Natural Channel Design Review Checklist

Prepared By:

Baker Engineering NY, Inc.

William A. Harman, PG

U. S. Fish and Wildlife Services

Richard R. Starr

January 2008

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Introduction

The U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office and Michael Baker Corporation (Baker) has produced, at the request of the Environmental Protection Agency – Wetlands Division (EPA), a natural channel design review checklist (Appendix A) and this supporting document which EPA can use to review stream restoration designs developed using the natural channel design methodology. The checklist provides guidance on important items to consider when reviewing natural channel designs. It is intended to provide the reviewer with a rapid method for determining whether a project design contains an appropriate level of information. While the checklist provides a method for identifying major design shortcomings, no review can ensure project success. The ultimate responsibility for a successful project lies with the project owner, designer, and contractor.

This document presents a brief description of the checklist items by the following sections: Watershed and Geomorphic Assessment, Preliminary Design, Final Design, and Maintenance and Monitoring Plans. The checklist only includes items that relate to creating a stable channel using natural channel design methodologies. Therefore, other restoration tasks such as permitting, flood studies, construction methods and documents, and other items not directly related to creating a stable channel design are **not** included in the checklist. Additionally, most design projects involve additional design deliverables between the preliminary design and final design. This checklist does not include sections for additional design deliverables because the review process is the same. As other deliverables are provided, the reviewer must determine if the design is within the design criteria. Lastly, a reviewer must conduct a site visit of the proposed project area and reference reach site. The reviewer must verify that the stream assessment accurately documented existing stability conditions; the stream design adequately addressed all site opportunities and/or constraints; and the reference site is stable and the appropriate reference.

It is important to note that for the purposes of this review checklist, natural channel design is defined as the application of fluvial geomorphology to create stable channels that do not aggrade or degrade over time and that maximize hydrologic, hydraulic, and biologic functions given site constraints.

1.0 Watershed and Geomorphic Assessment

Checklist Items:

***Watershed Assessment* (1.1)**
Was the watershed assessment methodology described?
Was the project drainage area provided?
Was the percent impervious cover for the watershed provided?
Was the current land use described along with future conditions?
Were watershed hydrology calculations performed?
***Basemapping* (1.2)**
Does the project include basemapping?

Geomorphic Assessment **(1.3)**
Was the geomorphic assessment methodology described?
Were vertical and lateral stability analyses completed?
Was it shown whether the instability was localized or system-wide?
Was the cause and effect relationship of the instability identified?
Was the channel evolution predicted?
Were constraints identified that would inhibit restoration?
Hydraulic Assessment **(1.4)**
Was a hydraulic assessment completed?
Was stream velocity, shear stress, and stream power shown in relation to stage and discharge?
Bankfull Verification **(1.5)**
Was a bankfull verification analysis completed?
Were USGS gages or regional curves used to validate bankfull discharge?
If a regional curve was used, were the curve data representative of the project reach data?
If gages or regional curves were not available, were other methods, such as hydrology and hydraulic models used?

1.1 Watershed Assessment

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

It is important to know the project drainage area, because many of the hydrologic, hydraulic, and geomorphic equations and 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. It is impossible to review design elements without knowing the drainage area.

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

A watershed with rapidly changing landuses is one of the most challenging settings for a stream restoration project because the design will need to accommodate future conditions. Therefore, it is important to know the current landuse as well as the future build-out potential. If a watershed is currently rural, but is becoming urban, it is important to know that the design takes these changes into account.

The watershed assessment task often includes hydrologic calculations to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year discharges. These calculations are used to quantify channel hydraulics and to complete a flood study, if one is required. If the Federal Emergency Management Agency

(FEMA) or the local floodplain manager does not require a flood study, complex watershed hydrologic calculations may not be necessary, especially if the watershed has a gage station or is undeveloped. In these cases, discharges may be obtained directly from gage records or estimated from U.S. Geologic Service (USGS) regression equations, regional curves, or Manning's equation and cross section geometry from the project channel. Velocity (v) in feet per second can be estimated using Manning's equation as follows:

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

R = the hydraulic radius (ft), defined as the wetted perimeter divided by the cross sectional area,
S = water surface slope (ft/ft),
n = roughness coefficient. See Appendix D for n values.

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 re-arranging the continuity equation as follows:

(3) $V = Q/A$.

In this case, Manning's equation is not necessary. This calculation provides a simple, but useful check to determine if the 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 10 ft/s, this is an indicator that the channel may erode vertically and/or laterally.

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

1.2 Basemapping

It is critical that the project include adequate basemapping. The basemap is a topographic map, usually with 1 ft contour lines, that also includes the existing channel alignment, utilities, large trees, roads, property boundaries, and other constraints. 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 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 are the result of previous 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. Rosgen (2006a) provides a detailed methodology for completing watershed assessments for river stability.

1.3 Project Reach Geomorphic Assessment

Most stream restoration projects address problems with vertical stability, lateral stability, or both. These are identified in the geomorphic assessment. For the purpose of completing the review checklist, the geomorphic assessment pertains to the project reach only and not the entire watershed. Vertical instability is a more difficult problem to solve than lateral instability. It is important to know if the stream is unstable, whether the instability is localized or system-wide, and the cause of instability (i.e., cause and effect relationship). An example of localized instability is an eroding streambank beneath a powerline where the vegetation has been removed from the streambank, likely along the outside of a bend. An example of system-wide instability is a headcut that is migrating up the channel as a result of past channelization and the subsequent increase in slope. Both of these examples are related to direct modifications to the stream; however, land use changes in the watershed can also indirectly cause channel instability. For example, an increase in impervious surface and stormwater outfalls increases peak discharge. The effect can be channel enlargement through bank erosion, bed erosion, or both.

Part of the channel stability assessment should include a discussion of channel evolution. It is critical to know if the stream is trending towards increased stability or further instability. This helps to determine the level of restoration needed. For example, a simple land management change may be all that is required (e.g., fencing cows out of a stream) or the channel geometry may need to be re-constructed. The Simon channel evolution model and channel evolution by stream type are provided in Appendix B. For additional information on the Simon Channel Evolution Model, refer to Chapter 7 in *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG, 1998).

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

The majority of the watershed and geomorphic assessment data are used to determine the cause and effect relationships between the watershed and the stability and functionality of the stream. Complex watershed assessments are not required for every stream restoration project. However, the methods used to complete the assessment should be described in order to make this determination. Project reports that simply state a watershed assessment was completed are not sufficient. Furthermore, it should be noted whether the assessment was completed in the field or in the office.

1.4 Hydraulic Assessment

The hydraulic assessment uses information from the watershed hydrologic assessment to quantify flood stage, stream velocity, shear stress, and stream power. These parameters are used to evaluate pre- and post-restoration flood conditions and aid in designing the channel. Depending on floodplain requirements, the hydraulic analysis may be simple or complex. Copeland et al. (2001) provides a detailed overview of hydraulic design methods for stream restoration projects.

1.5 Bankfull Verification

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

The return interval for the bankfull discharge is typically between 1 and 2 years. This has been determined 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 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.

