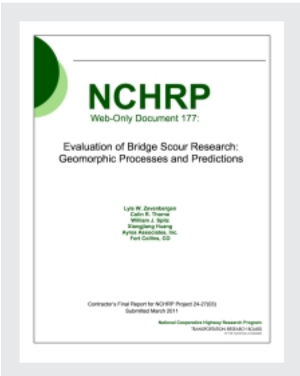


# Evaluation of Bridge Scour Research: Geomorphic Processes and Predictions

## DETAILS

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# CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# 1. INTRODUCTION

The primary cause of bridge failure in the United States is related to scour and stream instability. More bridges fail or are severely damaged by these "hydraulic" problems than all other causes combined. Scour, whether contraction, pier, or abutment, is primarily an issue during extreme flood events. Stream instability, which is related to geomorphic processes and sediment transport, can cause problems at bridge foundations not only during floods, but also during normal flow conditions. This is because degradation and channel migration may expose a foundation gradually. Long-term aggradation can reduce the flow capacity of a bridge, resulting in an increased risk of roadway overtopping and failure and an increased risk of scour due to bridge pressure flow scour.

Current practice for bridge design includes calculation of contraction scour, local pier and abutment scour, long-term degradation, and channel migration. The foundation should be designed for the "total scour," which is the sum of scour components plus the channel instability components. Scour is expected during floods; it is the precise amount of scour that is often difficult to predict with great certainty. Stream instability may not even be anticipated or recognized as a potential problem in the bridge design process. Piers are often designed for an existing angle of attack that changes over time as the channel migrates. A foundation designed for one bed elevation may become exposed due to either degradation or channel migration and the designer may not have even been aware of the potential for these types of stream instability. Therefore, this research project is valuable to the engineering community from several standpoints. Bridge designers must recognize the importance of geomorphic concepts and be able to use these concepts to identify whether a bridge has or will have problems caused by channel instability. If stream instability or its potential is identified, then there must be practical techniques for estimating their effects over the life of the bridge.

The FHWA HEC-20 manual "Stream Stability at Highway Structures" (Lagasse et al. 2001) provides bridge designers with methods of identifying stream stability problems and for making predictions of the amounts of channel instability over the life of a bridge. This is important information for bridge designers, although it must be recognized that the predictions often involve significant uncertainty. The bridge design team must decide how to use information on stream instability, such as designing the bridge to accommodate potential future conditions or attempting to control channel instability as it occurs. Accommodation typically involves longer bridges and deeper foundations. The advantages of accommodating potential channel change in design include more resilient structures, reduced scour, avoidance of cost and permitting issues associated with future countermeasures, and reduced risk associated with bridge failures. The primary disadvantage is the upfront cost it requires, though this may be far less significant than the life-cycle costs of increased maintenance.

Many factors contribute to stream instability. These include sediment supply, flow rates, bed, bank and floodplain materials, vegetation, geotechnical stability, land use change, flood control, urbanization, and base level. Therefore, in addition to evaluating recent completed research, the research team also communicated with other research teams who are conducting related research. These include the other two bridge scour evaluation projects on pier scour (NCHRP 24-27(01)) and abutment scour (NCHRP 24-27(02)) and the rock scour project (NCHRP 24-29).

## 1.1 Research Objectives

> **[RFP] The objectives of this research are to (1) critically evaluate the results of research completed since 1990 on fluvial geomorphic processes and predictions related to channel stability in comparison with current practice**

> **and (2) develop recommendations for adoption of specific research results by AASHTO and their use by the engineering community in general.**
>
> **This research should include stability in cohesive soils, cohesionless soils, and rock; NCHRP's primary interests in this project are long-term degradation and aggradation and lateral migration. In conducting this research, the contractor will coordinate with the contractors for Projects 24-27(1), "Evaluation of Bridge-Scour Research: Pier Scour Processes and Predictions," 24-27(02), "Evaluation of Bridge-Scour Research: Abutment Scour Processes and Predictions," and 24-29, "Scour at Bridge Foundations on Rock."**

The scope and objectives of this research were to evaluate recent geomorphic research in comparison to existing methods for predicting channel instability. The research team focused on long-term aggradation and degradation and on lateral channel migration. Although these are reach-scale processes (not local to the pier or abutment or limited to vicinity of the bridge opening), the focus was on how these processes impact highway structures. Therefore, the methods described herein are practical for use by bridge designers at state Departments of Transportation and their design consultants. The research team was also tasked with providing recommendations on whether this research should be adopted by AASHTO (or potentially by individual states or FHWA).

## 1.2 Research Approach

### 1.2.1 Overview

HEC-20 "Stream Stability at Highway Structures" (Lagasse et al. 2001) is the primary document for assessing stream instability at highway structures. The training course based on HEC-20 (FHWA National Highway Institute Course 135046 "Stream Stability and Scour at Highway Bridges") provides several examples of bridge failures caused by stream instability. The US Highway 51 bridge over the Hatchie River in Tennessee failed in 1989 primarily due to lateral channel migration exposing a floodplain pier that was not as deeply embedded as the adjacent channel piers. The 1995 failure of the Interstate 5 bridge over Arroyo Pasajero in California was partially due to 10 feet of degradation, some of which was probably head-cutting, that it experienced over a 28-year period. These failures caused several fatalities and extensive disruption to transportation services. Therefore, stream stability issues extend beyond bridge design to the evaluation of existing bridges and to bridge inspection and maintenance. Stream instability can also increase scour potential by increasing the angle of attack at a pier or by increasing the amount of woody debris that is available to collect on a bridge.

In HEC-20, the three-level approach is used as a framework for evaluating geomorphic processes and stream instability and offers varying levels of sophistication in dealing with stream instability analysis. The three-level approach was not developed for HEC-20; it had been used in the river engineering field for many years. A basic premise of the three-level approach is that lower levels are important for informing higher levels. A lower level of analysis may also be sufficient for identifying and addressing minor stream stability problems so there is no need to advance to higher levels.

Level 1 is primarily used for assessment. Conducting a Level 1 assessment provides the engineer with a greater familiarity of the river system and an understanding of the dominant processes. Level 1 can be used to determine if channel instability exists or if it is likely to be a problem in the future. Level 2 includes more in-depth review and quantitative analysis. For a scour evaluation this level contains hydraulic analysis and scour calculations. For a stream stability analysis this level may include making a prediction of long-term change using readily available information. Level 3 is the most advanced. This level is needed for the minority of bridges located where the system is so complex that detailed methods are required to obtain the desired level of understanding. Even if it is known at the beginning of a project that Level 3 methods will be required, many of the Level 1 and 2 components will still be extremely useful. Through time, the methods included in the various levels can be modified, updated, and moved to other levels.

The research team believes that more recent research can be included to enhance the approaches currently included in HEC-20 and, potentially, replace some of them. For example, updates to the HEC-RAS model simplify some sediment transport analyses potentially making sediment continuity computations obsolete. As a concept, sediment continuity is essential and should be discussed. As other technology advances, some Level 3 approaches may be shifted to Level 2 (or from Level 2 to Level 1). The amount of information that is available online makes some evaluations much easier. For example, obtaining historic aerial photography used to involve much more effort that it does now. Aerial photo comparisons and evaluations may now well be entirely within the context of Level 1. Through the activities described in the following tasks, the research team was able to thoroughly evaluate new technology to provide AASHTO with sound recommendations on incorporating this technology into practice. The research team also evaluated whether the items could be considered as Level 1, 2, or 3.

### 1.2.2 Research Tasks

The tasks outlined below were conducted to provide recommendations on revising or making additions to current practice:

Task 1. Conference Call with Panel

> **[RFP] Prior to starting work, participate in a conference call with the NCHRP project panel to discuss the research approach.**

In lieu of a conference call, a kickoff meeting was held at the FHWA offices in Lakewood, Colorado. The kickoff meeting was conducted on June 2, 2009.

Task 2. Compile Bibliography of Research

> **[RFP] Compile a bibliography of the research literature on fluvial geomorphic processes and predictions related to channel stability completed since 1990. The compiled literature shall include research sponsored by NCHRP, FHWA, and other agencies and institutions.**
>
> **[RFP Special Note] The following document will be useful for this project: unpublished agency report for NCHRP Project 20-07(178), "Evaluation and Update of NCHRP Project 24-08, 'Scour at Bridge Foundations: Research Needs'," The panel considers the above document as the primary reference for completion of the Task 1 literature review. While it is not the intent to exclude other useful sources, an exhaustive literature search is neither expected nor required.**

NCHRP Project 20-07(178) (Lagasse and Zevenbergen 2004) served as the starting point of the bibliography. **Table 1.1** shows research projects that Project 20-07(178) identified as pertaining to the topic of geomorphology. With the exception of the Maryland SHA project (Maryland Stream Survey), particular interest was placed on these publications. The MDSHA *Manual for Hydrologic and Hydraulic Design*, "Chapter 14: Stream Morphology and Channel Crossings" was reviewed as a replacement for the other MDSHA project. **Table 1.2** shows research projects that Project 20-07(178) placed under other categories, but which may contain useful material related to geomorphology, especially channel degradation or lateral migration. For example, NCHRP 24-26, "Effect of Debris on Bridge-Pier Scour" contains information on field reconnaissance and the geomorphic conditions, such as lateral migration, that are likely to produce debris. These were also included for evaluation.

Table 1.1. Research Included in Geomorphology Category of Project 20-07(178).

| Project Number or Sponsor | Title | Research Agency | Year of Completion* |
|---|---|---|---|
| NCHRP 24-16 | Methodology for Predicting Channel Migration | Ayres Associates | 2003 |
| FHWA | Method for Assessing Stream Channel Stability at Bridge in Physiographic Regions Across the U.S.** | Penn. State Univ. | 2004 |
| **FHWA-HRT-05-072 | Assessing Stream Channel Stability at Bridges in Physiographic Regions | Penn. State Univ. | 2006 |
| Pennsylvania DOT | Bridge Scour Assessment Indices | | On-going |
| CALTRANS | Design of Countermeasures for Meander Migration | CALTRANS / UC Davis | 2003 |
| Georgia DOT | Channel Restoration at Bridges | J.B. Trimble / Ayres Assoc. | 2006*** |
| Maryland SHA | Maryland Stream Survey | USGS, FHWA, US Fish & Wildlife Service | - |
| Texas DOT | Guidance for Soils Properties-Based Prediction of Meander Migration Rate | Texas A&M/Texas Trans. Institute | 2004 |

Notes:
* As reported in NCHRP 20-07(178)
** See updated reference for this publication.
*** Not including construction and monitoring.

Table 1.2. Other Potentially Valuable Research Included in Other Categories of Project 20-07(178).

| Project Number or Sponsor | Title | Research Agency | Year of Completion* | Category** |
|---|---|---|---|---|
| NCHRP 24-06 | Expert System for Stream Stability and Scour Evaluation | Univ. of Wash. | 1999 | 6 |
| Florida DOT | Develop Rock/Clay Scour Prediction Procedure | OEA Inc. | 2004 | 1 |
| Kansas DOT | Downstream Effect of Enlarged Waterway Openings | Univ. of Kansas | Ongoing+ | 4 |
| NCHRP 24-19 | Environmentally Sensitive Channel and Bank Protection Measures | Salix Applied Earthcare | 2005 | 8 |
| NCHRP 24-26 | Effects of Debris on Bridge-Pier Scour | Ayres Associates | 2010 | 1 |

Notes: * As reported in NCHRP 20-07(173), most are not complete.
** 1 = Bridge Near-Field Processes and Prediction
** 4 = Numeric Models
** 6 = Inspection and Monitoring
** 8 = Countermeasures
+ Published in 2006 as Kansas Department of Transportation Report KTRAN-KU-04-9

Although an intensive literature search was not intended, there were several publications that were reviewed as part of this task. The Journal of Hydraulic Engineering was used as the primary scientific journal as part of NCHRP 20-07(178) and was also used for this study. Other journals that were included are *Water Resources Research*, *Geomorphology*, *Earth Surface Processes and Landforms*, and *Journal of the American Water Resources Association*.

The research team also included papers presented at ASCE Water Resources Engineering Conferences. A starting point for this was the "Stream Stability and Scour at Highway Bridges Compendium" (Richardson and Lagasse, eds. 1998). This compendium includes a section on stream instability and geomorphology. Another useful source for the bibliography was ASCE's "Sedimentation Engineering – Processes, Measurements, Modeling, and Practice" (Garcia ed. 2008). This ASCE manual includes chapters that are very relevant to the topic of this project, including sediment transport, fluvial geomorphology, stream bank erosion and width adjustment, river meandering and channel stability, and engineering geomorphology.

To keep the bibliography and subsequent research applicable to the topics of primary interest to AASHTO, the focus was on channel stability and specifically on channel aggradation, degradation (including headcutting and base level lowering), and lateral migration. The research was evaluated relative to the practicality of use to state DOTs and their consultants. Of course, a method that is "practical" for Level 3 could involve considerably more effort than a Level 2 approach, but is required to address the problem.

<u>Task 3. Critical Review and Prioritize Research</u>

> **[RFP] Critically review the research literature compiled in Task 2. Prepare a prioritized list based on a qualitative assessment that ranges from research results that could be adopted by AASHTO to promising research results not yet conclusive enough for adoption. Submit the list for written NCHRP approval before proceeding with Task 4.**

The research team critically reviewed the research identified in Task 2 to develop a list of research results that are likely to be of value to AASHTO. The results were categorized into research that can be adopted by AASHTO to research that is promising but not yet conclusive. To provide a baseline for Task 3, a review of current practice was developed based on the contents of HEC-20, HEC-18, and HDS 6. The research was evaluated in comparison to current practice. After panel comment, 60 documents were included for the in-depth evaluation in Task 4. The research team identified how a research item can be incorporated into HEC-20 and if it could replace or enhance current methods. In the execution of this task, the research team was also able to identify where there are gaps in the current state of practice and in recent research. These gaps were used to formulate recommendations for future research needs (Task 5).

<u>Task 4. In-Depth Evaluation of Priority Research</u>

> **[RFP] Carry out an in-depth evaluation of the technical adequacy and limitations of the research results approved by NCHRP in Task 3. Document the strengths and limitations of the research results.**

Under this task, the research team evaluated the technical adequacy and limitations based on several criteria. The original criteria were as follows:

1. How does the research relate to the current state of practice?
2. Is the research founded in scientific theory?
3. Does the research adequately describe the physical process?
4. Has the research been tested by the original researcher?
5. Has the research been cited by other researchers or practitioners?
6. What conditions has the research been applied?
7. Is the research of practical use or could it be made practical?
8. What are the strengths of the research?
9. What are the limitations of the research?
10. Does the research pertain to a single physiographic region or is it broadly applicable?
11. Does the research pertain to a limited set of channel conditions or is it broadly applicable?

Upon further examination, the original criteria were modified slightly to eliminate redundancies. The modified criteria are provided in Chapter 3.

Task 5. Recommendations and Research Needs

> **[RFP] Develop draft recommendations for possible adoption of specific research results by AASHTO. Clearly document the breadth of application and limitations of each recommended result. Propose, in priority order, concise scopes of work for research needed to fill gaps where evaluated research results are not ready for adoption by AASHTO and use by the engineering community in general. Submit the draft recommendations to NCHRP for review. The research agency will be required to meet with the project panel approximately 1 month later to obtain NCHRP approval before beginning Task 6.**

The recommendations aspect of Task 5 was included as Item 8 of the Task 4 critical review. The research team has identified nine candidate research needs. Some of the research needs are modifications of those identified in NCHRP 24-8 "Scour at Bridge Foundations: Research Needs" (U. of Louisville Research Foundation 1996). The titles of the research statements are:

- Impacts of River Basin Modification and Climate Change on Bridge Safety
- Prediction of Headcut Migration and Scour at Bridges
- Bridge Crossings on Active Alluvial Fans
- Coupling Advanced Numerical Modeling with Sediment Transport and Bank Mechanics in Bridge Reaches – Aggradation, Degradation, Contraction Scour and Channel Widening
- Impacts of Vegetation Restoration, Rehabilitation and Stabilization on Channel Stability in Bridge Reaches
- Permitting and Associated Bridge Design Requirements
- Bend and Confluence Scour Near Bridges
- Advanced Mapping and Monitoring Tools for Bridges

Task 6. Draft Final Report

**[RFP] Submit a draft final report documenting the entire research effort, including the prioritized list from Task 3 and the evaluations from Task 4; the recommendations and scopes of work from Task 5 shall be included in an appendix to the report. The research agency will be required to meet with the project panel approximately 1 month later to obtain NCHRP approval of the draft final report before beginning Task 7.**

Task 7. Revised Final Report

**[RFP] In accordance with direction and comments from the NCHRP project panel during draft report review and the Task 6 meeting, prepare a revised final report for use by AASHTO and FHWA in evaluating potential changes to existing bridge-scour manuals and guidance documents and developing future research projects.**

# 2. REVIEW OF CURRENT PRACTICE

For this project, current practice is defined as the guidance that is contained in the three FHWA documents that address the topics of geomorphology, aggradation, degradation, lateral migration and channel widening. The three documents are HEC-20 "Stream Stability at Highway Structures: 3rd Edition" (Lagasse et al. 2001), HEC-18 "Evaluating Scour at Bridges: 4th Edition" (Richardson and Davis 2001), and HDS 6 "River Engineering for Highway Encroachments: Highways in the River Environment" (Richardson et al. 2001). HEC-20 is the primary FHWA reference that addresses these topics. HEC-18 includes discussion of these topics only to the extent that stream instability is a component of total scour at a bridge. HDS 6 addresses these topics at a higher level because it is a more comprehensive treatment of river engineering, especially regarding sediment transport, river morphology and river response.

**Table 2.1** shows the current practice as a matrix based on the type of analysis (geomorphology, aggradation/degradation, and lateral migration/channel widening) subdivided into three levels of analysis (assessment, analysis, and advanced methods). Chapter 3 of HEC-20 is an in-depth discussion of the three level approach and provides the following rationale for this approach, which states:

> *The analysis of any complex problem should begin with an overview or general evaluation, including a qualitative assessment of the problem and its solution. This fundamental initial step should be directed towards providing insight and understanding of significant physical processes, without being too concerned with the specifics of any given component of the problem. The understanding generated from such analyses assures that subsequent detailed analyses are properly designed.*
>
> *The progression to more detailed analyses should begin with application of basic principles, followed as required, with more complex solution techniques. This solution approach, beginning with qualitative analyses, proceeding through basic quantitative principles and then utilizing, as required, more complex or state-of-the-art solution procedures assures that accurate and reasonable results are obtained while minimizing the expenditure of time and effort.*

In **Table 2.1**, each analysis type and level is further divided into topics and the pertinent sections of HEC-20, HEC-18, and HDS 6 are identified. There are a total of 33 topics (12 related to geomorphology, 13 related to aggradation and degradation, and 8 related to lateral migration and widening. As expected, the majority of the topics are addressed in HEC-20, several are addressed in HDS 6, and relatively few are addressed in HEC-18. The following sections provide brief discussions on the topics included in Table 2.1.

## 2.1 Geomorphology Level 1 Topics

### 2.1.1 Geomorphic Factors

HEC-20, Section 2.3 describes the geomorphic factors that affect stream stability. These factors are presented in **Figure 2.1** (Figure 2.6 from HEC-20), which was adapted from Brice and Blodgett (1978). Although these factors are not presented as a classification system, a wide variety of stream characteristics are categorized. HDS 6, Section 5.4.1 uses the same figure (Figure 2.1) and presents it as a simple classification system oriented primarily to lateral stability.

Table 2.1. Current Practice Based on Type and Level of Analysis.

| Level of Analysis | Level 1 – Assessment (qualitative or conceptual) | | Level 2 – Analysis (quantitative) | | Level 3 – Advanced Methods (in-depth quantitative) | |
|---|---|---|---|---|---|---|
| FHWA Manual | HEC-20 (HEC-18) | HDS 6 | HEC-20 (HEC-18) | HDS 6 | HEC-20 (HEC-18) | HDS 6 |
| **Type of Analysis** | | | | | | |
| Geomorphology | Geomorphic Factors | | Channel Response | | Stream Reconnaissance | |
| | 2.3 | 5.4.1 | 4.4 | 5.5 | 4.2, App. C | - |
| | Channel Type/Sediment Load | | Lane Relationship | | Complex Response | |
| | 3.5.3 | 5.4.1 | 4.4.2 | 5.5.1 | 4.4.4 | - |
| | Rapid Assessment | | Lane S-Q thresholds | | | |
| | 4.5, App. D | - | 4.4.2 | 5.4.5 | | |
| | Channel Classification | | Channel Evolution | | | |
| | 4.3 | 5.4.1 | 2.2 | - | | |
| | Aerial Photo Review | | Aerial Photo Evaluation | | | |
| | 6.2.2 | 8.1.4 | 6.2.2 | - | | |
| | | | | | | |
| Aggradation and Degradation | Bridge Inspection Records | | Rating Curve Shifts | | Sediment Transport Modeling | |
| | 3.3.1, 6.3.1, (4.3.1, 11.2, 11.3.8) | - | 3.6.7, (4.3.2) | - | 6.3.3 | 4.9, 5.6.2 |
| | Field Evidence | | Sediment Continuity | | Physical Modeling | |
| | 6.3.1 | - | 2.4.2, 6.3.3 | - | 3.7 | 5.6.1 |
| | Lane Relationship | | Equilibrium Slope | | Erodibility Testing | |
| | 4.4.2 | 5.5.1 | 6.3.2 | - | (App. L & M) | |
| | Base Level Change (+/-) | | Incipient Motion | | | |
| | 6.3.2 | - | 3.6.5, 6.3.2 | 3.5 | | |
| | Headcuts and Nickpoints | | Armoring | | | |
| | 6.3.2 | 5.2.4 | 3.6.6, 6.3.2 | - | | |
| | | | | | | |
| Lateral Migration and Channel Widening | Bridge Inspection Records | | Aerial Photo Evaluation | | Sediment Transport Modeling Including Geotechnical Stability | |
| | 3.3.1 (11.2, 11.3.8) | - | 6.2.2 | - | | |
| | Field Evidence | | Geotechnical Stability | | App. B | - |
| | 2.3.9, 3.5.4 | 5.8.1 | 2.3.9, App. B | - | | |
| | Aerial Photo Review | | Regime Equations | | | |
| | 6.2.2 | - | - | 5.4.6 | | |
| | | | Channel Evolution | | | |
| | | | 2.2 | - | | |

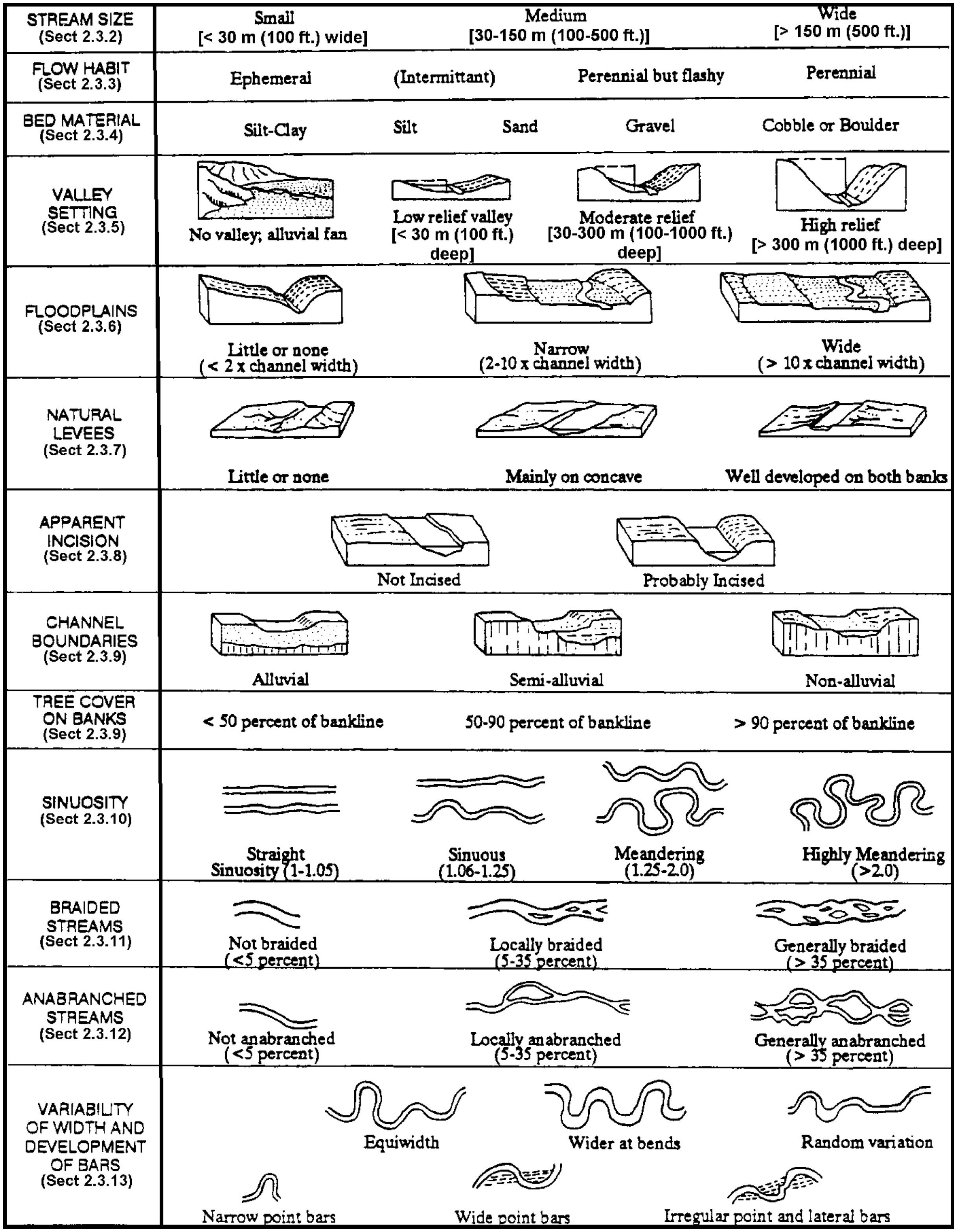


Figure 2.1. Geomorphic factors that affect stream stability (adapted from Brice and Blodgett).

The characteristics include:

- Stream size
- Flow habit
- Bed material
- Valley setting
- Floodplains
- Natural levees
- Apparent incision
- Channel boundaries
- Tree cover on banks
- Channel sinuosity
- Channel braiding
- Channel anabranching, and
- Variability of channel width and development of point bars

Some of these factors indicate that a channel is more susceptible to stream lateral or vertical instability. For example, a channel with well-developed natural levees tends to have lower rates of lateral migration.

### 2.1.2 Channel Type and Sediment Load

HEC-20, Section 3.5.3 and HDS 6, Section 5.4.1 present a figure from Shen et al. (1981) (**Figure 2.2**), that relates channel form (straight, meandering and braided) and sediment load (suspended, mixed and bed load) to relative stability (high stability to low stability). This figure illustrates how meandering alluvial channels may range from low to high stability depending on the mode of sediment transport.

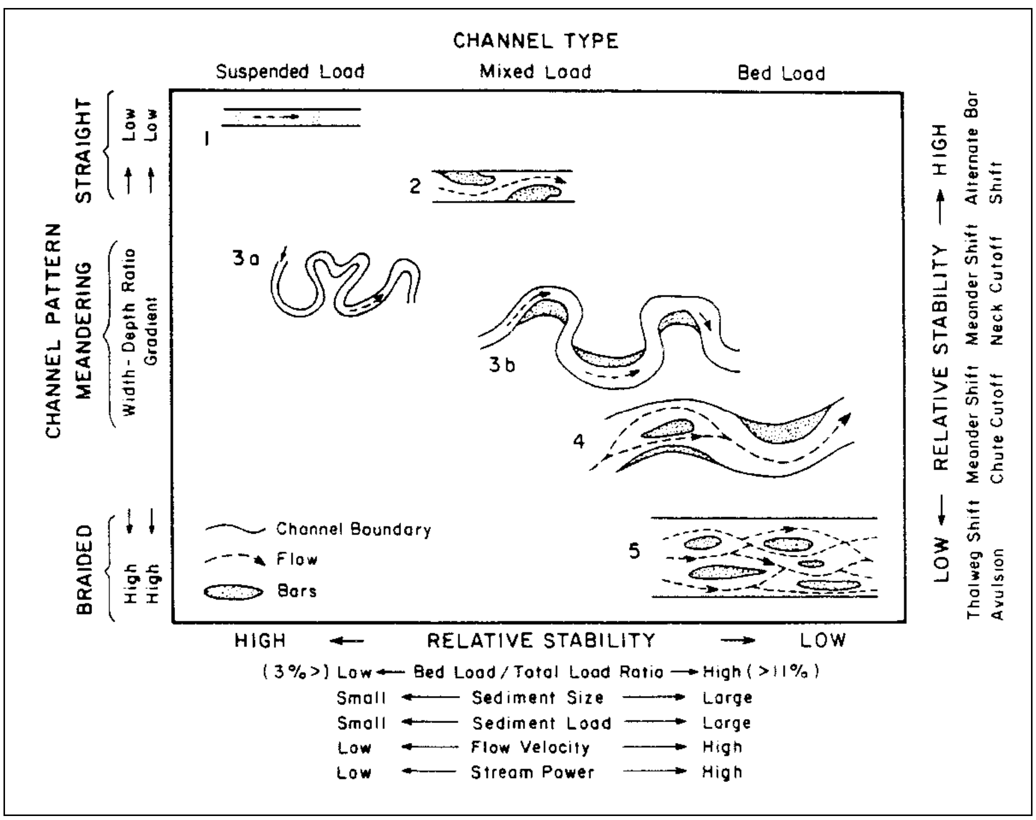


Figure 2.2. Channel classification and relative stability as hydraulic factors are varied (after Shen et al.).

### 2.1.3 Rapid Assessment

HEC-20, Section 4.5 and Appendix D present an approach that incorporates several factors (channel characteristics, hydraulic and sediment transport characteristics) to quickly rate a channel from poor (highly unstable) to excellent (highly stable). The factors are:

- Bank soil texture and coherence
- Average bank slope angle
- Vegetative bank protection
- Bank cutting
- Mass wasting or bank failure
- Bar development
- Debris jam potential
- Obstructions, flow deflectors, and sediment traps
- Channel bed material consolidation and armoring
- Shear stress ratio
- Approach angle to bridge or culvert
- Bridge or culvert distance from meander impact point
- Percentage of channel constriction

The factors are rated from 1 (excellent) to 12 (poor) and have assigned weights. The resulting weighted sum can be related to overall stability, lateral stability, or vertical stability. The primary reference is Johnson et al. (1999) and an in-depth review of an expanded and improved version of this methodology (Johnson 2006) was performed under Task 4 of this project.

### 2.1.4 Channel Classification

HEC-20, Section 4.3 and HDS 6, Section 5.4.1 address channel classification. The treatment in HEC-20 is more comprehensive. It includes classifications based on channel pattern by Brice (1975), mode of sediment transport and channel pattern by Schumm (1977 and 1981), mountain channel classifications by Montgomery and Buffington (1997), and the Rosgen method, which includes measures of entrenchment, width-depth ratio, sinuosity, channel slope, and bed material (Rosgen 1994 as presented by Thorne 1997).

HEC-20 indicates that channel classification systems are useful communicating tools for describing and categorizing the characteristics of a stream reach. It is the channel characteristics, however, that are important in identifying processes and the associated channel responses. As a Level 1 method, channel classification is a valuable first step in evaluating channel stability and predicting channel change.

### 2.1.5 Aerial Photo Review

Aerial photography is mentioned 30 times in HEC-20, 7 times in HEC-18, and 33 times in HDS 6. Many of the instances where aerial photography is mentioned in HEC-20 relate to geomorphic assessment, especially as it relates to lateral channel migration. HEC-20, Section 6.2.2 includes a 2-page discussion on the use of aerial photography for evaluation and prediction of lateral migration. HEC-20 and HDS 6 note that aerial photography is useful not only for recording channel location through time, but also for evaluating current and historic channel characteristics (width, radius of curvature, meander wave length, and sinuosity), vegetation, land use, thalweg variability, sand bars, river controls, geologic formations, bank protection, relic channels, channel and overbank sediment deposits. HDS 6 also notes that headcuts can be located through time based on the channel disturbance that is easily identified on aerial photography.

## 2.2 Geomorphology Level 2 Topics

### 2.2.1 Channel Response

HEC-20, Section 4.4 and HDS 6, Section 5.5 provide a general discussion of channel response to change. Each document indicates that there are a large number of variables that are involved in channel response and that predicting river response is a complex task. Channels can respond to changes in flow, sediment supply (quantity and size), and vegetation or can respond to channel straightening, cut-offs, or other modifications. The following sections describe Level 2 topics that address predicting the type of channel response that can be expected based on certain types of change.

### 2.2.2 Lane Relationship

HEC-20, Section 4.4.2 and HDS 6, Section 5.5.1 discuss the Lane relationship (Lane 1955). The Lane relationship is a useful conceptual tool for relating channel response to a change in the system. The relationship is a proportionality between discharge (Q), median sediment size ($D_{50}$), sediment discharge ($Q_s$), and channel slope (S). The relationship is: $QS \sim Q_sD_{50}$. If the relationship represents a system in equilibrium, then a change in one or more variables will initially put the system out of equilibrium. Another variable would have to respond to bring the system back into equilibrium. For example, an increase in sediment supply would require an increase in slope to bring the system back into equilibrium if discharge and sediment size are assumed to remain constant. An increase in slope would typically infer aggradation, but could also result from straightening of a meandering channel. This relationship is a useful tool for thinking about channel response but does not make any quantitative predictions. It also does not identify other possible channel responses, such as widening.

### 2.2.3 Lane Slope-Discharge Thresholds

HEC-20, Section 4.4.2 and HDS 6, Section 5.4.5 provide a discussion of slope-discharge thresholds developed by Lane (1957) and Leopold and Wolman (1960). The thresholds discriminate channels that tend to be braided, transitional between braided and meandering, and meandering. These relations illustrate that a channel can respond to a change in discharge and/or slope by changing its form. If the channel slope increases because of an increase in sediment supply, a change from meandering to transitional or from transitional to braided may also occur. Like the Lane relationship, this is useful conceptual tool for channel response.

### 2.2.4 Channel Evolution

HEC-20, Section 2.2 provides a brief discussion of channel evolution in the context of channel incision leading to widening, then aggradation and eventually relative stability (from Schumm et al. 1984). The section also references the topic of complex channel response that is addressed in a later section.

### 2.2.5 Aerial Photo Evaluation

For the purpose of this discussion of current practice, aerial photo evaluation is distinguished from aerial photo review (Section 2.1.5) based on the level of effort and purpose of quantifying a change in channel morphology. HEC-20, Section 6.2.2 discusses the need to rectify aerial photography to reduce distortion, especially when using older photography or photography that was not intended for detailed use. Once distortion has been removed from the photography, detailed measurements of bank location can be made and rates of channel migration can be determined.

## 2.3 Geomorphology Level 3 Topics

### 2.3.1 Stream Reconnaissance

Conducting a site visit, reviewing aerial photos and maps, and reviewing the geomorphic factors sheet (Figure 2.1) would constitute a Level 1 stream reconnaissance. The rapid assessment would require additional information, including bank angle and other observations. In HEC-20, Section 4.2 and Appendix C, include a detailed level of reconnaissance developed by Thorne (1998). The reconnaissance includes local, reach scale and watershed scale observations. It is intended to be a comprehensive approach to documenting stream channel and watershed conditions. Therefore, it can also be simplified and tailored for use in individual regions. The sections and major parts of the reconnaissance forms are:

Section 1. Scope and Purpose

Section 2. Region and Valley Description

- Part 1. Area Around River Valley
- Part 2. River Valley and Valley Sides
- Part 3. Floodplain (Valley Floor)
- Part 4. Vertical Relation to Channel to Valley
- Part 5. Lateral Relation of Channel to Valley

Section 3. Channel Description

- Part 6. Channel Description
- Part 7. Bed Sediment Description

Section 4. Bank Survey

- Part 8. Bank Characteristics
- Part 9. Bank-Face Vegetation
- Part 10. Bank Erosion
- Part 11. Bank Geotechnical Failures
- Part 12. Bank Toe Sediment Accumulation

### 2.3.2 Complex Response

HEC-20, Section 4.4.4 provides a brief discussion on the topic of complex response. This discussion is provided in the context of progressive versus episodic change, such as gradual meander bend growth may result in a natural cut-off that produces a period of rapid channel change. Another example of complex response that is discussed is base level lowering causing degradation to progress up through the channel and tributaries. As the tributaries produce more sediment the main channel may then respond with a period of aggradation.

## 2.4 Aggradation and Degradation Level 1 Topics

### 2.4.1 Bridge Inspection Records

There are two instances where bridge inspection is mentioned in HEC-20 related to the topic of stream instability. The first reference is in Section 3.3.1 (Data Needs for Level 1 Analyses), where it states "Typically, a cross section of the bridge waterway at the time of each inspection will provide a chronological picture of the bridge waterway." The second reference is in Section 6.3.1 (Overview of Vertical Channel Stability) where it states ("Bridge inspection reports, which should include soundings at each bent, are a valuable tool for assessing historic channel vertical stability and can be used to predict future trends." HEC-18 provides more in-depth discussion of the use of bridge inspection records to identify lateral and vertical stream instability problems, primarily in Sections 4.3.1, 11.2, and 11.3.8. Section 4.3.1 discusses the use of bridge inspection cross sections to identify aggradation and degradation trends. Section 11.2 indicates that the office review conducted prior to a bridge inspection should include review of prior bridge inspections cross sections to identify aggradation, degradation and lateral movement. Section 11.3.8 states that a bridge inspector should compare the current cross section to previous cross sections, and may want to do so while still on site.

### 2.4.2 Field Evidence

Only one reference to field evidence of degradation is included in the overview of vertical channel stability (Section 6.3.1 of HEC-20). The statement is "Direct evidence of channel degradation includes (1) exposed utility crossings, (2) exposed bridge foundations, (3) channel banks failing due to excessive height and (4) comparison of channel profiles and cross sections.

