11.0 Streambank and Shoreline Protection

11.1 Overview of Practice

Streambank and Shoreline Protection systems address erosion these water courses. Implementation of the BMP may include reworking the physical bank of the stream or shoreline in question, and will always include vegetating or revegetating the riparian buffer or shoreline associated with the eroded area(s). Native plant materials are used to the highest extent possible and feasible. Additional practices associated with this practice include Stream and Shoreline Protection (NRCS standard #580), Tree and Shrub Establishment (NRCS standard #612), Access Control (NRCS standard #472), Riparian Forest Buffer (NRCS standard #391), and Critical Area Planting (NRCS standard #342). Streambank and Shoreline Protection does NOT include in-stream structures or any other “hardened” structures nor does it include manipulation of the channel bed or pattern of the stream. Any work that would include structures or manipulation of the channel bed or pattern would be considered stream restoration projects. Streambank and shoreline protection systems will NOT be along ocean shorelines where constant wave actions are found.

11.2 Purpose

Streambank and Shoreline Protection systems are installed to control and eliminate bank and shoreline erosion issues. While similarities exist, streambanks and shorelines have differing erosion influences. The design for each will be treated separately in this chapter with the primary focus being on streambank treatments.

11.3 Definitions

Stream restoration and bank stabilization uses specific terms to describe the stream and its stability. Below are a few selected definitions of terms used in this chapter.

Bankfull discharge– is the discharge or flow at which natural channel maintenance is most effective and is generally measured in cubic feet per second (cfs). The bankfull discharge, and associated elevation (depth of flow) of that discharge, is also known as the stream-forming flow. It generally has a recurrence interval of 1 to 2 years. This discharge, and the associated elevation, bankfull stage, is where the highest velocities occur in stream channels. This discharge and the associated depth is where the channel is seeking to access a floodplain to spread the flow and velocity and is therefore used in the design of stream restoration and stabilization projects.

Bankfull discharge, the elevation and cross-sectional area at bankfull, are an integral part of understanding streambank stabilization projects and are due further study. The following link provides information regarding the indicators in-stream on how the bankfull discharge and subsequent elevations associated with this discharge can be determined.

https://content.ces.ncsu.edu/finding-bankfull-stage-in-north-carolina-streams

Bankfull stage- the elevation at which the bankfull discharge occurs. Effective channel maintenance at the bankfull stage is the discharge (flow) where natural sediments are properly transported and delivered, where naturally forming bars, bends, and meanders are created without the effect of accelerated erosion, and generally where the stream, at that point of assessment, is stable and functioning with distinct morphological characteristics.

Flood Stage – (see Bankfull stage above)

Pattern, dimension, and profile – these physical characteristics will be defined separately, but together form the basis for proper, natural stream characteristics and function. When one or more of these physical characteristics are altered or changed, the stream will experience degradation from the natural, stable state. Conversely, to repair a stream, one or more of these characteristics must be altered or manipulated to reduce erosion. With streambank protection (stabilization) projects, only the dimension can be altered to reduce erosion.

Dimension (cross-sectional area) - is the cross-sectional area of the stream, or the width and depth and the associated shape of the channel. The dimension is particularly important at the bankfull stage (defined above) and at the flood prone width (not to be confused with a FEMA "floodplain"). It is critical that a cross-section be measure at a riffle (where the thalweg is in or near the center of the bankfull width) as this is the only location where the flood prone area width is measured. Cross-sections in other features are also helpful but all design calculations are based on the riffle. The bankfull cross-sectional area is the dimension where the stream channel has met its natural capacity to maintain non-erosive velocities and is the break point for where the bankfull discharge begins. Equations to determine these critical elements for design are shown further in this chapter. For streambank protection (stabilization) projects, only the dimension can be altered to correct the identified erosion problem.

Pattern – is the meander or curvature of the channel and is defined generally by the sinuosity of the channel. Looking from a bird's eye view, someone assessing a stream's meander pattern would note the spacing (distance between) of the curves in the channel, the radius of those curves, how wide the curves would be from outside bend to outside bend (belt width). Amplitude is defined as the center of bend to center of bend.

Profile – is the slope of the stream, and its components including riffles and pools, and the entrance and exit slopes of those components. Effectively it is the same as taking slope measurements along a grassed waterway or farm field, only along the stream's channel bed at the deepest part of the channel (see Thalweg below). Measurements should also be taken at the water surface of each bed feature (riffle, pools, etc.) and at bankfull if good indicators are present.

Meander – the sinuosity of a stream, or the curves and straight areas for a given section or reach of a stream being assessed.

Thalweg – the deepest part of the channel commonly confused with the centerline.

Riffle – is the shallow portion of the stream. In a stable stream, riffles develop considerable kinetic energy that is dissipated by the pool system that follows. The length of the riffle varies depending on the stream type.

Pool – is the slow flowing, deep portion of a stream system. Pools, in a pristine stream system, dissipate the significant energy that the riffle system develops.

Point bars – deposits of sediment on the edges of streams, typically on the inside of bends. Unstable, or building point bars will generally have little or no vegetation on them and may have sharp exit slopes on the back 1/3 of the bar. Stable point bars generally exhibit a flat top that will be at the bankfull elevation. In many cases, stable point bars will have woody vegetation on them. In cobble or large gravel systems, woody vegetation may not be present. Unstable bars often have annual or no vegetation with the back slopes (the last third of the bar) being sharp and not gentle.

Central bars – deposits of sediment that form and island in the middle of a stream. ***NOTE:*** Central bars are an indicator that the stream is too wide to be able to carry its bedload during storm events. They also tend to create bank erosion/instability. As a result, central bars indicate that the stream is a candidate for stream restoration and not stabilization.

Transverse bars – are deposits of sediment that are almost completely continuous across (or transversing) the entire width of the streambed, usually at an angle across the stream. Transverse bars may also indicate instability and cause excessive near bank stress.

Flood prone width – is the area adjacent to the stream channel that is inundated or saturated at flows less than or equal to two times the maximum riffle depth at the bankfull stage. Simply take bankfull maximum depth (bankfull to thalweg depth) determination, multiply by 2 to find the flood prone depth, add this to the elevation at the max depth, then find this elevation either side of the stream channel and measure the width. Note that the flood prone area width is only measured at the riffle cross-sections.

Entrenchment ratio - is the ratio of the width of the flood-prone area to the s bankfull width of the channel. As an example, if the flood-prone width was 38 and the bankfull width 17, the entrenchment ratio would be 2.24.

Stream morphology – the shape of a stream and how it has, or will, change over time. The pattern, dimension, and profile of a stream.

11.4 Use of This Practice

Streambank and Shoreline Protection or Stream Restoration projects can often be one of the more challenging practices to design, and it may also be one of the more challenging to identify as well. Have no fear, however, as a determination rests on three basic elements as to which practice and standard a stream project will ultimately end up being. They are:

1) If structures are used (i.e. J-hook or cross vanes), it will always be a Stream Restoration BMP
2) If the meander pattern of the channel is manipulated, it will always be a Stream Restoration project
3) If the bed of the channel (slope) is to be manipulated, it will always be a Stream Restoration project

Streambank and Shoreline Protection projects will only shape the banks, potentially including the installation of a bankfull bench (non-structural practice), and will have vegetation planted in association with the bank grading work that may be necessary to ensure stabilization of the exposed bank. Grading work is allowable and accepted, in conjunction with the development of a bankfull bench, if necessary, and in association with “laying back the banks”. The removal, transitioning, and/or development of point bars into a bankfull bench can be acceptable provided no structures are necessary to stabilize the bars once removed or developed as this is not deemed to be manipulation of the channel bed. The installation of any structures requires the approval of a Professional Engineer and would move the practice to a Stream Restoration project.

11.5 General

Several factors result in streambank erosion. These include (but are not limited too) an increase in the impervious surface in the watershed, an increase in the near-bank shear stresses, a lack of or removal of bank vegetation and adjacent riparian buffer areas, or manipulation of the pattern, dimension, and/or profile of the stream’s physical attributes. Usually there will be visual signs, in addition to the bank failure itself, that are indicators that the stream’s morphology is changing. Unstable point bars, transverse bars, central bars, lengthening of riffles disproportionate to other stream features, and long, shallow pools are many times indicators of a stream exhibiting signs of significant changes occurring. For Streambank and Shoreline Protection BMPs, these indictors of instability should be minimal in and around the project area. The presence of these indicators, that the stream is in a state of significant transition, will reduce the success rate for any repairs as the stream most likely will be experiencing increased erosion in the near future. In most cases, these streams would need a Stream Restoration BMP to control the erosion and would become a more complicated project. Additionally, if urban infrastructure is present and potentially being compromised, a deeper assessment of the situation is warranted. When instability and adjacent constraints are present, Streambank and Shoreline Protection measures likely would not be the solution to these erosion problems.

Point bar depositional pattern (note the size of the gravel present) in the meanders of the stream. The point bar is not well developed and the gradation indicates this stream is going through significant changes and a more thorough assessment is needed prior to any streambank repair or restoration design.

Sewer line being compromised by bank erosion. Note the fine sediments on the far bank, a point bar consisting of primarily fine sands. A sharp exit slope (the downstream side of the sediment bar) is prevalent on the back of this bar. Note the vegetation, consisting primarily of annual weeds with little to no woody vegetation present within the bankfull elevation. This would not be well suited to a streambank and shoreline protection project but would be better suited to a stream restoration project, particularly as significant infrastructure is being compromised.

This location is not constrained by adjacent utilities or landuse. Although the watershed is fairly large, this site could lend itself to a stabilization project.

11.5.1 Assessing the project and its watershed

A full evaluation of the project area and the watershed it drains should be made by the conservationist to assess and ensure project success. All efforts should be made to gather as much pertinent information that will not only go into the design, but to help with construction issues. Some important questions to consider, and have answers for, include:

- Is this a streambank/shoreline stabilization project or is this a stream restoration project?
    - Will structures be needed to stabilize the stream or do only the banks need to be graded and vegetated? If structures are necessary, a PE or Division engineer must perform and/or seal the design
    - Will the channel gradient need to be altered? If so, it is a restoration project.
    - Will the meander pattern (sinuosity) of the stream need to be altered? If so, it is a restoration project.
    - Are you unsure if this is a restoration or stabilization project? Consider discussing this or having a site visit with someone with more experience ; it likely may be a restoration project.
- Is this a transitioning watershed where considerable urban development has recently occurred or may take place in the near future?
    - If so, ensure that stabilization will solve the problem and that restoration will not be needed in the future.
    - If some of the sediment indicators (shown above) are beginning to form substantially, stabilization may not, and likely will not solve the bank erosion issue.
    - Check with the local subdivision, zoning, and/or sediment and erosion control officials in the county to determine if any large-scale projects are in queue for the watershed. If so, consider the impact such a development will have on the project.
- Can ingress and egress (access in and out of site) be readily obtained?
    - Is there sufficient room to get the necessary equipment in place to perform the work?
    - Will any infrastructure be compromised, or potentially affected by the work to be performed?
    - Will a significant portion of the grounds (lawn, landscaping, fencing, etc) be affected by the ingress/egress?
    - Septic tanks? Water lines?
    - Are there any easements that may be affected?
- What type and size equipment will I need?
    - Will any trees or stumps be removed from the banks or site? Consider the breakout weight of the boom on the backhoe equipment.
    - If a backhoe is used, does the normal boom have the length necessary to reach all the grading work to be performed? Extensions or longer booms can be rented if the grading contractor does not have access to one.
    - Should I use the large or small bucket or both?
    - Can a tandem dump truck get in and out of the site should one be needed?

11.5.2 The Rosgen Stream Classification System

Dave Rosgen, PhD and renowned hydrologist, developed a classification system that can be used globally to help determine not only how a stream has formed over time, but also how a stream may form in the future given changes in the hydrology of its watershed. This system also provides the user with a rather clear picture of the stream based on its characteristics. Using an alpha-numeric system (A, B, C, 1, 2, 3) to organize streams, Dr. Rosgen took years of intense data in developing the system. A student could delve very deep into this subject; many have dedicated their life's work to understanding and employing this system. This guide will provide a basic understanding of the design and implementation of streambank stabilization practices.

11.5.2.1.1 The basic stream classes

As mentioned above, Rosgen uses an alpha-numeric system, A, B, C, 1, 2, 3. The letter denotes the stream type based on dimension, pattern, and profile (see chart below) and the number designates the type of bedload material, or channel substrate, that the stream has. Certain stream types will only appear within certain landscapes and watersheds. For example, note the Aa+ stream; it has a slope of > 10%. These stream types would not be found in the coastal plain or piedmont regions of the state, they are step-pool type streams found only in the mountains. It is possible to find a very small reach of a stream section that may act like an Aa+ stream in the piedmont, perhaps at a culvert outlet on the side of a slope, but it is highly unlikely anyone would find a true stream of this type for a significant reach in these two regions. Similarly look at the DA stream type. It always has a slope, or longitudinal profile, of <0.5%. Generally, no one would find this stream type in the slopes of the mountains, other than in the floodplain or valley, as the topography does not allow this type of stream system to form. In working with stabilization projects, most of the candidate streams will be B, C, F, and G type streams. Most other stream types require an engineering design due to the need for structures.

Prior to detailing each stream type more in-depth below, let's define some terms that are used in stream classification.

Definitions (Keep in mind that these are based on measurements collected at a riffle cross-section)

Entrenchment ratio – is defined as the flood prone width divided by the bankfull width. The flood prone width is measured at two (2) times the maximum depth at bankfull and perpendicular to the fall of the valley at the riffle cross-section. This ratio effectively tells you how contained runoff flow is within the stream. The lower the number, the more vertical the walls or banks are generally. The higher the number, the more width at flood prone stage. Vertical walls can of course lead to bank failure and erosion.

Width/Depth Ratio – is defined as the bankfull width divided by the mean bankfull depth at the riffle cross-section. The values give the user a couple of useful indicators regarding stream health:

1) **Distribution of stream energy** – those streams with high width/depth ratios (wide and shallow streams) have a much higher tendency to erode as storm surges bring water elevations to exposed, non-rooted banks
2) **Describing cross-sections –** the width/depth ratio also provides the user with insight into how the channel looks while standing in the bed and how that may lead to potential erosion during storm

events. The low width/depth ratio streams will have vertical walls, those with moderate width/depth ratios will have a parabolic shape or one vertical and one shallow sloped bank.

