U.S. Fish & Wildlife Service

Analytical Design Review Checklist

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Stream Mechanics

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Introduction

The U.S. Fish and Wildlife Service – Chesapeake Bay Field Office (Service) has entered into a partnership with the Maryland Department of Environment (MDE), and Maryland State Highway Administration (SHA) to update the Natural Channel Design Review Checklist (NCD V3) and develop three new design checklists. The three new checklists include: analytical design (AD), valley restoration design (VRD), and regenerative storm conveyance design (RSCD). The development of new checklists is based on the request from MDE to provide review checklists for commonly used design approaches in Maryland.

A new, stand-alone checklist manual has been created for each checklist; therefore, this document only includes the Analytical Design Review Checklist. While there are a number of standard questions in each checklist, the decision to create individual stand-alone documents was based on ease of use. By creating individual documents for each checklist, users will not be required to refer to other checklist documents for guidance where standard questions may have been initially addressed.

Each checklist is provided in Appendix A and provides questions about important items to consider when reviewing stream restoration designs. The Checklist is intended to provide the reviewer with a method for determining if a project design contains an appropriate level of information 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.

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.

While a review checklist has been available for the NCD approach since 2008, the checklists for the other design approaches are new. Therefore, these checklists are being released as final drafts. The Service requests feedback from users for one year. The Service will then revisit and potentially revise the checklists based on feedback.

Checklist Structure

All four checklists have the same structure. There are four columns for most questions, which include Submitted, Acceptable, Page Number and Comments (Figure 1). The reviewer answers "yes", "no" or "partially" 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 - Does the project include basemapping?" Under the Submitted column, the reviewer would respond with "yes" if the designer submitted a basemap. If the basemap was inadequate, the reviewer would respond with "no" under the Acceptable column and then describe why under Comments.

Item	Submitted (Y/N/P)	Acceptable (Y/N/P)	Page #	Comments
1.0 Basemapping and Hydraulic Assessment				
1.1 Basemapping				
1.1a Does the project include basemapping?				
1.2 Hydraulic Assessment				
1.2a Was the project drainage area provided?				
1.2b Was a hydraulic assessment completed?				
1.2c Was stream velocity, shear stress and stream power shown in relation to stage and discharge?				

Figure 1: Review Checklist Structure

Other questions are not as straightforward in terms of fitting the checklist structure. For example, under Section 3.2 In-Stream Structures, question 3.2d asks, "Will the in-stream structures provide the intended stability?" For questions that seem to warrant a direct answer, the reviewer should still follow the two-step process: (1) Determine if the designer *Submitted* information that answers this question, even if it is more implicit in the report than explicit; and (2) 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: Basemapping, Preliminary Design, Final Design and Overall Design Review. Since the checklist is primarily for natural channel designs, the Rosgen steam classification system and Priority Levels of Restoring Incised Channels are referenced throughout the test. 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.

Analytical Design Approach

The Analytical Design approach is a subset of the broader Alluvial Channel Design Methodology described in Chapter 9 of the United States Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook (NEH) 654. The theory supporting the Analytical Approach is that channel dimensions can be calculated from physically-based equations including continuity, hydraulic resistance, and sediment transport. These equations require that a design discharge and inflowing sediment concentration be estimated. The design discharge may include the bankfull discharge, effective discharge, or other user-defined discharge. Bank material characteristics and estimates of the bed material composition are also required. The primary result is a channel stability curve that predicts riffle depth and average channel slope for a range of channel widths. Generally, other empirically based methods are used to design meander geometry and bed form profiles.

Key Variables

The equations used in the Analytical Approach solve a suite of dependent variables based on several independent variables. A list of dependent and independent variables is provided in Table 1.

Independent Variables (Model Input)	Dependent Variables (Model Output)
Discharge	Width
Sediment Inflow	Depth
Bed Material Composition	Slope
Bank Material Composition	Planform

Table 1: Independent and Dependent Variables Used in the Analytical Approach

1.0 Basemapping and Hydraulic Assessment

1.1 Basemapping

1.1a 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, e.g., 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, e.g., 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.

1.2 Hydraulic Assessment

1.2a 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 (e.g., bankfull width, mean depth and cross-sectional area) versus drainage area. Drainage area also significantly influences water yield, specifically how much and how quickly, and water yield is required for most hydrologic and hydraulic models. 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.

1.2b Was a hydraulic assessment completed?

A hydraulic assessment can be used to determine stream power and 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.

1.2c 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 or tables of stream velocity, shear stress and/or stream power versus stage or discharge (Figure 2). 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.

Little Tuscarora Stream Restoration					
Flood Event	**Discharge (cfs)**	**Stage (ft)**	**Velocity (ft/s)**	**Shear Stress (lb/sq ft)**	**Stream Power (lb/ft s)**
BKF	116	296.25	3.86	0.63	2.42
2 Year	197	296.67	5.05	1.02	5.16
10 Year	540	297.83	6.42	1.44	9.27
100 Year	1292	299	6.09	1.15	6.99

Figure 2: Example Stream Power Versus Stage and Discharge.

1.3 Bankfull Verification

Users of the Analytical Approach may or may not attempt to identify bankfull indicators or estimate the bankfull discharge for the project reach. This section was included for those practitioners who do estimate bankfull discharge and dimensions and, if not, to provide a place for the practitioner to explain to the reviewer alternative methods for determining channel size. Typically, users of the Analytical Approach use some type of geomorphic assessment to estimate channel bottom width before using the Stable Channel Design approach. This provides a comparison between a geomorphic and analytical (modeling) approach (USDA-NRCS, 2007). A reviewer may require the practitioner to compare their design discharge to a bankfull discharge, especially if bankfull regional curves are available.

1.3a Were bankfull verification analyses completed?

The bankfull stage is the elevation of the water surface during a bankfull flow (Figure 3). 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. 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 bank erosion and/or bed aggradation of sediment.

Figure3: South Fork Mitchell River, Stream Restoration Project during a bankfull event.
(Photo by Will Harman.)

1.3b Were USGS gages or regional curves used to validate bankfull discharge and cross sectional 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 critical 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 riffle bankfull cross-sectional area and discharge compares to the curve, along with a description of how these values were determined. Design riffle cross sectional area can come from a stable riffle located within or immediately upstream or downstream of the project area or based on a dominant and consistent geomorphic feature identified as part of the project area longitudinal survey. Either method is useable to compare to a regional curve. The design riffle cross sectional should plot within the scatter of data used to develop the regional curve. If not, the designer should explain why. An example of a regional curve is shown in Figure 4. Appendix C provides a list of regional curves developed by Somerville (2010) for various regions throughout the United States.

If a regional curve is not available, a watershed-specific regional curve can be used. Watershed specific regional curves are developed from stable riffle cross sections on other stream reaches within the project area watershed. Gage stations are not required but can be included. If a gage is available, then a watershed-specific regional curve can be used to calculate a bankfull return interval, Manning's "n", and bankfull velocity.

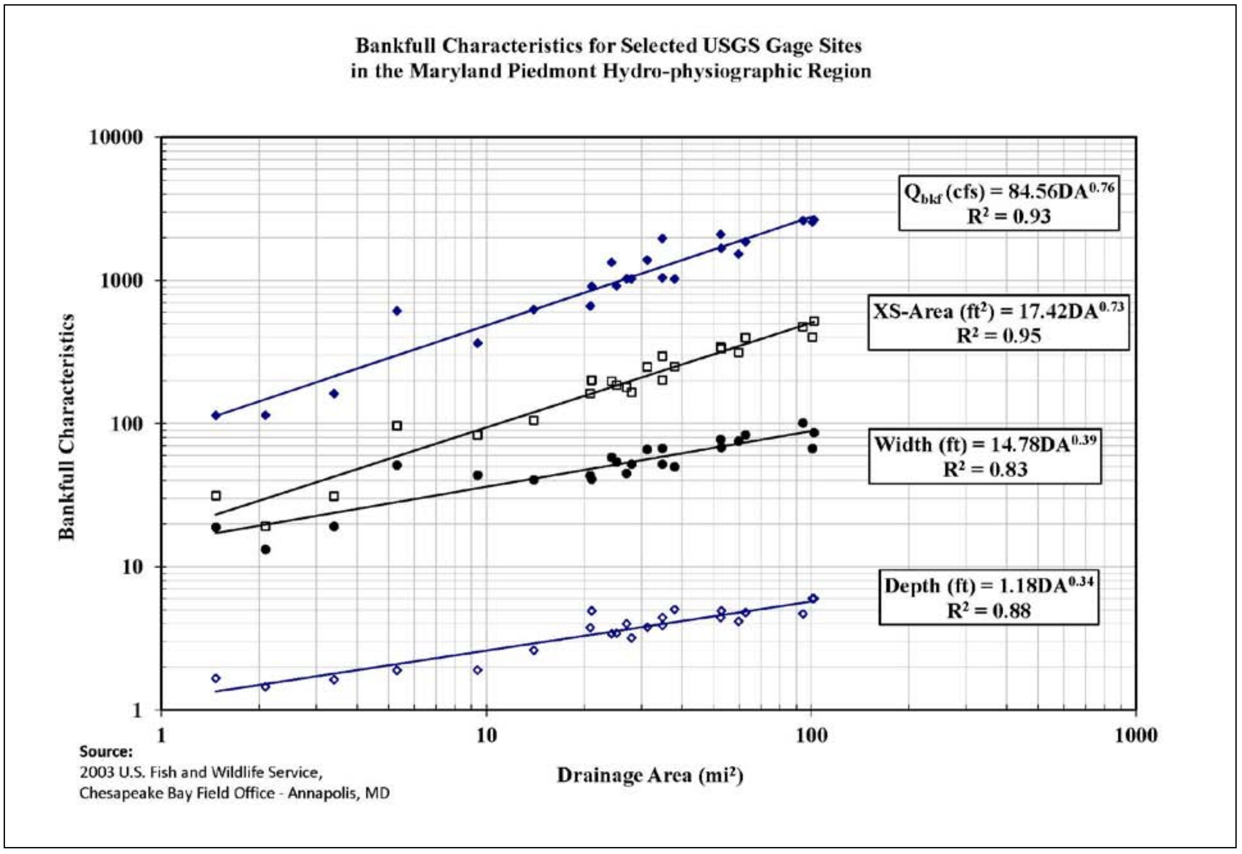

Figure 4: MD Piedmont Regional Curve from McCandless and Everett 1999.

1.3c If a regional curve was used, were the curve data representative of the project 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.

1.3d If gages or regional curves were not available, were other methods, such as hydrology and hydraulic models, used?

Some regions of the United States 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.

2.0 Preliminary Design

The preliminary design uses data from the hydraulic analysis, watershed and stream assessments (accomplished as a previous effort) and sediment transport analysis 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 Sediment Transport

2.1a Did the sediment transport analysis include an evaluation of sediment supply (i.e., sediment supply amount and source(s))?

The reviewer should look for two things. First, the practitioner should perform some type of broad-level sediment supply analysis. This should include investigations of upstream bank erosion through stream walks, windshield surveys, aerial photo analysis, etc. Other sediment sources should also be identified, including cropland erosion, gravel roads, hillslopes, etc. These investigations may include a combination of quantitative and qualitative measures to provide an overall assessment of sediment supply. The reviewer (and practitioner) needs to know if the project reach receives high, medium, or low levels of sediment supply. Projects with very low sediment supply have more design freedom than streams with medium to high levels of sediment supply. In other words, project reaches that must transport sediment have a greater risk of future instability if errors are made in designing channel dimension, pattern, and profile.

Second, once the broad-level sediment supply assessment is completed, a quantitative analysis of the upstream sediment supply reach is performed. This review is completed under question 2.1d: Was a sediment transport analysis completed for the supply reach and project reach?

2.1b Were SAM, HEC-RAS modelling or other tools used to determine stable channel and floodplain dimensions based on sediment transport and/or resistance to shear stress?