### 2.4.3 Lane Relationship

The Lane Relationship, as discussed in the geomorphology section, is a Level 1 approach for qualitatively assessing the potential for aggradation and degradation.

### 2.4.4 Base Level Change

Base level control is mentioned once in HEC-18 and more than 20 times in both HEC-20 and HDS 6, although only HEC-20 includes a specific, though brief, discussion on base level change as it relates to degradation. The discussion occurs in the context of headcuts and nickpoints in Section 6.3.2.

### 2.4.5 Headcuts and Nickpoints

Headcuts and nickpoints are mentioned frequently in HEC-20 and in HDS 6. Each document includes specific discussion related to these topics including Section 6.3.2 (Degradation Analysis) in HEC-20 and Section 5.2.4 (Nickpoint Migration and Headcutting) in HDS 6. HDS 6 suggests that these features can be identified and tracked in aerial photography, especially in more arid climates, due to easily identified channel disturbance immediately downstream of these features. It is also suggested that the drop height can be used as an estimate of future degradation upstream of the headcut or nickpoint.

## 2.5 Aggradation and Degradation Level 2 Topics

### 2.5.1 Rating Curve Shifts

HEC-20, Section 3.6.7 provides a detailed explanation of using rating curve shifts (specific gage analysis) as Step 7 of a Level 2 analysis for evaluating channel degradation. A specific gage analysis tracks the stage for a specific discharge through time as the rating curve at a stream gage is updated. A low discharge is typically selected because the difference in water surface and bed elevation can be assumed to be quite consistent for low flow rates. HEC-18, Section 4.3.2 also discusses specific gage analysis. This is a Level 2 analysis because it involves data evaluation, but it does not provide any information related to the cause of degradation (or aggradation). A prediction of future change can be in the form of a linear extrapolation or it can asymptotically approach a constant elevation if the data indicate a trend toward future stability.

### 2.5.2 Sediment Continuity

The sediment continuity concept states that, in an alluvial channel, if the sediment supply is not in balance with the sediment transport capacity, then either aggradation or degradation will occur. If sediment supply exceeds transport capacity, aggradation is expected, and if sediment supply is less than transport capacity, degradation is expected. This concept is discussed in HEC-20, Section 2.4.1.

HEC-20, Section 6.3.3 provides guidance on performing a sediment continuity analysis. A sediment continuity analysis compares sediment supply to sediment transport capacity for a period of time and uses the volumetric difference to estimate an amount of aggradation or degradation. The transport capacity is computed using applicable sediment transport formulas. Sediment supply can be estimated in several ways, one of which is to apply the sediment transport formula to a supply reach that has been identified as being stable because it is in equilibrium with its sediment supply. Several reaches can be evaluated by using the sediment transport capacity of each reach as the supply for the next downstream reach.

A sediment continuity analysis is not considered sediment transport modeling because the channel geometry and hydraulic variables are not modified as a result of the computed aggradation or degradation. The time period for this analysis can be a single event hydrograph or a long-term analysis based on flow-duration curves.

The live-bed and clear-water contraction scour equations in HEC-18 are based on sediment continuity analysis. Each equation determines the amount of contraction scour to match the sediment transport capacity of the constricted section to the sediment supply from the upstream, unconstructed "approach" section. For live-bed, the sediment supply is determined as the transport capacity of the approach section. For clear-water, the sediment supply is zero, so the sediment continuity analysis is reduced to an incipient motion or zero-transport condition. The contraction scour is computed for ultimate conditions and the amount of time is not determined, although there are cases when the amount of contraction scour can be limited by the duration of intense flow.

### 2.5.3 Equilibrium Slope

A channel that has a sediment transport capacity equal to the sediment supply is in a state of equilibrium. If the sediment supply, flow rate or some other variable is altered, then the channel will respond. If an adjustment in slope is assumed, then an equilibrium slope analysis can be used to estimate the new channel equilibrium slope for the altered condition. HEC-20, Section 6.3.2 includes a subsection on equilibrium slope analysis. Two methods are provided to determine the equilibrium slope for zero sediment supply. One uses Shields incipient motion concept and the other uses the Meyer-Peter Muller equation for the beginning of sediment transport. The equilibrium slope section also provides two relationships for an altered sediment supply. One is derived for a known sediment supply and the other is derived for a ratio of existing to future sediment supply.

Once the future equilibrium slope is determined, then the amount of degradation can be estimated by projecting this slope from a downstream base-level control up to the location of interest. This approach does not predict the amount of time it will take for the channel to reach the new condition, nor does it consider other types of channel response, such as channel widening.

### 2.5.4 Incipient Motion

The concept of incipient motion deals with the hydraulic condition when a sediment particle begins to move. HDS 6, Section 3.5 includes considerable discussion and background on this topic. HEC-20, Section 3.6.5 provides a discussion on incipient motion as part of a Level 2 analysis and Section 6.3.2 provides two (of many possible) methods for calculating the shear stress and the associated particle size that would at the beginning-of-motion condition. An incipient motion analysis does not, by itself, predict degradation. It is, however, an important part of many other types of degradation analyses, including sediment transport, equilibrium slope and armoring.

### 2.5.5 Armoring

An armor layer forms on a channel bed when the hydraulic forces are sufficient to transport the smaller fraction of the bed material, leaving the coarser fraction as a layer at the bed surface. HEC-20, Section 3.6.6 provides a discussion of armoring and Section 6.3.2 provides a method for estimating the amount of degradation that would be required to produce an armor layer. This amount of degradation may be used to limit to the amount of degradation that is computed by other approaches. Some sediment transport models include armoring in their formulation. The results of an armoring calculation must be evaluated for the potential of a greater flow disturbing the armor layer and restarting the degradation process.

## 2.6 Aggradation and Degradation Level 3 Topics

### 2.6.1 Sediment Transport Modeling

Sediment transport modeling involves hydraulic modeling coupled with sediment transport calculations. The cross section geometry is updated as the channel bed aggrades or degrades. In some models there is also the ability to include channel widening. Sediment transport models incorporate the concepts of sediment supply, sediment transport capacity, sediment continuity, incipient motion, and armoring to determine channel response over individual hydrographs or many years and decades. The strength of sediment transport models is the fact they are not as limited by the assumptions built into simpler methods. They are limited by the complexity and effort required for their application, making them a clear

Level 3 procedure. As with simpler methods, sediment transport modeling is also limited by the uncertainties inherent in any sediment analysis.

HEC-20, Section 6.3.3 discusses the data needs for sediment transport modeling and mentions two sediment transport models. Most sediment transport models include many transport equations as options. HDS 6, Section 4.9 discusses the applicability of 20 different sediment transport equations for various sediment size classes and lists the sediment transport formulas that are included in a number of models. HDS 6, Section 5.6.2 discusses sediment transport models in general and provides specific discussions on a number of individual models.

Neither HEC-20 nor HDS 6 provides any guidance on the application of any sediment transport model nor do these documents recommend the use of one model over another. Models are updated frequently and new models are always being developed. Therefore, any specific information in HEC-20 or HDS 6 is likely to be outdated shortly after publication. Because all sediment transport formulas and sediment transport models have strengths, weaknesses and limitations on their applicability, the guidance documents must be general and leave it to the users to select appropriate technology for any application.

### 2.6.2 Physical Modeling

Physical modeling of hydraulic and sediment transport is discussed briefly in HEC-20, Section 3.7 and HDS 6, Section 5.6.1, although the discussion relates primarily to localized issues rather than the large-scale issues surrounding aggradation and degradation. HDS 6 also includes the topic of similitude, distortion and limitations that result from scaling sediment. As a method for estimating aggradation or degradation, physical modeling appears to have extremely limited applicability.

### 2.6.3 Erodibility Testing

Except for the process of headcutting, aggradation and degradation are generally analyzed in the context of alluvial channels. If a bedrock layer is present, it is usually treated as a limit to degradation. One may still need to consider the potential for degradation in erosion resistant, but erodible, clay, and rock materials. These topics are not discussed in HEC-20 and only briefly mentioned in HDS 6. The most detailed discussion of erosion of clay and rock are presented in HEC-18, Appendices L and M. Appendix L discusses the erosion of clay based on laboratory testing to determine critical shear stress and the erosion rate as a function of excess shear stress. The discussion is in the context of pier scour, but could be applicable to other types of scour and degradation. Appendix M indicates that similar approaches can be used for erodible rock material and provides a description of the Erodibility Index Method (Annandale 1995, 1999), where the erodibility index is related to available stream power. Some sediment transport models incorporate erosion of resistant layers based on excess stream power, so these types of formulations can be incorporated into degradation analyses.

## 2.7 Lateral Migration and Channel Widening Level 1 Topics

### 2.7.1 Bridge Inspection Records

The discussion of bridge inspection records under the topic of aggradation and degradation is also applicable to the topic of lateral migration and channel widening.

### 2.7.2 Field Evidence

Field evidence of channel migration and channel widening are discussed in HEC-20, Sections 2.3.9 and 3.5.4, and in HDS 6, Section 5.8.1. Field evidence includes bank condition, bank erosion and mass wasting, and also the presence of large point bars that often indicate channel migration.

### 2.7.3 Aerial Photo Review

The discussion of aerial photo review under the geomorphology topic is also applicable to the topic of lateral migration and channel widening.

## 2.8 Lateral Migration and Channel Widening Level 2 Topics

### 2.8.1 Aerial Photo Evaluation

The discussion of aerial photo evaluation under the geomorphology topic is also applicable to the topic of lateral migration and channel widening. Careful examination of aerial photos provides information that can be used to predict future channel conditions.

### 2.8.2 Geotechnical Stability

Channel bank retreat may be the direct result of erosion but is often the result of geotechnical mass-failure of the bank. Erosion of the bank toe or channel deepening may cause an unstable bank condition, especially if the bank is weakened due to saturation. HEC-20, Section 2.3.9 and Appendix B include significant discussion on this topic, including the type of bank failures and the processes controlling these failures. General guidance is provided on the analysis of bank failure and retreat, but no specific equations or relationships are presented.

### 2.8.3 Regime Equations

A regime channel is an alluvial channel that has attained, more or less, a state of equilibrium with respect to erosion and deposition. Regime equations relate stable alluvial channel dimensions or slope to discharge and sediment characteristics. HDS 6, Section 5.4.6 includes discussion of regime equations on the topic of hydraulic geometry of alluvial channels. Channel widening can be estimated as a function of the change in channel forming discharge using the "downstream" regime relations. In the context of changing the channel forming discharge, regime equations bear a conceptual similarity to the Lane qualitative relationship for channel response.

### 2.8.4 Channel Evolution

The discussion of channel evolution under the geomorphology topic is also applicable to the topic of lateral migration and channel widening.

## 2.9 Lateral Migration and Channel Widening Level 3 Topics

### 2.9.1 Sediment Transport Modeling Including Geotechnical Stability

Sediment transport models have primarily focused on aggradation and degradation of the channel because this is the part of the channel that is directly involved in the transport of sediment. Channel banks are sources of sediment and bank stability is impacted by channel degradation and through the fluvial entrainment of bank toe materials. Therefore, channel bank geotechnical stability has been included in sediment transport models. This can be done by assigning a critical bank height as an input to the model or by performing geotechnical stability calculations within the sediment transport model. The volume of bank material from a mass failure then becomes a sediment source. HEC-20, Appendix B includes discussion of a sediment transport model that includes geotechnical stability analysis of bank retreat (Osman and Thorne 1988, Thorne and Osman 1988).

# 3. RESEARCH PRIORITIZATION AND EVALUATION

## 3.1 Research Prioritization

The purpose of Task 3 was to critically review the research literature compiled in Task 2 (the annotated bibliography in **Appendix A**) and to prepare a prioritized list based on a qualitative assessment of the research. After completion of the critical review, the research team submitted a prioritized list of documents to the panel. Later, the prioritized list was updated according to the comments from the panel members. The annotated bibliography included in Appendix A includes only the publications that were included in the prioritized list.

Each document in the annotated bibliography was categorized into, based on its primary topic, (1) Geomorphology, (2) Reconnaissance, (3) Aggradation/Degradation, (4) Channel Migration, (5) Channel Widening, (6) Sediment Dynamics, and (7) Numerical Modeling. Among the 186 publications reviewed, 52 were in the topic of Geomorphology, 27 in Reconnaissance, 21 in Aggradation/Degradation, 33 in Channel Migration, 14 in Channel Widening, 11 in Sediment Dynamics, and 28 in Numerical Modeling. **Table 3.1** shows the total number of publications in each topic.

For each publication, the research results were classified based on the suitability in providing useful information in its corresponding topic. Specifically, the publications were assigned an ID depending on whether it **D**efinitely, **M**ay, or definitely **N**ot addressed the topic applicable to the project. Next, even if a paper definitely addressed the topic, it may not be suitable for AASHTO adoption and inclusion in FHWA documents (e.g. HEC-20). Therefore, each document was assigned a rank, based on a qualitative assessment of what is already included in HEC-20 and what studies could be used to enhance HEC-20. The ranks are:

- 1 = Research or method could be incorporated into FHWA documents (or already is in FHWA documents but could be updated based on more recent work)
- 2 = Research or method is promising, but probably not ready to be included into FHWA documents
- 3 = Research or method is not suited for inclusion into FHWA documents

The research team then considered only publications with a D-1 for in-depth review in Task 4. **Table 3.1** shows the number of D-1 publications per topic. As provided in **Appendix B**, each document is identified by number in the annotated bibliography, a brief description, and the reason(s) for the D-1 rank. Although all 186 publications in the annotated bibliography were ranked, Appendix B includes only the 60 documents ranked D-1.

Table 3.1. Summary of Prioritization.

| Topic | Total Number of Publications | Number of D-1 Publications |
|---|---|---|
| Geomorphology | 52 | 17 |
| Reconnaissance | 27 | 8 |
| Aggradation/Degradation | 21 | 6 |
| Channel Migration | 33 | 9 |
| Channel Widening | 14 | 10 |
| Sediment Dynamics | 11 | 4 |
| Numerical Modeling | 28 | 6 |
| **Total** | 186 | 60 |

Finally, the 60 publications from all 7 topics were prioritized for the in-depth review under Task 4. Many of the documents that have been removed were superseded by later papers by the same author(s). For example, References 3.23 and 3.24 were removed from the in-depth review because they were contained within Reference 10.1 (which also includes some newer material), References 3.5 and 3.6 were dropped from the in-depth review as these were superseded by 3.2, and References 5.37 and 5.40 were not included in the prioritized list because these were incorporated into References 5.46 and 5.48. In addition, several books made the in-depth review list more than once as they cover at least two topics. Seven chapters from ASCE's "Sedimentation Engineering" manual, Reference 10.0, contain information on Geomorphology, Aggradation/Degradation, Channel Migration, and Channel Widening. Similarly, Melville and Coleman's "Bridge Scour," Reference 3.18, covers Aggradation/Degradation, Channel Migration, and Channel Widening, and Maryland Office of Bridge Development's "Chapter 14: Stream Morphology and Channel Crossings," Reference 1.2, contains information on Aggradation/Degradation and Channel Migration. A summary of the number of recommended publications for each topic is shown in **Table 3.2**.

Table 3.2. Summary of Recommendations.

| Topic | Number of D-1 Publications | Number of Recommended Publications |
|---|---|---|
| Geomorphology | 17 | 8 |
| Reconnaissance | 8 | 4 |
| Aggradation/Degradation | 6 | 3 |
| Channel Migration | 9 | 8 |
| Channel Widening | 10 | 6 |
| Sediment Dynamics | 4 | 2 |
| Numerical Modeling | 6 | 5 |
| **Total** | 60 | 36 |

## 3.2 In-Depth Evaluation of Priority Research

Under Task 4, the research team conducted an in-depth evaluation of the technical adequacy and limitations of the research results approved by NCHRP in Task 3 and documented strengths and limitations of the research results. The original criteria included:

1. How does the research relate to the current state of practice?
2. Is the research founded in sound scientific theory?
3. Does the research adequately describe the physical process?
4. Has the research been tested by the original researcher?
5. Has the research been validated in practice by other researchers or practitioners?
6. What conditions has the research been applied?
7. Is the research of practical use or could it be made practical?
8. What are the strengths of the research?
9. What are the limitations of the research?
10. Does the research of pertain to a single physiographic region or is it broadly applicable?
11. Does the research pertain to a limited set of channel conditions or is it broadly applicable?

Upon further examination, the original criteria were modified slightly to eliminate redundancies. The modified review criteria included the following changes. Question 1 was modified by removing the word "How" to make it a yes, or no answer. We included a discussion of how the research relates to the topic and whether it is an extension or advancement of current practice. Question 7 deals with the practicality of the research. It was renumbered to be question 2 and the answer to this question includes a discussion of whether the research is a Level 1, 2, or 3 approach. Questions 2 and 3 were combined because adequately describing the physical process is a requirement for being founded in sound scientific theory. The modified question (3) also includes empirical evidence as part of this review criterion. Question 4 is unchanged. We found that Question 5 was difficult to evaluate systematically. Rather than eliminate the question we checked the number of times the reference is cited by other papers in the technical literature. This was done by tracking the paper in Google Scholar (http://scholar.google.com/) and noting the number of citations. A large number of citations usually indicates higher quality research. A note is included when a paper is recent (2009) and few citations are expected. Questions 6 and 10 are considered to be qualifiers that impact the strengths and weaknesses of the research (Questions 8 and 9) or would be covered within the context of the other remaining questions. Questions 8 and 9 were kept unchanged. One final item was added to the list, which is our recommendation (Task 5) on whether the research should be adopted by AASHTO and included in the next revision of HEC-20. The modified critical review questions are:

1. Does the research relate to the current state of practice?
2. Is the research practical or could it be made practical?
3. Is the research founded in sound scientific theory or substantial empirical evidence?
4. Has the research been tested by the original researcher?
5. Has the research been cited by others?
6. What are the strengths of the research?
7. What are the limitations of the research?
8. Recommendation.

The following provides a brief description of the findings for each of the 7 research topics. The complete evaluation of each research item, including whether the item should be adopted by AASHTO or included in HEC-20, is in **Appendix C**. **Tables 3.3 through 3.9** provide a summary of the strengths, weaknesses, and recommended analysis level (1, 2, or 3) of the recommended papers for each research topic.

### 3.2.1 Geomorphology

Geomorphology represents one of the three types of analysis that are addressed under HEC-18, HEC-20, and HDS 6. All three types of analysis are further subdivided into three levels of analysis (assessment, analysis, and advanced methods) as shown in Table 2.1. As shown in the table, there are 12 topics related to Geomorphology, 5 of which are under the Level 1 analysis, 5 under the Level 2 analysis, and 2 under the Level 3 analysis. Given the importance of geomorphic factors in evaluating stream stability at bridges, it was determined that Geomorphology should be one of the seven primary research topics to be evaluated. Of the 17 Geomorphology research references submitted, the 8 that are recommended are:

- Downstream hydraulic geometry of alluvial channels
- Channel avulsions on alluvial fans
- Rosgen classification system and "Natural Channel Design" (see note at the end of this section)
- Toolkit for fluvial system analysis
- Regional risk analysis of channel stability
- Fundamental concepts of fluvial geomorphology and river mechanics
- Current state of practice for applying geomorphology to river engineering
- Environmental performance standards for bridges

Table 3.3. Strengths and Weaknesses of Recommended Methods in Geomorphology Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Geomorphology** | | | |
| **3.11**. Lee and Julien 2006. Downstream Hydraulic Geometry of Alluvial Channels | 2 | 1. Presents massive database (1,485 sites).<br>2. Covers wide range of flow conditions for sand/gravel/cobble streams with meandering to braided planforms.<br>3. Database used to calibrate and validate new and improved hydraulic geometry equations.<br>4. 95% of the calculated hydraulic geometry parameters between 50% and 200% of field measurements.<br>5. Equations can be used as a template to indicate whether or not a channel is in regime. | 1. Equations only apply to stable alluvial channels.<br>2. Range on calculated hydraulic geometry parameters (50% to 200% of observations) is large.<br>3. Wohl (2004) indicates regime equations have mixed results for mountain streams.<br>4. Relationships can be expected to be poorly suited to describe resistance to flow.<br>5. Relationships are strictly only applicable to the data sets from which they were derived. |
| **5.47**. Field 2001. Channel Avulsion on Alluvial Fans in Southern Arizona. | 2 | 1. Provides guidance on identifying and predicting sites of potential avulsion on active alluvial fans upstream of a highway crossing.<br>2. Could be used to identify and implement countermeasures to prevent potential avulsions. | 1. It is not known if methodology has been implemented specifically for the protection of transport infrastructure.<br>2. Methodology predicts the location of a potential avulsion, but the predicting the timing may be more subjective because it depends on occurrence of flow events. |
| **7.1.** Simon et al. 2007. Critical Evaluation of the Rosgen classi-fication and associated "Natural Channel Design" Methods (see note at the end of this section). | 2 | 1. Explains why stream channel design and restoration should be based on physically-based analyses and process-based approaches that are currently available and which are founded on well-established scientific and engineering literature. | 1. Authors have been known to be very critical of Rosgen. Consequently, those in the restoration business are likely to turn a deaf ear to these criticisms.<br>2. Only further research and documenting of the success or failure of Rosgen's approach will determine whether or not it will stand the test of time. |
| **7.2** Bledsoe et al. 2007. GeoTools: A Toolkit for Fluvial System Analysis, | 2 | 1. GeoTools has been designed to provide a wide range of useful information from a parsimonious set of inputs and to bypass the need for individual investigators to produce custom, "homegrown" data analysis tools. | 1. Risk-based models based on metrics from Geo-Tools require regional calibration.<br>2. Even though GeoTools has undergone beta testing on a range of different computer types and configurations, compatibility problems may still exist. |
| **9.13**. Bledsoe 2000. Regional Risk Analysis of Channel Stability. | 2 | 1. The mobility index has explanatory power practically equaling that of models containing slope, discharge, and D50 as separate independent variables, especially for sand bed channels.<br>2. The approach can be for predicting channel instability and scaling channel processes across diverse geological and climatic regions.<br>3. Logistic regression models that use mobility index can predict unstable channel forms.<br>4. Logistic models also provide a means of gauging channel sensitivity to modest changes in the controlling variables. | 1. Predictions of widening in gravel bed channels are less reliable due to uncertainties associated with defining the bank characteristics. |
| **10.6.** Schumm and Harvey 2008 Engineering Geomorphology. Chapter 18, ASCE Sediment Engineering Manual | 1/2 | 1. Chapter provides a concise review of the current state of practice.<br>2. Covers a number of concepts that are not included in HDS 6 and HEC-20 but which should be added.<br>3. Covers systems approach to evaluating channel stability at a site; consideration of geomorphologic factors that influence landforms (engineering sites) and hazards associated with them, and, development of dimensionless stability numbers for evaluating incised channel evolution. | 1. The chapter does not provide any original research<br>2. The concepts and approaches identified by the authors only provide general guidance on how one can identify existing hazards or problems and potentially identify future hazards or problems as they relate to a particular site. |
| **10.7**. Biedenharn et | 1/2 | 1. Chapter provides a good overview of fluvial | 1. Chapter does not provide any original |

| Table 3.3. Strengths and Weaknesses of Recommended Methods in Geomorphology Topic. | | | |
|---|---|---|---|
| **Paper Number Authors and Title** | **Level** | **Strengths** | **Weaknesses** |
| **Geomorphology** | | | |
| al. 2008. Funda-mentals of Fluvial Geomorphology. Chapter 6, ASCE Sediment Engineering Manual | | geomorphology and river mechanics concepts that will be of use to engineers.<br>2. Many of these concepts are covered only generally in HEC-20 and HDS 6. | research and is primarily a reference tool. |
| **11.1.** Oregon Dept. of Transportation 2005. OTIA III State Bridge Delivery Program Environ-mental Performance Standards | 1/2 | 1. Research reported addresses an issue that is very important to DOTs, which is avoiding difficulties in permitting.<br>2. Research also addresses the philosophy of sound bridge design, which includes avoiding stream stability issues over the life of the bridge.<br>3. Each of these are goals is addressed by considering the function, continuity and connectivity of the stream and floodplain. | 1. Fluvial design standard was targeted at conditions in Oregon so other standards would need to be developed for other regions.<br>2. Another limitation, even potentially for Oregon, pertains to definition of the 'functional floodplain'.<br>3. There are no theoretical explanations given for defining the functional floodplain as 2.2 times the bankfull width.<br>4. No justification is given for using the 10-year recurrence interval flood as the reference discharge for zero contraction scour. |

Note on Reference 7.1. Reference 7.1 became part of the literature database based on the search criteria and specific journals that were included. It addresses limitations of Rosgen's methodologies as perceived by the authors of Reference 7.1. In order to not provide an exclusively one-sided discussion of Rosgen's approaches by this project, Reference 7.1 should be considered as a starting point for considering both limitations and benefits these approaches. Lave (2009) provides a discussion which could serve as a source for discussing both sides of this issue. From the standpoint of this project, it is important to frame the discussion in the context of HEC-20, which is not a restoration manual. Only six pages of HEC-20 are devoted to channel restoration concepts. Rosgen's work related to Natural Channel Design (NCD) as a restoration method should be discussed in the HEC-20 restoration concepts section. NCD is not pertinent to predicting types and rates of channel instability because that is not the intent of NCD. As indicated by Lave (2009), the Rosgen NCD approach has as its stated goal the design of stable channels that do not adjust in dimension, horizontally or vertically. Although this goal may be shared by bridge engineers, in most cases it is better to recognize the potential for channel instability and allow for future channel adjustments in the design process.

### 3.2.2 Reconnaissance

Reconnaissance of a bridge site is an important tool for collecting appropriate data and information for use in the assessing stream stability at the site and, therefore, is included as one of the seven primary research topics to be evaluated. Although not a specific type of analysis, bridge site reconnaissance provides data and information relative to the various factors identified for each of the three types of analysis (Table 2.1) as follows:

Level 1 – geomorphic factors, channel type, rapid assessment, field evidence, headcuts and nickpoints

Level 2 – channel evolution, armoring, geotechnical stability

Level 3 – stream reconnaissance, erodibility testing

Therefore, per Task 2 of this project, a bibliography was completed that included research literature conducted since 1990 covering Reconnaissance and related topics. Of the 8 Reconnaissance research references submitted, the 4 that are recommended for inclusion are:

- Assessment of channel stability at bridges in physiographic regions
- Geomorphic analysis of large alluvial rivers based on widely accepted classification and analysis techniques
- Digital mapping at bridge sites for detailed, advanced reconnaissance and monitoring
- Diagnostic approach to assessing and monitoring stream channels

Table 3.4. Strengths and Weaknesses of Recommended Methods in Reconnaissance Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Reconnaissance** | | | |
| **1.3**. Johnson 2006, Assessing Stream Channel Stability at Bridges in Physiographic Regions | 2 | 1. This method avoids averaging out problematic conditions by rating vertical and lateral stability separately from overall stability.<br>2. Several rating factors in the prior "Rapid Assessment" technique have been modified or replaced.<br>3. Data sheets have been revised to make the method more systematic.<br>4. Physiographic regions have influenced selection of stability factors to make the method broadly applicable.<br>5. The method is targeted at identifying problems that could be of concern in a relatively short period of time (2-year inspection interval). | 1. Because the method is simplified, there is risk of incorrect characterization. However, this limitation is countered by the recommendation that an indication of instability should lead to additional site investigation. |
| **5.44**. Thorne 2002 Geomorphic Analysis of Large Alluvial Rivers, | 3 | 1. Research includes a systematic and flexible approach to dealing with catchment, reach and project scales.<br>2. For each scale, a specific item or deliverable is identified, data requirements are identified, and a relative level of effort is identified. | 1. Its use may be limited as it is a Level 3 analysis of geomorphological assessment, though for complex problems or large river crossings this would be a valuable resource. |
| **6.1**. Hauet et al. 2009. Digital Mapping of Riverine Waterway Hydrodynamic and Geomorphic Features | 3 | 1. Research provides an approach for detailed monitoring how river features near a bridge change through time using oblique (distorted) digital photography.<br>2. Method may also be used to measure map flow velocities and pattern of water currents. | 1. Specialized equipment, software, and training are required.<br>2. Method proposed would only be applicable to limited conditions. |
| **7.10**. Montgomery and MacDonald 2002. Diagnostic Approach to Stream Channel Assessment and Monitoring, | 2/3 | 1. Recognizes complexities of fluvial systems and range of responses that can occur.<br>2. Identifies processes rather than forms.<br>3. Requires investigation of the stream channel within the context of the watershed and geomorphic system.<br>4. Does not try to oversimplify, but ties channel assessment with potential responses.<br>5. Indicates which channel types are more susceptible to instability from specific changes in sediment and discharge.<br>6. Method is flexible and adaptable. | 1. Any diagnosis system is susceptible to bias or misinterpretation.<br>2. System requires more comprehensive information than is typically collected or available.<br>3. System requires experienced field staff with knowledge beyond that gained from training workshops and short courses.<br>4. Authors acknowledge a bias towards mountainous western streams.<br>5. These limitations make widespread adoption of the method unlikely. |

### 3.2.3 Aggradation / Degradation

Degradation is the long-term lowering of bed elevation. It can be a significant component of total scour, but is not caused by the bridge or highway constriction. Rather than occurring only in the vicinity of the bridge, degradation extends well up- and downstream of the bridge. There are two primary causes of degradation; sediment deficiency and headcuts. Sediment deficiency results when there is an imbalance between the sediment supply and the sediment transport capacity in a river reach. The reasons for this imbalance include reservoirs, urbanization, and other land use changes. Headcuts (and nickpoints) progress from downstream and result from base level lowering. Aggradation also results from a sediment imbalance when the sediment supply exceeds sediment transport capacity. Although not a scour component, aggradation impacts bridge hydraulic capacity and should be considered in design. Of the 6 Aggradation/Degradation research items considered, the 3 that are recommended are:

- MDSHA cumulative degradation method, pool base-level method and degraded stream profile method
- Methods included in Melville and Coleman "Bridge Scour" manual
- Stream gage regression method

Table 3.5. Strengths and Weaknesses of Recommended Methods in Aggradation/Degradation Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Aggradation/Degradation** | | | |
| **1.2.** MDSHA 2007 Guidance on evaluation of long-term channel degradation, Chapter 14: Manual for Hydrologic and Hydraulic Design. | 2 | 1. Cumulative Degradation Method and Pool Base-Level Method are reasonable and uncomplicated ways to estimate long-term channel degradation.<br>2. Pool Base-Level Method does not require a downstream control point.<br>3. Estimation of Degraded Stream Profile uses the riffle-crest line to calculate the degraded stream profile, which is a good first-order approximation.<br>4. These methods are useful alternatives to using detailed sediment transport models. | 1. These methods are primarily relevant to wadeable gravel-bed streams with a pool-riffle morphology.<br>2. The range of channel slope covered extends only from 0.2% to 4%. |
| **3.18.** Melville & Coleman 2000. Quantitative assessment of aggradation and degradation, Section 4.3 in Bridge Scour. | 2 | 1. Regime Formulations are easy to follow.<br>2. Tractive Force and Competent Velocity Methods are physically based, so that they have the potential to produce reliable results.<br>3. Methods described have simple equations that are not difficult to apply. | 1. Graphical redistribution of the average scour depth to obtain the maximum scour depth is subjective.<br>2. Regime Formulations are not generally applicable: for example that of Lacey (1930) was designed for uncontracted sandy alluvial channel and that of Blench (1969) is valid only in well-maintained sand-bed irrigation canal systems.<br>3. The limitations of the Tractive Force Method are not discussed.<br>4. The Competent Velocity Methods of Neill (1973), Alvarez and Alfaro (1973) and Holmes (1974) all have limitations. |
| **4.14**. James, 1997. Channel Incision on the Lower American River, California, from Stream-flow Gage Records. | 2 | 1. Regression approach is simple to apply (spreadsheet) and can be used for any long-term gage.<br>2. The paper illustrates the gage analysis approach and shows how bridge inspection records can be used for verification. | 1. Only valid for locations with a nearby, long-term gage.<br>2. Use of extrapolation for predicting future degradation is a significant limitation. However, residual plots indicate time trends of reduced degradation if these are present. |

### 3.2.4 Channel Migration

This topic refers specifically to changes through time in the location of the channel of a watercourse that occur due to retreat of one bank at an erosion rate that is approximately matched by advance of the opposite bank through accretion. Channel migration results in lateral movement of the channel across the floodplain either through incremental shifting at a rate related to channel width or more rapid relocation of the channel through an avulsion.