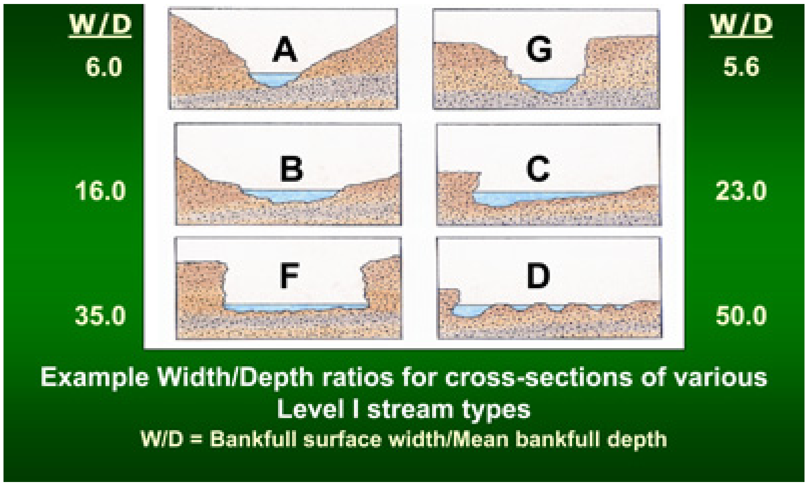


Figure 11-1 Stream types and example width/depth ratios

Sinuosity – the higher the sinuosity ratio, the more curves and meanders the stream will have. Sinuosity describes how the stream has adjusted its slope in relation to the slope of the valley. Sinuosity can be measured by measuring the total channel length along the thalweg of the reach in question to the valley length of that segment. The valley length would be a straight line from the beginning to end points and should be measured in the field. If there are clear aerial photos and excellent land marks to note in the field adjacent to the beginning and ending of the surveyed reach, valley length can be double checked in the office.

Slope – the slope, developed from data collected in the longitudinal profile, is the difference in water surface elevation from one defined point in the stream (head of a riffle) to the same type of stream feature just downstream of the studied reach, and dividing by the distance along the thalweg. This slope is the slope of the **water surface** measured at the same location as the thalweg. The average water surface slope can be used as the bankfull slope as bankfull indicators can be difficult to find in the field, especially on streams in need of stabilization.

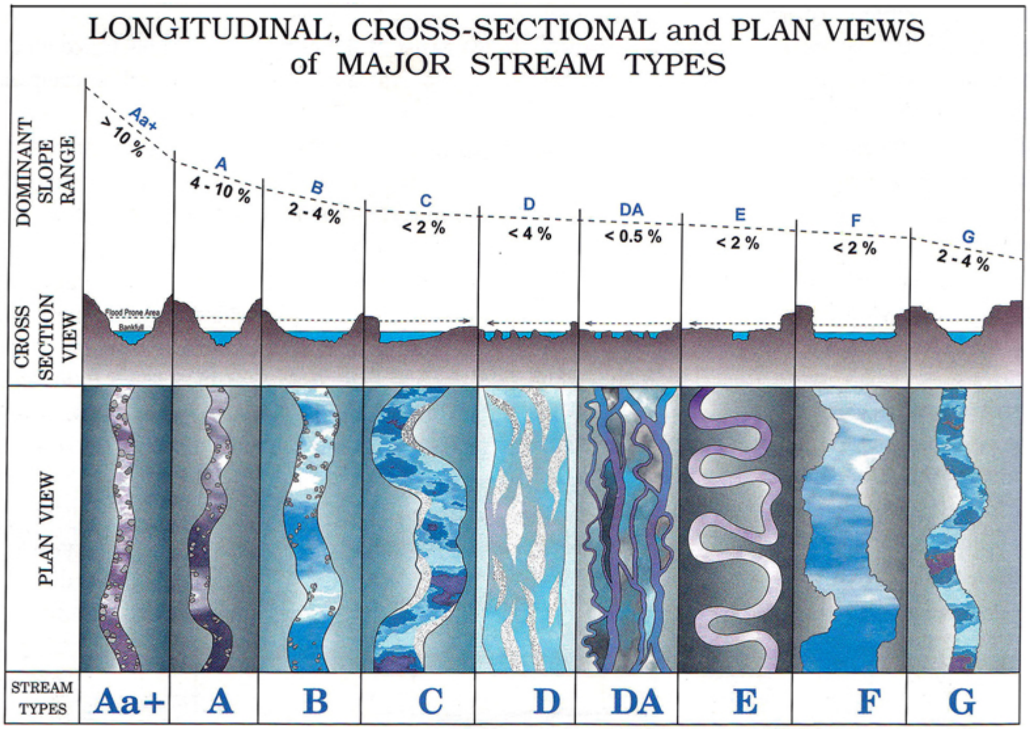


Figure 11-2 Rosgen stream types, the plan and cross-sectional views, and the predominant slope ranges associated with each stream type

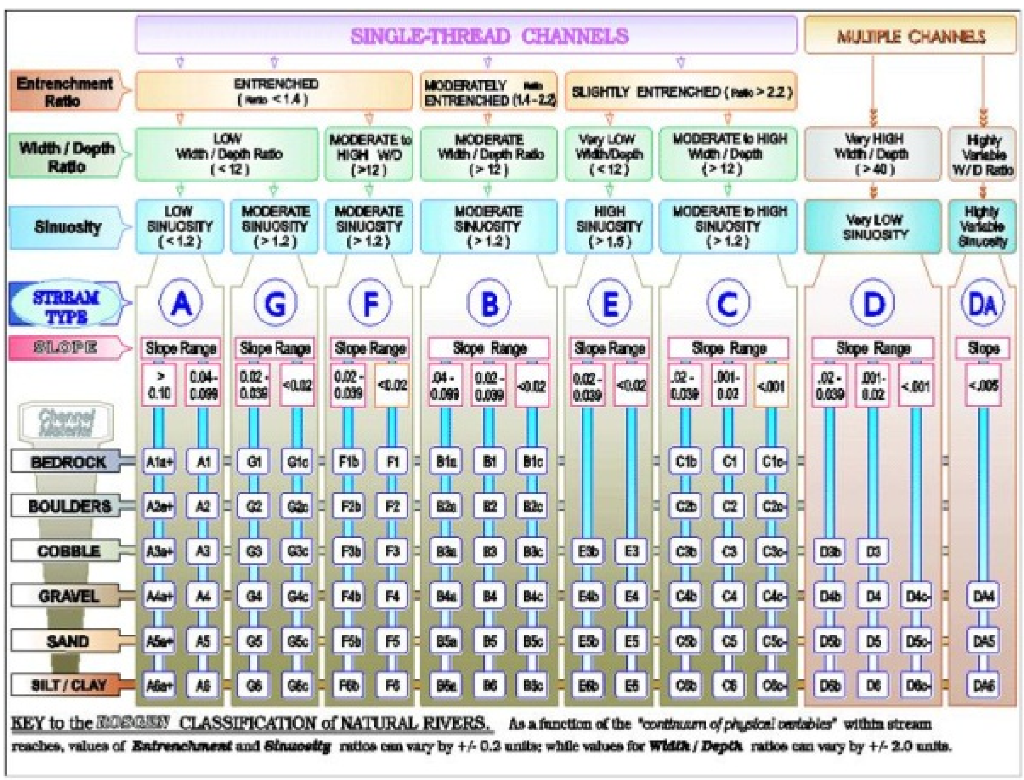


Figure 11-3 The Rosgen stream types (including bedload materials) and their associated sinuosity, width/depth, and entrenchment ratios

11.5.2.1.2 “A a+” stream type

“A a+” stream systems are generally thought of as step-pool type streams. They have slope of > 10% and are found largely on the upper reaches of the watershed. They have little sinuosity (<1.2) and seldom get out of channel during even large storm events, having an entrenchment ratio of <1.4 and a width-to-depth ratio of <12. Usually seen in the mountains, but culvert outlets on a slope and other similar type systems can mimic (or be) Aa+ types. Due to high slopes and presence of large rock, repairs on these stream types will be completed by engineers.

11.5.2.1.3 “A” stream type

“A” stream types are similar to “A a+”, but have a slope range of 4% - 10% and will have about the same sinuosity as an “A a+”,but less than every other stream type (<1.2). These streams are usually headwater streams. They are entrenched, with a ratio of <1.4 and have a low width/depth ratio (<12), and flows seldom get out of bank. “A” type streams are usually found in the mountains and due to slopes and need for grade control structures, very seldom will anyone other than an engineer design repairs of these stream types.

11.5.2.1.4 “B” stream type

This type stream is a little further down the watershed than the “A a+” and the “A”, having a 2% - 4% bankfull/water surface slope (longitudinal profile). These tend to be stable streams, having little to moderate sinuosity (>1.2 ratio), but when they do erode, they can be very destructive. **“B”** streams are moderately entrenched with an entrenchment ratio between 1.4 and 2.2 and a width/depth ratio >12 (the width/depth on A type streams are <12).

11.5.2.1.5 “C” stream type

“C” type streams are a common “fixit” stream that is often used in a stabilization design. Bankfull benches are readily integrated into “C”-type streams. The bankfull/water surface channel slope is less than2%; the stream has moderate to high sinuosity (>1.2 ratio) and a moderate to high width/depth ratio (>12). These streams are slightly entrenched with a ratio >2.2. “C” type streams access the flood prone area during events with flow greater than bankfull discharge. Often depositional features such as point bars will be present.

11.5.2.1.6 “D” type streams

“D” type streams are also known as braided channels, having at least three (3) threads/channels at bankfull flow. They will have many strong depositional features such as central point bars. They have extreme width/depth ratios at >40, and very low sinuosity. Slope ranges are less than 2%. These streams can readily “change course” with each storm event as the depositional features shift with the multiple channels. In North Carolina, very few “D” streams are found. Generally, these will not be encountered with stabilization projects as an engineer will most likely create structures and a new channel to mitigate these types of streams.

11.5.2.1.6 "D_A" type streams

"D_A" streams are again braided or multi-channeled streams but vary considerably in their width/depth ratio and their sinuosity. Their channels will be interconnected, and there could likely be oxbows, remnant or active, within their channeled system. These are found on wide floodplains usually in the coastal plain, and have slope ranges of <0.5% (very flat, often less than 0.1%). As with the D type streams, it is unlikely that a conservationist would encounter these on a stream stabilization job. These stream types can challenge the most-versed stream restoration engineers.

11.5.2.1.7 "E" type streams

"E" type streams are the most efficient at dissipating flood waters and storm events as they get "out of bank" quickly. This is due to their inherently low width/depth ratios (<12) and being slightly entrenched (ratios >2.2). These stream types generally having the highest sinuosities (>1.5). "E" type streams are found at slopes <2%. Conservationists will likely not encounter these stream types in the course of their work but may well run across a former "E" type stream that has eroded into what is now likely a "C", "F", or "G" type.

11.5.2.1.7 "F" type streams

"F" type streams are highly entrenched (ratio <1.4) with moderate to high width/depth rations (>12), and moderate sinuosity (>1.2). "F" type streams have slopes less than 2%. [SR1]They are always incised, often with steep banks. During moderate storm events, the stream flow will stay within the banks of the stream, increasing sheer stress. "F" streams are working to create a "C" or "E" stream through high bank erosion and development of bars. These stream types are potential projects sites for stream stabilization work.

11.5.2.1.8 "G" type streams

"G" (Gully) type streams look much like an "A" type at the cross-section with similar high entrenchment ratios (<1.4) and low width/depth ratios (<12). They have steep slopes (longitudinal profiles of 2% - 4%) and low to moderate sinuosity >1.2. These streams are generally transitioning to an "F" type stream during the channel evolution process. During moderate storm events, runoff from these streams will also remain in-bank and have high quantities of sediment loss through bank erosion. These are another stream type seen while performing stream stabilization work.

11.5.2.1.9 The numeric component of the stream classification system defines the bed material characteristics of the stream Bed materials are those that best describe the rocks/sand/gravel in the bottom of the stream channel but also includes some of the bank material up to bankfull. The numeric rating is classified by the particle size as shown in the chart below (in inches). Often millimeters are used to measure the bed material, not inches. The chart below shows both measurements. This topic is discussed further in section 11.5.2.3.3 below, along with methodologies on how to take the actual measurement. The channel materials will of course have impact on the stability of the stream pre- and post-construction.

Rosgen Class	Channel Material	Particle Size - Inches	Particle Size - Millimeters
1	Bedrock	Bedrock	> 1096 mm
2	Boulder	> 10 in	266 mm - 1095 mm
3	Cobble	2.5 in - 10 in	65 mm - 265 mm
4	Gravel	0.08 in - 2.5 in	3 mm - 64 mm
5	Sand	0.04 in - 0.08 in	0.062 mm - 2 mm
6	Silt/Clay	< 0.04 in	< 0.062 mm

11.5.2.2 Data collection

Basic surveying and data collection is necessary to get sufficient information to perform the design. When gathering the necessary information, the following equipment will be needed:

- Dumpy, laser, or hand level
- Survey rod
- Measuring tape
- Ruler in millimeters
- Something to use as a temporary benchmark-to stay until project is complete

Pins or clamps, or other such devices to keep the measuring tape level as it is stretched across the stream to survey will be helpful. Rocks have been used more than once as an improvisation tool. The following should be collected for the design, construction inspections, and subsequent “As-Builts”:

- Cross-sections at any points of variance from at least 50 feet beyond the flood prone area or top of bank, whichever is greater. At least one riffle cross-section should be picked as the classification cross-section to be used for calculations and comparisons.
- Shots along the thalweg for the length of project and at least 100 feet up and downstream from end of project. Remember to always start and end at the head of the same type of feature—typically a riffle.
    - Water surface profile shots (top of water) at the beginning of project and at the end of project.
    - Occasional top of low bank shots
- Any other pertinent areas that may affect the design or the cut and fill calculations or estimates and waste areas.

Many times, natural levees are formed at the top of bank. These should be captured in the survey as well. After collection of the data, estimate the amount of material that will be removed and potentially areas that may need some fill (most permits allow a certain amount of fill should it be needed). Look for appropriate areas to waste any excess material if your cuts are greater than the fills. Document these and determine the best method for utilizing any excess material that may come from the construction. A contractor will be interested to hear, in the pre-construction meeting, an estimate of the “waste” material and where the placement may be. If it has to be removed from the site, anticipate much greater costs for the project. Make every effort to move as little excess material the shortest distance.

