Natural Channel Design
REVIEW CHECKLIST

StreamMechanics

EPA 843-K-12-006

Prepared by

STREAM MECHANICS, PLLC

William A. Harman, PG

US FISH AND WILDLIFE SERVICE

Richard R. Starr

APPROPRIATE CITATION:
Harman, W., R. Starr. 2011. Natural Channel Design Review Checklist. US Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD and US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division. Washington, D.C. EPA 843-B-12-005

Funding for the Natural Channel Design Review Checklist was provided by the US Environmental Protection Agency and the US Fish and Wildlife Service.

Bull Trout Photo Credit: *Joel Sartore-National Geographic Stock with Wade Fredenberg.*

Table of Contents

List of Figures & Tables

List of Appendices

Introduction

Stream Mechanics and the US Fish and Wildlife Service — Chesapeake Bay Field Office (Service) have produced a Version 2 of The Natural Channel Design Review Checklist. The Checklist and supporting document was funded through a cooperative agreement between the Environmental Protection Agency — Wetlands Division (EPA) and the Service. Version 2 of the Checklist represents additions and modifications to existing questions, as well as updates to the supporting text and appendices. These changes are based on feedback from a pilot workshop with select EPA and US Army Corps of Engineers staff, as well as evaluations from subsequent workshops with a variety of participants.

The Checklist is provided in Appendix A and provides guidance on important items to consider when reviewing natural channel designs. Natural channel design is defined as the application of fluvial geomorphology to create stable channels that do not aggrade or degrade over time and that maximize stream functions given site constraints (Figure 1). The Checklist is intended to provide the reviewer with a rapid method for determining whether a project design contains an appropriate level of information. And while the Checklist is structured around the natural channel design methodology, it could be used to evaluate designs using other approaches. Ultimately, the Checklist provides a method for identifying major design shortcomings; however, no review can ensure project success. The final responsibility for a successful project lies with the project owner, designer and contractor.

FIGURE 1: MICKEY REACH, TRIBUTARY OF THE MITCHELL RIVER

Source: Michael Baker Corporation; Photo by Will Harman

The Checklist only includes questions relating to assessment and design tasks. Therefore, other restoration tasks such as permitting, flood studies, construction methods and other items are **not** included in the Checklist. This Checklist does not include sections for additional design deliverables because they do not affect the technical review process. As other deliverables are provided, the reviewer must still determine if the design is within the design criteria and has a high potential to succeed.

Below is a list of other items that should be considered when using the Checklist:

- It is highly recommended that the reviewer conduct a site visit to determine if the assessment and design accurately document what is observed at the site. The reviewer should also look for additional constraints (as well as restoration opportunities) that might have been left out of the report.
- If a reference reach was surveyed, the reviewer should visit the reference reach (if possible) to determine if the reference reach is stable and appropriate for a natural channel design project.

- It is important to note that designers may not always complete every item listed in this Checklist. That is acceptable, especially for experienced designers. If the designer is submitting the Checklist as a permit requirement, they should simply state why they did not need to address that issue.

CHECKLIST STRUCTURE

There are four columns for most questions, which include Submitted, Acceptable, Page Number and Comments. The reviewer answers "yes" or "no" for Submitted and Acceptable and provides a reason/explanation for Comments. A column is also provided to cite the page number where the information is discussed in the report. This format is straightforward for some questions, like "1.1a — Was the watershed assessment methodology described?" Under the Submitted column, the reviewer would respond with "yes" if the designer submitted a description of the watershed methodology. If the description was inadequate, the reviewer would respond with "no" under the Acceptable column and then describe why under Comments.

Other questions are not as straightforward in terms of fitting the Checklist structure. For example, under Section 3.3 In-Stream Structures, question 3.3d asks, "Will the in-stream structures provide the intended stability?" For these questions that seem to warrant a direct answer, the reviewer should still follow the two-step process: (1) Asking if the designer *Submitted* information that answers this question, even if it is more implicit in the report than explicit; (2) The reviewer can decide if the information is *Acceptable* and *Comment* on their reason.

Finally, there are places in the Checklist where the reviewer can provide overall comments and impressions about the assessment and design. These sections do not require a "yes" or "no" for Submitted or Acceptable.

This document follows the order of the Checklist (Appendix A) and includes the following sections: Watershed and Geomorphic Assessment, Preliminary Design, Final Design, Maintenance and Monitoring Plans, and Overall Design Review. Since the Checklist is primarily for natural channel designs, the Rosgen stream classification system and his Priority Levels of Restoring Incised Channels are referenced throughout the text. Therefore, the classification key and a description of the priority levels of restoration are provided in Appendix B. Reviewers who are not familiar with the classification key or the priority levels may want to read this appendix before using the Checklist.

1.0 Watershed and Geomorphic Assessment

Section 1 provides questions about the watershed and geomorphic assessment. The watershed assessment questions are designed to determine if basic information was collected to make existing and future hydrology calculations based on land use changes in the watershed. These questions are not intended to evaluate a comprehensive watershed management plan to assess overall water quality. The geomorphic questions pertain to the project reach and address issues with developing the basemap, geomorphic assessment (vertical and lateral stability), hydraulic assessment and bankfull verification. These questions provide critical information that is needed to complete the design.

1.1 » WATERSHED ASSESSMENT

1.1a Was the watershed assessment methodology described?

If a watershed assessment was completed, it is important that the methods used to complete the assessment are described. Watershed assessments range from simple office-based data collection using geographic information systems (GIS) to intensive field data-collection efforts. Data collection, data sources and methods used to analyze the data should be described.

1.1b Was the project drainage area provided?

This is an important question because many of the hydrologic, hydraulic and geomorphic relationships are expressed as functions of drainage area. For example, regional hydraulic geometry curves (regional curves) are log-log plots comparing channel dimensions (i.e., bankfull width, mean depth and cross-sectional area) versus drainage area. It is impossible to review this and other design elements without knowing the drainage area. Drainage area is typically provided in square miles for natural channel designs.

1.1c Was the percent impervious cover for the watershed provided?

The percent impervious cover is used to determine if the project reach is located in an urban or rural watershed. Urban and rural watersheds have different hydrologic characteristics, and these differences must be considered by the designer. This is particularly critical if the designer proposes a change (increase) in bankfull discharge from the pre-restoration to design condition. Typically, watersheds with impervious cover greater than 15% are considered urban.

1.1d Was the current land use described along with future conditions?

A watershed with rapidly changing land uses is one of the most challenging settings for a stream restoration project because the design will need to accommodate future conditions. If a watershed is currently rural, but is becoming urban, the design must take these changes into account. Therefore, it is important to know the current land use and the future build-out potential. This question provides the reviewer with a sense of how risky the project may be, i.e., a project in a watershed where impervious coverage is rapidly increasing is more risky than a rural, stable watershed.

1.1e Were watershed hydrology calculations performed?

The watershed assessment task often includes hydrologic calculations to estimate the 2-, 5-, 10-, 25-, 50- and 100-year discharges. These calculations are used to quantify channel hydraulics (Section 1.3) and to complete a flood study, if one is required. If the Federal Emergency Management Agency (FEMA) or the local floodplain manager does not require a flood study, complex watershed hydrologic calculations may not be necessary, especially if the watershed has a gage station or is predominantly forested. In these cases, discharges may be obtained directly from gage records or estimated from US Geologic Service (USGS) regression equations, regional curves, or Manning's equation and cross-section geometry from the project channel. Manning's equation and n values are provided in Appendix C.

Extensive hydrologic estimates may not be necessary if the project reach has access to a wide floodplain. In this case, flows greater than the bankfull discharge will spread out over the floodplain, and the increase in depth, shear stress and velocity will be minimal. However, if a project reach is located in a confined valley, flow estimates for the 2- through 100-year event should be quantified. Channel stability under these flow conditions are evaluated during the hydraulic and geomorphic design process.

1.2 » BASEMAPPING

1.2a Does the project include basemapping?

It is critical that the project include adequate basemapping. The basemap is a topographic map, usually with 1-foot contour lines, that also includes the existing channel alignment, utilities, large trees, roads, property boundaries and other constraints or important features. Typically, basemaps are produced using a Total Station instrument that calculates survey points in x, y and z coordinates. This data set is imported into a software program that analyzes the coordinate geometry (COGO). From there, the data set is imported into Computer Aided Design (CAD) software, where the basemap is developed and used for the design. For complex projects, especially urban projects, the basemap should be tied to "real world" coordinates, i.e., state plane system. A USGS 1:24,000 quadrangle or aerial photograph is not a sufficient basemap for design purposes, especially for projects that include new channel alignments and utility relocations. The basemap may also be used to record stability and geomorphic assessment results, i.e., location of eroding streambanks, headcuts and cross sections.

Some design projects were identified as the result of previous, more comprehensive watershed assessment studies. Geomorphic assessments, completed as part of a watershed assessment, often use existing aerial photographs and topographic maps as a basemap for recording stability problems. This is a useful technique for the assessment and for developing concept designs, but should not be used as the basemap for the final design that will be used by contractors to build the project.

1.3 » HYDRAULIC ASSESSMENT

1.3a Was a hydraulic assessment completed?

Most stream restoration projects will include some type of hydraulic assessment. The level of assessment will vary based on the complexity of the project. For example, urban projects in FEMA-regulated floodplains will have more complex assessments than simple bank stabilization projects in rural environments. Copeland et al. (2001) provides a detailed overview of hydraulic design methods for stream restoration projects.

1.3b Was stream velocity, shear stress and stream power shown in relation to stage and discharge?

The design report should include a discussion about flow dynamics. The primary purpose is to determine the erosive power of channel and flood flows. This is often shown through plots of stream velocity, shear stress and/or stream power versus stage or discharge. Flow dynamics should, at a minimum, be assessed for the bankfull discharge plus flood flows. Projects that include fish passage or other low-flow velocity requirements will require base-flow assessments.

1.4 » BANKFULL VERIFICATION

It is important for the design document to describe the methods used for determining the bankfull stage and discharge. This should include a description of field methods and geomorphic indicators used to identify the bankfull stage and methods used to determine the bankfull discharge, such as regional curves, Manning's equation or HEC HMS/HEC-RAS. Harman (2000) provides guidelines for identifying the bankfull stage using geomorphic indicators and regional curves.

1.4a Were bankfull verification analyses completed?

The identification and verification of bankfull stage and discharge is one of the most important components of a natural channel design. The bankfull stage is the elevation of the water surface during a bankfull flow (Figure 2). This stage is often identified in the field by a geomorphic indicator, such as the top of the bank, slope break, highest part of a point bar or a scour line. The bankfull discharge is the flow that fills the active channel and represents the breakpoint between channel-forming processes and floodplain processes. It is assumed for most projects that the bankfull discharge equals the effective discharge, which is the flow that transports the most sediment over a long period of time. For natural channel designs, bankfull or effective discharge is used as the design discharge. It is important that channels not be sized to carry flows greater than bankfull because this may result in channel erosion and/or bed aggradation of sediment.

FIGURE 2: SOUTH FORK MITCHELL RIVER, STREAM RESTORATION PROJECT DURING A BANKFULL EVENT

Photo by Will Harman

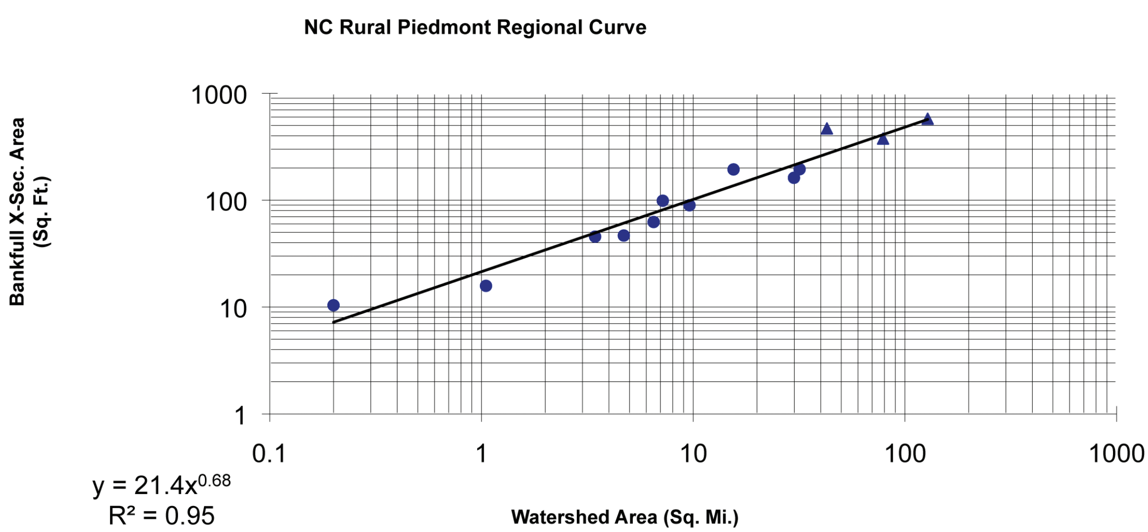
1.4b Were USGS gages or regional curves used to validate bankfull discharge and area?

The return interval for the bankfull discharge is typically between 1 and 2 years (Leopold et al., 1992). This has been verified through the development of regional curves throughout the United States. These curves plot the bankfull discharge, cross-sectional area, width and mean depth versus drainage area. The data for regional curves come from field surveys at USGS gage stations, where the geomorphic indicator is correlated with the gage plate and discharge. This information, along with a flood frequency analysis, is used to determine the return interval. McCandless and Everett (2002) provide a detailed overview of the methods for creating regional curves. It is critically important that the bankfull discharge and return interval come from the geomorphic indicator of the bankfull stage. Some regional curves have been developed by calculating the bankfull discharge based on a 1.5-year return interval. The 1.5-year interval is the average return interval for bankfull, but does not necessarily correlate with the geomorphic indicator of bankfull.

Poor techniques for determining the bankfull discharge and dimensions are common in natural channel designs. In addition to using regional curves based only on the 1.5-year discharge, some designs simply use the 2-year discharge from hydrology models, such as TR-55, to estimate the bankfull discharge. Bankfull discharge rarely, if ever, has a recurrence interval greater than 2 years. This approach often results in an overly large channel with excess shear stress and stream power.

If regional curves are available, the design report should show how the design bankfull dimension and discharge compares to the curve, along with a description of how these values were determined. If a regional curve is not available, a gage station can be used as a guide to determining the return interval for bankfull (using field indicators at the gage). A gage can also be used to back-calculate Manning's "n" for estimating velocity and then discharge at the project site. An example of a regional curve is shown in Figure 3. Appendix C provides a list of regional curves developed by Somerville (2010) for various regions throughout the United States.

FIGURE 3: NC PIEDMONT REGIONAL CURVE FROM HARMAN ET AL., 1999



1.4c If a regional curve was used, were the curve data representative of the project reach data?

The curves are limited to the hydrophysiographic region represented by the data. In other words, a project site in the arid West cannot use a regional curve developed from data in the humid Southeast. In addition, since bankfull discharge is produced from rainfall/runoff relationships, a curve developed from rural data may not be applicable in an urban environment. It is important to verify that the regional curve applied to a specific project is representative of the site data.

1.4d If gages or regional curves were not available, were other methods, such as hydrology and hydraulic models, used?

Some regions of the US do not have regional curves, or the designer chose to design the riffle dimension using other methods, like hydrology and hydraulic models. If the designer chose to use a different method, but a regional curve is available, the reviewer should compare the design riffle dimension and discharge with the regional curve. If there are significant differences between the curve and modeling results, a justification should be provided by the designer. If curves are not available, the designer should show the return interval of the discharge that completely fills the channel. The return interval should be less than 2.0 and preferably closer to 1.5 or less if supported by sediment transport analyses.

1.5 » PROJECT REACH GEOMORPHIC ASSESSMENT

1.5a Was the geomorphic assessment methodology described?

Most stream restoration projects address problems with vertical stability, lateral stability or both. These are identified in the geomorphic assessment. For the purpose of completing the Review Checklist, the geomorphic assessment pertains to the project reach only and not the entire watershed. The design document should include a geomorphic assessment, and the methods and techniques used to complete the assessment should be described or at least referenced.

1.5b Were vertical and lateral stability analyses completed?

This is a critical element of the geomorphic assessment. Some form of vertical and lateral stability assessment should be performed and the methods used described. Vertical instability is a more difficult problem to solve than lateral instability and may require additional assessments and analysis to determine cause-and-effect relationships. Vertical assessment methods may include floodplain connectivity assessments, sediment transport analyses and visual observations like locating headcuts. An example of a headcut is shown in Figure 4. Headcuts dramatically lower the bed elevation, creating an incised channel. Lateral stability assessments typically include measuring streambank erosion potential or measuring actual erosion rates. An example of an eroding streambank that is threatening a road is shown in Figure 5.

FIGURE 4: VERTICAL INSTABILITY — A HEADCUT THAT IS MIGRATING UP AN EPHEMERAL CHANNEL.

Photo by Will Harman

FIGURE 5: LATERAL INSTABILITY/STREAMBANK EROSION THAT IS THREATENING A ROAD.

Photo by Will Harman

1.5c Was it shown whether the instability was localized or system-wide?

It is important to know if the stream is unstable, whether the instability is localized or system-wide and the cause of instability (i.e., cause-and-effect relationship). An example of localized instability is an eroding streambank beneath a power line where the vegetation has been removed from the streambank, likely along the outside of a bend. An example of system-wide instability is a headcut that is migrating up the channel as a result of past channelization and the subsequent increase in slope. Both of these examples are related to direct modifications to the stream; however, land use changes in the watershed can also indirectly system-wide instability. For example, an increase in impervious surface and stormwater outfalls increases peak discharge. The effect can be channel enlargement through bank erosion, bed erosion or both.

1.5d Was the cause-and-effect relationship of the instability identified?

It is important that the design report makes a connection between the results of the geomorphic assessment and the cause of those results. For example, if the stream is incised or actively degrading, what is the cause of the vertical instability? It could be caused by channelization, an increase in runoff or both. Streambank erosion could be caused by cattle access to the channel, high/steep streambanks devoid of vegetation and many more causes. Identifying the cause-and-effect relationship for the channel instability will help determine the restoration potential.

1.5e Was the channel evolution predicted?

Part of the channel stability assessment should include a discussion of channel evolution. It is critical to know if the stream is trending towards increased stability or further instability. This helps to determine the level of restoration needed (restoration potential). For example, a simple land management change may be all that is required (i.e., fencing cows out of a stream), or the channel geometry may need to be reconstructed because the pattern is rapidly adjusting or the stream is severely incised. The Simon Channel Svolution Model and channel evolution by stream type are provided in Appendix D. For additional information on the Simon Channel Evolution Model (CEM), refer to Chapter 7 in *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG, 1998). In addition, Appendix D includes 12 stream type successions by Rosgen, which is provided in his Level III workshop. Nine stream type successions are shown in Rosgen (2006a) with project examples of several scenarios. The stream type changes include a wider range of scenarios than the CEM and may be more useful for determining restoration potential.

1.5f Were constraints identified that would inhibit restoration?

Most projects have some constraints that prevent full restoration. Examples of constraints that prevent restoration of channel pattern include underground utilities, roads and adjacent cropland/pastureland. Vertical adjustments are often constrained by flooding concerns and culvert/bridge crossings.

1.5g Should this stream reach be a restoration project?

The design report should include a section that pulls all of the geomorphic assessment data together to determine overall stability and trend. The trend is based on the channel evolution analysis in combination with the geomorphic assessment results. This information is then compared to the project constraints to determine restoration potential, which is the highest level of restoration that can be achieved for the project reach, given the level of instability, the evolutionary trend and the constraints.

1.5h Overall Geomorphic Assessment Comments

This section of the Checklist provides the reviewer with a place to put his/her overall comments about the quality of the geomorphic assessment and whether or not the information provided is sufficient to determine baseline conditions and restoration potential.

2.0 Preliminary Design

Once the geomorphic and hydraulic analyses have been completed, the results can be used to create project-specific design goals and restoration potential. From there, the design criteria and a conceptual design can be developed. This information should generally be completed and presented to the stakeholders before proceeding to final design.

2.1 » GOALS AND RESTORATION POTENTIAL

2.1a Does the project have clear goals and objectives?

Every stream restoration project, large or small, should have clearly stated goals and objectives. The goals should answer the question, "What is the purpose of this project?" Goals may be as specific as stabilizing an eroding streambank that is threatening a road, or as broad as improving stream functions to match reference reach conditions. It is common to see a goal that reads, "The purpose of this project is to restore channel dimension, pattern and profile." The problem with this goal is that it fails to state *why* there is a need to change the channel geometry. The goal should address a problem, which could be a stability issue, a functional issue or both. Examples of goals based on improving stream functions are provided in Appendix E. The Stream Functions Pyramid is also provided in Appendix E as an aid in developing goals and objectives.

The question about project goals and objectives is provided after the geomorphic and hydraulic assessment because this information is needed to determine functional improvement (lift). In other words, once the stability problem and/or functional impairment are understood, clear goals and objectives can be articulated. This will lead to designs that focus on solving a functional problem rather than simply addressing dimension, pattern and profile. It will also help the reviewer understand why the project is being proposed.

2.1b Was the restoration potential based on the assessment data provided?

Based on the watershed, hydraulic and geomorphic assessment results, the restoration potential should be provided. The restoration potential should state the highest level of restoration attainable given the site constraints. For example, if a stream has been channelized and relocated to the edge of the valley to increase agricultural production, but the landowner is willing to take the land out of production, the restoration potential may be to reconstruct a meandering channel through the original floodplain. The entire floodplain may be converted into a bottomland hardwood forest with riparian wetlands. If the landowner is not willing to take the land out of production, the restoration potential may be to create a non-meandering step-pool channel without making major adjustments to pattern. In this case, a narrower buffer would be established.

2.1c Was a restoration strategy developed and explained based on the restoration potential?

The restoration strategy explains how the goals and objectives are going to be achieved based on the restoration potential. For incised channels, the Rosgen Priority Levels of Restoring Incised Channels (Appendix B) is a common restoration strategy. The priority level is based on the restoration potential. The strategy may then be more specific to address function-based goals and objectives, i.e., bed form diversity and complexity to support a certain species of interest, or a higher sinuosity (lower slope and velocity) to encourage denitrification and development of riparian wetlands.

2.2 » DESIGN CRITERIA

2.2a Were design criteria provided and explained?

