

SALTWATER INTRUSION MODELING OF THE SAVANNAH HARBOR EXPANSION PROJECT

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Abstract. The Army Corp of Engineers (ACOE) hired CDM to develop a 3-dimensional ground water model of the Savannah harbor area, with the intent to use the model to simulate saltwater intrusion from the Savannah River harbor area, both under present conditions and under the proposed conditions after dredging. The model includes modules to simulate flow, transport (using particle tracking), and density driven flow using a coupled flow and transport code suitable for simulation of saltwater intrusion and leakage. Model simulations were designed to assess the rate and magnitude of downward leakage of saltwater along the river caused by the steep decline in heads in the Upper Floridan Aquifer in the Savannah area due to pumping. Comparative runs were made under present day conditions, and after proposed dredging of the harbor, which would result in a decrease in the thickness of underlying Miocene Confining Unit deposits.

BACKGROUND

The US Army Corps of Engineers (ACOE) is conducting an Environmental Impact Statement (EIS) on the proposed dredging of Savannah harbor. An essential part of the EIS is to investigate potential impacts of the dredging on the water quality of the Upper Floridan aquifer, with concern focused on the downward leaking of saltwater through the Miocene Confining Unit into the Upper Floridan aquifer. CDM was tasked with the development of a 3-dimensional numerical model of the ground water hydrologic system focused on the navigation channel within Savannah Harbor. The model makes use of CDM's own DYNSTEM set of finite element codes, including DYNFLOW (ground water flow), DYNTRACK (contaminant particle tracking), and DYNCF (coupled flow and transport). The objectives for the modeling work were to develop a groundwater model focused on the Savannah River harbor area and to project chloride changes in the Upper Floridan aquifer due to dredging of the navigation channel using a range of plausible hydraulic properties.

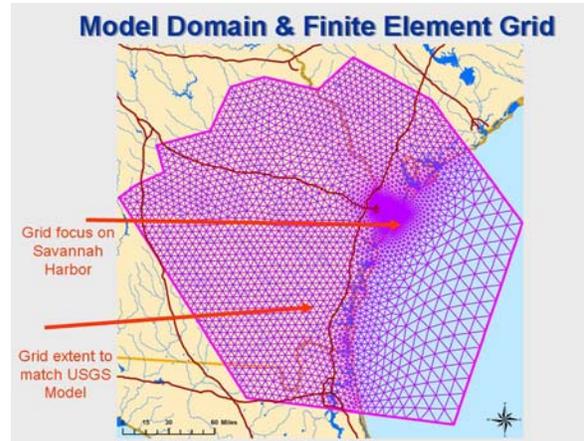


Figure 1 Model extent and grid.

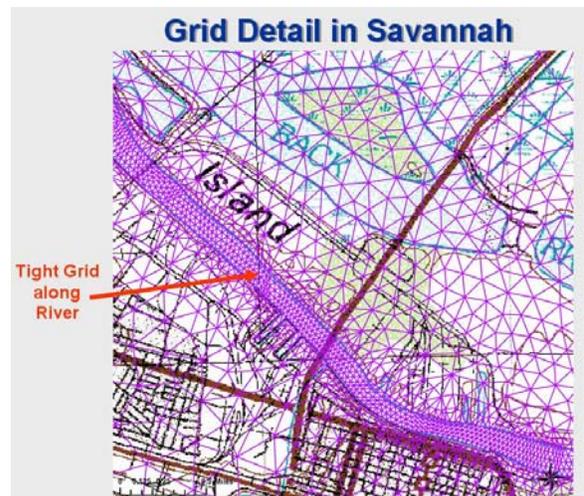


Figure 2 Node spacing in harbor area.

MODEL STRUCTURE

The model uses a finite element code, and consists of 8,257 nodes per model level and 16,362 elements per layer. The grid uses a variable spacing to capture the natural hydrologic boundary conditions used by the existing USGS Savannah Area MODFLOW model, but also to focus on the Savannah River in the area of the harbor (Figure 1).

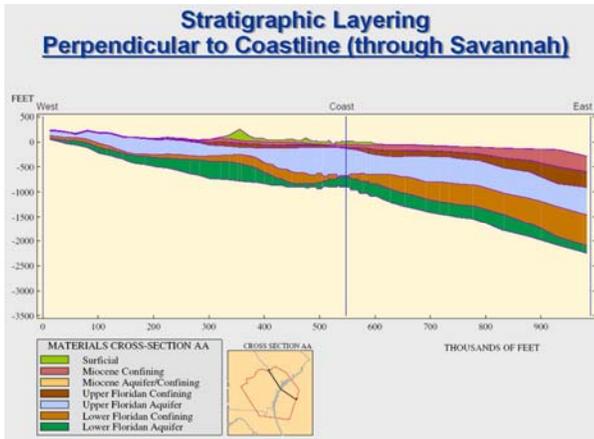


Figure 3 Cross-section of model layers.

