

FLOODPLAIN SEDIMENT TRAPPING, HYDRAULIC CONNECTIVITY, AND VEGETATION ALONG RESTORED REACHES OF THE KISSIMMEE RIVER, FLORIDA

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Abstract

The channelized Kissimmee River is undergoing the world's largest river restoration program, with several thousands of hectares of wetlands being reconnected to 70 river km of naturalized channel. We monitored floodplain sediment dynamics between 2007 and 2009 recording sediment deposition, erosion, texture, organic content, and bulk density at 87 sites in the restored reach and 14 sites in an unrestored reach. There were two flooding events during the study, one as an annual flood event and the second as higher than a 5-year flood event. Sedimentation dynamics and character varied by flood, landscape type, distance from preferential over-bank flow routes, elevation, and to a lesser degree, vegetation. Preliminary studies on soil phosphorus concentrations indicate that the restored floodplain is trapping high amounts of total phosphorus (1.42 mg/g), a nutrient that is currently impacting areas downstream Lake Okeechobee. Results indicate that the restored river reach provides sediment and possibly organic material to the reconnected wetlands. Continued research (2010-2012) is focusing on long-term monitoring, comparing gross deposition with soil subsidence, and furthering our understanding of the variables impacting sedimentation and sediment character in south Florida.

INTRODUCTION

Natural floodplains serve many ecological and hydrological purposes including sediment and nutrient trapping, flood stage and velocity dampening, and they support a diverse habitat for flora and fauna. The diverse functions of floodplains are often negatively impacted by human alterations to channel flow through dam construction, stream channelization, and canal and levee construction. Impacts may include dramatic reductions in the peak stages, frequency and duration of over bank flows, and sediment transport (dams, Williams and Wolman 1984), and a dramatic reduction in overbank flow and attendant sediment trapping (channelization/levees, Hupp et al. 2009).

The Kissimmee River suffers from both dam construction (lock control structures) and, perhaps, more pervasively from channelization. The river lost approximately 8000 ha of wetlands after channelization between 1962 and 1971. A multi-phase restoration program is currently being implemented to recreate, or restore, 70 km of river channel and return natural hydroperiods to several thousand hectares of floodplain wetlands. The river restoration program is the world's largest to date. Two of the five canal reaches have been restored to create one river reach (designated Pool B/C derived from the pre-restoration reaches). The downstream canal reach Pool D is scheduled to be restored in the near future to create one river reach (Pool B/C/D) with the upstream and downstream canal reaches (Pool A and E respectively) remaining channelized and controlled by lock structures for flood abatement purposes.

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. Our specific objectives include the quantification and interpretation of floodplain sedimentation patterns, fluxes, and character (sediment size, bulk density, organic content) relative to flood frequency and magnitude, landform, and vegetation type. Ultimately our results can be used to facilitate the development of a sediment budget. This report 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 and continued from 50 to 575 meters across the floodplain. Thirteen transects were in the restored river reach (87 clay feldspar pads, Fig. 1), 3 transects were in

channelized, yet un-restored Pool D (14 clay feldspar pads, Fig 1).