The development of design criteria is one of the most important tasks in a natural channel design. Design criteria provide the numerical guidelines for designing channel dimension, pattern and profile. These criteria can come from a number of sources; however, the most common method for the natural channel design approach is from reference reach surveys (Rosgen, 1998). If possible, reference reach survey results (ratios) should be compared to other methods, including analytical models (Copeland et al., 2001), regime equations (Hey, 2006) and results from project monitoring and evaluation. Lessons learned from past project evaluations should play a major role in making final design criteria decisions. Examples of design criteria, including reference reach ratios, are provided in Appendix F, along with a list of parameters that should be measured from the plan sheets as part of the design review.

2.2b Were multiple methods used to prepare design criteria?

For complex projects, it is best if multiple methods are used to develop a final set of design criteria. Ultimately, professional judgment is required to select the final criteria, which is why design experience is critically important. Many designers, for example, rely solely on reference reaches to develop their design criteria. The reference reach approach requires that the appropriate stream type be designed for the given valley type, geology and land use. If the valley is confined, for instance, the approach dictates that a Bc stream type should be designed. Also, the pre-existing stream type may be different than the proposed stream type, i.e., the existing stream was a F4, but the proposed channel is a B4c because of channel confinement caused by lateral constraints.

While this is an acceptable approach, there are limitations. First, reference reaches are difficult to find in many parts of the United States that have experienced urban and suburban growth. Second, most reference reaches in the East are found in mature bottomland hardwood forests where the pattern has been primarily dictated by large trees. In other words, these streams are not free to form their pattern. This results in pattern ratios that are not suitable for design projects, which are often constructed in valleys denude of woody vegetation. This is why reference reach ratios should be compared to evaluation results from past projects and why multiple techniques for developing design criteria should be used.

2.2c Are the design criteria appropriate, given the site conditions and restoration potential?

Ultimately, many of the design ratios will be different than the reference reach ratios due to site conditions. For example, the radius of curvature ratio, bankfull width/depth ratio, pool width ratio, meander width ratio and others are adjusted to create a design that can evolve towards the reference condition over time. This is needed because the project site is often devoid of floodplain vegetation, whereas the reference reach was a mature forest. These adjustments allow the stream to evolve towards the reference condition over time as the buffer becomes established.

In addition, the design criteria should match the restoration potential. For example, if the restoration potential is a Rosgen Priority 3, then the design criteria should come from a Bc. In all cases, ratios used for design criteria should come from streams with similar valley slopes, bed material and vegetation communities; however, they do not necessarily need to be from the same hydrophysiographic region (Hey, 1996).

2.3 » CONCEPTUAL DESIGN

2.3a Was a conceptual channel alignment provided and developed within the design criteria?

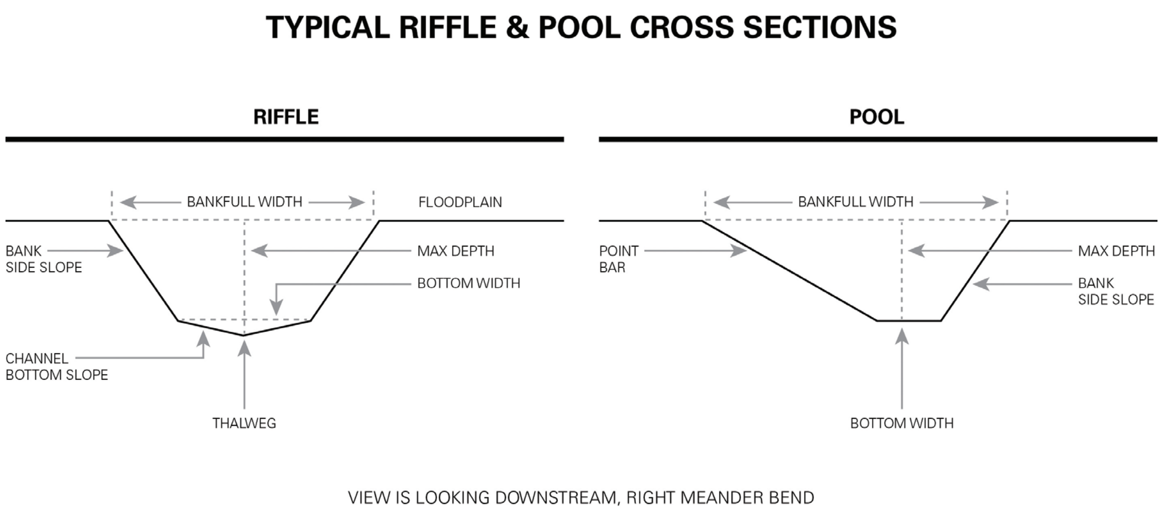
The most important part of the preliminary design is that it shows the proposed channel alignment. Typically, the alignment includes the centerline and bankfull width. This alignment should be approved by stakeholders prior to proceeding into the design phase. It is common to see projects move past the proposed alignment stage into design without the approval of the stakeholders; this is a mistake that can cost the project significant time delays and increased costs. All of the design elements are tied to the proposed channel alignment; therefore, making small changes to the alignment at the 90% stage requires the designer to start the entire design process over again.

At this stage, the reviewer should also check to make sure the pattern matches the belt-width requirements. For meandering streams, the belt width should be at least 3.5 times the bankfull width. This does not include the buffer width, just the lateral extent of the stream. If the belt width is less than 3.5 times the bankfull width, the pattern should reflect a step-pool morphology.

2.3b Were typical bankfull cross sections provided and developed within the design criteria?

Typical bankfull cross sections for at least the riffle and pool should be provided. Larger streams may also include typical cross sections for runs and glides. The typical cross sections should show, at a minimum, the bankfull width, bottom width, maximum depth, mean depth and bank slopes. The reviewer should make certain that the preliminary alignment and typical cross sections meet the design criteria. Typical cross section drawings for the preliminary design are shown in Figure 6.

FIGURE 6: A TYPICAL RIFFLE AND POOL CROSS SECTION SHOWING KEY MEASUREMENTS



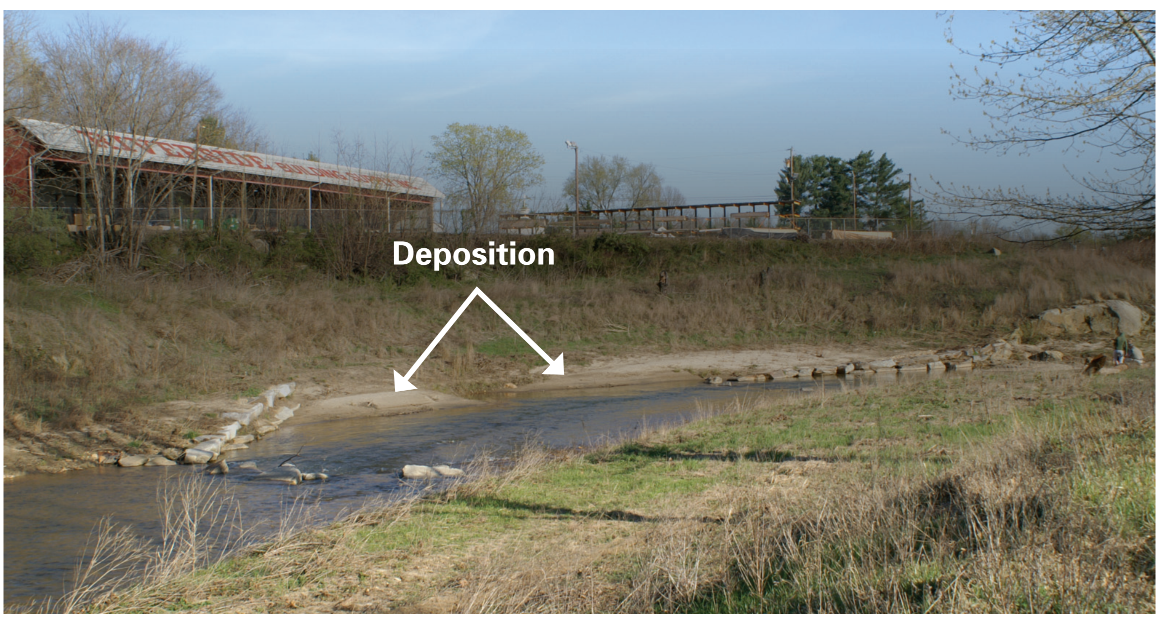
2.3c Were typical drawings of in-stream structures provided and their use and location explained?

At this stage, typical in-stream structures, their approximate location along the alignment and the purpose of the structure should be shown. Examples of J-hook vanes used to stabilize an eroding streambank are provided in Figures 7 and 8. The typical detail includes a design drawing of the structure showing how the structure is to be constructed. At this point, the structures do not need to be tied to the alignment, and design elevations are not required. In-stream structures shown at this stage allow the reviewer to see how the designer generally plans to stabilize the bed and bank until permanent vegetation is established.

FIGURE 7: AN ERODING STREAMBANK ALONG A PREVIOUSLY DESIGNED FLOOD CONTROL CHANNEL

Source: Michael Baker Corporation; Photo by Will Harman

FIGURE 8: J-HOOK VANES, A BANKFULL BENCH, AND GEOMETRY ADJUSTMENT WERE USED TO STABILIZE THE ERODING BANK. Note the deposition (sand) along the toe of the bank, which was created by the vanes.



Source: Michael Baker Corporation; Photo by Will Harman.

2.3d Was a draft planting plan provided?

A draft planting plan may also be included with the preliminary design. The planting plan should show the proposed temporary and permanent species list and their corresponding planting zones. It is important that the temporary planting plan includes herbaceous species for summer and winter. The temporary planting plan is primarily used for erosion control. The permanent planting plan should include vegetation that is native to the project area. It is not critical that the draft planting plan be part of the preliminary design, unless vegetation species selection is important to the stakeholder. This is common for projects located in golf courses, urban parks and some residential developments. In these cases, the vegetation plan can be one of the most important parts of the design and could affect whether or not the project proceeds to final design.

2.3e Overall Conceptual Design Comments

This line on the Checklist provides a place for the reviewer to provide overall conceptual design comments. These may include comments about the suitability of the alignment and whether or not it appears like a meandering channel is being forced into a confined setting (based on meander width ratio and sinuosity). Comments could also discuss whether or not the conceptual design fits the restoration goals, objectives, restoration potential and design criteria.

3.0 Final Design

Once the conceptual design has been approved, the project will move into the final design phases. The actual phases may vary based on requirements by the stakeholder or regulatory process. For example, many stakeholders require 30%, 60%, 90% and final design submittals; however, the specific requirements and format of the design varies greatly. The Checklist is not meant to replace plan sheet or design report formatting and structure, but rather, to help ensure that the pertinent information is adequately addressed. Typically, the final design phase focuses on creating plan sheets and construction documents that are used during the construction phase.

3.1 » NATURAL CHANNEL DESIGN

The natural channel design is typically shown in a set of plan sheets and specifications, with the final set sealed by a Professional Engineer. These plan sheets and specifications are used by contractors to build the project. It is important to review the design against the design criteria discussed in the Conceptual Design section (2.3).

There are a variety of resources that can be used to review the natural channel design process. The Rosgen Geomorphic Channel Design methodology is described in Chapter 11 of the NRCS handbook: Part 654 — Stream Restoration Design (2007). An overview of the natural channel design process is described by Hey (2006) and Doll et al., (2003) provides a design manual for natural channels.

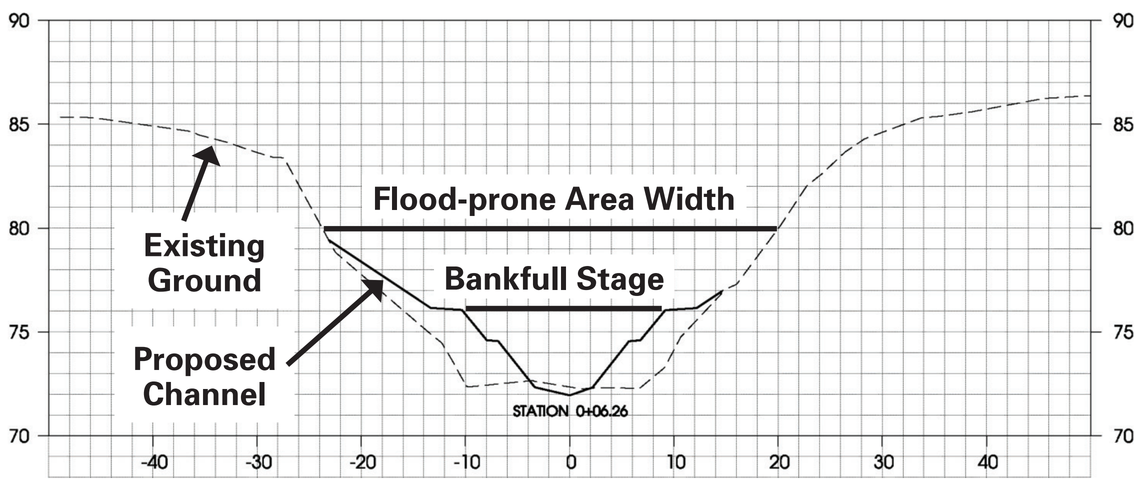
3.1a Was a proposed channel alignment provided and developed within the design criteria?

The proposed channel alignment with stationing should be shown on the basemap. This alignment is important because the profile and cross section design in the CAD software use the alignment stationing as a reference. In other words, the bulk of the design is linked to the alignment.

3.1b Were proposed channel dimensions provided and developed within the design criteria?

Proposed dimensions are often shown as typical cross sections (Section 2.3b) and later as actual cross sections, plotted as the proposed design versus the existing ground surface. The cross section should be sized to carry the bankfull discharge. Flows larger than bankfull should be transported on a floodplain (in alluvial valleys) or a floodprone area (in colluvial valleys). It is helpful if the design cross sections are overlaid with the existing ground, so that areas of cut and fill are made clear. The bankfull stage should be identified so that the reviewer can tell that the bankfull stage corresponds with the top of the streambank. An example of a proposed cross sections overlaid with the existing ground is shown in Figure 9.

FIGURE 9: PROPOSED CROSS SECTION OVERLAID WITH THE EXISTING GROUND. These are often shown on a set interval throughout the length of the project reach and are used by the contractor to excavate the channel and floodplain (if needed).



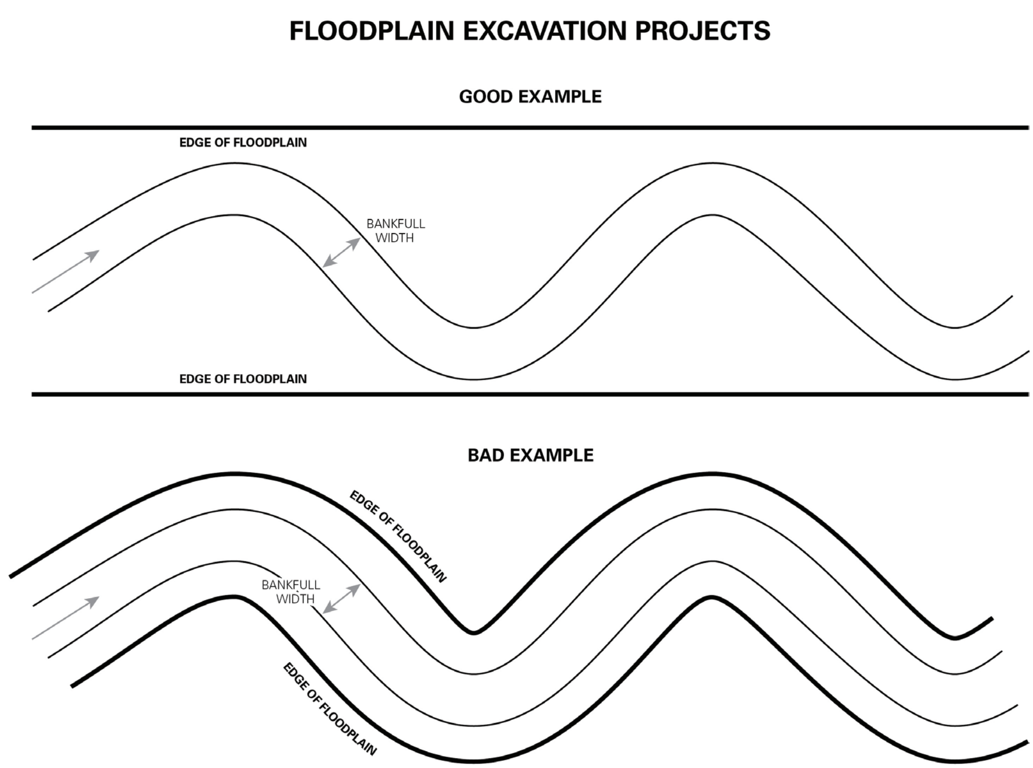
Source: US Fish and Wildlife Service, Chesapeake Bay Field Office

3.1c Do the proposed channel dimensions show the adjacent floodplain or flood-prone area?

The cross sections should extend far enough across the valley so that the adjacent floodplain width can be determined (See Figure 9). From this information, the reviewer can determine if the entrenchment ratio is sufficient for the design stream type. The entrenchment ratio (ER) is determined by dividing the flood-prone area width by the bankfull width at a riffle. The flood-prone area width is measured at an elevation that is two times greater than the bankfull riffle max depth. If the ER is less than 1.4, the stream is entrenched or vertically confined (stream types A, G and F). If the ER is between 1.4 and 2.2, the stream is moderately entrenched and is classified as a B stream type. Streams with an ER greater than 2.2 are not entrenched, having access to a well-developed floodplain (stream types C, E and DA). It should be noted that an adjustment of +/- 0.2 in the ER is allowed without changing stream type to account for natural variability (Rosgen, 2006a). Therefore, natural channel designs that include bankfull benches associated with B channels should have an ER that is at least 1.4. Natural channel designs for C and E channels should include ER levels that exceed 2.2; higher numbers mean that designs are more likely to remain stable during flood events.

For projects that included excavated floodplains (Rosgen Priority 2), the ER should exceed 2.2, and the meander width ratio should exceed a minimum of 3.5. In addition, the floodplain should be excavated as straight as possible, i.e., the stream should meander, but the floodplain should not. Unfortunately, numerous past projects have constructed meandering streams with a meandering floodplain, which often cause channel and floodplain erosion during large flows. An example of a proper and improper plan view of floodplain excavation is shown below in Figure 10.

FIGURE 10: PLAN VIEW OF PROPER AND IMPROPER EXCAVATION OF FLOODPLAIN LIMITS



3.1d Was a proposed channel profile provided and developed within the design criteria?

The proposed profile is important because it, along with the pattern, establishes the overall grade for the channel. It also shows feature slopes for riffles and pools. It is helpful if the existing ground elevation and the bankfull elevations are shown on the profile. This information shows if the proposed channel has access to a floodplain at flows greater than the bankfull stage for the entire length of the project. If it does not, the design will likely include the excavation of a floodplain or bankfull bench. It is important that the proposed channel not be incised. To ensure this, the reviewer should check to see that the bank height ratio is near 1.0 along the profile, especially along the riffles. If the bankfull stage equals the top of the streambank/elevation of the floodplain, then the bank height ratio is 1.0. Ideally, the bank height ratio should not exceed 1.2. See Appendix F for an illustration and equation of the bank height ratio.

3.1e Were specifications for materials and construction procedures provided and explained (i.e., in-stream structures and erosion control measures)?

Specifications should be provided that describe construction means and methods, construction sequencing, and the quantity and quality of materials, especially for in-stream structures and erosion-control measures. Examples include the size and type of boulders and shear stress value for erosion-control matting. Specifications are provided for other items as well, but from a stability perspective, it is most important to review the in-stream structures and erosion-control measures.

3.2 » SEDIMENT TRANSPORT

3.2a Was a sediment transport analysis necessary?

Most, but not all, projects will require some form of sediment transport analysis. Sediment transport analysis is one of the more complex components of a natural channel design. These analyses usually address questions about the ability of the stream to transport sediment particles of a certain size (competency) and load (capacity). There are a variety of references available to learn more about sediment transport. Two include Rosgen (2006a) in Chapter 2 of *Watershed Assessment of River Stability and Sediment Supply* and Wilcock et al., (2009).

Projects that may not require sediment transport analysis include those with low sediment supply from the upstream watershed. Examples include low-gradient coastal plain streams and highly urbanized streams. Projects located in bed load transport reaches with upstream sources of sediment should include sediment transport analysis.

3.2b If necessary, was the type of sediment transport analysis explained?

If sediment transport analyses are required, it is important to know why one type of sediment transport analysis was selected over another. The type and distribution of the bed material governs the complexity of the analyses, i.e., bed material composed of all sand requires fewer analyses than cobble, gravel and sand mixtures. Some important questions to ask include: Were sediment transport competency calculations completed, but not sediment transport capacity, and if so, why? If sediment transport capacity calculations were completed, were explanations provided for the selected equations?

3.2c Were graphs or relationships created that show shear stress, velocity and stream power as a function of stage or discharge?

Graphs and/or relationships created that show shear stress, velocity and stream power as a function of stage or discharge can be helpful in comparing sediment transport characteristics before and after restoration. These relationships can also show the break between channel processes and floodplain processes, i.e., the rate of increasing shear stress should decrease sharply above the bankfull stage.

3.2d Did sediment transport capacity analysis show that the stream bed would not aggrade or degrade over time?

If sediment transport capacity analysis is needed, then the results should show that the project reach is unlikely to aggrade or degrade. This is often accomplished by comparing the stream reach to an upstream supply reach to ensure that the design reach transports the same amount of sediment as the upstream reach. In addition, other techniques, such as SAMWin and the Copeland stability curve, are used to show aggradation/degradation potential (Copeland, 2001). If possible, the riffle dimension results from this analysis should be compared to watershed-specific regional curves.

3.2e Did sediment transport competency analysis show what particle sizes would be transported with a bankfull discharge?

If the stream has a gravel bed and sediment transport competency analysis is needed, the results should show the particle size that is transported at the bankfull stage. If the design shows that shear stress is still significantly increasing above the bankfull event (i.e., confined valleys), the particle sizes should be shown for these flows as well. The shear stress associated with a bankfull discharge should show that the largest particle of the subpavement or bar sample is mobile. Rosgen (2006a) provides detailed methods about performing competency analysis in Chapter 5.

