Conference Proceedings Paper for the 4th Federal Interagency Hydrologic Modeling Conference
Las Vegas, NV June 2010

POTENTIAL MITIGATION APPROACH TO MINIMIZE SALINITY INTRUSION IN THE LOWER SAVANNAH RIVER ESTUARY DUE TO REDUCED CONTROLLED RELEASES FROM LAKE THURMOND

Paul A. Conrads, Hydrologist, U.S. Geological Survey – SC Water Science Center, Columbia, SC, pconrads@usgs.gov; James M. Greenfield, TMDL Specialist, U.S. Environmental Protection Agency -- Region IV, Atlanta, GA, Greenfield.jim@usepa.gov;

Abstract: The Savannah River originates at the confluence of the Seneca and Tugaloo Rivers, near Hartwell, Ga. and forms the State boundary between South Carolina and Georgia. The J. Strom Thurmond Dam and Lake, located 187 miles upstream from the coast, is responsible for most of the flow regulation that affects the Savannah River from Augusta to the coast. The Savannah Harbor experiences semi-diurnal tides of two high and two low tides in a 24.8-hour period with pronounced differences in tidal range between neap and spring tides occurring on a 14-day and 28-day lunar cycle. The Savannah National Wildlife Refuge is located in the Savannah River Estuary. The tidal freshwater marsh is an essential part of the 28,000-acre refuge and is home to a diverse variety of wildlife and plant communities.

The Southeastern U.S. experienced severe drought conditions in 2008 and if the conditions had persisted in Georgia and South Carolina, Thurmond Lake could have reached an emergency operation level where outflow from the lake is equal to the inflow to the lake. To decrease the effect of the reduced releases on downstream resources, a stepped approach was proposed to reduce the flow in increments of 500 cubic feet per second (ft^3/s) intervals.

Reduced flows from 3,600 ft^3/s to 3,100 ft^3/s and 2,600 ft^3/s were simulated with two previously developed models of the Lower Savannah River Estuary to evaluate the potential effects on salinity intrusion. The end of the previous drought (2002) was selected as the baseline condition for the simulations with the model. Salinity intrusion coincided with the 28-day cycle semi-diurnal tidal cycles. The results show a difference between the model simulations of how the salinity will respond to the decreased flows. The Model-to-Marsh Decision Support System (M2MDSS) salinity response shows a large increase in the magnitude (> 6.0 practical salinity units, psu) and duration (3-4 days) of the salinity intrusion with extended periods (21 days) of tidal freshwater remaining in the system. The Environmental Fluid Dynamic Code (EFDC) model predicts increases in the magnitude of the salinity intrusion but only to 2 and 3 psu and the intrusion duration greater than a week.

A potential mitigation to the increased salinity intrusion predicted by the M2MDSS would be to time pulses of increase flows to reduce the magnitude of the intrusion. Seven-day streamflow pulses of 4,500 ft^3/s were inserted into the constant 3,100 ft^3/s streamflow condition. The streamflow pulses did substantially decrease the magnitude and duration of the salinity intrusion. The result of the streamflow pulse scenario demonstrates how alternative release patterns from Lake Thurmond could be utilized to mitigate potential salinity changes in the Lower Savannah River Estuary.

INTRODUCTION

The Savannah River originates at the confluence of the Seneca and Tugaloo Rivers, near Hartwell, Ga., and forms the State boundary between South Carolina and Georgia (fig. 1). From Lake Hartwell, the Savannah River flows through two physiographic provinces, the Piedmont and the Coastal Plain. The city of Augusta, Ga., is on the Fall Line, which separates these two provinces. The slope of the river ranges from an average of about 3 feet per mile in the Piedmont to less that 1 foot per mile in the Coastal Plain (Sanders and others, 1990). Upstream from the Fall Line, three large Federal multi-purpose dams (Lake Hartwell, Richard B. Russell Lake, and J. Strom Thurmond Lake) provide hydropower, water supply, recreational facilities and a limited degree of flood control. Thurmond Dam is responsible for most of the flow regulation that affects the Savannah River from Augusta to the coast (Sanders and others, 1990).

