SAVANNAH HARBOR DEEPENING PROJECT
USGS/USFWS MARSH SUCESSION MODEL
MARSH/WETLAND IMPACT EVALUATION

June 2007

Purpose:

The purpose of the Marsh Succession Modeling is to determine the impacts of deepening the Savannah Harbor navigation channel; specifically, the effect on the tidal marsh vegetation communities as a result of salinity increases in the system. The marsh succession modeling was used to provide estimates of tidal marsh vegetation communities within the freshwater and brackish marshes of the Back, Middle, and Front rivers under various deepening and sea level rise conditions.

Model Input Conditions:

Predictions of salinity input for the MSM were developed through the use of a separate hydrodynamic and salinity computer model. The Environmental Fluid Dynamic Code (EFDC) model developed by Dr. John Hamrick and currently supported by Tetra Tech for U.S. Environmental Protection Agency (USEPA) Office of Research and Development (ORD), USEPA Region 4, and USEPA Headquarters was used in this effort. Although a number of models provide some of the features necessary for modeling the hydrodynamics in the Savannah River Estuary, the EFDC hydrodynamic and sediment transport model linked with the Water Quality Analysis Simulation Program (WASP) was determined to provide the most appropriate features necessary for the overall Savannah Harbor Expansion Project study (Tetra Tech, 2006).

EFDC solves three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable-density fluid. Dynamically-coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature are also solved (USEPA, 2007). The boundary conditions of the EFDC model used in simulating the processes of the Savannah River Estuary consist of: offshore salinity, temperature, and water surface elevation; upstream flow and temperature; adjacent marsh areas; and meteorological forcing conditions. The main model coefficients are: bathymetry, bottom roughness and vertical mixing. The EFDC model predicts time series of the surface water elevation, currents, flow, temperature, and salinity as a result of changes in the channel geometry. Details on the Savannah Harbor EFDC model development, calibration and validation is provided in Tetra Tech, 2006 *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project* report.

The EFDC hydrodynamic model makes predictions of water level and salinity parameters within the confines of the estuarine rivers and main tidal creeks. The project needed a way to translate salinity predictions in those hydraulic channels to the marshes where the vegetation communities occur. To accomplish this, the Georgia Ports Authority (GPA) employed the Columbia, South Carolina office of the US Geological Survey (USGS) to develop a tool capable of translating EFDC riverine predictions across the estuary to the marsh root zones. The variability of pore-water salinity in the tidal marshes is a result of the adjacent river salinity concentration, the tidal creek connections to the river, elevation of the marsh and surrounding berms, soil type and the conditions of old abandoned rice fields and berms, and volume of water within the marsh (USGS, 2007). In order to simulate the dynamic response of the water level and salinity in the tidal marshes, the USGS, in collaboration with Advance Data Mining, developed the Model-to-Marsh (M2M) decision support system. The M2M was developed using data-mining techniques and artificial neural network (ANN) models.

The M2M model uses time-series data of the salinity, and water levels in the rivers networks near the USGS and ATM marsh gaging sites to simulate water level and pore water salinity within the adjacent marsh. To predict the change in water level and pore water salinity in the marsh likely to result from a potential harbor deepening, simulated water-level and salinity changes in the river resulting from proposed geometric channel changes as predicted by the EFDC model are used. Using the USGS river network time series as input for the marsh, the ANN models accommodate the integration of output from the EFDC model. Details on the Savannah Harbor M2M system development and validation is provided in Conrads et al., 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*.

The wetland/marsh impact evaluation input data was developed by the Savannah Harbor Expansion Wetland Interagency Coordination Team. The group developed four model input scenarios for evaluation (See Table 1).