The data for regional curves come from field surveys at USGS gage stations, where the geomorphic indicator is correlated with a known elevation. This information, along with a flood frequency analysis, is used to determine the return interval. McCandless and Everett (2002) provide a detailed overview of the methods for creating regional curves. It is critically important that the bankfull discharge and return interval come from the geomorphic indicator of the bankfull stage. Some regional curves have been developed by defining the bankfull discharge as the 1.5 year storm. The 1.5 year event 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 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-yr discharge event 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.

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

2.0 Preliminary Design

Checklist Items:

***Goals and Restoration Potential* (2.1)**
Does the project have clear goals?
Was the restoration potential based on the assessment data provided?
Was a restoration strategy developed and explain based on the restoration potential?

***Design Criteria* (2.2)**
Were design criteria provided and explained?
Were multiple methods used to prepare design criteria?

***Conceptual Design* (2.3)**
Was a conceptual channel alignment provided?
Were typical bankfull cross sections provided?
Were typical in-stream structures provided?
Was a draft planting plan provided?

2.1 Goals and Restoration Potential

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 improving hydrologic, geomorphic, and biologic functions. 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 C.

The goals may also state if the project is being completed to produce mitigation credits or simply for restoration. This is important because mitigation projects often require more justification than a restoration project. It is also important to know the funding source along with the requirements of the funding agency.

Based on the watershed and geomorphic assessment data, the restoration potential should be provided. The restoration potential should state the highest level of restoration attainable given the site constraints. For example, if a stream has been channelized and re-located 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 re-construct a meandering channel through the original floodplain. The entire floodplain may be converted into a bottomland hardwood forest. If the landowner is not willing to take the land out of production, the restoration potential may be to create a non-meandering step-pool channel without making major adjustments to pattern. In this case, a 30 to 50 foot buffer may be planted.

2.2 Design Criteria

The development of design criteria is one of the most important tasks in a natural channel design. Design criteria provide the numerical guidelines for designing channel dimension, pattern, and profile. 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 empirical relationships. 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 D along with a list of parameters that should be measured from the plan sheets as part of the design review.

For complex projects, it is best if multiple methods are used to develop a final set of criteria. Ultimately, professional judgment is required to select the final criteria, which is why design experience is critically important. For example, many designers rely solely on reference reaches to develop their design criteria. The reference reach approach requires that the appropriate stream type be designed for the appropriate valley type, geology, and land use. For example, if the valley is confined, the approach dictates that a B stream type should be designed. Also, the pre-existing stream type may be different than the proposed stream type, i.e., the existing stream was a C4, but the proposed channel is a B4c because of channel confinement.

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

2.3 Conceptual Design

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

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

At this stage, typical in-stream structures should be shown along with their approximate location along the alignment. 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.

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 woody 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 landowner. 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.

3.0 Final Design

Checklist Items: ***Natural Channel Design* (3.1)**

Was a proposed channel alignment provided and developed within the design criteria?
Were proposed channel dimensions provided and developed within the design criteria?
Do the proposed channel dimensions show the adjacent floodplain or flood prone area?
Was a proposed channel profile provided and developed within the design criteria?

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

***Sediment Transport* (3.2)**
Was sediment transport analysis required?
If required, was the type of sediment transport analysis explained?
Were existing versus design relationships of shear stress, velocity, and stream power versus stage or discharge provided?
Did sediment transport capacity analyses show that the stream bed would not aggrade or degrade over time?
Did sediment transport competency analysis show what particle sizes would be transported with a bankfull discharge?
For gravel/cobble bed streams, does the proposed design move particles that are larger than the D100 of the stream bed?
***In-Stream Structures* (3.3)**
Based on the assessment and design, were in-stream structures required for lateral stability?
Based on the assessment and design, were in-stream structures required for vertical stability?
If required, was the reason for their location and use explained?
Will the in-stream structures provide the intended stability?
Were detail drawings provided for each in-stream structure?
***Vegetation Design* (3.4)**
Was a vegetation design provided?
Does the design address the use of permanent vegetation for long-term stability?

3.1 Natural Channel Design

The natural channel design is typically shown in a set of plan sheets and specifications, with the final set sealed by a Professional Engineer. These plan sheets and specifications are used by contractors to build the project. It is important to review the design against the design criteria discussed in the Conceptual Design section (2.3). The Rosgen Geomorphic Channel Design methodology is described in Chapter 11 of the NRCS handbook: Part 654 – Stream Restoration Design (2007). An overview of the natural channel design process is described by Hey (2006). Doll et al., (2003) provides a design manual for natural channels. Other methods are described in the handbook as well.

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

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

Finally, the cross sections should extend far enough across the valley so that the adjacent floodplain width can be determined. 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 floodprone area width by the bankfull width at a riffle. The floodprone 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's that exceed 2.2; higher numbers mean designs that are more likely to remain stable during flood events.

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 D, Morphological Measurements and Ratios – Dimension for an illustration and equation of the bank height ratio.

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 Sediment Transport

Most, but not all, projects will require some form of sediment transport analysis. Sediment transport analysis is one of the more complex components of a natural channel design. These analyses usually address questions about the ability of the stream to transport sediment particles of a certain size (competency) and load (capacity). Rosgen (2006a) provides an overview of sediment transport in Chapter 2 of *Watershed Assessment of River Stability and Sediment Supply*.

Projects that may not require sediment transport analysis include those with low sediment supply from the upstream watershed. Examples include low gradient coastal plain streams and highly urbanized streams. Projects located in bed load transport reaches with upstream sources of sediment should include sediment transport analysis. If sediment transport analyses are required, it is important to know why one type of sediment transport analysis was selected over another. The type and distribution of the bed material governs the complexity of the analyses, i.e., bed material composed of all sand requires fewer analyses than cobble, gravel, and sand mixtures. Some important questions to ask include: Was sediment transport competency calculations completed, but not sediment transport capacity? Why? If sediment transport capacity calculations were completed, were explanations provided for the selected equations?

Existing versus design relationships of shear stress, velocity, and stream power versus 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.

If sediment transport analyses are required, were the calculations used as an aid in designing channel dimension and slope? Sediment transport competency and capacity can be used to help design a channel that can transport the water and sediment delivered by the watershed so that the channel bed does not degrade or aggrade. Sediment transport competency analysis is used to predict the particle size that can be entrained for a given flow. Typically, for gravel/cobble bed streams, the designer tries to move particle sizes that correspond with the bankfull discharge, without moving the largest particles sampled from the bed (D100).

3.3 In-Stream Structures

Most, but not all, projects require the use of in-stream structures. Examples of projects that may not need in-stream structures include small streams in low gradient valleys, 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.

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. Bioengineering techniques may be used to stabilize eroding streambanks. A general description of in-stream structures and their benefit to water quality is provided in Appendix E.

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. Detail drawings should be provided for each type of in-stream structure or erosion control measure.

3.4 Vegetation Design

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

4.0 Maintenance and Monitoring Plans

Checklist Items:

Maintenance Plan **4.1**
Was a maintenance plan provided?
Does it clearly state when maintenance will be required and if so, is it quantifiable?
Does it clearly state how erosion will be addressed and by whom?

