GEOMORPHIC MONITORING OF THE KISSIMMEE RIVER RESTORATION:

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by

Joann Mossa[1], Allen Gellis[2], Cliff R. Hupp[3], James Leroy Pearman[4], Ursula Garfield[1] Edward Schenk[3], Jim Rasmussen[1], José Valdés[5] and Philip Habermehl[4]

[1]*Department of Geography, University of Florida, Gainesville, FL 32611*

[2]*U.S. Geological Survey, Maryland-Delaware-DC Water Science Center, Baltimore MD 21228*

[3]*U.S. Geological Survey, National Research Program, Reston, VA 20192*

[4]*U.S. Geological Survey, Orlando, FL 32826*

[5]*South Florida Water Management District, West Palm Beach, FL 33416*

Edited by:
Joann Mossa, University of Florida,
and
José Valdés, South Florida Water Management District

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Project Manager: José Valdés, SFWMD

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

Joann Mossa[1], Cliff R. Hupp[2], Allen Gellis[3] and Jose Valdes[4]

[1]*Department of Geography, University of Florida, Gainesville, FL 32611*

[2]*U.S. Geological Survey, National Research Program, Reston, VA 20192*

[3]*U.S. Geological Survey, Maryland-Delaware-DC Water Science Center, Baltimore MD 21228*

[4]*South Florida Water Management District, West Palm Beach, FL 33416*

Introduction

Alteration of rivers for flood control, water supply, and other purposes has been a pervasive activity worldwide and nationwide, particularly in the last few centuries. Large numbers of the world's major rivers have been dammed or channelized, typically for flood-control purposes (Dynesius and Nilsson, 1995; Nilsson et al., 2005; Gregory, 2006). Impacts to riverine ecoystems associated with channelization include loss of connectivity, changes in hydrology, changes in channel form, and habitat alteration (e.g. Graf, 2006). Rivers in the Coastal Plain of the United States have many such alterations because of problems with flooding and the need for navigation (Hupp et al., 2009). Some of these altered rivers, generally in developed countries including the United States and elsewhere, are now sites of river restoration or rehabilitation (Bernhardt et al., 2006).

The lower Kissimmee River, Florida (Figure 1-1), with a basin area of 7804 km^2, is one example of river channelization that led to significant ecosystem damage, followed by river restoration activity. This river restoration effort is among the largest worldwide. The upper Kissimmee River headwaters north of Lake Kissimmee are in an area known as the Upper Chain of Lakes, which is dominated by internal drainage and karst features including sinkholes and lakes. The lower Kissimmee River flows between two large lakes (Lakes Kissimmee and Okeechobee) and is in a low-gradient swale formed by late Tertiary marine processes, carbonate solution, and subsidence (White, 1970).

Prior to channelization, the hydrology of the Kissimmee River was unique among North American Rivers (Toth et al., 1998). Prolonged overbank flooding was likely an important driver in establishing and maintaining an ecosystem rich in various forms of aquatic biota, but most notably wetland plants and water birds. Historic floods were long-lasting, with some events exceeding bankfull for several months continuously (Toth et al., 2002; Warne et al., 2000). Many portions of the floodplain were inundated most of the year (Toth et al., 1998). Other unique characteristics of this meandering channel are described in Table 1-1.

Notable modifications to the Kissimmee River date back to the Seminole Wars in the mid-1800s, which opened up the basin for development, and the ranchers and farmers who settled in the

basin began to drain the swampland. Large tracts of land in the basin were drained in the 1880s by Hamilton Disston, a wealthy Pennsylvania businessman, spurred partly by the Swamp and Overflowed Land Act of 1850. Dredging, clearing, and snag removal were performed to maintain navigation, and cutoffs were made at some sinuous meander bends (Bousquin, 2005). When the Herbert Hoover dike was built following the devastating Okeechobee Hurricane of 1928, the lowermost portion of the lower Kissimmee River was channelized with an accompanying 10.4 km (6.5 mi)-long levee (Bousquin, 2005). Although a construction date of 1938 is given elsewhere (U.S. Army Corps of Engineers, 1969; Bosquin et al., 2005), aerial photography discussed later in this report shows that much of the channelization of the river near Lake Okeechobee occurred sometime between 1944 and 1954.

