FLOW SIMULATION IN EVERGLADES NATIONAL PARK

Raymond W. Schaffranek, Research Hydrologist (rws@usgs.gov), Ami L. Riscassi, Physical Scientist (ariscass@usgs.gov), and Daniel J. Nowacki (dnowacki@usgs.gov), Environmental Science Assistant, U.S. Geological Survey, Reston, Virginia

Abstract: A hydrodynamic/transport model has been developed by the U.S. Geological Survey to simulate flow through the wetlands of Everglades National Park into Florida Bay and the Gulf of Mexico. Hydrologic processes were incorporated in the hydrodynamic model to account for rainfall, evapotranspiration, vegetative-resistance, and wind-stress effects on flow in the shallow-depth (< 1 meter) seasonally dry wetlands. Global Positioning System, remote sensing, and in situ monitored data were used to implement the two-dimensional vertically integrated model. Simulated and measured water-surface-elevation and flow-velocity comparisons demonstrate the accuracy of the model in replicating flow conditions in the wetlands. The model simulates wetland flows, tidal flows, and flow interactions at the land-margin interface of the Everglades with Florida Bay and the Gulf of Mexico to provide insight for evaluating restoration scenarios.

INTRODUCTION

The coastal interface of the freshwater wetlands of the Everglades with Florida Bay and the Gulf of Mexico is primarily within Everglades National Park (ENP). Salinities in nearshore embayments of northern Florida Bay are tempered by runoff from the Everglades (Robblee and others, 2001) and are particularly sensitive to water-management practices that reduce freshwater inflow (McIvor and others, 1994). Since the onset of water-management controls, modified inflows to Florida Bay coincide with changes in the bay's natural pattern of salinity fluctuation, suggesting a cause-and-effect relationship (Brewster-Wingard and others, 1999). State and Federal agencies are working jointly on modifications to hydraulic control structures, removal of flow barriers, and improvements in water-management practices to reestablish more natural flows through the wetlands of the Everglades to Florida Bay and the Gulf of Mexico.

Hydrologic models are used extensively by south Florida water-management agencies for designing, implementing, and evaluating the Comprehensive Everglades Restoration Plan. The principal model used is the South Florida Water Management Model (SFWMM) (MacVicar and others, 1984), developed by the South Florida Water Management District (SFWMD). Recently, a new Regional Simulation Model (RSM) has been developed by the SFWMD and applied to south Florida (SFRSM) to replace the SFWMM for use in restoration scenario testing (Lal and others, 2005). Both the SFWMM and SFRSM neglect inertia terms in the governing shallow-water flow equations, restricting their ability to simulate tidal flows and interactions with wetland flows at the land-margin interface of the Everglades with Florida Bay and the Gulf of Mexico. Moreover, neither model can simulate solute transport for assessment of coastal salinities. The U.S. Geological Survey (USGS) two-dimensional surface-water integrated flow and transport model (SWIFT2D) (Schaffranek, 2004) has been modified and applied to simulate flow through the wetlands of ENP and tidal interactions with coastal systems. SWIFT2D has been coupled to the three-dimensional ground-water flow and solute-transport model SEAWAT (Guo and Langevin, 2002). SEAWAT has been implemented to simulate ground-water flow and salt transport in the aquifer of the southern Everglades (Langevin and others, 2004) and the

coupled SWIFT2D/SEAWAT model has been used to assess inflows to Florida Bay (Swain and others, 2004). The domain of this coupled model implementation has since been expanded to include the entire wetlands and coastal ecotone of ENP to evaluate inflows to the Gulf of Mexico as well. The SWIFT2D component of this expanded model implementation, referred to as the Tides and Inflows in the Mangroves of the Everglades (TIME) model, is discussed in this paper.

