DEVELOPMENT OF A VARIABLE-DENSITY GROUNDWATER FLOW MODEL FOR THE TAYLOR SLOUGH AREA

ABSTRACT

The U.S. Geological Survey recently completed the development and calibration of the Southern Inland and Coastal Systems (SICS) model, which simulates overland flow within the Taylor Slough area and uses a flow term as a rough approximation of groundwater leakage. The SICS model domain is bounded to the north and west by Old Ingraham Highway, to the east by the C-111 canal, and to the south by Florida Bay. The SICS model was calibrated to measured water levels, coastal flows, and surface-water salinities for a 7-month period between July 15, 1996 and February 28, 1997. The simulation period for the SICS model was recently increased to 2 years, beginning July 16, 1996 and ending June 9, 1998.

To better quantify leakage between surface water and groundwater within the SICS area, a preliminary groundwater flow and solute-transport model was developed for the SICS model domain using the same grid. The groundwater model simulates variable-density groundwater flow for the same 2-year period as the SICS surface-water model. The SEAWAT code, which is a combined version of MODFLOW and MT3D, was used for the simulations. The groundwater model contains 10 layers, each 2.8-meters thick. General-head boundaries were assigned to the perimeter of each layer in the model. Salinities for the general-head boundaries were estimated from an airborne electrical resistivity survey of the area. General-head boundaries also were applied to the top of the groundwater model to represent surface water. Results from the SICS model were used to assign spatially and temporally varying stages and salinities to the overlying general-head boundaries. When cells in the SICS model were dry, recharge and evapotranspiration were applied to the groundwater model cells. Conductance values for the general-head boundaries were calculated using maps of peat thickness and estimates of vertical hydraulic conductivity. Values for other aquifer parameters, such as horizontal hydraulic conductivity, anisotropy ratio, storativity, porosity, and dispersivity were obtained from the literature or estimated through calibration.

Preliminary results from the model show good correlation with measured water levels at three monitoring wells (Figure 1). Simulation results for 2 months, one in the wet season and one in the dry season, show two apparent differences in aquifer leakage. During the wet season (e.g. June 1997) (Figure 2), leakage is downward, from the surface water into the aquifer. During the dry season (e.g. November 1996) (Figure 3), most of the leakage is upward, from the aquifer into the wetlands. Some variation from these trends has been observed along the Buttonwood Embankment and near Taylor Slough Bridge, where aquifer recharge and discharge respectively occur during most of the year.

Future plans for SICS modeling include (1) developing a fully integrated surface-water and groundwater model using an explicit link between SWIFT2D and SEAWAT to simulate leakage and the transfer of associated salt concentrations, and (2) driving the integrated model with predictive results from the South Florida Water Management District model.

INTRODUCTION:

Groundwater/ surface water interactions are a source of uncertainty in numerical models in southern Florida. To determine the extent of these interactions a preliminary integrated variable-density flow and solute transport model was developed to quantify the leakage between surface water and groundwater in the Taylor Slough area (figure 1). The grid shown in figure 1 was used for the Southern Inland and Coastal Systems (SICS) surface water model, which used the model code SWIFT2D. In order to create an integrated flow model the use of the exact same grid from the surface water model was necessary for the groundwater portion of the model. Simulated stage and concentration output from the SWIFT2D model run were used as the initial inputs for the flow model, which used the variable-density solute transport model code SEAWAT. The map shown also depicts the locations of four coastal creeks, three groundwater wells, three surface water monitoring sites, and three selected groundwater model cells where simulated leakage values were calculated. Figures 2-4 show the simulated surface water stages of the SWIFT2D model run plotted with actual measured values at the monitoring sites. The high level of correlation between these plots supports the use of these results for the groundwater flow model. Figure 5 shows the simulated concentration profile for one day of the surface water model run.

