Validation of Spatially Continuous EDEN Water-Surface Model for the Everglades, Florida

2008 EDEN Report

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Abstract

The Everglades Depth Estimation Network (EDEN) is an integrated network of real-time water-level monitoring, ground-elevation modeling, and water-surface modeling that provides scientists and managers with current (2000-present), on-line water-stage and water-depth information for the entire freshwater portion of the Greater Everglades (Telis, 2006). Continuous daily spatial interpolations of the EDEN network stage data are presented on grid with 400-square-meter spacing. EDEN offers a consistent and documented dataset that can be used by scientists and managers to: (1) guide large-scale field operations, (2) integrate hydrologic and ecological responses, and (3) support biological and ecological assessments that measure ecosystem responses to the implementation of the Comprehensive Everglades Restoration Plan (CERP) (U.S. Army Corps of Engineers, 1999). The target users are biologists and ecologists examining trophic level responses to hydrodynamic changes in the Everglades. The first objective of this report is to validate the spatially continuous EDEN water-surface model for the Everglades, Florida developed by Pearlstine *et al.* (2007) by using an independent field-measured dataset. The second objective is to demonstrate two applications of the EDEN water-surface model: to estimate site-specific ground elevation by using the validated EDEN water-surface model and observed water depth data; and to create water-depth hydrographs for tree islands. We found that there are no statistically significant differences between model-predicted and field-observed water-stage data in both southern Water Conservation Area (WCA) 3A and WCA 3B. Tree island elevations were derived by subtracting field water-depth measurements from the predicted EDEN water surface. Water-depth hydrographs were then computed by subtracting tree island elevations from the EDEN water stage. Overall, the model is reliable by a root mean square error (RMSE) of 3.3 cm. By region, the RMSE is 2.48 cm and 7.76 cm in WCA 3A and 3B, respectively. This new landscape-scale hydrological model has wide applications for ongoing research and management efforts that are vital to restoration of the Florida Everglades. The accurate, high-resolution hydrological data, generated over broad spatial and temporal scales by the EDEN model, provides a previously missing key to understanding the habitat requirements and linkages among native and invasive populations, including fish, wildlife, wading birds, and plants. The EDEN model is a powerful tool that could be adapted for other ecosystem-scale restoration and management programs world-wide.

Introduction

Spatially explicit hydrologic information can be critical in understanding and assessing changes in biotic communities in wetland ecosystems worldwide. In the Florida Everglades there have been numerous efforts to measure and link daily and seasonally fluctuating surface-water depth to biotic communities (Loveless, 1959; Craighead, 1971; McPherson, 1973; Cohen, 1984; Newman *et al.*, 1996; Busch *et al.*, 1998; Ross *et al.*, 2000; Hendrix and Loftus, 2000; Gawlik, 2002; Chick *et al.*, 2004; Palmer and Mazzotti, 2004; Trexler *et al.*, 2005). Repeated field measurement is a traditional way to obtain such information, but it is labor intensive and does not provide information on continuous spatial variability across a large area. Taking systematic field measurements across space and time is difficult since the Everglades comprise remote and inaccessible areas. Alternatively, hydrologic models are frequently used in ecological research in the Everglades (Walters *et al.* 1992, Curnutt *et al.*, 2000, Immanuel *et al.*, 2005).

Over 200 real-time stage monitoring gages have been placed throughout the Everglades by various agencies with different monitoring needs to automatically measure stage and transmit the data either via radio or satellite. The Everglades Depth Estimation Network (EDEN) is funded by the Comprehensive Everglades Restoration Plan (CERP) and the US Geological Survey (USGS) Priority Ecosystem Sciences (PES) with collaborative support between federal and state government agencies, scientists in south Florida, and the University of Florida. This project integrates existing and new telemetered water-level gages into a single network and, in combination with high resolutions ground elevation modeling, generates a daily continuous water surface and water depth for the freshwater greater Everglades. This project provides investigators with tools to infer other hydrologic characteristics such as recession rates, time since last dry period, water-surface slope, and hydroperiod.

This report documents the procedures, methods, and results of validating the EDEN water-surface model in Water Conservation Areas (WCA) 3A South and 3B by using model-interpolated water stage/level data and field-measured data. Two applications of the EDEN water-surface model are also presented.

Procedures and Methods

EDEN Network

The USGS retrieves water-level data daily from 253 gaging stations (Figure 1 and Appendix A) including 225 telemetry-enhanced gages that record and transmit several water level values throughout the day, mostly hourly from recorders ranging approximately from 81º07’19W to 80 º13’05W in easting and 25 º13’27N to 26º 40’47N in northing in south Florida. Figure 2 shows two examples of gage stations. An additional 28 gages do not have telemetry and are manually read and added to the network. All transmitted data are entered and stored in the National Water Information System (NWIS), a database operated by the USGS. The 13 USGS gages in the EDEN network bordering the Gulf of Mexico are not used in the surfacing interpolations described in this report. Thus, there are a total of 240 gages used for water surface interpolation of the freshwater Everglades.

Among the 240 stations, 23 stations (EDEN stations) were established to record water stage data in July 2006, based on proximity analysis of 400 m resolution grid maps to improve overall accuracy of spatial prediction of water surface and water depth. To obtain a complete daily gage data set in the EDEN network for the period beginning January 2000 to current, artificial neural network models were used to provide an estimate/hindcast of water stage at the new gage sites over the historic record (January 2000 to July 2006). Details are provided in Conrads and Roehl (2006, 2007).

All gages in the EDEN network are operated and maintained by four separate agencies including Everglades National Park (ENP), South Florida Water Management District (SFWMD), Big Cypress National Preserve (BCNP), and the USGS. The NWIS database transmits all recorded data to a local USGS FTP server where it is available for surfacing. Gage data and its metadata are available for preview and downloading at the EDENweb (http://sofia.usgs.gov/eden).

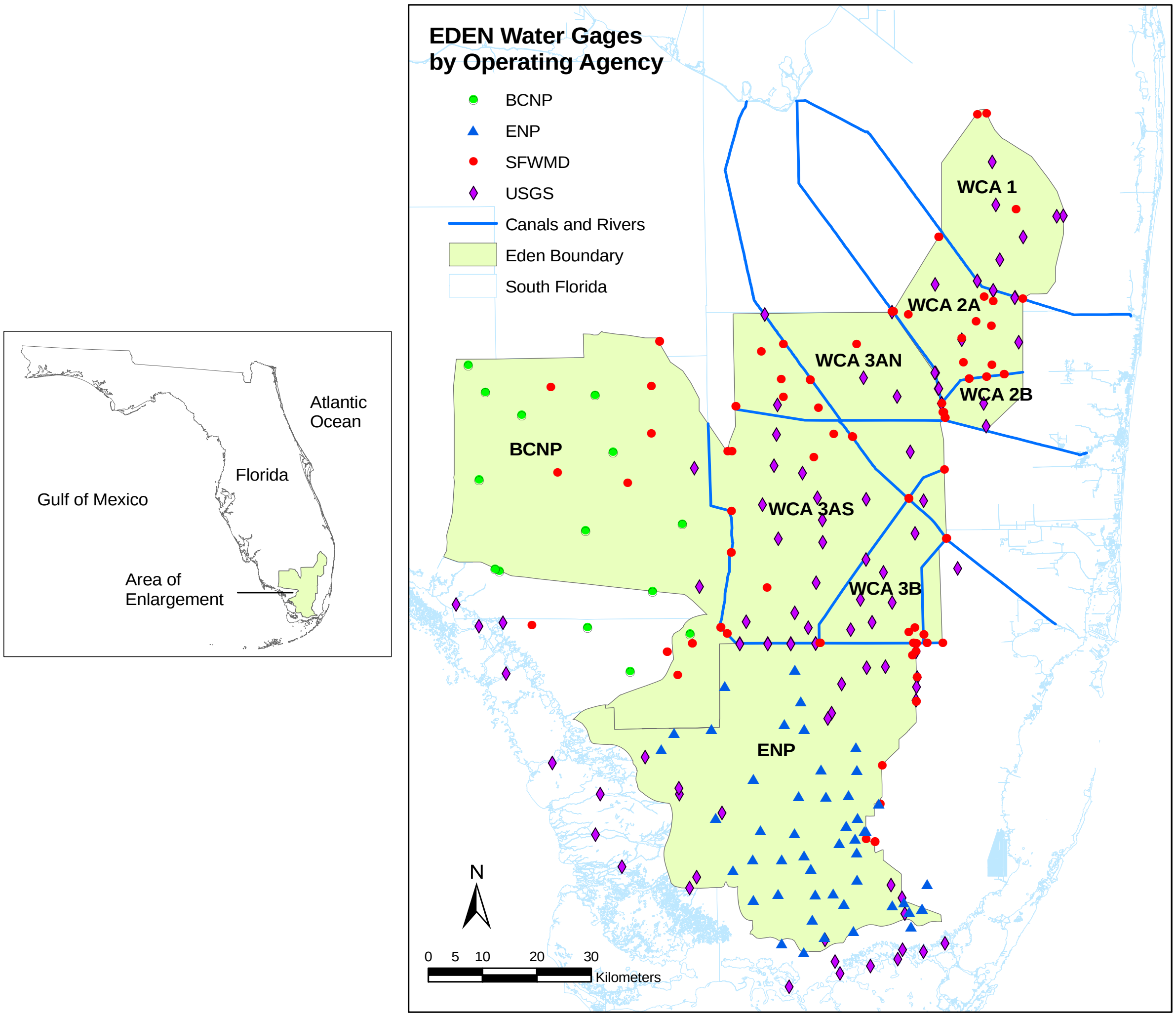

Figure 1. Location of water-stage gages collected in the EDEN network. Water Conservation Areas (WCA) 2 and 3 are subdivided by canals. WCA3A is further subdivided into a northern (WCA3AN) and southern (WCA3AS) region.

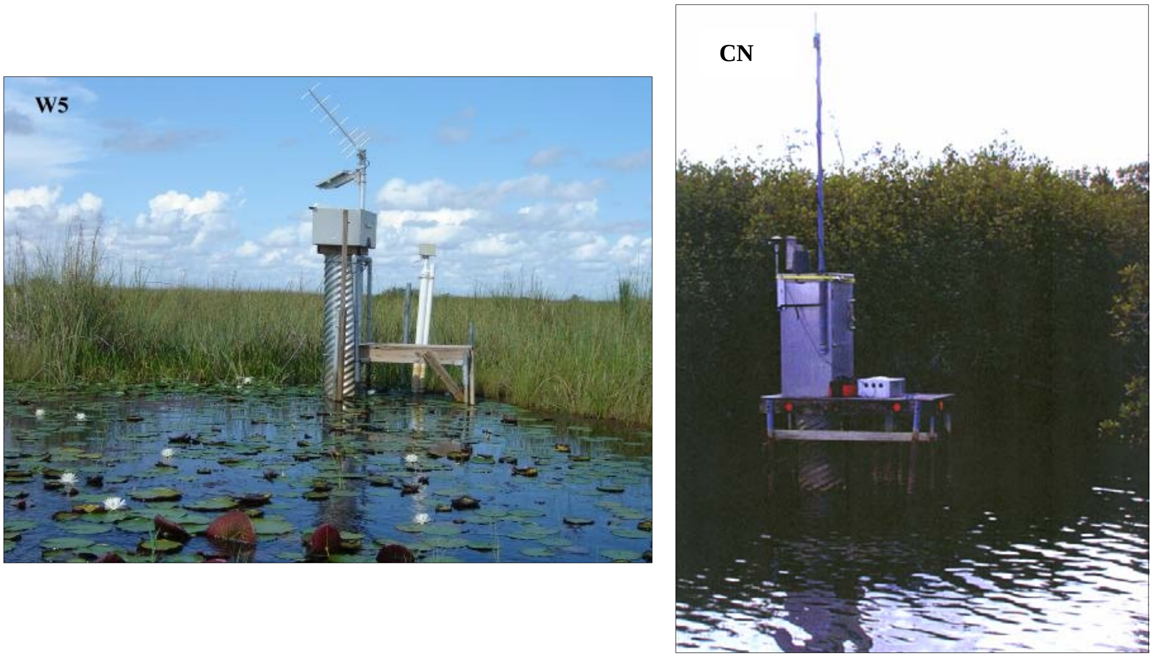

Figure 2. Example of water stage gages in the EDEN network. Left: water stage gage (W5) in WCA 3A via near real-time satellite communication. Right: water stage gage (CN) in Everglades National Park via near real-time radio communication.

The EDEN area is divided in eight distinct sections by canals and levees, with five sections belonging to three distinct water conservation areas surrounded by canals and levees (Figure 1). Abrupt water levels discontinuities among the sections complicate interpolation across the entire area. Water level near section boundaries is further influenced by the SFWMD’s operation of massive pumps and canals to distribute water for natural areas, agriculture, urban use and flood protection.

Generally, there are two categories of gaging stations: marsh stations (away from canals) and canal stations. In locations where canal stations are at a structure across a levee, gages are frequently paired so that there is a gage on both sides of the levee to measure differences in water stage created by the levee and structure. These paired gaging stations are referred to as “head” and “tail” stations (Figure 3). Canal stations may or may not have a continuous hydrologic connection with stations further out in the marsh.

To prepare a range of dates for surfacing, data retrieved from gaging stations in National Geodetic Vertical Datum of 1929 (NGVD 29) is converted to North American Vertical Datum of 1988 (NAVD 88) (Telis, 2006) and the median value for each day is calculated. Daily median values are used for the interpolation algorithm to reduce the influence of occasional incorrect extreme values in the data.

Figure 3. Example of head (UP) and tail (DN) gaging stations at S-11C. S-11C is a control structure in the levee dividing Water Conservation Area 2A from Water Conservation Area 3A-North.

The canal and levee boundaries act as major discontinuities in the EDEN area, and water levels from one section have minimal or no influence into adjacent sections. Steep changes in elevation can occur between areas at these levees. Since stratification of the data is not feasible due to the limited number of water gages, boundary conditions were simulated by linearly interpolating along both sides of levees in the canals using head and tail stage data. Simulated data at these pseudo-stations were re-sampled every 200 m and re-introduced into the interpolation exercise (Figure 4). The marsh gage data together with the interpolated data along canals represent the new extended data used for water surface modeling. In this way, data from the marsh in one conservation area would not influence the values in the marsh across a canal in a different area. Even though track data (very densely sampled preferential lines) alone may be problematic for interpolation, the mixture of track data along canals and levees, plus randomly distributed stage data, and the provision to use only the closest data point to the interpolated location in each of the eight sectors of a search neighborhood (see below) overcomes some of the problems. Nevertheless, a reduced confidence in the interpolated surface occur close to canal.

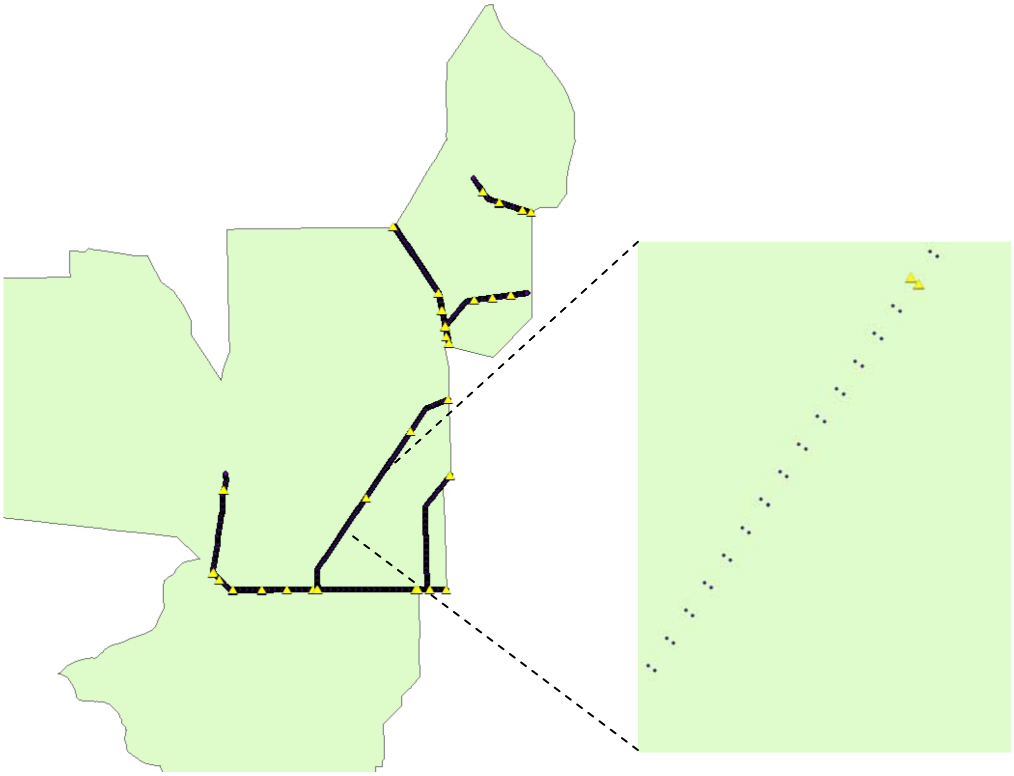

Figure 4. Levee and canal locations where boundary conditions were created for interpolation. The yellow triangles are the locations of water-stage gages. The close-up illustrates linear interpolation of head and tail pseudo-stations every 200m along a levee.