3.2f For gravel/cobble bed streams, does the proposed design move particles that are larger than the D100 of the stream bed?

Typically, for gravel/cobble bed streams, the designer tries to move particle sizes that correspond with the bankfull discharge, without moving the largest particles sampled from the bed (D100). If the design is transporting all of the grain sizes, the risk of degradation is high. The reviewer can calculate the bankfull boundary shear stress and use the graph in Appendix F as a quick check of the particle size that is being transported at the bankfull stage. The upper line from the graph should be used. This value is then compared to the grain size distribution from the project site (bed material only).

In some projects, especially urban projects, moving particles greater than the D100 is unavoidable. In these cases, in-stream structures will be required to provide grade control and immobile riffles.

3.3 » IN-STREAM STRUCTURES

Most, but not all, projects require the use of in-stream structures. Examples of projects that may not need in-stream structures include small streams in low gradient valleys, i.e., a small coastal plain stream. In-stream structures are often required in newly constructed channels to provide bank (lateral) and/or bed (vertical) stability. In-stream structures may be constructed from rock or wood depending on their use and availability of materials. Some in-stream structures are also used to improve aquatic habitat. Rosgen (2006b) provides a description of the cross vane, w-weir and J-hook vane. It is important that the right type of structure be used for the right problem and in the appropriate size stream. For example, rock vanes and cross vanes are difficult to build in streams with drainage areas less than one square mile. In all cases, in-stream structures and bank stabilization techniques should be designed after channel geometry has been addressed. In-stream structures cannot typically correct channel pattern problems.

3.3a Based on the assessment and design, were in-stream structures necessary for lateral stability?

Most projects will require some type of bank protection to prevent erosion until the permanent vegetation is established. There is a wide range of techniques that can be used, including vanes, root wads, toe wood, erosion control matting, transplants, bioengineering, etc. The type of structure selected should be based on the potential for the bank to erode. The Tables 1 and 2 below can be used as a general guide for in-stream structures and bioengineering methods.

TABLE 1: GUIDANCE FOR SELECTING IN-STREAM STRUCTURES TO PROVIDE BANK PROTECTION

In-Stream Structure for Lateral Stability	Relative Strength to Provide Bank Protection	Relative Cost
Root Wads	Moderate for medium size streams High for small streams	Low to high depending on availability (onsite = low)
Log Vanes	Low to moderate for small streams	Low to moderate depending on availability (onsite = low)
Rock Vanes and J-hooks	High	Moderate to high

TABLE 2: GUIDANCE FOR SELECTING BIOENGINEERING PRACTICES FOR BANK PROTECTION

Bioengineering Method	Relative Strength to Provide Bank Protection	Relative Cost
Brush Mattress	Moderate	Moderate to high
Brush Layers	Moderate	Moderate to high
Live Stakes	Low	Low
Geolifts	High	High
Fascines	Moderate	Moderate
Transplants	High	Low (must come from onsite)
Erosion Control Matting	Low to moderate	Low to moderate

3.3b Based on the assessment and design, were in-stream structures necessary for vertical stability?

If degradation after restoration construction is a concern, in-stream structures can be used to provide vertical stability — typically at the riffles. Grade control is needed when channel beds have been raised (Priority 1) and then lowered at the downstream end or when channels have been re-meandered through a floodplain with sand and silt material mixed with the gravel. There are many other examples as well, and the reason for grade control should be explained in the design report. In-stream structures for grade control include cross vanes, step-pools, constructed riffles and others.

3.3c If needed, was the reason for their location and use explained?

The reason for the use and location of in-stream structures should be provided. For example, a rock J-hook vane may be designed to reduce stress along the outside of a meander bend and to promote scour in the pools. The structure should be located so that the velocity vector intercepts the triangle formed by the vane, i.e., the vane is slightly downstream of where the vector intercepts the bank. The velocity vector is a flow line that is parallel to the banks in riffle sections, but hits the outside of the meander bend. The triangle is formed by the vane arm and bank, looking upstream. It "catches" the velocity vector and rolls water towards the center of the channel. Note that this does not correlate with the point of curvature and point of tangency for the bend. The vectors often intercept the bank closer to the apex of the bend than these two points. An example of a J-hook vane turning the velocity vector is shown in Figures 11 and 12.

FIGURE 11: J-HOOK VANE AT BASE FLOW. The triangle is formed from the vane arm where the fisherman is standing and the streambank. The structure is placed downstream of where the velocity vector intercepts the bank.

Source: Michael Baker Corporation; Photo by Will Harman

FIGURE 12: SAME J-HOOK VANE DURING A HIGHER FLOW. Notice how the triangle "catches" the velocity vector and rolls the water back towards the center of the channel, reducing energy next to the bank and creating a pool in the center of the channel.

Source: Michael Baker Corporation. Photo by Will Harman.

Root wads, toe wood, bioengineering methods and other similar methods do not change the direction of the stream flow like a vane. Rather, these structures "armor" the bank, protecting the soil material from erosion and providing aquatic habitat, i.e., cover. These structures are placed throughout the meander arc length with particular attention to the apex and lower (downstream) portion of the bank where the potential for bank erosion is highest.

3.3d Will the in-stream structures provide the intended stability?

There is an art and science to designing in-stream structures and most designers have their own preferences about which structures to use and how to install them. This makes reviewing in-stream structures difficult; however, the reviewer should focus on the relationship between the type of in-stream structure used and its role in providing stability. It is important to look for stream areas that may be vulnerable to short-term erosion (bed or bank) and to make sure that these areas have some form of protection. Examples include medium- to large-size streams with new channel construction and sandy banks.

New channel bottoms are often prone to degradation because an armor/sub-armor layer has not formed. Structures such as constructed riffles are often used to provide grade control in these situations. The outside of meander bends needs some form of protection through in-stream structures and/or bioengineering. Erosion control matting is typically used to stabilize riffle bank slopes.

3.3e Were detail drawings provided for each type of in-stream structure?

Detail drawings should be provided for each type of in-stream structure or erosion control measure. These drawings are typically part of the plan set, but key structures could be included in the report. The reviewer should check to see if these structures are appropriate given the restoration approach, need for vertical and/or lateral stability, habitat needs and constraints.

3.4 » VEGETATION DESIGN

3.4a Was a vegetation design provided?

Every stream restoration project should have a vegetation design tailored to the needs of the project. Too often, boiler plate vegetation designs are included that do not address specific site needs or the goals and objectives of the project.

3.4b Does the design address the use of permanent vegetation for long-term stability?

The vegetation design should include temporary and permanent planting plans. The temporary planting plan is used for erosion control because it quickly establishes an herbaceous cover. The species used are often governed by local erosion and sedimentation control laws. The permanent vegetation plan should include native grasses, shrubs and trees (as appropriate for the region) and should be shown in zones, such as along the streambank, floodplains and terraces.

3.4c Overall Final Design Comments

This section provides a place for overall final design comments based on the questions above. The reviewer can address major concerns or apparent deficiencies in the design and request additional information if necessary.

4.0 Maintenance and Monitoring Plans

While maintenance and monitoring is not part of the design process, all design reports should provide a maintenance plan and most projects, especially mitigation projects, will include a monitoring plan. Questions about both are provided below.

4.1 » MAINTENANCE PLAN

4.1a Was a maintenance plan provided?

Stream restoration projects are most vulnerable to bank, bed and upland erosion immediately after construction. With each growing season, the permanent vegetation becomes more established and the streambanks and floodplain become more stable. In new channels, bankfull flows establish a natural sorting of the bed material, providing armor and sub-armor layering of the bed. Therefore, it is important for the project to include a maintenance plan that describes how short-term (up to 3-5 years) erosion problems will be addressed. Some level of maintenance is required on most projects.

4.1b Does it clearly state when maintenance will be required and if so, is it quantifiable?

The plan should state when maintenance will be required. Problems that need to be addressed are typically bed or bank erosion where the channel adjusts beyond the design criteria or in-stream structures where the boulders have moved and are now causing instability problems. Routine stream walks of the project can help determine the need for maintenance.

4.1c Does it clearly state how erosion will be addressed and by whom?

The maintenance plan should also provide a method for clear lines of communication by determining who is responsible for maintenance. This includes identifying the entity responsible for monitoring the site (qualitatively and/or quantitatively) and a process for handling simple repair approaches. The plan should also list the party responsible for financing the repair. A misunderstanding about who is responsible and who pays for repairs often leads to tense discussions between the contractor, designer and owner. At times this leads to needed repairs not being performed because of these conflicts. In extreme cases, it could also lead to arbitration or lawsuits.

4.2 » MONITORING PLAN

4.2a Was a monitoring plan provided?

A monitoring plan may or may not be provided depending on the source of funding. The majority of stream restoration projects being completed for mitigation credits require some level of monitoring, usually for 3 to 10 years. Projects funded by federal and state grants may require monitoring, but often do not.

4.2b Does it state who is required to conduct the monitoring?

If a monitoring plan is submitted with the design, it should state who is responsible for the monitoring, including contact information (name, address, phone number, email address).

4.2c Does it have measurable performance standards?

Long-term quantitative monitoring is valuable because it can provide information about the overall success of the project, i.e., whether or not the project met its goals. The monitoring plan should include performance standards that provide measurable success criteria. The design criteria and reference reach information should be used to establish the performance criteria. Monitoring should quantify that the as-built and monitored condition does not deviate from the design criteria/reference reach range. This does not mean that the post-construction channel will not change; it will likely adjust, but it should adjust in a positive direction. For example, many alluvial channel projects are designed with a riffle width/dept ratio greater than 12 (a C stream type). Over time, the channel narrows and the width/depth ratio decreases to less than 12 (an E stream type). This is a positive trend in channel evolution.

4.2d Is monitoring required for at least 3 years?

It takes several years for the permanent vegetation to establish. Therefore, if monitoring is required, it should last at least 3 years after construction. Additional monitoring is always useful, but may not be necessary from a stability perspective.

5.0 Overall Design Review

This last section incorporates all of the above information into a final review. The goal here is to determine the overall likelihood of success.

5.0a Does the design address the project goals and objectives?

Based on the results from the above questions, the reviewer should determine if the design addresses the project goals and objectives. For example, if the objective was to reduce incision and bank erosion, the design should show reductions in the bank height ratio and provide connectivity to an adjacent floodplain or flood-prone area.

5.0b Are there any design components that are missing or could adversely affect the success of the project?

In addition, the reviewer should take another overall look at the design to determine if there are any critical elements that are missing or that could adversely affect the success of the project. For example, if there is a large upstream sediment supply from eroding banks, a sediment transport analysis is critical to designing a stable channel.

5.0c Does the project have a high potential for success?

Based on all of the above information, the reviewer should determine if the project has a high potential for success, or if the risk of failure outweighs the potential for functional lift. If the project is considered too risky, specific concerns should be given. This will provide the designer with an opportunity to address and potentially remedy the concerns.

6.0 References

Copeland, R.R, D.N. McComas, C.R. Thorne, P.J. Soar, M.M. Jones and J.B. Fripp. 2001. Hydraulic Design of Stream Restoration Projects. United States Army Corps of Engineers (USACOE), Washington, D.C. ERDC/CHL TR-01-28. *http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA400662&Location=U2&doc=GetTRDoc.pdf*

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

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream Corridor Restoration: Principles, Processes, and Practices. GPO item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3. *http://www.nrcs.usda.gov/technical/stream_restoration/*

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

Harman, W.A. 2000. River Course Fact Sheet No. 3: Finding Bankfull Stage in North Carolina Streams. NC Stream Restoration Institute, North Carolina State University. AG-590-3. *http://www.bae.ncsu.edu/programs/extension/wqg/srp/rv-crs-3.pdf*

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

Leopold, L.B., M.G. Wolman, J.P. Miller. 1992. Fluvial Processes in Geomorphology. Dover Publications, Inc. New York.

McCandless, T.L. and R.A. Everett. 2002. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Piedmont Hydrologic Region. US Fish and Wildlife Service, Annapolis, MD. CBFO-S02-02. *http://www.fws.gov/chesapeakebay/streampub.html*

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

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

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

Rosgen, D.L. 2006b. The Cross-Vane, W-Weir and J-Hook Vane Structures (Updated 2006). Their Description, Design and Application for Stream Stabilization and River Restoration. Wildland Hydrology, Inc., Ft. Collins, CO. *http://www.wildland-hydrology.com/assets/The_Cross_Vane_W-Weir_and_J-Hook_Structures_Paper_Up-dated_2006%20.pdf*

Wilcock, P., J.Pitlick and Y. Cui. 2009. Sediment Transport Primer, Estimating Bed-Material Transport in Gravel-bed Streams. United States Department of Agriculture, Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-226. May, 2009.

Natural Channel Design Review Checklist

Appendices

Appendix A
Natural Channel Design Review Checklist

Natural Channel Design Review Checklist

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

Project: ______________________
Engineer: ______________________

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

Natural Channel Design Review Checklist

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

Project: ______________________
Engineer: ______________________

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

Natural Channel Design Review Checklist

Project Design Checklist **Reviewer:** ____________________
Date: ____________________

Project: ____________________
Engineer: ____________________

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

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ____________________
Date: ____________________

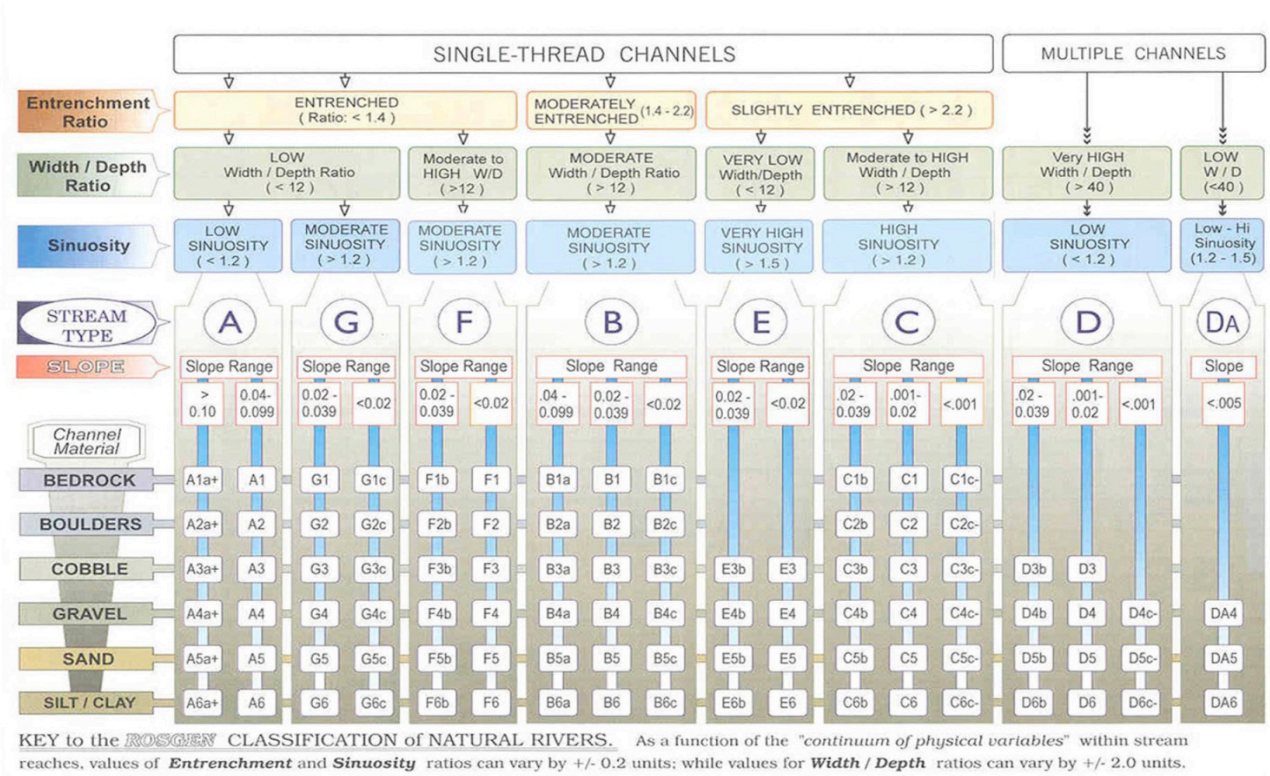
Project: ____________________
Engineer: ____________________

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

Appendix B

Stream Classification Key and Rosgen Priority Levels of Restoration

Figure B1: The Rosgen Stream Classification Key. A detailed description of the stream classification system can be found in *Applied River Morphology* by Dave Rosgen.



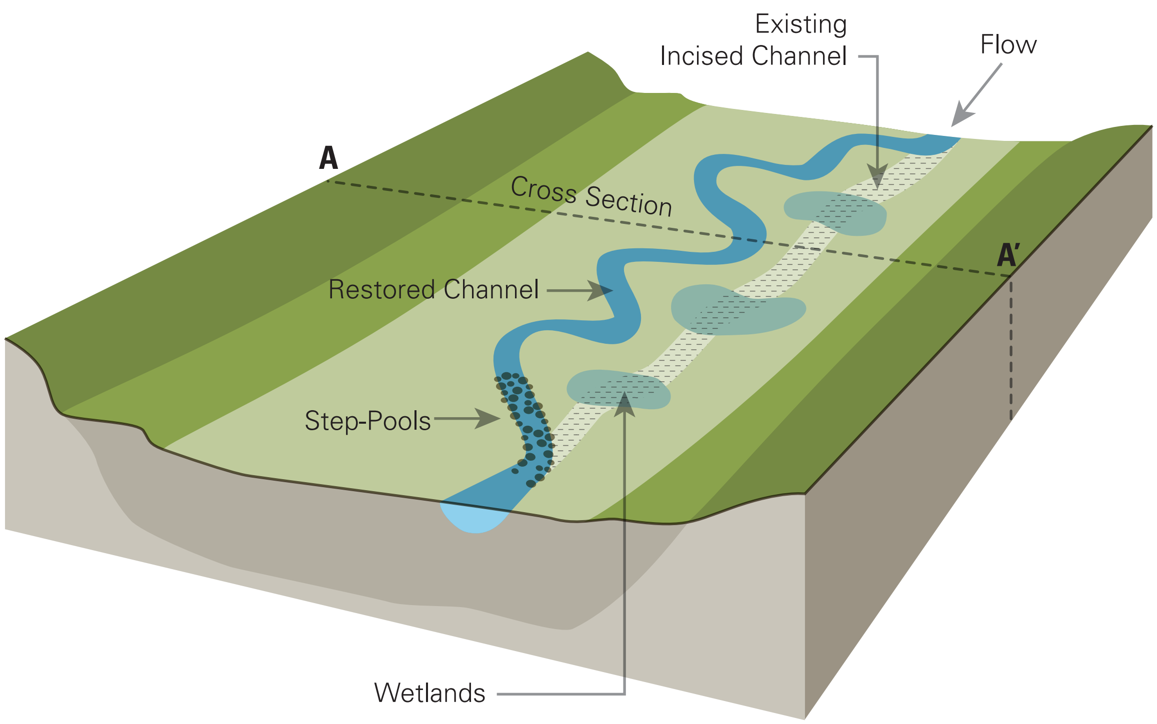
Priority Levels of Restoring IncisedChannels

The “Rosgen Priority Levels” range from Priority Level 1 to Priority Level 4 and are chosen based on factors including both physical and economic constraints. A brief description of the Priority Levels is provided below and a more detailed description can be found in Rosgen (1997).

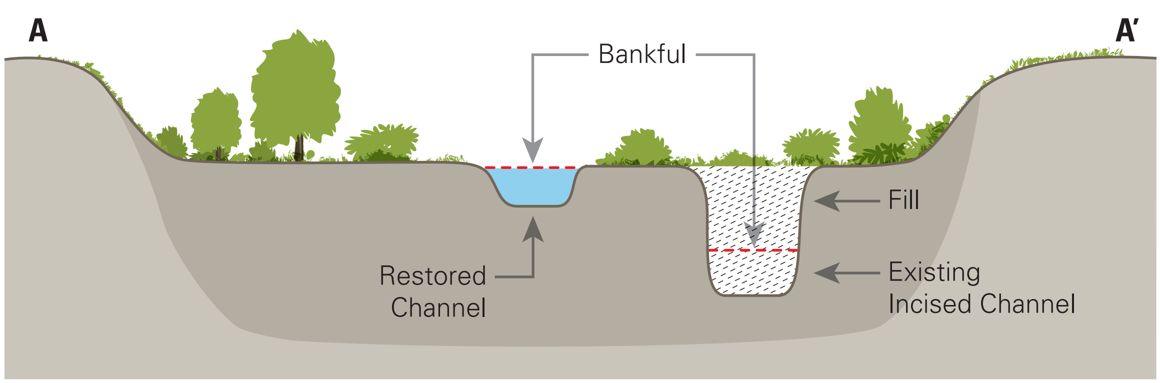
A Priority Level 1 restoration creates a new stable channel that is reconnected to the previous (higher in elevation) floodplain. A new stream channel is excavated on the original floodplain by raising the stream bed elevation. This approach requires an abrupt change in bed elevation at the upstream end of the project, e.g., culvert outfall or knickpoint. The former incised channel is filled, converting it to a floodplain feature. This approach is used in areas where there are few lateral constraints and where flooding on the adjacent land can be increased. An example of the plan form and dimension improvements created by a Rosgen Priority 1 is shown in Figure 1.