FIGURE 1: TAYLOR SLOUGH WITH SICS MODEL GRID AREA

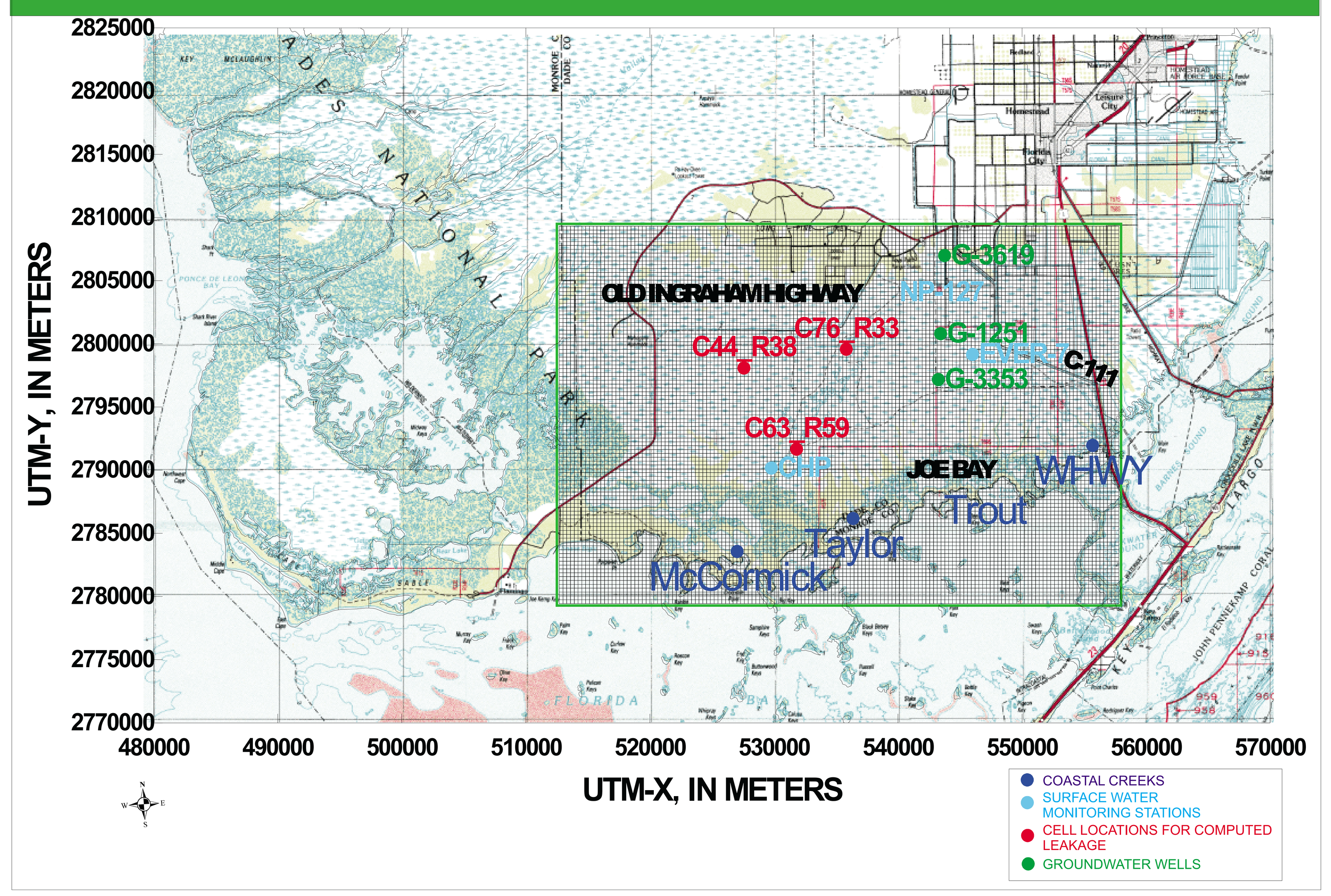


FIGURE 5: SICS SIMULATED CONCENTRATION FOR OCTOBER 10,1996

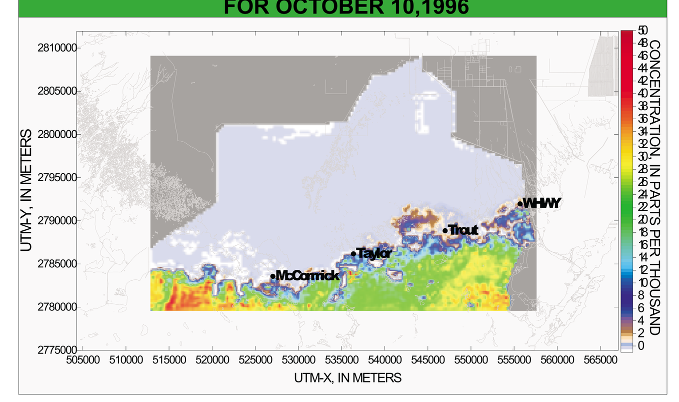


FIGURE 2: SICS MODEL RESULTS AND MEASURED STAGES AT CRAIGHEAD POND

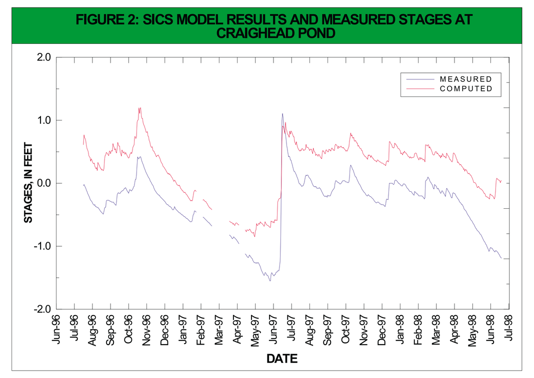


FIGURE 3: SICS MODEL RESULTS AND MEASURED STAGES AT EVER-7

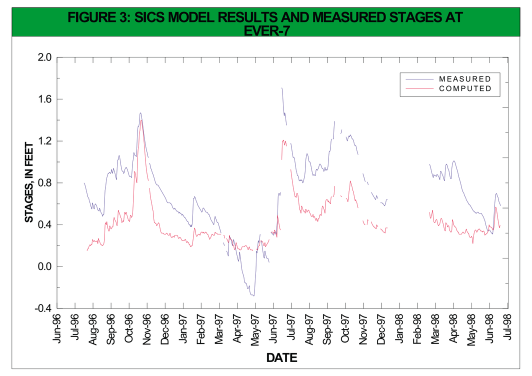


FIGURE 4: SICS MODEL RESULTS AND MEASURED STAGES AT NP-127

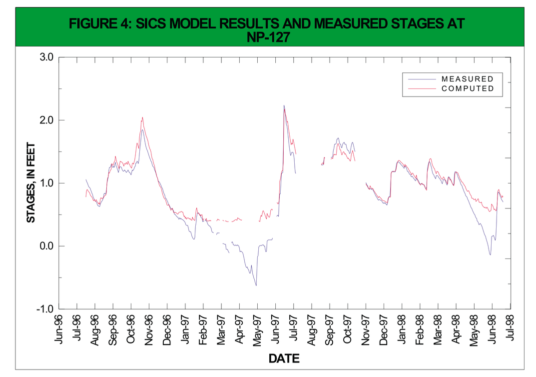


TABLE 1: AQUIFER PARAMETERS		
NAME	VALUE	COMMENTS
Horizontal Hydraulic Conductivity:	**7500.0 Meters/Day**	The hydraulic conductivities listed here are calibrated within a data range acquired from Fish & Stewart (1991).
Vertical Hydraulic Conductivity:	**7.5 Meters/Day**	
Anisotropy Ratio:	**1000:1**	
Storativity:		
SF1 (Layer 1):	**1.0**	
SF1 (Layer 2-10):	**1.0×10^{-5}**	
SF2 (All Layers):	**0.2**	
Specific Yield:	**0.2**	Values acquired from Merritt (1996)
Porosity:	**0.2**	Values acquired from Merritt (1996)
Peat Hydraulic Conductivity:	**0.2405**	Value is the Harmonic mean of the Hydraulic Conductivity measured by Harvey, & others (2000)

MODEL DESIGN:

The process of designing the flow model started with the setup of the model grid. Layer one of the grid, which is 148 columns by 98 rows, came from the SICS model. Ten layers were used in the groundwater flow model to better represent the variable density portion of the model. The thickness of each layers 2-10 were set to 3.2 meters, based upon the depth of the Biscayne aquifer in the model area. Inactive cells delineate the bottom of the Biscayne aquifer and are shown in gray (figure 6). The land surface elevation upon which the thickness of layer one was based is also shown in figure 6. Once the grid was developed, the hydraulic characteristics of the Biscayne aquifer were roughly approximated and are listed in table 1.

The next step was to use the simulated stages from the SICS model as designated external general head boundary conditions for layer one of the model. These stages vary for each day of the model run period, therefore the general head boundaries change from one stress period to the next. Figure 7 shows the spatial distribution of the general heads for the first day of the model run. The open spaces in the figure are cells that have gone dry during the surface water model run; a net recharge term is applied to these cells. A schematic that shows how either a general head boundary condition or a net recharge term was applied to each cell in the groundwater model is shown in figure 8. During the development process, it was discovered that a layer of peat in the study area could act as a semi-confining unit, therefore the designation of peat thickness was necessary in the model. Using field data the measured thickness of peat in certain locations was krigged over the entire model grid area (figure 9). These interpolated values and the harmonic mean of measured vertical hydraulic conductivities of the peat layer were used to calculate the vertical hydraulic conductance for layer one.

