SAVANNAH HARBOR DEEPENING PROJECT
ATM MARSH SUCESSION MODEL
MARSH/WETLAND IMPACT EVALUATION

May 2007

Purpose:

The purpose of the marsh succession modeling (MSM) 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 are 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 through 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 Applied Technology and Management (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 are 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.**

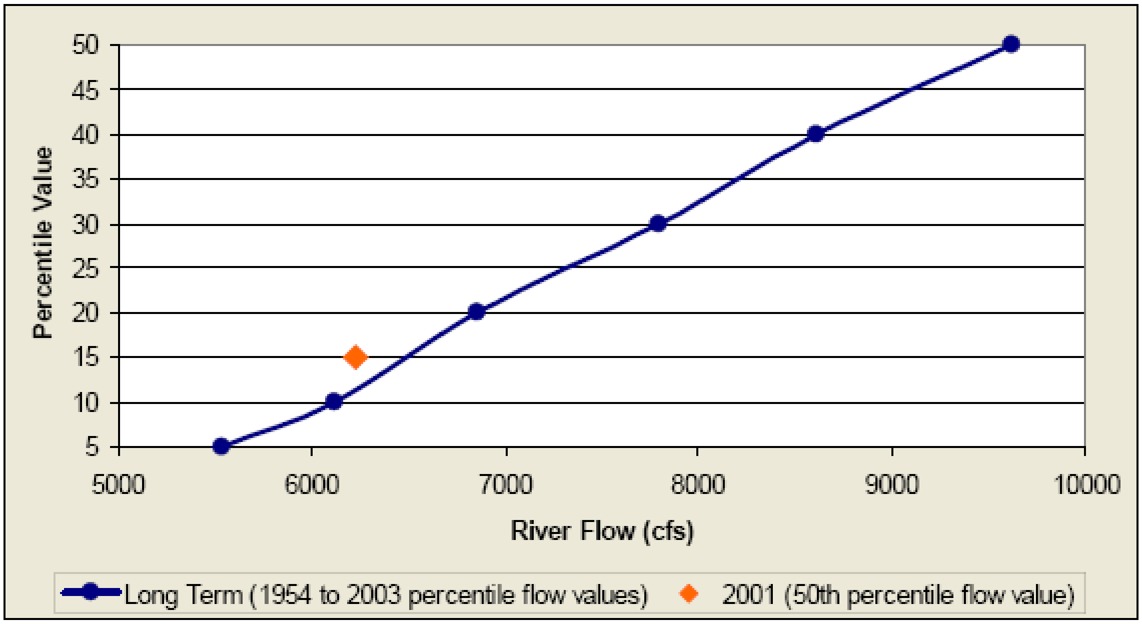
Average/typical river flows needed for the Basic Evaluation and Sensitivity Analysis #2A and B were determined using recorded gage data for Savannah River at Clyo, GA. The EFDC model has continuous input boundary conditions for a 7 year period (1997 - 2003) available for simulation. 1997 was found to 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 at the upstream and downstream boundaries during marsh data collection and for which the model was developed were within the gradient range of 0 to 14.5 part per thousand (ppt) with river flows between 4,320 – 14,100 cfs.

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- depth), 44-, 45-, 46-, and 48-ft depths) 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 the marsh based on average/typical river flow and existing sea level. The evaluation period is 1 March to 1 October 1997.