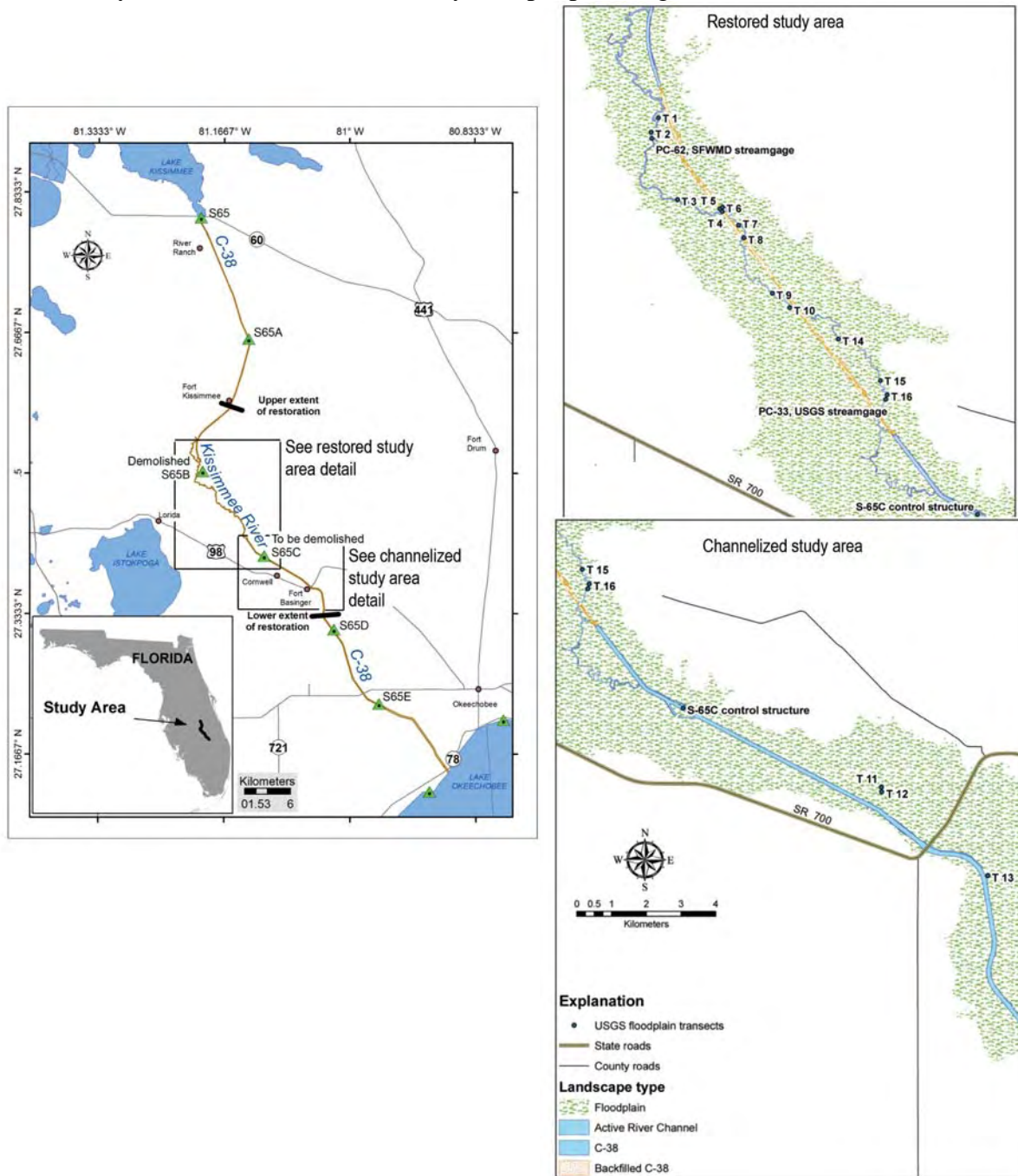


Figure 1. Kissimmee River including lock structures and detailed maps of transect location in both the restored study area in Pool B/C and the still channelized, unrestored Pool D. Transects on Pool D begin near the remnant river channel, not the channelized active river (labeled as the C-38 canal). Portions of the figure from Joann Mossa and Ursula Garfield, University of Florida.

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 (carbon and phosphorus were measured in a subset of these points).

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 USGS streamgage (SFWMD river structure PC-33, USGS streamgage 02269160). All sites were established in the winter/spring of 2007 and measured periodically for deposition; the most recent measurements were taken in May 2009. Thus, all sites were monitored for two (2007 and 2008) wet seasons. The SFWMD operated PC-62 streamgage upstream of the USGS streamgage was used to determine the flow regime during the study (Fig. 1). 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. 2).

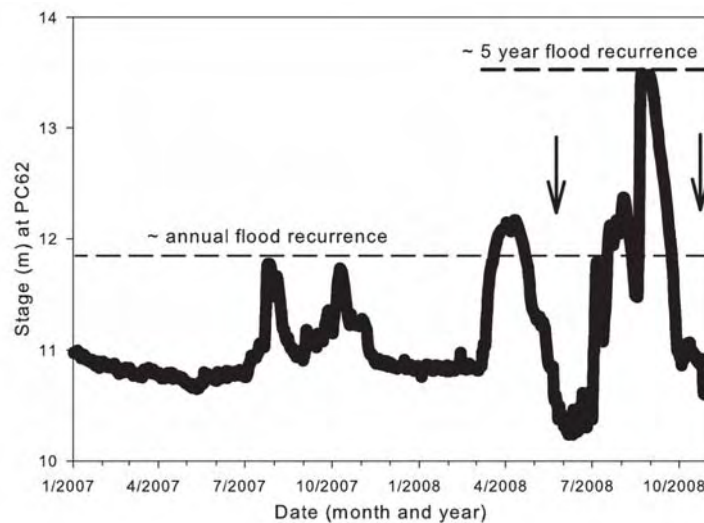


Figure 2. Mean daily flow measured at the PC 62 streamgage near the old Pool B/C control structure. Arrows indicate our sediment measurement dates. The approximate annual and 5-year flood recurrence is also noted (from Leroy Pearman, USGS Orlando, FL personal communication).

