

SAVANNAH HARBOR EXPANSION PROJECT CHATMAN
COUNTY, GEORGIA AND JASPER COUNTY, SOUTH
CAROLINA: FINAL GENERAL RE-EVALUATION RE-
PORT AND ENVIRONMENTAL IMPACT STATEMENT
JANUARY 2012

COMMUNICATION

FROM

THE ASSISTANT SECRETARY OF THE ARMY,
CIVIL WORKS, THE DEPARTMENT OF
DEFENSE

TRANSMITTING

THE CORPS' FINAL GENERAL RE-EVALUATION REPORT AND
ENVIRONMENTAL IMPACT STATEMENT

PART 6 OF 15



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FINAL
GENERAL RE-EVALUATION REPORT
SAVANNAH HARBOR EXPANSION PROJECT
Chatham County, Georgia and Jasper County, South Carolina

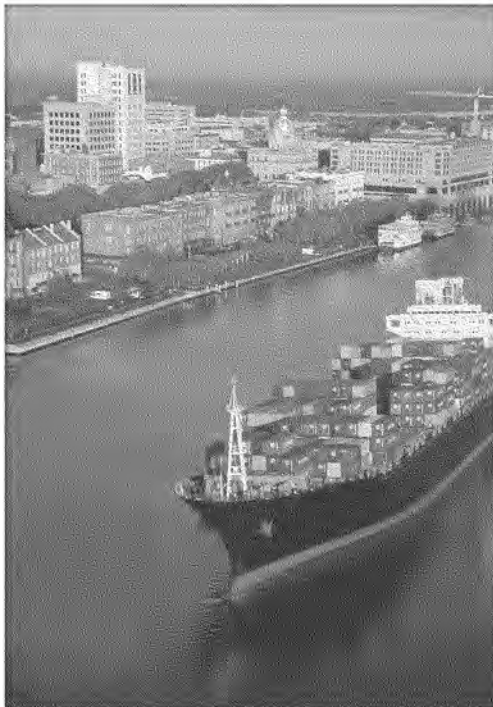
January 2012
(Revised July 2012)

Appendix C
Attachment 3
Parts 33-40

Volume 6



US Army Corps of
Engineers
Savannah District
South Atlantic Division



Savannah Harbor Expansion Project

Mitigation Evaluation for Marsh/Wetland Impacts

November 2007



Introduction

This report combines the voluminous output generated for evaluation of 12 Mitigation Plans for the Savannah Harbor Deepening Project. The proposed Harbor Deepening Project is expected to have environmental impacts throughout the Savannah River estuary. The environmental impacts to wetlands and marshes adjacent to the estuary, particularly freshwater tidal wetlands, are the focus for this evaluation and the results of the study are summarized in this report.

Background

The Savannah River estuary is comprised not only of the Savannah River which houses the port facilities, but also of a several smaller rivers that wind their way through marshland and have various man-made and natural connections to the main river itself. The various connections and the extremes of the tidal prism combine to form a complex system that moves massive volumes of water during each tidal cycle. Due to the complexity of the system, a hydrodynamic model (EFDC) was used to quantify the amount of water moving throughout the estuary and evaluate the salinity content at various points over a wide range of tidal and flow conditions. The model enables a more subjective evaluation of each of the mitigation features. Details of the model development and calibration for use in the Savannah Harbor Expansion Project can be found in *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project* prepared by Tetra Tech, Inc., dated January 30, 2006.

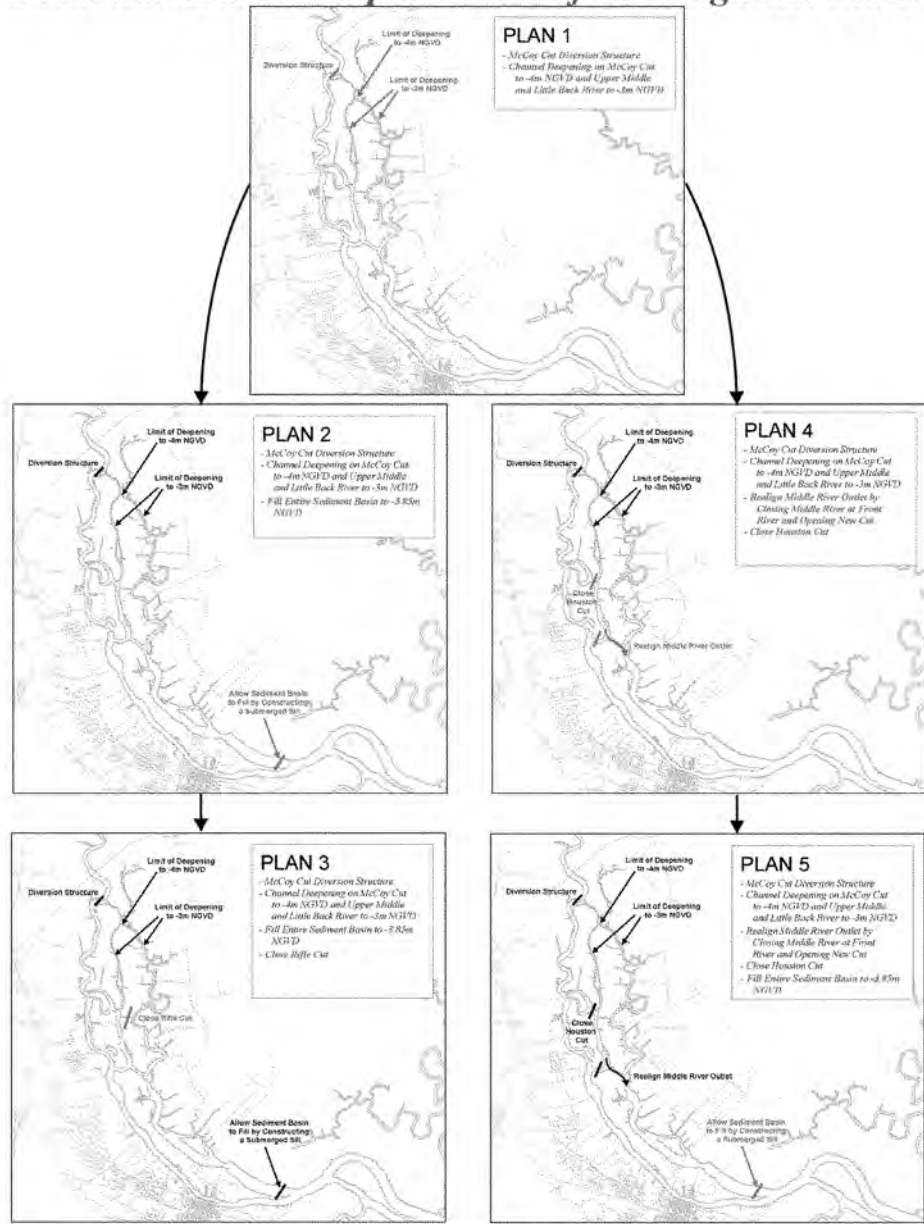
Mitigation Plans

There are 12 Mitigation Plans evaluated in this report which were developed over the course of many months. The development of the Mitigation Plans began by evaluating single adjustments or features made to the estuary and the impact on salinity movement. The purpose of each mitigation feature is to limit the amount of salinity intrusion into the estuary that would inevitably increase due to deepening the harbor. As mitigation features were evaluated and deemed helpful in salinity reduction they were combined to evaluate their effectiveness as a whole. Due to the complexities of the river system combined features could behave differently than they had as single features. All features were initially evaluated under a 48 ft deepened condition and the results were compared to the salinity regime expected under the existing conditions. The goal is to develop a feature or combination of features that reduce the intrusive salinity impacts due to deepening the harbor to zero.

The first 5 Mitigation Plans have several features combined in an additive manner to determine their effectiveness. See Figure 1 for graphical representation. There are two additive feature paths out of the five plans. Plan 3 builds on Plans 2 and 1 and Plan 5 is built from Plans 4 and 1. A detailed description of each of the plans is on the following pages:

Figure 1. Mitigation Plans 1 – 5

Savannah Harbor Expansion Project Mitigation Plans



----- Decision Point -----

Continue forward with additional mitigation features building on Plan 3 or Plan 5?

Plan 1: The main mitigation feature of Plan 1 is a diversion structure on Front River to route a portion of the freshwater coming down Front River to Little Back and Middle River through McCoy's Cut. To better facilitate the movement of freshwater through the cut to Little Back and Middle River, channel deepening is proposed from an average elevation of -3.1m NGVD to -4.0m NGVD from the Front River/McCoy Cut connection to the Middle/Little Back River junction and from an average elevation of -2.1m NGVD to -3.0m NGVD on both Little Back River and Middle River for a distance of approximately 1600m from the junction. The diversion structure combined with the channel deepening on McCoy Cut, Middle River and Little Back River allow for a portion of the freshwater flowing down the Savannah River to flow through the Back River system and combat salinity intrusion into these largely freshwater areas.

Plan 2: Mitigation Plan 2 builds on Plan 1. It contains all the features of Plan 1 plus filling in the sediment basin. The sediment basin is situated at the confluence of Back River and Front River near Old Fort Jackson. The modeled existing conditions bottom elevation of the sediment basin averages -12.8 m NGVD. Dredging records show that the sediment basin fills quickly and the depth at any given time varies greatly depending on the amount of dredging it receives. The proposed bottom elevation for the sediment basin under Plan 2 is -3.85m NGVD, which corresponds to the sill elevation at the tidegate structure bordering the upstream side of the sediment basin. Much of the Back River bottom elevation above the tidegate is also at or above -3.85m NGVD. Filling in the sediment basin would allow an extension of the more shallow depths in the Back River and would impede salinity movement upstream.

Plan 3: Mitigation Plan 3 builds further on Plan 2 by adding the feature to close Rifle Cut. The modeling showed that there is quite a bit of lateral movement with the tides across Front, Middle, and Back River through Steamboat River, Houston Cut and Rifle Cut. Depending on the freshwater flows coming downstream and the variations in the tidal cycle (neap or spring) the lateral flows across the system can provide large amounts of freshwater or large amounts of saline water. Closing Rifle Cut eliminates the lateral saltwater flowpath from Middle to Back River on the incoming tide. Its closure also eliminates a flowpath for freshwater flow coming down Back River to leave on the outgoing tide. This creates more freshwater availability for the areas downstream of Rifle Cut, especially during critical flow conditions.

Plan 4: Plan 4 begins the second additive feature path option and builds on Plan 1. It includes the diversion structure, deepening on McCoy, Middle and Little Back River and realigning the Middle River outlet through New Cut and Back River. The plan also includes closing Houston Cut. Realigning Middle River and closing Houston Cut removes the two lower connections between Middle and Front River and isolates the Middle and Back River from lateral salinity movement. It also eliminates the loss of freshwater flows coming downstream through McCoy Cut through the outlets to Front River and makes more freshwater available for the lower portions of Middle and Back River. The closure of Houston Cut is key in the effectiveness of realigning Middle River. In trial runs where Houston Cut was not closed under these same conditions we found much higher salinity concentrations in Middle River due to the lateral movement allowed across the cut.

Plan 5: Building on Plan 4, Plan 5 also has the additional feature of filling in the sediment basin. The sediment basin was modeled as described above in Plan 2 under the same logic that it

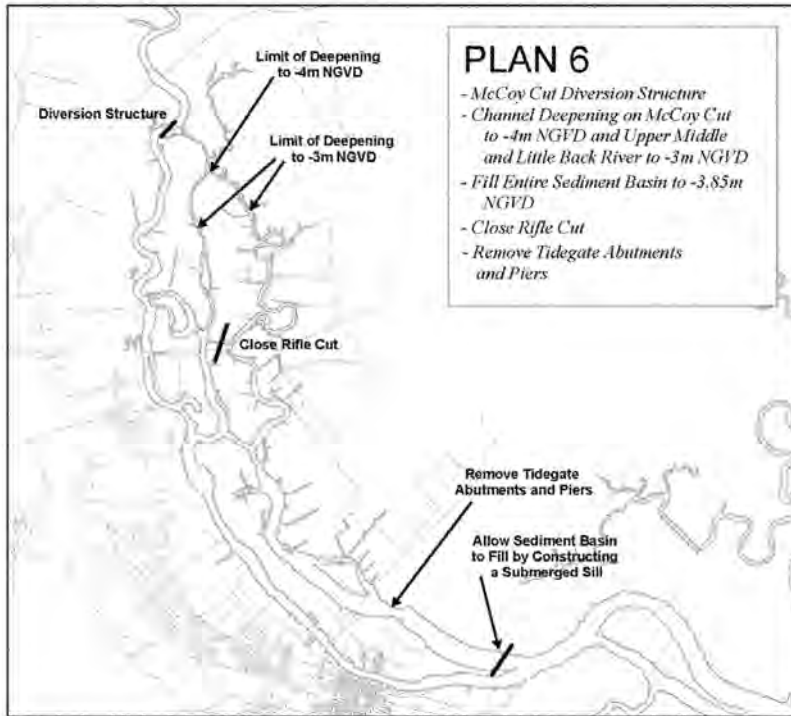
would limit salinity intrusion coming up Back River through the deep basin. However, it was necessary to evaluate this feature with the additional features that were added in Plan 4 to determine their combined effectiveness.

Extensive modeling was done on these 5 plans described above and the results were provided to the team to decide to continue forward with additional additive mitigation features to Plan 3 or Plan 5. The two plans are very different yet, they strive to reach the same goals of reducing the impacts due to deepening to zero. After extensive discussion and review, not only of impacts to wetlands but also impacts to fish habitat and water quality, it was decided to move forward with Plan 3. One of the major factors in choosing Plan 3 over Plan 5 was found by evaluating the tidal amplitude and how that changed with the different mitigation features. Plans 4 and 5 do a very good job at eliminating salinity intrusion into Middle, Back, and Little Back River. However, in the effort to remove salinity the volumes of water coming in on each tidal cycle were lowered from what they are currently to a point that was considered unacceptable. The lowered tidal peaks could pose a hazard to upland tidal wetlands that are wetted only during the high peaks of the incoming tide.

The following mitigation plans described all build on the foundation laid out in Mitigation Plan 3. The additional plans were developed in search of the most effective mitigation plan to protect the estuary from the negative environmental impacts associated with deepening the harbor.

Plan 6: Mitigation Plan 6 has the same features of Plan 3 with the diversion structure, channel deepening on McCoy Cut, and upper Middle and Little Back River, Rifle Cut closed and the sediment basin filled. In addition to the features in Plan 3, Plan 6 also has the tidegate abutments and piers removed. See Figure 2. The removal of the tidegate abutments and piers helps to provide more tidal movement through the lower portion of Back River and increases its flushing capacity. Salt water that has entered on the incoming tide will be able to flush with less restriction on the outgoing tide.

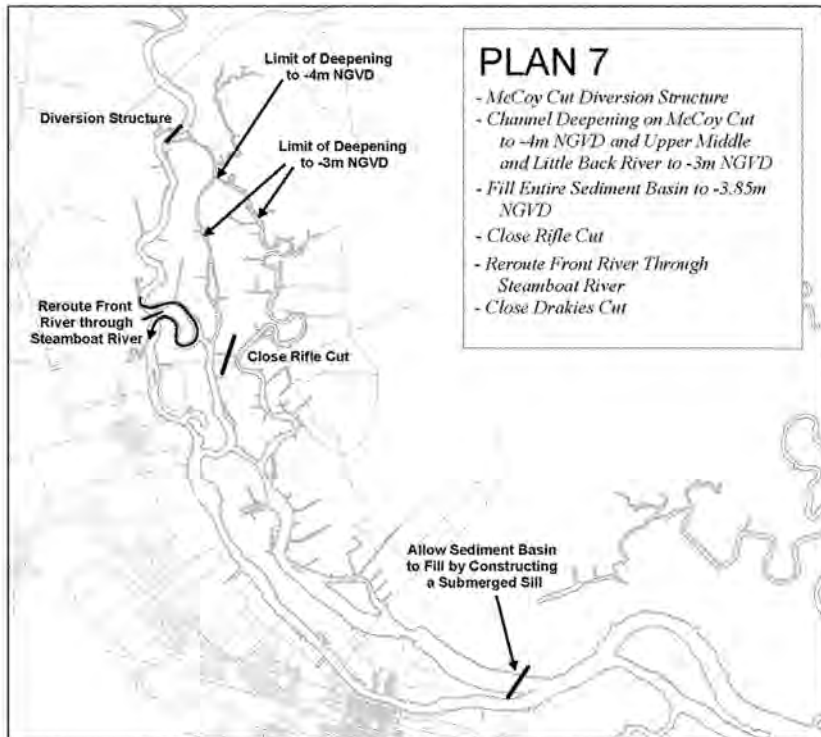
Figure 2. *Mitigation Plan 6*



Plan 7: Mitigation Plan 7 has the features described in Plan 3 and an additional feature that basically lengthens the Front River by approximately 2 miles. The additional feature reroutes Front River through Steamboat River by closing Drakies Cut. Historically, the Front River channel flowed through Steamboat River and Drakies Cut was a man made feature that aided in navigation. The proposed feature in Plan 7 would restore the natural bend in the river but it

would be deepened and widened to maintain the channel geometry that currently exists in that area of Front River. Currently Steamboat River has an average bottom elevation of -1.85m NGVD and a top width that varies throughout the reach from less than 60m to over 100m. In the vicinity of Drakies Cut, Front River has an approximate bottom elevation of -10.4m NGVD and top width of 190m. By rerouting Front River through the 2 mile bend, the channel is essentially lengthened and salinity has a longer path to travel before reaching areas upstream of Steamboat than it currently has under the existing condition. Also, rerouting the freshwater flow through Steamboat coming downstream on Front River will allow it to have access to Middle River through Houston Cut. However, the same access routes to Middle River would be available for saline water coming upstream on the incoming tide.

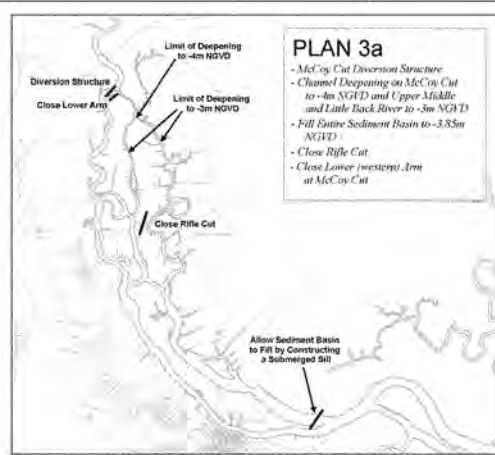
Figure 3. Mitigation Plan 7



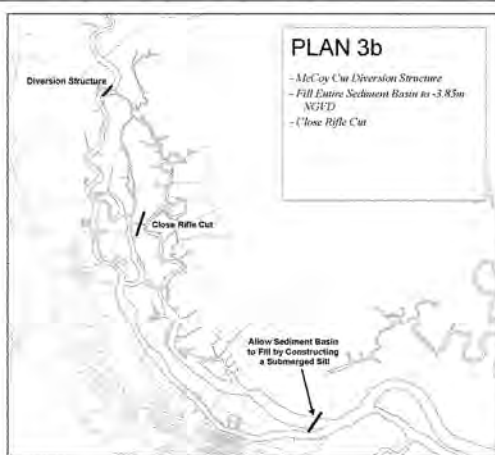
When it was realized that Plan 6 and 7 again did not provide complete mitigation for the deepening impacts, in particular for the tidal freshwater marshes, additional measures were evaluated. Again, building on the features laid out in the most promising plan evaluated to this point, Mitigation Plan 3. Plans 3a, 3b and 3c are described in Figure 4.

Figure 4. Mitigation Plan 3a, 3b and 3c

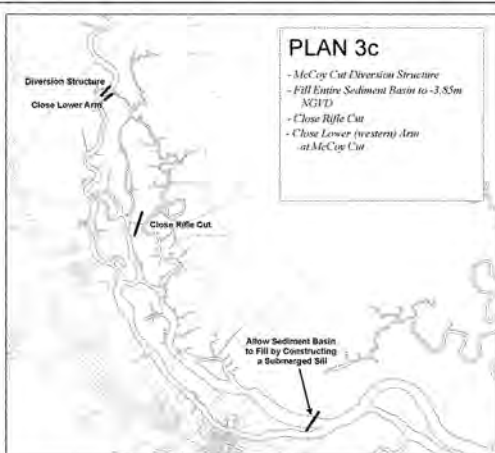
Plan 3a: Plan 3a includes the mitigation feature of closing the lower (western) arm at McCoy's Cut. This cut is approximately 750m long where McCoy Cut is only 250m long. The preferential tidal flowpath from Front River to access the junction of McCoy Cut and the lower arm would be through McCoy Cut, because of the shorter distance for the water to have to travel. By closing this lower arm, the flow coming in McCoy Cut from Front River will not have the opportunity to exit the Back River System until points further downstream. The changes made to the cut will most likely have a more localized effect in the vicinity of McCoy Cut. Because the arm is shallow, narrow and long, the benefits from its closure will not likely translate great distances downstream on Little Back River and Middle River.



Plan 3b: Plan 3b has the same features of Plan 3, but excluding the deepening on McCoy Cut, Little Back and Middle River. During the planning process many different diversion structure sizes and channel lengths and depths on the upper reaches of Middle and Little Back Rivers were evaluated. The channel deepening described first in Plan 1 had the greatest potential to provide benefits. However, excluding the channel deepening in this area in combination with the other features described in Plan 3 was a combination that could still have great benefit without the added cost.



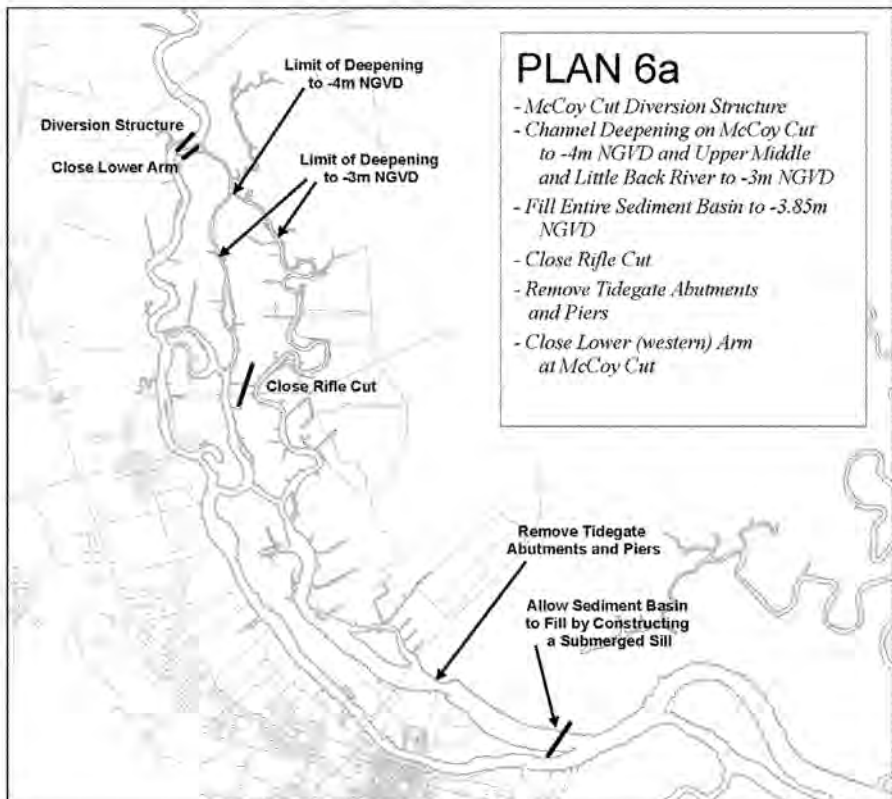
Plan 3c: Plan 3c is a combination of the two features modified in Plans 3a and 3b. Plan 3c has the diversion structure on Front River, the lower (western) arm at McCoy Cut closed, Rifle Cut closed and the Sediment Basin filled. This plan evaluates the necessity of deepening McCoy Cut and the upper reaches of Middle and Little Back with the implementation of the lower arm closed.



In addition to the benefits gained in impact reduction through implementation of Plan 3, Plan 6 also shows a great deal of potential. However, Plan 6 does not provide full mitigation for the impacts from harbor deepening. In an effort to reduce the impacts to zero, additional features were evaluated building on Mitigation Plan 6. The two additional Plans 6a and 6b are presented below.

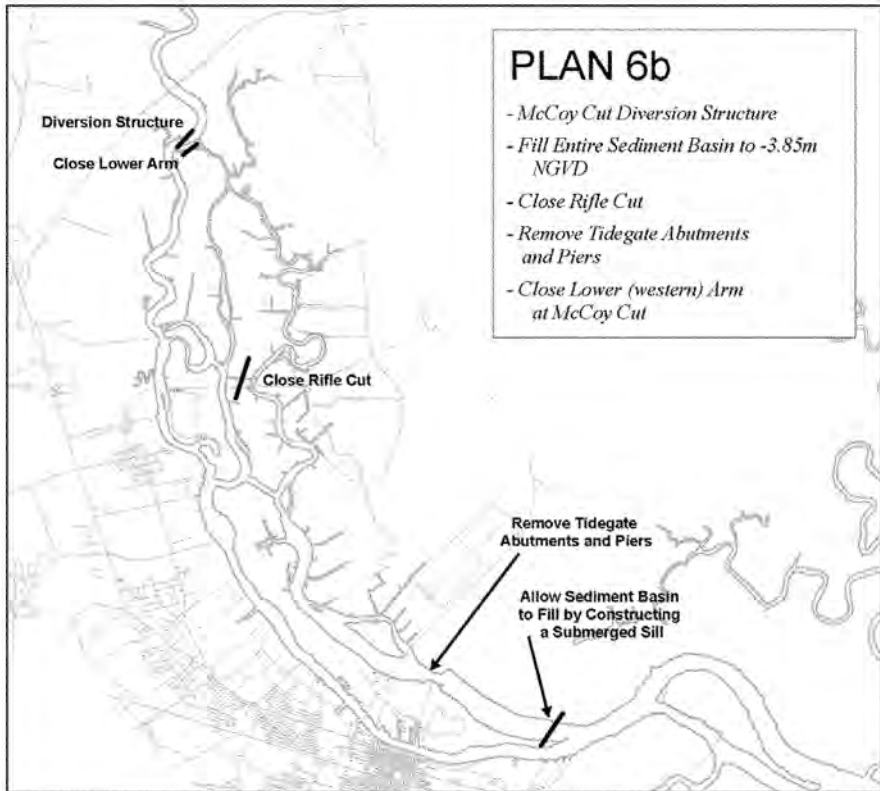
Plan 6a: Mitigation Plan 6a has the same features as Plan 6, diversion structure on Front River, channel deepening on McCoy Cut, upper Middle and Little Back Rivers, Rifle Cut closed, the Sediment Basin filled, the tidegate abutments and piers removed, plus one additional feature closing the lower (western) arm at McCoy Cut. This plan maximizes the potential for additional freshwater flows to enter the Back River System at McCoy Cut and flow downstream through Middle, Back and Little Back Rivers. It also has features that will limit salt water intrusion through the sediment basin into Back River.

Figure 6. *Mitigation Plan 6a*



Plan 6b: Mitigation Plan 6b has the same features as Plan 6, except for channel deepening on McCoy Cut, upper Middle and Little Back Rivers. Also, one feature is added, closing the lower (western) arm at McCoy Cut. This plan is very similar to Plan 6a and allows for isolation of one of the mitigation features to determine its effectiveness. The feature that 6a includes and 6b excludes is channel deepening on McCoy Cut, upper Middle and Little Back Rivers

Figure 7. Mitigation Plan 6b

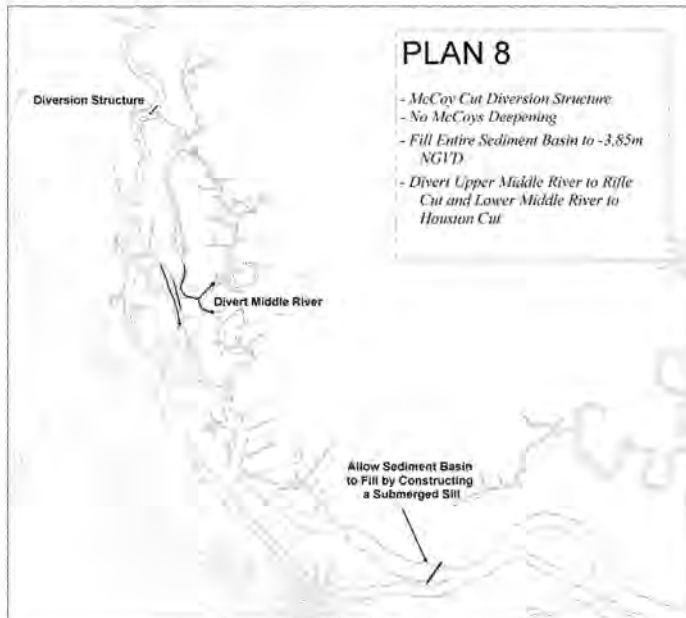


Ineffective Plans/Features

During the screening process several mitigation features were proposed and then tested with the model. The screening process allowed for features to be evaluated subjectively with quantitative output to determine their effectiveness. Many features and combinations of features were examined before the final mitigation plans were formed. The screening process also allowed time to determine the most effective channel geometry for deepening, widening, and filling associated with many of the features. Greater detail about the selection process for the mitigation plans can be found in the main report document for this project.

One additional plan that was evaluated but largely excluded from the reporting process is Plan 8. See Figure 8. Plan 8 includes a diversion structure on Front River, filling the sediment basin, and diverting Middle River. Diverting of Middle River in this plan differs greatly from that described in Plans 4 and 5. In Plan 8 the lower portion of Middle River would be routed through Houston Cut and the upper portion of Steamboat River and the upper portion of Middle River would be routed through Rifle Cut. After an initial evaluation, Plan 8 was found to cause too great an impact on the tidal prism especially within the Back River System. For the same reasons mentioned above in discussion of the decision between Plan 3 and 5, Plan 8 was excluded from further analysis. It is included here to document that it was evaluated and considered as plan to mitigate the impacts due to deepening the navigation channel, but along with many of the other mitigation features and combinations screened, it was found to be ineffective.

Figure 8. *Mitigation Plan 8*



Output

Due to the fact that the decision making process required large volumes of information disseminated during the mitigation planning, the output was reported to the team as it was developed. As a result, the output was issued in seemingly unorganized bits and pieces. Fortunately, we have catalogued and compiled all of the different pieces here in this report. See Table 1.

Table 1. *Mitigation Plan Evaluation Reports*

Title	Contents	Date
<i>Wetland/Marsh Mitigation Plan Evaluation</i>	Evaluation of Mitigation Plans 1 – 5 for salinity impacts under 4 different flow scenarios and 4 different navigation channel depths.	<i>April 2007</i>
<i>Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts with Additional Mitigation Plans</i>	Evaluation of Mitigation Plans 3a, 3b, 3c, 6 and 6b under one flow scenario and three different navigation channel depths.	<i>August 2007</i>
<i>Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts Plan 6a ONLY</i>	Evaluation of Mitigation Plan 6a under one flow scenario and three different navigation channel depths.	<i>August 2007</i>
<i>Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts Plan 7 ONLY</i>	Evaluation of Mitigation Plan 7 under one flow scenario and two different navigation channel depths.	<i>October 2007</i>

Results

The results for each Mitigation Plans outlined above can be found in the reports listed in the Table 1. Please see each individual report for details on each plans effectiveness. For details on the plan formulation process and reasons for choosing the selected mitigation plan please see the main report document for this project.

Wetland/Marsh Mitigation Plan Evaluation

April 2007

Savannah Harbor Expansion Project
Wetland/Marsh Mitigation Plan Evaluation
MARSH Acreages Impacted ONLY

Deepening Only
No Mitigation Options

		Acreages Negatively Impacted (fresh to salt)		Acreages Positively Impacted (salt to fresh)		Net Impact (net negative), net positive	
		50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance
Basic Evaluation 1997- Existing Sea Level	44-ft	1633.2	0	0	0	(1633.2)	0.0
	45-ft	1633.2	0	0	0	(1633.2)	0.0
	46-ft	1633.2	0	0	0	(1633.2)	0.0
	48-ft	1932.2	299	0	0	(1932.2)	(299.0)
Sensitivity Analysis #1 2001- Existing Sea Level	44-ft	469.2	494.2	0	0	(469.2)	(494.2)
	45-ft	768.2	494.2	0	0	(768.2)	(494.2)
	46-ft	768.2	494.2	0	0	(768.2)	(494.2)
	48-ft	768.2	494.2	0	0	(768.2)	(494.2)
Sensitivity Analysis #2A 1997- 25cm Sea Level Rise	Existing	1287.4	299	0	0	(1287.4)	(299.0)
	44-ft	1932.2	299	0	0	(1932.2)	(299.0)
	45-ft	1932.2	299	0	0	(1932.2)	(299.0)
	46-ft	1932.2	299	0	0	(1932.2)	(299.0)
Sensitivity Analysis #2B 1997- 50cm Sea Level Rise	Existing	1932.2	299	0	0	(1932.2)	(299.0)
	44-ft	1932.2	1210.8	0	0	(1932.2)	(1210.8)
	45-ft	1932.2	1457.9	0	0	(1932.2)	(1457.9)
	46-ft	1932.2	1457.9	0	0	(1932.2)	(1457.9)
	48-ft	1932.2	1457.9	0	0	(1932.2)	(1457.9)

1997 Conditions- Average Historic Flow, Temperature, and Tidal Conditions- March through October 1997

2001 Conditions- Historic Low Flow, Average Temperature and Tidal Conditions- March through October 1997

Savannah Harbor Expansion Project
Wetland/Marsh Mitigation Plan Evaluation
MARSH Acreages Impacted ONLY

Plan 1

-McCoy Cut Diversion Structure;

-Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD

		Acreages Negatively Impacted (fresh to salt)		Acreages Positively Impacted (salt to fresh)		Net Impact (net negative), net positive	
		50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance
Basic Evaluation 1997- Existing Sea Level	44-ft	988.4	0	0	0	(988.4)	0.0
	45-ft	988.4	0	0	0	(988.4)	0.0
	46-ft	988.4	0	0	0	(988.4)	0.0
	48-ft	988.4	0	0	0	(988.4)	0.0
Sensitivity Analysis #1 2001- Existing Sea Level	44-ft	469.2	0	0	664.7	(469.2)	664.7
	45-ft	469.2	0	0	664.7	(469.2)	664.7
	46-ft	469.2	0	0	664.7	(469.2)	664.7
	48-ft	469.2	0	0	417.6	(469.2)	417.6
Sensitivity Analysis #2A 1997- 25cm Sea Level Rise	44-ft	988.4	0	0	0	(988.4)	0.0
	45-ft	1287.4	0	0	0	(1287.4)	0.0
	46-ft	1287.4	0	0	0	(1287.4)	0.0
	48-ft	1633.2	299	0	0	(1633.2)	(299.0)
Sensitivity Analysis #2B 1997- 50cm Sea Level Rise	44-ft	1287.4	299	0	0	(1287.4)	(299.0)
	45-ft	1633.2	299	0	0	(1633.2)	(299.0)
	46-ft	1633.2	299	0	0	(1633.2)	(299.0)
	48-ft	1932.2	299	0	0	(1932.2)	(299.0)

1997 Conditions- Average Historic Flow, Temperature, and Tidal Conditions- March through October 1997

2001 Conditions- Historic Low Flow, Average Temperature and Tidal Conditions- March through October 1997

Savannah Harbor Expansion Project
Wetland/Marsh Mitigation Plan Evaluation
MARSH Acreages Impacted ONLY

Plan 2

- McCoy Cut Diversion Structure;
 -Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD;
 -Fill Entire Sediment Basin to -3.85m NGVD

		Acreages Negatively Impacted (fresh to salt)		Acreages Positively Impacted (salt to fresh)		Net Impact (net negative), net positive	
		50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance
Basic Evaluation 1997- Existing Sea Level	44-ft	988.4	0	0	0	(988.4)	0.0
	45-ft	988.4	0	0	0	(988.4)	0.0
	46-ft	988.4	0	0	0	(988.4)	0.0
	48-ft	988.4	0	0	0	(988.4)	0.0
Sensitivity Analysis #1 2001- Existing Sea Level	44-ft	469.2	0	0	664.7	(469.2)	664.7
	45-ft	469.2	0	0	664.7	(469.2)	664.7
	46-ft	469.2	0	0	417.6	(469.2)	417.6
	48-ft	469.2	0	0	0	(469.2)	0.0
Sensitivity Analysis #2A 1997- 25cm Sea Level Rise	44-ft	988.4	0	0	0	(988.4)	0.0
	45-ft	988.4	0	0	0	(988.4)	0.0
	46-ft	1287.4	0	0	0	(1287.4)	0.0
	48-ft	1633.2	299	0	0	(1633.2)	(299.0)
Sensitivity Analysis #2B 1997- 50cm Sea Level Rise	44-ft	1287.4	299	0	0	(1287.4)	(299.0)
	45-ft	1633.2	299	0	0	(1633.2)	(299.0)
	46-ft	1633.2	299	0	0	(1633.2)	(299.0)
	48-ft	1932.2	299	0	0	(1932.2)	(299.0)

1997 Conditions- Average Historic Flow, Temperature, and Tidal Conditions- March through October 1997

2001 Conditions- Historic Low Flow, Average Temperature and Tidal Conditions- March through October 1997

Savannah Harbor Expansion Project
Wetland/Marsh Mitigation Plan Evaluation
MARSH Acreages Impacted ONLY

Plan 3

- McCoy Cut Diversion Structure;
- Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD;
- Fill Entire Sediment Basin to -3.85m NGVD;
- Rifle Cut Closed

		Acreages Negatively Impacted (fresh to salt)		Acreages Positively Impacted (salt to fresh)		Net Impact (net negative), net positive	
		50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance
Basic Evaluation 1997- Existing Sea Level	44-ft	988.4	0	453	345.8	(535.4)	345.8
	45-ft	988.4	0	453	345.8	(535.4)	345.8
	46-ft	988.4	0	453	345.8	(535.4)	345.8
	48-ft	1287.4	0	453	345.8	(834.4)	345.8
Sensitivity Analysis #1 2001- Existing Sea Level	44-ft	469.2	0	345.8	417.6	(123.4)	417.6
	45-ft	469.2	0	345.8	417.6	(123.4)	417.6
	46-ft	469.2	0	345.8	417.6	(123.4)	417.6
	48-ft	768.2	494.2	345.8	0	(422.4)	(494.2)
Sensitivity Analysis #2A 1997- 25cm Sea Level Rise	44-ft	1287.4	299	453	345.8	(834.4)	46.8
	45-ft	1287.4	299	453	345.8	(834.4)	46.8
	46-ft	1287.4	299	453	0	(834.4)	(299.0)
	48-ft	2055.6	299	0	0	(2055.6)	(299.0)
Sensitivity Analysis #2B 1997- 50cm Sea Level Rise	44-ft	1586.4	299	0	0	(1586.4)	(299.0)
	45-ft	1586.4	299	0	0	(1586.4)	(299.0)
	46-ft	2055.6	299	0	0	(2055.6)	(299.0)
	48-ft	2055.6	299	0	0	(2055.6)	(299.0)

1997 Conditions- Average Historic Flow, Temperature, and Tidal Conditions- March through October 1997

2001 Conditions- Historic Low Flow, Average Temperature and Tidal Conditions- March through October 1997

Savannah Harbor Expansion Project
Wetland/Marsh Mitigation Plan Evaluation
MARSH Acreages Impacted ONLY

Plan 4

- McCoy Cut Diversion Structure;
- Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD;
- Realign Middle River Outlet by Closing Middle River at Front River and Opening New Cut;
- Close Houston Cut

		Acreages Negatively Impacted (fresh to salt)		Acreages Positively Impacted (salt to fresh)		Net Impact (net negative), net positive	
		50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance
Basic Evaluation 1997- Existing Sea Level	44-ft	1334.2	0	210.1	598	(1124.1)	598.0
	45-ft	1334.2	0	0	598	(1334.2)	598.0
	46-ft	1334.2	0	0	598	(1334.2)	598.0
	48-ft	1334.2	0	0	598	(1334.2)	598.0
Sensitivity Analysis #1 2001- Existing Sea Level	44-ft	469.2	0	345.8	417.6	(123.4)	417.6
	45-ft	469.2	0	598	716.6	128.8	716.6
	46-ft	469.2	0	598	0	128.8	0.0
	48-ft	469.2	494.2	598	0	128.8	(494.2)
Sensitivity Analysis #2A 1997- 25cm Sea Level Rise	44-ft	1334.2	0	0	598	(1334.2)	598.0
	45-ft	1803.4	0	0	598	(1803.4)	598.0
	46-ft	1803.4	0	0	598	(1803.4)	598.0
	48-ft	1803.4	0	0	598	(1803.4)	598.0
Sensitivity Analysis #2B 1997- 50cm Sea Level Rise	44-ft	1803.4	0	0	299	(1803.4)	299.0
	45-ft	1803.4	0	0	299	(1803.4)	299.0
	46-ft	1803.4	0	0	299	(1803.4)	299.0
	48-ft	1803.4	0	0	0	(1803.4)	0.0

1997 Conditions- Average Historic Flow, Temperature, and Tidal Conditions- March through October 1997

2001 Conditions- Historic Low Flow, Average Temperature and Tidal Conditions- March through October 1997

Savannah Harbor Expansion Project
Wetland/Marsh Mitigation Plan Evaluation
MARSH Acreages Impacted ONLY

Plan 5

- McCoy Cut Diversion Structure;
- Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD;
- Realign Middle River Outlet by Closing Middle River at Front River and Opening New Cut;
- Close Houston Cut;

		Acreages Negatively Impacted (fresh to salt)		Acreages Positively Impacted (salt to fresh)		Net Impact (net negative), net positive	
		50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance
Basic Evaluation 1997- Existing Sea Level	44-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	45-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	46-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	48-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
Sensitivity Analysis #1 2001- Existing Sea Level	44-ft	469.2	0	1153.9	1015.6	684.7	1015.6
	45-ft	469.2	494.2	1153.9	598	684.7	103.8
	46-ft	469.2	494.2	1153.9	598	684.7	103.8
	48-ft	469.2	494.2	1153.9	0	684.7	(494.2)
Sensitivity Analysis #2A 1997- 25cm Sea Level Rise	44-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	45-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	46-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	48-ft	1457.6	0	663.1	1153.9	(794.5)	1153.9
Sensitivity Analysis #2B 1997- 50cm Sea Level Rise	44-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	45-ft	988.4	0	663.1	1153.9	(325.3)	1153.9
	46-ft	1457.6	0	663.1	808.1	(794.5)	808.1
	48-ft	1457.6	0	663.1	598	(794.5)	598.0

1997 Conditions- Average Historic Flow, Temperature, and Tidal Conditions- March through October 1997

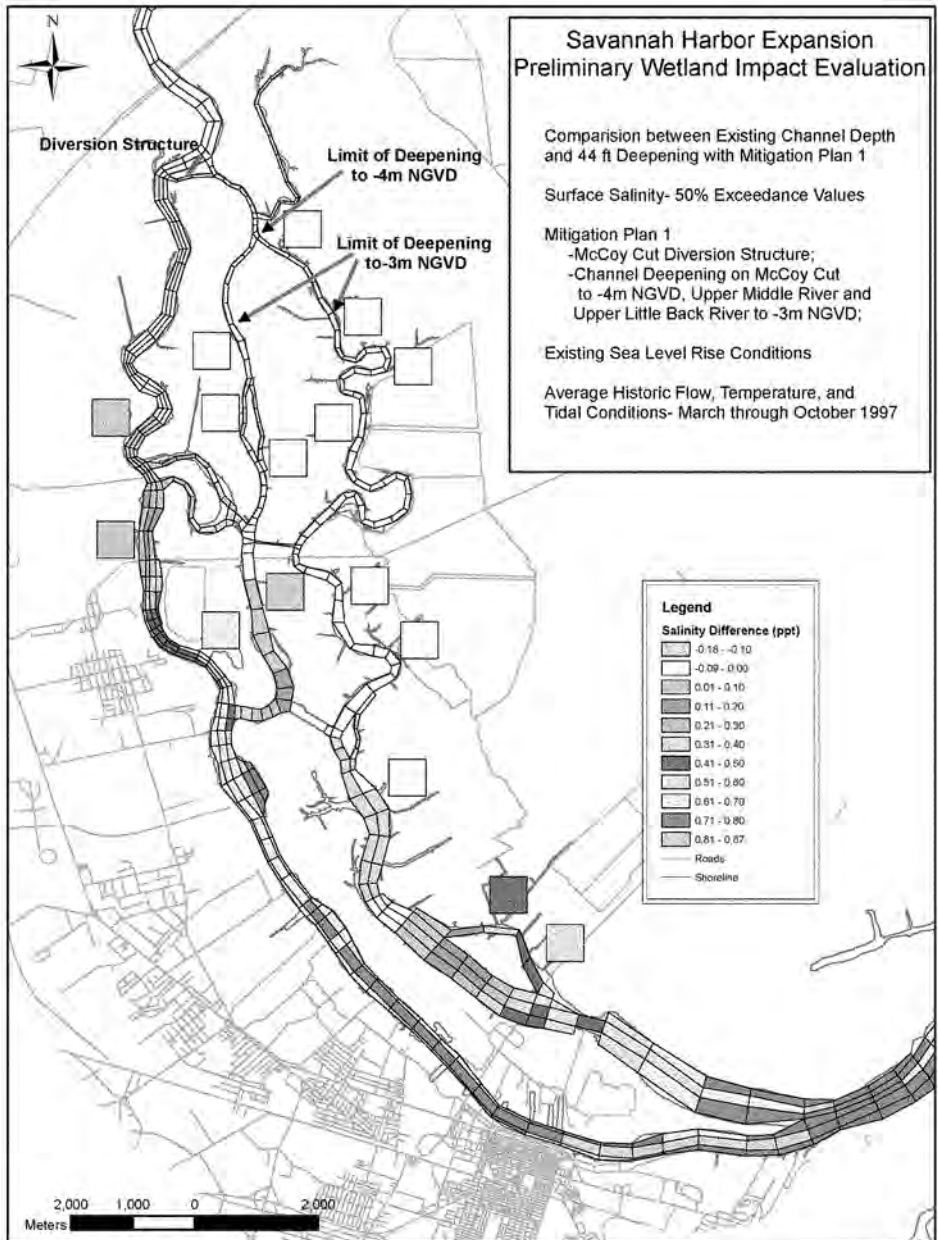
2001 Conditions- Historic Low Flow, Average Temperature and Tidal Conditions- March through October 1997

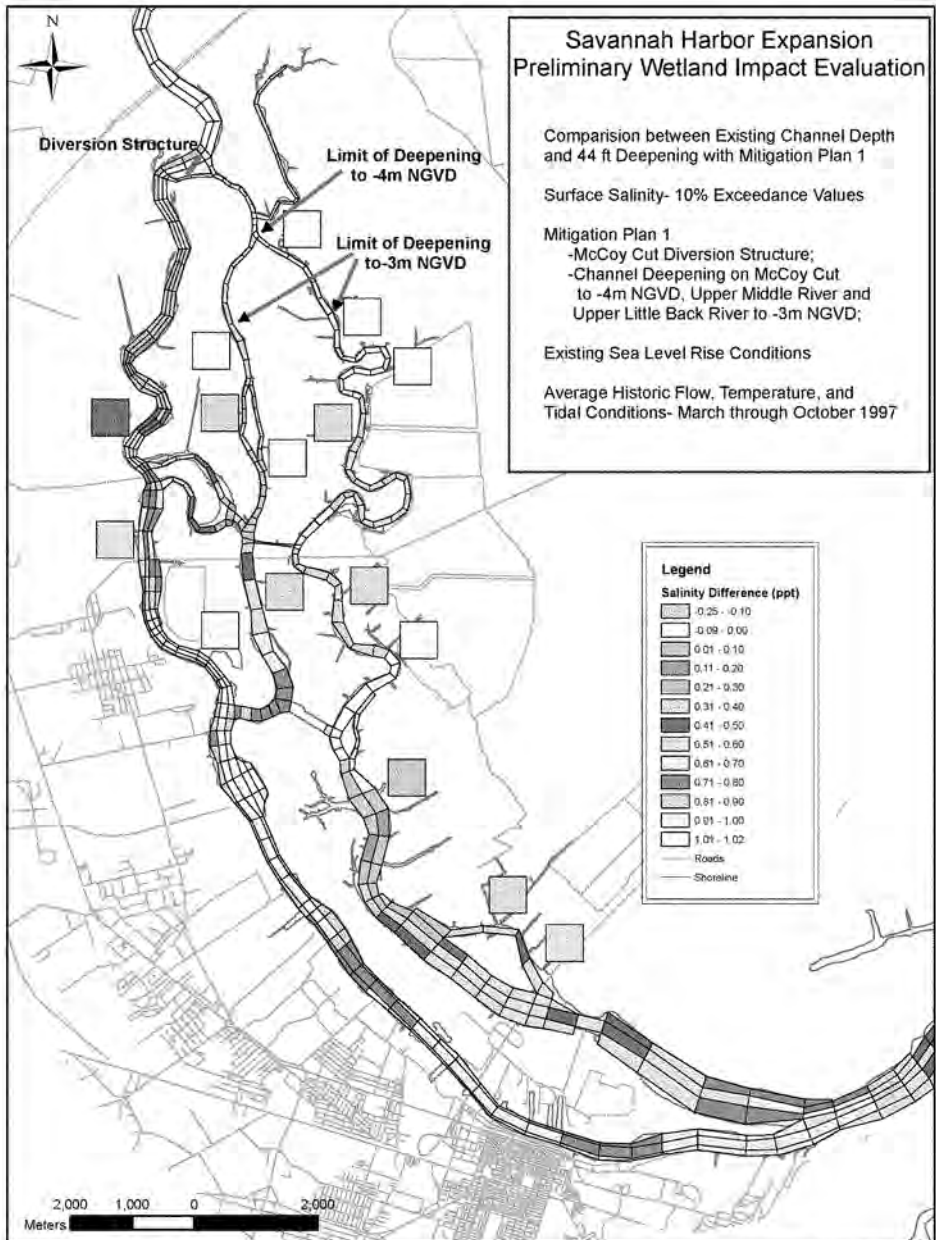
MITIGATION PLAN 1

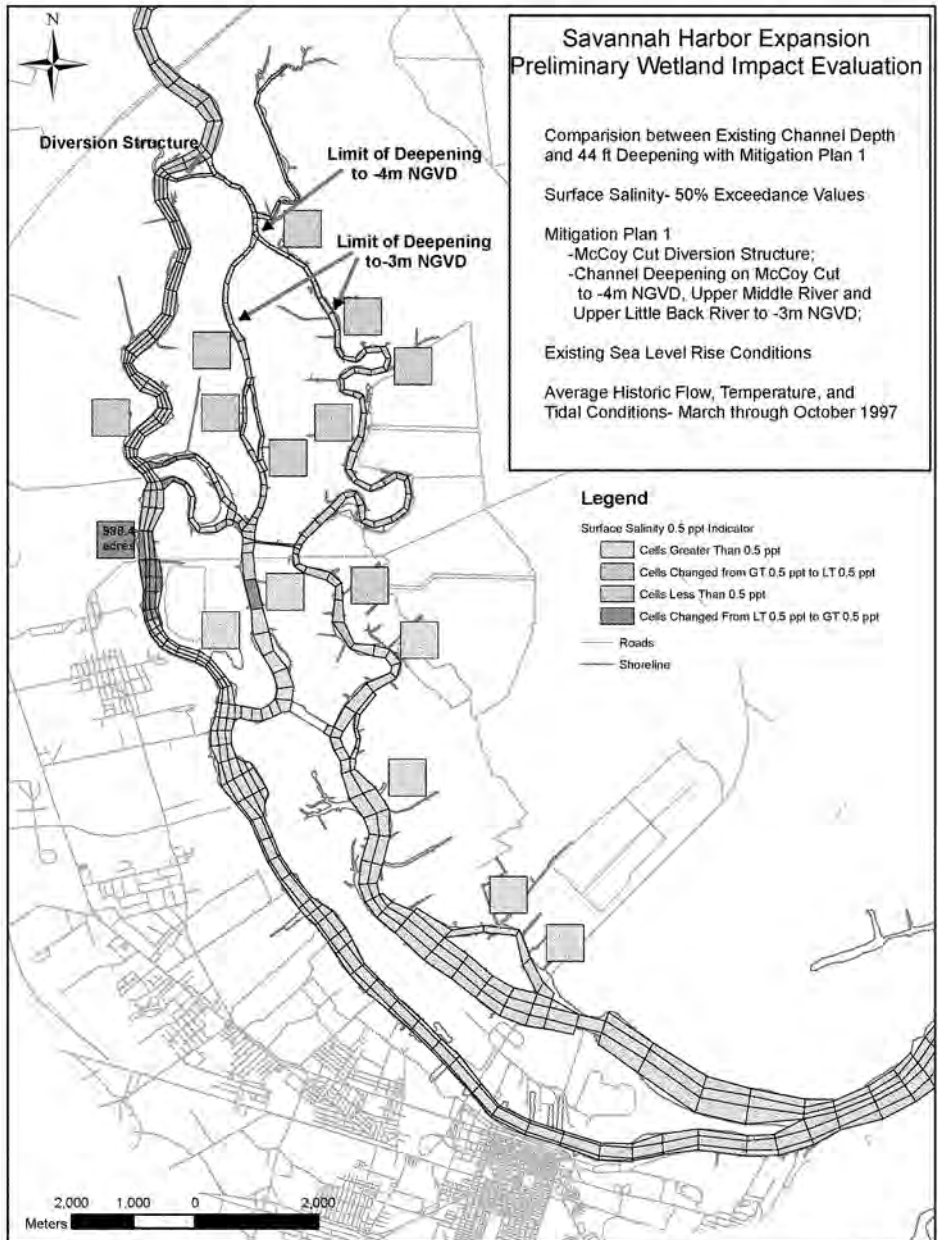
- *McCoy Cut Diversion Structure*
- *Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD*