Table 1- Model Input Conditions

RUN SCENARIO	RIVER FLOW	SEA LEVEL RISE	EVALUATION PERIOD
Basic Evaluation	Average/Typical	Existing Sea Level	1-March to 1-October
Sensitivity Analysis #1	Low Flow/Dry	Existing Sea Level	1-March to 1-October
Sensitivity Analysis #2A	Average/Typical	25 cm Sea Level Rise	1-March to 1-October
Sensitivity Analysis #2B	Average/Typical	50 cm Sea Level Rise	1-March to 1-October

**25 and 50 cm sea level rise conditions were specified by the Interagency Coordination Team, based on Environmental Protection Agency and National Oceanic Atmospheric Administration projections.*

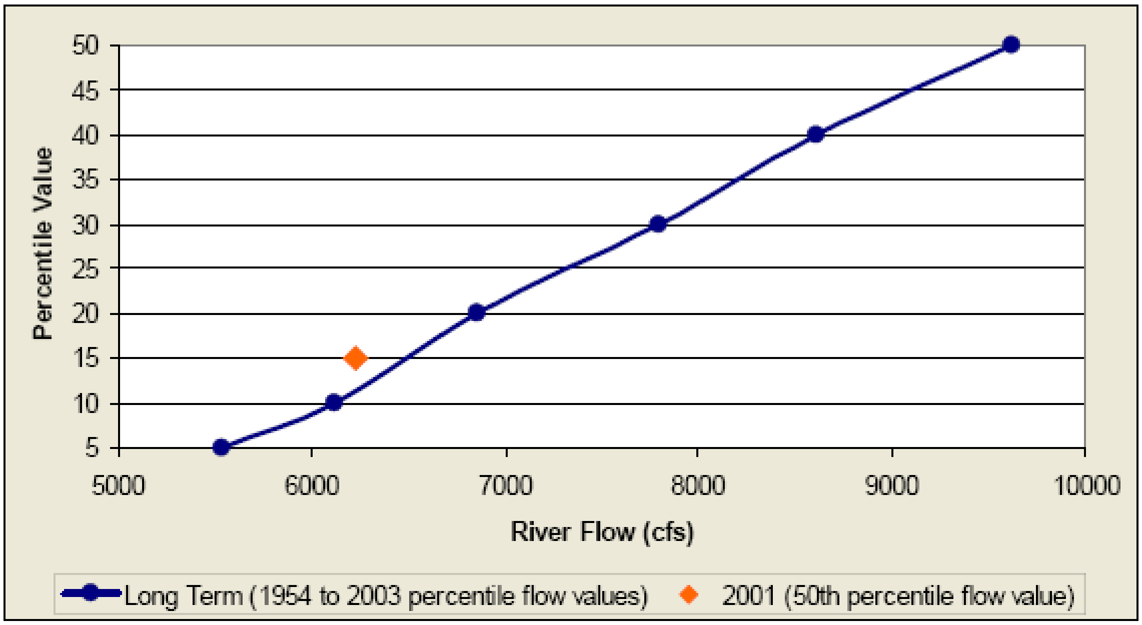
Average/typical river flows needed for the Basic Evaluation and Sensitivity Analysis #2A and B were determined using recorded gage data for Savannah River at Clyo, GA. The EFDC model has continuous input boundary conditions for a 7 year period (1997 - 2003) available for simulation. 1997 was found to have flow conditions representative of the long term average flows.

Table 2- Average River Flows from USGS gaging station at Clyo, GA

Period of Record	Mar. (cfs)	Apr. (cfs)	May (cfs)	June (cfs)	July (cfs)	Aug. (cfs)	Sept. (cfs)	Oct. (cfs)	Overall (cfs)
Long Term (1954-2003)	*17,998*	*17,205*	*12,029*	*10,254*	*9,118*	*9,035*	*8,566*	*8,615*	**11,603**
1997 Only	*22,016*	*11,380*	*12,527*	*9,729*	*8,853*	*9,944*	*6,370*	*7,627*	**11,056**
Percent Difference	*-22%*	*34%*	*-4%*	*5%*	*3%*	*-10%*	*26%*	*11%*	**5%**

The maximum percent difference is 34% occurring in April, meaning April of 1997 had less freshwater flowing downstream into the estuary than the long term average. Overall, the percent difference between the long term average and 1997 is 5%. Therefore, the growing season (March through October) of 1997 was considered to be an average flow period for modeling purposes. The flow boundary conditions for Sensitivity Analysis #1 are low flow or dry year conditions. Using the recorded gage data at Clyo, GA, 2001 (March through October) was considered to be a low flow/dry period (See Figure 1).

