a minimum of 5 feet, or all the way across the bankfull bench, whichever is greater.

6.A root wad can be installed below the header log to help lock the logs into the streambank as directed by the Engineer. Root wads shall be installed as described herein and as shown on the construction drawings.

7.The voids in the structure shall be filled as described above.

8.The geotextile fabric shall be installed as described above.

9. The structure shall be backfilled with stone as described above.

J-Hook Vane

1.Jj-hook vanes shall be used for streambank protection, and in-stream habitat.

2.The j-hook vane shall be constructed by installing abutting courses of footer and header rock in a “J” formation in plan view. The header and footer rocks in the middle third of the bottom width of the channel shall be installed perpendicular the flow, to form an invert with the top of the header rock installed at the same elevation as the proposed streambed. The header and footer rocks in the outside of the meander bend in the outside third of the bottom width of the channel shall be installed to form an arm that ties into the header invert. This arm shall be constructed such that adjoining rocks in the arms slope evenly upward from the elevation of the proposed streambed at the header invert, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambanks at the bankfull elevation. At the direction of Engineer, the structure arms may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slopes. This arm of the vane shall be constructed such that it is angled 20 to 30 degrees from the stream bank towards the middle third of the bankfull channel, where the arms connect to the header invert. Contractor shall install an abutting course of rock footers and headers perpendicular to flow to create a sill at the end of the vane arm (at the downstream end of the vane). This sill shall be installed at the proposed bankfull elevation. The header rock on this arm shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 4-7% to the end header rock resting at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope. The header and footer rocks in the inside of the meander bend in the inside third of the bottom width of the channel shall be installed to form an arm that ties into the header invert. This arm shall be constructed such that adjoining rocks in the arms slope evenly upward from the elevation of the proposed streambed at the header invert, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambanks at 1/4 to 1/3 the bankfull elevation. At the direction of Engineer, the structure arms may be constructed up to and tied into a different elevation in order to achieve the correct structure arm slopes. This arm of the vane shall be constructed such that it is slightly angled downstream from where it ties into the header invert as directed by the Engineer. Contractor shall install an abutting course of rock footers and headers perpendicular to flow to create a sill at the end of the vane arm (at the downstream end of the vane). This sill shall be installed at the same elevation as the end of adjacent vane arm. The header rock on this arm shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 1-2% to the end header rock resting at 1/4 to 1/3 the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into a different elevation in order to achieve the correct structure arm slope.

3.The structure shall be constructed by first installing footer rocks on the channel bed under the footprint of the entire structure to establish a sound foundation on which to install header rocks. The footer rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 4-7% on the arm on the outside of the meander bend to the end header rock resting at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope. Adjacent header rocks shall taper up at a slope of approximately 1-2% on the arm on the inside of the meander bend to the end header rock resting at 1/4 -1/3 the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into a different elevation in order to achieve the correct structure arm slope.

5.Adjacent to the outermost header rock, a rock sill shall be constructed where each vane arm ties into the proposed streambank to prevent higher stream flows from cutting into the streambank and washing around the arm. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The voids in the structure shall be filled as described above.

7.The geotextile fabric shall be installed as described above.

8.The structure shall be backfilled with stone as described above.

Grade Control J-Hook Vane

1.Grade control j-hook vanes shall be used for grade control, streambank protection, and in-stream habitat.

2.The grade control j-hook vane shall be constructed by installing abutting courses of footer and header rock in a “J” formation in plan view. The header and footer rocks in the middle third of the bottom width of the channel shall be installed perpendicular the flow, to form an invert with the top of the header rock installed at the same elevation as the proposed streambed. The header and footer rocks in the outside of the meander bend in the outside third of the bottom width of the channel shall be installed to form an arm that ties into the header invert. This arm shall be constructed such that adjoining rocks in the arms slope evenly upward from the elevation of the proposed streambed at the header invert, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambanks at the bankfull elevation. At the direction of Engineer, the structure arms may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slopes. This arm of the vane shall be constructed such that it is angled 20 to 30 degrees from the stream bank towards the middle third of the bankfull channel, where the arms connect to the header invert. Contractor shall install an abutting course of rock footers and headers perpendicular to flow to create a sill at the end of the vane arm (at the downstream end of the vane). This sill shall be installed at the proposed bankfull elevation. The header rock on this arm shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 4-7% to the end header rock resting at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope. The header and footer rocks in the inside of the meander bend in the inside third of the bottom width of the channel shall be installed to form an arm that ties into the header invert. This arm shall be constructed such that adjoining rocks in the arms slope evenly upward from the elevation of the proposed streambed at the header invert, in the downstream direction, towards the stream bank, where they shall tie into the proposed streambanks at 1/4 to 1/3 the bankfull elevation. At the direction of Engineer, the structure arms may be constructed up to and tied into a different elevation in order to achieve the correct structure arm slopes. This arm of the vane shall be constructed such that it is slightly angled downstream from where it ties into the header invert as directed by the Engineer. Contractor shall install an abutting course of rock footers and headers perpendicular to flow to create a sill at the end of the vane arm (at the downstream end of the vane). This sill shall be installed at the same elevation as the end of adjacent vane arm. The header rock on this arm shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 1-2% to the end header rock resting at 1/4 to 1/3 the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into a different elevation in order to achieve the correct structure arm slope.

3.The structure shall be constructed by first installing footer rocks on the channel bed under the footprint of the entire structure to establish a sound foundation on which to install header rocks. The footer rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks starting at the thalweg, working out and up towards the stream banks. Adjacent header rocks shall taper up at a slope of approximately 4-7% on the arm on the outside of the meander bend to the end header rock resting at the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into an elevation less than bankfull in order to achieve the correct structure arm slope. Adjacent header rocks shall taper up at a slope of approximately 1-2% on the arm on the inside of the meander bend to the end header rock resting at 1/4 -1/3 the bankfull elevation. At the direction of Engineer, the structure arm may be constructed up to and tied into a different elevation in order to achieve the correct structure arm slope.

5.Adjacent to the outermost header rock, a rock sill shall be constructed where each vane arm ties into the proposed streambank to prevent higher stream flows from cutting into the streambank and washing around the arm. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The voids in the structure shall be filled as described above.

7.The geotextile fabric shall be installed as described above.

8.The structure shall be backfilled with stone as described above.

Step Pool Channel

1.Step pool channels shall be used for grade control, streambank protection and in-stream habitat.

2.Step pool channels shall be constructed by installing abutting courses of footer and header rock perpendicular to the flow. The header and footer rocks in the center of the channel shall be installed perpendicular the flow, to form a step with the top of the header rock installed at the same elevation as the proposed streambed. The invert of this step shall be in the center of the channel and be 0.1-0.2 feet lower than the rest of the step. The header and footer rocks in the left and right of the step shall be installed to form the channel banks at a maximum slope of 2:1 as shown in the construction documents. Contractor shall install an abutting course of rock footers and headers perpendicular to flow to create a sill where the step ties into the streambank. This sill shall be installed at the proposed bankfull elevation. The pool sections downstream of the steps shall be excavated to the required depth for each reach and be rounded in shape and 1.3 times the top of bank width at the center of the pool. The center of the pool should be at least 0.5 feet deeper than the edges. The pool shall be undercut to a minimum of 8 inches to allow for stone. An 8 inch (minimum) layer of stone backfill shall be installed throughout the pool. The outer edges of the pool and the side slopes shall only have an 8 inch (minimum) layer of large stone backfill installed.

3.The steps shall be constructed by first installing footer rocks on the channel bed under the footprint of the entire structure to establish a sound foundation on which to install header rocks. The footer rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks starting at the invert, working out and up towards the stream banks. Footers shall be installed so that 1/4 – 1/3 of the length is downstream edge of the header rock to act as a splash rock.

5.Adjacent to the outermost header rock, a rock sill shall be constructed where the sill ties into the proposed streambank at the bankfull elevation (or lower if directed by Engineer as described above) to prevent higher stream flows from cutting into the streambank and washing around the arm. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The voids in the structure shall be filled as described above.

7.The geotextile fabric shall be installed upstream of each step as described above.

8.The steps shall be backfilled with stone as described above.

Double Wing Deflectors

1.Double wing deflectors are used for streambank protection, narrowing overly wide channels and creating in-stream habitat.

2.The double wing deflector shall be constructed by installing abutting courses of footer and header rock to form “D” shape adjacent to the streambanks in plain view. The double wing deflector shall be constructed in overly wide areas of stream and shall occupy the outside 1/3 of the bottom width of the channel on both sides. The double wing deflectors shall be constructed as 3 adjoining arms (arm x, arm y, arm z). Arm x shall be constructed such that adjoining rocks in the arm slopes evenly upward from 1/3-1/2 the bankfull elevation at the top of the rocks where arm x connects to arm y, in the downstream direction, towards the stream bank at 2-4% slope, where it shall tie into the proposed streambank. Arm y shall be constructed parallel to the flow such that adjoining rocks in the arm have zero slope and the top of the rocks are at 1/3-1/2 the bankfull elevation and the ends of arm y connect to arm x on its downstream end and arm z on its upstream end. Arm z shall be constructed such that the adjoining rocks in the arm have zero slope and connects on its downstream end to arm y and ties into the streambank on its upstream end. Arms x and z shall be constructed such that they are angled 20 to 30 degrees from the stream bank towards the center of the channel.

3.The structures shall be constructed by installing footer rocks on the channel bed under the footprint of arm x to establish a sound foundation on which to install header rocks and installing the rocks for arms y and z. Only arm x is footered. The rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks for arm x or on top of suitable substrate material for arms y and z.

5.Adjacent to the outermost header rocks or arms z and x, a rock sill shall be constructed where each vane arm ties into the proposed streambank to prevent higher stream flows from cutting into the streambank and washing around the arms. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The structure shall be backfilled with stone backfill as directed by the Engineer.

7.The voids in the structure shall be filled as described above.

8.The geotextile fabric shall be installed as described above.

Single Wing Deflectors

1.Single wing deflectors are used for streambank protection, narrowing overly wide channels and creating in-stream habitat.

2.The single wing deflector shall be constructed by installing abutting courses of footer and header rock to form "D" shape adjacent to the streambank in plain view. The single wing deflector shall be constructed in overly wide areas of stream and shall occupy the outside 1/3 of the bottom width of the channel. The single wing deflectors shall be constructed as 3 adjoining arms (arm x, arm y, arm z). Arm x shall be constructed such that adjoining rocks in the arm slopes evenly upward from 1/3-1/2 the bankfull elevation at the top of the rocks where arm x connects to arm y, in the downstream direction, towards the stream bank at 2-4% slope, where they shall tie into the proposed streambank. Arm y shall be constructed parallel to the flow such that adjoining rocks in the arm have zero slope and the top of the rocks are at 1/3-1/2 the bankfull elevation and the ends of arm y connect to arm x on its downstream end and arm z on its upstream end. Arm z shall be constructed such that the adjoining rocks in the arm have zero slope and connects on its downstream end to arm y and ties into the streambank on its upstream end. Arms x and z shall be constructed such that they are angled 20 to 30 degrees from the stream bank towards the center of the channel.

3.The structures shall be constructed by installing footer rocks on the channel bed under the footprint of arm x to establish a sound foundation on which to install header rocks and installing the rocks for arms y and z. Only arm x is footered. The rocks shall be installed by excavating a trench large enough to accommodate the installation of both the header and footer rocks, as well as an area upstream of the perimeter of the structure large enough to accommodate plugging of any voids in the structure rock and installation of the geotextile fabric and stone backfill. At the direction of Engineer, two or more parallel, abutting rows of footer rocks may be required, depending upon the nature of the rock and/or the streambed material.

4.The header rock shall be placed on top of the footer rocks for arm x or on top of suitable substrate material for arms y and z.

5.Adjacent to the outermost header rocks of arms z and x, a rock sill shall be constructed where each vane arm ties into the proposed streambank to prevent higher stream flows from cutting into the streambank and washing around the arms. This sill shall be constructed perpendicular from the streambank to extend a minimum of 6 feet, or all the way across the bankfull bench, whichever is greater.

6.The structure shall be backfilled with stone backfill as directed by the Engineer.

7.The voids in the structure shall be filled as described above.

8.The geotextile fabric shall be installed as described above.

Root Wads

1.Root wads are used for streambank protection and in-stream habitat.

2.Root wads shall be a minimum of 10 feet long and the trunk shall be a minimum of 10 inches in diameter. The root mass shall be a minimum of 2 feet in diameter. The root wads shall be constructed by one of two methods:

Drive Point Method

Sharpen the end of the trunk with a chainsaw before driving it into the bank. Orient the root wad upstream so that the stream flow meets the root wad at a 90 degree angle, deflecting the flow away from the bank. The root wad shall be installed so that 1/2 the trunk thickness and root mass is below the streambed.

Trenching Method

If the root wad cannot be driven into the bank of the bank needs to be reconstructed, the trenching method shall be used. This method requires that a trench be excavated for the log portion of the root wad. A footer log shall be installed underneath the root wad in a trench excavated parallel to the streambank and below the streambed. The root wad shall be installed so that 1/2 the trunk thickness and root mass is below the streambed.

Transplants shall be installed on the streambank to anchor the root wad and to protect the streambank as directed by the Engineer.

In-stream structures shall be constructed in accordance with the respective details. The work for each includes the excavation, placement of rock, wood, and all other materials, and backfill associated with the installation of in-stream structures.