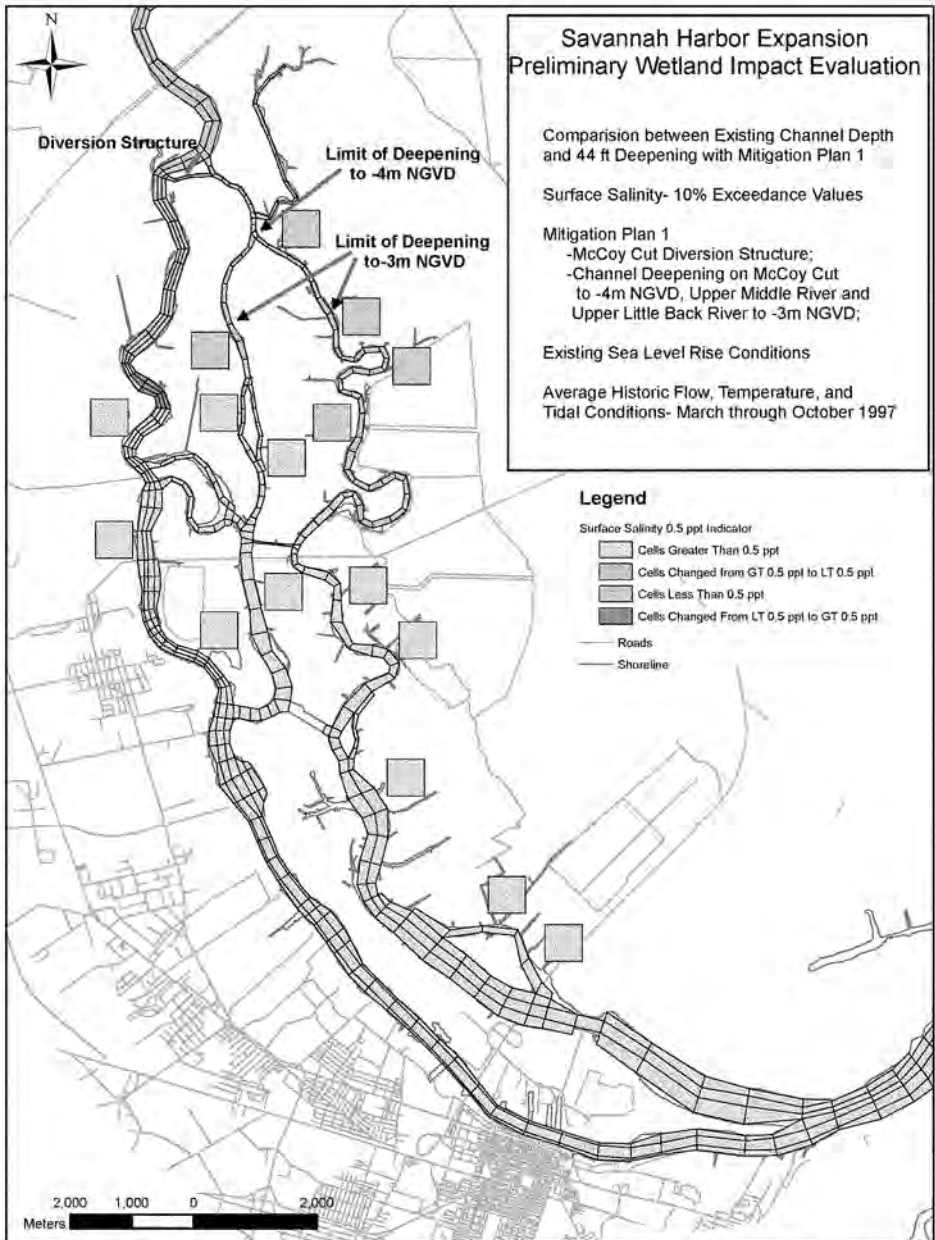
44-ft Deepening

Basic Evaluation



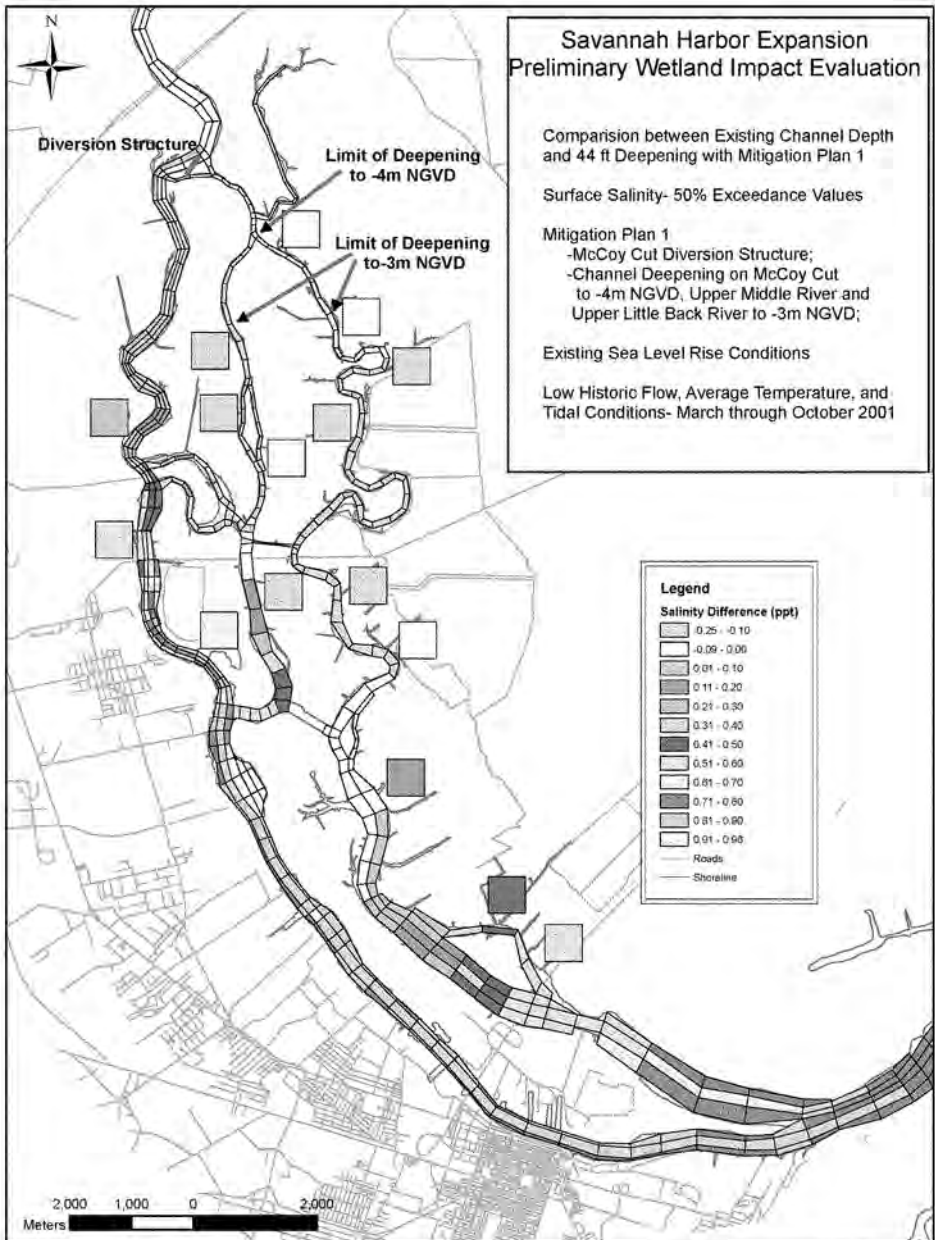


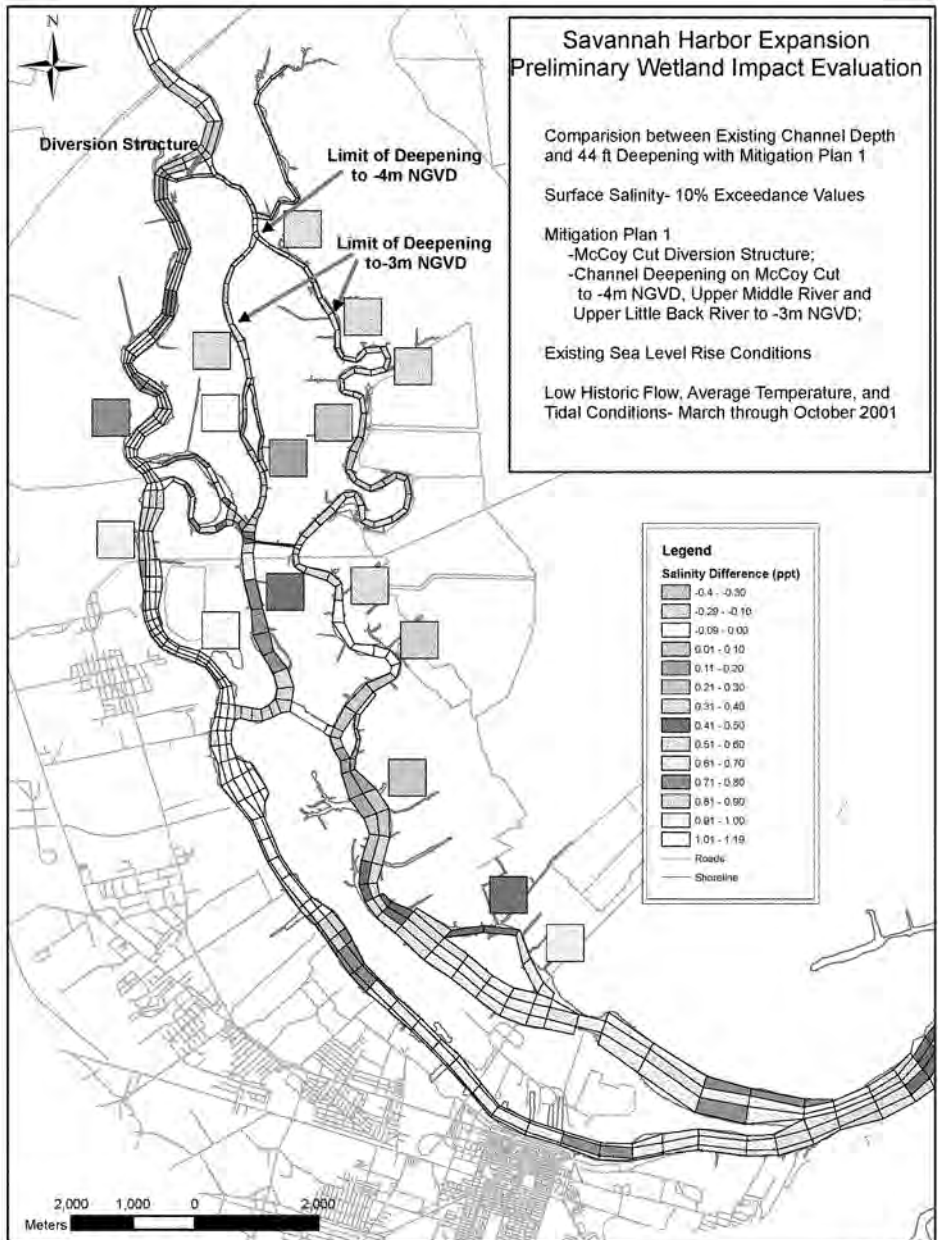


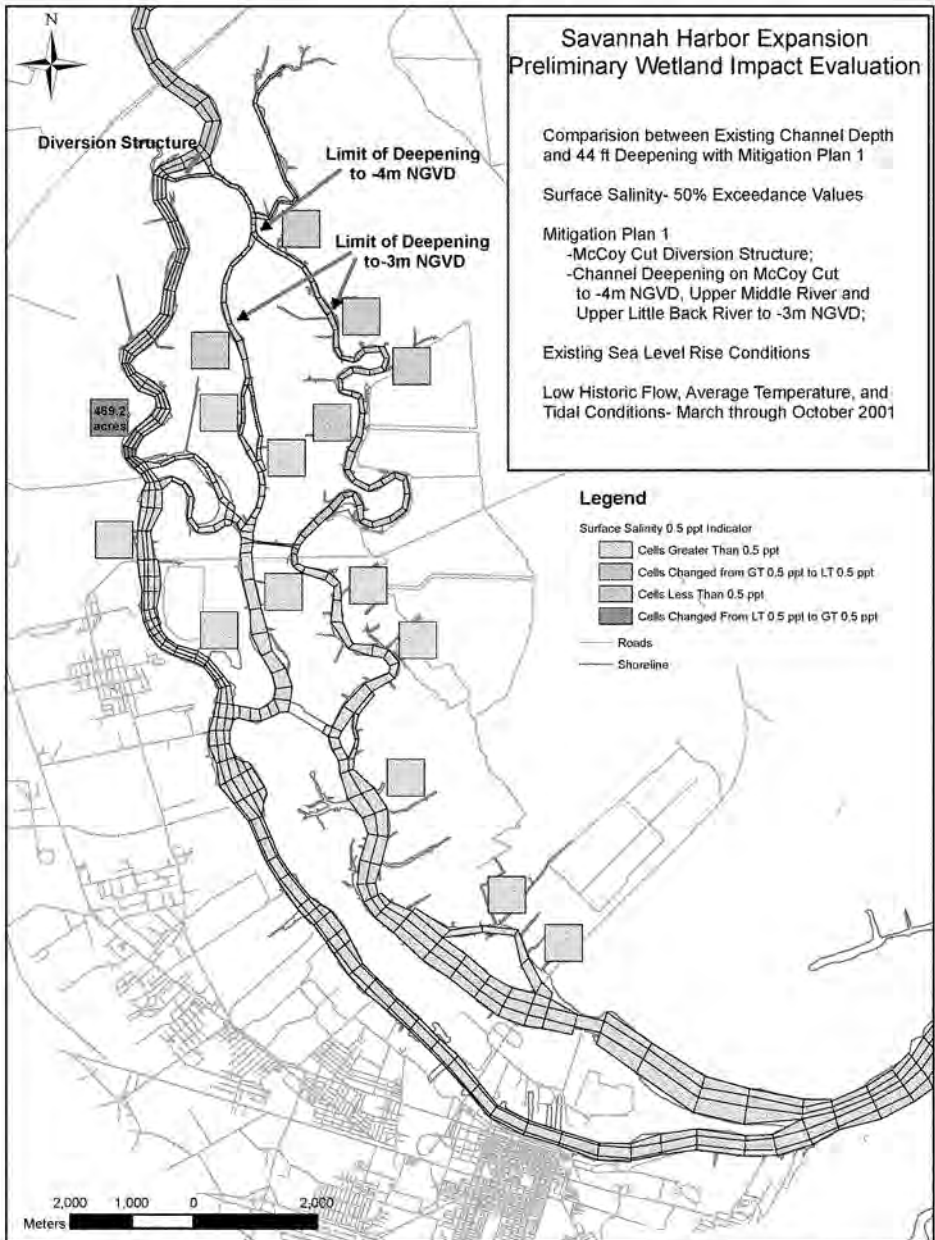


January 2007

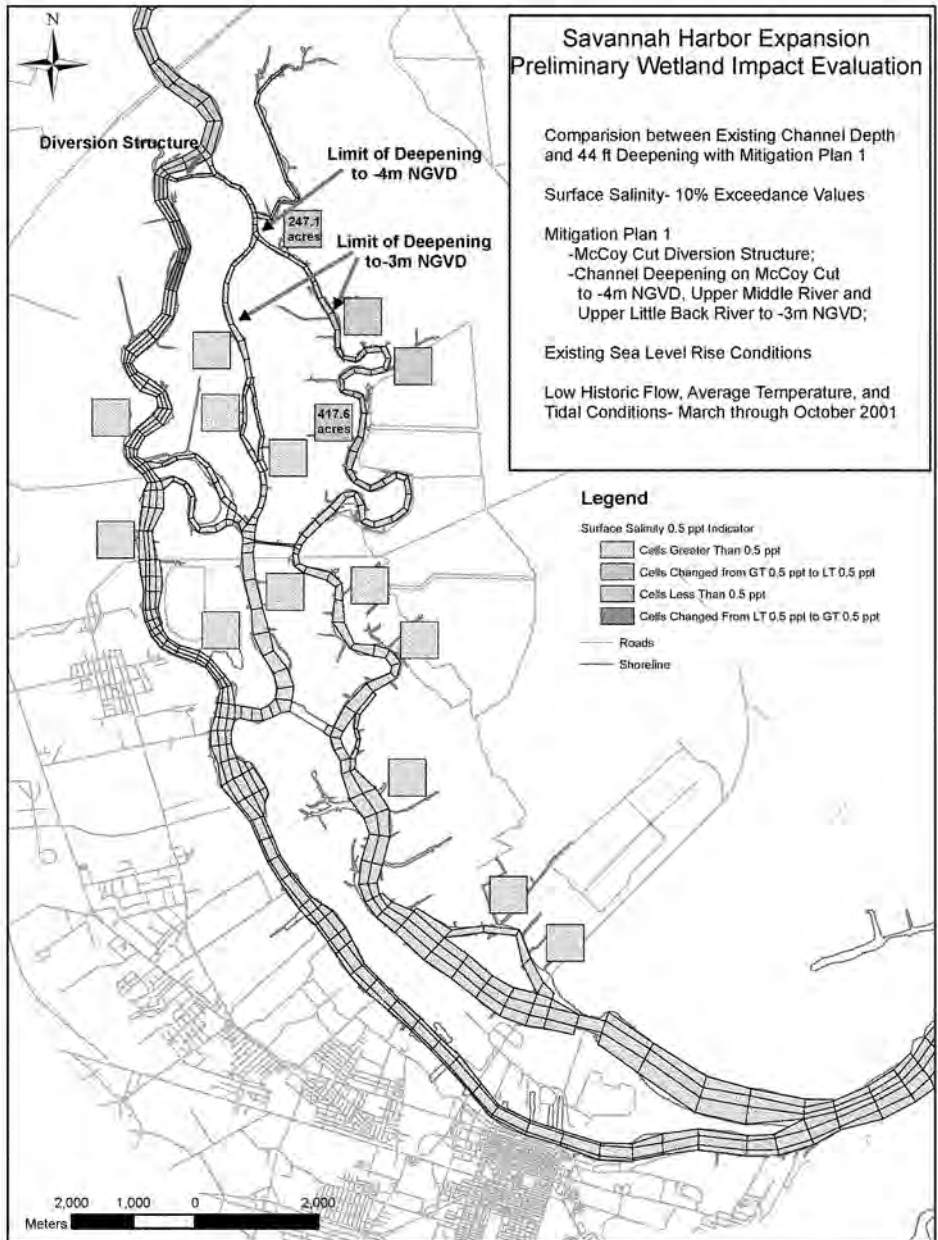
Sensitivity Analysis #1



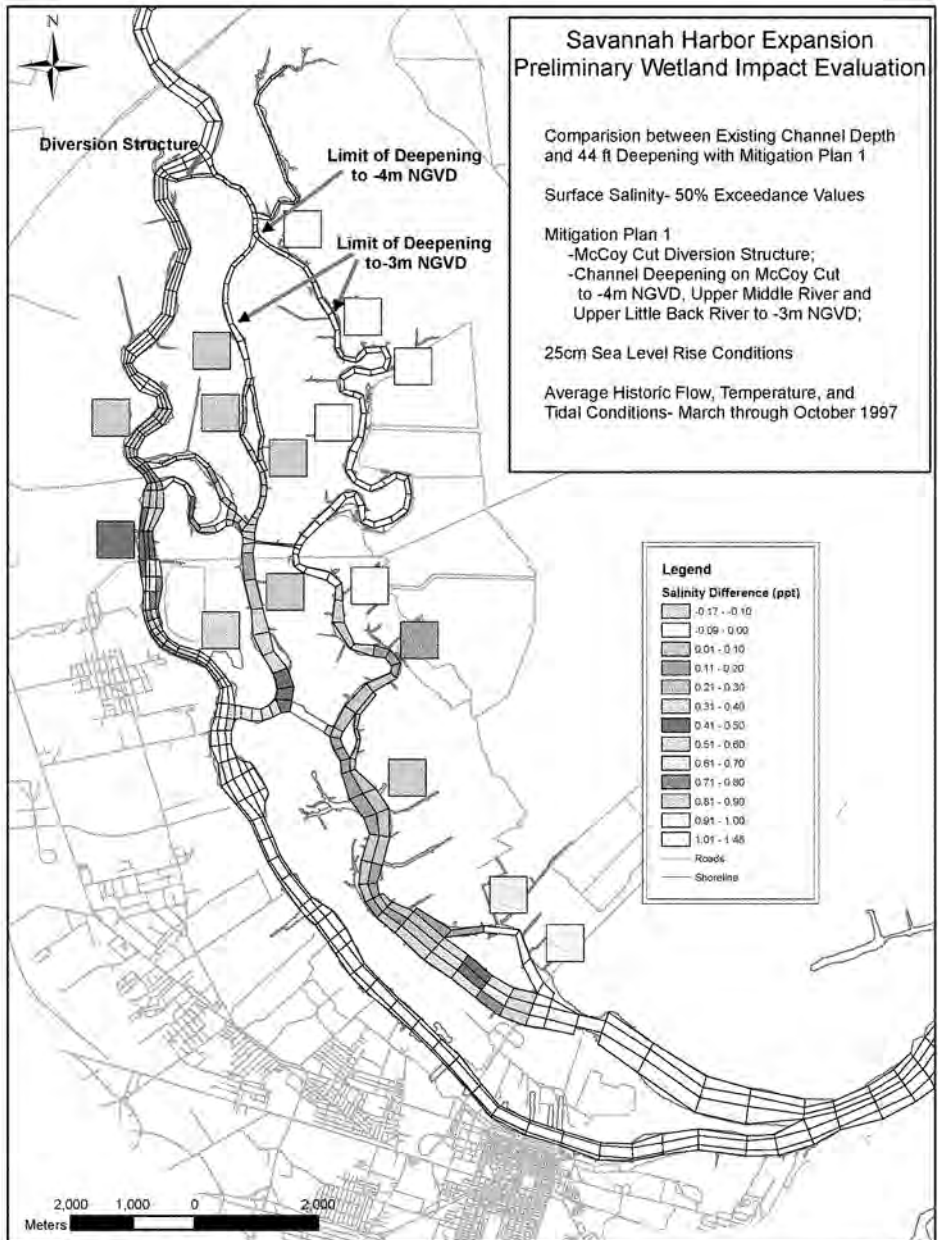


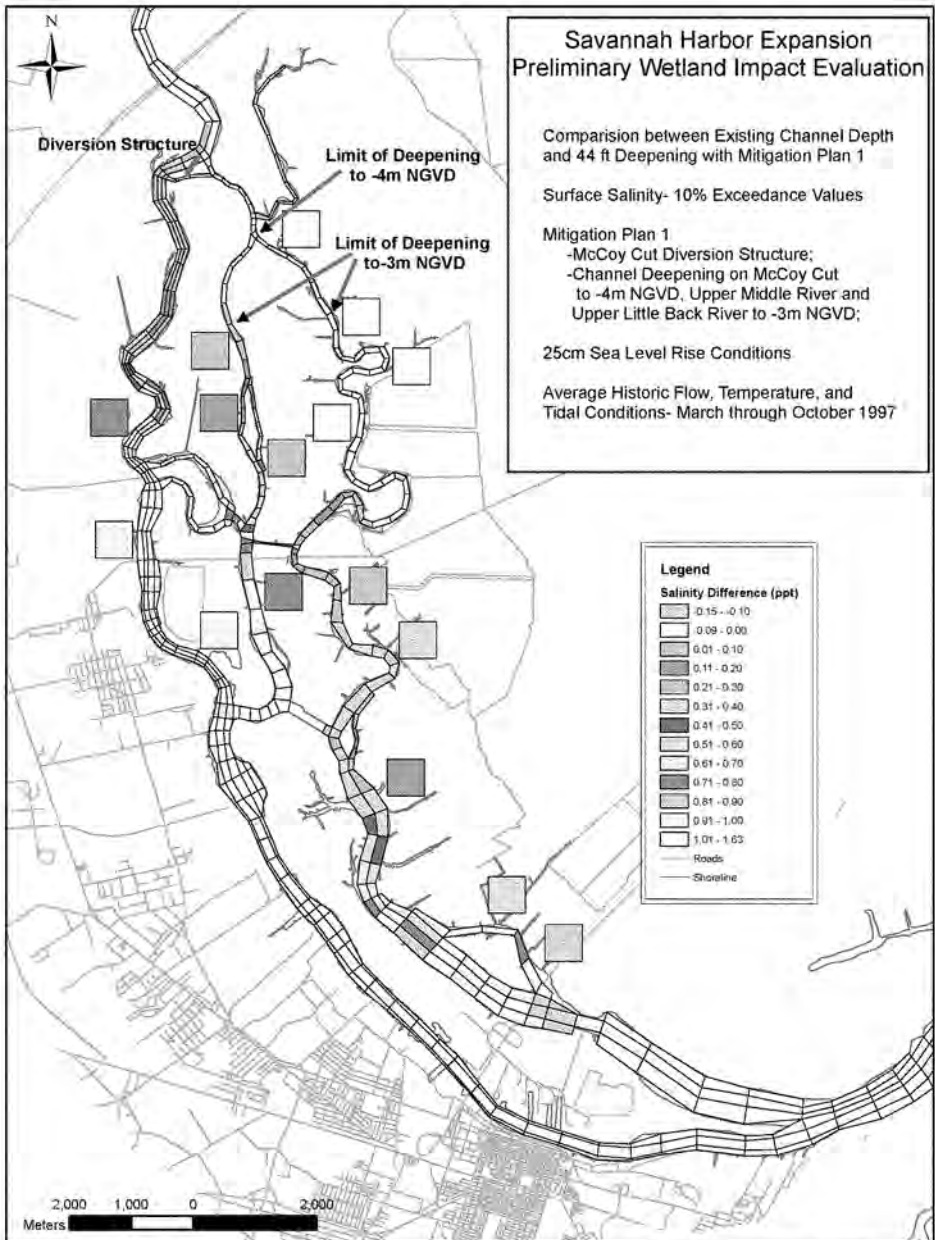


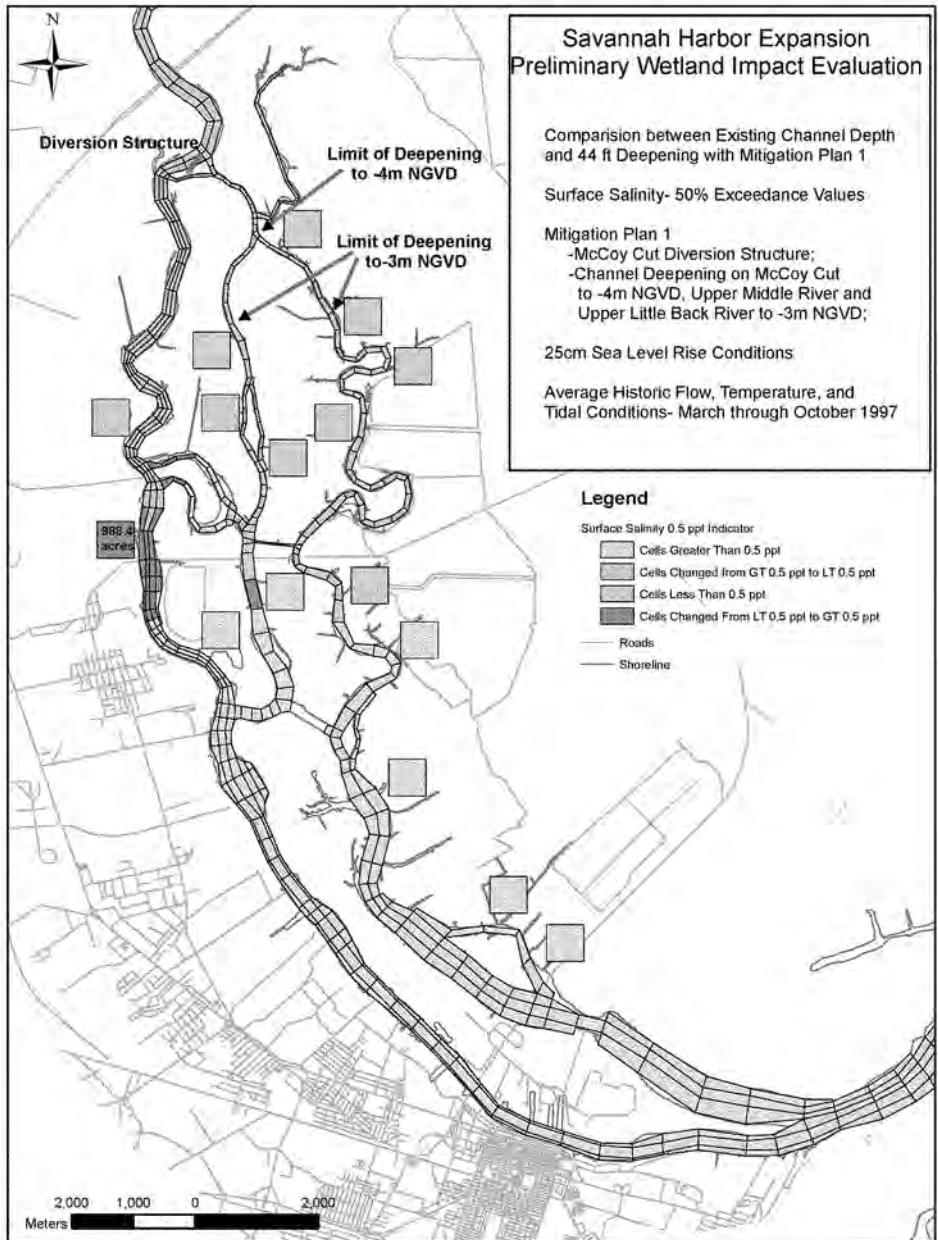
January 2007



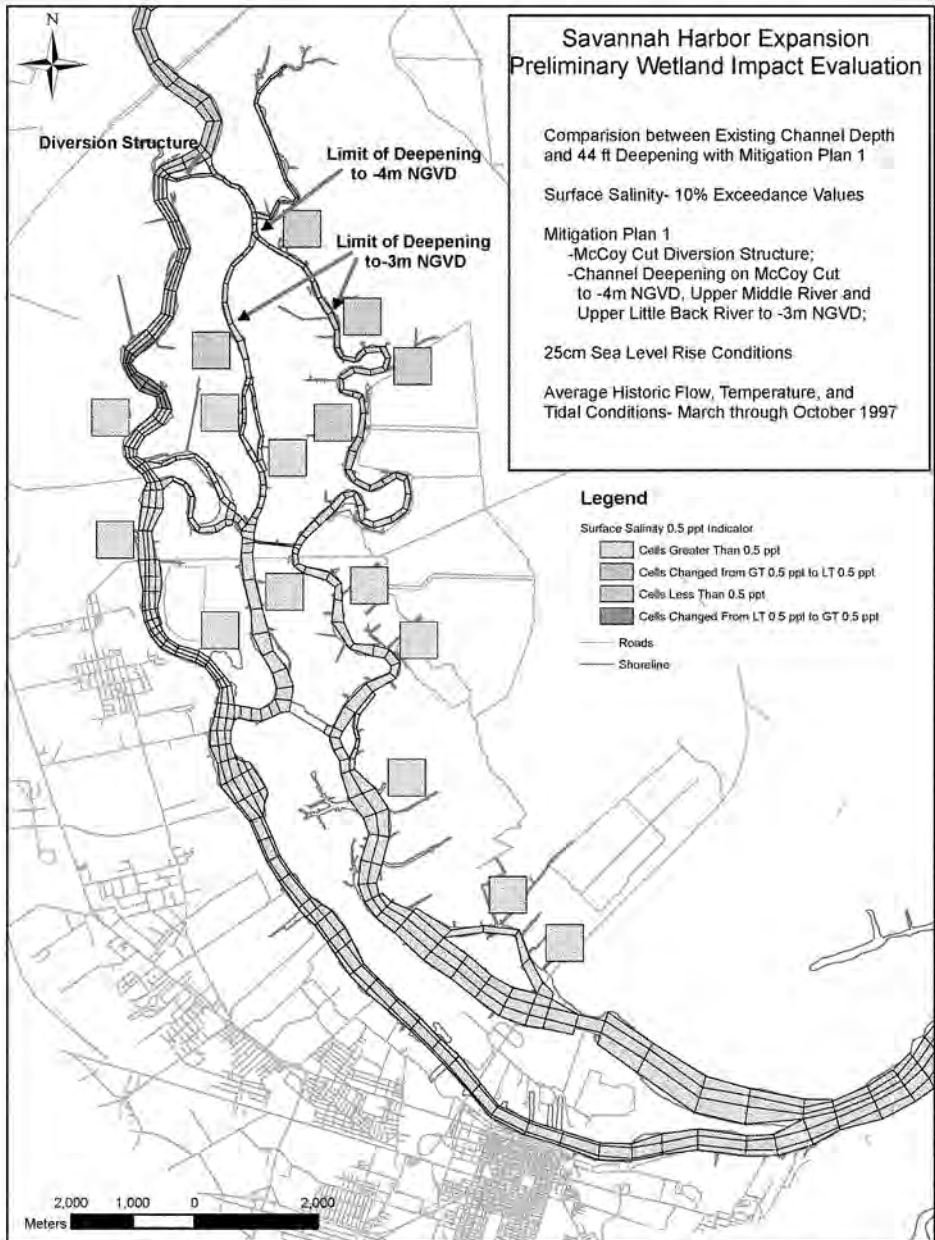
Sensitivity Analysis #2A





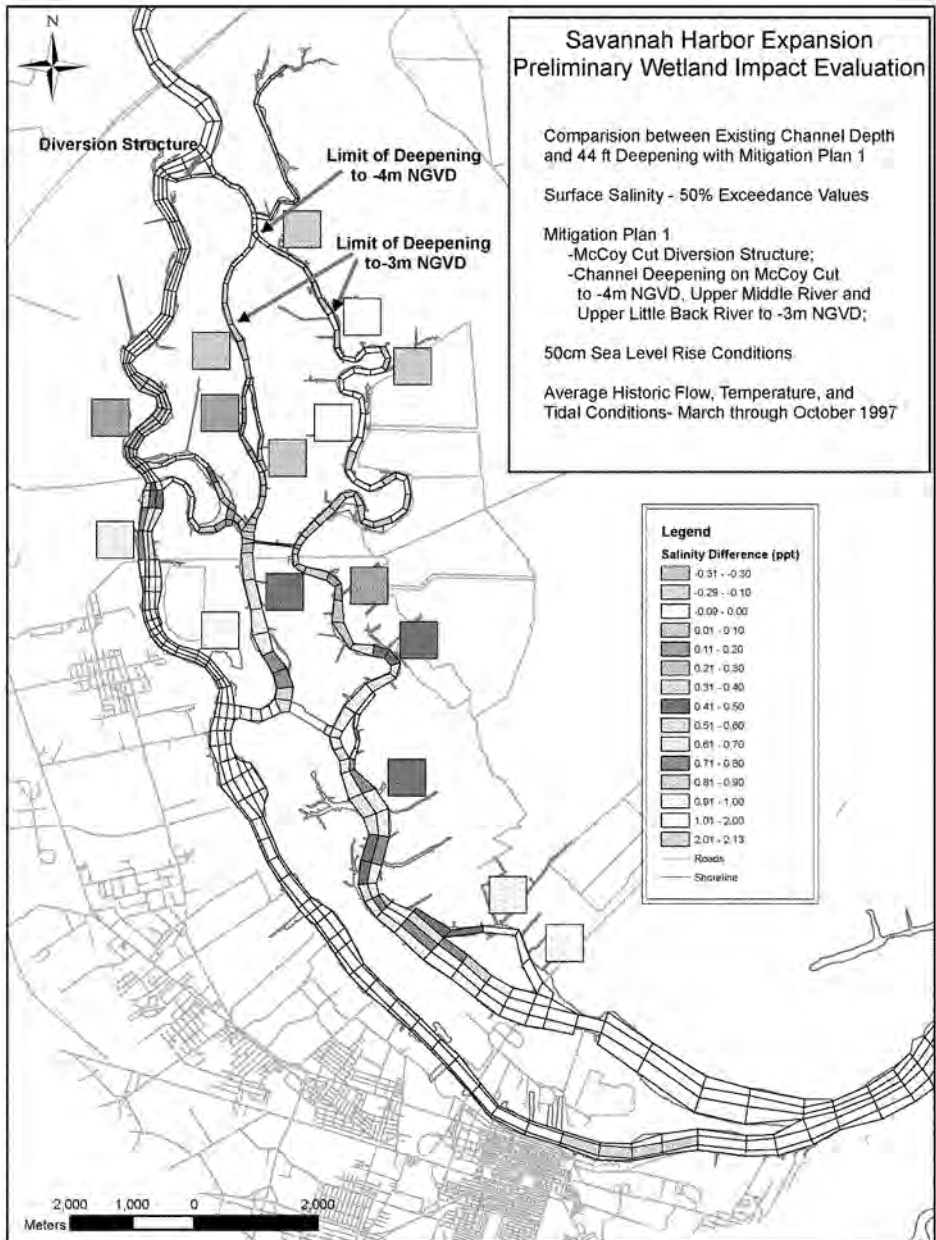


January 2007

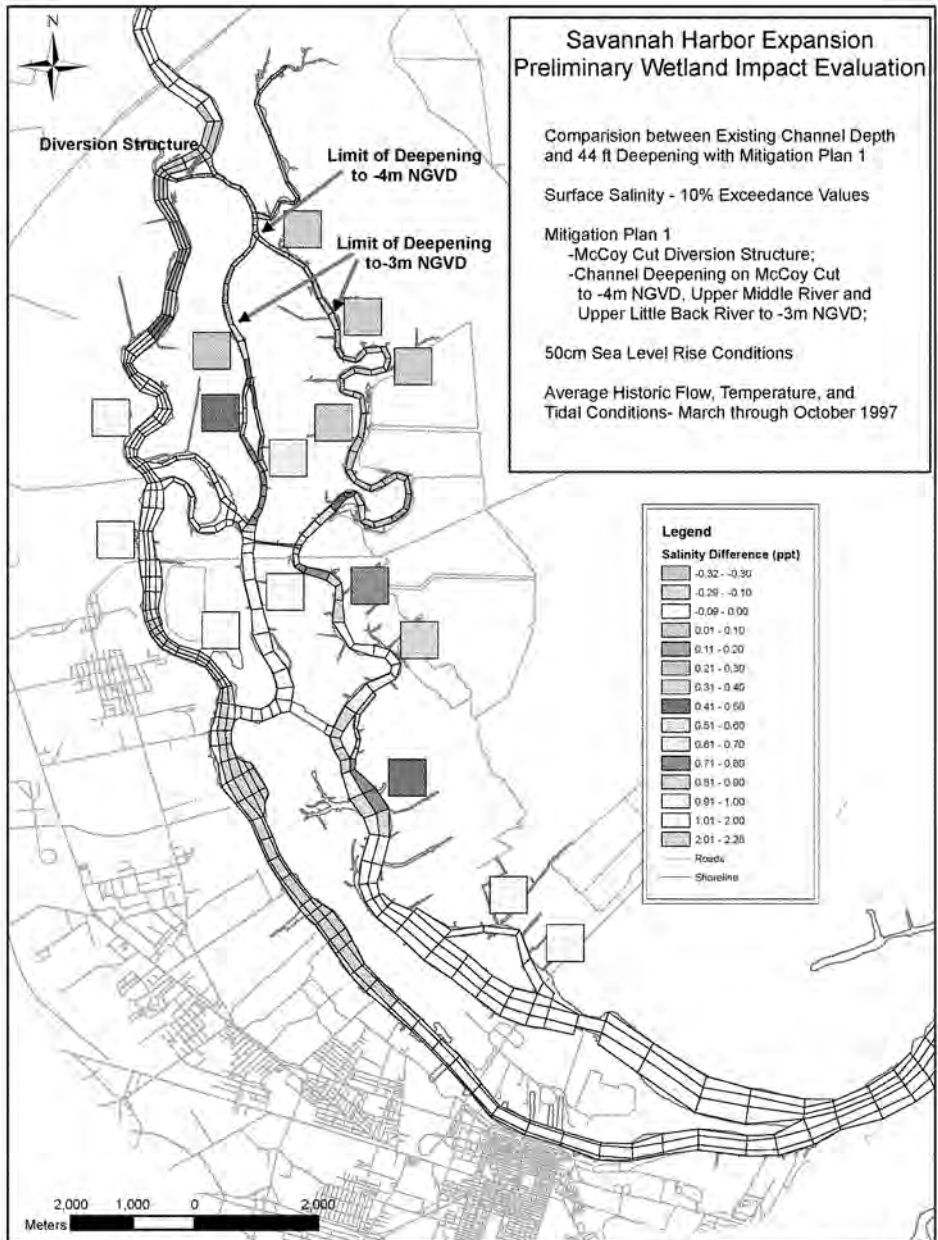


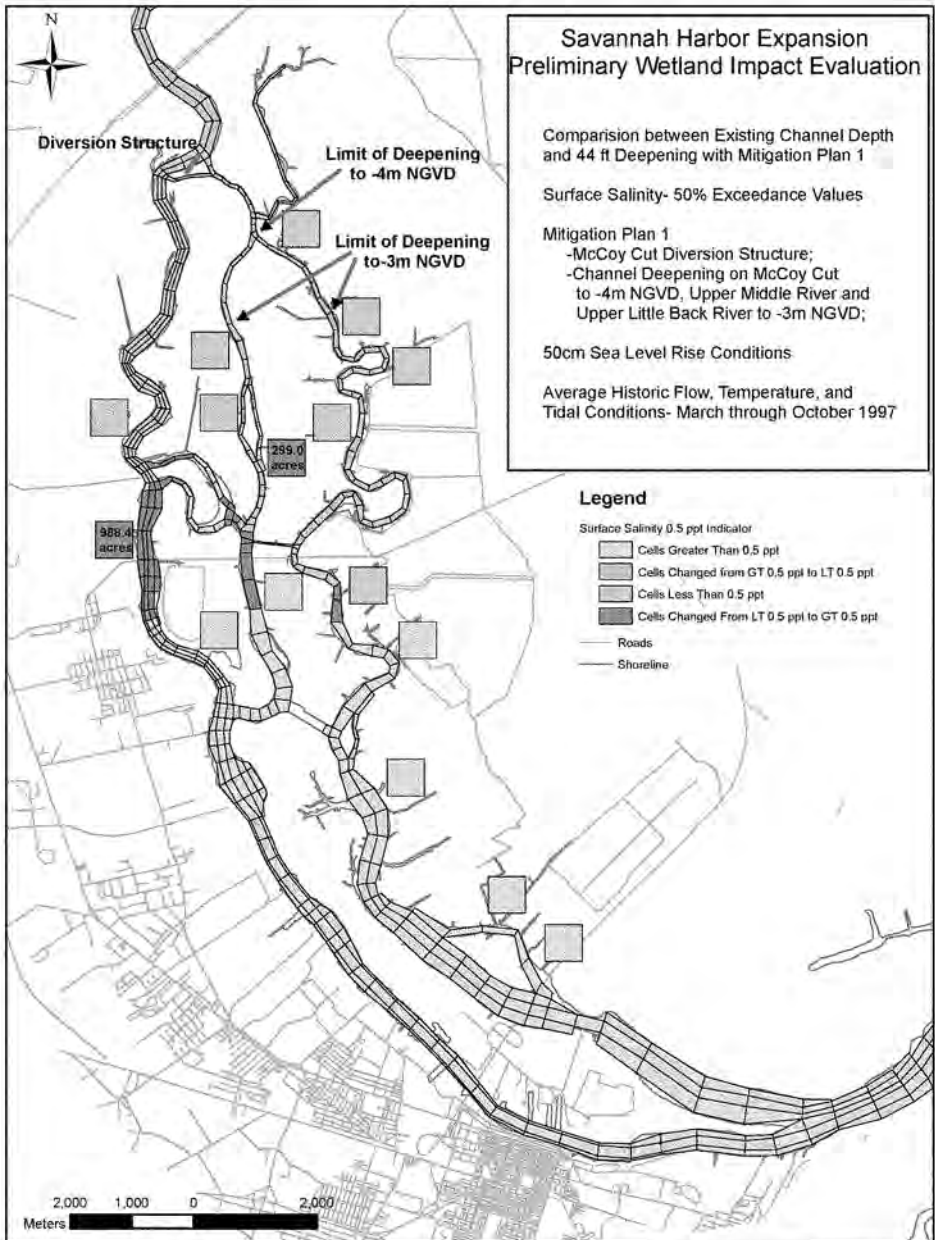
January 2007

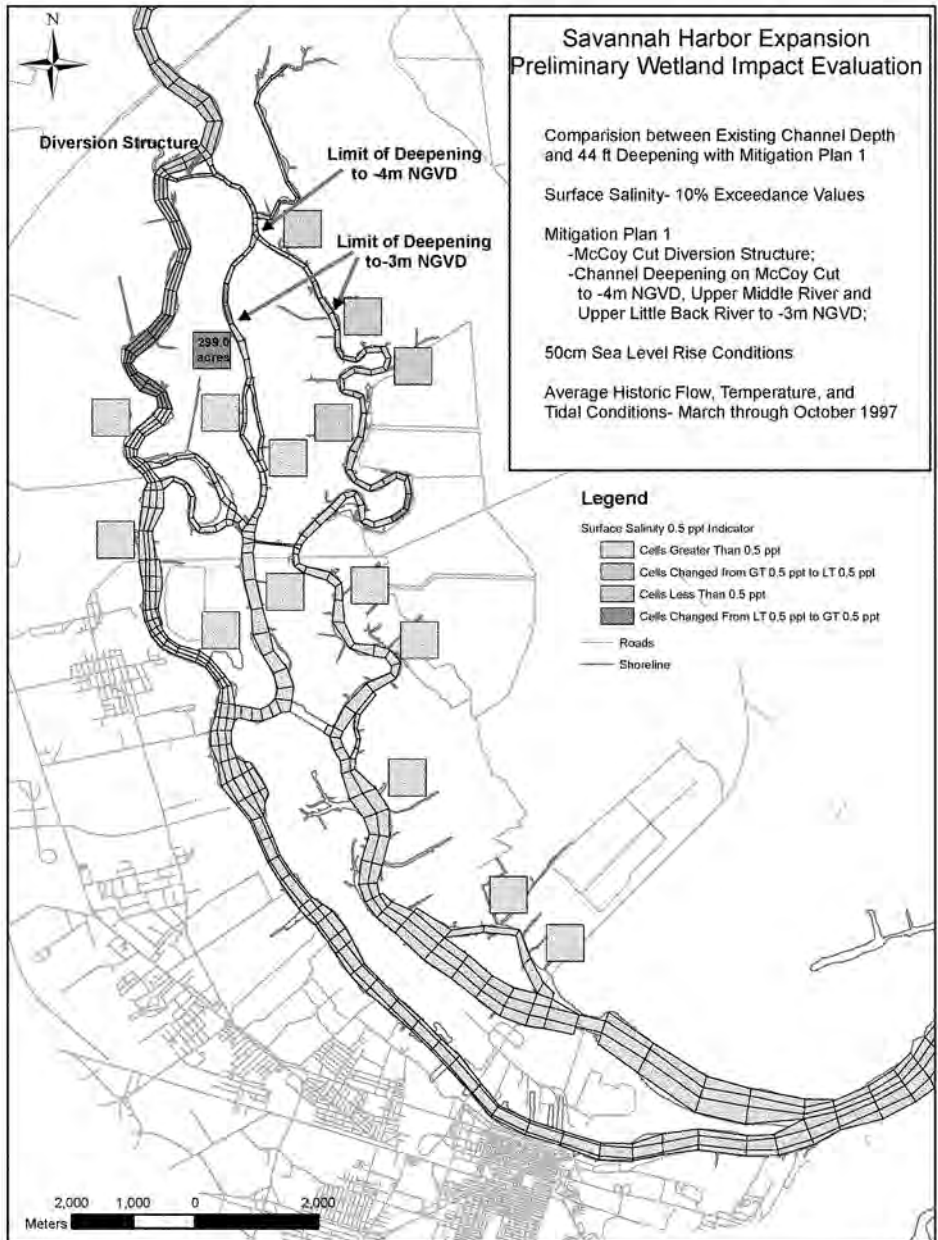
Sensitivity Analysis #2B



January 2007



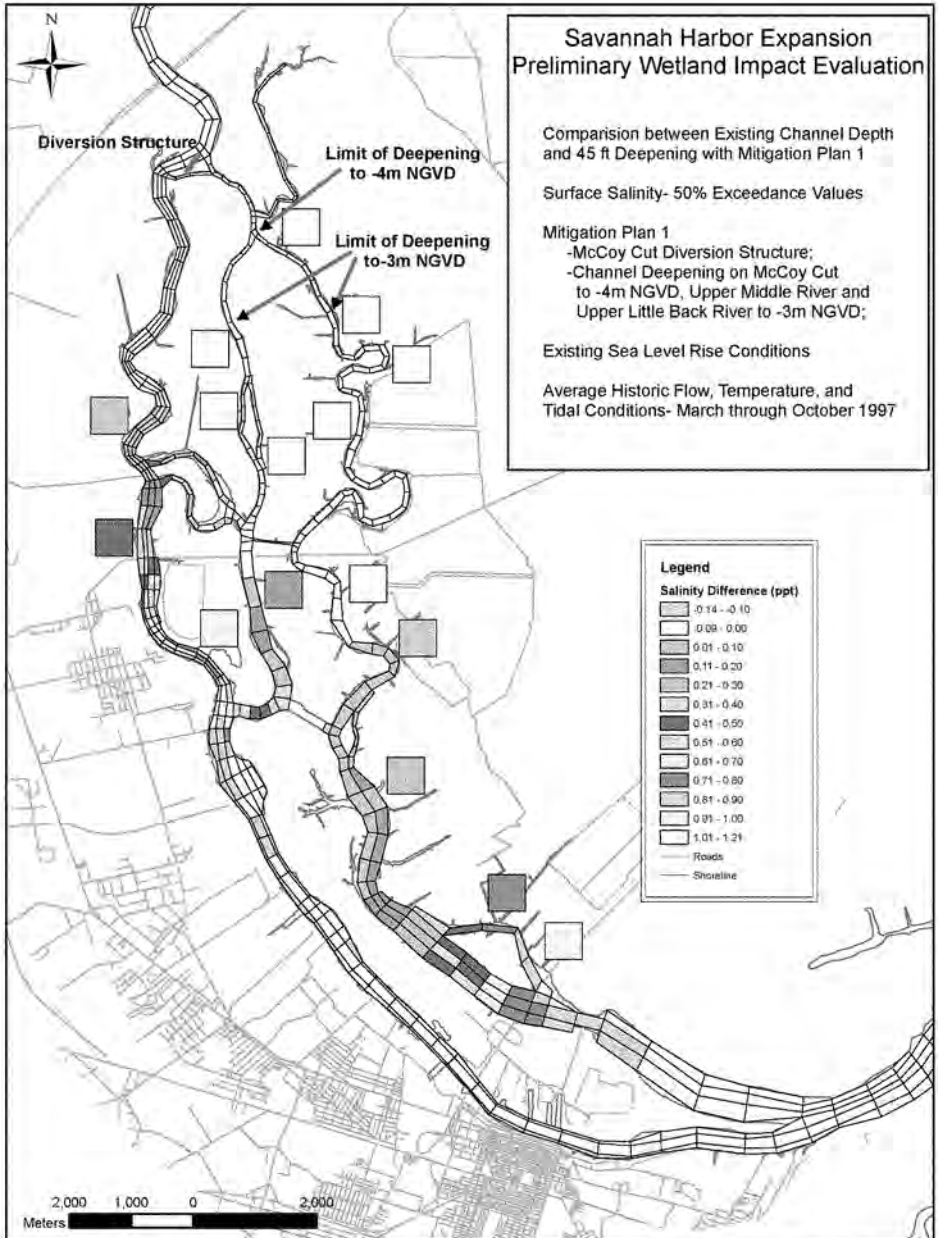


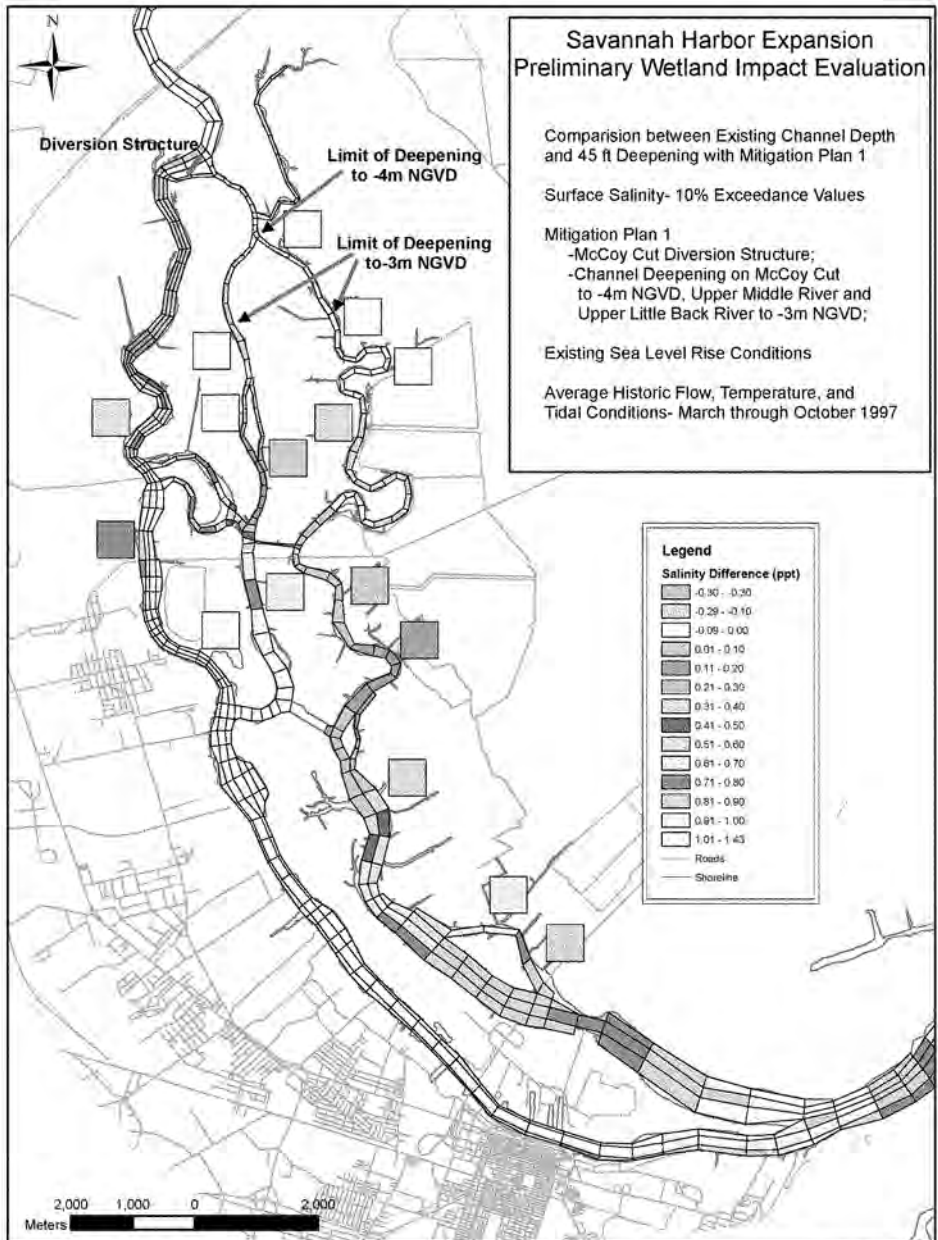


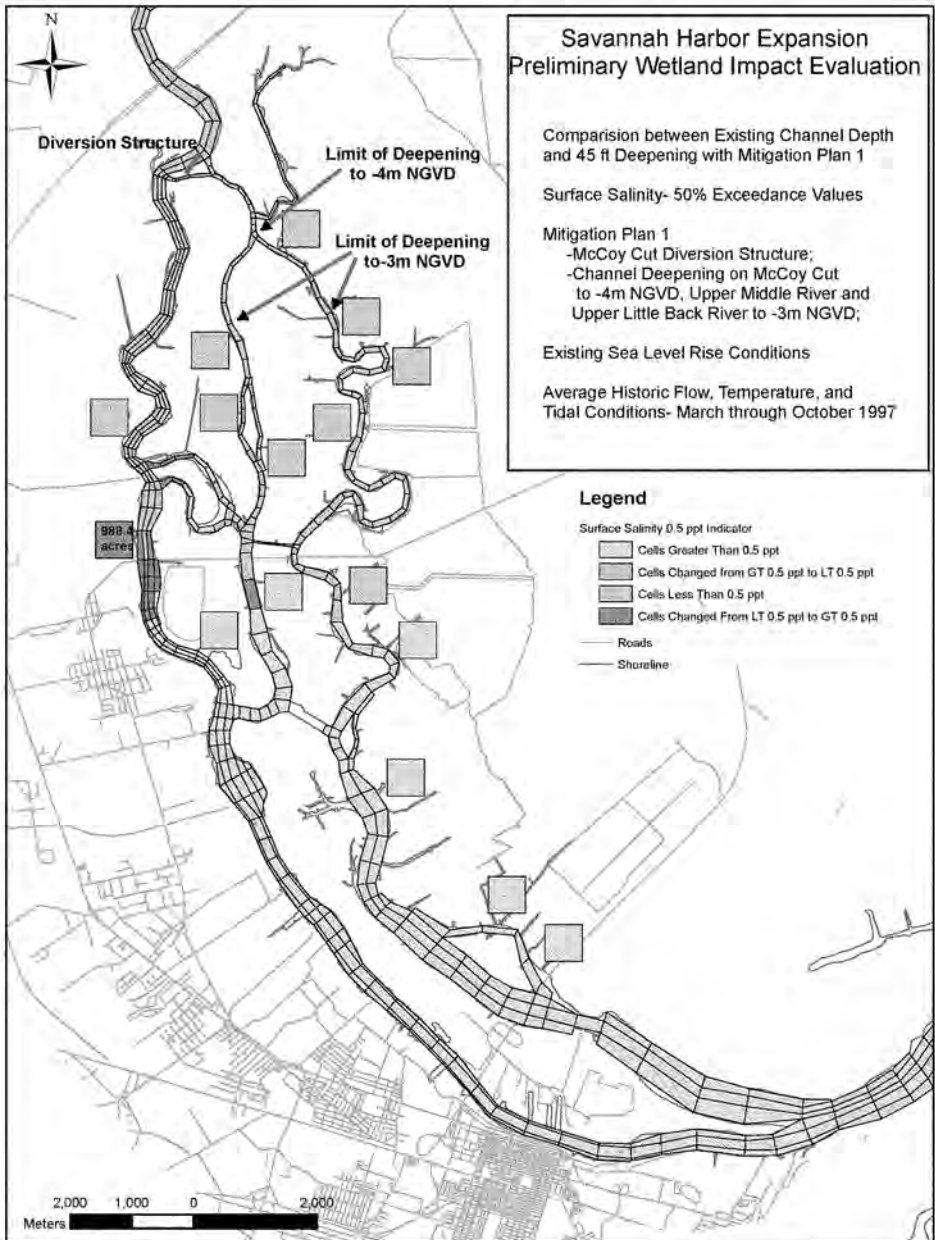
January 2007

