River Restoration Toolbox
Practice Guide 5

Geomorphic Channel Design

Iowa Department of Natural Resources

April, 2018

Table of Contents

EXECUTIVE SUMMARY .... **I**

1.0 INTRODUCTION **1**

2.0 GEOMORPHIC CHANNEL DESIGN **1**
2.1 BACKGROUND INFORMATION 1
2.1.1 Description & Key Sources of Information 1
2.1.2 Minimum Qualifications 2
2.2 REFERENCE REACH DATA 3
2.2.1 Use of Reference Reaches 3
2.2.2 Characteristics of a Reference Reach 3
2.2.3 Minimum Data Requirements 5
2.2.4 Development of Dimensionless Ratios 6
2.3 DESIGN REACH ASSESSMENT 10
2.3.1 Identifying Impairments 10
2.3.2 Minimum Data Requirements 11
2.3.3 Assessment Analysis 12
2.4 CHECKING FOR SEDIMENT TRANSPORT 14
2.4.1 Competence 14
2.4.2 Capacity 18
2.5 ALLUVIAL CHANNEL DESIGN 21
2.5.1 Narrative Description 21
2.5.2 Key Design Components 21
2.5.3 Example Calculations 22
2.6 THRESHOLD CHANNEL DESIGN 28
2.6.1 Narrative Description 28
2.6.2 Key Design Components 29
2.6.3 Example Calculations 30
2.7 STEP POOL CHANNEL DESIGN 32
2.7.1 Narrative Description 32
2.7.2 Key Design Components 32
2.7.3 Example Calculations 32
2.8. Minimum Design Report Requirements 35
2.9. Minimum Plan Requirements 36

3. REFERENCES **38**

LIST OF TABLES

Table 1. River Reach Summary Data (Rosgen 2009) 8
Table 2. River Reach Summary Data (Rosgen 2009) 9
Table 3. Summary of Design Reach Stability Conditions (Rosgen 2009) 13

Table 4. Example Proposed Design Table (Rosgen, 2015) 25
Table 5. Example Proposed Design Table (Rosgen, 2015) 26
Table 6. Example Proposed Design Profile Table (Rosgen, 2015) 27
Table 7. Allowable Channel Velocities (USDA, 2007) 31

LIST OF FIGURES

Figure 1. Key to the Rosgen Stream Classification System (USDA, 2007) 5
Figure 2. General Procedure to Calculate Sediment Competence (USDA, 2007) 15
Figure 3. Sediment Competence Data Table (Rosgen 2009) 16
Figure 4. Sediment Capacity Transport Flow Chart (USDA, 2007) 18
Figure 5. Example Bankfull Discharge Regional Curve 23
Figure 6. Example Bankfull Area Regional Curve 23
Figure 7. S-Line Depicting Erosive & Non-Erosive Channel Conditions (USDA, 2007) 30
Figure 8. Channel Slope vs Pool to Pool Spacing to Bankfull Width (Rosgen, 2006) 32

Executive Summary

The goal of geomorphic channel design is to maximize stream function(s) by assimilating and addressing a variety of fundamental geomorphic processes to produce self-maintaining river systems. A river system includes not only the river channel, but also its interrelated components including adjacent floodplains, wetlands, and accompanying riparian communities. Creating the stable form that incorporates functions necessary for success involves re-establishing physical stability integrating the processes responsible for creating and maintaining the dimension, pattern, and profile of rivers. Such form variables are dependent on the driving variables of flow and sediment, as well as the boundary conditions of channel materials, riparian vegetation, boundary roughness, and the slope, width and sinuosity of its valley (Rosgen 2011).

This practice provides an overview of three dominant varieties of geomorphic channel design, all of which rely on a reference reach to predict channel geometry along with sediment transport analysis to validate the stream can pass the sediment delivered by the watershed. The following three design techniques are detailed in this report:

1. Alluvial Channel Design (mobile channel boundary)

2. Threshold Channel Design (fixed channel boundary)

3. Step Pool Channel Design (fixed channel boundary on steep slopes)

In general, geomorphic channel design should be considered when major restoration activities are warranted such as channel realignment or significant changes in dimension, pattern and profile are needed due to geomorphic instabilities within the system. There must also be sufficient length of channel (greater than 20 bankfull widths) to carry out a geomorphic channel design.

The *River Restoration Toolbox Practice Guide 5: Geomorphic Channel Design* (Practice Guide) has been developed to assist with the presentation of design and construction information for stream restoration in Iowa. It is intended to provide guidance to:

- Those responsible for reviewing and implementing stream restoration,

- Engineers and other professionals responsible for the design of stream restoration projects,

- Others involved in stream restoration at various levels who may find the information useful as a technical reference.

The Practice Guide includes a written assessment of the geomorphic channel design practice and describes a variety of geomorphic channel design techniques. The descriptions included herein are intended to provide fundamental discussions of the various techniques, and examples of the types of calculations required for the various methods. Users should consult the various references for a more detailed description of the design technique.

The information in the Practice Guide is intended to inform practitioners and others, and define typical information required by the State of Iowa to be included with the use of geomorphic channel design techniques. The information and drawings are not meant to represent a standard design method for any type of technique and shall not be used as such. The Practice Guide neither replaces the need for site-specific engineering and/or landscape designs, nor precludes the use of information not included herein.

The Practice Guide may be updated and revised to reflect up-to-date engineering, science, and other information applicable to Iowa streams and rivers.

1.0 INTRODUCTION

A wide range of methodologies have been developed for designing stream restoration projects. Along with each of these methodologies is a unique definition of what stream restoration means. Regardless of the definition, stream restoration should incorporate multiple disciplines and requires a good understanding of physical, chemical, and biological processes. The geomorphic channel design approach to river restoration emulates natural river systems and was initially developed to help redirect the manner in which past traditional river works have impacted natural river systems (NRCS, 2007).

2.0 GEOMORPHIC CHANNEL DESIGN

2.1 BACKGROUND INFORMATION

2.1.1 Description & Key Sources of Information

The goal of geomorphic channel design is to maximize stream function(s) by assimilating and addressing a variety of fundamental geomorphic processes to produce self-maintaining river systems. It should be noted that geomorphic stability does not necessarily imply ecological stability, however, a properly functioning channel with respects to geomorphology often provides increased habitat over unstable systems. A river system includes not only the river channel, but also its interrelated components including adjacent floodplains, wetlands, and accompanying riparian communities. Creating the stable form that incorporates functions necessary for success involves re-establishing physical stability integrating the processes responsible for creating and maintaining the dimension, pattern, and profile of rivers. Such form variables are based on the driving variables of flow and sediment, as well as the boundary conditions of channel materials, riparian vegetation, boundary roughness, and the slope, width, and sinuosity of its valley (Rosgen 2011). River stability is defined as a river or stream's ability in the present climate to transport the stream flows and sediment of its watershed, over time, in such a manner that the channel maintains its dimension, pattern and profile without either aggrading or degrading (Rosgen 1996).

The methods presented in this chapter are heavily grounded in Natural Channel Design (NCD) methods, however, contain exceptions for alternative methods of analysis utilizing a threshold approach whereby the channel bed at a riffle is fixed. In general, geomorphic channel design should be considered when major restoration activities are warranted such as channel realignment or significant changes in dimension, pattern and profile are needed due to geomorphic instabilities within the system. There must also be sufficient length of channel (greater than 20 bankfull widths) to carry out a geomorphic channel design. If the stream is of high quality, and is not impaired due to geomorphic instabilities, a less invasive approach, such as riparian buffering or the use of limited structures may be a more appropriate solution.

The intent of this practice is to provide a general overview of the critical design elements in the geomorphic channel design process and provide an example of some of the required calculations. Many sources of information exist to guide restoration practitioners through the geomorphic channel design process. There are also training courses that practitioners can attend. Additional information, and detailed design guidance, can be found in the following documents:

- National Engineering Handbook Part 654 – Stream Restoration Design, USDA NRCS August 2007.
- Watershed Assessment of River Stability & Sediment Supply, Rosgen, 2009.
- Natural Channel Design (NCD): Fundamental Concepts, Assumptions & Methods, Rosgen, 2011.
- Guidance for Stream Restoration, U.S. Forest Service, May 2017.
- Natural Channel Design Checklist, US EPA, 2011

2.1.2 Minimum Qualifications

It is imperative that restoration practitioners have experience with field data collection, design, and construction. Being involved in all three of these phases yields invaluable experience and the ability to address challenges encountered during construction. Conversely, the experiences and lessons learned during construction allow practitioners to improve subsequent designs so that they are more easily constructible, practical, and sustainable. A tremendous amount of institutional knowledge is developed during the field data collection and design process that needs to be utilized during the construction phase. This is why the restoration practitioner responsible for the design should also be involved with the construction phase of the project.

The successful design and implementation of a geomorphic channel design project requires input from a multi-disciplinary team of restoration practitioners. The following are key minimum qualifications that a restoration practitioner must possess.

- A strong academic and applied science background in hydrology, hydraulics, geomorphology, geology, engineering, ecology, and/or biology.
- Demonstrated assessment, design, and construction oversight experience. At a minimum, the practitioner should have 4 years of experience designing stream restoration projects and/or over 10,000 feet of channel design experience. As an alternative, an individual may be working under the direct supervision of an experienced professional that meets the above requirements.
- Continuing education and/or training focused specifically on geomorphic channel design.

2.2 REFERENCE REACH DATA

A reference reach is a stable stream that has adjusted to the driving variables and boundary conditions within a watershed in such a way as to be self-maintaining. Reference reaches do not necessarily represent pristine systems. Instead a reference reach refers to the stable, most probable form that, over time and in the present climate, transports the water and sediment produced by its watershed in such a manner that the stream maintains its dimension, pattern, and profile without aggrading or degrading (Rosgen 1996).

This section provides an overview of reference reaches. Detailed descriptions and procedures can be found in many reference manuals including, but not limited to:

- USDA NRCS National Engineering Handbook Part 654 – Stream Restoration Design.
- River Stability Field Guide, Wildland Hydrology.
- A Function Based Framework for Assessment & Restoration Projects, Stream Mechanics.

2.2.1 Use of Reference Reaches

A reference reach is a stable stream that represents the same potential stream type, valley type, flow regime, sediment regime, streambank type, and riparian vegetation community as the existing reach. Estimates for stable channel design width, depth, and slope in an alluvial channel can be made using channel dimensions from a similar stable reference reach. The concept is that alluvial streams will evolve to the same stable channel dimensions, given the same independent driving hydraulic variables. Reference reaches are selected based on the potential conditions of the impaired, existing reach and are initially stratified by valley type and stream type. In some circumstances, it may be prudent to combine multiple or refine individual reference reaches into what is often referred to as a reference condition. Reference reaches are frequently mature systems and many characteristics of the channel may take time to develop in a stable fashion (i.e. steep banks, undercut banks, tight meander bends); thus, it is wise for the designer to temper many of the dimensionless ratios that come from a single reference reach. This is especially the case for the radius of curvature, which may be influenced by vegetation.

