



U.S. Fish and Wildlife Service

# Rapid Stream Restoration Monitoring Protocol

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# RAPID STREAM RESTORATION MONITORING PROTOCOL

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Coastal Program  
Stream Habitat Assessment and Restoration  
U.S. Fish and Wildlife Service  
Chesapeake Bay Field Office

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## I. INTRODUCTION

The U.S. Fish and Wildlife Service, Chesapeake Bay Field Office (Service) and the City of Baltimore (City) entered into a cooperative agreement (Agreement #51410-1902-5119) to enhance cooperation and coordination to facilitate the conservation, enhancement, and restoration of stream and riparian habitats in the Baltimore City watershed. These habitats are scarce and often impaired, and their conservation and restoration are critical for the Federal Trust Resources, such as migratory birds and anadromous fish.

Under this agreement, the Service has developed a rapid stream restoration monitoring protocol to evaluate the functional stability of stream restoration projects. Monitoring is critical in both evaluating whether the project achieved its restoration objective(s) and analyzing a project's cost-benefit. The cost-benefit analysis assesses the cost of habitat/resource benefits achieved from the restoration project. Restoration monitoring will also provide data to improve restoration designs and increase the success of restoration projects. An increase in successful projects will result in increased benefits to the Federal Trust Resources.

The rapid stream restoration monitoring protocol can be applied to almost any stream restoration project design approach (i.e. regenerative storm conveyance, sand berm seepage systems, Natural Channel Design, valley restoration, among others). It uses visual observations to evaluate the functional stability of stream restoration projects and focuses on vertical stability, lateral stability, riparian condition and instream structures (i.e. log vane, w-weir). Note that it *does not* evaluate any physicochemical or biological functions. The parameters used to evaluate vertical stability, lateral stability, and riparian conditions are based on the document: *A Function-Based Framework for Stream Assessment and Restoration Projects*, (Harman et.al. 2012). The function-based framework is illustrated by a functional pyramid, which is a five-level hierarchical framework that categorizes stream functions and parameters that describe those functions. The evaluation of instream structures is based on structure performance and integrity. The rapid methodology uses these function-based parameters to identify restoration success and recommend future actions. Recommended future actions will always include the rapid assessment protocol, at least through the required monitoring period, but may also include two other recommendations. The first recommendation can be for intensive survey monitoring. Intensive survey monitoring involves detailed measurements at the location of stream adjustment to determine the stability trend of these adjustments. If the results of the intensive survey monitoring show the stream is trending towards degradation, then remediation and/or repair is required. The second recommendation can be for remediation and/or repair. Remediation and/or repair is required if the rapid survey shows that there are widespread stream adjustments that will cause further damage and contribute to other structural or functional problems.

It is not the intent of the Service to promote a rapid stream restoration monitoring survey over a more intensive survey. Clearly, a more intensive survey will provide a more definitive assessment of restoration success. Furthermore, a more intensive survey may be necessary depending on the goal(s) of the monitoring, as in the case where the evaluators are trying to assess the functional success of a specific restoration technique. However, the Service recognizes that project implementers often do not perform restoration monitoring due to a lack of

time and/or funds. The Service developed this monitoring methodology to address this issue and provide a minimum standard for assessing project success.

## II. PROTOCOL PURPOSE AND OBJECTIVES

The purpose of this protocol is to rapidly monitor stream restoration success and identify any potential stream adjustments that may lead to failure.

The Service and City worked together to develop protocol objectives for the rapid restoration monitoring survey protocol. The following list provides the most significant objectives:

- Develop a function-based rapid and standardized method to evaluate the stability and functional success of a restored stream
- Establish a minimum standard necessary to evaluate the stability and functional success of a restored stream
- Promote consistent and reproducible results
- Identify situations that require additional monitoring
- Identify potential causes for impairment
- Identify potential corrective actions

## III. EVALUATOR QUALIFICATIONS

Although this report provides stepwise procedures, the use of the rapid stream restoration monitoring protocol requires a well-experienced evaluator. Reducing subjectivity is a goal of the monitoring protocol. However, this protocol is primarily visually based, and therefore requires a skilled evaluator to implement correctly.

The evaluator must be knowledgeable of fluvial geomorphic and watershed processes, and be well trained in the design approach used for the restoration. For example, if the restoration project follows a natural channel design approach the evaluator must be experienced in identifying bankfull. The evaluator should have extensive training and experience in stream assessment, including the assessment techniques presented in the manuals *Stream channel reference sites: An illustrated guide to field technique* (Harrelson et al. 1994), *River Stability Field Guide* (Rosgen 2008), and *A Function-Based Framework for Stream Assessment and Restoration Projects*, (Harman et.al. 2012). Furthermore, it is preferred that the evaluator be familiar with restoration design and construction.

## IV. RAPID STREAM RESTORATION MONITORING PROTOCOL

The rapid stream restoration monitoring protocol report consists of eight main sections: A) design approach, B) bankfull determination, C) limits of investigation, D) rapid stream restoration monitoring form, E) evaluation attribute definitions, F) monitoring procedures, G) limited stream measurements, and H) monitoring recommendations.

If the evaluator was not responsible for the restoration design and/or implementation, the evaluator should contact the project designer and implementer to discuss the project design and

construction. Prior to any field monitoring, the evaluator will review all previous baseline assessments, design, and monitoring reports. The evaluator will be familiar with the design characteristics, hydrologic and hydraulic assessments, restoration objectives, project constraints and limitations, and restoration design criteria.

## A. DESIGN APPROACH

There is a variety of successful design approaches applicable to stream restoration. For example, common design approaches include analytical based, regenerative storm conveyance, sand berm seepage systems, Natural Channel Design, and valley/base flow approaches (Photos 1-4). Different design approaches have different design criteria and performance standards. This protocol includes evaluation parameters appropriate for all design approaches. However, the evaluator must be familiar with the performance standards associated with the design approach. Some of these performance standards are included in section E of this document.



Photo 1. Regenerative Storm Conveyance  
(Underwood & Associates)



Photo 2. Natural Channel Design (U.S.  
Fish and Wildlife Service)



Photo 3. Regenerative Storm Conveyance/  
Valley Restoration (Biohabitats)



Photo 4. Valley Restoration (Landstudies)

## B. BANKFULL DETERMINATION AND HYDRAULIC ASSESSMENT

In some restoration approaches (i.e. Natural Channel Design and conveyance channels), the identification of bankfull is crucial to success. Bankfull discharge is the discharge (or range of discharges) responsible for the formation and maintenance of the stream channel dimensions, planform patterns and longitudinal profile. The stream typically develops bankfull field indicator(s), such as a significant slope break or floodplain feature, along the stream banks at the bankfull stage (Figure 1). An accurate determination of the bankfull indicator(s) is a critical aspect of stream restoration project evaluation because evaluators will use bankfull to assess stream stability and function and collect stream measurements.

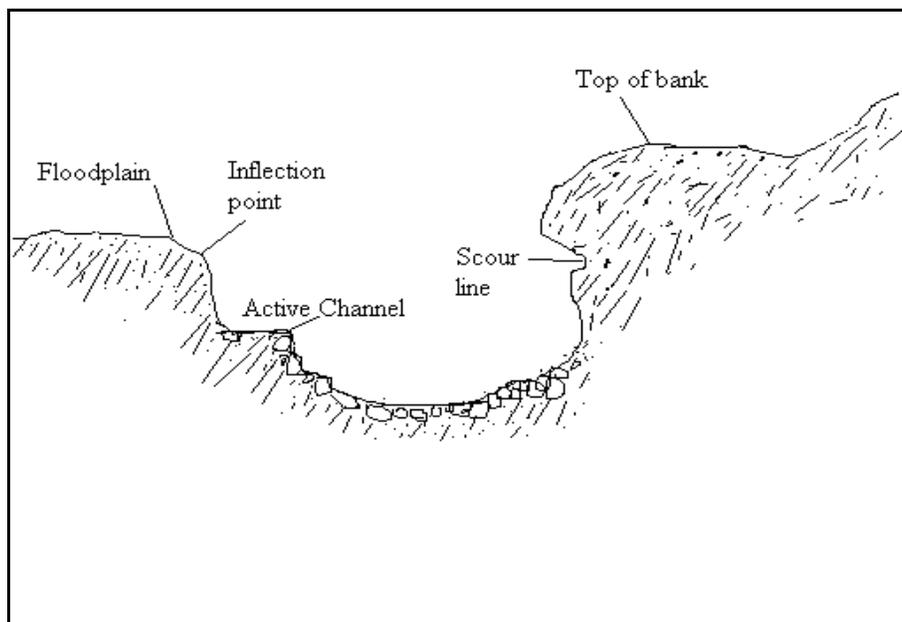


Figure 1. Potential Bankfull Indicators (McCandless and Everett 2002)

To ensure an accurate determination of bankfull, the evaluator will compare bankfull field indicators with bankfull data/information provided in any available assessment and design reports. The evaluator will compare the bankfull information with gage station data and available regional bankfull curves.