Sediment transport analysis is one of the more complex components of a stream 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). 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. An important question to ask includes: Were sediment transport competency and capacity calculations completed? If not, the practitioner should provide a reason. If so, the practitioner should provide a narrative that describes the model used and why it was selected. The narrative should provide a discussion about model assumptions, limitations, applicability to the project site, and if the model was calibrated with measured data. Note, calibrating sediment transport models with measured data is rare due to the time and expense required.

Some projects do not require sediment transport modeling. Projects that may not require sediment transport modeling 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. Results of the sediment supply analysis completed under question 2.1a will help in determining the appropriate level of sediment transport analysis.

A practitioner may use multiple methods to determine the channel dimension, such as the modeling results and watershed-specific regional curves. They may use several methods and look for “converging lines of evidence,” which is considered “best practice.” It is important for the reviewer to understand how the practitioner calculated the channel dimension and slope in this process. If the practitioner did not compare the modeling results with bankfull regional curves, and regional curves are available, the reviewer should make this comparison to determine if the results are acceptable.

Hydraulic and sediment transport modeling are performed together in order to predict channel dimension and slope. Typically, the U.S. Army Corps of Engineers, Stable channel Analytical Method (USACE-SAM) is used for this purpose (Copeland et al., 2001). This routine is now part of HEC-RAS, making it easier to link the hydraulic analysis with the sediment transport analysis. The model calculates a range of stable channel dimensions given a design discharge and sediment concentration. An example from the NEH 654 is shown below in Figure 5.

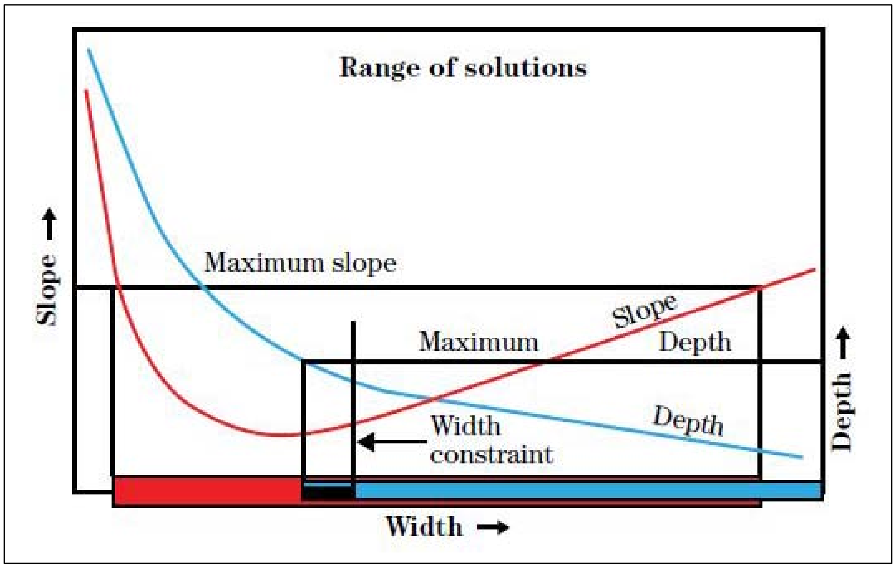

Figure 5: Stability curve from Stable channel Analytical Method (Figure 9-14 in NEH 654).

Additionally, there are other computer models and spreadsheets that may be used to perform hydraulic and sediment transport calculations. In any case, the practitioner should provide a narrative that describes the model used and why it was selected. The narrative should provide a discussion about model assumptions, limitations, applicability to the project site, and if the model was calibrated with measured data. Note, calibrating sediment transport models with measured data is rare due to the time and expense required.

2.1c Was a sediment transport analysis completed upstream (supply reach) and within project reach using a range of sediment transport rates?

The models used in questions 2.1b and c should also be used to assess sediment transport in the supply reach. At a minimum, this analysis is used to calculate sediment inflow to the project reach. The NEH 654 suggests the following input data for this analysis: base width, side slope, average slope, bank roughness coefficient, additional channel roughness and meandering coefficients for Cowan method, bed material D50, bed-material gradation coefficient, and water discharge. These parameters will vary if the bed is comprised of sand rather than gravel. The important point for the reviewer is that a sediment transport analysis should be completed for the supply reach, in addition to the sediment supply analysis completed under question 2.1a. In addition, it is ideal for the practitioner to evaluate a range of sediment supply rates depending on whether or not the project reach is supply limited or transport limited. The reviewer will have more confidence in designs that use a range of supply rates than those that just analyze the design discharge and flood discharge.

2.1d Was sediment transport measured?

All models have limitations in their ability to predict sediment transport. However, the variability in model predictions can be reduced if the model is calibrated with field measured sediments. If sediment transport was measured, the practitioner should describe the collection methods used and how the data were used to calibrate the model.

2.1e Were multiple discharges used to evaluate channel and floodplain stability?

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, e.g., the rate of increasing shear stress should decrease sharply above the bankfull stage. It is important that the practitioner analyzes flood flows in addition to the design discharge, as shown in Figure 2. This will provide some confidence that the channel will be stable under a range of flows and not just a design or bankfull flow.

2.1f Did the sediment analysis show the potential for the stream channel and floodplain to aggrade or degrade after analyzing multiple discharges?

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. If possible, the riffle dimension results from this analysis should be compared to watershed-specific regional curves.

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 (e.g., confined valleys), the particle sizes should be shown for these flows as well.

2.1g If the reach has a sediment supply, does the design state how it will be addressed?

If a stream reach has a sediment supply, it can only be addressed in one of two ways: transporting it through the reach or storing it within the reach. If the designer proposes to transport the sediment supply through the reach, use the results from question 2.1g to determine if the sediment will be transported. If the designer proposes to store the sediment within the reach, the design must demonstrate that the location and rate of sediment aggradation does not adversely affect the overall functions of the stream. For example, an aggradation rate that inundates or smoothers critical stream features would adversely affect stream functions. On the other hand, an aggradation rate that does not inundate or smother critical stream features and vegetation can establish on depositional areas would not adversely affect stream functions. In fact, aggradation, at an appropriate rate, is a naturally occurring process in many stream systems.

2.2 Goals and Restoration Potential

2.2a Does the project have clear goals and measureable 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 (Harman et al., 2012). The Stream Functions Pyramid can be used as an aid in developing goals and objectives. The goals should relate to the function-based parameters and the objectives should relate to the measurement methods and performance standards.

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.

2.2b 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 health of the upstream watershed, results from the reach assessment, and site constraints (Harman et al., 2012). 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 upstream watershed is mostly forested and healthy, than the restoration potential is level 5 on the Stream Functions Pyramid. This means that the project has a strong potential for restoring biological functions back to a reference condition. If the same site has an urban watershed, the restoration potential is Level 3, meaning that a stable channel can be created, but it may not support biology at a reference condition (Harman et al., 2012).

2.2c 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 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 more specifically address function-based goals and objectives, e.g., 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.

2.3 Design Criteria

2.3a Were design criteria provided and explained?

The development of design criteria is one of the most important tasks in a 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.

2.3b Was the method used to determine channel width and discharge described?

For the most part, this question should be answered with question 2.1c. The difference is that question 2.1c deals with the actual modeling effort and this question deals with the final decision. The results from 2.1c provides a range of solutions for channel bottom width. This question also provides a place to review how the design discharge was determined, e.g., from bankfull regional curves or hydrology and hydraulic models. Ideally, the practitioner will use a variety of methods to determine the design discharge, including modeling, regional curves, site investigations, etc. Essentially, this question can be used to combine the results from the geomorphic assessment (bankfull determination) and sediment transport analysis. The design report should provide a narrative about why the final width and discharge was selected. The additional questions under section 2.3 will help the reviewer determine if the information submitted is acceptable.

2.3c Were geomorphic principles used to select the design discharge and width?

Most practitioners of the Analytical Approach also perform geomorphic assessments of the project reach and sometimes perform reference reach surveys and develop bankfull regional curves. Generally, the reviewer will have more confidence in the final selection of channel width and discharge if the selection was based on multiple approaches, including geomorphic principles. A good approach is to use a bankfull regional curve or stable riffle from the project reach to select the bankfull width. The design discharge may be selected from a bankfull regional curve, which would be considered as based on geomorphic principles and then compared to the modeling result.

2.3d Were hydrology and hydraulic models used to determine the design discharge?

Some practitioners may use hydrology and hydraulic models to select the design discharge rather than use a bankfull regional curve or to compare the curve with the model. This analysis should include a rainfall/runoff analysis of the watershed, typically using HEC-HMS, and may be compared to channel hydraulics (stage versus discharge) relationships from stable riffles at the project site. A good approach is to use a combination of geomorphic principles (regional curves) with hydrology and hydraulic models.

2.3e Was the design discharge compared to bankfull discharge from appropriate regional curve?

The Analytical Design Approach may or may not include an analysis to estimate the bankfull discharge or dimensions. However, regulators may want to see a comparison of the baseflow channel dimensions and discharge with a local bankfull regional curve. Comparison should show that the Analytical Design channel dimensions plot reasonably well the appropriate regional curve.

2.3f If yes to 2.3d, were the similarities and differences explained?

If the practitioner used a regional curve as discussed in question 2.3b, this will be an easy question to answer. If the practitioner only used hydrology and hydraulic models to select the design discharge, and a regional curve from the same hydrophysiographic region is available, the reviewer can compare the design discharge to the regional curve. If the design discharge is significantly higher than the bankfull discharge, there is concern that the channel will be overly large, i.e., incised. It may be okay if the design discharge is less than the bankfull discharge if the sediment supply is very low. Regardless, major differences between the design discharge and bankfull discharge should be explained by the practitioner and acceptable to the reviewer.

2.3g Was the return interval for the design discharge provided?

This is a helpful way to determine if the design discharge will result in a channel that is well-connected to the floodplain. The return interval for the design discharge, which is also the discharge that fills the channel, should be less than 2 years.

2.3h 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 meandering stream channel, then the design criteria should come from a stream in an alluvial valley 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, 2006).

2.4 Conceptual Design

2.4a Was the conceptual channel alignment provided and developed within the design width and slope range?

The Analytical Approach does not explicitly prescribe methods for laying out the channel planform. In general, the planform can be checked to ensure that the channel width matches the design width from the modeling output, e.g., SAM. The planform sinuosity can also be checked against the channel slope output from SAM. For specific planform design elements, such as, belt width or amplitude, meander wavelength, and radius of curvature more empirical approaches are typically used. These empirical approaches could include local reference reaches or relationships in Copeland and McComas (2001). A better approach is to use design criteria from reference reaches with similar valley slopes, bed material, and stream type as the project reach (Hey, 2006). A list of common reference reach and design criteria data is provided in Appendix F of Harman and Starr (2011). The reviewer should verify that the proposed alignment is within the design criteria.

2.4b Were typical channel cross sections provided and developed within the design width and depth range?

The Analytical Approach provides width and depth information for the riffle cross section. The conceptual design should match the width and depth determined from the modeling effort or design criteria selection. Typical cross section drawings for the preliminary design are shown in Figure 6. Other cross sections (runs, pools, and glides) should be checked against local reference reach data or design criteria in Appendix F of Harman and Starr (2011). As part of the review, the reviewer should make certain that the typical cross sections meet the design criteria.