FIGURE 1: ROSGEN PRIORITY LEVEL 1 RESTORATION APPROACH

PLAN VIEW

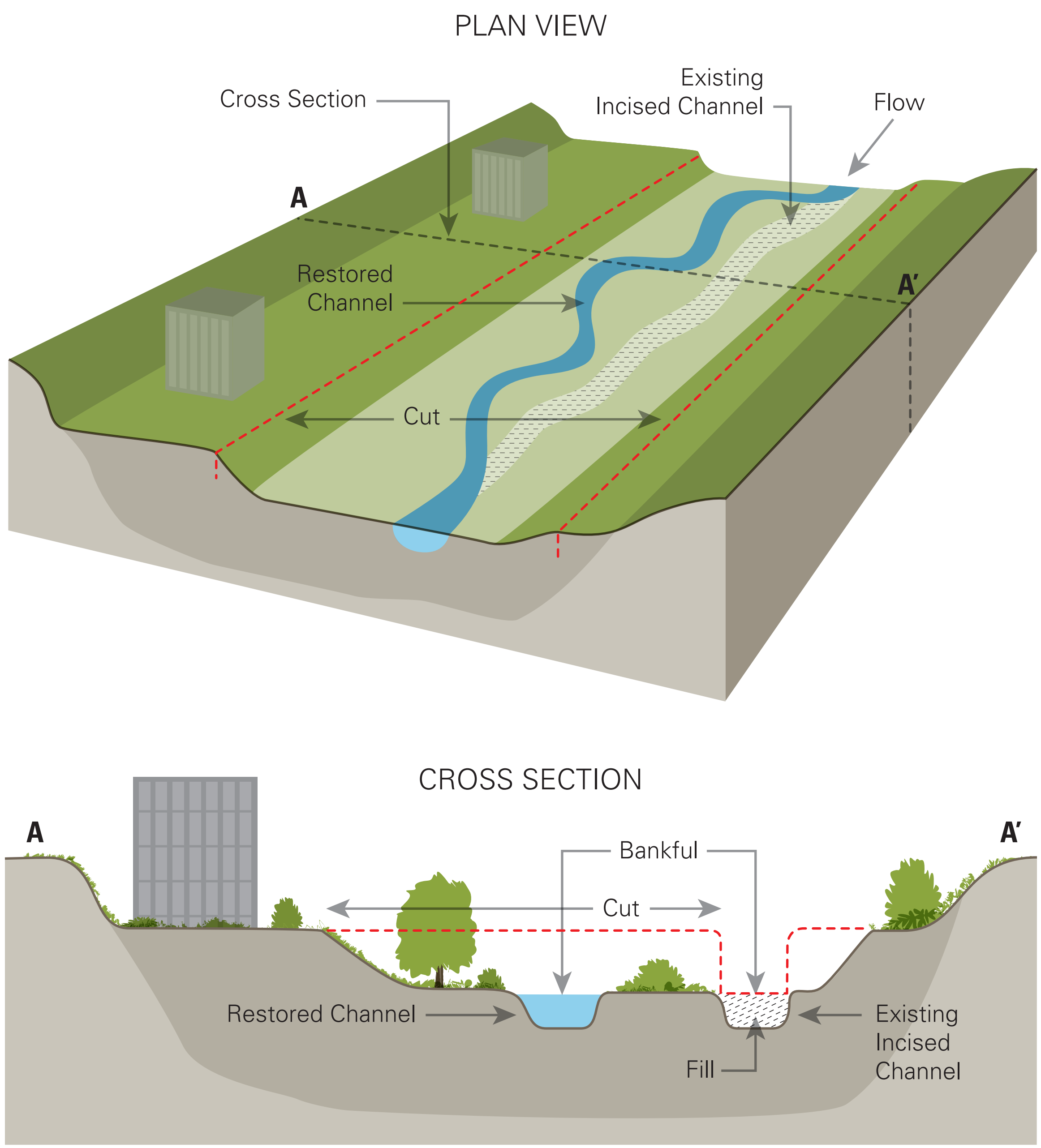


CROSS SECTION



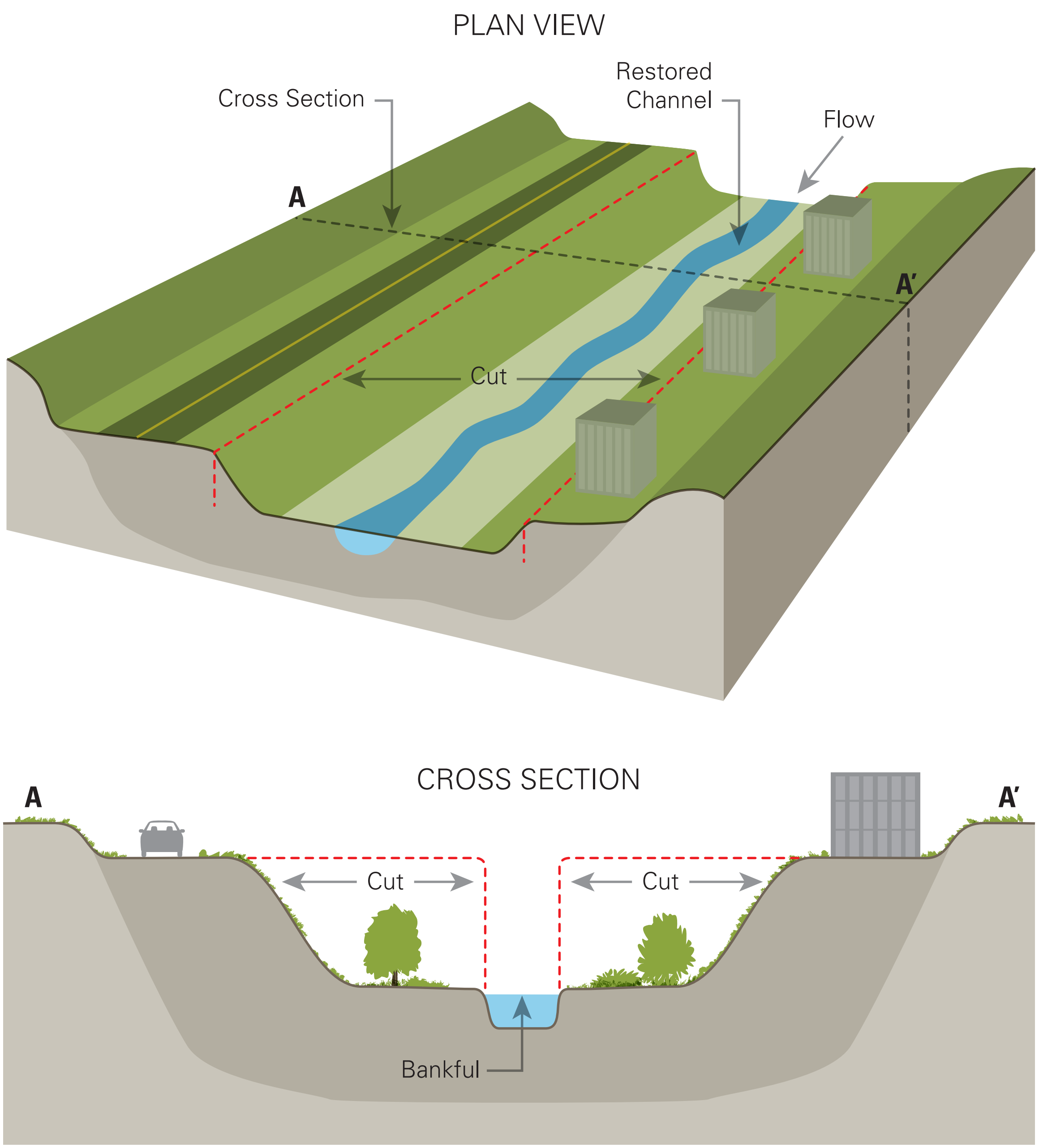
A Priority Level 2 restoration also creates a new stable channel that is connected to the floodplain, but the floodplain is excavated at the existing bankfull elevation, i.e., the bed elevation of the stream remains nearly the same. The formerly channelized and incised stream is re-meandered through the excavated floodplain. This approach is typically used if there is not a knickpoint or other abrupt change in grade upstream of the project, in larger streams, or in cases where flooding cannot be increased on adjacent property. A plan view and cross section example is shown below in Figure 2.

FIGURE 2: ROSGEN PRIORITY LEVEL 2 RESTORATION APPROACH



A Priority Level 3 restoration converts a channelized and incised channel, often with poor bed form diversity, into a step-pool type of channel. The existing channel alignment stays nearly the same. Bankfull benches are excavated at the existing bankfull elevation to provide limited floodplain connectivity. In-stream structures are required to dissipate energy along the streambanks and to create step/pool bed forms. Priority Level 3 is often used where constraints inhibit meandering and flood elevations cannot be increased, e.g., urban environments. A plan view and cross section example is shown below in Figure 3.

FIGURE 3: ROSGEN PRIORITY LEVEL 3 RESTORATION APPROACH



A Priority Level 4 restoration stabilizes the channel in place, using in-stream structures and bioengineering to decrease stream bed and streambank erosion. This approach is typically used in highly constrained environments, such as backyards and highway right-of-ways. A Priority Level 4 is rarely used to create stream mitigation credits and is generally not considered restoration, only stabilization.

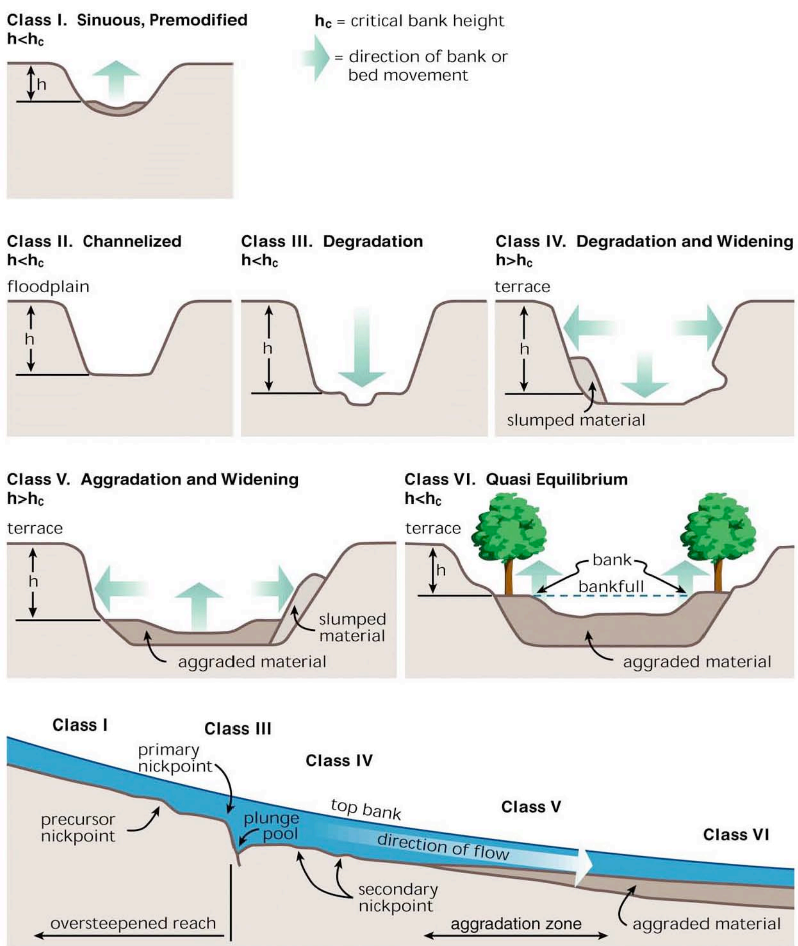
References

Rosgen, D.L., 1997. A Geomorphological Approach to Restoration of Incised Rivers. *In:* Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, S.S.Y. Wang, E.J. Langendoen, and F.D. Shields (Editors). University of Mississippi, Oxford, Mississippi.

Appendix C
Simon Channel Evolution Model
Channel Evolution by Stream Type

The following is from *Stream Corridor Restoration: Principles, Processes and Practices* (FISRWG, 1998). The web address for this document is extremely long; however, the document can be found by searching for "stream corridor restoration" on the NRCS web page at www.nrcs.usda.gov. The document can be ordered by calling (888)-526-3227.

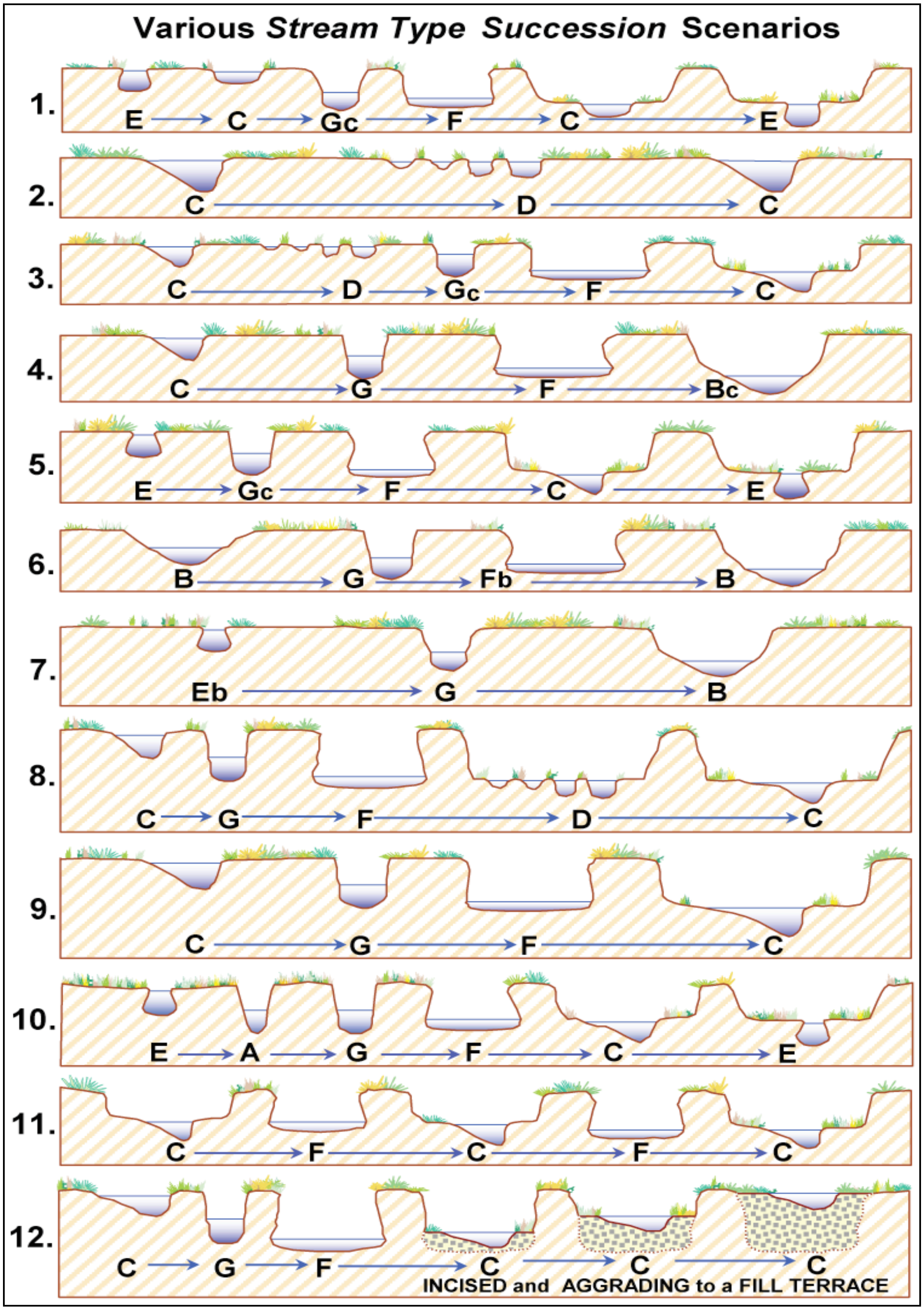
Simon Channel Evolution Model



Source: Simon, 1989; US Army Corps of Engineers, 1990.
Fig. 7.14 -- Channel evolution model..
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

Source: Simon, 1989

The following is from the Rosgen Level 3 Workshop, River Assessment and Monitoring.



Appendix D
Regional Curves and Manning's Equation

The following list of regional curves is an excerpt from Appendix A of *Stream Assessment and Mitigation Protocols: A Review of Commonalities and Differences* by Somerville (2010). The entire document can be downloaded from http://water.epa.gov/lawsregs/guidance/wetlands/wetlandsmitigation_index.cfm or http://stream-mechanics.com/resources-html/.

Hydraulic Regional Curves for Selected Areas of the United States

NOTE: Not all of the following references have been subject to the same level of independent review. In addition to investigations published in peer-reviewed literature, this list also includes works undertaken pursuant to university degree programs and specific restoration projects carried out by both the private and public sector. Moreover, some references are the result of symposia, workshops, etc., and information contained therein may have had little review outside of the individual document's collaborators.

ALABAMA
Metcalf, C. 2005. Alabama riparian reference reach and regional curve study. U.S. Fish and Wildlife Service, Panama City Fisheries Resource Office. Panama City, FL.

ARIZONA
Moody, T. and W. Odem. 1999. Regional relationships of bankfull stage in central and southern Arizona, in D.S. Olsen and J.P. Potyondy (eds), Wildland Hydrology, American Water Resources Association Specialty Conference Proceedings, June 20-July 2, 1999: Bozeman, MT, TPS-99-3, 536 p.

Moody, T., M. Wirtanen and S.N. Yard. 2003. Regional Relationships for Bankfull Stage in Natural Channels of the Arid Southwest, Natural Channel Design, Inc. Flagstaff, AZ. 38 p. http://www.naturalchanneldesign.com/NCD%20Reports.htm

CALIFORNIA
Dunne, T.D. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, NY.818 p.

COLORADO
Elliot, J.G. and K.D. Cartier. 1986. Hydraulic geometry and streamflow of channels in the Piceance Basin, Rio Blanco and Garfield Counties, Colorado. U.S. Geological Survey Water Resources Investigations Report 85-4118. http://pubs.er.usgs.gov/usgspubs/wri/wri854118

Yochum, S. 2003. Regional Bankfull Characteristics for the Lower Willow Creek Stream Restoration, USDA NRCS Northern Plains Engineering Team, Lakewood, CO. 22 p. http://www.willowcreede.org/floodcontrol/WillowCreekRegionalBankfullCharacteristics.pdf

FLORIDA
Metcalf, C. 2004. Regional Channel Characteristics for Maintaining Natural Fluvial Geomorphology in Florida Streams. U.S. Fish and Wildlife Service, Panama City Fisheries Resource Office. Panama City, FL.

Metcalf, C.K., S.D. Wilkerson, and W.A. Harman. 2009. Bankfull regional curves for north and northwest Florida streams. Journal of the American Water Resources Association 45(5): 1260-1272.

GEORGIA
Pruitt, B.A. 2001. Hydrologic and soil conditions across hydrogeomorphic settings. PhD dissertation, University of Georgia, Athens, GA. 223.p. http://www.libs.uga.edu/science/

IDAHO
Emmet, W.W. 1975. The channels and waters of the Upper Salmon River area, Idaho. U.S. Geologic Survey, Professional Paper 870-A. U.S. Government Printing Office, Washington, D.C. 116 p.

KANSAS
Emmert, B.A. 2004. Regional curve development for Kansas. In J.L. D'Ambrosio (ed). Proceedings Self-Sustaining Solutions for Streams, Wetlands, and Watersheds, 12-15, September 2004. St. Paul, Minnesota. American Society of Agricultural Engineers, St. Joseph, MI. http://asae.frymulti.com/conference.asp?confid=sww2004

KENTUCKY
Mater, B.D., A.C. Parola, Jr., C. Hansen and M.S. Jones. 2009. Geomorphic Characteristics of Streams in the Western Kentucky Coal Field Physiographic Region of Kentucky. Final Report prepared by University of Louisville, Stream Institute for the Kentucky Division of Water, Frankfort, KY.
http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/Attachments/10/WesternKYCoalfields.pdf

Parola, A.C., Jr., K. Skinner, A.L. Wood-Curini, W.S. Vesely, C, Hansen, and M.S. Jones. 2005. Bankfull Characteristics of Select Streams in the Four Rivers and Upper Cumberland River Basin Management Units. Final Report prepared by University of Louisville, Stream Institute for the Kentucky Division of Water, Frankfort, KY.

Parola, A.C., Jr., W.S. Vesely, A.L. Wood-Curini, D.J. Hagerty, M.N. French, D.K. Thaemert and M.S. Jones. 2005. Geomorphic Characteristics of Streams in the Mississippi Embayment Physiographic Region of Kentucky. Final Report prepared by University of Louisville, Stream Institute for the Kentucky Division of Water, Frankfort, KY.
http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/Attachments/10/WesternKYCoalfields.pdf

Parola, A.C., Jr., W.S. Vesely, M.A. Croasdaile, C. Hansen, and M.S. Jones. 2007. Geomorphic Characteristics of Streams in the Bluegrass Physiographic Region of Kentucky. Final Report prepared by University of Louisville, Stream Institute for the Kentucky Division of Water, Frankfort, KY.
http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/Attachments/8/Bluegrassstreamsreport.pdf

Pruitt, B.A., W.L. Nutter, and W.B. Ainslie. 1999. Estimating flood frequency in gaged and ungaged watersheds, In K.J. Hatcher (ed.) *Proceedings of the 1999 Georgia Water Resources Conference*, March 30-31, 1999, University of Georgia, Athens, GA.
http://www.gwri.gatech.edu/uploads/proceedings/1999/PruittB-99.pdf

Vesely, W.S., A.C. Parola, Jr., C. Hansen and M.S. Jones. 2008. Geomorphic Characteristics of Streams in the Eastern Kentucky Coal Field Physiographic Region of Kentucky. Final Report prepared by University of Louisville, Stream Institute for the Kentucky Division of Water, Frankfort, KY.
http://water.ky.gov/permitting/Lists/Working%20in%20Streams%20and%20Wetlands/Attachments/9/EasternKYCoalfields.pdf

MAINE

Dudley, R.W. 2004. Hydraulic geometry relations for rivers in coastal and central Maine: U.S. Geological Survey Scientific Investigations Report: 2004-5042, 30 p.
http://water.usgs.gov/pubs/sir/2004/5042/

MARYLAND

Chaplin, J.J. 2005. Development of regional curves relating bankfull-channel geometry and discharge to drainage area for streams in Pennsylvania and selected areas of Maryland, U.S. Geologic Survey, Scientific Investigations Report 2005-5147.