The Engineer may adjust the excavation limits to improve the channel foundation conditions during construction.

Excavated material shall be placed on the upstream side of the structures or transported to a stockpile location as directed by the Engineer.

Unless otherwise approved by the Engineer, excavation to prepare subgrade for the installation of in-stream structures shall be consecutive and continuous. Once the excavation of a structure has begun, the structure will be completed by the end of the workday. All equipment shall be removed from the stream at the end of each workday.

Any accumulation of sediment in the channel shall be cleaned as needed during construction and at the end of construction as directed by the Engineer.

Contractor and Engineer shall observe all in-stream structures during normal stream flow conditions. Contractor shall adjust rock, logs, root wads, stone or any other items as directed by Engineer before such structures will be considered complete.

Method of Measurement and Payment:

Geotextile Fabric: **Incidental to each in-stream structure**

Nails: **Incidental to each in-stream structure**

Stone: **Incidental to each in-stream structure**

Rock Vane: **Per each (EA) installed**

Rock Cross Vane: **Per each (EA) installed**

Constructed Riffle: **Per each (EA) installed**

Log Vane: **Per each (EA) installed**

J-hook Vane: **Per each (EA) installed**

Grade Control J-hook Vane: **Per each (EA) installed**

Step Pool Channel: **Per each (EA) installed**

Double Wing Deflectors: **Per each (EA) installed**

Single Wing Deflectors: **Per each (EA) installed**

Rootwads: **Per each (EA) installed**

TRANSPLANTED VEGETATION TECHNICAL SPECIFICATIONS

Description

The work shall consist of the removal, handling, storage, transport, and replanting of available on-site native species vegetative material for the purpose of streambank stabilization and enhancement of stream habitat.

Methods and Materials

The Contractor shall provide a rubber tired or track loader for the excavation, transport and installation of transplanted vegetation. The Contractor must have approval from the Engineer before using any other type of equipment for installing transplants.

Shrub and trees less than 3 inches in diameter shall be salvaged on-site in areas designated for construction, access areas, and other sites that will necessarily be disturbed. Vegetation to be transplanted will be identified by the Engineer. Transplanted vegetation shall carefully be excavated with rootballs and surrounding soil remaining intact. Care shall be given not to rip limbs or bark from the shrub and tree transplants. Vegetation should be transplanted immediately, if possible. Otherwise, transplanted vegetation shall be carefully transported to designated stockpile areas and heeled-in in constantly moist soil or sawdust in an acceptable manner appropriate to weather or seasonal conditions. The solidity of the plants shall be carefully preserved. Individual transplants shall range in size from 0.5 to 2 square yards in size.

Installation of shrub and tree transplants shall be located in designated areas along the top of the stream bank or in floodplain restoration areas as directed by Engineer. Soil in the area of vegetation transplants shall be loosened to a depth of at least one foot. This is only necessary on compacted soil. Transplants shall be replanted to the same depth as they were originally growing. The planting trench or hole shall be deep and wide enough to permit the roots to spread out and down without J-rooting. The plant stem shall remain upright. Soil shall be replaced around the transplanted vegetation and tamped around the shrub or tree firmly to eliminate air pockets.

Spacing and location of vegetation transplants will be determined on-site by the Engineer.

Method of Measurement and Payment:

Transplanted Vegetation: **Per each (EA) installed**

LIVE STAKING TECHNICAL SPECIFICATION

Description

The work shall consist of the planting of live stakes on channel banks to be protected from erosion. The Contractor will be responsible for identifying a source for live stakes near the project site, collecting and delivering the live stakes to the project site, and installation of the live stakes. Staking must take place during the dormant season.

Methods and Materials

Live stakes may be of the following species:

Scientific Name	Common Name	% Planted By Species	Wetland Tolerance
Cephalanthus occidentalis	Buttonbush	10%	OBL
Salix nigra	Black Willow	10%	OBL
Salix sericea	Silky Willow	40%	OBL
Sambucus canadensis	Elderberry	40%	FACW-
Total		**100%**	

Live stake materials should be dormant and gathered locally or purchased from a reputable commercial supplier. Stakes should be ½ to 2 inches in diameter, 2 to 3 feet in length, and living based on the presence of young buds and green bark. Stakes shall be angled on the bottom and cut flush on the top with buds oriented upwards. All side branches shall be cleanly trimmed so the cutting is one single stem. Stakes should be kept cool and moist to improve survival and to maintain dormancy.

Harvesting and planting shall take place during the dormant season. Stakes should be installed approximately 2 feet apart along the stream banks throughout the channel sections. Live stakes shall be installed along streambanks above the base flow water surface elevation. Site variations may require slightly different spacing. Stakes shall be driven into the ground, through the coir fiber matting, using a rubber hammer or by creating a pilot hole and slipping the stake into it. The stakes should be tamped in at a right angle to the slope with 4/5 of the stake installed below the ground surface. At least two buds (lateral and/or terminal) shall remain above the ground surface. The soils shall be firmly packed around the hole after installations. Split stakes shall not be installed. Stakes that split during installations shall be replaced.

Method of Measurement and Payment:

***Live Staking:* Per each (EA) installed**

GEOLIFT TECHNICAL SPECIFICATIONS

Description

The work of "Geolift" covered by this section consists of preparation, excavation and installation of all materials required for proper installation of geolifts. Geolifts are revetment structures composed of stone, compacted soil, erosion control matting, geotextile materials, and live branch cuttings or whips used to increase bank stability.

Methods and Materials

The stone backfill used for construction the geolift shall be as specified herein.

The geotextile fabric used to construct geolifts shall be as specified herein. Fabric".

The live branch cuttings or whips shall be placed using live stake species as specified herein. Live branch cuttings or whips are made of slender woody material that range from 3/8 inch to 1 inch diameter and 5 foot to 10 foot lengths.

The coir fiber matting shall meet the material requirements as specified herein.

Soil and rock placed in the geolifts shall be free of debris and suitable for planting.

Geolifts shall preferably be installed during the dormant season when live branch cuttings or whips can be incorporated. Construction shall begin with the excavation of a trench for the stone key and the slope against which the geolift will be constructed. Lay geotextile fabric in the excavated trench as shown on the plans. Place stone backfill to form a relatively uniform surface up to the channel base flow elevation. Place layer of coir fiber matting over stone and place first lift of soil over the matting, leaving sufficient overlap on the matting to completely wrap the soil lift. Compact soil lifts using the excavator bucket. Wrap compacted soil lift with coir fiber matting. Install live branch cuttings or whips in between each lift using the brush layering installation technique specified herein. Live branch cutting bundles shall be installed at 5 linear feet per bundle approximately 2-3 branches thick. The basal ends of the live branch cuttings or whips shall contact the back of the excavated slope and shall extend 6 inches from the slope face. Construct subsequent lifts in similar fashion to reach design top of bank elevation. The face of the completed geolift shall match the design bank side slope.

If geolifts are not constructed in the dormant season, and live cuttings are not available during construction, geolifts shall be live staked on 1 foot by 1 foot spacing during the following dormant season.

Method of Measurement and Payment:

Geolift: **Per linear foot (LF) installed**

BRUSH MATTRESS TECHNICAL SPECIFICATIONS

Description

The work of “Brush Mattress” covered by this section consists of preparation, excavation and installation of all materials required for proper installation of brush mattresses. Brush Mattresses are composed of compacted soil, coir fiber matting, and live branch cuttings used to increase bank stability.

Methods and Materials

The live branch cuttings or whips shall be placed using live stake species as specified herein. Live branch cuttings or whips are made of slender woody material that generally range from 3/8 inch to 1 inch diameter and 5 foot to 10 foot lengths. Live branches shall be cut from fresh, green, healthy, dormant parent plants.

Coir fiber matting shall meet the material requirements as specified herein.

Soil and woody material placed in the brush mattress shall be free of debris and suitable for planting.

Brush Mattresses shall be placed on compacted backfill material, tied together using biodegradable twine or rope as approved by the Engineer, and staked into the bank as shown in plans. The dead stakes are required to secure the cuttings in place and prevent toe erosion at normal baseflow conditions. The toe of the brush mattress must be kept wet to ensure sprouting during the growing season. Live branch cuttings shall be oriented in criss-crossed layers in slight manmade depressions along the embankment. The butt ends shall alternate to provide a uniform mat thickness of at least 12 inches and a minimum percentage of air voids.

Once in position, the mattress shall be bound with biodegradable twine or rope and secured with 2-foot wooden dead stakes spaced at 3-foot maximum intervals. The twine shall be tied to notches in the stakes before they are driven into the ground; this allows for tension to develop in the twine when the stakes are driven, thereby pulling the mattress firmly to ground. Upon being bound and secured to the ground, the mattress shall be covered with alternating layers of soil and water until only a portion of the top layer of branches is exposed, but all butt ends must be covered. The use of alternating applications of soil and water helps to insure a proper soil-branch interface to initiate growth. The brush layer shall be covered with 3 inches of on-site soil material.

Immediately following delivery to the project site, all live branches, if not promptly installed, shall be heeled-in in constantly moist soil or sawdust in an acceptable manner corresponding to accepted horticultural practices or as specified in the vegetation planting specification herein.

Method of Measurement and Payment:

Brush Mattress: **Per square yard (SY) installed**

BRUSH LAYER TECHNICAL SPECIFICATIONS

Description

The work of "Brush Layer" covered by this section consists of preparation, excavation and installation of all materials required for proper installation of brush layers. Brush layers are composed of compacted soil, coir fiber matting, and live branch cuttings used in conjunction with other toe stabilization or bioengineering techniques to increase bank stability.

Methods and Materials

The live branch cuttings or whips shall be placed using live stake species as specified herein. Live branch cuttings or whips are made of slender woody material that range from 3/8 inch to 1 inch diameter and 5 foot to 10 foot lengths. Live branches shall be cut from fresh, green, healthy, dormant parent plants.

Coir fiber matting shall meet the material requirements as specified herein.

Soil and woody material placed in the brush layers shall be free of debris and suitable for planting.

Brush Layers shall be placed on compacted backfill material on horizontal benches, tied together using biodegradable twine or rope as shown in plans. The toe of the brush layer must be kept wet to ensure sprouting during the growing season. Live branch cuttings shall be oriented in criss-crossed layers in slight manmade depressions along the embankment. The butt ends shall alternate to provide a uniform mat thickness of at least 12 inches and a minimum percentage of air voids.

Once in position, the mattress shall be bound with the using biodegradable twine or rope and secured with 2-foot wooden dead stakes spaced at 3-foot intervals. The biodegradable twine or rope shall be tied to notches in the stakes before they are driven into the ground; this allows for tension to develop in the biodegradable twine or rope when the stakes are driven, thereby pulling the mattress firmly to ground. Upon being bound and secured to the ground, the brush material shall be covered with alternating layers of soil and water until only a portion of the top layer of branches is exposed, but all butt ends must be covered. The use of alternating applications of soil and water helps to insure a proper soil-branch interface to initiate growth. The brush layer shall be covered with 3 inches of on-site soil material.

Immediately following delivery to the project site, all live branches, if not promptly installed, shall be heeled-in in constantly moist soil or sawdust in an acceptable manner corresponding to accepted horticultural practices or as specified in the vegetation planting specification herein.

Method of Measurement and Payment:

Brush Layer: **Per square yard (SY) installed**

LIVE FASCINE TECHNICAL SPECIFICATIONS

Description

The work of “Live Fascine” covered by this section consists of preparation, excavation and installation of all materials required for proper installation of fascines. Live fascines are composed of live branch cuttings bundled together used in conjunction with other toe stabilization or bioengineering techniques to increase bank stability.

Methods and Materials

The live branch cuttings bundles shall be placed using live stake species as specified herein. Live branch cuttings are made of long woody material that range from 3/8 inch to 1 inch diameter and 5 foot to 20 foot lengths depending on site conditions.

Live branch cuttings shall be tied together using biodegradable twine or rope at a thickness of 6 to 8 inch diameter. The fascine should be placed in a shallow trench 12 to 18 inches as shown on the plans.

Once in position, the live fascines shall be bound with biodegradable twine or rope and secured with 2-foot wooden dead stakes spaced at 3-foot maximum intervals. The twine shall be tied to notches in the stakes before they are driven into the ground; this allows for tension to develop in the twine when the stakes are driven, thereby pulling the fascine firmly to ground. Upon being bound and secured to the ground, the fascine shall be covered with alternating layers of soil and water until only a portion of the top layer of branches is exposed, but all butt ends must be covered. The use of alternating applications of soil and water helps to insure a proper soil-branch interface to initiate growth. The fascine shall be covered with 3 inches of on-site soil material.

Immediately following delivery to the project site, all live branches, if not promptly installed, shall be heeled-in in constantly moist soil or sawdust in an acceptable manner corresponding to accepted horticultural practices or as specified in the vegetation planting specification herein.

Method of Measurement and Payment:

Live Facine: **Per linear foot (LF) installed**

TOE WOOD TECHNICAL SPECIFICATIONS

Description

The work of "Toe Wood" covered by this section consists of preparation, excavation and installation of all materials required for proper installation of toe wood.

Toe wood structures are revetment structures composed of woody material, compacted soil, and coir fiber matting used to increase bank stability. Brush layering may incorporated when constructed during the dormant season or when dormant cuttings can be obtained.