Lateral migration in a bridge reach can pose a geomorphic hazard through altering the alignment of the channel relative to the bridge, generating scour adjacent to one of the abutments and in severe cases threatening to flank the bridge entirely. It also generates additional sediment load and recruits large woody debris that may increase the risk of partial or complete blockage. Of the 9 Channel Migration research references submitted, the 8 that are recommended are:

- Channel lateral movement zone
- Aerial photo comparison method
- Methods presented by Melville and Coleman
- Vegetation influence on migration
- Multiple bend cutoffs risks
- Wood and logjam risks
- Channel realignment to reduce hazard
- Theory and modeling related to channel migration

Table 3.6. Strengths and Weaknesses of Recommended Methods in Channel Migration Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Channel Migration** | | | |
| **1.2.** MDSHA 2007. Guidance on evaluation of lateral channel movement, Chapter 14 in Manual for Hydrologic & Hydraulic Design. | 2 | 1. Delineation of the Channel Lateral Movement Zone and the frequency analysis of lateral channel movement are an improvement from Aerial Photo Review in HEC-20.<br>2. Approach presented is straightforward. | 1. The procedure for delineating the Channel Lateral Movement Zone is still coarse. However, the manual states that a more detailed explanation of this procedure is under development. |
| **1.6.** NCHRP 24-16 2004. Method ology for predicting channel migration. | 2 | 1. History of lateral migration at actual site in question provides a sound basis for prediction of future behavior.<br>2. Attributes like soil strength and vegetation are implicitly accounted for in observed and predicted migration rates.<br>3. Widely proven performance of R/W as a reasonable predictor of bend evolution.<br>4. Extensive empirical database.<br>5. Capability to adapt method to available data/ expertise. | 1. The main limitation is that because analysis is based on past history at the site, predictions may be unreliable if watershed or climate changes impact the hydrological or sediment regimes.<br>2. Application of the more sophisticated versions of the model use GIS software that is now out of date. |
| **3.18.** Melville and Coleman 2000. Bridge Scour (especially, Section 4.8). | 1/2 | 1. The research reported has been selected by the authors as being suitable for assessing the likelihood, rate and hazard associated with channel migration in both dynamically stable and unstable streams. | 1. Main limitations stem from limited research, development & testing of methods presented.<br>2. Some methods presented have been superseded by later versions developed since this book was published. |
| **4.8.** Perucca et al. 2007. Significance of the riparian vegetation dynamics on meandering river morphodynamics | 2/3 | 1. Research establishes vegetation growth and decay interact with fluvial processes in meandering rivers, influencing rates, spatial & temporal distributions of channel migration.<br>2. It demonstrates reliable channel migration predictions are only possible when vegetation dynamics are taken into account.<br>3. It shows vegetation cannot be treated as a passive attribute of riparian zone when assessing channel migration hazards at bridges. | 1. The complexity of the models, heavy data requirements and the need for advanced modeling expertise currently preclude practical application of the method.<br>2. The fluvial model uses a linear theory, which is known to be an inadequate representation of meander behavior.<br>3. Thirdly, models fail to account for changes in river width, variation of flow resistance with vegetation density, and influence of woody debris entering stream due to bank retreat. |

Table 3.6. Strengths and Weaknesses of Recommended Methods in Channel Migration Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Channel Migration** | | | |
| **5.6**. Hooke 2004. Cutoffs galore!: occurrence and causes of multiple cutoffs on a meandering river. | 2 | 1. Research identifies that the probability of occurrence of a cluster of meander cutoffs (resulting in lateral channel migration and/or realignment that may pose a bridge hazard) might be predictable based on preexisting sinuosity relative to a critical value for planform instability.<br>2. Research is based on a theory that is increasingly accepted in fluvial geomorphology, coupled with well documented evidence obtained from the River Bollin, UK.<br>3. Long-term study of actual meandering stream | 1. The critical value for planform instability is poorly defined. A maximum value of 3.14 is suggested for unconstrained rivers, but this decreases with the degree of meander confinement due to limited width of the channel migration zone.<br>2. To be generally applicable, the relationship between critical sinuosity and degree of confinement needs to be better defined based on further research at well documented sites on meandering rivers in a range of physiographic regions. |
| **5.20**. Brummer et al. 2006. Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA | 1/2/3 | 1. The research demonstrates that the addition or removal of large wood has marked impacts on avulsive channel migration.<br>2. The paper presents Level 1 & 2 rules of thumb to estimate channel response.<br>3. Numerical analyses presented in the paper could be used at Level 3 where risks justify this. | 1. The geographical scope of the study is limited to the Pacific Northwest and the findings may not be simply transferable to other physiographic regions of the USA.<br>2. The models used are quasi-steady and do not account for the geomorphic impacts of rapidly varying flow in flashy streams. |
| **9.2**. Odgaard 2008. Stability Analysis in Stream Restoration | 2/3 | 1. This research provides a scientifically-based alternative to use of a 'reference' reach when realigning a problematic channel to reduce hazards associated with channel migration. | 1. The design method has not yet been tested or applied by practitioners.<br>2. The approach is too new to have been proven to reducing risks associated with channel migration in bridge reaches. |
| **10.2**. Odgaard and Abed 2007. River Meandering and Channel Stability. | 3 | 1. This chapter presents a concise review of theory and modeling practice in the analysis of river meandering and channel migration. | 1. Coverage focuses mainly on theories, analyses and stabilization measures with which the authors are particularly associated. |

### 3.2.5 Channel Widening / Narrowing

This topic refers specifically to changes in the top bank width of a channel that occur through time due to net retreat or advance of the banklines. Changes in width trigger further adjustments to the hydraulic geometry of the channel involving the wetted perimeter, mean depth, hydraulic radius, roughness, energy slope, and flow velocity. Extreme widening or narrowing are also associated with planform metamorphosis, which is the relatively rapid transformation of, for example, a meandering planform into a braided channel (with extreme widening), or *vice versa* (with extreme narrowing). Widening in a bridge reach can pose a geomorphic hazard through increasing the degree of constriction scour at the bridge, generating scour adjacent to the abutments and, in severe cases, threatening to flank the bridge entirely on one or both sides. It also generates additional sediment load and recruits large woody debris that may increase the risk of partial or complete blockage. Narrowing may increase velocities and general scour depths within the narrower channel. Of the 10 Width Adjustment research items submitted, the 6 that are recommended are:

- Regional bankfull width relationships
- Error estimation from aerial photos
- Logistic analysis of channel pattern
- Predicting channel pattern change
- Bank erosion and vegetation effects
- Methods presented in ASCE "Sedimentation Engineering"

Table 3.7. Strengths and Weaknesses of Recommended Methods in Change in Channel Width Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Change in Channel Width** | | | |
| **5.2.** Faustini et al. 2009. Downstream variation in bankfull width of wadeable streams across the conterminous United States | 2/3 | 1. This research uses advanced statistical analyses of a very large, national database.<br>2. Relationships are easy to apply and allow estimates of the expected width to be made on the basis of only the drainage area and bed material type (gravel or sand) at the study site. | 1. Utility is limited by weak regression relationships and high uncertainties in expected widths for some ecoregions.<br>2. Relationships are inapplicable to large rivers (wider than 75 meters or with drainage areas > 10,000 km$^2$).<br>3. Impacts of human activities in the watershed are poorly explained in several ecoregions. |
| **5.38**. Mount et al. 2003. Estimation of error in bankfull width comparisons from temporally sequenced raw and corrected aerial photographs | 2 | 1. Provides a simple method to assess errors involved in estimating widening rates from historical sequences of aerial photographs, which are often ignored by practitioners using historical aerial photographs. | 1. Application of the error estimation method requires some practitioner training in photogrammetry which may limit widespread uptake and validation of the method in the USA. |
| **5.46**. Bledsoe and Watson 2001. Logistic analysis of channel pattern thresholds: meandering, braiding, and incising. | 2 | 1. Relatively high predictive capacities of the statistical models presented for stability versus instability in sand and gravel-bed rivers.<br>2. The fact that application of these models requires only basic data on discharge, slope and bed material size. | 1. Statistical treatment has no causal basis. It cannot explain why a stream is stable or unstable.<br>2. Influences of sediment supply and bank erosion resistance are not accounted for.<br>3. Streams that plot as stable on the diagrams may still exhibit instability. |
| **5.48**. Lewin and Brewer 2001. Predicting Channel Patterns. Includes discussion by van den Berg and Bledsoe (**5.40**) and Reply by Lewin and Brewer (**5.37**). | 2 | 1. Shows that practitioners must not put too much faith in simple predictors of channel planform type, stability and vulnerability to change.<br>2. Points out that simple predictors may misclassify 10 to 15% of channels.<br>3. States that predictors should not be used in isolation or where risk of mis-classifying a channel is severe. | 1. This research does not provide any improvement in the capability for simple prediction of planform pattern type, stability or vulnerability to change.<br>2. It merely points out problems with existing methods. |
| **7.17**. Beeson and Doyle, 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. | 1 | 1. Presents case study of directly observed bank retreat that occurred during high flow events on four Canadian rivers in 1990.<br>2. Erosion was five times more likely at unvegetated vs. vegetated bends.<br>3. 34 of 35 bends that experienced severe bank retreat (greater than 45 meters) were unvegetated. | 1. Research is based on just four, medium sized rivers in British Columbia.<br>2. Findings may not be representative of other rivers of different sizes, with different types of vegetation or in different ecoregions of North America.<br>3. Further research is needed to generalize the findings |
| **10.1**. ASCE TC 2006. Streambank erosion and river width adjustment. Chapter 7: Sedimentation Engineering. | 2 | 1. Older Channel Evolution Models are updated.<br>2. Bank and fluvial stability factors are used to identify channel evolution stages.<br>3. Numerical Width Adjustment Models are improved to make acceptable predictions of width adjustment.<br>4. A procedure to handle width adjustment problems is proposed. | 1. Numerical Width Adjustment Models remain unproven because very few appropriate laboratory and field data sets are found to be suitable for testing them.<br>2. No universal Width Adjustment Model exists that is applicable to all the situations encountered by practitioners. |

### 3.2.6 Sediment Dynamics

Sediment plays an essential role in fluvial processes. Most geomorphic processes and forms of a river system are related to changes in sediment conditions. Channels adjust their vertical and horizontal dimensions in response to the imbalance between upstream sediment supply and the reach's sediment transport capacity. For example, sediment trapping in reservoirs can result in severe riverbed lowering downstream, while excessive sediment resulting from landslides and bank erosion can lead to significant channel aggradation. When sediment supply from upstream reaches reduces, a braided river reach may alter itself to be a single-thread channel. Even when sediment supply matches sediment transport capacity, channels migrate by eroding banks and depositing sediment at point bars. Therefore, the identification of sediment source areas in the river system will benefit the understanding of ongoing geomorphic processes. In addition, sediment movement at the channel bottom has an influence on the reach's bed configuration, hydraulic resistance, and flood conveyance capacity. Of the 4 Sediment Dynamics research items, the 2 recommended for inclusion in HEC-20 are:

- Channel forming discharge expanded discussion
- Rosgen's WARSSS (Watershed Assessment of River Stability and Sediment Supply) concepts

Table 3.8. Strengths and Weaknesses of Recommended Methods in Sediment Dynamics Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Sediment Dynamics** | | | |
| **3.9**. Doyle et al. 2007. Channel-forming discharge | 2 | 1. The article emphasizes that the use of a recurrence interval or bankfull discharge may only be applicable for generally stable channels. | 1. Definition of effective discharge is subjective. Further justification is required for the use of '75% of sediment moved'.<br>2. Multiple discharges might be used for different purposes in stream restoration. |
| **11.1**. Rosgen. Watershed Assessment of River Stability and Sediment Supply | 2 | 1. The procedure involves most factors that control watershed processes, and is easy to follow. | 1. Final stage of WARSSS might recommend a sediment transport model due to the complex channel response.<br>2. Care must be taken when using a reference condition. |

### 3.2.7 Numerical Modeling

Numerical modeling is a valuable tool for simulating a river system's geomorphic changes as most geomorphic processes are difficult to reproduce in terms of time scale. Numerous flow and sediment transport models have been developed or updated since 1990, partly because the computing power has been significantly growing. These models are quite different from each other at least in the following ways. First, flow and sediment movement are described in a one-dimensional, two-dimensional, or three-dimensional domain. Second, flow is modeled to be steady, quasi-steady, or unsteady. Last, the complexity of models indicates how many hydraulic and geomorphic processes are included in them and how they couple processes with different temporal and spatial scales. Note that not a single model can fit modeling needs in all circumstances, as each model has its strengths and limitations. In addition, not all models are well calibrated or validated: some are still theoretical, some have been calibrated with laboratory data, and only a few of them have been calibrated with both laboratory and field data. Numerical modeling, as a Level 3 procedure, requires a huge amount of effort, such as field data collection, parameterization, and calibration. Therefore, this topic does not include all available numerical models, but contain a few well-calibrated models and papers that provide reviews and instructions for flow and sediment transport modeling. Of the 6 Numerical Modeling research references, the 5 that are recommended are:

- CONCEPTS model discussion
- Sediment transport modeling review
- CCHE2D model discussion
- Discussion of 1-D sediment transport modeling
- Discussion of 2- and 3-D sediment transport modeling

Table 3.9. Strengths and Weaknesses of Recommended Methods in Numerical Modeling Topic.

| Paper Number Authors and Title | Level | Strengths | Weaknesses |
|---|---|---|---|
| **Numerical Modeling** | | | |
| **3.2**. Langendoen et al. 2009. Model incision and widening with calibration | 3 | 1. The model presented (CONCEPTS) is able to simulate channel width adjustment based on the fundamental physical processes responsible for bank retreat. | 1. CONCEPTS assumes one-dimensional, gradually-varying flow, does not simulate secondary flow.<br>2. The model is truly valid only for straight channels or channels of very low sinuosity. |
| **3.7** Papanicolaou et al. 2008. Sediment transport modeling review | 2/3 | 1. The article provides review comments for most available sediment transport models, and some insights about model application, strengths, and limitations. | 1. To engineering practitioners, the review may too be abstract and focused on the modeling and numerical computation aspects of sediment transport prediction. |
| **3.20**. Jia and Wang 2000. 2D hydro-dynamic and sediment transport model | 3 | 1. The model presented (CCHE2D) can predict channel migration including the effects of secondary flows, which are simulated in the model. | 1. Though CCHE2D uses near bank shear stress to compute bank toe and surface erosion including secondary flow effects, it does not consider most bank failure mechanisms. |
| **10.4**. Thomas & Chang 2006. 1D model of sedimen-tation processes, Chapter 14: Sedimen-tation Engineering | 2/3 | 1. In this summary chapter the authors provide useful insights and lessons about 1D computational sedimentation models for engineering practitioners based on long experience. | 1. Coverage of how to apply 1D computational sedimentation models is descriptive and wordy. It could be improved by including flowcharts and tables. |
| **10.5**. Spasojevic & Holly 2006. 2D and 3D models of obile-bed hydrodynamics and sedimentation, Chapter 15: Sedimentation Engineering | 3 | 1. Gives a clear introduction to the complicated procedure for numerical modeling of hydrodynamics and sedimentation that is useful background knowledge for practitioners,<br>2. Provides three examples that engineering practitioners can easily refer to. | 1. Approaches reviewed do not include bank mechanics, which is an important part of changes in channel morphology. |

# 4. RECOMMENDATIONS AND RESEARCH NEEDS

Under this task, the research team developed draft recommendations for possible adoption of specific research results by AASHTO. This task required that the breadth of application and limitations of each recommended result be clearly documented. The research team proposed, concise scopes of work for research needed to fill gaps in stream stability analysis practice or where evaluated research results are not ready for adoption by AASHTO and use by the engineering community in general. Draft recommendations were submitted to NCHRP for review prior to beginning Task 6. Working with the project Panel, the first two topics were considered "critical" priority, the next three topics were considered "high" priority, and the remaining three topics were considered "medium" priority. The research needs topics are:

- Critical Priority
  - Impacts of River Basin Modification and Climate Change on Bridge Safety
  - Prediction of Headcut Migration and Scour at Bridges
- High Priority
  - Bridge Crossings on Active Alluvial Fans
  - Coupling Advanced Numerical Modeling with Sediment Transport and Bank Mechanics in Bridge Reaches – Aggradation, Degradation, Contraction Scour and Channel Widening
  - Impacts of Vegetation, Restoration, Rehabilitation and Stabilization on Channel Stability in Bridge Reaches
- Medium Priority
  - Permitting and Associated Bridge Design Requirements
  - Bend and Confluence Scour Near Bridges
  - Advanced Mapping and Monitoring Tools for Bridges

The following briefly describes the research needs that were recommended to the panel. Detailed research statements that include the research objective, tasks, any special notes, and the estimated cost and duration for each are provided in **Appendix D**.

## 4.1 Impacts of River Basin Modification and Climate Change on Bridge Safety

As population densities increase and use of natural resources changes or intensifies in many basins, the impacts of agriculture, forestry, quarrying/mining, gravel extraction, dam construction and removal, river training, removal of riparian vegetation, construction and urbanization are likely to have increasingly adverse effects on bridge safety throughout affected watersheds. The effects of river basin modification and climate change relevant to bridges include channel degradation or aggradation, widening, regime change from meandering to braiding, increased rates of channel shifting, proclivity for bar formation and increased supply of debris.

If watershed climate changes, this directly affects precipitation volumes and distributions leading to further direct and indirect impacts on channel stability via changes in runoff, natural

vegetation, land-use and sediment yields. Although uncertainty clouds the issue of climate change, the implications for basin-scale channel instability, with adverse impacts to bridge safety regionally and nationally, are so serious that research is now critical.
Bridge engineers need tools to assess the vulnerability of bridges to potential changes in flow regime and catchment sediment supply associated with catchment modification or climate change. The aim of the proposed research is distillation of available literature and guidance on how to assess river basin sensitivity to modification and climate change, in the context of known hydrological and geomorphic processes and responses. Only those process-response mechanisms likely to adversely affect bridges would be considered. The study is primarily intended to be qualitative, but with as much quantification as the generality of the topic allows. Outcomes should include recommended strategies for identifying and responding to bridge problems likely to be induced by basin modification or climate change based on risk assessment leading to prioritized programs for basin-wide programs of bridge replacement or countermeasures to keep risks to acceptable levels.

## 4.2 Prediction of Headcut Migration and Scour at Bridges

Headcuts, also known as nickpoints, are erosional features where an abrupt drop occurs in the stream bed elevation. Headcuts often result from base level lowering that generates one or more episodes of stream bed incision or degradation that migrates upstream through the drainage network. The drop created by a headcut can be vertical, near vertical, or steep (knickzone) in homogeneous boundary materials and overhanging when weaker layers are overlain by a more erosion resistant layer. Headcuts increase the chance of bridge failure due to scour, degradation, and channel widening and have contributed to past bridge failures such as the I-5 failure over Arroyo Pasajero in California in 1995. Thus, four interrelated stream stability and scour processes related to headcuts determine the risk to bridges along the affected stream: (1) plunge pool depth (2) overall amount of long-term bed degradation, (3) triggering of channel widening and (4) rate of upstream headcut migration. Therefore, the objective of this research is to develop practically applicable predictive equations for each of these processes. The research will include a review of the literature, laboratory studies, and other information related to each of the headcut processes listed above plus evaluation of hydraulic design, scour performance, and morphological relationships for engineered grade control and drop structures that can be used to stabilize aggressive headcuts. Data should be obtained for a variety of field conditions for development and testing of generalized, predictive relationships. These data should include: current and historical channel hydraulics, bed material properties and morphologies, and headcut geometries, scour, and rates of migration. It is anticipated that additional investigation may be required through controlled laboratory experiments coupled with numerical modeling using Computation Fluid Dynamics (CFD).

## 4.3 Bridge Crossings on Active Alluvial Fans

Alluvial fans are fan-shaped landforms created by the distribution of significant volumes of sediment by confined and unconfined flow moving from higher to lower elevations. Alluvial fans are common throughout the western continental United States and Alaska. They are found predominantly in or along mountainous regions where flash floods, heavy precipitation, geology, and active tectonics play an important role in their development. Problems associated with active alluvial fans include flooding (sheet flow and uncertain flow paths), localized aggradation and degradation, channel shifts (avulsions), landslides and debris flows, and other hazards that have long-ranging consequences for bridge crossings. Because alluvial fans are constructed by the successive episodic and unpredictable shifting of stream flows or the successive passage of debris (colluvial) flows down different routes, alluvial fans are inherently unstable environments for bridges. Given the rapid growth of urban development onto alluvial fans in recent years, the design of bridge crossings and roadways must consider the inherent long-term instability of such sites.

Thus, the purpose of the proposed project is the development of a manual that outlines the general character of an alluvial fan, discusses active alluvial fan processes in detail, and provides guidance on incorporating alluvial fan processes and impacts in the bridge design. A brief search of the Google Scholar reveals that a wealth of relevant data and information (more than 15,000 references) has been published in the last 20 years with regard to alluvial fans and fan processes. This project will consist of an analysis and distillation of the available data and information and the preparation of a manual similar to HEC-20, but specifically tailored to bridge crossings on active alluvial fans. Given the wealth of data and information that is available on this subject, it is anticipated that no independent numerical, experimental, or field work will be needed.

## 4.4 Coupling Advanced Hydraulic Modeling with Sediment Transport and Bank Mechanics in Bridge Reaches – Aggradation, Degradation, Contraction Scour and Channel Widening

Reach-scale channel widening is a common response to stream bed degradation or aggradation while lateral channel migration is a progressive change in the position of the stream that occurs in both vertically stable and unstable channels. Local, and in some cases extreme, channel widening can occur within the bridge opening due to contraction scour. Both channel widening and lateral channel migration can cause bridge problems such as poor flow alignment, abutment outflanking or destabilization, and scour at piers not designed to be in the main channel. Although several numerical models are available for predicting channel degradation or aggradation, only a few models have been developed for predicting channel widening and lateral channel migration.

Contraction scour is primarily caused by flow acceleration and increased shear stresses and sediment transport capacity in the contracted opening at bridges. The empirical equations for calculating contraction scour are mainly based on sediment transport theory and initiation of motion, so a significant uncertainty is associated with the prediction of contraction scour depth. A numerical model that simulates changes in both bed elevation and channel width would provide better predictions of contraction scour.

Bank erosion is the mechanism of channel widening and lateral channel migration, and is a complicated process affected by numerous factors such as hydraulic conditions (erosion), bank height/angle, bank materials, and vegetation (geotechnical stability). Coupling of a two-dimensional flow and sediment model with bank failure mechanisms has not received concerted attention. In order to generate a realistic distribution of boundary shear stress, better represent secondary flow within meandering channels, and properly model complex bank mechanics, a two-dimensional hydraulic model coupled with an advanced bank stability analysis is actually needed. The proposed project will improve an existing two-dimensional flow and sediment transport model by adding a module that realistically simulates potential bank failure mechanisms. It is not intended to build this model from scratch, but to extend a widely-used and well-validated model.

## 4.5 Impacts of Vegetation Restoration, Rehabilitation and Stabilization on Channel Stability in Bridge Reaches

Research in river mechanics and fluvial geomorphology has recently established that vegetation exerts much stronger influences on channel forms and processes than was previously thought. For example; rates of bank erosion and lateral channel shifting are significantly lower along rivers flowing through mature, riparian corridors than where native vegetation has been removed from the banks, patterns of vegetation on floodplains have been shown to materially alter channel planform patterns and their evolution, and the presence of large woody debris has been found to limit degradation in incised channels. Further evidence of the profound impacts of vegetation is significant changes in channel form observed where invasive species have colonized aquatic and riparian areas. These findings come at a time when vegetation, both living and dead, is being increasingly reintroduced to channels in river restoration, rehabilitation and stabilization projects.

Despite this new knowledge and growing trends for re-introduction of vegetation to managed rivers, relatively little is known concerning how vegetation of different types located in different zones of the river physically interact with bank stability and the fluvial processes of sediment scour, transport and deposition that are responsible for channel migration and change in the vicinity of bridges. This makes it difficult to assess the risks associated with vegetation succession and management (clearance, cutting or re-introduction as part of river restoration) in the channel upstream of and around bridge crossings. To address this gap in knowledge, research is required to establish causal links between vegetation and fluvial processes at the site and reach scales. The aim would be to allow bridge engineers to assess the benefits and risks associated with different types, densities and spatial distributions of vegetation upstream and around bridge crossings based on scientific and, wherever possible, quantitative relationships. The objectives of the research would be to, among other things, develop practically applicable tools to enhance existing risk assessment methods for channel scour, deposition and lateral shifting at bridges so that they can account explicitly for both the beneficial and adverse impacts of the presence, removal, or re-introduction of vegetation. Ultimately, guidelines would be formulated for assessing vegetation related risks and benefits with respect to designing bridges and implementing countermeasures.

## 4.6 Permitting and Associated Bridge Design Requirements

State Departments of Transportation (DOT) have numerous hydraulic design standards for bridges over waterways. DOTs also have an obligation to meet regulatory requirements and obtain relevant permits and resource agency approvals for construction of bridges and countermeasures. These requirements address potential impacts on flood insurance, flood hazards, navigation, water pollution, environmental protection, and protection of fish and wildlife. Federal, State, and local agency involvement can be extensive. The permitting and approval process is often cited as a major impediment for efficient delivery of new bridges, bridge replacements, and countermeasures.

Bridge hydraulic design focuses on hydraulic efficiency. However, environmental agencies have additional concerns that include aquatic, riparian, and floodplain habitat, fish passage, and wildlife passage. This project will focus on meeting the environmental concerns related to bridge design with the goal of developing model agreements that can be tailored by individual DOTs in coordination with State environmental agencies and USFWS. These agreements would establish additional performance criteria that, if met, would significantly streamline the agency approval process by directly addressing environmental concerns. The criteria may include minimum setback distances between abutments and channel banks, requirements for clear spanning certain channels, limits on the location and number of piers in channels, constraints on exposed riprap aprons, minimum deck clearance for wildlife passage, and limits on increased velocities and shear stresses for frequent (2- to 10-year recurrence interval) flood conditions.

In addition to the benefits of streamlined permitting and reduced environmental impacts, there are other, long-term benefits that DOTs can expect from this research. These include bridges with (1) fewer debris problems, (2) reduced scour, (3) fewer stream instability problems, (4) reduced long-term maintenance, (5) extended service life, and (6) fewer countermeasures.

## 4.7 Bend and Confluence Scour Near Bridges

Bend and confluence scour are related phenomena, the first characteristic of meandering streams and the second characteristic of braided streams. Both are produced by secondary flow cells generated by streamline curvature. In meandering streams, the outside of bends tend to scour during floods and the inside fills. As a result, bed elevations on the outside of bends appear deceptively high during low flow. Bridges are commonly placed on the outside of bends, as this often allows for the anchoring of one end against a valley wall. Correct placement of pier footings and abutments is contingent upon the recognition of the amount of bend scour that might be expected during a flood.

While braided streams are less common than meandering streams in the continental USA, they can be found in the western part of the country and abound in Alaska. Confluence scour occurs where two anabranches of a braided stream flow together. Confluence scour can lead to flow depths as much as five times the ambient values in anabranches. Experience in New Zealand suggests that bridges on braided streams are most likely to fail when a confluence forms at a pier. Confluence scour of essentially the same type also occurs when a large tributary enters the main stem of a meandering or wandering river with a slowly changing planform.

While the effect of bend and confluence scour on bridges is well recognized in the technical literature, quantitative methods for predicting scour depths are provided in neither of the standard manuals HEC-18 and HEC-20 for bridge design. A concise design manual providing quantitative methods for evaluating bend and confluence scour at bridge crossings is needed.

## 4.8 Advanced Mapping and Monitoring Tools for Bridges

Bridge inspection, an important step for ensuring the safety of a bridge, is conducted to identify changing conditions of a bridge structure and changing channel conditions in the vicinity of the bridge. Changing channel conditions, such as bank erosion, channel migration, and neck cutoffs, can greatly increase the threat to the foundations of piers and abutments. Existing channel conditions are compared with previous observations and data to identify potential threats to the bridge elements. Bridge inspections are performed biennially or soon after a large flood event. However, the current bridge monitoring procedures are time-consuming and labor-intensive, and the collected monitoring data is usually incomplete, qualitative, and subjective. Bridge inspections often neglect channel stability, which are a major cause of bridge failures. Even when bridge inspectors are aware of bank retreat as potential threat, visual inspection can easily miss this type of progressive change. More automated bridge monitoring could be highly valuable, especially for bridges with scour critical conditions.

Advanced mapping and monitoring technologies have recently been a research area due to an increasing demand of consistent and reliable bridge monitoring and reconnaissance data. In a digital mapping study sponsored by Iowa DOT, morphological features such as river bank positions and floodplain edges were identified on the ortho-rectified riverside images through an image processing algorithm, and a surface velocity analysis was conducted by applying Large Scale Particle Image Velocimetry (LSPIV) on image sequences of the river flow. This methodology appears to be a relatively inexpensive and practical tool for routine bridge inspections at high-risk bridges. The goal of the proposed research is to test and advance this technology, and to prepare guidelines of standard procedures for the application of advanced mapping and monitoring tools in bridge inspections.

## 4.9 Other Recommendations

Chapter 3 provides the recommendations to AASHTO for adoption of specific research results related to geomorphic processes and predictions. The primary manual used by the U.S. transportation community on this topic is HEC-20 (Lagasse et. al 2001). An update of HEC-20 could incorporate many of the research results included in Chapter 3 without significantly reorganizing the manual because the additions could be incorporated into existing manual sections. In some cases, new sections would need to be written to cover recommended topics more thoroughly, such as a gravel bed river section. One recommendation for an update of HEC-20 is to follow the three level approach theme throughout the manual. Currently, HEC-20 presents the three level approach as a stream stability analysis procedure. When a topic, such as lateral stability, is presented in a subsequent section of the manual, the methods are not assigned to a specific level. A modest amount of reorganization regarding grouping and discussing the various approaches in relation to the three level approach may improve the utility of HEC-20.

Because Level 1 methods are more qualitative and conceptual, they play an important role in identifying stream stability problems at bridge. Therefore, Level 1 methods must have in-depth coverage in HEC-20. Level 2 approaches provide quantitative tools for estimating the severity of stream stability problems and predicting future conditions. Level 2 approaches are also selected to provide reasonable results at a level of effort that is justifiable for the majority of bridges. This level should also be covered in detail in HEC-20. Level 3 approaches are reserved for highly complex problems when it is determined that Level 2 is insufficient to address a problem without excessive uncertainty or risk. Therefore, Level 3 approaches should be discussed in HEC-20, but not in the same detail as Levels 1 and 2. Level 3 methods should be discussed in concept by providing some description, guidance, and references. The strengths and limitations of all methods regardless of level should also be included in HEC-20.

## 5. REFERENCES

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# APPENDIX A

## Annotated Bibliography
## (of Priority Research only)

# CONTENTS

## 4.0 Articles from "Water Resources Research"



## 5.0 Articles from "Geomorphology"

**NCHRP Project 24-27(03)**

# Evaluation of Bridge-Scour Research: Geomorphic Processes and Predictions

## Annotated Bibliography

## 1.0 Research Included in Geomorphology Category of NCHRP Project 20-07(178)

1.1 Briaud, J.L., Hamn, C., Kuang, A., Chung, Y., Park, N., Wang, W., and Yeh, P., 2007. Report FHWA/TX-07/0-4378-1, 315 pp. FHWA/TX-07/0-4378-1 Establish Guidance for Soils Properties-Based Prediction of Meander Migration Rate.

*Meander migration costs the Texas Department of Transportation (TxDOT) millions of dollars to protect affected bridges and highway embankments, as illustrated by the case histories accumulated by this research team in phase 1 of this work. These histories include the SH 105 bridge over the Brazos River, the US 90 bridge over the Nueces River, the SH 105 bridge over the Trinity River, the US 59 bridge over the Guadalupe River, and the SH 80 bridge over the Guadalupe River. One recent meander migration threat (FM 787 at the Trinity River) required a $300,000 emergency countermeasure and a $5.6 million replacement bridge.*

*Several solutions for predicting the movement of meanders have been proposed in the past. This report shows these solutions to be unreliable. The solution outlined in this report considers soil erodibility as an independent parameter influencing meander migration. Other conventional parameters such as flow velocity, meander radius of curvature, river width, and others are part of the proposed solution. Through a combination of well-instrumented large-scale flume tests, quality numerical simulations, and fundamental laboratory erosion tests, a simple and reliable solution is developed.*

1.2 Maryland State Highway Agency (MDSHA), 2007. Office of Bridge Development Manual for Hydrologic and Hydraulic Design: Chapter 14: Stream Morphology and Channel Crossings.

*This chapter presents guidance developed and implemented by the Office of Bridge Development (OBD) specifically for Maryland streams. These procedures outline the approach to be used in evaluating the morphology of a stream reach in the vicinity of a waterway crossing. Similar guidance on several provided procedures has not been found to be available in Federal manuals or other publications accessible to the public. Most of the guidance in Chapter 14 is based on the results of studies and investigations conducted since the mid-1990s in Maryland.*

*The investigations from which these techniques were developed targeted wadeable gravel-bed stream that generally maintain a pool-riffle morphology and have channel slopes of 0.2% to 4%; may of the techniques, however, may be found to be applicable to stream o f other morphologies. Chapter 14 includes guidance on assessing long-term changes in channel bed elevation, channel lateral movement, sediment dynamics, debris, and bend scour.*

1.3 Johnson, P.A., 2006. Assessing Stream Channel Stability at Bridges in Physiographic Regions, Federal Highways Administration Publication No. FHWA-HRT-05-072, 147 pp.

*The objective of this study was to expand and improve a rapid channel stability assessment method developed previously by Johnson et al. (1999) to include additional factors, such as major physiographic units across the United States, a greater range of bank materials and complexities, critical bank heights, stream types and processes, sand bed streams, and in-channel bars or lack of bars. Another goal of this study was to tailor Thorne's reconnaissance method for bridge inspection and stability assessment needs.*

1.6 Lagasse, P.F., Spitz, W.J., Zevenbergen, L.W. and Zachmann, D.W. 2004. NCHRP Report 533, Handbook for Predicting Stream Meander Migration.

*The report presents a methodology for predicting the rate and extent of stream meander migration. The method includes a screening and classification system for meandering streams. Map and aerial photo comparison techniques were developed using photogrammetric principles to record the location of meander banklines. A stream meander prediction methodology was then developed by extrapolating the bend position and characteristics. Limitations and sources of error were identified. An ArcView-based data logger and channel migration predictor was provided as part of the research.*

## 2.0 Potentially Valuable Research Included in Other Categories of NCHRP Project 20-07(178)

2.5 Palmer, R., Turkiyyah, G., and Harmsen, P., 1999. NCHRP Project 24-19, CAESAR: An Expert System for Evaluation of Scour and Stream Stability, Transportation Research Board of the National Academies, National Cooperative Highway Research Program Report 426, 23 pp.

*This report describes the design, construction, and testing of CAESAR (Catalog And Expert Evaluation of Scour Risk And River Stability), an expert system for the evaluation of scour and stream stability. CAESAR assists bridge scour inspectors with several elements of the bridge scour inspection process, including cross-section plotting; storage of bridge design data; storage of historical scour inspections; note editing and storage; digital photograph storage, viewing, and retrieval; and independent scour risk evaluation. The CAESAR system was field-tested at five state DOT offices across the country. At each state, the system was demonstrated and then used to evaluate typical bridges. The DOT officials compared the system's conclusions with their own conclusions and provided their comments on the system interface. As CAESAR neared completion, it was used to evaluate 25 case studies in order to demonstrate its ability to provide conclusions similar to those provided by human bridge scour experts.*

*The state DOT officials indicated that CAESAR conforms well with state scour inspection practices and provides adequate features to assist with the bridge scour inspection process. Bridg3e scour inspectors easily answered the questions posed by the CAESAR system about bridge site characteristics. In addition, the officials indicated CAESAR could be helpful in organizing inspection records, digital photographs, and other data resulting from bridge inspections. Finally, the officials indicated that CAESAR's conclusions matched their conclusions at the sites visited.*

*The conclusion of the research is that CAESAR can be readily implemented into state scour inspection processes and will perform its designed function to assist with bridge scour inspection process and provide an assessment of scour risks at bridge sites.*

## 3.0 Articles from ASCE "Journal of Hydraulic Engineers"

3.2 Langendoen, E.J., Wells, R.R., Thomas, R.E., Simon, A., and Bingner, R.L., 2009. Modeling the Evolution of Incised Streams III: Model Application, Journal of Hydraulic Engineering.

*Incision and the ensuing widening of alluvial stream channels represent important forms of channel adjustment. Two accompanying papers have presented a robust computational model for simulating the long-term evolution of incised and restored or rehabilitated stream corridors. This work reports on applications of the model to two incised streams in northern Mississippi, James Creek, and the Yalobusha River, to assess: (1) its capability to simulate the temporal progression of incised streams through the different stages of channel evolution; and (2) model performance when available input data regarding channel geometry and physical properties of channel boundary materials are limited (in the case of James Creek). Model results show that temporal changes in channel geometry are satisfactorily simulated. The mean absolute deviation (MAD) between observed and simulated changes in thalweg elevations is 0.16m for the Yalobusha River and 0.57m for James Creek, which is approximately 8.1 and 23% of the average degradation of the respective streams. The MAD between observed and simulated changes in channel topwidth is 5.7% of the channel topwidth along the Yalobusha River and 31% of the channel topwidth along James Creek. The larger discrepancies for James Creek are mainly due to unknown initial channel geometry along its upper part. The model applications also emphasize the importance of accurate characterization of channel boundary materials and geometry.*

3.7 Papanicolaou, A.N., Elhakeem, M., Krallis, G., Prakash, S., Edinger, J., 2008. Sediment Transport Modeling Review - Current and Future Developments, Journal of Hydraulic Engineering, ASCE.

*The use of computational models for solving sediment transport and fate problems is relatively recent compared with the physical models. With the rapid developments in numerical methods for fluid mechanics, computational modeling has become an attractive tool for studying flow/sediment transport and associated pollutant fate processes in such different environments as rivers, lakes, and coastal areas. Representative processes in these environments include bed aggradation and degradation, bank failure, local scour around structures, formation of river bends, fining, coarsening and armoring of streambeds, transport of point source and nonpoint source pollutant attached to sediments, such sediment exchange processes as settling, deposition, and self-weight consolidation; coastal sedimentation; and beach processes under tidal currents and save action.*

*The objectives of this article are twofold. First, the article aims to trace the developmental stages of current representative (1D, 2D, and 3D) models and describe their main applications, strengths, and limitations. The article is intended as a first guide to readers interested in immersing themselves in modeling and at the same time sets the stage for discussing current limitations and future needs. Second, the article provides insight about future trends and needs with respect to hydrodynamic/sediment transport6 models.*

3.9 Doyle, M.W., Shields, D., Boyd, K.F., Skidmore, P.B., and Dominick, D. 2007. Channel-Forming Discharge Selection in River Restoration Design, Journal of Hydraulic Engineering.

*The concept of channel-forming ($Q_{cf}$) or dominant discharge is now a c cornerstone of river channel restoration design. Three measures of channel-forming discharge are most commonly applied: effective discharge ($Q_{eff}$), bankfull discharge ($Q_{bf}$), and a discharge of a certain recurrence interval ($Q_{ri}$), which theoretically are similar in geomorphically stable channels. The latter two measures have become particularly widely applied in some channel restoration design procedures, often to the exclusion of $Q_{eff}$ analyses, despite the additional utility of $Q_{eff}$ analysis for most channel design problems. We quantify the three measures of $Q_{cf}$ for four case studies and then follow this with a synthesis of previously published studies to illustrate sources of variability. This synthesis suggests that agreement among the three measures of $Q_{cf}$ is best for snowmelt-hydrology, nonincised channels with coarse substrate. Departures from these conditions result in greater discrepancy between the measures. Channel incision produces $Q_{bf}$ far greater than $Q_{eff}$, and flashy hydrology is associated with generally larger, briefer, and more frequent $Q_{eff}$. Regional mean or median values for the relative magnitudes of the three measures can be tightly constrained, but site to site variation is quite large. The construction of accumulative sediment discharge curve and associated determination of $Q_{eff}$ allows quantification of the sediment budget of a channel for a given hydrologic regime, which provides process-based insight of drivers of current and future trajectories of channel stability, and is thus the recommended measure of channel-forming discharge. Reliance on only return-interval or bankfull discharge for channel design is not recommended for channel design activities.*

3.11 Lee, Jong-Seok and Julien, P.Y., Julien, 2006. Downstream Hydraulic Geometry of Alluvial Channels, Journal of Hydraulic Engineering.

*This study extends the earlier contribution of Julien and Wargadalam in 1995. A larger database for the downstream hydraulic geometry of alluvial channels is examined through an online regression analysis. The database consists of a total of 1,485 measurements,1, 125 of which describe field data used for model calibration. The remaining 360 field and laboratory measurements are used for validation. The data used for validation include sand-bed, gravel-bed, and cobble-bed streams with meandering to braided planform geometry. The five parameters describing downstream hydraulic geometry are: channel width W, average flow depth, mean flow velocity V, Shields parameter $\tau^*$, and channel slope S. The three independent variables are discharge Q, median bed particle diameter $d_s$, and either channel slope S or Shields parameter $\tau^*$ for dominant discharge conditions. The regression equations were tested for channel width ranging from 0.2 to 1,100 m, flow depth from 0.01 to 16 m, flow velocity from 0.02 to 7 m/s, channel slope from 0.0001 to 0.08, and Shields parameter from 0.001 to 35. The exponents of the proposed equations are comparable to those of Julien and Wargadalam (1995), but based on $R^2$ values of the validation analysis, the proposed regression equations perform slightly better.*

3.16 Shields, Jr., F.D., Copeland, R.R., Klingeman, P.C., Doyle, M.W., and Simon, A., 2003. Design for Stream Restoration, Journal of Hydraulic Engineering.

*Stream restoration, or more properly rehabilitation, is the return of a degraded stream ecosystem to a close approximation of its remaining natural potential. Many types of practices (dam removal, levee breaching, modified flow control, vegetative methods for streambank erosion control, etc.) are useful, but this paper focuses on channel reconstruction. A tension exists between restoring natural fluvial processes and ensuring stability of the completed project. Sedimentation analyses are a key aspect of design since many projects fail due to erosion or sedimentation. Existing design approaches range from* *relatively simple ones based on stream classification and regional hydraulic geometry relations to more complex two-and three-dimensional numerical models. Herein an intermediate approach featuring application of hydraulic engineering tools for assessment of watershed geomorphology, channel-forming discharge analysis, and hydraulic analysis in the form of one-dimensional flow and sediment transport computations is described.*

3.18 Melville, B.W. and Coleman, S.E., 2000. Bridge Scour, Water Resources Publications, LLC, Highlands Ranch, Colorado, 11.0 Sections from "Bridge Scour" by Melville and Coleman.

*The book covers the description, analysis and design for scour - including channel lateral and vertical instability - at bridge foundations. Chapter 4 includes guidance on qualitative geomorphic concepts (Section 4.2), aggradation and degradation (Section 4.3), bend scour (Section 4.5), bed forms (Section 4.7) and lateral channel erosion (Section 4.8) and a general design method incorporating these processes.*

3.20 Jia, Y. and Wang, S.S.Y., 1999. Numerical Model for Channel Flow and Morphological Change Studies, Journal of Hydraulic Engineering.