In addition to bankfull discharge and indicators, the evaluator must be familiar with baseflow, low flow (e.g. low flow bench), floodplain, and floodprone channel characteristics. Proper identification and interpretation of these stream features are important for evaluating channel stability and the functional success of the restoration project.

## C. LIMITS OF INVESTIGATION

The evaluation area dictates the limits of investigation. The monitoring reach should start and end at the point where the restoration has no visible influence on the stream. Typically, the monitoring reach will start upstream at the beginning of the restoration and extend downstream beyond the end of the restoration, to the point where there are no visible indications that the restoration is influencing the stream. For example, the monitoring reach would extend to include

any erosion resulting from bank revetments, even if the erosion occurs downstream of the original project limits. If the restoration is influencing the stream beyond the upstream project limit, such as backwater and deposition resulting from an instream structure, the monitoring reach will begin at the upstream limit of the deposition. The evaluator should include the entire monitoring reach for evaluation, including areas that are currently stable and functioning. This will ensure documentation of any areas that change from stable to unstable in future years due to restoration elements.

## **D. RAPID STREAM RESTORATION MONITORING FORM**

The Service prepared a rapid stream restoration monitoring form (monitoring form) to assist with efficiency and consistency of the monitoring survey (Figure 2). For discussion purposes, the Service has divided the monitoring form into six general sections: 1) project information, 2) station identification, 3) problem description, 4) recommended actions, 5) measurements, and 6) evaluation attributes. Detailed descriptions of terminology used in the form are in section E of this document.

The monitoring form includes the most common situations that an evaluator would encounter during a monitoring survey. However, if the monitoring form does not accurately describe or evaluate the situation, the evaluator should provide a description in the description spaces provided on the form. Examples of a blank and completed monitoring form are located in Appendix A.

### **1. Project Information**

This section allows the evaluator to record general information about the restoration project such as the project name, location, and description. For more complicated or larger restoration projects the evaluator may wish to divide the project into smaller reaches and provide descriptions for each of the smaller reaches.

### **2. Station Identification**

This section allows the evaluator to record the specific station or station interval (e.g. Station 0+00 to 1+00) that the evaluator is assessing. In most situations, the evaluator will use a station interval. However, the evaluator may use a specific station when assessing a discrete location, such as an outfall. If the evaluator is only assessing one stream bank or assessing each bank separately, it is important to identify which bank the evaluator is assessing. For

**Project Information**

|                   |  |       |  |                      |  |  |  |           |  |  |  |
|-------------------|--|-------|--|----------------------|--|--|--|-----------|--|--|--|
| Stream Name:      |  | Crew: |  | Project Description: |  |  |  | Comments: |  |  |  |
| Project Name:     |  | Date: |  |                      |  |  |  |           |  |  |  |
| Project Location: |  |       |  |                      |  |  |  |           |  |  |  |

| Station | Identification Number | Problem Description |                   |  |          |                |   | Recommended Actions |                                  |             | Measurement(s) |                    |
|---------|-----------------------|---------------------|-------------------|--|----------|----------------|---|---------------------|----------------------------------|-------------|----------------|--------------------|
|         |                       | Vertical Stability  | Lateral Stability | Indicator(s)                           | Severity | Implication(s) | Cause(s)  | Description         | Type                             | Description |                | Monumented Survey? |
|         |                       | Vertical Stability  | Lateral Stability | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15 | 1 2 3    | 1 2 3          | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15<br>16 17 |                     | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 |             | Yes No         |                    |
|         | Photograph(s):        | Other:              |                   | Other:                                 | Other:   | Other:         | Other:  |                     | Other:                           |             |                |                    |
|         |                       | Vertical Stability  | Lateral Stability | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15 | 1 2 3    | 1 2 3          | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15<br>16 17 |                     | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 |             | Yes No         |                    |
|         | Photograph(s):        | Other:              |                   | Other:                                 | Other:   | Other:         | Other:  |                     | Other:                           |             |                |                    |
|         |                       | Vertical Stability  | Lateral Stability | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15 | 1 2 3    | 1 2 3          | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15<br>16 17 |                     | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 |             | Yes No         |                    |
|         | Photograph(s):        | Other:              |                   | Other:                                 | Other:   | Other:         | Other:  |                     | Other:                           |             |                |                    |
|         |                       | Vertical Stability  | Lateral Stability | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15 | 1 2 3    | 1 2 3          | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15<br>16 17 |                     | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 |             | Yes No         |                    |
|         | Photograph(s):        | Other:              |                   | Other:                                 | Other:   | Other:         | Other:  |                     | Other:                           |             |                |                    |
|         |                       | Vertical Stability  | Lateral Stability | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15 | 1 2 3    | 1 2 3          | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 14 15<br>16 17 |                     | 1 2 3 4 5 6 7 8 9<br>10 11 12 13 |             | Yes No         |                    |
|         | Photograph(s):        | Other:              |                   | Other:                                 | Other:   | Other:         | Other:  |                     | Other:                           |             |                |                    |

**Station Identification**      **Problem Description**      **Recommended Actions**      **Measurements**

Figure 2. Rapid Stream Restoration Monitoring Form

consistency, this protocol will determine the left and right bank while facing downstream. This section also allows the evaluator to record a unique identification number that the evaluator will also record on the restoration plan and/or geomorphic map. The Service also provides a space for recording photograph numbers and descriptions.

### **3. Problem Description**

This section allows the evaluator to give a detailed and standardized description of the problem. There are multiple components to the problem description portion of the protocol. First, the section allows the evaluator to describe the type (i.e., vertical stability, lateral stability, riparian condition, and structure) and indicator(s) of the problem. The functional and structural-based evaluation attributes of the indicators associated with each type are described in more detail in section E of this document. If multiple problems are present in a reach, the Service recommends that the evaluator complete a separate description of each problem. In addition, the evaluator should complete a separate description if the area is stable.

The Problem Description section also describes the severity and implications of the problem. The severity is a description of the magnitude of the problem (i.e. localized or wide spread) and the persistence of the problem (i.e. temporary or permanent). The implication of the problem describes the potential trend of the problem. The evaluator will predict whether the problem will improve over time, get worse over time, or require immediate remediation. The evaluator will also have an opportunity to identify the apparent cause of the problem. The monitoring form provides additional space for the evaluator to record a more detailed description of the problem. The information from the Problem Description portion of the assessment will determine restoration success and guide further actions.

### **4. Recommended Actions**

This section allows the evaluator to recommend no action, additional monitoring, or suggest corrective action(s) to remediate the problem. The evaluator should be familiar with the recommendation thresholds discussed in the Monitoring Recommendations section of this report (section H).

### **5. Measurements**

This section allows the evaluator to record any field measurements necessary to evaluate the restoration project. A list of common field measurements is in the evaluation attribute table located on the back of the monitoring form. In some cases, it may be necessary for the evaluator to develop dimensionless ratios and/or compare the field measurements to the design criteria

### **6. Evaluation Attributes**

This section provides a table with a description of the numeric attributes used in the monitoring form, and provides a list of common field measurements that may be useful in

evaluating the restoration project. The attributes are listed in a table format and are assigned numeric values that will be used in the monitoring form to describe the condition of the restoration project. The evaluation attributes are located on the back of the monitoring form.

