MULTI-SCALE GEOMORPHIC ASSESSMENT APPROACH FOR STREAMS IN THE SOUTHERN ILLINOIS REGION: CASE STUDY, BIG CREEK WATERSHED, PULASKI AND UNION COUNTIES, ILLINOIS

BY

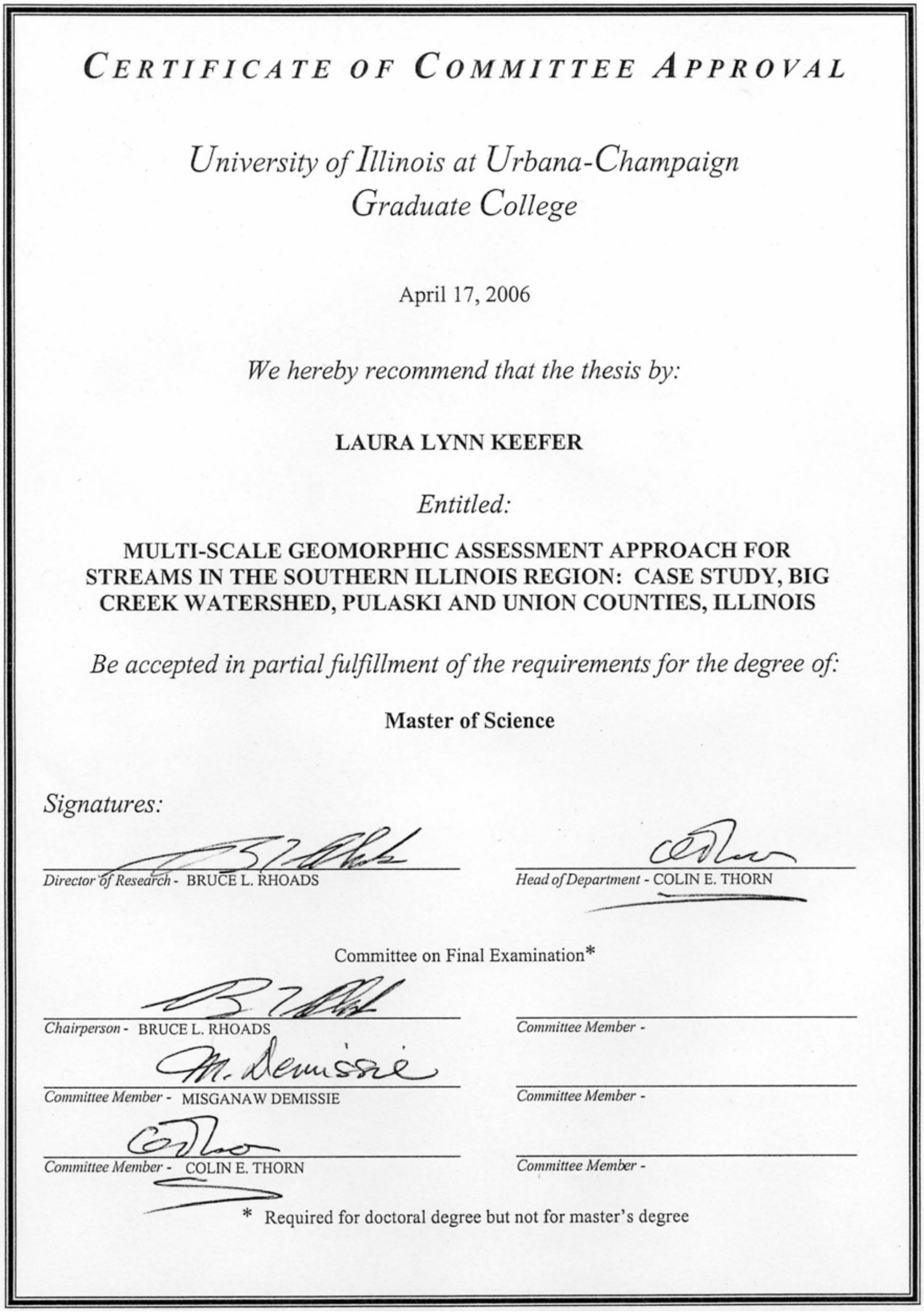
LAURA LYNN KEEFER

B.S., University of Illinois at Urbana-Champaign, 1990

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Geography
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2006

Urbana, Illinois



CERTIFICATE OF COMMITTEE APPROVAL

University of Illinois at Urbana-Champaign
Graduate College

April 17, 2006

We hereby recommend that the thesis by:

LAURA LYNN KEEFER

Entitled:

MULTI-SCALE GEOMORPHIC ASSESSMENT APPROACH FOR STREAMS IN THE SOUTHERN ILLINOIS REGION: CASE STUDY, BIG CREEK WATERSHED, PULASKI AND UNION COUNTIES, ILLINOIS

Be accepted in partial fulfillment of the requirements for the degree of:

Master of Science

Signatures:

Director of Research - BRUCE L. RHOADS

Head of Department - COLIN E. THORN

Committee on Final Examination*

Chairperson - BRUCE L. RHOADS

Committee Member -

M. Demissie
Committee Member - MISGANAW DEMISSIE

Committee Member -

Committee Member - COLIN E. THORN

Committee Member -

* Required for doctoral degree but not for master's degree

Abstract

Human alteration of stream channels and land use initiates responses in a fluvial system that can increase flooding, erosion, and sedimentation, which, in turn, impact aquatic habitat, property, and water quality. Geomorphic assessment approaches have been developed to evaluate channel response to disturbances for various regions of the United States and there is concern regarding the appropriateness of applying them in regions for which they were not developed, particularly Illinois. Channel responses to disturbances tend to be more subtle in Illinois as compared to the dramatic responses in the mountainous northwest, arid southwest, and coastal plains. Also, channel disturbance issues are complex and dynamic, consequently the evaluation of these issues requires extensive training and formal research experience. Due to pressure by policy makers and resource managers for rapid assessments and natural channel designs for stream restorations, some assessment approaches have been developed and applied by non-geomorphologists and extended beyond credible use. Lack of standardization between approaches has proven difficult to compare disturbance response mechanisms within and between physiographic regions, as well as establishing long-term research of these mechanisms.

A standardized, systematic geomorphic assessment approach for evaluating past conditions, extant character, and potential future adjustments of stream channels in Illinois was developed and evaluated. The methodology draws from components of approaches developed in the United States. The approach was applied to the Big Creek watershed in the Cache River Basin in the southern region of Illinois – a fluvial system that has been severely impacted both directly and indirectly by human activities.

The geomorphic assessment approach has three levels of investigation that incorporates temporal- and spatial-scale analysis, standardizes the systematic collection of data, compares and contrasts multiple lines of evidence to characterize the watershed and channels, and utilizes three approaches to evaluate prevailing channel process response mechanisms to infer potential future channel adjustments. Several components overcame inconsistent datasets found in Big Creek and integrated multi-scale information to infer future several channel adjustment processes. The results for the case study watershed, Big Creek, revealed that the complex geology and multiple human disturbances has produced four separate channel responses that will require separate, but integrated, attention of the watershed and channel reaches.

Dedication

This thesis is dedicated to my husband, Donald A. Keefer, and children, Ryan and Jenna. To Don, who without his support I would never have discovered my potential. To Ryan and Jenna, who have always known their mother to be in school, I hope I have been an example and inspiration so that one day they may discover their potential.

Acknowledgements

I would sincerely like to thank my advisor, Dr. Bruce L. Rhoads, for providing me the opportunity and freedom to discover a field of research that has helped me realize my career aspirations. His support and patience were heroic.

I would also like to thank my committee members Dr. Colin Thorn, UIUC-Department of Geography, and Dr. Misganaw Demissie, Illinois State Water Survey, for their thoughtful review of this thesis.

I am truly humbled by Mike Demissie's support and confidence in my abilities throughout my years at the Illinois State Water Survey. His continued support allowed me to expand our current research of Big Creek at the Illinois State Water Survey to include my thesis topic. His expertise in open-channel hydraulics was also valuable and illuminating.

There was a "cast of thousands" who significantly contributed to this research. Many thanks go to those who assisted me in the field: Rich Allgire, John Beardsley, Mark Guetersloh, Don Keefer, Dave Prosser, Dennis Sharp, and David Webber. I am grateful to the many landowners in Big Creek for allowing access to their property, as well as several local, state, and federal agencies for graciously providing data and information. I am particularly grateful to several colleagues for many discussions, as well as patiently elucidating concepts of flow frequency analysis, open-channel hydraulics, sediment transport, bank stability issues, channel evolution models, and dendro-geomorphology: David Crowder, Mike Demissie, Cliff Hupp, Vern Knapp, Yanqing Lian, and Andrew Simon. My warmest appreciation to Becky Howard and Patti Hill for their support and faith in me.

Many thanks go to a multitude of friends and colleagues for all their support. Finally, to my family, Harbison and Keefer, who gave me unwavering moral support and encouragement – my deepest gratitude to you all! I can finally give the answer everyone has been waiting to hear, “Yes … I’m done now”.

Table of Contents

List of Tables x
List of Figures xi
1. Introduction 1
  1.1. Direct and Indirect Effects of Humans on Stream Geomorphology 2
  1.2. Spatial Variability of Channel Response to Human Disturbance 4
  1.3. Geomorphic Assessment of Human Impacts on River Systems 7
  1.4. Physical Setting of Illinois in the Midwestern United States 8
  1.5. Objectives of Study 9
  1.6. Thesis Structure 11
2. Literature Review of Geomorphic Assessment Approaches 13
3. Multi-Scale Geomorphic Assessment Approach in Illinois Streams 25
  3.1. Watershed-Scale Characterization Method 28
    3.1.1. Watershed-Scale Characterization Data Sources 32
    3.1.2. Case Study Watershed: Big Creek 33
    3.1.3. Big Creek Case Study: Watershed-scale Characterization 38
      3.1.3.1. Historical Analysis – (1) Establish current physical character of watershed 38
      3.1.3.2. Historical Analysis – (2) Identify potential direct and indirect influences 41
      3.1.3.3. Historical Analysis – (3) Hydraulic and channel geometry (flow and sediment) 51
      3.1.3.4. Initial Field Survey – Document extant physical character of the stream channel 55
    3.1.4. Results of Watershed-Scale Characterization 61
    3.1.5. Discussion of Method 65
  3.2. Reach-Scale Characterization Method 68
    3.2.1. Reach-Scale Characterization Data Sources 76
    3.2.2. Big Creek Case Study: Reach-scale Characterization 77
    3.2.3. Results of Reach-Scale Characterization 83
    3.2.4. Discussion of Method 86
  3.3. Evaluation and Assessment Method 87
    3.3.1. Big Creek Case Study: Evaluation and Assessment 90
    3.3.2. Results of Evaluation and Assessment Method 98
    3.3.3. Discussion of Method 109
4. Conclusions 112
  4.1. Suggestions for Future Research 115
References 118

Appendix A Watershed-Scale Characterization Data Source Description 128
Appendix B Completed Channel-stability Index Sheet 135
Appendix C Spatial Distribution of Channel Stability Index Variables in Watershed 136
C-1 Percent bank stability (right bank/left bank) 137
C-2 Percent woody vegetative cover (right bank/left bank) 138
C-3 Primary bed material 139
C-4 Degree of floodplain separation (incision) 140
Appendix D Example of Completed Geomorphic Assessment Stream-Evaluation Data Sheet – Site BC-8 141

List of Tables

Table 3.1 Data types in historical analysis of watershed-scale characterization 29

Table 3.2 Drainage, flood, and water-level-control projects in the Cache River Basin....36

Table 3.3 Results of initial field survey 60

Table 3.4 Assessment of evaluation results 107

List of Figures

Figure 3.1 Channel-stability index sheet used in watershed-scale characterization, initial field survey component 31

Figure 3.2 Location of the Cache River and its major tributaries (Demissie et al., 2001) 34

Figure 3.3 Channel planforms for pre-1938, 1938, and 1998 43

Figure 3.4 Dam #3 –typical control structure installed in Big Creek during the 1930-40s: a) low flow [depth from top of wing-wall to crest is 3.66 m], b) high flow [note stream gage], and c) 5-yr flow overtopping structure 45

Figure 3.5 Annual precipitation and 10-year moving average of precipitation at Anna, Illinois (Demissie et al., 2001) 46

Figure 3.6 Annual temperature and 10-year moving average of temperature at Anna, Illinois...47

Figure 3.7 Area of selected crops harvested in Union and Pulaski Counties.............48

Figure 3.8 Big Creek channel profiles from pre-1938 to 2003 54

Figure 3.9 Examples of mass bank failures and large woody debris in middle reaches of Big Creek..56

Figure 3.10 Location of field sites...57

Figure 3.11 Spatial distribution of channel stability index score and stage of channel evolution 59

Figure 3.12 Geomorphic assessment stream-evaluation (GASE) data sheet used in reach-scale characterization...69

Figure 3.13 Upstream and downstream views from ISWS #500 for 1999 and 2003...79

Figure 3.14 Pre-channelization, channelization, and 2003 cross-sections and elevations for Sites BC-8, 10, and 17 82

Figure 3.15 Particle size distributions for bed, bank, and suspended sediment material 85

Figure 3.16 Change in channel morphology as a function of disturbed channel gradient and fluvial environment (Simon and Downs, 1995)....................90

Figure 3.17 Longitudinal profile of a) Big Creek and b) modeled reach......................93

Figure 3.18 Stream power for modeled reach (300 m moving average)......................94

Figure 3.19 Water surface profile for $Q_{1.5}$, Q_5, and Q_{10} 94

Figure 3.20 Comparison of planform between 1938, 1998, and 2004 imagery..........101

Figure 3.21 Hydraulic depth, width, and velocities for modeled reach 103

1. Introduction

Alteration of stream channels and land use initiates responses in a fluvial system that can increase flooding, erosion, and sedimentation, which, in turn, impact aquatic habitat, property, and water quality. Resource managers and policy makers require stream restoration techniques that ameliorate environment impacts through the implementation of natural channel designs, rather than typical ‘hard’ engineering approaches. To determine appropriate natural channel designs, there needs to be an understanding of fluvial processes and channel form relationships, as well as the magnitude and type of process responses due to disturbances in various physical/physiographic settings around the United States. Many geomorphic assessment approaches have been developed in various regions of the United States or United Kingdom and there is concern regarding the appropriateness of applying these approaches in regions for which they were not developed. Most approaches have been developed for regions where channel responses tend to be dynamic, such as the mountainous northwest, arid southwest, and coastal plains.

For the most part, it is generally accepted that channel disturbance issues are complex and dynamic, and that evaluation of these issues requires extensive training and formal research experience. Nevertheless, policy makers and resource managers demand rapid “cookbook” assessments, and natural channel designs with implementation times of conventional engineering projects (Kondolf, 1998, p. 41; Miller and Ritter, 1996, p. 298; Newson, 1995, p. 415). Such approaches have been developed by non-geomorphologists from basic principles of fluvial geomorphology and extended beyond credible use (Gillilan, 1996, p. 5; Juracek and Fitzpatrick, 2003, p. 668; Kondolf and Piegay, 2003, p.

3; Simon et al., 2005). Problems with some of these approaches include inability to reliably predict outcomes of implemented channel designs, reliance on template approaches (reference reach or analog) and empirically derived methods (Skidmore et al., 2001), reliance on experience of the observer (Johnson and Heil, 1996, p. 1289) and lack of investigation of the entire fluvial system to determine the influences that may have initiated channel adjustments (Brookes and Sear, 1996, p. 77; Callahan, 2001, p. 3; Newson, 1995, p. 419).

1.1 Direct and Indirect Effects of Humans on Stream Geomorphology

Natural stream channels are dynamic systems that adjust their form in response to direct and indirect changes in transport capacity and sediment supply. Alluvial channels transport material eroded from uplands and channel margins, and the form of the channel is a function of streamflow, sediment character, and channel material (Leopold, 1994). Channel responses to environmental influence are complex with channel form responding to the interaction of the flow and sediment, but changes in form, in turn, influencing the interaction between flow and sediment (Knighton, 1998). So many factors control process-response mechanisms in streams that, under constant environmental conditions, a channel can assume a variety of morphologic configurations (Leopold, 1994). Moreover, channel shape and planform can continually change nonlinearly over time even during periods of constant environmental conditions (Rhoads, 2003). For this reason a channel is considered in “dynamic equilibrium” or “stable” when changes in channel character are minimal over management time horizons, which for most purposes, is on the order of several decades (Thorne et al., 1996; Rhoads, 2003).

Channel process-response mechanisms are initiated through indirect changes in transport capacity and sediment supply. A reduction in sediment input often causes erosion of the channel perimeter to balance the sediment transport capacity. Channel geometry, slope, and planform will adjust to accommodate the net sediment deficit. Even when sediment inputs and outputs remain balanced, an increase in transport capacity can initiate increased bank erosion or channel instability. Changes in watershed-scale conditions that can affect transport capacity include: urbanization, conversion of land to agriculture, and clearing of riparian corridors. These tend to increase overland runoff and decrease hydraulic resistance of channels, thereby increasing velocities (stream power) within the stream and enhancing the capacity for the channel to erode its perimeter. The channel responds either by increasing lateral rates of migration or by incising into the alluvial material in which it has formed. Enhanced rates of bank erosion or the development and headward retreat of knickpoints on the channel bed are local indicators of system-wide change. Adjustments to accommodate indirect changes can propagate through a channel network until a relative balance in sediment flux is achieved.

Direct changes in a fluvial system also can initiate abrupt changes in transport capacity and sediment supply, which may induce time-dependent channel adjustments (Simon, 1994). Human influences are an example of direct and catastrophic change, such as channelization of rivers by straightening, dredging of channels for flood control, and improved urban or rural land drainage (Rhoads, 1995). The impacts of direct changes are similar to indirect ones, but involve local disruptions of fluvial processes that can result in severe “disequilibrium”. The reduction of channel length by straightening, considered the most severe type of direct change, often sets into motion channel responses upstream and downstream of the area of maximum disturbance (AMD). Immediately upstream of the AMD, where the channel deepens and widens, sediment quantity and character changes, while downstream of the AMD, the channel aggrades until a balance in transport capacity and sediment supply is restored (Simon, 1994; Simon and Downs, 1995). Undesirable side effects of this adjustment include degradation of habitat, loss of structures and property, and permanently altered hydraulic conditions.

1.2 Spatial Variability of Channel Response to Human Disturbance

The magnitude, type, and position of channel responses to disturbances in the fluvial network are variable throughout the United States. Studies in the mountainous Northwest (Oregon and Washington), the arid Southwest (Arizona), and the low-relief Midwest have documented various types of channel adjustments to disturbances (Barnard and Melhorn, 1982; Rhoads, 1990b; Whiting and Bradley, 1993; Rhoads and Herricks, 1996; Montgomery and Buffington, 1997; Rhoads and Urban, 1997; Simon and Rinaldi, 2000; Urban and Rhoads, 2003). Montgomery and Buffington (1997) and Whiting and Bradley (1993) both describe process domains in mountainous streams that transport sediment (colluvium or debris flows) supplied episodically from steep hillslopes. Downstream low-gradient, meandering alluvial channels respond to sediment inputs by forming braided channels (Montgomery and Buffington, 1997, p. 608). This classification scheme identifies domains in the drainage network based on the ratio between transport capacity and sediment supply. The episodic sediment inputs are indirect, natural disturbances; however, any changes in transport capacity or sediment supply due to development or insensitive logging practices can also exacerbate downstream sediment loading.

Rhoads (1990a) describes how increased transport capacity generated by channelization of Santa Rosa Wash in south-central Arizona resulted in bed degradation through migrating headcuts and subsequent channel widening. Fluvial adjustments in disturbed arid-region rivers are episodic with major headcut migration occurring only during floods, implying that channel recovery may occur over time scales of decades to centuries (Rhoads, 1990a). Accelerated channel degradation and widening due to human modification (channelization) have been reported in some portions of the loess area of the Midwestern United States. Simon and Rinaldi (2000) show that many channels in western and southern regions of the Midwest (western and southeastern Iowa, northeastern Kansas, and northwestern Missouri) have undergone four- to five-fold increases in channel depth and width through migrating headcuts. In western Tennessee and southeastern Nebraska many streams exhibit similar but less severe responses to channelization than those in western Iowa.

Aerial reconnaissance of streams in western Illinois and east-central Iowa (central Midwest region) suggests that channels are in a late stage of recovery compared to those in other regions due to the thickness of the loess cap, which is thinner in eastern Iowa and western Illinois than it is further to the west (Simon and Rinaldi, 2000). Channel incision in thin loess areas quickly reaches coarse underlying material, which initiates an initial phase of channel recovery characterized by downstream aggradation and reduction in bank heights (Simon and Rinaldi, 2000).

Natural meandering rates of low-energy streams in east-central Illinois are nearly imperceptible, whereas recovery rates following channelization either have been undetectable or have exceeded low natural rates of channel migration (Barnard and

Melhorn, 1982; Rhoads and Herricks, 1996; Rhoads and Urban, 1997; Landwehr and Rhoads, 2003; Rhoads, 2003; Urban and Rhoads, 2003). Unlike the dramatic increases in width and depth of channels in western and southeastern Iowa, northeastern Kansas, and northwestern Missouri, channels in eastern-Illinois respond mainly by forming mildly sinuous low flow channels within the trapezoidal ditches produced from channelization (Rhoads and Herricks, 1996). Barnard and Melhorn (1982) found similar responses in a west-central Indiana stream where considerable meander development took place immediately following channelization (1932) in higher gradient segments (0.0014 to 0.0027) and virtually no adjustments occurred in lower gradient segments (0.0010 to 0.0014). Based on stream power-to-sinuosity threshold analyses, Barnard and Melhorn (1982) estimated that recovery of a meandering planform may take as long as 165 years. As with the eastern-Illinois streams, in-channel bar development followed by increasing channel sinuosity seems to be the predominant form of channel adjustment.

Channel response to direct impacts is not only variable across the United States but can vary within a region or state, such as the Midwest and Illinois. Streams in the western and southern regions of the Midwest respond by incising and widening. The eastern region has lower stream power and responds by lateral migration with slow rates of recovery. The central region incises and widens to a lesser degree than the western region but also moves to later stages of recovery sooner due to the availability of coarse material below a thinner loess cap.

Studies by Barnard and Melhorn (1982), Rhoads and Herricks (1996), Urban and Rhoads (2003), and Simon and Rinaldi (2000) demonstrate the variability in channel responses within Illinois. The physical setting of Illinois streams presents striking contrasts to other Midwest (north-central) states. Generally, Illinois is more extensively glaciated, lower relief, and has the lowest mean elevation (Leighton et al., 1948, p. 16-17), which makes the whole-sale application of extant geomorphic assessment approaches debatable.

1.3 Geomorphic Assessment of Human Impacts on River Systems

Geomorphic assessment methods used to evaluate channel responses to human disturbance vary widely. In the mountains of the northwest United States, Montgomery and MacDonald (2002) describe a diagnostic approach to assess mountain stream channels. These channels are evaluated for temporal and spatial variability, historical conditions (using aerial photographs, engineering projects, and stream gage records), channel type or classification (Montgomery and Buffington, 1997), and changes in riparian and valley bottom vegetation. Field indicators for valley bottom and active channel characteristics, such as slope, valley confinement, channel entrenchment, riparian vegetation, overbank deposits, channel pattern, bank conditions, gravel bars, pool characteristics, and bed material are collected (Montgomery and MacDonald, 2002). In the arid Southwest, Rhoads (1990a and 1990b) used historical sources (General Land Office Survey records, U.S. Geological Survey topographic maps, aerial photographs, and historical flooding photographs), current channel cross-section surveys, floodplain and channel material particle-size analysis, current aerial photographs, flood survey reports, U.S. Geological Survey stream gaging records, and modeling. These data were used to establish type and rates of channel adjustments as well as the magnitude and frequency of fluvial processes. Simon and Rinaldi (2000) determined channel adjustment trends using historical bed-elevations, bank profiles, shear-strength tests, bed-material particle sizes, stages of channel evolution, and dendrochronologic evidence. They were able to take advantage of several prior technical studies in the region and supplement their analyses by collecting additional data during field reconnaissance trips. Geomorphic analyses in eastern Illinois by Rhoads and Herricks (1996) and Urban and Rhoads (2003) used GIS analysis of historical aerial photography to establish meander rates, one-dimensional hydraulic modeling, stream power analysis, and study of alternate bar formations. Barnard and Melhorn (1982) analyzed historical aerial photography, original engineering plans of the channelization projects, cross-section surveys, channel longitudinal profiles, bank material, evolution of channel bedform conceptual model, and stream power to sinuosity threshold analyses.

These studies all had similar objectives in that they sought to characterize the types, rates, and magnitudes of channel adjustment due to direct human modifications with the goal of providing geomorphic-process information for management strategies to ameliorate future channel responses. Each study, however, employed slightly different approaches of geomorphic evaluation. These differences were due to constraints in data availability, resources, as well as differences in goals related to the programmatic issues of the funding agent and participating researchers. More importantly, even though the goals of these studies were assumed to be accomplished, the lack of standardization in methods makes it difficult to compare results and to re-evaluate the study areas at a later time.

1.4 Physical Setting of Illinois in the Midwestern United States

The Midwest United States is broadly composed of five physiographic provinces: Superior Upland, Great Plains, Central Lowlands, Interior Highlands, and Coastal Plain.

Three of the provinces, Superior Upland, Great Plains, and Central Lowlands, have experienced glacial advances at one point or more. The states of Wisconsin and Illinois are unique in that “glacial lobes from both the east and west of Hudson Bay invaded them and attained the southernmost limit of continental glaciation in the northern hemisphere (Frye et al., 1965, p. 43)”. The current surficial deposits and materials in Midwest provinces vary in depositional processes, age, physical and chemical characteristics, and thicknesses, all of which determines distinct regional topography, landforms, and terrains (Fullerton et al., 2003). Because Illinois and Wisconsin experienced the greatest number of glacial advances, they also contain the most varied glacial deposits in the Midwest (Frye et al., 1965, p. 43). A mantle of loess (windblown silt) covers and obscures most of the surficial deposits and materials in the five provinces. There are variations in loess thickness and particle size distribution across the provinces. Loess tends to be thickest and coarsest (~30m) in eastern Nebraska and becomes thinner and finer downwind to the east and southeast toward Illinois, Indiana, Kentucky, Tennessee, and Mississippi (Kohfeld and Muhs, 2001; Lutenengger, 1987, p. 28; Ruhe, 1969, p. 33, 37; Shroba et al., 2001, p. 5).

1.5 Objectives of Study

The purpose this study is to develop an Illinois region-specific geomorphic assessment approach by adapting components and techniques from approaches developed in other geographic regions and in Illinois. Although many hydrologic, physical, and geomorphic data collection and analysis techniques (tools) are widely accepted as key elements for evaluating fluvial systems in geomorphic investigations (Kondolf and

Piegay, 2003, p. 5), the challenge is to appropriately apply these tools and interpret the resulting data for distinct physiographic settings.

Specific objectives of the study are to: 1) develop and evaluate a standardized, systematic geomorphic assessment methodology for evaluating past conditions, extant character and potential future adjustments of stream channels in Illinois and 2) apply this methodology using a case study in Big Creek in the southern part of Illinois – a fluvial system that has been severely impacted both directly and indirectly by human activities. This methodology development is a first step toward the evaluation of stream channels in other regions of Illinois that respond differently to disturbances.

The first objective is aimed at fulfilling the need for standardized protocols for geomorphologic evaluation of fluvial systems in Illinois recognizing distinct physiographic divisions and varied stream channel responses to disturbances. The development of standardized protocols is essential for several watershed-management initiatives in Illinois, including programs such as the Illinois River Ecosystem Restoration Framework (Illinois Department of Natural Resources, 2004). These protocols would also set the stage for post-project evaluations and long-term monitoring of potential future channel adjustments.

The second objective seeks to contribute to an improved understanding of channel adjustments in response to human activities within a geographic region of Illinois where such adjustments have not been studied extensively in a geomorphic context. Although Big Creek and its watershed have been influenced substantially by indirect effects (conversion of forest and wetlands to agricultural land) and by direct effects (straightening, dredging, channel diversions) since the late 19th century, the geomorphic response of the system to these effects has yet to be evaluated systematically. The results of the geomorphic assessment are two-fold. First, the development and performance of this method will contribute to an assessment tool that could be applied to watersheds in the southern Illinois region. Also, the results will provide resource managers in the Big Creek watershed with information that can be used to help achieve objectives and goals outlined in the Big Creek watershed restoration plan (Guetersloh, 2002).

1.6 Thesis Structure

This thesis is organized into four chapters: introduction, literature review, method development, and conclusions. Chapter 2 reviews popular geomorphic assessment approaches from around the United States and United Kingdom in the context of the physiographic and geographic setting for which they were developed. The strengths and weaknesses of these approaches as they relate to their relative applicability to Illinois are important to understand the rationale and development of this proposed approach. Chapter 3 presents the development of the proposed geomorphic assessment approach using the Big Creek watershed as a case study. The approach is comprised of three phases; therefore the chapter is divided into three sections. Each section will present the objective of each phase, rationale for utilization of components adapted from approaches discussed in Chapter 2, demonstrate the application of each component using data from Big Creek, and a discussion of assessment results and evaluates the performance of the geomorphic assessment approach. The final chapter contains conclusions about the performance of the approach through its ability to discover components of geomorphological significance when assessing fluvial systems for stream channel stability. The adaptability of this approach to other physiographic regions of Illinois will be suggested for future research.

2. Literature Review of Geomorphic Assessment Approaches

The initial paradigms for explaining landforms date back to the late-19th century with work by (Davis, 1899) and (Gilbert, 1877). The Davisian model, the geographic cycle or cycle of erosion, was heavily influenced by evolutionary theory and proposed that landscapes were formed by initial geological uplift followed by distinct stages of landscape forms produced in an orderly sequence (youth, maturity, and old age) (Rhoads and Thorn, 1996). The temporal and spatial scales addressed by this model were on the order of millennia and kilometers and lacked explanation of erosion and sedimentation physical processes at any scale (Church, 1996). Davis considered time as a principal variable in the development of landscapes with the effects of geology becoming less of a control as landscapes proceeded through a cycle (Osterkamp and Hupp, 1996; Ritter, 1978). Gilbert, on the other hand, believed that landforms reflected “an equality of action between process and geology” and that geology is always an important factor (Ritter, 1978; p. 7). Gilbert also recognized the need for theories to be mutually consistent at all scales, where spatial scales should match time scales of observable processes (Church, 1996). He relied heavily on background knowledge (physics and chemistry) as evidence to prove or disprove causal hypotheses (Rhoads and Thorn, 1996). Gilbert is credited with first proposing “dynamic equilibrium” (Osterkamp and Hupp, 1996) and his process-based approach has dominated the field of geomorphology for the last 50 years (Rhoads and Thorn, 1996).

Even though Gilbert introduced process-based observation in geomorphology before Davis, the Davisian “cycle of erosion” dominated the field until the mid-20th century when a shift to process-oriented approaches emerged in geomorphology as a ‘return to Gilbert’ (Rhoads and Thorn, 1996). Some of the key work came from Horton (1945), Strahler (1950), Leopold and Maddock (1953), Hack (1957, 1960), Leopold, Wolman, and Miller (1964), Schumm and Lichty (1965) where quantitative analyses of process and statistical descriptions of landscapes (Ritter, 1978), as well as, allometry, topology, and a variety of statistical techniques, emerged in the 1960s and 1970s which essentially replaced Davis’s cycles. Another important development that occurred with this shift to a process approach was an increasing emphasis on application of geomorphology to practical problems. Research began to focus on the responses of geomorphic systems to human influences. As environmental management of these systems, especially rivers, has become more popular within society, the need has arisen to employ geomorphological techniques to assess system dynamics for the purpose of management.

A search of literature on current approaches to the geomorphic assessment of rivers yielded many results (Brice, 1982; Schumm et al., 1984; Frissell et al., 1986; Simon, 1989; Trimble and Cooke, 1991; Bryan et al., 1995; Simon and Downs, 1995; Downs and Thorne, 1996; Kondolf and Downs, 1996; Thorne et al., 1996; Montgomery and Buffington, 1997; Federal Interagency Stream Restoration Working Group, 1998; Thorne, 1998; Johnson et al., 1999; Kuhnle and Simon, 2000; Rhoads, 2003; Trimble, 1998; Whiting and Bradley, 1993; Rosgen, 1994; Rosgen, 1996). Some techniques are used for overall system-wide analyses and others are strict classification schemes, processed-based analyses, or a combination of both. The main differences among these approaches are 1) temporal and spatial scales of application, 2) region of application, 3) objective of the approach, and 4) the perspective of the discipline that developed the approach. Key methods are discussed below to demonstrate the breadth of current geomorphic assessment approaches around the country.

Classification systems for mountainous streams have been developed by Whiting and Bradley (1993) and Montgomery and Buffington (1997). Both systems are process-based, recognizing hillslope and channel gradients, valley and channel depth and widths, and sediment size as primary factors in describing transport capacity and sediment discharge processes. The Whiting and Bradley (1993) scheme concentrates on classifying processes in upland headwater channels in mountain watersheds dominated by colluvial material. They refer to the classification scheme as ‘process domains’ divided into three characterizations, or panels, of primary factors. The first ‘panel’ classifies the relationship between channel gradient and hillslope stability into four process domains. One of these domains is differentiated into a second panel due to channels in this domain tending to have gradients insufficiently steep to transport debris flows produced by hillslopes prone to landslides. This second panel differentiates four process domains based on three parallel curves describing the relationship between channel and valley widths. The results of these two panels provide the first part of an alphanumeric code in this classification scheme. The third panel characterizes the relationship between median grain size and the product of channel slope and average channel (bankfull) depth, which roughly represents a Shields diagram. There are six domains where distinctions are based on Shields criterion, sediment size, armoring, and mode of grain movement either by saltation or suspension. The third panel provides the second part of the alphanumeric code. The code classifies channels by the potential of hillslopes to contribute material and the channel to transport the material downstream (Whiting and Bradley, 1993).

These domain codes essentially map the physical channel processes and their relative rates within a headwater fluvial system.

The classification of channel-reach morphology presented by Montgomery and Buffington (1997) covers the entire fluvial system in a mountain environment from the colluvial-material dominated, steep headwaters to low-gradient alluvial valleys and floodplains. Their scheme relates channel morphology with processes to predict channel responses to human and natural disturbances. The spatial linkages of these processes within a watershed assists in understanding current channel conditions, predict channel response to disturbances, and interpret the causes of historical channel changes (Montgomery and Buffington, 1997). Seven channel-reach types are presented based on three primary channel substrates: colluvium, bedrock, and alluvium (cascade, step pool, plane bed, pool riffle, and dune ripple). A downstream progression of these channel-reach types was observed which reflects a sequence of local factors that control channel slope, discharge, sediment supply, bedrock lithology, and disturbance history (Montgomery and Buffington, 1997). A general trend was observed between sediment supply and transport capacity to drainage area for the five alluvial channel-reach types. Transport capacity and sediment supply have an inverse relationship, as drainage area increases; transport capacity decreases while sediment supply increases. The authors also describe a continuum between colluvial, alluvial, and bedrock valley segments where colluvial valleys are transport limited, due to high hillslope to channel coupling that allows debris to accumulate in the valley bottoms, and bedrock valley segments are supply limited, due to increased slopes and shear stresses. Channel-reach types in alluvial valley segments take on broad ranges of transport capacity and sediment supply ratios relative to weaker hillslope to channel coupling. These are illustrated in bed morphologies reflecting roughness configurations that dissipate energy (Montgomery and Buffington, 1997; p. 606). These relationships define process-linkage characterizations that can be used to understand channel responses to natural and human disturbances.

A river classification system by Rosgen (1994, 1996) includes a four level hierarchy of river inventory and assessment. This system is based on fluvial-geomorphic principles developed in Leopold et al., 1964). Stream pattern morphology is related to eight hydrologic and morphologic variables. The first level broadly characterizes a stream into one of eight stream types based on valley morphology and channel relief, pattern, shape and dimension. Level II is the most data intensive and further delineates stream types using direct field measurements of channel patterns, entrenchment ratio, width/depth ratio, sinuosity, channel material, and slope. The third level describes the existing conditions, or “state”, that influence channel responses. This level also provides methodologies to predict channel responses by determining the departure from reference stream conditions. The fourth level is a verification of Level III by directly measuring reach-specific information on channel processes and evaluating the effectiveness of installed restoration practices.

The Rosgen scheme has been the subject of much criticism based on its tendency for geomorphic convergence, uncertain applicability across physical environments (Juracek and Fitzpatrick, 2003), reliance on template (reference reach or analog) and empirically derived methods (Skidmore et al., 2001), and lack of investigation of the entire fluvial system to determine the influences that may have initiated channel adjustments (Brookes and Sear, 1996; Callahan, 2001; Newson, 1995).