From Augusta, Ga., the Savannah River flows 187 miles to the coast (fig. 1). The lower Savannah River is a deltaic system that branches into a series of interconnected distributary channels in the vicinity of the Savannah National Wildlife Refuge (fig. 2). The hydrology of the system is dependent upon precipitation, runoff, channel configuration, streamflow, and seasonal and daily tidal fluctuations (Latham 1990; Pearlstine and others, 1990). Savannah Harbor experiences semi-diurnal tides of two high and two low tides in a 24.8-hour period with pronounced differences in tidal range between neap and spring tides occurring on a 14-day and 28-day lunar cycle. Periods of greatest tidal ranges are known as "spring" tides and the period of lowest tidal amplitude are known as "neap" tides. The tidal amplitude in the lower parts of the estuary is approximately 5 to 6 feet (ft) during neap tides and greater than 8 ft during spring tides. The resultant interaction of stream flow and tidal range allows the salinity intrusion to be detected more than 25 miles upstream near the Interstate 95 (I-95) bridge and the tidal water-level signal to reach approximately 40 miles upstream, near Hardeeville (fig. 2; Bossart and others, 2001).

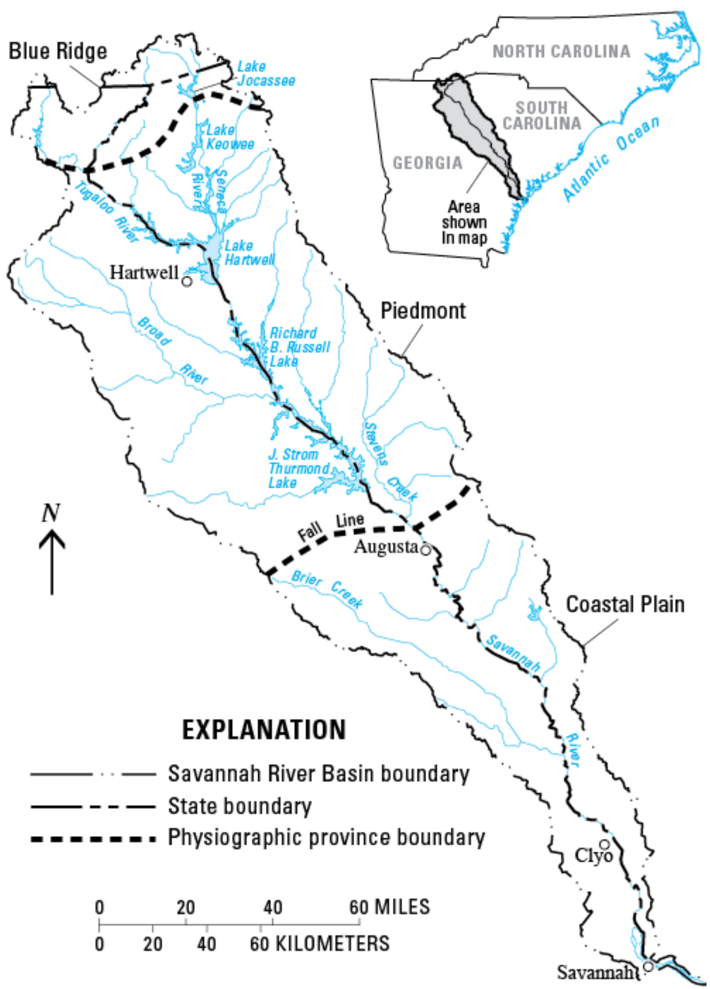

Figure 1. The Savannah River Basin in South Carolina, Georgia, and North Carolina

The Savannah Harbor, as with many major estuarine systems, meets many local and regional water-resource needs. The tidal parts of the Savannah River provide water supply for coastal South Carolina and Georgia, habitat for the extensive freshwater marsh, assimilative capacity for municipal and industrial dischargers, and navigation for a major shipping terminal on the East Coast. With increases in industrial and residential development in Georgia and South Carolina, there are competing, and often conflicting, interests in the water resources of the Savannah River. As part of a proposed deepening of Savannah Harbor and modification of the navigation channel geometry, the environmental effect on many of the ecological and economic resources in Savannah, including the freshwater tidal marshes, are being evaluated by State and Federal resource agencies.

Two important resources are located in the Savannah River Estuary – the Savannah National Wildlife Refuge (SNWR) and the Georgia Ports Authority (GPA) at Port Wentworth. The tidal freshwater marsh is an essential part of the 28,000-acre SNWR (http://www.fws.gov/savannah/). The SNWR is home to a diverse variety of wildlife and plant communities. Neighboring the SNWR, the GPA maintains two deepwater terminal facilities – Garden City Terminal and Ocean Terminal. To support navigation and the terminal activities of the GPA, the river channel and turning basins are maintained by dredging below U.S. Highway 17 Bridge (Houlihan Bridge) to approximately 20 miles offshore from the harbor entrance.