As a result of prolonged flooding in the 1940s due to hurricanes, a larger-flood-control project was authorized for much of central and south Florida. The Kissimmee portion of the project included structures in the upper basin and channelization and structures in the lower Kissimmee River from 1962 to 1971. The historic channel, which was sinuous with anabranches, was dredged to a straight canal named C-38 with a much larger below-bankfull channel capacity. The river length was shortened from 167 to 90 km (Whalen et al. 2002) and its gradient was steepened in the process. Six large, gated water and grade- control structures with locks were placed along the course, creating pools along C-38 upstream of each structure. Dredging increased the width and depth of the river channel for navigation. In most places, historic channels were left largely intact, except in localized areas where dredge spoil blocked or obliterated their form. The project resulted in the loss of about 8000 ha of wetlands; drastic declines in bird, fish, and other animal populations due to decreases in wetlands; and substantial reductions in water quality (Bousquin et al., 2005). Even before the channelization project was completed, various groups advocated for restoration of the river.

An ecosystem restoration project was authorized by Congress with the Water Resources Development Act in 1992. Work, conducted jointly by the South Florida Water Management District (SFWMD) and the U.S. Army Corps of Engineers, began in the late 1990s and is scheduled for completion in 2013 (Bousquin, 2008). The goals of the restoration are to reestablish ecological integrity to the Kissimmee River and floodplain. The project's main components include demolition and removal of two of the six water-control structures (S-65B and S-65C) (Fig. 1-1) and accompanying locks; backfilling of about one-third or 35 km of C-38; excavation of pre-1960 main channels that were obliterated by dredge spoil; and land acquisition to allow prolonged floodplain overtopping. S65-B was demolished in June 2000 and about 12.9 km of C-38 was backfilled in the first phase of the project (Bousquin, 2008). Another 3.2 km of canal was backfilled in 2006/2007 in what was formerly Pool B and is now considered Pool B/C. The current phase (2009) involves backfilling 6.4 km of canal in Pool B, and in coming years, another 14.5 km of canal, mostly in Pool D, will be backfilled and S-65C will be demolished. Flow will be redirected into the former primary channels of the historic floodplain to reestablish wetland conditions; about 40% of the channelized reach will be restored to meandering "natural" conditions.

The restoration is of unprecedented cost (≈$620 million) (Bousquin, 2008) and scale and includes various types of monitoring, strategies, and targets to evaluate success (Bousquin et al. 2005). The Kissimmee River provides a major source of water for the Everglades, where a

restoration effort is underway. The intent of the Everglades restoration is to bring the quantity, quality, spatial patterns, and timing of flow much closer to historical conditions, and thus is strongly tied to success of the Kissimmee restoration efforts.

Objectives and Goals

Stability and sedimentation monitoring are stipulated in the Integrated Feasibility Report/Environmental Impact Statement (IFR/EIS) (US Army Corps of Engineers, 1991) as integral programs in the Kissimmee River Restoration Evaluation Program (KRREP) (presently scheduled to run though 2017). The IFR/EIS recognizes that: "many of the determinations that have been made regarding sedimentation issues have not been site-proven in similar settings. The program will begin prior to construction to gather baseline data, and will continue until such time as it can be established that the components of the project are stable." (Sect. 10.3.3).

Stable rivers have achieved an equilibrium between water discharge, channel slope, sediment load, and bed material. This relation proposed by Lane (1955) is commonly expressed as:

$$Q_s \bullet D_{50} \propto Q_w \bullet S \qquad (1)$$

where Q_w is the water discharge, S is the slope, Q_s is the bed material load, and D_{50} is the median size of the bed material.

This relation defines a proportionality between sediment load, particle size, stream discharge, and slope. A change in any one of the variables in the Lane relationship sets up a series of mutual adjustments in the companion variables. These adjustments can directly change the morphology of the river, with possible consequences to the aquatic habitat. A channel that is in equilibrium (stable) will have adjusted to these four variables such that the sediment transported into the reach is transported out, without significant deposition of sediment in the bed or aggradation, excessive bed scour or degradation, nor changes in its planform character (Mackin, 1948; Rosgen, 1996). This does not equate to a "static" condition because a river channel is free to migrate laterally across the floodplain by eroding one of its banks and depositing sediment on the opposite bank at a similar rate.

