U.S. Fish & Wildlife Service

Stream Assessment Protocol

Anne Arundel County Maryland

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STREAM ASSESSMENT PROTOCOL
ANNE ARUNDEL COUNTY, MARYLAND

By: Richard R. Starr

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

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Prepared in cooperation with:
The Anne Arundel County Department of Public Works – Watershed, Ecosystems, and Restoration Services

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I. INTRODUCTION

Anne Arundel County Department of Public Works – Watershed, Ecosystems, and Restoration Services, Maryland (County) and the U.S. Fish and Wildlife Service (Service) – Chesapeake Bay Field Office have entered into a cooperative agreement (Agreement # 1902-5041) to conduct stream assessments and investigations. Under the conditions of the agreement, a Scope of Work (SOW) has been approved for the Service to develop a stream assessment protocol for new and re-development projects and an associated training module.

Currently, the Anne Arundel County Office of Planning and Zoning has review and approval responsibility for new and re-development projects. Currently, there are numerous methods used to assess stream stability conditions. The County has requested that the Service develop standard protocols for stream assessment as required under the County's Stormwater Management Practices and Procedures Manual and to provide instruction and training on applying the protocols.

This document contains a rapid stream assessment protocol and a detailed stream assessment protocol. This document also provides guidelines and standard forms for both protocols.

II. PROTOCOL OBJECTIVES

Objectives of Protocol

- To provide the County and its contractors with a standardized method for determining existing stream character and stability condition.
- The protocol should allow for comparison between reviewers **(***e.g. county regulators and developers***).**
- The protocol should be rapid, quantitative, and definitive.

III. ASSESSMENT OVERVIEW

The stream assessment protocol consists of three main components: 1) limits of investigation, 2) rapid stream assessment, and 3) detailed stream assessment. The intended use of this assessment protocol is to determine existing stream character and stability condition.

The use of the rapid stream assessment protocol, as with most rapid methods, requires well-experienced practitioners. While reducing subjectivity was a goal during the development of the assessment protocol, some assessment parameters require skilled practitioners to assess correctly. Assessors must be knowledgeable in fluvial geomorphic and watershed processes and be well trained and experienced in identifying bankfull geomorphic indicators.

IV. POINT OF INVESTIGATION

The point of investigation defines the limits of the assessment, hereafter referred to as Assessment Reach. The Assessment Reach should be from the proposed development point of origin, downstream to the point where the influence of the proposed development no longer affects the receiving stream. Many factors can influence how far downstream impacts are realized by a proposed development. One of the methods to determine the Assessment Reach is through hydrologic modeling. Hydrologic modeling can show where increases of storm water runoff, from the proposed development, increases the volume of stream flows. However, modeling is not required as part of the initial impact assessment. Later in the assessment process, if the proposed development is determined to have impacts on the stream, a hydrologic model is required to redefine the limits of assessment.

Currently Anne Arundel County stormwater management regulations require a developer to determine the limits of assessment based on a man-made or natural restriction point downstream of the proposed development. While the stream reach within the restricted area may remain stable, the increased impervious surfaces as part of the proposed development could produce a significant flow regime change resulting in stream adjustments of the reach below the restricted area. Research (Schuler 1994) has shown that impacts can occur to streams with watersheds having as little as 6 to 15 percent impervious surfaces.

Based on the potential for flow regime changes to impact stream condition, compute the ratio of the proposed development project area to the watershed drainage area to determine of the limits of assessment. The proposed development area cannot represent greater than 10 percent of the watershed at the point where the proposed development discharges into the stream. If the proposed development area is less than 10 percent of the watershed, no further assessments are required. If the proposed development area is greater than 10 percent of the watershed, then the limits of assessment is determined by the point, downstream of the proposed development, where the proposed development area no longer represents more than 10 percent of the watershed. For example, if the proposed development is 10 acres and the watershed drainage area is 100 acres, then no further assessments are required. However, if the proposed development is 10 acres and the watershed drainage area is 50 acres, then further assessment is required to a point downstream where the watershed is 100 acres. Assessment Reaches shall not extend into stream reaches subject to tidal control.

V. RAPID STREAM ASSESSMENT

The rapid stream assessment has two components: stream characterization and stability assessment. The data collected as part of the stream characterization includes general watershed characteristics, bankfull determination, and stream classification. The data collected as part of the stream stability assessment includes vertical stability, lateral stability, and overall reach stability. The information within this section describes the assessment parameters and the procedures to implement the assessment method. Each parameter section within the assessment form is shown in this section as part of the parameter description. The rapid stream assessment forms are in Appendix A. A checklist of the procedures is in Appendix B

A rapid assessment shall be completed for each Rosgen stream type and stability condition existing within the Assessment Reach. If the Assessment Reach stream characteristics are not homogenous, divide the Assessment Reach into sub reaches. For example, two Rosgen C4 stream types may exist within the Assessment Reach. One C4 reach is stable and the other C4 reach has widespread instability. A separate assessment form must be completed for each of these reaches. Assessors should determine if there are areas within the Assessment Reach that have noticeable differences in the following steam characteristics when determining when more than one rapid assessment is required for the Assessment Reach:

- Dominate streambank stability condition
- Stream channel incision
- Stream channel entrenchment
- Sinuosity

Photo documentation is required with each rapid assessment form completed. The photo documentation should support the assessment determinations recorded on the assessment forms. At the minimum, the following items should be photographed:

- Overall assessment area
- Streambank stability conditions
- Head cuts and/or bed aggradation areas, if existing
- Infrastructure (e.g., utilities, bridges, etc.), if existing
- Adjacent land uses/vegetation

A. Rapid Stream Characterization

1. Watershed Characterization

There are two primary purposes for the watershed characterization data. First, is to gain an understanding of how land uses and land cover influence stream character and stability through changes in flow regime. The second is to gain an understanding of how the immediate land uses and land cover influence the stream within the Assessment Reach.

Flow regime can vary greatly depending upon the landscape character of the watershed. The rate and volume of flow that reaches a stream system has a direct relationship to stream characteristics, stream stability conditions, and bankfull discharge. A watershed that is highly developed will have a different flow regime than a predominantly forested watershed. The stormwater runoff from a highly developed watershed will reach the stream rapidly, in a large volume, and have very little retention and groundwater recharge. This type of flow regime increases stream energy and sediment transport capability. Consequently, streams in urban watershed are typically unstable and characterized as deeply incised with a high width to depth ratio. While in a predominantly forest watershed, runoff will reach the stream more slowly and in less volume resulting in a lower stream energy and greater retention and groundwater recharge.

WATERSHED CHARACTERIZATION
Land use/Land cover Data (from County, MBSS data, GIS Hydro, or Other):
% Urban: ____ % Suburb: _____ % Agr.: _____ % Forest: ____ % Imp.: ____
Valley Type or Description:
Adjacent LU/LC:
Significant Upstream Land Cover and/or Land uses that influence stream character and stability:

Land uses and land cover adjacent to and upstream of the Assessment Reach also influence stream characteristics and stream stability. Dense development upstream of a stream can create concentrated flows, which in turn increases stream energy thus resulting in the potential for stream erosion. Conversely, a well vegetated riparian corridor provides stability support through the rooting systems of the vegetation. Knowledge of adjacent land uses and land cover is required information to develop an understanding of the overall character and stability condition of the stream.

The data collection for the percentages of land use and land cover is an office exercise. Varieties of GIS sources exist to obtain this data. Some GIS sources include the County, Maryland Department of Natural Recourses, Maryland State Highway GIS Hydro, and Maryland Office of Planning. Record on the assessment form what source was used to obtain land use and land cover percentages.

The valley type of the Assessment Reach influences the character of a stream as well as the response of a stream to land use and land cover changes. Valley type description can be obtained by using Rosgen's valley type classification system (Rosgen 2006) or by providing a brief narrative describing valley shape, slope, geology, etc.

Use field observations and aerial photography to record adjacent land use and land cover. If vegetation exists on the streambank and within the riparian buffer, provide a description of the vegetation. The vegetation description should include the type of vegetation (e.g., annual and perennial vegetation, grasses, vines, shrubs, understory, and canopy) and location of vegetation. Describe the location of vegetation on the streambank in relation to bankfull (e.g., entire bank, mostly on the upper portion of the bank above bankfull, sporadically across the bank above and below bankfull, etc.), provide a percentage of the bank covered by vegetation, and provide a percentage of the banks within the Assessment Reach covered by vegetation. Provide the width and density of the riparian buffer and the percentage of the reach assessment with a riparian buffer. The density is a percentage of the ground covered by the vegetation within the riparian buffer.

2. Bankfull Validation

BANKFULL VALIDATION			
Regional Curve:	Rural Coastal Plain Curve		Urban Coastal Plain Curve
BF Cross Sectional Area	__________	BF Depth	__________
BF Width	__________	BF Discharge	__________

Bankfull discharge characterizes the range of discharges that is effective in shaping and maintaining a stream. Over time, geomorphic processes adjust the stream capacity and shape to accommodate the bankfull discharge within the stream. Bankfull discharge is strongly correlated to many important stream morphological features (*e.g.,* bankfull width, drainage area, etc.) and is the critical parameter used in characterizing a stream and assessing stream stability. Bankfull discharge is also a critical parameter used in natural channel design procedures as a scale factor to convert morphological parameters from a stable reach of one size to a disturbed reach of another size.

The validation of bankfull starts as an office exercise by using the regional curves (Figures 1 and 2) developed by the U.S. Fish and Wildlife Service (McCandless 2003) and Clear Creek Consulting (Powell 2007) (Figure 3). Use the Service regional curves if the impervious surfaces of the watershed are less than 15 percent and the Clear Creeks Consulting curve if the impervious surfaces of the watershed are greater than 15 percent. Indicate on the assessment form which curve was used and record the bankfull stream dimensions and discharge. Use this information to validate bankfull field measurements taken as part of the stream characterization and classification section of the assessment form. Note that the Assessment Reach bankfull channel dimensions and discharge may not plot within the data of either curve. If this occurs, consider the drainage area characteristics (i.e., percent imperviousness, basin size, shape, and slope, land use, etc.) and its influence on the flow regime. A steep, narrow-shaped drainage area with high imperviousness may result in a larger volume of storm runoff entering a stream. Whereas a shallow, broad-shaped drainage area that is mostly forested may result in less storm runoff entering a stream.

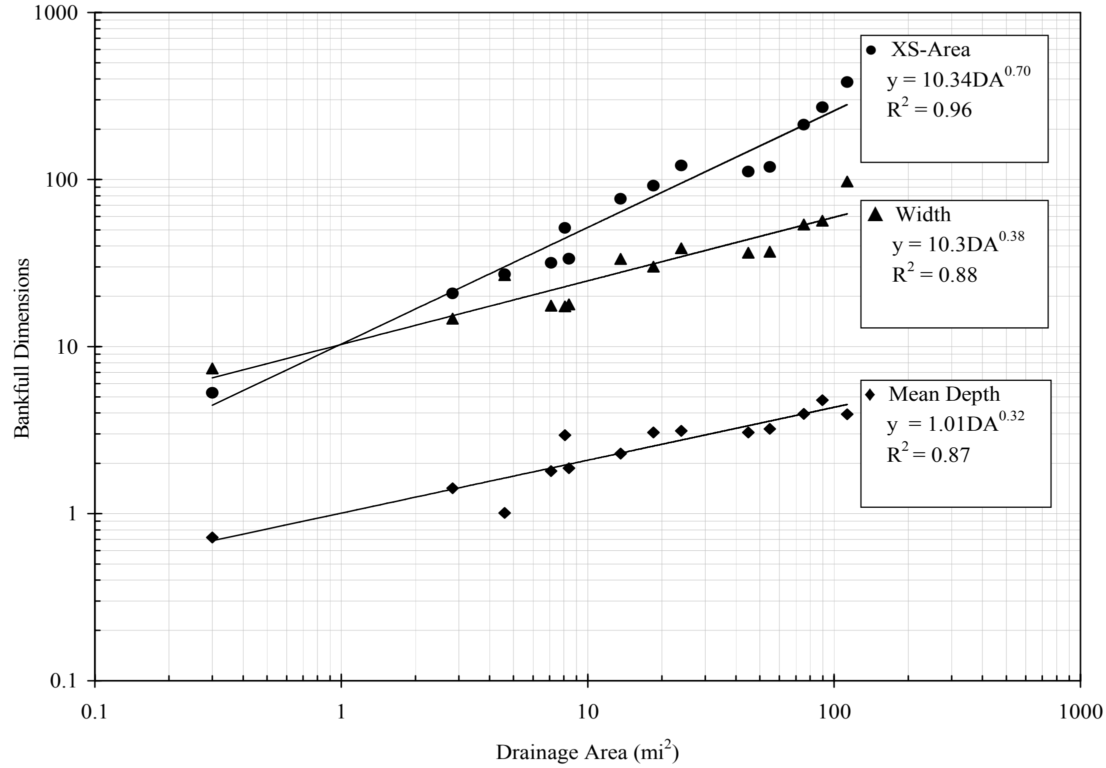


Figure 1. Bankfull channel dimensions as a function of drainage area for Coastal Plain survey sites (n = 14). (McCandless, 2003)

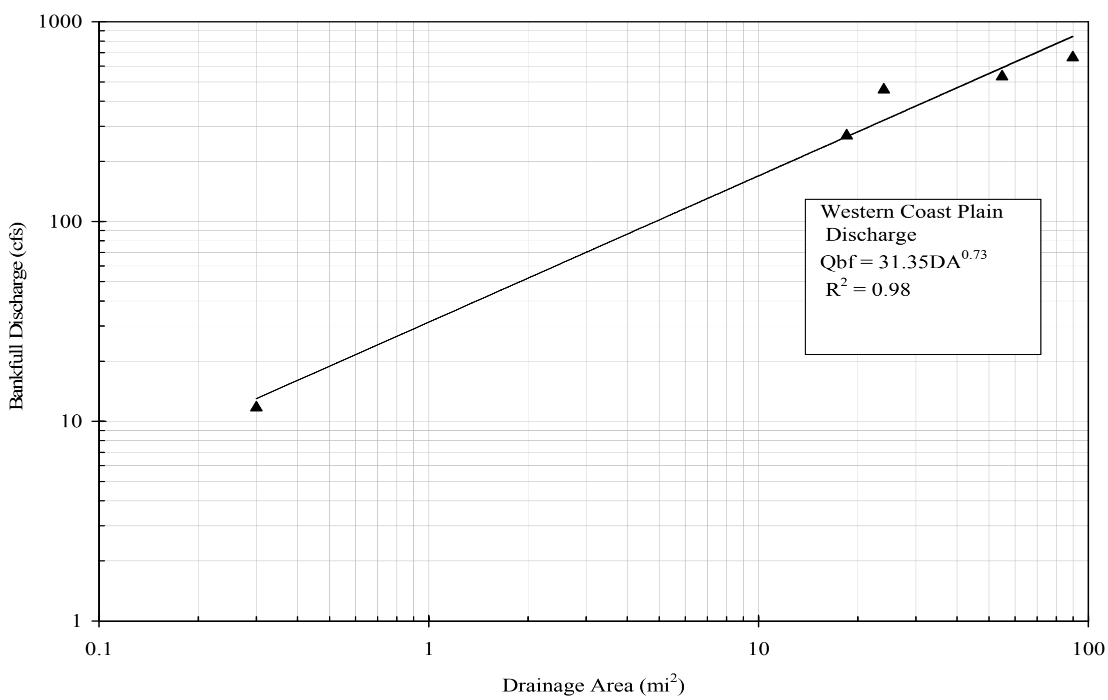


Figure 2. Bankfull discharge as a function of drainage area for Western Coastal Plain survey sites (n = 5). (McCandless, 2003)

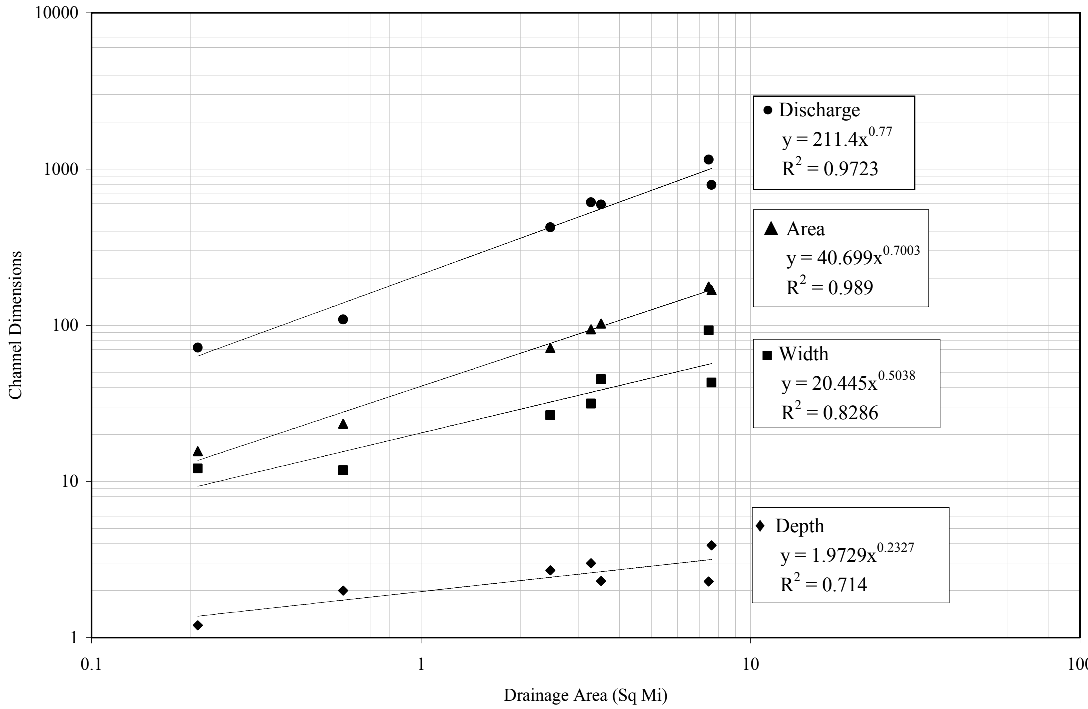


Figure 3. Bankfull channel dimensions and discharge as a function of drainage area for urban watersheds in the coastal plain hydrologic region, Maryland (n = 7). (Powell, 2007)

3. Stream Characterization and Classification

STREAM CHARACTERIZATION AND CLASSIFICATION			
Channel: Single Thread Braided		Entrenchment	__________
BF Width	__________	Reach D50	__________
BF Depth	__________	Riffle D84	__________
WS Slope	__________	Sinuosity	__________
BF Discharge	__________	Width/Depth Ratio	__________
Dominate BF Feature			
Rosgen Stream Type:			

The classification of the Assessment Reach is used to standardize the characterization of the stream. The stream classification uses the Rosgen Stream Classification system (Rosgen 1996). This part of the assessment requires the collection of field measurements in relation to the geomorphic feature associated with the bankfull discharge event. Refer to Rosgen (1996) for a description of the required data and field collection procedures.

Compare the field measurements with the stream dimension data derived from the regional curve to ensure the appropriate geomorphic feature was identified as bankfull. Record a description of the geomorphic feature associated with the bankfull discharge on the assessment form. For a detailed discussion on bankfull geomorphic indicators, refer to the report *Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Piedmont Hydrologic Region* (McCandless and Everett 2002).

B. Rapid Stream Stability Assessment

1. Lateral Stability

There are five parameters used to determine lateral stability: 1) width/depth ratio, 2) dominant bank erosion hazardous index (BEHI), 3) dominant near bank stress (NBS), 4) presence of bank armoring, and 5) presence of specific lateral erosion causes. The overall lateral stability is determined based on the findings of the individual assessment parameters.

LATERAL STABILITY
Width/Depth Ratio: ______ Rating: Stable Unstable
Dominant BEHI: Score: _____ Rating: Very Low Low Moderate High Very High Extreme
Dominant NBS: Low Moderate High Extreme
Presence of bank armoring: Yes No Description:
Presence of specific lateral erosion causes: Yes No Description:
Overall Lateral Stability: Stable Unstable: Localized Widespread

The key in determining whether lateral erosion is localized or widespread is whether the lateral erosion is or has the potential to cause system-wide changes to the stream channel dimensions, bed profile, and geometry pattern. If the erosion causes system-wide changes then it is considered widespread lateral instability. Localized lateral instability conditions are typically associated with a specific cause. For example, outfalls, culverts, ford crossings, and localized removal of vegetation cause, in most situations, localized bank erosion.

The Assessment Reach has localized lateral instability if bank erosion is present and the following reach conditions exist:

- The width/depth ratio is stable;
- The dominant BEHI rating is moderate or less;
- The dominant NBS is moderate or less; and
- Less than 20 percent of the streambanks lack vegetation or have site-specific bank erosion within the Assessment Reach.

The Assessment Reach has widespread lateral instability if bank erosion exists and the following conditions exist:

- The dominant BEHI rating is high or greater;
- The width/depth ratio rating is unstable;
- The dominant near bank stress rating is high or extreme; and
- Greater than 50 percent of the streambanks lack vegetation and/or are actively eroding.

Definition of Individual Assessment Parameters

<u>Width/depth Ratio</u> – Width/depth ratio is the ratio of bankfull width to bankfull mean depth in the riffle cross section. The stability rating of width/depth ratio is based on Rosgen stream type. Use the following criteria to determine width/depth ratio rating (Rosgen 1996):

- Rosgen stream type B – less than 20 is stable; otherwise unstable
- Rosgen stream type C – less than 28 is stable; otherwise unstable
- Rosgen stream types F, G, and D are unstable

Criteria is not listed for Rosgen stream types A and E because if the width/depth ratio is higher than 12, than the stream would classify as a different Rosgen stream type.

<u>Dominant Bank Erodibility Hazardous Index</u> – The Bank Erodibility Hazardous Index (BEHI) assessment method was developed by Rosgen (Rosgen 2001a) to predict the potential for a bank to erode based on several physical parameters. Figure 4 shows the assessment parameters and is the field form used to conduct a BEHI assessment. Table 1 shows the values of the assessment parameters. Refer to Rosgen (2006) for a description on the BEHI data collection procedures.

