Simulations of the Dynamics of Surface Water-Groundwater Interactions in a Coastal Environment During a 25-Year/72-Hour Storm

William C. Hutchings and *David L. Tarbox*
HSA Engineers & Scientists, Tampa, Fl, USA

ABSTRACT

The effects of the 25-year/72-hour storm were simulated with a numerical, variable-density model for a site located in Southeast Florida. The modeling was conducted to evaluate the effects of the storm on surface water-groundwater interactions and general groundwater flow throughout this coastal Biscayne aquifer environment. The modeled storm event is expected to generate 0.32 meters of precipitation within 72 hours. Storm water discharge to surface water and drainage wells was simulated with a surface water model and the results were included in a flow/solute transport model.

Lake stages significantly increase to approximately 1.35 m; however, these levels are designed to be less than the adjacent groundwater levels resulting in the creation of hydraulic sinks and strong vertical upward flow. Salinities within the lakes generally increase due to the convergent flow from approximately 500 to 2500 milligrams per Liter (mg/L). The water table rapidly drops following the storm event and, after approximately one week, the groundwater elevations across the site are within approximately 0.3 meters of static conditions. The normal shallow groundwater flow pattern is also generally resumed one week after the storm event. Deep groundwater flow is generally upward and seaward, from the western part of the site following the storm event; which appears to be due to the increased recharge to the aquifer throughout the area and the discharge to the drainage wells. The deep drainage wells accommodate the design discharge and, at the peak of the discharge, decrease the salinity concentration from approximately 35,000 parts per million (ppm) to an average of 15 ppm in the vicinity of the wells resulting in vertical flow.

INTRODUCTION

This numerical model was constructed to evaluate the effects of the 25-yr/72-hour storm on surface water-groundwater interactions in this coastal environment. The site is located in the vicinity of North Miami, Dade County, Florida. Due to the proximity of the Site to Biscayne Bay and the historical lowering of the water table, seawater intrusion has occurred and the underlying Biscayne aquifer is occupied by both fresh and saline water separated by a transition zone. As a result of these conditions, the variable-density model, SEAWAT-2000 (Langevin et al., 2003), was used to simulate groundwater flow in this environment.

The setting is a large-scale, modern, residential community, with a catchment area of 193.54 acres that includes two artificial lakes approximately 7.6 m deep. Pervious areas represent 84.9 acres or 43.9% with storm water designed to discharge to retention ponds, lakes, and to drainage wells. Storm water management was designed with a surface water model and the results are included in the SEAWAT-2000 model. The surface water-groundwater interactions are potentially affected by the amount of rainfall, surface water elevations, depth of the surface water bodies, and aquifer characteristics. The effects of the event on the steady state flow field throughout the surficial aquifer are also evaluated.

METHODOLOGY

The model includes various natural hydrologic boundaries in order to create the natural groundwater and surface water system. The 17-layer model consists of 81 columns (6,785 m) that range from 200 m near the western and eastern model boundaries to 13.5 m within the site and 76 rows (5,270 m) that range from 100 m near the northern and southern boundaries to 17 m within the site.

Biscayne Bay and Arch Creek (located south of the site) are modeled as constant heads with an average elevation of 0.22 meters and a salinity or total dissolved solids (TDS) concentration of 35,000 parts per million (ppm). The Oleta River is simulated with the river package with a decreasing linear hydraulic gradient and increasing TDS concentrations downgradient towards Biscayne Bay. The Mangrove Preserve is in direct hydraulic connection with Biscayne Bay and is modeled with a constant head; however, the depth of the saline water in the preserve is less than the depth associated with Biscayne Bay and Arch Creek Canal. In contrast the altered mangrove preserve is a fairly static water body that appears to be isolated from the tidal effects of Biscayne Bay; therefore, the drain package was used to simulate this environment.

For the steady state simulation the lakes on-site were simulated with cells whose hydraulic conductivities are set at 10,000 m/day in order to represent the natural steady state stage. The steady state salinity-flow vector distribution across the calibrated model is depicted on **Figure 1**. For the post-development simulations, the lake stages were modeled with both the constant head and river packages and the lake stages were input every 6 hours for 84 hours. The surfaces of Ibis and Southeast lakes were set to the design elevations (1.37 m and 1.33 m, respectively) determined from the HydroCAD 8.0 model (HydroCAD Software Solutions LLC, 2006) provided by ES Consultants, Inc. An additional simulation was conducted with the lake stages set at maximum elevations of approximately 2.75 m. The surfaces of the lakes are set to the design elevations by the constant heads and the high-K cells allow mixing to occur. Since the constant heads cannot be turned off during a simulation, the lakes were also modeled with the river package. Use of the river package allows the lake stages to be set at the elevations determined by the HydroCAD model and the package to be turned off after the peak stage, thereby, allowing the lakes to respond naturally to the cessation of the storm event.

