GEOMORPHIC MONITORING OF THE KISSIMMEE RIVER RESTORATION:

2006-2009

by

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION AND OBJECTIVES

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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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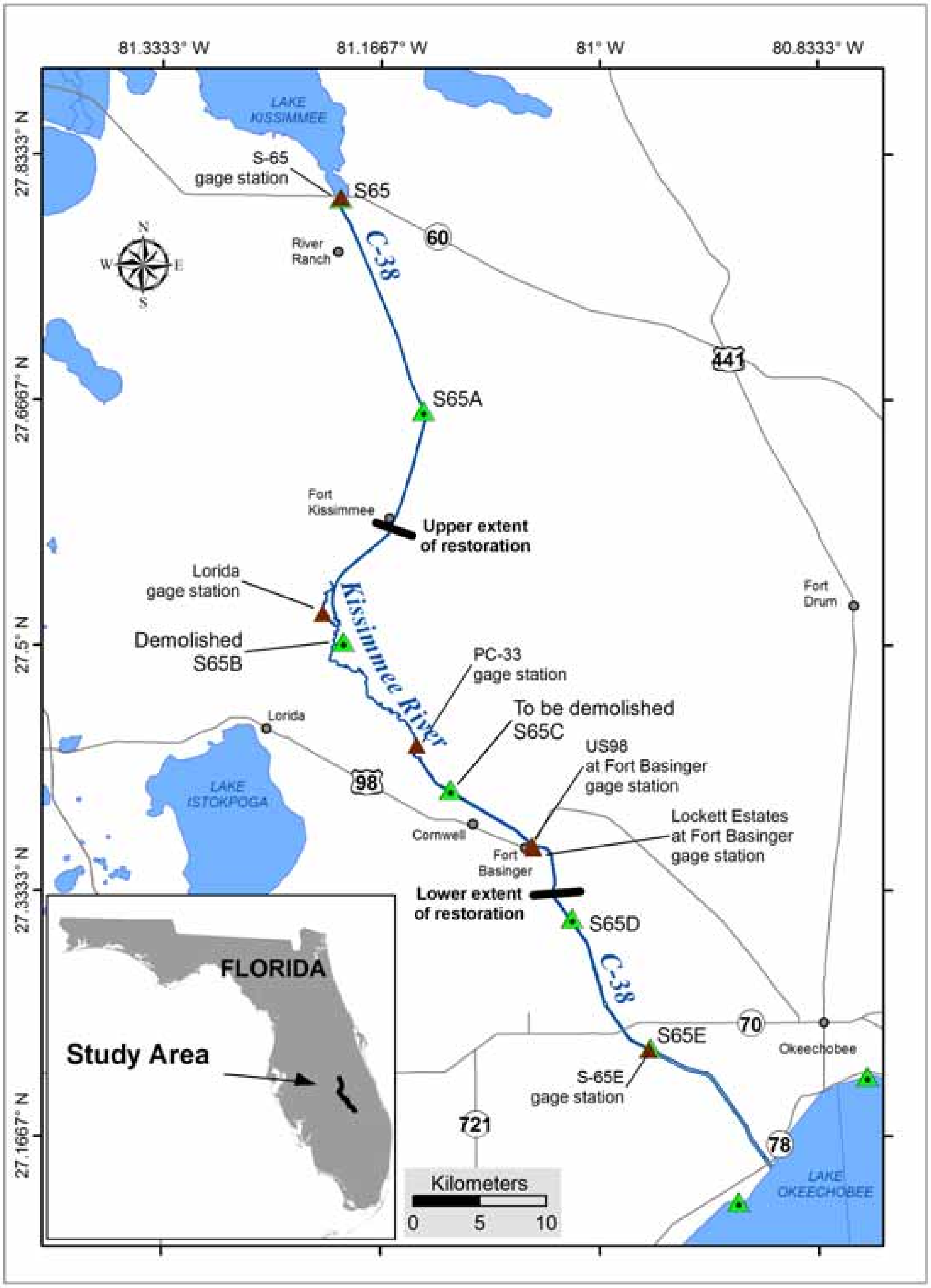

Figure 1-1. Location of the lower Kissimmee River, C-38, and major structures.

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

CHAPTER 2

STREAMFLOW AND FLUVIAL SEDIMENT TRANSPORT IN POOL C, RESTORED SECTION OF THE KISSIMMEE RIVER, 2007-2008

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Introduction and Objectives

The Kissimmee River Restoration Project was authorized by Congress in 1992 to restore more than 64 km^2 (square kilometers) of river/floodplain ecosystem including 69 km of meandering river channel and 10,900 hectares (ha) of wetlands. Although biologic monitoring is an integral and active part of the Kissimmee River restoration, by 2007 geomorphic monitoring that included sediment transport was lacking. In 2007, the U.S. Geological Survey (USGS) entered into a cooperative agreement with the South Florida Water Management District (SFWMD) to determine sediment transport characteristics of the restored section of the Kissimmee River in Pool C. Sediment transport characteristics that are monitored include suspended-sediment concentrations and loads, bedload, and bed material. In addition, the organic content of suspended sediment and bedload was determined. This chapter describes methods and results of the sediment transport monitoring from July 2007 through September 2008 in the Kissimmee River in Pool C.

Methods

Sediment is any particulate matter that can be transported by fluid flow. Fluvial sediment is sediment transported by rivers by maintaining the finer particles (clays, silts, and fine to medium sand) in suspension with turbulent currents and by rolling or skipping the coarser particles along the streambed. The sediment in suspension is suspended sediment and the sediment rolling or skipping along the channel bed is bedload. Measurement of discharge is an important factor in determining the transport characteristics of suspended sediment and bedload, including initiation of transport and total flux. The following section outlines the methods used to determine flow and sediment transport in the Kissimmee River.

Gage Height and Daily Discharge Determination

Data for this study were collected at the USGS streamflow-gaging station on the Kissimmee River at PC-33 near Basinger, Florida (USGS ID 02269160) (Figure 2-1). The drainage area of the station is 5,270 km^2. Data collection began on June 7, 2007 with the measurement and recording of gage height and velocity data. These data are collected on 30-minute intervals and transmitted by satellite to the USGS office in Orlando, FL. Due to the variable backwater conditions that exist at the site as a result of being 6 km upstream from structure S-65C (Figure1-1), a conventional gage height versus discharge rating is inadequate for discharge computation. An index-velocity rating was developed as an alternative method. Index-velocity ratings utilize two ratings processed concurrently to compute discharge. The first is a cross-section area rating versus gage height that computes cross-sectional area based on the gage height. The second is a mean velocity rating comparing the measured velocity from the velocity meter (index velocity) to the mean channel velocity obtained from the individual discharge measurements. Instantaneous discharge is the product of the area (square meters) multiplied by the mean channel velocity (meters per second) measured at the gage. Daily mean discharges (cubic meters per second; m^3/s) are computed from these time series data.

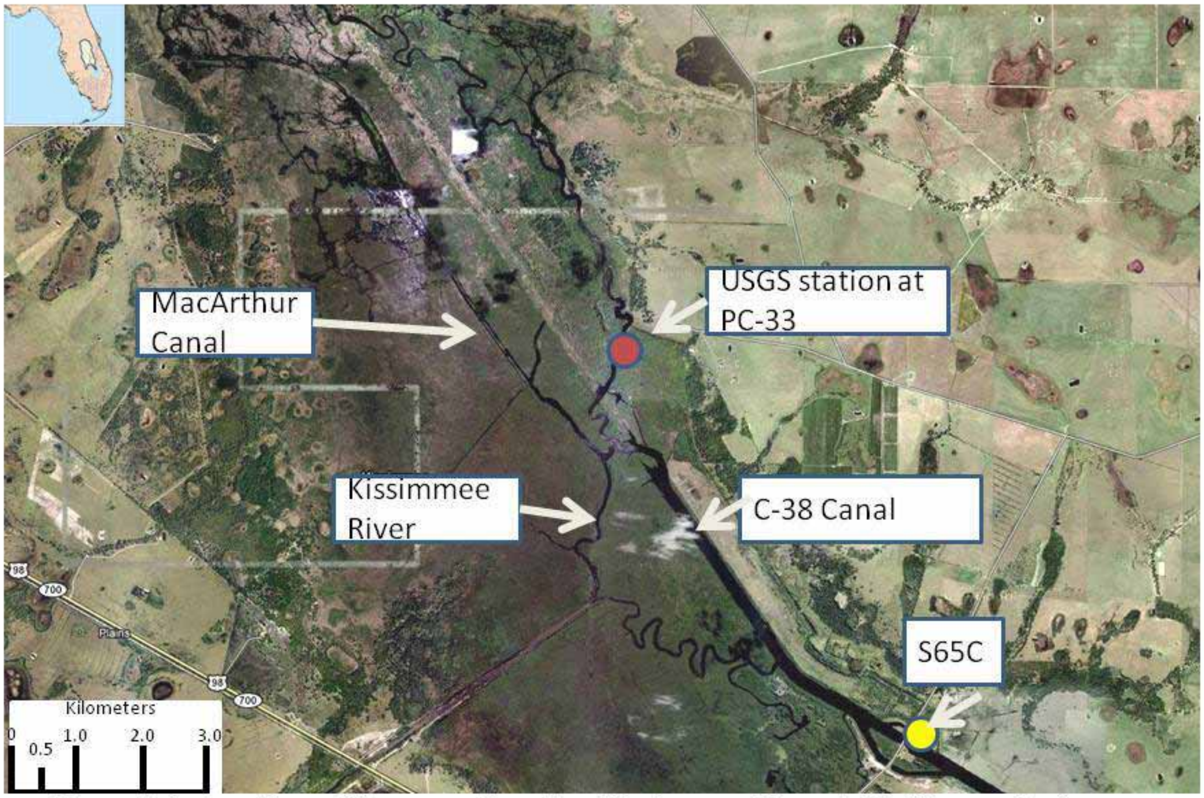

Figure 2-1. Location of the sampling site, Kissimmee River at PC-33 near Basinger, Florida, where streamflow, suspended sediment, bedload, and bed material sampling were conducted.

Discharge measurements (cubic meters per second) were made at the gaging station on a periodic basis (approximately 6 times per year) with additional measurements made during extreme flow conditions such as floods or droughts to develop and maintain the stage-area and index-velocity ratings. Measurements were made by using a boat-mounted Acoustic Doppler Current Profiler (ADCP). The ADCP measures depth and velocity in numerous vertical profiles across the stream channel as the boat traverses the cross section or transect. These values are accumulated and a resultant stream discharge is calculated. A more detailed explanation of this type of instrumentation and measuring technique can be found in the USGS publication Mueller and Wagner (2009).

Discharges at the gaging station are only computed in the restored portion of the channel and did not include flow that entered the floodplain. During high flow events, when the flow in the channel exceeds 50 cubic meters per second (m^3/s), a substantial volume of flow goes overbank through a breach in the natural levee, upstream of the streamflow-gaging station on the right bank. This level of flow is considered to approximate the bankfull discharge. The flow that goes overbank, enters the partially backfilled MacArthur Canal and re-enters the Kissimmee River between the streamflow-gaging station and structure S-65C (Fig. 1-1). During periods of high flow, the flow that goes overbank can be estimated using discharge recorded at the S-65C structure which is managed by the South Florida Water Management District (SFWMD) (*http://my.sfwmd.gov/dbhydroplsql*; last accessed on December 4, 2009). The difference of the mean daily discharge computed at the USGS streamflow station from the mean daily discharge at the S-65C structure is estimated to be the flow that went overbank and bypassed the station.

Sediment Data Collection

Sediment data were collected for this project from July 21, 2007 through September 30, 2008. Suspended-sediment, bedload, and bed material data were collected as part of the sediment monitoring plan for the Kissimmee River Restoration Project (KRRP). The sediment data were collected at the USGS streamflow-gaging station Kissimmee River at PC-33 near Basinger, FL (USGS ID 02269160). The data collected were used to compute daily, monthly, and annual suspended-sediment loads, compute bedload transport for periods of high flows, and describe the composition of the bed material for varying flow conditions.

Suspended Sediment Sampling Protocol

Suspended-sediment samples used in the computation of suspended-sediment loads were collected using both manual and automatic samplers. Manual suspended-sediment samples were collected at various points (stations) in the cross section using the Equal Width Increment (EWI) and Equal Discharge Increment (EDI) method (Edwards and Glysson, 1999) by using a U.S. Series depth-integrating DH-59 rope sampler. The manual suspended-sediment samples were collected from a boat where a tagline was deployed across the river to mark distances along the sampling section. Manual suspended-sediment samples were collected during scheduled bimonthly site visits, as well as during periods of high flows. An automatic pumping sampler with a peristaltic pump was installed at the site to collect suspended-sediment samples on a more frequent interval. From July 21, 2007 through November 21, 2007, the automatic sampler was programmed to collect a suspended-sediment sample every 12 hours. From November 21, 2007 through September 30, 2008, the automatic sampler was programmed to collect a suspended-sediment sample every 24 hours after a review of the data indicated that daily samples were adequate to define sediment transport characteristics. The automatic samplers collect samples from a point in the channel and thus should be calibrated to cross-sectional samples. For the range of flow conditions, manual samples collected using either the EDI or EWI method were used to compute correction coefficients that adjust the concentrations from the pumped samples to be more representative of the average concentrations in the cross section. Application of correction coefficients was dependent on flow conditions. For low flows, a correction coefficient was applied when the difference between the manual and pumped sample concentrations was greater than 20%. For higher flows, corrections were applied when the difference was greater than 10%. The correction coefficients were applied until it appeared that the automatic sampler was pumping a sample more representative of the cross section.

Water samples were sent to the USGS Kentucky Water Science Center Sediment Laboratory in Louisville for analysis of suspended-sediment concentrations. Concentrations were determined by the evaporation or filtration method (Guy, 1969). The concentration of suspended sediment is equal to the ratio of the dry weight of sediment to the volume of the water-sediment mixture. This concentration is computed as a weight-to-weight ratio and is expressed in parts per million (ppm). A conversion factor is used to convert parts per million to milligrams per liter (mg/L) based on the assumption that water density is equal to 1.000 g/mL (gram per milliliter) plus or minus 0.005 g/mL, temperature is from 0^{o} to 29^{o} C, specific gravity of suspended sediment is 2.65, and the dissolved solids concentration is less than 10,000 mg/L (Guy, 1969). For suspended-sediment concentrations less than 15,900 ppm, the conversion factor is equal to 1.0. Daily suspended-sediment loads were computed using the subdivision method (Porterfield, 1972) with the USGS-software Program, Graphical Constituent Loading Analysis System (GCLAS).

Selected suspended-sediment samples were also analyzed in the USGS Kentucky Sediment Laboratory for percent organics and percent sand. Organic percentage of the suspended sediment is determined through loss-on-ignition (LOI) analysis, where a dry sediment sample is burned at 550^{0} C for 1 hour (Fishman and Friedman, 1989). The LOI corresponds to the organic part of the suspended sediment and the remaining mass is the inorganic portion. Sand/fine separations are used to determine sample concentration and the amount of material that is less than or greater than sand size (0.062 mm; millimeter). The term “fine fraction” refers to particles that pass through a 0.062-mm mesh sieve and “sand fraction” refers to particles large enough to be retained on a sieve.

Bedload Sampling Protocol

Bedload samples were collected during the same site visit when suspended-sediment samples were collected. Bedload samples were collected using the EWI method following protocols established by Edwards and Glysson (1999). A minimum of 20 discrete at-a-point bedload samples were taken in a cross section using a BLH-84 bedload sampler with a mesh size of 0.125 mm. The length of time the sampler was left on the channel bed was dependent on flow conditions and ranged from 60 to 120 seconds. During times of low flow, three points on the channel cross section were initially selected to determine the presence of moving bed conditions. If bedload was collected in any of the three points, a complete bedload sample was collected at all 20 sampling locations.

When bedload transport was confirmed, bedload samples at each discrete vertical were bagged for subsequent dry weighing. Each individual bag (including those denoting “zero” catches), were identified. At other visits, bedload was sampled using the EDI method but the materials from each vertical were composited into one sample. Samples were sent to the USGS Cascades Volcano Observatory where they were oven-dried at 103^{0} C, weighed in grams (g), and sieved through the following sieve openings:

16.0 mm
8.0 mm
4.0 mm
2.0 mm
1.0 mm
0.5 mm
0.25 mm
0.125 mm
0.063 mm

Select bedload samples were sent to the USGS National Research Program Dendrochronology Laboratory in Reston, Virginia, for LOI to determine percent organics. Approximately 5 g of each bedload sample was dried for 24 hours at 110^0 C. The samples were allowed to cool in a desiccator, and then they were weighed to within 0.01 g precision. Samples were then burned for 16 hours at 400^o C in a muffle furnace. Afterwards, the cooled sample was weighed again and the percent mass lost was recorded as the organic content of the sample.

A bedload-rating curve is produced from the relation of discharge and measured bedload transport. Daily bedload transport is computed using the line of best fit from the bedload-rating curve and applied to the mean discharge for each day of the study period. The line of best fit is typically a power function in the form of $Qb = C_1Q^{c2}$; where Qb is bedload, Q is discharge, and C1 and C2 are coefficients. The transformation of data using the line of best fit is logarithmic and can cause a bias in the data. To correct for this bias, the Quasi-Maximum Likelihood Estimator (QMLE) method was used. A more complete explanation of the bias estimator and QMLE methodology is described in Ferguson (1986) and at the USGS Internet site *http://co.water.usgs.gov/sediment/bias.frame.html* (last accessed July 1, 2009).

Bottom-Material Sampling Protocol

For a range of flow conditions, bed-material samples were collected from the bed of the Kissimmee River at the USGS streamflow gaging station Kissimmee River at PC-33 near Basinger, FL. A BMH-60 bed-material sampler was used to collect bed-material samples. Samples were collected in the centroids of flow determined during the EDI measurement. Typically, five centroids were used in the EDI. Bed-material samples were sent to the USGS Cascades Volcano Observatory where they were dried and weighed in the same manner as bedload samples. Particle-size distribution was performed on each sample using the same size breaks as used for bedload.

Effective Discharge Computation

The dimensions of a channel in many river systems have been found to be related to a single discharge or an effective discharge (Wolman and Miller, 1960; Biedenharn et al., 2000). Channel- forming flows can be estimated using three methodologies: (1) bankfull discharge, referring to the discharge that fills the channel to the top of its banks; (2) recurrence interval discharge, typically assigned to flows between the mean annual and 5-year recurrence interval; and (3) effective discharge, or the class of flows that transports the most sediment (Biedenharn et al., 2000). Although effective discharge can be computed for suspended sediment, bedload, or total load, bedload is considered the portion of sediment movement that will affect channel morphology (Ward and Trimble, 2004).

Effective discharge computations were made for the Kissimmee River using procedures outlined by Biedenharn et al. (2000). Several steps are necessary to compute the effective discharge. In the first step, a histogram of mean daily flows is created. Biedenharn et al. (2000) and Crowder and Knapp (2005) recommend at least 25 classes of flow, while making sure that the first class does not have the highest frequency. When an adequate mean-daily discharge histogram is constructed, bedload transport (megagram, Mg) is assigned for the midpoint of each class. The bedload transport is computed from the bedload rating curve and the QMLE method is used to correct for any bias.

The bedload transport value determined for each midpoint discharge class is multiplied by the number of occurrences of discharge in that class. The resultant bedload transport values are plotted as a histogram, which is termed the “collective bedload discharge” (Biedenharn et al., 2000). The highest value on the collective bedload discharge histogram is the effective discharge.

Results

Discharge

Daily discharges were computed using the time series discharges computed from the recorded stage and velocity data, and the stage-area and index-velocity ratings previously described. Daily and monthly streamflow for the period July 21, 2007 to September 30, 2008 are shown in Figure 2-2. The mean daily discharge for this period was 24.5 m^3/s. Low-flow conditions from July 21, 2007 through July 2, 2008, interrupted by some wetter periods in March and April 2008, prevailed and the mean-daily streamflow for this period was 15.7 m^3/s. Beginning on July 3, 2008, tropical storm activity caused wetter conditions and the mean daily discharge for the period July 3 through September 30, 2008 was 58.0 m^3/s, which is 3.5 times higher than the earlier period. The highest mean daily discharge during the period of study, 157 m^3/s, occurred on August 22, 2008 as a result of heavy rains associated with Tropical Storm Fay. For the period August 19 to September 22, 2008, 3.11×10^8 m^3 of flow went overbank (fig. 2-2), which is 52% of the total flow for this period (restored channel + overbank flows) and 25% of the total flow for the period of study.

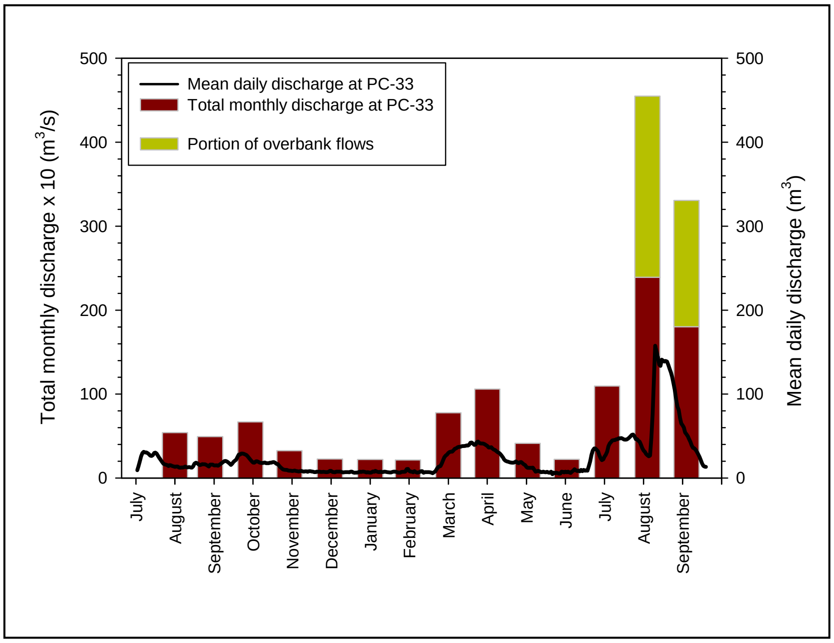

Figure 2-2. a) Mean daily and total monthly discharge for the restored section of the Kissimmee River at PC-33 near Basinger, Florida. Also included are the portion of flows that went overbank from August 19 to September 22, 2008.

Suspended Sediment

During the period of study July 21, 2007 to September 30, 2008, 574 samples of suspended-sediment were analyzed for concentration. Of the 574 samples, 150 were analyzed for percent organics and 28 were analyzed for percent sand (<0.063 mm). A transport curve of discharge versus suspended-sediment concentration is shown in Figure 2-3. Suspended-sediment concentrations range from 5 mg/L to 800 mg/L (Figure 2-3). The highest value of suspended-sediment concentration, 800 mg/L, was collected on August 22, 2008, at 07:05 a.m. during Tropical Storm Fay.

A comparison of the organic content of suspended-sediment against discharge shows a weak relation (R^2=0.07) of increasing organic concentration with discharge (Figure 2-4a). The highest value of organic concentration of suspended sediment was 21 mg/L for the sample collected on August 22, 2008, at 2:34 p.m. during Tropical Storm Fay. A comparison of sand in suspension against instantaneous discharge shows that at higher discharges more sand is in suspension (Figure 2-4b). The percent of sand in suspension ranged from 2% at low flows to 78% at higher flows (Figure 2-4b).

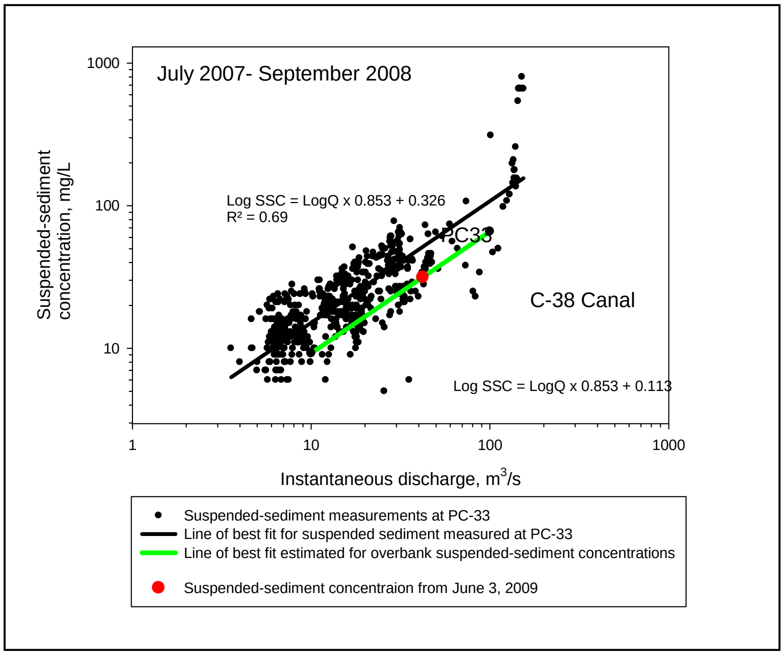

Figure 2-3. Suspended-sediment transport curve for the restored section of the Kissimmee River at PC-33 near Basinger, Florida, July 21, 2007 through September 30, 2008. Also included is the line of best fit used to estimate suspended-sediment concentrations in the overbank portion of flow.
[SSC = suspended-sediment concentration, mg/L; Q = Discharge, m^3/s]

Monthly suspended-sediment loads are shown in Figure 2-5 and in Table 2-1. Similar to mean monthly discharges, the highest monthly loads are observed in August and September 2008. The total suspended-sediment transported during the period of study, July 21, 2007 to September 30, 2008, was 78,912 Mg (Table 2-1). The 8 highest daily suspended-sediment loads all occurred between August 21 to August 31, 2008, during Tropical Storm Fay and total 40,652 g, which is 52% of the total suspended-sediment load transported in the restored channel (78,912 Mg) for the period of study. Suspended-sediment load transported during the highest daily streamflow (10,158 Mg on August 22, 2008) was 13% of the total suspended-sediment load in the restored channel for the period of study.

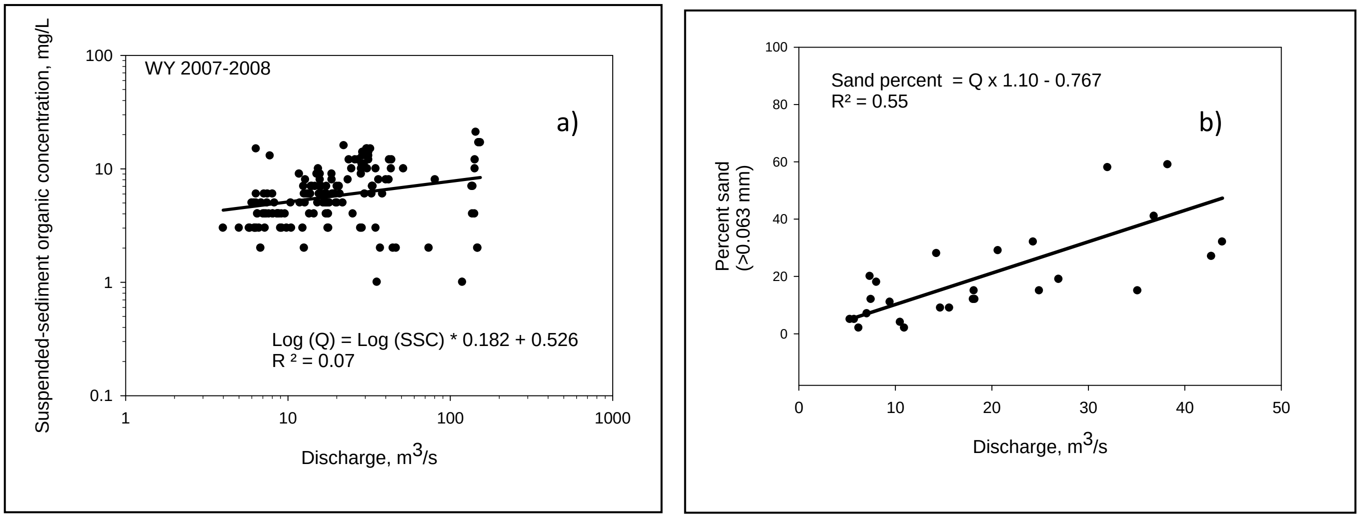

Figure 2-4. (a) Organic suspended-sediment transport curve for Kissimmee River at PC-33 near Basinger, Florida, July 21, 2007 through September 30, 2008. (b) Discharge versus percent sand in suspension.
[SSC = organic suspended-sediment concentration, mg/L; Q = Discharge, m^3/s]

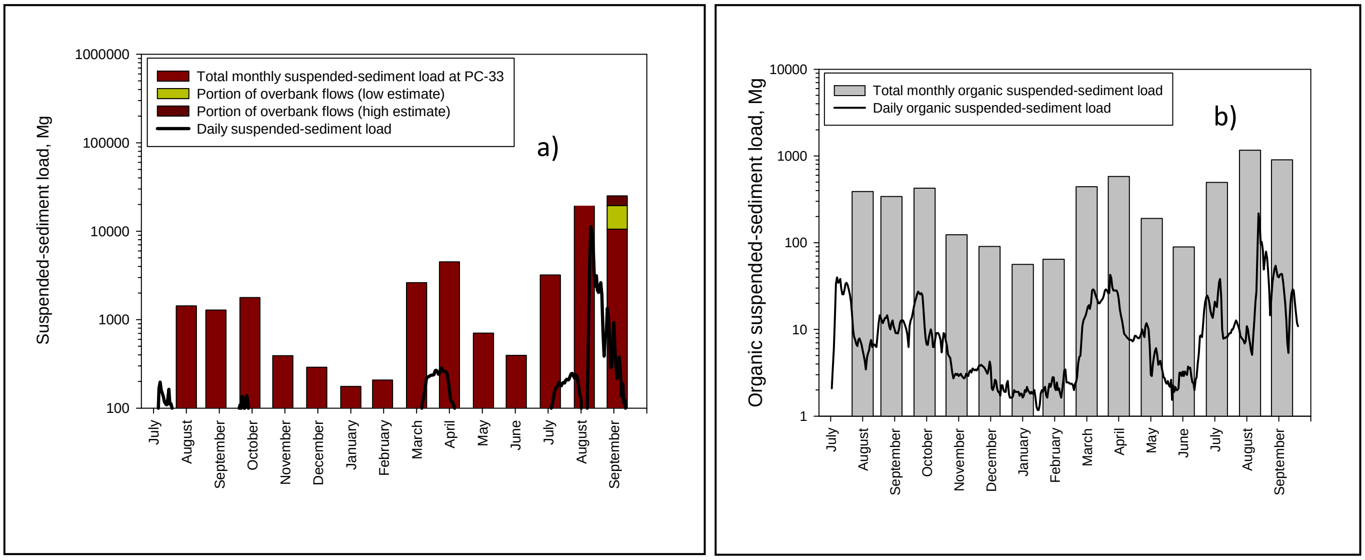

Figure 2-5. (a) Total suspended-sediment load for the restored section of the Kissimmee River at PC-33 near Basinger, Florida. Also included are the portion of flows that went overbank from August 19 to September 22, 2008. (b) Organic suspended-sediment load for the restored section of the Kissimmee River at PC-33 near Basinger, Florida.

Table 2-1. Sediment load transported as suspended, organic and inorganic suspended sediment, bedload, and as organic and inorganic bedload, Kissimmee River at PC-33 near Basinger, Florida, July 21 2007 to September 30, 2008.

Month	Year	Suspended sediment load measured in restored channel, Mg	Suspended sediment load estimated for MacArthur Canal, Mg [1]	Bedload, Mg	Organic suspended-sediment, % of total suspended-sediment load, measured in restored channel)	Inorganic suspended-sediment,% of total suspended-sediment load, measured in restored channel)	Organic bedload, % of total bedload	Inorganic bedload, % of total bedload
Jul 21-31	2007	1,026		0.56	25	75	77	23
Aug.	2007	1,433		0.27	27	73	78	19
Sept.	2007	1,282		0	27	73	0	0
Oct.	2007	1,784		0.23	24	76	83	13
Nov.	2007	391		0	32	68	0	0
Dec.	2007	290		0	31	69	0	0
Jan.	2008	176		0	32	68	0	0
Feb.	2008	208		0	31	69	0	0
Mar.	2008	2,616		3.8	17	83	44	55
Apr.	2008	4,494		8.8	13	87	35	65
May	2008	704		0	27	73	0	0
Jun.	2008	394		0	23	77	0	0
Jul.	2008	3,208		13	15	85	25	75
Aug.	2008	50,388	20,026 – 32,703	3,245	2	98	1	99
Sept.	2008	10,518	8,934 – 14,589	964	9	91	2	98
Total		78,912	28,960 – 47,292	4,236	7	93	1	99

Total suspended-sediment load for period of study = 107,872 to 126,204 Mg
Total sediment load for period of study = 112,108 to 130,440 Mg

[1] Suspended-sediment loads in MacArhur Canal were estimated for the period August 19 through September 22, 2008. A range in suspended-sediment loads are provided based on two sediment transport curves (fig. 2-3).

Monthly organic suspended-sediment loads are shown for the restored portion of the Kissimmee River in figure 2-5b. The total suspended-sediment load minus the organic suspended-sediment load is the inorganic suspended-sediment load. Comparing organic and inorganic monthly suspended-sediment loads shows that for the wettest months, August and September 2008, the majority of the suspended-sediment load is inorganic (Figure 2-6a). Although both inorganic and organic suspended-sediment concentrations increase with flow, inorganic concentration increases are higher with respect to increasing flow than organic concentrations (Figure 2-6b). This finding could indicate that, at higher discharges, more inorganic sediment is eroded and transported relative to the organic component.

Flows went overbank upstream of the PC-33 station, between August 19 and September 22, 2008, flowed down the MacArthur Canal, and entered the Kissimmee River below PC-33. During this period, flow and suspended-sediment measurements were not made in MacArthur Canal. However, in June of 2009, flows again went overbank and a discharge measurement and a suspended-sediment sample were made on June 3, 2009 in the MacArthur Canal. The suspended-sediment concentration was 31.5 mg/L and the discharge was 42.1 m^3/s. At the time of this measurement, the MacArthur Canal was 23 m wide and 3 m deep. When plotted on the sediment-transport curve, the suspended-sediment concentration of 31.5 mg/L falls below the line of best fit (Figure 2-3).

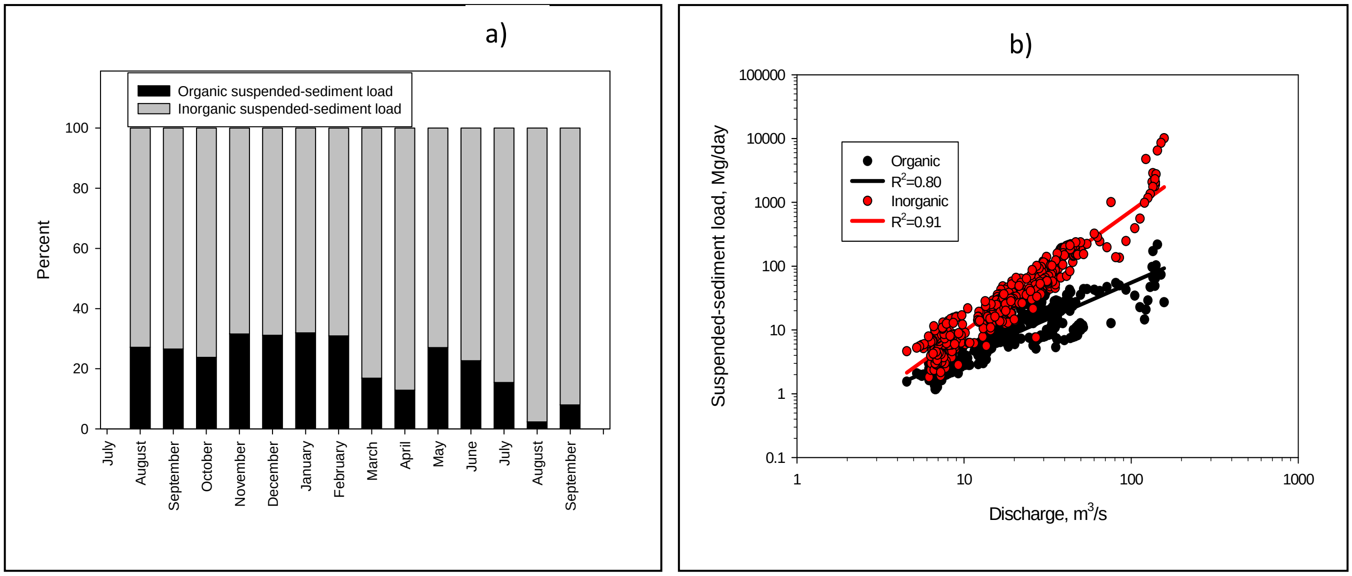

Figure 2-6. (a) Monthly organic and inorganic suspended-sediment load percentages for the restored section of the Kissimmee River at PC-33 near Basinger, Florida. (b) Sediment transport curves of organic and inorganic suspended sediment.

Suspended-sediment concentrations for the overbank flow during the period August 19 through September 22, 2008, were estimated using two sediment-transport curves. One estimation was based on the line of best fit of the sediment-transport curve for all suspended-sediment samples (Figure 2-3). The other estimate was based on the line of best fit of the sediment-transport curve adjusted to the suspended-sediment concentration sampled in MacArthur Canal, while preserving the slope of the line (Figure 2-3). By using both of these estimates, a range in suspended-sediment loads that were transported overbank and bypassed the station at PC-33 was provided.

The daily suspended-sediment load (Mg/day) for the overbank flows was computed as the suspended-sediment concentration (mg/L), estimated from both sediment-transport curves (Figure 2-3), times the mean-daily discharge (m^3/s) of the overbank flows and multiplied by a conversion factor (0.0864) (Porterfield, 1972). Overbank discharge was not measured but was estimated using discharge recorded at the S-65C structure which is managed by the South Florida Water Management District (SFWMD) (*http://my.sfwmd.gov/dbhydroplsql*; last accessed on December 4, 2009). The difference of the mean daily discharge computed at the USGS streamflow station from the mean daily discharge at the S-65C structure is estimated to be the flow that went overbank and bypassed the station.

The suspended-sediment load transported in the overbank flow was estimated to range from 28,960 to 47,292 Mg (Table 2-1), which is 33 to 45% of the total suspended-sediment transported in the Kissimmee River during this period [restored channel suspended-sediment load (57,783 Mg) + overbank suspended-sediment load (28,960 to 47,292 Mg)]. The overbank contribution of sediment was 27 to 37% of the total suspended-sediment load (overbank + restored channel; 107,872 to 126,204 Mg/yr) for the period of study. It is understood that the suspended-sediment loads shown here for the overbank flows represent an estimate. In the future, additional samples will be collected in MacArthur Canal to better establish the suspended-sediment loads that were transported overbank.

Suspended-sediment data are not available on the Kissimmee River near the restored area of Pool C prior to channelization, during the channelized period, or directly after restoration. Therefore, the suspended-sediment data (concentrations and loads) presented here serve as a point of reference for future collection to determine whether concentrations and loads will increase, decrease, or remain steady over time. Although suspended-sediment data are not available at this location, suspended-sediment concentration data are available downstream at the Kissimmee River at S-65E near Okeechobee, FL (USGS station ID: 02273000; drainage area 7,474 km^2) (Figure 1-1). Suspended sediment data for the Kissimmee River at S-65E near Okeechobee was obtained from the USGS National Water Information Site (NWIS) Internet site (*http://waterdata.usgs.gov/nwis*). Suspended-sediment concentration data were plotted for both stations against normalized discharge (Figure 2-7). Normalized discharge is the instantaneous discharge divided by the drainage area (cubic meters per second by square kilometers; $m^3/s/km^2$). Figure 2-7 shows that suspended-sediment concentrations at Kissimmee River at PC-33 near Basinger, FL, are higher than the Kissimmee River at S-65E near Okeechobee, FL, at the same normalized discharge (Figure 2-7). However, the period of data at the Kissimmee River at S-65E near Okeechobee is from 1973 through 1998, which is after channelization and before restoration. It is not clear if the suspended-sediment concentrations at Kissimmee River at PC-33 near Basinger are higher as a result of restoration (Figure 2-7). Other factors that may influence the differences in the suspended-sediment concentrations between the two stations are climatic variability between the time periods, the effects of tributaries, the influence of drainage area, and the containment of flow within the channel banks prior to restoration. The stations are located in different parts of the watershed, which can have an effect on each station’s proximity to sediment sources and sites of deposition, both of which will affect suspended-sediment concentrations.

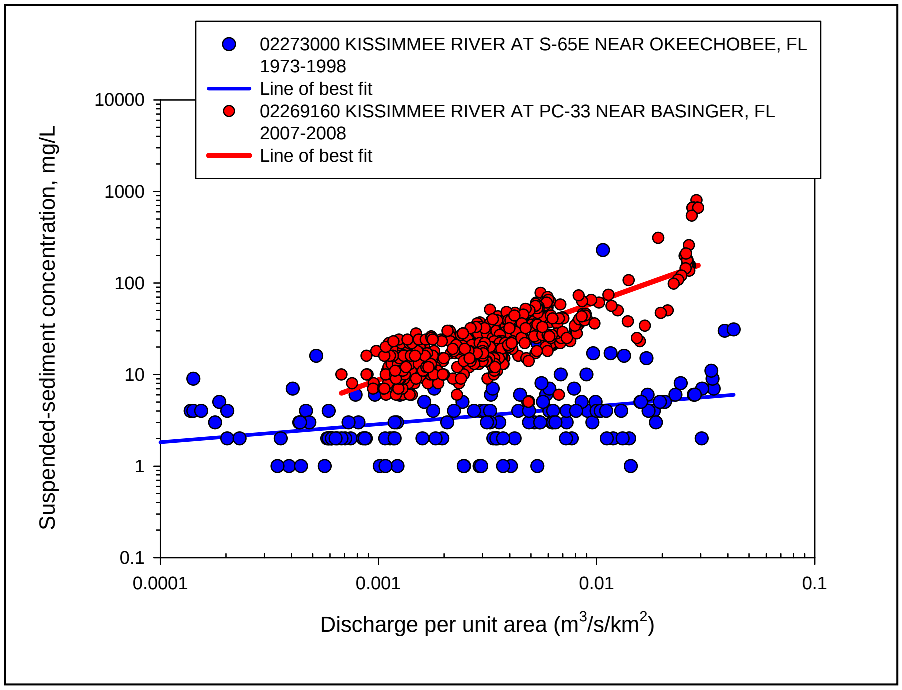

Figure 2-7. Comparison of suspended-sediment concentrations from the Kissimmee River at PC-33 near Basinger (this study) to Kissimmee River at S-65E near Okeechobee (1973-1998). Discharge is normalized by drainage area.

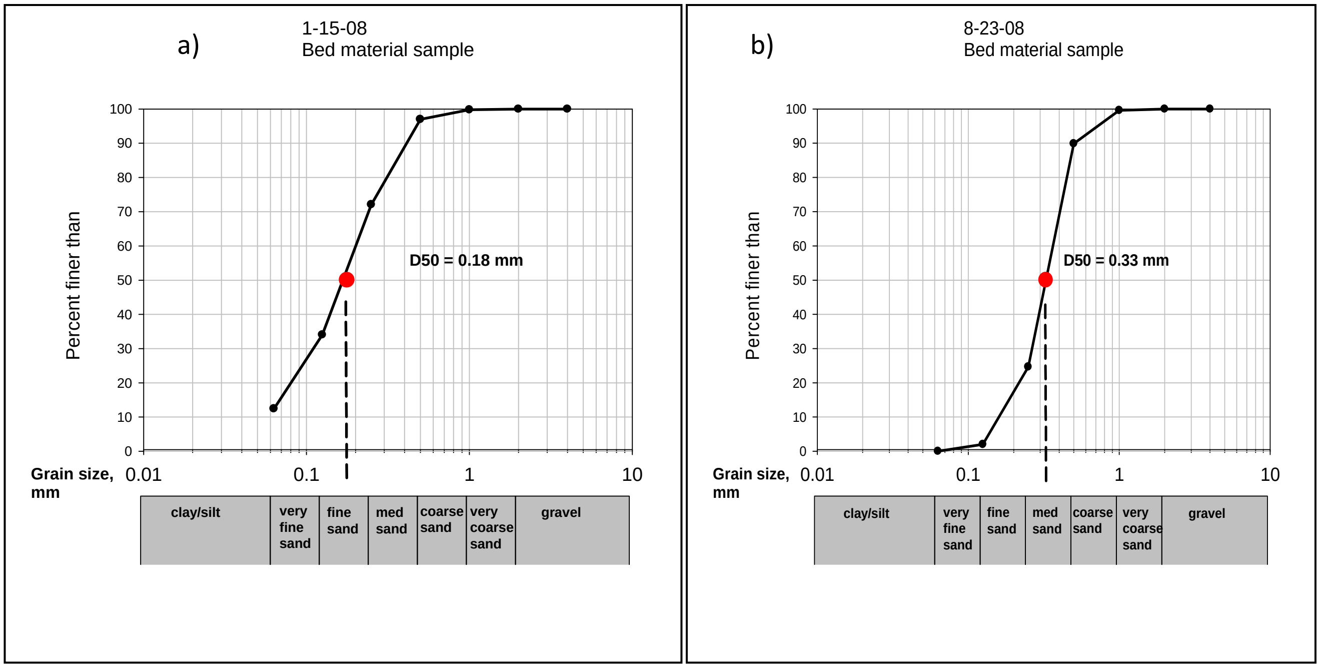

Figure 2-8. Size distributions of bed-material samples composited for the entire cross section for (a) January 15, 2008 and (b) August 23, 2008.

Bed-Material Summary

Samples of bed material were taken in the Kissimmee River on January 15 and August 23, 2008. The samples on January 15, 2008, were taken during a period of relatively low flows and the samples on August 23, 2008, were taken during Tropical Storm Fay (Figure 2-2). The distribution of grain sizes at all sample locations for January 15, 2008 and August 23, 2008 are shown in Figure 2-8a,b. The median grain size along the bed of the Kissimmee River measured on January 15, 2008, ranges from silt and clay to medium sand. A coarsening of grain size is observed from the left to the right bank (Figure 2-9).

The distribution of grain sizes for the entire cross section on January 15, 2008, which was weighted by the mass at each sampling station, showed a median grain size of 0.18 mm; a fine sand (Figure 2-8a). The median grain size along the bed of the Kissimmee on August 23, 2008 was a medium sand (0.33 mm) composited from all sampling transects (Figure 2-8b) with a slight coarsening to the right bank (Figure 2-9). The increase in flow during August 2008 appears to have scoured the finer grain sizes resulting in a coarser bed than that of January 2008.

Bedload

Bedload transport was measured five times between July 21, 2007 and September 30, 2008 (Table 2-2). At four other times during this period when the station was visited on a routine basis, the BL-84 bedload sampler did not record bedload transport. The bedload transport curve is shown in Figure 2-10a. The highest bedload transport measured was on August 23, 2008 during Tropical Storm Fay at a discharge of 152 m^3/s when 430 Mg of sediment was transported (Table 2-2). The lowest bedload transport measured was on March 20, 2008 at a discharge of 33.1 m^3/s when 0.11 Mg of sediment was transported (Table 2-2).

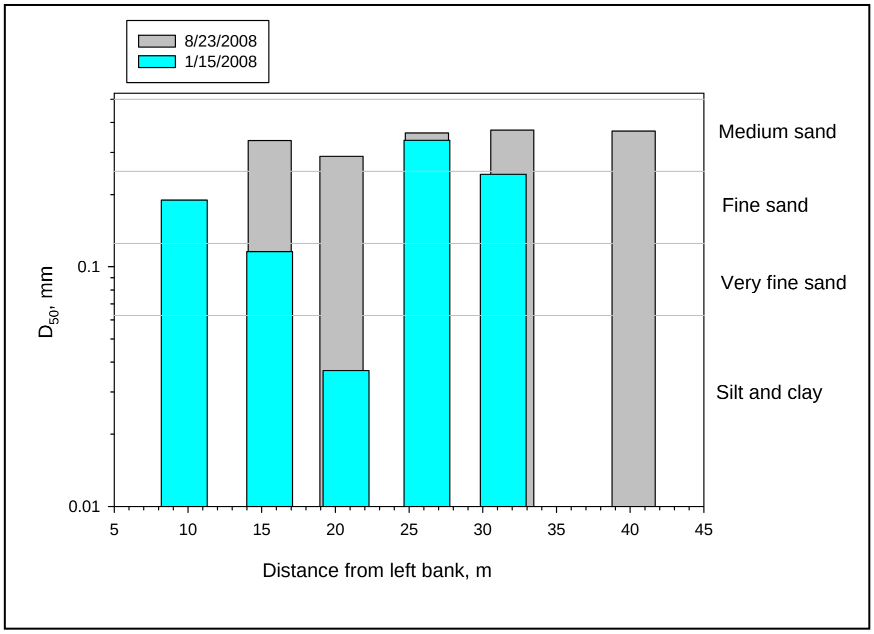

Figure 2-9. Median grain size (D_{50}) of bed-material samples taken at several verticals along the channel cross section, January 15, 2008 and August 23, 2008.

Table 2-2. Summary of bedload measurements for the period July 21, 2007 through September 30, 2008 at the Kissimmee River at PC-33 near Basinger, Florida.

Date of Measurement	Start time (EST)	Discharge, m^3/s	Moving bed velocity, m/s	Average velocity, m/s	Total Width, ft	Bedload, Mg/day	% Organics	% sand	D_{50}, mm
3/20/2008	13:24	33.1		0.31	42.7	0.11*	37	84	0.38
7/19/2008	14:48	44.7			42.7	1.1*	46	93	0.38
8/23/2008	12:04	152	0.11		42.7	430	1	99	0.36
8/28/2008	12:52	140	0.05		42.7	283		100	0.39
8/28/2008	14:16	140	0.05		42.7	238*	1	99	0.41

* Bedload was sampled at several transects and composited into one sample

For two bedload measurements made on August 23 and August 28, 2008, bedload was reported at each sampling transect (Figure 2-11a,b). For the bedload measurements made on March 20, 2008 and July 19, 2008, bedload transport from each transected was composited into one sample (Table 2-2). Bedload transport is variable across the channel with lower rates near the channel margins (Figure 2-11a,b). Size distributions for the bedload that were collected at each sampling transect on August 23 and August 28, 2008, are shown in Figure 2-12. Bedload material was coarsest for the August 28, 2008 sample (Figure 2-12). Size distribution of bedload measurements made on July 19, August 23, and August 28, 2008 are similar to the August 23, 2008 bed-material size distribution (Figure 2-12). To obtain a median grain size for the bedload samples on March 20, 2008 and July 17, 2008, each vertical was weighted to the entire mass from each cross section. The median grain size of bedload was similar for all flows ranging from 0.36 to 0.41 mm (Table 2-2). The median grain size of bedload is slightly higher than the median grain size of bed material. This result may be due to the 0.125 mm mesh size of the bedload sampler that would lose some of the finer material (34% and 2% of the bed material was less than 0.125, collected on January 15 and August 23, 2008, respectively (Figure 2-12). Some of the finer bed material can also become suspended at certain flows and thus the bedload grain size would be coarser. The bedload measurement made on March 20, 2008 and two of the transects made on August 23, 2008 are finer grained than the other bedload measurements (Figure 2-12). The March 20, 2008 bedload sample was the lowest measured at 0.11 Mg/day (megagram per day) and was collected during the lowest sampled discharge (Table 2-2).

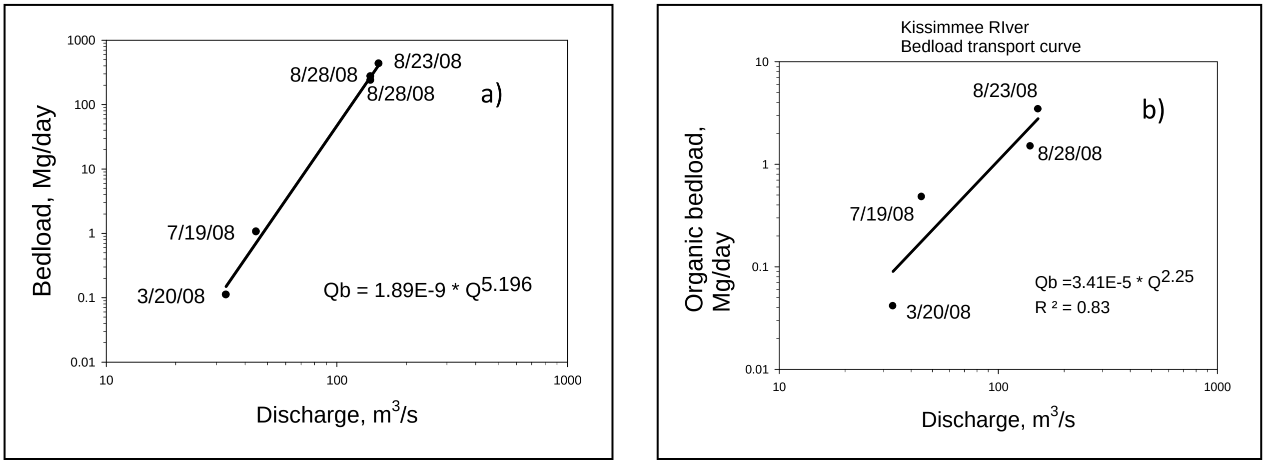

Figure 2-10. Bedload transport curve for Kissimmee River at PC-33 near Basinger, Florida, July 21, 2007 – 9/30/2008. (a) Total bedload transport curve and (b) organic bedload transport curve. [Qb = Bedload, Mg; Q= discharge, m^3/s].

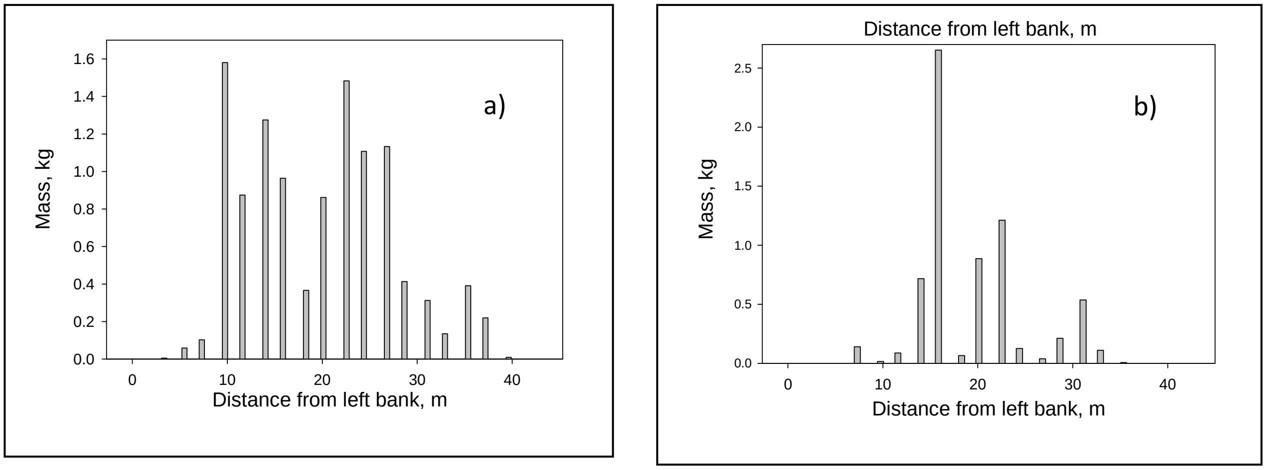

Figure 2-11. Bedload transport reported for each sampling section (a) August 23, 2008 and (b) August 28, 2008. Twenty verticals were sampled on each date. On 8/23/2008, 2 of the 20 verticals showed no bedload. On 8/28/2008, 6 of the 20 verticals showed no bedload.

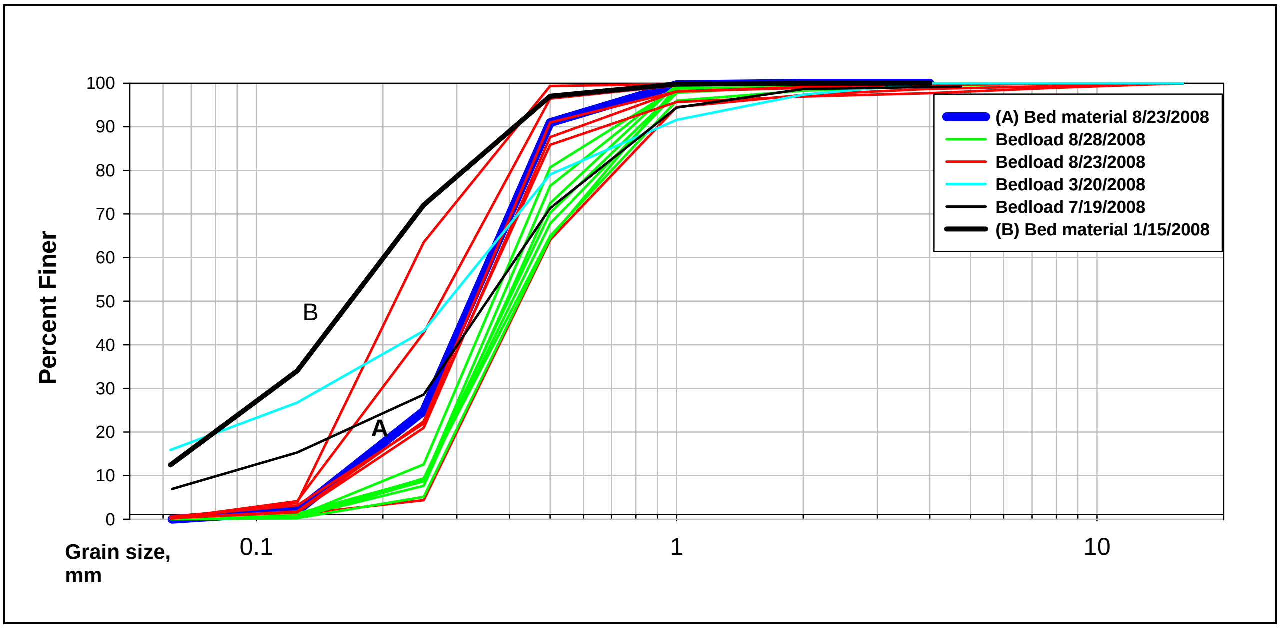

Figure 2-12. Size distributions of bedload at individual sampling transects for the samples collected between July 21, 2007 and September 30, 2008. Also shown are the bed-material size distributions for January 15, 2008 and August 23, 2008.

Maximum measurements of instantaneous velocity near the channel bed on March 20, 2008 were close to 30.0 cm/s (centimeters per second). The median grain size of the bed material from two measurements (Figure 2-8) varied from 0.18 to 0.33 mm, a fine sand and medium sand, respectively. Examination of the Hjulstrum curve for the initiation of sediment transport indicates that for the range of median bed-material found on the Kissimmee River, sediment movement is initiated when the velocity at the channel bed approaches 20 cm/s (Figure 2-13). The discharge measurement made on March 20, 2008 of 33.1 m^3/s had velocities near the bed that are just above the threshold to initiate bedload transport. Based on these relations, a discharge of 28.3 m^3/s was assigned the discharge at which bedload transport begins.

Daily bedload transport was determined by using the line of best fit from the bedload transport curve (Figure 2-10a) applied to the mean daily discharge record at Kissimmee River on days when the daily-mean discharge exceeded 28.3 m^3/s. Daily bedload values were totaled to obtain monthly loads (Figure 2-14a' Table 2-2). The total bedload for the period of study (4,236 Mg) is 3 to 4 % of the total sediment load (112,108 to 130,440 Mg) [bedload (4,236 Mg)+ restored suspended-sediment load (78,912 Mg) + estimates of suspended-sediment transported overbank (28,960 to 47,292 Mg)].

The percent organic material was determined for 4 of the 5 bedload measurements (Table 2-2). Organic percentage of the bedload was higher during the lower flows (Table 2-2). An organic bedload transport curve was produced and the line of best fit was applied to the mean daily discharge to obtain daily organic bedload transport (Figure 2-10b). The daily organic bedloads were summed to obtain monthly organic bedload values. The organic bedload was divided by the total bedload transport to obtain the percentages of the total bedload that was organic. The inorganic daily bedload transport is computed by subtracting the organic from the total bedload. Percentages of inorganic bedload ranged from 15 to 99% and percentages of organic bedload ranged from less than 1 to 85% (Figure 2-14b).

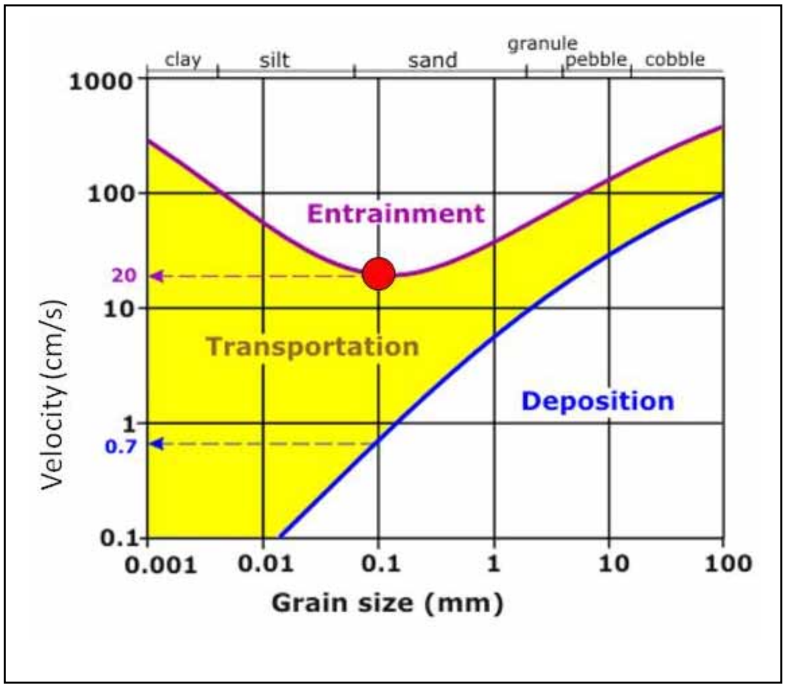

Figure 2-13. Hjulstrum curve for the initiation of sediment motion. The red circle indicates the range of median bed material found on the Kissimmee River, which would be entrained at velocities near 20 cm/s.

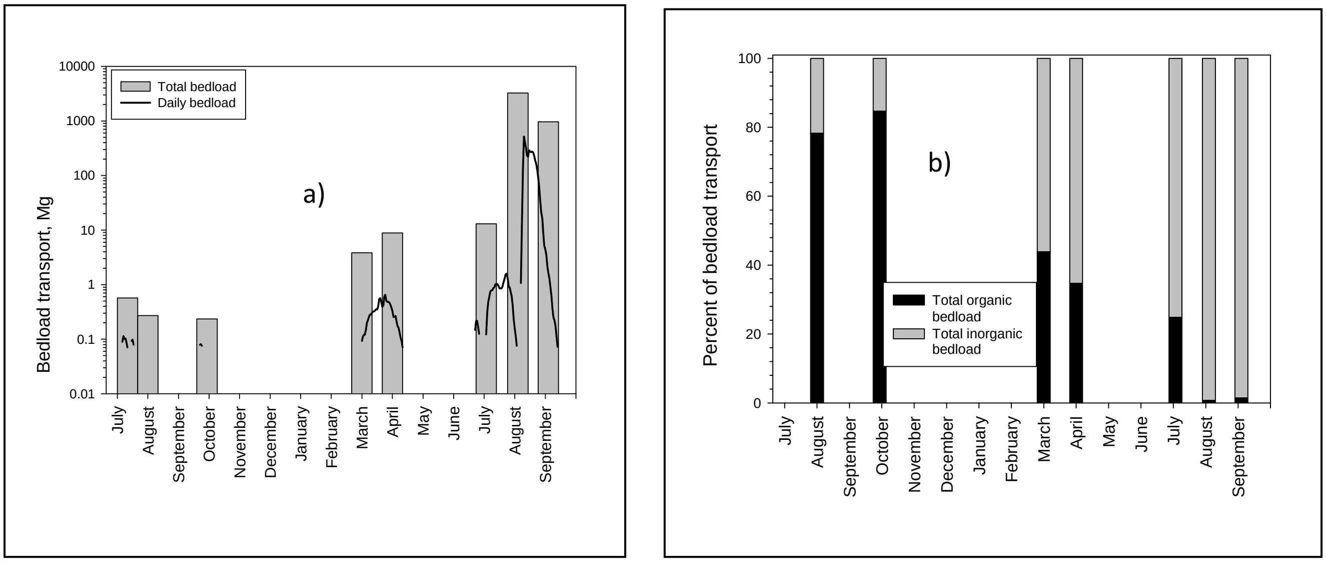

Figure 2-14. (a) Monthly bedload transport, August 2007 – September, 2008. (b) Percent of monthly bedload transport that is organic and inorganic.

Effective Discharge

A cross section of the Kissimmee River at PC-33 is shown in Figure 2-15. Bankfull flow occurs at a discharge of approximately 50 m^3/s. The histogram of mean daily discharges for the period July 21, 2007 through September 30, 2008 was created using 78 flow classes of 2.0 m^3/s size (Figure 2-16). The large number of size classes was required to ensure that the largest size class did not occur in the first class and that higher discharges were included. The histogram illustrates that the majority of flows are 7 m^3/s (n= 116; Figure 2-16). The large number of flows at 7 m^3/s is partially due to the controlled flow on the Kissimmee River, which attempts to maintain a minimum gage height necessary for navigation purposes. The bedload transport curve is shown in Figure 2-16 along with the collective bedload discharge histogram. There are two high points on the collective bedload discharge histogram; one value at 47 m^3/s, the other value at a higher flow of 139 m^3/s. The lower value at 47 m^3/s is close to the value we have selected as bankfull discharge (50 m^3/s); thus, the Kissimmee River's channel morphology could be related to the effective discharge. The higher effective discharge value at 139 m^3/s could be due to the large number of high flows that occurred during Tropical Storm Fay that clustered in this size class. Since flows are out of bank at 139 m^3/s, it seems unlikely that these are channel-forming flows but may be flows that impact the floodplain.