Trimble and Cooke (1991) and Trimble (1998) outline the value of historical resources in geomorphologic research in the United States. They argue that it is not possible to comprehend how current processes developed without an appreciation of the past. The resources they describe are: travel and exploration accounts, newspapers and journals, instrumented land surveys, topographic surveys, geology, soil, soil erosion surveys, aerial photographs, ground-based landscape photography, land-use statistics, drainage and irrigation records, climatological records, and stream and sediment discharge records. Many of these sources are valuable in establishing sediment degradation/aggradation rates when contrasted with similar current data and provide insight into the human impacts on channel adjustment process over historical periods of time. Historical analysis also aids in the understanding the dynamics of geomorphic processes, thereby enhancing the ability to predict channel response with and without engineering. (Trimble, 1998)

An approach for evaluating potential instability in streams on a watershed-scale was developed by Simon and Downs (1995). This approach is an extension of a study that evaluated potential bridge scour in West Tennessee (Simon et al., 1989). It has been used extensively by the USGS in the Rocky Mountains, Great Plains, Valley and Ridge, Piedmont, and Atlantic and Gulf Coastal Plains physiographic regions. A modular approach that includes initial site evaluations, GIS-based data input and management, ranking of relative channel instability, identification of spatial trends, ranking of socio-economic impacts, identification of critical sites, and collection of additional field data to determine magnitude and type of future channel instabilities was presented. The data gathering techniques in this approach originally were developed for use at bridge crossings; however, it has been modified to assess general channel instabilities at other locations (Simon and Downs, 1995). The information collected from many site evaluation sites are mapped, using GIS, to present the spatial distribution of channel stability/instability, physical characteristics, or stage of channel evolution, which can be used to identify system-wide trends in channel adjustment (Simon and Downs, 1995). To determine the magnitude and style of future channel adjustments, additional data is collected at fewer sites. The sites and type of additional data collected is determined by which of four methods are used: numerical alluvial-channel models, regime equations, empirical models of channel evolution, and empirical relations based on process dominance in different fluvial environments. The preferred method is the empirical models of channel evolution (Simon and Hupp, 1992). When a stage of channel evolution is not available, a four-stage process was developed, based on previous studies by the authors, and is composed of: 1) characterization of expected stable channel morphologies by identifying the type of fluvial environment under study (dominant boundary sediments and general physiographic setting), 2) determining threshold values of stream power to assess the likelihood of channel instabilities, 3) estimate the style of channel adjustment by using channel gradient as a surrogate for type of fluvial environment, and 4) estimating the likely form of future channel adjustments using any of the 3 stages described above to determine the current stage of channel evolution, from which future forms and processes can be inferred.

Thorne, Allen and Simon (1996) present a three-fold approach for geomorphic studies: river reconnaissance, analysis (qualitative and quantitative), and assessment. The field data gathered during river reconnaissance uses the Simon and Downs (1995) method for initial screening of the entire fluvial system, then qualitatively interprets the processes from channel form using careful observations across the whole system (Thorne et al., 1996). The quantitative analysis uses more detailed field reconnaissance techniques of specific reaches to determine geomorphic (stable/unstable) and management (pristine and vulnerable/ engineered and recovering naturally/engineered and terminal) status. These techniques include evaluation of flow conditions, bed and bank materials, type, density and location of riparian vegetation, bankfull channel morphology, planform geometry, and flow hydraulics. Thorne and others (1996) use these data to assess channel stability by contrasting current bankfull channel geometry and hydraulic conditions with those predicted by regime equations based on dominant or effective discharge. A case study is presented for the River Blackwater in southwest England to demonstrate the approach.

The approach initially developed in Thorne and others (1996) was eventually published as a book, Stream Reconnaissance Handbook, by Thorne (1998) (personal communication; Thorne, 2003). The book includes comprehensive evaluation sheets and provides detailed guidance on the field methods and equipment to effectively complete the reconnaissance sheets for use in characterizing streams, collate and archive data for further engineering and geomorphic analyses, supply input for stable channel designs, assessments, modeling, training of field staff, and serve as a permanent record of stream conditions that transcends tenure of staff and engineering time-spans (Thorne, 1998). A cursory reconnaissance using the channel-stability index sheet by Simon and Downs (1995) is recommended when staff is unfamiliar with the study area. If possible a broad view of the area from some vantage point or fly-over is also suggested. The basis for designing a geomorphic study is discussed in the context of integrating geomorphology with river engineering project designs. This approach was developed by the UK Environment Agency during the Brahmaputra River (India) Training Study (BRTS) and is a blueprint for methodological steps for performing geomorphic studies. Thorne (1998) promotes the importance of a thorough and coherent approach using a multi-step progressive reconnaissance study, which begins with a broad watershed baseline study and concludes with a detailed investigation of critical reaches. The data obtained from the reconnaissance is used in geomorphic classifications and contributes to the "analysis and prediction necessary to support sustainable river engineering, conservation and management" (Thorne, 1998, p. 37).

Kuhnle and Simon (2000) performed a pilot study to develop scientifically defensible procedures to facilitate the development of clean-sediment Total Maximum Daily Loads (TMDLs) for U.S. streams and rivers. In general, a revised methodology for evaluating sediment-impaired streams is being developed using datasets from the Sierra Cascade Mountain and Coastal Plain physiographic regions. An existing technique was modified to determine representative sediment-transport relationships for reference and disturbed channels. The sediment-transport relations of stable (reference) and unstable (disturbed) channels are correlated with stages of channel evolution. This correlation is based on the hypothesis that unstable channels (stages III, IV, and V) carry higher sediment concentrations for a given flow than stable channels (stages I and VI) and may be a means to detect significant departures, thereby possibly establishing reference conditions as goals for stream management (Kuhnle and Simon, 2000). This method still needs field verification in other physiographic regions by performing geomorphic assessments on streams with instantaneous sediment concentration data. Kuhnle and Simon (2000) modified the channel-stability index variables and site evaluation form used in Simon and Downs (1995) to better evaluate stream channel conditions. The bridge-scour variables used in the original study were removed and variables that reflect channel characteristics associated with sediment-transport relationships were added.

A protocol was developed by Rhoads (2003) to characterize stream channel conditions in Illinois at sites where bendway weirs have been installed or being considered as a bank stabilization technique. It is a manual for individuals with little or no experience in fluvial geomorphology. It does introduce basic concepts on stream-channel form and dynamics and bendway weir theory as an erosion-control technique (Rhoads, 2003). The manual sets out a well-organized approach for conducting geomorphological characterizations at a reach-scale. It presents the technical elements and skills needed to conduct a characterization and organizes them into office-, field-, and advanced field-based components. Rhoads (2003) accounts for the realities of conducting any field-based study under variable levels of available resources (time, personnel, and equipment) by including three grades of progressively increased investigation and the associated elements for each grade. The level of experience in fluvial geomorphology required for each grade is also indicated. There is a qualitative discussion of the geomorphological characterization of five field study sites used in the development of the manual.

The main objective of this thesis is to fulfill the need for standardized, systematic protocols for geomorphologic evaluation and characterization of past conditions, extant character, and potential channel adjustments of fluvial systems in Illinois. To meet this objective, a geomorphic assessment approach needs to characterize the temporal and spatial context of the watershed and channel, identify regionally relevant process-response mechanisms, provide appropriate information collection and management techniques, and repeatability to document channel response over time. Of the approaches discussed above, the techniques of Trimble and Cook (1991), Simon and Downs (1995), Thorne (1998), Trimble (1998), Kuhnle and Simon (2000), and Rhoads (2003) contribute to this objective. The classification systems by Whiting and Bradley (1993), Montgomery and Buffington (1997), and Rosgen (1994, 1996), while useful in a general sense, were all developed for rivers and streams in the mountainous northwest of the United States, and therefore have limited utility for understanding channel response in the comparatively low-relief environments of Illinois.

Most of the approaches were not developed in Illinois except for the meander bend geomorphic characterization protocols (Rhoads, 2003). Rhoads (2003) has a tiered approach to characterization that addresses temporal and spatial scales, as well as presenting detailed field sheets and protocols. Even though these protocols emphasize data collection techniques associated with the characterization of bendway weirs, many aspects of the protocols and field sheets also require strong documentation of the channel morphology, which lends itself to repeatability for post-project appraisal. Thus, this approach provides a sound starting point for the development of a generalized geomorphic assessment methodology.

The importance of establishing the historical context of a channel is the greatest strength of the techniques by Trimble and Cooke (1991) and Trimble (1998). These techniques enhance the ability to estimate potential future channel adjustments. Historical analysis should be an essential component of any geomorphic assessment scheme.

The investigative approaches and data collection techniques in Simon and Downs (1995), Thorne (1998), and Kuhnle and Simon (2000) provide a standardized and systematic method for organizing geomorphic data that can be adapted to geomorphic assessment of rivers in Illinois. The modular approach in Simon and Downs (1995) establishes the spatial distribution of channel character to determine adjustment processes by systematically applying site evaluation sheets, GIS-based data management, and secondary site evaluations. The results provide input for qualitatively or quantitatively determining the magnitude and type of future channel adjustments. Thorne (1998) created a handbook that describes field reconnaissance techniques with associated field data sheets for gathering information throughout a fluvial system. The level of detail is extensive, but in some situations may not be necessary; consequently the datasheets can be modified to suit the study area and investigative needs.

3. Multi-Scale Geomorphic Assessment Approach in Illinois Streams

There are many tools and analytical techniques for geomorphic-based assessments of the character of a stream channel (Kondolf and Piegay, 2003). Such assessments are conducted to address perceived stream channel stability issues, usually at a reach scale and usually by non-geomorphologists with limited understanding of geomorphic processes and geologic controls. This lack of understanding can lead to poorly conceived investigative questions and employment of a limited range of geomorphic tools (Kondolf and Piegay, 2003). Moreover, the integration and whole-sale application of specific tools across a wide range of environmental settings has resulted in considerable debate (Miller and Ritter, 1996; Kondolf, 1998; Skidmore et al., 2001). To understand how fluvial processes and channel form interact over multiple temporal and spatial scales, assessments that range from individual reaches to entire watersheds are essential (Kondolf, 1995; Downs and Thorne, 1996; Kondolf and Downs, 1996; Fitzpatrick, 2001; Frothingham et al., 2002).

The approach to geomorphic assessment for streams in Illinois and similar environments in the Midwest incorporates components from assessment methods developed for a variety of physiographic regions. The assessment framework is aimed at guiding management activities by providing a systematic, geomorphic evaluation of the processes responsible for current channel characteristics. Components of the assessment are organized into a framework that endeavors to determine past and current geomorphic processes through a comparative analysis of temporal and spatial data (Kondolf and Piegay, 2003). This convergence of multiple lines of evidence to assess channel responses to the historical disturbances responsible for the current channel character is instrumental for inferring future channel responses to management activities (Montgomery and MacDonald, 2002). The assessment methodology sets the stage for the development of long-term datasets to monitor and study future channel adjustments as well as to conduct post-project evaluations for adaptive management opportunities (Downs and Kondolf, 2002).

The multi-scale geomorphic assessment involves collection and analysis of data at watershed- and reach-scales. It is essential to assess channels at multiple temporal and spatial scales to facilitate understanding of the underlying factors and events leading to the existing channel appearance (Rhoads, 1990b; Kondolf, 1995; Newson, 1995; Downs and Thorne, 1996; Kondolf and Downs, 1996; Thorne et al., 1996; Rhoads and Urban, 1997; Fitzpatrick, 2001; Frothingham et al., 2002; Montgomery and MacDonald, 2002). Whereas several assessment approaches incorporate methods for investigating spatial variability of channel instabilities (Brice, 1982; Downs, 1995; Simon and Downs, 1995; Brookes and Sear, 1996; Downs and Thorne, 1996; Kondolf and Downs, 1996; Thorne et al., 1996; Thorne, 1998; Kuhnle and Simon, 2000; Frothingham et al., 2002), few incorporate a historical analysis of qualitative and quantitative observations which defines the temporal context for extant channel character (Kondolf, 1995; Trimble, 1998; Downs and Kondolf, 2002; Montgomery and MacDonald, 2002; Juracek and Fitzpatrick, 2003). To address this concern, the assessment methodology draws upon historical information on watershed and channel conditions, extant data on geologic, topographic, and hydrologic attributes that govern stream dynamics, and field data on current channel conditions. By evaluating the disturbance history, watershed-scale controls, and current channel conditions, it becomes possible to infer the causal mechanisms producing the channel conditions (Montgomery and MacDonald, 2002) and extrapolate them to infer potential future channel adjustments.

The data required to infer future channel adjustments is dependent on the "degree to which independent variables of hydrology and sediment supply can be quantified (Skidmore et al., 2001, p. 9)". Numerical alluvial-channel models require the most data and analyses, as well as modeling experience. Regime equations also depend upon the availability of large amounts of data and involve uncertainties in estimating stable channel geometries (Simon and Downs, 1995). Empirical models of channel evolution (Simon and Hupp, 1992) are typical used when channel incision and widening has been identified as the dominant channel adjustment process. The convergence of several lines of evidence may compose a characterization of expected channel morphologies by 1) identifying the type of fluvial environment under study (dominant boundary sediments and general physiographic setting), 2) determining threshold values of stream power to assess the likelihood of channel instabilities (Bull, 1979; Barnard and Melhorn, 1982; Graf, 1983; Baker and Costa, 1987; Brookes, 1987; Simon, 1992; Rhoads, 1995; Knighton, 1999; Rhoads, 2003), or 3) estimating the style of channel adjustment by using channel gradient as a surrogate for type of fluvial environment, whereby the future forms and processes can be inferred (Simon and Downs, 1995).

This assessment methodology has three levels of investigation: watershed-scale characterizations, reach-scale characterizations, and evaluation/assessment. The two scales are analogous to the network and planform scalar structure of river systems presented by Frothingham and others (2002). The remainder of this chapter describes the assessment components using the Big Creek-Cache River watershed in the southern

Illinois region as a case study. For each level of investigation there will be a discussion of the method objectives, data sources, implementation of the method in Big Creek, results of the method in Big Creek, and a discussion of the method performance.

3.1 Watershed-Scale Characterization Method

The objective of a watershed-scale characterization is to determine the temporal and spatial context for the current physical condition of the stream channel by determining the spatial extent or position of channel adjustments that are responding to direct or indirect influences (Rhoads, 1990b; Trimble and Cooke, 1991; Thorne, 1998; Trimble, 1998; Downs and Kondolf, 2002; Rhoads, 2003). This objective is met by performing a comparative analysis of the historical and recent watershed and stream channel data over time to determine the existence of direct and indirect influences to which the channel may be responding. Trimble and Cooke (1991) and Trimble (1998) discuss the use of historical resources in geomorphologic research. Many of the resources (Table 3.1) are valuable in establishing sediment degradation/aggradation rates when contrasted with current data and provide insight into the human impacts on channel adjustment processes over longer periods of time. They also aid in understanding the dynamics of geomorphic processes, thereby enhancing the ability to predict channel response with and without engineering (Downs and Thorne, 1996; Trimble, 1998). Historical resources are fraught with inconsistencies and often provide little or no documentation of quality controls. Therefore, appropriate rigor needs to be applied when compiling such data. The data interpretation should be performed using geomorphological experience and insights that realize their value as well as limitations (Kondolf and Downs, 1996; Thorne, 1998; Rhoads, 2003).

Table 3.1. Data types in historical analysis of watershed-scale characterization (modified from Trimble and Cook, 1991)

Watershed Boundary
Geology
Surficial Materials
Physiography
Climate
Land Use
Soil Surveys
Topographic Maps
Aerial Photography
Drainage Projects
Channel Gradient
Streamflow
Sediment
Bridge Surveys
Bathymetric Surveys
Ground-based Photography
Interviews/News Media
Narrative Accounts
Travel Accounts
Past Scientific Studies

The watershed-scale characterization has two techniques of investigation: historical analysis and initial field survey. The historical analysis is the synthesis of all available information on the watershed and stream channel features. The initial field survey includes current field data describing the general physical character and geometry of the channel.

The objectives of the historical analysis are to synthesize and contrast historical and recent information (Table 3.1) to 1) establish the physical character of the watershed, 2) identify possible direct and indirect influences in the fluvial system that effect sediment supply and sediment transport capacity, and 3) correlate available data with associated observed channel form so it can be interpreted in the context of channel-influencing events (Kondolf and Downs, 1996). These three objectives contribute to understanding the process-response mechanisms that are active within the channel (Trimble and Cooke, 1991). The results of the historical analysis may reveal compelling evidence of possible local or system-wide channel responses (Simon and Downs, 1995). Such evidence would include abrupt changes in channel planform, significant river engineering projects, major shifts in land use, trends in climate, and changes in flow duration and flood frequency.

The objective of the initial field survey is to establish the extant character of the stream channel throughout the network. The initial field survey is essentially a field-data collection component where relative channel stability is determined based on the physical features of the channel and basic channel geometry throughout the network. The benefits of determining the watershed context of channel features and response mechanisms has been reported by many investigators (Rhoads, 1990b; Trimble and Cooke, 1991; Kondolf and Downs, 1996; Rhoads and Urban, 1997; Thorne, 1998; Trimble, 1998; Downs and Kondolf, 2002; Frothingham et al., 2002; Rhoads, 2003). Also, this information supplements the objectives in the historical analysis, as well as providing the relative spatial extent of current channel characteristics.

There are two components to the initial field survey: 1) site selection and 2) collection of basic field data. The site selection process involves evaluation of aerial photographs and physical maps to achieve an adequate spatial density of sites which contains the widest range of channel conditions (Simon and Downs, 1995). The information gleaned from geologic/surface material maps, soil surveys, and topographic maps can identify areas with distinct physical differences, in which more sites may be positioned. Suspected unstable sites are included in this survey. Accessibility and landowner permission will also be factors in selecting the final site locations.

The basic field data collection component is a modification of the channel-stability ranking scheme (Figure 3.1) from Kuhnle and Simon (2000). The channel-stability ranking scheme has two elements: 1) rapid measurement of reach-averaged channel geometry and bank angles, bed and bank material descriptions, and reach gradient and 2) ranking of channel characteristics into a channel-stability index. These

CHANNEL-STABILITY RANKING SCHEME*

Station # ____________ **Station Description:** ______________________________

Date: ____________ **Crew:**_______________ **Site Coordinates:**____________________

Pictures: ☐ U/S ☐ D/S ☐ X-section ☐ LB ☐ RB **Samples:**____________________________

Pattern: ☐ Meandering ☐ Straight ☐ Braided ☐ Drainage Ditch**

Field Measurements: Reach length:__________________ Est. Reach Slope:______________

Avg channel widths: (top)______(bottom)______ Avg/Max channel depth:_______/_______

LB angle (avg):_______________ RB angle (avg):_____________

Primary bank material:_______________ Primary bed material: *(See #1)*

(GP=gravel; SP=sand; ML=silt; CL=clay; BR=bedrock)

1. Primary bed material

	Bedrock	*Boulder/Cobble*	*Gravel*	*Sand*	*Silt/Clay*	
	0	1	2	3	4	

2. Bed Protection

a)	*Yes*					
OR	0		*#Banks*			
b)	*No*	*(with)*	*Protection*	*One (L or R)*	*Both*	
	1			2	3	

3. Degree of floodplain separation/incision** (Relative elevation of "normal" low water; floodplain/terrace @100%)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
	4	3	2	1	0	

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
	0	1	2	3	4	

5. Streambank erosion (Each bank over reach length)

	None	*Fluvial*	*Mass wasting (failures)*	
Left	0	1	2	
Right	0	1	2	

6. Stream bank instability (Percent of each bank failing over reach length)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
Left	0	0.5	1	1.5	2	
Right	0	0.5	1	1.5	2	

7. Established woody vegetative cover (Percent of each bank face over reach length)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
Left	2	1.5	1	0.5	0	
Right	2	1.5	1	0.5	0	

8. Occurrence of bank/bar accretion (Percent of each bank with fluvial deposition over reach length)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
Left	2	1.5	1	0.5	0	
Right	2	1.5	1	0.5	0	

9. Stage of Channel Evolution (If applicable)

I	*II*	*III*	*IV*	*V*	*VI*	
0	1	2	4	3	1.5	

OTHER OBSERVATIONS:

Total Score:

* Adapted from Kuhnle and Simon (2000)

Figure 3.1. Channel-stability index sheet used in watershed-scale characterization, initial field survey component.

two elements characterize the relative degree of channel stability between reaches throughout the watershed. The rapid field measurements are estimated using a laser rangefinder, hand level, hand-held particle size analyzer, and a Unified Soil Classification System card. The channel-stability index is the sum of nine evenly weighted physical channel characteristics (Simon and Downs, 1995). In general, sites with a channel-stability index greater than 20 have substantial potential for critical instability and an index of 10 and lower are considered relatively stable (Simon and Downs, 1995). Sites with an index between 10 and 20 have potential to become unstable (personal communication; Simon, June 2003). The principal use of the channel-stability index is to determine the relative distribution of the stability rankings between sites to detect possible system-wide channel responses. It is not intended to be used to infer channel stability/instability for isolated reaches. All sites are ranked and mapped using GIS by the channel-stability index and each variable to present their spatial distribution. The mapped indices and variables are used to identify possible system-wide trends in channel character. If trends are not present, identified instabilities may be assumed to be localized (Simon and Downs, 1995).

3.1.1 Watershed-Scale Characterization Data Sources

This approach is developed specifically for use in Illinois landscapes to take advantage of datasets available in, or even unique to, Illinois. Also, the usefulness of this approach is further enhanced by the identification of the source and location of datasets. As discussed, there are several objectives in the watershed-scale characterization therefore the associated data sources are grouped by objective. This organization will provide a systematic method to analyze the data to meet the associated objective. For details on the data sources used in this characterization, refer to Appendix A.

3.1.2 Case Study Watershed: Big Creek

This geomorphic assessment methodology was developed within the Big Creek watershed in the Cache River Basin. This watershed was chosen on the basis of federal, state, and local stakeholder interest, a need for a comprehensive geomorphic analysis, likelihood of diverse and long-term datasets, history of landowner/stakeholder cooperation, and active studies and programs aimed at understanding the erosion processes in the watershed with the intention of implementing erosion control projects.

The Cache River Basin is located in extreme southern Illinois just upstream of the confluence of the Ohio and Mississippi Rivers and consists of two distinct drainage basins (Figure 3.2). The Upper Cache River watershed area is 953 km^2 and drains directly into the Ohio River. The Lower Cache River has a drainage area of 927 km^2 and drains into the Mississippi River through a diversion channel. The Cache River-Cypress Creek Wetland is located in the Lower Cache River valley and has two tributaries: Big Creek (135 km^2) and Cypress Creek (120 km^2). Each of these tributaries drains a high-relief headwater area and flows into the nearly flat valley bottom of the Lower Cache River and the Cache River-Cypress Creek Wetland (Demissie, Soong et al., 1990b). The wetlands are known for being the northern most extent of cypress-tupelo gum tree stands in the country, some more than 1,000 years old, and include eight officially designated Illinois Nature Preserves.

The Cache River basin occupies only 1.5% of the land area in the State of Illinois, but contains 91% of the high-quality swamps, 42% of the shrub swamp, and 11.5% of the

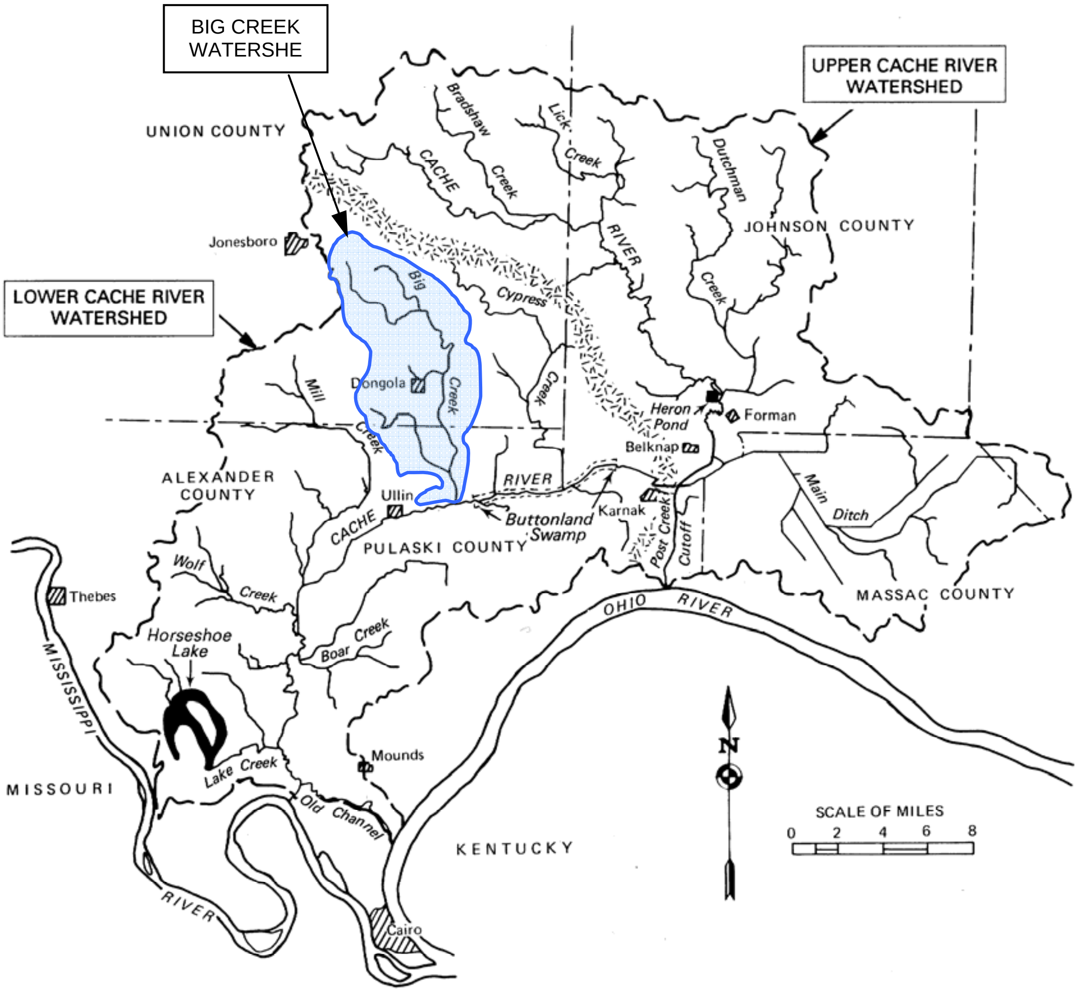


Figure 3.2. Location of the Cache River and its major tributaries (Demissie et al., 2001).

high-quality floodplain forest in the state (Illinois Department of Natural Resources, 1997). Nearly 104 Illinois endangered or threatened species are found in this area and seven of these species have federal threatened or endangered status. In 1994 the Cache River-Cypress Creek Wetland was designated one of nineteen wetlands on the RAMSAR List of “Wetlands of International Importance” in the United States for its role in sustaining waterfowl and shorebirds that use the Mississippi flyway. This designation puts the Cache River-Cypress Creek Wetland into the same class as more famous U.S. wetland systems such as the Florida Everglades and the Okefenokee Swamp (Illinois Department of Natural Resources, 1997). The National Parks Service has designated three National Natural Landmarks in the basin.

Over the last century, substantial changes have occurred in the Cache River watershed, which directly affected the fluvial dynamics of Big Creek. The confluence of the Cache River was originally at the Ohio River south of Mounds, Illinois (Figure 3.2). However, the Cache River has been subject to intensive drainage, flood, and water-level control since 1915 (Table 3.2). The most significant engineering project was the modification of Post Creek, a small, north-south tributary to the Cache River (Figure 3.2). Post Creek originally flowed north from the hills between the Cache and Ohio River valleys to its confluence with the Cache River near the town of Karnak. In an effort to facilitate reclamation (drainage) of the land for agricultural use, Post Creek was ditched through the hills in its headwaters to the Ohio River (Hutchison, 1984). This action connected the Cache River with the Ohio River. Since then, Post Creek has been referred to as the Post Creek Cutoff because this modification literally cut the Cache River watershed in half (now known as the Upper and Lower Cache River watersheds). The

Upper Cache River, draining high sloping uplands, now drains into the Ohio River over a much shorter path and no longer provides flow through the Cache River-Cypress Creek Wetlands. Backwater from floods on the Ohio and Mississippi Rivers precipitated the building of a major levee system to alleviate backwater flooding in the Cache River watershed. The Cache River Levee is several miles long and runs in a northeast-southwest direction, just east of Karnak, Illinois and west of the Upper Cache River/Post Creek cutoff confluence.

Table 3.2. Drainage, flood, and water-level-control projects in the Cache River Basin (Demissie, Soong et al., 1990b)

Period	*Project*
1905	Major channelization, including the Post Creek Cutoff, proposed by the Cache River Drainage Commission
1915	Post Creek Cutoff and Forman Floodway constructed
1930s	Channelization of the lower Cache River
1950	Lower Cache River outlet diverted from the Ohio to Mississippi River
1952	Reevesville and Cache River levees constructed by the USCOE
1960s	Dredging and clearing of the Lower Cache River in the Buttonland Swamp area
1982	Low-head channel dam built in Buttonland Swamp (Cache River-Cypress Creek Wetlands) by Save the Cache, Inc.
1986	Cache River levee breached by Big Creek Drainage District #2; levee repaired by drainage district as ordered by the COE

Logging, conversion of forest to agriculture, and many drainage alteration projects (e.g., flood and water-level control) that were implemented in the Lower Cache River watershed over the last century have led to substantial changes in runoff and sediment supply (Demissie, Soong et al., 1990b). These changes have set into motion channel adjustment responses that caused erosion of the uplands and channel perimeter. Consequently, Big and Cypress Creeks deliver high suspended-sediment loads to the low-energy Lower Cache River-Cypress Creek Wetland (Demissie, Soong et al., 1990b). The result is high rates of sediment deposition and high levels of turbidity in the wetlands, which in turn has endangered ancient cypress and tupelo tree stands and other sensitive components of the ecosystem. Demissie and others (1990b) have identified Big Creek as the tributary that contributes a significant portion (nearly 70%) of the suspended sediment load to the wetland.

Interest and resources from local and state organizations to reduce sediment loading from Big Creek also makes it suitable for developing the geomorphic assessment approach. Engineering and land management projects to reduce the upstream erosion and downstream sedimentation from the Big Creek watershed into the Lower Cache River wetlands are in progress. A study by the Illinois State Water Survey (ISWS) modeled the hydrology of the Big Creek watershed and investigated runoff management alternatives, such as detention storage in the watershed to reduce peak discharges, thereby reducing the sediment transport capacity, and redirect high suspended sediment laden high-discharge waters away from the wetlands (Demissie et al., 2001). That study is being used as a major criterion for detention basin construction in the watershed.

Another effort in Big Creek is the installation of instream restoration projects to stabilize the channel, which has been identified as a primary source of downstream sediment. Channel instabilities were initially determined by federal, state, landowner concerns and followed up by limited field-inspection. The results of a comprehensive geomorphic assessment will be an important contribution to verifying the need for restoration projects by determining the extent of channel adjustments, mechanisms responsible for these adjustments, and whether the adjustments will continue.

Information on the type and rate of the adjustments would be particularly helpful in identifying appropriate mediating projects, locations, and design, as well as post-project appraisals.

3.1.3 Big Creek Case Study: Watershed-Scale Characterization

A watershed-scale characterization was performed for the Big Creek watershed and stream channel. The following are the results of the two techniques of investigation and presented by the objectives of those techniques.

3.1.3.1 Historical Analysis – (1) Establish current physical character of watershed

Physiography (geomorphology, surficial materials, geology). Big Creek-Cache River Basin is located in one of two glacial driftless areas in Illinois. The elevation in the Big Creek watershed ranges from 195 to 100 meters msl. The watershed crosses two major physiographic provinces: Interior Low Plateaus Physiographic Province-Shawnee Hills Section (also referred to as the "Illinois Ozarks") to the north and the Coastal Plains Province-Bottomland Section (Leighton et al., 1948) to the south. The Shawnee Hills Section is a dissected upland, underlain by Mississippian and Pennsylvanian bedrock and its boundary is marked by the Illinoisan glacial drift boundary to the north and the overlapping Coastal Plain sediments to the south (Leighton et al., 1948, p. 31). The Pennsylvanian ridge defines the upland boundary of the watershed and is dissected by mature valleys and the majority of the watershed is a maturely dissected plateau on Mississippian bedrock (Leighton et al., 1948). A deep weathered zone of gravel overlain by loess indicates that a long period of stable conditions followed their deposition and that the major period of valley-cutting occurred late in the Tertiary (Leighton et al., 1948).

The southern portion of the Big Creek watershed, which merges with the Cache River Valley, is in the Coastal Plain Province also known as the Mississippi Embayment. The Cache River Valley forms the northern edge of this province and "is an abandoned segment of the trunk portion of a major drainage system (Ohio River)" (Frankie et al., 1997, p. 55). The geomorphic history of this area is complex. The valley has been scoured and filled with each glacial cycle in the area and played a role in the drainage pattern and current positions of the Ohio, Cumberland, and Tennessee Rivers.

The surficial material is Wisconsin and Holocene age alluvium and is covered by 3-5 meters of Peoria Loess (Leighton et al., 1948). The lithology exposed in the Big Creek valley is mainly slackwater lake sediments dominated by stratified silt and clay and commonly covered by less than 2 m of Peoria loess (Berg and Greenpool, 1994). It is underlain by Mississippian interbedded limestone, shale, and sandstone between 0 and 6 m from the surface (Berg and Greenpool, 1994). Karst features in central Union County were noted by Leighton and others (1948) and observed during field visits in which streamflow was interrupted by a 4500 m section of dry limestone, chert-gravel channel bed.

*Soils***.** Soil associations within the watershed can be divided into two groups; those found along the stream corridor and those found on the ridges and hillsides in the uplands (U. S. Department of Agriculture, 1968, 1979). Wakeland-Hammond (Union County) and Bonnie-Belknap (Pulaski County) associations occur in the stream corridors. The Wakeland-Hammond soils are formed on nearly level slopes and along streams in the dissected uplands. The Wakeland forms in silty alluvial deposits, is poorly drained, and lies on broad floodplains of large streams. The Hammond is a well-drained silt loam found on high-gradient narrow floodplains. The Bonnie-Belknap soil association is a poorly drained silt loam found mostly in the bottomlands around the confluence of Big Creek and the Cache River. Soil associations found on the ridges and hillsides in the uplands are Alford and Hosmer (Union County) and Alford-Hosmer (Pulaski County). In Union County the Alford is found on gently sloping to moderately steep hillsides and develops in loess. This 1.5 m thick soil has a surface layer of silt loam and a silty clay loam subsoil that overlies a cherty limestone. The main management concern for this soil is erosion. The Hosmer is similar to the Alford but also has a compact and brittle fragipan below the subsoil and moderate permeability. Erosion is the main management concern. The Alford-Hosmer soil association in Pulaski County is found on rounded, rolling to steep hills to the north and south of the Cache River. The Alford is well drained and moderately permeable. The Hosmer soil occupies the areas around the upper part of some drainage ways and on the lower part of slopes (U. S. Department of Agriculture, 1968). Again, erosion is listed as a management hazard on these soils.

Climate. Precipitation and temperature data were retrieved from the Midwest Climate Center. The 30-year (1971-2000) annual mean precipitation for the area is 122.48 cm with a range of 168.99 cm (1982) to 77.27 cm (1980). The 30-year (1971-2000) annual mean temperature is 13.8°C with a range of 14.9°C (1991) to 12.4°C (1979).

Land Use. Land cover information for the Big Creek watershed was obtained from *Land Cover of Illinois: 1999-2000* (Luman and Weicherding, 1999) and U.S. General Land Office Survey 1804 and 1843 records (Illinois Natural History Survey, 2002). These sources were in GIS format; therefore the datasets could be directly analyzed at the watershed scale. Agricultural land use acreage was obtained from the Illinois

Agricultural Statistics records for Pulaski and Union County for 1925-2002, Pulaski and Union County soil survey reports for 1968 and 1979 (U. S. Department of Agriculture, 1968, 1979), and crop residue management data for 1989-2002 (Conservation Technology Information Center, 1989, 2002). These datasets are available at a county-level scale only.

The 1999 watershed land cover data by Luman and Weicherding (1999) reports approximately 42.6% in rural grassland, 29.3% in crop production, 17.9% in forest, 5.2% in wetland, 3.7% in urban or built-up land, and 1.2% in surface water or barren and exposed lands. In 1999, cropland area calculated from the Illinois Agricultural Statistics (IAS) data was 31.6% of Union and Pulaski counties, which is comparable to the 29.3% of cropland within the Big Creek watershed calculated from the Luman and Weicherding (1999) land cover data. Because of the similarity in these estimates it is assumed that the Union and Pulaski County crop statistics are representative of crops within in the Big Creek watershed.

3.1.3.2 Historical analysis– (2) Identify potential direct and indirect influences

Topographic maps, aerial photography, ground-based photography. Adjustments in channel planform over time were determined by using GIS techniques on georectified historical and recent aerial photography. The 1998 USGS Digital Ortho-Quadrangles (DOQs) were readily available for Big Creek (Illinois Geospatial Clearinghouse). Aerial photographs from 1938 were previously scanned and geo-rectified by the Illinois State Geological Survey (ISGS). To determine if undocumented channelization projects occurred prior to the 1938 photography, a 1920 15-minute (1:62,500) series quadrangle map was digitally scanned. Fresh channel cutoffs were quite apparent on the 1938 photography and coincided with the channel planform shown on the 1920 topographic map. The 1920 map was transparently overlaid on the 1938 photography and used as a guide to construct a “pre-1938” channel planform.

Figure 3.3 shows the channel planform for pre-1938, 1938, and 1998. The lower half of the Big Creek channel experienced major cutoffs between 1938 and 1998. From pre-1938 to 1938, Big Creek lost 9.4 km (21%) of its length and another 6.4 km between 1938 and 1998. The total loss of channel length in Big Creek was 15.8 km (35%). The lower half of Big Creek experienced a significant portion of this loss (58%). The abruptness of the channel planform shifts in the lower half of Big Creek is indicative of channelization projects for improved drainage. Reduction of channel length increases the slope and thereby the fluvial energy. This increase in energy can initiate significant channel adjustments, such as upstream migration of headcuts and excessive downstream sediment deposition.

Drainage projects, road and causeway construction plans, and bathymetric surveys. Big Creek had at least 4 major channel modification projects. These projects were performed by the Department of Public Works and Buildings, Division of Waterways in the late 1930s and early 1940s. These projects involved channel straightening with construction of levees and large grade-control structures on the lower half of Big Creek. The channel length in this section was reduced by 58%, doubling the channel gradient. The confluence of Big Creek with the Cache River was moved 1.6 km downstream. Almost all the loss in channel length between 1938 and 1998 is accounted for by the channelization projects documented from 1939 to 1945. There have been no significant channelization projects in Big Creek since 1945.