EDEN Water-Surface Model

The EDEN water-surface model was created by Pearlstine *et al.* (2007) with use of the radial basis function interpolation and the multiquadric method in ArcGIS 9.x (Johnston *et al.* 2003). The continuous mathematical representation of the water surface was sampled further on a 400 x 400 m grid spacing to record the interpolated values. The interpolated data range from January 1, 2000 to present. Details of EDEN grid, ground surface elevation sampling and modeling are in Jones and Price (2007a, 2007b), and Pearlstine *et al.* (2007).

The multiquadric method was first established by Hardy in1968 and made public in 1971 (Hardy, 1971, 1977). Later it was demonstrated mathematically that this method is a case of biharmonic analysis in an arbitrary number of dimensions (Dyn and Levin, 1980, 1983; Barnhill and Stead, 1984; Hardy and Nelson, 1986; Michelli, 1986; Foley, 1987; Sirayanone, 1988; Hardy and Sirayanone, 1989; Madych and Nelson, 1990). The multiquadric equations are also continuously differentiable integrals. The method was tested on both "real world" data in geophysics, surveying and mapping, photogrammetry and remote sensing, digital terrain models and hydrology, as well as on mathematical surfaces. Franke (1982) gave a critical account and comparison of 29 interpolation methods tested on generated mathematical surfaces from sparse and scattered data. None of the methods investigated by Franke (1982) belonged to the kriging family. Hardy's multiquadric method performed the best or the second best in Franke's study: "In terms of fitting ability and visual smoothness, the most impressive method included in the tests is the "multiquadric" method, due to Hardy. … The method … yields consistently good results, often giving the most accurate results of all tested methods" (Franke, 1982, pp. 191).

Radial Basis Function (RBF) is referred to as an exact interpolation technique because the interpolated surface always passes exactly through the data points. RBF interpolations use a set of n radial basis functions, one for each location, while minimizing the total curvature of the surface (Johnston *et al.*, 2003). Thus, the predictor is a linear combination of the radial basis function

$$Z(s_0) = \sum_{i=1}^{\hat{n}} \omega_i \phi(d)$$

where $\phi(d)$ is a radial basis function with $d = \|s_i - s_0\|$ the Euclidian distance between the prediction location s0 and each known data location si and ω_i the equation weights. In Figure 5 for three different locations, the RBF surface is illustrated in a different line type. For a set of coordinates of a predicted value location, the predictor will be formed by summing the weighted functions ϕ_1, ϕ_2, ϕ_3 for each known location. Weighting enforces the condition that when predicting a measured value, this value is predicted exactly (Johnston *et al.*, 2003). One difference between a simple Inverse Distance Weighting (IDW) and RBF interpolation is that IDW will have no predicted values below or above the minimum or maximum measured values, respectively. RBF predicted values, however, could be outside the measured values interval.

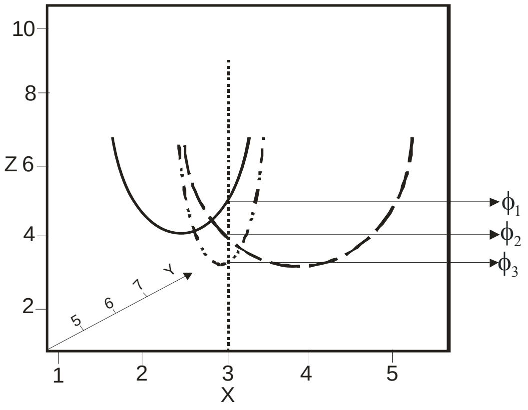

Figure 5. RBF prediction concept (modified after Johnson *et al.*, 2003, p. 127) $Z(x, y) = w_1\phi_1 + w_2\phi_2 + w_3\phi_3$, where $x = 3, y = 4$

The RBF selected for this study uses the multiquadric function, defined as: $\phi(d) = (d^2 + r^2)^{1/2}$, where r is the smoothing or the shape parameter. If r is small, the resulting interpolated surface has minimal curvature forming a cone like basis function with the generated surface being very "tight" around the data points (Kansa and Carlson, 1992, Golberg *et al.*, 1996, Johnston *et al.*, 2003). As r increases the curvature of the function gradually flattens until the basis function is almost flat (Kansa and Carlson, 1992, Golberg *et al.*, 1996). There is much discussion about how to choose the shape parameter r, but no fool-proof method exists, only empirical formulas. The majority of the empirical formulas tie the parameter r to the scale of the problem at hand, the distribution of data, and their density (Hardy, 1977, 1988, 1990; Gopfert, 1977; Franke, 1982; Golberg *et al.*, 1996; Rippa, 1999; and Ferreira *et al.*, 2005). Others made the parameter r dependent only to the data points measured value z_i (Carlson and Foley, 1991) or used a variable parameter r instead of a constant one for large datasets (Kansa, 1990 a and b; Kansa and Carlson, 1992).

Florida Department of Environmental Protection (FDEP) Benchmark Network

The FDEP benchmark network contains 31 benchmarks in WCA 3 (Figure 6; Appendix B). Vertical control on those 31 benchmarks was established with GPS by Smith (2005). The vertical control information was "Blue-booked" and submitted to the National Geodetic Survey (NGS).

The metadata information is:

Horizontal Classification: 1ST Order
Horizontal Datum: NAD 83
Vertical Datum: NAVD 88
Locality: In Everglades West of Miami Florida
Geoid: 2003
Date of Field Work: June 1, 2, 3, 4, 5, 14, 15, 16, 17, 18 & 19, 2005
Date of Computation: July 2005
Total Number of Stations: 50
    New Stations - 31
    Control Stations - 19

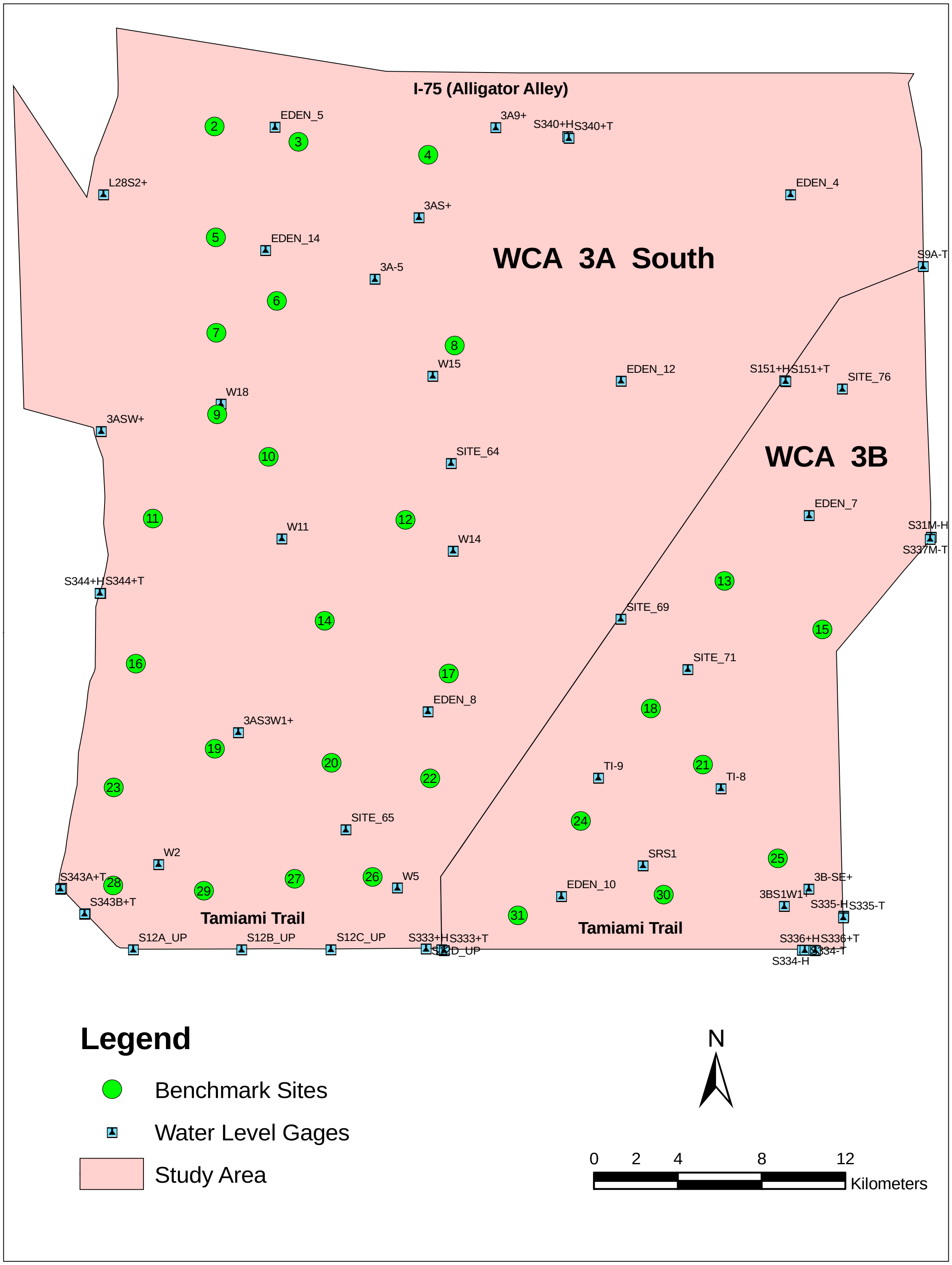

Figure 6. FDEP benchmark sites and EDEN water level gages in WCA 3A South and 3B.

Data Collection

Field water-elevation data at the benchmarks of the FDEP network were collected by Florida Atlantic University in southern WCA3A (83 observations) and WCA3B (8 observations) from April through September 2007, and are used to validate the EDEN water-surface model in these areas. The Everglades has distinct dry (October-May) and wet (June-September) seasons. There are 16 observations in the dry season and 75 in the wet season (Table 1). For the eight observations collected in WCA 3B in August 2007, the field team used a helicopter rather than an airboat because there was not a continuous water surface around some bench marks.

Water-surface elevations were measured at a total of 24 benchmarks established by FDEP in WCA3A and in WCA3B between I-75 (Alligator Alley) and the Tamiami Trail. When water-surface levels were at or above the benchmark lid, the distance from the benchmark bar to the water surface (a positive number) was measured directly with a meter stick to the nearest mm. Water-surface elevation was then calculated as: benchmark bar elevation + distance from bar to water surface. When water surface levels were below the level of the benchmark lid (as shown in Figure 7), two measurements were made, the distance from the benchmark bar to the lid (a positive number) and the distance from the lid to the water surface (a negative number). Water-surface elevation was then calculated as: benchmark bar elevation + distance from bar to lid + distance from lid to water surface.

Figure 7. Illustration of how water-surface elevation measurements were made at FDEP elevation benchmarks.

Information Available

Table 1 lists the 91 field-measured water-stage (level) data (observed stage) at 24 FDEP benchmarks from April 2007 to September 2007 sorted by FDEP benchmark IDs (BM_ID). Modeled water-stage data (predicted stage) for the corresponding benchmarks and days were extracted from the EDEN water-surface model by using the EDEN xyLocator program developed by the Joint Ecosystems Modeling Laboratory at the University of Florida (http://sofia.usgs.gov/eden/edenapps/xylocator.php). EDEN xyLocator returns values from EDEN spatial hydrology time-series at specific x, y coordinates over a specified time period. The predicted water-surface value is for a 400m grid cell that the measured point resides. With this available information, field-measured water surface data at the benchmark sites can be compared with the modeled water-level data.

Table 1. Field-measured and model-predicted water-stage data at FDEP benchmarks in WCA 3A South and WCA 3B

N	BM_ID [a]	Date	Season [b]	Observed stage (cm)	Predicted stage (cm)	Stage difference [c] (cm)
1	4	9/3/2007	Wet	266.8	271.7	4.9
2	4	9/4/2007	Wet	267.0	271.9	4.9
3	4	9/5/2007	Wet	267.5	271.8	4.3
4	6	9/12/2007	Wet	267.5	267.0	-0.5
5	6	9/17/2007	Wet	269.8	269.2	-0.6
6	6	9/18/2007	Wet	269.4	268.8	-0.6
7	8	8/15/2007	Wet	245.1	248.7	3.6
8	8	8/21/2007	Wet	243.2	246.9	3.7
9	8	8/22/2007	Wet	243.0	246.6	3.6
10	8	8/23/2007	Wet	242.3	246.2	3.9
11	8	9/12/2007	Wet	243.1	247.1	4.0
12	9	9/18/2007	Wet	263.4	263.2	-0.2
13	10	8/20/2007	Wet	249.4	249.6	0.2
14	10	8/21/2007	Wet	249.0	249.3	0.3
15	10	8/22/2007	Wet	248.6	249.0	0.4
16	12	8/8/2007	Wet	225.6	228.6	3.0
17	12	8/9/2007	Wet	225.7	228.5	2.8
18	12	8/13/2007	Wet	228.4	230.5	2.1
19	12	8/14/2007	Wet	228.7	231.6	2.9
20	13	8/31/2007	Wet	177.9	178.3	0.4
21	14	6/20/2007	Wet	223.2	222.8	-0.4
22	14	6/21/2007	Wet	221.1	222.2	1.1
23	14	6/25/2007	Wet	219.4	219.6	0.2
24	14	6/26/2007	Wet	218.0	218.8	0.8
25	14	7/2/2007	Wet	224.8	223.1	-1.7
26	14	7/9/2007	Wet	222.6	223.3	0.7
27	14	7/10/2007	Wet	221.9	222.9	1.0

Table 1 continued.

N	BM_ID [a]	Date	Season [b]	Observed stage (cm)	Predicted stage (cm)	Stage difference [c] (cm)
28	15	8/31/2007	Wet	159.1	141.5	-17.6
29	17	5/10/2007	Dry	204.8	206.0	1.2
30	17	5/14/2007	Dry	202.0	204.0	2.0
31	17	5/16/2007	Dry	203.6	206.5	2.9
32	17	6/4/2007	Wet	208.6	210.3	1.7
33	17	6/5/2007	Wet	207.6	209.6	2.0
34	17	6/6/2007	Wet	206.9	209.1	2.2
35	17	6/7/2007	Wet	208.2	211.7	3.5
36	17	6/11/2007	Wet	208.1	211.2	3.1
37	17	6/12/2007	Wet	207.2	210.0	2.8
38	17	6/13/2007	Wet	208.4	210.5	2.1
39	17	7/3/2007	Wet	213.1	214.7	1.6
40	17	7/5/2007	Wet	213.1	216.5	3.4
41	17	7/10/2007	Wet	215.0	217.4	2.4
42	17	7/12/2007	Wet	214.0	216.2	2.2
43	18	8/31/2007	Wet	176.0	177.7	1.7
44	19	4/30/2007	Dry	219.5	218.9	-0.6
45	19	5/1/2007	Dry	219.1	217.8	-1.3
46	19	5/2/2007	Dry	218.6	217.2	-1.4
47	19	8/1/2007	Wet	226.5	225.0	-1.5
48	20	5/2/2007	Dry	211.1	213.7	2.6
49	20	6/18/2007	Wet	218.3	218.8	0.5
50	20	6/19/2007	Wet	218.5	219.8	1.3
51	20	7/11/2007	Wet	215.9	217.7	1.8
52	20	7/16/2007	Wet	220.7	221.3	0.6
53	20	9/12/2007	Wet	223.4	225.9	2.5
54	21	8/31/2007	Wet	164.2	162.7	-1.5
55	22	5/3/2007	Dry	205.3	202.9	-2.4
56	22	5/7/2007	Dry	206.0	204.1	-1.9
57	22	5/8/2007	Dry	205.0	202.5	-2.5
58	22	5/9/2007	Dry	204.3	201.3	-3.0
59	22	5/10/2007	Dry	203.2	200.5	-2.7
60	22	6/13/2007	Wet	207.0	206.8	-0.2
61	22	6/14/2007	Wet	206.6	206.8	0.2
62	22	6/18/2007	Wet	211.2	214.2	3.0
63	22	7/16/2007	Wet	214.1	215.3	1.2
64	22	7/17/2007	Wet	214.2	215.0	0.8

Table 1 continued.