A key question is whether the restored Kissimmee River channel will be stable under the new flow and sediment conditions. As the Kissimmee River responds to restoration, what types of channel change may occur and what predictions of morphological change can be made if the channel is unstable under the restored conditions?

The objectives of this project are to establish a long-term geomorphic monitoring plan for the KRRP that will meet the requirements stipulated in the IFR/EIS and provide the SFWMD with data to implement comprehensive, adaptive river-management approaches. This report provides an overview of the initial objectives and findings of several types of geomorphic monitoring conducted from 2006-2009 by staff at the University of Florida and the U.S. Geological Survey to address the requirements of the IFR/EIS. Monitoring included measurement of streamflow, suspended sediment, bed load, bed material sampling, and floodplain sedimentation studies conducted by staff at the U.S. Geological Survey. Channel cross-section monitoring, bottom sediment coring, and geospatial analysis were conducted by staff at the University of Florida. These studies expand on previous on previous work conducted by SFWMD which proposed two

geomorphic attributes (point bar formation and organic deposition in remnant river channels) for which specific expectations were developed to evaluate the restoration of the Kissimmee River (SFWMD, 2005; Anderson et al., 2005a & b; Frei et al. 2005).

Unfortunately, pre-channelization geomorphic data are generally lacking for the Kissimmee River. Pre-channelization sediment data are non-existent. Floodplain data on deposition rates and composition are lacking. Information on pre-channelization channel morphology is summarized in relation to hydraulic geometry and sinuosity (Warne, 2000) but does not include detailed cross-sectional geometry. Without pre-channelization data, the current geomorphic data become the standard at which to access future changes in the Kissimmee River. As more data are collected over time, a better understanding of the relations between sediment transport, channel morphology, floodplain processes, and biologic measurements will be developed. Understanding these relations can take many years, and determining these relations with only three years of monitoring data is difficult. Thus the geomorphic data collected over the last three years provide us with some preliminary understanding of how the Kissimmee River is operating. More importantly, an infrastructure has been created to understand future changes in the Kissimmee River geomorphic system.

Table 1-2 identifies the monitoring components included in this project and their relation to the IFR/EIS requirements. Chapters included in this report are organized by monitoring components as detailed in the table and described below.

Streamflow and Fluvial Sediment Transport (Chapter 2). Monitoring was undertaken in a restored section of the Kissimmee River channel (Pool C) to characterize its sediment transport characteristics. Measurements were undertaken of: (1) streamflow, (2) sediment size, suspended sediment concentrations and loads, (3) bedload, and (4) bed material.

Floodplain Monitoring (Chapter 3). The objectives of floodplain monitoring include the quantification and interpretation of floodplain sedimentation patterns, fluxes, and character (sediment-size class, bulk density, organic material content) relative to flood frequency and magnitude, landform, and dominant vegetation type.

Channel Cross Sections (Chapter 4). Channel cross-section monitoring was conducted to learn more about the variability of different types of cross sections, focusing primarily on restored portions of the river, and to assess whether cross sections of different types or in different locations vary in their stability over time.

Bottom Sediment Monitoring (Chapter 5). The objectives of bottom sediment monitoring were to characterize organic riverbed sediments in unrestored runs of the lower Kissimmee River (Pool D). This work was a continuation and refinement of investigations of the organic layer undertaken in Pool C in connection with Phase I restoration (SFWMD, 2005; Anderson et al., 2005a & b; Frei et al., 2005).

Geospatial Analysis of Channel Planform Changes (Chapter 6). Photogrammetric monitoring of channel changes over large areas, focusing on the time since restoration, complements ground-based monitoring of channel cross sections to assess geomorphic stability. This study was a

continuation and expansion of point bar formation investigations undertaken in Pool C in connection with Phase I restoration (SFWMD, 2005; Anderson et al, 2005a; Frei et al., 2005). Changes in the number and size of point bars were documented and spatial variations in sinuosity and lateral migration along the river were examined. Data for the entire project were stored in a geodatabase.