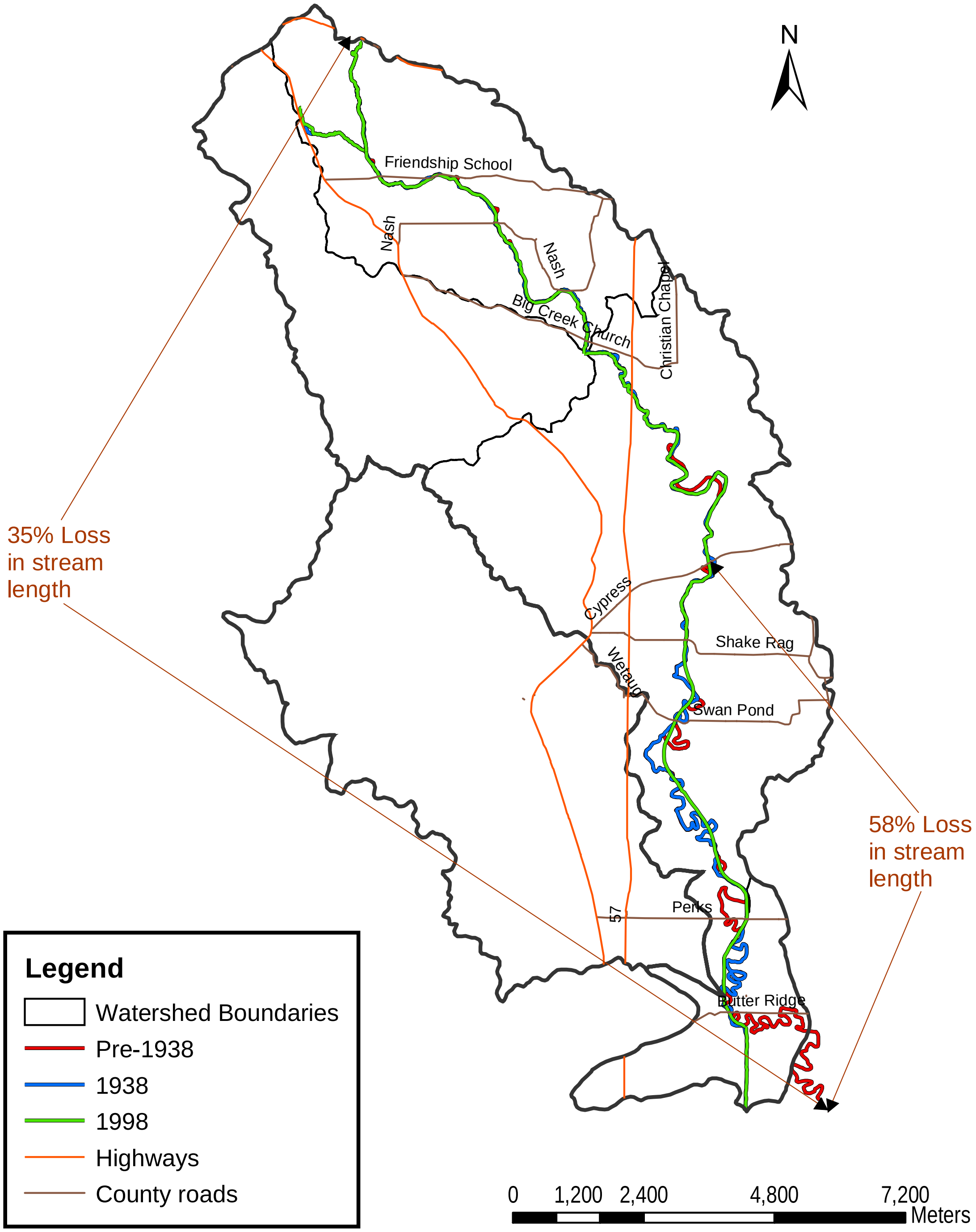


Figure 3.3 Channel planforms for pre-1938, 1938, and 1998.

Pre- and post-channelization cross-sections and channel elevations show that the channel was not substantially deepened, averaging 4.25 m in channel depth. However, the top of bank widths were usually increased or narrowed to an average of 15 m in width. During this period, six control structures (dams) were constructed throughout the channelized reaches (Figure 3.4). It is assumed that the purpose of the dams was to dissipate the increase in energy from the increase in gradient caused by the straightening. Some dams reduced the cross-sectional area of the constructed trapezoidal channels by approximately 18% and others equaled the new cross-sectional area but the crest elevations were higher than the new downstream bed elevation. The 1999 aerial photography shows major blowouts below at least three of the six dams. These three are assumed to be the dams constructed with narrow openings relative to the upstream channel cross-section. Project plans from 1954 show an attempt to repair a blowout below the sixth structure. The repair project plans call for widening of the 1944 channel design below Dam #6 and reinforcement of the banks with stone and rip-rap. However, the 1999 aerial photography shows a major blowout at this structure, therefore, it is unclear as to whether the repair failed or was never performed.

Climate and Land Use.

Climate. Fluctuations in precipitation and temperature influence runoff and vegetation patterns, which can effect transport capacity and sediment supply of rivers (Knighton, 1998). The long-term (1896-2003) annual mean precipitation at the Anna, Illinois station is 120.60 cm. Demissie and others (2001) performed a 10-year moving average on the 100-year record, which showed the wettest 10-year period was from 1942-1951 (137.16 cm) and the driest 10-year period was 1959-1968 (109.22 cm) (Figure 3.5). They

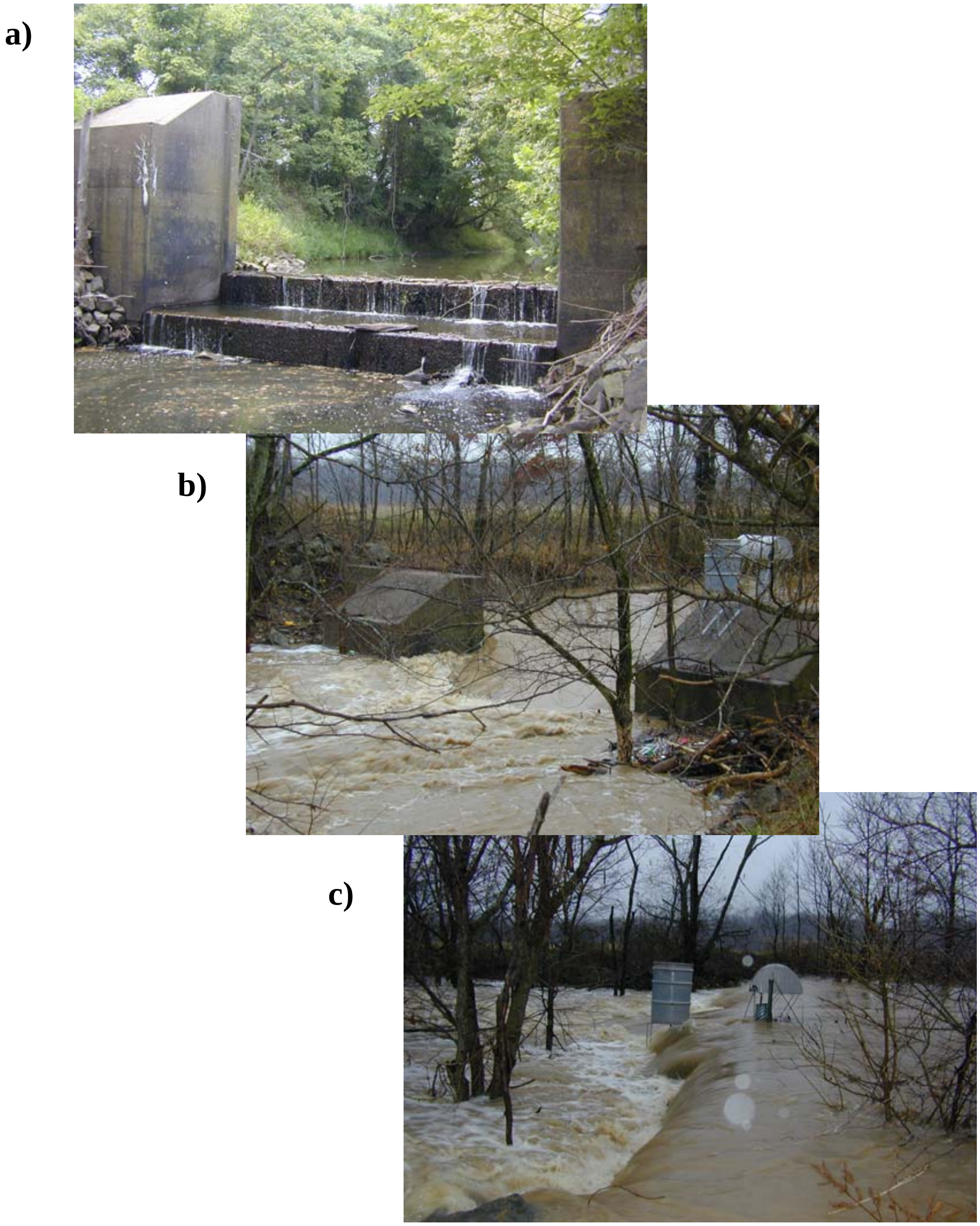


Figure 3.4 Dam #3 - typical control structure installed in Big Creek during the 1930-40s: a) low flow [depth from top of wing-wall to crest is 3.66 m], b) high flow [note stream gage], and c) 5-yr flow overtopping structure.

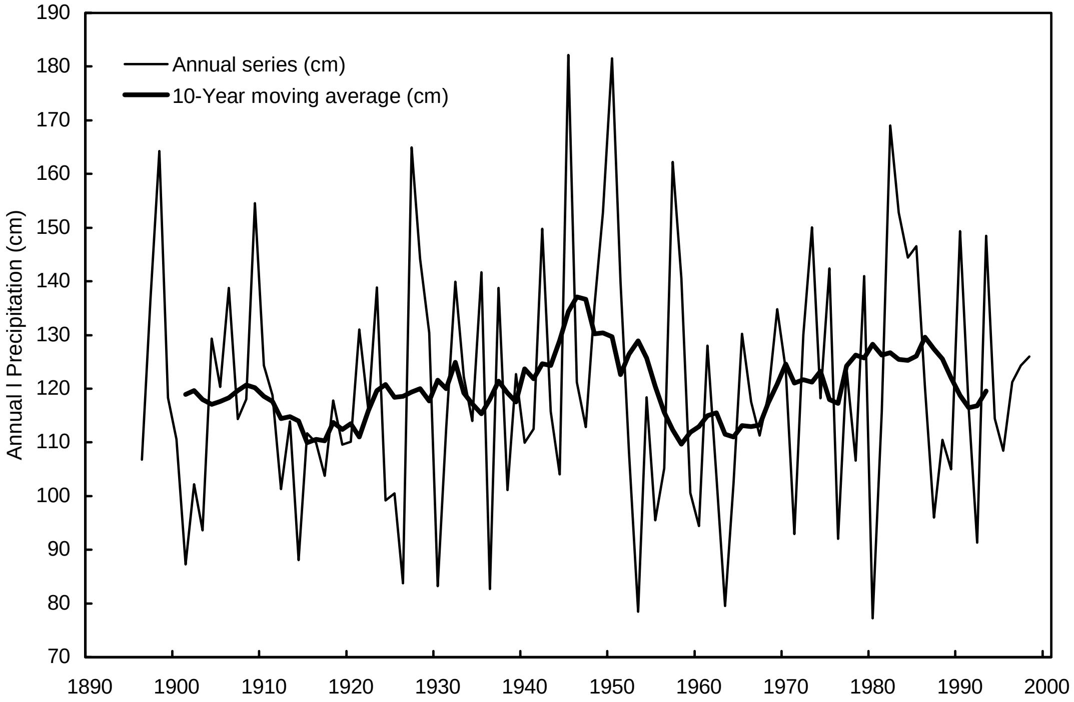


Figure 3.5. Annual precipitation and 10-year moving average of precipitation at Anna, Illinois (Demissie et al., 2001).

found no long-term trends in annual precipitation. Their analysis also showed that the occurrence of the 24-hour, 2-year rainfall event, rainfall in excess of 8.89 cm, was fairly uniform over the period of record. The long-term (1896-2003) annual mean temperature at the Anna, Illinois station is 14.1° Celsius (C). A comparison of the annual mean temperature for 3 periods in the long-term record (1896-1949; 1950-1970; 1971-2000) was 14.3, 13.8 and 13.8°C, respectively. A 10-year moving average was performed on the period of record, which showed a 1°C decline in temperature from the early part of the 20th century to the 1970s and an increase by 0.5 °C to the 1990s (Figure 3.6).

Land Use/Land Cover. Land use practices and various land covers affect runoff rates in a watershed, which influences transport capacity in streams. In an urban setting, impermeable surfaces can significantly increase runoff rates. Forest, grasslands, pastures

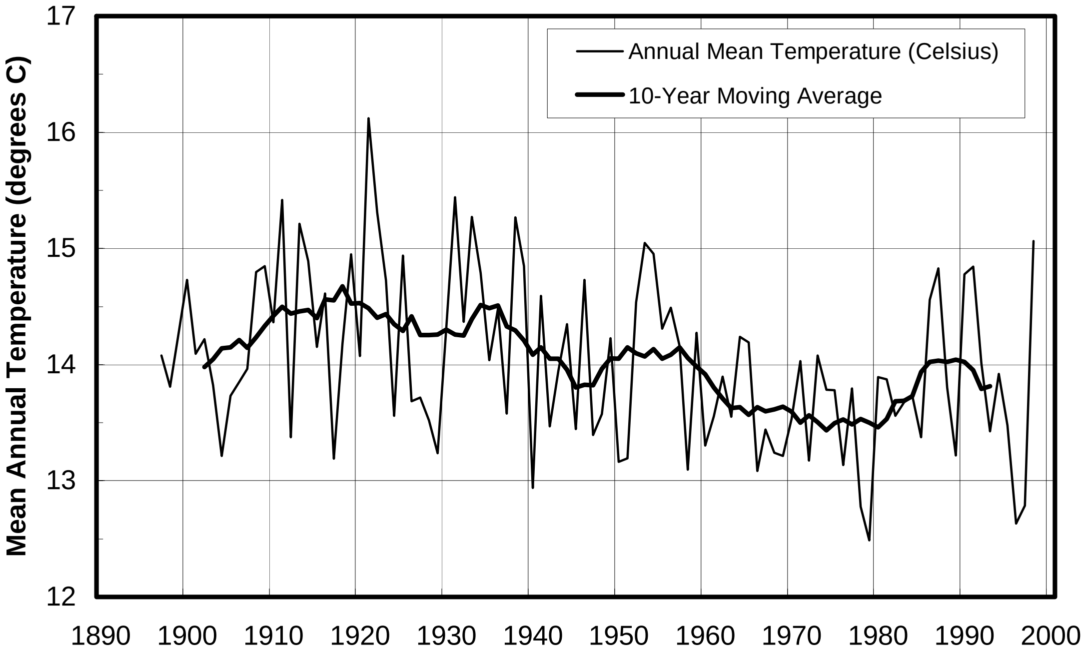


Figure 3.6. Annual temperature and 10-year moving average of temperature at Anna, Illinois.

and wetlands increase infiltration and reduce runoff. Rowcrop agriculture tends to have higher runoff rates than small grain production, however, conservation tillage and increases in crop residue promote increased infiltration. Documenting trends in land uses and land cover can reveal indirect disturbances in a fluvial system.

Analysis of annual agricultural crop production was performed using data from the Illinois Agricultural Statistics Service (IAS) summed for Union and Pulaski Counties from 1925-2002. The annual area of crops harvested is for corn, soybeans, sorghum, and small grains: wheat, oats, and hay.

Land cover has experienced a major shift within the watershed over the last 150 years (Figure 3.7). Information from the 1804 to 1843 General Land Office plat maps (Illinois Natural History Survey, 2002) indicate 98% of the land cover in the Big Creek watershed was in forest and the remainder as wetland/water. In contrast, 17.9% of the

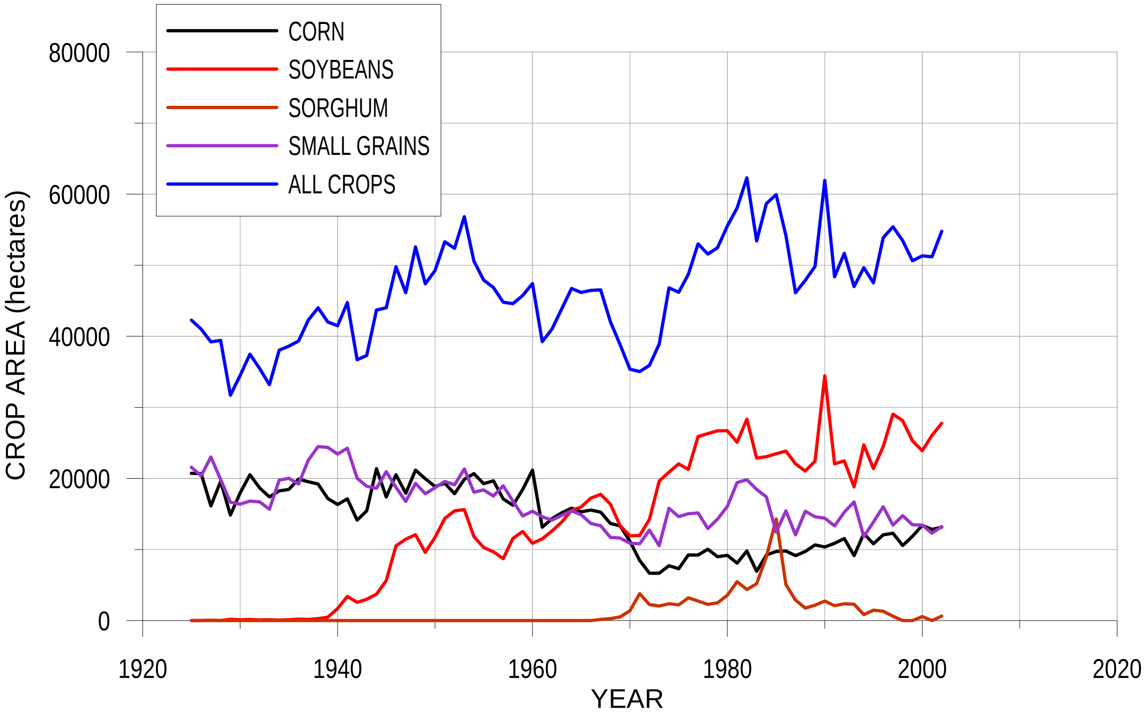


Figure 3.7. Area of selected crops harvested in Union and Pulaski Counties.

1999 land cover was in forest (Luman and Weicherding, 1999). Illinois Agricultural Statistics show agricultural crop acreage has changed very little from 1925 (26%) to 2002 (34%) with row crops shifting from 50% to 75% of the total crop area. There is anecdotal information from the Union County Soil Survey that apple and peach orchards and vegetables were significant in 1979 but were declining in favor of row crops. Orchards were located in the uplands and vegetables were grown in the narrow bottomlands. Erosion was reported as a minor problem in the sod-covered orchards but was higher in the areas that produced vegetables (U. S. Department of Agriculture, 1979). In 1999, orchards and vegetables accounted for only 0.3% of the land cover in the watershed. A visual inspection of the 1938 aerial photography reveals that orchards covered a significant area of the upper Big Creek watershed, whereas the 1999 photography shows only a handful of orchards. This cursory inspection also confirmed that several areas occupied by orchards in 1938 were replaced with row crops and open fields in 1999. However, since total cultivated land cover seems to not have shifted significantly over the last 77 years it is assumed that between 1979 and 1999 orchards were also converted to land covers other than row crops. The 1968 Pulaski County soil survey reports the 1959 census for areas in agriculture, woodland, and pasture, as well as significant numbers of livestock and chickens (20,000 to 36,000), but no mention of orchards.

Crop residue management data were retrieved from the CTIC for 1989 and 2002 (entire dataset covers 1989-2002) (Conservation Technology Information Center, 1989, 2002) to assess current surface runoff impacts. The dataset presents the area of selected crops in conservation tillage (no-till, ridge-till, and mulch-till), reduced-tillage (15-30% residue), and conventional-tillage (0-15% residue). Between 1989 and 2002, conservation tillage significantly increased by 46 % at the expense of the other tillage practices.

Past scientific studies, travel accounts, and news media. The accounting of direct and indirect disturbances in a fluvial system from information garnered from past scientific investigations, travel accounts or news media gives a temporal context to current channel character and may provide unique insights into channel adjustment rates. An extensive search for previously collected data was made for the Big Creek-Cache River basin watershed. The ISWS has been studying the Cache River area since 1985 (Demissie et al., 1987; Demissie, 1989; Demissie, Soong et al., 1990a, 1990b; Demissie, Soong and Camacho, 1990; Allgire, 1991; Demissie and Xia, 1991; Demissie et al., 1992; Allgire and Cahill, 2001; Demissie et al., 2001; Keefer et al., 2006). Also, a library search uncovered several more studies in the general area (Brigham, 1978; Fitzgerald, 1987; Middleton, 1995; Sengupta, 1995; Holmes, 1996; Shasteen et al., 2002). The studies by Fitzgerald (1987), Holmes (1996) and Sengupta (1995) were in the Upper Cache River or Cypress Creek watersheds, whereas the Brigham (1978), Middleton (1995), Shasteen and others (2002), and Dodd et al., 2005) studies had ecological data directly in the Big Creek watershed.

In 1976 and 1977 the water quality of the Cache River Basin was determined by field sampling of benthic macro-invertebrate communities at 151 sites (Brigham, 1978). Brigham (1978) had five stations on Big Creek, which overlapped with initial field survey stations selected for this study. Shasteen and others (2002) reported 1999 data on land use, water chemistry, fish population and flesh, aquatic macroinvertebrates, stream habitat, and sediment chemistry. This study had two sites on Big Creek, which overlapped with sites from Brigham (1978) and this study. The site in upper Big Creek was listed as fully supporting for overall use and aquatic life and the lower Big Creek site was listed as partial supporting for overall use and aquatic life. Stream habitat data provided substrate percent, some channel geometry, and percent pool-run-riffle. Middleton (1995) studied cypress-tree seed dispersal during floods as a potential natural hydrologic restoration method for former agricultural fields next to the wetlands. The hydrologic data used in the study was obtained from Demissie and others (1990b). A 1975 interview of a long-time resident of Ullin, Illinois reveals that local landowners may have been responsible for a channelized section of Big Creek at the confluence with Cache River (Shawnee Community College, 1975), which may account for engineering plans not being discovered for this section.

3.1.3.3 Historical analysis– (3) Hydraulic and channel geometry (flow and sediment)

Streamflow records and sediment data. In lower Big Creek a long-term continuous recording stream gaging station has been in operation for Water Years (WY) 1940-1971 by the U.S. Geological Survey (USGS #05600000) and WY1985-present by the Illinois State Water Survey (ISWS #502). A peak crest gage has been operating at this site since WY71 by the USGS. A second stream gage (ISWS #500) has been in operation in upper Big Creek for WY2000-present. Runoff, flow duration, and peak flows at the ISWS #502 station were analyzed through 1998 by Demissie and others (2001). Comparison of annual runoff with coincident annual precipitation shows a good relationship, which implies trends in runoff is closely associated with precipitation (Demissie et al., 2001). Their flow duration analysis shows that daily flows on Big Creek range from more than 14 cms to less than 0.03 cms and had a greater magnitude of sustained low flows during dry periods (Demissie et al., 2001). When the flow record was separated between the two streamgaging periods (WY1940-1971 and WY1985-1998), the flow duration curve for the WY1985-1998 again showed greater sustained low flows as opposed to zero flows being more common during WY1940-1971. Given that runoff is shown to be generally correlated with precipitation and no trends in precipitation are observed, the discrepancy in the flow durations during low flows between the two streamgaging periods is most likely due to changes in land use (personal communication; Knapp, October 2003).

Sediment discharge records are available for the downstream Big Creek streamgage (ISWS #502) for WY1985-1988 (Demissie, Soong et al., 1990b) and WY1999-present and the upstream streamgage (ISWS #500) during WY2000-present.

However, both of these records are not long enough to determine trends in sediment yield. A preliminary comparison of the sediment yields during WY 2000-2002 show that ISWS #502 has higher yields than ISWS #500. Suspended-sediment particle-size distribution data was available at both stations for WY2000-2003. A sub-set of this data was analyzed for the highest discharges recorded during the period of record. It was assumed that the highest discharges would be well-mixed and more representative of particles being transported by the channel. The median particle size of suspended sediment at ISWS #500 had a range of 0.008-0.011 mm (fine silt) and ISWS #502 had a range of 0.0019-0.018 (fine-medium silt).

Sedimentation rates in a waterbody, such as a reservoir or lake, are a reflection of erosion rates in a fluvial system. Estimation of sedimentation rates can reveal the extent of the erosion and, when sufficient data are available, a tool for inferring future rates for management consideration. There are several studies that have estimated sedimentation rates in the Cache River-Cypress Creek wetlands (Demissie et al., 1992; Allgire and Cahill, 2001; Keefer et al., 2006). Demissie and others (1992) estimated sedimentation rates by combining two methods: sediment budget and radiometric analyses. The sediment budget analysis was based on three years of sediment yield records (WY1986-WY1988) and the radiometric dating technique used Cesium-137 (^{137}Cs) to determine sedimentation rates from 1963 to 1988. In 2000, Allgire and Cahill (2001) collected twice as many cores as the 1992 study for radiometric dating (^{137}Cs). Annual sedimentation rates varied from 0.2 cm to >2.0 cm depending on the depositional environment (Allgire and Cahill, 2001) which were similar to the rates determined by ^{137}Cs in 1988 (Demissie et al., 1992). Keefer and others (2006) included sediment yield data between WY1986-2002 to recalculate rates using the sediment budget method reported by Demissie and others (1992). These rates were then compared to the longer term Allgire and Cahill (2001) ^{137}Cs rates for 1963-2000. The rates determined by these two methods are very similar. Annual sedimentation rates by the sediment budget method for the 17-year period (1986-2002) averaged 0.79 cm (0.3 – 2.3 cm) and the radiometric method for the 38-year period (1963-2000) averaged 0.86 cm (0.2 - >2.0 cm). Demissie and other (1990b) report that Big Creek delivers 70% of the sediment yield to the wetland, which makes the wetland sedimentation rates a reflection of erosion process in Big Creek. Based on the negligible difference between the short- and long-term sedimentation rates, it is assumed that erosion rates in Big Creek have not appreciably shifted for nearly 40 years. Keefer and others (2006) also reported that the Cache River-Cypress Creek Wetland rates were lower than rates for nearby lakes (1.3 cm/yr) (Bogner et al., 1985; Bogner et al., 1997) but significantly higher than deposition rates for Coastal Plain wetlands, which ranged from 0.15-0.54 cm/yr (Hupp, 2000).

Channel geometry. Documented changes in channel gradient and cross-section were sporadic due to the lack of data to compare historical undisturbed channels or channelized geometries with recent measurements (Figure 3.8). However, in 1999 and 2002 the ISWS surveyed the channel profile with cross-sections as an initial investigation of suspected channel instabilities. The profile generally covers the middle reaches of Big Creek. Cross-sections located in the downstream section of the profile have distinct v-shapes with average bank angles ranging from 16 to 33 degrees, whereas the upstream cross-sections are very trapezoidal in shape with nearly flat or mounded channel beds and 30 to 50 degree bank angles. The profile gradients in the upstream and downstream

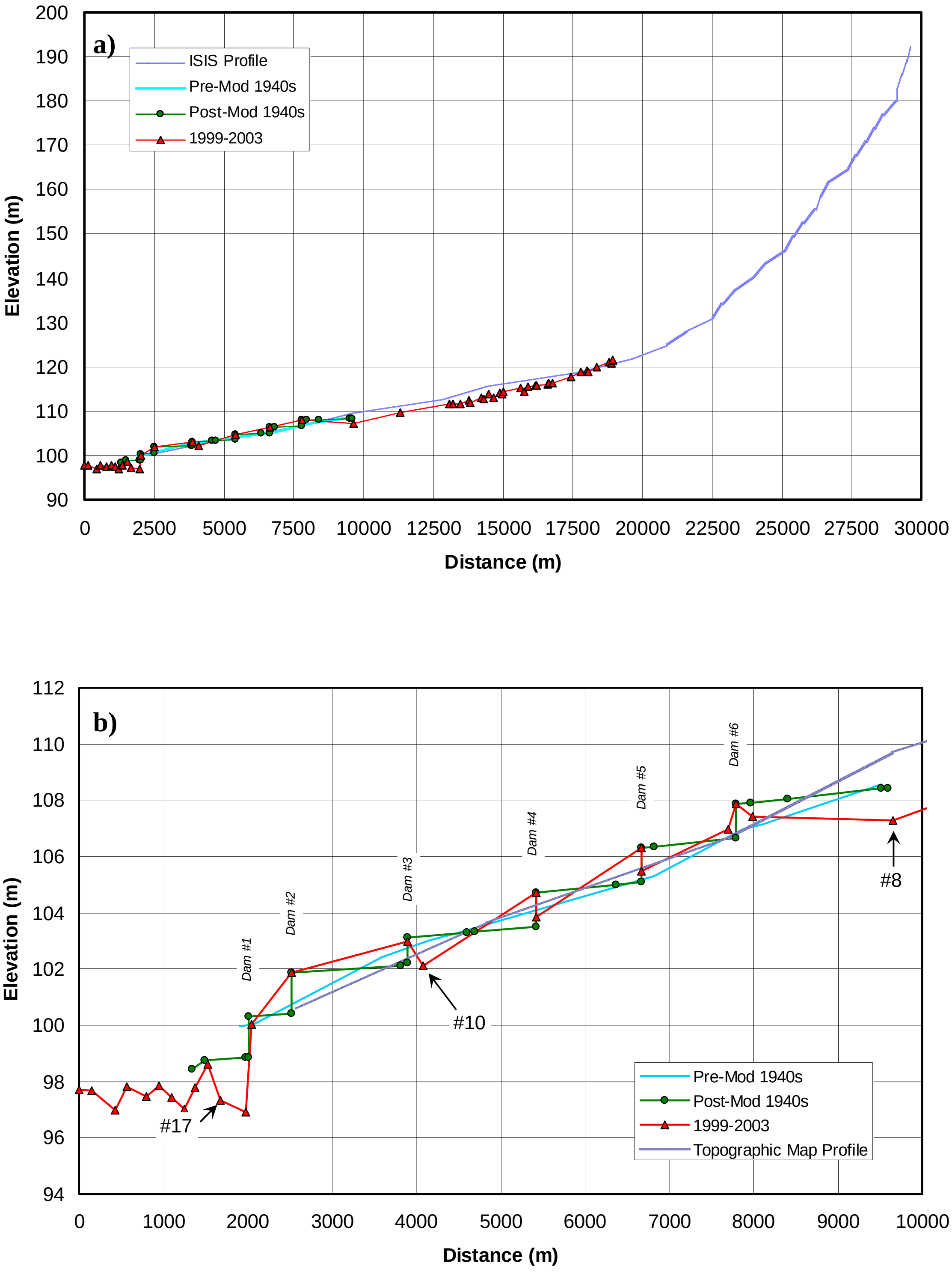


Figure 3.8. Big Creek channel profiles from pre-1938 to 2003: a) entire channel length and b) channelized reach containing control structures.

reaches are 0.00309 and 0.00131, respectively. Photographs of the channel throughout the downstream reach reveal recent rotational slip failures, fallen and tilted trees, negligible woody shrub-type vegetation on the banks, and excessive large wood debris (Figure 3.9). The instrumented survey of the middle reaches of Big Creek shows two different channel cross-section shapes which could be a crude indicator of geological controls on channel processes. The V-shaped channel is indicative of an incising channel, whereas the wide and flat channel with mounded beds may indicate an area of aggradation.

3.1.3.4 Initial field survey – Document extant physical character of the stream channel

Field sites were selected based on watershed physical characteristics, land cover, channelization history, and hydrologic data. Big Creek crosses two major physiographic regions, which have a strong influence on many physical characteristics when choosing field sites. The valley profile, watershed relief, proximity of bedrock to the surface, and surficial material guided the site locations to be spread between the upper and lower stream reaches. The two active streamgaging stations made it advantageous to select several sites up- and downstream of these locations for possible future modeling efforts. The type of surficial material and land cover were fairly uniform across the watershed, which essentially supported an even distribution of sites. A total of 23 sites were initially selected, but three were dropped due to lack of accessibility from landowners, and two subsequently were added for a total of 22 sites (Figure 3.10). This was a ratio of 1 site for every 6.6 km^2 of Big Creek.

The basic channel morphology data and scores for each variable from the channel-stability ranking scheme (Figure 3.1 and Appendix B) were entered into

Figure 3.9 Examples of mass bank failures and large woody debris in middle reaches of Big Creek.

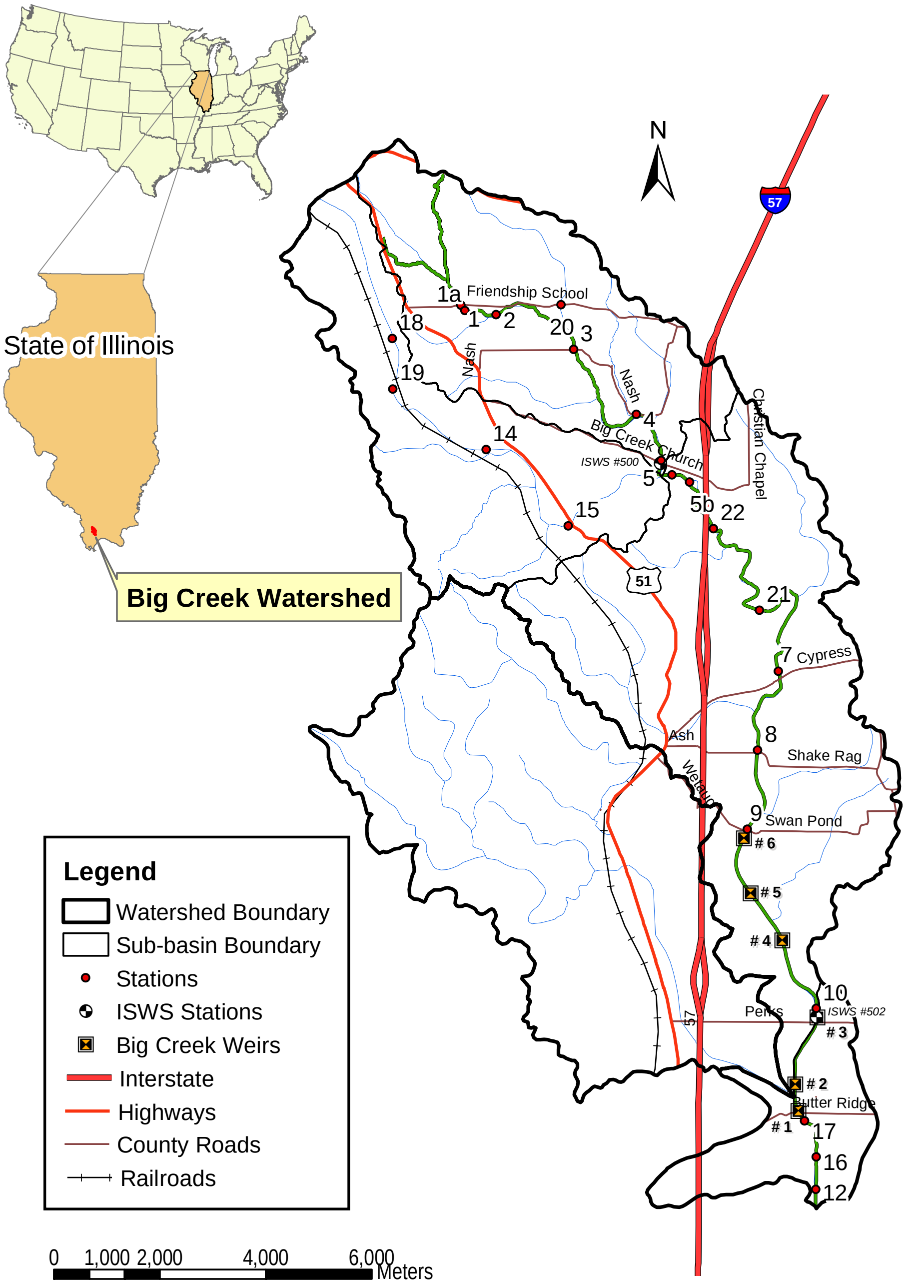


Figure 3.10. Location of field sites.

spreadsheet, plotted against stream distance, and illustrated in a GIS system to view the spatial distribution of selected variables (Figure 3.11 and Appendix C). Basic channel morphology data consisted of reach length and slope, average channel width and depth, angle of both banks, and descriptions of bed and bank material. The data was estimated using a laser rangefinder, hand level, hand-held particle size analyzer, and a Unified Soil Classification System card.

Channel-stability indexes ranged from 8.0 to 29.0 (Table 3.3). Seven of the 22 sites had indexes greater than 20 indicating unstable channels and 4 sites were at or below 10 indicating stabile channels. All four of the stable sites were located in upper Big Creek and 6 of the 7 unstable sites were in the mid-reaches between the two ISWS streamgages. The other unstable site was in upper Little Creek, a tributary to Big Creek. Many variables showed a significant change where Interstate-57 (I-57) crosses Big Creek. Width/depth ratios upstream of I-57 had a wide range of ratios (3-10.0), whereas downstream of I-57 the ratios were narrower (3.66-5.45). Primary bed material upstream of I-57 ranged from gravel to bedrock and downstream ranged from sand to silt-clay. The mechanism of erosion in upper reaches was predominantly fluvial, whereas mass wasting was found more often in the lower reaches. Below I-57 average bank angles were 39° and 34°, left and right banks, respectively. Bank angles above had one bank with a low angle (average of 38°) accompanied with a high angle bank (average of 70°). Bank heights ranged from 1-4.5 m and 4.5-6.5 m in the upper and lower Big Creek regions, respectively.