Methods and Materials

Coir fiber matting shall meet the material requirements as specified herein.

Logs shall meet the requirements specified herein.

Large stone backfill shall meet the requirements specified herein.

Geotextile fabric shall meet the requirements as specified herein.

Live fascines shall meet the requirements as specified herein.

The Contractor shall place a trench 18 inches below the bed elevation of the channel, using large stone backfill as specified to provide a stable platform/base. On top of the base, build up woody material and/or brush packed in tight and consisting of a mix of sizes so that space within the revetment is well filled. Filler material should be hardwood to the maximum extent possible. This material shall extend into the channel but shall not occupy more than 1/3 of the submerged area. Space should be well filled with wood material and all woody material should be at or below the normal water level, so that it stays covered by water to minimize decay.

The top surface of the woody fill material should be dense enough to support soil back fill. Woody material may need to be held down, so that it does not float, using a temporary weight so that a 1 inch layer of back fill can be placed on the woody fill material to provide soil contact for a layer of dormant live brush cuttings (brush layering). This is only done when dormant cuttings are available.

Dormant cuttings shall be placed on top of the fill material to form brush layering as detailed in the plans that are at and just above the normal water level. Fill on top of the live branches (or woody material/brush if live branches are not available) should be accomplished with one or more soil lifts wrapped in coir fiber matting according to the toe wood detail. Soil lifts shall be constructed as described in the Geolift specification.

When dormant live cuttings are not available during construction of the structure, toe wood structures shall be live staked on 1 foot by 1 foot spacing during the following dormant season.

Method of Measurement and Payment:

Toe Wood: **Per linear foot (LF) installed**

TOE WOOD. Toe wood structures are revetment structures composed of woody material, compacted soil, and coir fiber matting used to increase bank stability. Brush layering may incorporated when constructed during the dormant season or when dormant cuttings can be obtained. Coir fiber matting shall meet the material requirements as specified in 157-2.12, Coir Fiber Matting. Logs and stone shall meet the requirements designated in this specification. Filter fabric shall meet the requirements as specified in Section 152-2.2.

The Contractor shall place a trench 18 inches below the bed elevation of the channel, using larger material as necessary to provide a stable platform/base. On top of the base, build up woody material and/or brush packed in tight and consisting of a mix of sizes so that space within the revetment is well filled. Filler material should be hardwood if possible. This material shall extend into the channel but shall not occupy more than 1/3 of the submerged area. Space should be well filled with wood material and all woody material should be at or below the normal water level, so that it stays covered by water to minimize decay.

The top surface of the woody fill material should be dense enough to support soil back fill. Woody material may need to be held down, so that it does not float, using a temporary weight so that a 1 inch layer of back fill can be placed on the woody fill material to provide soil contact for a layer of dormant live brush cuttings (brush layering). This is only done when dormant cuttings are available.

Dormant cuttings shall be placed on top of the fill material to form brush layering as detailed in the plans that are at and just above the normal water level.

Fill on top of the live branches (or woody material/brush if live branches are not available) should be accomplished with one or more soil lifts wrapped in coir fiber matting according to the toe wood plan detail. Soil lifts shall be constructed as described in the Geolift specification.

When dormant live cuttings are not available during construction of the structure, toe wood structures shall be live staked on 1 foot by 1 foot spacing during the following dormant season.

APPENDIX K

U.S. Army Corps of Engineers (USACE)
Fort Worth District

Annual Monitoring Report Form

This form includes the required elements of an annual monitoring report for compensatory mitigation projects, mitigation bank sites, and in-lieu fee project sites in accordance with the final rule on compensatory mitigation published April 10, 2008 (see 33 CFR 332.6) and Regulatory Guidance Letter 08-03 published October 10, 2008. Please consult instructions included at the end prior to completing this form.

Contents

BACKGROUND FOR ANNUAL MONITORING REPORTS

The final rule on compensatory mitigation states the following (see 33 CFR 332.6):

Monitoring the compensatory mitigation project site is necessary to determine if the project is meeting its performance standards, and to determine if measures (i.e., remedial actions) are necessary to ensure that the compensatory mitigation project is accomplishing its objectives. The submission of monitoring reports to assess the development and condition of the compensatory mitigation project is required, but the content and level of detail for those monitoring reports must be commensurate with the scale and scope of the compensatory mitigation project, as well as the compensatory mitigation project type. The mitigation plan must address the monitoring requirements for the compensatory mitigation project, including the parameters to be monitored, the length of the monitoring period, the party responsible for conducting the monitoring, the frequency for submitting monitoring reports to the district engineer, and the party responsible for submitting those monitoring reports to the district engineer.

The district engineer must determine the information to be included in monitoring reports. This information must be sufficient for the district engineer to determine how the compensatory mitigation project is progressing towards meeting its performance standards, and may include plans (such as as-built plans), maps, and photographs to illustrate site conditions. Monitoring reports may also include the results of functional, condition, or other assessments used to provide quantitative or qualitative measures of the functions provided by the compensatory mitigation project site.

The permittee or sponsor is responsible for submitting monitoring reports in accordance with the special conditions of the Department of the Army permit or the terms of the instrument. Failure to submit monitoring reports in a timely manner may result in compliance action by the district engineer.

Monitoring reports must be provided by the district engineer to interested federal, tribal, state, and local resource agencies, and the public, upon request.

Part I: Project Overview

Box 1 Project or Mitigation Bank Name:	**USACE Permit Number (if applicable):**

Box 2 Name of Party Responsible for Conducting Monitoring:		
Title:	**Company:**	
Mailing Address:		
E-mail Address:		
Work Phone with area code	**Fax #**	**Cell Phone #**
Date(s) Monitoring was Conducted (mm/dd/yyyy):		

Box 3 Briefly describe the purpose of the approved project:
Is the permittee in compliance with all permit conditions (if applicable)? ☐ Yes ☐ No **Explain:**
Describe the acreage or linear feet and type of aquatic resources impacted by the approved project (if applicable):
Describe the mitigation acreage or linear feet and type of aquatic resources authorized to compensate for aquatic impacts:
Describe any schedule changes for the approved project and/or the compensatory mitigation project (if applicable):

Box 4 Describe the mitigation project location, including any identifiable landmarks on the site and information to locate the site perimeter(s):
Latitude and longitude of the mitigation site (Decimal Degrees):

Box 5 Date(s) the compensatory mitigation project commenced and/or was completed:

Box 6 Are the performance standards being met: ☐ Yes ☐ No

Box 7 Summarize the activities that occurred since the previous report submission, including the progress of authorized work (if applicable), the progress of mitigation activities, and the date(s) of any recent corrective or maintenance activities conducted:

Box 8 Describe any specific recommendations for any additional corrective or remedial actions that the USACE should consider and approve prior to initiation:

Part II: Requirements

Box 9 List the monitoring requirements and performance standards (as specified in the approved mitigation plan, mitigation banking instrument, or special conditions of the Department of the Army permit):

Evaluate whether the compensatory mitigation project site is successfully achieving the approved performance standards or trending toward success:

Has a table been included for comparing the performance standards to the conditions and status of the developing mitigation site? (see instructions)

☐ Yes, Attached ☐ No

Part III: Summary Data

Box 10 Summary data should be provided to substantiate the success and/or potential challenges associated with the compensatory mitigation project (see instructions)

Describe the baseline conditions of the mitigation area (initial report only):

Has photo documentation been provided to support the findings and recommendations referenced in the monitoring report and to demonstrate whether the compensatory mitigation project is meeting applicable performance standards?

☐ Yes, Attached ☐ No

Have the results of functional, condition, or other assessments (e.g., tree/shrub planting survival, herbaceous ground cover) used to provide quantitative or qualitative measures of the functions provided by the compensatory mitigation project site been included?

☐ Yes, Attached ☐ No

Part IV: Maps and Plans

Box 11 Indicate if maps have been provided to show the location of the compensatory mitigation site in relation to the following (see instructions)**:**

	Included in Attachment D
Landscape Features	☐
Habitat Types	☐
Photograph Reference Points	☐
Transects/Sampling Data Points	☐
Other Features	☐

Have as-built plans been included in Attachment D? ☐ Yes ☐ No

Part V: Conclusions

Box 12 Summarize the conditions of the compensatory mitigation project:

If performance standards are not being met, provide a brief explanation of the difficulties and potential remedial actions proposed: **Provide a timetable/schedule for the proposed remedial actions:**
Provide any additional information or comments for the USACE to consider:

Part VI: Mitigation Bank Items (for mitigation banks only)

Box 13 Provide a summary of the credit transactions for the previous year, including the beginning and ending balance of available credits: **Has an annual ledger report been included (see instructions)?** ☐ Yes ☐ No
For financial assurances and long-term management funding, provide an accounting of the beginning and ending balances for the previous year including any deposits and withdrawals: **Provide information on the amount of required financial assurances, including an assessment of the adequacy of this amount and any proposed adjustments or releases:** **Provide information on the status of the financial assurances, including their potential expiration:**
Provide any additional monitoring information required by the Mitigation Banking Instrument:

Part VII: Attachments

	Included
A. Table Comparing Performance Standards to Conditions of Mitigation Site	☐
B. Color Photographs	☐
C. Assessment Results	☐
D. Maps and Plans	☐
E. Annual Mitigation Bank Ledger Report	☐
F. Other:	☐

End of Form

Instructions: [please do not include these pages when submitting form]

1) The content and schedule for monitoring reports should follow the specifications in the Department of the Army permit, mitigation banking instrument, or approved mitigation plan. Monitoring reports should be concise and effectively provide the information necessary to assess the status of the compensatory mitigation project. Reports should provide information necessary to describe the site conditions and whether the compensatory mitigation project is meeting its performance standards. This includes an overview of site conditions and functions as well as appropriate supporting data.

2) **Box 9:** A table is the recommended option for comparing the performance standards to the conditions and status of the developing mitigation site. For example, a table could have columns for "performance standards", "mitigation site conditions", and "success" with a row such as "herbaceous ground cover of 80 percent or above three years after planting" in the first column, "herbaceous ground cover equals 85 percent" in the second column, and "yes" in the third column. The table should list the performance standards specified in the approved mitigation plan, mitigation banking instrument, or special conditions of the Department of the Army permit. The table should compare the performance standards to the conditions and status of the mitigation site based on data collected during monitoring.

3) **Box 10:** Submitted photos should be formatted to print on a standard 8.5-inch by 11-inch piece of paper, dated, and clearly labeled with the direction from which the photo was taken. The photo location points should also be identified on the appropriate maps.

4) **Box 11:** Maps and plans should clearly delineate the mitigation site perimeter(s). Each map or diagram should be formatted to print on a standard 8.5-inch by 11-inch piece of paper and include a legend and the location of any photos submitted for review.

5) **Box 13:** The annual ledger account for mitigation bank credits should show the beginning and ending balance of available credits and permitted impacts for each resource type, all additions and subtractions of credits, any other changes in credit availability (e.g., additional credits released, credit sales suspended), and any other information required by the mitigation banking instrument.

6) **Attachments:** Check the box in Part VII for those attachments that are included, and place a cover sheet or tab with each attachment behind the last page of the form. If Attachment F is needed for other information, include an appropriate title in the form and on the cover sheet or tab.

DEPARTMENT OF THE ARMY
GALVESTON DISTRICT, CORPS OF ENGINEERS
P. O. BOX 1229
GALVESTON TX 77553-1229

CESWG-PE-R

MEMORANDUM FOR All Regulatory Personnel

SUBJECT: Interim SWG Stream Condition Assessment Standard Operating Procedure

1. General: The purpose of this document is to provide a set of Standard Operation Procedures (SOP) and requirements for addressing stream mitigation in the Galveston District. This SOP will only be applicable only when direct impacts occur within the stream bed of a water of the United States. While the intent of the SOP is to assess the current functional condition of a stream and determine the appropriate functional credits to offset for any unavoidable loss, the SOP is not intended to take the place of project specific review which may result in adjustments to compensation requirements. Aquatic resources evaluated under this SOP shall be delineated in accordance with Regulatory Guidance Letter 05-05 - Ordinary High Water Mark Identification and wetlands present in the stream and/or riparian buffer shall be delineated in accordance with 1987 Corps of Engineers Wetland Delineation Manual and any appropriate Regional supplement. Applicants should defer to 33 CFR 332, Compensatory Mitigation for Losses of Aquatic Resources, for guidance on mitigation requirements not specifically addressed in this SOP. This SOP should only be used after a permit applicant has first avoided and minimized project impacts and the district engineer determines compensatory mitigation is necessary to offset unavoidable impacts to aquatic resources. The amount of required compensatory mitigation must be, to the extent practicable, sufficient to replace lost aquatic resource functions associated with the stream bed.