Figure 1- River Flows from USGS gaging station at Clyo, GA



The long term Clyo gage data shows that low flow values range from 5,534cfs (5th percentile) to 6,858 cfs (20th percentile). The 50th percentile flow value during 2001 is 6,228 cfs. This value, 6,228 cfs, is approximately the 15th percentile value when looking at the long term Clyo flow data. Therefore, 2001 was considered a low flow/dry year for model simulations.

The two sea level rise conditions used in Sensitivity Analysis #2A and B were modeled by adding an additional 25 or 50 cm, depending on the run scenario, to the water surface elevations on the open ocean boundary cells in the EFDC model. The sea level rise sensitivity analyses are based only on a change in the ocean boundary water surface elevation. There was no consideration of any potential change in the ocean boundary salinity density in EFDC modeling effort.

All other model boundary inputs remain unaltered and correspond to the run time of 1 March to 1 October for 1997 or 2001, depending on the run scenario being modeled.

Model Limitations:

The reliability of the model is dependent on the quality of the data and range of measured conditions used in its development. The available period of record for the river and/or marsh data-collection networks can limit the conditions that the given model can accurately simulate. The pore water salinity observed during marsh data collection and for which the model decision trees were developed for the MSM were within the gradient range of 0 to 7 ppt with river flows between 4,320 – 39,600 cfs.

USGS marsh sampling stations used to determine the ecological community response to changes in the pore water salinity were located throughout the marsh, but these were predominantly stratified along the Back River to document tide gate disruptions in the 1980's. Three marsh sites were added in the freshest areas of the Front and Middle rivers in 2000. Community compositions and distributions along the more saline sections of the Middle and Front rivers did not provide as much coverage and likely have less predictive value (Welch, 2006).

The majority of the misclassification and error in the model came from a mixed community of *Eleocharis montevidensis* (ELEMO), *Scirpus validus* (SCIVA) and *Zizaniopsis miliacea and Polygonum* spp (ZIZMI_POLSP) groups all occurring at low salinities, < 52 m from the nearest creek but in soils with > 55 % organic content. This leaf consisted of 18 % of the data samples and was representative of the highly competitive, variable and diverse marshes that occur in the more freshwater areas of the Savannah River (Welch and Kitchens, 2006).

The model simulates long term impacts from changes in pore water salinity within the marsh system from harbor deepening and sea level rise. Other aspects of extreme short term events such as riverine floods and storm surges and impacts of climate change, such as CO concentration, and the varying response of C3 and C4 plants were are not evaluated.

Output Generated:

Two types of maps were generated to aid in evaluation of the salinity impacts of deepening on the freshwater marshes: (1) plan view maps showing distributions of the predicted marsh vegetation communities (baseline conditions (42-ft depth), 44-, 45-, 46-, and 48-ft depth) and (2) plan view maps showing changes in distribution of the predicted marsh vegetation communities from baseline conditions.

To help further aid in the evaluation of salinity impacts of deepening on the freshwater and brackish tidal marshes tables providing the predicted total acreages of each vegetation community for both the without project condition and each deepening scenario and net changes in acreages of each type of vegetation community under each deepening scenario are provided. These tables are intended to provide reviewers with a sense of the general magnitude of the patterns of simulated changes that are depicted in the ecological community maps.

Findings:

Basic Evaluation: The Basic Evaluation includes five model runs each with a different channel depth: existing conditions (42-ft depth), 44-ft, 45-ft, 46-ft and 48-ft depths. The input conditions for the runs are pore water salinity of marsh sediments based on average/typical river flow and existing sea level. The evaluation period is 1 March to 1 October 1997.