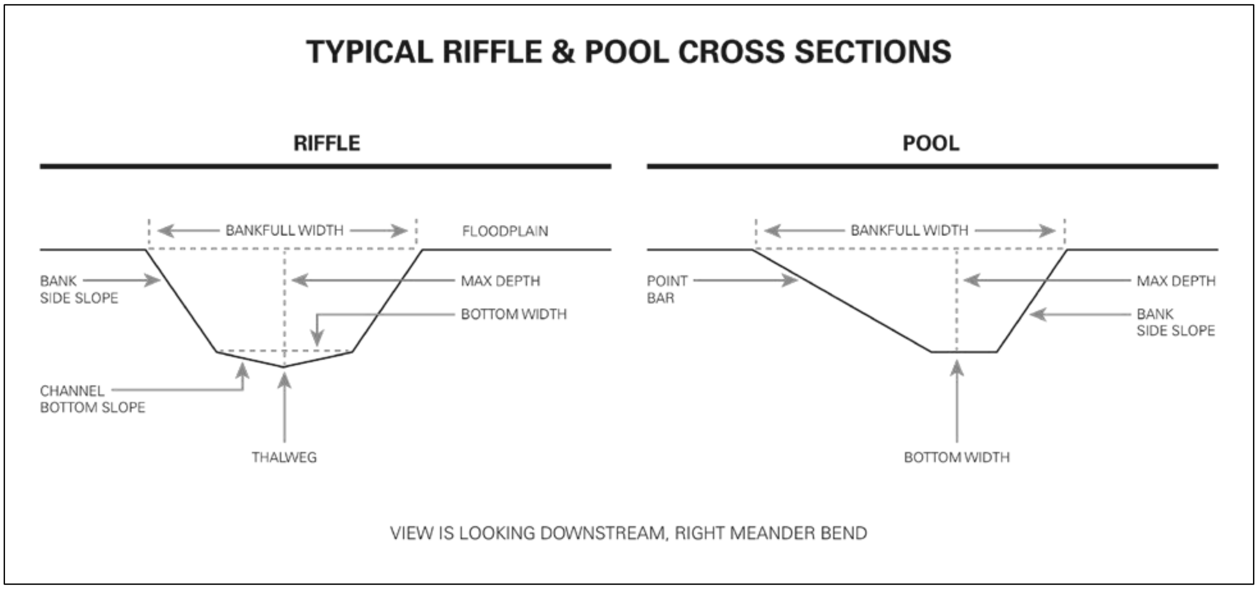

Figure 6: A typical riffle and pool cross section showing key measurements.

2.4c Were methods used to design the plan form and bed forms described and match the design criteria shown in the Design Review Checklists, Appendix F?

Approaches for designing bed form diversity are not specifically described in analytical design manuals. Again, the depths and slope of the riffles, run, pools, and glides should be checked against local reference reach data or design criteria in Appendix F of Harman and Starr (2011). If the practitioner stated that a meandering channel is the design plan form, the reviewers should measure the range of belt widths and verify that the meander width ratio (belt widths divided by bankfull width) is greater than 3.5 (average) and that the sinuosity is greater than 1.2. Serious erosion has been observed in projects where the designer tries to force sinuosity into a confined setting. This is even more critical in projects with excavated floodplains. In addition to having an average meander width ratio greater than 3.5, designers should avoid "meandering" the floodplain by creating excavated floodplains that parallel the bankfull lines. Both of these issues are discussed in Harman and Starr (2011).

2.4d 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. As part of the review, the reviewer should make certain that the preliminary in-stream and floodplain structures meet the design criteria.

Figure 7: An eroding streambank along a previously designed flood control channel.
(Source: Michael Baker Corporation; Photo by Will Harman.)

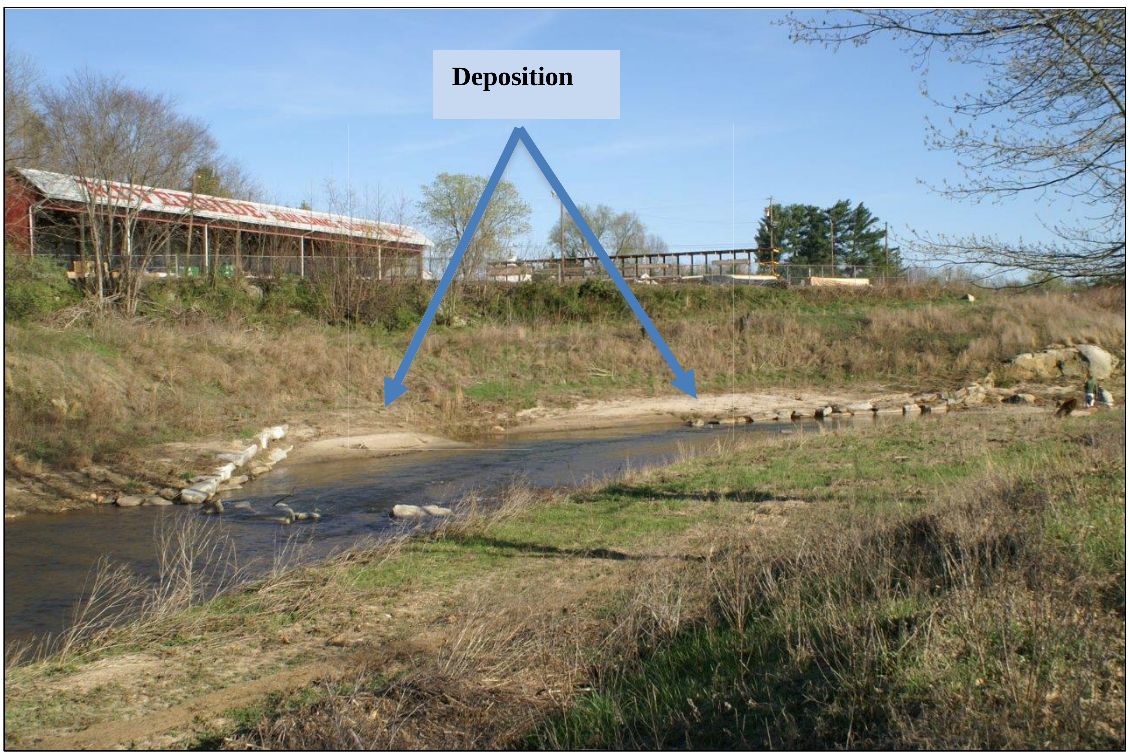

Figure 8: J-hook vanes, a bankfull bench, and geometry adjustment were used to stabilize the eroding bank. Note the deposition (sand) along the toe of the bank, which was created by the vanes.
(Source: Michael Baker Corporation; Photo by Will Harman.)

2.4e 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.

2.4f 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 Channel Geometry

3.1a Was the rationale for providing a final width, depth and slope combinations provided?

This question refers to the graph from the Stability Curve (Figure 5) that shows a range of widths, depths, and slopes so the designer will need to select a final set of values. This decision should be based on an assessment of various methods if possible, e.g. modeling and empirical relationships like regional curves, and not just of Figure 5. A good approach is to use Figure 5 as a comparison to a design dimension and slope. If the depth and slope for the design width are on the line, the design may be close enough to equilibrium. The depth or slope is above the line, the design may be erring on the side of degradation. This could be desirable if there is a large sediment supply. However, too much depth or slope could lead to head cuts and incision. Depths or slopes below the line could lead to aggradation, which may or may not be harmful depending on the upstream supply. In other words, this method should be used as an aide in making decision decisions about riffle width, depth and slope, rather than a definitive result.

3.1b Does the proposed channel carry the design discharge?

For the final design, the hydraulic model should be run again to show that the design discharge fills the design channel to approximately the top of the streambank.

3.1c Do the width, depth, and slope selections plot between the aggradation and degradation regions over various flood flows?

This should be answered with question 3.1a and b.

3.1d 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 (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.

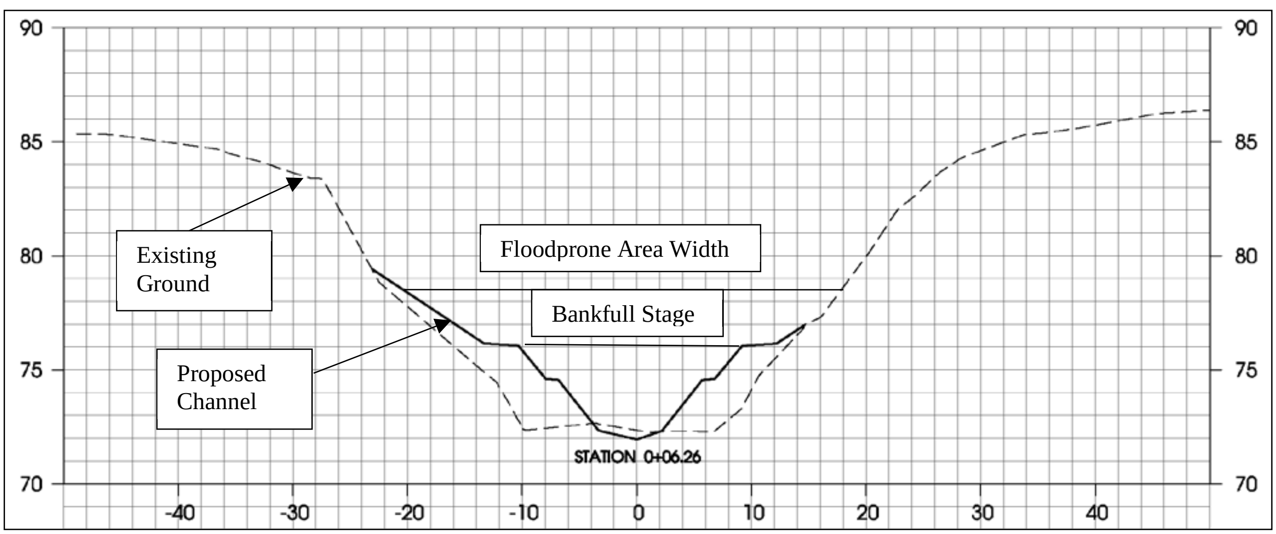

Figure 9: Proposed cross section overlaid with the existing ground. These are often shown on a set interval throughout the length of the project reach and are used by the contractor to excavate the channel and floodplain (if needed).
(Source: US Fish and Wildlife Service, Chesapeake Bay Field Office)

For projects that included excavated floodplains, 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, e.g., 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.

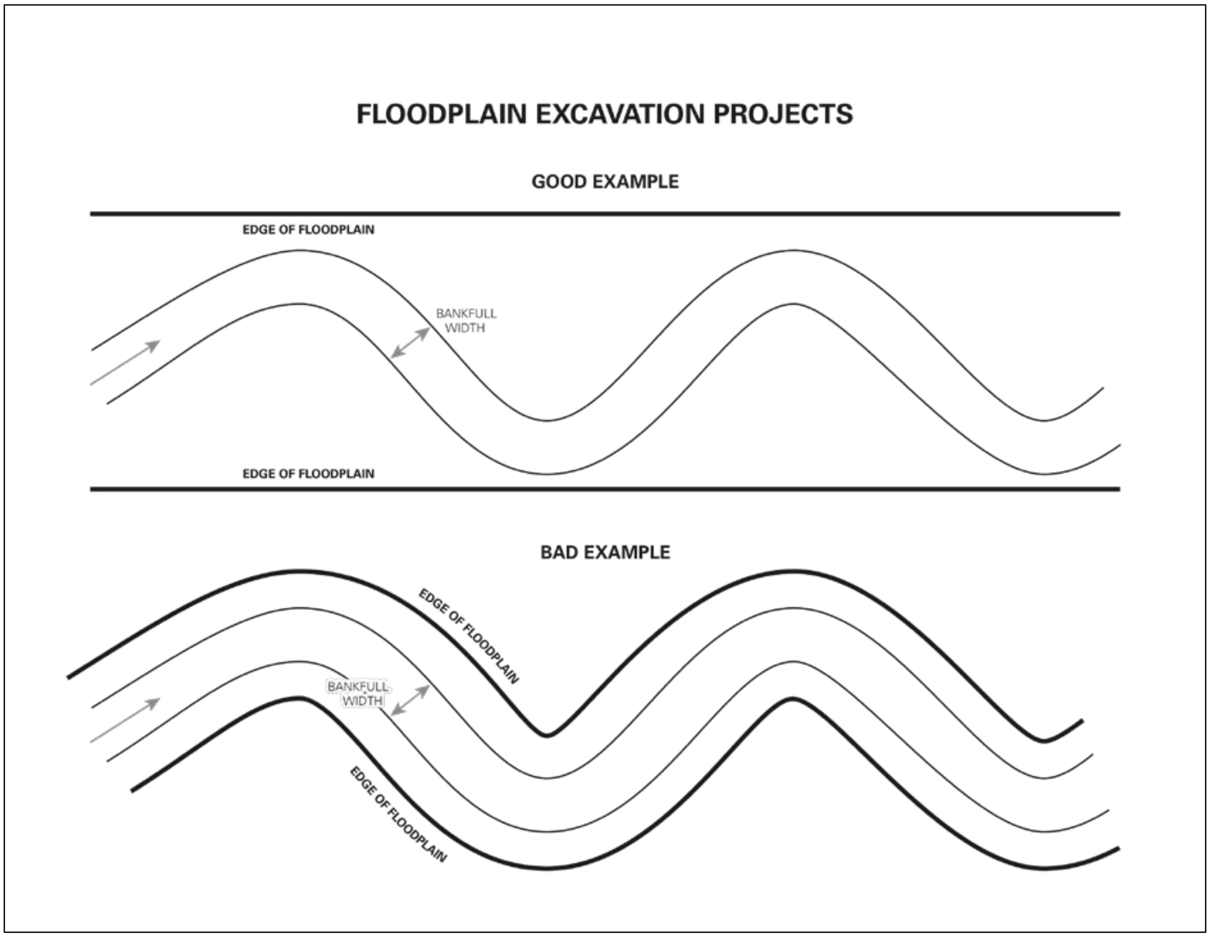

Figure 10: Plan view of proper and improper excavation of floodplain limits.