The dominant BEHI is derived by the bank stability condition that represents the largest portion of all the existing bank stability conditions within the stream Assessment Reach. If there are two bank stability conditions equally representative, select the higher of the two ratings.

<u>Dominant Near Bank Stress</u> – Near bank stress is associated with the shear stress generated by the stream against streambanks. Use Figure 5 to determine the existing near

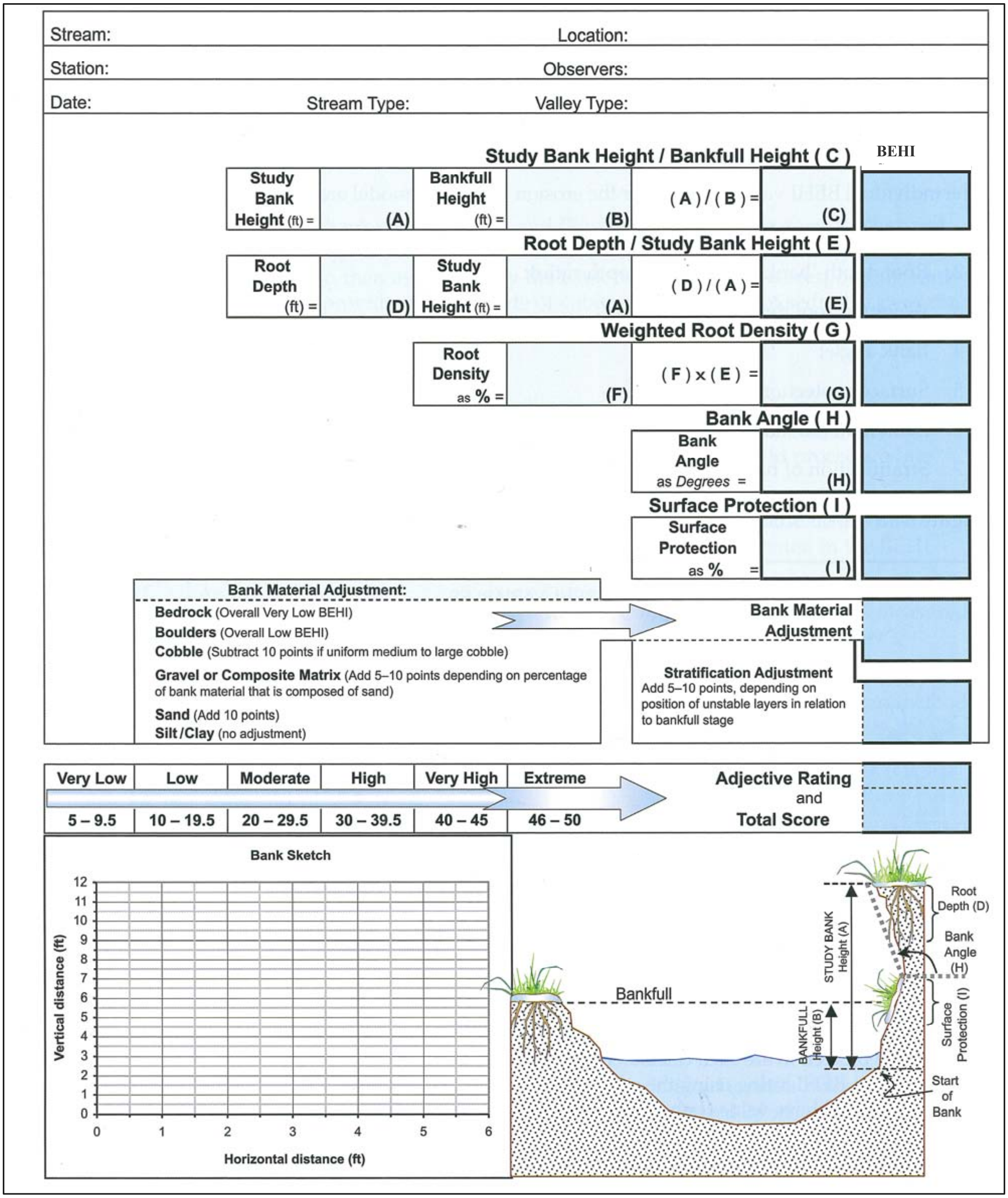
bank stress conditions within the Assessment Reach. The dominant near bank stress is derived by the near bank stress condition that represents the largest portion of all the existing near bank stress conditions within the stream Assessment Reach. If there are two near bank stress conditions equally representative, select the higher of the two stress ratings. Consider the following factors when determining the NBS rating (Rosgen 2001b):

- The maximum depth location will influence the NBS rating. For example, a cross section with the maximum depth located in the middle has a lower NBS rating than a cross section with the maximum depth located in the outer one third of the stream.
- Chute cutoff return flows and split channels converging against study banks will cause a disproportionate energy distribution in the near bank region and NBS ratings will be extreme.
- Depositional features such as transverse bars and/or central bars will also create a disproportionate distribution of energy in the near bank region and NBS estimate ratings should be adjusted upward due to high velocity gradients. For central bars, estimate both outside banks.
- Evaluate the individual channels of a braided reach separately based on the distribution of energy in the near bank region.

Table 1. BEHI Values (Rosgen 2006)

Bank Erosion Hazard Index Values								
			Bank Erosion Potential					
			Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
Erodibility Variable	*Bank Height/ Bankfull Height*	Value	1.0 - 1.1	1.11 - 1.19	1.2 - 1.59	1.6 - 2.09	2.1 - 2.8	>2.8
		Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
	Root Depth/ Bank Height	Value	1.0 - 0.9	0.89 - 0.5	0.49 - 0.3	0.29 - 0.15	0.14 - 0.05	<0.05
		Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
	Weighted Root Density	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 5.0	<5.0
		Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
	Bank Angle	Value	0 - 20	21 - 60	61 - 80	81 - 90	91 - 119	>119
		Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
	Surface Protection	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 10	<10
		Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10

- If the stream slope directly upstream of a study bank is steeper than the average reach slope, adjust the NBS rating upward one rating.
- Exclude depositional areas along the streambanks (e.g., point bars) when determining the dominant near bank stress within the Assessment Reach.



Stream: Location:

Station: Observers:

Date: Stream Type: Valley Type:

BEHI

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)

Weighted Root Density (G)

Root Density as % =	(F)	(F) x (E) =	(G)

Bank Angle (H)

Bank Angle as *Degrees* =	(H)

Surface Protection (I)

Surface Protection as % =	(I)

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt /Clay** (no adjustment)

Bank Material Adjustment

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score

Figure 4. BEHI Assessment Form (Rosgen 2006)

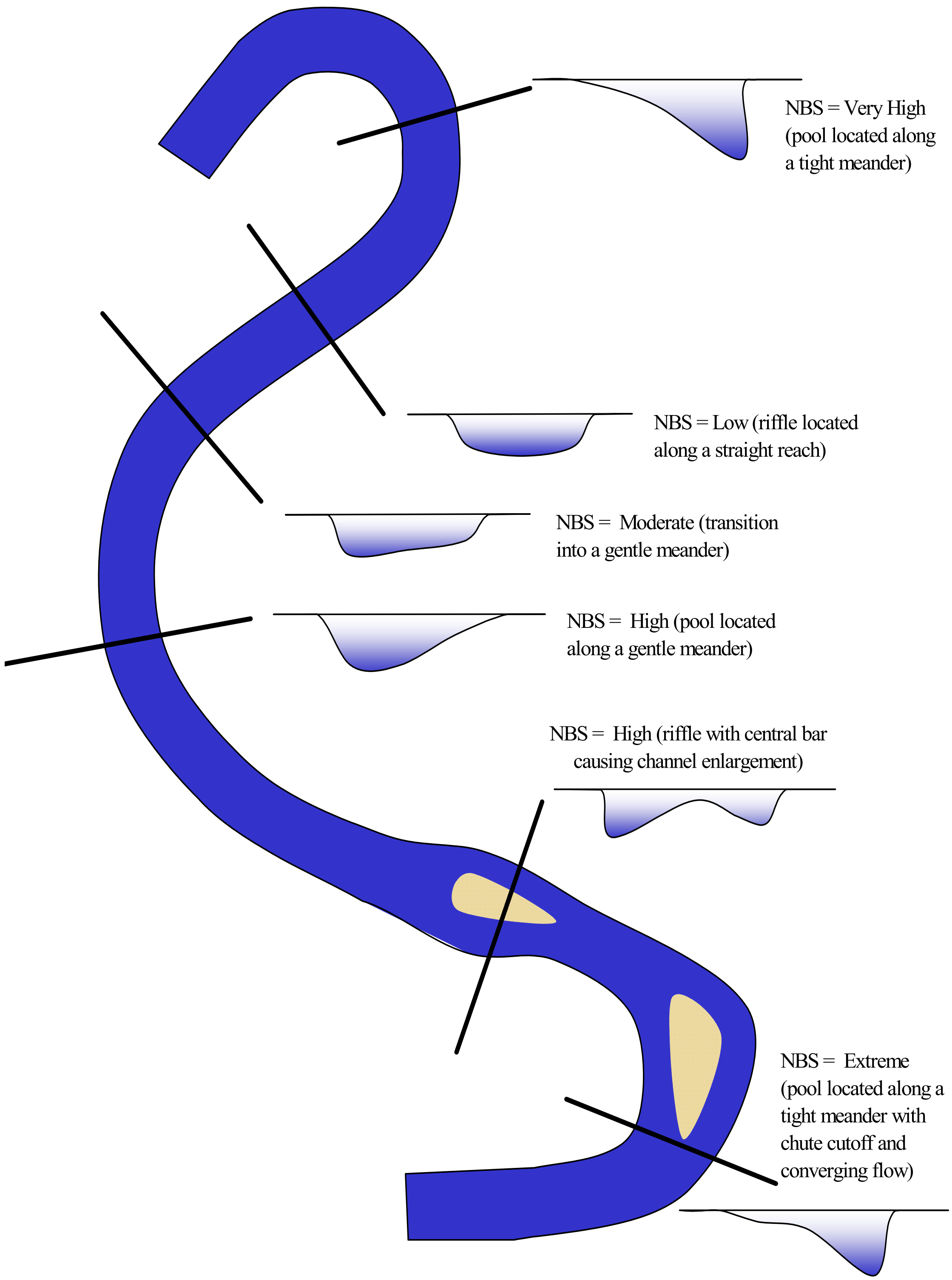


Figure 5. Near bank stress conditions (Rosgen 2001b).

Presence of Bank Armoring – Bank armoring can be natural (e.g., vegetation, boulders, bedrock, etc.) or man-made (riprap, gabions, concrete, sheet piled walls, etc.). If armoring exists, describe the type of armoring, the location of armoring, the percent of bank armored, and the percentage of banks armored within the Assessment Reach. Note whether or not if the armoring is effective in protecting the bank and provide reason for effectiveness (e.g., bank armoring eroding at the toe and subject to failure in the near future).

2. Vertical Stability

VERTICAL STABILITY
Incision Ratio: ______ Rating: Not Incised Slightly Moderately Highly Extremely
Presence of headcut: Yes No Description:
Presence of bedcontrol: Yes No Description:
Presence of deposition: Yes No Description:
Bed Features: Riffle/Pool Riffle/Run Run/Pool Plane Step/Pool Cascade
Bed Definition: Well Defined Moderately Well Defined Poorly Defined
Overall Vertical Stability: Stable Degrading Aggrading

There are five parameters to determine vertical stability: 1) incision ratio, 2) presence of a headcut, 3) presence of bedcontrol, 4) presence of deposition, and 5) bed features. The first four parameters are clear indicators of vertical stability and the fifth parameter is a supporting indicator. The overall vertical stability is determined based on the findings of the individual assessment parameters. The stream is vertically degrading if any one of the following conditions exists:

- Incision ratio greater than 1.6;
- Presence of a headcut in any part of the stream reach, even if there is bedcontrol located somewhere within the stream reach; or
- Incision ratio of 1.3 to 1.5 and poorly defined bed features.

The stream is vertically aggrading if the stream has a high width/depth ratio (use the same width/depth ratio ratings outlined in Section V.B1. Lateral Stability), incision ratio of less than 1.0, and there is a significant presence of depositional features. Significance is determined by depositional features that are actively forming throughout the entire stream reach (e.g., lateral and mid channel bars) and not just point bars located on the inside of a meander bend.

Definition of Individual Assessment Parameters

Incision ratio – Incision ratio is a ratio of the bankfull height to the top of lowest bank height (Figure 6). The following is a list of incision ratios and their corresponding rating based on Rosgen 2001:

- 1.0 – No incision
- 1.1 to 1.2 – Low incision
- 1.3 to 1.4 – Moderate incised
- 1.5 – 1.6 – High incision
- >1.7 Very High incision

Headcut – A headcut is stream erosion represented by a retreat, vertical or nearly vertical of the channel bed. If a headcut exists, describe the height and location (e.g., near the downstream end of the Assessment Reach, in the middle of the Assessment Reach, etc.) of the headcut.

Bed Control – Bed control can be natural (e.g., large woody debris, boulders, bedrock, etc.) or man-made (utility crossings, dams, culverts, etc.). If bed control exists, describe the type, location, and percent of the bed within the Assessment Reach controlled. Note whether or not if the bed control is in potential jeopardy of failing (e.g., under cutting) in the near future and whether it adversely impacts lateral stability (e.g., check dam redirect stream flows towards streambanks).

Depositional Features – The characterization of depositional features is used to determine bed aggradation. A stream that does not have sufficient power to transport sediment load will aggrades. Figure 7 illustrates a variety of depositional features. Categories B1 and B2 represent stable conditions. Categories B3 and B4 represent the beginning of an aggradation problem. Categories B5, B6, B7, and B8 represent streams with moderate to severe aggradation problems. Determine which category that best represents the reach assessment depositional features and state whether the reach is aggrading. A lack of depositional features could indicate vertical degradation and is addressed in the presence of bed features below.

Bed Features – The definition of bed features (e.g., riffles, pools, runs, glides, etc.) is a secondary indicator of streambed stability. A stream reach which pool areas are shallow, because of deposition, is an indicator of aggradation. A stream which the bed features are poorly defined, because of scour, is a potential indication of streambed degradation.

Bank Height/Bankfull Height Ratio:

$$\text{Ratio} = \frac{\text{Top of Bank Height}}{\text{Bankfull Height}} = \frac{8\text{ft.}}{4\text{ft.}} = 2$$

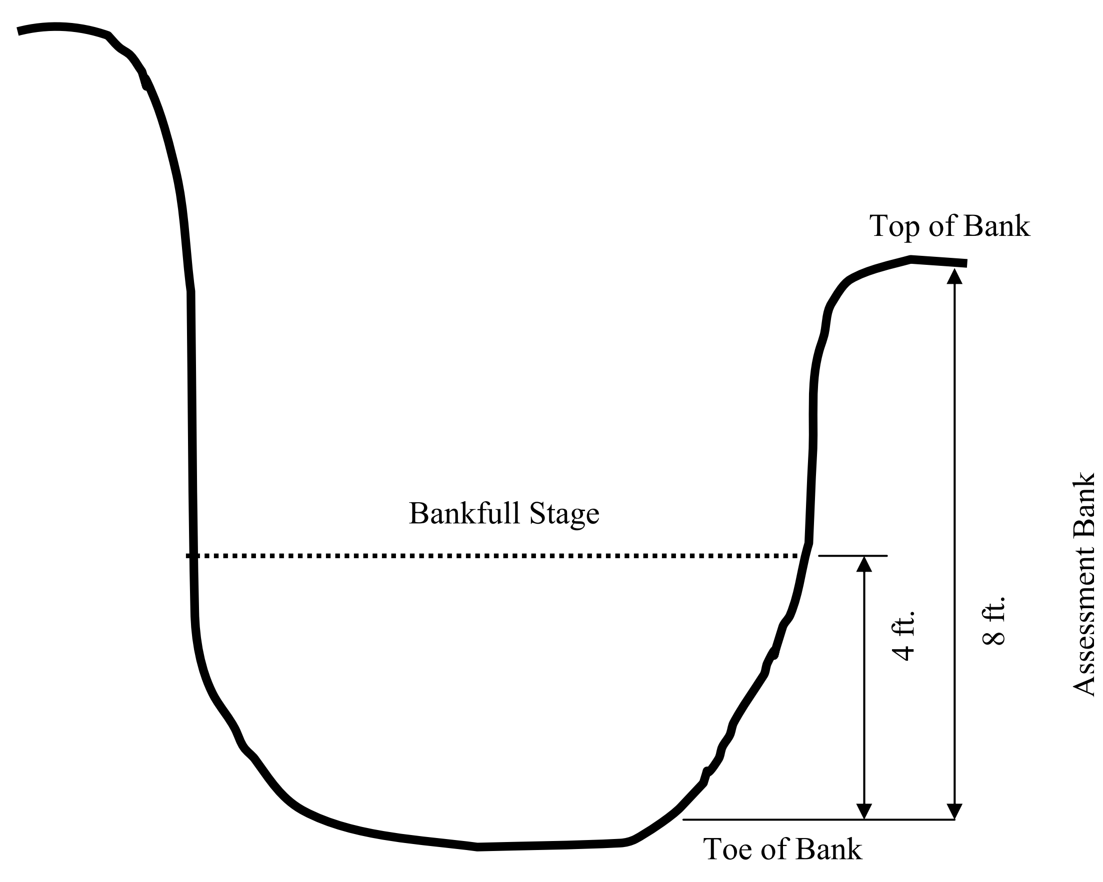


Figure 6: Incision Ratio

Describe what type of bed features exist within the Assessment Reach and how well they are defined. Use the following criteria to determine how well the bed features are defined:

- Well defined – greater than 95 percent of the streambed is well defined (pools two to three times deeper, at bankfull, than riffles).
- Moderately defined – at least 50 to 70 percent of the streambed is moderately defined (pools one and a half to two times deeper, at bankfull, than riffles).
- Poorly defined – greater than 50 percent of the streambed is poorly defined (pools as deep, at bankfull, as riffles or there is no distinction between riffles and pools).

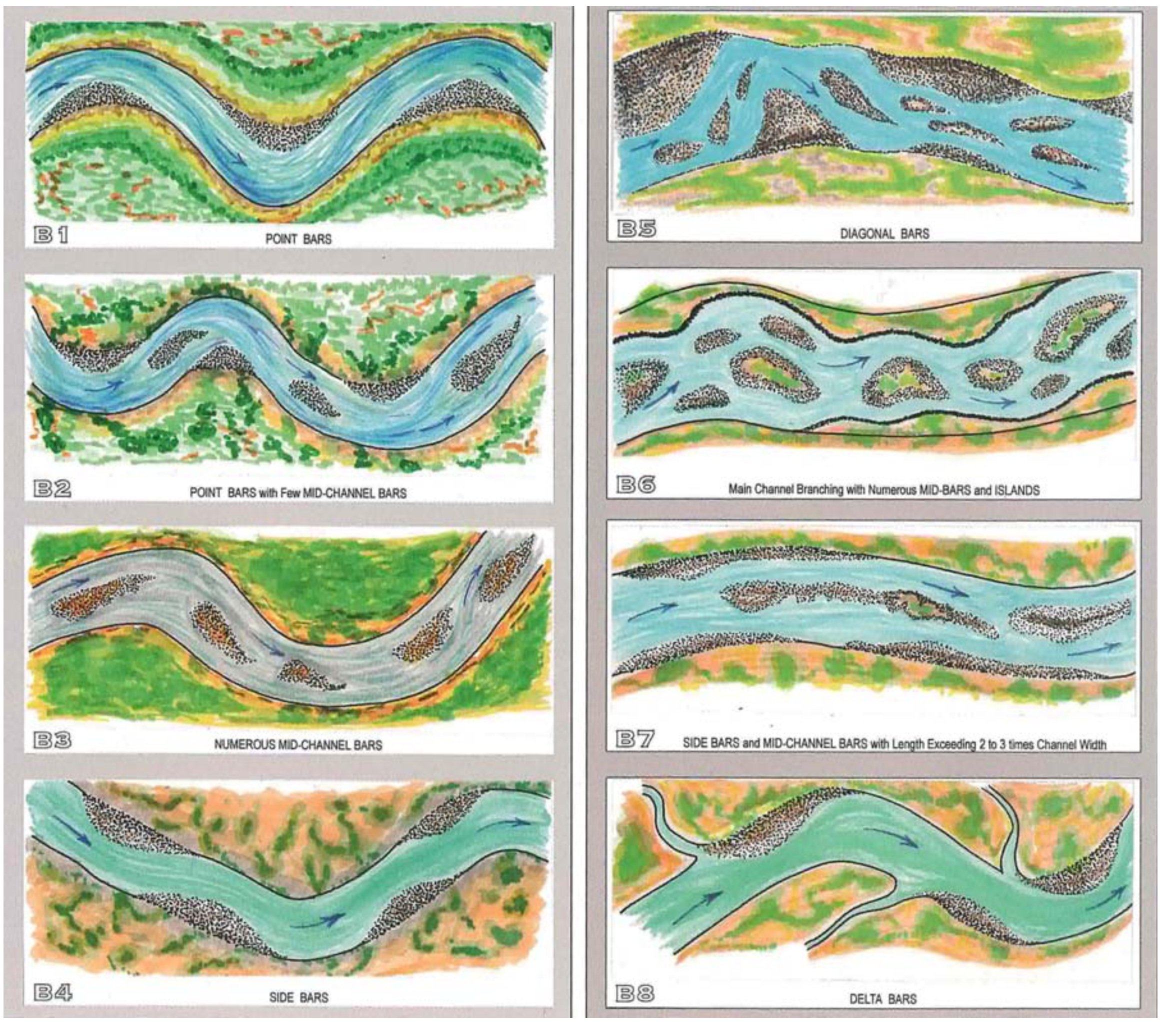


Figure 7. Example depositional areas (Rosgen 1996).