Stages of channel evolution (Simon, 1989) was also divided at I-57. The downstream reaches of Big Creek had Stages III-V, whereas the upstream area had

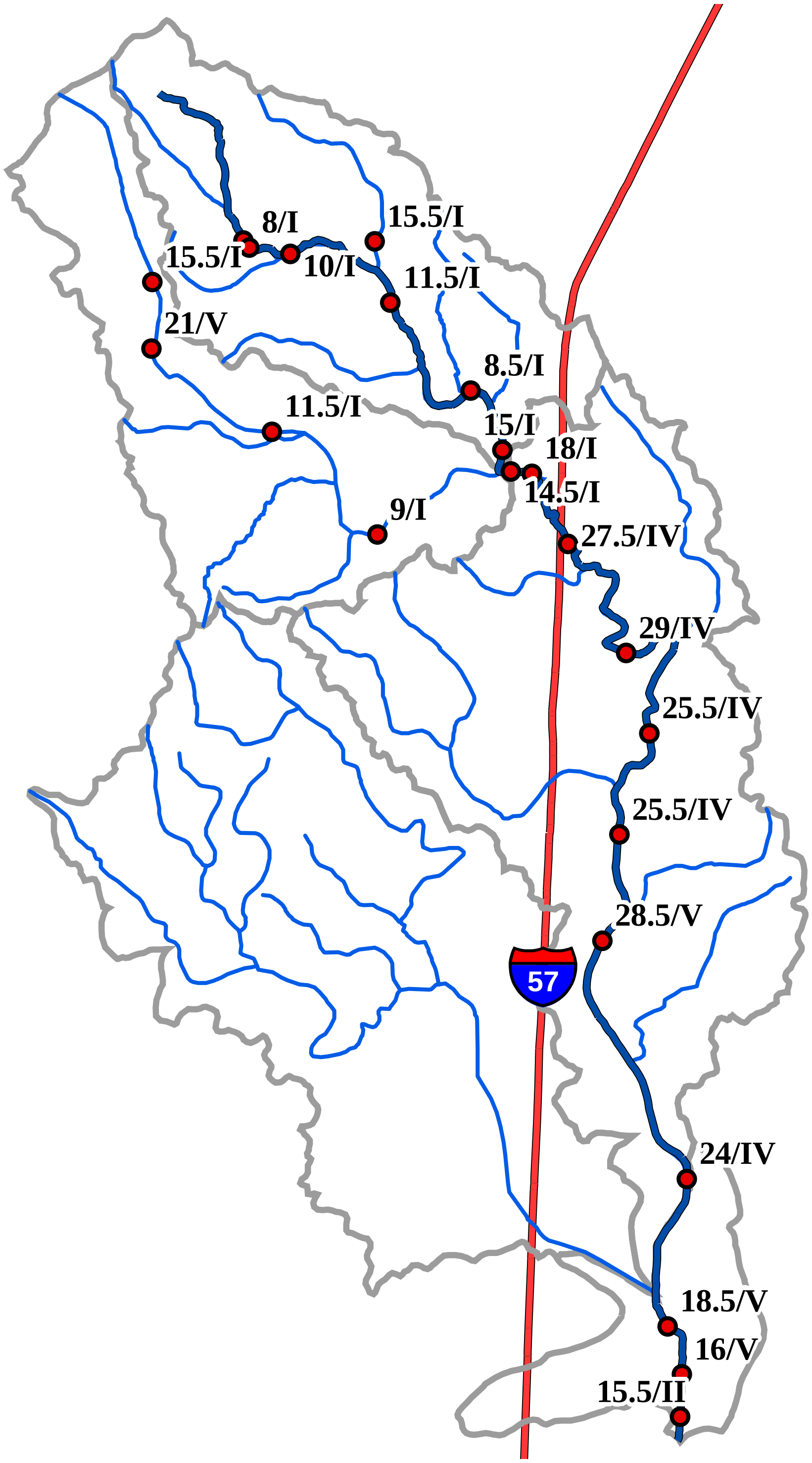


Figure 3.11 Spatial distribution of channel stability index score and stage of channel evolution.

Table 3.3. Results of initial field survey

Site #	Distance (m)	Avg. Width (m)	Avg. Depth (m)	W/D Ratio	LB Angle (deg)	RB Angle (deg)	Bank Material Left	Bank Material Right	Bed Material	Primary Bed Material	Bed Protection	Degree of Floodplain Separation/Incision	Degree of Constriction	Streambank Erosion LEFT	Streambank Erosion RIGHT	Stream Bank Instability LEFT	Stream Bank Instability RIGHT	Established Riparian Woody-Vegetative Cover LEFT	Established Riparian Woody-Vegetative Cover RIGHT	Occurrence of Bank/Bar Accretion LEFT	Occurrence of Bank/Bar Accretion RIGHT	Stage of Channel Evolution (Score)	Stage of Channel Evolution (Stage)	Channel Stability Index
1	25144									2	0	4	0	1	0	0	0	0	2	0.5	2	0	1	11.5
1.1*	25044	16.00	1.60	10.0	20	29	0	0	0	2	0	1	0	0	0	0	0	2	2	0.5	0.5	0	1	8.0
2	24387	11.61	1.55	7.5	35	85	0	rock	0	1	0	3	0	0	0	0	0	1	1	2	2	0	1	10.0
3	22356	15.27	3.66	4.2			0	0	BR	0	0	2	2	1	1	0	0	1	1	2	1.5	0	1	11.5
4	21106						0	0	0	2	0	2	0	0	0	0	0	0.5	0	2	2	0	1	8.5
5*	18897	16.28	2.62	6.2	51	75	BR	ML-CL	GP	2	1	3	1	0	1	0.5	0	1	1.5	2	2	0	1	15.0
5.1*	18382	29.26	3.66	8.0			ML-CL	BR	GP	2	0	3	0	2	0	2	0.5	1.5	0.5	1.5	1.5	0	1	14.5
5.2	18064	56.24	4.57	12.3	80	20	ML-CL	ML-CL	GP-SP	3	1	3	0	2	1	2	1	2	1	2	0	0	1	18.0
7*	11322	22.86	5.58	4.1	32.5	30	ML	ML	SP	3	1	4	0	2	2	1	1	2	2	2	2	3.5	4	25.5
8	9627	21.76	5.08	4.3	27	33	CL	CL	CL	4	1	3	0	2	2	1.5	0.5	2	2	1.5	2	4	4	25.5
9	7984	20.12	5.49	3.7			0	0	0	4	1	3	0	2	2	1.5	1	1.5	1	1.5	2	3	5	28.5
10*	4084	16.55	4.45	3.7	39	30	CL	CL	CL	4	1	3	0	2	1	1.5	0	2	1.5	2	2	4	4	24.0
12#*	427	29.90	5.49	5.5	40	35	0	0	0	3	1	3	0	1	1	0	0	1	1	1.5	2	1	2	15.5
14	23520						0	0	0	2	0	3	1	0	1	0	0.5	1	1	1	1	0	1	11.5
15	21052						0	0	0	2	1	3	1	0	0	0	0	0.5	0.5	0.5	0.5	0	1	9.0
16#*	953	24.69	5.03	4.9	53	53	0	0	0	3	1	2	0	2	0	1	0	1.5	0.5	1	1	3	5	16.0
17#*	*1676*	*26.24*	*6.49*	*4.0*	*45*	*25*	*0*	*0*	*0*	*3*	*1*	*3*	*0*	*0*	*2*	*0*	*0.5*	*2*	*2*	*1*	*1*	3	5	*18.5*
18	27351	6.13	1.83	3.4	80	80	ML	ML	GP-SP	2	0	2	0	1	1	1	1.5	1.5	1.5	2	2	0	1	15.5
19	25822	4.57	1.55	2.9	80	80	ML	ML	GP	2	0	3	2	2	2	1	1	1.5	1.5	1	1	3	5	21.0
20	23355	2.74	0.91	3.0	65	80	ML	ML	GP-SP	2.5	0	2	0	2	1	1	0.5	1	1.5	2	2	0	1	15.5
21	13836	25.00	6.30	4.0	35	64	ML-CL	ML-CL	CL-BR	4	2	4	0	2	2	2	2	1.5	1.5	2	2	4	4	29.0
22	16605	30.00	5.00	6.0	33	75	ML	ML	CL-SP	4	1	4	0	2	2	1.5	1.5	2	2	2	1.5	4	4	27.5

\# *Located below weirs and subject to Cache River backwater*

* *Reconnaissance Sites*

mostly Stage I (1 of the 13 sites were listed as Stage V). This would generally characterize Big Creek as proceeding through the stages of channel evolution starting upstream of its confluence to downstream of I-57 and pre-modified conditions upstream of I-57. The ‘degree of floodplain separation’ (incision) values had a range of 3-4 downstream of I-57, where stage of channel evolution values were predominantly Stage IV (threshold). Upstream of I-57, where Stage I (pre-modified) dominated the area, the degree of floodplain separation values ranged from 2 to 4. However, high degrees of floodplain separation are not compatible with Stage I channels. Field notes (April – October 2003) indicated dry gravel beds at many of these Stage I sites. The degree of floodplain separation is based on the percent of the relative elevation of normal low flow with respect to the floodplain or terrace being 100% of the elevation. Since “normal” low flow in this karst area is technically “no” flow, a dry bed would be 0% of the elevation and result in a very high degree of floodplain separation.

Basic channel morphology data on bank material showed that, except for a few sites noting bedrock on one bank, silt and clay are the dominant bank material throughout the channel length. The percent of bank erosion was unevenly distributed throughout the watershed. Most of the sites had greater than 50% of the banks covered in woody vegetation. The occurrence of bank/bar accretion was also unevenly distributed.

3. 1.4 Results of Watershed-Scale Characterization

The watershed-scale characterization was able to reveal that indirect and direct influences have occurred in the Big Creek watershed. Row crop land cover, which tends to increase runoff, was shown to have increased in the 1970s and is now the dominant agricultural land cover. Anecdotal information indicated that sod-covered, low-erosion fruit orchards were prevalent in the mid-20th century and by 1999 accounted for only 0.3% of agricultural land cover. Flow duration analysis shows a noticeable increase in low flows between WY1940-1971 and WY1985-1998, which was shown to not be associated with any trends in climate. The shift in high-runoff land cover (row crop production) seems to be supported by this increase in low flows. Severe channelization occurred between 1920 and 1945 in the lower reaches of Big Creek where 58% of the channel length was removed. Between 1945 and 1998 there were minor changes in planform, most likely due to variation in scale and quality of the topographic maps and aerial photographs used for the analyses. There seems to be no other channelization efforts since 1945.

Analysis of the basic channel morphology data and channel-stability indices indicates there are two types of channel adjustments occurring in Big Creek (Table 3.3). Most channel features group into two distinct regions of the Big Creek watershed, lower and upper, generally divided where I-57 crosses Big Creek. The channel in the lower reaches have adjusted through incision and widening following the model of channel evolution, while the upper reaches seem to have been widening with minor meander extensions. The lower reaches are ranked as having high potential for critical instability, passing through stage IV channel evolution and have high degrees of incision. These reaches have a narrow range of width/depth ratios, deep average channel depths, bed material ranging from sand to silt-clay, bank material is predominantly silt-clay, mass-wasting is the mechanism of bank erosion, and bank angles average 34 degrees. In contrast, the upper reaches are ranked as having stable channels under natural fluvial processes (stage I), high degrees of floodplain separation, wide ranges of width/depth ratios, shallow average channel depths, gravel to bedrock channel beds, predominantly silt-clay bank material, fluvial processes are the bank erosion mechanism, and wide ranges of bank angles.

The channel features in the lower reaches of Big Creek seem to complement and support each other. The narrow range of width/depth ratios is a reflection of the channelization history in the area. The symmetrical 34-39 degree bank angles in silt-clay banks may be indicative of channel widening to accommodate excess stream powers. Even though the degree of floodplain separation is high and the banks are experiencing geotechnical failures, field notes indicate fairly flat channel beds, which may be indicative of late-stage IV (threshold) channels.

The several basic channel morphology and channel indices results for the upper reaches of Big Creek show distinctly different channel response mechanisms. The resistant channel beds (bedrock), shallow average channel depths, wide range of width/depth ratios, as well as higher ratio values, low and high angle banks paired within reaches, silt-clay bank material, and fluvial erosion processes, may be indicators of a stream channel tending toward lateral migration or widening. Also, the degree of floodplain separation was not a relevant morphologic feature to consider in areas with karst or resistant/armored channel beds. However, the juxtaposition of this variable against other index variables shows it to be a strong indicator of channel adjustment processes other than incision.

The estimated sedimentation rates in the Cache River-Cypress Creek Wetlands (Keefer et al., 2006) have not appreciably shifted between 1963 and 2002. Because Big Creek is the major contributor of sediment to the wetland (Demissie, Soong et al., 1990b), the wetland sediment rates are assumed to be representative of sediment delivery from Big Creek. This implies that Big Creek has been slowly adjusting from at least 20 years after channelization to present; nearly 40 years. However, channel adjustment rates immediately following channelization are still unknown, although the influence of the six dams (control structures) installed during channelization should be considered and may support an assumption that adjustments for the first 20 years after channelization were also slow. This could imply that the evolution to relatively stable channels in lower Big Creek could take several more decades.

The overall evaluation of the watershed-scale characterization results gives reasonable evidence that long-term, system-wide adjustments are active in the lower watershed due to severe channelization of the lower watershed channel and the conversion of upper watershed landscapes to high runoff land use practices. These adjustments are progressing through stages of channel evolution (Simon, 1989). Stage IV produces the highest erosion in the channel evolution process, although stage V channels will continue to erode the channel through mass bank failures during the widening process. Flattening of bank angles and bed-level recovery are indicators of restabilization stage VI. Based on the geologic controls in the upper watershed (bedrock beds), it is unlikely that channel incision will migrate upstream of I-57. A more detailed and focused field investigation needs to be performed in the lower and middle reaches of Big Creek to provide quantitative and defensible information for resources managers to base future best management practices.

3.1.5 Discussion of Method

This watershed-scale characterization method used several techniques of investigation as reported by Trimble and Cooke (1991), Simon and Downs (1995), Trimble (1998), and Rhoads (2003). These techniques were compiled to provide a watershed-scale context of past and current channel conditions thus discovering the process-response mechanisms responsible for the current channel character.

The historical analysis technique was significant in identifying several physical controls and anthropogenic influences which have had a profound effect on Big Creek over the last 100 years. The comparison, contrasting, and supplementation of the elements in this technique (Table 3.1) were instrumental in reconstructing the channel character over time. Investigation of the physiography, geology, and surficial materials in the watershed revealed major physical influences on the type of channel adjustments encountered. The most significant of which is the difference between two major physiographic provinces. The lack of any trends in climate in combination with the flow duration analyses provided evidence that the changes in low-flow duration were controlled by changes in land use. Linking agricultural crop acreage with current land cover information allowed for extrapolation of land uses to the early part of the 1900s to document indirect influences. Even though information from early and current county soil survey books was anecdotal, it supplemented and supported the trend in land use conversion that appears to have been responsible for the increase in low-flows over the last 30 years. The removal of major channel lengths in the lower reaches of Big Creek was documented by four elements: 1) historical and recent aerial photography, 2) historical 15-minute topographic map, 3) engineering plans accounting for most of the channelization projects, and 4) narrative accounts. The aerial photography and topographic maps clearly documented the channel shortening over time; however the engineering plans and narrative account confirmed the cause as channelization. Inspection of aerial photography between 1938 and 1999 concluded no significant changes in planform. The channelization engineering plans contained pre- and post-project channel geometry and gradient, albeit for the lower channel reaches only, which determined some sites selected for the initial field survey. Studies by Demissie and others (1992), Allgire and Cahill (2001), and Keefer and others (2006) provided a unique opportunity to approximate a rate of channel adjustment responding to direct and indirect influences documented in the historical analysis.

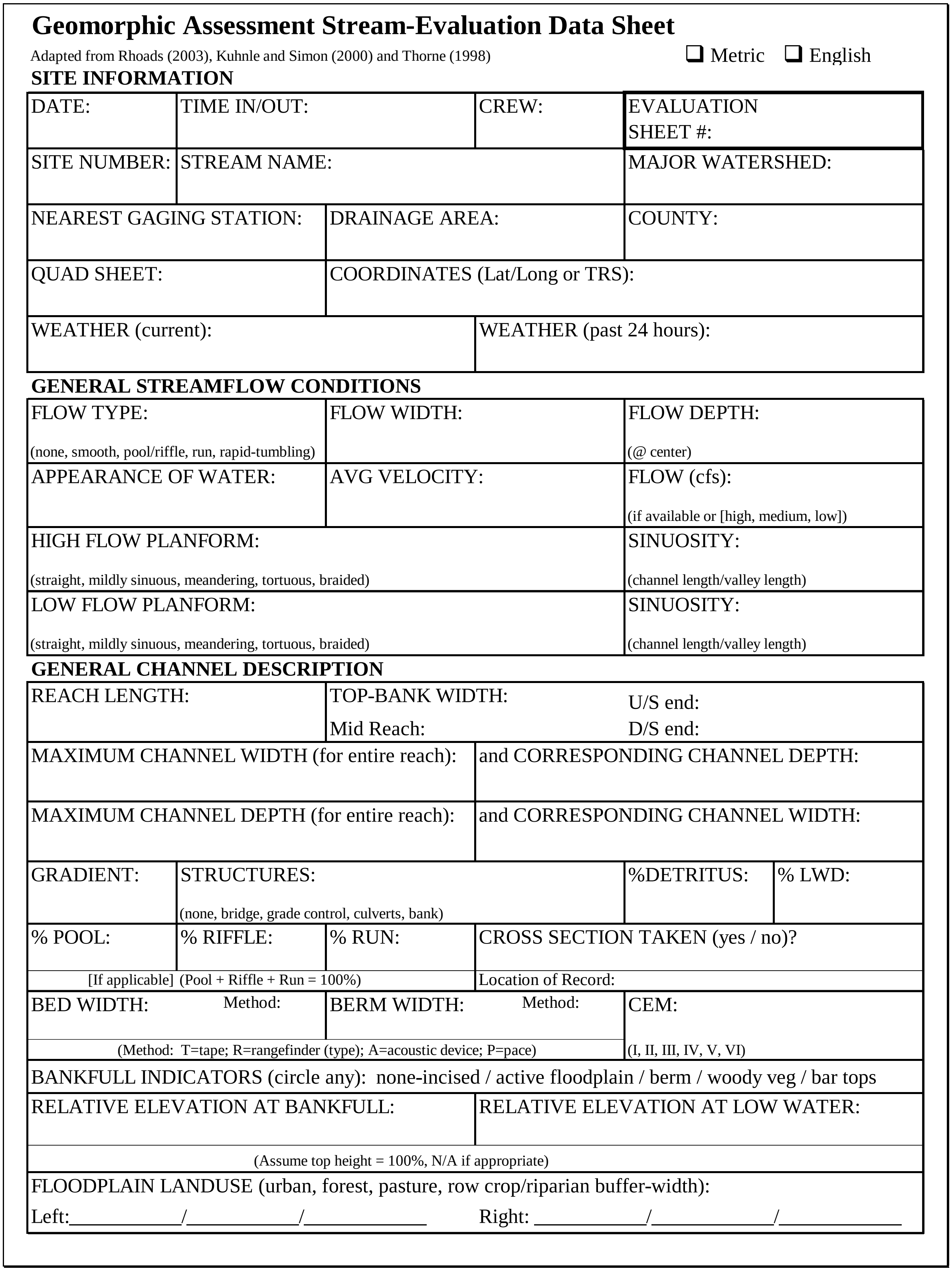
The initial field survey confirmed a channel character that was expected from the historical analysis. The physiographic control was apparent in the rapid measurement of reach channel geometry and the channel-stability ranking scheme. Most channel measurements and characteristics showed an appreciable relative difference in the vicinity of where I-57 crosses Big Creek. The channel-stability ranking scheme was originally developed for use in bridge scour investigations where channel incision and widening was the prevailing style of channel response to disturbances. This is obviously the style of channel response in the lower reaches of Big Creek and, except for the abrupt change in geology resulting in resistant beds, most likely would have been the response in the upper reaches due to increased gradient and erodible bank material. The field survey measurements were rough and not meant to determine channel stability in isolation. Therefore, the utilization of the basic channel data and channel-stability ranking scheme was confined to evaluating the relative differences between the 22 stations to determine the spatial distribution of channel features. The scheme can be repeated at a later time to evaluate the status of system-wide adjustments. Channel adjustment rates were roughly determined as slow for Big Creek, on the order of decades, consequently the field survey would be most informative when performed in approximately 10 years.

As discussed above, the historical analyses and initial field survey provided a respectable evaluation of the current physical character of the Big Creek watershed, identification of direct and indirect influences, and detected changes in the channel character corroborating the identified influences. Big Creek is a well-studied watershed with a wealth of historical engineering and hydrologic data and recent sediment studies, which proved to be an advantage for this characterization. However, even these advantages were sporadically located throughout the watershed, showing that even a watershed with this much information suffers the same drawbacks as other watersheds: temporally and spatially inconsistent datasets (Kondolf and Downs, 1996). The application of this watershed-scale characterization in watersheds with little or, more likely, no hydrologic, sediment, and channelization data will have limitations when determining results. Because the channel-stability ranking scheme was developed for channels that adjust through stages of channel evolution, it is unclear how applicable it will be in channels that respond differently to disturbances. However, this scheme may still prove useful when a spatial distribution of channel features is not apparent. Performing the initial field survey still serves as a systematic way to inspect the channel being investigated, provides for rough channel measurements, and, when contrasted with the historical analyses, could focus efforts on localized instabilities for more intensive reconnaissance.

3.2 Reach-Scale Characterization

There are two objectives of a reach-scale characterization. The first is to document the extant character of stream channels in the watershed by collecting field data on channel morphology. The second is to collect data that spatially coincides with historical site data compiled in the watershed-scale characterization and that allows for temporal evaluation of the study area. The objectives are accomplished by collecting and recording detailed, quantitative data at a subset of sites drawn from the initial field survey. These sites are hereafter referred to as “reconnaissance sites”. Several factors are used to select the reconnaissance sites: representativeness of channel adjustment trends revealed in the watershed-scale characterization, such as spatial variations in bed and bank material or physiography; comparable historical data to document temporal changes in channel morphology; accessibility; and resources.

Field visits to reconnaissance sites will determine the segment of stream reach to collect and record information identified in the Geomorphic Assessment Stream-Evaluation (GASE) data sheets (Figure 3.12). The definition of a ‘reach’ used in this study follows Thorne (1998, p. 50): that it represent a single geomorphic unit (i.e. pool-riffle sequence) and ideally covers a length of 5-10 times the channel width. The GASE data sheets are an integration of methods from Kuhnle and Simon (2000), Rhoads (2003), and Thorne (1998). The main purpose of a formal field data sheet is to serve as a permanent, standardized record of a site for a specific period in time, as well as provide supporting information for a final evaluation of the stream dynamics (Thorne, 1998;



Geomorphic Assessment Stream-Evaluation Data Sheet

Adapted from Rhoads (2003), Kuhnle and Simon (2000) and Thorne (1998) ☐ Metric ☐ English

SITE INFORMATION

DATE:	TIME IN/OUT:	CREW:	EVALUATION SHEET #:
SITE NUMBER:	STREAM NAME:		MAJOR WATERSHED:
NEAREST GAGING STATION:	DRAINAGE AREA:		COUNTY:
QUAD SHEET:	COORDINATES (Lat/Long or TRS):		
WEATHER (current):		WEATHER (past 24 hours):	

GENERAL STREAMFLOW CONDITIONS

FLOW TYPE: (none, smooth, pool/riffle, run, rapid-tumbling)	FLOW WIDTH:	FLOW DEPTH: (@ center)
APPEARANCE OF WATER:	AVG VELOCITY:	FLOW (cfs): (if available or [high, medium, low])
HIGH FLOW PLANFORM: (straight, mildly sinuous, meandering, tortuous, braided)		SINUOSITY: (channel length/valley length)
LOW FLOW PLANFORM: (straight, mildly sinuous, meandering, tortuous, braided)		SINUOSITY: (channel length/valley length)

GENERAL CHANNEL DESCRIPTION

REACH LENGTH:	TOP-BANK WIDTH: Mid Reach:	U/S end: D/S end:

MAXIMUM CHANNEL WIDTH (for entire reach):	and CORRESPONDING CHANNEL DEPTH:
MAXIMUM CHANNEL DEPTH (for entire reach):	and CORRESPONDING CHANNEL WIDTH:

GRADIENT:	STRUCTURES: (none, bridge, grade control, culverts, bank)	%DETRITUS:	% LWD:

% POOL:	% RIFFLE:	% RUN:	CROSS SECTION TAKEN (yes / no)?
[If applicable] (Pool + Riffle + Run = 100%)			Location of Record:

BED WIDTH: Method:	BERM WIDTH: Method:	CEM:
(Method: T=tape; R=rangefinder (type); A=acoustic device; P=pace)		(I, II, III, IV, V, VI)

BANKFULL INDICATORS (circle any): none-incised / active floodplain / berm / woody veg / bar tops

RELATIVE ELEVATION AT BANKFULL:	RELATIVE ELEVATION AT LOW WATER:
(Assume top height = 100%, N/A if appropriate)	

FLOODPLAIN LANDUSE (urban, forest, pasture, row crop/riparian buffer-width):

Left:___________/___________/____________ Right: ___________/____________/____________

Figure 3.12. Geomorphic assessment stream-evaluation (GASE) data sheet used in reach-scale characterization.

CHANNEL BED DESCRIPTION

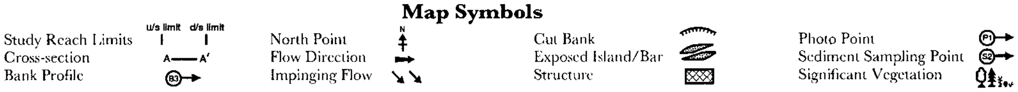
BED MORPHOLOGY: (flat, uniform; scour holes; pool-riffle sequence)	BED CONTROLS: (none; bedrock; cohesive materials; armoured; structure; rip-rap)
PRIMARY BED-MATERIAL TYPE:	SECONDARY BED-MATERIAL TYPE:

(GP=gravel; SP=sand; ML=silt; CL=clay; BR=bedrock)

POOL SUBSTRATE: (GP with firm SP; Soft SP with ML-CL; All ML-CL; All SP; Hard Pan CL; Rock)	ACTIVE BED DEPOSITION: (GP-SP, SP, ML, CL)

BED EXPOSED: (% Area out of water)	EXPOSED BED FORMS: (attached point bar, mid channel, alternate)	
KNICKPOINT PRESENT? (Yes / No)	HEIGHT:	MATERIAL: (GP, SP, ML, CL, BR)

Planform Sketch:



SEDIMENT SAMPLES:	CH________	CH________	CH________	CH________

Figure 3.12. Continued.

LEFT BANK DESCRIPTION

REACH TYPE: (I=inside; O=outside; S=straight	BANK HEIGHT: (average or range)	BANK ANGLE: (average)
WIDTH OF RIPARIAN ZONE:	% WOODY COVER:	% HERBACEOUS COVER:

BANK SURFACES (yes, no):

VF__________ UB__________ SL__________ DS__________ CB__________ CS/Bar_______

(VF=vertical face; UB=upper bank; SL=slough line; DS=depositional surface; CB=cutbank; CS/Bar=channel shelf)

HEIGHT OF VF:	HEIGHT OF CB:	DIST. OF TENSION CRACK FROM VF:

SURFICIAL MATERIAL:

VF_____/_____ UB_____/_____ SL_____/_____ DS_____/_____ CB_____/_____ CS/Bar___/____

(Origin / Type) (I=insitu, D=deposited, F=failed / CL=clay, ML=silt, SP=sand, GP=gravel)

TYPE OF ACCRETED SEDIMENT (N=none, SP=sand, ML=silt, CL=clay):

DOMINANT TYPE OF EROSION PROCESS ON:

VF__________ UB__________ SL__________ DS__________ CB__________ CS/Bar_______

(N=none-stable, MW=mass wasting, F=fluvial erosion, S=sapping, D=deposition)

Bank Sketch:

Profile Symbols

SEDIMENT SAMPLES:	LB_________	LB_________	LB_________	LB_________

Figure 3.12. Continued.

RIGHT BANK DESCRIPTION

REACH TYPE: (I=inside; O=outside; S=straight	BANK HEIGHT: (average or range)	BANK ANGLE: (average)
WIDTH OF RIPARIAN ZONE:	% WOODY COVER:	% HERBACEOUS COVER:

BANK SURFACES (yes, no):

VF__________ UB__________ SL__________ DS__________ CB__________ CS/Bar_______

(VF=vertical face; UB=upper bank; SL=slough line; DS=depositional surface; CB=cutbank; CS/Bar=channel shelf)

HEIGHT OF VF:	HEIGHT OF CB:	DIST. OF TENSION CRACK FROM VF:

SURFICIAL MATERIAL:

VF_____/_____ UB_____/_____ SL_____/_____ DS_____/_____ CB_____/_____ CS/Bar___/____

(Origin / Type) (I=insitu, D=deposited, F=failed / CL=clay, ML=silt, SP=sand, GP=gravel)

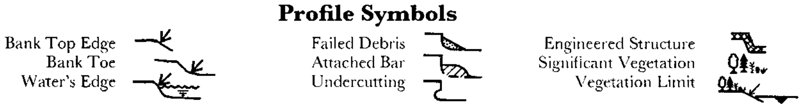
TYPE OF ACCRETED SEDIMENT (N=none, SP=sand, ML=silt, CL=clay):

DOMINANT TYPE OF EROSION PROCESS ON:

VF__________ UB__________ SL__________ DS__________ CB__________ CS/Bar_______

(N=none-stable, MW=mass wasting, F=fluvial erosion, S=sapping, D=deposition)

Bank Sketch:



SEDIMENT SAMPLES:	RB________	RB________	RB________	RB________

Figure 3.12. Continued.

PHOTOGRAPHIC RECORD

DATE:	CAMERA TYPE:	PHOTOGRAPHER:

PHOTO CHECKLIST:

☐ U/S
☐ Channel Bed
☐ Structures
☐ Mid-reach
☐ Left Bank
☐ LB Riparian
☐ D/S
☐ Right Bank
☐ RB Riparian

Remember: add a recognizable scale in all pictures; record photo number; and time of day (shadows)

PHOTO #	DESCRIPTION

MISCELLANEOUS OBSERVATIONS

Figure 3.12. Continued.

FIELD CHECKLIST

☐ Binoculars
☐ Bottled water
☐ Calculator
☐ Camera (preferrably digital)
☐ Cell phone
☐ Clipboard (field sheets)
☐ Compass (Silva/Brunton)
☐ Field backpack
☐ Field book
☐ Field Sheets
☐ First-aid kit (small)
☐ Geologic hammer
☐ Grain size chart
☐ Gravelometer
☐ Handheld GPS
☐ Increment borer
☐ Insect repellent
☐ Laser rangefinder
☐ Level (Abney level/clinometer)
☐ Map: Air Photos
☐ Map: Bedrock
☐ Map: Plat (landowner info)
☐ Map: Road atlas
☐ Map: Surficial materials
☐ Map: Topographic
☐ Measuring tape/stakes/pins
☐ Pocket Rod/Surveying Rod/Range Pole/Staff
☐ Probe rod (tile probe, etc.)
☐ Raingear
☐ Soil Probe (bank sampling)
☐ Trenching tool/plastic bags/permanent marker
☐ Wading boots

☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________
☐ ______________________

Figure 3.12. Concluded.

Rhoads, 2003). Most of the information on the data sheets is qualitative in nature, such as sketches of bed and bank forms and photographs of channel features for documentation, but is more focused and detailed than data collected in the initial field survey. The purpose of photographs in this characterization is to capture features missed during the initial field survey, replicate views from historical photographs, and provide a more complete visual document for future assessments (Rhoads, 2003). The quantitative information includes several surveyed channel cross-sections, collection of bed and bank material for particle size distribution analysis, and estimates on the extent and type of riparian vegetation.

The GASE data sheets have 5 main components: 1) general reach information, 2) channel bed description, 3) left and right bank descriptions, 4) photographic record, and 5) field equipment/supply checklist. Most of the site information can be retrieved in the office but the exact extent of the selected reach needs to be determined in the field. The first component covers site information, general streamflow conditions, and general channel description. The general streamflow conditions are made by observation and streamflow measurements. Most of the information in the general channel description section can be determined from surveyed cross-section measurements. The number and placement of surveyed cross-sections within a reach is dependent on the uniformity of bank and bed features and available historical data locations. Floodplain landuse for both sides of the channel are also noted.

The second component covers channel bed information that describes bed morphology and controls, primary and secondary bed-material types, pool and exposed-bed material and forms, planform sketch, and record of bed material samples. The left and right bank components include information on bank geometry, distinct bank shapes and associated material, geotechnical indicators, riparian zone vegetation, dendrogeomorphic indicators, erosional and depositional processes, bank sketch, and record of bank material samples. The use of dendrogeomorphic techniques to date geomorphic events, such as flooding, mass wasting of banks or significant accreted sediment, has been useful in evaluating degrading and aggrading stream environments (Hupp and Simon, 1991; Simon and Hupp, 1992; Hupp and Osterkamp, 1996; Hupp, 1999; Hupp and Bornette, 2003). The photographic record includes a checklist of minimally required channel features with a recognizable scale. Finally, expanding on the *Stream Reconnaissance Handbook* by Thorne (1998), a checklist is included for field equipment and supplies required to complete the data sheets.

3.2.1 Reach-Scale Characterization Data Sources

The reach-scale characterization is dependent on the data sources and results of the watershed-scale characterization (Appendix A). Spatial distribution of channel adjustments, as indicated by the watershed-scale characterization, is the initial step in the reconnaissance site selection process. Multiple physically-based data sources from the historical analysis and initial field survey are then used to focus on areas of geomorphic significance in the adjustment processes. Data sources from the historical analysis are physiographic boundaries, surface and bedrock geology, land cover, and channel disturbance history. Many of these data sources reveal underlying physical controls which can strongly influence style and rate of channel adjustments. From the initial field survey, pronounced changes in channel character are used to establish zones of geomorphic uniformity. The data sources include the relative changes in bed and bank material character, channel geometry, and vegetation throughout the stream network. Once the sites are selected based on the integration of these multiple data sources, the GASE data sheets (Figure 3.12) are the only other data source used in the reach-scale characterization.

3.2.2 Big Creek Case Study: Reach-Scale Characterization

A reach-scale characterization was performed for the Big Creek stream channel. The following is a presentation of the data collected at the reconnaissance sites using the GASE data sheets (Figure 3.12 and Appendix D), results of the characterization for Big Creek, and discussion of the performance of the reach-scale characterization method.

The eight sites selected for field reconnaissance for the Big Creek watershed were distributed between the two general regions identified in the watershed-scale characterization (Figure 3.9). Two sites are in the upper Big Creek region (BC-1a and 5) and six in the lower region (BC-7, 8, 10, 12, 16, and 17). Three of the six (BC-12, 16, and 17) are near the confluence with the Cache River. Site BC-10 is within the reaches containing the 6 dam structures (located between dams 3 and 4) and sites BC-7 and BC-8 are upstream of dam 6. Three of the lower region sites (BC-8, 10, and 17) had historical cross-section and elevation data. Three sites (BC-7, 12, and 16) were included mainly to extend bed elevation data for a stream profile that was taken in 1999 and 2003 by the ISWS.

Upper Region. The upper Big Creek region sites bound the karst reach known to influence low flow discharges. Site BC-1a is the reach with the highest width/depth ratio (10.0) and lowest bank angles (20 and 29, left and right). The channel planform is mildly sinuous with typical bar unit sequences (pool, riffle and pointbar channel forms). The channel bed forms are predominantly gravel and nearly 75% of the bed is exposed in the downstream portion of the reach. The base of the meander cutbanks in the reach exposes a 0.25-0.5m layer of gravel. The gravel is similar in bed material size and near the same elevation as the channel bed (field estimated d_{50} range of 32-45 mm). A thin rod was used to probe the channel bed to indicate possibility of armoring. The rod could not penetrate the gravel to any notable depth. In the bank the gravel is overlain by 1.5-2.0 m of a silty-clay loess (d_{50} = 0.022 mm). The riparian corridor is approximately 15 m wide with 15% woody cover (mostly shrubs) on the left bank and nearly 100% herbaceous cover on the right.

Site BC-5 is 6247 m downstream of BC-1a and 50 m upstream of the ISWS #500 streamgage. Unlike BC-1a, the reach is straight with pool/riffle/run sequences in the low-flow channel and few detached bars. Approximately 25-30% of the gravel bed (d_{50} = 45 mm) is exposed and a rod penetrated the gravel to a depth of 20 cm indicated a loose and mobile bed. Inspection of ISWS #500 photographs from 1999 and 2003 (Figure 3.13) show some shifts in the channel form features mostly indicated by displacement of gravel. The left bank is mostly bedrock and the right is steep (2.5 m high) with the same median bank material as BC-1a (0.022 mm). There is no evidence of the gravel layer that was present in the banks at BC-1a. The left bank riparian zone is >10 m with 40% woody cover (mostly trees). The right bank has a narrow riparian zone (3 m) composed of 30% woody cover, and beyond that a rowcrop field. The pools within the site reach are shallow (< 0.3 m). However, a brief inspection downstream of ISWS #500 (past ISWS #500), revealed much deeper pools (0.5-1.0 m). The bed in these deeper pools is mostly a silt/sand mix with some pebbles and the probe penetrated the bottom by 15 cm.


a) 1999 upstream view from ISWS #500

b) 2003 upstream view from ISWS #500

c) 1999 downstream view from ISWS #500

d) 2003 downstream view from ISWS #500

Figure 3.13. Upstream and downstream views from ISWS #500 for 1999 and 2003.