*In this paper a depth-integrated 2D hydrodynamic and sediment transport model, CCHE2D, is presented. It can be used to study steady and unsteady free surface flow, sediment transport, and morphological processes in natural rivers. The efficient element method is applied to discretize the governing equations, and the time marching technique is used for temporal variations. The moving boundaries were treated by locating the wet and dry nodes automatically in the cases of simulating unsteady flows with changing free surface elevation in channels with irregular bed and bank topography. Two eddy viscosity models, a depth-averaged parabolic model and a depth-averaged mixing length model, are used as turbulent closures. Channel morphological changes are computed with considerations of the effects of bed slope and the secondary flow in curved channels. Physical model data have been used to verify this model with satisfactory results. The feasibility studies of simulating morphological formation in meandering channels and flows in natural streams with in-stream structures have been conducted to demonstrate its applicability to hydraulic engineering research/design studies of stream stabilization and ecological quality among other problems.*

3.22 Karim, F., 1999. Bed-Form Geometry in Sand-Bed Flows, Journal of Hydraulic Engineering.

*A new method is proposed for predicting relative bed-form height h/d in sand-bed flows. The proposed method is based on the concept of relating energy loss due to form drag to the head loss across a sudden expansion in open channel flows. A unique feature of the proposed method is that it can be applied to various bed forms, i.e., ripples, dunes, antidunes/standing waves, and transitional bed regimes that occur in alluvial flows. The relation thus developed was applied to a large number (251 flows, 14 different data sets) of laboratory and river data, and was found to give good agreement with the observed h/d values. In a comparison of prediction accuracies with seven existing relationships, the proposed method was found to give significantly better agreements with the observed data. Future improvements in the prediction of h/d will depend on improved formulations of the two parameters incorporated in the present relation, i.e., energy loss coefficient K, and the relative bed-form length L/d for various bed configurations. More research is needed to develop better formulations for these parameters.*

3.30 Julien, P.Y. and Klassen, G.J., 1995. Sand-Dune Geometry of Large Rivers During Floods, Journal of Hydraulic Engineering.

*The geometry of lower regime bed forms in several large sand-bed rivers is investigated during average and flood conditions. The van Rijn method is revised because it generally underpredicts the dune height of most large rivers around the world. During floods in large sand-bed rivers, upper-regime plane bed is not necessarily obtained when T = 25. Both parameters describing dune height and dune steepness do not decrease as the transport-stage parameter T increases in the range 10 < T < 25. The analysis of bed-form data during large floods on the Meuse River and the Rhine River branches indicates that both the dune height and length generally increase with discharge while dune steepness remains relatively constant. A reasonable approximation of the wavelength is* $\lambda \cong 6.5\ h$*, where h is the flow depth. The dune height* $\Delta$ *varies as a function of the depth h and median grain size* $d_{50}$*. Estimates can be obtained by* $\Delta \cong 2.5\ h^{0.7} d_{50}^{0.3}$

3.31 Julien, P.Y. and Wargadalam, J., 1995. Alluvial Channel Geometry: Theory and Applications, Journal of Hydraulic Engineering.

*The downstream hydraulic geometry of alluvial channels, in terms of bankfull width, average flow depth, mean flow velocity, and friction slope, is examined from a three-dimensional stability analysis of noncohesive particles under two-dimensional flows. Four governing equations (flow rate, resistance to flow, secondary flow, and particle mobility) are solved to analytically define the downstream hydraulic geometry of noncohesive alluvial channels as a function of water discharge, sediment size, Shields number, and streamline deviation angle. The exponents of hydraulic geometry relationships change with relative submergence. Four exponent diagrams illustrate the good agreement with several empirical regime equations found in the literature. The analytical formulations were tested with a comprehensive data set consisting of 835 field channels and 45 laboratory channels. The data set covers a wide range of flow conditions from meandering to braided, sand-bed and gravel-bed rivers with flow depths and channel widths varying by four orders of magnitude. Figures illustrate the results of the three-part analysis consisting of calibration, verification, and validation of the proposed hydraulic geometry equations. Field and laboratory observations are in very good agreement with the calculations of flow depth, channel width, mean flow velocity, and friction slope.*

## 4.0 Articles from "Water Resources Research"

4.8 Perucca, E., Camporeale, C., and Ridolfi, L., 2007. Significance of the riparian vegetation dynamics on meandering river morphodynamics, Water Resour. Res., 43, W03430, doi:10.1029/2006WR005234.

*A river and its surrounding riparian vegetation are two dynamical systems that interact through several hydrological, geomorphological, and ecological processes. This work focuses on the role played by vegetation on meandering river morphodynamics: River planform evolution forces the riparian vegetation dynamics, which, in turn, affect the mechanical characteristics of the river banks and influence the meandering dynamics of the river itself. It follows that despite the fact that a traditional engineering approach considers vegetation as a static element the study of river morphodynamics should be coupled with the riparian vegetation evolution. To this end, a fluid dynamic model of meandering rivers is here coupled with a process-based model for the riparian biomass dynamics. The feedback of vegetation on river morphology is provided by a relation that links the biomass density to the bank erodibility. The numerical results highlight (1) the remarkable effects of the vegetation dynamics on meander evolution and (2) the role of the temporal scales of* *vegetation growth and decay in relation to typical morphodynamic scales. In particular, the differences with respect to the constant erodibility case can be of the order of tens or hundreds of meters (10–20% of the meander wavelength), and peculiar meander shapes that do not show the usual marked upstream skewness emerge.*

4.14 James, L.A., 1997. Channel Incision on the Lower American River, California, from Streamflow Gage Records, Water Resour. Res., 33(3), 485–490.

*Channel incision along the lower American River from 1905 to 1995 is investigated using channel cross-section plots and statistical analysis of stage-discharge data from two streamflow gages located at three sites. Channel incision lowered thalweg elevations at rates of up to 8.2 cm yr−1, and flow stages decreased at rates of up to 4.3 cm yr−1 for periods lasting several decades. At a critical flood risk location in Sacramento, flow stages lowered 2 m from 1924 to 1970. Channel incision was the result of channel recovery from aggradation due to hydraulic gold-mining sediment and was exacerbated by sediment storage behind dams. Prolonged erosion and transport of historical alluvium in this river suggest that G.K. Gilbert's symmetrical sediment wave model is inappropriate for the lower American River and may not adequately allow for the importance of sediment storage and remobilization in fluvial systems.*

## 5.0 Articles from "Geomorphology"

5.2 Faustini, J.M., Kaufmann, P.R., and Herlihy, A.T., 2009. Downstream variation in bankfull width of wadeable streams across the conterminous United States.

*Bankfull channel width is a fundamental measure of stream size and a key parameter of interest for many applications in hydrology, fluvial geomorphology, and stream ecology. We developed downstream hydraulic geometry relationships for bankfull channel width w as a function of drainage area A, w=α Aβ, (DHGwA) for nine aggregate ecoregions comprising the conterminous United States using 1588 sites from the U.S. Environmental Protection Agency's National Wadeable Streams Assessment (WSA), including 1152 sites from a randomized probability survey sample. Sampled stream reaches ranged from 1 to 75 m in bankfull width and 1 to 10,000 km2 in drainage area. The DHGwA exponent β, which expresses the rate at which bankfull stream width scales with drainage area, fell into three distinct clusters ranging from 0.22 to 0.38. Width increases more rapidly with basin area in the humid Eastern Highlands (encompassing the Northern and Southern Appalachians and the Ozark Mountains) and the Upper Midwest (Great Lakes region) than for the West (both mountainous and xeric areas), the southeastern Coastal Plain, and the Northern Plains (the Dakotas and Montana). Stream width increases least rapidly with basin area in the Temperate Plains (cornbelt) and Southern Plains (Great Prairies) in the heartland. The coefficient of determination (r2) was least in the noncoastal plains (0.36–0.41) and greatest in the Appalachians and Upper Midwest (0.68–0.77). DHGwA equations differed between streams with dominantly fine bed material (silt/sand) and those with dominantly coarse bed material (gravel/cobble/boulder) in six of the nine analysis regions. Where DHGwA equations varied by sediment size, fine-bedded streams were consistently narrower than coarse-bedded streams. Within the Western Mountains ecoregion, where there were sufficient sites to develop DHGwA relationships at a finer spatial scale, α and β ranged from 1.23 to 3.79 and 0.23 to 0.40, respectively, with r2N0.50 for 10 of 13 subregions (range: 0.36 to 0.92). Enhanced DHG equations incorporating additional data for three landscape variables that can be derived from GIS - mean annual precipitation, elevation, and mean reach slope - significantly improved equation fit and predictive value in several regions, most notably the Western Mountains and the Temperate Plains. Channel width was also related to human disturbance. We examined the influence of human disturbance on* *channel width using several indices of local and basin wide disturbance. Contrary to our expectations, the data suggest that the dominant response of channel width to human disturbance in the United States is a reduction in bankfull width in streams with greater disturbance, particularly in the Western Mountains (where population density, road density, agricultural land use, and local riparian disturbance were all negatively related to channel width) and in the Appalachians and New England (where urban and agricultural land cover and riparian disturbance were all negatively associated with channel width).*

5.6 Hooke, J.M., 2008. Cutoffs galore!: occurrence and causes of multiple cutoffs on a meandering river.

*The creation of cutoffs and of oxbow lakes is a well-known phenomenon of meandering rivers, but views on the extent to which they are inherent in meander behavior have varied. Assumptions of meander behavior have shifted from those of stability and equilibrium to recognition of gradual evolution and increased complexity of form. Alternative explanations of cutoff occurrence are discussed here in relation to a remarkable set of cutoffs that occurred in one reach of the River Bollin, UK, for which long-term historical evidence of meander evolution existed and which has been monitored for change and processes over the last 20 years. The cutoffs occurred during the high floods of winter 2000-2001. A series of hypotheses is examined, including the occurrence of floods and effects of hydrological changes. Although the flood events actually caused the cutoffs, the long-term pattern accords with ideas of chaotic behavior and sinuosity of a river reaching a critical state at which clustering of meander cutoffs takes place. It is suggested that the occurrence of the cutoffs can be explained as inherent in meander behavior.*

5.9 Thorndycraft, V.R., Benito, G., and Gregory, K.J., 2008. Fluvial geomorphology: A perspective on current status and methods.

*Fluvial geomorphology seeks to study river landform history, understand formative processes, and predict changes using a combination of field observation, experimental studies and numerical models. A resurgence in fluvial geomorphology is taking place, fostered for example by its interaction with river engineering, and the availability of new analytical methods, instrumentation and techniques. These have enabled development of new applications in river management, landscape restoration, hazard studies, river history and geoarchaeology. This paper presents a perspective on recent advances in fluvial geomorphology, and introduces a selection of papers presented during the Fluvial Geomorphology and Palaeohydrology session within the Sixth International Conference on Geomorphology held in Zaragoza (Spain) in September 2005.*

5.11 Brasington, J. and Richards, K., 2007. Reduced-complexity, physically-based geomorphological modeling for catchment and river management.

*Introduction Sustainable water resource management requires integrated assessment of the physical, biological and hydraulic functions of rivers and their catchments. This holistic philosophy demands that land, water and environmental managers have access to appropriate modeling and simulation tools to guide strategy and help refine decision making. However, the time and space scales for such management (involving multi-decadal timescales incorporating land-use and climate change scenarios, and whole-catchment spatial scales) are intermediate in relation to the scales of process understanding and modeling typical of recent research in surface earth and environmental systems. For example, the conceptual framework underpinning research into hydraulics and fluvial sediment transport has largely relied on experimental flume studies and computational fluid dynamics (CFD). By contrast, our knowledge of the larger scale, longer* *term impacts of climate and land-use change on channel dynamics is traditionally derived from the sedimentary record. The dynamics of the mesoscale (broadly 100–102 km and 101–103 years), that characterize the behavior and evolution of river and catchment systems over relevant planning and management horizons, lie between these two approaches. This scale also requires process models that can accommodate and even implicitly solve the changing boundary conditions governing land-surface mass and energy fluxes. While such adaptive modeling is not theoretically beyond conventional CFD methods, the need to frequently remesh their complex computational domains creates a significant computational overhead that severely restricts the time and space scales of model applications and precludes exhaustive parameter space exploration. Modeling this 'intermediate scale' nevertheless still requires solutions embedded in physical theory, albeit simplified to appropriate levels of complexity in order to reduce computational and parametric overheads and thus allow for time-efficient simulation and uncertainty analysis. Recent advances in this field have sought to achieve these ends through the development of novel spatial and cellular algorithms, efficient discretization methods and an increasing reliance on high quality topographic data. Specific examples include topography based hillslope hydrological models (TOPMODEL), raster storage-cell models for floodplain inundation (LISFLOOD) and cellular automaton models of channel dynamics and landscape evolution (CHILD, CEASAR). Of course, such simplification introduces a new set of problems, since it implies that weakly-physical or empirical parameterizations are necessary in place of previously well-constrained properties or variables. Additional complexity then emerges in that the nature of these parameterizations may themselves be scale dependent and not easily transferred. The mismatch between physical theory and the practical estimation of model parameter values is well recognized in hydrology. For example, the transmissivity parameterization in TOPMODEL is highly sensitive to grid resolution and less physically tractable than it appears in the underlying theory (see Brasington and Richards,1998). However, such scale dependence is also evident in more complex distributed hydrological models (Beven,1989), as well as in the more physically complete schemes of CFD, where boundary roughness is partitioned between grain and form components differently as the grid resolution changes (Lane and Richards, 1998;Nicholas, 2001). However, in some of the reduced complexity approaches described in the papers in this collection, the balance of physical description matched to computational parsimony is often extended to extreme levels. For example, in many of the hydrological routing procedures described, algorithms appear less designed to provide physically-realistic solutions even to already simplified momentum equations than to facilitate simple computational solutions (for example, the scanning algorithms designed to smooth predicted routing directions). The aim of this collection of papers on the theme of" reduced-complexity models" or RCMs, based on a session at the European Geophysical Union meeting in Vienna in May 2005, is to demonstrate and discuss these and other emerging computational methods focusing on river and catchment processes, which target the intermediate time and space scales relevant to environmental management. The contributions in the original Vienna meeting outlined theoretical developments and discussed approaches to model parameterization, data integration and uncertainty analysis, as well as providing results from particular management-oriented case studies. They also covered substantive areas ranging from floodplain inundation modeling, through sediment supply from hillslopes and transport in channels, to channel and landscape dynamics. The rationale for this collection is that the development and application of reduced-complexity models (RCMs) appears to be emerging as a significant area of research in geomorphology and it is timely, therefore, to present a set of papers that explain the potential, debate the problems and illustrate a range of applications. We venture to hope that it might therefore provide something of a landmark and catalyze further research on this front. In this brief introduction to the compilation, we outline some of the key underlying themes and issues, and present a summary of the contents of the collection.*

5.20 Brummer, C.J., Abbe, T.B., Sampson, J.R., and Montgomery, D.R., 2006. Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA.

*We combine hydraulic modeling and field investigations of logjams to evaluate linkages between wood-mediated fluctuations in channel-bed-and water-surface elevations and the potential for lateral channel migration in forest rivers of Washington state. In the eleven unconfined rivers we investigated, logjams were associated with reduced channel gradient and bank height. Detailed river gauging and hydraulic modeling document significant increases in the water-surface elevation upstream of channel-spanning wood accumulations. Logjams initiated lateral channel migration by increasing bed-or water-surface elevations above adjacent banks. Because the potential for a channel to avulse and migrate across its floodplain increases with the size and volume of instream wood, the area of the valley bottom potentially occupied by a channel over a specified timeframe—the channel migration zone (CMZ)- is dependent on the state of riparian forests. The return of riparian forests afforded by current land management practices will increase the volume and caliber of wood entering Washington rivers to a degree unprecedented since widespread clearing of wood from forests and rivers nearly 150 years ago. A greater supply of wood from maturing riparian forests will increase the frequency and spatial extent of channel migration relative to observations from wood-poor channels in the period of post-European settlement. We propose conceptual guidelines for the delineation of the CMZs that include allowances for vertical fluctuations in channel elevation caused by accumulations of large woody debris.*

5.21 Goudie, A.S., 2006. Global warming and fluvial geomorphology.

*Future global warming has a number of implications for fluvial geomorphology because of changes in such phenomena as rates of evapotranspiration, precipitation characteristics, plant distributions, plant stomatal closure, sea levels, glacier and permafrost melting, and human responses. Potential changes in rivers are outlined in this review in the context of changes in the intensity of rainfall, the activity of tropical cyclones, runoff response (including that of Europe, dry lands and high latitude environments), and geomorphological reactions, including rates of soil erosion. In general, however, much work remains to be done to establish the full range of geomorphological responses that may take place in fluvial systems.*

5.26 Millar, R.G., 2005. Theoretical regime equations for mobile gravel-bed rivers with stable banks.

*A system of rational regime equations is developed for gravel-bed rivers with stable banks using the optimality theory (OT). The optimality theory is based on the premise that equilibrium river geometry is characterized by an optimum configuration, defined here as maximum sediment-transport efficiency. Theoretical dimensionless equations are derived for width, depth, slope, width/depth ratio, and meandering–braiding transition. Independent dimensionless variables comprise discharge, sediment concentration, and relative bank strength, lV, which is defined as the ratio of the critical shear stresses for the bank and bed sediments. Discharge exponents and general form of the equations agree well with previously developed empirical relations. Relative bank strength, lV, is used to parameterize the influence of riparian vegetation on bank strength and is evaluated by calibrating against observed width/depth ratio. Once calibrated, the hydraulic geometry of natural gravel rivers is well described by the theoretical equations, including discrimination between meandering and braiding channels. The results provide strong support for the assumption that equilibrium or regime river behavior is equivalent to an optimal state and underline the importance of bank strength and sediment load as controls on hydraulic geometry.*

5.29 Eaton, B.C. and Millar, R.G., 2004. Optimal alluvial channel width under a bank stability constraint.

*To properly predict alluvial channel width using rational regime models, an analysis of bank stability must be included in the model. When bank stability is not considered, optimizations assuming maximum sediment transport capacity (MTC) typically under-predict alluvial channel width for natural and laboratory streams. Such discrepancies between regime model predictions and observed channel widths have been used to argue that optimizations such sat do not describe the behavior of alluvial systems. However, rational regime models that explicitly consider bank stability exhibit no such bias and can predict alluvial channel widths quite accurately. We present an analysis of both laboratory and natural alluvial channels, using both kinds of models, and demonstrate the importance of bank stability in constraining optimization solutions. We also identify a scale effect, whereby the effect of vegetation on bank strength declines as the absolute scale of the system increases. We argue that comparisons of alluvial channel widths against predictions from rational regime models unconstrained by bank stability are inappropriate, because they introduce a known and quantifiable bias (toward under-prediction by the model) due to the absence of a bank stability constraint.*

5.38 Mount, N.J., Louis, J., Teeuw, R.M., Zukowskyj, P.M., and Stott, T., 2003. Estimation of error in bankfull width comparisons from temporally sequenced raw and corrected aerial photographs.

*This study investigates the propagation of error through image-to-image comparison of 285 river bankfull width measurements of the Afon Trannon, mid-Wales. Bankfull width is quantified from both aerial photographs analyzed as rectified images in ERDAS Imagine OrthoMax and raw images in Paintshop Pro. A method for the robust estimation of bankfull width measurement error through temporal sequences of scanned aerial photographs is presented and the improvement in accuracy achieved using rectified imagery is quantified. Results from this study are placed in the context of previously published rates of bankfull width change, from a wide range of river scales, and the bankfull change rates for robust medium-term analysis using approximately 1:10,000 historical aerial photography are identified.*

5.44 Thorne, C.R., 2002. Geomorphic analysis of large alluvial rivers.

*Geomorphic analysis of a large river presents particular challenges and requires a systematic and organized approach because of the spatial scale and system complexity involved. This paper presents a framework and blueprint for geomorphic studies of large rivers developed in the course of basic, strategic and project-related investigations of a number of large rivers. The framework demonstrates the need to begin geomorphic studies early in the pre-feasibility stage of a river project and carry them through to implementation and post-project appraisal. The blueprint breaks down the multi-layered and multi-scaled complexity of a comprehensive geomorphic study into a number of well-defined and semi-independent topics, each of which can be performed separately to produce a clearly defined, deliverable product. Geomorphology increasingly plays a central role in multi-disciplinary river research and the importance of effective quality assurance makes it essential that audit trails and quality checks are hard-wired into study design. The structured approach presented here provides output products and production trails that can be rigorously audited, ensuring that the results of a geomorphic study can stand up to the closest scrutiny.*

5.46 Bledsoe, B.P. and Watson, C.C., 2001. Logistic analysis of channel pattern thresholds: meandering, braiding, and incising.

*A large and geographically diverse data set consisting of meandering, braiding, incising, and post-incision equilibrium streams was used in conjunction with logistic regression analysis to develop a probabilistic approach to predicting thresholds of channel pattern and instability. An energy-based index was developed for estimating the risk of channel instability associated with specific stream power relative to sedimentary characteristics. The strong significance of the 74 statistical models examined suggests that logistic regression analysis is an appropriate and effective technique for associating basic hydraulic data with various channel forms. The probabilistic diagrams resulting from these analyses depict a more realistic assessment of the uncertainty associated with previously identified thresholds of channel form and instability and provide a means of gauging channel sensitivity to changes in controlling variables.*

5.47 Field, J., 2001. Channel avulsion on alluvial fans in southern Arizona.

*Historical aerial photographs and field observations on five fluvially dominated alluvial fans in southern Arizona demonstrate that channel avulsion invariably occurs where bank heights are low and often at channel bends. Channel abandonment occurs through stream capture when overland flow from the main channel accelerates and directs headward erosion of smaller channels heading on the fan surface. Five distinct channel morphologies observed on the fans are related to different stages of the avulsion process and can be used to identify areas on a fan surface that are prone to avulsion. A descriptive model of channel avulsion illustrates how the morphology of a single channel reach will evolve through time as it captures the main flow path and is itself eventually abandoned. Immediately following avulsions, small preexisting channels that capture flow from the main channel will typically experience three fold or greater increases in channel width. Subsequent large floods can be stably conveyed through these high-capacity reaches. An uninterrupted sequence of sediment-charged small flows, however, will eventually begin to back-fill the wide channels as vegetation growth stabilizes the banks. The stabilized and back-filled channels are now prone to abandonment during large floods because the decrease in the channel's capacity leads to the generation of overland flow beyond the margins of the shallowed channels. The action of the small aggrading floods is critical in the avulsion process since the greatest amount of overland flow is generated where bank heights are lowest. As a result, both small and large floods are effective agents of landscape change on the fans. Channel avulsions on the five fans are not completely random events in space and time because their occurrence is controlled by the relative positioning of low banks along the main channel and smaller channels draining the fan surface. Consequently, the location and timing of future channel avulsions can potentially be anticipated in an effort to improve flood hazard assessment on fluvial fans in the rapidly urbanizing southwestern United States.*

5.48 Lewin, J. and Brewer, P.A., 2001. Predicting channel patterns.

*The proposed distinction between meandering and braided river channel patterns, on the basis of bankfull specific stream power and bed material size, is analyzed and rejected. Only by using regime-based estimates of channel widths rather than actual widths. has discrimination been achieved, and it is argued that this procedure is unacceptable. An alternative is to explore the patterning processes underlying the marked pattern scatter on bankfull stream power bed material size plots. Of the five sets of patterning processes, large-scale bedform development and stability is seen as especially important for meandering and braiding. For gravel-bed rivers, bedforms developed at around or above* *bankfull stage appear important for pattern generation, with braiding relating to higher excess shear stress and Froude number. There seems to be an upper threshold to both meandering and braiding which is achieved at extreme discharges and steep gradients, as on steep alluvial fans, rather than for the rivers with available flow data here considered. For sand-bed rivers with greater excess shear stress, the equivalent upper plane bed threshold may occur below bankfull, with bed material mobility and bedform modification occurring over a wider range of sub-bankfull discharges. Sand-bed channel margin outlines appear to be less perturbed by bedform effects than gravel bed planforms, and they may have naturally straight or sinuous planforms. Bedform relief may nevertheless lead to some being designated as braided when viewed at low flows. It is concluded that the use of a single-stage stream power measure and bed material size alone is unlikely to achieve meandering braiding discrimination.*

5.49 Simpson, C.J. and Smith, D.G., 2001. The braided Milk River, northern Montana, fails the Leopold–Wolman discharge-gradient test.

*The Milk River, the northernmost tributary to the Missouri–Mississippi River system, exhibits an anomalous sand-bed braiding reach in an otherwise meandering system. Shortly after leaving Alberta and entering Montana the river suddenly changes to braiding and maintains this pattern for 47 km before entering Fresno Reservoir. Measured stream gradient and bankfull discharge in the braiding reach severely fail the Leopold and Wolman, U.S. Geol. Surv. Prof. Pap. 282BŽ1957.39xslope–discharge test for differentiating channel patterns. While channel slope has long been regarded as one of the primary variables associated with braiding, our data from the sand-bed Milk River do not support this relationship. Instead, the data show that the braiding reach has a lower channel slopeŽ0.00047.than the meandering reachŽ0.00055.. Coupled with a constant discharge the unit length stream power is comparable between the two reaches. At the morphologic transition between meandering and braiding, a dramatic reduction in channel bank strength occurs where the sampled silt–clay content declines from 65% in the meandering reach to 18% in the braiding. This enables channel widening which is reflected in a60% reduction in unit area stream power in the braiding reach. Thus, sediment transport capacity declines and channel bars are deposited. During waning flows, these bars are dissected, producing a braiding morphology. We suggest that for sand-bed braiding rivers the silt–clay percentage in the channel banks may be more important than slope. A review of the original Leopold and Wolman, U.S. Geol. Surv. Prof. Pap. 282BŽ1957.39x dataset, and many subsequent analyses, reveals that most braided rivers studied were gravel-bed. As a result, causal variables associated with braiding in sand-bed environments may need a thorough evaluation.*

5.51 Dade, W.B., 2000. Grain size, sediment transport and alluvial channel pattern.

*The Shields parameter, a dimensionless bed shear stress which can be expressed as a ratio of the slope, depth and characteristic properties of bed material in an alluvial channel, has been observed in natural rivers to take on modal values for the regimes of bedload, mixed-load and suspension transport Dade, W.B., Friend, P.F., 1998. Grain size, sediment-transport regime and channel slope in alluvial rivers. J. Geology, 106: 661–675.x. Such conditions correspond to channel geometries associated with conserved sediment flux and thus to a state of approximate equilibrium in which the channels are neither aggrading nor degrading to a significant degree. These findings are extended here to accommodate the effects of channel width in the context of a comprehensive data set on stable, perennial rivers. The new analysis reconciles existing empirical and theoretical approaches to predict alluvial channel geometry.*

## 6.0 Articles from "Earth Surface Processes and Landforms"

6.1 Hauet, A., Muste, M., and Ho, H-C., 2009. Digital mapping of riverine waterway hydrodynamic and geomorphic features.

*This paper proposes an innovative, non-intrusive method for mapping waterway characteristics in riverine areas. The technique uses photogrammetry to provide quantitative information about the dry area in the vicinity of the waterways (banks and floodplain) and image processing algorithms to characterize the flow. Riverside images of a riverine area are decomposed into quasi-planar areas and ortho-rectified and re-assembled to obtain a panoramic ortho-view of the area of interest. Morphological features of interest (such as river bank positions, flood plain edges, mud deposits, vegetation and erosion patterns) are then identified on the ortho-view and mapped digitally. Image sequences of the river flow are recorded, allowing a surface velocity analysis to be obtained through Large Scale Particle Image Velocimetry (LSPIV). Finally, the mapped elements and the surface velocities are displayed together in a GIS-like visualization. Through the presentation of a case study of a flood event at a culvert site, this paper demonstrates the capability of the technique to monitor characteristics of waterways over time. The method is inexpensive (a conventional video or digital camera can be used), fast and requires minimum preparation. It can be applied in such important river-related research areas as morphodynamic and sediment transport studies. It also fosters an improved understanding of the coupling between the river and its banks, which is essential for river restoration and eco-habitat studies. The present methodology is readily available for implementation in routine bridge inspections, fitted with an easy-to-use graphical interface.*

6.2 Raven, E.K., Lane, S.N., Ferguson, R.I., and Bracken, L.J., 2009. The spatial and temporal patterns of aggradation in a temperate, upland, gravel-bed river.

*Intensive field monitoring of a reach of upland gravel-bed river illustrates the temporal and spatial variability of in-channel sedimentation. Over the six-year monitoring period, the mean bed level in the channel has risen by 0·17 m with a maximum bed level rise of 0·5 m noted at one location over a five month winter period. These rapid levels of aggradation have a profound impact on the number and duration of overbank flows with flood frequency increasing on average 2·6 times and overbank flow time increasing by 12·8 hours. This work raises the profile of coarse sediment transfer in the design and operation of river management, specifically engineering schemes. It emphasizes the need for the implementation of strategic monitoring programmes before engineering work occurs to identify zones where aggradation is likely to be problematic. Exploration of the sediment supply and transfer system can explain patterns of channel sedimentation. The complex spatial, seasonal and annual variability in sediment supply and transfer raise uncertainties into the system's response to potential changes in climate and land-use. Thus, there is a demand for schemes that monitor coarse sediment transfer and channel response.*

6.3 Surian, N., Mao, L., Giacomin, M., and Ziliani, L., 2009. Morphological effects of different channel forming discharges in a gravel-bed river.

*The study analyses the morphological response of a gravel-bed river to discharges of different magnitude (from moderate events that occur several times a year to a 12-year flood) and so defines the range of formative discharges for single morphological units (channels, bars, islands) and a range of magnitude of morphological activity from the threshold discharges for gravel transport and minor bar modification up to flows causing major morphological changes. The study was conducted on the Tagliamento River, a large gravel-bed river in north-eastern Italy, using two different methods, analysis of aerial* *photographs and field observation of painted gravel particles. The available photographs (five flights from August 1997 to November 2002) and the two commissioned flights (June 2006 and April 2007) do not define periods with a single flood event, but the intervals are short enough (11 to 22 months) to have a limited number of flood events in each case. The fieldwork, which involved cross-section survey, grain-size analysis and observation of painted sediments, complemented the aerial surveys by allowing analysis of channel response to single flood events. Substantial morphological changes (e.g., bank erosion of several tens of metres up to more than 100 m) associated with flood events with a recurrence interval between 1·1 year and 12 years have been documented. Multiple forming discharges were defined based on the activity of different morphological units. Discharges equal to 20–50% of the bankfull discharge are formative for the channels, whereas the bankfull discharge (1·1 year flood in this case of the Tagliamento River) is formative for low bars. Larger floods, but still relatively frequent (with a recurrence interval less than five years), are required for full gravel transport on high bars and significant morphological changes of islands.*

## 7.0 Articles from "Journal of the American Water Resources Association"

7.1 Simon, A., Doyle, M., Kondolf, M., Shields Jr., F.D., Rhoads, B., and McPhillips, M., 2007. Critical Evaluation of How the Rosgen Classification and Associated "Natural Channel Design" Methods Fail to Integrate and Quantify Fluvial Processes and Channel Response, Journal of the American Water Resources Association, Volume 43, Issue 5, p. 1117 – 1131.

*This paper's primary thesis is that alluvial streams are open systems that adjust to altered inputs of energy and materials, and that a form-based system largely ignores this critical component. Problems with the use of the classification are encountered with identifying bankfull dimensions, particularly in incising channels and with the mixing of bed and bank sediment into a single population. Its use for engineering design and restoration may be flawed by ignoring some processes governed by force and resistance, and the imbalance between sediment supply and transporting power in unstable systems. The Rosgen classification is probably best applied as a communication tool to describe channel form but, in combination with "natural channel design" techniques, are not diagnostic of how to mitigate channel instability or predict equilibrium morphologies. For this, physically based, mechanistic approaches that rely on quantifying the driving and resisting forces that control active processes and ultimate channel morphology are better suited as the physics of erosion, transport, and deposition are the same regardless of the hydro-physiographic province or stream type because of the uniformity of physical laws.*

7.2 Bledsoe, B.P., Brown, M.C., and Raff, D.A., 2007. GeoTools: A Toolkit for Fluvial System Analysis, Journal of the American Water Resources Association, Volume 43, Issue 3, p. 757 – 772.

*GeoTools is a suite of analysis tools for fluvial systems written in Visual Basic for Applications/Excel. Based on flow time series and basic geomorphic data, GeoTools automates computation of numerous hydrologic, hydraulic, and geomorphic descriptors including effective discharge, sediment transport and yield, temporal distributions of hydraulic parameters (e.g., shear stress and specific stream power), cumulative erosion potential, channel stability indices, and over 100 flow regime metrics.*

7.10 Montgomery, D.R. and MacDonald, L.H., 2002. Diagnostic Approach to Stream Channel Assessment and Monitoring, Journal of the American Water Resources Association, Volume 38, Issue 1, p. 1 – 16.

*Authors suggest that a diagnostic procedure, not unlike that followed in medical practice, provides a logical basis for stream channel assessment and monitoring. This paper offers a conceptual framework for diagnosing channel condition, evaluating channel response, and developing channel monitoring programs. However, the formulation of specific diagnostic criteria and monitoring protocols must be tailored to specific geographic areas because of the variability in the controls on channel condition within river basins and between regions. The diagnostic approach to channel assessment and monitoring requires a relatively high level of training and experience, but proper application should result in useful interpretation of channel conditions and response potential.*

7.14 Merigliano, M.F., 1997. Hydraulic Geometry and Stream Channel Behavior: A Uncertain Link, Journal of the American Water Resources Association, Volume 33, Issue 6, p. 1327 – 1336.

*Several studies, using empirical and theoretical bases, are reviewed here to illustrate the relation between hydraulic geometry and channel behavior, but the relations are not always consistent. Hydraulic geometry variables are easy to measure and readily available, but they do not always reflect what may be more important ones such as turbulence, the velocity distribution profile, and distribution and cohesion of sediment particles. This paper illustrates some of these problems, provides some solutions, and addresses need for more work to better predict stream channel behavior from hydraulic geometry.*

7.17 Beeson, C.E. and Doyle, P.F., 1995. Comparison of Bank Erosion at Vegetated and Non-Vegetated Channel Bends, Journal of the American Water Resources Association, Volume 31, Issue 6, p. 983 – 990.

*Bends without riparian vegetation were found to be nearly five times as likely as vegetated bends to have undergone detectable erosion during the flood events. Major bank erosion was 30 times more prevalent on non-vegetated bends as on vegetated bends. The likelihood of erosion on semi-vegetated bends was between that of the vegetated and non-vegetated categories of bends.*

7.21 Booth, D.B., 1990. Stream-Channel Incision Following Drainage-Basin Urbanization, Journal of the American Water Resources Association, Volume 26, Issue 3, p. 407 – 417.

*Urbanization of a drainage basin results in pervasive hydrologic changes that in turn initiate long-term changes in stream channels. Increases in peak discharges and in durations of high flows result in either quasi-equilibrium channel expansion, where cross-section area increases in near-proportion to the discharge increase, or catastrophic channel incision, where changes occur far out of proportion to the discharge increases that initiated them. Simple map overlays, nearly irrespective of contributing drainage area, provide a valuable planning tool for identification of susceptible terrain. Where such conditions exist, basal shear stress provides a quantifiable parameter for predicting likely problems, although knickpoints are typical in such settings and confound simple calculation of sediment-transport rates.*

## 8.0 Papers from ASCE Conferences 1991 – 1998 (from ASCE "Stream Stability and Scour at Highway Bridges: Compendium of Papers, ASCE Water Resources Engineering Conferences, 1991-1998)

8.2 Schumm, S.A. and Lagasse, .F., 1998. Alluvial Fan Dynamics – Hazards to Highways, Water Resources Engineering, P. 298.

*Alluvial fans are very dynamic landforms, that can create significant hazards to highways, as a result of floods, debris flows, deposition, channel incision, and avulsion. A three-part investigation of fan characteristics is proposed that can identify potential hazards and aid the highway engineer in planning and hazard mitigation.*

8.4 Voight, R.L., Jr., Toro-Escobar, C.M., and Parker, G., 1997. Research Needs in Geomorphology Pertaining to Bridge Scour, Hydraulic Engineering, P. 141.

*The failure of bridges across rivers is a well known problem facing the transportation engineer. It is typically associated with bed or bank scour, and may not be directly due to inadequate structural design. Research to date on bridge scour has tended to focus on processes in the immediate vicinity of bridge piers or abutments. These processes are, however, influenced in a fundamental way by larger geomorphic processes, which reflect both natural and human-induced change. For example, meandering rivers tend to shift, inexorably leading to a deterioration in angle of approach. Lowered base level on a stream due to, e.g., river training works can lead to upstream-migrating degradation on tributaries. The degradation itself can endanger bridge piers; the channel widening commonly associated with it can endanger abutments and approaches. This paper summarizes that part of a study conducted for the National Cooperative Highway Research Board (NCHRP 24-8) that pertains to research needs in geomorphology as they affect bridge scour problems.*

8.9 Cotton, G.K., 1995. Effect of Geomorphic Hazards on Bridge Reliability, Hydraulic Engineering, P. 790.

*A method for addressing the effect of river morphology on hydrologic reliability at bridges. Geomorphic hazards are part of a set of hydrologic hazards at bridges. In general, we can identify four types of hydrologic hazards that can cause bridge failure. We can identify two general groups of geomorphic hazards: natural river instability due or river instability created by man-caused actions. We can classify the remaining hydrologic hazards as at-bridge hazards that are the result hydraulic conditions created by the obstruction of the river valley by the bridge during a flood.*

8.10 Johnson, P.A. and Simon, A., 1995. Reliability Of Bridge Foundations In Unstable Alluvial Channels, Hydraulic Engineering, P. 1041.