3. Overall Reach Stability

OVERALL REACH STABILITY
Stream Sensitivity: Very Low Low Moderate High Very High Extreme
Potential Sediment Supply: Very Low Low Moderate High Very High Extreme
Recovery Potential: Excellent Very Good Good Fair Poor Very Poor
Evolution Stability Sequence:
Evolution Stability Trend: Stable Degrading Aggrading Recovering
Overall Reach Stability: Stable Unstable: Localized Widespread
Potential Cause of Instability:

There are four parameters used to determine overall reach stability: 1) stream sensitivity, 2) potential sediment supply, 3) recovery potential, and 4) evolution stability trend. The first three parameters are based on Rosgen stream type and are used as support information in determining overall reach stability. Each Rosgen stream type has a set of specific characteristics that relate to stability condition. Table 2 assigns ratings to these specific characteristics based on their stability conditions and stream type (Rosgen 1996). Use Table 2 to select the appropriate ratings based on the Rosgen stream type of the Assessment Reach. The stream sensitivity, potential sediment supply, and recovery potential ratings of the Assessment Reach are useful pieces of information, along with the vertical and lateral stability ratings, that can assist in determining the overall reach stability rating.

Rosgen (1999, 2001b, 2006) has developed nine various stream type succession scenarios that illustrate phases of stability, instability, and recovery (Figure 8). Knowing the phase of stability and stream type succession of the Assessment Reach provides an understanding of current stability conditions and allows for predictions of future stability conditions. The central tendency of rivers is to seek stability. If a disturbance occurs that results in stream disequilibrium, the central tendency of the stream is to under go adjustments until the original stable form is reestablished (i.e., same Rosgen stream type). This is true even if the stream base level has changed. However, sometimes there are factors (i.e., non-erosive materials, vegetation, etc.) that will influence the direction of stream adjustments and the stream will establish a new stable form (i.e., different Rosgen stream type). Figure 9 is a graphic example that shows stream succession in a cross section and plan view form. Use Figure 8 to select the evolution stability trend that best represents the stability condition of the Assessment Reach based on the lateral and vertical stability data collected. Consider the factors influencing stream adjustment and whether the stream will reestablish its original stable form and establish a new stable form. Then record which phase the Assessment Reach is within the trend (e.g., stable, degrading, aggrading, and recovering).

Table 2. Management interpretations of various stream types (Rosgen 1996)

Stream type	Sensitivity to disturbance[a]	Recovery potential[b]	Sediment supply[c]
A1	very low	excellent	very low
A2	very low	excellent	very low
A3	very high	very poor	very high
A4	extreme	very poor	very high
A5	extreme	very poor	very high
A6	high	poor	high
B1	very low	excellent	very low
B2	very low	excellent	very low
B3	low	excellent	low
B4	moderate	excellent	moderate
B5	moderate	excellent	moderate
B6	moderate	excellent	moderate
C1	low	very good	very low
C2	low	very good	low
C3	moderate	good	moderate
C4	very high	good	high
C5	very high	fair	very high
C6	very high	good	high
D3	very high	poor	very high
D4	very high	poor	very high
D5	very high	poor	very high
D6	high	poor	high
Da4	moderate	good	very low
DA5	moderate	good	low
DA6	moderate	good	very low
E3	high	good	low
E4	very high	good	moderate
E5	very high	good	moderate
E6	very high	good	low
F1	low	fair	low
F2	low	fair	moderate
F3	moderate	poor	very high
F4	extreme	poor	very high
F5	very high	poor	very high
F6	very high	fair	high
G1	low	good	low
G2	moderate	fair	moderate
G3	very high	poor	very high
G4	extreme	very poor	very high
G5	extreme	very poor	very high
G6	very high	poor	high

a. *Includes increase in streamflow magnitude and timing and/or sediment increases.*
b. *Assumes natural recovery once cause of instability is corrected.*
c. *Includes suspended and bedload from channel derived sources and/or stream adjacent slopes.*

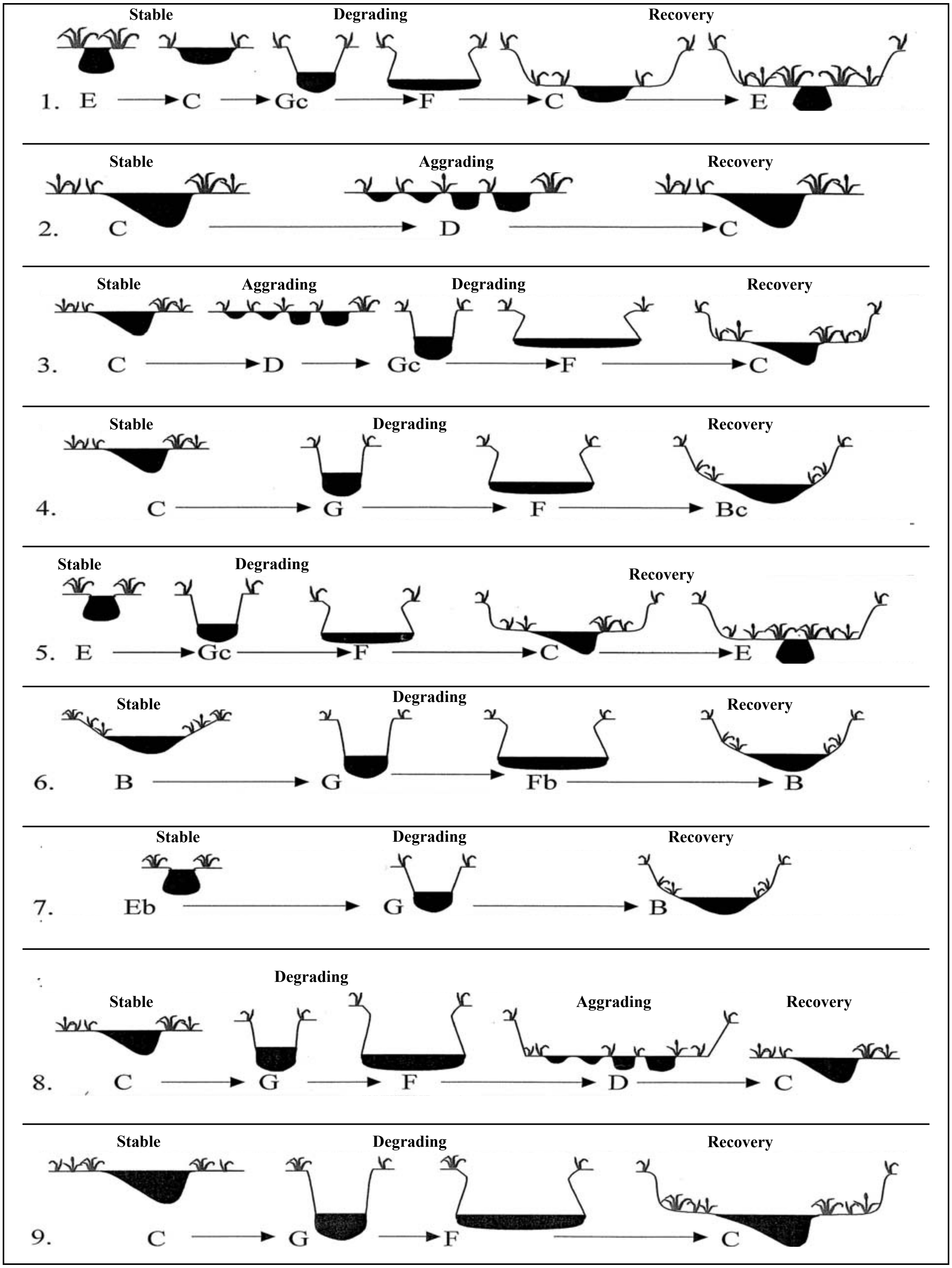


Figure 8. Various Stream Type Succession Scenarios (Rosgen 2001b)

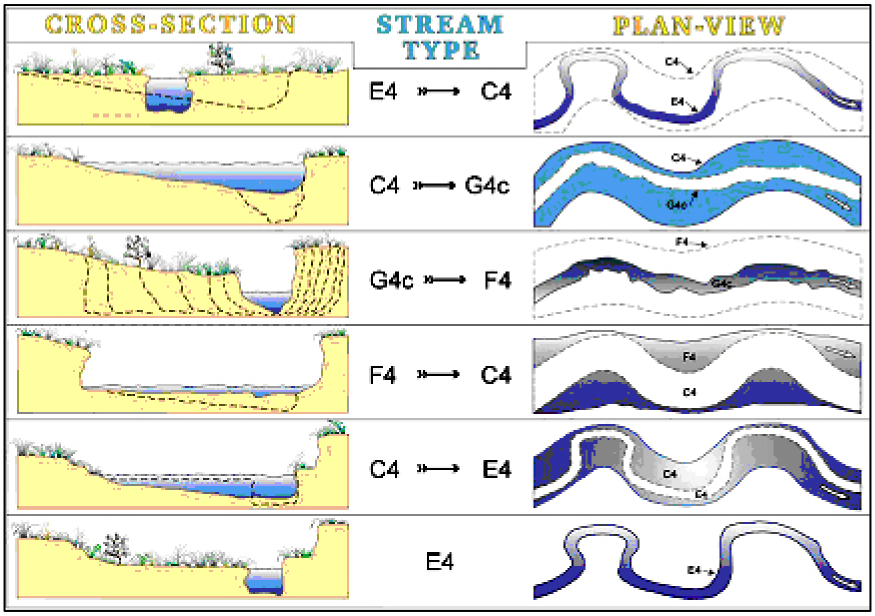


Figure 9. Examples of Stream Succession (Rosgen 1996).

Provide a narrative description of the potential cause of instability. Use the data from both the stream characterization and stability assessment forms when recording the description. The narrative should identify the potential cause of instability and clearly explain, based on fluvial geomorphic processes, how the cause has resulted in the stream instability.

The overall reach stability is determined based on the findings of the overall reach stability assessment parameters and the vertical and lateral stability assessment findings. The stream has localized instability conditions if any one of the following conditions exists:

- The overall lateral stability has a rating of localized instability;
- The evolution stability trend has a rating of recovering.

The stream has widespread instability if any one of the following conditions exists:

- The overall lateral stability has a rating of widespread instability;
- The overall vertical stability has a rating of aggrading or degrading; and
- The evolution stability trend has a rating of aggrading or degrading.

VI. DETAILED STREAM ASSESSMENT

The detailed stream assessment follows the assessment methodology developed by Rosgen (Rosgen 2006). It has main four components to characterize and assess streams: 1) bankfull determination, 2) stream characterization, 3) reference reach survey, and 4) stability condition assessment. This report will briefly describe the data collection and analyses for each of the components. Refer to *A Stream Channel Stability Assessment*

Methodology (Rosgen 2001) for description of survey and assessment procedures. Data collection and analysis forms used for each component are in Appendix A. Additionally, a checklist of the procedures and products of the detailed assessment are in Appendix B.

A. Detailed Stream Assessment Methodology

Bankfull Determination – Section V.A.2. Bankfull Determination outlines the procedures to determine bankfull. However, if a U.S. Geologic Survey (USGS) gage station is near the Assessment Reach, survey the gage to further verify the bankfull determination as part of the detailed assessment. Complete the USGS gage station form in Appendix A. Refer to McCandless et al (2002) for detailed description of survey procedures.

Stream Characterization – The stream characterization data not only describes the existing morphological character of the Assessment Reach, it is required for the departure from potential analysis conducted as part of the stability condition assessment. Therefore, conduct a characterization survey of the assessment stream reach and classify the stream using the Rosgen Stream Classification System. The survey should include channel dimensions, planform dimensions, flood prone dimensions, longitudinal profile, and channel substrates. Enter this data into Stream Channel Classification and Reference Reach Summary Data forms in Appendix A.

Reference Reach – The reference reach data is used as a basis of comparison in relation to the Assessment Reach. Therefore, collect the same data for the reference reach survey as the data collected for the stream characterization and complete the same data forms.

Stability Condition Assessment – The stability condition assessment determines the extent and magnitude of instability through a departure from potential analysis. The departure from potential analysis uses data collected as part of the stream characterization and reference reach survey as well as field measurements of vertical and lateral stability indicators. The vertical and lateral field data collected includes:

- BEHI (lateral stability)
- NBS (lateral stability)
- Pfankuch (channel stability)
- Meander patterns
- Deposition patterns
- Debris/channel blockage
- Bank erosion summary
- Sediment supply
- Stream evolution
- Incision ratio (vertical stability)
- Stream channel scour/deposition potential
- Sediment Capacity Model (PowerSed)
- Bar sampling

B. Stream Stability Condition Rating

Complete the Stability Summary form and all of the supporting stability forms (located in Appendix A) to determine the stability condition and stability rating of the assessment stream reach. The sediment supply (channel source) rating at the bottom of the Stability Summary form equates to stability condition. If the sediment supply rating is very high, then the stream stability condition is very high. Conversely, if the sediment supply rating is low, then the stream stability condition is stable.

Prepare a detailed narrative that describes the stability condition of the Assessment Reach. Base the narrative on the data collected and analyses conducted as part of the detailed stream assessment and describe the relationship of the fluvial geomorphic processes to the stability condition of the Assessment Reach. Use the departure from potential analysis to assist in relation description.

Glossary

Aggradation: The vertical accumulation of sediment on the channel bed or lateral accumulation of sediment on the stream bank.

Bank Erosion Curve: A graph that provides annual lateral erosion rates for combinations of near bank shear stresses and bank erodibility conditions.

Bank Erosion Hazard Index: A measure of bank erodibility that uses bank height, bankfull height, root depth, root density, bank angle, surface protection, bank materials, and bank stratification.

Bank Height Ratio: A measure of the vertical containment of the stream represented by the ratio of low bank height to maximum depth.

Bankfull: The discharge(s) that is responsible for maintaining the stream channel dimension, pattern, and profile.

Belt Width (Meander Width): The linear amplitude(s) between two sequential meanders, measured from outside of each meander.

Dominant Bank Erosion Hazard Index: The bank erodibility condition that is most representative of the study reach.

Dominant Near Bank Shear Stress: The near bank shear stress that is most representative of the conditions in a study reach.

Bar Deposition: An accumulation of sediment on the stream channel bed that rises above baseflow.

Deposition Pattern: A planform characterization of the deposition location and form.

Degradation: The vertical loss of sediment on the channel bed or lateral loss of sediment on the stream bank.

Drainage Density: A ratio of stream miles to drainage area that measures the concentration of the drainage network of a stream.

Entrenchment: The horizontal containment of a stream that is measured by a ratio of floodprone width to bankfull width.

Ephemeral Stream: A stream that flows only during and immediately after periods of rainfall or snow melt.

Facet Feature: The bed forms of a stream typically consisting of riffles, runs, pools, and glides.

Floodplain: The riparian area that is flooded when the stream exceeds its bankfull capacity, which is important in attenuating the erosive forces of stormflows.

Floodprone Width: The lateral distance between the two points on either side of the stream that are at an elevation twice that of bankfull.

Glide: The transition between the bottom of the pool to the top of the riffle that is represented by a rising channel bed.

Headcut: Channel erosion represented by a retreat, vertical or nearly vertical of the channel bed.

Incision: A measure of the vertical containment of the stream represented by the ratio of low bank height to maximum depth.

Inflection Point: The slope break(s) along the stream bank where the orientation of the bank transitions from a vertical to horizontal angle.

Intermittent Stream: A stream that flows a considerable portion of the time, but ceases to flow occasionally or seasonally when water demands exceed the available water supply.

Land Use/Land Cover: A description of the land activities/natural resources within a delineated area.

Lithology: A general description of the physical characteristics and properties of a rock.

Meander: A bend in the stream that is responsible for dissipating stream energy.

Meander Length: The linear distance between the meanders for an entire meander wavelength, measured from the apex of each meander.

Meander Pattern: A planform characterization of the meander location and form.

Meander Wave: A series of three meanders starting at the apex of a meander, continuing through another meander, and ending at the apex of the next meander.

Meander Wavelength: The linear distance between the apexes of an entire meander wavelength.

Meander Width Ratio: A ratio of meander width to bankfull width.

Near Bank Shear Stress: The measured or estimated shear stress associated with the third of the channel closest to the study bank.

Perennial stream: A stream that contains water at all times except during extreme drought.

Pool: The section of stream between the bottom of the run and the top of the glide that is responsible for dissipating stream energy.

Radius of Curvature: The arc length to the outside of the meander, at the departure points of meander.

Riffle: A facet feature that is steeper and shallower than a pool, and functions as a grade control feature.

Run: The transition between the bottom of the riffle to the top of the pool that is represented by a descending channel bed.

Scour: Channel degradation either along the bank or on the bed due to stormflows.

Shear Stress: The measured or estimated erosional forces associated with stream flow, measured in pounds per square feet.

Sinuosity: The measure of how much a stream meanders represented by a ratio of stream thalweg distance to straight valley distance.

Slope Break: The vertical intersection of two different slope angles along the bank profile.

Soil Association: A soil classification with distinct soil characteristics and properties that is identified by the United States Department of Agriculture – Soil Conservation Service.

Stream Succession: The evolutionary stage(s) of a stream as it attempts to reach a stable state described using the Rosgen stream classification types.

Undercut: A concave shaped scour along the stream bank, resulting from bank erosion.

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APPENDIX A
STANDARD ASSESSMENT FORMS

A-1 RAPID STREAM ASSESSMENT FORMS

RAPID STREAM CHARACTERIZATION
Anne Arundel County, Maryland

Watershed: ____ Stream: ________________________________

Date:____ Crew: __________________________________

Drainage Area: _____________________________________

Page __1__ of __2__

WATERSHED CHARACTERIZATION

Land use/Land cover Data (from County, MBSS data, GIS Hydro, Other):

% Urban:________ % Suburb:________ % Agr.:_______ % Forest:________ % Imp.:_______

Valley Type or Description:

Adjacent LU/LC:

Significant Upstream Land Cover and/or Land uses that influence stream character and stability:

BANKFULL VALIDATION

Regional Curve: Rural Coastal Plain Curve Urban Coastal Plain Curve

BF Cross Sectional Area ________________ BF Depth ________________

BF Width ________________ BF Discharge ________________

STREAM CHARACTERIZATION AND CLASSIFICATION

Channel: Single Thread Braided	Entrenchment	________________
BF Width ________________	Reach D50	________________
BF Depth ________________	Riffle D84	________________
WS Slope ________________	Sinuosity	________________
BF Discharge ________________	Width/Depth Ratio	________________

Dominant BF Feature:

Rosgen Stream Type:

Cross Section Sketch:

RAPID STREAM STABLITY ASSESSMENT
Anne Arundel County, Maryland

Watershed: ________________________________
Stream: ______________________________
Date:____________________________________
Crew: _______________________________
Rosgen Stream Type: ______________________
Page ____2____ of ____2____

LATERAL STABILITY

Width/Depth Ratio: ________________ Rating: Stable Unstable

Dominant BEHI: Score: _________ Rating: Very Low Low Moderate High Very High Extreme

Dominant NBS: Low Moderate High Extreme

Presence of bank armoring: Yes No Description:

Presence of specific lateral erosion causes: Yes No Description:

Overall Lateral Stability: Stable Unstable: Localized Widespread

VERTICAL STABILITY

Incision Ratio: __________________ Rating: Not Incised Slightly Moderately Highly Extremely

Presence of headcut: Yes No Description:

Presence of bedcontrol: Yes No Description:

Presence of deposition: Yes No Description of Deposition Feature:

Bed Feature Type: Riffle/Pool Riffle/Run Run/Pool Plane Step/Pool Cascade

Bed Definition: Well Defined Moderately Well Defined Poorly Defined

Overal Veritcal Stability: Stable Degrading Aggrading

OVERALL REACH STABILITY

Stream Sensitivity: Very Low Low Moderate High Very High Extreme
Potential Sediment Supply: Very Low Low Moderate High Very High Extreme
Recovery Potential Very Low Low Moderate High Very High Extreme
Evolution Stability Sequence:
Evolution Stability Trend: Stable Degrading Aggrading Recovering

Overall Reach Stability: Stable Unstable: Localized Widespread

Potential Cause of Instability:

General Notes:

ROSGEN - REACH BEHI AND NBS FIELD FORM

Stream:	**Bank Label:**	**Comments:**
Reach:	**BEHI Rating:**	
Observer (s):	**NBS Estimate Rating:**	
Survey Date:		

Erodibility Variable			**Index**
Bank Height (ft) A	Bankfull Height (ft) B	A/B	
Root Depth/Bank Height			
Root Depth (ft) C	C/A		
Weighted Root Density			
Root Density (%) D	D*(C/A)		
Bank Angle			
Bank Angle (degrees)			
Surface Protection			
Surface Protection (%)			
Materials: Upper-sandy loam. Lower-gravel with sand matrix			
Stratification: Boundary between sandy loam and gravel			
TOTAL SCORE:			

Bank Sketch and Near Bank Shear Stress cross section sketch

Bank Erosion Hazard Index

Erodibility Variable		Bank Erosion Potential: Very Low	Low	Moderate	High	Very High	Extreme
Bank Height/ Bankfull Height	Value	1.0 - 1.1	1.11 - 1.19	1.2 - 1.59	1.6 - 2.09	2.1 - 2.8	>2.8
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Root Depth/ Bank Height	Value	1.0 - 0.9	0.89 - 0.5	0.49 - 0.3	0.29 - 0.15	0.14 - 0.05	<0.05
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Weighted Root Density	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 5.0	<5.0
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Bank Angle	Value	0 - 20	21 - 60	61 - 80	81 - 90	91 - 119	>119
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Surface Protection	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 10	<10
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10

Bank Materials

Bedrock (Bedrock banks have very low bank erosion potential)
Boulders (Banks composed of boulders have low bank erosion potential)
Cobble (Subtract 10 points. If sand/gravel matrix > 50% of bank material, then do not adjust)
Clay/Silt Loam (Add 5 points)
Gravel (Add 5-10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points if sand is exposed to erosional processes)
Silt/Clay (+ 0: no adjustment)

Stratification

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

Total Score

Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
5-10	10-20	20-30	30-40	40-45	45-50

A-2 DETAILED STREAM ASSESSMENT FORMS

- **USGS GAGE STATION FORM**
- **STREAM CHANNEL CLASSIFICATION AND REFERENCE FORMS**
- **STABILITY CONDITION ASSESSMENT FORMS**

USGS GAGE STATION FORM

Worksheet 2-1. Sample form to record gage station and field data from *The Reference Reach Field Book* (Rosgen and Silvey, 2007).