FIGURE 9: CONTOUR PLOT OF PEAT THICKNESS IN MODEL DOMAIN

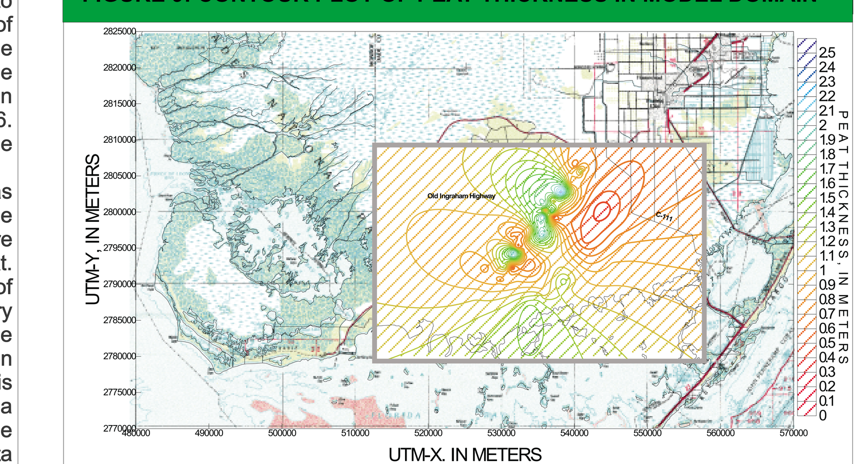


FIGURE 6: SICS AREA LAND SURFACE ELEVATION & DELINEATION OF THE BOTTOM OF THE BISCAYNE AQUIFER

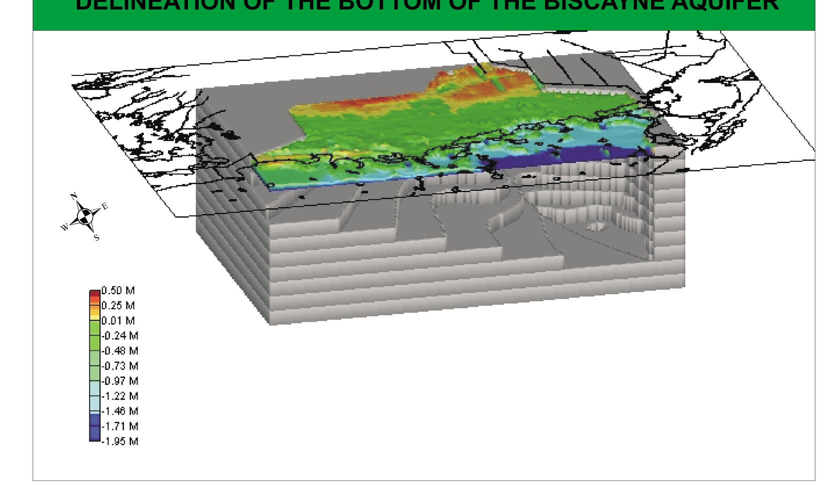


FIGURE 7: GENERAL HEAD BOUNDARY FOR DAY ONE OF MODEL RUN

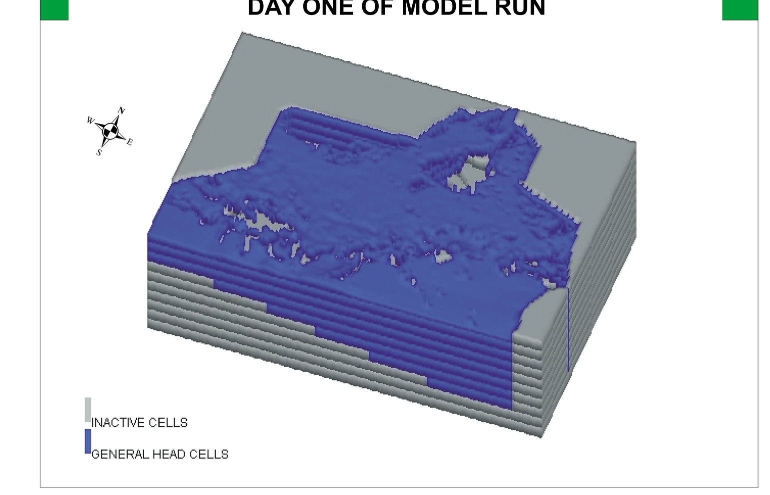
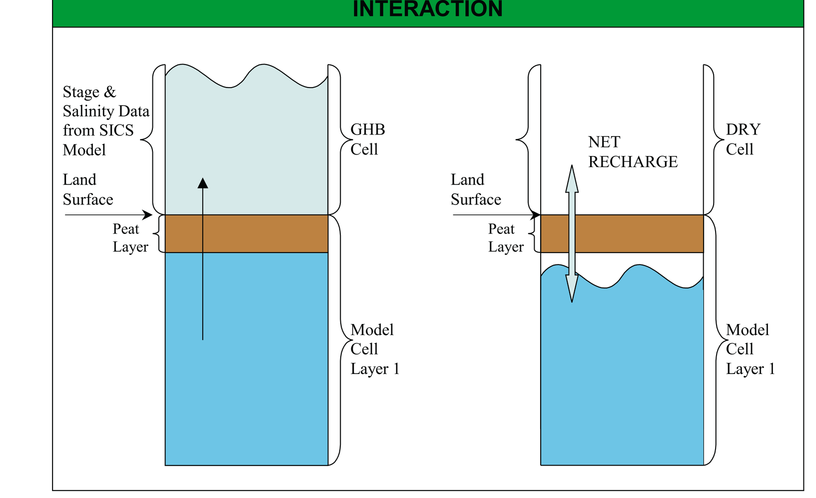


FIGURE 8: NET RECHARGE & SURFACE WATER/ GROUNDWATER INTERACTION



MODEL RESULTS:

HEADS:

The results for the simulated heads from the SEAWAT groundwater flow model are shown in Figures 10 - 13. Figure 10 displays the model simulated head differences versus actual measured head differences. The data for this plot is from heads measured at different times and from many locations in the Taylor Slough area. Figures 11-13 display the simulated hydralic heads from the model run plotted with the actual measured water levels in wells G-3353,G-3619, and G-1251. Wells G-3353 and G-3619 are located in layer one of the model and well G-1251 is in the third layer. The locations of these wells are shown in Figure 1. The plots suggest that the groundwater model is simulating the hydraulic heads closely at these locations.