Summary, Conclusions, and Recommendations (Chapter 7). The main findings of all components of this study are summarized in this chapter.. Where relevant, portions of the project that were connected spatially are compared. For instance, floodplain sedimentation pads were co-located along cross-sectional transects of different types. Based on the findings of various aspects of the study, scientific understanding can guide future plans for geomorphic monitoring of the Kissimmee River Restoration.

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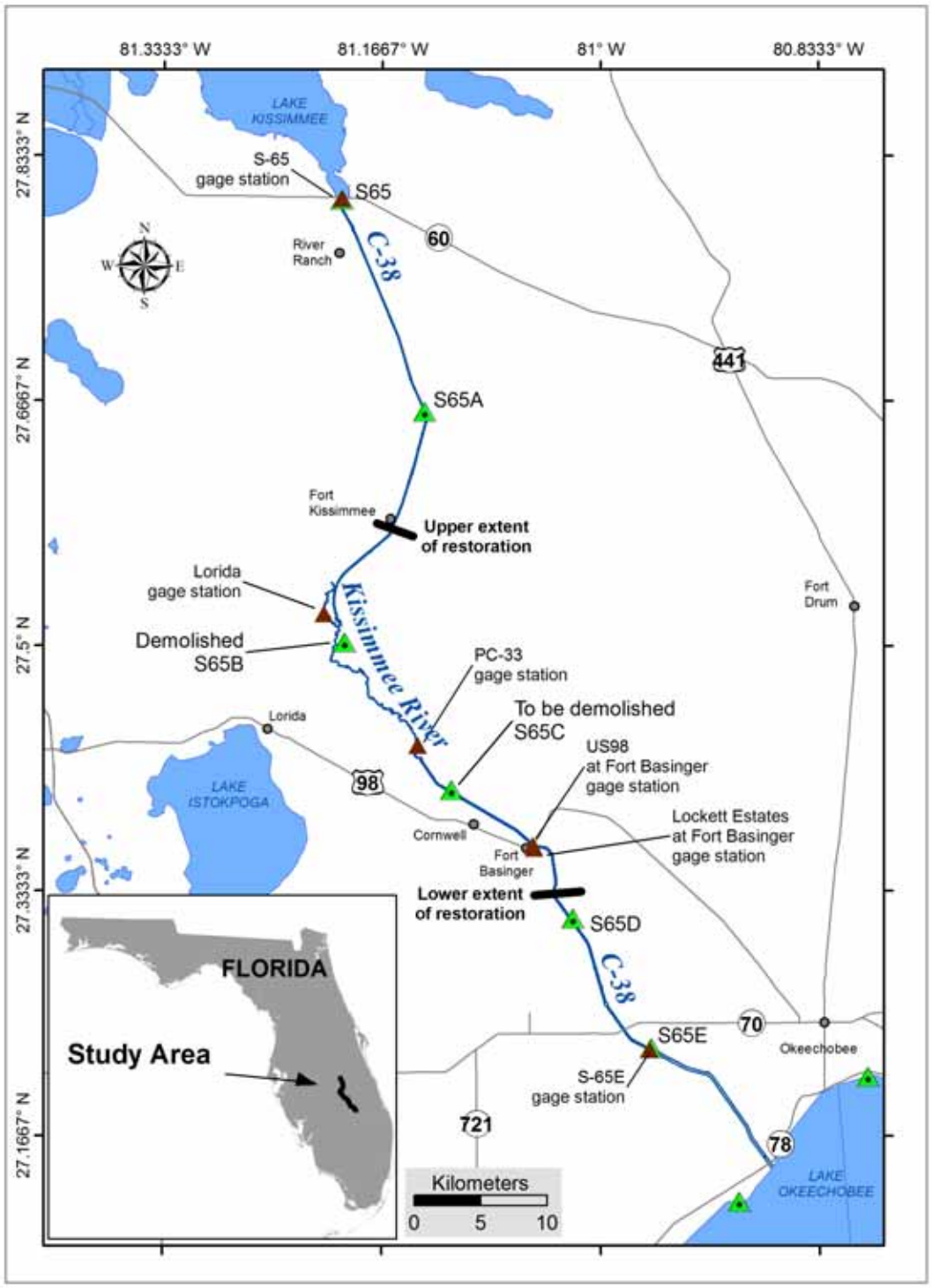

Figure 1-1. Location of the lower Kissimmee River, C-38, and major structures.