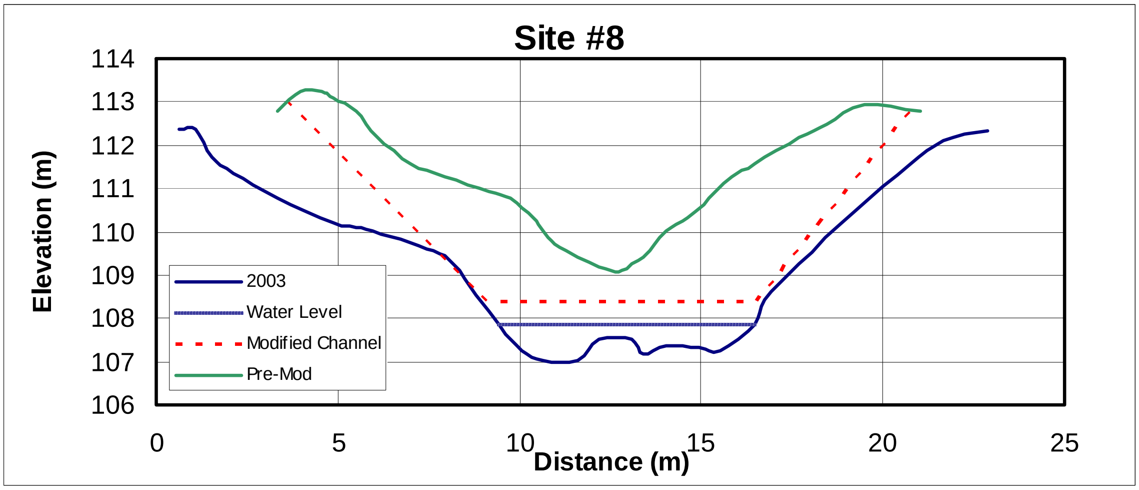
Lower Region. The median particle size for bank material throughout the lower Big Creek region ranges from 0.012 to 0.022 mm (fine- to medium-silt). Bank angles are somewhat varied and average 30 to 35 degrees. The channel width, depth, and bank angles at BC-7 and BC-8 are very similar. Probing of the channel bed at BC-7 revealed approximately 0.5 m of loose sand (d_{50} = 0.35 mm) overlying a firm clay, which was penetrated by 5 cm. The channel bed at BC-8 is a firm, mottled clay overlain by a thin layer of loose silt. The BC-10 channel bed is flat and composed of firm clay. Probe penetration of the bed at BC- 8 and 10 was limited to ~5 cm. The median bed particle size at BC-10 is approximately 0.0029 mm. Site BC-17, 12, and 16 median bed material size is 0.5 mm. The water depth at these sites averaged 2.5 m and required a boat to survey cross-sections and collect bed material samples using a Ponar grab sampler.

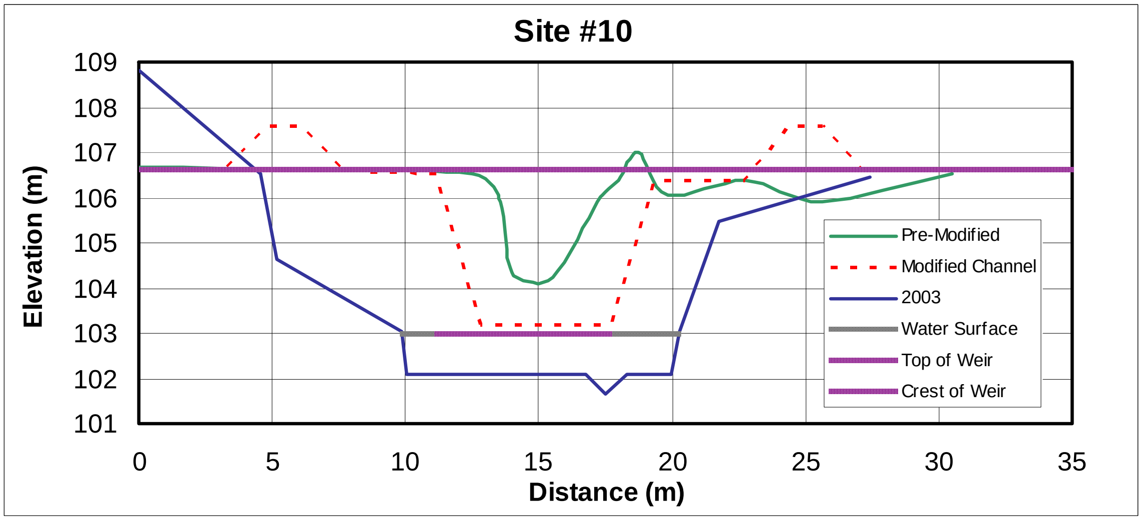
Woody vegetative cover (trees) on the channel banks ranged from 10% to 40%. The BC-8 reach was fairly straight and most of the trees on the left bank are rotationally slipping down the bank. Several tilt sprouts were cut from two trees and rings indicated 1 and 5 years since the bank failures. Two gullies were noted as migrating 0.5-1m into the agricultural field from the top of the left bank. Both banks have 15% woody (tree) cover. The BC-10 right bank was 40% covered with trees down to the edge of water, whereas the left alternated between patches similar to the right bank or fully exposed failing banks. Most of the trees in this reach were estimated to be about 20 years old with the oldest ones having diameters of 0.6 m. Woody cover in the reach at BC-17 ranged 25-30% with only trees and no shrubs.

Two of the lower region sites (BC-12 and BC-16) are located between BC-17 and the mouth of Big Creek. The water depth in this segment of Big Creek was greater than

2.5 m and could only be accessed by boat. The median bed material at these sites was 0.36-0.38 mm. These sites also have similar width and depths as BC-17. Site BC-16 had much higher bank angles (53 degrees) than BC-17 and BC-12. This site has active bank failures by mass wasting and observable accretion and fluvial reworking on the failed material at the bank toe. Sites BC-16 and 12 are known to be heavily influenced by flood backwater from the Cache River. A subsequent geotechnical bank study performed by the ISWS and NRCS at BC-16 revealed that the failures are due to a highly plastic clay layer at the base of the bank and is exacerbated by positive pore-water pressure due to flood backwater from the Cache River.

The first of the three historical sites is BC-8, near Shake Rag Road. Site BC-10, the second site, is 5803 m downstream of BC-8 and the third (Site BC-17) is 2269 m downstream of BC-10 (Figure 3.14). Sites BC-8 and BC-17 are upstream and downstream, respectively, of the 6434-m reach that contains the six dams. Site BC-10 is between dam 3 and 4. Currently, BC-10 has a smaller channel width and depth, lower width/depth ratio, and larger channel-bed width than the other two sites. For these same channel geometries, BC-17 is slightly larger than BC-8. It should be noted that the confluence of lower Little Creek (watershed area of 41 km^2) with Big Creek occurs approximately 500 m upstream of BC-17. Undisturbed, channelized, and current cross-section data exist at BC-8 and BC-10, except BC-17 which does not have undisturbed data (Figure 3.14). The channelization projects at BC-8 and BC-10 resulted in a 1 m lowering of the channel bed and a 15% to 32% increase in channel width. Since channelization, the channel bed lowered 1 m at BC-8 and BC-10 and 2 m at BC-17. Channel width increased by 27% at BC-8 and doubled at BC-10 and BC-17.





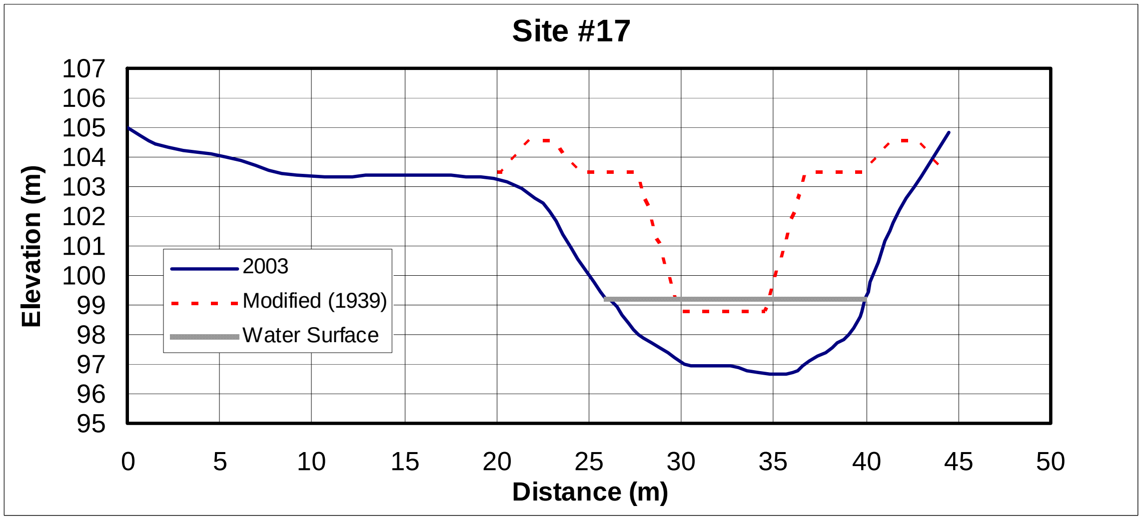


Figure 3.14. Pre-channelization, channelization, and 2003 cross-sections and elevations for Sites BC-8, 10, and17.

3.2.3 Results of Reach-scale Characterization

The information collected at the reconnaissance sites for the reach-scale characterization expands upon results of the watershed-scale characterization. New information acquired from the reach-scale characterization includes patterns in channel bed composition, dendrogeomorphic indicators of geomorphic events, and correlations in particle size distributions.

Analysis of the bed material results indicates a downstream change in particle size. The BC-1a channel bed consists of gravel and exhibits armoring. It is reasonable to assume that the gravel layer in the lower banks, which is very similar in character to the gravel bed, is the source of this bed material. The channel bed at BC-5 has this same size gravel but is loose and actively shifting. The initial field survey site photographs and index sheets at BC-2, 3, and 4, between BC-1a and 5, indicate gravel and/or exposed bedrock channel beds with a gravel layer in the base of the banks at BC-2 and 3. The channel width doubles after the confluence of Upper Little Creek and Big Creek where the gravel channel bed becomes braided. A large cutbank farther downstream does not expose a gravel layer as seen upstream of BC-5. However, the channel bed composition changes to almost equal parts of sand and gravel which is penetrated by a probe to approximately 0.5 m. The lower region of Big Creek has firm clay beds at BC-7, 8, and 10 with 0.5 m of loose sand overlying the bed at BC-7 and thin layers of silt at all downstream sites.

This information provides evidence of an expected downstream fining of bed material but does not address the source of the fine material which is being deposited in the sensitive Cache River wetlands. Analysis of the bed, bank, suspended sediment, and wetland particle size distributions indicates the median size of the suspended sediment at the ISWS stations is nearly the same as the bank material collected throughout Big Creek (Figure 3.15). The d_{50} at ISWS #500 and #502 ranges from 0.008-0.011mm (fine silt) and 0.019-0.018 mm (fine-medium silt), respectively. These particle sizes fall within 0.012-0.022 mm (medium silt) range of d_{50} for the bank material encountered at all sites. The size of the particles in the Cache River wetlands is fine silt that is being deposited at a rate of 0.79-0.86 cm/yr (Keefer et al., 2006).

Dendrogeomorphic techniques were applied at two sites with significant tree disturbance on the channel bank. Many of the fallen trees were still living and vertical tilt sprouts were dated at 1 and 5 years old. The tilt sprouts were sampled in late-summer 2003 which correlates with the 2002 and 1999 growing seasons. Streamflow records at the ISWS #502 streamgaging station show the last two highest annual peak discharge events occurred in WY2002 (74.5 cms) and WY1999 (69.1 cms) with return intervals of 5- and 4-year, respectively. The next previous annual peak discharge of this magnitude occurred in WY1986 (75.9 cms). It is assumed that the failing banks are the result of these extreme hydrologic events and are either not indicative of a system-wide disturbance or are events that have compounded existing systemic instabilities.

Overall, the reach-scale characterization results have determined that the source of the fines being deposited in the Cache River wetlands is the channel banks throughout the fluvial system. Based on the three studies by the ISWS (Demissie et al., 1992; Allgire and Cahill, 2001; Keefer et al., 2006), it is reasonable to assume that the source of the fines have mostly likely been the Big Creek channel banks since the 1960s. Dendrogeomorphic techniques, in combination with historical streamflow records and

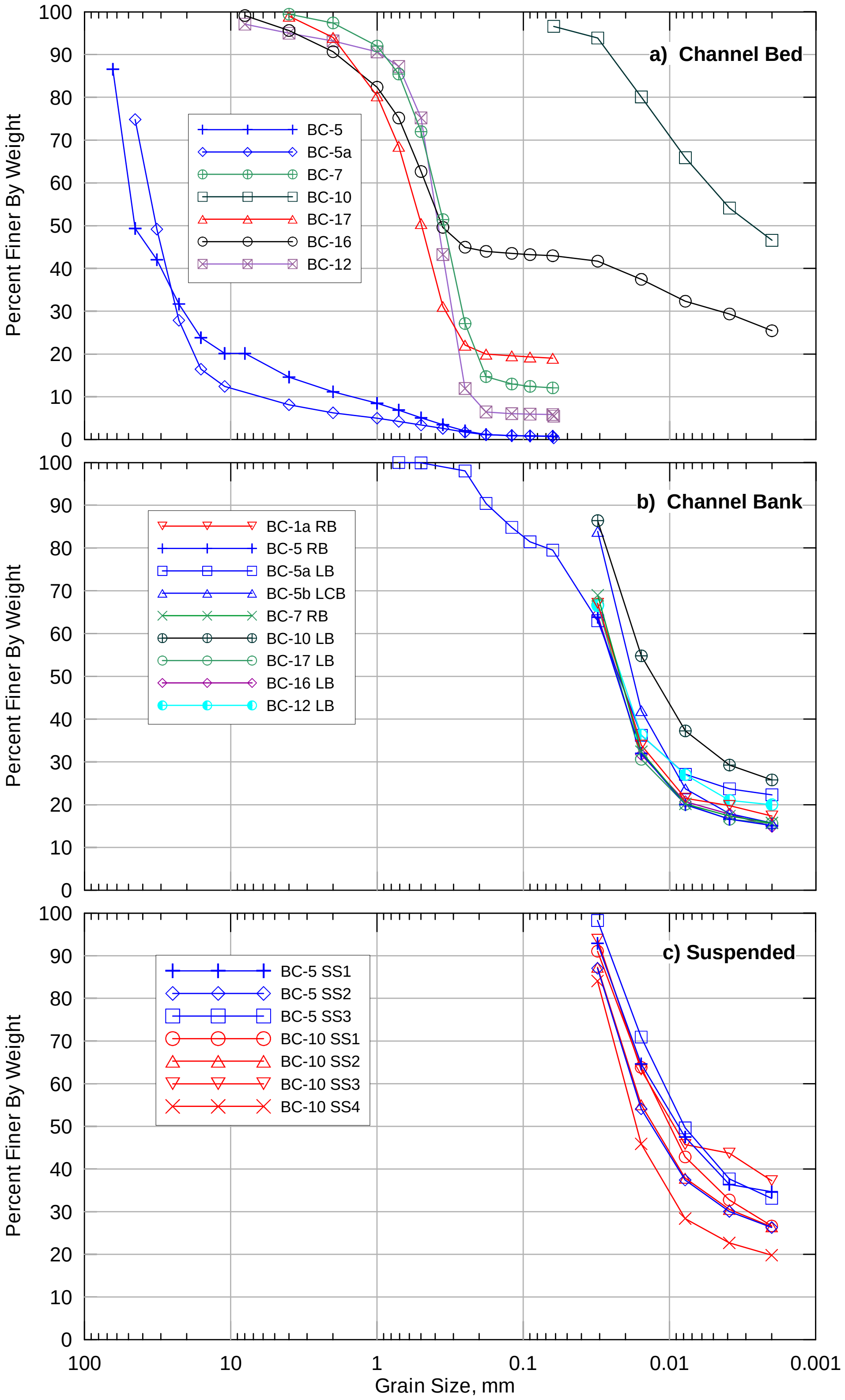


Figure 3.15. Particle size distributions for bed, bank, and suspended sediment material.

sediment-duration curves, have shown that the extreme streamflow events are linked to the massive bank failures in the channel and responsible for the most of the sediment loading to the wetlands. This information will be useful when computing stream power in the channel to determine potential future adjustments.

3.2.4 Discussion of Method

The reach-scale characterization enhanced the watershed-scale characterization by increasing the level of detail of information on channel conditions. The positioning of some reconnaissance sites at the limited historical data locations was critical in demonstrating that the reaches in the lower Big Creek region have deepened and widened since the channelization and control structure projects sixty years ago (Figure 3.14). Even though the particle composition of the banks and bed throughout Big Creek were fairly obvious during the watershed-scale characterization, it was the inclusion of laboratory particle size distribution analyses, coupled with suspended sediment and wetland distributions that determined the banks as the major source of the sediment aggradation in the Cache River wetlands. Adding dendrogeomorphic techniques to areas of known bank failures and being able to link those to streamflow events of a particular frequency and magnitude gave insight to the dominant sediment transport mechanism in the watershed. The sediment-duration curve from Demissie and others (1990b) contributed to this conclusion.

In general, the reach-scale characterization method was an asset for determining the sediment source and transport mechanisms in Big Creek. However, as in the watershed-scale characterization, this study area had the advantage of a historical streamflow and sediment record. In the absence of the particle size data for the suspended sediment and wetland deposits, sampling the wetland bottoms for particle size distribution may lead an investigator to a similar, albeit weaker, conclusion. Regional streamflow equations can be substituted for streamflow records to determine the magnitude of discharges which induce major bank failures. Streamflow records from long-term streamgaging stations are more accurate, therefore the results from regional equations must be used cautiously.

A major advantage to the reach-scale characterization method is the systematic, detailed recording and documentation of key stream channel geometry and morphologic features at important locations throughout the fluvial system. This allows future investigations to repeat the data collection using consistent data collection techniques thereby formulating more conclusive estimates of future channel adjustment processes and rates. This also has application for post-project appraisals of any installed upland best management practices and in-stream restoration efforts.

3.3 Evaluation and Assessment Method

The objective of the evaluation and assessment phase is to analyze the changes in channel character over time to determine potential future adjustments of the stream channel throughout the fluvial system. The watershed- and reach-scale characterizations concentrate on documenting past conditions and extant character of a channel. The temporal and spatial elements compiled in both of these characterizations are used to evaluate the channel responses to direct and indirect influences to date and then extrapolate trends in adjustments to infer the type and magnitude of potential future channel adjustments.

The process for evaluating channel responses is not straightforward due to variations and availability of historical and recent data from one fluvial system to the next. Regardless, this method focuses on a process of documenting and evaluating changes in channel characteristics to infer the causal mechanisms producing the current channel morphology, thereby identifying future potential channel adjustments. The evaluation process is a convergence of several lines of evidence that composes a characterization of expected channel adjustment morphologies by either identifying the type of fluvial and physical environment, determining threshold values of stream power to assess the likelihood of further channel instabilities, or estimating the style of channel adjustment by using channel gradient as a surrogate for type of fluvial environment, whereby the future forms and processes can be inferred (Simon and Downs, 1995). The multiple lines of evidence increase the likelihood of overcoming the absence or limitations of data to make reasonable inferences of future channel morphologies.

The identification of the type of fluvial and physical environment is determined by the watershed- and reach-scale characterizations. These characterizations establish the physical setting of the watershed, disturbance history, channel adjustment process responses, and changes in sediment supply and transport capacity. The evaluation of these characterizations determines the active channel adjustment processes, magnitude, and rate which provide insight into expected channel morphologies.

The likelihood of further channel instabilities can be investigated by determining whether there is available energy to adjust the channel. The information collected at the reach-scale reconnaissance sites is used to estimate stream power at those sites. When independent variables of hydrology and sediment supply are available, hydraulic modeling may be used as an additional tool to further analyze specific reaches for potential channel instabilities. Hydraulic modeling may be performed at critical reaches for streamflows as indicated by the watershed- and reach-scale characterizations. Dendrogeomorphic indicators can be used to roughly determine channel adjustment rates. Identifying the probability of occurrence of channel forms as described by Bledsoe and Watson, 2001) can be used to determine the likelihood of other channel forms.

The last line of evidence is the use of channel gradient as a surrogate for the type of fluvial environment to estimate the style and magnitude of future channel adjustments. This approach by Simon and Downs (1995) assumes that channel adjustment processes are associated with various fluvial environments (Simon and Downs, 1995; p. 227). They describe an empirical relationship between the ratio of the change in channel width to change in channel depth (index of channel change, I_c) and disturbed channel gradient for diverse fluvial systems (low-gradient, coastal plain, and upland-alpine regions). The relationships vary along a bell curve according to the fluvial environment (Figure 3.16; from Simon and Downs, 1995; p.230,). Briefly, proceeding from left to right of the curve, low gradient channels such as those found in lowland, coastal plain streams adjust vertically due to finer, cohesive channel material; higher energy, steeper streams with gravel beds tend to adjust laterally and produce wide and shallow channels; and finally very steep, mountainous upland streams adjusts vertically due to very coarse beds and shallow high-velocity streamflows (Simon and Downs, 1995; p. 229). By combining the disturbed channel gradient from this relationship with the observed channel character, the expected channel adjustments can be more narrowly determined when used with the two other lines of evidence discussed above.

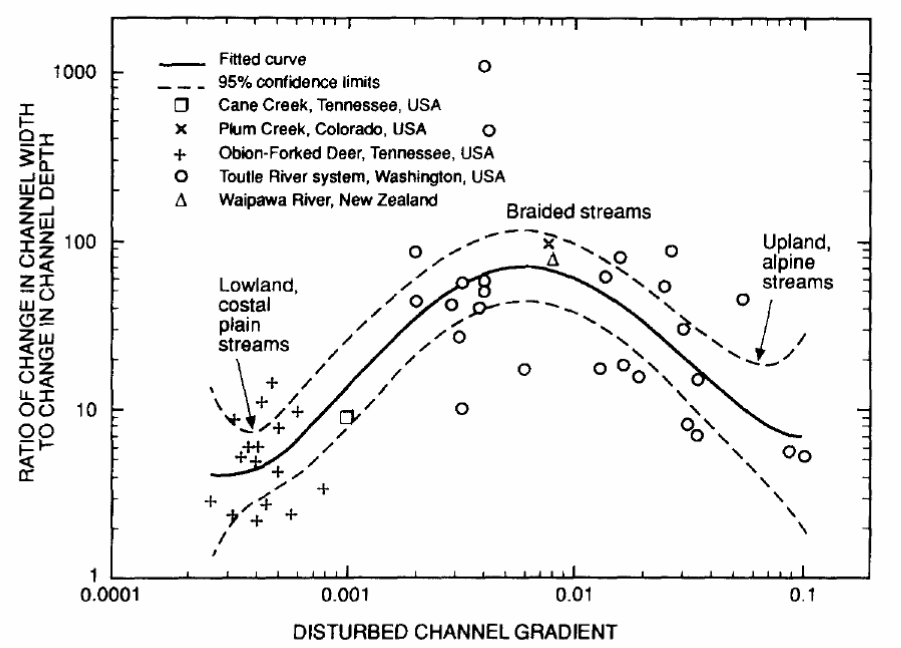


Fig. 3.16. Change in channel morphology as a function of disturbed channel gradient and fluvial environment (Simon and Downs, 1995).

The type of data needed for any of these evaluation methods is similar to Table 3.1: channel cross-section surveys, bed/bank material, channel gradient/profiles, flow duration and flood frequency, channel planform.

3.3.1 Big Creek Case Study: Evaluation and Assessment

The type of fluvial and physical environment in the Big Creek watershed was established by the watershed- and reach-sale characterizations. The watershed-scale characterization showed that the watershed occupies two distinct physical environments strongly defined by two major physiographic provinces (Interior Lowlands and Coastal Plains). The upper Big Creek region is high sloping (.0061) with narrow valleys controlled by bedrock outcrops and gravel beds, whereas the lower region is in a relic, oversized river valley with very low slopes (0.0011) in fine cohesive material. The more catastrophic channel adjustment response, incision and widening, occurred in the mid-reaches straddling the two physical environments. The character of these reaches is typically cohesive silt-clay banks and bed with intermittent bedrock outcrops. The characterization also determined that profound changes in land cover and severe channelization were responsible for initiating the observed channel responses. The channelization projects shifted the sinuosity of Big Creek in the lower region from 2.2 to nearly 1. The current width/depth ratios in this region are the same as the pre-channelization ratios; however, cross-sectional areas have increased nearly two- and three-fold since channelization. The upper region channels appear to be fairly stable with mostly fluvial erosion of the banks, pool/riffle bed morphology, no change in sinuosity (1.2), and low bank heights that accommodate flood flows.

The watershed-scale characterization identified the middle reaches of Big Creek as proceeding through stages of channel evolution and was estimated to be in a late-stage IV (incision and widening) of adjustment. Stage IV ‘threshold’ channels experience the greatest channel instabilities by undergoing bed degradation, basal bank erosion, and slab, rotational, and pop-out failures of the banks (Simon, 1989). Stage V ‘aggradation’ channels are the beginning of the recovery process toward stability and are characterized by bed aggradation, development of a meandering thalweg, and deposition of material forming alternating bars. Continuing bank failures and reworking of the failed material leads to flattening of the bank angles (Simon, 1989). Analysis of stream power thresholds could reveal whether these reaches will continue to be an unstable stage IV channel or starting the process toward stability (stage V). One method to determine this is the computation of stream power in these critical reaches and compare it to the 35 watts per meter^2 (Wm^{-2}) threshold as defined by Brookes (1987) to discriminate between stable and unstable channels following channel disturbance.

The stream power was computed for 15,051 meters of channel using a HEC-RAS (Brunner, 2002) model developed by the ISWS (Figure 3.17). The modeled reach is located between the two ISWS streamgages (#500 and #502) and was calibrated with the observed data from those stations as well as channel geometry and profile data. For the purpose of this study the model was run for the 1.5- and 5-year annual peak discharge ($Q_{1.5}$ and Q_5). The $Q_{1.5}$ was selected to represent the most frequent streamflows. The Q_5 was selected based on the dendrogeomorphic indicators (tilt sprout dating) of recent mass wasting bank failures identified by the reach-scale characterization. The bank failures observed during those field visits were linked to the 4- and 5-year return flows in the 1999 and 2002 streamgage record at ISWS #502. Hence, the Q_5 was selected as an important channel forming flow and would be a good candidate for discriminating between stable and unstable channels.

The model results showed variable values of stream power throughout the reach due to discrete changes in channel geometry and forms, such as pool/riffles and exposed bedrock. Therefore, a 300 meter moving average was computed to smooth the results and detect broader reach values (Figure 3.18). The $Q_{1.5}$ and Q_5 stream power values downstream of the I-57 bridge were well below 35 Wm^{-2}, whereas upstream the $Q_{1.5}$ and Q_5 approached or exceeded the 35 Wm^{-2} threshold. Stream power at the bridge was the highest computed for both flows in the entire modeled reach. Further investigation into the water profiles for the $Q_{1.5}$, Q_5, and even a Q_{10} reveals that the I-57 bridge is a constriction and pools all three return flows (Figure 3.19). Furthermore, when water profiles are plotted with bank elevations, even the Q_{10} within the modeled reach cannot achieve an elevation to connect with the floodplain, which ranges from 3 to 4 meters

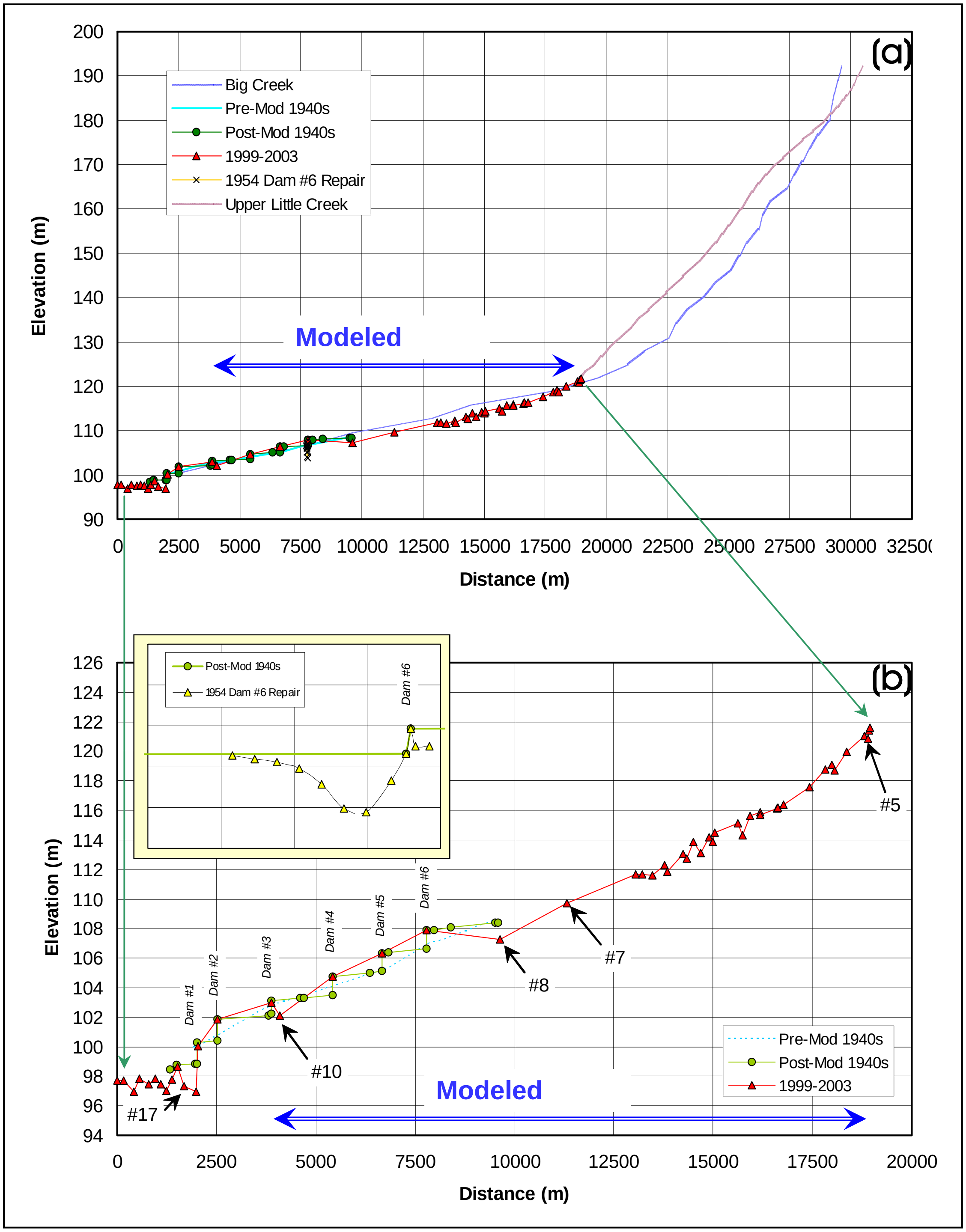


Figure 3.17. Longitudinal profile of a) Big Creek and b) modeled reach.

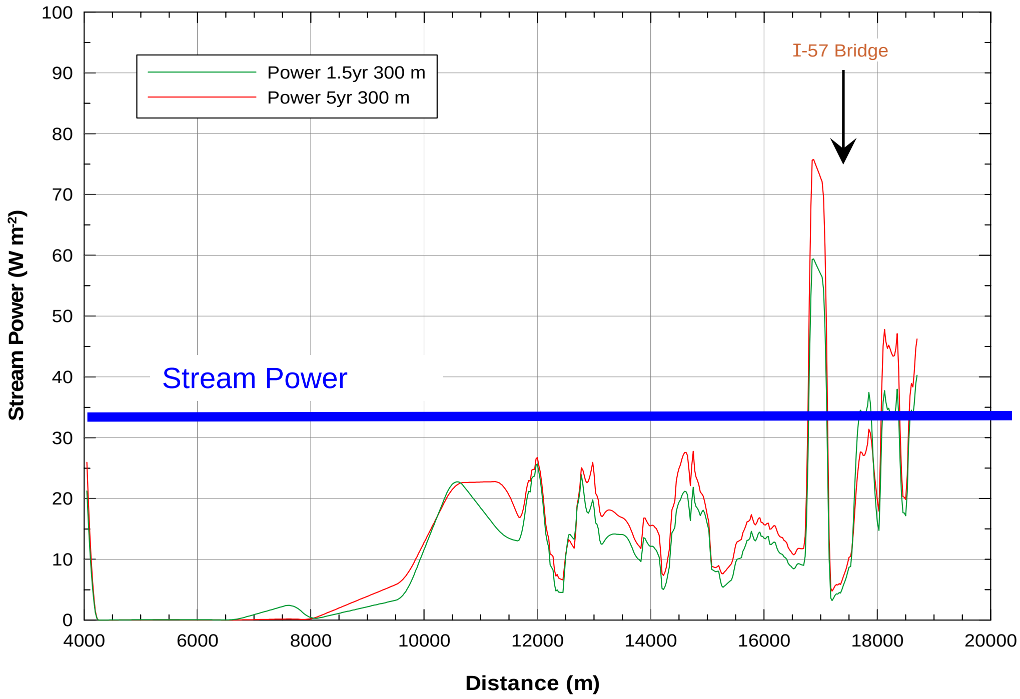


Figure 3.18 Stream power for modeled reach (300 m moving average).

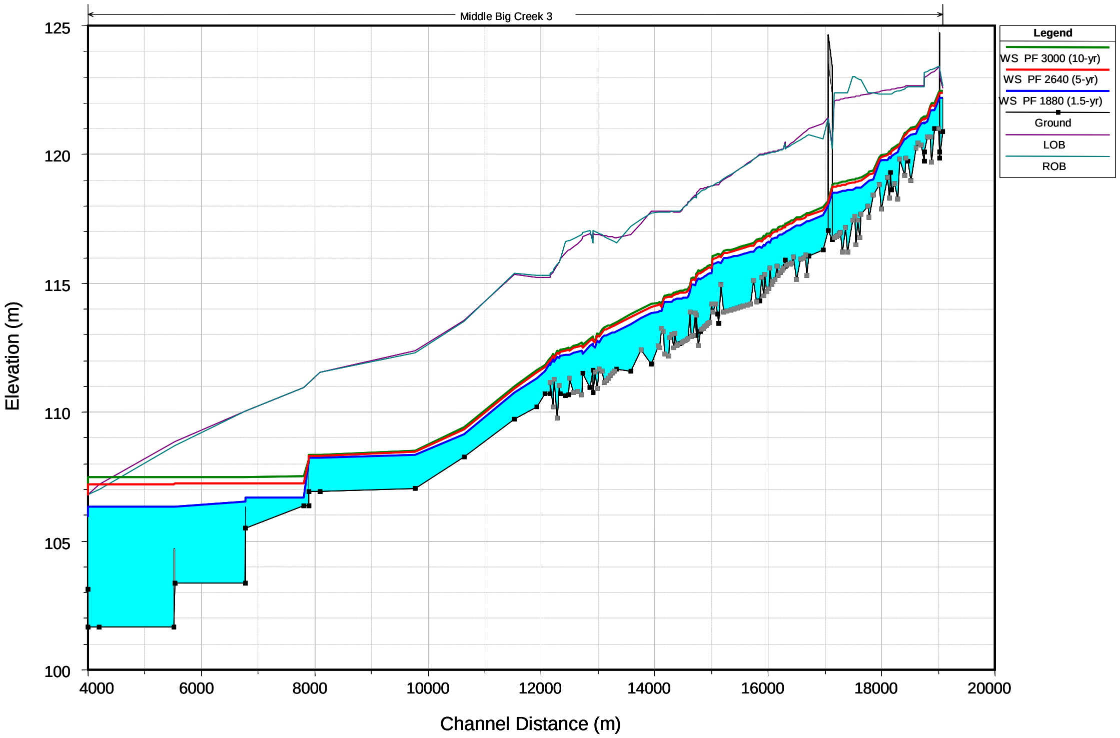


Figure 3.19 Water surface profile for $Q_{1.5}$, Q_5, and Q_{10}.

above the Q_{10} water profile elevation. This is also an indication of the extent of the channel incision. The low stream power for both the $Q_{1.5}$ and Q_5 below I-57 is interpreted as having insufficient energy to further degrade the channel in the reach. Consequently, these channels are more likely in early-stage V rather than late-stage IV and, by definition, have started the process toward stability.

Channel gradient can be used as a surrogate for the type of fluvial environment to estimate the overall style and magnitude of future channel adjustments (Simon and Downs, 1995). When sufficient channel profile data is available, zones of channel bed degradation, aggradation, or no net change can be detected to establish the magnitude and type of channel adjustments which have already occurred and possibly infer future adjustments.

Limited channel elevation data were available for Big Creek (Figure 3.8). The only historical channel profiles recovered were those from the channelization design plans in the lower Big Creek region. The plans document the pre-channelization elevations where the natural channel crossed the design center-line planform and the profile of the designed channel along with the crests of the six dams. Recent profile data consisted of a 7200 m surveyed channel profile (1999 and 2003) between BC-5 and BC-7, a separate 2000 m survey from dam #1 to the mouth of Big Creek (2003), and discrete bed elevation data at watershed- and reach-scale sites (2003). Due to the intermittent location and frequency of this data, it was only possible to determine a ratio of change in channel width to change in channel depth (index of channel change, I_c) for 3 locations in the lower region (Figure 3.14). However, in combination with topographic profile information, some general observations can be made of the current gradients that may lend some insight for determining future style of channel adjustments.