FIGURE 10: SEAWAT COMPUTED HEAD DIFFERENCE VS. MEASURED HEAD DIFFERENCE

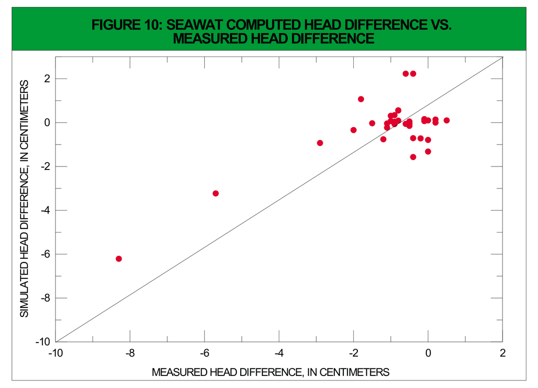


FIGURE 11: SEAWAT COMPUTED WATER LEVELS & MEASURED WATER LEVELS AT WELL G-1251

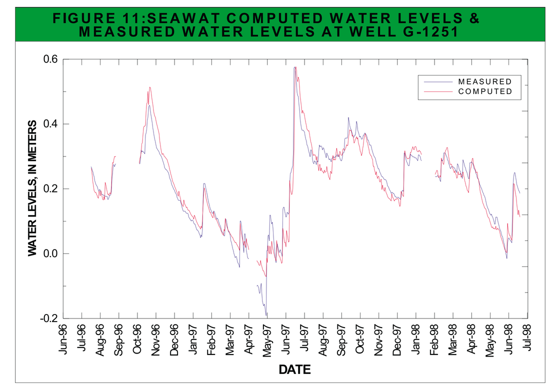


FIGURE 12: SEAWAT COMPUTED WATER LEVELS & MEASURED WATER LEVELS AT WELL G-3353

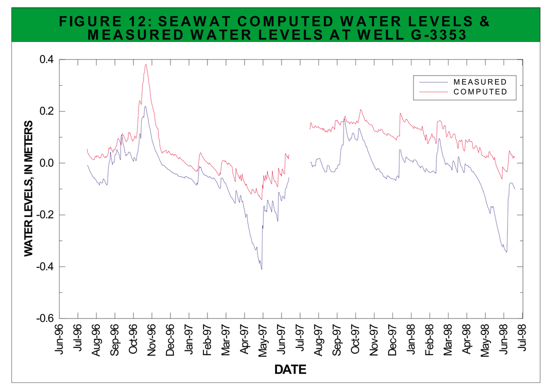
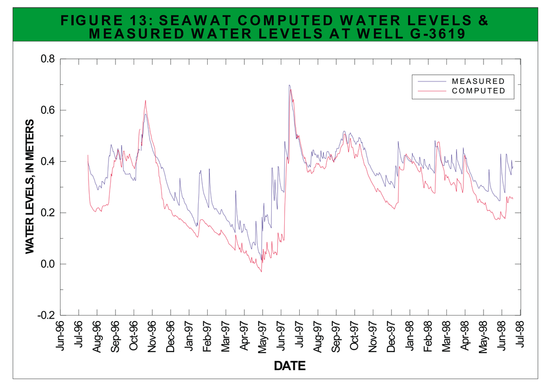


FIGURE 13: SEAWAT COMPUTED WATER LEVELS & MEASURED WATER LEVELS AT WELL G-3619



MODEL RESULTS:

CONCENTRATIONS:

SEAWAT was used to solve the coupled variable-density groundwater flow and solute transport equations for freshwater equivalent heads and solute concentrations in the groundwater flow model. In order to obtain a distribution of saltwater that is more representative of the real system in the study area, the model is run until the concentrations in the aquifer reach a quasi-equilibrium state. To simulate this in the model, final concentrations from each model run were used as initial concentrations for each ensuing run of the transient model, which in this case took 20 runs (5hours per run, for a total run time of 4 days). Figure 14 displays the results of the aquifer mass balance for these simulations. At the end of the final run, the distribution of concentration on the final day of the model period was evaluated. These results are displayed in figures 15-17. Figure 15, 16 and 17 show the 0, 17.5, and 30 ppt iso-surfaces, respectively.