As numerous studies have shown (Odum and others, 1984; Latham, 1990; Gough and Grace, 1998; Howard and Mendelsson, 1999), the salinity gradient is a driving force in shaping the vegetative communities of a tidal marsh. The freshwater-dominated parts of the tidal marsh may be the most sensitive of the tidal marshes to alterations of environmental gradients. Freshwater tidal marshes generally have a greater diversity of plant communities compared to saltwater tidal marshes. In the late 1970s, the tidal freshwater wetlands of the lower Savannah River were estimated at 5,538 acres (Tiner, 1977). Since that time, the

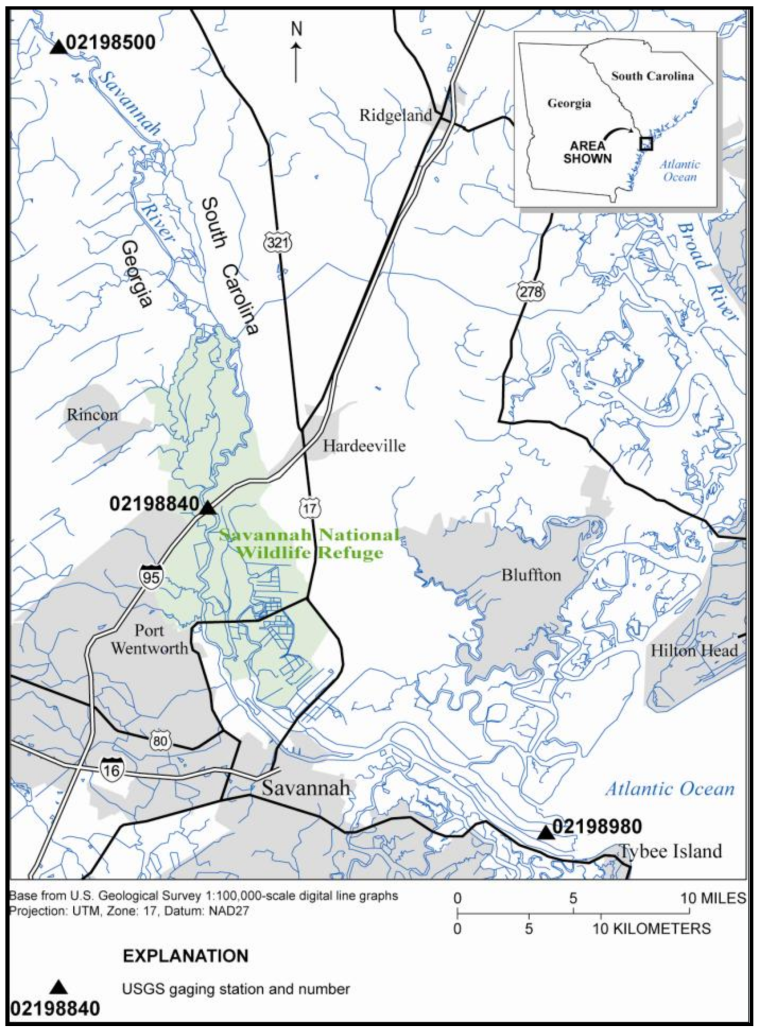

Figure 2. Map showing the location of the Savannah River at Clyo, Ga., (station 02198500) and the I-95 (station 02198840) gages.

amount of tidal freshwater marsh in the Savannah Estuary has been reduced due to salinity intrusion by approximately 40 percent to 2,269 acres (E. EuDaly, U.S. Fish and Wildlife Service-retired, written commun., December, 2009). The remaining tidal freshwater marsh is an essential part of the 28,000-acre SNWR.

Drought Conditions in the Southeast: The Southeastern U.S. experienced severe drought conditions in 2008 and if the conditions had persisted in Georgia and South Carolina, the Savannah River Reservoirs could have reached Level 4 of the Savannah River Basin Drought Contingency Plan (U.S. Army Corps of Engineers, 1989, 2006). Level 4 allows for a reduction of discharges from Thurmond Dam to the net tributary inflow to the reservoir (fig. 1). To decrease the effect of the reduced releases on downstream resources, a stepped approach was proposed to reduce the flow in increments of 500 cubic feet per second (ft^3/s) in weekly intervals. The current minimum release of 3,600 ft^3/s would be followed by reductions to 3,100 ft^3/s and 2,600 ft^3/s.