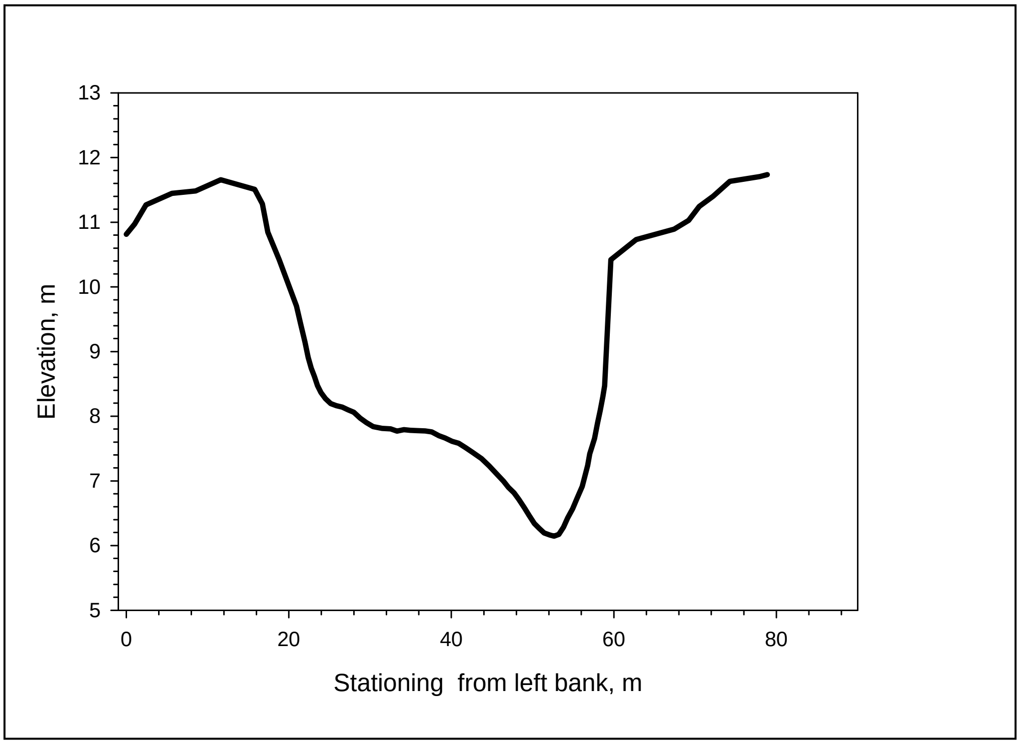

Figure 2-15. Cross-sectional geometry, Kissimmee River at PC-33, May 5, 2009

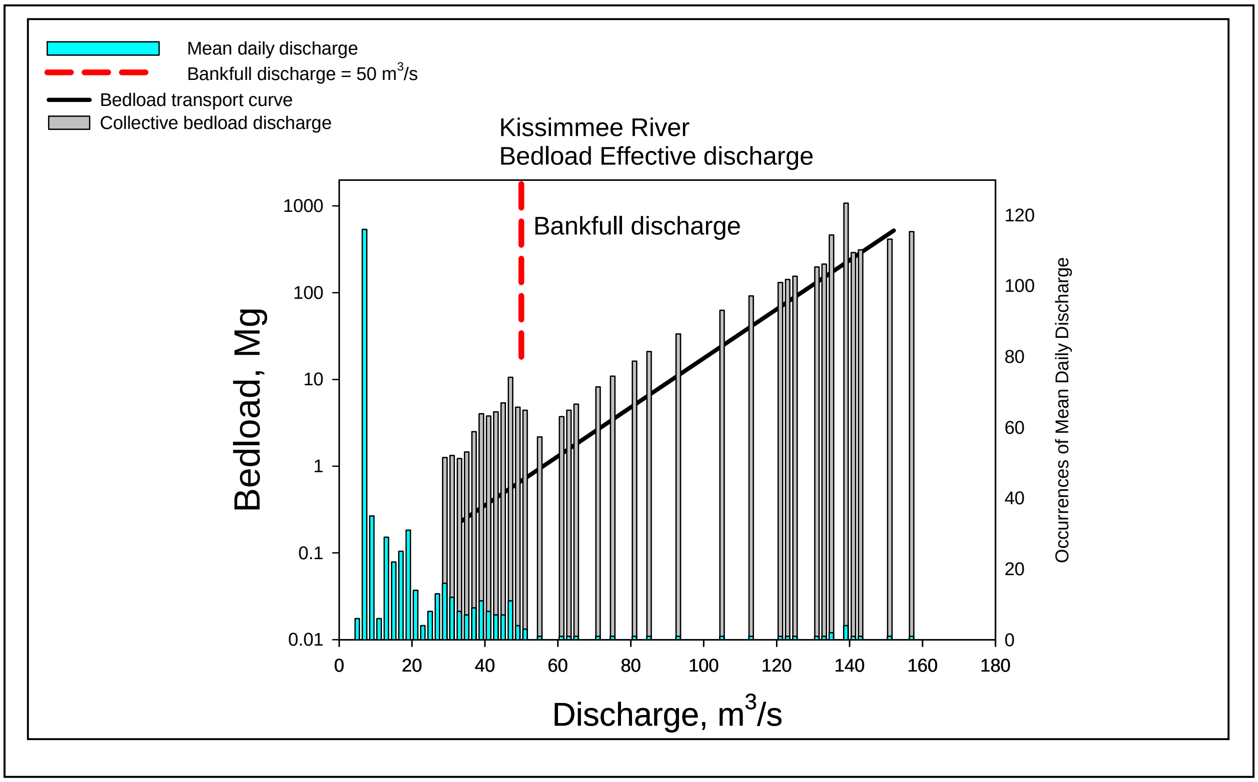

Figure 2-16. Effective discharge computations for the Kissimmee River at PC-33.

Summary of Sediment Transport

The Kissimmee River is a fine to medium grained sand-bed river. Suspended-sediment ranges from 2% sand to 78% sand, at low and high flows, respectively. The organic content of the suspended sediment increases with flow ranging from 3 mg/L at low flows to 21 mg/L at higher flows (Figure 2-6). Organic percentage of the suspended-sediment loads range from 31% during low-flow months to 2% for high-flow months, indicating that relative to flow, inorganic suspended sediment increases are greater with flow than organic suspended sediment.

Incipient motion of bedload begins at 28.3 m^3/s. The median grain size of bedload was similar for all flows ranging from 0.36 to 0.41 mm. The largest particle size transported as bedload was 1 to 2 mm at flows that reached 140 and 152 m^3/s. Organic percentage of the bedload ranges from 85% during low flow months to less than 1% at high flows (Figure 2.14b).

Total sediment load (suspended-sediment in the restored section + overbank suspended sediment + bedload) for the period July 21, 2007 through September 30, 2008 was 112,108 to 130,440 Mg (Table 2-1). Of the total sediment load, 78,912 Mg was transported in the restored section. Overbank flows occurred from August 19 to September 22, 2008 (9% of the study period) and accounted for 52% of the total flow (restored channel + overbank flows) during this period and 25% of the total flow for the period of study. The overbank flows were estimated to have transported 28,960 to 47,292 Mg of suspended sediment, which is 33 to 45% of the total suspended-sediment transported in the Kissimmee

River from August 19 to September 22, 2008. For the period of study overbank suspended-sediment transport is estimated at 27 to 37 % of the total suspended-sediment load (107,872 to 126,204 Mg/yr). Seven percent of the suspended-sediment transported in the restored channel was organic suspended-sediment, and 93 %was inorganic suspended-sediment.

Bedload transport was 4,236 Mg (3 to 4 percent of the total sediment load). The median grain size of the bed material was a fine to medium sand and incipient motion of bed material occurred at approximately 28.3 m^3/s. The organic percentage of the bedload was greater than 25% (up to 85%) during the low flow period of July 2007 through July 2008, to less than 25% (as low as 0.9%) during the high flow period, July through September, 2008 (Table 2-1).

Many river basin studies report sediment yield as the annual suspended-sediment load divided by drainage area. The total suspended-sediment load for the period of this study was estimated to range from 107,872 to 126,204 Mg. Dividing this total by the number days in operation (437 days) and multiplying by 365 provides an estimate of the annual suspended-sediment load (90,099 to 105,411 Mg). Dividing this annual total by the drainage area (5,270 km^2) produces a sediment yield ranging from 44.3 to 51.8 Mg/km^2/year. Effective discharge computations indicate that the majority of sediment is transported at 47 m^3/s and 139 m^3/s. The 47 m^3/s effective discharge value is near the bankfull discharge of 50 m^3/s, and could be the channel-forming flow. The higher 139 m^3/s effective discharge value may be related to the frequent large flows that occurred during Tropical Storm Fay. These flows may be important in floodplain processes but more research is needed to confirm this.

The importance of storms in transporting sediment is highlighted by the data collected in the Kissimmee River. During the period of study, 52% of the total suspended-sediment load (40,651 of 78,918 Mg) was transported in 8 days between August 21 and 31, 2008 and 56% of the total bedload (2,362 of 4,238 Mg) was transported in 7 days between August 22 and 30, 2008. For both the suspended sediment and bedload, this transport occurred during Tropical Storm Fay. An important question remaining is what is the source of this sediment? Large amounts of bank erosion were observed on the Kissimmee River (see Chapter 3 on floodplain processes) and in some reaches the Kissimmee River scoured its bed (see Chapter 4 on channel cross-section monitoring). Both bank erosion and the channel bed are potential sources for suspended sediment and bedload. Future studies directed at constructing a sediment budget for the Kissimmee River may be able to determine the important sediment sources.

Comparison of suspended-sediment concentration data from the Kissimmee River at PC-33 near Basinger, FL (2007 through 2008) to Kissimmee River at S-65E near Okeechobee (1973 through 1998) indicates that suspended-sediment concentrations are higher at PC-33 near Basinger at the same normalized discharge than at the Kissimmee River at S-65E near Okeechobee. The sediment data collected at the Kissimmee River at S-65E near Okeechobee, from 1973 through 1998 were collected when the stream was channelized. As a result of the discontinuity between the data collection periods at the two locations, and the lack of any suspended-sediment data at the PC-33 station, the cause of the higher suspended-sediment concentrations on the Kissimmee River at PC-33 near Basinger is unclear. Since suspended-sediment data are not available on the Kissimmee River near the restored parts of Pool C prior to channelization, during the channelized period or directly after restoration, the suspended-sediment data (concentrations and loads) presented herein serve as a point of reference to determine whether concentrations and loads increase, decrease, or remain steady over time.

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CHAPTER 3

KISSIMMEE RIVER FLOODPLAIN MONITORING

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Introduction

Natural floodplains serve many ecological and hydrological purposes including sediment and nutrient trapping, flood stage and velocity dampening, and support a diverse habitat for flora and fauna. Human alterations to the landscape such as flow regulation through dam construction, stream channelization, and canal and levee construction may lead to channel incision or filling and large changes in sediment supply conditions depending on the geomorphic setting. Most of the world's largest rivers have been dammed (Nilsson et al. 2005). The downstream impacts from dam construction that most affect the floodplain are typically dramatic reductions in the peak stages, frequency and duration of over bank flows, and sediment transport (Williams and Wolman 1984). Additionally, stream channelization has been a common, albeit controversial, practice along many rivers in parts of the Coastal Plain (Simon and Hupp 1992, Hupp and Bazemore 1993) to reduce flooding and facilitate row-crop or livestock agriculture on floodplains. The impact on the riparian zone is a dramatic reduction in overbank flow and attendant sediment trapping (Hupp et al. 2009).

In general, dam construction and channelization greatly impact the connectivity of the floodplain to sediment-laden flood flow, either by reductions that compromise the trapping function of the floodplain or by anomalous connectivity increases that facilitate extreme sedimentation (Hupp et al. 2008). The Kissimmee River suffers from both dam construction and, perhaps, more pervasively from channelization. Geomorphic analyses (Leopold et al. 1964, Jacobson and Coleman 1986, Noe and Hupp 2005, Hupp et al. 2008) verify that riparian retention of sediment and associated material is a common and important fluvial process, yet retention time of sediment (Malmon et al. 2005) and biogeochemical transformation during storage (Noe and Hupp, 2009) may be the most poorly understood, generally unquantified aspects of sediment, both mineral and organic, and associated material (e.g. macro nutrients) budgets (Hupp 2000).

The USGS entered an agreement with the South Florida Water Management District (SFWMD) to monitor the hydrologic reconnection of the floodplain to the newly restored Kissimmee River channel. The general objectives of the study are to establish a long-term floodplain monitoring plan for the Kissimmee River Restoration Program and provide SFWMD with data to implement comprehensive adaptive river management approaches. Our specific objectives 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. Ultimately our results can be used to facilitate the development of a sediment budget, including floodplain trapping and material (eg. carbon) sequestration. This chapter presents our methods and initial results (2007-2009) for floodplain sedimentation and floodplain sediment character.

Methods

Site/Transect Selection and Establishment

We established 16 sediment monitoring transects generally aligned perpendicular to the channel that began on the river edge (usually within 5 m from edge) and continued from 50 to 575 meters across the floodplain. Thirteen of the transects were in the restored reach of the river (86 clay feldspar pads, Fig. 3-1a), 3 transects were in channelized, yet un-restored Pool D (14 clay feldspar pads, Fig 3-1b). Transects were numbered from upstream to downstream, with the exception of transects 14, 15, and 16 which were added in January 2008. Transects had 3 to 11 sampling points, typically equally spaced along transect, where periodic measurements were made of deposition rate, texture, bulk density and composition (C and P concentrations were measured in a subset of these points); these sampling points were numbered consecutively starting with the lowest number nearest the channel.

Selection of transects was stratified based on representative floodplain vegetation, landscape type (borrow, backfill, and, original floodplain), and location within the restored reach. We believe this non-random sampling design allows for a reasonably unbiased estimate of sedimentation rates along the restored reach. Each transect was leveled in detail using a laser level. Bank heights were measured near the beginning of each transect from the top of the bank to the low water elevation; all bank height and elevation measurements were normalized to water elevation using a series of stage gages maintained by the SFWMD. Water elevations were tied to a new fully implemented discharge gage operated by the USGS (SFWMD river structure PC-33, USGS streamgage 02269160). Datum for this USGS gage is sea level, e.g. 1 m on the gage is 1 m above sea level (NGVD of 1929). All sites were established in the winter/spring of 2007 and measured periodically for deposition; the most recent measurements were taken in December 2008. Thus, all sites were monitored for two (2007 and 2008) wet seasons. Average annual discharge as measured by the USGS gage at PC-33 was 24.5 m^3/s for calendar year 2008. Portions of this chapter will refer to the PC-62 gage operated by the SFWMD. The PC-62 gage is upstream of the USGS streamgage and, unlike PC-33, its stage measurements were not affected by the pooling effect at the S65C lock during the no flow regime when the all of the river structures were closed to preserve upstream lake levels (Fig. 3-2). Both gages are within our study area; transects 1, 2 and 3 are near PC-62 and transects 14, 15, and 16 are near PC-33.

Sediment Deposition and Sampling

Artificial marker layers (clay pads) were placed at each sampling point, typically spaced along transect at intervals of approximately 50 meters. These markers are made by placing powdered white feldspar clay approximately 20 mm in thickness over an area of about 0.5 m^2 on the sediment surface that has been cleared of coarse organic detritus. This clay becomes a fixed plastic marker after absorption of moisture that permits accurate measurement of short-term net vertical accretion (Baumann et al. 1984, Hupp and Bazemore 1993, Kleiss 1996, Ross et al. 2004). The clay pads were examined periodically and measured for depth of burial during the course of study. Landscape spikes were placed on the edges of claypads to measure possible erosion and to aid in re-locating the claypad (Fig. 3-3).

Sediment samples were taken near all clay pads at both the beginning and end of the study. The last sample was, when possible, taken from the soil surface to a depth matching that of deposition above the claypad so that current (past two wet seasons) processes were reflected in the sediment analyses. Sediment sample analyses included: 1) bulk density, by taking a known sample volume, which was then dried and weighed, 2) size class composition by dry sieving with various screen sizes in a vibratory sieve shaker, and 3) organic fraction of the top five centimeters of floodplain sediment by a “loss on ignition” (LOI) procedure (Nelson and Sommers 1996). Approximately five grams of each soil sample was dried for 24 hours at 110 C. The samples were then allowed to cool in a dessicator, weighed to within 0.01 grams precision and burned for 16 hours at 400 C in a muffle furnace. The cooled sample was re-weighed and the percent mass lost was recorded as the organic content of the sample.

Sediment particle size was determined by grinding a known amount of oven-dried sediment with a mortar and pestle and then processing the sediment through a sonic sieve for 12 minutes. Sieved sediment was examined under a low power microscope to check for electrostatically bound particles and clay colludes which would require further sediment grinding and re-sieving. Samples were sieved until at least 95% of the particles were separated into individual grains for accurate sieving. Sediment size is reported as a weight fraction with sediment divided into categories of greater than 0.5 mm (coarse sand), between 0.25 and 0.5 mm (sand), 0.125 and 0.24 mm (fine sand), 0.062 and 0.124 mm (very fine sand), and less than 0.063 mm (silt and clay). A modified sediment size index was used to classify the soil texture for each site. The index is detailed in Kroes and Hupp (in press) and makes use of phi size class units (Krumbein, 1936). The index multiplies the size proportion by the inverse of its phi unit; resulting in a simple quantitative measure of soil texture. The coarse sand fraction is multiplied by five, sand by four, fine sand by three, very fine sand by two, and silt and clay by one. The index was used to provide an intuitive measure of soil texture: the index value increases with increasing grain size.

Results

Hydrologic regime

From the beginning of the study in January 2007 until May 2007 there was no flow in the channel due to low water levels upstream in Lake Kissimmee and associated actions to mitigate those water levels. During this period, water levels at upstream sections of the restored channel were lower than normal lows with dry sediment on the majority of the floodplain with moist depressions and sloughs. Areas of the restored channel near the downstream lock structure experienced a sustained high water stage due to water ponding behind the S-65C control structure. Floodplain depressions and sloughs were inundated and most areas of the floodplain were moist to very wet. Establishment of transects 14, 15, and 16 was delayed until January 2008 due to the ponding effect of the no-flow hydrologic regime in the first half of 2007.

Between the re-establishment of flow and our first sampling date in May of 2008 there was only one overbank event that inundated the majority of the floodplain. This spring flood crested above bankfull elevation at PC62 (near transects 1, 2, and 3) and had a return interval of approximately one year (Fig. 3-2, Leroy Pearman, USGS Orlando, FL, personal communication). The water stage in June 2008 dropped to approximately 0.6 m lower in elevation than the stage during the no-flow hydrologic regime, and was the lowest stage during the study period. By July, however, summer rains increased stage, culminating with Tropical Storm Fay creating the highest flows of the study period. A full description of the hydrologic record for PC-33 is available in the preceding chapter. We sampled our transects again in December 2008 to measure floodplain dynamics after the fall flood. Our measurements in early May 2009 documented deposition in Pool D and sediment samples were taken from nearly all sites in Pool B/C for post-study sediment characterization.

Floodplain sediment deposition rates

Floodplain sediment deposition was measured on 82 pads in Pool B/C, erosion was detected on one pad, and 4 pads were lost during the study period. Total deposition rates ranged from -7.9 mm/yr (erosional) to 110 mm/yr (part of a levee building event from Tropical Storm Fay). Mean sediment deposition was 15.0 mm/yr for Pool B/C (n = 82). Total deposition rates measured in May 2008 before Tropical Storm Fay ranged from 0 mm/yr to 29.8 mm/yr (near a slough). The mean deposition rate was 6.7 mm/yr for Pool B/C (n = 81). The mean deposition rate from the spring 2008 flooding event was within the range of typical deposition for wetlands in the Southeastern US (Hupp 2000). The overall deposition rate (15 mm/yr) is high due to the effect of the Tropical Storm Fay event and possibly erosion and resuspension of sediment from continued restoration efforts upstream of our study site (Fig. 3-4).

Sediment deposition was measured on 8 pads in Pool D, erosion measured at two pads and 4 pads were lost during the study period. Deposition rates ranged from -5.0 mm/yr (erosional) to 7.5 mm/yr. Mean sediment deposition was 1.3 mm/yr in Pool D for the entire study period and 1.6 mm/yr when measured in May 2008; both means are an order of magnitude lower than the restored reach (n = 12). Sedimentation in Pool D can be attributed to autochthonous organic dry deposition, intra-floodplain sediment transport, and aeolian processes.

Mean sediment deposition rate by transect increases in the restored reach as the channel nears the S-65C control structure (Fig. 3-5). Transect 15 and 16 are exceptions, transect 15 because the pads are located on a natural hummock, upland, isolated from overbank flow and transect 16 because of preferential flow on the right bank (opposite bank) floodplain into the unrestored C-38 canal remnant (discussed more fully in Pearman chapter).

Mean organic content is provided in Fig. 3-5b. The highest deposition rates were in the furthest upstream transects and in the downstream segment of the restored reach. The percent soil organic matter varied widely but was generally highest near floodplain depressions or side channels. The highest proportions of organic matter were at transect 2 (35.4%), where the three pads sampled an area of wetland shrubs adjacent to a side channel, and transect 3 (33.7%) where the pads sampled a wetland forest with several depressions and one slough. The lowest percent organic matter was recorded at transect 5 (3.7%), a transect exclusively on the backfilled C-38 canal, and transect 15 (7.6%), where the pads are arranged on a natural hummock isolated from overbank flow. Percent organic content on the floodplain increased significantly ($p < 0.002$, T-test) after overbank flow was returned to the system (Table 3-1). The increase of organics, with no noticeable change in vegetation, suggests that a large portion of the organic matter arrived with overbank flows.

Landscape effects on sedimentation

The restored Kissimmee River floodplain can be separated into 4 categories, backfilled C-38 canal, borrow areas to backfill the canal, original floodplain, and elevated spoil regions adjacent to connector segments of the channel. Landscape designations were assigned by the SFWMD and provided in a GIS format for our analysis. The majority of our study area was natural floodplain with large sections of borrow to fill the C-38 canal (Fig. 3-6). Sediment deposition, organic content, and bulk density varied greatly between landscape type, likely driven by the elevation differences between types (Table 3-2, Fig. 3-7). Natural floodplain represents the majority of our study area and has the highest proportions of organic matter of the three dominant landscape types. Borrow areas have the highest total deposition rates but the lowest median deposition rates (mean = 18.1 mm/yr, median = 5.0 mm/yr). The discrepancy is largely due to a few high deposition rates measured at transect 14 and because the majority of the borrow measurement sites are on the East floodplain opposite from the dominant overbank flow pathways on the West floodplain. The highest median deposition rate was on the natural floodplain (7.2 mm/yr) as was the highest percent organic content (27.2%). Estimates for total mass deposited on the floodplain are provided in Table 3-2; note the orders of magnitude difference in organic and mineral deposition between landscape types. There are three orders of magnitude difference in mass per year (Mg/yr) organic sediment deposited between landscape types.

Total observed deposition, back calculated from the deposition rate, can be compared to in-channel sediment transport results described in Chapter II. The median mass deposited from the two storm events was 159,660 Mg, with 119,433 of that total consisting of mineral sediment and 40,226 Mg consisting of organic material. The natural floodplain trapped the majority of both the mineral and organic sediment (78% and 87%, respectively). The backfilled C-38 canal trapped only 0.6% of the observed organic matter indicating that as a landscape type it is either a poor site for net primary production (low autochthonous input, created from living organic matter at a measurement site) or that it does not collect allochthonous organic material from the channel or from other areas on the floodplain (indicating a limited floodplain trapping function). Total sediment load measured at the PC-33 gage between July 21, 2007 and September 30, 2008 was 83,155 Mg with 77,501 Mg of the sediment as mineral and 5654 Mg as organic material. The floodplain trapped more sediment than passed through the PC-33 gage indicating that during flooding events more than half of the suspended sediment is trapped on the floodplain. The floodplain also traps nearly 8 times as much organic matter as passes through the gage as either suspended or bedload sediment. How much of the organic material is autochthonous and how much is brought in from upstream is still unknown.

All 14 sites in Pool D are considered to be in a floodplain landscape. Data from Pool D was not used in the analyses unless noted in order to ensure appropriate comparisons of landscape function along the restored channel. The mean percent organic content in Pool D was 21.1%, lower than both borrow and natural floodplain areas but higher than backfilled C-38 canal. Presumably the somewhat xeric/nutrient poor nature of backfilled areas limits biotic productivity (organic material production) regardless of hydroperiod patterns.

Sediment texture, as defined by an inverse phi scale, was taken at approximately half of the sites prior to December 2008, and nearly all of the sites in December 2008. All sites were dominated by very fine to fine sand (63 to 125 micron diameter) with coarser sediment in the backfilled canal than either the borrow or floodplain area. Sediment texture trends in the borrow and floodplain landscape types appear to be driven by channel processes with coarser sediments near the channel and dominant flood flow paths.

SFWMD completed a vegetation survey of the floodplain in 2004. The data is provided in a GIS coverage that we used for floodplain deposition analyses. All of our backfill sites (n=12) are composed of wet prairies. Borrow areas are composed primarily of wet prairies in high areas (n=15) and wetland shrubs in depressions or lowlands (n=4, ANOVA, p=0.05). Undisturbed floodplains have a variety of vegetation communities with no apparent trend with elevation.

Vegetation effects

Vegetation can influence flow patterns, velocity, and sediment settling on floodplains (Darby 1999, Larsen et al. 2007) largely due to its effect on velocity by increasing surface roughness. The SFWMD vegetation map provides a means to analyze the potential impact of vegetation on sedimentation rates and sediment character in the Kissimmee River basin. In general upland herbaceous communities occupied the higher ground on the floodplain. The majority of the floodplain consists of wet prairie. Wetland forests occupy much of the same elevation range as wet praires; in contrast, wetland shrubs generally, with exceptions, occupy lower elevation areas. While not statistically significant, the highest rates of total deposition occur in wetland shrub communities, while the lowest rates occur in wetland forests. The highest sediment organic content was in wetland forests.

Elevation and flow effects on sedimentation

Elevation was measured by laser level and referenced using nearby stage gages tied to mean sea level. There are weak relationships between both elevation and distance from channel with sediment deposition ($R^2 = 0.11$ and 0.14 respectively, Fig. 3-8). A finer spatial scale may facilitate understanding of deposition patterns (Figs. 3-9, 3-10). Deposition rates may be most affected by connectivity to the suspended sediment laden main stem. Connectivity is a function of several factors including elevation, distance along dominant overbank flow routes, and intervening vegetation. Dominant flow paths are complicated on the Kissimmee floodplain and are likely driven by side-channels, dominant slough patterns, other microtopography (e.g. backfilled areas, natural hummocks, etc) that appear related to historic (prior to channelization) anabranching side channels, and distance from the main Kissimmee River channel (Figs. 3-9 and 3-10). The highest deposition rates on transect 10 were near or at sloughs, depressions, and the main channel. Coarse grained deposits (fine sand) occur almost exclusively at sites adjacent to the main channel and presumably result from natural levee construction. Fine grained (silt and clay dominated) deposits occur primarily near sloughs and depressions away from levee deposits. Organic content of sediment tended to be greatest in fine-grained deposits.

Geomorphic changes after Tropical Storm Fay (sand splays, channel erosion)

Tropical Storm Fay passed over the Kissimmee River Basin on August 19th 2008 creating one of the two overbank flow events during the study. The flood event had a large impact on the channel and floodplain with noticeable erosion on straight and cut banks, sometimes producing several meters of bank retreat. New channel and point bars were also created by the event, predominantly composed of sand. The floodplain was modified by the event, especially adjacent to the channel where sand splays added in excess of 30 cm of sediment in a levee building event. Prior to the storm we documented 3 transects that started at a natural bank (no spoil) and lacked the typical levee associated with most fluvial river systems. Fluvial landforms associated with alluvial rivers are displayed in Fig. 3-11. The transects that lacked natural levees were T1, T5, and T6. We also noted 4 transects that had levees, T3, T7, T10, and T16 (the levee at T16 was severely eroded during the large flood event). Transects 4 and 8 were positioned on connector river reaches and had artificial spoil levees. The other 4 transects were indeterminate based on our surveying priorities. Sand splays were evident at T3, T5, T7, T9, T10, and T14 as well as several reaches between transects (Fig. 3-12). Continued monitoring will allow us to evaluate the re-establishment of levees in areas affected by the restoration program (connectors, recarved reaches) and the natural maintenance of levees in less impacted reaches (reconnected reaches).

Sediment texture changed significantly ($p < 0.001$, T-test) from the beginning of the study to after the spring flood in May 2008 (Table 3-3). Initially the majority of the floodplain sampled had a mean diameter near 63 microns, classified as very fine sand. The sediment fined into the silt/clay range after the relatively small flood in spring 2008 and then coarsened again after Tropical Storm Fay with the influx of mineral sand (Table 3-3). The smaller spring event appears to have mostly redistributed organic material. Whereas, the larger fall event moved considerable mineral sediment near the channel and simultaneously deposited large amounts (greater than the spring flood) of organic material in areas away from the channel. About 25% of all sediment trapped on the Kissimmee River floodplain is organic (Table 3-2).

Phosphorus concentration at select floodplain sites

Total phosphorus was measured using an inductively coupled plasma optical emission spectrometer (ICP-OES) for selected samples from the Kissimmee River floodplain. Floodplains may act as an effective sink for several pollutants; one of the best studied is the nutrient phosphorus, which is a major contributor to eutrophication in South Florida. Sediment concentrations of total phosphorus in the Kissimmee River floodplain indicate that the system has some of the highest phosphorus concentrations of studied floodplains in the southeast US (Greg Noe, USGS Reston, VA, personal communication). Phosphorus concentrations increase linearly with organic content, making the sloughs and depressions the greatest sinks for phosphorus (Table 3-4). At this point, additional discussion on nutrients is limited and beyond the scope of the present effort. Nutrients are, however, a primary concern downstream where the eutrophic Lake Okeechobee receives these potentially high phosphorus loads.

Future research

Floodplain sedimentation studies are relatively rare yet very important for determining restoration success, pollution abatement, and for understanding wetland biogeochemical processes, biodiversity, and ecosystem service/function. Continued floodplain monitoring in the Kissimmee Basin could include a greater monitoring effort in Pool D to capture the sediment and landscape dynamics as the reach is restored. Continued monitoring of pre-existing transects would also be useful; during the two year study we measured deposition after only two events. Further monitoring will allow us to determine sedimentation rates for a variety of flood scenarios and will allow us to determine whether the results we have presented are typical for this system. This added information may help managers better assess the time scale needed to determine the successful restoration of adjacent wetlands and will greatly increase the body of knowledge in wetland restoration, especially hydroperiod and hydrological connectivity fields of restoration. Basic research with broad applicability would include direct measurement and analyses of flow velocities and suspended sediment concentration over monitoring areas (claypads) along existing/new transects; particular landforms or vegetation types could be identified that best facilitate floodplain trapping and storage of sediment and contaminants.

Measuring landscape subsidence would also be rewarding as a method to compare gross deposition (using clay pads) with soil loss through soil oxidation and compaction. This coupled subsidence-deposition method has been used successfully in other wetland systems and could be especially important for Pool D pre and post-restoration for determining not only changes in landscape but also for quantifying the amount of carbon sequestered or released at a landscape scale.

Our two year study failed to capture a wildfire event and was not intended to analyze the effects of bioturbation (feral hogs and alligator wallows). Both occurrences could have significant impacts on sediment organic content, sediment texture, measured deposition rates, and overbank flow patterns. Although it has yet to substantially affect most of our sedimentation estimates, bioturbation occurs commonly on the floodplain. A wildfire has yet to occur on the floodplain but is a relatively common event in Southern Florida.

Table 3-1. Change in sediment organic content at initial sampling (Feb. 2007) and after the two floods.

	Organic content in percent		
Site	Feb-2007	Feb-2008	May-2009
1.1	11.6	17.4	11.6
1.2		30.0	17.3
1.4		35.9	41.0
1.5	4.3	8.9	36.7
1.6		35.5	12.6
1.7	11.7	37.5	48.2
2.1	15.7	71.5	51.8
2.2	10.3	48.7	51.3
2.3	7.7	80.5	3.1
7.3	1.3		5.8
7.5	3.2		19.0
16.1		22.0	15.7
16.2		12.9	24.4
16.3		34.3	36.2
16.4		20.2	18.1
Mean	**8.2**	**35.0**	**26.2**

Table 3-2. Floodplain area by landscape type, median sedimentation rate separated by area, gross rate, percent organic, and approximate mass per year.

	Sedimentation rate and characteristics								
Landscape type	Area m^2	Rate mm/yr	Percent organic	Density g/cm3	Total mass g/m2*yr		Total mass Mg/yr	Mineral Mg/yr	Organic Mg/yr
Borrow	4,341,000	5.0	22.7	0.53	2,659		11,545	8,920	2,624
Backfill	1,007,000	6.9	5.7	0.85	5,873		5,914	5,580	334
Floodplain	23,559,000	7.2	27.2	0.45	3,285		77,394	56,336	21,058
Open water	320,000					Sum:	**94,853**	**70,836**	**24,017**

Table 3-3. Changes in sediment texture with time on the Kissimmee River floodplain. The Kroes Index is an indicator of sediment size, a value of 1 indicates that 100% of the sediment is less than 63 microns (100% silt/clay), a value of 2 indicates that the sediment is dominated by sizes around 125 microns (very fine sand) with values approaching 3 indicating that the sample is dominated by more fine sands (250 microns).

Site	**Kroes Index Feb-2007**	**Feb-2008**	**May-2009**
1.1	2.2		2.2
1.2		1.4	2.1
1.4		1.1	2.1
1.5	2.0	1.4	1.5
1.6		1.3	2.3
1.7	1.7	1.1	1.9
2.1	2.2	1.1	1.4
2.2	2.5	1.1	1.9
2.3	1.9	1.1	2.3
7.3	2.8		2.6
7.5	2.4		2.2
10.5	1.7		1.7
10.8	2.3		1.7
16.1		2.0	1.8
16.2		2.0	2.1
16.3		2.1	2.2
16.4		1.7	2.6
Mean	**2.2**	**1.4**	**2.0**

Table 3-4. Total phosphorus (TP) and percent soil organic material (SOM) at selected Kissimmee River floodplain sites determined by Greg Noe, USGS Reston, VA in March 2008.

Site	SOM	TP (mg/g)
8.2	4.8	0.5
8.3	12.8	1.3
8.4	30.9	1.5
8.5 rep1	14.3	1.6
8.5 rep2	20.2	1.6
8.5 mean	17.3	1.6
8.6	12.0	1.2
10.2-3	27.2	1.2
10.3	30.3	1.3
10.4	3.8	0.1
10.6	46.4	2.3
10.6	52.9	2.8

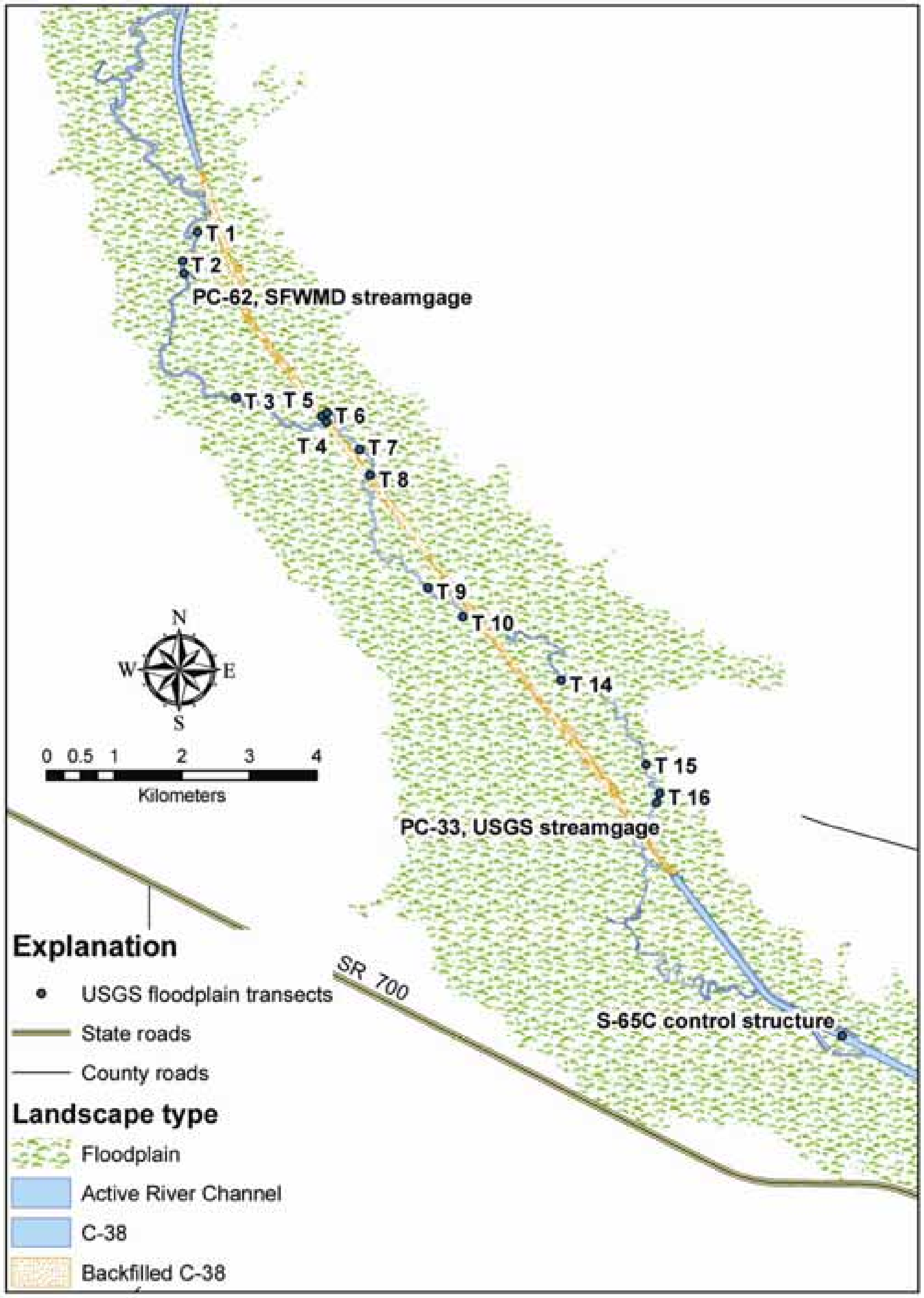

Figure 3-1a. Restored Kissimmee River study area with floodplain transects and pertinent river structures labeled.

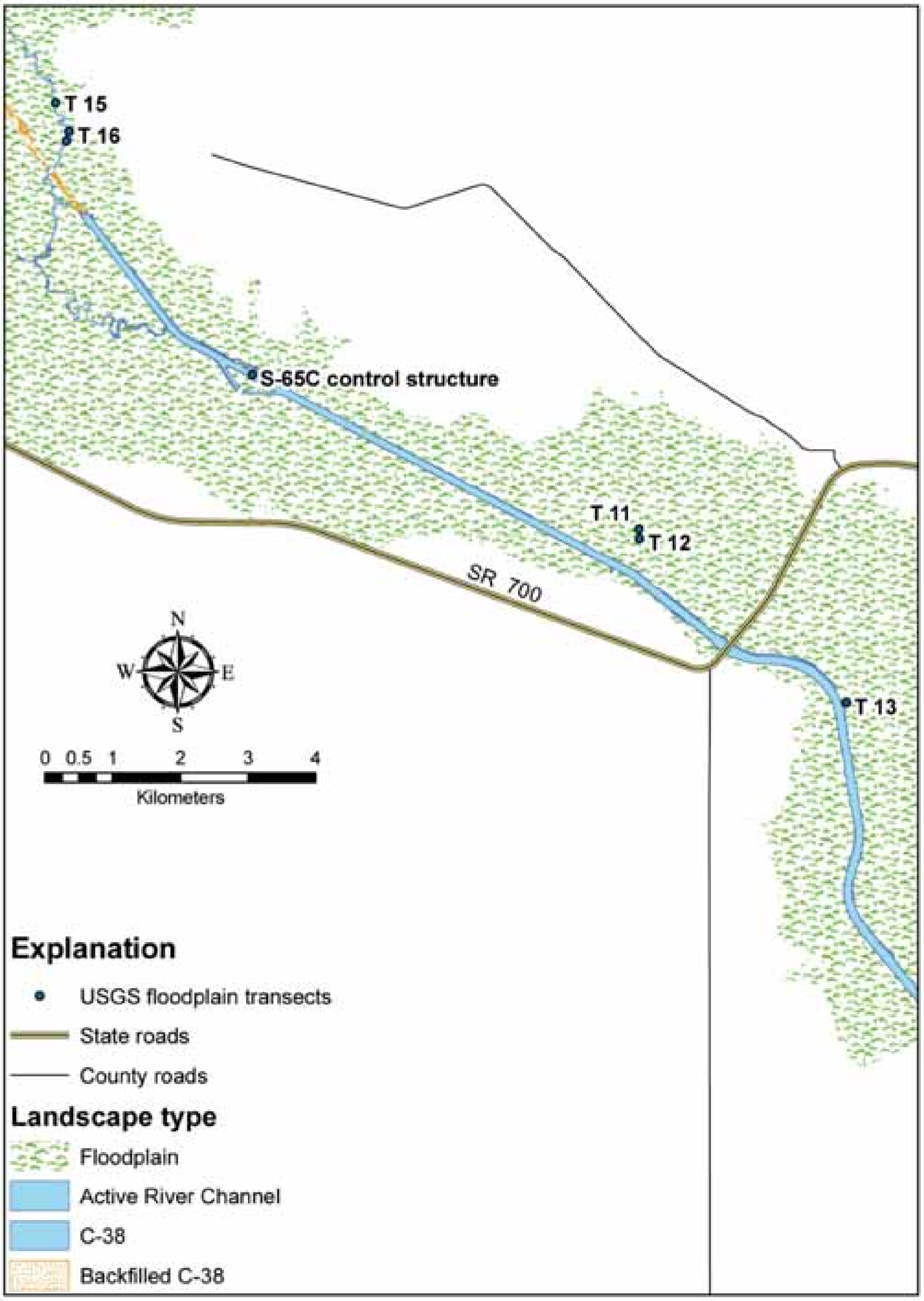

Figure 3-1b. Unrestored Kissimmee River study area with floodplain transects and pertinent river structures labeled.

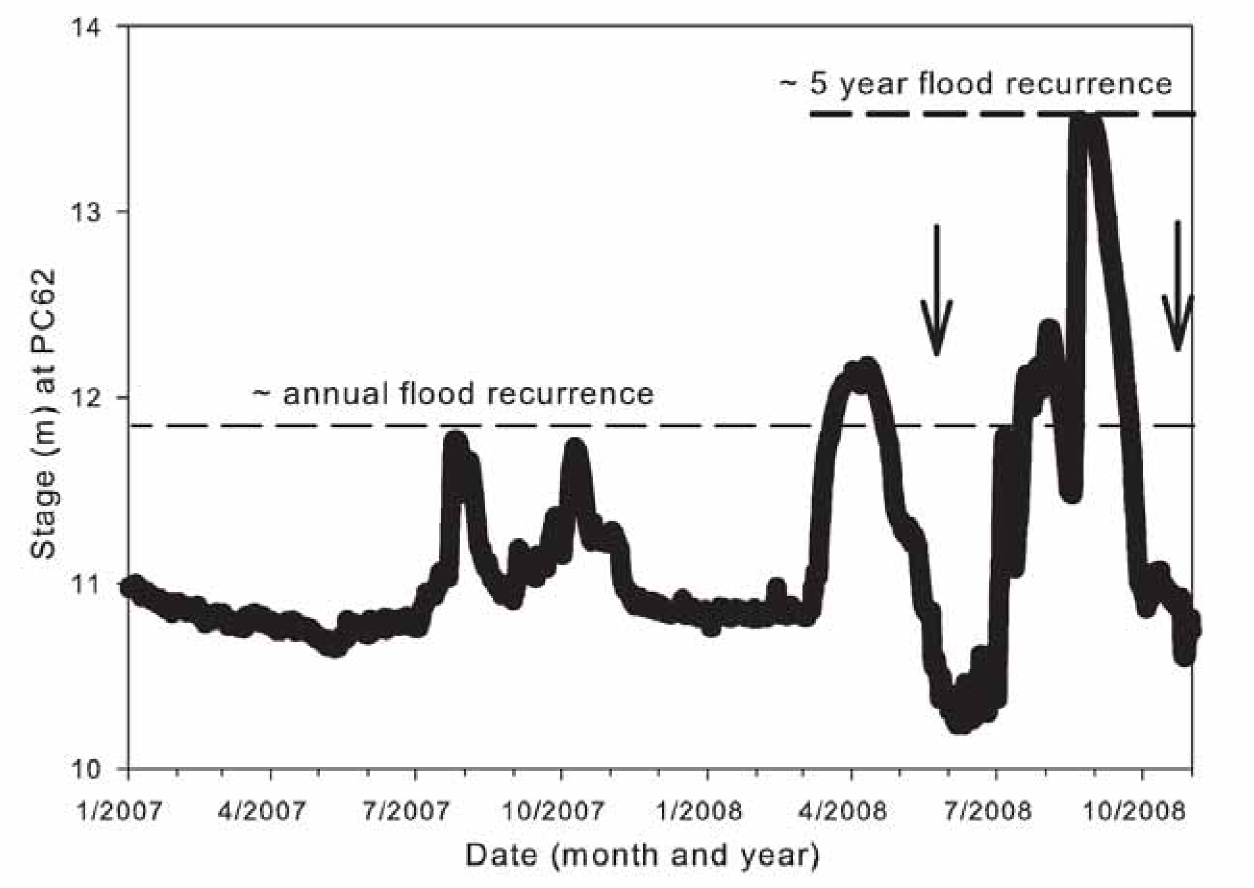

Figure 3-2. Mean daily flow measured at the PC 62 streamgage near the old Pool B/C control structure. Arrows denoted our sediment measurement dates. The approximate annual and 5 year flood recurrence is also noted (from Leroy Pearman, USGS Orlando, personal communication).

Figure 3-3. Typical feldspar clay pad with associated sediment horizon pins and fenced exclosure. Exclosures were used only in Pool D to prevent disturbance form cows or other grazers. Photo credit: Edward Schenk, USGS.

May

December

Figure 3-4. Levee deposition measured in May 2009 after the spring flood and measured again in December 2008 after Tropical Storm Fay. The white layer is cored feldspar clay pad. Note the difference in sediment texture from the two distinct floods. The spring flood deposit is mostly organic and fine material while the flood deposit is mostly fine sand. Photo credit: Edward Schenk, USGS.

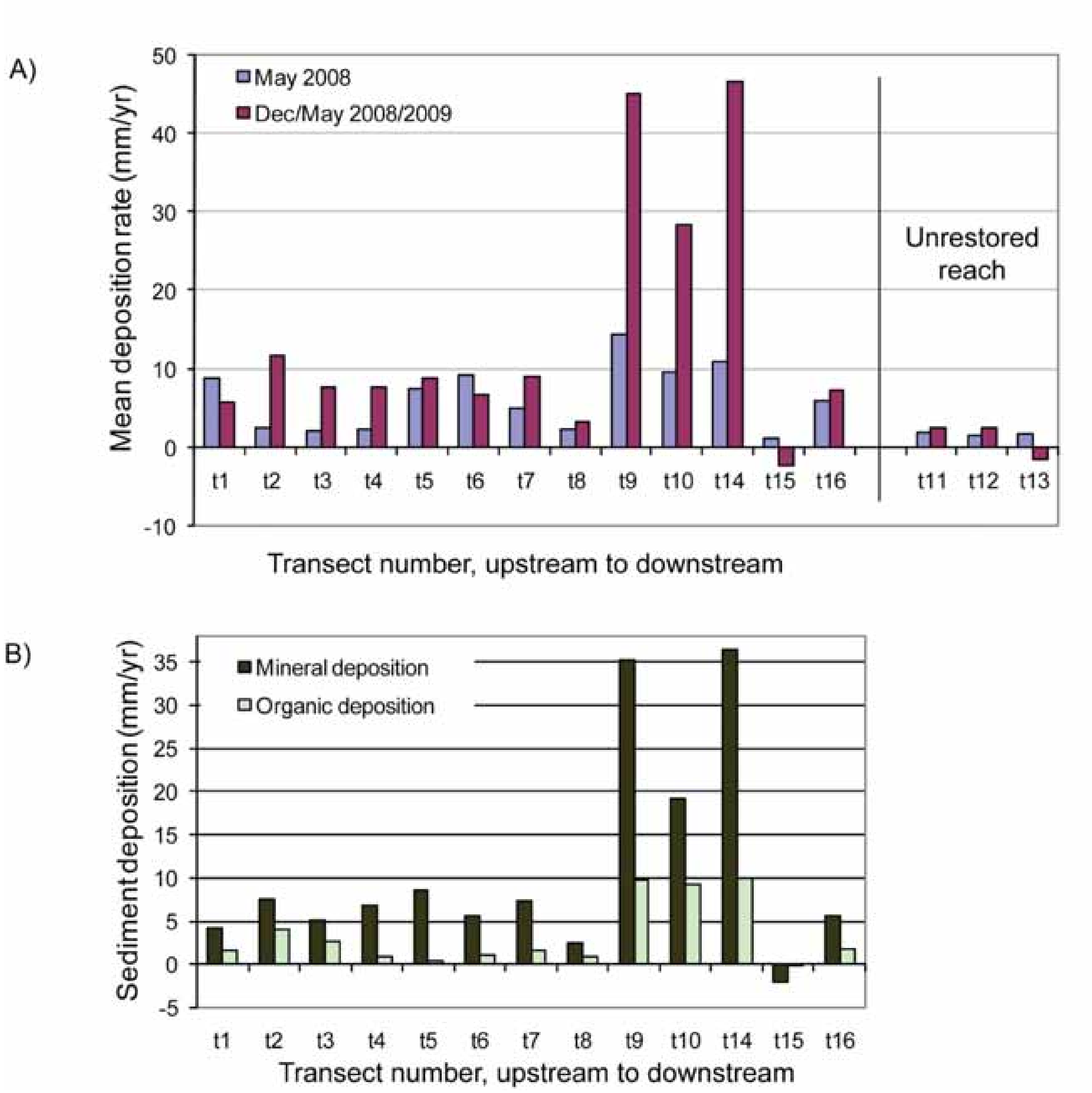

Figure 3-5. A) Mean sedimentation by transect from upstream to downstream determined for the spring flood and for the entire study period. The difference in deposition rates includes the impact of Tropical Storm Fay. B) Mean mineral and organic sedimentation by transect from upstream to downstream.

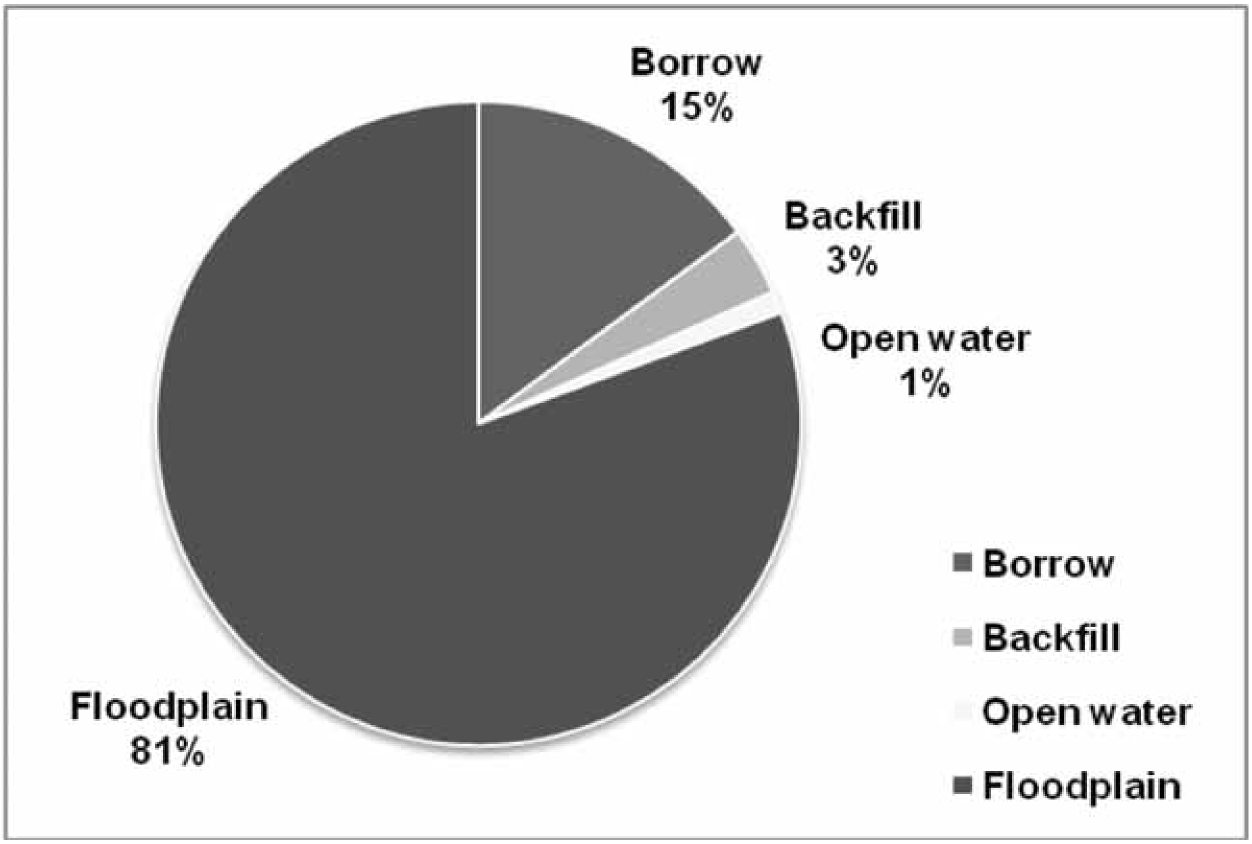

Figure 3-6. Percent floodplain types by area between transect 1 and transect 16 from near the bottom of old Pool B to near the bottom of old Pool C. Original floodplain dominates with large areas of borrow for the backfilled C-38 canal.

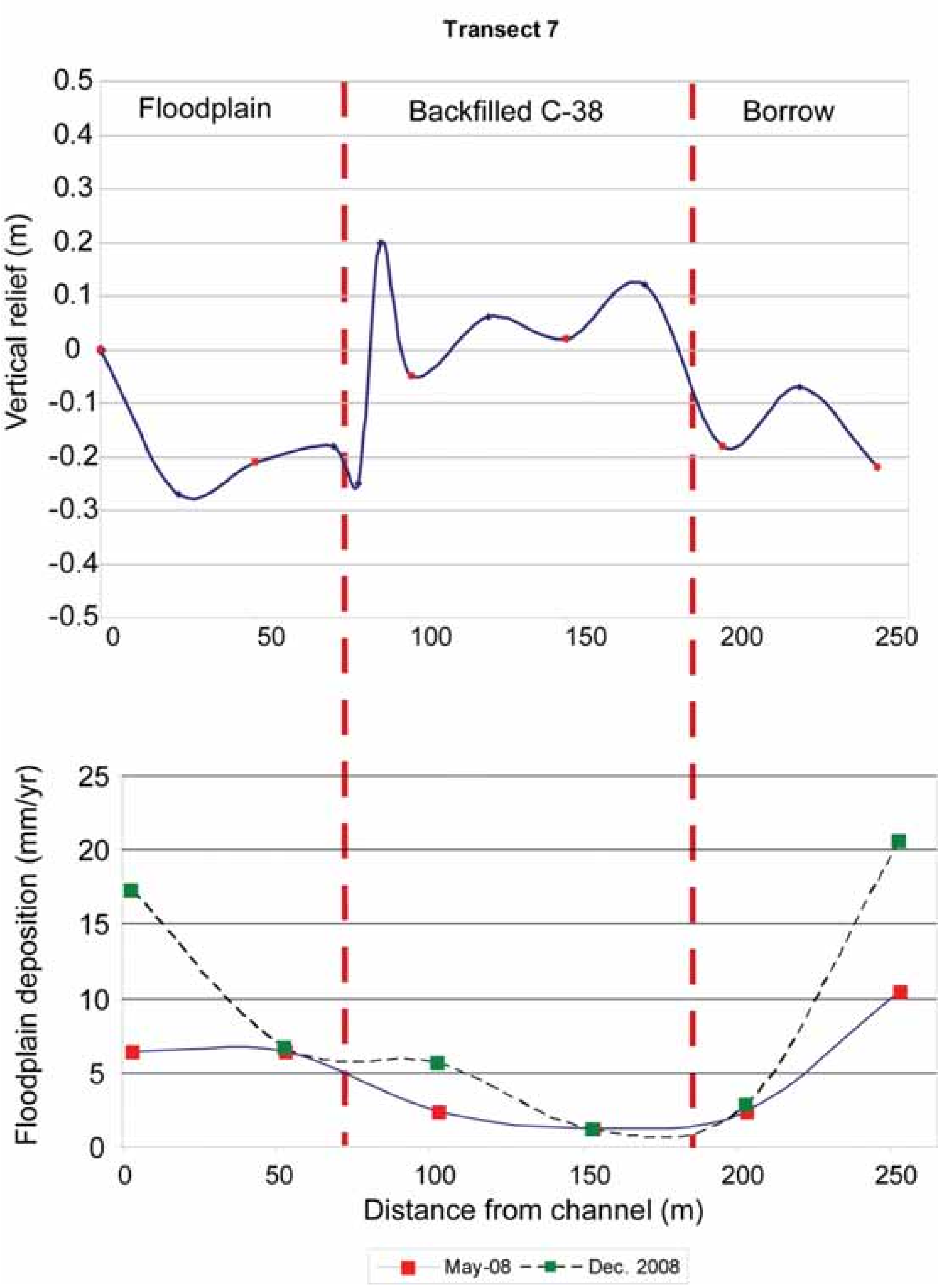

Figure 3-7. A) Microtopography differences among 3 landscape types on the Kissimmee River floodplain. Red points on the lines indicate clay pad locations within the site. B) Floodplain sediment deposition rates at the same site. Higher sedimentation occurs near the channel and in the natural floodplain and borrow landscape types and the lowest deposition occurs in the high elevation areas of the backfilled C-38 canal.

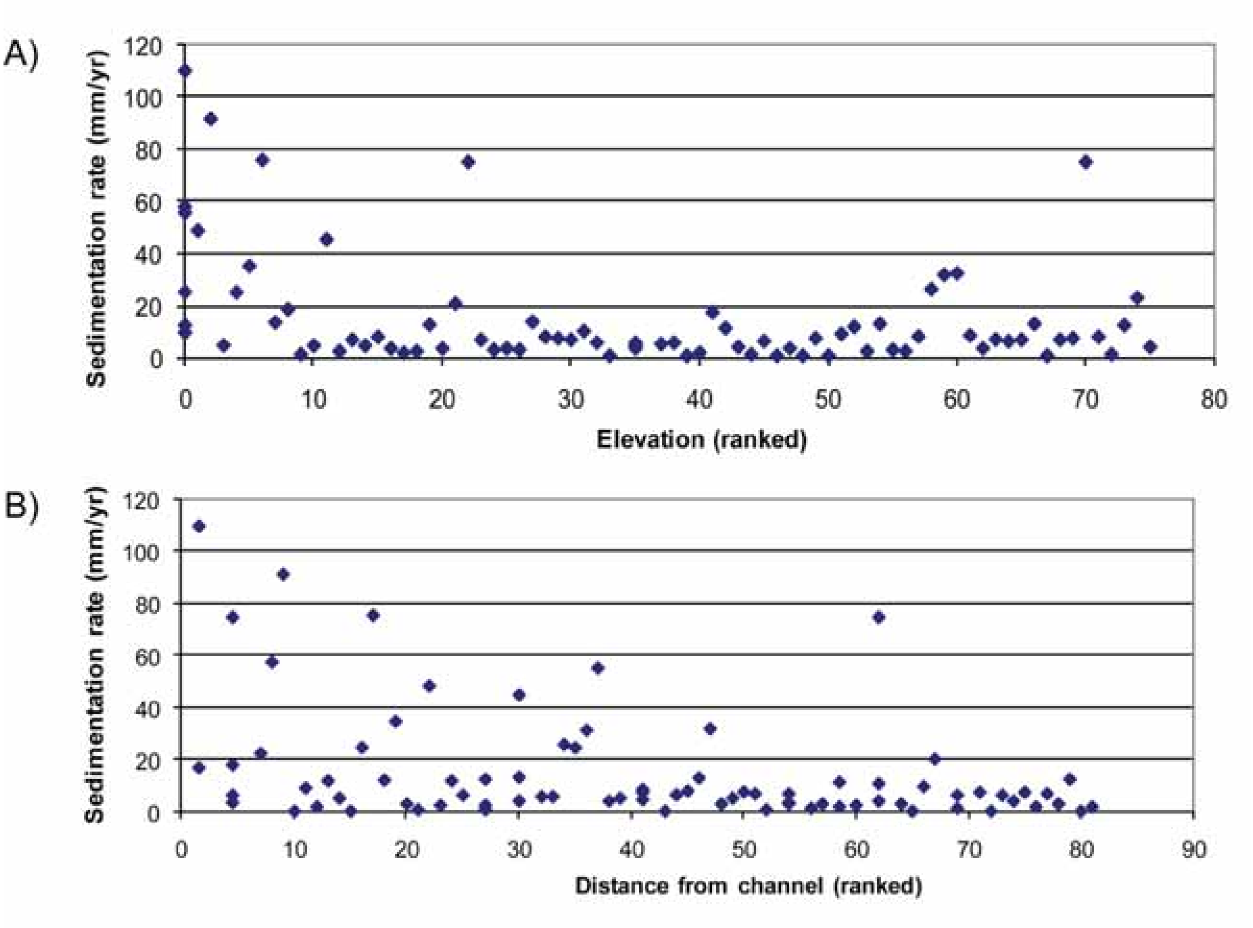

Figure 3-8. Sediment deposition (mineral + organic) by A) elevation above an arbitrary river stage transformed by rank (lower rank equals lower claypad on the landscape) and B) by distance from main channel also transformed by rank. In general the sites with the highest deposition were lowest on the landscape and/or closest to the main channel.

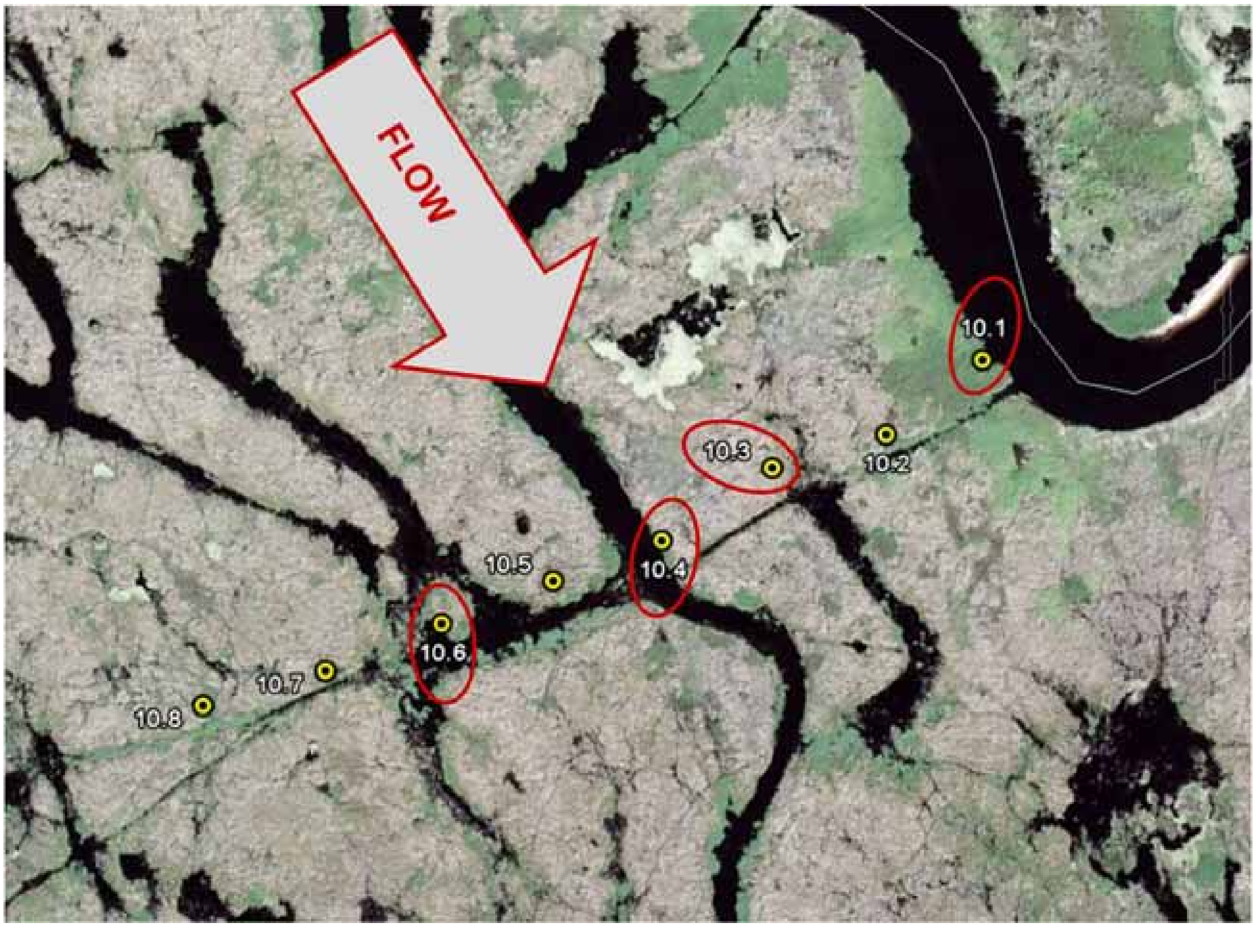

Figure 3-9. Side channels and sloughs at transect 10, main channel is adjacent to transect 10 pad 1 (10.1 on figure). Observed high deposition areas are outlined in red. All four high deposition sites are adjacent to a high flow route during flooding. The deposition results are in the following figure.