Ecological Community Shift maps provided in Appendix A show changes in marsh vegetation communities throughout the estuary associated with salinity changes from channel deepening. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front, Middle and Little Back rivers. The largest changes in vegetation communities are in the *Murdannia keisak and Zizaniopsis miliacea (*MK/ZM) and *Eleocharis montevidensis* (EM+) classes along the upper reaches of the Little Back River. In this area there is an increase of *E. montevidensis* and *Z. miliacea* (EM/ZM) and *Scirpus validus* and *Z. miliacea* (SV/ZM). Other large changes are seen in the SV/ZM and EM/ZM dominated classes near the secondary channels along the Back River south of New Cut. In this area there is an increase in the co-dominated *Spartina alterniflora* and *S. validus* (SA/SV) class. Along the Front River the largest simulated changes are in the EM+ class near Steamboat River. In these location areas of the EM+ class is replaced largely by a co-dominated EM/ZM class. Along the Middle River, the largest changes are north of Steamboat River, in the EM/ZM class. In these areas portions of the EM/ZM class is replaced largely by SV/ZM.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. The maximum increases are generally found on the Front River where the deepening is occurring and along the more freshwater location of the Little Back River. A quick view of the Wetland/Marsh Impact table provided in Appendix A does not tell the full story of salinity impacts associated with deepening. The Ecological Community maps and the Ecological Community Shift maps in Appendix A 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 the marsh 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 provided in Appendix B show changes in marsh vegetation communities throughout the estuary associated with changes in salinity from channel deepening. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front, Middle and Little Back rivers. The largest change in vegetation communities are in the EM/ZM class along the Little Back and Front river; the EM+ dominated class along the Front River north of Steamboat River; and the *Z. miliacea* (ZM+) dominated class along the Little Back River. Areas of the EM/ZM class along the Little Back River are replaced largely by classes dominated by SA/SV and MK/ZM under the 2-foot deepening, *S. validus* (SV+) and MK/ZM under the 3-foot deepening and SV/ZM under the 4- and 6-foot deepenings. Areas of the EM/ZM co-dominated class along the Front River near Steamboat River are replaced largely by classes co-dominated by *S. validus* (SV/EM and SV/ZM). Areas of the EM+ dominated class along the Front River north of Steamboat River are replaced largely by classes co-dominated by EM/ZM. Areas of the ZM+ dominated class along the Little Back River are replaced largely by classes co-dominated with MK/ZM under the 2- and 3-foot deepenings and EM/ZM under the 4- and 6-foot deepenings. Along the Middle River north of Steamboat River, areas of the EM/ZM dominated class are replaced largely by a co-dominated SV/EM class under the 6-foot deepening condition. Other changes are seen in the SV/ZM and EM/ZM dominated classes near the secondary channels along the Back River. In this area there is an increase in SA/SV.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. The maximum increases are generally found on the Front River where the deepening is occurring and along the freshwater of the Little Back River; however, with increasing channel depth there are increased losses of freshwater tidal marsh vegetation communities along the Middle River north of Steamboat River as well. A quick view of the Wetland/Marsh Impact table provided in Appendix B does not tell the full story of salinity impacts associated with deepening. The Ecological Community maps and the Ecological Community Shift maps provided 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 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 Shift maps provided in Appendix C show changes in marsh vegetation communities throughout the estuary associated with salinity changes from channel deepening under 25 cm sea level rise. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front, Middle and Little Back rivers. The largest changes in vegetation communities are in the co-dominated MK/ZM class along the upper reaches of the Little Back River and the EM+ and EM/ZM dominated classes along the Little Back and Front rivers. Areas of the MK/ZM class along the upper reaches of the Little Back River are replaced largely by classes dominated by EM/ZM under the 2- and 3-foot deepenings and EM/ZM and SV/ZM under the 4- and 6-foot deepenings. Areas of the EM/ZM dominated class along the Little Back River are replaced largely by classes co-dominated by SV/ZM and ZM+. Areas of the EM/ZM dominated class along the Front River near Steamboat River are replaced largely by classes co-dominated with *S. validus* (SV/EM and SV/ZM). Areas of the EM+ class along the Little Back River and Front River near Steamboat River are replaced largely by an EM/ZM dominated class. Other large changes are seen in the SV/ZM and EM/ZM dominated classes near the secondary channels along the Back River and along areas of the Front River south of Steamboat River. In these areas there are increases in the SA/SV and SV+ classes.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. The maximum increases are generally found on the Front River where the deepening is occurring and along the more freshwater Little Back River. A quick view of Wetland/Marsh Impact table provided in Appendix C does not tell the full story of salinity impacts associated with deepening. The Ecological Community maps and the 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 marsh sediments based on average/typical river flow and a 50 cm sea level rise. The evaluation period is 1 March to 1 October 1997.