2. Resources: The purpose of the SOP is to provide predictable and repeatable assessment of compensatory mitigation requirements for the Galveston District Regulatory Branch. In development of this stream condition assessment tool; information from existing documents has been copied, sometimes in its entirety, without appropriate citation. The following are the Corps Regulatory documents and peer reviewed literature sources used in the development of the tool:

- 33 CFR Part 332 - Compensatory Mitigation for Losses of Aquatic Resources
- Regulatory Guidance Letter (RGL) 05-05 - Ordinary High Water Mark Identification.
- Regulatory Guidance Letter (RGL) 08-03 - Minimum Monitoring Requirements for Compensatory Mitigation Projects
- Compensatory Stream Mitigation Standard Operation Procedures and Guidelines. March 2009. Mobile District Corps of Engineers.
- Unified Stream Methodology. January 2007.Norfolk District Corps of Engineers.
- National Water and Climate Center Technical Note 99–1-Stream Visual Assessment Protocol, December 1998 Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling
- Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish-Second Edition, 1999. Environmental Protection Agency; Office of Water; Washington, D.C.
- Regionalization of the Index of Biotic Integrity for Texas Stream. 2002. Linam, Gordon W.; Kleinsasser, Leroy J.; and Mayes, Kevin B.
- Surface Water Quality Monitoring Procedures, Volume 2: Methods for Collecting and Analyzing Biological Assemblage and Habitat Data.2007. Texas Commission on Environmental Quality
- Rosgen, D.L. 2001. A Practical Method of Computing Streambank Erosion Rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference, Vol. 2, pp. II - 9-15, March 25-29, 2001, Reno, NV.

3. Interim Assessment: The Galveston District will initiate a one-year trial implementation of each available level of the SWG Stream Condition Assessment prior to finalization. Comments may be submitted during the entire one-year implementation trial and will be reviewed and incorporated into the administrative record prior to the District's finalization of the procedure.

4. Organization of SOP: The SOP is divided into three sections: 1) Stream Assessment Tool; 2) Assessment of Stream Impacts; and 3) Determining Compensation Requirements. Important stream functions measured include the ability to transport water, transport sediment, support and maintain a community of organisms and provide a safe water supply.

- Stream Assessment Tool This section, found in Appendix A, describes a tiered process for establishing the current condition of the stream function. For the purpose of this tool, the stream types include:
    - Level 1: All Ephemeral & Intermittent Streams, all Intermittent Streams with Perennial Pools will be evaluated using Level 1. In addition, all Perennial Streams and Wadeable Rivers where the proposed impacts are less than 500 linear feet will be evaluated using Level 1. The parameters sampled under Level 1 include; 1) Visual Channel Assessment; 2) Riparian Buffer Assessment; 3) Visual In-Stream Habitat Assessment; and 4) Visual Channel Alteration Assessment.
    - Level 2: Perennial Streams and/or Wadeable Rivers where the proposed impacts are equal to or greater than 500 linear feet. The parameters sampled under Level 2 include: UNDER DEVELOPMENT
    - Level 3: Complex or controversial stream projects on Perennial Streams and Wadeable Rivers. Level 3 is for use only when the district engineer determines that a Level 2 assessment is inadequate to assess the condition of a stream. The parameters sampled in a Tier 3 assessment include: UNDER DEVELOPMENT
- Procedure for assessment of Impacts on Stream Condition (debits) This section describes an impact classification system based on the extent to which the proposed impact is expected to impair the stream. Five Impact Classifications are outlined based on the severity of their affect on the stream by altering bankfull depth, slope, velocity, flow resistance, sediment size, sediment load, and bankfull discharge. The Assessment of Stream Impacts is found in Appendix B.
- Level 1, 2 and 3 Stream Condition Assessment Compensation Evaluation Procedure (credits) This section describes the methods and alternatives for fulfilling the Compensation Requirement for both onsite and offsite compensation, and explains the process. Compensation may be achieved through re-establishment, rehabilitation & enhancement and through a limited amount of preservation. The Determination of Compensation requirements is found in Appendix C.

5. Reporting Requirements

- Stream Assessment Report The investigator shall provide a detailed report of the stream assessment, with justification for all conclusions. Justifications should include photographic evidence, drawings and species lists. The stream shall be delineated in accordance with Regulatory Guidance Letter 05-05 - Ordinary High Water Mark Identification and wetlands present in the stream and/or riparian buffer shall be delineated in accordance with 1987 Corps of Engineers Wetland Delineation Manual and any appropriate Regional supplement. Submitted surveys shall be in accordance with the Galveston District Standard Operating Procedure for Recording Jurisdictional Delineations using Global Position Systems.

- Mitigation Plan The applicant shall provide a compensatory mitigation plan in accordance with the 33 CFR 332.4(c). In order to realize a final, stable stream design, the mitigation plan must address land use changes, as well has a history of the streams drainage basin, both at the local and watershed level, since these changes often cause disequilibrium of upstream delivery of water flow and sediment that result in stream deficiencies. The extent and cause of the deficiencies need to be discussed. Performance measures shall be ecologically based and that are objective and verifiable.

- Monitoring Plan The applicant shall provide compensatory mitigation monitoring plan reports in accordance with Regulatory Guidance Letter 08-03 - Minimum Monitoring Requirements for Compensatory Mitigation Projects. Monitoring shall include at a minimum an annual assessment of the compensatory mitigation site utilizing the Tiered Stream Assessment Tool until such time as the applicant has received written concurrence from the District Commander that the compensatory mitigation project has met its objectives and no additional monitoring reports are required.

6. Conclusion: The District goal is a no net loss of aquatic resource function. Branch personnel should use the SWG-Tiered Stream Condition Assessment to assess jurisdictional stream impacts and are responsible for verifying tool results when submitted by applicants. Aquatic resources impacted by the project located outside of the stream bed shall be evaluated with the appropriate assessment protocols. Additional agency coordination that would delay further permit processing is not required. There may be unique circumstances where a mitigation ratio greater than one-to-one is required to account for: the likelihood of success; differences between the functions lost at the impact site and the functions expected to be produced by the compensatory mitigation project; temporal losses of aquatic resource functions; the difficulty of restoring or establishing the desired aquatic resource type and functions; and/or the distance between the affected aquatic resource and the compensation site. The rationale for the required replacement ratio and the functional assessment must be documented in the administrative record for the permit action.

7 July 2011
DATE

Fred L. Anthamatten
Chief, Regulatory Branch

Appendix 1
Level 1-Stream Condition Assessment Procedure
For All Ephemeral and Intermittent Streams and for Impacts less than 500 Linear Feet to Intermittent Streams with Perennial Pools, Perennial Streams and Wadeable Rivers

1.0 Stream Impact Site Assessment

Regulated impacts are proposed to various types and qualities of streams. Therefore, it is important to assess the condition of the stream being impacted and use this condition as a baseline in determining the appropriate compensation. The Level 1 assessment is used for all impacts to ephemeral and intermittent streams and for impacts less than 500 linear feet to intermittent streams with perennial pools, perennial streams and wadeable rivers. The parameters sampled under Level 1 include; 1) Visual Channel Assessment; 2) Riparian Buffer Assessment; 3) Visual In-Stream Habitat Assessment; and 4) Visual Channel Alteration Assessment.

The fundamental unit for evaluating stream impacts is the stream assessment reach (SAR). All streams assessed under Level 1 with proposed impacts occurring to less than 500 linear shall use 3 fixed-distance SARs of 350 linear feet. Ephemeral and Intermittent streams with impacts greater than 500 linear feet will add one fixed-distance SAR for each additional 500 feet of impact. Perennial Streams with proposed impacts to 500-linear feet or greater shall use the Level 2 Stream Condition Assessment Procedure. SARs must be placed no less than 125 feet apart and no great than 200 feet apart.

1.1 Visual Channel Condition Parameter

Under most circumstances, channels respond to disturbances or changes in flow regime in a sequential, predictable manner. The way a stream responds to changes by degrading to a lower elevation and eventually re-stabilizing at that lower elevation is the basic premise behind the stream channel evolutionary process. The differing stages of this process can be directly correlated with the current state of stream stability. The purpose of evaluating channel condition is to determine the current condition of the channel cross-section, as it relates to this evolutionary process, and to make a correlation to the current state of stream stability. These evolutionary processes apply to the majority of stream systems and assessment reaches due to the fact that the majority of stream systems are degrading, aggrading, healing, or stable.

For a Level 1 Stream Condition Assessment, channel condition will be determined by visually assessing certain geomorphological indicators. These indicators include: channel incision; access to original or recently created floodplains; channel widening; channel depositional features; rooting depth compared to streambed elevation; streambank vegetative protection; and streambank erosion. Each of the categories describes a particular combination of the state of these geomorphological indicators which generally correspond to a stream channel stability condition at some stage in the evolution process.

1.1.1 Visual Channel Condition Variable

The Visual Channel Condition Variable is an assessment of the cross-section of the stream, along the SAR. The channel condition of each SAR is assessed using the following five stream conditions: optimal; sub-optimal; marginal; poor; and severe. A Condition Variable (CV) is given for each condition; however, there may be cases where the stream lies between the descriptions. In these cases, a CV between those provided may be used. Scores for this category range from 1 for the most severe condition to 5 for the most optimal condition. The stream evaluator needs to identify the current channel condition by visually assessing the channel's geometry, the channel's stability and the channel's ability to connect to the active floodplain.

Channel Geometry: The evaluator should visually assess the channel profile by assessing the degree of incision and/or widening. Channel incision is a common response of alluvial channels that have excess amounts of flow energy or stream power relative to the sediment load. This change in flow regime results in the stream eroding the stream bed, causing steep, easily eroded banks. If the cohesiveness of the bank material is very low, such as loose sand, the channel will erode the banks and have a wide cross-section compare to its depth. This instability presents itself as an over-widened channel.

Channel Stability: The channel stability is assessed by looking for visual indicators of stability or instability. In a stable stream, the pattern of erosion and deposition occurs in an orderly and predictable fashion. One of the most common depositional features of stable streams in this region is the creation of point bars. A point bar is a crescent-shaped depositional feature located on the inside of a stream bend or meander. Point bars are composed of well sorted sediment with a very gentle slope at an elevation below bankfull and very close to the baseflow water level. Since point bars are low-lying, they are often overtaken by stream flow and can accumulate driftwood and other debris during times of high water levels. Another common feature of a stable stream is a bankfull bench. A bankfull bench is a flat or shallowly sloped area above bankfull that slows high velocity flows during flows above bankfull. The bank of a stable stream will also be well vegetated with either herbaceous or woody species or may have a natural rock surface. These banks are stabilized by these surfaces, thereby reducing or preventing erosion. Finally, an indication of a stable stream may simply be an absence of indicators of an unstable stream channel.

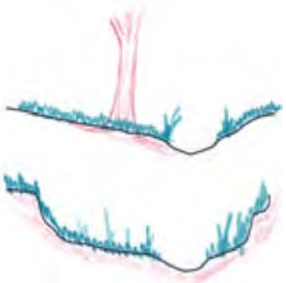
Indicators of an unstable stream channel include depositional features such as mid-channel bars, transverse bars, and transient sediments, as well as erosion features such as erosion scars, denuded banks, and threaded channels. Mid-channel bars and transverse bars are landforms in a stream channel that begin to form when the discharge is low and the stream is forced to take the route of less resistance by flowing in locations of lowest elevation. Over time, the stream begins to erode the outer edges of the bar, causing it to remain at a higher elevation than the surrounding areas. The water level decreases even more as the river laterally erodes the less cohesive bank material, resulting in a widening of the river and a further exposure of the bar. As the discharge increases, material may deposit about the bar since it is an area in the stream of low velocity due to its higher elevation than the surrounding areas.

Active Floodplain Connection: Active floodplain is the land between the active channel at the bankfull elevation and the terraces that are flooded by stream water on a periodic basis. Natural channels at or immediately below surrounding floodplain elevations will be connected to the active floodplain. Channels that are deeply incised or channelized will be below the elevation of the floodplain and will no longer be able to flood the floodplain during normal high-water events.

1.1.2 Identifying Visual Channel Condition Variable

The **SAR** is assessed for the condition of the channel by using the five categories described below.

***Optimal*-Score 5**

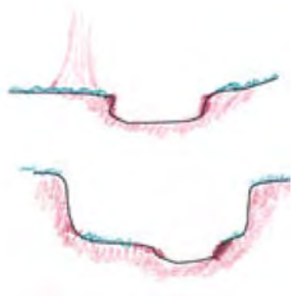


Channel Geometry: These channels show very little incision or widening and little or no evidence of active erosion or unprotected banks.
Channel Stability: visual indicators of this stability include: 1) vegetative surface protection or natural rock stability present along 80% or more of the banks; 2) stable point bars and bankfull benches may be present; 3) mid-channel bars and transverse bars are rare and if transient sediment deposition is present, it covers less than 10% of the stream bottom;
Floodplain Connection: the channel has access to the active floodplain or has fully developed wide bankfull benches.
Additional Information: In addition, no bulkheading or riprap may be present along the SAR for an ***Optimal*** score, regardless of channel profile.

***Suboptimal*-Score 4**

Channel Geometry: These channels are slightly incised and contain a few areas of active erosion or unprotected banks.
Channel Stability: visual indicators of this slight instability include: 1) vegetative surface protection or natural rock stability present along 60-79% of both banks; 2) depositional features such as point bars and bankfull benches are likely present; 3) if transient sediment is present, it affects or buries 10-40% of the stream bottom.
Active Floodplain: the stream has access to bankfull benches, or newly developed floodplains along portions of the reach
Additional Information: suboptimal channels may show evidence of past channel alteration, but should exhibit notable recovery a natural channel. In addition, a stream channel is visually characterized as ***Suboptimal*** if 1-25% of the SAR is bulkhead or riprap, regardless of channel profile.

***Marginal*-Score 3**



Channel Geometry: These channels are often incised or their course has been widened, but to a lesser degree than the ***Severe*** and ***Poor*** channel conditions.

