CROSS SECTIONAL VARIABILITY OF THE RESTORED KISSIMMEE RIVER, FLORIDA

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Abstract
River restoration is an emerging science, and monitoring is an important component of evaluating success. The Kissimmee River in south-central Florida was channelized into C-38 during the 1960s and is the site of the world’s largest river restoration project. This paper focuses on one aspect of geomorphic monitoring being conducted by the authors. Twenty cross-sectional transects were established in 2007 in both restored and unrestored sections of river and have been resurveyed annually. In the restored portion, transects were located in remnant reaches (the original channel, now with restored flow), recarved reaches (buried by spoil, then dug out by heavy equipment), and connector reaches (reaches built across the backfilled C-38). Only the connectors were notably different, considerably wider and shallower than the others. All four transects in the connector reaches had bars or islands, suggesting insufficient velocities to move the sediment. Connectors also differ in planform, having an artificially straight, or angular appearance not characteristic of natural systems. If adaptive management approaches are invoked, connector channels in areas yet to be restored can be better designed to minimize the potential for sedimentation and to create a more natural appearance.

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 associated with increases in population and technology. Large numbers of the world’s major rivers are dammed or channelized (Dynesius and Nilsson, 1995; Nilsson et al., 2005; Gregory, 2006), and impacts to riverine ecosystems associated with changes in connectivity, hydrology, form, and habitat are well known (e.g. Graf, 2006). Some of these altered rivers, generally in developed countries, are now sites of river restoration or rehabilitation (Bernhardt et al., 2006).

The Lower Kissimmee River (Fig. 1), with a basin area of 7804 km², is one prominent Florida example of river alteration and subsequent ecosystem damage. The historic channel, which was sinuous with anabranches, was changed to a straight canal named C-38 with a much larger below-bankfull channel capacity. Six large gated water control structures with locks were placed along the course. The river length was shortened from 167 to 90 km (Whalen et al. 2002) and its gradient was steepened in the process. Dredging was performed to increase 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 almost 8000 ha of wetlands, drastic declines in bird, fish and other animal populations that due to decreases in wetlands and substantial reductions in water quality (Bosquin et al., 2005). Even before it was completed, various groups advocated for restoration of the river.
Figure 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.

An ecosystem restoration project was authorized by Congress with the Water Resources Development Act in 1992. Work began in the late 1990s and is scheduled for completion in 2012. The project’s main components include demolition and removal of two of the six water...
control structures (S-65B and S-65C) 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 12.1 km of C-38 was backfilled shortly thereafter, and 3.2 km more recently, mostly in Pool C. Another 20.1 km of canal, mostly in Pool D, will be backfilled and S-65C demolished in the coming years. Flow will be redirected into the former primary channels of the historic floodplain to reestablish wetland conditions. The restoration is of unprecedented cost (≈$578 million) and scale and includes various types of monitoring and strategies and targets to evaluate success (Bousquin et al. 2005). In addition to being an ecologically important area locally, the area also provides a major source of water for the Everglades, where a far more costly (≈$10 billion) rehabilitation effort is underway. This paper discusses some findings of the channel cross section monitoring, but there are concurrent sediment and geomorphic studies of bottom sediments, channel planform changes, flow, suspended sediment and bed load, and floodplain sedimentation (Mossa et al., 2010, Gellis et al, 2010; Schenk and Hupp, 2010).

CHANNEL MONITORING GOALS: CROSS-SECTIONAL TRANSECTS

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 in Pools A through D and surveyed in early 2007, the first year of the project and one additional transect was placed in Pool D in 2009. Transects were surveyed annually to evaluate their stability and can also be resurveyed 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 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 2). The connector channels appear wider than either the remnant or recarved channels (Figure 2), and were designed that way to reduce velocities and minimize potential erosion to the backfilled areas.

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?
Figure 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).

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

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

Figure 3. 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.

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 3). 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 3) 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. A minimum of 20 points were collected along each profile, including all major geomorphic breaks.

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.

Figure 4. Transect locations in Persimmon Mound Run (left), Pool A (no plans for restoration) and Montsdeoca Run (right), Pool C (restored, now has sand bars reflecting restored flow). In both, transects 1 and 4 are considered straight reaches and Transects 2 and 3 are bendways in both.
RESULTS

Aerial photographs with locations and field photographs of some transects are shown from upstream to downstream (Figures 4 to 7). The most interesting finding was that the connector transects were very different than the other transects. In general, the connectors were much wider on average, about 100 m, in contrast with 30m for the recarved and remnant types. Also, connectors were shallower than the remnant and recarved reaches.

The Montsdeoca South connector in Pool B/C shows marked changes, particularly during 2009, the most recent year of monitoring (Figure 5). 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 5). Field photographs show that this bar is becoming stabilized with vegetation (Figure 6).

The other connector surveyed was downstream of Fulford Run, also known as the Fulford South connector (Figure 7). The bar here is only growing slightly (Figure 7), 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.

Figure 5. Two transects and associated locations 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 6. South of Montsdeoca Run, a bar has formed in the Montsdeoca Connector (Poll B/C). This bar was emergent during February 2007 field sampling (left) and fully vegetated in January 2009 (right).

Figure 7. Two transects and associated locations in a connector south of Fulford Run (Pool B/C), 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.

A plot comparing the width and depth of remnant, recarved and connector shows that the first two types of transects were fairly similar in geometry, but the connector transects were very different than the other transects. First, they were much wider on average, about 100 m, in contrast with 30m for the other types (Figure 8). Second, connectors were shallower than the remnant and recarved reaches (Figure 8). The wider geometry seemed to promote the
development of either an island or submerged. At low flow, the bars in both the Montsdeoca south connector and Fulford south connectors were subaerial, visible in the field, and consisted dominantly of sand. None of the other 17 transects surveyed showed a bar in the middle of the channel. Bendways and straight reaches were not notably different in their width-depth (Figure 9). 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.

![Wetted Channel Dimensions](image1)

Figure 8. Comparison of the wetted channel dimensions of the 20 transects sampled based on 2007 data. 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.

![Wetted Channel Dimensions](image2)

Figure 9. Bendways and straight reaches were not notably different in their width-depth ratios.
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; this formed bars that 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 3). Fay made landfall in August 2008 and produced large amounts of rainfall, over 250 mm in many location and over 675 mm locally (http://www.hpc.neep.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.

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 criterion was 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 stable. 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.
Acknowledgments and Disclaimers
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REFERENCES