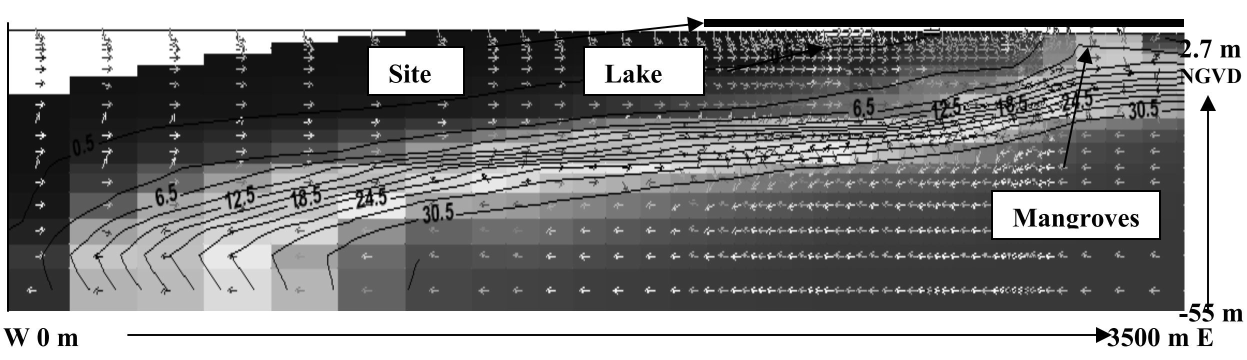

Figure 1. Steady state salinity-flow vector cross-sectional diagram (CI =3 g/l from 0.5 g/l)

The western boundary of the model determines the groundwater flux to Biscayne Bay and was set to a specified head of (1.0 m) with the constant head package (Lietz et al., 2002). In addition, a simulation was conducted with the western boundary modeled as a general head boundary with a constant head in the Everglades to confirm the elevation of the specified head. When simulating the 25-year/72-hour storm, the constant head along the western boundary of the model was switched to a general head boundary located 3,500 meters west of the general head boundary cells with a head elevation of 1.7 meters, in order to allow groundwater within the model to fluctuate.

The post-development model is constructed with land-use categories to represent current and predicted conditions. Areas occupied by roads and buildings are assigned recharge rates consistent with urban development runoff coefficients and retention basins are assigned recharge rates based on wetland runoff coefficients. In addition, the system of 28 drainage wells is simulated with all wells screened in the lower layer of the model. The discharge rates to the wells are generally consistent with the time-varying rates determined from the HydroCAD model. HydroCAD rates vary every two hours and the SEAWAT-2000 model rates represent rates that take place every six hours. These differences should not significantly affect the results. The discharge rates and total volumetric discharge to each well vary. For example, the discharge rates for a high volume well cluster range from 905 to 47,456 m^3/day. Considering 11 basins, the maximum rates per basin (over a six-hour period) range from 7,975 in basin 3 to 119,449 cubic meters per day (m^3/day) in Phase 1A, with an average of 31,354 m^3/day.

RESULTS & CONCLUSIONS

Results of the post-development simulation with the design lake elevations of 1.37 and 1.33 m are depicted in the salinity-flow vector cross section diagram after 72-hours (**Figure 2**). This figure depicts the three dimensional convergent flow to Ibis Lake resulting in the increased TDS. The effects of the drainage wells are evident by the decreased TDS near the base of the aquifer and the upward and seaward flow. Seaward flow is due to the regional recharge and discharge to the drainage wells. The water table elevation in the vicinity of the site is also generally lower in the post-development simulation because of the reduced infiltration and discharge of storm water primarily by drainage wells to the lower Biscayne aquifer. Northwest of the site, a hydraulic mound is created in both the pre and post-development simulations due to the additional recharge and the regional boundary configurations. Results of the post-development simulation with the design lake elevations of approximately 2.75 m are depicted in the salinity-flow cross-section diagram (**Figure 3**) after 72-hours. In contrast to the previous simulations, the lakes create downward vertical flow increasing discharge through the bottom of the lakes and seaward flow.