2.2.2 Characteristics of a Reference Reach

Reference reaches must reflect specific conditions of flow regime, sediment regime including sediment sizes, streambank materials, and the riparian vegetation community of the project site subject to alteration. Stream order and stream size must also be considered; stream order of the reference reach should generally fall within one order of the proposed design reach. Characteristics of a reference reach are as follows:

- A reach length of 20 bankfull widths or two meander wavelengths to capture the natural variability inherent in stream systems.
- Stable dimension, pattern, and profile verified by time-trend analysis.
- Predominantly stable channel banks.
- Same bed material as the project reach.
- Same stream type (See Figure 1Key to the Rosgen Stream Classification System) as the proposed stream type for the project reach.
- Channel boundaries are not constrained and free to adjust.
- Estimates of bankfull discharge are able to be made using regional curves, bankfull indicators, and gage analysis (http://iowafloodcenter.org/projects/stream-stage-sensor/).
- For projects with specific target species, the reference reach would ideally support that target community.

Locations of reference reaches, in order of preference are as follows:

1. Immediately upstream or downstream of the project reach.
2. In the same watershed as the project reach.
3. In the same hydrophysiographic region as the project reach.
4. In the same valley type with similar rainfall.

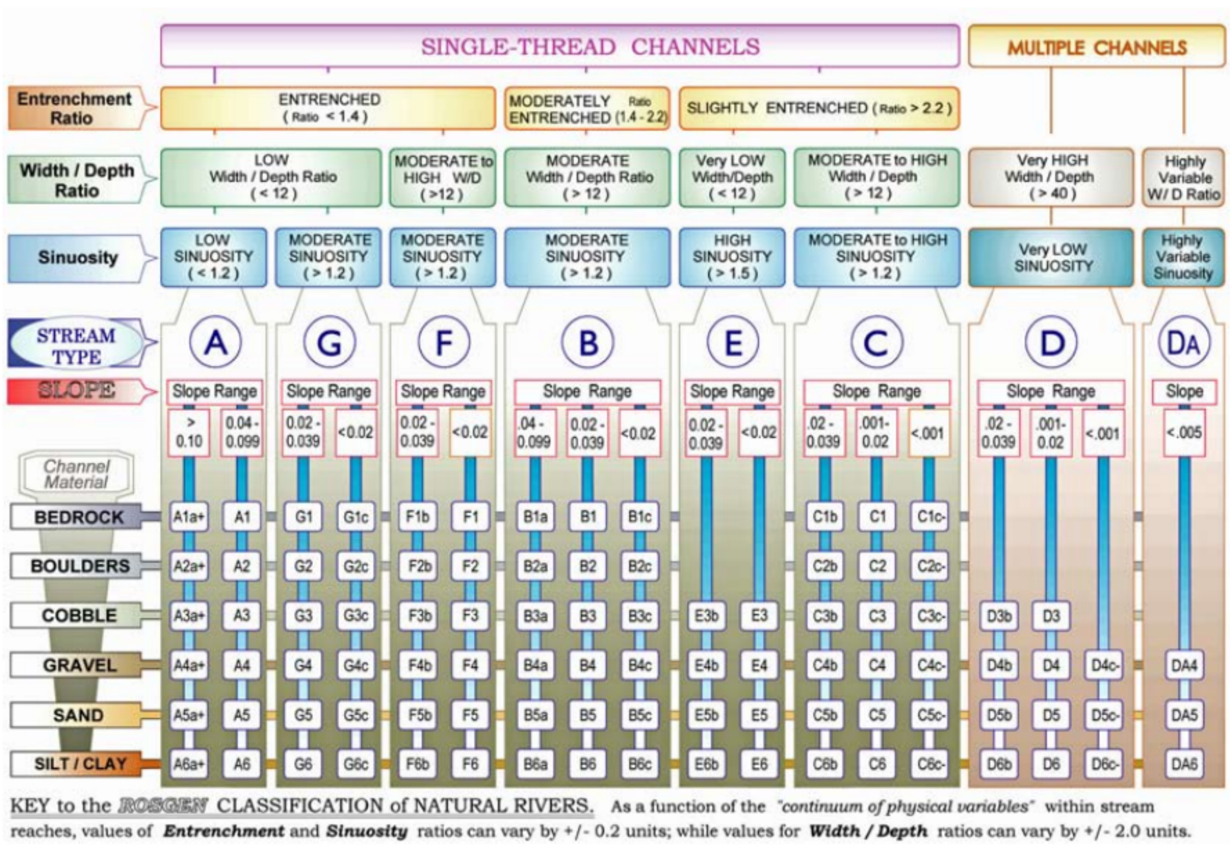

Figure 1. Key to the Rosgen Stream Classification System (USDA, 2007)

2.2.3 Minimum Data Requirements

The following minimum data requirements are intended to provide the practitioner with foundational information required to design a stream restoration project. Additional reference reach information can be obtained to support higher stream functions (macroinvertebrate community, water chemistry, etc.) but are not included in this section.

- Longitudinal Profile Survey (thalweg, water surface, bankfull, and low bank elevation).
- Cross Section Survey (riffle, run, pool, glide, step).
- Pebble Counts.
    - Representative – This pebble count is intended to sample all bed features within the bankfull channel and is ultimately used for stream classification. The study reach is divided into two categories: pools and riffles. The total distance of the reach is divided into total pool length and total riffle length. Samples are then

collected based on the percentage of pools and riffles in the study reach. A minimum of 100 observations are required.

- Active Bed – This pebble count characterizes bed material only at the surveyed riffle cross section and is used for hydraulic calculations. A minimum of 100 samples are taken within the active bed of the channel.

- Sediment Samples
    - Bar Samples - A core sample obtained on a point bar on the lower one-third of a bend, halfway between the bankfull stage and thalweg. This sample represents the size of bedload transport at bankfull stage.
    - Pavement/Sub-Pavement Samples – Sediment samples that are obtained when bar samples can't be collected. These samples are taken in the active riffle cross section.
- Riparian Vegetation Assessment.
- Geomorphic Assessments.
- Classification of Valley Type (see "Hierarchical Delineation of Fluvial Landscapes & Associated Stream Types" graphic, Wildland Hydrology) and Stream Type (see Figure 1: Key to the Rosgen Classification System).
- Hydrologic/Hydraulic data.
- Other assessment protocols as appropriate.

2.2.4 Development of Dimensionless Ratios

The reference reach is used to develop dimensionless relationships that represent the stable dimension, pattern, and profile for a given stream type and valley type. Ranges of values are then determined for each morphologic variable to represent the natural variability inherent in stream systems. The general process for developing dimensionless ratios is outlined below:

- Determine bankfull cross section geometry at a riffle for the reference reach and project reach.
- Determine ranges of geomorphic variables for the reference reach by surveying numerous cross sections and taking multiple pattern and profile measurements for each variable.

- Develop dimensionless ratios for the reference reach dividing by a normalization parameter, such as bankfull width, bankfull mean depth, bankfull cross section area (at a riffle), or channel slope at bankfull stage.

- Calculate dimensional values for the project reach by multiplying the dimensionless ratios for the reference reach by the dimensional values for the project reach.

A summary of the data typically collected to develop dimensional and dimensionless values for the reference reach and project reach is provided in Table 2.

Table 1. River Reach Summary Data (Rosgen, 2009)

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

River Reach Dimension Summary Data

Riffle Dimensions*, **, ***

Riffle Dimensions*, **, ***	Mean	Min	Max		Riffle Dimensions & Dimensionless Ratios****	Mean	Min	Max
Riffle Width (W_{bkf})				ft	Riffle Cross-Sectional Area (A_{bkf}) (ft^2)			
Riffle Mean Depth (d_{bkf})				ft	Riffle Width/Depth Ratio (W_{bkf} / d_{bkf})			
Riffle Maximum Depth (d_{max})				ft	Riffle Max Depth to Riffle Mean Depth (d_{max} / d_{bkf})			
Width of Flood-Prone Area (W_{fpa})				ft	Entrenchment Ratio (W_{fpa} / W_{bkf})			
Riffle Inner Berm Width (W_{ib})				ft	Riffle Inner Berm Width to Riffle Width (W_{ib} / W_{bkf})			
Riffle Inner Berm Depth (d_{ib})				ft	Riffle Inner Berm Depth to Mean Depth (d_{ib} / d_{bkf})			
Riffle Inner Berm Area (A_{ib})				ft^2	Riffle Inner Berm Area to Riffle Area (A_{ib} / A_{bkf})			
Riffle Inner Berm W/D Ratio (W_{ib} / d_{ib})								

Pool Dimensions*, **, ***

Pool Dimensions*, **, ***	Mean	Min	Max		Pool Dimensions & Dimensionless Ratios****	Mean	Min	Max
Pool Width (W_{bkfp})				ft	Pool Width to Riffle Width (W_{bkfp} / W_{bkf})			
Pool Mean Depth (d_{bkfp})				ft	Pool Mean Depth to Riffle Mean Depth (d_{bkfp} / d_{bkf})			
Pool Cross-Sectional Area (A_{bkfp})				ft	Pool Area to Riffle Area (A_{bkfp} / A_{bkf})			
Pool Maximum Depth (d_{maxp})				ft	Pool Max Depth to Riffle Mean Depth (d_{maxp} / d_{bkf})			
Pool Inner Berm Width (W_{ibp})				ft	Pool Inner Berm Width to Pool Width (W_{ibp} / W_{bkfp})			
Pool Inner Berm Depth (d_{ibp})				ft	Pool Inner Berm Depth to Pool Depth (d_{ibp} / d_{bkfp})			
Pool Inner Berm Area (A_{ibp})				ft^2	Pool Inner Berm Area to Pool Area (A_{ibp} / A_{bkfp})			
Point Bar Slope (S_{pb})				ft/ft	Pool Inner Berm Width/Depth Ratio (W_{ibp} / d_{ibp})			

Run Dimensions*

Run Dimensions*	Mean	Min	Max		Run Dimensionless Ratios****	Mean	Min	Max
Run Width (W_{bkfr})				ft	Run Width to Riffle Width (W_{bkfr} / W_{bkf})			
Run Mean Depth (d_{bkfr})				ft	Run Mean Depth to Riffle Mean Depth (d_{bkfr} / d_{bkf})			
Run Cross-Sectional Area (A_{bkfr})				ft	Run Area to Riffle Area (A_{bkfr} / A_{bkf})			
Run Maximum Depth (d_{maxr})				ft	Run Max Depth to Riffle Mean Depth (d_{maxr} / d_{bkf})			
Run Width/Depth Ratio (W_{bkfr} / d_{bkfr})				ft				