Monitoring Plan **4.2**
Was a monitoring plan provided?
Does it state who is required to conduct the monitoring?
Does it have measurable performance standards?
Is monitoring required for at least 3 years?

4.1 Maintenance Plan

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

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

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

4.2 Monitoring Plan

A monitoring plan may or may not be provided depending on the source of funding. The majority of stream restoration projects being completed for mitigation credits require some level of monitoring, usually for 3 to 10 years. Projects funded by federal and state grants may require monitoring, but often do not. If a monitoring plan is submitted with the design, it should state who is responsible for the monitoring, including contact information, e.g. name, address, phone number, email address.

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

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

5.0 Overall Design Review

Checklist Items: ***Overall Design Review*** **5.1**
Does the design address the project objectives?
Are there any design components that are missing or could adversely affect the success of the project?

5.1 Overall Design Review

This item provides the reviewer with the opportunity to comment on the overall quality of the design. Based on the results from the above questions, the reviewer should determine if the design addresses the project objectives. For example, if the objective was to reduce incision and bank erosion, the design should show reductions in the bank height ratio and connectivity with an adjacent floodplain or floodprone area. 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.

6.0 References

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Appendix A
Natural Channel Design Review Checklist

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ______________________
Date: ______________________

Project: ______________________
Engineer: ______________________

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

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ______________________
Date: ______________________

Project: ______________________
Engineer: ______________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Comments
2.0 Preliminary Design			
2.1 Goals and Restoration Potential			
Does the project have clear goals?			
Was the restoration potential based on the assessment data provided?			
Was a restoration strategy developed and explained based on the restoration potential?			
2.2 Design Criteria			
Were design criteria provided and explained?			
Is the design criteria representative of reference reaches within the project area or of the same valley type, geology, and land use?			
2.3 Conceptual Design			
Was the conceptual channel alignment provided and developed within the design criteria?			
Were typical bankfull cross sections provided and developed within the design criteria?			
Were typical drawings of in-stream structures provided and their use and location explained?			
Was a draft planting plan provided?			
3.0 Final Design			
3.1 Natural Channel Design			
Was a proposed channel alignment provided and developed within the design criteria?			
Were proposed channel dimensions provided and developed within the design criteria?			
Do the proposed channel dimensions show the adjacent floodplain or flood prone area?			
Was a proposed channel profile provided and developed within the design criteria?			
Were specifications for materials and construction procedures provided and explained for the project (i.e., in-stream structures, erosion control measures, etc.)?			

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ____________________
Date: ____________________

Project: ____________________
Engineer: ____________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Comments
3.2 Sediment Transport			
Was sediment transport analysis required?			
If required, was the type of sediment transport analysis explained?			
Were existing versus design relationships of shear stress, velocity, and stream power versus stage or discharge provided?			
Did sediment transport capacity analyses show that the stream bed would not aggrade or degrade over time?			
Did sediment transport competency analysis show what particle sizes would be transported with a bankfull discharge?			
For gravel/cobble bed streams, does the proposed design move particles that are larger than the D100 of the stream bed?			
3.3 In-Stream Structures			
Based on the assessment and design, were in-stream structures required for lateral stability?			
Based on the assessment and design, were in-stream structures required for vertical stability?			
If required, was the reason for their location and use explained?			
Will the in-stream structures provide the intended stability?			
Were detail drawings provided for each in-stream structure?			
3.4 Vegetation Design			
Was a vegetation design provided?			
Does the design address the use of permanent vegetation for long term stability?			
4.0 Maintenance and Monitoring Plans			
4.1 Maintenance Plan			
Was a maintenance plan provided?			
Does it clearly state when maintenance will be required and if so, is it quantifiable?			
Does it clearly state how erosion will be addressed and by who?			

Natural Channel Design Review Checklist

Project Design Checklist

Reviewer: ______________________
Date: ______________________

Project: ______________________
Engineer: ______________________

Item	Submitted (Y/N)	Acceptable (Y/N)	Comments
4.2 Monitoring Plan			
Was a monitoring plan provided?			
Does it have measurable, quantifiable performance standards?			
Does it have clearly defined thresholds of success and failure?			
Is monitoring required for at least 3 years?			
Does it state who is required to conduct the monitoring?			
5.0 Overall Design Review			
Does the design address the project objectives?			
Is there any component of the design that adversely affects the success of the project?			