3.1e Was a proposed channel profile and plan form provided and developed within the design criteria?

The proposed channel alignment/plan form with stationing should be shown on the basemap (Figure 11). 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. Furthermore, channel plan form can influence lateral stability. If a stream, within an alluvial valley, has a MWR of less than 3.5, then bank erosion could occur. It is critical that alluvial stream systems have appropriate plan in order to transport sediment and reduce stream energy.

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. Additionally, the reviewer should verify that the stream facet slopes, lengths, and depths are within the design criteria. Pool-to-pool spacing should also be verified.

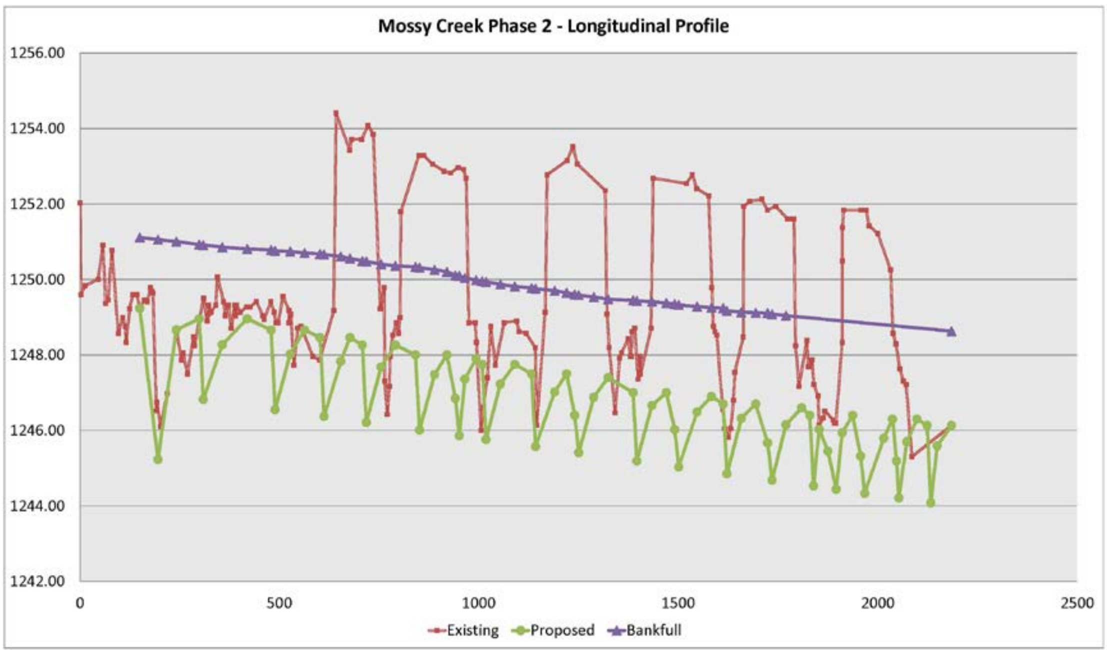

Figure 11: Example Longitudinal Profile

3.1f Did project constraints like right-of-ways or flood control requirements affect the width/depth/slope section? If so, was the risk of instability described?

In some proposed projects, there is limited area for storage of flood flows. In these particular cases, stream energy can adversely affect stream channel and floodplain stability. If this condition exists, the designer should describe how the increased energy will be addressed to reduce stream and floodplain degradation.

3.1g Will the project tie-ins have no change to upstream and downstream existing stability conditions?

Stream restoration projects have the potential to change stream stability conditions upstream and downstream of the project area. In most cases it can only prevent changing current upstream and downstream stability conditions. However, there can be times where positive or negative effects could occur. For example, if there is a head cut within the project area that will be halted as part of the restoration actions, then future upstream degradation will be prevented. However, if the proposed stream restoration improves sediment transport, the potential exists for downstream reaches to receive an increase in sediment load. Also, the review should check to see if the upstream and downstream tie-ins reconnect with the existing stream channel alignment.

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

Specifications should be provided that describes 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 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, e.g., 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 1 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.

3.2a 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 are 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 below can be used as a general guide for in-stream structures and bioengineering methods.

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 (on-site = low)
Log Vanes	Low to Moderate for small streams	Low to Moderate depending on availability (on-site = low)
Rock Vanes and J-hooks	High	Moderate to High

Table 2: Guidance for selecting in-stream structures to provide 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 on-site)
Erosion Control Matting	Low to Moderate	Low to Moderate

Table 3: Guidance for selecting bioengineering practices for bank protection

3.2b 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 and then lowered at the downstream end or when channels have been re-meandered into 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.

3.2c 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 12 and 13.

Figure 12: 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 13: 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, e.g., 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.

3.2d 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 need some form of protection through in-stream structures and/or bioengineering. Erosion control matting is typically used to stabilize riffle bank slopes.

3.2e Were in-stream structures (or changes to geometry) needed to provide stability at tie-in locations with the existing channel?

This question is similar to question 3.1d but focuses on whether in-stream structures are needed to prevent instability from upstream and downstream instability conditions. For example, if there is a headcut downstream of the proposed project area, the designer should demonstrate that grade control will be installed to a depth deeper than the potential degradation associated with the headcut. Or if the upstream channel alignment tie-in will cause severe lateral erosion, the designer should demonstrate how the increased erosion energy will be addressed.

Additionally, sometimes stream restoration projects raise the bed elevation and/or change the dimension and plan form geometry of the project reach. For large geometry changes like this, the designer may need to provide a transition reach into and out of the project reach. For the upstream section, this might mean creating sediment trap areas (splays), starting with lower sinuosities, and gradually increasing the width of a floodplain bench. For the downstream tie-in, in-stream structures are typically used. These may include some type of step-pool channel or riffle grade control. The reviewer should look for evidence that the designer considered tie-ins as part of the overall stability of the project.

3.2f 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.

3.3 Vegetation Design

3.3a 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.

3.3b 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.

3.3c 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 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.

4.0a 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.

4.0b 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.

4.0c 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.

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Analytical Design Review Checklist

Appendices

Appendix A

ANALYTICAL DESIGN REVIEW CHECKLIST

Project Design Checklist

Reviewer: ______________________

Date: ______________________

Project: ______________________

Engineer: ______________________

Item	Submitted (Y/N/P)	Acceptable (Y/N/P)	Page #	Comments
1.0 Basemapping and Hydraulic Assessment				
1.1 Basemapping				
1.1a Does the project include basemapping?				
1.2 Hydraulic Assessment				
1.2a Was the project drainage area provided?				
1.2b Was a hydraulic assessment completed?				
1.2c Was stream velocity, shear stress and stream power shown in relation to stage and discharge?				
1.3 Bankfull Verification				
1.3a Were bankfull verification analyses completed?				
1.3b Were USGS gages or regional curves used to validate bankfull discharge and cross sectional area?				
1.3c If a regional curve was used, were the curve data representative of the project data?				
1.3d If gages or regional curves were not available, were other methods, such as hydrology and hydraulic models used?				
2.0 Preliminary Design				
2.1 Sediment Transport				
2.1a Did the sediment transport analysis include an evaluation of sediment supply (i.e., sediment supply amount and source(s))?				
2.1b Was SAM, HEC-RAS modelling or other tool used to determine stable channel and floodplain dimensions based on sediment transport and/or resistance to shear stress?				
2.1c Was a sediment transport analysis completed upstream (supply reach) and within the project reach using a range of sediment transport rates?				
2.1d Was sediment transport measured?				
2.1e Were multiple discharges used to evaluate channel and floodplain stability?				
2.1f Did the sediment analysis show the potential for the stream channel and floodplain to aggrade or degrade after analyzing multiple discharges?				
2.1g If the reach has a sediment supply, does the design state how it will be addressed?				
2.2 Goals and Restoration Potential				
2.2a Does the project have clear goals and measurable objectives?				
2.2b Was the restoration potential based on the assessment data provided?				
2.2c Was a restoration strategy developed and explained based on the restoration potential?				