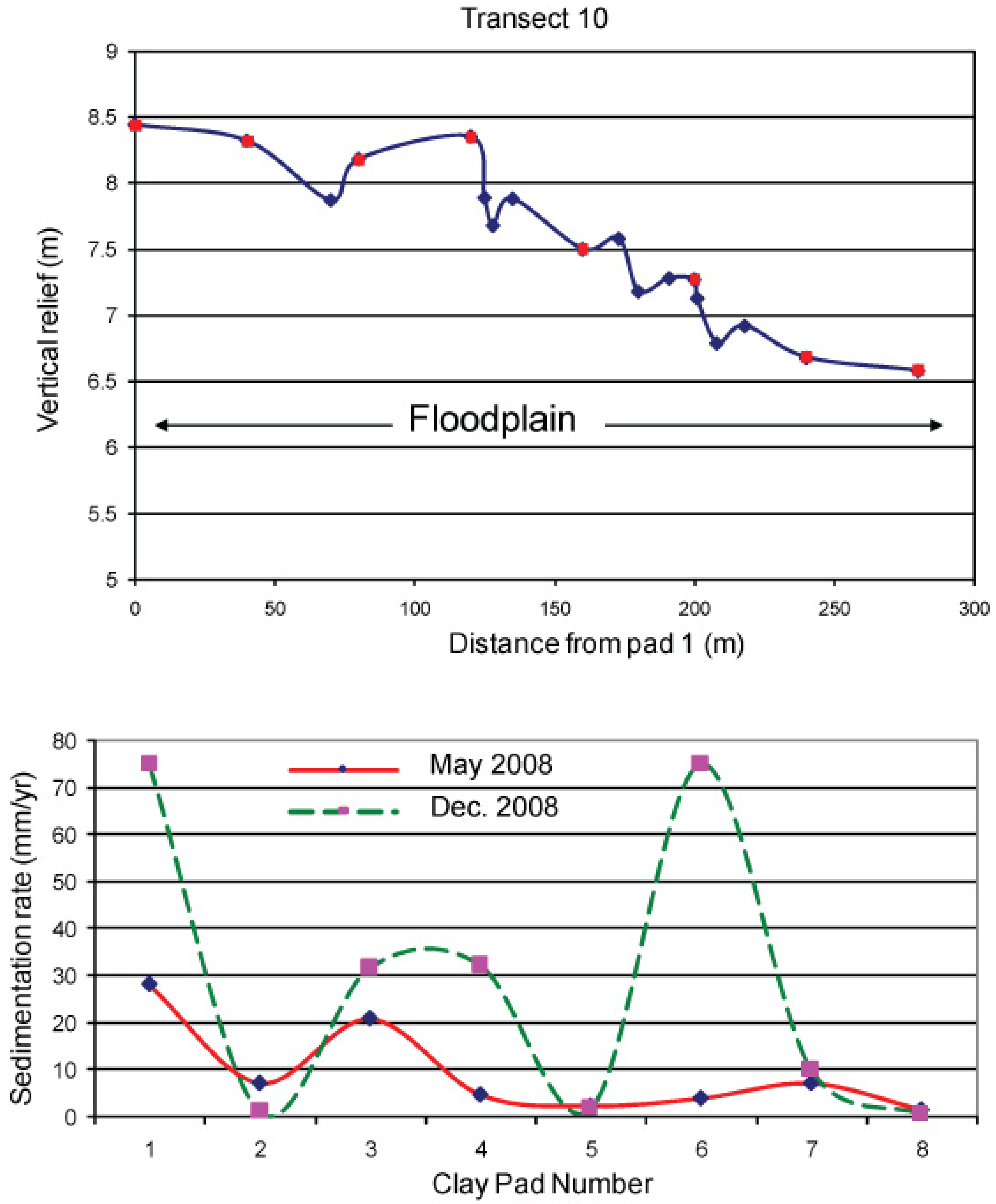

Figure 3-10. A) Microtopography of transect 10 starting at pad 1 adjacent to the main channel and moving out across the floodplain. Red circles indicate clay pads on figure A) and figure B) only includes claypad sites. B) Sediment deposition rates at transect 10 after the two floods.

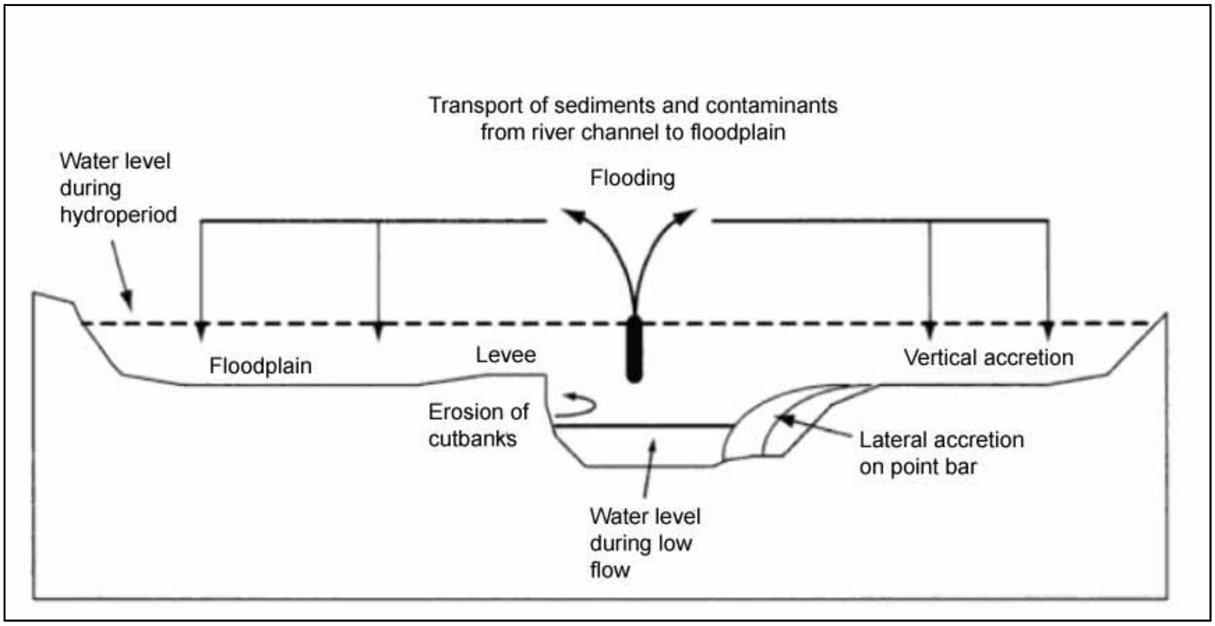

Figure 3-11. Typical geomorphic cross-section and sediment processes for an alluvial river (from Hupp 2000).

Figure 3-12. A sand splay 26 cm deep (levee building event), measured in December, 2008 between transect 3 and transects 4, 5, and 6. Photo credit: Edward Schenk, USGS.

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CHAPTER 4

CHANNEL CROSS SECTION MONITORING

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Introduction

Channel stability and sedimentation monitoring are presented in the IFR/EIS (Integrated Feasibility Report/Environmental Impact Statement) as integral programs in the Kissimmee River Restoration Program (KRRP). The objectives of channel monitoring are 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. A total of 20 transects were placed along the river and surveyed in early 2007, the first year of the project (Figure 4-1). The same transects were surveyed annually over the next two years to evaluate their stability and one additional transect was placed in 2009. Additionally, they serve as a baseline and can be resurveyed at a future date after key events (major floods, destruction of S65-C, restoration in Pool D, etc.). Cross sections in unrestored portions of the river were used as control stations for comparative purposes.

The three major types of river reaches that occur in the restored portion of the river are as follows: 1) remnant channels, which are former channels that were essentially left intact during channelization; 2) recarved channels, which were artificially excavated to to approximate the geometry of former channels buried by spoil during channelization; and 3) connector channels, which are short segments of channel that go across backfilled portions of C-38 and are in approximately the same position as former channels (Figure 4-2). The connector channels appear wider than either the remnant or recarved channels, and were designed that way to reduce velocities and minimize potential erosion to the backfilled areas (Figure 4-3).

Within each of these types of reaches there are also variations. Both remnant channels and recarved channels may show differences between bendways and straight reaches. Generally, bendways show an asymmetric form and straight reaches are typically more symmetric. The connector reaches are straight, and it is unknown how much variation occurs in this group. The major questions are thus: 1) how do the cross sections differ in geometry between the three groups (remnant, recarved, connector)?; 2) how do the cross sections differ within the three groups (straight vs. bendway in both remnant and recarved channels, transects in different connectors)?; and 3) which cross sections changed the most over time?

Methods

Cross sections were established with emplaced monuments for annual surveying in each of these three types of river reaches to examine how they differ in form and how they might change in form over time (Figure 4-1, Table 4-1). Four transects were placed in a run in Pool A for comparative purposes, allowing for eventual assessments in the BACI (before-after-control-impact) design (Stewart-Oaten et al, 1986; Smith, 2001). Of the runs in Pool A, Persimmon Mound Run was chosen because of its length (portions were distant from C-38) and width, which allowed access by motorboat. In Pool B/C, Montesdeoca Run is a remnant run. Four transects were selected for sampling, two on bendways and two on straight reaches. Montsdeoca South is a straight connector run in Pool B/C that crosses backfilled C-38, just south of Montsdeoca Run. Two transects were selected for sampling in this short reach. Fulford Run is a recarved run in Pool B/C. Four transects were selected for sampling, two on bendways and two on straight reaches. Fulford South is a straight connector run in Pool B/C that crosses backfilled C-38, just south of Fulford Run. Two transects were selected for sampling in this short reach. In addition, transects were also surveyed in two runs in Pool D, Caracara Run and Chandler Run. The land uses in each were very different, with Caracara Run largely used for cattle ranching and Chandler Run densely forested. One additional transect was placed in 2009 in Ft. Basinger Run, a very short run that is forested on the east side and has some development on the west side.

Field work was conducted in January or February of each year (2007: Feb 18 to March 2; 2008: Jan 22–25 and Feb 11-15; 2009: Jan 11-16 and 25-30). Water levels in all three years at this time were relatively low (35-36 ft stage at Lorida) (Figure 4-4). The highest water levels during the study period occurred in August 2008, in the aftermath of Tropical Storm Fay. Stages were in excess of 45 ft (Figure 4-4) and covered large portions of the floodplain. Comparable water levels had been reached in 2003, 2004 and 2005, but had otherwise not occurred since 1993.

General locations of transects were selected a priori. The specific locations of transects were selected in the field, including access considerations such as riparian cover and bank steepness. Transect sites were marked with two metal stakes painted orange and blue to allow repeat surveying of the same locations, and stake locations were recorded with a Trimble XPS GPS. A line was placed across the channel with one person surveying and the other in a boat (motorboat, inflatable or Kevlar kayak). Surveying was conducted with a Sokia 30X auto level and an expanding survey rod (Figure 4-5). Each transect was surveyed with a level with a minimum of 20 points collected along the profile, including all major geomorphic breaks. Horizontal bank erosion pins and vertical erosion/deposition pins were also placed on each bank to measure localized changes at future visits.

The survey data were input in spreadsheets. Elevations along transects were transformed according to the difference from the base of the stake on the left bank. Distance was also expressed relative to the stake on the left bank. Wetted width was computed as the distance from the left to the right edge of water. Cross sectional area was computed as the sum of all trapezoids measured (width between successive distance points multiplied by the mean of the depths at those distance points). Mean depth was computed as the area divided by the width. Wetted width-depth ratios were computed by dividing width by mean depth. Because the surveys extend to the stakes, these measurements can be adjusted to another level that is not dependent on water depth (e.g. approximate bankfull or other consistent datum, such as level of lowest stake) to measure changes in geometry over time.

Bank erosion pins were installed along monumented and surveyed transects in 2007 and 2008 in pool A, pool B/C and pool D. The erosion pins were on average 2 mm thick and 43 cm long made of metal. The diameter and length of pin was chosen to prevent disturbance of the river bank and to prevent stabilization of the bank by the pins (Lawler 1993). Each pin was inserted into the bank leaving approximately 3 cm exposed. The exposed portions of the pins were painted orange. Both horizontal and vertical pins were placed and relative distance to the monument and top of bank was recorded for each pin installed. The amount of erosion and deposition was recorded annually in 2008 and 2009 when each transect was resurveyed. Depth of deposition and amount erosion was measured with a rigid ruler. If loose pins were found a value of -43 cm was assigned (Harden et a. 2009). Transects were surveyed annually and a metal detector was used to find the pins at that time.

Results

Transect locations and plots of all 21 transects measured are shown in order from upstream to downstream (Figures 4-6 - 4-25). Remnant and recarved transects were fairly similar in geometry, and transects in bendways and straight reaches only differed slightly. The connector transects were very different than all the other transects in three ways. First, they were much wider on average, about 100 m, in contrast with 30m for the other types (Figures 4-13, 4-19 and 4-26). Second, connectors were shallower than the remnant and recarved reaches (Figures 4-13, 4-19 and 4-26). All four transects surveyed across the connector channels showed the development of either an island or submerged bar (Figures 4-13, 4-19 and 4-26). At low flow, the bar in both the Montsdeoca south connector and Fulford south connectors were subaerial, visible in the field, and consisted dominantly of sand (Figure 4-14). None of the other 17 transects surveyed showed a bar in the middle of the channel (Figures 4-7, 4-8, 4-10, 4-11, 4-16, 4-17, 4-21, 4-23 and 4-25).

Bendways and straight reaches were not notably different in their width-depth ratios in the initial year of monitoring (Figure 4-27). On average, bendways are deeper and narrower, although the range from minimum to maximum for both width and depth largely overlaps for these two types of channels.

Examining each of the locations, some appeared to change more than others from 2007 to 2009. The four transects in Pool A in Persimmon Mound Run (Figures 4-7 and 4-8) appeared to decrease in area or channel capacity, particularly during 2009, the most recent year of monitoring. It was not expected that there would be change because Persimmon Mound Run is not being restored and has no flow, but such changes could be influenced by vegetative factors or ranching activities, which occur along the reach. The trend of change is as expected, with the channel bottom filling somewhat, perhaps partly due to organics. In Pool B/C, where restoration has begun, the straight remnants in Montsdeoca Run had minimal changes over the study period. Cross section 1 appears slightly deeper and cross section 4 shows a minimal amount of bank erosion (Figure 4-10). The two cross sections in Montsdeoca Run bendways showed very different changes (Figure 4-11); cross section 2 migrated slightly but cross section 3 showed a fairly dramatic increase in channel capacity, mostly due to widening or bank erosion at 0 to 4 m below the monument. It is not apparent why these would have such a different response. The

Montsdeoca South connector in Pool B/C also shows marked changes, particularly during 2009, the most recent year of monitoring (Figure 4-13). In cross section 1, the bar is becoming wider by about 5-10 m on each side, limiting navigation to a small section. In cross section 2, the bar experienced about 50 cm of sedimentation across nearly 50 m of width. It is unknown what the source of the sediment is, but certainly some of it could have come from upstream erosion of areas such as cross section 3 in Montsdeoca Run (Figure 4-11). Also in Pool B/C, Fulford Run transects in straight reaches show some migration, but no pronounced change in channel capacity (Figure 4-16). Fulford Run transects in bendways again have different responses; cross section 2 seemed to increase markedly (>10%) in channel capacity in 2009, whereas cross section 3 was fairly stable (Figure 4-17). Downstream of Fulford Run is the Fulford South connector. The bar here is only growing slightly (Figure 4-19), less so than the Montsdeoca connector, but now emergent during low water like the Montsdeoca connector. Cross section 1 seems to have enlarged in 2009. The timing of the widening could be partly due to the effects of Tropical Storm Fay in August 2008. In Pool D, there is no restoration and thus no flow at this point in time. As expected, Caracara Run transects were rather stable (Figure 4-21). The Ft. Basinger transect was established in 2009 (Figure 4-23), although it is likely stable as well. Chandler Run is heavily vegetated and the most difficult of the sites to survey. Both transects also are fairly stable over the study period (Figure 4-25).

Analysis of the erosion pins was hampered in pool A with vegetation and higher water in 2008 and 2009. Pins were found in 2008 in Persimmon Mound Run at all transects (Table 4-2), with only one pin along each of transects PM01 and PM03 having deposition of 3cm and 7 cm, respectively, though this may be due to an increase in water level and organic cover.

Pool B/C was an active channel with many areas where erosion pins were placed close to the bank edge slumping into the river. In Montsdeoca Run starting with transect MN02 the left bank had large deposits covering the erosion pins in 2008 and 2009 (Table 4-3), but no pins were found on the right bank. MN03 had areas that had slump on the right bank, but no pins were found on the left bank. No pins were found either year for MN04 transect. Montsdeoca South connector (Table 4-4) showed significant areas where slumping occurred on the right bank in both years, while the left bank in 2008 showed little change with minimal erosion. Fulford Run transects (Table 4-5) showed significant slumping of bank material on transect FF01 and the left bank of FF02 and FF03. FF04 transect had minimal change in 2008, but pins were not found in 2009. The Fulford South connector (Table 4-6) showed little change in 2008 except for one pin found in slump on transect FS01 left bank. In 2009 FS01 left bank pins were not recovered and showed some erosion on the right bank. FS02 transect left bank show significant areas of deposition, but a pin found in water did have significant erosion while the right bank showed minimal deposition.

Caracara Run erosion pins (Table 4-7) showed no significant change for either 2008 or 2009. This area is heavily impacted by cattle and a few pins were found loose, most likely dislodged by cattle moving along the paths where the erosions pins were placed. Erosion pins placed in Chandler Run (Table 4-7) showed minimal change with the largest being in 2008 along CH02 left bank. This deposition was most likely caused by organics due to the higher water levels.

CH01 show some deposition for one pin located on the right bank in both years and minimal erosion in 2009 on one pin on the left bank.

Discussion and Conclusions

Very few restoration efforts of this scale have taken place in channelized rivers. From a geomorphic perspective, there is not an appreciable difference between the channel geometry of transects taken in different reaches, with the exception of the connector channels. These were built wider than the other types of channels, with the intent of protecting backfilled C-38, by having greater channel capacity which in turn would mean less velocity and erosion along the potentially vulnerable sides. However, due to the lower velocities associated with larger cross-sectional areas, some sediment had deposited in the middle of both connectors, forming bars have become vegetated islands. None of the other 17 transects at straight reaches or bendways show development of mid-channel bars. Also, mid-channel bars were not evident elsewhere in the field or from interpreting the Digital Ortho Quarter Quads throughout the restored portion of the river.

The biggest changes overall were noted during sampling in 2009. Many of these changes were likely due to Tropical Storm Fay, the largest flood in over 3 years prior (Figure 4-4). Fay made landfall in August 2008 and produced large amounts of rainfall, over 10” in large portions of Florida and up to 25” in localized areas (http://www.hpc.ncep.noaa.gov/tropical/rain/fay2008filledrainblk.gif) . Some sections of the river changed more than others, and the biggest changes overall occurred with the bar in the Montsdeoca South connector.

The erosion pin analysis identified areas of the river channel where erosion and deposition was occurring. But because these changes were significant during high water events 30 of the 75 pins (40%) placed in 2008 were not found in 2009. Erosion pin analysis did not show any significant change in either of the unrestored pools (Pool A & D). To understand what is occurring after significant events, a shorter temporal field return would be required. A return period of less than one year is typical in an actively changing channel (Lawler 1993).

Ecosystem restoration in south Florida, including the Kissimmee River and the Everglades, increasingly recognizes the value of thinking adaptively for ecosystem management. Adaptive management allows for changes in natural resource management policies and actions based on the combination of new scientific and socio-economic information (Holling 1978; Lee 1999). Preliminary results suggest that the restoration to-date is creating ecological improvements (Colangelo, 2007) and is likely to meet a number of the criteria for ecological success or restoration expectations, but judging geomorphologic success has different challenges. Palmer and others (2005) suggested some guidelines to evaluate ecologically successful river restoration. One criteria stated that the guiding image should take into account not only the average condition or some fixed value of key system variables (including geomorphology) but should also consider the range of these variables and the likelihood they will not be static. By engineering this portion of the channel much larger than its natural geomorphic range, it seems that connector reaches have not been stable so far (it was not built or designed with the bar initially) and will likely continue to experience more deposition and bar growth over time until its channel capacity is more like the other reaches. Continued monitoring of these connectors will confirm how the bars change in size and the rates of change. Establishing additional transects in different connectors soon after other portions of the river are restored will help document whether these reaches continue to be sites of bar development or whether adaptive management can result in improved engineering of these vulnerable portions of the channel.

Recommendations for Restoration

1) Inform the Corps of Engineers about findings of the geometry and bar development in the connectors. Although the connectors are not causing problems, their appearance is strongly anthropogenic rather than natural. While it may not affect the integrity of the restoration of the river beyond the reach scale, it may affect the perception of the restoration project in that it does not resemble a natural channel or its historical predecessor. They could likely be built smaller, perhaps 20-50% wider than other reaches rather than in excess of 100%.

2) Similarly, the connectors appear strongly anthropogenic in terms of the angles of crossings and straightness in planform geometry. The angles of crossings across backfilled C-38 could be modified and designed to more closely resemble a natural river. It is unknown whether this would affect the function of the river beyond the reach scale, but it probably does not have a major ecological impact. However because it appears artificial from space for individuals who examine this area using Google Earth software (http://earth.google.com/), it may also have an effect on the perception of the restoration effort.

Recommendations for Improved Monitoring

1) Inform the University of Florida staff about progress of the restoration phases currently underway, specifically when each new connector is completed. It may be beneficial to monitor new connectors soon after they are constructed to measure the sequence of bar and island development, whether the connectors are made smaller or not. It also will be beneficial to monitor other types of reaches soon after the restoration rather than up to 5 years post-construction as done in this project. If new transects are established as the project continues, some of these should capture the early stages post-restoration.

2) Focus more detailed efforts in the future on the nature of bank erosion and the role of various processes in sediment contribution. Create a spatially extensive set of markers for monitoring bank erosion, and visit those multiple times a year, particularly before and after overbank flooding. Bank erosion processes should be investigated more fully around connectors in restored reaches. In particular, Montsdeoca Run showed some widening and Montsdeoca South connector showed notable changes in bar size, possibly due to Tropical Storm Fay. In reaches that are not yet restored, it would be worthwhile to investigate the role of animals and possibly other factors on bank erosion processes. Some investigation could also be done from a submarine perspective, perhaps by

recording channel bottoms with a GPS-sonar type of unit. A targeted investigation of bank erosion on the river with a more comprehensive field monitoring program could be a topic for a Masters thesis in the near future.

Acknowledgments and Disclaimers

The opinions and interpretations expressed herein, and any errors that may be present, are of the authors and not that of the South Florida Water Management District. However, credit is due to many Kissimmee River restoration personnel who contributed in various ways. José Valdes was the project manager for this study, provided scientific suggestions and arranged logistical support. District personnel including Amber Graham and Brent Anderson assisted with boat transport and field work. Lawrence Spencer assisted with GPS logistics. Bonnie Rose provided imagery. David H. Anderson and David J. Colangelo reviewed and improved an earlier version of this report. University of Florida Geography graduates Jeff Cooley and Michael Suharmadji assisted with field work.

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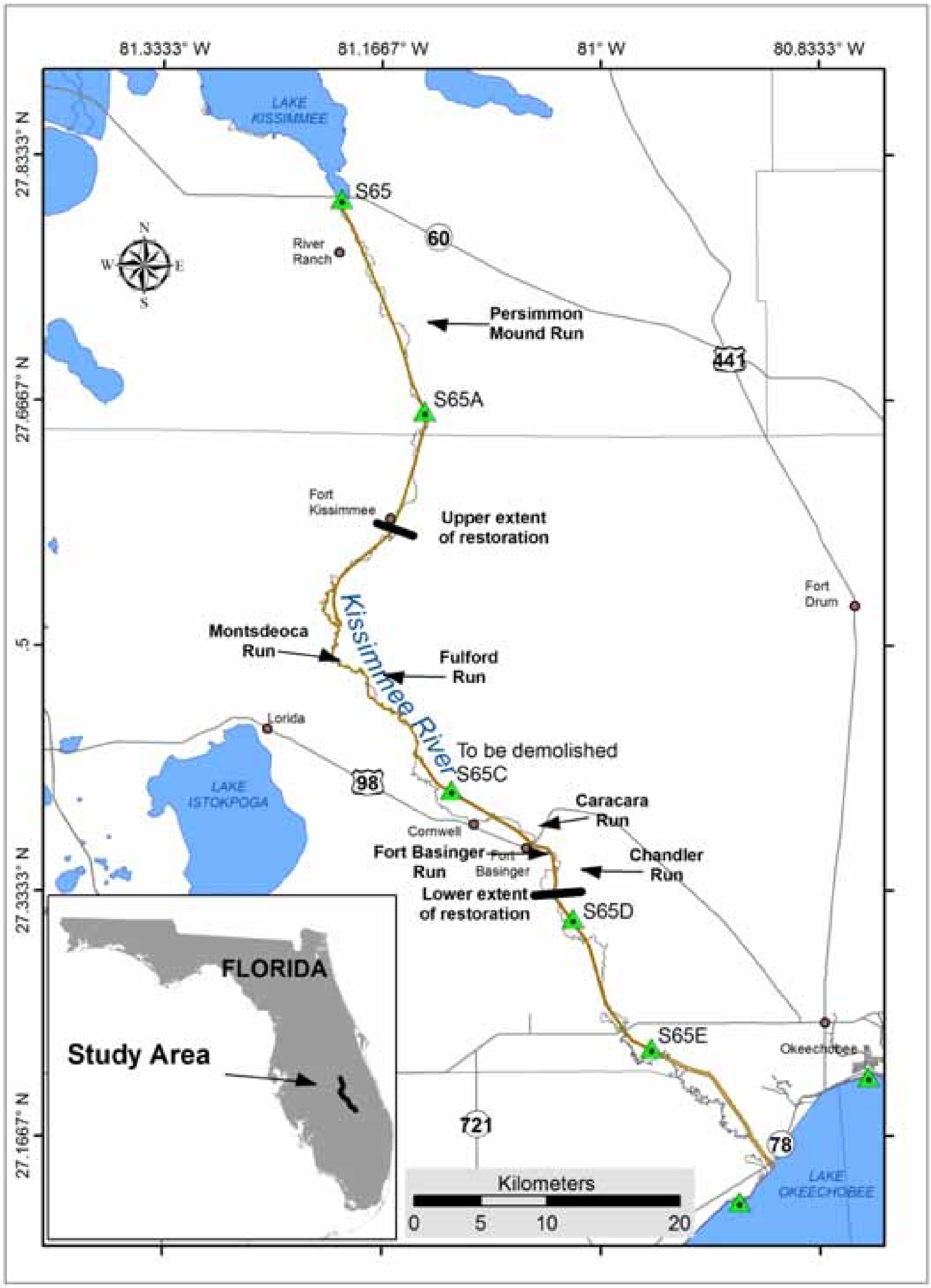

Figure 4-1. Location of the Lower Kissimmee River and its major restoration features. Runs where cross-sectional transects were conducted are labeled. The area currently restored is in Pool B-C (upstream of S-65C). Eventually, more of this reach and portions of the river now in Pool D will be restored.

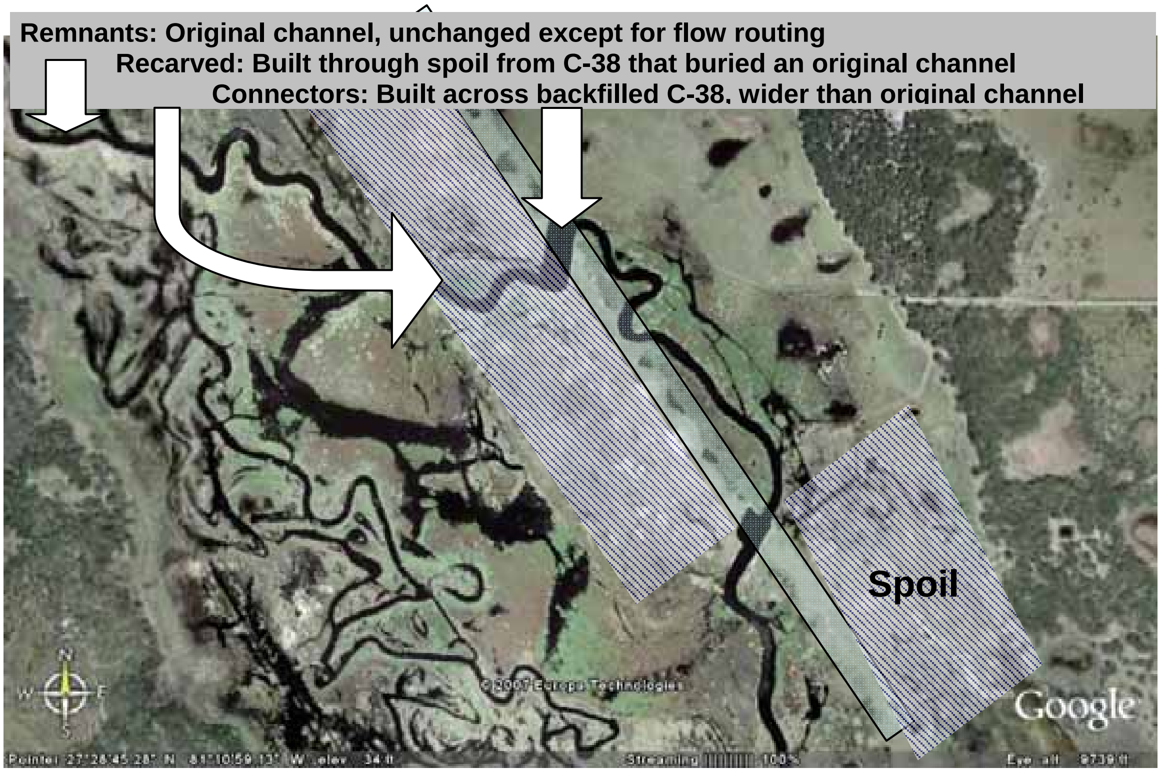

Figure 4-2. Types of cross sections in restored portions of the Kissimmee River. Remnants were left as is, recarved portions were dredged through former spoil deposits, and connectors go across backfilled C-38 (Source: www.googleearth.com).

Figure 4-3. Restored portion of the Kissimmee River, Pool B/C. Remnants were left as is, recarved portions were dredged through former spoil deposits, and connectors go across backfilled C-38. Backfilled areas appear to have more ponding than the adjacent floodplain (Source: http://www.saj.usace.army.mil/dp/Kissimmee/Aerial_1.jpg), although in time the difference may be reduced.

Table 4-1. Locations of survey transects. S indicates a straight reach, and B is a bendway on a meander.

Run Name	Pool	Transect Type	Year Installed	Number
Persimmon Mound	A	Remnant (control)	2007	4 (2S, 2B)
Montesdeoca	C	Remnant	2007	4 (2S, 2B)
Montesdeoca South	C	Connector	2007	2
Fulford	C	Recarved	2007	4 (2S, 2B)
Fulford South	C	Connector	2007	2
Caracara	D	Remnant (pasture)	2007	2 (1S, 1B)
Ft. Basinger	D	Remnant (mixed)	2009	1
Chandler	D	Remnant (forest)	2007	2 (1S, 1B)
TOTAL				21

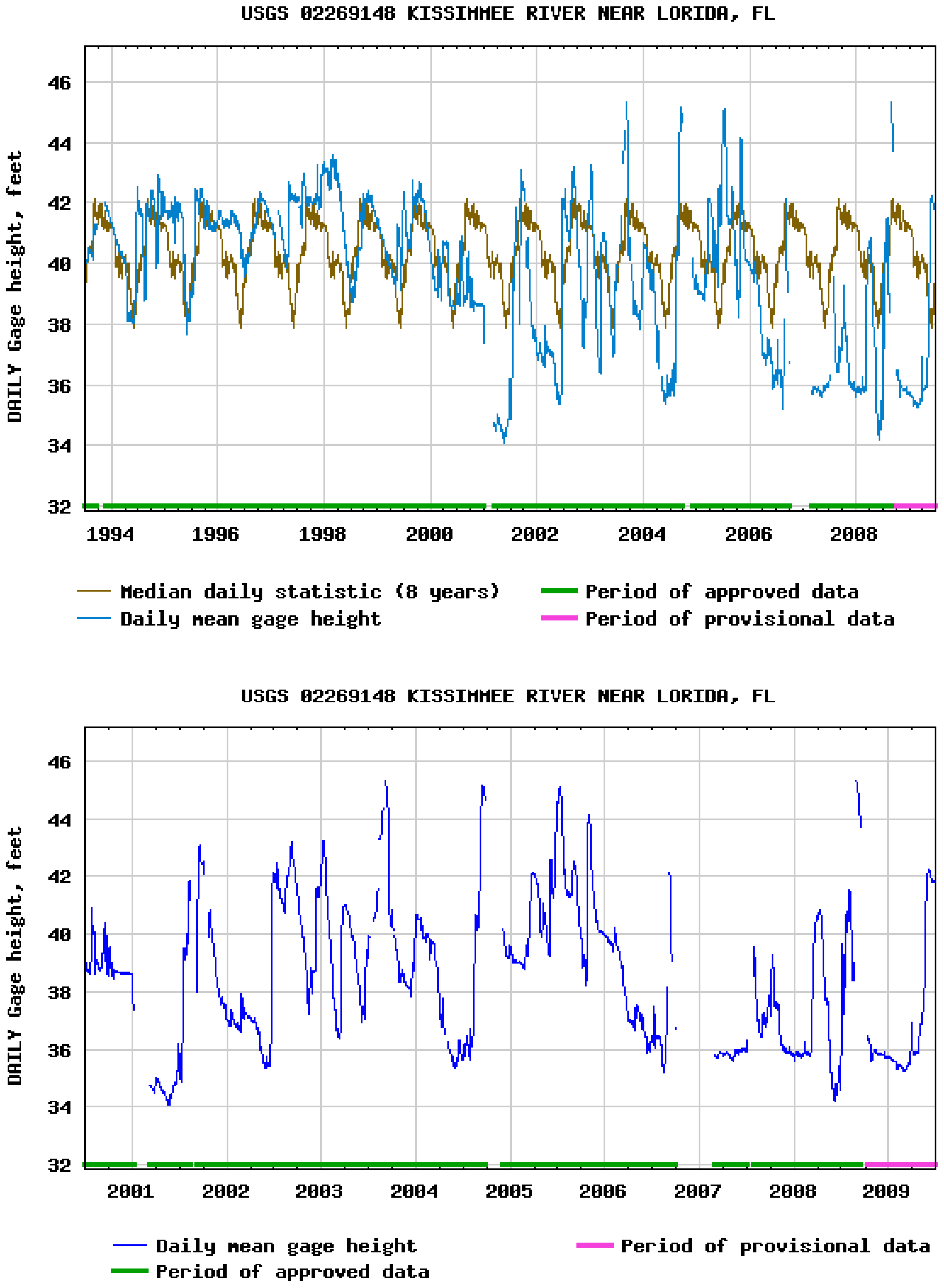

Figure 4-4. Gage height on the Kissimmee River near Lorida since July 1993. Demolition of S65-B was during June 2000, and soon thereafter there was more water level variation

downstream. Water levels were relatively low and consistent (35-36 ft) during field monitoring during January-February 2007, 2008 and 2009.

Figure 4-5. Survey methods using survey rod, level and rope along designated river transects. This photograph was taken in January 2009 in Persimmon Mound Run in Pool A.

Source: UF
Date: 5/8/2007
Created by: U Garfield
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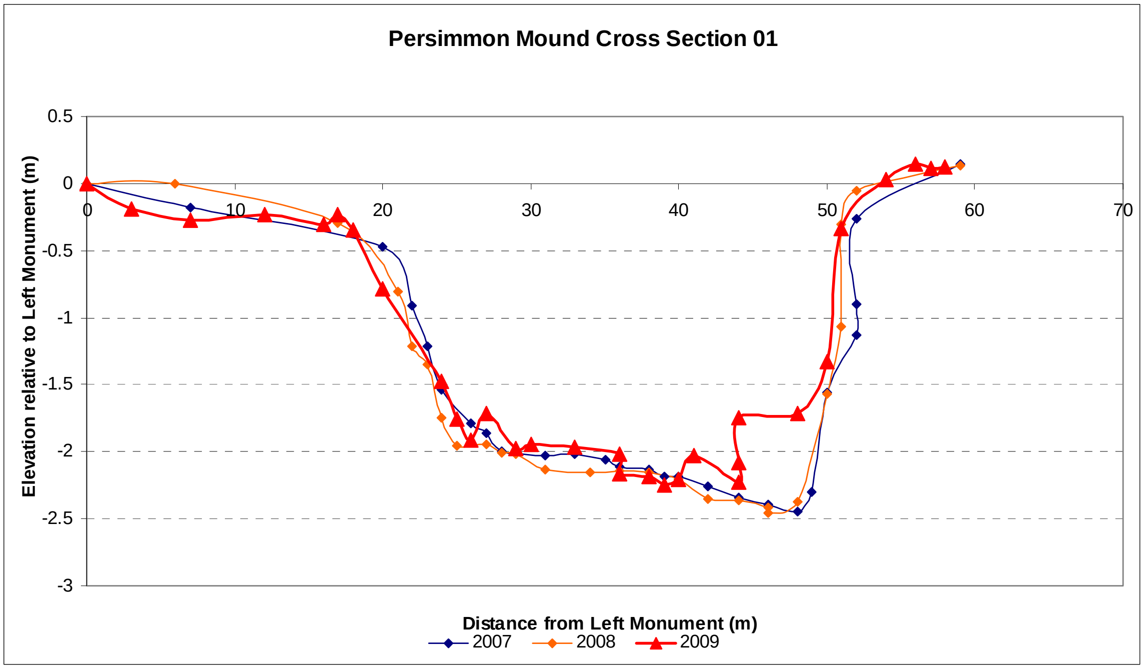
Figure 4-6. Transect locations in Persimmon Mound Run, Pool A. Transects 1 and 4 are considered straight reaches and Transects 2 and 3 are bendways.



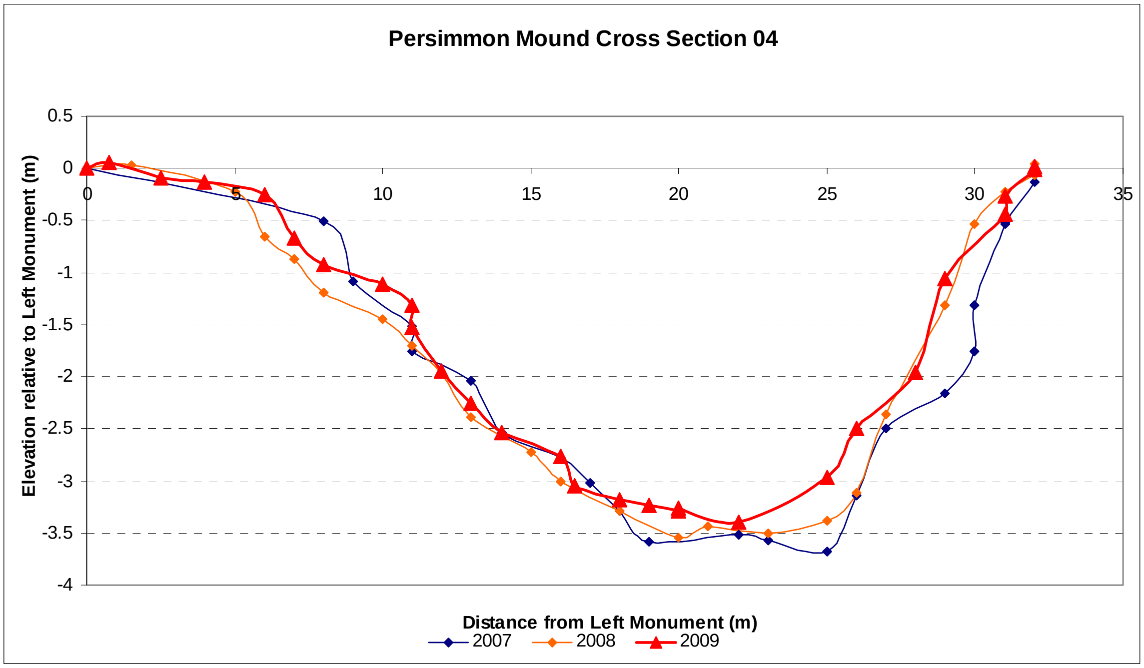
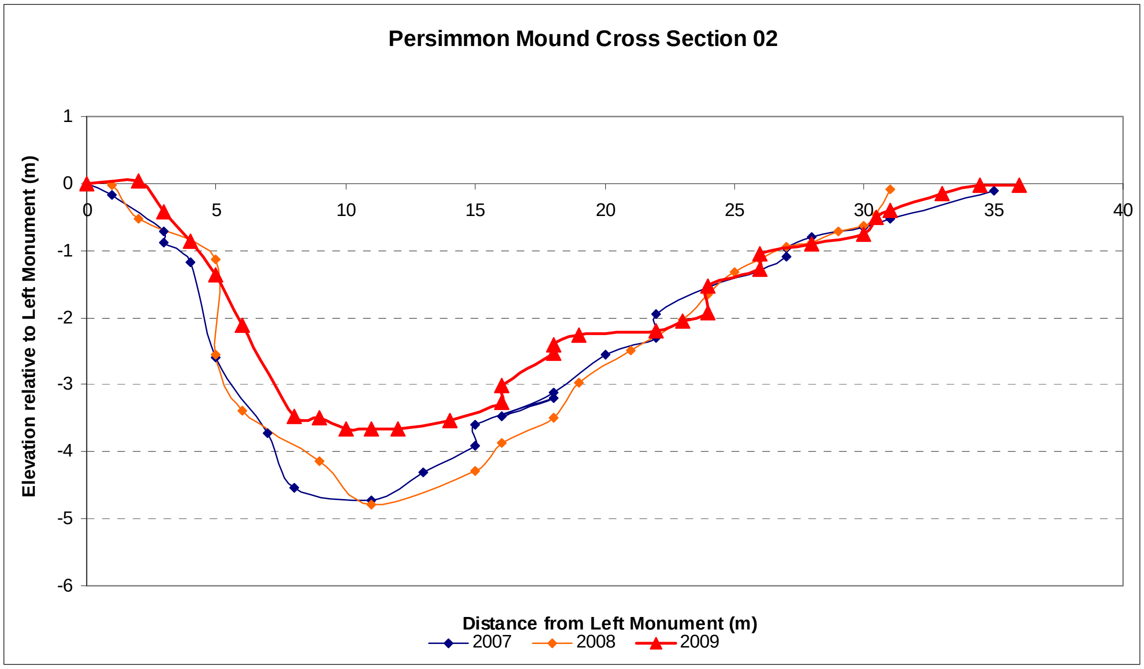


Figure 4-7. Two transects in Persimmon Mound Run, both in straight reaches of Pool A. Survey dates 2/28/07, 1/28/08 and 1/16/09.



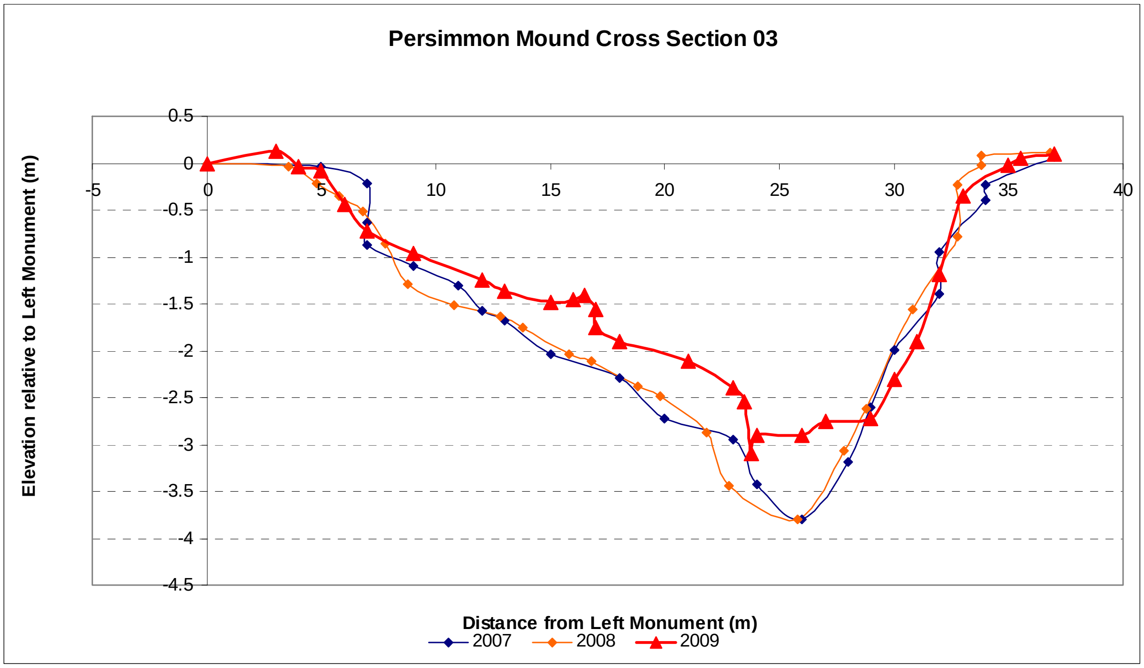


Figure 4-8. Two transects in Persimmon Mound, both in bendways of Pool A. Survey dates 2/28/07, 1/28/08 and 1/16/09.

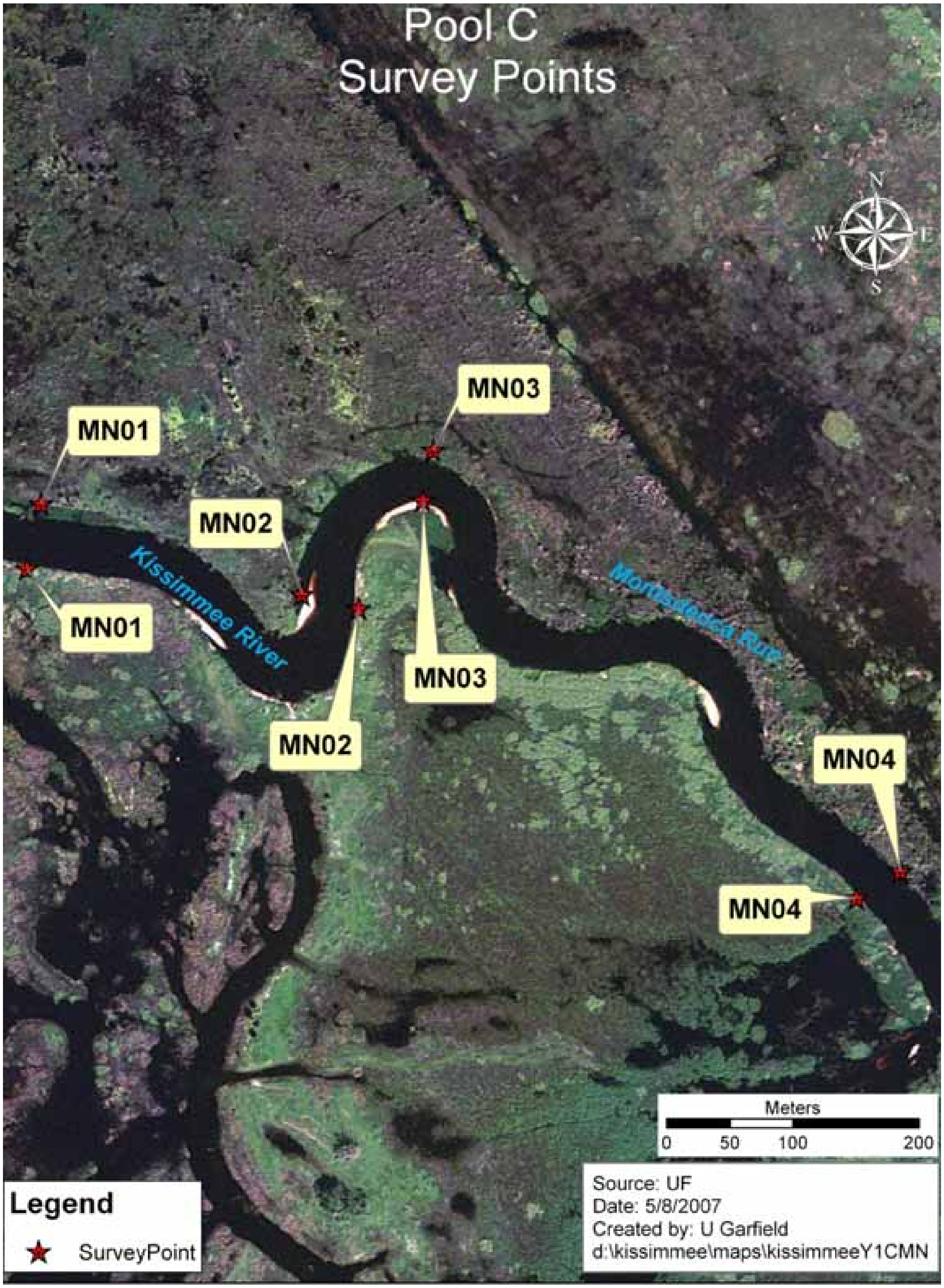
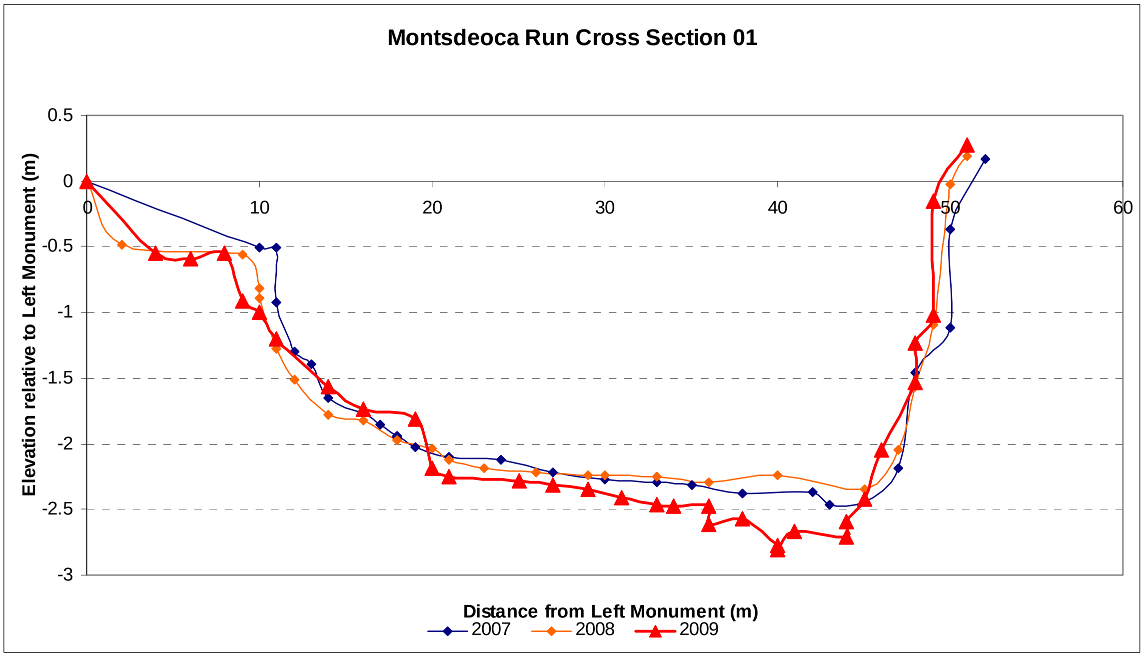


Figure 4-9. Transect locations in Montsdeoca Run, Pool C. Transects 1 and 4 are considered straight reaches and Transects 2 and 3 are bendways located across the bar apex.



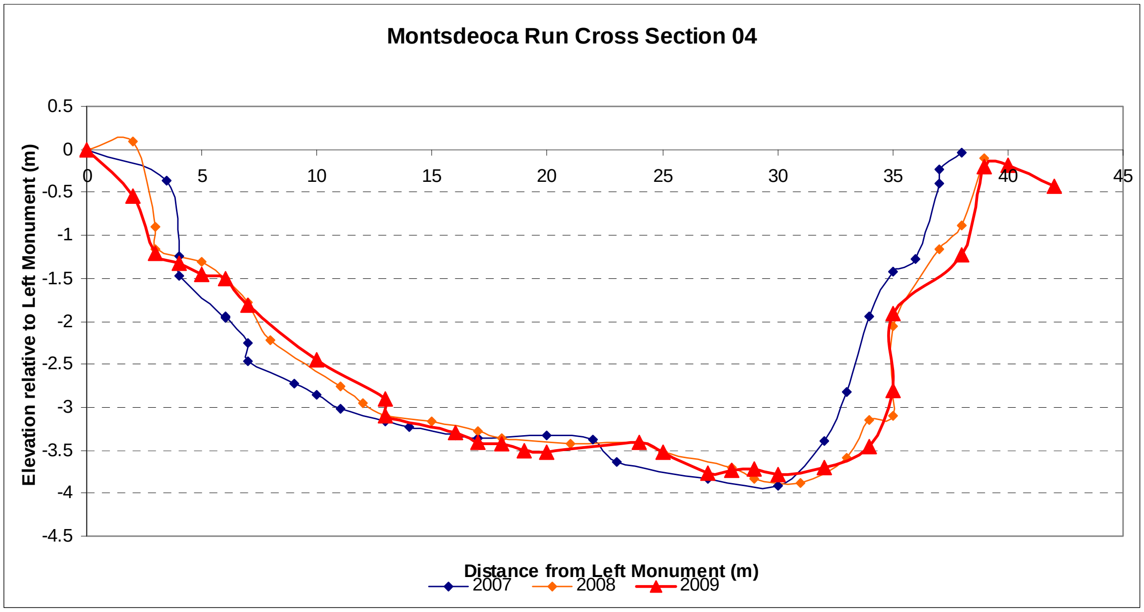
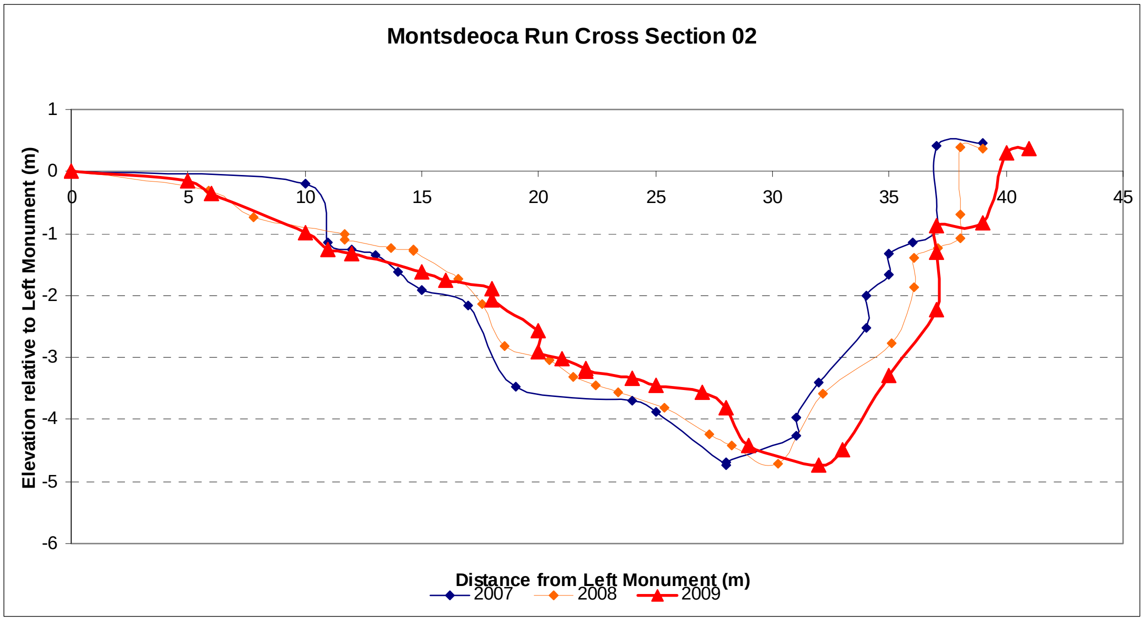


Figure 4-10. Two transects in Montsdeoca Run, both in straight remnant reaches of Pool C. Like most other cross sections in remnant reaches, the channel was about 30 m wide and did not have a mid-channel bar. Survey dates 2/27/07, 1/22/08 and 1/13/09.



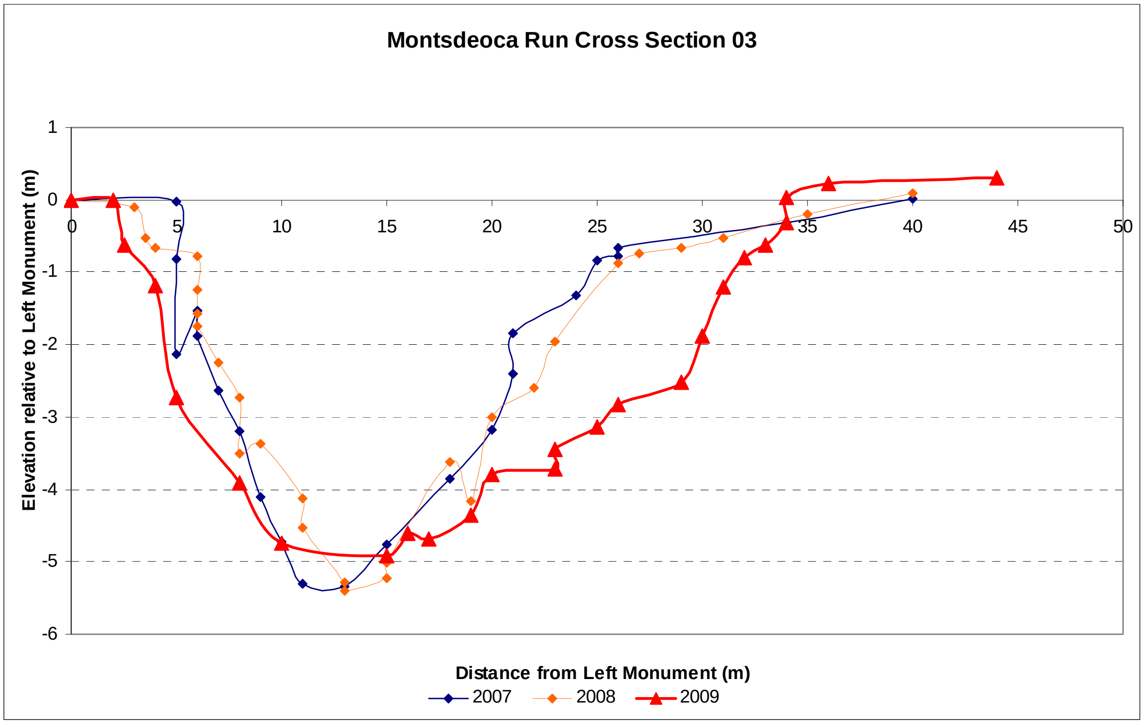


Figure 4-11. Two transects in Montsdeoca Run, both in bendway remnant reaches of Pool C. Like most other cross sections in remnant reaches, the channel was about 30 m wide and did not have a mid-channel bar. Survey dates 2/27/07, 1/22/08 and 1/13/09.

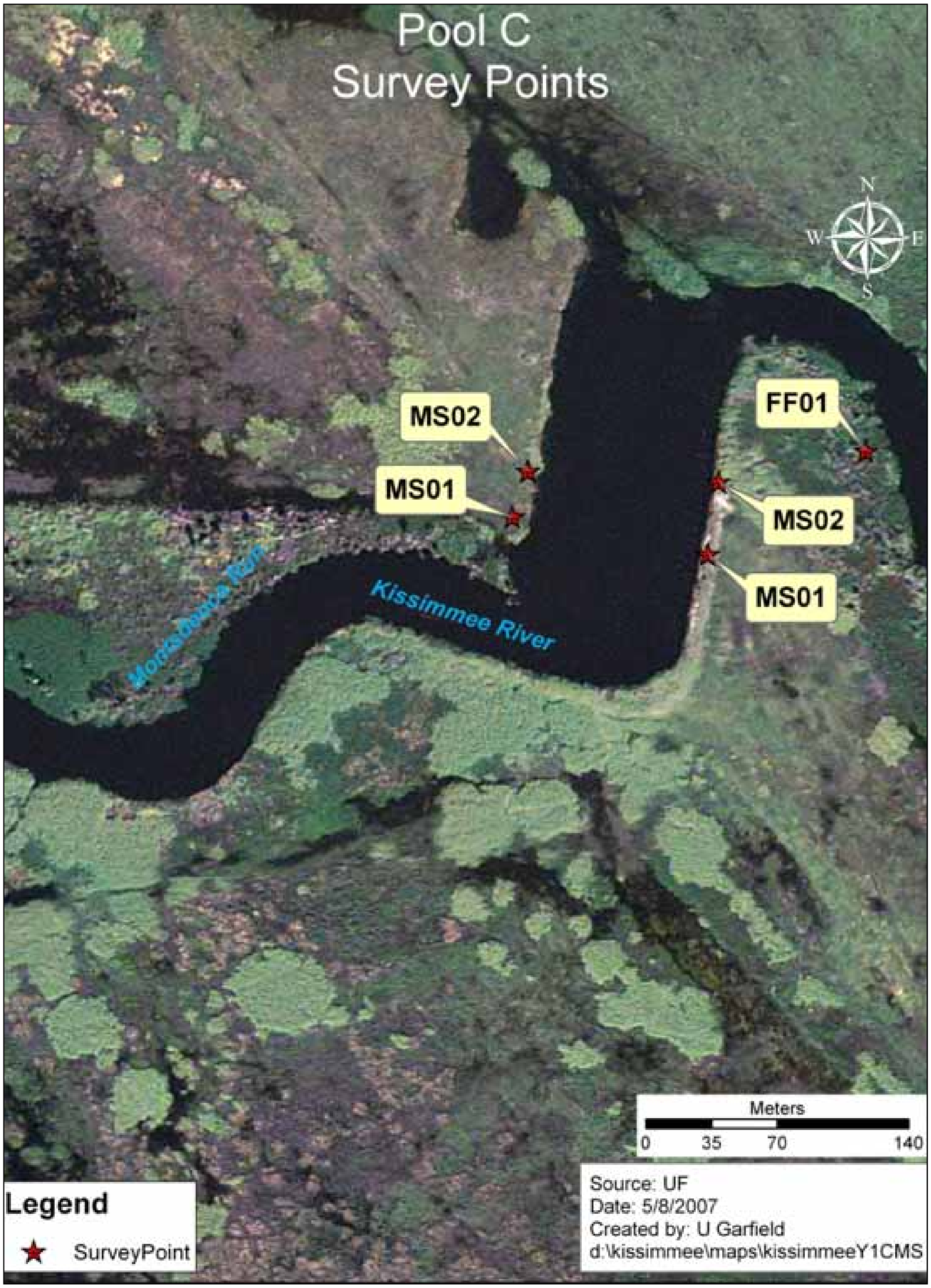


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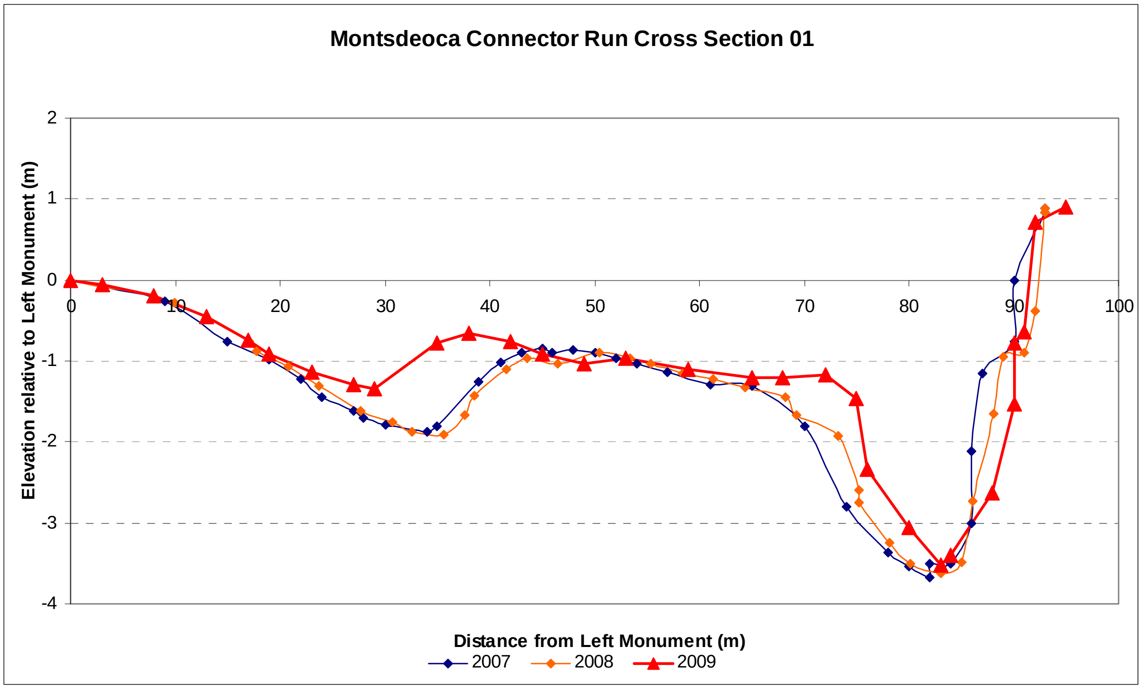
Figure 4-12. Transect locations in Montsdeoca South, a connector with two transects.