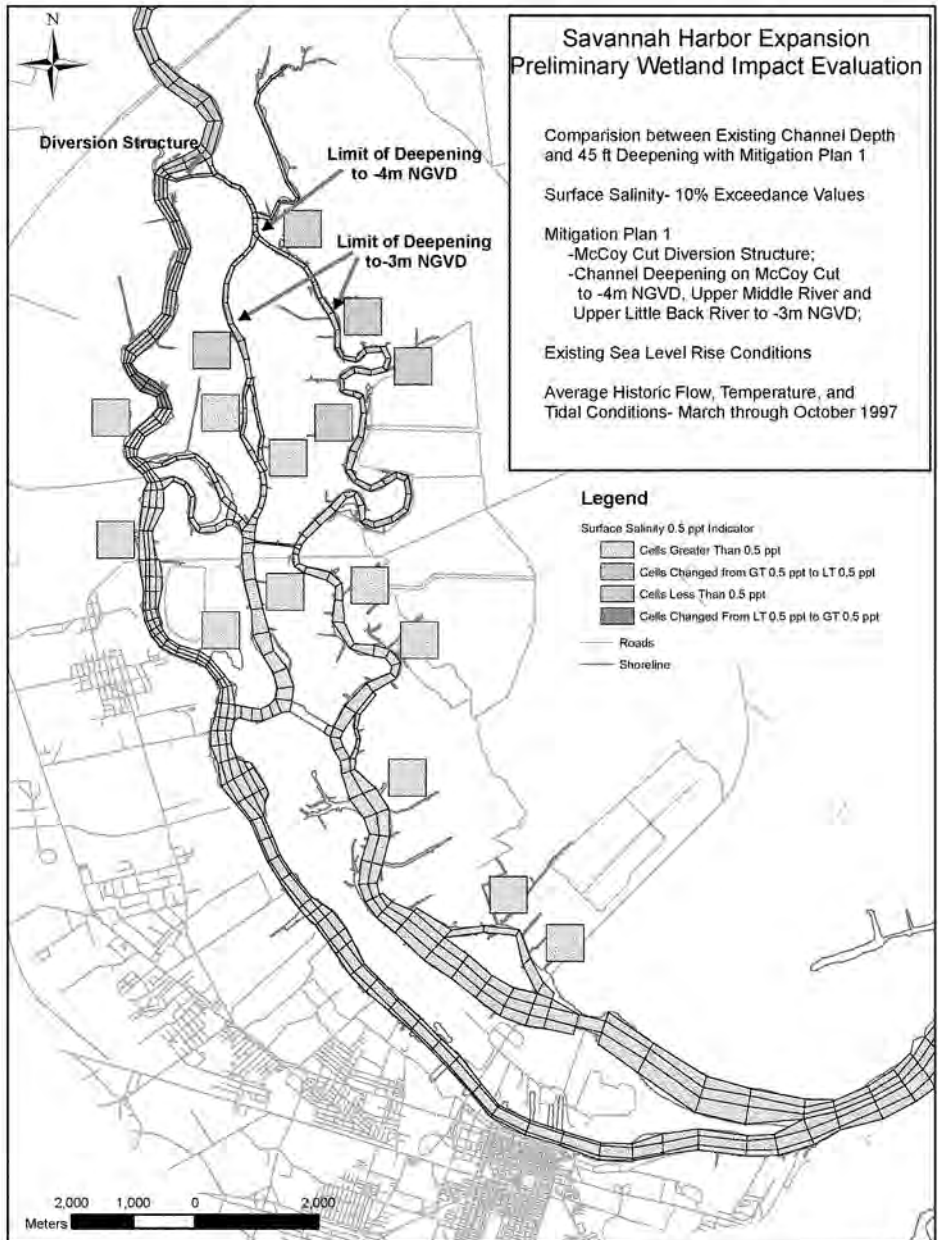
45-ft Deepening

Basic Evaluation

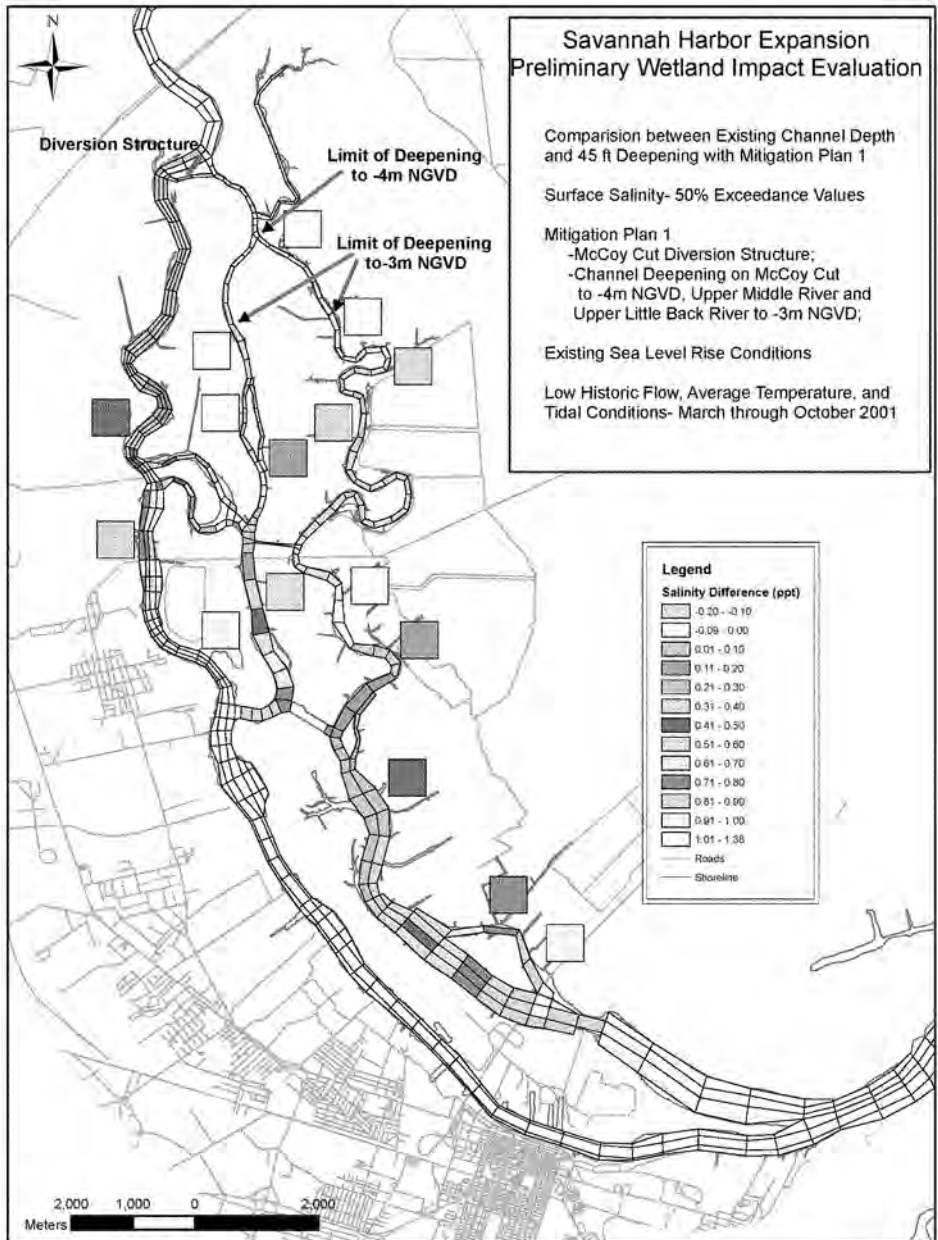


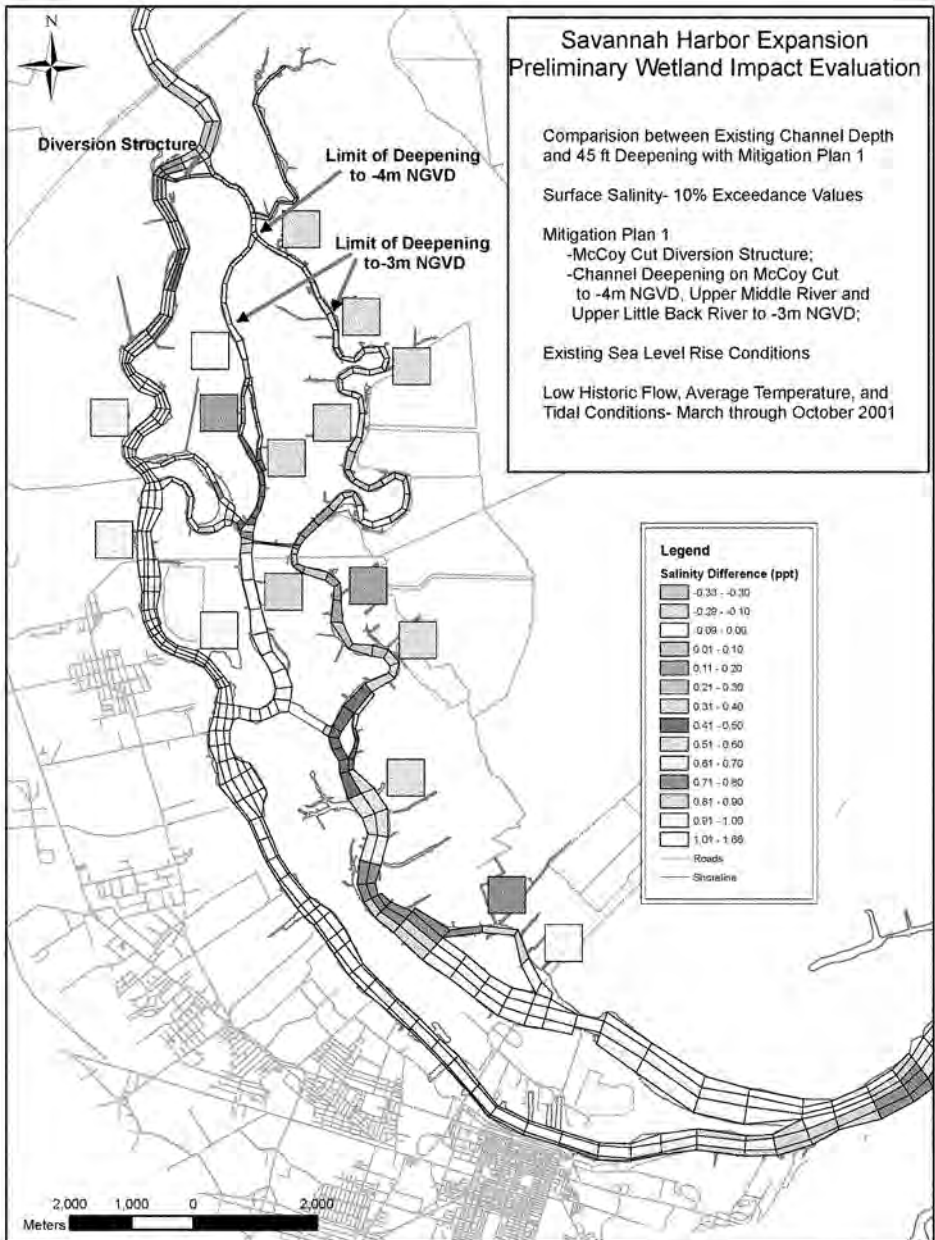


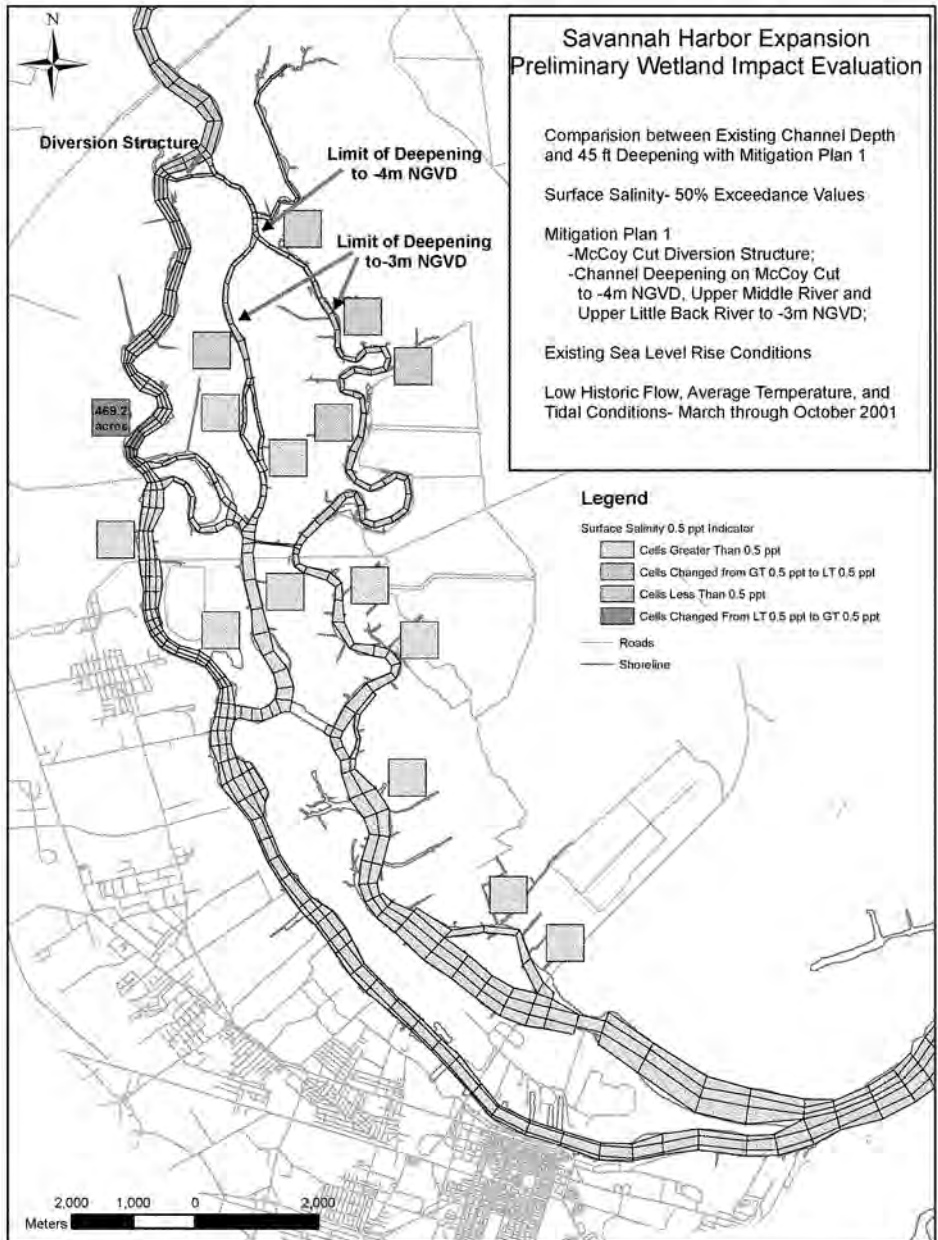


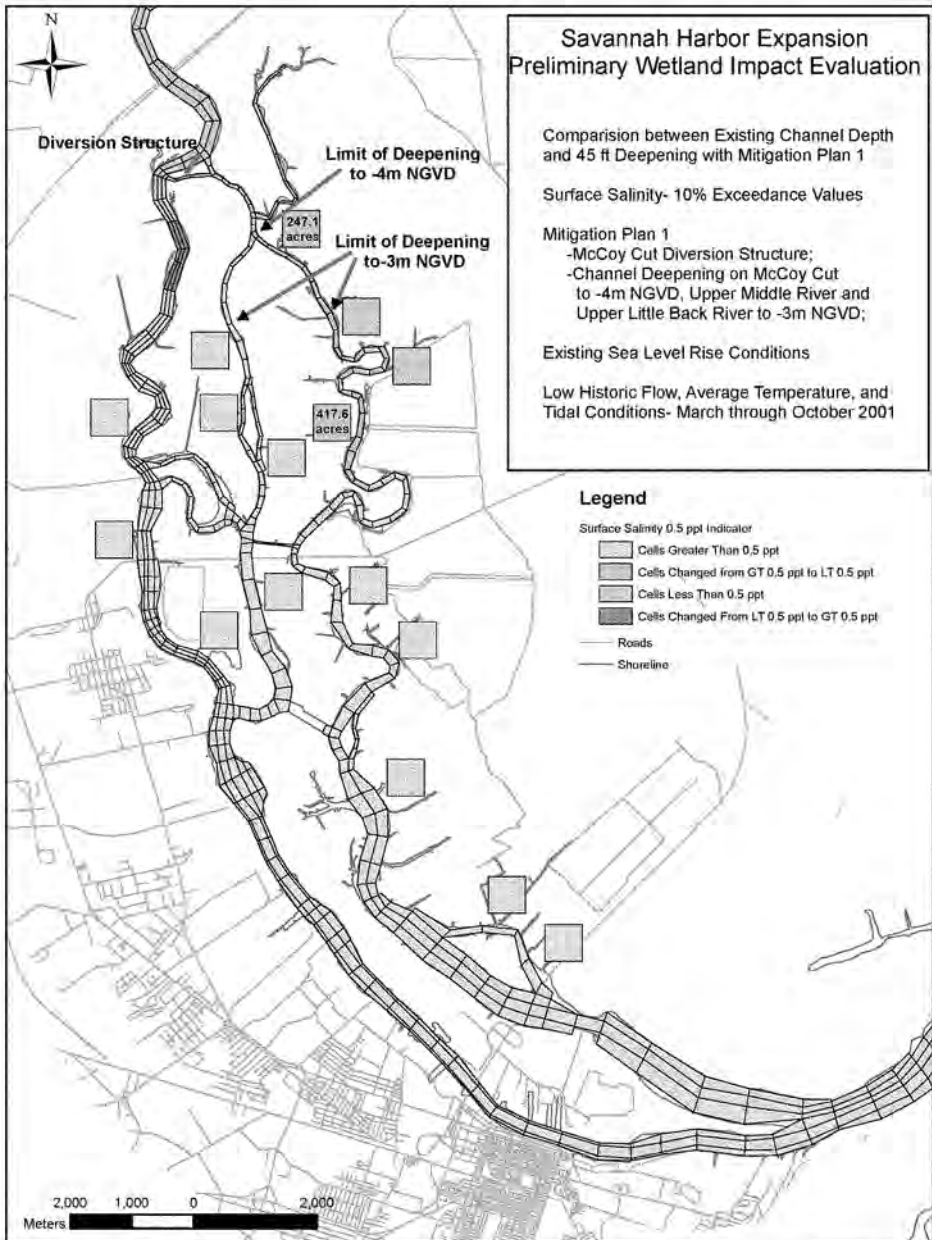


Sensitivity Analysis #1



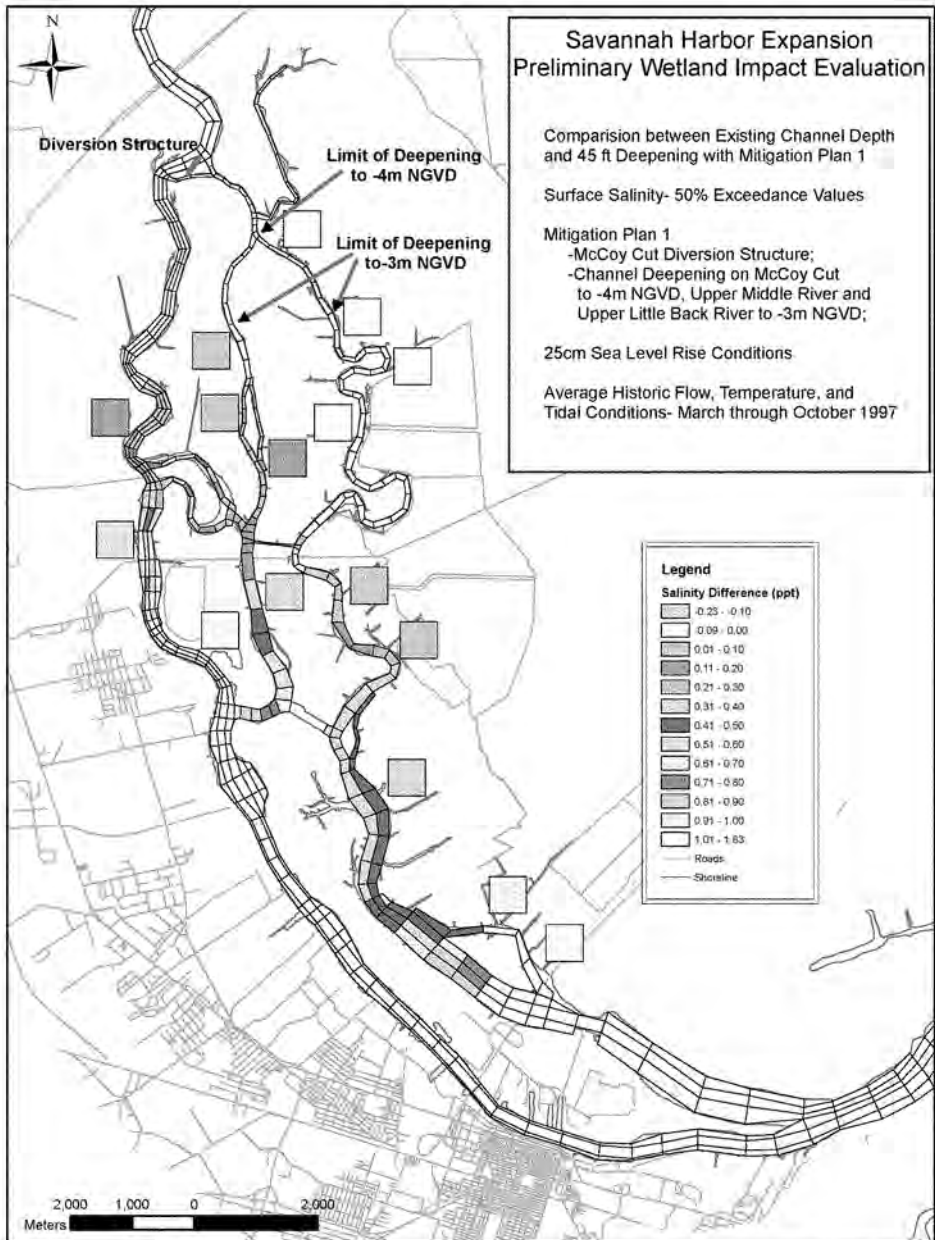


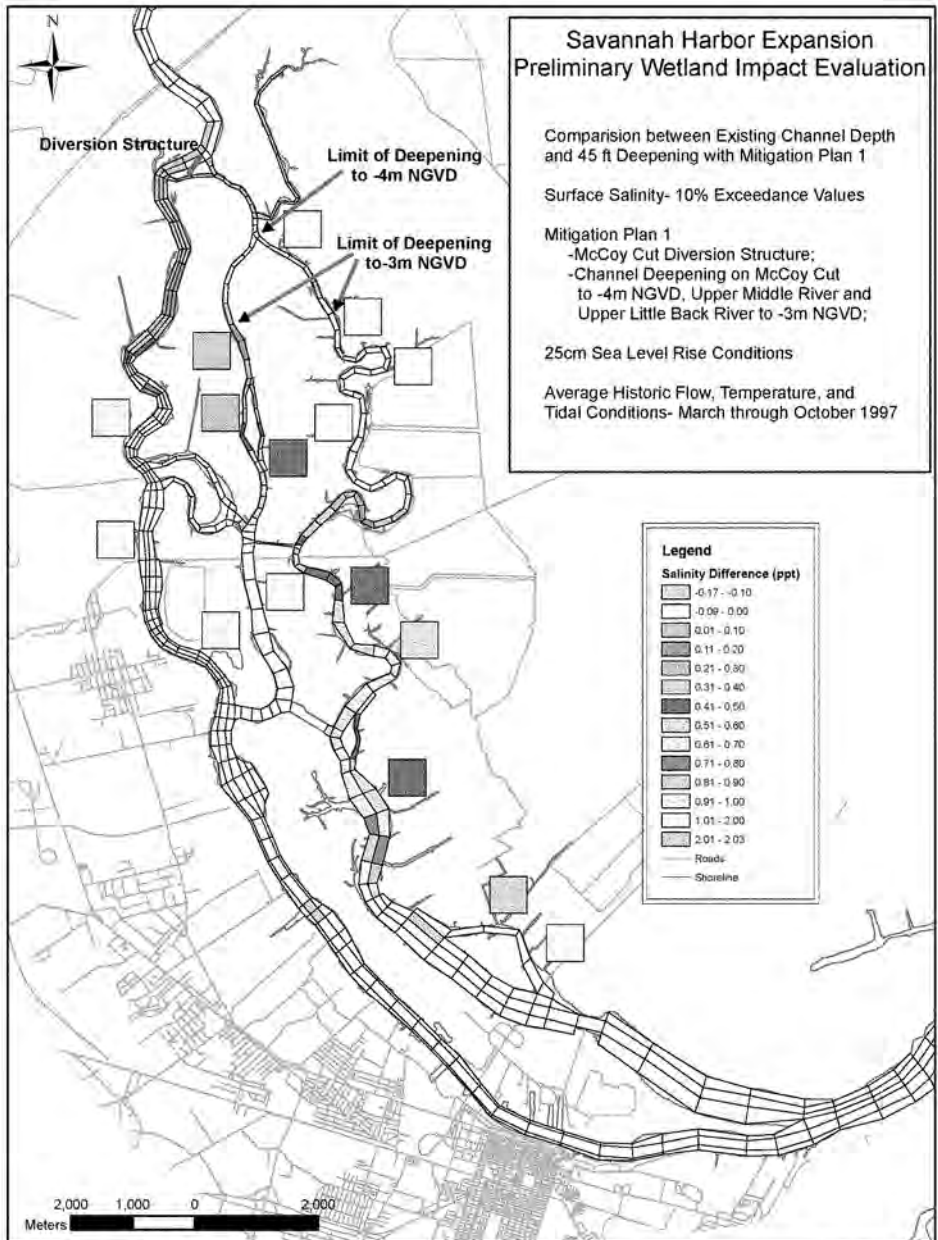


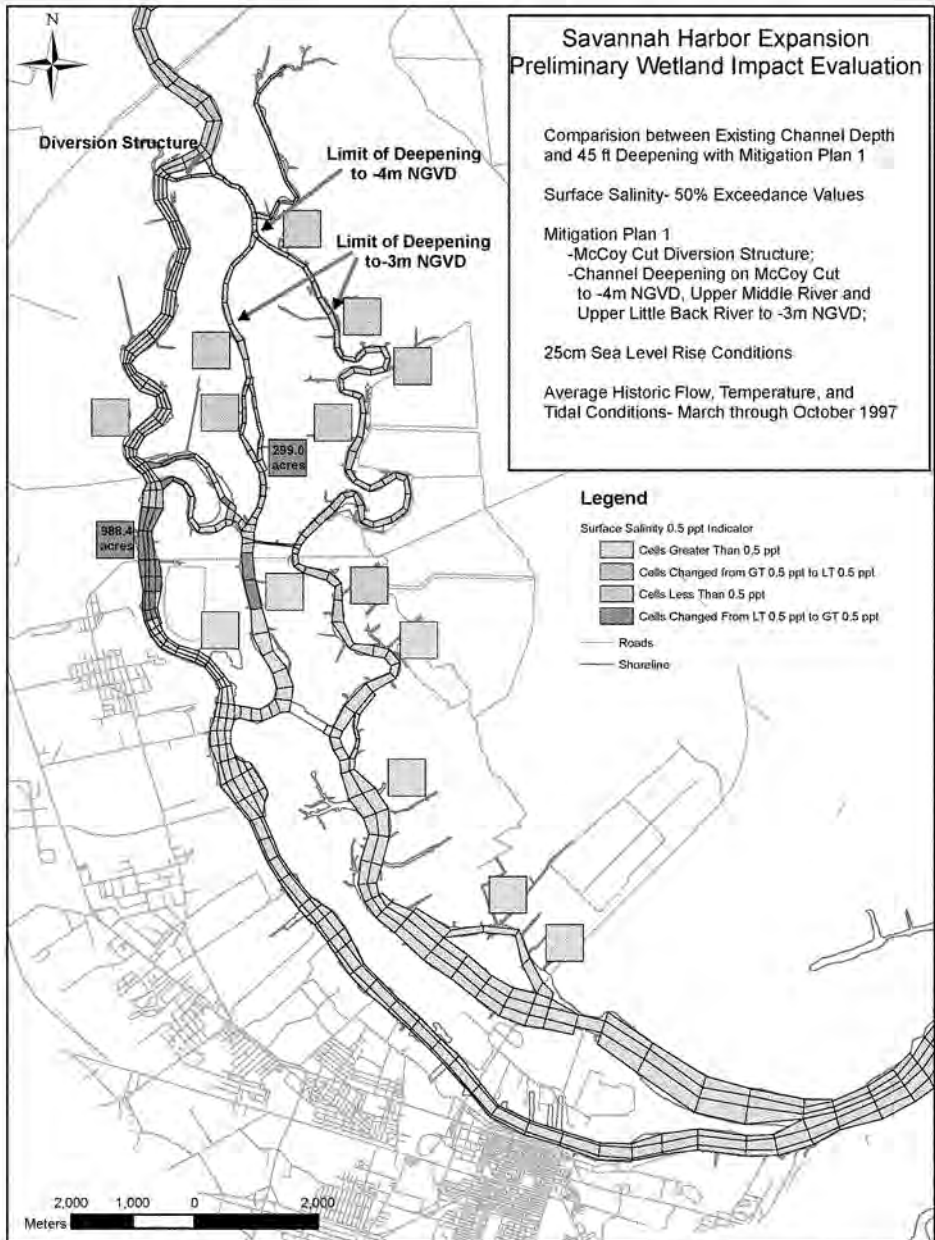


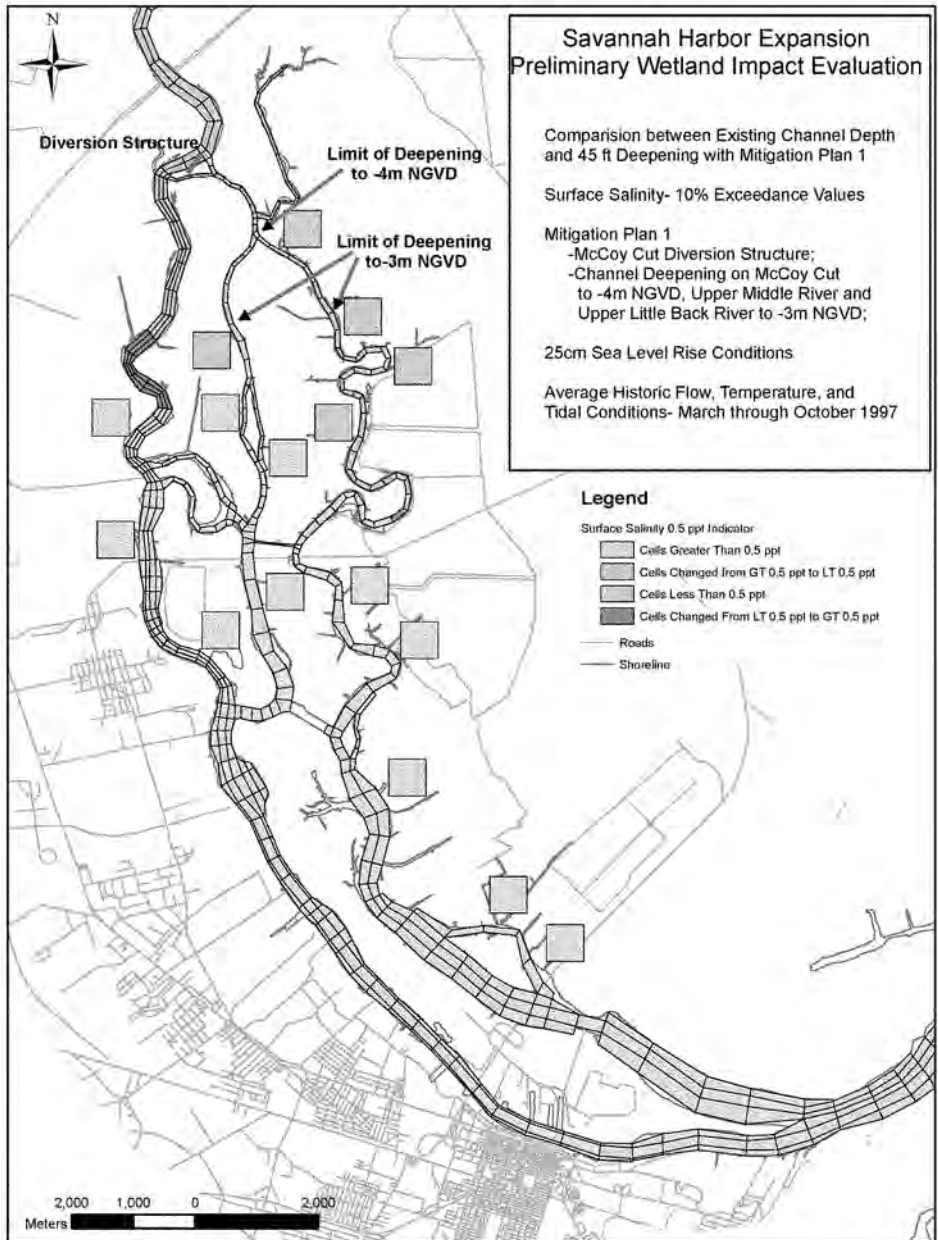
January 2007

Sensitivity Analysis #2A

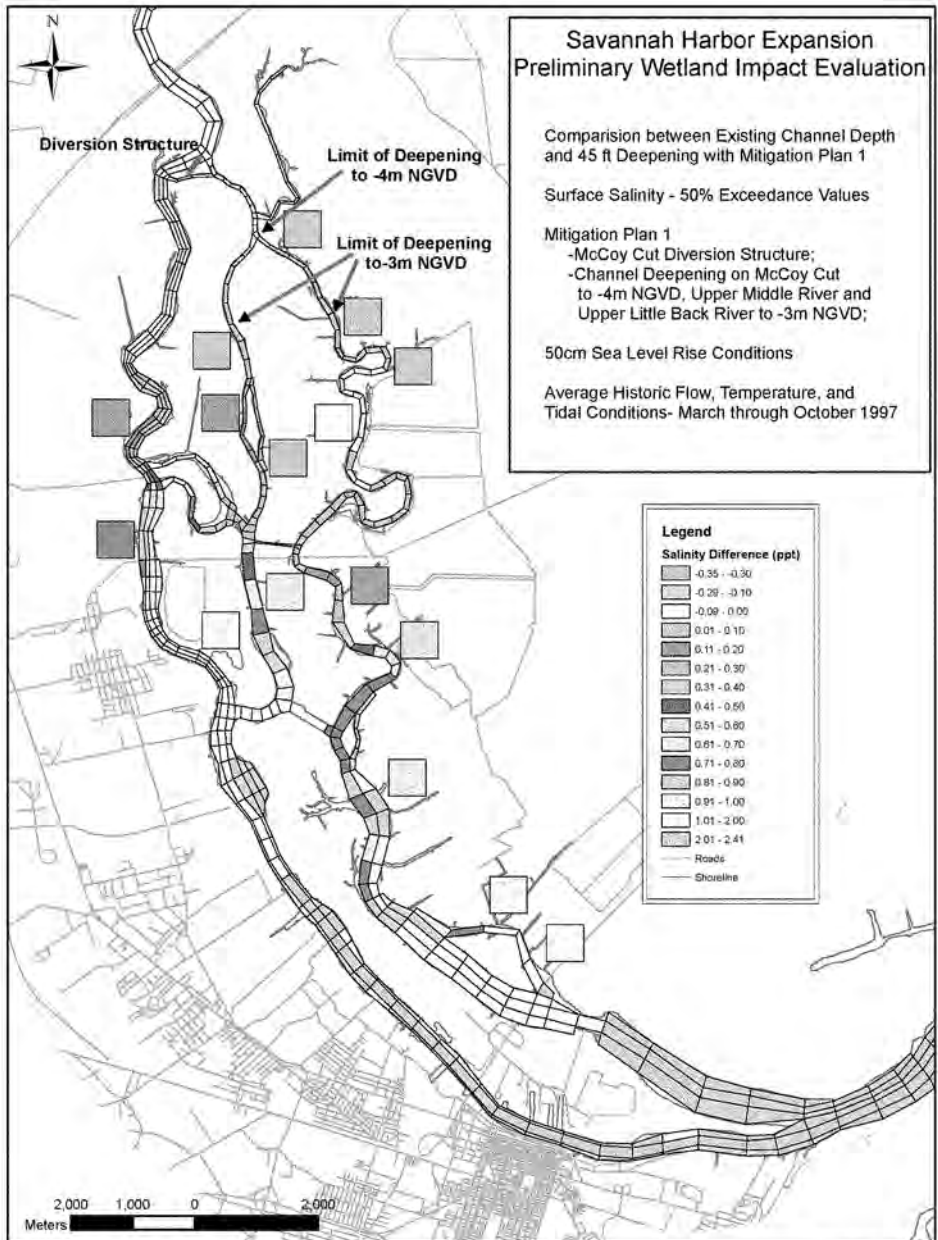




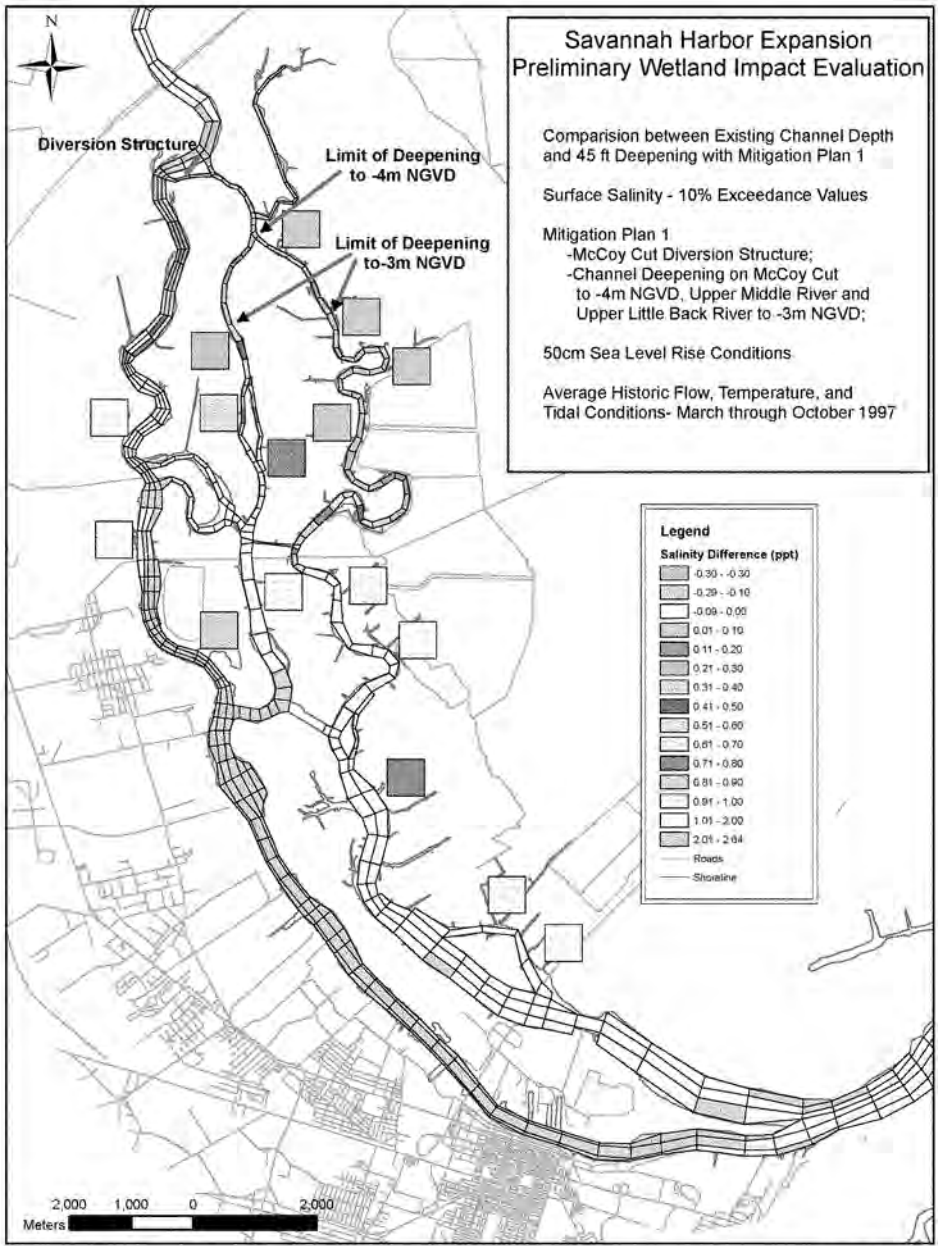


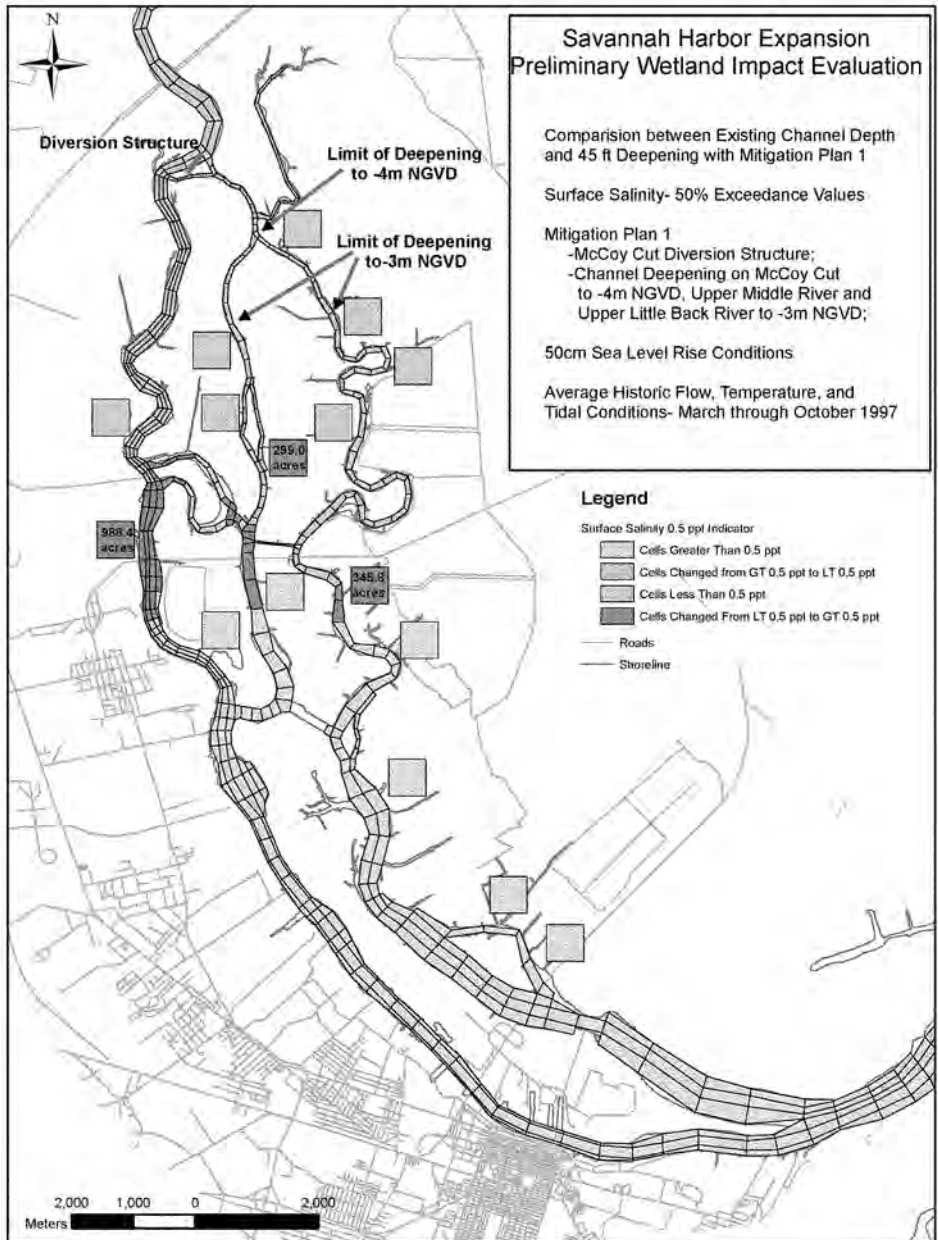


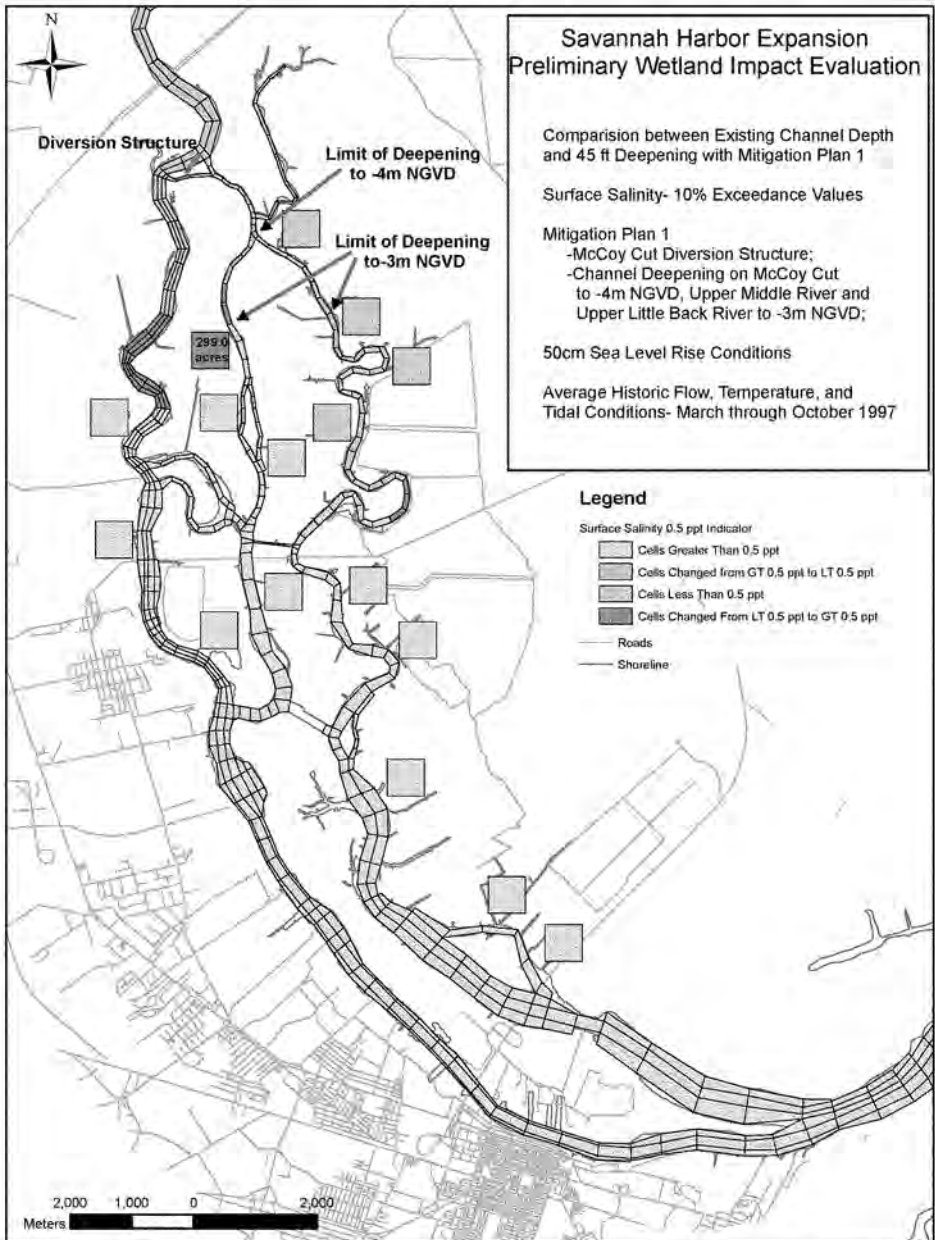
Sensitivity Analysis #2B



January 2007



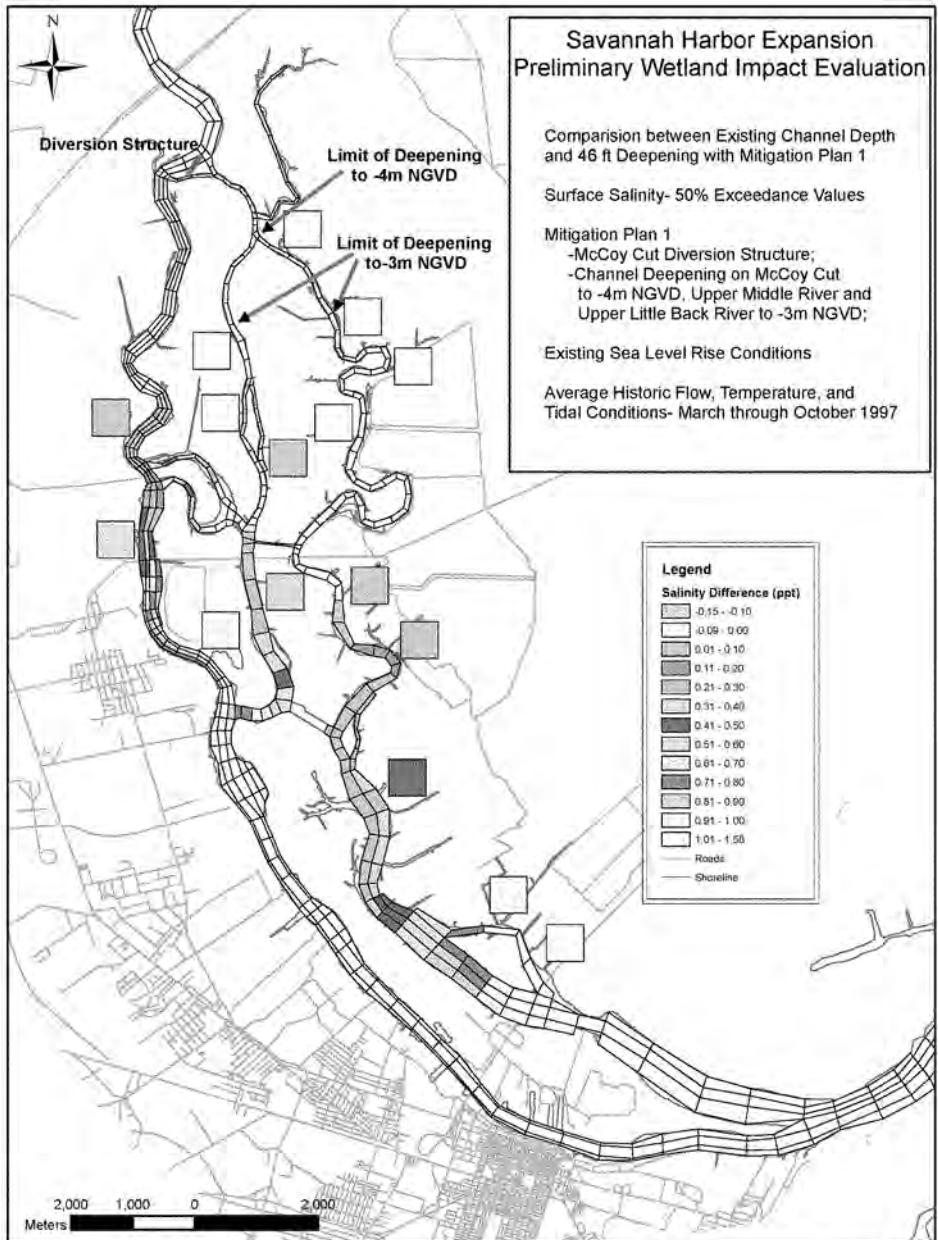


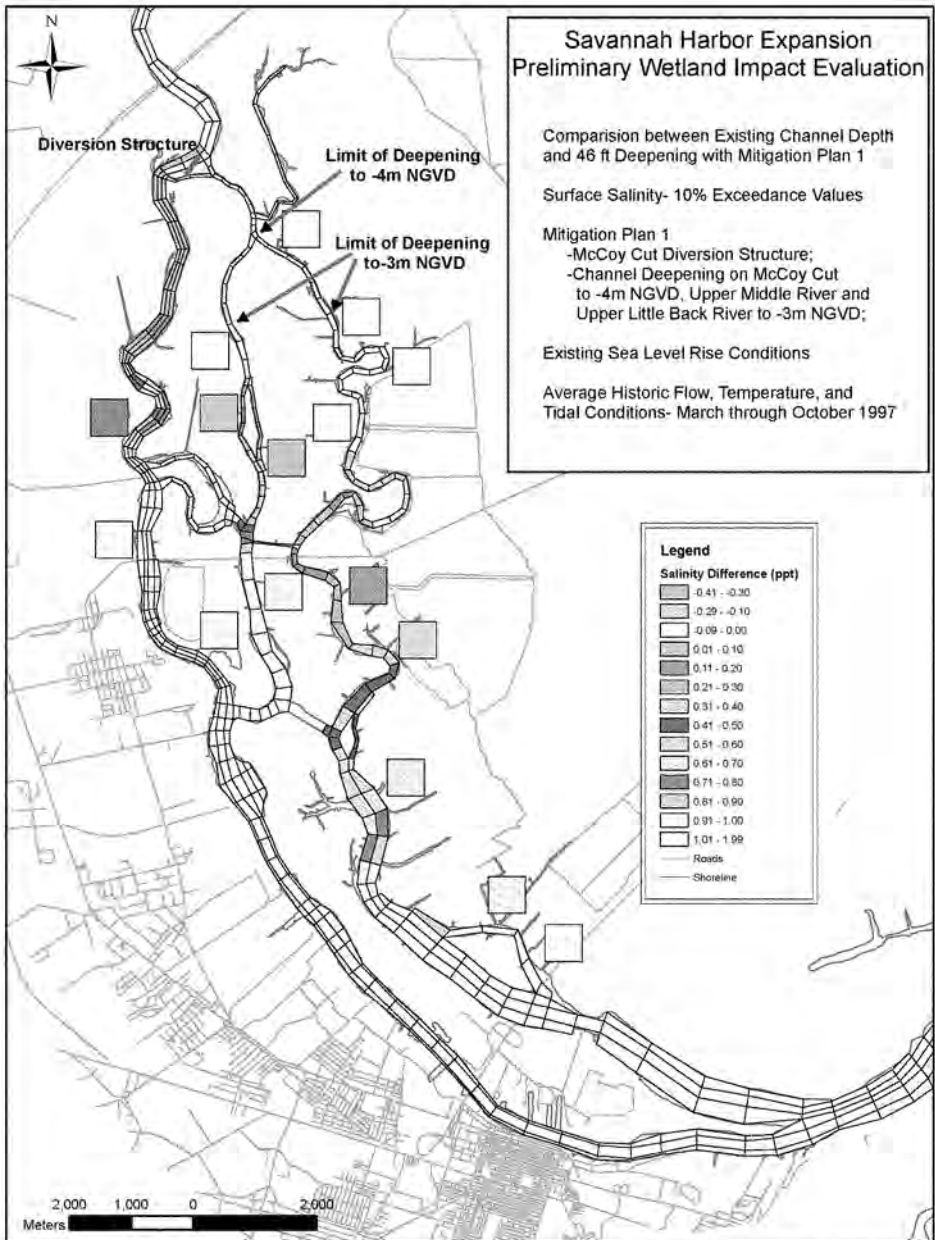


January 2007

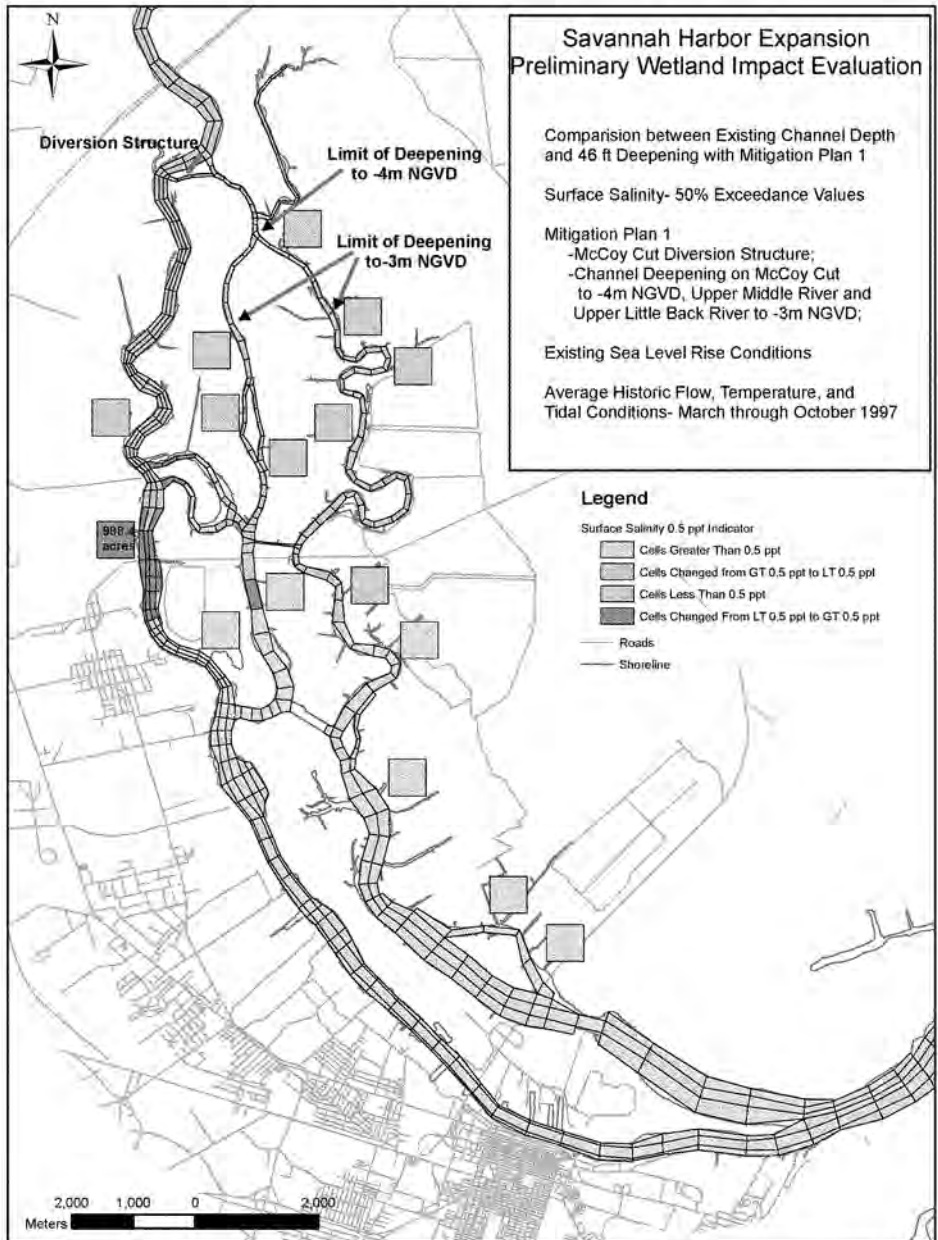
46-ft Deepening

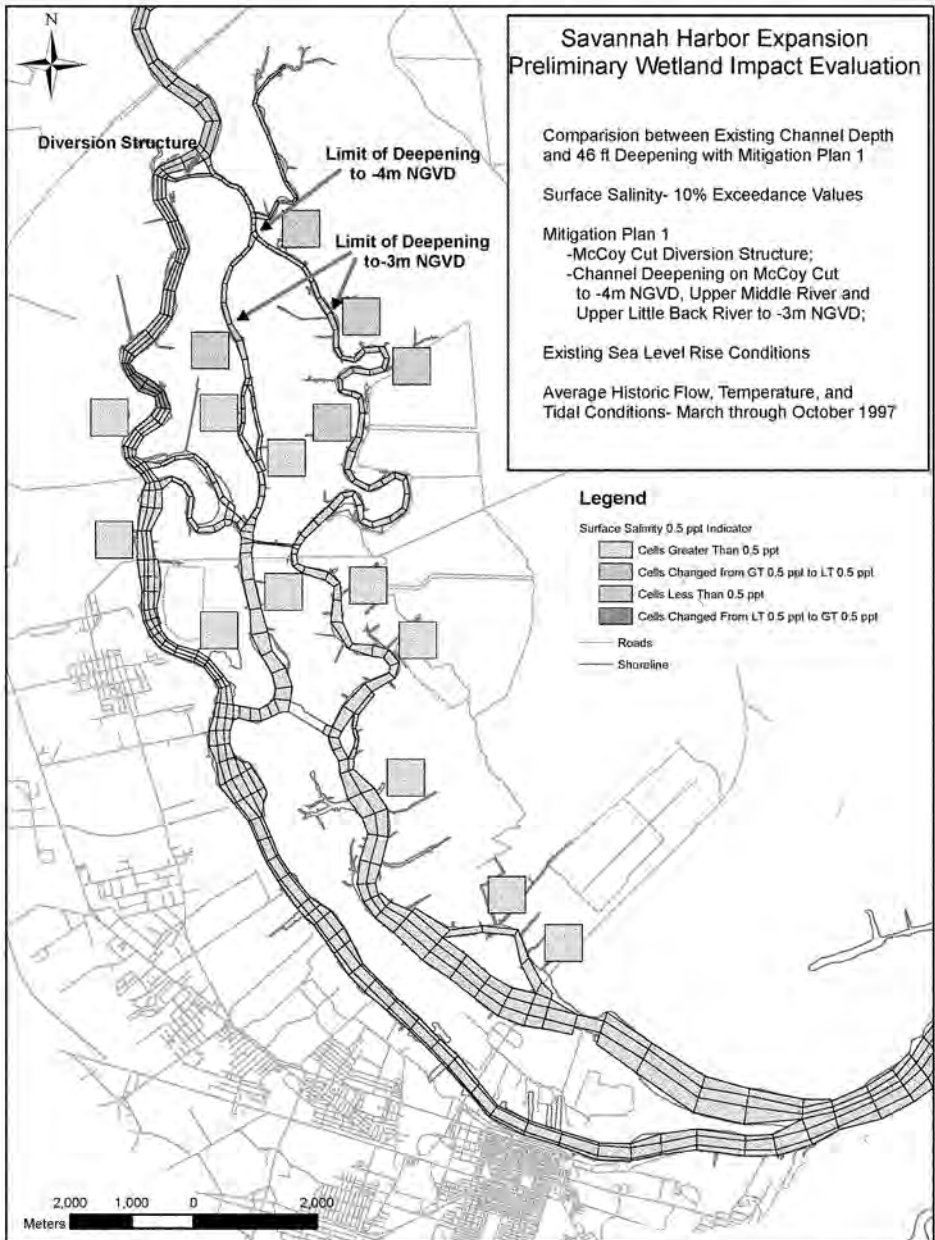
Basic Evaluation