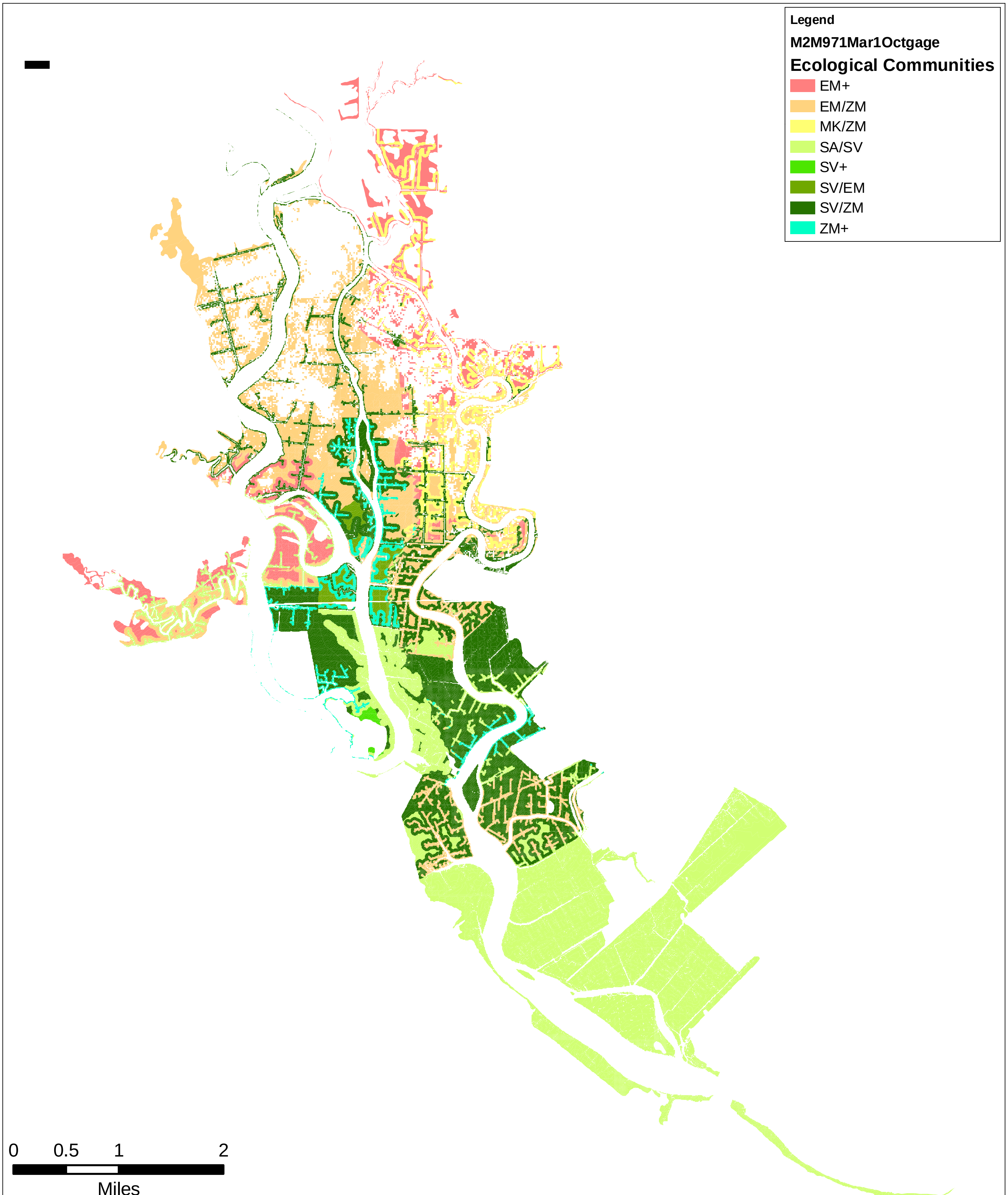
Ecological Community Shift maps provided in Appendix D show changes in marsh vegetation communities throughout the estuary associated with salinity changes from channel deepening under a 50 cm sea level rise. The impacts with deepening just an additional 2 ft, extend above Steamboat River on the Front, Middle and Little Back rivers. The largest change in vegetation communities are in the co-dominated EM/ZM class along the Front, Middle and the Little Back rivers and the SV/ZM dominated class along the Back, Little Back, Middle, and Front rivers. Areas of the EM/ZM dominated class along the Front and the Middle rivers are replaced largely by classes of SV/EM and SV/ZM. Whereas areas of the EM/ZM dominated class along the Little Back River are replaced largely by classes co-dominated by SA/SV and SV+ under the 4- and 6-foot deepenings. Areas of the SV/ZM dominated class near the secondary channels along the Back, Little Back, Middle, and Front rivers are replaced largely by SA/SV and SV+ classes.