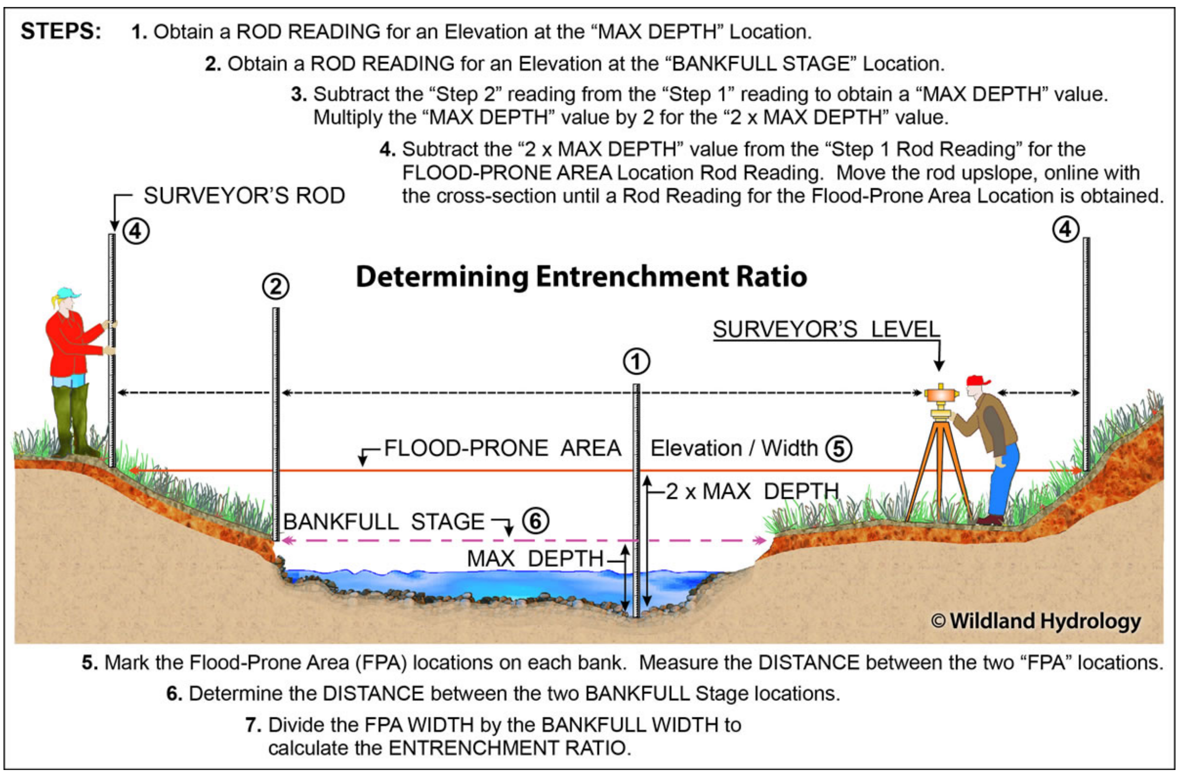
It would also be good to look at the soils information and data. It is helpful to know if there are alluvial floodplain deposits, whether rock or a constricting clay layer is present, and if a large amount of sand can be anticipated. Soils data can also provide information about connectivity to the existing flooplain and more pertinent information.

Historical aerials are one other source of good information. A stroll back through time will help gain an understanding of the watershed, how it has developed over the years, and how the adjacent flood plain area has developed. County GIS data may have information regarding zoning, soils, infrastructure, and other pertinent items; it's worth a look at the data! A quick discussion with county subdivision staff may give insight into future development as well. All these sources should be utilized to gather design information. Any existing infrastructure such as roads and utilities should be identified.

11.5.2.3 Other data to collect

There is other data that is necessary to a streambank stabilization and protection design. These include the Flood-prone Width, the Entrenchment Ratio, the Particle Size of the bed material, the Water Surface Slope, and the Channel Sinuosity. Defined in an earlier section, these are explained in more detail below and shown in the following illustration.

Field data collection techniques are illustrated in the "Stream Channel Reference Sites: An Illustrated Guide to Field Technique" specifically Sections 6 through 8 and Section 11.
(https://www.fs.fed.us/rm/pubs_rm/rm_gtr245.pdf)



11.5.2.3.1 Flood-Prone Width

The flood-prone width is easily defined and readily measured in the field. It is simply the width of the channel and adjacent flood-prone area measured at an elevation twice the bankfull maximum depth at a riffle (NOT the average channel depth). If the maximum depth at bankfull is 1.8 feet, shoot grade at 3.6 feet from the thalweg at the maximum depth either side of the channel and measure that width as illustrated above.

11.5.2.3.2 Entrenchment Ratio

The Entrenchment Ratio is also readily calculated. Defined, it is the Flood-prone area width (W_{fpa}) divided by the bankfull width (W_{bkf}). Shown in an equation, it is: W_{fpa} / W_{bkf}. As an example, if the bankfull width (W_{bkf}) was determined to be 28.4 and the Flood-prone width (W_{fpa}) was surveyed to be 72.8, the Entrenchment Ratio would be calculated as:

$$\mathbf{ER} = W_{fpa} \mathbin{\mathbf{/}} W_{bkf}$$

$$\mathbf{ER = 72.8/28.4}$$

$$\mathbf{ER = 2.56}$$

11.5.2.3.3 Channel Materials

The channel materials provide the habitat for macro-invertebrates and other stream-based wildlife. The D_{50} particle size (50^{th} percentile of the sampled materials) represents the median or dominant diameter of the channel materials. Distribution of particles sizes can be graphed and gives a good visual representation of the materials found in any particular channel. Generally, if the distribution is limited to one-size, it is an indication of a stream in transition. The method to determine particle size of the channel materials is as follows:

- Measure the length of riffles and pools in the stream (reach in question) beginning at the head of riffle and ending at a head of riffle.
- Determine the percentage of each both pools and riffles (i.e. 60% pools and 40% riffles)
- Take the equivalent percentage of samples from each stream portion.

The riffles are the primary focus as this portion of the stream generally has more effect on overall stream health based upon channel material/particle size distribution. To determine the channel materials for riffles:

- Determine bankfull at the cross section being sampled.
- Stretch a tape from bankfull elevation across the stream to the same bankfull elevation.
- Determine the width of channel and divide that by the number of samples needed in this cross section to get the sample spacing distance.
- Use a ruler that measures in millimeters.

- At the sample spacing distance, reach down with one finger. The first particle touched should be picked up and measured.
- When measuring the size, measure across the intermediate axis of the particle (not the longest or the shortest axis).
- Record the tally on the worksheet.
- Once the appropriate number of particles have been measured, determine the D_{50} particle size.
- If desired, determine the other distribution sizes (silts, gravels, cobbles, etc).
- There are worksheets to record and graph these measurements.

11.5.2.3.4 Average Water Surface Slope

The average water surface slope is determined from the longitudinal profile. It is the elevation difference of water surface measurements at the thalweg) and is measured over the stream length in question at similar types of bed features (riffle to riffle or pool to pool). It can be measured one of two ways generally, both using the standard below:

- Lay a tape in the thalweg section along the length of the reach in question.
- Start at the head of a riffle and end at the head of a riffle downstream of the project area. When looking at longitudinal profile always start and stop at the same type of bed feature (head of riffle to head of riffle works best).
- Take measurements at gradient break points and at set distances along the reach.
- Record both the thalweg and the water surface profiles.
- Calculate after completed survey.
- Use the longitudinal profile spreadsheet to further understanding (worksheet).
    - The longitudinal profile (long-pro) spreadsheet will graph the survey, giving a visual representation of the survey.

Two Methods:

1). After surveying the thalweg, lift the rod at the same point to where the bottom of the rod is just touching the water surface and have the surveyor record this reading, or;

2). When surveying the longitudinal profile at the thalweg, turn the rod sideways to where there is no "meniscus" or heightened flow from the rod in the water. Measure the depth of the water at the thalweg and record in the engineering filed book. Using this method, be extremely careful not to exacerbate the readings due to the "meniscus" or the "dam flow" caused by the rod.

After completion of the survey, calculate readings and determine the water surface slope from the water surface readings (do not use the thalweg readings).

11.5.2.3.5 Channel Sinuosity

The channel sinuosity is the meander or amount of curvature and bends of the stream. It is defined as the stream length (SL) divided by the length of the "valley" (VL: the valley length being a straight line as measured from the beginning of the stream reach in question to the end of the stream reach being studied). This can be somewhat difficult to measure in the field; be prepared to make one or more instrument turns to survey. For reaches with a clear site line, use the length of the reach as measured through the thalweg as stream length, SL. Then beginning and ending at the same locations, measure the straight-line length between these two spots as valley length.

The channel sinuosity will always be greater than one. A completely straight channel, cut with heavy equipment in a completely straight line, would have a channel sinuosity of 1. As an example, you have measured the stream reach in question using a tape laid along the thalweg. Measured stream length (SL) is 647 feet. Measured carefully, in a straight line from the beginning to the end of the longitudinal profile survey, the valley distance is of 578 feet. Channel sinuosity would be calculated as:

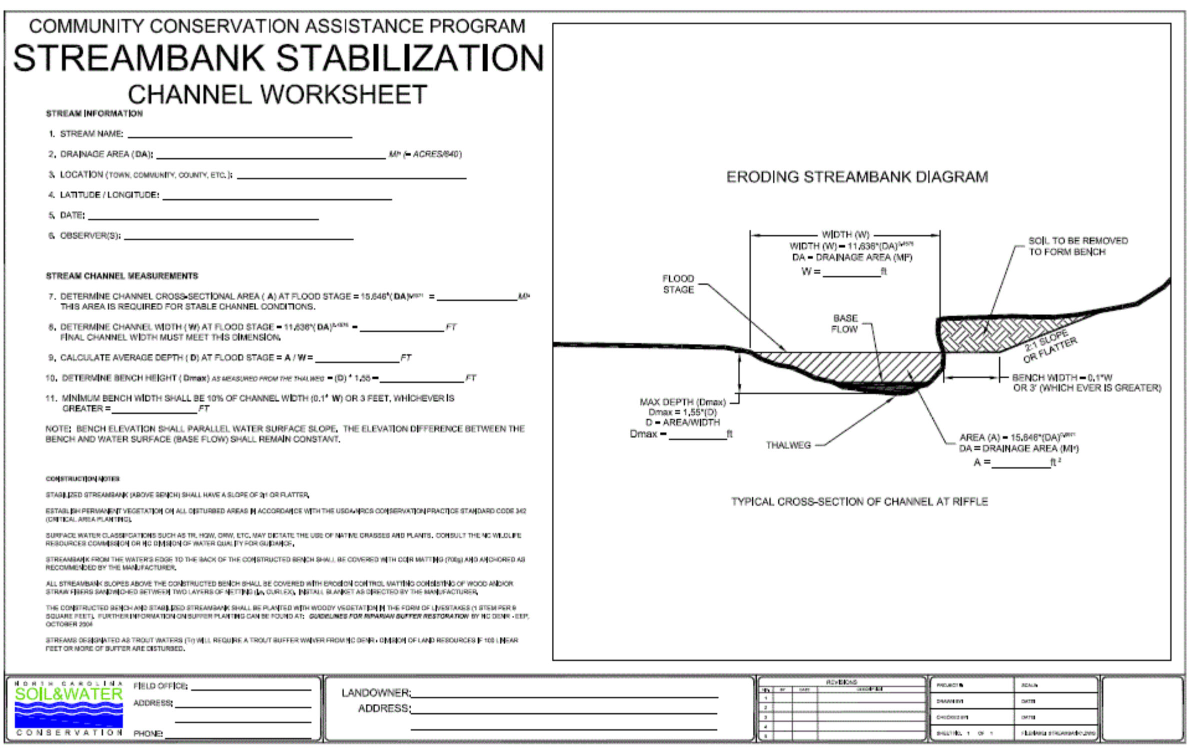
$$\mathbf{K = Sl/VL}$$

$$\mathbf{K = 647/578}$$

$$\mathbf{K = 1.12}$$

11.5.4   The Streambank Worksheet

The streambank sheet (below) has been developed to enable the designer one location to perform all operations necessary to determine the appropriate bankfull dimensions for a stabilization project. Check in the appendices (Appendix A) for a better version of this graphic. Have the worksheet with you as you go through this exercise. The graphic below is just that, a graphic, and is not intended for you to be able to use it functionally.



11.5.4.1 Dimension using the worksheet

The dimension of the stream, or the cross-sectional area, is a critical element in determining proper streambank and shoreline protection measures. Two cross-sectional areas are to be determined when designing a streambank and shoreline stabilization project, the bankfull and the flood-prone elevations at the cross-sections. Determining the proper width and depth (cross-sectional area) is necessary to ensure bank stability when performing a streambank and shoreline stabilization project. These measurements ***must*** be made at the riffle. It is preferable to also find a stable riffle either upstream or downstream of the project area and make the same measurements.

11.5.4.2 Determining channel cross-sectional area at bankfull with the worksheet

The proper channel cross-sectional area (A) at the bankfull is critical in stabilizing streambanks. The cross-sectional area of this element of the channel is the width multiplied by the mean (or average) depth at bankfull. Determining the cross-sectional area at this stage is performed by using the following formula, with the regional curves in all examples below being referenced from the "NC Rural Mountain and Piedmont Regional Curves (Stream Gage Stations)". These regional curves are provided below the examples:

$$\mathbf{Y\ (sq\ ft) = 19.133 * DA^{0.6539}}$$

Where:

Y = cross-sectional area in square feet

DA = drainage area in square miles

19.133 is a constant defined by the Regional Curves

0.0.6539 is an exponent coefficient defined by the Regional Curves

Example: *determine the cross-sectional area at flood stage for watershed with a drainage area of 510 acres.*

Answer:

First convert the watershed drainage area from acres to square feet. There are 640 acres per square mile:

510 acres/640 acres per square mile = 0.8 square miles

$Y = 19.133 * (0.8\ \text{sq miles})^{0.6539}$

Y = 19.133 * 0.8642

Y = 16.5 sq ft

11.5.4.3 Determining channel width (W) at bankfull stage

The proper channel width (W) at flood stage is another necessary calculation to perform when designing a streambank stabilization project. This will be the width at the point of bankfull discharge. It is determined by the following formula:

$$\mathbf{W = 17.41 * DA^{0.3692}}$$

Where:

W = channel width at flood stage (aka bankfull width) in feet

DA is the drainage area of the watershed

17.41 is a constant defined by the Regional Curves

0.3692 is an exponential coefficient defined by the Regional Curves

Using the same example as above, the project has a 510 acre drainage area:

Answer: 510 acres/640 acres per square mile = 0.8 square miles

$W = 17.41 * (0.8 \text{ sq miles})^{0.3692}$

$W = 17.41 * 0.9209$

W = 16.0 ft

11.5.4.4 Determining *average* channel depth (D) at bankfull stage

The ***average*** depth at flood stage is critical in determining the bankfull bench elevation (to be calculated next!). Average depth is readily calculated once the cross-sectional area has been determined and the width of the channel at flood stage is known. It is simply the cross-sectional area divided by the width, shown in the formula:

$$\mathbf{D = A/W}$$

Where:

D = the average channel depth

A = the cross-sectional area

W = channel width

Using the same example as above, with a 510 acre drainage area, where the calculated cross-sectional area is 16.5 sq ft and the width is 16.0 feet:

Answer:

D = A/W

D = 16.5sq ft/16.0ft

D = 1.03 feet

Important!!! Remember, this is the average depth!

11.5.5 Determining the bench height (D_{max})

The bankfull bench height (or elevation) is critical in determining the elevation where the runoff from the 1 to 2 year, 24-hour storm event will begin to “spill out” onto the newly constructed, graded flat area. As discussed earlier in this chapter, the most kinetic energy and erosive velocities occur at the bankfull stage. By utilizing the streambank and shoreline protection BMP, and subsequently developing the bankfull bench, these erosive velocities will be dissipated as the storm surge reaches this elevation calculated and installed in the field.