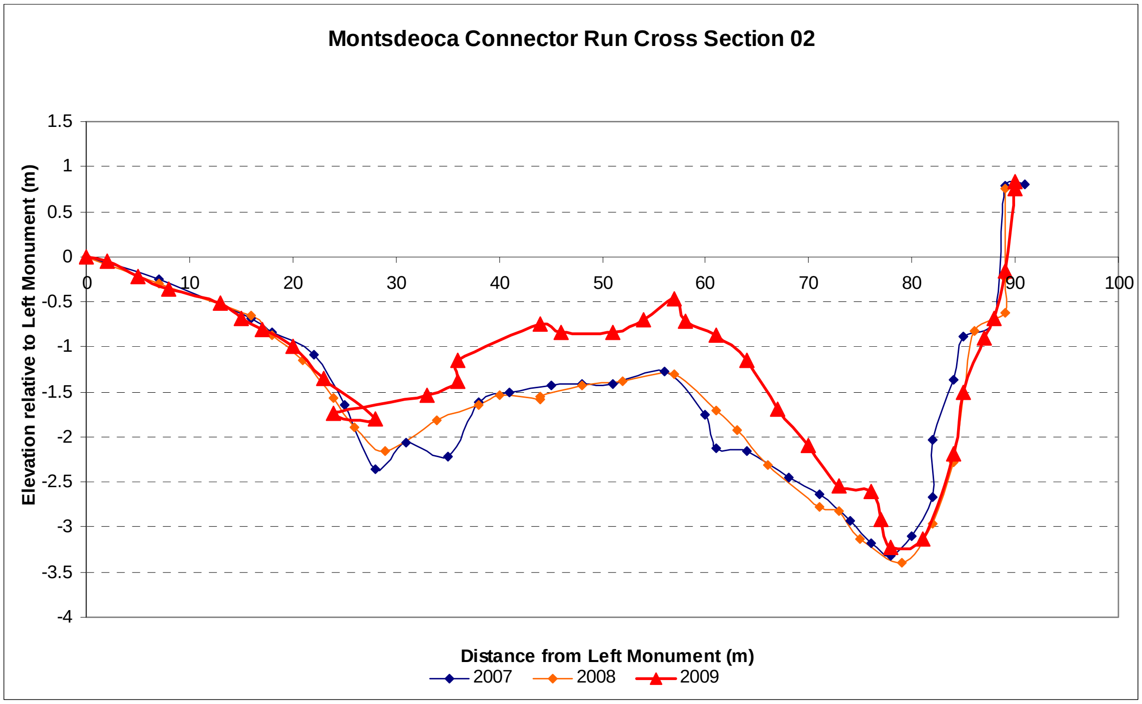


Figure 4-13. Two transects in the connector south of Montsdeoca Run, showing a channel over 80 m wide that has developed a mid-channel bar or island. Survey dates 3/1/07, 1/23/08 and 1/14/09.

Figure 4-14. South of Montsdeoca Run, a bar has formed in the Montsdeoca Connector. This bar was emergent during February 2007 field sampling and fully vegetated in January 2009.

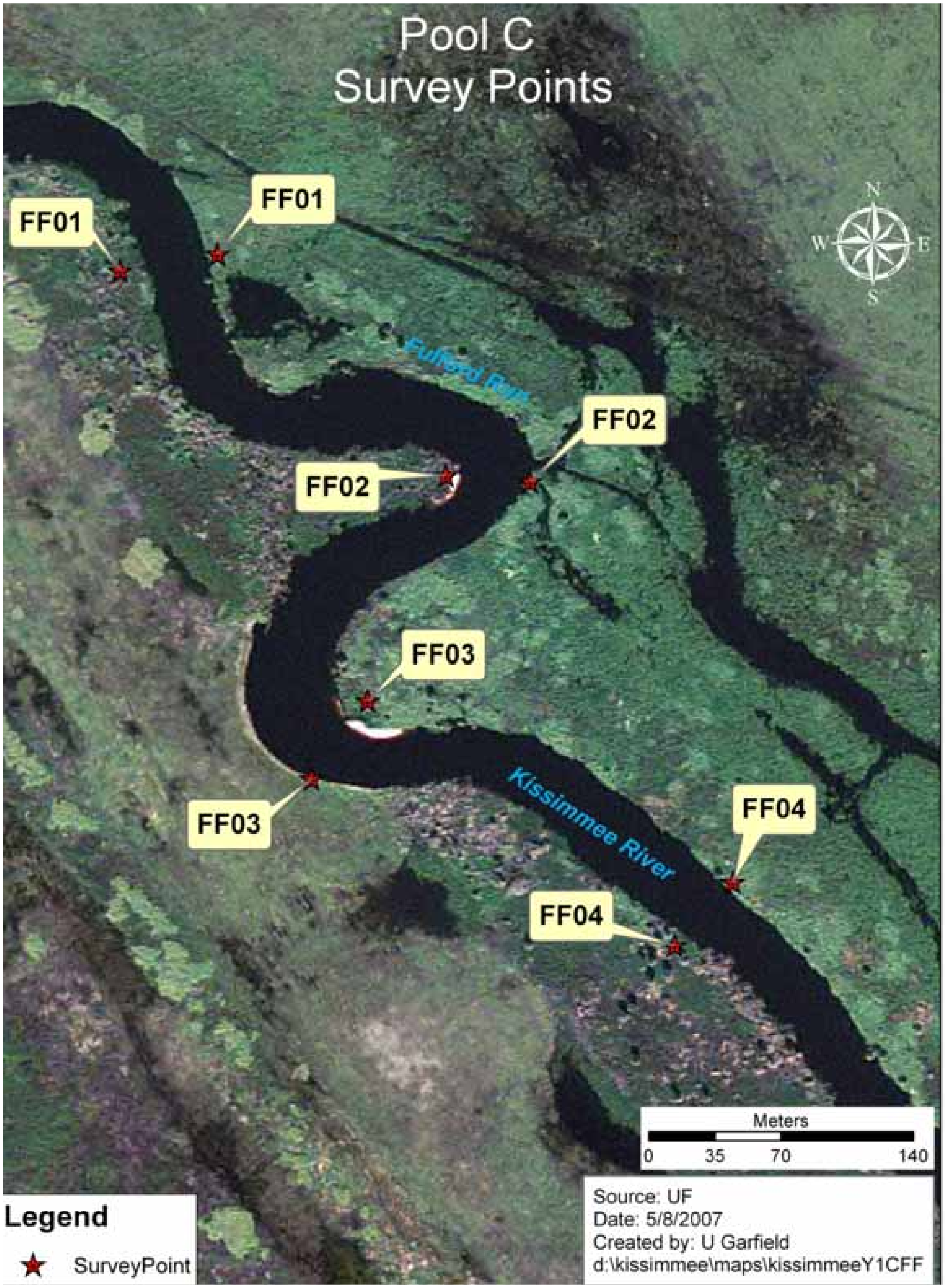
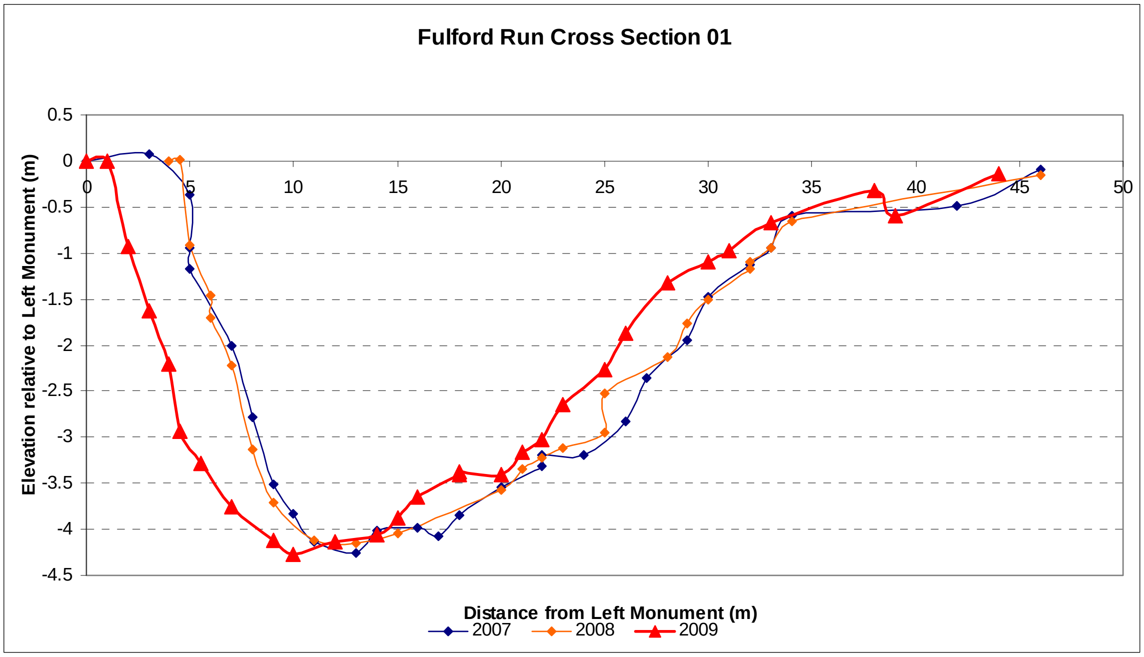


Figure 4-15. Transect locations in Fulford Run. Transects 1 and 4 are considered straight reaches and Transects 2 and 3 are bendways as they cross the bar apex.



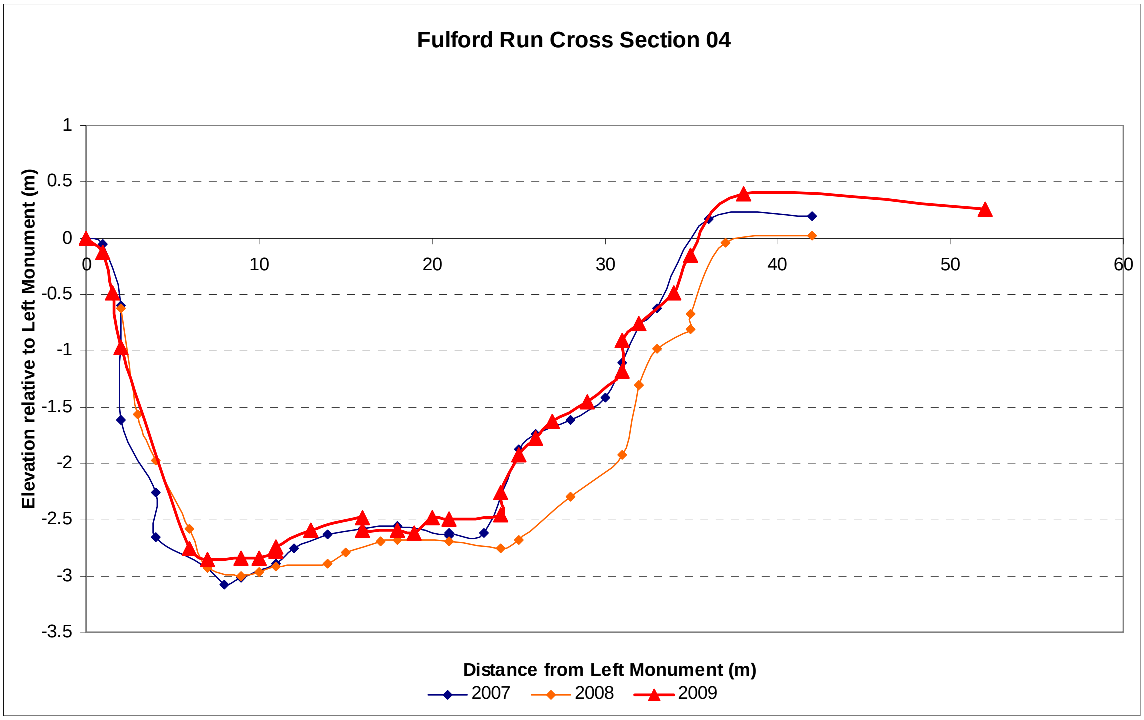
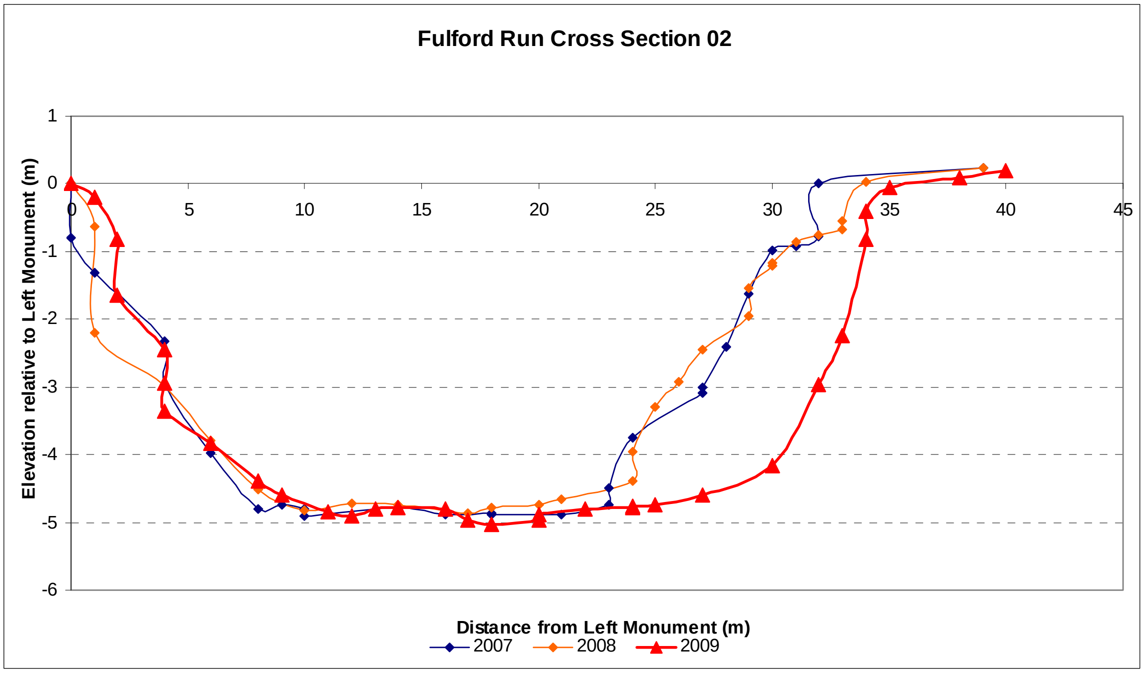


Figure 4-16. Two transects in Fulford Run, both in straight recarved reaches of Pool C. Like most other cross sections in remnant reaches (no modification other than restored flow) or recarved reaches, the channel was about 30 m wide and did not have a mid-channel bar. Survey dates 2/23/07, 1/24/08 and 1/15/09.



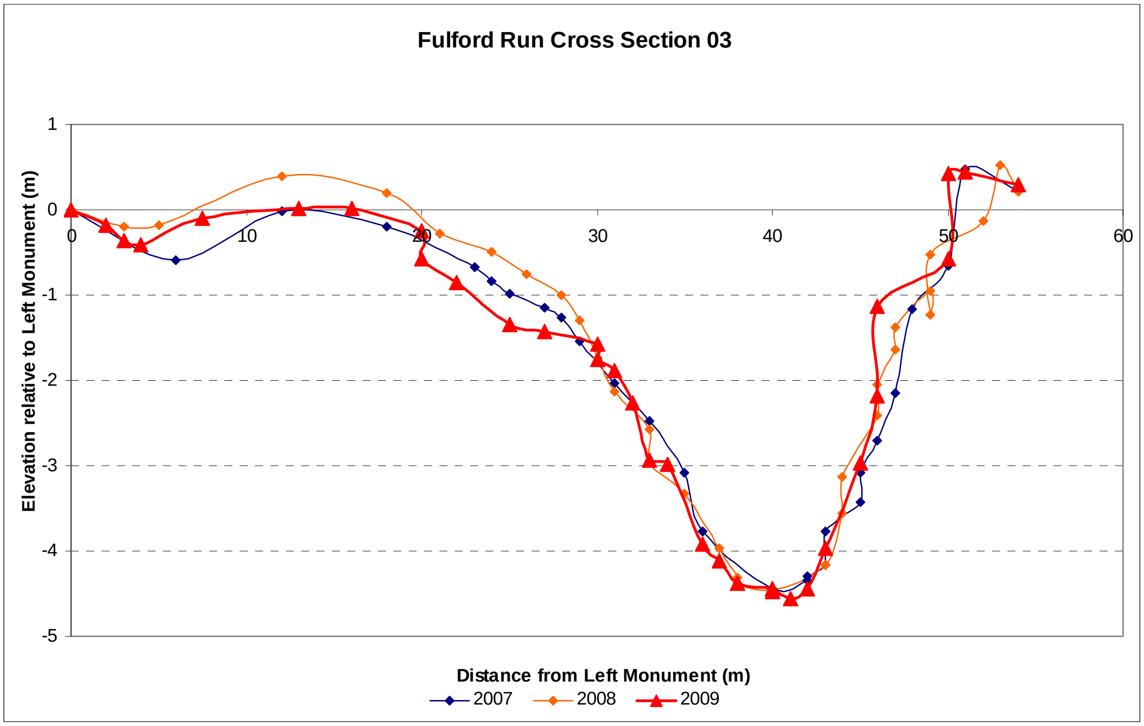


Figure 4-17. Two transects in Fulford Run, both in recarved bendways of Pool C. Like most other cross sections in recarved reaches, the channel was about 30 m wide and did not have a mid-channel bar. Survey dates 2/23/07, 1/24/08 and 1/15/09.

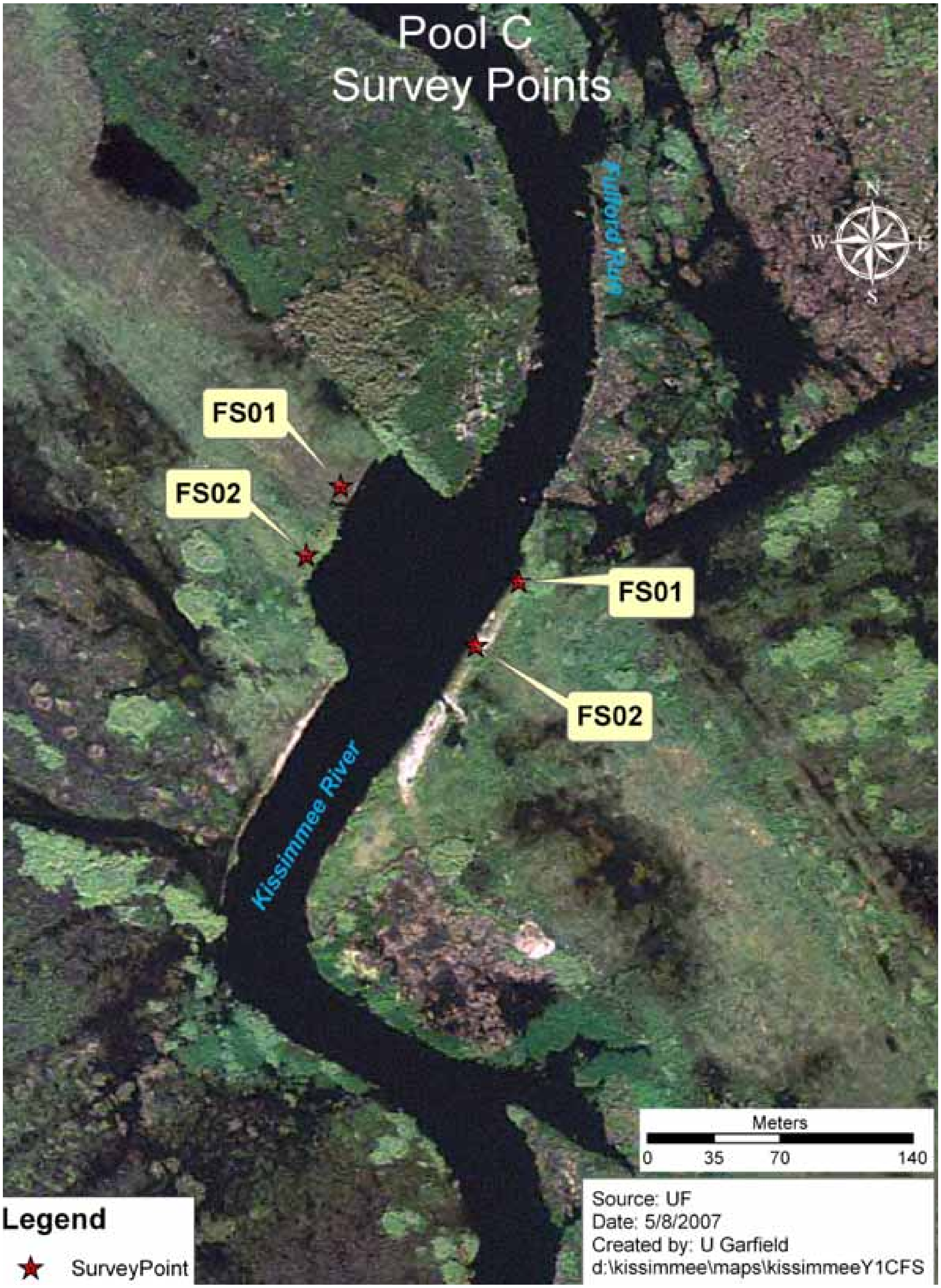
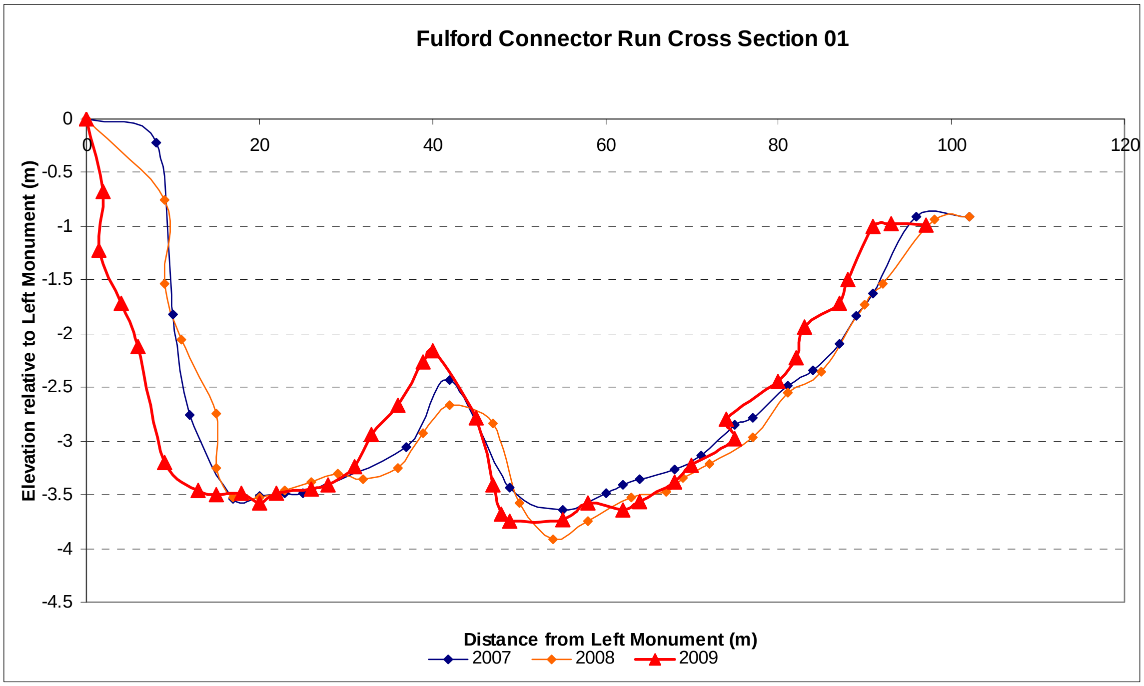


Figure 4-18. Transect locations in Fulford Connector or Fulford South, Pool C.



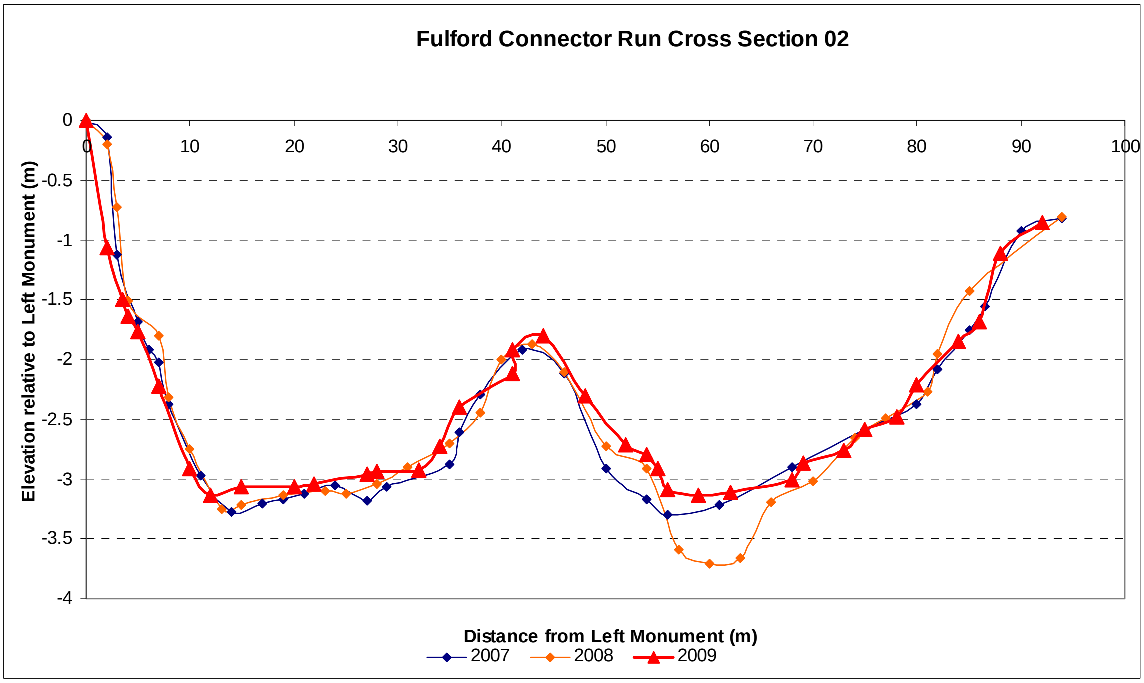


Figure 4-19. Two transects in a connector south of Fulford Run, showing a channel over 80 m wide that has developed a mid-channel bar or island. Survey dates 2/26/07, 1/23/08 and 1/14/09.

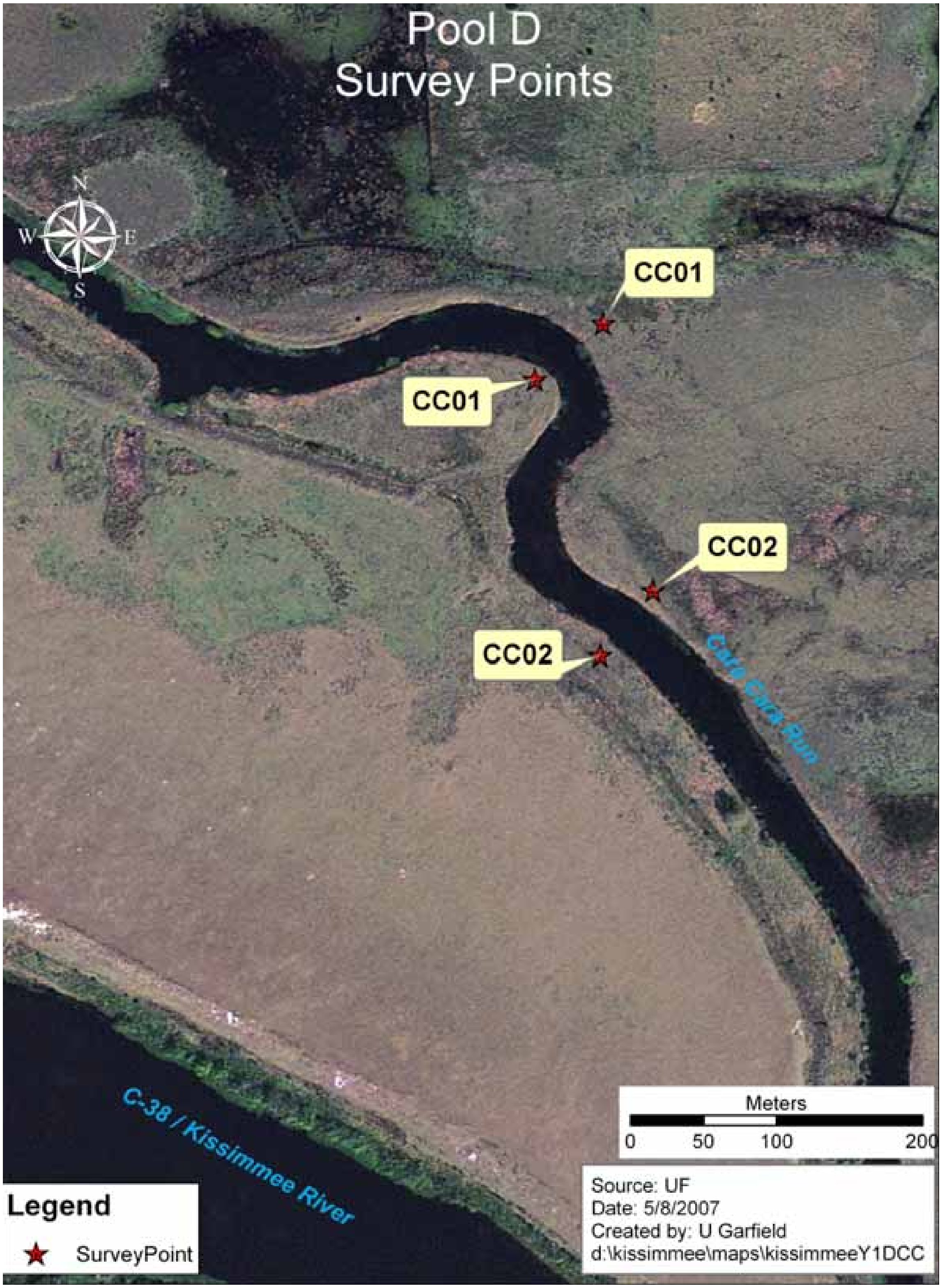


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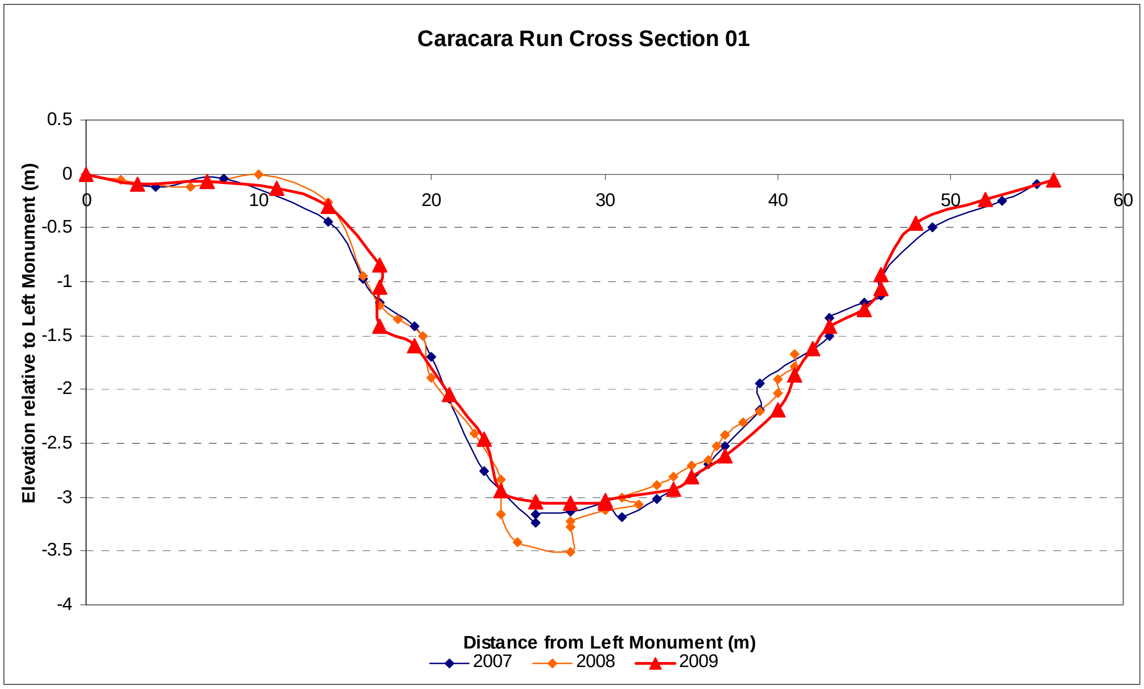
Figure 4-20. Transect locations in Caracara Run, Pool D. Transect 1 is in a bendway and Transect 2 is in a straight reach.



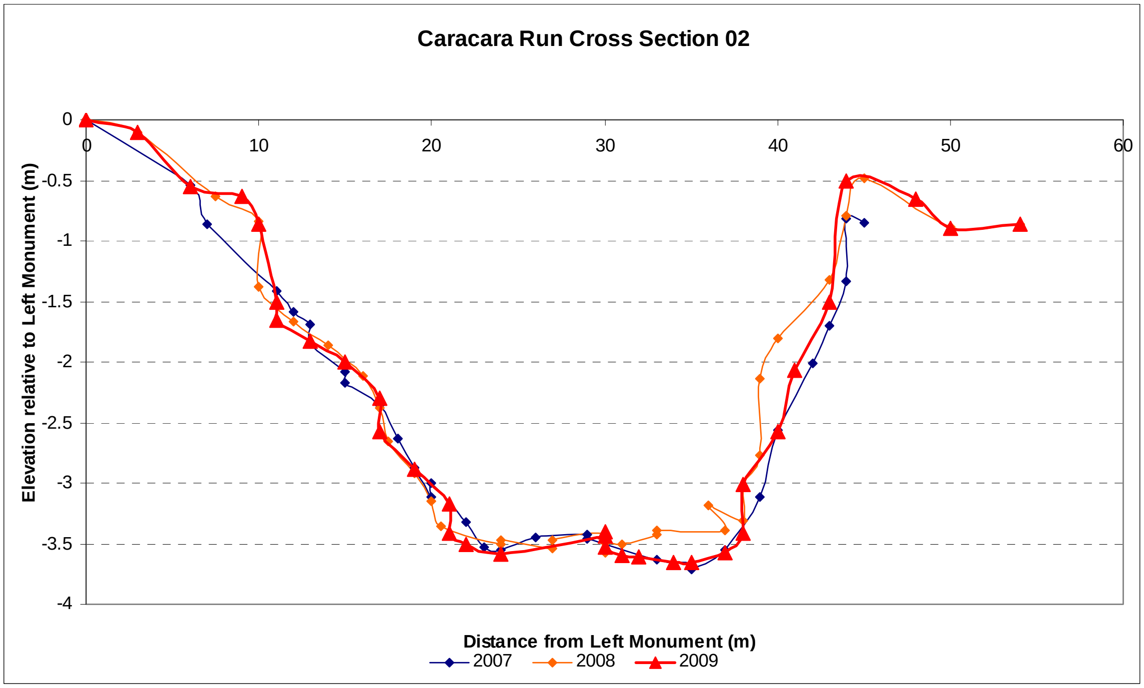


Figure 4-21. Transects in Caracara Run, Pool D. Transect 1 is in a bendway and Transect 2 is in a straight reach. The channel is about 30 m wide. Survey dates for transect 01 are 2/19/07, 2/11/08 and for transect 02 survey dates are 2/20/07, 2/11/08 and 1/12/09.

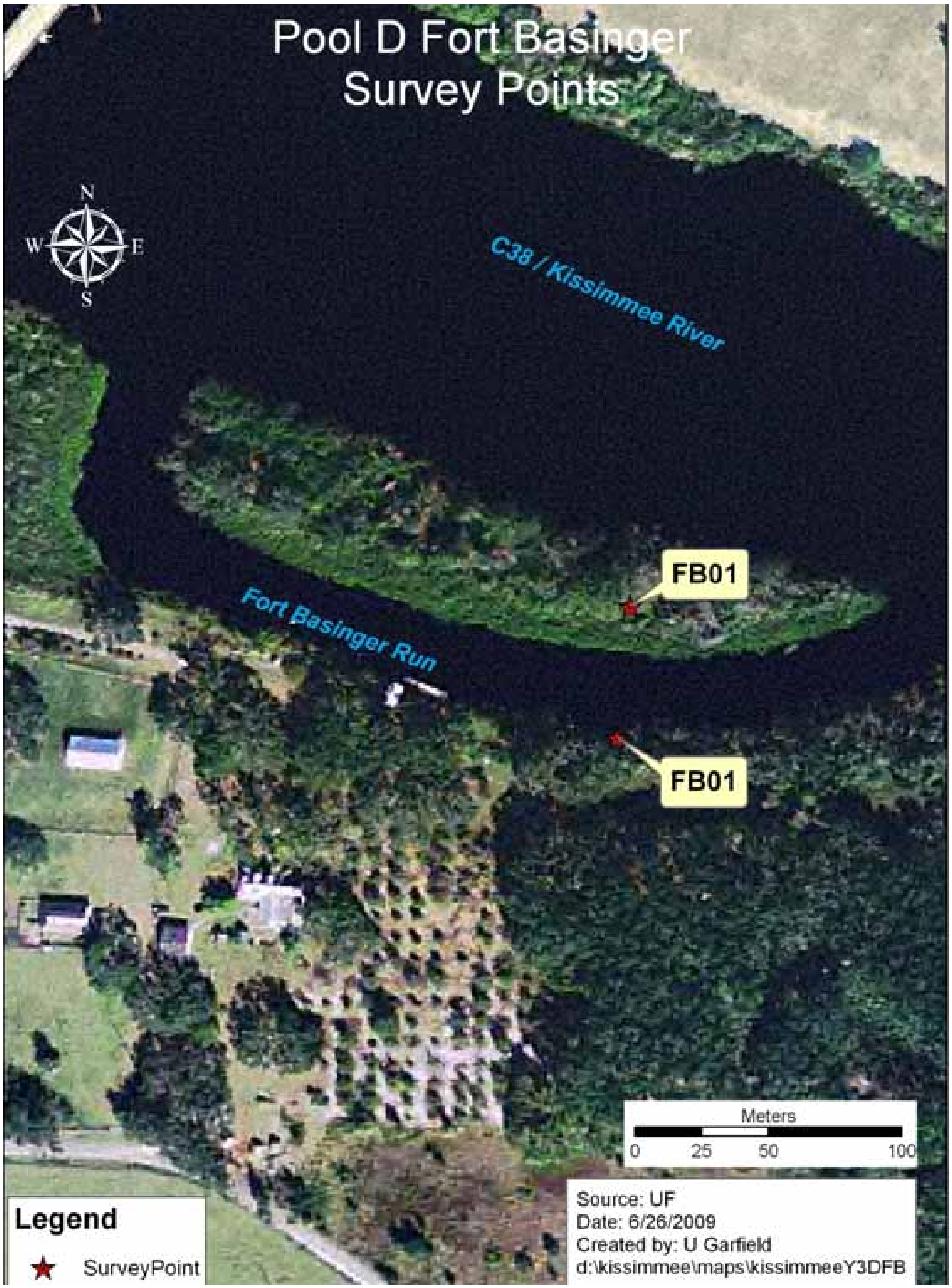


Figure 4-22. Transect location in Ft. Basinger Run, Pool D. This is a very short run where a new transect was placed in 2009.

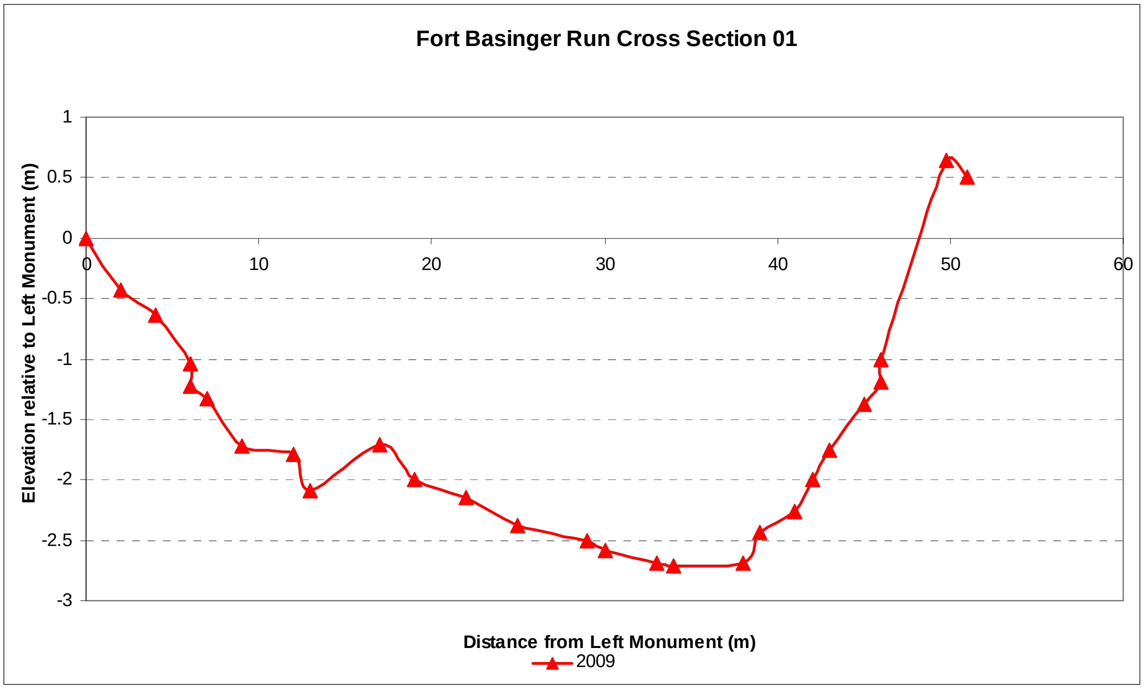
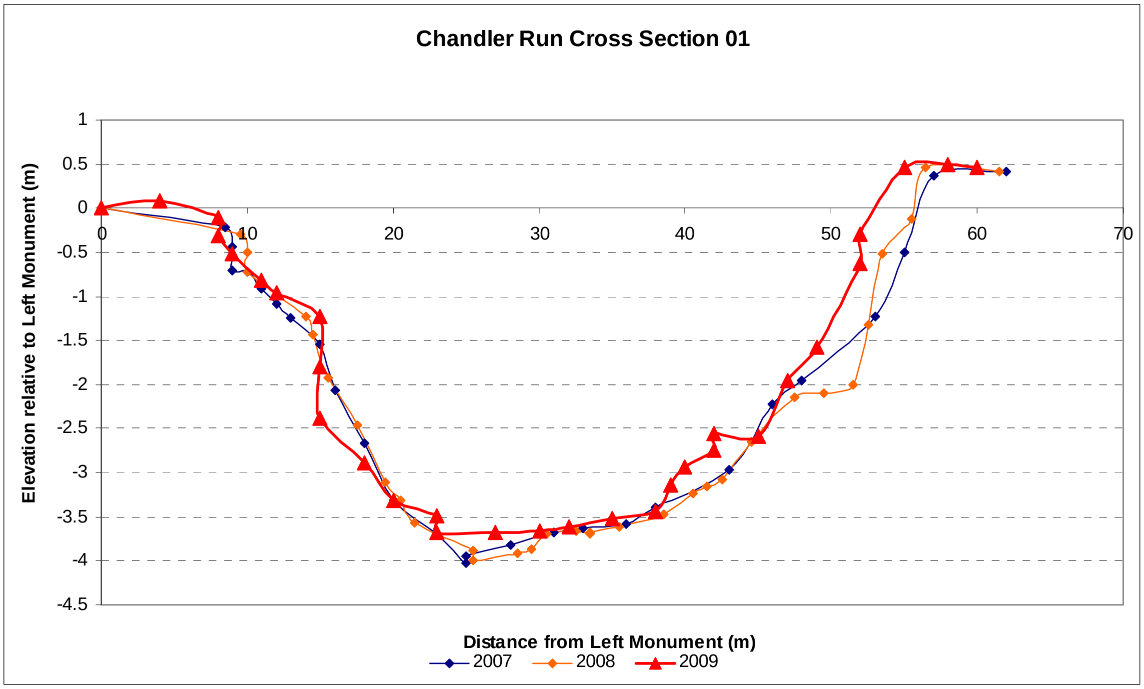


Figure 4-23. Cross-sectional morphology of a transect in Ft. Basinger Run, Pool D. This is a very short run where a new transect was placed in 2009. Survey date 1/12/09.

Figure 4-24 Transect locations in Chandler Run, Pool D. Transect 1 is in a bendway and Transect 2 is in a straight reach.



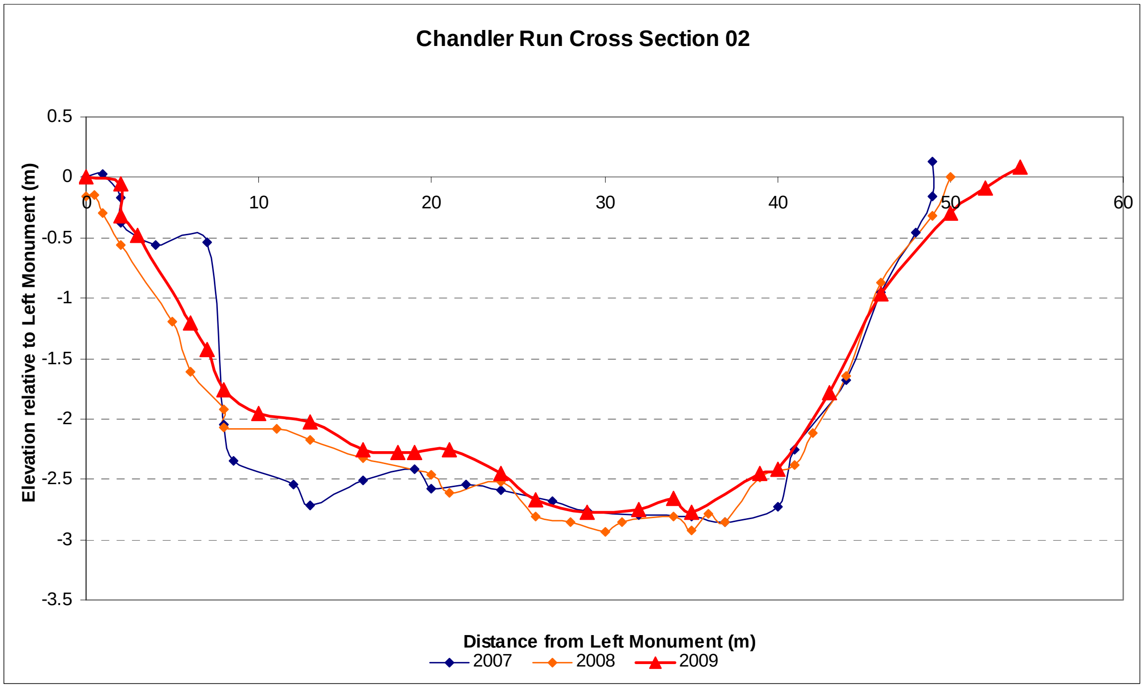


Figure 4-25. Transects in Chandler Run, Pool D. Transect 1 is in a bendway and Transect 2 is in a straight reach. The channel is about 30 m wide and did not have a mid-channel bar. Survey dates for transect 01 are 2/21/07, 2/14/08 and 1/12/09. Survey dates for transect 02 are 2/22/07, 2/14/08 and 1/12/09.

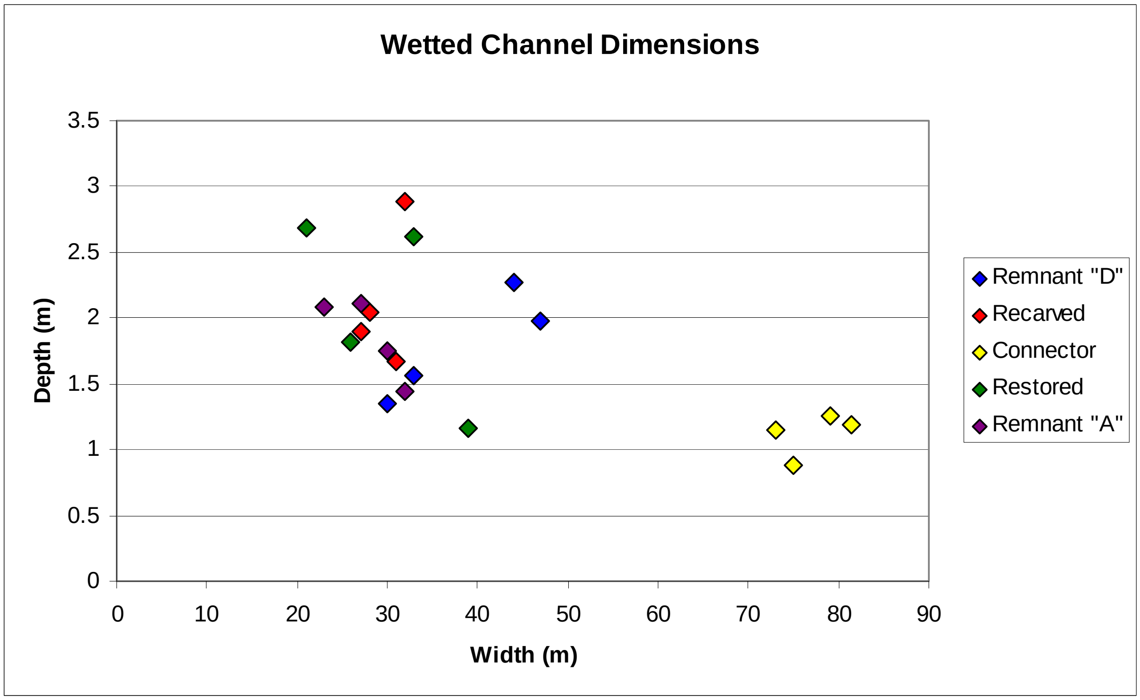


Figure 4-26. Comparison of the wetted channel dimensions of the 20 transects sampled. The connectors are the only transects which are appreciably different, much wider and somewhat shallower compared to the other types. Pool A will not be restored but remnants in Pool D will eventually be restored. Reaches labeled restored, connector and recarved are all in Pool C.

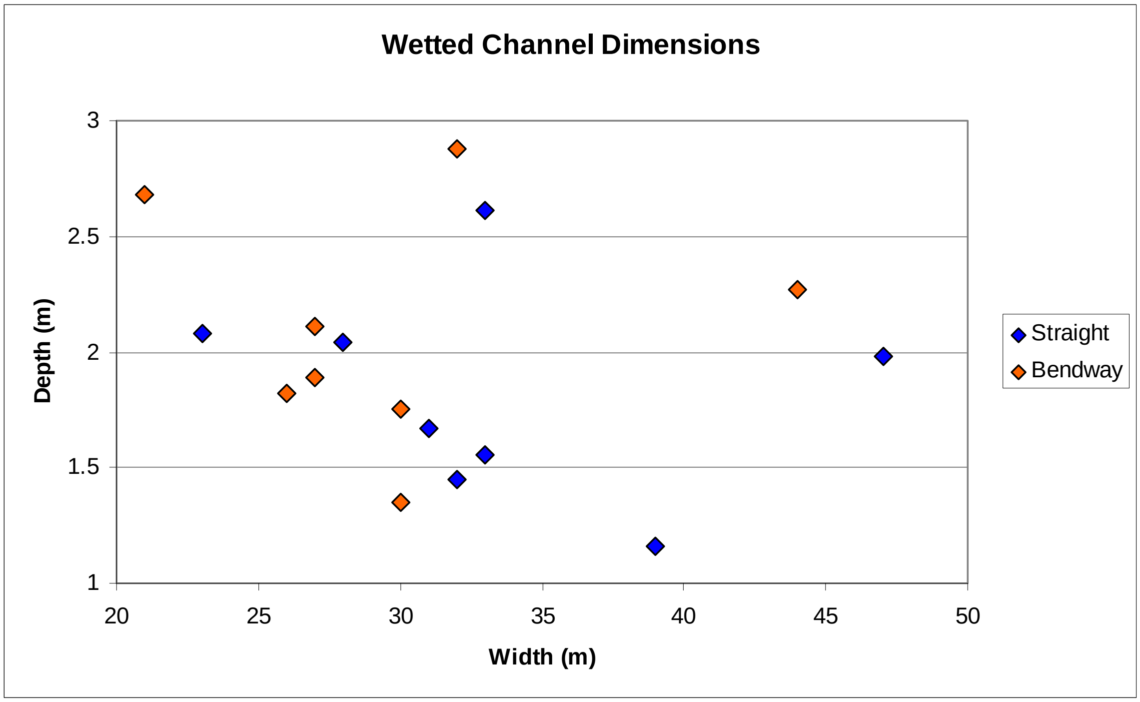


Figure 4-27. Bendways and straight reaches were not notably different in their width-depth ratios in the initial year of monitoring.

Table 4-2. Bank erosion pin monitoring 2007-2009 for Persimmon Mound Run Pool A.

Transect/Bank	Pin#	Horiz/Vert	2008 (cm)*	2009 (cm)*
pm01R	p1	v	0.0	nf
pm01R	p2	v	0.0	nf
pm01R	p3	v	0.0	nf
pm01R	p4	h	0.0	nf
pm01L	p1	v	3.0	nf
pm02R	p1	v	0.0	nf
pm02R	p2	v	0.0	nf
pm02R	p3	h	0.0	nf
pm02L	p1	v	0.0	nf
pm02L	p2	h	0.0	nf
pm03R	p1	v	7.0	nf
pm03R	p2	v	0.0	nf
pm03R	p3	h	0.0	nf
pm03L	p1	v	0.0	nf
pm03L	p2	v	0.0	nf
pm03L	p3	h	0.0	nf
pm04R	p1	v	0.0	nf
pm04R	p2	v	0.0	nf
pm04R	p3	h	0.0	nf
pm04L	p1	v	nf	nf
pm04L	p2	v	nf	nf

*Positive numbers indicate deposition, negative numbers indicate erosion, entries with -43 indicate pin found in slump and nf indicates pin was not found.

Table 4-3. Bank erosion pin monitoring 2007-2009 for Montsdeoca Run Pool B/C.

Transect/Bank	Pin#	Horiz/Vert	2008 (cm)*	2009 (cm)*
mn01R	p1	v	nf	0
mn01R	p2	h	nf	0
mn01R	p3	h	nf	-43
mn01L	p1	v	-3.2	3
mn01L	p2	v	0.0	3
mn01L	p3	v	0.0	0.5
mn02R	p1	v	nf	nf
mn02R	p2	h	nf	nf
mn02R	p3	h	nf	nf
mn02R	p4	h	nf	nf
mn02L	p1	v	4.0	21
mn02L	p2	v	1.0	16
mn02L	p3	v	8.0	16
mn02L	p4	v	7.0	-10
mn03R	p1	v	3.0	0
mn03R	p2	v	4.5	8
mn03R	p3	v	0.0	-43
mn03R	p4	v	0.0	-43
mn03L	p1	v	nf	nf
mn03L	p2	h	nf	nf
mn04R	p1	v	0.0	-43
mn04R	p2	v	-43.0	-43
mn04R	p3	v	-43.0	-43
mn04R	p4	h	-43.0	nf
mn04L	p1	v	nf	0.2
mn04L	p2	v	nf	0.3
mn04L	p3	v	nf	0.4
mn04L	p4	h	nf	

*Positive numbers indicate deposition, negative numbers indicate erosion, entries with -43 indicate pin found in slump and nf indicates pin was not found.

Table 4-4. Bank erosion pin monitoring 2007-2009 for Montsdeoca South connector Pool B/C.

Transect/Bank	Pin#	Horiz/Vert	2008 (cm)*	2009 (cm)*
ms01R	p1	v	0.7	3
ms01R	p2	v	0.0	-1
ms01R	p3	v	-43.0	-43
ms01R	p4	h	-43.0	
ms01R	p5	h	-43.0	
ms01L	p1	v	0.0	nf
ms01L	p2	v	0.0	nf
ms01L	p3	v	0.0	nf
ms01L	p4	v	0.0	nf
ms02R	p1	v	0.0	5
ms02R	p2	v	0.0	-43
ms02R	p3	v	0.0	-43
ms02R	p4	h	-43.0	
ms02R	p5	h	0.0	
ms02L	p1	v	-2.5	nf
ms02L	p2	v	-2.0	nf
ms02L	p3	v	-1.0	nf
ms02L	p4	v	-1.0	nf

*Positive numbers indicate deposition, negative numbers indicate erosion, entries with -43 indicate pin found in slump and nf indicates pin was not found.

Table 4-5. Bank erosion pin monitoring 2007-2009 for Fulford Run Pool B/C.

Transect/Bank	Pin#	Horiz/Vert	2008 (cm)	2009 (cm)
ff01R	p1	v	-43.0	nf
ff01R	p2	v	-43.0	nf
ff01R	p3	v	-43.0	nf
ff01R	p4	h	-43.0	
ff01L	p1	v	0.0	nf
ff01L	p2	h	0.0	nf
ff01L	p3	h	-43.0	nf
ff01L	p4	h	-43.0	
ff02R	p1	v	0.0	10
ff02R	p2	v	0.0	5
ff02R	p3	h	0.0	2
ff02R	p4	h	0.0	-43
ff02R	p5	h	0.0	0
ff02L	p1	v	0.0	nf
ff02L	p2	v	0.0	nf
ff02L	p3	v	-43.0	nf
ff02L	p4	h	-43.0	
ff03R	p1	v	0.0	-6
ff03R	p2	h	0.0	8
ff03R	p3	h	0.0	-5
ff03R	p4	v	0.0	2
ff03L	p1	v	7.0	-43
ff03L	p2	v	5.0	-43
ff03L	p3	v	0.0	-16
ff04R	p1	v	0.0	2
ff04R	p2	v	0.0	1
ff04R	p3	v	0.5	-4
ff04L	p1	v	0.0	nf
ff04L	p2	v	3.0	nf
ff04L	p3	v	1.0	nf

*Positive numbers indicate deposition, negative numbers indicate erosion, entries with -43 indicate pin found in slump and nf indicates pin was not found.

Table 4-6. Bank erosion pin monitoring 2007-2009 for Fulford South connector Pool B/C.

Transect/Bank	Pin#	Horiz/Vert	2008 (cm)*	2009 (cm)*
fs01R	p1	v	0.0	0
fs01R	p2	v	0.0	-1
fs01R	p3	v	0.0	-3
fs01L	p1	v	0.0	nf
fs01L	p2	v	0.0	nf
fs01L	p3	v	0.0	nf
fs01L	p4	v	-43.0	nf
fs02R	p1	v	0.0	2
fs02R	p2	v	0.0	0
fs02R	p3	v	0.0	4
fs02L	p1	v	0.0	4
fs02L	p2	h	0.0	-6.5
fs02L	p3	v	0.5	16
fs02L	p4	v	0.7	13

*Positive numbers indicate deposition, negative numbers indicate erosion, entries with -43 indicate pin found in slump and nf indicates pin was not found.

Table 4-7. Bank erosion pin monitoring 2007-2009 for Caracara and Chandler Runs Pool D.

Transect/Bank	Pin#	Horiz/Vert	2008 (cm)*	2009 (cm)*
cc01R	p1	v	0.0	3
cc01R	p2	v	3.0	1
cc01R	p3	v	0.0	0
cc01R	p4	h	0.0	
cc01L	p1	v	0.0	0
cc01L	p2	v	0.0	0
cc01L	p3	v	0.0	0
cc01L	p4	h	0.0	
cc01L	p5	h	0.0	
cc02R	p1	v	0.0	0
cc02R	p2	v	0.0	0
cc02R	p3	h	0.0	2
cc02R	p4	h	0.0	
cc02R	p5	h	0.0	
cc02L	p1	v	0.0	0
cc02L	p2	v	0.0	0
cc02L	p3	v	0.0	
cc02L	p4	h	0.0	0
cc02L	p5	h	0.0	0
ch01R	p1	v	0.0	0
ch01R	p2	v	3.0	5
ch01R	p3	v	0.0	0
ch01R	p4	h	0.0	0
ch01L	p1	v	0.0	0
ch01L	p2	v	0.0	0
ch01L	p3	h	0.0	0
ch01L	p4	h	0.0	-5
ch02R	p1	v	0.0	0
ch02R	p2	v	0.0	0
ch02R	p3	v	0.0	0
ch02R	p4	v	0.0	0
ch02L	p1	v	2.0	0
ch02L	p2	v	1.0	0
ch02L	p3	v	5.0	0
ch02L	p4	h	0.0	0

*Positive numbers indicate deposition, negative numbers indicate erosion, entries with -43 indicate pin found in slump and nf indicates pin was not found.

CHAPTER 5

BOTTOM SEDIMENT OBSERVATIONS

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Introduction and Objectives

River channel perimeters can be a source or sink of sediments. Alteration of rivers for flood control, water supply, and other purposes, can cause the channel perimeter to function differently. Large numbers of the world's major rivers are dammed or channelized (Dynesius and Nilsson, 1995; Nilsson et al., 2005; Gregory, 2006), and portions of these rivers may function as sinks more so than in the past. Some of these altered rivers, generally in developed countries, are now sites of river restoration or rehabilitation (Bernhardt et al., 2006). Once flow is restored in these rivers, it is uncertain what will happen to the large quantities of organic and finer sediments that accumulated in these reaches.

When the Kissimmee River was channelized from 1962 to 1971, the original channel was largely left intact, creating several runs or abandoned channel reaches that were no longer receiving flow (Figure 5-1). These quiescent runs or channels allowed for deposition of fine and organic sediments on a river bed that presumably was originally sand-dominated. The organics come largely from decaying plant material within the runs, some being sprayed annually with herbicides to allow for boat traffic. The fines may come from local bank sources or from upstream or may have an origin due to spoil dumping in association with dredging from the channelization process (Figure 5-2). However, other bank materials including sand and other types of inorganic and organic materials may be added to the channel bed, particularly in sections with cattle that cause bank disturbances. Boat wakes and other animals may also cause bank failures and sediment contributions.

The objectives of bottom sediment monitoring were to characterize the sediments of the bed of runs in unrestored portions of the lower Kissimmee River (Pool D). This work was a continuation and refinement of investigations indicating the mitigation of the organic/marl riverbed layer in Pool C following Phase I restoration (SFWMD, 2005; Anderson et al., 2005a). The restoration expectation in remnant river channels is that mean thickness of substrate overlying bed deposits will decrease by >65%, percent of samples without substrate-overlying river bed deposits will increase by ≥165%, and the thickness of substrate-overlying river bed deposits at the thalweg will decrease by ≥70% (Anderson et al., 2005b). The current study seeks to establish the basis for providing a comprehensive response in the future (pending further studies) to the question of whether the organic sediments deposited on remnant river channels disappears through burial *in situ* by migrating sands or through erosion and downstream transport (possibly ending up in Lake Okeechobee).

Methods

The area of interest was in Pool D, from the beginning of Riverwoods Run to the end of Chandler Run. These runs have been quiescent since construction of C-38 in the 1960s, and have accumulated fine and organic sediments plus sands and other materials from bank failures. The bed is not currently active or mobile as in most alluvial rivers, but will likely become that way following restoration. Bottom sediments and organic layers were cored in portions of the river that were not yet restored when water levels were relatively low early each calendar year (Figure 5-3). Still, water depths locally exceeded 3m, which made coring a challenge. Riverwoods and Caracara runs are dominated by cattle pasture (Figure 5-4). Chandler Run is forested (Figure 5-5).

Each sample was collected with a vacuum piston corer with a two inch outside diameter core tube modified from the design of Fisher *et al.* (1992). The bottom portion was made of polycarbonate tubing to see the layers and the upper portion was made mostly of galvanized steel that was welded together to withstand boat and other movements (Figure 5-6). The corer was positioned carefully above the site and the piston cable was anchored securely to the boat to ensure that the soil water interface was collected in an undisturbed condition. Each core was collected in a single push from the water column to a depth where much more resistance was encountered and it became difficult to core any deeper. This resistant zone was generally sand-dominated, and presumably is the sand bed of the old Kissimmee River. Thus in most cases, the bottom of the core was sandy, although in some cases, loose sands may have fallen out or the upper fine and organic layers were so thick that this was not encountered. All cores were withdrawn from the sediments with the piston fixed in place and a firm vacuum seal so that sediment mixing between layers was minimized.

Once the core was retrieved, it was capped at the bottom and then photographed before the vacuum piston was removed (Figure 5-6). All cores layers were identified and measured through the clear wall of the core tube before extruding. Each core was extruded out the top of the core tube to preserve the integrity of the largely liquid layer at the soil water interface and was characterized in the field. Texture and wet Munsell color were evaluated, along with any notable features on a data sheet (Figure 5-7). Most of the cores were over 50 cm deep, with some cores extending over 1 m below the riverbed surface.

Cores were characterized into 3 basic categories: sand, fines (silt & clay) and organics based on field textures and classifications developed in 2007 based on labwork. The organics included very loose materials also called floc, more consolidated materials with slightly darker Munsell colors, and fibrous peaty layers. For purposes of simplifying graphics, these were grouped into one category. The flocs are the most likely to be resuspended once flows are resumed, and the other organic layers are more resistant to erosion. The fine sediments were similar to the organics in consistency, but lighter in Munsell color. Water depths sampled, and basic core descriptions and thicknesses were graphed in spreadsheets. The original bottom was inferred for most cores as a thick sand layer. In some cases, it was uncertain whether the original bottom had or had not been reached. In other cases, it seemed unlikely that the bottom was reached. These data were then annotated in spreadsheets.

In early 2007, two transects were cored in each Caracara and Chandler runs (Table 5-1). Five cores were taken in each transect to characterize the cross-sectional variability. An additional core near the thalweg of each transect was acquired about 3 m downstream for comparative purposes. All thalweg/lab analysis cores (cores located near the deepest point in the channel) were stored upright in the boat until after all coring was finished and the boat could put in for detail extruding. The other (non-thalweg) cores were extruded on the boat immediately after collection and photography and were characterized. Most of the cores were over 50 cm deep, with some cores extending over 1 m below the riverbed surface.