Summary....*USGS GAGE STATION* Data/Records for
STREAM CHANNEL CLASSIFICATION

Station NAME:				Station Number:	
LOCATION:					
Period of RECORD:		yrs		Mean Annual DISCHARGE:	cfs
Drainage AREA:	acres		mi^2	Drainage Area Mn ELEV:	ft
Reference REACH SLOPE:		ft/ft		Valley Type:	
Stream Type:				HUC:	__ __ __ __ __ __ __ __ __ __ __ __

"BANKFULL" CHARACTERISTICS

Determined from FIELD MEASUREMENT			Determined from GAGE DATA Analysis		
Bankfull WIDTH (W_{bkf})		ft	Bankfull WIDTH (W_{bkf})		ft
Bankfull Mean DEPTH (d_{bkf})		ft	Bankfull MEAN DEPTH (d_{bkf})		ft
Bankfull Xsec AREA (A_{bkf})		ft^2	Bankfull Xsec AREA (A_{bkf})		ft^2
Wetted PERIMETER (W_p)		ft	Wetted PERIMETER (W_p)		ft
Bankfull STAGE (Gage Ht)		ft	Bankfull STAGE (Gage Ht)		ft
Est. Mean VELOCITY (u)		ft/sec	Mean VELOCITY (u)		ft/sec
Est. Bkf. DISCHARGE (Q_{bkf})		cfs	Bankfull DISCHARGE (Q_{bkf})		cfs

Bankfull DISCHARGE associated with **"field-determined"** Bankfull STAGE (From Gage Height reading at Staff Plate and tabular Stage-Discharge curve data)		cfs
Recurrence Interval (Log-Pearson) associated with **"field-determined"** Bankfull Discharge		yrs

From the *Annual Peak Flow Frequency Analysis* data for the Gage Station, determine:

1.5 Year **R.I.** Discharge......... =		cfs	**10** Year **R.I.** Discharge......... =		cfs
2.0 Year **R.I.** Discharge..........=		cfs	**25** Year **R.I.** Discharge.........=		cfs
5.0 Year **R.I.** Discharge..........=		cfs	**50** Year **R.I.** Discharge......... =		cfs

MEANDER GEOMETRY

Meander Length (L_m)		ft	Radius of Curvature (R_C)		ft
Belt Width (W_{blt})		ft	Meander Width Ratio (W_{blt}/W_{bkf})		ft/ft

HYDRAULIC GEOMETRY

Based on *USGS Discharge Summary Notes* data (Form 9-207) and regression analyses of measured discharge (**Q**) with the hydraulic parameters of Width (**W**), Area (**A**), Mean Depth (**d**) & Mean Velocity (**u**), determine the *intercept coefficient* (**a**) and the *slope exponent* (**b**) values for a power function of the form **Y = aX^b**, when **Y** is one of the selected hydraulic parameters and **X** is a given discharge value (**Q**).

	Width (**W**)	Depth (**d**)	Area (**A**)	Velocity (**u**)
Intercept Coefficient: (**a**)				
Slope Exponent: (**b**)				

Hydraulic Radius: R = A / W_p		ft	**Manning's "n"** at Bankfull Stage		Coeff.

$$"n" = 1.4865\ [(\text{Area})\ (\text{Hydraulic Radius}^{2/3})\ (\text{Slope}^{1/2})]\ /\ Q_{bkf}$$

Worksheet 4-7. Procedure to validate hydraulic relations.

Validation of Hydraulic Relationships Using Gaging Station Data

1. Obtain the drainage area associated with the gaging station.
2. Obtain the field-determined bankfull discharge at the gaging station(s) (**Figure 2-3**).
3. Obtain the bankfull channel dimensions from the gaging station hydraulic geometry relationships (discharge vs. width, depth, area and velocity)
4. Measure the average water surface slope.
5. Perform an active bed pebble count on the riffle to obtain D_{84}.
6. Determine the stream type.
7. Solve for Manning's "n" at the bankfull stage: $n = (1.49R^{2/3}S^{1/2})/u$ (use the bankfull mean velocity from Step 3).
   Calculate relative roughness: R/D_{84}. Make sure that D_{84} is converted from millimeters to feet. Hydraulic radius (R) and mean depth (d_{bkf}) are
8. often used interchangeably when width/depth ratios are greater than 12.
9. Calculate shear velocity: $u^* = (gRS)^{1/2}$.
10. Calculate friction factor: u/u*.
11. Plot bankfull discharge as a function of drainage area on the appropriate regional curve.
12. Plot bankfull channel dimensions as a function of drainage area on the appropriate regional curve (note stream type of plotted values using unique symbols).
13. Plot relative roughness by friction factor (**Figure 2-18**) (Example in **Figure 4-10**).
14. Plot Manning's "n" by friction factor (**Figure 2-19**) (Example in **Figure 4-11**).
15. Plot Manning's "n" by stream type (**Figure 2-20**) (Example in **Figure 4-12**).

Gage Station Name: **Gage Station #:**

1	2	3a	3b	3c	3d	4	5	6	7	8	9	10	11
Drainage Area	Bankfull Discharge	Bankfull Width	Bankfull Mean Depth	Bankfull Area	Bankfull Velocity	Ave. Water Surface Slope	D_{84}		Stream Type	Manning's "n"	Relative Roughness	Shear Velocity	Friction Factor
(mi^2)	Q_{bkf} (cfs)	W_{bkf}	d_{bkf} (ft)	A_{bkf} (ft^2)	u_{bkf} (ft/s)	S (ft/ft)	(mm)	(ft)			R/D_{84} (ft/ft)	u* (ft/s)	u/u*

STREAM CHANNEL CLASSIFICATION AND REFERENCE FORMS

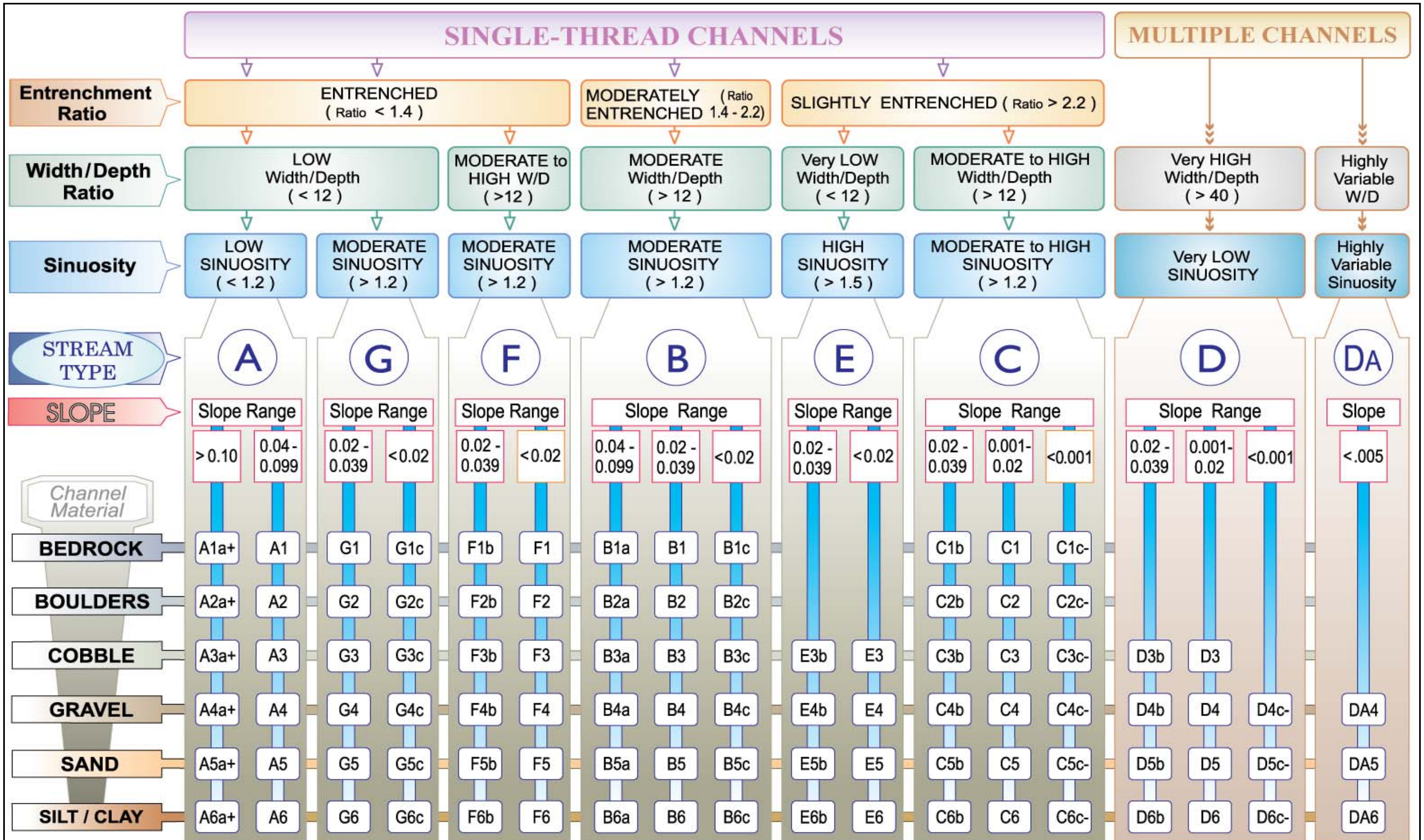
Worksheet 2-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen , 2006b).

Stream:		
Basin:	Drainage Area: acres	mi^2
Location:		
Twp.&Rge:	Sec.&Qtr.:	
Cross-Section Monuments (Lat./Long.):		Date:
Observers:		Valley Type:

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.		ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).		ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.		ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.		ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.		ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.		ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).		ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.		mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.		ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).		

Stream Type → [ ] ← **See Classification Key (Figure 2-21)**

Figure 2-21. Stream classification key for natural rivers.



KEY to the ***ROSGEN*** CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units, while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

Worksheet 2-4. Morphological relations, including dimensionless ratios of river reach sites (Rosgen, 2006b; Rosgen and Silvey 2007).

Stream:		Location:	
Observers:	Date:	Valley Type:	Stream Type:

River Reach Summary Data

Channel Dimension

Mean Riffle Depth (d_{bkf})		ft	Riffle Width (W_{bkf})		ft	Riffle Area (A_{bkf})		ft^2
Mean Pool Depth (d_{bkfp})		ft	Pool Width (W_{bkfp})		ft	Pool Area (A_{bkfp})		ft^2
Mean Pool Depth/Mean Riffle Depth		d_{bkfp}/d_{bkf}	Pool Width/Riffle Width		W_{bkfp}/W_{bkf}	Pool Area / Riffle Area		A_{bkfp}/A_{bkf}
Max Riffle Depth (d_{maxrif})		ft	Max Pool Depth (d_{maxp})		ft	Max Riffle Depth/Mean Riffle Depth		
Max Pool Depth/Mean Riffle Depth			Point Bar Slope		ft/ft	Inner Berm Width (W_{ib})		ft
Inner Berm Depth (d_{ib})		ft	Inner Berm Width/Depth Ratio		W_{ib}/d_{ib}	Inner Berm Area (A_{ib})		ft^2
Streamflow: Estimated Mean Velocity at Bankfull Stage (u_{bkf})					ft/s	Estimation Method		
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})					cfs	Drainage Area		mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Meander Wavelength (L_m)				ft	Meander Length Ratio (L_m/W_{bkf})			
Radius of Curvature (R_c)				ft	Radius of Curvature/Riffle Width (R_c/W_{bkf})			
Belt Width (W_{blt})				ft	Meander Width Ratio (W_{blt}/W_{bkf})			
Individual Pool Length				ft	Pool Length/Riffle Width			
Pool to Pool Spacing				ft	Pool to Pool Spacing/Riffle Width			
Riffle Length				ft	Riffle Length/Riffle Width			

Channel Profile

Valley Slope (VS)		ft/ft	Average Water Surface Slope (S)		ft/ft	Sinuosity (VS/S)	
Stream Length (SL)		ft	Valley Length (VL)		ft	Sinuosity (SL/VL)	

Low Bank Height (LBH)	start	ft	Max Riffle Depth	start	ft	Bank-Height Ratio (BHR) (LBH/Max Riffle Depth)	start	
	end	ft		end	ft		end	

Facet Slopes	Mean	Min	Max		Dimensionless Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})				ft/ft	Riffle Slope/Average Water Surface Slope (S_{rif} / S)			
Run Slope (S_{run})				ft/ft	Run Slope/Average Water Surface Slope (S_{run} / S)			
Pool Slope (S_p)				ft/ft	Pool Slope/Average Water Surface Slope (S_p / S)			
Glide Slope (S_g)				ft/ft	Glide Slope/Average Water Surface Slope (S_g / S)			

Feature Midpoint [a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})				ft	Max Riffle Depth/Mean Riffle Depth (d_{maxrif} / d_{bkf})			
Max Run Depth (d_{maxrun})				ft	Max Run Depth/Mean Riffle Depth (d_{maxrun} / d_{bkf})			
Max Pool Depth (d_{maxp})				ft	Max Pool Depth/Mean Riffle Depth (d_{maxp} / d_{bkf})			
Max Glide Depth (d_{maxg})				ft	Max Glide Depth/Mean Riffle Depth (d_{maxg} / d_{bkf})			

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay				D_{16}					mm
% Sand				D_{35}					mm
% Gravel				D_{50}					mm
% Cobble				D_{84}					mm
% Boulder				D_{95}					mm
% Bedrock				D_{100}					mm

[a] Min, max, mean depths are ave. mid-point values except pools: taken at deepest part of pool.
[b] Composite sample of riffles and pools within the designated reach.
[c] Active bed of a riffle.
[d] Height of roughness feature above bed.

STABILITY CONDITION ASSESSMENT FORMS

Worksheet 3-22. Summary of stability condition categories.

Stream:				Location:				
Observers:			Date:	Stream Type:		Valley Type:		
Channel Dimension	Mean bankfull depth (ft):	Mean bankfull width (ft):	Cross-section area (ft^2):	Width of flood-prone area (ft):	Entrenchment ratio:			
Channel Pattern	Mean: Range:	MWR:	Lm/W_{bkf}:	Rc/W_{bkf}:	Sinuosity:			
River Profile and Bed Features	Check: ☐ Riffle/pool	☐ Step/pool	☐ Plane bed	☐ Convergence/divergence	☐ Dunes/antidunes/smooth bed			
	Max bankfull depth (ft): Riffle	Pool	Depth ratio (max/mean): Riffle	Pool	Pool to pool spacing:	Ratio	Slope: Valley:	Average bankfull:
Level III Stream Stability Indices	Riparian vegetation	Current composition/density:	Potential composition/density:	Remarks: Condition, vigor and/or usage of existing reach:				
	Flow regime:	Stream size and order:	Meander pattern(s):	Depositional pattern(s):	Debris/channel blockage(s):			
	Degree of incision (Bank-Height Ratio):	Degree of incision stability rating:	Modified Pfankuch stability rating (numeric and adjective rating):					
	Width/depth ratio (W/d):	Reference W/d ratio (W/d_{ref}):	Width/depth ratio state $(W/d) / (W/d_{ref})$:	W/d ratio state stability rating:				
	Meander Width Ratio (MWR):	Reference MWR_{ref}:	Degree of confinement (MWR / MWR_{ref}):	MWR / MWR_{ref} stability rating:				
Bank Erosion Summary	Length of reach studied (ft):	Annual streambank erosion rate: (tons/yr)	(tons/yr/ft)	Curve used:	Remarks:			
Sediment Capacity (POWERSED)	☐ Sufficient capacity	☐ Insufficient capacity	☐ Excess capacity	Remarks:				
Entrainment/ Competence	Largest particle from bar sample (mm):	$\tau =$	$\tau^* =$	Existing $depth_{bkf}$:	Required $depth_{bkf}$:	Existing $slope_{bkf}$:	Required $slope_{bkf}$:	
Successional Stage Shift	→ → → → →			Existing stream state (type):	Potential stream state (type):			
Lateral Stability	☐ Stable	☐ Mod. unstable	☐ Unstable	☐ Highly unstable	Remarks/causes:			
Vertical Stability (Aggradation)	☐ No deposition	☐ Mod. deposition	☐ Ex. deposition	☐ Aggradation	Remarks/causes:			
Vertical Stability (Degradation)	☐ Not incised	☐ Slightly incised	☐ Mod. incised	☐ Degradation	Remarks/causes:			
Channel Enlargement	☐ No increase	☐ Slight increase	☐ Mod. increase	☐ Extensive	Remarks/causes:			
Sediment Supply (Channel Source)	☐ Low	☐ Moderate	☐ High	☐ Very high	Remarks/causes:			

Worksheet 2-2. Computations of velocity and bankfull discharge using various methods (Rosgen, 2006b; Rosgen and Silvey, 2007).

Bankfull VELOCITY / DISCHARGE Estimates

Site		Location	
Date	Stream Type	Valley Type	
Observers		HUC	__ __ __ __ __ __ __ __ __ __ __ __

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional AREA		A_{bkf} (ft^2)	Bankfull Mean DEPTH		D_{bkf} (ft)
Bankfull WIDTH		W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$		W_p (ft)
D_{84} @ Riffle		Dia. (mm)	D_{84} mm / 304.8 =		D_{84} (ft)
Bankfull SLOPE		S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p		R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)		
Drainage AREA		DA (mi^2)	Shear Velocity $u^* = \sqrt{gRS}$		u* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 \text{Log}\{R / D_{84}\}] u^*$		ft / sec		cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness (Figs. 2-18, 19) $u = 1.4865 * R^{2/3} * S^{1/2} / n$ n =		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39 S^{.38} R^{-.16}$ n = Note: This equation is for applications involving **steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ c) Manning's 'n' from Stream Type n =		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = Yr.		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A		ft / sec		cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1. For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in est. method 1.

Option 2. For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in est. method 1.

Option 3. For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/ uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

Figure 2-20. Manning's "n" by stream type.

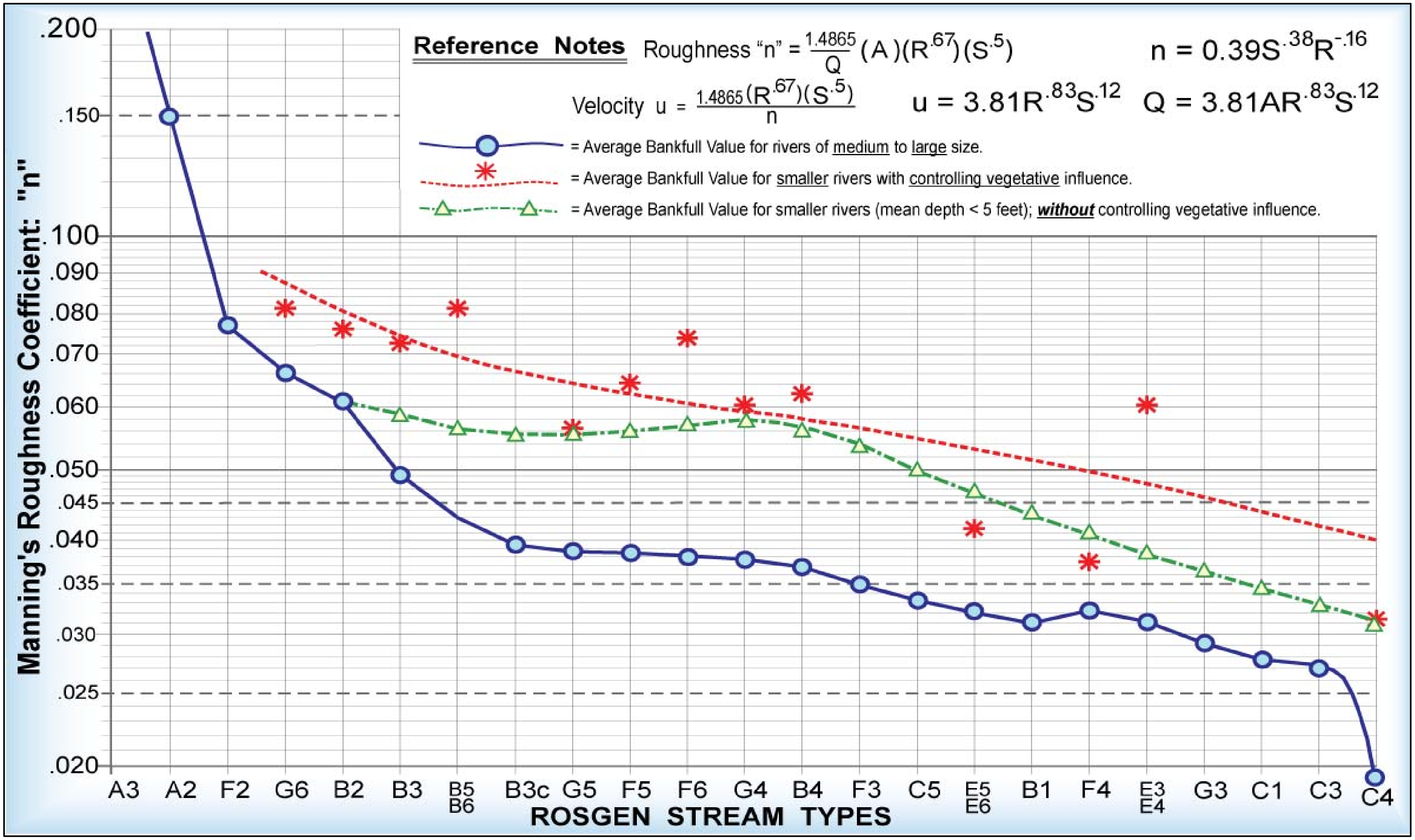
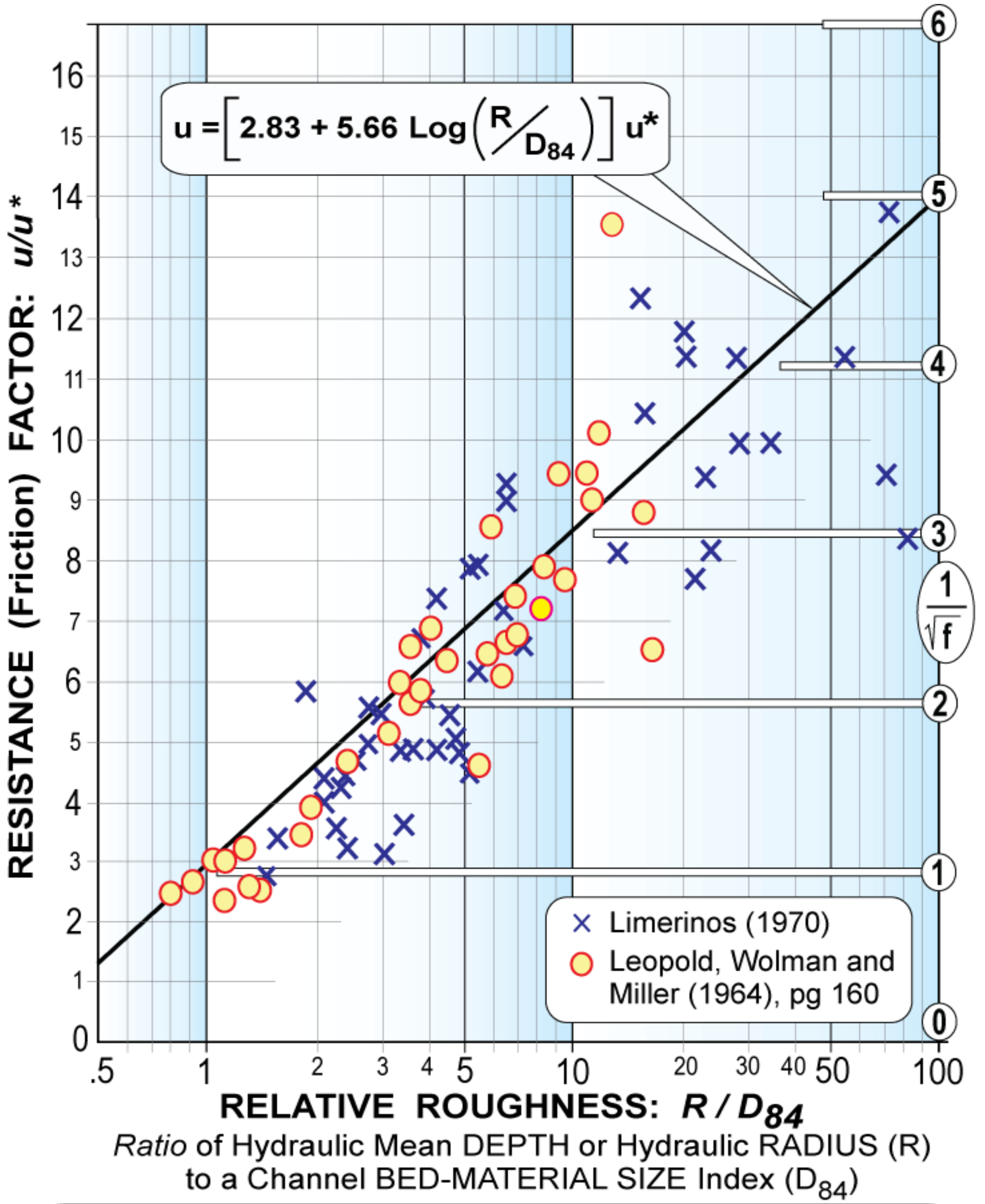