Channel Stability: Visual indicators of a marginal stream include: 1) erosional scars present on 40-59% of both banks; 2) vegetative surface protection may be present on 40-59% of the banks; 3) the streambanks may consist of some vertical or undercut banks or nickpoints associated with headcuts; 4) portions of the bankfull channel may still widen while some portions are beginning to narrow; 5) temporary and transient sediment deposit covers 41-60% of the natural stream bed or bottom.

However, streams that have degraded channel profiles which are recovering will exhibit different characteristics, including: 1) presence of depositional features such as point bars, mid-channel bars, transverse bars, and bank full benches may be forming or present; 2) channels have a V-shape; 3) vegetative surface protection is present on greater than 40% of the banks but evidence of instability can be observed in unvegetated areas.

Active Floodplain: Marginal streams have no connection to the active floodplain.

Additional Information: In addition, a stream channel is visually characterized as ***Marginal*** if 26-50% of the SAR is bulkhead or riprap, regardless of channel profile.

***Poor*-Score 2**

Channel Geometry: These channels are over-widened or are incised. These channels are vertically and/or laterally unstable and are more likely to widen rather than incise further.

Channel Stability: visual indicators of over-widening and incision include: 1) both banks are near vertical with shallow to moderate root depths; 2) erosional scars present on 60-80% of the banks; 3) vegetative surface protection present on 20-39% of both banks and is insufficient to prevent significant erosion from continuing; 4) between 61-80% of the natural stream bed or bottom (pools and riffles) is covered by substantial sediment deposition, often uniformed-sized materials; 5) depositional features such as point bars and bank full benches are absent.

Active Floodplain: ***Poor*** streams are not connected to the active floodplain.

Additional Information in addition, a stream channel is visually characterized as ***Poor*** if 51-80% of the SAR is bulkhead or riprap, regardless of channel profile.

***Severe*-Score 1**

Channel Geometry: Severe channels are deeply incised (or excavated) with vertical and/or lateral instability and may likely continue to incise or widen.
Channel Stability: visual indications of a deeply incised stream include: 1) the streambed elevation is below the average rooting depth; 2) both banks are vertical or undercut; 3) vegetative surface protection present on less than 20% of the banks and is not preventing erosion from continuing; 4) bank sloughing present; 5) erosional scars or raw banks present on 81-100% of the banks; 6) 81% or more of the natural streambed or bottom (pools and riffles) is covered by substantial sediment deposition; 7) Multiple thread channels and/or subterranean flow may be present in certain aggrading channels. Note: Stable multiple thread channels naturally occur in some low-gradient streams and should not be given a Severe Parameter Condition score.
Active Floodplain: ***Severe*** streams are not connected to the active floodplain
Additional Information: In addition, a stream channel is visually characterized as ***Severe*** if the channels have been altered or channelized or the entire SAR is bulkhead or riprap, regardless of stream profile. An altered channel may be straight, with high banks, have dikes or berms, lack flow diversity, often have uniform-sized bed materials, and are missing or have non-native or invasive riparian vegetation along the bank.

1.2 Riparian Buffer Parameter

A Riparian buffer is defined as the zone of vegetation adjacent to streams, rivers, creeks or bayous. These vegetated zones are important in intercepting and controlling nutrients entering into the system. As such, it is considered a best management practice to include a riparian buffer in a compensatory mitigation plan as well as being an important consideration in the review of proposed impacts to the stream. Buffer width is positively related to nutrient removal effectiveness by influencing retention through plant sequestration or removal through microbial denitrification. This parameter is not intended to be a detailed vegetative cover survey, but instead, is a qualitative evaluation of the cover types that make up the riparian buffer. For the purpose of this assessment, the buffer is measured from the verified ordinary high water mark of the stream. The Buffer Value (BV) for this parameter is determined by evaluating what cover type occupies what percent of the total riparian buffer area for 100 feet on each side of the ordinary high water mark of the stream channel within the SAR. The total riparian buffer assessment area on each side of the stream is calculated by multiplying the length of the SAR by 100 feet. The left bank (LB) and right bank (RB) are determined by facing downstream. The Riparian Buffer measurement is taken along the ground and is not an aerial distance from the stream bank.

The ideal riparian buffer would be 100% coverage of the assessment area by the native woody vegetation community with no additional land use. If the buffer is a mixed land use (example: 33% forested, 33% cropland, and 34% pavement), it is possible that the buffer could contain multiple condition categories. In that case, each condition category present within the buffer is scored and weighted by the percent it occupies within the buffer. An estimate of the percent area that each cover type occupies may be made from visual estimates made on-the-ground or by measuring each different area to obtain its dimensions. Multiple intrusions of roads, houses, developments, etc., into the 100-foot zone may require more detailed measurements to determine percentages. The observed cover types should be categorized and scored accordingly, based upon the parameter category description.

1.2.1 Riparian Buffer Condition Variable

The SAR is assessed for the condition of the Riparian Buffer to calculate the Riparian Buffer Variable (BV) using the five categories described below.

***Optimal*-Score 5**
Native woody community species represent greater than 60% coverage with wetlands present within the SAR. No maintenance and/or grazing within the buffer.

Suboptimal

High Suboptimal-Score 4.5: Native woody community species represent greater than aerial 60% coverage *with no* wetlands present within the buffer and no maintenance or grazing within the buffer OR native community species represent between 30-60% aerial coverage *with* wetlands present and no maintenance or grazing within the buffer.

Low Suboptimal-Score 4: Native woody community species between 30-60% aerial coverage with no wetlands present and maintenance or grazing activities present within the buffer.

***Marginal*-Score 3**
Native woody community represents less than aerial 30% coverage with no maintenance or grazing activities present.

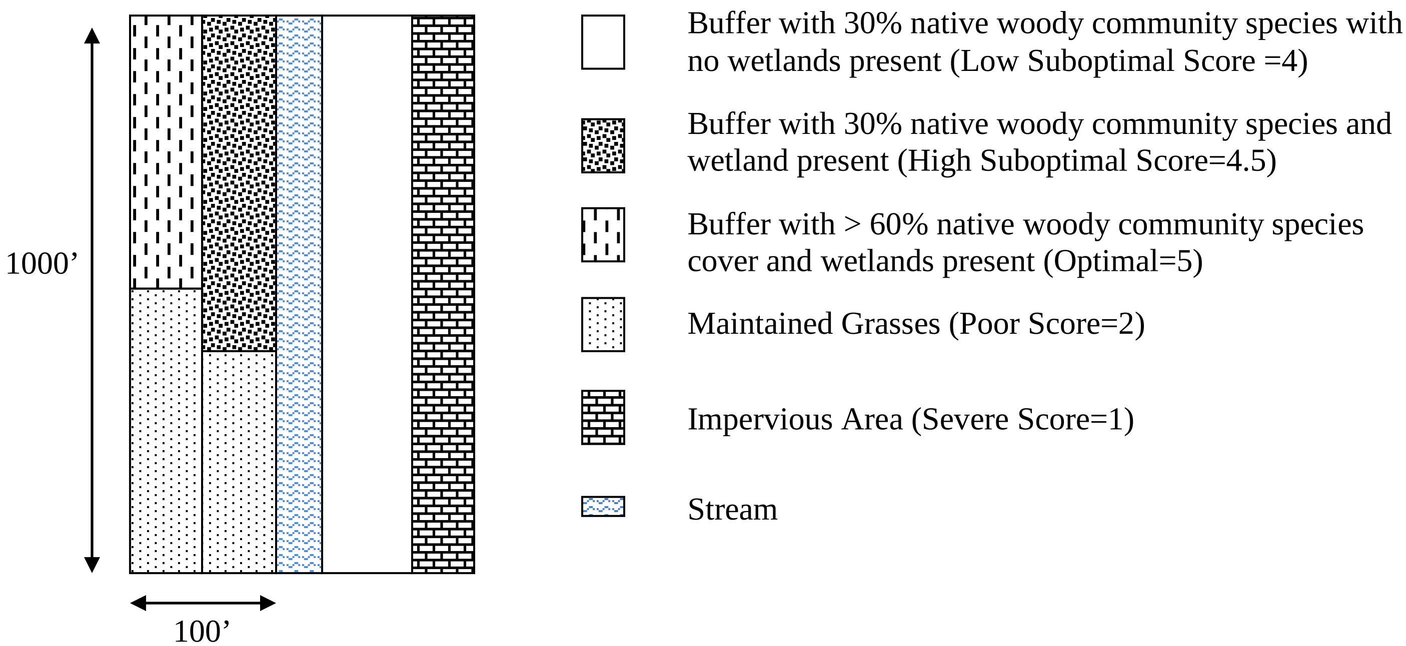
***Poor*-Score 2**
The area is dominated by one or more of the following: lawns; mowed or maintained right-of-way; no-till cropland; actively grazed pasture; sparsely vegetated non-maintained area; recently seeded and stabilized; or other comparable condition**.**

***Severe*-Score 1**
The area is dominated by: impervious surfaces; mine spoil lands; denuded surfaces; conventional tillage; active feed lots; or other comparable conditions.

1.2.2 Identifying Riparian Buffer Condition

When a buffer is simply one vegetation community, determining the appropriate buffer condition variable is simple. However, often times the buffer in the SAR is a mixed community. Since a single variable is required for the calculations, an example of how to calculate a multiple condition buffer is included to explain the method.

EXAMPLE 1: Calculating Multiple Condition Riparian Buffer



<u>Right Buffer</u>

The buffer located on the right bank is comprised of:

1) A 60-foot by 1000-foot (or 60%) Low Suboptimal Score (or 4) area
2) A 40-foot by 1000-foot (or 40%) Severe Score (or 1) area.

Therefore, the equation to calculate the Right Buffer is:

<u>Left Buffer</u>

The buffer located on the left bank is comprised of:

1) A 50-foot by 500-foot (or 25%) Optimal Score (or 5) area,
2) A 50-foot by 750-foot (or 37.5%) High Suboptimal (or 4.5) area
3) One 50-foot by 500-foot and one 50-foot by 250-foot (or a total of 37.5%) of Poor Score (or 2) area.

Therefore, the equation to calculate the Left Buffer is:

The final variable for BV is calculated by averaging the two buffer scores.

1.3 Visual In-Stream Habitat Parameter

The In-Stream Habitat assessment considers the habitat suitability for effective colonization or use by fish, amphibians, and/or macroinvertebrates. This parameter does not consider the abundance or types of organisms present, nor does it consider the water chemistry and/or water quality of the stream. This parameter includes the relative quantity and variety of natural structures in the stream which are available as refugia, feeding, or sites for spawning and nursery functions of aquatic macrofauna. A wide variety and/or abundance of in-stream habitat features provide macroinvertebrates and fish with a large number of niches, thus increasing species diversity. As variety and abundance of cover decreases, habitat structure becomes homogenous, diversity decreases, and the potential for recovery following disturbance decreases.

1.3.1 Identifying In-Stream Habitat Types

This assessment measures the availability of physical habitat diversity within a stream. **Each habitat type must be clearly visible and present in measurable amounts and have a high likelihood of having a long-term presence to score**. Habitat types included in this parameter are:

- Logs/large woody debris: Fallen trees or parts of trees that provide structure and attachment for aquatic macroinvertebrates and hiding places for fish.

- Deep pools: Areas characterized by a smooth undisturbed surface, generally slow current, and deep enough to provide protective cover for fish (75-100% deeper than prevailing stream depth).

- Overhanging vegetation: Trees, shrubs, vines, or perennial herbaceous vegetation that hang immediately over the stream surface, providing shade and cover.

- Coarse substrates: Naturally occurring gravel (0.079 inches in smallest dimension) or larger particle sizes.

- Undercut banks: Eroded areas extending horizontally beneath the surface of the bank forming underwater pockets used by fish for hiding and protection.

- Thick rootwads: Dense mats of roots (generally from trees) at or beneath the water surface forming structure for invertebrate attachment and fish cover.

- Dense macrophyte beds: Beds of native emergent or submerged aquatic vegetation thick enough to provide invertebrate attachment and fish cover.

- Riffles or Runs: Areas characterized by moderately swift current and relatively shallow depth (usually less than 18 inches).

- Flats: Areas with still, unbroken surface, but a shallow, uniform bottom that are filled with aquatic vegetation.

- Back water pools: Logs, root wads, boulders or stream banks can cause backwater pools to form as water swirls around the obstacle.

- Plunge pools: Plunge pools are formed where waterfalls over a boulder or log. The falling water scours a hole where juvenile and adult fish often hide.

1.3.2 In-Stream Habitat Variable

The SAR is assessed for the condition of In-Stream Habitat to determine the appropriate Habitat Variable (HV**)** using the following five categories.

***Optimal*-Score 5**

Greater than four (4) types of habitat present in the SAR. Conditions are favorable for colonization by a diverse and abundant epifaunal community, and there are many suitable areas for epifaunal colonization and/or fish cover.

***Suboptimal*-Score 4**

Four (4) types of habitat present in the SAR. Conditions are mostly desirable, and are generally suitable for full colonization by a moderately diverse and abundant epifaunal community.

***Marginal*-Score 3**

Three (3) types of habitat present in the SAR. Conditions are generally suitable for partial colonization by epifaunal and/or fish communities.

***Poor*-Score 2**

Two (2) or fewer types of habitat present in the SAR. Conditions are generally unsuitable for colonization by epifaunal and/or fish communities.

***Severe*-Score 1**

No habitat types present in the SAR.