Glide Dimensions*

Glide Dimensions*	Mean	Min	Max		Glide Dimensions & Dimensionless Ratios****	Mean	Min	Max
Glide Width (W_{bkfg})				ft	Glide Width to Riffle Width (W_{bkfg} / W_{bkf})			
Glide Mean Depth (d_{bkfg})				ft	Glide Mean Depth to Riffle Mean Depth (d_{bkfg} / d_{bkf})			
Glide Cross-Sectional Area (A_{bkfg})				ft	Glide Area to Riffle Area (A_{bkfg} / A_{bkf})			
Glide Maximum Depth (d_{maxg})				ft	Glide Max Depth to Riffle Mean Depth (d_{maxg} / d_{bkf})			
Glide Width/Depth Ratio (W_{bkfg} / d_{bkfg})				ft/ft	Glide Inner Berm Width/Depth Ratio (W_{ibg} / d_{ibg})			
Glide Inner Berm Width (W_{ibg})				ft	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})			
Glide Inner Berm Depth (d_{ibg})				ft	Glide Inner Berm Depth to Glide Depth (d_{ibg} / d_{bkfg})			
Glide Inner Berm Area (A_{ibg})				ft^2	Glide Inner Berm Area to Glide Area (A_{ibg} / A_{bkfg})			

Step**

Step Dimensions**	Mean	Min	Max		Step Dimensionless Ratios****	Mean	Min	Max
Step Width (W_{bkfs})				ft	Step Width to Riffle Width (W_{bkfs} / W_{bkf})			
Step Mean Depth (d_{bkfs})				ft	Step Mean Depth to Riffle Mean Depth (d_{bkfs} / d_{bkf})			
Step Cross-Sectional Area (A_{bkfs})				ft	Step Area to Riffle Area (A_{bkfs} / A_{bkf})			
Step Maximum Depth (d_{maxs})				ft	Step Max Depth to Riffle Mean Depth (d_{maxs} / d_{bkf})			
Step Width/Depth Ratio (W_{bkfs} / d_{bkfs})				ft/ft				

Table 2. River Reach Summary Data (Rosgen, 2009)

	Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Channel Pattern	Linear Wavelength (λ)				ft	Linear Wavelength to Riffle Width (λ / W_{bkf})			
	Stream Meander Length (L_m)				ft	Stream Meander Length Ratio (L_m / W_{bkf})			
	Radius of Curvature (R_c)				ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})			
	Belt Width (W_{blt})				ft	Meander Width Ratio (W_{blt} / W_{bkf})			
	Arc Length (L_a)				ft	Arc Length to Riffle Width (L_a / W_{bkf})			
	Riffle Length (L_r)				ft	Riffle Length to Riffle Width (L_r / W_{bkf})			
	Individual Pool Length (L_p)				ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})			
	Pool to Pool Spacing (P_s)				ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})			

Channel Profile	Valley Slope (S_{val})		ft/ft	Average Water Surface Slope (S)		ft/ft	Sinuosity (S_{val} / S)		
	Stream Length (SL)		ft	Valley Length (VL)		ft	Sinuosity (SL / VL)		
	Low Bank Height (LBH)	start	ft	Max Bankfull Depth (d_{max})	start	ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start	
		end	ft		end	ft		end	

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

	Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Channel Profile	Max Riffle Depth (d_{max})				ft	Max Riffle Depth to Mean Riffle Depth (d_{max} / d_{bkf})			
	Max Run Depth (d_{maxr})				ft	Max Run Depth to Mean Riffle Depth (d_{maxr} / d_{bkf})			
	Max Pool Depth (d_{maxp})				ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})			
	Max Glide Depth (d_{maxg})				ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})			
	Max Step Depth (d_{maxs})				ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})			

2.3 DESIGN REACH ASSESSMENT

2.3.1 Identifying Impairments

The causes of impairment should be identified prior to beginning the geomorphic channel design process. Understanding the type and extent of each impairment can help assist in the development of restoration strategies, management plans, and prevention of future instabilities. The primary causes of impairment in stream systems, and subsequent loss of function, are frequently a result of:

- Direct Disturbance – Straightening of planform, profile modifications, cross section modifications, channel hardening or lining, floodplain encroachment, etc.
- Hydrologic Modification – Change in streamflow magnitude, volume, timing, and/or duration.
- Sedimentological Modification - Change in sediment concentration, loading, size, and/or type.
- Altered Riparian Vegetation – Change in vegetation type, density, extent, and/or vigor.

The list below outlines some possible indicators of channel instability in stream systems for both degradation and aggradation scenarios. When looking for these indicators, along with others, it is important to evaluate the design reach along with reach sections upstream and downstream of the design reach to gain an understanding of the surrounding conditions.

Evidence of Degradation

- Terraces (abandoned flood plains)
- Perched channels or tributaries
- Headcuts and nick-points
- Exposed pipe crossings
- Suspended culvert outfalls
- Undercut bridge piers
- Exposed or tree roots
- Leaning trees
- Narrow/deep channel

- Banks undercut on both sides/excessive erosion
- Armored bed
- Hydrophytic vegetation located high on bank
- Points of diversion for irrigation have been moved upstream
- Failed revetments due to undercutting

Evidence of Aggradation

- Buried structures such as culverts and outfalls
- Reduced bridge clearance
- Presence of mid-channel, transverse, and/or lateral bars
- Outlet of tributaries buried in sediment
- Significant sediment deposition in flood plain
- Buried vegetation
- Channel bed above the floodplain elevation
- Significant backwater in tributaries
- Uniform sediment deposition across channel
- Hydrophobic vegetation located low on bank or dead in flood plain

2.3.2 Minimum Data Requirements

The following minimum data requirements are intended to provide the practitioner with foundational information required to assess the condition of the design reach. Additional assessment information can be obtained to support higher stream functions (macroinvertebrate community, water chemistry, etc.) but are not included in this section. Data collected for the design reach is compiled in Table 3.

- Longitudinal Profile Survey (thalweg, water surface, bankfull, and low bank elevation).
- Cross Section Survey (riffle, run, pool, glide, steps).
- Pebble Counts:

- Representative – This pebble count is intended to sample all bed features within the bankfull channel and is ultimately used for stream classification. The study reach is divided into two categories: pools and riffles. The total distance of the reach is divided into total pool length and total riffle length. Samples are then collected based on the percentage of pools and riffles in the study reach. A minimum of 100 observations are required.

- Active Bed – This pebble count characterizes bed material only at the surveyed riffle cross section and is used for hydraulic calculations. A minimum of 100 samples are taken within the active bed of the channel.

- Sediment Samples:

    - Bar Samples - A core sample obtained on a point bar on the lower two-thirds of a bend, halfway between the bankfull stage and thalweg. This sample represents the size of bedload transport at bankfull stage.

    - Pavement/Sub-Pavement Samples – Sediment samples that are obtained when bar samples can't be collected. These samples are taken in the active riffle cross section.

- Riparian Vegetation Assessment.

- Geomorphic Assessments.

- Hydrologic/Hydraulic data.

- Classification of Existing and Potential Valley Type and Stream Type.

2.3.3 Assessment Analysis

The assessment data collected for the design reach is compared to the assessment data for the reference reach in order to quantify the degree of instability for the design reach. The categories in Table 3 are populated with data collected from the design reach assessment and with data generated from comparing specific features from the design reach to those of the reference reach.

Table 3. Summary of Design Reach Stability Conditions (Rosgen, 2009)

Summary of Stability Conditions Categories										
Stream:					Location:					
Observers:			Date:		Stream Type:			Valley Type:		
Channel Dimension	Mean Bankfull Depth (ft):	Bankfull Width (ft):	Cross-Sectional Area (ft^2):	Width/Depth Ratio:	Entrenchment Ratio:					
Channel Pattern	Mean: Range:	λ/W_{bkf}:	L_m/W_{bkf}:	R_c/W_{bkf}:	MWR:	Sinuosity:				
Streamflow	Bankfull Mean Velocity ($\bar{u}_{bkf}$) (ft/sec):	Bankfull Discharge (Q_{bkf}):	Estimation Method:	Drainage Area (mi^2):						
River Profile & Bed Features	Check: ☐ Riffle/Pool ☐ Step/Pool ☐ Plane Bed ☐ Convergence/Divergence ☐ Dunes/Antidunes/Smooth Bed									
	Max Bankfull Depth (ft):	Riffle	Pool	Depth Ratio (max to mean):	Riffle	Pool	Pool-to-Pool Spacing:	Ratio	Slope Valley:	Water Surface:
Level III Stream Stability Indices	Riparian Vegetation	Current Composition/Density:	Potential Composition/Density:	Remarks: Condition, Vigor & Usage of Existing Reach:						
	Flow Regime:	Stream Size & Order:	Meander Patterns:	Depositional Patterns:	Debris/Channel Blockages:					
	Degree of Incision (Bank-Height Ratio):	Degree of Incision Stability Rating:	Modified Pfankuch Stability Rating (Numeric & Adjective Rating):							
	W/d Ratio State (W/d) / (W/d_{ref}):	W/d Ratio State Stability Rating:	Degree of Confinement (MWR / MWRref):	MWR / MWRref 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:	Required Depth:	Existing Slope:	Required Slope:			
Stream Succession	→ → → → →	Existing Stream State (Type):	Potential Stream State (Type):							
Lateral Stability	☐ *Stable* ☐ *Mod. Unstable* ☐ *Unstable* ☐ *Highly Unstable*	Remarks:								
Vertical Stability (Aggradation)	☐ *No Deposition* ☐ *Mod. Deposition* ☐ *Ex. Deposition* ☐ *Aggradation*	Remarks:								
Vertical Stability (Degradation)	☐ *Not Incised* ☐ *Slightly Incised* ☐ *Mod. Incised* ☐ *Degradation*	Remarks:								
Channel Enlargement	☐ *No Increase* ☐ *Slight Increase* ☐ *Mod. Increase* ☐ *Extensive*	Remarks:								
Sediment Supply (Channel Source)	☐ *Low* ☐ *Moderate* ☐ *High* ☐ *Very High*	Remarks:								

2.4 CHECKING FOR SEDIMENT TRANSPORT

A key to predicting river instability and associated loss of function relies on knowing the ability of a stream to move the sediment size and sediment volume contributed by the watershed and stream banks. There are two types of sediment transport calculations that should be completed for each project: sediment competence and sediment capacity.

