Journal of Hydrology 390 (2010) 1–12

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Spatially distributed modeling of surface water flow dynamics in the Everglades ridge and slough landscape

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ARTICLE INFO

Article history:
Received 21 March 2009
Received in revised form 10 May 2010
Accepted 12 June 2010

This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of Ehab A. Meselhe, Associate Editor

Keywords:
Everglades
Ridge and slough
Distributed model
Hydraulic resistance
Flow velocity
Hydroperiod

SUMMARY

A two-dimensional, spatially distributed flow dynamics model was developed and tested for a 1.5 by 4 km area of the patterned ridge and slough landscape of the Florida Everglades. This model is intended to support a deepened understanding of the system ecohydrological dynamics, and provide a useful tool for management decision support. The model was constructed with a fine enough mesh structure to ensure proper representation of ridge and slough topographic detail as well as capture local hydrologic influences. Upstream and downstream stage data collected near the study area in central Water Conservation Area 3A were used to establish the initial and boundary conditions. Water velocities measured in the ridges and sloughs over a 3-year period were used to calibrate and verify the model. Hydraulic resistance was computed using a power-law relationship with water depth. The simulated water levels, water depths, and flow velocities showed good agreement with the 3-year field-monitored data with percent model errors of approximately 4%, 12%, and 10%, respectively. Computed differences in hydraulic resistance between ridge and slough were reduced significantly during the storm season compared to the dry season. This suggests that more solute and suspended solid mass can be redistributed from the sloughs to the ridges in particular during wet seasons, due to the weakened heterogeneity of hydraulic resistance during high flows.

1. Introduction

Spatially distributed flow dynamics models can be used by aquatic ecosystem scientists and managers to help understand or predict hydrological, biogeochemical, or ecological changes over various time scales. In aquatic systems such as wetlands where key ecological processes are strong functions of the spatio-temporal changes in hydrodynamic parameters (i.e. water depth and flow velocity), integrating reactive transport models with ecosystem models enables testing of environmentally critical hypotheses through both hind- and forecasting scenarios. However, to obtain meaningful simulation or prediction results, one cannot overemphasize the importance of a robust flow dynamics model developed at a spatial scale consistent with the modeling purpose.

Human intervention to the Everglades during the last century has caused the loss of historic surface flow. The disturbed hydrology has been suspected as a trigger of the partial loss of the unique ridge and slough landscape pattern in the central Everglades. Currently, temporal variation of hydrodynamic features in the remnant Everglades is mainly controlled by water management practices regulating flow (usually stormwater) from upstream hydraulic structures (Harvey et al., 2009). For the recent and proposed future restoration efforts, the role of surface water flow and organic-rich sediment (flocculent materials) transport as well as spatio-temporal change in hydroperiod has been highlighted due to the importance of physical and ecological impacts on the landscape formation, maintenance, and degradation (SCT, 2003; Leonard et al., 2006; Larsen et al., 2007, 2009; Noe et al., 2007). Restoring a more natural hydropattern and improving water quality in this ecosystem are critical components of the Comprehensive Everglades Restoration Plan (CERP) (Perry, 2004), including decompartmentalization – removal of canals and levees to restore the historic sheetflow through the remnant Everglades (i.e. to increase hydrologic connectivity of the system). While simple water balance models may be adequate for broad water resource management, a well developed flow dynamics model can play a foundational role in developing more advanced modeling tools to understand current hydrological and ecological effects on the wetland ecosystem and predict the future changes from the wetland ecosystem restoration.

Compared to recent systematic monitoring efforts on water flow and solute/particle transport in the patterned landscape of the Everglades (Saiers et al., 2003; Harvey et al., 2005b, 2009; Bazante et al., 2006; Leonard et al., 2006; Noe et al., 2007; Huang et al., 2008), physically based, spatially distributed modeling

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doi:10.1016/j.jhydrol.2010.06.023

studies with local- or intermediate-scale (i.e. beyond pilot or mesocosm scales) have been rarely reported in this unique wetland ecosystem. The primary reason may be due to the difficulties in obtaining high resolution spatial data for model development (bathymetry, peat depth, vegetation type and density) and spatio-temporally distributed hydrologic data necessary for model setting, calibration, and validation, including field observations in both ridges and sloughs. Model grids in regional-scale models are too coarse to represent the topographic and vegetative heterogeneities effectively. The physical differences between ridges and sloughs form different flow characteristics. The average ponding depths, hydroperiods, flow velocities, and the transported water and solute fluxes are all different between the ridge and slough habitats (Noe and Childers, 2007). The different surface water flow characteristics regulate the formation and distribution of bimodal vegetative habitat, which impacts the flow again by creating different hydraulic resistances, ultimately controlling the landscape stability directly or indirectly.

The significance of heterogeneous topography and vegetation for understanding and modeling wetland flow characteristics have been well documented (Martinez and Wise, 2003; Dierberg et al., 2005; Jenkins and Greenway, 2005; Min and Wise, 2009). However, these impacts were not fully considered in previous spatially distributed regional modeling efforts for the bimodal ridge and slough landscape (SFWMD, 1994; Bolster and Saiers, 2002; SFWMD, 2005a) despite the acknowledged differences in hydrologic/hydraulic characteristics of ridges and sloughs. The objective of the present study was to examine the significance of topographic and the associated vegetative (in terms of hydraulic resistance) bimodality on the ridge and slough flow dynamics, which have not been considered in previous flow dynamics modeling efforts. The South Florida wetland ecosystem may be one of the best study areas in the world to develop and test such a model due to decades of continuous and extensive hydrologic monitoring.

