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Sheet Flow in the Ridge and Slough Landscape of Everglades Water Conservation Area 3A

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Introduction

Sheet flow velocities were monitored continuously from August 2005 through March 2006 at a remnant ridge and slough site (3A-5) in central water conservation area 3A (WCA-3A) (fig. 1). The primary objective of the study was to quantify sheet flow behavior in order to evaluate the effect of particulate transport on maintenance of the ridge and slough landscape.

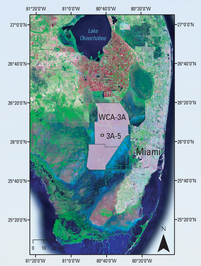

Figure 1. Satellite image showing location of site 3A-5.

Site Description

Ridges and sloughs have a predominant north-south alignment at site 3A-5 (fig. 2A) and the topography is representative of remnant ridge and slough landscape. A 3D plot of topographic data derived from five transect surveys is shown in figure 2B. Transect data indicate that the maximum difference between ridge and slough elevations is 20-30 cm and the increase from slough to ridge elevation through the vegetative transition zone typically occurs over 10-20 m. At site 3A-5, the slough including the vegetative transition zones is about 80 m wide and a 20-cm increase in elevation from the slough to the eastern ridge occurs non-uniformly over a distance of about 10 m (fig. 2C).

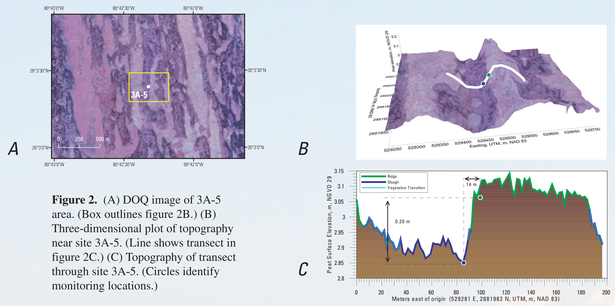

Figure 2. (A) DOQ image of 3A-5 area. (Box outlines figure 2B.) (B) Three-dimensional plot of topography near site 3A-5. (Line shows transect in figure 2C.) (C) Topography of transect through site 3A-5. (Circles identify monitoring locations.)

Monitoring Program

In August 2005, two monitoring stations were established at site 3A-5, one on the edge of a ridge and the other 14 m to the west in the slough (fig. 2C). Flow velocity, water level, water temperature, air temperature, and conductivity data were collected continuously at both locations. During site visits, vertical velocity profiles were measured at 1.5 or 3 cm depth increments. Wind conditions also were monitored. A summary of data collected at the site is presented in figure 3. Gaps in the graph indicate missing, errant, or suspect data.

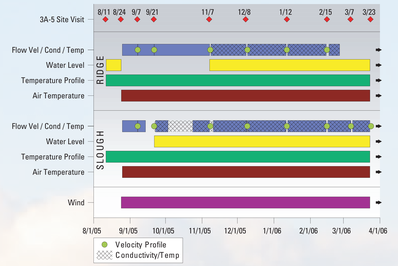

Figure 3. Summary of data collected at site 3A-5 from August 2005 through March 2006.

Sheet Flow Behavior

Sheet flow velocities were measured continuously at a fixed depth in the water column using acoustic Doppler velocity (ADV) meters suspended vertically from rigid frames erected in the *Nymphaea odorata* slough (fig. 4A) and on the adjacent *Cladium jamaicense* ridge (fig. 4B). Whenever water levels were sufficiently high, flow velocities were sampled at a common depth below the water surface at both locations.

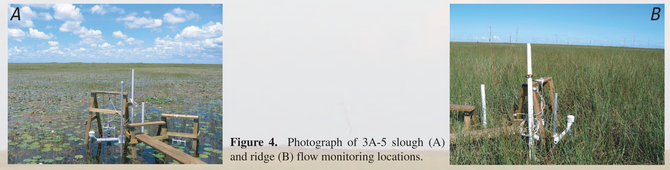

Figure 4. Photograph of 3A-5 slough (A) and ridge (B) flow monitoring locations.

Point Flow Velocities

Ninety percent of flow velocities measured in the slough were between 0.11 and 0.56 cm/s with a mean of 0.31 cm/s and flow directions generally varied between south and south-southeast with a mean direction 159° east of due north (fig. 5A). On the ridge, ninety percent of flow velocities were between 0.06 and 0.54 cm/s with a mean of 0.28 cm/s and flow directions generally varied between south and southeast with a mean direction 153° east of due north (fig. 5B). The increase in flow velocity on October 24, 2005 was due to Hurricane Wilma. For periods of concurrent data, the mean flow velocity of 0.39 cm/s in the slough was 34% faster than the 0.29 cm/s mean velocity on the ridge.