The attribute table is presented in a similar format as the monitoring form and is partitioned by problem type (i.e. vertical stability, lateral stability, etc). Each problem type is divided into five evaluation attribute categories: 1) Problem Indicator(s), 2) Severity, 3) Implication(s), 4) Apparent Cause(s), and 5) Recommended Action(s). Definitions of the evaluation attributes are in the Evaluation Attribute Definitions section of this report (section E). Figure 3 is a partial evaluation attributes table. A complete attribute table is located in Appendix A.

| RAPID STREAM MONITORING EVALUATION ATTRIBUTES |   |   |   |   |                                      |  |
|---|---|---|---|---|--------------------------------------|--|
| Vertical Stability                            | Lateral Stability   | Riparian Condition  | Structure   | Measurements  |                                      |  |
| 1 None (no problem indicators)                | 1 None (no problem indicators)  | 1 None (no problem indicators)  | 1 None (no problem indicators)  | $W_{bk}$  | Bankfull Width (ft)                  |  |
| 2 Degradation                                 | 2 Decrease in meander width ratio   | 2 Bare ground present   | 2 Collapsed structure   | $D_{bk}$  | Bankfull Depth (ft)                  |  |
| 3 Increase bank height ratio                  | 3 Increase in meander width ratio   | 3 Problem Types   | Unstable/re rocks   | Measurement Description   | Depth Ratio                          |  |
| 4 Decrease bank height ratio                  | 4 Lateral scour/undercut  | 4 Poor riparian survival  | 4 Flow piping   |   | Channel Width (ft)                   |  |
| 5 Scour                                       | 5 Planform/radius of curvature adjustments                                      | 5 Poor riparian width   | 5 Lack of adequate pool depth/pool formation                                    | $D_{ac}$  | Active Channel Depth (ft)            |  |
| 6 Incorrect pool-to-pool spacing              | 6 Cutoff channel development  | 6 Other   | 6 Accelerated vertical scour/exposed footer rocks                               | $W_{fp}$  | Floodprone Width (ft)                |  |
| 7 Increase bank vegetation                    | 7 Bank vegetation   |   | 7 Accelerated lateral scour/scour along deposition area at the structure        | E   | Entrenchment Ratio                   |  |
| 8 Poor pool depth variability                 | 8 Bank deposition   |   | 8 Accelerated deposition in pool  | $L_m$   | Meander Length (ft)                  |  |
| 9 Poorly defined facet features               | 9 Dominant BEHI and NBS rating of moderate or greater                           |   | 9 Buried structure  | $W_{bit}$   | Beltwidth (ft)                       |  |
| 10 Decrease in facet slope                    | 10 Other  |   | 10 Accelerated lateral scour upstream/downstream of the structure               | MWR   | Meander Width Ratio                  |  |
| 11 Deposition/Bar Development                 |   |   | 11 Other  | K   | Sinuosity                            |  |
| 12 Aggradation                                |   |   |   | $R_c$   | Radius of Curvature (ft)             |  |
| 13 Increase in entrenchment                   |   |   |   | $R_c/W_{bk}$  | Ratio of Curvature to Bankfull Width |  |
| 14 Decrease in entrenchment                   |   |   |   | BHR   | Bank Height Ratio                    |  |
| 15 Other                                      |   |   |   | $S_{ave}$   | Reach Average Stream Slope           |  |
| Severity                                      | 1 Temporary scour or deposition formation                                       | 1 Localized bank erosion; minor loss of bank material; BEHI and/or NBS have a rating of low or less   | 1 Temporary riparian degradation  | 1 Minor stress on the structure; still functioning as intended                  | $S_{facet}$                          | Facet Slope  |
|   | 2 Localized scour or bar formation; minor changes to bed characteristic         | 2 Localized, moderate bank erosion; moderate loss of bank material; BEHI and NBS have a rating of moderate                                      | 2 Localized riparian degradation  | 2 Partial failure of structure; minimally functioning as intended               | BEHI                                 | Dominant Bank Erosion Hazard Index                                     |
|   | 3 Widespread scour or bar formation; extensive changes to bed characteristics   | 3 Widespread erosion of entire bank; bank actively eroding and substantial loss of bank material; BEHI and NBS have a rating of high or greater | 3 Widespread riparian degradation   | 3 Complete structural failure; no longer functioning as intended                | NBS                                  | Dominant Near Bank Shear Stress (specify method used to determine NBS) |
| Implication(s)                                | 1 Not expected to worsen or cause further problems; may stabilize over time     | 1 Not expected to worsen or cause further problems; may stabilize over time   | 1 Not expected to worsen or cause further problems; may stabilize over time     | 1 Not expected to worsen or cause further problems; may stabilize over time     | $D_{50}$                             | Bed Particle Size (50th Percentile) (mm)                               |
|   | 2 Expected to worsen over time  | 2 Expected to worsen over time  | 2 Expected to worsen over time  | 2 Expected to worsen over time  | $D_{84}$                             | Bed Particle Size (84th Percentile) (mm)                               |
|   | 3 Immediate concern; will cause further damage and contribute to other problems | 3 Immediate concern; will cause further damage and contribute to other problems   | 3 Immediate concern; will cause further damage and contribute to other problems | 3 Immediate concern; will cause further damage and contribute to other problems | $D_{bar}$                            | Largest Particle Size on Bar (mm)                                      |

Figure 3. Partial Evaluation Attributes Table

## E. EVALUATION ATTRIBUTE DEFINITIONS

Although stream restoration practitioners commonly use the evaluation attributes selected for the protocol, the Service has elaborated on several terms to improve interpretation and data collection consistency. The performance measures provided are from the document: *A Function-Based Framework for Stream Assessment and Restoration Projects*, (Harman et.al. 2012).

### 1. Vertical Stability Description

Parameters associated with vertical stability typically refer to conditions of the streambed, and include measurements that describe sediment transport and floodplain connectivity.

#### a) Bedform Diversity Parameters

Monitoring sediment transport processes will allow an evaluator to determine whether a stream reach is stable, aggrading or degrading. The simplest way to measure sediment transport is by using parameters that describe bedform diversity.

- i. Pool-to-pool Spacing: Pool-to-pool spacing measures the frequency of pools in the stream reach (Figure 4). The measurement is a distance, measured along the centerline, between the deepest points of two pools. The value is converted into a dimensionless ratio by dividing the distance by the bankfull riffle width. Severe bank erosion tends to occur when pool-to-pool spacing ratio is less than three or greater than eight. As pool-to-pool spacing in a stream increases, the risk of bed instability increases. A summary of pool-to-pool spacing ratios are located in Table 1.

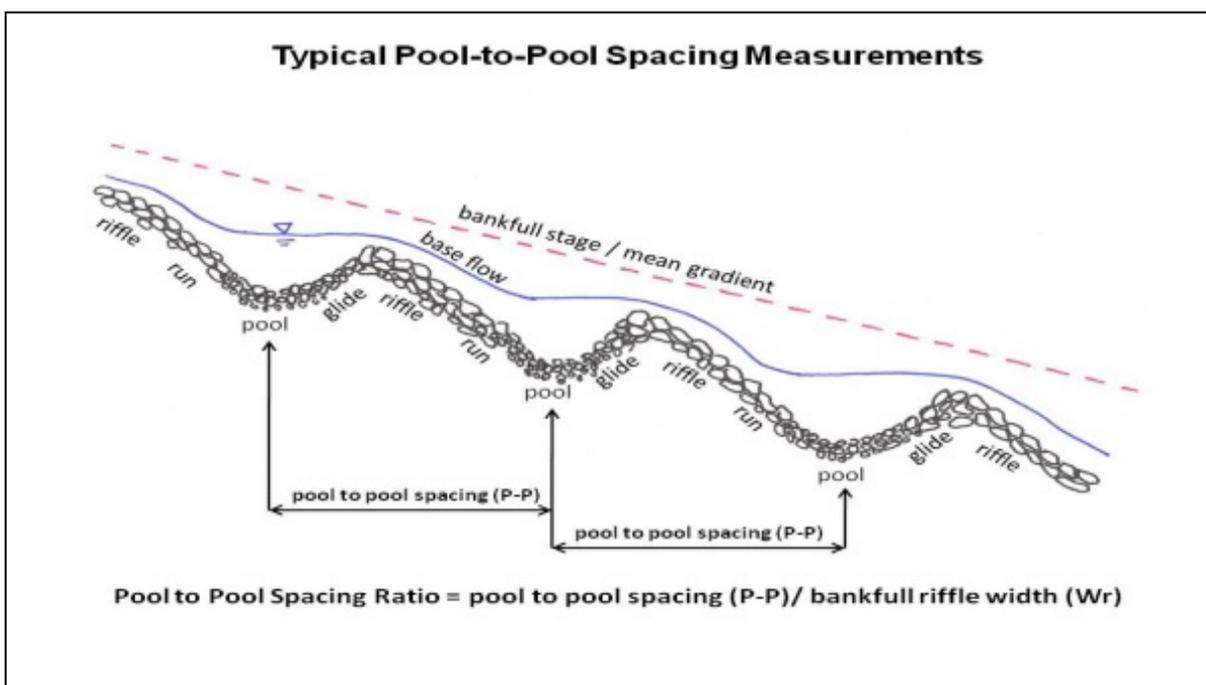


Figure 4. Pool-to-Pool Spacing (Harman et. al. 2012)

| <b>Table 1. Pool-to-Pool Spacing Ratio Summary</b>                               |                  |                           |                 |
|--|------------------|---------------------------|-----------------|
| Pool-to-Pool Spacing Ratio   | Stability Rating |                           |                 |
|  | Functioning      | Functioning-At-Risk       | Not Functioning |
| <b>Perennial Streams in Alluvial Valleys (C,E Stream Types)</b>                  |                  |                           |                 |
| Watersheds > 10 mi <sup>2</sup>  | 5.0 to 7.0       | 3.5 to 5.0 and 5.0 to 7.0 | <3.0 and > 7.0  |
| Watersheds < 10 mi <sup>2</sup>  | >1.5             | 1.2 to 5.0 and 7.0 to 8.0 | <3.5 and >8.0   |
| <b>Moderate Gradient Perennial Streams in Colluvial Valleys (B Stream Types)</b> |                  |                           |                 |
| Slope Between 3 and 5%   | 2.0 to 4.0       | 4.0 to 6.0                | >6.0            |