The thalweg samples brought back in 2007 were dried in a laboratory oven with open air circulation. Each sample was removed from its sample cup and transferred to an aluminum drying tin and then weighed wet. After weighing, the samples were dried at approximately 105° C until the samples were completely dry and then reweighed after cooling. Loss on Ignition (LOI) to evaluate organics and carbonates was calculated using procedures recommended by Heiri *et al.* (2001). The samples were then transferred from a drying tin to a ceramic crucible with an already calculated empty weight and weighed again to establish the sample pre-LOI dry weight. The crucibles containing the samples were placed in a high temperature baffle furnace and cooked for five hours at 550° C. After exactly five hours at a furnace temperature of 550° C the furnace was shut down and the samples were given overnight to cool. The following day the crucibles containing the samples were removed from the oven and weighed to determine the post LOI weight. This information was then used in the following equation to calculate the percent loss on ignition.

$$LOI_{550} = \left(DW_{550} - DW_{105} / DW_{550}\right) \times 100$$

Next, the percentage of carbonates was determined. After the %LOI was calculated the samples were returned to the furnace and heated to 950° C and cooked for two hours. After exactly two hours at 950° C the furnace was shut down and the sample was given overnight to cool. The following day the crucibles and samples were weighed again to calculate the percent loss of carbonates or LOI at 950° C.

$$LOI_{950} = \left(DW_{950} - DW_{550} / DW_{105}\right) \times 100$$

Once organics and carbonates were removed, remaining portions of the samples were then run through a #230 (62µ) sieve to separate the coarse- and fine-fractions for particle size estimation. These were then weighed to determine the percent sand and percent silt and clay by mass. Once organics and carbonates were removed, remaining portions of the samples were then run through a #230 (62µ) sieve to separate the coarse- and fine-fractions for particle size estimation. These were then weighed to determine the percent sand and percent silt and clay. Core data and lab data were both input in spreadsheets to produced graphs.

In early 2008, six transects were cored in Caracara and Chandler runs in Pool D and described on data sheets (Table 5-2). For each run, three transects were in straight reaches and three in bendways (Table 5-2). Similarly, two transects, one at a straight reach and the other at a bendway, were sampled in Persimmon Mound Run of Pool A, allowing for eventual assessments in the BACI (before-after-control-impact) design (Stewart-Oaten et al, 1986; Smith, 2001). This run was chosen because of its length (portions were distant from C-38) and width, which allowed access by motorboat.

Given the large amount of variability observed in close proximity (3-m downstream) to the cross sectional transects, coring in 2009 was conducted at random points along the centerline, in Pool D from Riverwoods Run through Chandler Run. It was decided to limit sampling to the centerline because this was furthest from the channel boundaries where associated disturbances (cattle trampling, vegetative spraying, failures induced by boat wakes) might cause localized disruption of the sedimentary sequences. The bed sediments of cores collected close to the bank in past years showed layering which was more complex as a result of multiple disturbances along the system. The centerline for the Pool D runs was digitized from 2004 DOQQ imagery, FL Stateplane East projection, MrSID format. Cores were taken along the centerline to minimize contributions from bank failures, including disturbances from cattle. The centerline feature was transformed into a point features using Xtools Pro version 5.3.0 with a point to point distance of 1 meter using the "Convert Features to Points" tool.

A random number generator was run for the entire data set of 17821 points. Out of these points, 100 were chosen as possible coring point locations as determined by the random number generator from the website: http://www.random.org/integers/ . No duplicate numbers were generated from the 100 attempts. Of the first 50 points (numbers) selected randomly, 13 were on dry land or in C-38. To bring the total core points to 50 the next 13 numbers generated were chosen and locations verified using the 2004 DOQQs. Of the 50 random core point locations, 34 were in Riverwoods Run, 10 were in Caracara Run, 2 were in Ft. Basinger Run and 6 were in Chandler Run. The coordinates of these randomly chosen locations were saved as waypoints in a GPS, and were navigated to by boat. Coring was done within 3 m of the selected location, aiming to be near the center of the channel. The boat position was maintained by using an anchor and long poles for temporary support (Figures 5-8, 5-9 and 5-10).

Results

Locations of cores collected in 2007 are shown in Figures 5-11 to 5-17 and the generalized descriptions are shown in Figures 5-18 to 5-25. In Caracara Run (Figure 5-12), the surface organic layer was very thin (generally less than 2 cm). In Transect 1 (Figures 5-12 and 5-13) in the straight reach, two of the five cores had no surficial organic material (Figure 5-18). The thalweg core had a buried organic layer which was 11 cm, thicker than any surficial layer on this transect. Because the top of it was 70 cm below the bed surface, it likely would have been missed with many other coring devices. Even in close proximity, cores were often different. For instance, in Transect 1 in Caracara Run, the thalweg core and a core taken 3 m downstream were very different. In the thalweg, there was a relatively thin (2 cm) organic layer, but in the downstream core, it was relatively thick (70 cm) (Figure 5-19). In Transect 2, the bendway (Figures 5-12 and 5-14), the surface organic layer was also 2 cm or less (Figure 5-20). One of the cores had a buried organic layer which was 10 cm thick. A core in a similar geomorphic position downstream instead had a buried organic layer which was 24 cm thick (Figure 5-21). Given the complexity of the bed, and the uncertainty of the spatial and temporal variation of processes there, these layers may not be temporally (stratigraphically) correlated.

One hypothesis under consideration was that organic layers would be thicker nearer the sides, as that was where the spraying for invasive aquatic vegetation was concentrated. However, there was no discernible pattern in either of these transects. Nor was the thickest organic layer always at the top. In Caracara Run, the thickest layer in both transects 1 and 2 was buried. The variation between the two cores collected in close proximity was much more different than expected. A possibly confounding factor may be bank failures associated with cattle activity in pastures.

In Chandler Run (Figures 5-15 to 5-17), the thickest organic layer was always at the top (Figures 5-22 to 5-25). Where the channel geometry was asymmetric (bendway), it was located on the shallower side (Figure 5-22). Where the channel geometry was symmetric (straight), thick organic layers were found on both sides of the channel (Figure 5-24). At both transects in this run, the thalweg core and nearby downstream core were much more similar (Figures 5-23 and 5-25).

The sediments overlying the firmer sand bed averaged about 20% organic (maximum of about 50% organic) and for the most part less than 10% carbonate (Figure 5-26). Thus, the sediments were of dominantly of mixed clastic lithology, even though they have a very dark appearance. Thus, even though these sediments are thick in places, those concerned with potential flushing should consider that organics may comprise a smaller percent of these deposits than might be interpreted on appearance alone.

After preliminary work in 2007, a decision was made at the kickoff meeting to examine more transects in both Caracara and Chandler Runs in 2008 to see if other patterns emerged. Some coring was also conducted in Persimmon Mound Run in Pool A as a possible control for future studies. Coring was also conducted in Montsdeoca Run in Pool B/C to ascertain the current nature of bed materials in restored sections of the river. There were three cores collected in Montsdeoca, none characterized in detail, because they were sandy at the surface and sandy throughout. Thus, if fines or organics had been present, these were likely flushed to a downstream location. This implies that substantial erosion of the riverbed, on the order of about 1 m if the thicknesses were similar to other runs, has occurred in the restored reaches.

The location (Figure 5-27) and generalized descriptions (Figures 5-28 to5-31) of cores collected in 2008 in Persimmon Mound Run of Pool A are shown. Persimmon Mound Run is a fairly shallow run with abundant organics. In general, organic and fine deposits tend to be thickest in the deeper sections (Figures 5-28 to 5-31).

Six transects were collected in Caracara Run (Figure 5-32) in 2008 and their core descriptions are found in Figures 5-33 to 5-38. It was not unusual to find sand deposits overlying organics near the channel boundary (Figures 5-33, 5-34 and 5-35). Sometimes the sand layer at the base had discernible organic layers (Figures 5-36, 5-37 and 5-38). In general, there appeared to be more fine and organic sedimentation in deeper sections.

Six transects were also sampled in Chandler Run (Figure 5-39) in 2008. Core descriptions of these transects are found in Figures 5-40 to 5-45. In general, Chandler Run was deeper than Caracara Run and had more organic sedimentation. Some portions were currently 4.6m deep at low water, and the thickness of organic sediments suggested that they may have been as much as 6 m originally (Figure 5-43). It was not uncommon for there to be more than 1 m of fine and organic sediments in the cores in this run (Figures 5-40, 5-41, 5-43, and 5-44). This also may be true of additional cores, as the sand bottom was not reached in some cases (Figures 5-40, 5-43, and 5-45).

Again, based on discussions at the following kickoff meeting, a different sampling strategy was used for 2009 involving random sampling along the centerline. Location and generalized descriptions of cores collected in 2009 are shown in Figures 5-46 to 5-53.

A total of 32 cores were collected in Riverwoods Run in 2009 (Figures 5-46 to 5-49). Seven of the ten cores in the uppermost portion of Riverwoods Run had over 0.5m of organic and fine sediment before reaching the more resistant sand layer, assumed to be the bottom of the channel before the river was channelized (Figure 5-46). All were located in water depths over 1.5 m. Core 8, collected in water depths over 2 m, the deepest of this group, also had the more than 1 m of fine and organic sediments, the thickest of this group. The other three cores (numbers 5-7) were located in a shallower stretch of channel with depths ranging from 1-1.2 m and all had a thick sand layer within 10 cm of the surface.

The upper middle portion of Riverwoods Run began with a shallow stretch of 1.1-1.4 m water depths; these six cores all had a thick sand layer was within 0.3 m of the surface (Figure 5-47). In four of these cores, the thickness of fines and organics was less than 10 cm. The next four cores were in deeper water, between 1.6-1.9 m; the quantity of fine and organic sediments was thicker than in the shallower stretch, averaging about 0.5 m and ranging from 0.35-0.7 m (Figure 5-47). Cores in the lower middle portion of Riverwoods Run had variable water depths from 0.9 to 1.7 m water depths (Figure 5-48); in all cores, sand was within 0.3m of the surface. In the first seven cores, sand was within 0.1m of the surface. In the last four cores in the lowermost portion of Riverwoods Run, the thick sand layer was generally within 0.3 m of the surface (Figure 5-49). Water depths ranged from 1.5 to 1.8 m. Overall, it seemed like the upper portion of this run had more fine and organic sedimentation that the lower portion of the run. Local anomalies occurred in shallower areas in which the sand was generally very close to the surface of the bed.

Ten cores were collected in Caracara Run in 2009 (Figures 5-50 and 5-51). As with Riverwoods Run, it seemed like the upper portion of this run had more fine and organic sedimentation that the lower portion of the run. Water depths where the first six cores were taken were fairly uniform and all close to 1 m (Figure 5-50). However, the sand layer was found at variable depths ranging from 1.0 to 1.8 m, suggesting that the bottom topography may have become more uniform through local sedimentation (Figure 5-50). Water depths where the next four cores were taken were more variable, ranging from 0.9 to 1.8 m (Figure 5-51). The original bottom topography, however, may have been more variable as the cores currently in deep water typically have more fines and organics, suggesting more sedimentation in these locations (Figure 5-51). It is unknown how much of this sedimentation is associated decaying plant material within the runs (some being sprayed annually with herbicides to allow for boat traffic) or from local bank sources including disturbances from large animals and boat wakes or from upstream or from spoil dumping in association with dredging from the channelization process. Not knowing the origin, it is difficult to know when most of this was deposited.

Only two cores were collected in the very short Ft. Basinger Run in 2009 (Figure 5-52). The water depths here varied from 1.4 to 2.3 m, with both cores having 0.6 m or more of organic and fine sediments. Given the short length of the run, neither of these locations is very far from C-38, and it is possible both are influenced by its proximity to the canal.

Six cores were collected in Chandler Run in 2009, all upstream of the tributary (Figure 5-53). Chandler Run is the most heavily forested run and seems to be deeper overall than the others. Depths where cores were collected ranged from 1.8 to over 3.4 m. Fine and organic sedimentation here is more than some of the other runs, perhaps in part due to the increased depths. A few cores have about 1 m of fine and organic sediments, and possibly more as the sand bottom was not reached due to the thickness of sediments and higher water depths (Figure 5-53).

The data for all 52 cores collected in 2009 were summarized in a spreadsheet. For each core, the inferred bottom was inferred from a thick sand layer. If the sand layer was within the core and less than 10 cm thick, with more fines and organics below, this was not considered the sand bottom. In most cases, a second thicker layer lower in the core was found. The water depth to the original bottom was calculated by adding up the fine and organic layers plus the sampling water depth. Sedimentation was calculated by adding the organic and fine layers and any thin intervening sand layers. Minimum thicknesses were used where the bottom had not yet been reached (5 of 52 cores). Best guesses about the bottom were made in the 9 of 52 cases where it was uncertain. Depth of the original bottom was graphed with inferred sedimentation (Figure 5-54). There seems to be a general correlation with the depth of the inferred original bottom and fine and organic sedimentation. Deeper areas, because of the larger cross sections, seem to be areas of greater sedimentation. Correlations of these two variables was fairly good ($r^2 = 0.54$).

Discussion and Conclusions

Coring the bed of the Lower Kissimmee River is challenging logistically, and this effort is the most comprehensive investigation of bottom sediments in the river to-date. There are not many comparable examples of this type of bottom sediment sampling in rivers with sandy and mixed bed lithology. Most other studies involve surface sampling of coarse sediments, or a comparison of the armor or coarse sediments at the top with the sub-armor layer or finer sediments below. Nor was there any detailed bed sampling of the Lower Kissimmee River prior to channelizing it in the 1960s. It would have been very helpful to have had either sediment or bathymetric data to make interpretations about the sedimentation in the runs, but since that was not possible inferences or best guesses were made from modern cores.

In 2007, coring along the cross-sectional transects established for surveying (Chapter 4) suggests that the sediments collected near the sides of the channel may be confounded by bank failures or other mechanisms which bring in sandy sediments. Also, it was learned that the thalweg core was often different from a thalweg core collected about 2 m downstream. The reasons for the bottom variability in this river could be due to a number of factors prior to and since channelization, such as initial differences in bed topography, disturbances created by channelization, and modern activities in the floodplain. In some cases, a sandy bottom was not reached, and in other cases the inferred initial sandy bottom had organic layers, possibly associated with historic flood events.

Coring in 2008 confirmed that the bottom sediments collected closer to the channel sides showed disturbances that may reflect bank failures. The greater number of cores showed that fine and organic sedimentation tends to be greatest where the inferred initial bottom depth was greatest. As during sampling in the prior year, a sandy bottom was not reached in all cases, especially in the deep portions of Chandler Run. In some cases the inferred initial sandy bottom had layers with fine and organic layers, possibly associated with historic flood events which may have brought in floodplain material or backwater from Lake Okeechobee on the failing limb.

Of the 52 cores collected in 2009, the original sand bottom was likely reached in 38 cores, and possibly in 9 others. For the 5 other cores where the original bottom was likely not reached, it was assumed that the presumed sand bottom was close below. The depth to the bottom of the core was used to calculate the minimum amount of sedimentation and the presumed depth to the original riverbed. The mean thickness of fine and organic sedimentation across the 52 cores acquired in Pool D based on such assumptions was 38 cm. There seems to be some spatial patterns in areas that have the greatest inferred sedimentation. The upper and upper middle portions of Riverwoods Run, has more than the lower portion. On aerial photographs, this upper portion seems to be more closed in by vegetation. The spatial patterns may also be due to spatial variations in water depth, as the areas that are currently the shallowest seem to have the least fine and organic sedimentation.

It was found that there generally tends to be more fine and organic sedimentation in places that were (and in most cases still are) deeper portions of the runs. If this generalization is true, than some rough estimates of fine and organic material deposited in these runs can be made if the data are combined with more bathymetry. Thus, more collection of bathymetric data may be helpful in better understanding the thickness of sediments. Repeat bathymetric surveys, before and after restoration, could also be helpful in ascertaining or estimating the quantity of materials removed. Coupled with repeat coring following this random sampling design, it can be assessed how much sediment thicknesses have changed and how much the depths (subtracted from a consistent datum) have changed. These two lines of evidence put together will make for a better understand of the fate of the fine and organic sediments in Pool D following the restoration.

Acknowledgments and Disclaimers

The opinions and interpretations expressed herein, and any errors that may be present, are of the authors and not that of the South Florida Water Management District. However, credit is due to many Kissimmee River restoration personnel who contributed in various ways. José Valdes was the project manager for this study, provided scientific suggestions and arranged logistical support. District personnel including Amber Graham and Brent Anderson assisted with boat transport and field work. Lawrence Spencer assisted with GPS logistics. Bonnie Rose provided imagery. University of Florida Geography graduates Jeff Cooley and Michael Suharmadji assisted with field work.

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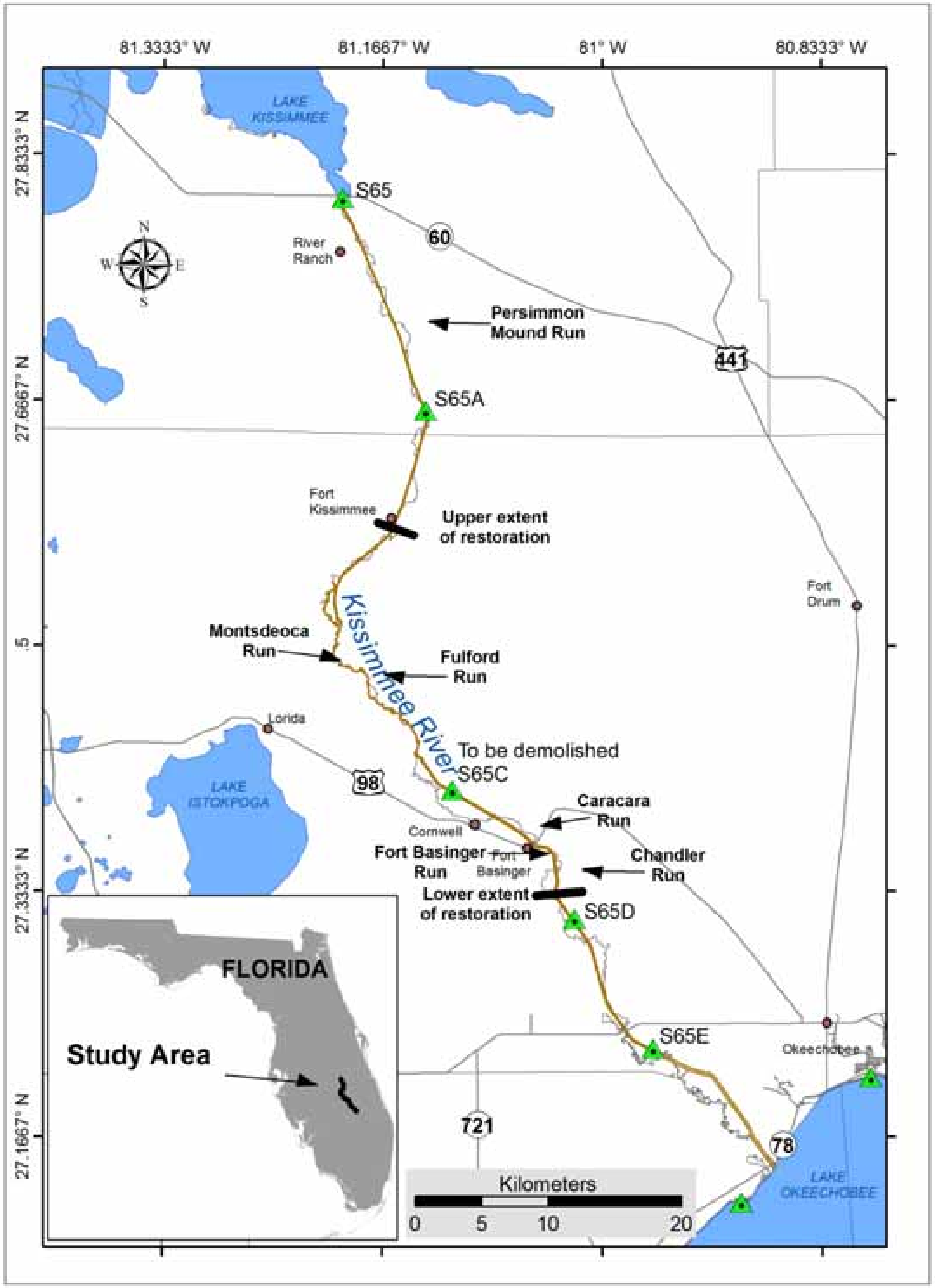


Figure 5-1. Location of the Lower Kissimmee River and its major restoration features. Runs where coring was conducted are labeled. The area currently restored is in Pool B-C (upstream of S-65C). This chapter focuses on 2009 coring in Pool D, where the river will eventually be restored.

Figure 5-2. Variable bank sediments upstream in Pool C (Montsdeoca Run)

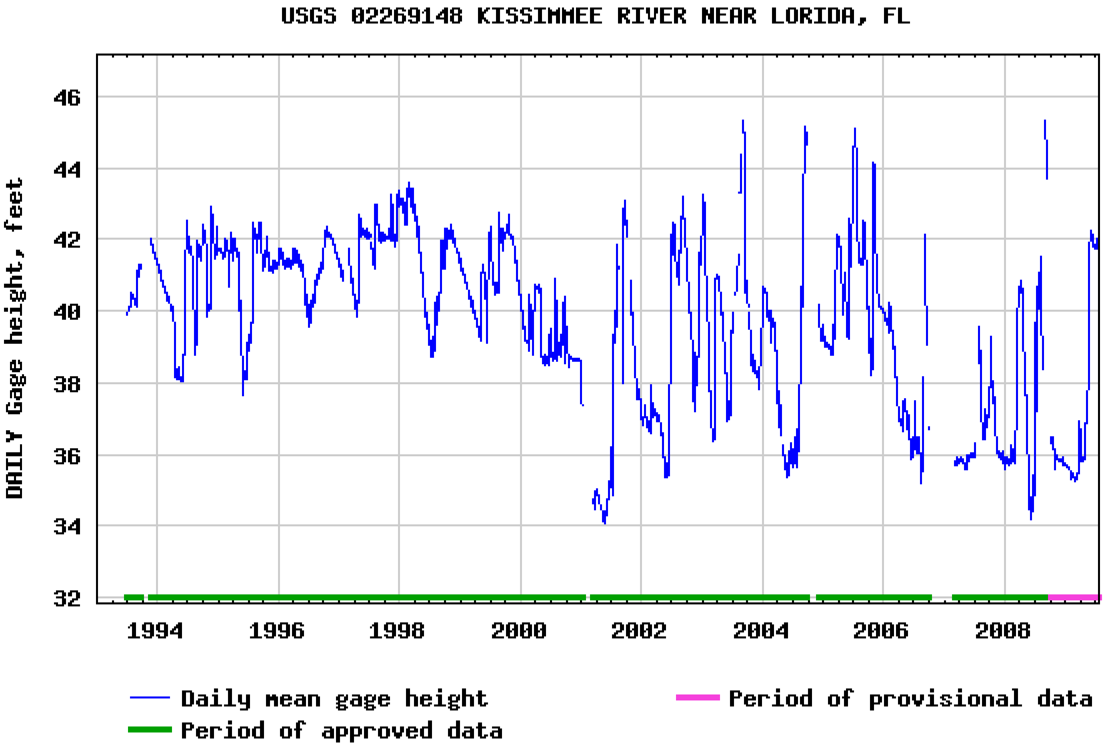


Figure 5-3. Gage height on the Kissimmee River near Lorida since January 1993. Water levels were relatively low and consistent (35-36 ft) during coring in January-February 2007, 2008 and 2009. Demolition of S65-B was during June 2000, after which water level variations have increased. Stages have been about 4 feet lower and 2 ft higher since July 2000, compared to the period between 1993 and June 2000.

Figure 5-4. Typical land use and land cover in Caracara Run. Riverwoods Run is similar.

Figure 5-5. Typical land use and land cover in Chandler Run.

Figure 5-6. This photograph shows the length of polycarbonate tubing and how the bottom sediments of the Kissimmee River can be described. In this core, organic and fine sediments overlie a sand bottom, presumably the bed of the channel prior to channelization.

KISSIMMEE RIVER BED SEDIMENT CORES

Station ***Site*** ***Date***
Location ***Latitude*** ***Longitude***

Transect Position

Sediment Layer #	***Depth (cm)***	***Composition (Est.)***	***Sediment Type***	***Root Content***	***Cohesiveness***	***Munsell Color***	***Variability***
KEY							
Numbered 1, 2, 3 from top to bottom	*Depth below surface of water*	*Dom. Inorganic (>70%)*	*Clay-dominated*	*Roots abundant*	*In an open palm, does it run between your fingers?*	*See book*	*Uniform*
		Dom. Organic (>70%)	*Silt-dominated*	*Roots common*	*Solid*		*Mixed*
		Mixed org/inorg. (30-70%)	*Sand-dominated*	*Roots few*	*Liquid*		*Layered*

Figure 5-7. Core description data sheet used for Kissimmee Restoration study.

Table 5-1. Locations of coring transects in 2007. S indicates a straight reach, and B is a bendway on a meander.

Run Name	Pool	Transect Type	Number of Transects (2007)	Number of Cores (2007)
Caracara	D	Remnant (pasture)	2 (1S, 1B)	12
Chandler	D	Remnant (forest)	2 (1S, 1B)	12
TOTAL				24

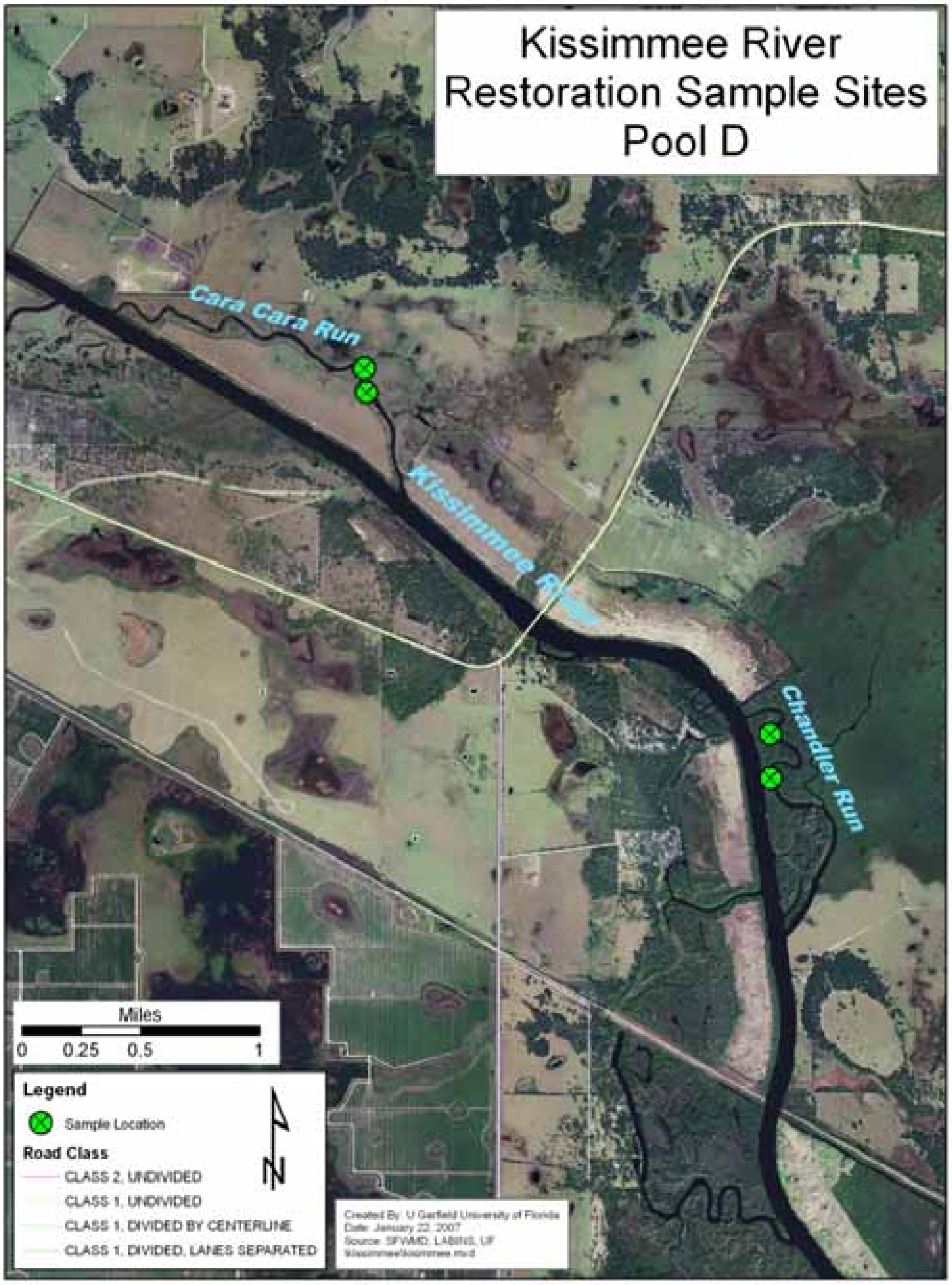
Table 5-2. Locations of coring transects in 2008. S indicates a straight reach, and B is a bendway on a meander.

Run Name	Pool	Run Type	Number of Transects	Number of Cores
Persimmon Mound	A	Control (pasture)	2 (1S, 1B)	14
Montesdeoca	C	Restored		3
Caracara	D	To be restored (pasture)	6 (3S, 3B)	30
Chandler	D	To be restored (forest)	6 (3S, 3B)	30
TOTAL			14	77

Figure 5-8. Coring the streambed with vacuum piston corer. Photograph shows galvanized pipe extension.

Figure 5-9. Stabilizing the boat with PVC pipes to streambed to facilitate coring.

Figure 5-10. Stabilizing the boat with anchor and checking the GPS for randomly selected predetermined coring location.



Created By: U Garfield University of Florida
Date: January 22, 2007
Source: SFWMD, LABINS, UF
kissimmee\kissimmee.mxd

Figure 5-11. Locations of transects in Caracara and Chandler Runs where cores were collected in 2007.

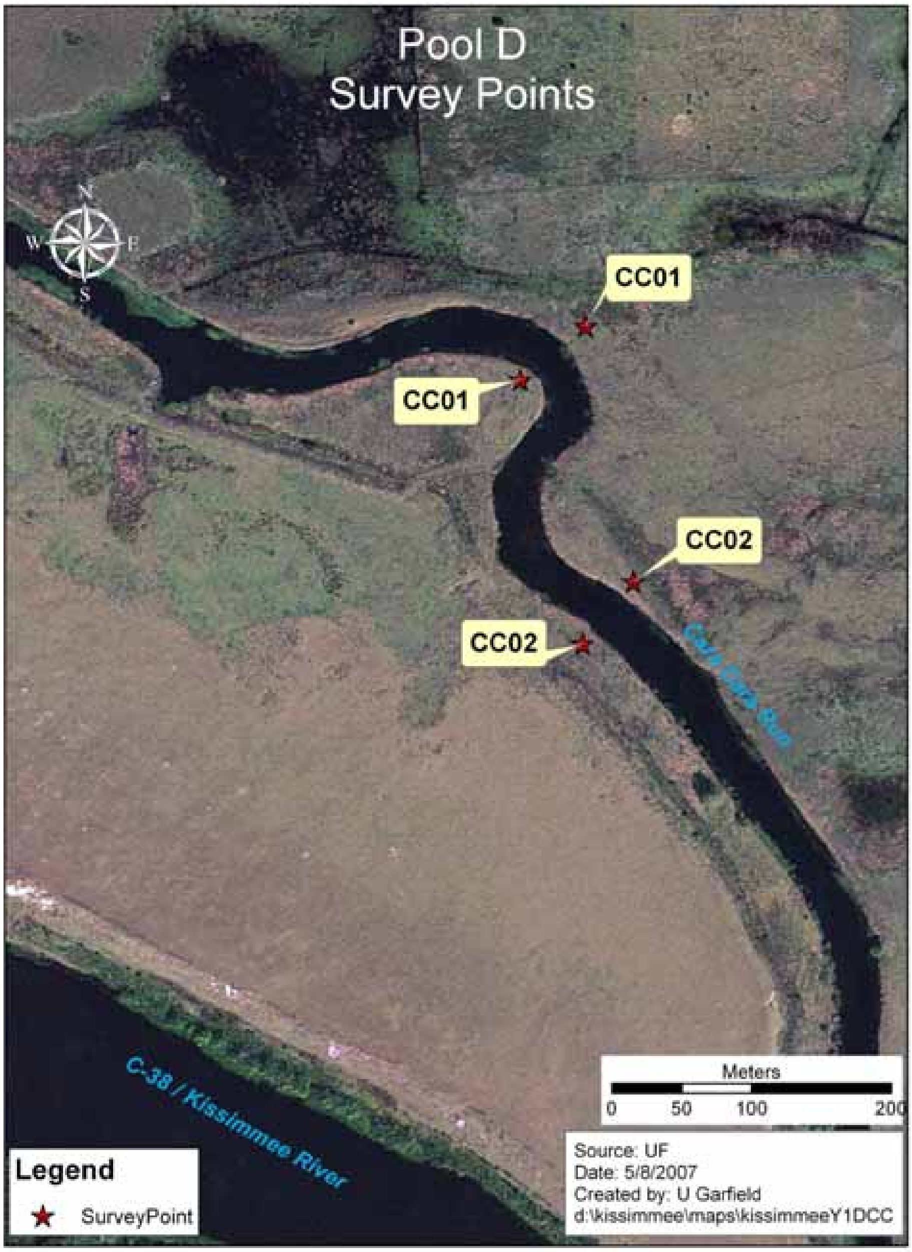


Figure 5-12. Coring in 2007 was conducted at the same locations as survey transects. This image shows locations of Caracara Run Transects 1 and 2.

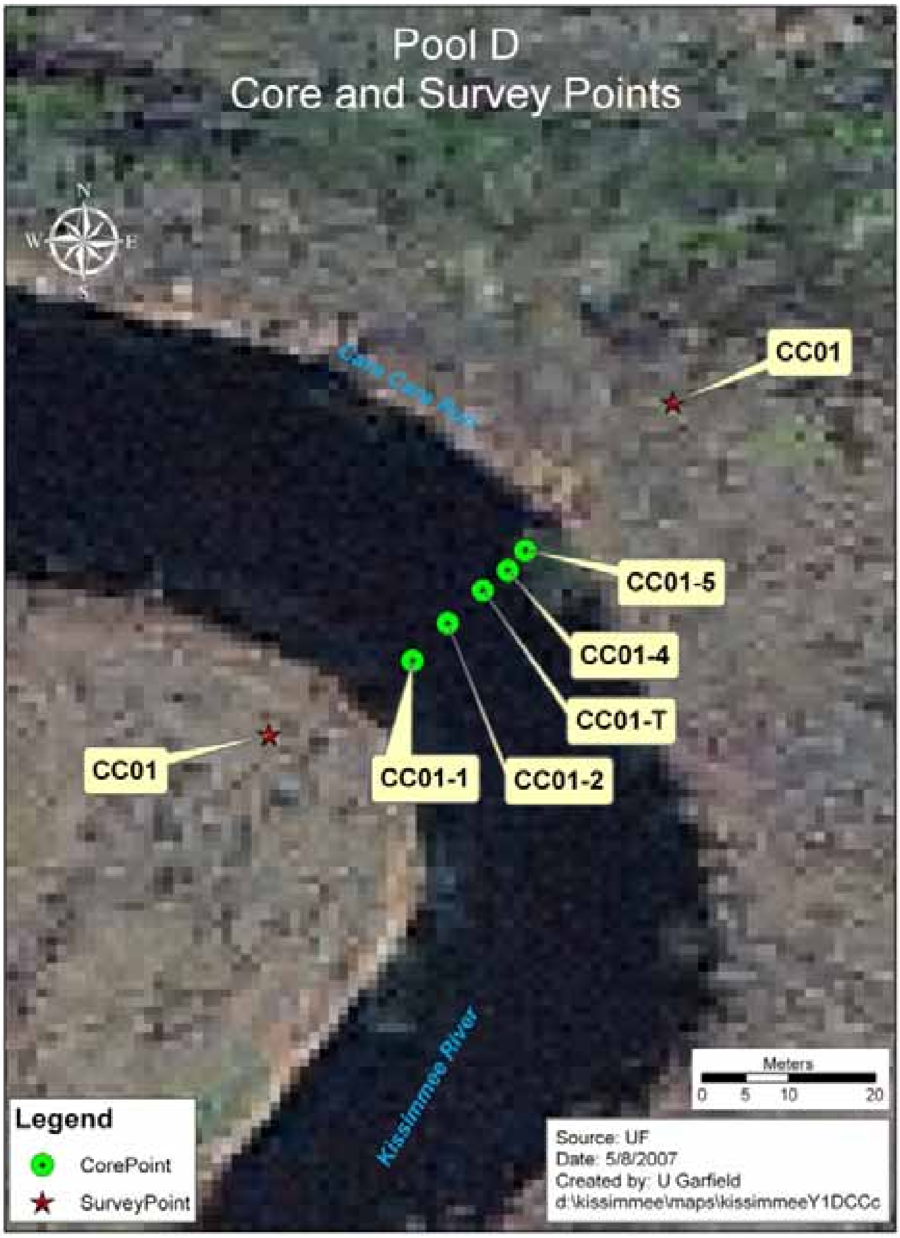


Figure 5-13. Caracara Run Transect 1. Coring in 2007 was conducted at the same locations as survey transects. Location where the 5 cores were obtained are shown with the thalweg core labeled T. An additional core was collected approximately 2 m downstream for comparison.

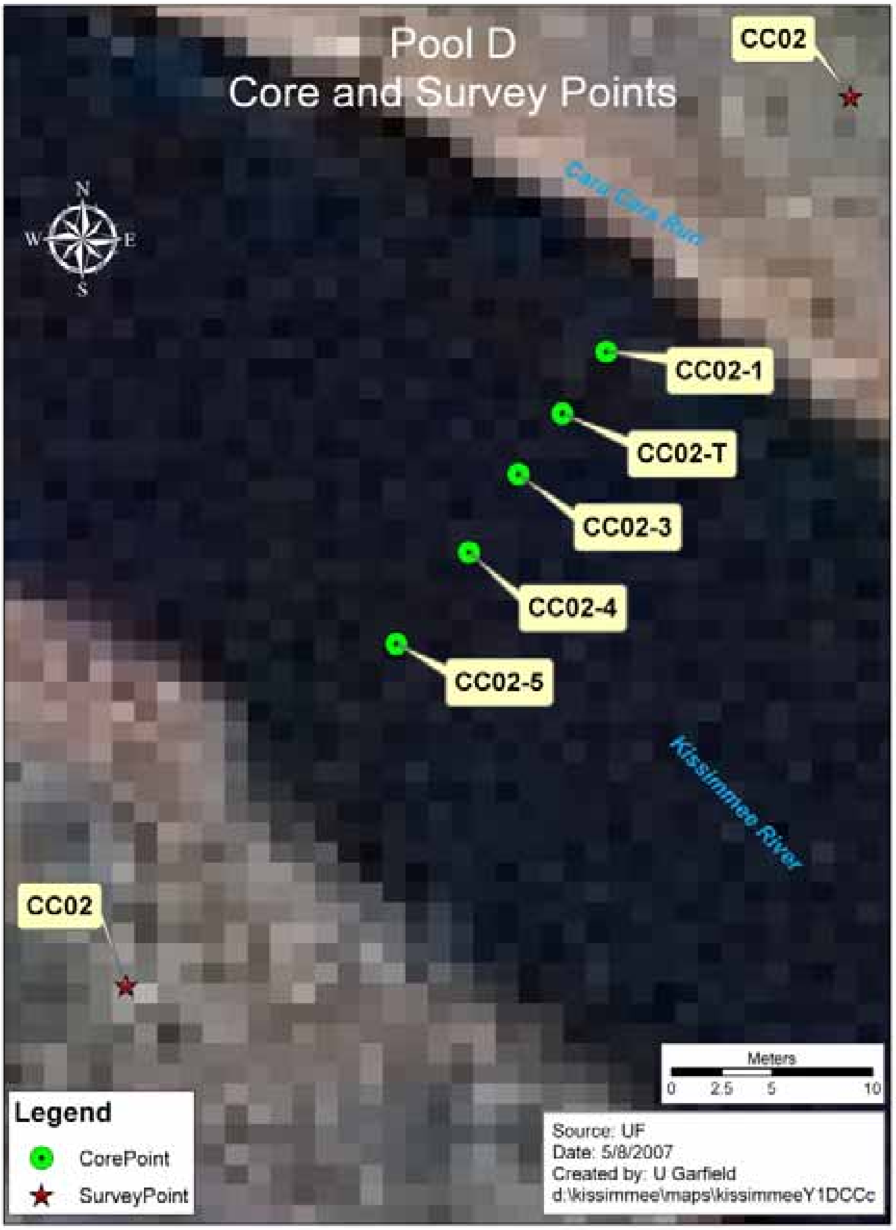


Figure 5-14. Caracara Run Transect 2. Coring in 2007 was conducted at the same locations as survey transects. Location where the five cores were obtained are shown with the thalweg core labeled T. An additional core was collected approximately 2 m downstream for comparison.

Figure 5-15. Coring in 2007 was conducted at the same locations as survey transects. This image shows locations of Chandler Run Transects 1 and 2.

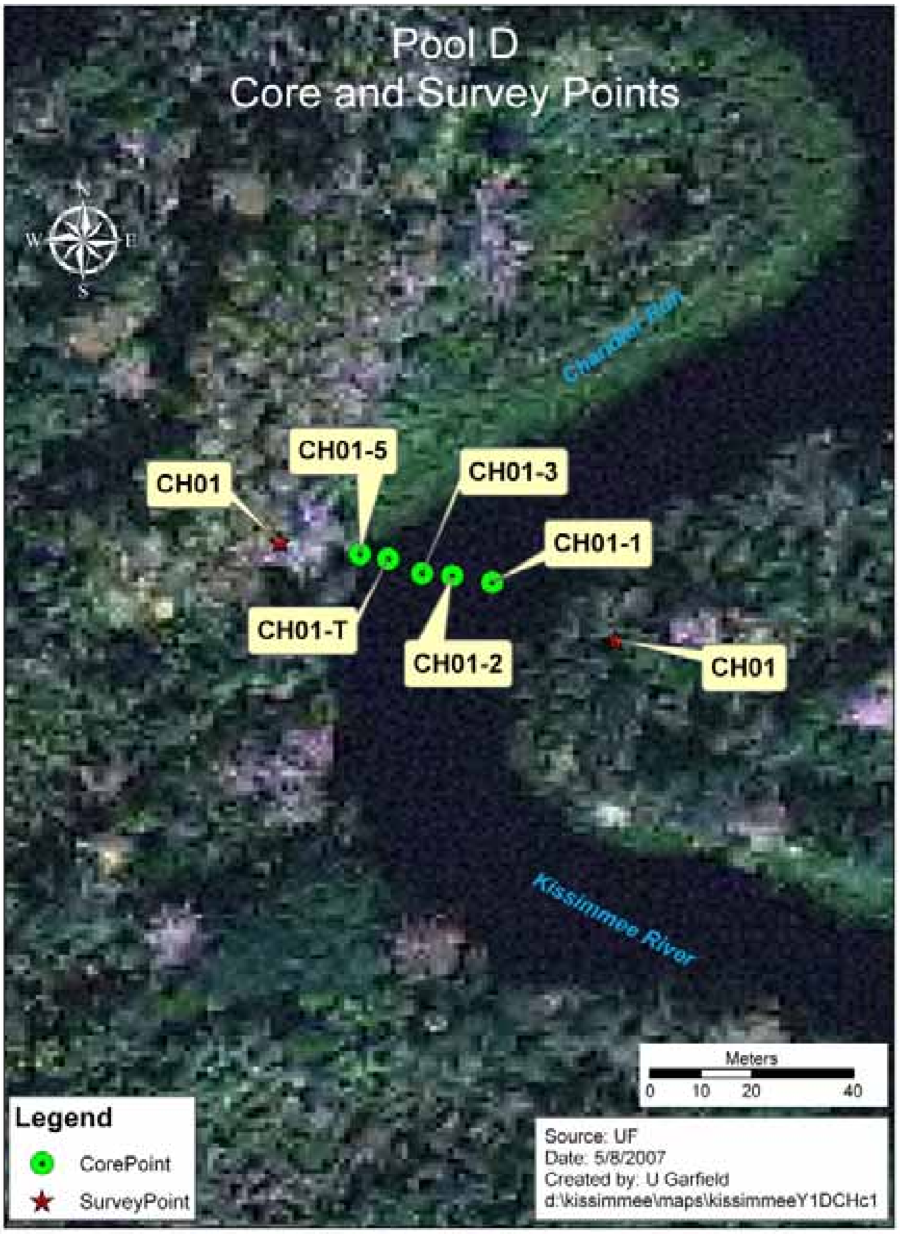


Figure 5-16. Chandler Run Transect 1. Coring in 2007 was conducted at the same locations as survey transects. Location where the five cores were obtained are shown with the thalweg core labeled T. An additional core was collected approximately 2 m downstream for comparison.

Pool D
Core and Survey Points

Source: UF
Date: 5/8/2007
Created by: U Garfield
d:\kissimmee\maps\kissimmeeY1DCHc2

Figure 5-17. Chandler Run Transect 2. Coring in 2007 was conducted at the same locations as survey transects. Location where the 5 cores were obtained are shown with the thalweg core labeled T. An additional core was collected approximately 1 m downstream for comparison.

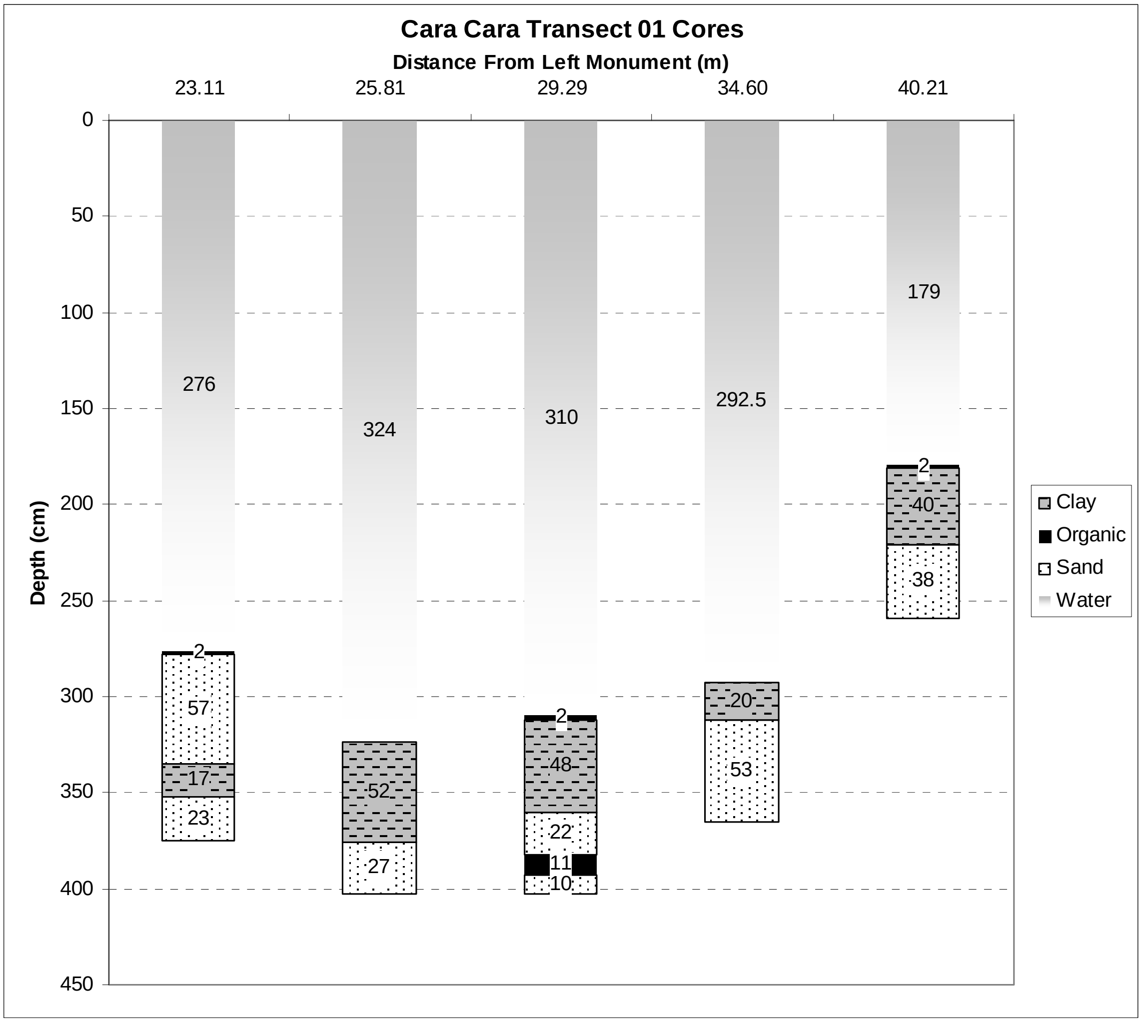


Figure 5-18. Major stratigraphic layers in Caracara Run, Transect 1 from 2007 core sampling.

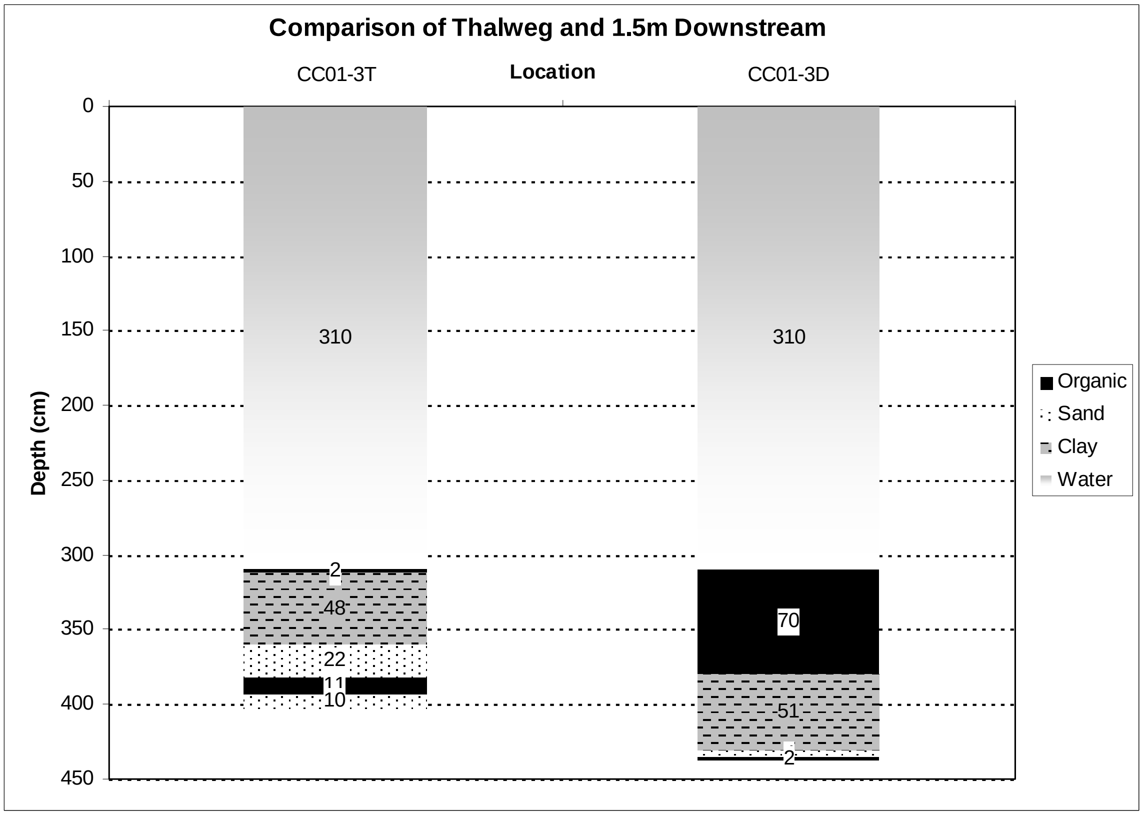


Figure 5-19. Comparison of major stratigraphic layers in Caracara Run, Transect 1, thalweg core vs. core 1.5 m downstream from 2007 core sampling.

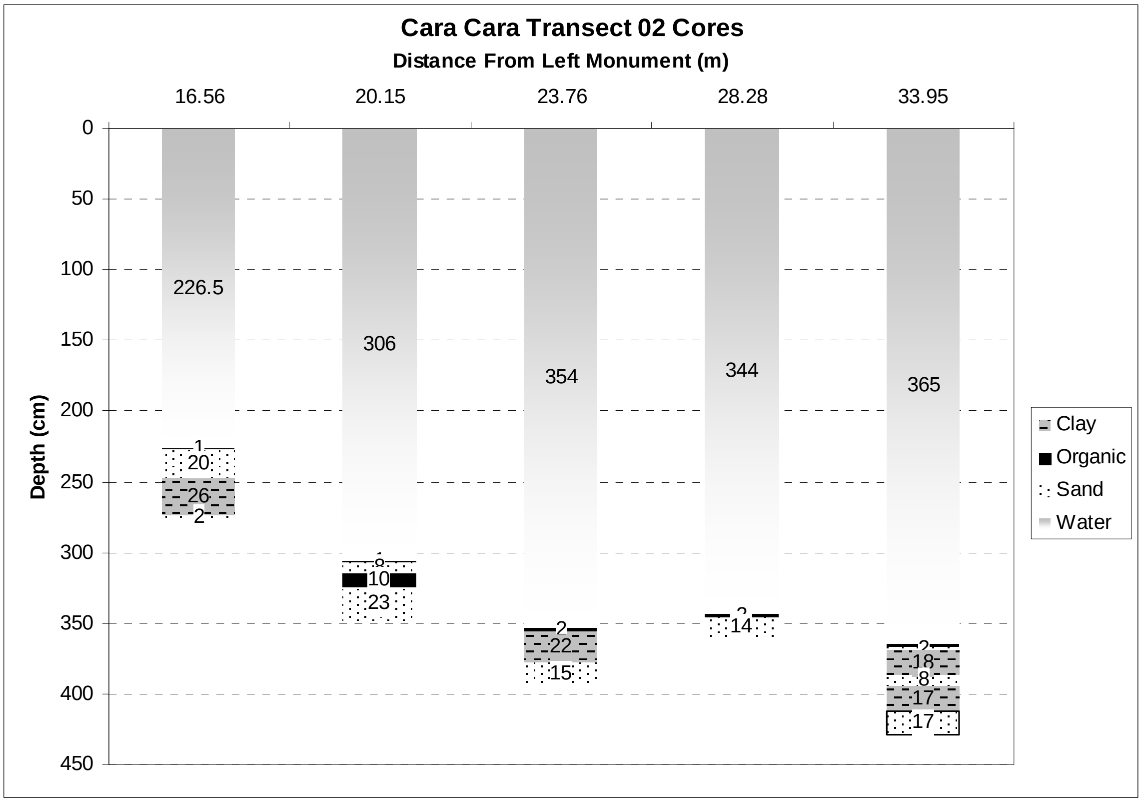


Figure 5-20. Major stratigraphic layers in Caracara Run, Transect 2 from 2007 core sampling.

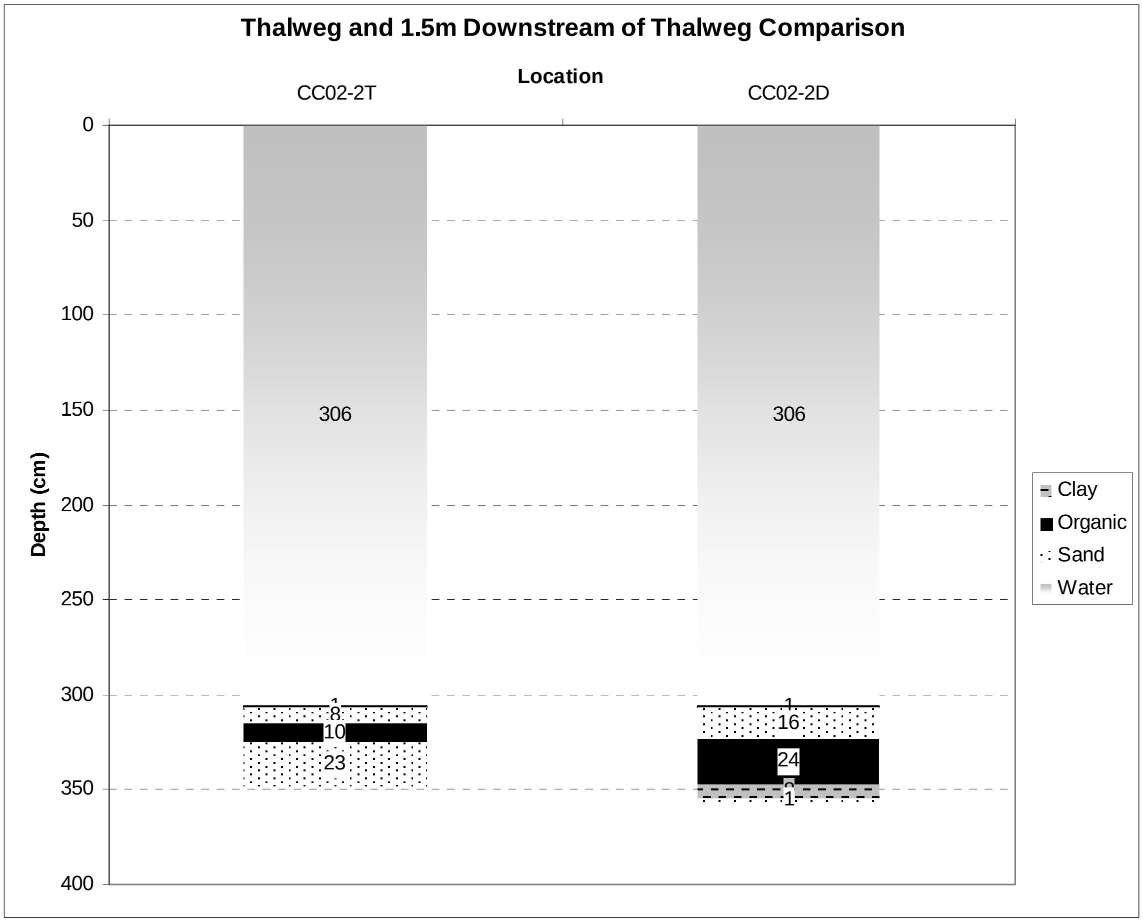


Figure 5-21. Comparison of major stratigraphic layers in Caracara Run, Transect 2, thalweg core vs. core 1.5 m downstream from 2007 core sampling.

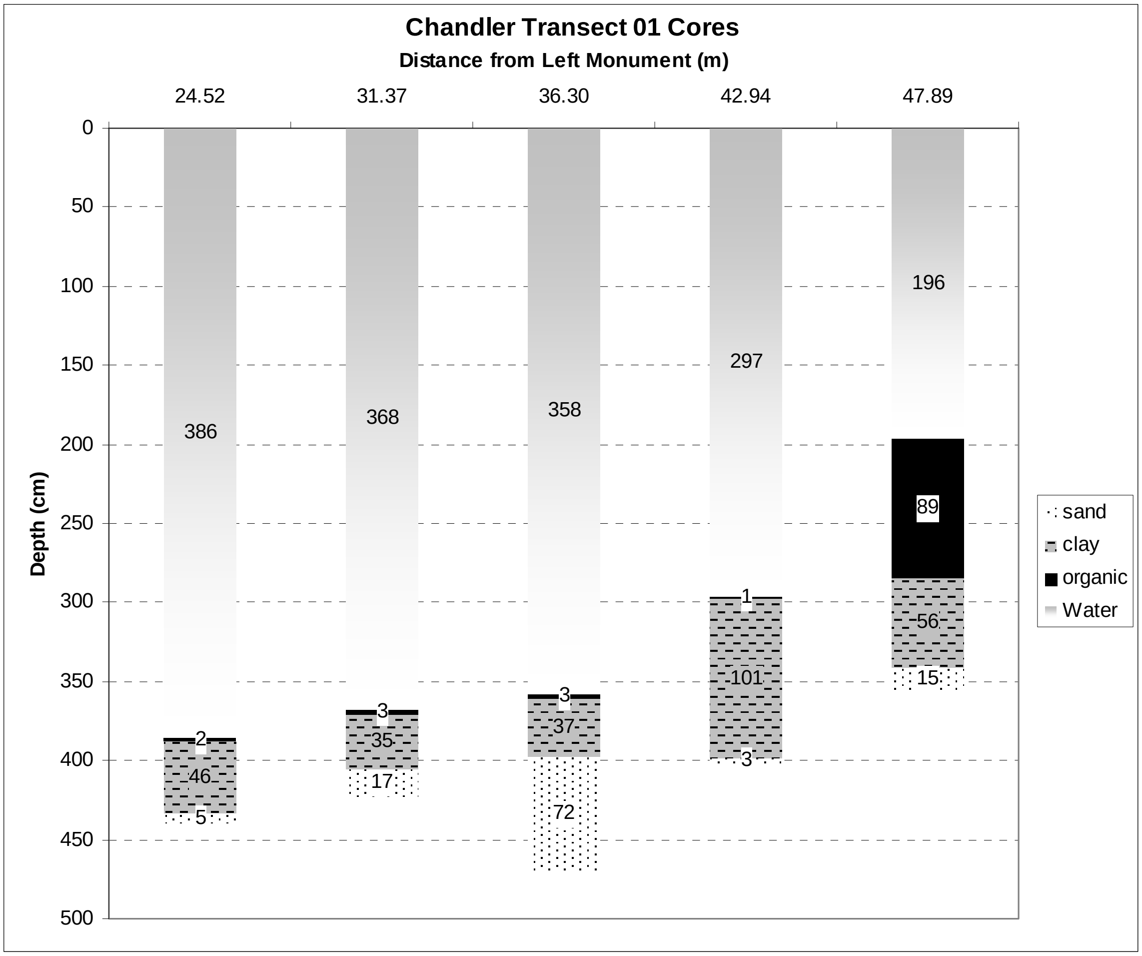


Figure 5-22. Major stratigraphic layers in Chandler Run, Transect 1 located at a bendway from 2007 core sampling.

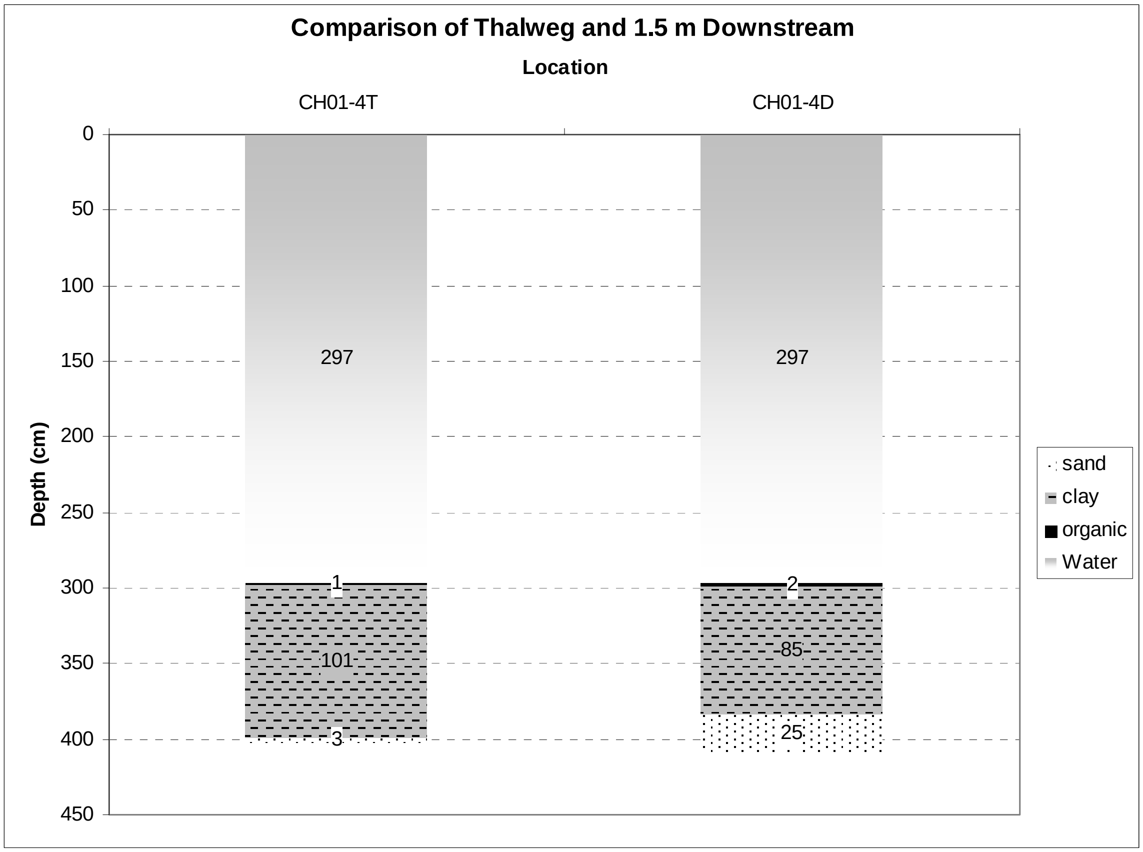


Figure 5-23. Comparison of major stratigraphic layers in Chandler Run, Transect 1, thalweg core vs. core 1.5 m downstream from 2007 core sampling.