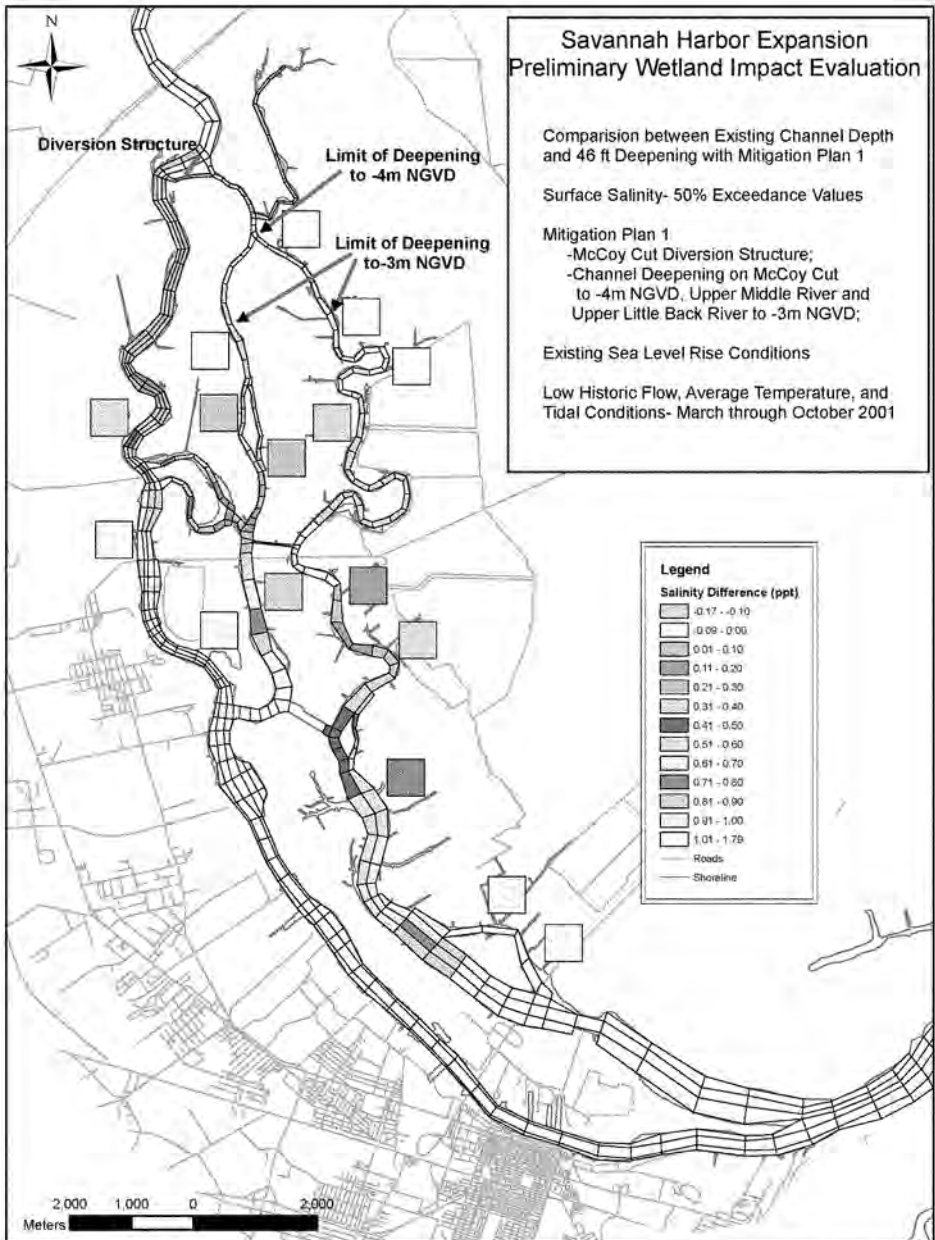


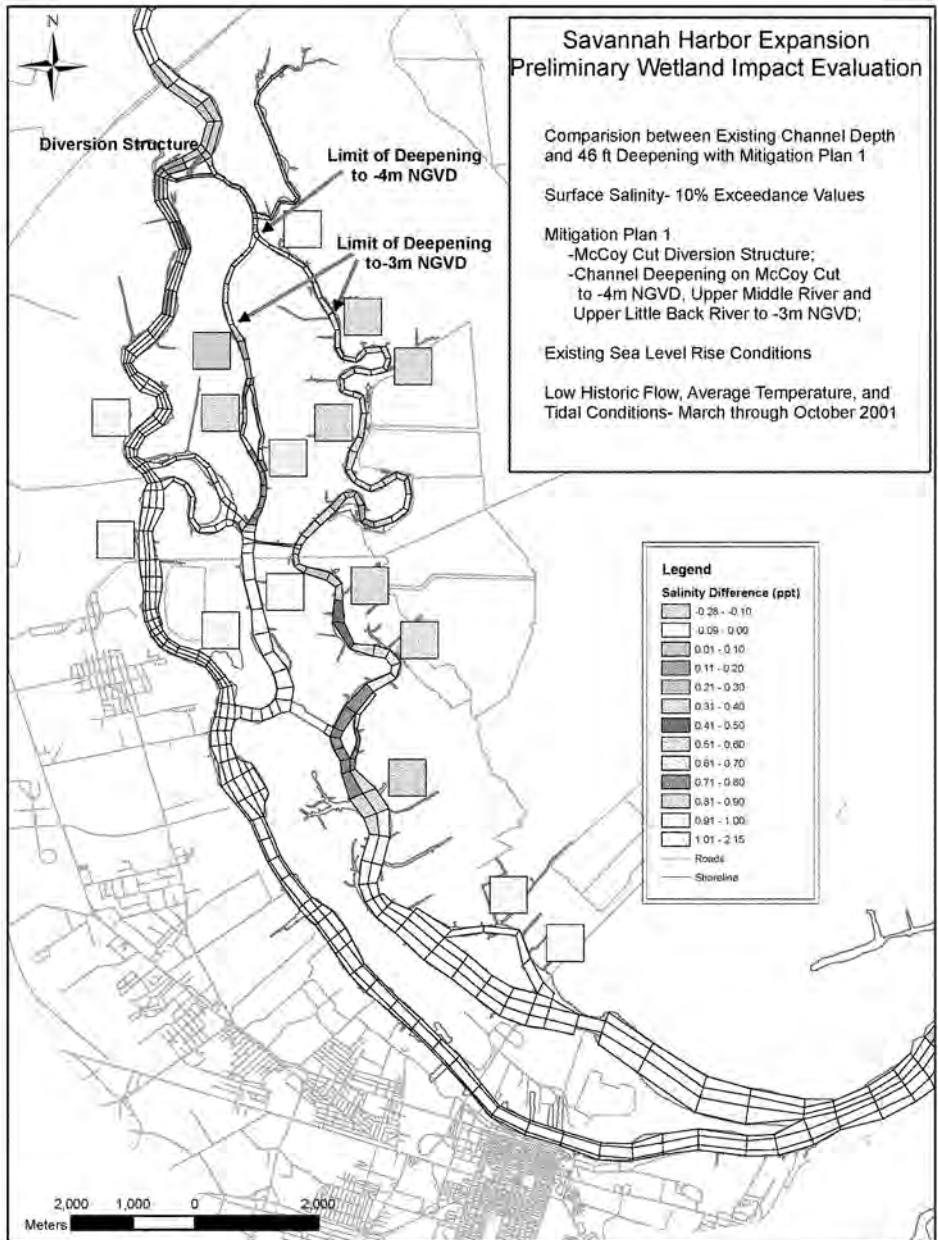
January 2007

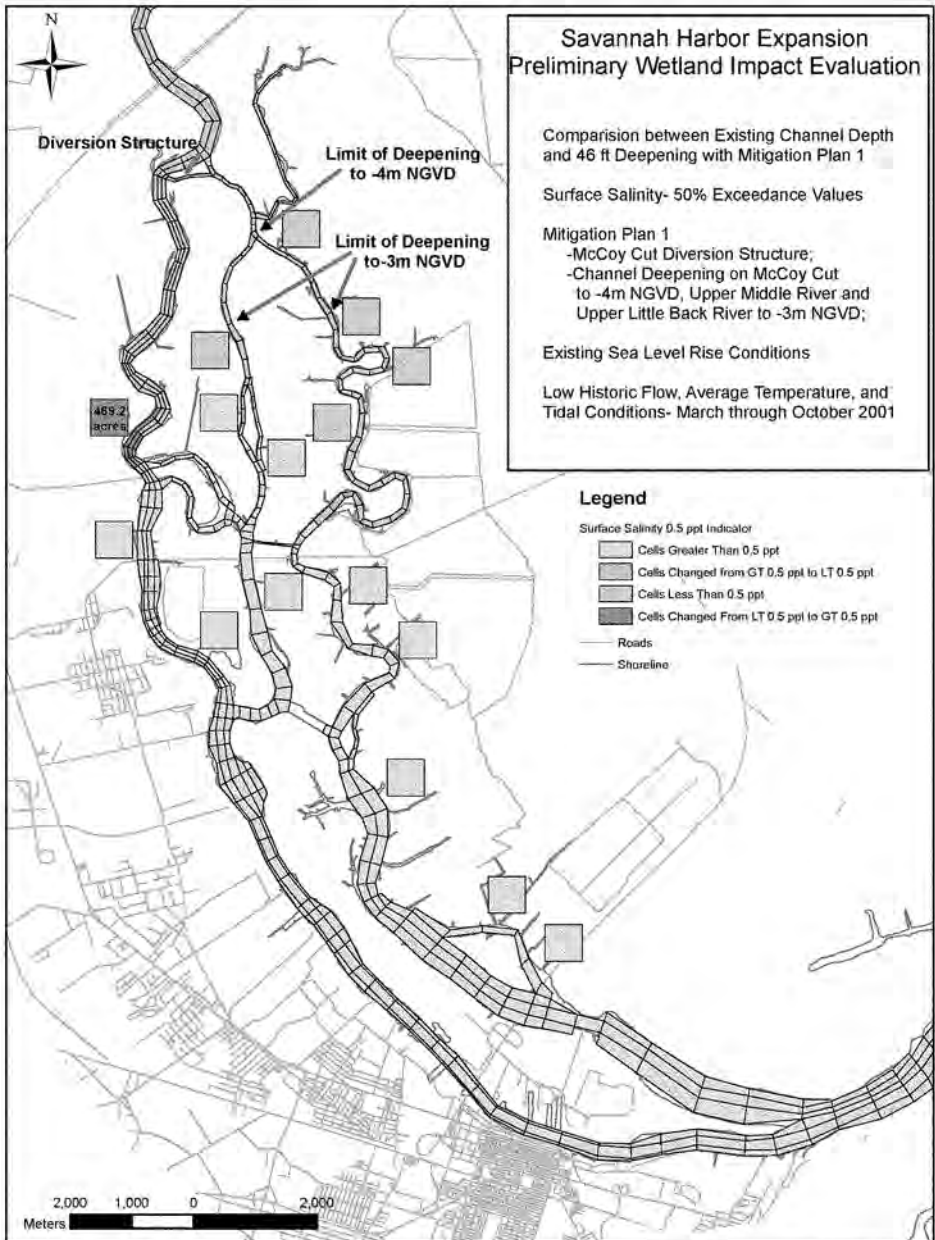




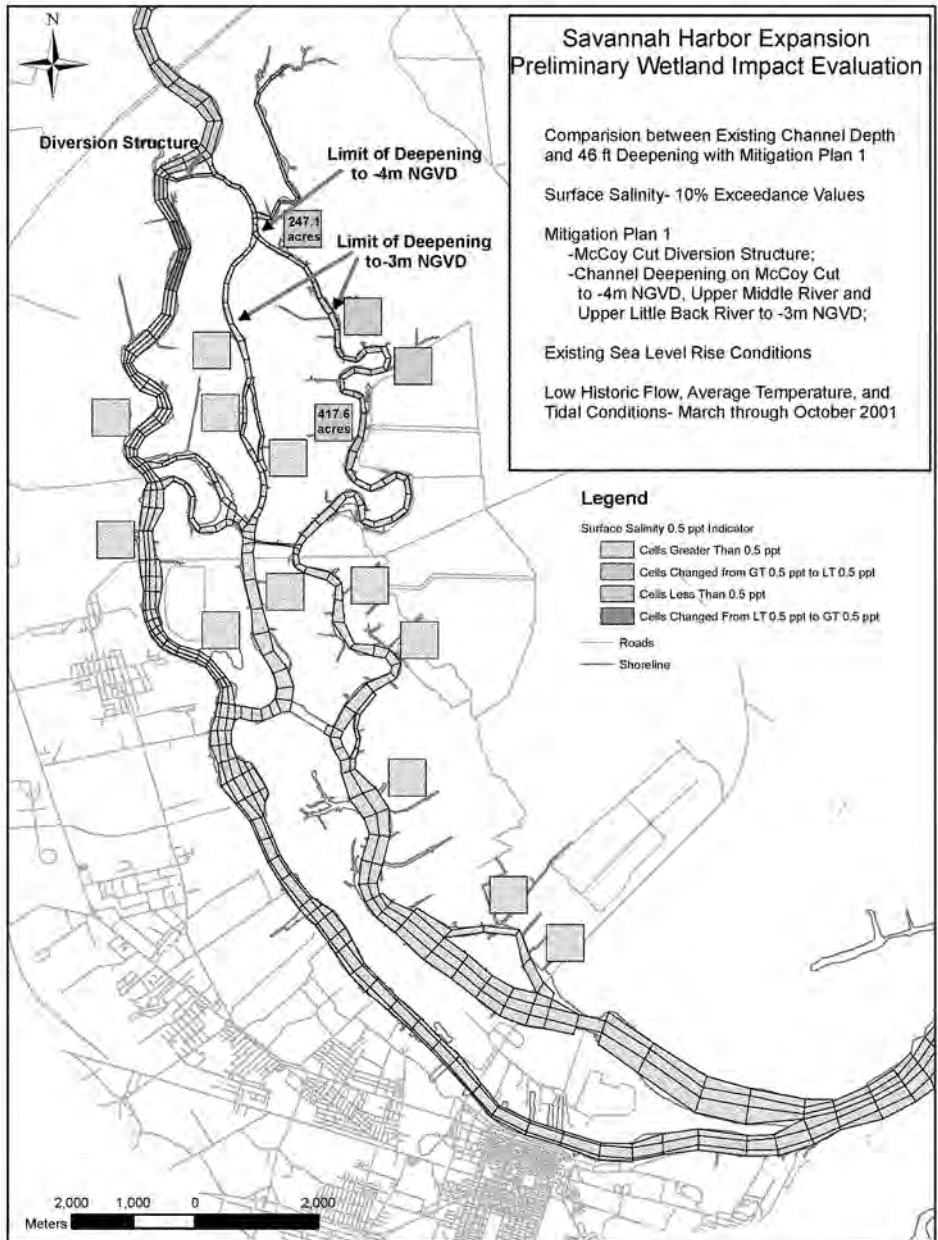
Sensitivity Analysis #1



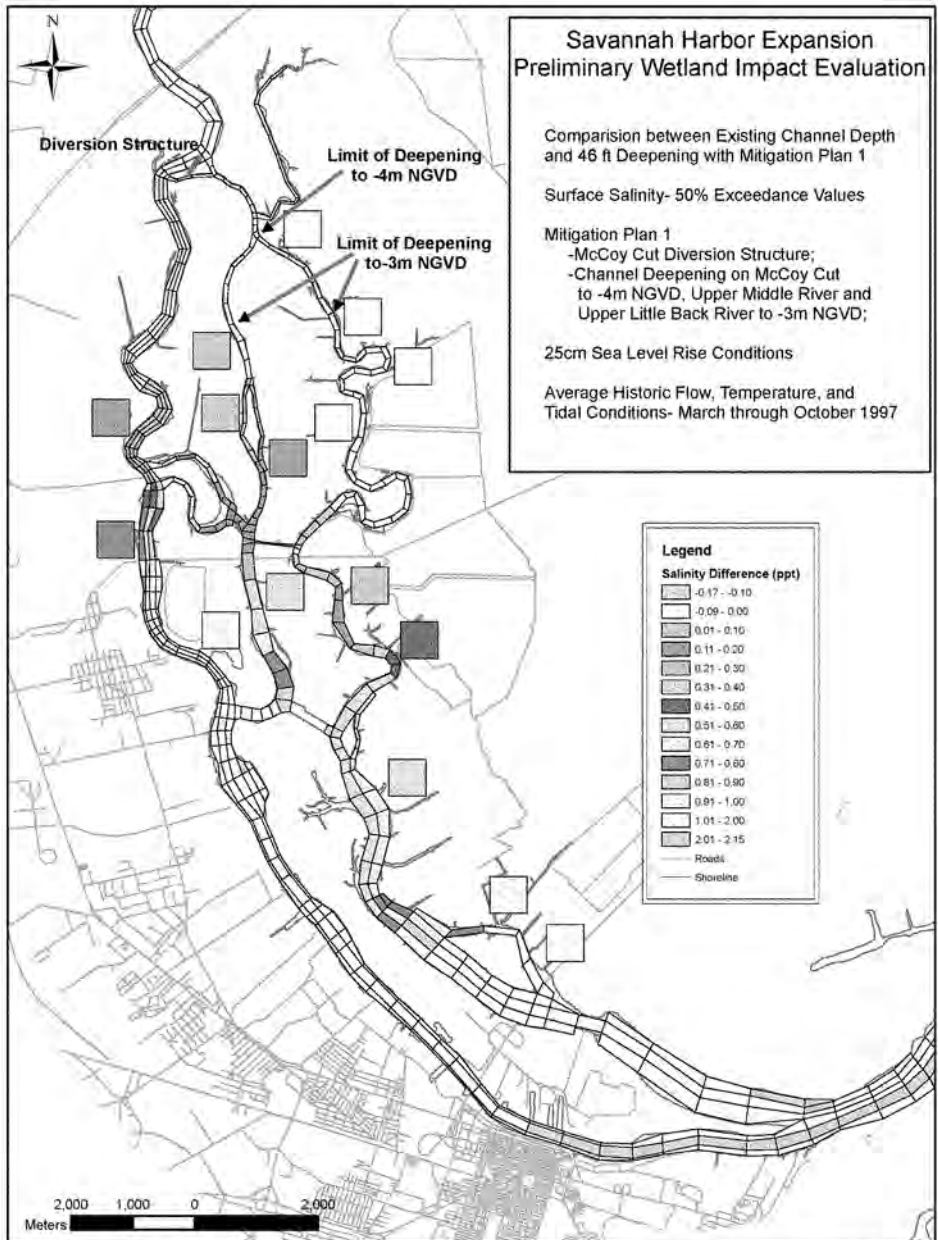


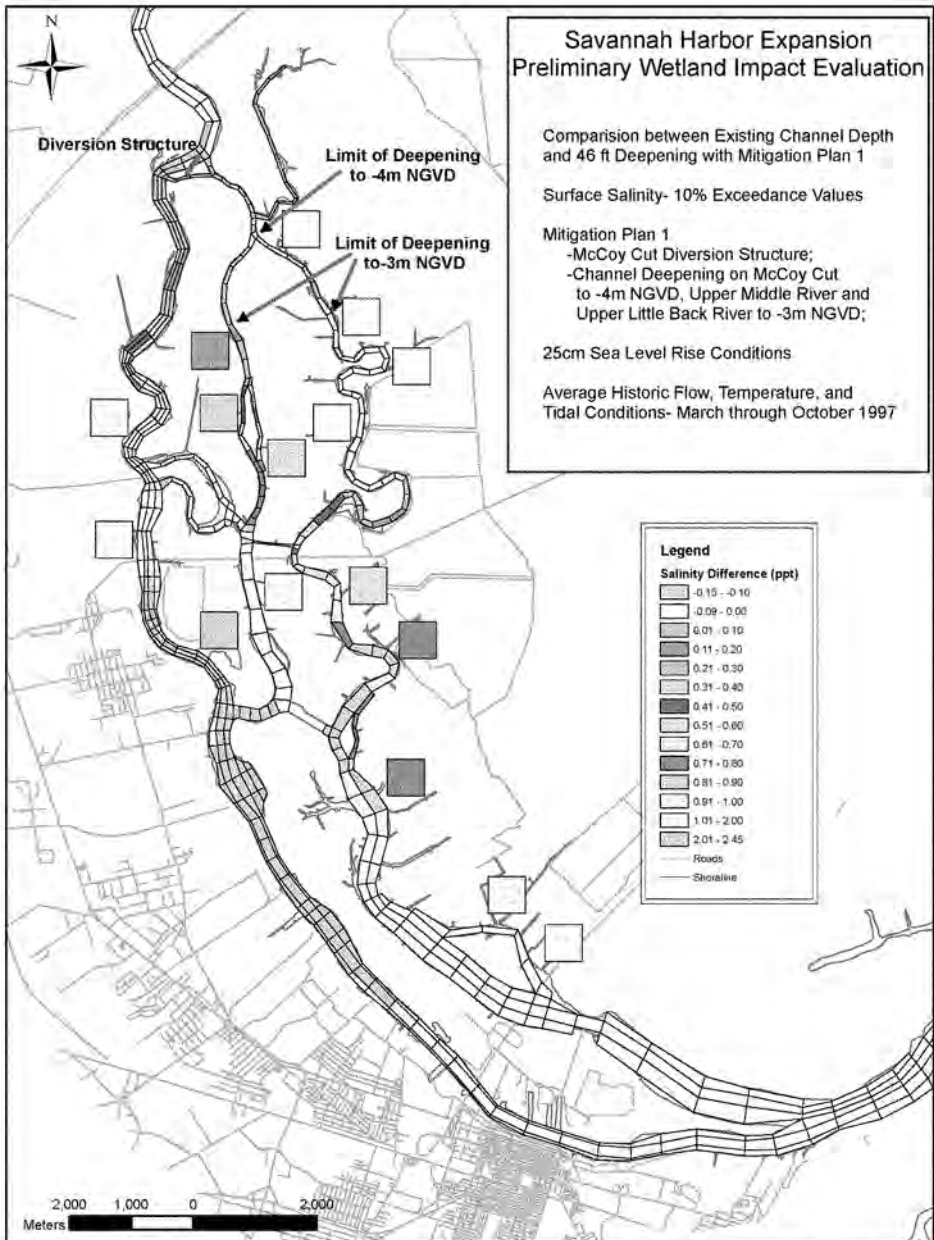


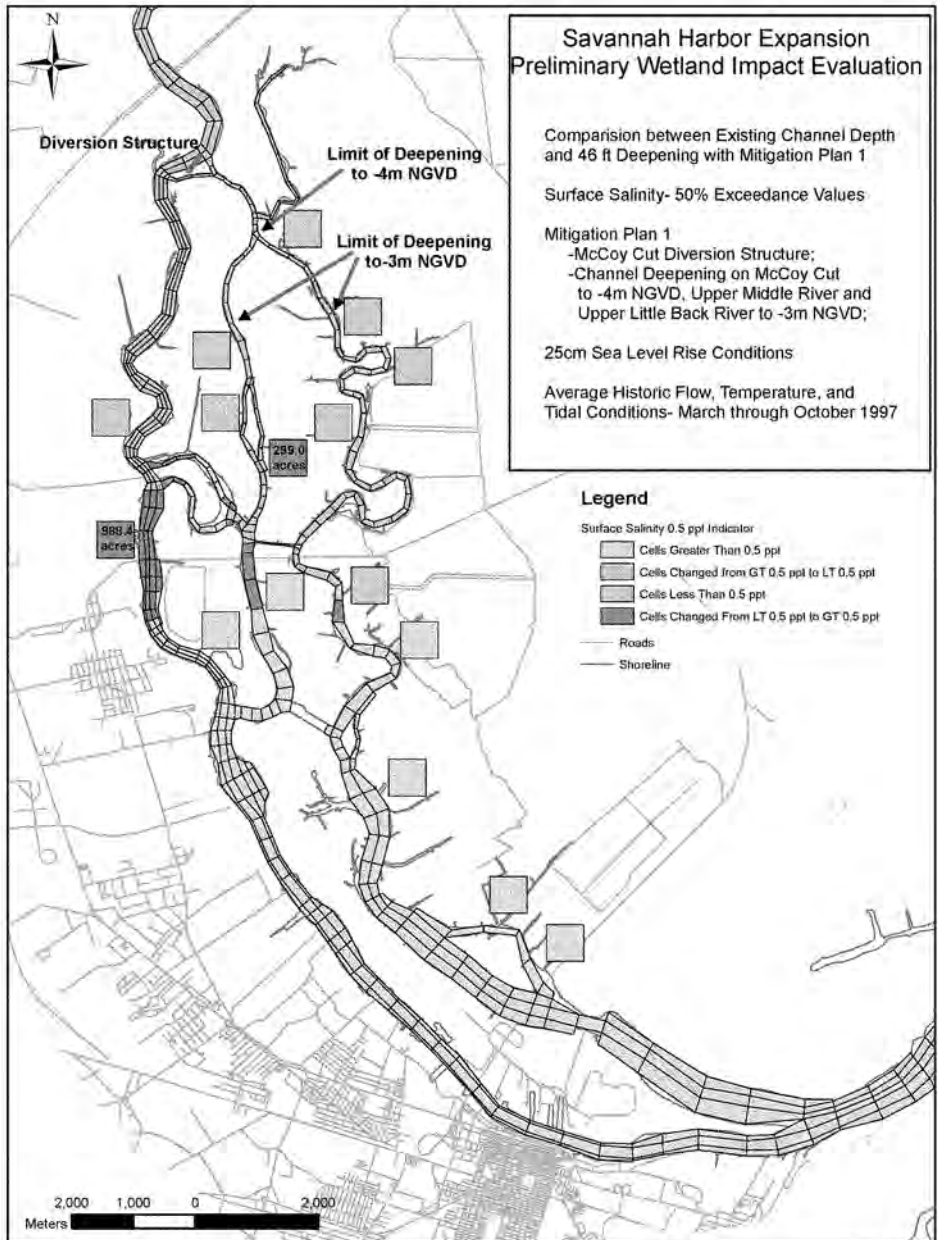
January 2007

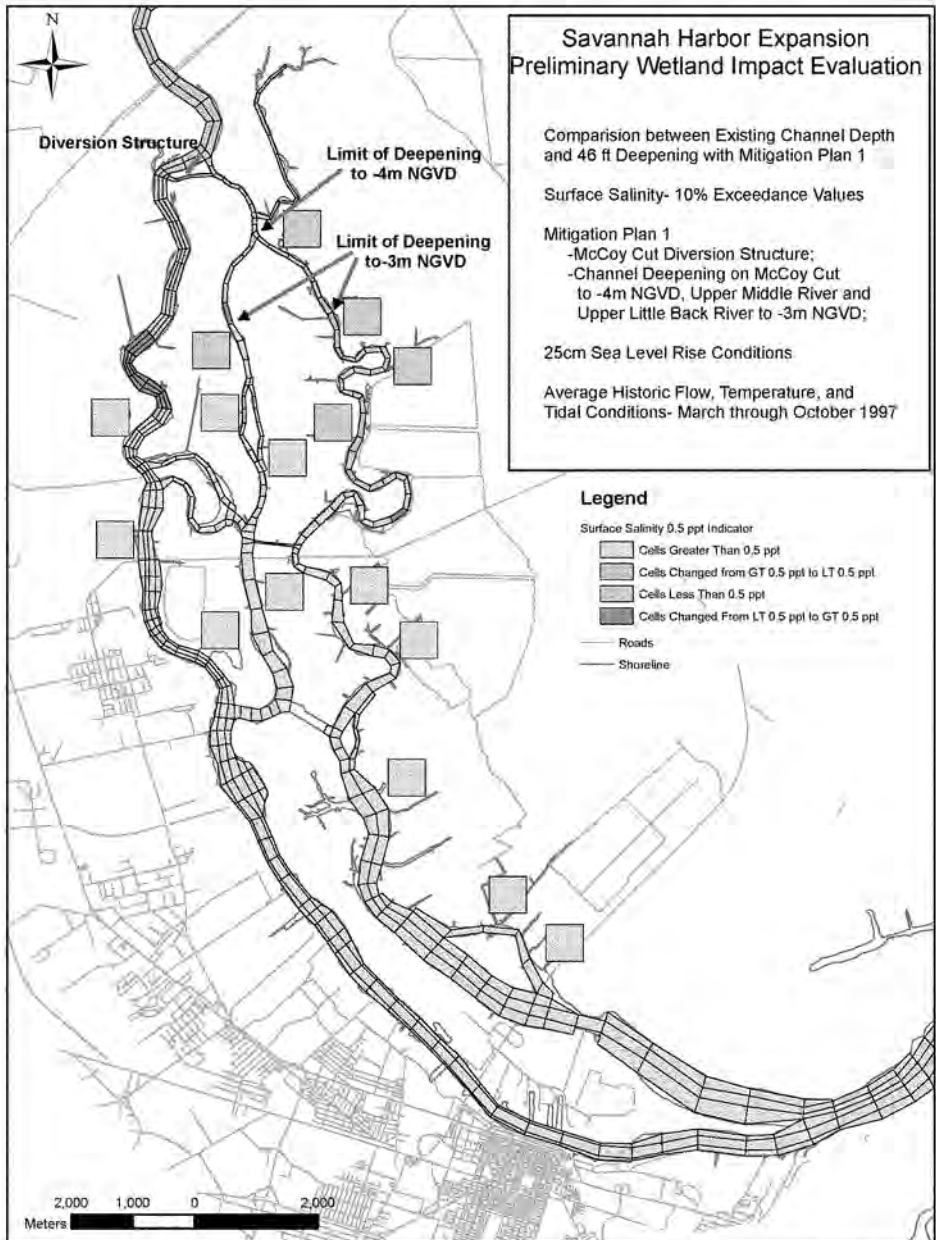


Sensitivity Analysis #2A

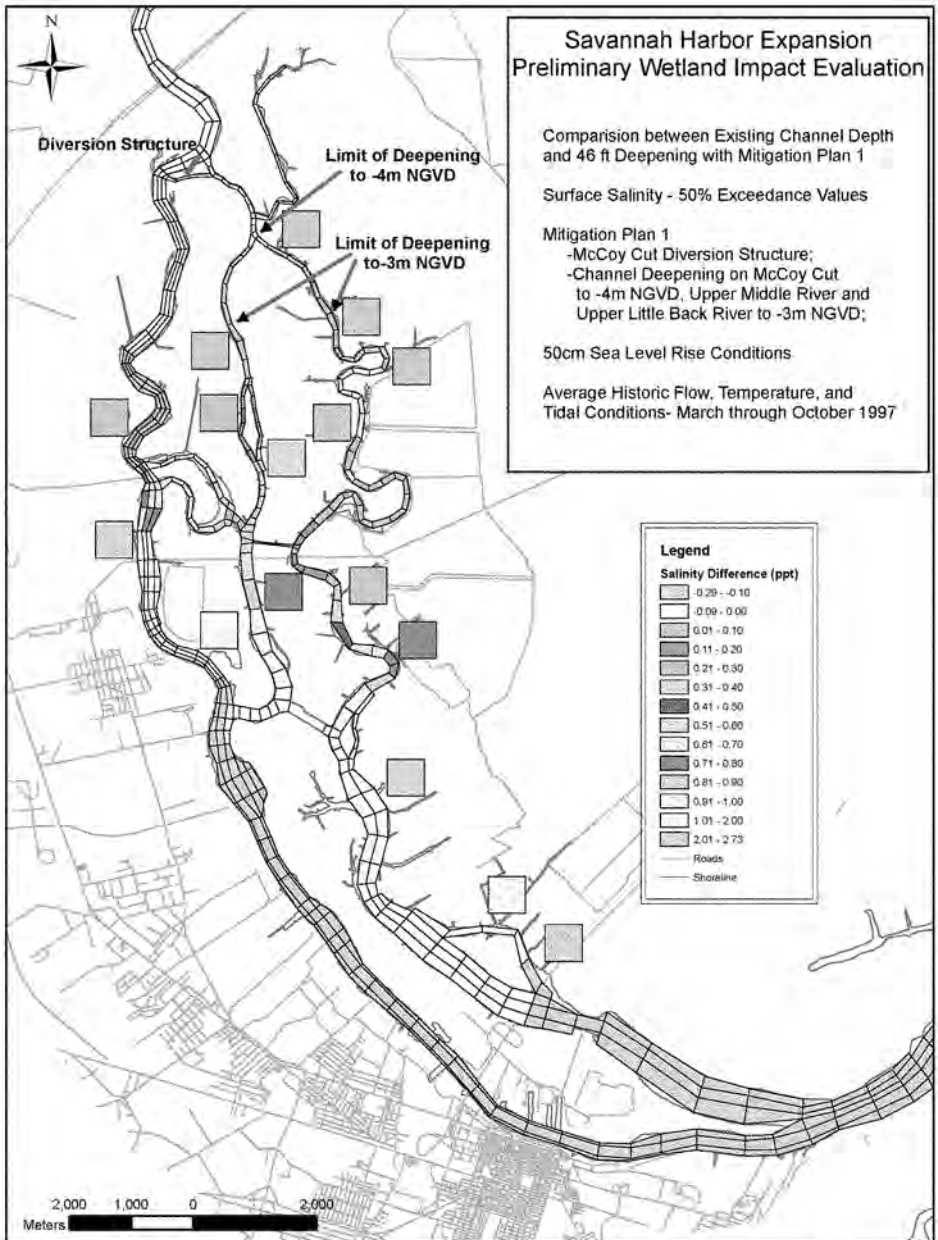




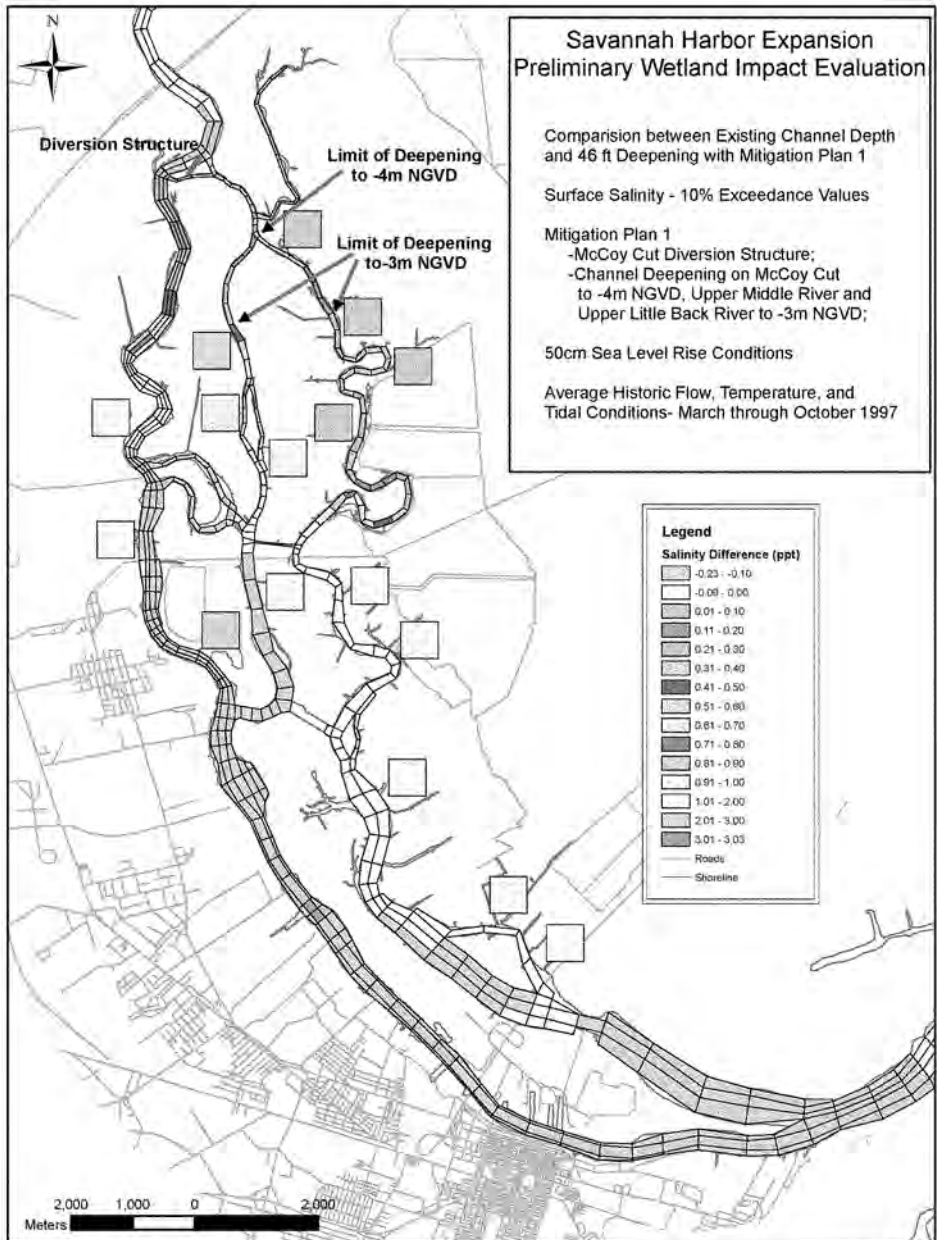




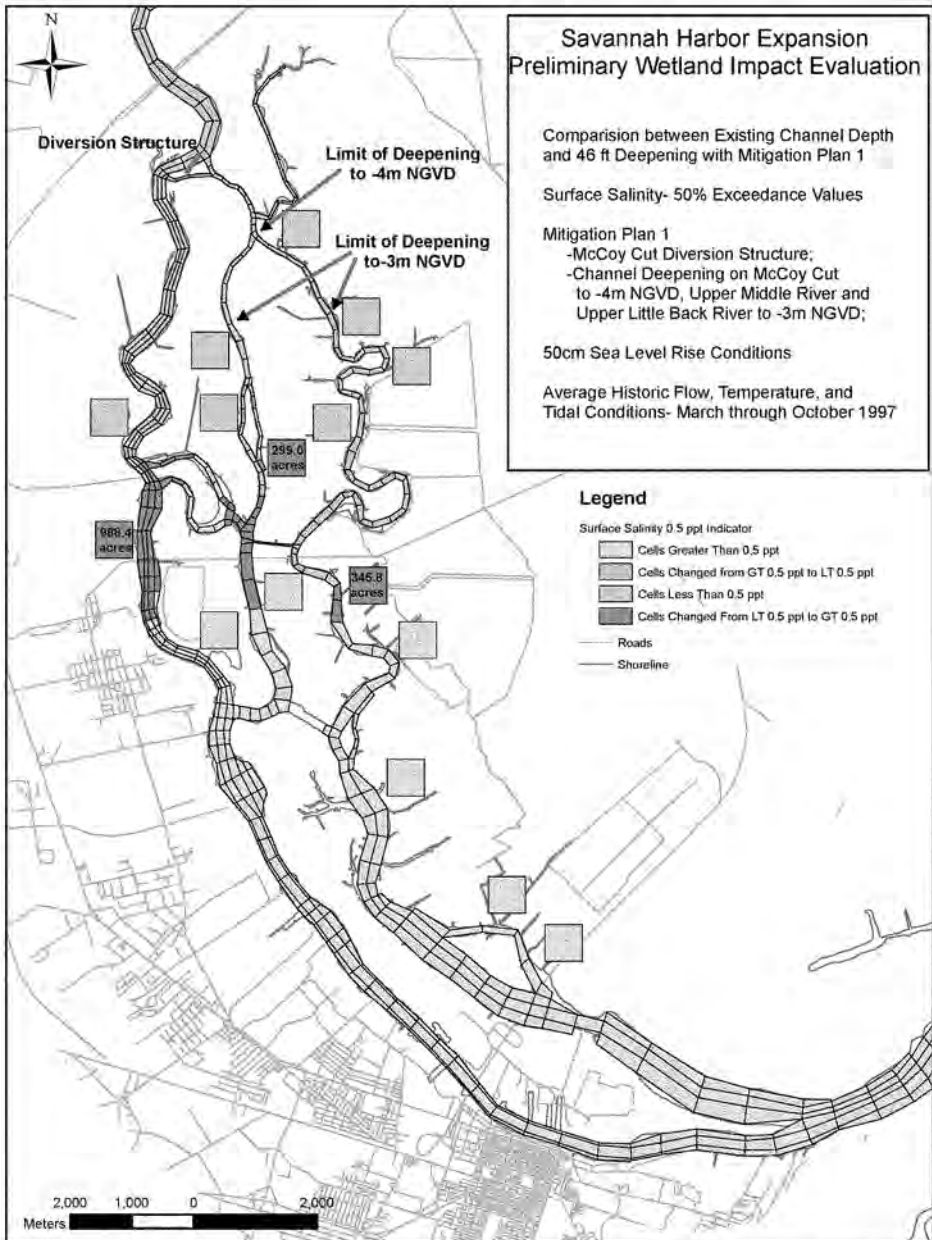
Sensitivity Analysis #2B

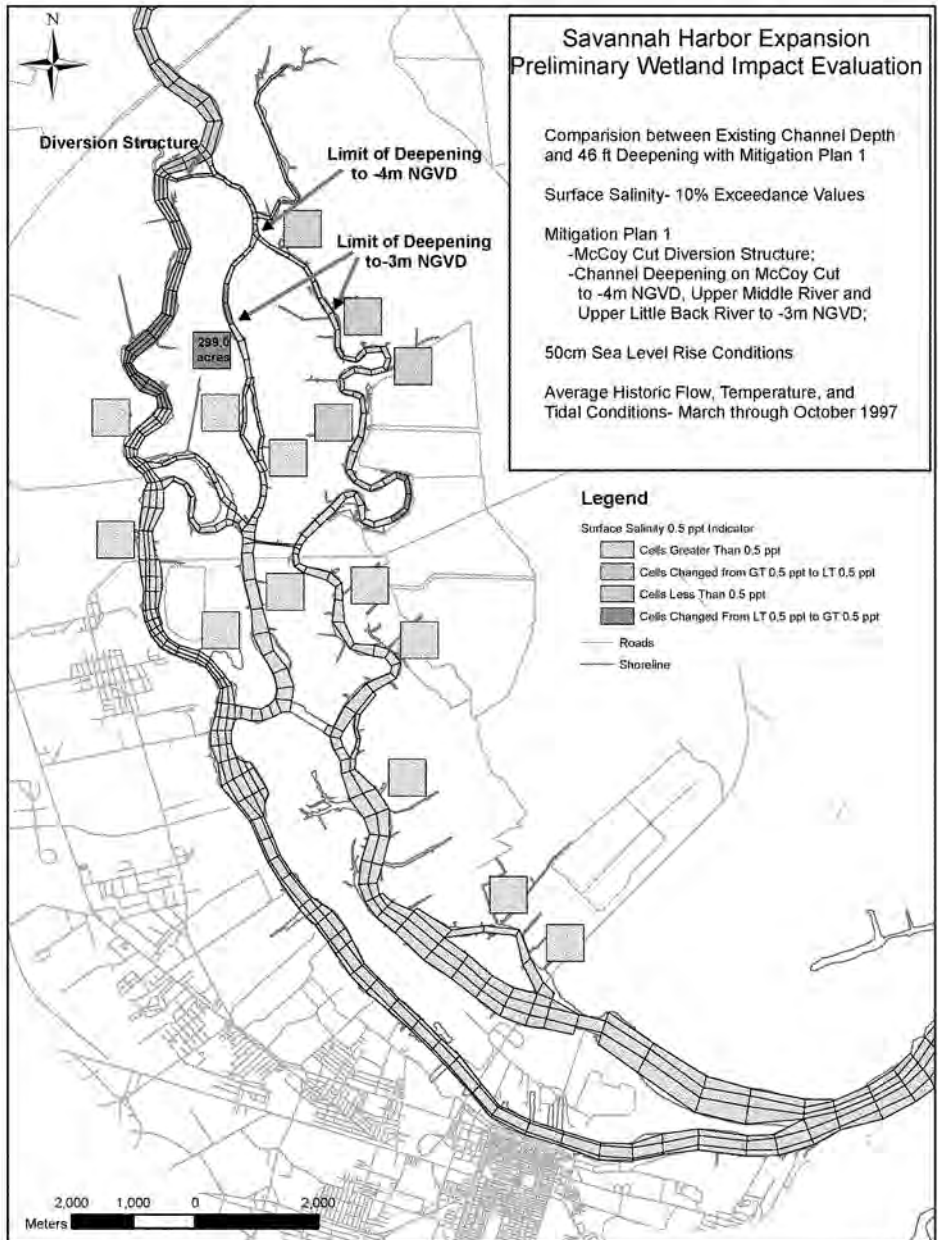


January 2007



January 2007

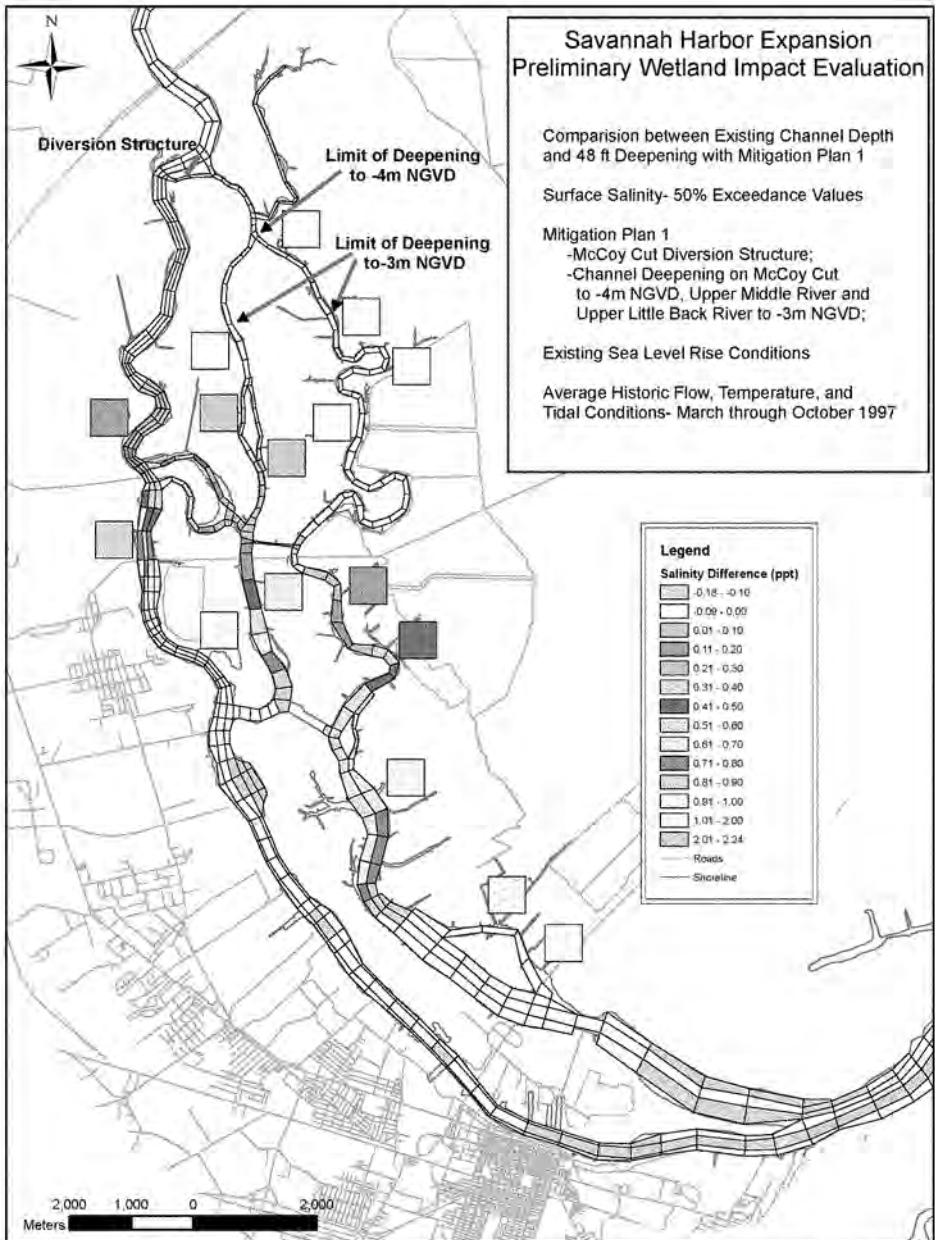




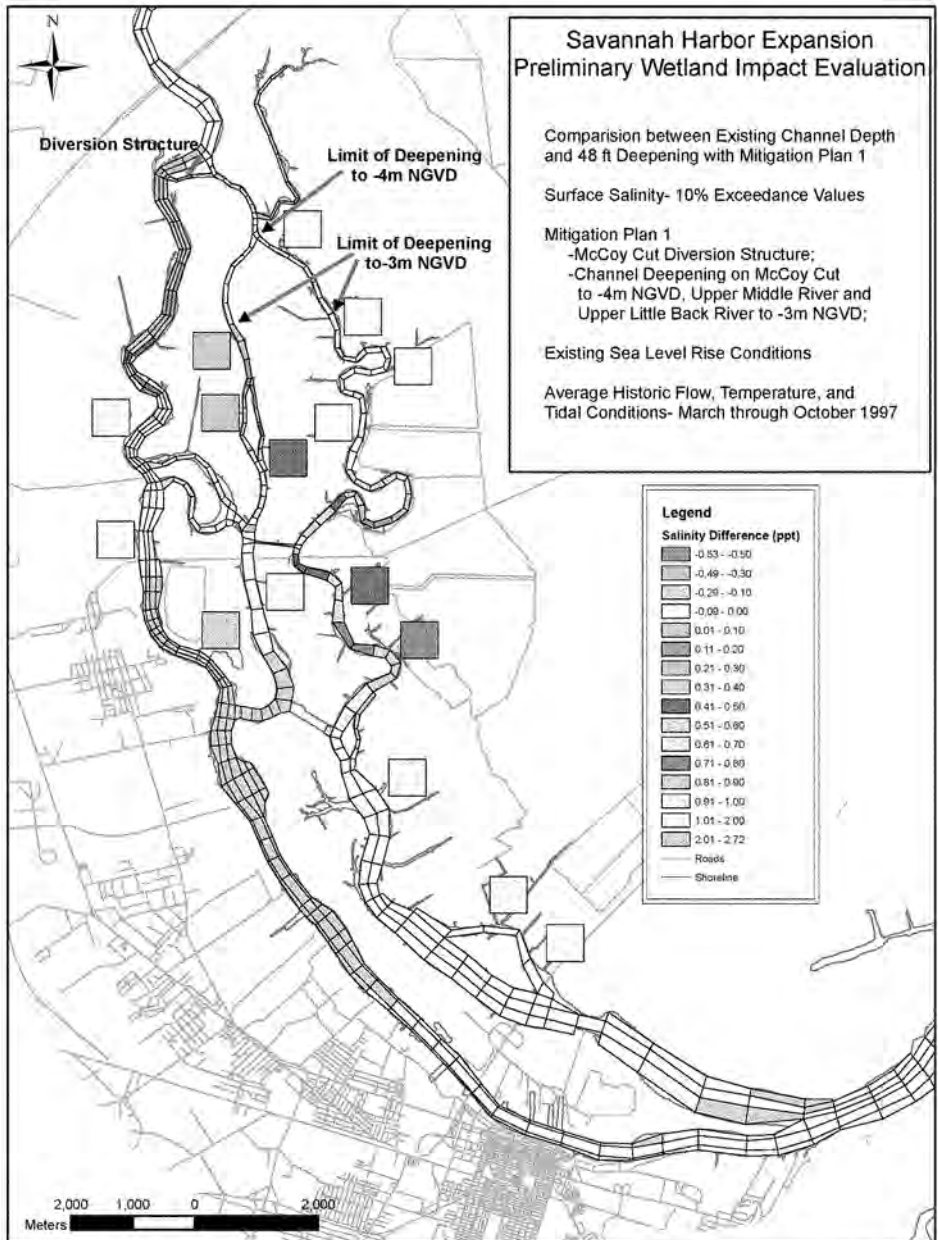
January 2007

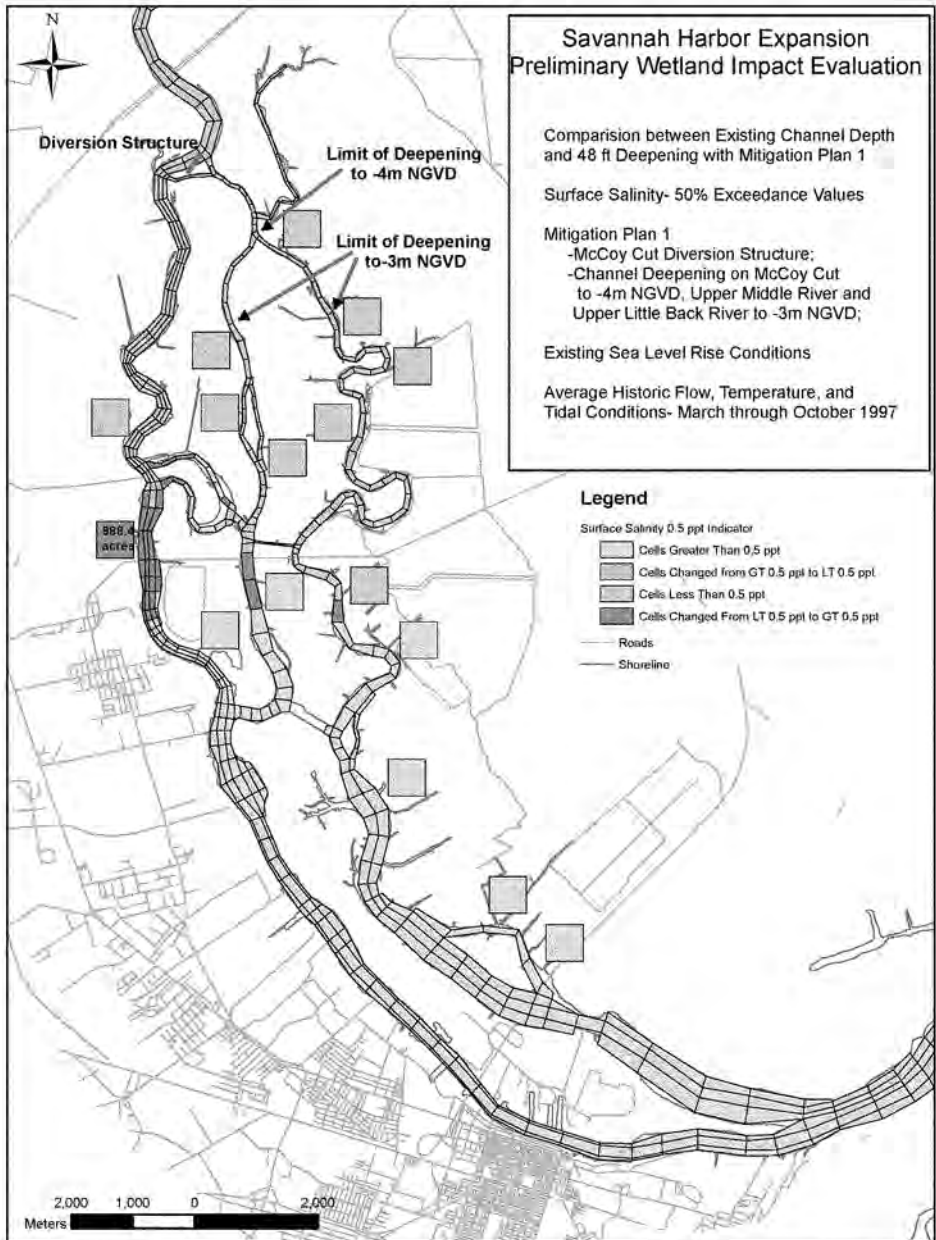
48-ft Deepening

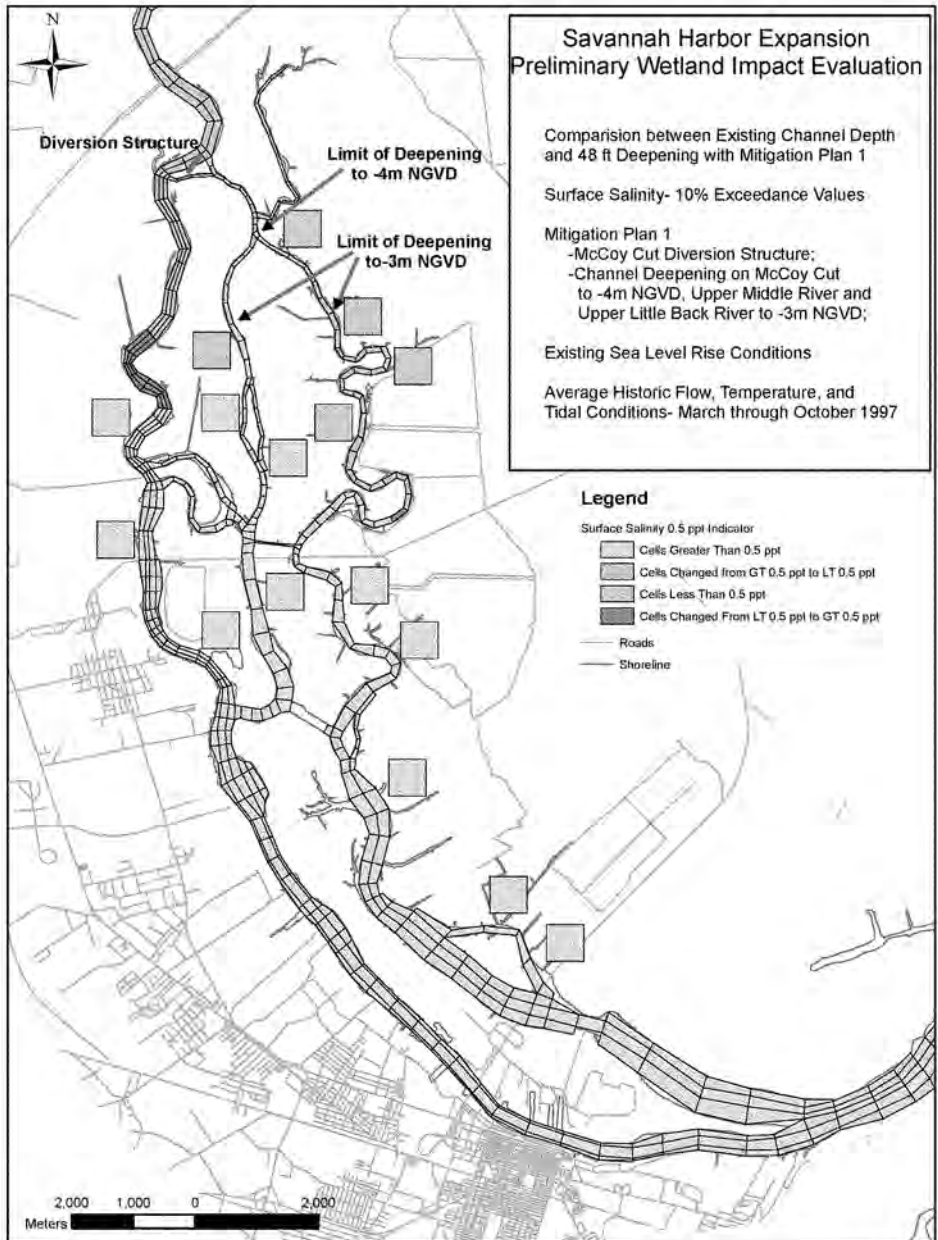
Basic Evaluation



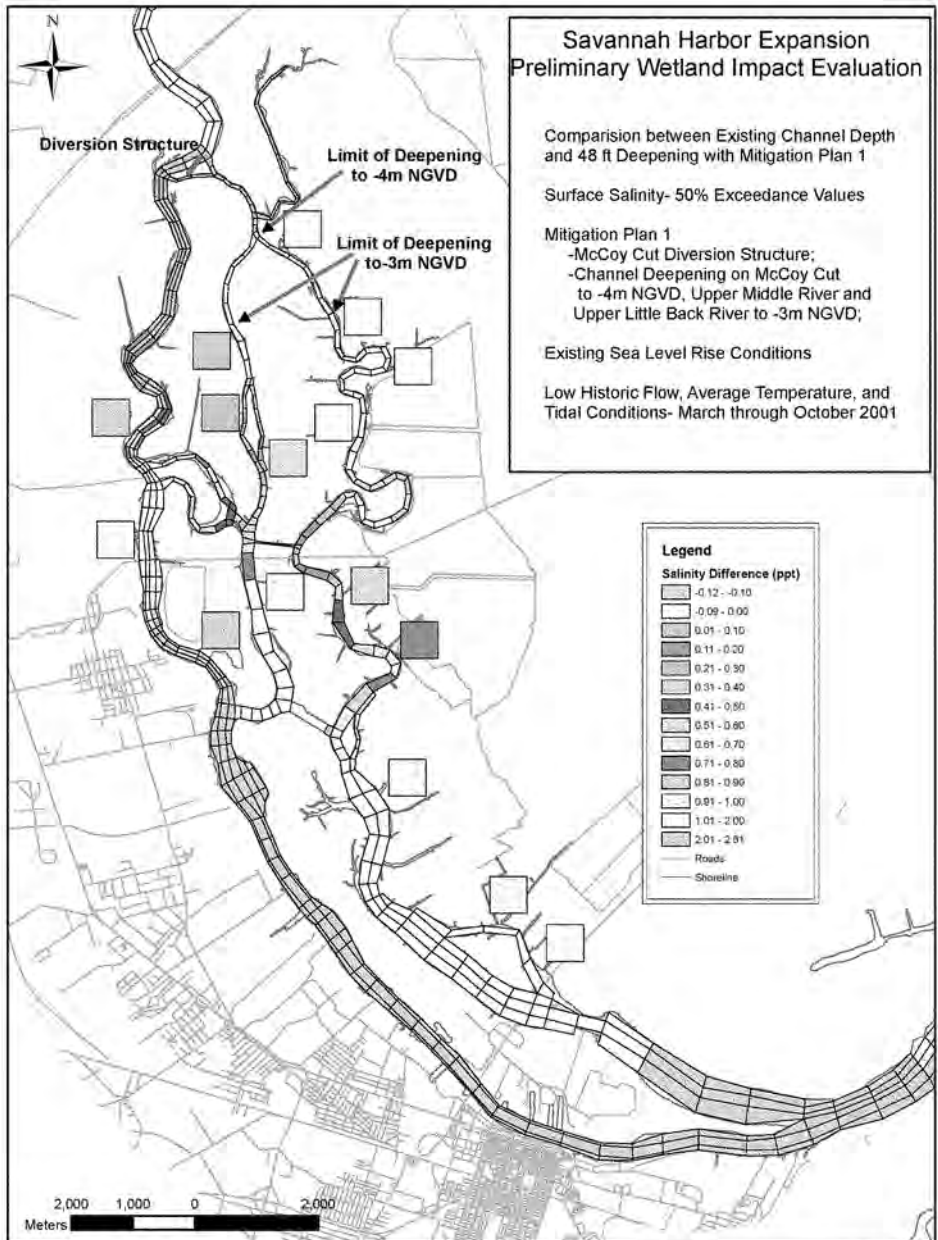