N	BM_ID[a]	Date	Season[b]	Observed stage (cm)	Predicted stage (cm)	Stage difference[c] (cm)
65	23	8/7/2007	Wet	221.3	224.7	3.4
66	24	8/31/2007	Wet	171.0	172.7	1.7
67	25	8/31/2007	Wet	149.1	142.8	-6.3
68	26	6/5/2007	Wet	208.6	208.5	-0.1
69	26	7/17/2007	Wet	219.0	216.2	-2.8
70	26	7/18/2007	Wet	218.6	216.1	-2.5
71	26	7/19/2007	Wet	218.2	215.6	-2.6
72	27	4/25/2007	Dry	211.8	207.3	-4.5
73	27	4/26/2007	Dry	211.7	206.6	-5.1
74	27	7/23/2007	Wet	222.4	218.4	-4.0
75	27	7/24/2007	Wet	221.0	219.1	-1.9
76	27	7/26/2007	Wet	225.8	222.1	-3.7
77	27	7/30/2007	Wet	223.2	222.0	-1.2
78	27	9/12/2007	Wet	219.7	221.4	1.7
79	28	8/27/2007	Wet	227.2	223.8	-3.4
80	28	8/28/2007	Wet	226.3	223.2	-3.1
81	28	8/29/2007	Wet	226.3	222.9	-3.4
82	28	9/11/2007	Wet	223.9	222.4	-1.5
83	28	9/12/2007	Wet	223.4	221.9	-1.5
84	29	4/23/2007	Dry	214.0	210.8	-3.2
85	29	4/24/2007	Dry	213.0	209.9	-3.1
86	29	7/26/2007	Wet	224.8	222.7	-2.1
87	29	7/30/2007	Wet	223.8	222.5	-1.3
88	29	7/31/2007	Wet	223.2	222.1	-1.1
89	29	8/1/2007	Wet	222.7	221.9	-0.8
90	30	8/30/2007	Wet	161.4	160.5	-0.9
91	31	8/30/2007	Wet	171.4	160.3	-11.1

[a] Benchmark locations in Figure 6.

[b] Dry season (October-May) and wet season (June-September).

[c] Stage difference = predicted water stage – observed water stage. Positive and negative values indicate an over or under prediction bias by the model, respectively.

Analysis Methods

Two independent analyses were performed: one at the University of Florida and the other at Florida Atlantic University. Graphic, statistical, and geographic information systems (GIS) analyses were used to validate the EDEN water-surface model. As a powerful data integration and spatial analysis tool, we used ArcGIS to aggregate, synthesize, and analyze the observed and predicted datasets, and to identify spatial relationships.

A thorough comparative analysis of the benchmark data and the EDEN time series is first presented. This report then presents such error statistics as MAE (Mean Absolute Error, measuring average magnitude of error), MBE (Mean Biased Error, measuring average error), and RMSE (Root Mean Squared Error). Nonparametric statistical analysis methods are employed to examine the statistical relationship between those observed and predicted data by using SAS software (SAS Institute Inc., 2004), including Spearman's rank correlation analysis, Wilcoxon signed rank test for paired data, and Kruskal-Wallis nonparametric analysis of variance (ANOVA).

To further assess the agreement between benchmark data and EDEN model predictions, without the confounding effect of spatiotemporal autocorrelation, ArcGIS was used to generate the spatial distance matrix among benchmark sites and benchmark water elevation measurements were temporally detrended using a temporal trend model derived from regional stage data. Spearman's rank correlation analyses of the temporally detrended data were corrected for the significance inflation caused by spatial autocorrelation using SAM (Spatial Analysis in Macroecology) software developed by Rangel *et al.* (2006).

Statistical Analysis Results

To validate the daily water-surface model, an independent data set was collected at 24 benchmark sites in WCA 3A South and WCA 3B from April 2007 through September 2007, by the field personnel at Florida Atlantic University and University of Connecticut. These data proved invaluable in validating agreement between predicted and observed water-surface elevation over most of WCA3 and identifying errors in the model.

A graduated symbol map is created in ArcGIS to identify the spatial pattern of interpolation errors, which is based on the differences from model predicted and observed water-stage data (Figure 8). There are four benchmarks with absolute errors more than 5 cm, and three of them, including two over 10 cm, are located within WCA 3B. The highest absolute interpolation difference in WCA 3A South is 5.1 cm. Those high interpolation errors mainly occur near EDEN boundaries of Tamiami Canal, L-30 Canal, and L-67 Canal (Figure 8).

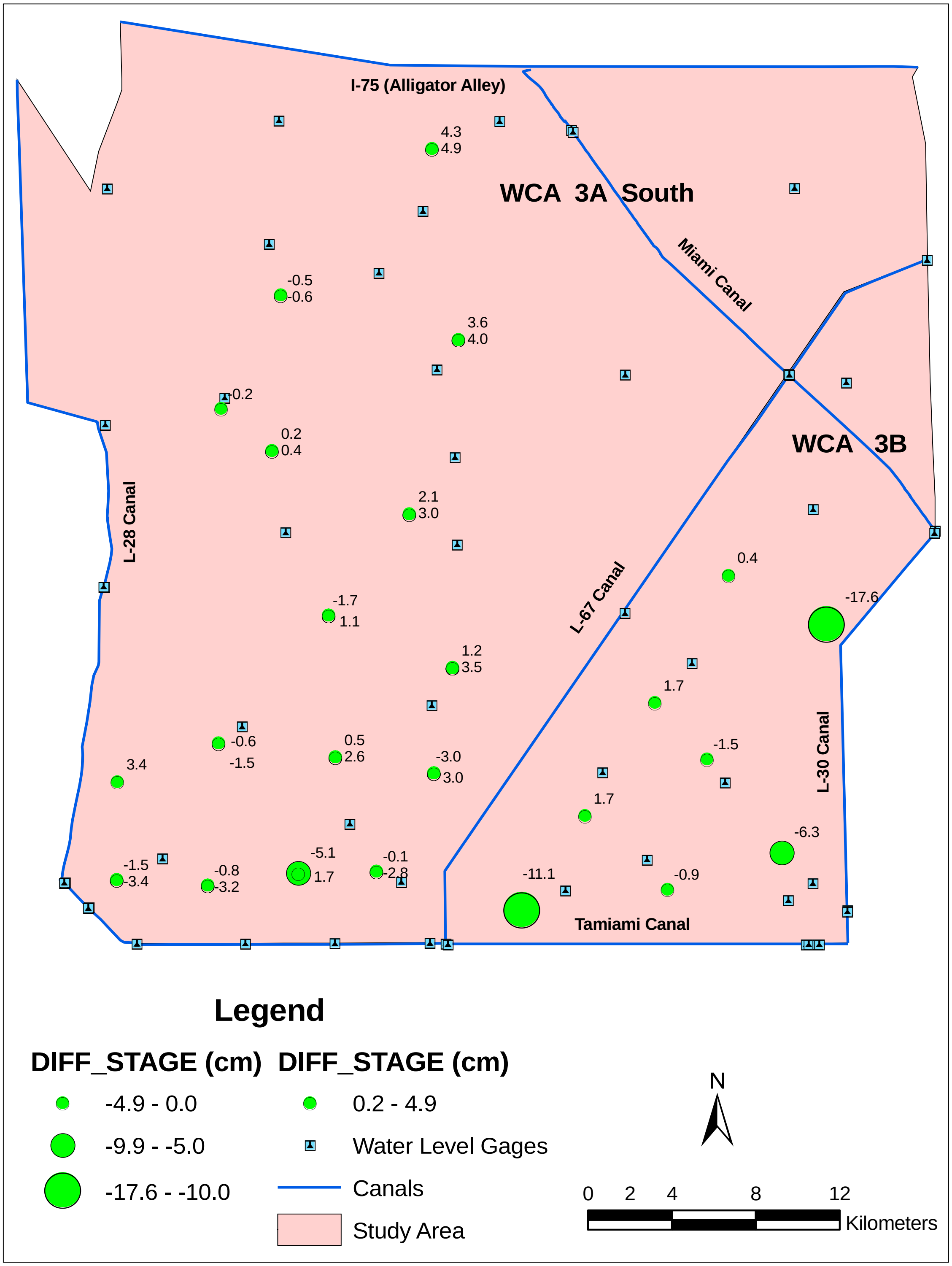

Figure 8. Water stage validation at FDEP benchmark sites in WCA 3A South and 3B. DIFF_STAGE (unit: cm) = predicted water stage – observed water stage. The minimum and maximum water stage differences (DIFF_STAGE) are labeled at the benchmarks. Underestimates and overestimates are represented by negative and positive values, respectively.

The interpolation errors were then analyzed by using statistical analysis methods, including error statistics (MAE, MBE, and RMSE), Spearman's rank correlation analysis, Wilcoxon signed rank test for paired data, and Kruskal-Wallis nonparametric ANOVA. The differences between interpolated and observed water stage together with three types of error statistics are summarized in Table 2. The definitions of MAE, MBE, and RMSE are as follows (Willmott, 1982; Li *et al.*, 2006; Sousa *et al.*, 2007):

MAE (Mean Absolute Error) = $\frac{1}{N}\sum_{i=1}^{N}\left|P_i - O_i\right|$

MBE (Mean Biased Error) = $\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)$

RMSE (Root Mean Squared Error) = $\left[\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)^2\right]^{1/2}$

where N is the number of observations, P_i s are the predicted/interpolated values, and O_i s are the observed values.

These different error formulations are all valid measures of accuracy but may reveal slightly different interpretations. The MAE is a weighted average of the absolute errors. The MBE (also called mean error) is a measure of the bias of model predictions – whether the model over or under estimate the measured data. Positive and negative MBEs indicate an over or under prediction bias by the model, respectively. Mean biased errors near zero may be misleading because negative and positive discrepancies in the simulations can cancel each other (Conrads and Roehl, 2007). Both MAE and RMSE measure residual errors, which give a global idea of the difference between the observed and modeled values (Sousa *et al.*, 2007). The RMSE measures error magnitude and addresses the limitations of MBE. In addition, large errors have a greater impact on RMSE than in the MAE or MBE. The units of the MAE, MBE, and RMSE statistics are the same as the variable simulated by the model. For model evaluation the RMSE is often more informative (Willmott, 1981). The RMSE of WCA 3A South (2.48 cm) is less than that of WCA 3B (7.76 cm), and the overall RMSE is 3.3 cm.

Table 2. Major statistics of interpolation errors for water stage[a]

Type	N	MIN (cm)	MAX (cm)	Standard deviation	Standard error[b]	MAE	Mean (MBE)	RMSE
WCA 3A South, 3B	91	-17.6	4.9	3.32	0.35	2.38	-0.08	3.30
WCA 3A South	83	-5.1	4.9	2.47	0.27	2.11	0.32	2.48
WCA 3B	8	-17.6	1.7	6.97	2.46	5.15	-4.2	7.76

[a] Interpolation error (water-stage difference) = predicted water stage – observed water stage.

[b] Standard error = standard deviation / $\sqrt{N}$.

Before any parametric statistical tests were used, the normality of data distribution was tested. According to the Shapiro-Wilk normality test results in Table 3, only the predicted and observed water-stage data in WCA 3B are normally distributed. Three data transformation methods, square root, logarithmic, and inverse (Hartwig and Dearing, 1979), were applied to normalize the water-stage data in both WCA 3A South and WCA 3B, and in WCA 3A South, respectively (Appendix C). The water-stage difference in WCA 3A South and WCA 3B was the only variable that follows a normal distribution after square root transformation. However, only 50 positive water-stage differences out of 91 had square root values. None of the transformation methods was appropriate. Therefore nonparametric statistical analysis methods were applied. Nonparametric statistics concerns statistical inference without assuming that the data come from a specified family of distribution (e.g., normal). Nonparametric methods are often the only way to analyze nominal or ordinal data and draw statistical conclusions. The Spearman's rank correlation analysis is first used to examine the relationship between predicted and observed water stage and water depth. As a nonparametric technique, the Spearman's rank correlation coefficient (Spearman, 1904; Snedecor and Cochra, 1989) is a measure of linear association between two variables when only ordinal (rank order) data are available. The Spearman's rank-correlation coefficient (r_s) is defined as:

$$r_s = 1 - \frac{6\left[\sum_{i=1}^{n} D_i^2\right]}{n(n^2-1)}$$

, i =1, 2, …n, where n is the number of observations, and D_i is the difference between ranks associated with two variables. Values of r_s can range from –1.0 to +1.0, where values near 1.0 indicate a strong positive association between the rankings, and values near -1.0 indicate a strong negative association between the rankings.

Since the p-values are less than 0.05 (Table 3), the null hypothesis of no correlation is rejected. Thus, we can conclude that there are significant positive correlations between the observed stage values and predicted ones.

Table 3. Shapiro-Wilk normality distribution tests and Spearman's rank correlation analysis between observed and predicted water stage data

Type	Variable	Normality test p-value (Shapiro-Wilk)	Spearman's rank correlation coefficient (r_s)	P-value of r_s
WCA 3A South, 3B	Observed_Stage	<0.0001	0.98	<0.0001
	Predicted_Stage	<0.0001		
WCA 3A South	Observed_Stage	<0.0001	0.98	<0.0001
	Predicted_Stage	<0.0001		
WCA 3B [a]	Observed_Stage	0.7133	0.83	0.0102
	Predicted_Stage	0.2472		

[a] For WCA 3B, the parametric Pearson's correlation coefficient is 0.8998 ($p = 0.0023$).

Since the water stage differences in WCA 3A South and 3B, and in WCA 3A South are not normally distributed, the Wilcoxon signed rank test (Wilcoxon, 1945; Siegel and Castellan, 1988) is used to test the median difference in paired data (Table 4). This test is the non-parametric equivalent of the paired t-test, and is used when the assumption of normally distributed differences is violated. All the p-value of the water stage differences are greater than 0.05 (Table 4), and this concludes that there are no statistically significant differences in the predicted and observed water-stage data.

Table 4. Shapiro-Wilk normality distribution tests and Wilcoxon's signed rank tests for the differences between observed and predicted water stage data

Type	Variable	Normality test p-value (Shapiro-Wilk)	Wilcoxon's signed rank test statistic	P-value (Wilcoxon)
WCA 3A South, 3B	Difference_Stage [a]	<0.0001	166.5	0.5129
WCA 3A South [b]	Difference_Stage	0.10	263.0	0.2346
WCA 3B [c]	Difference_Stage	0.079	-8.0	0.2969

[a] Difference_Stage = predicted water stage - observed water stage.

[b] For WCA 3A South, the test statistic of pairwised t-test is -1.19 ($p = 0.2371$).

[c] For WCA 3B, the test statistic of pairwised t-test is 1.7 ($p = 0.1321$).

The Kruskal-Wallis nonparametric analysis of variance (ANOVA) was used to examine the water stage differences spatially, temporally, and among different vegetation types. The Kruskal-Wallis test for k independent groups is the nonparametric version of one-way ANOVA when the normality assumption of ANOVA is not met, and is a generalization of the Wilcoxon test for two independent samples. The Kruskal-Wallis test (Kruskal and Wallis, 1952; Siegel and Castellan, 1988) compares between the medians of two or more samples to determine if the samples have come from different populations. The test statistic of the Kruskal-Wallis test is:

$$H = \frac{12}{n(n+1)}\left(\sum_{j=1}^{k}\frac{R_j^2}{n_j}\right) - 3(n+1)$$

where n is the sum of sample sizes in all groups, k is the number of groups, R_j is the sum of ranks in the j^{th} group, and n_j is the number of values in the j^{th} group (j = 1, 2, … , k).