*Stream channels in many parts of the United States experience system-wide instabilities as a result of natural or human-imposed disturbances. Bridges and other structures in and adjacent to unstable streams can be adversely affected as the stream adjusts toward a lower energy state. Channel bed-degradation can undermine bridge foundations and bank widening by mass-wasting processes can result in undermining abutments and foundations on the flood plain. In this study, the reliability of bridge foundations under unstable channel conditions, specifically conditions of channel bed degradation and bank widening, is quantified.*

8.13 March, D.E., Abt, S.R., and Thorne, C.R., 1993. Bank Stability Analyses Verses Field Observations, Hydraulic Engineering, P. 881.

*The concept and process of stream bank stabilization design through the development and use of limiting stability curves for the comparison of existing bank height/angle combinations to predicted failure bank height/angle combinations is examined. Progressive bank failure along the outside of meander bends on Long Creek in northern Mississippi has been monitored for failure mode and bank height/angle combinations. Maximum allowable bed scour and/or bank migration graphs have been developed for the study reach cross sections. Bank stability analyses have been compared to field observations to test the applicability of bank failure analysis as a design aid.*

## 9.0 Papers from ASCE Conferences 1998 – 2008

9.2 Odgaard, A.J., 2008. Stability Analysis in Stream Restoration World Environmental and Water Resources Congress 2008: Ahupua'a. Proceedings of the World Environmental and Water Resources Congress.

*A perturbation stability analysis is used for development of a stable-channel alignment. By introducing a small perturbation into the equations governing flow and sediment transport and analyzing the growth rate of the perturbation, the analysis leads to the `dominant' channel-wavelength and the channel alignment that has the greatest stability. A channel with such alignment will be the least destructive in terms of bank erosion and migration, and it will be a channel with minimal maintenance requirements. Graphs are developed that describe the dominant meander wavelength and phase shift as a function of primary flow and sediment variables. A numerical example is provided showing how the graphs are used to determine the optimum channel alignment given flow and sediment characteristics. Two channel stabilization projects are also described that benefitted from the stability analysis.*

9.13 Bledsoe, B.P. and Watson, C.C., 2000. Regional Risk Analysis of Channel Instability Watershed Management & Operations Management, Proceedings of Watershed Management and Operations Management.

*In many watersheds, land use changes and hydraulic modifications have directly resulted in accelerated geomorphic activity and excessive sedimentation. Channel adjustment by erosion can be expected to occur if specific stream power exceeds a threshold of critical stream power. Excess stream power in stable meandering channels may result in a variety of responses that potentially range from extreme widening and braiding to extreme incision. Such extensive changes in channel pattern and morphology usually result in significant degradation of water quality and ecological integrity. An energy-based index grounded in geomorphic threshold theory was developed to improve the prediction of channel response to land use changes and hydraulic modifications. A very large and geographically diverse data set consisting of stable meandering rivers, braided rivers, and severely incised rivers was used in conjunction with logistic regression analysis to develop a probabilistic approach to predicting thresholds of channel instability in meandering channels. Simple variables such as slope, median bed material size, 2-year discharge, and drainage area are used as independent variables to estimate the risk associated with varying levels of excess specific stream power relative to sedimentary characteristics. Results indicate that simple indices of specific stream power derived from data that are readily available for most areas can provide accurate predication of thresholds of channel instability at the regional scale. This approach facilitates rapid identification of channels that are at highest risk of severe morphologic change due to an imposed increase in stream power and most sensitive to changes in the controlling variables. The approach provides tools for improved management of stream ecosystems through regional risk assessment, land use planning, and prioritization of stream and watershed management efforts.*

## 10.0 Chapters from ASCE "Sedimentation Engineering" Manual

García, M.H. (ed.), 2006. Manual 110, Sedimentation Engineering. American Society of Civil Engineers.

### *10.1 Chapter 7: Streambank Erosion and River Width Adjustment, James E. Pizzuto and the ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment*

*Channel morphology usually changes with time and in both width and depth. Although changes in channel depth caused by aggradation or degradation of the riverbed can be simulated, changes in width cannot. Currently, models of river width adjustment can be divided into two broad approaches: (1) those based on extremal hypotheses, and (2) those based on the geofluvial approach. The former have been used in engineering practice more frequently than the latter, which are at present used essentially as research tools. However, geofluvial approaches have the potential to become adopted as standard engineering tools.*

### *10.2 Chapter 8: River Meandering and Channel Stability, Jacob Odgarrd and Jorge D. Abad*

*The basic strategy is to stabilize the channel alignment and the channel cross section. The river should maintain a natural alignment (a path of easy bends of reverse curvature) and have a cross section that can accommodate the river's water and sediment regime. A good practice is to find a relatively stable reach of the river, determine channel and alignment characteristics for that reach and then apply those characteristics to the reach to be stabilized. A complementary approach is to calculate alignment characteristics using stability theory. The technologies for channel stability range from the construction of revetments and dikes, vanes or weirs, to dredging.*

### *10.3 Chapter 10: Bridge Scour Evaluation, J.R. Richardson and E.V. Richardson*

*Analysis of long-term bed elevation changes must be made using the principles of river mechanics in the context of a fluvial system analysis. A method for organizing such an analysis is to use a three-level fluvial system approach. This method provides three levels of detail in an analysis, (1) qualitative determination based on general geomorphic and river mechanic relationships, (2) engineering geomorphic analysis using established qualitative and quantitative relationships to establish the probable behavior of the stream system in various scenarios of future conditions, and (3) quantifying the changes in bed elevation using available physical process mathematical models such as BRISTARS, HEC-6, or SAMwin, extrapolation of present trends, and engineering judgment to assess the result of the changes in the stream and watershed.*

### *10.4 Chapter 14: Computational Modeling of Sedimentation Process, William A. Thomas and Howard Chang*

*A computational sedimentation model includes the five basic processes of sedimentation: erosion, entrainment, transportation, and deposition of mixtures of sediment particles, and compaction of sediment deposits. Of paramount importance is the fact that computational sedimentation models may include only some of the equations that are needed to predict the morphology of a river channel. Therefore, the river morphology equations that are included in one-dimensional computational sedimentation models need to be identified, and the model should then be used in combination with river morphology principles to perform the desired sediment study.*

### *10.5 Chapter 15: Two- and Three-Dimensional Numerical Simulation of Mobile-Bed Hydrodynamics and Sedimentation, Miodrag Spasojevic and Forrest M. Holly, Jr.*

*Two-dimensional (depth-averaged) fixed bed modeling has reached a certain maturity and seen moderate use. But after a promising beginning, development of two-dimensional (depth-averaged) mobile-bed modeling has taken a back seat to three dimensional. Meanwhile, three-dimensional fixed-bed modeling is rapidly becoming an effective engineering tool, and its mobile-bed counterpart is receiving considerable developmental attention and enjoying some success in practical engineering use.*

### *10.6 Chapter 18: Engineering Geomorphology, S.A. Schumm and M.D. Harvey*

*The major objectives of this chapter were to bring to the attention of the engineering profession (1) the importance of system history, (2) the need to view a specific problem in a system context, and (3) the importance of geologic and geomorphic variables in engineering activities.*

### *10.7 Chapter 6: Fundamentals of Fluvial Geomorphology, D.S. Biedenharn, C.C. Watson, and C.R. Thorne*

*The purpose of this chapter is to present an overview of some basic concepts of fluvial geomorphology and river mechanics, with an emphasis on their application to engineering design of channel rehabilitation projects. In this chapter, "channel rehabilitation" is used in a broad sense that encompasses all aspects of channel modification to achieve a desired channel improvement, whether for river restoration, flood control, navigation, water supply, channel stability, sediment control, or other beneficial use. Regardless of the goals of the rehabilitation project, sound understanding of geomorphic processes and forms in fluvial systems is essential to successful performance of channel rehabilitation projects.*

## 11.0 Other References

### *11.1 Oregon DOT, 2005, OTIA III State Bridge Delivery Program Environmental Performance Standards*

*ODOT has an obligation to ensure that any proposed activities authorized pursuant to the wetland permits and ESA consultation effort have sought to adequately minimize potential effects to sensitive resources. In addition, performance standards also satisfy other statutory and policy requirements such as Section 4(f) of the Federal Highway Act and the Governor's Executive Order on Sustainability, as well as Federal and State requirements for handling and disposal of waste and hazardous materials.*

*The Environmental Performance Standard information provided below is intended to limit or avoid impacts to the environment (including state and federal listed species, wetlands, and Waters of the United States and the State of Oregon) through the use of proper construction and construction related practices. To meet the goals of the Environmental Performance Standard for construction activities, projects will be restricted to the following terms and conditions unless otherwise specifically authorized by the regulatory agencies.*

*Designers and Contractors are required to comply with all State and Federal laws, regulations and permits that apply to the specific activities undertaken even if they are not addressed in the performance standard. DEQ and the Lane Regional Air Pollution Authority retain authority to enforce Oregon statutes and administrative rules within their respective jurisdictions. Terms used in the environmental performance standards have the meaning defined in the applicable statute or administrative rule.*

### *11.2 Rosgen, D.L., 2006. WARSSS – Watershed Assessment of River Stability and Sediment Supply – an Overview*

*WARASS integrates the disciplines of hydrology, geomorphology, geology, engineering, soil and plant science into a watershed assessment methodology. WARSSS is a three-phase methodology that:*

- *Identifies specific locations and processes adversely affected by various land uses*
- *Provides a consistent, quantitative analysis of sediment supply and channel stability*
- *Predicts hillslope, hydrologic and channel processes contributing to sediment yield and river impairment*
- *Establishes a basis for site- and process-specific mitigation*
- *Documents a better understanding of the cumulative effects of various land uses on the water resources*

*The EPA has supported and peer reviewed WARSSS as an alternative to numeric standards for "clean sediment TMDLs." WARSS is also used in river restoration by documenting the cause and consequence of impairment and establishing criteria for natural channel design.*

# APPENDIX B

## Prioritized Research (D-1s)

## Geomorphology

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 3.11 Lee and Julien, 2006 | Extends work by Julien and Wargadalam (1995) on the topic of hydraulic geometry relationships. | Although this topic may be less applicable to HEC-20 than to HDS-6, this reference should be considered for inclusion into either of these documents. The Julien and Wargadalam (1995) paper is referenced in HDS 6. |
| 3.31 Julien and Wargadalam, 1995 | Alluvial channel geometry | The downstream hydraulic geometry of alluvial channels was developed from a 3D stability analysis of noncohesive particles under 2D flows. The resulting regime equations are quantitatively tested with an extensive dataset consisting of 835 fields channels and 45 laboratory channels for meandering and braided sand-bed and gravel-bed channels. The analytical results are in very good agreement with several empirical relationships. This is referenced in HDS 6 and could be updated. |
| 5.9 Thorndycraft et al., 2008 | Overview of fluvial geomorphology | Review recent progress in fluvial geomorphology and provides a summary of special issues. Could be used to determine future research needs. |
| 5.21 Goudie, 2006 | Global warming and fluvial geomorphology | Describes some potential responses in fluvial systems to global warming. |
| 5.47 Field, 2001 | Channel avulsion on alluvial fans | A descriptive model to depict the process of channel avulsion on fluvially dominated alluvial fans in Southern Arizona. |
| 5.51 Dade, 2000 | Alluvial channel geometry | A new analysis is conducted to relate sediment grain size and mode of transport in a river to channel pattern. The data set is comprehensive. The author stated that the new analysis reconciles existing empirical and theoretical approaches to predict alluvial channel geometry. This paper should be read with other articles like 3.31 |
| 6.3 Surian et al., 2009 | Morphological effects of different discharges | Geomorphic response of a gravel-bed river was analyzed through field observations of painted sediments. Multiple formative discharges were proposed for different morphological units like channels, low bars, high bars, islands. Multiple formative discharges may be better than a single dominant discharge for engineering geomorphology. |

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 7.1 Simon et al., 2007 | Critical review, of Rosgen method, highlighting inconsistencies and identifying technical problems of Rosgen's "natural channel design"' approach. | Reference to this paper should accompany any reference to the Rosgen method and 'natural channel design' approaches to channel design and/or stream restoration. If criticisms in this paper are included, positions in support of Rosgen would also be appropriate. |
| 7.2 Bledsoe et al., 2007 | GeoTools | This software adds to the toolkit already available to the GeoTools package that combines functions for effective discharge calculations, sediment transport analyses, characterizing bed disturbance regimes, and over 100 hydrologic metrics in a flexible spreadsheet-based format. |
| 7.14 Merigliano, 1997 | Stream channel behavior | Illustrates some problems about theoretical and empirical hydraulic geometry. It should be useful for investigating regime equations. |
| 7.21 Booth, 1990 | Channel incision due to urbanization | Investigates how urbanization affects channel incision and proposes two modes (incision and expansion). |
| 8.2 Schumm and Lagasse, 1998 | Alluvial fan dynamics | A descriptive way to depict alluvial fan characteristics. Referenced in HEC-20. |
| 9.13 Bledsoe and Watson, 2000 | Stream power index, channel stability threshold | Develops an energy-based index derived from geomorphic threshold theory to improve the prediction of channel response to land-use changes and hydraulic modifications. The index could be an evaluation tool. |
| 10.6 Schumm and Harvey | Engineering Geomorphology | Provides information on the importance of geology and geomorphology to engineering design and analysis projects. |
| 10.7 Biedenharn et al., 2000 | Fundamentals of fluvial geomorphology | Presents and overview of basic fluvial geomorphic concepts and the application of these concepts to engineering design projects involving channels. |
| 11.1 Oregon DOT, 2005 | Environmental performances standards | Provides an example of addressing environmental concerns through standardized approaches. The standardization streamlines the permitting process. |

## Reconnaissance

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 1.3 FHWA-HRT-05-072, 2007 | Improved Rapid Channel stability assessment | This assessment methodology has promise and is referenced in HEC-20. But there are a small number of streams used to define the major stream characteristics necessary to fully represent the range of channels. There are 8 major physiographic regions that are broken up into 25 subregions, yet this methodology is base only on 57 crossings spread over just half of the subregions. |
| 2.5 NCHRP 24-06 CAESAR Expert System, 1999 | CAESAR - Expert system for evaluating scour and stream stability | Although this cataloging/evaluation software may be very useful as a database and analysis tool, it may need to be updated significantly. In addition, the software/evaluation tools do not appear to adequately address the collection and evaluation of some important geomorphic factors pertinent to evaluating channel instability. |
| 3.16 Shields et al., 2003 | Intermediate approach for stream restoration | Although this methodology is intended for stream restoration projects and it is meant to be used on a large scale basis covering reaches that are much larger than the bridge reach. However, does provide good info on evaluating channel stability. |
| 5.44 Thorne, 2002 | Geomorphic analysis of large alluvial rivers | This paper provides a framework for conducting detailed geomorphic studies/analyses as part of any project on a large river. Much of this info is duplicated in HEC-20. |
| 6.1 Hauet et al., 2009 | Digital mapping of riverine waterway | Intriguing methodology with considerable potential for use in stability evaluation. Author indicates it is inexpensive, fast, requires minimum preparation, and is readily available for implementation in routine bridge inspections. Originally developed for Iowa DOT. |
| 7.10 Montgomery & MacDonald, 2002 | Conceptual framework for diagnosis, evaluation, monitoring | Some of the discussion on diagnostic characteristics and monitoring in this paper could be incorporated into HEC 20 as additional material and used in scour assessments. |
| 8.9 Cotton, 1995 | Effect of geomorphic hazards on bridge reliability | Presents method for addressing the effect of river morphology on hydrologic reliability at bridges. Based on HEC 18 and 20 among other guidelines. Could be used to assess potential future instability. |
| 8.10 Johnson and Simon, 1995 | Quantify reliability of bridge foundations under long-term channel-adjustment processes | Potential next step in scour evaluations - analysis of channel-adjustment processes during channel evolution with a reliability analysis to determine the likelihood of bridge failure. Info can be used to determine maintenance or mitigation needs. |

## Aggregation and Degradation

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 1.2 MSHA Chapter 14, 2007 | Assessment of stream morphology. This chapter includes guidance on long term changes in bed elevation. | Several procedures are not covered in FHWA manuals, but may have general applicability. Material is primarily relevant to gravel-bed streams with pool-riffle morphology. |
| 3.18 Melville and Coleman, Bridge Scour, Section 4.3, 2000 | Includes approaches for estimating degradation that range from qualitative to quantitative. | Some of the quantitative approaches, including regime and competent velocity methods, are not referenced in HEC-20. These equations should be reviewed for possible discussion. |
| 4.14 James, 1997 | Channel incision along the lower American River is investigated using channel cross-section plots and statistical analysis of gage data. | Although these methods are already recommended in HEC-20, this paper could be used as an excellent example of these fundamental approaches. |
| 6.2 Raven et al., 2009 | Monitored erosion and aggradation over 6 years. Illustrates importance of sediment supply and transport capacity. | The study concludes that coarse sediment transport may be highly variable over short time periods and may result in large amounts of aggradation. |
| 8.4 Voight et al., 1997 | Identifies shifting channels and degradation as research needs in geomorphology. | Identifies several research needs related to geomorphology problems at bridges. These include (1) channel widening resulting from aggradation and degradation, (2) a manual on alluvial fan problems, (3) bend and confluence scour, (4) basin modification impacts on scour, (4) incremental channel shift. These research needs should be revisited related to this project. |
| 10.3 Richardson and Richardson, 2006 | Bridge scour evaluation | Long-term bed elevation change is discussed as a part of a bridge scour evaluation. |

## Channel Migration

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 1.1 Texas Migration Rate, 2007 | The report includes a review of selected papers and documents and concludes that no existing method is suitable for predicting meander migration. A new approach incorporating a soil property is proposed. | The approach developed in this report is based on idealized meander bends and simplified flow and bank erodibility analyses. However, it is specifically intended for use in assessing risks associated with bend migration/extension in the vicinity of bridges in Texas. |
| 1.2 MSHA Chapter 14, 2007 | Assessment of stream morphology at channel crossings and culverts. This manual presents a multi-level approach to assessing stream morphology and morphological change. | While many of the techniques and methods presented in this chapter are already well known and represent existing practice. The interpretation of morphology relies on the Rosgen method. There are elements of the chapter that could be usefully incorporated into HEC-20 and perhaps HDS-6. |
| 1.6 NCHRP 24-16 Report 533, 2004 | Presents an empirical method for predicting the rate and extent of meander bend migration based on historical trends. | The NCHRP method is now 6 years old and there should be sufficient practical experience with it to assess its utility in routine applications. Depending upon its performance in terms of practicality and reliability (especially bearing mind the findings of the Texas study 1.1). |
| 4.8 Perucca et al., 2007 | Investigates how river-riparian vegetation interactions affect river meandering. Couples a physically based morphodynamic model with a process-based model of vegetation. | This paper is important as it demonstrates clearly the significant role that riparian vegetation can play in meander planform morphology and dynamics. The findings may have major implications for river management in the vicinity of bridges. The numerical method requires further development and testing before it could be used in engineering applications, but the general points made about the importance of riparian vegetation should be brought to the attention of river/bridge engineers. |

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 5.6 Hooke, 2004 | Cutoffs are inherent to meander behavior. Flood events were observed to cause multiple cutoffs but long-term evolution accords with ideas that a river reaches a critical state at which clustering of meander cutoffs is likely to take place. | The findings in this study have relevance in that they demonstrate that ideas of equilibrium in the channel planform of meandering rivers may be misguided. Instead relatively long periods of progressive and incremental lengthening are interrupted by short periods of intense shortening through a cascade of cutoffs. This should raise awareness among river and bridge engineers that management based on concepts of channel equilibrium are inapplicable to meandering rivers. |
| 5.20 Brummer et al., 2006 | Log jams reduce channel gradient and bank heights while increasing the probability of lateral shifting by channel avulsion. Hence, the width of the channel migration zone is greater when riparian forests are restored. | Restoration of riparian corridors means that there is likely to be more wood in US rivers in future. This research suggests that lateral migration rates and extents will be increased as a result. Conceptual guidelines for accounting for wood jam impacts on bed elevations are presented. This research is important given the large number of river restoration schemes involving trees that are likely to occur upstream of bridges in the future. Increased supply of wood and morphological responses must be anticipated in bridge design and risk management. |
| 5.46 Bledsoe and Watson, 2001 | An energy-based index was used to estimate the risk of channel instability associated with specific stream power relative to sedimentary characteristics. | Probabilistic diagrams resulting from logistical regression analyses depict the uncertainty associated with previously identified thresholds of channel form and instability and provide a means of gauging channel sensitivity to changes in controlling variables. These stability diagrams could be useful for estimating the risk of lateral channel migration causing a hazard at a bridge crossing. (publications 5.37, 5.40, 5.46, 5.48 are considered together) |

| Publication | Description | Reason for Qualitative Rank |
| --- | --- | --- |
| 5.48 Lewin and Brewer, 2001 | The distinction between meandering and braided river channel patterns, on the basis of bankfull specific stream power and bed material size, is analyzed and rejected. | This paper concludes that the use of a single-stage stream power measure and bed material size alone is unlikely to achieve meandering versus braiding discrimination. However, in their closure to discussion by Van den Burg and Bledsoe, the authors back away from this bold conclusion somewhat. Nevertheless, there are serious criticisms of the most commonly used planform prediction diagrams that must be considered. (publications 5.37, 5.40, 5.46, 5.48 are considered together) |
| 5.49 Simpson and Smith, 2001 | A braided reach of the Milk River, severely fail the Leopold and Wolman slope–discharge test for differentiating channel patterns. | Transition between meandering and braiding is associated with a dramatic reduction in channel bank strength. This enables channel widening which is reflected in a 60% reduction in unit area stream power in the braiding reach. Thus, sediment transport capacity declines and channel bars are deposited. Hence, this paper again stresses the importance of bank strength to channel pattern. |
| 9.2 Odgaard, 2008 | Perturbation stability analysis is used to predict a stable-channel alignment. | Graphs are used to determine the optimum channel alignment for given flow and sediment characteristics. Two channel stabilization projects are also described that benefitted from the stability analysis. The approach is simple to apply and could be used in designing re-alignment schemes for laterally unstable channels in the vicinity of bridge crossings. |
| 3.18 Melville and Coleman, Bridge Scour, Section 4.8, 2000 | Methods to predict both the rate and distribution of channel shifting for streams | Information related to channel migration from a number of sources is presented. Most of the information is dated and the reliability of the various methods is not discussed. |
| 10.2 Odgaard and Abad, 2006 | River meandering and channel stability | Discussion of approaches for developing a relatively stable channel planform when channel realignment is necessary. |

## Channel Widening

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 3.18 Melville and Coleman, 2000 | Chapter 4 – channel lateral and vertical instability | This chapter draws together a great deal of research and experience relevant to geomorphic hazards at bridges. While it is somewhat dated, there are techniques and rules of thumb that may still be usable. |
| 5.2 Faustini et al., 2009 | Downstream variation in bankfull width | Presents predictive equations for bankfull width as a function of drainage area based on a nationwide sample of streams in the conterminous United States. The equation varied by sediment size, also related to human disturbance, mean annual precipitation, elevation, mean slope etc. These equations could be used as a reference for bankfull width. |
| 5.29 Eaton and Millar, 2004 | An extremal hypothesis (maximum sediment transport capacity) is used to predict optimal channel width. | This paper demonstrates that use of unconstrained maximum sediment transport capacity models equate to assuming that all stream banks are highly resistant to erosion and results in a predictable and consistent under prediction of alluvial channel widths, especially when banks are composed of highly erodible, noncohesive sand, or gravel. Hence, bank stability must be considered when predicting width using an extremal hypothesis approach such as minimum stream power or maximum transport capacity. |
| 5.38 Mount et al., 2003 | Estimation of channel width from air photographs is commonly undertaken as part of level 2 studies of channel widening or shifting around bridges. This paper deals with the errors involved. | The error analysis method presented here represents a simple, yet effective, means of estimating error associated with image-to-image comparison of bankfull width. The uncertainties associated with error in this approach to estimating width and width changes must not be ignored. This particular paper is a bit dated, but could be used for this purpose. |
| 7.17 Beeson and Doyle, 1995 | The effect of vegetation on bank erosion at bends during floods was investigated for a river in Canada. Erosion was 5 times more likely at non-vegetated bends. | The authors conclude that their findings prove the effectiveness of bank vegetation in reducing erosion risk at bends. They stress that the importance of riparian vegetation in buffering against erosion should be brought to the attention of land owners and competent authorities. |

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 8.13 March et al., 1993 | Bank stability analyses are applied to retreating banks in Long Creek, MS. The sensitivity of banks to destabilization by lateral erosion or toe scour is demonstrated. | The simple approach to checking the stability and sensitivity to destabilization of stream banks presented in this paper is a template for how the risks associated with bank failure and retreat around bridges might be assessed. While the models used in the paper have been superseded, the framework for risk assessment is still valid. |
| 10.1 Pizzuto, 2006 | Streambank erosion and river width adjustment | Discusses factors influencing bank erosion and channel width adjustment and provides a range of methods that can be used to predict channel width adjustment. |

## Sediment Dynamics

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 3.9 Doyle et al., Channel Forming Discharge, 2007 | Paper compares the use of effective discharge, bankfull discharge, and a recurrence interval discharge as measures of the channel forming discharge. | The paper concludes that the effective discharge, though most computationally intensive, is the best estimate for channel forming discharge. Use of a recurrence interval or bankfull discharge may only be applicable for generally stable channels. For reclamation or restoration of a disturbed channel, use of the reference reach concept should be limited to a stable channel in a physiographically similar setting. |
| 3.22 Karim, 1999 | Predict relative bed-form height | Not very applicable to this project, but should be considered in contraction scour. Predicts relative bed-form heights. Bed-form geometry is dependent upon individual floods. |
| 3.30 Julien and Klassen, 1995 | Sand-dune geometry | Not applicable to this project, but should be considered in contraction scour. Estimates bed-form height relative to wave length. Bed-form geometry is dependent upon individual floods. |
| 11.2 Rosgen, 2006 | Watershed assessment of river stability and sediment supply | Provides a systematic method for assessing watershed sediment sources, sediment supply and channel processes related to sediment yield. |

## Numerical Modeling

| Publication | Description | Reason for Qualitative Rank |
|---|---|---|
| 3.2 Langendoen et al., 2009 | Model incision and widening with calibration | A computer model CONCEPTS, which simulates the evolution of incised stream systems, was tested against observed adjustment of two incised streams in northern Mississippi. The model can satisfactorily predict different stages of channel evolution, bed elevation change, and channel width change. However, the application reach should be adequately characterized. |
| 3.7 Papanicolaou et al., 2008 | Sediment transport modeling overview | The article reviews a list of current representative flow/sediment transport models (1D, 2D, and 3D). It is a good reference about model application, strength, and limitations. |
| 3.20 Jia and Wang, 2000 | CCHE2D – 2D hydrodynamic and sediment transport model | The CCHE2D model simulates unsteady, turbulent, free surface flows and sediment transport, and is able to simulate morphological change processes of alluvial streams. It was verified by two separate tests: one experiment channel, the other is a natural channel. |
| 5.11 Brasington and Richards, 2007 | Overview of geomorphological modeling | An overview of geomorphic models. Could be used for reference. |
| 10.4 Thomas and Chang, 2006 | 1D Numerical models for sedimentation processes | One-dimensional numerical sediment transport models account for many of the processes involved in erosion, transport and deposition of sediment in rivers. River morphology is not completely addressed in these models. |
| 10.5 Spasojevic and Holly, 2006 | 2D and 3D flow and sediment transport models | One dimensional models have utility for extended river reaches and time periods, but cannot resolve local details of flow and sediment dynamics. Two and three dimensional models provide increasing degrees of detail over smaller areas and time scales. The advantages and limitations of 2- and 3-dimensional models are discussed for sediment studies. |

# APPENDIX C

## Critical Review of Priority Research

## Geomorphology

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| 3.11 Lee and Julien, 2006<br>"Downstream Hydraulic Geometry of Alluvial Channels," ASCE Journal of Hydraulic Engineering |
| 1. Does the research relate to the current state of practice?<br>Yes. Downstream hydraulic geometry relationships are widely used to describe river response. This study improves the current regime equations using a non-linear regression analysis of a massive dataset compiled from the datasets of numerous other researchers. Earlier versions of these relationships are discussed in HDS 6. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, as is + Level 2. Although the research is of practical use in the preliminary sizing of channels or in the general prediction of river response, the usefulness of the research is limited. These relationships are not included in but should be discussed in HEC-20. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. This study builds upon previous work by others. The simple power functions that were previously developed for evaluating channel response to changing discharge have been used extensively. This research improves the practicality and usefulness of these Downstream Hydraulic Geometry (DHG) relationships. However, recent work also suggests that these regime relationships have limitations. |
| 4. Has the research been tested by the original researcher?<br>Unknown, at least on other channels. Research is based on analysis of multiple datasets from other studies. |
| 5. Has the research been cited by others?<br>Google Scholar found only 3 citations of this paper. |
| 6. What are the strengths of the research?<br>This study uses a massive database (1,485 measurements) compiled from other researcher's datasets and builds upon it. This database covers a wide range of flow conditions for sand/gravel/cobble streams with meandering to braided planform geometry. The database was used to calibrate and validate new and improved equations. The verification and validation of the proposed equations are in very good agreement with actual field and laboratory observations, with 95% of the calculated hydraulic geometry parameters within 50% and 200% of the field measurements. These regime equations can also be used as a template to indicate whether or not a channel is in regime. |

| 3.11 Lee and Julien, 2006 (continued)<br>"Downstream Hydraulic Geometry of Alluvial Channels," ASCE Journal of Hydraulic Engineering |
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| 7. What are the limitations of the research?<br>Limitations are that these revised regime equations are for stable alluvial channels only. In addition, the calculated hydraulic geometry parameters are only within 50% and 200% of the field measurements, which is a fairly large range. The equations do not cover channels that are in adjustment or are unstable, nor do they account for complex response or dynamic equilibrium. Also, Wohl (2004) indicates that regime equations have mixed results for mountain streams because they have different or variable channel boundaries. Wohl suggests that mountain rivers behave as fully alluvial rivers in terms of having well-developed DHG relationships for average annual flows, but where the ratio of stream power to sediment size falls below a specific threshold value, DHG relationships are poorly developed. However, Lee and Julien (2008) indicate that their database "is somewhat rich in data for gravel and cobble-bed streams, and lean in sand-bed river data" and that their new equations "may become better suited to define the downstream hydraulic geometry of mountain channels with such coarse bed material." They also point out that DHG relationships can be expected to be poorly suited to describe resistance to flow relationship. Finally, as stated by (10.7) Biedenharn et al. (2008): "Regime relationships are empirical, which means that the relationships are derived from observed physical correlations and are strictly only applicable to the data sets from which they were derived." This is particularly evident in the number of derived empirical equations for river meander and channel size that are currently used (see FISRWG 1998). |
| 8. Conclusions.<br>Recommended for inclusion into HEC-20 and updating HDS 6. However, any discussions on the use of regime equations should include an emphasis on the limitations of those equations as a channel design or restoration tool, especially with regard to the impacts of complex response. This research was cited by only 3 other researchers. |

3.31 Julien and Wargadalam, 1995 (*Superseded by Ref. 3.11 – Lee and Julien, 2006)*
"Alluvial Channel Geometry: Theory and Application" ASCE Journal of Hydraulic Engineering

This research has been extended through further work and, therefore, superseded by Lee and Julien, 2006.

| 5.9 Thorndycraft et al. 2008<br>"Fluvial Geomorphology: A perspective on Current Status and Methods," Geomorphology |
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| 1. Does the research relate to the current state of practice?<br>This paper only presents a perspective on recent advances in fluvial geomorphology and introduces a selection of papers relating to these advances. It does not provide any detailed research information, data, or analyses relevant to the current state of practice. |
| 2. Is the research of practical use or could it be made practical?<br>No. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>This paper does not present any new, modified, or advanced research. |
| 4. Has the research been tested by the original researcher?<br>No. |
| 5. Has the research been cited by others?<br>No. Google Scholar found no citations of this paper. |
| 6. What are the strengths of the research?<br>Provides an overview of new research and recent advancements. |
| 7. What are the limitations of the research?<br>This paper does not present any research. |
| 8. Conclusions.<br>Not recommended. |

5.21 Goudie, 2006
"Global Warming and Fluvial Geomorphology" Geomorphology

1. How does the research relate to the current state of practice?
   No. This topic is not addressed in HEC-20. The paper outlines the potential changes or impacts that may occur as they relate to extrapolation into the future of recent trends of global warming.
2. Is the research of practical use or could it be made practical?
   No. Although climate changes associated with global warming would impact rivers and streams, there are no definitive predictions of how meso and micro-scale climates in North America may change during the $21^{st}$ century and, therefore, no definitive predictions on how channels may respond.
3. Is the research founded on sound scientific theory or substantial empirical evidence?
   Yes. The theory behind the 'green house effect' is proven in theoretical and applied physics and has been established for over 40 years. The vast majority of climate scientists (especially outside the USA) recognize that global warming has been happening and sea levels rising for decades. However, the conclusion that the climate change is driven by anthropogenic emissions of $CO^2$ remains controversial. The premise of the paper is that as global warming continues, which the paper assumes is a foregone conclusion, channels will respond. The paper indicates that global warming may increase or decrease rainfall amounts and intensities regionally, leading to changes in the geographic and seasonal distributions of precipitation. This makes deterministic predictions of actual channel responses to global warming impossible with the currently available climate models.
4. Has the research been tested by the original researcher?
   No, because it is based on hypothetical future conditions.
5. Has the research been cited by others?
   There are multiple global climate models that perform variably in hindcasting past climate. As a result, the identification of potential changes is based averaging the predictions of multiple models and uncertainties remain large. Downscaling from GCMs to regional or local models is even less reliable. Google Scholar identified 25 citations of this paper.
6. What are the strengths of the research?
   The paper provides a vision of the potentially marked and wide scale impacts on fluvial systems that will need to be dealt with if global warming does actually continue.
7. What are the limitations of the research?
   The subject of whether global warming is anthropogenically driven is controversial. While most governments, several US States and many international companies are already acting to reduce $CO^2$ emissions and adapt to climate change, the empirical data and model predictions concerning climate change are not universally accepted by the scientific community. Recently, attempts have been made to cast doubt on the current and potential impacts of increased $CO^2$ levels on global climate in order to counter, or at least dilute, the global warming argument. If global warming does continue, there is currently no accurate way to identify the location, magnitude, duration, timing, and type of weather events that may occur. Consequently, much of the discussion of the potential impacts in this paper is speculative at best.
8. Conclusions.
   Not recommended. More thorough research and evidence/data is needed to prove global warming. Ignoring the potential for climate change is also not recommended. Although this paper may not be particularly well suited for inclusion, this topic should not be ignored in HEC-20, but treatment should be balanced: that is it should reflect the weight of evidence for and against anthropogenic global warming avoiding the presumption that AGW is inevitable, and discussing the best approach to dealing with potential future impacts that relate to unknown future regional climatic conditions.