1.4 Visual Channel Alteration Parameter

This parameter considers direct impacts to the stream channel from anthropogenic sources. The SAR may or may not have been altered throughout its entire length.

Examples of channel alterations evaluated in this parameter that may disrupt the natural conditions of the stream include, but are not limited to, the following:

- Straightening of channel or other channelization
- Stream crossings (bridges and bottomless culverts)
- Riprap, articulated matting, concrete aprons, gabions, or concrete blocks along streambank or in streambed
- Manmade embankments on streambanks, including spoil piles
- Constrictions to stream channel or immediate flood prone area such as any culverts, levees, weirs, and impoundments
- Livestock impacted channels (i.e., hoof tread, livestock in stream, *etc*.)

It is important to note that this parameter evaluates the physical alteration, separate from the impact the alteration is having on the assessment reach. Any impact to the assessment reach resulting from the alteration (i.e. scouring, head cuts, vertical banks, etc.) is accounted for in the Visual Channel Condition Parameter. Any revegetation or natural re-stabilization of the channel is also accounted for in the Visual Channel Condition Parameter. For example, consider two SARs, each with similar bridges: the first reach shows no adverse effects to the stream channel or banks; the second shows significant scouring. The alteration is the bridge, not the effects of the bridge; therefore it is the length of bridge relative to the length of the assessment reach that is evaluated.

The presence of a structure does not necessarily result in a reduced score. For instance, a bridge that completely spans the floodplain would not be considered an alteration. Also, the stream evaluator is cautioned not to make assumptions about past alterations. Incision can be mistaken for channelization.

1.4.1 Channel Alteration Categories

The SAR is assessed for the extent of anthropogenic channel alterations to determine the appropriate Visual Channel Alteration Variable (AV) using the following four Categories. The evaluator selects the category most representative of the assessment reach.

***Optimal*-Score 5:**Channelization, dredging, alteration, or hardening absent. Stream has unaltered pattern or has normalized. No dams, dikes, levees, culverts, riprap, bulkheads, armor, drop structures or withdrawal structures.

***Suboptimal*-Score 4:**Less than 30% of the SAR is impacted by any of the channel alterations listed above. Alteration or channelization is present, usually adjacent to structures such as bridge abutments or culverts. Evidence of past alteration may be present, but stream pattern and stability have recovered; recent alteration is not present. Withdrawals present, but no observable affect on flow.

***Marginal*-Score 3:** Between 31 - 60% of reach is impacted by any of the channel alterations listed above. If the stream has been channelized, normal stable stream meander pattern has not recovered. Withdrawals, although large enough to have an observable affect flow, have no observable affects on habitat or biota.

***Poor*-Score 2:** Between 61 - 90% of reach is impacted by any of the channel alterations listed above. If the stream has been channelized, normal stable stream meander pattern has not recovered. Withdrawals affect flow, habitat, and biota.

***Severe*-Score 1:** Greater than 90% of reach is impacted by any of the channel alterations listed above. Greater than 90% of banks shored with gabion, riprap, or cement. Channels entirely lined with riprap. Withdrawals are large enough to have severe loss of flow and little to no habitat or biota. The channel is deeply channelized or structures are present that prevent access to the floodplain or dam operations prevent flood flows.

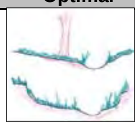
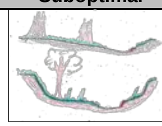
Routine Stream Assessment Data Form for Level 1 Streams

U.S. Army Corps of Engineers Galveston District

File Number	Applicant	Stahler Stream Order	8 Digit HUC	Date	SAR #	Impact/SAR length	Impact Factor

Name(s) of Evaluator(s)	Steam Name and Type

1. Channel Condition: Assess the cross-section of the stream and prevailing condition (erosion, aggradation)

	Optimal	Suboptimal	Marginal	Poor	Severe	
						
Visual Channel Condition Parameter	Channel shows very little incision or widening and little or no evidency of erosion or unprotected banks. Indicators of stability inc lude greater than 80% vegetative cover on the banks, stable point bars and bunkfull benches may be present, mid-channel and transverse bars are rare or transient. The stream has access to active floodplain or fully developed bankfull benches. No bulkheading or riprap may be present	Channel is slightly incised and contains a few areas of active erosion. Indicators of instability include vegetative cover or natural rock protection only present along 660-80% of the SAR, point bars and bankfull benches are likely present and transient sediment is present along 10-40% of the stream bottom. The stream has access to bankfull benches or developed floodplains along portions of the reach. Channel may show evidence of past channel alteration, but should be exhibiting notable recovery of a natural channel. Bulkhead and riprap are limited to 1-25% of the SAR.	Channel is incised or has had its course widened. Indicators of instability include the presence of erosional scars on 40-60% of the SAR, vegetative cover or natural rock only found on 40-60% of the SAR, vertical or undercut banks, or nickpoints associated with headcuts may be present and portions of the channel may be widening while other portions of the channel are narrowing, and transient sediments are found in 40-60% of the natural stream bed or bottom. The stream does not have acces to the active floodplain. Bulkheading or riprap is found along 25-50% of the SAR.	Channel is over-widened or are incised with vertically or laterally unstable banks. Visual indicators of over-widening and incision include near vertical bankis with shallow root depths, erosional scars present along 60-80% of the SAR, vegetative cover or natural rock is limited to 20-40% of the SAR, substantial sediment deposition of uniformed-size material is present along 60-80% of the SAR and pint bars anbd bankfull benches are absent. The stream does not have access to an active floodplain . Bulkheading and riprap are present along 50-80% of the SAR.	Channel is deeply incised or excavted with vertical or lateral instability in the stream bank. Indicators of instability includethe streambed elevation is located below the rooting depth, both banks are vertical or undercut, vegetative surface protection or natural rock is only found along 20% or less of the SAR, the bank is sloughing an erosional scars or raw banks present on 80-100% of the SAR and 80% or more of the natural streambed is covered by substantial sediment resulting in threaded channels. The stream does not have access to an active floodplain.	**CI**
Score	5	4	3	2	1	

Notes:

2. RIPARIAN BUFFERS: Assess both bank's 100 foot riparian areas along the entire SAR.

	Optimal	Suboptimal		Marginal	Poor	Severe
Riparian Buffers	Native woody species represent greater than 60% of the coverage and wetlands are present.	Native woody community species represent greater than 60% coverage with *NO* wetlands present within the buffer **OR** native woody community species represent 3-60% coverage with wetlands present. No maintenance or grazing activities.	Native woody community species represent between 30-60% coverage with *NO* wetlands present. No maintenance or grazing activities.	Native woody communty represents less than 30% coverage with no maintenance or grazing activities.	The buffer is dominated by one or more of the following: lawns, mowed or maintained right-of-way, no-till cropland, actively grazed pasture, sparsely vegetated non-maintained area, recently seeded and stabilized or other comparable condition.	The area is dominated by impervious surfaces, mine spoil lands, denued surfaces, conventional tillage row crops, active feed lots or comparable conditions.
Condition Scores		High = 4.5	Low = 4			

Notes:

Right Bank	% Riparian Area>							0%			
	Score >										
									CI= (Sum % RA * Scores*0.01)/2		
Left Bank	% Riparian Area>							0%	**Rt Bank CI >**	0.00	**CI**
	Score >								**Lt Bank CI >**	0.00	0.00

3. INSTREAM HABITAT: **Logs or largewoody debris, deep pools, overhanging vegetation, coarse substrate, undercut banks, thick rootwards, dense macrophyte beds, riffls or runs, flats back water pools and plunge pools.**

	Optimal	Suboptimal	Marginal	Poor	Severe	
Instream Habitat/ Available Cover	Greater than four (4) in-stream habitat types are present in the SAR	Four (4) types of habitat present in the SAR	Three (3) types of habitat present in the SAR	Two (2) or fewer types of habitat present in the SAR	No habitat types found in the SAR	**CI**
Score						

Notes

Stream Impact Assessment Form Page 2

Project #	Applicant	Locality	Cowardin Class.	HUC	Date	Data Point	SAR length	Impact Factor

4. CHANNEL ALTERATION: Stream crossings, riprap, concrete, gabions, or concrete blocks, straightening of channel, channelization, embankments, spoil piles, constrictions, livestock

	Optimal	Suboptimal	Marginal	Poor	Severe
Channel Alteration	Channelization, dredging, alteration or hardening absent. Stream has unaltered patter or has normalize. No dams, dikes, levees, culverts, riprap, bulkheads, armor, drop structures or withdrawal structures within the SAR.	Less than 30% of the SAR is impacted by dredging, dams, dikes, levees, culverts, riprap, bulkheads, armor, drop structures or withdrawal structures. Evidence of past alteration may be present, but stream pattern and stability have recovered. Withdrawals, if present, have no observable affect on flow	Between 30-60 % of the SAR is impacted by dredging, dams, dikes, levees, culverts, riprap, bulkheads, armor, drop structures or withdrawal structures. Evidence of past alteration may be present, but stream pattern and stability are beginning to recovered. Withdrawals, if present, have may have an observable affect on flow, but no observable affect on habitat or biota.	Between 60-90 % of the SAR is impacted by dredging, dams, dikes, levees, culverts, riprap, bulkheads, armor, drop structures or withdrawal structures. Evidence of past alteration is present, and stream pattern and stability are not recovering. Withdrawals, if present, have may have an observable affect on both flow and habitat or biota.	Between 90-100% of the SAR is impacted by dredging, dams, dikes, levees, culverts, riprap, bulkheads, armor, drop structures or withdrawal structures. Withdrawals, if present, are large enough to have severe loss of flow and cause little to no habitat or biota.
SCORE					

Notes

REACH CONDITION INDEX and STREAM CONDITION UNITS FOR THIS REACH

NOTE: **The CIs and RCI should be rounded to 2 decimal places. The CR should be rounded to a whole number.**

THE REACH CONDITION INDEX (RCI) >>	**0.00**
RCI= (Sum of all CI's)/5	
COMPENSATION REQUIREMENT (CR) >>	**0**
CR = RCI X LF X IF	

INSERT PHOTOS:

DESCRIBE PROPOSED IMPACT:

Appendix 2
Level 2 Stream Condition Assessment Procedure
For All Perennial Streams and/or Wadeable Rivers Where the Proposed Impacts are Equal To or Greater than 500 Linear Feet.

UNDER DEVELOPMENT

Appendix 3
Level 3 Stream Condition Assessment Procedure
For All Complex or Controversial Stream Projects on Perennial Streams and Wadeable Rivers.

Appendix 4
Procedure for Assessment of Impacts on Stream Condition

Permitted impacts result in a variety of impairments to a stream's ability to transport water, transport sediment, support and maintain a community of organisms and provide a safe water supply. Impacts affect streams by altering bankfull depth, slope, velocity, flow resistance, sediment size, sediment load, and bankfull discharge.

Different types of impacts should be assessed based on the extent to which they are expected to impair the stream. Impacts shall be characterized into one of five classifications: 1) Severe; 2) Major; 3) Moderate; 4) Minor; and 5) Negligible. Each Impact Classification has a corresponding **Impact Factor (IF)**; the more severe the impact, the higher the **IF**.

If an impact is not listed or is unauthorized, then the District Engineer shall determine on a case-by-case basis the most applicable Impact Classification. If multiple impacts occur within the **SAR**, the highest applicable **IF** is used for that reach.

4.1 Impact Classification

Severe-IF Score 5
Elimination or filling of stream channel, impoundments (flooding of stream channel); hardening both sides of stream bed (i.e., concrete, gabions, concrete blocks, riprap, countersunk & non-countersunk culverts) Channel Alteration: (i.e., modifications to profile or habitat features; straightening or adverse sinuosity modifications; modifications to cross section or width/depth ratio through widening or narrowing bankfull channel, deepening bankfull channel, channel constriction, mining) permanent low water crossings

Major-IF Score 4
Hardening of stream banks (i.e., concrete, gabions, concrete blocks, riprap, bottomless culverts and other similar structures),

Moderate-IF Score 3
Bridge construction activities and associated structures (e.g., piers, columns, etc.) in the stream channel.

Minor –IF Score 2
Culverts and/or crossing that do not restrict flow or cause downstream scour; temporary coffer dams or crossings utilizing best management practices

Temporary- If Score 1
Impacts are temporary and the site will be returned to pre-construction contours and elevations with no permanent loss of aquatic function. .

Appendix 5
Level 1, 2 and 3 Stream Condition Assessment Compensation Evaluation Procedure

5.0 Determination of Compensation Requirements (Credits)

This section describes the methods and alternatives for fulfilling the **Compensation Requirement (CR),** representing the total stream compensation required for the project, for both onsite and offsite compensation, and explains the process. Using this process ensures that crediting on-site and off-site compensation projects, evaluating and approving stream compensation banks and in-lieu fee fund projects through the Interagency Review Team are all credited in the same manner. This process does not include a method for crediting out-of-kind compensation between streams and wetlands. These activities may serve to fulfill the **CR** in certain situations, but will be evaluated on a case-by-case basis.

The process categorizes compensation methods for various levels of stream enhancement and restoration as well as riparian buffer preservation activities. The compensation may be further refined by applying appropriate Adjustment Factors (AF) to the credits obtained through the various activities.

The following provides details on compensation practices and guidelines for using the Compensation Crediting Form. This method is applicable to streams assessed under Level 1, 2 and 3 Stream Condition Assessment procedures.