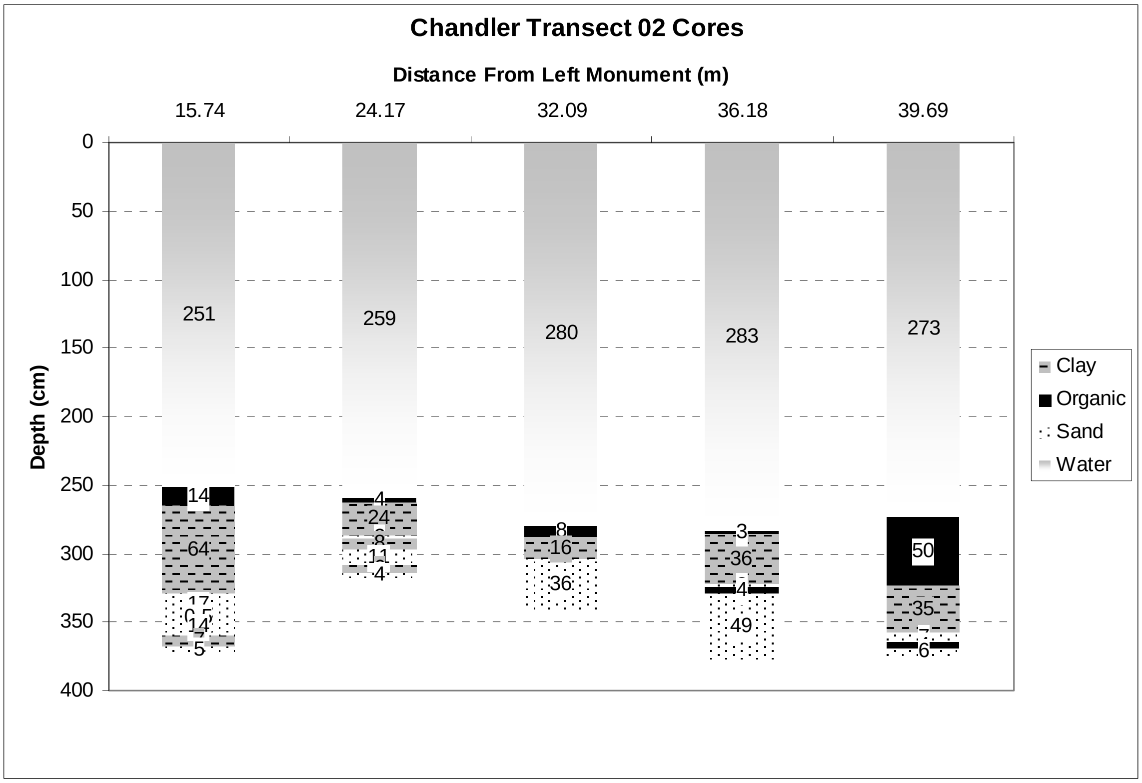


Figure 5-24. Major stratigraphic layers in Chandler Run, Transect 2, located at a straight reach from 2007 core sampling.

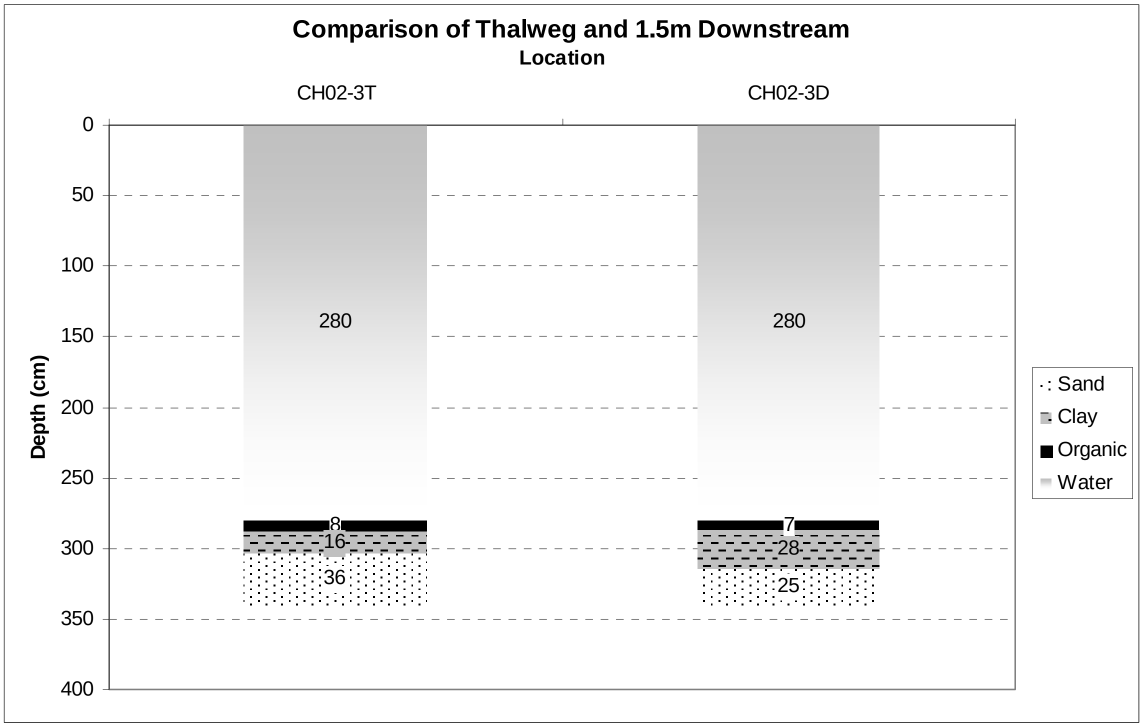


Figure 5-25. Comparison of major stratigraphic layers in Chandler Run, Transect 2, thalweg core vs. core 1.5 m downstream from 2007 core sampling.

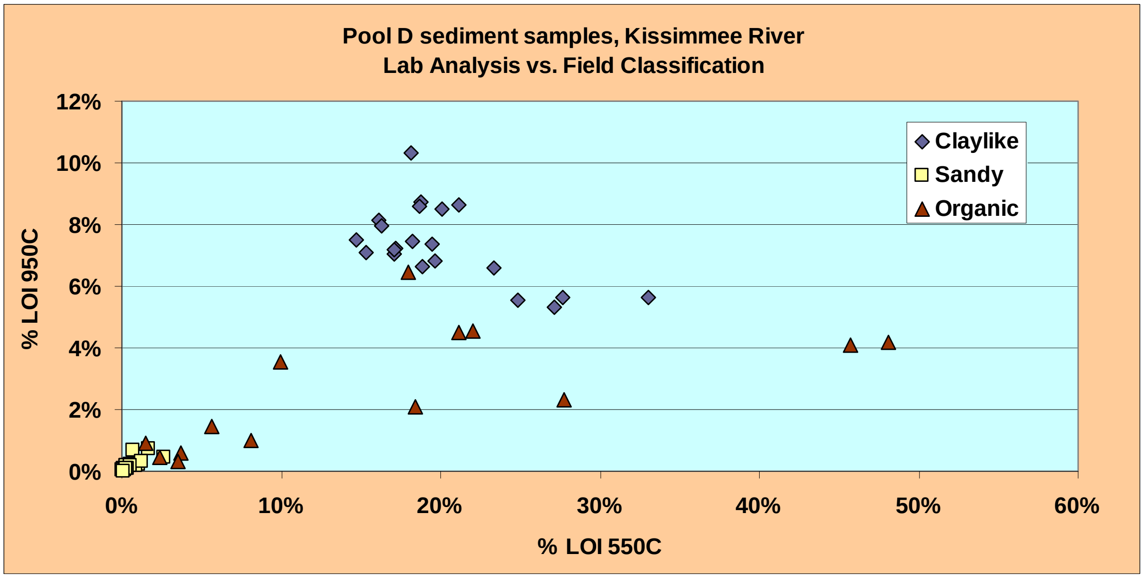


Figure 5-26. The very dark organic layers were still all less than 50% organic matter, averaging closer to 20%. Some layers contained up to 10% carbonate material and these also tended to have similarly high organic content, averaging close to 20%. Sand layers typically had less than 3% organic matter and less than1% carbonate. These were all analyzed from 2007 core layers.

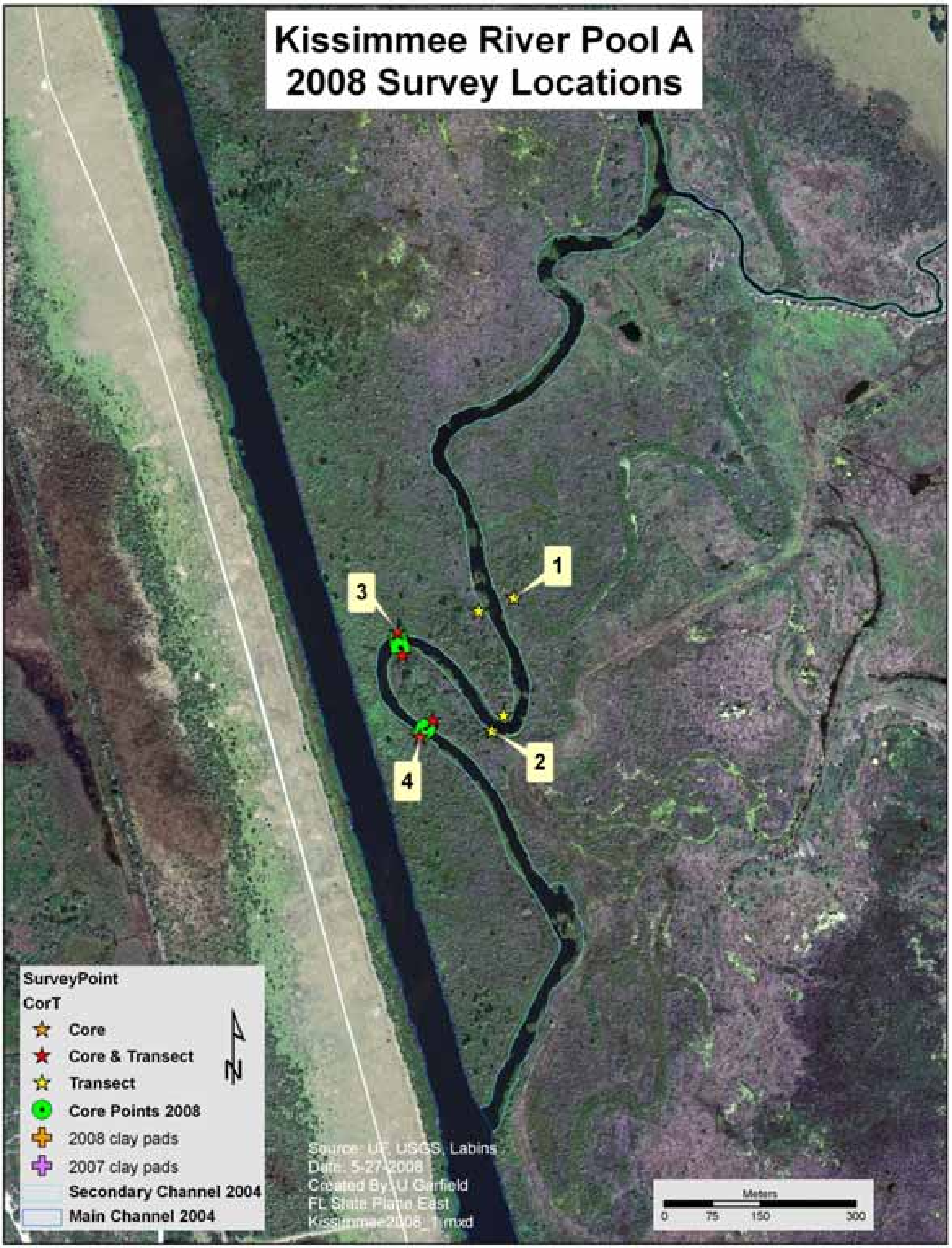


Figure 5-27. Coring in 2008 in Persimmon Mound Run was conducted at the same locations as two of the survey transects. Coring was conducted along Transects 3 and 4.

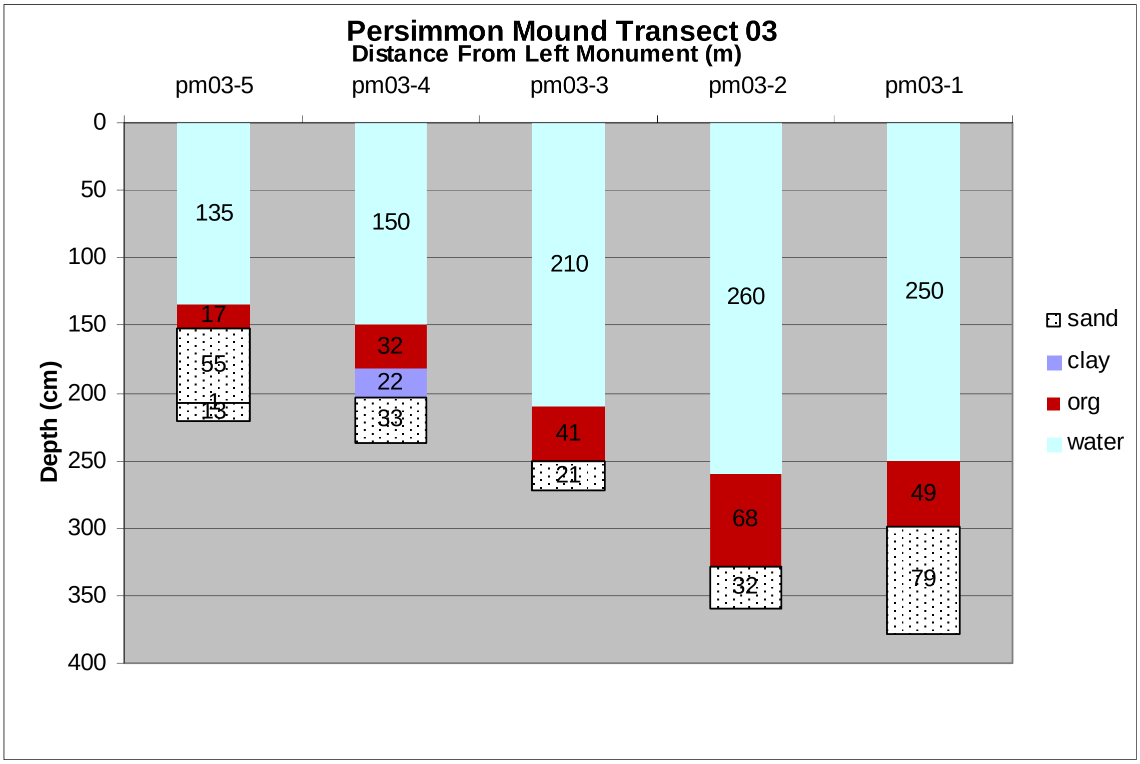


Figure 5-28. Coring in 2008 in Persimmon Mound Run along Transect 3 shows abundant organic and fine sediments. The fine and organic sediments are thickes in the thalweg and the deepest portions of the channel in general.

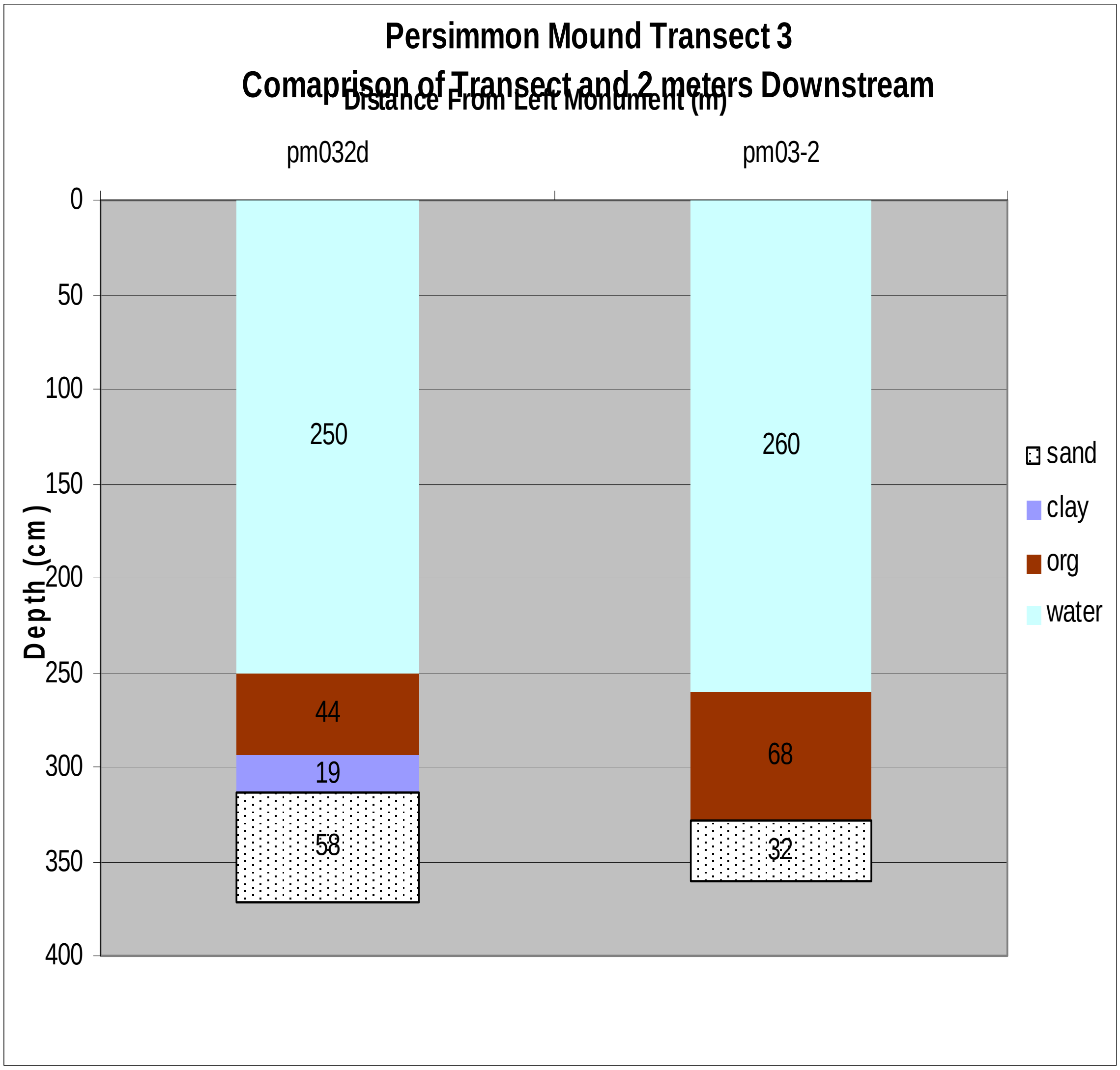


Figure 5-29. Coring in 2008 in Persimmon Mound Run along Transect 3, comparing the thalweg core with a core 2 m downstream.

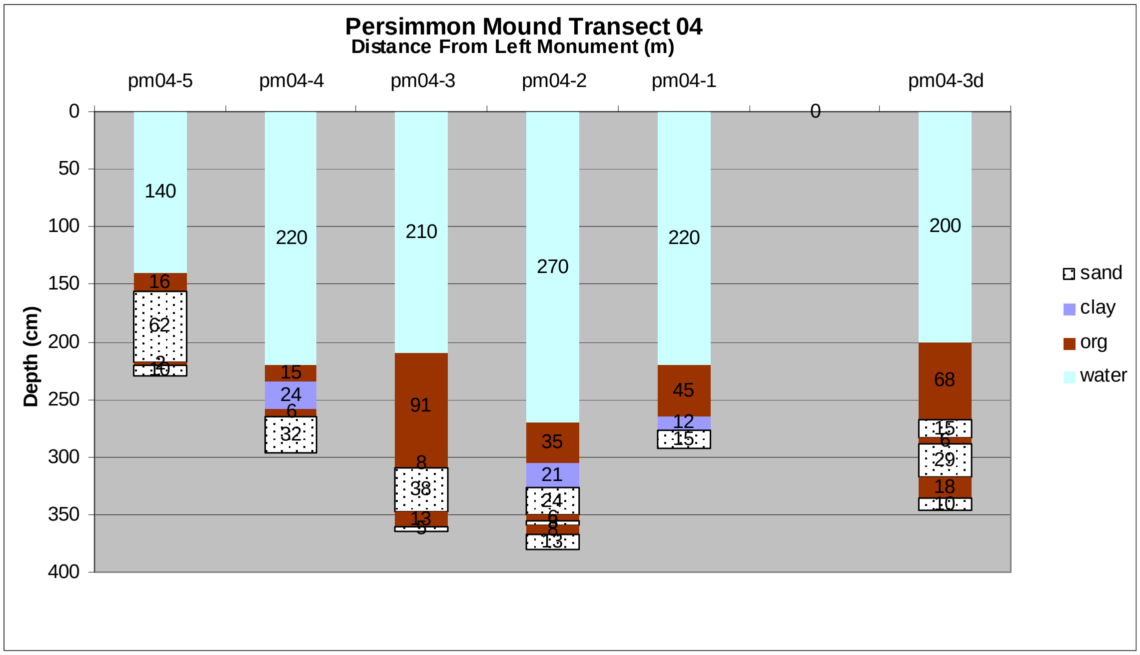


Figure 5-30. Coring in 2008 in Persimmon Mound Run along Transect 4 shows abundant organic and fine sediments.

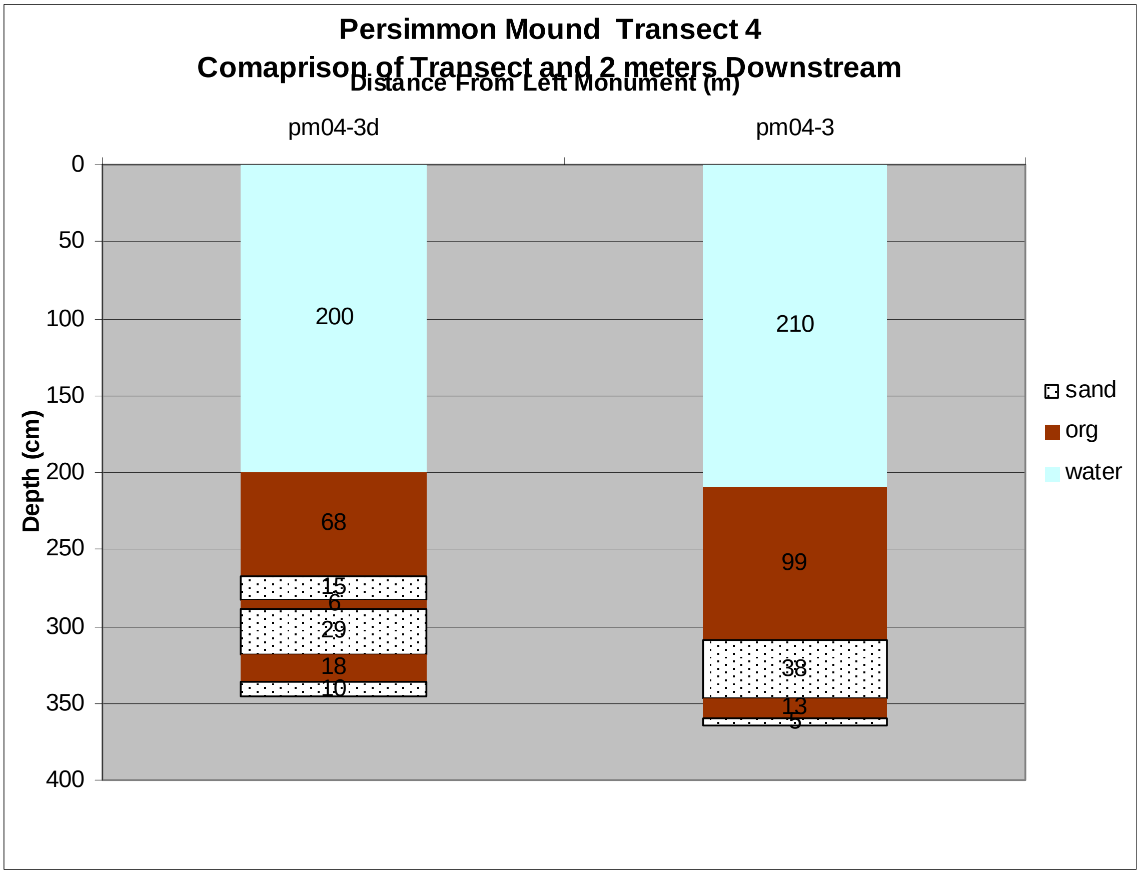
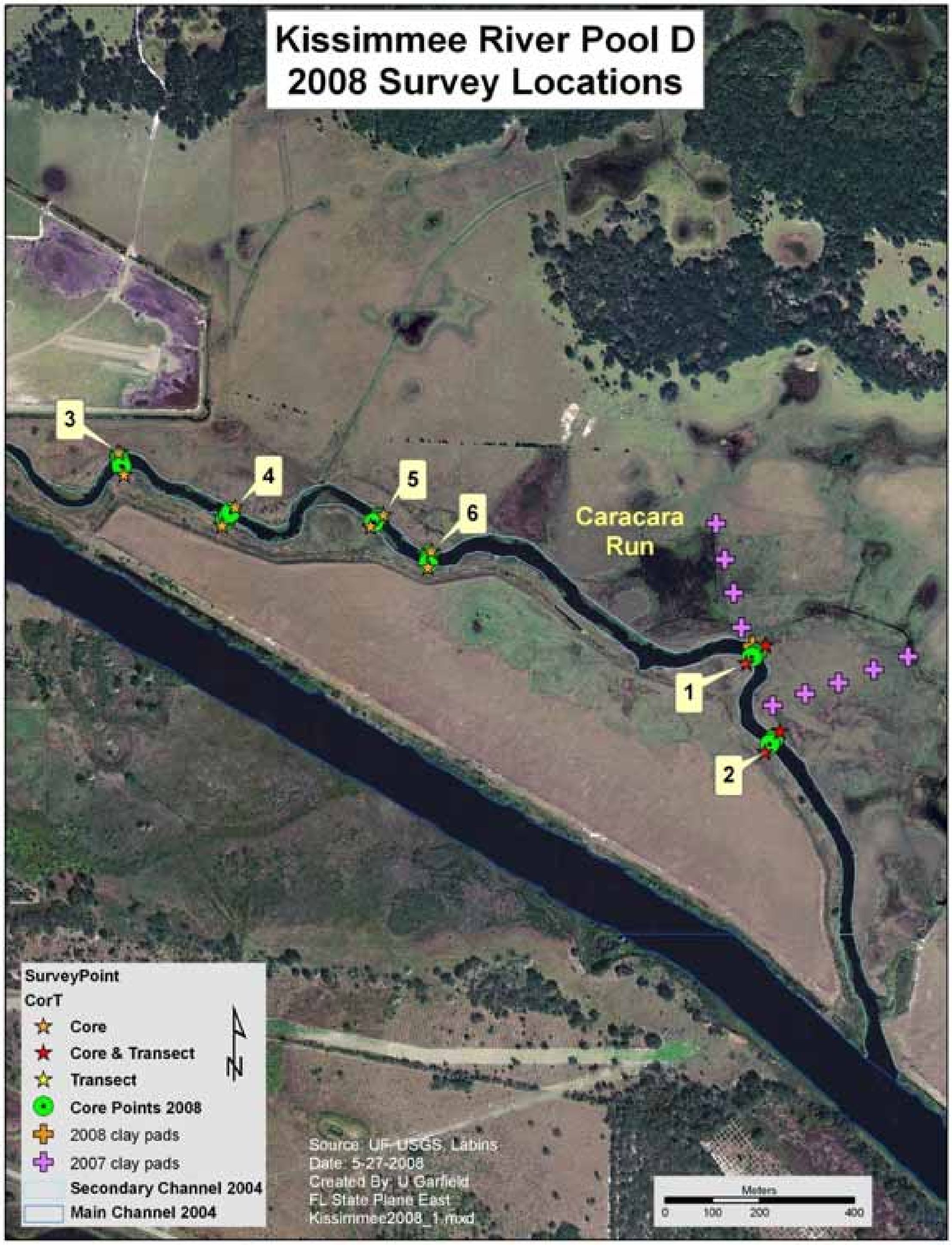


Figure 5-31. Coring in 2008 in Persimmon Mound Run along Transect 4, comparing the thalweg core with a core 2 m downstream.



Source: UF-USGS, Labins
Date: 5-27-2008
Created By: U Garfield
FL State Plane East
Kissimmee2008_1.mxd

Figure 5-32. Coring in 2008 in Caracara Run was conducted at six transects. Two of them were the same transects as 2007 and were survey transects. Four transects (#s 3-6) were added.

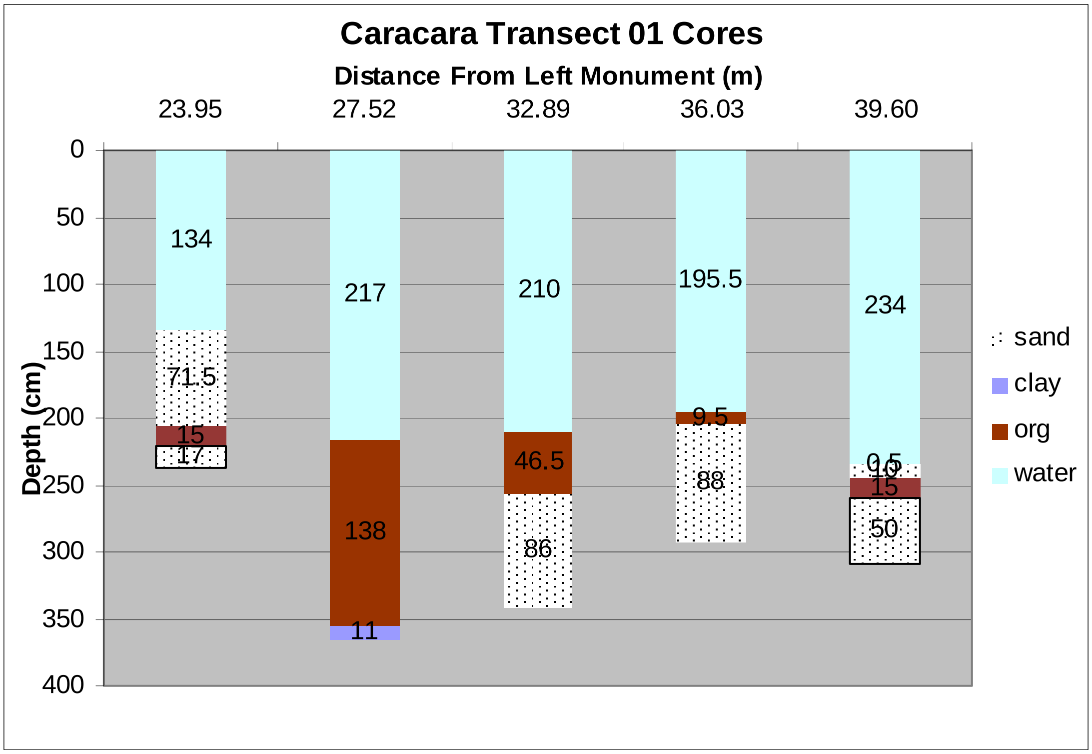


Figure 5-33. Transect 1 of 2008 in Caracara Run showing thick fine/organic accumulation in the thalweg and sandy layers overlying organics on the channel boundaries. In the thalweg, the thick material was about 1.5m and possibly more (this was one of few cores where the firmer sand bottom was not reached). The two sides have sand on finer, possibly from bank failures. The three middle cores have thickest fine and organic deposits.

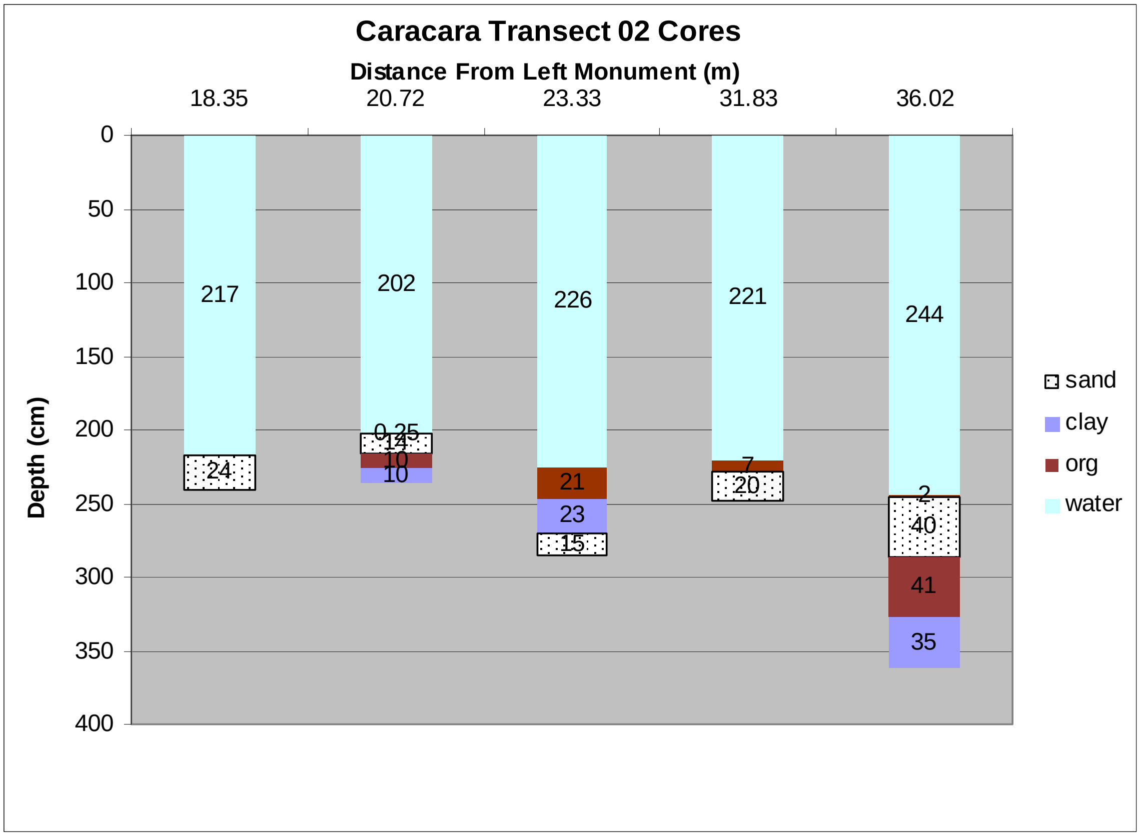


Figure 5-34. Transect 2 of 2008 in Caracara Run. The cores at the sides have sands over fine and organic sediments, possibly from bank failures. The middle core has the thickest fine and organic deposits.

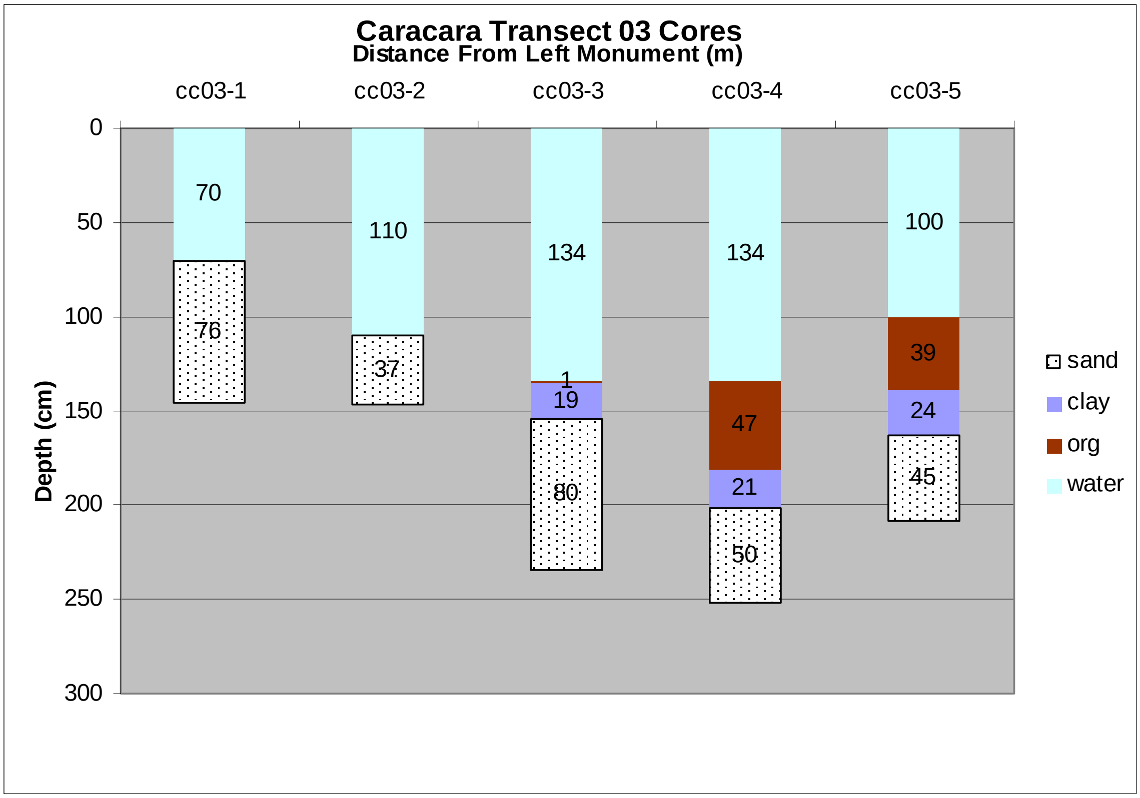


Figure 5-35. Transect 3 of 2008 in Caracara Run showing sandy surface layers along the shallower side of the channel, and thicker organic and fine layers on the deeper sided of the channel.

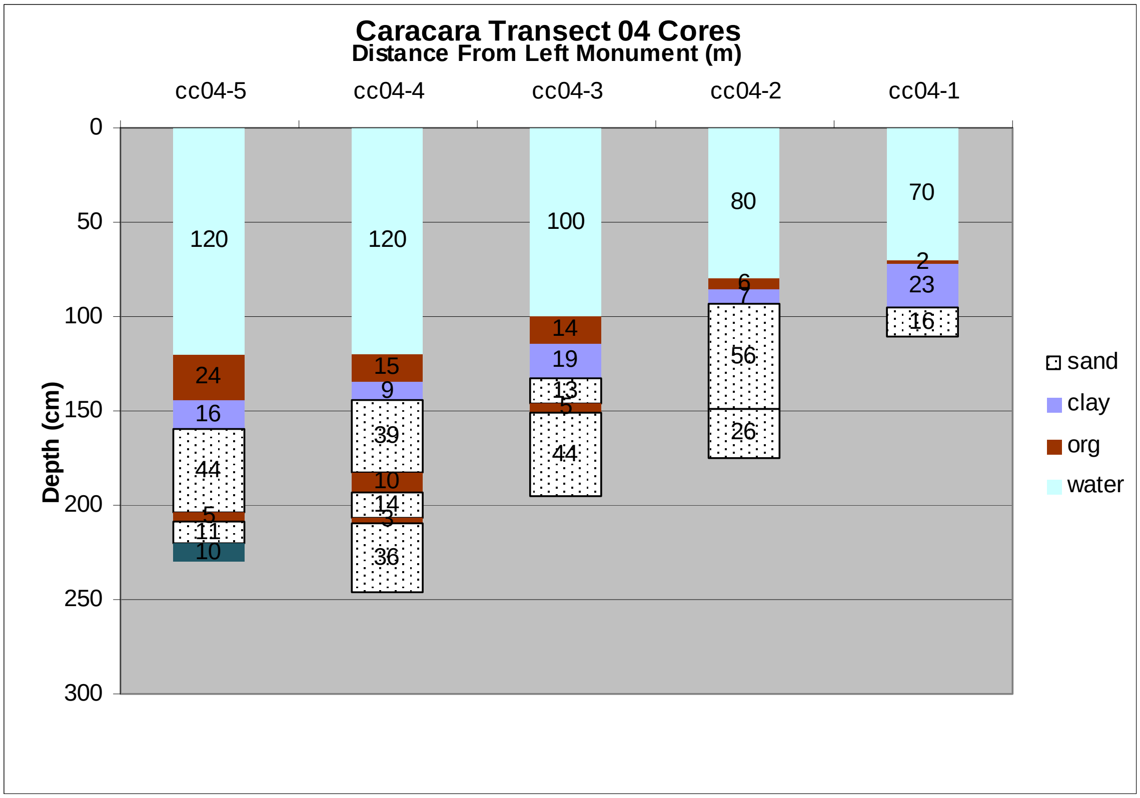


Figure 5-36. Transect 4 of 2008 in Caracara Run showing more organic and fine accumulation in the thalweg. At this site, there is no sand above the fines, suggesting bank failures may not have occurred. The sand deposit (original bed?) appears to show some layering, possibly from historic floods before channelization.

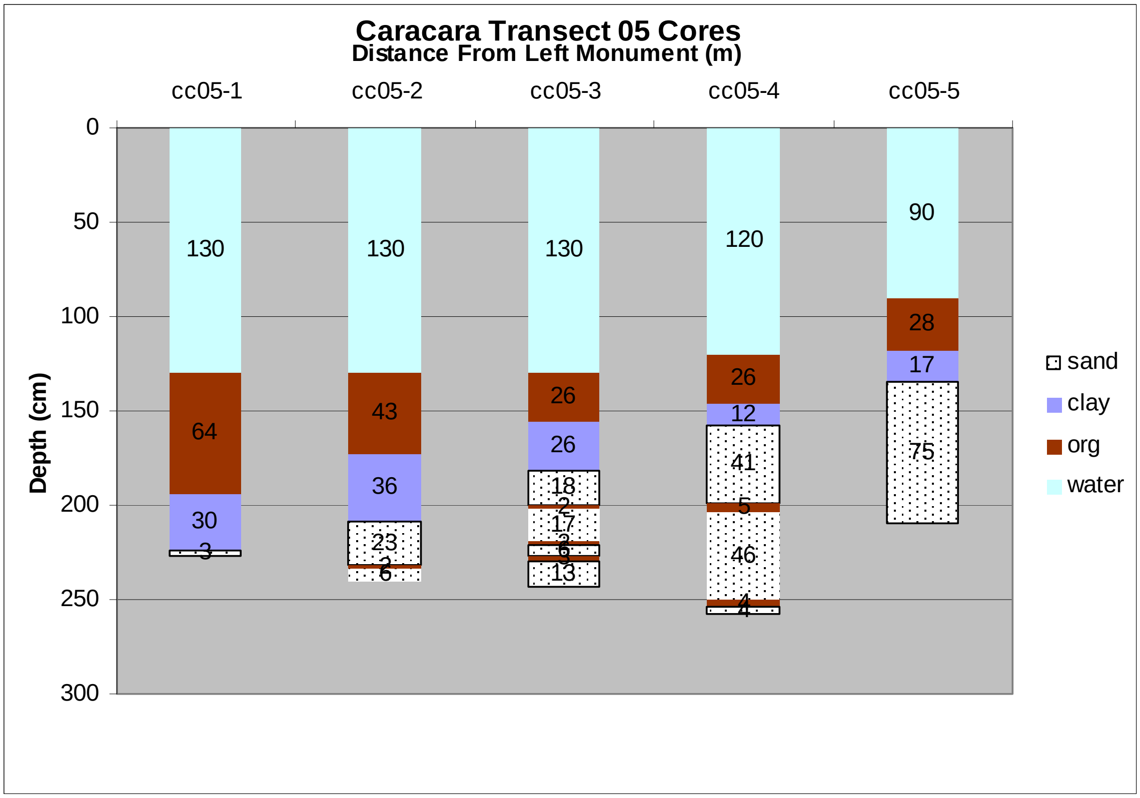


Figure 5-37. Transect 5 of 2008 in Caracara Run shows appreciable organic and fine accumulation across the channel. At this site, there is no sand overlying the fines, suggesting bank failures may not have occurred. The sand deposit (original bed?) appears to show some layering, possibly from historic floods before channelization.

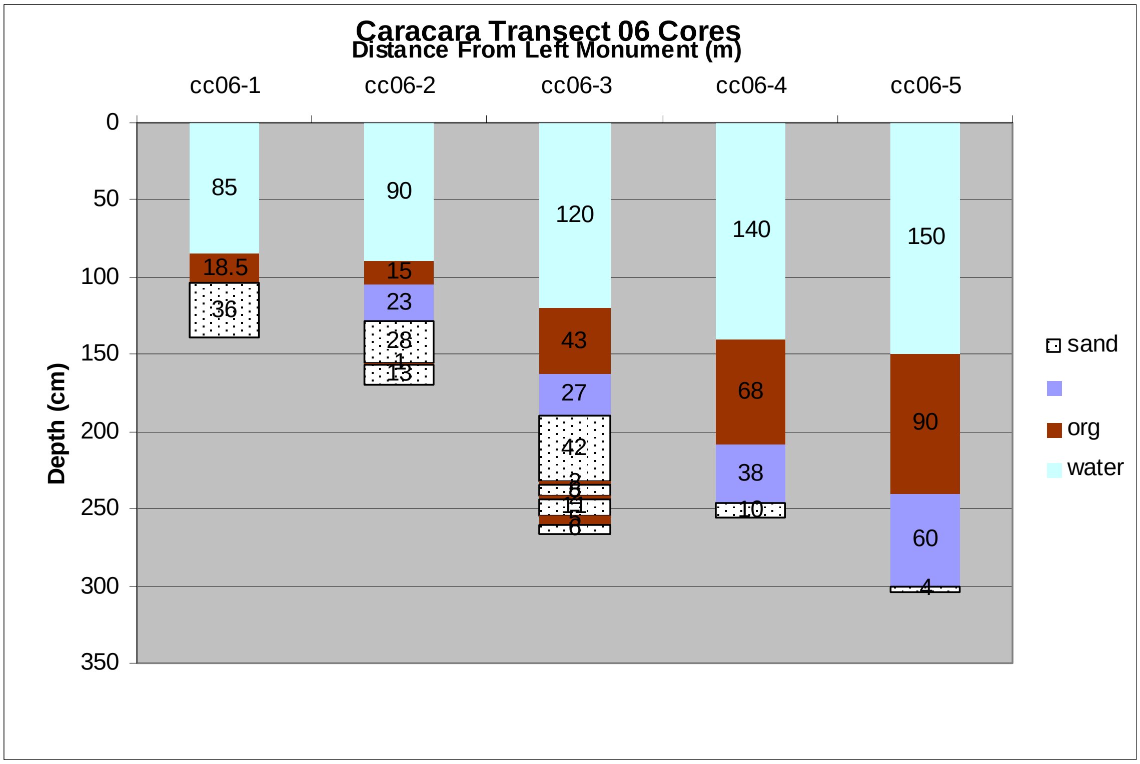


Figure 5-38. Transect 6 of 2008 in Caracara Run shows appreciable organic and fine accumulation across the channel, especially at the thalweg or bank with 150 cm accumulation. At this site, there is no sand overlying the fines, suggesting bank failures may not have occurred. The sand deposit (original bed?) in the middle of the channel appears to show some layering, possibly from historic floods before channelization.

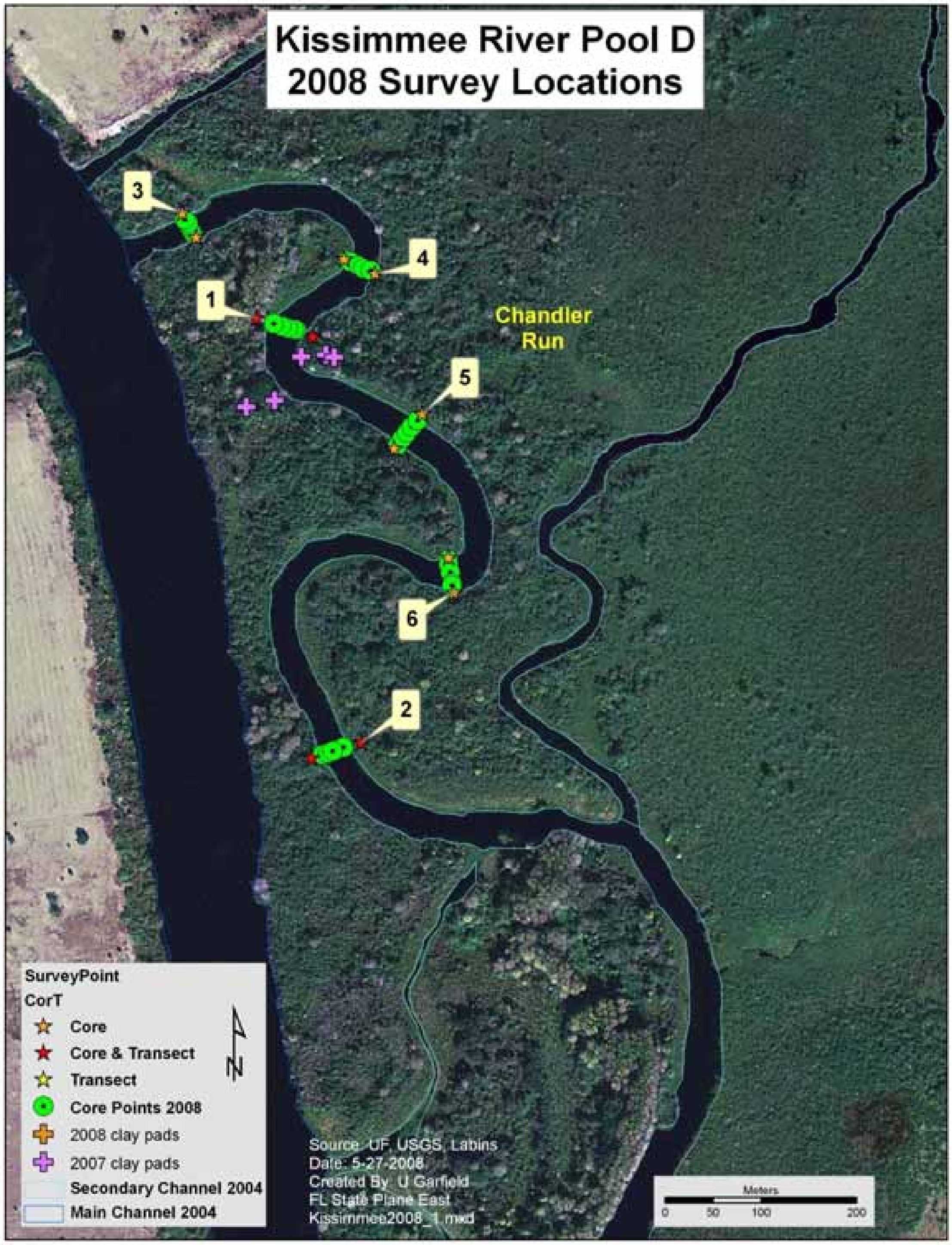


Figure 5-39. Coring in 2008 in Chandler Run was conducted at six transects. Two of them were the same transects as 2007 and were survey transects. Four transects (#s 3-6) were added.

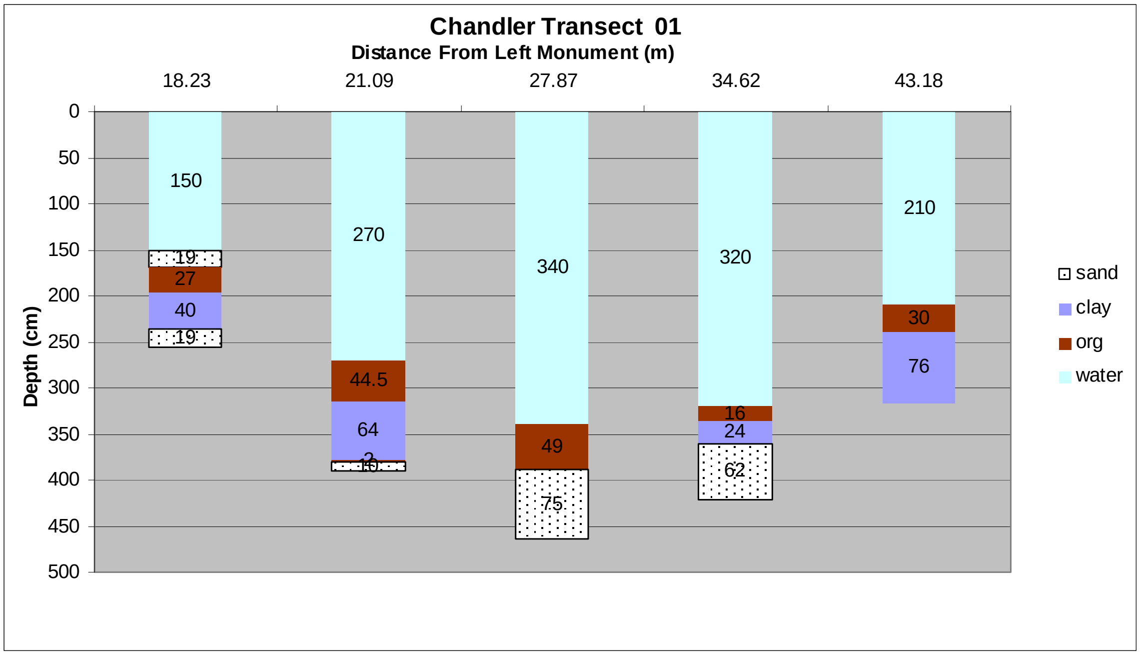


Figure 5-40. Chandler Run generally had more fine sediment accumulation, possibly due to more local organic input or the greater depth of the channel. Bank disturbance appeared lower than in Caracara Run, and sand deposits overlying fine or organic materials were generally thinner and less prevalent. In some cases, the sane bottom was not reached.

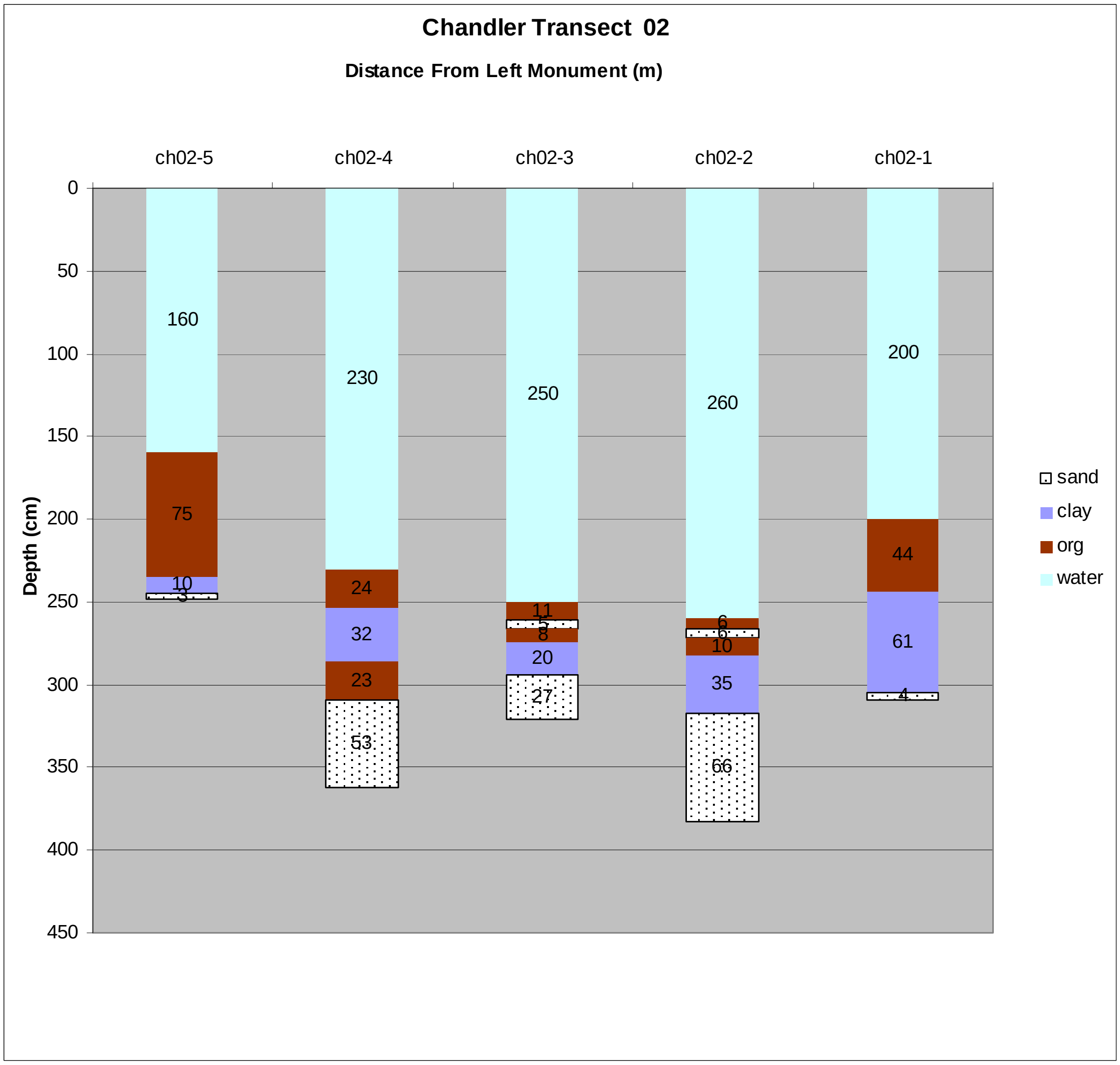


Figure 5-41. Chandler Run generally had more fine sediment accumulation than Caracara, possibly due to more local organic input or the greater depth of the channel. Bank disturbance appeared lower than in Caracara Run, and sand deposits overlying fine or organic materials were generally thinner and less prevalent. In this transect, fine and organic deposits were over or close to 1 m near the channel boundaries.

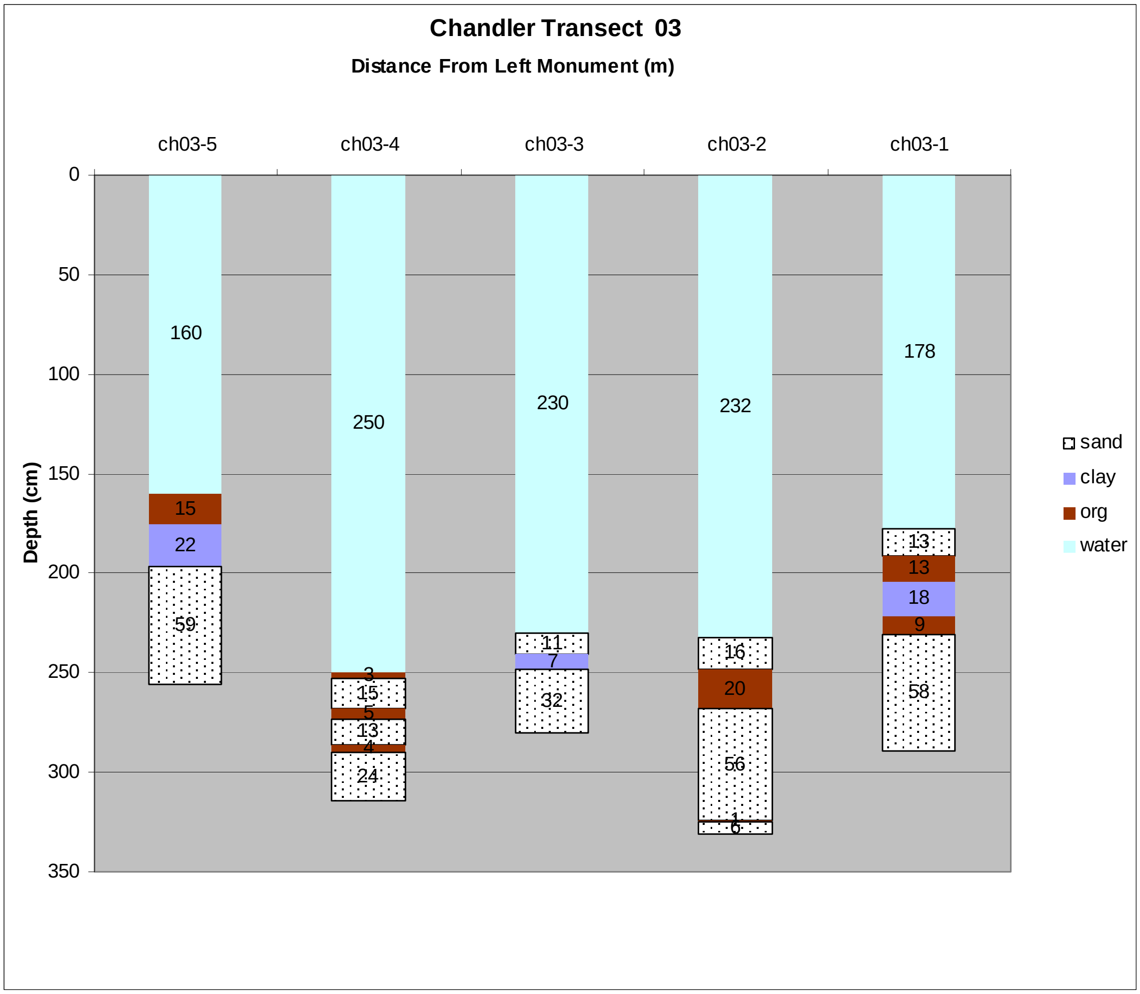


Figure 5-42. Chandler Run at Transect 3 did have some sandy deposits near the surface. The souce of this sand is unknown. This was different than most of the other transects sampled.

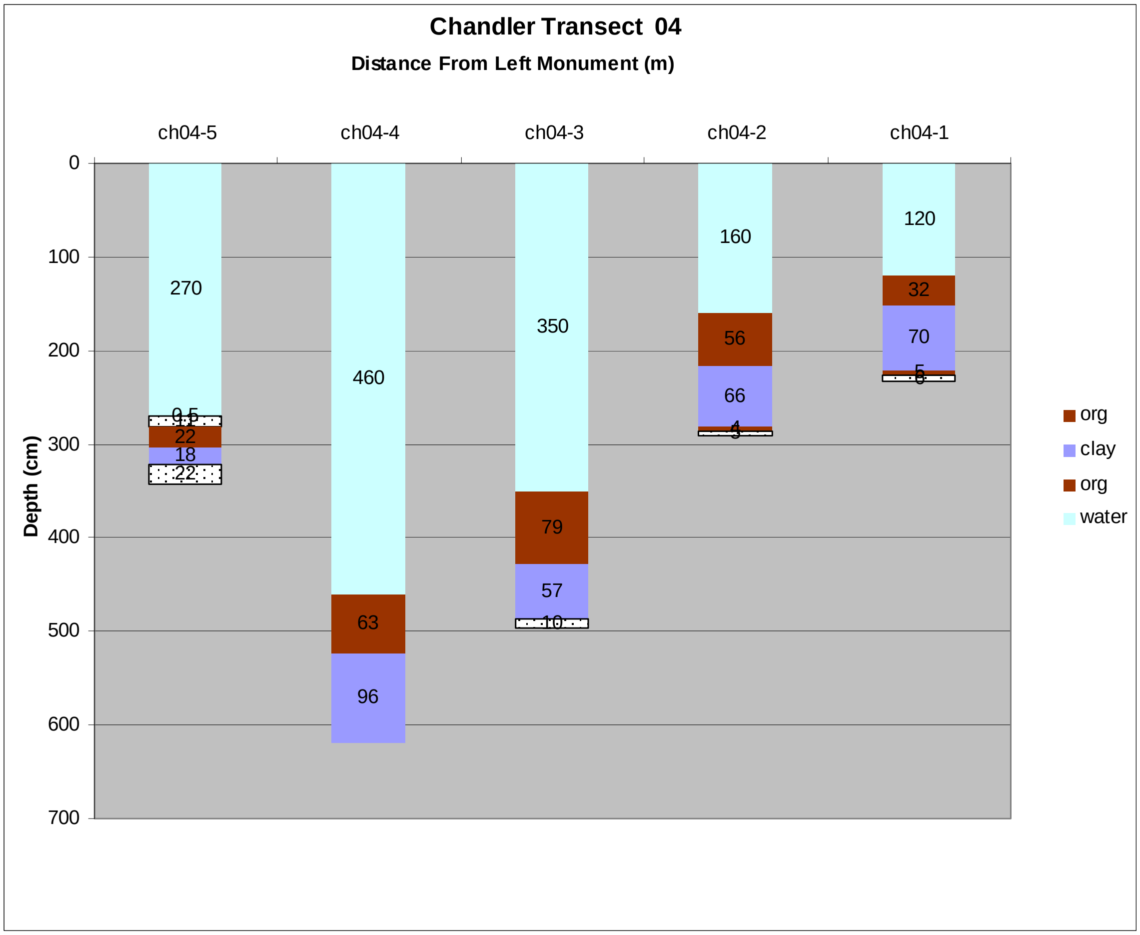


Figure 5-43. Chandler Run Transect 4 had appreciable fine sediment accumulation and was deeper than most of the other transects with a maximum depth over 4.6 m. The original channel was likely much deeper than 6 m at low water in the thalweg.