FIGURE 14: SEAWAT AQUIFER MASS BALANCE RESULTS FOR 20 CONSECUTIVE RUNS

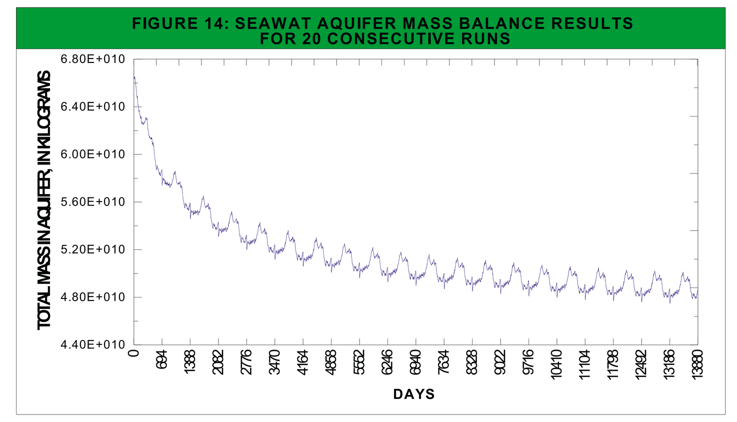


FIGURE 15: SEAWAT SIMULATED CONCENTRATION ISO-SURFACE 0 PPT

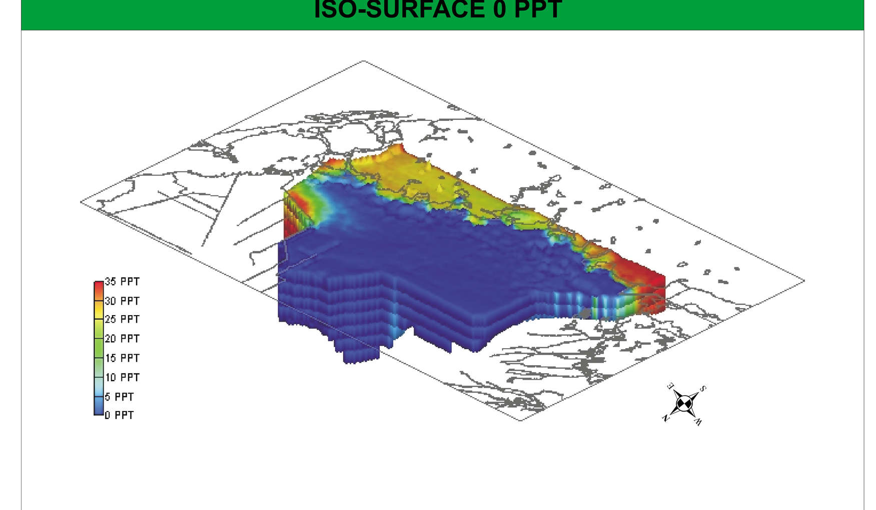


FIGURE 16: SEAWAT SIMULATED CONCENTRATION ISO-SURFACE 17.5 PPT

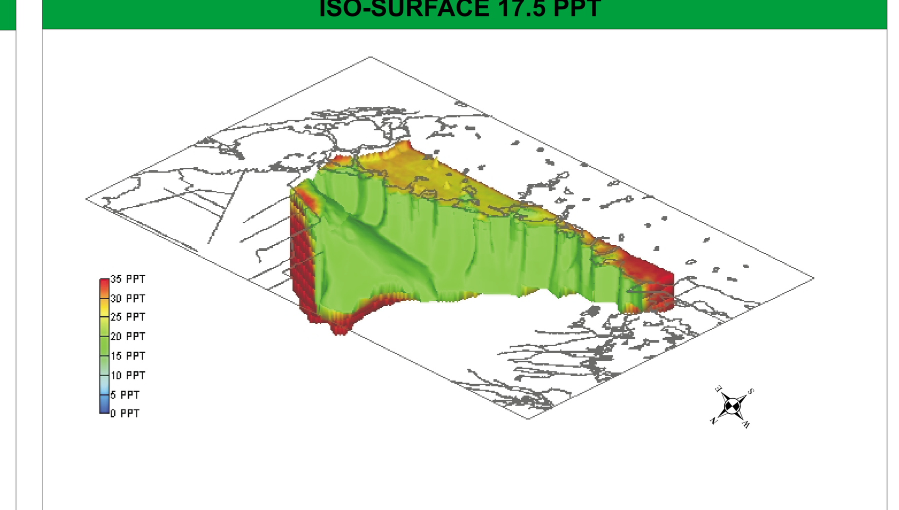
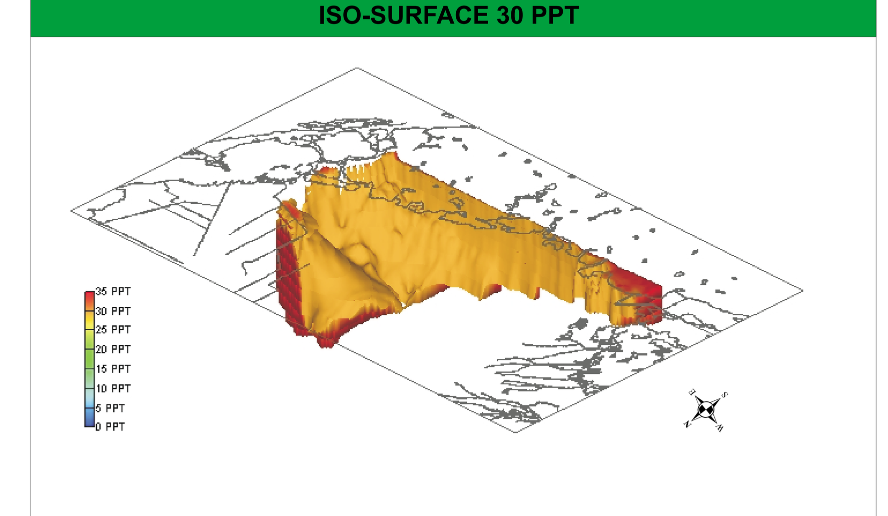