MODEL IMPLEMENTATION

The TIME model domain is delimited by a rectangular grid of 194 east-west and 174 north-south 500-m-square cells with an origin at Universal Transverse Mercator metric coordinates 461000 East and 2779000 North, North American Datum of 1983 (NAD 83). Within the rectangular grid, the irregularly shaped computational domain of the model, shown in figure 1, extends from
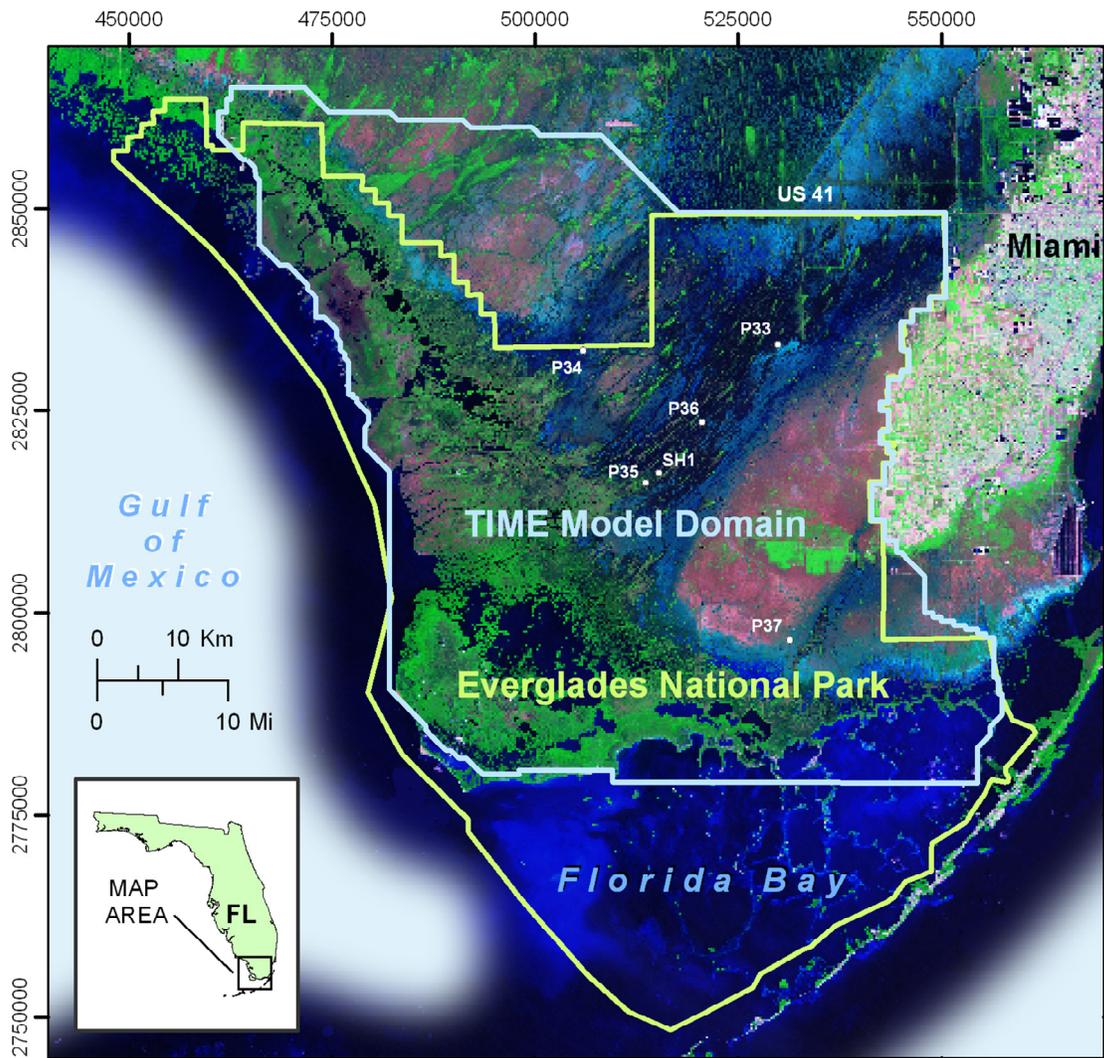
Base from U.S. Geological Survey South Florida satellite image map, 1993
Universal Transverse Mercator projection, NAD 83, Zone 17, m

Figure 1. South Florida satellite image (1:500,000 scale) showing Everglades National Park boundary (yellow line), TIME model domain (blue line), and monitoring sites P33-P37 and SH1.

an eastern boundary along canal levees and road embankments west and south of Miami to a western boundary along the southwest Gulf Coast and from a northern boundary along US 41 west of Miami to a southern boundary in northern Florida Bay. Land-surface elevations were interpolated from topographic data collected by the USGS in the wetlands using airborne Global Positioning System (GPS) techniques (Desmond, 2003) and bathymetric data obtained from USGS and National Oceanic and Atmospheric Administration (NOAA) hydrographic surveys.