The channel gradient above and below I-57 is 0.0061 and 0.0011, respectively. This demarcation in the physical environment was established by the characterizations, but is too broad to infer style and magnitude of future channel adjustments. The highest channel gradient (0.0077) is from the headwaters to the upstream end of the modeled reach (BC-5). Bedrock controls the channel gradient and the beds are transporting gravel. The banks are not high but are nearly vertical with evidence of fluvial erosion due to the lack of stable vegetation. In this type of environment, any increase in runoff will result in channel widening only. Visual inspection of 1938 and 1999 aerial photography of these reaches indicates minor channel planform changes, a reduction in riparian vegetative cover over the channel, and exposed gravel beds in both time periods.

From BC-5 to I-57 the gradient declines to 0.0022, but is still controlled by intermittent bedrock outcrops and additional influx of gravel delivered from the Upper Little Creek tributary. The channel is wider than upstream of this confluence, meandering is slightly more pronounced, abundant gravel forms mid-channel bars which lead to braiding, mass bank failures are more evident, and there is deposition of large woody debris (LWD). The drainage area of Upper Little Creek (20 km^2) is similar to Big Creek (22 km^2) at this junction and doubles the flow, which accounts for the change in the channel geometry in the vicinity of the confluence. Downstream of the confluence zone of influence there is evidence of actively retreating cutbanks and a meandering, low-flow thalweg in the gravel bed within the main channel. The fluvial environment of this reach is heavily influenced by the energy gradient and the combined bedload from the two streams and is likely to continue adjusting to accommodate this aggrading environment.

The channel gradient decreases to 0.0011 between I-57 and BC-7. This reach exhibits the most severe channel degradation due to incision and widening. Outcropping bedrock was observed, but is not as evident as in the upstream reach. Bed and banks consist mostly of cohesive silt and clays. Channels are v-shaped and between 5 and 6 meters deep. Major rotational slips are the mechanism of bank failures. Excessive LWD occurs throughout the reach, and almost no gravel was found in the bed. This lower gradient cohesive channel is vulnerable to vertical degradation mechanisms (Simon, 1992). Severe incision and widening are apparent but determining whether this fluvial environment will continue to adjust in this manner is inconclusive based on channel gradient alone.

The channel gradient of the reach dominated by the six control structures is 0.0019, slightly higher than the previous reach, and from dam #1 to the confluence with the Cache River the bed of the creek is nearly level. The three sites for which historical-channel geometry data are available are located in this reach (BC-8, 10, and 17). The BC-8 site is the farthest upstream in the reach and least likely to be effected by the control structures. Plotting the index of channel change (I_c) versus disturbed channel gradient for these locations on the Simon and Downs (1995) bell curve, positions these sites with Cane Creek, a tributary of the Hatchie River in west-Tennessee. This creek is 350 km^2, somewhat larger than Big Creek, drains the bluffs next to the Mississippi River, has an average slope of 0.002, was channelized in the 1970s, and has had grade control structures installed (Simon and Hupp, 1992). There are no bedrock controls and the landscape is covered by thick loess. Even though the I_c relationship of these sites seems to correlate with Cane Creek, it is unlikely that this would be a sole predictor of future channel changes due to the profound influence of the six control structures and bedrock controls. Therefore, channel gradient cannot be used in the reach as a reliable surrogate to estimate style and magnitude of future channel adjustments.

3.3.2 Results of Evaluation and Assessment Method

The purpose of this evaluation was to develop a characterization of channel morphologies based on the convergence of several lines of evidence drawn from the previous characterizations and subsequent analysis of that data. Based on all the analysis of available data, the current channel morphologies divide the Big Creek channel into four distinct reaches identified as: 1) upper reach – headwaters to the confluence of Big and Upper Little Creeks, 2) confluence reach - confluence of Big and Upper Little Creeks to I-57, 3) middle reach – I-57 to BC-7, and 4) channelized reach – BC-8 to the confluence of Big Creek with the Cache River. Potential future channel adjustments of these four reaches are complicated by watershed management activities that have recently been initiated and will continue for the next 1-2 years. The watershed management activities include projects to 1) reduce peak discharge by installing many small detention ponds in the watershed uplands and 2) lower stream gradient in middle reach to promote bank stability. Between 2002 and 2004, 24 detention ponds have been installed throughout the watershed and 52 more are planned for 2005 and 2006. The placement and projected decrease in peak discharge was estimated by the ISWS HEC-1 model (Demissie et al., 2001). It should be noted that the purpose of this model was to reduce the peak discharge of Big Creek at its confluence with the Cache River. The reduction in peak discharge was part of a larger hydraulic modeling effort for the Lower Cache River. Seven rock weirs have been installed in middle reach starting at I-57 and continue for 800 meters downstream with the possibility of 3-4 more in the near future. Stream barbs were installed in the confluence reach at a major cutbank 500 m downstream of the Big and Little Creeks confluence to keep the stream from migrating farther into an agricultural field.

Big Creek upper reach currently exhibits only minor bank erosion and no vertical degradation due to major bedrock controls. Observations since 1999 at ISWS #500 (BC-5) indicate that the gravel bed moderately shifts after significant flow events, but essentially maintains pool and riffle positions. Historical data on channel profiles or channel geometry were not available; however, the analysis of aerial photography reveals no substantial changes in planform. Therefore it is assumed that upper reach will continue to exhibit its current channel form with minor fluvial erosion. The reduction of peak discharge as a result of the installation of upland detention ponds may slow the fluvial bank erosion.

The channel morphology in confluence reach is largely influenced by the increase in flow from Little Creek and the complex channel morphologies caused by the confluence of Big and Little Creeks. Although the drainage areas are similar, the gradient of Little Creek is lower than that of Big Creek (0.0045 compared to 0.0077). The channel width of Big Creek nearly doubles in this reach and there are obvious bank failures downstream. In the upper section of this reach, the stream is forced to impinge and undercut the left bank (right bank is bedrock) due to flow deflection and subsequent deposition of gravel downstream of the confluence. Downstream of the confluence zone of influence is a large cutbank and from this point to the end of confluence reach the gravel reduces in size and percent sand increases. Gravel and sand is deposited and forms unstable point and mid-channel bars with abundant LWD lodged in irregularly spaced pools. The banks are also being impinged by the stream due to deposition of bedload. The ISWS HEC-RAS model computed stream power over 35 Wm^{-2} for the $Q_{1.5}$ and Q_5 in this reach. The observed deposition and reworking of the material in this reach is also evident in changes in planform and morphology between 1938 and 1998 aerial photography and 2004 infrared images (Figure 3.20). In the absence of watershed management practices to reduce the energy of these flows, the confluence reach is likely to continue this pattern of adjustment. The installation of the upland detention ponds should somewhat reduce the stream power in this reach. The ISWS HEC-1 model predicted reduction of peak discharge at the confluence with the Cache River and it is reasonable to assume some peak discharge reduction farther upstream, but the magnitude of the peak discharge reduction is unknown at this time. Furthermore, channel morphologies downstream of confluences are complex and highly dynamic (Best, 1988; Rhoads and Kenworthy, 1995).

Field visits to middle reach revealed the deepest channels along Big Creek, a v-shaped morphology, extreme bank mass wasting, and abundant LWD (Figure 3.9). Erosion of the silt-clay bed has intermittently exposed bedrock. Except for a short distance immediately downstream of I-57, the bed is virtually devoid of gravel save for sand and small pebbles deposited on some of the failed bank material near the toe. The stream power analysis showed that this reach has insufficient energy to degrade the channel; therefore, middle reach is upgraded to a stage V channel. The HEC-RAS model

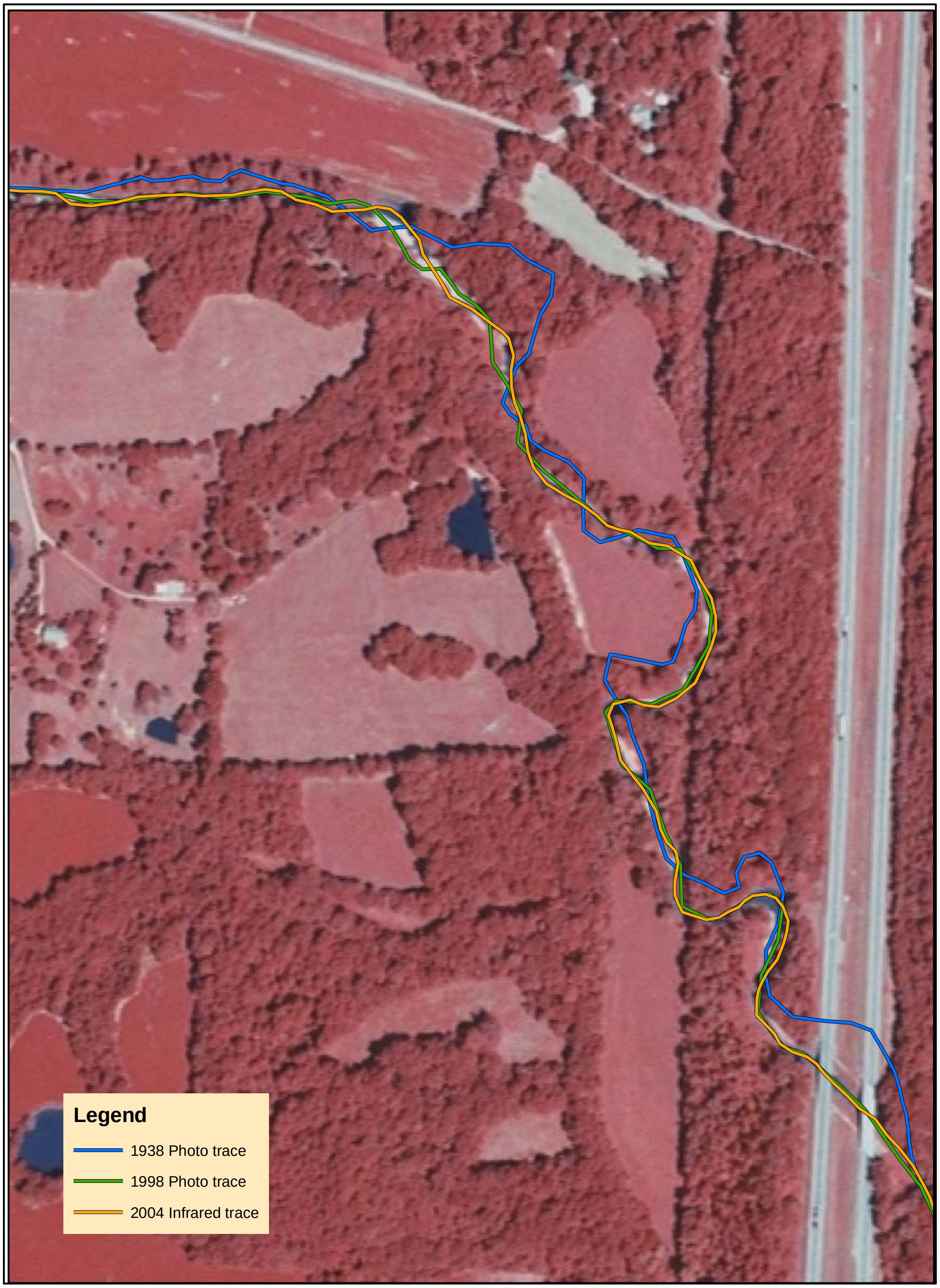


Figure 3.20 Comparison of planform between 1938, 1998, and 2004 imagery.

shows that middle reach has higher velocities than the other reaches (Figure 3.21). This high velocity can still remove failed material at the bank toe and allow for continued bank failures through the stage V of channel evolution until the banks are laid back to below critical bank height. Even though less material is eroded and transported downstream at this stage as compared to stage IV, it is not insignificant over a long period of time. Based on the sedimentation rate discussion in the reach-scale characterization section, it is expected that, without intervention, it may yet take 10-20 years for middle reach to pass through this process.

The combination of reducing peak discharge through the application of upland detention basins and direct treatment of extremely incised channels with stone structures to reduce velocities should shorten this stage of channel evolution (Shields et al., 1999). It seems opportune that both of these applications are being actively installed in the watershed. The rock weirs installed below I-57 are intended to contribute toward stabilizing bank toes and reduce erosion. However, the location and design of the rock weirs was determined outside of the context of this study, consequently their actual effectiveness is not quantifiable. A potential post-project appraisal could be made by incorporating the weir geometries into the ISWS HEC-RAS model to make this determination.

The fluvial environment of channelized reach is one of artificial control, an artifact of the six flow control dams and levee system built during the 1930s-40s. The straightened channel between the dams has deepened and widened since dam construction (Figure 3.14). Several locations in this reach exhibit rotational bank failures in the vicinity of the dam backwater influence. The failures are assumed to be slipping at

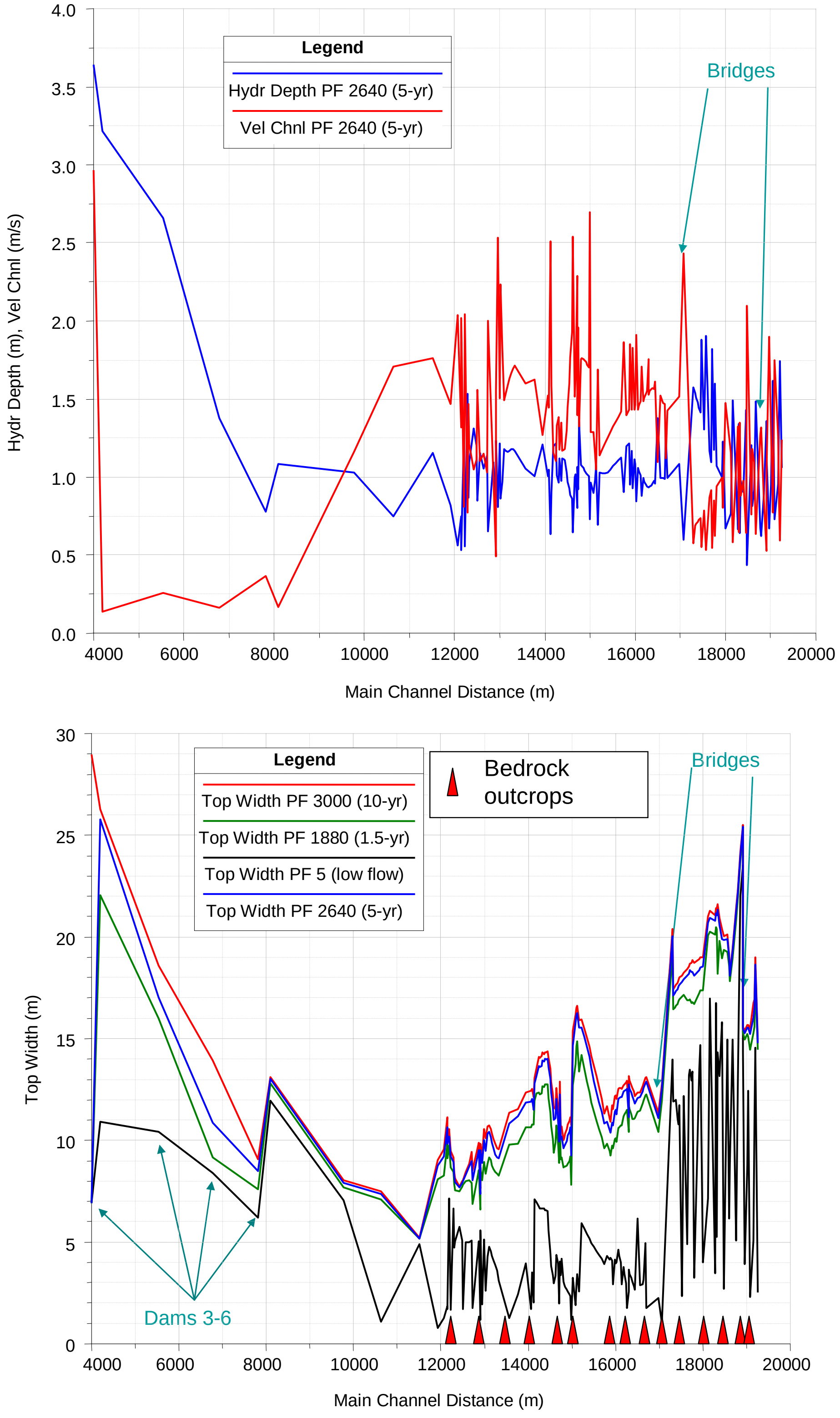


Figure 3.21 Hydraulic depth, width, and velocities for modeled reach.

a slow rate as evidenced by the eccentric growth of the trunks of mature tilting trees. Bank saturation from dam backwater and positive pore-water pressure seems to be the bank failure mechanism. Otherwise, the structures play a vital role in controlling the slope through most of the reach, which without, could set into motion profound and catastrophic channel adjustments upstream and massive deposition of sediment in the wetlands. The age of these structures is of concern and leaves the possibility that a failure of any one of them would initiate an upstream headcut leading to subsequent failure of upstream dams. This scenario gives insight into a distinct future channel adjustment.

Marked shifts in fluvial environment, bed material size, channel gradient, and hydraulics appear to converge at I-57, which was constructed in the 1950s. Previously, these shifts were attributed to a fundamental change in physiographic environment. The abrupt change in bed material size, stream power, and channel morphology at this location cannot be completely explained by physiography. The ISWS HEC-RAS model computed very low stream power immediately upstream of I-57, which was due to water being backed up from the bridge for over 800m upstream (Figure 3.19). The channel character in this backwater area is one of significant deposition of sand and gravel on pointbars and development of mid-channel bars, as well as active erosion of the banks on the outside of meander bends. Big Creek currently approaches the bridge on a 45 degree angle coming out of a meander bend and the bridge piers and abutments are oriented to that angle. The bridge design plans and aerial photography show that the channel was moved to this position by eliminating a gentle meander (Figure 3.20). The deposition of sand and gravel, the backwater modeled upstream of I-57, and the lack of gravel downstream of I-57 all support the conclusion that the I-57 bridge is interrupting bedload and may be responsible for local bed degradation downstream of the bridge. It is likely that the installation of the rock weirs will reduce the effect of the degradation and stabilize the banks in this immediate area.

The disturbances responsible for the adjustment processes in middle and channelized reach are determined to be a combination of land use conversion (forest to agriculture) and channelization. Both altered the transport capacity and sediment supply in these two reaches that resulted in the various degrees of channel degradation and deposition of sediment in the wetlands. The entire length of the channelized reach experienced straightening and increased flow area; however, flow control structures were not installed throughout the reach. At the time of channelization and dam construction (1930-40s) there was not the benefit of streamflow data. Assuming the design flows were adequately estimated, the effect of future increases in runoff may not have been anticipated, thereby not requiring more structures upstream and leaving these reaches relatively unprotected.

A likely response scenario is that increases in runoff from land use conversion may have aggravated the lack of gradient control in the upper section of channelized reach, setting into motion a series of headcuts through the unprotected channelized section. The result would have been moderate increases in channel depth and width as compared to the design channel geometries (see Figure 3.14, Site #8). When the headcuts migrated upstream into the undisturbed channel of middle reach, increases in channel depth and width would have occurred due to the large difference in channel geometries between the channelized and middle reaches. Channel bed degradation and bank failures would produce increased sediment yield. An increase in runoff may also be partly responsible for the incision and widening between the control structures. As discussed earlier, the construction of the I-57 bridge in the 1950s has had an effect on local conveyance. However, this also is an area of bedrock control and it is reasonable to assume that this part of the creek may have been responsible for halting the headward migration of incision and widening.

The geomorphic assessment is comprised of the current channel and watershed character and the potential future channel adjustments with and without intervention (Table 3.4). The assessment also lists recommendations for future investigation to fill data gaps and improve inference of future channel adjustments.

Table 3.4 Assessment of evaluation results

Reach Name	Current Conditions	Potential Future Response
Upper	• Minor fluvial bank erosion but not quantified • Bedrock controls	• Without intervention: Continued minor bank erosion • Intervention: Assume some reduction in bank erosion due to detention basin installation • Recommendation: Set erosion pins in some banks to quantify rate of bank erosion
Confluence	• Channel morphology largely controlled by confluence dynamics • Depositional environment due to gravel bed load from Big and Little Creeks • Stream power sufficient to adjust channel – unstable reach • I-57 bridge constricts flow, creating backwater during all flows	• Without intervention: Continue channel adjustment through lateral adjustments • Intervention: Reduction in peak discharges from detention pond installations assumed to bring some improvement but not quantifiable at this time • Recommendations: o Obtain results current ISWS modeling to estimate peak discharge reduction in reach o Monitor future cutbank migration
Middle	• Severely incised channel with active bank mass wasting and abundant LWD • Stream power insufficient to further degrade channel bed • CEM early - stage V (Threshold) • Bedrock control near I-57 bridge has halted migrating headcut	• Without intervention: Channel will continue to widen and produce suspended sediment to wetland until below critical bank height: ~10-20 years • Intervention: Peak discharge reduction and in-channel stone structures may shorten stage V channel evolution • Recommendation: Re-run HEC-RAS model to quantify effectiveness of stone structures and incorporate ISWS modeling results for predicted reduction of peak discharges

Channelized	• 1930s-40s: 58% reduction in channel length due to drainage projects; installation of 6 dams; channel levees on both sides • Some rotational slip failures upstream of dams • Dams provide critical stability for reach but are aging	• Without intervention: o Continued minor bank failures upstream of dams o Possible dam failure will result in catastrophic channel adjustment and increased deposition of sediment into wetland • Intervention: Reduction in peak discharges from detention pond installations assumed to bring some improvement but not quantifiable at this time • Recommendations: o Engineering inspection of dams for structural soundness o Extend HEC-RAS model through entire channelized reach; acquire more profile and channel geometry. Determine character of flow conveyance around dams. Use ISWS modeling results to estimate peak discharge reduction in reach

3.3.3 Discussion of Method

The evaluation and assessment method analyzed the cumulative data drawn from the temporal and spatial characterizations of the watershed and channel to infer potential future channel adjustments in Big Creek. The method utilized three approaches for evaluating the data to increase the likelihood of reasonable inferences of expected channel morphologies, which are: 1) identify type of fluvial and physical environment, 2) determine thresholds of stream power, and 3) use channel gradient as a surrogate for type of fluvial environment. These approaches are not mutually exclusive when estimating potential adjustment processes. It was expected that data could be so limited that any of the three approaches may not be feasible. Thus the inclusion of other approaches increased the likelihood of overcoming that limitation and still make reasonable inferences. This occurred many times when evaluating Big Creek. The disparity of data forced the evaluation of different reaches with various combinations of the three approaches. In this respect, the approaches used in the evaluation and assessment method as reported by Simon and Downs (1995) were effective.

The identification of the type of fluvial and physical environments was already apparent from the watershed- and reach-scale characterizations. The evaluation and assessment method synthesized the characterizations within the context of estimating potential future channel adjustments. Establishing the prevailing channel adjustment responses to past disturbances based on changes in sediment supply and transport capacity allows for extrapolation of those trends of adjustments. This also facilitated the characterization of Big Creek into four distinct channel reach morphologies by establishing their watershed context, relationship of each reach to geologic controls, computation of stream power, and the ability to perform hydraulic modeling for a large segment of the creek profile.

The evaluation and assessment method capitalizes on the systematic data compilation in the watershed- and reach-scale characterizations. The flexibility in drawing on several sources of information and performing three types of integrated analysis is the chief strength of this method. This approach is also more suited to an investigator that is trained in and/or has an informed appreciation for hydraulics, hydrology, geology, stream channel adjustment processes, and dynamics of sediment transport. This knowledge allows for the development of a team of experts in these areas from which to draw and coordinate information and insights (Fitzpatrick, 2001; Rhoads, 2003; Simon et al., 2005).

As stated in the watershed- and reach-scale characterizations, Big Creek has a large amount of data but suffers from inconsistency in the spatial and temporal coverage of this information. This limitation makes it difficult to infer future channel adjustment processes and channel morphologies. The Big Creek case study demonstrated that the evaluation and assessment method has the ability to overcome these shortcomings. For example, using channel gradient as a surrogate for fluvial environment will be a weak component if historical stream profiles or bed elevations are lacking. However, the combination of hydraulic modeling, establishment of the fluvial and physical environment, and the disturbance history proved more powerful in this case study. The modeling had the advantage of an extensive streamgaging record; however, regional flow equations could have been substituted using data gathered in the watershed- and reach-scale characterizations. Furthermore, the channelization and dam construction plans were helpful in establishing that some channel deepening and widening had occurred since construction and provided the dam structure dimensions for the modeling. If these plans had not been available, the structures and channel could have been surveyed for the HEC-RAS model input, albeit this would have amounted to more work for the assessment. Also, the reduction in channel length would have to be determined using channel planform analysis of aerial photography and not from the channelization plans. Even with the plans, the modeling could have benefited from channel surveying between the structures to compute the stream powers in the channelized reach to determine whether the channel is adjusting currently regardless of past adjustments. Understanding the inadequacies of information gathered during the watershed- and reach-scale characterizations provides guidance for more extensive data collection to accommodate analyses in the evaluation and assessment method phase.

4. Conclusions

This study has contributed to the understanding of channel adjustment response processes to disturbances by developing a geomorphic assessment approach that takes into account the varied and subtle disturbance response characteristic of Illinois streams. The geomorphic assessment approach adapted tools and components from other approaches developed for regions of the U.S. that were physiographically different from Illinois and have more dramatic channel adjustment responses. Due to the varied and subtle responses in Illinois streams, the approach combined temporal and spatial components to detect channel adjustment processes. A historical analysis component was incorporated to comprehend the process-response mechanisms responsible for the current channel character. The approach included a spatial component to understand the influence that an entire fluvial system has on local channel adjustment processes, thereby providing a watershed context for the observed channel morphology. A framework for systematic data collection and compilation in the watershed- and reach-scale characterizations was developed. The evaluation and assessment method has the flexibility to draw on the characterization data and perform an integrated analysis using multiple lines of evidence to infer potential future channel adjustments (Simon and Downs, 1995). The integrated analysis method utilizes three approaches for evaluating the data to overcome data limitations and establish reasonable inferences about channel adjustment.

The geomorphic assessment approach is an improvement over other approaches for application in southern Illinois streams. Improvements include collection of historical and physical information on the entire fluvial system; standardized, systematic data collection and record keeping; and three methods of evaluation to provide multiple lines of evidence. As demonstrated in the Big Creek case study, an investigation limited to a reach-scale would have overlooked the multiple channel adjustment responses and erroneously assumed only one response mechanism. In several instances the watershed-scale initial field survey confirmed the channel character that was expected from the influences and physical setting identified in the historical analysis. As expected, this convergence of several lines of evidence provided better understanding of the prevailing process-response mechanisms and influence of physical controls. Finally, the evaluation and assessment method integrated three approaches to evaluate potential future channel adjustments. Multiple approaches overcome expected data limitations and increase the likelihood of making reasonable inferences.

Big Creek is somewhat atypical of other watersheds in the region because of the availability of extensive hydrologic, hydraulic, physical, and historical data. However, it is typical in the sense that data availability is inconsistent over time and space. Although the approach was developed to accommodate inconsistent datasets, it is unclear how sensitive the method is to fluvial systems with much less available data. The channel-stability ranking scheme was initially developed for channels that respond to disturbance by incising and widening (channel evolution model). The restriction to incising channels could be considered a weakness; however, the index did correctly indicate the stable reaches of the upper reach. The addition of basic channel geometry to the index in the initial field survey and contrasting it with the historical analysis appears to have supported the index results. The channel-stability index should be conservatively applied in other Illinois watersheds until its reliability is ascertained. The addition of detailed mapping of channel morphology, along with bank erosion monitoring at the reconnaissance sites, would have proved useful for better understanding the spatial pattern of shear stresses and establishing adjustment rates.

Field data collection concentrated only on the main stem of Big Creek. There are two main tributaries to Big Creek and 3 minor tributaries. Only the Upper Little Creek tributary was visited during the watershed-scale characterization phase. When evaluating the extent of the incision and widening of the middle reach, it was apparent that even an initial field visit, with some attention on gully development and dendrogeomorphic indicators, would have assisted in estimating the extent and rates of adjustment. When time is not a factor, incorporating tributaries into the initial site visit phase or into follow-up site visits may be prudent.

Overall, this geomorphic assessment approach is an improvement on approaches available from other regions in the United States. The inclusion of temporal and spatial data, comparison and contrasting of multiple lines of data, and several evaluation approaches increased the likelihood of overcoming data limitations. However, the biggest obstacle to effective assessment of river geomorphology is inconsistent or lack of hydrologic, hydraulic, and channel planform/geometry data over extended time scales. Many of the classification- and empirically-based approaches discussed were developed because of the paucity of long-term data. Consequently, there is a need to establish benchmark sites in river channels to monitor the extent and rate of channel changes to better understand process-response mechanisms.

Application of the geomorphic assessment methodology to the Big Creek-Cache River Basin has contributed to the understanding of channel adjustment response processes to direct disturbances in this watershed. A major finding is that the complex geology and disturbance history of Big Creek produces spatial variations in channel response.

In conclusion, the two main objectives of this study were achieved: 1) develop and evaluate a standardized, systematic geomorphic assessment methodology for evaluating past conditions, extant character and potential future adjustments of stream channels in southern Illinois region and 2) test this methodology using a case study in Big Creek, as well as document and characterize the channel adjustment processes in this severely disturbed fluvial system. This geomorphic assessment approach is a first step toward the evaluation of channels in other regions of Illinois.

4.1 Suggestions for Future Research

This study benefited from a 20-year research program carried out by the Illinois State Water Survey (ISWS) to study the complex hydrology, hydraulics, and sediment transport in the Cache River Basin (Demissie et al., 1987; Demissie, 1989; Demissie, Soong et al., 1990a, 1990b; Demissie, Soong and Camacho, 1990; Allgire, 1991; Demissie and Xia, 1991; Demissie et al., 1992; Allgire and Cahill, 2001; Demissie et al., 2001; Keefer et al., 2006). The results of these studies have been instrumental in applying scientifically defensible data to watershed management programs for the benefit of the Cache River Basin ecosystem. Future research is suggested to build and improve the geomorphic assessment approach developed in this study as follows:

- Apply this approach to another watershed in the southern Illinois region. The Big Creek watershed is physically similar to other watersheds in this driftless region of Illinois. Although Big Creek has the advantage of being a heavily studied watershed, the testing in another watershed is prudent.
- Perform a sensitivity analysis to determine important datasets in the geomorphic assessment process. Big Creek had more datasets available as compared to others but did suffer from inconsistency. Nevertheless, modifications to the Big Creek data, such as using regional streamflow equations rather than measured data, would provide insight into possible differences in the stream power analysis. Other datasets, engineering plans for the channelization projects, could be entirely disregarded, which would impact the evaluation of the channelized reach.
- Apply this approach in another region of Illinois. The geomorphic assessment approach developed from this study has already been applied to current ISWS assessment efforts in the Illinois River Basin Assessment Framework (Illinois Department of Natural Resources, 2004). The performance of this approach for this region is planned.

The evaluation and assessment method made recommendations to further study Big Creek to supply more quantitative data and benefit the recovery of Big Creek and the Cache River-Cypress Creek wetlands:

- Establish measured rates of channel erosion for 1-2 years would generate a benchmark to compare rates measured in a future assessment or post-project appraisals.

- Incorporate the as-built measurements of the stone weir structures located downstream of I-57 into the ISWS HEC-RAS model to assess their effect on the stream power in middle reach. Add other structures to the model to determine an effective number and spacing to reduce velocities and stabilize the banks in middle reach.
- Coordinate with the ISWS HEC-HMS modeling efforts to incorporate predicted reduced peak discharges into the HEC-RAS model to assess the hydraulic impacts.
- Repeat the geomorphic assessment in 5-8 years to determine any changes in the Big Creek channel that might evaluate the effectiveness of the watershed management projects and the applicability to other regions of Illinois.

References

Allgire, R. 1991. Comparison of 1987 and 1989 Bed Profile Surveys of the Lower Cache River. Illinois State Water Survey, Contract Report 508, Champaign, IL, 8 pp.

Allgire, R. L. and R. A. Cahill. 2001. Benchmark Sedimentation Survey of the Lower Cache River Wetlands. Illinois State Water Survey, Contract Report 2001-17, 42 pp.

Baker, V. R. and J. E. Costa. 1987. Flood Power. *in* Catastrophic Flooding. L. Mayer and D. Nash (eds.). Boston, Allen & Unwin. p. 1-21.

Barnard, R. S. and W. N. Melhorn. 1982. Morphologic and Morphometric Response to Channelization: The Case History of Big Pine Creek Ditch, Benton County, Indiana. *in* Applied Geomorphology. R. G. Craig and J. L. Craft (eds.). London, Allen and Unwin. p. 224-239.

Berg, R. C. and M. R. Greenpool. 1994. Stack-Unit Map of Paducah 1 X 2 Degree Quandrangle: Geologic Materials to a Depth of 15 Meters. Champaign, IL, Illinois State Geological Survey.

Best, J. L. 1988. Sediment Transport and Bed Morphology at River Channel Confluences. *Sedimentology*. 35:481-498.

Bledsoe, B. P. and C. C. Watson. 2001. Logistic Analysis of Channel Pattern Thresholds: Meandering, Braiding, and Incising. *Geomorphology*. 38:281-300.

Bogner, W. C., W. P. Fitzpatrick and D. S. Blakley. 1985. Sedimentation Rates in Horseshoe Lake, Alexander County, Illinois. Illinois State Water Survey, Contract Report 364, 55 pp.

Bogner, W. C., S. D. Lin, D. L. Hullinger and R. K. Raman. 1997. Diagnostic-Feasibility Study of Vienna Correctional Center Lake, Johnson County, Illinois. Illinois State Water Survey, Contract Report 619, 113 pp.

Brice, J. C. 1982. Stream Channel Stability Assessment. U.S. Department of Transportation, Federal Highway Administration, Final Report FHWA/RD-82/021, 42 pp.

Brigham, A. R. 1978. An Assessment of the Water Quality of the Cache River Basin Derived from a Biological Investigation. Illinois Natural History Survey, Urbana, IL, 73 p. pp.

Brookes, A. 1987. The Distribution and Management of Channelized Streams in Denmark. *Regulated Rivers*. 1:3-16.

Brookes, A. and D. A. Sear. 1996. Geomorphological Principles for Restoring Channels. *in* River Channel Restoration: Guiding Principles for Sustainable Projects. J. A. Brookes and F. D. Shields (eds.). John Wiley & Sons Ltd. p. 75-101.

Brunner, G. W. 2002. Hec-Ras, River Analysis Systsem Hydraulic Reference Manual. U.S. Army Corps of Engineers Hydrologic Engineering Center CPD-69, 262 pp.

Bryan, B. A., A. Simon, G. S. Outlaw and R. Thomas. 1995. Methods for Assessing Channel Conditions Related to Scour-Critical Conditions at Bridges in Tennessee. U.S. Geological Survey, Water-Resources Investigations Report 94-4229, Nashville, TN, 54 pp.

Bull, W. B. 1979. Threshold of Critical Power in Streams. *GSA Bulletin*. 90 (part 1):453-464.

Callahan, P. 2001. Root Rap or Restoration Is Rosgen-Ism Helping or Hurting Our Streams and Rivers? *Proceedings of the Proceedings of the 2001 ASCE Wetlands Engineering and River Restoration*, August 27-31, 2001, Reno, Nevada, ASCE. p. 3.

Church, M. 1996. Space, Time and the Mountain - How Do We Order What We See? *in* The Scientific Natural of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology, 27-29 September 1996. B. L. Rhoads and C. E. Thorn (eds.). John Wiley & Sons Ltd. p. 147-170.

Conservation Technology Information Center. 1989. National Crop Residue Management Survey, Conservation Technology Information Center.

Conservation Technology Information Center. 2002. National Crop Residue Management Survey, Conservation Technology Information Center.

Davis, W. M. 1899. The Geographical Cycle. *Geographical Journal*. 14 (5):481-504.

Demissie, M. 1989. Sediment Yield and Accumulation in the Lower Cache River. Illinois State Water Survey, Miscellaneous Publication 108, 22 pp.

Demissie, M., W. F. Fitzpatrick and R. A. Cahill. 1992. Sedimentation in the Cache River Wetlands: Comparison of Two Methods. Illinois State Water Survey, Miscellaneous Publication 129, Champaign, IL, 43 pp.

Demissie, M., H. V. Knapp, P. Parmar and D. Kriesant. 2001. Hydrology of the Big Creek Watershed and Its Influence on the Lower Cache River. Illinois State Water Survey, Contract Report 2001-06, Champaign, IL, 114 pp.

Demissie, M., P. B. Makowski, T. W. Soong and N. G. Bhowmik. 1987. Cache River Basin Project Progress Report. Illinois State Water Survey, Contract Report 422, Champaign, IL, 28 pp.

Demissie, M., T. W. Soong, R. Allgire, L. Keefer and P. Makowski. 1990a. Appendices: Cache River Basin: Hydrology, Hydraulics, and Sediment Transport. Volume 1: Background, Data Collection, and Analysis & Volume 2: Mathematical Modeling. Illinois State Water Survey, Contract Report 486, Champaign, IL, 238 pp.

Demissie, M., T. W. Soong, R. Allgire, L. Keefer and P. Makowski. 1990b. Cache River Basin: Hydrology, Hydraulics, and Sediment Transport. Volume 1: Background, Data Collection, and Analysis. Illinois State Water Survey, Contract Report 484, Champaign, IL, 173 pp.

Demissie, M., T. W. Soong and R. Camacho. 1990. Cache River Basin: Hydrology, Hydraulics, and Sediment Transport. Volume 2: Mathematical Modeling. Illinois State Water Survey, Contract Report 485, Champaign, IL, 101 pp.

Demissie, M. and R. Xia. 1991. Channel Stabilizing Structures for the Upper Cache River. Illinois State Water Survey, Contract Report 511, Champaign, IL, 21 pp.