Ecological Community Shift maps in Appendix A show predicted changes in marsh vegetation communities throughout the estuary associated with pore water salinity changes within the marsh from channel deepening. These maps are a comparison between the baseline average/typical river flow under existing sea level and each deepened condition. The predicted impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front and Middle rivers. The largest change in vegetation communities are in the *Eleocharis montevidensis, Galium tinctorum and Sagittaria latifolia* (ELEMO_GALTI_SAGLT) community along the Middle River north of Steamboat River. In this location there is an increased presence of *Zizaniopsis miliacea, Polygonum* spp. and *Murdania kesiak* (ZIZMI_POLSP_MURKE) and *Scirpus validus* (SCIVA). Other changes are seen in the SCIVA dominated community along the Back River south of New Cut and in the ZIZMI_POLSP_MURKE dominated community along the Middle and Front rivers near Steamboat River and the Back River north of New Cut. Portions of the intermediate/transitional SCIVA community are replaced by a brackish community dominated by *Spartina* spp. (SPASP), with subdominants *Scirpus robustus* (SCIRO) and *Aster tenuifolius* (ASTTE). Portions of the freshwater community ZIZMI_POLSP_MURKE are replaced by an intermediate/transitional community dominated SCIVA.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. Although all the deepening scenarios show an impact on the freshwater tidal marsh communities the largest community shifts are seen under the 6-foot deepening scenario. A quick view of the Wetland/Marsh Impact Evaluation table in Appendix A does not tell the full story of pore water salinity impacts to freshwater tidal marsh communities with deepening. The Ecological Community maps and Ecological Community Shift in Appendix A maps provide a clearer picture of what is happening in the areas of greatest concern: Middle, Little Back, and Back rivers.

Sensitivity Analysis #1: Sensitivity Analysis #1 includes five model runs each with a different channel depth: existing conditions (42-ft depth), 44-ft, 45-ft, 46-ft and 48-ft depths. The input conditions for the runs are pore water salinity of marsh sediments based on low flow/dry river flow and existing sea level. The evaluation period is 1 March to 1 October 2001.

Ecological Community Shift maps in Appendix B show changes in marsh vegetation communities throughout the estuary associated with pore water salinity changes within the marsh from channel deepening. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front and Middle rivers. The largest change is in the *E. montevidensis (*ELEMO) dominate community along the Front and Middle rivers north of Steamboat River and in the *E. montevidensis, S. Validus, and Z. miliacea and Polygonum* (ELEMO, SCIVA, ZIZMI_POLSP) community located adjacent to the primary and secondary channels along the Front and Middle rivers. In these areas there is a shift to a SCIVA dominate community. Other areas of community shifts are along the Back River and lower Middle River. In these areas the freshwater community dominated by ZIZMI_POLSP is replaced by an intermediate/transitional community dominated by SCIVA. Areas of the intermediate/transitional community dominated by SCIVA are replaced in dominance by the brackish community species of SPASP and SCIRO.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. Although all the deepening scenarios show an impact on the freshwater tidal marsh communities the largest community shifts are seen under the 6-foot deepening scenario. The maximum increases are generally found on the Front River where the deepening is occurring and along the

Middle River; however, under the 6-foot deepening there is a greater shift in communities along the Little Back River. A quick view of the Wetland/Marsh Impact Evaluation table in Appendix B does not tell the full story of pore water salinity impacts with deepening. The Ecological Community maps and Ecological Community Shift maps in Appendix B provide a clearer picture of what is happening in the areas of greatest concern: Middle, Little Back, and Back rivers.

Sensitivity Analysis #2A: Sensitivity Analysis #2A includes five model runs each with a different channel depth: existing conditions (42-ft depth), 44-ft, 45-ft, 46-ft and 48-ft depths. The input conditions for the runs are pore water salinity of marsh sediments based on average/typical river flow and a 25 cm sea level rise. The evaluation period is 1 March to 1 October 1997.