- ii. **Depth Variability:** Depth variability compares pool and riffle depths. Depth variability is determined by measuring pool depth at the bankfull stage in each pool along the reach, and dividing these depths by the representative mean riffle depth at the bankfull stage. This measurement is the Pool Max Depth ratio. Since depth variability is an indicator of how the stream is processing sediment, if the ratios are similar (i.e. < 1.2) that indicates that the pools are of the same depth as the riffles and are likely filling with sediment. It is preferable to have a range of ratios. Common depth variability ratios are in Table 2.

| <b>Table 2. Depth Variability Ratio Summary</b>                                  |                  |                     |                 |
|--|------------------|---------------------|-----------------|
| Depth Variability Ratio  | Stability Rating |                     |                 |
|  | Functioning      | Functioning-At-Risk | Not Functioning |
| <b>Perennial Streams in Alluvial Valleys (C,E Stream Types)</b>                  |                  |                     |                 |
| Gravel Bed Streams   | >1.5             | 1.2 to 1.5          | <1.2            |
| Sand Bed Streams   | >1.2             | 1.1 to 1.2          | <1.1            |
| <b>Moderate Gradient Perennial Streams in Colluvial Valleys (B Stream Types)</b> |                  |                     |                 |
|  | >1.5             | 1.2 to 1.5          | <1.2            |

- iii. **Degradation and Scour:** Bed degradation and scour both refer to vertical erosion or loss of bed grade or elevation (Photo 5); however, the difference between these terms is the extent of vertical erosion. Bed degradation refers to wide spread bed grade loss, while scour refers to localized grade loss. When determining bed scour, the evaluator should differentiate between normal bed scour and unintentional or excessive scour. For example, the evaluator would expect to find scour downstream of an outfall; however, an indication of excessive scour is an advancing headcut (Photo 6) that is threatening to undermine the outfall. Poorly defined bed features are often associated with degradation and scour.



Photo 5. Vertical Erosion



Photo 6. Headcut

- iv. Aggradation and Deposition: Bed aggradation and deposition both refer to an increase in bed grade or elevation; however, the difference between these terms is the extent of the grade increase. Bed aggradation is a wide spread grade increase, while deposition refers to a localized grade increase (Photo 7). Similar to scour, the evaluator should differentiate between normal deposition and unintentional or excessive deposition. For example, the evaluator would expect to find deposition upstream of a rock cross vane (Photo 8); however, a partially buried structure would be an indication of excessive deposition. Other indicators of aggradation and deposition are bar formation and poorly defined bed features.



Photo 7. Widespread Aggradation



Photo 8. Appropriate Structure Deposition

- v. Facet slope Increase or Decrease: Facet slopes measurements are indicators of the quality and stability of the bedform. In a functioning system, the evaluator would expect to see steep, shallow riffles and flat pools. However, extremes in the facet slopes can indicate bed degradation or aggradation. For example, if riffles become too steep, larger particles are transported downstream, leading to degradation. In addition, although pools should be relatively flat, if the pool slope approaches zero this is an indicator that the pool may be more likely to fill. These measures are also related to pool-to-pool spacing. For example, as facet slope increases pool-to-pool spacing decreases (Harman et.al. 2012).

b) Floodplain Connectivity Parameters

Monitoring floodplain connectivity will give an indication of the vertical containment of the stream.

- i. Bank Height Ratio (BHR): BHR is a direct measure of incision. Incision is a measure of the vertical containment of a stream, which is the ratio of the low top of bank height to bankfull height (Figure 5). The evaluator can assess incision at a specific point or evaluate the trend of incision by comparing one location with one farther upstream or downstream. Stability ratings for BHR values are provided in Table 3.

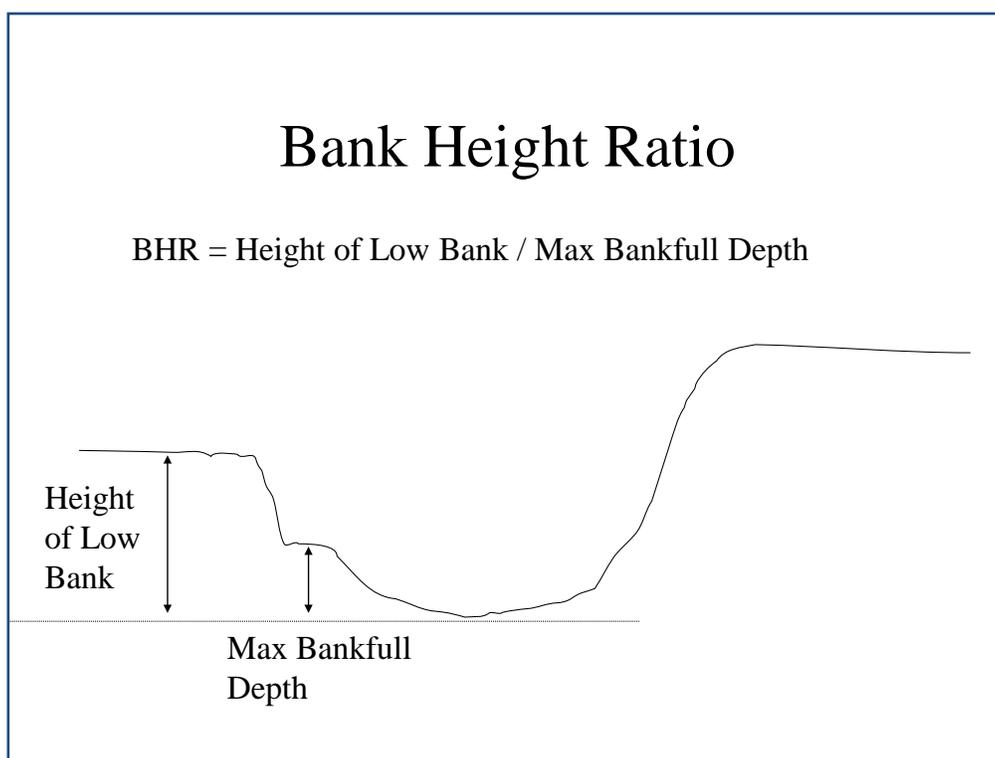


Figure 5. Bank Height Ratio

| <b>BHR</b> | <b>Stability Rating</b> |
|------------|-------------------------|
| <1.0 - 1.1 | Functioning             |
| 1.11 – 1.5 | Functioning-At-Risk     |
| >1.5       | Not Functioning         |

- ii. Entrenchment: Entrenchment is a measure of vertical containment of the floodprone area, which is the ratio of the floodprone width and bankfull width (Figure 6). Similar to incision, the evaluator can assess entrenchment at a specific point or evaluate the trend of entrenchment by comparing one location with one farther upstream or downstream. Stability ratings for entrenchment values are provided in Table 4.