Vegetation classifications were assigned from 1997 Landsat Thematic Mapper images to evaluate hydrologic processes and empirical coefficients in the model (Jones and Neubauer, 2004) as illustrated in figure 2. Twenty land-cover classifications derived from Landsat images

(A)

(B)

Resistance coefficient - Vegetation type

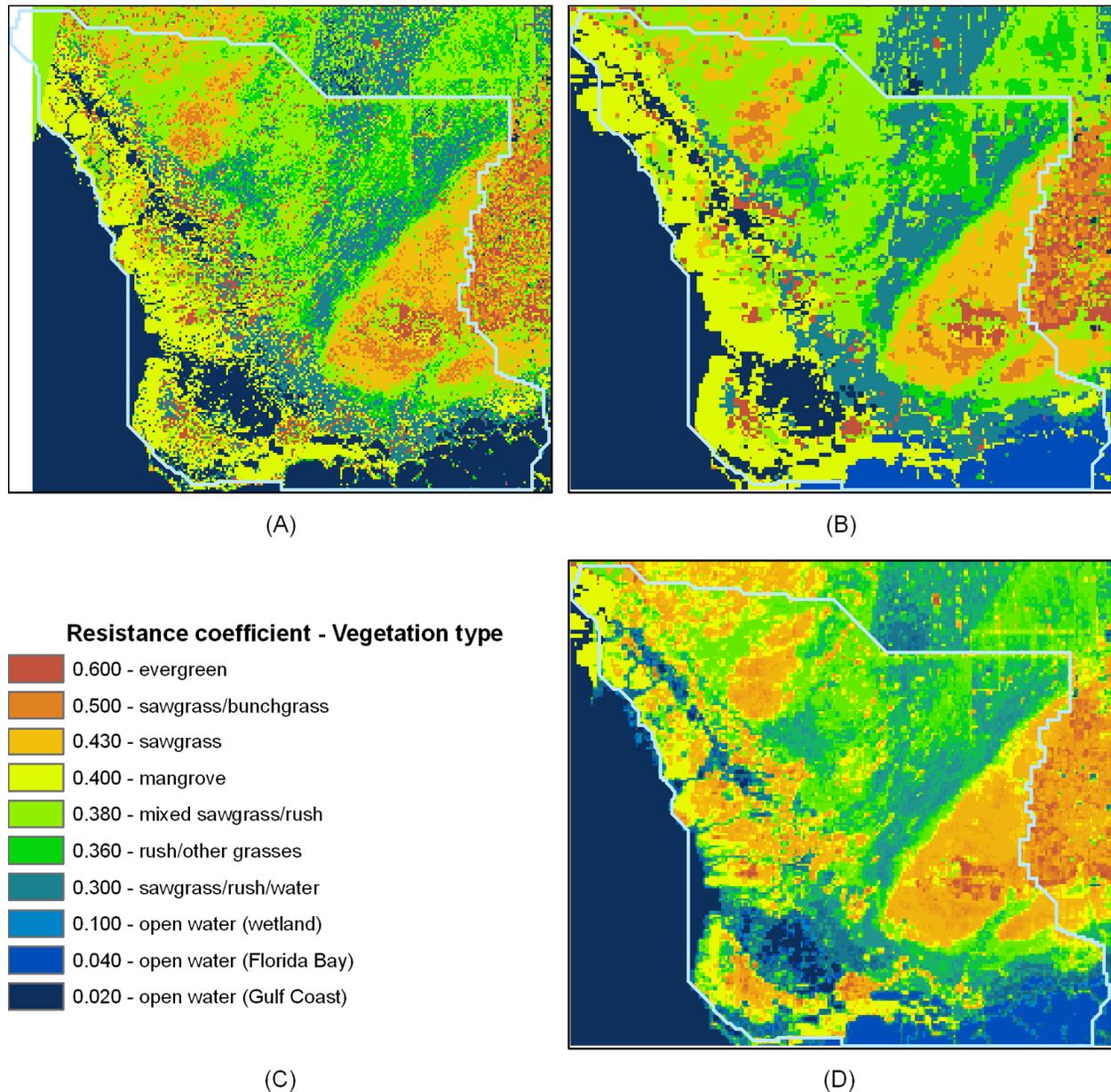|	
	0.600 - evergreen
	0.500 - sawgrass/bunchgrass
	0.430 - sawgrass
	0.400 - mangrove
	0.380 - mixed sawgrass/rush
	0.360 - rush/other grasses
	0.300 - sawgrass/rush/water
	0.100 - open water (wetland)
	0.040 - open water (Florida Bay)
	0.020 - open water (Gulf Coast)

