Design of a Spreader Swale System for Restoration of the South Florida Ecosystem

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ABSTRACT

Restoration of the South Florida ecosystem is a major task for the US Army Corps of Engineers and the South Florida Water Management District. The objective of the task is to redistribute the available water among the people, the agriculture interests, and the ecosystem. One aspect of this redistribution is an effect to provide a broad distribution of surface water entry locations into the bays along the east coast (Biscayne Bay, Manatee Bay, and Barnes Sound). In an effort to restore natural wetlands, several structures, management plans, and scenarios are considered. One of the plans releases fresh water from the existing canals through a system of shallow spreader swales throughout the eastern and southeastern coastal areas of South Florida. The spreader swale system consists of a delivery canal and shallow swales where water flows is transformed from channel flow to a more natural overland sheet flow. The spreader swale system model includes 1-D canal network routing, 2-D overland flow, 3-D subsurface flow, and flow through the interface of any two sub-domain of the spreader system. The physics-based watershed model, WASH123D, was used to simulate hydrologic process in South Florida's complex watersheds. These watersheds are characterized by flat terrain with strong surface water and groundwater interactions. The paper presents an example of a spreader swale system and demonstrates the flexibility and efficiency of the model as applied to a project small-scale problem.

1. BACKGROUND

Restoration of the South Florida ecosystem is a major task for the US Army Corps of Engineers and the South Florida Water Management District. The objective of the task is to redistribute the available water among the people, the agriculture interests, and the ecosystem. The Biscayne Bay Coastal Wetlands (BBCW) Project is one more than 60 restoration projects that comprise the Comprehensive Everglades Restoration Plan (CERP). The goal of the BBCW Project is to restore or enhance freshwater wetlands, tidal wetlands, and near shore bay habitat. Biscayne Bay relies on substantial amounts of distributed freshwater from the South Florida watershed to sustain its estuarine ecosystem. The distribution of water, its timing, quality and quantity, have all been changed over the last 100 years by a combination of water resources development, agriculture, and urbanization (Davis, 1994). Current restoration efforts in southern Florida are examining alternative water management plans that could change the quantity and the timing of freshwater delivery to the bay by restoring coastal wetlands along the western shoreline of Biscayne Bay. The BBCW Project evaluates a number of alternatives to determine the best restoration plan to restore the bay waters. One common feature among these alternatives is to use a spreader swale system to redistribute available surface water to Biscayne Bay, Manatee Bay, and Barnes Sound. This paper will describe how this spreader swale system can be modeled and will illustrate the modeling approach with an example.

2. SPREADER SWALE SYSTEM

A typical spreader swale system consists of a delivery canal, a spreader canal, and a storm water treatment area (STA) (Figure 1). The system involves 1-D canal flow routing, 2-D overland flow routing, 3-D subsurface flow, and surface/sub-surface flow interaction (1-D/2-D, 1-D/3-D, and 2-D/3-D) within the spreader system. The coupled 1-D/2-D/3-D model of spreader system was developed and utilizing the WASH123D numerical code (Yeh et al, 2006) to simulate hydrologic processes of spreader canal. The WASH123D is a first-principal, physics-based model that conceptualizes a watershed system as a combination of 1-D canal networks, 2-D overland regimes, and 3-D subsurface media.

