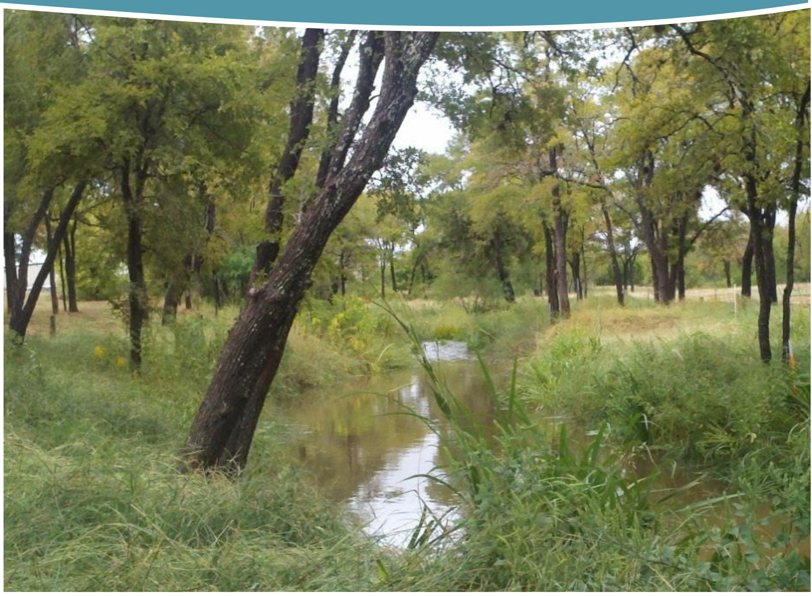
Natural Channel Design Protocol

San Antonio, Texas

SAN ANTONIO RIVER AUTHORITY
Leaders in Watershed Solutions

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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 for providing 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.

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**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.*

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UPDATES TO VERSION 1

The Regional Curves are being revised. When completed, the updated curves will be incorporated as an appendix to this manual. In addition, Reference Reach information will be incorporated into Chapter 7 and included as additional design criteria in Chapter 8.

Chapter 4 (Characteristics of the San Antonio River Watershed) was added to provide background information on the San Antonio River Watershed, including average rainfall, geology, percent impervious, and impoundments, to help understand the impact of the local watershed on stream restoration projects.

Section 8.1 was revised to focus on the Stream Functions Pyramid Framework (SFPF) and provide additional information about application of the framework.

Section 8.6.7 (Use of Models to Assess Stream Design) was added to describe opportunities to use two-dimensional (2D) and other hydraulic models to assess locations of potential erosion and impacts of in-stream structures.

Appendix A no longer includes the "Regional Equations for Estimation of Peak-Streamflow Frequency for Natural Basins in Texas." This text can be downloaded from the USGS at http://pubs.usgs.gov/wri/wri964307/pdf/wri4307.pdf.

Appendix B (SARA Contact Information) was removed, therefore all Appendices from version 1 were moved up one location in the Appendices Table of Contents. Contact information can be found on Page i of this document.

Appendix K (USACE Monitoring Templates and Guidance) from version 1 of this document was removed.

Appendix J (Stream Restoration Approaches and Techniques) was added to provide guidance for practitioners on selecting the restoration approach or technique that provides the most functional lift for a project.

Appendix K provides the Channel Geometry and In-stream Structure Inspection Form that provides guidance and information to be collected for post-construction inspections.

Appendix L (East Salitrillo Creek Restoration Project) was added to provide an example case study project.

Appendix M (Assessment and Design Submittal Checklist) was added to provide a checklist that will aid with submittals and help ensure that practitioners provide the right information during various stages of the project design.

Appendix N (Cost Estimate) was added to help estimate costs for potential stream restoration projects.

Appendix O (Regional Curves) was added as a reference to the most up-to-date Regional Curve data for the San Antonio River Watershed.

Appendix P was added help the practitioner determine the overall health of the watershed draining to the project reach with a Catchment Assessment Form. This will allow determination of function based goals and objects for a project.

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.

Downcut - A geological process by which water deepens the channel of a stream by removing material from the stream bed.

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.

Epikarst - A weathered zone of enhanced porosity on or near the surface of many karst landscapes where water is stored in enlarged joints and bedding planes.

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.

Green Infrastructure - Sustainable pollution reduction practices that also provide ecosystem services. These include both preserved natural areas and man-made BMPs.

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 designates 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.

Karst - A landscape formed from the dissolution of soluble rocks such as limestone, dolomite and gypsum. It is characterized by sinkholes, caves, and underground drainage systems.

Knickpoint: Abrupt, steep changes in the stream profile.

Littoral - the portion of the river located adjacent to the bank.

Low Impact Development - stormwater management and land development strategy that emphasizes conservation and the use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely reflect pre-development hydrologic functions. These techniques have been shown to improve water quality, reduce localized flooding and, when incorporated into a project's design early in the process, reduce overall costs.

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 apexes 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 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 the 'tightness' of an individual meander bend that is negatively correlated with sinuosity. This is measured from the center of the bankfull channel to the intersection point of two lines that perpendicularly 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
A_p	Pool Area
A_r	Riffle Area
AU	Assessment Units
BANCS	Bank Assessment for Non-Point Source Consequences of Sediment
BEHI	Bank Erosion Hazard Index
BFE	Base Flood Elevation
BFW	Bankfull Width
BH	Bank Height
BHR	Bank Height Ratio
BKF	Bankfull
BMP	Best Management Practice
B_r	Riffle Bankfull Width
CAD	Computer Aided Design
CL	Channel Length
CLOMR	Conditional Letter of Map Revision
COGO	Coordinate Geometry
CWA	Clean Water Act
D	Depth
d_{bkf},D_{bkf}	Mean Bankfull Riffle Depth
D_{gl}	Glide Depth
D_m	Run Depth
D_{max}	Maximum Riffle Depth
D_p	Mean Pool Depth
D_{pmax}	Maximum Pool Depth
EPA	Environmental Protection Agency
ER	Entrenchment Ratio
FEMA	Federal Emergency Management Agency
FPW	Floodprone Area Width
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
K	Sinuosity
LA	Load Allocation
LID	Low Impact Development
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
SFPF	Stream Functions Pyramid Framework
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
TMDL	Total Maximum Daily Load
TOB	Top of Bank
TPDES	Texas Pollution Discharge Elimination System
TWDB	Texas Water Development Board
TXRAM	Texas Rapid Assessment Method
u	Mean Velocity
USACE	United States Army Corps of Engineers
USGS	United States Geological Service
V	Velocity
VL	Valley Length
VS	Valley Slope
W	Width
W_{blt}	Belt Width
W_{fpa}	Flood Prone Area Width
WLA	Waste Load Allocation
W_p	Pool Width
W_r	Riffle Bankfull Width

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, stream restoration practitioners, 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 improve retention and attenuation of 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, green infrastructure, 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 United States Army Corps of Engineers (USACE) permitting requirements and minimize impacts. The benefits and limitations of several different approaches and techniques are discussed in *Appendix J* to this report.

> *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.*

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, some functional lift may be achieved through stream restoration methods based on the goals established for a project. A framework for setting project goals and objectives is discussed in

Section 8.1. 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 progresses and is completed. 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 primary purpose of the watershed assessment is to understand impacts from the upstream watershed on the project reach and the potential impacts from future conditions. This chapter describes the parameters that are recommended to assess the watershed and hydrology. These include drainage area, percent impervious cover, and land use. Other watershed information that can be considered may include geology, soils, topography, climate, and storm water infrastructure. The assessment can also provide information about potential sources of stream impairments and pollutants, opportunities for use of best management practices, and potential stakeholders. 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 4*).

Watershed Assessments can provide important information about the impact of the watershed on the project area, including:

1. *Drainage Area*
2. *Percent Impervious Cover*
3. *Land Use*
4. *Geology*
5. *Soils*
6. *Topography*
7. *Climate*
8. *Storm Water Infrastructure*

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 (often referred to as "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.

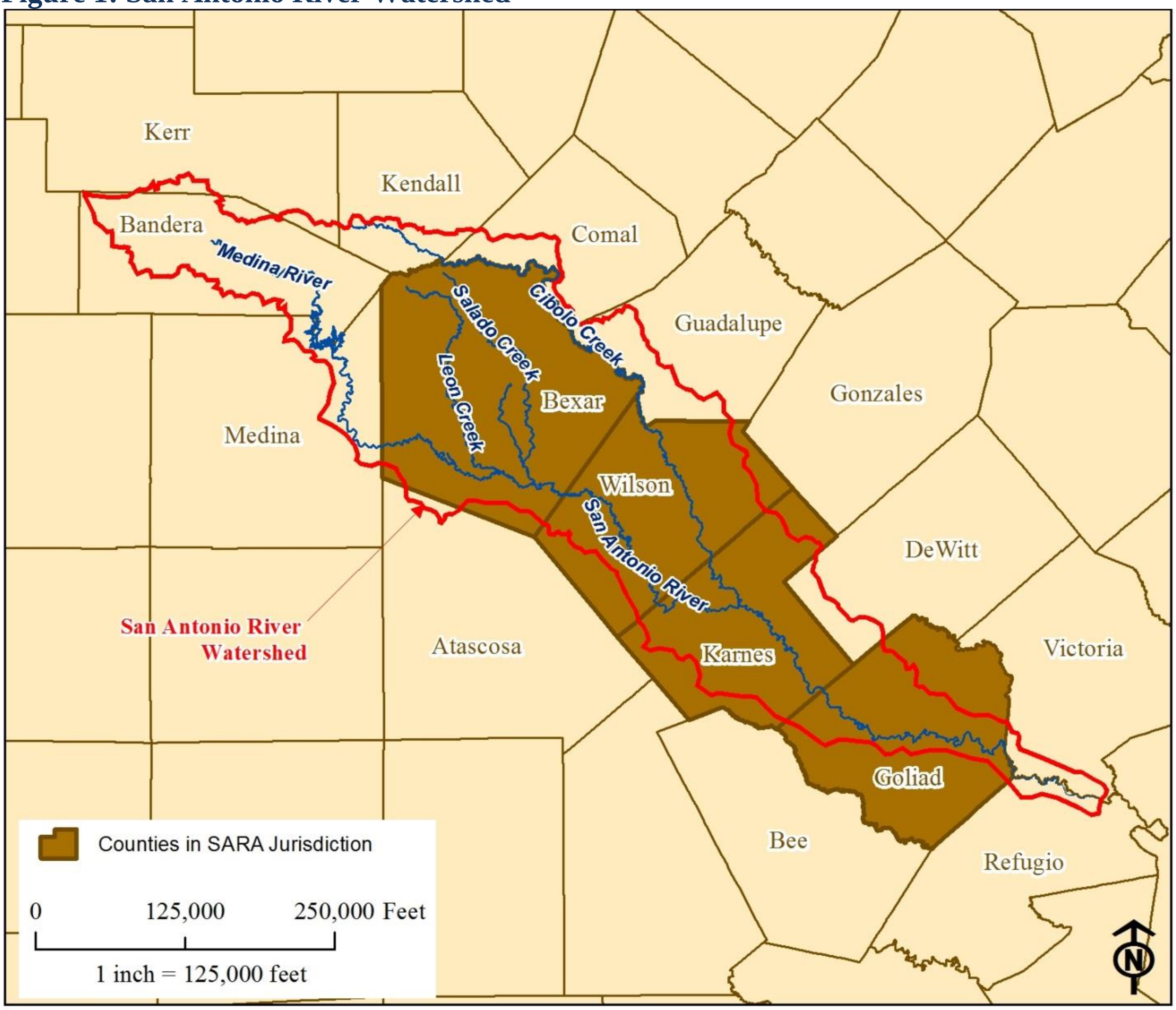
A key element to take into consideration when performing a watershed assessment in the San Antonio Region and surrounding Texas Hill Country is water table loss. Each project must take into this loss into consideration and incorporate design elements to retain water on site with oxbows and onsite wetland features, as practical for a given site. Other elements that must be evaluated during the watershed assessment include 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, 2013) and white paper, *Process to Obtain Peak Discharge Data and Update or Modify Hydrology Models* (SARA, 2007). The modeling standards were originally released in 2005 and updated in 2013.

4.0 CHARACTERISTICS OF THE SAN ANTONIO RIVER WATERSHED

The San Antonio River Watershed includes approximately 4,180 square miles of drainage area that extends from Kerr and Bandera counties in the central Texas Hill Country southeast toward the Gulf of Mexico. The San Antonio River starts within the City of San Antonio, at an artesian spring fed by the Edwards Aquifer, and includes approximately 240 stream miles. Several tributaries feed into the river from upstream of the city and the river joins the Guadalupe River just upstream of Guadalupe Bay. The major subwatersheds within the San Antonio River Watershed are those of the Medina River, Leon Creek, Salado Creek, Cibolo Creek, Upper San Antonio River, and Lower San Antonio River. The San Antonio River, major tributaries, counties, and the boundaries of the watershed are shown in Figure 1. As shown in the figure, the northwest boundary of the watershed begins at the Medina River subwatershed in Bandera and Kerr Counties.

Figure 1: San Antonio River Watershed



GIS Data Source: San Antonio River Authority, 2014.

Data regarding the San Antonio River Watershed, the counties, and streams within the watershed can be downloaded from the San Antonio River Authority's website.

To learn what data is available for the San Antonio River Watershed and streams within the watershed, SARA can be contacted through the following Online Request Form.

More information can also be found on the SARA website, https://www.sara-tx.org

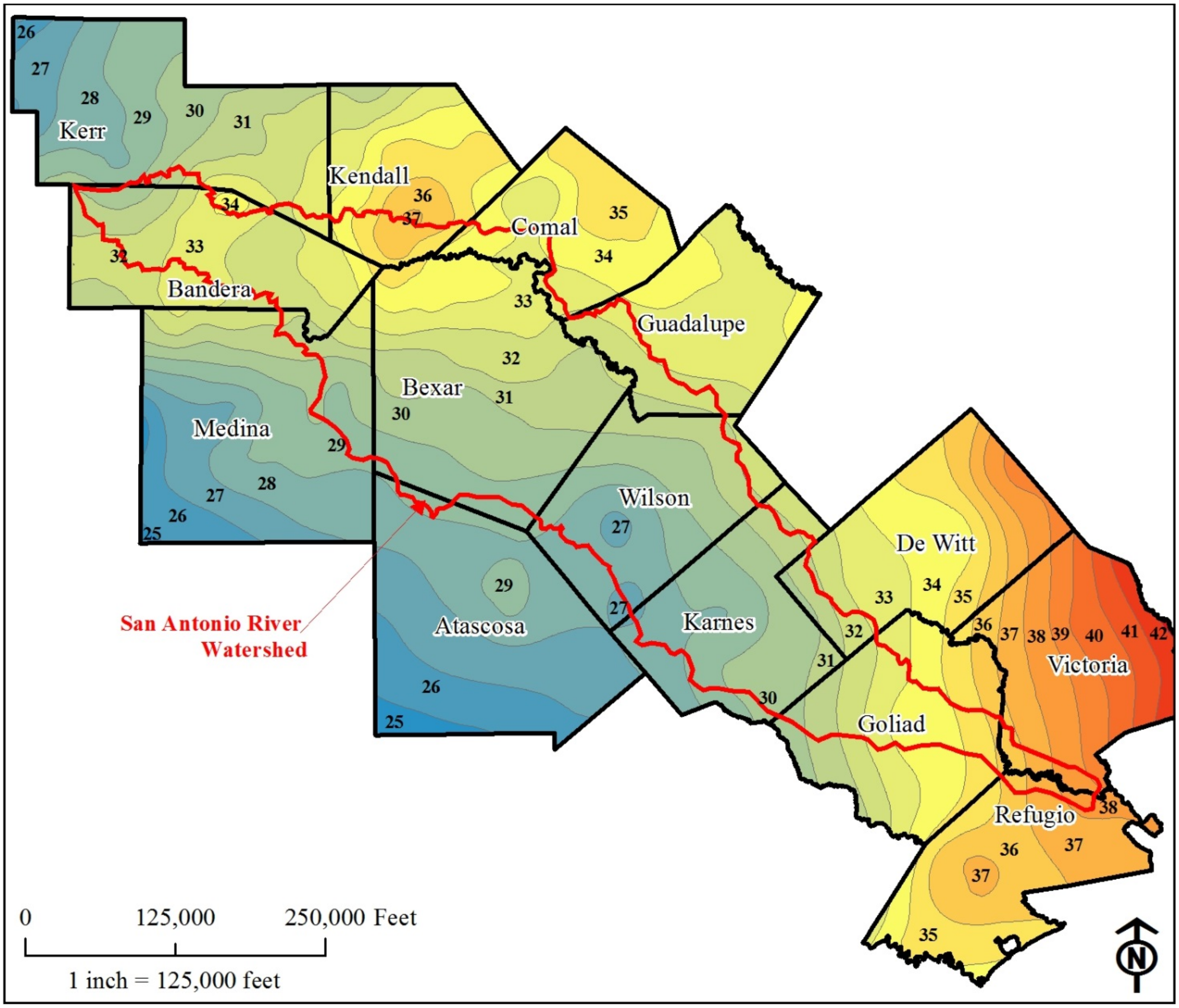
4.1 Climate

The San Antonio region experiences a modified subtropical climate (NOAA, 2010). The north-west part of the San Antonio River Watershed is located just east of a semi-arid area and as the watershed moves downstream (south and east) toward the coast, the climate becomes more wet and humid (NOAA, 2010). Annual rainfall within the San Antonio River Watershed counties range from 25 to 42 inches based on data collected between 1981 and 2010 (USDA/NRCS, 2012). However, the monthly and annual precipitation amounts are highly variable (NOAA, 2010). The annual rainfall for the watershed is shown in Figure 2. Rainfall intensities below 1.1 inches per hour make up 90% of the annual rainfall and 78% of the annual runoff is from storms that are an inch or less (TCEQ, 2005). The summer months typically have limited rainfall; however, heavy rainfall events do occur, usually due to storms off the Gulf of Mexico or stalled cool fronts. On average, the heaviest rainfalls occur in May, September, and October and the driest months are from December through March, and July (NOAA, 2010). Rainfall data can be downloaded for the entire nation through the United States Department of Agriculture Natural Resources Conservation Service Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/).

Areas in the northern portion of the San Antonio River Watershed are part of what is known as "Flash Flood Alley." In this area, storms tend to stall out along the Balcones escarpment, creating rainfall events that have dumped record amounts of rain usually in less than 48 hours. The steep slopes, thin soils, exposed bedrock, and sparse vegetation also cause rapid runoff, adding to the flash flood potential (Votteler, 2000).

The average monthly temperatures for the region range from the 50s in winter to the 80s in summer (NOAA, 2010). Summers are often long with a more tropical climate and daily temperatures above 90 degrees over 80% of the time. During the winter, freezing temperatures occur on average during 20 days out of the year.

Figure 2: Annual Rainfall throughout the San Antonio River Watershed



GIS Data Source: USDA/NRCS, 2012.

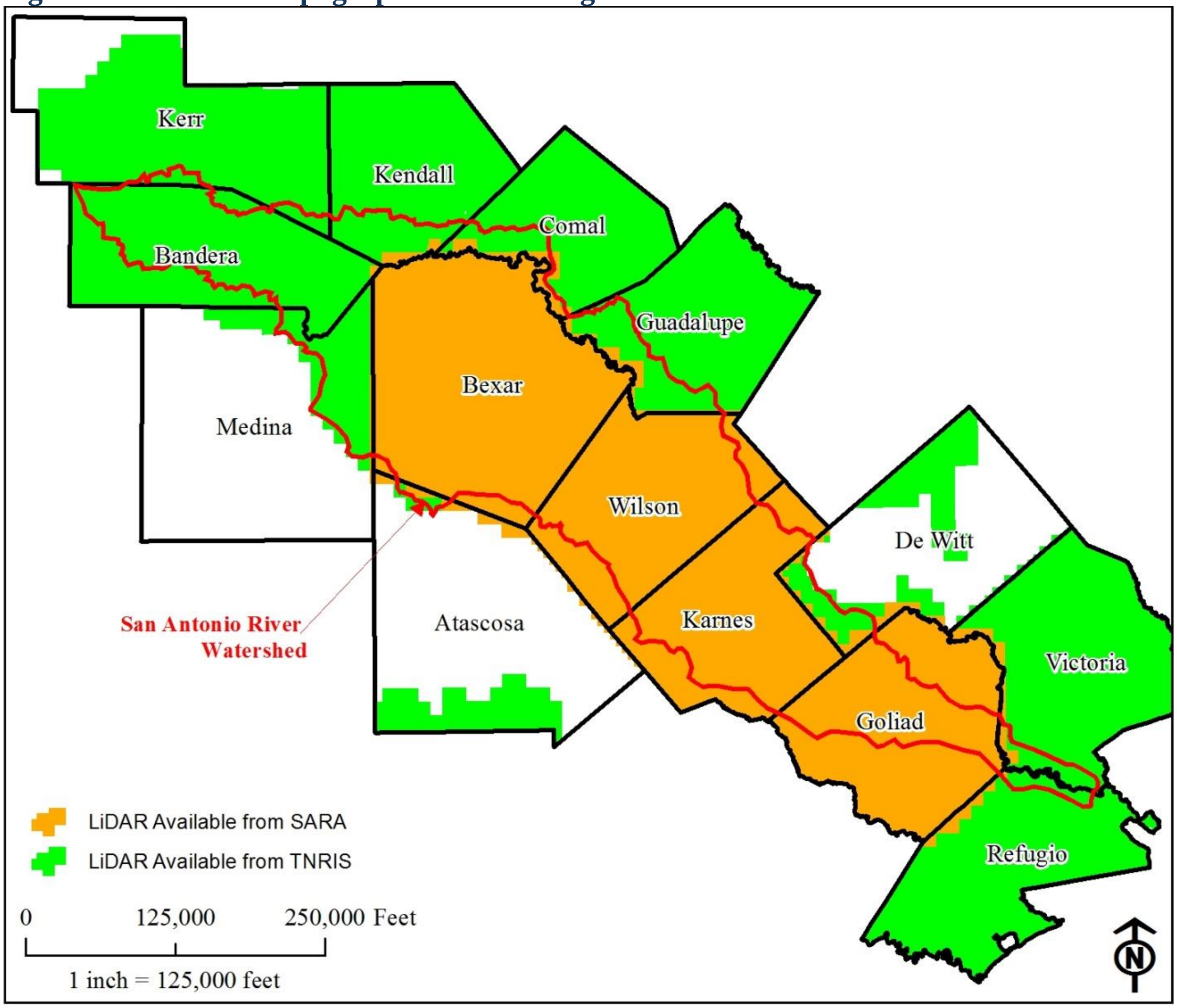
4.2 Topography

Elevations range from about 2,300 feet above sea level in the head waters of the Medina River to about 2 feet at the outfall in Refugio County. The physiography varies from rough and rugged terrain with narrow valleys and thin soil cover above the Balcones escarpment at the Northwest portions of the watershed to flat prairie areas near the mouth of the river (TWC, 1963). Runoff from the San Antonio region is slow due to soils on nearly level to gently sloping uplands and stream terraces. Slope gradients range from 0 to 3% and sometimes up to 5% (USGS, 1997).

LiDAR data are available from SARA for Bexar, Wilson, Karnes and Goliad Counties and information for obtaining this data is available through www.sara-tx.org. LiDAR is also available for areas outside these four counties, as shown in **Figure 3**. The Texas Natural Resource Information

System (TNRIS) offers LiDAR for various locations throughout Texas. Additional information for those areas can be found at https://tnris.org/order-data/. If LiDAR is not available for the study area, TNRIS also has a collection of Digital Elevation Models from the USGS that are available for download at http://www.tnris.org/get-data.

Figure 3: Available Topographic Data throughout the San Antonio River Watershed



GIS Data Source: San Antonio River Authority, 2014 and TNRIS, 2014.

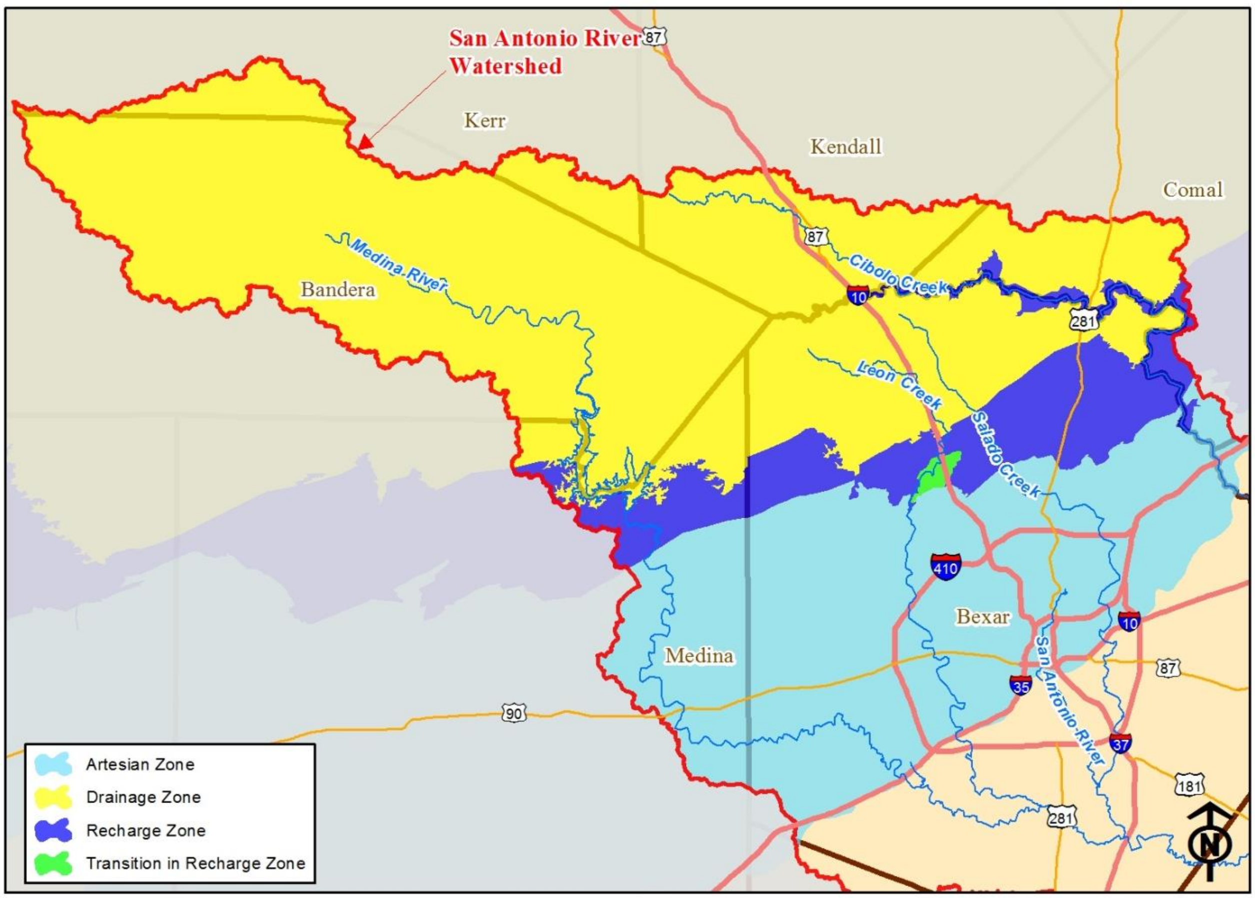
4.3 Soil and Geology

The upper portion of the San Antonio River Watershed is located within the Edwards Plateau of the Great Plains. Soils on the Edwards Plateau are primarily thin limestone. The steep slopes, sparse vegetation, thin soils, and underlying geology in this area contribute to high runoff rates (TIFP & SARA, 2011). Downstream of the Balcones Fault line, the watershed is located within the Gulf Coastal Plains region (NOAA, 2010). The soils in the Gulf Coastal Plains area consist of deeper, well drained, slowly permeable soils formed in ancient alluvial sediments. The soils are on nearly level to gently sloping, plane to slightly concave erosional uplands and stream terraces. These are formed in calcareous clay loams 6 to 10 feet thick over mudstone or sandstone (USGS, 1997). Soil information for specific project areas can be downloaded from the Natural Resources Conservation Service (NRCS) Web Soil Survey at http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Figure 4 shows the portions of the San Antonio River Watershed that are located within the four main zones of the Edwards Aquifer. The northwest portion of the San Antonio River Watershed is located within the drainage zone of the Edwards Aquifer. The drainage zone includes the catchment area to the recharge zone of the Edwards Aquifer. The aquifer outcrops to the land surface within the recharge zone allowing large quantities of water flow directly into the aquifer through sinkholes, caves, and fractures at the surface. Approximately 75 to 80% of the total recharge to the aquifer is estimated to occur when streams and rivers cross the recharge zone (Eckhardt, 2014).

The boundary for the Edwards Aquifer can be obtained from the Texas Water Development Board at http://www.twdb.texas.gov/mapping/gisdata.asp.

Figure 4: Edwards Aquifer Zones and the San Antonio River Watershed



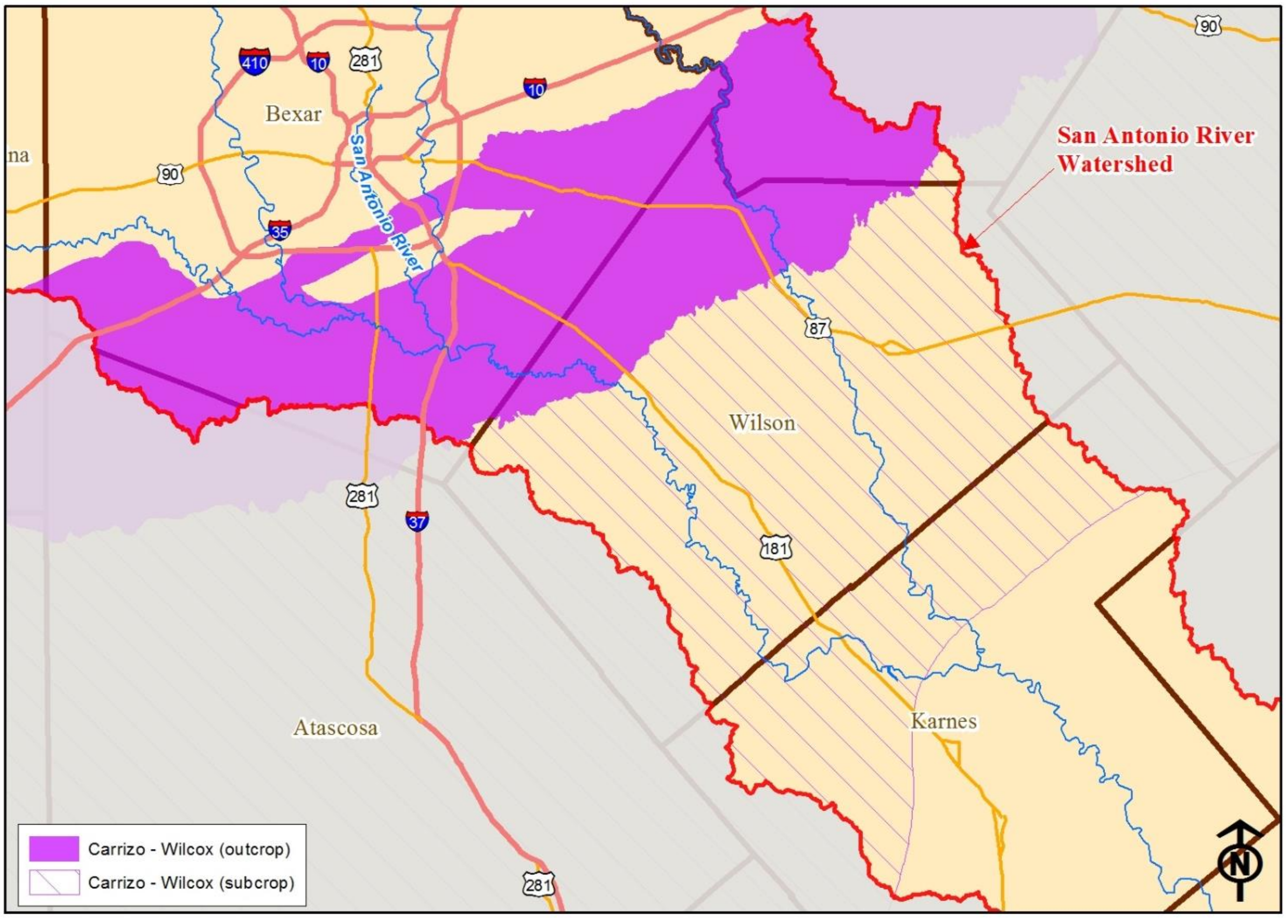
GIS Data Source: Edwards Aquifer Authority, 2006.

The Edwards Aquifer is a karst aquifer and creates a unique and complex set of conditions for the upper San Antonio River watershed hydrology. Karst aquifers are formed from the dissolution of soluble rocks, including limestone present in this region. The aquifer has large numbers of karst features where surface water and ground water are interconnected, creating a single flow system.

Karst features usually develop in areas where soluble bedrock has dissolved creating potentially large conduits. These features may include sinkholes, sinking streams, disappearing streams, caves, and karst streams. Karst systems may have unique impacts on hydrology, such as internal drainage through sinkholes, underground diversions, temporary groundwater storage in an epikarst zone, rapid flow through conduits, and discharge of subsurface water into perennial springs from conduits. For these areas, data requirements for hydrogeological investigations and hydrology studies require more intense investigation and the flow system cannot be characterized by conventional methods (Taylor and Greene, 2008). Karst streams can be inactive during low flow and rarely contain year round flow, unless covered by impermeable layers. Flow in karst streams usually occurs when flow rates exceed the infiltration rate of the karst features (Stokes et al., 2006).

The central portion of the San Antonio River Watershed lies over the southern portion of the Carrizo-Wilcox Aquifer, as shown in **Figure 5**.

Figure 5: Carrizo-Wilcox Aquifer and the San Antonio River Watershed



GIS Data Source: TWDB, 2006.

The Wilcox Group and the overlying Carrizo Formation form a hydrologically connected system known as the Carrizo-Wilcox aquifer. This aquifer covers Louisiana, Arkansas, and over 60 counties in Texas. The southern region of the Carrizo-Wilcox aquifer receives the majority of its water from the Rio Grande, Nueces, San Antonio, Guadalupe, Colorado, and Lavaca River basins. The Carrizo-Wilcox aquifer is formed mostly of sand mixed with gravel, silt, clay, and lignite. Irrigation is the predominant water use in the South Texas region, causing water level declines in the aquifer by as much as 100 feet (Thorkildsen and Price, 1991).

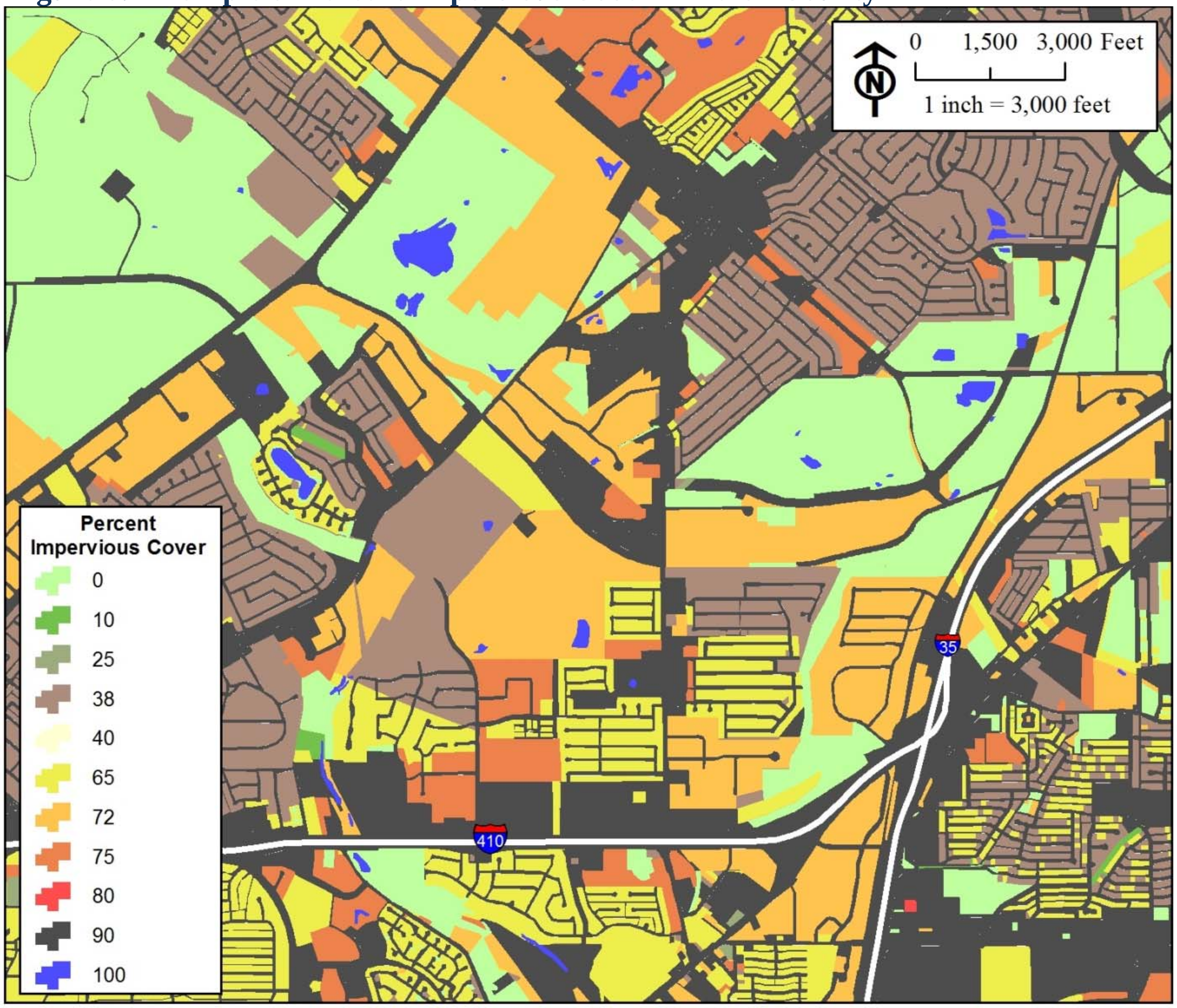
4.4 Land Use

The San Antonio River watershed includes both low density rural areas and high density urban areas. Because of the impact of impervious cover on the hydrograph, the land use and percent impervious of the project drainage area must be considered by the designer. Typically, watersheds with impervious cover greater than 15% are considered urban and will result in increased peak flow and reduced time of concentration. Impervious cover data are often estimated based on land use type. **Figure 6** shows the percent impervious cover for a sample area in east central Bexar County.

Existing and future land use data for Bexar County is available upon request and approval from the San Antonio River Authority. Requests can be submitted at https://www.sara-tx.org/public_resources/contact_us.php?to=cfeizollahi. Existing land use for the Edwards Aquifer is available for download from Texas Commission on Environmental Quality at https://www.tceq.texas.gov/gis/metadata/edw_lulc_met.html. For all other areas, the National Land Cover Database offers 30-meter resolution raster land use data and can be downloaded from the United States Department of Agriculture's Natural Resources Conservation Service Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/).

The percent of developed land in the upstream watershed and amount of impervious surface can have significant impacts on hydrology and sediment supply. Impervious cover increases downstream peak flows and reduces the time of concentration. Streams with highly impervious watersheds often have a reduced sediment supply from the contributing watershed. The risk of erosion increases with increasing drainage area, increasing percent impervious cover, and the erodibility of bank particles.

Figure 6: Example of Percent Impervious Cover in Bexar County



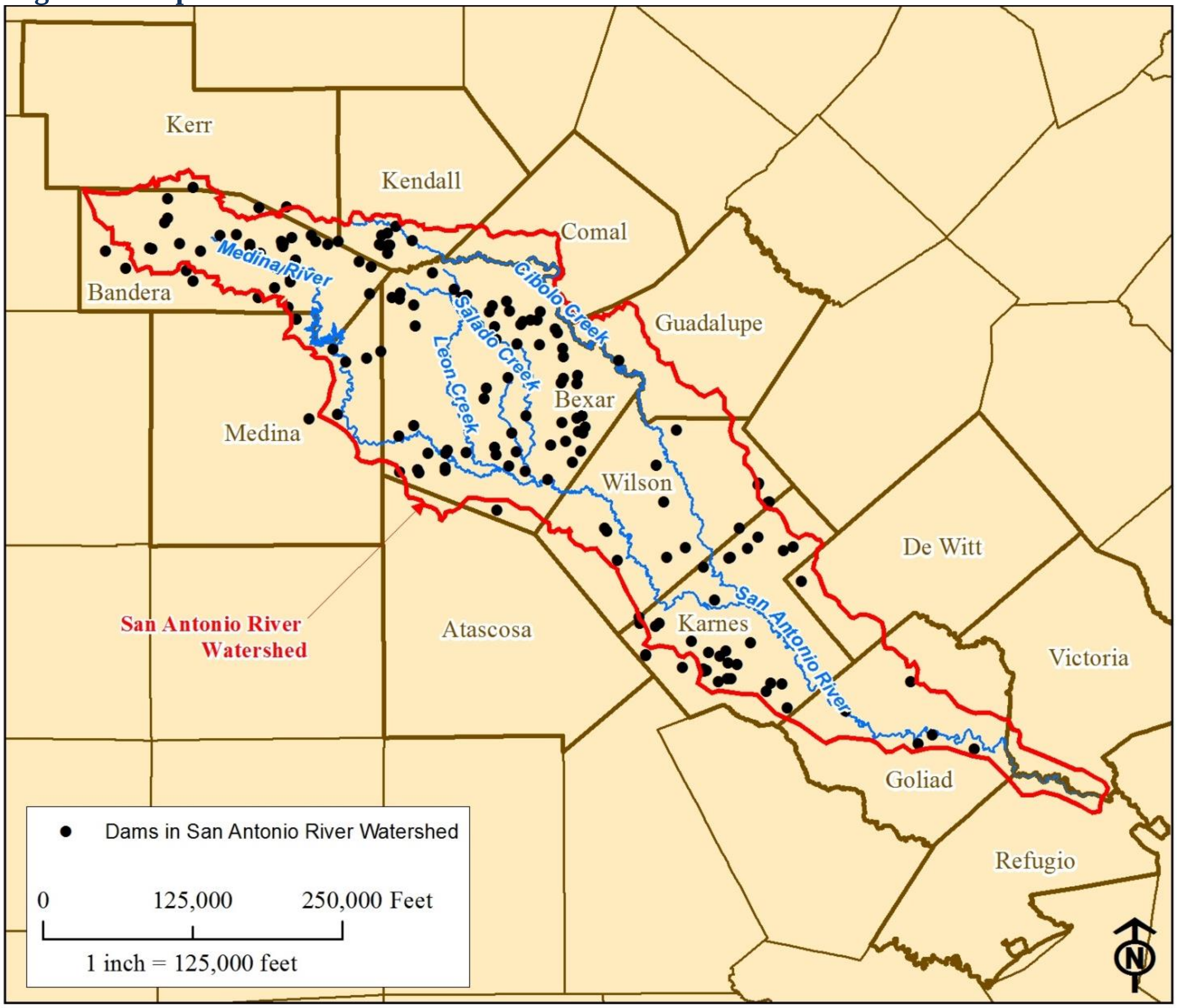
GIS Data Source: San Antonio River Authority, 2014.

4.5 Impoundments

The San Antonio River Watershed includes a large number of dams and drainage systems designed primarily for flood control. The watershed includes a large number of public and private dams. The locations of dams in the watershed are shown in **Figure 7**. Dams and other impoundments have an impact on the hydrology of the watershed, sediment transport, stream stability, water quality and habitat. These impacts may be especially significant in the upper reaches of the San Antonio River Watershed. During low flow periods, the impoundments may leave portions of creeks disconnected throughout the watershed, which is further complicated during times of drought when creeks can become dry.

Information on the location of dams in the San Antonio Watershed is available for download from SARA at https://www.sara-tx.org.

Figure 7: Impoundments in the San Antonio River Watershed

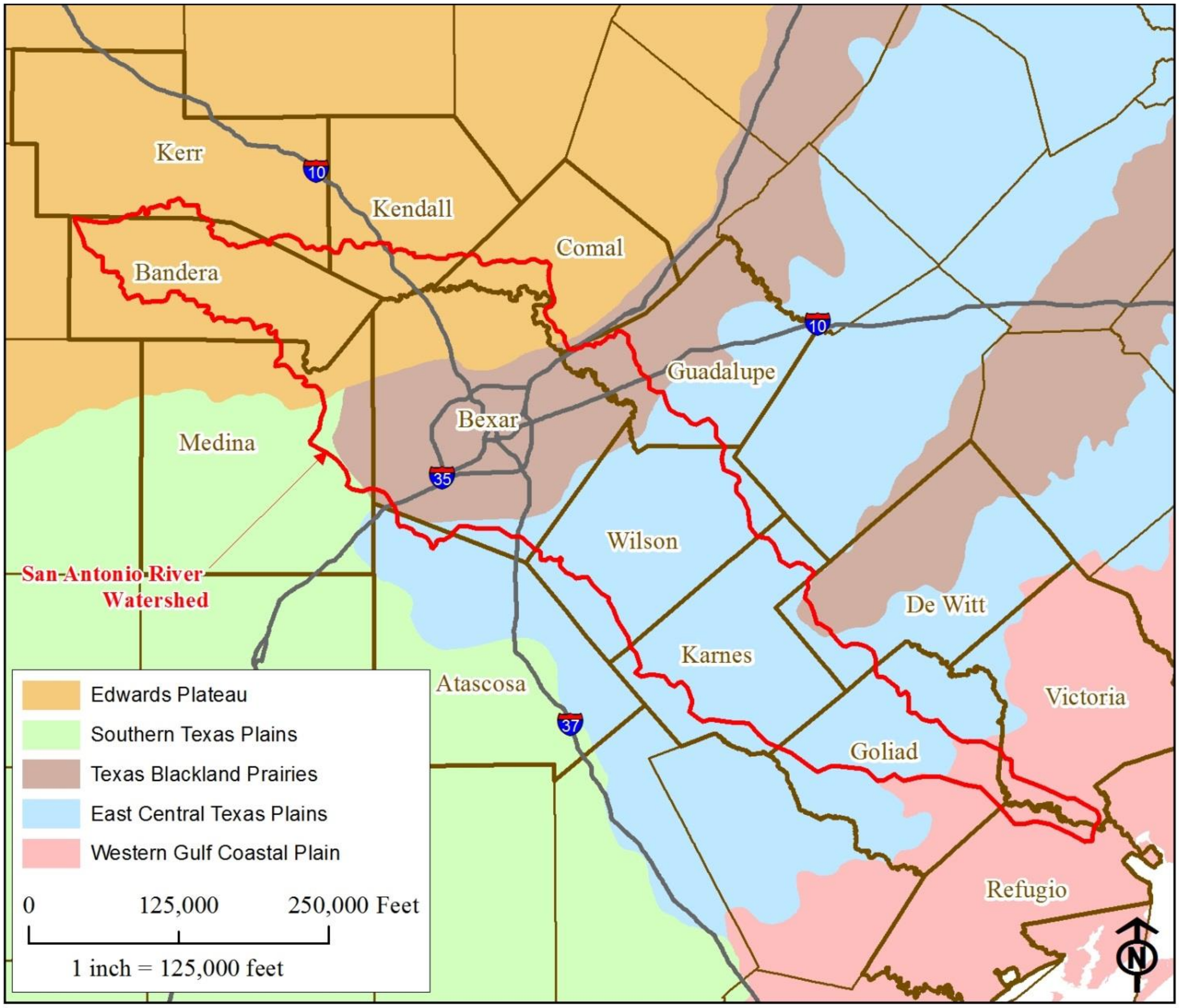


GIS Data Source: San Antonio River Authority, 2014.