Dodd, H. R., W. Neisler and D. H. Wahl. 2005. Evaluation of Watershed Management Practices for Improving Stream Quality in the Illinois Watershed Program. Illinois Natural History Survey, Aquatic Ecology Technical Report 2005/02, 104 pp.

Downs, P. W. 1995. River Channel Classification for Channel Management Purposes. *in* Changing River Channels. A. Gurnell and G. Petts (eds.). John Wiley & Sons, Ltd. p. 347-365.

Downs, P. W. and G. M. Kondolf. 2002. Post-Project Appraisals in Adaptive Management of River Channel Restoration. *Environmental Management*. 29 (4):477-496.

Downs, P. W. and C. R. Thorne. 1996. A Geomorphological Justification of River Channel Reconnaissance Surveys. *Transactions of the Institute of British Geographers*. 21 (3):455-468.

Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration: Principles, Processes, and Practices. Federal Interagency Stream Restoration Working Group, National Engineering Handbook NEH 653.

Fitzgerald, W. J. 1987. Erosion and Sedimentation Report: Cache River Basin. U.S. Department of Agriculture, Soil Conservation Service, Carbondale, IL, 31 pp.

Fitzpatrick, F. A. 2001. A Comparison of Multi-Disciplinary Methods for Measuring Physical Conditions of Streams. *Geomorphic Processes and Riverine Habitat Water Science and Application*. 4:7-18.

Frankie, W. T., R. J. Jacobson, J. M. Masters, N. L. Rorick, A. K. Admiraal, M. R. Jeffords, S. M. Post, M. A. Phillips and E. Jones. 1997. Guide to the Geology of the Mississippi Embayment Area, Johnson and Pulaski Counties, Illinois. Illinois State Geological Survey, Field Trip Guidebook FG 1997D, Champaign, IL, 72 pp.

Frissell, C. A., W. J. Liss, C. E. Warren and M. D. Hurley. 1986. A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context. *Environmental Management*. 10 (2):199-214.

Frothingham, K. M., B. L. Rhoads and E. E. Herricks. 2002. A Multiscale Conceptual Framework for Integrated Ecogeomorphological Research to Support Stream Naturalization in the Agricultural Midwest. *Environmental Management*. 29 (1):16-33.

Frye, J. C., H. B. Willman and R. F. Black. 1965. Outline of Glacial Geology of Illinois and Wisconsin. *in* The Quaternary of the United States-- a Review Volume for the 7th Congress of the International Association for Quaternary Research. J. H. E. Wright and D. G. Frey (eds.). Princeton University Press. p. 43-61.

Fullerton, D. S., C. A. Bush and J. N. Pennell. 2003. Map of Surficial Deposits and Materials in the Eastern and Central United States. U. S. Geological Survey, I-2789.

Gilbert, G. K. 1877. *Geology of the Henry Mountains (Utah)*. U.S. Geographical and Geological Survey of the Rocky Mountains Region. U.S. Government Printing Office, Washington, D.C., 160 pp.

Gillilan, S. 1996. *Use and Misuse of Channel Classification Schemes*. Stream Notes. Stream Systems Technology Center, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Center, Fort Collins, Colorado, pp.

Graf, W. L. 1983. Downstream Changes in Stream Power in the Henry Mountains, Utah. *Annals of the Association of American Geographers*. 73 (3):373-387.

Guetersloh, M. 2002. Big Creek Watershed Restoration Plan: A Component of the Cache River Watershed Resource Plan. Illinois Department of Natural Resources, 1-26 pp.

Hack, J. T. 1957. Studies of Longitudinal Stream Profiles in Virginia and Maryland. U.S. Geological Survey, Geological Survey Professional Paper 294-B, Washington, D.C., 97 pp.

Hack, J. T. 1960. Interpretation of Erosional Topography in Humid Temperate Regions. *American Journal of Science*. 258-A:80-97.

Holmes, R. 1996. Hydraulic, Geotechnical, Geomorphic, and Biologic Data for the Cache River/Heron Pond Area in Southern Illinois. U.S. Geological Survey, Open-File Report 96-467, Urbana, IL, 1-21 pp.

Horton, R. E. 1945. Erosional Development of Streams and Their Drainage Basins; Hydrophysical Approach to Quantitative Morphology. *Bulletin of the Geological Society of America*. 56:275-370.

Hupp, C. R. 1999. Relations among Riparian Vegetation, Channel Incision Processes and Forms, and Large Woody Debris. *in* Incised River Channels: Processes, Forms, Engineering and Management. S. E. Darby and A. Simon (eds.). West Sussex, England, John Wiley & Sons. p. 219-246.

Hupp, C. R. 2000. Hydrology, Geomorphology, and Vegetation of Coastal Plain Rivers in South-Eastern USA. *Hydrological Processes*. 14:2991-3010.

Hupp, C. R. and G. Bornette. 2003. Vegetation as a Tool in the Interpretation of Fluvial Geomorphic Processes and Landforms in Humid Temperate Areas. *in* Tools in Fluvial Geomorphology. G. M. Kondolf and H. Piegay (eds.). John Wiley & Sons, Ltd. p.

Hupp, C. R. and W. R. Osterkamp. 1996. Riparian Vegetation and Fluvial Geomorphic Processes. *Geomorphology*. 14:277-295.

Hupp, C. R. and A. Simon. 1991. Bank Accretion and the Development of Vegetated Depositional Surfaces Along Modified Alluvial Channels. *Geomorphology*. 4:111-124.

Hutchison, M. D. 1984. Lower Cache Preservation Plan. The Nature Conservancy, Chicago, IL, 97 pp.

Illinois Department of Natural Resources. 1997. The Cache River Basin: An Inventory of the Region's Resources. Illinois Department of Natural Resources, Springfield, IL, 22 pp.

Illinois Department of Natural Resources. 2004. Illinois River Ecosystem Restoration Monitoring and Watershed Assessment Framework, A. Holtrop and M. Pegg (eds.). Prepared for U.S. Army Corps of Engineers-Rock Island District, 158 pp.

Illinois Natural History Survey. 2002. Land Cover of Illinois in the Early 1800s. 2003.

Johnson, P. A., G. L. Gleason and R. D. Hey. 1999. Rapid Assessment of Channel Stability in Vicinity of Road Crossing. *Journal of Hydraulic Engineering* (June 1999):645-651.

Johnson, P. A. and T. M. Heil. 1996. Uncertainty in Estimating Bankfull Conditions. *Water Resources Bulletin*. 32 (6):1283 -1291.

Juracek, K. E. and F. A. Fitzpatrick. 2003. Limitations and Implications of Stream Classification. *Journal American Water Resources Association*. 39 (3):659-670.

Keefer, L. L., R. Allgire and R. A. Cahill. 2006. Integrating Two Sedimentation Rate Methods to Determine Channel Adjustment Rates. *Proceedings of the Joint Federal Interagency Conference: 8th Federal Interagency Sedimentation Conference & 3rd Federal Interagency Hydrologic Modeling Conference*, April 2-6, 2006, Reno, Nevada.

Knighton, A. D. 1999. Downstream Variation in Stream Power. *Geomorphology*. 29:293-306.

Knighton, D. 1998. *Fluvial Forms and Processes*. Oxford University Press, New York, New York, 383 pp.

Kohfeld, K. E. and D. R. Muhs. 2001. Mid-Continental USA Gridded Maps of Loess Thickness. NOAA/NGDC Paleoclimatology Program, #2001-049, Boulder CO, USA.

Kondolf, G. M. 1995. Geomorphological Stream Channel Classification in Aquatic Habitat Restoration: Uses and Limitations. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 5:127-141.

Kondolf, G. M. 1998. Lessons Learned from River Restoration Projects in California. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 8:39-52.

Kondolf, G. M. and P. W. Downs. 1996. Catchment Approach to Planning Channel Restoration. *in* River Channel Restoration: Guiding Principles for Sustainable Projects. A. Brookes and F. D. S. Jr. (eds.). John Wiley & Sons, Ltd. p. 129-148.

Kondolf, G. M. and H. Piegay. 2003. Tools in Fluvial Geomorphology: Problem Statement and Recent Practice. *in* Tools in Fluvial Geomorphology. G. M. Kondolf and H. Piegay (eds.). John Wiley & Sons, Ltd. p. 3-22.

Kuhnle, R. A. and A. Simon. 2000. Evaluation of Sediment Transport Data for Clean Sediment Tmdls. USDA-ARS National Sedimentation Laboratory, NSL Report No. 17 Oxford, Mississippi, 60 pp.

Landwehr, K. and B. L. Rhoads. 2003. Depositional Response of a Headwater Stream to Channelization, East Central Illinois, USA. *River Research and Applications* (19):77 - 100.

Leighton, M. M., G. E. Ekblaw and L. Horberg. 1948. Physiographic Divisions of Illinois. State Geological Survey, Report of Investigations no. 129, Urbana.

Leopold, L. B. 1994. *A View of the River*. Harvard University Press, Cambridge, Massachusetts, 298 pp.

Leopold, L. B. and T. Maddock. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. USGS, Professional Paper 252, 57 pp.

Leopold, L. B., M. G. Wolman and J. P. Miller. 1964. *Fluvial Processes in Geomorphology*. Dover Publications, New York, New York, 522 p. pp.

Luman, D. and T. Weicherding. 1999. Land Cover of Illinois: 1999-2000, Illinois State Geological Survey. 2003.

Lutenengger, A. J. 1987. In Situ Shear Strength of Friable Loess. *Catena Supplement*. 9:27-34.

Middleton, B. 1995. The Role of Flooding in Seed Dispersal: Restoration of Cypress Swamps Along the Cache River, Il. Water Resources Center, University of Illinois at Urbana-Champaign, Urbana, IL, 97 pp.

Miller, J. R. and J. B. Ritter. 1996. An Examination of the Rosgen Classification of Natural Rivers. *Catena*. 27:295-299.

Montgomery, D. R. and J. M. Buffington. 1997. Channel-Reach Morphology in Mountain Drainage Basins. *GSA Bulletin*. 109 (5):596-611.

Montgomery, D. R. and L. H. MacDonald. 2002. Diagnostic Approach to Stream Channel Assessment and Monitoring. *Journal American Water Resources Association*. 38 (1):1-16.

Newson, M. D. 1995. Fluvial Geomorphology and Environmental Design. *in* Changing River Channels. G. P. Angela Gurnell (eds.). John Wiley & Sons, Ltd. p. 413-432.

Osterkamp, W. R. and C. R. Hupp. 1996. The Evolution of Geomorphology, Ecology, and Other Composite Sciences. *Proceedings of the The Scientific Nature of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology*, 1996, John Wiley & Sons, Ltd. p. 415 - 441.

Rhoads, B. L. 1990a. Hydrologic Characteristics of a Small Desert Mountain Stream: Implications for Short-Term Magnitude and Frequency of Bedload Transport. *Journal of Arid Environments*. 18:151-163.

Rhoads, B. L. 1990b. The Impact of Stream Channelization on the Geomorphic Stability of an Arid-Region River. *National Geographic Research*. 6 (2):157-177.

Rhoads, B. L. 1995. Stream Power: A Unifying Theme for Urban Fluvial Geomorphology. University of Illinois, Urbana, 1-15 pp.

Rhoads, B. L. 2003. Protocols for Geomorphic Characterization of Meander Bends in Illinois. Urbana, IL, University of Illinois at Urbana-Champaign, Department of Geography**:** 130.

Rhoads, B. L. and E. E. Herricks. 1996. Naturalization of Headwater Streams in Illinois: Challenges and Possibilities. *in* River Channel Restoration: Guiding Principles for Sustainable Projects. J. A. Brookes and F. D. Shields (eds.). John Wiley & Sons, LTD. p. 331-367.

Rhoads, B. L. and S. T. Kenworthy. 1995. Flow Structure at an Asymmetrical Stream Confluence. *Geomorphology*. 11:273-293.

Rhoads, B. L. and C. E. Thorn. 1996. Observation in Geomorphology. *Proceedings of the The Scientific Nature of Geomorphology: Proceedings pf the 27th Birmingham Symposium in Geomorphology, 27-29 September 1996*, Sept 1996, John Wiley & Sons, Ltd. p. 21-56.

Rhoads, B. L. and M. A. Urban. 1997. Human-Induced Geomorphic Change in Low-Energy Agricultural Streams: An Example Form East-Central Illinois. *Proceedings of the Management of Landscapes Disturbed by Channel Incision*, Oxford, MS, Center for Computational Hydroscience and Engineering, The University of MIssissippi. p. 968-973.

Ritter, D. F. 1978. *Process Geomorphology*. Wm C. Brown Company Publishers, 603 pp.

Rosgen, D. L. 1994. A Classification of Natural Rivers. *Catena*. 22:169-199.

Rosgen, D. L. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, Colorado, 390 pp.

Ruhe, R. V. 1969. *Quaternary Landscapes in Iowa*. Iowa State University Press, Ames, Iowa, 255 pp.

Schumm, S. A., M. D. Harvey and C. C. Watson. 1984. *Incised Channels: Morphology, Dynamics and Control*. Water Resources Publications, 200 pp.

Sengupta, R. 1995. Fluvial Sedimentology of Cypress Creek, Union, Jackson, and Pulaski Counties, Southern Illinois., M.S. Thesis, Southern Illinois University, Carbondale, IL, 130 p. pp.

Shasteen, S. P., M. R. Matson, M. M. King, J. M. Levesque, G. L. Minton, S. J. Tripp and D. B. Muir. 2002. An Intensive Survey of the Cache River Basin: Data Summary, Summer 1999. Illinois Environmental Protection Agency, IEPA/BOW/02-021, Marion, Illinois, 37 p. pp.

Shawnee Community College. 1975. Shawnee Community College, Local History Project: Pulaski County, Personal Interview with Genevieve Brown. 2003.

Shields, F. D., Jr., A. Brookes and J. Haltiner. 1999. Geomorphological Approaches to Incised Stream Channel Restoration in the United States and Europe. *in* Incised River Channels: Processes, Forms, Engineering and Management. S. E. Darby and A. Simon (eds.). West Sussex, England, John Wiley & Sons. p. 371-394.

Shroba, R. R., T. R. Brandt and J. C. Blossom. 2001. Surficial Geologic Map of the Greater Omaha Area, Nebraska and Iowa. U.S. Geological Survey, MF-2391.

Simon, A. 1989. A Model of Channel Response in Disturbed Alluvial Channels. *Earth Surface Processes and Landforms*. 14:11-26.

Simon, A. 1992. Energy, Time, and Channel Evolution in Catastrophically Disturbed Fluvial Systems. *Geomorphology* (5):345-372.

Simon, A. 1994. Gradation Processes and Channel Evolution in Modified West Tennessee Streams: Process, Response, and Form. US Geological Survey, Professional Pater 1470, 1-85 pp.

Simon, A. and P. Downs. 1995. An Interdisciplinary Approach to Evaluation of Potential Instability in Alluvial Channels. *Geomorphology*. 12:215-232.

Simon, A., M. W. Doyle, G. M. Kondolf, F. D. Shields, Jr., B. L. Rhoads, G. E. Grant, F. A. Fitzpatrick, K. E. Juracek, M. McPhillips and J. MacBroom. 2005. How Well Do the Rosgen Classification and Associated "Natural Channel Design" Methods Integrate and Quantify Fluvial Processes and Channel Response? *Proceedings of the World Water and Environmental Resources Congress 2005,* Anchorage, AK, ASCE. p. 12.

Simon, A. and C. R. Hupp. 1992. Geomorphic and Vegetative Recovery Processes Along Modified Stream Channels of West Tennessee. U.S. Geological Survey, Open-File Report 91-502, Nashville, Tennessee, 142 pp.

Simon, A., G. S. Outlaw and R. E. Thomas. 1989. Evaluation, Modeling, and Mapping of Potential Bridge Scour, West Tennessee. *Proceedings of the National Bridge Scour Symposium*, Federal Highway Administration. Report FHWA-RD-90-035, p. 112-129.

Simon, A. and M. Rinaldi. 2000. Channel Instability in the Loess Area of the Midwestern United States. *Journal American Water Resources Association*. 36 (1):133 -150.

Skidmore, P. B., F. D. Shields, Jr., M. W. Doyle and D. E. Miller. 2001. A Categorization of Approaches to Natural Channel Design. *Proceedings of the 2001 ASCE Wetlands Engineering and River Restoration*:1-12.

Strahler, A. N. 1950. Equilibrium Theory of Slopes Approached by Frequency Distribution Analysis. *American Journal of Science*. 248:800-814.

Thorne, C. R. 1998. *Stream Reconnaissance Handbook*. John Wiley & Sons, Ltd., New York, 1-129 pp.

Thorne, C. R., R. G. Allen and A. Simon. 1996. Geomorphological River Channel Reconnaissance for River Analysis, Engineering and Management. *Transactions of the Institute of British Geographers*. 21 (3):469-483.

Trimble, S. W. 1998. Dating Fluvial Processes from Historical Data and Artifacts. *Catena*. 31:283-304.

Trimble, S. W. and R. U. Cooke. 1991. Historical Sources for Geomorphological Research in the United States. *Professional Geographer*. 43 (2):212-228.

U. S. Department of Agriculture. 1968. Soil Survey of Pulaski and Alexander Counties, Illinois. U.S. Government Printing Office, Illinois Agricultural Experment Station Soil Report No. 85, Washington, D.C., 121 and maps pp.

U. S. Department of Agriculture. 1979. Soil Survey of Union County, Illinois. U.S. Government Printing Office, Washington, D.C., 143 and maps pp.

Urban, M. A. and B. L. Rhoads. 2003. Catastrophic Human-Induced Change in Stream-Channel Planform and Geometry in an Agricultural Watershed, Illinois, USA. *Annals of the Association of American Geographers*. 94 (3):783-796.

Whiting, P. J. and J. B. Bradley. 1993. A Process-Based Classification System for Headwater Streams. *Earth Surface Processes and Landforms*. 18:603-612.

Appendix A Watershed-Scale Characterization Data Source Description

The historical analysis has three objectives: 1) establish current physical character of the watershed, 2) identify possible direct and indirect disturbances to the sediment supply and transport capacity of the streams, and 3) document changes in the hydrology, channel geometry, and sediment character over time. The main objective of the initial field survey is to establish the extant physical character of the stream channel throughout the watershed and is primarily accomplished through field data collection. It should be noted that the field data collection will supplement the third objective in the historical analysis. Also, several data sources will be used in 2 or more of these objectives, which makes their retrieval particularly important.

Historical Analysis Technique – (1) Establish current physical character of watershed

- Watershed boundary and streams/waterbodies – The watershed boundary is used to determine the spatial extent of the knowledge base needed for the assessment, such as the drainage area of watershed and sub-watersheds, and an important GIS layer to retrieve other spatial datasets. One of those datasets would be streams/waterbodies, which establishes current drainage patterns.
    - Illinois Natural Resources Geospatial Data Clearinghouse – Water Resources and Hydrology Data page: http://www.isgs.uiuc.edu/nsdihome/webdocs/st-hydro.html
    - USDA, NRCS Geospatial Data Gateway: http://datagateway.nrcs.usda.gov/
    - USGS – The National Map: http://nationalmap.usgs.gov/ or http://geography.usgs.gov/products.html

- Physiographic regions, surficial materials, and geology – The land surface and sub-surface exerts a significant physical control on the flow of water. This data establishes the physical context of the watershed and will be used to infer potential future adjustment processes.
    - Physiographic classification of Illinois
        - http://www.isgs.uiuc.edu/nsdihome/outmeta/physio.html
    - Surficial materials and loess thicknesses
        - http://www.isgs.uiuc.edu/nsdihome/outmeta/quat96.html
        - http://www.isgs.uiuc.edu/quaternary/loess_thickness_map.htm
    - Geology
        - http://www.isgs.uiuc.edu/nsdihome/outmeta/stslope.html
        - http://www.isgs.uiuc.edu/nsdihome/outmeta/stack-st.html
- Soils, climate, and land use – The
    - Soils maps
        - Soil Survey Geographical Database (SSURGO) http://soildatamart.nrcs.usda.gov/ or http://datagateway.nrcs.usda.gov/GatewayHome.html
    - Climate data
        - Midwest Regional Climate Center (MRCC) – *recent and historical* http://sisyphus.sws.uiuc.edu/index.html
    - Land use
        - National Land Cover Data Set (NLCD) – *recent data only* http://datagateway.nrcs.usda.gov/GatewayHome.html

Historical Analysis Technique – (2) Identify potential direct and indirect influences: The identification of direct and indirect influences on the landscape involves recent and historical changes in climate, landscape, and hydrography. These included not only abrupt (direct) changes but more subtle changes where trends may be detected. Changes in channel planform can be documented and, when quality of data is sufficient and time permits, rates of channel migration can be computed.

- Topographic maps, aerial photography, ground-based photography – Visual inspection of current and historical topographic maps, aerial photography, and ground-based photography can qualitative locate possible changes in landform over time and narrow the search for abrupt (direct) changes due to engineering projects.
    - Topographic maps and aerial photography are available from the Illinois Geospatial Clearinghouse http://www.isgs.uiuc.edu/nsdihome/ISGSindex.html :
        - Recent topography: http://www.isgs.uiuc.edu/nsdihome/webdocs/drgs/
        - Historical plat maps: http://landplats.ilsos.net/Flash/Welcome.html
        - Illinois Digital Orthophoto Quarter Quadrangle (DOQ) Data: http://www.isgs.uiuc.edu/nsdihome/webdocs/doqs/
        - Historical aerial photography (limited): http://www.isgs.uiuc.edu/nsdihome/webdocs/ilhap/ or the University of Illinois at Urbana-Champaign, Map & Geography Library
- Drainage projects, road and causeway construction plans, and bathymetric surveys – Typically engineering projects required instrumented surveying and can supply some of the best measured stream channel geometry and, conversely, are quite random. Definitive sources are not routine and require locating the data through many phone

calls with several local and state agencies. The inspection of recent and historical topographic maps and aerial photography can locate abrupt changes in planform, therefore narrowing the search to only a few geographic areas and possible fewer agencies to contact. Below is a list of federal, state, and local data sources to start the search:

- U.S. Army Corps of Engineers:
    - Chicago District; St. Louis District; Rock Island District; Louisville District; Memphis District;
- Illinois Department of Natural Resources – Office of Water Resources:
    - http://dnr.state.il.us/owr/OWR_index.htm
    - Annual Report of the Division of Waterways – These reports cover drainage projects undertaken by the State of Illinois in the early-1900s and are available at the University of Illinois at Urbana-Champaign library.
- Illinois Department of Transportation: http://www.dot.state.il.us/default.asp
- County-level Road Commissions: These agencies are usually small and understaffed. It is recommended that they not be contacted until all other data sources are retrieved and the initial field survey is conducted. This reduces the likelihood of putting undue burden on these organizations for data of questionable value and focusing efforts on areas that show more promise.

- Climate and land use – The style and magnitude of indirect influences in a watershed can be identified through changes in land use and climate. Documenting changes in land use is problematic due to the lack of pre-settlement data but some information is available

  - Climate
    - Midwest Regional Climate Center (MRCC) – *recent and historical* http://sisyphus.sws.uiuc.edu/index.html
  - Land use
    - National Agricultural Statistics Service: http://www.nass.usda.gov:81/ipedb/
    - Illinois Natural History Survey - 1800s Government Land Office Survey maps: ftp://kestrel.inhs.uiuc.edu/pub/
    - Illinois Department of Agriculture: http://www.agr.state.il.us/gis/landcover.html
    - County Soil Surveys: The older volumes of the Soil Survey reports provide anecdotal information on dominant land uses in the county.
- Past scientific studies, travel accounts, and news media – Literature searches for reports and publications on scientific and non-scientific sources of information are necessary but slow. Many studies can be located through websites of several federal and state agencies. Travel accounts and news media publications are best searched through university, college, and local libraries.
  - Illinois Department of Natural Resources – Office of Scientific Research:
    - Illinois State Water Survey: http://www.sws.uiuc.edu/
    - Illinois State Geological Survey: http://www.isgs.uiuc.edu/
    - Illinois Natural History Survey: http://www.inhs.uiuc.edu/
    - Illinois State Museum: http://www.museum.state.il.us/
  - Illinois Environmental Protection Agency:

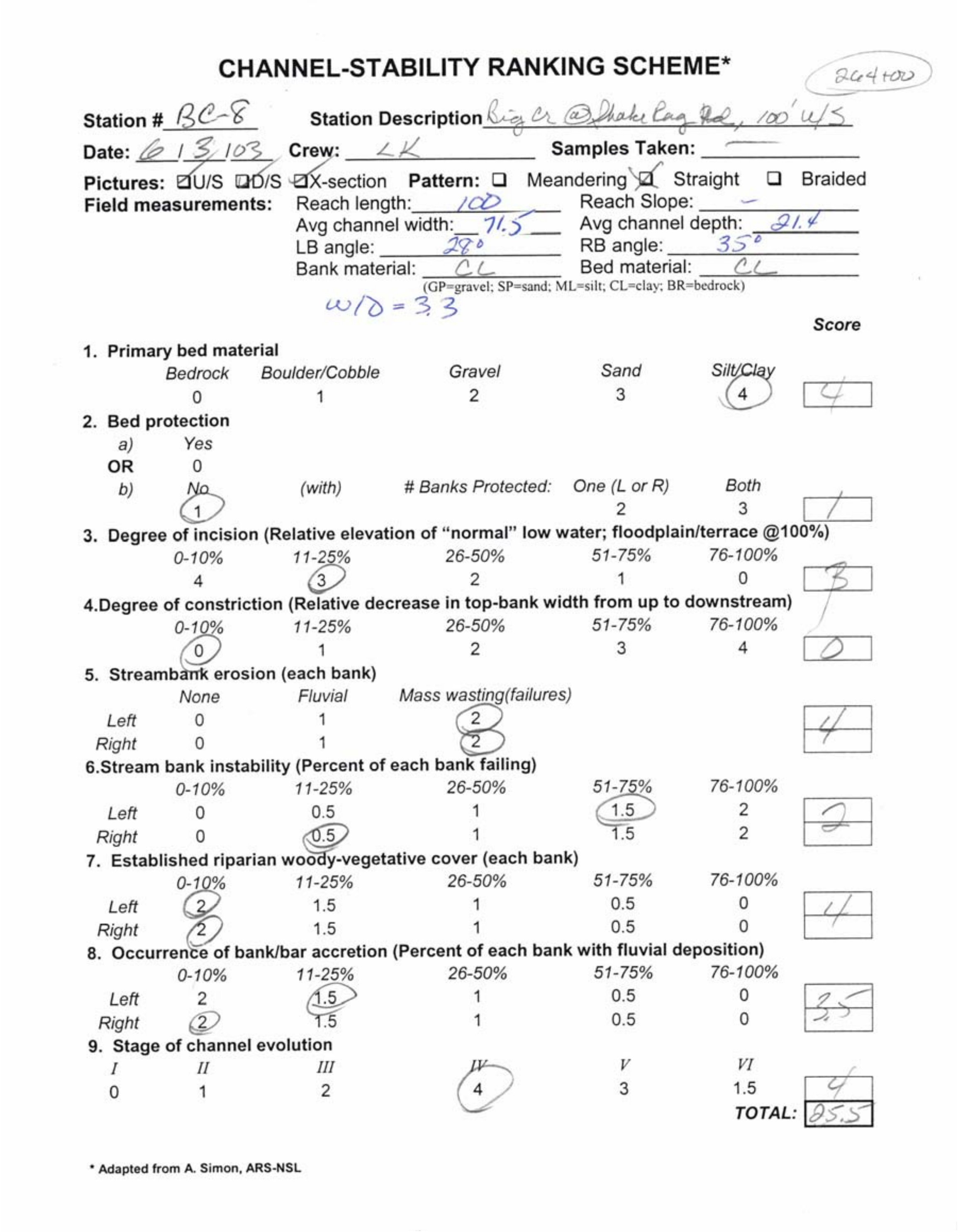
        - Intensive Basin Surveys: http://www.epa.state.il.us/water/surface-water/river-stream-mon.html
    - U.S. Geological Survey-Illinois District: http://il.water.usgs.gov/

Historical Analysis Technique – (3) Hydraulic and Channel Geometry (flow and sediment): Many datasets retrieved in the two prior objectives will be used to document changes in streamflow frequency, sediment character, and channel geometry. This information will be used to determine if adjustments have occurred and, if so, what is the style and magnitude of those adjustments. This third objective will supplement the initial field survey of this characterization.

- Streamflow records and sediment data – This data is readily available but can be limited in duration and number of locations. Study-specific data may be found in scientific reports (see above).
    - U.S. Geological Survey: http://waterdata.usgs.gov/IL/nwis/
    - Illinois State Water Survey: http://www.sws.uiuc.edu/data.asp
- Channel geometry (cross-sections and gradient) – Channel geometry is generally not readily available. If available, they may be found in scientific publications or any of the sources listed above (Drainage projects, road and causeway construction plans, and bathymetric surveys). Changes in channel geometry may also be implied from ground-based oblique photography.

Initial Field Survey Technique – Document the extant physical character of the stream channel: The data sources gathered and summarized from the historical analysis are used to determine the density and spatial distribution of the field sites. However, the main source of data for the initial field survey comes from the basic field data collection and channel-stability ranking scheme (Figure 3.1).

Appendix B Completed Channel-stability Index Sheet



CHANNEL-STABILITY RANKING SCHEME*

264+00

Station # BC-8 **Station Description** Big Cr @ Shake Rag Rd, 100' U/S

Date: 6/3/03 **Crew:** LK **Samples Taken:** —

Pictures: ☑U/S ☑D/S ☑X-section **Pattern:** ☐ Meandering ☑ Straight ☐ Braided

Field measurements:

Reach length: 100

Reach Slope: —

Avg channel width: 71.5

Avg channel depth: 21.4

LB angle: 28°

RB angle: 35°

Bank material: CL

Bed material: CL

(GP=gravel; SP=sand; ML=silt; CL=clay; BR=bedrock)

w/D = 3.3

1. Primary bed material

						Score
	Bedrock	*Boulder/Cobble*	*Gravel*	*Sand*	*Silt/Clay*	
	0	1	2	3	[✓ 4]	4

2. Bed protection

a)	*Yes*					
OR	0					
b)	*No*	*(with)*	*# Banks Protected:*	*One (L or R)*	*Both*	
	[✓ 1]			2	3	1

3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @100%)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
	4	[✓ 3]	2	1	0	3

4.Degree of constriction (Relative decrease in top-bank width from up to downstream)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
	[✓ 0]	1	2	3	4	0

5. Streambank erosion (each bank)

	None	*Fluvial*	*Mass wasting(failures)*	
Left	0	1	[✓ 2]	4
Right	0	1	[✓ 2]	

6.Stream bank instability (Percent of each bank failing)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
Left	0	0.5	1	[✓ 1.5]	2	2
Right	0	[✓ 0.5]	1	1.5	2	

7. Established riparian woody-vegetative cover (each bank)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
Left	[✓ 2]	1.5	1	0.5	0	4
Right	[✓ 2]	1.5	1	0.5	0	

8. Occurrence of bank/bar accretion (Percent of each bank with fluvial deposition)

	0-10%	*11-25%*	*26-50%*	*51-75%*	*76-100%*	
Left	2	[✓ 1.5]	1	0.5	0	3.5
Right	[✓ 2]	1.5	1	0.5	0	

9. Stage of channel evolution

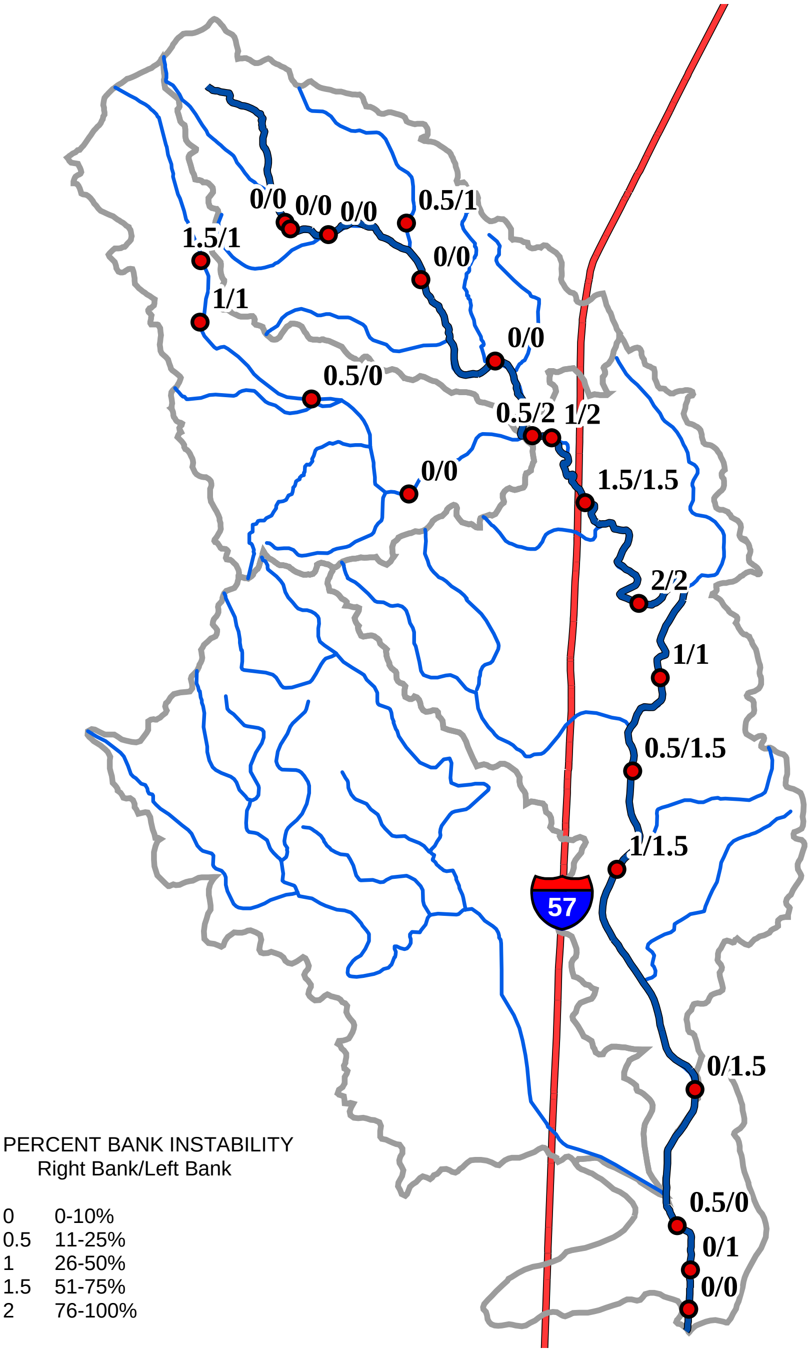
I	*II*	*III*	*IV*	*V*	*VI*	
0	1	2	[✓ 4]	3	1.5	4
					TOTAL:	25.5

* Adapted from A. Simon, ARS-NSL

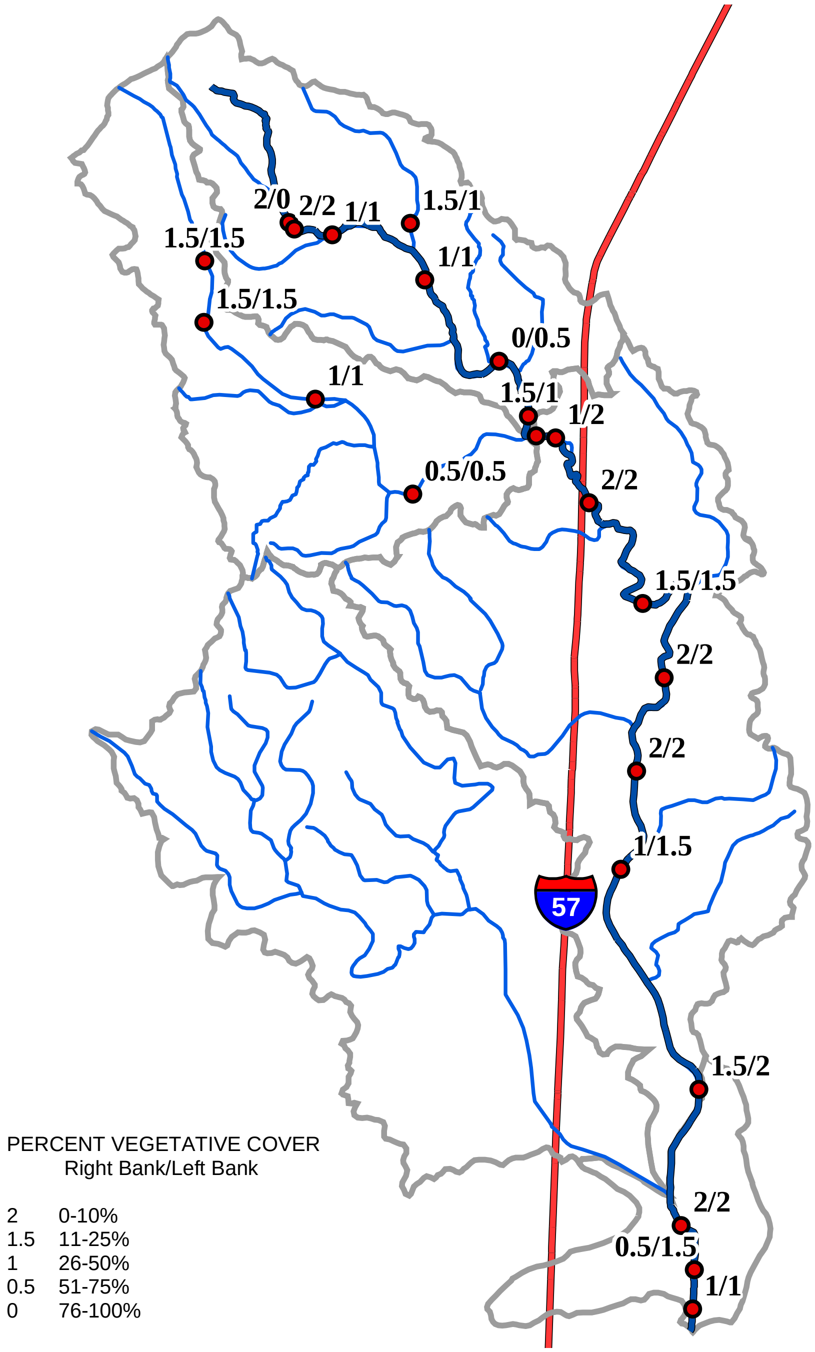
Appendix C Spatial Distribution of Channel Stability Index Variables in Watershed