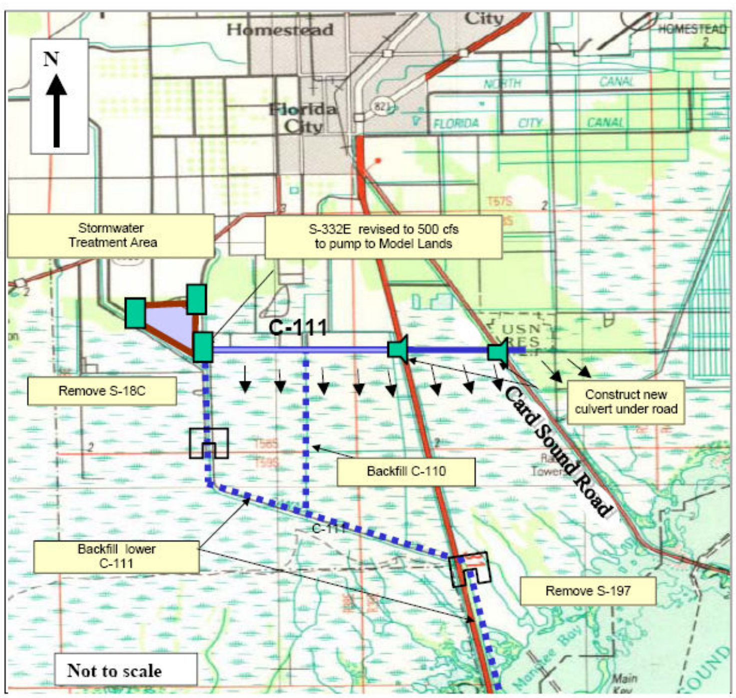

FIGURE 1. A typical spreader swale system

3. COUPLED 1-D/2-D/3-D MODEL

Topographic data from the BBCW Project was used to identify model boundaries and existing hydraulic impediments, such as US Highway 1 and Card Sound Road. In addition to these existing features, the hydraulic structures associated with the spreader system were used to construct the discretized domain of interest. For this model a delivery canal was placed in the domain to distribute water originating at the western boundary. Downstream of the delivery canal, a STA was incorporated into the model domain to simulate the surface impoundments required to regulate flow to the spreader canal. East of the STA, a 6.5 mile spreader canal was incorporated into the mesh to distribute flow from the STA to the adjacent overland area. The 2-D mesh used to model the overland domain covered an area of approximately 208 square miles and was discretized with 7,276 triangular elements and 3,751 nodes. The 3-D mesh used to model the subsurface geology was composed of three material layers (Figure 2). Each material layer has two vertical elements. The top material layer represents land uses (wetland, cropland, rangeland, urban, and canal bottom) of model domain. The middle material layer represents the Miami Oolite formation. The bottom material layer represents the Fort Thompson Formation. The 3-D mesh was generated based on the geologic conceptual model developed for the BBCW Project (Cheng, 2006). The 3-D domain contains 43,656 elements and 26,257 nodes. The delivery canal has 6 elements and 7 nodes. The spreader canal has 22 elements and 24 nodes. The bottom width of the spreader canal is 50 ft with a trapezoidal cross section and 1 to 4 (H:V) side slopes. The north bank of spreader canal is 0.5 ft higher than south bank. This setup allows water to flow to the south when the canal is flooded. Figure 3 shows a graphical representation of the boundaries and surface features included in the model.