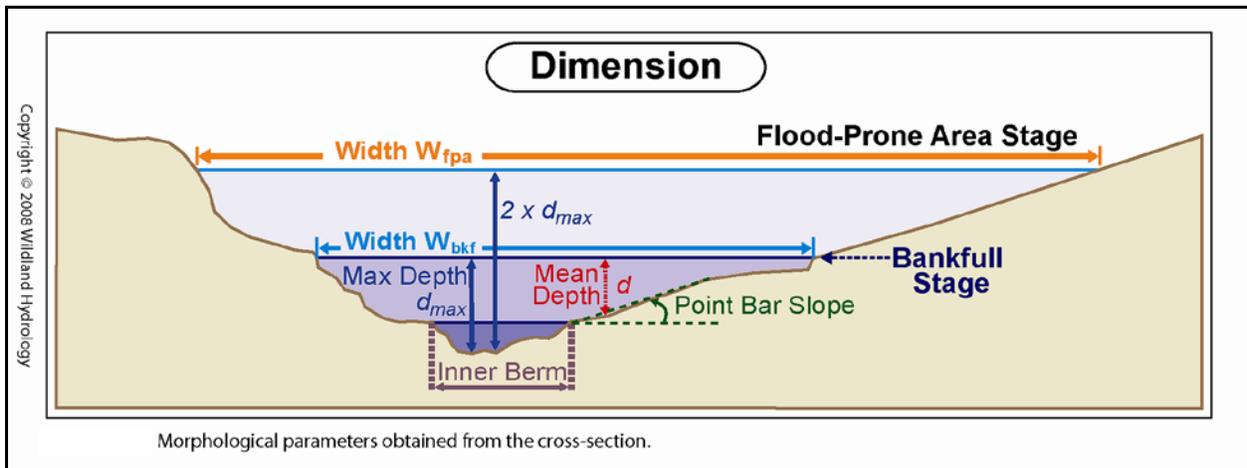


Figure 6. Entrenchment Ratio (Rosgen 2008)

| Channel Entrenchment Ratio | Stability Rating |                     |                 |
|----------------------------|------------------|---------------------|-----------------|
|                            | Functioning      | Functioning-At-Risk | Not Functioning |
| C, DA, and E Stream Types  | >2.2             | 2.1 to 1.4          | <1.4            |
| B Stream Types             | >1.4             | 1.3 to 1.2          | <1.2            |

**2. Lateral Stability Problem Description**

Parameters associated with lateral stability typically refer to problems with the stream banks, and contain measures that evaluate confinement, planform, and bank migration. Confinement measurements represent the lateral containment of the stream. Streams that are laterally confined often exhibit channel enlargement, lateral accretion, high bank erosion rates, and sediment transport problems.

- a) Meander Width Ratio (MWR): MWR is the ratio of the beltwidth to bankfull width and is a way to measure confinement, or the lateral containment of the stream planform (Figure 7). It is typically used for streams located in alluvial valleys that are free to adjust laterally. The straightening of a meandering stream (i.e. a C or E type channel) from either anthropogenic or natural causes is an example of an increase in confinement. A stream that increases its beltwidth through lateral erosion is an example of a decrease in confinement. MWR may not apply to all restoration approaches. For example, planform is not a critical design element for valley restoration projects and sand seepage berms because they are low energy streams with low sediment supply. For the purpose of this protocol, changes in confinement are a reach wide condition. Stability ratings for MWR are in Table 5. The protocol captures localized planform adjustments in the categories below.

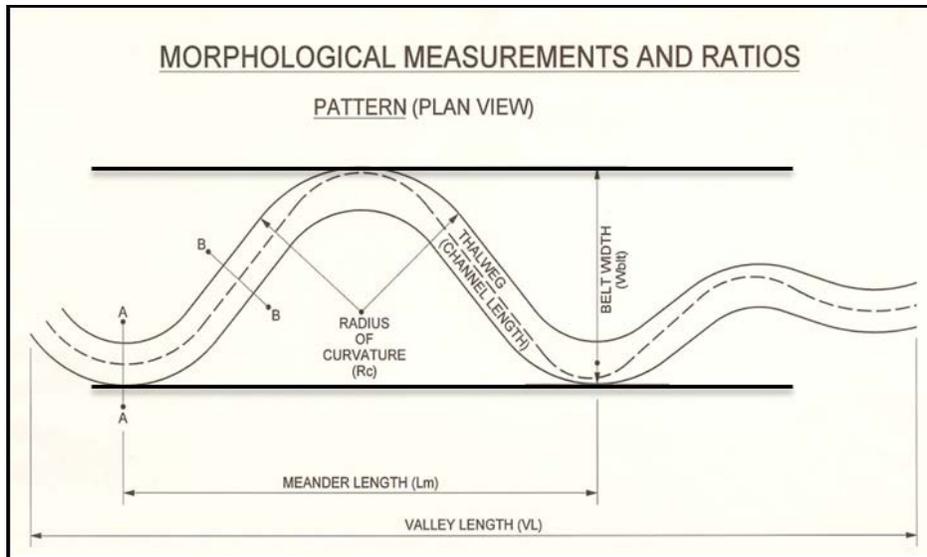


Figure 7. Meander Width Ratio (Harman et. al. 2012)

| Table 5. Meander Width Ratio Summary |                     |
|--------------------------------------|---------------------|
| MWR for C and E Stream Types         | Stability Rating    |
| $\geq 3.5$                           | Functioning         |
| 3.0 to 3.5                           | Functioning-At-Risk |
| $>1.5$                               | Not Functioning     |

b) Planform Adjustments

Although planform adjustments affect stream confinement, the attributes described below refer to localized planform adjustments.

- i. Radius of Curvature Adjustments: Changes in radius of curvature indicate planform adjustments. It is the measure of the tightness of an individual meander bend and is expressed as a ratio to the bankfull channel width (Rosgen 2008)(Figure 8).

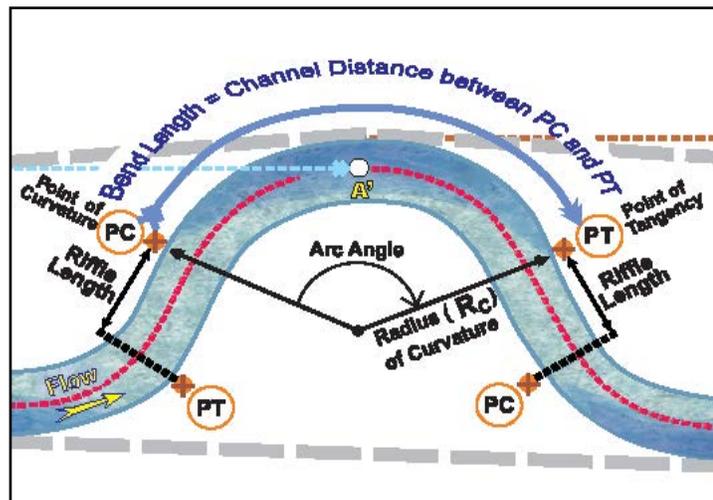


Figure 8. Radius of Curvature (Rosgen 2008)

- ii. Cutoff Channel Development: A stream with very tight meander bends and small radius of curvature measurements can start to develop cutoff channels.

c) Bank Migration

Bank migration parameters are a function of bank materials, vegetative cover, and in-stream hydraulic forces. These parameters address erosion potential of the stream banks.

- i. BEHI/NBS: Combinations of Bank Erodability Hazard Index (BEHI) and Near Bank Stress (NBS) assess the bank’s potential to erode and the shear stress placed on the bank. BEHI incorporates simple measurements and visual observation to determine the bank erodability potential while NBS involves observations of channel flow characteristics to assess the bank shear stress. When these two assessments are combined, a loss of bank (in linear feet) can be predicted on an annual basis using bank erosion rate curves. The ratings for both BEHI and NBS range from very low to extreme. The measurements can be a quantitative measure of every bank following the methods described in *A Watershed Assessment for River Stability and Sediment Supply (WARSSS)* (Rosgen 2006) or more rapidly through qualitative predictions. Table 6 illustrates the functional categories for BEHI/NBS combinations.

| <b>BEHI Rating</b>             | <b>Stability Rating</b>  |                            |                         |
|--------------------------------|--------------------------|----------------------------|-------------------------|
|                                | <b>Functioning</b>       | <b>Functioning-At-Risk</b> | <b>Not Functioning</b>  |
| Low BEHI Rating                | Very Low to Moderate NBS | Moderate to Very High NBS  | Extreme NBS             |
| Moderate BEHI Rating           | Very Low to Low NBS      | Low to High NBS            | High to Extreme NBS     |
| High and Very High BEHI Rating | N/A                      | Low to Moderate NBS        | Moderate to Extreme NBS |
| Extreme BEHI Rating            | N/A                      | Low NBS                    | Low to Extreme NBS      |

- ii. Lateral Scour or Undercut: Presence of lateral scour is a visual determination of current or potential bank migration. The rate of scour or undercut will determine the severity of the lateral adjustment. Bank scour is severe if the rate of scour resulted in the stream not being able to maintain its channel dimensions (i.e., width and depth). In this case, an evaluator would notice that the stream has a high width/depth ratio. Another example of severe bank scour is the loss of riparian vegetation or streamward leaning trees (Photo 9).