The general trend is a loss of freshwater tidal marsh occurring with the increased channel depth. The maximum increases are generally found on the Front River where the deepening is occurring and along the more freshwater Little Back River. A quick view of the Wetland/Marsh Impact Evaluation table in Appendix D does not tell the full story of pore water salinity increase associated with deepening. The Ecological Community map 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.

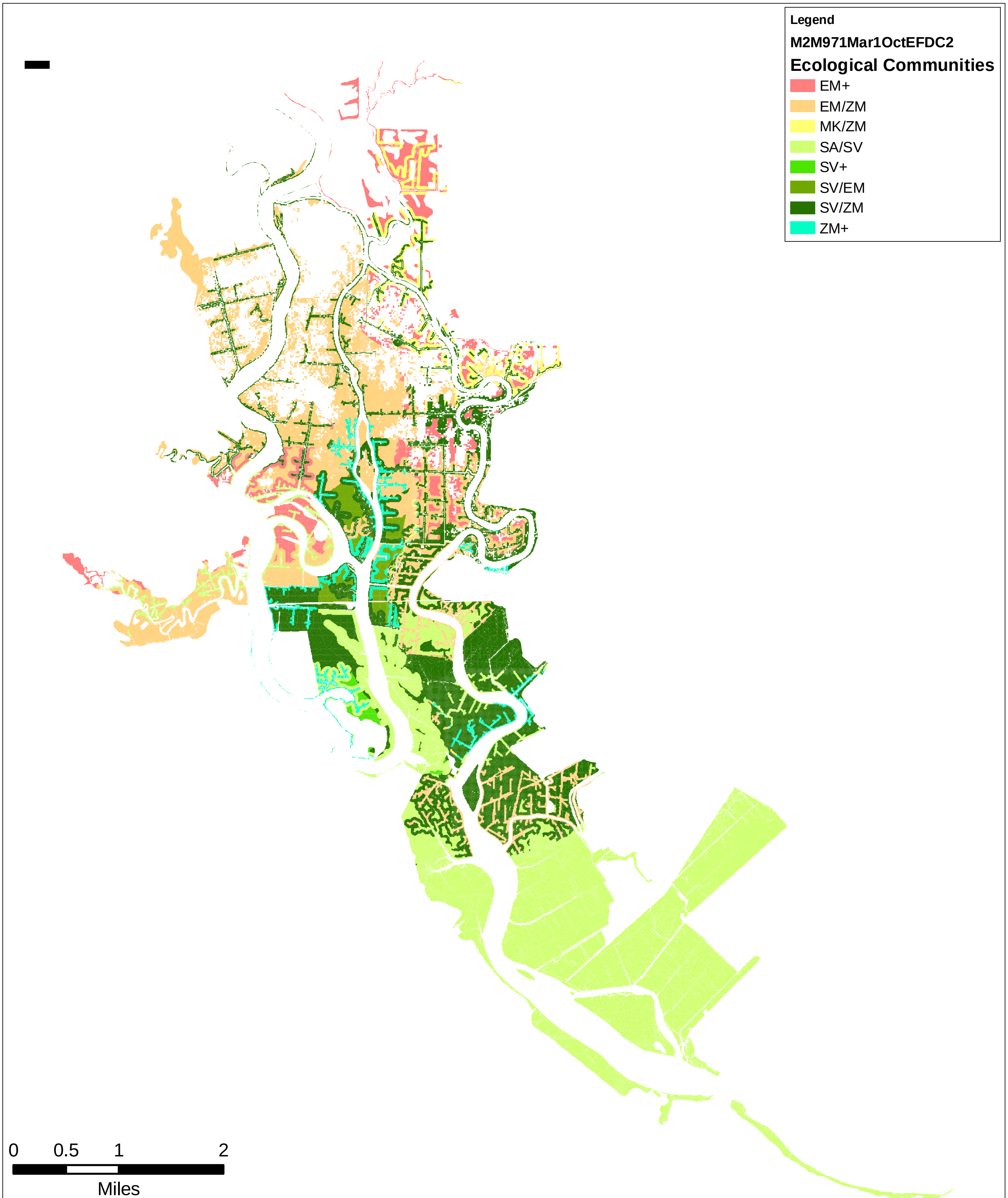
APPENDIX A
BASIC EVALUATION
ECOLOGICAL COMMUNITY MAPS &
ECOLOGICAL COMMUNITY SHIFT MAPS