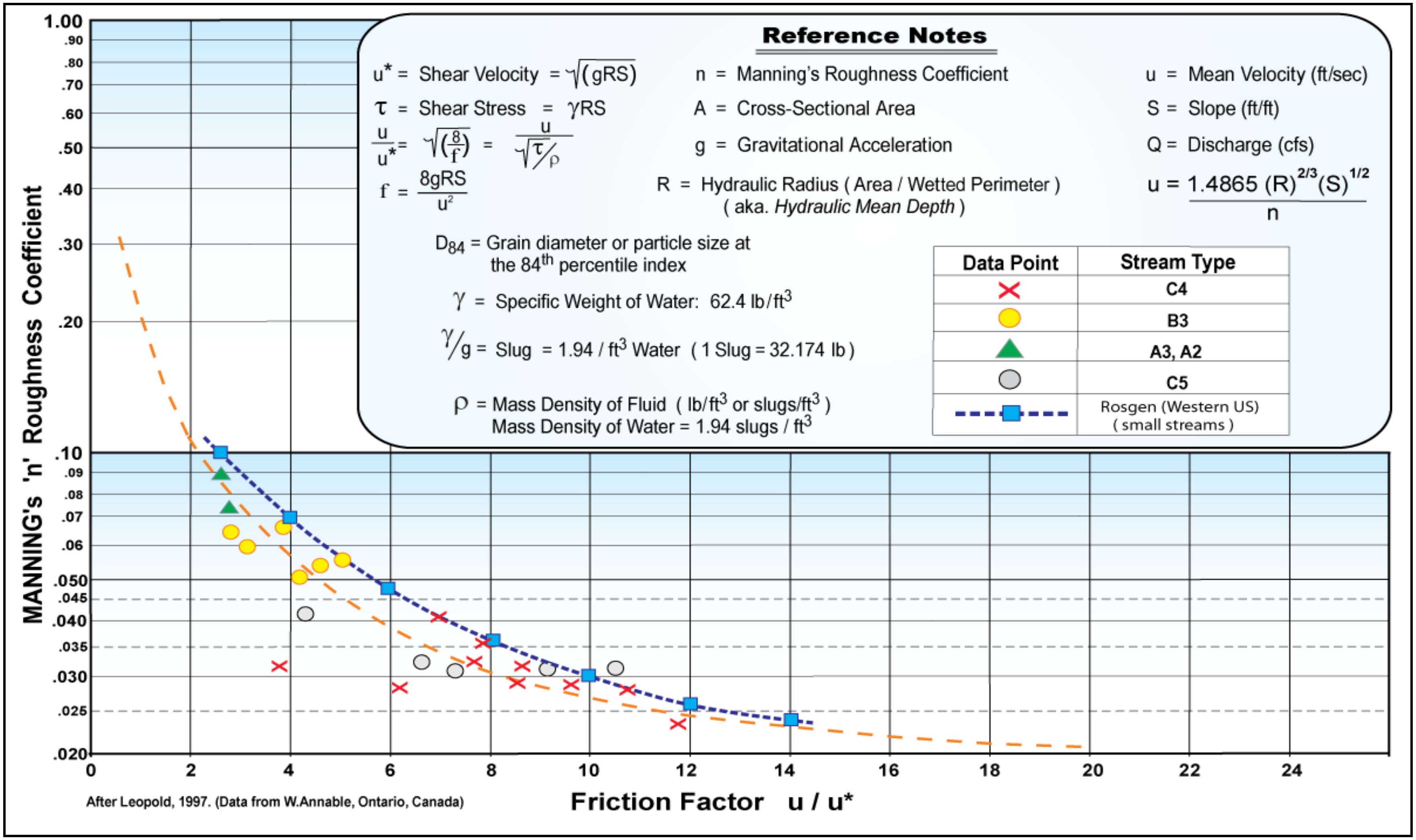
Figure 2-18. Relative roughness (R/D_{84}) vs. friction factor (u/u^*).



The relation of channel *bed-particle size* to *hydraulic resistance*, developed with river data collected from a variety of Eastern and Western streams.

Resistance factors, **u/u^*** and **$1/\sqrt{f}$**, are shown as a function of **Relative Roughness**; i.e., a *Ratio* of Hydraulic Mean Depth (**d**), or Hydraulic Radius (**R**), to a bed-material size index (**D_{84}**), as taken from field measurements (Leopold, Wolman and Miller, 1964).

Figure 2-19. Friction factor (u/u*) vs. Manning's roughness coefficient "n".



A20

Worksheet 3-1. Riparian vegetation composition/density used for channel stability assessment.

Riparian Vegetation

Stream:			Location:	
Observers:	Reference reach ☐	Disturbed (impacted reach) ☐		Date:
Existing species composition:			Potential species composition:	

	Riparian cover categories	Percent aerial cover*	Percent of site coverage**	Species composition	Percent of total species composition
1. Overstory	Canopy layer				
					100%
2. Understory	Shrub layer				
					100%
3. Ground level	Herbaceous				
					100%
	Leaf or needle litter			**Remarks:** Condition, vigor and/or usage of existing reach:	
	Bare ground				
			Column total = 100%		

*Based on crown closure.
**Based on basal area to surface area.

Worksheet 3-2. Flow regime variables that influence channel characteristics, sediment regime and biological interpretations.

FLOW REGIME

Stream:	Location:							
Observers:							Date:	
List ALL COMBINATIONS that APPLY..............☞								

General Category

E	Ephemeral stream channels: Flows only in response to precipitation
S	Subterranean stream channel: Flows parallel to and near the surface for various seasons - a sub-surface flow that follows the stream bed.
I	Intermittent stream channel: Surface water flows discontinuously along its length. Often associated with sporadic and/or seasonal flows and also with Karst (limestone) geology where losing/gaining reaches create flows that disappear then reappear farther downstream.
P	Perennial stream channels: Surface water persists yearlong.

Specific Category

1	Seasonal variation in streamflow dominated primarily by snowmelt runoff.
2	Seasonal variation in streamflow dominated primarily by stormflow runoff.
3	Uniform stage and associated streamflow due to spring-fed condition, backwater, etc.
4	Streamflow regulated by glacial melt.
5	Ice flows/ice torrents from ice dam breaches.
6	Alternating flow/backwater due to tidal influence.
7	Regulated streamflow due to diversions, dam release, dewatering, etc.
8	Altered due to development, such as urban streams, cut-over watersheds or vegetation conversions (forested to grassland) that change flow response to precipitation events.
9	Rain-on-snow generated runoff.

Worksheet 3-3. Stream order and stream size categories for stratification by stream type.

Stream Size and Order

Stream:

Location:

Observers:

Date:

Stream Size Category and Order ☞

Category	STREAM SIZE: Bankfull width		Check (✓) appropriate category
	meters	feet	
S-1	0.305	<1	☐
S-2	0.3 – 1.5	1 – 5	☐
S-3	1.5 – 4.6	5 – 15	☐
S-4	4.6 – 9	15 – 30	☐
S-5	9 – 15	30 – 50	☐
S-6	15 – 22.8	50 – 75	☐
S-7	22.8 – 30.5	75 – 100	☐
S-8	30.5 – 46	100 – 150	☐
S-9	46 – 76	150 – 250	☐
S-10	76 – 107	250 – 350	☐
S-11	107 – 150	350 – 500	☐
S-12	150 – 305	500 – 1000	☐
S-13	>305	>1000	☐

Stream Order

Add categories in parenthesis for specific stream order of reach. For example a third order stream with a bankfull width of 6.1 meters (20 feet) would be indexed as: S-4(3).

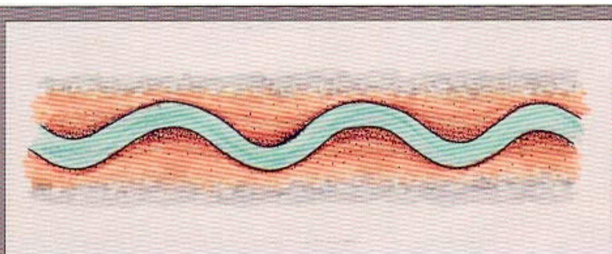
Worksheet 3-4. Meander pattern relations used for interpretations for river stability.

Meander Patterns

Stream:	Reach:
Observers:	Date:

List ALL CATEGORIES that APPLY ☞					

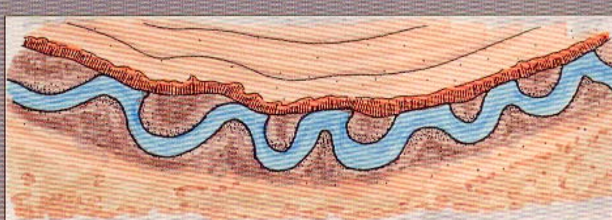
Various Meander Pattern variables modified from Galay et al. (1973)



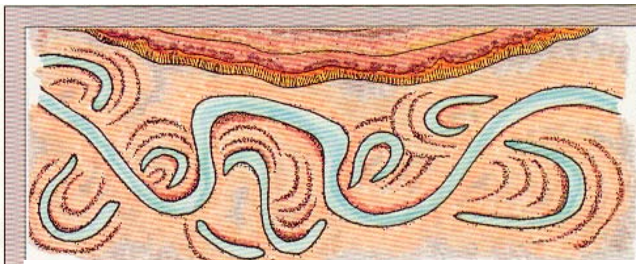
M1 REGULAR MEANDERS

M2 TORTUOUS MEANDERS

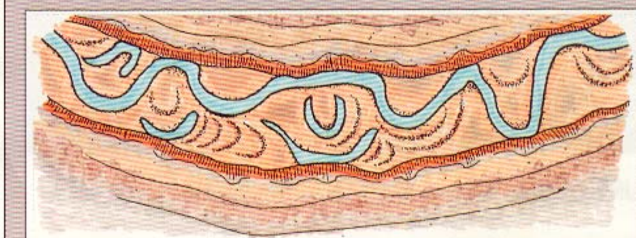
M3 IRREGULAR MEANDERS



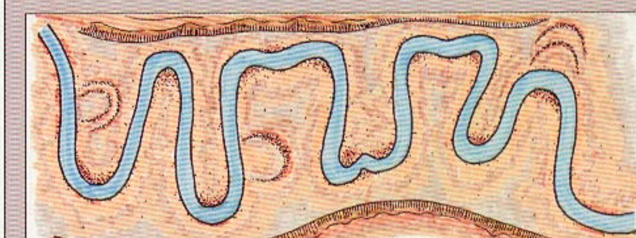
M4 TRUNCATED MEANDERS



M5 UNCONFINED MEANDER SCROLLS



M6 CONFINED MEANDER SCROLLS



M7 DISTORTED MEANDER LOOPS

M8 IRREGULAR MEANDERS with oxbows and oxbow cutoffs

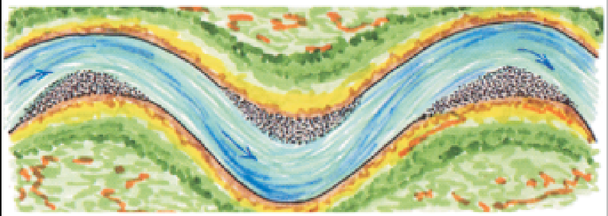
Worksheet 3-5. Depositional patterns used for stabiilty assessment interpretations.

Depositional Patterns

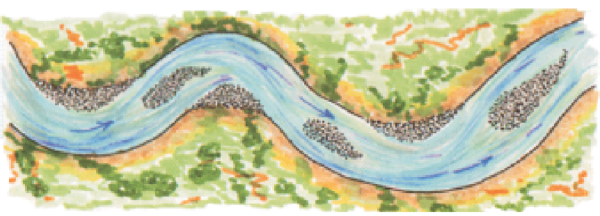
Stream:	Reach:
Observers:	Date:

List ALL CATEGORIES that APPLY ☞					

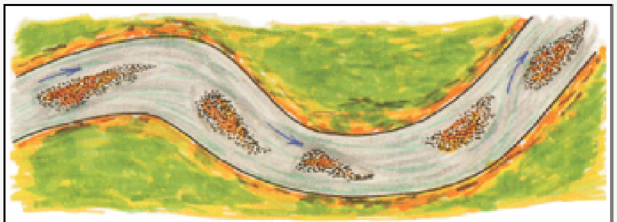
Various Depositional Features modified from Galay et al. (1973)



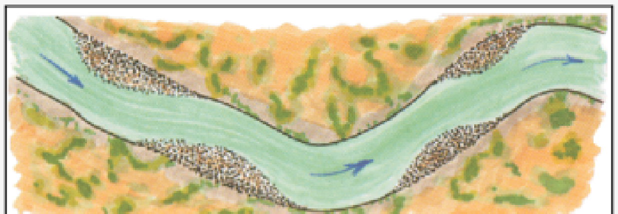
B1 POINT BARS



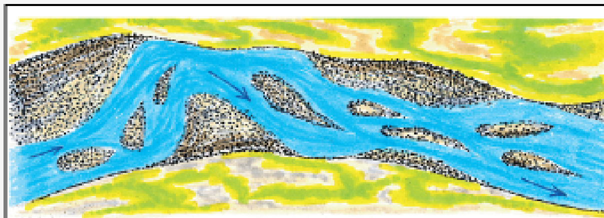
B2 POINT BARS with Few MID-CHANNEL BARS



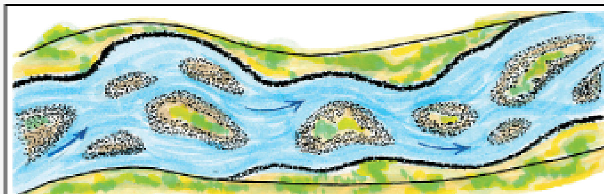
B3 NUMEROUS MID-CHANNEL BARS



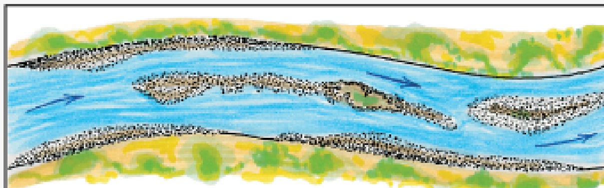
B4 SIDE BARS



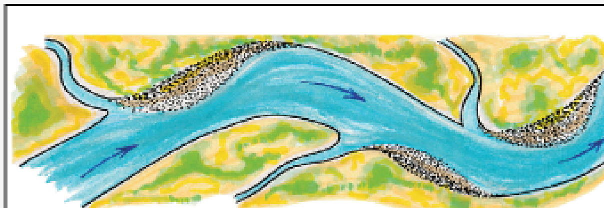
B5 DIAGONAL BARS



B6 Main Channel Branching with Numerous MID-CHANNEL BARS and Islands



B7 SIDE BARS AND MID-CHANNEL BARS with Length Exceeding 2 to 3 Channel Widths



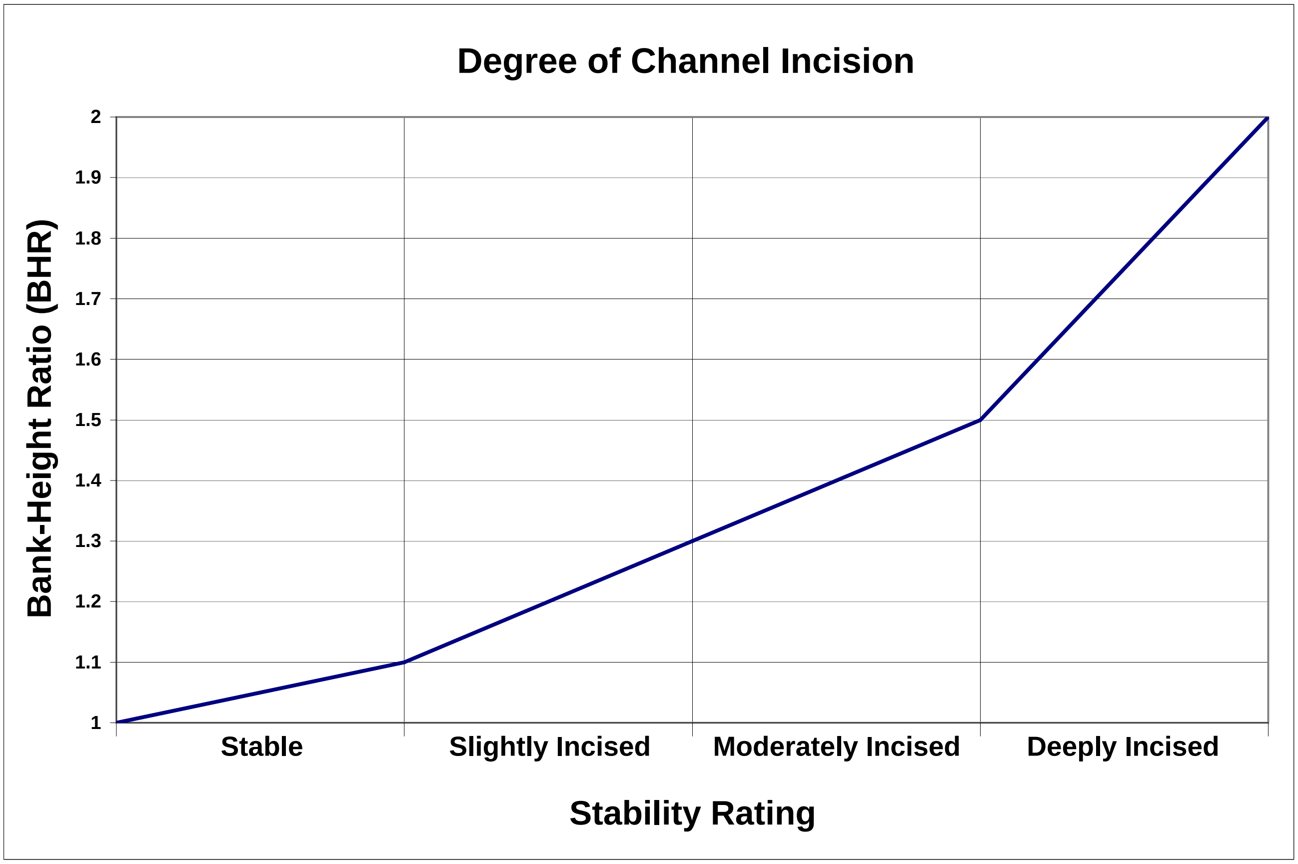
B8 DELTA BARS

Worksheet 3-6. Various categories of in-channel debris, dams and channel blockages used to evaluate channel stability.