Six major land cover types reclassified for the EDEN network are: (1) slough or open water, (2) wet prairie, (3) ridge or sawgrass and emergent marsh, (4) upland, (5) exotics and cattail, and (6) other (mostly wetland shrub and wetland forested) (Telis, 2006). Those types were aggregated from the Florida Gap Analysis Program (FLGAP) dataset (Florida Cooperative Fish and Wildlife Research Unit, 2005) and the South Florida Water Management District (Rutchey *et al.*, 2005).

The results in Table 5 indicate that there is insufficient evidence to reject the null hypothesis that the water stage differences are the same in WCA 3A South and WCA 3B ($p > 0.05$), and that there are statistically significant differences between predicted and observed water-stage data for dry and wet seasons, and for three vegetation types (Sawgrass, Exotics and Cattail, and Upland).

Table 5. Kruskal-Wallis nonparametric ANOVA tests for the differences between observed and predicted water stage data by season, region, and vegetation type.

Source	Class	N	Median Difference[a] (cm)	df [b]	Kruskal-Wallis test statistic (*H*)	P-value of *H*
Season	Dry (November – May)	16	-2.15	1	7.0428	0.008
	Wet (June – October)	75	0.6			
Region	WCA 3A South	83	0.4	1	3.4761	0.0623
	WCA 3B	8	-1.2			
Vegetation	3: Sawgrass	72	-0.2	2	12.4469	0.002
	4: Upland	13	3.6			
	5: Exotics and Cattail	6	1.55			

[a] Median difference = the median of water stage differences (predicted – observed). The mean differences are: -1.44 (dry), 0.21 (wet), 0.32 (WCA 3A South), -4.2 (WCA 3B), -0.62 (sawgrass), 2.19 (upland), and 1.55 (exotics and cattail).

[b] Degrees of freedom.

As a further validation of comparisons between EDEN predictions and benchmark data, Spearman's rank correlation coefficient was also calculated using temporally detrended data to remove temporal autocorrelation and a modified significance test (Rangel *et al.*, 2006) that corrects for the significance inflation caused by spatial autocorrelation. The results of these analyses (Table 6, $p < 0.05$) confirm that EDEN predictions show excellent, highly significant agreement with benchmark data in both WCA 3B and southern WCA 3A, as reported in the previous section.

Table 6. Spearman's rank correlations between observed and predicted values for temporally detrended water stage data, with degrees of freedom and significance tests corrected for spatial autocorrelation according to the method of Dutilleul (1993) as implemented by Rangel *et al.* (2006).

Type	Spearman's rank correlation coefficient	Corrected df[a]	Corrected p-value
WCA 3A South, 3B	0.909	17.29	<0.001
WCA 3A South	0.882	5.542	<0.001
WCA 3B	0.833	5.277	<0.004

[a] Corrected degrees of freedom.

The plot of observed versus expected values for all benchmarks (Figure 9) shows that the greatest deviation between observed and expected values occurred in the lower range of water surface elevations. A visual comparison of the observed and predicted water surface elevation is presented in Figure 10 (a-d); each plot shows the observed values and the times series of predicted values for individual benchmarks.

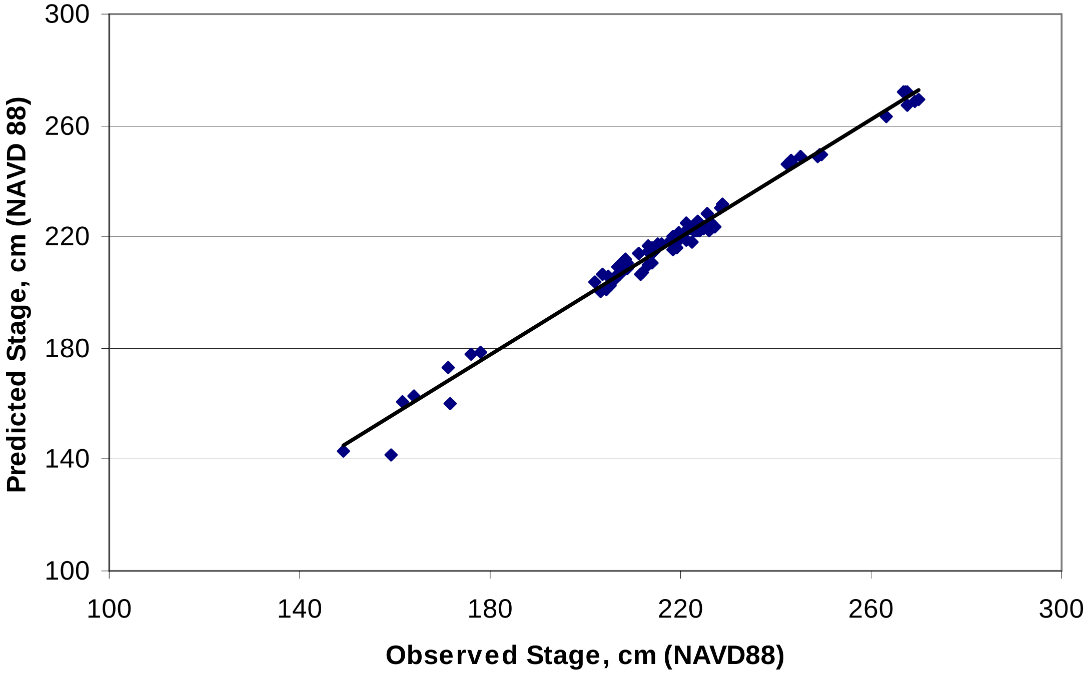

Figure 9. Comparison of observed water stage at FDEP elevation benchmarks and predicted water stage from the EDEN water-surface model.

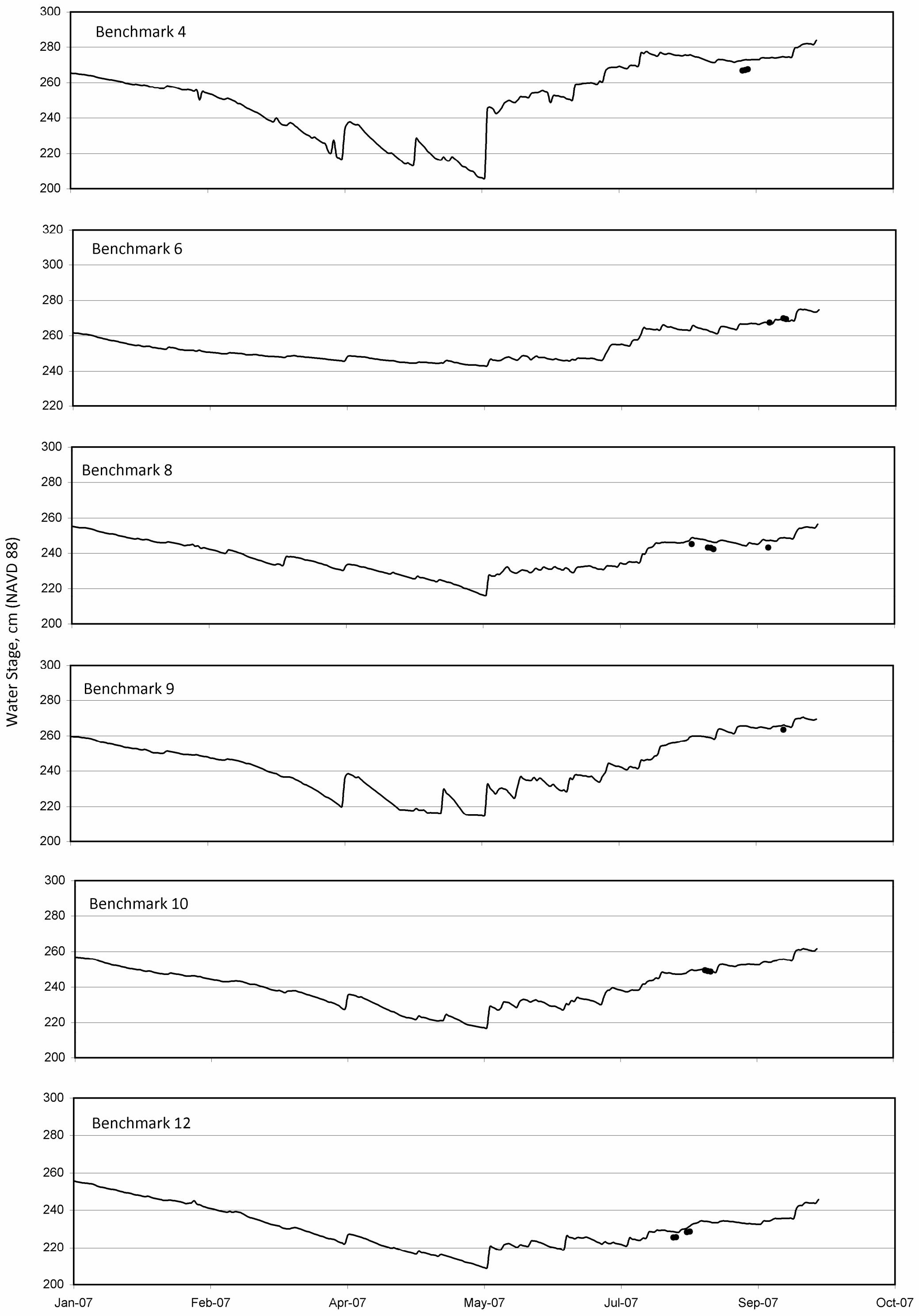

Figure 10a. Comparison of the time series of predicted water stage from the EDEN water-surface model (—) and observed water stage at the indicated elevation benchmarks (●).

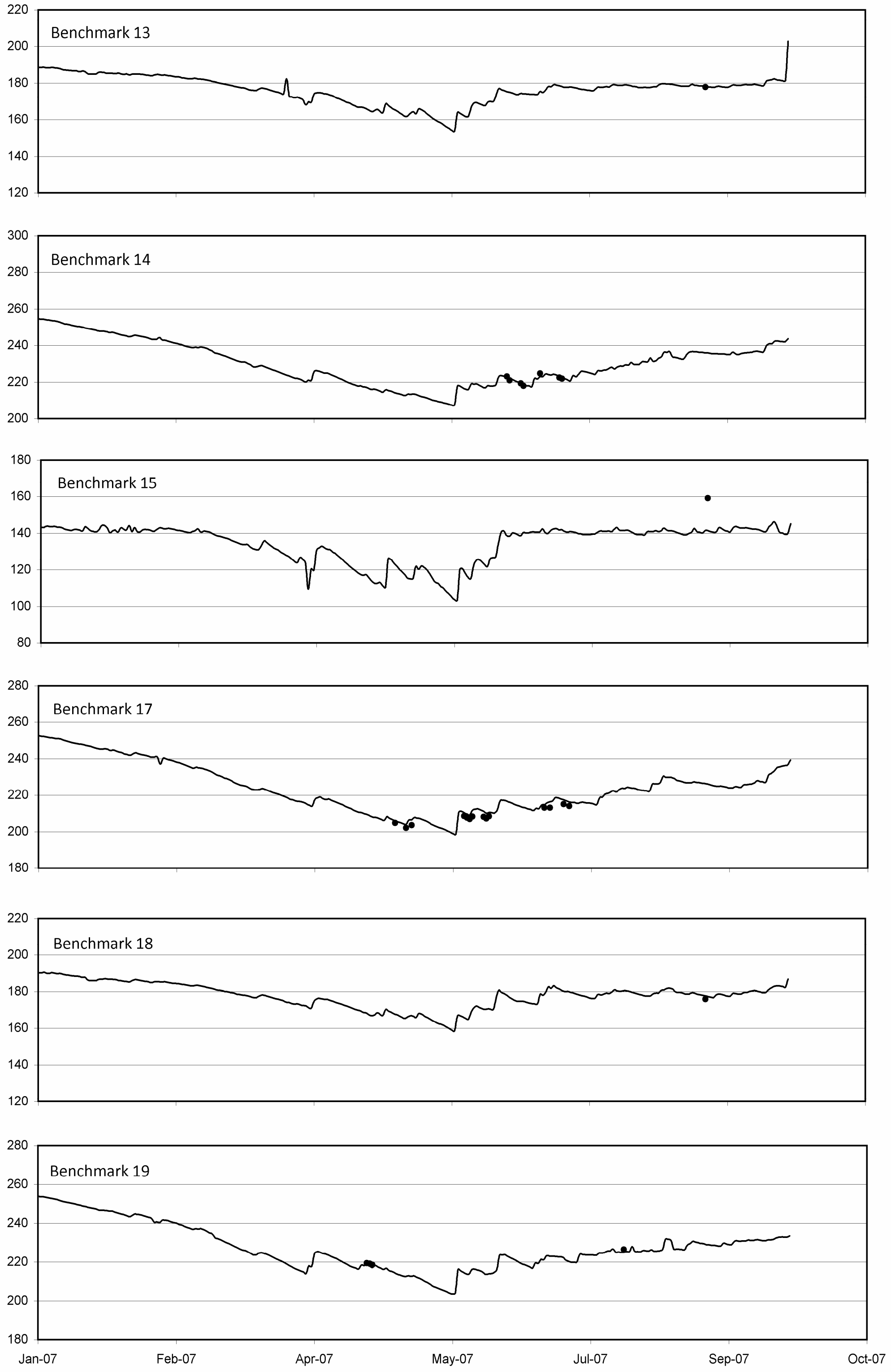

Figure 10b. Comparison of the time series of predicted water stage from the EDEN water-surface model (—) and observed water stage at the indicated elevation benchmarks (●).

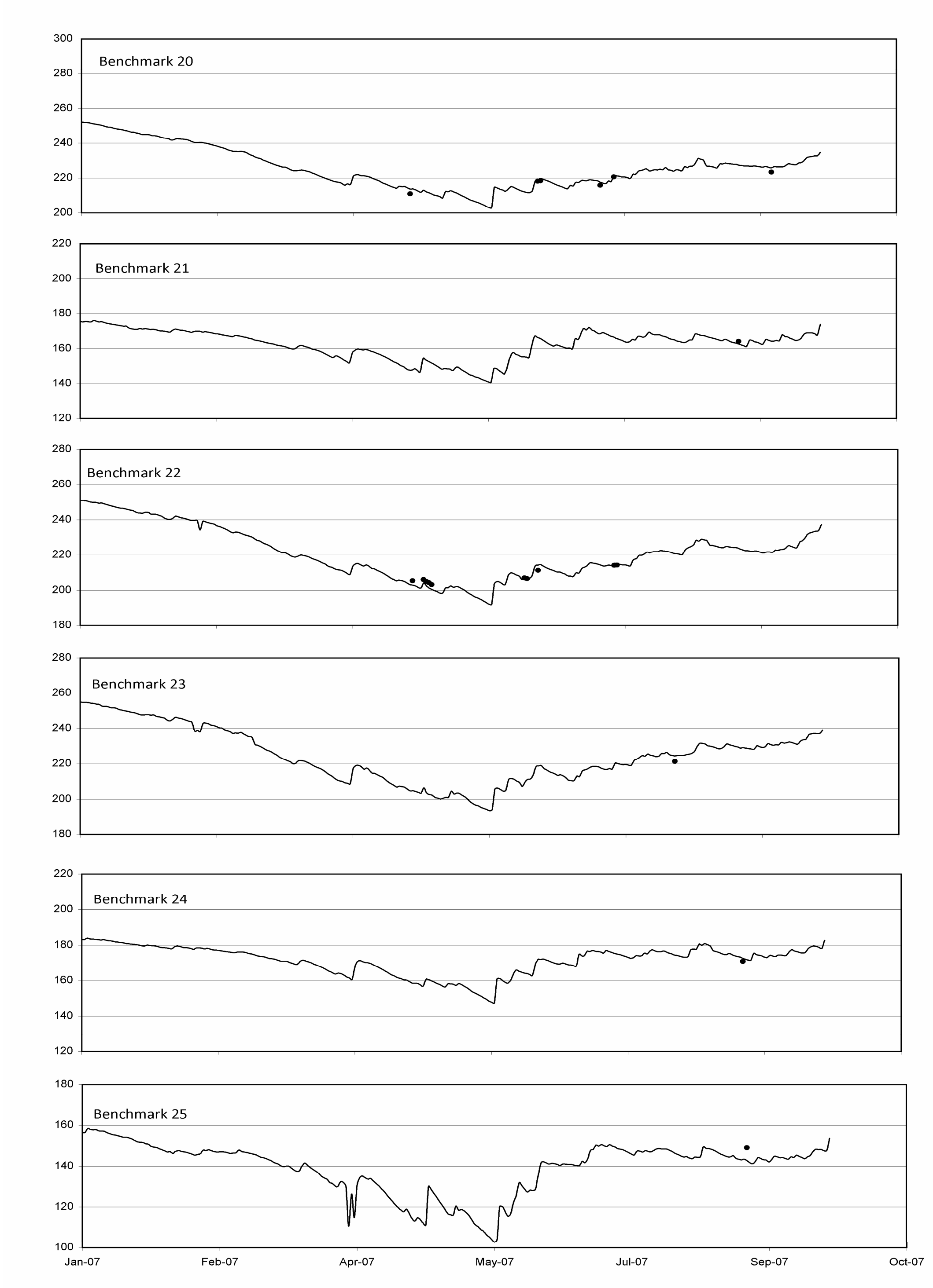

Figure 10c. Comparison of the time series of predicted water stage from the EDEN water-surface model (—) and observed water stage at the indicated elevation benchmarks (●).