Reduced flow releases affect the salinity intrusion in the Lower Savannah River Estuary. The location of the saltwater-freshwater interface is a balance between upstream river flows and downstream tidal forcing (fig. 3). During periods of high streamflow, it is difficult for salinity to intrude upstream, and thus, the saltwater-freshwater interface is moved downstream towards the ocean. During periods of low streamflow, salinity is able to intrude upstream; subsequently, the saltwater-freshwater interface is moved upstream. During periods of medium streamflow and greater (streamflow greater than 10,000 ft^3/s at Savannah River at Clyo, Ga.), the salinity values are low. During periods of low flow (streamflow less than 5,000 ft^3/s), salinity values increase.

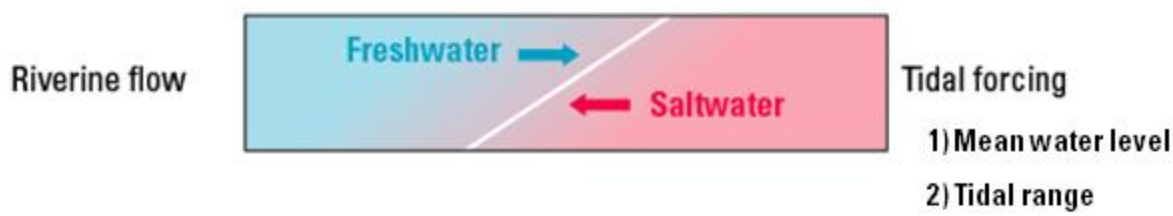

Figure 3. Conceptual model of the location of the freshwater-saltwater interface.

MODELING APPROACH

The reduced flows were simulated with two previously developed models of the Lower Savannah River Estuary to evaluate the potential effects on salinity intrusion. The models are the Model-to-Marsh Decision Support System (M2MDSS; Conrads and others, 2006) developed by the U.S. Geological Survey (USGS) and Advanced Data Mining International (ADMI) and the Environmental Fluid Dynamic Code (EFDC; Hamrick, 1992; Tetra Tech, 2005) developed by U.S. Environmental Protection Agency and Tetra Tech. The empirical M2MDSS was trained using data-mining algorithms that include artificial neural network (ANN) models. Eleven years of data were used to train the ANN models. The 3-dimensional mechanistic model, EFDC was calibrated and validated using continuous data collected in the summers of 1999 and 1997, respectively, and confirmed using 7 years of continuous data from 7 USGS streamgages in the estuary. Flow inputs for both models are streamflows at USGS streamgage 02198500, Savannah River at Clyo, Ga. (fig. 2).

The end of the previous drought (2002) was selected as the baseline condition for the simulations with the models. Figure 4 shows hourly salinity time series at the I-95 Bridge (fig. 2) and the simulated salinity from each model. The coefficient of determination (r^2) for the EFDC model and M2MDSS for the 6-month simulation period are 0.10 and 0.90, respectively. The root mean square error for the two models are 0.10 and 0.03 practical salinity units (psu), respectively. Salinity intrusion coincided with the 28-day cycle semi-diurnal tidal cycles. The majority of the salinity intrusions during 2002 were less than 0.2 psu and the durations were for two hours or less for one or two tides. The exception is the intrusion that occurred on August 7, 2002 when the salinity increased to over 4 psu when Tropical Storm Christobal stalled off the South Carolina coast. The EFDC model generally over predicts the salinity values, over predicts the magnitude of the 28-day salinity intrusion, and under predicts the large intrusion event in early August. The M2MDSS better simulates the 28-day salinity intrusion cycle and the larger intrusion events in August and December 2002.