Ecological Community Change maps in Appendix C show shifts in marsh vegetation communities throughout the estuary associated with pore water salinity changes from channel deepening. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front and Middle rivers. The largest change in vegetation communities are in the ELEMO_GALTI_SAGLT community along the Front, Middle and Back rivers north of Steamboat River. In these locations there is an increased presence of ZIZMI_POLSP_MURKE and SCIVA. Other large changes are seen in the SCIVA dominated community along the Back River and lower Middle River near New Cut and in the ZIZMI_POLSP_MURKE dominated communities along the Front, Middle and Back rivers. Areas of the SCIVA community along the Back and lower Middle River is replaced by a dominate SPASP community, with subdominants SCIRO and ASTTE. Areas of the ZIZMI_POLSP_MURKE dominate community along the Front Middle and Back rivers are replaced by SCIVA.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. The largest community shifts are seen under the 6-foot deepening scenario. In addition to changes in distributions of communities the results of the 6-foot deepening under 25 cm sea level rise, indicate significant structural and compositional change in the ELEMO dominated community along the Front, Middle and Little Back rivers. This compositional change is indicated by a loss in species diversity. With the 6-foot deepening there is a loss of salt-sensitive subdominants like GALTI and SAGLT. Other areas of compositional change are seen along the Back River in the more saline communities. This area shows a loss in subdominant ASTTE, which is a mildly salt-tolerant species. A quick view of the Wetland/Marsh Impact Evaluation table in Appendix C does not tell the full story of pore water salinity impacts associated with deepening. The Ecological Community maps and Ecological Community Shift maps in Appendix C provide a clearer picture of what is happening in the areas of greatest concern: Middle, Little Back, and Back rivers.

Sensitivity Analysis #2B: Sensitivity Analysis #2B includes five model runs each with a different channel depth: existing conditions (42-ft depth), 44-ft, 45-ft, 46-ft and 48-ft depths. The input conditions for the runs are pore water salinity of the marsh based on average/typical river flow and a 50 cm sea level rise. The evaluation period is 1 March to 1 October 1997.