4.6 Ecology of the San Antonio River Watershed

The San Antonio River basin is located within five Texas ecoregions: the Edwards Plateau (Hill Country), the Texas Blackland Prairies, the East Central Texas Plains, Western Gulf Coastal Plains and the Southern Texas Plains, though the bulk of the watershed is within the first three of these ecoregions listed, as shown in **Figure 8**. The Edwards Plateau is separated by the Balcones Escarpment, a geologic fault zone that divides the Edwards Plateau from the coastal plains and is dominated by karst topography in areas of the limestone plateau. The Texas Blackland Prairie region is composed of clayey soils and contains higher percentages of cropland than adjacent regions, though large areas are being converted for urban and industrial use. This is definitely the case within Bexar County, where the portion of the San Antonio River Watershed that includes Blackland Prairie is highly urbanized. The East Central Texas Plains has sands in the uplands and clay in the low-lying areas, with many areas of dense clay that impact water movement. The area is mostly used for pasture and range (Griffith et al. 2004).

Figure 8: Ecoregions for the San Antonio River Watershed



GIS Data Source: EPA, 2012.

4.7 Water Quality

During the planning phase of a potential stream restoration project, practitioners should consider water quality impairments at or downstream of the proposed sites. Numerous studies have been or are currently being conducted to assess the potential impact of stream restoration on water quality downstream. Improvements to the riparian buffer, native vegetation density, and stream stability are several components to stream restoration projects that are considered to have a positive impact on downstream water quality. In addition, structural BMPs, green infrastructure, and LID devices improve the receiving waters quality and should be considered as part of stream restoration projects. In partnership with the Bexar Regional Watershed Management (BRWM), SARA developed a manual that outlines standard practice for design and implementation of BMPs and LID, the San Antonio River Basin LID Technical Guidance Manual (Dorman, et al., 2013).

The Texas Commission on Environmental Quality (TCEQ) assesses the condition of surface waters throughout the State of Texas. The assessments are based on support of designated beneficial uses determined by compliance with water quality objectives. As required under Sections 303(d) and 305(b) of the Federal Clean Water Act, the TCEQ prepares a list of impaired waters to be released every two years, referred to as the 303(d) list. The findings are provided in the Texas Integrated Report of Surface Water Quality.

The TCEQ has released the draft 2014 report for waterbodies within the San Antonio region. The supporting documents include the draft 303(d) list summary of impaired water body-pollutant combinations, the water bodies with concerns for use attainment and screening levels, and also a detailed water body assessment for the San Antonio Basin. The predominant water quality impairments within the region are fecal indicator bacteria (twelve segments are listed) and low dissolved oxygen (four segments are listed). However, there are also listings for impaired fish community in two segments, and one listed segment each for PCBs in edible tissue, impaired macrobenthic community, and chloride.

Table 4-1: 2014 Draft 303(d) Listings (Category 5) for the San Antonio River Basin

Segment ID	Reach	Water Body	Pollutant	Listing Category
1901A	01	Escondido Creek	bacteria	5c
1901B	01	Cabeza Creek	bacteria	5c
1902	01	Lower Cibolo Creek	bacteria	5b
1902	02	Lower Cibolo Creek	bacteria	5b
1902	03	Lower Cibolo Creek	bacteria	5c
1902C	01	Clifton Branch	bacteria	5c
1902C	01	Clifton Branch	depressed dissolved oxygen	5c
1903	02	Medina River below dam	bacteria	5c
1905	01	Medina River Above Medina Lake	impaired fish community	5c
1906	04	Lower Leon Creek	depressed dissolved oxygen	5a
1906	03	Lower Leon Creek	PCBs in edible tissue	5a
1906	04	Lower Leon Creek	PCBs in edible tissue	5a
1906	05	Lower Leon Creek	PCBs in edible tissue	5a
1906	06	Lower Leon Creek	PCBs in edible tissue	5a
1908	02	Upper Cibolo Creek	bacteria	5c
1908	01	Upper Cibolo Creek	chloride	5c
1908	02	Upper Cibolo Creek	chloride	5c
1908	03	Upper Cibolo Creek	chloride	5c
1910	03	Salado Creek	impaired macrobenthic community	5c
1910D	01	Menger Creek	bacteria	5c
1910D	01	Menger Creek	depressed dissolved oxygen	5c
1911	09	Upper San Antonio River	impaired fish community	5c
1911B	01	Apache Creek	bacteria	5a
1911C	01	Alazan Creek	bacteria	5a

Segment ID	Reach	Water Body	Pollutant	Listing Category
1911C	02	Alazan Creek	bacteria	5c
1911D	01	San Pedro Creek	bacteria	5a
1911D	02	San Pedro Creek	bacteria	5c
1911E	01	Sixmile Creek	bacteria	5c
1911H	01	Picosa Creek	depressed dissolved oxygen	5c
1911I	01	Martinez Creek	bacteria	5c

The predominant pollutants of concern, fecal indicator bacteria and low dissolved oxygen, should be considered during project planning and design. Stream restoration practitioners can use this data to determine one or more specific water quality parameters to target when implementing projects.

A review by Mayer, et al. (2007) of scientific literature on the impact of riparian buffer width on nitrogen loads to water bodies found a positive relationship between wider buffers and nitrogen removal effectiveness; however, the effectiveness varied significantly and other factors. Vegetation, subsurface hydrology, and subsurface biogeochemistry were also suggested in the report to play a role on nitrogen loads. Riparian buffers may also reduce sediment loads through filtration and settling, as a result, reducing sediment associated pollutants (including fecal bacteria, PCBs, and nutrients. An established buffer with canopy provides shade producing cooler stream temperatures for inland streams.

5.0 REGIONAL CURVES

5.1 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. Regional curves have been developed for the entire San Antonio region by SARA. This tool can be used in the San Antonio Region as an aid in watershed planning and conceptual designs. 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.

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) (Merigliano, 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., 2006).

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.

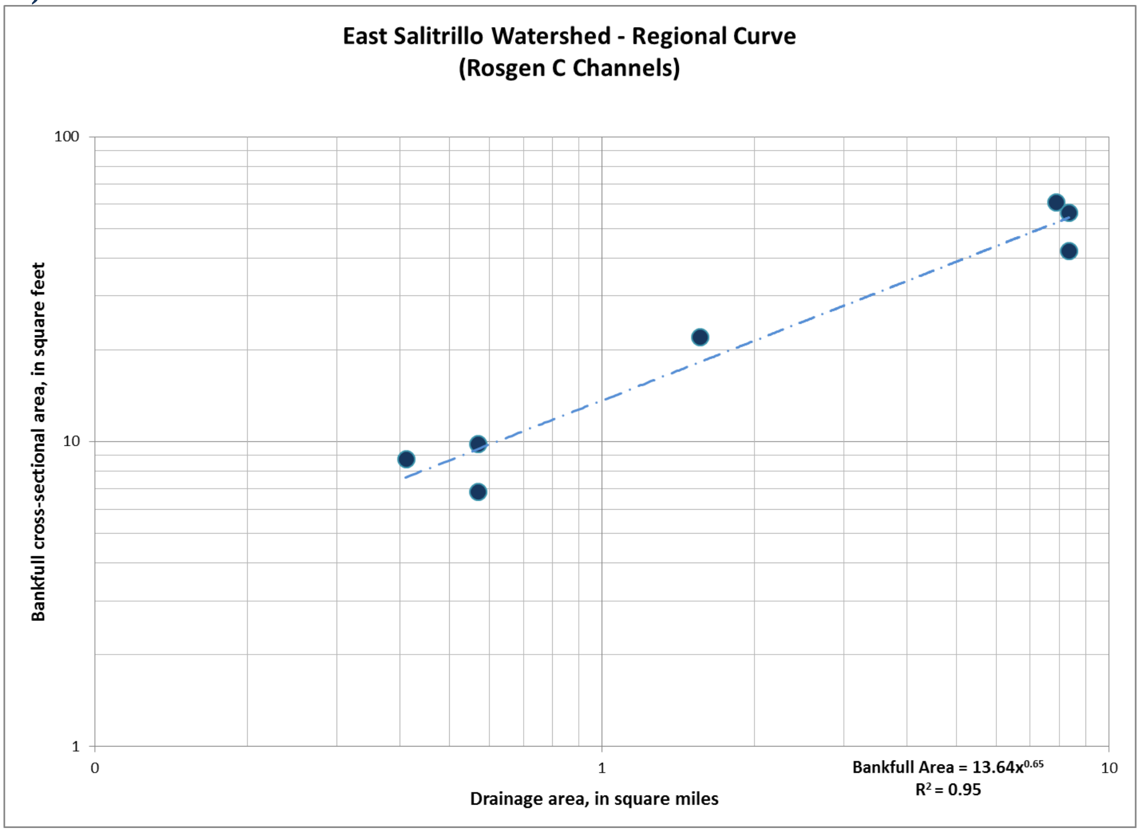
Gage station analyses throughout the United States have shown that the average return interval for the bankfull discharge is approximately 1.5 years, which equates to a 66.7% annual exceedance probability (Dunne and Leopold, 1978). Leopold et al. (1995) described floodplains which had a bankfull return 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.

More specifically, regional curves were 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). A map showing the hydrophysiographic regions is provided in *Appendix A*. Eighteen study sites were used, primarily within the upper portion of the San Antonio region and within Bexar County to develop the regional curve. The regional curve effort included statistical analysis to understand the impact of explanatory variables other than drainage area on the dimensions. Power function regression equations and multivariate statistics were used. The results show that drainage area is the best single predictor of channel dimension. The regional curves and supporting information are presented in *Appendix O*. Additional information and regional curve updates can be obtained through SARA.

5.2 Watershed-Specific Regional Curves

Watershed-specific regional curves are focused on smaller watersheds than the regional curves and as a result, should provide a more accurate representation of the geomorphic conditions of streams within that watershed. These can be used as an aid in designing the pilot or low flow channel within flood control projects. Existing Regional Curve study sites within a watershed of interest can be used as a starting point and expanded upon to develop the watershed-specific curves. An example of a watershed-specific regional curve that was developed for a demonstration project in the East Salitrillo Creek Watershed is shown in **Figure 9**, but should only be used for projects that are in or near the East Salitrillo Creek Watershed. Additional information and the curves for the East Salitrillo Creek Watershed can be found in *Appendix L*.

Figure 9: East Salitrillo Creek Watershed –Regional Curve (Bankfull Area vs Drainage Area)



Source: SARA, 2015.

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 B*. 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 **Figure 9** and *Appendix L* for 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 B* along with Rosgen (2006) is encouraged to provide a thorough understanding of the regional curve development process.

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 (see *Chapter 11*). 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 (for more information, refer to: https://www.sara-tx.org/public_services/gis_information/data/GISDataStandards/SARA_As_Built_Plans_Modified.pdf).

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:

1. **Identify the type of stream instability (e.g. vertical instability, lateral instability)**
2. **Identify the extent of the stream impairment (e.g. localized, widespread)**
3. **Identify the cause(s) of the stream impairment**
4. **Present the bankfull characteristics and discharge for the project site**
5. **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. Practitioners should use best available data for aerials within each of the four counties under SARA jurisdiction). 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:

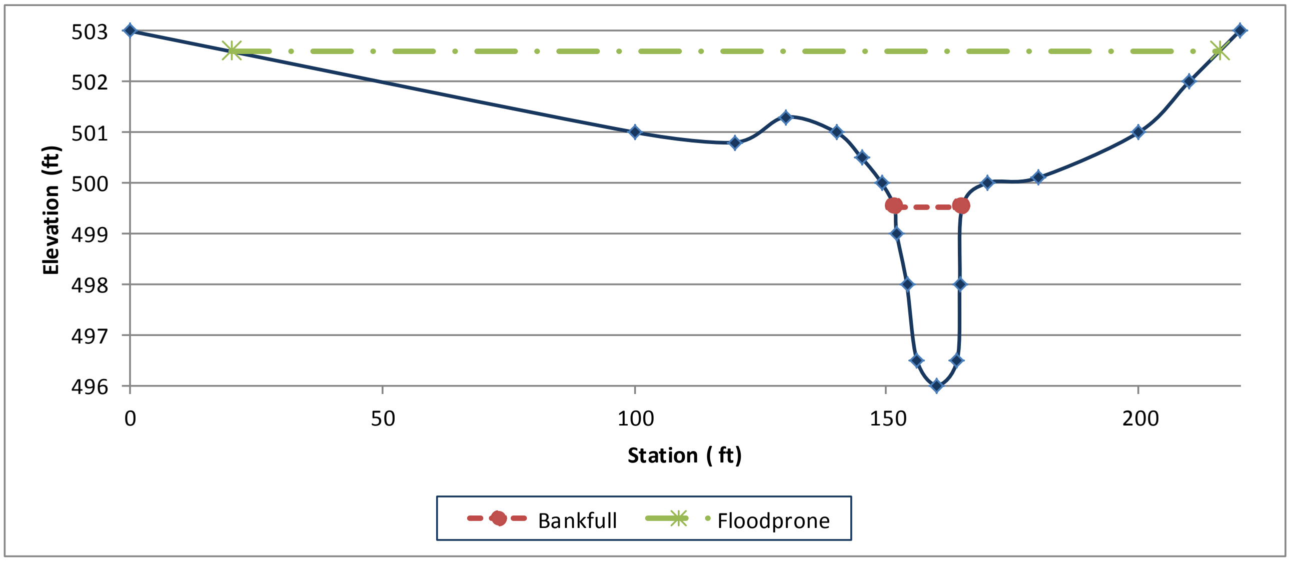
1. **Location of benchmarks**
2. **Direction of stream flow**
3. **North arrow**
4. **Map scale**
5. **Valley cross-section sketch**
6. **Terrace location and heights**
7. **Location of trees, rocks, debris and other features**
8. **Pool/riffle sequences**
9. **Gravel and sand bars**
10. **Cross-section locations**
11. **Longitudinal profile alignment and stationing**
12. **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 10** below.

Figure 10: Example cross-section survey plot and bankfull parameters

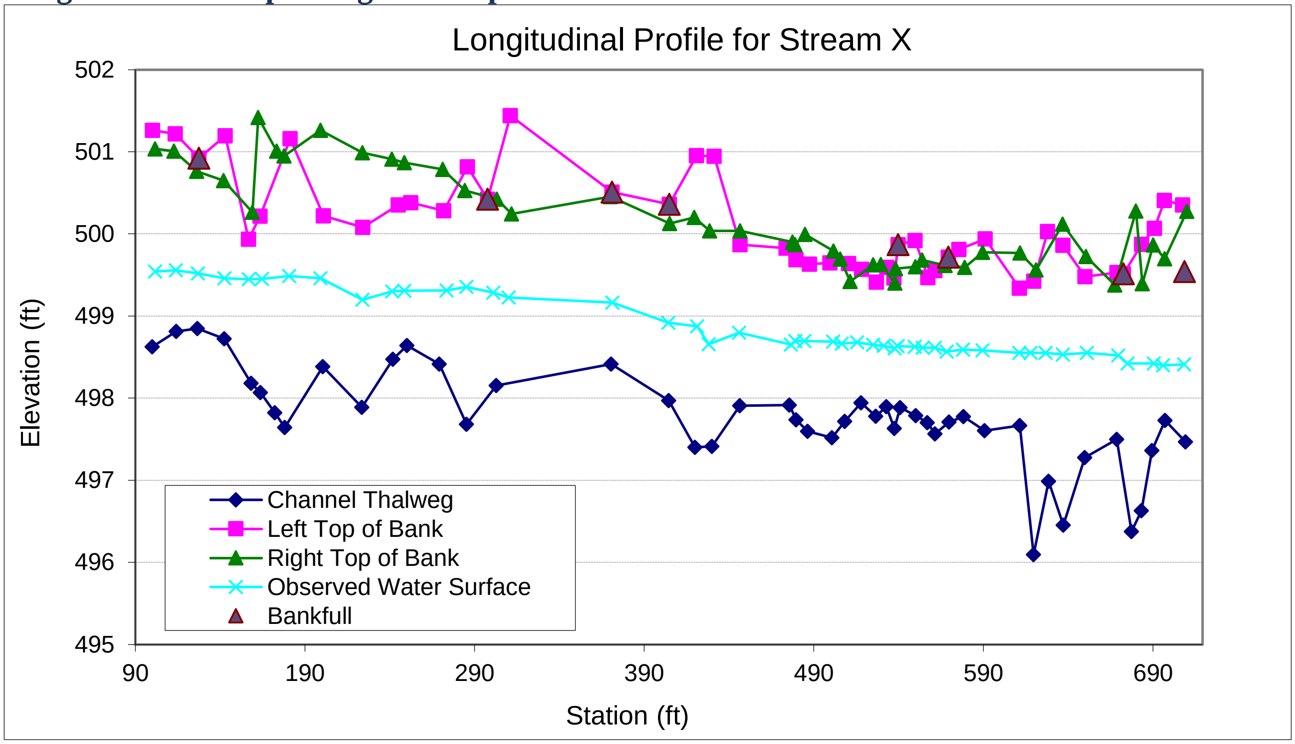
Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Riffle	E	20.3	13.47	1.51	3.4	8.94	1.2	8.2	499.52	500.28



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 11** for an example longitudinal profile.

Figure 11: 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

<u>Gravel and Cobble Bed Systems</u>

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 (see section 6.3). The numbers that follow the lettered stream type are provided in **Table 6-1**.

Table 6-1: Particle Size Designations

Type	Designation	Size Range
Bedrock	1	N/A
Boulder	2	> 256 mm
Cobble	3	64 – 256 mm
Gravel	4	2 – 64 mm
Sand	5	0.062 – 2 mm
Silt/Clay	6	< 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 USACE. 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 Chapter 5 on Regional Curves) 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 6.2.2*).

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 11*). 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:

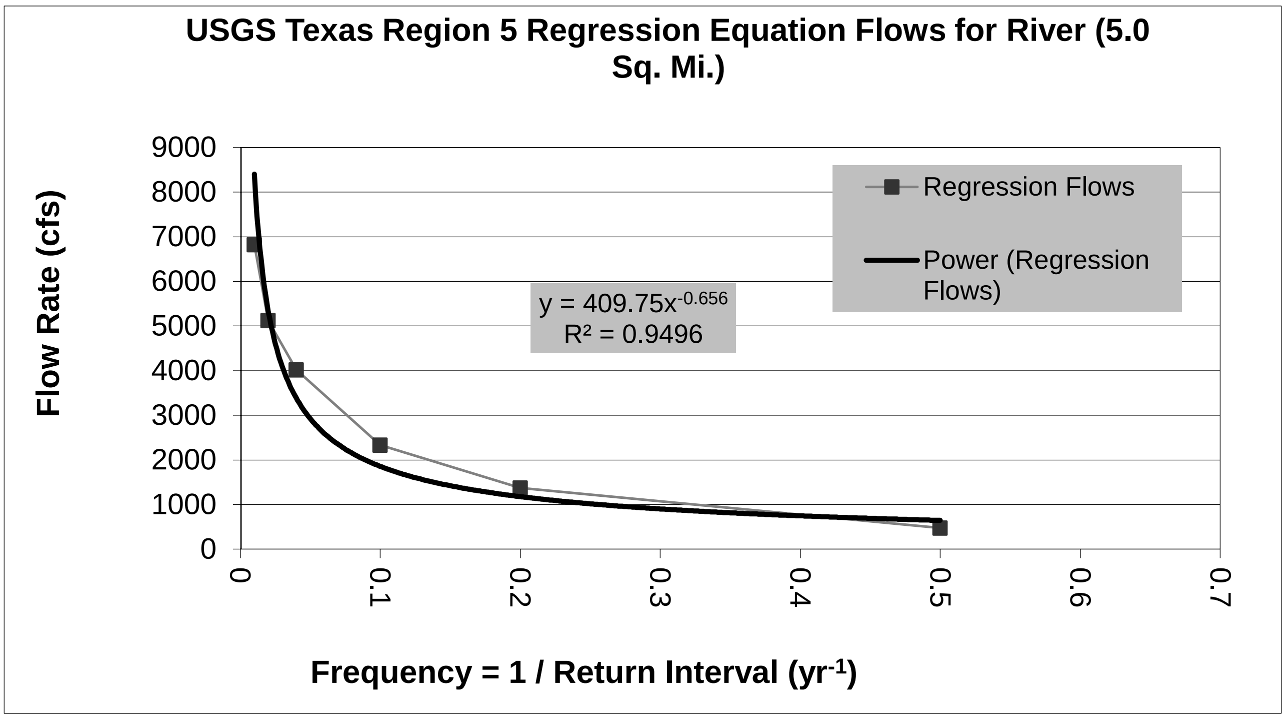
$Q_2=159A^{0.680}$

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

This is an example of flow estimate equations that can be used in the region. Additional studies have been performed. In 2009, Asquith published an approach to estimate regional annual peak-streamflow frequency estimates for nine recurrence intervals.

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 12** below can be developed, and the equation of the best fit power function can be plotted.

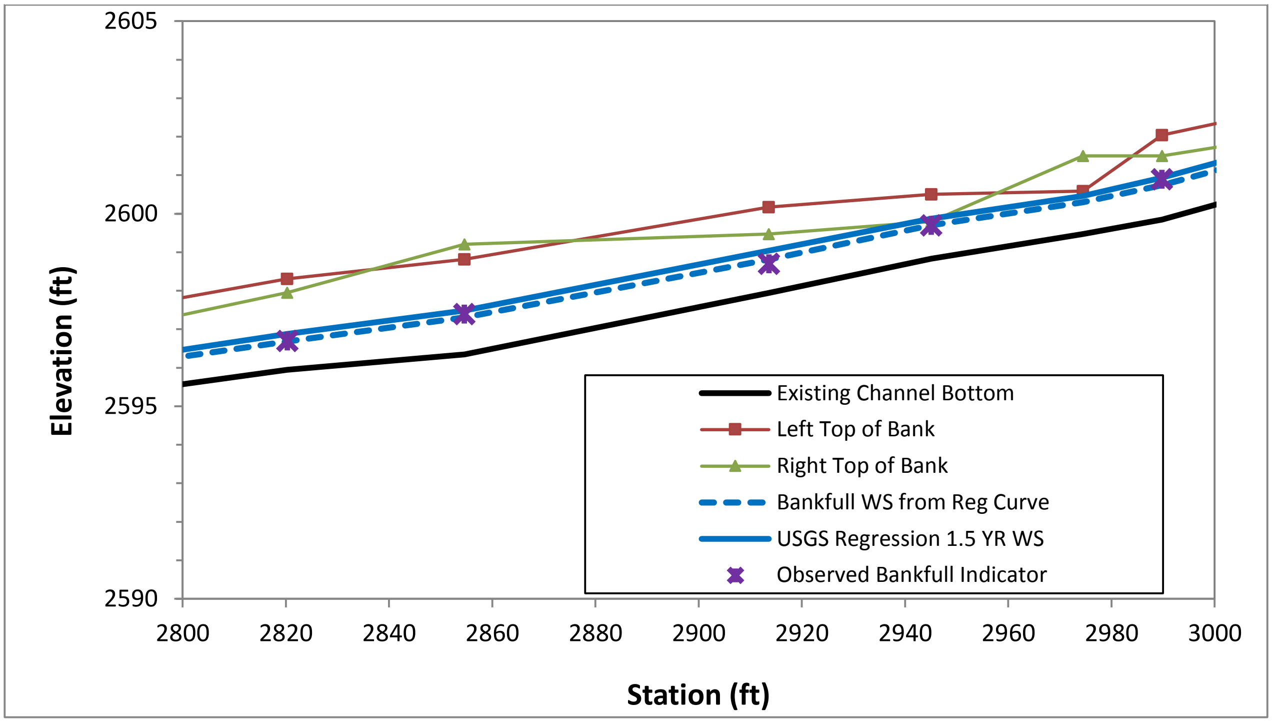
Figure 12: Example Application of USGS Texas Region 5 Regression Equation



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

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 13** 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 13: Comparison to Observed Bankfull Indicators with HEC-RAS Water Surface Profile Simulations

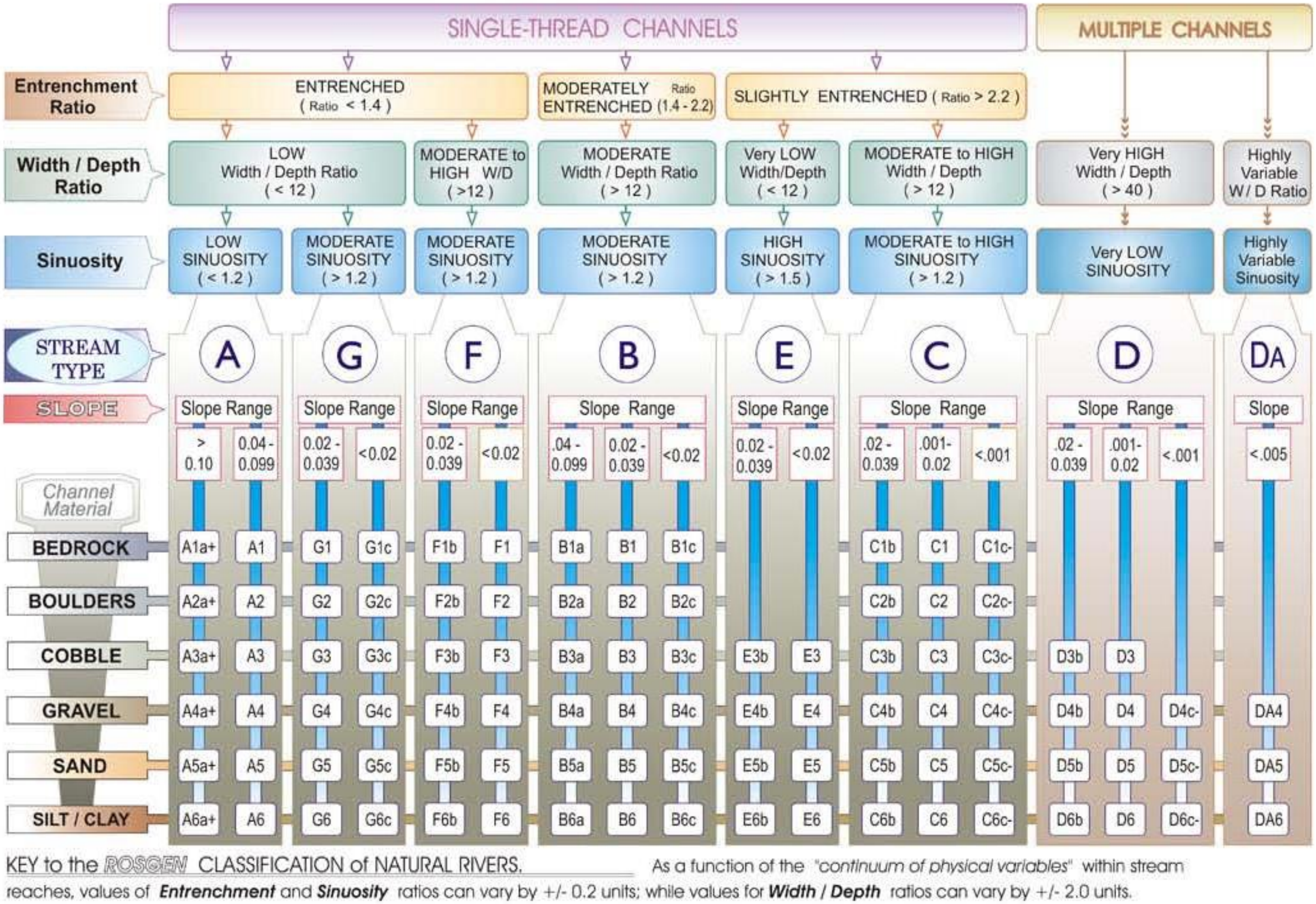


6.3 Stream Classification

In the Rosgen stream classification method (Rosgen, 1994, 1996), cross-sections are surveyed at riffles for the purpose of stream classification. **Figure 14** 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 15** 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).

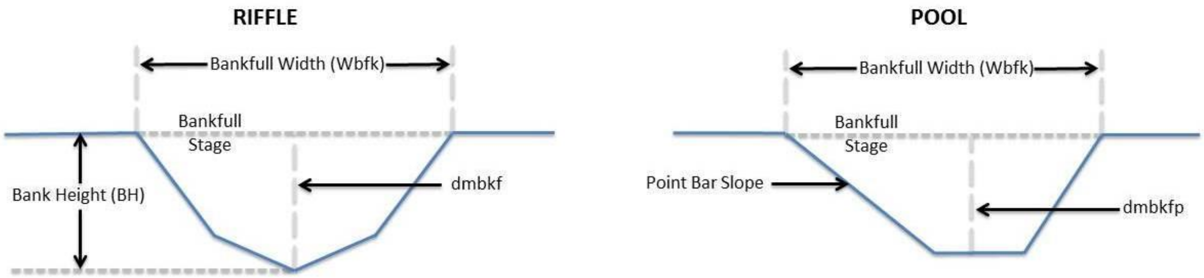
Finally, the numbers that coincide with each bed material classification are used as part of the Level II classification (see *Section 6.1.4.3*). For example, a Rosgen "E3" stream type is a narrow and deep, cobble-dominated channel, with access to a floodplain that is greater than two times its bankfull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

Figure 14: Classification Key for Natural Rivers



Source: Rosgen, 1996

Figure 15: Channel Dimension Measurements and Ratios



Channel Dimension Calculations
POOL WIDTH/RIFFLE WIDTH (Wbkfp/Wbkf)
MAX POOL DEPTH / MEAN RIFFLE DEPTH (dmbkfp/dbkf)
MAX RIFFLE DEPTH / MEAN RIFFLE DEPTH (dmbkf/dbkf)
RIFFLE WIDTH / MEAN RIFFLE DEPTH (Wbkf/dbkf)

$$\text{MEAN RIFFLE DEPTH (dbkf)} = \frac{\text{RIFFLE AREA (dbkf)}}{\text{BANKFULL WIDTH (Wbkf)}}$$

$$\text{BANK HEIGHT RATIO (BHR)} = \frac{\text{BH}}{\text{dmbkf}}$$

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

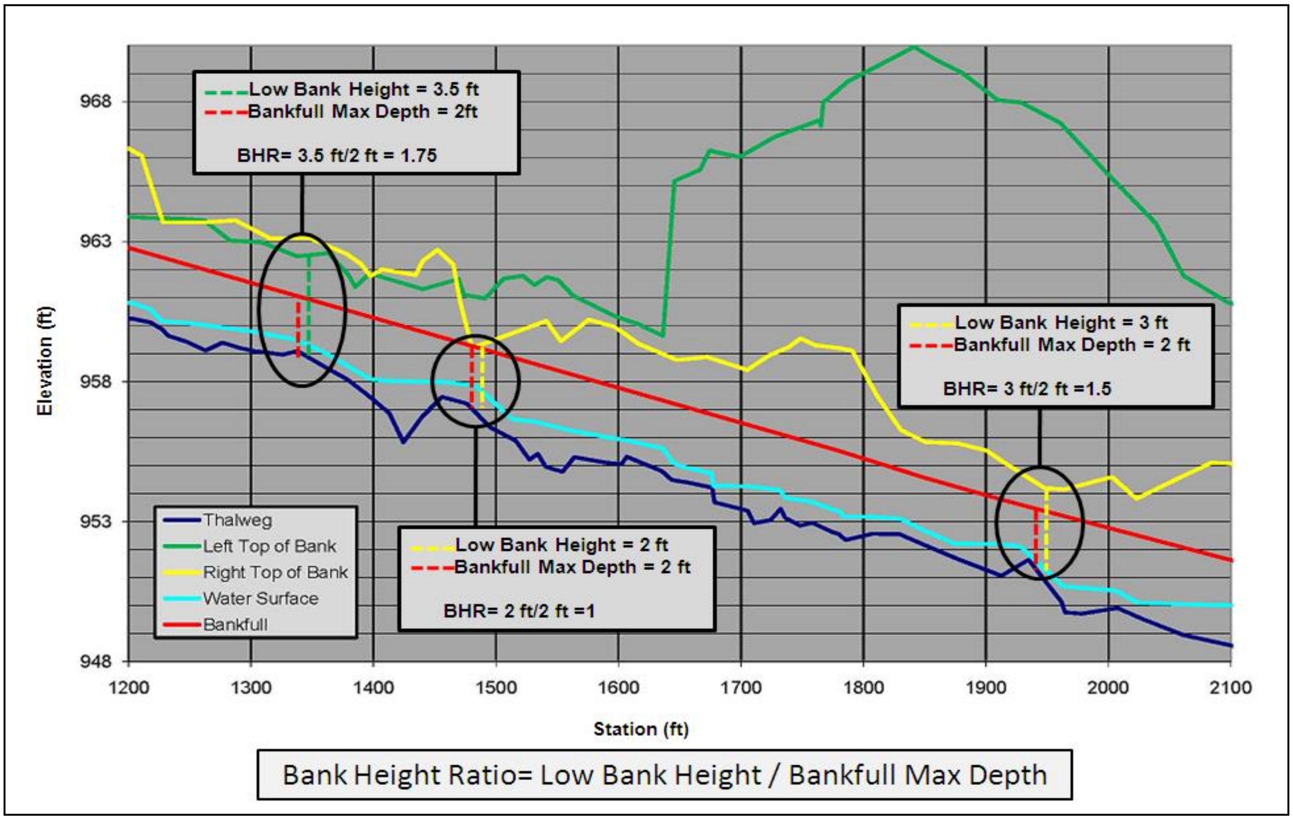
Bank height ratios are measured in the field to assess the degree of channel incision. The bank height ratio is measured as the ratio of the lowest bank height divided by a maximum bankfull depth. **Table 6-2** shows the relationship between bank height ratio (BHR) and vertical stability developed by Rosgen (2001), and **Figure 16** illustrates the method for calculating BHR.

Table 6-2: 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 16: Method for Calculating Bank Height Ratio (BHR)

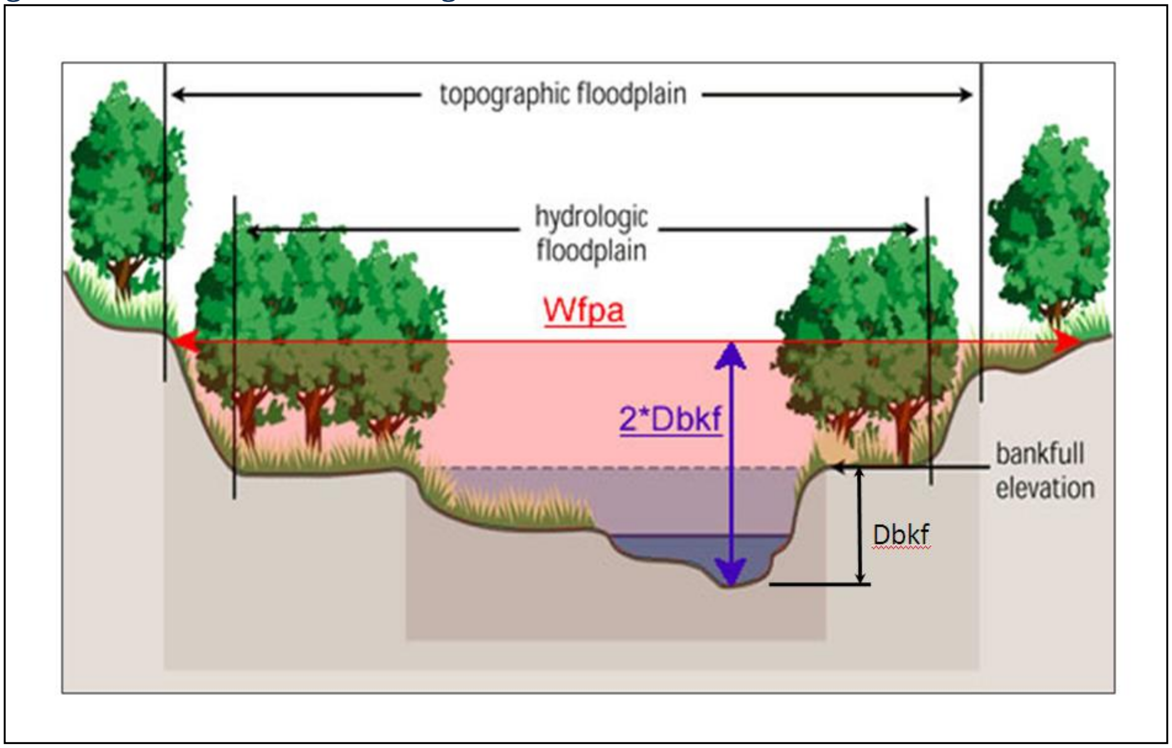


Source: Reprinted with permission from Stream Mechanics.

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 17.**

Figure 17: 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 knickpoint. 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. The Regional Modeling Standards developed by SARA, include a section on sediment transport (SARA, 2013).

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. If hard bedrock outcrops are evident along the channel, further incision of the channel is unlikely. Hanging outfall pipes, headwalls, and undercut trees are indicators that the channel has incised in the past and may be continuing.

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).

6.5.1 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.

6.5.2 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**
- **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, plane beds, 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,**

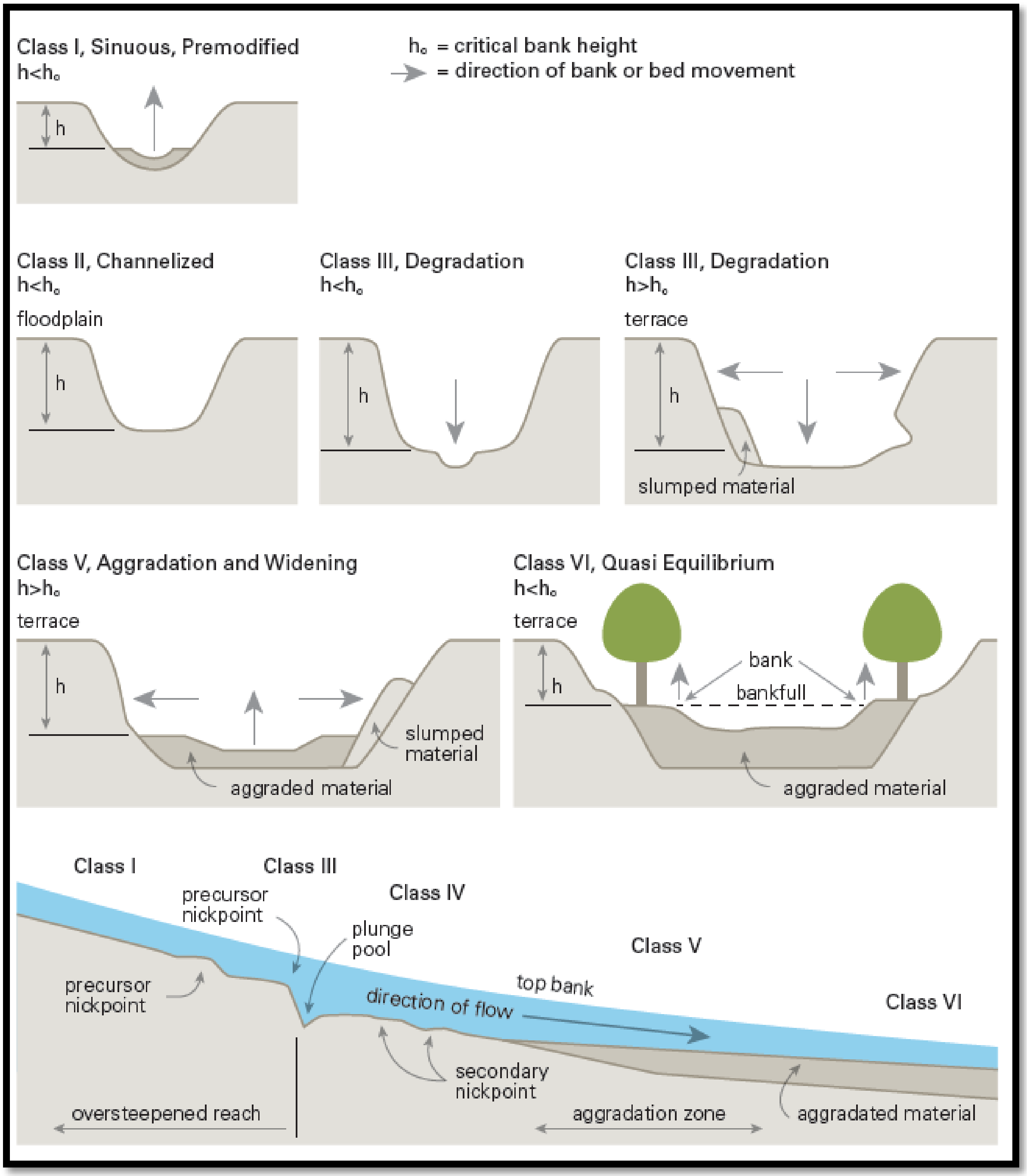
IV. **degradation and widening,**

V. **aggradation and widening, and**

VI. **quasi-equilibrium.**

Figure 18 illustrates the six steps of the Simon Channel Evolution Model.

Figure 18: Simon Channel Evolution Model

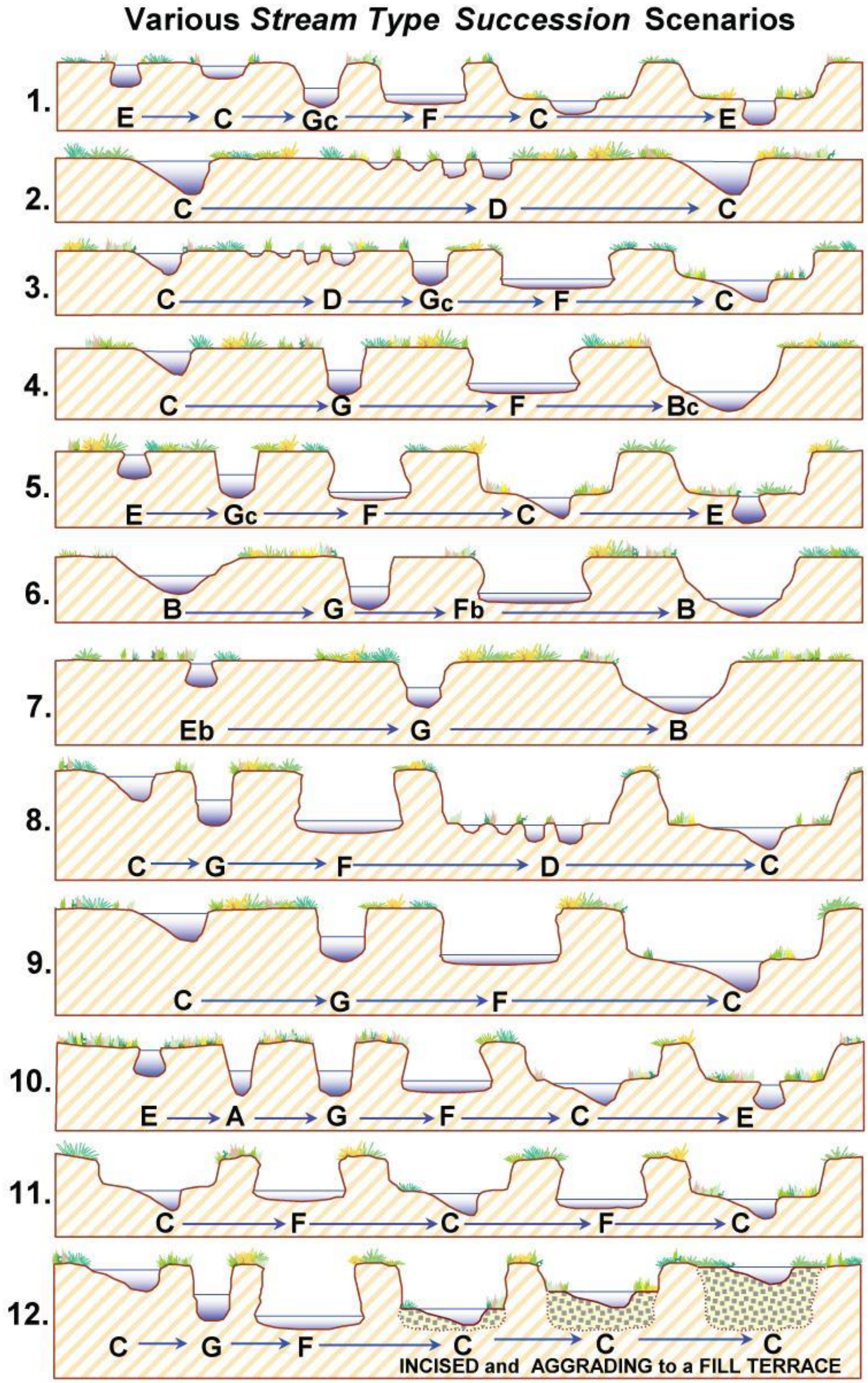


Source: Adapted from FISRWG (1998) and Simon (1989)

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 19**.