Sediment competence is the ability of the river to move the largest particle made available from the immediate upstream supply. Sediment capacity is the ability of the river to move the quantity (volume) of incoming sediment on an annualized basis. Detailed procedures for calculating sediment competence and capacity are provided in the following design references:

- National Engineering Handbook Part 654 – Stream Restoration Design, USDA NRCS August 2007.
- Watershed Assessment of River Stability & Sediment Supply, Rosgen, 2009.

2.4.1 Competence

Sediment competence calculations are appropriate for gravel, cobble, and boulder-bed stream systems. Sand-bed streams are not evaluated for competence because the entire bed is assumed to be mobile at the bankfull discharge. The general premise of sediment competence evaluation is to compare existing channel hydraulics to the hydraulic conditions required to mobilize the largest anticipated particle size during bankfull flow. With this information, a general determination of channel stability can be made. Sediment competence calculations require the following data:

- **Sediment Samples:**
  - Bar Samples - A core sample obtained on a point bar on the lower two-thirds of a bend, halfway between the bankfull stage and thalweg. This sample represents the size of bedload transport at bankfull stage.
  - Pavement/Sub-Pavement Samples – Sediment samples that are obtained when bar samples can’t be collected. These samples are taken in the active riffle cross section.
- **Pebble Count** – Taken at the active riffle bed.
- **Hydraulic Data** – Bankfull water surface slope, mean depth, dimensionless shear stress, dimensional shear stress.

The general procedure for calculating sediment competence is outlined in Figure 2. The data table used to summarize sediment competence calculations is provided in Figure 3.

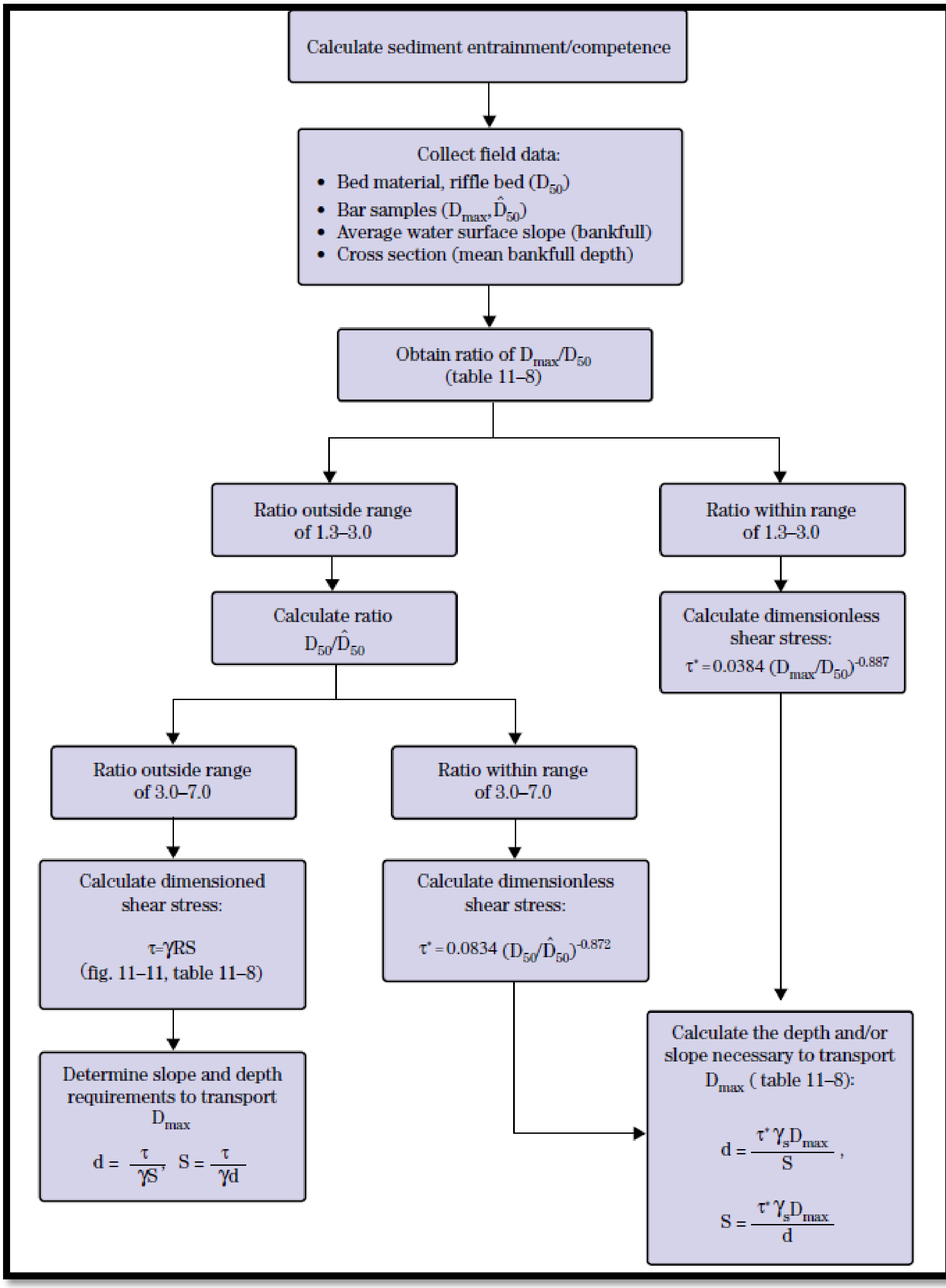

Figure 2. General Procedure to Calculate Sediment Competence (USDA, 2007)

Stream:			Reach:		
Observers:				Date:	
Enter required information					
	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:	$\tau^* = 0.0834\left(\frac{D_{50}}{\hat{D}_{50}}\right)^{-0.872}$	
	D_{max} / D_{50}	Range: 1.3 – 3.0	Use equation 2:	$\tau^* = 0.0384\left(\frac{D_{max}}{D_{50}}\right)^{-0.887}$	
	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)		$d = \frac{\tau^* \gamma_s D_{max}}{S}$	
	Circle:	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)		$S = \frac{\tau^* \gamma_s D_{max}}{d}$	
	Circle:	Stable Aggrading Degrading			
Sediment competence using dimensional shear stress					
	Bankfull shear stress $\tau = \gamma d S$ (lb/ft^2) (substitute hydraulic radius, R, with mean depth, d)				
	Moveable particle size (mm) at bankfull shear stress (fig. 11-11)				
	Predicted shear stress required to initiate movement of D_{max} (mm) (figure 11-11)				
	Predicted mean depth required to initiate movement of D_{max} (mm)			$d = \frac{\tau}{\gamma S}$	
	Predicted slope required to initiate movement of D_{max} (mm)			$S = \frac{\tau}{\gamma d}$	

Figure 3. Sediment Competence Data Table (Rosgen, 2009)

Following the flow chart provided in Figure 2 and worksheet provided in Figure 3, two sets of hydraulic computations are generated:

1. Existing hydraulic and sediment characteristics:
    a. Measured largest particle from the bar sample.
    b. Mean depth and slope at bankfull stage.
2. Predictive hydraulic and sediment characteristics:
    a. Using critical dimensionless shear stress:
        i. Mean bankfull depth required to entrain the largest particle from the bar sample.
        ii. Bankfull water surface slope required to entrain the largest particle from the bar sample.
    b. Using critical shear stress:
        i. Largest movable particle size at bankfull shear stress.
        ii. Shear stress required to initiate movement of the largest particle from the bar sample.
        iii. Mean bankfull depth required to entrain the largest particle from the bar sample.
        iv. Bankfull water surface slope required to entrain the largest particle from the bar sample.

With this information, a general determination of channel aggradation or degradation can be made by comparing the existing hydraulics and sediment characteristics of the results of the predictive hydraulic and sediment calculations. Note that if the channel is stable with respects to sediment competence, it may still be subject to aggradation/degradation with respects to sediment capacity. If the channel is found to be subject to aggradation or degradation, then variables should be adjusted until the channel can transport sediment with respects to both sediment competence and capacity. A number of variables may be adjusted if this is the case, with width/depth ratio (riffle), sinuosity, channel bankfull slope and mean bankfull depth (riffle) being the most common adjusted variables.

2.4.2 Capacity

A primary objective of Geomorphic Channel Design is creating a channel capable of transporting the ***quantity*** of sediment delivered by upstream erosion, entrainment, and transport processes. Sediment transport capacity analyses compliment sediment transport competency analyses aimed at evaluating the ***size*** of particle that can be entrained (moved) at a particular flow. Total annual sediment yield is a useful property for evaluating sediment transport capacity, as it serves as a prediction of the total quantity of sediment transported through a particular cross section based on the annual flow and the quantity of sediment available for transport. Since flow is independent of changes to the river dimensions and the relationship between flow and sediment transport is based on field conditions, the total sediment yield can be used to evaluate changes to river geometry and associated hydraulics. Figure 4 illustrates the process for evaluating sediment transport capacity.