Savannah Harbor Expansion Project - Wetland/Marsh Impact Evaluation

ATM Savannah Marsh Succession Model 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

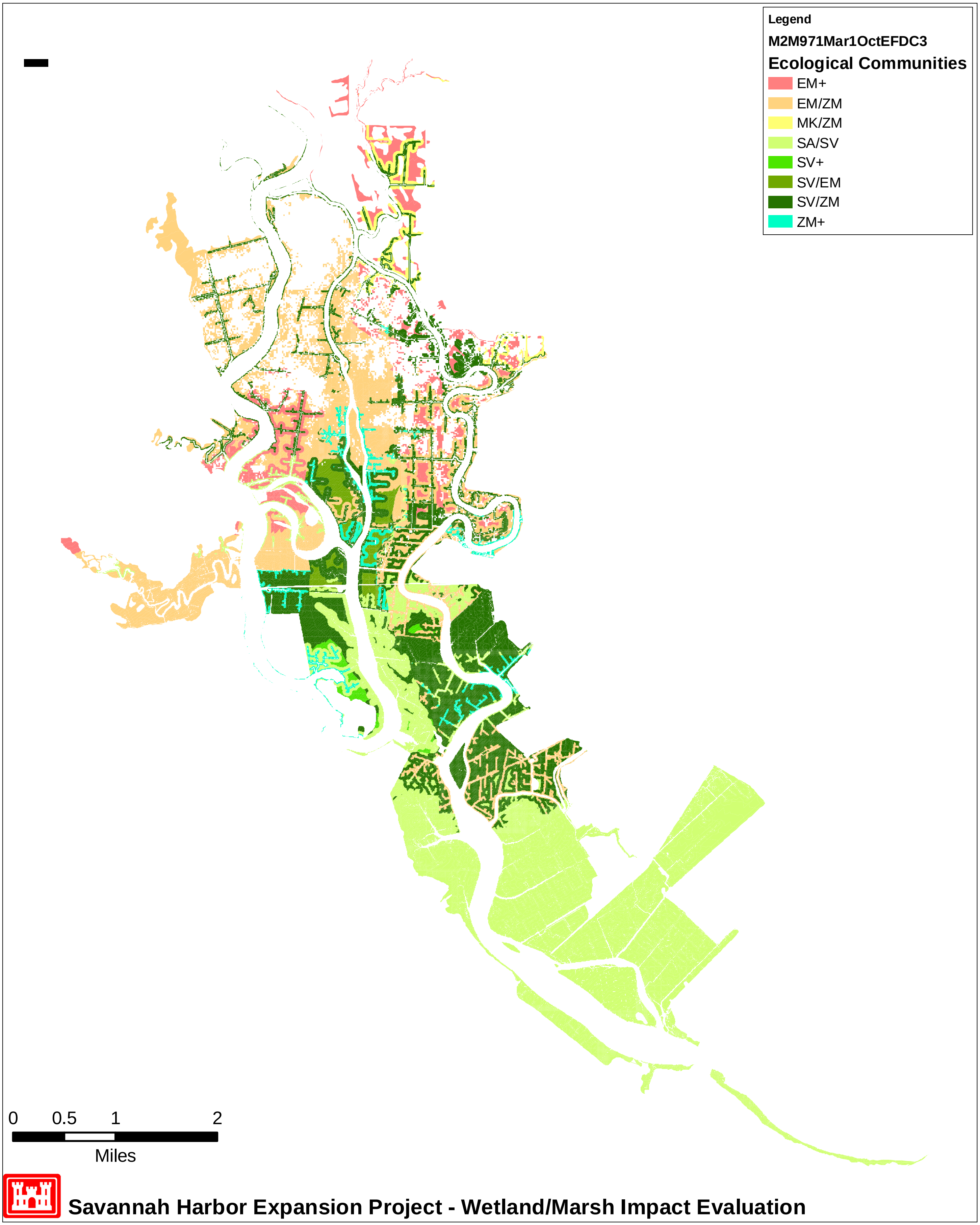
March 2007



Savannah Harbor Expansion Project - Wetland/Marsh Impact Evaluation

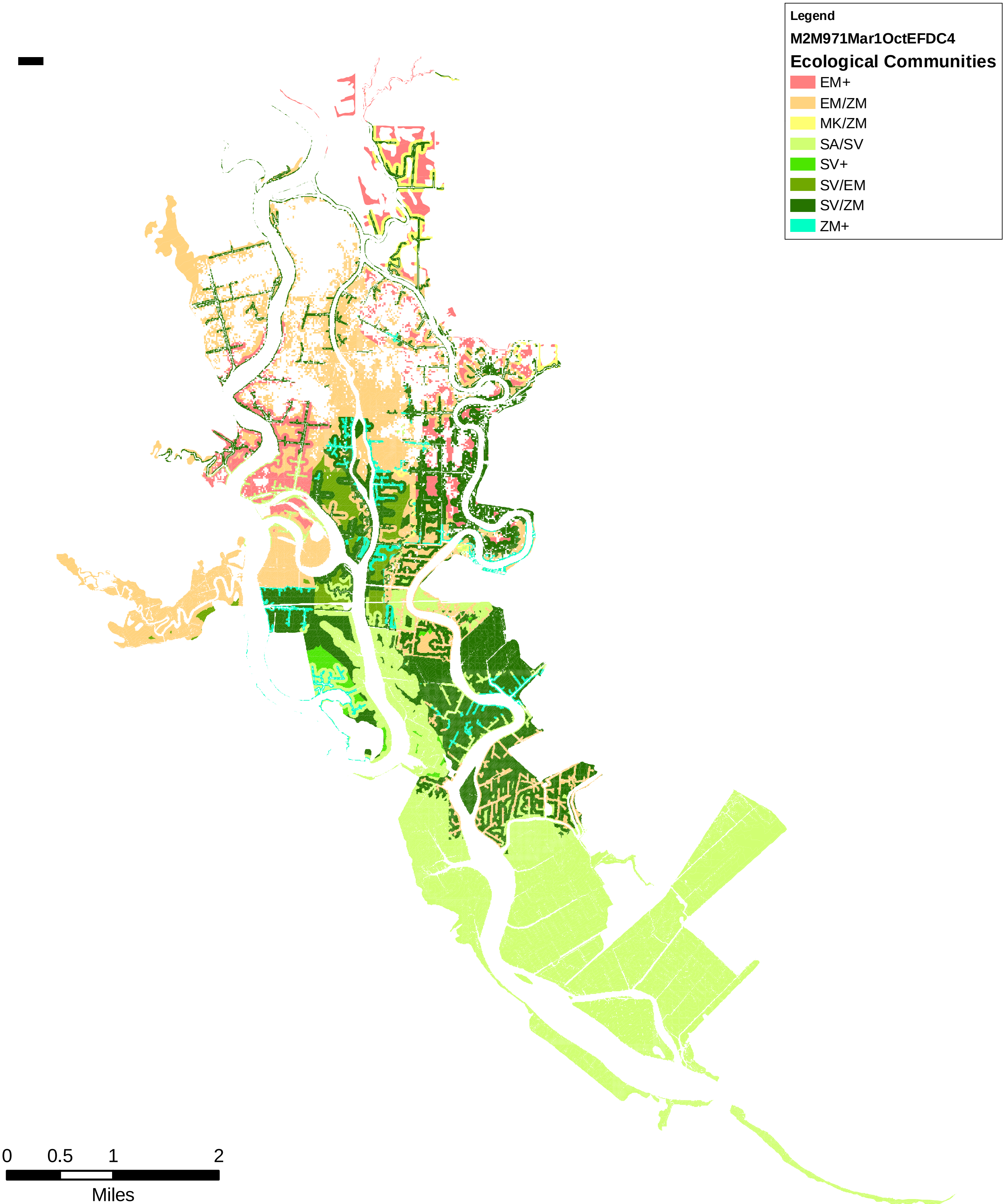
ATM Savannah Marsh Succession Model Predicted Ecological Community
44 Foot Depth (2 Foot Deepening)
Values Based on EFDC and M2M Output using Historic Average Flow, Temperature, and Tidal Conditions
1 March through 1 October 1997 (1997 best represents average historic conditions from the available data set)
Existing Sea Level Conditions