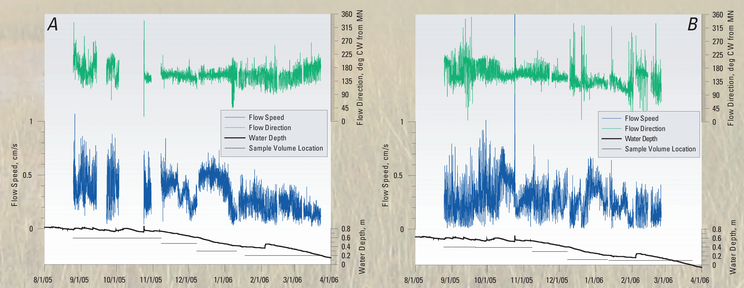

Figure 5. Bi-hourly flow velocities at 3A-5 slough (A) and ridge (B) locations with approximate water and sample depths shown.

Daily Mean Flow Velocities

Vectors representing daily mean flow velocities at the slough (A) and ridge (B) locations are shown in Figure 6. Flow directions were southerly at the onset of monitoring at both locations and gradually shifted to the south-southeast in the slough and to the southeast on the ridge. Ninety percent of the daily means of all flow velocities were between 0.12 and 0.52 cm/s in the slough and 0.12 and 0.48 cm/s on the ridge. By contrast, ninety percent of the daily means of flow velocities measured at five wetland sites in Shark River Slough, Everglades National Park, from July 1999 to July 2003 were between 0.46 and 2.29 cm/s.

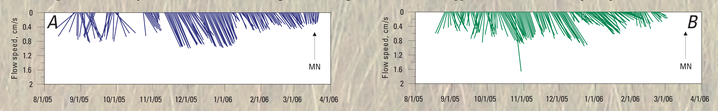

Figure 6. Daily-averaged flow velocities at 3A-5 slough (A) and ridge (B) locations shown as vectors relative to magnetic north.

Vertical Velocity Profiles

Eight vertical velocity profiles were collected in the slough over a depth range of 48 cm (fig. 7A) and six were collected on the ridge over a depth range of 47 cm (fig. 7B). Mean flow velocities for the profile data ranged between 0.11 and 0.41 cm/s in the slough (table 1) and between 0.20 and 0.55 cm/s on the ridge (table 2). In the middle part of the wet season when water levels were high, mean flow velocities were similar at the ridge and slough and velocities were nearly uniform with depth. As water levels declined after Hurricane Wilma, mean flow velocities increased and velocities departed from uniform in the vertical at both locations. For all profiles, the maximum velocity on the ridge typically occurred about 10 cm above the surface of floc layer whereas minimum velocities occurred within 10 cm of the floc surface in the slough. Velocities closest to the top of the floc surface, i.e., within 3 cm, were typically less than depth-averaged velocities. High flow velocities measured at both locations on December 9 when water levels were relatively low and falling are likely the result of rainfall that occurred during the 4 days prior to the profiles.

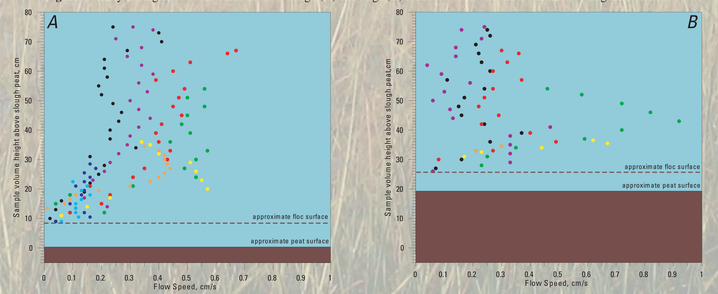

Figure 7. Vertical velocity profiles at 3A-5 slough (A) and ridge (B) locations between September 2005 and March 2006.

Date	Depth to floc, cm	Mean flow speed, cm/s	Mean flow direction, deg
9/7/2005	68	0.33	179
9/22/2005	72	0.21	170
11/8/2005	63	0.40	168
12/9/2005	53	0.41	155
1/12/2006	33	0.38	151
2/15/2006	28	0.30	146
3/7/2006	26	0.14	172
3/24/2006	20	0.11	191

Table 1. Flow velocities and water depths in 3A-5 slough.