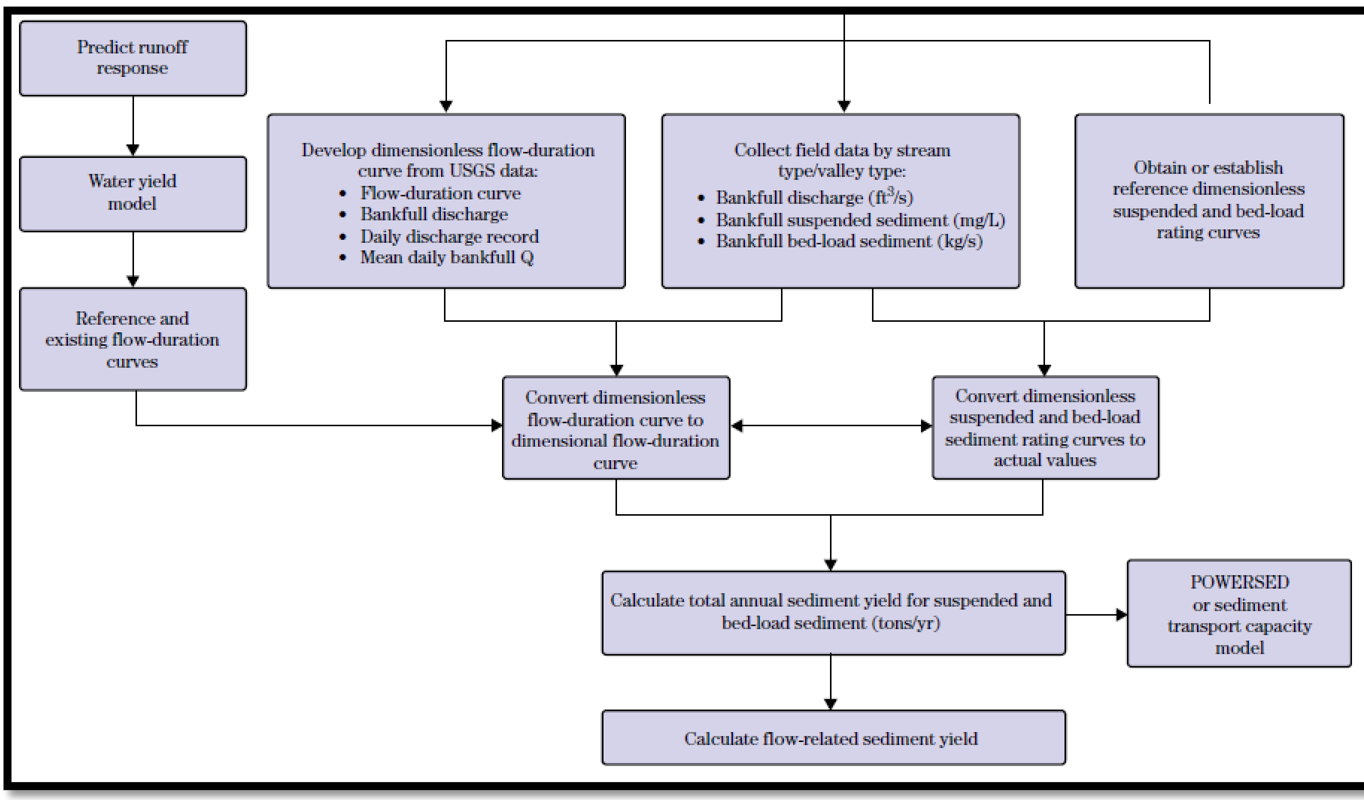

Figure 4. Sediment Capacity Transport Flow Chart (USDA, 2007)

2.4.2.1 FLOWSED/POWERSED

One available methodology to compute rational results for evaluating sediment transport capacity is the use of the FLOWSED and POWERSED models. FLOWSED and POWERSED are two models used in concert for predicting annual sediment yield in rivers and evaluating changes in sediment transport capacity between two conditions for a particular segment of river. FLOWSED computes a total annual sediment yield based on a Flow Duration Curve (FDC), which is a distribution of flows over a typical water year based on data from a stream gage, and a

Sediment Rating Curve (SRC), which is a relationship between flow and transport rate. SRCs can be derived from a Dimensionless Sediment Rating Curve (DSRC), which are derived from extensive array of measured bankfull bedload and suspended load transport rates and made dimensionless, accordingly, using respective bankfull discharge and sediment transport rates. The resultant relationships are non-linear and stratified by Good/Fair or Poor stream conditions per the Pfankuch stability rating (Pfankuch, 1975). SRCs can also be calculated using a variety of sediment transport equations. Note that sediment transport equations were often developed for specific conditions and can be off be an order of magnitude, or more. Care must be taken in selecting the appropriate sediment transport equation, as the implications for appropriate channel design dimensions could similarly be off by orders of magnitude.

POWERSED integrates the dimensionless flow-duration curves in FLOWSED for a comparative (supply) reach by stream power, which is calculated for each stage based on hydraulic geometry. This relationship is then applied to the evaluation reach in a similar manner to predict the annual sediment yield. Using stream power accounts for changes in velocity, slope, hydraulic radius and/or roughness, providing a means for determining the effects of changes in hydraulic geometry and boundary conditions on transport capacity. Once complete, the output of the POWERSED model is a comparison of the annual yield of a supply reach to an evaluation reach. Multiple scenarios can be evaluated to ascertain the effects changes in slope, width/depth, and other hydraulic conditions have on transport capacity. The comparative (supply) reach represents the total annual sediment available to the system and the evaluation reach embodies the quantity of sediment the cross section of interest is capable of transporting. Agreement in the annual sediment yield between the comparative (supply) and evaluation reaches indicates stability of the evaluation reach. If the supply is greater than the capacity of the evaluation reach, the channel is predicted to be in a state of aggradation; conversely, if the supply is less than the capacity of the evaluation reach, the channel is said to be in a state of degradation.

Model inputs include:

- ***Cross section of sediment supply reach***—a reach that is transporting sediment without aggrading or degrading; this cross section can be scaled up or down to match the bankfull properties of the cross section being evaluated. Note that the cross section does not necessarily need to be located within a reference reach. Ideally the supply reach cross section is located on the same stream as the study reach. If a supply cross section is not available in close proximity to the study reach, it can either be located upstream or downstream or within a nearby watershed.
- ***Cross section of channel to be evaluated***—this generally is a reach being assessed against a reference condition for departure analysis or a design cross section being evaluated for capacity**.**
- ***Bankfull discharge***—this is necessary for the supply reach, evaluation reach and gage.
- ***Mean Daily Equivalent for bankfull discharge***—this relationship is important for deriving the flow duration curve from daily mean flow data; the relationship between the bankfull discharge (typically a momentary maximum value) and the mean daily flow for the day on which a bankfull flow occurs is important for extrapolating flow

values, particularly on rainfall driven systems (bankfull discharge and its mean daily equivalent are often equal on snow melt driven systems).

- ***Bankfull bedload transport rate***—ideally this value is measured at the site where the evaluation is being performed.
- ***Bankfull suspended sediment transport rate***—this includes both total suspended sediment and total suspended sediment less wash load.
- ***Stream gage peak annual and mean daily flows for nearby stream***—this is derived from a nearby gage and is scaled up or down based on the bankfull discharge at the study site.
- ***Dimensionless Sediment Rating Curve (DSRC)***—Rosgen and others has derived dimensionless sediment rating curves for bedload and suspended sediment for Good/Fair and Poor Pfankuch stability ratings (Troendle, 2001). Custom DSRCs for a specific area should also be considered.

Model output includes:

- ***Flow Duration Curve***—the gage data input into the model is made dimensionless by bankfull discharge and then scaled up or down to the supply reach by bankfull discharge; likewise, the mean daily equivalent for the bankfull discharge is also generated by the model.
- ***Sediment Rating Curves (SRCs)***—using the bankfull bedload and suspended sediment transport rates, the dimensionless rating curve input above is made dimensional, resulting in a relationship between discharge and transport rate for bedload, total suspended sediment and total suspended less wash load
- ***FLOWSED***—total annual sediment yield based solely on the flow duration curve and sediment rating curves.
- ***POWERSED Results for Supply Reach***—by integrating the total rates for bedload and suspended less wash load by unit stream power, the model predicts a total predicted annual sediment yield for the supply reach, which is essentially the quantity of sediment available to the system.
- ***POWERSED Results for Evaluation Reach***—the transport/unit stream power relationship is applied to the evaluation cross section to predict the total annual sediment yield, which is essentially the total transport capacity of the reach being evaluated.

2.4.2.2 Other Sediment Transport Equations

Note many other sediment transport equations are available which generate a sediment rating curve (SRC). Ultimately sediment yield is predicted based on the flow duration curve (which indicates the percent of time the stream is at various discharges for an average year) and the SRC (which predicts how much sediment is moved for a given discharge). For more information on sediment transport equations refer to Chapter 9 of National Engineering Handbook Part 654 – Stream Restoration Design, USDA NRCS, August 2007 as well as Complexity of Bedload Transport in Gravel Bed Streams: Data Collection, Prediction, and Analysis, Hinton, 2012.

2.5 ALLUVIAL CHANNEL DESIGN

2.5.1 Narrative Description

Alluvial rivers are free to adjust dimension, pattern, and profile in response to hydraulic changes. Alluvial streams flow through channels with bed and banks made of sediments transported by the stream. In alluvial streams, the independent variables that drive the hydraulic design of the channel are discharge, sediment inflow, and bed and bank-material composition. The dependent or design variables are width, depth, slope, and planform. Channel-forming discharge is typically used to determine preliminary channel dimensions, but the full range of expected discharges should be used to evaluate the design and the ability of the channel to handle flood flows (USDA, 2007)

Alluvial channel design techniques are generally used for movable boundary systems and streams with beds and banks made of unconsolidated sediment particles. In an alluvial channel, there is a continual exchange of the channel boundary material with the flow (USDA, 2007). Therefore, the design of an alluvial channel as part of a restoration project requires an assessment of sediment continuity and channel performance for a range of flows. A wide variety of sources and techniques are available to the designer for designing stable alluvial channels.

2.5.2 Key Design Components

There are several methods available for completing an alluvial channel design. The preferred method is through the use of a reference reach. Estimates for stable channel design width, depth, and slope in an alluvial channel can be made using channel dimensions from a similar stable channel (reference reach). The concept is that alluvial streams will evolve to the same stable channel dimensions, given the same independent driving hydraulic variables (NRCS 2007). Key design components for the reference reach approach consist of applying dimensionless ratios describing the reference reach dimension, pattern, and profile to develop dimensional values for the design reach. In order to successfully apply the reference reach method, it is imperative that the practitioner correctly quantify the bankfull flow for the design project. The incorrect quantification of bankfull flow will result in the generation of erroneous dimensional values being extracted from the reference reach data.

Once the basic design is derived based on dimensionless ratios, the design must be checked for sediment transport competence and capacity as described in section 2.4 above. If the channel is found to be subject to aggradation or degradation, then variables should be adjusted until the channel can transport sediment with respects to both sediment competence and capacity. A number of variables may be adjusted if this is the case, with width/depth ratio (riffle), sinuosity, channel bankfull slope and mean bankfull depth (riffle) being the most common adjusted variables, as these variables directly affect shear stress.

Generally, the riffle cross section and basic pattern variables should be determined first. Sediment transport/riffle geometry should then be checked through an iterative process until a successful design is achieved. Afterwards, the remaining cross section and profile features (pool, runs, glides, etc.) should be calculated. If the channel is at risk for some minor degradation, the use of grade control structures should be considered to minimize channel downcutting.

2.5.3 Example Calculations

The following example calculation outlines the computational sequence for the initial design for an alluvial channel dimension, pattern, and profile using the reference reach method. It is important to note that solutions obtained using the reference reach method should be verified with sediment transport competency and capacity calculations and refined if necessary. This is also just meant to be an example of some of the calculations and is not an exhaustive list. Refer to the sources in Section 2.1.1 for more detailed information.

Problem

The project reach is located in a watershed where regional curves have been developed for several stable stream segments. The project reach has a drainage area of 3 square-miles and has been damaged by overgrazing. You have obtained reference reach information from a stable stream system downstream of the project reach and will be using this data to develop a preliminary design. Some of the reference reach data obtained includes, bankfull width (38.8 feet), mean depth (1.7 feet), pool to pool spacing (245.6 feet), radius of curvature (132.4 feet), and meander wavelength (467.2 feet).