Table 1-1. Geomorphic and hydrologic characteristics of the pre-channelized Kissimmee River (Koebel, 1995; Warne, 1998, 2000)

Low gradient 0.057 to 0.09 m/km
Sinuous channel 165 km long (sinuosity = 1.67- 2.1)
Bankfull width (15-35 m)
Bankfull depth (1-3.5 m)
Bankfull discharge: Upper reaches (40 m^3/s), Lower reaches (57 m^3/s)
Entrenchment ratio (floodplain width/ bankfull width >20)
Floodplain ~2 to 5 km wide
Low suspended-sediment concentrations (assumed)
Entrainment of fine-medium grained sand during bankfull discharge
River flows generally exceeded 7.0 m^3/s 95 percent of the time, andoverbank flooding occurred 35-50% for the period 1934-1960.
River velocities averaged less than 0.6 m/s
When inundated, water depths were generally 0.3 to 0.7 m, with depth greater than 1 m occurring over 40 percent of the floodplain
The historic floodplain was covered by approximately 14,100 hectares of wetlands

Table 1- 2. Basis and relationship of geomorphic monitoring components to Kissimmee River restoration evaluation.

Monitoring Component	Type of Restoration Evaluation Program Investigation*	IFR/EIS Requirement	Metrics	Restoration Success Criterion
Streamflow and Sediment Transport (Chapter 2)	Phase I Trajectory	IFR/EIS: *This program will include monitoring of suspended and bedloads at a range of discharge conditions to assure that gradually developing problems with sediment and erosion control, if they occur, do not go undetected and lead to greater or catastrophic problems (Sect. 10.3.3).*	Suspended and bedload sediment transport rates.	The sediment load of the Kissimmee River in relation to its hydrologic regime is conducive to maintaining a stable system analogous to its historic counterpart
Floodplain Monitoring (Chapter 3)	Phase I Trajectory, Phase II/III Baseline	IFR/EIS: *Overall monitoring of the project area will be conducted so that any mass transport to Lake Okeechobee can be detected.*	Overbank sedimentation rates and fluxes.	Post-restoration sedimentation on the floodplain will occur at rates comparable to that which occurred in the pre-channelized system.
Channel Cross-Section Monitoring (Chapter 4)	Phase I Trajectory, Phase II/III Baseline	IFR/EIS: *The program…will monitor the stability of banks and bed of the river channels (Sect. 10.3.3).* *Features normally submerged and subjected to erosional forces will be monitored to determine stability (Sect. 10.3.4).*	Erosional/depositional rates of restored riverbed and banks.	The restored Kissimmee River system is a stable C5 system (Rosgen, 1996), as was its historic counterpart.
Bottom Sediment Monitoring (Chapter 5)	Phase II/III Baseline	IFR/EIS: *Measurements of river-channel habitat parameneters including depth…and substrate characteristics (Sect. 10.3.1, Habitat Studies).* *Overall monitoring of the project area will be conducted so that any mass transport to Lake Okeechobee can be detected (Sect. 10.3.3).*	Thickness and stratigraphic position of pre-restoration riverbed organic deposits.	Pre-restoration organic deposits on the riverbed will be removed through erosion or *in situ* burial by sands.
Geospatial Analysis of Channel Planform Changes (Chapter 6)	Phase I Trajectory, Phase II/III Baseline, Reference Conditions	IFR/EIS: *The program…will monitor the stability of banks and bed of the river channels (Sect. 10.3.3).*	Fluvial system (planform) geomorphic changes.	The restored Kissimmee River system will be a stable system with a dominant meandering channel, sand bars, an active floodplain and secondary channels, as was its historic counterpart.

***Trajectory**: Post-restoration conditions; **baseline**: pre-restoration conditions; **reference**: pre-channelization conditions