Cinotto, P.J. 2003. Development of regional curves of bankfull-channel geometry and discharge for streams in non-urban Piedmont Physiographic Province, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 03-4014, 27 p.
http://pa.water.usgs.gov/reports/wrir03-4014.pdf

Doheny, E.J. and G.T. Fisher. 2007. Hydraulic geometry characteristics of continuous record streamflow-gaging stations on four urban watersheds along the main stem of Gwynns Falls, Baltimore County and Baltimore City, Maryland: U.S. Geological Survey Scientific Investigations Report 2006–5190, 24 p. http://pubs.usgs.gov/sir/2006/5190/

Keaton, J.N., T. Messinger and E.J. Doheny. 2005. Development and analysis of regional curves for streams in the non-urban valley and Ridge physiographic provinces, Maryland, Virginia, and West Virginia: U.S. Geological Survey Scientific Report 2005-5076, 116 p.
http://pubs.usgs.gov/sir/2005/5076/sir05_5076.pdf

Krstolic, J.L. and J.J. Chaplin. 2007. Bankfull regional curves for streams in the non-urban, non-tidal Coastal Plain Physiographic Province, Virginia and Maryland: U.S. Geological Survey Scientific Investigations Report 2007–5162, 48 p. http://pubs.usgs.gov/sir/2007/5162/pdf/SIR2007-5162.pdf

McCandless, T.L. and R.A. Everett. 2002. Maryland stream survey: bankfull discharge and channel characteristics of streams in the Piedmont hydrologic region: U.S. Fish and Wildlife Service, Annapolis, Maryland, CBFO-S02-01, 163 p. http://www.fws.gov/chesapeakebay/pdf/Piedmont.pdf

McCandless, T.L. and R.A. Everett. 2003. Maryland stream survey: bankfull discharge and channel characteristics of streams in the Allegheny Plateau and the Valley and Ridge hydrologic region: U.S. Fish and Wildlife Service, Annapolis, Maryland, CBFOS03-01, 92 p. http://www.fws.gov/chesapeakebay/pdf/plateauweb.pdf

McCandless, T.L. 2003. Maryland stream survey: bankfull discharge and channel characteristics of streams in the Coastal Plain hydrologic region: U.S. Fish and Wildlife Service, Annapolis, Maryland, CBFO-S03-02, 89 p. http://www.fws.gov/chesapeakebay/pdf/plain.pdf

Miller, K.F. 2003. Assessment of channel geometry data through May 2003 in the mid-Atlantic highlands of Maryland, Pennsylvania, Virginia, and West Virginia: U.S. Geological Survey Open-File Report 03-388, 22 p.

White, K.E. 2001. Regional curve development and selection of a references reach in the non-urban lowland sections of the piedmont physiographic province, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 01-4146, 20 p. http://pa.water.usgs.gov/reports/wrir01-4146.pdf

MASSACHUSETTES

Bent, G.C. and A.M. Waite. (In review). Methods for estimating bankfull channel geometry and discharge for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2008–XXXX, XX p.

MICHIGAN

Mistak, J.L. and D.A. Stille. 2008. Regional hydraulic geometry curve for the Upper Menominee River, Fisheries Technical Report 2008-1, Michigan Department of Natural Resources, Lansing, MI. http://www.michigan.gov/deq/0,1607,7-135-3313_3684_41228-141575--,00.html

Rachol, C.M. and K. Boley-Morse. 2009. Estimated Bankfull Discharge for Selected Michigan Rivers and Regional Hydraulic Geometry Curves for Estimating Bankfull Characteristics in Southern Michigan Rivers. U.S. Geologic Survey, Scientific Investigations Report 2009-5133, 300 pp. http://pubs.er.usgs.gov/usgspubs/sir/sir20095133

MINNESOTA
Padmanabhan, G. and B.H. Johnson. 2010. Regional Dimensionless Rating Curves to Estimate Design Flows and Stages. Journal of Spatial Hydrology 10(1): 41-75. http://www.spatialhydrology.com/journal/papersping2010/Regional%20Dimensionless%20Rating%20Curves.pdf

MONTANA
Lawlor, S.M. 2004. Determination of Channel-Morphology Characteristics, Bankfull Discharge, and Various Design-Peak Discharges in Western Montana. U.S. Geologic Survey, Scientific Investigations Report 2004-5263, Reston, VA. http://pubs.usgs.gov/sir/2004/5263/

NEW ENGLAND
Bent, G.C. 2006. Equations for estimating bankfull-channel geometry and discharge for streams in the northeastern United States, In Proceedings of the Joint Federal Interagency Conference, 3rd Federal Interagency Hydrologic Modeling Conference and 8th Federal Interagency Sedimentation Conference, Reno, Nevada, April 2-6, 2006. http://pubs.usgs.gov/misc/FISC_1947-2006/pdf/1st-7thFISCs-CD/8thFISC/8thFISC.pdf

NEW MEXICO
Jackson, F. 1994. Documenting channel condition in New Mexico. Stream Notes Special Summer Issue 1994, Stream Systems Technology Center, U.S. Forest Service, Fort Collins, CO. pg 3-5.

Moody, T., M. Wirtanen and S.N. Yard. 2003. Regional Relationships for Bankfull Stage in Natural Channels of the Arid Southwest, Natural Channel Design, Inc. Flagstaff, AZ. 38 p. http://www.naturalchanneldesign.com/NCD%20Reports.htm

NEW YORK
Baldigo, B. 2004. Regionalization of channel geomorphology characteristics for streams of New York State, excluding Long Island: U.S. Geological Survey, New York Water Science Center. http://ny.water.usgs.gov/projects/summaries/2457-A29-1.html

Bent, G.C. 2006. Equations for estimating bankfull-channel geometry and discharge for streams in the northeastern United States: Proceedings of the Joint Federal Interagency Conference, Book of Abstracts, 3rd Federal Interagency Hydrologic Modeling Conference and 8th Federal Interagency Sedimentation Conference, Reno, NV, April 2-6, 2006, 314 p.

Miller, S.J. and D. Davis. 2003. Optimizing Catskill Mountain regional bankfull discharge and hydraulic geometry relationships: Proceedings of the American Water Resources Association, 2003 International Congress, Watershed management for water supply systems, New York City, NY, June 29-July 2, 2003, 10 p. http://home2.nyc.gov/html/dep/pdf/resources/smp.pdf

Mulvihill, C.I., A.G. Ernst and B.P. Baldigo. 2005. Regionalized equations for bankfull discharge and channel characteristics of streams in New York state: hydrologic region 6 in the southern tier of New York: U.S. Geological Survey Scientific Investigations Report 2005-5100, 21 p. http://ny.water.usgs.gov/pubs/wri/sir055100/sir2005-5100.pdf

Mulvihill, C.I., A.G. Ernst and B.P. Baldigo. 2006. Regionalized equations for bankfull discharge and channel characteristics of streams in New York State: hydrologic region 7 in western New York: U.S. Geological Survey Scientific Investigations Report 2006-5075, 14 p. http://ny.water.usgs.gov/pubs/wri/sir065075/sir2006-5075.pdf

Mulvihill, C.I., A. Filopowicz, A. Coleman and B.P. Baldigo. 2007. Regionalized equations for bankfull discharge and channel characteristics of streams in New York State—hydrologic regions 1 and 2 in the Adirondack region of northern New York: U.S. Geological Survey Scientific Investigations Report 2007-5189, 18 p. http://pubs.usgs.gov/sir/2007/5189/

Mulvihill, C.I. and B.P. Baldigo. 2007. Regionalized equations for bankfull discharge and channel characteristics of streams in New York State—hydrologic region 3 east of the Hudson River: U.S. Geological Survey Scientific Investigations Report 2007–5227, 15 p. http://pubs.usgs.gov/sir/2007/5227/pdf/SIR2007-5227.pdf

Powell, R.O., S.J. Miller, B.E. Westergard, C.I. Mulvihill, B.P. Baldigo, A.S. Gallagher and R.R. Starr. 2004. Guidelines for surveying bankfull channel geometry and developing regional hydraulic-geometry relations for streams of New York State: U.S. Geological Survey Open-File Report 03-092, 20 p.
http://ny.water.usgs.gov/pubs/of/of03092/of03-092.pdf

Westergard, B.E., C.I. Mulvihill, A.G. Ernst and B.P. Baldigo. 2005. Regional equations for bankfull discharge and channel characteristics of stream in New York State -hydrologic region 5 in central New York: U.S. Geological Survey Scientific Investigations Report 2004-5247, 16p. http://ny.water.usgs.gov/pubs/wri/sir045247/

NORTH CAROLINA

Doll, B.A., A.D. Dobbins, J. Spooner, D.R. Clinton and D.A. Bidelspach. 2003. Hydraulic geometry relationships for rural North Carolina Coastal Plain streams, NC Stream Restoration Institute, Report to NC Division of Water Quality for 319 Grant Project No. EW20011, 11 pp. http://www.bae.ncsu.edu/programs/extension/wqg/srp/techresources.html

Doll, B.A., D.E. Wise-Frederick, C.M. Buckner, S.D. Wilkerson, W.A. Harman, R.E. Smith and J. Spooner. 2002. Hydraulic geometry relationships for urban streams throughout the Piedmont of North Carolina. Journal of the American Water Resources Association 38(3): 641-651.

Harman, W.H., G.D. Jennings, J.M. Patterson, D.R. Clinton, L.O. Slate, A.G. Jessup, J.R. Everhart and R.E. Smith. 1999. Bankfull hydraulic geometry relationships for North Carolina streams, in D.S. Olsen and J.P. Potyondy (eds) Proc. Wildland Hydrology Symposium, June 30-July 2, 1999, Bozeman, MT. American Water Resources Association. http://www.bae.ncsu.edu/programs/extension/wqg/srp/techresources.html

Harman, W.H., D.E. Wise, M.A. Walker, R. Morris, M.A. Cantrell, M. Clemmons, G.D. Jennings, D. Clinton and J. Patterson. 2000. Bankkfull regional curves for North Carolina mountain streams, Pgs 185-190 in D.L. Kane (ed) Proc. AWRA Conference on Water Resources in Extreme Environments, Anchorage, AK.
http://www.bae.ncsu.edu/programs/extension/wqg/srp/techresources.html

Sweet, W.V., and J.W. Geratz. 2003. Bankfull hydraulic geometry relationships and recurrence for North Carolina's Coastal Plain. Journal of the American Water Resources Association 39(4): 861-871.

NORTH DAKOTA

Padmanabhan, G. and B.H. Johnson. 2010. Regional Dimensionless Rating Curves to Estimate Design Flows and Stages. Journal of Spatial Hydrology 10(1): 41-75.

OHIO

Chang, T.J., Y.Y. Fang, H. Wu and D.E. Mecklenburg. 2004. Bankfull channel dimensions in southeast Ohio, in Proceedings of the Self-Sustaining Solutions for Streams, Wetlands, and Watersheds Conference, American Society of Agricultural Engineers, September 2004: 9 p.

Sherwood, J.M. and C.A. Huitger. 2005. Bankfull characteristics of Ohio streams and their relation to peak streamflows: U.S. Geological Survey Scientific Investigations Report 2005-5153, 38 p. http://pubs.usgs.gov/sir/2005/5153/pdf/Bankfull_book.pdf

OKLAHOMA

Dutnell, R.C. 2010. Development of Bankfull Discharge and Channel Geometry Relationships for Natural Channel Design in Oklahoma Using a Fluvial Geomorphic Approach, Masters Thesis, University of Oklahoma, Norman, OK. 95 p.
http://www.riverman-engineering.com/index_files/Page473.htm

OREGON

Kuck, T.D. 2000. Regional Hydraulic Geometry Curves of the South Umpqua Area in Southwestern Oregon. Stream Notes, January 2000, Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Ft. Collins, CO.
http://stream.fs.fed.us/news/streamnt/pdf/SN_1_00.pdf

PENNSYLVANIA

Chaplin, J.J. 2005. Development of regional curves relating bankfull-channel geometry and discharge to drainage area for streams in Pennsylvania and selected areas of Maryland, U.S. Geologic Survey, Scientific Investigations Report 2005-5147.

Cinotto, P.J. 2003. Development of regional curves of bankfull-channel geometry and discharge for streams in non-urban Piedmont Physiographic Province, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 03-4014, 27 p.
http://pa.water.usgs.gov/reports/wrir03-4014.pdf

Miller, K.F. 2003. Assessment of channel geometry data through May 2003 in the mid-Atlantic highlands of Maryland, Pennsylvania, Virginia, and West Virginia: U.S. Geological Survey Open-File Report 03-388, 22 p.

White, K.E. 2001. Regional curve development and selection of a references reach in the non-urban lowland sections of the piedmont physiographic province, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 01-4146, 20 p. http://pa.water.usgs.gov/reports/wrir01-4146.pdf

SOUTH CAROLINA

Arcadis. 2004. *Development of South Carolina Rural Piedmont Regional Curves.* Presented at the 2004 NC SRI Southeastern Regional Conference on Stream Restoration. June 21-24, 2004, Winston-Salem, North Carolina.

TENNESSEE

Babbit, G.S. 2005. Bankfull Hydraulic Geometry of Streams Draining the Southwestern Appalachians of Tennessee. Master's Thesis, University of Tennessee. Knoxville, TN. http://www.researchgate.net/publication/36180144_Bankfull_hydraulic_geometry_of_streams_draining_the_Southwestern_Appalachians_of_Tennessee_electronic_resource_

Smith, D. and L. Turrini-Smith. 1999. Western Tennessee fluvial geomorphic regional curves: Report to U. S. Environmental Protection Agency, Region IV, Water Management Division, August 31, 1999. Atlanta, GA.

VERMONT

VDEC. 2006. Vermont regional hydraulic geometry curves. Vermont Department of Environmental Conservation, River Management Program, January 2006, 4 p. http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess.htm

VIRGINIA

Austin, S.H. 2006. Hydraulic geometry equations and coefficients, Virginia Department of Forestry website, http://www.dof.virginia.gov/wq/ref-streams-hyd-geo-coeff.shtml

Keaton, J.N., T. Messinger and E.J. Doheny.2005. Development and analysis of regional curves for streams in the non-urban valley and Ridge physiographic provinces, Maryland, Virginia and West Virginia: U.S. Geological Survey Scientific Report 2005-5076, 116 p. http://pubs.usgs.gov/sir/2005/5076/sir05_5076.pdf

Krstolic, J.L. and J.J. Chaplin. 2007. Bankfull regional curves for streams in the non-urban, non-tidal Coastal Plain Physiographic Province, Virginia and Maryland: U.S. Geological Survey Scientific Investigations Report 2007–5162, 48 p. http://pubs.usgs.gov/sir/2007/5162/pdf/SIR2007-5162.pdf

Lotspeich, R.R. 2009. Regional Curves of Bankfull Channel Geometry for Non-Urban Streams in the Piedmont Physiographic Province, Virginia. U.S. Geological Survey Scientific Investigations Report 2009-5206, 51 p. pubs.usgs.gov/sir/2009/5206/pdf/sir2009-5206.pdf

Miller, K.F. 2003. Assessment of channel geometry data through May 2003 in the mid-Atlantic highlands of Maryland, Pennsylvania, Virginia and West Virginia: U.S. Geological Survey Open-File Report 03-388, 22 p.

WEST VIRGINIA

Keaton, J.N., T. Messinger and E.J. Doheny. 2005. Development and analysis of regional curves for streams in the non-urban valley and ridge physiographic provinces, Maryland, Virginia and West Virginia: U.S. Geological Survey Scientific Report 2005-5076, 116 p. http://pubs.usgs.gov/sir/2005/5076/sir05_5076.pdf

Messinger, T. and J.B. Wiley. 2004. Regional relations in bankfull channel characteristics determined from flow measurements at selected stream-gaging stations in West Virginia, 1911-2002: U.S. Geological Survey Water-Resources Investigations Report 03-4276, 43 p. http://pubs.usgs.gov/wri/wri034276/

Messinger, T. 2009. Regional curves for bankfull channel characteristics in the Appalachian Plateaus, West Virginia: U.S. Geological Survey Scientific Investigations Report 2009-5242, 43 p. http://pubs.usgs.gov/sir/2009/5242/

Miller, K.F. 2003. Assessment of channel geometry data through May 2003 in the mid-Atlantic highlands of Maryland, Pennsylvania, Virginia, and West Virginia: U.S. Geological Survey Open-File Report 03-388, 22 p.

WYOMING

Dunne, T.D. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, NY. 818 p.

Manning’s Equation – Used to Estimate Velocity and Discharge

Velocity (v) in feet per second can be estimated using Manning’s equation as follows:

(1) $V = 1.49*R^{2/3}*S^{1/2}/n$, where

R = the hydraulic radius (ft), defined as the wetted perimeter divided by the cross sectional area,
S = water surface slope (ft/ft),

Once the velocity has been estimated, discharge (Q) in cubic feet per second can be calculated from the continuity equation, as follows:

(2) $Q = VA$, where

V = velocity (ft/s)
A = cross sectional area (ft^2).

If discharge and cross-sectional area are already known, then velocity can be calculated by rearranging the continuity equation as follows:

(3) $V = Q/A$.

In this case, Manning’s equation is not necessary. This calculation provides a simple, but useful check to determine if the average bankfull velocity is in a reasonable range. For example, C and E stream types with valley slopes between 0.5 percent and 1.5 percent often have bankfull velocities between 3 and 5 ft/s. If the bankfull velocity is 7 ft/s, this is an indicator that the design bankfull discharge may be too high.

Estimating Manning's n Values

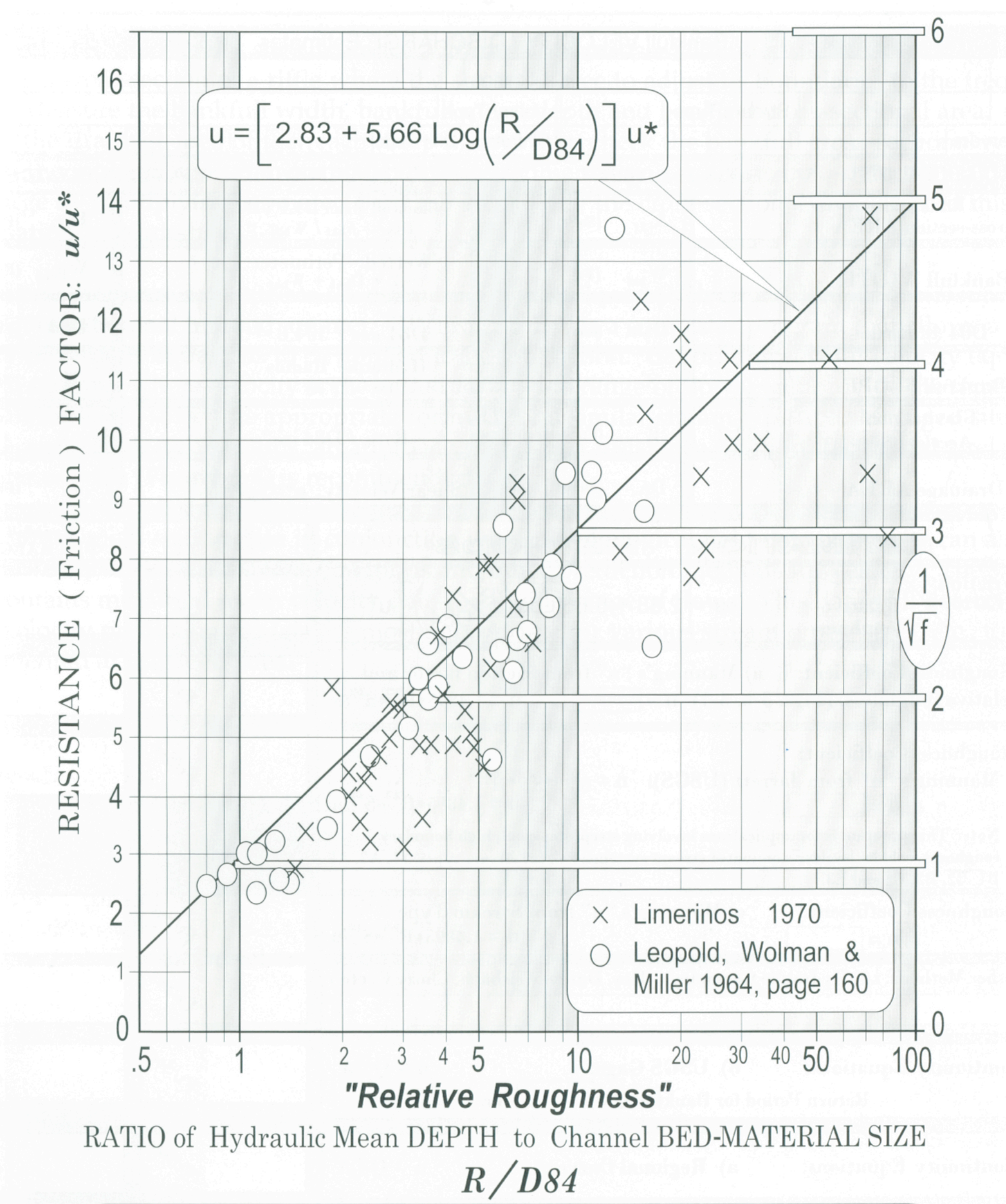
There are a variety of ways to estimate the roughness coefficient "n." A few are provided below.

Table D1: Table of Manning's n values, adapted from *Physical Hydrology* by Lawrence Dingman. The data set is from Chow (1959).

Type of Channel and Description	n Minimum	n Normal	n Maximum
Minor streams (top width at flood stage <100 ft)			
Streams on plain			
1. Clean, straight, full stage, no riffles or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, but lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
Floodplains			
Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160

An alternate method for gravel bed streams is to use data from the project reach and the graph below to determine the Resistance (Friction) Factor. Once the Resistance Factor is known, a second graph can be used to determine the Manning's n value. These two graphs are from *The Reference Reach Field Book* by Dave Rosgen. An overview of the method is described in *Watershed Assessment of River Stability and Sediment Supply*, also by Dave Rosgen.