(C)

(D)

Figure 2. Landsat Thematic Mapper vegetation image (A), model vegetation grid (B), resistance-coefficient values assigned to vegetation (C), and model resistance-coefficient grid (D).

were aggregated into one open-water and seven vegetation classes to produce the 30.5-m Landsat-scale grid in figure 2A. The 500-m model vegetation grid in figure 2B was produced from the 30.5-m grid in figure 2A based on the dominant vegetation class in model cells for evaluation of evapotranspiration (ET) and wind-stress effects. Manning resistance-coefficient values, evaluated from measured wetland flow velocities and water-surface slopes (Lee and others, 2004), were assigned to the vegetation and open-water classes as shown in figure 2C with different resistance-coefficient values assigned to wetland, Florida Bay, and Gulf Coast open-water cells. Resistance values were prorated from the 30.5-m grid in figure 2A to produce the 500-m model-coefficient grid in figure 2D for evaluation of vegetative flow resistance. During flow simulations, ET is evaluated from input solar radiation using Priestly-Taylor equations developed for each vegetation class (German, 2000). Sheltering coefficients, assigned to each vegetation class based on the height and composition of emergent plant material, are multiplied by the open-water drag coefficient to reduce wind-stress effects in vegetated cells. Resistance-coefficient and ET values are adjusted as functions of simulated flow depths during model runs.

Inflows to the model domain are regional rainfall, and wetland and coastal boundary fluxes. Hourly rainfall grids spatially interpolated from data collected at 47 rain gages operated by the SFWMD, National Park Service (NPS), and USGS and supplemented by rainfall estimates from the National Weather Service's Next Generation Radar (NEXRAD) obtained from the University of Miami Rosensteil School of Marine and Atmospheric Science quantify precipitation input. Hourly wetland, canal, culvert, and structure water levels and flow discharges define freshwater inflows at wetland boundaries. Tidal water levels and salt concentrations, obtained from USGS and NOAA gages, are interpolated along the open-water boundaries of the Gulf Coast and Florida Bay and input at 15-minute intervals to define coastal flow and transport fluxes.

FLOW SIMULATION

Results from a 4-month simulation produced by the TIME surface-water model using data from May-August 1999 demonstrate the model's resolution, accuracy, and capability of representing flow conditions. Instantaneous flow directions, water depths, and prominent flow features in the wetlands and at the land-margin interface with coastal systems are reasonably simulated by the model as is illustrated by the plot of flow velocities shown as vectors superimposed on flow depths in figure 3. The black line in the southern part of the model domain is the ENP Road and the white vertical line extending into the model domain from the northern boundary is a canal levee. For optimal visualization of model results, only every fourth flow vector is plotted and larger flow velocities in coastal systems are not shown. Simulated flow conditions agree well with the typical flow pattern evident in the satellite image shown in figure 1. Neglecting model results subject to initial-condition errors in the month of May, during the 3-month period of June-August 1999 mean simulated water-surface elevations are within the ±15 cm accuracy of USGS GPS land-surface elevations as referenced to North American Vertical Datum of 1988 (NAVD 88) (Desmond, 2003). Simulated flow velocities are within the 0.3 to 2.5 cm/s 95-percentile range of point velocities measured in ENP wetlands (Schaffranek and Riscassi, 2004).