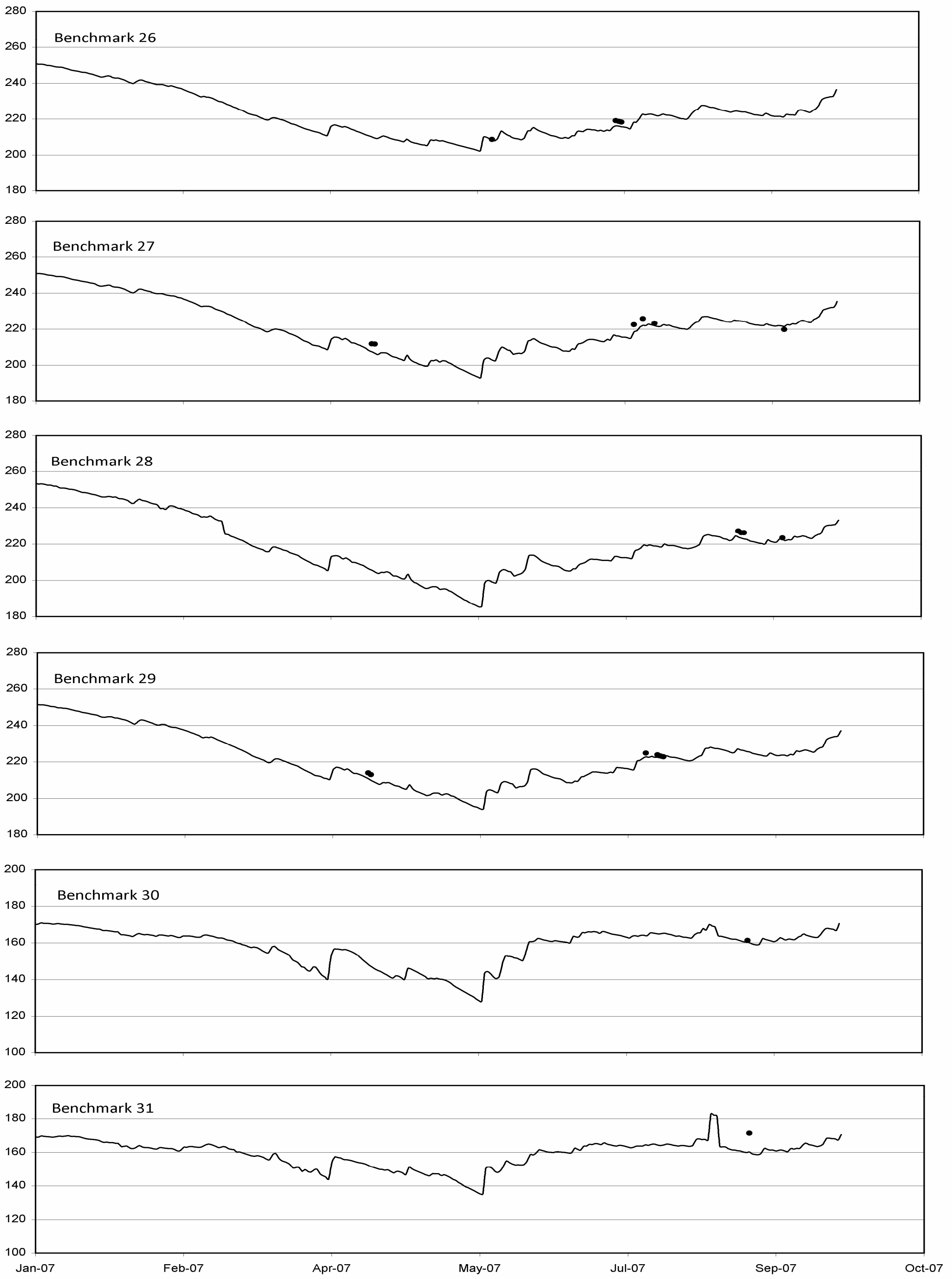

Figure 10d. Comparison of the time series of predicted water stage from the EDEN water-surface model (—) and observed water stage at the indicated elevation benchmarks (●).

EDEN Water-Surface Model Applications

Estimation of Ground Elevation

After the EDEN water-surface model is validated, ground elevation for specific locations can be estimated by using the valid predicted water surface data and available field-measured water depth data from principal investigators. The formula is: ground elevation = predicted water stage – observed water depth. An application of the EDEN water-surface model, shown in Figure 11, is the estimation of ground elevations for tree islands in central and southern WCA 3A.

Estimation of Water-Depth Hydrographs

Another application, shown in Figure 12, makes use of the EDEN time series of water surface elevations within individual grid cells to generate the time series of above or below-ground water depth for three tree islands in WCA3A. The calculation formula is: water depth = predicted water stage – estimated tree island elevation. Water depth measured at a tree island on a given day is related to the EDEN water surface elevation for the same day to determine the offset between the EDEN water surface and the ground level of the tree island. The offset is then used to generate the hydrograph of water depth for that tree island from the EDEN time series. Measures of hydrological conditions such as hydroperiod and maximum inundation depths, from January 2000 to the present, can be derived from the resulting hydrograph.

System-wide water-depth hydrographs could be obtained when ground elevation from a digital elevation model (DEM) is subtracted from EDEN water stage (Pearlstine *et al.*, 2007). Jones and Price (2007a, 2007b) developed the EDEN DEM (400m resolution) of the ground surface by using the USGS Airborne Height Finder (AHF) system installed on a helicopter. The EDEN DEM was produced based on input data of approximately 400m sample spacing and +/- 15cm vertical accuracy.

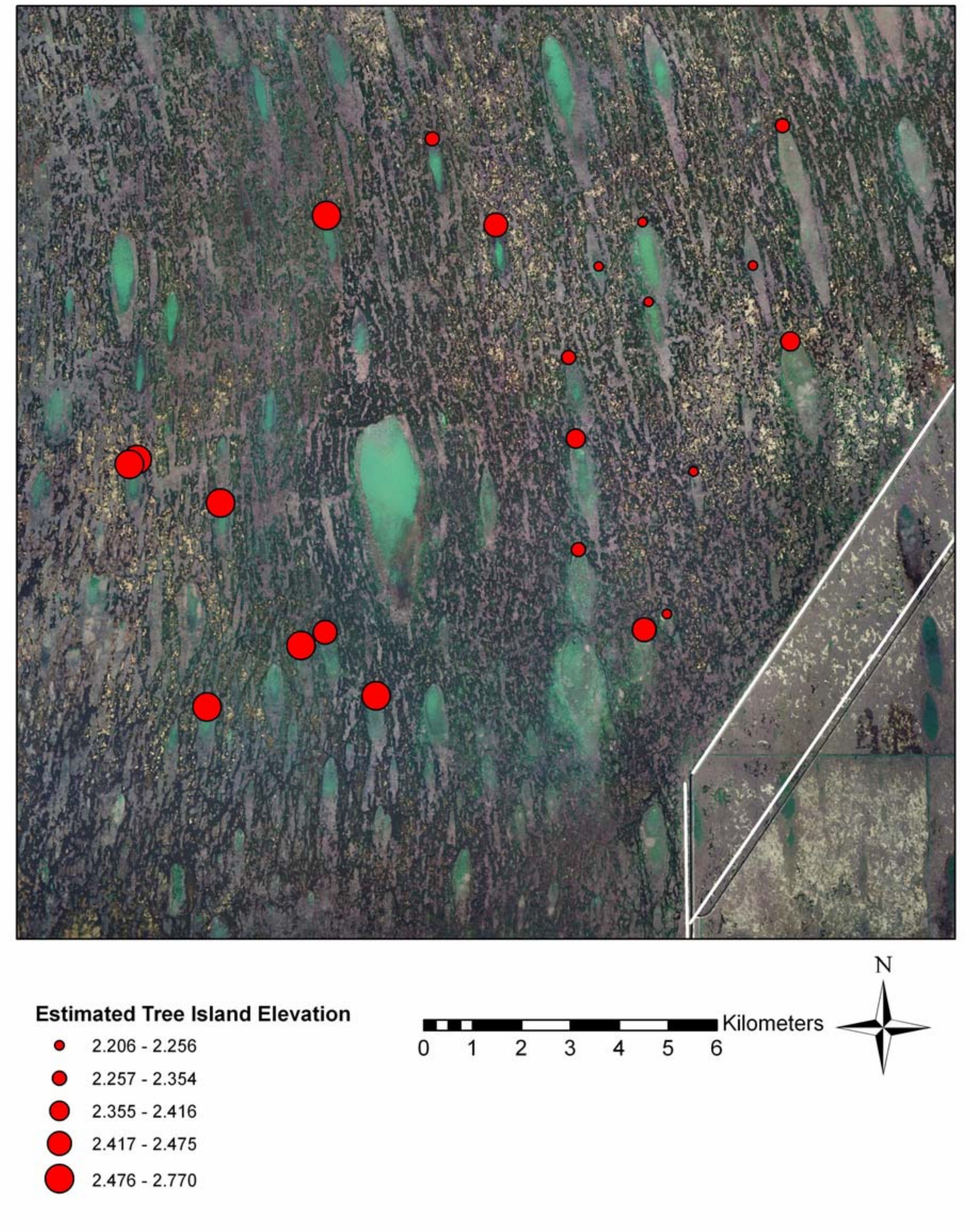

Figure 11. Estimates of tree island elevations (units: m; vertical datum: NAVD 88) in WCA 3A, calculated by subtracting water depth measured at a tree island, on a given date, from the predicted EDEN water surface for the grid cell in which that tree island is located, on the same date.

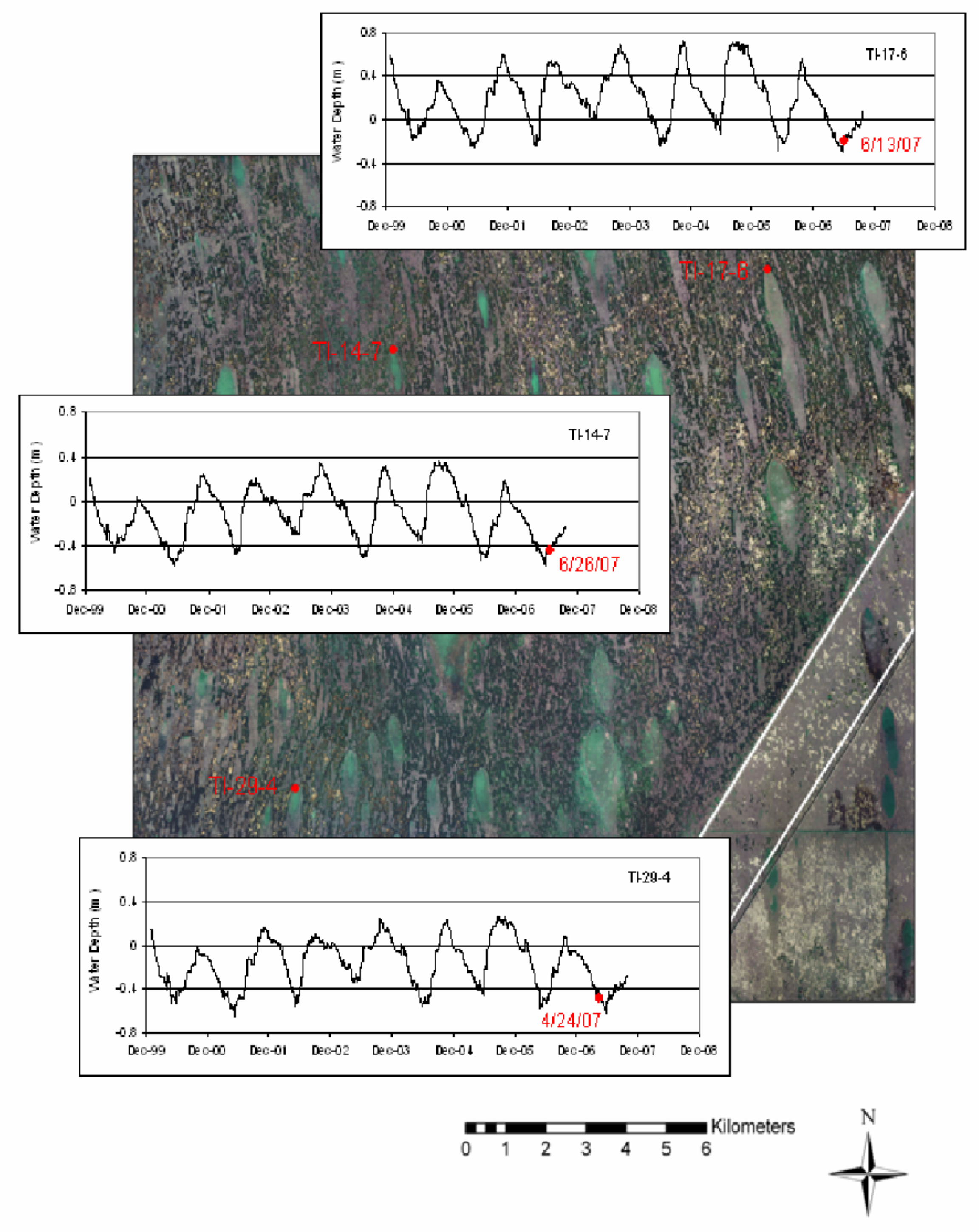

Figure 12. Example of water-depth time series for three tree islands in WCA 3A. Water depths and GPS locations were measured for each tree island on the dates indicated. Time series of water-surface elevation within the corresponding EDEN grid cells were then used to generate the time series of above or below-ground water depths for each tree island. Water depths are in meters relative to a ground-surface height of 0 for each island (water depth = predicted water stage – estimated tree island elevation).

Discussion and Conclusions

In this report we find that there are no statistically significant differences between model-predicted and field-observed water-stage data in WCA 3A South and 3B, and that the model is reliable by an overall RMSE prediction error of 3.3 cm. After removing spatiotemporal autocorrelation, Spearman's rank correlation analysis confirms that EDEN predictions show highly significant agreement with benchmark data in both WCA 3B and WCA 3A South. The RMSE for WCA 3A South (2.48 cm) is less than that of WCA 3B (7.76 cm).

Water surface at four of the benchmark locations used to validate the EDEN water-surface model had absolute errors of more than 5 cm, and three of them, including two over 10 cm, are located within WCA 3B. When a benchmark reports high interpolation errors, it is likely to be near boundaries. For Benchmark 15 (water-stage difference = -17.6 cm) in WCA 3B, there are no nearby water level gages (Figure 8), and the benchmark is close to L-30 Canal. While Benchmark 31 (water-stage difference = -11.1 cm) is close to Tamiami Canal and L-67 Canal. BM31 has almost twice the error of BM25 (water stage difference = -6.3 cm), however BM30 is very accurate. A closer look is needed to examine the underlying factors. We suspect that BM31 and BM25 are in corners of the canals, which might play a role. For BM15, the long interpolation of the adjacent canal might introduce the error. The field data in WCA 3B in August of 2007 were not collected by airboat due to the unusual dry field conditions. There was not a continuous water surface around the area of some of the bench marks. This may also have affected the surface provided by the EDEN surface model at that time. The authors agree if the opportunity arises during the 2008 wet season that the FAU hydrobiological field team revisit the benchmark network in area 3B and remeasure the surface.