Appendix A

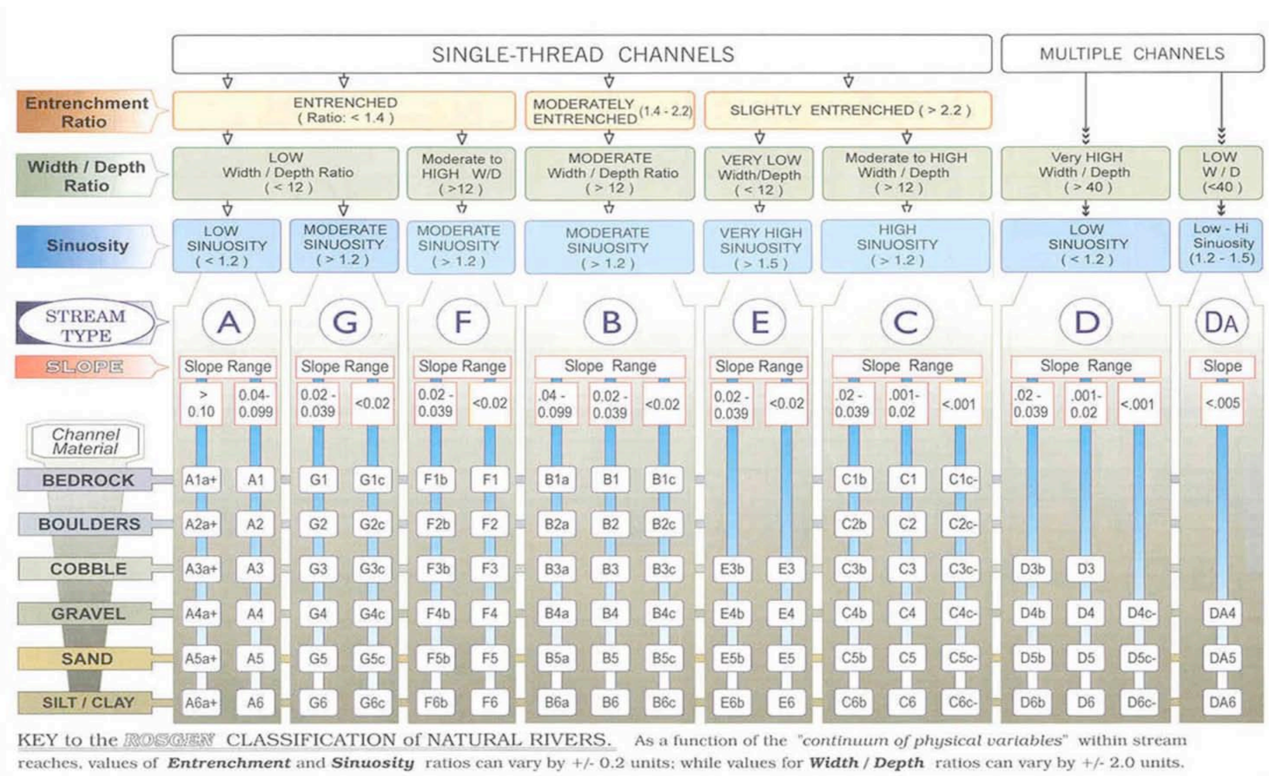
Item	Submitted (Y/N/P)	Acceptable (Y/N/P)	Page #	Comments
2.3 Design Criteria: Width and Discharge				
2.3a Were design criteria provided and explained?				
2.3b Was the method used to determine channel width and discharge described?				
2.3c Were geomorphic principles used to select the design discharge and width?				
2.3d Were hydrology and hydraulic models used to determine the design discharge?				
2.3e Was the design discharge compared to bankfull discharge from appropriate regional curve?				
2.3f If yes to 2.3d, were the similarities and differences explained?				
2.3g Was the return interval for the design discharge provided?				
2.3h Are the design criteria appropriate given the site conditions and restoration potential?				
2.4 Conceptual Design				
2.4a Was the conceptual channel alignment provided and developed within the design width and slope range?				
2.4b Were typical channel cross sections provided and developed within the design width and depth range?				
2.4c Were methods used to design the plan form and bed forms described and match the design criteria shown in the Design Review Checklists, Appendix F?				
2.4d Were typical drawings of in-stream structures provided and their use and location explained?				
2.4e Was a draft planting plan provided?				
2.4f Overall Conceptual Design Comment(s)				
3.0 Final Design				
3.1 Channel Geometry				
3.1a Was the rationale for providing a final width, depth and slope combinations provided?				
3.1b Does the proposed channel carry the design discharge?				
3.1c Do the width, depth, and slope selections plot between the aggradation and degradation regions over various flood flows?				
3.1d Do the proposed channel dimensions show the adjacent floodplain or flood prone area?				
3.1 e Was a proposed channel profile and plan form provide and developed within the design criteria?				
3.1f Did project constraints like right-of-ways or flood control requirements affect the width/depth/slope section? If so, was the risk of instability described?				
3.1g Will the project tie-ins have no change to upstream and downstream existing stability conditions?				
3.1h Were specifications for materials and construction procedures provided and explained for the project (i.e., in-stream structures and erosion control measures)?				

Appendix A

Item	Submitted (Y/N/P)	Acceptable (Y/N/P)	Page #	Comments
3.2 In-Stream Structures				
3.2a Based on the assessment and design, were in-stream structures necessary for lateral stability?				
3.2b Based on the assessment and design, were in-stream structures needed for vertical stability?				
3.2c If needed, was the reason for their location and use explained?				
3.2d Will the in-stream structures provide the intended stability?				
3.2e Were in-stream structures (or changes to geometry) needed to provide stability at tie-in locations with the existing channel?				
3.2f Were detail drawings provided for each type of in-stream structure?				
3.3 Vegetation Design				
3.3a Was a vegetation design provided?				
3.3b Does the design address the use of permanent vegetation for long term stability?				
3.3c Overall Final Design Comment(s)				
4.0 Overall Design Review				
4.0a Does the design address the project goals and objectives?				
4.0b Are there any design components that are missing or could adversely affect the success of the project?				
4.0c 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.



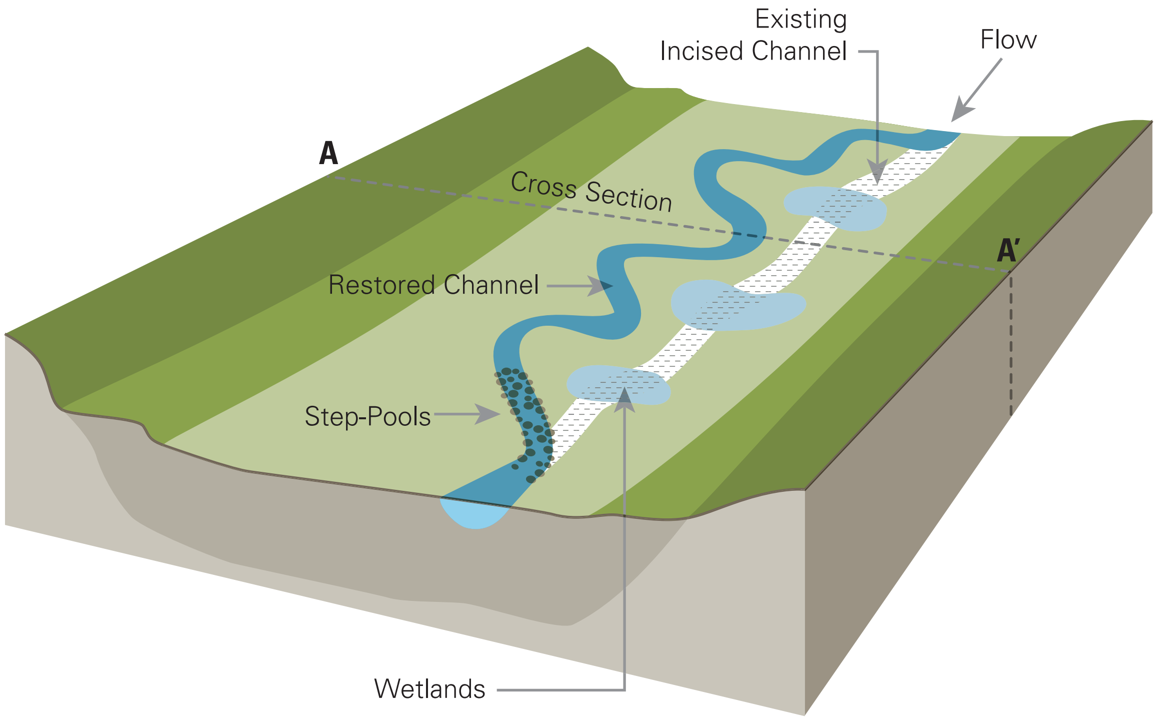
Priority Levels of Restoring IncisedChannels

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).

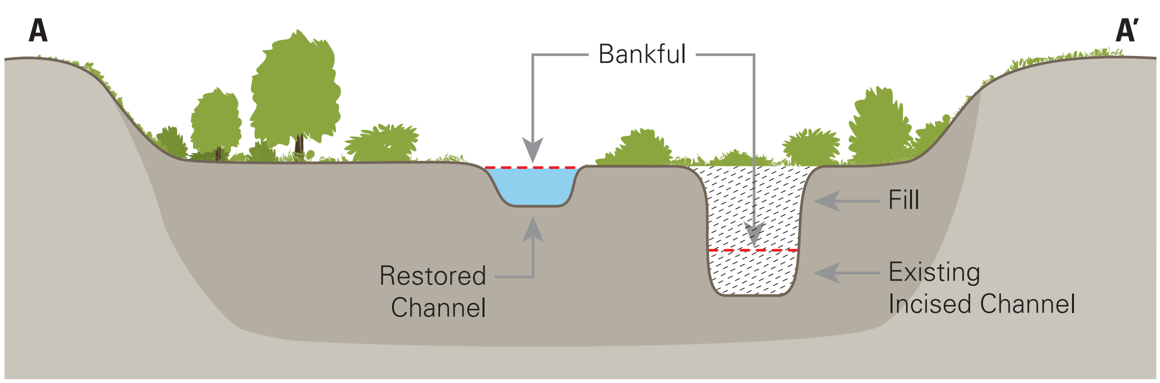
A Priority Level 1 restoration creates a new stable channel that is reconnected to the previous (higher in elevation) floodplain. A new stream channel is excavated on the original floodplain by raising the stream bed elevation. This approach requires an abrupt change in bed elevation at the upstream 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

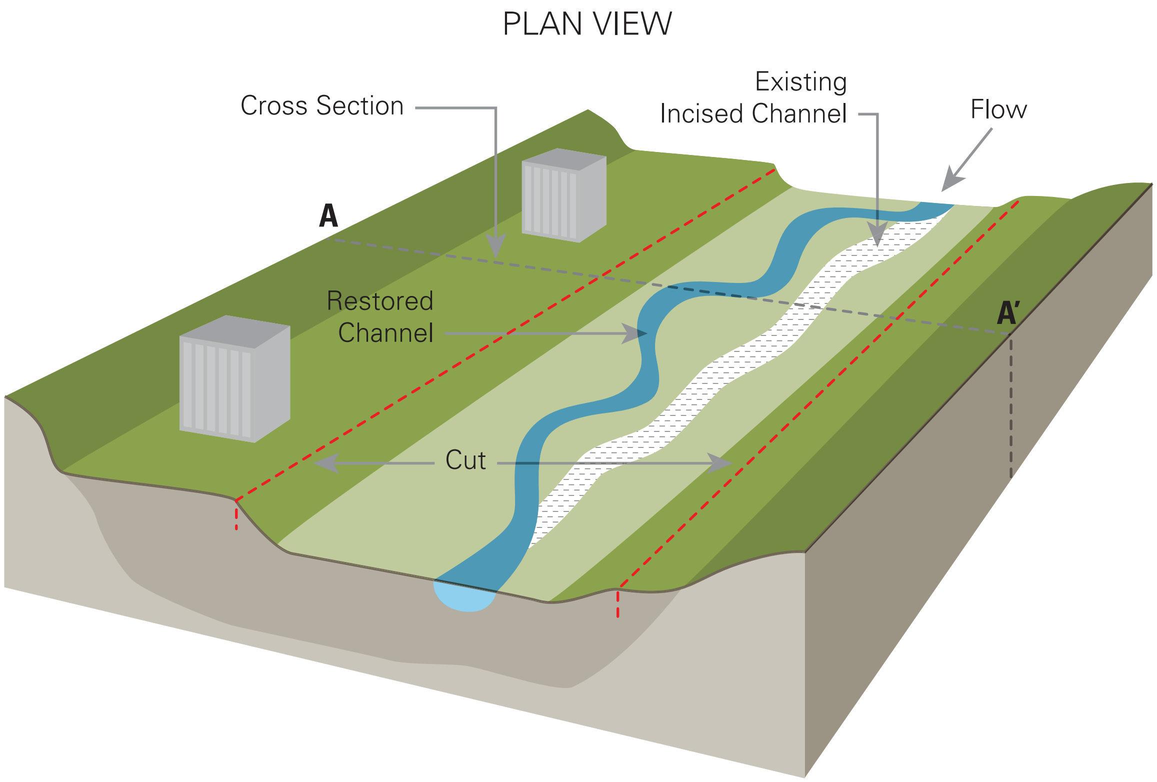


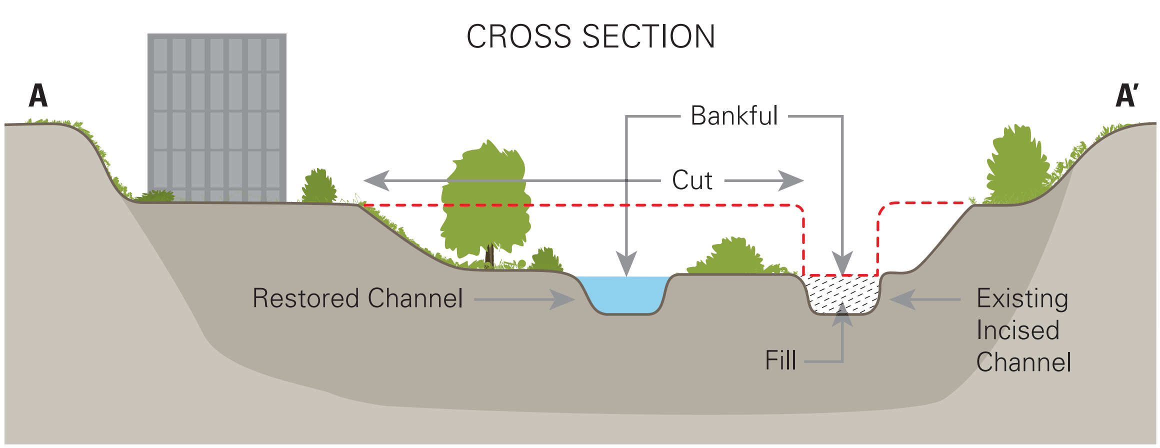
CROSS SECTION



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.