Simulated and measured water-surface elevations and flow velocities, represented by dashed and solid lines, respectively, in figure 4, are presented to demonstrate model accuracy. Simulated results are mean values for the 500-m-square cell containing the monitoring stations at the sites

shown in figure 1. Water-surface elevations simulated and measured at NPS gages P33-P37 are shown in figures 4A-E. For the 3-month period of June-August 1999, mean simulated minus measured water-surface elevation differences are -0.057, -0.044, 0.127, -0.003, and -0.035 m at monitoring sites P33, P34, P35, P36, and P37, respectively. Similar agreements were achieved between simulated and measured water-surface elevations at other sites. Simulated flow speeds and directions are plotted with point velocities measured at USGS site SH1 in figures 4F and 4G, respectively. Mean simulated flow velocities agree in direction and are 0.48 cm/s slower than measured point velocities. Model-simulated water depths, flow speeds and directions, and flow patterns reasonably represent flow conditions within ENP.
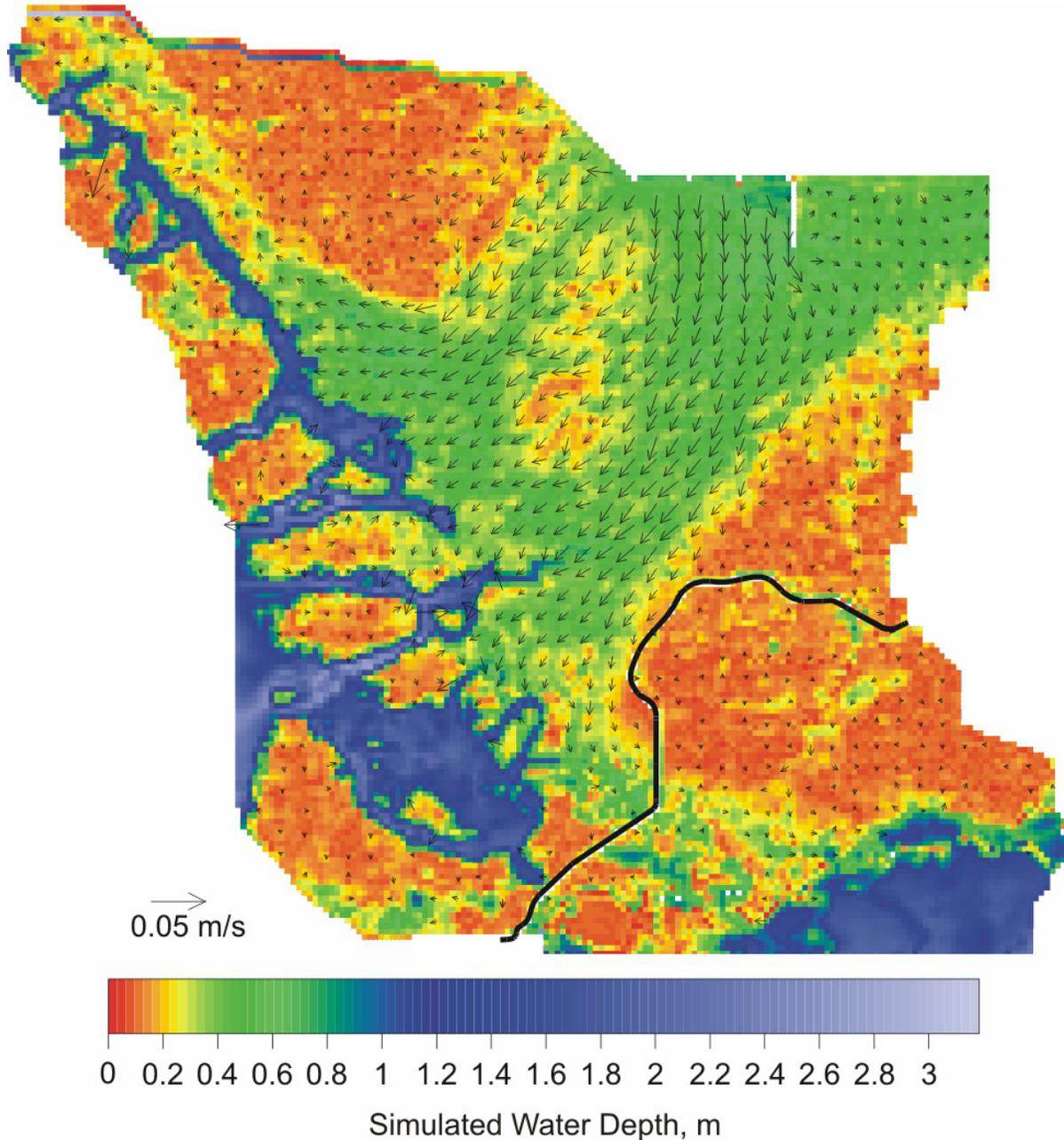