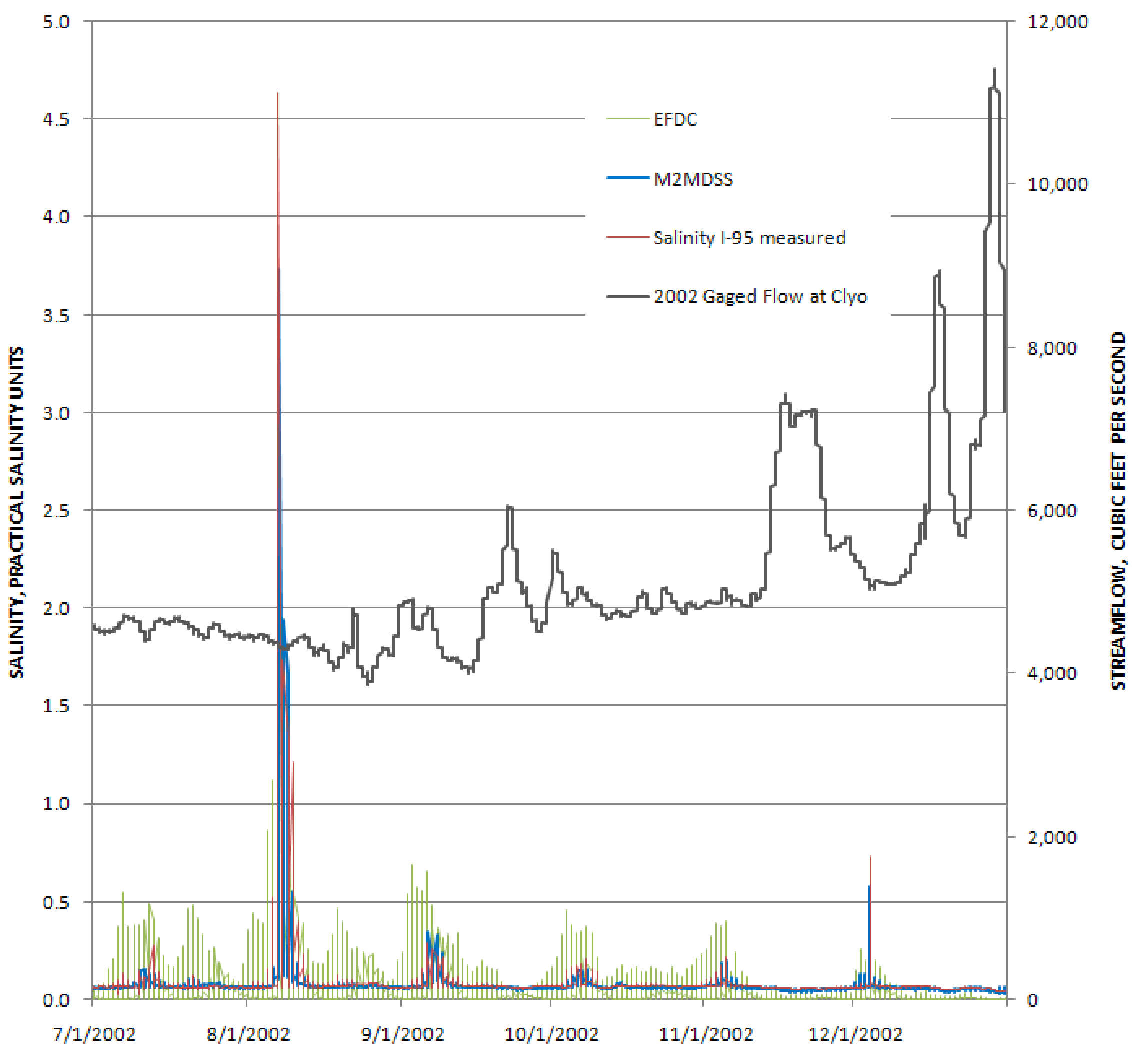

Figure 4. Measured and simulated hourly salinity values for the USGS streamgage at I-95 for the period June 1 to December 31, 2002.

For any modeling effort, empirical or mechanistic, the reliability of the model is dependent on the completeness of the datasets and on the quality of the data and range of measured conditions used for training or calibrating the model. Often models used for environmental regulation or planning simulate conditions beyond the range of data used to calibrate or train a model. It should be noted that both models must extrapolate beyond the range of data used to train and calibrate the models to simulate the proposed decreases in controlled releases.

To relate these flows to values at Savannah River at Augusta, Ga. (station 02197000), an assumption on the inflow between Augusta and Clyo is required. For the period October 22, 2007 (the beginning of 3,600 ft^3/s flows from Thurmond) to January 22, 2008, median inflow between Augusta and Clyo (after applying a simple routing) was 535 ft^3/s. Assuming a tributary inflow of 500 ft^3/s between Augusta and Clyo, the simulated flow conditions are approximately analogous to a flow condition of 2,600 ft^3/s at Augusta.

MODEL RESULTS AND DISCUSSION

The modeling results show a difference of how the estuary will respond to the decreased flows (fig. 5). The M2MDSS salinity response shows a large increase in the magnitude (> 6.0 psu) and duration (3-4 days) of the salinity intrusion. The salinity intrusion event still occurs on a 28-day cycle and also simulates extended periods (21-days) of tidal freshwater remain in the system at I-95. The EFDC model predicts increases in the magnitude of the salinity intrusion but only to 2 and 3 psu and the duration is greater than a week. The EFDC salinity intrusion predictions occur on a 14-day cycle and does not show extended periods of freshwater in the upper estuary but an overall increase in the minimum salinity of greater than 0.5 psu. The EFDC predicts a change in the estuary type from tidal freshwater (a maximum of 0.5 psu) to an oligohaline estuary (a maximum of 5 psu).