ANOVA comparisons of the differences between observed and predicted surface elevations in the wet and dry seasons (Table 5), showed that the median overestimate during the dry season (2.15 cm) was significantly different from the median overestimate (0.7 cm) during the wet season. However, field data collection was for four months of wet season (June - September) and only two months of dry season (April and May). Among 91 observations, only eight were in WCA 3B, a single record for a benchmark site, and those eight observations were all taken in the wet season (August). Any interpretations in terms of model over- or under-estimation should be made with caution due to limited and unbalanced observations. This is also confirmed by the mean differences of -1.44cm (underestimate) and 0.28cm (overestimate) for the dry and wet seasons, respectively.

Missing or faulty gage data and boundary conditions have some localized impacts on the water surface in the EDEN network. The EDEN station network is operated by four agencies to meet their individual missions for operations, regulations, planning, and research. To meet their goals the stations are operated at different time lines and tolerances for missing gage record. Ideally, EDEN surface model requires no missing record and if there are missing records, they are estimated to produce the best quality modeled surface. However each agency has different guidelines and procedures on estimating missing record. For example, the USGS discourages estimating stage data and only estimate flow data, and removes data for periods when the water gage is dry. EDEN surfaces may be affected by these agency data management decisions. The verification of the model surface in this report uses a data set of measurements at the FDEP benchmarks from April-September 2007. In WCA 3A and 3B, the unoperational water gage stations at the time of these measurements were 6 (April), 6 (May), 9 (June), 11 (July), 5 (August), and 2 (September), respectively (Table D1 in Appendix D), which appear to have no effects. However system wide there were 90 stations not operating for short periods (Table D2 in Appendix D) that caused localized problems in the surfacing (Figure D1 and Table D3 in Appendix D). The user needs to take into account that there are local problems with the water surface caused by changing boundary conditions and missing or faulty gage data. Since the model input dataset for 2007 is provisional, with the inaccurate data removed from the dataset and model rerun, the over or under-estimate problems at Location A, C, D, E, and F (Figure D1 in Appendix D) are expected to be solved.

The water depth data that are derived using the method presented in this report are more accurate than those obtained by subtracting the ground DEM from the EDEN water surface, as discussed in Pearlstine *et al.* (2007), since the estimated site-specific ground elevation is more accurate than that from the regional 400 m resolution EDEN DEM grid (Jones and Price, 2007a, 2007b). Also, this method is much more cost-effective for individual sites. For a location, only one field water depth measurement is needed to build a continuous water depth hydrograph from 2000 to current. Moreover, a better digital ground elevation map could be created by combining ground elevation points derived from the thousands of water depth measurements available from researchers in the Everglades and the DEM data from the AHF system.

In summary, the model predicted water stage data are highly correlated to field-measured data before and after removing spatial and temporal autocorrelation, and there are no statistically significant differences between predicted and observed water-stage data in both WCA 3A South and 3B. Overall the model RMSE prediction error is 3.3 cm (2.48 cm for WCA 3A South and 7.76 cm for WCA 3B).

Users need to be cautious of some over- or under-estimate problems caused by missing or faulty gage data and boundary conditions (locations and dates identified in Appendix D; mainly due to provisional model input dataset of 2007; and confidence index maps in Pearlstine *et al.*, 2007). However, given the fact that the model is developed for such a large and complex area and across a long time period, the validation confirms that the EDEN water-surface model developed by Pearlstine *et al.* (2007) is a reliable and useful water stage and water depth estimation tool for support of ecological and biological assessments in the Everglades, Florida.

For future work, more field observations of dry and wet seasons and in another six benchmark sites in WCA 3A South are needed to fully evaluate the EDEN water-surface model. It is also desirable to obtain some field water-surface data in other water conservation areas. The model would be improved by closer examination of the causes of interpolated estimation errors at benchmarks 25, 30 and 31. Additionally, to obtain more accurate water-depth data, a better regional digital elevation map could be produced by subtracting available field water-depth measurements from model-predicted water stage in the Everglades.

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Appendices

Appendix A: Listing of EDEN Water Stage Gaging Stations

EDEN water-stage stations with updated UTM coordinate values are listed below in two tables, separated by marsh gages and canal gages. Marsh gages include marsh, marsh structure and river gages. Canal gages include canal and canal structure. Canal and marsh indicate stations located in uncontrolled regions, canal structure indicates a station located within a canal at a structure, usually with an associated station on the other side of the structure, marsh structure indicates a station located in the marsh at a structure, usually with an associated station on the other side of the structure. In both cases, the associated station does not have to be of the same type (canal or marsh).

Geographic coordinates (Latitude, Longitude) are in NAD83 datum. UTM coordinates are zone 17N, NAD83, meters. EDEN-funded water-level gaging stations are highlighted. Additional metadata for each station is provided at http://sofia.usgs.gov/eden .

Table A1. Marsh stations sorted by location. (Note: Tidal gages in the Gulf of Mexico basin were not used in the surface-water interpolation for the freshwater Everglades)

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
Big Cypress National Preserve							
BCA1	Marsh	BCNP	26°14'33"	-81°19'14"	467985.60	2902579.23	Yes
BCA10	Marsh	BCNP	25°42'49"	-81°01'19"	497798.55	2843968.89	Yes
BCA11	Marsh	BCNP	25°47'21"	-81°06'00"	489974.43	2852339.53	Yes
BCA12	Marsh	BCNP	26°11'29"	-81°05'12"	491340.70	2896882.12	Yes
BCA13	Marsh	BCNP	26°05'35"	-81°03'13"	494638.96	2885990.32	Yes
BCA14	Marsh	BCNP	26°02'40"	-81°18'00"	469987.92	2880640.29	Yes
BCA15	Marsh	SFWMD	26°02'23"	-81°01'36"	497332.16	2880083.11	Yes
BCA16	Marsh	SFWMD	26°03'24"	-81°09'20"	484439.83	2881968.62	Yes
BCA17	Marsh	SFWMD	26°12'18"	-81°10'05"	483210.67	2898397.49	Yes
BCA18	Marsh	SFWMD	26°12'24"	-80°58'59"	501692.78	2898571.30	Yes
BCA19	Marsh	SFWMD	25°47'35"	-81°12'08"	479726.72	2852781.94	Yes
BCA2	Marsh	BCNP	26°11'46"	-81°17'19"	471164.52	2897434.26	Yes
BCA20	Marsh	SFWMD	25°42'23"	-80°56'05"	506549.00	2843170.54	Yes
BCA3	Marsh	BCNP	26°09'24"	-81°13'18"	477845.59	2893052.76	Yes
BCA4	Marsh	BCNP	25°57'26"	-81°06'14"	489599.28	2870950.61	Yes
BCA5	Marsh	BCNP	25°58'06"	-80°55'35"	507368.80	2872179.04	Yes
BCA6	Marsh	BCNP	25°51'07"	-80°58'52"	501892.72	2859287.93	Yes
BCA7	Marsh	BCNP	25°53'12"	-81°15'44"	473732.23	2863159.23	Yes
BCA8	Marsh	BCNP	25°53'25"	-81°16'13"	472926.09	2863560.77	Yes
BCA9	Marsh	BCNP	25°46'42"	-80°54'44"	508801.02	2851138.96	Yes
EDEN_1	Marsh	USGS	25°51'38"	-80°53'42"	510520.53	2860245.60	Yes
EDEN_6	Marsh	USGS	26°03'55"	-80°54'14"	509613.26	2882916.52	Yes
L28_GAP	Marsh	SFWMD	26°07'28"	-80°59'00"	501666.20	2889465.50	Yes
LOOP1_H	Marsh structure	SFWMD	25°45'41"	-80°54'28"	509247.95	2849262.84	Yes
LOOP1_T	Marsh structure	SFWMD	25°45'40"	-80°54'28"	509247.97	2849232.08	Yes
LOOP2_H	Marsh structure	SFWMD	25°44'48"	-80°57'14"	504624.55	2847630.07	Yes
LOOP2_T	Marsh structure	SFWMD	25°44'48"	-80°57'15"	504596.69	2847630.06	Yes

Table A1 continued.

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
Everglades National Park							
A13	Marsh	ENP	25°29'50"	-80°42'45"	528893.78	2820037.51	Yes
C111_wetland_east_of_FIU_LTER_TSPH5	Marsh	USGS	25°17'40"	-80°31'12"	548320.95	2797638.29	Yes
CP	Marsh	ENP	25°13'39"	-80°42'14"	529825.32	2790171.73	Yes
CR2	Marsh	ENP	25°29'55"	-80°37'18"	538022.17	2820214.15	Yes
CR3	Marsh	ENP	25°29'48"	-80°39'46"	533891.05	2819987.72	Yes
CT27R	Marsh	ENP	25°18'03"	-80°29'19"	551478.18	2798357.45	Yes
CT50R	Marsh	ENP	25°18'46"	-80°31'15"	548229.80	2799668.15	Yes
CV5NR	Marsh	ENP	25°18'08"	-80°29'15"	551589.44	2798511.68	Yes
CY2	Marsh	ENP	25°19'39"	-80°40'58"	531925.53	2801249.97	Yes
CY3	Marsh	ENP	25°19'40"	-80°45'02"	525104.23	2801266.29	Yes
DO1	Marsh	ENP	25°22'19"	-80°41'27"	531103.44	2806169.62	Yes
DO2	Marsh	ENP	25°23'18"	-80°44'39"	525734.39	2807973.10	Yes
E112	Marsh	ENP	25°25'26"	-80°36'35"	539246.82	2811943.09	Yes
E146	Marsh	ENP	25°15'13"	-80°39'59"	533595.29	2793071.95	Yes
EDEN_3	Marsh	USGS	25°30'44"	-80°55'59"	506727.07	2821669.04	Yes
EPSW	Marsh	ENP	25°16'17"	-80°30'29"	549532.76	2795089.58	Yes
EVER4	Marsh	USGS	25°20'37"	-80°32'42"	545785.71	2803074.02	Yes
EVER6	Marsh	ENP	25°17'49"	-80°30'41"	549186.82	2797918.26	Yes
EVER7	Marsh	ENP	25°18'31"	-80°32'32"	546078.48	2799199.22	Yes
EVER8	Marsh	ENP	25°20'42"	-80°28'42"	552493.75	2803252.29	Yes
L31W	Marsh	ENP	25°26'13"	-80°35'23"	541253.62	2813394.85	Yes
MET-1	Marsh	USGS	25°43'13"	-80°35'18"	541295.94	2844771.35	Yes
NCL	Marsh	ENP	25°14'33"	-80°44'40"	525737.25	2791824.34	Yes
NE1	Marsh	USGS	25°41'31"	-80°38'04"	536678.99	2841620.09	Yes
NE2	Marsh	USGS	25°43'16"	-80°33'14"	544750.93	2844874.86	Yes
NE4	Marsh	USGS	25°38'29"	-80°39'10"	534854.15	2836016.61	Yes
NE5	Marsh	USGS	25°37'54"	-80°39'35"	534159.83	2834938.17	Yes
NESRS3	Marsh	SFWMD	25°44'26"	-80°30'16"	549702.86	2847045.87	No
NP201	Marsh	ENP	25°43'00"	-80°43'10"	528144.43	2844336.98	Yes
NP202	Marsh	ENP	25°39'43"	-80°42'31"	529244.56	2838279.40	Yes
NP203	Marsh	ENP	25°37'22"	-80°44'19"	526242.23	2833935.83	Yes
NP205	Marsh	ENP	25°41'19"	-80°50'52"	515273.99	2841209.02	Yes
NP206	Marsh	ENP	25°32'39"	-80°40'19"	532956.81	2825245.45	Yes
NP44	Marsh	ENP	25°26'00"	-80°43'13"	528126.95	2812961.02	Yes
NP46	Marsh	ENP	25°19'06"	-80°47'45"	520549.03	2800212.76	Yes
NP62	Marsh	ENP	25°26'18"	-80°46'58"	521841.46	2813502.99	Yes
NP67	Marsh	ENP	25°19'46"	-80°39'01"	535195.83	2801473.43	Yes
NP72	Marsh	ENP	25°23'41"	-80°42'11"	529868.22	2808689.13	Yes
NTS1	Marsh	ENP	25°26'12"	-80°35'34"	540946.47	2813363.15	Yes
NTS10	Marsh	ENP	25°27'37"	-80°36'18"	539709.76	2815974.08	Yes
NTS14	Marsh	ENP	25°24'59"	-80°38'19"	536343.94	2811104.39	Yes
NTS18	Marsh	ENP	25°29'02"	-80°33'59"	543582.91	2818600.78	Yes
OL	Marsh	ENP	25°15'49"	-80°36'47"	538962.92	2794193.70	Yes
OT	Marsh	ENP	25°34'43"	-80°57'52"	503570.92	2829019.52	Yes
P33	Marsh	ENP	25°36'50"	-80°42'08"	529897.73	2832959.20	Yes
P34	Marsh	ENP	25°36'27"	-80°56'27"	505940.80	2832219.45	Yes
P35	Marsh	ENP	25°27'35"	-80°51'52"	513627.54	2815860.64	Yes
P36	Marsh	ENP	25°31'38"	-80°47'44"	520541.55	2823344.19	Yes
P37	Marsh	ENP	25°17'03"	-80°41'18"	531377.57	2796450.17	Yes
P38	Marsh	ENP	25°22'10"	-80°50'00"	516767.66	2805867.27	Yes
R127	Marsh	ENP	25°21'11"	-80°36'22"	539633.08	2804100.35	Yes
R3110	Marsh	ENP	25°26'46"	-80°37'34"	537591.82	2814399.18	Yes
RG1	Marsh	ENP	25°34'53"	-80°36'28"	539390.95	2829384.86	Yes

Table A1 continued.