Figure 19: Various Stream Type Succession Scenarios



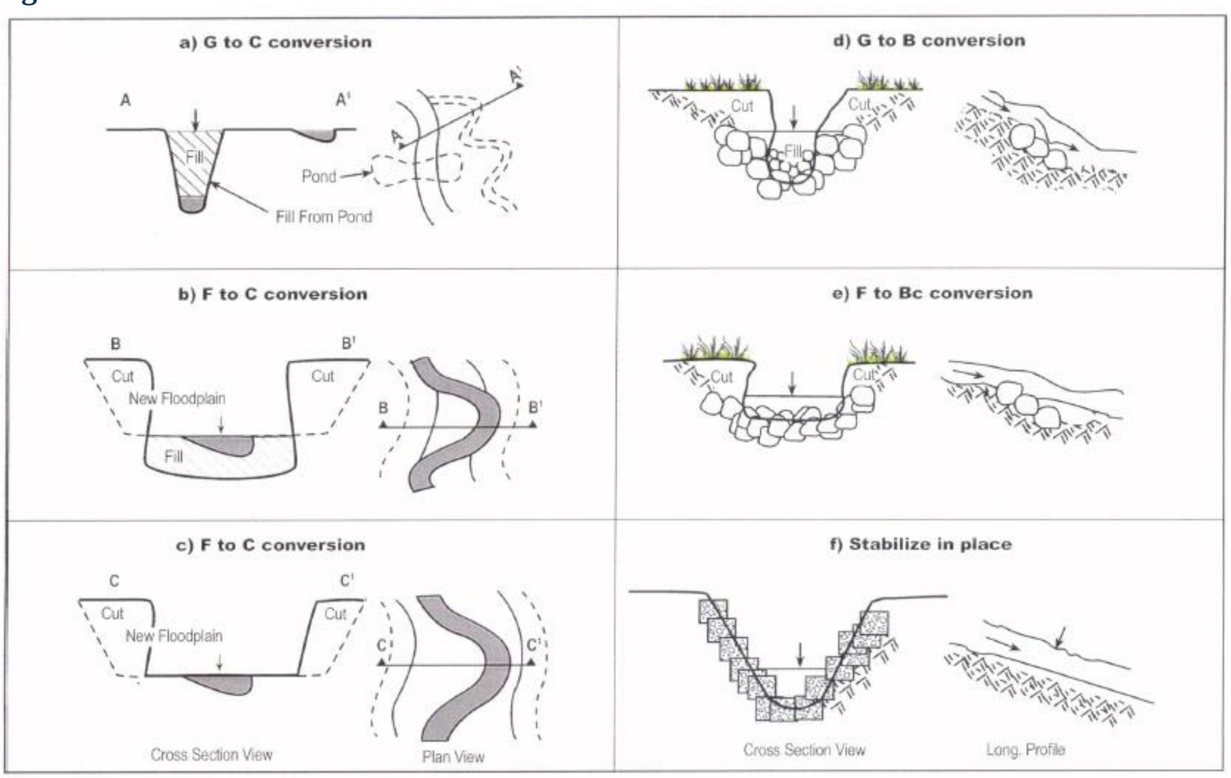
Source: Wildland Hydrology

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. There are 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*. As part of the Watershed Master Plans, SARA has developed a stream restoration potential assessment framework and completed planning level assessments of the condition of various streams within the San Antonio River watershed. Additional information about these assessments is available through SARA.

Figure 20: Restoration Priorities for Incised Channels



Source: Rosgen, 1997

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; these values could then be compared to the measured width-depth ratios of an impaired stream. Impaired streams that are experiencing significant bank erosion and widening would likely exhibit higher width-depth ratios than the reference reach 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 7*. Reference reach data represent the stable channel condition that is to be achieved through the restoration design. As discussed in *Chapter 7*, 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 restoration and relocation, 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 developed 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 types as the proposed design reach after restoration (i.e. C4, E5, etc.)**
- **Same valley type and approximate slope as study reach**
- **Same bed materials 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:

- US Geological Survey Quadrangle Maps – 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.
- Aerial Photographs – 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. These may not be available for all counties / areas. 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).

- Windshield Surveys – 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.
- Discussions with Local Residents – 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.
- Looking Upstream and Downstream of the Project Reach – 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 C*. 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)

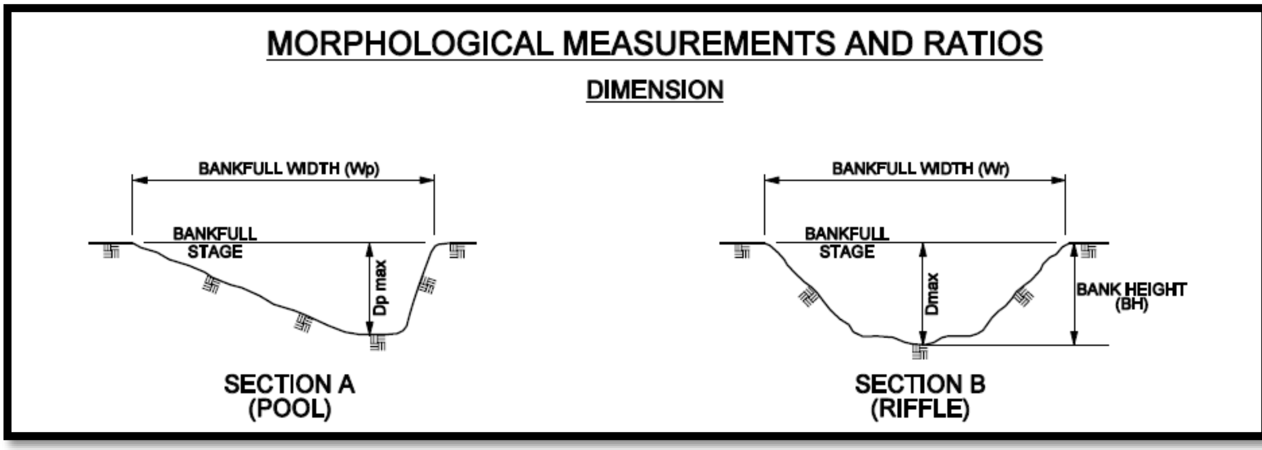
At least two riffle and one pool cross-sections are to be surveyed. For perennial streams with a drainage area greater than 5 square miles, a glide and run cross-section should also be completed. Points are taken at each break in slope along the cross-section, including the top of bank, bankfull, inner 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 21** along with information on measurement locations.

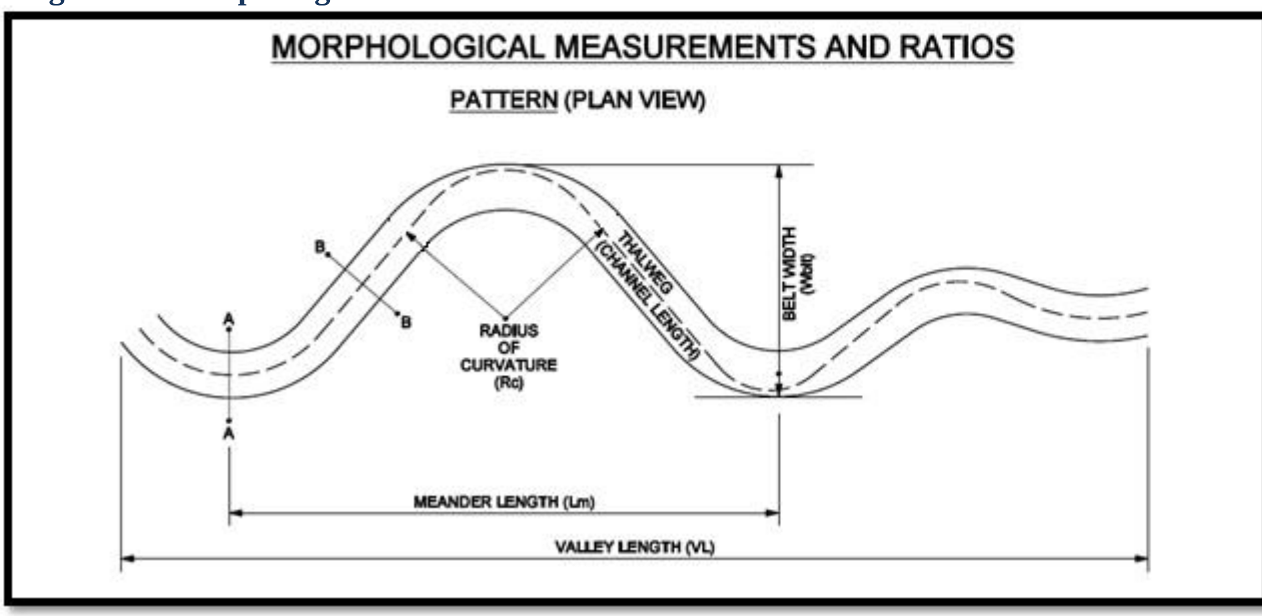
Figure 21: Morphological Measurements and Ratios – Dimension



7.3.2 Channel Pattern Survey

As shown in **Figure 22,** important measurements relating to the stream pattern are the linear meander length (L_m), radius of curvature (R_c), and belt width (W_{blt}). The figure 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 22: Morphological Measurements and Ratios - Pattern



7.3.3 Channel Profile Survey

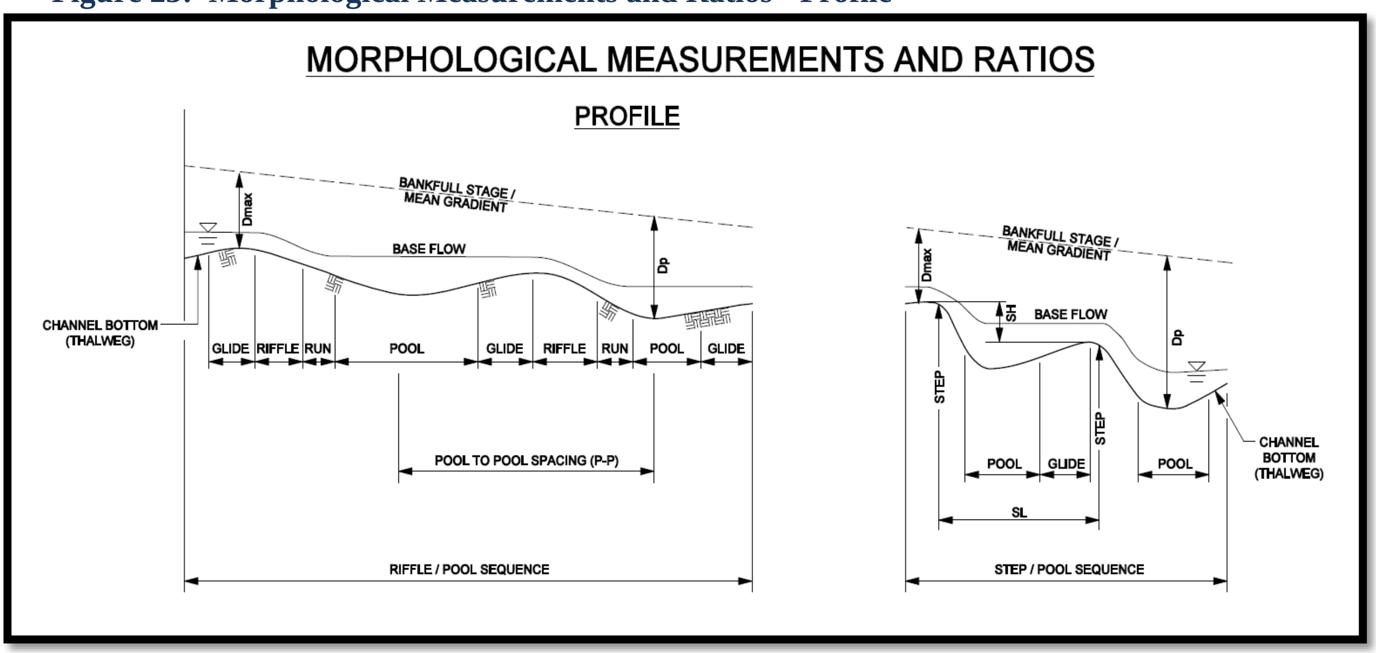
The length of the channel profile survey shall be at least two full meander wavelengths or 20 times the channel width at bankfull. This length will be sufficient to pick up multiple sets of riffle, run, pool, and glide features in order to determine their corresponding spacing. The slope of the channel 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 23 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 23: 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 D*.

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 21** 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 22** 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 23** 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 Reference Reach Database

SARA developed a reference reach database that will include data collected by SARA, their consultants, and other partners. More details are included in *Appendix O* 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 D*.

8.0 NATURAL CHANNEL DESIGN METHODS

The preceding chapters provide a discussion of concepts, data collection, and stream and geomorphic assessments. This chapter and those that follow discuss application of these concepts and results to design stream restoration projects. 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 Stream Functions Pyramid Framework

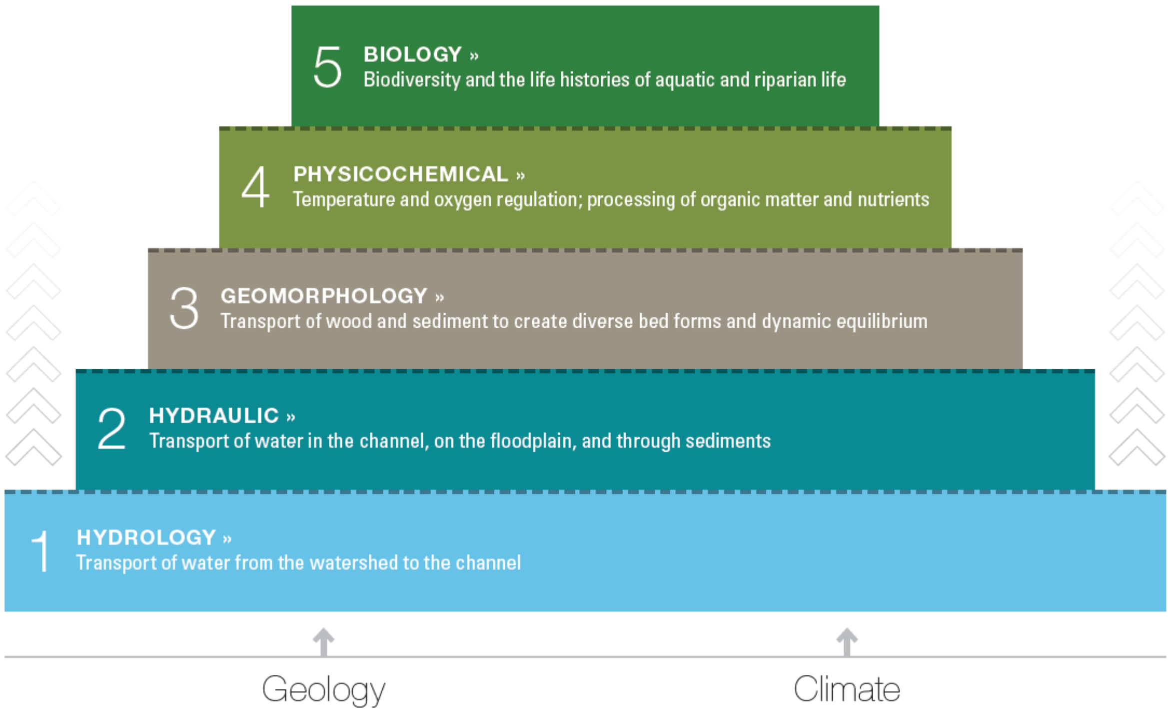
Natural channel design seeks to restore stream functions in a logical order, recognizing that higher level functions are supported by lower level functions. Harman et al. (2012) provides a framework for developing function-based assessments and setting goals and objectives based on the potential for functional lift. The framework is based on the Streams Function Pyramid which is shown in **Figure 24**.

The Stream Functions Pyramid includes five functional categories:

- Level 1 = Hydrology,
- Level 2 = Hydraulics,
- Level 3 = Geomorphology,
- Level 4 = Physicochemical, and
- Level 5 = Biology.

The Pyramid is based on the premise that lower-level functions support higher-level functions and that they are all influenced by local geology and climate. Each functional category is defined by a functional statement. For example, the functional statement for Level 1, Hydrology is "the transport of water from the watershed to the channel," which supports all other functions. Many interrelationships exist between these functional categories and the cause and effect relationships flow up and down the Pyramid. These relationships are important and should be considered when developing a natural channel design project. However, from a stream assessment and restoration perspective the important question for practitioners is, "what supporting functions are required to restore a desired level of function?" The hierarchical structure of the Pyramid provides the conceptual foundation to quantify functional lift.

Figure 24: Stream Functions Pyramid – Overview



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The Stream Functions Pyramid *alone* is a hierarchy of stream functions and does not provide a specific mechanism for addressing functional capacity, establishing performance standards, or communicating functional lift. The diagram in **Figure 25** expands the Pyramid concept into a more detailed Framework to quantify functional capacity, established performance standards, and show functional lift. The Stream Functions are the five levels of the Stream Functions Pyramid graphic that was discussed above and shown in **Figure 24.** The remainder of the framework is a “drilling down” approach that provides more detailed forms of analysis and quantification of functions. The Function-Based Parameters describe and support the functional statements within each functional category. The Measurement Methods are specific tools, equations, assessment methods, etc. that are used to quantify the Function-Based Parameter. There can be more than one Measurement Method for a single Function-Based Parameter. An example is shown below in **Table 8-1** for Floodplain Connectivity, a Function-Based Parameter. In this example, three Measurement Methods are used to quantify one Function-Based Parameter.

Figure 25: Stream Functions Pyramid Framework

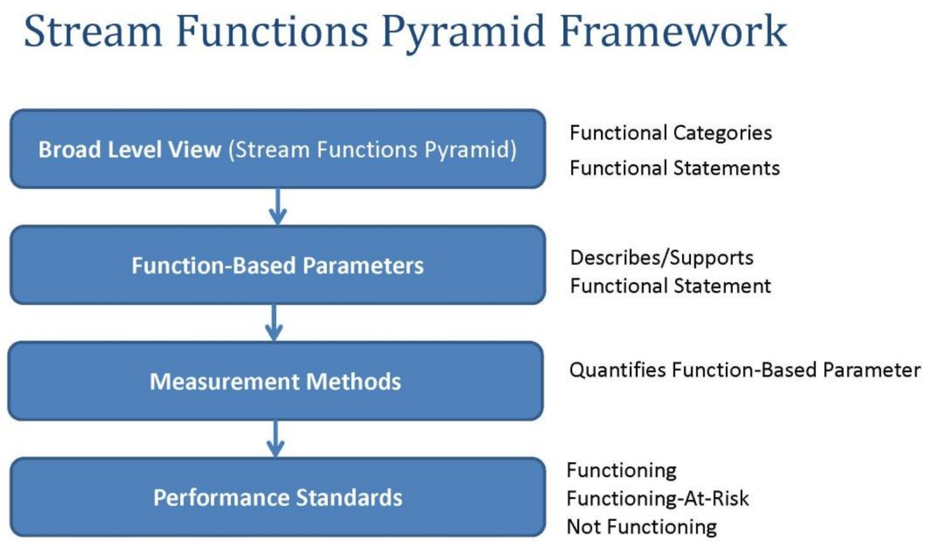

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Table 8-1: Example Measurement Methods used to Quantify the Floodplain Connectivity Function-Based Parameter

Functional Category	Function-Based Parameter	Measurement Method (Examples)
Level 2: Hydraulics	Floodplain Connectivity	Bank Height Ratio
		Entrenchment Ratio
		Stage / Discharge Relationships

A list of Parameters and Measurement Methods is provided with additional details in Appendix A of Harman et al., (2012), including a table showing Type of Measurement Method (Tool, Technique, Metric, or Assessment Approach), Level of Effort (Rapid, Moderate, or Intensive), Level of Complexity, and Direct versus Indirect measure of a function. This list of Parameters and Measurement Methods provide a starting point for proposed Parameters and Measurement Methods for the SFQ tool.

Performance Standards are used to determine functional capacity at the Measurement Method level and are stratified by Functioning, Functioning-At-Risk, and Not Functioning. Using the example from **Table 8-1,** Performance Standards are added to the three Measurement Methods as shown in **Table 8-2**.

Table 8-2: Example Performance Standards for three Measurement Methods used to quantify Floodplain Connectivity.

Functional Category	Function-Based Parameter	Measurement Method	Functional Capacity Performance Standard		
			F	FAR	NF
Level 2: Hydraulics	Floodplain Connectivity	Bank Height Ratio	1.0 to 1.2	1.3 to 1.5	>1.5
		Entrenchment Ratio	>2.2	2.0 to 2.2	<2.0
		Return Interval	1.0 to 1.4	1.5 to 2.0	> 2.0

Note: F = Functioning, FAR = Functioning-At-Risk, and NF = Not Functioning

Definitions for Functioning, Functioning-At-Risk, and Not Functioning are provided below:

- Functioning – A Functioning score means that the measurement method is quantifying the functional capacity of one aspect of a function-based parameter in a way that **does support** a healthy aquatic ecosystem. A single functioning measurement method, out of several measurement methods, may not mean that the function-based parameter is functioning. Therefore, functional capacity is "rolled up" to the parameter level and not determined at the measurement method level. Results can then be "rolled up" to the functional category level and as a final determination across all functional categories.

- Functioning-At-Risk – A Functioning-At-Risk score means that the measurement method is quantifying or describing one aspect of a function-based parameter in a way that **can support** a healthy aquatic ecosystem. In many cases, this indicates the function-based parameter is adjusting in response to changes in the reach or the watershed. The trend may be towards lower or higher function. A Functioning-At-Risk score implies that the aspect of the function-based parameter, described by the measurement method, is between Functioning and Not Functioning.

- Not Functioning – A Not Functioning score means that the measurement method is quantifying or describing one aspect of a function-based parameter in a way that **does not support** a healthy aquatic ecosystem. A single not functioning measurement method may not mean that the function-based parameter is not functioning.

8.1.1 **Determining Restoration Potential**

Restoration potential is the highest level of restoration that can be achieved given the results from a catchment assessment, results from the reach-scale assessment, and the project constraints. The highest level of restoration refers to a level on the Stream Functions Pyramid. A restoration potential of Level 5 means that the project has the potential to restore biological functions back to a functioning condition, i.e., a reference condition. This can only happen if the catchment health is good enough to support that level of biology and the constraints do not prevent the practitioner from implementing the required activities.

If the catchment health is somewhat impaired and/or the constraints limit the restoration activities, then the restoration potential will be less than Stream Function Pyramid Framework (SFPF) Level 5. This doesn't mean that there won't be some biological improvement, just not back to what a stream reach in a forested watershed may have. This also doesn't mean that the project shouldn't be pursued; however, the design goals and objectives should focus on lower-level functions rather than biology.

Many stream restoration projects in the San Antonio region will focus on channel stability because the catchment health is unknown or impaired. There are often lateral or financial constraints as well. In this scenario, the restoration potential is Level 3. If the project is exceptionally long and has adjacent sources of nutrient inputs, the upstream catchment will not support reference quality biology, and there are few lateral constraints, the restoration potential is a Level 4 (physiochemical). A Level 4 may also be achievable for natural channel design projects that include Low Impact Development or Stormwater BMPs.

The practitioner will describe the restoration potential in a narrative format as part of the natural channel design. A catchment assessment form is included in *Appendix P* to help the practitioner determine the overall health of the watershed draining to the project reach. If the watershed health is very high, then the restoration potential will be high. If the overall catchment health is low, then the restoration potential will be a Level 3 at best. The practitioner should also evaluate the project constraints to help determine the restoration potential. Constraints are human-created conditions that will limit the restoration potential. Examples include adjacent sewer lines, flood impacts, and infrastructure.

8.1.2 **Developing Function-Based Goals and Objectives**

Design goals and objectives can be developed concurrently with the restoration potential. Design goals are statements about why the project is needed. They are general intentions and often cannot be validated. Objectives are more specific. They help explain how the project will be completed. Objectives are tangible and can be validated, typically by the performance standard. Examples of design goals include: restore native fish habitat (Level 3 goal), restore native fish biomass (Level 5), restore the stream to a biological reference condition (Level 5), Reduce sediment supply from eroding streambanks (Level 3), and reduce nutrient inputs (Level 4). All of these goals communicate why the project is being undertaken. Example objectives include: increasing floodplain connectivity, establishing a riparian buffer, and increasing bed form diversity. These objectives can't stand alone, but with the goals, they can describe what the practitioner will do to address the functional impairment. The objectives can be quantitative as well. For example: floodplain connectivity will be improved by reducing the bank height ratio from 2.0 to 1.0. Now, functional lift is being communicated and the performance standard is established for monitoring.

The design goals and objectives are communicated in a narrative form as part of the natural channel design. The design goals are then compared to the restoration potential to ensure that the goals do not exceed the restoration potential. For example, it is not possible to have a design goal of restoring native fish biomass (Level 5) if the restoration potential is Level 3, meaning that the catchment health and constraints will not support the fish species of interest. However, the goal could be revised to restore the physical habitat for the fish species of interest, e.g. riffle-pool sequences, cover from a riparian buffer, and improvements to channel substrate. This is a Level 3 goal that matches the Level 3 restoration potential. If watershed-level improvements are implemented (e.g., through LID), over time, the restoration potential could shift from a Level 3 to 5. Notice however, that this requires reach-scale and watershed-scale restoration.

8.1.3 **Communicating Functional Lift**

Practitioners can use the SFPF to communicate the proposed functional lift of a natural channel design projects. A list of function-based parameters by restoration potential is provided below in **Table 8-3**. These parameters, along with their Measurement Methods and Performance Standards from Harman et al., (2012) can be used to show functional lift on the form provided in *Appendix J.* Practitioners should consult with SARA to determine if new Measurement Methods and Performance Standards have been developed. In addition, practitioners can propose Measurement Methods and Performance standards with approval from SARA.

Table 8-3: List of Function-based Parameters by Restoration Potential

Restoration Potential	Function-Based Parameter
Level 3	Level 2: Hydraulics – Floodplain Connectivity Level 3: Geomorphology – Bed form diversity, lateral stability, riparian vegetation
Level 4	Same as Level 3, plus: Level 1: Hydrology – Runoff Level 4: Physicochemical – Nutrients, Temperature
Level 5	Same as Level 3 and 4, plus: Level 1: Hydrology – Flow Duration Level 5: Biology – Macroinvertebrates and fish (if perennial)

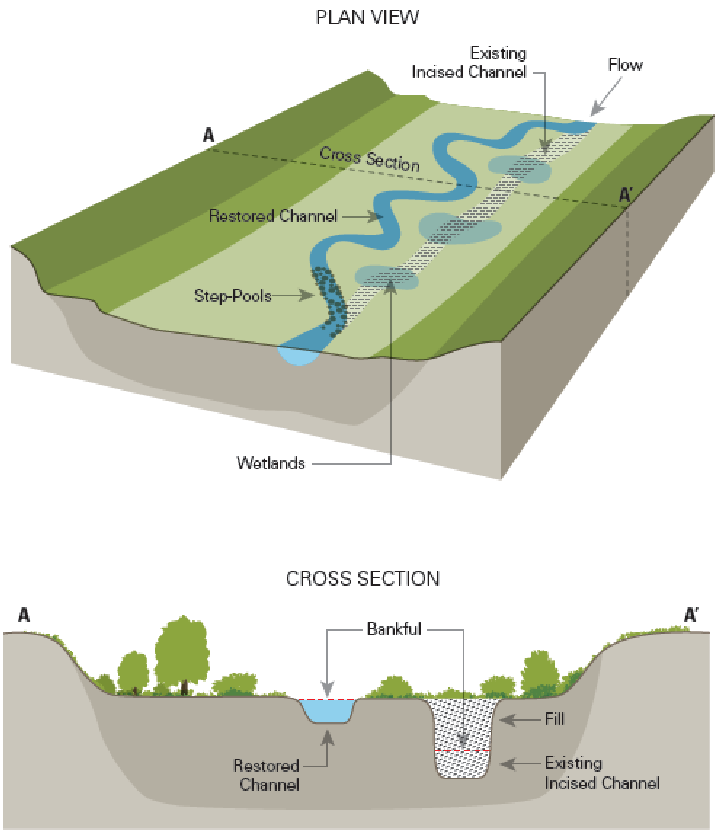
8.2 Restoration Alternatives for Incised Streams

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. The system was also designed to 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.

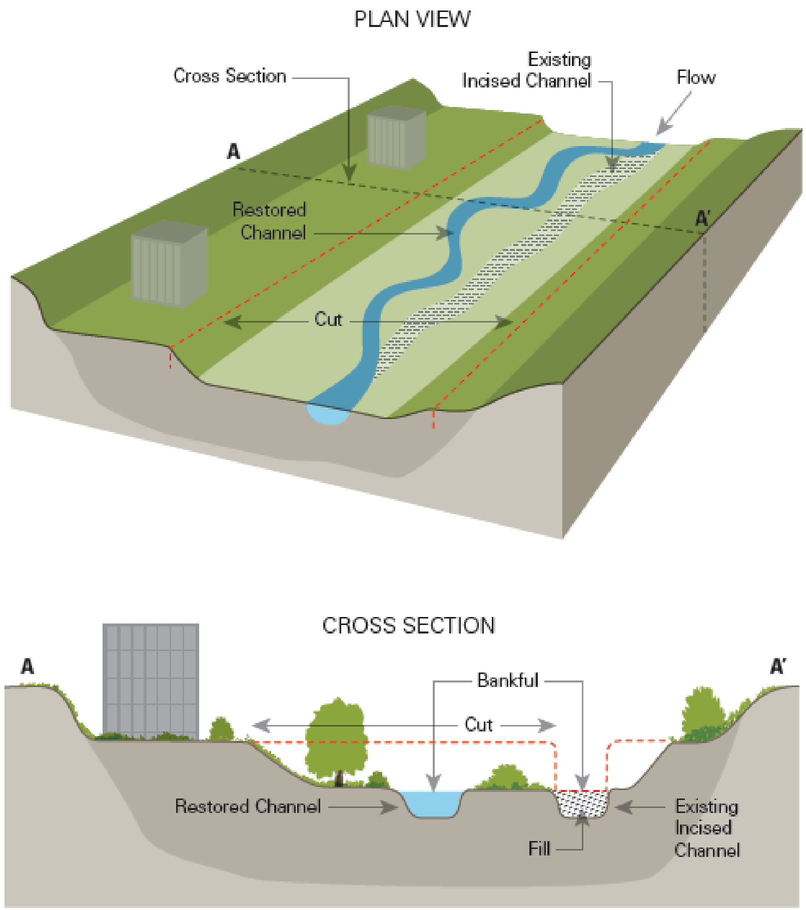
Figure 26: Priority 1 Restoration



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 27: Priority 2 Restoration



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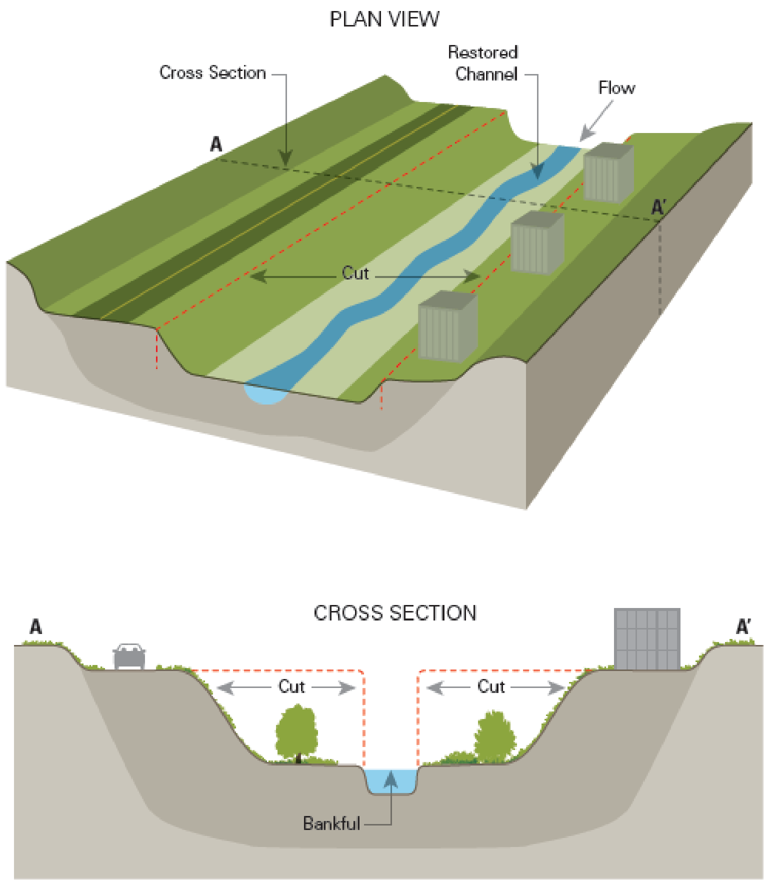
- Priority 3 – Converts a straight channel to a different stream type while leaving the existing channel in place, by excavating bankfull benches at the existing bankfull elevation. Effectively, the valley for the stream is made more bowl-shaped. This approach uses in-stream structures to dissipate energy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

Figure 28: Priority 3 Restoration



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- 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).

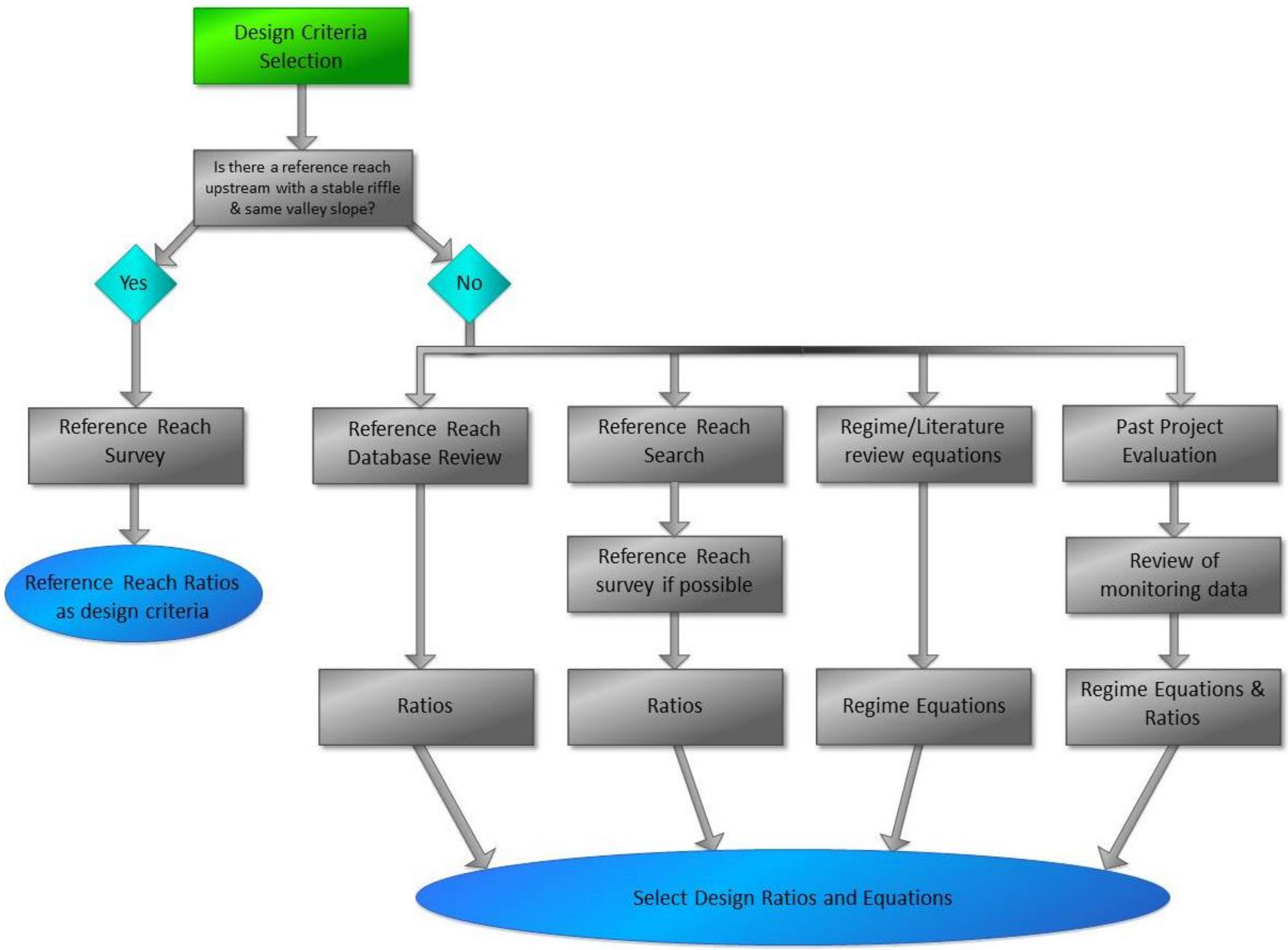
This section describes the basic design steps for completing a natural channel design but is not to be used as a comprehensive design methodology. Design criteria can and should come from a number of different sources. Lessons learned from past project evaluations should play a major role in making final 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 29 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 29: 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 Geomorphology Methodology 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 = $APbkf_{ref}$ / $WPbkf_{ref}$

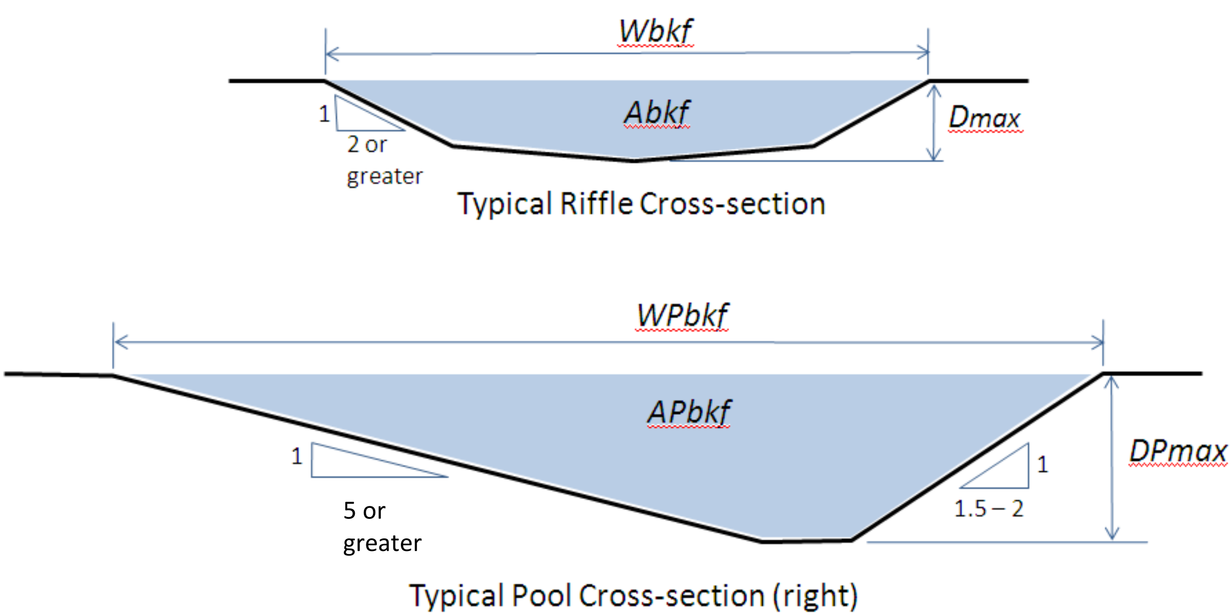
Step 9. Calculate the bankfull max pool depth as DPmax = dbkf * ($DPmax_{ref}$ / $dbkf_{ref}$)

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 30**. 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 30: Typical Design Shape for Channel Cross-Section Design

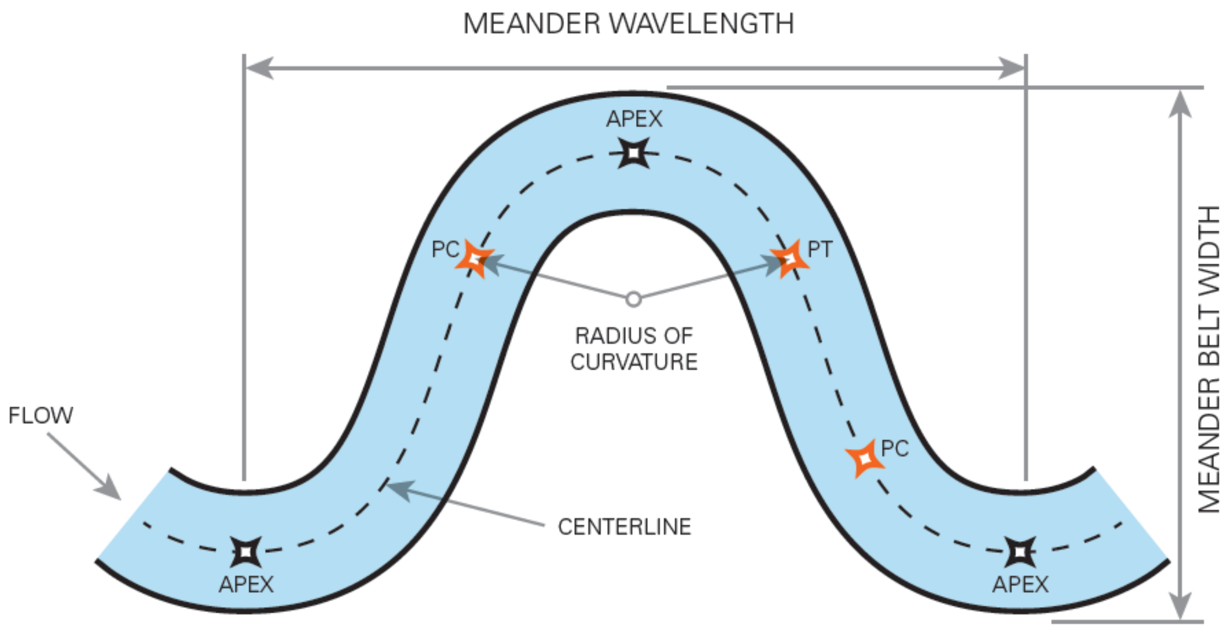


8.5.2 Design the Channel Pattern

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 31.**

Figure 31: Parameters that Describe Channel Pattern



PC = Point of Curvature = point at which the straight section of a riffle meets the curved section of a meander bend.

PT = Point of Tangency = point at which the curved section of a meander bend meets the straight section of a riffle.

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).

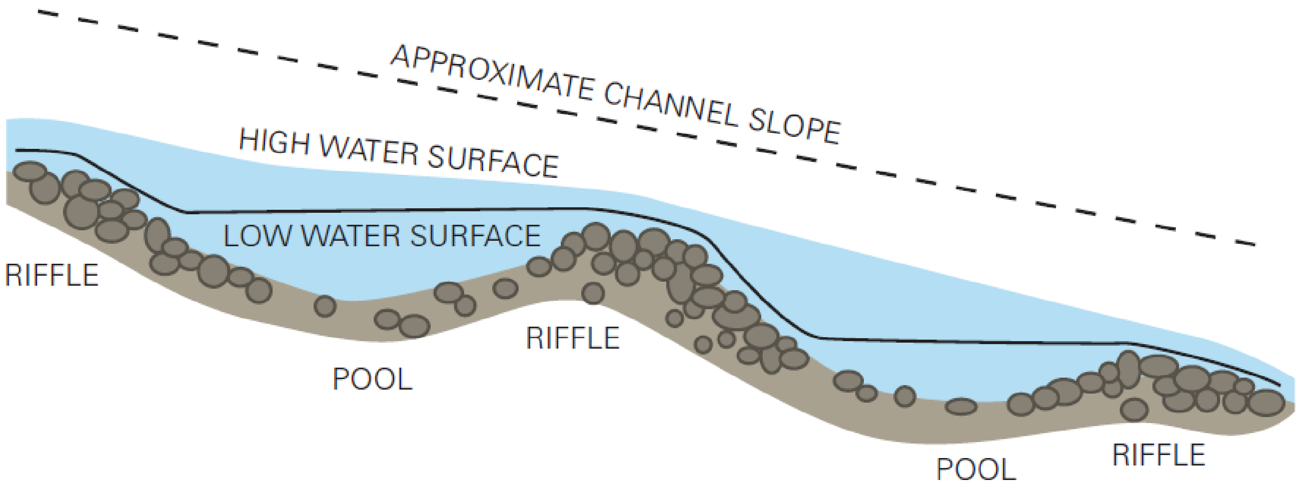
Step 8. Measure the valley length (VL).

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 32**). 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 32: 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. 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 $Srun = S * (Srun_{ref} / S_{ref})$

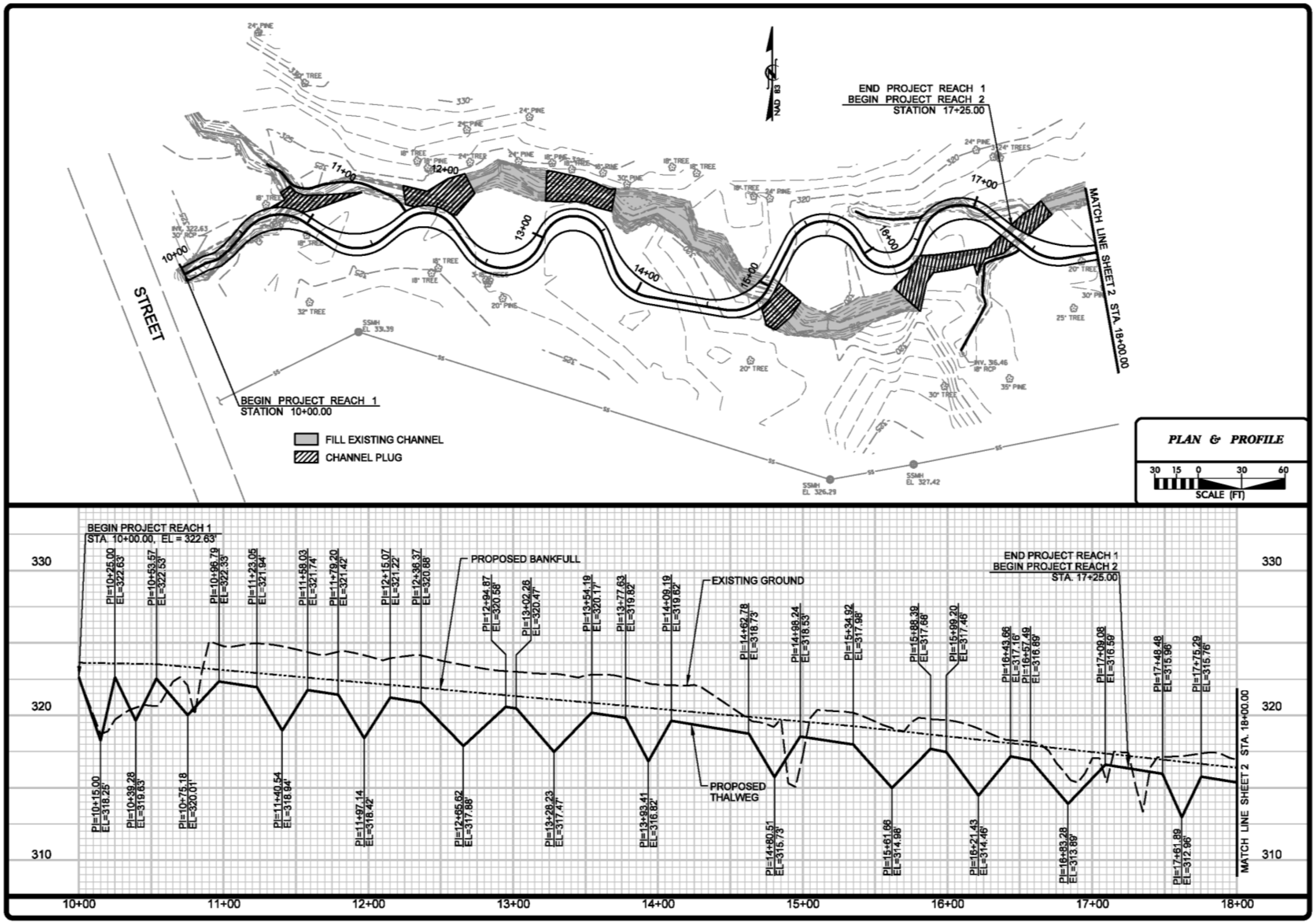
Step 5. Calculate the glide slope as $Sglide = S * (Sglide_{ref} / S_{ref})$

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 (see *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%. 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 33 presents typical plan and profile views of a proposed natural channel design, which should be submitted by the consultant.