Solution

The regional curve shown in the graph below represents bankfull flow as a function of drainage area. Applying the drainage area of 3 square-miles to the power function below yields a bankfull flow of approximately 21.3 cubic feet-per-second.

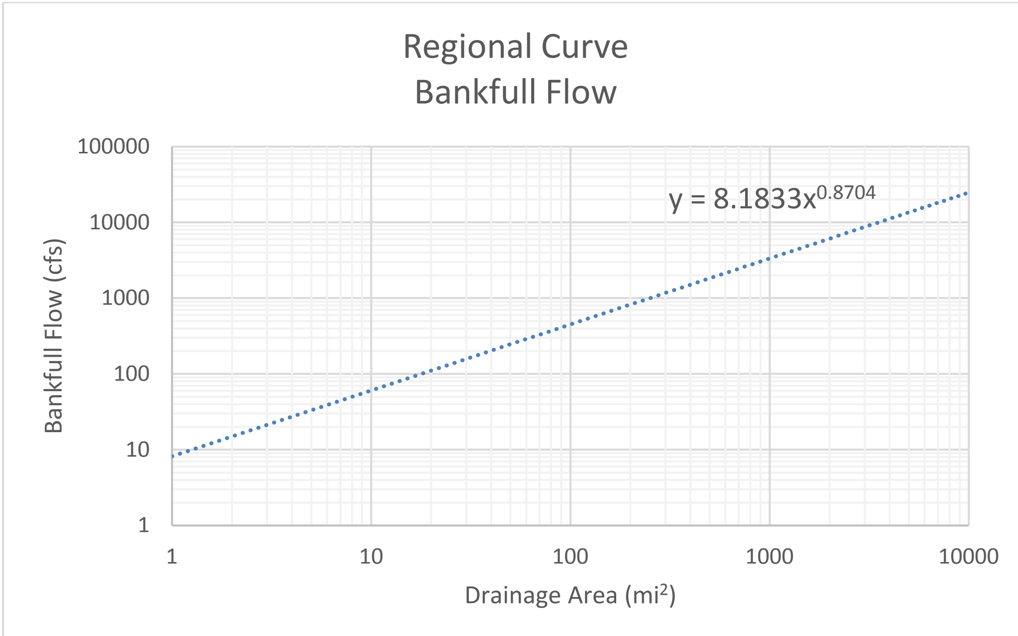

Figure 5. Example Bankfull Discharge Regional Curve

The regional curve shown in the graph below represents bankfull cross section area as a function of drainage area. Applying the drainage area of 3 square-miles to the power function below yields a bankfull cross section area of approximately 11.5 square feet.

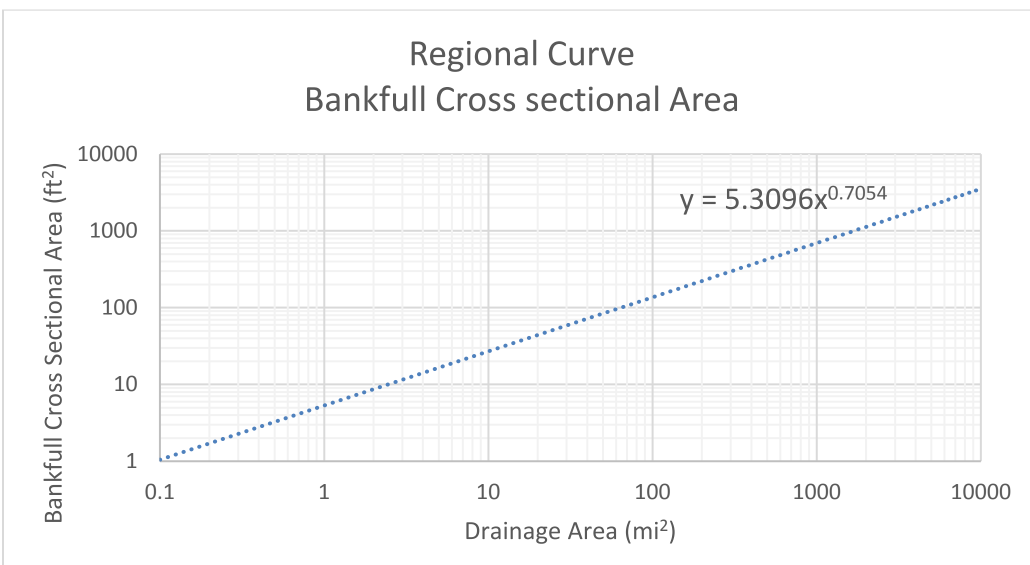

Figure 6. Example Bankfull Area Regional Curve

The reference reach data can be utilized to calculate dimension and pattern values by applying the estimated bankfull cross section area for the project reach. Begin by solving for Riffle Mean Depth and Width as shown below.

1. Solve for the design Riffle Mean Depth (d_{bkf})

   a) Area (A_{bkf}) = Width (W_{bkf}) * d_{bkf}

   b) Width to Depth Ratio = W_{bkf}/d_{bkf}

   c) Therefore: d_{bkf} = sqrt (A/(W_{bkf}/d_{bkf})) = sqrt(11.5/(38.8/1.70)) = 0.71 feet

2. Solve for the design Width

   a) W_{bkf} = A_{bkf} / d_{bkf} = 11.5 / 0.71 = 16.2 feet

3. Solve for the design Pool to Pool Spacing

   a) $P\text{-}P_{ref}/W_{bkf\ ref}$ = 245.6 / 38.8 = 6.33

   b) $P\text{-}P_{des}$ = 6.33 * W_{bkf} = 6.33 * 16.2 = 102.5 feet

4. Solve for the design Radius of Curvature

   a) $R_{c\ ref}$ / $W_{bkf\ ref}$ = 132.4 / 38.8 = 3.41

   b) $R_{c\ des}$ = 3.41 * W_{bkf} = 3.41 * 16.2 = 55.3 feet

5. Solve for Meander Wavelength

   a) MWL_{ref} / $W_{bkf\ ref}$ = 467.2 / 38.8 = 12.04

   b) MWL_{des} = 12.04 * W_{bkf} = 12.04 * 16.2 = 195 feet

The tables below show both the parameters obtained from the reference reach and those calculated for the proposed design reach. Dimensions used for the design reach are obtained directly from the reference reach ratios. After riffle cross sectional and stream pattern information is determined, it is necessary to check for sediment transport competency and capacity. Note that this table is available in spreadsheet format on Iowa DNR's website.

Table 4. Example Proposed Design Table (Rosgen, 2015)

	Variable	Proposed Design Reach		Reference Reach	
Riffle Dimensions	Riffle Width, ft (W_{bkf})	*Mean:*	16.2	*Mean:*	38.8
		Min:	15.2	*Min:*	37.8
		Max:	17.4	*Max:*	39.8
	Riffle Mean Depth, ft (d_{bkf})	*Mean:*	0.71	*Mean:*	1.70
		Min:	0.66	*Min:*	1.51
		Max:	0.76	*Max:*	1.88
	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:*	22.8	*Mean:*	22.8
		Min:	20.1	*Min:*	20.1
		Max:	26.4	*Max:*	26.4
	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:*	11.5	*Mean:*	66.0
				Min:	57.0
				Max:	75.1
	Riffle Maximum Depth (d_{max})	*Mean:*	1.16	*Mean:*	2.79
		Min:	1.11	*Min:*	2.65
		Max:	1.23	*Max:*	2.95
	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:*	1.641	*Mean:*	1.641
		Min:	1.559	*Min:*	1.559
		Max:	1.735	*Max:*	1.735
Pool Dimensions	Pool Width, ft (W_{bkfp})	*Mean:*	14.9	*Mean:*	35.8
		Min:	13.2	*Min:*	31.5
		Max:	16.7	*Max:*	40.0
	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	0.923	*Mean:*	0.923
		Min:	0.812	*Min:*	0.812
		Max:	1.031	*Max:*	1.031
	Pool Mean Depth, ft (d_{bkfp})	*Mean:*	0.97	*Mean:*	2.32
		Min:	0.95	*Min:*	2.27
		Max:	0.99	*Max:*	2.37
	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	1.365	*Mean:*	1.365
		Min:	1.335	*Min:*	1.335
		Max:	1.394	*Max:*	1.394
	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	15.4	*Mean:*	15.4
		Min:	13.3	*Min:*	13.3
		Max:	17.6	*Max:*	17.6
	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	14.5	*Mean:*	83.2
		Min:	12.5	*Min:*	71.6
		Max:	16.5	*Max:*	94.7
	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	1.261	*Mean:*	1.261
		Min:	1.085	*Min:*	1.085
		Max:	1.435	*Max:*	1.435
	Pool Maximum Depth (d_{maxp})	*Mean:*	2.05	*Mean:*	4.90
		Min:	1.89	*Min:*	4.52
		Max:	2.20	*Max:*	5.27
	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	2.882	*Mean:*	2.882
		Min:	2.659	*Min:*	2.659
		Max:	3.100	*Max:*	3.100

Table 5. Example Proposed Design Table (Rosgen, 2015)