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
RG2	Marsh	ENP	25°32'33"	-80°36'21"	539599.02	2825078.93	Yes
SP	Marsh	ENP	25°23'19"	-80°47'50"	520397.44	2807994.71	Yes
Taylor_Slough_wetland_at_E146	Marsh	USGS	25°14'57"	-80°39'58"	533624.49	2792579.87	Yes
TMC	Marsh	ENP	25°36'50"	-80°52'20"	512829.22	2832931.80	Yes
TS2	Marsh	ENP	25°24'00"	-80°36'24"	539561.88	2809298.62	Yes
TSH	Marsh	ENP	25°18'39"	-80°37'50"	537186.36	2799417.86	Yes
S12A_T	Marsh structure	USGS	25°45'41"	-80°49'16"	517938.81	2849271.77	Yes
S12B_T	Marsh structure	USGS	25°45'42"	-80°46'10"	523119.86	2849310.58	Yes
S12C_T	Marsh structure	USGS	25°45'42"	-80°43'37"	527381.73	2849318.72	Yes
S12D_T	Marsh structure	USGS	25°45'42"	-80°40'55"	531894.31	2849328.84	Yes
S332B_T	Marsh structure	SFWMD	25°32'58"	-80°33'38"	544145.25	2825862.22	Yes
S332_T	Marsh structure	SFWMD	25°25'19"	-80°35'26"	541174.92	2811733.54	Yes
Water Conservation Area 1							
NORTH_CA1	Marsh	USGS	26°35'38"	-80°21'13"	564361.19	2941618.52	Yes
SITE_7	Marsh	USGS	26°31'11"	-80°20'49"	565066.87	2933407.44	Yes
SITE_8C	Marsh	USGS	26°30'01"	-80°13'21"	577479.30	2931322.94	Yes
SITE_8T	Marsh	USGS	26°29'59"	-80°14'05"	576261.65	2931254.09	Yes
SITE_9	Marsh	USGS	26°27'51"	-80°17'49"	570082.42	2927280.64	Yes
SOUTH_CA1	Marsh	USGS	26°25'29"	-80°20'26"	565757.42	2922888.94	Yes
WCA1ME	Marsh	SFWMD	26°30'39"	-80°18'36"	568753.21	2932442.20	Yes
Water Conservation Area 2A							
2A300	Marsh	SFWMD	26°14'47"	-80°24'29"	559116.94	2903105.37	No
EDEN_11	Marsh	USGS	26°22'58"	-80°27'35"	553893.80	2918188.10	Yes
SITE_17	Marsh	USGS	26°17'12"	-80°24'39"	558819.22	2907564.92	Yes
SITE_19	Marsh	USGS	26°16'56"	-80°18'22"	569277.05	2907124.53	Yes
WCA2E1	Marsh	SFWMD	26°21'07"	-80°21'10"	564579.11	2914822.32	No
WCA2E4	Marsh	SFWMD	26°18'35"	-80°21'23"	564242.08	2910144.28	No
WCA2F1	Marsh	SFWMD	26°21'36"	-80°22'11"	562884.01	2915706.13	No
WCA2F4	Marsh	SFWMD	26°19'02"	-80°23'05"	561409.97	2910961.15	No
WCA2RT	Marsh	SFWMD	26°19'48"	-80°30'35"	548928.32	2912322.94	No
WCA2U1	Marsh	SFWMD	26°14'29"	-80°21'21"	564335.21	2902576.49	No
WCA2U3	Marsh	SFWMD	26°17'17"	-80°24'39"	558818.52	2907718.74	No
S10A_T	Marsh structure	USGS	26°21'33"	-80°18'46"	568566.11	2915642.85	Yes
S10C_T	Marsh structure	USGS	26°22'16"	-80°21'09"	564596.17	2916945.24	Yes
S10D_T	Marsh structure	USGS	26°23'18"	-80°22'55"	561649.51	2918838.25	Yes
S11A_H	Marsh structure	USGS	26°10'37"	-80°26'54"	555127.07	2895396.64	Yes
S11B_H	Marsh structure	USGS	26°12'09"	-80°27'14"	554559.99	2898224.56	Yes
S11C_H	Marsh structure	USGS	26°13'47"	-80°27'35"	553964.64	2901236.98	Yes
S144_H	Marsh structure	SFWMD	26°13'06"	-80°23'52"	560157.83	2900002.92	No
S145_H	Marsh structure	SFWMD	26°13'19"	-80°21'57"	563346.98	2900418.07	No
S146_H	Marsh structure	SFWMD	26°13'32"	-80°20'01"	566563.70	2900834.14	No
Water Conservation Area 2B							
EDEN_13	Marsh	USGS	26°10'35"	-80°22'17"	562816.46	2895370.05	Yes
SITE_99	Marsh	USGS	26°08'14"	-80°22'01"	563281.73	2891034.49	Yes
S141_H	Marsh structure	SFWMD	26°09'02"	-80°26'32"	555750.30	2892476.69	No
S144_T	Marsh structure	SFWMD	26°13'05"	-80°23'52"	560157.97	2899972.15	No
S145_T	Marsh structure	SFWMD	26°13'18"	-80°21'57"	563347.13	2900387.30	No
S146_T	Marsh structure	SFWMD	26°13'31"	-80°20'00"	566591.60	2900803.52	No
Water Conservation Area 3A							
3A10	Marsh	SFWMD	26°16'46"	-80°44'23"	525986.11	2906657.28	No
3A11	Marsh	SFWMD	26°13'06"	-80°44'37"	525611.24	2899888.56	No
3A12	Marsh	SFWMD	26°10'09"	-80°40'32"	532423.10	2894458.68	No
3A-5	Marsh	USGS	26°03'24"	-80°42'19"	529481.03	2881992.65	Yes
3A9	Marsh	SFWMD	26°07'23"	-80°38'51"	535240.68	2889359.31	No

Table A1 continued.

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
3AN1W1	Marsh	SFWMD	26°11'17"	-80°44'24"	525978.68	2896536.09	Yes
3ANE	Marsh	SFWMD	26°16'44"	-80°36'17"	539464.80	2906629.89	Yes
3ANW	Marsh	SFWMD	26°16'00"	-80°46'49"	521939.44	2905234.65	Yes
3AS	Marsh	SFWMD	26°05'01"	-80°41'03"	531585.55	2884981.57	Yes
3AS3W1	Marsh	SFWMD	25°51'27"	-80°46'15"	522962.10	2859923.05	Yes
3ASW	Marsh	SFWMD	25°59'24"	-80°50'09"	516430.82	2874586.72	Yes
EDEN_12	Marsh	USGS	26°00'42"	-80°35'17"	541222.59	2877040.84	Yes
EDEN_14	Marsh	USGS	26°04'10"	-80°45'27"	524254.59	2883396.97	Yes
EDEN_4	Marsh	USGS	26°05'36"	-80°30'25"	549305.17	2886113.29	Yes
EDEN_5	Marsh	USGS	26°07'25"	-80°45'10"	524715.52	2889396.58	Yes
EDEN_8	Marsh	USGS	25°52'00"	-80°40'50"	532005.36	2860957.08	Yes
EDEN_9	Marsh	USGS	26°13'19"	-80°35'32"	540732.67	2900327.21	Yes
SITE_62	Marsh	USGS	26°10'29"	-80°45'04"	524871.31	2895057.28	Yes
SITE_63	Marsh	USGS	26°11'20"	-80°31'51"	546878.08	2896687.07	Yes
SITE_64	Marsh	USGS	25°58'32"	-80°40'09"	533115.99	2873018.65	Yes
SITE_65	Marsh	USGS	25°48'53"	-80°43'11"	528093.47	2855195.68	Yes
W11	Marsh	USGS	25°56'34"	-80°45'00"	525031.57	2869370.75	Yes
W14	Marsh	USGS	25°56'14"	-80°40'06"	533210.16	2868773.67	Yes
W15	Marsh	USGS	26°00'51"	-80°40'40"	532243.48	2877292.48	Yes
W18	Marsh	USGS	26°00'07"	-80°46'44"	522127.95	2875917.89	Yes
W2	Marsh	USGS	25°47'59"	-80°48'32"	519158.29	2853518.55	Yes
W5	Marsh	USGS	25°47'21"	-80°41'43"	530550.21	2852371.06	Yes
S11A_T	Marsh structure	USGS	26°10'37"	-80°26'57"	555043.79	2895396.28	Yes
S11B_T	Marsh structure	USGS	26°12'09"	-80°27'18"	554448.98	2898224.09	Yes
S11C_T	Marsh structure	USGS	26°13'46"	-80°27'39"	553853.78	2901205.76	Yes
S142_T	Marsh structure	SFWMD	26°09'36"	-80°26'47"	555329.37	2893520.88	No
S150_T (SFWMD)	Marsh structure	SFWMD	26°20'05"	-80°32'22"	545960.23	2912835.01	Yes
S150_T (USGS)	Marsh structure	USGS	26°20'05"	-80°32'22"	545960.23	2912835.01	No
S343A_H	Marsh structure	SFWMD	25°47'21"	-80°51'19"	514509.23	2852343.69	Yes
S343B_H	Marsh structure	SFWMD	25°46'42"	-80°50'38"	515652.45	2851145.31	Yes
S344_H	Marsh structure	SFWMD	25°55'08"	-80°50'11"	516385.06	2866711.57	Yes
Water Conservation Area 3B							
3BS1W1	Marsh	SFWMD	25°46'50"	-80°30'40"	549017.78	2851473.08	Yes
3B-SE	Marsh	SFWMD	25°47'17"	-80°29'58"	550184.38	2852308.04	No
EDEN_10	Marsh	USGS	25°47'07"	-80°37'02"	538377.06	2851960.83	Yes
EDEN_7	Marsh	USGS	25°57'08"	-80°29'55"	550198.51	2870488.89	Yes
SITE_69	Marsh	USGS	25°54'24"	-80°35'20"	541175.72	2865412.37	Yes
SITE_71	Marsh	USGS	25°53'05"	-80°33'24"	544411.25	2862992.67	Yes
SITE_76	Marsh	USGS	26°00'28"	-80°28'57"	551787.22	2876647.73	Yes
SRS1	Marsh	USGS	25°47'55"	-80°34'42"	542271.35	2853449.30	Yes
TI-8	Marsh	USGS	25°49'57"	-80°32'28"	545989.77	2857214.74	Yes
TI-9	Marsh	USGS	25°50'14"	-80°35'58"	540141.95	2857718.58	Yes
S9A_T	Marsh structure	SFWMD	26°03'41"	-80°26'38"	555625.88	2882600.90	Yes
Florida Bay (Tidal Rivers)							
Joe_Bay_2E	River	USGS	25°13'55"	-80°31'28"	547898.04	2790715.76	Yes
McCormick_Creek_at_mouth	River	USGS	25°10'04"	-80°43'54"	527040.62	2783552.68	Yes
Mud_Creek_at_mouth	River	USGS	25°12'12"	-80°35'00"	541976.49	2787527.86	Yes
Stillwater_Creek	River	USGS	25°13'42"	-80°29'11"	551732.60	2790329.99	Yes
Upstream_Taylor_River	River	USGS	25°12'42"	-80°38'52"	535481.65	2788432.09	Yes
Taylor_River_at_mouth	River	USGS	25°11'28"	-80°38'20"	536383.20	2786158.28	Yes
Trouth_Creek_at_mouth	River	USGS	25°12'54"	-80°32'00"	547009.25	2788836.29	Yes
West_Highway_Creek	River	USGS	25°14'34"	-80°26'49"	555699.07	2791945.27	Yes
Gulf of Mexico (Tidal Rivers)							
Bottle_Creek_at_Rookery_Branch	River	USGS	25°28'06"	-80°51'15"	514652.96	2816827.8	Yes

Table A1 continued.

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
Broad_River_near_the_Cutoff	River	USGS	25°30'06"	-81°04'36"	492287.91	2820513.2	Yes
Upstream_Broad_River	River	USGS	25°30'04.7"	-80°55'56"	506811.43	2820460.2	Yes
Chatham_River_near_the_Watson_Place	River	USGS	25°42'34"	-81°14'58"	474967.37	2843542.6	Yes
Harney_River	River	USGS	25°25'52.4"	-81°05'08.3"	491388.61	2812700.5	Yes
Lopez_River_Near_Lopez_Campsite	River	USGS	25°47'30"	-81°17'58"	469971.82	2852658.1	Yes
Lostmans_River_below_Second_Bay	River	USGS	25°33'21"	-81°09'52"	483473.78	2826506.9	Yes
Upstream_Lostmans_River	River	USGS	25°33'57"	-80°59'41"	500530.11	2827604.1	Yes
New_River_at_Sunday_Bay	River	USGS	25°47'52"	-81°15'19"	474401.14	2853325.5	Yes
North_River_Upstream_of_Cutoff	River	USGS	25°20'19"	-80°54'47"	508742.28	2802458.4	Yes
Upstream_North_River	River	USGS	25°21'29"	-80°54'00"	510026	2804598	Yes
Shark_River_Below_Gunboat_Island	River	USGS	25°22'31"	-81°02'12"	496303.9	2806516.3	Yes
Turner_River_nr_Chokoloskee_Island	River	USGS	25°49'44"	-81°20'29"	465777.31	2856790.2	Yes

Table A2. Canal stations sorted by location.

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
C111 Canal							
S18C_T	Canal structure	USGS	25°19'15"	-80°31'30"	547807.24	2800558.69	Yes
L28 Canal							
L28S1	Canal	SFWMD	26°05'38"	-80°50'34"	515721.92	2886090.99	Yes
L28S2	Canal	SFWMD	26°05'38"	-80°50'05"	516527.46	2886091.99	Yes
S140_H	Canal structure	SFWMD	26°10'18"	-80°49'40"	517210.49	2894706.47	Yes
S343A_T	Canal structure	SFWMD	25°47'20"	-80°51'20"	514481.41	2852312.90	Yes
S343B_T	Canal structure	SFWMD	25°46'41"	-80°50'39"	515624.64	2851114.51	Yes
L28 Interceptor Canal							
S190_T	Canal structure	SFWMD	26°16'60"	-80°58'04"	503216.95	2907062.23	Yes
L30 Canal							
S335_H	Canal structure	SFWMD	25°46'34"	-80°28'59"	551832.70	2850991.63	Yes
S335_T	Canal structure	SFWMD	25°46'32"	-80°28'59"	551832.95	2850930.10	Yes
S337_T	Canal structure	SFWMD	25°56'30"	-80°26'28"	555960.44	2869343.21	Yes
L31N Canal							
L31N_1	Canal	USGS	25°44'54"	-80°29'52"	550368.24	2847909.73	Yes
L31N_3	Canal	USGS	25°44'48"	-80°29'51"	550396.80	2847725.26	Yes
L31N_4	Canal	USGS	25°42'07"	-80°29'45"	550582.88	2842773.27	Yes
L31N_5	Canal	USGS	25°41'10"	-80°29'49"	550478.07	2841019.43	Yes
L31N_7	Canal	USGS	25°39'48"	-80°29'53"	550376.15	2838496.57	Yes
L31NN	Canal	SFWMD	25°44'47"	-80°29'51"	550396.92	2847694.50	Yes
L31NS	Canal	SFWMD	25°42'08"	-80°29'45"	550582.76	2842804.03	Yes
G211_H	Canal structure	SFWMD	25°39'36"	-80°29'52"	550405.43	2838127.53	Yes
G211_T	Canal structure	SFWMD	25°39'33"	-80°29'52"	550405.78	2838035.25	Yes
L31W Canal							
S175_H	Canal structure	SFWMD	25°25'05"	-80°34'26"	542852.37	2811308.15	Yes
S175_T	Canal structure	SFWMD	25°25'03"	-80°34'26"	542852.56	2811246.63	Yes
S332D_T	Canal structure	SFWMD	25°28'59"	-80°33'51"	543806.57	2818509.23	Yes
L38E Canal							
S141_T	Canal structure	SFWMD	26°09'03"	-80°26'33"	555722.40	2892507.33	No
S142_H	Canal structure	SFWMD	26°09'37"	-80°26'41"	555495.81	2893552.35	No
S143_T	Canal structure	SFWMD	26°10'34"	-80°26'54"	555127.46	2895304.34	No
S34_H	Canal structure	SFWMD	26°09'02"	-80°26'33"	555722.53	2892476.57	Yes
S7_T	Canal structure	SFWMD	26°20'07"	-80°32'12"	546237.21	2912897.53	Yes
L39 Canal							
S10A_H	Canal structure	USGS	26°21'36"	-80°18'45"	568593.34	2915735.29	Yes
S10C_H	Canal structure	USGS	26°22'18"	-80°21'09"	564595.86	2917006.77	Yes
S10D_H	Canal structure	USGS	26°23'19"	-80°22'54"	561677.07	2918869.15	Yes
S39_H	Canal structure	SFWMD	26°21'21"	-80°17'53"	570037.05	2915281.57	Yes
L40 Canal							
G300_T	Canal structure	SFWMD	26°40'37"	-80°21'48"	563347.29	2950812.70	Yes
L6 Canal							
G339_H	Canal structure	SFWMD	26°27'48"	-80°27'09"	554576.30	2927112.93	Yes
G339_T	Canal structure	SFWMD	26°27'48"	-80°27'10"	554548.61	2927112.81	Yes
L7 Canal							
G301_T	Canal structure	SFWMD	26°40'31"	-80°22'49"	561662.20	2950619.81	Yes
Miami Canal							
S151_H	Canal structure	SFWMD	26°00'42"	-80°30'36"	549033.58	2877067.80	Yes
S151_T	Canal structure	SFWMD	26°00'40"	-80°30'35"	549061.61	2877006.38	Yes
S31_H	Canal structure	SFWMD	25°56'33"	-80°26'26"	556015.68	2869435.74	Yes
S339_H	Canal structure	SFWMD	26°13'04"	-80°41'27"	530883.50	2899838.53	Yes
S339_T	Canal structure	SFWMD	26°13'01"	-80°41'25"	530939.22	2899746.37	Yes
S340_H	Canal structure	SFWMD	26°07'09"	-80°36'48"	538657.75	2888938.33	Yes
S340_T	Canal structure	SFWMD	26°07'06"	-80°36'45"	538741.34	2888846.29	Yes

Table A2 continued.