Photo 9. Leaning Trees from Excessive Lateral Erosion

- iii. Bank Deposition: Bank deposition is also an indicator of lateral migration. Often, deposition will occur when the opposite bank is scouring or eroding. This can occur because the stream increases its width/depth ratio as it scours and loses its ability to transport sediment. However, lateral bar development can accelerate bank scour. This can occur if the deposition increases the width/depth ratio and redirects energy to the opposite bank. Therefore, determining the width/depth ratio of a stream can assist in understanding the potential cause of bank scour.
- iv. Loss of Bank Vegetation: Bank vegetation plays an important role in stabilizing banks. Without it, banks can be more prone to erosion and lateral migration. The loss of such vegetation can indicate ongoing bank erosion, or be an early predictor of future problems.

### **3. Riparian Condition Problem Description**

Measurements to determine riparian condition are dependent on the goals of the project. Parameters that describe riparian composition, density, and width are commonly used when determining riparian condition. Evaluation of these parameters provides information about the health of the riparian buffer, and can give an indication of stream channel stability.

a). Bare Ground Present: The presence of bare ground exposed in the buffer is an indication of poor ground cover. The less ground cover present, the lower the riparian buffer success. The amount of bare ground present can be determined visually, or through quadrat sampling of the average bare ground exposed in the buffer. The stability ratings are in Table 7.

|                                       | <b>Stability Rating</b> |
|---------------------------------------|-------------------------|
| Mostly Good Ground Cover              | Functioning             |
| Mostly Bare Soil with No Ground Cover | Functioning-At-Risk     |
| Mostly Impenetrable Surface           | Not Functioning         |

b). Species Composition: Species composition refers to the presence of non-native or invasive species. Depending on the goals of the project, the presence of invasive or non-native species in a riparian buffer can be undesirable. Often, non-native species will out-compete native species, resulting in a riparian buffer that differs from the original planting plan. In order to determine species composition, evaluators must have knowledge about the planting plan and the ability to identify riparian plant species. Evaluators can estimate species composition visually, or use prism or fixed radius sampling. Stability ratings for species composition are in Table 8.

| <b>Species Composition</b> | <b>Stability Rating</b> |
|----------------------------|-------------------------|
| Mostly Native Species      | Functioning             |
| Mostly Invasive Species    | Functioning-At-Risk     |
| All Invasive Species       | Not Functioning         |

c). Riparian Buffer Stability: Riparian stability refers to the survival success of the buffer. Survival can be dependent on a variety of factors. The evaluator should indicate whether poor survival is due to improper planting plan, improper implementation of planting plan, natural causes, or development, among others. Ratings for riparian survival are in Table 9.

| <b>Riparian Stability</b> | <b>Stability Rating</b> |
|---------------------------|-------------------------|
| >85% Survival             | Functioning             |
| 50 – 84% Survival         | Functioning-At-Risk     |
| < 50% Survival            | Not Functioning         |

d). Riparian Buffer Width: Buffer width is a measure of vegetative distance from the stream and is measured moving away from the top of the streambank, perpendicular to the fall line of the valley. It can be an estimate or direct measurement. Stability ratings for riparian buffer width are in Table 10.

| <b>Vegetative Distance from Stream</b> | <b>Stability Rating</b> |
|--|-------------------------|
| >150 feet                              | Functioning             |
| 30 – 150 feet                          | Functioning-At-Risk     |
| <30 feet                               | Not Functioning         |

#### 4. Instream Structure Problem Description

These measurements describe specific attributes of instream structures installed during restoration. All parameters directly relate to either the function or installation of structures.

a). Accelerated Scour: Accelerated scour refers to localized bed erosion or grade loss. When determining bed scour, the evaluator should differentiate between normal bed scour and unintentional or excessive scour. For example, the evaluator would expect to find scour downstream of a rock cross vane; however, an exposed rock footer is an indication of excessive scour (Photo 10). Another indication of excessive scour is if there is scour within an area of a structure that is supposed to be a depositional area (i.e., the bankward side of a vane arm).



Photo 10. Failed Structure

b). Buried Structure and Accelerated Deposition: These categories refer to an accumulation of sediment associated with an instream structure. The difference between these categories is the extent or amount of accumulated sediment, where the buried structure category refers to the complete loss of function due to sediment. Accelerated deposition is a localized accumulation of sediment where the structure still maintains its function. Accelerated deposition can be the beginning stages of buried structure (Photo 11).

c). Other Structural Failures: Parameters such as a collapsed structure, lack of pool depth, piping, or repositioned or exposed rocks also indicate a structure failure. The evaluator should indicate why these failures are occurring. For example, the evaluator will determine whether the structure was designed incorrectly, installed incorrectly, or both.



Photo 11. Buried Structure

## F. FIELD MONITORING PROCEDURES

This section provides a general description of the monitoring survey procedures and is not an all-inclusive stepwise protocol. The evaluator should review this protocol prior to performing the monitoring, and determine if any additional information or steps are necessary to evaluate the restoration project accurately. An example of a completed monitoring form is in Appendix A of this document.

1. Prior to the monitoring survey, the evaluator will review and be familiar with the following information, which will allow the evaluator to better assess the success and function of the stream restoration project:
  - Stream assessment report(s)
  - Restoration design report(s)
  - Hydrologic and hydraulic report(s)
  - Restoration design plans
  - Restoration as-built plans
  - Rapid stream restoration monitoring protocol
  - Rapid stream restoration monitoring form
2. During the monitoring survey, the evaluator will need the following information to evaluate and document the success and function of the stream restoration project:
  - Rapid stream restoration monitoring field form
  - Evaluation parameter definitions
  - Restoration design plans
  - Restoration as-built plans

3. The evaluator will need the following field equipment to conduct the monitoring survey:
- Measuring tape
  - Survey rod
  - Camera

This list provided above is the least amount of field equipment necessary to conduct the monitoring survey; additional field equipment may make the survey more efficient or may be necessary for some field measurements.

4. The evaluator will determine the limits of investigations. The evaluator will record the limits of investigation on the restoration as-built plans.
5. The evaluator will assess and document the entire length of stream within the monitoring reach, including stable reaches. The intervals for documenting reaches will depend on how similar the channel conditions are within the monitoring reach, the length of the restoration project, and the size of the stream. In general, fewer monitoring stations are necessary for projects with uniform channel conditions, small restoration projects, and smaller streams. At a minimum, proper documentation of the monitoring reach will include completing the monitoring form and recording the location and direction of the photograph on the restoration as-built plans. For subsequent monitoring years, the evaluator will attempt to take the photographs from the same location and perspective.
6. If multiple types of problems are present in a reach (e.g. bed and bank erosion), the evaluator will evaluate each problem separately and complete a problem description for each problem.
7. For larger and/or complex restoration projects, the Service recommends that the evaluator draw a geomorphic map of the restoration project using mylar overlaid on the restoration as-built plans.
8. In addition to recording any measurements and/or ratios on the monitoring form, the evaluator will also record and illustrate where and how the measurements were taken on the restoration as-built plans.

## **G. LIMITED STREAM MEASUREMENTS**

When necessary, the evaluator will collect limited stream measurements and calculate dimensionless stream relationships (e.g. bankfull width, beltwidth, radius of curvature) to determine if the restored stream characteristics/conditions are within the range of the restoration design criteria. The restoration design criteria are developed from reference stream data, and represent the target design range for various stream characteristics. For example, if the evaluator observes erosion at a stream meander, it may be necessary to measure the radius of curvature to determine if the radius of curvature is within the design criteria. Furthermore, by dividing the radius of curvature by the bankfull width, the evaluator can develop a dimensionless ratio and determine the potential cause of erosion (i.e., the ratio is too small and generating excessive shear stress).

When collecting the stream measurements, the evaluator will follow standard survey techniques such as those presented in the manuals *Stream channel reference sites: An illustrated guide to field technique* (Harrelson et al. 1994), and *River Stability Field Guide* (Rosgen 2008).

A list of common stream measurement and dimensionless ratios are provided in Appendix A. However, the evaluator should not be limited by this list. If there are other measurements that could assist the evaluator in assessing the project, the evaluator should take those measurements.