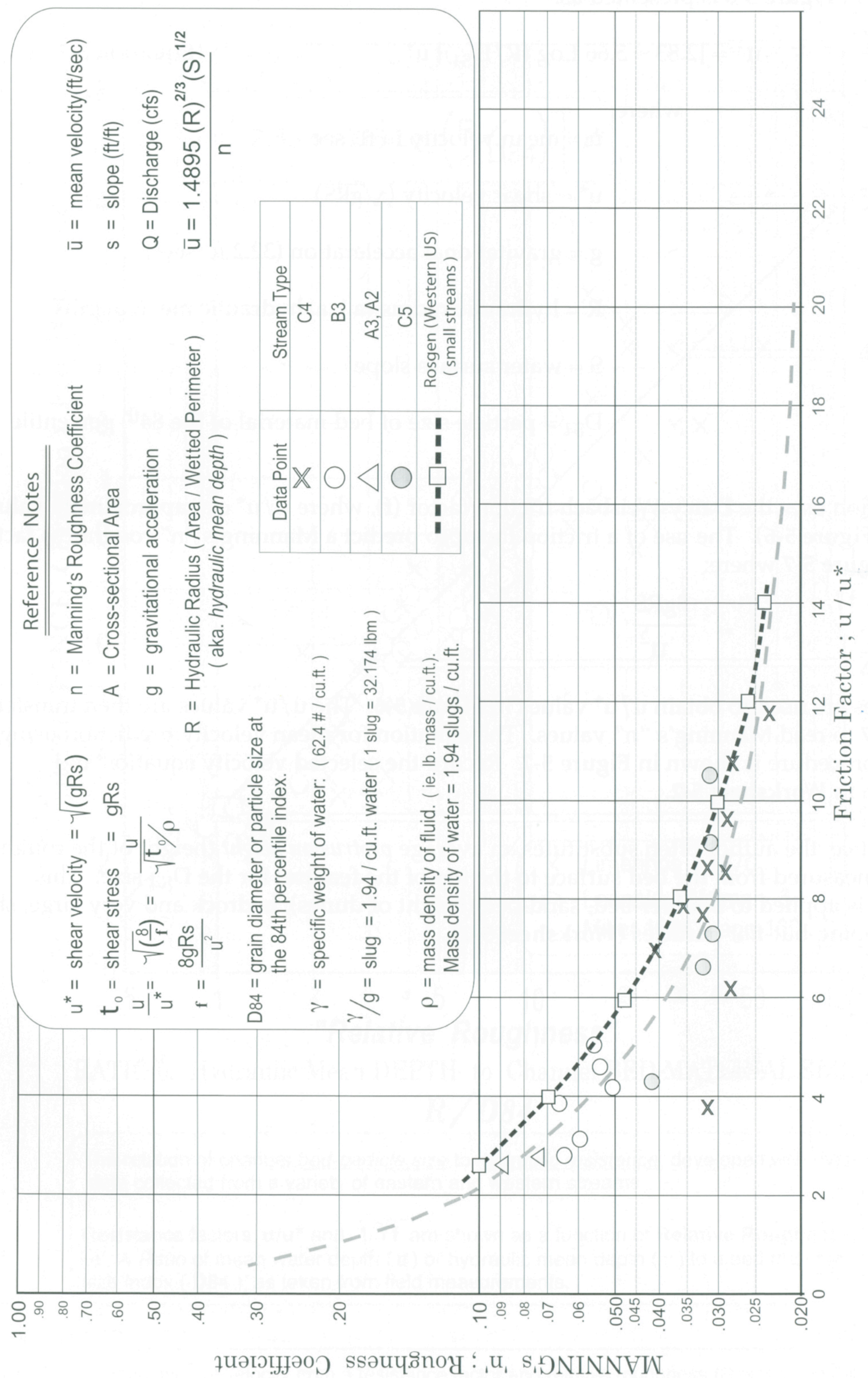
Figure D1: Resistance (Friction) Factor versus Ratio of Mean Depth to Bed Material Size



The relation of channel <u>bed-particle size</u> to <u>hydraulic resistance</u>, developed with river data collected from a variety of eastern and western streams.

Resistance factors, **u/u*** and **1/√f** are shown as a function of **Relative Roughness**, i.e., A *Ratio* of mean water depth (**d**) or hydraulic mean depth (**r**) to a bed-material size index (**D84**), as taken from field measurements.

Figure D2: Manning's n Roughness Coefficient versus Friction Factor



Appendix E
Design Goals and Objectives

Definition of Goals and Objectives

Every stream restoration project, large or small, should have clearly stated goals. The goals should answer the question, "What is the purpose of this project?" Goals may be as specific as stabilizing an eroding streambank that is threatening a road, or as broad as creating functional lift to the maximum extent possible (based on a comparison to a reference condition). Unfortunately, it is common to see a goal that reads, "The purpose of this project is to restore channel dimension, pattern and profile so that the channel doesn't aggrade or degrade over time." The problem with this goal is that it fails to state *why* there is a need to change the channel geometry (dimension, pattern and profile). The goal should address a *problem*, which could be a stability issue, a functional issue or both. The Stream Functions Pyramid described below can be used as an aid in developing function-based goals.

Stream Functions Pyramid

The Stream Functions Pyramid, developed by Harman (2009), provides an approach that organizes stream functions in a pyramid form to illustrate that goal setting, stream assessment methodologies and stream restoration must address functions in a *specific order*. A broad-level view is shown in Figure E1. The functional categories have been modified from Fischenich (2006) to more closely match functions with parameters that are commonly used in the fields of hydrology, hydraulics, geomorphology, physicochemistry (called physicochemical on the pyramid) and biology. This helps the practitioner match the project goal with the corresponding stream functions to avoid the problems described by Fischenich (2006) and Somerville (2010), where practitioners design ineffective projects because they ignore the underlying hydrology, hydraulic and geomorphic functions. Through monitoring, these functions can then be used to determine the overall benefit of the stream restoration project by comparing the baseline functional value to the post restoration value, i.e., the functional lift.

Figure E2 shows a more detailed view of the Pyramid and includes parameters that can be used to describe the function in its corresponding category. These parameters can be structural measures or actual functions, meaning that they are expressed as a rate and relate to a stream process that helps create and maintain the character of the stream corridor. For example, within the Hydrology category, flood frequency is a parameter that can be used to quantify the occurrence of a given discharge. It is not a function, but it does provide critical information about the transport of water from the watershed to the channel, which is a function. Runoff is a parameter and a function (in the Hydrology category). It directly quantifies the amount of water that is being transported from the watershed to the channel, is expressed as a rate (often in cubic feet per second) and helps to define the character of the stream channel. However, the intent of the Pyramid is to use a variety of parameters (structural and/or functions) to describe the overall function of the category, in this case the transport of water from the watershed to the channel. If applied in this way, all parameters on the Pyramid can be thought of as function-based.

Ultimately, the suite of parameters selected will be dependent on the project's goals and budget, since some parameters can be measured quickly and inexpensively and others require long-term monitoring and expensive equipment.

Figure E1: Stream Functions Pyramid

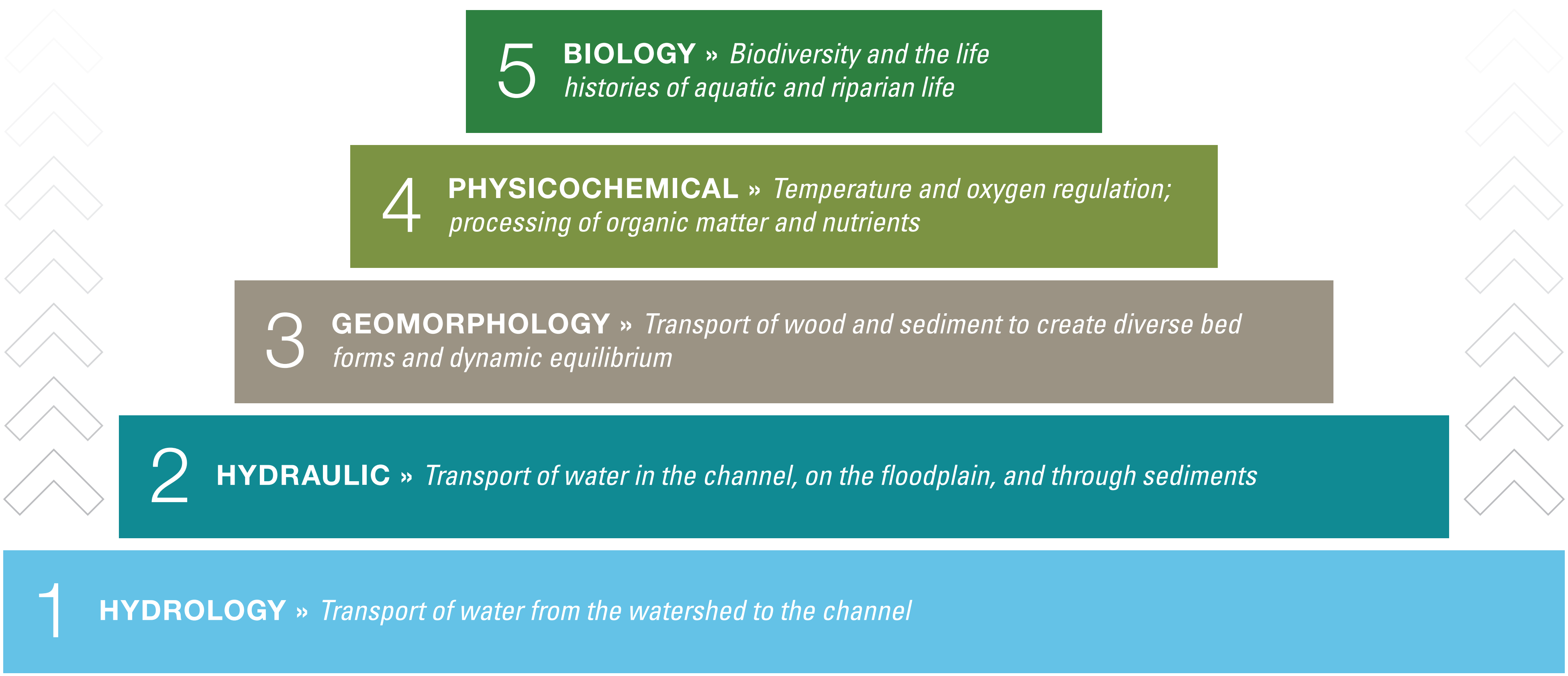


Figure E2: Stream Functions Pyramid

A Guide for Assessing & Restoring Stream Functions » FUNCTIONS & PARAMETERS

5 — BIOLOGY »
FUNCTION: *Biodiversity and the life histories of aquatic and riparian life*
PARAMETERS: *Microbial Communities, Macrophyte Communities, Benthic Macroinvertebrate Communities, Fish Communities, Landscape Connectivity*

4 — PHYSICOCHEMICAL »
FUNCTION: *Temperature and oxygen regulation; processing of organic matter and nutrients*
PARAMETERS: *Water Quality, Nutrients, Organic Carbon*

3 — GEOMORPHOLOGY »
FUNCTION: *Transport of wood and sediment to create diverse bed forms and dynamic equilibrium*
PARAMETERS: *Sediment Transport Competency, Sediment Transport Capacity, Large Woody Debris Transport and Storage, Channel Evolution, Bank Migration/Lateral Stability, Riparian Vegetation, Bed Form Diversity, Bed Material Characterization*

2 — HYDRAULIC »
FUNCTION: *Transport of water in the channel, on the floodplain, and through sediments*
PARAMETERS: *Floodplain Connectivity, Flow Dynamics, Groundwater/Surface Water Exchange*

1 — HYDROLOGY »
FUNCTION: *Transport of water from the watershed to the channel*
PARAMETERS: *Channel-Forming Discharge, Precipitation/Runoff Relationship, Flood Frequency, Flow Duration*

In summary, goals should be based on the functions that are shown in the figure E1 above. Objectives should be based on the function-based parameters shown in E2. Examples are provided below.

Examples of Function-Based Goals and Objectives

Examples of function-based goals and objectives are provided below. The goals are broader than the objectives and communicate why the project is being pursued. The objectives are more specific and can be quantified and evaluated using a variety of measurement methods and performance standards.

Table E1: Example Goals and Objectives.

Goals	Objectives
Restore base flow conditions to a reference condition.	1. Increase flow duration to meet species requirements (Level 1). 2. Restore flow dynamics requirements for species survival (Level 2).
Improve populations of native trout species.	1. Provide adequate flow duration (Level 1). 2. Provide floodplain connectivity (Level 2). 3. Reduce sediment supply from eroding streambanks (streambank erosion rates) (Level 3). 4. Improve bed form diversity (Level 3). 5. Improve the riparian vegetation to provide bank stability and cover (Level 3). 6. Incorporate large woody debris storage to provide habitat for benthic organisms (Level 3). 7. Reduce water temperature and improve dissolved oxygen (basic water chemistry) (Level 4). 8. Increase the biomass of native trout (fish communities) (Level 5).
Reduce channel maintenance, e.g., dredging, and improve aquatic habitat in flood control channels.	1. Reduce runoff through implementation of stormwater best management practices (Level 1). 2. Create a bankfull channel and floodplain bench to transport water in the channel and on the floodplain, thereby providing some floodplain connectivity (Level 2). 3. Create a bankfull channel to improve sediment transport capacity (Level 3). 4. Create alternating riffles and pools to improve bed form diversity (Level 3). 5. Plant riparian vegetation to provide stability and cover (Level 3).
Reduce streambank erosion along the outside of a meander bend to protect an adjacent road. Note: geometry is stable, just bank erosion from the removal of vegetation and subsequent lateral migration. Not a mitigation goal.	1. Reduce streambank erosion rates (bank migration/lateral stability) (Level 3). 2. Improve riparian vegetation composition and density to provide long-term bank stability (Level 3).
Reduce sediment supply from eroding streambanks.	1. If incised, provide floodplain connectivity. 2. Reduce streambank erosion rates (bank migration/lateral stability) (Level 3). 3. Improve riparian vegetation composition and density to provide long-term bank stability (Level 3).

Appendix F
Sample Design Criteria and Reference Reach Data

Table F1 provides sample design criteria from NC streams. Will Harman compiled this information from reference reach surveys and the evaluation of monitoring data from a variety of stream restoration projects. Many of the design ratios are different than the values from reference reach survey ratios based on "lessons learned" from the monitoring data. This data set provides the reviewer with conservative ratios for the stream types shown; however, ratios may vary for streams with different valley slopes, bed material, and vegetation type. Therefore, this is only provided as a guide for reviewing projects and should not be "blindly" used for design purposes.

Table 1: Design Criteria for C, E, and B stream types

	Common Design Ratios											
Parameter	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C4		C5		E4		E5		B4		B4c	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	3.5	5.0	4.0	6.0	4.0	6.0	4.0	6.0	4.0	6.0
Width to Depth Ratio, W/D (ft/ft)	10.0	15.0	10.0	14.0	10.0	12.0	10.0	12.0	12.0	18.0	12.0	18.0
Riffle Max Depth Ratio, Dmax/Dbkf	1.2	1.5	1.1	1.4	1.2	1.4	1.1	1.3	1.2	1.4	1.2	1.4
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1
Meander Length Ratio, Lm/Wbkf	7.0	14.0	7.0	14.0	5.0	12.0	5.0	12.0	N/a	N/a	N/a	N/a
Rc Ratio, Rc/Wbkf	2.0	3.0	2.0	3.0	2.0	3.0	2.0	3.0	N/a	N/a	N/a	N/a
Meander Width Ratio, Wblt/Wbkf	3.5	8.0	3.5	8.0	3.5	10.0	3.5	10.0	N/a	N/a	N/a	N/a
Sinuosity, K	1.20	1.40	1.2	1.5	1.3	1.6	1.3	1.6	1.1	1.2	1.1	1.3
Valley Slope, Sval (ft/ft)	0.0050	0.0150	0.002	0.010	0.002	0.010	0.002	0.006	0.020	0.030	0.005	0.015
Riffle Slope Ratio, Srif/Schan	1.2	1.5	1.1	1.2	1.2	1.5	1.1	1.2	1.1	1.8	1.1	1.8
Run Slope Ratio, Srun/Srif	0.50	0.80	0.5	0.8	0.5	0.8	0.5	0.8	N/a	N/a	N/a	N/a
Glide Slope Ratio, Sglide/Schan	0.30	0.50	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Pool Slope Ratio, Spool/Schan	0.00	0.20	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.4	0.0	0.4
Pool Max Depth Ratio, Dmaxpool/Dbkf	1.5	3.5	1.2	2.5	2.0	3.5	1.2	2.5	2.0	3.5	2.0	3.5
Pool Width Ratio, Wpool/Wbkf	1.2	1.7	1.1	1.7	1.2	1.5	1.1	1.5	1.1	1.5	1.1	1.5
Pool-Pool Spacing Ratio, Lps/Wbkf	3.5	7.0	3.5	7.0	3.5	5.0	3.5	5.0	0.5	5.0	1.5	6.0

Table F2 provides sample reference reach data from NC streams. Will Harman compiled this data from the NC reference reach database, published by NC Department of Transportation and reference reach surveys conducted by Michael Baker Corporation. This data set provides typical reference reach ratios for C, E and B stream types throughout NC and can be used to compare a restoration project to the typical reference reach condition for geomorphology. This data can be used to show how a project reach compares to a reference before and after restoration.

Table 2: Common reference reach ratios for C, E, and B stream types

	Common Reference Reach Ratios											
Parameter	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C4		C5		E4		E5		B4		B4c	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	3.5	5.0	4.0	6.0	4.0	6.0	4.0	6.0	4.0	6.0
Width to Depth Ratio, W/D (ft/ft)	10.0	15.0	10.0	14.0	10.0	12.0	10.0	12.0	12.0	18.0	12.0	18.0
Riffle Max Depth Ratio, Dmax/Dbkf	1.2	1.5	1.1	1.4	1.2	1.4	1.1	1.3	1.2	1.4	1.2	1.4
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.1
Meander Length Ratio, Lm/Wbkf	7.0	14.0	7.0	14.0	5.0	12.0	5.0	12.0	N/a	N/a	N/a	N/a
Rc Ratio, Rc/Wbkf	2.0	3.0	2.0	3.0	1.5	2.5	1.2	2.5	N/a	N/a	N/a	N/a
Meander Width Ratio, Wblt/Wbkf	3.0	8.0	3.0	8.0	2.0	10.0	2.0	10.0	N/a	N/a	N/a	N/a
Sinuosity, K	1.20	1.40	1.2	1.5	1.3	1.6	1.3	1.6	1.1	1.2	1.1	1.3
Valley Slope, Sval (ft/ft)	0.0050	0.0150	0.002	0.010	0.002	0.010	0.002	0.006	0.020	0.030	0.005	0.010
Riffle Slope Ratio, Srif/Schan	1.2	1.5	1.1	1.2	1.2	1.5	1.1	1.2	1.1	1.8	1.1	1.8
Run Slope Ratio, Srun/Srif	0.50	0.80	0.5	0.8	0.5	0.8	0.5	0.8	N/a	N/a	N/a	N/a
Glide Slope Ratio, Sglide/Schan	0.30	0.50	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Pool Slope Ratio, Spool/Schan	0.00	0.20	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.4	0.0	0.4
Pool Max Depth Ratio, Dmaxpool/Dbkf	1.5	3.5	1.2	2.5	2.0	3.5	1.2	2.5	2.0	3.5	2.0	3.5
Pool Width Ratio, Wpool/Wbkf	1.0	1.7	1.0	1.7	0.7	1.5	0.7	1.5	1.1	1.5	1.1	1.5
Pool-Pool Spacing Ratio, Lps/Wbkf	3.0	7.0	3.0	7.0	2.5	5.0	2.5	5.0	0.5	5.0	1.2	6.0

The following are design elements that should be measured by the reviewer and compared to the design criteria table listed above. Ideally, the reviewer will review all of the design criteria; however, the following parameters are the most critical from a stability perspective.

Design Element	Plan Sheet Location
Bank Height Ratio	Cross sections and Profiles
Entrenchment Ratio	Cross sections and Plan Views
Width/Depth Ratio	Cross sections and Plan Views
Bankfull Riffle Width	Plan Views and Cross Sections
Bankfull Pool Width	Cross Sections
Riffle Max Depth Ratio	Cross Sections
Belt Width	Plan Views
Meander Wavelength	Plan Views
Radius of Curvature	Plan Views
Sinuosity	Plan Views

Other Sources of Reference Reach Data

Hey, R.D. 2006. Fluvial Geomorphological Methodology for Natural Stable Channel Design. *Journal of American Water Resources Association*. April 2006. Vol. 42, No. 2. pp. 357-374. AWRA Paper No. 02094.

Rinaldi, M. and P.A. Johnson. 1997. Stream Meander Restoration. *Journal of the American Water Resources* Association. Vol. 33, No 4. pp 855-866. AWRA Paper No. 96135.

Starr, R. R., T.L. McCandless, C.K. Eng, S.L. Davis, M.A. Secrist and C.J. Victoria. 2010. Western Coastal Plain Reference Reach Survey. Stream Habitat Assessment and Restoration Program, U.S. Fish and Wildlife Service, Chesapeake Bay Field Office. CBFO-S10-02. http://www.fws.gov/chesapeakebay/streampub.html

Competency Curve

For gravel bed streams, the design criteria can also be evaluated by comparing the design depth to the required depth if pavement and bar/subpavement samples are collected along with a riffle cross section and slope measurement. The method for calculating the required depth is provided by Rosgen (2006a). If a bar/subpavement sample has not been collected, the reviewer can check to see what size particle should be transported at a bankfull discharge by calculating the boundary shear stress as follows and using the curve in Figure F1.

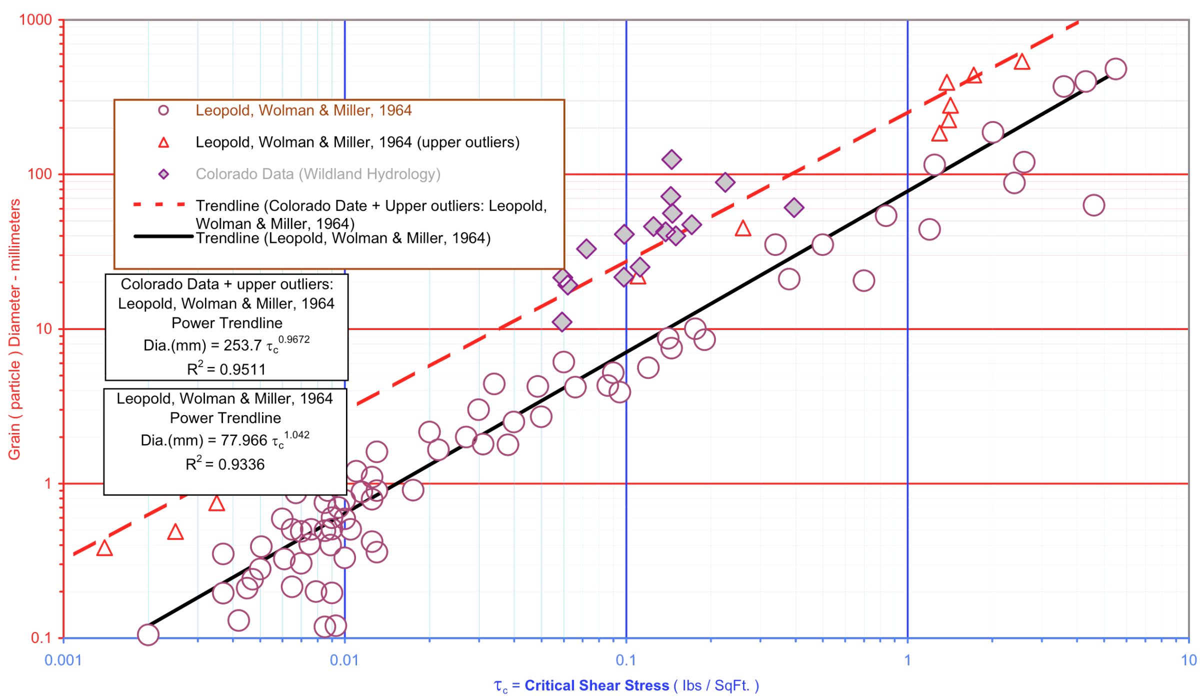
Boundary shear stress is calculated as:

(2) $\tau = \gamma RS$, where

τ = Boundary Shear Stress (lbs/ft^2)
R= Hydraulic Radius (Ft), measured from the bankfull stage
S= Average Water Surface Slope

Once the boundary shear stress in known, the upper curve is used in Figure F1 to predict the particle that is transported during a bankfull discharge.