5.1 Re-Establishment Credits (3 credit per linear foot)

Re-establishment means the manipulation of the physical, chemical, and biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource. Re-establishment shall result in a net gain in aquatic resource. Re-establishment activities include the process of converting an unstable, altered, or degraded stream corridor, including flood-prone areas, to a natural stable condition considering recent and future watershed conditions. The re-establishment process shall target the Optimal and/or Suboptimal standards set forth in the Conditional Assessment Procedure or may be based on pre-approved reference sites. This process supports the re-establishment of the stream's biological, chemical and physical integrity, including transport of the water and sediment produced by its watershed in order to achieve dynamic equilibrium. Re-establishment activities may include: 1) the re-establishment of a channel on the original floodplain, using a relic channel or constructing a new channel; 2) re-establishment of a floodplain at the existing level or higher but not at the original level; or 3) re-establishment of a channel with a flood prone area, but without an active floodplain.

5.1.1 Re-establishment Restrictions

The difference between projects that are credited as reestablishment and projects that are credited as rehabilitation or enhancement, is whether or not changes are necessary to address the current channel's dimension, pattern, and profile, to produce a stable channel.

All three geomorphic characteristics (i.e., pattern, profile, and dimension) are required to be addressed, as well as a net gain in aquatic area, for a stream to receive re-establishment credit. Rehabilitation or enhancement credit is given in all other situations when only two geomorphic variables are addressed to produce a stable channel or there is no net gain of aquatic resource area. Additional restrictions include:

1. No rehabilitation and/or enhancement activities can be coupled with restoration on the same linear foot of stream channel.

2. Restoration mitigation credits cannot be generated for stream channel or stream bank restoration if the mitigation segment is within 300 feet of a dam or a channelized/piped stream reach.

3. Credit is limited to three credits per linear foot of the compensation stream including the buffer work.

4. No artificial hydrology allowed

5. Water rights must be established.

6. Re-establishment may not be utilized as compensation for stream relocation projects where the relict stream channel is filled.

5.2 Rehabilitation or Enhancement Credits

Rehabilitation means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of repairing natural/historic functions to a degraded aquatic resource. Similarly enhancement means the manipulation of the physical, chemical, or biological characteristics of a site to heighten, intensify, or improve a specific aquatic resource function(s). Neither rehabilitation nor enhancement will result in a gain in aquatic resource area. For this reason, rehabilitation and enhancement credits are determined the same way. Stream rehabilitation and enhancement activities may include physical alterations to the channel that do not constitute re-establishment but that directly augment channel stability, water quality, and stream ecology in accordance with a reference condition, where appropriate. In order for a site to be considered rehabilitation, pre-approved reference sites must be utilized to establish the natural/historic function goals. However, enhancement process shall simply target the Optimal and Suboptimal standards set forth in the Conditional Assessment Procedure. Rehabilitation or enhancement activities may include in-stream and/or streambank activities, but in total improve only one or two of the following geomorphic variables – dimension, pattern, and profile. There are 6 activities included in the rehabilitation or enhancement category: 1) In-stream structures constructed of natural materials that provide channel stability (cross vanes, j hooks, etc); 2) Habitat structures that provide habitat for aquatic species (fish boards, root wads, etc); 3) Bankfull bench creation; 4) Laying Back Banks; 5) Bioremediation Techniques; and 6) Stream Bank Planting. Structures constructed by non-natural materials, such as concrete or metal, may be considered on a case-by-case basis and shall only be approved when no natural alternative is feasible. These compensation activities shall directly improve the stability of, or enhance, the streambanks, streambed, and in-stream habitat.

5.2.1 Rehabilitation or Enhancement Credit Determinations

In-stream Structures (1 credit per linear foot)
This activity includes natural structures that are specifically designed and result in grade control and/or bank stabilization. Accepted structures include, but are not limited to, cross-vanes, j-hook vanes, native material revetments, W rock weirs, rock vortex weirs, log-vanes, constructed riffles, and step-pools. These structures may be created out of appropriate sized rock or logs, boulders or cobbles based on the size of the stream and the flow regime. Structures not listed will be considered on case-by-case basis. Normally, a pool should be constructed in combination with these structures, however, if one is not constructed this does not alter the credit provided.

Habitat Structures (0.5 credit per linear foot)
This activity includes structures designed specifically for habitat creation. Although, In-stream structures typically provide habitat, they are constructed for channel stability and will not receive credit for Habitat Structures. Habitat Structures do not typically contribute to channel stability, however bank stability is required for successful habitat structures. Accepted structures include, but are not limited to, submerged shelters, fish boards or bank cover, floating log structures, root wads, and half-log cover. Riffle and pool complexes and over hanging vegetation do not qualify for credit in this activity. Technical design of in-stream structures should mimic natural structures found in the reference stream.

Bankfull Bench Creation (0.25 credit per linear foot per bank)
This activity involves the creation of a bankfull bench along one or both of the stream banks. This activity may result in less than the proper entrenchment ratio but does result in a stable channel. The compensation plan should state, and the plan sheets should clearly demarcate, the length (in linear feet) of stream channel where bankfull benches are proposed.

Lay Back Bank (0.25 credit per linear foot per bank)
This activity involves the manual manipulation of the bank slope but does not create a bankfull bench or floodplain. The compensation plan should state, and the plan sheets should clearly demarcate, the length (in linear feet) of stream channel where laying back the banks is proposed.

Bioremediation Techniques (0.25 credit per linear foot per bank)
This activity primarily relates to the use of coir logs or similar materials for bank stabilization. Techniques and materials in this category include, but are not limited to, live fascines, branch packing, brush mattresses, coir logs, and natural fiber rolls. More than one of these materials or techniques may be warranted over the same stream length. In this case, no additional credit will be applied for that length. In other words, the compensation plan should include all bioremediation techniques required over a particular length. Techniques and materials other than those listed will be considered on a case-by-case basis for approval.

Streambank Planting (0.25 credit per foot per bank)
This activity includes the installation of plants other than seed, seed is a required construction BMP with no lift given, along the immediate stream bank area. This is primarily done for streambank stabilization. This activity includes live stakes, dormant post/stakes, branch layering, and the installation of plants.

5.2.2 Rehabilitation or Enhancement Restrictions

1. Activities cannot be credited as both Re-establishment and rehabilitation or enhancement activities.
2. A structure cannot be credited as both an In-stream Structure and a Habitat Structure.
3. Mechanical bank work cannot be credited as both Bankfull Bench and Laying Back Bank.
4. Bioremediation Techniques do not include Erosion Control matting.

5.3 Riparian Buffer Credits

Stream mitigation projects require protected riparian buffers. This compensation category includes establishment or enhancement of riparian buffer zones and requires appropriate monitoring and site protection in perpetuity. With some exception, livestock shall not access riparian buffers within compensatory mitigation sites. Livestock exclusion is normally accomplished by fencing stream corridors and may include the construction of stream crossings with controlled access and with stable and protected stream banks. No more than one livestock crossing is allowed per 1,000 linear feet of stream mitigation. The width of the livestock crossing and any length of affected stream downstream will be deducted from the total length of the stream mitigation segment. After cattle have been removed, impacted riparian buffers must be restored or enhanced and may not be used for preservation purposes only. Additional activities restricted from the riparian buffer include: 1) timber harvesting; 2) any off-road vehicles; 3) horses; or 4) or any other activity that may affect the water quality and/or aquatic habitat. The Riparian Buffer Credit category includes the following four activities: 1) Buffer Re-Establishment; 2) Heavy Buffer Planting; 3) Light Buffer Planting; and 4) Preservation Only.

The minimum buffer width for which mitigation credit will be earned is100 feet on both sides of the stream as measured from the top of the ordinary high water mark, perpendicular to the channel. Up to an additional 100 feet of buffer may be included for credit; however, buffer in excess of 100 feet will be credit at a prorated amount. Narrower buffer widths may be approved on a case-by-case basis.

5.3.1 Riparian Buffer Credits

Buffer Re-Establishment (0.5 per linear foot for the inner 100 feet/0.25 per linear foot for the outer 100-200 feet)

Credit for this activity is given when impervious surfaces; mine spoil lands; denuded surfaces; conventional tillage; active feed lots; or other comparable conditions are removed and the buffer area is replanted with target species. Annually abatement to ensure invasive species eradication for the duration of the monitoring period and the success of the target species is required. Invasive species are those included in the Texas Invasive Plant and Pest Council database. For a current, comprehensive list of species, visit http://www.texasinvasives.org/invasives_database/index.php.

Heavy Buffer Planting (0.5 per linear foot for the inner 100 feet/0.25 per linear foot for the outer 100-200 feet)

Credit for this activity is given when the buffer area requires extensive planting (example: 400 stems per acre or more) and may include balled and burlapped specimens and/or containerized specimens. Annually abatement to ensure invasive species eradication for the duration of the monitoring period and the success of the target species is required. Invasive species are those included in the Texas Invasive Plant and Pest Council database. For a current, comprehensive list of species, visit http://www.texasinvasives.org/invasives_database/index.php.

Light Buffer Planting (0.25 per linear foot for the inner 100 feet/0.25 per linear foot for the outer 100-200 feet)

Credit for this activity is given when the buffer area requires only light or supplemental planting. This activity would involve planting at less than ideal densities (example: less than 400 stems per acre), either because vegetation is already present, a seed source is present, or the project does not otherwise warrant it.

Preservation Only (No Work Proposed)

Credit for this activity is given when no work to a riparian buffer area is proposed but that area will be placed under perpetual protection through an appropriate real estate instrument. Riparian buffer preservation may account for no more than 20% of credits generated by the mitigation plan and must meet the requirements contained in 33 CFR Part 332.3(h) on preservation. Credit is given based on the quality of the stream preserved. Additional credit is given for the preservation of High Quality streams (streams with an RCI from 4 to 5). Low Quality streams are those with an RCI from 2-4 to 1.24. Preservation will not be allowed for streams that score below an RCI of 2. When preservation of high-quality buffer is conducted on streams where stream re-establishment, rehabilitation or enhancement activities are proposed, the credit for Low Quality streams is applied since the compensation proposal has not yet resulted in an improvement. For the inner 100 feet, High Quality streams receive 0.1 credit per linear feet and Low Quality streams receive 0.05 credit per linear foot. For the outer 100 feet, all streams receive 0.05 credit per Percent Area.

5.3.2 Riparian Buffer Restrictions:

1. Buffer proposals for less than 100 feet in width or greater than 200 feet in width, on either side of the stream, must be approved on a case -by-case basis.

2. When appropriate plant community species are removed in order to perform re-establishment, rehabilitation or enhancement activities, the areas to be replanted cannot be credited toward heavy or light buffer planting. These areas will be credited as Preservation Only.

3. No area of buffer can be credited under more than one Riparian Buffer category.

5.4 Adjustment Factors

Adjustment Factors **(A_F)** are used to account for exceptional or site specific circumstances associated with the compensation site. These circumstances may provide ecological benefits or detriments that must be accounted for when determining credits. The Adjustment Factors are applied only when ecological and/or water quality function is affected by the action.

Each A_F activity is scored within a prescribed range. The range is to account for variation in activities and conditions that warrant **A_F** credit. Examples are given for each of the ranges. The agency representative shall make this determination on a case-by-case basis and use best professional judgment.

5.4.1 Credit Adjustments

Riparian Buffers with Wetlands (0.25 per linear foot of buffer with wetland)

Increased compensation will be offered for riparian buffers were medium to high quality wetlands, as determined by an approved functional assessment, are created, enhance or restored. Wetlands included in this adjustment factor shall not be utilized for compensatory mitigation to offset the authorized impacts to wetlands. A credit may be given at a rate of 0.25 credits per linear foot of buffer with a medium to high quality wetland.

Ripairan Buffers Under 100 feet (-0.25 per linear foot of buffer under 100 feet)
In rare cases, stream mitigation will be authorized in areas where land use prohibits the minimum buffer of 100ft.

Sites where buffers will not be the minimum 100ft from the middle of the stream will have an adjustment factor of -0.25 credits per linear foot of buffer under 100-feet. The following factors are considered when determining if the reduced buffer will be authorized: 1) quality of remaining buffer (e.g wetlands present), and 2) the water quality and/or stream bank stability benefits of the stream restoration/enhancement activities.

Livestock Exclusion (-0.5 per linear foot of buffer subject to grazing)
Sites where livestock will be excluded will have no additional credit awarded for this management technique.

Sites where livestock will not be excluded will have an adjustment factor of -0.5 credits per linear foot of buffer subject to grazing and must have an approved management plan. The following factors are considered when determining an approved grazing regime and monitoring protocol for a management plan: 1) the number and type of livestock, and 2) the water quality and streambank stability impacts.