From the average channel depth, the bankfull bench elevation is determined with the following formula:

$$D_{max} = D * 1.55$$

Where:

D_{max} = bankfull bench height

D = average depth (calculated above)

Using the same example as above, average depth was calculated to be 1.03 feet. To find the elevation of the bankfull bench to be constructed:

Dmax = D * 1.55

D_{max} = 1.03 ft * 1.55

D_{max} = 1.60 feet above the thalweg or the deepest portion of the riffle

The bankfull bench should be installed 1.60 feet above the thalweg. This will allow the high energy, highly erosive water to begin spilling out onto a “mini-floodplain” prior to extensive bank erosion occurring.

11.5.6 Determining the minimum bench width W_{bench}

The width of the bankfull channel calculation is necessary to ensure the proper development of the “mini-floodplain” to be constructed so that what were once erosive, high-energy velocities, are reduced to those that the newly formed bank can withstand without eroding. Using the previously calculated width of the basic channel, calculating the width of the bench is a simple procedure as follows:

W_{bench} = 0.1 * W (or a minimum of 3 feet wide, whichever is greater)

Where:

W_{bench} = width of the bankfull bench

0.1 – is a constant that represents 10%
W = Width of the cross-sectional area

Using the same example as above, the average width calculated was 16.0 feet. To find the width of the bankfull bench to be constructed:

W_{bench} = 0.1 * W

W_{bench} = 0.1 * 16.0 feet

W_{bench} = 1.60 feet

As noted above however, the minimum bench width will be 3 feet , so in this case, the** W_{bench} **= 3 feet

Let's review the example problem in determining the proper channel dimensions for the streambank erosion issue:

The watershed area is 510 acres.

For the cross-sectional area:

Y (sq ft) = 19.133 * DA $^{0.6539}$

Y = 16.5 sq ft.

For the width at bankfull stage:

W = 17.41 * DA $^{0.3692}$

W = 16.0

For the average depth:

D = A/W

D = 1.03 ft

For the bench height or elevation:

D_{max} = D *1.55

D_{max} = 1.60 ft

For the bench width:

W_{bench} = 0.1 * W (or a minimum of 3 feet wide, whichever is greater)

W_{bench}= 1.60 ft (use the minimum of 3 feet wide)

Important note: the above example provides the proper dimension for the given watershed as studied at the point of repair. When repairing more than one eroded area on a given reach, or section of stream, it is acceptable to use the dimensions as calculated above, provided a similar channel dimension exists at both points of repair. Should the existing channel dimensions differ significantly, recalculate the dimensions for both sections needing repair based upon the increased watershed. Adjustments to the width and depth, while maintaining the same cross-sectional area of the bankfull bench, can be altered to fit the existing terrain of the problem channel(s). They should also be compared to the stable riffle cross-section measured upstream or downstream of the study site.

11.5.7 Other Methods for estimating the dimension or cross-sectional area for streambank and shoreline protection

While the above streambank stabilization worksheet is an excellent source for design of this practice, and is an officially recognized method, other methods exist for estimating the cross-sectional area for a project. **NOTE:** ***please read carefully the disclaimers that come with the methods listed below. While used in the design of such practices, they are NOT recognized as a definitive source and caution needs to be exercised when employing them.***

11.6 Regional Curves for North Carolina

Credit should be given to those that have had significant influence in the development of natural stream design methods that are used in both streambank stabilization and stream restoration projects. Dave Rosgen, a student of the famed geomorphologist Luna Leopold (son of the renowned conservationist Aldo Leopold), dedicated his life to furthering Dr. Leopold's work regarding stream and river systems and their ability to function in a natural state, particularly after significant hydrologic changes in the watershed. Drs. Rosgen and Leopold's work has enabled thousands of miles of streams to be improved and restored through hard work in collecting the data necessary to determine with predictability how a stream will react to changes in its watershed. Without these significant accomplishments, local districts would not have completed the stabilization of many eroded banks throughout the state.

North Carolina has a rich history regarding streambank protection (stabilization) and stream restoration work. North Carolina State University Biological and Agricultural (NCSU – BAE) Department, in conjunction with Natural Resource Conservation (NRCS), helped develop what are known as "Regional Curves" for determining the dimension of stream channels in North Carolina based on the work of Drs. Rosgen and Leopold. Again, without the dedicated hard work of Will Harman, Greg Jennings, and the NCSU Water Quality Group, coupled with Angela Gragg (formerly Angela Jessup), Dick Everhart, Alan Walker, Tommy Burchette, and Jerry Pate with NRCS, the efforts employed by the local districts to significantly reduce bank erosion based on these principals would be far lacking (please, apologies to the many other uncredited individuals whose hard and good work made this possible). It is worthy to note the dedication by these individuals and to pay tribute to those that have furthered their work, ongoing today. These individuals include our own Division and District employees (Daphne Cartner, Jeff Young, and Cindy Safrit) who have helped with the Rosgen trainings, sponsored by Resource Institute (formerly Pilot View RC&D) over the years. These classes are still being offered and give the attendee in-depth training to further their understanding of streambank stabilization and restoration systems. A note of gratitude to those that have worked diligently to further the studies of these complex systems.

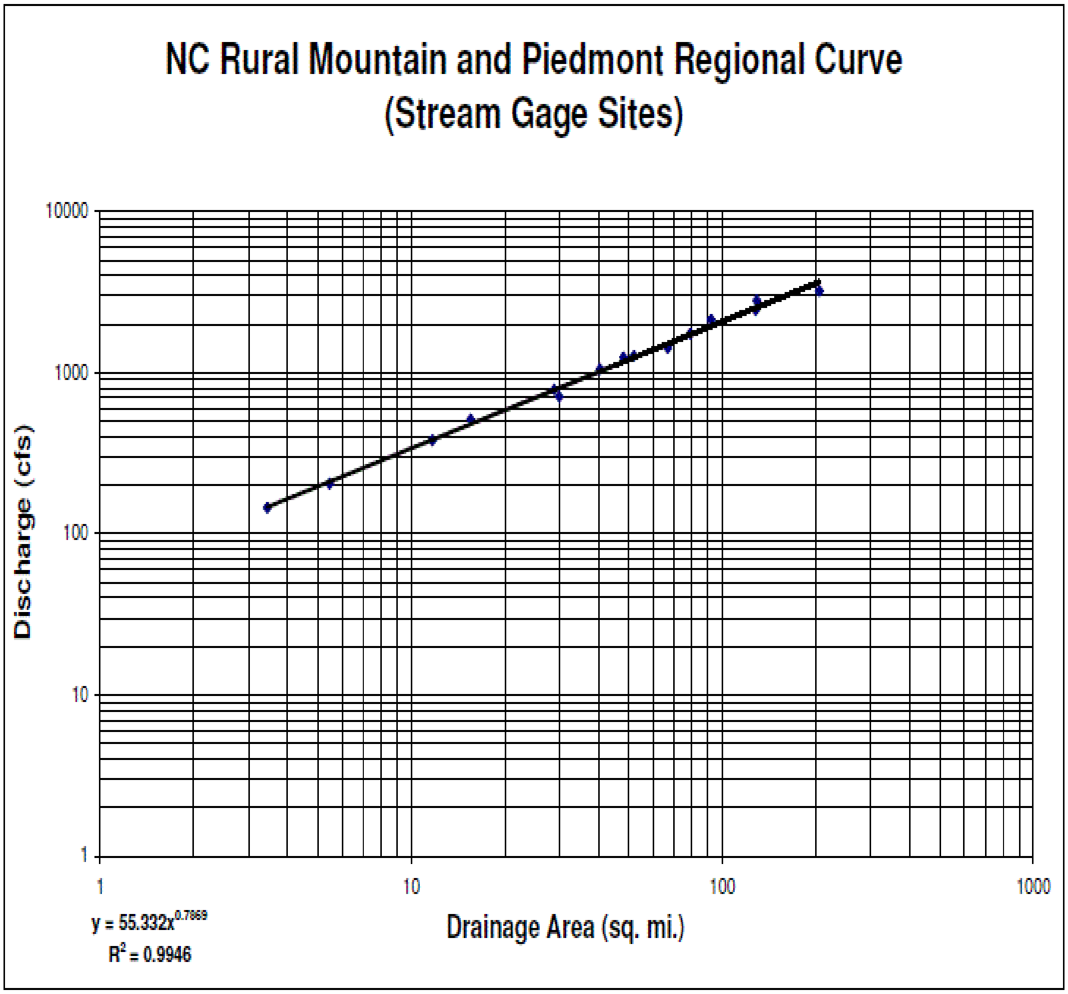
The Regional Curves, also known as the bankfull hydraulic geometry relationships, have been based on US Geologic Survey (USGS) gaged stream sites along with non-gaged sites on many streams in the Mountains and Piedmont physiographic regions of the state. Based upon this extensive data gathering, the geometric relationships of the stream cross-sectional dimensions were graphed in conjunction with the watershed area they are a function of. The discharge relationship has also been graphed as a function of the watershed size. Based upon this data, a regression equation was developed for both the cross-sectional area and the discharge as a function of the watershed drainage area for the Mountains and Piedmont.

Coastal plain channel gradients are very slow, resulting in differing channel dimension relationships to the size of the watershed. These slow-moving streams have other hydraulic and hydrologic factors associated with them that result in varying curves from the “norm”. Stating this, and while there may not be much streambank stabilization/protection work to be performed in the truly Coastal Plain region, care should be taken in relating the regional curves to the Coastal Plain. Regarding the mountains, seasonal rainfall amounts vary significantly across the region, varying from 40 inches to upward of 80 inches per year. The Regional Curves developed for the mountain region do consist of data points across the spectrum of this variance, yet a set of usable curves was derived from this set of data.

These Regional Curves allow the user to get a scientifically-based determination of what the stream dimension (cross-sectional area) based on the watershed size should be at the bankfull stage. Bankfull discharge was also calculated and graphed on the Regional Curves. While these are not “officially” recognized as conclusive data, and are not recognized as the definitive source for the design of streambank stabilization and restoration, they have been utilized significantly in preparing designs. They have also been used extensively by those with considerable knowledge and experience in stream stabilization/restoration work as a significant means with which to gauge the effectiveness of a design. To boil all this down, while the Regional Curves are not identified as a stand-alone method of design for these practices, they offer a very reasonable starting point with which to complete a design and can be used to correlate what a “full” design may require for the dimension, or the hydraulic geometric relationship needed on a practice for a given watershed.

One additional note needs to be made. The graph lines begin at an approximately 3.3 square mile drainage area (approximately 2,100 acres). The end point of the graph line ends at just over 200 square miles, equivalent to 128,000 acres. For drainage areas less than 3.3 square miles, or 2,100 acres, use the regression equation shown for each physiographic region. For watersheds within the 3.3 to 200 square miles, or the 2,100 to 128,000-acre drainage areas, you may use the graph itself while checking accuracy against the equation. It is always recommended to check drawn lines against the equation (always!). It is highly doubtful designs for stream stabilization and protection will be conducted on sites with greater than a 128,000 acre drainage area.

11.6.1 The Mountains and Piedmont Discharge Curve:



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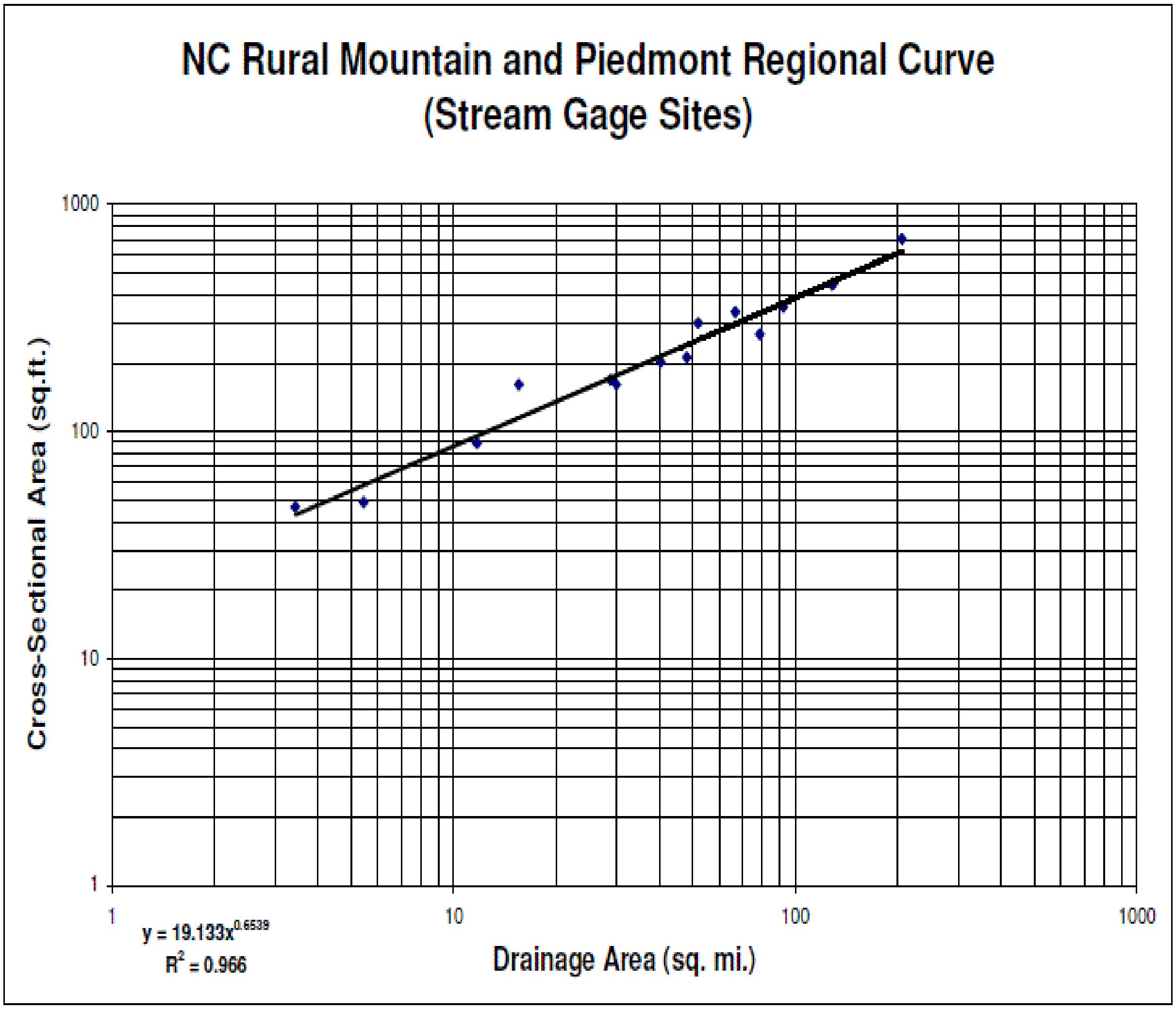
The graph shows the Drainage area in square miles on the X axis and the relationship to Discharge on the Y axis. Note the equation on the lower left portion of the graph:

Y (cubic feet per second, or cfs) = 55.332 DA$^{0.7869}$ where DA = drainage area in square miles

11.6.2 The Mountains and Piedmont Cross-sectional Area Curve:



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The graph shows the Drainage area in square miles on the X axis and the relationship to the cross-sectional area in square feet (sq ft) on the Y axis. Note the equation on the lower left portion of the graph:

Y (square feet or sq ft) = 19.133 DA^{06539} where DA = drainage area in square miles

11.6.3 OK, I have the tables, now what do I do? (Example)

Again, these have never been officially “approved” for design purposes, but are widely used to help determine the proper dimension for stream stabilization and restoration work. Note that not only are there lines that transect the X and Y axes, but there is also an equation shown in a box in the lower left-hand side of the graph. Important note: ***The equation MUST be used for less than a 3.3 square mile or***

2,100 acre drainage area. If the drainage area in question is greater, please consult one of the Division engineers.