## **H. MONITORING RECOMMENDATIONS**

Regardless of the rapid monitoring results, the rapid monitoring survey should be conducted every year within the required monitoring period. If results of the rapid survey indicate potential structural or functional failure, the protocol requires that the project evaluator conduct a more intensive monitoring survey. During the more intensive survey, the Service proposes that project evaluators take measurements of the existing stream conditions and compare them to the proposed design criteria data to determine if remediation is required. Depending on the severity of the problems, this action can take two forms. The evaluator can recommend either a partially or fully monumented stream survey of the project reach. Regardless of the method selected, there are two possible outcomes. If the measurements are not outside of design criteria but there is potential for the stream to evolve outside of the criteria, then the evaluator should continue the monumented surveys to determine the stability trend over time. In this case, the evaluator does not move to remediation unless conditions evolve outside of the design criteria. However, if the measurements are outside of design criteria then remediation is required.

As of the issuance of this report, the Service has not prepared protocols for the more intensive monitoring surveys. However, this protocol has provided some guidance on when to make these recommendations.

The criteria for determining whether to recommend additional monitoring or restoration repair are based on the severity of the stream adjustments and the potential consequences of the adjustments. The evaluator will recommend intensive monitoring if the adjustment is localized and does not pose a significant threat to the success or function of the restoration. The evaluator will recommend restoration repair if the adjustment is widespread and poses a significant threat to the success or function of the restoration. A significant threat is defined as any condition that would result in failure to achieve any of the restoration objectives, failure of a restoration technique (e.g. rock cross vane) to function as intended, or damage to property beyond the limits of the restoration. For example, an evaluator should consider undermining of a rock cross vane and loss of grade control a significant threat.

Although the Service has provided recommendation guidance, the Service recognizes that the criteria are still general and subjective. However, the Service thinks that an experienced evaluator should easily be able to determine when repair is required.

## V. CONCLUSION

In recent years, there has been a strong emphasis by the restoration community to evaluate the success of stream restoration projects. However, time and financial constraints have often limited the opportunities to evaluate restoration projects. Restoration monitoring is critical in assessing whether the project achieved its restoration objective(s), improved restoration science to improve future restoration projects, and benefitted Federal Trust Resources.

The Service developed this rapid stream restoration monitoring protocol to promote monitoring by reducing the financial and time demands necessary to evaluate the success of a project. It is not the intent of the Service to promote a rapid monitoring survey over a more intensive survey, but to develop an alternative that addresses the constraints that prevents monitoring.

The purpose of this protocol is to evaluate the stability and functional success of a restoration project visually. Although this protocol relays primarily on observation, this protocol can effectively evaluate the success of a project and provide consistent and comparable results/recommendations when implemented by an experienced and prepared evaluator. In addition, the form and protocol are a “living document.” As long as there is an associated performance standard, the form can modified to add other indicators of instability.

**LITERATURE CITED**

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2. Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. U.S. Forest Service, Fort Collins, CO.
3. McCandless, T.L. & R.A. Everett. 2002. Maryland Stream Survey: Bankfull Discharge and Channel Characteristic of Streams in the Piedmont Hydrologic Region. U.S. Fish and Wildlife Service, CBFO-S02-01. Annapolis, MD.
4. Rosgen, D.L. 2006. A Watershed Assessment for River Stability and Sediment Supply (WARSSS). Wildland Hydrology Books, Fort Collins, Colorado.
5. Rosgen, D.L. 2008. River Stability Field Guide. Wildland Hydrology. Fort Collins, CO.

## **APPENDIX A**

| Stream Name:      |                       | Crew:                          |                                | Project Description:                   |                |          |  | Comments:           |                                  |                    |                |  |
|-------------------|-----------------------|--------------------------------|--------------------------------|--|----------------|----------|--|---------------------|----------------------------------|--------------------|----------------|--|
| Project Name:     |                       | Date:                          |                                |  |                |          |  |                     |                                  |                    |                |  |
| Project Location: |                       |                                |                                |  |                |          |  |                     |                                  |                    |                |  |
| Station           | Identification Number | Problem Description            |                                |  |                |          |  | Recommended Actions |                                  |                    | Measurement(s) |  |
|                   |                       | Type                           | Indicator(s)                   | Severity                               | Implication(s) | Cause(s) | Description                                  | Type                | Description                      | Monumented Survey? |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |
|                   |                       | Vertical Stability<br>Riparian | Lateral Stability<br>Structure | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 | 1 2 3          | 1 2 3    | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 14 15 16 17 |                     | 1 2 3 4 5 6 7 8 9 10<br>11 12 13 |                    | Yes No         |  |
|                   | Photograph(s):        | Other:                         |                                | Other:                                 | Other:         | Other:   |  | Other:              |                                  |                    |                |  |