Channel Blockages			
Stream:		Location:	
Observers:		Date:	
Description/extent		**Materials that upon placement into the active channel or flood-prone area may cause adjustments in channel dimensions or conditions due to influences on the existing flow regime.**	**Check (✓) all that apply**
D1	None	Minor amounts of small, floatable material.	☐
D2	Infrequent	Debris consists of small, easily moved, floatable material, e.g., leaves, needles, small limbs and twigs.	☐
D3	Moderate	Increasing frequency of small- to medium-sized material, such as large limbs, branches and small logs, that when accumulated, affect 10% or less of the active channel cross-section area.	☐
D4	Numerous	Significant build-up of medium- to large-sized materials, e.g., large limbs, branches, small logs or portions of trees that may occupy 10–30% of the active channel cross-section area.	☐
D5	Extensive	Debris "dams" of predominantly larger materials, e.g., branches, logs and trees, occupying 30–50% of the active channel cross-section area, often extending across the width of the active channel.	☐
D6	Dominating	Large, somewhat continuous debris "dams," extensive in nature and occupying over 50% of the active channel cross-section area. Such accumulations may divert water into the flood-prone areas and form fish migration barriers, even when flows are at less than bankfull.	☐
D7	Beaver dams: Few	An infrequent number of dams spaced such that normal streamflow and expected channel conditions exist in the reaches between dams.	☐
D8	Beaver dams: Frequent	Frequency of dams is such that backwater conditions exist for channel reaches between structures where streamflow velocities are reduced and channel dimensions or conditions are influenced.	☐
D9	Beaver dams: Abandoned	Numerous abandoned dams, many of which have filled with sediment and/or breached, initiating a series of channel adjustments, such as bank erosion, lateral migration, avulsion, aggradation and degradation.	☐
D10	Human influences	Structures, facilities or materials related to land uses or development located within the flood-prone area, such as diversions or low-head dams, controlled by-pass channels, velocity control structures and various transportation encroachments that have an influence on the existing flow regime, such that significant channel adjustments occur.	☐

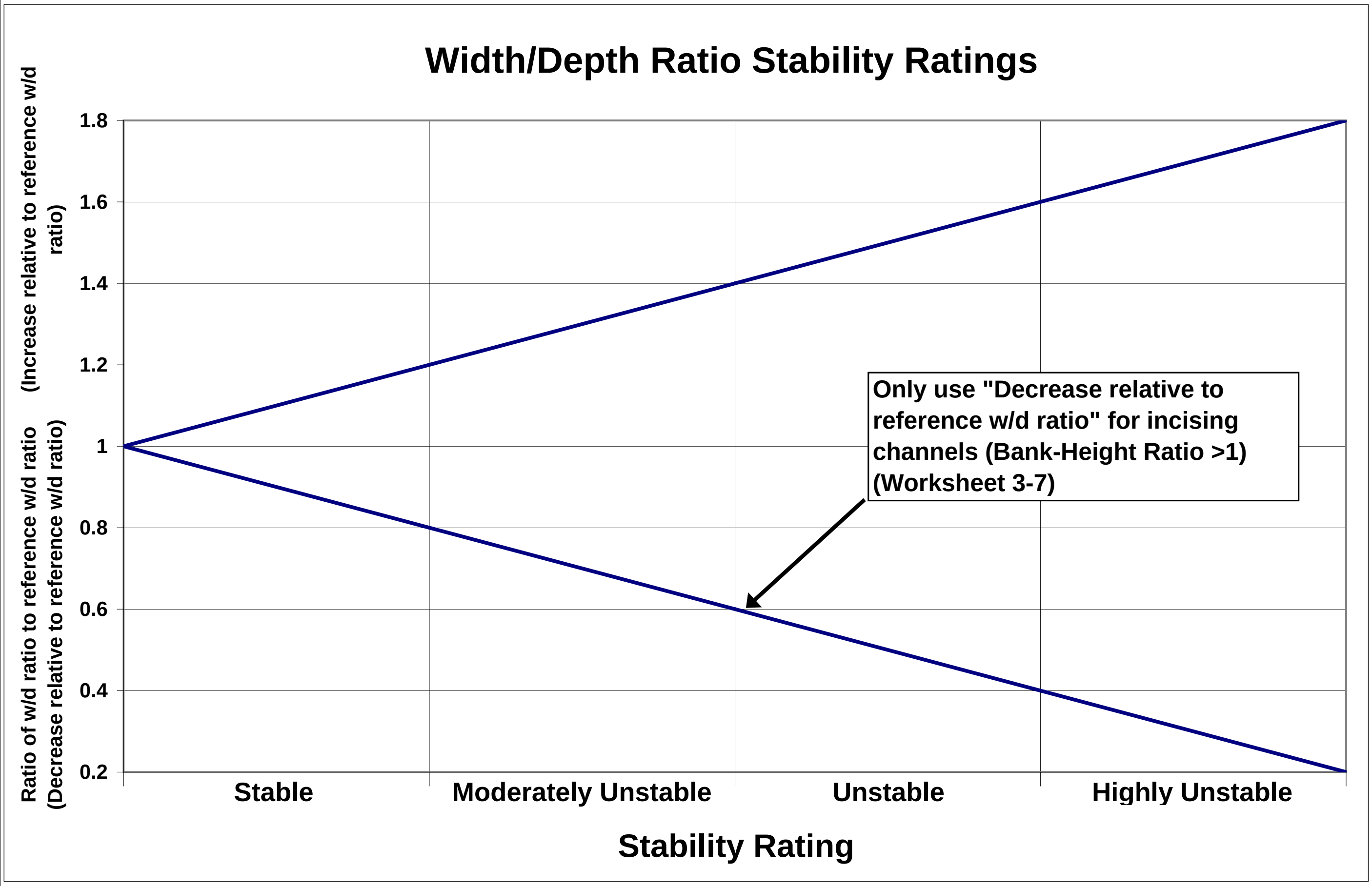
Worksheet 3-7. Relationship of Bank-Height Ratio (BHR) ranges to corresponding stream stability ratings.

Degree of Channel Incision			
Low Bank Height:		Bank-Height Ratio:	
Max Bankfull Depth:			
Degree of Channel Incision Stability Rating ☞			



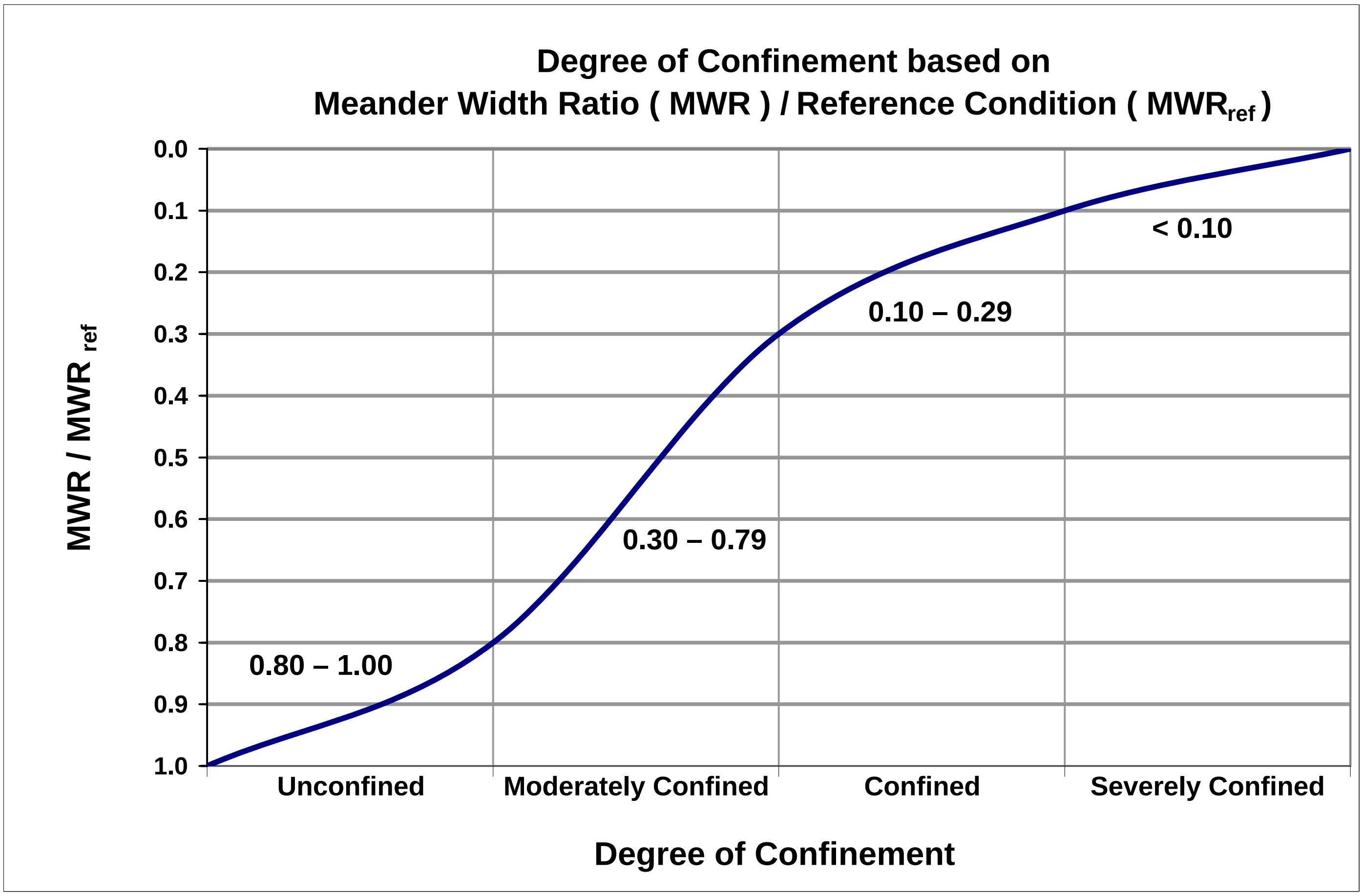
Worksheet 3-8. Stability ratings based on departure of width/depth ratio from reference condition.

Width/Depth Ratio State			
Existing Width/Depth Ratio:		Ratio of existing W/d to reference W/d:	
Reference Width/Depth Ratio:			
Width/Depth Ratio State Stability Rating ☞			



Worksheet 3-9. Degree of confinement based on Meander Width Ratio (MWR) divided by reference condition Meander Width Ratio (MWR_{ref}).

Degree of Confinement			
Existing Meander Width Ratio (MWR):		Ratio of MWR to MWR_{ref}:	
Reference Meander Width Ratio (MWR_{ref}):			
Degree of Confinement Stability Rating ☞			



Worksheet 3-10. Pfankuch (1975) channel stability rating procedure, as modified by Rosgen (1996, 2001c, 2006b).

Stream: | Location: | Valley Type: | Observers: | Date:

Location	Key	Category	Excellent – Description	Rating	Good – Description	Rating	Fair – Description	Rating	Poor – Description	Rating
Upper banks	1	Landform slope	Bank slope gradient <30%.	2	Bank slope gradient 30–40%.	4	Bank slope gradient 40–60%.	6	Bank slope gradient > 60%.	8
Upper banks	2	Mass erosion	No evidence of past or future mass erosion.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly yearlong.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
Upper banks	3	Debris jam potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	8
Upper banks	4	Vegetative bank protection	> 90% plant density. Vigor and variety suggest a deep, dense soil-binding root mass.	3	70–90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50–70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species and less vigor indicating poor, discontinuous and shallow root mass.	12
Lower banks	5	Channel capacity	Bank heights sufficient to contain the bankfull stage. Width/depth ratio departure from reference width/depth ratio = 1.0. Bank-Height Ratio (BHR) = 1.0.	1	Bankfull stage is contained within banks. Width/depth ratio departure from reference width/depth ratio = 1.0–1.2. Bank-Height Ratio (BHR) = 1.0–1.1.	2	Bankfull stage is not contained. Width/depth ratio departure from reference width/depth ratio = 1.2–1.4. Bank-Height Ratio (BHR) = 1.1–1.3.	3	Bankfull stage is not contained; over-bank flows are common with flows less than bankfull. Width/depth ratio departure from reference width/depth ratio > 1.4. Bank-Height Ratio (BHR) > 1.3.	4
Lower banks	6	Bank rock content	> 65% with large angular boulders. 12"+ common.	2	40–65%. Mostly boulders and small cobbles 6–12".	4	20–40%. Most in the 3–6" diameter class.	6	<20% rock fragments of gravel sizes, 1–3" or less.	8
Lower banks	7	Obstructions to flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
Lower banks	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12–24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
Lower banks	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges. Surfaces smooth and flat.	2	Corners and edges well rounded in 2 dimensions.	3	Well rounded in all dimensions, surfaces smooth.	4
Bottom	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, i.e., 35–65% mixture range.	3	Predominantly bright, > 65%, exposed or scoured surfaces.	4
Bottom	12	Consolidation of particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
Bottom	13	Bottom size distribution	No size change evident. Stable material 80–100%.	4	Distribution shift light. Stable material 50–80%.	8	Moderate change in sizes. Stable materials 20–50%.	12	Marked distribution change. Stable materials 0–20%.	16
Bottom	14	Scouring and deposition	<5% of bottom affected by scour or deposition.	6	5–30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30–50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
Bottom	15	Aquatic vegetation	Abundant growth moss-like, dark green perennial. In swift water too.	1	Common. Algae forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present.	4
			Excellent total =		Good total =		Fair total =		Poor total =	

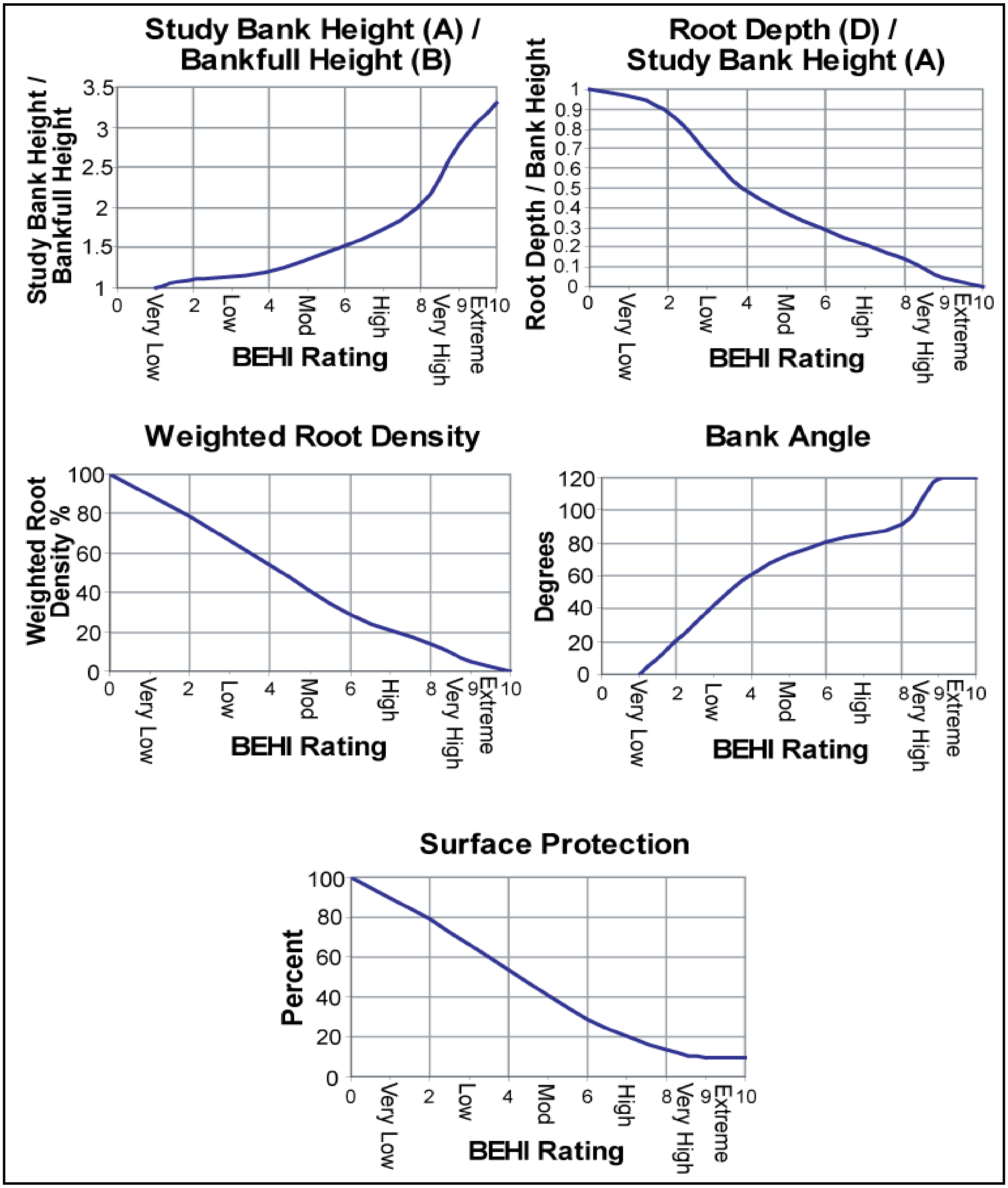
Stream type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+

Stream type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
Fair (Mod. unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

*Rating is adjusted to potential stream type, not existing.

Grand total =	
Existing stream type =	
*Potential stream type =	
Modified channel stability rating =	

Figure 3-7. Streambank erodibility criteria showing conversion of measured ratios and bank variables to a BEHI rating. Use **Worksheet 3-11** variables to determine BEHI score.



Worksheet 3-11. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use **Figure 3-7** with BEHI variables to determine BEHI score.

Stream:		Location:
Station:		Observers:
Date:	Stream Type:	Valley Type:

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	(A)	**Bankfull Height** (ft) =	(B)	(A) / (B) =	(C)	

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	**Study Bank Height** (ft) =	(A)	(D) / (A) =	(E)	

Weighted Root Density (G)

Root Density as **%** =	(F)	(F) × (E) =	(G)	

Bank Angle (H)

Bank Angle as *Degrees* =	(H)	

Surface Protection (I)

Surface Protection as **%** =	(I)	

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

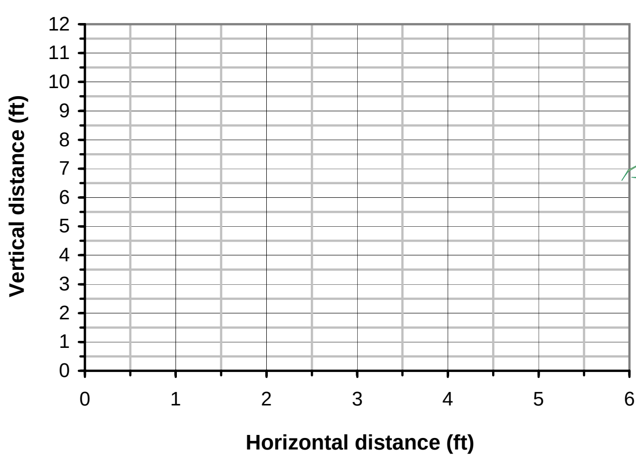
Bank Material Adjustment

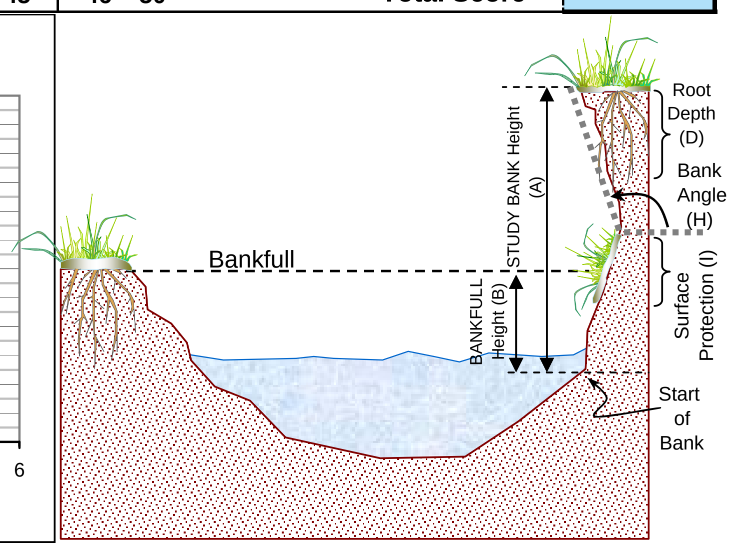
Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score

Bank Sketch





Worksheet 3-12. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream:	Location:	
Station:	Stream Type:	Valley Type:
Observers:		Date:

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})............................	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High Extensive deposition (continuous, cross-channel).. ....NBS = Extreme Chute cutoffs, down-valley meander migration, converging flow......................................NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)				

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	

Worksheet 3-13. Summary form of annual streambank erosion estimates for various study reaches.

Stream:				Location:			
Graph Used:		Total Bank Length (ft):				Date:	
Observers:			Valley Type:			Stream Type:	
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
Sum erosion subtotals in Column (7) for each BEHI/NBS combination					**Total Erosion (ft^3/yr)**		
Convert erosion in ft^3/yr to yds^3/yr {divide Total Erosion (ft^3/yr) by 27}					**Total Erosion (yds^3/yr)**		
Convert erosion in yds^3/yr to tons/yr {multiply Total Erosion (yds^3/yr) by 1.3}					**Total Erosion (tons/yr)**		
Calculate erosion per unit length of channel {divide Total Erosion (tons/yr) by total length of stream (ft) surveyed}					**Total Erosion (tons/yr/ft)**		

Figure 3-9. Relationship of BEHI and NBS to predict annual streambank erosion rates from Colorado data for streams found in sedimentary and/or metamorphic geology.