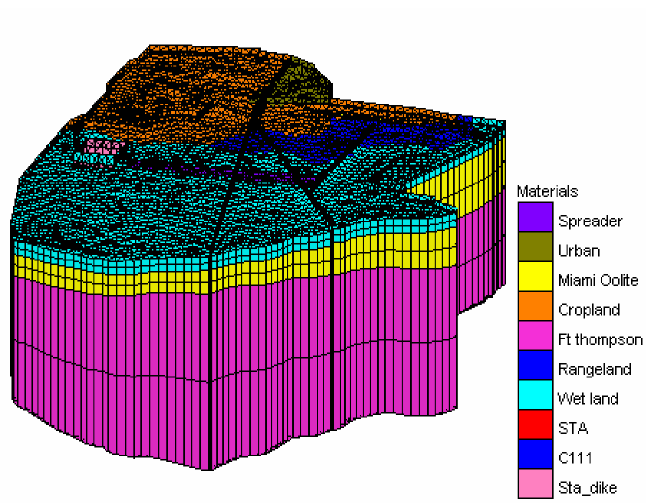

FIGURE 2. Oblique view of 3-D mesh

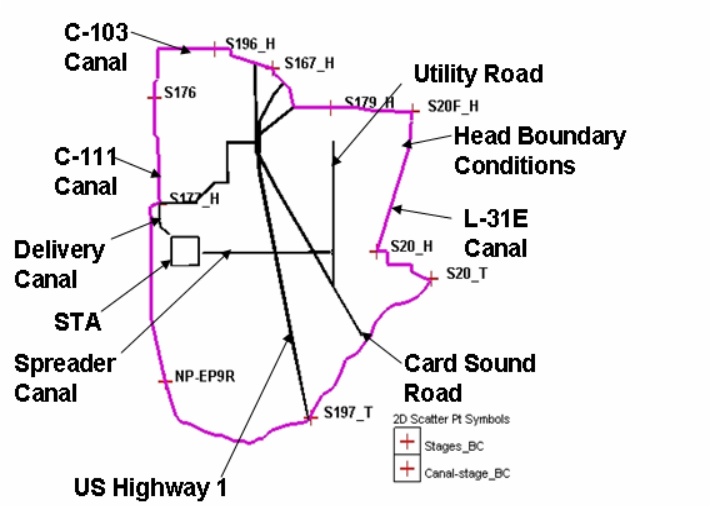

FIGURE 3. Spreader swale systems

4. SIMULATION OF SPREADER SWALE SYSTEM

The model parameters used in the simulation are provided in Table 1. These values were obtained from the calibration and validation of the Biscayne Bay Coastal Wetland Model (Cheng, 2006). The C-103 and C-111 canals were used as the north and west boundary. The L-31E canal was used as the east boundary. Observed head data collected at structures along these canals was used to assign boundary conditions for the simulation. The south boundary used the interpolated the heads at structures S20_T, S197_T, and NP_EP9R. The spreader swale system is designed to pump water from the delivery canal into STA. The STA distributes water into spreader canal by pumping or operating gates. Water flows into overland area when the stage of the spreader canal is higher than the south bank of the canal. To demonstrate how the spreader swale system works, four simulations were made.

1. Baseline: This simulation represents the existing conditions and serves as a basis of comparison to other cases. No water is distributed into the spreader canal system.
2. Scenario 1 (S1): The delivery canal pumps 200 cfs into STA and the STA distributes 200 cfs of water into the spreader canal.
3. Scenario 2 (S2): Same as Scenario 1 except the portion of utility road near the dead end of the canal was removed.
4. Scenario 3 (S3): Same as Scenario 1 except the bottom width of spreader canal was increased to 100 ft.

The model simulation time was the one month period between May 1 and May 31, 1995. The run time of the coupled 1-D/2-D/3-D model was about 9 hours in 12-processors of Cray XD1 system.

TABLE 1. Values of model parameters used for simulation

Material Type	K_h (ft/hr)	K_v (ft/hr)	**Overland Manning's Roughness**
Miami Oolite	1000	100	Not applicable
Ft. Thompson	800	80	Not applicable
Wetland	0.10	0.01	0.05
Cropland	0.10	0.01	0.15
Rangeland	0.10	0.01	0.10
Urban Area	0.10	0.01	0.01
Canal Bottom	250	25	0.035

The computed surface and sub-surface water levels differ for each simulation. Therefore, the simulation results are shown two parts, surface water and groundwater. The color shaded contours shown in Figures 4-7 represent the depth of surface water at the simulation time = 10 days. These water depth contours are shown in feet above ground surface.

The results of the baseline simulation shown in Figure 4 indicate that water is ponding south of the spreader swale system, primarily between US Highway 1 and Card Sound Road at end of 10 days. These ponded areas are the result of upland subsurface flow seeping to the overland area in the low lying area south of the spreader canal. Figure 5 shows that the aerial extent of the ponded area has increase as a result of the pumping introduced in simulation S1. The most obvious change from Figure 4 to Figure 5 is the area of additional ponding along the section of the spreader canal west of US Highway 1 and east of the STA. In order to increase wetted areas in east side of Card Sound Road, the lower parts of the utility road were removed. Figure 6 shows the results of this simulation (S2) where the wetted area has moved further southeast. Figure 7 shows the results of simulation S3 where the bottom width of spreader canal was increased from 50 ft to 100 ft. In this simulation the pattern of the ponding areas is similar to those in S1, indicating that the increased bottom width of the spreader canal does not significantly increase the overland flow south of the canal.

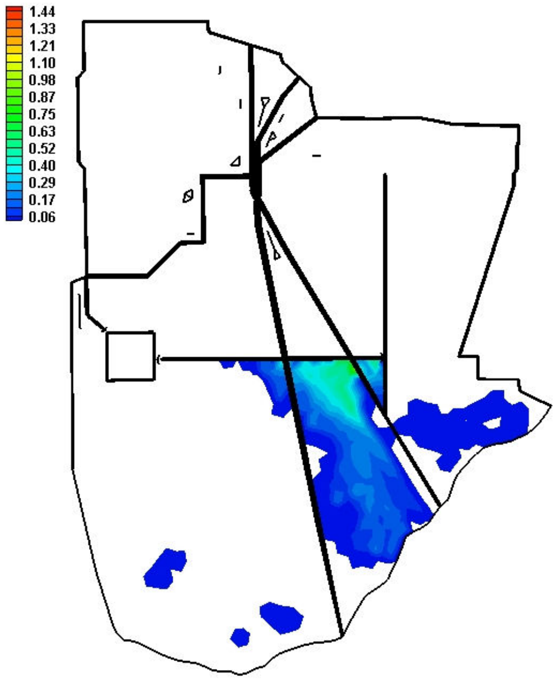

FIGURE 4. Water depth contours (Baseline)