To use the graph, first determine drainage area or watershed in square miles. If the drainage area is in acres, the conversion to square miles is easy; simply divide the number of acres by 640 (there are 640 acres in a square mile).

In the example, the watershed area is 2,880 acres. To determine the watershed in square miles, use the formula:

1 square mile = 640 acres

For a watershed of 2,880 acres, calculate the equivalent number of square miles

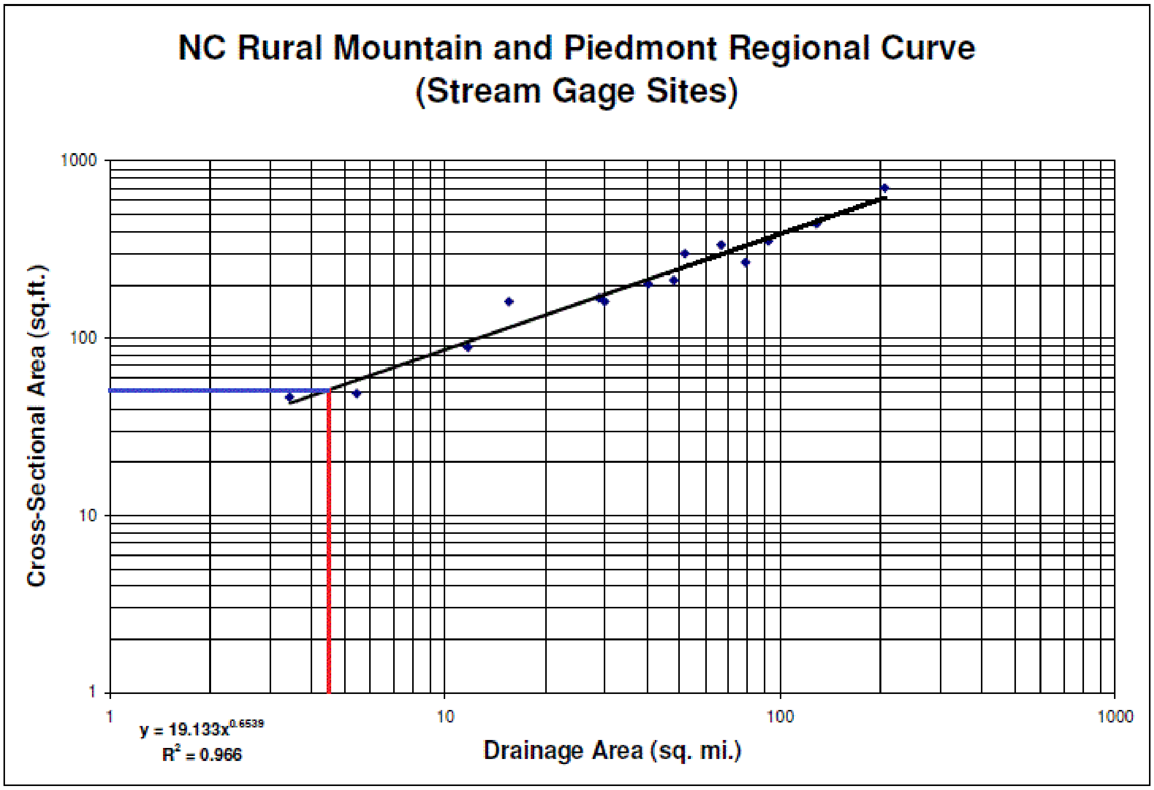
X square miles = 2,880 acres/640 acres

X = 4.5 square miles

11.5.6.3.1 Determining the Bankfull Cross-Sectional Area

11.5.6.3.1.1 Using the graph

To use the graph only portion of the Regional Curve, begin with drawing a line from the X-axis at the point of the watershed drainage area to where this straight line intersects the line developed from the data points (the red line in the example below). After determining the intersect line, now draw another straight line from the point of intersect to the Y-axis (the blue line in the example below). Looking carefully at the logarithmic lines on the Y-axis, the blue line is just past the 50 marker. This logarithmic scale intersects the Y-axis at a point of approximately 51 square feet on the Y-axis. This method truly is that simple!



11.5.6.3.1.2 Checking work by using the equation

To check the accuracy of the drawn lines, , use the equation in the lower left-hand side of the graph for the Urban Piedmont as follows:

Y = 19.133 DA**^{06539} **where x = drainage area in square miles

Y = 19.133 * $(4.5)^{0.6539}$

= 19.133 * 2.674

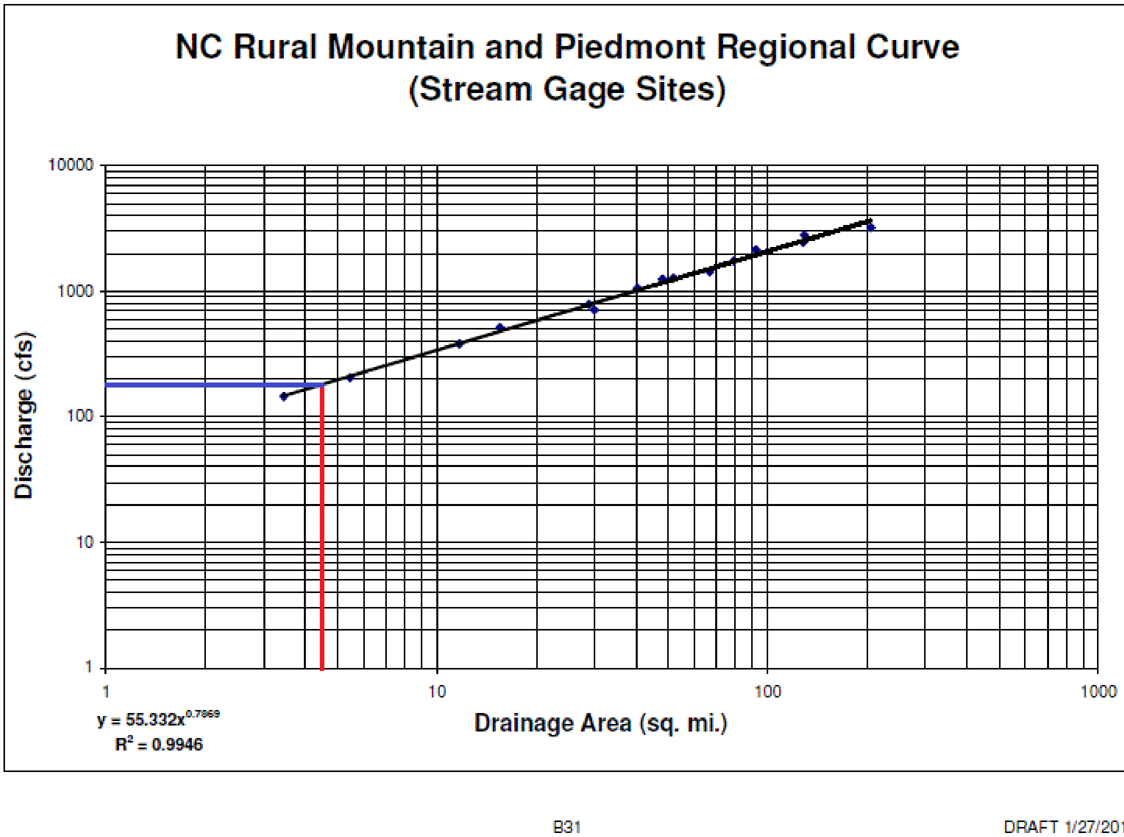
Y = 51.2 square feet

The simple line drawing method came up quite accurate (99%) when compared against the formula method. ***A comparison by using the equation is necessary to ensure accuracy, especially when extrapolating using this logarithmic scale.***

11.5.7.1 Determining the Discharge at Bankfull

11.5.7.1.1 Using the graph

Use the same method as above. Begin with drawing a line from the X-axis at the point of the watershed to where this straight line intersects the line developed from the data points (the red line in the example below). After determining the intersect line, now draw another straight line from the point of intersect to the Y-axis (the blue line in the example below). Looking carefully at the logarithmic lines on the Y-axis, the blue line is just below the 200 marker. This logarithmic scale intersects the Y-axis at a point of approximately 190 cubic feet per second (cfs) on the Y-axis.



11.5.7.1.2 Checking the work by using the equation

To check the work against the mathematical formula, use the equation in the lower left-hand side of the graph as follows:

$Y = 55.332\ DA^{0.7869}$

$Y = 55.332 * (4.5)^{0.7869}$

$= 55.332 * 3.266$

Y = 180.7 cubic feet per second (cfs)

The simple line drawing method came up just under 95% of the accuracy when compared against the formula method. ***Remember, a comparison is necessary to ensure accuracy, especially when extrapolating using this logarithmic scale.***

11.5.7.2 Determining the Bankfull Width and Depth

Discretion is left up to the designer to adjust the proper bankfull width and depth based upon the determined cross-sectional area as calculated using the equation above. The width and depth of the final grading work to be performed should equal the cross-sectional area as determined using the graph and equation. Considerations in determining the width and depth should be given to the existing channel dimensions, the shape of the erosion that has taken place to date, and the existing upstream and downstream channel dimensions. It is always wise to consider the dimensions of a stable reach of the same stream, or one that is the same stream type in a stable setting.

To use the example above, the designer would want to choose a width and depth for the final grading work to be performed that will equal the 51.2 square feet. Assuming the bankfull depth chose by the designer was 2.2 feet, the width would then be determined by simply dividing the cross-sectional area by 2.2:

51.2 sq.ft./2.2 ft = width

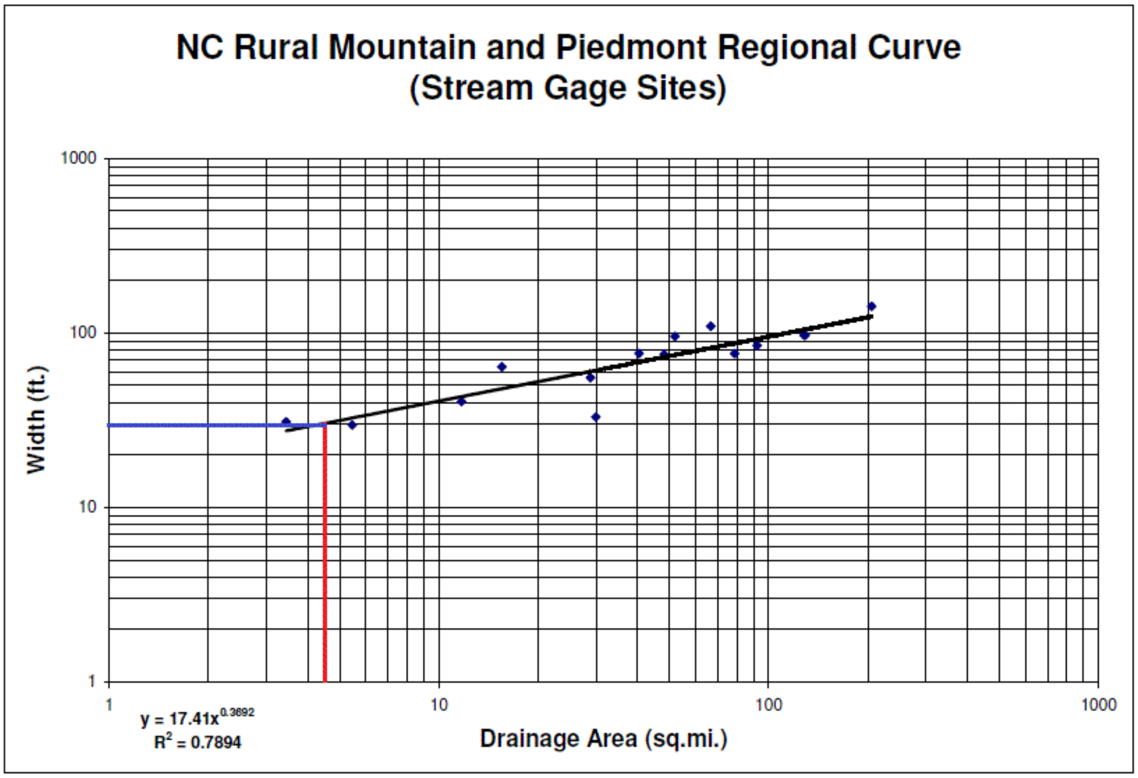
Bankfull width = 23.2 feet

11.5.7.3 Using the Regional Curves for determination of width and depth

Having said that discretion is left up to the designer, it would be a good idea to use the Regional Curves for width and depth to check against field evaluation. These curves, derived from the same sources as the discharge and cross-sectional area curves, provide a good starting point, or a good check against, what a designer may come up with in the field. Note that when using the logarithmic scale, exact values are hard to interpolate. It is always necessary to run the values against the equation shown in the chart.

11.5.7.3.1 Finding the bankfull width using the Regional Curves

The same process will be utilized, as shown above in the previous examples, by first drawing the red line from the X-axis at the point of the watershed drainage area to the line developed by the Regional Curve data. Use the same watershed drainage area of 4.5 square miles. At the point of intersect, draw the blue line to determine the bankfull width.



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The example gives us a value of approximately 27.5 feet.