January 2007

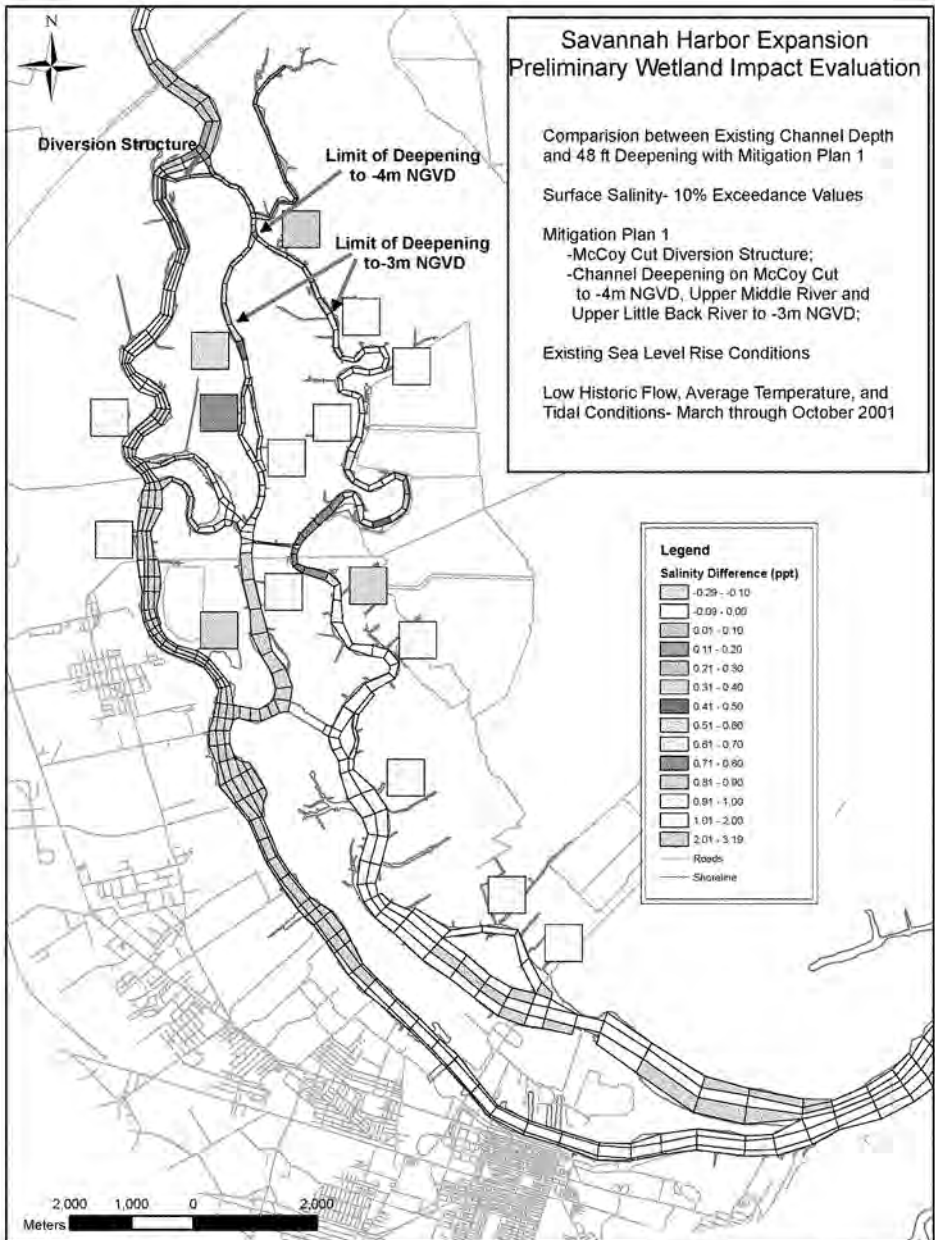


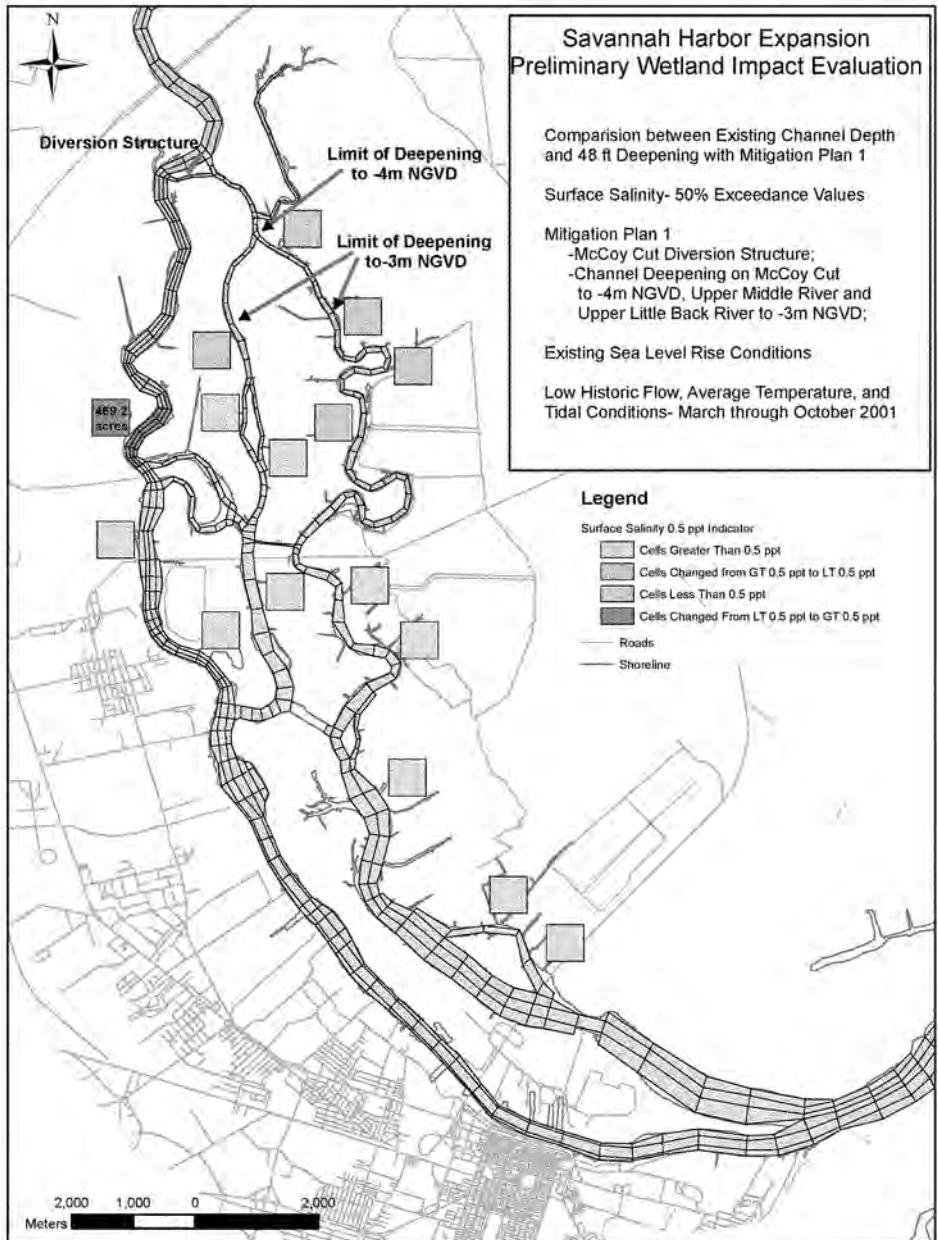


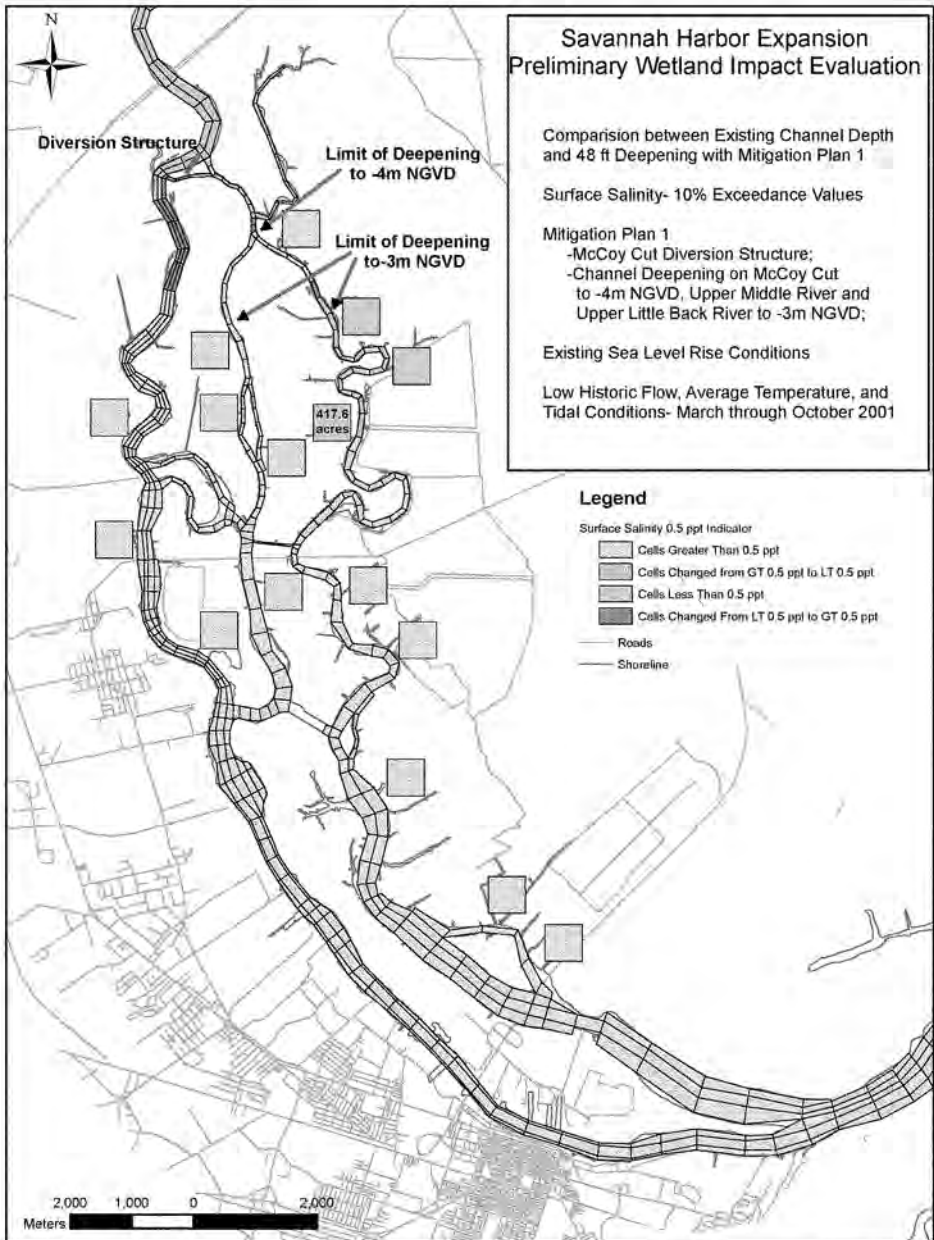


Sensitivity Analysis #1



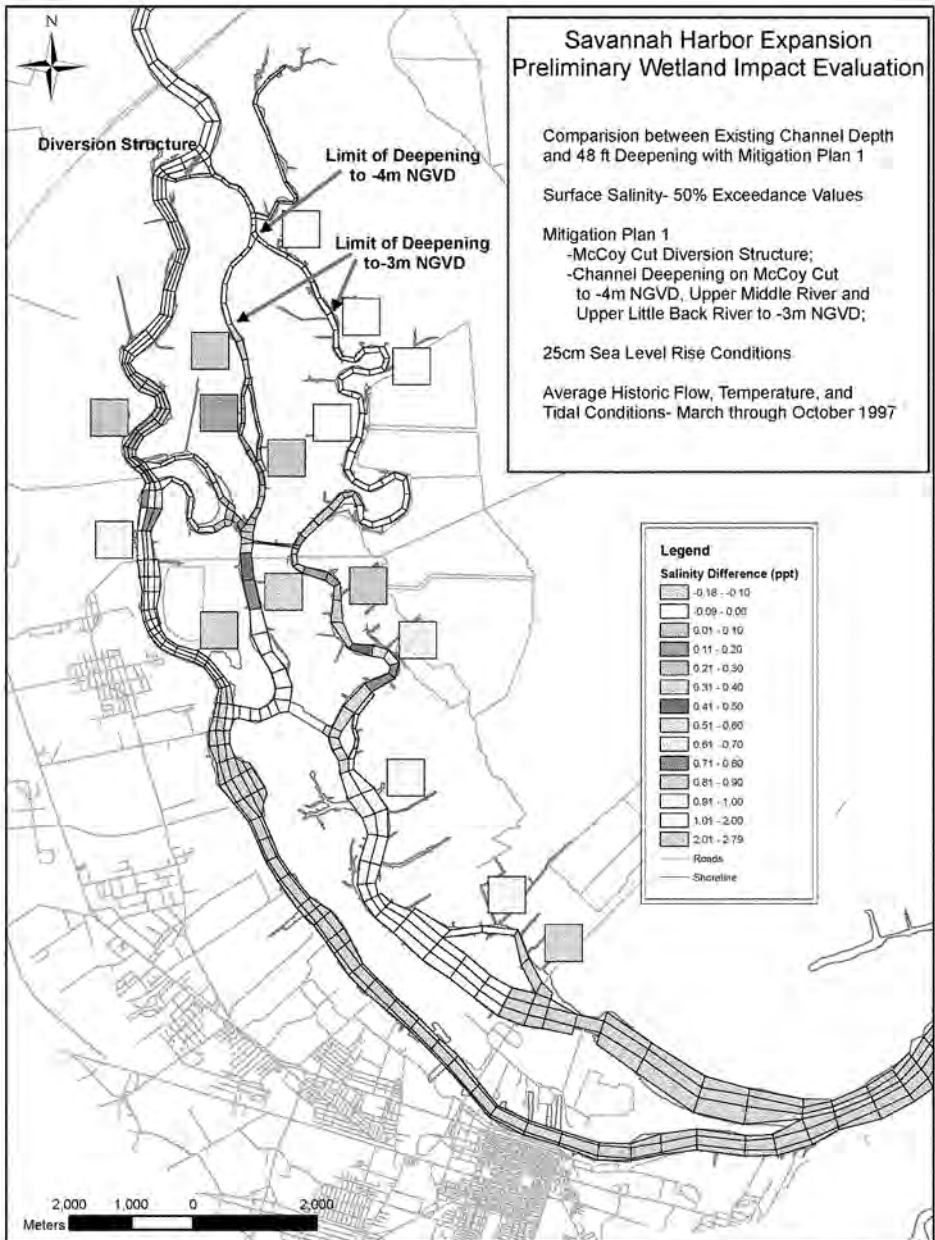


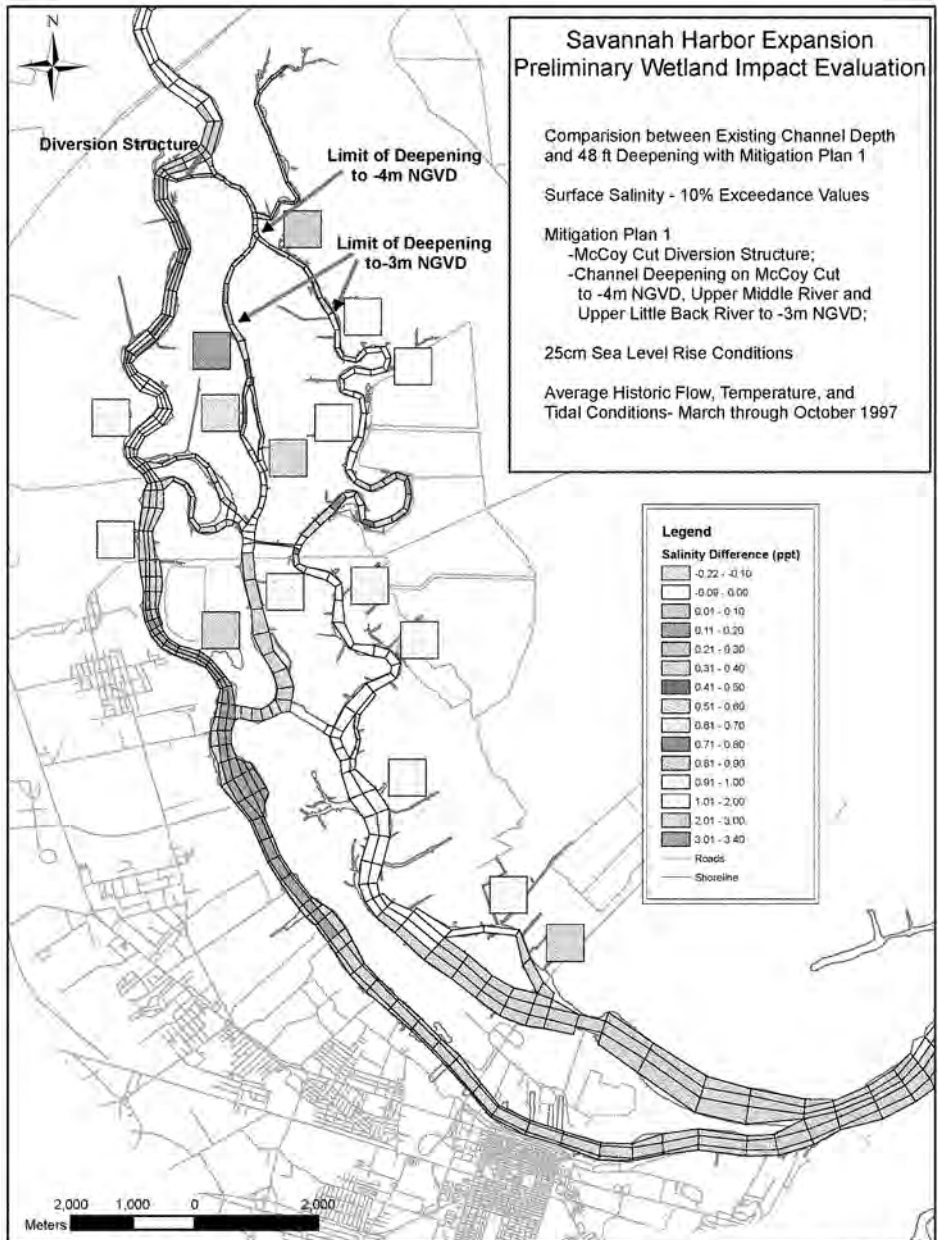


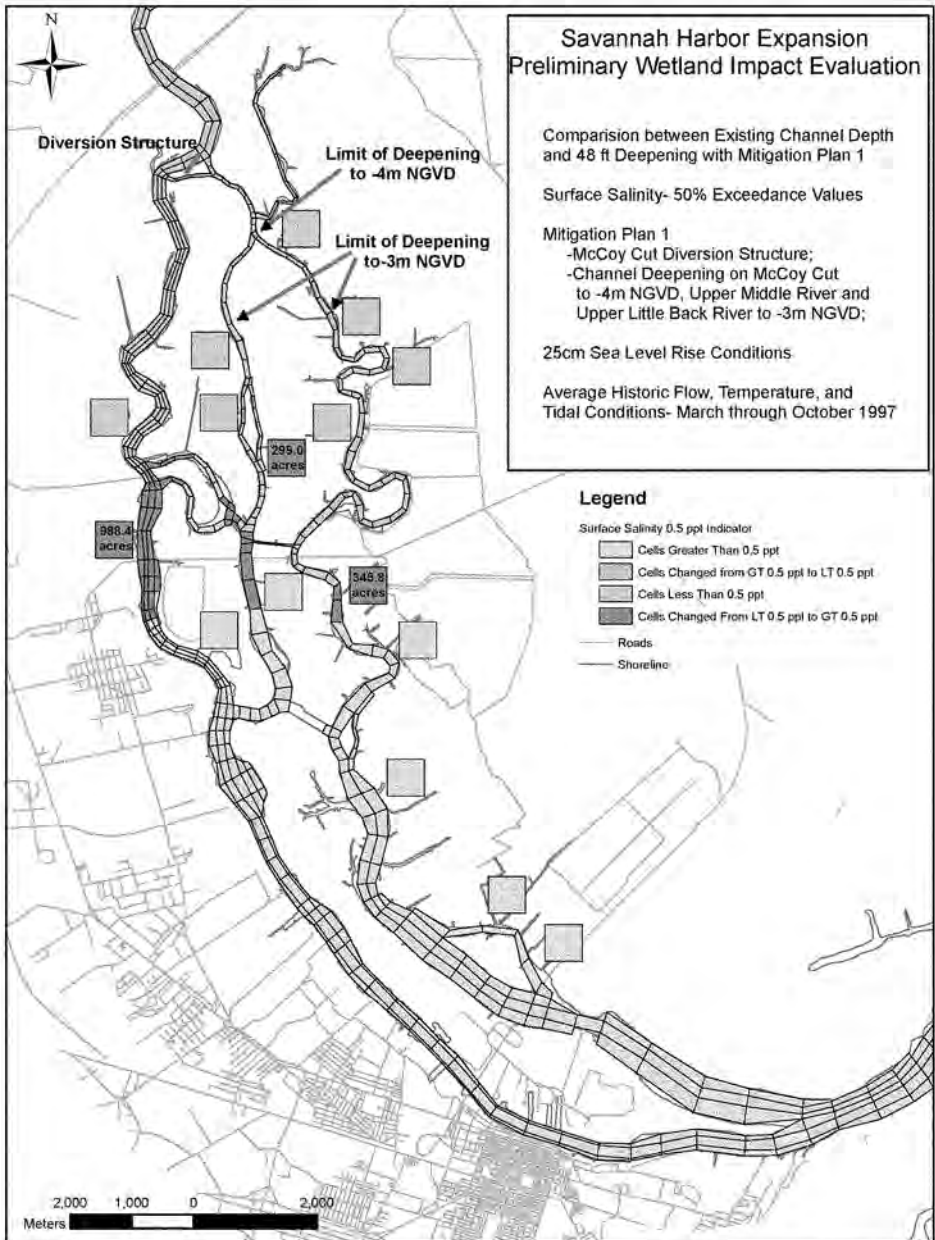


January 2007

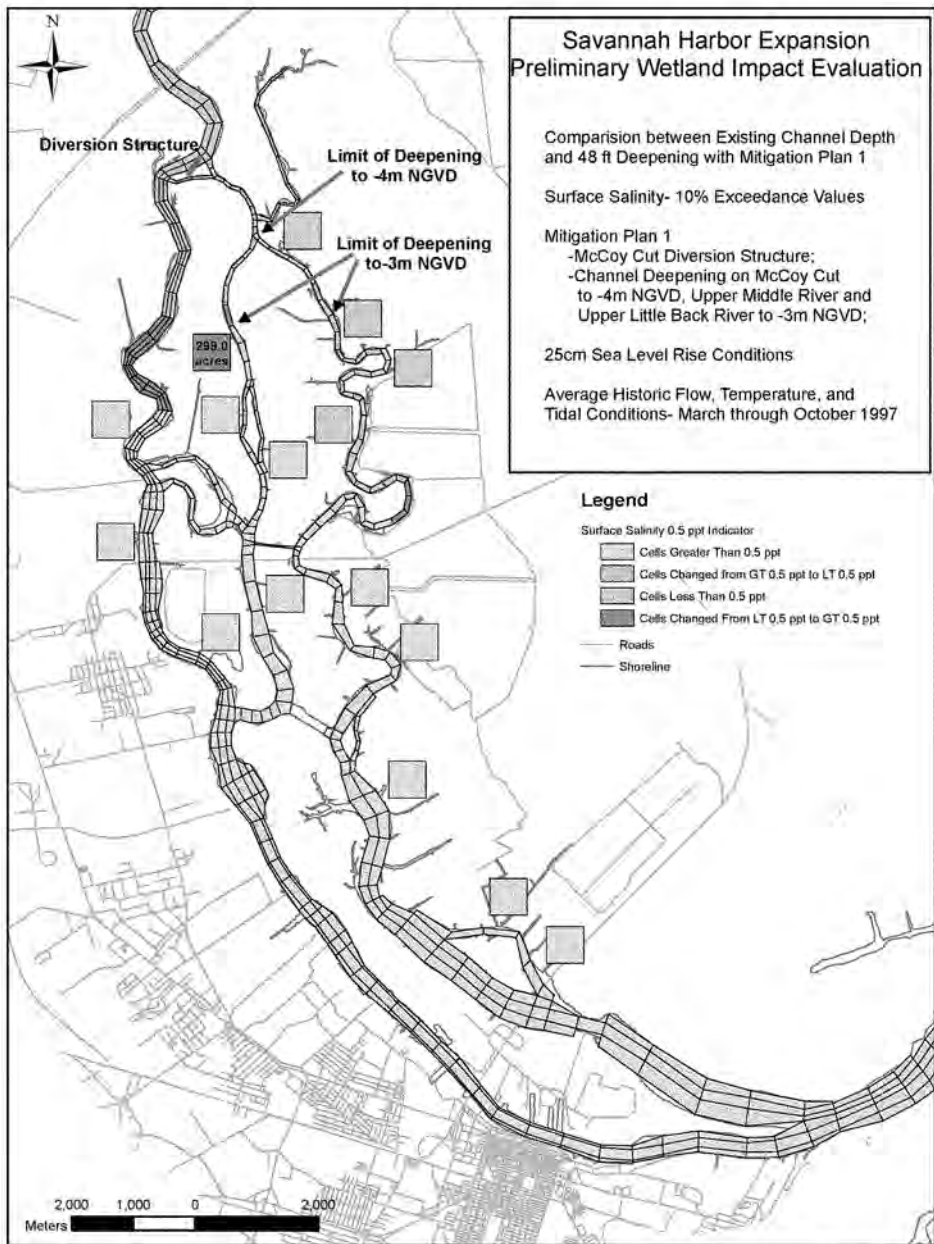
Sensitivity Analysis #2A



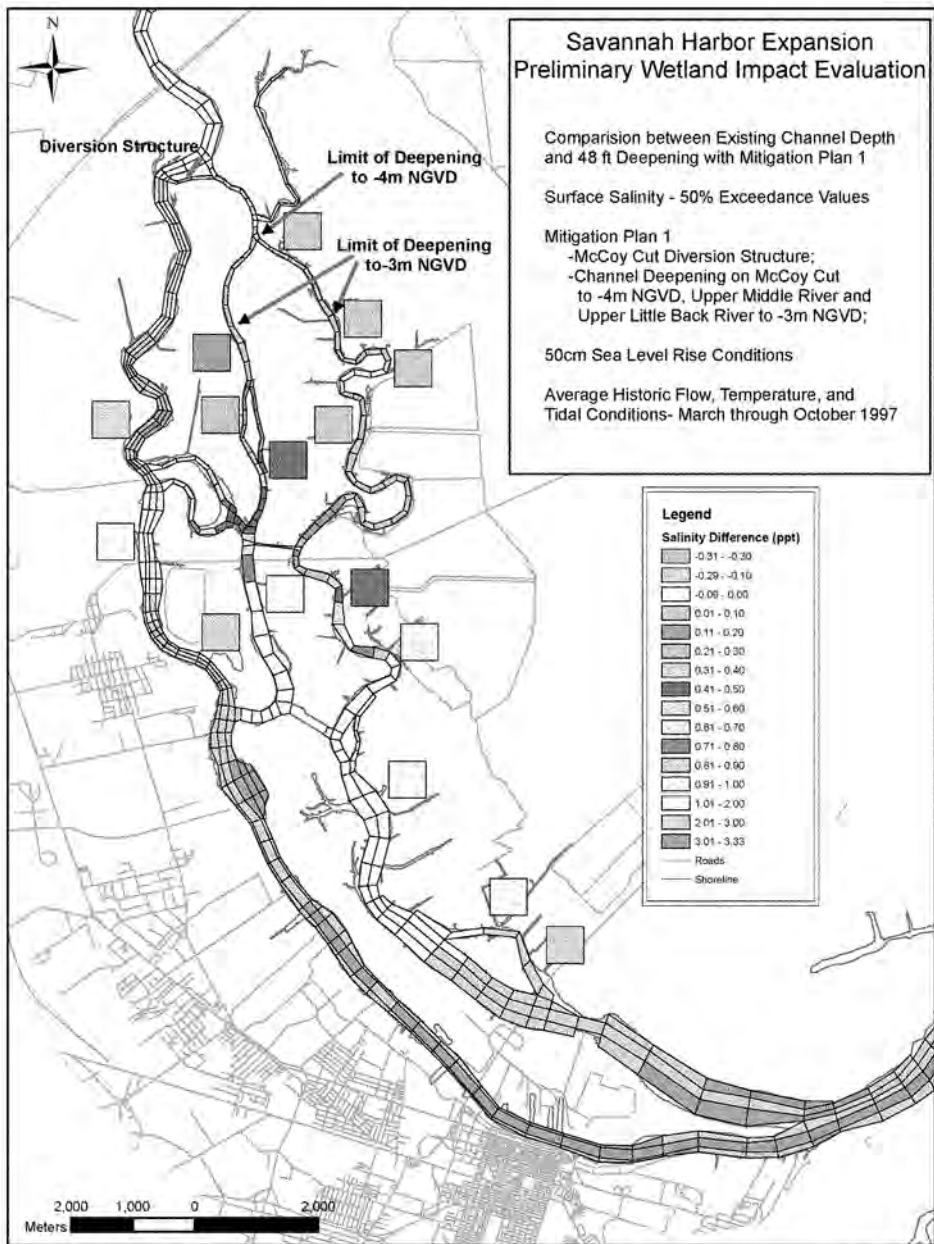


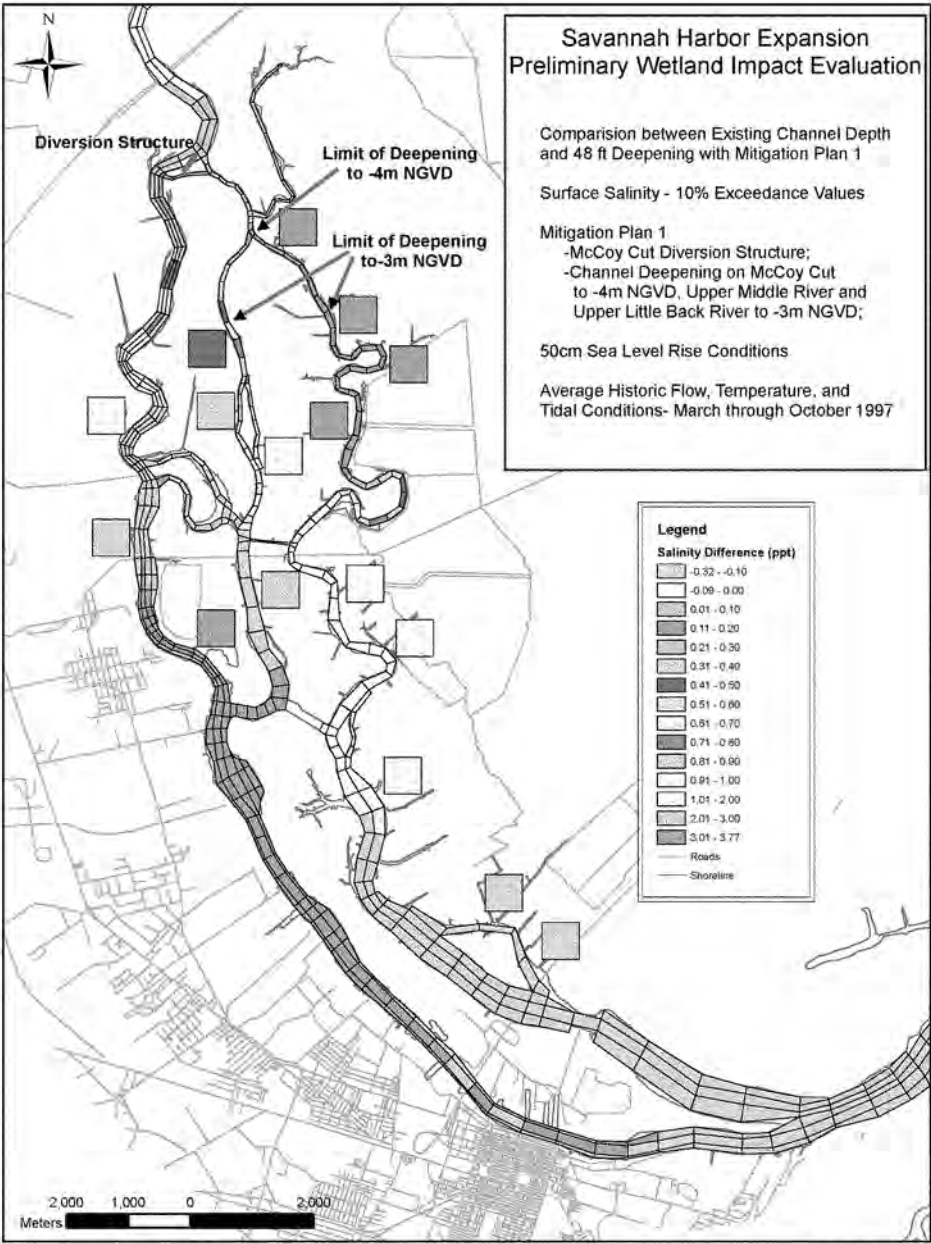


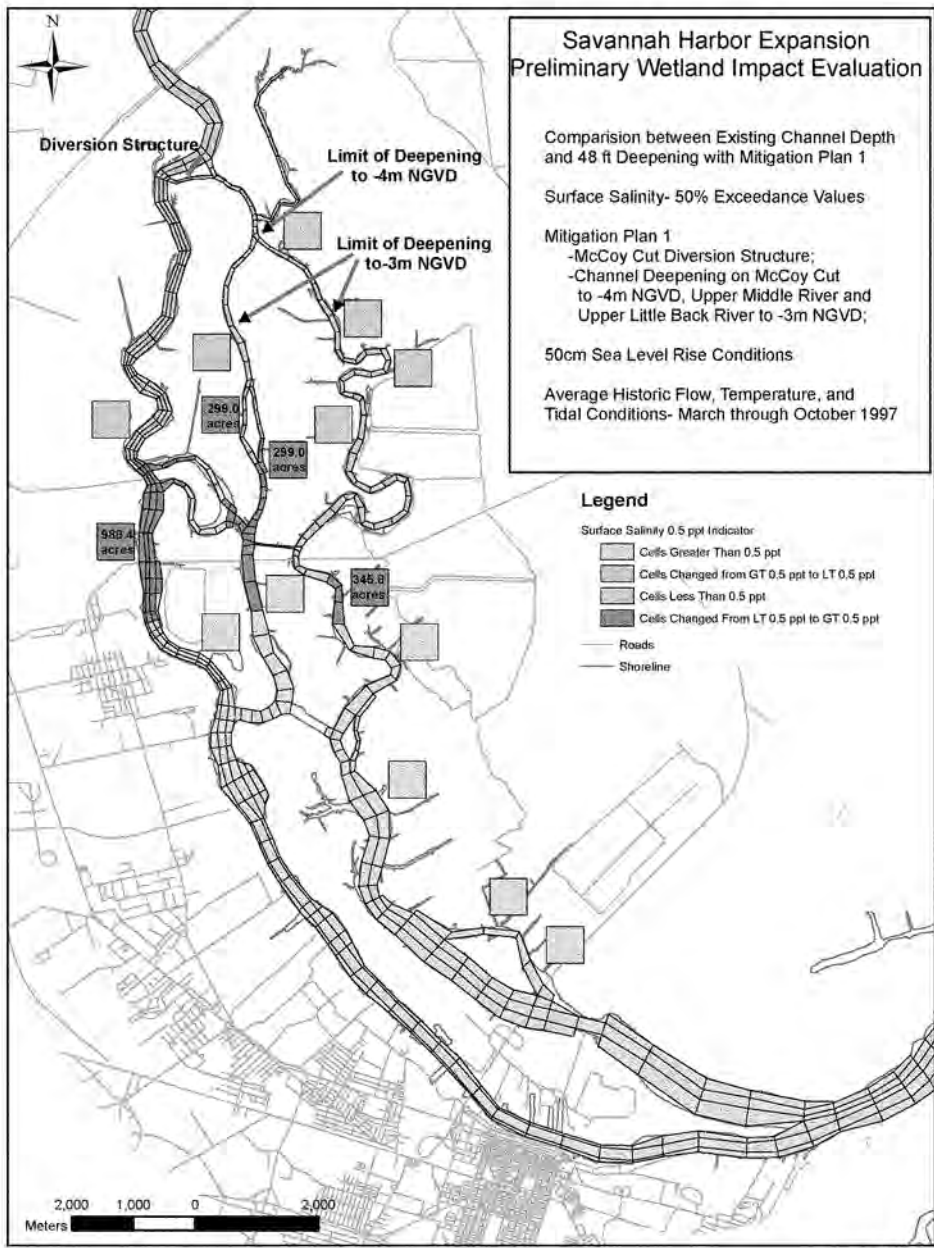
January 2007

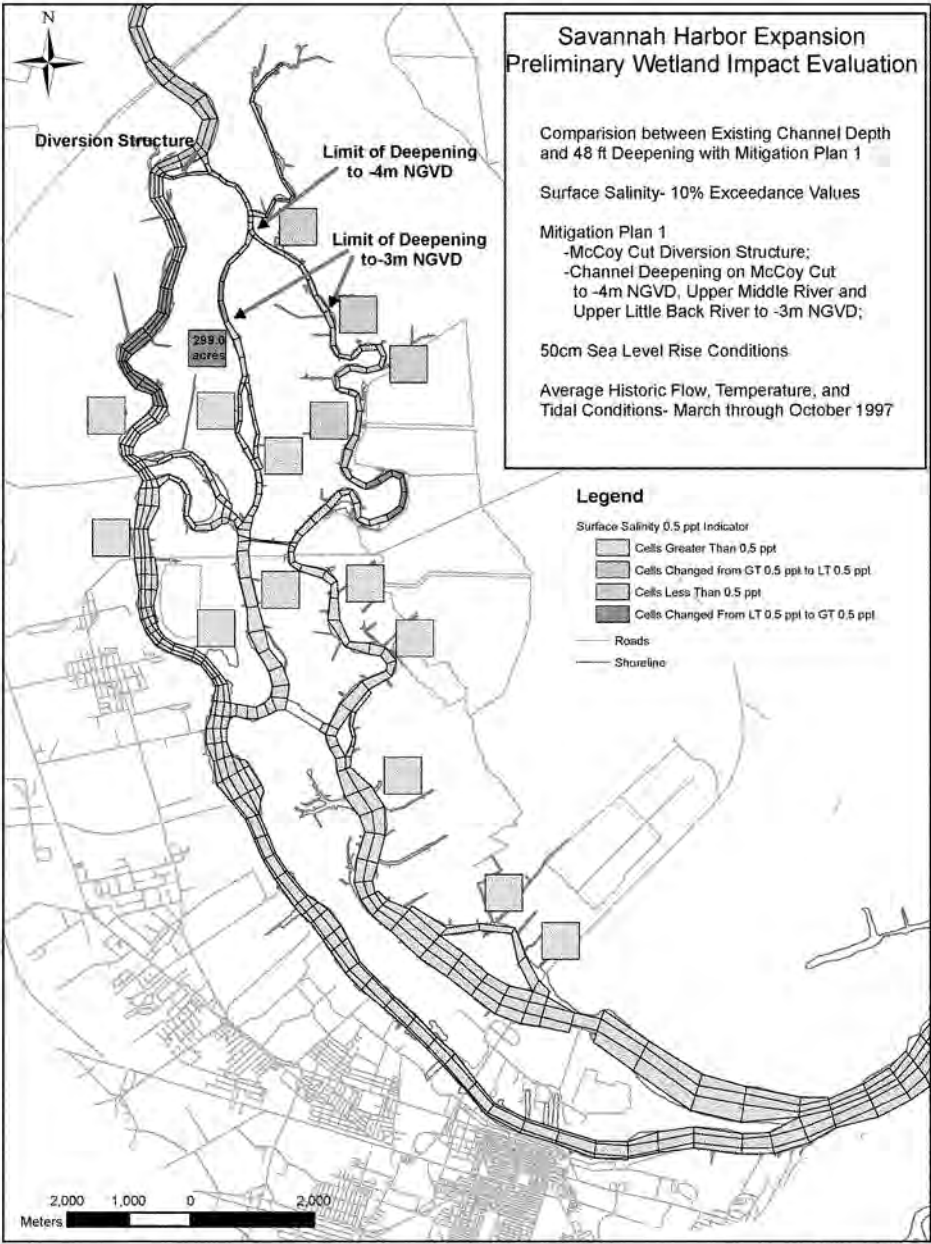


Sensitivity Analysis #2B







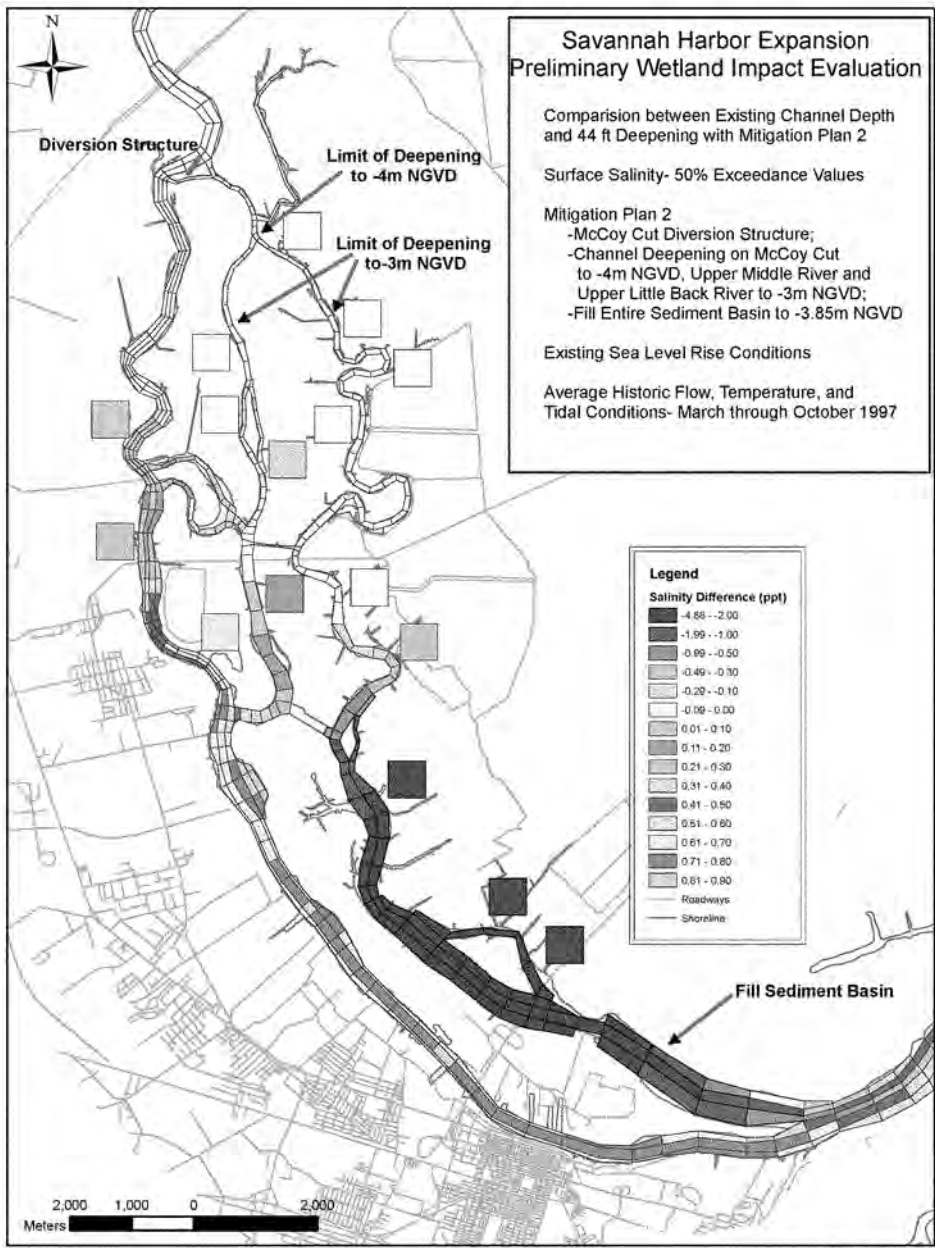


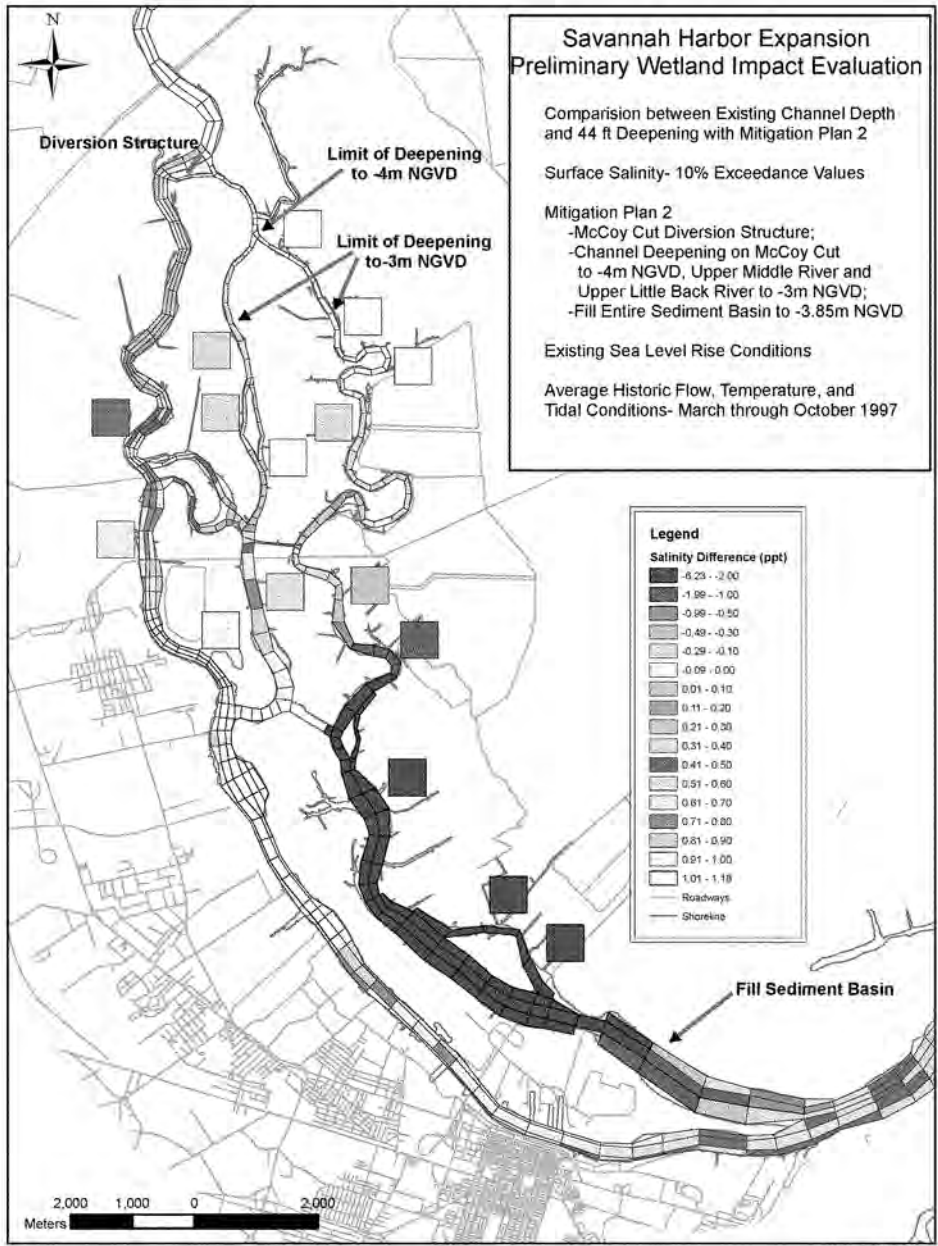
MITIGATION PLAN 2

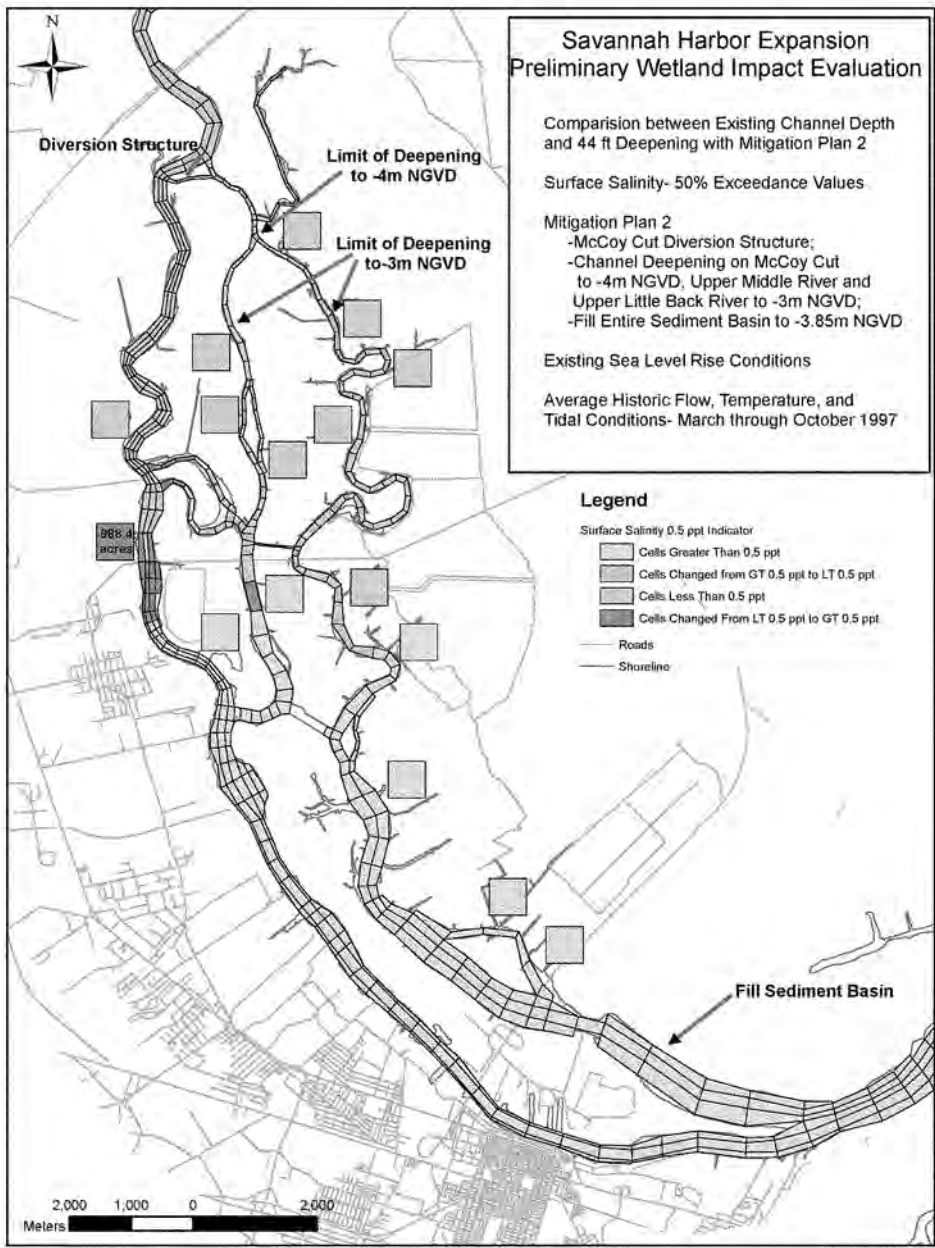
- *McCoy Cut Diversion Structure*
- *Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD*
- *Fill Entire Sediment Basin to -3.85m NGVD*