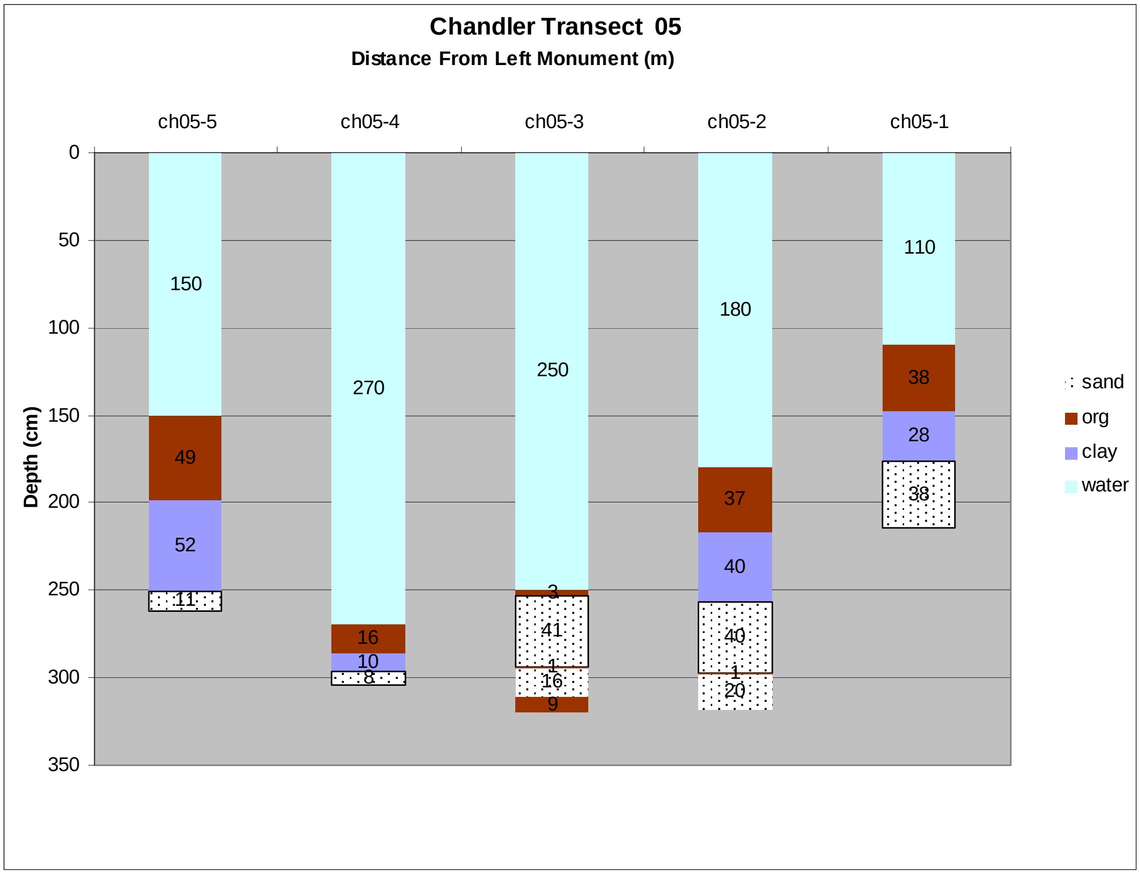


Figure 5-44. Chandler Run Transect 5 had fine sediment accumulation, especially near the channel boundaries.

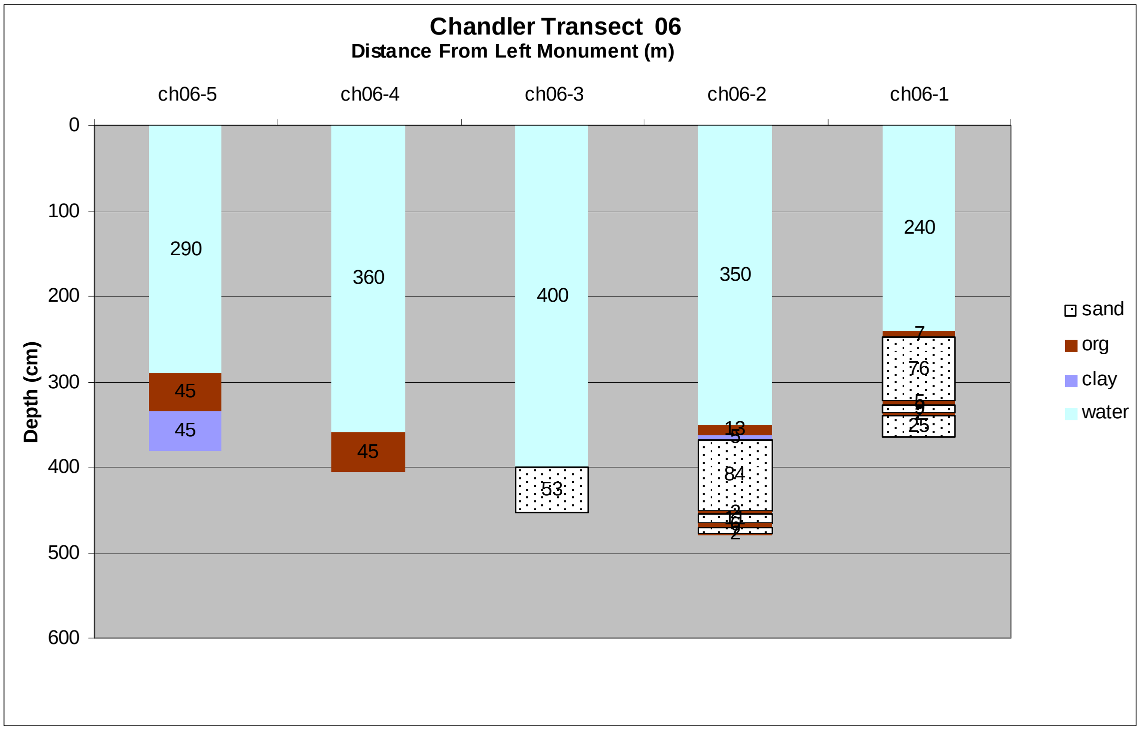
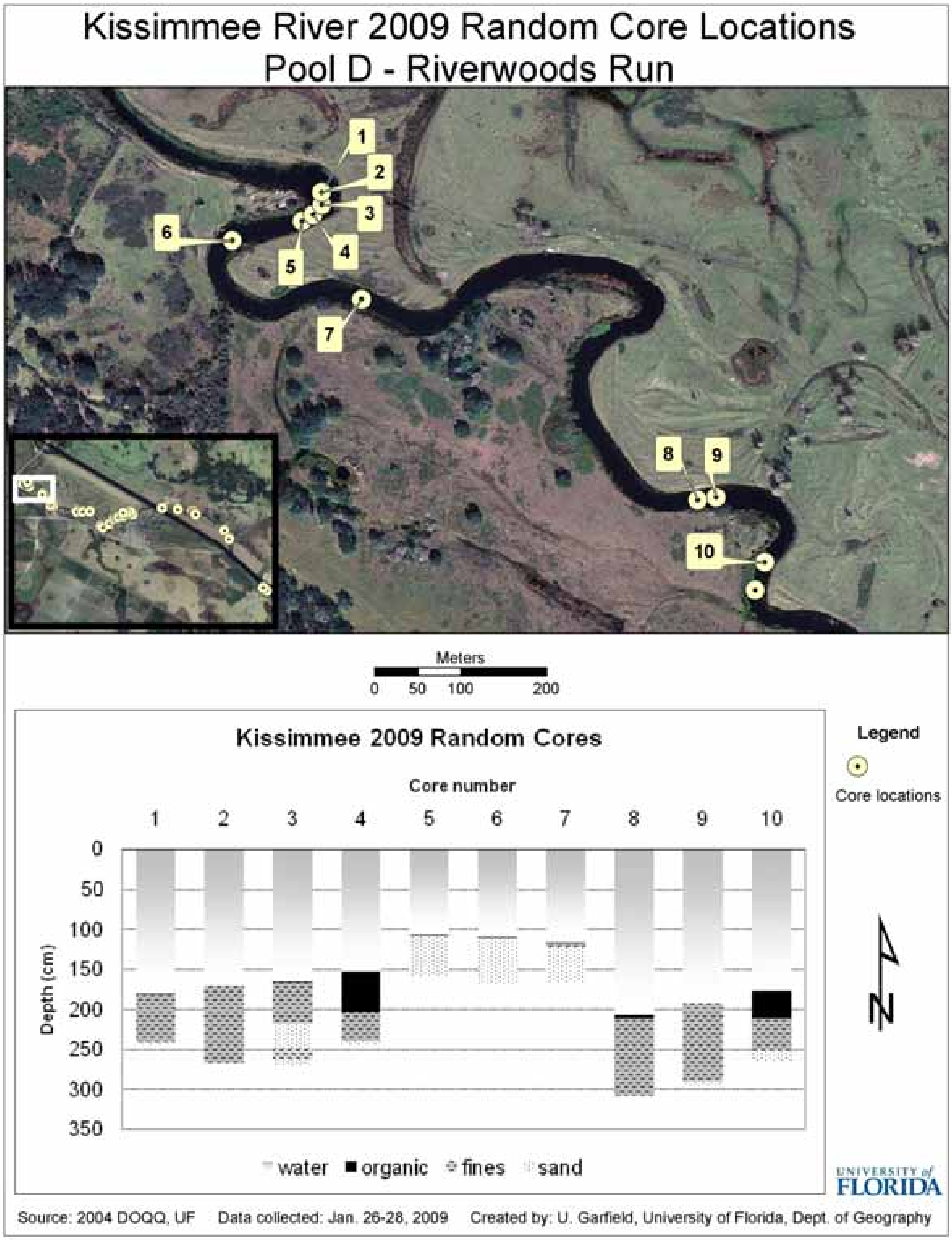
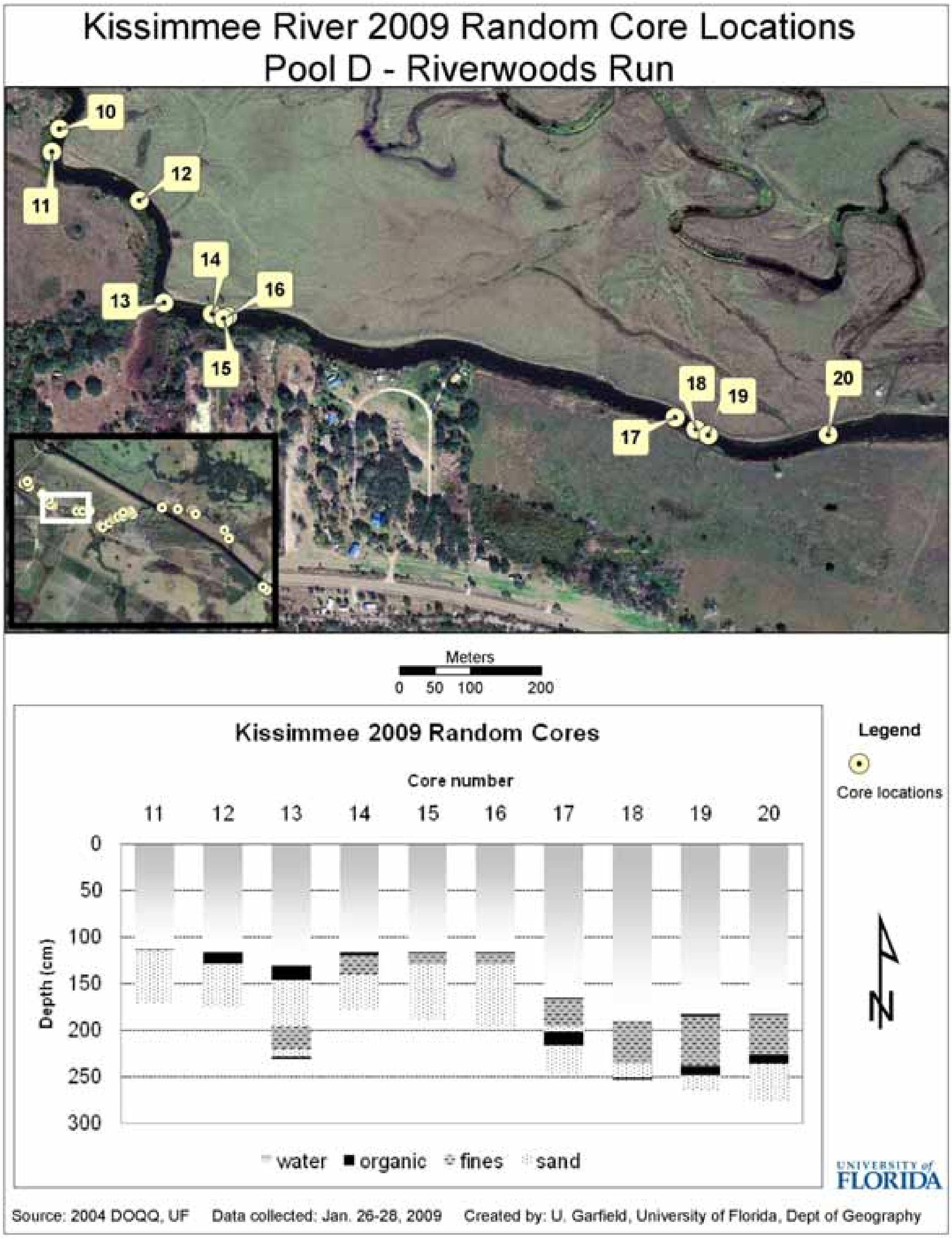


Figure 5-45. Chandler Run Transect 6 was another deep transect, with some portions as much as 4m depths. In some cases, a sand bottom was near the surface, whereas in other cores the bottom was not reached.



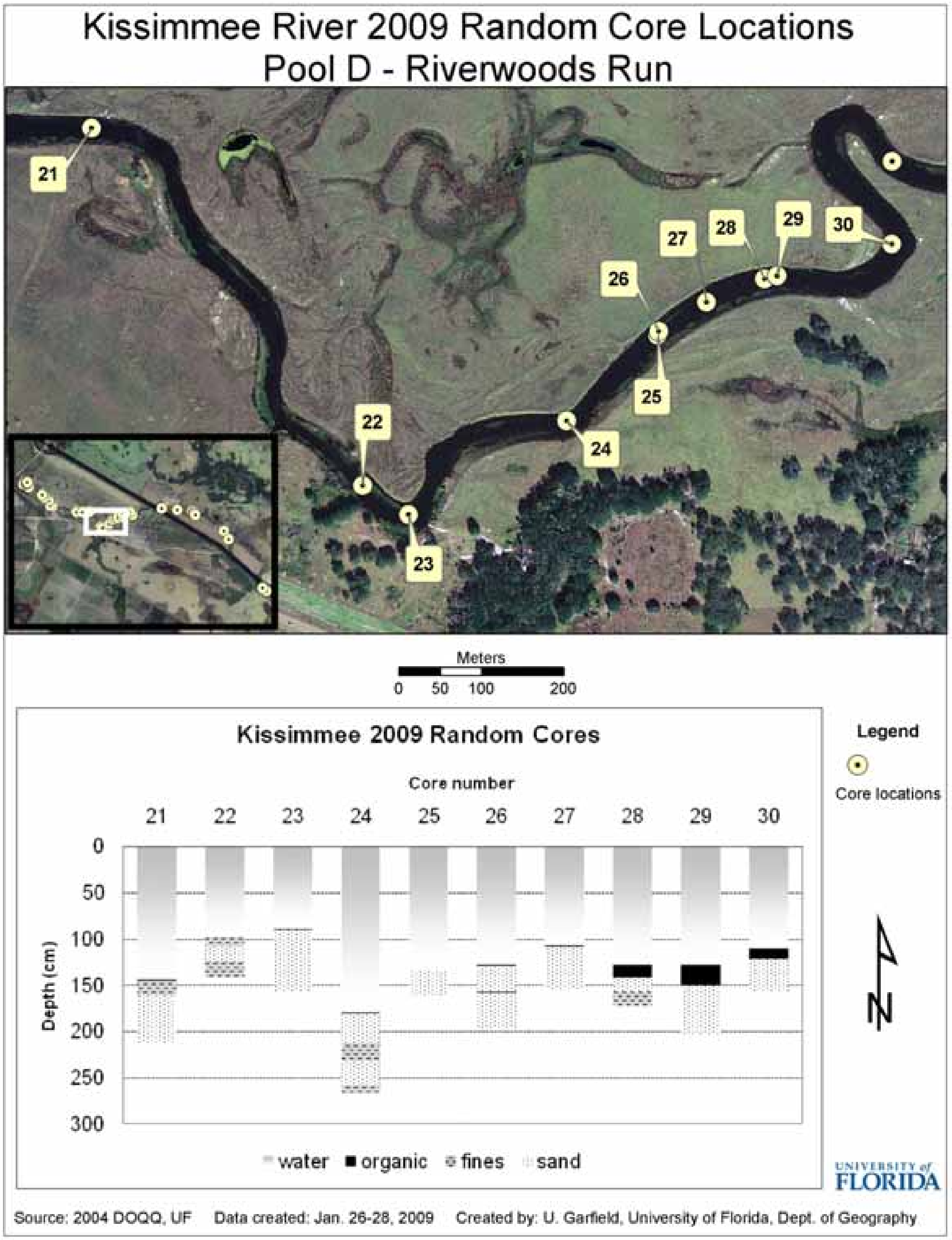
Source: 2004 DOQQ, UF Data collected: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept. of Geography

Figure 5-46. Location of cores collected in 2009 in the upper portion of Riverwoods Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.



Source: 2004 DOQQ, UF Data collected: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept of Geography

Figure 5-47. Location of cores collected in 2009 in the middle portion of Riverwoods Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.



Kissimmee River 2009 Random Core Locations
Pool D - Riverwoods Run

Source: 2004 DOQQ, UF Data created: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept. of Geography

Figure 5-48. Location of cores collected in 2009 in the lower portion of Riverwoods Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.

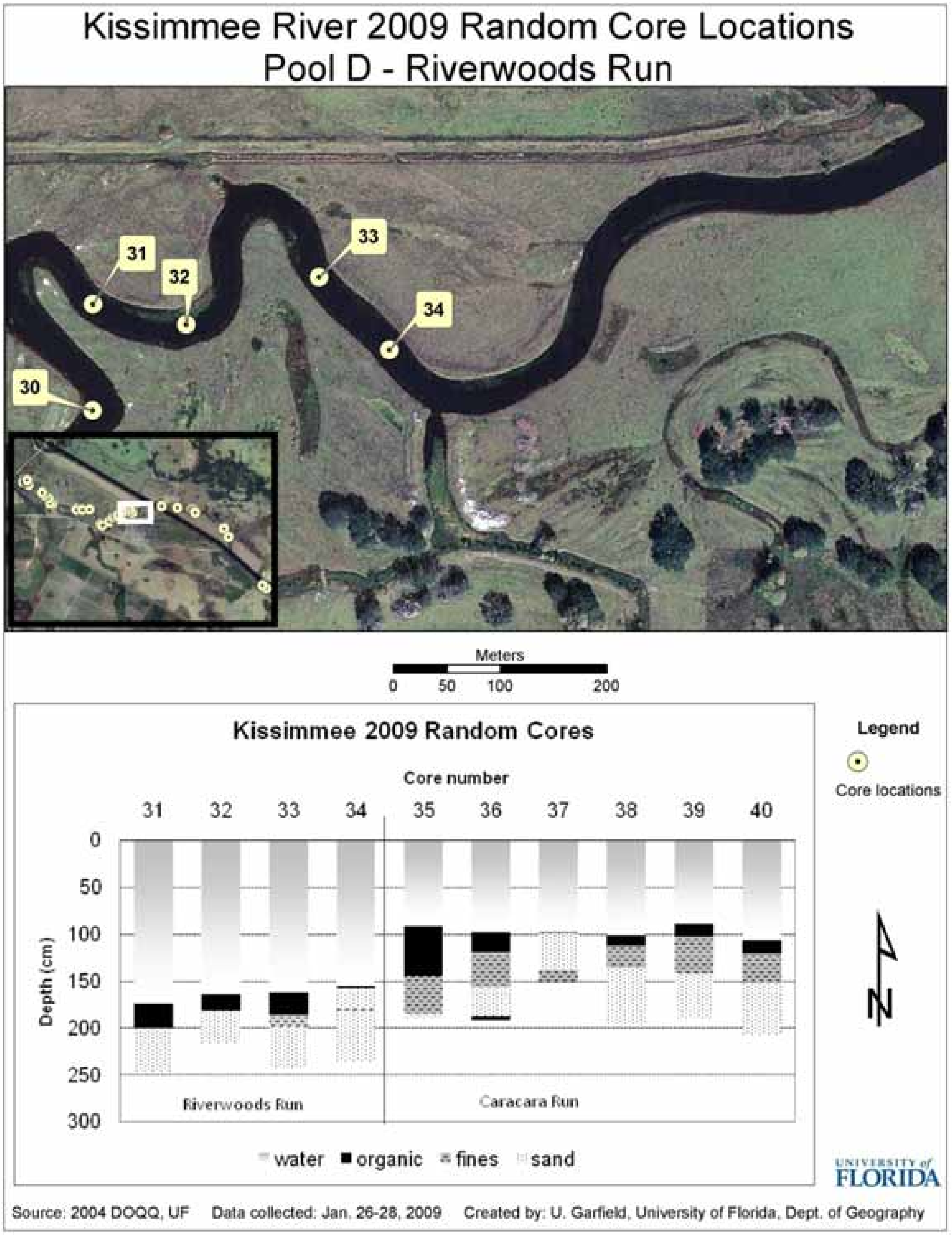
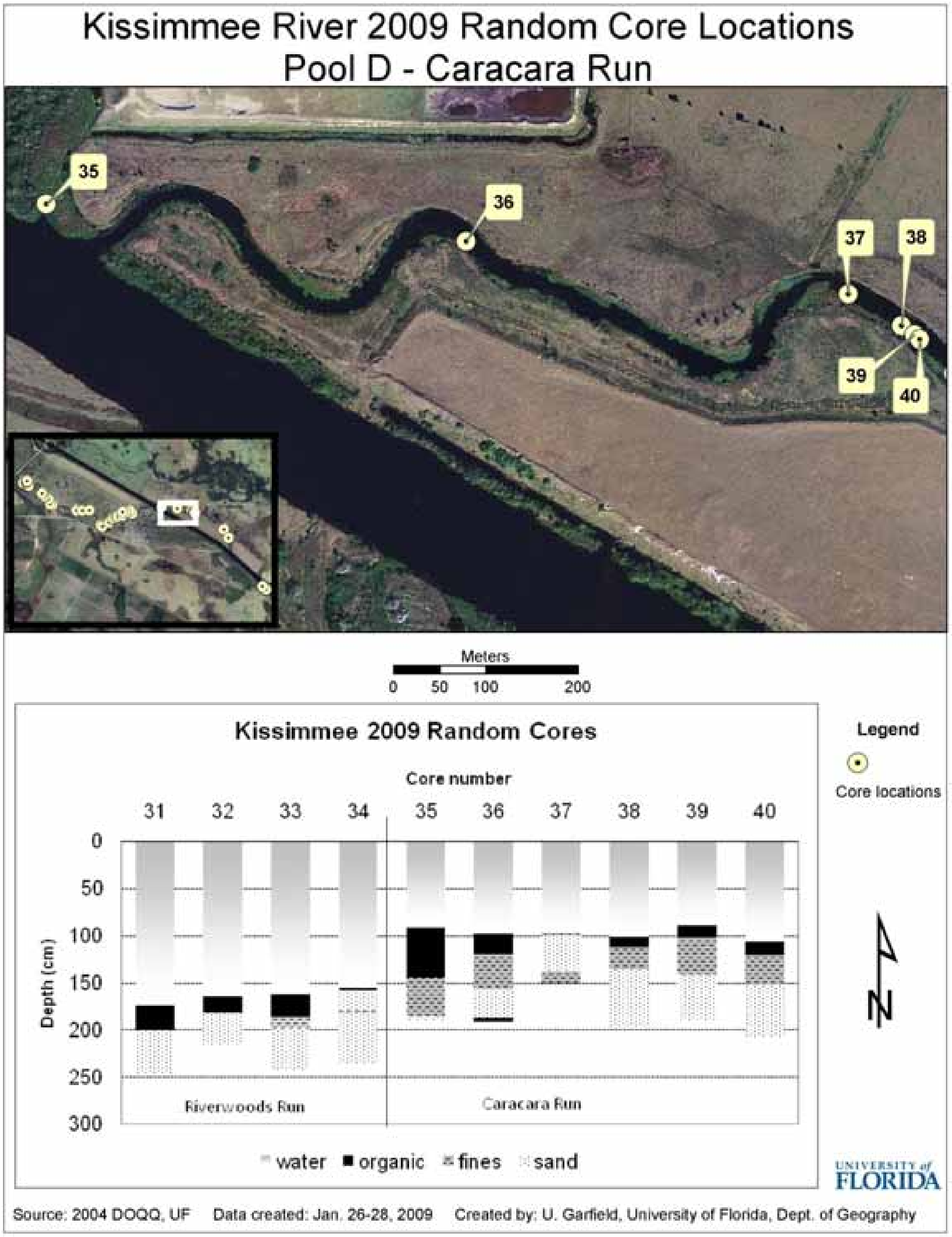
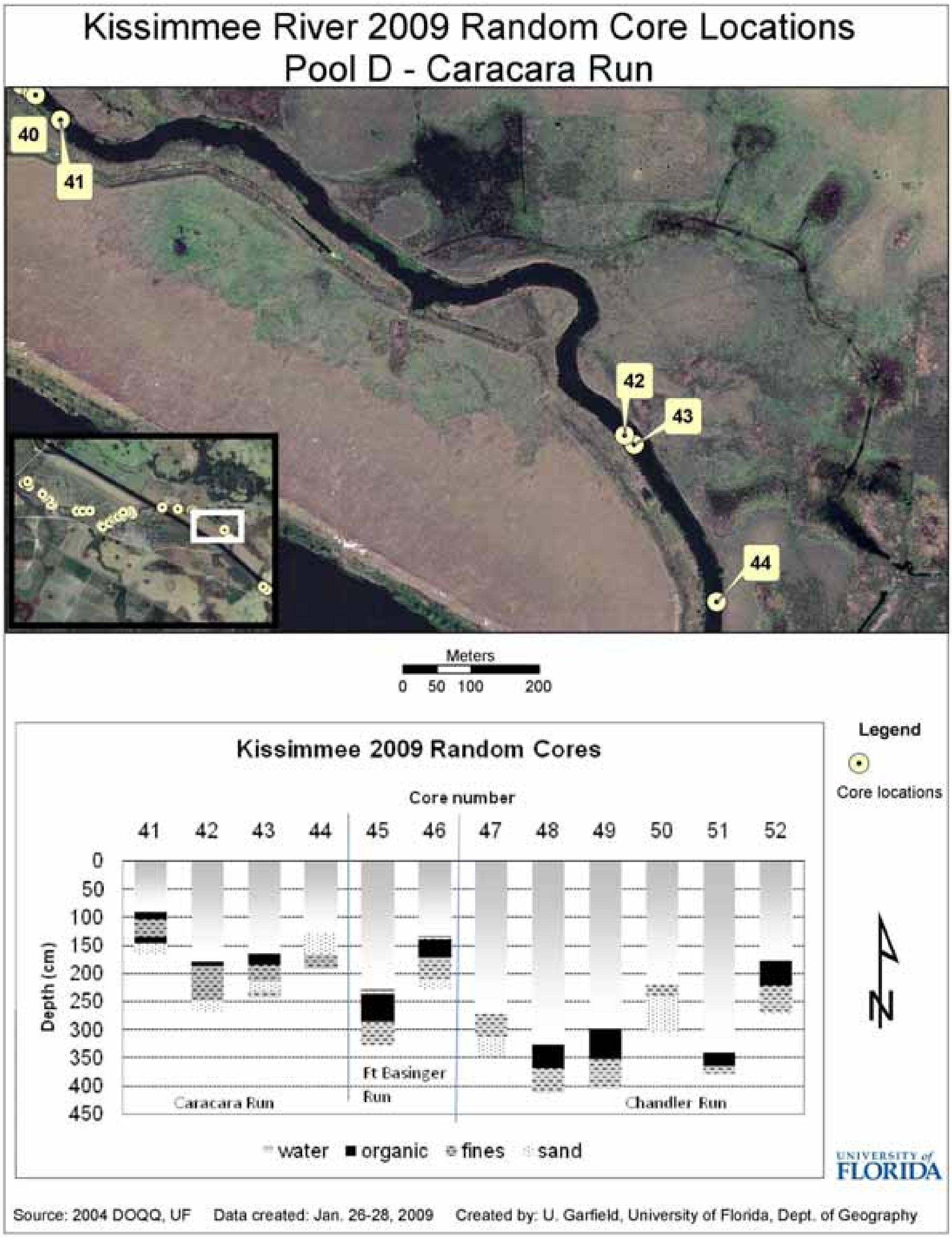


Figure 5-49. Location of cores collected in 2009 in the lowermost portion of Riverwoods Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.



Source: 2004 DOQQ, UF Data created: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept. of Geography

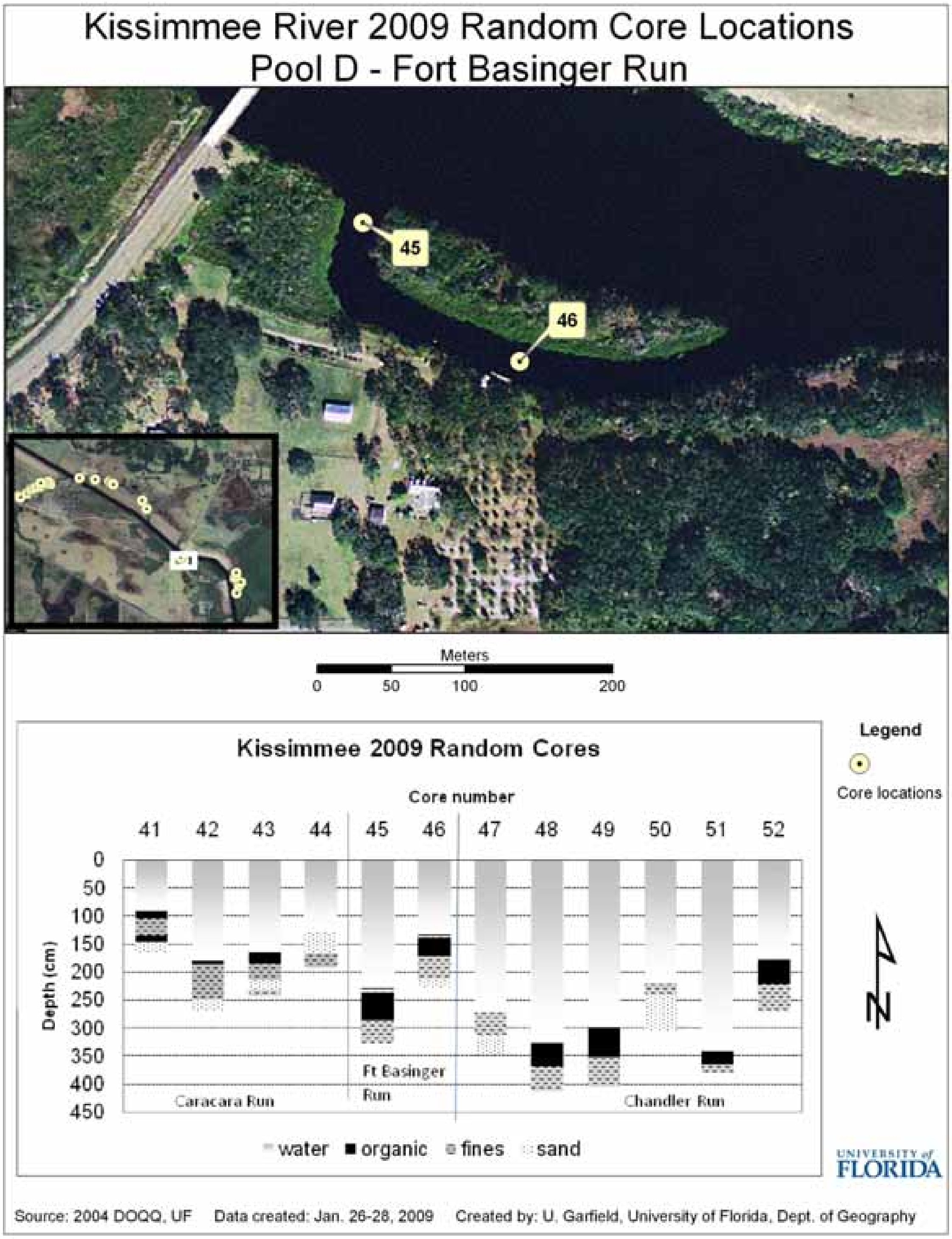
Figure 5-50. Location of cores collected in 2009 in the upper portion of Caracara Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.



Kissimmee River 2009 Random Core Locations
Pool D - Caracara Run

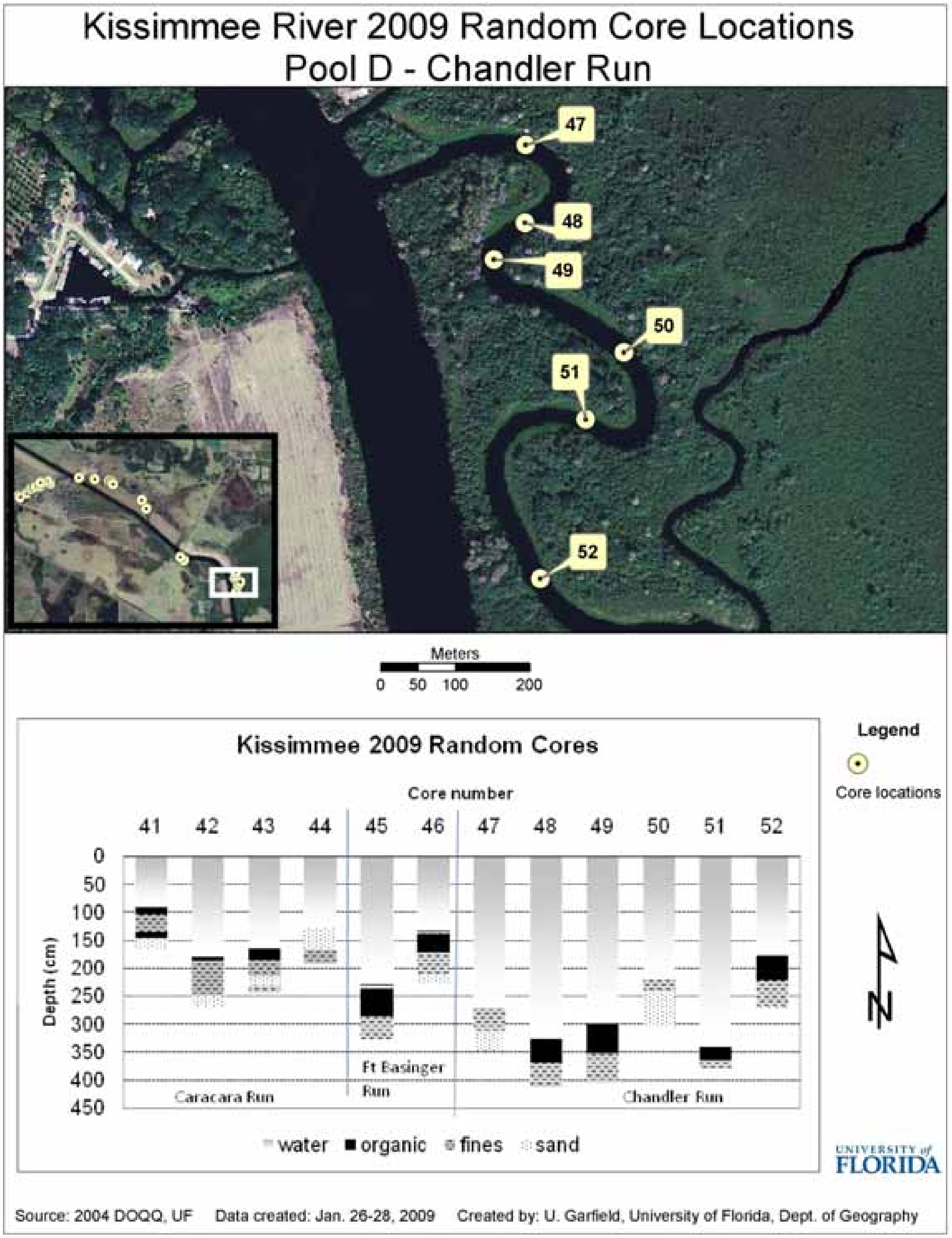
Source: 2004 DOQQ, UF Data created: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept. of Geography

Figure 5-51. Location of cores collected in 2009 in the lower portion of Caracara Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.



Source: 2004 DOQQ, UF Data created: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept. of Geography

Figure 5-52. Location of cores collected in 2009 in Fort Basinger Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.



Kissimmee River 2009 Random Core Locations
Pool D - Chandler Run

Source: 2004 DOQQ, UF Data created: Jan. 26-28, 2009 Created by: U. Garfield, University of Florida, Dept. of Geography

Figure 5-53. Location of cores collected in 2009 in Chandler Run. Cores were collected with a vacuum-piston auger and characterized into 3 basic categories: sand, fines (silt & clay) and organics. Water depths sampled, and basic core descriptions and thicknesses are graphed.

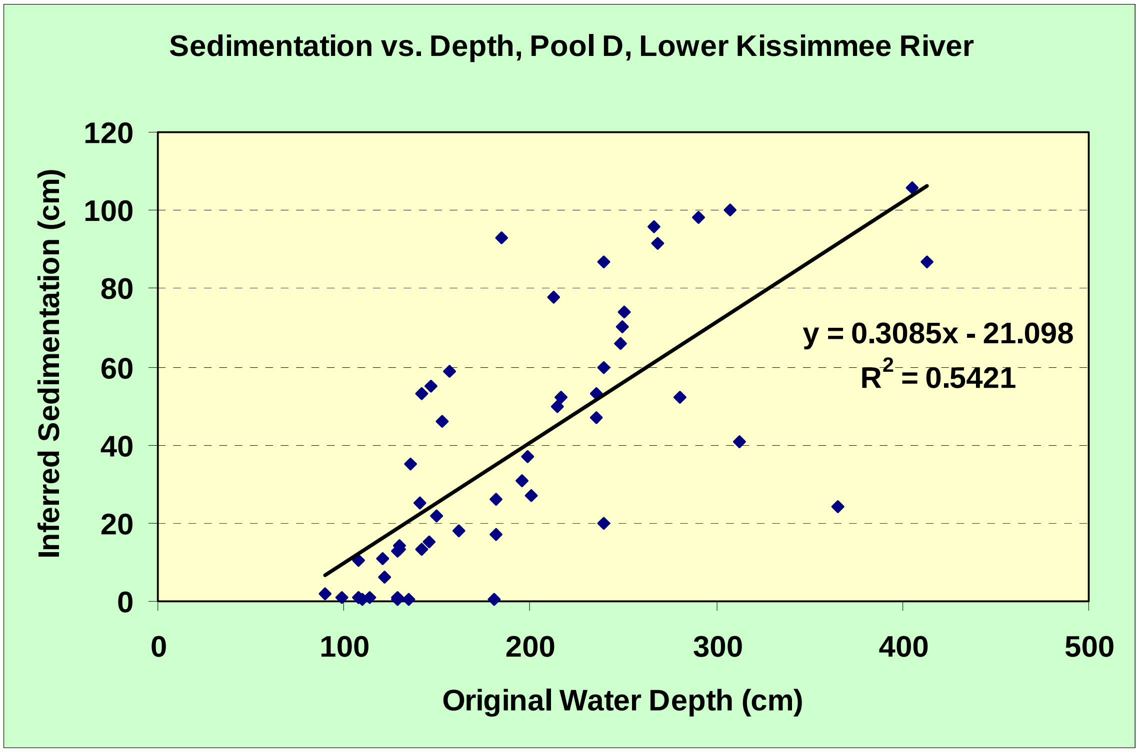


Figure 5-54. Correlation of inferred original bottom depth with inferred fine and organic sedimentation in 52 cores sampled in 2009 in Pool D. Areas that were deeper originallyseem to be areas of greater sedimentation.

CHAPTER 6

GEOSPATIAL ANALYSIS OF CHANNEL PLANFORM CHANGES

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Introduction and Objectives

Rivers are dynamic by nature, changing in response to variations in discharge and sediment supply. Such changes are quite variable in space, depending in part upon position within the basin, and natural factors that influence channel change including local variations in geology, soils, bank characteristics, vegetation and hydraulics. Human factors also influence channel changes, both directly by engineered projects including channelization, dredging, snag removals, dam construction, and bridge construction, and indirectly through altering floodplain land use such that erosion is more likely to occur during flood events. Additionally, channel changes are variable in time, depending somewhat on the timing of floods and droughts, and the timing of fires and land use changes, and other factors that would influence vulnerability. Human activities, including land use changes, affect discharge and sediment supply, typically by increasing peak flows and increasing the quantities of sediment considerably (Wolman and Schick 1967, Gregory and Walling 1973, Dury 1977, Allan 1995). Resulting physical changes in rivers may include deposition of channel bars, transportation of different sized sediments, erosion of channel banks, shifting channel bottoms, and changes in channel position and pattern. Particular human activities, such as removal of floodplain vegetation, decrease the resistance of banks to erosion thus making rivers more susceptible to channel changes. The presence of cows in riparian areas can also be a notable geomorphic agent (Trimble and Mendel, 1994).

The Lower Kissimmee River is a unique river in its form and process (Figure 6-1). One important component of restoring the river is better documentation of what the form and rates of change were like originally. Iit is also important to understand how the river form has been changing since the restoration has begun and how that compares to historical conditions.

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. In particular, the number and area of sand bars was expected to change as flows have been restored to different runs through backfilling of C-38. One of the restoration expectations is that “points bars will form on the inside bends or river channel meanders with an arc angle of >70°” (Frei et al., 2005). This study was a continuation and expansion of investigations undertaken in Pool C in connection with Phase I restoration which found a substantial increase in post-restoration point bar formation on meander bends as compared to the channelization period (SFWMD, 2005; Anderson et al., 2005a). In addition to documenting changes in the number and size of sand bars, this study also and also examines spatial variations in sinuosity and lateral migration along the river. Data for the entire project were also stored in a geodatabase.

Methods

To benefit this project and to be able to eventually answer more questions about the river form and stability, the UF Department of Geography is constructing a geodatabase with historic and recent images and data of the river. Currently, five time-periods of photography or imagery are available (Table 6-1). Black and white photography were collected in 1944 (Feb 7 & 27, April 13) and 1954-58 (1954 Jan 24; 1957 March 2; 1958 Jan 17 & 27, March 15). Color infrared photography is available for 1994 (March 11 &15). True color photography is available for 2005-06 (2005 Jan 1-31 Highlands; 2005 Oct 1 Osceola; 2006 Jan 15 Polk; 2006 Mar 1 Okeechobee). In addition, 1901 maps with some bathymetry are also being added to the geodatabase for future analysis. If other useful images are found, they may eventually be added.

Water levels influence the types of features that can be seen and their sizes, particularly the sand bars. Sand bars would be completely drowned at high water levels and would generally be exposed, larger, and more plentiful at low water levels. Imagery in the geodatabase was collected at a range of water levels (Table 6-2). Most of the 1950s data were at very high discharges and water levels (about five times the flow of other periods) where features such as sand bars would be drowned (Table 6-2; Figure 6-2). It would not be appropriate to compare sand bars from this time to other time periods with lower water levels, however, this timestep is useful for identifying major changes in channel course. The water level conditions of the 1940s imagery are similar to the recent data from 2004-2005 and 2005-2006, thus it is reasonable to compare point bars from the two time periods. The 1994 water levels are less than 1 ft higher than the more recent imagery, thus these should still be appropriate for careful comparisons (Figure 6-3).

ARC GIS v. 9.3 Geographic Information Systems (GIS) was used for the spatial analysis of all the datasets. Using vector data in a GIS was the best method for this study because it shows a greater accuracy for delineating boundaries of river banks and for calculating areas of irregular polygons such as mine pits. Vector data are also very efficient for overlaying and intersecting polygons. Microsoft Excel spreadsheets were used for the quantitative analysis. This allowed for sorting of the data, creating graphs, and performing simple calculations.

Channel boundaries were digitized into a vector-based Geographic Information System (GIS), using ESRI ArcGIS. Both banks were digitized in order to give the river width and the ability to do analyses based on area. The digitizing scale for the primary channel was set to 1:2,000 for the DOQQs. This scale was set so that one can still make out a reasonable channel boundary, but not zoomed out so much that important features of the river were missed. The two lines representing the channel boundary were converted to polygon features by tracing over the lines to create a new feature.

Point bars were digitized as polygon features from the aerial photographs and DOQQs at a spatial scale of 1:500. They were usually areas with higher spectral reflectance (white), typically located on the inside of a river bend. While digitizing the point bars, the edge was snapped to the river channel polygon to ensure a smooth transition between the two features. All features classes were checked to ensure polygons snapped together properly and did not overlap or leave gaps.

The channel centerline of the river was created in ArcGIS using the midpoint tool in the list of edit functions. Using the river polygon feature, clicking on each side of the polygon will create a vertex in the middle. This was done for the entire length of the river. Lateral migration was calculated using methods described by Larsen et al. (2006). The channel centerline from two time periods is used to create a polygon; the area of this polygon is then divided by the average length of the two centerlines to produce the lateral migration from the earlier time period to the later time period. This then can be divided by the number of years to obtain a migration rate. Calculations were all performed in ArcGIS and were computed for each reach block.

Results and Discussion

Maps were created of the major channel planform changes of the Lower Kissimmee River during three of the time periods: 1940s, 1950s, 2004 and 2006 (Figures 6-4 to 6-9). In Pool A, no major changes were evident between the 1940s and 1950s, but the canal which was built in the 1960s created a very different channel (Figure 6-4). In Pool B (now the upper portion of Pool B/C), more channel planform change was evident from the 1940s to 1950s, including minor cutoffs, avulsions and local migration (Figure 6-5). Most of the changes before channelization took place upstream of the northern limit of the restoration project. Of course, C-38 altered the channel markedly (Figure 6-5). The area that was formerly Pool C (now the lower portion of Pool B/C) is partially restored with more work, including removal of S65-C and backfilling, forthcoming (Figure 6-6). Some avulsions, a cutoff, and local migration are evident from the 1940s to 1950s (Figure 6-6). The main channel of the Lower Kissimmee River in Pool D has yet to be restored (Figure 6-7). Changes in the area to be restored include some lateral migration between the 1940s and 1950s. The canal C-38 greatly shortened the length of this reach (Figure 6-7). Pool E, which will not be restored, shows a large avulsion, a cutoff, and some lateral migration from the 1940s to 1950s (Figure 6-8). Channelization made this portion of the river much straighter (Figure 6-8). Planform changes in the main channel of the Lower Kissimmee River below Pool E to Lake Okeechobee from the 1940s to 2006 appear to be mostly anthropogenic (Figure 6-9). Anthropogenic changes began prior to the 1950s, as evident on the lowermost part of the channel (Figure 6-9). When C-38 was built in the 1960s, the uppermost part of this section was also modified (Figure 6-9).

The locations and amount of migration associated with cutoffs, avulsions and less catastrophic movements between 1944 and the 1950s (1954-58) by reach block are shown on a graph (Figure 6.10). There are several cutoffs and small avulsions in Pools A-D, mostly showing a maximum shift of 20 m or less. Pool E has a very large avulsion where the channel migrated up to 60 m. The even larger “migration” or change in position of the channel in the Lower Kissimmee River or C-38 below Pool E is anthropogenic (Figure 6.10). This section of the river was straightened and channelized years before the remainder of the river.

Prior to channelization, the Lower Kissimmee River had sand bars characteristic of a migrating sand bed river (Figure 6-11). The area of point bars in 1944 that sand bars were most abundant was in reach blocks 15-30 (mostly Pool A) and around reach block 115 (now Pool E). There were smaller bar areas in the other portions of the historic river. The river was channelized in between 1962-1971, and by 1994 all the sand bars had disappeared. They probably became covered with vegetation, and no new sand came in due to lack of flow and concomitant migration. By 2006, the restoration was well underway, and that included the removal of S65-B and backfilling in the lowermost portions of Pool B and uppermost portions of Pool C. As the flow velocities increased in the main channel, this allowed for sand bars to return, such that in many reach blocks there was more sand bar area than there had been in 1944. Perhaps, this was because there was less flow in secondary channels which were not connected with the main channel in the restoration plans. By 2005-06, the lowermost portions of Pool B and uppermost portions of Pool C had far more sand bar area than in 1944. A detailed examination of photography collected at several bendways (Figures 6-12 to 6-15) confirms the graphs where the geospatial data were digitized (Figure 6-11). The bars were mostly small in 1944, probably drowned in 1957, vegetated in 1994, and larger than before in 2006. As the restoration progressed, the sand bars grew as more flood events passed through the system. Reasons for the larger sand bars following restoration than in 1944 are unknown, but it may have to do with minor water level differences or flow pathway differences, such as fewer secondary channels, following restoration. It could also be due to more sand availability from bank erosion, and the recent disturbances associated with heavy machinery during the restoration process. Bar areas might also be larger because of the bed and bank disturbances caused by heavy machinery in the restoration process upstream. There appear to be some analogs of this scenario of disturbances influencing bar size in Pool E, where bars increased in size from 1944 to the 1950s following floods and floodplain disturbances (Figure 6-16 and 6-17). Following channelization, the area does not have many sand bars. These will likely not develop unless flows are later reintroduced into the runs.

Conclusions and Recommendations

The Lower Kissimmee River prior to channelization between 1944 and the 1950s (1954-58) shows migration of the main channel due to cutoffs, avulsions and less catastrophic movements. Most of these are fairly local avulsions, showing a maximum shift of 20 m or less in Pools A-D. Pool E has the largest avulsion, where the channel migrated up to 60 m.

Sand bars disappeared from the Lower Kissimmee following channelization. The channelization left much of the original main channel intact, but the lack of flow led to the disappearance and colonization of sand bars in the abandoned runs or former channel of the river. Once the channel was restored, sand bars increased in those areas with backfill where flow was reintroduced. After restoration, it appears that sand bar area is even more than the historic channel. One of the forthcoming goals is to determine how the characteristics of sand bars (number, size, location) changed over these decades of changing flow conditions. Detailed looks at specific bendways and runs will enhance the story and understanding of this phenomenon.

More data collection and analysis are planned with the geospatial data. This data set could be greatly enhanced by the addition of 1901 data. Other time steps are being sought to further document and understand this river and its dynamic natural and anthropogenic changes.

Acknowledgments and Disclaimers

The opinions and interpretations expressed herein, and any errors that may be present, are of the authors and not that of the South Florida Water Management District. However, credit is due to many Kissimmee River restoration personnel who contributed in various ways. José Valdes was the project manager for this study, provided scientific suggestions and arranged logistical support. Bonnie Rose provided imagery. University of Florida Geography graduate Michael Suharmadji assisted with digitizing.

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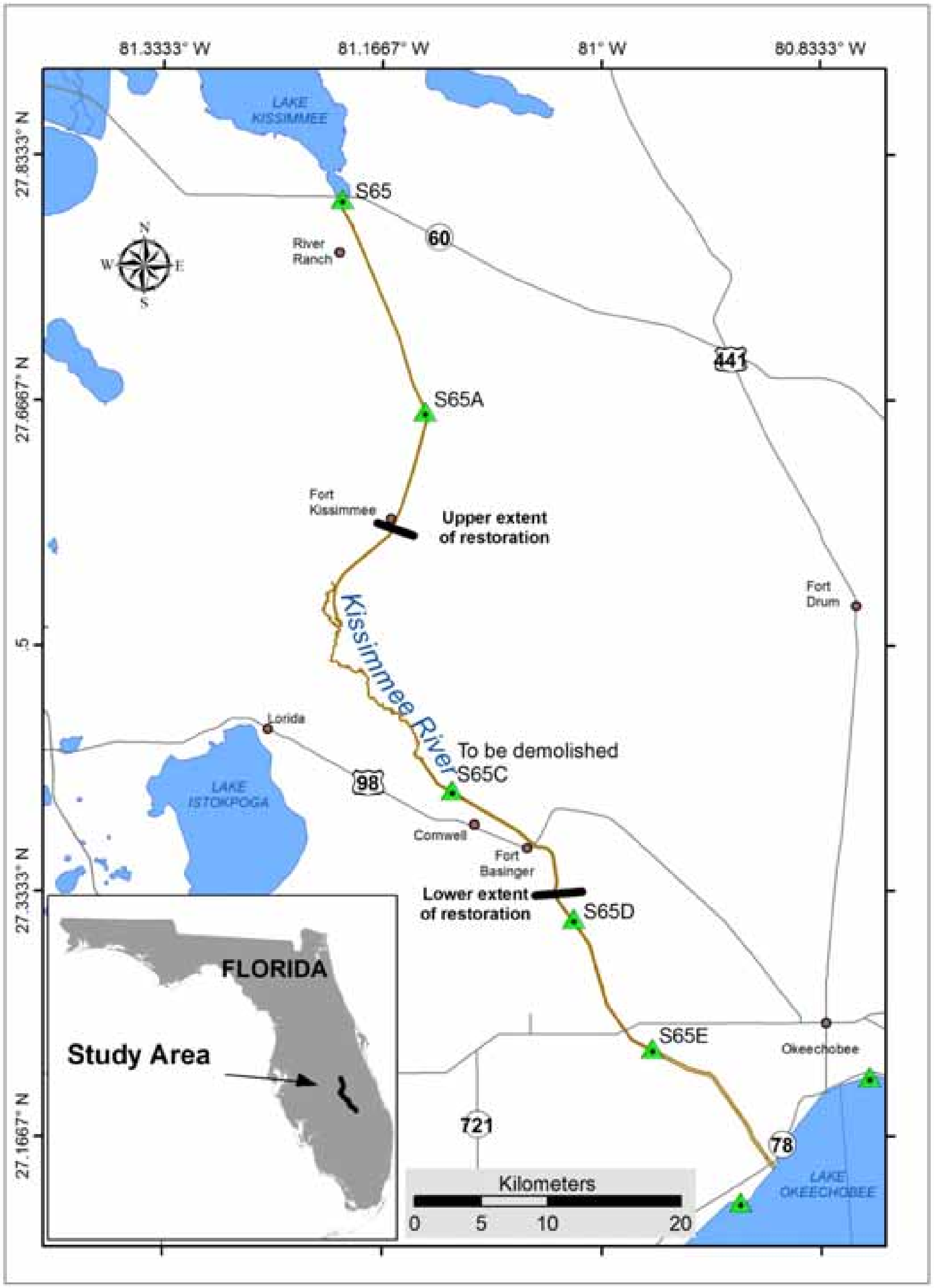


Figure 6-1. Location of the Lower Kissimmee River and its major restoration features. Geospatial analysis examined the entire lower Kissimmee River.

Table 6-1. Dates and type of imagery used to examine the Lower Kissimmee River.

Date	Imagery	Flydates	Scale/Resolution	Digitizing Scale	Point Bars
1940s	B/W	1944 Feb 7 & 27, April 13	1: 20,000	1:2000	1:500
1950s	B/W	1954 Jan 24; 1957 March 2; 1958 Jan 17 & 27, March 15	1: 20,000	1:2000	1:500
1994	Color IR	1994 March 11 &15	1 meter	1:2000	1:500
2005	True Color	2005 Jan 17-18	1 meter	1:2000	1:500
2005-06	True Color	2006 Jan 15 Polk; 2006 Mar 1 Okeechobee; 2005 Oct 1 Osceola; 2005 Jan 1-31 Highlands	1 foot	1:2000	1:500

Table 6-2. Dates and water conditions used to examine the Lower Kissimmee River.

Date	Imagery	Flydates	Discharge at Okeechobee	Stage at Lorida
1940s	B/W	1944 Feb 7 & 27, April 13	1010 & 860 cfs	N/A
1950s	B/W	1954 Jan 24; 1957 March 2; 1958 Jan 17 & 27, March 15	5220 cfs; 1050 cfs; 2160 & 2990 cfs, 3390 cfs	N/A
1994	Color IR	1994 March 11 &15	1970 & 2600 cfs	40.37 & 40.23 ft
2004-05	True Color	2005 Jan 17-18	N/A	39.08-39.1 ft
2005-06	True Color	2005 Jan 1-31 Highlands; 2005 Oct 1 Osceola; 2006 Jan 15 Polk; 2006 Mar 1 Okeechobee	N/A	38.99-39.44 ft; 39.97 ft; 39.8 ft; 39.09 ft

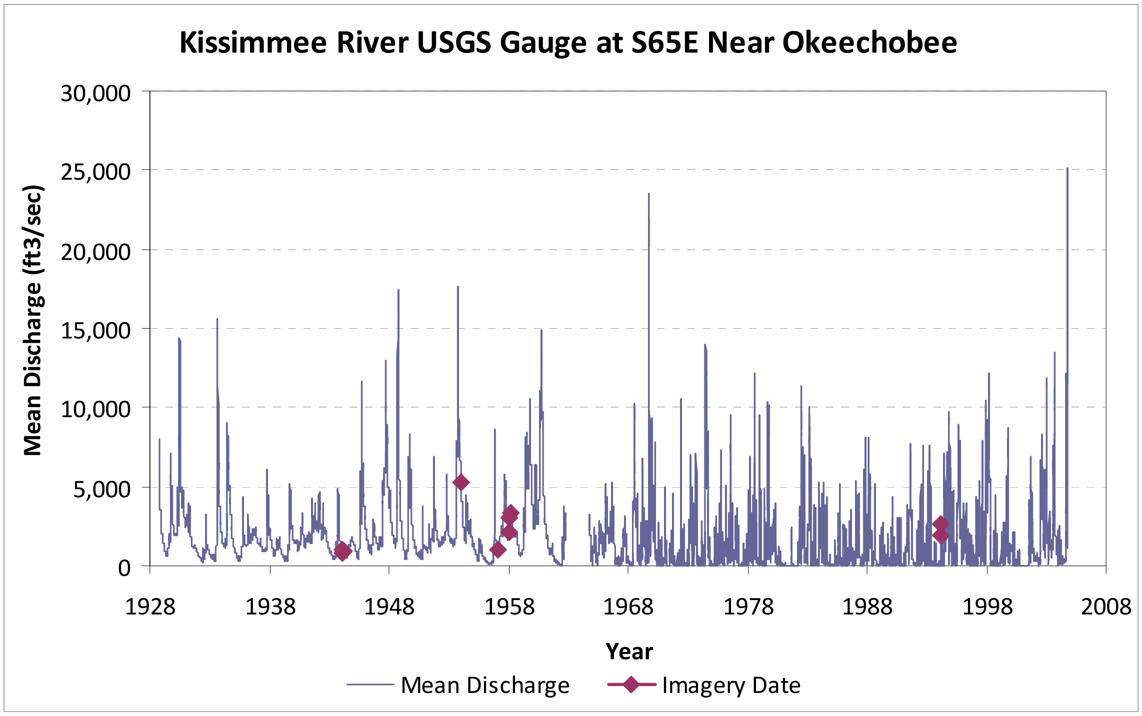


Figure 6-2. Discharges of the Lower Kissimmee River near Okeechobee, 1928-2004, showing relative flow conditions on dates when imagery was flown.

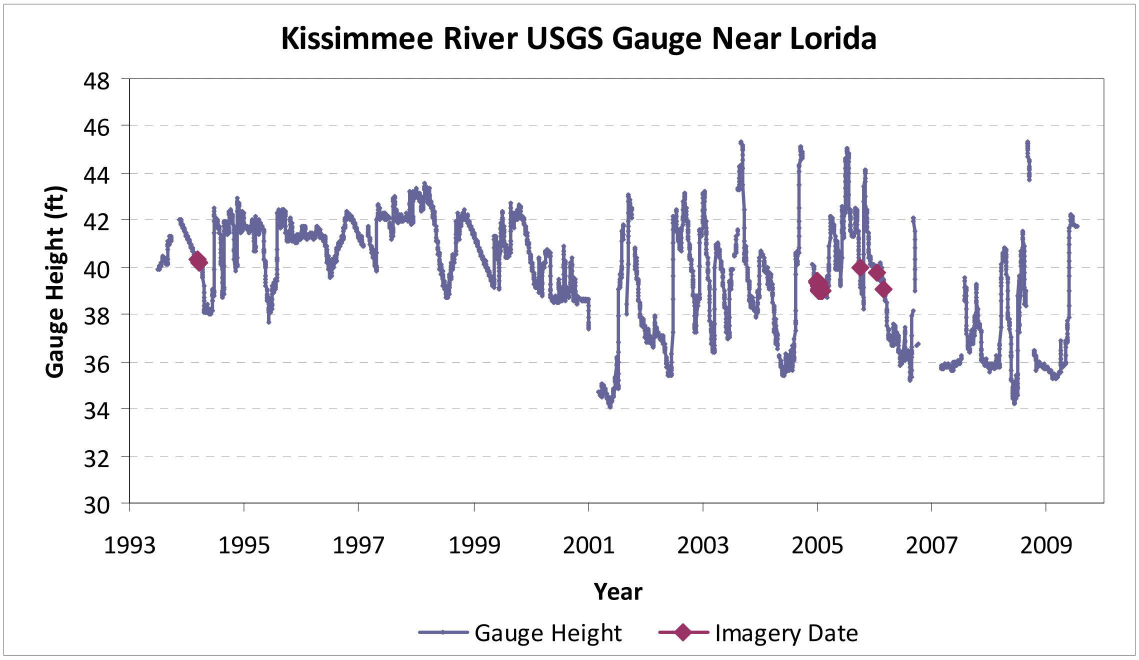


Figure 6-2. Stages or gauge heights of the Lower Kissimmee River near Lorida, 1993-2009, showing relative water level conditions on dates when imagery was flown.

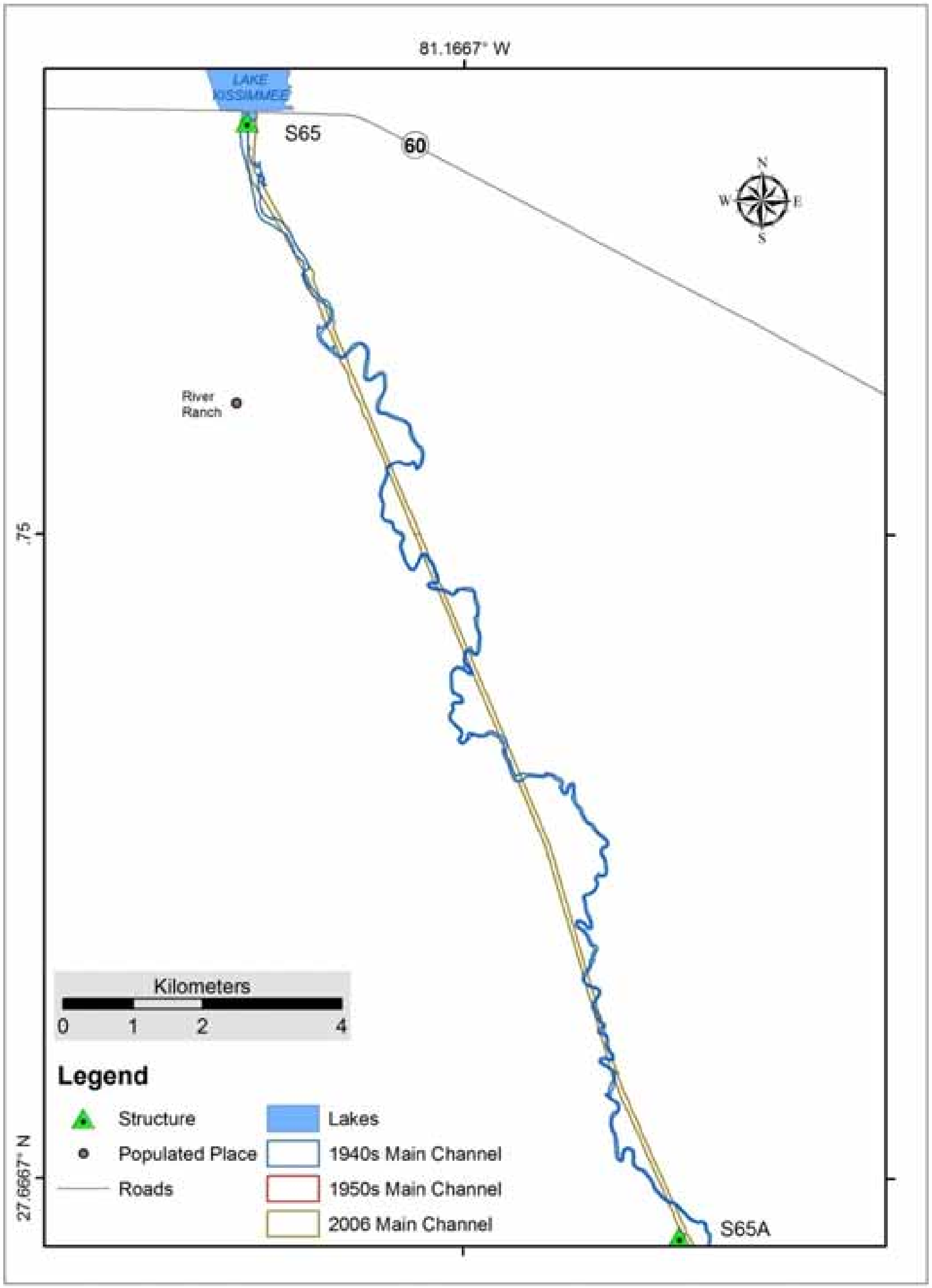


Figure 6-4. The main channel of the Lower Kissimmee River in Pool A during three different decades: 1940s, 1950s, and 2006. No changes were evident between the 1940s and 1950s and as a result 1950s channel is not visible on this map, but the canal which was built in the 1960s created a very different channel.