In this study, a two-dimensional (2-D), spatially distributed flow dynamics model was developed for the ridge and slough landscape and tested against hydrologic data, such as water level (h), depth (d), and flow velocity (v), collected from a typical ridge and slough area that is considered well-conserved. The modeling framework was the Regional Simulation Model (RSM) developed by the South Florida Water Management District (SFWMD). The RSM has been applied mainly for a large-scale (>10^3 km^2) basin with complex hydrology (Lal et al., 2005), but rarely used for relatively smaller-scale ($\sim$10 km^2) natural wetland systems. Hence, the second objective was to evaluate the usefulness of the RSM framework in predicting local- or intermediate-scale hydrology of the landscape accurately. The final objective was to evaluate the effect of limited spatial information on the ability to predict hydroperiods (seasonal pattern of water level in wetlands) and v in the Everglades ridge and slough landscape. Ultimately, this model can serve as the hydrodynamic foundation of a hydro-ecosystem model through linking with a transport and a reaction algorithm (RSM WQ; James and Jawitz, 2007) including both sediment transport and net peat accretion processes that may be different between ridge and slough habitats.

2. Site description

The selected model domain is a 1.5 by 4 km rectangle located approximately 4 km south of Alligator Alley (I-75) in Water Conservation Area 3A (WCA-3A, Fig. 1A and B). In this area the historic ridge and slough landscape pattern is considered to be well preserved (SCT, 2003; Harvey et al., 2009). The ratio of ridge and slough landscape is about 1:1 (Wu et al., 2006). Relatively higher-elevation ridge areas dominated by dense stands of sawgrass (*Cladium jamaicense*) have shallower d and shorter hydroperiod compared to adjacent lower-elevation sloughs, open water areas with plants accustomed to deeper d, such as *Nymphaea odorata*, *Eleocharis* spp., *Utricularia* spp., and *Panicum repens* (Fig. 1C). Jorczak (2006) reported that site J-1 located 2.4 km west of the model domain had an average topographic difference of 16 cm between ridge and slough and the difference increased toward

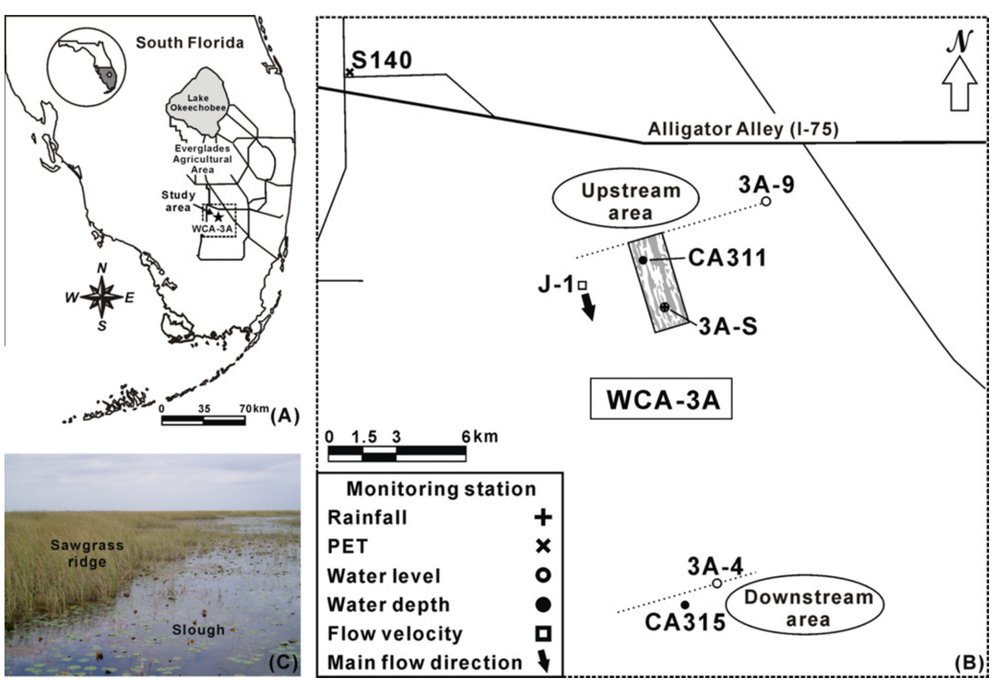

Fig. 1. Location maps of model domain and hydrometeorologic data monitoring stations: (A) regional map of study area in Water Conservation Area 3A, (B) enlarged view of study area (dotted rectangle in panel A) showing the location of model domain and hydrometeorologic data monitoring stations used for model development and calibration. The station numbers are from the SFWMD online database DBHYDRO, except station J-1, from Jorczak (2006), and (C) photograph showing the typical sawgrass-dominant ridge and open slough landscape in study area.