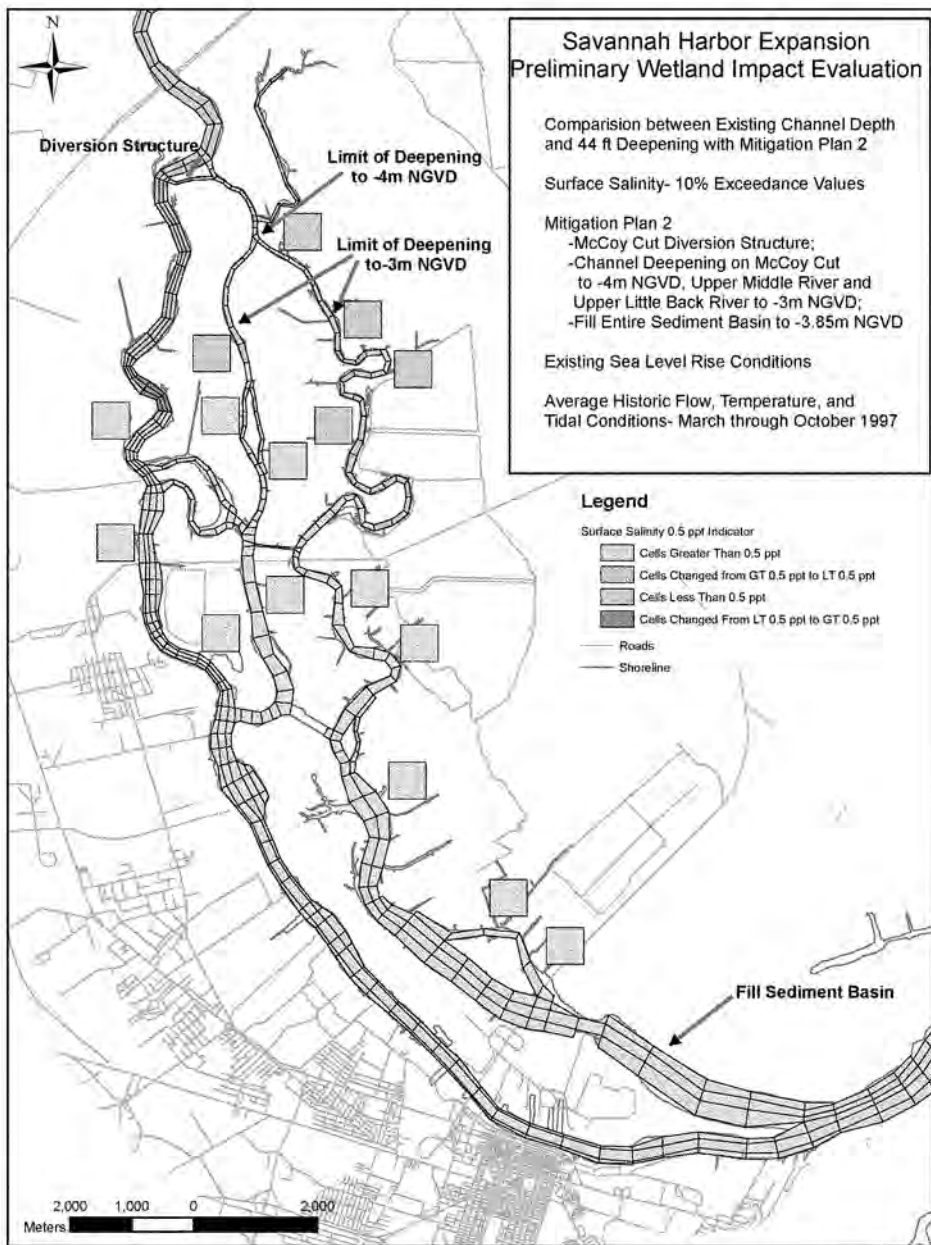
44-ft Deepening

Basic Evaluation

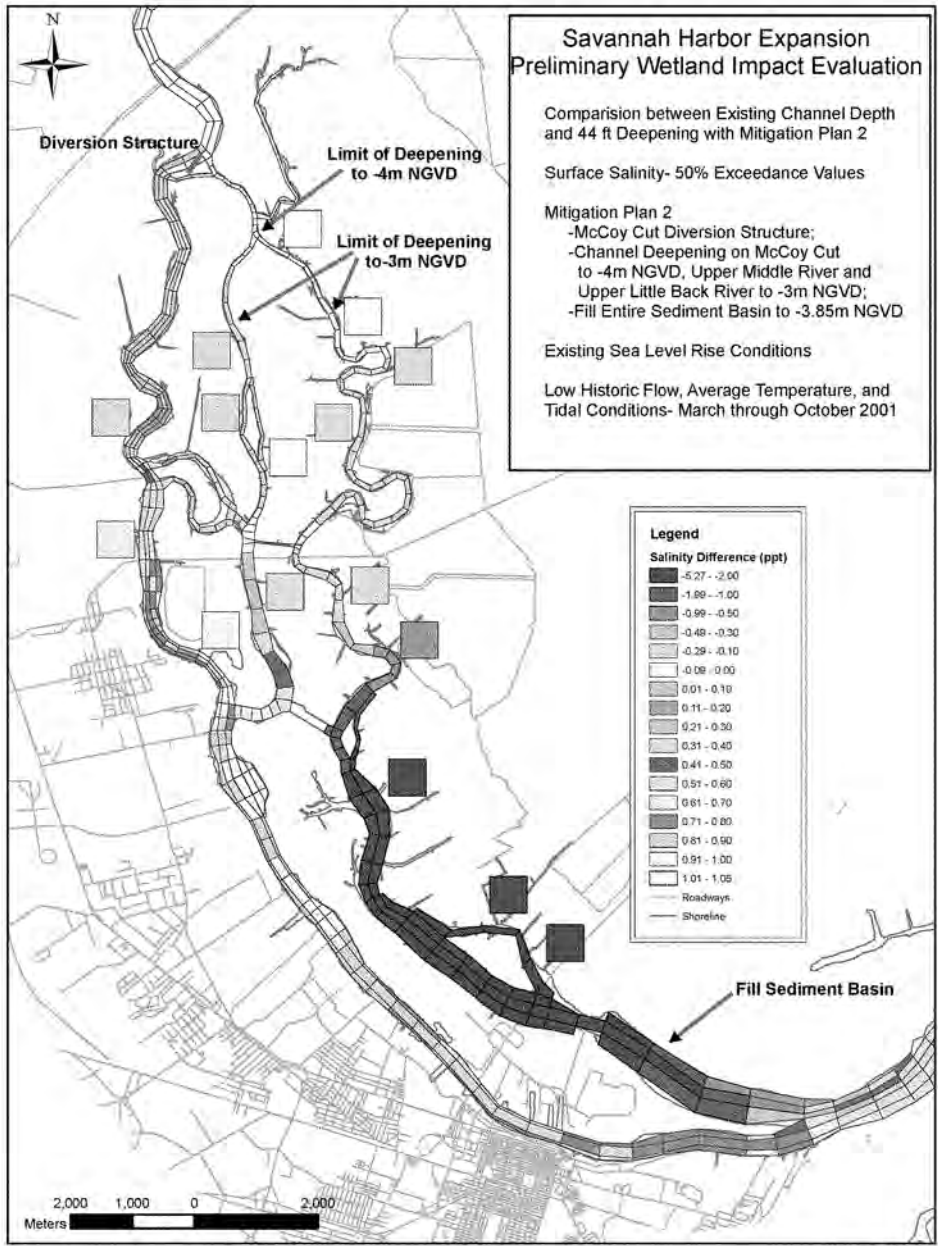


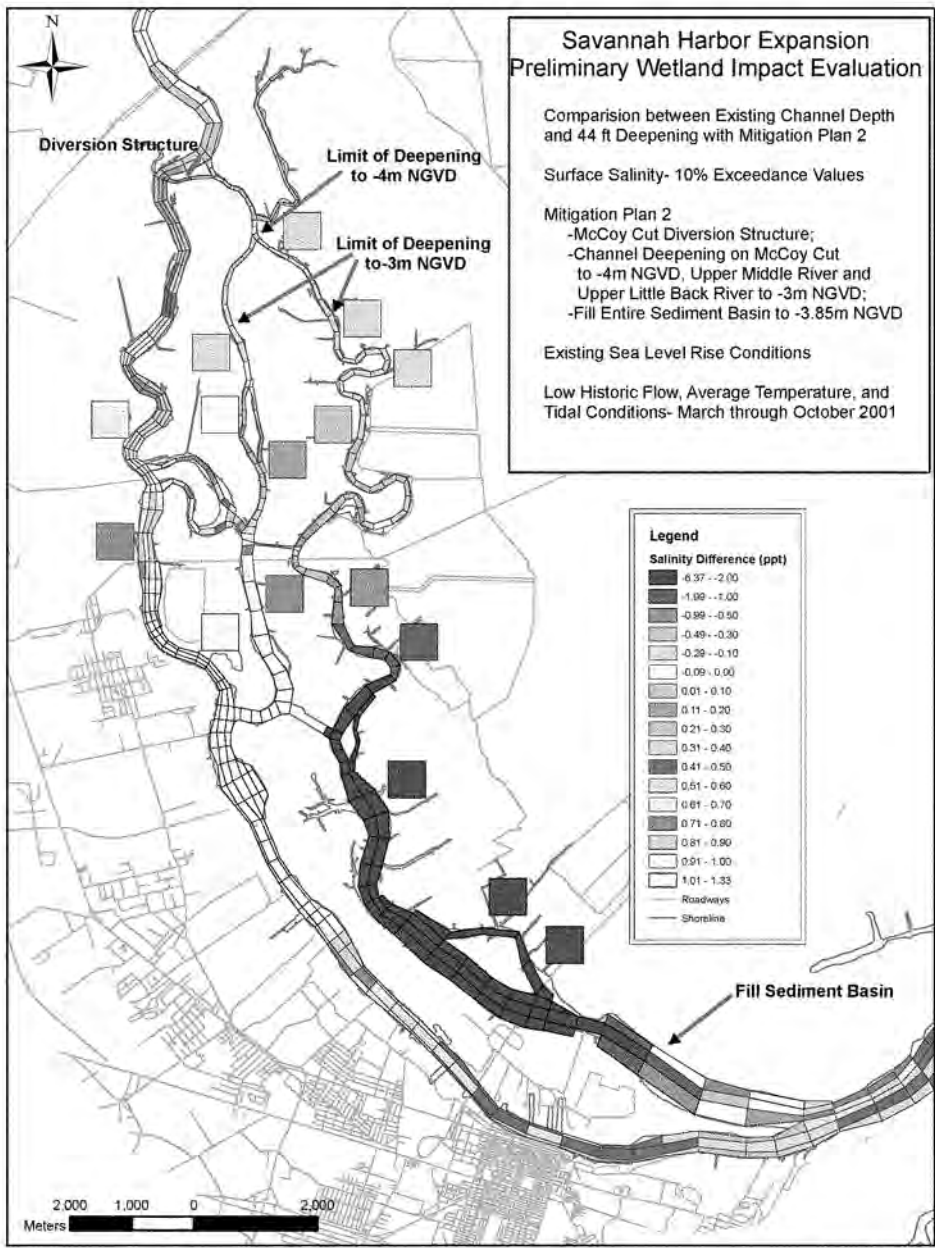


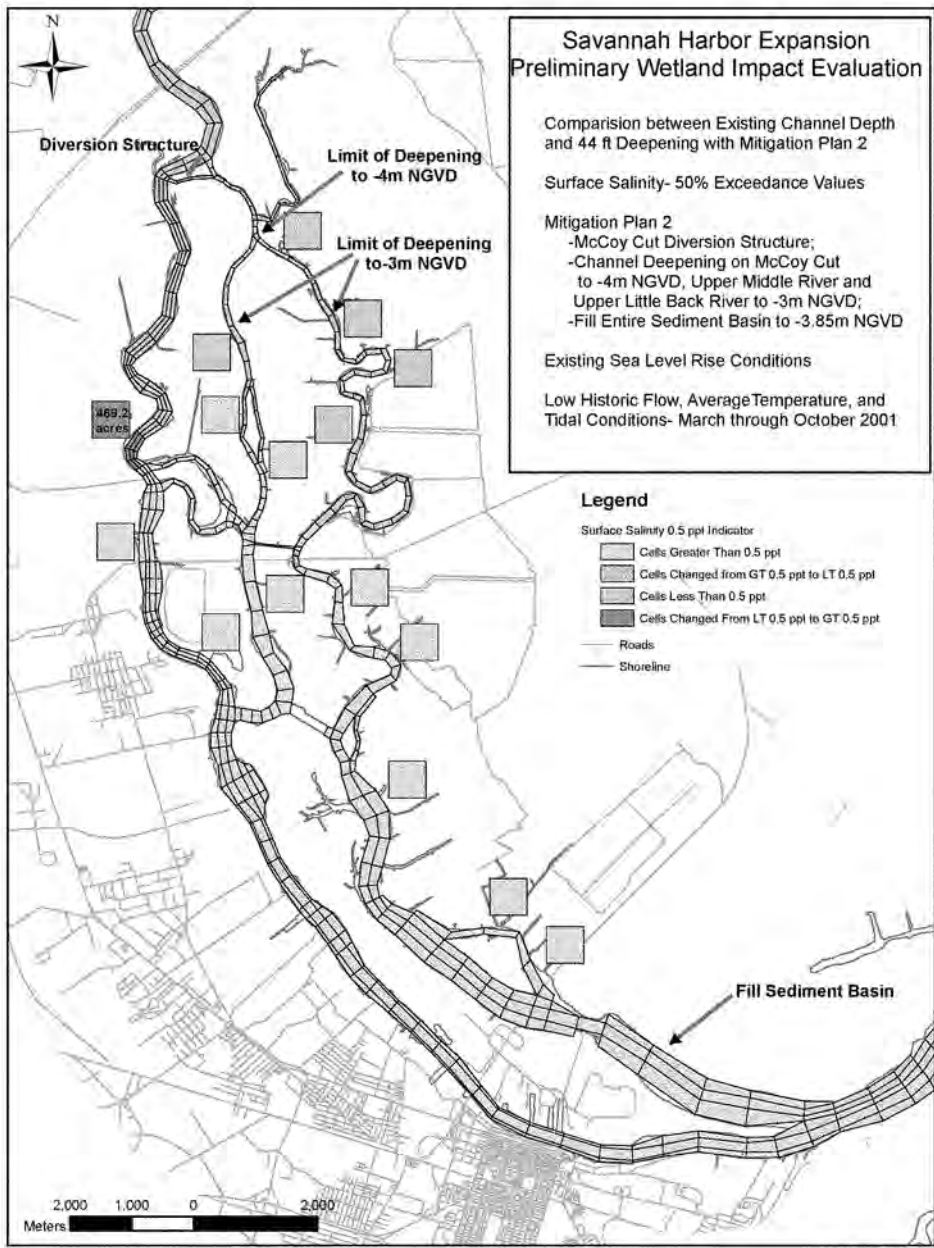


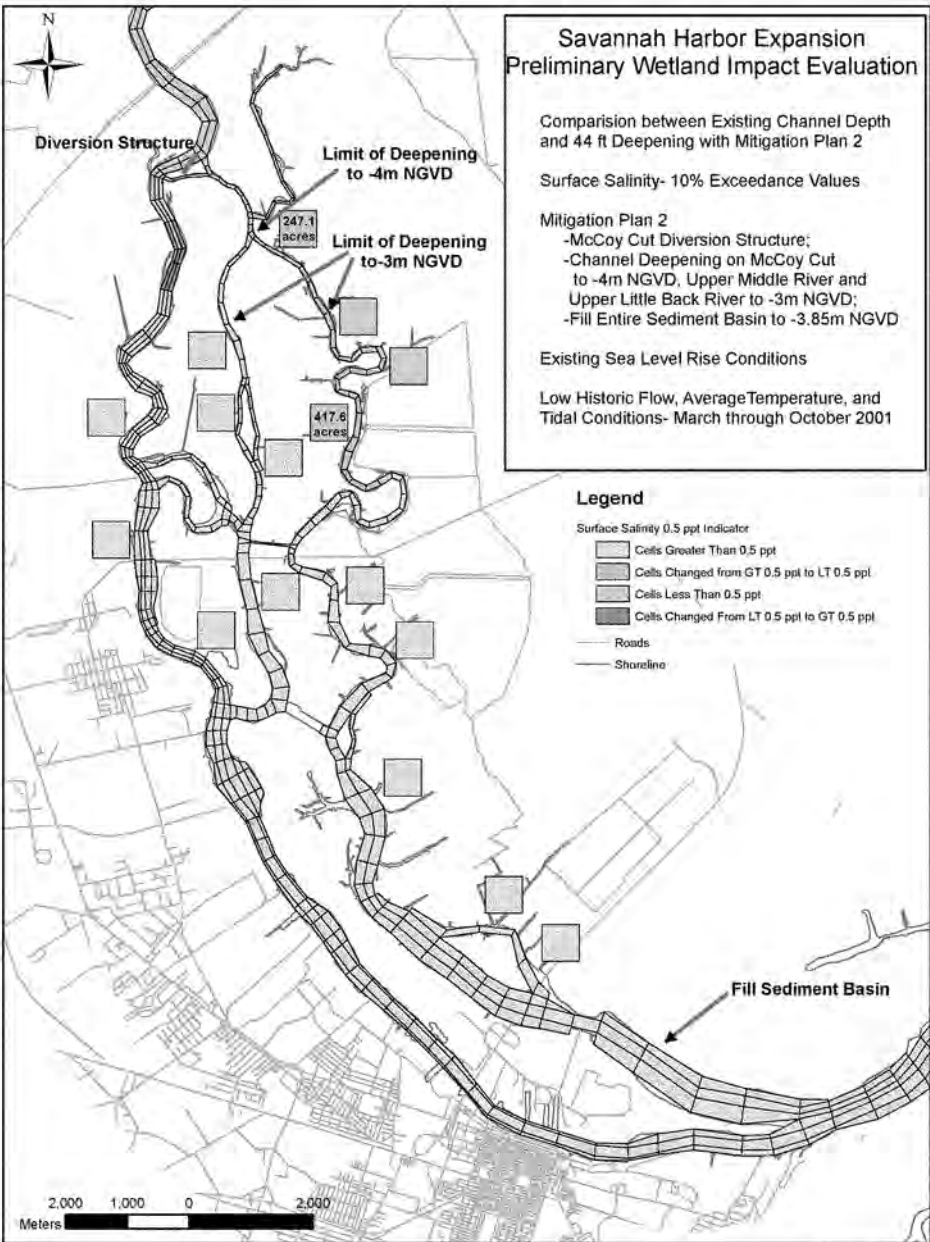


Sensitivity Analysis #1

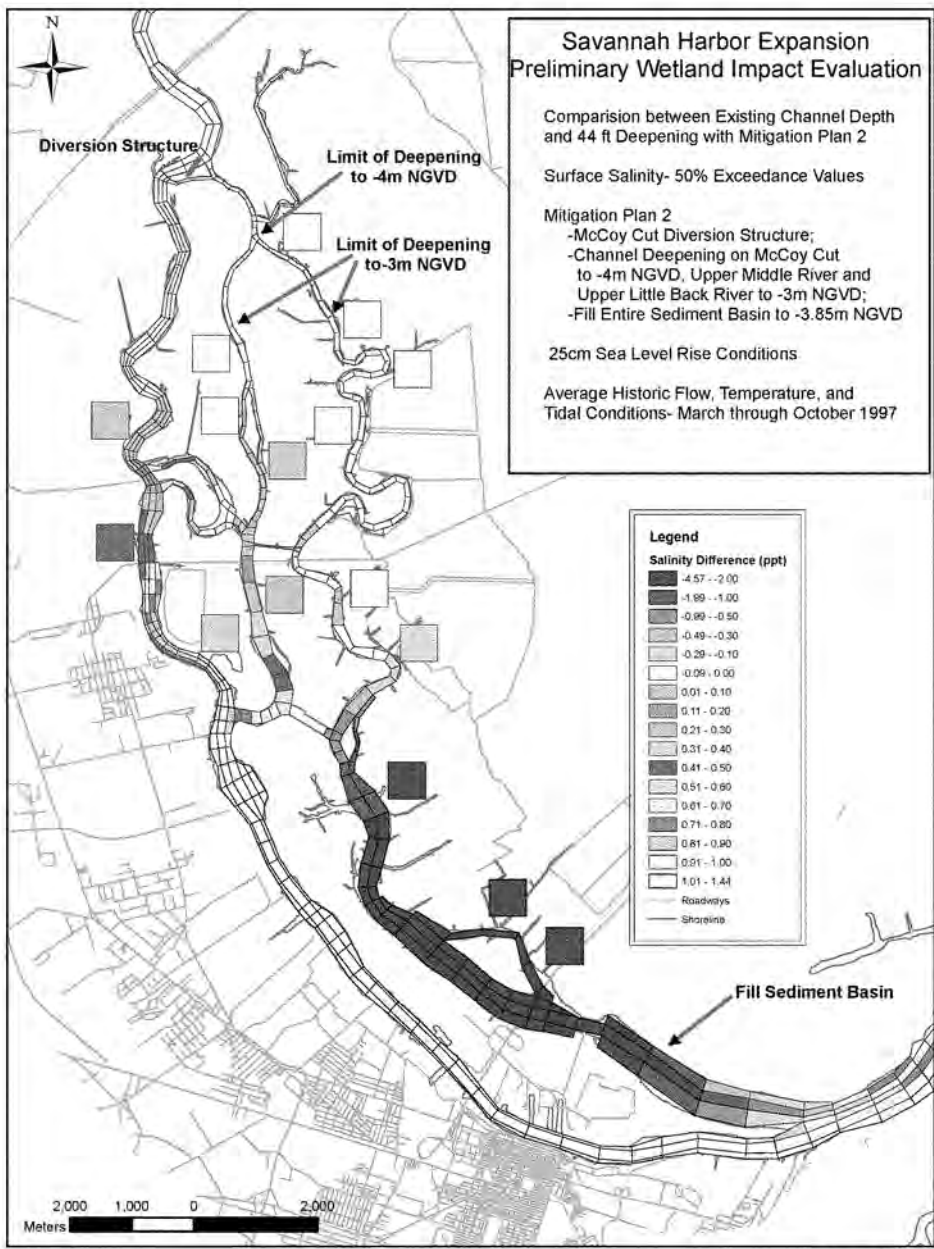


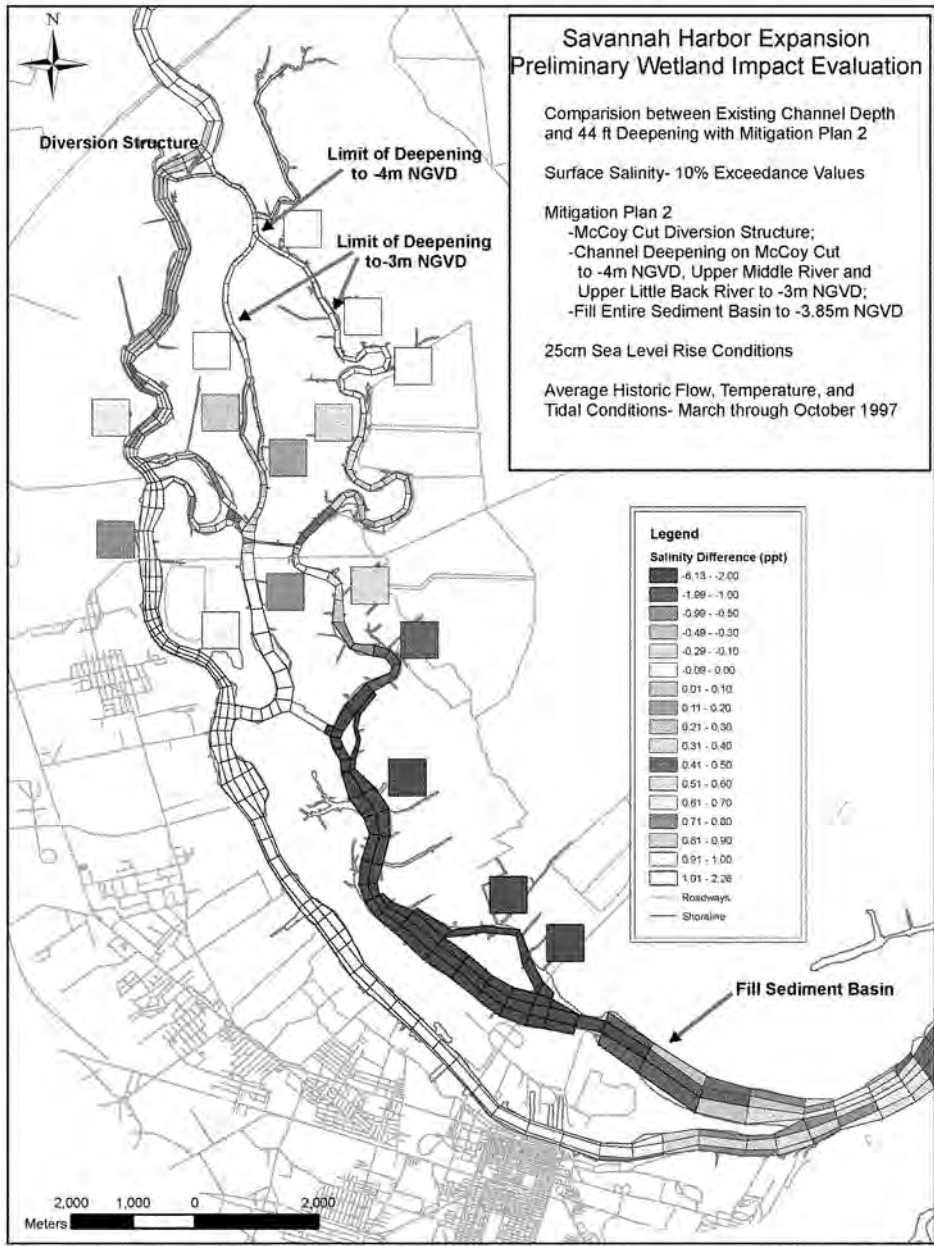


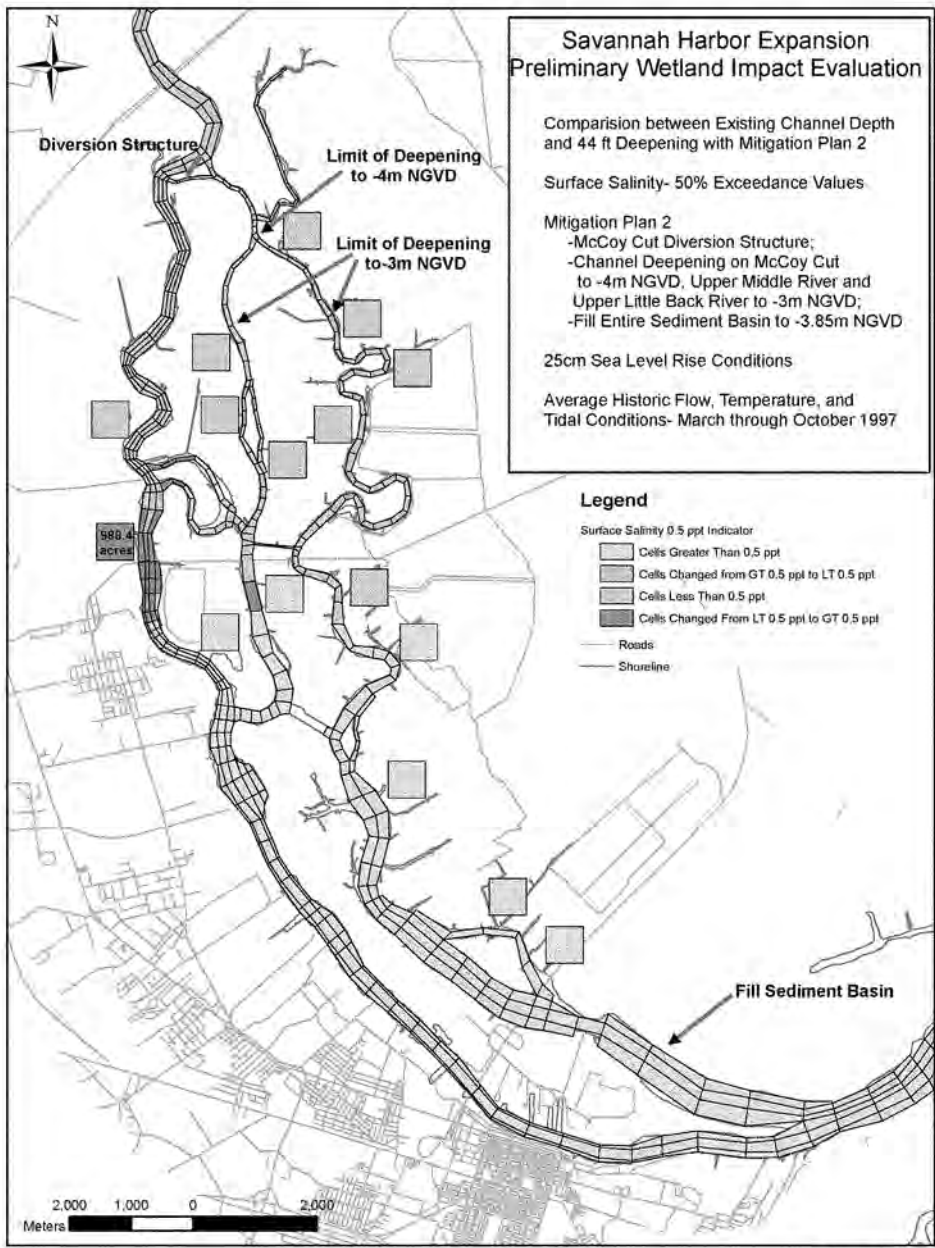


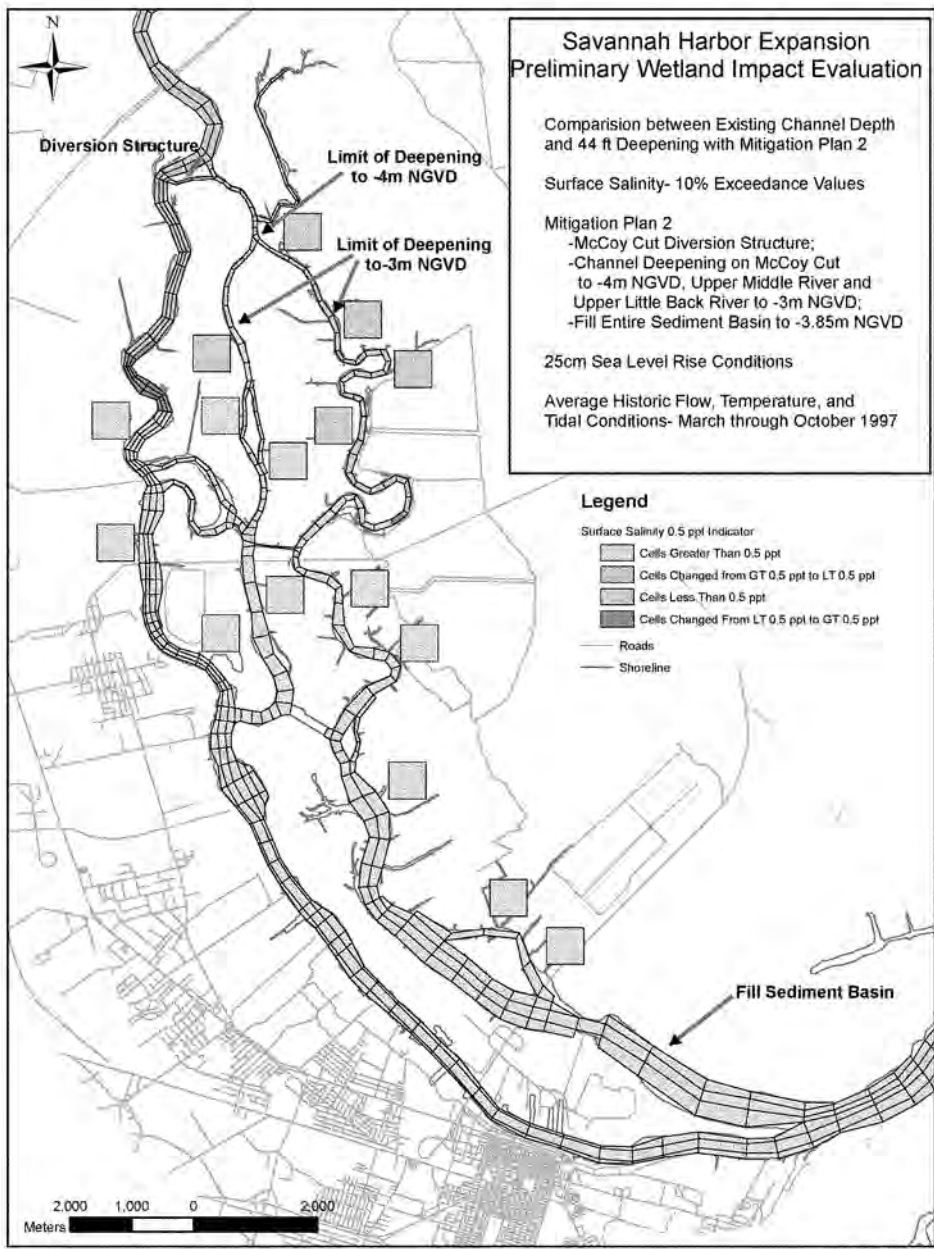


Sensitivity Analysis #2A

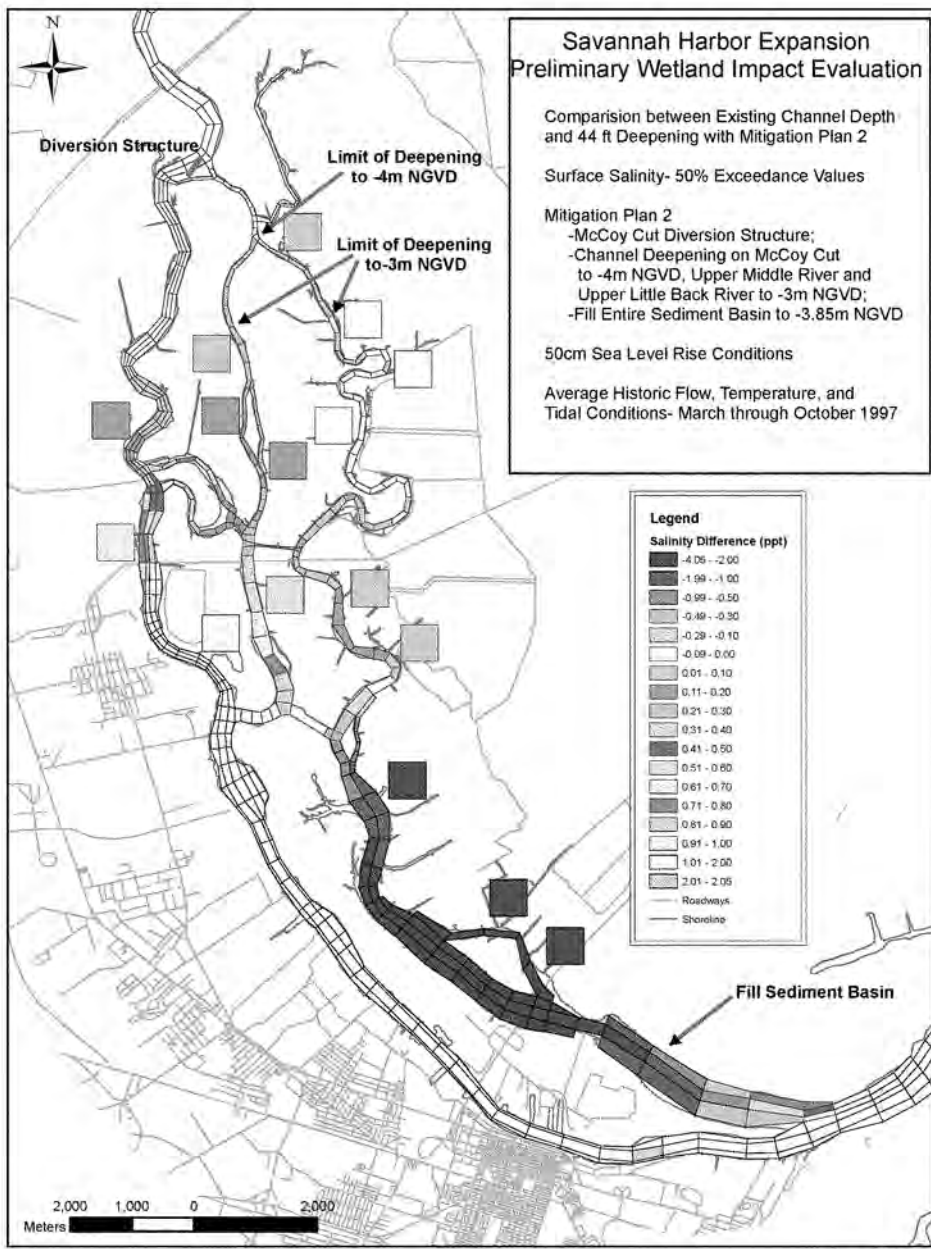


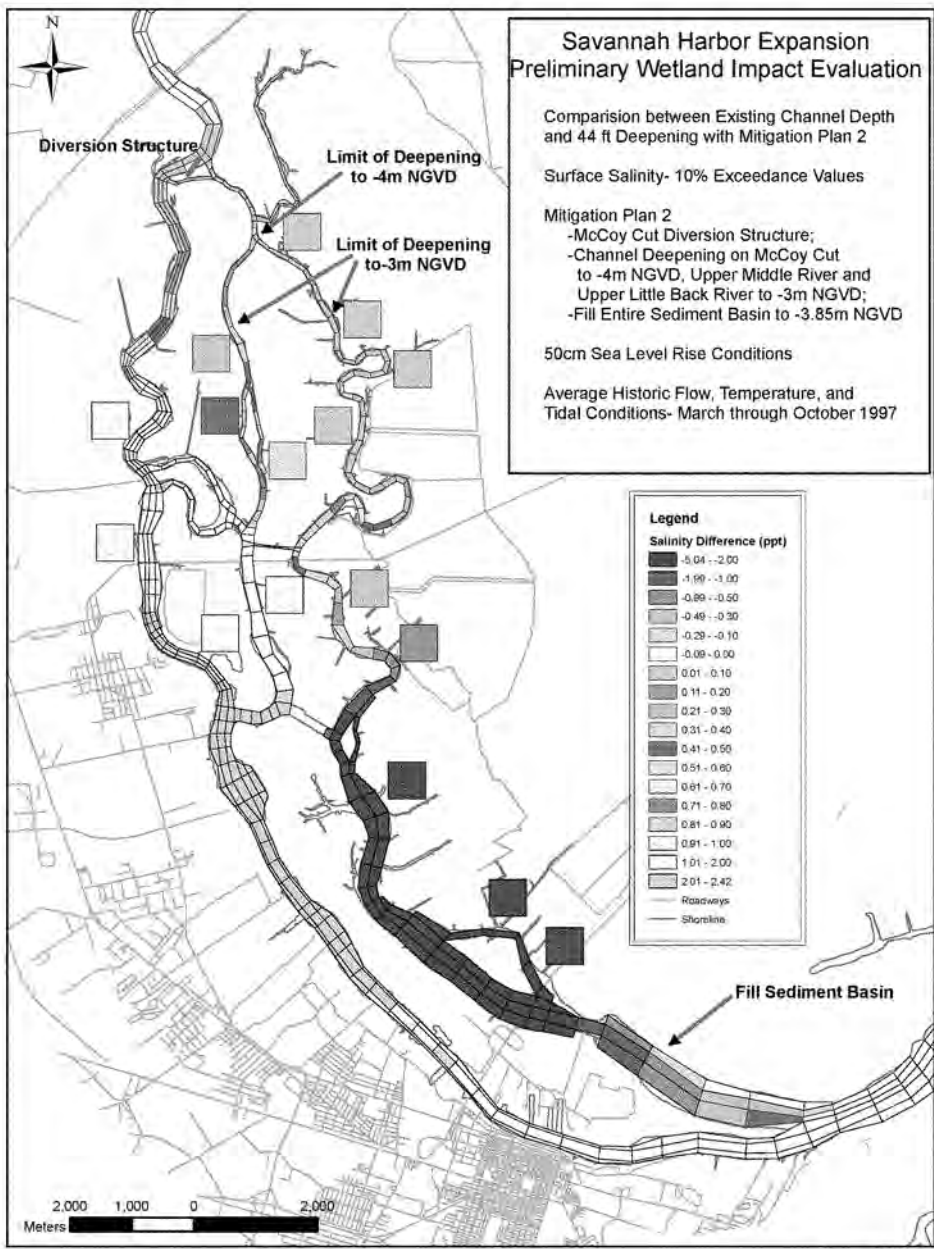


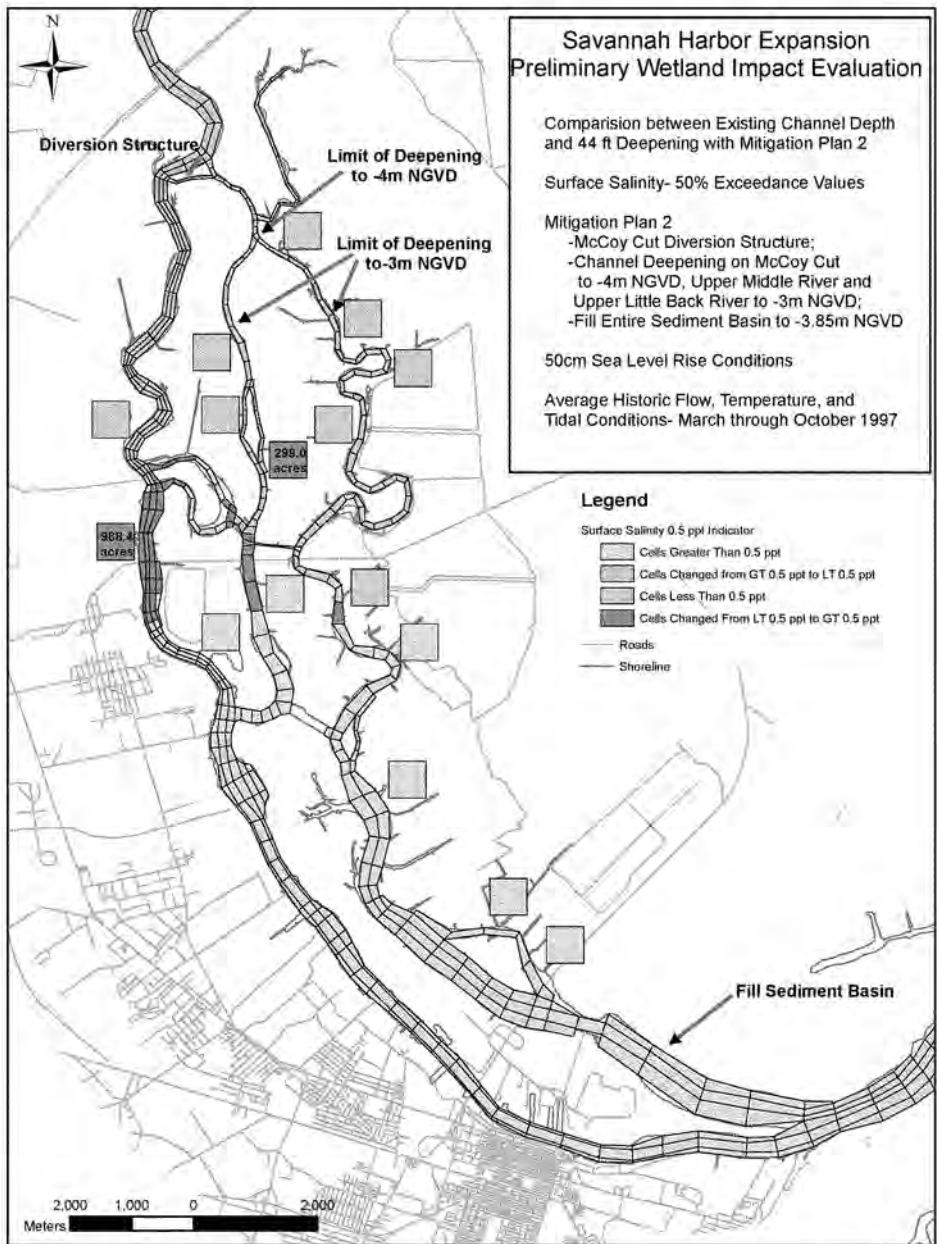


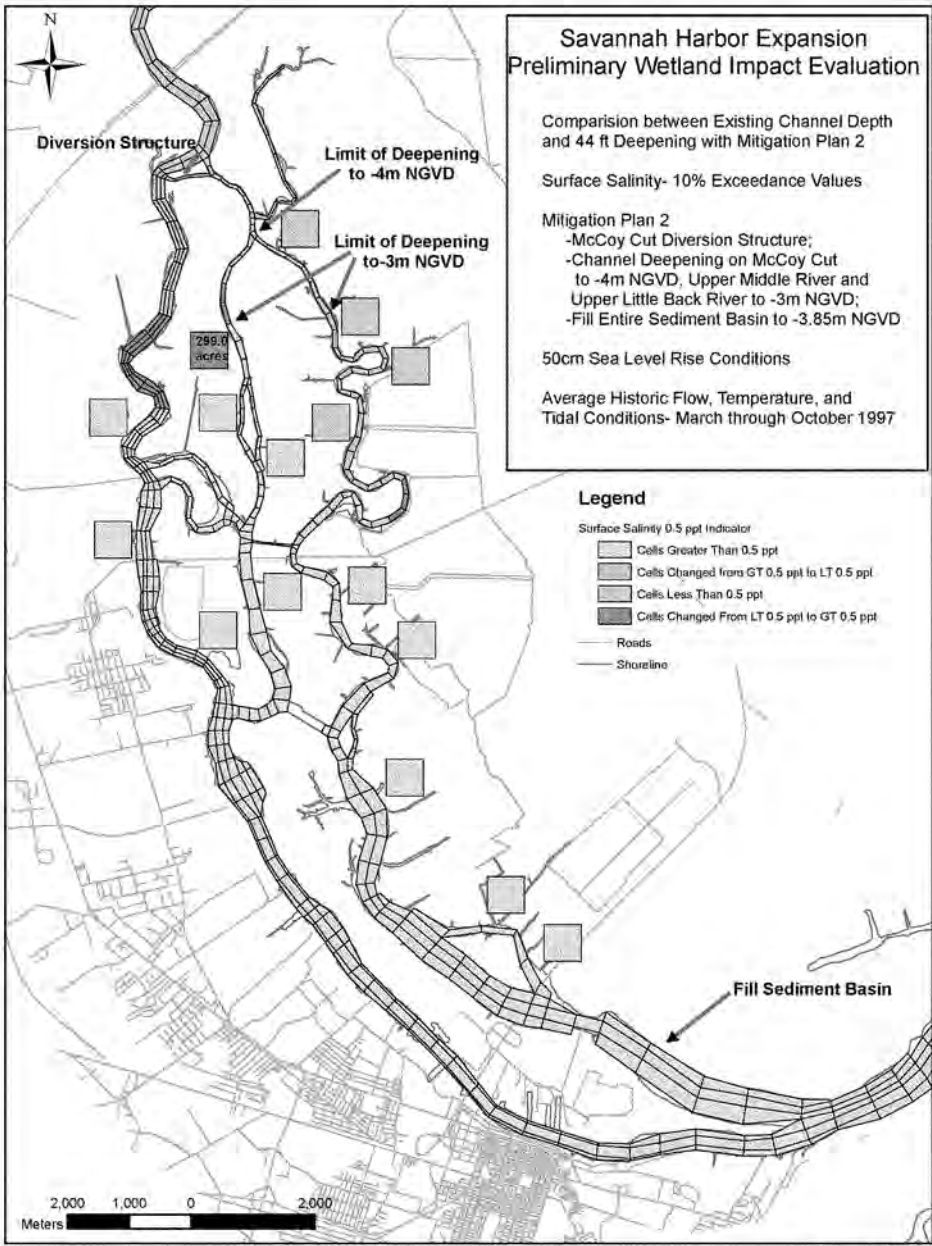


Sensitivity Analysis #2B



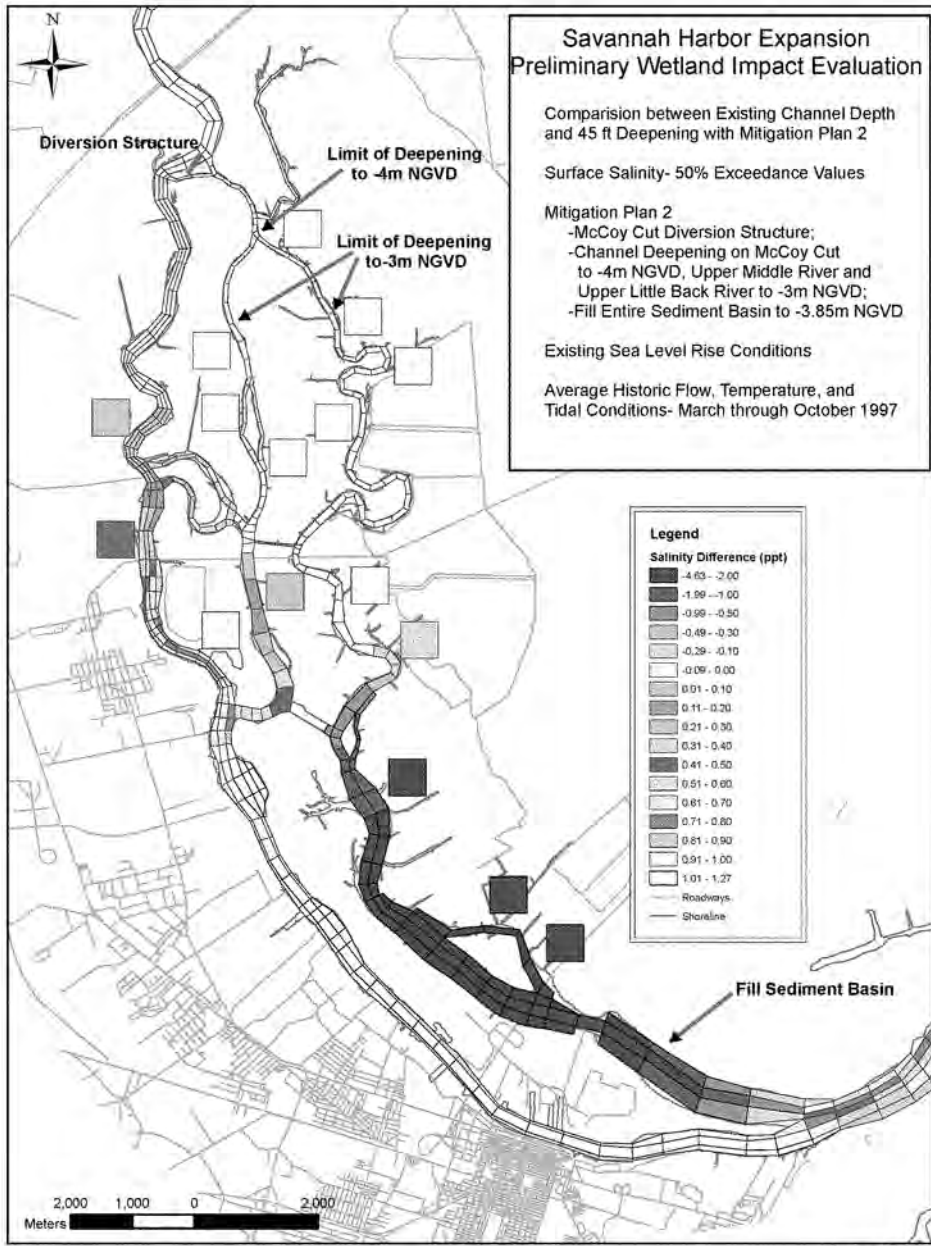


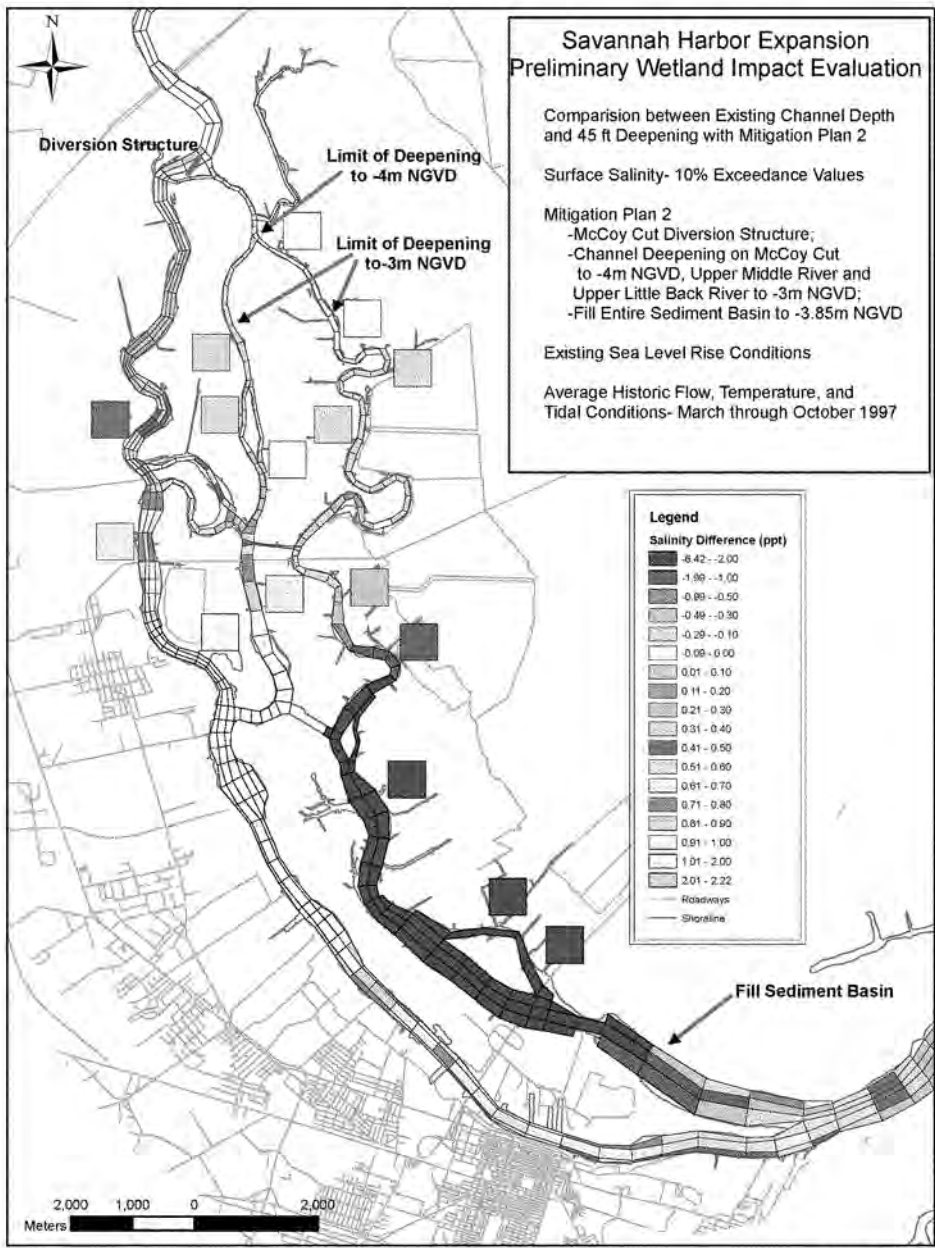


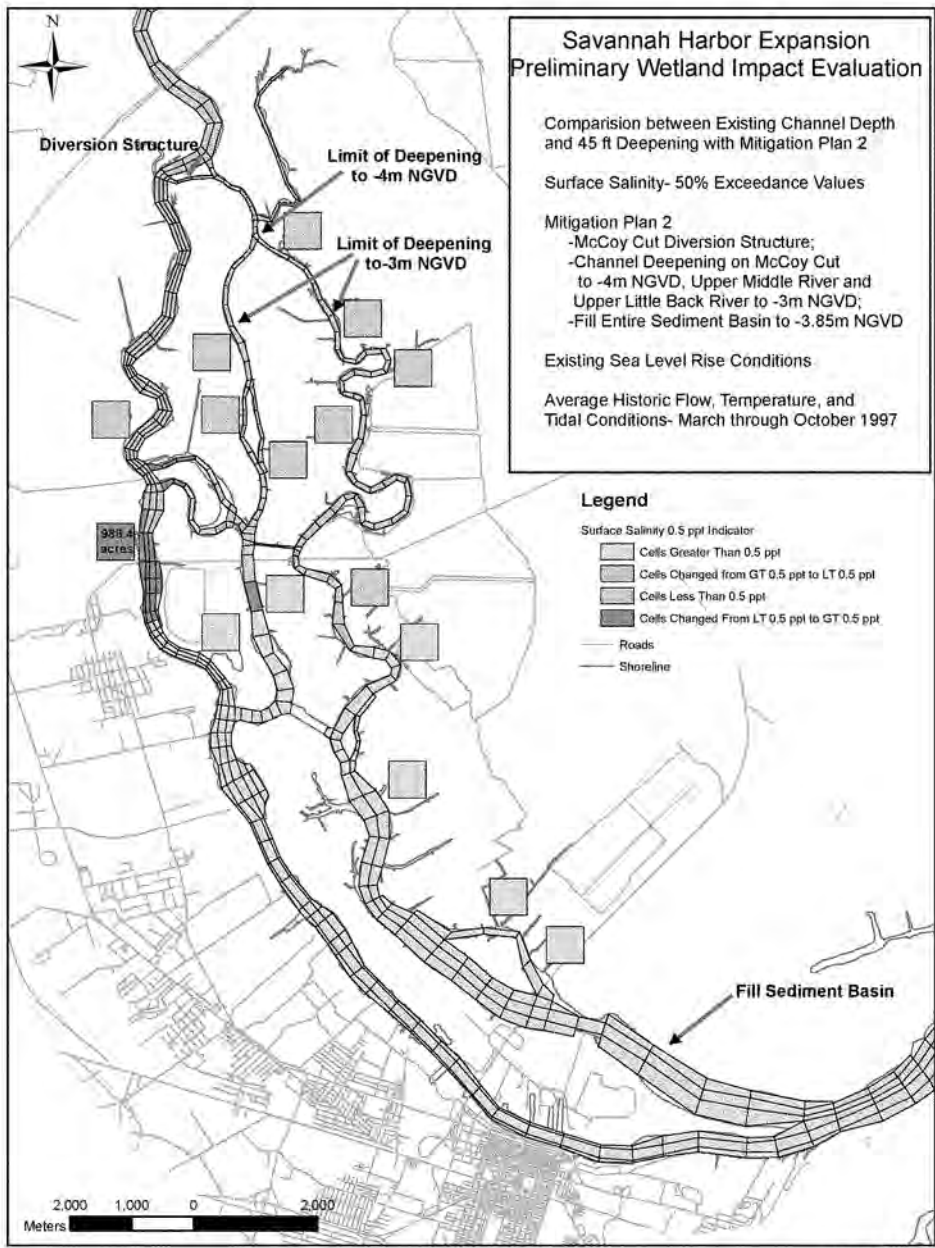


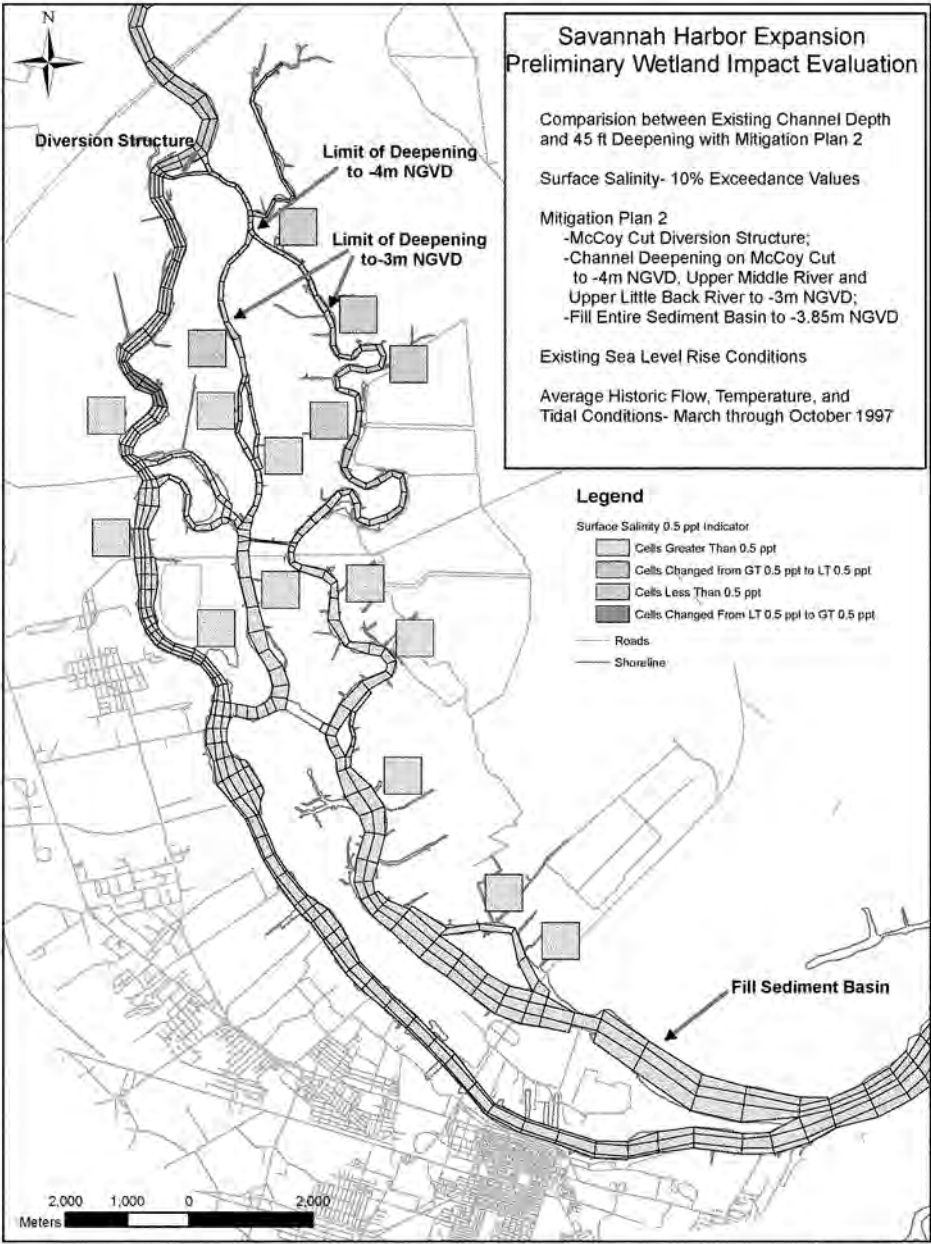
45-ft Deepening

Basic Evaluation

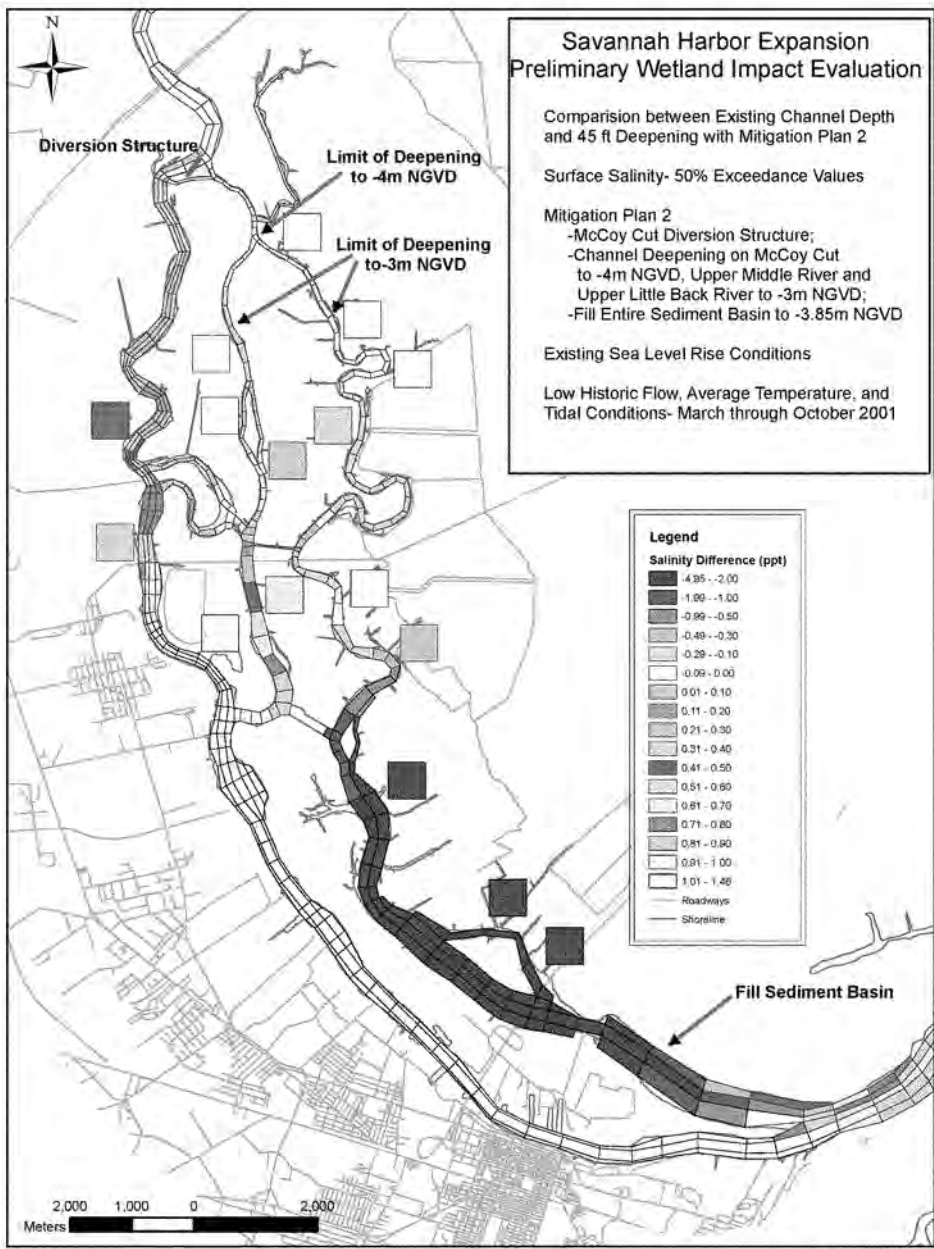