RAPID STREAM MONITORING EVALUATION ATTRIBUTES

|                       | Vertical Stability   | Lateral Stability  | Riparian Condition  | Structure  | Measurements   |
|-----------------------|--|--|---|--|--|
| Problem Indicator(s)  | 1 None (no problem indicators)   | 1 None (no problem indicators)   | 1 None (no problem indicators)  | 1 None (no problem indicators)   | $W_{100}$ Bankfull Width (ft)  |
|                       | 2 Degradation  | 2 Decrease in meander width ratio  | 2 Bare ground present   | 2 Collapsed structure  | $D_{50}$ Bankfull Depth (ft)   |
|                       | 3 Increase bank height ratio   | 3 Increase in meander width ratio  | 3 Invasive species present  | 3 Unstable/repositioned structure rocks  | $W_{100}/D_{50}$ Width/Depth Ratio                                   |
|                       | 4 Decrease bank height ratio   | 4 Lateral scour/undercut   | 4 Poor riparian survival  | 4 Flow piping through structure  | $W_{100}$ Active Channel Width (ft)                                  |
|                       | 5 Scour  | 5 Platform/radius of curvature adjustments   | 5 Poor riparian width   | 5 Lack of adequate pool depth/pool formation   | $D_{50}$ Active Channel Depth (ft)                                   |
|                       | 6 Incorrect pool-to-pool spacing   | 6 Cutoff channel development   | 6 Other   | 6 Accelerated vertical scour/exposed footer rocks  | $W_{10}$ Floodprone Width (ft)                                       |
|                       | 7 Increase in facet slope  | 7 Loss of bank vegetation  |   | 7 Accelerated lateral scour/scour along deposition area at the structure                                     | ER Entrenchment Ratio  |
|                       | 8 Poor pool depth variability  | 8 Bank deposition  |   | 8 Accelerated deposition in pool   | $L_m$ Meander Length (ft)  |
|                       | 9 Poorly defined facet features  | 9 Dominant BEH and NBS rating of moderate or greater   |   | 9 Butted structure   | $W_{100}$ Bankfull Width (ft)  |
|                       | 10 Decrease in facet slope   | 10 Other   |   | 10 Accelerated lateral scour upstream/downstream of the structure  | MWR Meander Width Ratio  |
|                       | 11 Deposition/Bar Development  |  |   | 11 Other   | K Sinuosity  |
|                       | 12 Aggradation   |  |   |  | $R_c$ Radius of Curvature (ft)                                       |
|                       | 13 Increase in entrenchment  |  |   |  | $R_c/W_{100}$ Ratio of Curvature to Bankfull Width                   |
|                       | 14 Decrease in entrenchment  |  |   |  | BHR Bank Height Ratio  |
|                       | 15 Other   |  |   |  | $S_{100}$ Reach Average Stream Slope                                 |
| Severity              | 1 Temporary scour or deposition formation  | 1 Localized bank erosion; minor loss of bank material; BEH and/or NBS have a rating of low or less   | 1 Temporary riparian degradation  | 1 Minor stress on the structure; still functioning as intended   | $S_{100}$ Facet Slope  |
|                       | 2 Localized scour or bar formation; minor changes to bed characteristics                                     | 2 Localized, moderate bank erosion; moderate loss of bank material; BEH and NBS have a rating of moderate                                      | 2 Localized riparian degradation  | 2 Partial failure of structure; minimally functioning as intended  | BEH Dominant Bank Erosion Hazard Index                               |
|                       | 3 Widespread scour or bar formation; extensive changes to bed characteristics                                | 3 Widespread failure of entire bank; bank actively eroding and substantial loss of bank material; BEH and NBS have a rating of high or greater | 3 Widespread riparian degradation   | 3 Complete structural failure; no longer functioning as intended   | NBS Dominant Near Bank Shear Stress (weir method used is stream NBS) |
| Implications(s)       | 1 Not expected to worsen or cause further problems; may stabilize over time                                  | 1 Not expected to worsen or cause further problems; may stabilize over time  | 1 Not expected to worsen or cause further problems; may stabilize over time     | 1 Not expected to worsen or cause further problems; may stabilize over time                                  | $D_{50}$ Bed Particle Size (50th Percentile) (mm)                    |
|                       | 2 Expected to worsen over time   | 2 Expected to worsen over time   | 2 Expected to worsen over time  | 2 Expected to worsen over time   | $D_{84}$ Bed Particle Size (84th Percentile) (mm)                    |
|                       | 3 Immediate concern; will cause further damage and contribute to other problems                              | 3 Immediate concern; will cause further damage and contribute to other problems  | 3 Immediate concern; will cause further damage and contribute to other problems | 3 Immediate concern; will cause further damage and contribute to other problems                              | $D_{100}$ Largest Particle Size on Bar (mm)                          |
| Apparent Cause(s)     | 1 None (no apparent cause)   | 1 None (no apparent cause)   | 1 None (no apparent cause)  | 1 None (no apparent cause)   | P-P Pool-to-Pool Spacing   |
|                       | 2 Localized sediment input from an immediate source  | 2 Drainage feature (e.g., tributary or outlet) entering stream   | 2 Improper post restoration planting plan                                       | 2 Incorrect use of structure   |  |
|                       | 3 Cross section width/depth ratio is less than the design criteria   | 3 Overland/over bank drainage  | 3 Improper implementation of planting plan                                      | 3 Improper installation  |  |
|                       | 4 Cross section width/depth ratio is larger than the design criteria   | 4 Improperly installed bank matting  | 4 Drought or other natural causes   | 4 Improper platform placement (installation/implementation)  |  |
|                       | 5 Excessive sediment input from watershed sources upstream of the project                                    | 5 Incorrect bank angle   | 5 Development   | 5 Improper design criteria   |  |
|                       | 6 Aggradation from in-stream vegetation, debris jam, or other channel obstruction                            | 6 Bank angle shallower than design criteria  | 6 Poor plant condition or seed source for existing conditions                   | 6 Improper channel dimension   |  |
|                       | 7 Scour from debris jam or other channel obstruction   | 7 Structure not functioning properly and leading to accelerated lateral scour or deposition  | 7 Grazing or other agricultural practices                                       | 7 Improper profile design  |  |
|                       | 8 Unstable drainage feature (e.g., tributary or outlet) entering stream                                      | 8 Scour from debris jam or other channel obstruction   | 8 Non-native or invasive species  | 8 Improper platform design   |  |
|                       | 9 Structure not functioning properly and leading to accelerated vertical scour or deposition                 | 9 Lack/loss of vegetation  | 9 Other   | 9 Improper material size   |  |
|                       | 10 Channel incision, loss of floodplain connectivity   | 10 Unstable bank material/fill   |   | 10 Change in flow regime   |  |
|                       | 11 Improper channel dimension  | 11 Channel incision; loss of floodplain connectivity   |   | 11 Extreme flood or flow event   |  |
|                       | 12 Improper profile design   | 12 Improper channel dimension  |   | 12 Structure not functioning properly and leading to accelerated vertical and/or lateral scour or deposition |  |
|                       | 13 Improper platform design  | 13 Improper profile design   |   | 13 Other   |  |
|                       | 14 Improper bed material size  | 14 Improper platform design  |   |  |  |
|                       | 15 Change in flow regime   | 15 Change in flow regime   |   |  |  |
|                       | 16 Extreme flood or flow event   | 16 Extreme flood or flow event   |   |  |  |
|                       | 17 Other   | 17 Other   |   |  |  |
| Recommended Action(s) | 1 No action  | 1 No action  | 1 No action   | 1 No action  |  |
|                       | 2 Remove debris jam, other obstruction, and/or excessive sediment  | 2 Armor bank   | 2 Supplement current planting   | 2 Regrade banks, repair matting, and/or replace vegetation   |  |
|                       | 3 Armor bed to prevent scour   | 3 Repair matting and/or replace vegetation   | 3 Invasives removal   | 3 Stabilize structure with rock material   |  |
|                       | 4 Modify channel dimensions or characteristics (e.g., active channel bench); reconnect channel to floodplain | 4 Regrade banks, repair matting, and/or replace vegetation   | 4 Re-plant riparian corridor  | 4 Repair unstable portion of structure   |  |
|                       | 5 Modify channel profile   | 5 Reinstall soil lifts and replace vegetation  | 5 Pest control  | 5 Rebuild or rebuild entire structure  |  |
|                       | 6 Modify channel platform  | 6 Stabilize channel banks with rock material   | 6 Other   | 6 Modify channel dimensions or characteristics (e.g., active channel bench); reconnect channel to floodplain |  |
|                       | 7 Construct grade control structure  | 7 Modify channel dimensions or characteristics (e.g., active channel bench); reconnect channel to floodplain                                   |   | 7 Modify channel profile   |  |
|                       | 8 Stabilize local sediment source  | 8 Modify channel profile   |   | 8 Modify channel platform  |  |
|                       | 9 Manage stormwater quantity   | 9 Modify channel platform  |   | 9 Stabilize local sediment source  |  |
|                       |  | 10 Construct grade control structure   |   | 10 Manage stormwater quantity  |  |
|                       |  | 11 Stabilize local sediment source   |   | 11 Other   |  |
|                       |  | 12 Manage stormwater quantity  |   |  |  |
|                       |  | 13 Other   |   |  |  |

## Common Stream Design Measurements and Ratios

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

| Parameter   | Common<br>Design Ratios |        |       |       |       |       |       |       |       |       |       |       |
|---|-------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|   | MIN                     | MAX    | MIN   | MAX   | MIN   | MAX   | MIN   | MAX   | MIN   | MAX   | MIN   | MAX   |
| Stream Type (Rosgen)  | C4                      |        | C5    |       | E4    |       | E5    |       | B4    |       | B4c   |       |
| Bankfull Mean Velocity, V <sub>bkf</sub> (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, D <sub>max</sub> /D <sub>bkf</sub>    | 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, D <sub>tob</sub> /D <sub>max</sub> (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, L <sub>m</sub> /W <sub>bkf</sub>        | 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, R <sub>c</sub> /W <sub>bkf</sub>                    | 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, W <sub>btl</sub> /W <sub>bkf</sub>       | 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, S <sub>val</sub> (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, S <sub>rif</sub> /S <sub>chan</sub>       | 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, S <sub>run</sub> /S <sub>rif</sub>           | 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, S <sub>glide</sub> /S <sub>chan</sub>      | 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, S <sub>pool</sub> /S <sub>chan</sub>        | 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, D <sub>maxpool</sub> /D <sub>bkf</sub>  | 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, W <sub>pool</sub> /W <sub>bkf</sub>         | 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, L <sub>ps</sub> /W <sub>bkf</sub>    | 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 2: Common reference reach ratios for C, E, and B stream types**

| Parameter   | Common<br>Reference Reach Ratios |        |       |       |       |       |       |       |       |       |       |       |
|---|----------------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|   | MIN                              | MAX    | MIN   | MAX   | MIN   | MAX   | MIN   | MAX   | MIN   | MAX   | MIN   | MAX   |
| Stream Type (Rosgen)  | C4                               |        | C5    |       | E4    |       | E5    |       | B4    |       | B4c   |       |
| Bankfull Mean Velocity, V <sub>bkf</sub> (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, D <sub>max</sub> /D <sub>bkf</sub>    | 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, D <sub>tob</sub> /D <sub>max</sub> (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, L <sub>m</sub> /W <sub>bkf</sub>        | 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, R <sub>c</sub> /W <sub>bkf</sub>                    | 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, W <sub>btl</sub> /W <sub>bkf</sub>       | 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, S <sub>val</sub> (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, S <sub>rif</sub> /S <sub>chan</sub>       | 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, S <sub>run</sub> /S <sub>rif</sub>           | 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, S <sub>glide</sub> /S <sub>chan</sub>      | 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, S <sub>pool</sub> /S <sub>chan</sub>        | 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, D <sub>maxpool</sub> /D <sub>bkf</sub>  | 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, W <sub>pool</sub> /W <sub>bkf</sub>         | 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, L <sub>ps</sub> /W <sub>bkf</sub>    | 3.0                              | 7.0    | 3.0   | 7.0   | 2.5   | 5.0   | 2.5   | 5.0   | 0.5   | 5.0   | 1.2   | 6.0   |

Source: Data from Dave Rosgen, Wildland Hydrology; Will Harman, Stream Mechanics; and USFWS-Chesapeake Bay Field Office