Appendix B
Simon Channel Evolution Model
Channel Evolution by Stream Type

Simon Channel Evolution Model

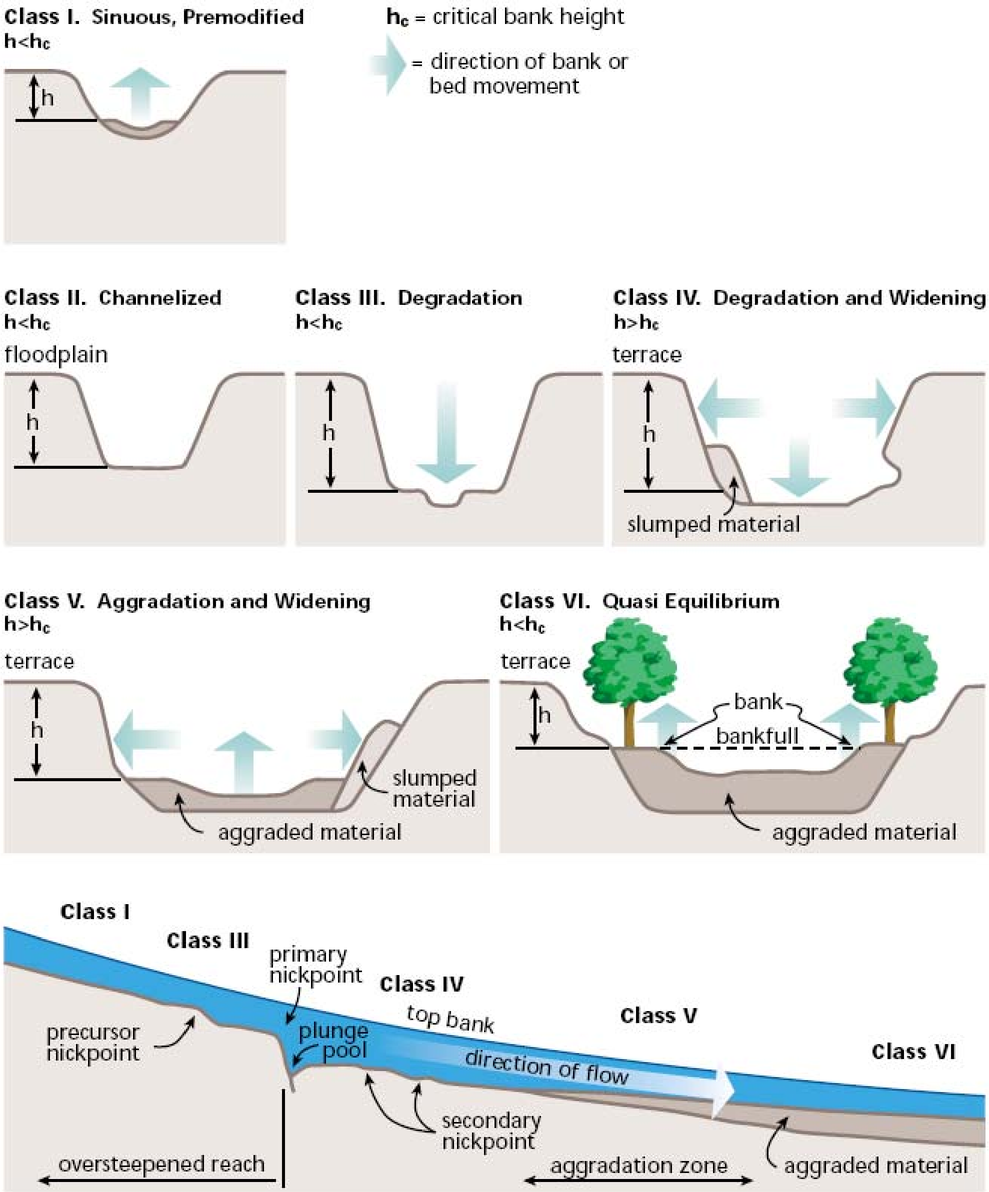
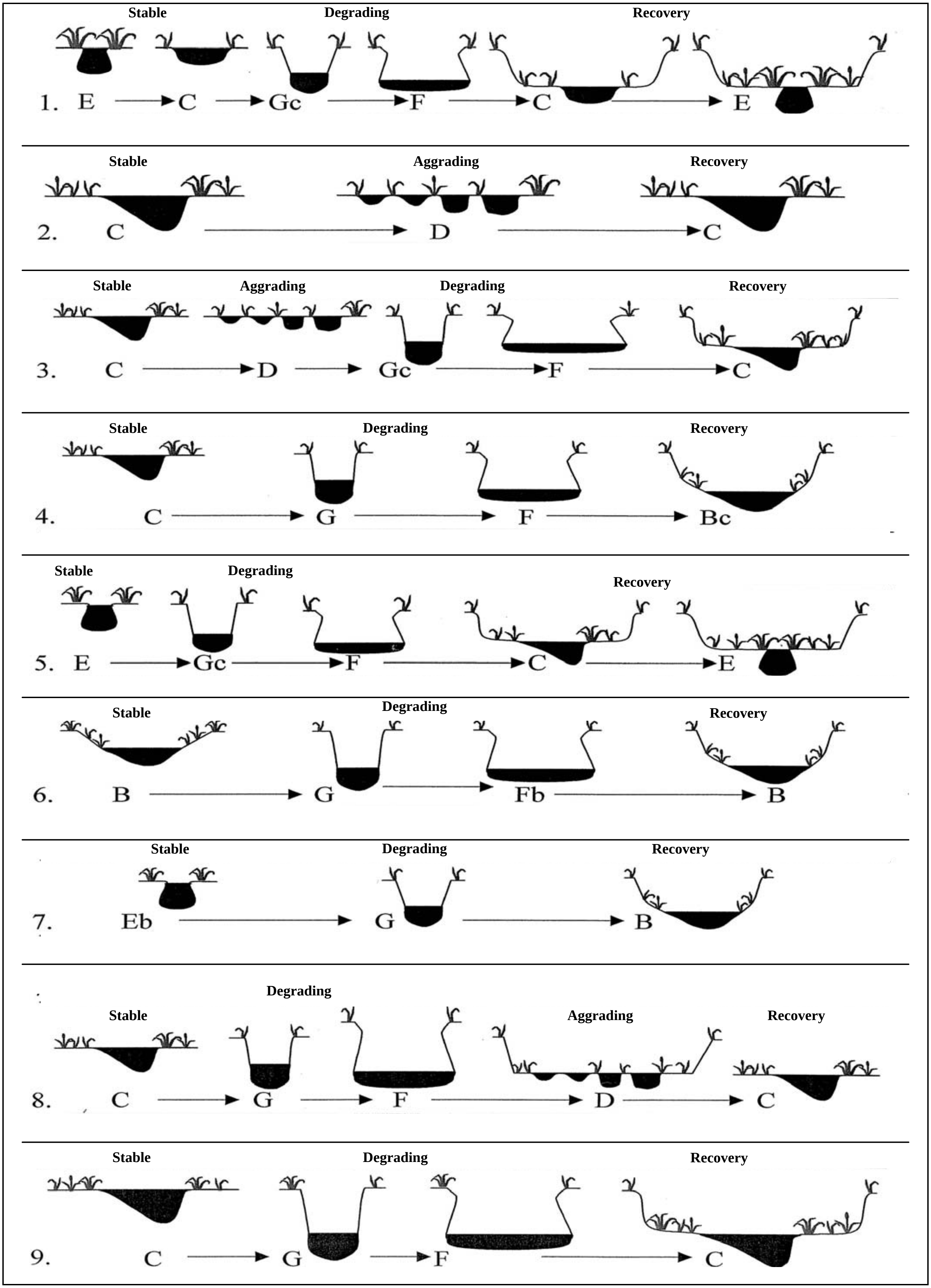


Figure 7.14: Channel evolution model. *A disturbed or unstable stream is in varying stages of disequilibrium along its length or profile. A channel evolution model theoretically may help predict future upstream or downstream changes in habitat and stream morphology.*

Source: Simon 1989, USACE 1990.

Rosgen Channel Evolution by Stream Type



Appendix C
Preliminary Design Objectives and Goals

Examples of Function-Based Goals and Objectives

Stream functions can be divided into three broad categories: hydrology, geomorphology, and biology. Hydrologic functions include the ability of the stream to transport water that is delivered by the watershed. These functions are often described in terms of channel conveyance or discharge. Alluvial channels convey water in an active channel, called the bankfull channel, and flood flows on a floodplain. Colluvial channels convey water in a bankfull channel and a floodprone area. It is the general intent of natural channel design to create bankfull channels with floodplains or floodprone areas.

Geomorphology functions are defined as the stream's ability to move water and sediment so that over a long period of time, the stream channel does not aggrade or degrade. This balance, or dynamic equilibrium, includes stream geometry (dimension, pattern, and profile) and its relationship with rainfall/runoff, geology, landuse, soil types, and vegetation. Dynamic equilibrium is assessed through sediment transport competency and capacity calculations. The results include a diversity of bedforms including steps/cascades/riffles, pools, runs and glides.

The restoration of hydrologic and geomorphologic functions provides a framework for restoring biologic functions. For example, by restoring an appropriately sized bankfull channel with a meandering pattern, a riffle-pool sequence is created. These riffles are used by macroinvertebrates, which are an important source of food for fish. Fish use the pool habitats for cover and rest. Thus, geomorphologic functions provide the bedform diversity that is important for a variety of stream organisms. Other biologic functions include riparian buffers that provide shade to the stream channel and dissipate flood flows. They also provide terrestrial homes for reptiles, mammals, and birds.

Example design goals for each category are provided below. Projects will not include all of these goals. Select, modify, or combine the goals that best suit the project by assessing the potential for restoration along with any constraints.