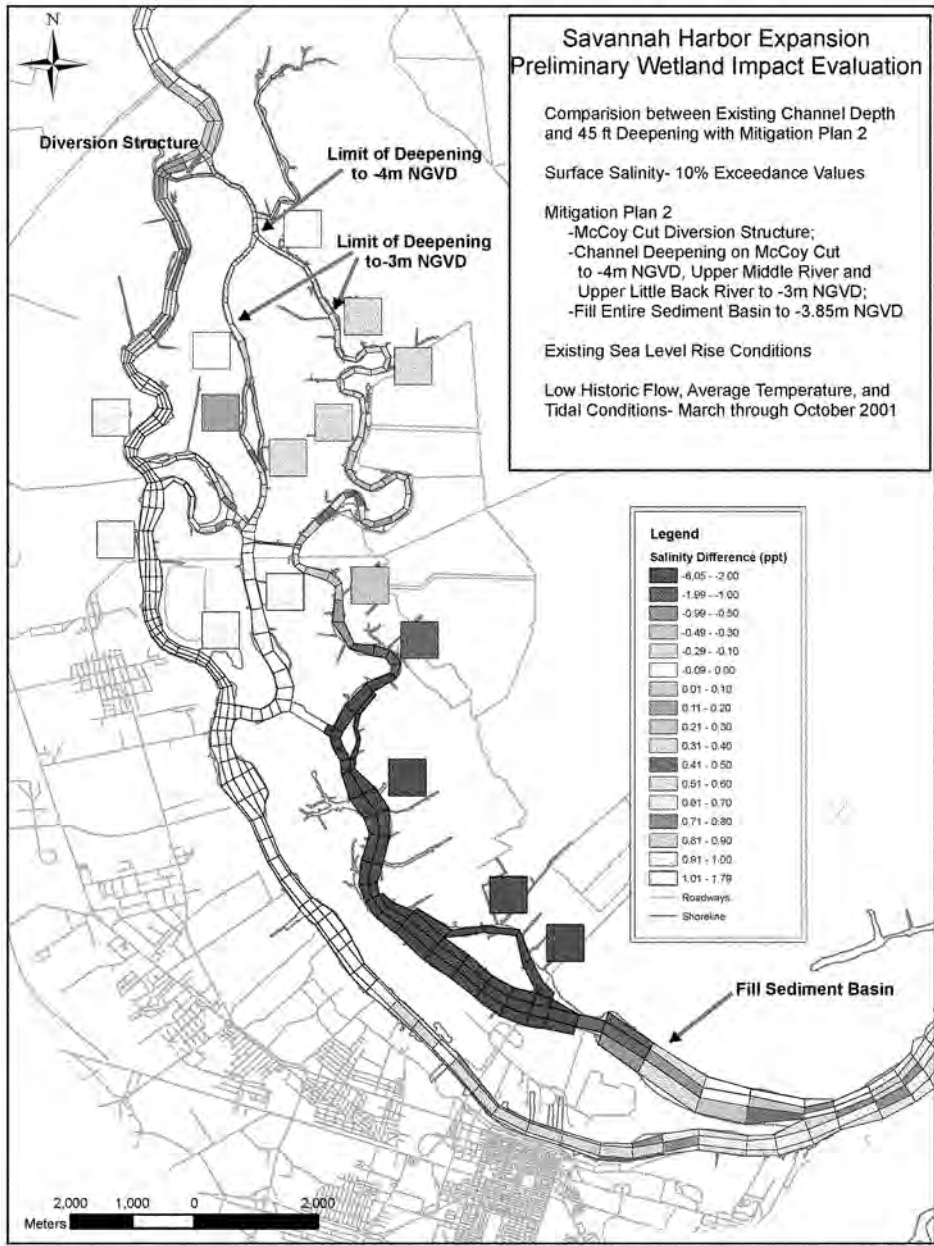


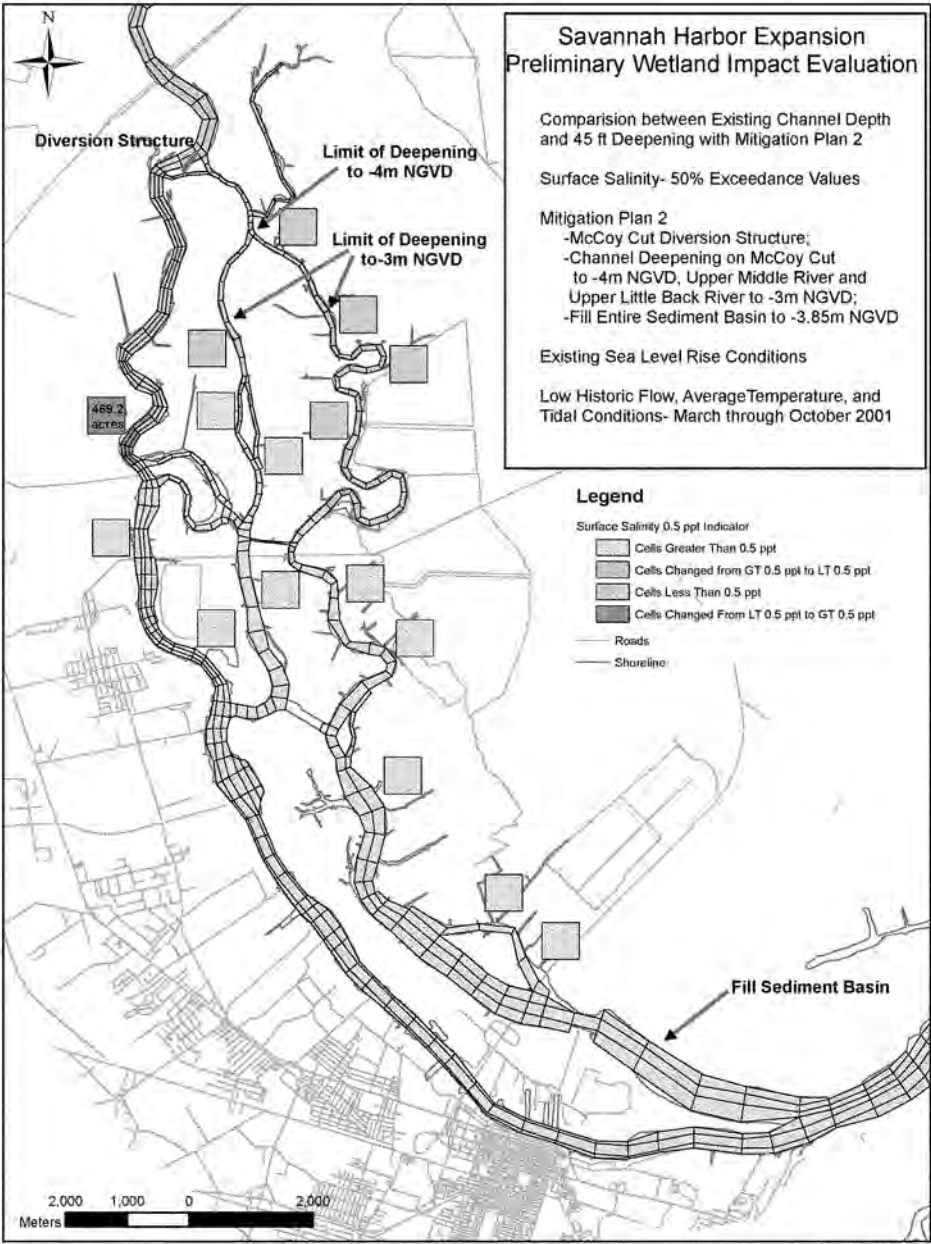


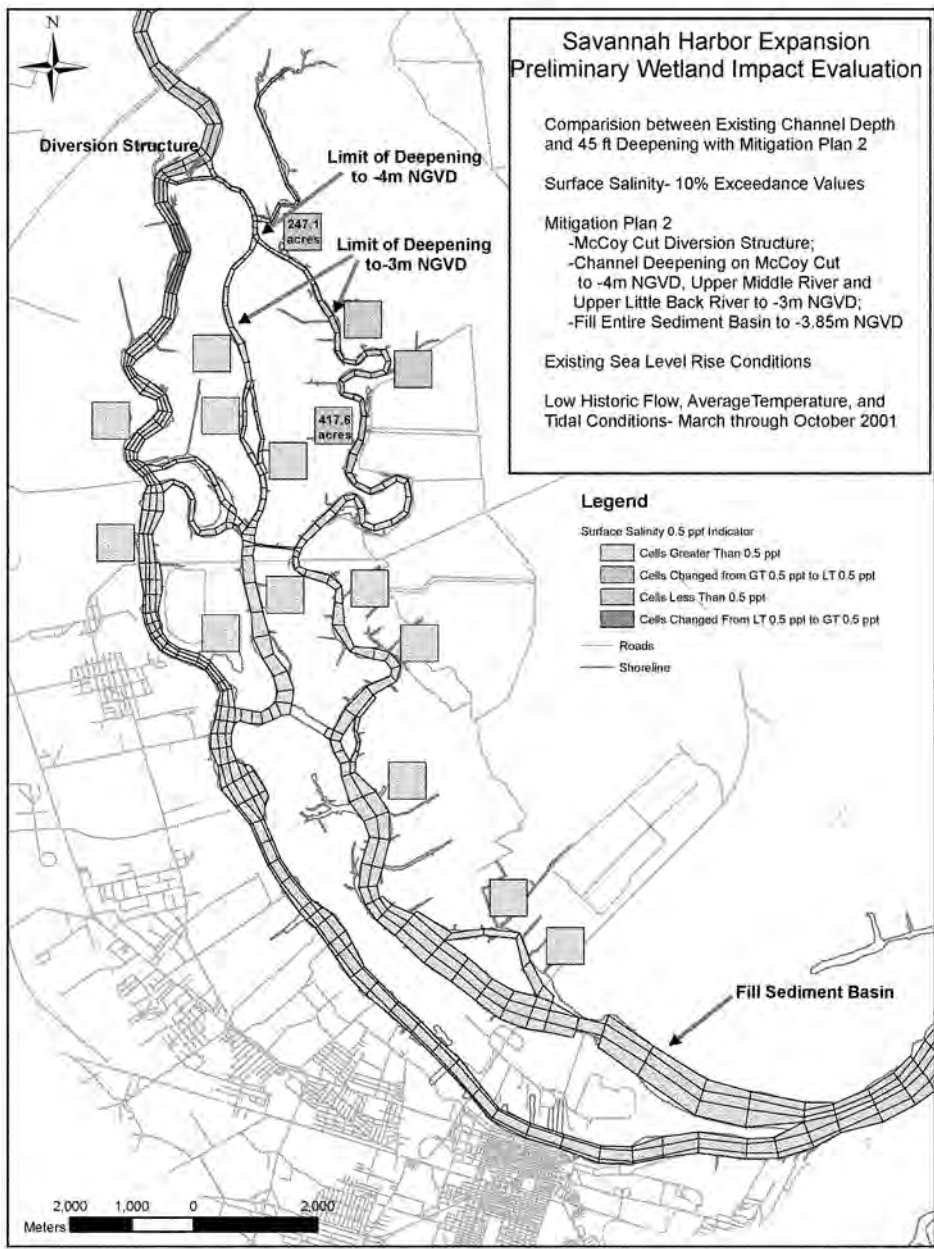


Sensitivity Analysis #1

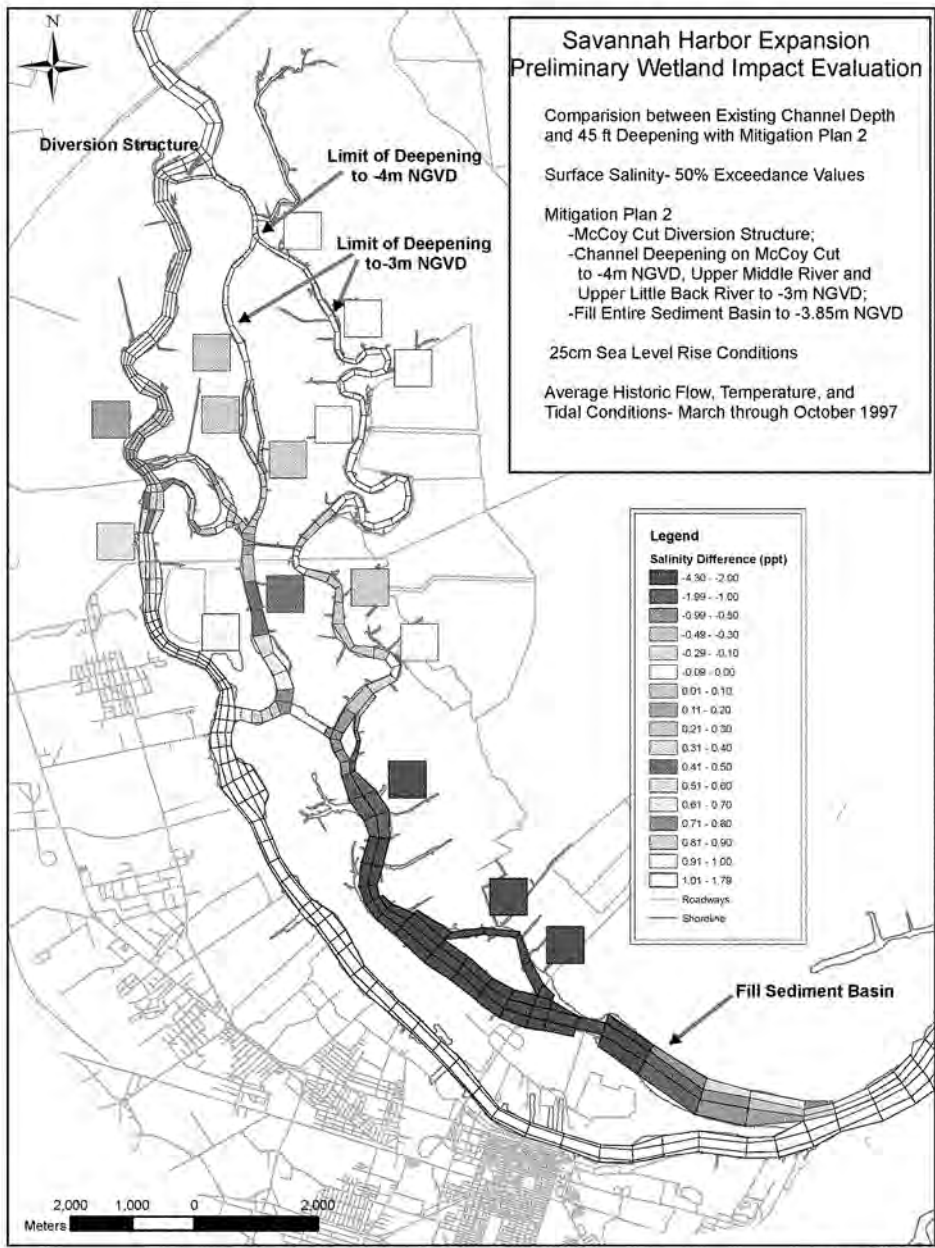


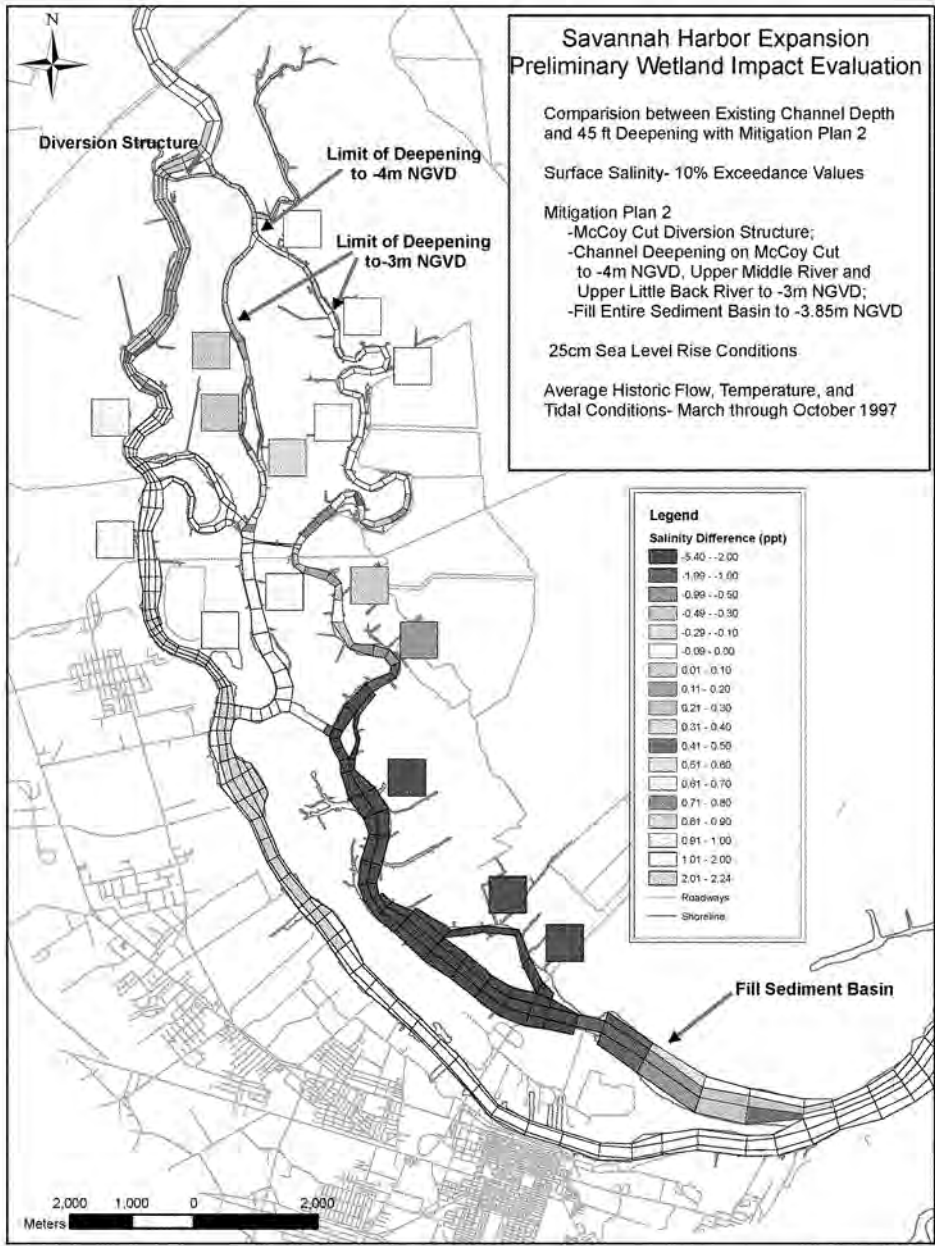


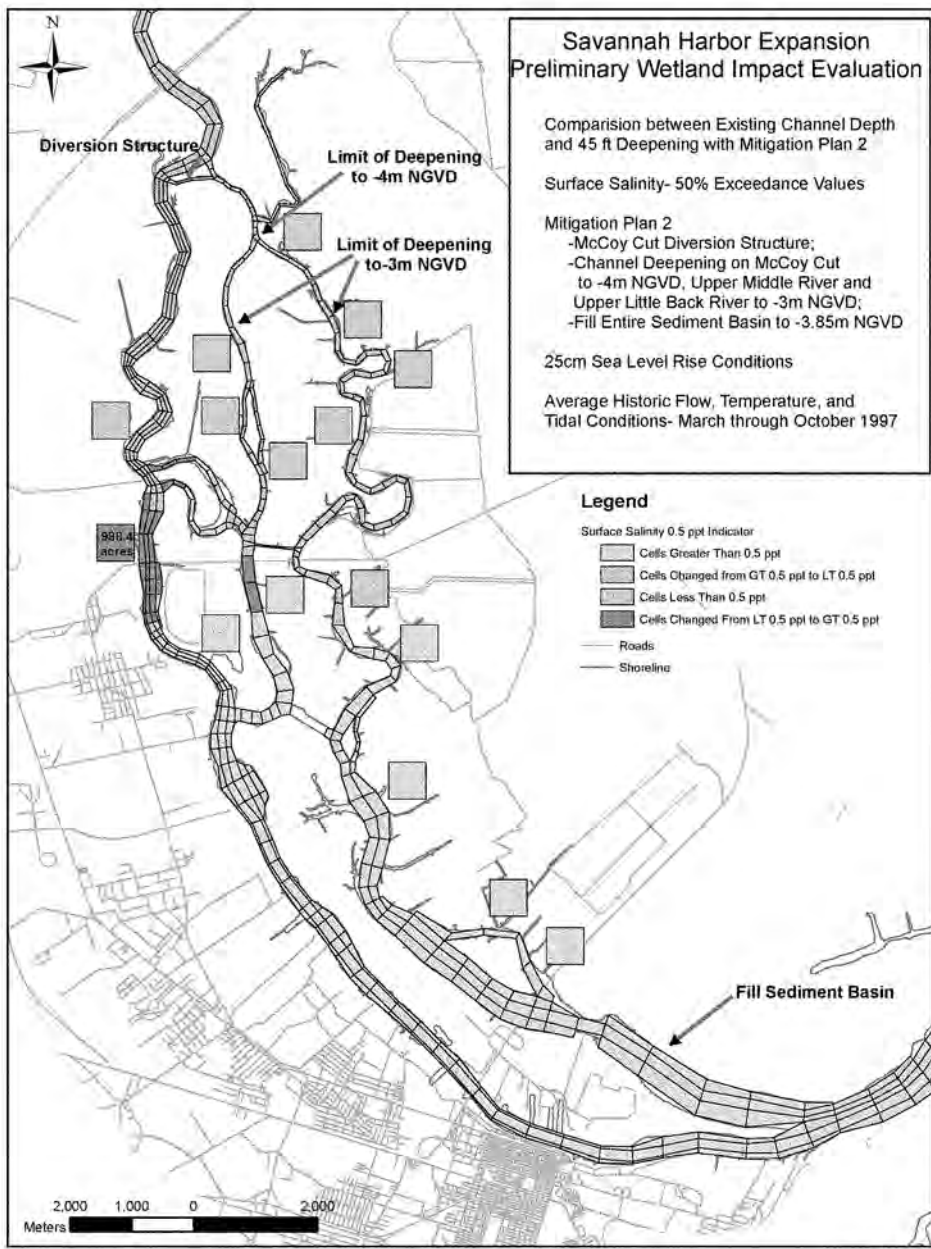


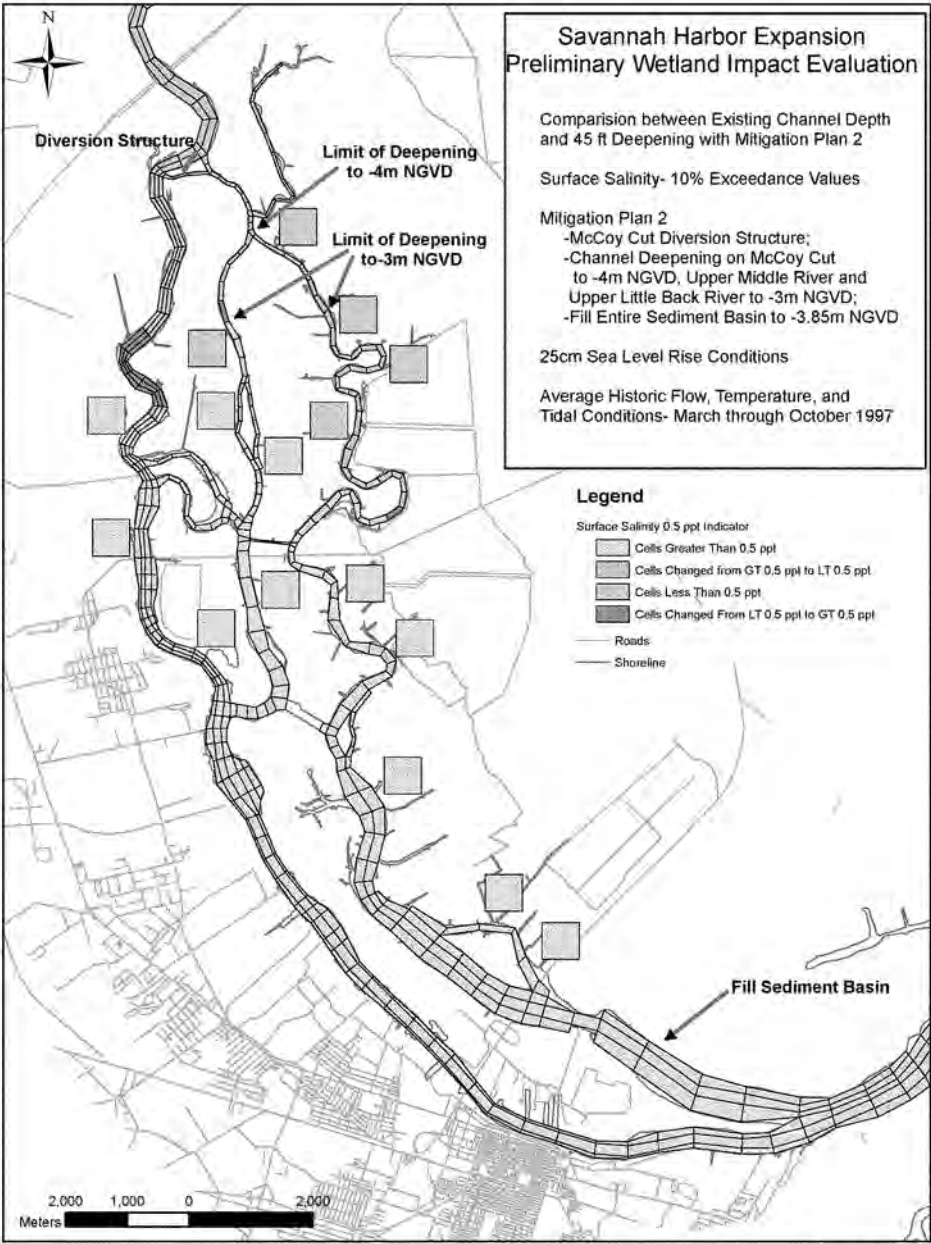


Sensitivity Analysis #2A

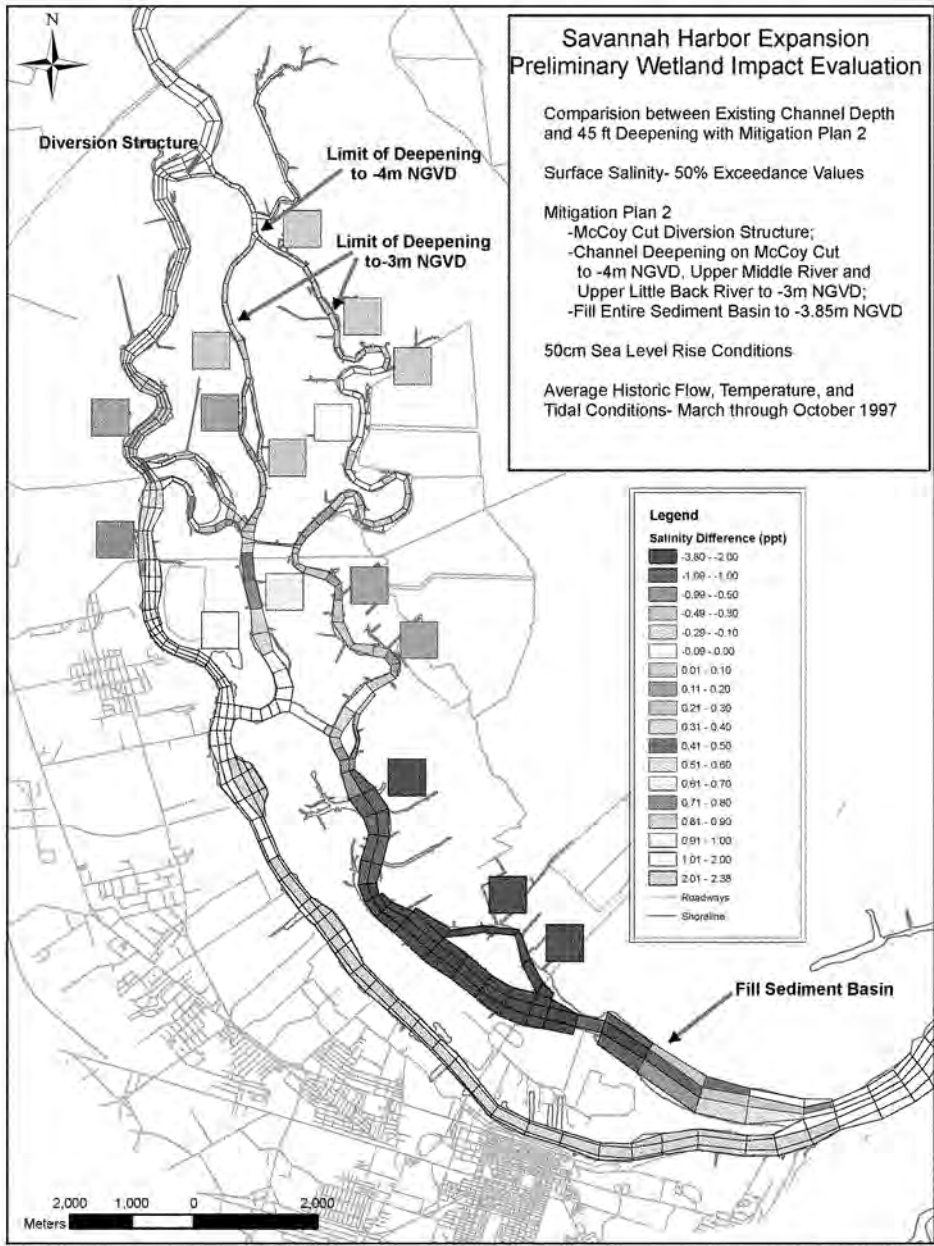


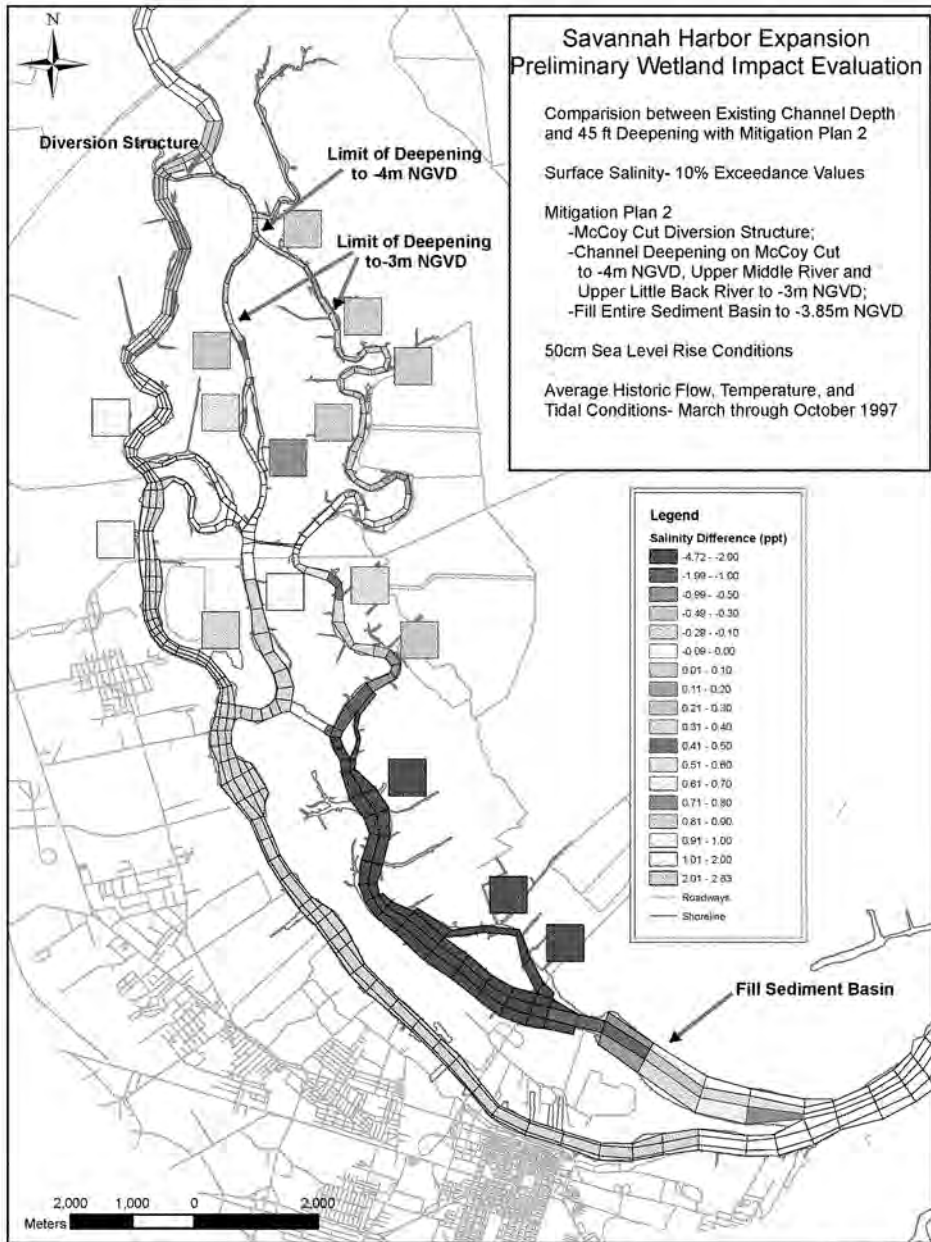


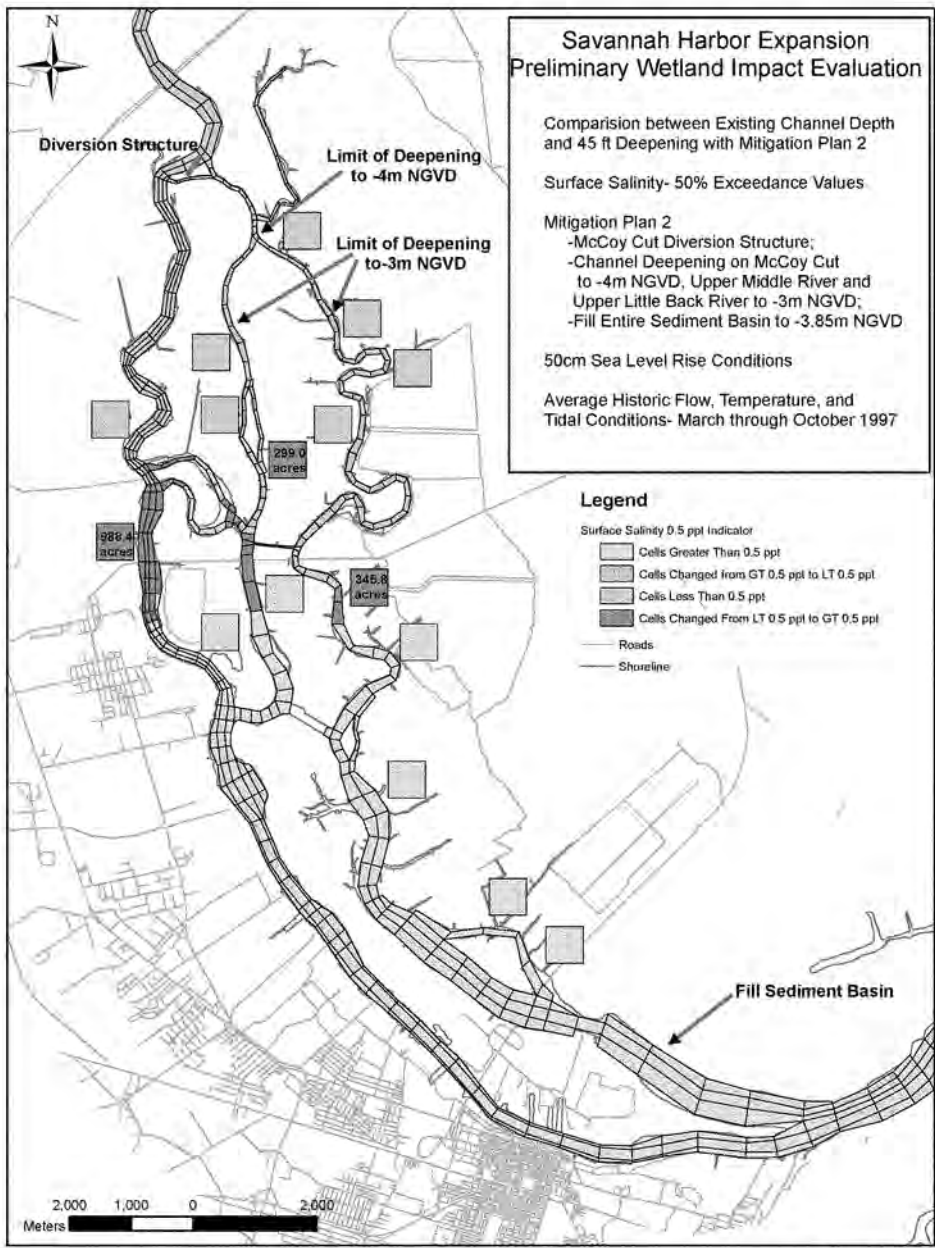


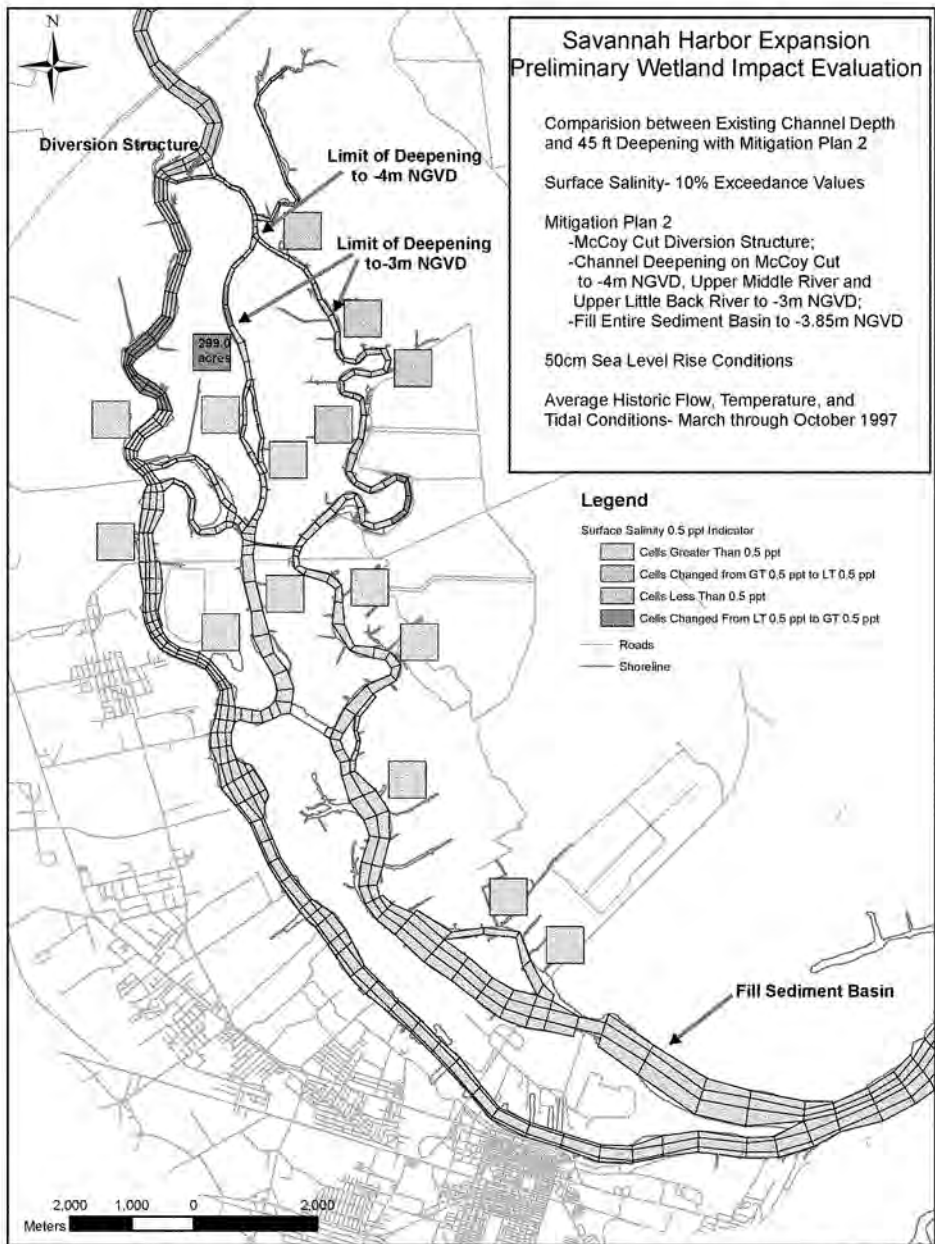


Sensitivity Analysis #2B



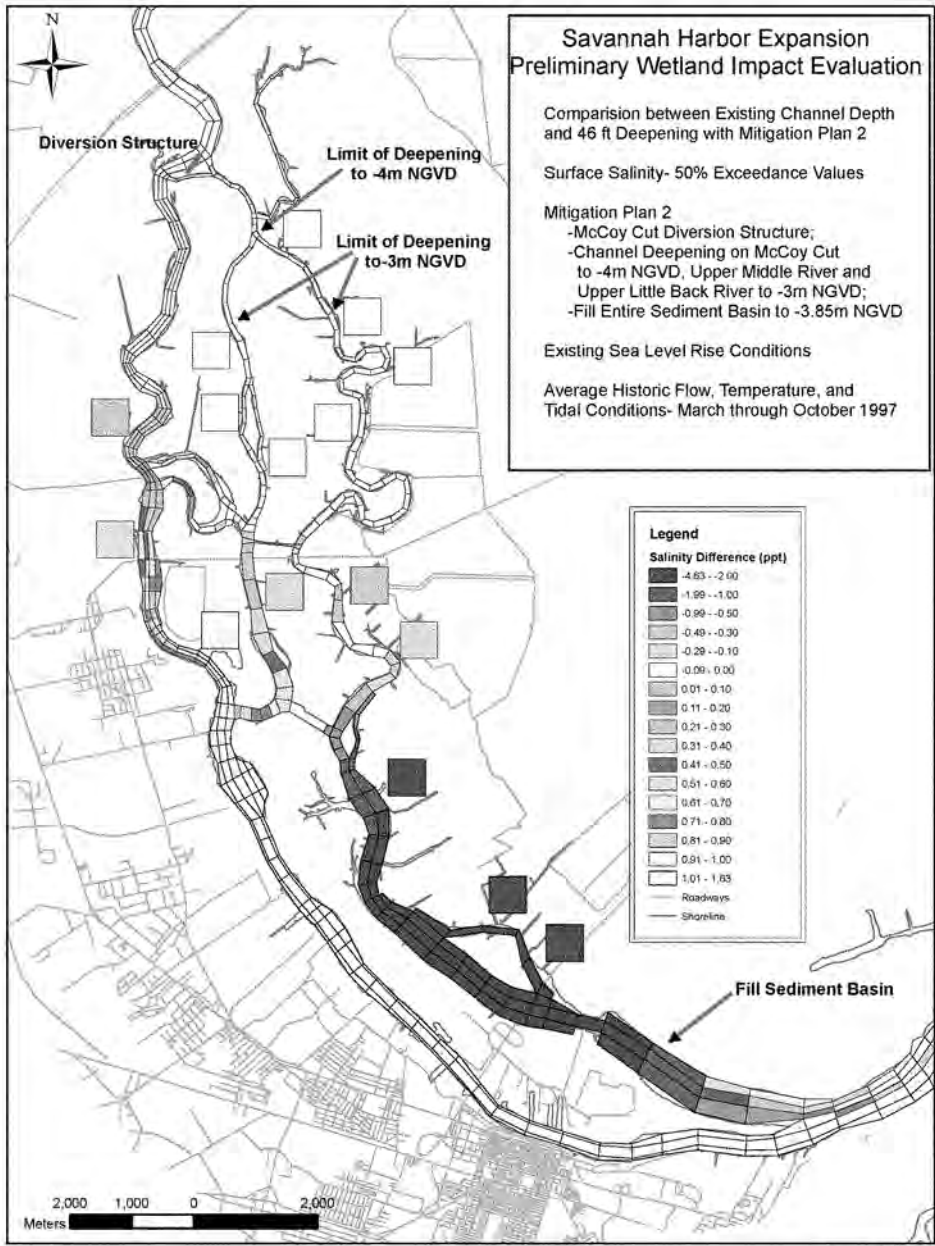


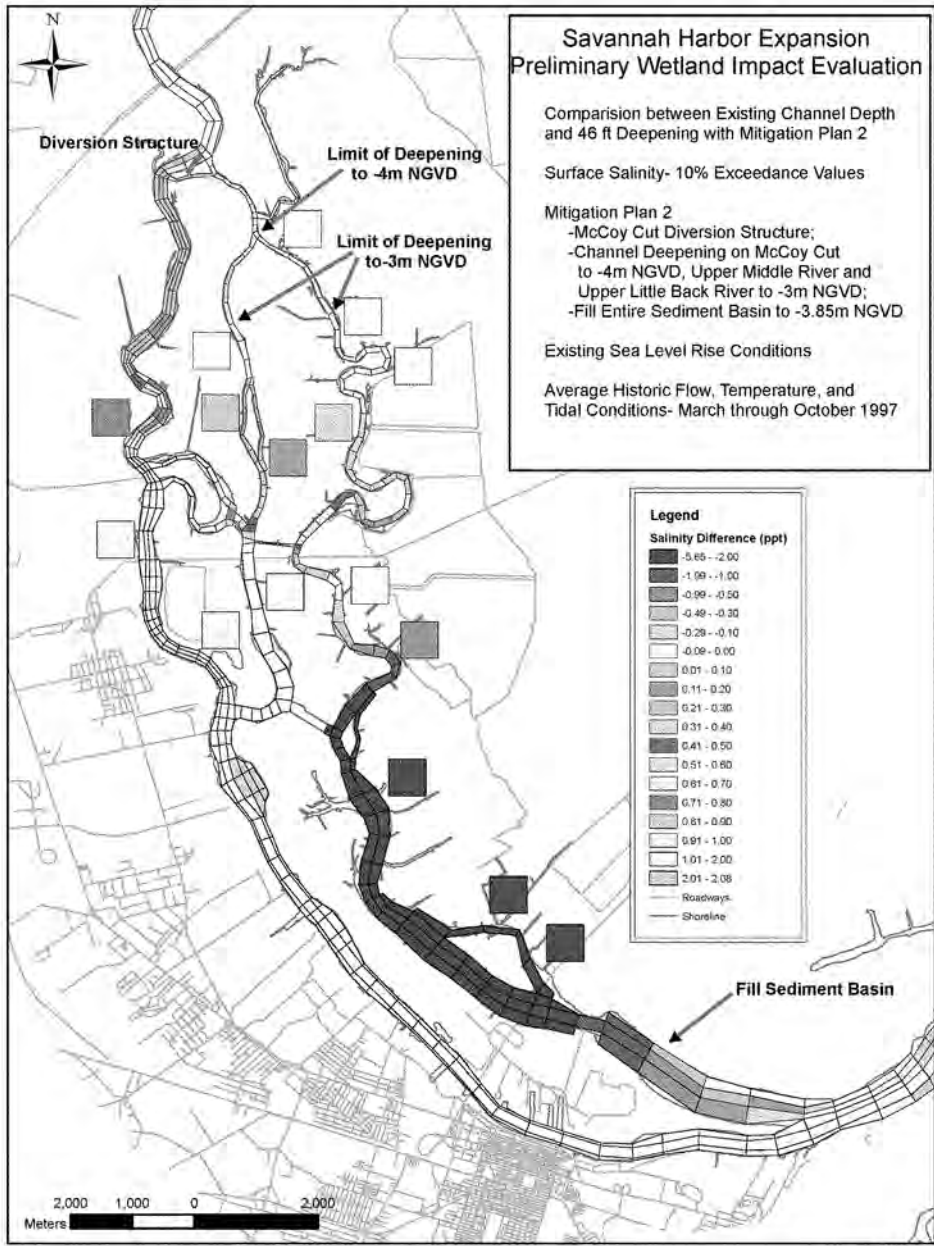


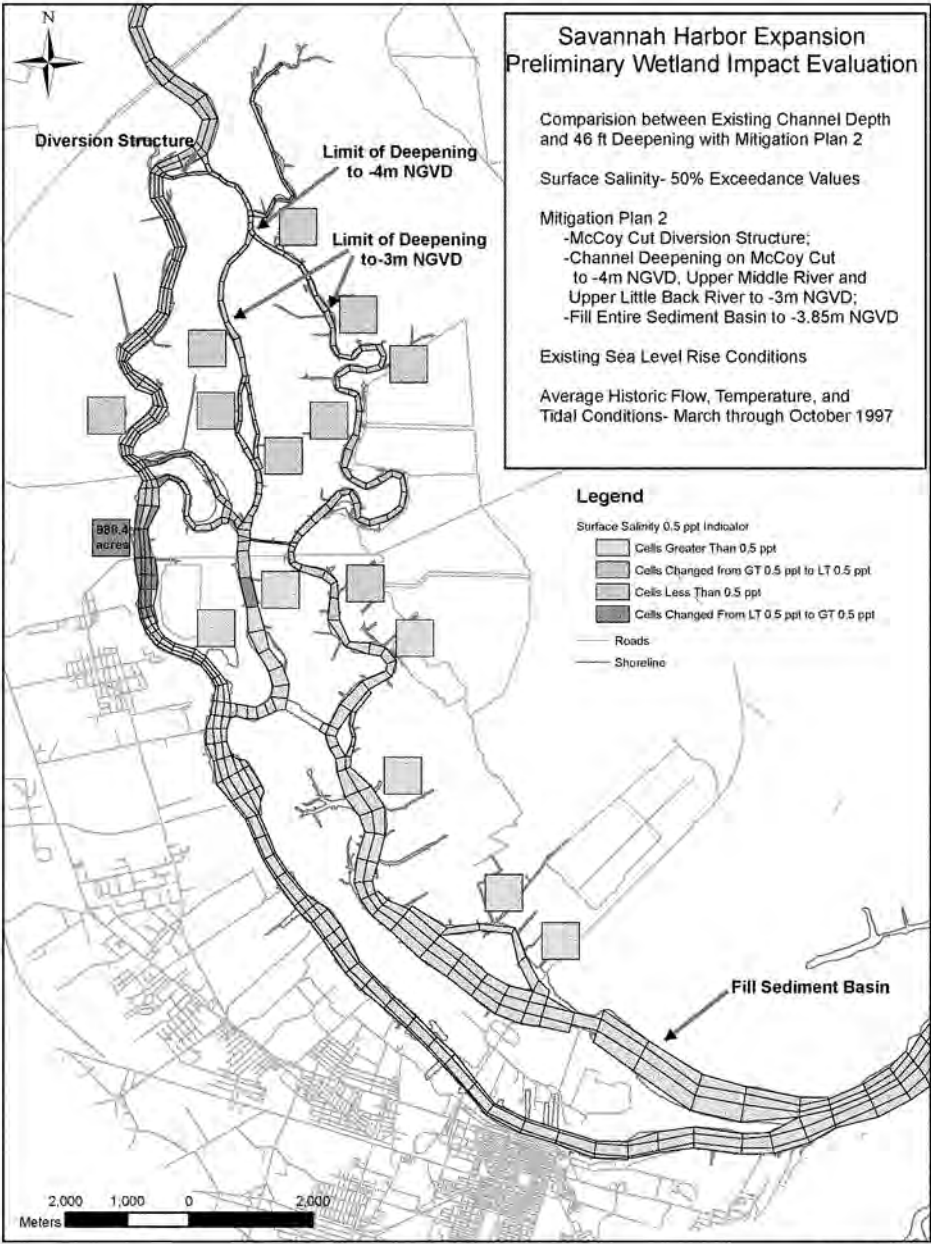


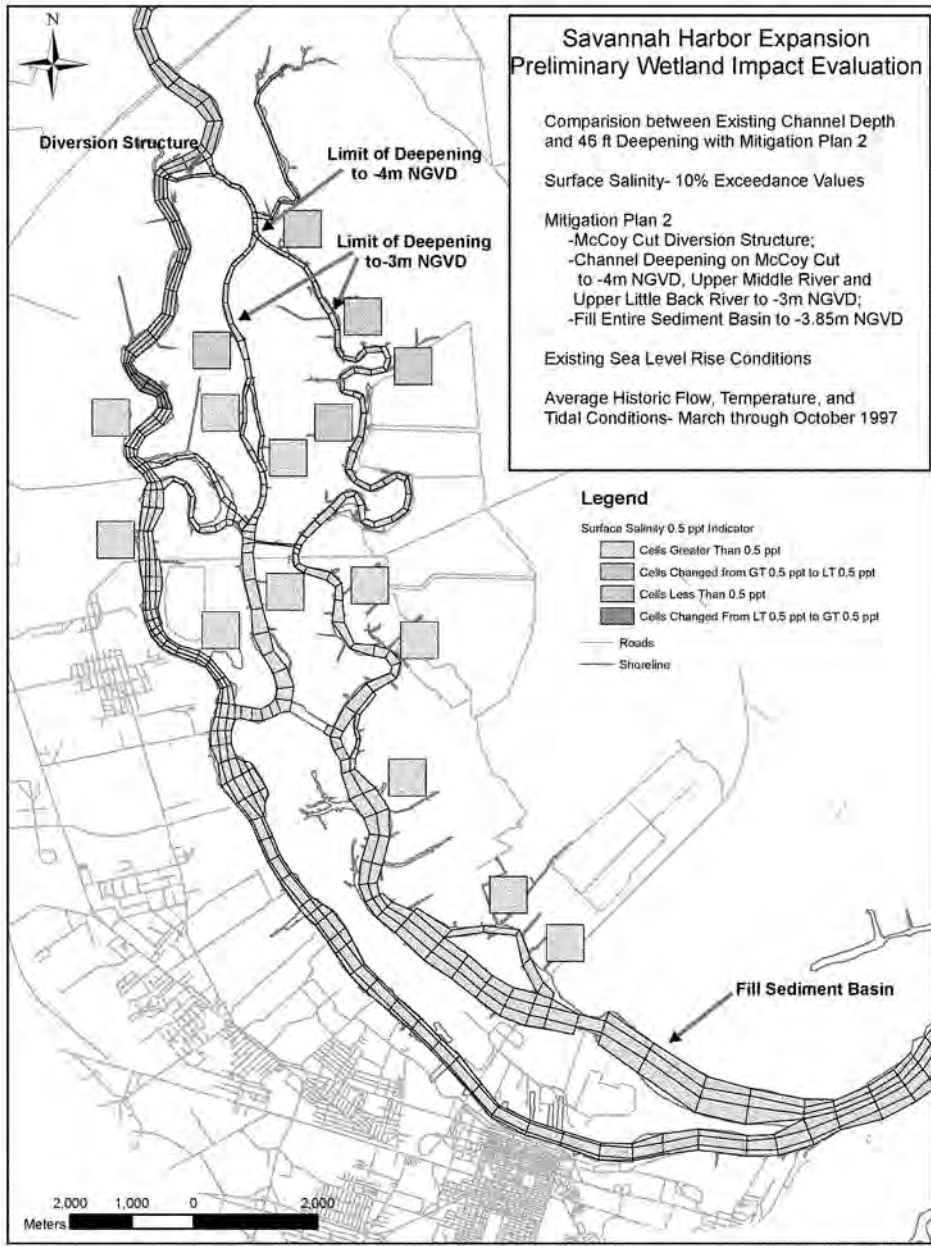
46-ft Deepening

Basic Evaluation

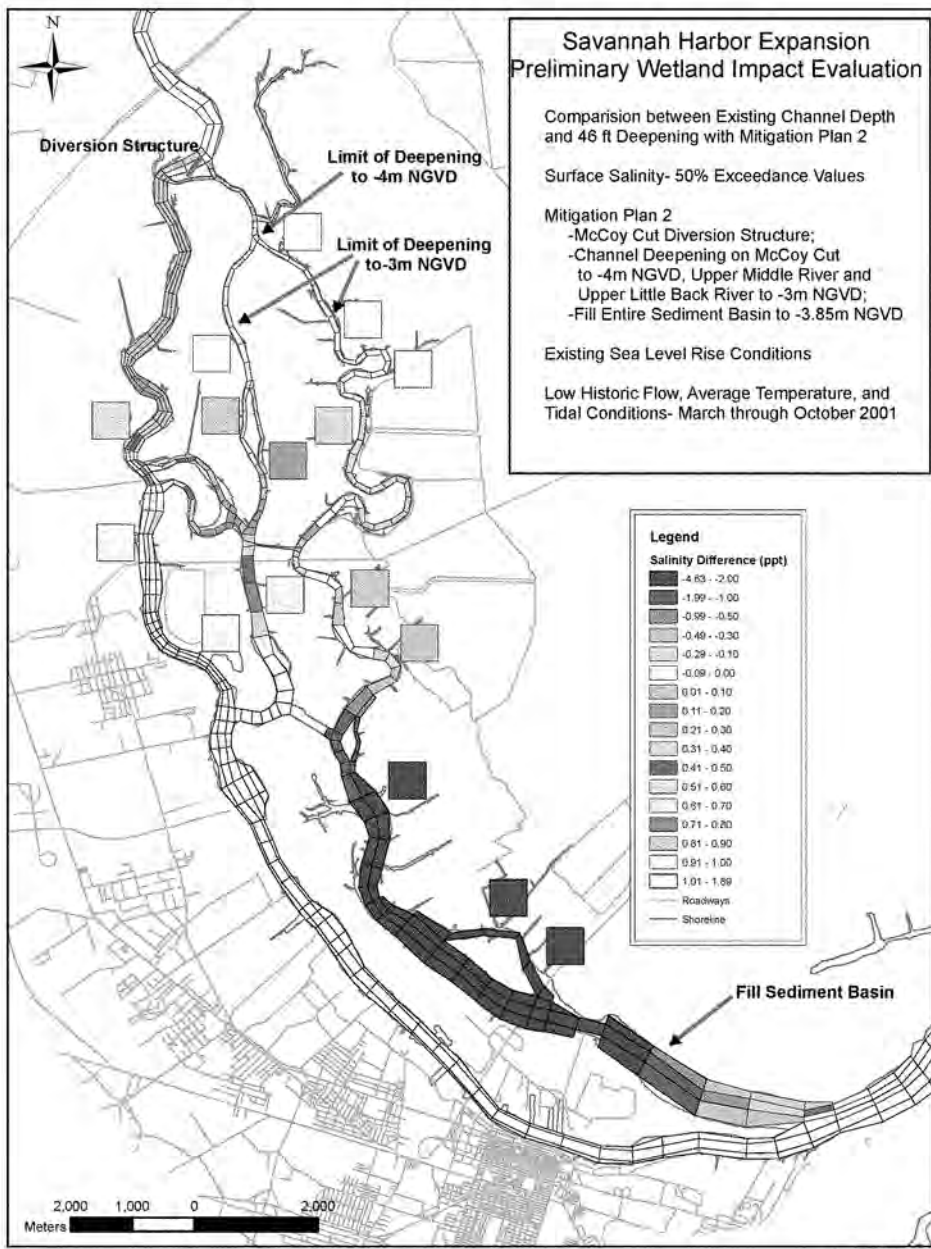


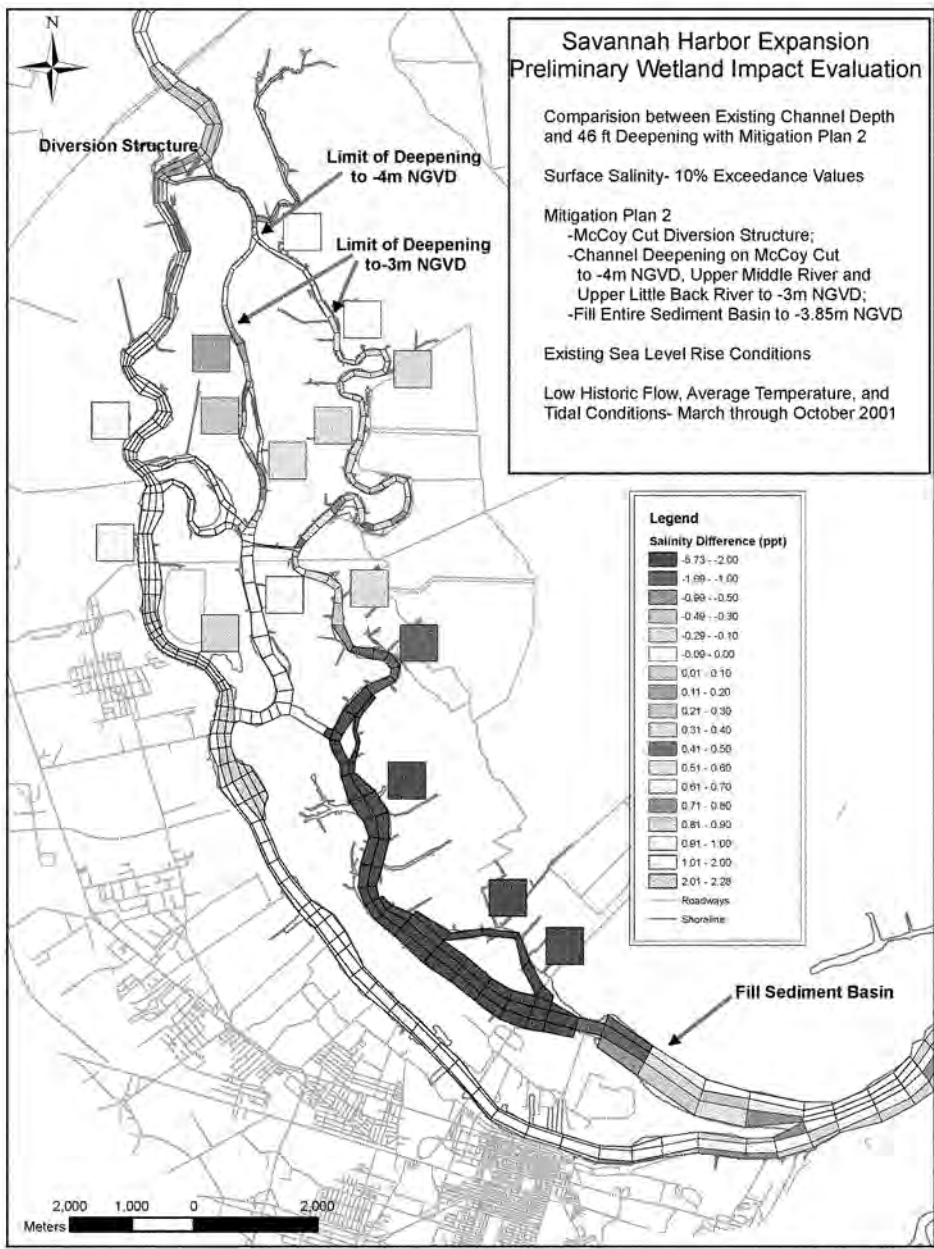


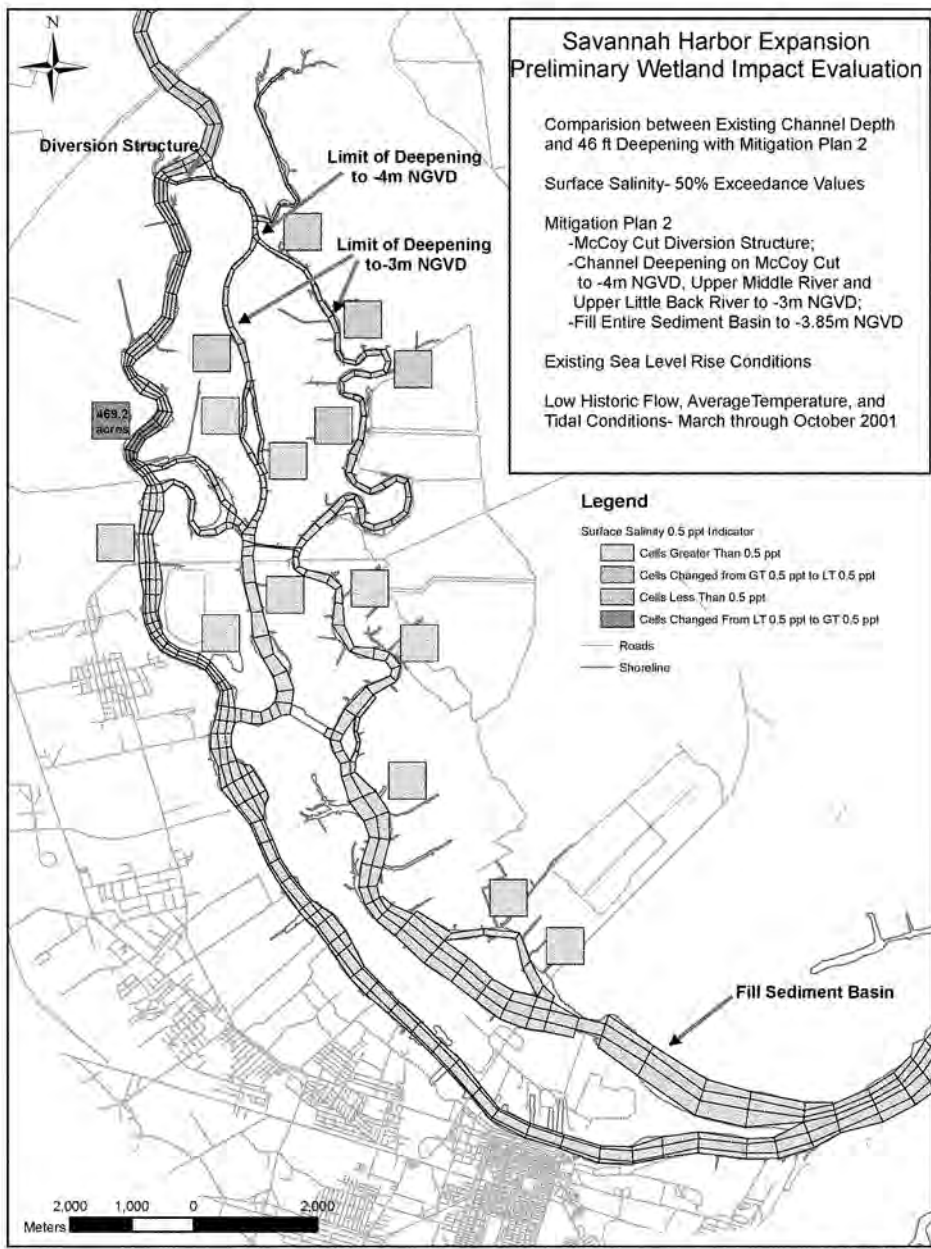


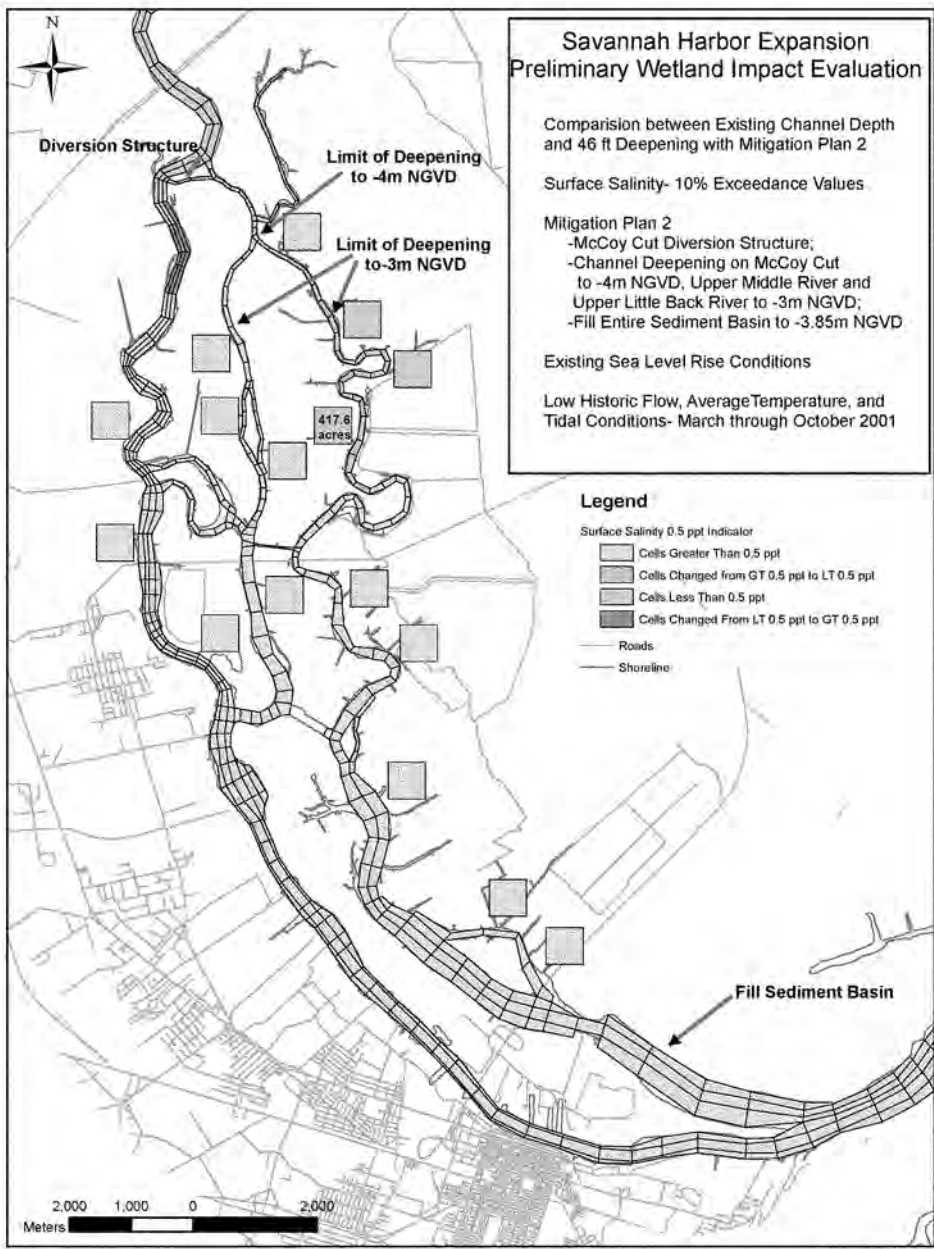