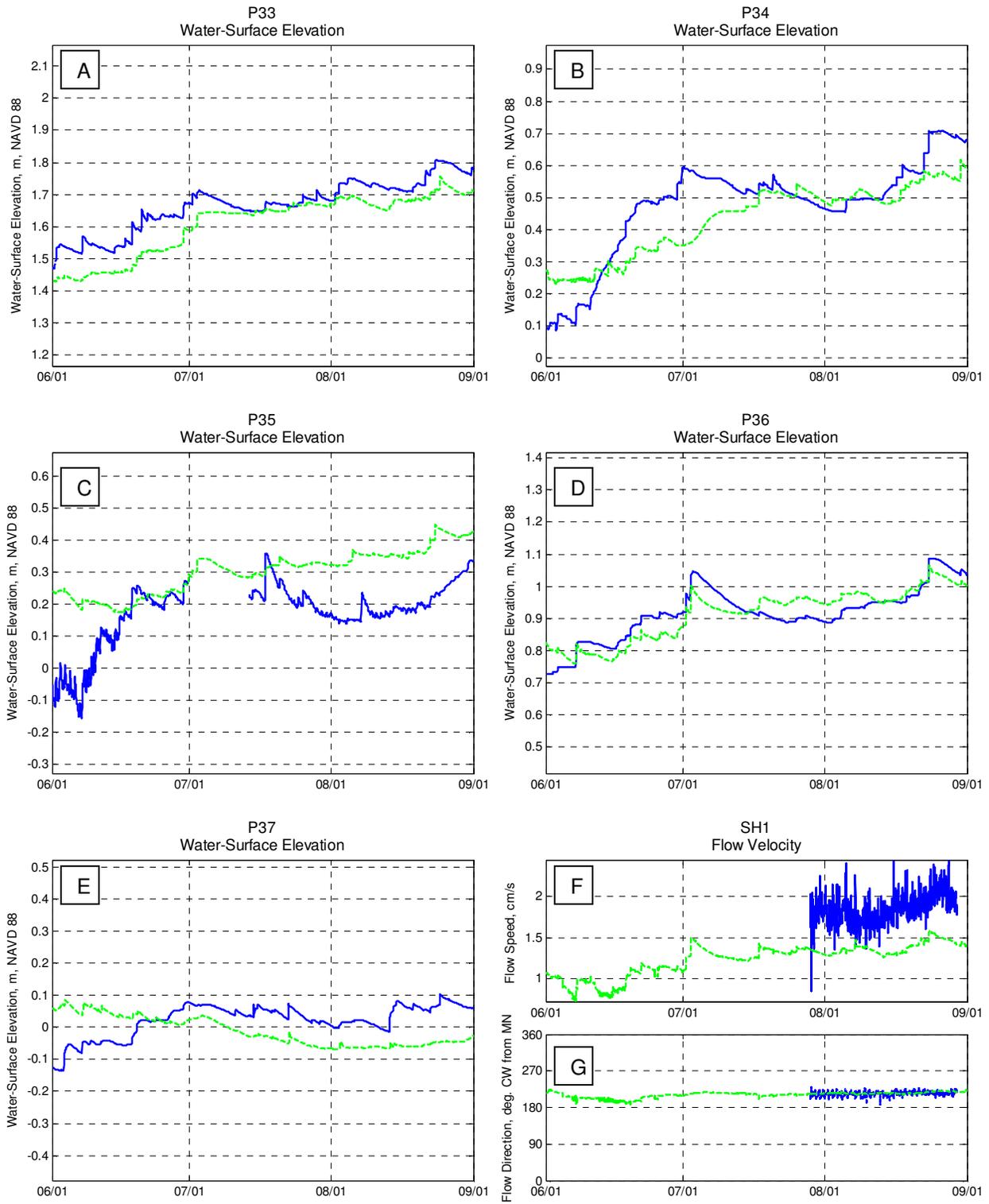Figure 3. Flow depths and velocities simulated by the TIME model.

Figure 4. Simulated (dashed green line) and measured (solid blue line) water-surface elevations at sites P33 (A), P34 (B), P35 (C), P36 (D), and P37 (E) and flow speeds (F) and directions (G) at site SH1.