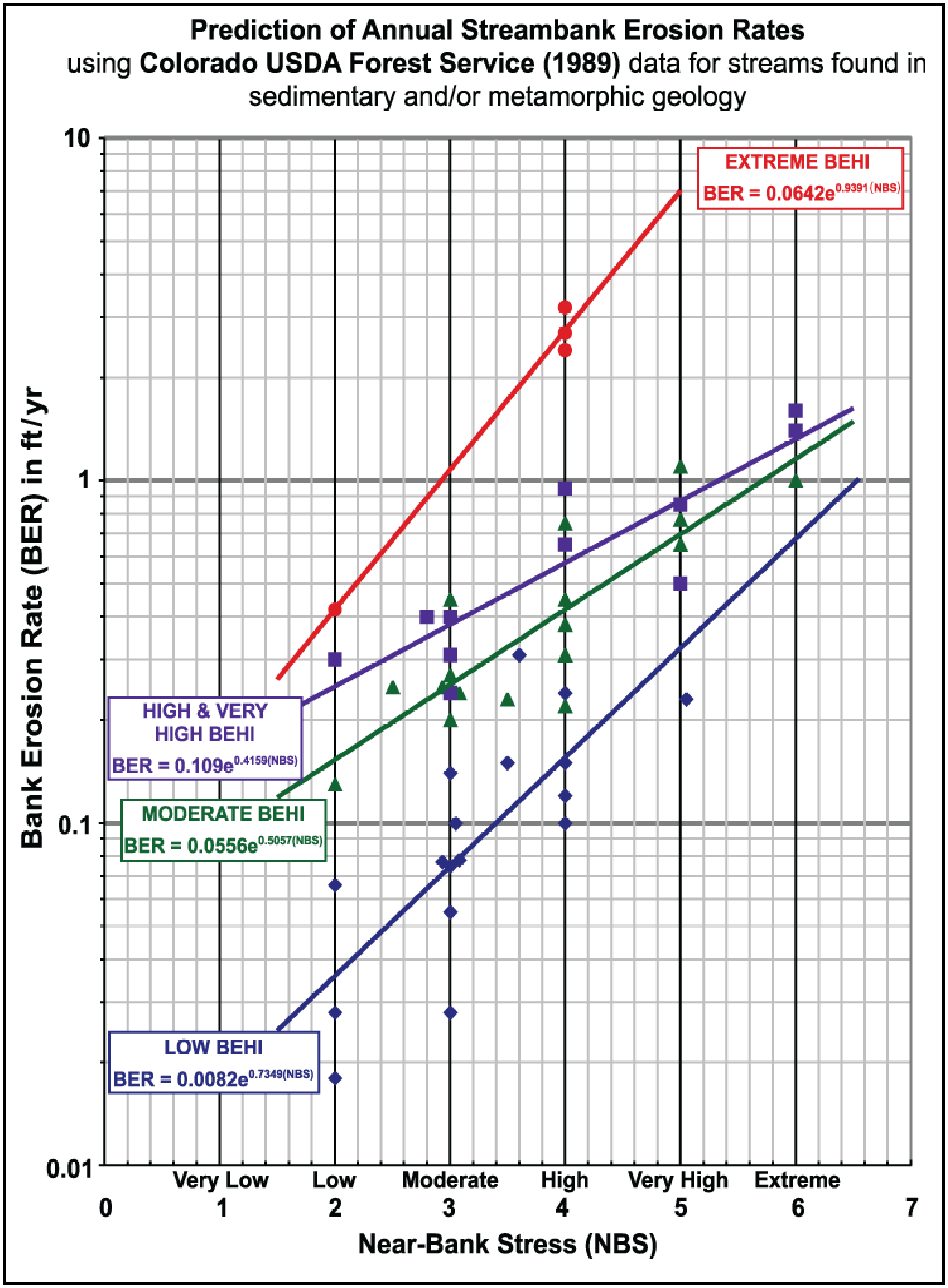
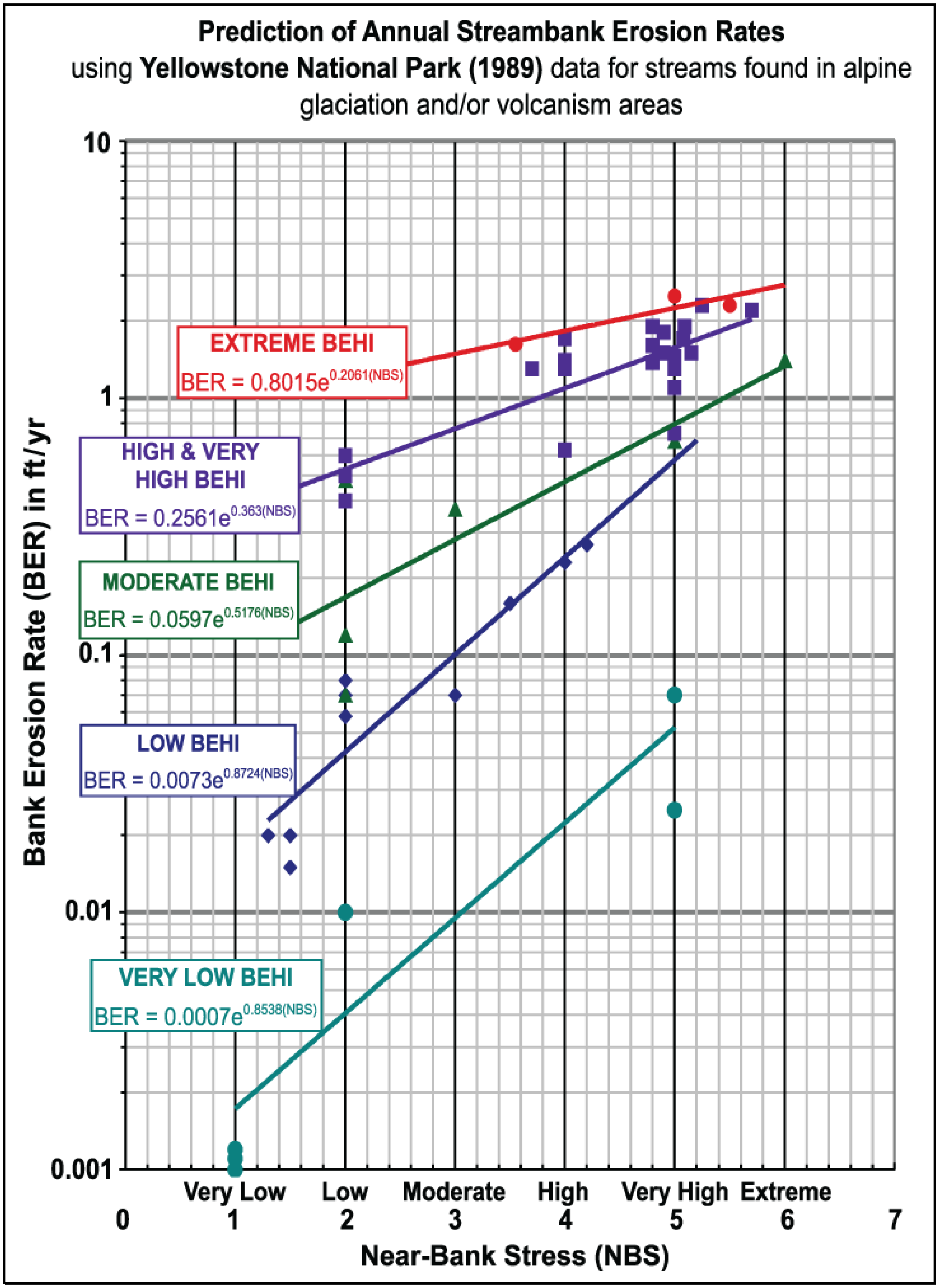


Figure 3-10. Relationship of BEHI and NBS to predict annual streambank erosion rates from Yellowstone National Park data for streams found in alpine glaciation and/or volcanism geology.



Worksheet 3-14. Sediment competence calculation form to assess bed stability.

Stream:			Stream Type:	
Location:			Valley Type:	
Observers:			Date:	

Enter Required Information for Existing Condition

	D_{50}	Riffle bed material D_{50} (mm)			
	$\hat{D}_{50}$	Bar sample D_{50} (mm)			
	D_{max}	Largest particle from bar sample (ft)		**(mm)**	304.8 mm/ft
	S	Existing bankfull water surface slope (ft/ft)			
	d	Existing bankfull mean depth (ft)			
1.65	γ_s	Submerged specific weight of sediment			

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress

	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1:	$\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$
	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2:	$\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$
	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:	

Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample

	d	Required bankfull mean depth (ft)	$d = \dfrac{\tau^* \gamma_s D_{max}}{S}$	(use D_{max} in ft)

Check: ☐ Stable ☐ Aggrading ☐ Degrading

Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample

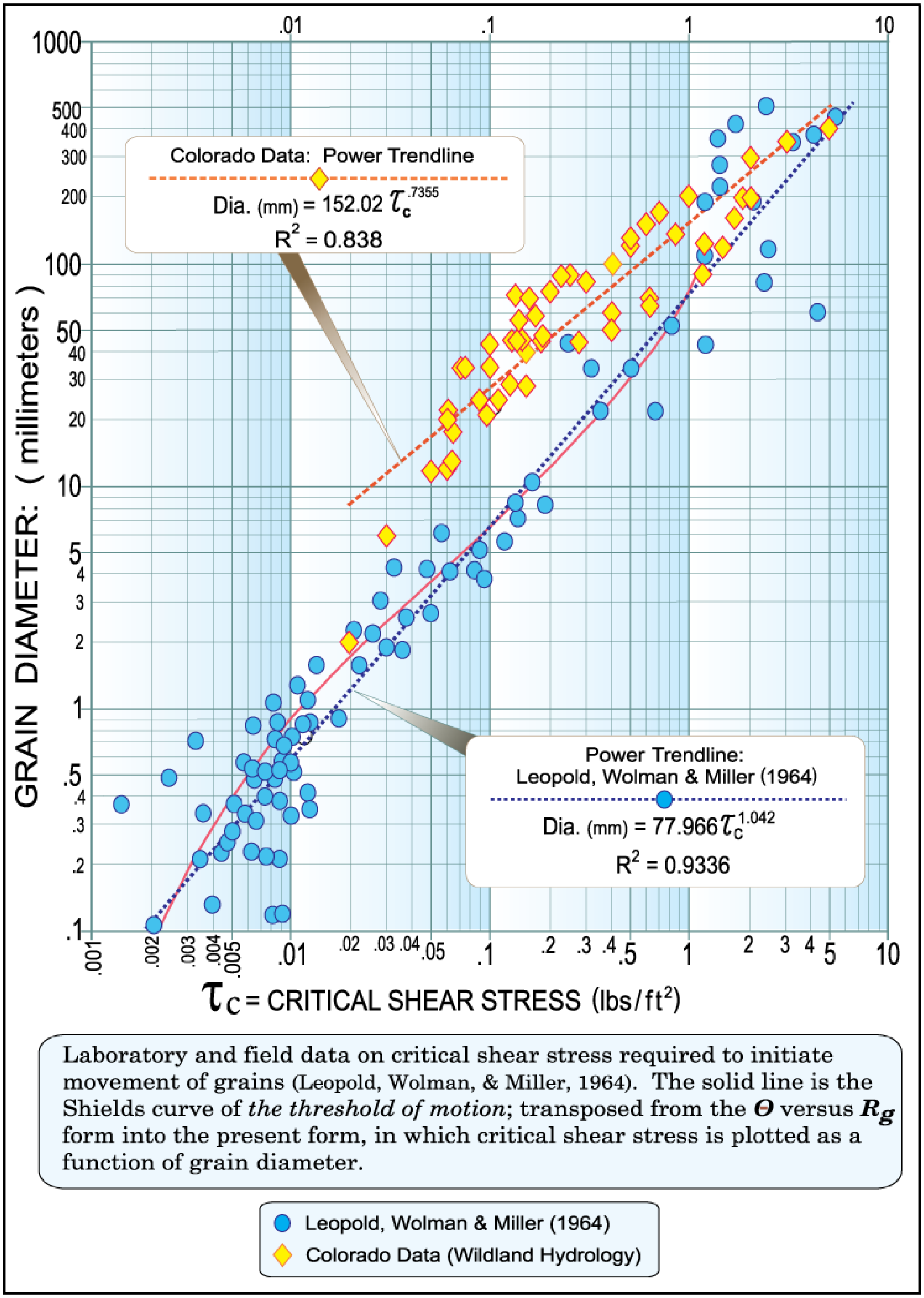
	S	Required bankfull water surface slope (ft/ft)	$S = \dfrac{\tau^* \gamma_s D_{max}}{d}$	(use D_{max} in ft)

Check: ☐ Stable ☐ Aggrading ☐ Degrading

Sediment Competence Using Dimensional Shear Stress

	Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope	
	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**	
	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**	
	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope	$\mathbf{d} = \dfrac{\tau}{\gamma \mathbf{S}}$
	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth	$\mathbf{S} = \dfrac{\tau}{\gamma \mathbf{d}}$

Figure 3-11. Critical shear stress required to initiate movement of bed-material grains following the Shields relation, as modified by field data from Colorado.



Worksheet 3-15. Bar sample data collection and sieve analysis form.

Point / Side BAR-BULK MATERIALS SAMPLE DATA: Size Distribution Analysis

Observers:

Stream: Location: Date:

Sub-samples	Catch Pan or BUCKET		Sieve SIZE mm		Sieve SIZE mm		Sieve SIZE mm		Sieve SIZE mm		Sieve SIZE mm		Sieve SIZE mm		Sieve SIZE mm		Sieve SIZE mm	
	Tare weight		Tare weight		Tare weight		Tare weight		Tare weight		Tare weight		Tare weight		Tare weight		Tare weight	
	Sample weights		Sample weights		Sample weights		Sample weights		Sample weights		Sample weights		Sample weights		Sample weights		Sample weights	
	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
Net wt. total																		
% Grand total																		
Accum. % =<																		

SURFACE MATERIALS DATA
(Two largest particles)

No.	Dia.	WT.
1		
2		

Bucket + materials weight	
Bucket tare weight	
Materials weight	
Materials less than:	mm

Be sure to add separate material weights to grand total

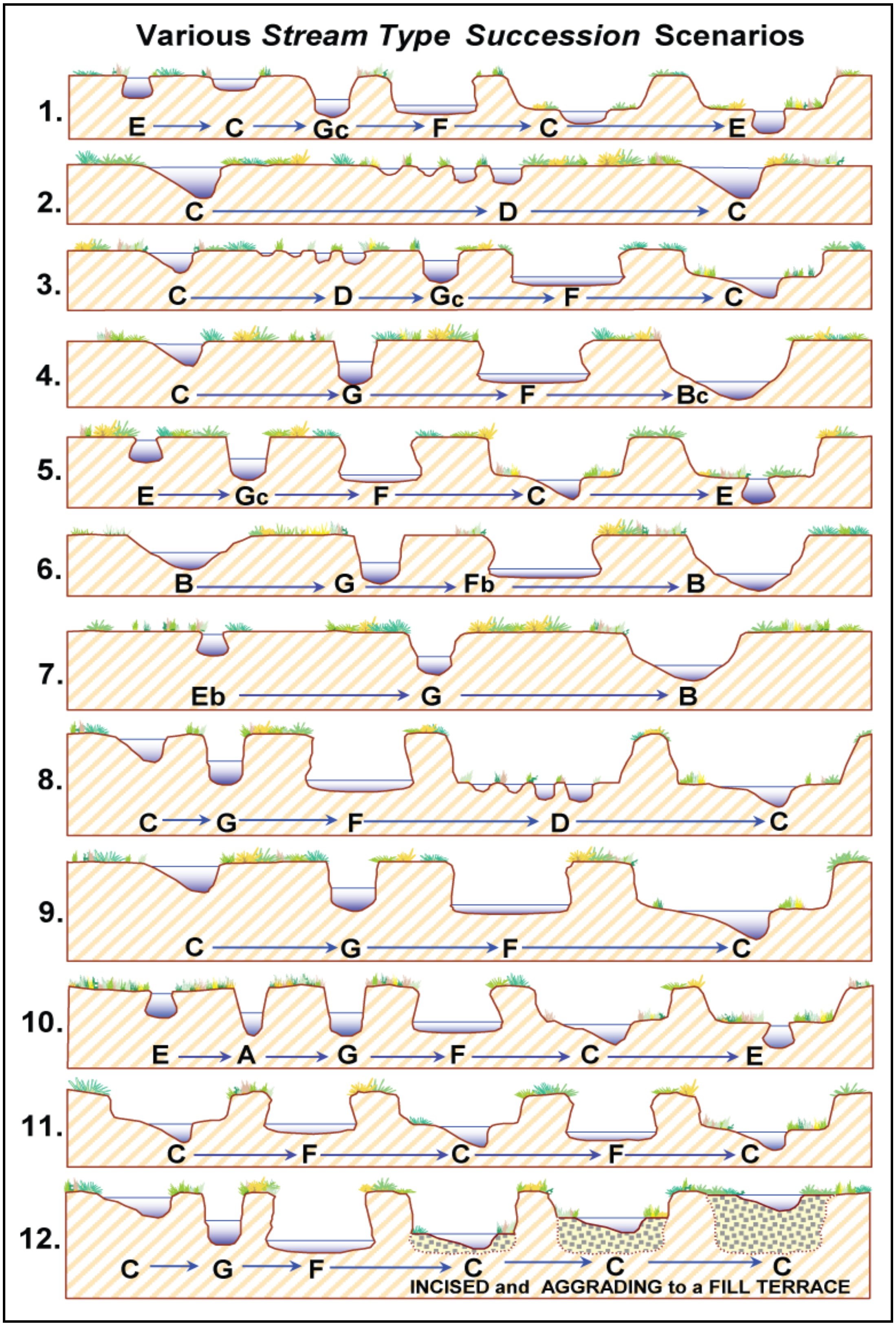
GRAND TOTAL SAMPLE WEIGHT

Sample location notes	Sample location sketch

Worksheet 3-16. Stability ratings for corresponding successional stage shifts of stream types. Check the appropriate stability rating.

Stream:	Stream Type:
Location:	Valley Type:
Observers:	Date:
Stream type changes due to successional stage shifts (Figure 3-14)	**Stability rating (check appropriate rating)**
Stream type at potential, (C→E), (F_b→B), (G→B), (F→B_c), (F→C), (D→C)	☐ Stable
(E→C), (C→High W/d C)	☐ Moderately unstable
(G→F), (F→D), (C→F)	☐ Unstable
(C→D), (B→G), (D→G), (C→G), (E→G)	☐ Highly unstable

Figure 3-14. Various channel successional scenarios.



Worksheet 3-17. Lateral stability prediction summary.

Stream:					Stream Type:
Location:					Valley Type:
Observers:					Date:
Lateral stability criteria (choose one stability category for each criterion 1–5)	**Lateral Stability Categories**				**Selected points (from each row)**
	Stable	**Moderately unstable**	**Unstable**	**Highly unstable**	
1 W/d ratio state (Worksheet 3-8)	< 1.2 **(2)**	1.2 – 1.4 **(4)**	1.4 – 1.6 **(6)**	> 1.6 **(8)**	
2 Depositional pattern (Worksheet 3-5)	B1, B2 **(1)**	B4, B8 **(2)**	B3 **(3)**	B5, B6, B7 **(4)**	
3 Meander pattern (Worksheet 3-4)	M1, M3, M4 **(1)**		M2, M5, M6, M7, M8 **(3)**		
4 Dominant BEHI / NBS (Worksheet 3-13)	L/VL, L/L, L/M, L/H, L/VH, M/VL **(2)**	M/L, M/M, M/H, L/Ex, H/L **(4)**	M/VH, M/Ex, H/L, H/M, H/H, VH/VL, Ex/VL **(6)**	H/H, H/Ex, Ex/M, Ex/H, Ex/VH, VH/VH, Ex/Ex **(8)**	
5 Degree of confinement (MWR / MWR_{ref}) (Worksheet 3-9)	0.8 – 1.0 **(1)**	0.3 – 0.79 **(2)**	0.1 – 0.29 **(3)**	< 0.1 **(4)**	
				Total points	
	Lateral stability category point range				
Overall lateral stability category (use total points and check stability rating)	**Stable 7 – 9** ☐	**Moderately unstable 10 – 12** ☐	**Unstable 13 – 21** ☐	**Highly unstable > 21** ☐	

Worksheet 3-18. Vertical stability prediction for excess deposition or aggradation.

Stream:	Stream Type:	
Location:	Valley Type:	
Observers:	Date:	

Vertical stability criteria (choose one stability category for each criterion 1–6)	Vertical Stability Categories for Excess Deposition / Aggradation				Selected points (from each row)
	No deposition	Moderate deposition	Excess deposition	Aggradation	
1 Sediment competence (Worksheet 3-14)	Sufficient depth and/or slope to transport largest size available (2)	Trend toward insufficient depth and/or slope-slightly incompetent (4)	Cannot move D_{35} of bed material and/or D_{100} of bar material (6)	Cannot move D_{16} of bed material and/or D_{100} of bar or sub-pavement size (8)	
2 Sediment capacity (POWERSED)	Sufficient capacity to transport annual load (2)	Trend toward insufficient sediment capacity (4)	Reduction up to 25% of annual sediment yield of bedload and/or suspended sand (6)	Reduction over 25% of annual sediment yield for bedload and/or suspended sand (8)	
3 W/d ratio state (Worksheet 3-8)	1.0 – 1.2 (2)	1.2 – 1.4 (4)	1.4 – 1.6 (6)	>1.6 (8)	
4 Stream succession states (Worksheet 3-16)	Current stream type at potential or does not indicate deposition/ aggradation (2)	(E→C) (4)	(C→High W/d C), (B→High W/d B), (C→F) (6)	(C→D), (F→D) (8)	
5 Depositional patterns (Worksheet 3-5)	B1 (1)	B2, B4 (2)	B3, B5 (3)	B6, B7, B8 (4)	
6 Debris / blockages (Worksheet 3-6)	D1, D2, D3 (1)	D4, D7 (2)	D5, D8 (3)	D6, D9, D10 (4)	
				Total points	

Vertical stability for excess deposition / aggradation (use total points and check stability rating)	Vertical stability category point range for excess deposition / aggradation			
	No deposition 10 – 14 ☐	**Moderate deposition** 15 – 20 ☐	**Excess deposition** 21 – 30 ☐	**Aggradation** > 30 ☐

Worksheet 3-19. Vertical stability prediction for channel incision or degradation.