Example Design Goals for Restoring Hydrology Functions:

1. Restore flood flows above the bankfull stage to an abandoned floodplain. Convert a terrace into an active floodplain, by raising the channel bed and associated water table.
2. Restore channel forming flows to the appropriately sized channel based on Dominant Discharge Theory.
3. Restore wetland and floodplain hydrology to meet the US Army Corps of Engineers definition of a wetland.
4. Dissipate flood energy by creating a meandering channel and new floodplain at the existing bankfull elevation. Partially restore lost floodplain and wetland functions.
5. Dissipate flood energy by creating a step-pool channel and floodplain bench at the existing bankfull elevation. Restore floodprone area functions.
6. For urban channels, restore bankfull discharge to pre-development levels by implementing watershed scale best management practices, providing grade control and/or recreating large floodplains.

7. Create a riparian buffer to reduce flood velocities on the floodplain and encourage infiltration and sediment deposition.

Example Design Goals for Restoring Geomorphology Functions:

1. Create a stable channel that does not aggrade or degrade over a long period of time.
2. Create streambanks that do not erode at rates above natural levels for reference reach streams of the same stream type.
3. For alluvial systems, restore a riffle-pool bedform sequence such that the pool to pool spacing and percent riffle-pool matches reference reach streams of the same stream type.
4. For colluvial systems, restore a step-pool bedform sequence such that the pool to pool spacing matches reference reach streams of the same stream type.

Example Design Goals for Restoring Biology Functions:

1. Create coarse grained riffles, via constructed riffles and proper profile design, to improve macroinvertebrate habitat and promote oxygenation of the water.
2. Increase the amount and complexity of large woody debris to improve fish habitat.
3. Create deep pools near cover structures (wood or rock) to improve fish habitat.
4. Create holding areas in riffles for fish habitat and passage, i.e. provide a diversity of flow velocities within a cross section and reach.
5. Create a riparian buffer using native plants to improve channel shade and terrestrial habitat.

Appendix D
Sample Design Criteria
Manning's n Table

Common Reference Reach Ratios for C, E and B Stream Types
Data Collected from reference reach streams in North Carolina Mountains and Piedmont
13-Sep-07

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

	Common Design Ratios			
Parameter	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C/E 4		B4	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	4.0	6.0
Width to Depth Ratio, W/D (ft/ft)	**10.0**	14.0	12.0	18.0
Riffle Max Depth Ratio, Dmax/Dbkf	1.1	1.3	1.2	1.4
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.1	1.0	1.1
Meander Length Ratio, Lm/Wbkf	7.0	12.0	N/a	N/a
Radius of Curvature Ratio, Rc/Wbkf	**2.0**	**3.0**	N/a	N/a
Meander Width Ratio, Wblt/Wbkf	3.5	8.0	N/a	N/a
Sinuosity, K	1.20	1.60	1.1	1.2
Valley Slope, Sval (ft/ft)	0.0050	0.0150	0.020	0.030
Riffle Slope Ratio, Srif/Schan	1.5	2.0	1.1	**1.8**
Run Slope Ratio, Srun/Srif	0.50	0.80	N/a	N/a
Glide Slope Ratio, Sglide/Schan	0.30	0.50	0.3	0.5
Pool Slope Ratio, Spool/Schan	0.00	0.20	0.0	0.4
Pool Max Depth Ratio, Dmaxpool/Dbkf	2.0	3.5	2.0	3.5
Pool Width Ratio, Wpool/Wbkf	**1.3**	**1.7**	1.1	1.5
Pool-Pool Spacing Ratio, Lps/Wbkf	4.0	7.0	1.5	5.0

Table 2: Common reference reach ratios for channel evolution and departure from stability analysis

	Common Reference Reach Ratios			
Parameter	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C/E 4		B4	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	4.0	6.0
Width to Depth Ratio, W/D (ft/ft)	**5.0**	12.0	12.0	18.0
Riffle Max Depth Ratio, Dmax/Dbkf	1.1	1.4	1.2	1.4
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.1	1.0	1.1
Meander Length Ratio, Lm/Wbkf	7.0	12.0	N/a	N/a
Radius of Curvature Ratio, Rc/Wbkf	**1.2**	**2.0**	N/a	N/a
Meander Width Ratio, Wblt/Wbkf	**3.0**	8.0	N/a	N/a
Sinuosity, K	1.20	1.60	1.1	1.2
Valley Slope, Sval (ft/ft)	0.0050	0.0150	0.020	0.030
Riffle Slope Ratio, Srif/Schan	1.5	2.0	1.1	**2.5**
Run Slope Ratio, Srun/Srif	0.50	0.80	N/a	N/a

Table 2 Cont: Common reference reach ratios for channel evolution and departure from stability analysis

	Common			
	Reference Reach Ratios			
Parameter	**MIN**	**MAX**	**MIN**	**MAX**
Glide Slope Ratio, Sglide/Schan	0.30	0.50	0.3	0.5
Pool Slope Ratio, Spool/Schan	0.00	0.20	0.0	0.4
Pool Max Depth Ratio, Dmaxpool/Dbkf	2.0	3.5	2.0	3.5
Pool Width Ratio, Wpool/Wbkf	**0.8**	**1.2**	1.1	1.5
Pool-Pool Spacing Ratio, Lps/Wbkf	4.0	7.0	1.5	5.0

Prepared By: Will Harman, PG
Michael Baker Corporation
Source: NC Department of Transportation reference reach database, evaluation of Baker Engineering projects

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
Belt Width	Plan Views
Meander Wavelength	Plan Views
Radius of Curvature	Plan Views
Sinuosity	Plan Views

Values of Manning's *n* for Channels of Various Types

Type of Channel and Description	*n*		
	Minimum	**Normal**	**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 flood ways 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

Source: Dingman, Lawrence S. 1994. Physical Hydrology. Prentice-Hall, Inc. New York, NY.