Potential Mitigation Approach to Minimize Salinity Intrusion: For salinity to intrude into the upper reaches of the Savannah River Estuary, a convergence of conditions needs to occur. During the 28-day spring tide that is associated with the new moon, streamflows need to be low. Elevated mean coastal water levels (fig. 3), such as occur during tropical storms, can exacerbate the magnitude of the salinity intrusion. Because of the periodicity of the lunar orbit, there is the opportunity to minimize salinity intrusion by increasing streamflows to limit the extent of salinity intrusion. A potential mitigation approach to the increased salinity intrusion predicted by the M2MDSS would be to time pulses of increase flows to reduce the magnitude of the salinity intrusion.

Seven-day streamflow pulses of 4,500 ft^3/s were inserted into the constant 3,100 ft^3/s streamflow condition in the M2MDSS simulation to evaluate the potential of reducing increases in salinity intrusion due to the reduced flows. The results of the streamflow pulses are shown in figure 6. The streamflow pulses did substantially decrease the magnitude and duration of the salinity intrusion. The intrusion events in September, October, and November of 2002 were reduced from over 6 psu to below 3, 1, and 0.5 psu, respectively. As previously discussed, the salinity intrusion event in August 2002 occurred when Tropical Storm Christobal was stalled along the

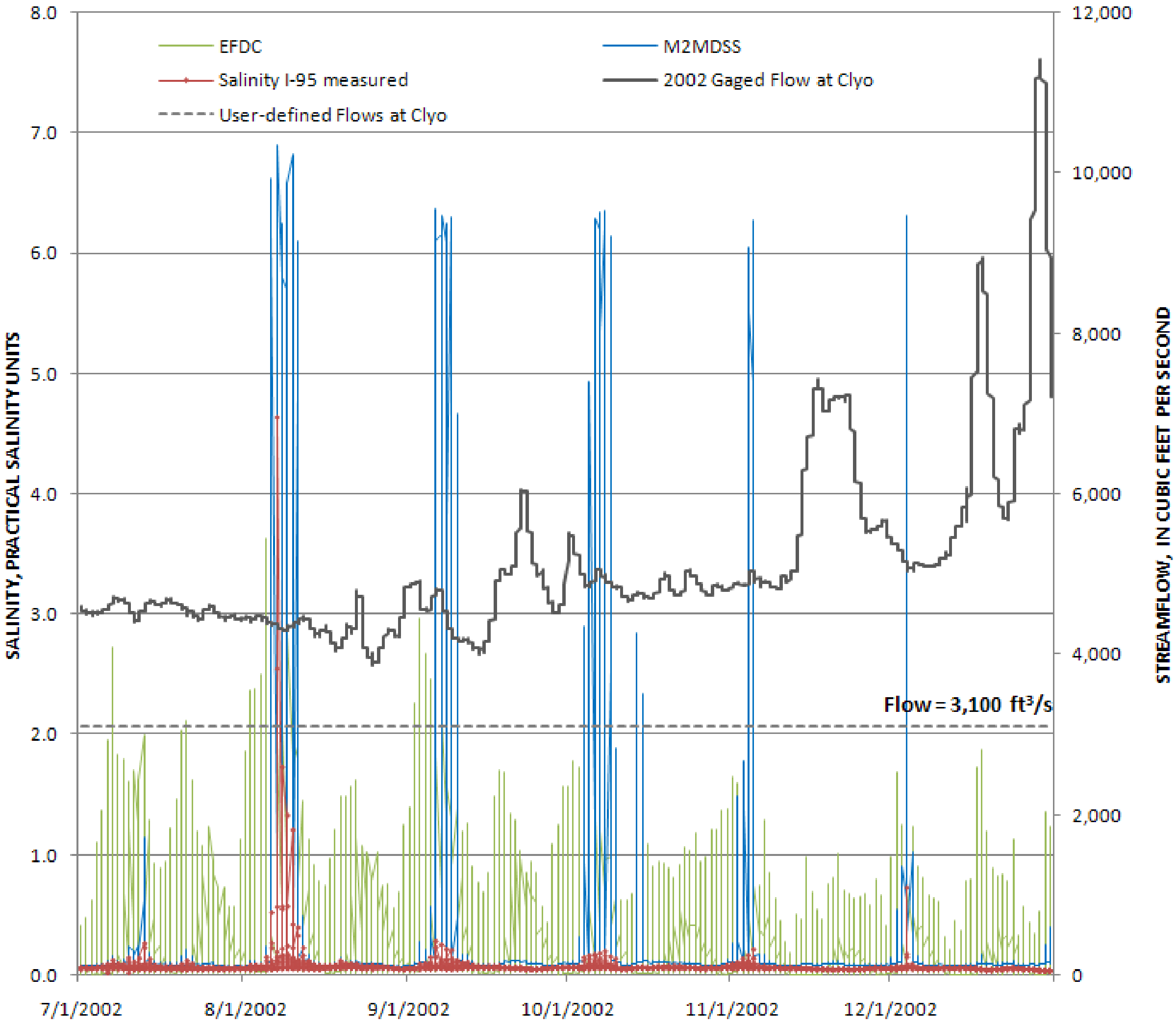

Figure 5. Hourly salinity response at I-95 to a user defined constant flow of 3,100 ft^3/s.

South Carolina coast. The pulsed flows did not reduce the magnitude of the predicted salinity intrusion due to the constant streamflow of 3,100 ft^3/s but did reduce the duration of the event.

The result of the streamflow pulse scenario demonstrates how alternative release patterns from Lake Thurmond could be utilized to mitigate potential salinity changes in the Lower Savannah River Estuary. Although additional water is released from Thurmond Lake to protect the tidal freshwater marshes of the Savannah National Wildlife Refuge, the volume is minimized by timing the releases to occur to have the maximum effect during the spring tide of the new moon. A similar mitigation approach could be used for other alterations to the system that would increase salinity intrusion including harbor deepening and sea-level rise due to climate change. The mitigation approach could also be used to protect other water resources including municipal and industrial freshwater withdrawals in the vicinity of the I-95 Bridge.