Figure 33: 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, *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}/ds_{50} = median diameter of the riffle bed (from 100 count in riffle or pavement sample)
d_{50}/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.

$$\tau_{ci} = 0.0834(d_{50}/ds_{50})^{-0.872}$$ **(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}/ds_{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.

$$\tau_{ci} = 0.0384(D_i/d_{50})^{-0.887}$$ **(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 Modified Shields Curve

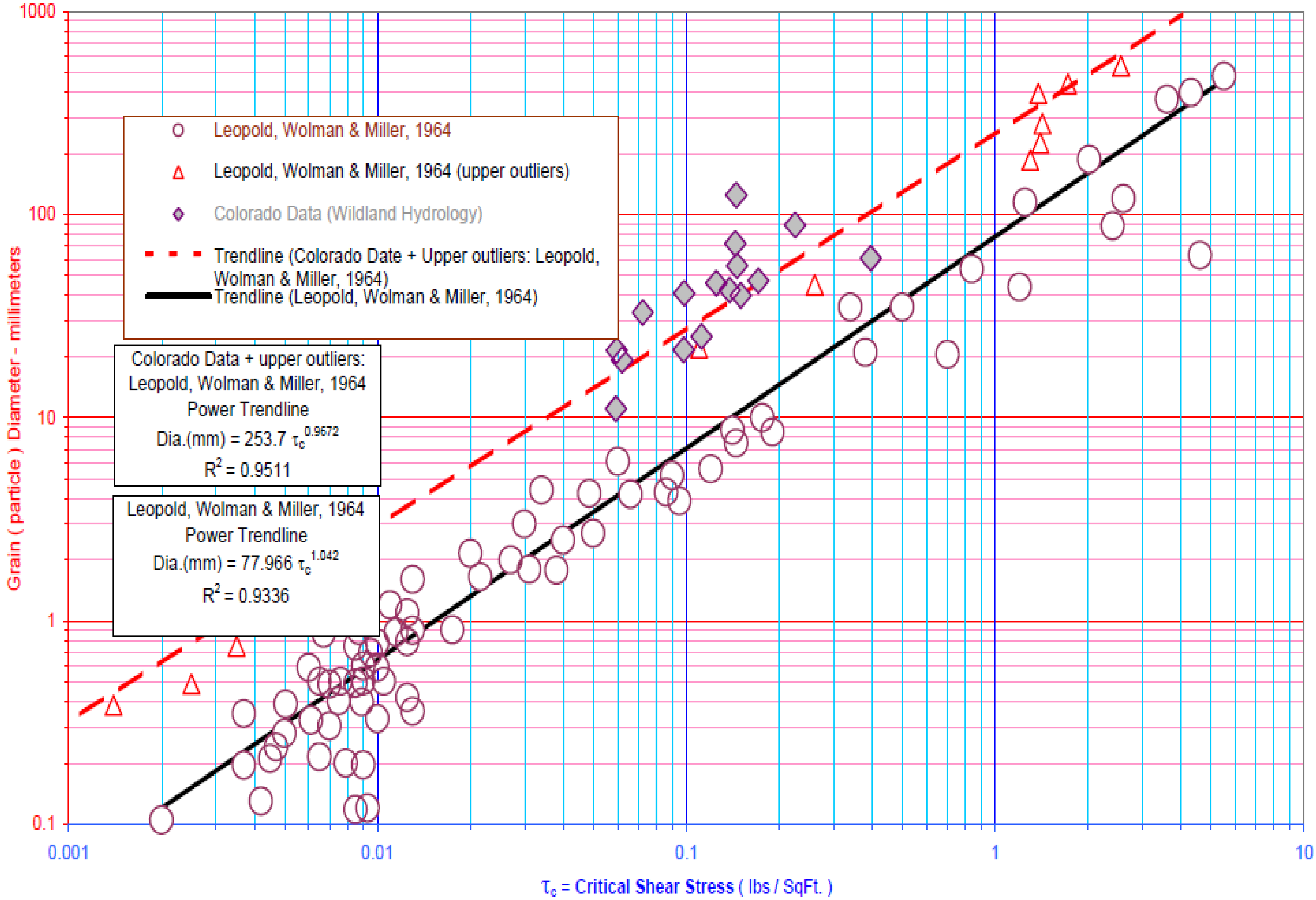
Rosgen (2006) provides a complement to the above required depth and slope calculations, by using the boundary shear stress from the design riffle cross-section and comparing it to the Colorado curve on **Figure 34** or a locally developed curve. Rosgen (2006) recommends using this method if the ratios 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 34**) 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 Colorado 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 34: 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. Also see *Section 8.6.7* on the use of models to assess stream design.

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 H* 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 10*.

- 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 10* 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 10*.

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 Use of Models to Assess Stream Design

Hydraulic models may provide some benefit during the design of stream restoration projects to identify potential locations of erosion and assist with stream design as part of a comprehensive evaluation. The revised *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling* was released in September 2013. In addition to modeling, it is important to assess the impact of natural and anthropogenic changes in the watershed and riverine environment that may impact the behavior of the watercourse. Additional information may include surficial mapping of the soils/geology, analysis of historical aerial photographs and topography/bathymetry to determine the behavior of the watercourse, and other elements described in this protocol. Where hydraulic/sediment transport hydraulic models are used, it is important to correlate the model to the historical and current observations, records, and other information about the waterbody and watershed.

Two-dimensional hydraulic models, such as FLO-2D (www.flo-2d.com), SRH-2D (developed by the U.S. Bureau of Reclamation - http://www.usbr.gov/pmts/sediment/model/srh2d/), and RAS2D (currently being develop by the U.S. Army Corps of Engineers), can be used during the design process to assess channel stability, floodplain stability, and structural design configuration. This section provides a summary of some of the potential capabilities and limitations of two-dimensional models for stream restoration projects. Additional guidance is provided in the model user manuals that can be accessed through the model websites.

For the assessment of channel stability, two-dimensional models can be used to generalize spatially where erosion is more likely to occur, based on depth-average velocities, shear stresses, and sediment transport in all river facets. The geometry of the stream can be modified within the model to bring these values into ranges acceptable for the project area. The models can also be used to evaluate lateral forces on stream banks to identify areas that may be prone to bank erosion and channel migration. In addition, the models can be used to evaluate the impacts that bridges and culverts have on sediment transport.

2D Modelling Software for NCD Design:

- *FLO-2D*
- *SRH-2D*
- *RAS2D*

To assess floodplain stability, two-dimensional models can be used to evaluate flood velocities and shear stresses on the floodplain and identify areas prone to erosion or deposition. In addition, the models can be used to evaluate areas prone to avulsion (meander cut-off) and the stability and function of constructed wetlands and off-channel detention.

Two-dimensional models can also be used to assess structural configurations. The models can be used to evaluate the hydraulic forces on structures that function in a two-dimensional flow regime (i.e. cross-vane structures, j-hooks, etc.). A structure can be modeled to optimize low stress along bank and higher stress in the channel. The models can also be used to determine how many structures are needed, the characteristics of the structures (length, angles, etc.), and to size materials. The configurations can also be evaluated through assessment of flow vectors associated with placement in channel bends. The models can potentially also be used to evaluate locations of erosion and deposition resulting from structure placement.

The information needed to develop a two dimensional model is the same as for a one-dimensional with exception to the digital terrain model (DTM) requirements. In order to gain the most benefit from a two-dimensional model, the DTM needs to be of sufficient resolution to depict all storage areas and flowpaths within the study area. The required vertical accuracy of the DTM depends on modeling objectives and project budget. In urban areas the vertical accuracy of the DTM needs to be much more resolute than it would typically need to be for a large-scale watershed application. Additionally, it is critical that field-based sediment information be obtained to ensure model results reflect project conditions (i.e. estimations of sediment data are not recommended). It is recommended that field-based data be collected for bed material, sediment concentration during design flow, and wash load data. However, there are limitations that should be considered. For example, the locations with high erosion potential may only be valid for the current state of the riverine environment. If the river is able and allowed to adjust laterally and/or vertically, then these locations of higher erosion potential could shift laterally or longitudinally over time. As a result, the hydraulic model would need to be updated to account for these changes.

Two-dimensional hydraulic models generally operate under the hydrostatic assumption, meaning that accelerations in the vertical direction are negligible. These models are two-dimensional in the horizontal plane and are not intended to be used for near-field problems where vortices, vibrations, or vertical accelerations are of primary interest. Vertically-stratified flow effects are beyond the capabilities of a two-dimensional hydraulic model.

Two-dimensional sediment transport models can be beneficial for modeling complex stream systems with a high degree of sinuosity and/or bedform variability. In general, unless a sediment transport model can be correlated to known conditions then it is generally unreliable, except in situations where it is used to compare the relative changes between modeled conditions. For applications where local scour estimations are required, or sediment modeling is needed for a minor to moderate sinuosity system, a one-dimensional model will provide sufficient information and require less resources to develop.

For the incorporation of features such as low-flow sinuosity (bankfull channel), pools, and riffles into these models, it is important to note that models may need adjustment based on changes to the system during large flood events. Maintaining a static "natural" setting may not be sustainable without some combination of controls in place to prevent channel movement and restrict flow/sediment.

More complex flows where vertical variations of variables are important should be evaluated using a three-dimensional model. There are commercially-available three-dimensional hydraulic models that incorporate sediment transport, but their performance in the riverine environment are more or less untested. In addition, more complex models have greater data needs, both in quantity and quality. Data limitations may preclude success.

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 24**, 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.

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. As an example, a stream that has a stable natural channel with development in the floodplain fringe will most likely have higher level stream functions such as temperature and oxygen regulation and biodiversity of aquatic and riparian life. Alternatively, 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. Stream restoration provides an opportunity to preserve the stable natural stream function and 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. For this scenario the project proponent has an opportunity to improve stream functions using a natural channel design approach where physical constraints allow.

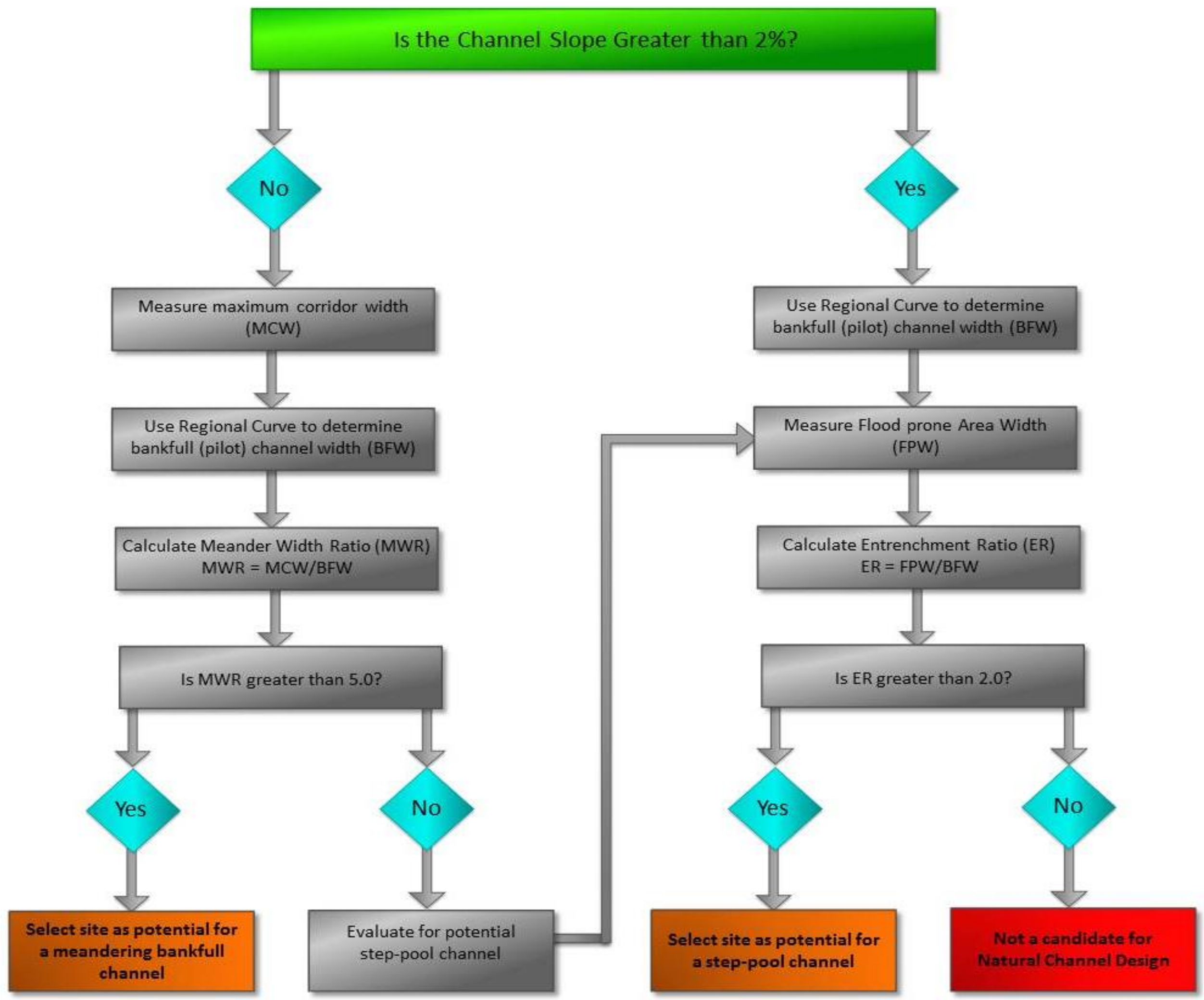
In the case where a stream has been completely channelized and/or hardened, a natural channel design approach is likely precluded unless the project goals and objectives call for restoration of a natural stream system. Such a project would inherently include high costs and buy-outs to provide a corridor 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 35** provides a flow chart for providing site selection criteria for potential use of natural channel design techniques in a flood control project.

Figure 35: Site Selection Criteria for Potential Use of Natural Channel Design Techniques in a Flood Control Project

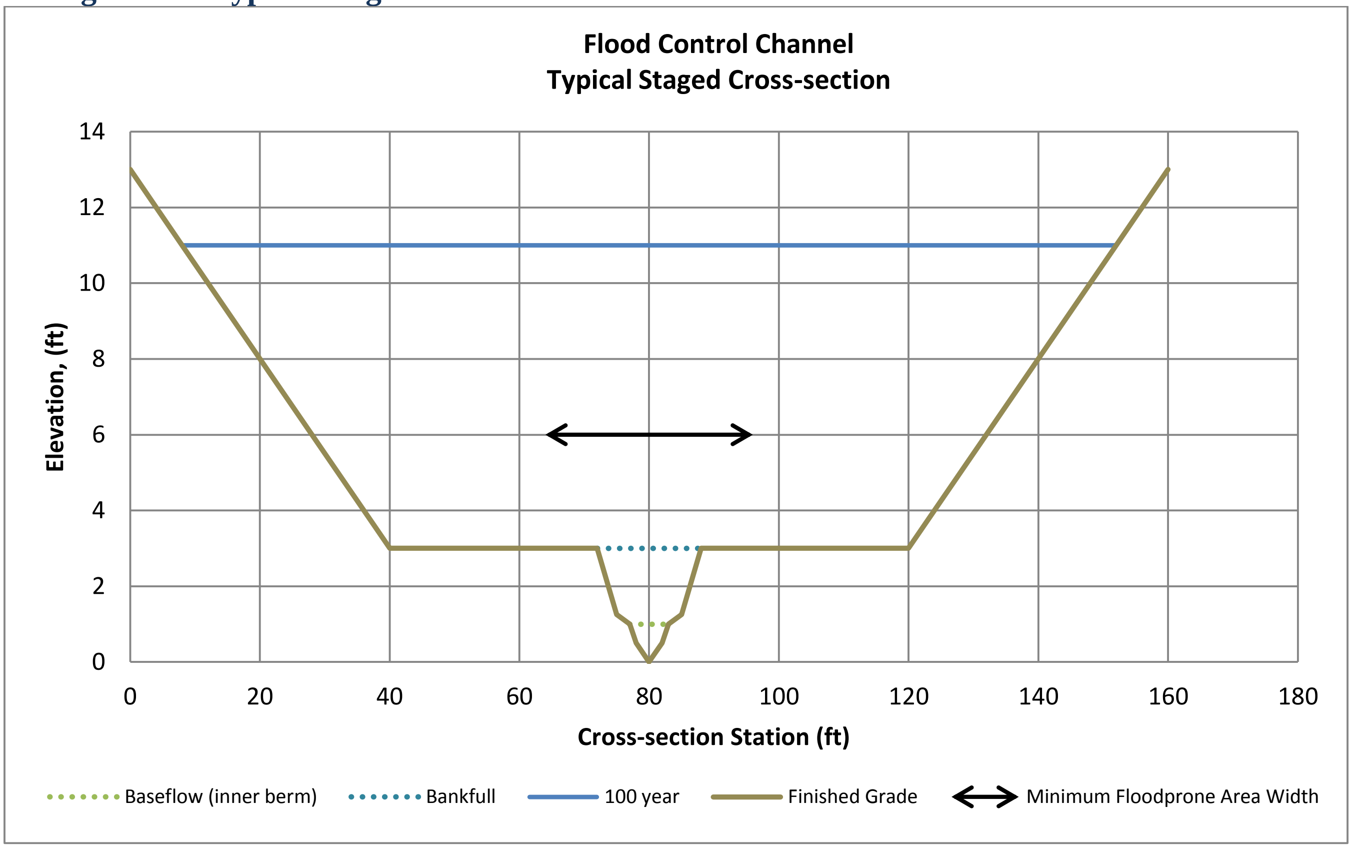


The first step is to look at the channel and valley slope. If the channel slope is less than 2%, a meandering pattern may be possible given that the meander width ratio (MWR) is greater than 5.0 following the steps on the left side of the flow chart. If the (MWR) is less than 5.0, a step-pool design 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 E*.

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 36** shows a typical staged cross-section for flood control channels.

Figure 36: Typical Staged Cross-section for Flood Control Channel



Refer to *Chapter 8* for development of bankfull channel design parameters.

10.0 IN-STREAM-STRUCTURES AND BIOENGINEERING

10.1 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 G*. 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).

10.2 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.

10.2.1 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 37: 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 G*. 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 G* 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.

10.2.2 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 38: 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%. 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 G*. 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.

10.2.3 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 39: Cross-vane Examples

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 G*. Additional design considerations for constructed cross-vanes include:

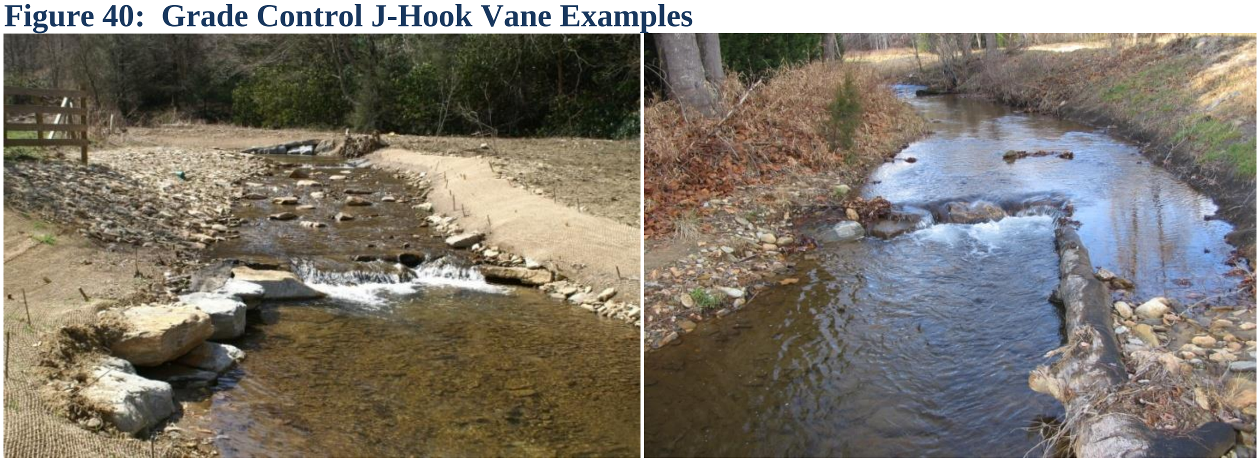
- Filter fabric, typically non-woven geotextile, should be used if the stream bed material is predominantly gravel or smaller size fraction, to ensure sealing of voids between boulders.
- For narrower streams (less than 20 feet), the width of the center of the structure (weir) should be set at 1/3 of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

10.2.4 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 40: 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 41**), 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 G*. 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

10.3 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 G*. 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 10-1)** provides guidance on selecting an in-stream structure bank stabilization practice based on the structure's ability to provide bank stability and cost.

Table 10-1: 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

10.3.1 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 41: 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 G*. 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.

10.3.2 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 42: 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 G*. Additional design considerations for log vanes include:

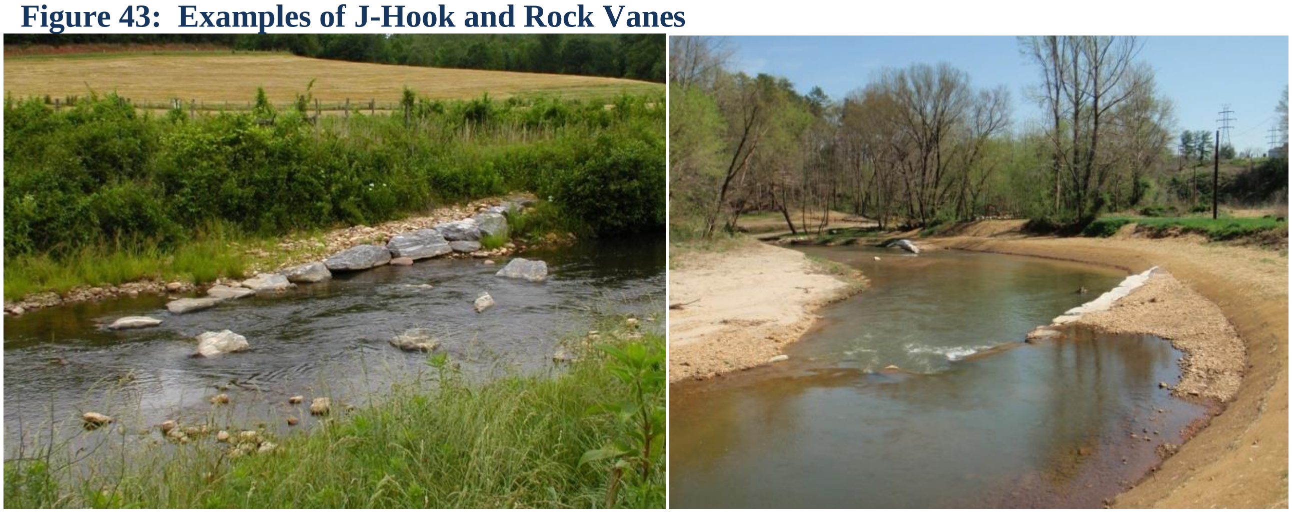
- Filter fabric, typically non-woven geotextile, should be used to ensure sealing of voids between logs.
- Ensure that the arm slopes are low, with arms tying into the banks at no higher than ½ bankfull stage.
- Log vanes are often secured to the stream bank using root wad(s) and/or transplants. Logs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

10.3.3 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 43: 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 G*. 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.

10.3.4 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 44: 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 G*. There are multiple options to covering the toe wood that can depend on available materials, cost, channel dimension, and site conditions.

10.4 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.

10.4.1 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 45: 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 G*. 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.

10.4.2 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 G*. 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.

10.4.3 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 46: 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 G*. 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.

10.5 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 G 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 10-2**) provides guidance on selecting common bioengineering practices based on the relative strength that the practice provides and the relative cost.

Table 10-2: 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

10.5.1 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.

10.5.2 **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.

10.5.3 **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.

10.5.4 **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.

10.5.5 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.

10.5.6 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% 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.

11.0 PLAN SHEETS 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 F* provides a template for the natural channel design report and required sections, as well as a copy of the NCD Review Checklist. *Appendix M* provides a tool for practitioners to use as an outline of the information that should be prepared and submitted for various states of the project, including 30%, 60%, 90%, and final design.

11.1 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 12* 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.

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. 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. The base map for all projects should be tied to 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's CAD (As-Built) Standards, available online at https://www.sara-tx.org/public_services/gis_information/FAQs.php).

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). *Appendix M* of this report outlines the information that should be prepared and submitted for different stages of the project, including 30%, 60%, 90%, and final design. *Appendix N* provides a summary that can be used to estimate project costs.

11.2 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.

11.3 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.

11.4 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.

11.5 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 ensure that the contractor completes critical phasing before moving on to later phases. This can help to insure that applicable permitting requirements are satisfied.

11.6 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.

11.7 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.

11.8 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.

11.9 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.

11.10 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.

11.11 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 H*. 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.

11.12 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. 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.

11.13 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.

11.14 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.

11.15 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.

12.0 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 11* 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 I*.

13.0 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, 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, 2013).

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.

13.1 Erosion and Sedimentation Control for Construction Sites

13.1.3 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 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.

13.1.4 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.

13.1.5 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.

13.1.6 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.

13.1.7 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.

13.1.8 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.

13.1.9 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.

14.0 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 with comprehensive watershed assessment and field data collection required to develop appropriate design criteria may not be good candidates for design build projects. 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. A Channel Geometry and In-stream Structure Inspection Form is included in *Appendix K* for guidance on post-construction inspections.

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, including:

- **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

15.0 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 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 grading
- Key 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.

16.0 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

17.0 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.

17.1 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**

17.2 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. Additionally, 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.

17.3 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. USACE monitoring templates, mitigation SOP, and other monitoring guidance information can be found on the Fort Worth and Galveston USACE websites, located at http://www.swf.usace.army.mil/Missions/Regulatory/Permitting/MitigationTemplates.aspx and http://www.swg.usace.army.mil/Portals/26/docs/regulatory/Streams/spn.stream_SOP_2013.pdf.

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.

17.4 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.

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Appendix A

Natural Channel Design Protocol

San Antonio, Texas

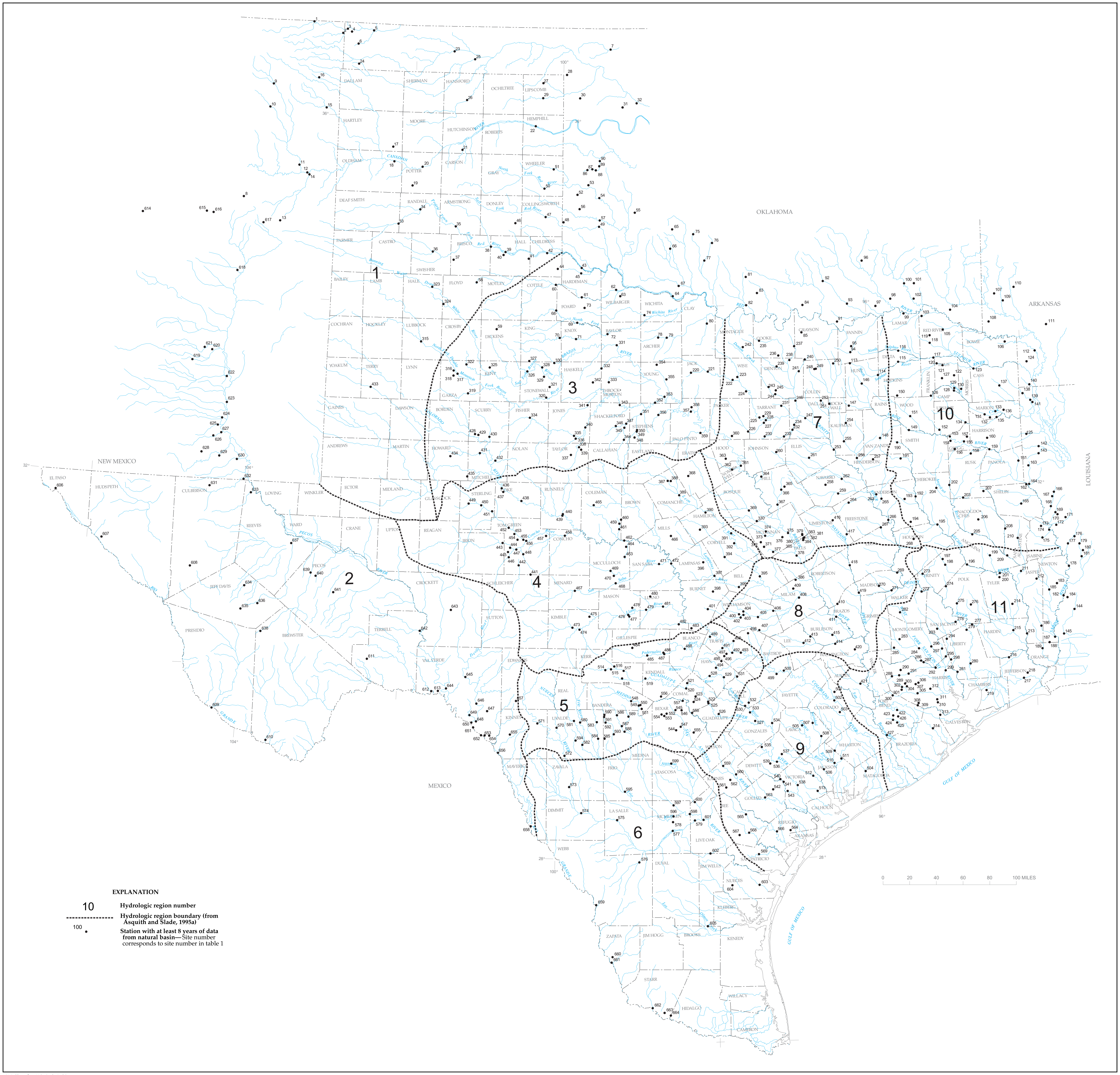
SAN ANTONIO RIVER AUTHORITY

Leaders in Watershed Solutions

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
TEXAS DEPARTMENT OF TRANSPORTATION

WATER-RESOURCES INVESTIGATIONS REPORT 96–4307
Locations of selected stations with natural basins—PLATE 1
Asquith, W.H., and Slade, R.M., Jr., 1997, Regional equations for estimation of peak-streamflow frequency for natural basins in Texas



Digital base from U.S. Geological Survey
Scale 1:2,000,000
Albers equal-area projection based on
Standard parallel 45.5 and 29.5 degrees

MAP SHOWING LOCATIONS OF SELECTED STATIONS WITH NATURAL BASINS IN AND NEAR TEXAS

By

William H. Asquith and Raymond M. Slade, Jr.

1997

Appendix B

Natural Channel Design Protocol
San Antonio, Texas

SAN ANTONIO
RIVER AUTHORITY
Leaders in Watershed Solutions

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 C

Natural Channel Design Protocol

San Antonio, Texas

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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.

<u>Cross Section:</u>

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

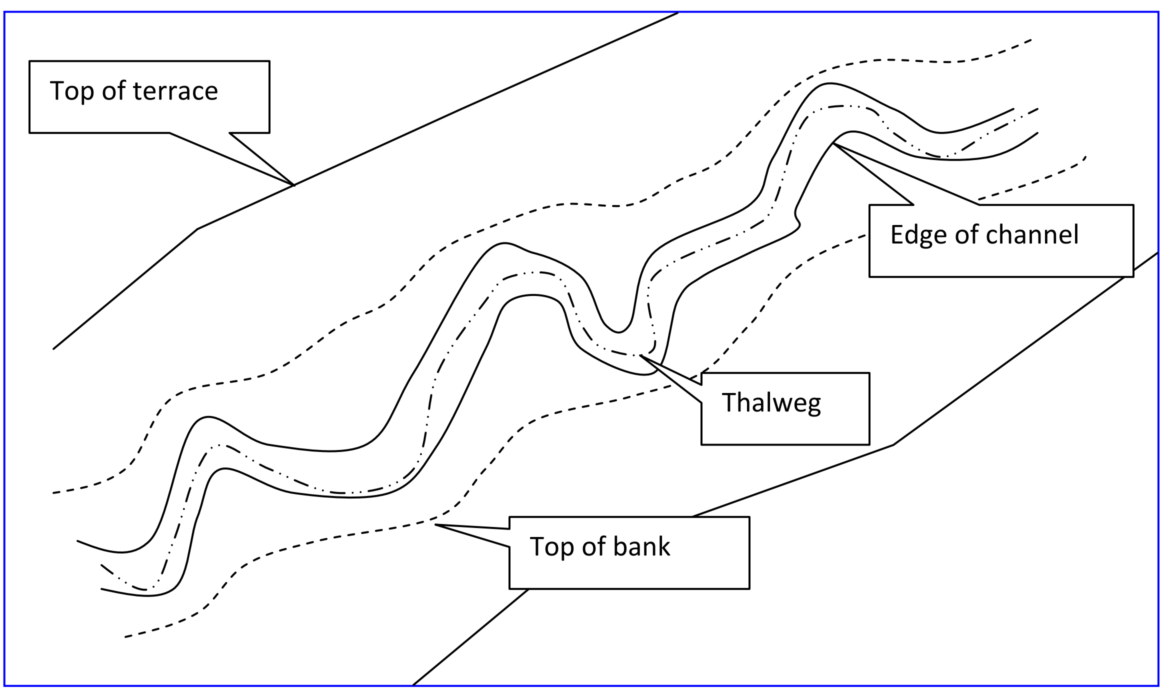
A2 – breakline for another feature such as edge of valley (top of terrace)

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 D

Natural Channel Design Protocol
San Antonio, Texas

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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 / end	ft / ft	Max Bankfull Depth (d_{max})	start / end	ft / ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start / 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

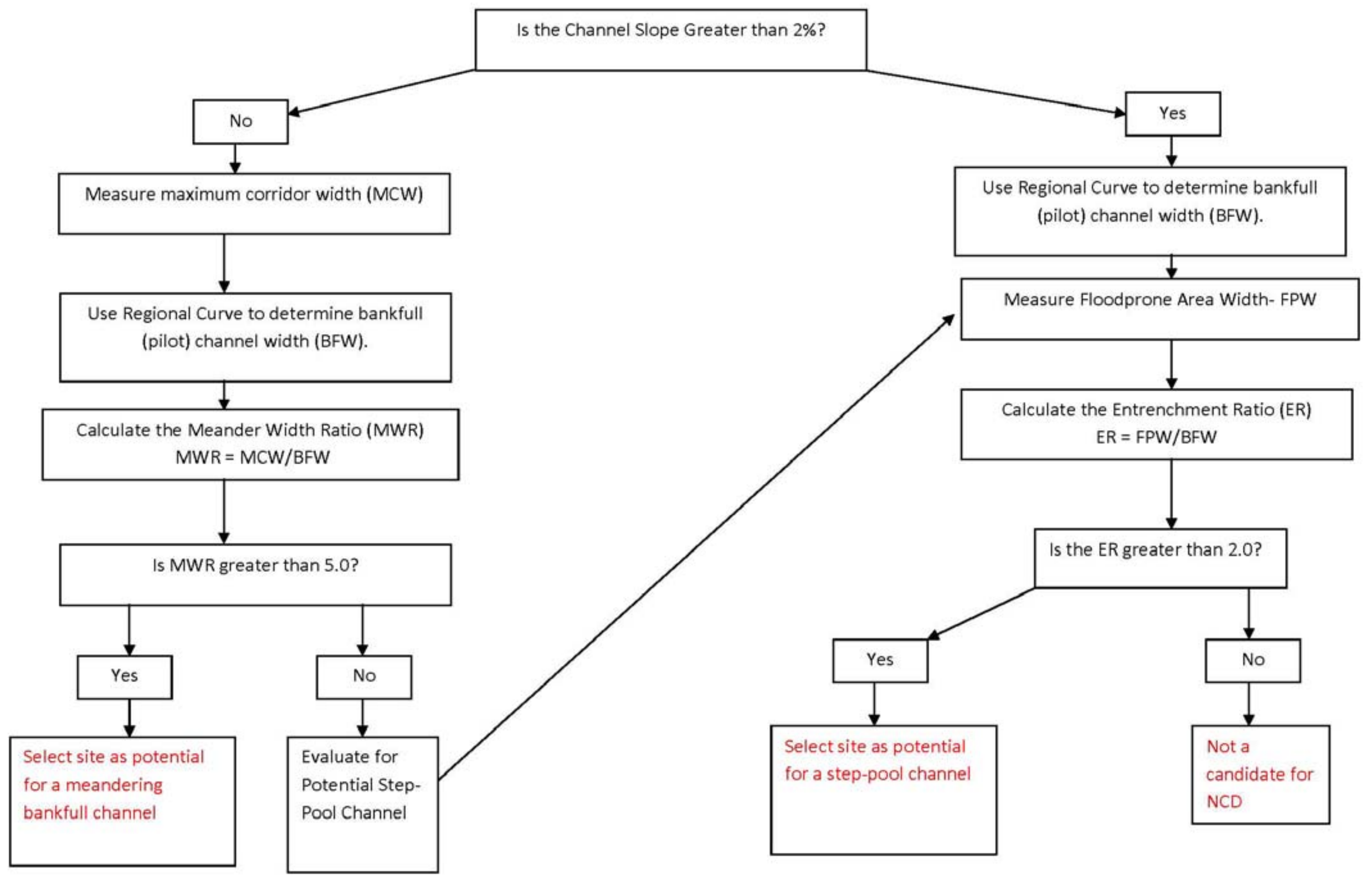
			BRRS = Barren soil
			HERB = Herbaceous
			LITT = Litter
			REST = Restoration Structure
			WOOD = Wood
			ROCK = Rock
			OTST = Other structure

Appendix E

SAN ANTONIO RIVER AUTHORITY
Leaders in Watershed Solutions

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

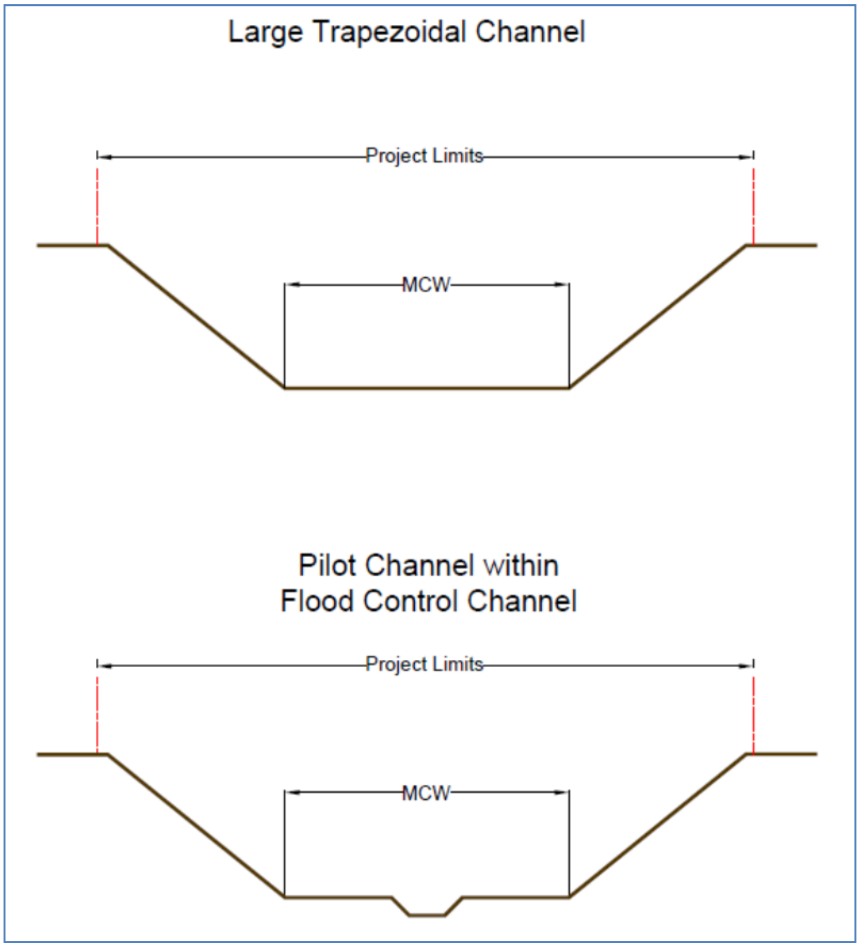
Channel Slope

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.

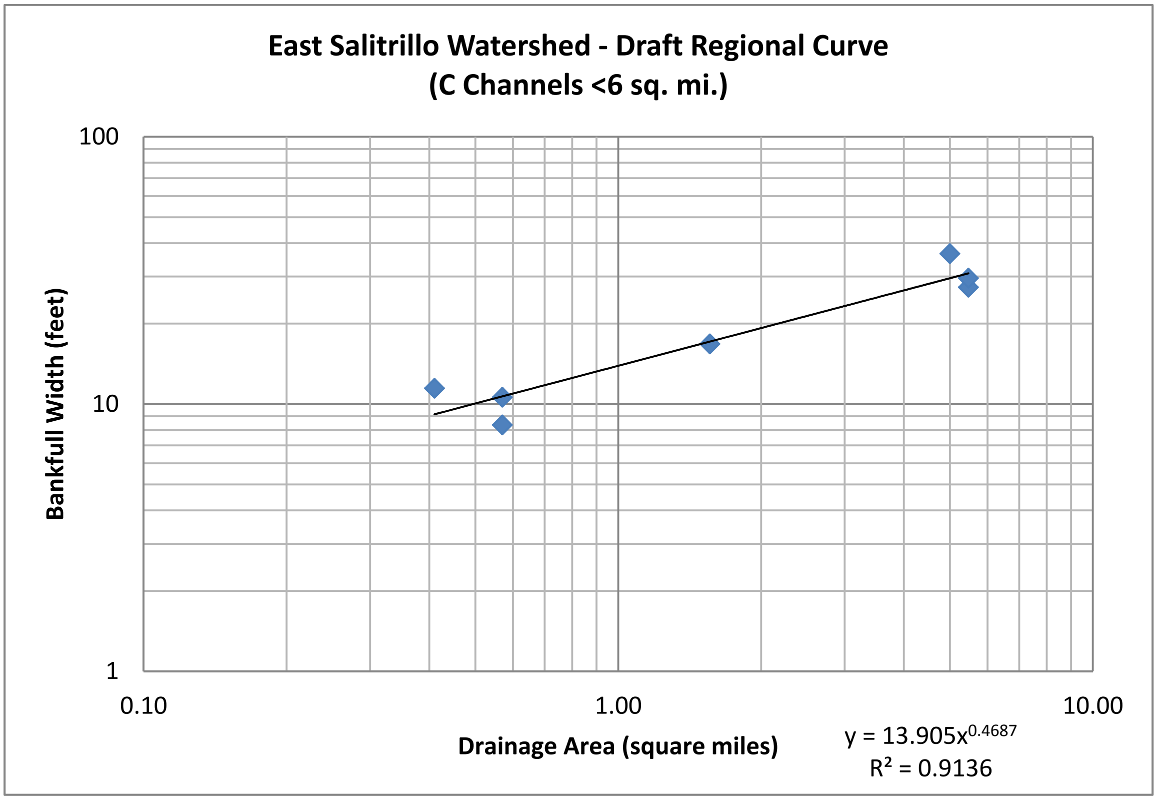
Figure 1 – Maximum Corridor Width Measurement



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)

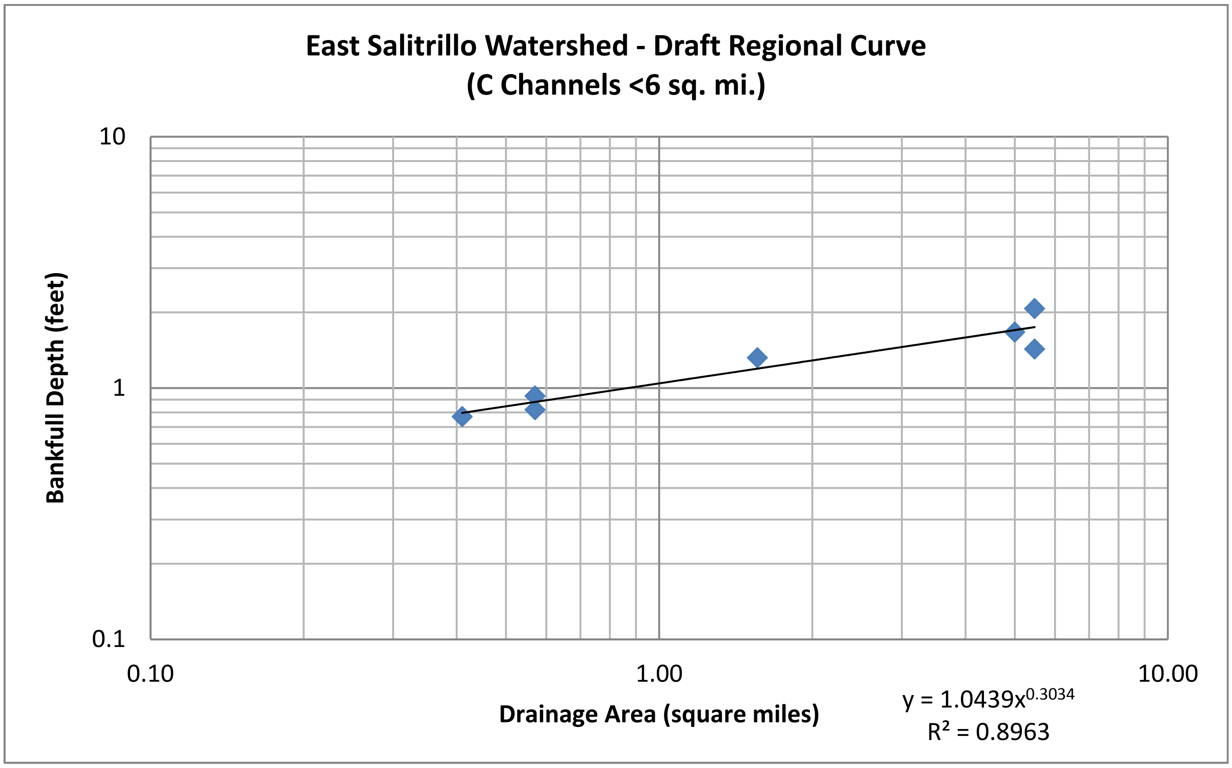
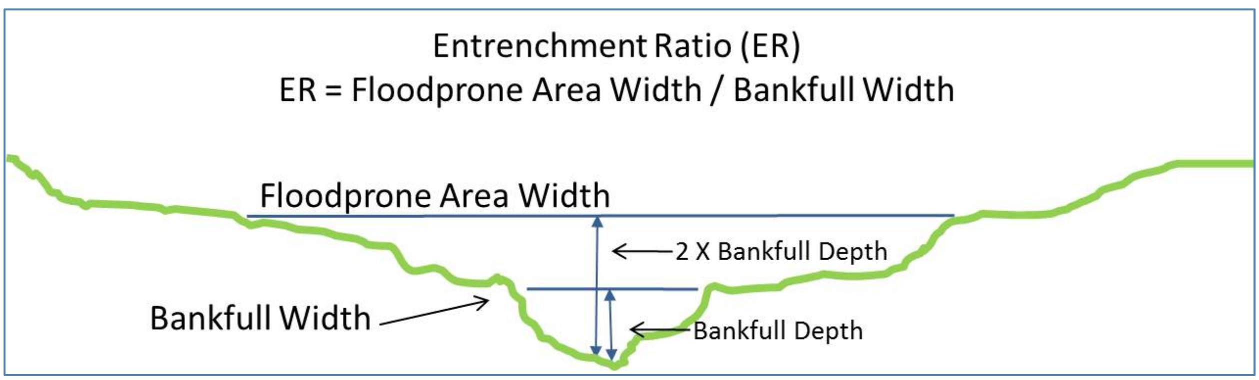


Figure 4 - Floodprone Area Width and ER Calculation



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.