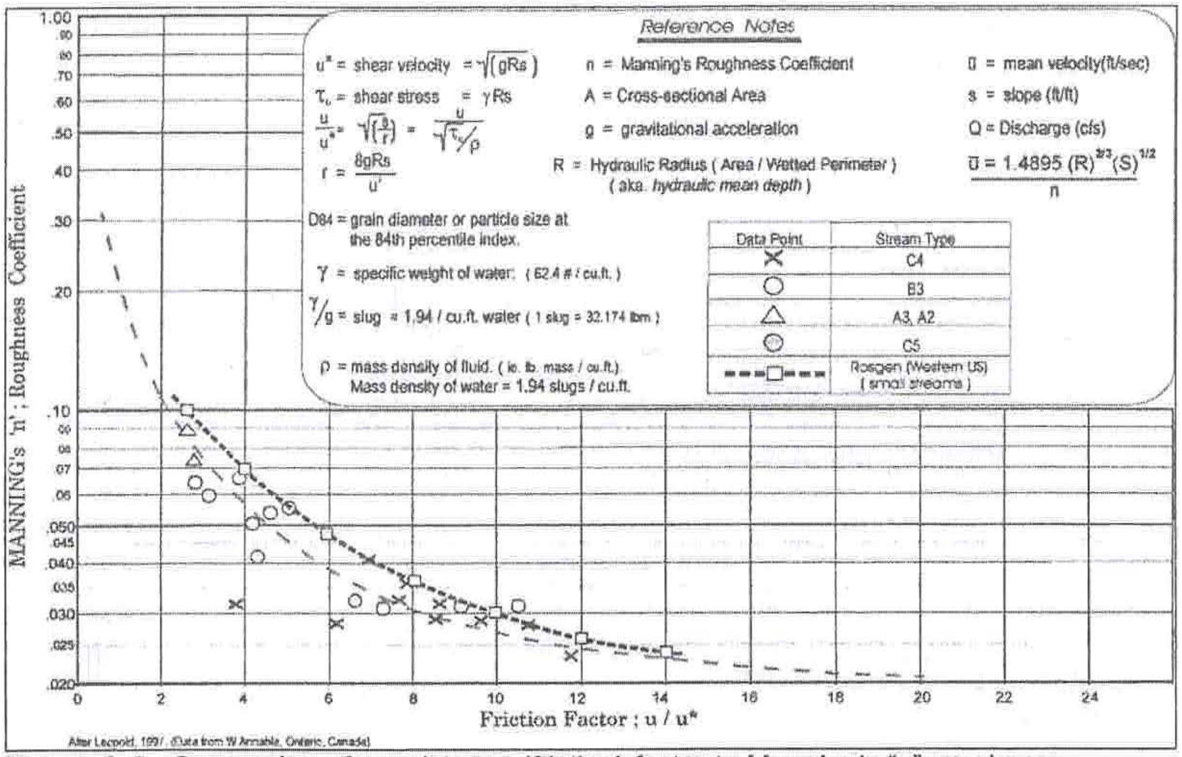


Figure A-2. Conversion of a resistance (friction) factor to Manning's "n" roughness coefficient.

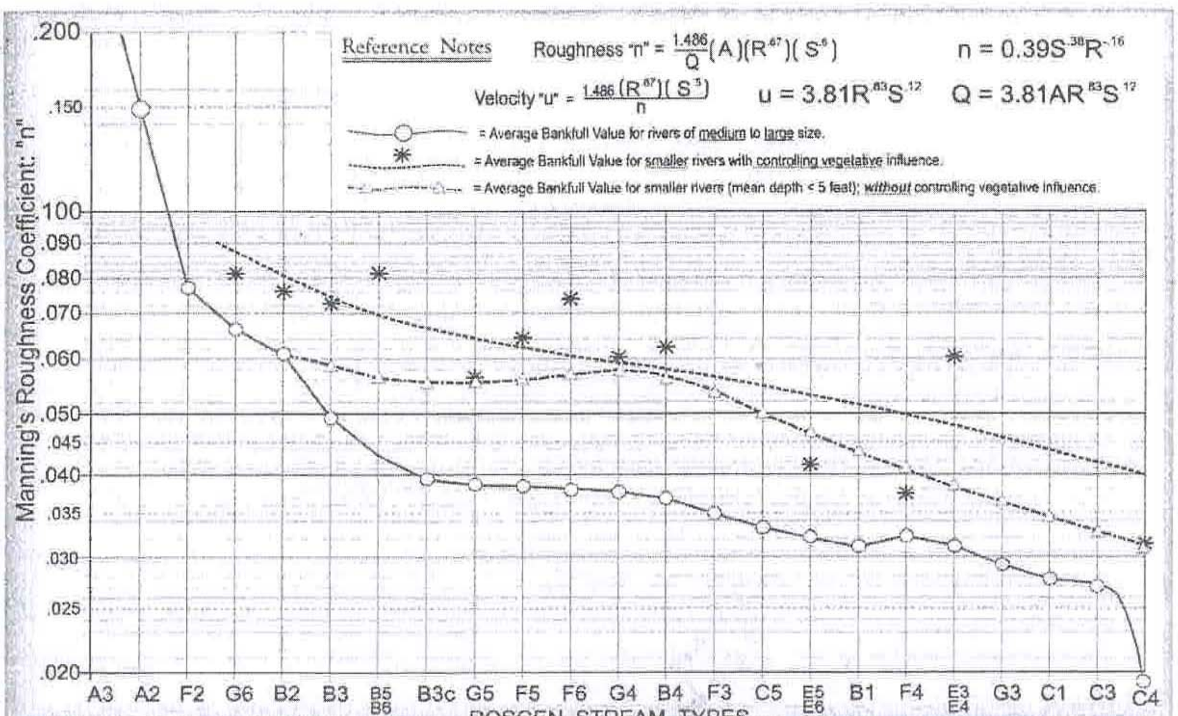
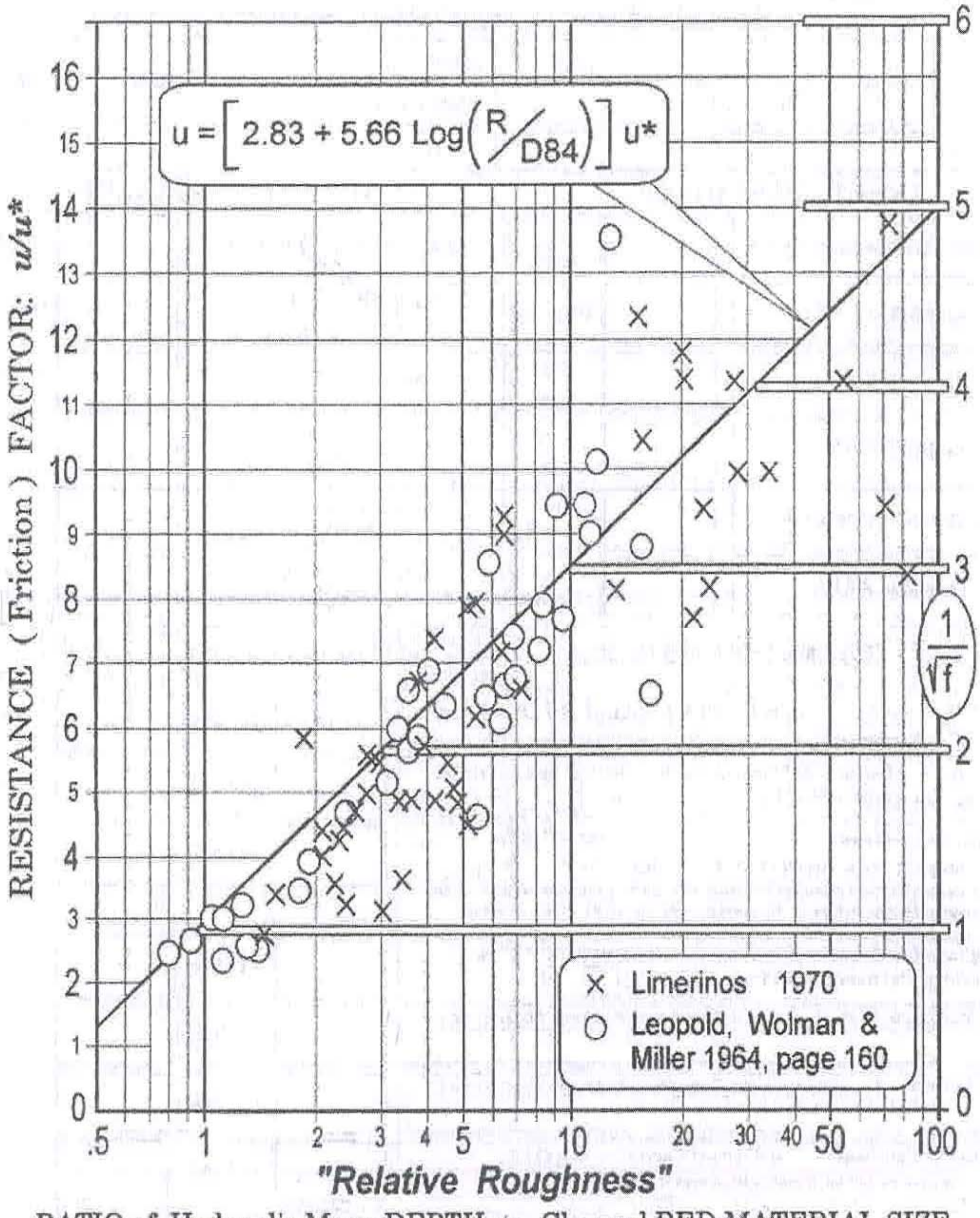