Sediment Deposition And Sampling

Artificial marker layers (clay pads) were placed at each sampling point. These markers are made by placing powdered white feldspar clay approximately 20 mm in thickness over an area of about 0.5 m² 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). 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.

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 volume, which was then dried and weighed, 2) size class composition by dry sieving 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. Sediment texture (particle size) was arranged according to phi size class units (Krumbein, 1936). Results are presented as silt/clay, very fine sand, fine sand, sand, and coarse sand fractionations.

RESULTS

Hydrologic Regime

There was no flow in the channel from the beginning of the study in January 2007 until May 2007 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; dry conditions existed on the majority of the floodplain except in moist depressions and some sloughs. Whereas 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. 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 (approximately 2.5 m above June 2008 levels). We sampled the transects again in December 2008 to measure floodplain dynamics after the fall flood. Our measurements in early May 2009 documented minor deposition in Pool D. 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 (erosion) 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 re-suspension of sediment from continued restoration efforts upstream of our study site.

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 (erosion) 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. 3a). 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 West floodplain (opposite bank) into the un-restored C-38 canal remnant.

Mean organic content is provided in Fig. 3b. 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. Mean percent organic content on the floodplain increased from 8.2% in February 2007 to 35.0% in February 2008 ($p < 0.002$, T-test) after overbank flow was returned to the system. The increase of organics, with no noticeable change in vegetation, suggests that a large portion of the organic matter arrived with overbank flows.