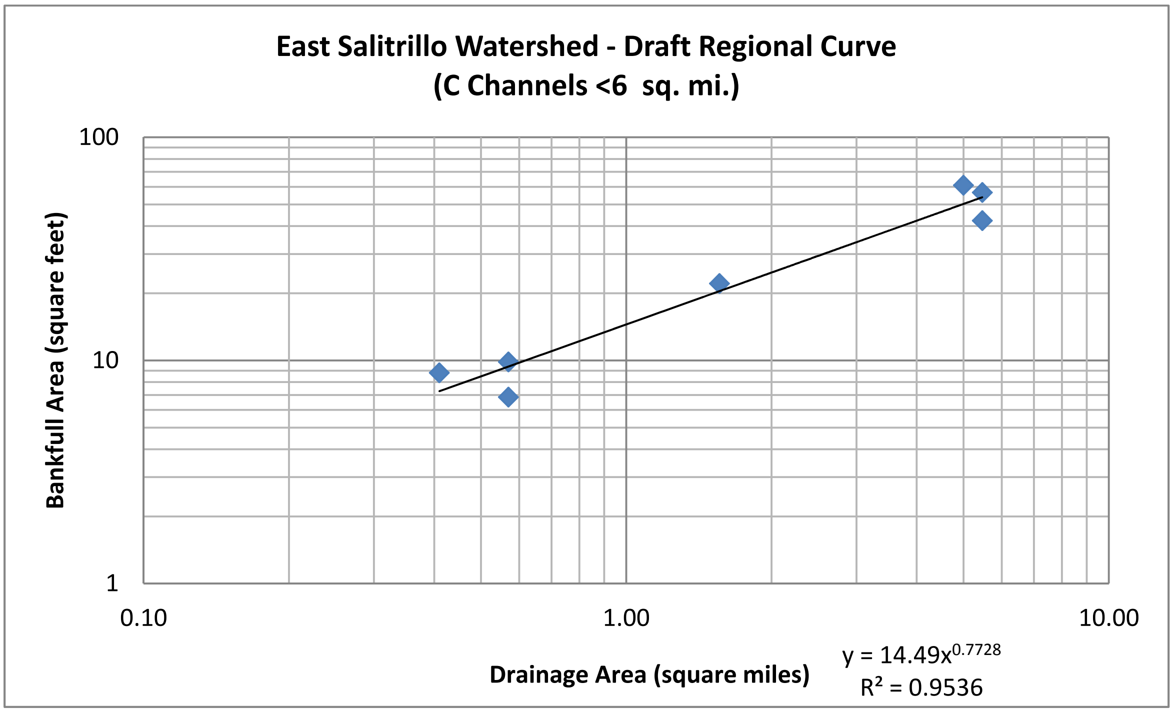
Optional Additional Analyses

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)



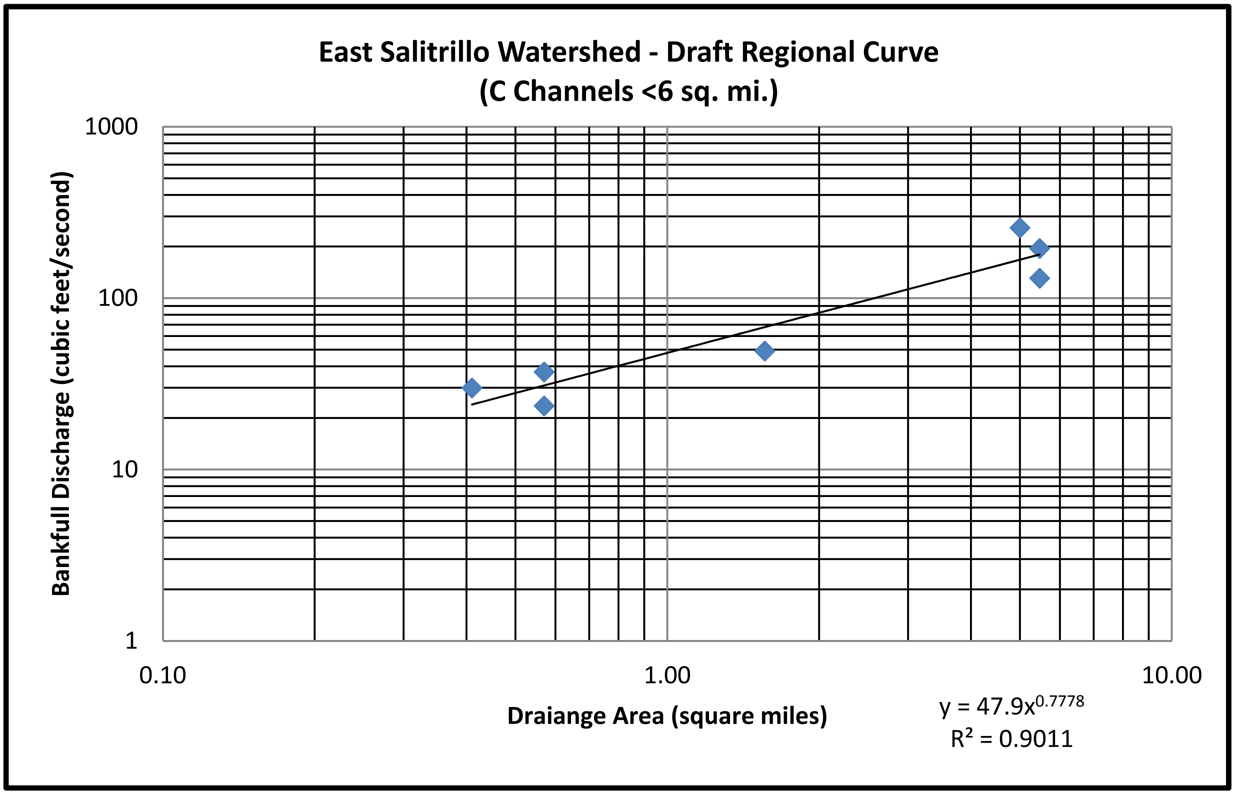
In-Stream Structures

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 F

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: ______________________

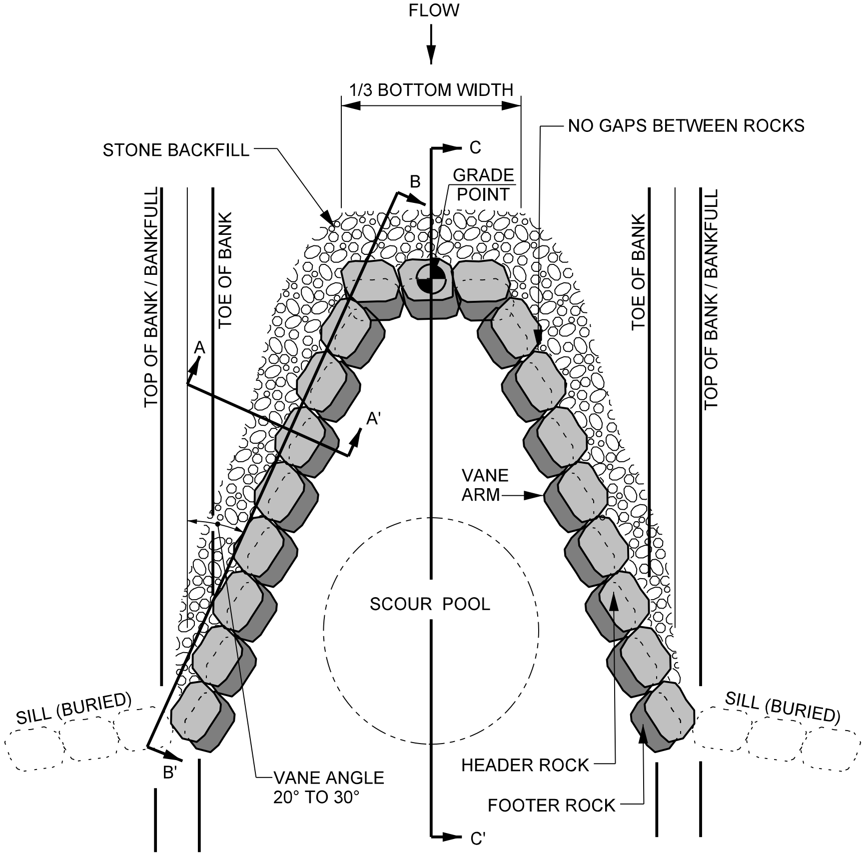
Project: ______________________
Engineer: ______________________

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?				

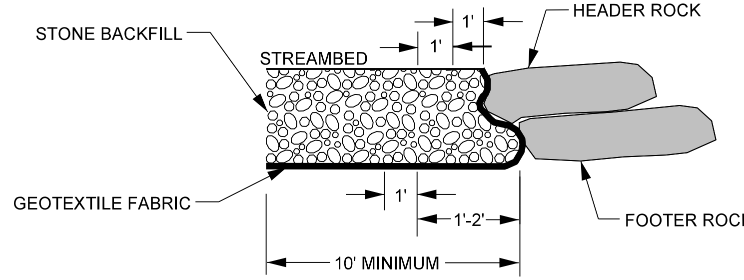
Appendix G

SAN ANTONIO
RIVER AUTHORITY
Leaders in Watershed Solutions

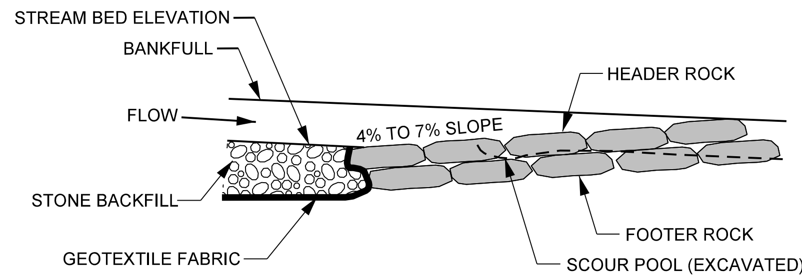
ROCK CROSS VANE



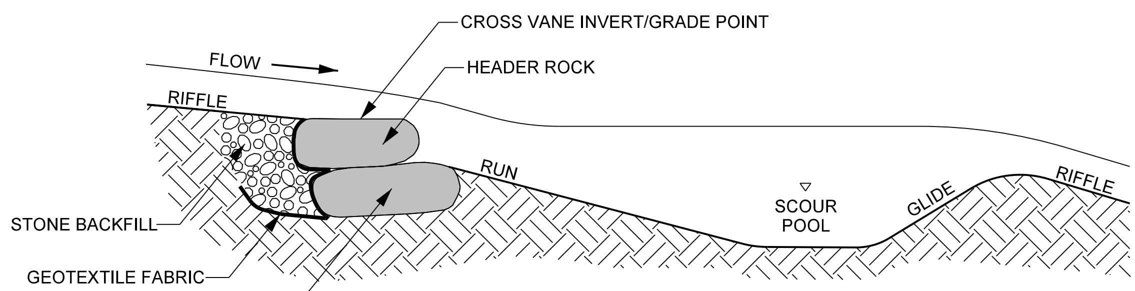
PLAN VIEW



SECTION A - A'



PROFILE VIEW B - B'
VANE ARM



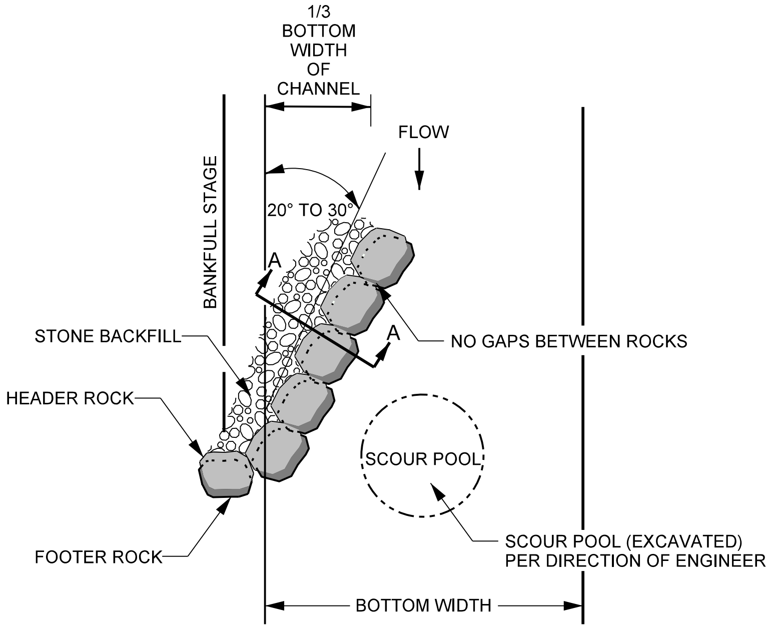
PROFILE VIEW C - C'

NOTES FOR ALL VANE STRUCTURES:

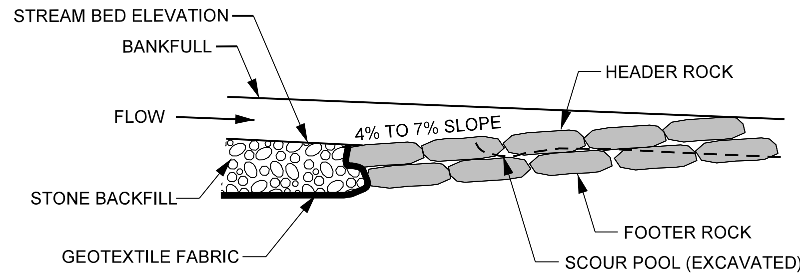
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. 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.

ROCK CROSS VANE

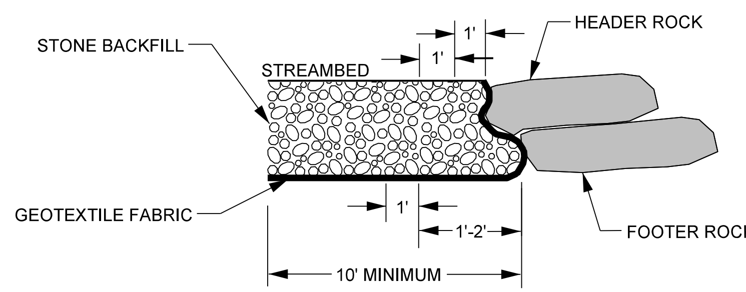
ROCK VANE



PLAN VIEW



PROFILE VIEW



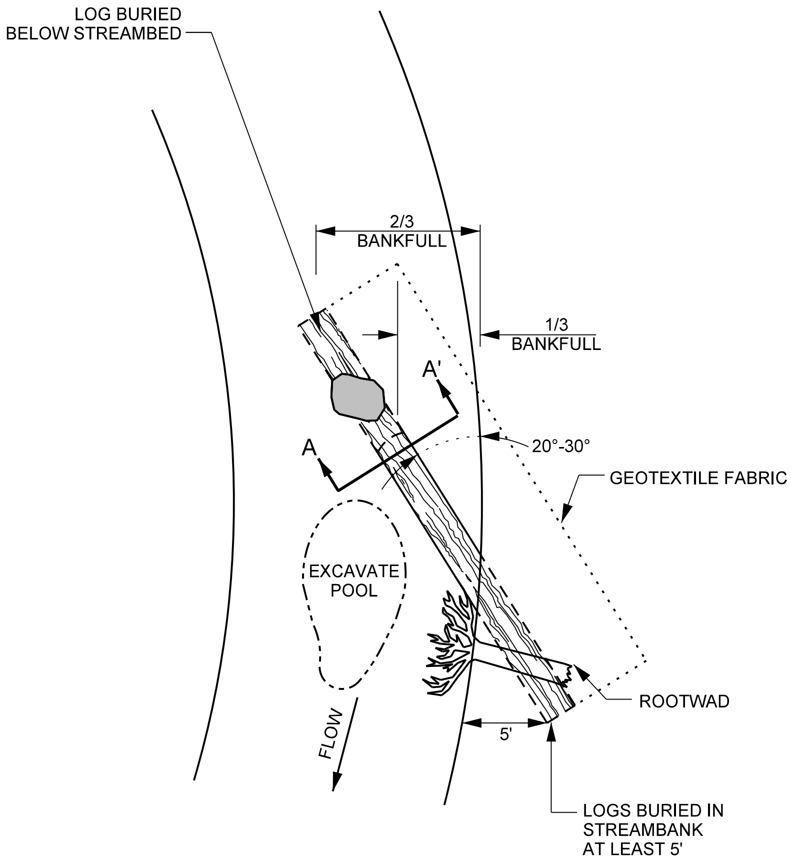
SECTION A - A

NOTES FOR ALL VANE STRUCTURES:

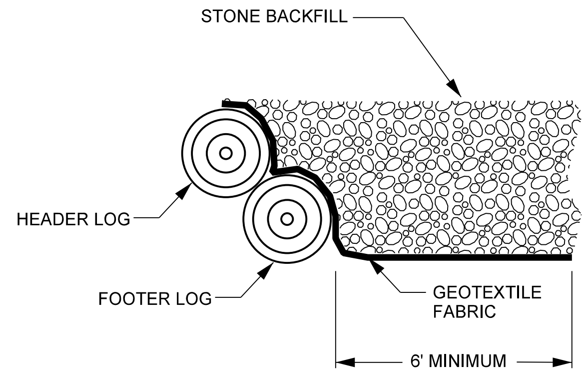
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. 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

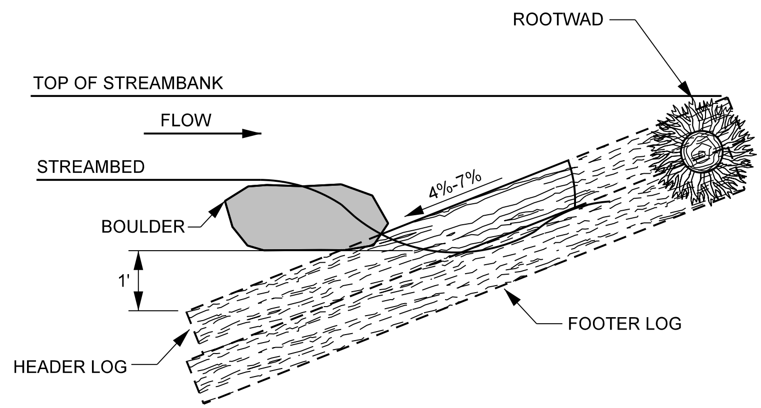
LOG VANE



PLAN VIEW



SECTION A - A'



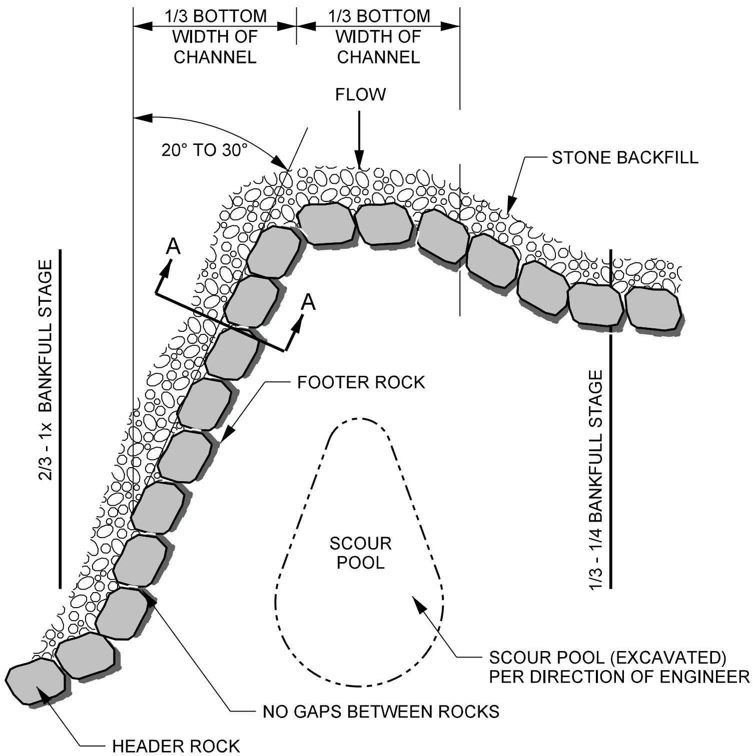
PROFILE VIEW

NOTES:

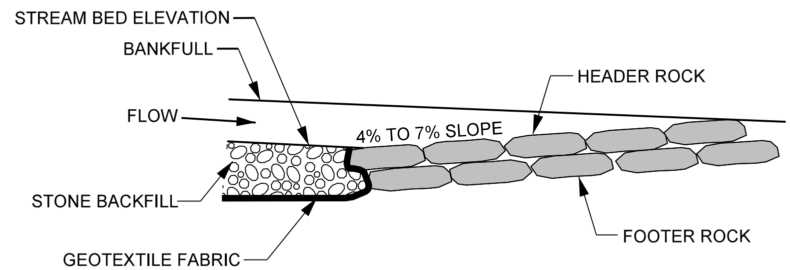
1. LOGS SHOULD BE AT LEAST 10" IN DIAMETER, RELATIVELY STRAIGHT, HARDWOOD, AND RECENTLY HARVESTED.
2. BOULDERS MUST BE OF SUFFICIENT SIZE TO ANCHOR LOGS.
3. SOIL SHOULD BE COMPACTED WELL AROUND BURIED PORTIONS OF LOGS.
4. ROOTWADS SHOULD BE PLACED BENEATH THE HEADER LOG AND PLACED SO THAT IT LOCKS THE 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

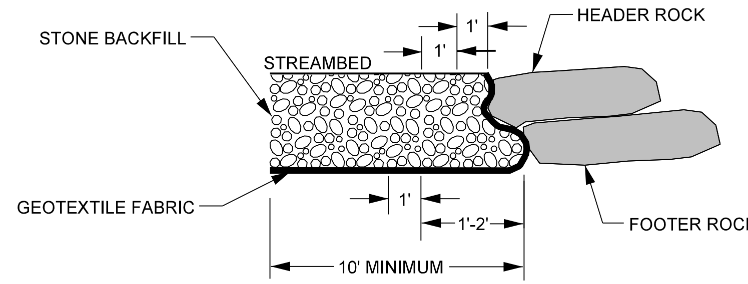
GRADE CONTROL J-HOOK VANE



PLAN VIEW



PROFILE VIEW



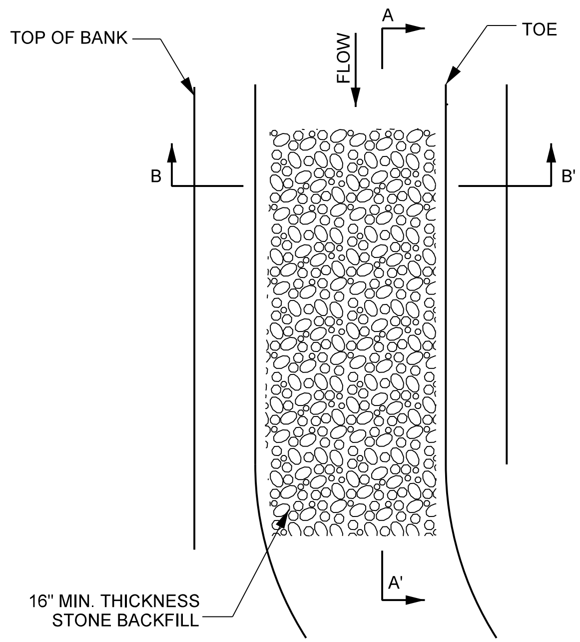
SECTION A - A

NOTES FOR ALL VANE STRUCTURES:

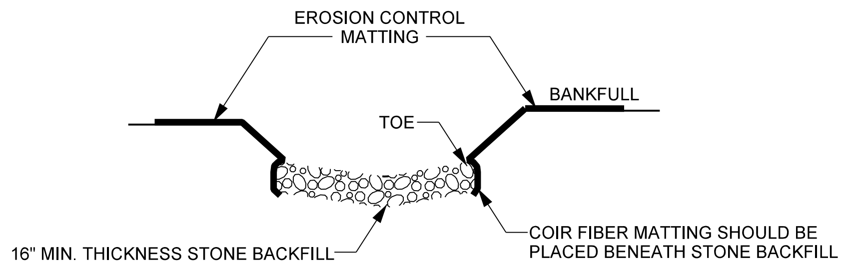
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. 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

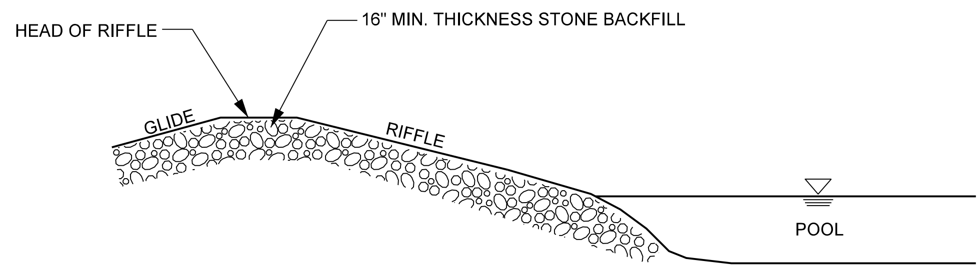
CONSTRUCTED RIFFLE



PLAN VIEW



SECTION B - B'



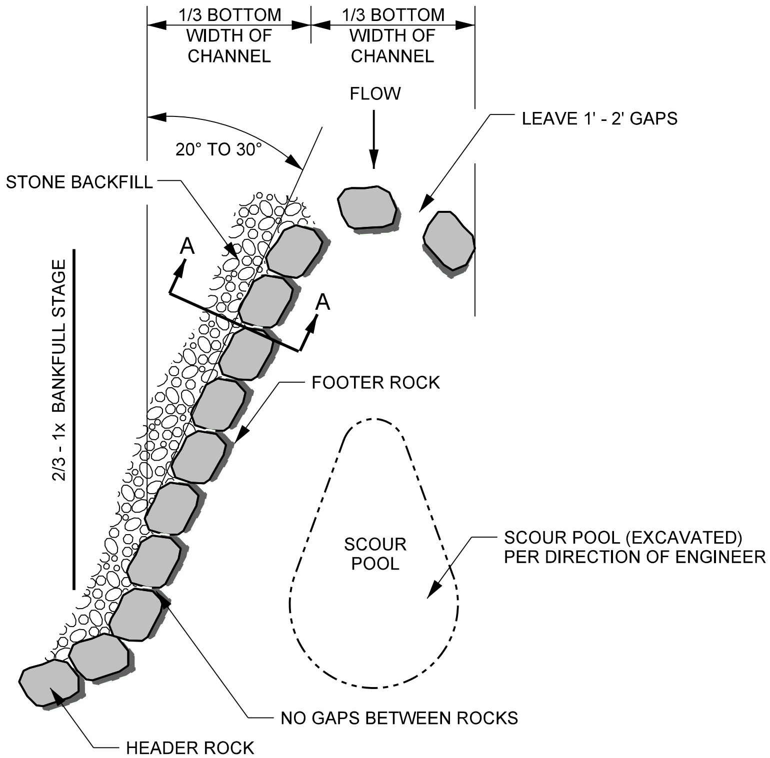
PROFILE A - A'

NOTES:

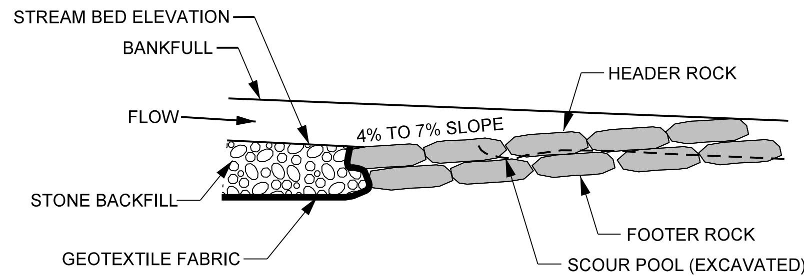
1. DIG A TRENCH BELOW THE BED FOR THE STONE BACKFILL.
2. FILL TRENCH WITH STONE BACKFILL.

CONSTRUCTED RIFFLE

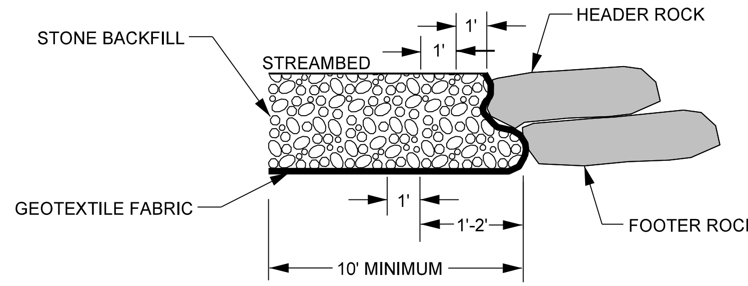
J-HOOK VANE



PLAN VIEW



PROFILE VIEW



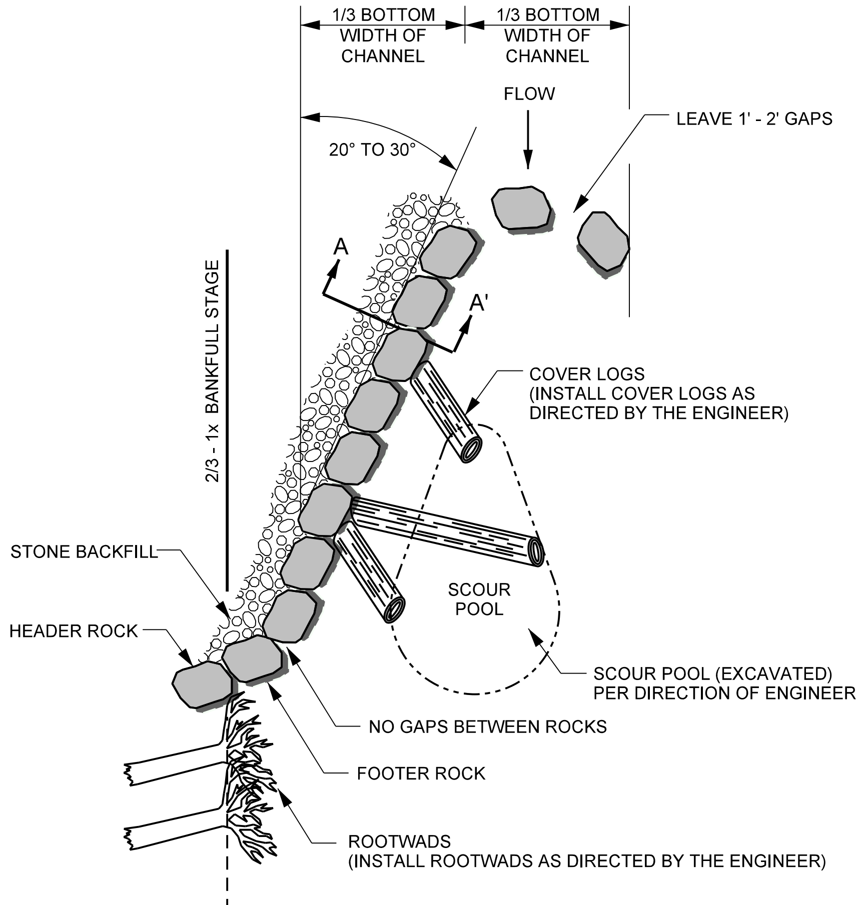
SECTION A - A

NOTES FOR ALL VANE STRUCTURES:

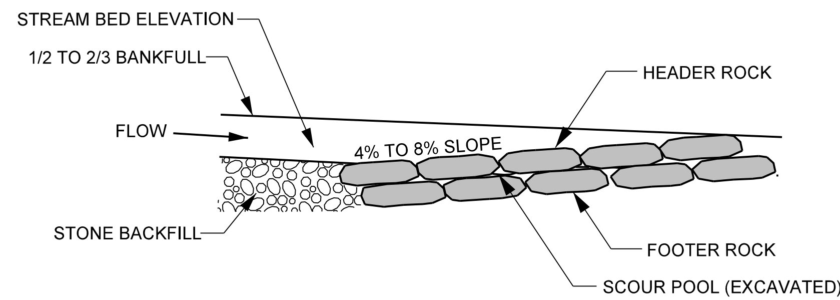
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. 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

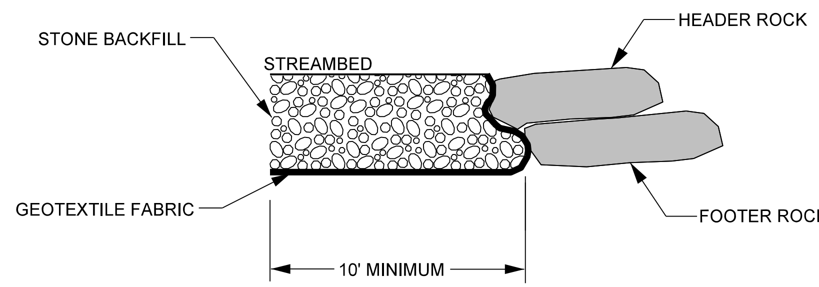
J-HOOK VANE WITH COVER LOG



PLAN VIEW



PROFILE VIEW



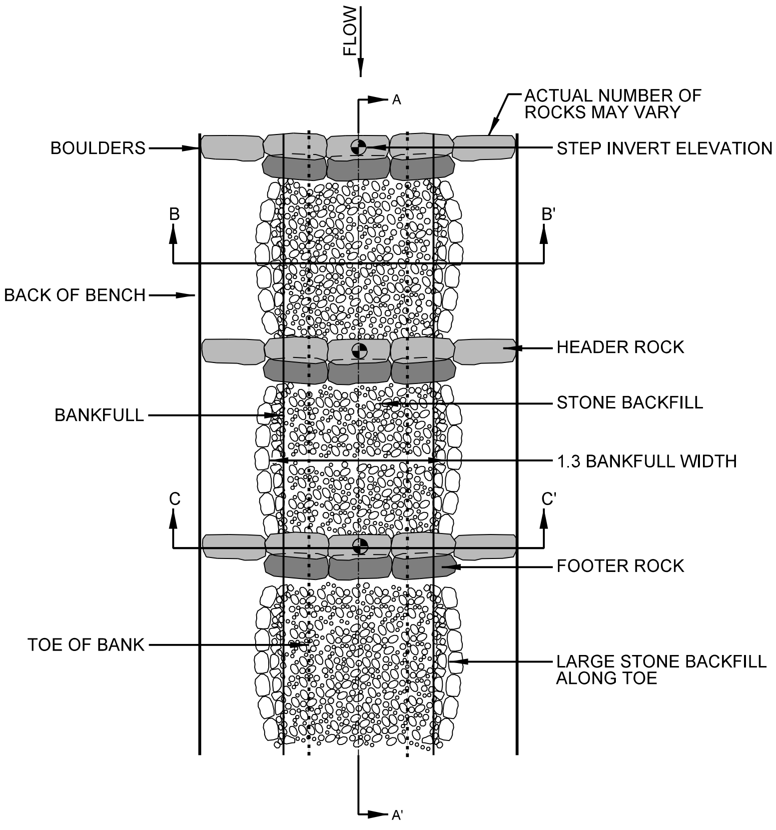
SECTION A - A'

NOTES FOR ALL J-HOOK STRUCTURES:

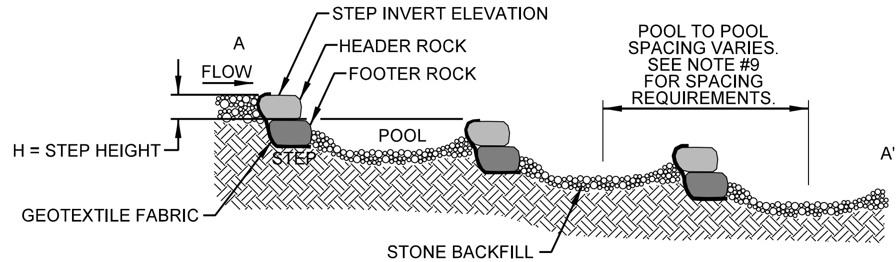
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. 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

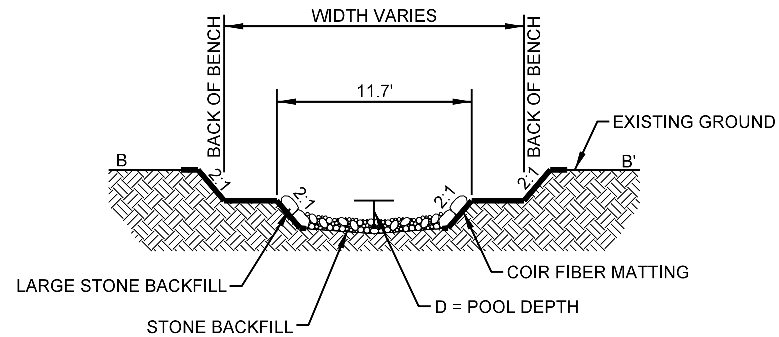
STEP POOL CHANNEL



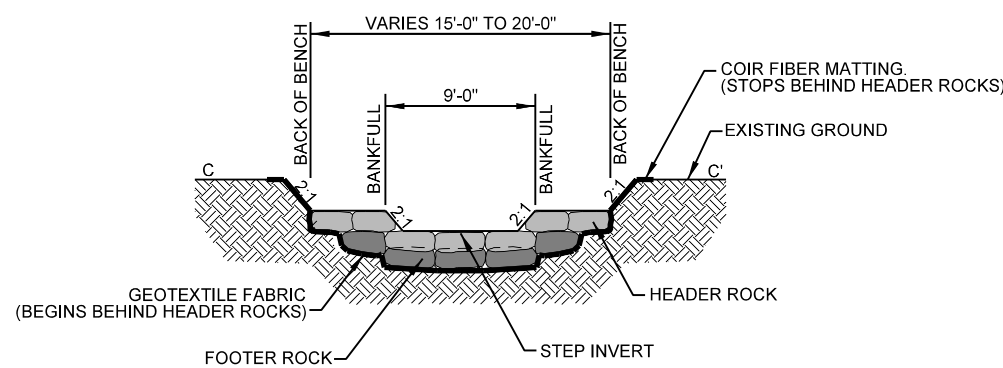
PLAN VIEW



PROFILE VIEW A-A'



POOL CROSS SECTION B-B'



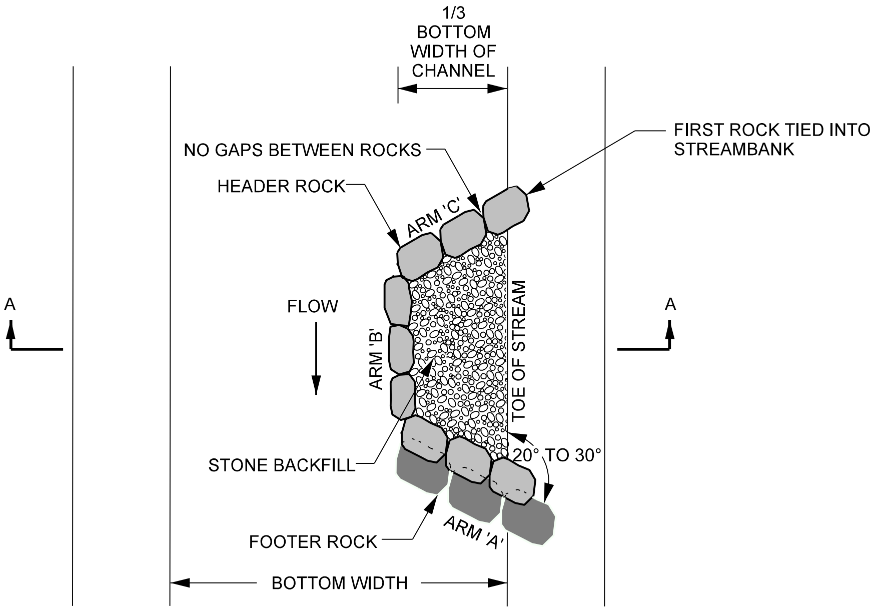
POOL CROSS SECTION C-C'

NOTES:

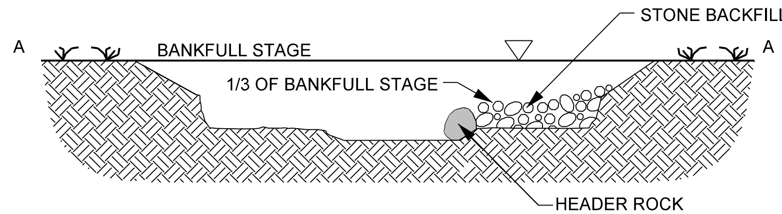
1. FOOTER ROCKS SHALL BE INSTALLED SUCH THAT 1/4 TO 1/3 OF THE LENGTH IS DOWNSTREAM OF THE HEADER ROCKS.
2. SOIL SHALL BE WELL COMPACTED AROUND BURIED PORTION OF FOOTER ROCKS WITH BUCKET OF TRACK HOE.
3. INSTALL GEOTEXTILE FILTER FABRIC UNDERNEATH FOOTER ROCKS.
4. UNDERCUT POOL BED ELEVATION 8 INCHES 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

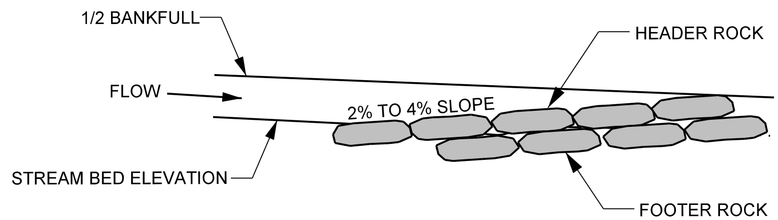
SINGLE WING DEFLECTOR



PLAN VIEW



SECTION A - A



ARM 'A' PROFILE VIEW

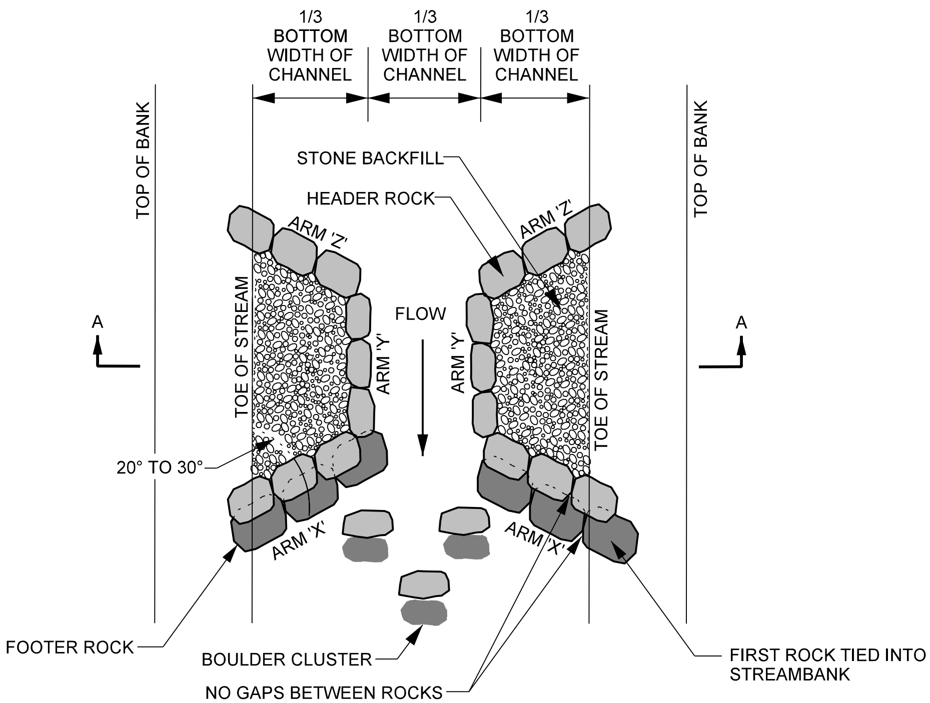
NOTE: NO SLOPE FOR ARMS B & C

NOTES:

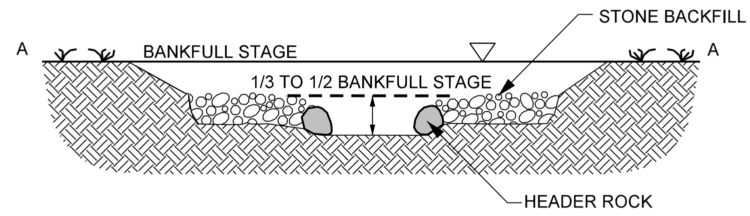
1. INSTALL GEOTEXTILE FABRIC BEGINNING AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWNWARD TO THE DEPTH OF THE BOTTOM FOOTER ROCK, AND THEN UPSTREAM TO A MINIMUM OF TEN FEET.
2. DIG A TRENCH BELOW THE BED FOR FOOTER ROCKS AND PLACE FILL ON UPSTREAM SIDE OF VANE ARM, BETWEEN THE ARM AND STREAMBANK.
3. 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