Figure A-3. Conversion of stream types to Manning's "n" roughness coefficient.



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

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

Figure A-1. Computation of velocity from a resistance factor and relative roughness.

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				

Daniels Run
Reference Reach Design Criteria

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

Daniels Run
Reference Reach Design Criteria

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

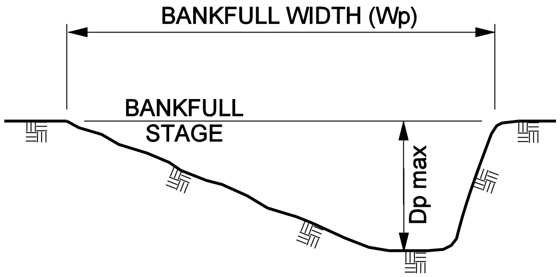
Daniels Run
Reference Reach Design Criteria

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

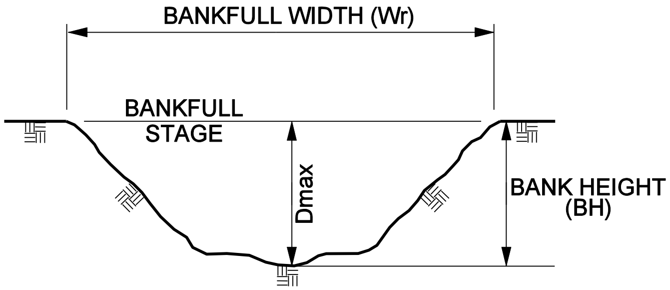
1. Data collected by Wildland Hydrology, Inc.
2. Data collected by the Service for the Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Piedmoı Hydrologic Region (McCandless and Everett 2002
3. Data collected by the Servic
4. Data collected by Clear Creeks Consultants,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

MORPHOLOGICAL MEASUREMENTS AND RATIOS

DIMENSION



SECTION A
(POOL)



SECTION B
(RIFFLE)

CHANNEL DIMENSION MEASUREMENTS
MAX POOL DEPTH (Dp max)
POOL WIDTH (Wp)
POOL AREA (Ap)
MAX RIFFLE DEPTH (Dmax)
MEAN RIFFLE DEPTH (Dbkf)
RIFFLE WIDTH (Wr)
RIFFLE AREA (Ar)
MAX RUN DEPTH (Drn)
MAX GLIDE DEPTH (Dgl)

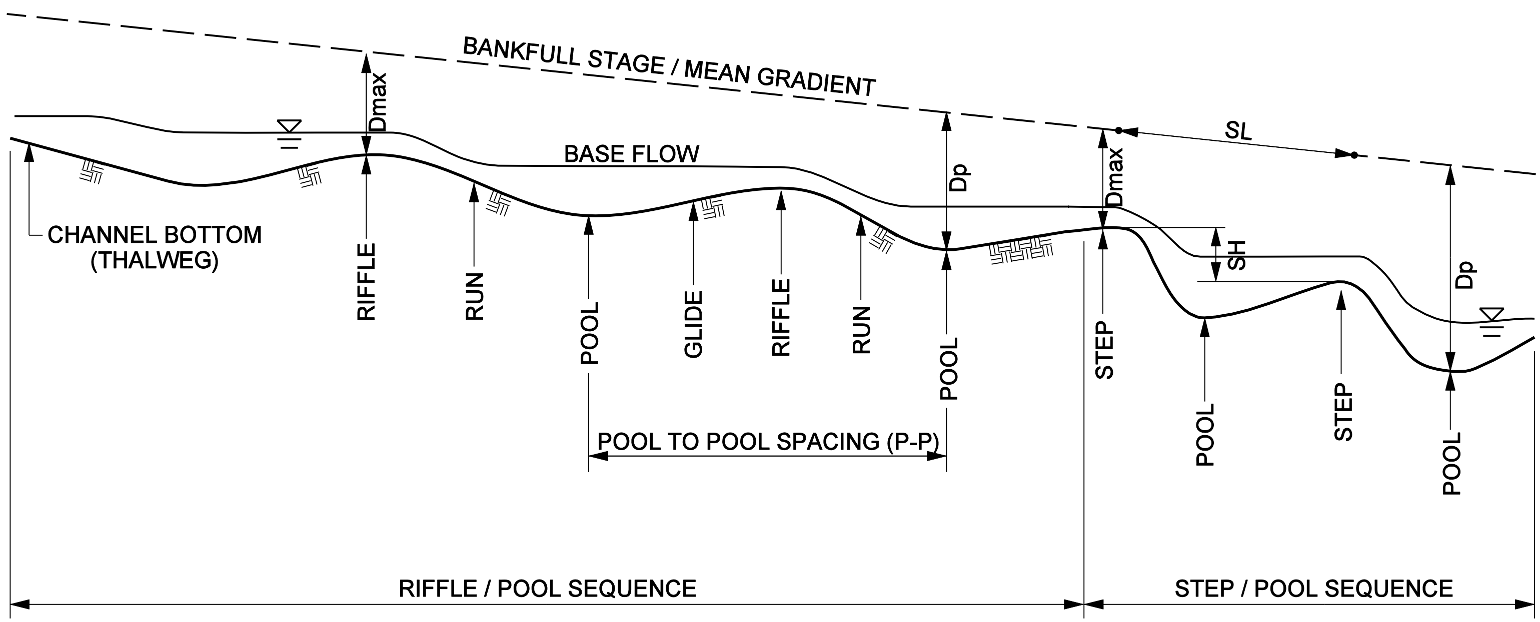
CHANNEL DIMENSION CALCULATIONS
RATIO: MEAN POOL DEPTH / MEAN RIFFLE DEPTH (Dp / Dbkf)
RATIO: POOL WIDTH / RIFFLE WIDTH (Wp / Wr)
RATIO: POOL AREA / RIFFLE AREA (Ap / Ar)
RATIO: MAX. POOL DEPTH / MEAN RIFFLE DEPTH (Dp max / Dbkf)
RATIO: LOWEST BANK HEIGHT / MAX. RIFFLE DEPTH (BHlow / Dmax)
RATIO: MAX RIFFLE DEPTH / MEAN RIFFLE DEPTH (Dmax / Dbkf)
RATIO: RIFFLE WIDTH / MEAN RIFFLE DEPTH (Wr / Dbkf)
RATIO: RUN DEPTH / MEAN RIFFLE DEPTH (Drn / Dbkf)
RATIO: GLIDE DEPTH / MEAN RIFFLE DEPTH (Dgl / Dbkf)
STREAMFLOW: ESTIMATED MEAN VELOCITY (u) @ BANKFULL STAGE
STREAMFLOW: ESTIMATED DISCHARGE (Q) @ BANKFULL STAGE