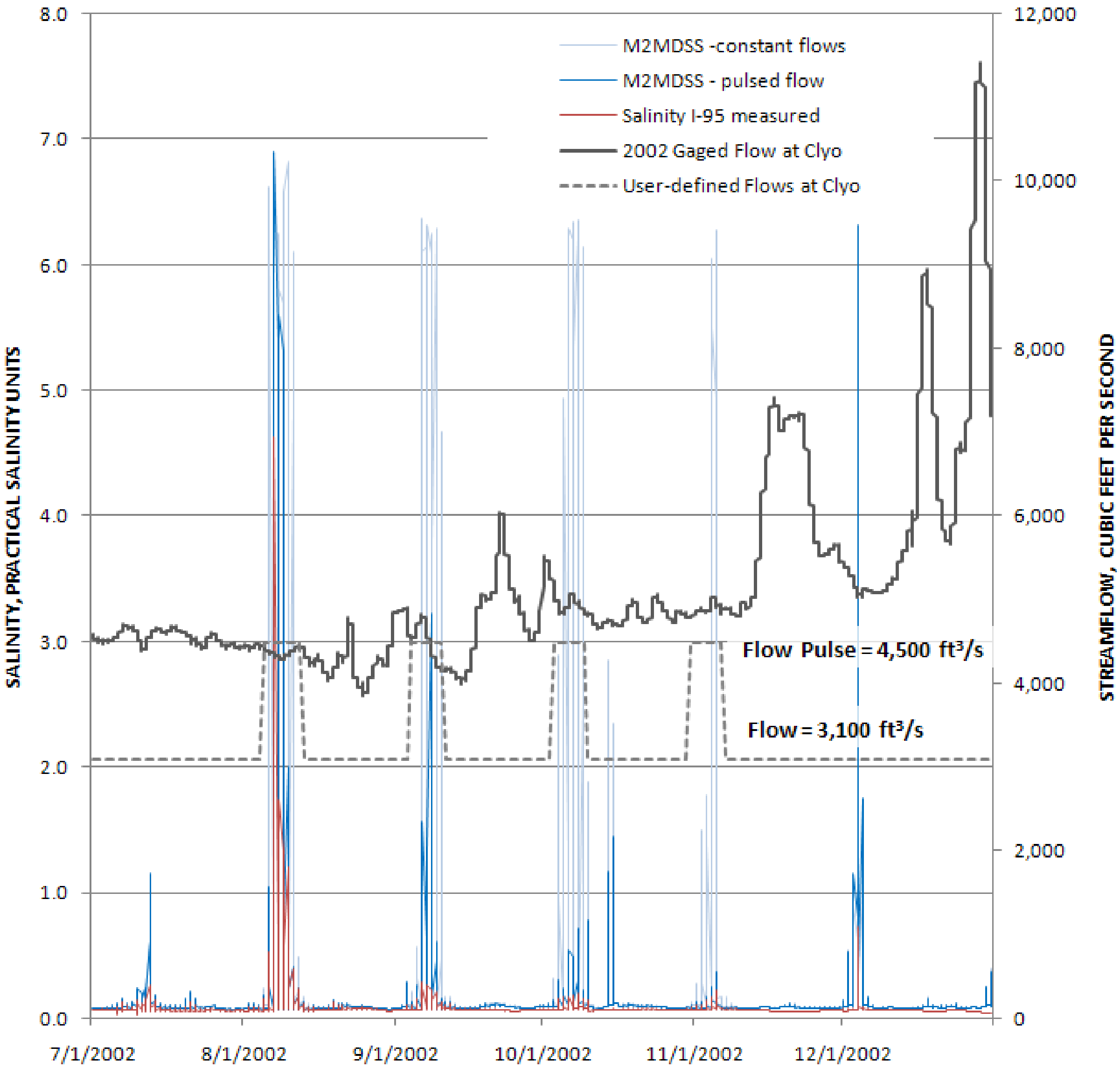

Figure 6. Hourly salinity response at I-95 to user defined hydrograph with streamflow pulsed inserted to minimize salinity intrusion.

REFERENCES

Bossart, J., Kitchens, W.M., and Dusek, M. L. (2001), Assessing salinity induced changes to tidal freshwater and oligohaline marsh habitats in the lower Savannah River. Watershed 2002 Specialty Conference, Fort Lauderdale 2002.

Conrads, P.A., Roehl, E.A., Daamen, R.C., and Kitchens, W.M. (2006), Simulation of water levels and salinity in the rivers and tidal marshes in the vicinity of the Savannah National Wildlife Refuge, Coastal South Carolina and Georgia: U.S. Geological Survey, Scientific Investigations Report 2006-5187, 134 p.

Gough, Laura and Grace, J.B. (1998), Effects of flooding, salinity, and herbivory on coastal plant communities, Louisiana, United States, Oecologia 117(4), p. 527-535.

Hamrick, J.M. (1992), A three-dimensional environmental fluid dynamics computer code: theoretical and computational aspects, The College of William and Mary, Virginia Institute of Marine Science. Special Report 317, 63 p.

Howard, R. J., and Mendelsson, I.A. (1999), Salinity as a constraint on growth of oligohaline marsh macrophytes – Salt pulses and recovery potential. American Journal of Botany 86, p. 795-806.

Latham, P.J. (1990), Plant distributions and competitive interactions along a gradient of tidal freshwater and brackish marshes. Dissertation presented to the graduate school of the University of Florida.