Figure F1: Sediment Transport Competency Curve from Rosgen (2006a)



Example Stream Morphological Tables

Tables F3 and F4 show a blank and completed stream morphology table, respectively. These examples are provided by the U.S. Fish and Wildlife Service, Chesapeake Bay Field Office. These forms are often completed as part of a natural channel design project.

Table F3: Blank Stream Morphology Table; Table F4: Example of a completed Stream Morphology Table

Selected Morphological Characteristics

No.	Variable	Symbol	Units		Project Site Data	Reference Reach Data	Proposed Design Criteria
1	Stream type						
2	Drainage area		mi^2				
3	Riffle Bankfull width	W_{bkf}	feet	Mean			
				Range			
4	Riffle Bankfull mean depth	d_{bkf}	feet	Mean			
				Range			
5	Width depth ratio	W/d		Mean			
				Range			
6	Riffle Bankfull cross sectional area	A_{bkf}	ft_2	Mean			
				Range			
7	Bankfull mean velocity	V_{bkf}	ft/sec	Mean			
				Range			
8	Bankfull discharge	Q_{bkf}	cfs	Mean			
				Range			
9	Riffle Bankfull maximum depth	d_{max}	feet	Mean			
				Range			
10	Max Riffle depth/ Mean riffle depth	d_{riff}/d_{bkf}		Mean			
				Range			
11	Low bank height to max d_{bkf} ratio			Mean			
				Range			
12	Width of flood prone area	W_{fpa}	feet	Mean			
				Range			
13	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean			
				Range			
14	Meander Length	L_m	feet	Mean			
				Range			
15	Ratio of meander length to bankfull width	L_m/W_{bkf}		Mean			
				Range			
16	Radius of curvature	R_c		Mean			
				Range			
17	Ratio: Radius of curvature to bankfull width	R_c/W_{bkf}		Mean			
				Range			
18	Belt Width	W_{blt}	feet	Mean			
				Range			
19	Meander width ratio	W_{blt}/W_{bkf}		Mean			
				Range			
20	Sinuosity	K		Mean			
				Range			
21	Valley Slope	S_{val}	ft/ft				
22	Average Water Surface Slope	S_{avg}	ft/ft	Mean			
				Range			
23	Pool Water Surface Slope	S_{pool}	ft/ft	Mean			
				Range			
24	Pool WS slope / Average WS slope	S_{pool}/S_{avg}		Mean			
				Range			
25	Riffle Water Surface slope	Sriff	ft/ft	Mean			
				Range			
26	Riffle WS slope / Average WS slope	S_{rifF}/S_{avg}		Mean			
				Range			
27	Run WS Slope	S_{run}/S_{avg}	ft/ft	Mean			
				Range			

Selected Morphological Characteristics

No.	Variable	Symbol	Units		Project Site Data	Reference Reach Data	Proposed Design Criteria
28	Run WS slope / Average WS slope	S_{run}/S_{avg}	ft/ft	Mean			
				Range			
29	Glide WS Slope	S_{glide}		Mean			
				Range			
30	Glide WS slope / Average WS slope	S_{glide}/S_{avg}	ft/ft	Mean			
				Range			
31	Maximum pool depth	d_{pool}	feet	Mean			
				Range			
32	Ratio of max pool depth to average bankfull depth	d_{pool}/d_{bkf}		Mean			
				Range			
33	Max Run Depth	d_{run}	feet	Mean			
				Range			
34	Ratio of max run depth to average bankfull depth	d_{run}/d_{bkf}		Mean			
				Range			
35	Max Glide Depth	d_{glide}	feet	Mean			
				Range			
36	Ratio of max glide depth to average bankfull depth	d_{glide}/d_{bkf}	feet	Mean			
				Range			
37	Pool width	W_{pool}	feet	Mean			
				Range			
38	Ratio of pool width to bankfull width	W_{pool}/W_{bkf}		Mean			
				Range			
39	Ratio of pool area to bankfull area	A_{pool}/A_{bkf}		Mean			
				Range			
40	Point bar slope	S_{pb}		Mean			
				Range			
41	Pool to pool spacing	p-p	feet	Mean			
				Range			
42	Ratio of pool to pool spacing to bankfull width	$p\text{-}p/W_{bkf}$		Mean			
				Range			
Materials							
	Particle Size Distribution Channel	D_{16}	mm				
		D_{35}	mm				
		D_{50}	mm				
		D_{84}	mm				
		D_{95}	mm				
	Particle Size Distribution Bar	D_{16}	mm				
		D_{35}	mm				
		D_{50}	mm				
		D_{84}	mm				
		D_{95}	mm				
	Largest Particle Size		mm				
Sediment Transport Validation							
	Bankfull shear stress	t	lbs/ft^2				
	Critical Sediment Size from Shield Curve	D_{crit}	mm				
	Minimum mean dbkf using critical dimensionless shear stress	d_r	feet				

Daniels Run
Reference Reach Design Criteria

No.	Variable	Symbol	Units		Colorado[1]	Maryland Piedmont[2]		Rock Creek, Washington, D.C.[3]	Silas Creek, Winston, NC[4]	Proposed	
1	Stream Type				C4	C4	B4/1c	B4/1c	B4/1c	C4	B4/1c
2	Drainage Area		mi^2	Mean	n/a	n/a	27.0	n/a	3.3	1.9	1.9
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3	Riffle Bankfull Mean Depth	d_{bkf}	ft	Mean	n/a	n/a	4.0	3.8	1.8	1.3	1.4
				Min	n/a	n/a	n/a	n/a	1.6	2.1	1.7
				Max	n/a	n/a	n/a	n/a	1.9	0.7	1.2
4	Riffle Bankfull Width	W_{bkf}	ft	Mean	n/a	n/a	44.8	89.6	25.6	19.0	21.0
				Min	n/a	n/a	n/a	n/a	23.1	n/a	n/a
				Max	n/a	n/a	n/a	n/a	28.0	n/a	n/a
5	Width/Depth Ratio	W/d_{bkf}		Mean	15.0	15.0	11.2	23.3	14.6	15.0	14.6
				Min	12.0	9.0	n/a	n/a	12.4	9.0	12.4
				Max	18.0	27.0	n/a	n/a	17.2	18.0	17.2
6	Riffle Bankfull Cross Sectional Area	A_{bkf}	ft^2	Mean	n/a	n/a	179.3	344.0	43.7	29.3	33.8
				Min	n/a	n/a	n/a	n/a	38.5	n/a	n/a
				Max	n/a	n/a	n/a	n/a	48.9	n/a	n/a
7	Riffle Bankfull Maximum Depth	d_{max}	ft	Mean	n/a	n/a	4.7	5.6	2.7	1.7	2.2
				Min	n/a	n/a	n/a	n/a	2.1	1.5	1.9
				Max	n/a	n/a	n/a	n/a	3.2	1.9	2.5
8	Max. Riffle Depth/Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.4	n/a	1.2	1.5	1.5	1.4	1.5
				Min	1.2	n/a	n/a	n/a	1.3	1.2	1.3
				Max	1.5	n/a	n/a	n/a	1.7	1.5	1.7
9	Mean Pool Depth	d_{bkfp}	ft	Mean	n/a	n/a	n/a	n/a	n/a	1.6	n/a
				Min	n/a	n/a	n/a	n/a	n/a	1.4	n/a
				Max	n/a	n/a	n/a	n/a	n/a	1.9	n/a
10	Mean Pool Depth/Mean Riffle Depth	d_{bkfp}/d_{bkf}		Mean	n/a	1.3	n/a	n/a	4.5	1.3	n/a
				Min	n/a	1.1	n/a	n/a	4.0	1.1	n/a
				Max	n/a	1.5	n/a	n/a	5.0	1.5	n/a
11	Pool Width	W_{bkfp}	ft	Mean	n/a	n/a	n/a	n/a	25.3	22.8	20.8
				Min	n/a	n/a	n/a	n/a	22.6	19.0	20.6
				Max	n/a	n/a	n/a	n/a	28.0	26.6	21.0
12	Pool Width/Riffle Width	W_{bkfp}/W_{bkf}		Mean	1.5	1.2	n/a	n/a	1.0	1.2	1.0
				Min	1.3	1.0	n/a	n/a	1.0	1.0	1.0
				Max	1.7	1.4	n/a	n/a	1.0	1.4	1.0
13	Pool Bankfull Cross Sectional Area	A_{pool}	ft^2	Mean	n/a	n/a	n/a	n/a	72.1	38.1	67.6
				Min	n/a	n/a	n/a	n/a	53.3	32.2	n/a
				Max	n/a	n/a	n/a	n/a	90.5	43.9	n/a
14	Pool Area/Riffle Area	A_{pool}/A_{bkf}		Mean	n/a	1.3	n/a	n/a	1.7	1.3	2.0
				Min	n/a	1.1	n/a	n/a	1.2	1.1	n/a
				Max	n/a	1.5	n/a	n/a	2.1	1.5	n/a
15	Max. Pool Depth	d_{mbkfp}	ft	Mean	n/a	n/a	n/a	9.2	4.5	3.0	3.7
				Min	n/a	n/a	n/a	n/a	4.0	2.4	3.5
				Max	n/a	n/a	n/a	n/a	5.0	3.9	3.9
16	Max. Pool Depth/Mean Riffle Depth	d_{mbkfp}/d_{bkf}		Mean	3.0	2.4	n/a	2.4	2.6	2.4	2.6
				Min	2.5	1.9	n/a	n/a	2.5	1.9	2.5
				Max	3.5	3.1	n/a	n/a	2.7	3.1	2.7
17	Low Bank Height	LBH	ft	Mean	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
18	Low Bank Height/Max. Riffle Depth	LBH/d_{mbkf}		Mean	n/a	n/a	n/a	n/a	1.0	1.0	1.0
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
19	Width of Flood Prone Area	W_{fpa}	ft	Mean	n/a	n/a	n/a	n/a	33.5	228.0	29.4
				Min	n/a	n/a	n/a	n/a	27.7	76.0	46.2
				Max	n/a	n/a	n/a	n/a	39.2	456.0	n/a
20	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	n/a	12.0	n/a	1.4	1.3	12.0	1.4
				Min	n/a	4.0	n/a	n/a	1.2	4.0	2.2
				Max	n/a	24.0	n/a	n/a	1.4	24.0	n/a
21	Point Bar Slope	$S_{pt. bar}$	ft/ft	Mean	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
22	Bankfull Mean Velocity	u_{bkf}	ft/sec	Mean	n/a	n/a	n/a	n/a	4.6	2.8	3.7
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
23	Bankfull Discharge	Q_{bkf}	cfs	Mean	n/a	n/a	n/a	n/a	199.0	109.5	125.6
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
24	Meander Length	L_m	ft	Mean	n/a	n/a	n/a	n/a	187.0	159.6	153.7
				Min	n/a	n/a	n/a	n/a	130.0	72.2	118.2
				Max	n/a	n/a	n/a	n/a	245.0	254.6	183.8
25	Meander Length Ratio	L_m/W_{bkf}		Mean	11.5	8.4	n/a	n/a	7.3	8.4	7.3
				Min	9.0	3.8	n/a	n/a	5.6	3.8	5.6
				Max	14.0	13.4	n/a	n/a	8.8	13.4	8.8
26	Radius of Curvature	R_c	ft	Mean	n/a	n/a	n/a	n/a	38.6	53.2	31.7
				Min	n/a	n/a	n/a	n/a	18.5	19.0	16.8
				Max	n/a	n/a	n/a	n/a	58.8	123.5	44.1
27	Ratio of Radius of Curvature/Bankfull Width	R_c/W_{bkf}		Mean	2.8	2.8	n/a	n/a	1.5	2.8	1.5
				Min	2.5	1.0	n/a	n/a	0.8	1.0	0.8
				Max	3.0	6.5	n/a	n/a	2.1	6.5	2.1

Daniels Run
Reference Reach Design Criteria

No.	Variable	Symbol	Units		Colorado[1]	Maryland Piedmont[2]		Rock Creek, Washington, D.C.[3]	Silas Creek, Winston, NC[4]	Proposed	
28	Belt Width	W_{blt}	ft	Mean	n/a	n/a	102.0	n/a	45.5	55.1	37.4
				Min	n/a	n/a	n/a	n/a	40.0	34.2	30.0
				Max	n/a	n/a	n/a	n/a	51.0	114.0	38.2
29	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	12.5	2.9	2.3	n/a	1.8	2.9	1.8
				Min	9.0	1.8	n/a	n/a	1.4	1.8	1.4
				Max	16.0	6.0	n/a	n/a	1.8	6.0	1.8
30	Individual Pool Length	L_{pool}	ft	Mean	n/a	n/a	n/a	166.0	n/a	28.5	n/a
				Min	n/a	n/a	n/a	n/a	n/a	19.0	n/a
				Max	n/a	n/a	n/a	n/a	n/a	38.0	n/a
31	Pool Length/Riffle Width	L_{pool}/W_{bkf}		Mean	1.5	n/a	n/a	1.9	n/a	1.5	n/a
				Min	1.0	n/a	n/a	n/a	n/a	1.0	n/a
				Max	2.0	n/a	n/a	n/a	n/a	2.0	n/a
32	Pool to Pool Spacing (based on pattern)	p-p	ft	Mean	n/a	n/a	n/a	n/a	76.6	114.0	63.0
				Min	n/a	n/a	n/a	n/a	27.2	95.0	24.8
				Max	n/a	n/a	n/a	n/a	126.0	133.0	94.5
33	Pool to Pool Spacing/ Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	6.0	n/a	n/a	n/a	3.0	6.0	3.0
				Min	5.0	n/a	n/a	n/a	1.2	5.0	1.2
				Max	7.0	n/a	n/a	n/a	4.5	7.0	4.5
34	Stream Length	SL	ft		n/a	n/a	n/a	n/a	n/a	n/a	n/a
35	Valley Length	VL	ft		n/a	n/a	n/a	n/a	n/a	n/a	n/a
36	Valley Slope	VS	ft/ft		n/a	n/a	n/a	n/a	0.0089	n/a	n/a
37	Average Water Surface	S	ft/ft		n/a	n/a	0.0022	0.0037	0.0082	0.0047	0.0051
38	Sinuosity	K		SL/VL	n/a	1.3	1.2	n/a	n/a	1.2	1.2
				VS/S	n/a	n/a	n/a	n/a	1.1	n/a	n/a
39	Riffle Slope (water surface facet slope)	S_{riff}	ft/ft	Mean	n/a	n/a	n/a	0.0141	0.0360	0.0106	0.0194
				Min	n/a	n/a	n/a	0.0053	n/a	0.0071	0.0073
				Max	n/a	n/a	n/a	0.0229	n/a	0.0141	0.0316
40	Ratio of Riffle Slope/ Average Water Surface Slope	S_{riff}/S		Mean	2.3	n/a	n/a	3.8	4.4	2.3	3.8
				Min	1.5	n/a	n/a	1.4	n/a	1.5	1.4
				Max	3.0	n/a	n/a	6.2	n/a	3.0	6.2
41	Run Slope (water surface facet slope)	S_{run}	ft/ft	Mean	n/a	n/a	n/a	0.0033	0.0070	0.0031	0.0045
				Min	n/a	n/a	n/a	0.0001	n/a	0.0024	0.0001
				Max	n/a	n/a	n/a	0.0080	n/a	0.0038	0.0110
42	Ratio of Run Slope/ Average Water Surface Slope	S_{run}/S		Mean	0.7	n/a	n/a	0.9	0.9	0.7	0.9
				Min	0.5	n/a	n/a	0.0	n/a	0.5	0.0
				Max	0.8	n/a	n/a	2.2	n/a	0.8	2.2
43	Pool Slope (water surface facet slope)	S_{pool}	ft/ft	Mean	n/a	n/a	n/a	0.0001	0.0000	0.0012	0.0000
				Min	n/a	n/a	n/a	n/a	0.0000	0.0009	0.0000
				Max	n/a	n/a	n/a	n/a	0.0819	0.0014	n/a
44	Ratio of Pool Slope/ Average Water Surface Slope	S_{pool}/S		Mean	0.3	n/a	n/a	0.0	0.0	0.3	0.0
				Min	0.2	n/a	n/a	n/a	0.0	0.2	0.0
				Max	0.3	n/a	n/a	n/a	16.1	0.3	n/a
45	Glide Slope (water surface facet slope)	S_{glide}	ft/ft	Mean	n/a	n/a	n/a	0.0001	0.0070	0.0019	0.0001
				Min	n/a	n/a	n/a	n/a	n/a	0.0014	n/a
				Max	n/a	n/a	n/a	n/a	n/a	0.0024	n/a
46	Ratio of Glide Slope/ Average Water Surface Slope	S_{glide}/S		Mean	0.4	n/a	n/a	0.0	0.9	0.4	0.0
				Min	0.3	n/a	n/a	n/a	n/a	0.3	n/a
				Max	0.5	n/a	n/a	n/a	n/a	0.5	n/a
	Step Slope (water surface facet slope)	S_{step}	ft/ft	Mean	n/a	n/a	n/a	0.1200	n/a	n/a	0.1654
				Min	n/a	n/a	n/a	0.0600	n/a	n/a	0.0827
				Max	n/a	n/a	n/a	0.1700	n/a	n/a	0.2343
	Ratio of Step Slope/ Average Water Surface Slope	S_{step}/S		Mean	n/a	n/a	n/a	32.4	n/a	n/a	32.4
				Min	n/a	n/a	n/a	16.2	n/a	n/a	16.2
				Max	n/a	n/a	n/a	45.9	n/a	n/a	45.9
47	Max. Run Depth	$d_{mbkfrun}$	ft	Mean	n/a	n/a	n/a	6.1	3.3	2.6	2.3
				Min	n/a	n/a	n/a	5.6	n/a	2.4	2.1
				Max	n/a	n/a	n/a	6.7	n/a	2.8	2.5
48	Ratio of Max. Run Depth/ Mean Bankfull Depth	$d_{mbkfrun}/d_{bkf}$		Mean	2.1	n/a	n/a	1.6	1.9	2.1	1.6
				Min	1.9	n/a	n/a	1.5	n/a	1.9	1.5
				Max	2.2	n/a	n/a	1.8	n/a	2.2	1.8
49	Max. Glide Depth	$d_{mbkfglide}$	ft	Mean	n/a	n/a	n/a	5.1	3.3	n/a	2.3
				Min	n/a	n/a	n/a	n/a	n/a	n/a	1.9
				Max	n/a	n/a	n/a	n/a	n/a	n/a	2.7
50	Ratio of Max. Glide Depth/ Mean Bankfull Depth	$d_{mbkfglide}/d_{bkf}$		Mean	n/a	n/a	n/a	1.3	1.9	n/a	1.6
				Min	n/a	n/a	n/a	n/a	n/a	n/a	1.3
				Max	n/a	n/a	n/a	n/a	n/a	n/a	1.9
	Max. Step Depth	$d_{mbkfstep}$	ft	Mean	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Ratio of Max. Step Depth/ Mean Bankfull Depth	$d_{mbkfstep}/d_{bkf}$		Mean	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Min	n/a	n/a	n/a	n/a	n/a	n/a	n/a
				Max	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Materials											
51	Particle Size Distribution of Stream	D_{16}	mm		n/a	n/a	n/a	0.4	n/a	n/a	n/a
		D_{35}	mm		n/a	n/a	0.1	21.3	n/a	n/a	n/a
		D_{50}	mm		n/a	n/a	0.4	54.5	n/a	n/a	n/a
		D_{84}	mm		n/a	n/a	32.0	238.2	n/a	n/a	n/a
		D_{95}	mm		n/a	n/a	59.6	402.0	n/a	n/a	n/a

Daniels Run
Reference Reach Design Criteria

No.	Variable	Symbol	Units	Colorado[1]	Maryland Piedmont[2]		Rock Creek, Washington, D.C.[3]	Silas Creek, Winston, NC[4]	Proposed	
52	Particle Size Distribution of Channel Material (active bed)	D_{16}	mm	n/a	n/a	0.1	n/a	0.3	n/a	n/a
		D_{35}	mm	n/a	n/a	6.0	n/a	0.9	n/a	n/a
		D_{50}	mm	n/a	n/a	12.7	n/a	22.6	n/a	n/a
		D_{84}	mm	n/a	n/a	36.4	n/a	200.0	n/a	n/a
		D_{95}	mm	n/a	n/a	59.6	n/a	>2048	n/a	n/a
53	Particle Size Distribution of Bar Material	D_{16}	mm	n/a	n/a	n/a	n/a	1.8	n/a	n/a
		D_{35}	mm	n/a	n/a	n/a	n/a	15.0	n/a	n/a
		D_{50}	mm	n/a	n/a	n/a	n/a	32.0	n/a	n/a
		D_{84}	mm	n/a	n/a	n/a	n/a	96.0	n/a	n/a
		D_{95}	mm	n/a	n/a	n/a	n/a	117.0	n/a	n/a
54	Largest Size Particle at	mm		n/a	n/a	n/a	n/a	n/a	n/a	n/a

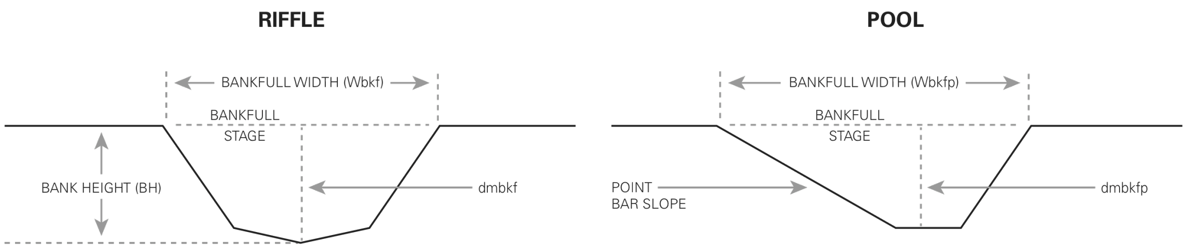
1. Data collected by Wildland Hydrology, Inc.
2. Data collected by the Service for the Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Piedmo Hydrologic Region (McCandless and Everett 2002
3. Data collected by the Service
4. Data collected by Clear Creeks Consultants, Inc

Morphological Measurements

Illustrations of how to measure stream morphology, including the dimensionless ratios, are shown below in Figures F2 – F4.