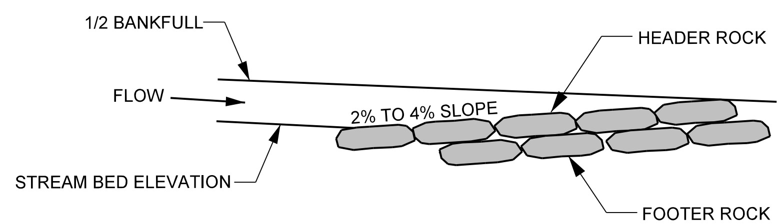
DOUBLE WING DEFLECTOR



PLAN VIEW



SECTION A - A



ARM 'X' PROFILE VIEW

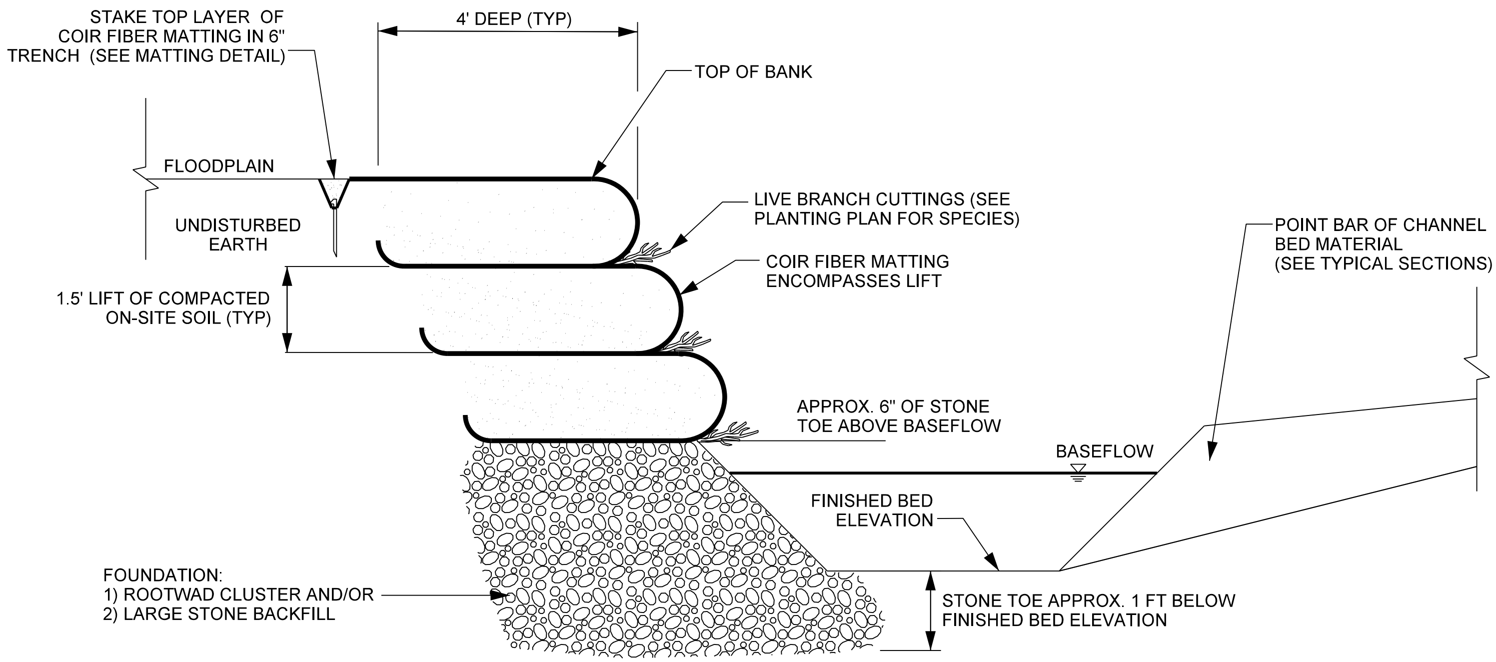
NOTE: NO SLOPE FOR ARMS Y & Z

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

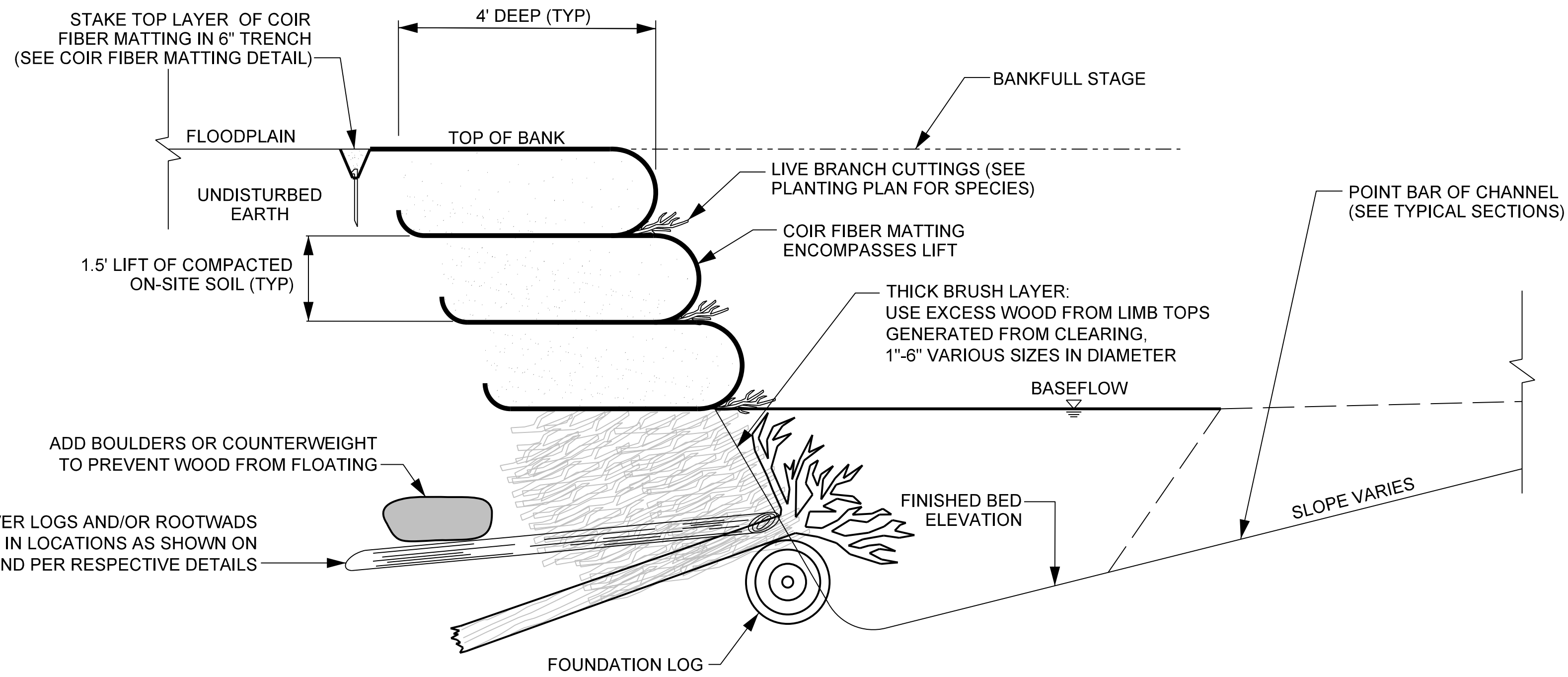
GEOLIFT



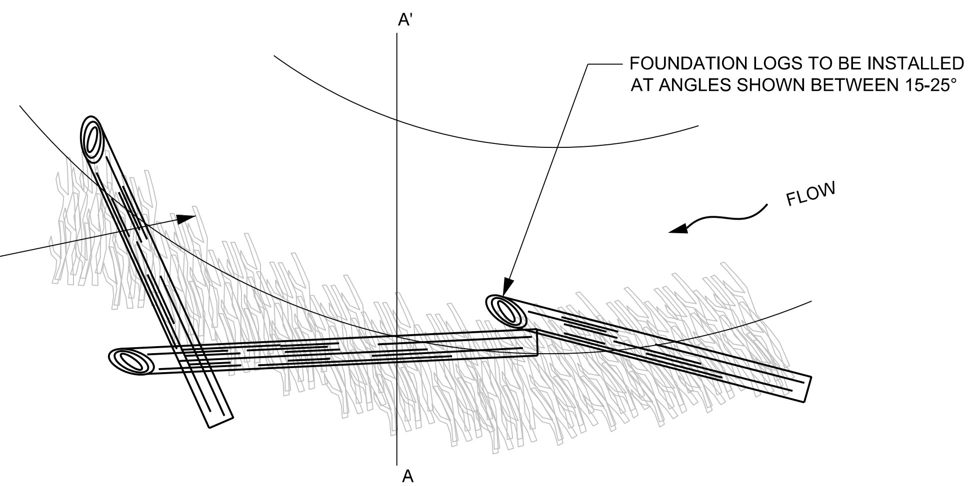
NOTES:
1. WHEN GEOLIFTS ARE BUILT ABOVE ROOTWAD CLUSTER, USE LARGE STONE BACKFILL BEHIND ROOT MASS TO BUILT FOUNDATION.

GEOLIFT

TOE WOOD WITH GEOLIFT



SECTION VIEW



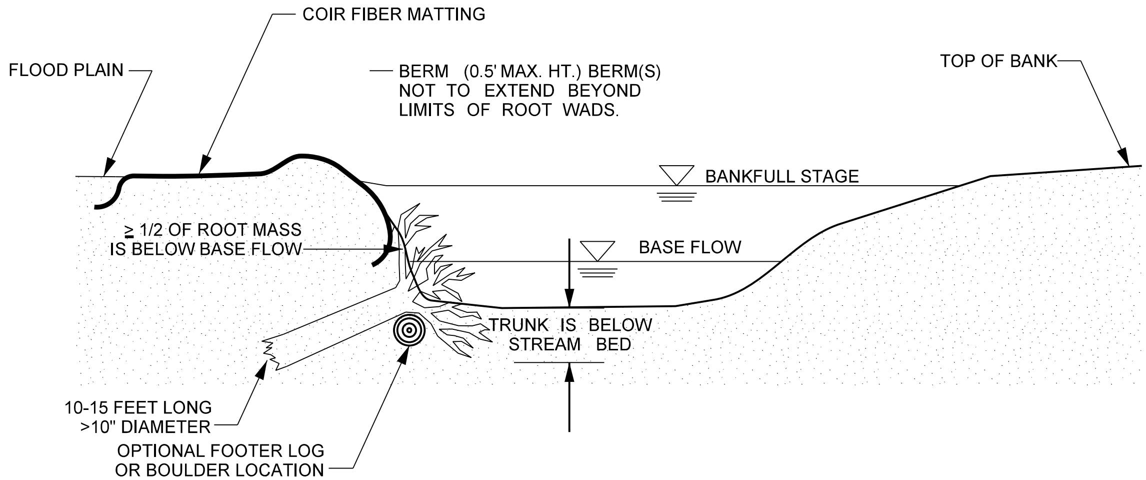
PLAN VIEW

PROJECT SPECIFIC SPECS

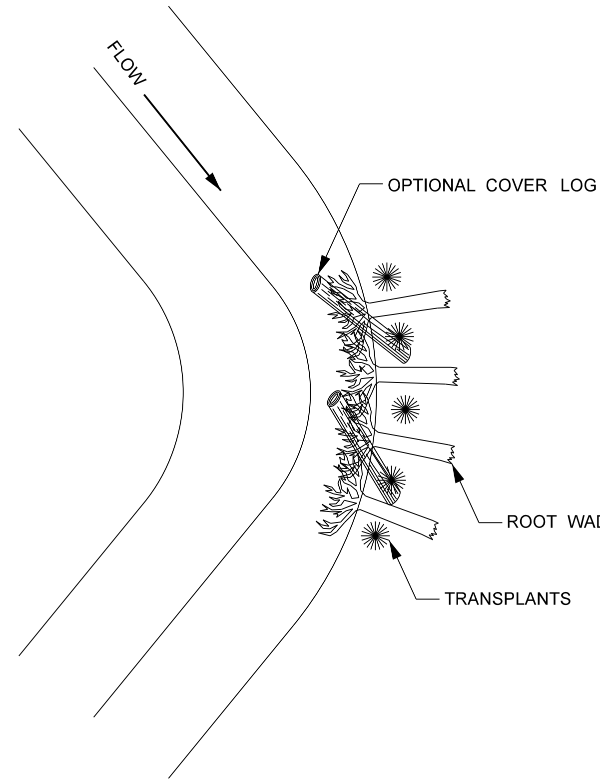
POOL WATER DEPTH	____________	FT
FOUNDATION HEIGHT	____________	IN
FOUNDATION WIDTH	____________	FT
BRUSH THICKNESS	____________	IN

TOE WOOD WITH GEOLIFT

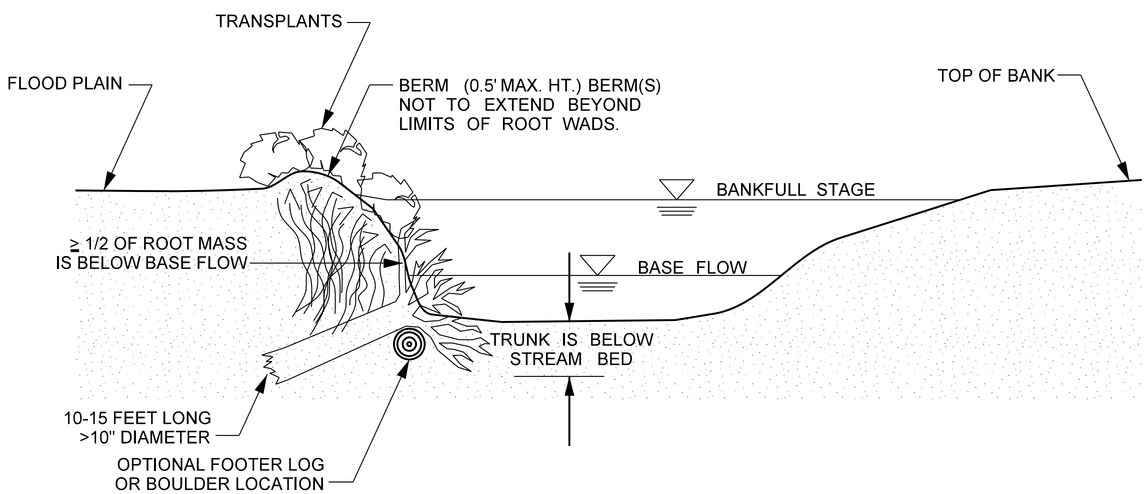
ROOT WADS WITHOUT TRANSPLANTS
CROSS SECTION VIEW
NTS



PLAN VIEW
NTS



ROOT WADS WITH TRANSPLANTS
CROSS SECTION VIEW
NTS



NOTES:

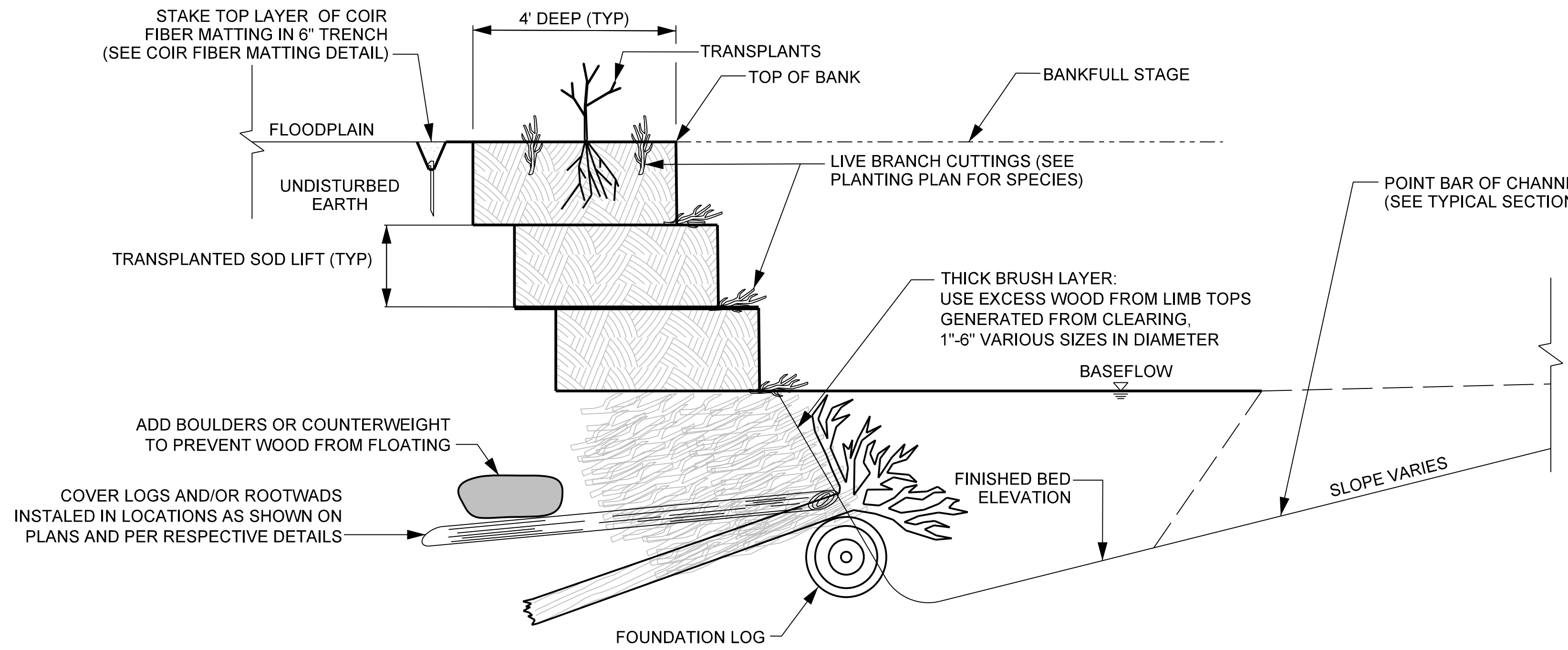
TRENCHING METHOD:
IF THE ROOT WAD CANNOT BE DRIVEN INTO THE BANK OR THE BANK NEEDS TO BE RECONSTRUCTED, THE TRENCHING METHOD SHOULD BE USED. THIS METHOD REQUIRES THAT A TRENCH BE EXCAVATED FOR THE LOG PORTION OF THE ROOT WAD. IN THIS CASE, A FOOTER LOG SHOULD BE INSTALLED UNDERNEATH THE ROOT WAD IN A 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:

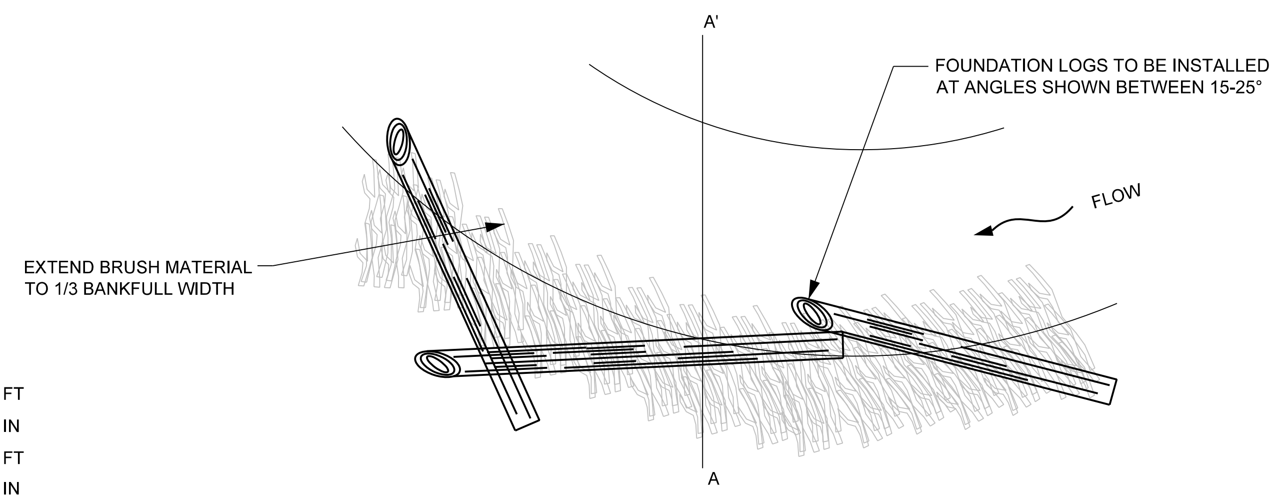
DRIVE POINT METHOD:
SHARPEN THE END OF THE LOG WITH A CHAINSAW BEFORE "DRIVING" IT INTO THE BANK. ORIENT ROOT WADS AS SHOWN, DEFLECTING THE WATER AWAY FROM THE BANK. A TRANSPLANT SHOULD BE PLACED ON THE DOWNSTREAM SIDE OF THE ROOT WAD IF A BACK EDDY IS FORMED BY THE ROOT WAD.

ROOT WADS

TOE WOOD WITH SOD AND TRANSPLANTS



SECTION VIEW



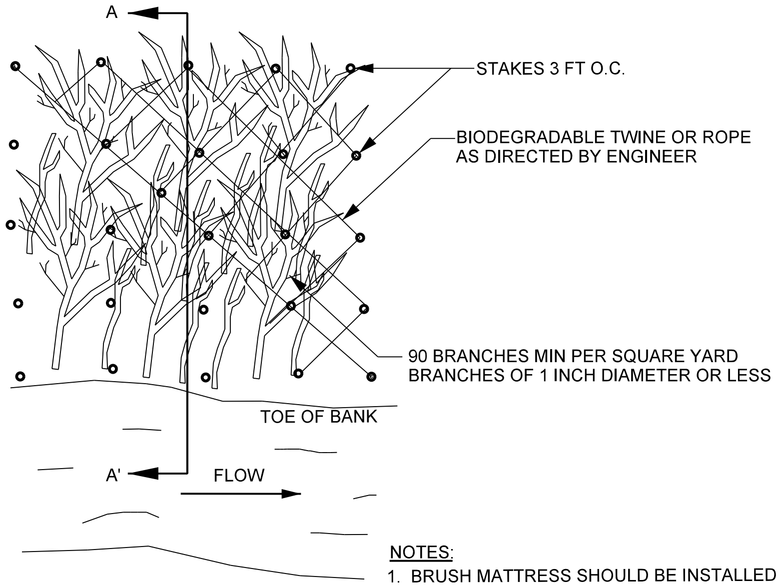
PLAN VIEW

PROJECT SPECIFIC SPECS

POOL WATER DEPTH ____________ FT
FOUNDATION HEIGHT ____________ IN
FOUNDATION WIDTH ____________ FT
BRUSH THICKNESS ____________ IN

TOE WOOD WITH SOD AND TRANSPLANTS

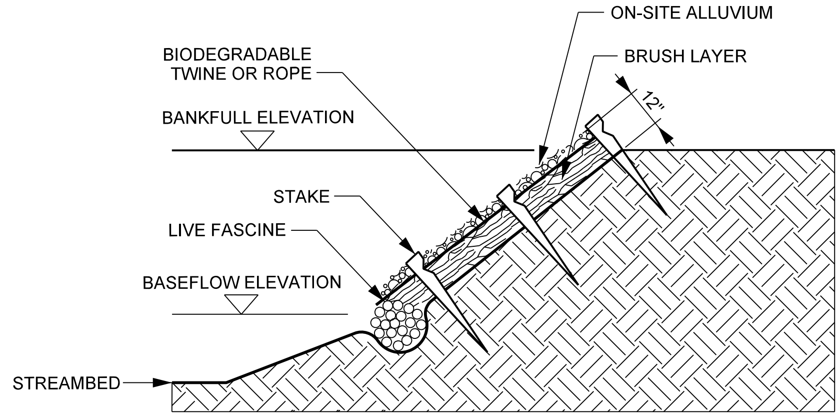
BRUSH MATTRESS



PLAN VIEW

NOTES:

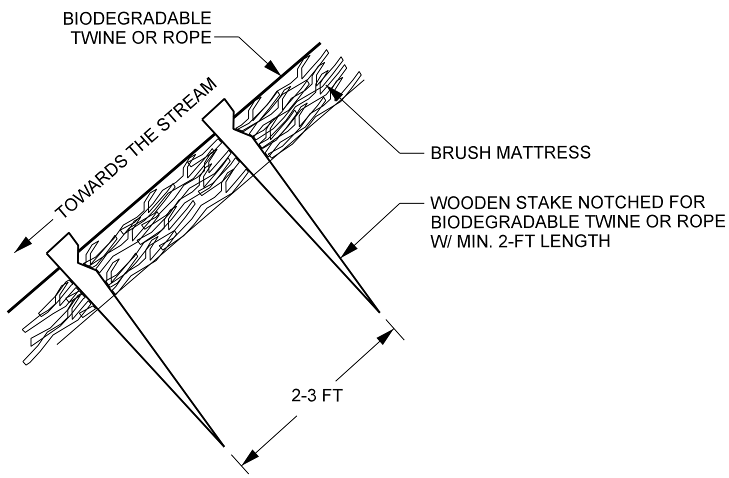
1. BRUSH MATTRESS SHOULD BE INSTALLED DURING VEGETATION DORMANCY.
2. ONLY USE SPECIES SPECIFIED FOR LIVE STAKES.
3. BACKFILL 3" OF ON-SITE ALLUVIUM OVER BRUSH LAYER.



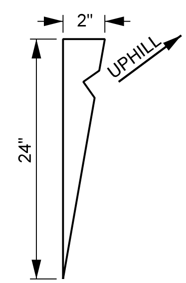
NOTES:

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



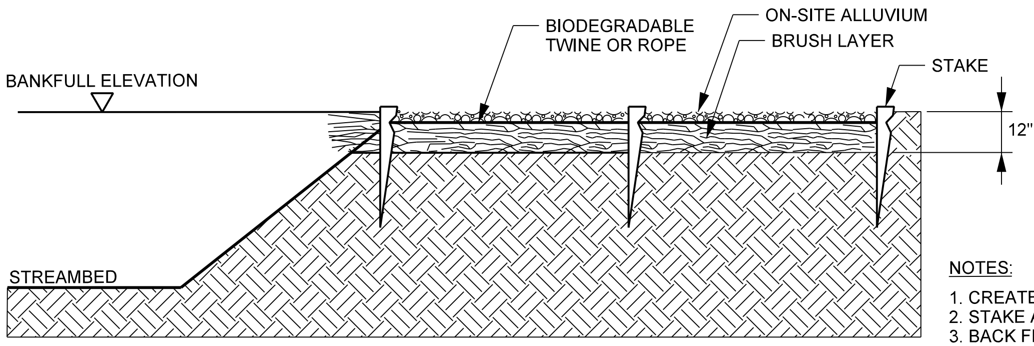
TYPICAL STAKE

NOTES:

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

BRUSH MATTRESS

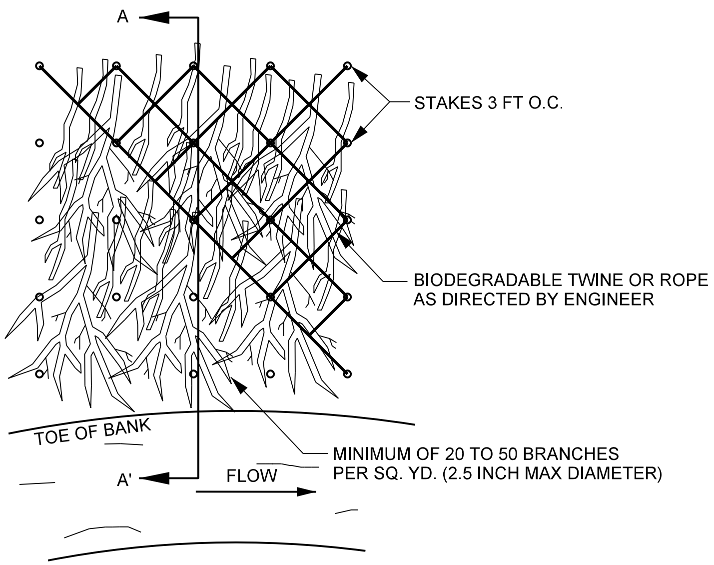
BRUSH LAYER

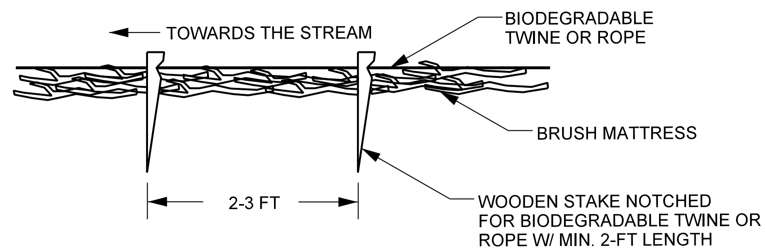


NOTES:

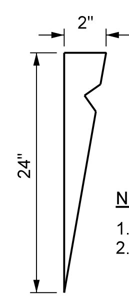
1. CREATE 12" DEEP TRENCH
2. STAKE AND SECURE BRUSH LAYER INTO TRENCH.
3. BACK FILL 3" OF ON-SITE ALLUVIUM OVER BRUSH LAYER.

CROSS SECTION A - A'





STAKE SPACING DETAIL



NOTES:

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

PLAN VIEW

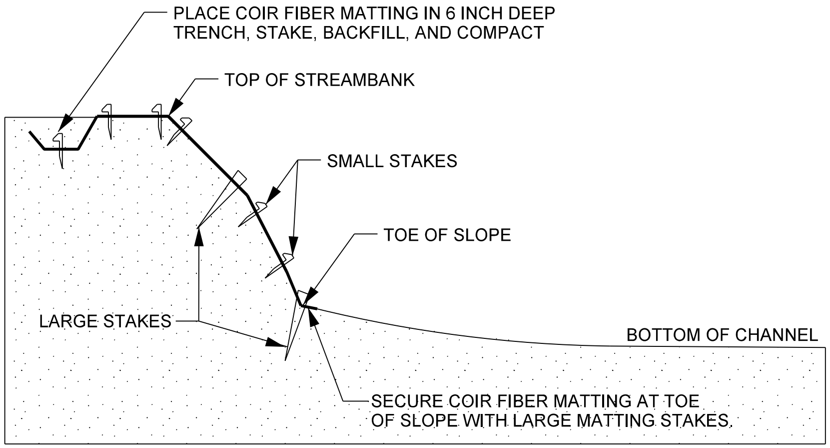
NOTES:

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.

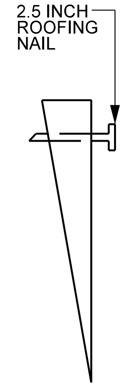
TYPICAL STAKE

BRUSH LAYER

COIR FIBER MATTING

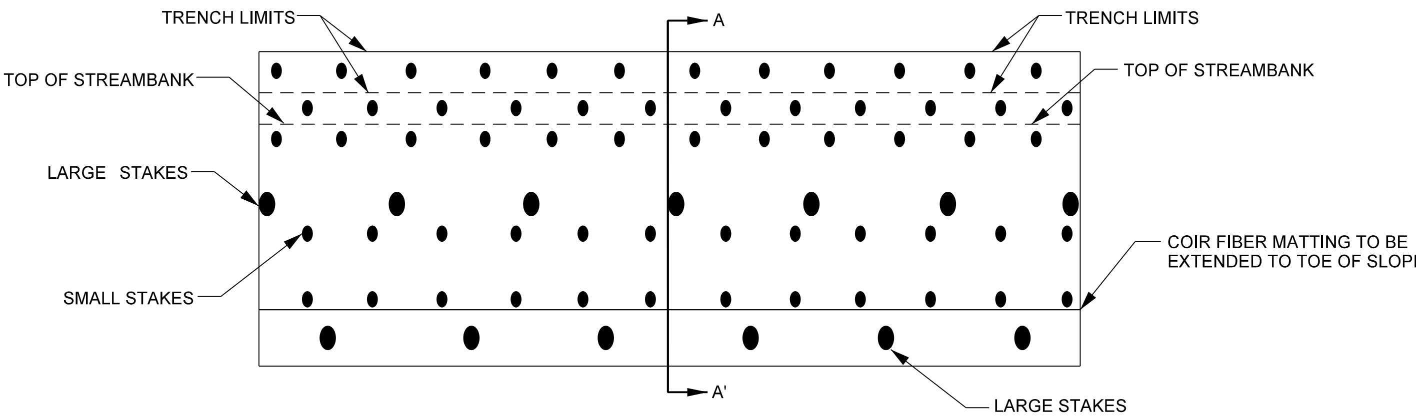


SECTION A - A'

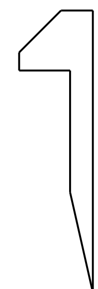


TYPICAL LARGE MATTING STAKE

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

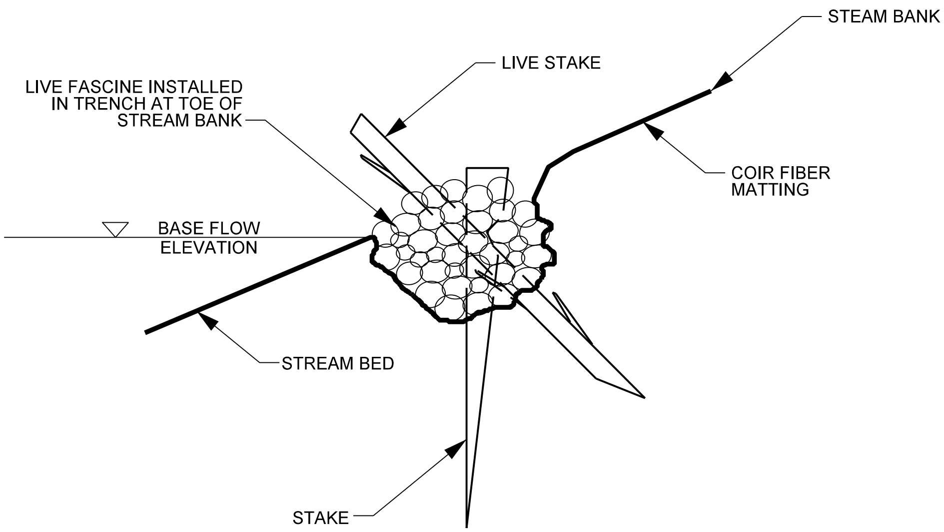
LEG LENGTH	11.00 IN (27.94 CM)
HEAD WIDTH	1.25 IN (3.18 CM)
HEAD THICKNESS	0.40 IN (1.02 CM)
LEG WIDTH	0.60 IN (1.52 CM) (TAPERED TO POINT)
LEG THICKNESS	0.40 IN (1.02 CM)
TOTAL LENGTH	12.00 IN (30.48 CM)

NOTES:

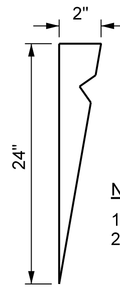
1. BANKS SHOULD BE SEEDED PRIOR TO PLACEMENT OF MATTING.
2. LARGE STAKES SHOULD NOT BE SPACED FURTHER THAN 18" APART.
3. PLACE LARGE STAKES ALONG ALL SEAMS, IN THE CENTER OF BANK, AND TOE OF SLOPE.

COIR FIBER MATTING

LIVE FASCINE



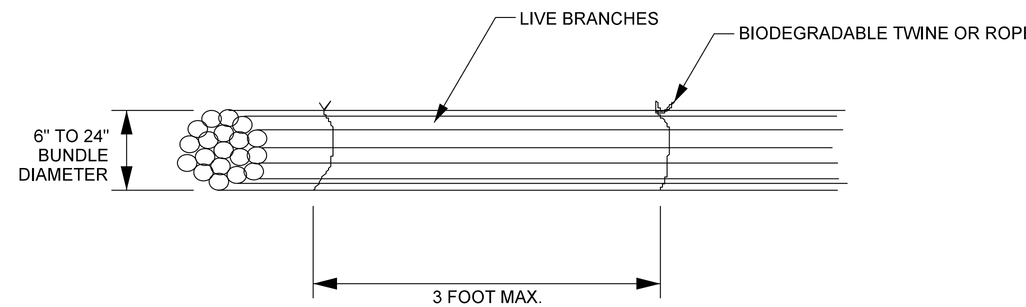
SECTION VIEW



NOTES:

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

TYPICAL STAKE

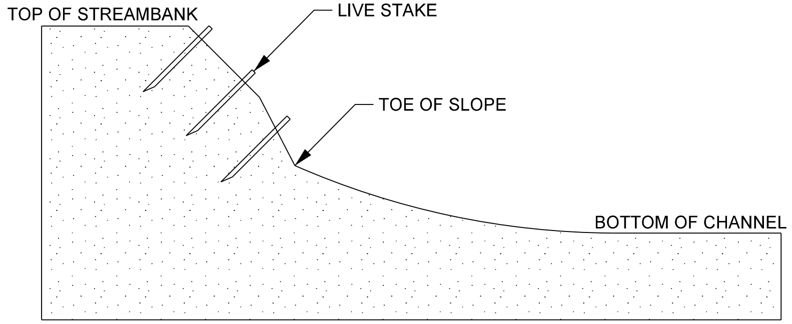


NOTES:

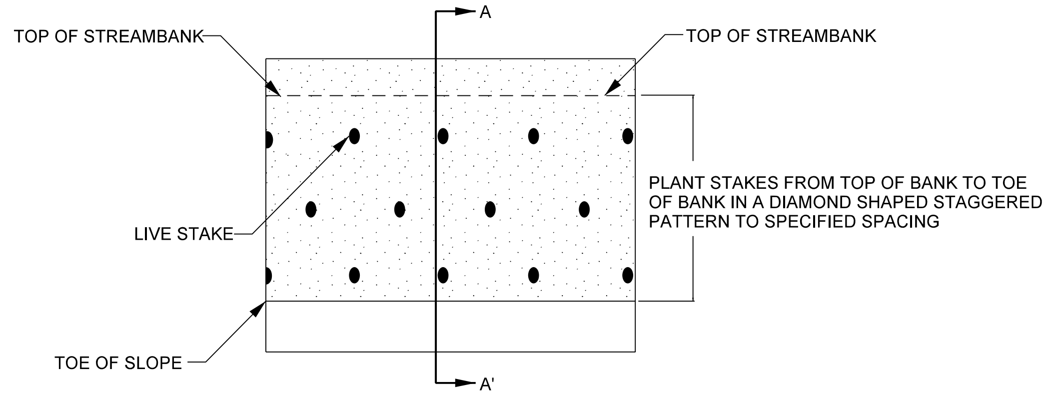
1. LIVE BRANCHES SHOULD BE 1/2 TO 2 INCHES IN DIAMETER.
2. STAGGER ORIENTATION OF CUTTINGS TO CREATE UNIFORM BUNDLE 5-20 FEET LONG AND VARY BASAL ENDS.
3. TRENCH DEPTH 2/3 DIAMETER OF BUNDLE.
3. WASH SOIL INTO TRENCHES TO BACKFILL AND CREATE GOOD SOIL CONTACT.
4. SECURE BUNDLE TIGHTLY WITH BIODEGRADABLE 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

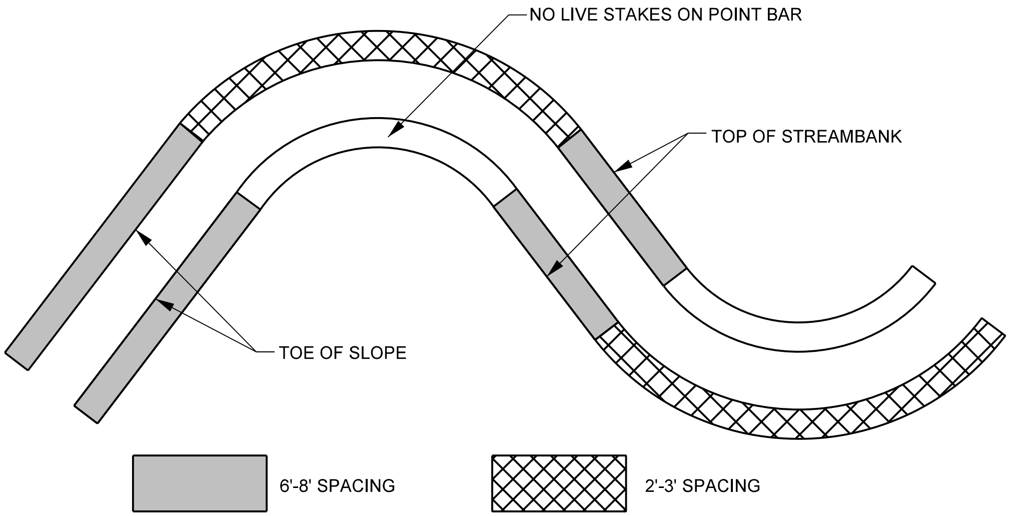
LIVE STAKING



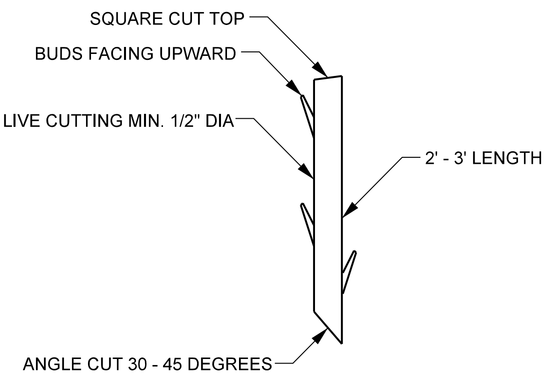
SECTION A - A'



PLAN VIEW



LIVE STAKE SPACING PLAN VIEW



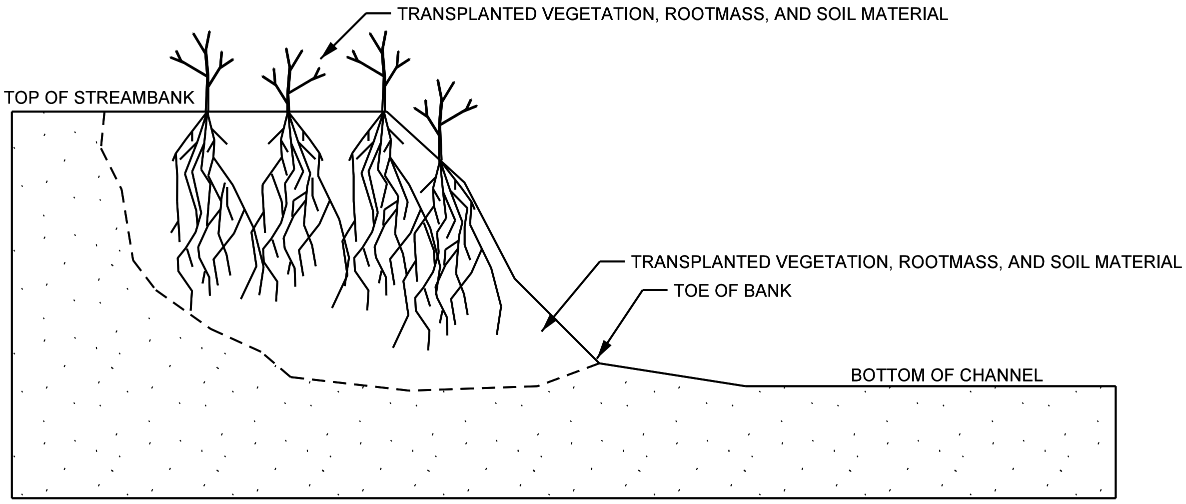
LIVE STAKE DETAIL

NOTES:

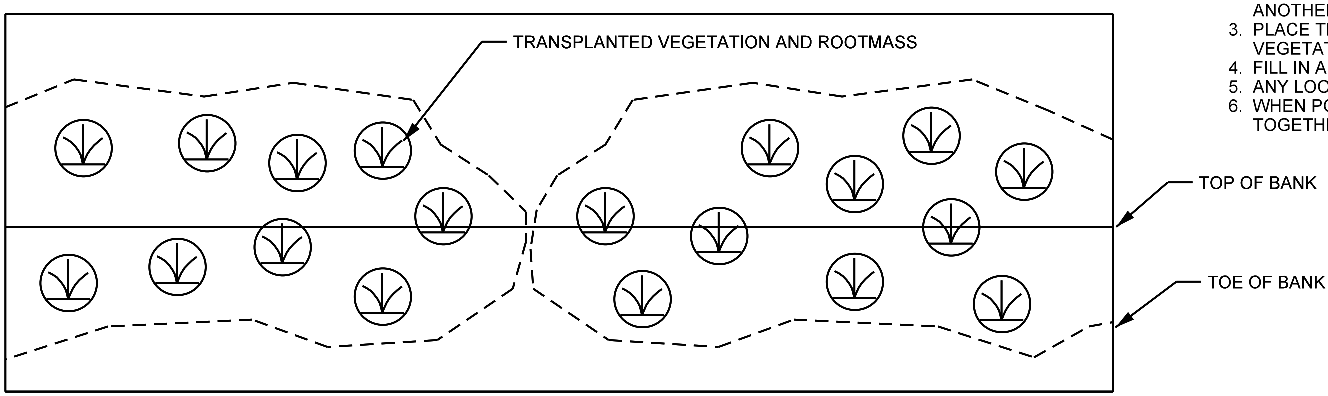
1. STAKES SHOULD BE CUT AND INSTALLED ON THE SAME DAY.
2. DO NOT INSTALL STAKES THAT HAVE BEEN SPLIT.
3. STAKES MUST BE INSTALLED WITH BUDS POINTING UPWARDS.
4. STAKES SHOULD BE INSTALLED PERPENDICULAR TO BANK.
5. STAKES SHOULD BE 1/2 TO 2 INCHES IN DIAMETER AND 2 TO 3 FT LONG.
6. STAKES SHOULD BE INSTALLED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

SAN ANTONIO
RIVER AUTHORITY
Leaders in Watershed Solutions

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 I

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.

<u>Grade Control J-Hook Vane</u>

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.

<u>Root Wads</u>

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 J

Natural Channel Design Protocol

San Antonio, Texas

SAN ANTONIO RIVER AUTHORITY

Leaders in Watershed Solutions

STREAM RESTORATION APPROACHES AND TECHNIQUES

The Natural Channel Design Protocol provides design guidance on how to implement the natural channel design methodology in the San Antonio Region. However, there are other stream restoration approaches available that could be applicable depending on the functional impairments and project goals. This section of the protocol provides an overview of three stream restoration approaches, including natural channel design, along with their strengths and weaknesses for addressing functional deficiencies common to San Antonio streams. In addition to restoration approaches, specific restoration techniques will be described and linked to the approaches. Guidance will be provided to help practitioners pick the best restoration approach and associated techniques to provide the most functional lift possible at a project site.

Restoration Approach versus Restoration Technique

A stream restoration *approach* is a broad level, comprehensive design methodology incorporating watershed characteristics, reach-scale assessments, and specific project constraints. Ideally, a restoration approach necessary to achieve the restoration potential will be identified and matched to an underlying problem in stream function. For this protocol, the following criteria were used to select existing restoration approaches:

- Recognized in the literature as a comprehensive design methodology for restoring or enhancing stream functions.
- Includes a collection of steps, tools, and techniques organized into logical procedures to achieve project and design goals and objectives.
- Likely addresses multiple stability and functional problems.
- Must be described in a manual, recognized as a standard of care, or referenced by the community of practitioners (i.e., has name recognition).