Station name	Type of station	Operating agency	Latitude	Longitude	UTM easting	UTM northing	Real time data daily
S8_T	Canal structure	USGS	26°19'52"	-80°46'27"	522537.17	2912372.84	Yes
North Feeder Canal							
S190_H	Canal structure	SFWMD	26°17'03"	-80°58'05"	503189.19	2907154.51	Yes
Pennsuco Wetlands							
NWWF	Canal	USGS	25°53'28"	-80°25'13"	558071.25	2863753.46	Yes
S380_H	Canal structure	SFWMD	25°45'41"	-80°26'54"	555321.10	2849375.36	Yes
Tamiami Canal							
G119_H	Canal structure	SFWMD	25°45'40"	-80°28'39"	552396.34	2849332.68	No
G119_T	Canal structure	SFWMD	25°45'40"	-80°28'37"	552452.05	2849332.90	No
S12A_H	Canal structure	USGS	25°45'44"	-80°49'16"	517938.69	2849364.06	Yes
S12B_H	Canal structure	USGS	25°45'44"	-80°46'10"	523119.75	2849372.10	Yes
S12C_H	Canal structure	USGS	25°45'44"	-80°43'37"	527381.60	2849380.24	Yes
S12D_H	Canal structure	USGS	25°45'44"	-80°40'54"	531922.02	2849390.43	Yes
S333_H	Canal structure	SFWMD	25°45'43"	-80°40'27"	532674.19	2849361.50	Yes
S333_T	Canal structure	SFWMD	25°45'42"	-80°40'23"	532785.69	2849331.02	Yes
S334_H	Canal structure	SFWMD	25°45'41"	-80°30'10"	549861.33	2849353.64	Yes
S334_T	Canal structure	SFWMD	25°45'41"	-80°30'05"	550000.61	2849354.16	Yes
S336_H	Canal structure	SFWMD	25°45'40"	-80°29'50"	550418.56	2849324.99	Yes
S336_T	Canal structure	SFWMD	25°45'40"	-80°29'48"	550474.28	2849325.20	Yes
S344_T	Canal structure	SFWMD	25°55'08"	-80°50'12"	516357.24	2866711.54	Yes
Water Conservation Area 3A							
S140_T	Canal structure	SFWMD	26°10'18"	-80°49'38"	517266.00	2894706.55	Yes

Appendix B: FDEP Benchmark Network

Benchmarks	Benchmark ID	GPS heights (Meters; NAVD 88)	Latitude - north (Deg. Min. Sec.; NAD 83)	Longitude - west (Deg. Min. Sec.; NAD 83)	UTM easting (X; NAD 83)	UTM northing (Y; NAD 83)
WCA3-1	1	2.687	26 12 23.47840	80 31 20.44359	547719.04484	2898643.01257
WCA3-2	2	2.908	26 07 24.87358	80 46 54.29521	521819.18063	2889387.51430
WCA3-3	3	2.749	26 07 00.55238	80 44 29.67677	525836.79230	2888646.66877
WCA3-4	4	2.691	26 06 39.53869	80 40 47.05515	532021.00065	2888013.98567
WCA3-5	5	2.783	26 04 29.60445	80 46 52.02552	521891.32523	2883995.85521
WCA3-6	6	2.559	26 02 48.89673	80 45 07.32926	524805.84131	2880903.07605
WCA3-7	7	2.628	26 01 58.76849	80 46 51.49907	521913.71824	2879355.77479
WCA3-8	8	2.63	26 01 37.88826	80 40 02.51564	533281.78344	2878737.46822
WCA3-9	9	2.584	25 59 49.38097	80 46 50.21436	521956.12071	2875375.56990
WCA3-10	10	2.426	25 58 42.45927	80 45 22.57397	524396.32186	2873321.26356
WCA3-11	11	2.537	25 57 04.91056	80 48 40.94421	518885.13782	2870311.33102
WCA3-12	12	2.496	25 57 02.26354	80 41 27.46044	530940.91185	2870252.84617
WCA3-13	13	1.933	25 55 24.03405	80 32 20.79123	546155.10040	2867275.76148
WCA3-14	14	2.491	25 54 22.78606	80 43 46.69194	527078.78298	2865338.34798
WCA3-15	15	1.744	25 54 06.77373	80 29 33.14752	550827.84051	2864916.29087
WCA3-16	16	2.472	25 53 15.44034	80 49 10.55824	518071.17251	2863251.20348
WCA3-17	17	2.422	25 52 59.02067	80 40 14.34800	532993.05703	2862775.08341
WCA3-18	18	1.881	25 52 02.67706	80 34 27.89479	542639.49665	2861069.56073
WCA3-19	19	2.46	25 51 00.71368	80 46 55.32644	521841.05300	2859112.49996
WCA3-20	20	2.449	25 50 38.15244	80 43 35.41730	527406.87158	2858428.88450
WCA3-21	21	1.699	25 50 33.47625	80 32 58.90338	545125.63728	2858333.81554
WCA3-22	22	2.394	25 50 12.97443	80 40 46.73895	532104.11632	2857664.95992
WCA3-23	23	2.488	25 49 59.89101	80 49 48.96207	517010.40004	2857234.39155
WCA3-24	24	1.863	25 49 04.87458	80 36 28.34955	539303.41170	2855589.64274
WCA3-25	25	1.62	25 48 05.00805	80 30 51.10269	548700.05669	2853779.31351
WCA3-26	26	2.362	25 47 37.64770	80 42 25.69232	529360.10575	2852880.47156
WCA3-27	27	2.369	25 47 34.94972	80 44 39.11045	525644.91066	2852789.78566
WCA3-28	28	2.381	25 47 24.86396	80 49 49.99294	516987.77809	2852465.51025
WCA3-29	29	2.385	25 47 16.01073	80 47 14.47342	521319.23715	2852199.48139
WCA3-30	30	1.731	25 47 07.99785	80 34 06.91634	543253.04790	2852006.59840
WCA3-31	31	1.796	25 46 36.23760	80 38 16.84874	536295.06957	2851008.67021

Appendix C: Data Transformation for Normalization of Variables

Transformation method	Region	Variable	Statistic (Shapiro-Wilk)	Normality test p-value (Shapiro-Wilk)
Square root	WCA 3A South, 3B	Observed_Stage	0.9004	<0.0001
		Predicted_Stage	0.8820	<0.0001
		Difference_Stage	0.9592	0.088 [a]
	WCA 3A South	Observed_Stage	0.8534	<0.0001
		Predicted_Stage	0.8472	<0.0001
Logarithmic	WCA 3A South, 3B	Observed_Stage	0.8869	<0.0001
		Predicted_Stage	0.8620	<0.0001
		Difference_Stage	0.8875	0.0002
	WCA 3A South	Observed_Stage	0.8656	<0.0001
		Predicted_Stage	0.8599	<0.0001
Inverse	WCA 3A South, 3B	Observed_Stage	0.8457	<0.0001
		Predicted_Stage	0.8042	<0.0001
		Difference_Stage	0.7640	<0.0001
	WCA 3A South	Observed_Stage	0.8884	<0.0001
		Predicted_Stage	0.8838	<0.0001

[a] This is the only variable that follows a normal distribution after data transformation. However, only 49 observations out of 91 have square root values. This method is not appropriate.

Appendix D: Missing Gage Data and Boundary Conditions

Table D1. Missing gage data in WCA 3A South and 3B.

Month	Number of gages with missing data
April	6
May	6
June	9
July	11
August	5
September	2

Table D2. Missing gage data in the EDEN network (4/1/2007 - 9/30/2007; 183 days in total).

Station	Agency	Days of missing data	Percent of days of missing data (%)
2A300	SFWMD	67	36.6
3A10	SFWMD	62	33.9
3A11	SFWMD	183	100.0
3A12	SFWMD	118	64.5
3A9	SFWMD	114	62.3
3AN1W1	SFWMD	9	4.9
3ANW	SFWMD	61	33.3
3AS	SFWMD	2	1.1
3AS3W1	SFWMD	37	20.2
3B-SE	SFWMD	183	100.0
3BS1W1	SFWMD	9	4.9
A13	ENP	47	25.7
BCA11	ENP	1	0.5
BCA18	SFWMD	92	50.3
BCA2	ENP	45	24.6
C111_WETLAND	USGS	58	31.7
CY3	ENP	6	3.3
DO2	ENP	11	6
E146	ENP	19	10.4
EDEN_11	USGS	22	12
EDEN_5	USGS	5	2.7
EPSW	ENP	178	97.3
G119_H	SFWMD	183	100.0
G119_T	SFWMD	183	100.0
JOEBAY2E	USGS	5	2.7
L28_GAP	SFWMD	5	2.7
L28S1	SFWMD	5	2.7
L28S2	SFWMD	5	2.7
L31NN	SFWMD	9	4.9
L31N_3	USGS	15	8.2
L31N_7	USGS	127	69.4
L31W	ENP	17	9.3
LOOP1_H	SFWMD	150	82
LOOP1_T	SFWMD	150	82
LOOP2_H	SFWMD	150	82
LOOP2_T	SFWMD	150	82
MUD	USGS	4	2.2
NE1	USGS	13	7.1
NE4	USGS	4	2.2
NESRS3	SFWMD	183	100.0

Table D2 continued.

Station	Agency	Days of missing data	Percent of days of missing data (%)
NTS1	ENP	3	1.6
OL	ENP	21	11.5
OT	ENP	134	73.2
RG1	ENP	39	21.3
S10A_DN	USGS	12	6.6
S10A_UP	USGS	26	14.2
S10C_DN	USGS	6	3.3
S10C_UP	USGS	4	2.2
S10D_DN	USGS	34	18.6
S10D_UP	USGS	2	1.1
S11A_UP	USGS	2	1.1
S11C_DN	USGS	3	1.6
S11C_UP	USGS	3	1.6
S141_H	SFWMD	183	100.0
S141_T	SFWMD	183	100.0
S142_H	SFWMD	183	100.0
S142_T	SFWMD	183	100.0
S143_T	SFWMD	183	100.0
S144_H	SFWMD	183	100.0
S144_T	SFWMD	183	100.0
S145_H	SFWMD	40	21.9
S145_T	SFWMD	40	21.9
S146_H	SFWMD	60	32.8
S146_T	SFWMD	60	32.8
S150_DN	SFWMD	177	96.7
S151_H	SFWMD	1	0.5
S151_T	SFWMD	2	1.1
S333_H	SFWMD	3	1.6
S333_T	SFWMD	3	1.6
S335_H	SFWMD	1	0.5
S340_H	SFWMD	15	8.2
S340_T	SFWMD	15	8.2
S344_H	SFWMD	126	68.9
S344_T	SFWMD	126	68.9
S8_DN	USGS	17	9.3
SITE_65	USGS	4	2.2
SITE_76	USGS	53	29
SITE_8C	USGS	2	1.1
TAYLORSLOUGH	USGS	57	31.1
TS2	ENP	183	100.0
W15	USGS	77	42.1

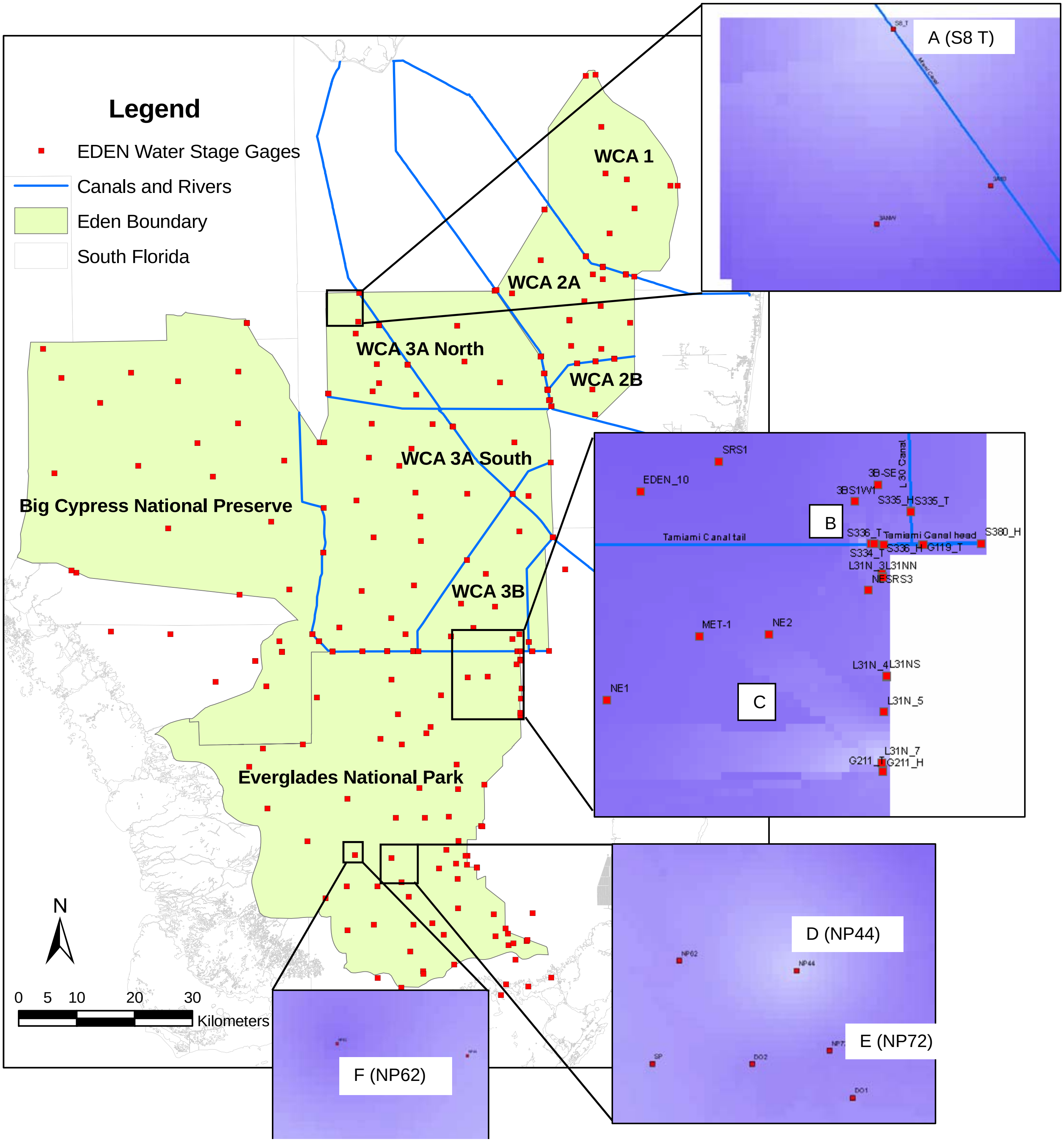
Table D2 continued.

Station	Agency	Days of missing data	Percent of days of missing data (%)
W18	USGS	107	58.5
WCA1ME	SFWMD	2	1.1
WCA2E1	SFWMD	183	100.0
WCA2E4	SFWMD	183	100.0
WCA2F1	SFWMD	183	100.0
WCA2F4	SFWMD	183	100.0
WCA2RT	SFWMD	183	100.0
WCA2U1	SFWMD	183	100.0
WCA2U3	SFWMD	183	100.0

Table D3. Missing or faulty gage data and boundary conditions in the EDEN network

Location	Date	Problem	Possible reason
A (Gage S8_T)	5/15/2007	under-estimate	Inconsistent gage readings (daily medians for those seven days range from -41.2 cm to -42.0 cm; average of other available 10-day daily medians in May 2007: 219.07 cm)
	5/22/2007	under-estimate	
	5/24/2007	under-estimate	
	5/26/2007	under-estimate	
	5/27/2007	under-estimate	
	5/28/2007	under-estimate	
	5/29/2007	under-estimate	
B	1/1/2005 - 9/30/2007	under-estimate	Boundary conditions
C	6/15/2007	under-estimate	Inconsistent gage readings (no missing data for nearby gages G211_H and G211_T; for gage L31N_7, daily medians for those nine days: -47.61 cm; no data for other days in June, July – September; average of available daily medians in May 2007: 94.7 cm)
	6/16/2007	under-estimate	
	6/17/2007	under-estimate	
	6/18/2007	under-estimate	
	6/19/2007	under-estimate	
	6/20/2007	under-estimate	
	6/21/2007	under-estimate	
	6/22/2007	under-estimate	
	6/27/2007	under-estimate	
D (Gage NP44)	7/5/2007	under-estimate	Inconsistent gage readings (daily median: -61.42 cm for 7/5/2007; average of other 30-day daily medians in July 2007: 92.96 cm)
E (Gage NP72)	9/27/2007	under-estimate	Inconsistent gage readings (daily medians for those four days: -45.72 cm; average of other 26-day daily medians in September 2007: 67.72 cm)
	9/28/2007	under-estimate	
	9/29/2007	under-estimate	
	9/30/2007	under-estimate	
F (Gage NP62)	1/25/2007	over-estimate	Inconsistent gage readings (daily median for 1/25/2007: 133.37 cm; average of other available 15-day daily medians in January 2007: 31.4 cm)

Figure D1. Missing or faulty gage data and boundary conditions in the EDEN network[a]



[a] Those identified errors except Location B are unusual due to the effects of provisional faulty gage data of 2007 (Details in Table C3).