Calculations for Determining Stream Compensation Credits

Step 1: Stream Impact Site Assessments

- Determine Length of Stream Assessment Reach
- Perform assessment and determine applicable variables:
    - Channel Condition Variable (CV) = Score 1-5
    - Riparian Buffer Variable (BV) (see Example 1)= Score =1-5
    - In-Stream Habitat Variable (HV)= 1-5
    - Channel Alteration Variable (AV)= 1-5
    - Vertebrate Variable (VV) (Tier 2 & 3 only) = Score 1-5
    - Macroinvertebrate Variable (MV) (Tier 3 only) = Score 1-5
- Calculate Stream Assessment Reach Condition Index (RCI) using the appropriate equation:
    - Tier 1 Equation: RCI = (CV+BV+HV+AV) ÷ 4
    - Tier 2 Equation: RCI = RCI = (CV+BV+HV+AV+VV) ÷ 4
    - Tier 3 Equation: RCI = (CV+BV+HV+AV+VV+MV) ÷ 4

Step 2: Determine Impact Factor (IF)

- Severe = 5
- Major = 4
- Moderate = 3
- Minor = 2
- Temporary=1

Step 3: Calculate Stream Compensation Requirement

- Calculate Compensation Requirement (CR) using the following equation:
- CR = Length of Impact (LI) × Reach Condition Index (RCI) × Impact Factor (IF)

Step 4 – 1 Determine Compensation Credit

- Determine Compensation Credit (CC) for Applicable Compensation Activities
    - Re-establishment = 3 credit per foot
    - Rehabilitation or Enhancement = 0.25-1 credits per foot per bank
    - Riparian Buffer Areas = 0.1-0.5 credits per foot
- Apply Applicable Adjustment Factors (AF)
    - Wetlands in Buffer = 0.25 credits per linear foot of wetland
    - Buffer less than 100ft = -0.25 credits per linear foot of reduced buffer
    - Livestock Exclusion = -0.5 credits per linear foot of grazed buffer

Step 5 – Evaluate Compensation Credit

- Calculate Total Compensation Credit (Total CC) 4
    - Total CC = (Re-establishment Credit + Rehabilitation or Enhancement Credit + Riparian Buffer Credit + Adjustment Factor (AF) Credit)

Step 6 - Total CC must be equal to Total CR

EQUATION 1: The equation is as follows:

Left Bank CI =SUM (%Area*Score)*0.01

Right Bank CI =SUM(%Area*Score)*0.01

Riparian CI = (Left Bank CI + Right Bank CI) / 2

Equation 2 RCI = (Sum of all CIs) ÷ 5

EQUATION 3:

Compensation Requirement (CR) = LI x RCI x IF

Where,

CR = compensation credits required

LI = length of impact (in linear feet)

RCI = Reach Condition Index (Form 1)

IF = Impact Factor (Table 1)

EQUATION 4:

Structure Credit = Length affected*Credit

Left Bank Credit =SUM (Length*Credit)

Right Bank Credit = SUM (Length*Credit)

Enhancement Credit = Structure Credit + Left Bank Credit + Right
Bank Credit

EQUATION 5

Total CC=SUM (Restoration Credit + Enhancement Credit + Riparian Buffer Credit

Calculations for Determining Stream Compensation Credits

Step 1: Stream Impact Site Assessments

- Determine Length of Stream Assessment Reach
- Perform assessment and determine applicable variables:
    - Channel Condition Variable (CV) = Score 1-5
    - Riparian Buffer Variable (BV) (see Example 1)= Score =1-5
    - In-Stream Habitat Variable (HV)= 1-5
    - Channel Alteration Variable (AV)= 1-5
    - Vertebrate Variable (VV) (Tier 2 & 3 only) = Score 1-5
    - Macroinvertebrate Variable (MV) (Tier 3 only) = Score 1-5
- Calculate Stream Assessment Reach Condition Index (RCI) using the appropriate equation:
    - Tier 1 Equation: RCI = (CV+BV+HV+AV) ÷ 4
    - Tier 2 Equation: RCI = RCI = (CV+BV+HV+AV+VV) ÷ 4
    - Tier 3 Equation: RCI = (CV+BV+HV+AV+VV+MV) ÷ 4

Step 2: Determine Impact Factor (IF)

- Severe = 5
- Major = 4
- Moderate = 3
- Minor = 2
- Temporary=1

Step 3: Calculate Stream Compensation Requirement

- Calculate Compensation Requirement (CR) using the following equation:
- CR = Length of Impact (LI) × Reach Condition Index (RCI) × Impact Factor (IF)

Step 4 – 1 Determine Compensation Credit

- Determine Compensation Credit (CC) for Applicable Compensation Activities
    - Re-establishment = 3 credit per foot
    - Rehabilitation or Enhancement = 0.25-1 credits per foot per bank
    - Riparian Buffer Areas = 0.1-0.5 credits per foot
- Apply Applicable Adjustment Factors (AF)
    - Wetlands in Buffer = 0.25 credits per linear foot of wetland
    - Buffer less than 100ft = -0.25 credits per linear foot of reduced buffer
    - Livestock Exclusion = -0.5 credits per linear foot of grazed buffer

Step 5 – Evaluate Compensation Credit

- Calculate Total Compensation Credit (Total CC) 4
    - Total CC = (Re-establishment Credit + Rehabilitation or Enhancement Credit + Riparian Buffer Credit + Adjustment Factor (AF) Credit)

Step 6 - Total CC must be equal to Total CR

EQUATION 1: The equation is as follows:

Left Bank CI =SUM (%Area*Score)*0.01

Right Bank CI =SUM(%Area*Score)*0.01

Riparian CI = (Left Bank CI + Right Bank CI) / 2

Equation 2 RCI = (Sum of all CIs) ÷ 5

EQUATION 3:

Compensation Requirement (CR) = LI x RCI x IF

Where,

CR = compensation credits required

LI = length of impact (in linear feet)

RCI = Reach Condition Index (Form 1)

IF = Impact Factor (Table 1)

EQUATION 4:

Structure Credit = Length affected*Credit

Left Bank Credit =SUM (Length*Credit)

Right Bank Credit = SUM (Length*Credit)

Enhancement Credit = Structure Credit + Left Bank Credit + Right Bank Credit

EQUATION 5

Total CC=SUM (Restoration Credit + Enhancement Credit + Riparian Buffer Credit

Appendix 6
Terminology

For the purpose of assessing the aquatic functions of streams, the following definitions may assist the investigator in understanding:

Active floodplain: the land between the active channel at the bankfull elevation and the terraces that are flooded by stream water on a periodic basis. This is not synonymous with the FEMA floodplain.

Back water pools: A pool type formed by an eddy along channel margins downstream from obstructions such as bars, rootwads, or boulders, or resulting from backflooding upstream from an obstructional blockage. Backwater pools are sometimes separated from the channel by sand or gravel bars

Bankfull: The water level, or stage, at which a stream, river or lake is at the top of its banks and any further rise would result in water moving into the flood plain. It may be identified by physical characteristics such as a clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.

Bankfull bench: a flat or shallowly sloped area above bankfull that slows high velocity flows during flows above bankfull.

Base flow: During most of the year, stream flow is composed of both groundwater discharge and land surface runoff. When groundwater provides the entire flow of a stream, baseflow conditions are said to exist.

Branch packing: Technique in which alternate layers of compacted backfill and live branches are used to restore voids, slumps, and holes in stream banks.

Buffer: an upland, wetland, and/or riparian area that protects and/or enhances aquatic resource functions associated with wetlands, rivers, streams, lakes, marine, and estuarine systems from disturbances associated with adjacent land uses.

Condition: the relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity, and functional organization comparable to reference aquatic resources in the region.

Coir logs: tightly bound cylinders of coir fibers (Coconut Fiber) held together by a coir fiber netting made from coir twine. They are generally available in 10 to 20 foot lengths and are 12 to 20 inches in diameter. They are excellent to use as a toe protection in areas of low velocity water flow. After installation, the coir fiber logs become saturated with water and vegetation can be planted directly on the logs.

Coarse substrates: naturally occurring gravel (0.079 inches in smallest dimension) or larger particle sizes.

Cross vanes: rock structures built below the water level to control the direction of flow within a stream. Various types of in-stream rock structures are used. One or more structures can be used to direct a stream's energy toward the center of the channel and relieve pressure on an eroding streambank.

Deep pools: areas characterized by a smooth undisturbed surface, generally slow current, and deep enough to provide protective cover for fish (75-100% deeper than prevailing stream depth).

Dense macrophyte beds: beds of native emergent or submerged aquatic vegetation thick enough to provide invertebrate attachment and fish cover.

Enhancement: the manipulation of the physical, chemical, or biological characteristics of an aquatic resource to heighten, intensify, or improve a specific aquatic resource function(s). Enhancement results in the gain of selected aquatic resource function(s), but may also lead to a decline in other aquatic resource function(s). Enhancement does not result in a gain in aquatic resource area.

Ephemeral stream: a stream with flowing water only during and for a short duration after, precipitation events in a typical year. Ephemeral stream beds are located above the water table year-round. Groundwater is not a source of water for the stream. Runoff from rainfall is the primary source of water for stream flow

Fascines: a rough bundle of brushwood used for strengthening an earthen structure, or making a path across uneven or wet terrain. Typical uses are protecting the banks of streams from erosion, covering marshy ground and so on.

Flats: areas with still, unbroken surface, but a shallow, uniform bottom that are filled with aquatic vegetation.

Intermittent stream: an intermittent stream has flowing water during certain times of the year, when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from rainfall is a supplemental source of water for stream flow.

J hooks: an upstream directed, gently sloping structure composed of natural materials. The structure can include a combination of boulders, logs and root wads and is located on the outside of stream bends where strong downwelling and upwelling currents, high boundary stress, and high velocity gradients generate high stress in the near-bank region. The structure is designed to reduce bank erosion by reducing near-bank slope, velocity, velocity gradient, stream power and shear stress

Logs/large woody debris: fallen trees or parts of trees that provide structure and attachment for aquatic macroinvertebrates and hiding places for fish.

Live fascines: long bundles of live woody vegetation buried in a streambank in shallow trenches placed parallel to the flow of the stream (Figure 1). The plant bundles sprout and develop a root mass that will hold the soil in place and protect the streambank from erosion.

Lunker structure: an artificial structure constructed along the bank of a stream designed to mimic undercut banks and provide habitat for fish species. These structures are generally found in high gradient streams.

Mid channel: landforms in a stream channel that begin to form when the discharge is low and the stream is forced to take the route of less resistance by flowing in locations of lowest elevation.

Overhanging vegetation: trees, shrubs, vines, or perennial herbaceous vegetation that hang immediately over the stream surface, providing shade and cover.

Perennial Stream: a stream that has flowing water year-round during a typical year. The water table is located above the stream bed for most of the year. Groundwater is the primary source of water for stream flow. Runoff from rainfall is a supplemental source of water for stream flow.

Plunge pools: plunge pools are formed where water falls over a boulder or log. The falling water scours out the stream bed

Point Bar: a point bar is a crescent-shaped depositional feature located on the inside of a stream bend or meander. Point bars are composed of well sorted sediment with a very gentle slope at an elevation below bankfull and very close to the baseflow water level.

Pool: is a stretch of a river or stream in which the water depth is above average and the water velocity is quite below average

Re-establishment: the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former aquatic resource. Re-establishment results in rebuilding a former aquatic resource and results in a gain in aquatic resource area and functions.

Rehabilitation: the manipulation of the physical, chemical, or biological characteristics of a site with the goal of repairing natural/historic functions to a degraded aquatic resource. Rehabilitation results in a gain in aquatic resource function, but does not result in a gain in aquatic resource area.

Riffle: a short, relatively shallow and coarse-bedded length of stream over which the stream flows at lower velocity and higher turbulence than it normally does in comparison to a pool. As a result of the lower velocity and heightened turbulence, small ripples are frequently found.

Riparian buffer: the zone of vegetation adjacent to streams, rivers, creeks or bayous, generally forested, that plays a key role in increasing water quality in associated streams

Rock weirs or rock vortex weirs: a structure designed to serve as grade control and create a diversity of flow velocities, while still maintaining the bed load sediment transport regime of the stream. The weir points upstream with the legs angling downstream at anywhere from a 15 to 30 degree angle relative to the stream bank. The legs are carried up the streambank to just above the bankfull elevation. The key component of the rock vortex weir is that the weir stones do not touch each other.

Root wads: commonly refers to the trunk of a tree with the roots attached, and the soil or dirt removed so that the roots are exposed. Individual rootwads are placed in series and utilized to protect stream banks along meander bends. A revetment can consist of just one or two rootwads or up to 20 or more on larger streams and rivers.

Run: A somewhat smoothly flowing segment of the stream.

Stream Bed: the substrate of the stream channel between the ordinary high water marks. The substrate may be bedrock or inorganic particles that range in size from clay to boulders. Wetlands contiguous to the stream bed, but outside of the ordinary high water marks, are not considered part of the stream bed

SAR: *see* STREAM ASSESSMENT REACH

Step pools: consist of a series of structures designed to dissipate energy in steep gradient sections of a stream. They are often used where a large nick point has formed and is migrating headward or where a channel has degraded below a culvert or outfall. They are made of large rock in alternating short steep drops and longer low or reverse grade sections. There are various configurations and arrangements of rock that can be utilized. The requirement is that whatever the design configuration chosen it must be stable at all flows, the rock must be large enough to be essentially immobile, and the drops should be low enough to allow aquatic life to migrate upstream

Stream Assessment Reach: A fixed-length segment of the stream being sampled.

Thick rootwads: dense mats of roots (generally from trees) at or beneath the water surface forming structure for invertebrate attachment and fish cover.

Transverse Bars: A slightly submerged sand bar extending perpendicular to the shoreline

Undercut banks: Eroded areas extending horizontally beneath the surface of the bank forming underwater pockets used by fish for hiding and protection.

Wadeable Rivers: A river is considered wadeable if it may be sampled in accordance with the procedure without a boat.