The physical activity used to improve a stream function is the restoration *technique*. Stream restoration techniques are narrower in scope than an approach, and are often used to solve a specific problem, like streambank erosion or to increase buffer width and composition. The implementation of a restoration approach is completed through the use of various restoration techniques. Each restoration approach can use one or more restoration techniques within the design process. **Table J-1** provides common restoration objectives and the functional benefit, restoration technique, and design approaches associated with achieving the objective.

Table J-1: Stream Restoration Techniques

Definition: Stream Restoration Techniques are used to solve a specific problem and are therefore narrower in scope than design approaches.
Abbreviations: Rosgen Natural Channel Design (NCD), Parola Integrated Valley and Wetland Restoration (IVW), Underwood Regenerative Design (RD)

Objective	Functional Benefit	Example Techniques
Remove channel obstructions	Allow organism passage	Dam removal Culvert removal Fish passage structures
Improve lateral stability / Reduce bank erosion	Provide organism habitat Reduce sediment supply	In-stream structures Bio-engineering Riparian re-vegetation Fencing
Improve vertical stability	Provide organism habitat Reduce sediment supply Improve or maintain floodplain inundation	In-stream structures Remeandering of straightened channel Raising channel or grading floodplain
Improve bed-form diversity, e.g., riffle-pool sequence	Provide organism habitat Dissipate energy	In-stream structures Remeandering of straightened channel Engineered logjams LWD placement Sediment removal Substrate addition Floodplain connectivity
Improve floodplain / riparian complexity	Provide organism habitat Improve species diversity Reduce flood flow velocity	Floodplain grading Creation of floodplain habitats Riparian re-vegetation Removal of invasive species Controlled burning Levee removal
Runoff treatment	Reduce nutrient loading Reduce peak flows	Stormwater BMPs Agricultural BMPs Buffer establishment
Reduce nutrient loading from adjacent land uses	Reduce nutrient loading	Floodplain connectivity Buffer establishment Floodplain grading Stormwater BMPs Agricultural BMPs
Improve groundwater / water interaction	Reduce nutrient loading Increase microbial functions Thermal regulation Increase base flow duration	Floodplain connectivity In-stream structures Remeandering of straightened channel Groundwater dams Engineered logjams LWD placement
Reduce stream temperature	Provide organism habitat	Buffer establishment Agricultural BMPs Floodplain connectivity In-stream structures Remeandering of straightened channel

The three most applicable restoration approaches for the San Antonio River are Natural Channel Design, Integrated Valley and Wetland Restoration, and Regenerative Design. Each approach is used for different applications depending upon a project's location in the watershed and functional problem. A project's location within the watershed is a major factor in determining the type of stream approach to use. In addition, watershed size; surrounding soil characteristics, land cover, and topography; in conjunction with precipitation, evapotranspiration, and infiltration rates influence the size and characteristics of the stream channel and can influence the approach selection. Functional problems arise from an imbalance in these stream characteristics creating stability issues or a physicochemical interaction creating undesirable water quality conditions. Often the functional problems for a stream are a combination of stability related issues and water quality concerns requiring practitioners to use a variety of restoration approaches and techniques to address the localized functional problem. The restoration techniques need to be aligned under a restoration approach to ensure the watershed condition and underlying causes of the functional problems are addressed holistically.

The following sections describe common stability related issues and known water quality concerns. These are outlined to provide an understanding of the issues facing restoration practitioners and how the three restoration approaches can be used to improve stream functions.

Common Stream Stability Problems in the San Antonio Region

Streams are dynamic systems that will change over time. Restoration practitioners are interested in maintaining a healthy stream environment by promoting the natural changes occurring over geologic time while mitigating the anthropogenic influences which create immediate change. Understanding the cause and effect relationship of stream equilibrium allows for a predictive response to changing factors. Lane (1955) qualitatively described stream equilibrium as a balance between sediment supply and stream power represented by the equation:

$$Q_S \times D_{50} \propto Q_W \times S$$

Where Q_S symbolizes the sediment load, D_{50} the grain size, Q_W the discharge, and S the stream slope. The equation indicates stable streams reach equilibrium when the resistive energy contained with the sediment supply of a stream corresponds to the active energy of the water within the stream. Therefore if one variable changes, the other three will adjust in an effort to re-establish equilibrium, the result of which produces aggradation or degradation within the system. For example, an increase in discharge will be met with either a decrease in slope, an increase in sediment load, an increase in sediment grain size, or more probable a combination of the three. By understanding the factors initiating an imbalance in stream equilibrium, restoration practitioners can use a visible response (i.e. stream bank erosion) to develop not just a restoration technique but a natural channel approach to address the change.

The San Antonio River Basin has undergone change over the years with the most notable impacts to stream corridors coming from the increase in impervious surface, stream corridor encroachment, and stream channel alteration. A Land Use Land Cover assessment using advanced atmospheric correction and object-oriented image analysis of moderate resolution satellite data from 1985 to 2003 revealed an approximate 33% increase in impervious surface in and around the San Antonio city limits (Owojori, 2005). The addition of impervious surface modifies the natural hydrology and hydrologic cycle by replacing natural vegetated areas with hardened surfaces such as pavement, buildings, and compacted soils. This results in more frequent over bank events, higher flood peaks, lower base flow in stream, and lower water table levels (Dorman, 2013). Increased urbanization coupled with the demand for agricultural production associated with population increase has resulted in encroachment within the stream corridors. The removal of the riparian buffer diminishes the natural pollutant removal mechanism while allowing for water to reach the stream channel quicker and in a concentrated form. Additionally, encroachment of the riparian stream corridor severely limits a channel's flood capacity often requiring the stream channel to handle flows in excess of the stable regime. By requiring the channel to retain the higher flows, channel velocities increase creating significant erosion potential. San Antonio's urbanization has also impacted the interior of stream channels through the use of hardening structures such as gabions and concrete flood channels. These systems may not seem to have stability issues until a sediment supply is introduced. The sediment starved system will begin to develop depositional features requiring maintenance crews to dredge the channels.

The three restoration approaches outlined below can be used to improve channel stability concerns, specifically concerns arising from an equilibrium imbalance associated with increased impervious area, encroachment, and channel alteration. For a majority of the channel stability problems associated with flood control channels, Natural Channel Design will be the best solution as discussed in Section 9.0. However, the other two approaches are presented to provide options for instances when Natural Channel Design does not provide the most functional lift. For example, a confined ephemeral tributary flowing from a parking lot to the main channel may be better suited for the Regenerative Design approach in order to achieve more nutrient removal. Use the information provided about each approach and the project areas constraints to determine which restoration approach provides the most functional benefit for the channel stability concern being addressed.

Common Water Quality Problems in the San Antonio Region

Water quality problems are summarized for each state on the "303d list", which is a reference to 40 CFR 130.7 of the Clean Water Act requiring all States to identify segments of impaired waterways and develop total maximum daily loads (TMDLs) to meet water quality standards. TMDLs include wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and margins of safety. The regulations require that states report their findings to the Environmental Protection Agency (EPA) biennially on April 1 of each even-numbered year. The segments on the 303d list are Category 5 impaired waters, or waters that require a TMDL. Other impaired waters, that either already have an EPA approved TMDL or fall into another Category 4 description, are not listed. The Texas Commission on Environmental Quality has combined this information into a report called the "Texas Integrated Report of Surface Water Quality" (Texas Integrated Report of Surface Water Quality, 2013). The full report documents all water bodies evaluated by indexing the following: impaired waters (Category 4 and 5), Category 5 waters without TMDLs (303d list), waters of concern (305b list), all waters recently listed, all waters recently delisted, and all categories by waterway segment. The various indices provide broad water quality categorization (categories by segment) down to a detailed analysis of the parameter not meeting the water quality standard and the means in which the standard is not being met (index of impaired waters). Therefore, stream restoration practitioners can use the

Integrated Report as a means to gauge the health of a water way by referencing each section of the report.

Within the Integrated Report, the San Antonio River is broken into two segments: the Lower San Antonio River, SegID 1901, and the Upper San Antonio River, SegID 1911. These broad segments are further subdivided into assessment units (AU) with the Lower San Antonio River having six assessment units, AU 1901_01 through AU 1901_06, and the Upper San Antonio River having nine assessment units, AU 1911_01 through AU 1911_09. Reviewing the Integrated Report by assessment unit provides a coarse level spatial examination of the San Antonio River. **Table J-2** summarizes each monitored parameter by the Integrated Report Section and assessment unit for the San Antonio River. The evident conclusion from the table is fecal indicator bacteria levels have been and continue to be a widespread pollutant of concern throughout the San Antonio River. Additionally, there has been some impairment to fish communities in two of the assessment units and while nutrient levels are not high enough to institute regulations, almost all nutrient parameters are of a high enough level to warrant consideration for regulation (Texas Integrated Report of Surface Water Quality, 2013). Finally, tributaries to the San Antonio River have additional water quality stressors not listed in **Table J-2** that may influence a specific project area.

Table J-2: Summary of the Texas Integrated Report for the San Antonio River

River Name	Segment ID (SegID)	Assessment Unit (AU)	303d List (Cat 5 no TMDL) Para-meter	303d List Cate-gory	303d List Date Listed	Impaired List (Cat 4 and 5 with TMDL) Parameter	Impaired List Category	Impaired List Carried Over from 2010	Concern List Parameter	Concern List Concern Level*
UPPER SAN ANTONIO RIVER	1911	_01	-	-	-	-	-	-	Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_02	-	-	-	Bacteria	4a	Yes	Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_03	-	-	-	Bacteria	4a	Yes	Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_04	-	-	-	-	-	-	Nitrate	CS
		_05	-	-	-	-	-	-	Nitrate/Orthophos phorus	CS
		_06	-	-	-	-	-	-	Nitrate	CS
		_07	-	-	-	Bacteria	4a	Yes	Impaired Habitat/Nitrate	CS
		_08	-	-	-	Bacteria	4a	Yes	Impaired Fish Community/ Impaired Habitat/Nitrate	CN:Impaired Fish Community CS: All Others
		_09	Impaired Fish	5c	2006	Impaired Fish	5c	No	Impaired Habitat/Nitrate/ Orthophosphorus	CS
LOWER SAN ANTONIO RIVER	1901	_01	-	-	-	Bacteria	4a	No	Nitrate/ Total Phosphorus	CS
		_02	Impaired Fish	5c	2012	Bacteria/ Impaired Fish	4a/ 5c	No/ No	Chlorophyll-a/ Impaired habitat/Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_03	-	-	-	Bacteria	4a	No	Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_04	-	-	-	Bacteria	4a	No	Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_05	-	-	-	Bacteria	4a	No	Nitrate/ Orthophosphorus/ Total Phosphorus	CS
		_06	-	-	-	-	-	-	Chlorophyll-a/ Nitrate/Orthophos phorus/Total Phosphorus	CS

*CN – Concern for near-attainment of Water Quality Standards
*CS – Concern for water quality based on screening levels

In an effort to combat the sources of pollution, stream restoration practitioners can use this data to determine one or more specific water quality parameters to target when implementing projects. On the broadest level, fecal indicator bacteria and fish impairment are the two pollution parameters of most concern across the San Antonio River. However, in the near future, nutrient control will likely become an important factor in water quality throughout the basin. Therefore, short term projects involving single, localized impacts (i.e. stream bank enhancement, single lot residential development) on the San Antonio River should primarily focus on reducing fecal indicator bacteria levels and improving fish habitat with additional consideration given to projects with added emphasis on reducing nutrient levels. However, long term, continually contributing impacts (i.e. large scale contiguous stream restoration, large scale development, linear infrastructure) on the San Antonio River should have a primary focus on integrating and installing nutrient reduction systems and controlling runoff into natural waterways. Natural channel design can provide the tools to limit the water quality stressors in the waterways. Through the introduction of riparian buffers nitrogen loads entering streams can be significantly reduced (Mayer 2007). Riparian buffers can also provide sediment settling areas and an established buffer with canopy provides shade producing cooler stream temperatures for inland streams. Tributaries and headwater systems designed to retain carbon and organic matter through interactions with ground water and increased residence times allow for nutrient removal (Berg 2010). Through the re-establishment of stream equilibrium, excessive sediment supply known to degrade aquatic macroinvertebrate and fish communities, is removed from the system (Waters 1995). Thus natural channel design falls into compliance with SARA's LID technical guidance to provide structural best management practices and planning techniques that are intended to reproduce predevelopment hydrologic conditions (Dorman 2013).

Description of Stream Restoration Approaches

Natural Channel Design

<u>Description</u>

Natural channel design is a restoration approach that addresses small to large transport channels. The goal is to accelerate the channel evolutionary process in order to achieve a stable condition. A stable condition is defined as a stream with the ability, over time (in the present climate), to transport the flows and sediment produced by its watershed in such a manner that the dimension, pattern, and profile are maintained without aggrading or degrading (Rosgen, 1996). For the purpose of determining stability, this approach uses two concepts: the bankfull discharge and the reference reach. The bankfull discharge is the discharge associated with the stage at the incipient point of flooding and is similar in concept to the effective, dominant, or channel forming discharge. The bankfull discharge is used as a "reference discharge" by providing the basis of comparison across stream systems. This basis of comparison can be implemented to classify streams into similar types, extrapolate morphological relations, and develop dimensionless ratios (Rosgen, 1998). By analyzing specific metrics within the dimensionless ratios, streams are classified by stability, watershed size, horizontal plan form, vertical profile, and channel bed material. Streams of similar classification therefore have similar characteristics and exist in similar landscapes/valleys. Given these similarities, a reference reach can be introduced as the stable preferred condition; then through dimensionless ratios, the reference reach can be mimicked in an effort to restore a degraded system. This process can only be realized once the evolutionary stage of the degraded channel is determined and a decision made about whether the channel should be returned to historical conditions or pushed forward to a different stable state.

<u>Strengths</u>

- Applicable in a large range of watershed sizes and landscape settings.
- Can be applied in ephemeral, intermittent, and perennial streams.
- Dominant restoration approach in the U.S. with many constructed projects and a large amount of monitoring data.

- Flexible design options to include passive and aggressive treatment options.
- Includes extensive stream geomorphic assessments as part of the design.
- Can be used in high energy environments like flood-channel retrofits.

Weaknesses

- The approach typically includes a single-thread channel design that is capable of transporting sediment, even in watersheds that have a very low sediment supply. The approach does not include a way to determine if a wetland or stream/wetland complex would provide greater functional lift in settings where channels may not have been historically present.
- Determining the bankfull discharge and dimension can be challenging in a semi-arid environment, and may require the development of watershed-specific regional curves.

Application

- While this approach can be applied in a wide range of watershed sizes, it is most applicable in stream reaches that have an upstream sediment supply and therefore require sediment transport through the project reach. However, the approach can be adapted to include small stream/wetland complexes if reference reach data can be obtained for these systems.

Integrated Valley and Wetland Restoration

Description

Integrated Valley and Wetland Restoration is a design approach developed by Art Parola, the Director of the Stream Institute and professor, at the University of Louisville. Parola describes this approach as a method that reinstates what may have been a very common pre-European settlement valley bottom ecosystem in the eastern United States. In restoration projects using this approach, floodplains and stream channels are constructed to reestablish the surface and subsurface processes that are believed to have occurred at the sites prior to human-imposed changes to the watershed’s hillslopes, valleys, and stream channels. These self-sustaining restorations have the capacity to adjust to changes in the watershed; they are able to maintain grade control and stable habitat without being constrained to a fixed form that would be necessitated by structures commonly installed to direct flow through the channel. The approach is based on design of valley topography to produce a high frequency, high duration and large extent of surface water and groundwater exchange between the channel and floodplain and to promote retention of organic matter, sediment, nutrients and water within the channel and floodplain (Parola Jr., 2011). In this approach, the channels, which are highly varied in dimensions and planform, and the floodplain surface are designed to evolve with vegetative succession and potential future beaver reestablishment. The channels and floodplains typically develop into stream-and-wetland complexes. The approach requires an understanding of the valley groundwater and surface water hydrologic systems and the characteristics of sediment loads to predict the likely channel forms and floodplain topography that will evolve. Although general characteristics of channels in the region are considered, reference reaches are not used in the design process.

Strengths

- Design does not include the determination of bankfull discharge and dimensions, which can be challenging in semi-arid environments.
- Creates a strong connection between the stream/wetland and the water table.
- Potential to assist in pollutant removal over time.
- Often increases base flow duration and retains organic matter.

Weaknesses

- Has not been attempted in a semi-arid environment with variable aquifer conditions. For the San Antonio region, it may be limited to artesian zones within the Edwards Aquifer.
- Can only be applied in watersheds with low sediment supply. When this approach is implemented in watersheds with high sediment supply, a depositional area is designed at the upstream end of the project reach, which may require long term maintenance.
- Complete valley reconstruction is sometimes required and can be economically prohibitive.
- Stream power and shear stress in flood control channels may be prohibitive.

Application

- The ideal application for this approach is in watersheds which support wetland and stream complexes and low sediment supply.
- Transitional headwater to single thread channel zones.
- Stream reaches where the goal is to retain water, sediment, and organic matter.

Regenerative Design

Description

The Regenerative Design was originally developed by Keith Underwood to restore Atlantic White Cedar using sand seepage berms. Since then, the approach has evolved into an effort to implement ephemeral channels as natural stormwater best management practices (BMPs) using design guidance developed by Anne Arundel County, MD (Flores et al., 2012). Similar to bioretention basins associated with parking lots, a Regenerative Design focuses on designing the functions of headwater systems as natural retention areas where appropriate vegetation and hydrologic interaction will promote the reduction of nutrients entering the downstream surface flow. This is achieved by combining a carbon rich stream bed to promote microbial and fungal metabolism, a system of riffles and pools to interrupt the flow path in order to maintain non-erosive flows, and native plant communities to stabilize the flow path, produce habitat, and contribute as a carbon source (Berg, 2010). Contrary to traditional bioretention basins, the Regenerative Design does not require large detention basins as it uses in-channel pool storage, greater flow lengths, and increased surface roughness associated with natural channels to compensate for volume containment as a means of retention. The creation of the long flow path, the use of riffle-pool sequencing, and the development of natural habitat are characteristic of stream designs. However, due to the nature of zero order headwater systems being low energy, low sediment supply systems and by engineering the riffle-pool sequencing, the need for a highly sinuous transport channel is eliminated. Instead, the flow path is created such that complex interactions occur between the collected water and groundwater during low flow events while functioning as a conveyance during increased flow events. Therefore, the Regenerative Design is suitable to the upper reaches of a watershed whether urbanizing or not. This concept can be incorporated into larger restoration projects that may include a different approach farther downstream, or this approach can substituted for existing stormwater BMPs where a connection to an existing natural channel is required.

<u>Strengths</u>

- Monitoring data has shown this approach is effective at reducing runoff and nitrogen loading in small headwater channels.
- Functions like a stormwater BMP.
- Applicable in landscapes where large detention facilities are not practical.
- Natural appearance is more aesthetically pleasing than common detention facilities.
- Once the sand seepage system has been established, long term maintenance is minimal.

<u>Weaknesses</u>

- The sites can require considerable short term maintenance until the sand seepage berms have been stabilized.

<u>Application</u>

- Small ephemeral-headwater channels. Not recommended in perennial streams.
- Stormwater outfalls.
- Along linear transportation projects where space can be limited by right of way.
- Could be used to treat stormwater runoff into flood control channels.

Conclusion

Based on a review of the Texas Integrated Report, fecal indicator bacteria and fish impairment are the two most common impairments occurring within the San Antonio River. Therefore, when restoration opportunities within the San Antonio River Basin become available, practitioners can target these impairment categories with specific restoration techniques. However, the restoration technique must also comply with the broader restoration approach to ensure the watershed and reach wide limitations have been identified and addressed. The restoration approach will also help determine success criteria for the restoration technique as the restoration technique's functional purpose will be confirmed through the steps and methodologies used within the restoration approach guidance.

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Appendix K

Channel Geometry and In-Stream Structure Inspection Form

Date: ____________________ Project Site: __________________________________

Inspected By: ____________________ Drainage Area (sqmi): ___________________________

Engineer and Contractor: ____

Channel Geometry

Item	Yes/No
1. Does riffle bankfull area match design criteria / regional curve?	
2. Does riffle W/D match design criteria / reference reach data?	
3. Does the riffle max depth/mean depth ratio match design criteria, i.e., does the max riffle depth equal the depth from the thalweg to the top of bank?	
4. Are the pools wider than the riffles and meet design criteria / reference reach data?	
5. Are the pools deeper than the riffles and meet design criteria / reference reach data?	
6. Is the bed vertically stable, e.g., no headcuts?	
7. Does the channel appear to be processing the sediment supply, e.g., no large aggradation areas?	
8. Are the streambanks laterally stable, e.g., BEHI Low to Moderate?	
9. If bank erosion is present, will it stabilize without intervention?	
10. For meandering channel designs (the designer is using meanders to dissipate energy), is the belt width at least 3.5 times wider than the belt width on average?	
11. If the average belt width is less than 3.5, does the designer use a step/riffle-pool design approach to dissipate energy?	

In-Stream Structures (Rock vanes and cross vanes)

Item	Yes/No
12. Are vane arm slopes less than 6%?	
13. Are vane angles between 20 and 30 degrees, creating a triangle that “catches” the velocity vectors?	
14. Are footer rocks “shingled” downstream?	
15. Do header rocks touch, preventing gaps that could create piping failure?	
16. Does the structure create a fish passage barrier?	
17. Is the structure located in the proper place to provide grade control and/or bank protection?	

In-Stream Structures (Root Wads and Toe Wood)

Item	Yes/No
18. Is the structure properly located?	
19. Does the woody material extend into the stream bed?	
20. Is the woody material secured to the bed and banks according to the plan specifications?	
21. Are there cover logs extending into the water column?	
22. Are transplants or bioengineering methods used above the woody material?	

Notes:

StreamMechanics

Field Form

Date: Project Site:

Measured By: Drainage Area (sqmi):

Geometry Measurements

Item	**Field Measurement Min-Max (Avg)**	**Design Criteria/Regional Curve/Reference Reach**	**Acceptable or Unacceptable (Yes/No/Unsure)**
1. Riffle Bankfull Area (sqft)			
2. Riffle Bankfull Width			
3. Riffle Bankfull Mean Depth			
4. Bank Height Ratio			
5. Riffle W/D			
6. Riffle max depth/mean depth			
7. Pool width/Riffle width			
8. Pool max depth/Riffle mean depth			
9. Belt width/Riffle width			

Rock Vane and Cross Vane Measurements

Item	**Field Measurement Min-Max (Avg)**	**Design Criteria/Regional Curve/Reference Reach**	**Acceptable or Unacceptable (Yes/No/Unsure)**
7. Vane arm slope			
8. Vane arm angle			

Streambank Erosion Observations:

Root Wad/Toe Wood Observations

Channel / Bedform Complexity Observations

Appendix L

CASE STUDY - EAST SALITRILLO CREEK RESTORATION PROJECT

L.1 Purpose

This case study provides a site reference for natural channel design in an urban setting and describes how the natural design process can be applied. In addition, this report provides multiple goals and lessons learned during assessment, design, construction, and post-restoration observations. The various restoration techniques, tools and approaches described herein generally follow the natural channel design protocols outlined in the Natural Channel Design (NCD) Protocol manual, but may not be widely applicable for every site.

L.2 Project Overview

The East Salitrillo Creek Restoration Project was conducted in 2011.The watershed area is shown in Figure L.1. The project included the restoration of 1,288 linear feet of perennial stream channel along East Salitrillo Creek. The East Salitrillo Creek Restoration project is located on the Judson High School campus in the City of Converse, Texas. The site is recognized as the first natural channel design project in the region. The purpose of the project was to demonstrate how utilizing a natural channel design process can improve stream health and functions, overall stability, bedform diversity, and riparian buffer vegetation in an urban corridor (see discussion of the Stream Function Pyramid in Section 8.1 and Appendix K of the NCD Protocol). The project also serves as an outdoor classroom for students to study aquatic and plant biology, water quality, in-stream habitat and stream mechanics. Based on monitoring observations over the last three years, the stream has maintained channel stability and native vegetation establishment during prolonged dry periods without continued irrigation or extensive maintenance.

The stream channel had degraded as a result of rapid urbanization and a lack of adequate stormwater controls. A diverse native planting regime was established and stormwater best management practices (BMPs) were incorporated at multiple outfalls to improve water quality from surrounding urban land use. Additionally, a flood study was performed and “no-rise” certification was obtained to illustrate that the FEMA 100-year water surface elevation actually lowered the base flood elevation (BFE) within the project area.

Figure L.1: Judson Case Study Location and Cross Section Locations

L.3 Watershed Assessment

The first step of the case study was to perform an assessment of the watershed (see Chapter 3 of the NCD Protocol). Watershed information for the site was compiled, such as drainage area, impervious cover, historical land use, development trends, geologic setting, soil types and terrestrial plant communities. Existing hydrology models for East Salitrillo Creek and drainage features were reviewed. The hydrology calculation methods evaluated flows for the 1.1-, 1.25-, 1.5-, 2-, 5-, 10-, 25-, 50-, and 100-year storm events within the project limits. The project watershed is considered urban with just under 40 % impervious area and is located within the larger Cibolo Creek Watershed. The watershed area at the downstream end of the project site was estimated to be 5 square miles (based on the impact of an upstream dam that reduces the effective drainage area) and drains predominately residential (93 percent) and commercial land intermixed with undeveloped lands. The estimated population in San Antonio for 2010 was 1.327 million, reflecting 16% growth between 2000 and 2010 (US Census Bureau, 2012). Based on that trend, it is estimated that the municipalities in the project area will undergo large growth in population and land area over the next 25 years.

The project site lies within the Blackland Prairie physiographic province and adjacent to the Edwards Plateau, South Texas Plains, and Post Oak Savannah physiographic provinces. The geology for the project site is comprised of Mesozoic (10 percent) and Cenozoic (90 percent) Eras. The Mesozoic strata consist of Upper Cretaceous marine deposits (shales, marls, and chalks). Natural Resources Conservation Service (NRCS) soil types, Houston Black gravelly/clay, and Tinn and Frio, were identified using NRCS soil survey data for Bexar County, along with on-site wetland investigations to confirm no hydric soils were present at the site. The project site was also examined for the presence of threatened and endangered species habitat; however, none were found. The NCD Protocol manual provides field inspection forms (Appendix P of the manual) and other information that can be used to guide collection of the necessary data.

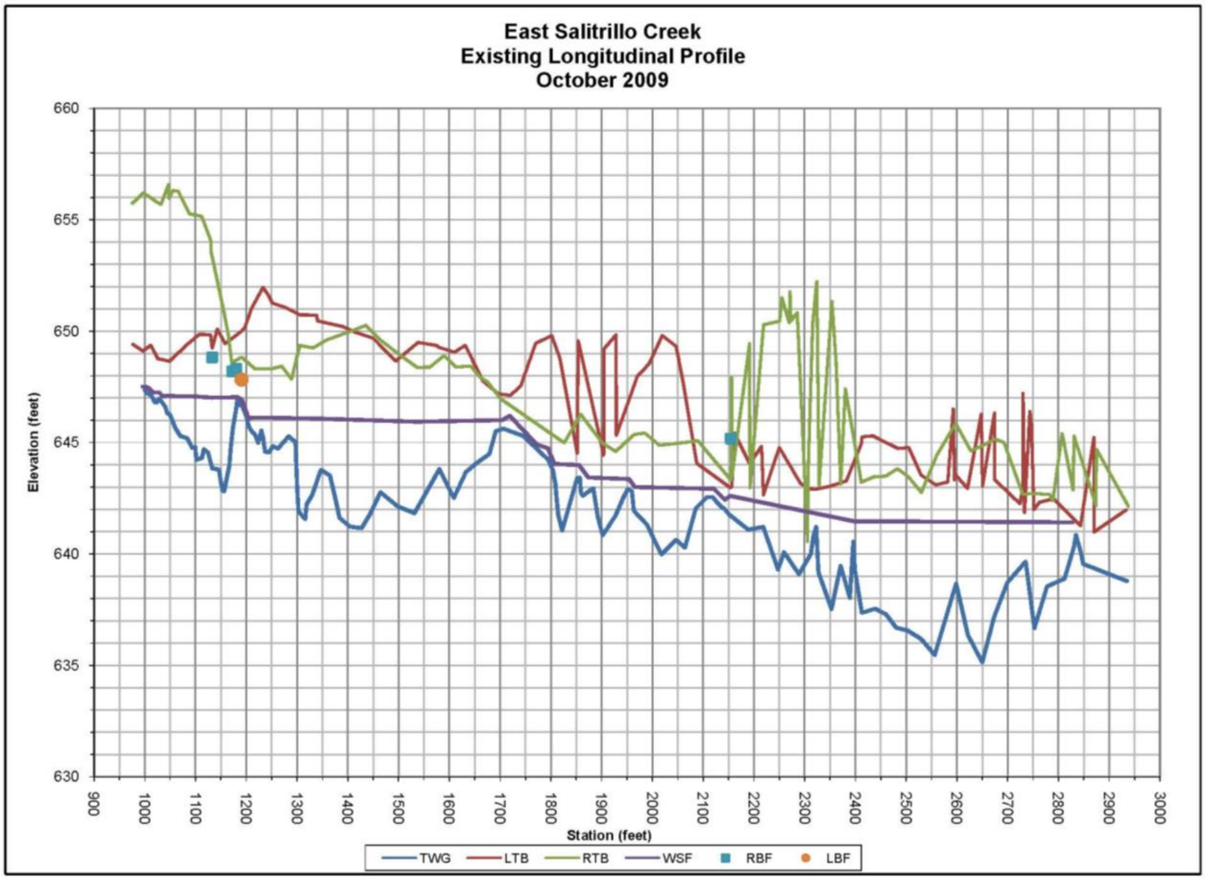
In addition to the watershed assessment, potential constraints and risks were identified and assessed during the conceptual design stage of the project. An on-site investigation was performed to identify utilities and associated easements, examined the hydrologic effects extending beyond the property boundaries of the project (hydrologic trespass), and evaluated impacts to the FEMA mapped floodplain. The costraints of the project included ball fields located on the east side of the channel, sewer lines, roads, and pedestrian paths.

L.4 Existing Conditions

Base Map Survey and Geomorphic Assessment

A base map survey was conducted to develop the project plan sheets (see Sections 12.0 and 12.1 of the NCD Protocol). A geomorphic assessment was completed to evaluate the current stream condition and stability and identify causes of impairment. A longitudinal profile survey was performed to measure frequency and spacing of bedform features such as riffles and pools, facet water surface slopes, and average channel slope. The survey results are shown in Figure L.2. In addition to the longitudinal profile, two cross-sections were surveyed in a riffle and pool at locations with stable bankfull indicators. The cross-section surveys were performed to measure representative bankfull channel dimension, such as cross-sectional areas, widths, and depths, and estimate the bank height ratio and the entrenchment ratio. Additional information that shows the cross sections and data collected for these is provided in the East Salitrillo Creek Stream Restoration Project report (SARA, 2010).

Figure L.2: Existing Longitudinal Profile



The team performed a pebble-count procedure (see Section 6.1.4.3 of the NCD Protocol) to characterize the bed material of the channel and gather information to classify the stream using the Rosgen stream classification method (see Section 6.3 of the NCD Protocol). A riffle pebble-count was performed to characterize the particle distribution of the riffle pavement and sub-pavement sample was also collected at the riffle cross-section. The pavement and sub-pavement samples were used to calculate sediment transport competency. Additional information about the pavement and sub-pavement analysis is provided in the East Salitrillo Creek Stream Restoration Project report (SARA, 2010).

Information collected during the geomorphic assessment and bed material sampling was used to classify the existing stream channel as a Rosgen C4. The (C) classification describes the form of the channel, while the (4) describes the median particle size of the reach, which is fine gravel. The geomorphic and sediment data collected for the project reach are summarized in Table L.1.

Table L.1 – Geomorphic and Sediment Data at the Project Reach

Parameter	X1	Units
Feature Type	Riffle	
Bankfull Width (W_{bkf})	36.5	Feet
Bankfull Mean Depth (d_{bkf})	1.7	Feet
Cross-Sectional Area (A_{bkf})	60.9	Square feet

Width/Depth Ratio (W/D ratio)	21.9	
Bankfull Max Depth (d_{mbkf})	3.5	Feet
Floodprone Area Width (W_{fpa})	>150	Feet
Entrenchment Ratio (ER)	>4	
Bank Height Ratio (BHR)	1.1	
Channel Materials (Particle Size Index – d_{50})	Medium Gravel	
d_{16}	<0.06	mm
d_{35}	<0.06	mm
d_{50}	6.5	mm
d_{84}	32-45	mm
d_{95}	600	mm
Water Surface Slope (S)	0.004	Feet per foot
Channel Sinuosity (K)	1.3	
Rosgen Stream Type	C4	

The existing stream shows signs of degradation and lateral instability as indicated by photographs taken at the site (Figure L.3 provides examples of pre-project erosion and instability). In addition, the sediment transport analyses indicated that the channel was degradational. The channel showed lateral instability due to unstable meander geometry. Onsite riffle degradation was also observed at the site after a large storm. This may have been due to natural adjustment.

Figure L.3: Existing Conditions Photographs

Bank erosion upstream of existing pool (Pre-project)

Field Assessment at eroded bank (Pre-project)


Highly eroded section adjacent to drainage Structure (Pre-Project)


Unstable bank (Pre-Project)

Bankfull Verification and Project Specific Regional Curve

Various methods were used to verify the bankfull stage and discharge for the project reach (see Section 6.2 of the NCD Protocol). Initially, when collecting data for the topographic survey, physical indicators of bankfull stage were marked and cross-sectional areas were measured in the field. Bankfull stage indicators included topographic breaks in slope and flat depositional features. As discussed below, the bankfull discharge was estimated using Manning's equation and based on the regional curve. Photos and cross sections of locations used in the design in the East Salitrillo Creek Stream Restoration Project report (SARA, 2010).

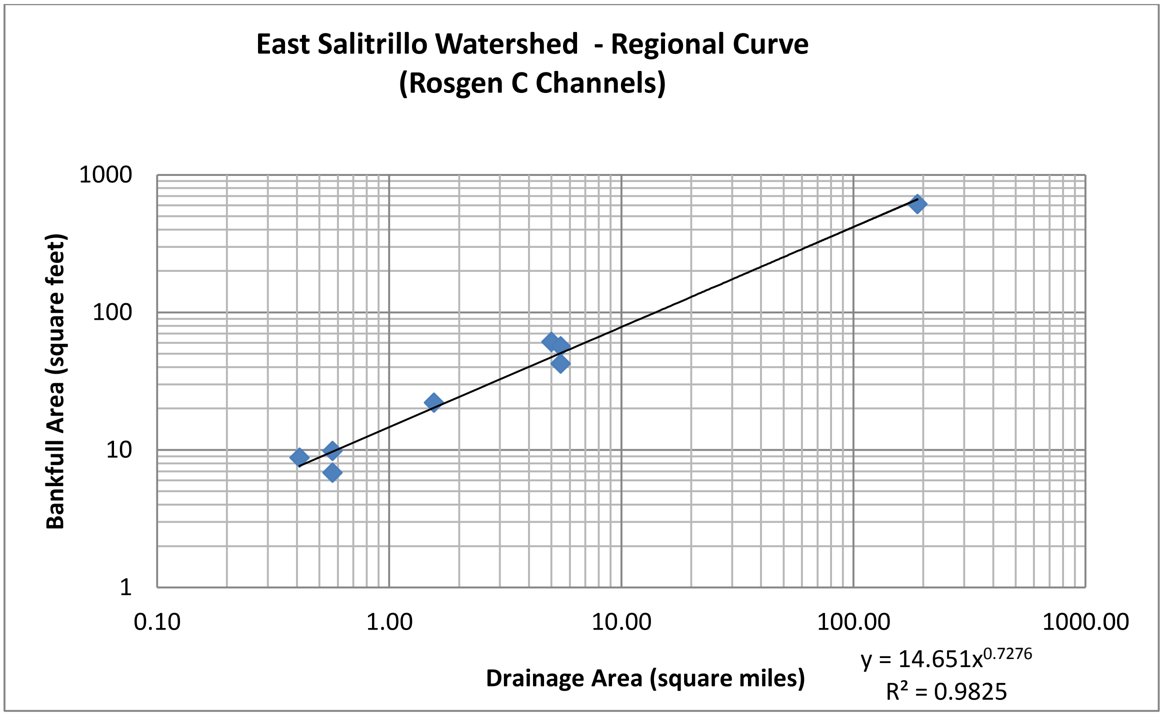
A project-specific regional curve was developed to further assist in determining a stable bankfull dimension that could be used in the design (see Section 5.3 of the NCD Protocol for a discussion of Regional Curve development). Pedestrian surveys were performed along channels within the East Salitrillo Creek watershed. Stable riffle cross-sections with consistent bankfull indicators were identified at 6 locations. Detailed cross-sectional surveys were conducted at each stable riffle identified. A water surface profile was developed for each stream in the vicinity of the riffle cross-sections by surveying water elevations at the head of riffle upstream and downstream of the cross-section. The water surface profile was then used to estimate an overall channel slope for each cross-section surveyed. The cross-sections were analyzed to determine the bankfull cross-sectional area, width, and average depth. Using the cross-sectional dimensions and overall channel slope, bankfull discharge was estimated using Manning's equation.

Site searches were performed to identify stable USGS gage stations within the same hydrophysiographic province as the project site. Of the gages visited, only the Salado Creek Gage at Loop 13 (USGS Gage station #08178800) had a stable riffle cross-section from which a bankfull stage could be determined. A detailed cross-sectional survey was conducted at the stable riffle. The water surface elevation at both the cross section and the gage station were also recorded. From the survey data, Baker determined the distance between the water surface and the bankfull stage at the riffle cross-section and added this distance to the water surface elevation collected from the gage station to extrapolate the bankfull elevation at the gage station. The bankfull elevation at the gage was determined to be 538.4 ft.

Historic records from the gage were reviewed to determine the recorded discharge associated with flows near the 538.4 ft elevation. Table A.2 summarizes the results from the gage records. Based on these recorded discharges, Baker estimated the bankfull discharge at the gage site to be

1,100 cfs. From the above data, bankfull area, width, depth, and discharge were then plotted against drainage area to develop project specific regional curves (See Figure L.4). The return interval was estimated to be 1.5 years.

Figure L.4: Bankfull Cross-Sectional Area Comparison



Bankfull discharge was estimated based on two methodologies, using Manning's equation and the regional curve. The Manning's equation was used to calculate a bankfull discharge at the riffle cross-sections for the East Salitrillo project reach. The Manning's roughness coefficient was individually selected for the reach based on factors including channel bed material, the presence of vegetation on the banks, and stream type. Bankfull discharge for East Salitrillo Creek was estimated to be 285 cubic feet per second (cfs). In addition, the discharge was estimated based on the regional curve.

Table L.2 USGS 08178800 Salado Creek at Loop 13 Gage Station Discharge Estimates
East Salitrillo Creek

Date	Stage (ft)	Elevation (ft)	Discharge (cfs)
3/16/1998	11.1	538.05	985
9/8/2002	11.33	538.28	827
9/12/2003	11.35	538.3	1,210
10/22/1998	11.41	538.36	1,030
11/24/2004	11.57	538.52	1,130
8/23/1998	11.58	538.53	1,100

Datum of Gage = 526.95 feet above sea level (NGVD29)
Retrieved from U.S. Geological Survey database http://waterdata.usgs.gov/nwis on 12/17/2009

The gage station receives drainage from a 186 square mile watershed, much larger than at the project site. The gage discharge data was considered, but did not define the bankfull discharge at the project site because of the significant difference in watershed area.

Stream Reference Reach Survey

A reference reach site was located within the same hydro-physiographic region at Seguin Creek south of Seguin, Texas and east of the project site (see Chapter 7 of the NCD Protocol for discussion of identification of reference reach sites and application of data collected at the sites). The site research was done using GIS to compare similarly sized creeks with stable, forested or lightly developed watersheds and coordinated windshield surveys of the identified reaches. A longitudinal profile survey was conducted along 584 linear feet of Seguin Creek to collect data on channel features such as water surface, thalweg, inner berm, bankfull, and top of bank. Two cross-section surveys were taken at one representative riffle and one pool to measure the top of bank, bankfull, inner berm, edge of water, thalweg, breaks in slope, and width of the floodprone area. Seguin Creek is classified as a small Bc to E-type channel. Additionally, a longitudinal profile survey of 223 linear feet of the reference reach along East Salitrillo Creek was conducted and two cross-sectional surveys. Reference reach sections of East Salitrillo Creek used in the analysis are located upstream and downstream of the project site. The creek is classified as an E-type channel with a low bank height ratio of 1.0. Channel geometry and stream pattern were also assessed to characterize the meander wavelength, belt width, and radius of curvature. Bed material samples were collected to estimate sediment transport competency. Using this data, dimensionless ratios for channel dimension, pattern and profile measurements were developed to assist with the natural channel design.

Table L.2 – Bed Material Sieve Analysis Results

Sieve Size	Cumulative (%) Retained	(%) Passing
1 inch	34	66
1/2 inch	53	47
No. 4	77	23
No. 10	90	10
No. 18	95	5
No. 35	97	3
No. 60	98	2
No. 120	99	1
No. 230	99	1

Notes: Collected at Judson H.S. Campus on October 9, 2009

L.5 Design Methodology

Stream Restoration Potential and Alternatives Assessment

In developing the design, different levels of restoration and enhancement were assessed with respect to site constraints, educational value and cost. The assessment was performed for various project alternatives. Section 8.1 of the NCD Protocol provides a discussion of the Stream Functions Pyramid Framework for developing function-based assessments and setting goals and objectives based on the potential for functional lift. The primary goals were to design and construct a stream with stable geomorphology, to improve aquatic habitat, improve water quality, and improve educational opportunities. Due to the lateral constraints created by school infrastructure (ball fields, roads, etc.), a Rosgen ‘Bc’ stream type was constructed to dissipate energy vertically instead of laterally and to provide a bankfull cross section competent to move water and sediment delivered to the reach with low bank slopes to encourage re-vegetation. The designed channel alignment resulted in an overall decrease in sinuosity and a slight increase in channel slope. In-stream structures were designed to provide grade control, bedform diversity, and aquatic habitat. Based on site characteristics and constraints, a Rosgen Priority Level 3 restoration concept was chosen. Additional goals included reducing energy from stormwater outfalls and providing safe pedestrian and maintenance access across the restored stream channel.

Table L.3 Design Criteria
East Salitrillo Creek

Parameter	Min	Max
Drainage Area, DA (sq mi)	5.0	
Stream Type (Rosgen)	Bc/C4	
Manning's Roughness Coeff., "n"	0.038	
Bankfull Discharge, Qbkf (cfs)	220	
Bankfull Riffle XSEC Area, Abkf (sq ft)	60.0	
Bankfull Mean Velocity, Vbkf (ft/s)	4.8	
Bankfull Riffle Width, Wbkf (ft)	33.0	
Bankfull Riffle Mean Depth, Dbkf (ft)	1.8	
Width to Depth Ratio, W/D (ft/ft)	18.0	
Riffle Max Depth @ bkf, Dmax (ft)	2.5	
Riffle Max Depth Ratio, Dmax/Dbkf	1.4	
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	
Sinuosity, K	1.1	
Valley Slope, Sval (ft/ft)	0.0055	
Channel Slope, Schan (ft/ft)	0.0045	
Slope Riffle, Srif (ft/ft)	0.005	0.011
Riffle Slope Ratio, Srif/Schan	1.1	2.5
Slope Pool, Spool (ft/ft)	0	0.0002
Pool-Pool Spacing, Lps (ft)	100	146

<u>Dimension, Pattern, and Profile</u>

Chapter 8 of the NCD Protocol describes design of NCD projects. For the Judson project, riffle cross-sections were sized and designed based on the estimates of the bankfull flow to retain the bankfull flow within the channel banks and to transport sediment delivered by the watershed. The designed channel cross-section allows for flows greater than bankfull to access the floodplain. The riffle cross-sectional area was calculated based on the project-specific regional curve. A higher width to depth ratio (18.0) for the Bc/C-type channel was selected. Side slopes for the riffle cross-section were built (3.5:1) to lower the risk of erosion and to aid in the establishment of vegetation. Using conservative channel dimension values has allowed the constructed channel to narrow over time as this vegetation develops.

Bedform diversity was improved throughout the project facet development (riffle, run, pool, glide, and step-pool) mimicking those characteristic of stable Bc-type channels. Reach slopes were designed to be appropriate for the channel type and to provide adequate sediment transport capacity and competency.

Riffles slopes throughout the design reaches are typically between 1.1 and 2.5 times the average slope of the channel. The maximum pool depth was constructed two-thirds of the distance along the profile from the tail of riffle to the downstream head of riffle. Most of the elevation changes occur over the riffles and step structures; as pools were designed with a near 0% slope to ensure constructability. Additionally, the longitudinal profile was optimized in conjunction with structure placement for aquatic habitat/fish passage.

<u>Sediment Transport and Hydraulic Analyses</u>

The critical shear stress and boundary shear stress analysis approaches were used to calculate the required depth and slope needed to transport particle sizes that could be entrained during a bankfull flow event. Existing riffle materials were coarse throughout the project reach. Sediment transport competency was also analyzed.

Table L.4 Existing Boundary Shear Stresses and Stream Power
East Salitrillo Creek

Parameter	Existing	Proposed
Bankfull Discharge, Q (cfs)	220	220
Bankfull Area (sq ft)	60.9	60
Mean Bankfull Velocity (cfs)	3.6	3.7
Bankfull Width, W (ft)	36.5	33.0
Bankfull Mean Depth, D (ft)	1.7	1.8
Width to Depth Ratio, W/D(ft/ft)	21.9	18.0
Wetted Perimeter (ft)	39.9	36.5

Table L.4 above summarizes the existing and proposed sediment competency calculations for East Salitrillo Creek. The critical depth and critical slope are the parameters at which the largest particle from the subpavement sample is mobilized. It was determined that East Salitrillo Creek is capable of moving larger particle sizes than the subpavement D_{100}. Additional analysis using the Colorado curve, a modified version of Shield's curve (USDA/NRCS, 2007) illustrated that the design reach could transport a particle size of 120 mm, which is over twice the size of the subpavement D_{100} of 45 mm. Therefore, the existing and design channel had the potential to incise due to bed degradation. There are a variety of ways to reduce the risk of degradation such as reducing the mean depth by increasing the bankfull width/depth ratio. However, the design width/depth ratio is 18, which is already fairly high when compared to reference reach ratios. Another option is to increase sinuosity to decrease slope. Creating a meandering channel with a wide belt width was not possible for this project given site constraints associated with the school infrastructure. Therefore, a straighter channel was constructed to dissipate energy vertically over step-pool structures. In addition, these structures (such as cross-vanes and constructed riffles) provide hard points in the bed or knickpoints which prevent the bed from degrading.