SUMMARY

The USGS two-dimensional, hydrodynamic, surface-water integrated flow and transport model SWIFT2D, with added hydrologic processes, is shown to simulate wetland flows and tidal interactions in Everglades National Park reasonably well. Simulated water-surface elevations are within the accuracy of measured land-surface elevations used to implement the model and simulated mean flow velocities are within the range of velocities measured at discrete points in the wetlands. Implementation of the SWIFT2D model to simulate Tides and Inflows in the Mangroves of the Everglades (TIME) has demonstrated the capabilities of the TIME model and its potential for providing insight into the effects of regulated freshwater inflows on salinities at the land-margin interface of the Everglades with Florida Bay and the Gulf of Mexico.

REFERENCES

Brewster-Wingard, L., Cronin, T., Wardlaw, B., Stone, J., Schwede, S., Ishman, S., Holmes, C., Halley, R., Marot, M. Dwyer, G. and Huvane, J. (1999) "Long-term Florida Bay salinity history: a synthesis of multi-proxy evidence from sediment cores," Proceedings 1999 Florida Bay and Adjacent Marine Systems Science Conference, November 1-5, 1999, Key Largo, FL, pp. 182-183. http://www.floridabay.org/pub/conf_proceedings/1999_ab.pdf

Desmond, G.B. (2003) "Measuring and mapping the topography of the Florida Everglades for ecosystem restoration," U.S. Geological Survey Fact Sheet 021-03, 4 p.

German, E.R. (2000) "Regional evaluation of evapotranspiration in the Everglades," U.S. Geological Survey Water-Resources Investigations Report 00-4217, 48 p.

Guo, Weixing, and Langevin, C.D. (2002) "User's guide to SEAWAT: A computer program for simulation of three-dimensional variable-density ground-water flow," U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A7, 77 p.

Jones, J.W., and Neubauer, J. (2004) "Land surface analysis of the Florida Everglades," U.S. Geological Survey Fact Sheet 2004-3132, 4 p.

Lal, A.M.W., Van Zee, R., and Belnap, M. (2005) "Case study: A model to simulate regional flow in south Florida," ASCE Journal of Hydraulic Engineering, v. 131, no. 4, pp. 247-258.

Langevin, C.D., Swain, E.D., and Wolfert, M.A. (2004) "Simulation of integrated surface-water/ground-water flow and salinity for a coastal wetland and adjacent estuary," U.S. Geological Survey Open-File Report 2004-1097, 30 p.

Lee, J.K., Roig, L.C., Jenter, H.L. and Visser, H.M. (2004) "Drag coefficients for modeling flow through emergent vegetation in the Florida Everglades," Journal of Ecological Engineering, v 22, pp. 237-248.

MacVicar, T.K., Van Lent, T., and Castro, A. (1984) "South Florida water management model documentation report," Technical Publication 84-3, South Florida Water Management District, West Palm Beach, FL.

McIvor, C.C., Ley, J.A., and Bjork, R.D. (1994) "Changes in freshwater inflow from the Everglades to Florida Bay including effects on biota and biotic processes: a review," in Everglades: The ecosystem and its restoration: S. M. Davis and J. C. Ogden, editors, St. Lucie Press, Delray Beach, FL, pp. 117-146.

Robblee, M.B., Clement, G., Smith, D., Halley, R. (2001) "Salinity pattern in Florida Bay: a synthesis (1900-2000)," Proceedings 2001 Florida Bay Science Conference, April 23-26, 2001, Key Largo, FL, pp. 34-36. http://conference.ifas.ufl.edu/FloridaBay/abstract.pdf

Schaffranek, R.W. (2004) "Simulation of surface-water integrated flow and transport in two dimensions: SWIFT2D user's manual," U.S. Geological Survey Techniques and Methods, book 6, chap. 1, section B, 115 p. http://pubs.water.usgs.gov/tm6b1/

Schaffranek, R.W., and Riscassi, A.L. (2004) "Flow velocity, water temperature, and conductivity at selected locations in Shark River Slough, Everglades National Park, Florida: July 1999-July 2003," U.S. Geological Survey Data Series 110. http://pubs.water.usgs.gov/ds110/

Swain, E.D., Wolfert, M.A., Bales, J.D., and Goodwin, C. R. (2004) "Two-dimensional hydrodynamic simulation of surface-water flow and transport to Florida Bay through the Southern Inland and Coastal Systems (SICS)," U.S. Geological Survey Water-Resources Investigations Report 03-4287, 69 p.