FIGURE 17: SEAWAT SIMULATED CONCENTRATION ISO-SURFACE 30 PPT



MODEL RESULTS:

LEAKAGE:

To characterize surface water/ groundwater leakage in the Taylor Slough area, leakage rates need to be evaluated in terms of temporal leakage and the spatial distribution of leakage. Temporal leakage rates for the model are displayed in figures 18-23, which show leakage at six selected cells, three of which also contain groundwater wells, the locations of which are shown in figure 1. Each plot displays the leakage rate (in terms of centimeters per day) for the duration of the transient model period. Flow into the aquifer in shown in red and flow out of the aquifer is shown in blue. The spatial distributions of the leakages are shown in figures 24-26. The total averaged daily leakage rate in the model area for the entire transient simulation model run is displayed in figure 24. The average daily leakage rate per cell was calculated by totaling daily leakage rates and dividing the total by 694 days. The areal daily leakage rates shown in figures 25-26 were calculated in a similar manner except that they were done on a monthly basis. Figure 25 shows the average leakage during the wet season for the month of June. Most of the leakage is downward seepage of surface water into the aquifer. Figure 26 displays the average leakage during the dry season in the month of November; here most of the leakage is upward, from the aquifer to land surface.

FIGURE 18: SEAWAT SIMULATED LEAKAGE RATE AT WELL G-1251

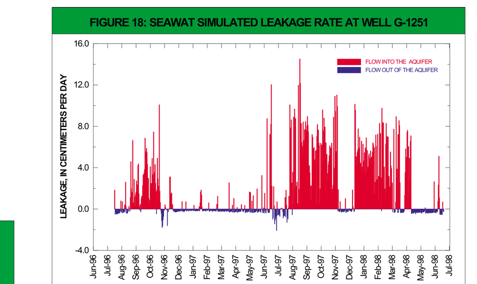


FIGURE 19: SEAWAT SIMULATED LEAKAGE RATE AT WELL G-3353

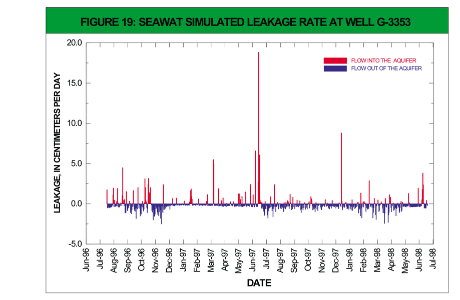


FIGURE 20: SEAWAT SIMULATED LEAKAGE RATE AT CELL (R33,C76)

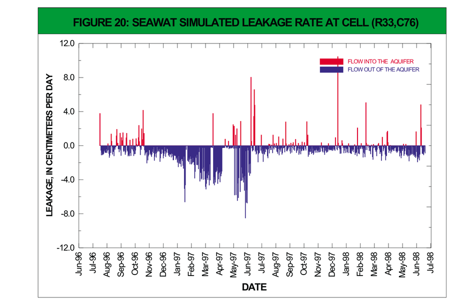


FIGURE 21: SEAWAT SIMULATED LEAKAGE RATE AT CELL (R38,C44)

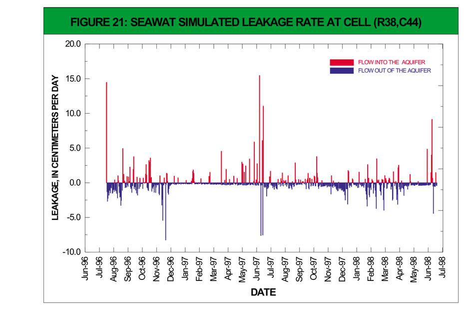


FIGURE 22: SEAWAT SIMULATED LEAKAGE RATE AT CELL (R59,C63)