	Variable	Proposed Design Reach		Reference Reach	
Channel Pattern	Linear Wavelength, ft (λ)	*Mean:*	**195.1**	*Mean:*	**467.2**
		Min:	**175.0**	*Min:*	**419.1**
		Max:	**207.4**	*Max:*	**496.7**
	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**12.040**	*Mean:*	**12.040**
		Min:	**10.800**	*Min:*	**10.800**
		Max:	**12.800**	*Max:*	**12.800**
	Stream Meander Length, ft (L_m)	*Mean:*	**222.0**	*Mean:*	**531.6**
		Min:	**199.3**	*Min:*	**477.2**
		Max:	**244.6**	*Max:*	**585.9**
	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**13.701**	*Mean:*	**13.701**
		Min:	**12.299**	*Min:*	**12.299**
		Max:	**15.101**	*Max:*	**15.101**
	Belt Width, ft (W_{blt})	*Mean:*	**81.7**	*Mean:*	**195.6**
		Min:	**65.0**	*Min:*	**155.6**
		Max:	**115.0**	*Max:*	**275.5**
	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**5.041**	*Mean:*	**5.041**
		Min:	**4.010**	*Min:*	**4.010**
		Max:	**7.101**	*Max:*	**7.101**
	Radius of Curvature, ft (R_c)	*Mean:*	**55.3**	*Mean:*	**132.4**
		Min:	**35.7**	*Min:*	**85.4**
		Max:	**73.2**	*Max:*	**175.2**
	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**3.412**	*Mean:*	**3.412**
		Min:	**2.201**	*Min:*	**2.201**
		Max:	**4.515**	*Max:*	**4.515**
	Arc Length, ft (L_a)	*Mean:*	**58.5**	*Mean:*	**140.2**
		Min:	**34.0**	*Min:*	**81.5**
		Max:	**82.9**	*Max:*	**198.6**
	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**3.613**	*Mean:*	**3.613**
		Min:	**2.101**	*Min:*	**2.101**
		Max:	**5.119**	*Max:*	**5.119**
	Riffle Length (L_r), ft	*Mean:*	**50.2**	*Mean:*	**120.3**
		Min:	**34.0**	*Min:*	**81.5**
		Max:	**65.0**	*Max:*	**155.6**
	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**3.101**	*Mean:*	**3.101**
		Min:	**2.101**	*Min:*	**2.101**
		Max:	**4.010**	*Max:*	**4.010**
	Individual Pool Length, ft (L_p)	*Mean:*	**35.7**	*Mean:*	**85.4**
		Min:	**29.1**	*Min:*	**69.8**
		Max:	**44.6**	*Max:*	**106.7**
	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**2.201**	*Mean:*	**2.201**
		Min:	**1.799**	*Min:*	**1.799**
		Max:	**2.750**	*Max:*	**2.750**
	Pool to Pool Spacing, ft (P_s)	*Mean:*	**102.5**	*Mean:*	**245.6**
		Min:	**81.0**	*Min:*	**194.0**
		Max:	**121.5**	*Max:*	**291.0**
	Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**6.327**	*Mean:*	**6.330**
		Min:	**5.000**	*Min:*	**5.000**
		Max:	**7.500**	*Max:*	**7.500**

The calculation of profile design features requires additional input of the proposed stream length and valley length, as show in the table below.

Table 6. Example Proposed Design Profile Table (Rosgen, 2015)

	Variable	Proposed Design Reach	Reference Reach
Sinuosity and Slope	Stream Length (SL)	**5650**	**2850**
	Valley Length (VL)	**5280**	**2500**
	Valley Slope (S_{val})	**0.0120**	**0.0114**
	Sinuosity (k)	SL/VL: **1.07**	SL/VL: **1.14** VS/S: **1.14**
	Average Water Surface Slope (S)	$S = S_{val}/k$ **0.0112**	**0.0100**
Water Surface Facet Slopes	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* **0.0183** *Min:* **0.0149** *Max:* **0.0237**	*Mean:* **0.0163** *Min:* **0.0133** *Max:* **0.0211**
	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **1.6300** *Min:* **1.3300** *Max:* **2.1100**	*Mean:* **1.6300** *Min:* **1.3300** *Max:* **2.1100**
	Pool Slope (water surface facet slope) (S_p)	*Mean:* **0.0011** *Min:* **0.0011** *Max:* **0.0025**	*Mean:* **0.0010** *Min:* **0.0010** *Max:* **0.0022**
	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **0.1000** *Min:* **0.1000** *Max:* **0.2200**	*Mean:* **0.1000** *Min:* **0.1000** *Max:* **0.2200**

2.6 THRESHOLD CHANNEL DESIGN

2.6.1 Narrative Description

A threshold channel is a channel in which movement of the channel boundary material is negligible during the design flow. The term threshold is used because the applied forces from the flow are below the threshold for movement of the channel bed. Therefore, the channel bottom is assumed to be non-moveable if the design stress is below the critical or recommended stress for the channel boundary. Design issues include assessing the limiting force and estimating the applied force. A requirement for a channel to be considered a threshold channel is that the sediment transport capacity must greatly exceed the inflowing sediment load so that there is no significant exchange of material between the sediment carried by the stream and the bed. Noncohesive material forming the channel boundary must be larger than what the normal range of flows can transport. For boundaries of cohesive materials, minor amounts of detached material can be transported through the system (NRCS 2007).

Examples of threshold channels include stream systems that are composed of very coarse material or erosion-resistant bedrock, clay soil, or grass lining. Streams where the boundary materials are remnants of processes no longer active in the stream system may be threshold streams. Examples are streambeds formed by high runoff during the recession of glaciers or dam breaks, streams armored due to degradation, and constructed channels where channel movement is unacceptable for the design flow (NRCS 2007). Additionally, if the stream system at one point had a significant sediment supply and that sediment source has been significantly reduce due to urbanization or construction of detention facilities, it may be necessary to design a threshold channel.

Threshold channels differ from movable bed or alluvial channels which show interaction between the incoming sediment load, flow, and channel boundary. In an alluvial channel, the bed and banks are formed from material that is transported by the stream under present flow conditions. The incoming sediment load and bed and bank material of an alluvial channel interact and exchange under design or normal flow conditions. Essentially, the configuration of a threshold channel is fixed under design conditions. An alluvial channel is free to change its shape, pattern, and planform in response to short- or long-term variations in flow and sediment (NRCS 2007).

Many sources and techniques for designing stable threshold channels are available to the restoration practitioner. This practice provides an overview and description of some of the most common threshold channel design techniques.

2.6.2 Key Design Components

With respects to channel features, a threshold channel should be designed in the same manner as an alluvial channel through the use of a reference reach (See Section 2.5 above). The main difference is that the riffles will be designed not to mobilize during a design storm event. Additionally, the design will also need to be checked relative to sediment transport capacity, as it is possible to design a channel so that the riffles do not mobilize, yet still have the channel subject to aggradation due to lack of sediment transport capacity. There are several different methods, outlined below, for designing a threshold channel to have riffles that do not mobilize. Additional detail for these design processes is outlined in NRCS NEH Part 654 – Stream Restoration Design.

- **Allowable Velocity Method** – To design a threshold channel using the allowable velocity method, average channel velocity is calculated for the proposed channel and compared to published allowable velocities for the boundary material. The average channel velocity in the design channel can be determined using a normal depth equation or a computer backwater model. Increased velocities at bends can be accounted for, using applicable charts and equations.

- **Allowable Shear Stress Method** – To design a threshold channel using the allowable shear stress approach, the average applied grain bed shear stress is compared to the allowable shear stress for the boundary material. The applied grain bed shear stress can be calculated from the hydraulic parameters determined for the design channel and the characteristics of the channel boundary material. This method also relies on sediment transport competency calculations similar to that described in Section 2.4.1 above.

- **Allowable Tractive Power Method** – To design a channel using this approach, the aggregate stability of saturated soils is assessed by use of the unconfined compression test. Soils in channels with unconfined compression strength versus tractive power that plot above and to the left of the S-line (Figure 7) have questionable resistance to erosion. Soils in channels with unconfined compression strength versus tractive power that plot below and to the right of the S-line can be expected to effectively resist the erosive efforts of the stream flow. Tractive power is defined as the product of mean velocity and tractive stress. Tractive stress is calculated using the Lane method for the appropriate soil characteristics.

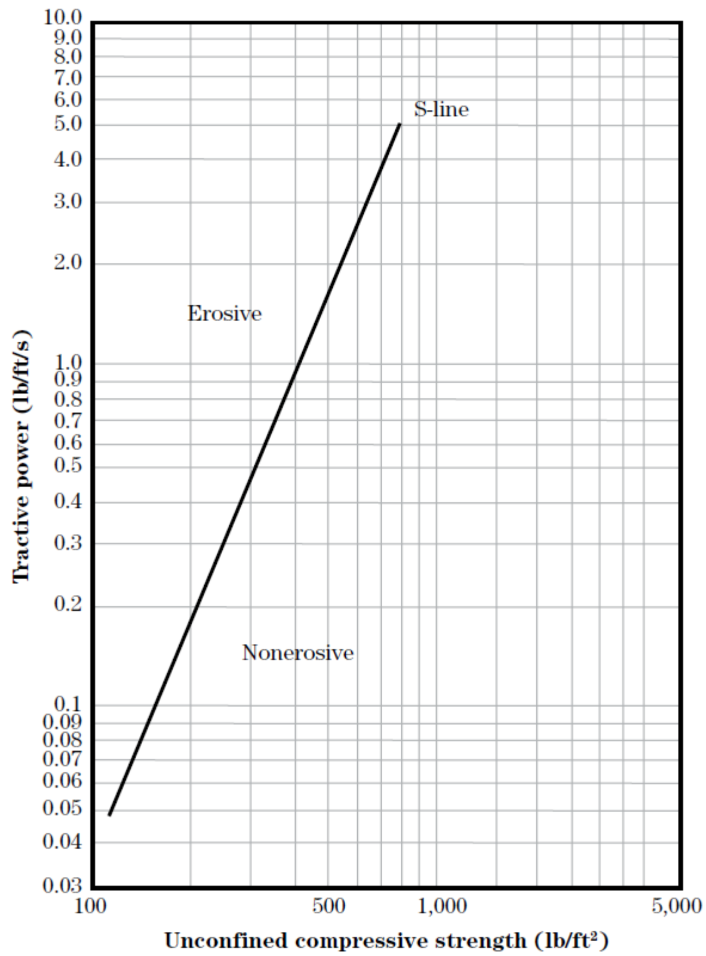

Figure 7. S-Line Depicting Erosive & Non-Erosive Channel Conditions (NRCS 2007)

2.6.3 Example Calculations

The following example calculation outlines the computational sequence for a threshold channel design using the allowable velocity method.

Problem

A proposed channel has a bottom width of 8 feet, side slopes of 2H:1V, and energy slope of 0.00085. The channel will flow at a normal depth of 4 feet at a discharge of 200 cubic feet per second. The soils are comprised of coarse sand. Check the channel stability using allowable velocity approach.

Solution

1. Solve for Average Channel Velocity

   a) Area = (8 feet * 4 feet) + 2*(((1/2)*(2*4 feet))*4) = 64 ft^2

   b) Q=VA→200 cfs = V*(64 ft^2)

   c) V = 3.12 ft/s

2. Determine Allowable Channel Velocity

   The allowable channel velocity is the greatest mean velocity that will not cause the channel boundary to erode. The allowable velocity can be approximated from tables that relate boundary material to allowable velocity. Allowable velocity can also be calculated by performing a critical velocity calculation, which is the velocity at incipient motion of the boundary material, with an added factor of safety. For this example problem, the data in Table 7 is used to determine allowable channel velocity.

Table 7. Allowable Channel Velocities (NRCS 2007)

Channel material	Mean channel velocity (ft/s)	(m/s)
Fine sand	2.0	0.61
Coarse sand	4.0	1.22
Fine gravel	6.0	1.83
Earth		
Sandy silt	2.0	0.61
Silt clay	3.5	1.07
Clay	6.0	1.83
Grass-lined earth (slopes <5%)		
Bermudagrass		
Sandy silt	6.0	1.83
Silt clay	8.0	2.44
Kentucky bluegrass		
Sandy silt	5.0	1.52
Silt clay	7.0	2.13
Poor rock (usually sedimentary)	10.0	3.05
Soft sandstone	8.0	2.44
Soft shale	3.5	1.07
Good rock (usually igneous or hard metamorphic)	20.0	6.08

   According to Table 7 the allowable channel velocity for coarse sand is 4 ft/s.