11.5.7.3.2 Checking the work by using the equation

To check the work against the mathematical formula, use the equation in the lower left-hand side of the graph as follows:

$Y = 17.41\ DA^{0.3692}$

$Y = 17.41\ (4.5)^{0.3692}$

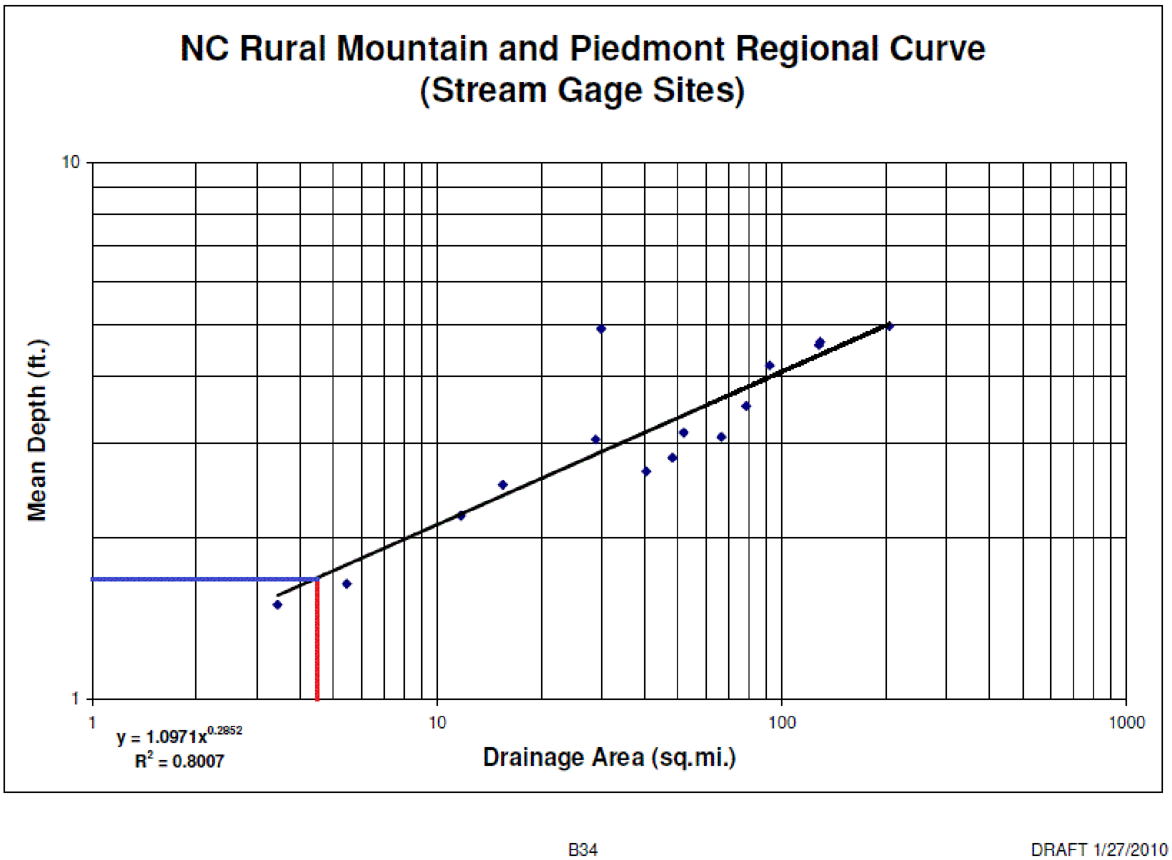
$Y = 17.41 * 1.7425$

Y = 30.3 feet

There are some variances when drawing the lines versus running the equations, in this case approximately a 10% variance. Again, experience and discretion, coupled with in-the-field observations, are critical in evaluating the design on these practices.

11.5.7.4.1 Finding the bankfull depth using the Regional Curves

The same process will be utilized, as shown above in the previous examples, by first drawing the red line from the X-axis at the point of the watershed drainage area to the line developed by the Regional Curve data. Use the same watershed drainage area of 4.5 square miles. At the point of intersect, draw the blue line to determine the bankfull depth.



The example gives us a value of approximately 1.8 feet.

11.5.7.4.1 Checking the work by using the equation

To check the work against the mathematical formula, use the equation in the lower left-hand side of the graph as follows:

$Y = 1.097\ DA^{0.2852}$

$Y = 1.097\ (4.5)^{0.2852}$

$Y = 1.097 * 1.5357$

$Y = 1.68$ feet

Again, there are some variances when drawing the lines versus running the equations, in this case approximately a 5% to 6% variance.

11.5.7.5 Comparison of values using the different methods

Let's compare all the methods to determine consistencies and variances among them, as shown in the table that follows:

Parameter	Graph/lines	Equation	Units
Cross-sectional regional curve	51	51.2	square feet
Width * Depth (cross-section) developed from the width and depth curves	49.5	50.9	square feet
Width from the curves	27.5	30.3	feet
Depth from curves	1.8	1.68	feet

As discussed above, experience and discretion, coupled with in-the-field observations, are critical in evaluating the design on these practices. The graph/line method should be followed by running the equations as a check, and should be compared with in-the-field observations. Most professionals that have been studying this work will generally put more confidence in the cross-sectional regional curves with having less confidence in the individual curves for the width and depth.

11.5.8 Methods for determining drainage area

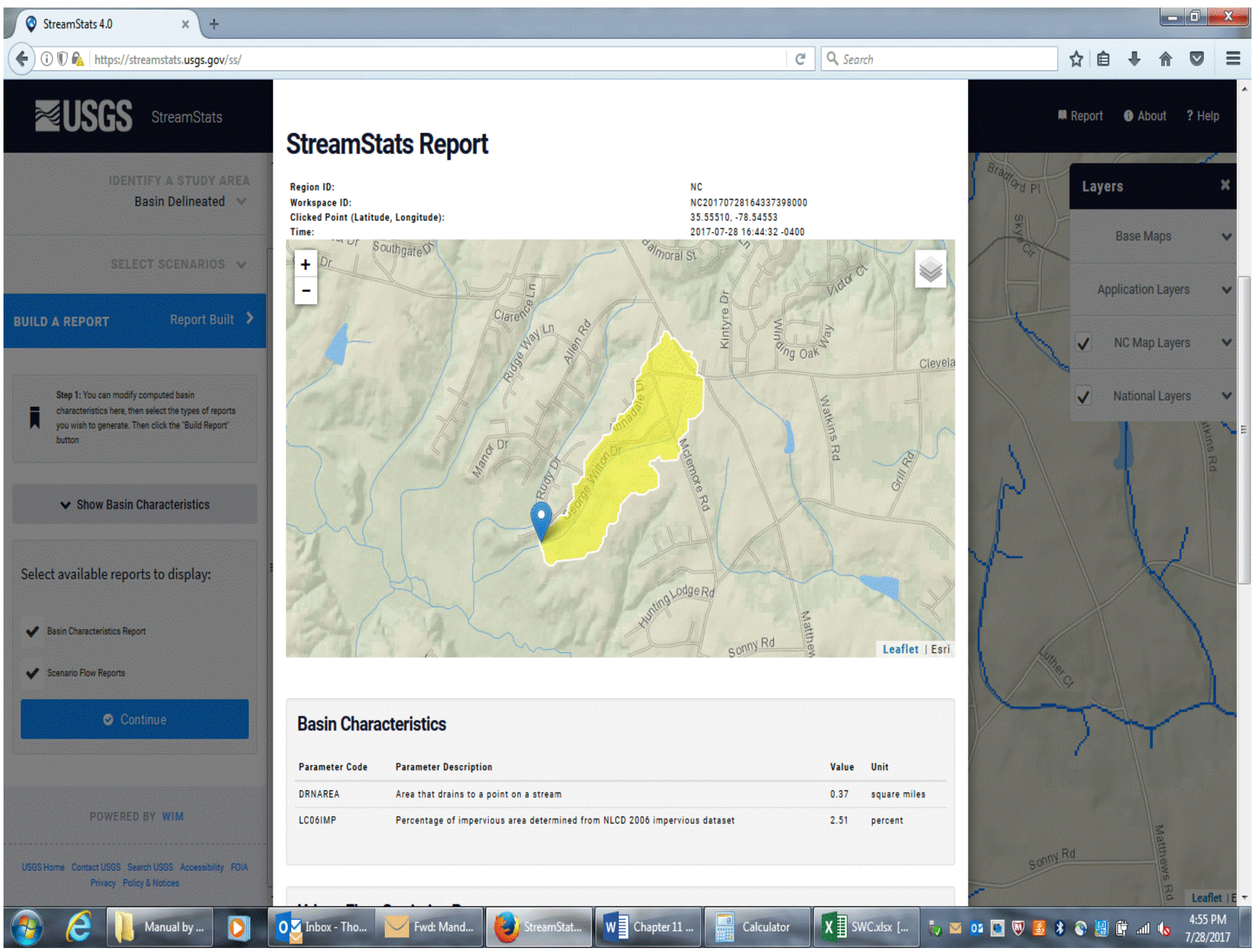
Having confidence in the drainage area for the project is essential in making the necessary calculations for determination of the bankfull components. There are several different methods that can be used to determine the watershed or drainage area for any given project.

11.5.8.1 USGS Streamstats

This is a powerful tool that is as easy as "point and click". From the link below, follow these simple steps to determine the watershed or drainage area (https://streamstats.usgs.gov/ss/):

- Type in the address of the area in question
- Select the state or region of the study area (comes up in a button)
- Click the "Delineate" button
- Click on the point of interest in the stream needed for determining the watershed/drainage area
- Wait approximately 30 seconds to one minute. A rolling circle will appear in the lower right-hand corner of the page stating "Delineating Basin"
- When completed, the window will disappear, and the box on the left side of the page will change, requesting in four separate boxes that 1) Clear Basin 2) Edit Basin 3) Download Basin or 4) Continue

- Usually the Continue button may be selected unless there is a need to re-delineate
- Click “Continue”
- After clicking Continue, a window in the lower right will appear stating “Regression Curves being determined”
- When completed, a list of Regression Based scenarios to choose from such as 1) Urban-Flow Statistics, 2) Low Flow Statistics, or 3) Seasonal Flow Statistics will be available. Click the “Urban Flow” option and then click “Continue”.
- The box on the left will state “Select Available Reports to Display” and offer the following options for most basins: Basin Characteristics Report and Scenario Flow Reports. Both will have check marks beside them as a default. Keep both checked and click “Continue”
- A report will be generated, giving the drainage area and other information associated with the delineated watershed.
- Print the report which is shown below:



Streamstats calculates the drainage area. Please note that the report also generates the impervious surface along with the other data, potentially including the bankfull stages and elevations.

Caution: Do not use the bankfull data unless extremely familiar with the watershed. The data is often outdated (example above is using 2006 impervious surface data as an example

and this watershed has changed significantly since that time.) The watershed or drainage area is, however, an excellent source of data.

11.5.8.2 GIS programs (ArcView as an example)

ArcView, one of the other Arc products, or another GIS based software program is a useful tool in delineating watersheds or drainage areas as well. Some add-on programs are available for ArcView as well, which provide the ability to "point and click" the watershed area much like the example given above. This add on does have a considerable expense associated with it. The method that comes standard with ArcView will involve being familiar with the watershed and delineating the drainage area by digitization.

11.5.8.3 Google Earth Pro

NCDA&CS Department GIS staff has made Google Earth Pro available to all district employees. This has a delineation watershed/drainage area tool available as well, very much like ArcView, where you delineate the watershed utilizing the mouse. Again, it is imperative that reconnaissance of the watershed has been completed. It is always a good idea to drive the watershed and to determine where culverts may lead to, or away from, the drainage area.

11.5.8.4 Planimetering

Using the planimeter can provide accurate results if used carefully. Most districts no longer use this method due to the ease and availability of other methods.

11.6 Erosion Control and Planting Materials, Mattings and blankets

There are many different erosion control materials available that are used for protection of seeding on the steep slopes associated with streambank stabilization and protection projects. Most are categorized by the type and the allowable velocities that they will withstand without erosion taking place beneath the fabric. There are four basic types of materials used: 1) Netting (synthetic or natural), 2) Biodegradable blankets (always made of natural materials), 3) Permanent Blankets (always made of synthetic materials), and 4) Turf Reinforced Matting (TRM, always made of synthetic materials and having three dimensions as opposed to two). The table below shows types of matting or blankets to use for specific needs and purposes:

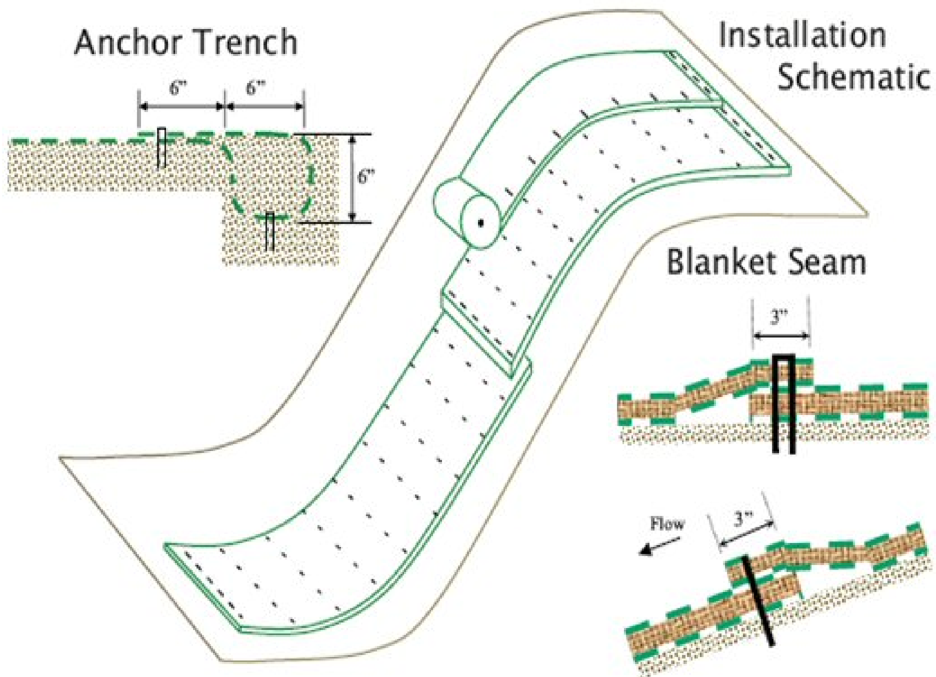
Type of Erosion Control Material*	Main Use and Purpose	Comments
Netting	Synthetic or natural fiber mesh installed over disturbed area to hold organic mulch and/or seed in place	Provides minimal structural erosion resistance. Mulch applied using standard procedures.
Biodegradable Erosion Control Blanket	Natural fiber blanket held together by netting to provide temporary erosion protection on slopes up to 1:1 and channels with permissible shear stress of up to 4 lbs/foot.	Provides one to five-year protection. Metal or wooden staples are used to anchor.
Permanent Erosion Control Blanket	Synthetic blanket material which provides permanent erosion control of slopes up to 1:1; channels with increased water flow velocities and increased sheer stress.	Provides minimal protection against wave action around ponds and lakes. Permanent erosion control blankets extend the limits of vegetation. Metal or wooden staples used as anchors.
Turf Reinforcement Matting	3-dimensional permanent synthetic mat that provides a matrix that greatly reinforce the root system of the desired vegetation for permanent erosion protection in high flow channels and on critical slopes.	Provides a substantial increase in erosion resistance. May provide erosion protection equivalent to stone or concrete liners in some applications.

*** Note: Only coir, or natural fiber materials are allowed in the channel and across the bankfull benches. The upper banks can have synthetic fabrics. Additionally, consult the manufacturer's specifications for the velocities these materials will withstand as they vary within the above-mentioned materials.***

11.6.1 Proper installation of erosion control materials

There is no definitive way with which to lay the material down, either downslope or across slope is acceptable. Generally, the contractor will install the fabric based on how fast and easy it will be to unroll the material and pin it. Usually, on shorter slopes where a bankfull bench has been constructed, the fabric will be installed along the slope, on or nearly on contour. In the foothills or mountains, where long, extensive slopes may be encountered, a contractor may choose to install the chosen fabric up and down the prevailing slope. What is important in laying and pinning the erosion control materials are how they are pinned to the soil, and in which direction they are pinned on the overlaps. The materials must be pinned with the fabric tight against the soil, never with voids and spaces between the material and the soil surface. This prevents runoff and/or channel flows from getting under the matting material and causing rill erosion. Overlaps should be pinned with a minimum 6-inch overlap and with the top layer over the bottom layer facing the downstream direction. On slopes, the overlap should again be a minimum of 6-inches and the top layer overlapping the bottom layer facing the downstream overland flow direction. When making turns with the roll of fabric, use a minimum of at least 6-inches overlap at the point of the turn. Pin the fabric again, as always, with the top of the overlap facing in the downstream and downslope directions.