5.26 Millar, 2005 (*Superseded by Ref. 3.11 – Lee and Julien, 2006*)
"Theoretical Regime Equations for Mobile Gravel-Bed Rivers with Stable Banks"
Geomorphology

This research has been extended through further work and, therefore, superseded by Lee and Julien, 2006. However, there is potential for further research under Task 5 because of incorporation of relative bank strength to parameterize the influence of riparian vegetation on bank strength.

| 5.47 Field, 2001<br>"Channel Avulsion on Alluvial Fans in Southern Arizona," Geomorphology |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. The current versions of HEC-20 and HDS 6 discuss alluvial fans in general, but provide no guidance on designing crossings or facilities on active alluvial fans. This research also provides another model of channel evolution, this one being specific to active alluvial fan processes. |
| 2. Is the research of practical use or could it be made practical?<br>Yes as is + Level 1 or 2. The research provides guidance on predicting locations of avulsions which could impact transportation facilities on an active alluvial fan. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research builds on previous work conducted by the author and others. |
| 4. Has the research been tested by the original researcher?<br>Unknown. This research is only based on an examination of historical aerial photos from 5 alluvial fans in southern Arizona. However, the researcher has conducted extensive work on these and other alluvial fans in southern Arizona and may have used this methodology on other projects. |
| 5. Has the research been cited by others?<br>Google Scholar identified 16 citations of this paper. |
| 6. What are the strengths of the research?<br>It provides guidance on identifying and predicting sites of potential avulsion on active alluvial fans that may exist upstream of a highway crossing. An avulsion upstream of a highway crossing could potentially impact either the crossing or the nearby highway alignment and, therefore, the methodology could be used to identify and implement countermeasures to potential avulsions. This methodology would improve the design guidance and recommendations in HDS 6 and HEC-20. |
| 7. What are the limitations of the research?<br>It is not known if the methodology has been implemented specifically for the protection of transportation facilities. The methodology allows for the prediction of the location of a potential avulsion, but the prediction of the timing of an avulsion may be more subjective because it is dependence on subsequent flow events. |
| 8. Conclusions.<br>Recommended. The whole subject of active alluvial fan and debris fan processes, the impacts to transportation facilities, and countermeasures should be explored in greater detail in HDS 6 and HEC-20. |

| 5.51 Dade, 2000<br>"Grain Size, Sediment Transport and Alluvial Channel Pattern," Geomorphology |
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| 1. Does the research relate to the current state of practice?<br>The new analysis reconciles existing empirical and theoretical approaches to predict alluvial channel geometry. The analysis is complimentary to detailed, empirical studies of multivariate controls of channel patterns undertaken by others. This analysis can be related to downstream hydraulic geometry relationships discussed in HDS 6. |
| 2. Is the research of practical use or could it be made practical?<br>No. The approach taken focuses on analytical predictions of pattern and is necessarily broad in scope. The approach attempts to predict one of two end members of channel planform; braided or meandering. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The study extends the work of Leopold and Wolman (1957), Parker (1976), and others. |
| 4. Has the research been tested by the original researcher?<br>Unknown. |
| 5. Has the research been cited by others?<br>Google Scholar identified 21 citations of this paper. |
| 6. What are the strengths of the research?<br>The analysis builds on the results of Parker's (1976) analysis to include the effects of grain size and sediment transport mode, and to eliminate channel width and depth as governing variables through the use of a critical stability parameter $\varepsilon$, which determines whether or not a channel pattern is meandering or braided. This critical value can then be used to define a threshold slope between the two end members. |
| 7. What are the limitations of the research?<br>The relationships were primarily developed from data acquired from predominately coarse-grained bedload streams. The author states that there are currently insufficient data to interpret patterns for suspended-load rivers and that, due to the paucity of data, the relationships in sandy, mixed-load rivers are less clear. In addition, the analysis has not considered the formative importance of rare, extreme transport events and the potential for complex evolution of alluvial systems in the short term. |
| 8. Conclusions.<br>Not recommended. |

| 6.3 Surian et al., 2009<br>Morphological Effects of Different Channel-Forming Discharges in a Gravel-Bed River |
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| 1. Does the research relate to the current state of practice?<br>No. Although the paper purports to consider the topic of channel forming discharge and discusses the concepts of effective discharge, it is actually only a discussion that different discharges have different impacts on different features. |
| 2. Is the research of practical use or could it be made practical?<br>No. There is no specific method that can be drawn from this paper, even though the observations are valid. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>While it is true that the gravel bed channel in the study became mobile at between 20 and 50 percent of bankfull and that high bars and islands were not impacted until much higher flows (5 to 10 year flow), this type of observation is true of all channels. The research also indicates that larger amounts of bank movement occurred during higher flows. What it does not do is evaluate whether lower flows, say the 2 year flow, cumulatively do more work than higher flows, which is the concept of channel forming discharge. All discharges do work; it's the cumulative amount of work that is the point of channel forming discharge concept. |
| 4. Has the research been tested by the original researcher?<br>The paper is based on data collected on the Tagliamento River in Italy. |
| 5. Has the research been cited by others?<br>Cited by 3 in Google Scholar, but only published in 2009. |
| 6. What are the strengths of the research?<br>The paper is a good example of using aerial photography combined with sediment tracking (painted gravel) to determine mobility and change in a grave bed river. |
| 7. What are the limitations of the research?<br>The research does not present any predictive approach that could be put into practice. |
| 8. Conclusion.<br>Not recommended. |

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| 7.1 Simon, et al., 2007<br>"Critical Evaluation of how the Rosgen classification and associated "Natural Channel Design" methods fail to integrate and quantify fluvial processes and channel response"<br>Journal of the American Water Resources Association |
| 1. Does the research relate to the current state of practice?<br>Yes. The authors point out that this and other critiques have been submitted in response to the fact that "the Rosgen classification system and its associated methods of "natural channel design" [NCD] have become synonymous to some with the term stream restoration and the science of fluvial geomorphology," and particularly because "the classification approach has become widely adopted by governmental agencies, particularly those funding restoration projects." The authors point out a number of inconsistencies and technical problems with the NCD approach noting that the NCD approach to engineering channel design is lacking in a scientifically based background and foundation. |
| 2. Is the research of practical use or could it be made practical?<br>Yes as is + Level 1. HEC-20 provides a general discussion of the Rosgen classification system, but only in the context of the types of fluvial classification systems currently being used. However, given the extensive use of NCD concepts and the Rosgen approach to stream restoration, cautionary information such as this and from other critical sources should be included in HEC-20 and HDS 6. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>This study suggests that the unproven NCD approach runs counter to standard civil engineering practice which is based on many years of research and methodologies that are documented in peer-reviewed literature. In contrast, the NCD methodology is an analog-empirical methodology that emphasizes form over process, which the authors point out can be problematic. |
| 4. Has the research been tested by the original researcher?<br>Yes, but the research does not provide any new, modified, or advanced research. The paper does point to a number of studies by other researchers as well as to case studies that document or highlight the problems with the NCD approach in channel design and restoration. |
| 5. Has the research been cited by others?<br>Yes. The researchers point to case studies that document or highlight the problems with the NCD approach in channel design and restoration. Google Scholar notes 31 citations of this paper as well as 7 citations of the discussion by Rosgen (2008) and 1 citation of the corresponding reply by the authors (2008). |
| 6. What are the strengths of the research?<br>The study points out that the field of stream channel design and restoration should use the existing physically-based analyses and process-based approaches that are currently available and which are founded on well-established scientific and engineering literature. |
| 7. What are the limitations of the research?<br>None, but the authors have been known to be ultra-critical of the Rosgen classification system and NCD approach and, therefore, those in the restoration business more than likely to turn a deaf ear toward these criticisms. Further research and extensive documentation of the success or failure of the NCD approach will prove crucial in whether or not the NCD approach will stand the test of time. |
| 8. Conclusions.<br>Recommended for inclusion into HDS 6 and HEC-20, but at a general level. Although her review seems somewhat biased in support of the Rosgen methodology, Lave (2009) has attempted to address some of the criticisms and suggests that both Rosgen and critics of the NCD approach should attempt to open up a more conciliatory and constructive dialogue, and collaborate on a national certification process for restoration practitioners. However, at this point there is considerable heated debate and head-butting between both sides of the issue, which doesn't appear to be resolved anytime soon. |

| 7.2 Bledsoe et al., 2007<br>"GeoTools: A Toolkit for Fluvial System Analysis," Journal of the American Water Resources Association |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. Based on input channel geometry and continuous flow series data, the modular suite of programs in GeoTools provides users with outputs including: (1) temporal distributions of hydraulic parameters including shear stress specific stream power and potential mobility of various particle sizes; (2) effective discharge and sediment yield based on a wide range of user-defined analysis options; (3) comparisons of changes in hydraulics, effective discharge sediment transport and yield as a result of altered flow regimes; (4) metrics related to channel form and potential biotic responses; (5) statistics on scour depth and numbers of flow events exceeding a critical shear stress criterion; and (6) over 100 hydrologic metrics. |
| 2. Is the research of practical use or could it be made practical?<br>Yes as is + Level 2 and 3. GeoTools is a suite of analysis tools for fluvial systems that automates computation of numerous hydrologic, hydraulic, and geomorphic descriptors including effective discharge, sediment transport and yield, temporal distributions of hydraulic parameters (e.g., shear stress and specific stream power), cumulative erosion potential, channel stability indices, and over 100 flow regime metrics. The package also serves as a post-processor for SWMM, and HSPF/BASINS model output. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. GeoTools contains a suite of tools to streamline computation of many metrics and descriptors commonly used in probabilistic modeling and assessment of hydrogeomorphic- ecological linkages in fluvial systems. |
| 4. Has the research been tested by the original researcher?<br>Yes. The researchers provide 3 focused case studies where GeoTools was specifically applied: a channel restoration project, a stormwater management/hydromodification study, and an analysis of the effects of flow regulation below an impoundment dam. |
| 5. Has the research been cited by others?<br>Unknown. Google Scholar only identifies 2 citations of this paper. |
| 6. What are the strengths of the research?<br>As indicated by the authors, "GeoTools has been designed to provide a wide range of useful information from a parsimonious set of inputs and to bypass the need for individual investigators to produce custom, "homegrown" data analysis tools. |
| 7. What are the limitations of the research?<br>The authors note that "Risk-based models based on metrics from Geo-Tools will undoubtedly require regional calibration." Even though GeoTools has undergone basic beta testing on a range of different computer types and configurations, compatibility problems may exist. These problems may be addressed in future versions. |
| 8. Conclusions.<br>Recommended for inclusion into HDS 6 and HEC-20, possibly as part of a Level 2 or 3 analysis, especially considering that the user can choose to calculate disturbance regime statistics describing bed stability and scour among other things. |

7.14 Merigliano, 1997 (*Superseded by Ref. 3.11 – Lee and Julien, 2006*)
"Hydraulic Geometry and Stream Channel Behavior: An Uncertain Link," Journal of the American Water Resources Association

This research has been extended through further work and, therefore, is superseded by Lee and Julien, 2006.

| 7.21 Booth, 1990<br>"Stream-Channel Incision Following Drainage-Basin Urbanization," AWRA Water Resources Bulletin |
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| 1. Does the research relate to the current state of practice?<br>No. This paper does not provide any new, modified, or advanced research. A considerable body of work and advanced research has been conducted over the 20 years since this paper was published as indicated by the number of citation (211) identified by Google Scholar. |
| 2. Is the research of practical use or could it be made practical?<br>No. The research is fairly old and dated. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research was conducted in King County, Washington. |
| 5. Has the research been cited by others?<br>211 citations in Google Scholar. |
| 6. What are the strengths of the research?<br>Contributes to the knowledge of incised channel processes with regard to urbanizing streams and builds upon the original work conducted by others such as Schumm et al. (1984) and Simon and Hupp (1986). |
| 7. What are the limitations of the research?<br>The author states that: "recognition of incision-susceptible terrain is clearly the most effective strategy for mitigation in urbanizing areas," which may not always be true, especially in areas with significantly different hydrologic and geologic conditions than that of the author's area of research. Also, the research is fairly dated and has been significantly advanced in the last 20 years and subsequently been superseded by others (for example see Darby and Simon 1999). |
| 8. Conclusions.<br>Not recommended. |

| 8.2 Schumm, 1998<br>"Alluvial Fan Dynamics – Hazards to Highways," Water Resources Engineering '98 (Proceedings of the 1998 International Water Resources Engineering Conference) |
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| 1. Does the research relate to the current state of practice?<br>Yes. This paper does not provide any new, modified, or advanced research. The methodology for alluvial fan identification and delineation developed by the NRC (1996) provides a basis for this paper and more recent work. A considerable body of work and advanced research has been conducted since this paper was published. Another more recent example is the FCDMC's "Piedmont Flood Hazard Assessment" user's manual (Hjalmarson 2003) which provides comprehensive guidelines for identifying and delineating alluvial fans and associated hazards. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. However, the NRC (1996) and FEMA (2003) provide guidance on identifying and delineating alluvial fans and determining appropriate countermeasures to alluvial fan hazards. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes, but the research and more recent work has extended the work identified in this paper. |
| 4. Has the research been tested by the original researcher?<br>No. |
| 5. Has the research been cited by others?<br>Numerous federal, state, and local agencies and public and private entities have used and are currently using the NRC and FEMA methodologies. Google Scholar did not identify any citations of this paper. |
| 6. What are the strengths of the research?<br>The paper doesn't provide any original research, but instead just reiterates the procedures set forth by NRC and FEMA. |
| 7. What are the limitations of the research?<br>It only describes and recommends the methodologies provided by NRC. |
| 8. Conclusions.<br>Not recommended. Methodologies developed by NRC, FEMA, FCDMC, and others supersede those identified in this paper. |

| 9.13 Bledsoe, 2000<br>"Regional Risk Analysis of Channel Stability," Watershed Management 2000 (Proceedings from the 2000 Watershed Management & Operations Management Conferences) |
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| 1. Does the research relate to the current state of practice?<br>The researchers developed an energy-based index (mobility index) grounded in geomorphic threshold theory to improve the prediction of channel response to land use changes and hydraulic modifications. The research is not covered in HDS 6 or HEC-20. |
| 2. Is the research of practical use or could it be made practical?<br>Yes as is + Level 2 or 3. The authors indicate that the "mobility index" is a simple, but robust, predictor of sand and gravel channel planform and stability and that, in many cases, the predictive accuracy of logistic models utilizing the mobility index as the only independent variable exceed 95%. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. Although methods for systematic evaluation of potential instability in alluvial channels are still young, the authors work builds upon and extends the research. Their results indicate that simple indices of specific stream power derived from data that are readily available for most areas can provide accurate prediction of thresholds of channel instability at the regional scale. |
| 4. Has the research been tested by the original researcher?<br>Yes. The authors demonstrated that logistic regression models can accurately predict unstable channel forms with a "mobility index" based on slope, median annual flood, and median bed material size. |
| 5. Has the research been cited by others?<br>Google Scholar did not identify any citations of this paper. |
| 6. What are the strengths of the research?<br>The authors suggest that the mobility index approach is extremely useful, not only as a tool for predicting channel instability, but for scaling channel processes across diverse geological and climatic regions. They also tout the accuracy of logistic regression models that use the mobility index to predict unstable channel forms and that the models provide a means of gauging channel sensitivity to modest changes in the controlling variables. |
| 7. What are the limitations of the research?<br>The authors note that the mobility index had explanatory power practically equaling that of models containing slope, discharge, and $D_{50}$ as separate independent variables, especially for sand bed channels, but prediction of widening in gravel bed channels is less certain due to bank characteristics. |
| 8. Conclusions.<br>Recommend. As stated by the authors, this generalized risk-based approach "facilitates rapid identification of channels that are at highest risk of severe morphologic change due to an imposed increase in stream power" as a result of watershed disturbances. |

| 10.6 Schumm and Harvey, 2008<br>"Chapter 18 – Engineering Geomorphology," ASCE Sediment Engineering Manual |
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| 1. Does the research relate to the current state of practice?<br>Yes – but advancement. The chapter provides a good summary of the current state of practice with regard to applying geomorphology to engineering problems. |
| 2. Is the research of practical use or could it be made practical?<br>Yes as is + Level 1 and 2. Although the chapter provides a fairly extensive in-depth review of applying geomorphology to engineering problems, it should be recommended reading as part of HEC-20 and HDS 6. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The chapter brings together and provides a good review of and case studies from the results of recent research by the authors and others. |
| 4. Has the research been tested by the original researcher?<br>Yes. Many of the concepts are based on research and projects conducted by the authors as provided in the case studies. |
| 5. Has the research been cited by others?<br>Many of the concepts are based on research and projects conducted by others as provided in the case studies. Not cited in Google Scholar. |
| 6. What are the strengths of the research?<br>The paper doesn't provide any original research, but instead provides a concise review of the current state of practice. A number of concepts that are not included in HDS 6 and HEC-20 could be included. The concepts include the systems approach to evaluating channel stability at a given site, consideration of the geomorphologic factors that influence landforms (engineering sites) and the hazards associated with them, and the development of dimensionless stability numbers for use in evaluating incised channel evolution. |
| 7. What are the limitations of the research?<br>The concepts and approaches identified by the authors only provide general guidance on how one can identify existing hazards or problems and potentially identify future hazards or problems as they relate to a particular site. |
| 8. Conclusions.<br>Recommended. This chapter provides a good discussion of the need for a close relationship between geomorphology and engineering. As discussed above, the concepts and approaches described by the authors should be included in HDS 6 and HEC-20. |

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| 10.7 Biedenharn et al., 2008<br>"Chapter 6 – Fundamentals of Fluvial Geomorphology," ASCE Sediment Engineering Manual |
| 1. Does the research relate to the current state of practice?<br>Yes, the chapter provides an overview on some basic concepts of fluvial geomorphology and river mechanics, but the chapter doesn't provide any original research. This chapter only provides a detailed overview on the fundamentals of fluvial geomorphology. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, but is practical primarily as an overview of basic concepts of fluvial geomorphology and river mechanics, specifically as they apply to engineering design of channel rehabilitation projects (in the broadest sense). The authors cover six fundamental concepts that they say should be considered in designing engineering works in rivers and watersheds. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The authors cover a number of well-established concepts and tools that are currently in use today. |
| 4. Has the research been tested by the original researcher?<br>No. However, many of the concepts, guidelines, and methodologies described by the authors are based on previous research by them and others. |
| 5. Has the research been cited by others?<br>Many of the concepts, guidelines, and methodologies identified by the authors are currently applied. Not cited in Google Scholar. |
| 6. What are the strengths of the research?<br>The chapter provides a good overview of fluvial geomorphology and river mechanics concepts that will be of use to engineers. Many of these concepts are covered only generally in HEC-20 and HDS 6. |
| 7. What are the limitations of the research?<br>The chapter doesn't provide any original research and is primarily a reference tool. |
| 8. Conclusions.<br>Recommended. This chapter could be referenced as part of HDS 6 and HEC-20 in order to provide the user with a good background and understanding of fluvial geomorphology. |

| 11.1 Oregon Dept. of Transportation, 2005<br>OTIA III State Bridge Delivery Program Environmental Performance Standards |
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| 1. Does the research relate to the current state of practice?<br>No, but possible advancement. The report establishes among a range of environmental standards, a Fluvial Performance Standard (pages 33-37) that, if met, promotes natural sediment transport in the bridge reach, provides for unaltered fluvial debris movement and longitudinal continuity and connectivity along the stream/floodplain system, and streamlines the permitting process for new (and replacement) bridges. At the highest level, the fluvial performance standard states: "Allow normative physical processes within the stream-floodplain corridor." |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The research identifies two easily determined approaches to set bridge and span lengths. These approaches indicate that the bridge span the functional floodplain (defined as up to 2.2 times the bankfull width or a length such that there is no contraction scour in the 10-year flood event. These bridge lengths are more sustainable in that there are fewer maintenance requirements floodplain habitat connectivity is achieved. Because determination of bankfull width and hydraulic analysis are required, this research would be Level 2. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>The research is founded in the empirical evidence of good bridge design practice (avoid piers in the channel or near channel banks, set abutments back from the channel, etc). However, the specifics of the research (definition of the functional floodplain, spanning the functional floodplain, selecting the 10-year event as a fluvially important flow) are not based on theory but stem primarily from the experience. |
| 4. Has the research been tested by the original researcher?<br>The fluvial standard has been applied in Oregon. A review of 46 bridges that were designed in accordance to the fluvial standard indicated that 30 bridges met the fluvial standard through "replace in kind," so there was no increase in cost compared to a standard replacement. Fifteen bridges were able to meet the fluvial standard at little or no additional cost by minor design modifications. One bridge required lengthening of four percent to meet the fluvial standard. By avoiding additional permitting requirements, the additional cost was probably offset by the more streamlined permitting process. |
| 5. Has the research been cited by others?<br>Not cited Google Scholar. |
| 6. What are the strengths of the research?<br>The research addresses one issue that is very important to DOTs, which is avoiding difficulties in permitting. The research also addresses the philosophy of sound bridge design, which includes avoiding stream stability issues over the life of the bridge. Each of these are goals are addressed by considering the function, continuity and connectivity of the stream and floodplain. |
| 7. What are the limitations of the research?<br>One significant issue is that the fluvial design standard was targeted at conditions in Oregon so other standards would need to be developed for other regions. The other limitation, even potentially for Oregon, is the definition of functional floodplain. There are no theoretical explanations given for defining the functional floodplain as 2.2 times the bankfull width and or why the 10-year recurrence interval flood is a goal for zero contraction scour. |
| 8. Conclusion.<br>Recommend that discussion of stream and floodplain connectivity be included in HEC-20 as a bridge design goal or philosophy. Also recommend that this topic be strongly considered for future research. |

## Reconnaissance

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| 1.3 Johnson, 2006<br>Assessing Stream Channel Stability at Bridges in Physiographic Regions, FHWA-HRT-05-072 |
| 1. Does the research relate to the current state of practice?<br>Yes, but an improvement. The research is based on the rapid channel assessment technique that was previously developed by the author and is included in HEC-20. However, it has been improved specifically for bridge inspection. The improvements are substantial. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The research is practical for a bridge inspection level of channel stability assessment, which puts this method squarely into Level 1. It uses a set of simplified stream reconnaissance forms based on Thorne's more complete forms specifically designed for information that bridge inspectors could quickly fill out. It then allows the inspector to assess overall stability, lateral stability and vertical stability of the channel. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes, it is based on much of the information contained in the technical literature. |
| 4. Has the research been tested by the original researcher?<br>The method was applied to 57 sites in 14 physiographic regions and provided reasonable, consistent results. |
| 5. Has the research been cited by others?<br>Reference not found in Google Scholar. But earlier work on the subject (Rapid Assessment of Channel Stability in the Vicinity of a Road Crossing, by Johnson, Gleason and Hey, Journal of Hydraulic Engineering, 1999) was cited 16 times in Google Scholar. |
| 6. What are the strengths of the research?<br>Although rating schemes are prone to averaging out problematic conditions, this method avoids that by rating vertical and lateral stability separately from overall stability. Several of the rating factors of the prior "Rapid Assessment" technique have been modified or replaced. Data sheets have been produced to make the method more systematic. Although the physiographic regions to not factor directly into the rating, they have influenced the selection of factors to make the method broadly applicable. Another strength is that is it targeted at identifying problems that could be of concern in a relatively short period of time (2-year inspection interval). |
| 7. What are the limitations of the research?<br>Because the method is simplified, there is risk of incorrect characterization. This limitation is countered by the recommendation that an indication of instability should lead to additional investigation. |
| 8. Conclusion.<br>Recommended for inclusion into HEC-20 as a replacement of the prior "Rapid Assessment" technique. It should be recognized that this method is intended primarily for bridge inspectors and that additional investigation is warranted when problems are identified. |

| 2.5 NCHRP Report 426, NCHRP 24-06, 1999<br>CAESAR: An Expert System for Evaluation of Scour and Stream Stability |
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| 1. Does the research relate to the current state of practice?<br>Yes. It may be an advancement because it not only includes a framework for collecting and storing bridge inspection data, but it also uses Bayesian approaches to estimate likelihood of channel instability and scour to identify whether structural elements are at risk. |
| 2. Is the research of practical use or could it be made practical?<br>The approach is data intensive and while it is meant to support bridge inspectors does not appear to be practical for their use. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. U sing observed data (bridge records) plus Bayesian approaches are widely accepted. |
| 4. Has the research been tested by the original researcher?<br>The researchers applied the system to 25 in four states (Illinois, North Carolina, Washington, and Arkansas). |
| 5. Has the research been cited by others?<br>Yes, by 1 in Google Scholar. The citation was an evaluation of CAESAR at 10 sites in Indiana, (Chen et al. 2000) which concluded that CAESAR is more data intensive and provides similar, though more conservative results to simpler approaches. |
| 6. What are the strengths of the research?<br>Caesar is very systematic in recording data. These data include bridge cross sections, structure information and site photos. In their testing, CAESAR did well at identifying potential risks. |
| 7. What are the limitations of the research?<br>The limitations include more intensive data requirements and, as per the independent test, no significant gain in outcome as compared with simpler methods. |
| 8. Conclusion.<br>Not recommended for inclusion in HEC-20 unless further validation studies indicate an increased value from using CAESAR. |

| 3.16 Shields et al., 2003<br><br>Design for Stream Restoration, Journal of Hydraulic Engineering |
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| 1. Does the research relate to the current state of practice?<br>Yes. Regarding the topic of reconnaissance and classification, it is not an advancement of current approaches. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. Level 2. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. It is based on well established approaches for data analysis. |
| 4. Has the research been tested by the original researcher?<br>Yes. Although not specifically reported as having been tested, the paper presents the material from the standpoint of experience from having used these approaches. |
| 5. Has the research been cited by others? Yes, by 72 in Google Scholar. |
| 6. What are the strengths of the research?<br>Provides a general approach for stream restoration design, of which reconnaissance and classification play a role. It is, therefore, a good reference to show the whole picture, especially related to stream restoration. |
| 7. What are the limitations of the research?<br>On the topic of reconnaissance and classification, it does not go into significant depth, or provide any new material. |
| 8. Conclusion<br>Not recommended on the topic of reconnaissance or classification. It could be considered as an additional reference in the "Channel Restoration Concepts" section in HEC-20. |

| 5.44 Thorne, 2002<br>Geomorphic Analysis of Large Alluvial Rivers, Geomorphology |
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| 1. Does the research relate to the current state of practice?<br>Yes, but an advancement. HEC-20 makes the case that Level 1 reconnaissance activities are an important step even when it is known a priori that a Level 2 or 3 analysis will be performed. This concept is advocated and advanced in this paper. In the context of large alluvial rivers, this paper represents a formal blueprint for conducting a catchment scale audit, fluvial audit and geomorphological dynamics assessment. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, it is practical as a Level 3 activity that may be necessary for a bridge crossing large alluvial river. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes, it is based on widely accepted classification and analysis techniques, many of which are already included in HEC-20 and HDS 6. It is not specifically tied to any single approach (much as Levels 1 and 2 are currently presented in HEC-20, this method is flexible and situation dependent). |
| 4. Has the research been tested by the original researcher?<br>Yes. A case study is included in the paper and references are made to four other published papers and reports that have used this approach. |
| 5. Has the research been cited by others?<br>Yes, 11 citations in Google Scholar. |
| 6. What are the strengths of the research?<br>The strengths of the research include a systematic and flexible approach to dealing with catchment, reach and project scales. For each scale, a specific item or deliverable is identified, data requirements are identified, and a relative level of effort is identified. |
| 7. What are the limitations of the research?<br>As a Level 3 analysis of geomorphological assessment, it may find limited use, though for complex problems or large river crossings this would be a valuable resource. |
| 8. Conclusion.<br>Recommended for inclusion in HEC-20. |

| 6.1 Hauet et al., 2009<br>Digital Mapping of Riverine Waterway Hydrodynamic and Geomorphic Features, Earth Surface Processes and Landforms |
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| 1. Does the research relate to the current state of practice?<br>No, this is well advanced beyond the current state of practice. This method uses digital photography and video. An oblique photography is decomposed into quasi-planar surfaces (which have been surveyed), ortho-recified, and reassembled into an ortho view of the area. Particle Image Velocimitry is used to measure flow velocities and streamlines. Changes over time can be identified through periodic visits to the site. The approach purports to be inexpensive for the amount of information obtained. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, practical or could be made practical. This approach appears to be of practical application for situations that call for detailed, advanced monitoring and reconnaissance at Level 3. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The methods of ortho-rectification of photos and Large Scale Particle Image Velocimetry are widely used and accepted. This approach applies these technologies to riverine mapping. |
| 4. Has the research been tested by the original researcher?<br>Yes. The methods are demonstrated in the journal article. |
| 5. Has the research been cited by others?<br>Not cited, but only published in 2009. |
| 6. What are the strengths of the research?<br>The strengths of the research are providing an approach for detailed monitoring of riverine features near a bridge and the ability to measure and map flow velocities and currents using oblique (distorted) digital photography. |
| 7. What are the limitations of the research?<br>Some specialized equipment, software, and training are required and it would only be applicable to limited conditions. |
| 8. Conclusion.<br>Recommended as a Level 3 approach for monitoring and reconnaissance at bridges or other locations where detailed information is required. |

| 7.10 Montgomery and MacDonald, 2002<br>Diagnostic Approach to Stream Channel Assessment and Monitoring, Journal of the American Water Resources Association |
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| 1. Does the research relate to the current state of practice?<br>Yes. This paper is consistent with the current state of practice in that it recognizes the range of processes and the complexities of identifying stream condition and response. It is also a moderate advancement it addresses the channel types that are more or less sensitive to changes in sediment and water supply. |
| 2. Is the research of practical use or could it be made practical?<br>They suggest that a diagnostic procedure is a logical basis for stream channel assessment. The description of the procedure shows that this is what is consistent with what is currently prescribed in HEC-20. The procedure itself is Level 2 or Level 3. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Diagnostic approaches are used widely, especially in the medical field. The approach is based on the extensive experience of the authors and on significant prior work. |
| 4. Has the research been tested by the original researcher?<br>This paper does not include specific reference to being tested, but it clearly has been developed based on extensive experience in the field. |
| 5. Has the research been cited by others?<br>Cited by 70 in Google Scholar. |
| 6. What are the strengths of the research?<br>The overall strength of the research is that it recognizes the complexities of fluvial systems and the range of responses that can occur. It does not try to oversimplify, but provides a flexible general approach to tie channel assessment with potential responses. It also indicates which channel types are more susceptible to instability from specific changes in sediment and discharge.<br>The paper lists the strengths as: (1) more comprehensive field data must be gathered to support the diagnosis, (2) the approach is intended to identify processes, (3) it is flexible and adaptable, (4) requires adequately trained and experienced personnel, (5) requires looking at the stream channel within the context of the watershed and geomorphic system. |
| 7. What are the limitations of the research?<br>The limitations that are discussed in the paper include: (1) any diagnosis system is susceptible to bias or misinterpretation, (2) the system requires more information than is typically collected, (3) the system requires experienced field staff beyond workshops and short courses. Another limitation is that the authors acknowledge a bias towards mountainous western streams. These limitations make its widespread adoption unlikely. |
| 8. Conclusion.<br>Recommended as a good reference in HEC-20 to support discussion of the range of responses that can occur in fluvial systems and the level of data and assessment that is needed to more adequately characterize the system. |

| 8.9 Cotton, 1999<br>Effect of Geomorphic Hazards on Bridge Reliability, Stream Stability and Scour at Highway Bridges – Compendium of Papers – ASCE conferences 1991-1998 |
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| 1. Does the research relate to the current state of practice?<br>No. Although the approach incorporates information consistent with HEC-20 recommendations, the goal of this publication is to present a stream stability weighting factor as part of an overall external hazard weighting factor. By combining four different hazard groups, bridges would then be ranked according to the relative vulnerability. |
| 2. Is the research of practical use or could it be made practical?<br>The computation for stream stability weighting factor is very simplistic and depends on channel type (Figure 5.13 of HDS 6) and the level of channel constriction. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>No. The stream stability factor increases with the amount of constriction and with the perceived level of channel instability, but the values are only recommended and not based on either theory or data analysis. |
| 4. Has the research been tested by the original researcher?<br>No. |
| 5. Has the research been cited by others?<br>Not cited by others in Google scholar. |
| 6. What are the strengths of the research?<br>The information for the stream stability factor is easily obtained. Also, many other types of hazards that bridge are exposed to are discussed, though these are all known hazards. |
| 7. What are the limitations of the research?<br>This is an overly simplistic view of stream instability that would be less reliable than using the same information and making a reasonably informed judgment. |
| 8. Conclusion.<br>Not recommended. Reference 1.3 is much more applicable. |

| 8.10 Johnson and Simon, 1995<br>Reliability of Bridge Foundations in Unstable Alluvial Channels, Water Resources Engineering. |
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| 1. Does the research relate to the current state of practice?<br>No. Reliability and uncertainty is not formally part of stream stability assessments, so this is an advancement. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The method demonstrates using a simple power function for estimating future bed elevation as a function of time, presumably from prior observations. Monte Carlo simulation is then used to include uncertainty. If the probability of structure failure is known as a function of elevation, then the probability of failure over time can be estimated. A similar approach could be used for channel widening. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes, these techniques are founded in statistical approaches. |
| 4. Has the research been tested by the original researcher?<br>Unknown. The example in the paper appears to be hypothetical rather and a case study. |
| 5. Has the research been cited by others?<br>No citations in Google Scholar. |
| 6. What are the strengths of the research?<br>The research provides a reasonable framework for including reliability and uncertainty into scour analyses. |
| 7. What are the limitations of the research?<br>It only includes rather simplistic approaches for predicting future degradation or widening. Until methods for incorporating uncertainty of all the scour components is developed, this research is incomplete. |
| 8. Conclusion.<br>Not recommended at this time. This topic, including other scour processes, is being advanced in NCHRP 24-34. |

## Aggradation/Degradation

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| 1.2 MDSHA, 2007<br>Guidance on evaluation of long-term channel degradation, Manual for Hydrologic and Hydraulic Design - Chapter 14 |
| 1. Does the research relate to the current state of practice?<br>Yes. This manual introduces numerous methods to characterize channel morphology or predict channel changes, including (a) Cumulative Degradation Method, (b) Pool Base-Level Method, and (c) Estimation of Degraded Stream Profile, which are used to assess long-term channel degradation. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level-2. These methods are easy to implement. (a) Cumulative Degradation Method and (b) Pool Base-Level Method only require a hand level and stadia or pocket rod. (c) Estimation of Degraded Stream Profile requires thalweg elevations, riffle crest elevations, and simple calculation. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. (a) Cumulative Degradation Method first locates a high-permanence base level point that controls the channel bed or water surface, and then measures vertical channel thalweg changes over low-flow high-gradient features, and finally accumulates possible modification of those features during the lifetime of a bridge.<br>(b) Pool Base-Level Method measures the depth to base level points in pools under low-flow conditions. Since the depth of each pool's base level point from the pool's water surface is roughly equal to the potential degradation of the current riffle-crest elevation, the depths of the low-flow water surface in pools to a base level point are an approximation of potential channel degradation.<br>(c) Estimation of Degraded Stream Profile is based on a channel evolution model and four associated assumptions (for details refer to MDSHA, 2007 or Ref. 1.2). Long-term channel changes are defined as the change in the riffle-crest line at any point along the streambed over the 60-to-100-year life of the crossing. The degraded stream profile is derived from two main parameters: the degraded base level point to represent the downstream boundary of the degraded stream profile, and the degraded riffle-crest slope. |
| 4. Has the research been tested by the original researcher?<br>Yes. Most of this guidance in Chapter 14 of the manual is based on the results of studies and investigations conducted since the mid-1990s in Maryland. |
| 5. Has the research been cited by others?<br>Yes. If not validated, the approaches are being applied in stream-related projects. |
| 6. What are the strengths of the research?<br>(a) Cumulative Degradation Method and (b) Pool Base-Level Method are reasonable to approximate long-term channel degradation, and not a complicated procedure. (b) Pool Base-Level Method does not require a downstream control point.<br>(c) Estimation of Degraded Stream Profile uses the riffle-crest line to calculate the degraded stream profile, which is a good first-order approximation.<br>These methods are alternatives to the detailed sediment transport models. |
| 7. What are the limitations of the research?<br>These methods are primarily relevant to wadeable gravel-bed streams with pool-riffle morphology. The channel slope ranges from 0.2% to 4%. |
| 8. Conclusion<br>All three methods are recommended for inclusion in HEC-20 and evaluation of long-term channel degradation. |

| 3.18 Melville & Coleman, 2000<br>Quantitative assessment of aggradation and degradation, "Bridge Scour," Section 4.3 |
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| 1. Does the research relate to the current state of practice?<br>Yes. The book section provides overview and comments on quantitative methods for use in the prediction of aggradation and degradation. Some methods were already incorporated into HEC-20, including Armoring-Based Design Methodologies. Other methods not covered by HEC-20 are (a) Regime Formulations (Lacey, 1930; Blench, 1969), (b) Tractive Force Methods (Henderson, 1966; Raudkivi, 1990), and (c) Competent Velocity Methods (Williman, 1970; Neill, 1973, 1987; Harris, 1988; Alvarez and Alfaro, 1973; Holmes, 1974). For details about the above references, please refer to the book "Bridge Scour." |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level-2. (a) Regime Formulations, (b) Tractive Force Methods, and (c) Competent Velocity Methods provide their own equations to calculate mean scoured flow depth. These equations are primarily related to design discharge, channel geometry, and sediment size, which are easy to obtain. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. (a) Regime Formulations are mainly based on regime equations (i.e., hydraulic geometry relationships).<br>(b) Tractive Force Methods are used to calculate maximum flow depth for which a material will be stable on a given channel slope.<br>(c) Competent Velocity Methods are based on the assumption that scour will proceed until threshold conditions are attained, the competent velocity being approximately equivalent to the mean flow velocity at the threshold condition for the bed material. These methods calculate an average scour depth. The maximum scour depth is based on graphical redistribution of the average scour depth. |
| 4. Has the research been tested by the original researcher?<br>The book section provides limited information about testing by the original researcher for the referenced studies. Therefore, for most methods, it is unknown, but most likely yes. The Competent Velocity Method of Alvarez and Alfaro (1973) was tested in sandy and gravel channels. |
| 5. Has the research been validated in practice by others?<br>(a) Regime Formulations are applied, although the book does not explicitly mention their application.<br>(b) Tractive Force Methods are related to an equation that predicts clear-water contraction scour depths.<br>(c) Competent Velocity Methods have been validated, recommended, and used for evaluation of bridge scour.<br>The Competent Velocity Method of Harris (1998) was recommended for bridges in Ontario, Canada.<br>The Competent Velocity Method of Alvarez and Alfaro (1973) was extensively used for gravel bed rivers in New Zealand.<br>The Competent Velocity Method of Holmes (1974) has been used by New Zealand Railways for many years. |

| 3.18 Melville & Coleman, 2000 (continued) |
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| 6. What are the strengths of the research?<br>(a) Regime Formulations have a simple equation, so they are easy to follow.<br>(b) Tractive Force Methods and (b) Competent Velocity Methods are physically based, so they are able to produce reliable results. Their equations are not difficult. |
| 7. What are the limitations of the research?<br>The graphical redistribution of the average scour depth to obtain the maximum scour depth is subjective.<br>(a) Regime Formulations are not generally applicable, because hydraulic geometry relationships are not often apparent. The Regime Formulation of Lacey (1930) was designed for uncontracted sandy alluvial channels. The Regime Formulation of Blench (1969) is valid only in well-maintained sand-bed irrigation canal systems with particular characteristics.<br>(b) Tractive Force Methods' limitations were not provided in the book section.<br>(c) Competent Velocity Methods: the Competent Velocity Method of Neill (1973) was found to underestimate the effects of armoring in gravel-bed rivers. The Competent Velocity Method of Alvarez and Alfaro (1973) was questioned about its logic and physical basis. The Competent Velocity Method of Holmes (1974) was questioned about not having a logical physical basis and consideration of bed material effects. |
| 8. Conclusion<br>These methods are recommended for consideration in HEC-20. However, the assumptions, limitations, and inadequacies of these methods should be emphasized so that a practitioner has a comprehensive understanding before they are applied. |

| 4.14 James, 1997<br>Channel Incision on the Lower American River, California, from Stream-flow Gage Records, Water Resources Research |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. Gage analysis is discussed in HEC-20 in the context of a specific gage plot to identify aggradation and degradation trends. This paper is advancement on that approach and a good case study. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. Level 2. Downloading gage data and performing the analysis in a spreadsheet would be a Level 2 effort. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The approach uses regression analysis to develop a stage-discharge relationship for a gage. It then looks at residual plots measured versus predicted stages through time to track bed degradation. This method is not tied to a specific discharge (specific gage analysis), though it does use the lower flow range. Therefore, it uses more of the observed data and may well be more efficient to use than the traditional specific gage plot. |
| 4. Has the research been tested by the original researcher?<br>Yes. The degradation amounts determined from the gage analysis were verified using bridge cross sections. |
| 5. Has the research been cited by others?<br>Yes. By 11 in Google Scholar. |
| 6. What are the strengths of the research?<br>The regression approach is simple to apply (spreadsheet) and can be used for any long-term gage. The paper illustrates the gage analysis approach and illustrates using bridge records as verification. Therefore, it also could serve as an illustrative example in HEC-20. |
| 7. What are the limitations of the research?<br>Only valid for locations with a nearby, long-term gage. The limitation of extrapolation for predicting future degradation is significant. However, the residual plots also show trends of reduced degradation through time. |
| 8. Conclusion:<br>Recommended for inclusion in HEC-20, especially since HEC-20's coverage of gage analysis is light. |

| 6.2 Raven et al., 2009<br>Monitored erosion and aggradation over 6 years, Earth Surface Processes and Landforms |
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| 1. Does the research relate to the current state of practice?<br>Yes. This study analyzed changes in channel morphology observed along a 5.6 km reach of a temperate, upland, gravel-bed river, and investigated the spatial and temporal nature of channel degradation and aggradation. |
| 2. Is the research of practical use or could it be made practical?<br>No. This study is an analysis of observed flow, sediment, and channel morphology. It emphasized the complex response of the channel to sediment supply and to hydrology. It did not produce any methods related to the evaluation of channel degradation and aggardation. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. This study was based on 6-year field monitoring data. |
| 4. Has the research been tested by the original researcher?<br>Not applicable, as the study did not propose a method to evaluate channel degradation or aggardation. |
| 5. Has the research been cited by others?<br>Cited by 1 in Google Scholar, but only published in 2009. |
| 6. What are the strengths of the research?<br>The most important finding is that coarse sediment transport in up-land river channels plays a significant role in flood risk. Other conclusions related to sedimentation include: (1) coarse sediment transport may be highly variable over short time period and may result in large amount of aggradation, (2) it is difficult to predict channel morphological response to potential changes in climate and land use. |
| 7. What are the limitations of the research?<br>The findings in this study are limited to a specific reach. |
| 8. Conclusion<br>Not recommended. The findings are not directly related to any methods used to evaluate channel degradation and aggradation. |

| 8.4 Voight et al., 1997<br>Identify shifting channels and degradation as research needs in geomorphology, Compendium of ASCE Papers (1991-1998) |
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| 1. Does the research relate to the current state of practice?<br>Yes. This article proposed a list of research needs in geomorphology that are related to bridge scour, for the purpose of providing useful and straightforward information to the bridge engineer. |
| 2. Is the research of practical use or could it be made practical?<br>No. This article did not include any approaches that are of practical use. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>No. This article emphasized the importance of proposed research needs in geomorphology by presenting geomorphologic problems and examples related to bridge scour. There are no theories or empirical evidence in this article. |
| 4. Has the research been tested by the original researcher?<br>No. There are not any research results in this article. |
| 5. Has the research been cited by others?<br>No citations in Google Scholar. |
| 6. What are the strengths of the research?<br>The article provided a list of research needs in geomorphology pertaining to bridge scour: (1) to develop a set of relations for predicting short-term channel widening in response to channel degradation and aggradation; (2) to compile a manual for bridge problems on alluvia fans; (3) to prepare a concise design manual providing quantitative methods for evaluating bend and confluence scour at bridges; (4) to acquaint the bridge engineer with the consequences of basin modification; and (5) to provide a set of guidelines for evaluating channel incremental channel shift, a numerical model, and a compendium of countermeasures. |
| 7. What are the limitations of the research?<br>Not applicable. |
| 8. Conclusion<br>Not recommended, but should be revisited in Task 5. |

| 10.3 Richardson & Richardson, 2006<br>Bridge Scour Evaluation, Sedimentation Engineering, Chapter 10 |
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| 1. Does the research relate to the current state of practice?<br>Yes. The chapter describes different kinds of scour related to bridge (contraction scour, local pier scour, abutment scour, and long-term degradation) and methods to evaluate bridge scour. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The methods introduced in this chapter are of practical use, but most of them are not directly related to stream instability (long-term degradation/aggradation, channel migration, etc.). |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. Those methods for bridge-scour evaluation were based on laboratory studies. |
| 4. Has the research been tested by the original researcher?<br>Most methods for bridge-scour evaluation in this chapter have been widely used in engineering practice. |
| 5. Has the research been cited by others?<br>Yes, by 4 in Google Scholar. |
| 6. What are the strengths of the research?<br>This chapter describes methods to evaluate bridge scour in most circumstances including tidal bridges. |
| 7. What are the limitations of the research?<br>The authors only gave some brief introduction to long-term evaluation, as the long-term degradation was not the focus. |
| 8. Conclusion<br>Not recommended, as this chapter is similar to HEC-18 in content, and does not provide useful information about the evaluation of long-term degradation. |