Baker

Baker Engineering NY, Inc.
8000 Regency Parkway
Suite 200
Cary, NORTH CAROLINA 27518
Phone: 919.463.5488
Fax: 919.463.5490

MORPHOLOGICAL MEASUREMENTS AND RATIOS

PROFILE



CHANNEL PROFILE MEASUREMENTS
VALLEY SLOPE (VS)
AVE. WATER SURFACE SLOPE (S)
RIFFLE SLOPE (Srif)
POOL SLOPE (Spool)
POOL TO POOL SPACING (P-P)
POOL LENGTH (PL)
RUN SLOPE (Srun)
GLIDE SLOPE (Sglide)
STEP HEIGHT (SH)
STEP LENGTH (SL)

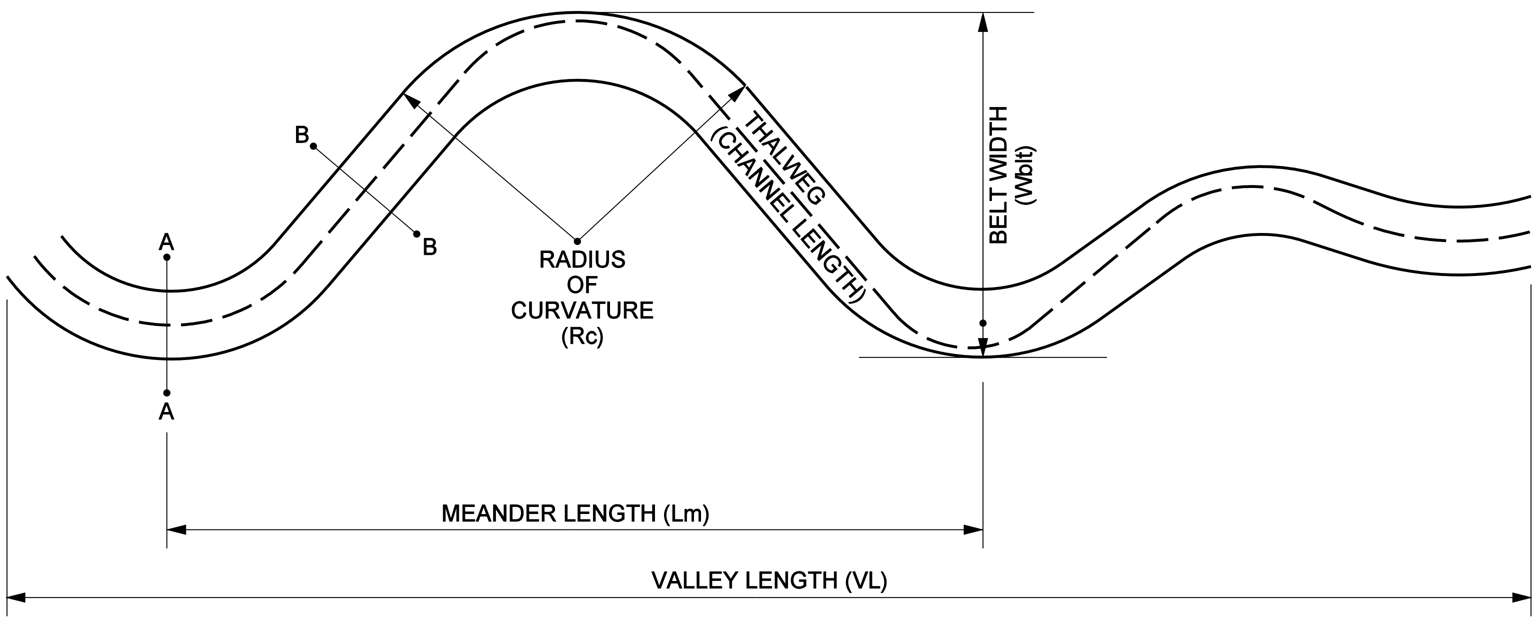
CHANNEL PROFILE CALCULATIONS
RATIO: RIFFLE SLOPE / AVERAGE WATER SURFACE SLOPE (Srif / S)
RATIO: POOL SLOPE / AVERAGE WATER SURFACE SLOPE (Spool / S)
RATIO: RUN SLOPE / AVERAGE WATER SURFACE SLOPE (Srun / S)
RATIO: GLIDE SLOPE / AVERAGE WATER SURFACE SLOPE (Sglide / S)
RATIO: POOL LENGTH / RIFFLE WIDTH (PL / Wr)
RATIO: POOL TO POOL SPACING / RIFFLE WIDTH (P-P / Wr)

Baker

Baker Engineering NY, Inc.
8000 Regency Parkway
Suite 200
Cary, NORTH CAROLINA 27518
Phone: 919.463.5488
Fax: 919.463.5490

MORPHOLOGICAL MEASUREMENTS AND RATIOS

PATTERN (PLAN VIEW)



CHANNEL PATTERN MEASUREMENTS
MEANDER LENGTH (Lm)
RADIUS OF CURVATURE (Rc)
BELT WIDTH (Wblt)

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

Baker

Baker Engineering NY, Inc.
8000 Regency Parkway
Suite 200
Cary, NORTH CAROLINA 27518
Phone: 919.463.5488
Fax: 919.463.5490

Appendix E
In-stream Structures

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 E-1 summarizes the uses of in-stream structures.

Table E-1 Proposed In-Stream Structure Types and Locations

Structure Type	Location
Root Wads	Outer meander bends and other areas of concentrated shear stresses and flow velocities along banks.
Brush Mattresses	Outer meander bends, areas where bank sloping is constrained, and 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 rootwads 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 re-direct 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 life cycles 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 rootwads, to provide additional structure in the pool.

Log Weirs

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

Appendix F
Additional References

Key Reference Material (Material that was not directly referenced in the body of the checklist, but is critical to understanding stream processes and natural channel design)

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Useful Web Sites/Pages for Additional Reference Material

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

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

NRCS Website. Regional Hydraulic Geometry Curves. Provides links to various regional curve web sites. http://wmc.ar.nrcs.usda.gov/technical/HHSWR/Geomorphic/

U.S. Fish and Wildlife Services, Chesapeakebay Field Office
http://www.fws.gov/chesapeakebay/streampub.htm

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

Wildland Hydrology reference materials
http://www.wildlandhydrology.com/html/references_.html