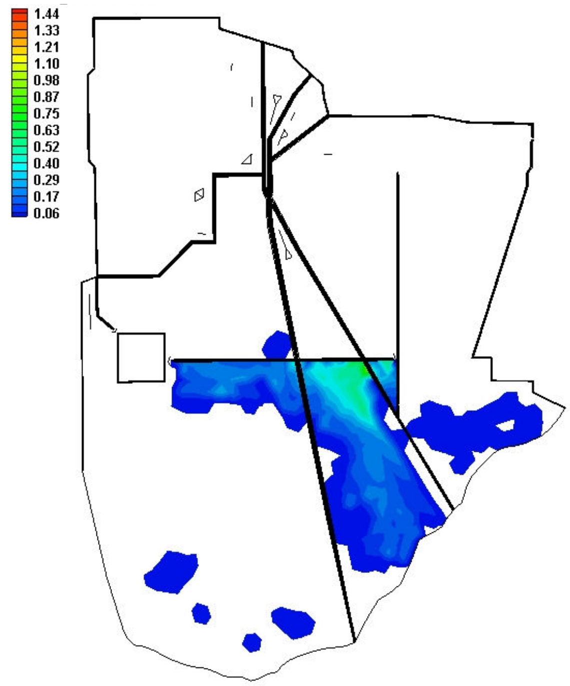

FIGURE 5. Water depth contours (S1)

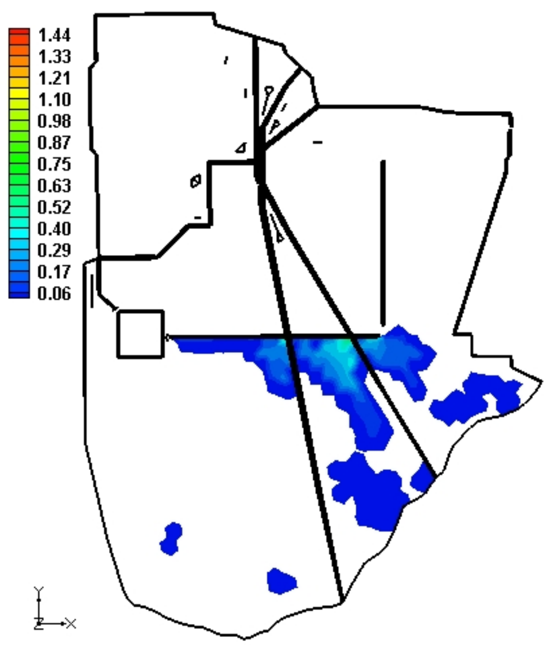

FIGURE 6. Water depth contours (S2)

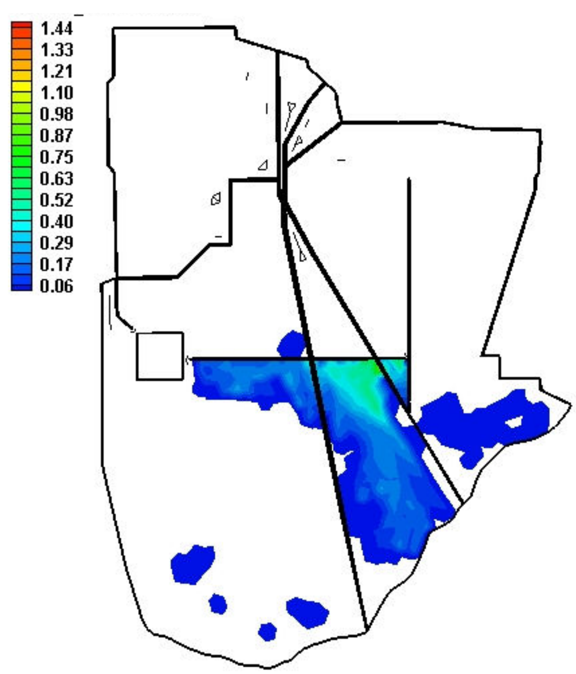

FIGURE 7. Water depth contours (S3)

To compare the impact of the different spreader configurations on groundwater, the computed total head at seven selected locations (Figure 8) was shown in Figures 9 through 14.