In addition, HEC-RAS was used to model the range of flows (bankfull to 100 year) in the proposed channel geometry. The purpose of the analysis was to confirm that the channel does not carry more than the bankfull discharge and that riffle shear stress values and depths are similar to results from the sediment transport analysis.

In-stream Structures and Bioengineering

A variety of in-stream structures were incorporated into the design to promote habitat, dissipate energy vertically, and provide grade control. Constructed riffles, rock cross vanes, double drop rock cross vanes, log and rock j-hooks, and root wads were incorporated into the design. To help create the pools, the design incorporated constructed riffles into cross vanes.

Riparian Vegetation Establishment

A vegetation and invasive species treatment plan was developed (see Chapter 12 and Appendix I of the NCD Protocol). Data from the existing conditions and reference reach surveys were referenced during design phase. The vegetation plan included a native stream bank and floodplain plant list, densities, soil and fertilizer requirements, and details for plant spacing and installation. Additionally, persistent invasive vegetation was identified during the site assessment and removed during construction.

L.6 Additional Water Quality Improvements

There are several drainage structures/outfalls within the project limits. In order to protect water quality improvements provided by the stream restoration, storage features were designed to allow for treatment of storm flows and energy dissipation prior to flows entering the newly restored channel. These features include a plunge pool at the outlet of the concrete channel within the floodplain, two bioswales, and a drop inlet structure combined with an ephemeral pool at stormwater outfall pipes within the floodplain.

Plunge Pool

An existing trapezoidal concrete channel drains storm water runoff from the adjacent school and outfalls to East Salitrillo Creek. The *Miramar Unit 8A Drainage report and the Schaefer Road Pavement, Utility and Drainage Improvement Plans* were provided and indicated that the channel has the capacity to convey the 100-year storm event flow of 622 cfs. Field inspection of the channel revealed that the outfall has been eroded and undermined. Improvements to this outfall included the construction of a plunge pool at the existing outfall that ties into new channel alignment.

The plunge pool was designed in accordance with the City of San Antonio's Texas Unified Development Code, Stormwater Management (January 2006) and the Federal Highway Administration's *HEC-14, Hydraulic Design of Energy Dissipaters for Culverts and Channels* (July 2006) and sized based on Allan and Estes's *A Morphological And Economic Examination Of Plunge Pools As Energy Dissipaters In Urban Stream Channels* (JAWRA, 2005). The United States Army Corp of Engineers' (USACE) HEC-RAS (version 4.0) modeling program was used to determine the 100-year design storm event depth and velocity at the outfall for the existing concrete channel. The HEC-RAS analysis indicated that the channel was flowing supercritical with Froude number values greater than 1.

Bioswales

Storm water runoff from the Judson High School discharges to East Salitrillo Creek though several existing drainage ways and pipes. Improvements included the construction of two bioswales to improve water quality and tie into the new design channel. The bioswales were designed in accordance with the City of San Antonio's Texas Unified Development Code, Stormwater Management (January 2006) with additional guidance from the *Design and Implementation of Solutions for Water Resources Management in San Cristobal de las Casas* (Yocum and others, 2007).

The bioswales were designed for the 2-year storm event and checked 100-year storm event capacity. Drainage plans for the Judson High School to the west were provided to obtain the design flows for the proposed bio-swales. The 2-year and 100-year storm event flows for the northern bioswale are 11cfs and 20 cfs, respectively. The 2-yearr and 100-year storm event flows for the southern bioswale are 32cfs and 61cfs, respectively. Uniform flow calculations were performed using the Hydraulic Design tool within HEC-RAS to check the design flow depths and velocities.

Based on site conditions and cost restrictions, the traditional bioswale design was slightly modified. Soil amendments were not included, and instead several storage areas with littoral shelves, separated by cascade riffles were designed. The cross-section for the riffle areas was sized based on the results from the Hydraulic Design tool within HEC-RAS. The littoral shelves were planted with wetland species to further aid with treatment and nutrient uptake.

Drop Structure and Ephemeral Pool

An existing 24-inch diameter reinforced concrete pipe was modified to safely convey storm flows into the new channel. The existing concrete splash pad was demolished and a 9 foot drop structure was constructed. Water is now routed through a 24-inch RCP, which was sized to carry the 100-year storm event. Water now flows onto a rip rap apron for energy dissipation, through an ephemeral pool and then a small channel, and is then discharged into East Salitrillo Creek. Details for the drop structure and ephemeral pool are located in the Plan Set available at from SARA by request.

L.7 Permitting

Permitting is discussed in Chapter 14 of the NCD Protocol.

404/401 Permit

A Wetlands Delineation Report was prepared detailing the results of the field investigations for the jurisdictional determination submittal to the USACE and the Texas Commission of Environmental Quality (TCEQ). Based on the preliminary findings, a 404/401 permit application package for a Nationwide Permit 27 (NWP 27) was completed with appropriate supporting documentation for permit approval from the USACE. A NWP 27 allows activities in waters of the U.S. associated with the enhancement or establishment of wetlands and riparian areas provided those activities result in a net increase in aquatic resource functions and services.

Erosion and Sedimentation Control

A Storm Water Pollution Prevention Plan (SWPPP) was prepared for the project in compliance with the TPDES Construction Stormwater Permit (TXR150000) under Section 402 of the Clean Water Act and Chapter 26 of the Texas Water Code.

FEMA Floodplain Considerations

The East Salitrillo Creek site is located within a FEMA Zone AE special flood hazard area with a floodway and executable effective models were not available during the design phase. The models are currently being re-built using information from FEMA during the DFIRM project. The floodplains mapped in the proposed DFIRM maps were redelineated from base flood elevations of the effective study. There was coordination with the local jurisdiction to determine allowable floodplain impacts. Because the design approach increased floodplain storage through creation of excavated floodplain benches, flood elevations were reduced and a no-rise certification was prepared. A Conditional Letter of Map Revision (CLOMR) and post-construction Letter of Map Revision (LOMR) were required to show changes to the base flood boundaries.

L.8 Site Construction

The pilot project was implemented using a design-build approach and intended to serve as a training opportunity for staff and field crew personnel. In accordance with the approved Mitigation Plan and regulatory permits (i.e., 401/404, NWP 27, Sediment and Erosion Control Plan, SWPPP), construction activities began in early January 2011 with site preparation, installation of sedimentation and erosion control measures and pump around operation, and the establishment of staging areas, haul roads, and stockpile areas. Materials were stockpiled as needed for the initial stages of construction. Suitable channel fill material and natural alluvium was harvested on-site from within the existing streambed. Survey grade stakes and offsets were set along the thalweg, storm water features, and limits of disturbance to direct the grading activities. The contractor used care as to not disturb mature hardwood trees throughout the project area.

Construction began on the upstream portion of the reach and proceeded downstream towards the northern bioswale. The work involved the enhancement of a single thread channel that was built mostly inline using a pump-around operation. The existing degraded channel was filled in slightly and banks were graded back to match the surrounding natural topographic contours. In-stream structures such as constructed riffles, root wads, cross-vanes and grade control j-hooks were installed to provide channel stability. The middle section, from station 16+00 to 22+00 was constructed as a step-pool system. The new channel alignment was reconnected with its active floodplain using a Priority Level 2 approach and a floodplain bench was graded as to let higher flow energies dissipate across the land surface.

Upon completion of restored channel segments, in-stream structures, erosion control matting (biodegradable coir fiber), and vegetation plantings, including permanent seeding, were installed before moving downstream. All disturbed areas were covered with temporary and permanent seed and straw to comply with the SWPPP permit requirements. All riparian buffer areas within the project boundaries are a minimum of 30 feet along both stream banks and protected by permanent bollard markings.

Additional site modifications were made to promote bedform diversity and increase vertical stability. Bank stabilization measures (vegetated geolifts and toe wood sod mats) were installed near station 14+00 and station 23+75 based on existing site conditions, material availability and best professional judgment. The bioswale elevations, in-stream structure locations, and other bioengineering placements were modified slightly from the design plans due to existing trees and site conditions.

The construction team met on March 3, 2011 and conducted a preliminary final walk through inspection, and generated a punch-list of final items to be completed. Upon channel work completion in March 2011, sedimentation and erosion control measures such as temporary stream crossings, rock check dams, and silt fence were removed and additional disturbed areas were stabilized with temporary and permanent seed and mulch before leaving the site. Punch list items were completed and the construction team demobilized in late March 2011 after the final walk inspection walk. An as-built survey was performed to document the completed construction and to create a baseline for future monitoring. Lastly, the vegetation planting of native trees, shrubs, and plugs were completed in late spring 2011. Irrigation lines were installed and vegetation was frequently watered until groundcover vegetation became established. Figure L.5 includes images taken during construction at the site.

Figure L.5: In-stream Structures and Bioengineering Treatments

Site vegetation planting

Rootwads with cover logs

Geolift

Toe wood sod mat

L.9 Maintenance

Maintenance for NCD projects is discussed in Chapter 17 of the NCD Protocol. A maintenance plan was prepared in coordination with Judson High School as part of the project. The maintenance plan includes visual site inspections, minor bank repairs, and warranty replacements. Maintenance activities were coordinated with the high school; these activities include:

- Initial inspections after larger 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,
- Weekly site watering during the first few months and then as needed during the first growing season, based on rainfall,
- Site access for maintenance and school needs,
- Controlling invasive and/or exotic vegetation,
- Controlling animal activity that may damage planted vegetation or site stability (i.e. beavers, voles, etc.), and
- Vandalism and/or unauthorized site access.

L.10 Monitoring and Evaluation

A site specific monitoring plan was developed to determine if project goals and objectives were achieved and to identify trends, or necessary corrective actions post-construction. Site assessments and monitoring activities are routinely conducted to document the pre- and post-restoration conditions. Inspections are completed at least once per year to document channel stability, structure condition, and buffer vegetation vigor. More frequent inspections are necessary if stability concerns are noted, or due to frequent/intense storm events.

Monitoring Stations

Cross-sectional surveys, reference photographs, and visual evaluations are performed to measure and compare changes in channel geometry over the course of the monitoring period. The monitoring stations include a representative cross-section riffle and pool feature. Each permanent cross-section is marked on both banks to establish the exact transect used. See Figure L.6 and L.7 for an example of cross-sectional survey data collected as part of the monitoring activities. Bank pins were installed at two different cross-sections in 2014. These will be used to monitor lateral erosion or deposition

Visual Assessments

Photographs are taken at the same cross-section locations along the stream. Photographs will be taken looking upstream and downstream in order to document site conditions and to evaluate channel aggradation or degradation, bank erosion, and success of riparian vegetation. Additional photographs are 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.

Figure L.6: Representative Pool Cross-section

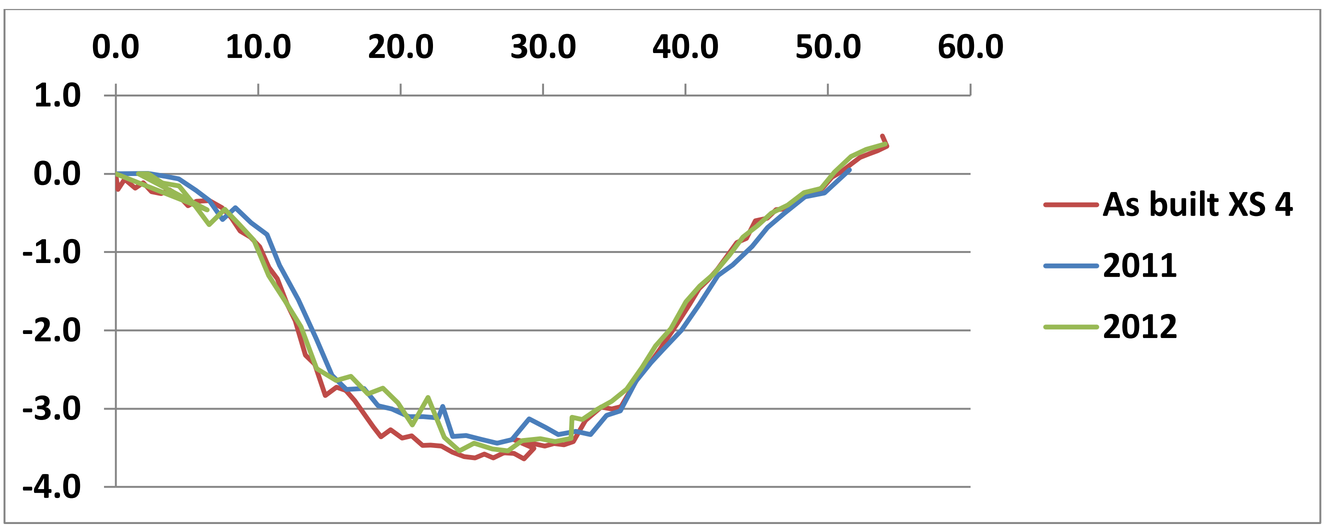


Figure L.7: Representative Cross-Section

L.11 Results

Based on monitoring observations over the past three years, the site appears to be geomorphically stable and achieving the goals and objectives as defined in the restoration plan. Project results include:

- Protected Infrastructure,
- Improved Sediment Transport,
- Safer Stream Corridor,
- Lowered Maintenance Costs,
- Trained staff,
- Increased Natural Aesthetics and Habitat, and
- Created Living Laboratory.

<u>Lessons Learned</u>

Appropriate corrective actions have been implemented such as controlling excessive vegetation in the channel, stabilizing floodplain scour from bus lot drainage, and minor structure repair. Operations crews initially worked with equipment operators with the intent of a learning/training exercise. As a lesson learned, construction schedules and training were based on crew availability and time and material costs played a role in the project timeline and budget. Figure L.8 shows pictures of the installation of in-stream structures.

Figure L.8: In-stream Structure Installation

The vegetation component of the project included live stakes, cuttings, container plants along the stream banks, riparian buffer planting which includes channel banks, floodplain benches, perimeter landscape areas, invasive species control, and herbaceous seeding. Vegetation establishment helps stabilize stream banks, creates habitat and a food source for wildlife, lowers water temperature by stream shading, and improves water quality by filtering overland flows. The planting of additional and/or more desirable native vegetation is an important aspect of any restoration design plan. Due to the urban setting of the project area, site aesthetics and safety played an important role in selecting and maintaining buffer vegetation.

Judson High School staff suggested that guidelines be implemented to protect water quality and stream stability functions of the buffer areas, but also address concerns regarding school safety and buffer maintenance. The primary concern has been that tall, dense vegetation within the channel bottom may increase the potential for channel erosion and decrease school district safety.

As a corrective action, thick overgrown herbaceous vegetation has been maintained within the thirty foot buffer boundaries which are delineated by perimeter bollards throughout the project area. Maintenance workers performing the work are supervised by the staff and cutting is conducted by workers on foot using equipment that will not disturb or injure planted woody vegetation (trees & shrubs). Invasive species vegetation are identified and removed from the buffer zone without disturbing the other vegetation. Establishing and managing riparian corridors continues to play a critical role in reducing water pollution, enhancing open space, and improving the health of East Salitrillo Creek.

Figure L.9: Pre- and Post-restoration Vegetation Conditions

Incorporating an operations and maintenance plan should address long term maintenance provisions after construction activities are complete. These can include items such as invasive species management, vegetation/channel/BMP damage repairs due to large storm events or extreme drought periods, BMP maintenance, turf/mow/trail areas and access to the geomorphic floodplain throughout the corridor. It is vital that all stakeholders agree to a plan that has clear goals, objectives and outcomes to ensure the project continues to thrive.

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Appendix M

Appendix M – Design Submittal Checklist

The design plan submittals will be prepared in stages, including 30%, 60%, 90% and final design completion. The primary purpose of the design submittal checklist is to ensure that pertinent information is included with the various stages of the project (30%, 60%, 90%, and final design). The basic information in these submittals will include, at a minimum, the following items:

1. <u>30% Submittal – Concept Design Plan Development</u>
   The Concept Plan is developed at approximately the 30% design level, and typically includes an overall graphic interpretation of the proposed design and a narrative or technical memorandum that describes the proposed plan for the site. The purpose of the Concept Plan is to allow the client, stakeholders, and landowners to evaluate and comment on the overall proposed plan approach for the site, prior to expending significant design effort. For example, it is imperative to have everyone involved to agree on an alignment and the general concept approach at this stage, prior to generating a longitudinal profile and cross-sections. The conceptual design phase considers the existing conditions data and assessments to properly evaluate and improve stream and wetland functions. The 30% concept design plan submission includes a title sheet, legend, base mapping, approach (i.e., restoration/enhancement/stabilization), proposed channel alignment, construction limits, buffer areas, utilities, and constraints. This submittal includes necessary assessment and design data relating to:
   - Project scope and description
   - Background information
   - Clearly defined goals and objectives of the project

2. <u>60% Submittal – Restoration Plan Documents and Permit Coordination</u>
   The restoration plan incorporates the modifications that were discussed and agreed upon at the concept plan stage, and typically includes a restoration plan report and 60% design drawings. The report will be developed and formatted per the current SARA manual standards. The 60% design drawings will include plan form, longitudinal profile, and typical section views of existing and proposed conditions. The plan view drawing(s) will show the existing and design channels, in-stream structure locations, grading plan, and extent of riparian buffer. The plan should also include other relevant features such as the proposed bedforms, facet features, vegetation planting plan, preliminary quantity calculations, typical detail drawings, construction access, the erosion and sedimentation control plan (SWPPP), tree protection plan (if necessary), and a preliminary construction cost estimate. The longitudinal profiles should show the existing and design thalweg and typical stream sections for riffles and pools.

   At this design phase, it is practical for the designer to coordinate with the applicable authorities, regulatory agencies (i.e. USACE, TCEQ, FEMA), and floodplain managers for submitting the necessary permit applications, coordinating potential utility relocations, and review hydraulic modeling completed during the preliminary design development. Permitting forms and applications should also be prepared by the designer and submitted with the regulatory agencies with the final restoration plan approval. Required permitting packages often include an application for a nationwide permit from the USACE and TCEQ to meet Section 404/401 requirements of the Clean Water Act, a sedimentation and erosion control plan (SWPPP), and a Letter of Map Revision (LOMR) proposal for projects that are conducted within FEMA regulated floodplains. The plan documents will be submitted to SARA for review and comment and will be incorporated into the draft and the final plan documents.

3. <u>90% Submittal – Final Design and Construction Documents</u>
   The 90% design plan submission addresses and incorporates the permit review comments into the final draft design plan and includes the addition of technical specifications or special provisions, and engineers' cost estimate and construction package for the client to solicit bids for construction of the project. The construction bid package may include the following components and documents:

   - Typical bid documents, including technical specifications/special provisions
   - General notes and construction sequence
   - Alignment and Geometry data
   - Structure tables
   - Stream and floodplain plans showing proposed alignment, grading limits, and in-stream structure types and locations
   - Grading plan with existing and proposed design contours
   - Grading plan for stormwater BMPs
   - Typical sections for the stream and floodplain
   - In-stream structure details
   - Locations of and details for non-traditional practices and devices
   - Outlet control details
   - Design stream profiles showing proposed centerline thalweg and bankfull lines
   - Planting plans, details, and proposed vegetation species lists
   - Erosion and sedimentation control measures
   - Cross-sections showing existing and proposed surfaces at regular intervals
   - Geotechnical specifications/evaluations such as borings, soils analysis, etc. (if necessary)

4. <u>100% Submittal – Final Design and Construction Documents</u>
   Once the 90% design plan submittal has been approved, the designer shall incorporate comments and prepare the final design and construction documents. These are the final documents that the contractor will use to bid and construct the project. These documents include the final plans sealed by a licensed professional engineer (TX PE), technical specifications or special provisions, and an engineers' final construction cost estimate.

   The bid phase services are considered separate and not included in the design submittal checklist. However, these services are typically required before the construction contract is awarded and include the following tasks:

- Distribution of bid packages including instructions to bidders, bonding/insurance requirements
- Attendance and conduction of the pre-bid meeting
- Preparation of addenda or clarifications to the bid package
- Attendance and conduction of the bid opening
- Preparation of a bid tabulation and bid certification
- Recommendations regarding contract award
- Construction contract preparation
- Attendance at and conduction of the pre-construction meeting

Natural Channel Design Review Checklist

Project Design Submittal Checklist

Reviewer: ______________________

Date: ______________________

Project: ______________________

Engineer: ______________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
1.0 30% Submittal – Concept Design Plan Development				
1.1 Goals and Restoration Potential				
1.1a Does the concept design plan have clear goals and objectives?				
1.1b Was the restoration potential based on the assessment data provided and clearly explained?				
1.1c Was a restoration strategy/approach developed and explained based on the restoration potential?				
1.1d Was a technical narrative included with the design to explain the approach, and if so, based on the restoration potential?				
1.2 Conceptual Design				
1.2a Was a basemap provided with the conceptual channel alignment and developed within the design criteria?				
1.2b Were typical bankfull cross sections provided and developed within the design criteria?				
1.2c Were typical drawings of in-stream structures provided and their use and location explained?				
1.2d Was a draft planting plan provided?				
1.2e Overall Conceptual Design Comment(s)				
2.0 60% Submittal – Restoration Plan Documents and Permit Coordination				
2.1 Restoration Plan				
2.1a Was a restoration plan included to support the design approach from the concept plan review and assessment data collected?				
2.1b Was the plan provided developed within the design criteria and follow SARA design guidelines?				
2.1c Overall Restoration Plan Comment(s)				
2.2 Permit Coordination and Documentation				
2.2a Were the appropriate permit applications submitted with the restoration plan and 60% design drawings?				
2.2b If necessary, were any potential permitting issues identified or explained?				
3.0 90% Submittal – Final Design and Construction Documents				
3.1 Construction Bid Package				
3.1a Does the final design plan clearly address and incorporate the permit agency and stakeholder comments?				
3.1b Do the construction documents include all the necessary components for the construction bid package?				
3.1c Do the construction documents include technical specification, engineers' cost estimate and if so, is it complete for bid solicitation and acceptable for the client?				
3.1d Overall 90% Design Comment(s)				

Natural Channel Design Review Checklist

Project Design Submittal Checklist

Reviewer: ______________________
Date: ______________________

Project: ______________________
Engineer: ______________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
4.0 100% Submittal – Final Design and Construction Documents				
4.0a Does the final design plan clearly address and incorporate the client/stakeholder comments?				
4.0b Are there any design components that are missing or could adversely affect the success of the project?				
4.0c Are the plans and document sealed by a licensed professional engineer?				
4.0d Is the estimated project cost acceptable to the client and stakeholders?				
4.0e Overall 90% Design Comment(s)				

Appendix N

Appendix N - Cost Estimation Summary

Overview and Purpose

Cost estimating is a required exercise for any NCD project and helps to establish a budget at various stages of project development. A cost estimate represents a prediction that is typically provided by the designer based on the best available industry data. There are various cost estimation methods and approaches that can be used for any NCD project; however, the level of effort can vary greatly depending on the intended function, client needs/budget and estimator's project experience.

This cost estimation summary is intended to be used as a basic budget planning tool used in conjunction with a comprehensive cost-benefit analysis when considering potential costs associated with natural channel design (NCD) projects. The financial responsibility of a NCD project is often shared between the stakeholders (owner), designer, and contractor. Available funding for NCD projects can come from a variety of sources such as grants, municipal bonds, capital improvements, and compensatory mitigation. The overall costs for implementing NCD projects vary widely based on goals and objectives, site conditions, physical constraints, restoration potential, mitigation/regulatory requirements, design approach and contractor experience.

The cost considerations included in this summary assume a range of site conditions that are common within the San Antonio region; however, may not be applicable for all NCD projects given that every site has its own unique challenges and cost considerations. The cost estimations focus on typical construction items (per unit), earthwork and/or measures used to construct NCD projects, while considering other costs associated with long term operations and maintenance programs (O&M) such as debris removal, vegetation pruning/mowing, and in-stream channel repairs.

General Cost Categories

The total costs to implement NCD projects include planning, design, construction, and subsequent operation and maintenance (O&M). The project costs can be broken down into general tasks or cost categories such as:

- Project administration,
- Land purchase / easement acquisition or deed restrictions,
- Planning and feasibility studies,
- Architectural and engineering design,
- Construction, including materials, earthwork, equipment, labor, financing/bonding,
- Field inspection or construction oversight, and
- The O&M and monitoring activities for subsequent years post-construction.

The weight of these general cost categories depends on the size, location and/or constraints of the project, as well as long-term management. Although construction cost can be the largest component, other cost components can be significantly important. For example, securing land or easement acquisition can be a major expenditure, especially for urban projects with higher land costs. Additionally, construction financing (insurance and bonding) costs often increase with the construction cost. Therefore, implementing NCD projects within existing easements or on publicly owned property can present significant financial savings for the stakeholders.

Additionally, it is often necessary to estimate the corresponding operations and maintenance (O&M) costs for the stream channel and its associated monitoring features (i.e., riparian buffer vegetation, LID green infrastructure/stormwater BMPs, public outreach) after construction is complete.

Long-term buffer maintenance of the riparian corridor must address safety concerns, debris removal for flood conveyance, selective cutting/pruning activities, invasive species control, and include educating workers and the community to the sensitivity of aquatic/terrestrial habitats and species vegetation that are both planted and propagated through natural colonization.

In this scenario, it is beneficial to compare the life cycle costs of existing expenditures that have already been allocated for utility maintenance within the NCD project corridor. Table 1 highlights a common NCD task breakdown structure.

Table 1. NCD Task Breakdown

Project Administration
Project Coordination
Stakeholder Meeting(s)
Environmental Planning/Screening
FHWA/NEPA Document
Letters to Regulatory Agencies
JD Stream/Wetland and T&E Investigations
SHPO and Archaeology
Public Notice and Citizen's Information Workshop
Respond to comments and Regulatory Coordination
Land Purchase / Easement Acquisition
Site Access / ROE Agreements
Survey for Conservation Easement
Coordination for Easement
Land Purchase
Legal fees
Design
Exist Conditions Topographic Survey
Prelim Design and Restoration Plan
Final Design / Construction Plans and Technical Specifications
Construction
Permits: SWPPP, 401/404, FEMA no-rise cert (CLOMR/LOMR, floodplain)
Construction Bonding/Insurance

Construction Admin, Observation, Layout & Inspection
Earthwork/Grading
Vegetation Planting
Monitoring Features such as flow gauges, cross-sections
As-Built Survey and Drawing Certification
Operations and Maintenance Budget
Channel and Vegetation Repairs, Monitoring and Maintenance (ave 3-5 yrs)
Public Outreach and Educational Signage

Cost Data Considerations

Historically, there are limited cost data for constructed NCD projects within San Antonio region and SARA's jurisdiction. It is important that a comprehensive database be developed and maintained to incorporate the appropriate project components. The database could contain other cost factors that go beyond price per foot in order to track and better quantify the economic and water quality benefits of NCD projects. The working database could expand on the cost categories above to include the following components:

- watershed size and conditions (imperviousness, percent developed),
- stream order (bankfull channel size),
- Low Impact Development (LID) /Best Management Practice (BMP) opportunities,
- restoration potential (functional uplift) and design approach, including earthwork associated with Rosgen Priority Levels I-IV,
- channel gradient, pool-to-pool spacing, frequency of in-stream stream structures,
- flood control and stormwater management/drainage networks

This dynamic database could eventually be used for various purposes such as "top-down" budget estimations, bid comparisons, and project justification. This information could allow stakeholders to set realistic expectations for project budgets, interpret economy of scale, and improve the cost control process. Additionally, as the number of NCD projects increase and methods become standardized, cost uncertainties will decrease over time.

Concept Plan Development

The development of preliminary design criteria and/or the concept plan form can provide useful information when estimating potential NCD project costs. This can be achieved by analysis and remote sensing of pre-existing digital data using a combination of GIS, CAD, and Google Earth. Along with a desktop review, site visits and "ground-truthing" existing data, or the collection of additional field data may be performed, although not always required for NCD projects. The following data can be compiled and interpreted to assist with the concept plan development:

- Current aerial photography
- Utility location/crossings
- Existing contours, TINs, local survey data
- HEC-RAS models and DFIRM data

- Regional curve data

The data listed above can be used to review watershed hydrography and size, project corridor boundary and riparian conditions, and to aid with reach designation and concept design approach / restoration options. Drainage areas can be delineated to the downstream terminus and used in relation with regional curves to adequately size the bankfull channel. Watershed land use and imperviousness data can be used to assess the extent of urban influence on stormwater runoff. If available, existing HEC-RAS models can be analyzed for each project reach using cross-sectional and longitudinal profile data.

Existing channel geometry and alignments can be reviewed to identify potential relocation opportunities within the riparian corridors. As part of the constraints analysis, culvert crossings, stormwater outfall locations, utilities, infrastructure, and areas of limited channel or floodplain confinement should also be identified throughout the corridor. This information can be review by the stakeholders and used to determine what, if any, restoration options are feasible and meeting overall goals and objectives are possible. Table 2 compares the basic restoration alternatives and stabilization options and relative costs. See Section 8 for further descriptions related to Restoration Priority Levels.

Table 2. Comparison of Restoration Levels / Stabilization Options

Priority Level	Relative Cost	Risk of Failure
1	Low / Moderate	Low
2	Moderate	Low / Moderate
3	Moderate / High	Moderate
4	High	High

Selecting the appropriate Restoration Alternative or Stabilization Options requires additional considerations that ultimately influence project cost such as:

Priority Levels 1 and 2

- Restores the most functions to the system.
- Higher probability of long term success.
- Generally requires a larger amount of land or ROW footprint.
- Flooding can be an issue if raising the bed elevation.

Priority Levels 3 and 4

- Generally requires lesser amount of land or ROW footprint.
- Increased flooding is not a concern, unless vegetation density changes significantly.
- Only limited functions can be restored.
- Long term stability is a concern.

Construction Methods

As described in Sections 12 & 13 in the SOP Manual, construction plans and technical specifications illustrate and describe all of the methods and components required to implement each of the various work items associated with the project construction. The work items include broad categories such as:

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

Similar to evaluating the general cost categories, the individual weight of these work items depends on the site conditions, location and/or constraints of the NCD project. Individual cost estimations can be evaluated for each work item depending of the level of effort required. Historically, earthwork and in-stream structures can be some of the largest construction costs, but can also vary significantly depending on the design approach and desired functional improvements. For example, a Priority Level 2 approach typically requires a much higher excavation cost as compared to Priority Levels 3 or 4.

However, providing a stream channel floodplain access, especially in confined urban corridors, is often a preferred restoration method and provides a higher functional uplift. Additionally, this approach can improve channel stability and thereby reduce the potential risks associated with stream bank erosion and structure damage, which ultimately reduces long term O&M costs associated with the project.

In-stream Structures

A preliminary construction cost estimate can be prepared for work related to installing in-stream structures as shown on the plan form design and typical details. Calculating rough costs for in-stream structure installation is a worthwhile exercise during the preliminary design phase for planning a project budget. Typical costs involved with installing in-stream structures include equipment, labor, and materials. It is important to emphasize that these cost estimates are to be used only as a guideline, since fluctuating material prices, contractor experience, and installation procedures can heavily influence overall construction costs. Factors that affect installation costs include site accessibility for crews and heavy equipment, local labor/equipment/material rates, and the distance over which boulders must be transported.

For example, installing a rock cross vane structure in a larger bankfull channel (i.e., > 20' wide) requires longer vane arms. This proves more costly because it typically requires larger boulders, additional stone backfill, and increased installation times. For the purposes of the example exercise shown in Table 3, costs assumptions related to installing in-stream structures such as rock cross vanes include the required stone materials (referenced price per tonnage quotes obtained from two local quarries in San Antonio), labor rates, and estimated construction time, but excluded additional channel excavation and incidental grading costs.

Table 3. Example Cost Estimation for In-stream Structures

Site Name / Reach ID	Prop Design Length (LF)	Total Structures	*Cost per Structure ($)	Pool-to-Pool Spacing Ratio (Pool Spacing / Bankfull Width)	Channel Slope, Schan (ft/ft)
SA Creek	1,000	~ 7 - 12	~ $6,000	~ 4 - 7	0.005
*See Attached In-stream Structure Cost Spreadsheet for further cost breakdown.					

Design criteria and parameter ranges allow for variations in the actual number of in-stream structures, type, size, and placement. Costs for installing in-stream structures includes materials and estimated construction time, but excludes additional excavation and final grading costs. It is expected that further modifications will be made during the formal design phase once additional information is obtained. For example, the number of grade control structures varies depending on the channel pattern/geometry (meandering v. step-pool), channel gradient, pool-to-pool spacing selection, and type of in-stream structures selected.

Earthwork

For preliminary cost estimation planning purposes, earthwork quantity calculations, including cut & fill volumes, stripping and subgrade, may be performed by hand or using CAD software to determine approximate earthwork volumes. Regardless of the earthwork calculation method (i.e., average end area method, prismoidal/grid, surface comparison), it is critically important that the engineer consider all facets of earthwork calculations during the formal design process to develop accurate estimates based on the design approach.

Earthwork typically includes, but is not limited to, all floodplain construction (including topsoil amendments), channel construction/ relocations, clearing and grubbing, ditch filling/plugging, and all other grading depicted on the plans. The Contractor typically performs his/her grading calculations and cost estimations separately to attain final surface elevations as shown on the plans and as described in the specifications.

Additionally, depending on existing soil conditions, topsoil can be excavated and stockpiled separately from the waste material so that it can be placed back on the floodplain to attain final surface elevations during the final phases of site grading. Earthwork is typically considered a part of lump sum grading. Contractor costs fluctuate widely (ex: ~$5/cubic yard to $15/cubic yard) based on fuels cost, type of on-site material, shrink/swell factor, time of year, mass hauling distance, and waste and borrow sources/availability.

Cost Contingencies

Many NCD projects include a budget allowance for contingencies or unexpected costs that occur during construction and throughout the monitoring and maintenance period. This contingency amount may be included within specific cost items or included in a single category of construction contingency. The amount of contingency is often based on historical experience, empirical cost data, and the anticipated challenges of the project that can be influenced by:

- Design modifications,
- Schedule adjustments/ weather delays,
- Management/Personnel changes,
- Change in site conditions,
- Additional permit and monitoring requirements (Mitigation, FEMA, SWPP, TMDLs), and
- Construction cost fluctuations (labor, materials, stone, fuel, equipment).

Cost Estimate Spreadsheets

A cost estimate spreadsheet for calculating construction costs and cross vain material costs is available by request from the San Antonio River Authority. An example of the spreadsheets is attached to this appendix.

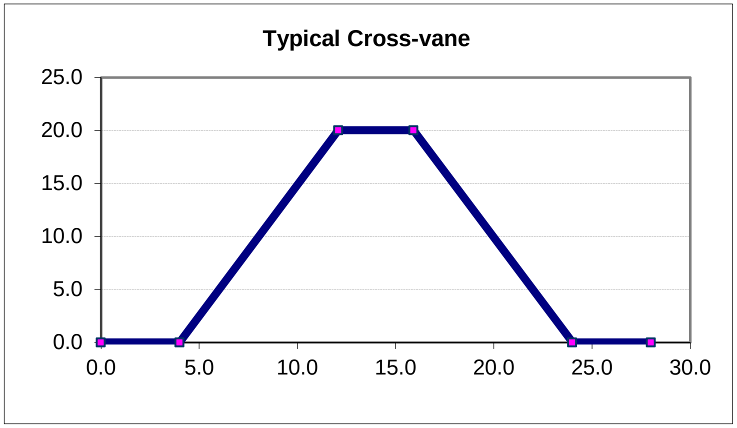
Cost Estimate Spreadsheet Example:

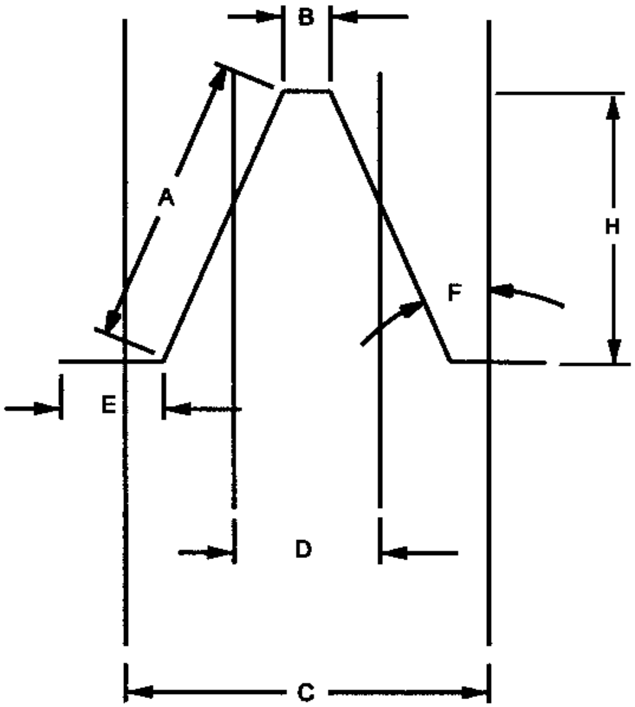
Enter Design Data in the Blue Boxes:

Riffle Bankfull Width (C) =	20.0 ft	
Riffle Max Bankfull Depth =	1.7 ft	
Riffle Bottom Width (D) =	11.6 ft	
Invert Length (B) =	3.8 ft	
Sill Length (E) =	4.0 ft	
Vane Arm Angle (F) =	22.0°	
Build Vane to :	0.7	X bankfull

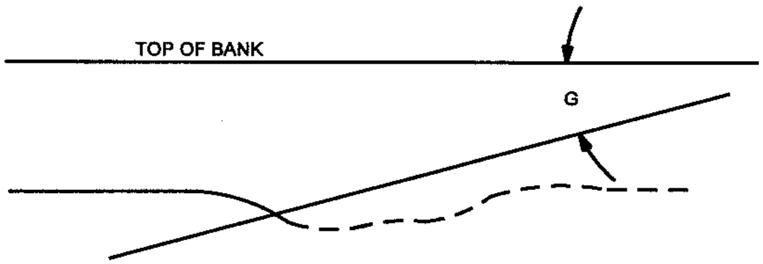
Calculated Values:

A	Vane Arm Length	21.6 ft
B	Invert Length	3.8 ft
C	Bankfull Width	20.0 ft
D	Bottom Width	11.6 ft
E	Sill Length	4.0 ft
F	Vane Arm Angle	22.0°
G	Vane Arm Slope	5.5%
H	Structure Length	20.0 ft





PLAN VIEW



PROFILE VIEW

Enter Design Data in the Blue Boxes:

Length of Boulders =	4.0 ft
Width of Boulders =	3.0 ft
Height of Boulders =	2.0 ft
Density of Boulders =	150.0 lbs/cu ft

Number of Boulder Rows (Header +Foote	2

Width of Filter Fabric Upstream of Structure (F) =	6.0 ft
Width of Aggregate A Layer (A)=	2.0 ft
Width of Aggregate B Layer (B) =	2.0 ft
Density of Aggregate A =	120.0 lbs/cu ft
Density of Aggregate B =	106.0 lbs/cu ft

Estimated Amount of Material Necessary per Structure:

Number of Boulders Necessary to Build Structure =	26
Tons of Boulders =	32.8
Volume of Aggregate A =	16.1 cu yds
Volume of Aggregate B =	16.1 cu yds
Tons of Aggregate A =	26.1
Tons of Aggregate B =	23.1
Amount of Filter Fabric =	61.1 sq yds

Assumptions:

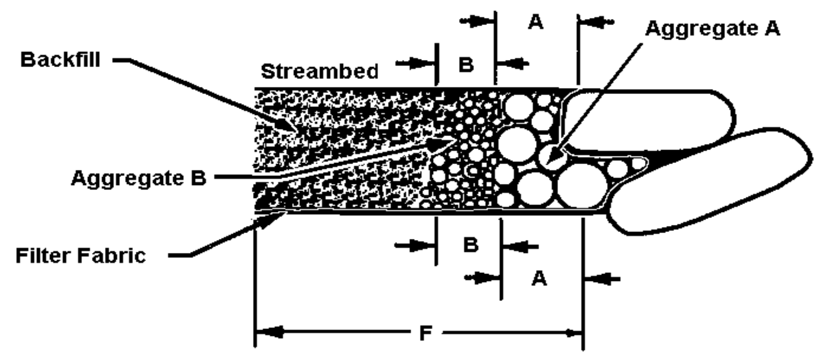
1.) Number of footer rocks per row = number of header rocks.

Calculated Values from Layout Sheet:

A	Vane Arm Length	21.6 ft
B	Invert Length	3.8 ft
C	Bankfull Width	20.0 ft
D	Bottom Width	11.6 ft
E	Sill Length	4.0 ft
F	Vane Arm Angle	22.0°
G	Vane Arm Slope	5.5%
H	Structure Length	20.0 ft

Typical Rock Density Data:

Solid Granite =	165.0 lbs/cu ft
Granite Rip-Rap =	120.0 lbs/cu ft
Granite Gravel =	106.0 lbs/cu ft



SECTION A-A'

In-Stream Structure Estimate

	Type of Structure		Number of structures			$ /each
	Rock X-vane	Rock Vane =.4	X-vanes	Rock J-hook	Rock J-hooks	
Number of Boulders Necessary to Build Structure =	26.0	10.4	7	0	0	
Tons of Boulders =	32.8	13.1	7	0	0	2,785
Tons of Aggregate A (4" rip rap)=	26.1	10.5	7	0	0	1,437
Tons of Aggregate B (8" rip rap) =	23.1	9.2	7	0	0	1,270
Square Yards of Geotextile Filter Fabric =	61.1	24.4	7	0	0	183

5,675	materials
1,000	labor and equipment
$6,675	total cost

Quantities Summary

	Total Rock X-vanes	Total Rock Vanes	TOTALS
Number of Boulders Necessary to Build Structure =	182.0	0.0	182.0
Tons of Boulders =	229.3	0.0	229.3
Tons of Aggregate A (4" rip rap)=	182.9	0.0	182.9
Tons of Aggregate B (8" rip rap) =	161.6	0.0	80.8
Square Yards of Geotextile Fabric =	427.8	0.0	427.8

Stone SizingTable

(per TxDOT Standard Specifications Book, Table 1, Item 432)	Required Stone Size (D50 in Inches)		
	Minimum	Average	Maximum
Washed #57 Stone	0.25	0.5	1.5
TxDOT/ AASHTO mix	2	4	6
TxDOT/ AASHTO mix	5	8	12
Class AI	5	10	17
Class I	9	14	23
Class II		19	
Class III		26	
Type I		34	
Type II		54	
Limestone Boulder			
36” x 24” x 24”			
48” x 36” x 24”			
72” x 60” x 48”			

General Notes:

1. The riprap shall be composed of a well-graded mixture. No more than 5.0% of the material furnished can be less than the minimum size specified nor more than 10.0% of the material can exceed the maximum size specified.

2. Boulder sizes vary per design and channel dimensions. Boulder size/selection shall be approved at the quarry or onsite before construction begins.

3. Representative rock samples shall be furnished by the Contractor and approved by the Project Inspector onsite prior to delivery.

Appendix O

Natural Channel Design Protocol

San Antonio, Texas

SAN ANTONIO
RIVER AUTHORITY
Leaders in Watershed Solutions

Appendix O – Regional Curves and Reference Reach Surveys / Design Criteria

For the latest Regional Curves and Reference Reach Surveys, please contact the San Antonio River Authority.

Appendix P

Catchment Assessment Form

Rater(s): ______________________________

Date: ______________________________

____

Purpose: This form is used to determine the project's restoration potential.

Overall Watershed Conditon H M L

CATCHMENT ASSESSMENT

	Categories	Description of Catchment Condition: Low	Medium	High	Rating (L/M/H)
1	Watershed impoundments	Impoundment(s) located within 1 mile upstream or downstream of project area and/or has a negative effect on project area and fish passage	No impoundment within 1 mile upstream or downstream of project area OR impoundment does not adversely affect project area but a blockage could exist outside of 1 mile and impact and fish passage	No impoundment upstream or downstream of project area OR impoundment provides beneficial effect on project area and allows for fish passage	
2	Organism Recruitment	Channel immediatley upstream or downstream of project reach is concrete, piped, or hardened.	Channel immediatley upstream or downstream of project reach has native bed and bank material, but is impaired.	Channel immediatley upstream or downstream of project reach has native bed and bank material.	
3	Located on or downstream of a 303(d) listed stream TMDL list	On or downstream of 303D and no TMDL/WS mgmt plan to address deficiencies	On or downstream of 303D and TMDL/WS Mgmt plan addressing deficiencies	Not on 303D list	
4	Concentrated Flow	Potential for concentrated flow/impairments to reach restoration site and no treatments are in place	Some potential for concentrated flow/impairments to reach restoration site, however, measures are in place to protect resources	No potential for concentrated flow/impairments from adjacent land use	
5	Percent of Catchment being Enhanced or Restored	Less than 40% of the total catchment area is within the project reach.	40 to 60% of the total catchment area is within the project reach.	Greater than 60% of the total catchment area is within the project reach.	
6	Impervious cover	Greater than 15%	7%- - 15%	Less than 6%	
7	Agricultural Land Use	Livestock access to stream and/or intensive cropland immediatley upstream of project reach.	Livestock access to stream and/or intensive cropland upstream of project reach. A sufficient reach of stream is between Ag. land use and project reach.	There is little to no agricultural land uses or the livestock or cropland is far enough away from project reach to cause no impact to water quality or biology.	
8	Land Use Change	Rapidly urbanizing/urban	Single family homes/suburban	Rural communities/slow growth or primarily forested	
9	NPDES Permits	Many NPDES permits within watershed or some within one mile of project reach	A few NPDES permits within watershed and none within one mile of project reach	No NPDES permits within watershed and none within one mile of project reach	
10	Distance to Roads	Roads located in or adjacent to project reach and/or major roads proposed in 10 year DOT plans	No roads in or adjacent to project reach. No more than one major road proposed in 10 year DOT plans.	No roads in or adjacent to project reach. No proposed roads in 10 year DOT plans.	
11	Watershed Hydrology (e.g., flow regime, basin characteristics)	Flashy flow regime as a result of land use, rainfall patterns, geology, and soils.	Moderate flashy flow regime as a result of land use, rainfall patterns, geology, and soils.	Not Flashy flow regime as a result of land use, rainfall patterns, geology, and soils.	
12	Specific Conductance (uS/cm at 25^{o}C)	Piedmont = >229; Blue Ridge = >66	Piedmont = 78-229; Blue Ridge = 41-66	Piedmont = <78; Blue Ridge = <41	
13	Percent Forested (Watershed)	<20%	>20% and <70%	>70%	
14	Riparian Vegetation	<50% of contributing stream length has > 25 ft corridor width	50-80% of contributing stream length has > 25 ft corridor width	>80% of contributing stream length has > 25 ft corridor width	
15	Sediment Supply	High sediment supply from upstream bank erosion and surface runoff	Moderate sediment supply from upstream bank erosion and surface runoff	Low sediment supply. Upstream bank erosion and surface runoff is minimal	
16	Other				