Odum, W.E., Smith, T.J.III, Hoover, J.K., and McIvor, C.C. (1984), The ecology of tidal freshwater marshes of the United States east coast: A community profile, U.S. Fish and Wildlife Service, FWS/OBS-83/17, Washington, D.C., 177 p.

Pearlstine, L.G. Latham, P.J., Kitchens, W.M., and Bartleson, R.D. (1990), Development and application of a habitat succession model for the wetland complex of the SNWR: volume II, final report, Submitted to the U.S. Fish and Wildlife Service, Savannah Coast Refuges, by the Florida Cooperative Fish and Wildlife Research Unit, Gainesville, Florida.

Sanders, C.L., Kubik, H.E., Hoke, J.T., and Kirby, W.H., (1990), “Flood frequency of the Savannah River at Augusta, Georgia,” U.S. Geological Survey Water-Resources Investigations Report 90-4024, 87 p.

Tetra Tech (2005), Development of the EFDC hydrodynamic model for the Savannah Harbor. Prepared for the U.S. Army Corps of Engineers – Savannah District, Tetra Tech, Inc. Atlanta, Georgia.

Tiner, R.W. (1977), An inventory of South Carolina’s coastal marshes, Office of Conservation and Management, South Carolina Wildlife and Marine Resources Department, Charleston, SC, Technical Report Number 23, 33 p.

US Army Corps of Engineers (1989), Savannah River Basin Drought Contingency Plan, avannah District, March 1989. H http://water.sas.usace.army.mil/pub/1989%20Drought%20Plan/DCP1989/

US Army Corps of Engineers (2006), Final Environmental Assessment and Finding of No Significant Impact Drought Contingency Plan Update Savannah River Basin, Savannah District, August 2006 http://water.sas.usace.army.mil/pub/Final%20SRB%20Drought%20EA%20Aug%2006/F final%20SRB%20Drought%20EA%20Aug%2006.pdf