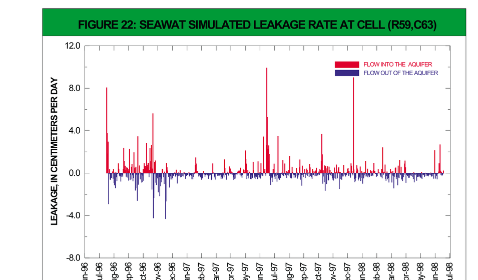


FIGURE 23: SEAWAT SIMULATED LEAKAGE RATE AT WELL G-3619

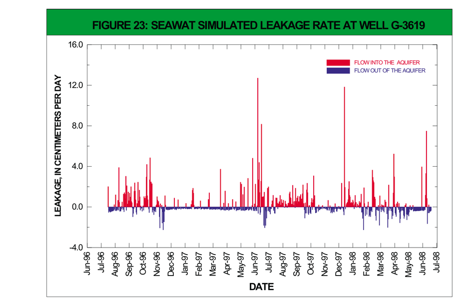


FIGURE 24: SURFACE WATER/ GROUNDWATER TOTAL AVERAGE LEAKAGE

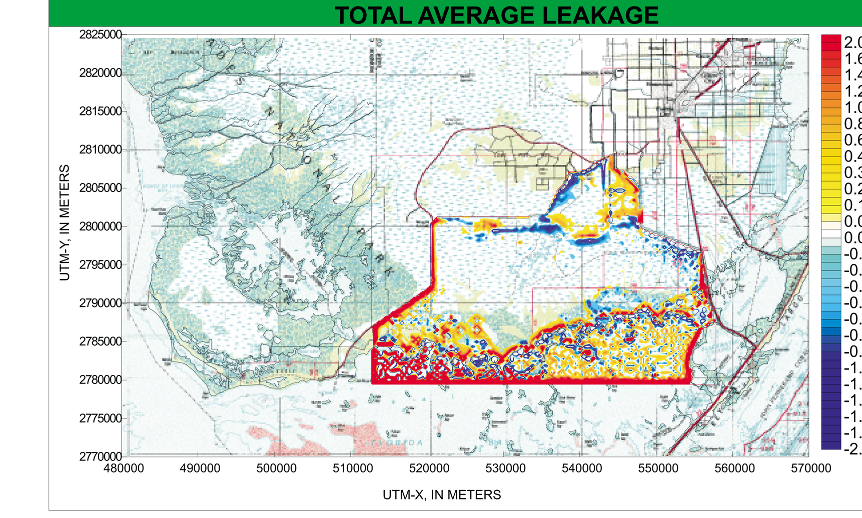


FIGURE 25: SURFACE WATER/ GROUNDWATER AVERAGE LEAKAGE FOR JUNE 1997

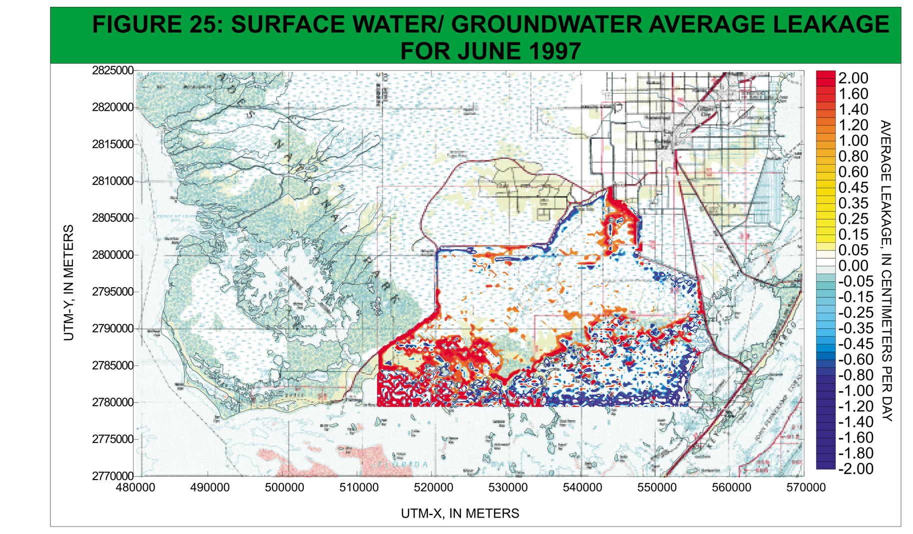
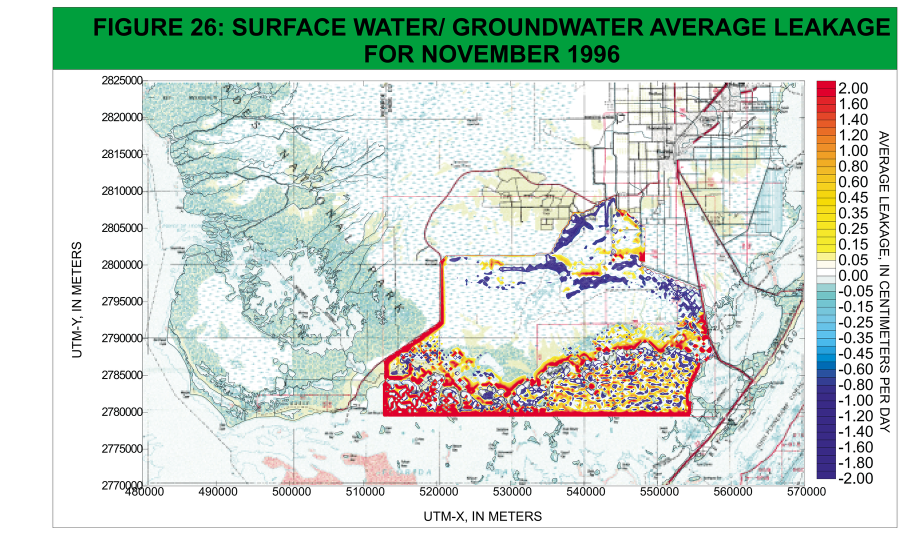


FIGURE 26: SURFACE WATER/ GROUNDWATER AVERAGE LEAKAGE FOR NOVEMBER 1996



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