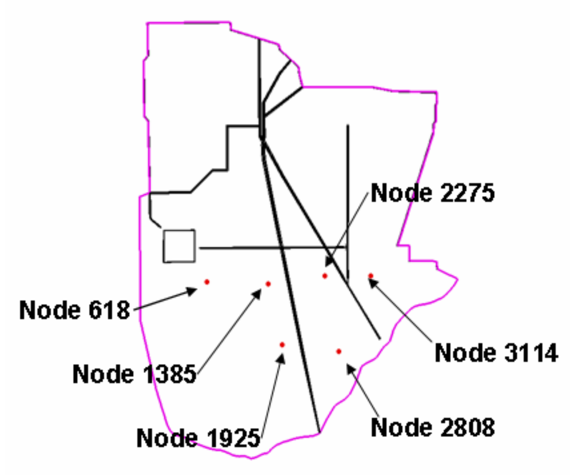

FIGURE 8. Groundwater node locations

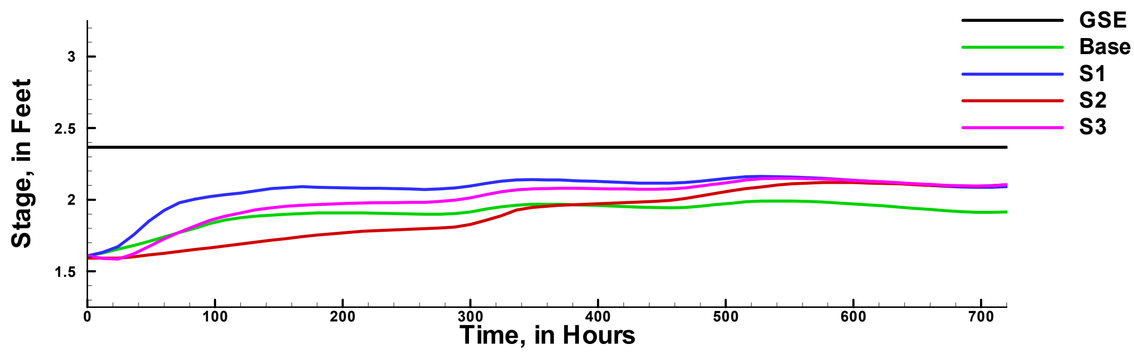

FIGURE 9. Water surface elevations at the node 618

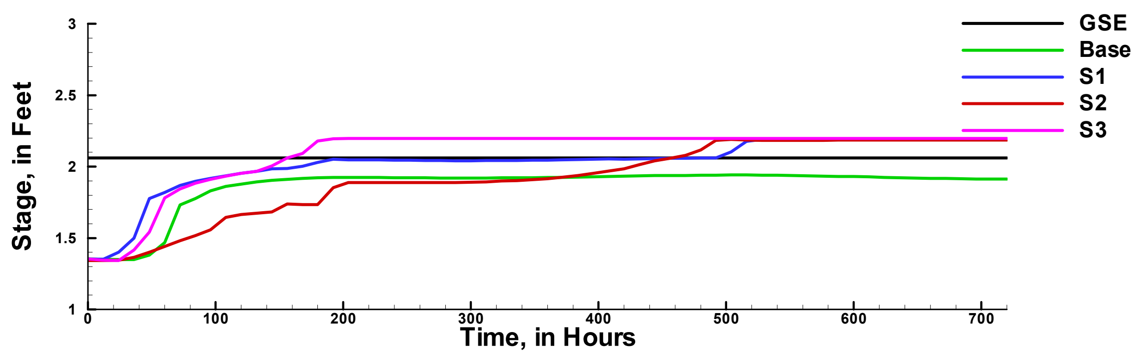

FIGURE 10. Water surface elevations at the node 1,385

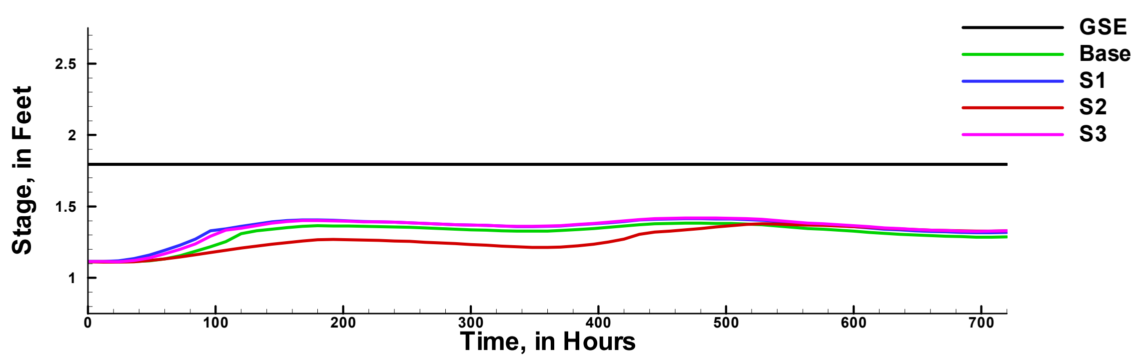

FIGURE 11. Water surface elevations at the node 1,925

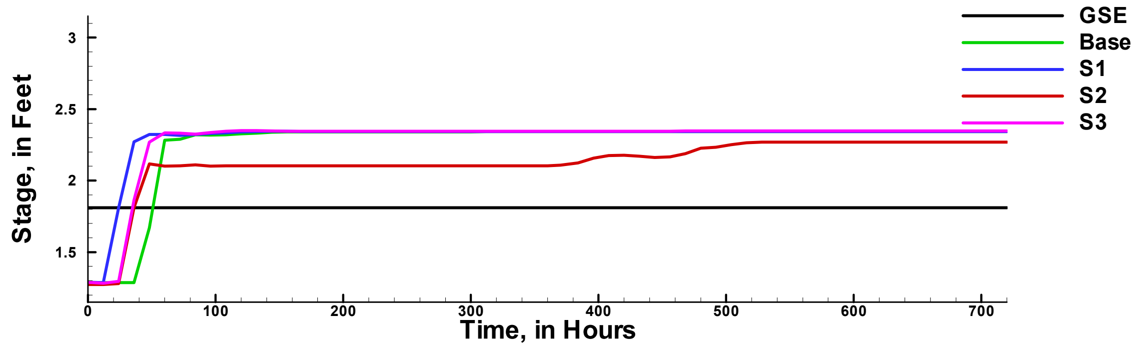

FIGURE 12. Water surface elevations at the node 2,275

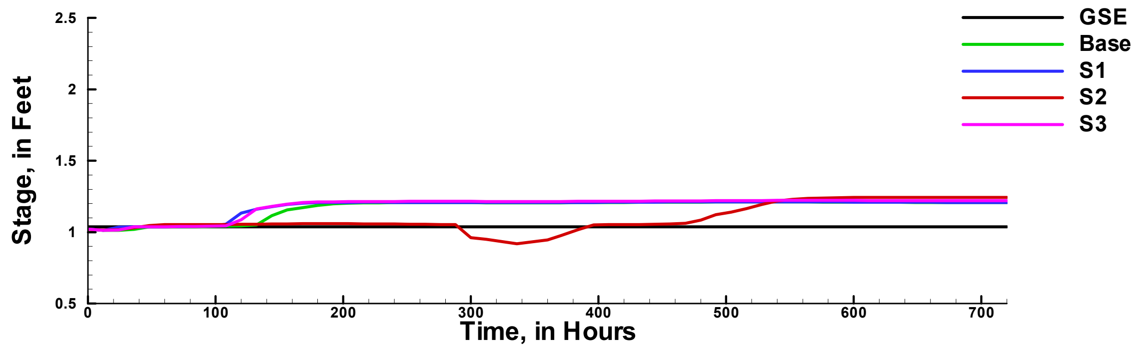

FIGURE 13. Water surface elevations at the node 2,808

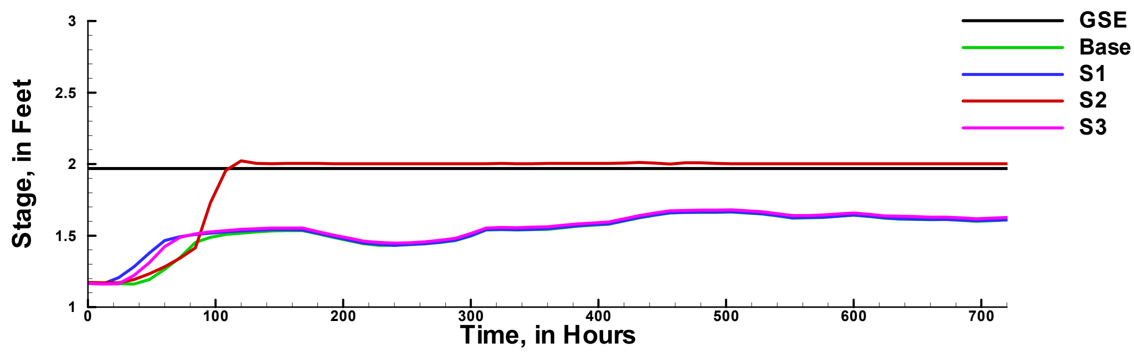

FIGURE 14. Water surface elevations at the node 3,114

Figure 9 shows the total head profiles at Node 618, located southwest of spreader canal. The computed heads at this node are below ground surface elevation (GSE) for all of the cases. However, after time = 600 hours, the computed heads for all three scenarios are approximately 0.2 ft above those computed for the baseline condition. Figure 10 shows the total head profiles at Node 1,385, located south of spreader canal in the center of the model. The computed heads for all of the alternatives indicate that the groundwater fully saturates to the surface, while the groundwater remains below the surface in the baseline. This indicates that the project goals are being achieved in this location. Figure 11 shows the total head profiles