Date	Depth to floc, cm	Mean flow speed, cm/s	Mean flow direction, deg
9/7/2005	56	0.20	158
9/21/2005	55	0.20	152
11/8/2005	45	0.29	156
12/9/2005	34	0.55	136
1/12/2006	13	0.47	133
2/15/2006	9	0.26	122
3/7/2006	3	*	*
3/24/2006	0	*	*

Table 2. Flow velocities and water depths on 3A-5 ridge.

Extreme Flow Event

On October 24, 2005, Hurricane Wilma traversed the Everglades from southwest to northeast, about 30 km north of site 3A-5 (fig. 8). Mean wind speed, measured 3 m above the water surface on site, ranged from 2-4 m/s prior to arrival of the hurricane to a maximum of 14.2 m/s during the hurricane, briefly falling to zero as the eye passed (fig. 9). Wind directions shifted from northwest to east and east-southeast during the hurricane. Water levels quickly rose to a peak of more than 12 cm, gradually declining to about 3 cm higher than pre-hurricane levels (fig. 9). Maximum flow velocities, measured 39 cm above the floc layer on the ridge, were 3.95 cm/s at 79° west of due north during strongest northwest winds before the eye and 4.89 cm/s at 112° east of due north 2.5 hours later during strongest east-southeast winds after the eye (fig. 9). Flow-velocity data recorded in the slough during the hurricane were invalid due to vegetation contaminating the ADV probe.

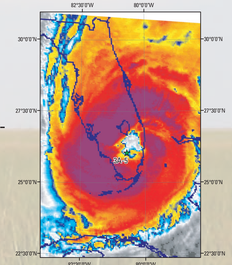

Figure 8. GOES-12 IR satellite image showing location of Hurricane Wilma at 7:55 AM EST on October 24, 2005.

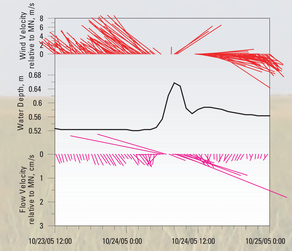

Figure 9. Wind speed, water depth, and flow velocity at 3A-5 ridge location before, during, and after Hurricane Wilma.

Mass Transport

Mass transport, in terms of unit-width discharge, was computed from water depths derived from water-level data and mean flow velocities estimated from point-velocity data recorded continuously at the ridge and slough locations. Three methods were used to approximate the mean velocity. In the first method the mean velocity was assumed equal to the point velocity and in the other two methods the mean velocity was estimated from linear and quadratic relations. Plots of these two relations, determined using concurrent data from five velocity profiles, (see fig. 7) are shown in figure 10. Coefficients of determination for both relations at both locations ranged from 0.93 to 0.99.

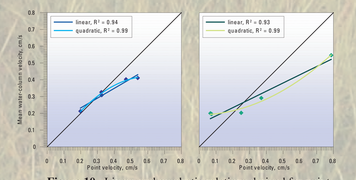

Figure 10. Linear and quadratic relations derived for point and mean velocities at ridge and slough monitoring locations.

Unit-width discharges were computed for each velocity profile and for all continuous ADV data recorded at the ridge and slough locations. Discharges computed from the continuous ADV data by the equal, linear, and quadratic methods were 111, 80, and 125 percent greater in the slough, respectively. Unit-width discharge computed from five concurrent velocity profiles was 67 percent greater in the slough (fig. 11).

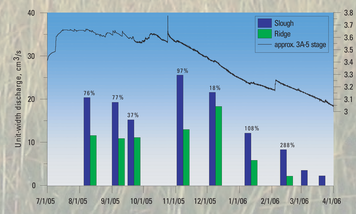

Figure 11. Unit-width discharges computed from velocity profiles. (Percentages are discharge differences relative to the ridge.)

Summary and Conclusions

Sheet flow velocities were measured continuously at fixed point in the water column and intermittently in vertical profiles at a remnant ridge and slough site in central WCA-3A from August 2005 through March 2006. The following findings were observed:

- Ninety percent of all velocities at the ridge and slough monitoring locations ranged between 0.08 and 0.55 cm/s. This is in deference to sheet flow velocities ranging between 0.46 and 2.29 cm/s ninety percent of the time during measurements made in ENP from July 1999 to July 2003.
- For periods of concurrent data, the mean flow velocity in the slough was 34% faster than on the ridge.
- The maximum velocity on the ridge typically occurred about 10 cm above the surface of floc layer whereas minimum velocities occurred within 10 cm of the floc surface in the slough.
- Maximum flow velocities during Hurricane Wilma were an order of magnitude greater than pre-hurricane velocities and flows reversed direction briefly as the eye passed. After the hurricane, velocities quickly returned to typical sheet flow conditions.
- Mass transport in the slough was approximately twice that on the ridge.

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