Stapling the fabric should be done to the manufacturer's specifications. Proper installation is dependent upon how tightly the material lays against the mulch and soil surface.



Proper fabric installation guide for up and down slope

Proper installation for across slope

11.7 Vegetation

Vegetation is obviously a critical component in streambank and shoreline protection systems. Timing is a key issue; grading projects may be completed during a season when proper plant materials are not conducive to being planted. When possible, time the grading work to coincide with the planting of the permanent vegetation. Temporary plantings can and should be utilized as quick covers or as an interim until it is time to plant the permanent vegetation.

Plants native to the region of the project should always be considered. This was generally more difficult to achieve in the not-too-distant past, but as these plant materials have become more popular and widely used, nurseries are beginning to have these available more readily. It is always wise to consult with a nursery operation prior to the project beginning to discuss stocks and costs of available materials. ***Ensure that plant species are non-invasive.***

Note that establishment of the plant material may take some time. Young plants will be subjected to more maintenance and considerations should be given to such potential hazards as a large, intense storm event, domestic livestock or wildlife browsing, and human traffic. Plan accordingly to the highest degree possible to reduce or eliminate threats from these and other sources.

Consideration should also be given to the pollinator species. The vegetative requirement for this practice presents itself with a somewhat unique opportunity to increase wildlife and/or pollinator species habitat, food, and cover requirements. Every consideration should be given to incorporate appropriate vegetation to help increase populations of pollinators. More information on these important species can be found at the link below:

http://www.ncagr.gov/pollinators/index.htm

The following standards are excellent sources of information for vegetative plantings on streambank and shoreline stabilization projects:

https://efotg.sc.egov.usda.gov/references/public/NC/NC342_CriticalArea_04-2014.pdf

Beginning on page 342-12, there are tables and specifications for grasses, legumes, shrubs, and trees, based on physiographic regions of the state, that can (and should) be used when vegetating the streambanks or shorelines. The Table on page 342-18 provides the user with various categories for plant materials including:

- Conservation uses
- Site adaptation
- Physiographic region adaptation
- Growth characteristics (slow, medium, rapid)
- Height characteristics

The conservationist/planner/designer, after discussion with the applicant, can utilize this table to select species that will fit the needs of both the necessary erosion control along with specialty needs of the client. As an example, a client may need, or want, low growing shrubbery along the bank of the stream in the Mountain region of the state. Sections D, E, and F all have shrub species. From those, the user would pick at least "***Conservation Use*"***" categories 1 and 2 (with the possible addition of others), the appropriate "***Adapted for Sites**"*** for the specific conditions on-site, the appropriate physiographic region labeled "***Adapted Area CP, P, Mtns"***, the proper mix of plant growth labeled "***Growth, Rapid, Medium, Slow",*** and the desired height from the column listed as ***"Height"***.

Another good source for determining appropriate plant materials for streambanks and shoreline projects is the USDA PLANTS database, main homepage shown at this link:

https://plants.usda.gov/java/

Look up specific plant materials by genus/species or common name in the search box or query a selective set based upon many different factors including:

- Distribution (down to state and county level)
- Taxonomy
- Ecology (includes native status)
- Legal status (includes wetland indicators)
- Morphology/Physiology (growth factors, flower color, growth habits, etc)
- Growth requirements (soils, drought, fertility, etc)
- Reproduction (fruit/seed, propagation)
- Suitability and Use (lumber, palatability)

This search engine can be found at the following link:

https://plants.usda.gov/adv_search.html

Many other search possibilities are present in the PLANTS database. Take a few minutes to explore the possible scenarios that may be useful for the project.

11.7.1 Vegetation Requirements

Item #3 in the standard for streambank and shoreline protection systems states the vegetative requirements clearly. Verbatim they are:

"***A minimum setback of 20 feet of undisturbed native vegetation or restored riparian area adjacent to the installed practice is mandatory in all situations. Division staff is authorized to approve contracts with a lesser setback for instances where site conditions make a 20-foot setback infeasible, but the Division may not approve a setback that is less than 10 feet".***

While 20 feet is the minimum (other than with the Division approved lesser setbacks), it is suggested to have a 50-foot buffer when performing stabilization on a streambank or shoreline. Ensure that there is not a 50-foot mandatory buffer requirement (or other mandatory requirement) in those watersheds designated for nutrient reductions. Ensure that local government requirements are met as well as some jurisdictions have increased buffer widths associated with streams.

11.8 Bioengineering Vegetative Practices

Bioengineering employs the use of tree branch cuttings and other native plant materials. Often, but not always, bioengineering methods are used in conjunction with "hard" structural practices to control streambank erosion. Bioengineering practices are included in this chapter for those soft erosion control methods as well as for gaining familiarity with a variety practices. ***Note: any hardened structural components to a stream erosion control system will require the use of an engineer and will be considered a stream restoration project.*** Chapter 16 of the Engineering Field Handbook (EFH), beginning on page 16-10, has some good information on vegetation used as bioengineering for streambank projects. This section defines some of the following planting methods in the bioengineering section:

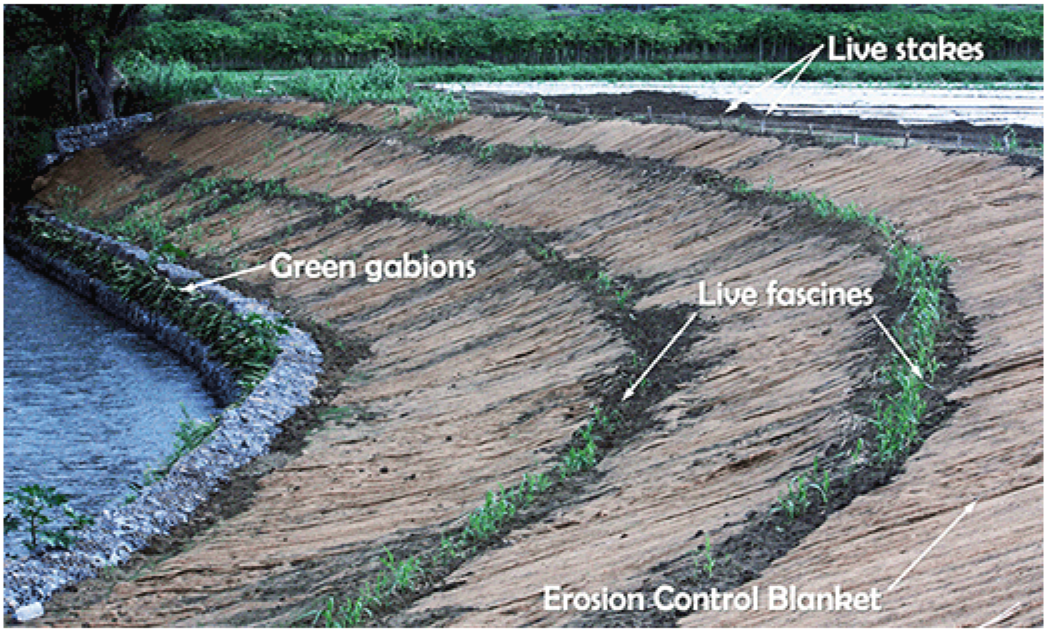
11.8.1 Live Stakes

Live stakes are cuttings from established trees usually in the range from 12" – 36" in length and ½ to 1-1/2 inches in diameter. Most often they are cut at a 45° angle on at least one side (the side to be inserted into the soil surface) and the other side remaining flat. The sharp, 45° angle side is simply plunged into the soil profile 8 to 24 inches or so (24 inches may be a bit long). Approximately 50 – 80% of the stake should be inserted into the ground and the soil sealed around it, usually by stepping around 1 to 4 sides of the newly inserted stake. Sometimes an engineer's hammer (2 to 4 pounds) or a dead blow hammer (filled with sand or shot) is used as a driver. Live stakes can be used, with care, to help tack down erosion control fabrics. Live stakes are generally spaced 1 to 4 stakes per square yard depending on species. Place the buds upward when planting. Black and silky willows, redosier and silky dogwoods, elderberry, arrowwood, ninebark, and alder are common species used for live stakes. Page 16-13 of Chapter 16 of the EFH has more information on live stakes

Installation of live stakes

11.8.2 Live fascines

Fascines are long bundles of cut wood from established trees very much like live stakes but usually longer. Use several pieces that are longer in order to provide a foundation for the smaller pieces that may be used. Pieces are bundled together using twine or even metal wire to keep them in a roll. Typical rolls are 4 to 8 feet long and 6 to 12 inches round. Fascines are commonly placed just below bankfull elevation to keep them moist at planting. They can be planted upslope, generally with less success. Usually a trench is dug (machine or by hand, machine suggested!). The bundle tied with twine or wire is placed in the trench and covered. Stakes, made from short 2x4s can be used to "tie down" the bundles. Matting is sometimes used over the fascine where the soil covers the trench filled with the bundles. The same plant materials used with live stakes are used with fascines. If many are to be made, consider building a set of "sawhorses". The sawhorses are three sets of 2x4s cut approximately 4 feet each, crossed in the center and bolted together to form an X shape. Metal rebar or cut pieces of 2x4s can be used to place the three sets of X-shaped horses together into the length of the fascine to be used. More information on fascines can be found in Chapter 16 of the EFH beginning on page 16-16.



Installation of live fascines. Please ignore the gabions for streambank stabilization practice! These fascines are planted above bankfull elevation and will likely have less success than if they were planted at or below the bankfull elevation

11.8.3 Other Methods

Other methods can be employed utilizing bioengineering to reduce and eliminate streambank erosion. The other methods generally utilize "hard structures" such as rock toe revetments, cribs or gabions, and rip-rap and therefore will not be fully covered in this chapter, but will be mentioned to affirm the distinction between "soft" and "hard" stabilization methods. Soft methods, those that do not use structures as a part of the erosion control, are acceptable under the Streambank and Shoreline Protection BMP whereas the hard structures would be considered Stream Restoration projects.

11.8.3.1 Brushmattress

Brushmatresses generally consist of a combination of live stakes and live fascines coupled with dead/cut brush. The materials are usually placed above stream-flowing conditions and upslope to areas needing stabilization. Often toe revetments consisting of rock are used in conjunction with the mattresses. Pages 16 - 30 through 16-32 in Chapter 16 of the EFH provides additional information.

11.8.3.2 Live Cribwalls

These structures are constructed cribs made of timbers or fencing materials usually, filled with rock, and placed in high velocity flow situations. The cribs are usually placed below natural flow conditions and terminate upslope above the waterline. The upper part of the cribs, and surrounding areas, have live stakes or other cut materials placed near the soil surface. The sprouts from the live cuttings provide vegetation for the lower flow areas where the crib structures provide erosion control on the high-flow regime areas. Pages 16-25 through 16-27 in Chapter 16 of the EFH provides additional information on this system.

11.8.3.3 Branchpacking

Branchpacking can be considered a non-structural BMP if rip-rap or other stone is not used as a toe revetment or as a high-flow stabilizer. As the name implies, live cuttings of branches are placed in a 6 inch to 18-inch layer, backfilled with soil, compacted until just the buds are showing, followed by another layer of brush material that is backfilled until the original slough is covered by the branchpacking. Used on smaller watersheds generally (less than 2,000 acres). Further information in Chapter 16 of the EFH, pages 16 – 19 through 16 – 21.

11.8.3.4 Vegetated Geogrids

Vegetated geogrids are similar to branchpacking except in geogrids each layer of the branchpacking is surrounded by a synthetic or natural geotextile. The toe revetments are often used, same as with the branchpacking. This method is mostly used on smaller watersheds. Additional information on pages 16-22 through 16-24 of Chapter 16 of the EFH.

11.9 Permitting for streambank stabilization protection projects

The streambank stabilization project will likely have a permit associated with it. The length of the area to be graded, the amount of grading per linear foot (and potentially total grading), and other factors will determine what type of permit is needed. Permitting for shoreline projects is discussed later in this chapter.

Remember that if the project falls within a specialty water (nutrient sensitive, trout, etc) or are in a CAMA county, buffer and/or additional permitting may be required. Some local jurisdictions may have their own set of requirements as well. Be sure to check with local county agency partners to ensure special local needs have been addressed. Below is some information regarding state and federal permitting.

Many projects may fall within one of the Nationwide Permits (NWP). As the NWP, 401 and 404, Section 10, and other potential permits change regularly, this section will not attempt to go into detail regarding the needs. One recent example is the newly authorized Regional General Permit (RGP or GPs) that became effective from the Corps of Engineers on January 1, 2017 and the newly updated NWP 13 for Bank Stabilization updated on March 19, 2017. The RGP fall within certain jurisdictional areas. The links below will serve as a guide for the proper permitting authorities.

https://ncdenr.s3.amazonaws.com/s3fs-public/Water%20Quality/Surface%20Water%20Protection/401/401%20Contacts_6-23-17_NonDOT.pdf – NC DEQ Regional Branch offices for 401 permitting

https://deq.nc.gov/about/divisions/water-resources/water-resources-rules/401-certification-express-review-statutes-rules-guides - 401 and Buffer Rules and Statutes

http://www.saw.usace.army.mil/Missions/Regulatory-Permit-Program/Contact/ - US Army Corps of Engineers contacts

http://www.saw.usace.army.mil/Missions/Regulatory-Permit-Program/Permits/2017-Nationwide-Permits/ - Information on Nationwide Permits (NWP)

http://saw-reg.usace.army.mil/NWP2017/2017NWP13.pdf - information on NWP 13, Bank Stabilization http://www.saw.usace.army.mil/Missions/Regulatory-Permit-Program/Permits/Regional-General-Permits/ - information on Regional General Permits (RGP or GPs)

http://www.saw.usace.army.mil/Missions/Regulatory-Permit-Program/Agency-Coordination/Trout.aspx - information regarding trout waters

http://www.saw.usace.army.mil/Missions/Regulatory-Permit-Program/Permits/Exemptions/ - information on exemptions

11.10 Pre-construction meetings, construction methods and inspections

So the design is completed, the permit is obtained, the contractor has been determined, and the owner is ready to begin work. What's the first step? It is always wise to have a pre-construction meeting (PCM) with all participating parties prior to the work beginning. This often saves headaches, and time, during the actual construction. If used wisely, the PCM allows both sides to stress the desired outcomes and allows questions to be asked and answered without the pressures of asking, and having to answer them, on-site while the equipment is rolling. Bring enough copies of plans to share with all involved. If work is to be subcontracted, or even if volunteers will be performing some of the work (such as the vegetation), it is wise to invite the contractor to be a part of the PCM. This not only allows "buy-in" on the project, but it also lets the entire group see the entire picture of the entire project. Subcontractors or volunteers will gain insight into how the project is to be implemented, and they will gain understanding as to when their services will be needed in the process.