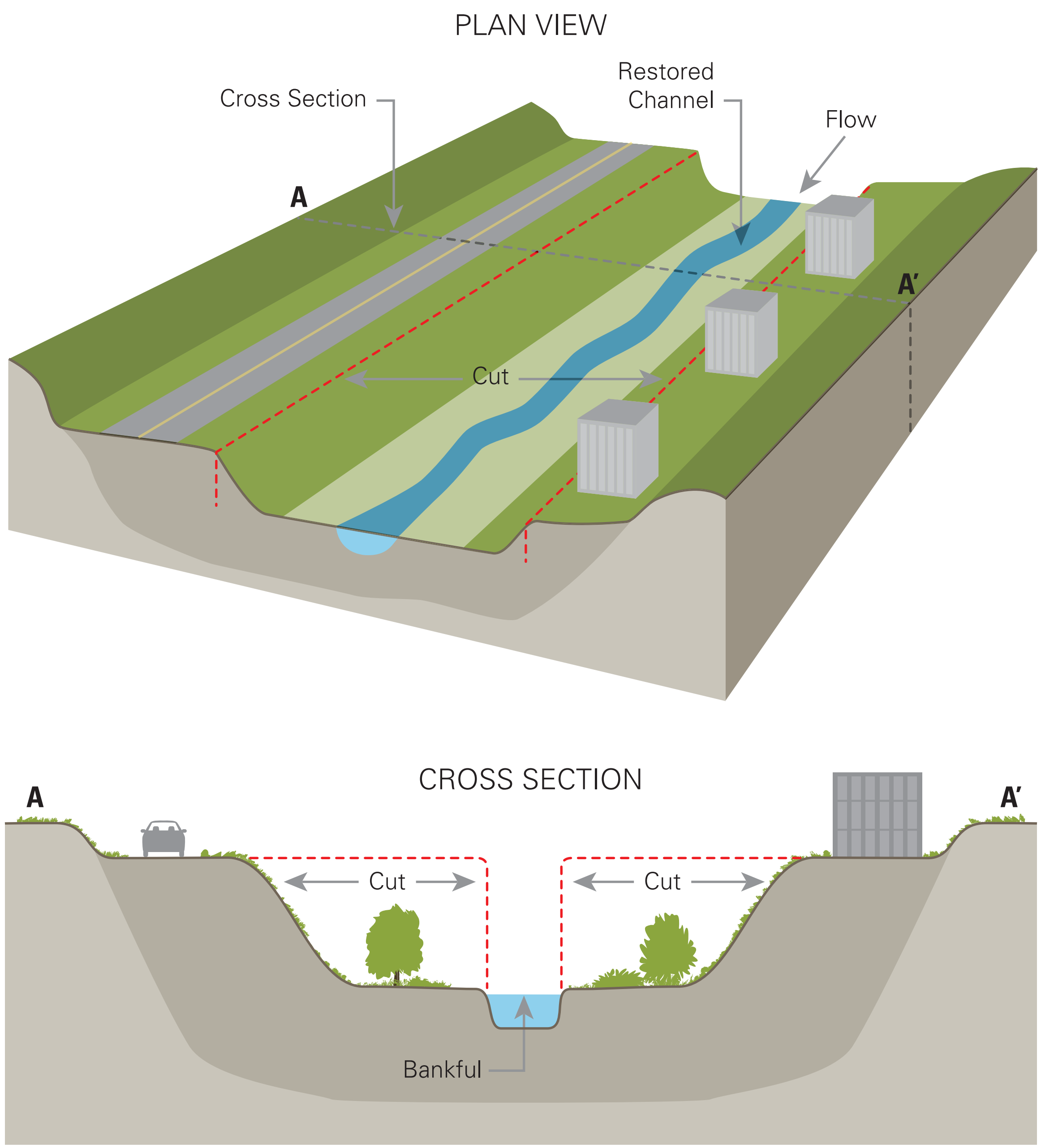
FIGURE 2: ROSGEN PRIORITY LEVEL 2 RESTORATION APPROACH





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.

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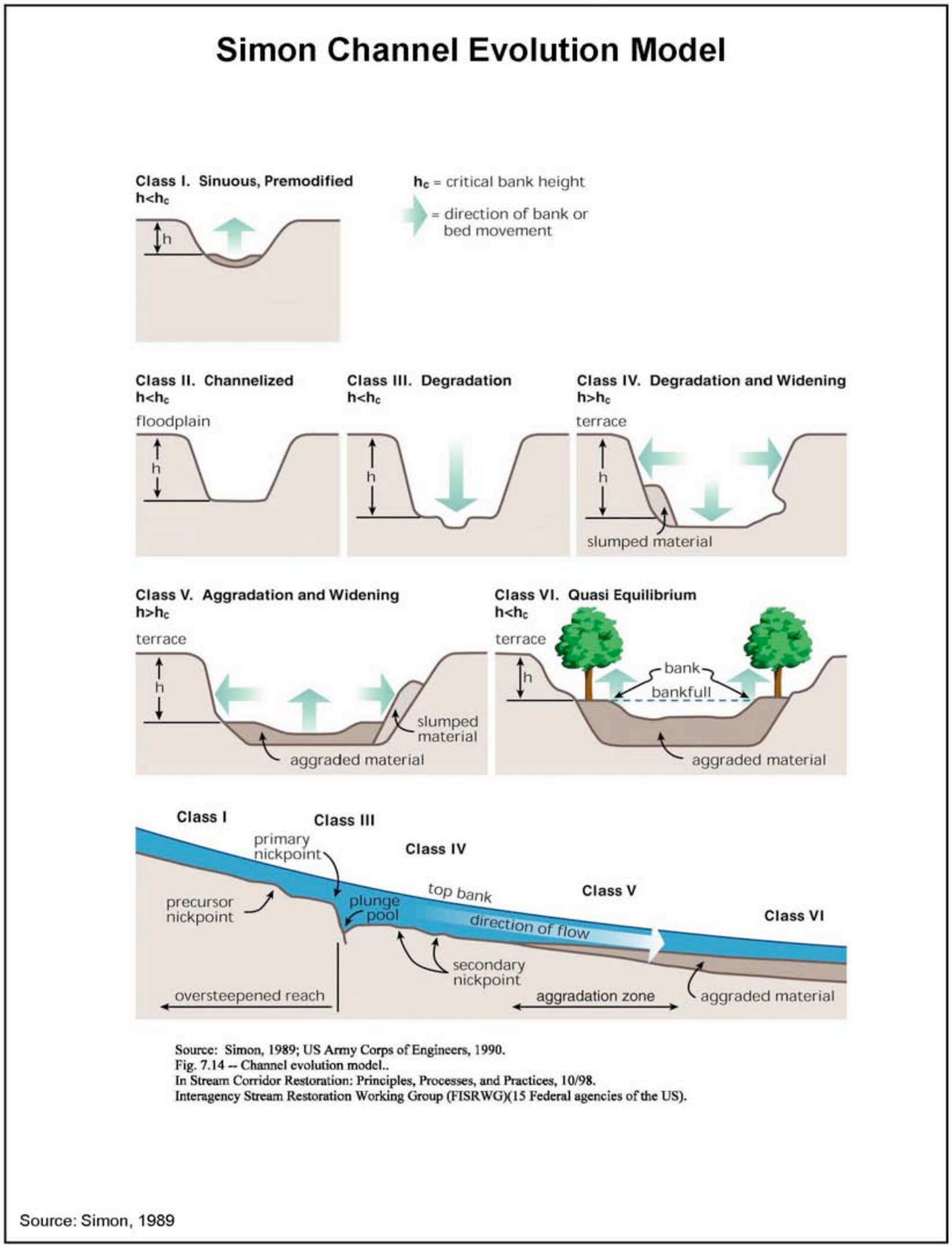
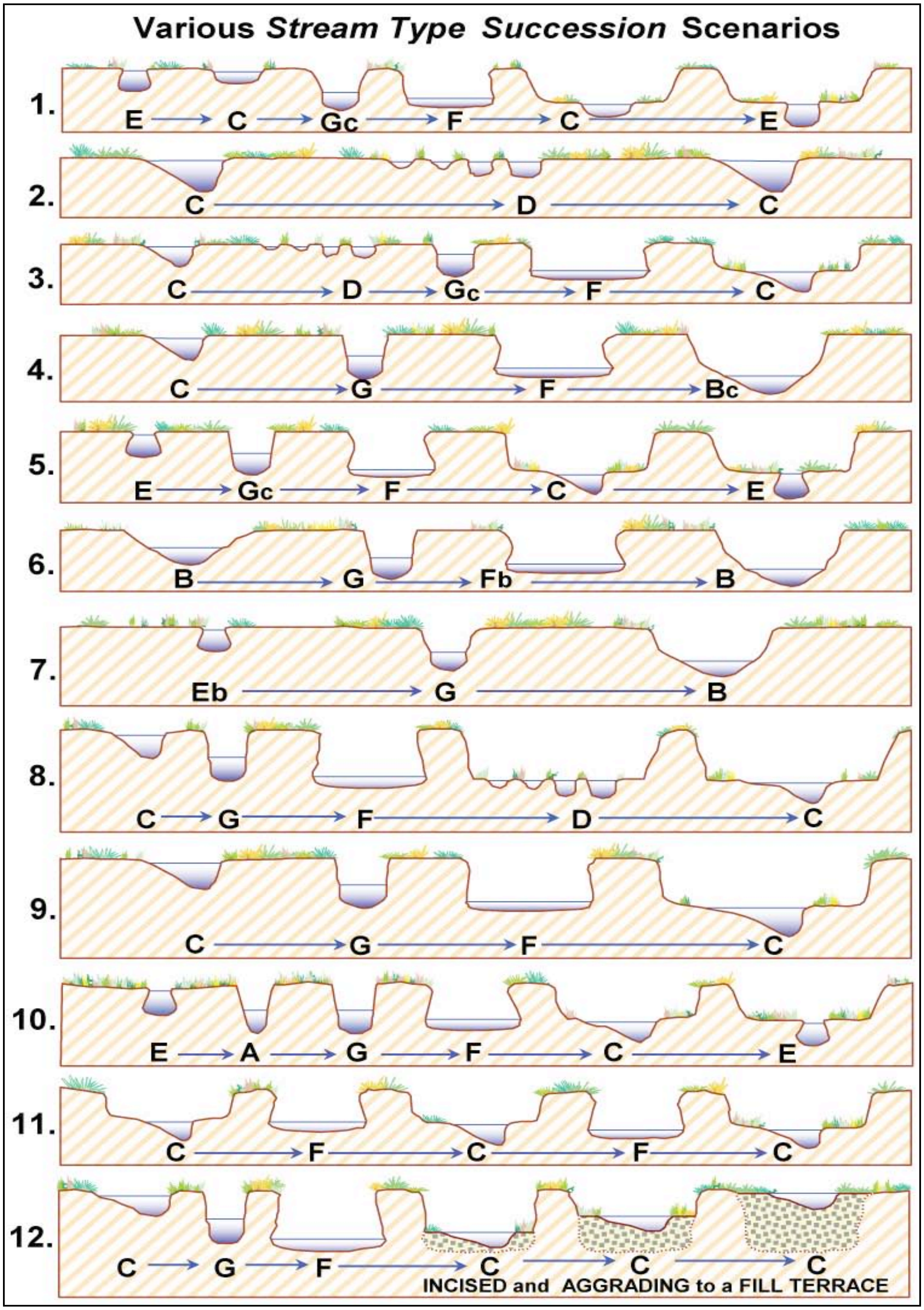
Appendix C
Simon Channel Evolution Model
Channel Evolution by Stream Type

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 Òstream corridor restorationÓon the NRCS web page at www.nrcs.usda.gov. The document can be ordered by calling (888)-526-3227.