Stream:	Stream Type:
Location:	Valley Type:
Observers:	Date:

Vertical stability criteria (choose one stability category for each criterion 1–5)	**Vertical Stability Categories for Channel Incision / Degradation**				**Selected points (from each row)**
	Not incised	**Slightly incised**	**Moderately incised**	**Degradation**	
1 **Sediment competence (Worksheet 3-14)**	Does not indicate excess competence **(2)**	Trend to move larger sizes than D_{100} of bar or > D_{84} of bed **(4)**	D_{100} of bed moved **(6)**	Particles much larger than D_{100} of bed moved **(8)**	
2 **Sediment capacity (POWERSED)**	Does not indicate excess capacity **(2)**	Slight excess energy: up to 10% increase above reference **(4)**	Excess energy sufficient to increase load up to 50% of annual load **(6)**	Excess energy transporting more than 50% of annual load **(8)**	
3 **Degree of channel incision (BHR) (Worksheet 3-7)**	1.00 – 1.10 **(2)**	1.11 – 1.30 **(4)**	1.31 – 1.50 **(6)**	> 1.50 **(8)**	
4 **Stream succession states (Worksheets 3-16 and 3-7)**	Does not indicate incision or degradation **(2)**	If BHR > 1.1 and stream type has w/d between 5–10 **(4)**	If BHR > 1.1 and stream type has w/d less than 5 **(6)**	(B→G), (C→G), (E→G), (D→G) **(8)**	
5 **Confinement (MWR / MWR_{ref}) (Worksheet 3-9)**	0.80 – 1.00 **(1)**	0.30 – 0.79 **(2)**	0.10 – 0.29 **(3)**	< 0.10 **(4)**	
				Total points	

	Vertical stability category point range for channel incision / degradation			
Vertical stability for channel incision/ degradation (use total points and check stability rating)	**Not incised 9 – 11** ☐	**Slightly incised 12 – 18** ☐	**Moderately incised 19 – 27** ☐	**Degradation > 27** ☐

Worksheet 3-20. Channel enlargement prediction summary.

Stream:					Stream Type:
Location:					Valley Type:
Observers:					Date:
Channel enlargement prediction criteria (choose one stability category for each criterion 1–4)	**Channel Enlargement Prediction Categories**				**Selected points** (from each row)
	No increase	**Slight increase**	**Moderate increase**	**Extensive**	
1 **Successional stage shift (Worksheet 3-16)**	Stream type at potential, (C→E), (F_b→B), (G→B), (F→B_c), (F→C), (D→C) **(2)**	(C→High W/d C), (E→C) **(4)**	(G→F), (F→D) **(6)**	(C→D), (B→G), (D→G), (C→G), (E→G), (C→F) **(8)**	
2 **Lateral stability (Worksheet 3-17)**	Stable **(2)**	Moderately unstable **(4)**	Unstable **(6)**	Highly unstable **(8)**	
3 **Vertical stability excess deposition/ aggradation (Worksheet 3-18)**	No deposition **(2)**	Moderate deposition **(4)**	Excess deposition **(6)**	Aggradation **(8)**	
4 **Vertical stability incision/ degradation (Worksheet 3-19)**	Not incised **(2)**	Slightly incised **(4)**	Moderately incised **(6)**	Degradation **(8)**	
				Total points	
	Category point range				
Channel enlargement prediction (use total points and check stability rating)	**No increase 8 – 10** ☐	**Slight increase 11 – 16** ☐	**Moderate increase 17 – 24** ☐	**Extensive > 24** ☐	

Worksheet 3-21. Overall sediment supply rating determined from individual stability rating categories.

Stream:		Stream Type:	
Location:		Valley Type:	
Observers:		Date:	
Overall sediment supply prediction criteria (choose corresponding points for each criterion 1–5)	**Stability Rating**	**Points**	**Selected Points**
1 Lateral stability (Worksheet 3-17)	**Stable**	**1**	
	Mod. unstable	**2**	
	Unstable	**3**	
	Highly unstable	**4**	
2 Vertical stability excess deposition/ aggradation (Worksheet 3-18)	**No deposition**	**1**	
	Mod. deposition	**2**	
	Excess deposition	**3**	
	Aggradation	**4**	
3 Vertical stability channel incision/ degradation (Worksheet 3-19)	**Not incised**	**1**	
	Slightly incised	**2**	
	Mod. Incised	**3**	
	Degradation	**4**	
4 Channel enlargement prediction (Worksheet 3-20)	**No increase**	**1**	
	Slight increase	**2**	
	Mod. increase	**3**	
	Extensive	**4**	
5 Pfankuch channel stability (Worksheet 3-10)	**Good: stable**	**1**	
	Fair: mod unstable	**2**	
	Poor: unstable	**4**	
		Total Points	

	Category point range			
Overall sediment supply rating (use total points and check stability rating)	**Low 5** ☐	**Moderate 6 – 10** ☐	**High 11 – 15** ☐	**Very High 16 – 20** ☐

Worksheet 4-1. Summary of annual data comparisons and time-trend change.

Data Comparison Form

Stream:		Reach:
Observers:	Date (Yr 1):	Date (Yr 2):

		Riffle XS:		Pool XS:		Glide XS:	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Cross-section Dimensions	Width (W_{bkf})						
	Mean Depth (d_{bkf})						
	Width/Depth Ratio (W/d)						
	Cross-Sectional Area (A_{bkf})						
	Max Bankfull Depth (d_{max})						
Pebble Count	D_{35} (mm)						
	D_{50} (mm)						
	D_{84} (mm)						
	D_{100} (mm)						

Pattern		Year 1	Year 2		Year 1	Year 2
	Meander Length Ratio (L_m/W_{bkf})			Pool Length/Riffle Width		
	Radius of Curvature to Riffle Width (R_c/W_{bkf})			Pool to Pool Spacing/Riffle Width		
	Meander Width Ratio (W_{blt}/W_{bkf})			Riffle Length/Riffle Width		

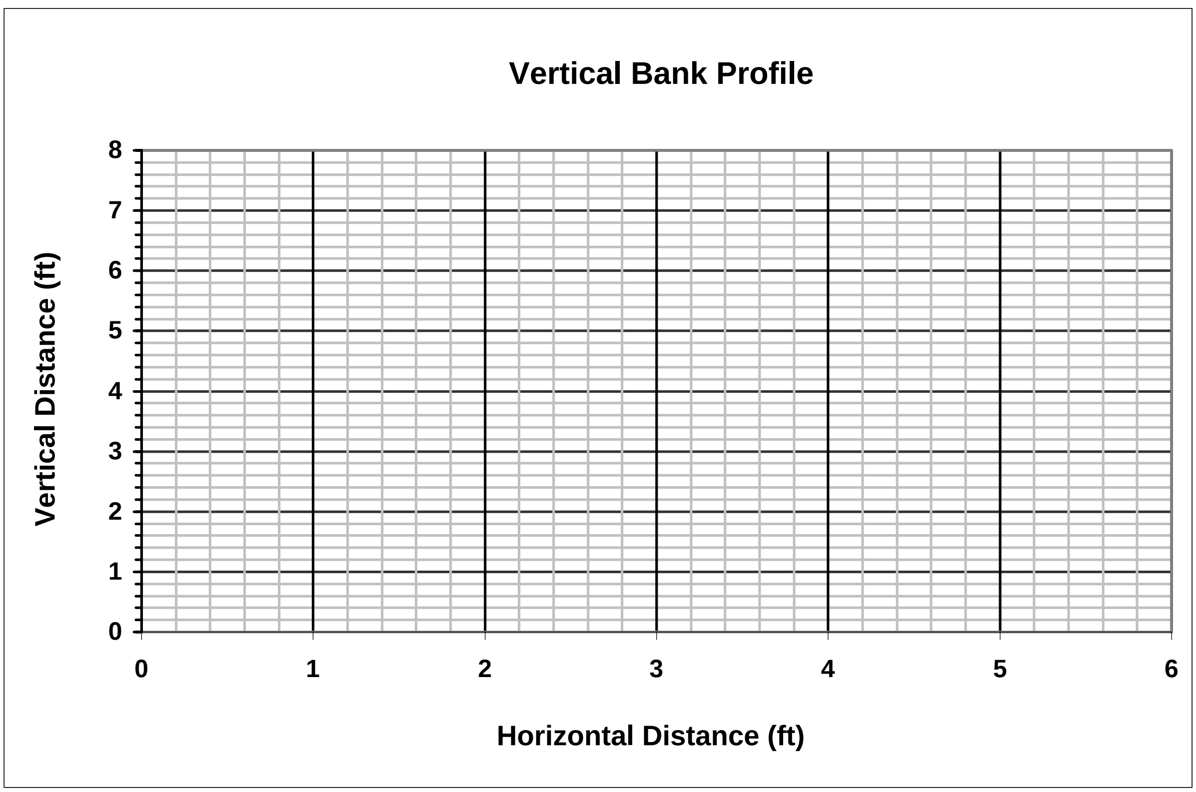
		Year 1	Year 2			Year 1	Year 2
	Revised Pfankuch Channel Stability Rating			Bar Sample	D_{35} (mm)		
	Bank-Height Ratio start: end:				D_{50} (mm)		
	Point Bar Slope				D_{84} (mm)		
	Sinuosity (k)				D_{100} (mm)		
Dimensionless Slope Ratios	Riffle Slope Ratio (S_{rif}/S)			Dimensionless Max Depth Ratios	Max Riffle Depth Ratio (d_{maxrif}/d_{bkf})		
	Run Slope Ratio (S_{run}/S)				Max Run Depth Ratio (d_{maxrun}/d_{bkf})		
	Pool Slope Ratio (S_p/S)				Max Pool Depth Ratio (d_{maxp}/d_{bkf})		
	Glide Slope Ratio (S_g/S)				Max Glide Depth Ratio(d_{maxg}/d_{bkf})		

Worksheet 4-2. Bank profile and bank erosion summary data form.

Bank Profile Form

Stream:	Observers:
Location:	Date:
Cross-Section:	BEHI Adjective Rating:
Bank:	NBS Adjective Rating:
Toe-Pin Station (ft):	Predicted Erosion (ft):
Toe-Pin Elevation (ft):	Measured Erosion (ft):

Date:			Date:		
Horizontal	**Vertical**	**Notes**	**Horizontal**	**Vertical**	**Notes**



Worksheet 4-3. Streambank erosion validation.

Streambank Erosion Validation

Stream:		Reach:
Observers:	Date - Yr 1:	Date - Yr 2:

		Year 1: Prediction		Year 2: Actual Values (Observed Values)	
Riffle XS:		BEHI Rating		BEHI Rating	
		NBS Rating		NBS Rating	
		Predicted Erosion (ft/yr) using Appropriate Curve (e.g., Colorado or Yellowstone Curve)		Measured Erosion from Bank Pins and Bank Profile (ft/yr)	
Glide XS:		BEHI Rating		BEHI Rating	
		NBS Rating		NBS Rating	
		Predicted Erosion (ft/yr) using Appropriate Curve (e.g., Colorado or Yellowstone Curve)		Measured Erosion from Bank Pins and Bank Profile (ft/yr)	
Pool XS:		BEHI Rating		BEHI Rating	
		NBS Rating		NBS Rating	
		Predicted Erosion (ft/yr) using Appropriate Curve (e.g., Colorado or Yellowstone Curve)		Measured Erosion from Bank Pins and Bank Profile (ft/yr)	

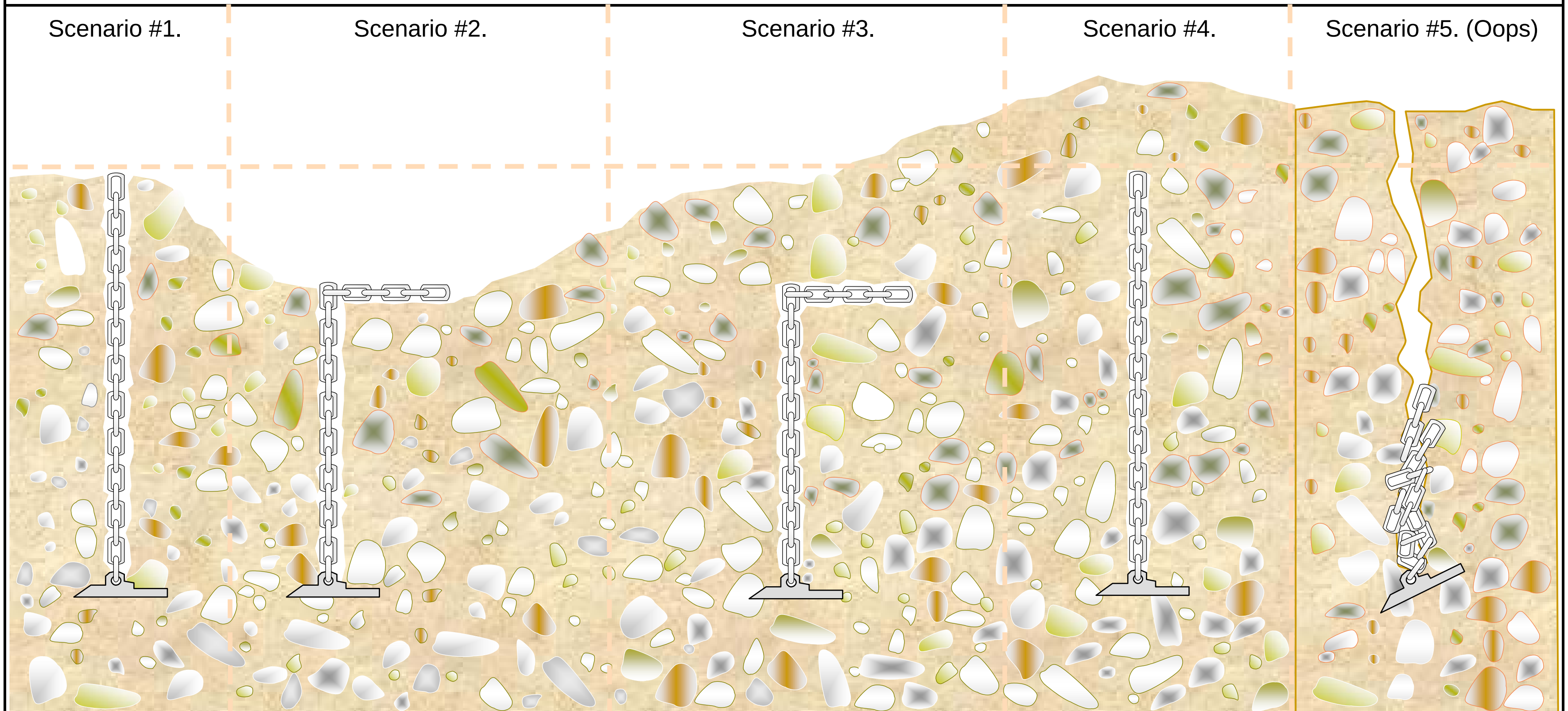
Plot Measured Erosion Values According to their Respective BEHI and NBS Ratings on Appropriate Curve; e.g., Colorado Curve (Figure 4-8) or Yellowstone Curve (Figure 4-9)

Worksheet 4-4. Field form to document scour chain results and corresponding bed-elevation changes.

Stream: Location:

Observers: Stream Type: Valley Type: Date:

		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1										
	Chain #2										
Glide	Chain #3										
	Chain #4										



[a] Scenario 2 or 3. Scenario 2: Enter length of chain exposed. Scenario 3: Enter length of chain exposed then subsequently buried.

[b] Scenario 3 or 4. Scenario 3: Enter elevation of bed at same station @ 2nd year. Scenario 4: Enter depth of material over chain.

[c] Scenario 3: Subtract 1st and 2nd year elevations to calculate net change in bed.

Worksheet 4-5. Dimensionless shear stress validation.

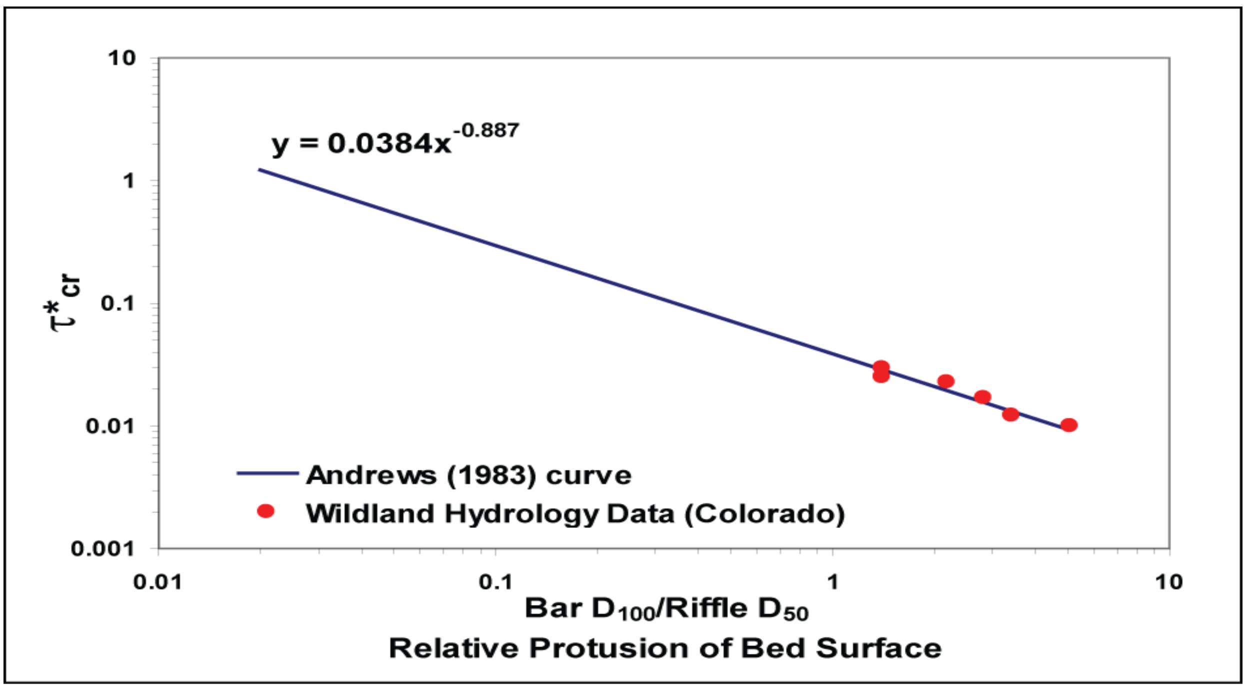
Competence Form to Validate Dimensionless Shear Stress (τ*)

Stream:		Reach:	
Observers:	Date (Yr 1):	Date (Yr 2):	

Year 1: Prediction (Values from Worksheet 3-14)		**Year 2: Actual Values (Observed Values)**	
Predicted Depth *d* (ft):		Measured Depth *d* (ft):	
Predicted Slope *S* (ft):		Measured Slope *S* (ft):	
Predicted τ^* Eq. 1: $\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$		D_{max} from Scour Chain or Bedload Sampler (ft):	
Predicted τ^* Eq. 2: $\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$		Actual $\tau^* = \dfrac{dS}{\gamma_s D_{max}}$	

Plot Actual τ^* and Year 1 Relative Protrusion of Bed Surface (Bar D_{100}/Riffle D_{50}) on Andrews Relation (1983)

Year 1: Bar Sample D_{100} (mm)		Year 1: Riffle Bed Material D_{50} (mm)	



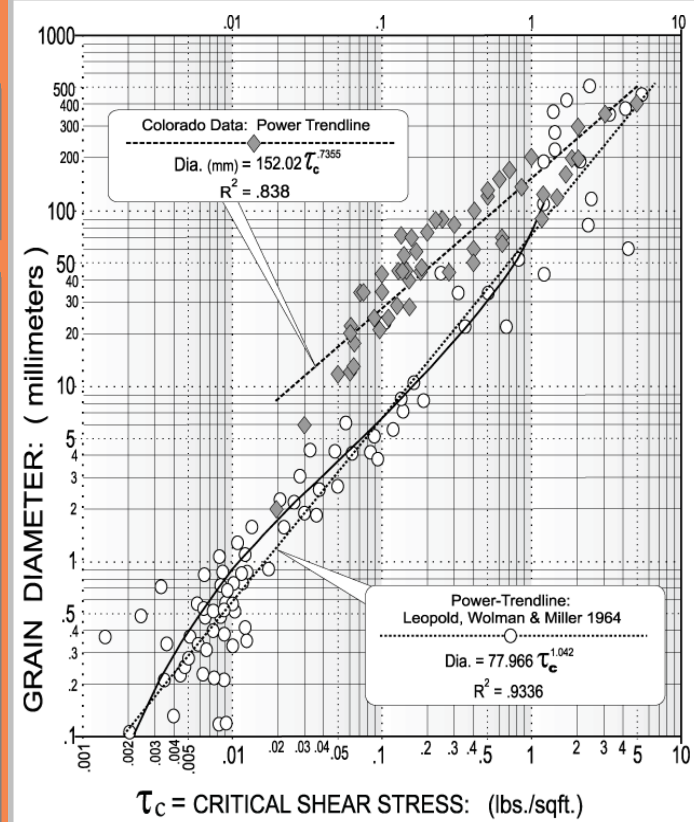
Worksheet 4-6. Dimensional shear stress validation.

Competence Form to Validate Dimensional Shear Stress (τ*)

Stream:	Reach:	
Observers:	Date (Yr 1):	Date (Yr 2):

Year 1: Prediction (Values from Worksheet 3-14)		Year 2: Actual Values (Observed Values)	
Predicted largest moveable particle size at bankfull shear stress (mm)		Measured largest size particle D_{max} (mm) from scour chain or bedload measurement	
Predicted Depth *d* (ft) $d = \frac{\tau}{\gamma S}$		Measured Depth *d* (ft):	
Predicted Slope *S* (ft) $S = \frac{\tau}{\gamma d}$		Measured Slope *S* (ft):	
		Bankfull shear stress $\tau = \gamma dS$ ($\gamma = 62.4$)	

Plot Bankfull Shear Stress τ on Shields/Colorado Relation Using Largest particle measured (D_{max}) and the Corresponding Bankfull Shear Stress (τ) →



Laboratory and field data on critical shear stress required to initiate movement of grains (Leopold, Wolman, & Miller 1964). The solid line is the Shields curve of *the threshold of motion*, transposed from the Θ versus R_g form into the present form, in which critical shear stress is plotted as a function of grain diameter.