3. Evaluate Stability

   The allowable channel velocity for coarse sand is 4 ft/s and the calculated velocity is 3.12 ft/s. Therefore, the channel is assumed to be stable since the calculated velocity is less than the allowable velocity.

2.7 STEP POOL CHANNEL DESIGN

2.7.1 Narrative Description

Step pool structures are designed to emulate the natural arrangement of large wood and rock in systems where large woody debris and native rocks are part of the boundary conditions that influence flow resistance and morphological characteristics, such as pool-to-pool spacing. Step pools provide energy dissipation, grade control, streambank stabilization, and fish habitat.

2.7.2 Key Design Components

Step pool structures can be used in steep and moderately steep stream systems to mimic the natural geomorphic features that develop over time. Step pool structures can also be used in gentler sloping stream systems to provide diversity and pocket water habitat. Key design components of step pool structures are outlined below. Design information should be extracted from reference reach information. Additionally, pool to pool spacing should be checked relative to Figure 8.

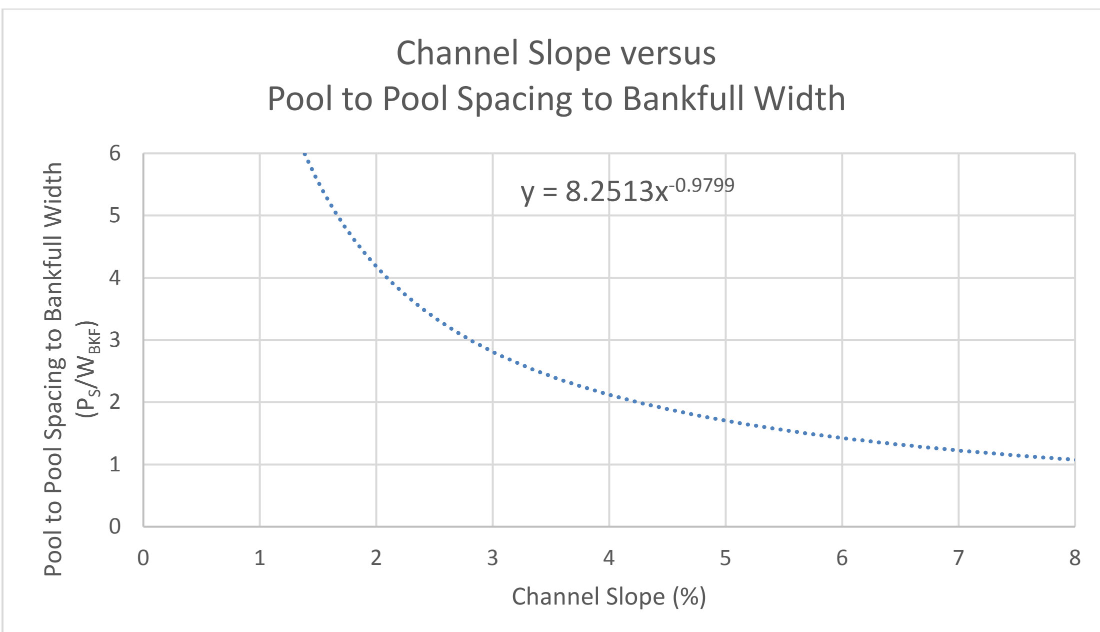

Figure 8. Channel Slope versus Pool to Pool Spacing to Bankfull Width (Rosgen, 2006)

2.7.3 Example Calculations

The following example calculation outlines the computational sequence for a step pool channel design.

Problem

A major flood event caused significant channel degradation downstream of an existing ditch diversion structure. A headcut is now migrating upstream and threatening the diversion. Filling the degraded channel is not an option because it is cost-prohibitive, and lateral floodplain grading isn't an option because of property constraints. The headcut needs to be stabilized in a way that allows for fish passage.

From regional curves that have been developed for this watershed, it is known that the bankfull cross section area is 5 square-feet and the stable width-to-depth ratio for riffles in this system is 15.

Solution

The project team has decided that the most appropriate design at this location are step pool structures at a 5% slope. You have collected reference reach information on several step pool systems in the same watershed as the project. The average dimensionless ratios from these surveys are summarized in the table below.

Design Parameter	Dimensionless Ratio
Step Width/Riffle Width	1
Step Max Depth/Riffle Mean Depth	1.2
Step Height/Mean Riffle Depth	2
Pool Width/Riffle Width	0.9
Pool Max Depth/Mean Riffle Depth	3.5
Pool-Pool Spacing (From Figure 8)	1.7

Riffle mean depth is calculated with the following two equations:

1. Abkf = Wbkf*dbkf → 5 ft^2=Wbkf*dbkf

2. Wbkf/dbkf=15

Combining equation 1 and equation 2 results in the following:

- 5 ft^2 = 15*$dbkf^2$ → dbkf = 0.58 ft

- Wbkf = 15*0.6 ft = 8.7 ft

Using the reference reach information provided in the table above along with known values of dbkf and Wbkf results in the following dimensional values for the proposed step pool design.

Design Parameter	Dimensioned Value
Step Width	8.7 ft
Step Max Depth	0.69 ft
Step Height	1.2 ft
Pool Width	7.8 ft
Pool Max Depth	2.0 ft
Pool-Pool Spacing	14.8 ft

The last step in the design process is to size the boulders in the step pool structures such that they do not mobilize during the design flood event. After conversations with the design team it has been decided that the 100-year flood shall be used as the design-flood event. Hydraulics information in the proposed step pool channel during the 25-year flood is outlined below:

- Q_{100} = 150 cfs
- Slope = .05 ft/ft

There are several methodologies for sizing boulders. It is recommended that multiple methods be used in making a final determination of boulder sizing for any project. For the purposes of this example problem, only one method will be used: Engineers Manual EM 1110-2-1601 published by the United States Army Corps of Engineers, which is valid for slopes between 2%-20%.

$$D_{30} = (1.95 * S^{0.555} q^{2/3})/g^{1/3}$$
$$D_{50} = D_{30}(D_{85}/D_{15})^{1/3}$$

Where:

- D_{30} = rock size of which 30 percent is finer (in)
- S = longitudinal channel slope (ft/ft)

- q = unit discharge, calculated as Q/W_{bottom} (cfs/ft)
- g = gravitational constant = 32.2 ft/s^2
- D_{50} = rock size of which 50 percent is finer (in)
- D_{85}/D_{15} is between 1.7 and 2.7

Solution:

- Using the design channel side slopes, calculate the Bottom Width. 2:1 side slopes were used here.
  - $W_{bottom} = W_{bkf} – 2*z*D_{max\ step} = 8.7 - 2*2*0.69 = 5.94$ ft
- q = 150 cfs/ 5.94 ft = 25.25 cfs/ft
- $D_{30} = (1.95*(0.05\ ft/ft^{\ 0.555})*(25.25\ cfs/ft^{\ 2/3}))/(32.2\ ft/s^2)^{1/3} = 1.0ft = 12in$
- $D_{50} = 12\ in * (2.2)^{1/3} = 15.6$ in

2.8. Minimum Design Report Requirements

The following outlines the minimum report requirements that are required to be submitted with the proposed design. In addition, the Iowa DNR's River Restoration BMP Toolbox Assessment Tool should also be completed and turned in with the design report.

1. Project Background
2. Project Location & Watershed Description (Assessment Tool – Project Info Tab)
3. Project Purpose (Assessment Tool – Project Info Tab)
4. Goals & Objectives (Assessment Tool – Project Info Tab)
5. Assessment Data (Design Reach & Reference Reach)
    a. Hydrologic (Assessment Tool – Project Info & Watershed Tabs)
    b. Hydraulic (Assessment Tool – Geometry Tab)
    c. Geomorphic (Assessment Tool – Watershed, Geometry & Calculated Tabs)
    d. Channel Evolution Stage (Assessment Tool – Bed Stability Tab)
    e. Geologic (Assessment Tool – Watershed & Geology Tabs)
    f. Ecologic (Assessment Tool – Habitat Tab)

   g. Biologic (Assessment Tool – Habitat Tab)

6. Design Hydrology
   a. Bankfull (Assessment Tool – Design Tab)
   b. Flood Flows
7. Cause of Instability (Assessment Tool – Planform Stability & Bed Stability Tabs)
8. Summary of Alternatives Considered (Assessment Tool – Ranking Tab)
9. Summary of Benefits & Risks
10. Channel Design (Assessment Tool – Design Tab)
    a. Opportunities & Constraints
    b. Channel Geometry (Dimension, Pattern, Profile) (Assessment Tool – Design Tab)
    c. Structure Design (Practice Guides 1, 6, 7 & 8)
    d. Revegetation Design (Practice Guides 2 & 3)
    e. In-Stream Habitat Design (Practice Guide 6)
    f. Hydraulics Analysis (Assessment Tool – Geometry & Design Tabs)
    g. Sediment Transport Analysis (Practice Guide 5)
    h. Design Assumptions
    i. Design References

2.9. Minimum Plan Requirements

The following outlines the minimum plan requirements that are required to be submitted with the proposed design. Additionally, a detailed set of specifications that includes methods and materials, such as allowable wood diameters, specific gravity and sizing of stone, placement guidelines, etc. should be provided.

1. Cover Page
   a. Location Information
   b. Vicinity Map
   c. Designer Information
   d. Channel Cross Section Geometry & Drainage Area
   e. Legend

2. General Notes
    a. Survey Control
    b. Conventional Symbols
3. Base Map Information (on all sheets where necessary)
    a. Property Boundaries
    b. Easements
    c. Roads
    d. Topography
    e. Utilities
    f. Structures
    g. Trees to be saved
4. Existing & Proposed Channel Cross Sections
    a. Low Flow Channel
    b. Bankfull Channel
    c. Flood Conveyance Area
5. Existing & Proposed Channel Pattern (Plan View)
    a. Centerline Station Location of Structures
    b. Centerline Station Location of Channel Profile Facets/Features
    c. Northing & Easting at Points of Curvature (PC), Points of Tangency (PT), and Structures
6. Existing & Proposed Channel Profile
    a. Location of Structures
    b. Location of Channel Profile Bed/Facet Features
    c. Station & Elevation at PC, PT, and Structures along Centerline
7. Structure Details
8. Revegetation Plan
9. Erosion Control Plan

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