Figure F2: Channel Dimension Measurements

CHANNEL DIMENSION MEASUREMENTS & RATIOS

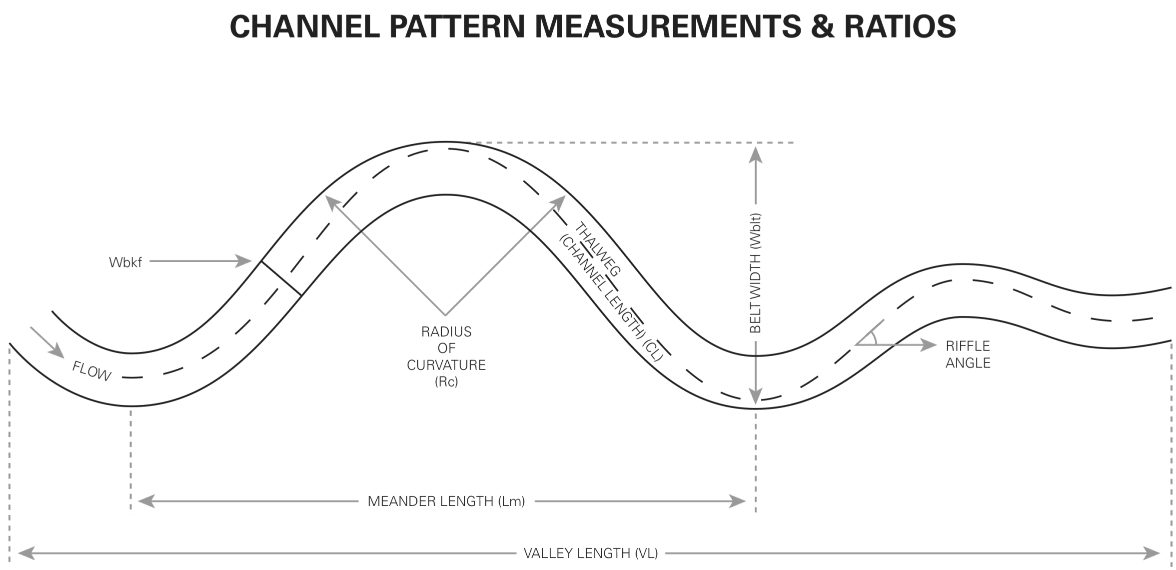


CHANNEL DIMENSION CALCULATIONS
POOL WIDTH / RIFFLE WIDTH (Wbkfp / Wbkf)
MAX. POOL DEPTH / MEAN RIFFLE DEPTH (dmbkfp / dbkf)
MAX. RIFFLE DEPTH / MEAN RIFFLE DEPTH (dmbkf / dbkf)
RIFFLE WIDTH / MEAN RIFFLE DEPTH (Wbkf / dbkf)

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

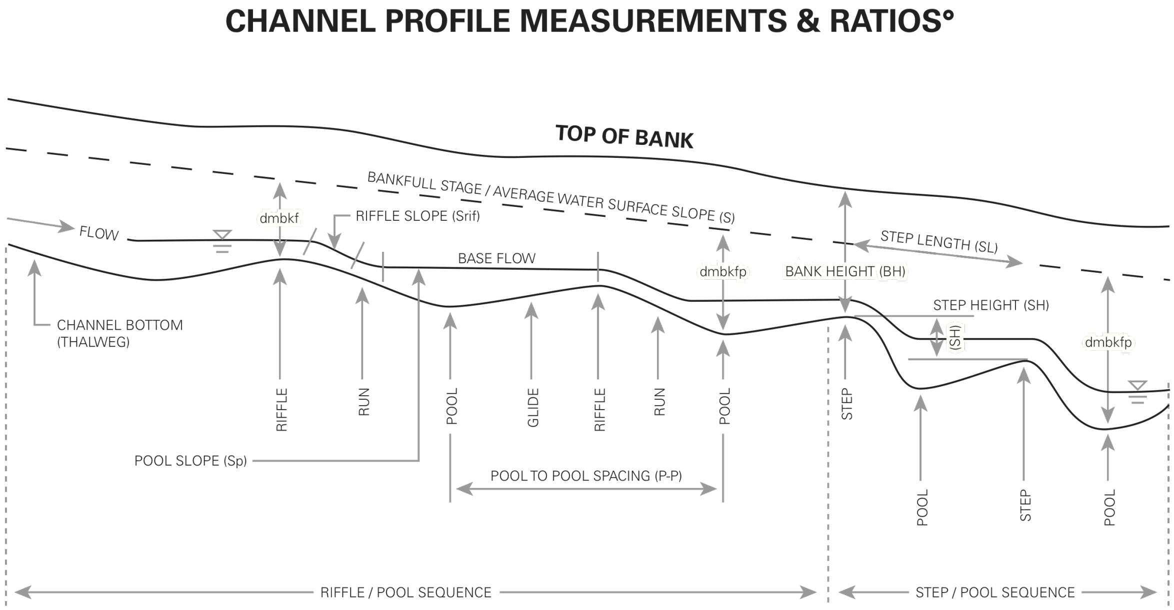
$$\text{BANK HEIGHT RATIO (BHR)} = \frac{\text{BH}}{\text{dmbkf}}$$

Figure F3: Channel Pattern Measurements



CHANNEL PATTERN CALCULATIONS
RADIUS OF CURVATURE / RIFFLE WIDTH (Rc / Wbkf)
MEANDER LENGTH / RIFFLE WIDTH (Lm / Wbkf)
MEANDER WIDTH RATIO (MWR = Wblt / Wbkf)
SINUOSITY (K) = CHANNEL LENGTH (CL) / VALLEY LENGTH (VL)

Figure F4: Channel Profile Measurements



CHANNEL PROFILE CALCULATIONS
PROFILE SLOPE / AVERAGE WATER SURFACE SLOPE (Srif / S)
POOL SLOPE / AVERAGE WATER SURFACE SLOPE (Spool / S)
POOL TO POOL SPACING / RIFFLE WIDTH (P-P / Wbkf)
BANK HEIGHT (BH) / MAX RIFFLE DEPTH (Dmbkf)

Appendix G
In-stream Structures

By: Will Harman[1], Kevin Tweedy[2], and Micky Clemmons[2]
[1] Stream Mechanics
[2] Michael Baker Corporation

Select In-Stream Structures

In-steam structures are used in restoration design to provide channel stability and promote certain habitat types. In-stream structures may be necessary because newly constructed channels often do not have dense riparian vegetation and roots that provide bank stability, nor do they exhibit a natural distribution of stream bed material that provides armoring during sediment transport. In-stream structures are used to provide stability to the system until these natural processes evolve to provide long-term stability and function to the system. Table G-1 summarizes the uses of in-stream structures.

Table G1: Proposed In-Stream Structure Types and Locations

Structure Type	Location
Root Wads	Outer meander bends; other areas of concentrated shear stresses and flow velocities along banks.
Brush Mattresses	Outer meander bends; areas where bank sloping is constrained; areas susceptible to high velocity flows.
Constructed Riffles	Used in typical riffle locations, such as between meander bends or long straight reaches of channel, especially in areas of new channel construction where natural bed sorting is not established.
Cross Vanes	Long riffles; tails of pools if used as a step; areas where the channel is overly wide; areas where stream gradient is steep and where grade control is needed.
Single Vanes and J-hooks	Outer meander bends; areas where flow direction changes abruptly; areas where pool habitat for fish species is desirable.
Cover Logs	Used in pools where habitat for fish species is desirable.
Log Weirs / Steps	Steps of smaller streams.

Root Wads

Root wads are placed at the toe of the stream bank in the outside of meander bends and other areas of concentrated shear stresses along stream banks for the creation of habitat and for bank protection. Root wads include the root mass or root ball of a tree, plus a portion of the trunk. They are used to armor a stream bank by deflecting stream flows away from the bank. In addition to stream bank protection, they provide structural support to the stream bank and habitat for fish and other aquatic animals. Banks underneath root wads tend to become slightly undercut, forming an area of deep water, shade and cover for a variety of fish species. Organic debris tends to collect on the root stems that reach out into the channel, providing a food source for numerous macroinvertebrate species.

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

Cross Vanes
Cross vanes are used to provide grade control, keep the thalweg in the center of the channel, and protect the stream bank. A cross vane consists of two rock or log vanes joined by a center structure installed perpendicular to the direction of flow. This center structure sets the invert elevation of the stream bed. Cross vanes are typically installed at the tails of riffles or pools (steep gradient streams) or within long riffle sections to promote pool formation and redirect flows away from streambanks. Cross vanes are also used where stream gradient becomes steeper, such as downstream end of a small tributary that flows into a large stream.
Due to the increased flow velocity and gradient, scour pools form downstream of cross vanes. Pool depth will depend on the configuration of the structure, flow velocity and gradient, and bed material of the stream. For many fish species, these pools form areas of refuge due to increased water depth, and prime feeding areas as food items are washed into the pool from the riffle or step directly upstream.

Single Vanes and J-Hooks
Vanes are most often located in meander bends just downstream of the point where the stream flow intercepts the bank at acute angles. Vanes may be constructed out of logs or rock boulders. The structures turn water away from the banks and redirect flow energies toward the center of the channel. In addition to providing stability to streambanks, vanes also promote pool scour and provide structure within the pool habitat. J-hooks are vane structures that have two to three boulders placed in a hook shape at the upstream end of the vane. The boulders are placed with gaps between them to promote flow convergence through the rocks and increased scour of the downstream pool. Due to the increased scour depths and additional structure that is added to the pool, J-hooks are primarily used to enhance pool habitat for fish species. The boulders that cause flow convergence also create current breaks and holding areas along feeding lanes. The boulders also tend to trap leaf packs and small woody debris that are used as a food source for macroinvertebrate species.

Constructed Riffle
A constructed riffle is created by placing coarse bed material in the stream at specific riffle locations along the profile. The purpose of this structure is to provide initial grade control and establish riffle habitat within the restored channel, prior to the formation of an armored streambed. Constructed riffles function in a similar way as natural riffles; the gravel and cobble surfaces and interstitial spaces are crucial to the lifecycles of many aquatic macroinvertebrate species.

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

Log Weirs
A log weir consists of a header log and a footer log placed in the bed of the stream channel, perpendicular or at an angle to stream flow, depending on the size of the stream. The logs extend into the stream banks on both sides of the structure to prevent erosion and bypassing of the structure. The logs are installed flush with the channel bottom upstream of the log. The footer log is placed to the depth of scour expected, to prevent the structure from being undermined. This weir structure creates a "step" – or abrupt drop in water surface elevation – that serves the same functions as a natural step created from bedrock or a log that has fallen into the stream. The weir typically forms a very deep pool just downstream, due to the scour energy of the water dropping over the step. Weirs are typically installed with a maximum height of 3 to 6 inches so that fish passage is not impaired. Log weirs provide bedform diversity, maintain channel profile, and provide pool and cover habitat.

Other Sources of In-Stream Structure Guidance

Rosgen, D.L. 2006. The Cross-Vane, W-Weir and J-Hook Vane Structures: Their Description, Design and Application for Stream Stabilization and River Restoration. Wildland Hydrology. Fort Collins, CO. http://www.wildlandhydrology.com/html/references_.html.

Appendix H
Additional References

Key Reference Material (This material was not directly referenced in the body of the Checklist, but may be helpful in understanding stream processes and natural channel design.)

Allan, J.D. London. 388 p. 1995. Stream Ecology: Structure and Function of Running Waters. Chapman and Hall Inc., New York, NY.

Brooks, A. and F.D. Shields, Jr. 1996. River Channel Restoration: Guiding principles for sustainable projects. John Wiley & Sons Ltd. West Sussex, England. 433 pp.

Bunte, K., A.R. Abt. 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel-and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-74. http://www.fs.fed.us/rm

Dingman, S.L. 1994. Physical Hydrology. Prentice-Hall, Inc. Upper Saddle River, NJ.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company. New York, NY.

Fischenich, J.C. 2006. Functional Objectives for Stream Restoration, *EMRRP Technical Notes Collection* (ERDC TN-EMRRP-SR-52). U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://el.erdc.usace.army.mil/elpubs/pdf/sr52.pdf.

Gordon, N.D., McMahon, T.A. and B.L. Finlayson. 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley and Sons, New York, NY.

Harman, W.A. 2009. The Functional Lift Pyramid (Presentation). Mid-Atlantic Stream Restoration Conference. Morgantown, WV.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K.Suggs., C. Miller. (In press.) Function-Based Framework for Developing Stream Assessments, Restoration Goals, Performance Standards and Standard Operating Procedures. U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds. Washington, D.C.

Knighton, David. 1992. Fluvial Form and Processes. Chapman and Hall Inc., New York, NY.

Leopold, L. B. 1994. A View of the River. Harvard University Press. Cambridge, Massachusetts. 298 pp.

Leopold, L.B., M.G. Wolman and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Company. San Francisco, CA. 511 pp.

McCandless, T.L. 2003. *Maryland stream survey: Bankfull discharge and channel characteristics in the Coastal Plain Hydrologic Region*. U.S. Fish and Wildlife Service. Annapolis, MD. CBFO-S03-02.

McCandless, T.L. 2003. *Maryland stream survey: Bankfull discharge and channel characteristics in the Allegheny Plateau and the Valley and Ridge Hydrologic Regions*. U.S. Fish and Wildlife Service, Annapolis, MD. CBFO-S02-02.

McCandless, T.L. and R.A. Everett. 2002. *Maryland stream survey: Bankfull discharge and channel characteristics in the Piedmont Hydrologic Region*. U.S. Fish and Wildlife Service, Annapolis, MD. CBFO-S02-02.

Rosgen, D.L. 2001. A Practical Method of Computing Streambank Erosion Rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference, Vol. 2, pp. II - 9-15, March 25-29, 2001, Reno, NV. http://www.wildlandhydrology.com/html/references_.html

Rosgen, David. 1996. Applied River Morphology. Printed Media Companies, Minneapolis, MN.

Rosgen, D.L. 1994. A classification of natural rivers. *Catena* 22:169-199.

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

Somerville, D.E. 2010. *Stream Assessment and Mitigation Protocols: A Review of Commonalities and Differences*. May 4, 2010, Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds . Contract No. GS-00F-0032M. Washington, DC.

Thorne, C. R., R.D. Hey and M.D. Newson. 1997. Applied Fluvial Geomorphology for River Engineering and Management. John Wiley and Sons Ltd. West Sussex, England. 376 pp.

Additional Reference Material (Additional reference material that may provide a more in-depth understanding of fluvial processes and aquatic habitats.)

Angermeier, P.L. and J.R. Karr. 1984. Relationships between Woody Debris and Fish Habitat in a Small Warmwater Stream. pp. 716-726. *Transactions of the American Fisheries.* Society 113.

Baltimore County Department of Environmental Protection and Resource Management. October 1988 (Rev. March 1990). Steep Slope and Erodible Soils Adjacent to Watercourses and Wetlands - Evaluation Guidelines.

Boulton, A.J., S. Findlay, P. Marmonier, E.H. Stanley and H.M. Valett. 1998. The Functional Significance of the Hyporheic Zone in Streams and Rivers. *Annu. Rev. Ecol*. Syst. 29:59-81.

Baltimore County Department of Environmental Protection and Resource Management. January 1991. A Methodology for Evaluating Steep Slopes and Erodible Soils Adjacent to Watercourses and Wetlands.

Bren, L.J. 1993. Riparian Zone, Stream and Floodplain Issues: A Review. *Journal of Hydrology* 150:277-299.

British Columbia. December 1996. Channel Assessment Procedure Guidebook. Forest Practices CODE of British Columbia, Ministry of Forests. Victoria, B.C.

Castelle, A.J., A.W. Johnson and C. Conolly. 1994. Wetland and Stream Buffer Size Requirements - A Review. *J. Environ. Qual*. 23:878-882.

Chesapeake Bay Program, Nutrient Subcommittee. EPA 903-R-95-004 CBP/TRS 134/95. August 1995. Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake Bay Watershed. 58 pp.

Correll, D.L. 1997. Buffer zones and water quality protection: general principles. pp. 7-17. Smithsonian Environmental Research Center, Edgewater, MD.

Cummins, K.W. Structure and Function of Stream Ecosystems. November 1974. MI State Univ., Hickory Corners, MI.

Gold, A.J. and D.Q. Kellogg. Modeling Internal Processes of Riparian Buffer Zones. Univ. of RI, Kingston, RI.

Gorman, O.T. and J.R. Karr. 1978. Habitat Structure and Stream Fish Communities. Purdue Univ., West Lafayette, IN: *Ecology* 59(3). pp. 507-515.

Groffman, P.M. 1997. Contaminant effects on microbial functions in riparian buffer zones. Institute of Ecosystem Studies, Millbrook, NY. pp. 83-91.

Gregory, K.J. 1987. River Channels, pp. 207-235 in Human Activity and Environmental Processes, K.J. Gregory and D.E. Walling, eds. John Wiley and Sons, New York, NY.34

Hammer, T. R. 1972. Stream channel enlargement due to urbanization. *Water Resources Research* 8: 1530-1540.

Herrington, R.B. and D.K. Dunham. A Technique for Sampling General Fish Habitat Characteristics of Streams. Intermountain Forest and Range Experiment Station, Ogden, UT.

Hickin, E.J. 1984. Vegetation and River Channel Dynamics. *Canadian Geographer*, XXVII. pp. 111-126.

Johnson, P.A., G.L. Gleason and R.D. Hey. June 1999. Rapid Assessment of Channel Stability in Vicinity of Road Crossing. *Journal of Hydraulic Engineering*. pp. 645-651.

Karr, J.R. Biological Integrity: A Long-Neglected Aspect of Water Resource Management. June 1990. *Ecological Applications*, 1(1). pp. 66-84.

Karr, J.R. and I.J. Schlosser. July 1978. Water Resources and the Land-Water Interface. *Science* Vol. 201. pp. 229-201.

Kondolf G.M. and H. Piegay. 2003. Tools in Fluvial Geomorphology. Wiley. West Sussex, England.

Leopold, L.B. and T. Maddock, Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper No. 252. 57 pp.

Limerinos, J.T. 1970. Determination of Manning's Coefficient from Measured Bed Roughness in Natural Channels. U.S. Geological Survey *Water Supply Paper* 1898-B, Prepared in cooperation with the California Department of Water Resources, U.S. Government Printing Office, Washington, DC.

Lowrance, R., R. Leonard and J. Sheridan. Managing riparian ecosystems to control nonpoint pollution. 1985. *Journal of Soil and Water Conservation,* Vol. 40, No. 1. pp. 87-91.

Mid-Atlantic Coastal Streams Workgroup. July 1997. Field and Laboratory Methods for Macroinvertebrate and Habitat Assessment of Low Gradient, Nontidal Streams.

Ministry of Natural Resources. June 1994. Natural Channel systems - An Approach to Management and Design. Ontario, Canada.

Montgomery, D.R. and J.M. Buffington. June 24, 1993. Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition. Timber, Fish and Wildlife TFW-SH10-93-002.

Mulholland, P.J. 1992. Regulation of nutrient concentration in a temperate forest stream: Roles of upland, riparian and instream processes. *Limnol. Oceanogr.* 37(7). pp. 1512-1526.

Myers, L.H. July 1989. Riparian Area Management. Bureau of Land Management Service Center Technical Reference 1737-3, Denver, CO.

Naiman, R.J. and H. Décamps. 1997. The Ecology of Interfaces: Riparian Zones. *Annual Rev. Ecol. Syst.* 28. pp. 621-58.

North Carolina Division of Water Quality, 401/Wetlands Unit. May 2000. Benthic Macroinvertebrate Monitoring Protocols for Compensatory Stream Restoration Projects. Interim, Internal Technical Guide.

Wilcock, P.R. Sediment Transport in the Restoration of Gravel-bed Rivers. Dept. of Geography and Environmental Engineering, John Hopkins University, Baltimore, MD. https://jshare.johnshopkins.edu/pwilcoc1/public_html/5.%20SedTransInStreamRestoration.pdf

Useful Websites for Additional Reference Material

NCSU Stream Restoration Program
http://www.bae.ncsu.edu/programs/extension/wqg/srp/

University of Louisville Stream Institute
https://louisville.edu/speed/civil/si

NRCS Website. Regional Hydraulic Geometry Curves. Provides links to various regional curve websites.
http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/home

Ohio Department of Natural Resources: Stream morphology spreadsheets
http://www.dnr.state.oh.us/soilandwater/water/streammorphology/default/tabid/9188/Default.aspx

Ohio State University: STREAMS Webpage
http://streams.osu.edu/

River Rat: Restoration Analysis Tool
http://www.restorationreview.com/

Stream Mechanics
http://stream-mechanics.com/

U.S. EPA Stream Mitigation Webpage
http://water.epa.gov/lawsregs/guidance/wetlands/wetlandsmitigation_index.cfm

U.S. Fish and Wildlife Services, Chesapeake Bay Field Office
http://www.fws.gov/chesapeakebay/streampub.html

USFS Stream Team Webpage for Stream Notes Newsletter
http://www.stream.fs.fed.us/news/index.html

Wildland Hydrology Reference Materials
http://www.wildlandhydrology.com/html/references_.html