Node spacing ranges from 25,000 to 50,000 feet offshore and in the inland areas, reducing down to only 100 to 150 feet along the river (Figure 2).

The model includes active layers representing the Lower Floridan and Upper Floridan aquifers, the Miocene Aquifer Units, and intervening confining units (Figure 3). CDM worked closely with the USGS, and the model is based on the property sets, layering schemes, and boundary conditions used in the recently updated USGS MODFLOW model of the coastal area (Payne et. al, 2003). The CDM model makes extensive use of the data from the recent ACOE program, which took core samples and pore water samples of Miocene material from a number of points along the river. The data provided a means to compare the model results against the rate of penetration of saltwater found in the core samples. CDM also made use of the GIS layering and hydraulic boundary conditions of the USGS model as the basis for the Savannah Harbor model. The Savannah Harbor model produced a range of results based on the most likely and worst case combinations of hydraulic properties and thickness of the Miocene confining unit based on reasonable ranges estimated from existing data.

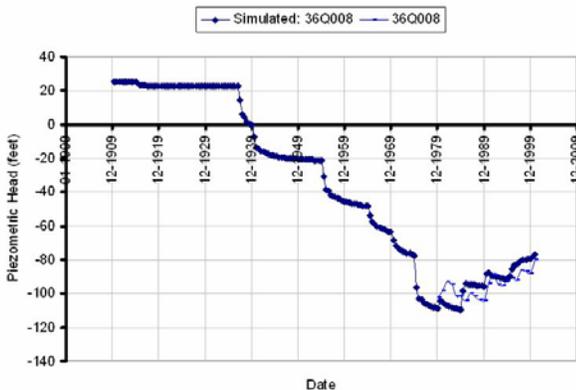


Figure 4 1900 -2000 calibration results.

MODEL SIMULATION RESULTS

Once calibrated, historical simulations of the period 1900 to 2000 were made to reproduce the known penetration of saltwater in the Miocene Confining Units, and several long-term transient simulations (80-200 years) were made in support of the EIS to predict the impacts of harbor dredging on the rate and extent of saltwater penetration.

Figure 4 shows the results of the 100-year historical simulation and the good agreement between simulated Upper Floridan heads compared with the head measurements in a monitoring well near the center of the cone of depression in Savannah.

For the historical simulation, river bottom elevations were based on available information on historical dredging, and the current thickness of the upper confining unit beneath the harbor as determined from geophysical surveys and drilling. Post-dredging conditions were based on the proposed final bottom elevations of the harbor channel.

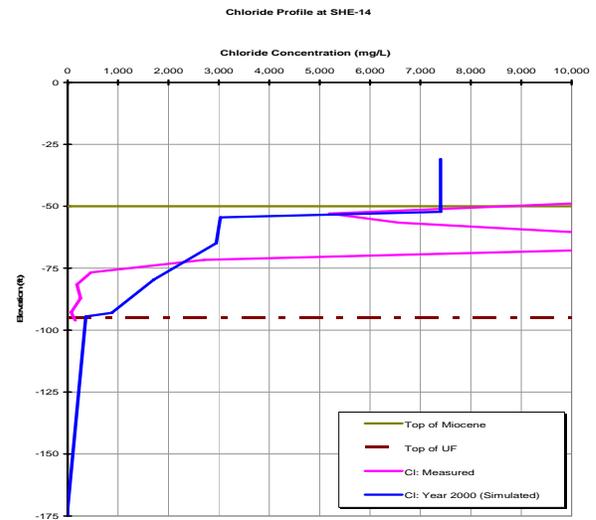


Figure 5 Simulated chloride concentration with depth and pore water sample results.

Several simulations of the period 1900 - 2000 were made using various estimates of the vertical hydraulic conductivity (K_v) of the Miocene confining unit. Figure 5 shows the simulated results at a boring location in the channel north of Tybee Island for the mid-range K_v . The simulation indicates that the model is somewhat overestimating the rate of saltwater penetration. Another simulation, using a lower K_v , underestimated the rate of saltwater intrusion, thus placing the most likely K_v somewhere between the two simulations. The model is able to reasonably reproduce the depth of penetration of saltwater and chloride concentration resulting from the heavy pumping during the period 1900 to 2000. These, and similar results at other boring locations along the

channel indicated that the model was suitable for making projection simulations of the next 200 years, isolating the impacts of harbor dredging from the expected penetration of saltwater that will occur due to the steep head gradient between the water table beneath the river and heads in the Upper Floridan aquifer.

Simulations were made with a range of Kv values for the periods 1990 – 2200, assuming constant pumping at today’s rate. Figure 6 compares the results of two pairs of projection simulations at the SHE-14 location north of Tybee Island at the mouth of the river. One pair lines show chloride concentrations over time, with the blue line representing conditions without dredging the harbor and the orange line representing conditions with the harbor dredged for the mid-Kv simulation. These results are likely to be overestimating the rate of saltwater penetration. The chloride concentrations are simulated at top of the Upper Floridan aquifer between the year 1990 and 2200. The results suggest that the harbor dredging will somewhat influence the concentration of salt water in the Upper Floridan, but that the primary cause of saltwater penetration is the pumping induced gradient. Ultimately, concentrations directly below the river could reach into the hundreds of mg/l chloride, but this might take anywhere from 25 to 100 years, depending on the Kv value of the Miocene confining unit. Note that the concentrations are similar for many years, and only become somewhat higher due to the dredging once the salt penetration approaches steady state. Steady state conditions could take more than 100 years to develop.