March 2007



ATM Savannah Marsh Succession Model Predicted Ecological Community
45 Foot Depth (3 Foot Deepening)
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

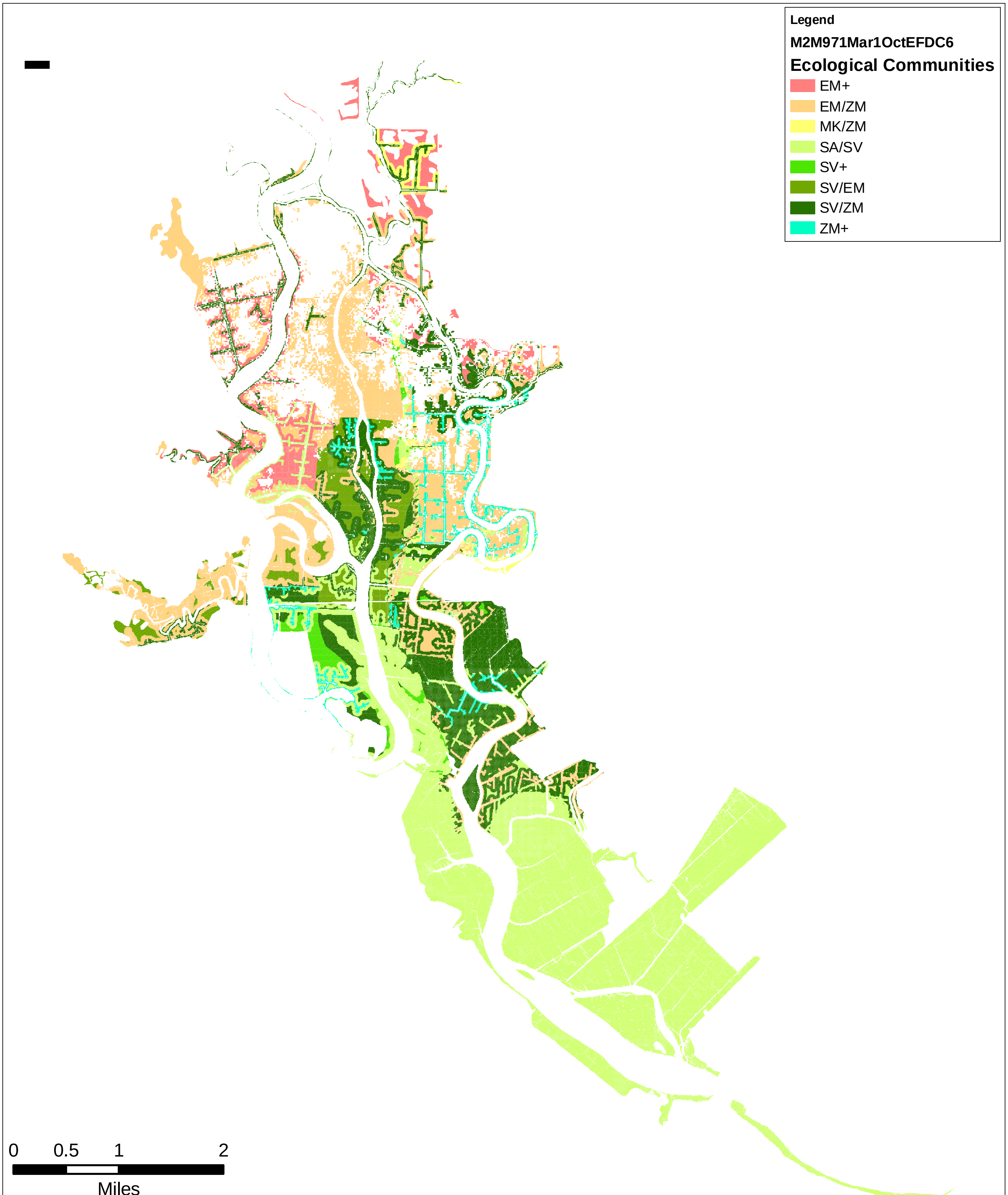
March 2007



Savannah Harbor Expansion Project - Wetland/Marsh Impact Evaluation

ATM Savannah Marsh Succession Model Predicted Ecological Community
46 Foot Depth (4 Foot Deepening)
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