at Node 1,925, located south of Node 1,385. The computed heads at this location did not fluctuate dramatically with the time. This appears to indicate that Node 1,925 is too far away from the spreader canal to feel its influences. Figure 12 shows the total head profiles at Node 2,275, located between the two flows barriers, of US Highway 1 and Card Sound road, and very close to the spreader canal. Due to these flow barriers, the computed heads at this location are always above ground surface. However, the with the removal of the utility road in S2, it appears that the spreader canal is able to lower the water level in this location and redistribute the water further to the east. Figure 13 shows the total head profiles at Node 2,808, located south of Node 2,275. The computed heads for this node are generally 0.2 ft above the ground surface. The time period it takes for simulation S2 to reach this same level is substantially longer than seen in the baseline and two other alternatives. This is the apparent result of the removal of the utility road, which previously acted as a hydraulic barrier to the flow discharged from the spreader canal. Figure 14 shows the total head profiles at Node 3,114, located south east of the spreader canal and utility road. Simulation S2 is the only alternative where the ground water saturates to the surface. A distinct unsaturated zone is noticeable for the baseline and other two scenarios. The removal of the utility road appears to allow a significantly larger quantity of water to flow into this area.

5. SUMMARY

This paper presents an example of how coupled surface/subsurface modeling can be used in the design of a spreader canal system. The results of these simulations indicate that the surface wetting fronts depend on the existing flow barriers and the terrain of the project area. The ground water tables also are good indicator of the wetting fronts. The physics-based watershed model, WASH123D, has demonstrated its ability to simulate the complex hydrologic process in the South Florida watershed.

6. ACKNOWLEDGEMENTS

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REFERENCES

Davis, S.M. and Ogden, J.C., (1994). *Phosphorus inputs and vegetation sensitivity in the Everglades*. Everglades the Ecosystem and Its Restoration. Delray Beach, St Lucie Press.

Yeh, G.-T., G. Huang, H.-P. Cheng, F. Zhang, H.-C. Lin, E. Edris, and D. Richards (2006), *A First-Principle, Physics-Based Watershed Model: WASH123D*, Chapter 9, Watershed Models, 653 pp., Edited by V. P. Singh and D. K. Frevert, CRC Press, Taylor & Francis Group.

Cheng, H. P., H. C. Lin, E. V. Edris, C. H. Tate, (2006). *Calibration and Validation of the Biscayne Bay Coastal Wetlands Model*. Draft Report, U. S. Army Engineer Research and Development Center.