C-1 Percent bank stability (right bank/left bank)
C-2 Percent woody vegetative cover (right bank/left bank)
C-3 Primary bed material
C-4 Degree of floodplain separation (incision)

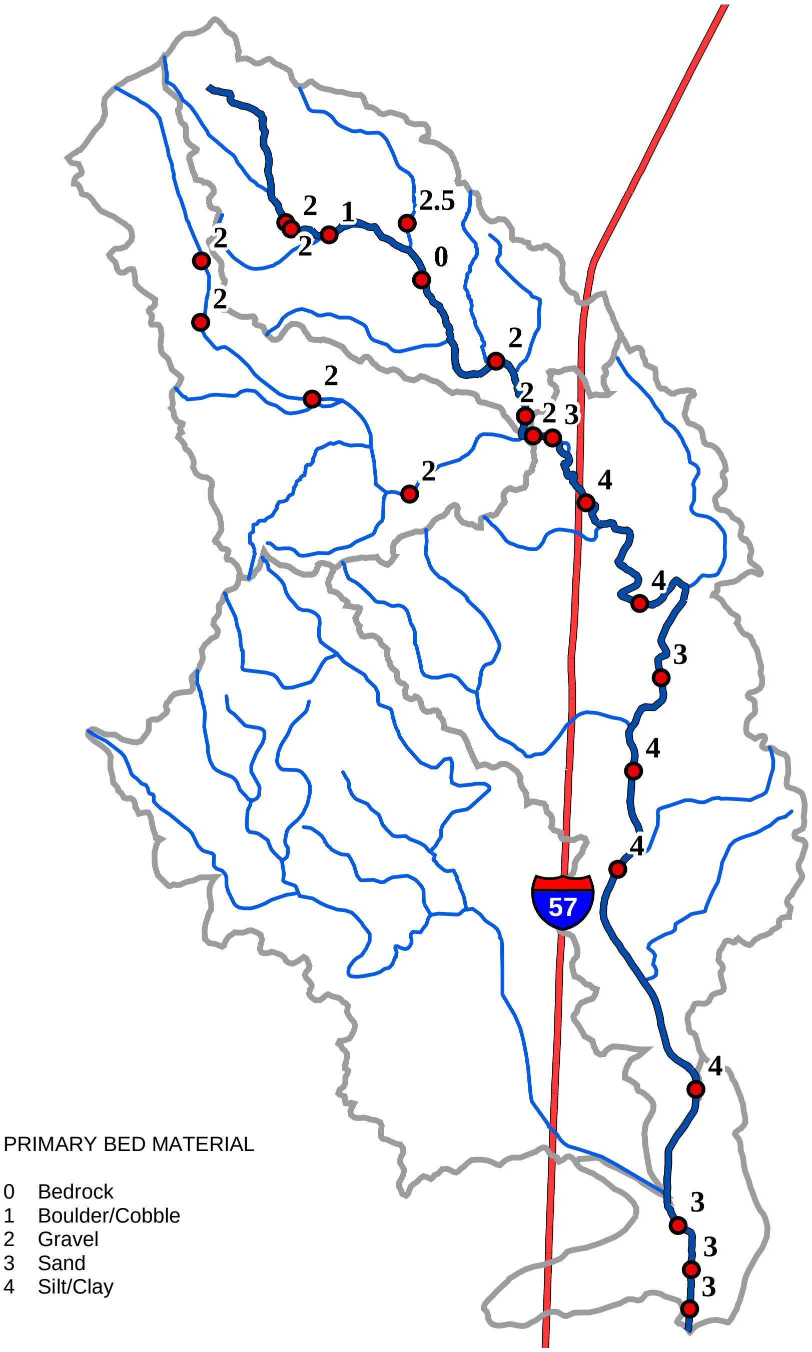
Appendix C-1 Percent bank stability (right bank/left bank)



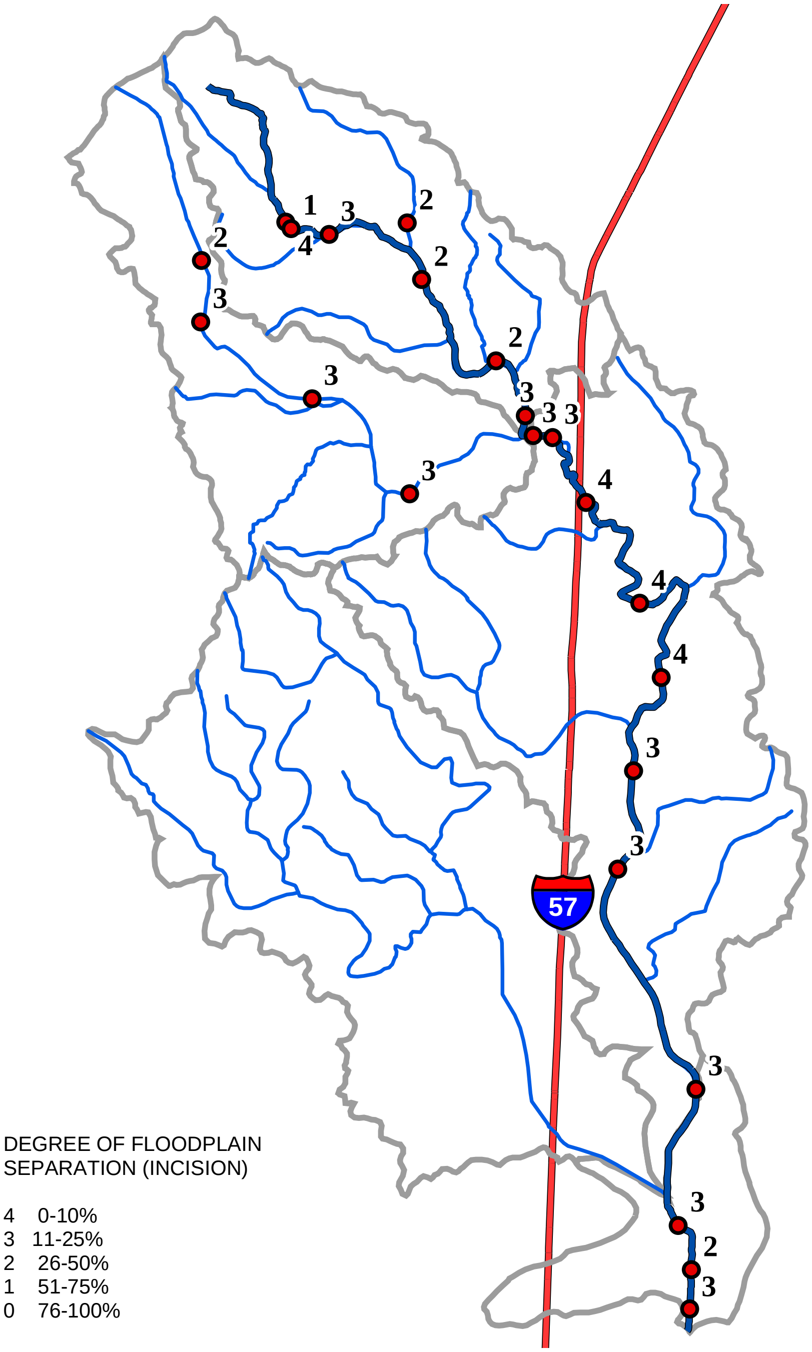
Appendix C-2 Percent woody vegetative cover (right bank/left bank)



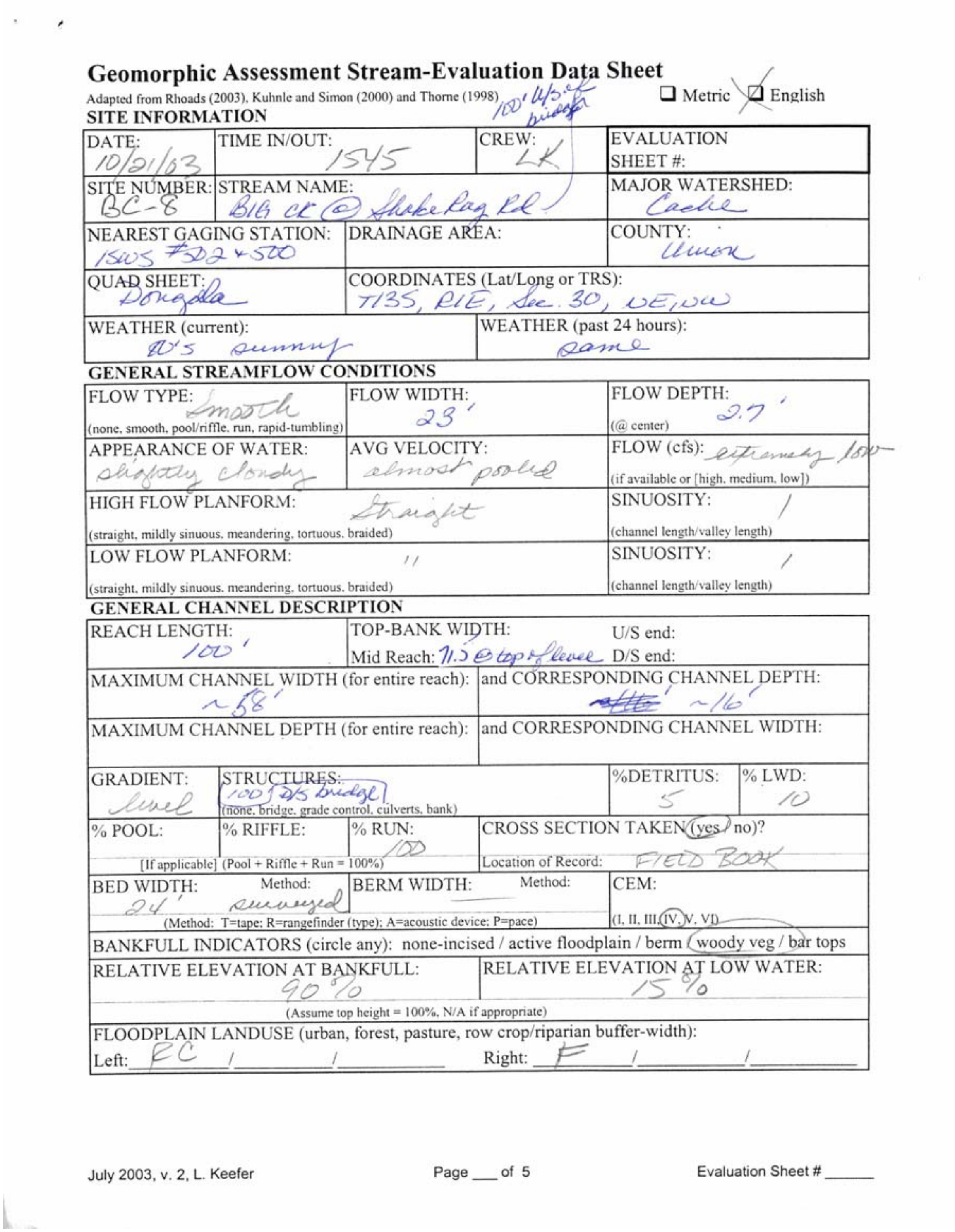
Appendix C-3 Primary bed material



Appendix C-4 Degree of floodplain separation (incision)



Appendix D Example of Completed Geomorphic Assessment Stream-Evaluation Data Sheet – Site BC-8



Geomorphic Assessment Stream-Evaluation Data Sheet

Adapted from Rhoads (2003), Kuhnle and Simon (2000) and Thorne (1998) 100' U/S of bridge

☐ Metric ☒ English

SITE INFORMATION

DATE: 10/21/03	TIME IN/OUT: 1545	CREW: LK	EVALUATION SHEET #:
SITE NUMBER: BC-8	STREAM NAME: BIG CK @ Shake Rag Rd		MAJOR WATERSHED: Cache
NEAREST GAGING STATION: USGS #032+500	DRAINAGE AREA:		COUNTY: Union
QUAD SHEET: Dongola	COORDINATES (Lat/Long or TRS): T13S, R1E, Sec. 30, NE, NW		
WEATHER (current): 80's sunny		WEATHER (past 24 hours): same	

GENERAL STREAMFLOW CONDITIONS

FLOW TYPE: smooth (none, smooth, pool/riffle, run, rapid-tumbling)	FLOW WIDTH: 23'	FLOW DEPTH: 2.7' (@ center)
APPEARANCE OF WATER: slightly cloudy	AVG VELOCITY: almost pooled	FLOW (cfs): extremely low (if available or [high, medium, low])
HIGH FLOW PLANFORM: Straight (straight, mildly sinuous, meandering, tortuous, braided)		SINUOSITY: 1 (channel length/valley length)
LOW FLOW PLANFORM: " (straight, mildly sinuous, meandering, tortuous, braided)		SINUOSITY: 1 (channel length/valley length)

GENERAL CHANNEL DESCRIPTION

REACH LENGTH: 100'	TOP-BANK WIDTH: Mid Reach: 71.5 @ top of levee	U/S end: D/S end:	
MAXIMUM CHANNEL WIDTH (for entire reach): ~58'		and CORRESPONDING CHANNEL DEPTH: ~16'	
MAXIMUM CHANNEL DEPTH (for entire reach):		and CORRESPONDING CHANNEL WIDTH:	
GRADIENT: level	STRUCTURES: (100' D/S bridge) (none, bridge, grade control, culverts, bank)	%DETRITUS: 5	% LWD: 10
% POOL:	% RIFFLE:	% RUN: 100	CROSS SECTION TAKEN ([✓ yes] / no)? Location of Record: FIELD BOOK
[If applicable] (Pool + Riffle + Run = 100%)			
BED WIDTH: 24' Method: surveyed	BERM WIDTH: — Method:	CEM: (I, II, III, [✓ IV], V, VI)	
(Method: T=tape; R=rangefinder (type); A=acoustic device; P=pace)			

BANKFULL INDICATORS (circle any): none-incised / active floodplain / berm / [✓ woody veg / bar tops]

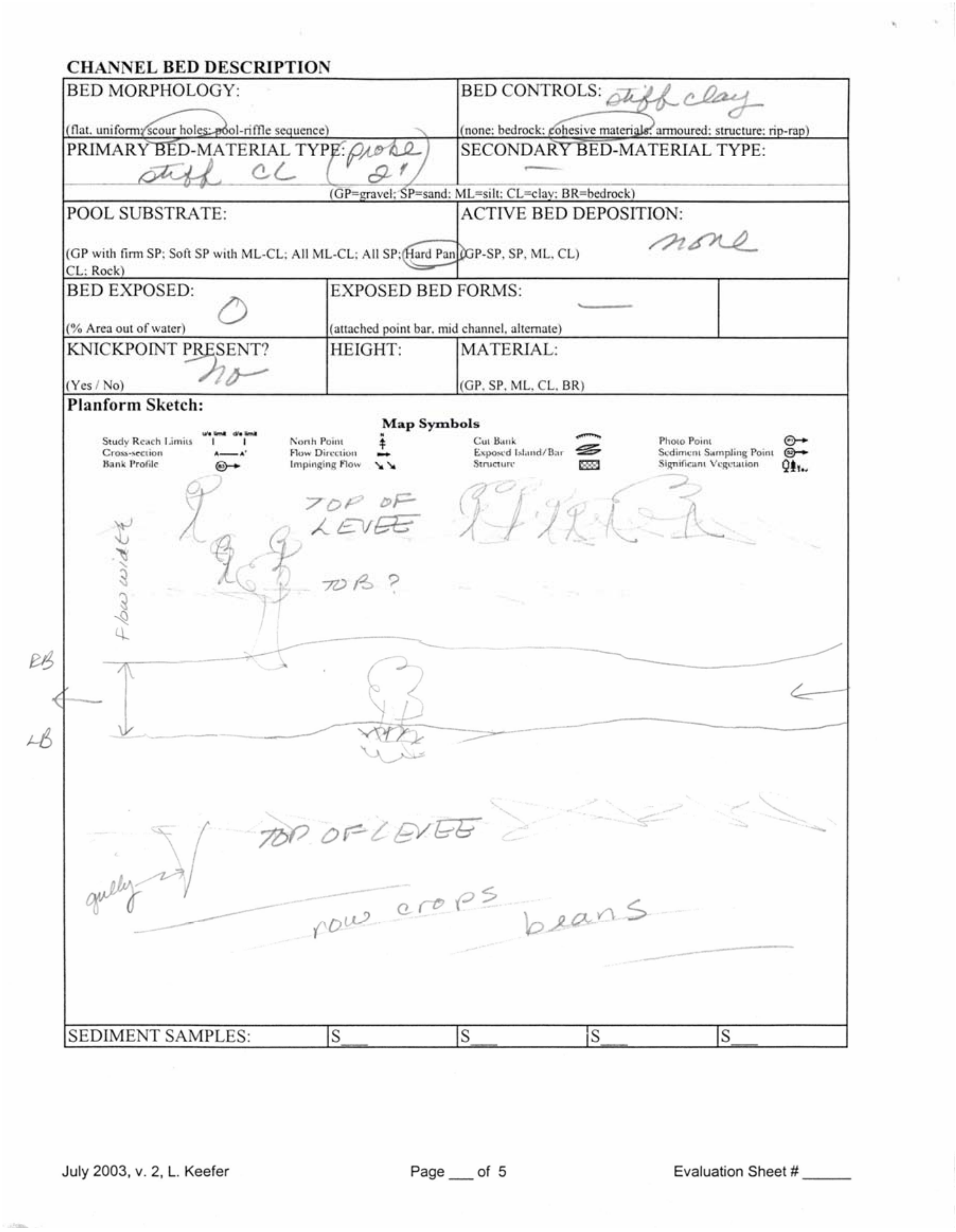
RELATIVE ELEVATION AT BANKFULL: 90%	RELATIVE ELEVATION AT LOW WATER: 15%

(Assume top height = 100%, N/A if appropriate)

FLOODPLAIN LANDUSE (urban, forest, pasture, row crop/riparian buffer-width):

Left: RC / / Right: F / /

July 2003, v. 2, L. Keefer Page ___ of 5 Evaluation Sheet # ______



CHANNEL BED DESCRIPTION

BED MORPHOLOGY: (flat, uniform; [✓ scour holes]; pool-riffle sequence)	BED CONTROLS: stiff clay (none; bedrock; [✓ cohesive materials]; armoured; structure; rip-rap)
PRIMARY BED-MATERIAL TYPE: probe 2' stiff CL	SECONDARY BED-MATERIAL TYPE: —
(GP=gravel; SP=sand; ML=silt; CL=clay; BR=bedrock)	
POOL SUBSTRATE: (GP with firm SP; Soft SP with ML-CL; All ML-CL; All SP; [✓ Hard Pan] CL; Rock)	ACTIVE BED DEPOSITION: none (GP-SP, SP, ML, CL)

BED EXPOSED: 0 (% Area out of water)	EXPOSED BED FORMS: — (attached point bar, mid channel, alternate)	
KNICKPOINT PRESENT? no (Yes / No)	HEIGHT:	MATERIAL: (GP, SP, ML, CL, BR)

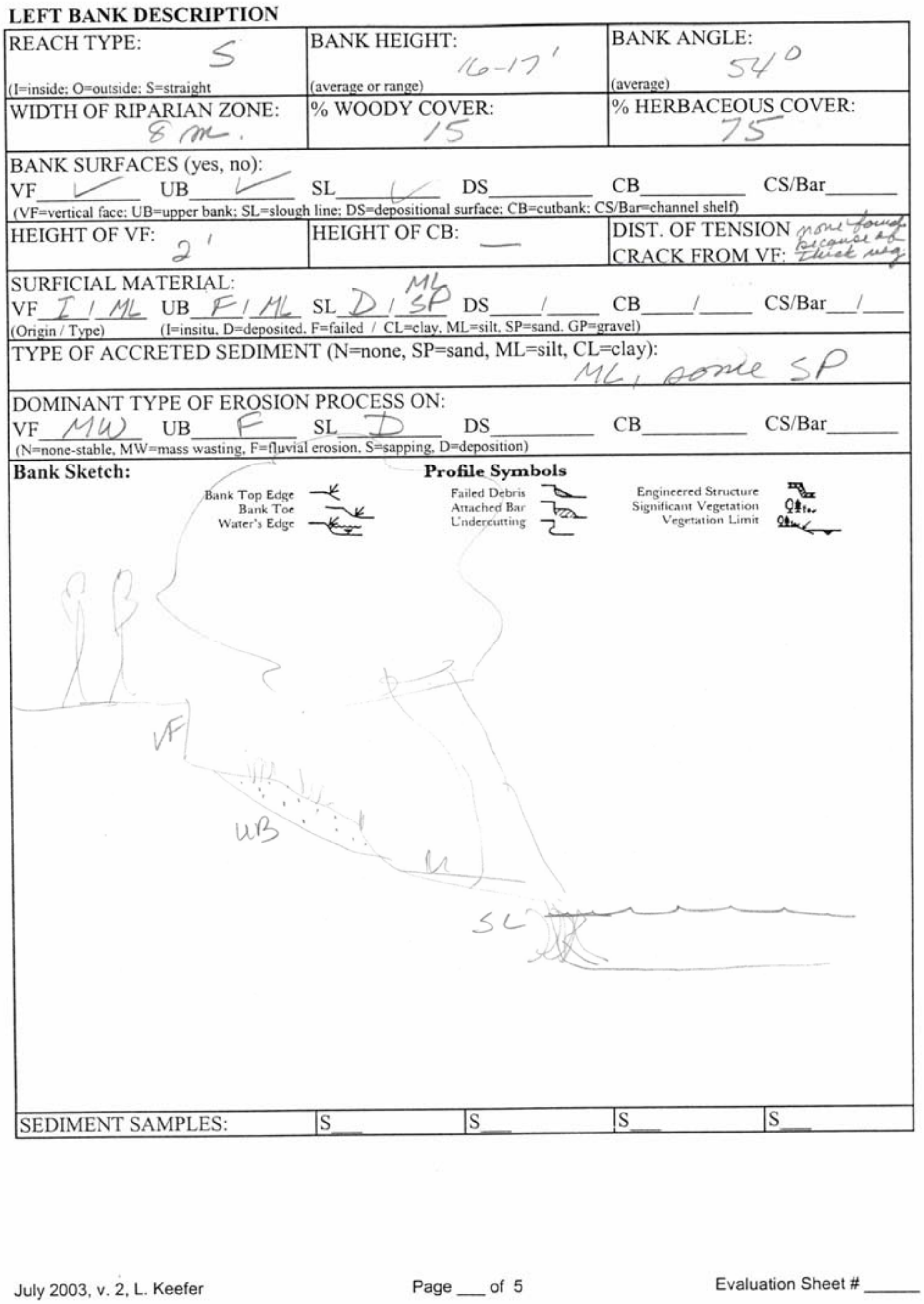
Planform Sketch:

Map Symbols

Study Reach Limits	North Point	Cut Bank	Photo Point
Cross-section	Flow Direction	Exposed Island/Bar	Sediment Sampling Point
Bank Profile	Impinging Flow	Structure	Significant Vegetation

SEDIMENT SAMPLES:	S___	S___	S___	S___

July 2003, v. 2, L. Keefer   Page ___ of 5   Evaluation Sheet # ______



LEFT BANK DESCRIPTION

REACH TYPE: S (I=inside; O=outside; S=straight	BANK HEIGHT: 16-17' (average or range)	BANK ANGLE: 54° (average)
WIDTH OF RIPARIAN ZONE: 8 m.	% WOODY COVER: 15	% HERBACEOUS COVER: 75

BANK SURFACES (yes, no):
VF ✓ UB ✓ SL ✓ DS ____ CB ____ CS/Bar ____
(VF=vertical face; UB=upper bank; SL=slough line; DS=depositional surface; CB=cutbank; CS/Bar=channel shelf)

HEIGHT OF VF: 2'	HEIGHT OF CB: —	DIST. OF TENSION CRACK FROM VF: none found because of thick veg.

SURFICIAL MATERIAL:
VF I / ML UB F / ML SL D / ML SP DS ___/___ CB ___/___ CS/Bar ___/___
(Origin / Type) (I=insitu, D=deposited, F=failed / CL=clay, ML=silt, SP=sand, GP=gravel)

TYPE OF ACCRETED SEDIMENT (N=none, SP=sand, ML=silt, CL=clay): ML, some SP

DOMINANT TYPE OF EROSION PROCESS ON:
VF MW UB F SL D DS ____ CB ____ CS/Bar ____
(N=none-stable, MW=mass wasting, F=fluvial erosion, S=sapping, D=deposition)

Bank Sketch:

Profile Symbols

SEDIMENT SAMPLES: S___ S___ S___ S___

July 2003, v. 2, L. Keefer Page ___ of 5 Evaluation Sheet # ______

RIGHT BANK DESCRIPTION

REACH TYPE: S (I=inside; O=outside; S=straight	BANK HEIGHT: 16-17' (average or range)	BANK ANGLE: 70° (average)
WIDTH OF RIPARIAN ZONE: 10 m	% WOODY COVER: 15	% HERBACEOUS COVER: 75

BANK SURFACES (yes, no):

VF ? UB ✓ SL____ DS____ CB____ CS/Bar____

(VF=vertical face; UB=upper bank; SL=slough line; DS=depositional surface; CB=cutbank; CS/Bar=channel shelf)

HEIGHT OF VF:	HEIGHT OF CB:	DIST. OF TENSION CRACK FROM VF:

SURFICIAL MATERIAL: CL

VF__/__ UB I / ML SL__/__ DS__/__ CB__/__ CS/Bar__/__

(Origin / Type) (I=insitu, D=deposited, F=failed / CL=clay, ML=silt, SP=sand, GP=gravel)

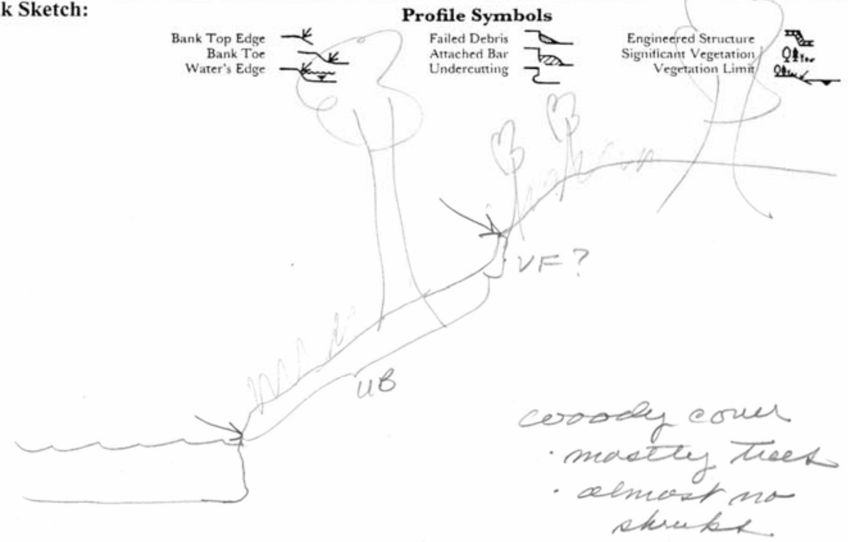
TYPE OF ACCRETED SEDIMENT (N=none, SP=sand, ML=silt, CL=clay): N

DOMINANT TYPE OF EROSION PROCESS ON:

VF____ UB F SL____ DS____ CB____ CS/Bar____

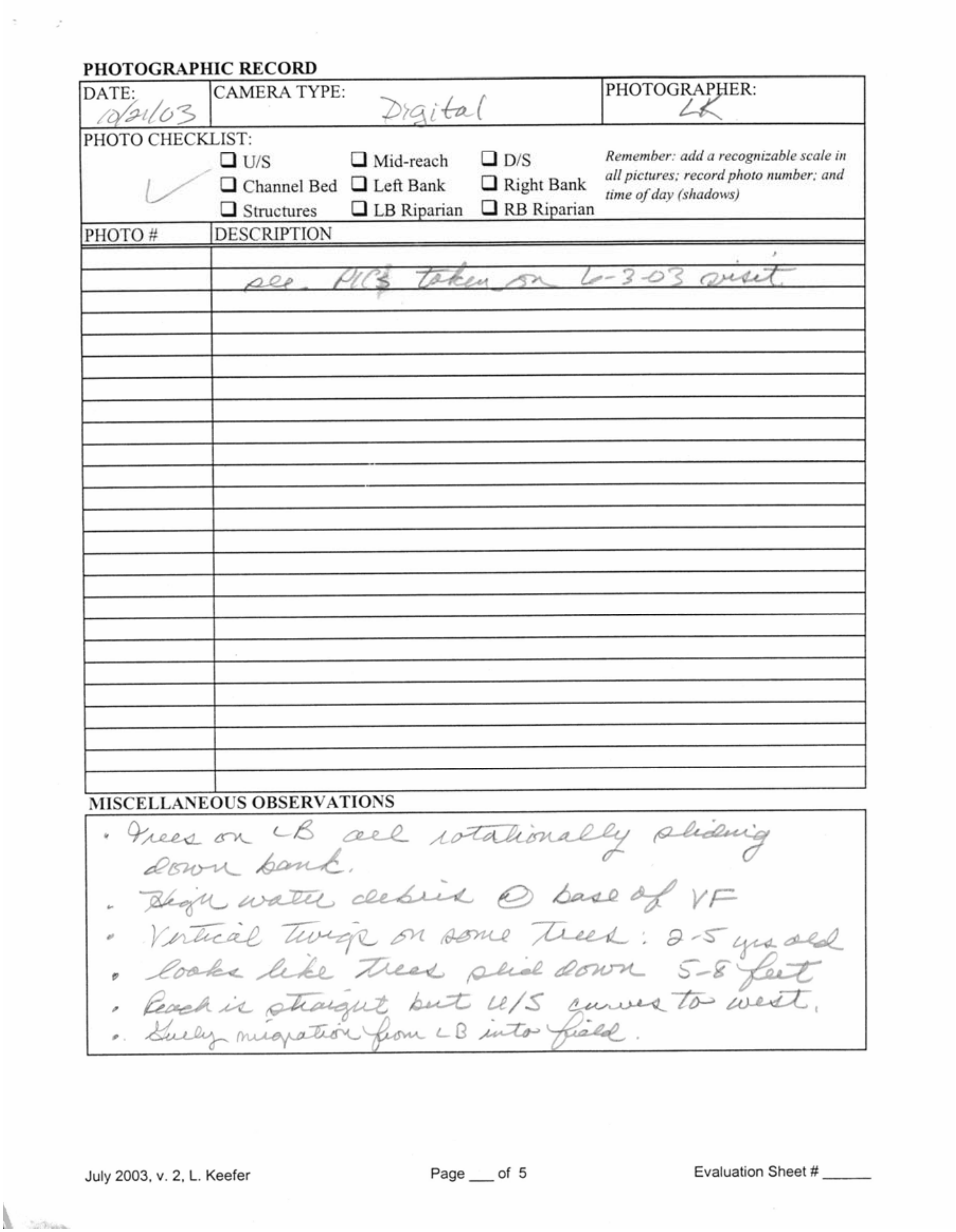
(N=none-stable, MW=mass wasting, F=fluvial erosion, S=sapping, D=deposition)

Bank Sketch:



woody cover
· mostly trees
· almost no shrubs

SEDIMENT SAMPLES: S__ S__ S__ S__



PHOTOGRAPHIC RECORD

DATE: 10/21/03	CAMERA TYPE: Digital	PHOTOGRAPHER: LK

PHOTO CHECKLIST: ✓

☐ U/S ☐ Mid-reach ☐ D/S
☐ Channel Bed ☐ Left Bank ☐ Right Bank
☐ Structures ☐ LB Riparian ☐ RB Riparian

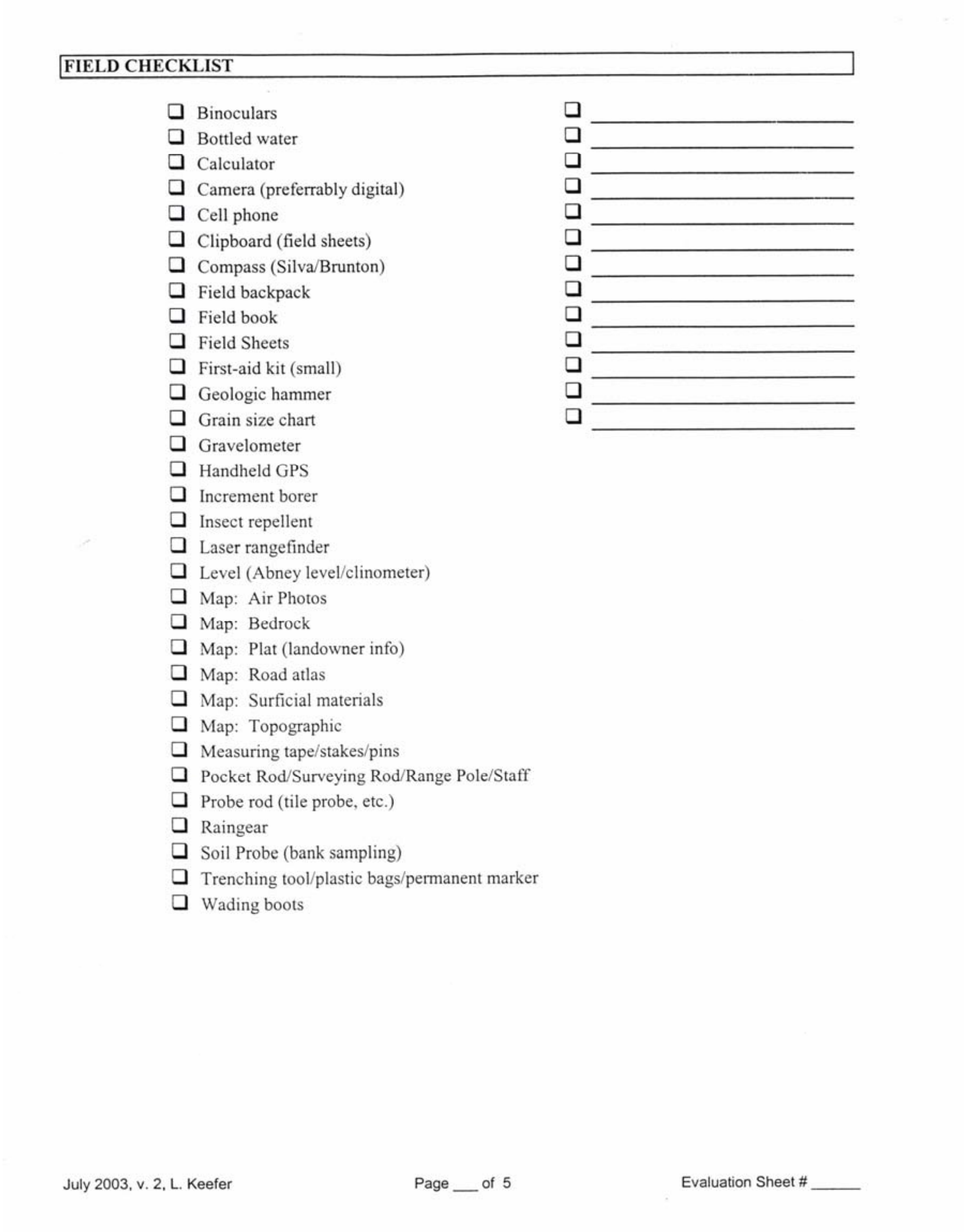
Remember: add a recognizable scale in all pictures; record photo number; and time of day (shadows)

PHOTO #	DESCRIPTION
	see PIC$ taken on 6-3-03 visit.

MISCELLANEOUS OBSERVATIONS

- Trees on LB are rotationally sliding down bank.
- High water debris @ base of VF
- Vertical twigs on some trees: 2-5 yrs old
- looks like trees slid down 5-8 feet
- Reach is straight but U/S curves to west.
- Gully migration from LB into field.

July 2003, v. 2, L. Keefer Page ___ of 5 Evaluation Sheet # ______



FIELD CHECKLIST

- ☐ Binoculars
- ☐ Bottled water
- ☐ Calculator
- ☐ Camera (preferrably digital)
- ☐ Cell phone
- ☐ Clipboard (field sheets)
- ☐ Compass (Silva/Brunton)
- ☐ Field backpack
- ☐ Field book
- ☐ Field Sheets
- ☐ First-aid kit (small)
- ☐ Geologic hammer
- ☐ Grain size chart
- ☐ Gravelometer
- ☐ Handheld GPS
- ☐ Increment borer
- ☐ Insect repellent
- ☐ Laser rangefinder
- ☐ Level (Abney level/clinometer)
- ☐ Map: Air Photos
- ☐ Map: Bedrock
- ☐ Map: Plat (landowner info)
- ☐ Map: Road atlas
- ☐ Map: Surficial materials
- ☐ Map: Topographic
- ☐ Measuring tape/stakes/pins
- ☐ Pocket Rod/Surveying Rod/Range Pole/Staff
- ☐ Probe rod (tile probe, etc.)
- ☐ Raingear
- ☐ Soil Probe (bank sampling)
- ☐ Trenching tool/plastic bags/permanent marker
- ☐ Wading boots

- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________
- ☐ ____________________

July 2003, v. 2, L. Keefer   Page ___ of 5   Evaluation Sheet # ______