## Channel Migration

| 1.1 Briaud et al., 2007<br>Establish guidance for soils properties-based prediction of meander migration rate |
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| 1. Does the research relate to the current state of practice?<br>No. This research does not relate to current practice in assessing geomorphic hazards at bridge crossings, but provides an alternative approach for meander migration assessment. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, it could be at Level 3. The method predicts channel migration in meandering rivers based on the planform geometry, bank soil strength and flow regime. It is presented in the form of a user-friendly computer program and could be applied practically based on basic training and some further development of the underlying model to generalize it. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is based on basic theories supplemented by empirical evidence pertaining to soil erosion. Representation of hydraulic and morphological processes in meandering rivers is, however, highly simplified. |
| 4. Has the research been tested by the original researcher?<br>No. The researcher was unable to test the underpinning models due to lack of funding. He recommends that the models be tested as a research priority. |
| 5. Has the research been validated by others?<br>Unknown. A web search did not reveal any citations of this document that would demonstrate that it has yet been independently validated. |
| 6. What are the strengths of the research?<br>The strength of this research is that it takes the strength of the bank soil into account when making predictions of future channel migration in meandering rivers in addition to considering the initial planform geometry and hydrological regime. |
| 7. What are the limitations of the research?<br>The limitations stem from the use of an idealized channel in a laboratory flume to generate values for the empirical variables and coefficients in the model. Also, the computer program used to run the model requires careful and well-informed judgments concerning representation of the study stream, for example in characterizing the planform using fitted circles. The demands of the prediction method for long-term hydrological records from a nearby gaging station further limit practical application of the approach. |
| 8. Conclusion<br>Not recommended. The only innovative contribution in the research lies in its consideration of soil strength as a parameter affecting meander migration rate. However, no account is taken of bank and riparian vegetation – which is at least as important as soil strength, and the representation of meander shifting as a simple hyperbolic function is unable to account for natural variability in bend migration associated with non-uniform bends and local variability due to the influence of artificial structures - such as revetments or variable bank and vegetation strength. |

| 1.2 MDSHA, 2007<br>Guidance on evaluation of lateral channel movement, Manual for Hydrologic and Hydraulic Design - Chapter 14 |
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| 1. Does the research relate to the current state of practice?<br>Yes, but an improvement. This manual describes some assessment techniques to characterize lateral channel movement and planform changes, including the procedure to delineate the Channel Lateral Movement Zone (CLMZ). |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The approach is of practical use in Level 1, as the delineation procedure of CLMZ is based on topographic maps and aerial photos. The analysis of measured maximum lateral movement of channel might put this approach in Level-2. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The boundaries of the CLMZ envelops the extent of likely channel migration and pathways for channel avulsion, and their development factors in (a) past channel movement, (b)potential pathways for channel avulsions, and (c) gradients influencing lateral migration.<br>A lateral movement frequency histogram is also developed based from the measured maximum lateral movement of channel to assess the frequency and magnitude of channel later movement within a time period. |
| 4. Has the research been tested by the original researcher?<br>Yes. Most of this guidance in Chapter 14 of the manual is based on the results of studies and investigations conducted since the mid-1990s in Maryland. |
| 5. Has the research been cited by others?<br>Yes, by 3 in Google Scholar. |
| 6. What are the strengths of the research?<br>The delineation of the CLMZ and the frequency analysis of lateral channel movement are an improvement from Aerial Photo Review in HEC-20. This approach is straightforward. |
| 7. What are the limitations of the research?<br>The procedure for delineating the CLMZ is still coarse. The manual states that a more detailed explanation of this procedure is under development. |
| 8. Conclusion<br>The procedure is recommended for inclusion in HEC-20 and evaluation of lateral channel migration. |

| 1.6 NCHRP 24-16, 2004<br>Methodology for predicting channel migration |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. The research relates to practice in using the history of channel migration around a bridge crossing as the basis for predicting future rates and spatial trends of bend migration in meandering rivers. |
| 2. Is the research of practical use or could it be made practical?<br>Yes – as is at Levels 1, 2 and 3. The research presents a series of increasingly sophisticated methods to predict bend migration based on the type of information and capability/expertise of the study team. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is founded on established theory concerning channel migration in meandering rivers coupled with a large (1,503 bend) data set from 89 rivers across the USA. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research included testing of the predictive method through hind casting at sites with well documented histories of channel migration. |
| 5. Has the research been validated by others?<br>Yes. There are several references in the literature to comparison of the NCHRP 24-16 approach with alternate prediction methods. Generally, it is found that the radius or curvature to width ratio (as used in the NCHRP method) provides a simple but adequate parameter from which to predict first order bend migration somewhat reliably in the medium term. |
| 6. What are the strengths of the research?<br>The strength is the fact that the history of lateral migration at the actual site in question provides the basis for prediction of future behavior. Hence, attributes like soil strength and vegetation are implicitly accounted for in observed and predicted migration rates. In essence, the river is the most complete model of itself. The widely proven performance of R/W as a reasonable predictor of bend evolution, coupled with the extensive empirical database and capability to adapt the method to the available data/expertise are further strengths. |
| 7. What are the limitations of the research?<br>The main limitation is that because analysis is based on past history at the site, predictions may be unreliable if watershed or climate changes impact the hydrological or sediment regimes. Also, application of the more sophisticated versions of the model use GIS software that is now out of date. |
| 8. Conclusion<br>Recommended. This method uses the actual history of channel migration at the study site and has wide applicability due to its broad, empirical basis. It presents a practical approach to predicting hazards associated with channel migration in meandering rivers. The probabilistic version deserves further research and development. |

| 3.18 Melville and Coleman, 2000<br>Bridge Scour (especially, Section 4.8) |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. The book does not report any original research on channel migration but does present several methods that can be used in practice to predict both the rate and distribution of channel shifting for streams with different geomorphic characteristics and planform patterns. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, it could be at Level 1, 2, or 3. The book presents a concise overview of the geomorphology and principal factors affecting channel migration. It also reports on qualitative methods (Level 1) and quantitative models (Levels 2 and 3) developed prior to 2000 that could be used in practice to predict the risks posed to bridges by lateral channel migration. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research reported is based on sound theories of bank erosion, bank stability and lateral migration in channels with meandering and braided planforms, backed in most cases by empirical data. |
| 4. Has the research been tested by the original researcher?<br>Yes. The researchers responsible for developing the methods and models reported in this book tested their approaches through applications to flume and/or field datasets. |
| 5. Has the research been validated by others?<br>Yes. The source references used in the book have been widely cited, with the research being positively commented upon in most independent tests. However, it should be noted that the weaknesses in several of the approaches have been identified and addressed in research subsequent to 2000 (when this book was published). |
| 6. What are the strengths of the research?<br>The strength of the research reported in this book is that it has been selected by the authors as being suitable for assessing the likelihood, rate and hazard associated with channel migration in both dynamically stable and morphologically unstable streams. |
| 7. What are the limitations of the research?<br>The limitations stem from the limited research, development and testing of the methods and the fact that some of them have been superseded by later versions published since this book was published. |
| 8. Conclusion<br>Recommended. The techniques reported in this book should be considered for inclusion in an updated version of HEC-20. Some should also be examined for suitability further research and development under NCHRP funding, including the Bank Energy Index (BEI) of Mussetter et al. (1995) and the concept of centripetal force (WET, 1990) that have potential but which require further research and development before they could be adopted in practice. |

| 4.8 Perucca et al., 2007<br>Significance of the riparian vegetation dynamics on meandering river morphodynamics |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. Current practice attempts to account for the risks to bridges associated with channel migration due to bend growth and migration in meandering streams, but does not account for the dynamic interactions that occur between fluvial processes and vegetation. |
| 2. Is the research of practical use or could it be made practical?<br>Yes: Level 1 now, Level 3 with development. The models used to predict channel migration and vegetation growth/decay are currently unsuitable for practical application. However, the relationship between relative channel migration rate and vegetation density could be used qualitatively in a Level 1 analysis to estimate the probability of a particular bend causing a hazard at a bridge in the period up to the next inspection. The models presented in this paper (or other similar models) could be developed into a reduced complexity, practical channel migration prediction tool that accounts for dynamic interaction between fluvial processes and vegetation. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is founded on an established theory for meander growth and shifting that is backed by observational data on meander behavior gathered from many rivers worldwide. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research is tested in the paper and shown to provide realistic results that demonstrate the important influence vegetation dynamics can have on meander growth and channel migration. However, the method was not tested against field or flume data. |
| 5. Has the research been validated by others?<br>The paper has been cited 11 times, mainly in Europe. The research has been found applicable to helping explain channel migration in meandering streams and the anabranches of braided rivers. |
| 6. What are the strengths of the research?<br>The strength of this research is that it establishes unequivocally that vegetation growth and decay interact with fluvial processes in meandering rivers to strongly influence rates, spatial distributions and temporal distributions of channel migration. It further demonstrates that reliable predictions of channel migration are only possible when the influence of vegetation dynamics is taken into account. The significance is that vegetation can no longer be ignored or treated as a passive attribute of the riparian zone when assessing channel migration hazards at bridges. |
| 7. What are the limitations of the research?<br>The main limitation is that the complexity of the models, heavy data requirements and the need for advanced modeling expertise currently preclude practical application of the method. Secondly, the fluvial model uses a linear theory (which is known to be an inadequate representation of meander behavior). Thirdly, the models fail to account for changes in river width, the variation of flow resistance with vegetation density, and the influence of woody debris entering the stream due to bank retreat. |
| 8. Conclusion<br>Recommended. This research should be cited in a revised HEC-20. It should be considered for further research to better account for the influence of vegetation dynamics on channel migration in meandering and braided streams. |

| 5.6 Hooke 2004<br>Cutoffs galore!: occurrence and causes of multiple cutoffs on a meandering river |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. This research represents an advance over current methods used to predict the probability that channel migration in a meandering stream will cause a hazard to bridge safety. This is because it identifies that the well recognized risks associated long periods of incremental growth in bend amplitude and downstream migration of bends may be interspersed with shorter periods of sinuosity reduction and channel realignment through multiple bend cutoffs that change the planform pattern, orientation and position of the channel. |
| 2. Is the research of practical use or could it be made practical?<br>Yes: Level 1 now, Level 2/3 with development. Qualitative use of the research reported in this paper is possible now. Further, the underpinning principle that the behavior of meandering rivers may be predicted on the basis that they are self-organized, dynamical systems could be developed into a practical, quantitative tool for predicting probability that a hazard to a bridge might occur due to rapid and abrupt lateral migration in a meandering river associated with the occurrence of a cluster of bend cutoffs. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is based on the theory of self-organized criticality reported by Stolum (1996 and 1998) coupled with long-term empirical observations on the River Bollin, UK. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research was tested by the author on the Rivers Bolin and Dane in the United Kingdom. |
| 5. Has the research been validated by others?<br>Yes. This paper has been cited 11 times in the context of studies of channel migration and channel management in meandering rivers in Europe, North and South America. Stolum's underlying theory has been cited nearly 100 times and is widely applied. |
| 6. What are the strengths of the research?<br>The main strength of this research is that it is based on a theory that is increasingly accepted in fluvial geomorphology, coupled with well documented evidence obtained from a long-term study of an actual meandering stream. The contribution that the research makes lies in its identification that the probability of occurrence of a cluster of cutoffs (resulting in lateral migration and/or realignment of the channel that may pose a hazard to a bridge) might be predictable based on the pre-existing sinuosity of the channel relative to a critical value for planform instability. |
| 7. What are the limitations of the research?<br>The main limitation of the research is that the critical value for planform instability is poorly defined. A maximum value of 3.14 is suggested for unconstrained meandering rivers and it is indicated that this value decreases with the degree of meander confinement due to limited width of the channel migration zone. However, to be generally applicable, the relationship between critical sinuosity and degree of confinement would have to be better defined based on further research at well documented sites on meandering rivers in a range of physiographic regions. |
| 8. Conclusion<br>Recommended. This research should be cited in any revised HEC-20. It should be considered for further research to better define the critical sinuosity for the possible occurrence of multiple cutoffs in meandering streams. |

| 5.20 Brummer et al., 2006<br>Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA |
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| 1. Does the research relate to the current state of practice?<br>Yes, advancement. This research represents an advance because current practice recognizes the wood-related risk to bridge stability and conveyance capacity associated with partial or complete blockage, but does not explicitly account for increased risk of channel migration through avulsions generated by logjams in the channel upstream of the bridge. |
| 2. Is the research of practical use or could it be made practical?<br>The research is of immediate practical use as part of Level 1, qualitative assessment of wood and logjam-related risks. It could also support Level 2 assessment based on rules of thumb for the influence of logjams on the width of the Channel Migration Zone (CMZ) presented in the paper. The modeling approach presented in the paper could be used to make quantitative estimates of wood and logjam related risks of channel avulsion in a Level 3 analysis. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>The research is founded on channel roughness and backwater curve analyses that represent established theories of flow resistance in open channel flow. |
| 4. Has the research been tested by the original researcher?<br>Yes. The researchers tested their approach at 11 locations in the Pacific Northwest. |
| 5. Has the research been validated by others?<br>Yes. The paper is cited 9 times on Google Scholar with the research being applied in river restoration schemes in the Pacific Northwest and Australia. |
| 6. What are the strengths of the research?<br>The strength of this research is its clear demonstration that the addition or removal of large wood has marked impacts on avulsive channel migration. Adding wood increases geomorphic risks at bridges associated with aggradation, avulsion and widening of the Channel Migration Zone (CMZ). Wood removal adds to risks associated with degradation. The paper presents Level 1 or 2 rules of thumb in both cases: wood addition may raise bed level and CMZ elevation by twice the diameter of the key log in a logjam; wood removal may induce up to 2 m of degradation. The numerical analyses presented in the paper could be used at Level 3 where risks justified detailed analyses. |
| 7. What are the limitations of the research?<br>The geographical scope of the study is limited to the Pacific Northwest and the findings may not be simply transferrable to other physiographic regions of the USA. The models used are quasi-steady and do not account for the geomorphic impacts of rapidly varying flow in flashy streams. |
| 8. Conclusion<br>Recommended for mention in an updated HEC-20 and immediate incorporation into Level 1 and 2 analyses based on stream reconnaissance and identification of possible impacts of logjams based on rules of thumb presented in the paper. Further research recommended to develop a robust Level 3 modeling capability for impacts of large wood and logjams on potential for channel degradation/aggradation, migration and the maximum width of the CMZ. |

| 9.2 Odgaard, 2008<br>Stability Analysis in Stream Restoration |
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| 1. Does the research relate to the current state of practice?<br>No. This research uses perturbation analysis to develop simple curves indicating stable meander wavelength as a function of sediment Froude number, width-depth ratio and friction factor. This approach is not currently used in practice with respect to the analysis of risks associated with channel migration at bridges. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, at Level 2 or 3. The approach presented requires little input data and could be applied to the analysis of problems caused by channel migration due to meander dynamics in the vicinity of bridges. It is a good alternative to trying to identify a 'reference reach' for re-alignment of the channel to reduce the hazard, and is far less demanding than morphological modeling. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is founded on perturbation theory, which is well established. However, there is only limited empirical evidence to support the theory. |
| 4. Has the research been tested by the original researcher?<br>Yes. The applicability and utility of the method is demonstrated through two case studies, one in the USA and one in Egypt. |
| 5. Has the research been validated by others?<br>Cited by 1 in Google Scholar. |
| 6. What are the strengths of the research?<br>The strength is that this research provides a scientifically-based alternative to use of a 'reference' reach when re-aligning a problematic channel to reduce the hazards associated with channel migration. |
| 7. What are the limitations of the research?<br>The limitation of the research is that the design method has not yet been tested or applied by practitioners. Also, the approach is too new to have been proven through post-project appraisal of the success of re-alignments based on it in reducing channel migration rates and associated problems. |
| 8. Conclusion<br>Recommended. This research has the potential to provide an intermediate level (Level 2) approach to designing re-alignments of meandering rivers to reduce the risk to bridges associated with channel migration. However, further testing is required to establish the practical utility and reliability of perturbation stability analysis as a design tool for practical application. |

| 10.2 Odgaard and Abed, 2007<br>River Meandering and Channel Stability |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. This book chapter presents a concise overview of channel instability in straight rivers and channel migration in meandering rivers. It does not present any new research, but usefully synthesizes existing knowledge and reports a range of analytical approaches to modeling and predicting channel migration in single-thread rivers. Some older methods of predicting instability associated with meandering-braiding transitions are also presented. The chapter also covers structural measure to reduce channel migration, emphasizing the use of 'Iowa Vanes' as an approach to bank stabilization at bends. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The analytical techniques reported in this chapter could be used in Level 3 investigations of hazards at bridges associated with bend growth and downstream migration in meandering rivers. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The authors cover multiple theories of flow hydraulics and channel migration in meandering rivers. They also cite the sources of empirical evidence on the characteristic morphologies and morphological behaviors of meandering rivers. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research reported in this chapter has been extensively tested by the authors over their careers. |
| 5. Has the research been validated by others?<br>The research reported in this chapter has been the subject of testing by multiple investigators over decades. However, no consensus has emerged to date concerning which is the best practical approach to explaining and predicting channel migration in meandering rivers. Cited by 3 in Google Scholar. |
| 6. What are the strengths of the research?<br>The strength of this chapter is that it presents a concise review of theory and modeling practice in the analysis of river meandering and channel migration. |
| 7. What are the limitations of the research?<br>The limitation of this chapter is that it is not inclusive. This is acknowledged by the authors. Coverage focuses mainly on theories, analyses and stabilization measures (e.g., Iowa Vanes) with which the authors are particularly associated. |
| 8. Conclusion<br>Recommended. This chapter provides a useful and update overview of river meandering and channel migration that should be cited in HEC-20. However, it should be set alongside coverage of other approaches that are not included in this review for completeness. |

### Channel Widening

| 3.18 Melville and Coleman, 2000<br>Bridge Scour (especially, Section 4.8.6) |
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| 1. Does the research relate to the current state of practice?<br>Yes. The book does not report any original research on channel widening but does present several methods that can be used in practice and represent advances over methods currently in use in the USA. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, it could be at Levels 2 or 3. The book reports that the models of Osman and Thorne (1988), Thorne and Osman (1988), Simon (1995) and Simon and Darby (1997) can be used to predict widening triggered by degradation in unstable streams with cohesive banks. While these models have been superseded academically by more advanced versions incorporating layered soils, vegetation effects and the effects of pore water pressure or suction. The point is that widening due to mass instability of the banks can and should be taken into account when assessing geomorphic hazards at bridges. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research reported is based on established theories of bank erosion, bank failure (geotechnical) and channel evolution in unstable, degrading streams, backed by empirical observations from both sand and gravel-bed rivers in different regions of the USA. |
| 4. Has the research been tested by the original researcher?<br>The original researchers tested their models through applications to flume and field datasets. |
| 5. Has the research been validated by others?<br>Yes. The source references used in the book have been widely cited, with the research being positively commented upon in most independent tests. However, it should be noted that weaknesses in the 1990s techniques have been identified and addressed in subsequent research published in the 2000s. |
| 6. What are the strengths of the research?<br>The strength of the research reported in this book is that it has been specifically selected by the authors as being suitable for assessing the likelihood, rate and hazards to bridges associated with widening in unstable streams. |
| 7. What are the limitations of the research?<br>The limitations stem from the limited testing of the some of the methods reported in the book and the fact that others have been superseded by subsequent development published after 2000. |
| 8. Conclusion<br>Not recommended. The commentary on widening processes is useful and the techniques for estimating and/or modeling channel widening reported in this book should be mentioned in an updated version of HEC-20. However, the particular models mentioned here have been superseded by later versions such as the ARS bank stability model and CONCEPTS. |

| 5.2 Faustini et al., 2009<br>Downstream variation in bankfull width of wadeable streams across the conterminous United States |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. The use of downstream hydraulic geometry relationships to predict stable width in alluvial channels is well established in practice, but this paper reports some recent, original research findings for 9 aggregate ecoregions covering all of the conterminous USA. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The research could be used immediately for Level 2 analysis of the likelihood of a geomorphic hazard occurring at a bridge due to channel widening in streams with widths between 1 and 75 meters and drainage areas between 1 and 10,000 $km^2$. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>The theory behind downstream hydraulic geometry analysis is long established and this research uses the large and reliable EPA National Wadeable Streams Assessment database including 1,588 sites nationwide. |
| 4. Has the research been tested by the original researcher?<br>Yes. The statistical strengths of the various regression relationships developed for channel width are tested by the researchers. |
| 5. Has the research been validated by others?<br>The paper was published in 2009 and so it is too new to have been widely cited, criticized or tested yet. |
| 6. What are the strengths of the research?<br>The academic strengths stem from the very large, national database on channel widths and drainage areas that underpins this research and the detailed statistical treatments performed to produce the regression relationships. The practical strengths rest on the ease of application of the relationships, which allow estimates of the expected width to be made on the basis of knowledge of only the drainage area and bed material type (gravel or sand) at the study site. |
| 7. What are the limitations of the research?<br>The utility of the research is limited by the weakness of the regression relationships for several ecoregions and associated high uncertainties in expected widths. Also, the relationships are inapplicable to large rivers (wider than 75 meters or with drainage areas greater than 10,000 $km^2$). Finally, the impacts of anthropogenic activities in the watershed are poorly explained in several ecoregions and further research is needed on this topic. |
| 8. Conclusion<br>Recommended. The relationships developed in this research should be added to the guidance on the estimation of expected width at bridge crossings in small to medium sized rivers based on drainage area and other pertinent parameters such as mean annual precipitation, elevation, channel slope and human disturbance. Consideration should be given to further research to improve the reliability and applicability of the downstream hydraulic geometry relationships reported in this research. |

| 5.29 Eaton and Millar, 2004<br>Optimal alluvial channel width under a bank stability constraint |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. Rational regime methods are commonly used to predict stable width in alluvial streams. This research illustrates the importance of taking bank stability into account when applying a rational regime approach based on the extremal hypothesis that channels adjust their width to achieve Maximum sediment Transport Capacity (MTC). |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The results of this research could be used at Level 2 to make first order estimates of the stable width for a stream in the vicinity of a bridge crossing based on the discharge, slope and median bed material size. Where the actual width is different to the expected width, this may be used a diagnostic of the likely trend and magnitude of width adjustment. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes, though the extremal hypotheses that streams adjust their form to reach a condition of MTC is not universally accepted. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research is tested using the Hey and Thorne (1986) data set for UK gravel-bed rivers. |
| 5. Has the research been validated by others?<br>The research has been cited 10 times in Google Scholar, but there is no clear evidence that the rational regime approach that applies a bank stability constraint has been independently validated. |
| 6. What are the strengths of the research?<br>The strength of the research lies in the way that it demonstrates the importance of considering bank stability when applying regime-type analyses to estimate the optimal width in alluvial channels. |
| 7. What are the limitations of the research?<br>The limitation of the research is the fact that many practitioners reject the use of extremal hypotheses in the prediction of stable channel form. Also, testing of the method is limited to a single data set for British gravel-bed rivers. |
| 8. Conclusion<br>Not recommended. Other than demonstrating the importance of bank stability to the stable form of alluvial rivers, this research adds little to the capability of practitioners to evaluate the risks to bridges that are associated with channel widening. |

| 5.38 Mount et al., 2003<br>Estimation of error in bankfull width comparisons from temporally sequenced raw and corrected aerial photographs |
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| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. The research highlights the errors involved in deriving changes in bankfull width from sequential aerial photographs. It presents a simple approach to estimating image-to-image errors and suggests ways of reducing these errors through rectifying the aerial photographs. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The research could be used immediately in Level 2 and 3 analyses of historical changes in channel width based on interpretation of sequential aerial photographs. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is based on sound photogrammetric theory. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research was tested for the Afon Trannon in Wales, UK, using a data set of 285 bankfull width measurements. |
| 5. Has the research been validated by others?<br>The research has been cited 10 times in Google Scholar and the content of the papers and reports citing the research suggest that it has been taken up and used in Europe and elsewhere. |
| 6. What are the strengths of the research?<br>The strength of this research lies in its provision of a simple method to assess the errors involved in estimating widening rates from historical sequences of aerial photographs. Practioners often fail to consider or report the error margins on their estimates of bankfull width and this reduces the validity of their evaluation of risks to bridges associated with channel widening. |
| 7. What are the limitations of the research?<br>The limitations of this paper stem from the fact that application of the error estimation method requires some practitioner training in photogrammetry and the lack of widespread up take and validation of the method in the USA. |
| 8. Conclusion<br>Recommended. Whenever historical aerial photographs are used to estimate changes in bankfull width and, hence, rates of widening, the results should routinely be accompanied by estimates of the likely error bands based on application of the simple method presented in this research. |

| 5.46 Bledsoe and Watson, 2001<br>Logistic analysis of channel pattern thresholds: meandering, braiding, and incising |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes, advancement. Threshold diagrams (for example: Leopold and Wolman, 1957; Lane, 1957; van den Berg 1995) are widely used in practice to predict stable channel planform and the propensity for channel instability (in the form of a sudden change in planform pattern). The logistic regression techniques applied in this research provide a significantly improved basis for such predictions. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The table and graphs provided could be practically applied now at Level 2. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes, the research is founded on application of a sound statistical theory to a large (270 case) data set drawn from rivers and stream around the world. |
| 4. Has the research been tested by the original researcher?<br>Yes. The success of the logistic regression is tested in terms of the percentage of correct versus mis-classifications for the 270 case dataset. |
| 5. Has the research been validated by others?<br>The paper has been cited 39 times in Google Scholar, the majority of these citations indicating application of the research in river management and restoration projects. However, the theoretical basis for the research and the practical reliability of its predictions has also been challenged (Lewin and Brewer, 2003). |
| 6. What are the strengths of the research?<br>The main strength lies in the relatively high predictive capacities of the statistical models for stability versus instability in sand and gravel-bed rivers and the fact that these predictions are require only basic data on discharge, slope and bed material size. |
| 7. What are the limitations of the research?<br>The statistical treatment has no causal basis – it cannot explain why a stream is stable or unstable and the influences of sediment supply and bank erosion resistance are not accounted for. There is also the possibility that streams that plot in the stable zones of the diagrams will still exhibit degradation or widening. |
| 8. Conclusion<br>Recommended. This research provides significantly more reliable predictions of stable planform type and the likelihood of channel instability through incision, widening or braiding than older, deterministic methods based on discharge, slope and bed material size. It should be applied in preference to older methods, while bearing in mind that it is not 100% reliable. |

| 5.48 Lewin and Brewer, 2001<br>Predicting Channel Patterns<br>Incorporates Discussion by van den Berg and Bledsoe (5.40) and Reply by Lewin and Brewer (5.37) |
|---|
| 1. Does the research relate to the current state of practice?<br>No. The analyses presented in this paper are not customarily included in channel pattern prediction methods used in current practice. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The message that caution should be exercised when making Level 2 predictions of planform stability and response based on simple measures of discharge, slope and bed material grain size. It can and should be incorporated into Level 2 practical guidance concerning the assessment of geomorphic hazards at bridges associated with channel pattern change. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is based on established theories regarding flow, sediment and channel dynamics in alluvial streams, coupled with analysis of a large, dataset from rivers world-wide. |
| 4. Has the research been tested by the original researcher?<br>Yes. The research is tested in the original paper and the reply to discussion. |
| 5. Has the research been validated by others?<br>The paper has been cited 19 times. The research was reviewed and commented on by van den Berg and Bledsoe, who validated the analyses and many of the conclusions. |
| 6. What are the strengths of the research?<br>The strength lies in the message this research sends practitioners to avoid putting too much faith in simple predictors of channel planform type, stability and vulnerability to change. The paper does not dismiss planform prediction diagrams outright, but points out that they may be expected to mis-classify channels about 10 to 15% of the time and should not be used in isolation or where the consequences of with mis-classifying a channel are severe. |
| 7. What are the limitations of the research?<br>The limitation of the research is that it does not provide any improvement in the capability for simple prediction of planform patter or stability. It merely points out problems with existing methods. |
| 8. Conclusion<br>Recommended. The criticisms leveled by the authors should accompany all references to planform prediction in the revised HEC-20 and the cautionary messages regarding the reliability of predictions and risk of mis-classification should be mentioned in Level 2 guidance on channel planform analysis. |

| 5.49 Simpson and Smith, 2001<br>The braided Milk River, northern Montana, fails the Leopold-Wolman discharge-gradient test |
|---|
| 1. Does the research relate to the current state of practice?<br>No. This paper presents a case study that demonstrates the fallibility of a well established planform prediction technique that is in wide practical usage. |
| 2. Is the research of practical use or could it be made practical?<br>The research could serve immediately as a cautionary tale for practitioners who lack the experience to realize that predictions of planform pattern, stability and change based on simple indices of discharge, slope and bed material size are subject to uncertainty. This message should accompany all Level 2 guidance on planform prediction and planform stability assessment around bridges. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The research is based on an extensive observations and data collected from the Milk River, Montana. |
| 4. Has the research been tested by the original researcher?<br>Not applicable. |
| 5. Has the research been validated by others?<br>The paper has only been cited 9 times in Google Scholar and there is limited evidence that its basis has been validated by others. |
| 6. What are the strengths of the research?<br>The strength lies the research's clear demonstration of the limited capacity of simple planform analysis methods to predict the occurrence of a braided reach in an otherwise meandering river. The paper illustrates that other variables – such as bank material erodibility, are important and should be taken into account when assessing the risks associated with channel migration and widening around bridges. |
| 7. What are the limitations of the research?<br>The research concerns a single study river in the vicinity of a major impoundment and thus there is no guarantee that its findings are generally applicable to other rivers and reaches that are not affected by impoundments. |
| 8. Conclusion<br>Not recommended. This paper delivers the message concerning the limited ability of a simple planform predictor. However, it is based on a single case study. It might be referenced in an updated HEC-20, but has little further to add to the analysis of risks associated with channel planform change and lateral migration. |

| 7.17 Beeson and Doyle, 1995<br>Comparison of bank erosion at vegetated and non-vegetated channel bends |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes, but advancement. This case study clearly demonstrates the effect that shrubs and trees at the outer banks of meander bends can have in reducing bank erosion during flood events. The stabilizing effect of vegetation is already known to many practitioners, but the evidence provided by the research adds weight to the argument that riparian vegetation significantly reduces rates of channel widening and channel migration in small to medium sized, meandering streams. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. The results of this case study could be provided in the relevant guidance literature to assist practitioners in making Level 1 assessments of the likelihood that channel widening or migration will pose a hazard to a bridge, based on the presence or absence of bank vegetation along a meandering stream. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The case study is consistent with theoretical research on the impacts of vegetation on bank erodibility and mass stability. The empirical data base of vegetation effects on bank retreat includes data for 748 separate bends on four rivers in Canada. |
| 4. Has the research been tested by the original researcher?<br>Yes. The researchers test the significance of their results using a chi-squared test. |
| 5. Has the research been validated by others?<br>This research is widely cited (72 times to date) and quoted, especially in papers related to the effects of riparian vegetation on channel widening and migration. |
| 6. What are the strengths of the research?<br>The strength of this research is that it is a case study based on directly observed bank retreat that occurred during high flow events on four Canadian rivers in 1990. The research documents that erosion was five times more likely at un-vegetated bends as it was at vegetated bends and it shows that 34 of 35 bends that experienced severe bank retreat (greater than 45 meters) were unvegetated. |
| 7. What are the limitations of the research?<br>The limitation of the research is that it is based on just four, medium sized rivers in British Columbia and so the findings may not be representative of other rivers of different sizes, with different types of vegetation or in different ecoregions. |
| 8. Conclusion<br>Recommended. This case study should be quoted in an updated HEC-20 to assist practitioners in making Level 1 evaluations of the risk to a bridge associated with channel widening and/or lateral migration at bends in meandering rivers based on the presence or absence of bank and riparian vegetation along the outer margin of the bend. |

| 8.13 March et al., 1993<br>Application of bank stability analysis in Long Creek, MS, Compendium of ASCE Papers (1991-1998) |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. This article developed an approach to check bank stability with respect to mass failure. Channel width adjustment is often caused by bank retreat triggered by mass instability. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level-2. The approach in this study is of practical use. The limiting stability curves were developed by comparing existing bank height/angle combinations with predicted failure bank height/angle combinations. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. This article studied two primary failure modes: slab failure and rotational failure. According to Thorne (1988), bank angles greater than 60 degrees tend towards slab failure, while bank angles less than 55 degrees tend towards rotational failure. |
| 4. Has the research been tested by the original researcher?<br>Yes. The bank stability analysis was tested against field observations on Long Creek in northern Mississippi. |
| 5. Has the research been cited by others?<br>Google Scholar could not find any citations. |
| 6. What are the strengths of the research?<br>The simple approach about bank stability analysis is a template for how the risks associated with bank failure and retreat around bridges might be assessed. |
| 7. What are the limitations of the research?<br>The article did not provide detailed information (e.g., equations) how the limiting stability curves were derived. The approach requires field and laboratory tests to get bank material physical properties. |
| 8. Conclusion<br>Not recommended. Had the procedure to develop limiting stability curves was provided, this may have been recommended. |

| 10.1 ASCE TC, 2006<br>Streambank erosion and river width adjustment, Sedimentation Engineering, Chapter 7 |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. This chapter introduces fluvial processes and bank mechanics involved in river width adjustment, evaluates methods for predicting equilibrium river width, describes a field-based approach and twelve quantitative models for assessing channel width adjustment, and identify research needs. |
| 2. Is the research of practical use or could it be made practical?<br>Yes. In this chapter, the Channel Evolution Model/Chanel Stability Diagram has been included in HEC-20 as a Level 2 analysis. Numerical Width Adjustment Models were also a Level 3 analysis in HEC-20.<br>This chapter also proposed a detailed procedure for approaching width adjustment problems faced by engineering practitioners. The procedure consists of eight steps, including reconnaissance (Level 1), application of empirical channel response model (Level 2), and application of numerical models (Level 3). |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The conceptual Channel Evolution Models of Harvey and Watson (1986), Thorne and Osman (1988), and Simon and Hupp (1992) were all based on the channel evolution sequence of Schumm et al. (1984).<br>The Channel Stability Diagram, another view of the channel evolution sequence of Schumm et al. (1984), distinguishes different channel evolution stages in terms of two dimensionless stability numbers: a measure of bank stability and a measure of fluvial stability.<br>Numerical Width Adjustment Models simulate physical processes related to flow, sediment transport, and bank mechanics. Every model has its own overall representation of involved processes. |
| 4. Has the research been tested by the original researcher?<br>The Channel Evolution Model has been widely applied by engineering practitioners.<br>Most Numerical Width Adjustment Models mentioned in the chapter were tested against laboratory and/or field data. |
| 5. Has the research been cited by others?<br>Cited by 4 in Google Scholar. |
| 6. What are the strengths of the research?<br>The Channel Evolution Models were updated due to a deeper understanding of watershed and channel dynamics.<br>The Channel Stability Diagram uses two measures (bank stability and fluvial stability) to identify channel evolution stages.<br>Numerical Width Adjustment Models were improved adequately to make some acceptable predictions of width adjustments.<br>The proposed procedure to handle width adjustment problems is reasonable. |
| 7. What are the limitations of the research?<br>At present very few appropriate laboratory and field data sets are found to be suitable for testing Numerical Width Adjustment Models.<br>No universal Width Adjustment Model exists that is applicable to all the circumstances. |
| 8. Conclusion<br>Recommended. The proposed procedure for approaching width adjustment problems is of practical use. |