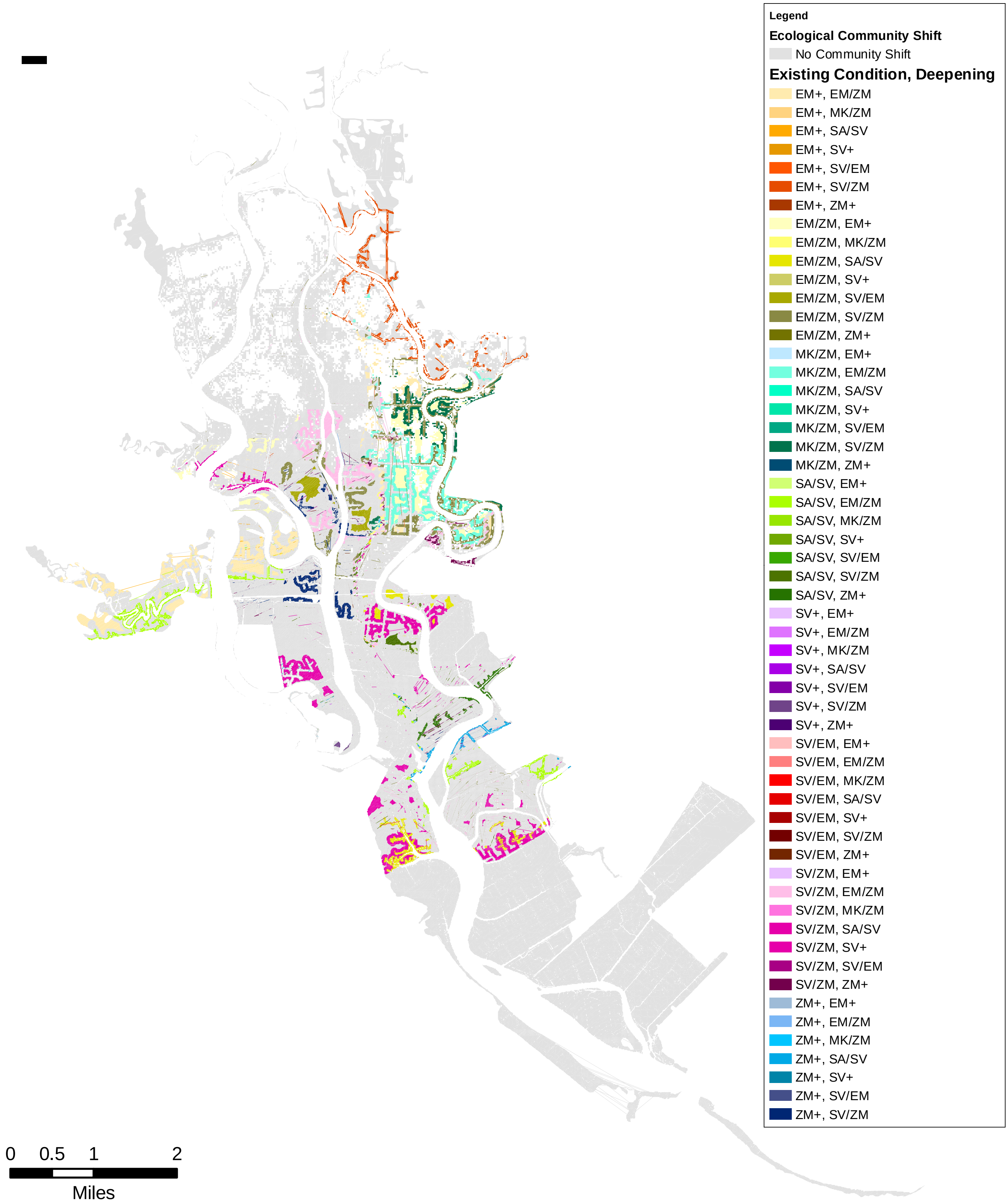
March 2007



Savannah Harbor Expansion Project - Wetland/Marsh Impact Evaluation

ATM Savannah Marsh Succession Model Predicted Ecological Community
48 Foot Depth (6 Foot Deepening)
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



Savannah Harbor Expansion Project - Wetland/Marsh Impact Evaluation

ATM Savannah Marsh Succession Model Predicted Ecological Community Shift
44 Foot Depth (2 Foot Deepening)
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