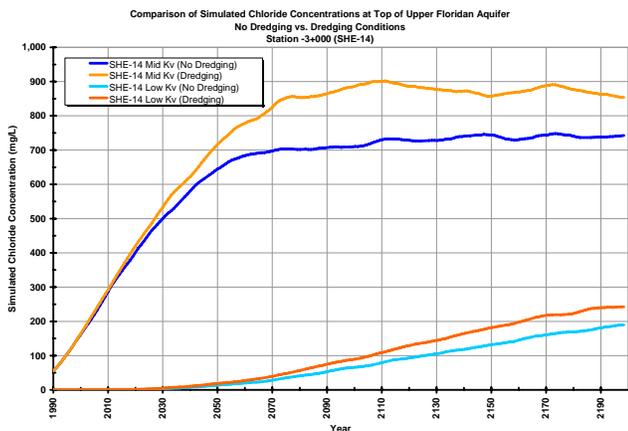


Figure 6: Chloride concentration over time with and without dredging at drill site SHE-14 North of Tybee Island.

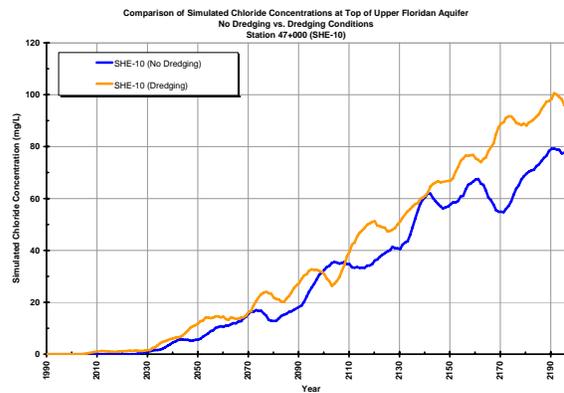


Figure 7: Chloride concentration over time with and without dredging at SHE-10 near Elba Island.

Figure 7 compares the results of the two projection simulations at the SHE-10 location near Elba Island just downstream of the confluence with the Back River. The graph also shows chloride concentrations over time, simulated at the top of the Upper Floridan aquifer between the year 1990 and 2200, directly beneath the river. The results again suggest that the harbor dredging will eventually (after perhaps 100 years) result in somewhat higher concentrations, but with equilibrium conditions not yet reached, the concentrations are below 100 mg/l chloride.

CONCLUSIONS

The simulations covered a range of parameters, and identified the vertical hydraulic conductivity of the Miocene confining unit as the key to the rate of saltwater penetration. A number of important conclusions can be drawn from the results.

- The modeling approach selected and the DYNCFIT code has successfully simulated the groundwater conditions in the Miocene Confining Unit and the Upper Floridan Aquifer beneath the Savannah River.
- The model is reasonably calibrated, and can simulate measured chloride penetration of the Miocene confining unit due to ground water pumping in the Savannah area over the past 100 years.
- If pumping is not reduced, saltwater intrusion into the Upper Floridan aquifer in the Savannah area is likely to occur over the next 25 to 100 years in areas where the Miocene confining unit is relatively thin, whether or not dredging is performed. Intrusion is primarily driven by the steep, pumping induced gradient between the surficial deposits beneath the river and the heads in the Upper Floridan Aquifer.
- Dredging of the harbor will result in the removal of some of the Miocene confining unit. Model simulation results suggest that this will cause

concentrations of chlorides in the water of the Upper Floridan aquifer directly beneath the river to increase by about 10 – 30 percent after 50 to 100 years, with breakthrough at some locations occurring a few years earlier than would have occurred without dredging.

- The simulated concentrations of chloride in the Upper Floridan Aquifer could increase to above the drinking water standard directly below the river after many years, whether or not dredging is performed. However, the model simulation results suggest that the concentrations are significantly diluted as the chloride plume moves away from the river toward the areas of heaviest pumping. Model simulated concentrations in nearby pumping wells, at steady state conditions after 50 to 100 years, are only in the tens of mg/l.

REFERENCES

Payne, D.F., Provost, A.M., and Voss, C.I., 2003, Parallel development of MODFLOW and SUTRA Models in coastal Georgia, South Carolina, and Florida: an approach to study regional ground-water flow and local saltwater intrusion. In: Proceedings of the 2003 Georgia Water Resource Conference, held April 23-24, 2003, at the University of Georgia, Kathryn J. Hatcher, ed., Institute of Ecology, the University of Georgia, Athens, Ga.