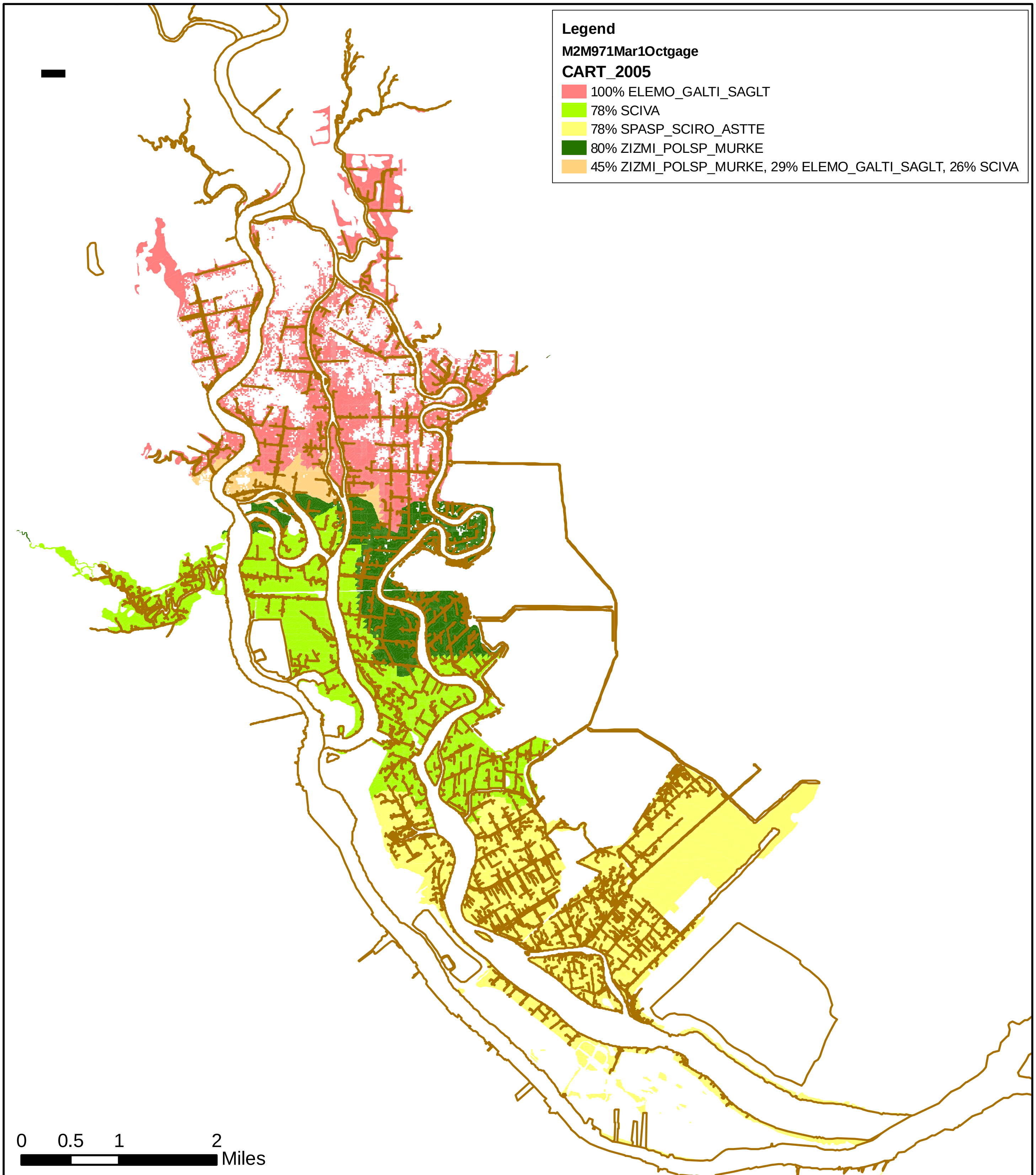
Ecological Community Change maps in Appendix D show shifts in marsh vegetation communities throughout the estuary associated with pore water salinity changes from channel deepening. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front and Middle rivers. The largest change in vegetation communities are in the ELEMO_GALTI_SAGLT community along the Front, Middle, and Back rivers north of Steamboat River. In these locations there is an increased presence of ZIZMI_POLSP and SCIVA. Other large changes are seen in the SCIVA dominated community along the Back River and lower Middle River near New Cut and in the ZIZMI_POLSP_MURKE dominated communities along the Front, Middle and Back rivers. Areas of the SCIVA community along the Back and lower Middle River are replaced in dominance by the brackish community species of SPASP and SCIRO. Areas of the ZIZMI_POLSP_MURKE dominate community along the Front Middle and Back Rivers are replaced by SCIVA.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. The largest community shifts are seen under the 6-foot deepening scenario. In addition to changes in distributions of communities the results of the 2-, 3-, 4- and 6-foot deepening with 50 cm sea level rise, indicate significant structural and compositional change in the E. *montevidensis* dominated community along the Front, Middle and Little Back rivers. This compositional change is indicated by a loss in species diversity. Under deepening with 50 cm sea level rise there is a loss of salt-sensitive subdominants like GALTI and SAGLT. Other areas of compositional change are seen along the Back River in the most saline communities. This area shows a loss in subdominant ASTTE, which is a mildly salt-tolerant species. A quick view of the Wetland/Marsh Impact Evaluation table in Appendix D does not tell the full story of pore water salinity impacts to freshwater marsh communities with deepening. The Ecological Community maps and Ecological Community Shift maps in Appendix D provide a clearer picture of what is happening in the areas of greatest concern: Middle, Little Back, and Back rivers.

Conclusion:

The MSM modeling predicts that there will be impacts on the freshwater marsh vegetation communities with each deepening. The level of impact depends directly on the proposed depth of the navigation channel. The trends indicate that as the navigation channel is deepened salinity intrudes further and further upstream resulting in a shift to more salt tolerant species. Rising sea levels results in salt tolerant species propagating even further upstream.

APPENDIX A
BASIC EVALUATION
ECOLOGICAL COMMUNITY MAPS &
ECOLOGICAL COMMUNITY SHIFT MAPS



Savannah Harbor Expansion Project - Wetland/Marsh Impact Evaluation

USGS/USFWS Savannah Marsh Succession Model CART 2005 Predicted Ecological Community
Existing Depth

Values Based on EFDC and M2M Output using Historic Average Flow, Temperature, and Tidal Conditions
1 March through 1 October 1997 (1997 best represents average historic conditions from the available data set)
Existing Sea Level Conditions

March 2007