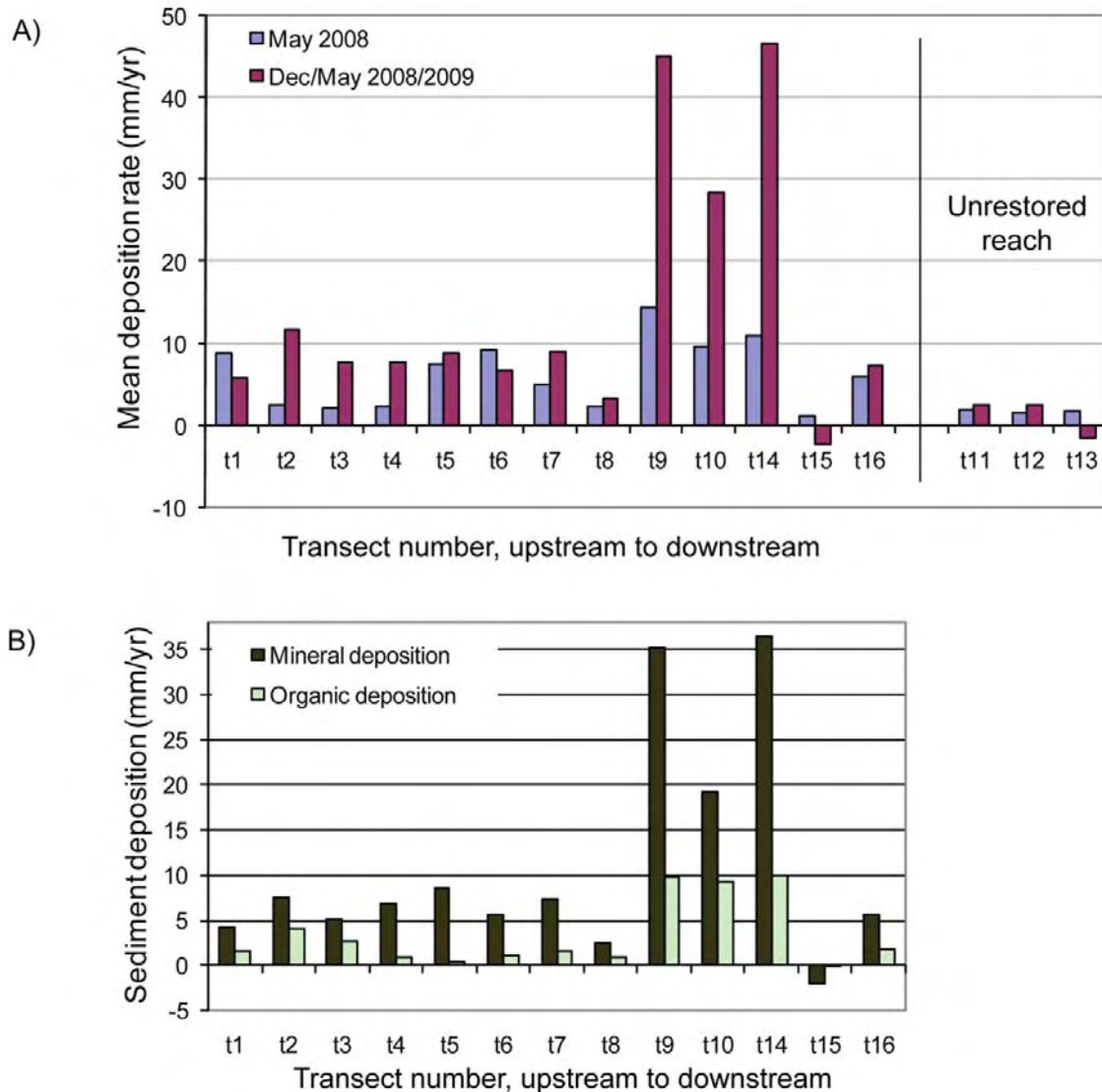


Figure 3. A) Mean sedimentation by transect from upstream to downstream determined for the spring flood and for the entire study period. The difference in deposition rates includes the impact of Tropical Storm Fay (August 19th, 2008). B) Mean mineral and organic sedimentation by transect from upstream to downstream.

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 to prevent stream piracy by the backfilled canal. Landscape designations were assigned by the SFWMD and provided in a GIS format for our analysis. The majority of the restored study area (between T1 and T16) was natural floodplain with large sections of borrow to fill the C-38 canal (Table 1). Sediment deposition, organic content, and bulk density varied greatly between landscape types, likely driven by the elevation differences between types (Table 1). Natural floodplain areas represent the majority of our monitored landscapes and has the highest

proportion 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 1.

Table 1. Floodplain area by landscape type, median sedimentation rate separated by area, gross rate, percent organic, and approximate mass per year.

Landscape type	Sedimentation rate and characteristics				Total mass g/m ² *yr	Total mass Mg/yr	Mineral Mg/yr	Organic Mg/yr
	Area m ²	Rate mm/yr	Percent organic	Density g/cm ³				
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

The median mass deposited from the two storm events was 159,660 Mg, with 119,433 of the 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) 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 (see Gellis et al., this volume). 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.

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 in the restored reach 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 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.

Vegetation Effects

SFWMD completed a vegetation survey of the floodplain in 2004. The data is provided in a GIS coverage used for floodplain deposition analyses. All 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 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 prairies; 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). A finer spatial scale may facilitate understanding of deposition patterns. 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 (Hupp et al. 2009). 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. The highest deposition rates on T10 were near or at sloughs, depressions, and the main channel. The sloughs crossing T10 convey over 25% of the total discharge during overbank events (Phil Habermehl, USGS Orlando, FL, personal communication). 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. Existing bar deposits increased and new channel and point bars were created by the event, all predominantly composed of sand. The floodplain was also 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. 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 had artificial spoil levees. The other 4 transects were indeterminate based on our surveys. Sand splays were evident at T3, T5, T7, T9, T10, and T14 as well as several reaches between transects. Continued monitoring should allow for the evaluation of the re-establishment of levees in areas affected by the restoration program and the natural maintenance of levees in less impacted reaches.

Sediment texture changed significantly ($p < 0.001$, T-test) from the beginning of the study to after the spring flood in May 2008. 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 to very fine sand after Tropical Storm Fay with the influx of mineral sand. 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 restored Kissimmee River floodplain is organic (Table 1).

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 (mean total phosphorus in mg/g = 1.42, $n = 12$) 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 ($R^2 = 0.74$, $p < 0.01$), making the sloughs and depressions the greatest sinks for phosphorus. Nutrients are a primary concern downstream where the eutrophic Lake Okeechobee receives these potentially high phosphorus loads.

CONCLUSIONS AND 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. The two-year study shows that the

restoration program has successfully reconnected the extensive floodplain with the river channel. Sedimentation rates and trends are typical of other Southeastern low gradient rivers with the exception of the organic content associated with the deposited sediment. Organic sedimentation appears to be higher than other Southeastern rivers. It appears that the Kissimmee River reflects both alluvial and blackwater characteristics (Hupp 2000). Currently we do not know if the high organic content is typical of other Floridian rivers due to the lack of floodplain sedimentation studies on the Florida peninsula.

Current (2010-2012) floodplain monitoring in the Kissimmee Basin includes a greater monitoring effort in Pool D to capture the sediment and landscape dynamics as the reach is restored. This effort will include a study measuring landscape subsidence to compare gross deposition with soil loss through soil oxidation and compaction. We are also monitoring pre-existing transects to increase the data set. Further monitoring will allow for the determination of sedimentation rates for a variety of flood scenarios and will help verify the generality of existing results. The 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 aspects of restoration. Basic research with broad applicability will 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 may also be identified to 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.

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