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



Appendix D
Regional Curves and ManningÕs 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 documentÕs collaborators.

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ManningÕs Equation ÐUsed to Estimate Velocity and Discharge

Velocity (v) in feet per second can be estimated using ManningÕs 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, ManningÕs 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 ManningÕs n Values

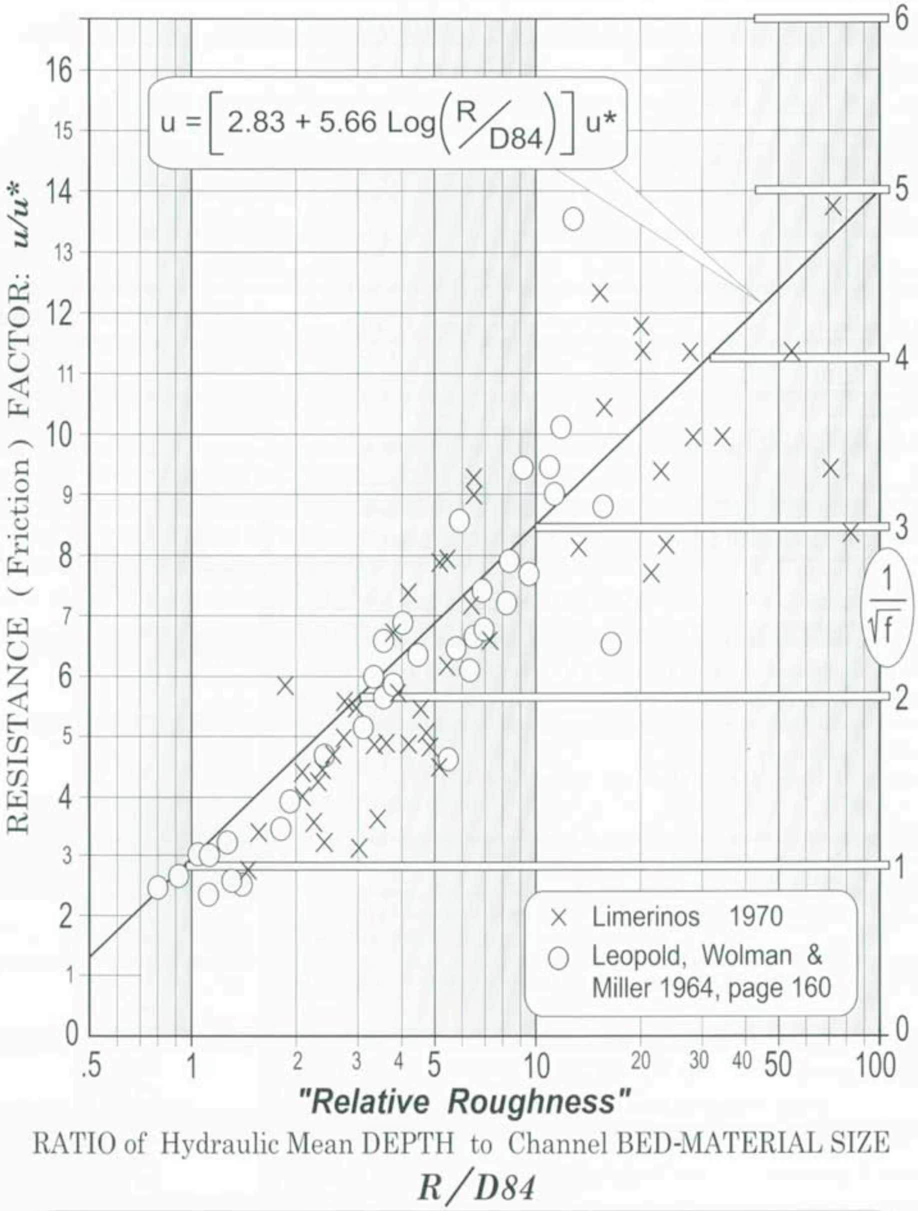
There are a variety of ways to estimate the roughness coefficient Òn.ÓA few are provided below.

Table D1: Table of ManningÕs 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 ManningǦ 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.

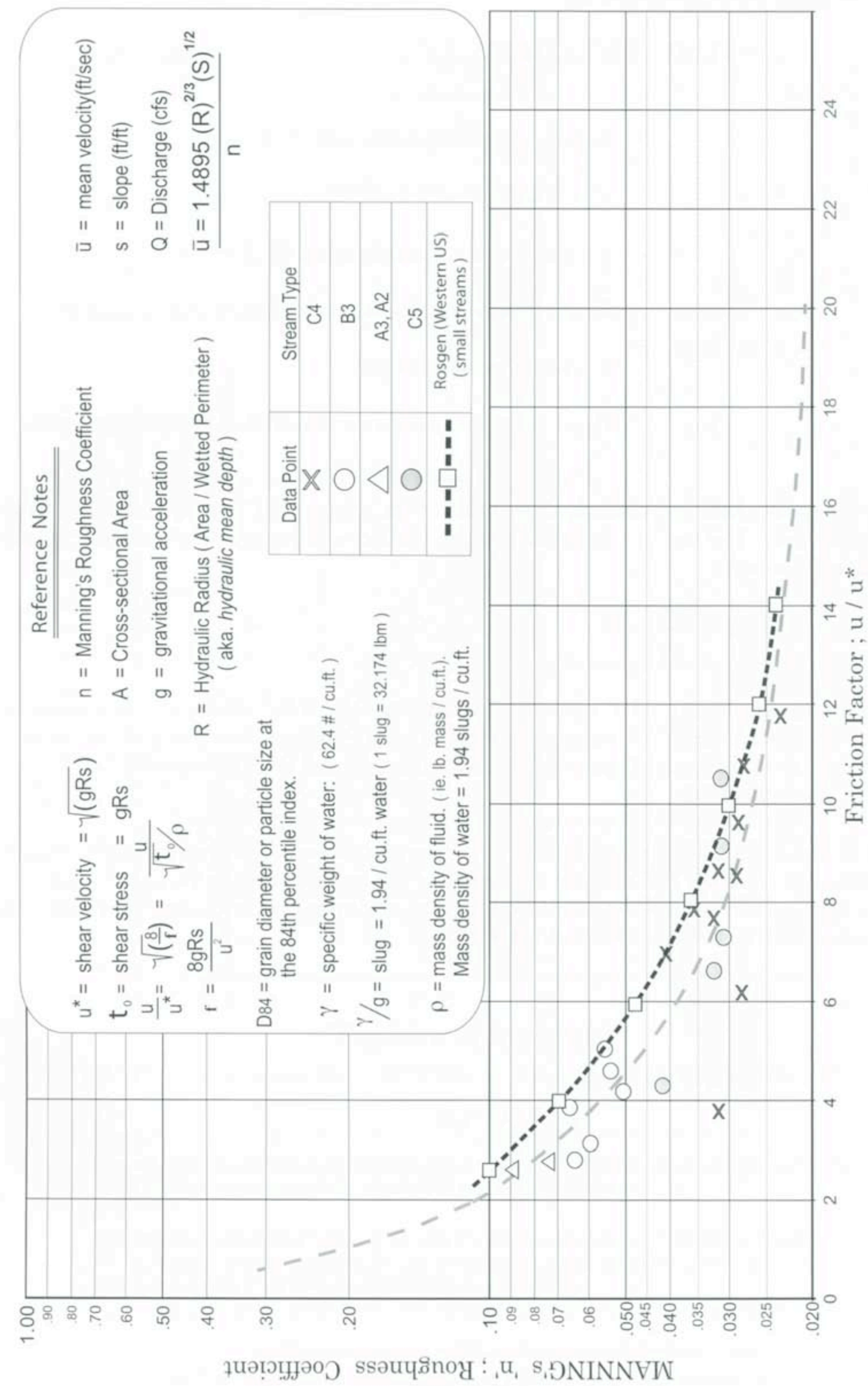
Figure D1: Resistance (Friction) Factor versus Ratio of Mean Depth to Bed Material Size



The relation of channel *bed-particle size* to *hydraulic resistance*, 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: ManningÕs 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.

Stream Functions Pyramid

A Guide for Assessing & Restoring Stream Functions » OVERVIEW

5 **BIOLOGY »**
Biodiversity and the life histories of aquatic and riparian life

4 **PHYSICOCHEMICAL »**
Temperature and oxygen regulation; processing of organic matter and nutrients

3 **GEOMORPHOLOGY »**
Transport of wood and sediment to create diverse bed forms and dynamic equilibrium

2 **HYDRAULIC »**
Transport of water in the channel, on the floodplain, and through sediments

1 **HYDROLOGY »**
Transport of water from the watershed to the channel

Geology

Climate

StreamMechanics

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

Geology

Climate

StreamMechanics

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.

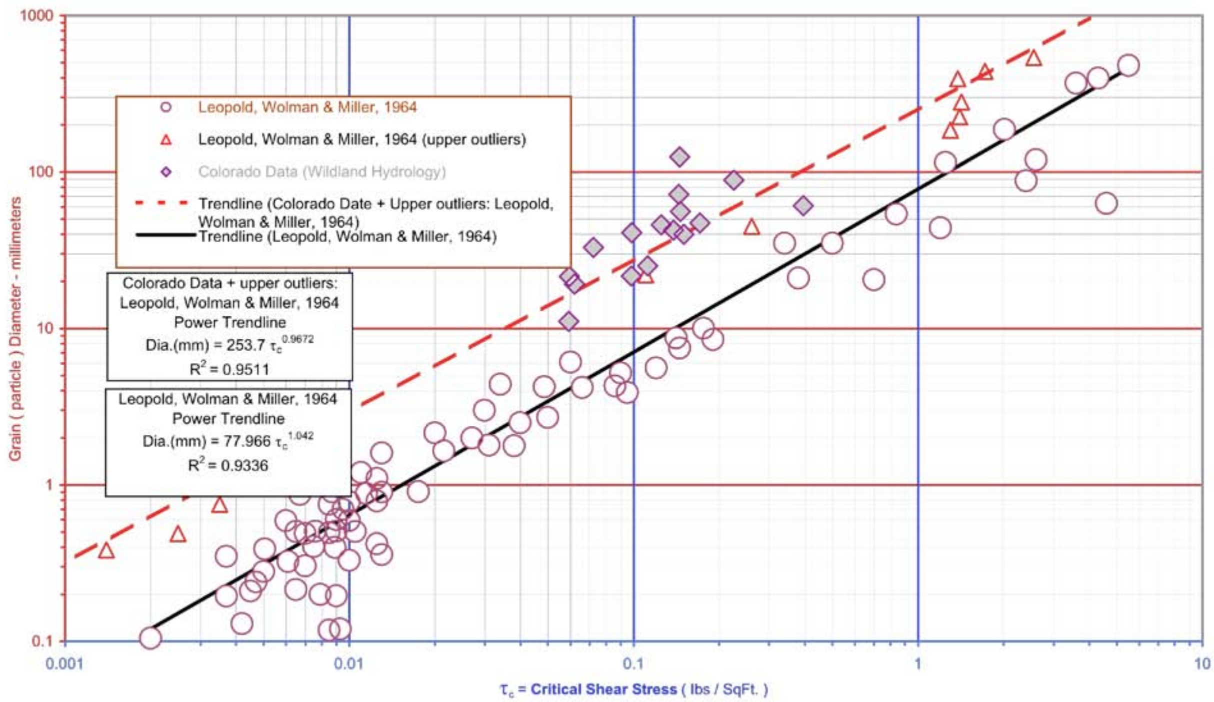
Boundary shear stress is calculated as:

(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		Mean			
			ft/ft	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				

Table F3 provides sample design criteria develop from NC and MD streams. The data came from Will Harma's data (Table F1) and USFWS Chesapeake Bay Field Office. The USFWS data is also based on reference surveys, monitoring data and lessons learned. These criteria are provide as a guide for reviewing projects and should not be "blindly" used for design purposes.

