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.