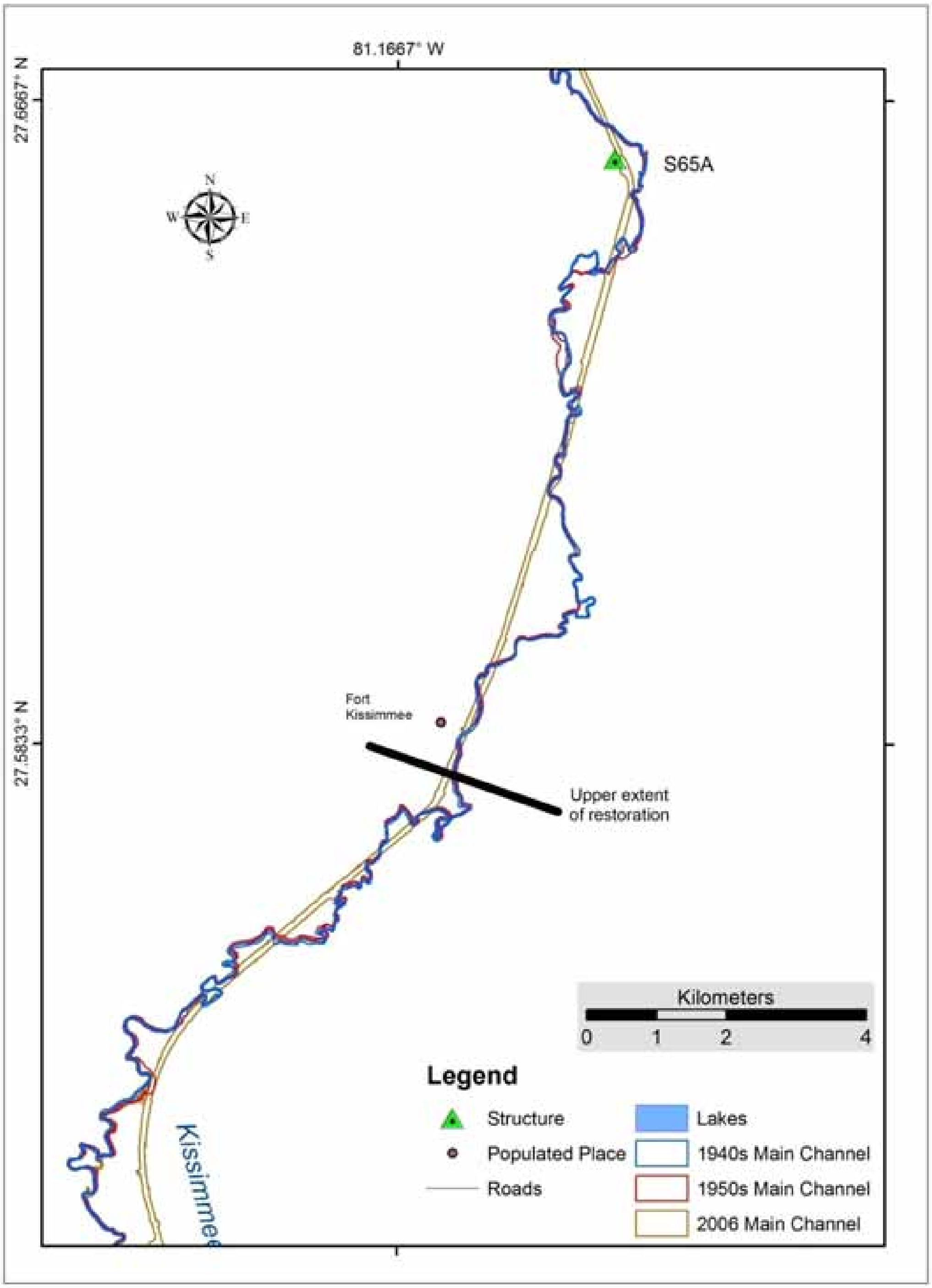


Figure 6-5. The main channel of the Lower Kissimmee River in Pool B during three different decades: 1940s, 1950s, and 2006. Some minor cutoffs, avulsions and local migration are evident from the 1940s to 1950s. When C-38 was built in the 1960s, it created a very different channel.

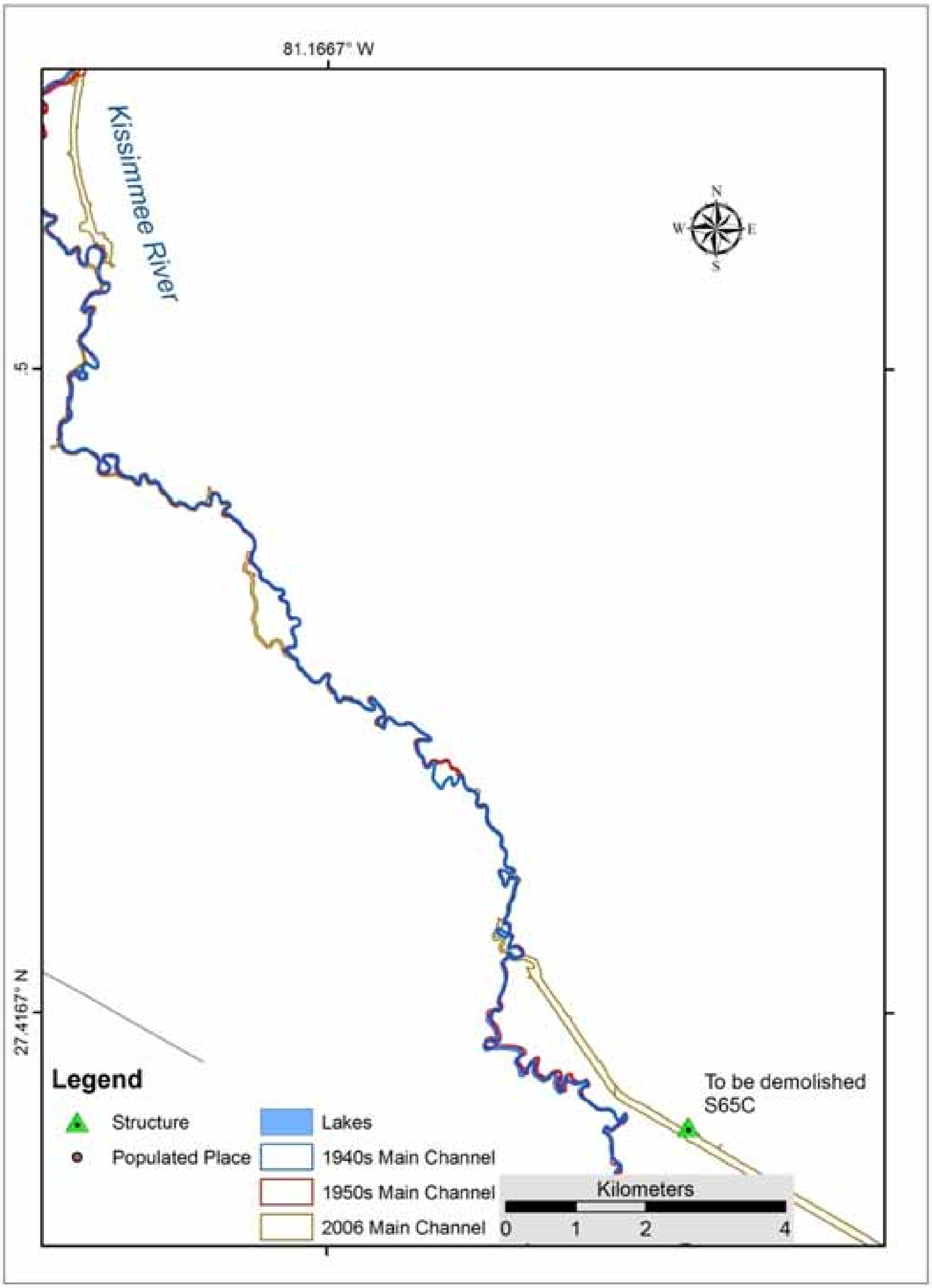


Figure 6-6. The main channel of the Lower Kissimmee River in Pool C during three different decades: 1940s, 1950s, and 2006. Some minor cutoffs, avulsions and local migration are evident from the 1940s to 1950s. When C-38 was built in the 1960s, it created a very different channel.

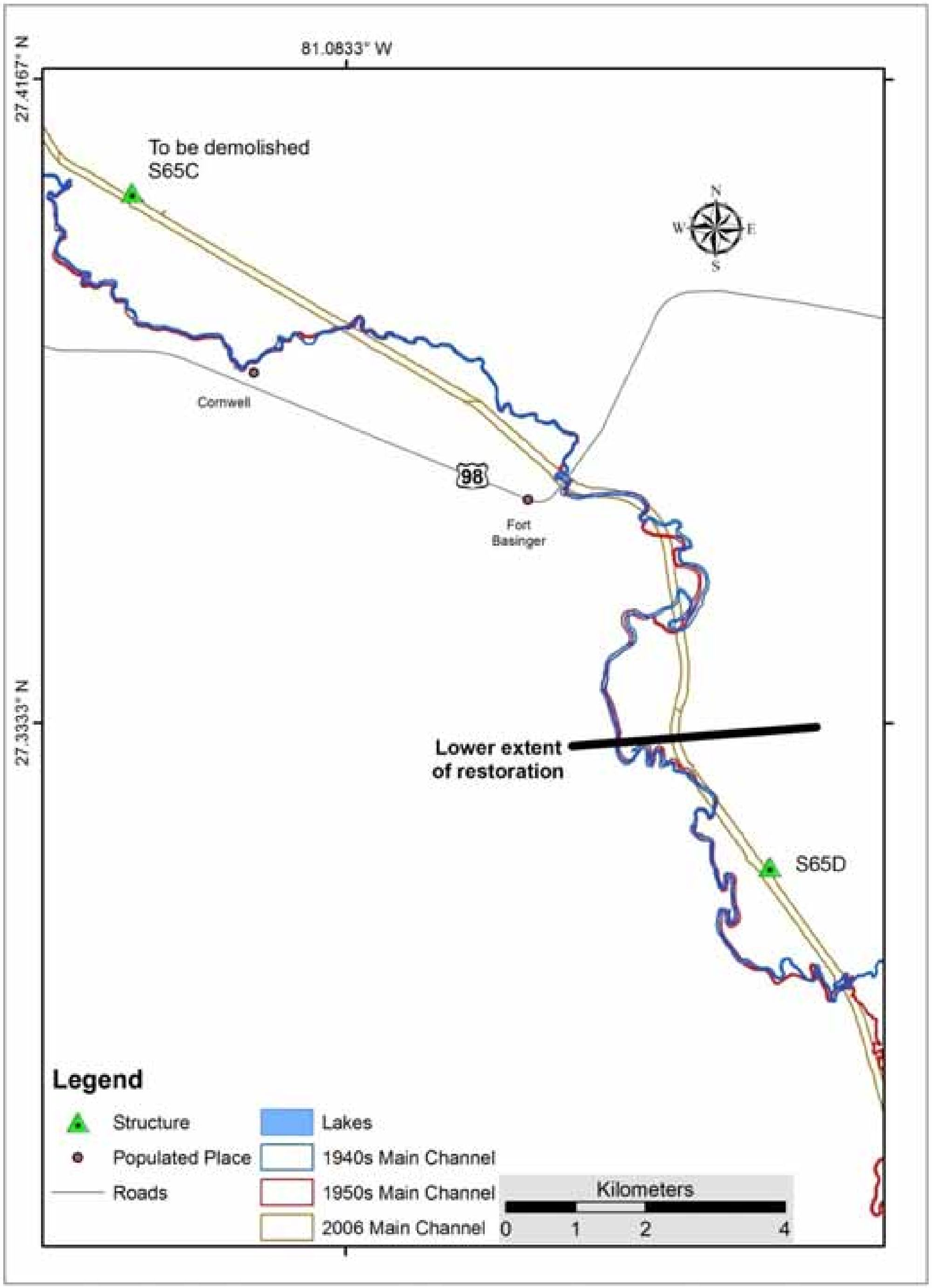


Figure 6-7. The main channel of the Lower Kissimmee River in Pool D during three different decades: 1940s, 1950s, and 2006. Changes in the area to be restored include some lateral migration between the 1940s and 1950s. The canal C-38 greatly shortened the length of this reach.

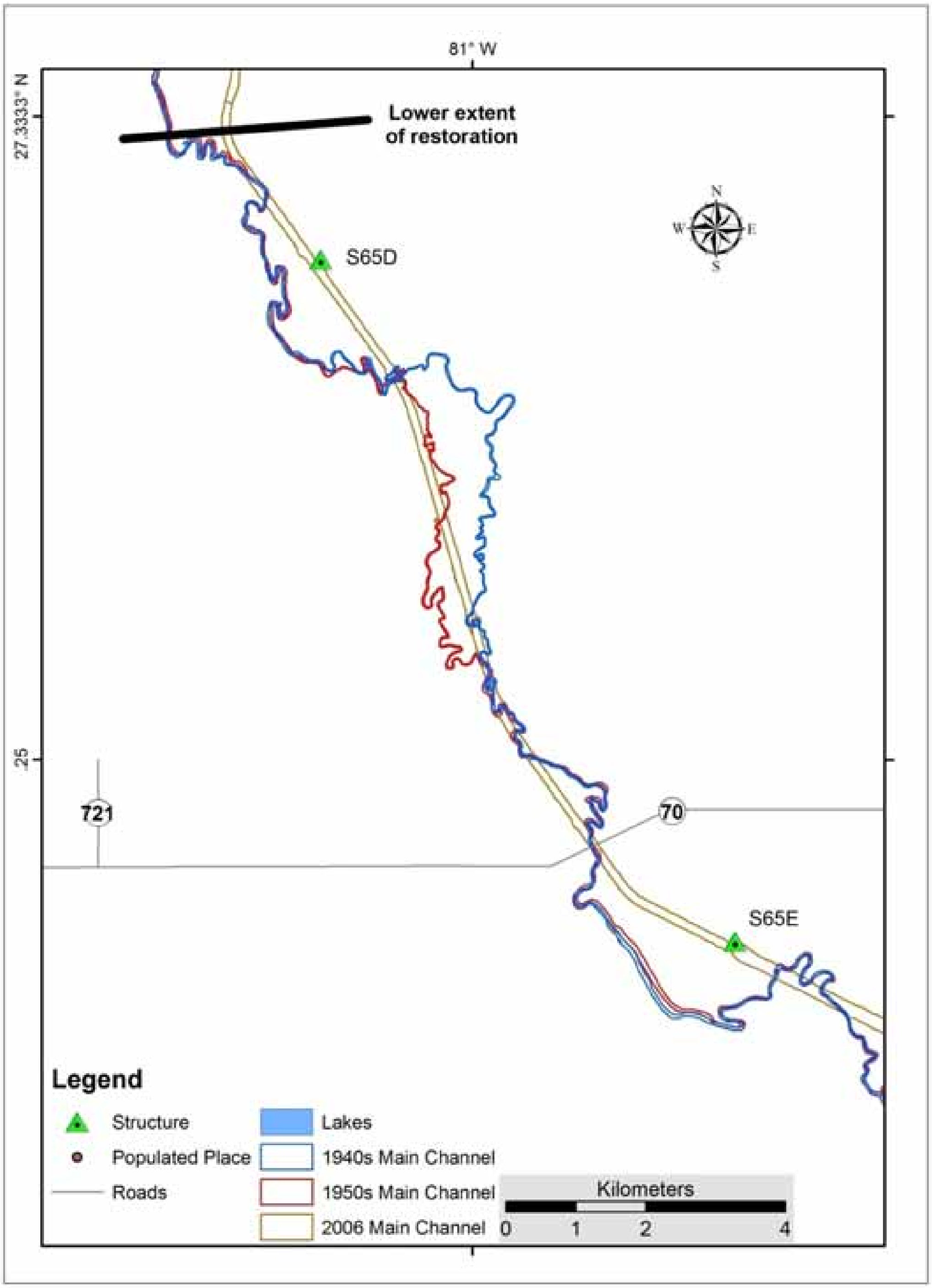


Figure 6-8. The main channel of the Lower Kissimmee River in Pool E during three different decades: 1940s, 1950s, and 2006. A large avulsion, a local cutoff and local migration is evident from the 1940s to 1950s. When C-38 was built in the 1960s, it created a very different channel.

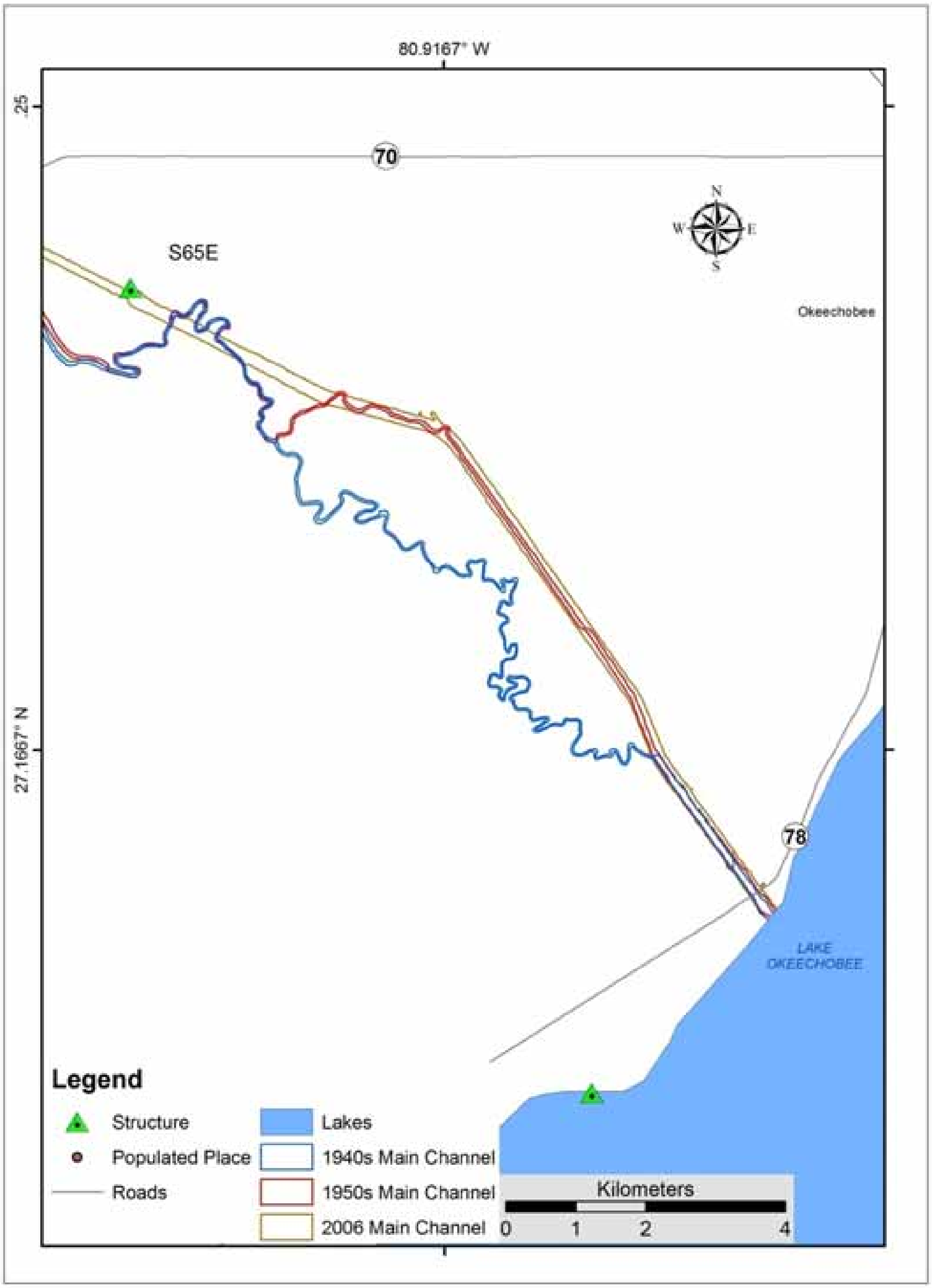


Figure 6-9. The main channel of the Lower Kissimmee River below Pool E to Lake Okeechobee during three different decades: 1940s, 1950s, and 2006. Anthropogenic changes began prior to the 1950s, as evident on the lowermost part of the channel. When C-38 was built in the 1960s, the uppermost part of this section was also modified.

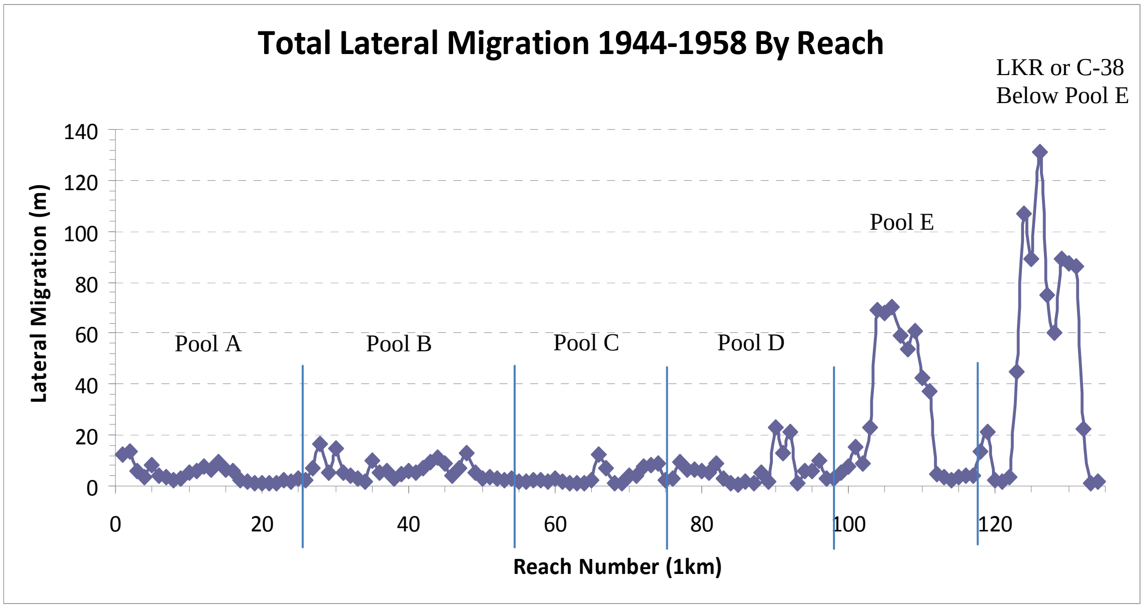


Figure 6-10. The locations and amount of migration associated with cutoffs, avulsions and less catastrophic planform movements between 1944 and the 1950s (1954-58) by reach block, Lower Kissimmee River.

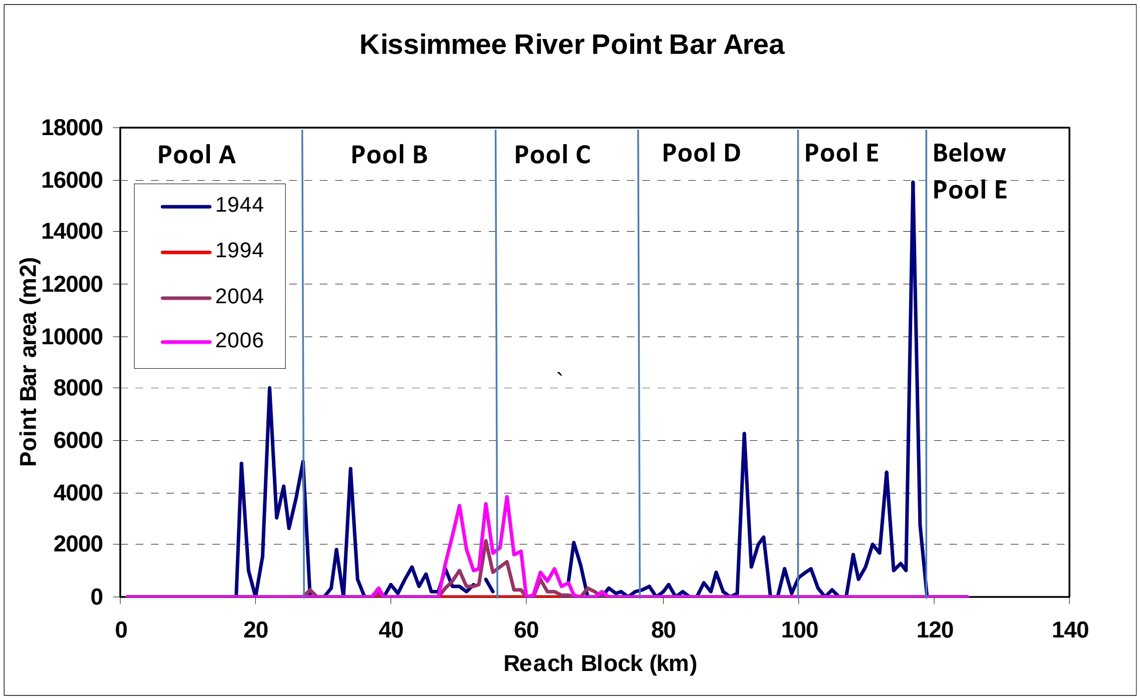
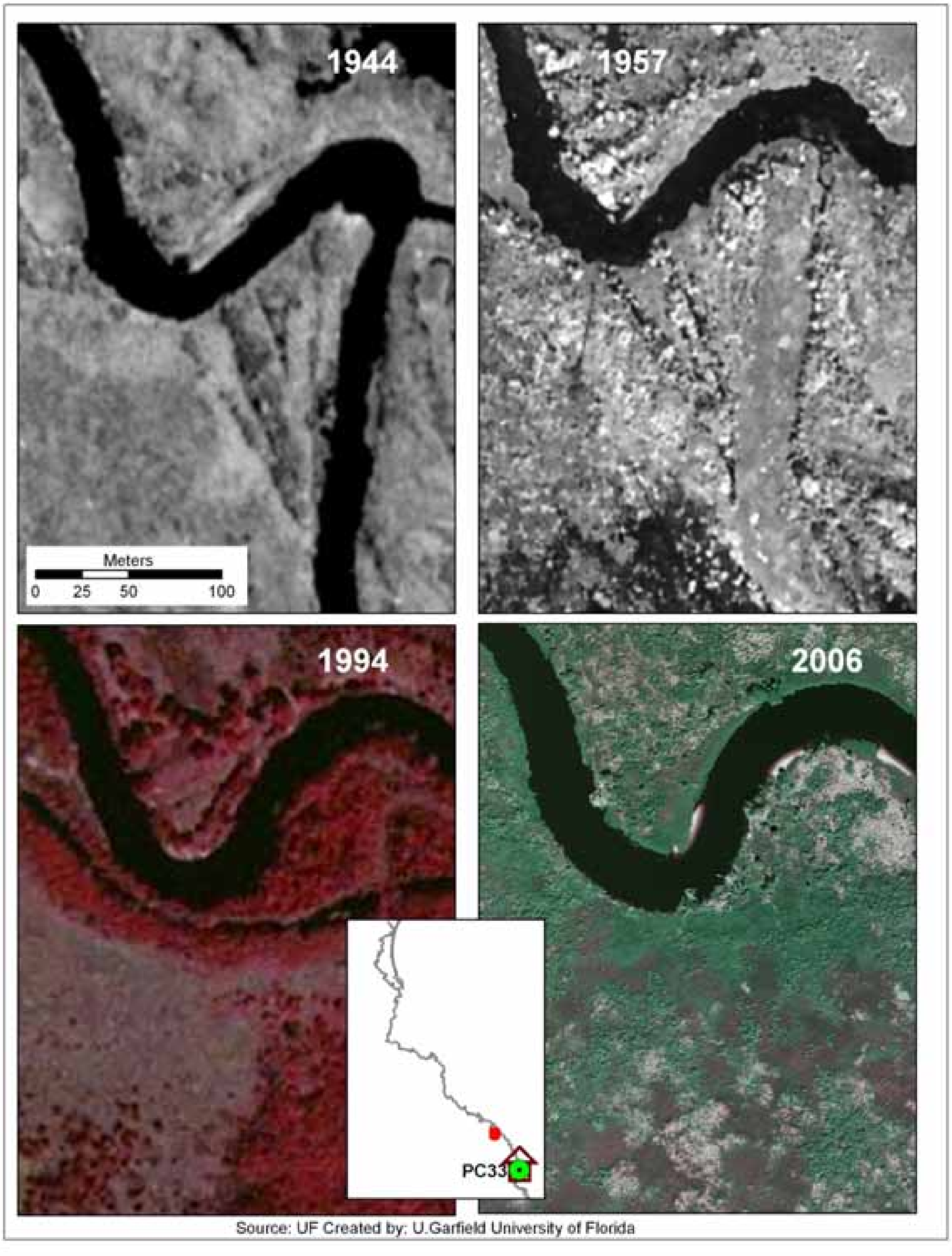
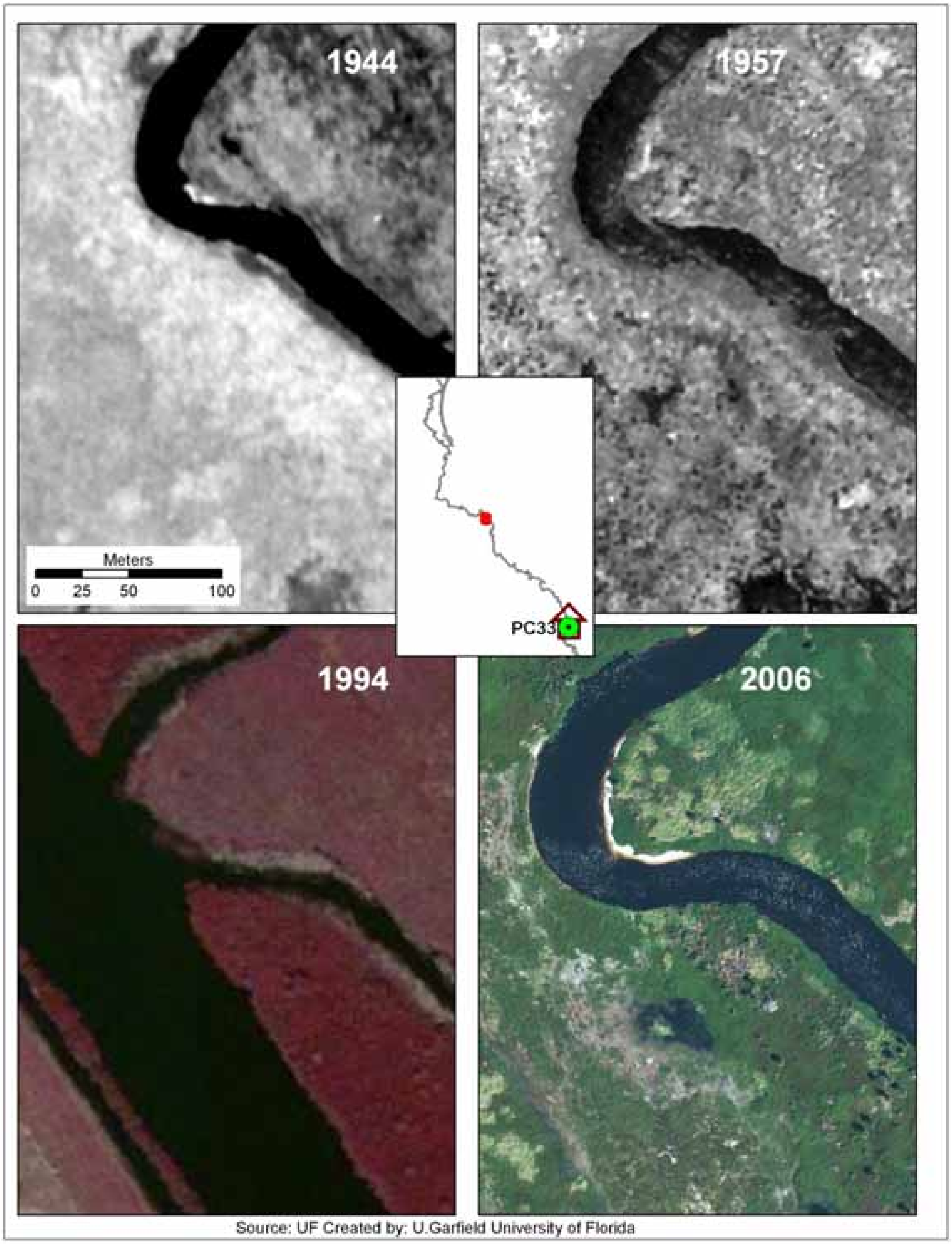


Figure 6-11. The locations and sizes of sand bars in the Lower Kissimmee River in 1944, 1994, 2004 and 2006 by reach block.



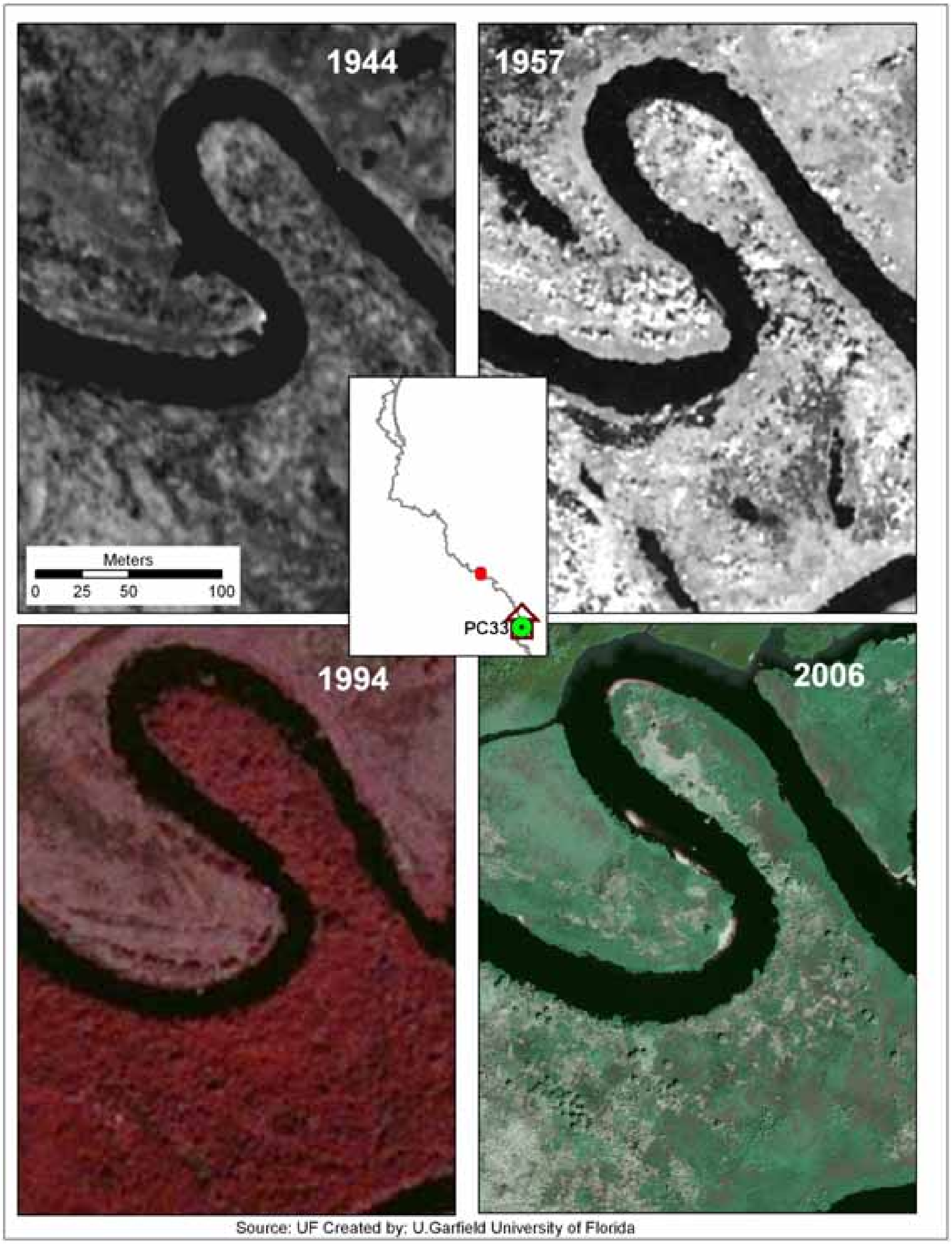
Source: UF Created by: U.Garfield University of Florida

Figure 6-12. Point bar formation upper Micco Bluff Run



Source: UF Created by: U.Garfield University of Florida

Figure 6-13. Point bar formation at Fulford Run transect FF03.



Source: UF Created by: U.Garfield University of Florida

Figure 6-14 Point bar formation near Oxbow 13 RC

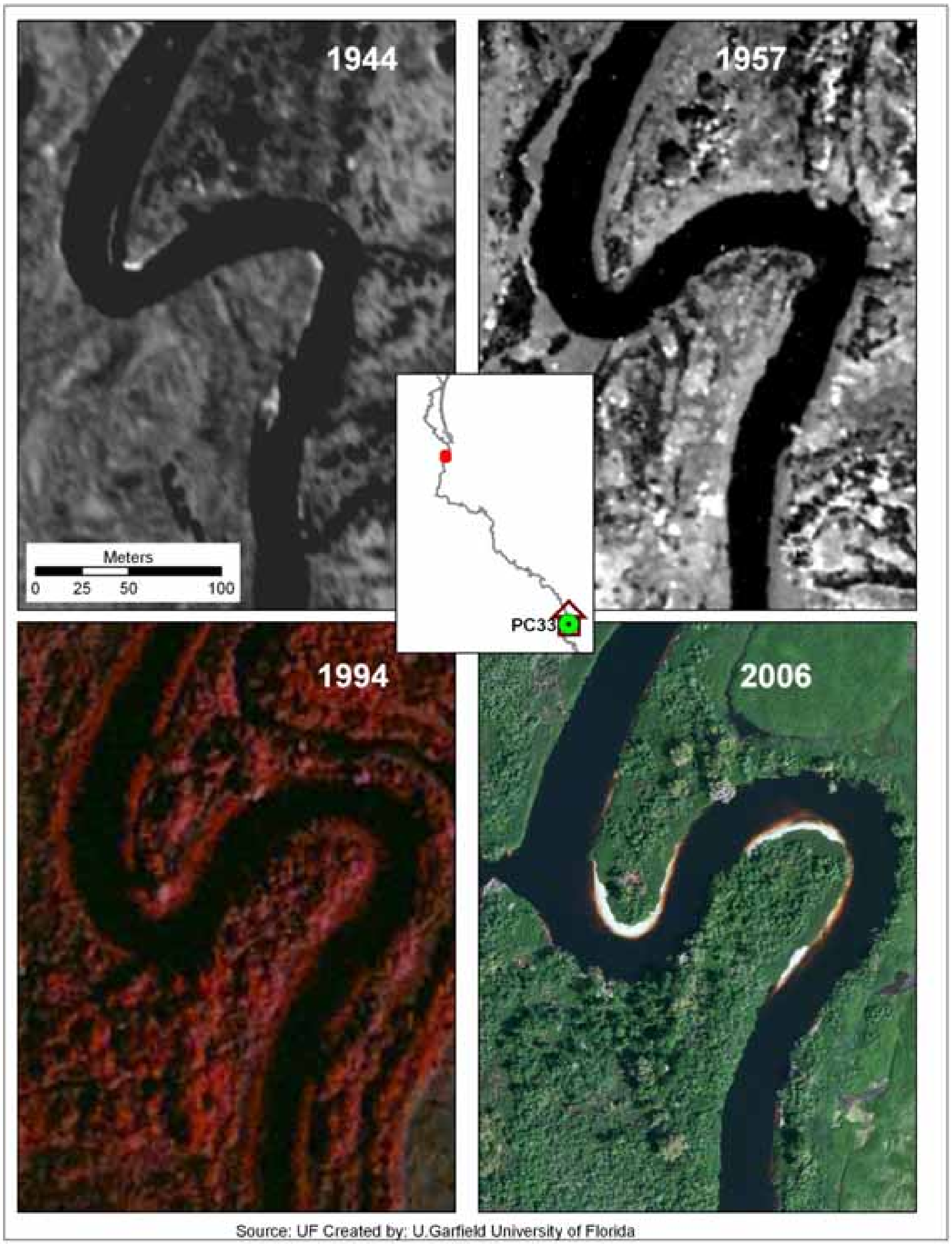


Figure 6-15. Point bar formation UBX Run

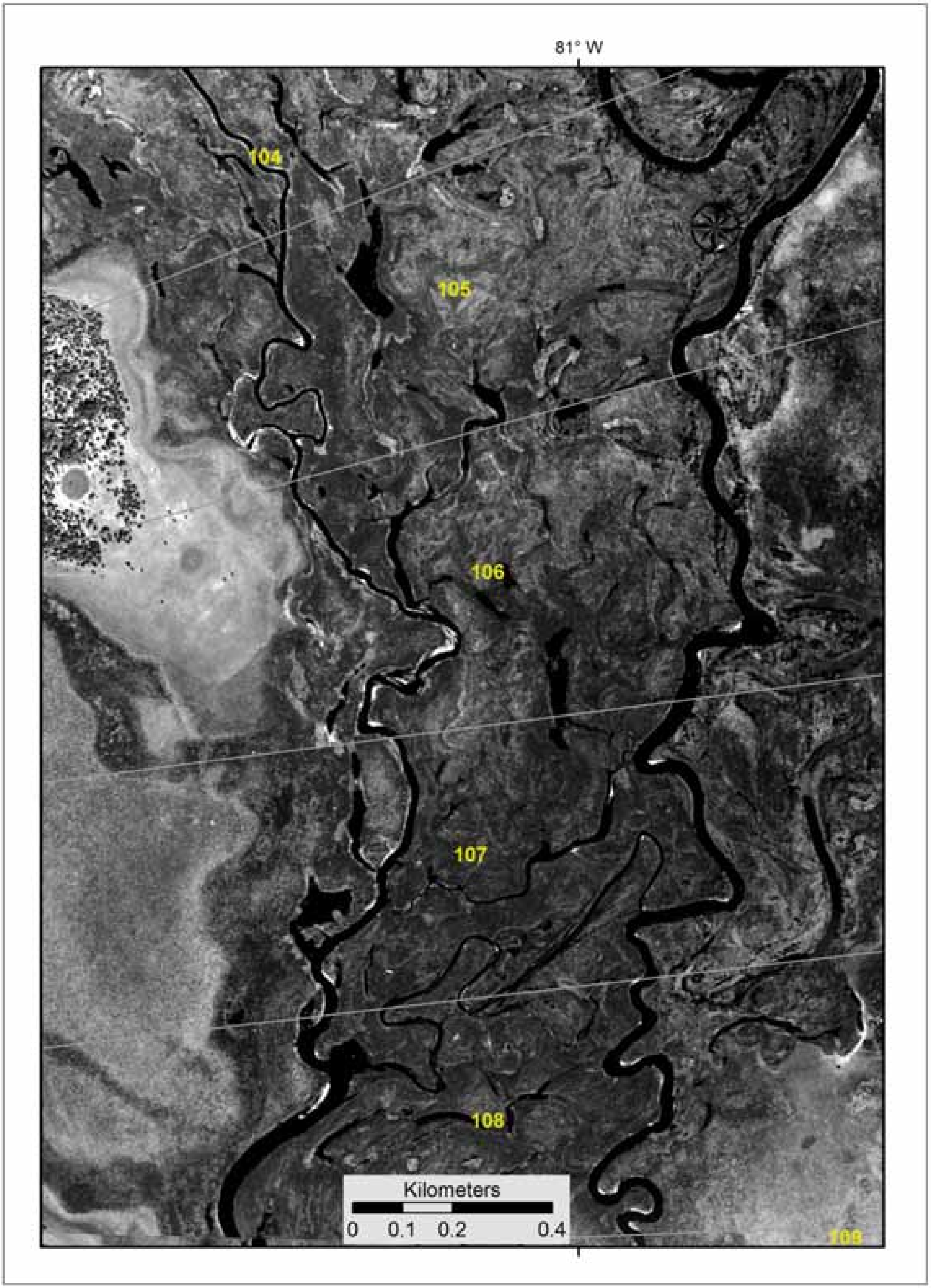


Figure 6-16. Aerial photography of the Lower Kissimmee River in reaches 104-108 from 1944 showing bars (white areas of high spectral reflectance).

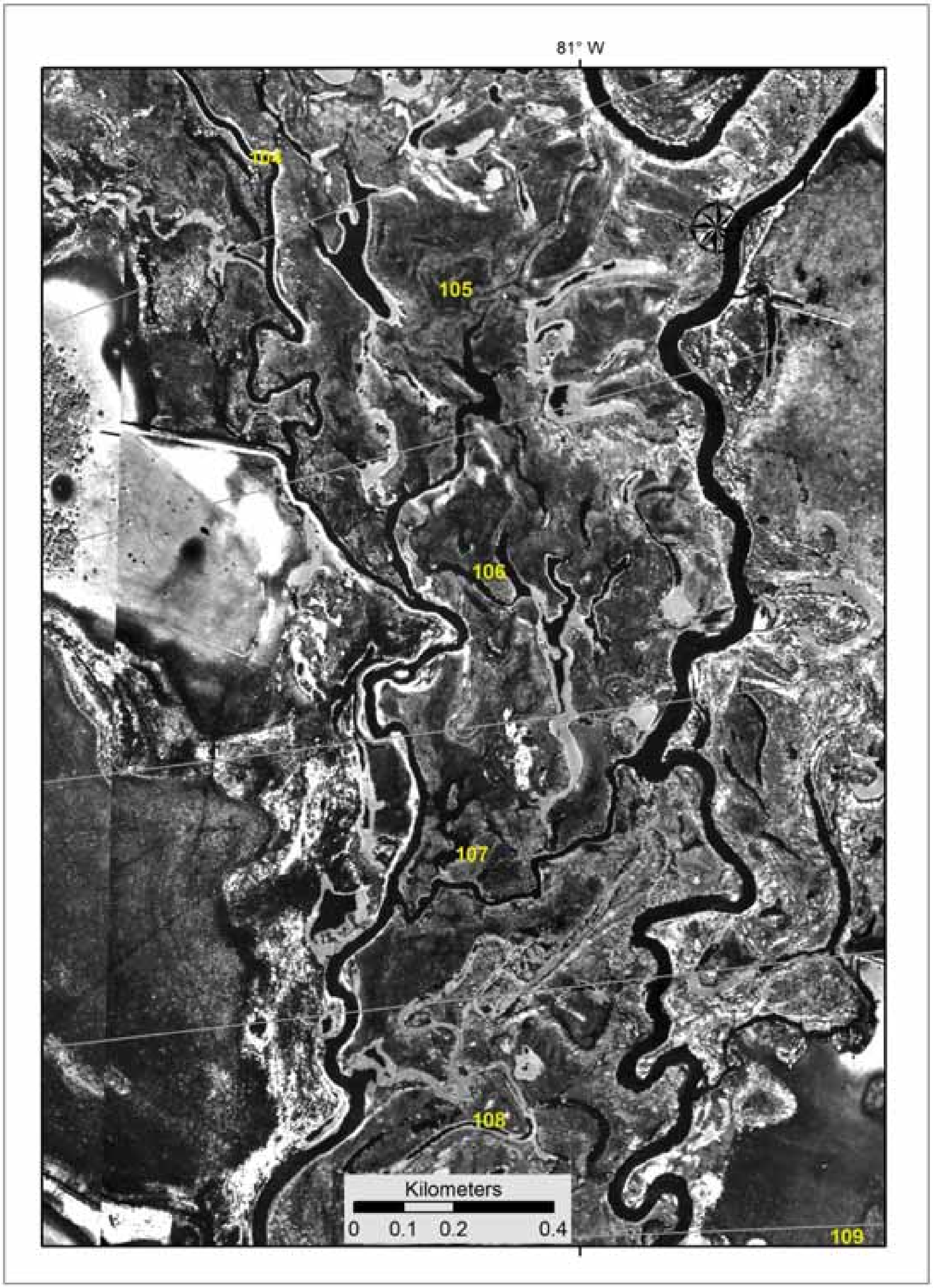


Figure 6-17. Aerial photograph of the Lower Kissimmee River in reaches 104-108 from the 1950s showing higher bar area (white areas of high spectral reflectance) due to a combination of recent floods and floodplain disturbances (ditch building in reaches 105-106..

CHAPTER 7

SUMMARY AND CONCLUSIONS

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Introduction

Rivers maintain a dynamic equilibrium among sediment transport, streamflow, and channel gradient. Disruption of any of these factors will lead to a commensurate change in channel morphology and possible consequences to the aquatic habitat. Best management of restored channels require the monitoring of sediment transport, streamflow, and channel gradient, along with channel morphology. Prior to channelization the Kissimmee River had a low channel gradient and long hydroperiods and thus geomorphic processes associated with this flow regime, were critical for supporting the original biodiversity of this ecosystem.

In 1992, the Kissimmee River Restoration Project (KRRP) was initiated to restore flow into the old channel system. The KRRP is the largest restoration effort currently underway in North America. Stability and sedimentation monitoring are presented in the IFR/EIS as integral programs in the KRRP monitoring plan. Critical to the success of the Kissimmee River Restoration is monitoring the geomorphic state of the river and understanding the relation of key geomorphic processes that influence its form and structure. The University of Florida together with the U.S. Geological Survey designed a geomorphic monitoring plan for three important geomorphic components of the Kissimmee River restoration: (1) sediment transport and channel-bed sedimentologic characteristics, (2) channel cross-sectional and planimetric morphology, and (3) floodplain processes. This chapter summarizes approaches and results of this geomorphic monitoring plan.

Sediment Transport

In July, 2007, a streamflow-gaging station was established on the Kissimmee River at PC-33 near Basinger, Florida (USGS streamflow station ID 022691600) (drainage area 5,270 km^2). Sediment transport characteristics that are monitored at the station include suspended sediment, bed load, and bed material. In addition, the organic content of the suspended sediment and bed load are monitored.

From July 21, 2007 through July 2, 2008, low flow conditions, interrupted by some wetter periods in March and April 2008, prevailed and the daily streamflow for this period was 15.7 m3/s. Beginning around July 3, 2008, wetter conditions occurred and the mean daily discharge for the period July 3, 2008 through September 30, 2008 was 58.0 m3s or 3.5 times higher than the earlier, about one year period (7/21/2007-7/2/2008). The wetter period from July to August 2008 was largely due to tropical storm activity. The highest mean daily discharge during the period of study, 157 m^3/s, occurred on August 22, 2008 during heavy rains associated with Tropical Storm Fay.

Suspended-Sediment and bedload transport in the Kissimmee River are strongly related to flow conditions. The Kissimmee River transports the majority of its suspended-sediment and bedload during periods of high flow. The 10 highest daily suspended-sediment loads were transported during Tropical Storm Fay, between August 21 to August 31, 2008, and totaled 44,600 Mg, which is 56 percent of the total suspended-sediment load for the period of study. The highest daily bedload transport occurred on August 23, 2008 during tropical storm Fay at a mean daily discharge of 157 m3/s when 749 Mg of sediment was transported, which was 20% of the total bedload discharge for the period of study.

The initiation of bedload transport occurs at 28.3 m3/s. The median grain size of bedload was similar for all flows ranging from 0.36 to 0.41 mm. The largest particle sizes transported as bedload was 1.0 to 2.0 mm for flows that reached 140 and 152 m^3/s. Organic percentage of the bedload ranged from 85% during low flow months to less than 1% at high flows.

Total sediment load (suspended-sediment plus bedload) for the period July 21, 2007 through September 30, 2008 was 83,155 Mg. Of the total sediment load, 78,918 Mg (95 %) was transported as suspended-sediment load and 4,237 Mg (5 %) was transported as bedload. Of the 78,918 Mg of suspended sediment, 5,614 Mg (7% of the total load) was transported as organic suspended sediment and 73,304 Mg (88% of the total load) was transported as inorganic suspended sediment. Of the 4,237 Mg of bedload, 53 Mg (<1% of the total load) was transported as organic bedload and 4,183 Mg (5% of the total load) was transported as inorganic bedload.

The Kissimmee River is a fine to medium grained sand-bed river. Suspended-sediment ranges from 2% sand to 78% sand, at low and high flows, respectively. The organic content of the suspended sediment increases with flow ranging from 3 mg/L at low flows to 21 mg/L at high flows. Organic percentage of the suspended-sediment load ranged from 31% during low flow months to 2% at for high flow months; indicating that inorganic suspended-sediment loads increase faster with rising discharge than organic suspended-sediment loads.

Effective discharge computations indicate that the majority of bedload sediment is transported at 47 m^3/s and 239 m^3/s. The 47 m^3/s effective discharge value is close to the bankfull discharge of 50 m^3/s and may be the channel forming flow. The channel forming flow is that discharge which is most effective in transporting sediment and forming the channel. The higher effective discharge at 239 m^3/s may be related to the frequent large flows that occurred during Tropical Storm Fay. These flows may be important in floodplain processes but more research is needed to confirm this.

The importance of storms in transporting sediment is highlighted by the monitoring data. During the period of study, over 50% of the total suspended-sediment load (78,918 Mg) was transported in 8 days and over 50% of the total bedload (4,237 Mg) was transported in 7 days. For both the suspended-sediment and bedload, this transport occurred during Tropical Storm Fay. Large amounts of bank erosion were observed on the Kissimmee River (see chapter on floodplain processes) and in some reaches the Kissimmee River scoured its bed (see chapter on cross-sectional channel geometry). Both bank erosion and the channel bed could be sources for suspended sediment and bedload. Future studies directed at constructing a sediment budget for the Kissimmee River may be able to determine the significant sediment sources.

Comparison of suspended-sediment concentration data from the Kissimmee River at PC-33 near Basinger, FL (2007 through 2008) to Kissimmee River at S-65E near Okeechobee (1973 through 1998) indicates that suspended-sediment concentrations are higher at PC33 near Basinger the same normalized discharge than at the Kissimmee River at S-65E near Okeechobee. It is unclear whether the higher suspended-sediment concentrations on the Kissimmee River at PC-33 near Basinger are due to the Kissimmee restoration or other factors. Suspended-sediment data is not available on the Kissimmee River near the restored portions of Pool C prior to channelization, during the channelized period, or directly after restoration. Therefore, the suspended-sediment data (concentrations and loads) presented here serve as reference values to determine if concentrations and loads increase, decrease, or remain steady over time.

Floodplain Processes

A long-term floodplain monitoring plan for the Kissimmee River Restoration Program was established to provide SFWMD with data to implement comprehensive adaptive river management approaches. Objectives of the plan included 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. Results will be used to facilitate the development of a sediment budget, including floodplain trapping and material (e.g. carbon) sequestration.

Sixteen floodplain sediment monitoring transects were established on the Kissimmee River in the winter/spring of 2007. These sites were re-measured in May 2008 and again in December 2008. Thirteen of the transects were in the restored reach (Pool B/C) of the river and contained 86 clay feldspar pads and 3 transects were in the channelized reach (Pool D) and contained 14 clay feldspar pads. Transects were aligned normal to the channel and extended from the river edge to 50 to 575 meters across the floodplain. Periodic measurements of the clay pads were made for: (1) deposition rate, (2) texture, (3) bulk density and (4) composition (C and P concentrations). From January 2007 until May 2007 low flow conditions prevailed on the Kissimmee River and water levels at upstream sections of the restored channel were lower than usual with dry conditions on the floodplain. During this low-flow period, areas of the restored channel near the S-65C control structure, experienced high water conditions due to water ponding behind the structure. Floodplain depressions and sloughs were inundated and most areas of the floodplain were moist to very wet. The wetter period in March and April 2008 led to one overbank flow in Pool C. Sediment deposition measured on 81 pads in Pool B/C in May 2008 averaged 6.7 mm/yr, ranging from 0 mm/yr to 29.8 mm/yr (near a slough). Higher flows associated with Tropical Storm Fay in August 2008 led to overbank flooding over an extended period. Floodplain sediment deposition measured on 82 pads in Pool B/C in December 2008, indicated a mean sedimentation rate of 15.0 mm/yr ranging from -7.9 mm/yr (erosional) to 110 mm/yr (part of a levee building event from Tropical Storm Fay). The high suspended-sediment and bedload transported during Tropical Storm Fay led to a greater supply of sediment available for the floodplain as shown by the higher floodplain sedimentation rates.

Tropical Storm Fay also had a large impact on the channel and floodplain with noticeable erosion on straight and cut banks, sometimes producing several meters of bank retreat. New channel and point bars were created. The floodplain was modified by the event, especially adjacent to the channel where sand splays added in excess of 30 cm of sediment in a levee building event. Other levees were severely eroded during the large flood event.

Sediment deposition rates measured on 8 pads in the unrestored Pool D, showed average deposition of 1.6 mm/yr in May 2008 and 1.3 mm/yr in December 2008. Both means are an order of magnitude lower than the restored reach. Sedimentation in Pool D can be attributed to autochthonous organic dry deposition, intra-floodplain sediment transport, and aeolian (wind) processes. The lower sedimentation rates in the unrestored Pool D section, illustrate the loss of connectivity between the floodplain and the channel. Thus, one objective of the Kissimmee River restoration to enhance overbank flooding onto the floodplain has been achieved. However, whether the depth and duration of this overbank flooding is similar to pre-restoration rates remains uncertain.

About 25% of all sediment trapped on the Kissimmee River floodplain is organic. Organic deposition rates were highest in the furthest upstream transects of Pool B/C and in the downstream segment of the restored reach. The percent soil organic matter was generally highest near floodplain depressions or side channels. Percent organic content on the floodplain increased significantly ($p < 0.002$, T-test) after overbank flooding attributed to Tropical Storm Fay.

Classifying the restored Kissimmee River floodplain into 4 landscape types: (1) backfilled C-38 canal, (2) borrow areas to backfill the canal, (2) original floodplain, and (4) elevated spoil regions adjacent to connector segments of the channel, showed that sediment deposition, organic content, and bulk density varied greatly between landscape type. Natural floodplains have the highest proportions of organic matter and borrow areas because of their lower elevations and proximity to the main channel have the highest total deposition rates. Analysis of vegetation and floodplain deposition rates indicated that the highest rates of total deposition occur in wetland shrub communities, while the lowest rates occur in wetland forests. The highest sediment organic content was in wetland forests.

The highest sediment deposition rates were near or at sloughs, depressions, or the main channel. Coarse grained deposits (fine sand) occur almost exclusively at sites adjacent to the main channel and presumably result from natural levee construction. Fine grained (silt and clay dominated) deposits occur primarily near sloughs and depressions away from levee deposits. Organic content of sediment tended to be greatest in fine-grained deposits.

All floodplain sites were dominated by very fine to fine sand (63 to 125 microns in diameter) with coarser sediment in the backfilled canal than either the borrow or floodplain area. Sediment texture changed significantly from a mean diameter near 63 microns at the beginning of the study to a fine silt/clay range after the spring flood in May 2008. Mean floodplain grain size coarsened again after Tropical Storm Fay with the influx of mineral sand.

Floodplains may act as an effective sink for several pollutants; one of the best studied is phosphorus. Sediment concentrations of total phosphorus in the Kissimmee River floodplain indicate that the system has some of the highest phosphorus concentrations of studied floodplains in the southeast U.S. (Greg Noe, personal communication). Phosphorus concentrations increase linearly with organic content, making the sloughs and depressions the greatest sinks for phosphorus.

Channel Cross-sectional Monitoring

There are three major types of river reaches that occur in the restored portion of the Kissimmee River as follows: 1) remnant channels that were left intact during channelization; 2) recarved channels or former channels that were buried by spoil during channelization and have been recarved to the approximate geometry of the former channel; and 3) connector channels that go across backfilled portions of C-38. The connector channels appear wider than either the remnant or recarved channels, and were designed that way to reduce velocities and minimize potential erosion on the backfilled areas. The approach to monitoring channel change in the restored section (Pool B/C) of the Kissimmee river channel cross sections was to: 1) benchmark how the cross-sectional geometry differs in the three types of channels (remnant, recarved, and connector); 2) determine how straight versus bendway reaches differ within the three groups, and 3) determine which cross sections changed the most over time.

To accomplish these goals, 21 total cross sections were benchmarked; 12 cross sections in Pool B/C with 4 cross sections on remnant channels, 4 cross sections on recarved channels, and 4 cross sections on connector channels. Within both the remnant and recarved channels, 2 and 2 cross sections were in straight and bendway reaches, respectively. Within connector channels, all 4 cross sections were in straight reaches, as this is how they were designed.

In addition to Pool B/C, for comparative purposes, 4 cross sections were benchmarked in the unrestored Pool A and 4 cross sections in Pool D. Cross sections were initially surveyed in February of 2007 and resurveyed in January 2008 and 2009. An additional transect was added in Pool D in 2009.

Connector channels were consistently different than remnant and recarved channels. Connector channels were on average 100m wide, which was wider than the other two types which averaged 30m. Connector channels were also shallower than the remnant and recarved channels. An island or submerged bar was common in the connector reaches and may be due to the reduced velocities associated with the wider channel. The reduction in velocity leads to sediment deposition and bar and island formation. The connector channels are designed and engineered channels. Because the connector channel is much larger than remnant and recarved channels, it seems that the connector reach has not acquired an equilibrium morphology. The connector channels will likely continue to experience more deposition and bar growth over time until it reaches an equilibrium form. Continued monitoring of these connectors will confirm how quickly they will change over time.

Bottom Sediment Observations

Channelization of the Kissimmee River left several runs or abandoned channel reaches intact but disconnected from the river flow. Without flow to transport any deposited material, sediment and organic material accumulated in the remnant channels. Once flow is restored in these reaches, it is uncertain what will happen to the large quantities of organic and finer sediments that accumulated. The objectives of bottom sediment monitoring were to characterize the bed or bottom sediments in the unrestored Pool D section of the lower Kissimmee River and to gain an insight into the amount and spatial trends in deposited material.

Fifty-two cores were collected in 2009 at various points along the channel centerline in Pool D. Most of the cores were over 50 cm deep, with some cores extending over 1 m below the riverbed surface. Of the 52 cores collected, the original sand bottom was possibly reached in 47 cores. Cores were characterized into 3 basic categories: sand, fines (silt & clay) and organics. The mean thickness of fine and organic sedimentation across the 52 cores acquired in Pool D was 38 cm. A general correlation ($r^2 = 0.54$) was observed between the depth of the inferred original channel bottom and fine and organic sedimentation. Deeper areas, because of the larger cross sections, seem to be areas of greater sedimentation.

Geospatial Analysis of Channel Planform Changes

One important component of monitoring the KRRP is better documentation and understanding of the planimetric channel form, rates of change, and comparisons to pre-restoration morphometry. Geospatial analysis of channel planform change was conducted in the Lower Kissimmee to understand channel changes (sinuosity and lateral migration) of the river over large areas since restoration. An additional focus was to document and monitor the number and size of sand bars. Five time-periods of imagery were analyzed: (1) 1944, (2) and 1954, (3) 1958, (4) 1994 and (5) 2005-06. The imagery was used to create planimetric channel maps for 3 time periods; 1940s, 1950s and 2006. In addition, 1901 maps with some bathymetry are also being examined to extend our knowledge of pre-channelization characteristics of the river. All geospatial data is stored in a geodatabase created and maintained by the University of Florida, Department of Geography.

In Pool A, no major changes except small avulsions were evident in the pre-channelized channel between the 1940s and 1950s. In Pool B (now the upper portion of Pool B/C), channel planform changes occurred from the 1940s to 1950s, including minor cutoffs, avulsions and local migration. Most of the changes before channelization took place upstream of the northern limit of the restoration project. Pool B, in the area that is now the lower portion of Pool B/C which is partially restored, showed some avulsions, a cutoff, and local migration from the 1940s to 1950s. In Pool D, some lateral migration is observed between the 1940s and 1950s. Pool E, which will not be restored, shows the largest avulsion up to 60m, and some lateral migration from the 1940s to 1950s. The even larger “migration” or change in position of the channel in the Lower Kissimmee River or C-38 below Pool E from the 1940s to 1950s is anthropogenic. This section of the river was straightened and channelized years before the remainder of the river. From the 1950’s to 2006, the major planform change in all sections of the Kissimmee River is creation of the C-38 canal.

Prior to channelization, the Lower Kissimmee River contained multiple sand bars -- characteristic of a migrating sand bed river. Sand bars were very abundant in Pool A and Pool E in 1944. Other portions of the pre-channelization river had smaller sand bars. The river was channelized between 1962-1971, and by 1994 all the sand bars had disappeared. By 2004, the post-restoration channel shows an increase in sand bars, where in many reaches more sand bar areas are evident than had been there in 1944. By 2005-06, the lowermost portions of Pool B and uppermost portions of Pool C show more sand bar area than in 1944 or 2004. One key question that remains is the source of this sand which may be related to bank erosion and river restoration construction. Future studies will be needed create a sediment budget for the Kissimmee River that will determine the rates of bank erosion.

Recommendations

Below are recommendations for communication with other parties, additional monitoring, and data collection to improve our understanding of geomorphic processes in the Kissimmee River and how it will respond to restoration.

- Future studies will be needed to establish a sediment budget for the Kissimmee River. This sediment budget will define the input, export, and storage of sediment . As part of the sediment budget, rates of bank erosion will be quantified and contrasted with rates of sediment transport, floodplain deposition, and sand bar development.

- Modeling bank erosion could be used to understand which flow regimes promote bank erosion and the magnitude of this erosion.

- Establishing additional transects in different connectors soon after other portions of the river are restored will help document whether these reaches continue to be sites of bar development or whether adaptive management can result in improved engineering of these vulnerable portions of the channel.

- The conclusion drawn here that connector channels are engineered too wide and at abrupt angles, should be communicated to the Army Corps of Engineers so future connector channels resemble the natural configuration of the river.

- Monitor other types of reaches soon after the restoration.

- Additional collection of bathymetric data may be useful in gaining a better understanding of the thickness of sediments and organic layering before and after restoration.

- Suspended sediment and bedload collection should continue at PC-33 to establish a longer period of sediment transport that can be used to understand channel morphologic changes and effective discharge regimes.

- Suspended sediment and bedload collection should continue at two streamflow and sediment stations that were installed on the Kissimmee River in 2009 in Pool D to document sediment transport before and after restoration (Kissimmee River at US 98 at Fort Basinger, FL, Station ID 02272500 and Kissimmee River at Lockett Estates at Fort Basinger FL, Station ID 02272502).

- Attempts should be made to construct pre-channelization characteristics of the Kissimmee River including pre-channelization floodplain deposition rates.

- Continued monitoring of the floodplain will evaluate the re-establishment of levees in areas affected by the restoration program (connectors, recarved reaches) and the natural maintenance of levees in less impacted reaches (reconnected reaches).

- Continued floodplain monitoring in the Kissimmee Basin could include a greater monitoring effort in Pool D to capture the sediment and landscape dynamics as the reach is restored.

- Further monitoring of floodplains will allow us to determine sedimentation rates for a variety of flood scenarios and will allow us to determine whether the results we have presented are typical for this system. This added information may help managers better assess the time scale needed to determine the successful restoration of adjacent wetlands and will greatly increase the body of knowledge in wetland restoration, especially hydroperiod and hydrological connectivity fields of restoration.

- Measuring floodplain subsidence would also be informative to compare gross deposition (using clay pads) with soil loss through soil oxidation and compaction.

- Future work may include detailed analysis of the phosphorous content of suspended sediment and floodplain sediment.

- Overall, continued floodplain monitoring in conjunction with sediment transport and channel dynamics information could provide important sediment trapping (ecosystem service) information and allow for the development of sediment budgets.