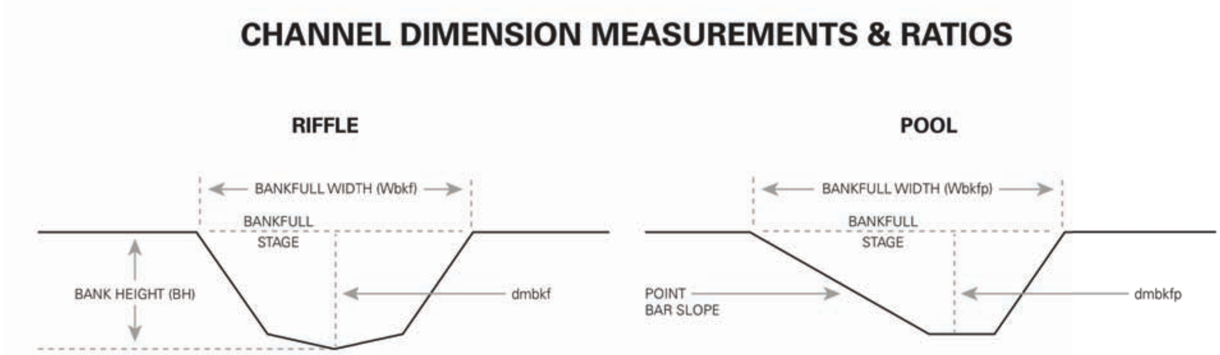
Table F3: Common design criteria for C, E, and B stream types

	Common Design Ratios													
Parameter	***MIN***	***MAX***	***MIN***	***MAX***	***MIN***	***MAX***	***MIN***	***MAX***	***MIN***	***MAX***	***MIN***	***MAX***	***MIN***	***MAX***
Stream Type (Rosgen)	*C4*		*C5*		*E4*		*E5*		*B3*		*B4*		*B4c*	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	3.5	5.0	4.0	6.0	4.0	6.0	n/a	n/a	4.0	6.0	4.0	6.0
Pattern														
Arc Length Ratio, Larc/Wbkf														
Lateral Scour Pools	1.0	3.5	1.0	3.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Compound Pools	3.5	6.0	3.5	6.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
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	n/a	n/a
High Bedload Stress	11.0	14.0	11.0	14.0	n/a	n/a	n/a	n/a	n/a	n/a	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	n/a	n/a
Radius of Curvature Ratio, Rc/Wbkf	2.0	3.0	2.0	3.0	2.0	3.0	2.0	3.0	4.0	6.0	n/a	n/a	n/a	n/a
High Bedload w/ coarse composite banks	3.0	4.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Riffle Angle (Based on Valley Fall)	30°	75°	30°	75°	30°	75°	30°	75°	n/a	n/a	n/a	n/a	n/a	n/a
Sinuosity, K	1.2	1.4	1.2	1.5	1.3	1.6	1.3	1.6	1.1	1.3	1.1	1.3	1.1	1.3
Profile														
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	1.0	1.1
Valley Slope, Sval (ft/ft)	0.005	0.015	0.002	0.010	0.002	0.010	0.002	0.006	0.020	0.030	0.020	0.030	0.005	0.015
Riffle														
Riffle Length Ratio, Lrif/Wbkf	3.0	5.0	n/a	n/a	n/a	n/a	1.0	1.8	n/a	n/a	n/a	n/a	n/a	n/a
Riffle Slope Ratio, Srif/Schan (ft/ft)	1.2	1.5	1.1	1.2	1.2	1.5	1.1	1.2	n/a	n/a	1.1	1.8	1.1	1.8
Riffle Max Depth Ratio, Dmax/Dbkf	1.2	1.5	1.1	1.4	1.2	1.4	1.1	1.3	n/a	n/a	1.2	1.4	1.2	1.4
Run														
Run Length Ratio, Lrun/Wbkf	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Run Slope Ratio, Srun/Srif	0.5	0.8	0.5	0.8	0.5	0.8	0.5	0.8	n/a	n/a	n/a	n/a	n/a	n/a
Run Max Depth Ratio, Dmaxrun/Dbkf	1.7	2.2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Run Width to Depth Ratio, Run w/d / Riffle w/d	0.4	0.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Pool														
Pool Length Ratio, Lpool/Wbkf	1.0	2.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1 - 2%													0.75	1.0
2 - 4%													0.5	0.75
4 - 6%													0.25	0.5
Pool Max Depth Ratio, Dmaxpool/Dbkf	1.5	3.5	1.2	2.5	2.0	3.5	1.2	2.5	n/a	n/a	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	n/a	n/a	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	n/a	n/a	0.5	5.0	1.5	6.0
1 - 2%													4.0	5.0
2 - 4%													3.0	4.0
4 - 6%													2.0	3.0
6 - 8%													1.5	2.0
8+%													1.0	1.5
Glide														
Glide Length Ratio, Lglide/Wbkf	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Glide Slope Ratio, Sglide/Srif	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	n/a	n/a	0.3	0.5	0.3	0.5
Glide Max Depth Ratio, Dmaxglide/Dbkf	1.4	1.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Glide Width Ratio, Wglide/Wbkf	1.5	1.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Glide Width to Depth Ratio, Glide w/d / Riffle w/d	1.1	1.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dimension														
Bankfull Bench Width Ratio, Bench Width / Wbkf	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	n/a	n/a	0.1	0.2	0.1	0.2
Point Bar Slope														
Small Streams	20.0	40.0	20.0	40.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Large Rivers	6.0	10.0	6.0	10.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
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	20.0	12.0	18.0	12.0	18.0

Morphological Measurements

Illustrations of how to measure stream morphology, including the dimensionless ratios, are shown below in Figures F2 ĐF4.

Figure F2: Channel Dimension Measurements

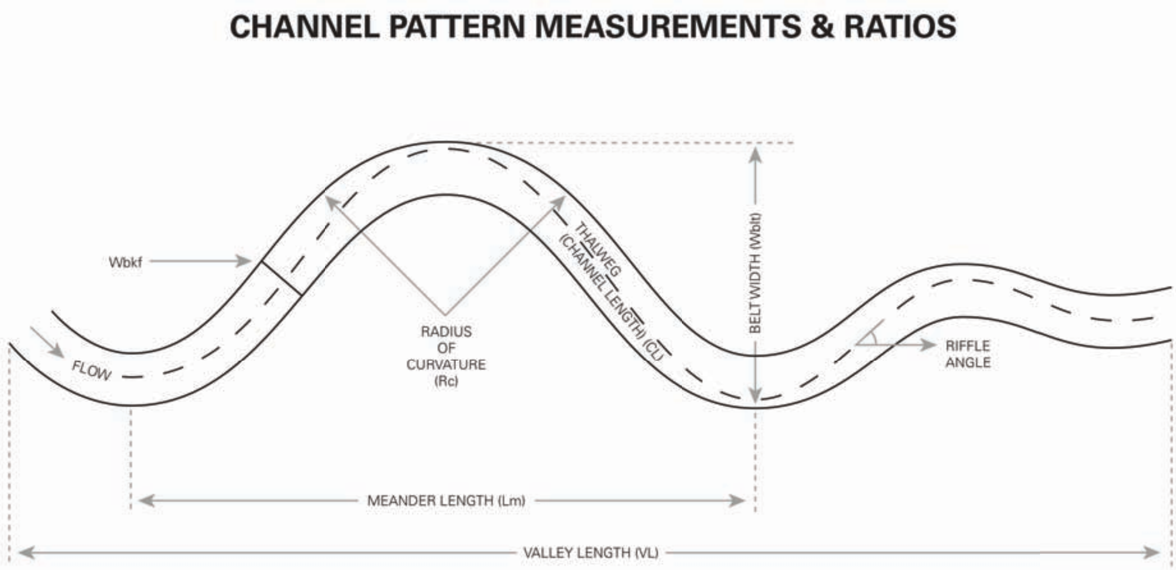


CHANNEL DIMENSION CALCULATIONS
POOL WIDTH / RIFFLE WIDTH (Wbkfp / Wbkf)
MAX. POOL DEPTH / MEAN RIFFLE DEPTH (dmbkfp / dbkf)
MAX. RIFFLE DEPTH / MEAN RIFFLE DEPTH (dmbkf / dbkf)
RIFFLE WIDTH / MEAN RIFFLE DEPTH (Wbkf / dbkf)

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

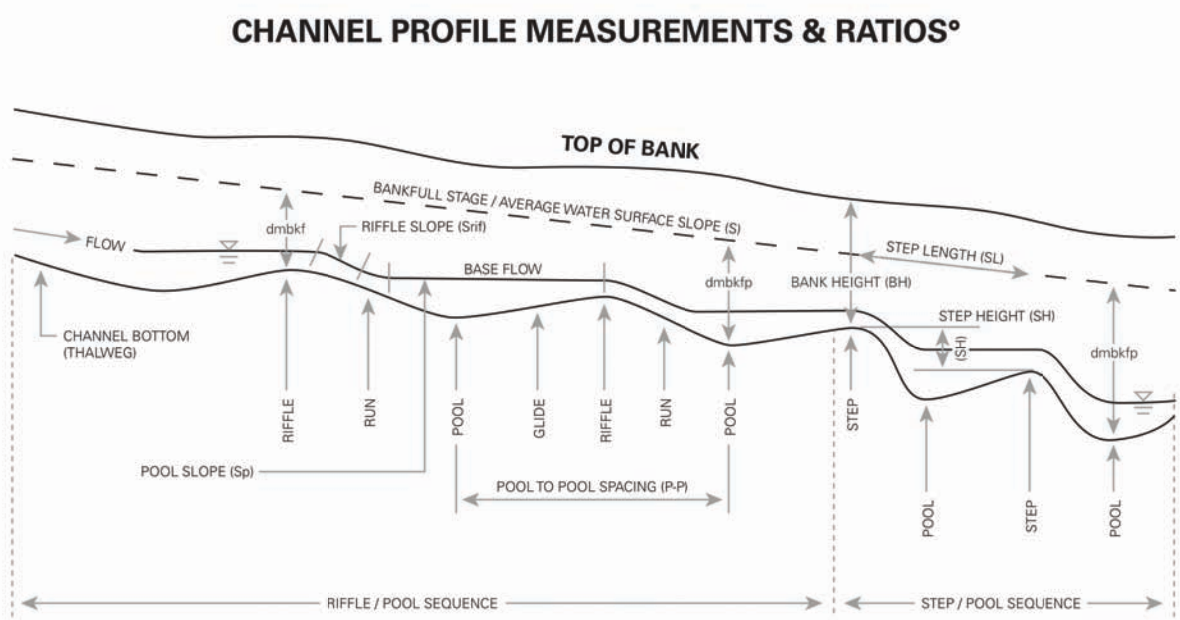
$$\text{BANK HEIGHT RATIO (BHR)} = \frac{\text{BH}}{\text{dmbkf}}$$

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 ÒstepÓÐor abrupt drop in water surface elevation Ðthat 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.

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Appendix H
Additional References

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http://www.bae.ncsu.edu/programs/extension/wqg/srp/

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

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