11.10.1 Construction equipment

There is a multitude of equipment that may be used on a specific project. Trackhoes and skid steer loaders are perhaps the most commonly used pieces of construction equipment used on streambank stabilization projects. It is worth taking a few minutes to understand the capacities of this equipment, some of the terminology used for this piece of equipment, and functions of this machinery. Examples of equipment used in excavation include a skid steer, a backhoe, a trackhoe, a wheeled excavator, loader, or bulldozer. The front-end loader's bucket capacities are obviously larger than other types of equipment and therefore can move more earth per load. The versatility of the different types of excavators surpasses the front-end loader. Both pieces of equipment become much more functional with "attachments", such as a "4-in-1" blade on a front-end loader and a "thumb" on an excavator.

Even large-scale jobs such as the one shown above can potentially be

streambank stabilization and not restoration projects

Each type of equipment has different bucket volume, lifting capacity, digging force and breakout force. These specifications make some equipment more versatile on a streambank stabilization than others.

Bucket capacity – is simply the volume that the bucket can hold and is a function of the width, length, and depth of the bucket. Most specifications on excavators and front-end loader bucket models measure the volume only. Some manufacturers also give the rated capacity for the filled and heaped buckets. Some contractors use this measure to help with quantity calculation on jobs paid by the yard. Most excavating equipment, large and small, can accommodate both large and small buckets. Large buckets are used when moving large amounts of material, small buckets may be used for detail work such as digging narrow trenches. Front-end loaders can obviously move more earth per bucket than a backhoe or trackhoe, but would have more limited reach capabilities.

Narrow bucket, small capacity for detail work. Larger bucket for moving larger quantities of soil.

Digging depth – the digging depth is the distance that the boom and bucket can reach or in the case of the front-end loader, the bucket alone. Many manufacturers make boom extensions on excavator to increase the length of the digging depth. This varies significantly by the size of the excavator and the effective length of the boom. As the digging depth increases, there will be an inverse relationship to the lift force and digging force the machine will be able to perform (without additional factors such as counterweights put on the machine).

Digging force – (also known as bucket cylinder force or bucket curling force) is the capacity rating in foot-pounds (often simply in pounds) that the bucket can penetrate the earth, curl its bucket, and pull out the excavated material. It is a function of the bucket volume, the hydraulics of the pistons in both the arms (boom and stick on backhoes) and the bucket, the construction of the bucket, and other pertinent parameters. This is important in the ability of the machine to pull out stumps, rock, earth, and other materials. This capacity varies dependent upon the size of the machine, the horsepower rating, the boom and stick lengths and hydraulic weights, and other similar factors.

Lift capacity – indicates the excavator's ability to safely hoist items, as a crane would. It is limited by the hydraulic capacity and the tipping capacity of the machine and is generally specified in the machine's operation and maintenance manual. With stream restoration work, it is not uncommon for a contractor to rely on the equipment's lift forces to install (or remove) root wads.

Breakout weight – is the capacity of the equipment to lift when utilizing all aspects of the machine's hydraulic systems vertically, including the "curl" function of the bucket. It would be the highest rated capacity of all the functions of the equipment. Using the breakout capacity, the equipment can remove stumps or other embedded materials.

The front-end loader's bucket capacities are obviously larger than the backhoe and therefore can move more earth per load. The versatility of the backhoe surpasses the front-end loader. Both pieces of equipment become much more functional with "attachments". A "4-in-1" blade on a front-end loader and a "thumb" on a backhoe greatly improve the ability of the equipment to grab materials such as rock and trees more efficiently and effectively. While other machinery is often used in streambank projects, these will not be discussed in detail in this chapter.

Backhoe bucket with thumb

Front-end loader with 4-in-1 bucket

11.10.2 Grading work

It is possible to complete an entire streambank stabilization project with just an excavator, whether it be a backhoe or track hoe, and a good operator, particularly if there is no waste associated with the cut and fill of a project. A backhoe can excavate the bankfull bench to the proper dimensions, prepare the ground for vegetation, potentially cut the trenches for the fascines and/or fabric, and help move materials for installing the fabric.

Chart providing some comparisons on the various forces for backhoes and front-end loaders. Consult the specific equipment for specific force load capabilities of the equipment to be used.

Equipment	Bucket Capacity	Digging Force	Digging Depth	Lift Force	Breakout Force
Small Skid Steer	N/A	4,340 foot-pounds	7 ft 4 inches	1023 lbs	4,684 lbs
Medium Skid Steer	N/A	6,966 foot-pounds	11 ft 3 inches	2,866 lbs	8,267 lbs
Large Skid Steer	N/A	8,600 foot-pounds	13 ft 9 inches	4,999 lbs	
Small Rubber Tire Backhoe	N/A	N/A	9 ft 7 inches	930 lbs	3,490 lbs
Medium Rubber Tire Backhoe	N/A	N/A	12 ft 6 inches	3,360 lbs	6,227 lbs
Large Rubber Tire Backhoe	N/A	N/A	14 ft 4 inches	6,560 lbs	9,190 lbs
Small Excavator	0.66 cu yds	20,751 lbs	19 ft 11 inches	5,766 lbs	12,823 lbs
Medium Excavator	0.72 cu yds	22,697 lbs	21 feet 4 inches	9,094 lbs	17,243 lbs
Large Excavator	4.06 cu yds	43,637 lbs	31 feet 9 inches	27,720 lbs	36,825 lbs
Small Rubber Tire Loader	1.3 cu yds	14,712 lbs	N/A	6,384 lbs	10,139 lbs
Medium Rubber Tire Loader	1.3 cu yds	N/A	N/A	6610 lbs	10,270 lbs
Large Rubber Tire Loader	1.8 cu yds	17,746 lbs	N/A	7,871 lbs	11,375 lbs
Small Track Loader	1.0 cu yd		N/A	8,895 lbs	10,700 lbs
Medium Track Loader	1.8 cu yds		N/A	18,867 lbs	15,710 lbs
Large Track Loader	3.7 cu yds		N/A	44,649 lbs	47,992 lbs

* For comparison, a southern red oak tree with the following dimensions weighs:

No stump, 8 inch dbh, 20 feet long = 318 lbs
No stump, 12 inch dbh, 20 feet long = 639 lbs
No stump, 18 inch dbh, 20 feet long = 2,011 lbs
Stump equation: $1.6402 * D^{2.199} H^{.406}$ (D = diameter in inches H = height in feet)
Southern red oak 8 inch stump = 535 lbs
Southern red oak 12 inch stump = 1,307 lbs
Southern red oak 18 inch stump = 3,188 lbs

Preparing the Site for Construction:

Staking the bankfull bench and the end of slopes where they tie to existing ground will allow a seasoned operator to outline work to be performed. Waste areas should be identified at the time of planning and designing, not when the construction has begun. Should significant waste be anticipated, consider the shortest distance with the best utilization of the waste material. Most projects should begin the grading work at the outlet, or downstream portion of the project. This will allow the slopes to be more easily graded and tied in with the existing ground, particularly at upstream end of the stabilized reach. Survey and mark off the bench width at sections where there is a change in the bankfull width, or at the points where there is a change in the existing channel widths. Providing stakes at the top of slope will also be helpful in ensuring the project is constructed according to plan

Be prepared to vegetate immediately following the grading work. Should construction occur during a time of year when planting is not optimal, use temporary seeding until permanent plantings can be installed. As part of the construction oversight of the project, plan to make frequent stops at the project, at least daily during grading and vegetation work. Perform necessary survey checks at critical times during the construction and adjust accordingly. Document the changes to the originally designed plans on the "As-Builts" and in the appropriate field books, worksheets, and other items. The contractor is responsible for determining the means and methods of constructing the project in such a way to meet the plans and specifications of the project. It is appropriate to observe and document when these methods do not result in an adherence to the plans and specifications within the specified time frame.

11.11 Shoreline Protection:

Use of Shoreline Protections is limited for the CCAP program due to the addition of the Marsh Sill BMP for coastal areas. This method encourages a living shoreline for erosion control along the coast. In isolated cases, CCAP funds can be used for shoreline protection along large ponds and lakes. If hard structures are necessary for shoreline protection, those contracts will need approval by a Division engineer and in most cases a Professional Engineer's seal. When using outside engineering sources, always remember that a Division engineer must ensure that the design meets the standards and specifications. It should be noted to the engineer designing the structure that this is NOT a peer review of the design, but an assurance that the design meets Division standards and specifications. This is a significant, and noteworthy difference.

Shoreline protection methods shall NOT be employed along the coastline or other areas where constant wave action will be realized. All revetments, bulkheads or groins are to be no higher than 3 feet (1 meter) above mean high tide, or mean high water in non-tidal areas. Structural shoreline protective treatments shall be keyed to a depth to prevent scour during low water. For the design of structural treatments, the site characteristics below the waterline shall be evaluated for a minimum of 50 feet (15 meters) horizontal distance from the shoreline measured at the design water surface. The height of the protection shall be based on the design water surface plus the computed wave height and freeboard. The design water surface in tidal areas shall be mean high tide. When vegetation is selected as the protective treatment, a temporary breakwater shall be used during establishment when wave run up would damage the vegetation.

Many times, there is existing vegetation along existing shorelines that can be utilized to reduce or eliminate the shoreline erosion. If the existing vegetation is being managed and cut to nominal lengths and at regular intervals, one approach may be to simply eliminate or significantly reduce any mowing or other high-impact maintenance that is taking place thus allowing the existing vegetation to grow. Similarly, some nominal plantings, coupled with reduced maintenance may be used to solve the erosion issue. An examination of the type and densities of the existing vegetation will help in determining if this method can be utilized. If significant rill erosion is present, or if a monoculture of lawn-variety plant materials with a shallow root system are present, this method will likely not succeed. Where native plants, particularly shrub or tree species and/or native grasses with deep root systems are present, this method may be successfully employed.

11.10.1 Permitting for shoreline protection projects

It almost all cases any manipulation of the shoreline will require a Coastal Area Management Act (CAMA) permit from the NC Division of Coastal Management. NC DCM encourages the use of "living shoreline" revetments and other natural alternatives that the local districts employ to reduce shoreline erosion while recognizing that groins, bulkheads, and other hardened structures may be a necessary part of the design. These "structures" can also many times utilize natural methods, such as oysters and stone, as efficient and effective alternatives to man-made materials. Utilization of such materials can often lead to increased habitat for native species. ***A permit must be obtained prior to any installation work beginning on shoreline protection projects.*** Information on obtaining the permit can be found below. Guidance on the permitting process can be found by contacting local Division of Coastal Management permitting officer.

https://deq.nc.gov/about/divisions/coastal-management/coastal-management-permit-guidance/permit-required - CAMA permit information

https://deq.nc.gov/about/divisions/coastal-management/coastal-management-permits/local-coastal-permit-officers - NC Division of Coastal Management (NC DCM) permitting officers

https://deq.nc.gov/about/divisions/coastal-management/coastal-management-permits - CAMA permits

Important Note: for shoreline protection projects only (not streambank protection (stabilization) projects, the use of revetments, bulkheads, or groins can be utilized provided they are accepted as a design alternative by the permitting agency.

11.8.2 Information sources for shoreline protection systems

There are some excellent sources for additional information on shoreline protection methods. Review these methods prior to planning any shoreline protection project. In particular, review the Living Shoreline Academy website. This free site, developed by a consortium of organizations interested in coastal habitat restoration, guides the planner through a series of training modules on designing these systems. Please see the links below for more information on this subject.

https://deq.nc.gov/about/divisions/coastal-management/coastal-management-estuarine-shorelines/stabilization - link to several websites containing more information on shoreline protection systems

https://www.livingshorelinesacademy.org/ - an online class developed specifically for designing living shoreline projects

EFH Chapter 16, Section 16.1602, pages 16-63 to 16-81 – NRCS Engineering Field Handbook

11.9 Operations and Maintenance

As with all practices, operations and maintenance (O&M) of streambank and shoreline protection systems is important. As this practice is installed in dynamic stream systems in some cases on large watersheds, O&M is crucial to this practice.

It is highly recommended to go to the newly completed site immediately after the first significant storm event. Having performed due diligence on the grading, vegetation, and matting, an overview of the work should show minimal to no damage or erosion present. Check the upper reaches of the fabric/matting for any signs of rills resulting from overland flow. Any rills, or other eroded areas, should be patched with the appropriate fill material, re-mulched and re-vegetated. If it is not the appropriate seeding season, plant a temporary mix and ensure permanent vegetation is re-planted as necessary during the appropriate season. Inspect the matting installation from the toe up to the "high water" marks to ensure that no erosion is occurring beneath the matting. All pins should be in place and the fabric should still be secured and making full contact with the ground surface. Any areas where the fabric/matting is found to have been compromised, or where it is found to be loose, should be re-pinned to where the erosion control material is firmly secured and making contact with the soil surface. If live stakes have been used, ensure that any high water, and the wrack line associated with it, did not pull the stakes up or cover them completely. Revegetate as necessary with permanent vegetation (if in season) or with a temporary until the planting season comes. Should any erosion be encountered during this initial visit, every effort should be made to immediately correct the minor issues found so that they do not become more serious. Periodic checks should be made until the vegetation gets well established, particularly after significant rain events. Small patch work is obviously easier and less costly to perform than repairing significant sections of work due lack of maintenance. For the first two years after construction is completed, visit the site seasonally or after large events. Once the vegetation is established and healthy, the concerns for maintenance lessen.

Shoreline O&M follows the streambank maintenance guide as described above with two additional important notes. The area between the normal and high wave action elevations should be checked for a secure placement of the fabric and/or matting materials. This same area should be checked for success of the planted/propagated plant materials as well.

The spring following the plantings, another visit should be made to check on the viability and success of the plantings. It is not uncommon to have some plant material that doesn't adapt to the changes and does not sprout. Propagation rates should be at least 50% and upwards of 80% would indicate good success. Take the time to get a solid count of the percentage of live material sprouting. Any "holes" in the planting pattern or areas that did not sprout should be considered for replanting. A temporary mixture may have to be planted until the following fall, dependent upon plant viability and planting dates. Ensure successful follow up with a written appraisal and note to the landowner/applicant. Complete, or nearly complete failures of plantings are uncommon, but do occur. These usually occur with improper planting dates, the wrong types of materials, or uncommon weather conditions. A temporary planting will be necessary in these cases, and efforts should be made to find plant materials that could be planted and survive in the spring and through the summer.   Plan to pre-order potentially limited plant materials for the upcoming fall planting season.

Any revegetation that may need to occur could present another opportunity to plant materials to encourage pollinator species, either as temporary or permanent materials. All considerations should be given to promote not only the erosion control aspects of this practice, but the ability to increase wildlife habitats.