## Sediment Dynamics

| 3.9 Doyle et al., 2007<br>Channel-forming discharge, Journal of Hydraulic Engineering |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. Channel-forming discharge is an event with a certain magnitude that is closely related to alluvial channels in equilibrium. This concept was widely applied in engineering practice, especially in river restoration design. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level-2. This study defined the effective discharge and proposed its use in river restoration design. The method to calculate the effective discharge is practical, although the estimate of the effective discharge is data intensive. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. In this study, a cumulative sediment discharge curve was developed from flow records and sediment transport equations. The effective discharge was defined as the discharge above which 75% sediment is moved. |
| 4. Has the research been tested by the original researcher?<br>Yes. The statistical analysis was performed in four river reaches representing variable hydrologic and geomorphic conditions. |
| 5. Has the research been cited by others?<br>Cited by 16 in Google Scholar. |
| 6. What are the strengths of the research?<br>The article emphasized that the use of a recurrence interval or bankfull discharge may only be applicable for generally stable channels. |
| 7. What are the limitations of the research?<br>The definition of effective discharge is subjective. It is required to justify the use of 75% of sediment moved. Multiple discharges (not just the effective discharge) might be used for different purposes in stream restoration. |
| 8. Conclusion<br>Recommended, this subject is included in HEC-20 and the added information can be useful. |

| 3.22 Karim, 1999<br>Bed configuration and hydraulic resistance, Journal of Hydraulic Engineering |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. Channel bed form geometry plays an important role in determining flow resistance and water level during floods. It is related to the interaction between the flow and the erodible channel bed through sediment transport. |
| 2. Is the research of practical use or could it be made practical?<br>No, but it is practical for use in the estimation of contraction scour and the design of countermeasures. Bed-form geometry is also dependent upon individual floods. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The article proposed a new method to predict relative bed-form height *h/d* in sand-bed flows. The development of the new method was based on the concept of estimating the energy loss due to form drag on bed forms from the consideration of head loss across a sudden expansion in open channel flows. |
| 4. Has the research been tested by the original researcher?<br>Yes. The relation about bed-from geometry was applied to a large number of laboratory and river data. |
| 5. Has the research been cited by others?<br>Cited by 24 in Google Scholar. |
| 6. What are the strengths of the research?<br>The proposed method was found to give better agreement with the observed bed-form heights for the 14 datasets. |
| 7. What are the limitations of the research?<br>The prediction of relative bed-form height is dependent upon improved formulations of two parameters: energy loss coefficient and relative bed-form length. |
| 8. Conclusion<br>Not recommended for HEC-20, as it is not closely related to changes in channel morphology. However, this information should be considered for HEC-18. |

| 3.30 Julien & Klassen, 1995<br>Sand-dune geometry, Journal of Hydraulic Engineering |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. Channel bed form geometry plays an important role in determining flow resistance and water level during floods. It is related to the interaction between the flow and the erodible channel bed through sediment transport. |
| 2. Is the research of practical use or could it be made practical?<br>No, but it is practical for use in the estimation of contraction scour and the design of countermeasures. Bed-form geometry is also dependent upon individual floods. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The article extends the applicability of van Rijn's method to predict dune height and dune length in larger rivers during floods. The analysis was based on bed-form data during larger floods on the Meuse River and the Rhine River branches. |
| 4. Has the research been tested by the original researcher?<br>Yes. The extended method was applied in the Meuse River and the Rhine River branches. |
| 5. Has the research been cited by others?<br>Cited by 51 in Google Scholar. |
| 6. What are the strengths of the research?<br>The study found that both dune height and length generally increases with discharge while dune steepness remains relatively constant during large floods. |
| 7. What are the limitations of the research?<br>The approximation of dune height and length is empirical. |
| 8. Conclusion<br>Not recommended for HEC-20, as it is not closely related to changes in channel morphology. However, this information should be considered for HEC-18. |

| 11.1 Rosgen (WARSSS)<br>Watershed Assessment of River Stability and Sediment Supply (WARSSS) |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. WARSSS is a tool to assess sediment problems within rivers and to address landscape and channel sensitivity and response to flood events. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level 1 or Level 2. WARSSS is of practical use, as it is a technical procedure that involves multiple steps including reconnaissance, screening, and prediction. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. WARSSS Step 1 – Reconnaissance Level Assessment locates potentially important problem areas based on topographic maps, aerial photos, land use maps, and soil maps.<br>WARSSS Step 2 – Screening Level Assessment uses a risk rating system to rate factors related to hillslope processes, hydrologic processes, and channel processes, and to screen out areas with low sediment yield. The purpose of this step is to identify areas with high risk associated with sediment or river stability problems.<br>WARSSS Step 3 – Prediction Level Assessment utilizes "reference condition" that represents stable natural land or stream systems to compare direction, rate, nature, and extent of departure from natural rates of sediment or natural stability. |
| 4. Has the research been tested by the original researcher?<br>Yes. WARSSS was applied in Wolf Creek in Colorado, Horseshoe Run and Sand Fork Run in West Virginia. |
| 5. Has the research been cited by others?<br>Cited by 3 in Google Scholar. WARSSS has been adopted by EPA. |
| 6. What are the strengths of the research?<br>The procedure involves most factors that control watershed processes, and is easy to follow. |
| 7. What are the limitations of the research?<br>The final stage of WARSSS might recommend a sediment transport model due to the complex channel response. Care must be taken when using a reference condition. |
| 8. Conclusion<br>Recommended, probably with some revisions related to stream stability. |

## Numerical Modeling

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|---|
| 3.2 Langendoen et al., 2009<br>Model incision and widening with calibration, Journal of Hydraulic Engineering |
| 1. Does the research relate to the current state of practice?<br>Yes. The computer model, **Con**servational **C**hannel **E**volution and **P**ollutant **T**ransport **S**ystem (CONCEPTS), can satisfactorily predict different stages of channel evolution, bed elevation change, and channel width change. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level-3. But the model application requires a detailed characterization of the stream reach. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. CONCEPTS is a physically based model, which simulates 1D hydraulic flow and most bank failure mechanisms. It considers noncohesive or cohesive bed-material, and multi-layer stream banks. |
| 4. Has the research been tested by the original researcher?<br>CONCEPTS was tested against laboratory experiments and observed channel adjustment of two incised streams in northern Mississippi. |
| 5. Has the research been cited by others?<br>Cited by 16 in Google Scholar. |
| 6. What are the strengths of the research?<br>CONCEPTS is able to simulate channel width adjustment by incorporating fundamental physical processes responsible for bank retreat. |
| 7. What are the limitations of the research?<br>CONCEPTS assumes one-dimensional, gradually-varying flow, thus it does not simulate secondary flow. It is truly valid only for straight channels or channels of very low sinuosity. |
| 8. Conclusion<br>Recommended for inclusion in HEC-20 as a reference for a Level 3 approach for detailed analysis of channel evolution. The limitations of CONCEPTS should be included. |

| 3.7 Papanicolaou et al., 2008<br>Sediment transport modeling review, Journal of Hydraulic Engineering |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. The article reviews a list of current representative hydrodynamic/sediment transport models (1D, 2D, and 3D). |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level 3. It is a good reference about model application, strengths, and limitations. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The authors compared 1D, 2D, and 3D models in terms of hydraulic processes, sediment transport processes, and numerical treatments, etc. |
| 4. Has the research been tested by the original researcher?<br>Yes. The article provided some brief information about calibration and verification for some models. |
| 5. Has the research been cited by others?<br>Cited by 6 in Google Scholar. |
| 6. What are the strengths of the research?<br>The article provides review comments for most available sediment transport models, and some insights about model application, strengths, and limitations. |
| 7. What are the limitations of the research?<br>To engineering practitioners, the review may be abstract about modeling and numerical computation. |
| 8. Conclusion<br>Recommended for inclusion in HEC-20 as a reference source. |

| 3.20 Jia and Wang, 2000<br>2D hydrodynamic and sediment transport model, Journal of Hydraulic Engineering |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. The 2D hydrodynamic and sediment transport model, CCHE2D, is able to simulate morphological change processes of alluvial streams. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level 3. The model application requires a lot of training and experience as the model is two-dimensional and utilizes the finite element method. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. CCHE2D is a physically based model, which simulates unsteady turbulent open channel flow and sediment transport including bed load and suspended sediment. The model considers the effects of transverse bed slope and the secondary flow in curved channels. |
| 4. Has the research been tested by the original researcher?<br>Yes. CCHE2D was tested against one experiment channel and one natural channel. |
| 5. Has the research been cited by others?<br>Cited by 36 in Google Scholar. |
| 6. What are the strengths of the research?<br>CCHE2D can predict channel migration as the secondary flow is simulated. |
| 7. What are the limitations of the research?<br>CCHE2D uses near bank shear stress to compute bank toe and surface erosion with the secondary flow effects. It does not consider most bank failure mechanisms. |
| 8. Conclusion<br>Recommended as a source reference in HEC-20 as CCHE2D is capable of simulating channel migration. The model's limitations should be mentioned. |

| 5.11 Bransiton & Richardson, 2007<br>Overview of geomorphical modeling, Geomorphology |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. The article includes some thoughts and discussions about the development and application of Reduced-Complexity Models (RCM, geomorphic models). |
| 2. Is the research of practical use or could it be made practical?<br>No, it is not practical for reach-scale channel migration. Most models in this study are landscape evolution models that deal with watershed processes – hydrologic and geomorphic processes. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. RCMs described in the article are physically-based. |
| 4. Has the research been tested by the original researcher?<br>Yes. The article provides some brief information about calibration of RCMs. |
| 5. Has the research been cited by others?<br>Cited by 5 in Google Scholar. |
| 6. What are the strengths of the research?<br>The article presented the theme of RCM and the concept of "intermediate time and space scales," and provides some comments on future research needs about geomorphical modeling. |
| 7. What are the limitations of the research?<br>The article focuses on river basin changes, not on channel morphology. |
| 8. Conclusion<br>Not recommended, but should be revisited in Task 5. |

| 10.4 Thomas & Chang, 2006<br>1D model of sedimentation processes, Sedimentation Engineering, Chapter 14 |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. This chapter introduces a systematic procedure for applying one-dimensional (1D) computational sedimentation models to the study of alluvial rivers. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level 3. This chapter could serve as a reference source for 1D sediment transport modeling, which addresses issues involved in sedimentation and channel morphology step by step. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. The procedure presented here includes the identification of river morphology equations, the classification of independent variables and dependent variables, the selection of physical models versus computation models, the collection of channel morphological data, sediment data, and hydrologic data, the calibration of computational models, the interpretation of modeling results, the illustration of an example application, and a list of available computational models. |
| 4. Has the research been tested by the original researcher?<br>Yes. The authors summarized this valuable procedure, based on their experiences related to the application of computational sedimentation models. |
| 5. Has the research been cited by others?<br>Cited by 4 in Google Scholar. |
| 6. What are the strengths of the research?<br>The procedure summarized by the authors provides insights and lessons about 1D computational sedimentation models for engineering practitioners. |
| 7. What are the limitations of the research?<br>The procedure for applying 1D computational sedimentation models is descriptive and lengthy. It could be improved by including some flowcharts and tables. |
| 8. Conclusion<br>Recommended for inclusion in HEC-20 as a reference. This chapter is a comprehensive reference source for 1D computational sedimentation models. |

| 10.5 Spasojevic & Holly, 2006<br>2D and 3D models of mobile-bed hydrohynamics and sedimentation, Sedimentation Engineering, Chapter 15 |
|---|
| 1. Does the research relate to the current state of practice?<br>Yes. This chapter presents a framework for understanding the conceptual bases of multidimensional models, alternative mathematical representations of relevant physical processes, alternative computational grid representations and their associated approximate numerical solution methods, and a sense of what can go wrong. |
| 2. Is the research of practical use or could it be made practical?<br>Yes, Level 3. This chapter is also a good reference source, as it provides a comprehensive view of multidimensional numerical hydrodynamics and sedimentation models. However, the reader was assumed to have a solid background in computational fluid dynamics and numerical computation. Therefore, the application of multi-dimensional sedimentation models requires training and experiences. |
| 3. Is the research founded on sound scientific theory or substantial empirical evidence?<br>Yes. In this chapter, the authors presented multidimensional hydrodynamics/ sedimentation modeling in a logic way. They (1) described typical problems that require multidimensional sedimentation modeling, (2) summarized mathematical bases for multidimensional hydrodynamics models, (3) overviewed treatments of flow-sediment interaction, (4) provided details about modeling near-bed sediment processes and suspended sediment, and the exchange between the two, (5) introduced empirical closure relations in modeling systems and numerical solution issues, (6) talked about data collection and model calibration, and (7) provided limited examples of multidimensional modeling. |
| 4. Has the research been tested by the original researcher?<br>Yes. This chapter provides three examples for the application of multidimensional numerical hydrodynamics/sedimentation modeling, where modeling results were compared with measured field data. |
| 5. Has the research been cited by others?<br>Cited by 4 in Google Scholar. |
| 6. What are the strengths of the research?<br>In this chapter, the authors gave a clear introduction of the complicated numerical modeling of hydrodynamics and sedimentation that is useful background knowledge for potential modelers, and presented three examples that engineering practitioners can refer to easily. |
| 7. What are the limitations of the research?<br>The authors did not include bank mechanics, which is an important part of changes in channel morphology. |
| 8. Conclusion<br>Recommended for inclusion in HEC-20 as a reference for multidimensional numerical hydrodynamics/sedimentation modeling. |

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# APPENDIX D

## Research Statements

# IMPACTS OF RIVER BASIN MODIFICATION AND CLIMATE CHANGE ON BRIDGE SAFETY

## Background

Engineering analyses of risks associated with channel changes at bridge crossings, although imperfect, have advanced to the stage that reliable predictions can be made for years or decades in advance. Predictions are based on established relationships linking channel changes (degradation, aggradation, lateral migration, widening, and planform change) to fluvial processes (flow hydraulics, sediment transport, bank erosion), bed and bank properties (bed particle size distribution, bank materials strength, vegetation) and morphology (channel cross-section geometry, slope and planform), coupled with knowledge of current and historical behavior of the river around the bridge crossing. Predictions made using such process-form relationships and local histories are reliable provided that the river's flow and sediment regimes, and especially the magnitudes and frequencies of flood events, are not changing.

However, as population densities increase and use of natural resources changes or intensifies in many basins, the impacts of agriculture, forestry, quarrying/mining, gravel extraction, dam construction and removal, river training, removal of riparian vegetation, construction and urbanization are likely to have increasingly adverse effects on bridge safety throughout affected watersheds. The effects of river basin modification and climate change relevant to bridges include channel degradation or aggradation, widening, regime change from meandering to braiding, increased rates of channel shifting, proclivity for bar formation and increased supply of debris.

Similarly, if watershed climate changes, this directly affects precipitation volumes and distributions leading to further direct and indirect impacts on channel stability via changes in runoff, natural vegetation, land-use and sediment yields. While the natural and anthropogenic causes of global warming are disputed, pronounced trends of sea level rise and unprecedented rainfall intensities recorded in recent storms in the USA suggest that climate may be changing globally and regionally. Although uncertainty clouds the issue of climate change, the implications for basin-scale channel instability, with adverse impacts to bridge safety regionally and nationally, are sufficiently serious that research is now critical.

Bridge engineers need tools to assess the sensitivity to disturbance of US river systems and identify the vulnerability of bridges in sensitive watershed to changes in flow regime and catchment sediment supply associated with catchment modification or climate change. The need for bridge replacement or remedial work to counter the effects of basin modification or climate change can then be evaluated and incorporated into planning. In some cases this information may be used to influence a proposed basin modifying activity through, for example, an environmental impact statement. Since the changes considered here are basin-wide, more than a single bridge is at stake. Economies of scale result if replacement programs or countermeasures are planned and prioritized for the affected basin rather than on an individual bridge basis.

## Objective

The objective of the proposed research is distillation of available literature and guidance on how to assess river sensitivity to basin modification and climate change, in the context of known hydrological and geomorphic processes and responses. Only fluvial process-response mechanisms likely to adversely affect bridges would be considered. The study would primarily be qualitative, but with as much quantification as the generality of the topic allows. Outcomes should include recommended strategies for identifying and responding to bridge problems likely to be induced by basin modification and climate change, based on risk assessment and leading to prioritized, basin-scale programs for bridge replacement or countermeasures to ensure that future risks are kept down to acceptable levels.

**Tasks**

1. Conduct a review of the relevant literature to identify methods and techniques suitable for characterising the sensitivity of a given river system (based on the geology, soils, topography, geometry, scale, hydrology, geomorphology, drainage pattern and development in its watershed) to changes in the hydrologic regime, the sediment regime or both.
2. Conduct a review of the relevant literature linking basin modification and climate change to changes in hydrologic and sediment regimes.
3. Use the results of (1) and (2) first, to develop a practical approach to predicting the types of channel change likely to adversely affect bridges (e.g. degradation, aggradation, lateral migration, widening, narrowing or planform change) that are expected to occur in response to basin modification or climate change and, second, to derive a practical approach to estimating the rate and spatial distribution of channel response throughout the fluvial system.
4. Modify existing engineering analyses of the risks associated with channel changes at bridge crossings so that they can be used to estimate how these risks would be expected to change in response to basin modification or regional climate change.
5. Based on the results of (4), recommend bridge replacement or remedial works necessary to counter the effects of basin modification or climate change.
6. Perform example applications of the risk analyses for selected watersheds in different climatic and physiographic regions to demonstrate the practical utility of the approaches developed in the project.

**Special Note**

Uncertainties associated with possible basin modifications, changes to climate, and river response to disturbance are high. Consequently, the analyses and tools developed in this project must be capable of dealing with uncertainty efficiently through, for example, use of reduced complexity models that can account for ranges of input variables and which can explore several possible modification/climate change scenarios, to produce probabilistic predictions for future geomorphic risks to bridges.

**Estimated Cost and Project Duration**

Cost - $400,000
Duration - 24 months

## PREDICTION OF HEADCUT MIGRATION AND SCOUR AT BRIDGES

### Background

Headcuts, also known as nickpoints, are erosional features where an abrupt drop occurs in the stream bed elevation. The drop can be vertical, near vertical, or steep (nickzone) in homogeneous materials and overhanging when weaker layers are overlain by a more erosion resistant layer. Headcuts can resemble small waterfalls when water is flowing over them and a plunge pool often forms at the base when the drop is at or near vertical. The channel not only degrades due to headcut formation, but may also widen significantly if bed lowering destabilizes the channel banks, both of which threaten the stability of bridges. Headcuts often result from base level lowering that generates one or more headcuts that migrate upstream through the drainage network. As a headcut moves upstream along the main stem, the base level of tributary channels is also lowered (rejuvenation), which consequently threatens structures along these channels as well. Headcuts increase the chance of bridge failure due to scour, degradation and channel widening and have contributed to past bridge failures such as the I-5 failure over Arroyo Pasajero, California in 1995.

### Objective

Four interrelated, stream stability and scour processes related to headcuts determine the risk to bridges along the affected stream: (1) plunge pool depth (2) overall amount of long-term bed degradation, (3) triggering of channel widening and (4) rate of upstream headcut migration. The objective of this research is to develop practically applicable predictive equations for each of these processes. The research will include a review of the literature, laboratory studies, and other information related to each of the headcut processes listed above plus evaluation of hydraulic design, scour performance, and morphological relationships for engineered grade control and drop structures that can be used to stabilize aggressive headcuts. Data should be obtained for a variety of field conditions for development and testing of generalized, predictive relationships. These data should include: current and historical channel hydraulics, bed material properties and morphologies, and headcut geometries, scour, and rates of migration.

### Tasks

1. Compile a bibliography of the research literature on the processes that create headcuts and nickzones, the characteristics of headcut/nickzone migration, and the potential hazards to bridges.
2. Critically review the compiled research literature and identify those applicable to bridges.
3. It is anticipated that additional investigation may be required through controlled laboratory experiments coupled with numerical modeling using Computation Fluid Dynamics (CFD).
4. Develop criteria for identifying conditions conducive to the development of headcuts and nickzones.
5. Provide guidance on incorporating headcut/nickzone processes and impacts into the design of bridge and highway facilities.
6. Identify potential countermeasures (e.g., grade control and drop structures) for incorporation into the design of bridges that may be impacted by headcuts and nickzones.

### Estimated Cost and Project Duration

Cost - $500,000
Duration – 36 months

## BRIDGE CROSSINGS ON ACTIVE ALLUVIAL FANS

### Background

Alluvial fans are fan-shaped landforms created by the distribution of significant volumes of sediment by confined and unconfined flow moving from higher to lower elevations. Alluvial fans are common throughout the western continental United States and Alaska. They are found predominantly in or along mountainous regions where flash floods, heavy precipitation, geology, and active tectonics play an important role in their development. Problems associated with active alluvial fans include flooding (sheet flow and uncertain flow paths), localized aggradation and degradation, channel shifts (avulsions), landslides and debris flows, and other hazards that have long-ranging consequences for bridge crossings. Because alluvial fans are constructed by the successive episodic and unpredictable shifting of stream flows or the successive passage of debris (colluvial) flows down different routes, alluvial fans are inherently unstable environments for bridges. However, alluvial fans have become popular places for urban development and in mountainous regions they are often the only feasible location for the placement of bridge crossings. For example, it is estimated that approximately 30% of the population of the Southwest United States lives on alluvial fans. The growth of urban development onto alluvial fans in recent years has been particularly rapid in areas such as southern California and the Phoenix and Tucson areas in Arizona. Therefore, the design of bridge crossings and roadways must consider the inherent long-term instability of such sites.

### Objective

The purpose of the proposed project is the development of a manual that outlines the general characteristics of an alluvial fan, discusses active alluvial fan processes in detail, and provides guidance on incorporating alluvial fan processes and impacts in the bridge design. A brief search of Google Scholar reveals that a wealth of relevant data and information (more than 15,000 references) has been published in the last 20 years with regard to alluvial fans and fan processes. This project will consist of an analysis and distillation of the available data and information and the preparation of a manual similar to HEC-20, but specifically tailored to bridge crossings on active alluvial fans. Given the wealth of data and information that is available on this subject, it is anticipated that no independent numerical, experimental, or field work will be needed. It is anticipated that no independent numerical, experimental, or field work will be needed.

### Tasks

1. Compile a bibliography of the research literature on the characteristics of alluvial fans, active alluvial fan processes, and countermeasures to alluvial fan hazards.
2. Critically review the compiled research literature and identify those applicable to bridges and highway structures on active alluvial fans.
3. Develop criteria for identifying alluvial fan hazards.
4. Provide guidance on incorporating alluvial fan processes and impacts into the design of bridge and highway facilities on alluvial fans.
5. Identify potential countermeasures for incorporation into the design of bridge and highway facilities that cross alluvial fans.

**Special Note**

A number of Federal, State, and County agencies and foreign countries have compiled detailed methodologies for dealing with active alluvial fans. A literature search should also be conducted of these sources as well. For example, state and county agencies in Arizona, Nevada, and California have developed criteria and methodologies for urban development in active alluvial fans.

**Estimated Cost and Project Duration**

Cost - $300,000
Duration - 24 months

## COUPLING ADVANCED NUMERICAL MODELING WITH SEDIMENT TRANSPORT AND BANK MECHANICS IN BRIDGE REACHES – AGGRADATION, DEGRADATION, CONTRACTION SCOUR, AND CHANNEL WIDENING

### Background

Natural channels not only change their depth through degradation or aggradation, but also change their width through channel widening, channel narrowing, or channel migration. Channel widening is a common response to channel bed degradation or aggradation, while lateral channel migration is a progressive change in the position of a stream that occurs in both vertically stable and unstable channels. Local, and in some cases extreme, channel widening can occur within the bridge opening due to contraction scour. Both channel widening and lateral channel migration can cause bridge problems such as poor flow alignment, abutment outflanking or destabilization, and scour at piers not designed to be in the main channel.

Contraction scour is primarily caused by flow acceleration and increased shear stress and sediment transport capacity in the contracted opening at bridges. The empirical equations for calculating contraction scour are mainly based on sediment transport theory and initiation of motion, so a significant uncertainty is associated with the prediction of contraction scour depth. A numerical model that simulates changes in both bed elevation and channel width would provide better predictions of contraction scour.

Numerical models for predicting channel degradation/aggradation usually assume no changes in channel width or make not-physically-based adjustments in channel width. Numerical models for predicting channel widening and lateral channel migration are not well developed, because the simulation of changes in channel width faces two major hurdles: one is bank failure mechanisms that are dependent upon hydraulic conditions (erosion), bank geometry, bank materials, and vegetation (geotechnical stability); the other is lateral channel migration that requires a two-dimensional (even three-dimensional) hydraulic model capable of representing secondary flow within meandering channels. In order to generate a realistic distribution of boundary shear stress, and properly model complex bank failure mechanisms, a two-dimensional flow and sediment transport model coupled with an advanced bank stability analysis is actually necessary.

### Objectives

The objectives of this research are to select a well-known two-dimensional flow and sediment transport model, and extend the model by adding a module that realistically simulates potential bank failure mechanisms. The proposed modeling research will provide insights into contraction scour and channel changes in both depth and width.

### Tasks

1. Compile a bibliography of the research literature on advanced flow and sediment transport modeling and bank failure mechanisms.
2. Develop a list of criteria to select an advanced flow and sediment transport model.
3. Critically review the complied research literature and select the model based on the criteria.
4. Develop a work plan for the development of the improved model to determine the functionality of the module that simulates bank failure mechanisms, the coupling scheme, and the testing of the improved model with lab or field data, etc.

5. Create the module for bank failure mechanisms in the coding level and add it to the model.
6. Test the improved model.

**Estimated Cost and Project Duration**

Cost - $600,000
Duration - 30 months

## IMPACTS OF VEGETATION RESTORATION, REHABILITATION AND STABILIZATION ON CHANNEL STABILITY IN BRIDGE REACHES

### Background

Research in river mechanics and fluvial geomorphology has recently established that vegetation exerts much stronger influences on channel forms and processes than was previously thought. For example; rates of bank erosion and lateral channel shifting are significantly lower along rivers flowing through mature, riparian corridors than where native vegetation has been removed from the banks, patterns of vegetation on floodplains have been shown to materially alter channel planform patterns and their evolution, and the presence of large woody debris has been found to limit degradation in incised channels.

Further evidence of the profound impacts of vegetation are significant changes in channel form observed where invasive species have colonized aquatic and riparian areas. These findings come at a time when vegetation, both living and dead, is being increasingly reintroduced to channels in river restoration, rehabilitation and stabilization projects.

Despite this new knowledge and growing trends for re-introduction of vegetation to managed rivers, relatively little is known concerning how vegetation of different types (grasses, shrubs, trees) located in different zones of the river (aquatic, riparian and floodplain) physically interact with bank stability and the fluvial processes of sediment scour, transport and deposition that are responsible for channel migration and change in the vicinity of bridges.

This makes it difficult to assess the risks associated with vegetation succession and management (clearance, cutting or re-introduction as part of river restoration) in the channel upstream of and around bridge crossings. To address this gap in knowledge, research is required to establish causal links between vegetation and fluvial processes at the site and reach scales, and the resulting impacts of geomorphic risks at bridges.

### Objectives

The objective of this research would be to establish causal links between vegetation, fluvial processes and channel stability in bridge reaches and establish guidance for bridge engineers on likely channel response to vegetation removal, management or re-introduction. This should allow bridge engineers to assess the benefits and risks to bridges associated with vegetation and its management based on scientific and, wherever possible, quantitative relationships.

### Tasks

1. Given the large amount of new data and information on vegetation, fluvial processes, channel change, and bank stability that is available, it is anticipated that no independent numerical, experimental, or field work will be needed. Hence, the first task would be to conduct a critical review of recently published techniques for characterizing the impacts of aquatic and riparian vegetation on fluvial processes, channel forms and channel stability.
2. Assemble a number of case histories of bridges where problems related to channel instability or migration occurred following vegetation management (clearance, modification or reintroduction).

3. Develop tools for assessing benefits and risks related to the presence, removal, or re-introduction of aquatic and riparian vegetation (including any associated organic debris) in bridge reaches.
4. Use the tools developed in Task (3) to formulate generalized, rules-based guidance for assessing all vegetation-related risks and benefits to bridges.

**Estimated Cost and Project Duration**

Cost - $300,000
Duration – 24 months

## PERMITTING AND ASSOCIATED BRIDGE DESIGN REQUIREMENTS

### Background

State Departments of Transportation (DOT) have numerous hydraulic design standards for bridges over waterways. These include flow frequency, road overtopping, deck freeboard, abutment setback, scour event, and scour check flood. DOTs also have an obligation to meet regulatory requirements and obtain relevant permits and resource agency approvals for construction of bridges and countermeasures. These requirements address potential impacts on flood insurance, flood hazards, navigation, water quality, environmental protection, and protection of fish and wildlife. Agency involvement can include FHWA oversight, FEMA backwater and floodplain encroachment limits, local "no-rise" certification, local floodplain use permit, US Army Corps of Engineers (USACE) 404 permit, US Coast Guard (USCG) permit, and coordination and approvals from State environmental agencies, US Fish and Wildlife Service (USFWS), and National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. The permitting and approval process is often cited as a major impediment for efficient delivery of new bridges, bridge replacements, and countermeasures.

Bridge hydraulic design focuses on hydraulic efficiency, which often involves minimizing the bridge length while not causing excessive backwater, velocity, scour and erosion. Environmental agencies have additional concerns that include aquatic, riparian, and floodplain habitat, fish passage, and wildlife passage. This project will focus on meeting the environmental concerns related to bridge design with the goal of developing model agreements that can be tailored by individual DOTs in coordination with State environmental agencies, NOAA Fisheries, and USFWS. These agreements would establish additional performance criteria that, if met, would significantly streamline the agency approval process by directly addressing environmental concerns. The criteria may include minimum setback distances between abutments and channel banks, requirements for clear spanning certain channels, limits on the location and number of piers in channels, constraints on exposed riprap aprons, minimum deck clearance for wildlife passage, and limits on increased velocities and shear stresses for frequent (2- to 10-year recurrence interval) flood conditions.

An example of this type of agreement is the fluvial performance standard, which is part of the Oregon DOT (2005) OTIA III State Bridge Delivery Program Environmental Performance Standards. The fluvial performance standard is intended to allow normative physical processes within the stream-floodplain corridor that promote natural sediment transport, provide unaltered debris movement, and allow longitudinal continuity and connectivity of the stream and floodplain for fish and wildlife passage.

In addition to the benefits of streamlined permitting and reduced environmental impacts, there are other, long-term benefits that DOTs can expect from this research. These include bridges with (1) fewer debris problems, (2) reduced scour, (3) fewer stream instability problems, (4) reduced long-term maintenance, (5) extended service life, (6) fewer countermeasures, and (7) greater long-term resilience in the face of climate change..

### Objective

The primary objective of this research is to develop model guidelines and agreements that State Departments of Transportation (DOTs) can use to the streamline environmental permitting and approval process. The established standards negotiated between individual State DOTs and permitting agencies would provide a means for bridge designs to limit habitat and environmental impacts. This research would not establish standards, but would develop model standards that would serve as a rational basis of negotiation at the State level.

**Tasks**

1. Contact State DOTs, USFWS, and NOAA Fisheries at national and regional levels and State environmental agencies to develop a list of environmental concerns specifically related to bridge hydraulic design (length, location, foundation locations, countermeasures, clearance, etc.).
2. Categorize the concerns based on environmental impact, bridge component, and regional or physiographic tendencies.
3. Develop rational, process-based criteria for addressing the concerns.
4. Develop model standards that address these concerns. These standards can be adopted by DOTs or can serve as a starting point for individual DOTs to negotiate agreements for streamlining the permitting and approval process.

**Estimated Cost and Project Duration**

Cost - $300,000
Duration – 24 months

## BEND AND CONFLUENCE SCOUR NEAR BRIDGES

### Background

Bend and confluence scour are related phenomena, the first characteristic of meandering streams and the second characteristic of braided streams. Both are produced by secondary flow cells generated by streamline curvature. In meandering streams, the outside of bends tend to scour during floods and the inside fills. As a result, bed elevations on the outside of bends appear deceptively high during low flow. Bridges are commonly placed on the outside of bends, as this often allows for the anchoring of one end against a valley wall. Correct placement of pier footings and abutments is contingent upon the recognition of the amount of bend scour that might be expected during a flood.

While braided streams are less common than meandering streams in the continental USA, they can be found in the western part of the country and abound in Alaska. Confluence scour occurs where two anabranches of a braided stream flow together. Confluence scour can lead to flow depths as much as five times the ambient values in anabranches. Experience in New Zealand suggests that bridges on braided streams are most likely to fail when a confluence forms at a pier. Confluence scour of essentially the same type also occurs when a large tributary enters the main stem of a meandering or wandering river with a slowly changing planform.

While the effect of bend and confluence scour on bridges is well recognized in the technical literature, quantitative methods for predicting scour depths are provided in neither of the standard manuals HEC-18 and HEC-20 for bridge design. A concise design manual providing quantitative methods for evaluating bend and confluence scour at bridge crossings is needed.

### Objectives

The objective of this research project is to develop a brief manual containing methods for predicting bend and confluence scour at bridges. The manual should be a self-contained document that would provide sufficient information immediate use until the information can be incorporated into the applicable FHWA manual (HEC-18).

### Tasks

Task 1: Conduct an international literature search of:

- Field and experimental results on bend and confluence scour
- Effect of such scour on bridges
- Predictive relations for such scour

Task 2: Use the data base to test the various relations gleaned from the literature. Reduce the relations to a subset which can be used for reliable predictions near bridge crossings. Apply these relations to case histories which involve bridges

Task 3: Write a concise manual explaining the phenomena of bend and confluence scour and how they affect bridges. Provide quantitative methods for evaluating both types of scour and include several worked examples of their application to bridge problems.

Special Notes: No independent experimental or field work on bend and confluence scour is to be performed under the auspices of this project. The available data base is likely sufficient.

**Estimated Cost and Project Duration**

Cost - $200,000
Duration – 15 months

## ADVANCED MAPPING AND MONITORING TOOLS FOR BRIDGES

### Background

The bridge is subject to changing conditions of the bridge structure and changing stream conditions in the vicinity of the bridge. Bridge failure in the United States primarily results from (1) scour that usually occurs during extreme flood events and (2) stream instability that can cause problems at bridge foundations not only during floods, but also during normal flow conditions. Changing stream conditions, such as bank erosion, channel migration, and neck cutoffs, can greatly increase the threat to the foundations of piers and abutments.

Bridge inspection, an essential step for ensuring the safety of a bridge, is performed biennially or soon after a large flood event. The potential threats to a bridge are identified by comparing the existing stream conditions with pervious observations and d data. However, the normal bridge monitoring procedure is time-consuming, and the collected monitoring data is usually incomplete, qualitative, and subjective. As the normal monitoring data is low in frequency, it can easily miss incremental changes related to stream instability. Therefore, automated real-time bridge monitoring could be highly valuable, especially for scour-critical bridges over the channels with significant stream instability.

Advanced mapping and monitoring technologies have been widely applied in industrial development and academic research. In a digital mapping study sponsored by Iowa DOT, morphological features such as river bank positions and floodplain edges were identified on the ortho-rectified riverside images through an image processing algorithm, and flow velocity was calculated by applying Large Scale Particle Image Velocimetry (LSPIV) on image sequences on the river flow. More and more advanced mapping and monitoring technologies appear to be relatively inexpensive and practical tools for bridge risk assessment.

### Objectives

The objectives of this research are to evaluate available advanced mapping and monitoring methods, to adapt these methods to bridge monitoring, and prepare guidelines of standard procedures for the application of advanced mapping and monitoring tools in bridge risk assessment. It is anticipated that no independent numerical, experimental, or field work will be needed.

### Tasks

1. Compile a bibliography of the research literature on advanced mapping and monitoring technologies.
2. Critically review the compiled research literature and identify those applicable for bridges and streams.
3. Evaluate the applicability and feasibility of supporting equipment and software, such as the installation and maintenance of equipment and the selection of image processing software.
4. Determine the geomorphic and hydraulic conditions under which a bridge should be monitored with advanced tools.

### Estimated Cost and Project Duration

Cost - $250,000
Duration - 18 months