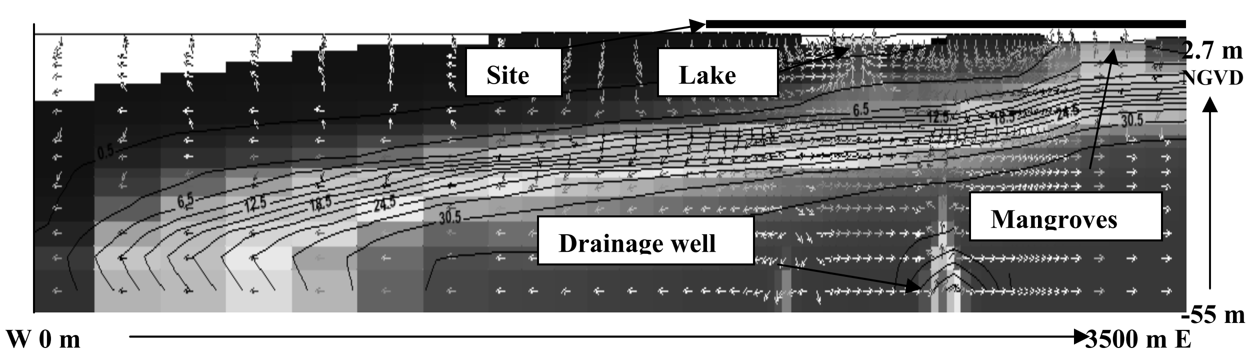

Figure 2. Salinity-flow vector cross-sectional diagram at 72 hrs (CI =3 g/l from 0.5 g/l)

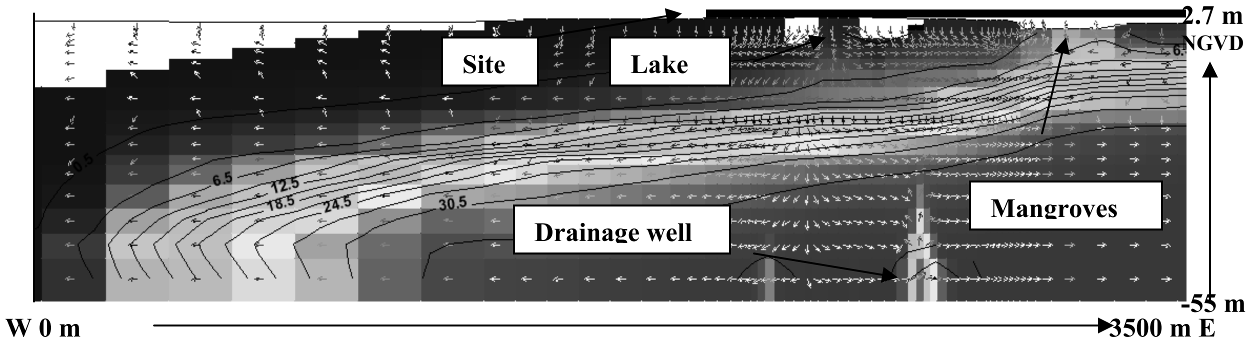

Figure 3. Salinity-flow vector cross-sectional diagram at 72 hrs and lake stages of 2.75 m (CI =3 g/l from 0.5 g/l)

From near the western end of the site, the deep groundwater flow is generally seaward, in contrast to steady state flow in which deep groundwater flows landward. This change in flow direction is due to the regional effects of the storm event and discharge to the drainage wells, and persists for approximately seven weeks following the event. A significant density difference between the injected storm water and the deep formation water exists for approximately two weeks following the storm event, creating upward groundwater flow. Normal groundwater elevations and flow patterns in the shallower parts of the aquifer are generally resumed approximately one week after the storm event. The groundwater elevations at this time are approximately 0.3 meters greater than the average steady state elevations. Deep groundwater flows eastward for more than four weeks and gradually this deep saline groundwater reverses and flows westward, establishing the average shallow freshwater, transition zone, and deep saline water configuration and characteristic flow. The drainage wells appear to accommodate the design discharge and, at the peak of the discharge, decrease the background salinity concentration from 35,000 ppm to the approximate range of 8,000 to 31,000 ppm, with an average of 15 ppm in the vicinity of the wells. During the storm event, the average horizontal groundwater flow direction is perturbed by vertical groundwater flow created as a result of the salinity and density differences between the TDS of the saline formation water and the injected freshwater. As a result of the brevity of the storm event and discharge, these differences range between 20 and 30 ppm one week following the storm event and become relatively minor after approximately four weeks, regardless a small upward flow of deep groundwater persists for several weeks or more.

REFERENCES

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Contact Information: William C. Hutchings, P.G., HSA Engineers & Scientists, 4019 East Fowler Avenue, Tampa, FL 33617 USA, Phone 813-971-3882; Fax 813-971-1862; Email: bhutchings@hsa-env.com