Sensitivity Analysis #1

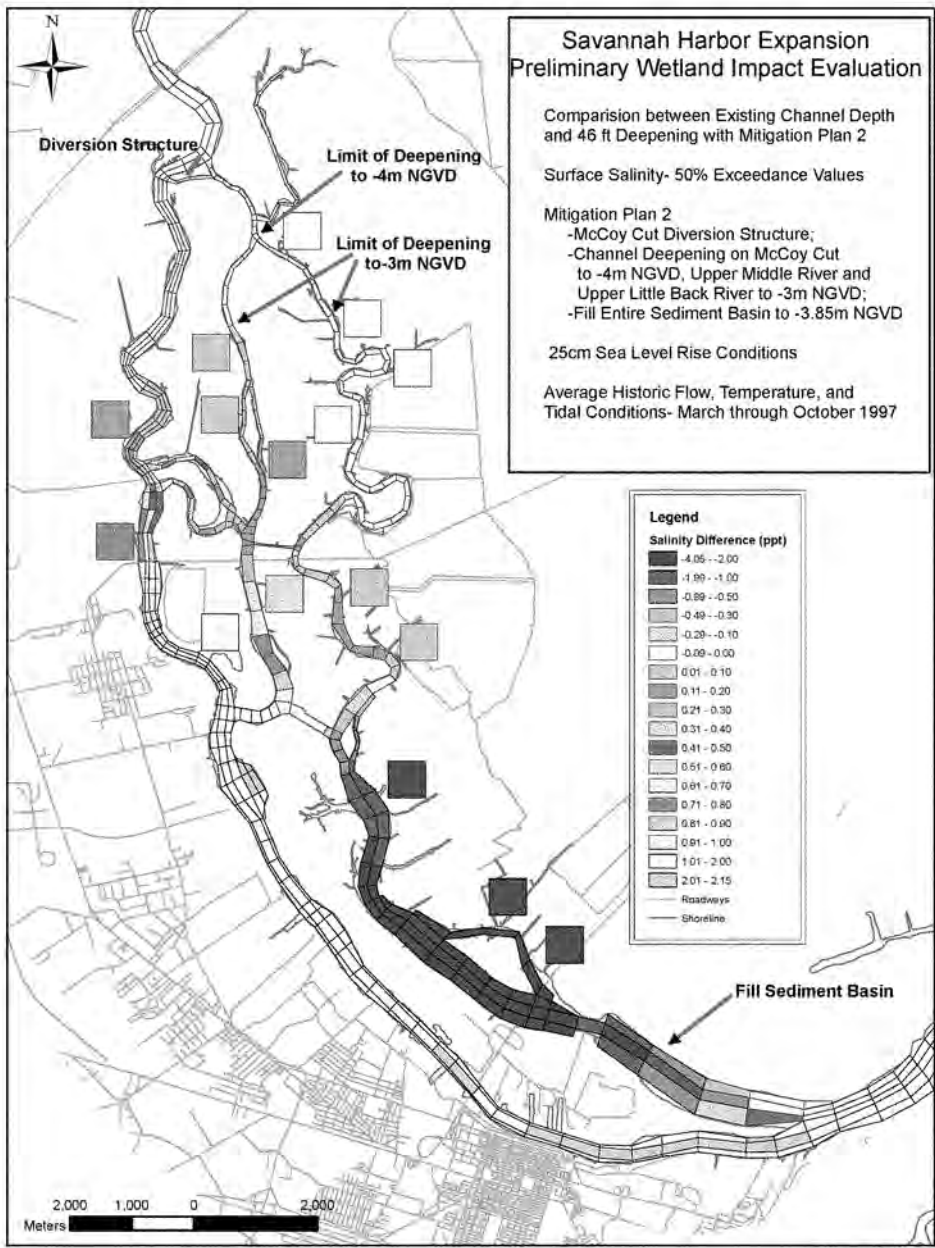


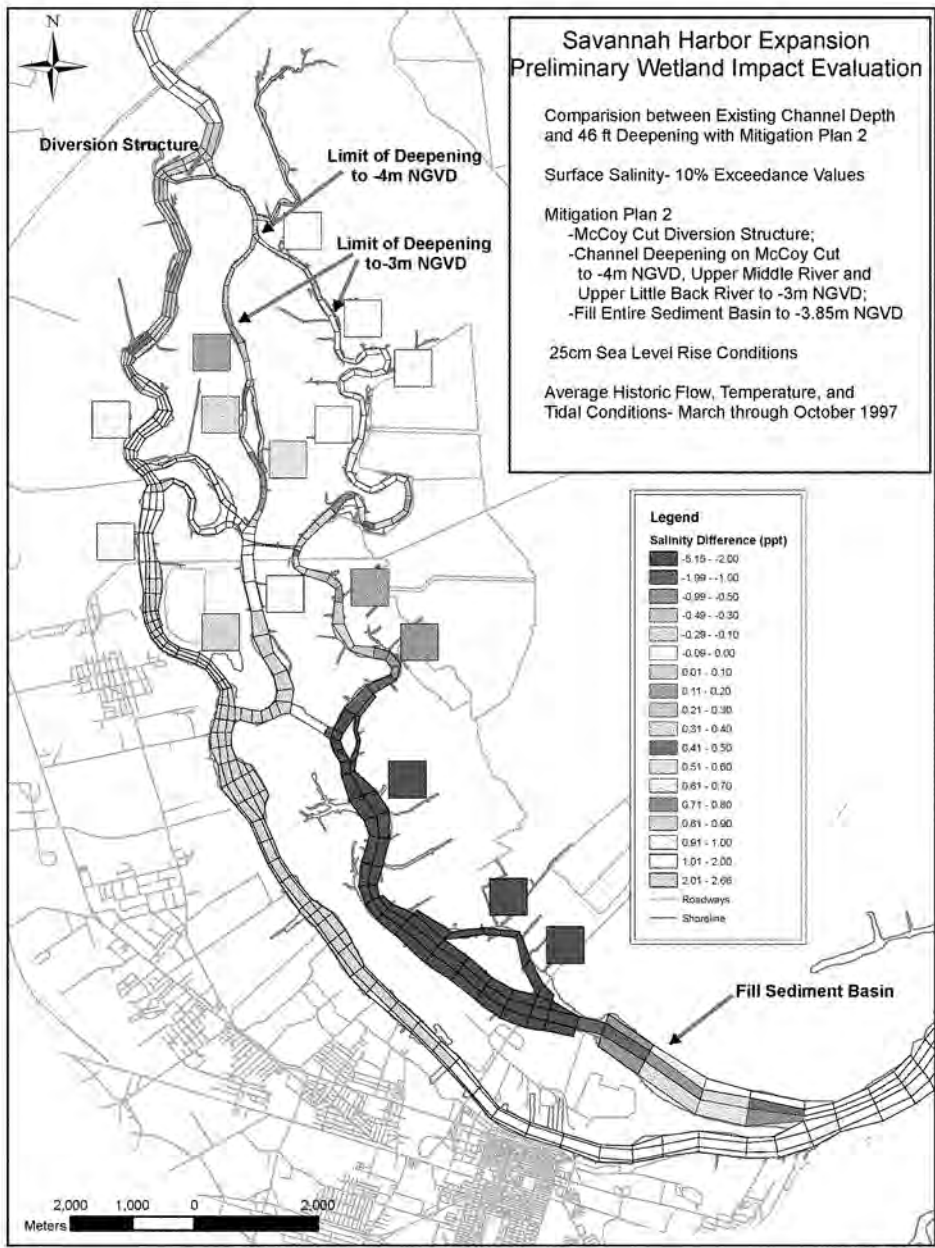


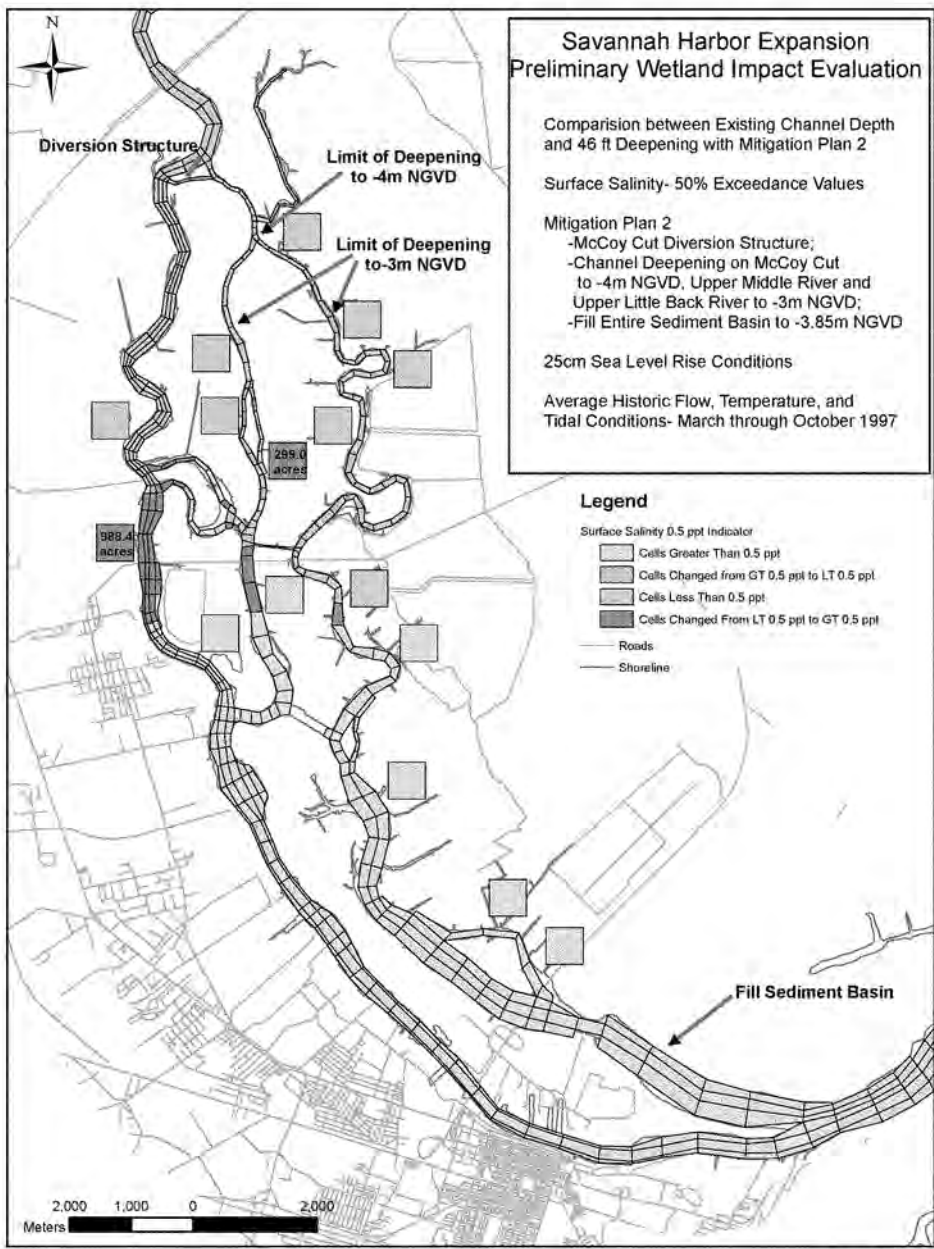


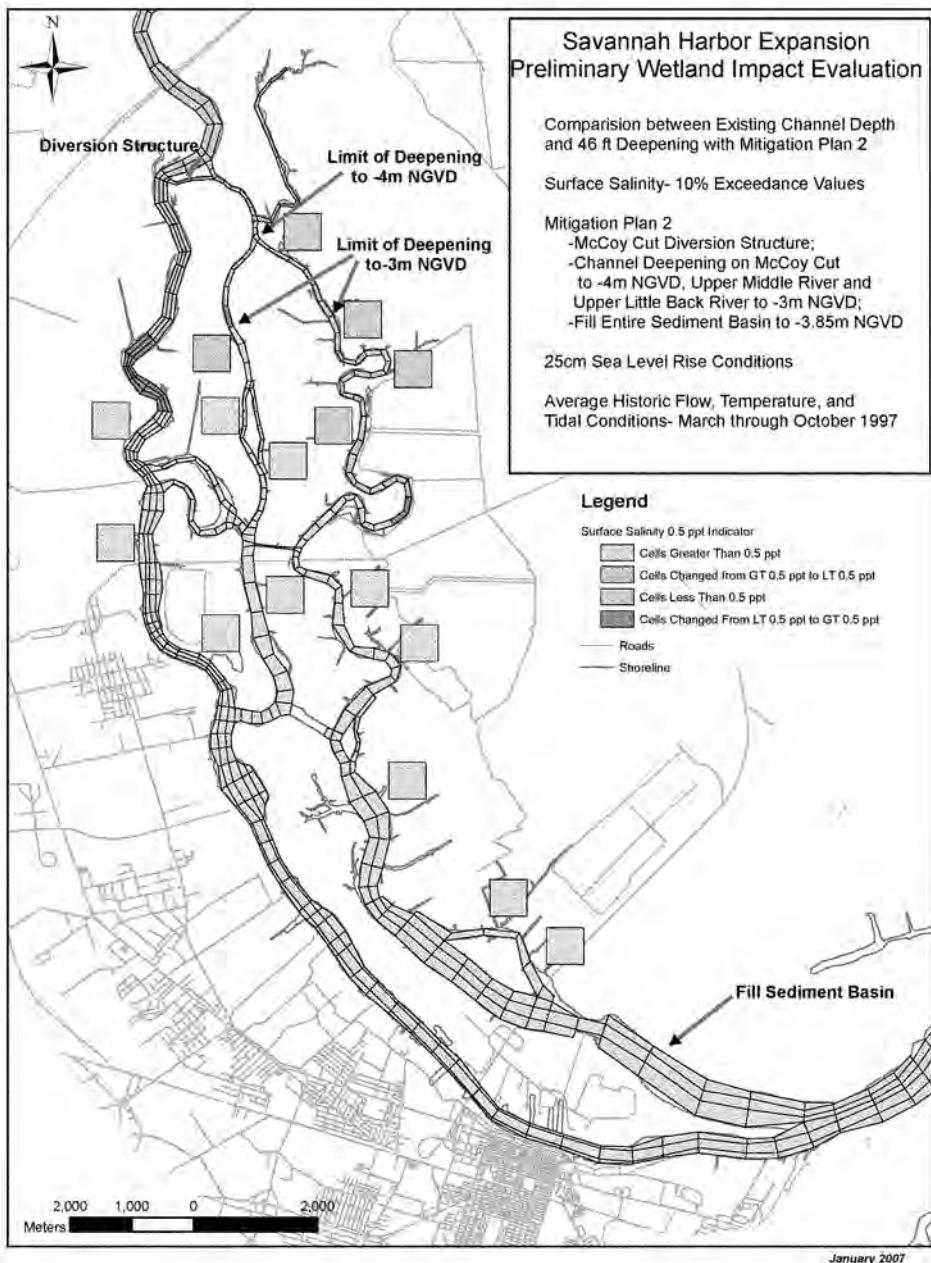


Sensitivity Analysis #2A

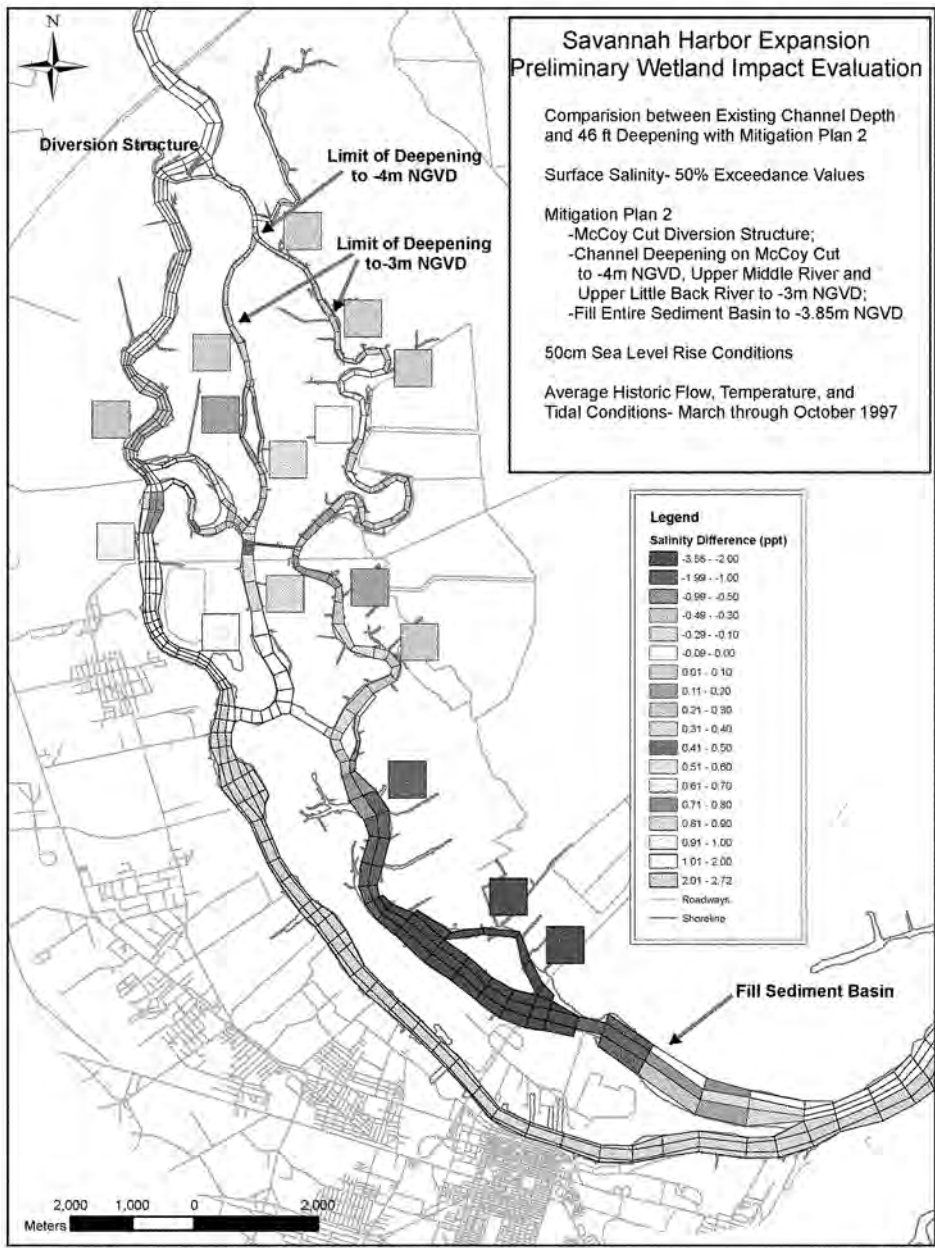


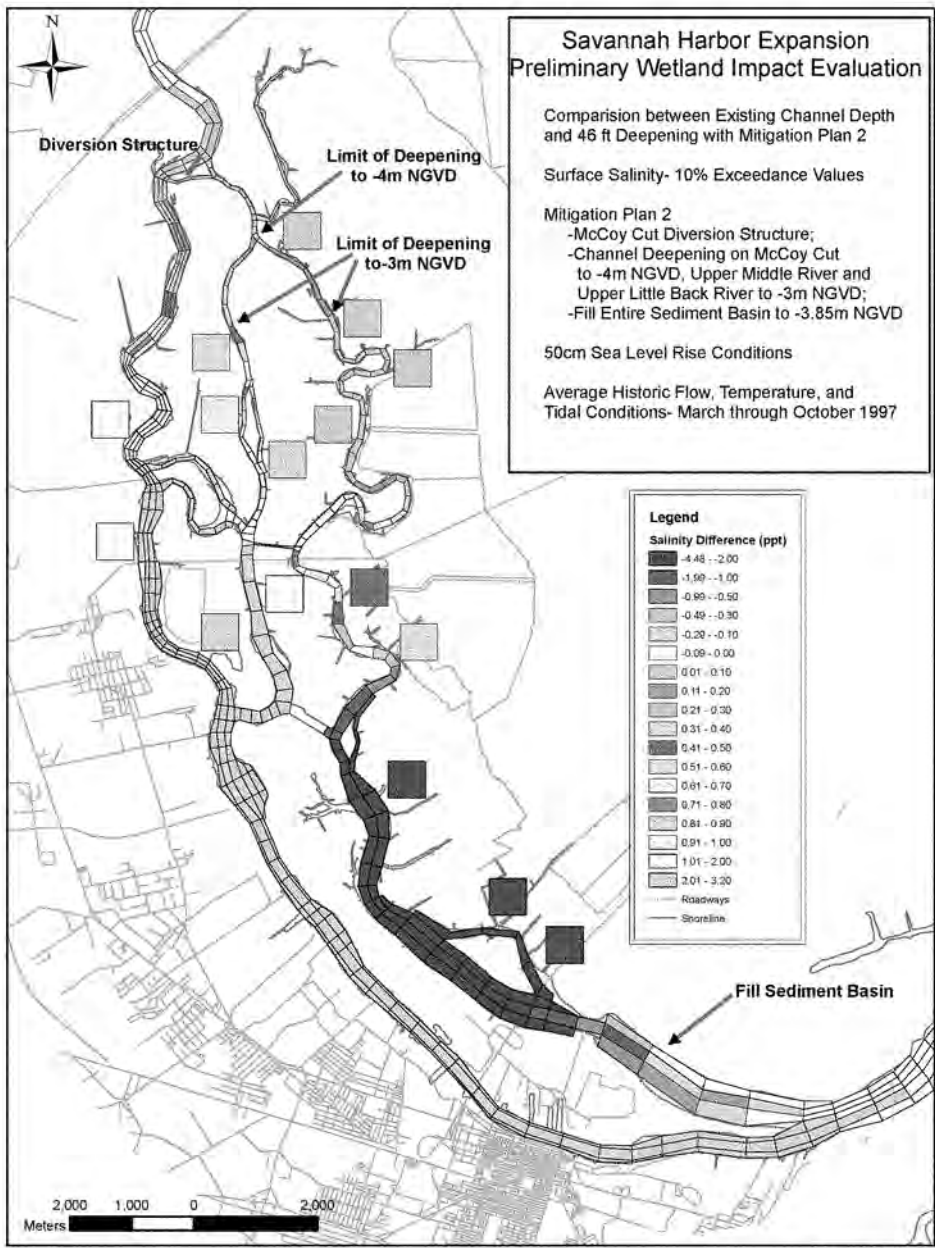


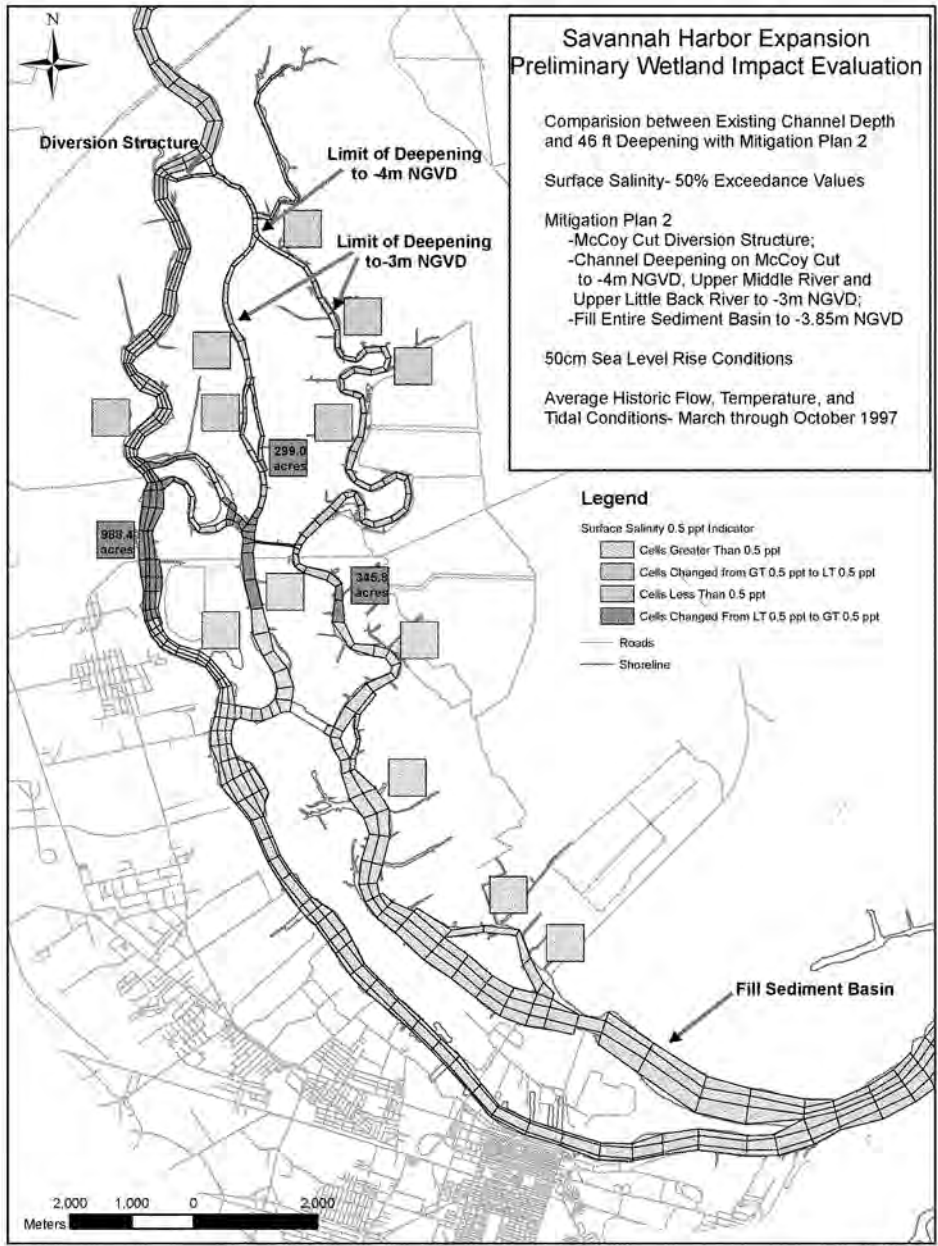


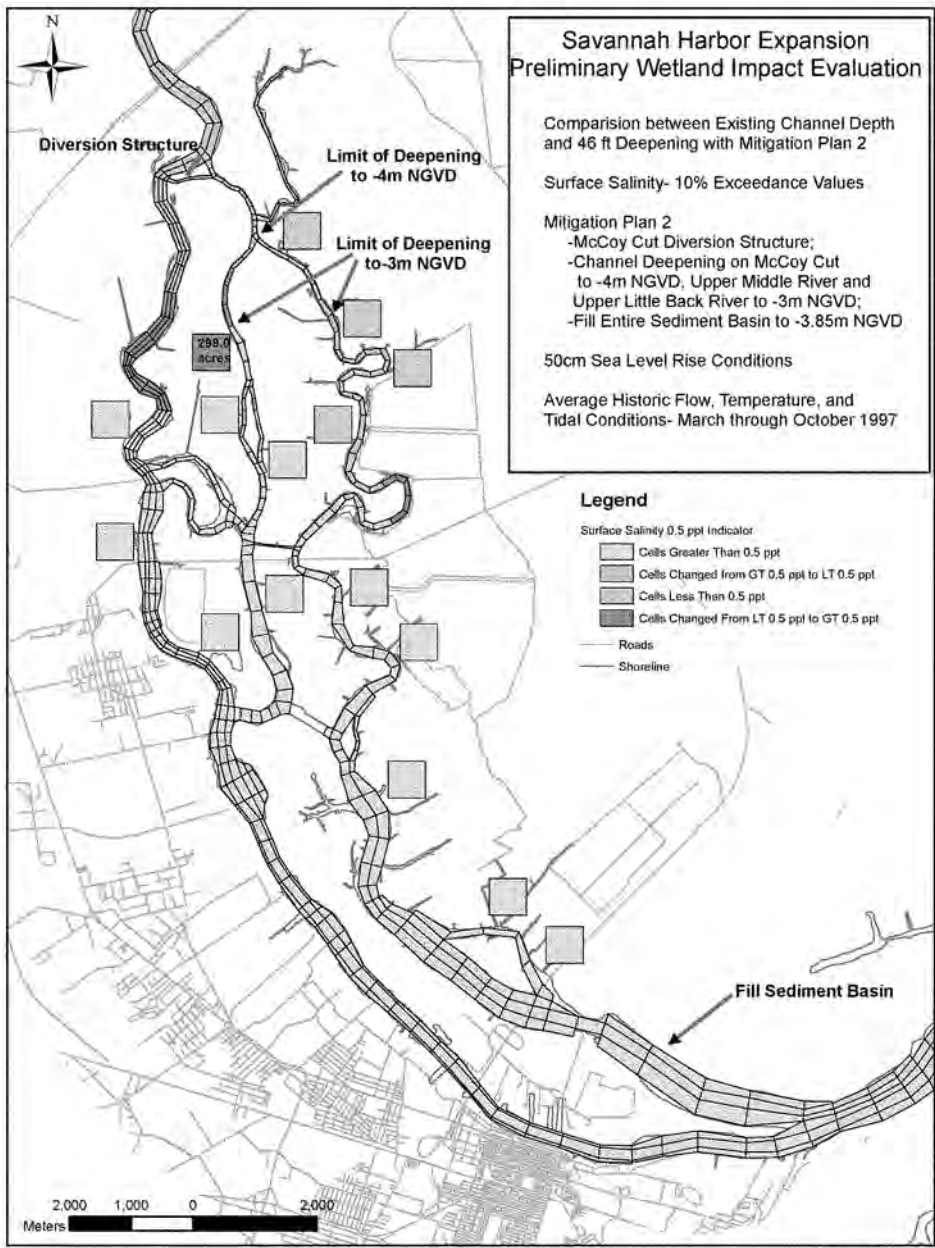


Sensitivity Analysis #2B



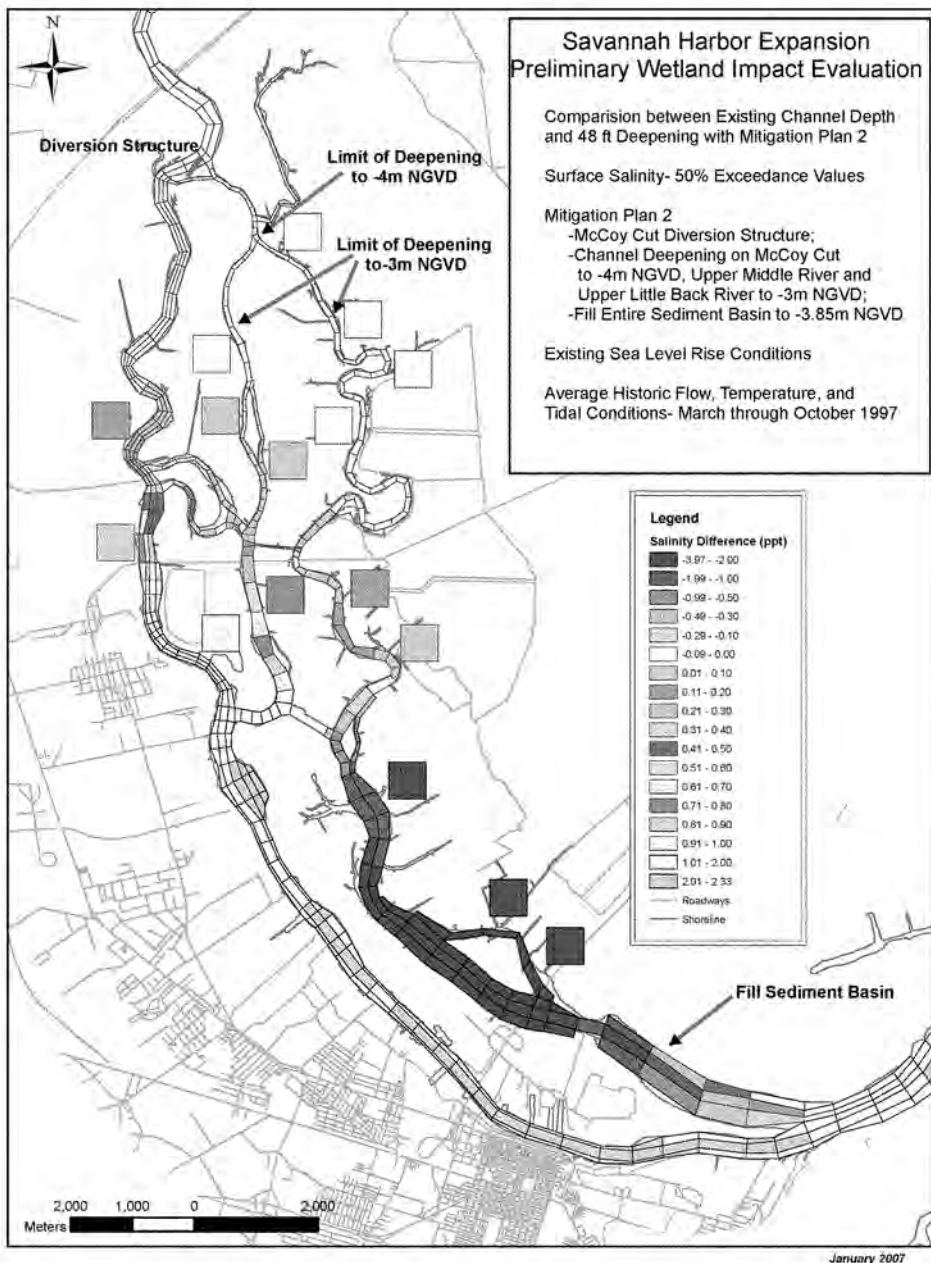


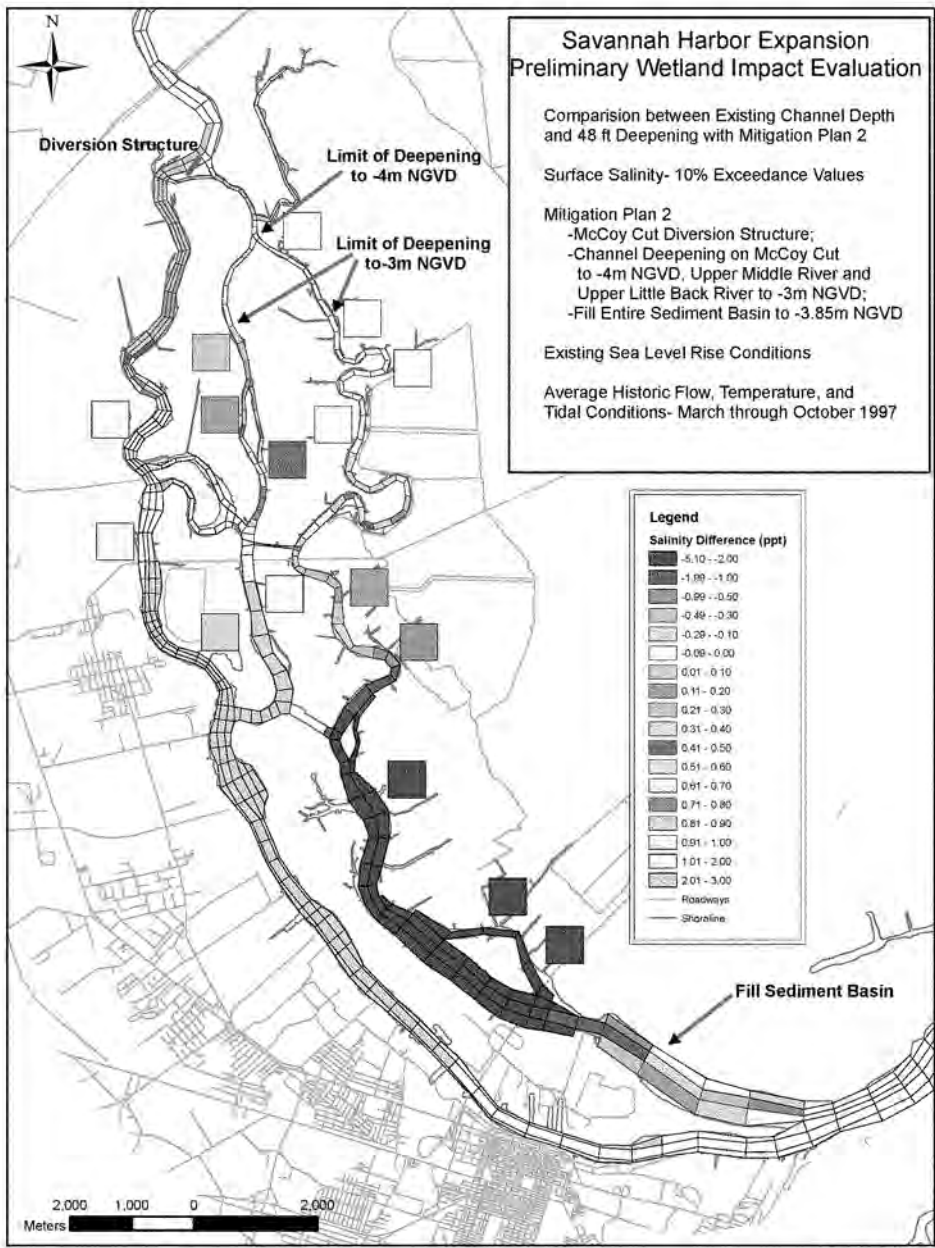


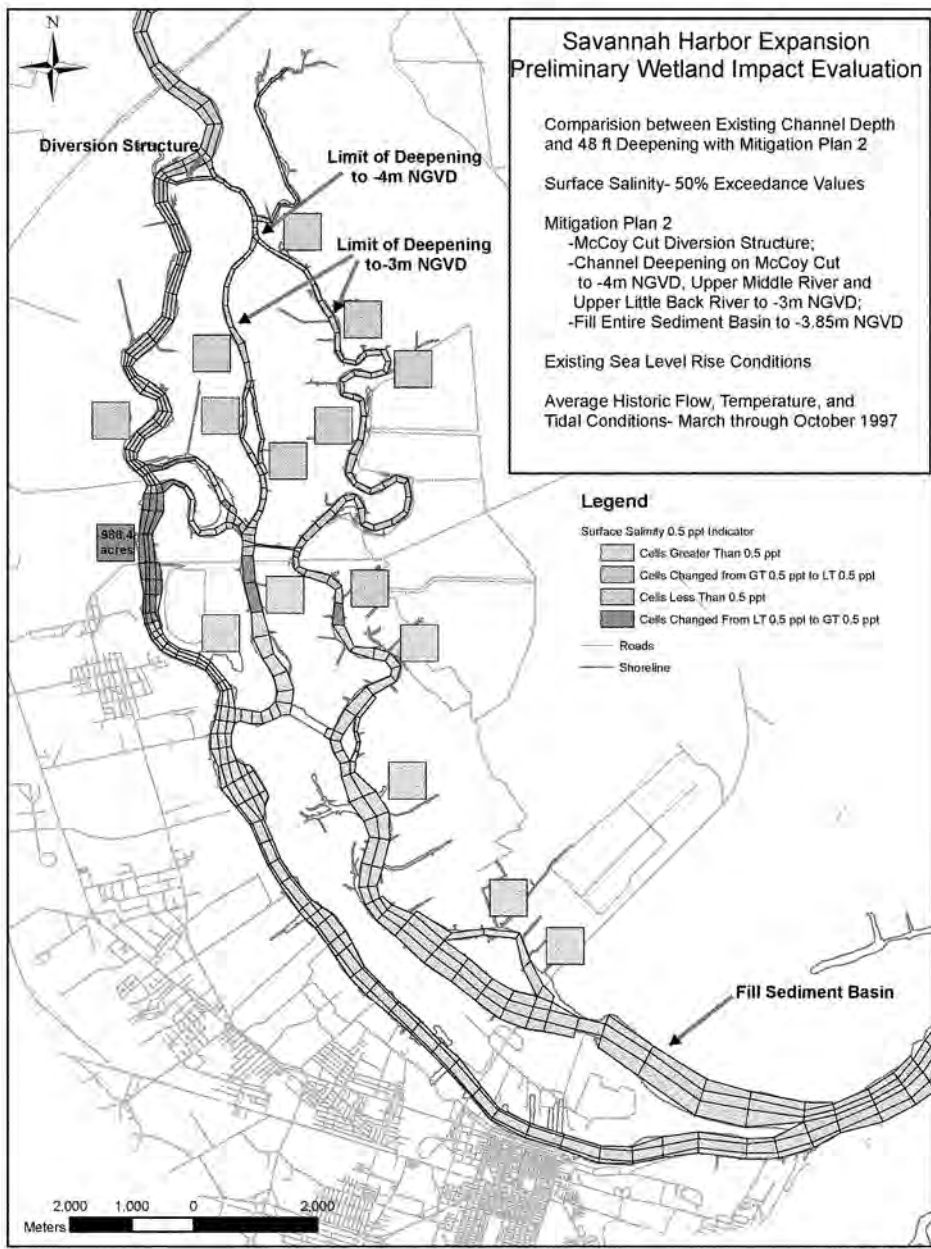


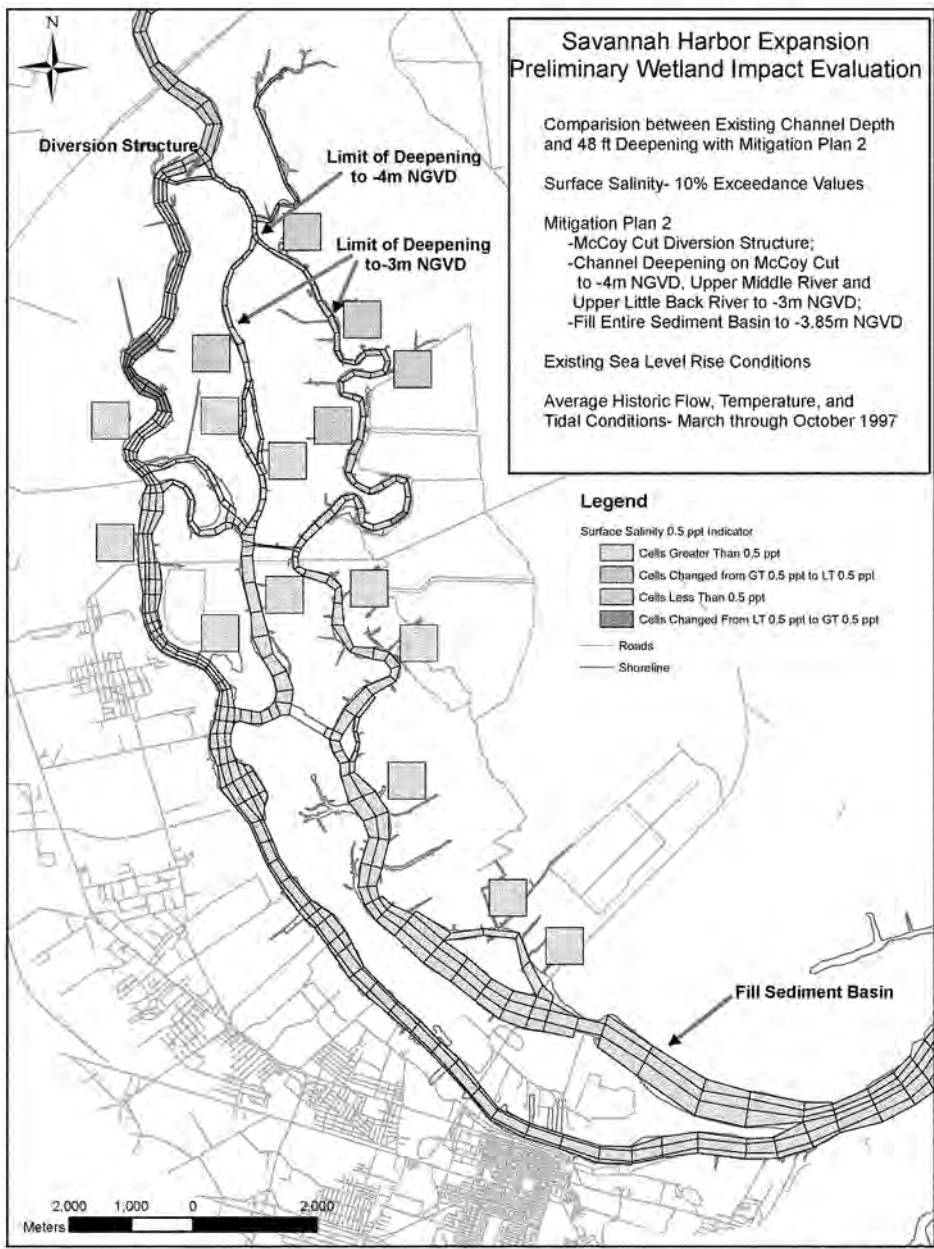
48-ft Deepening

Basic Evaluation

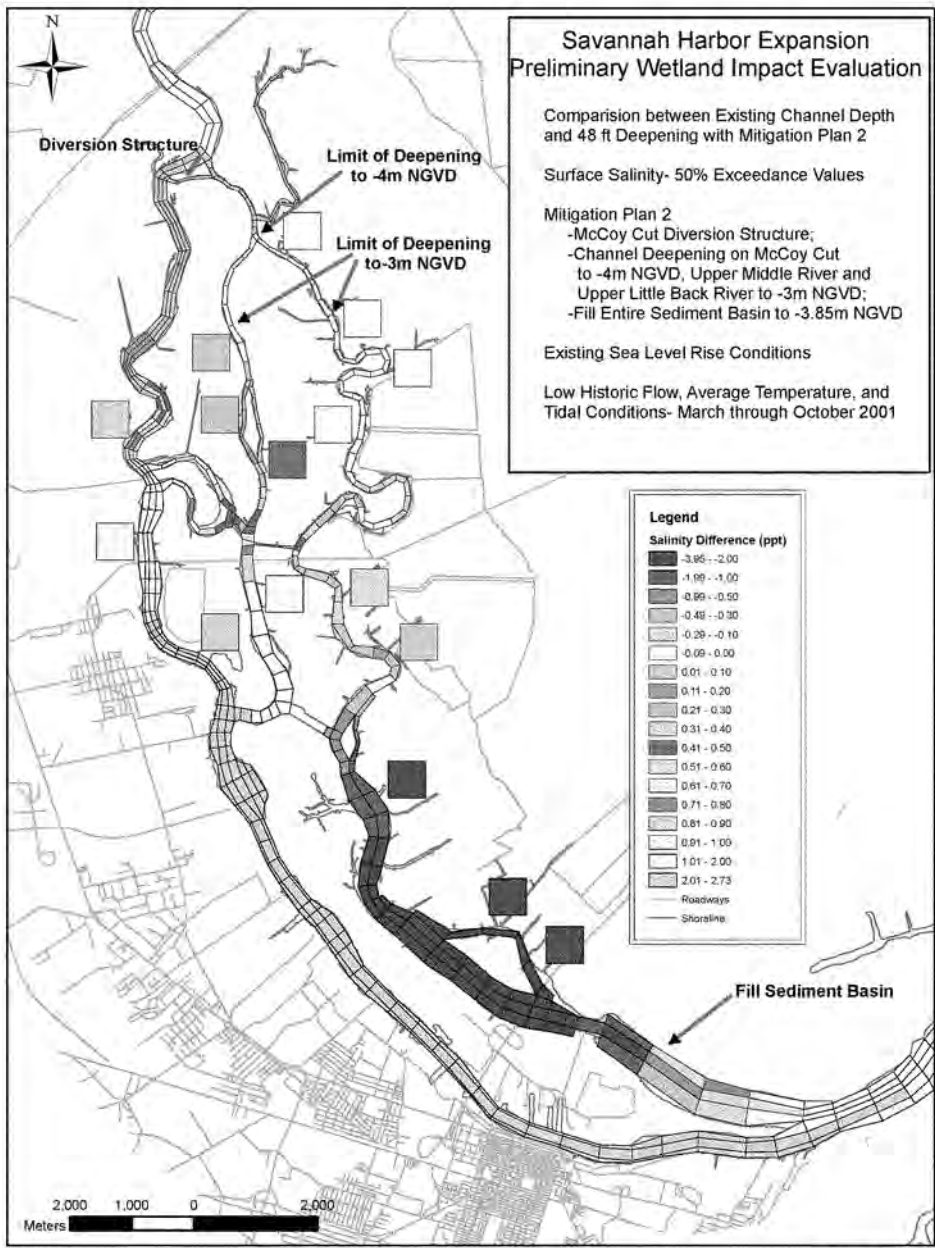


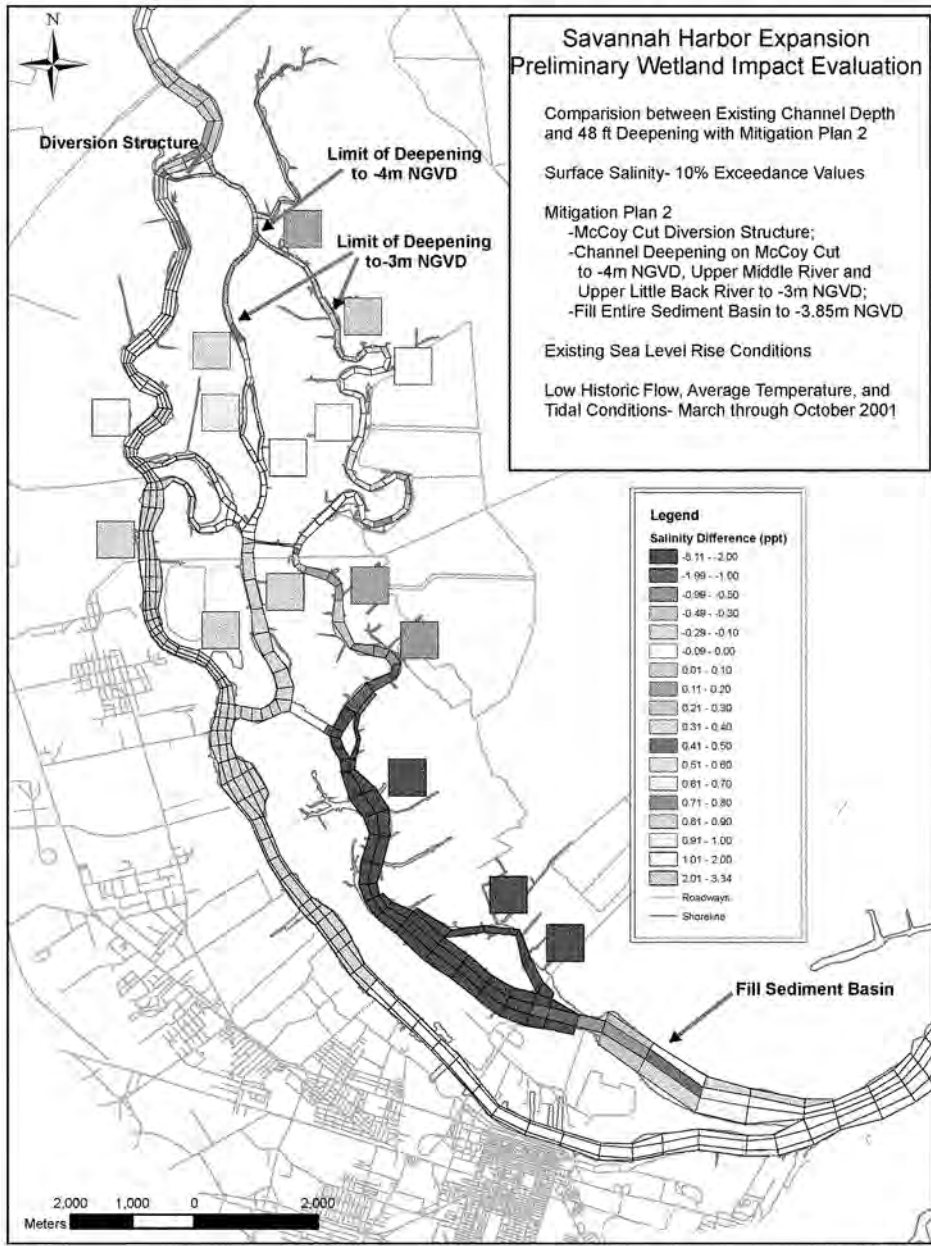


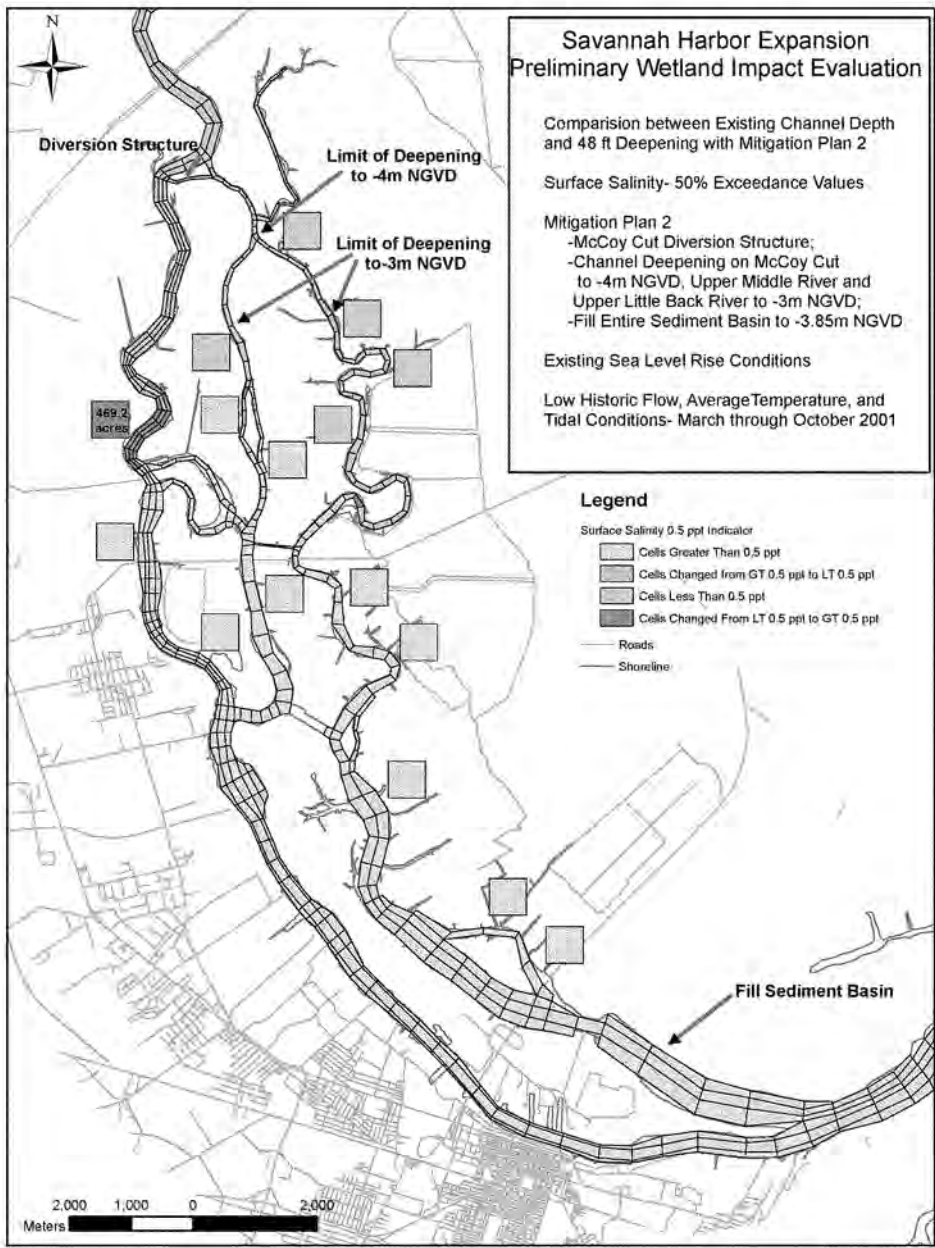


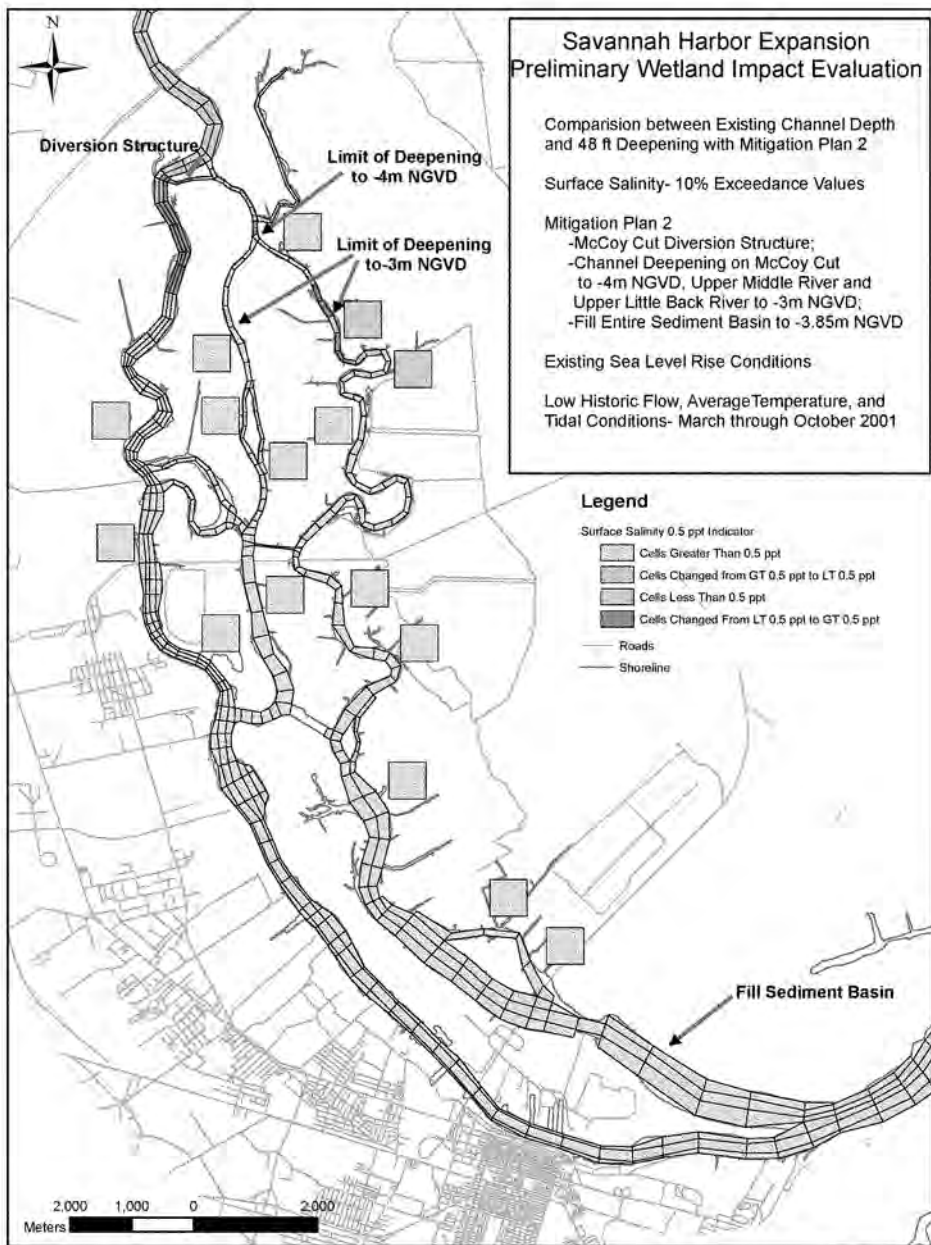


Sensitivity Analysis #1

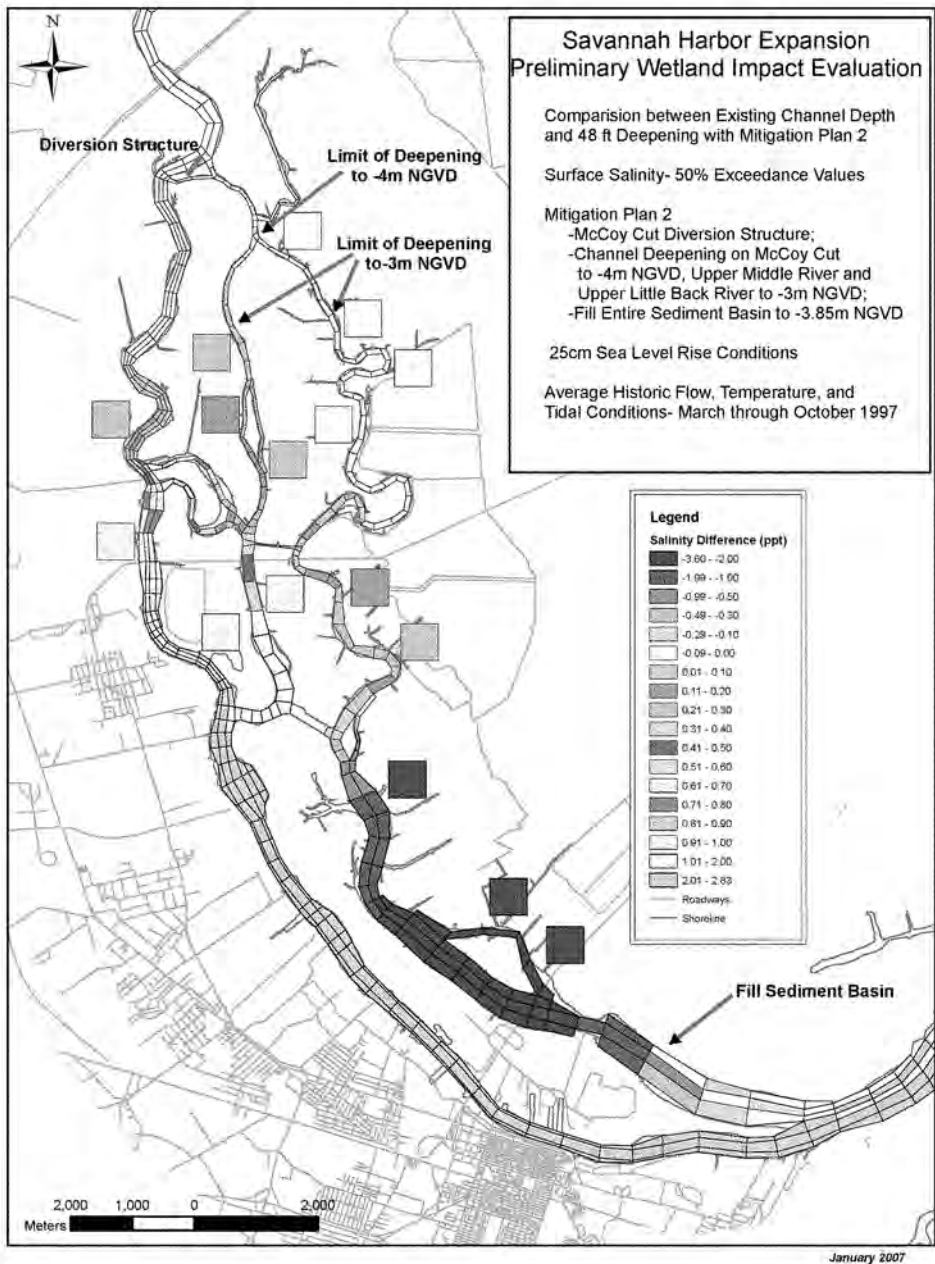


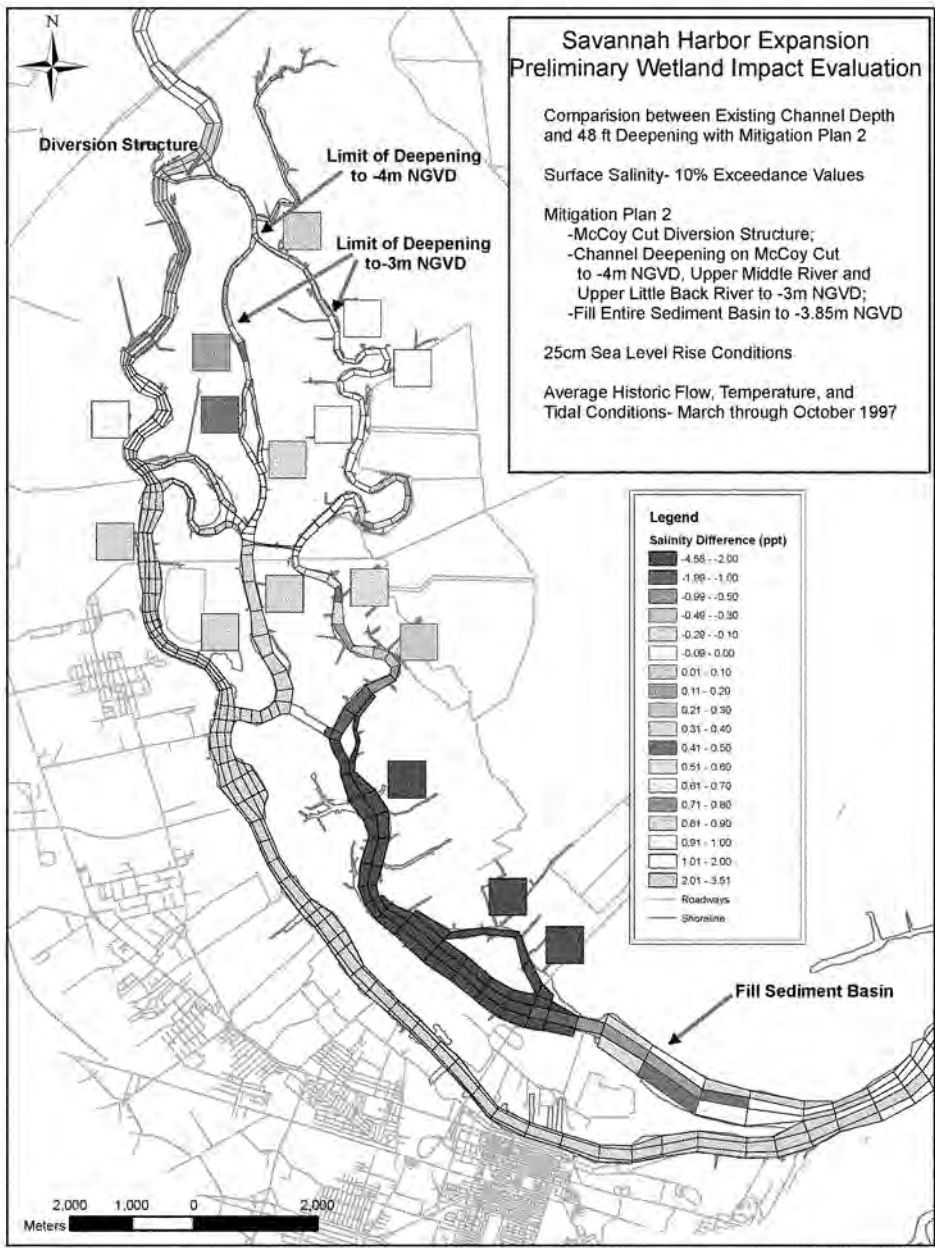


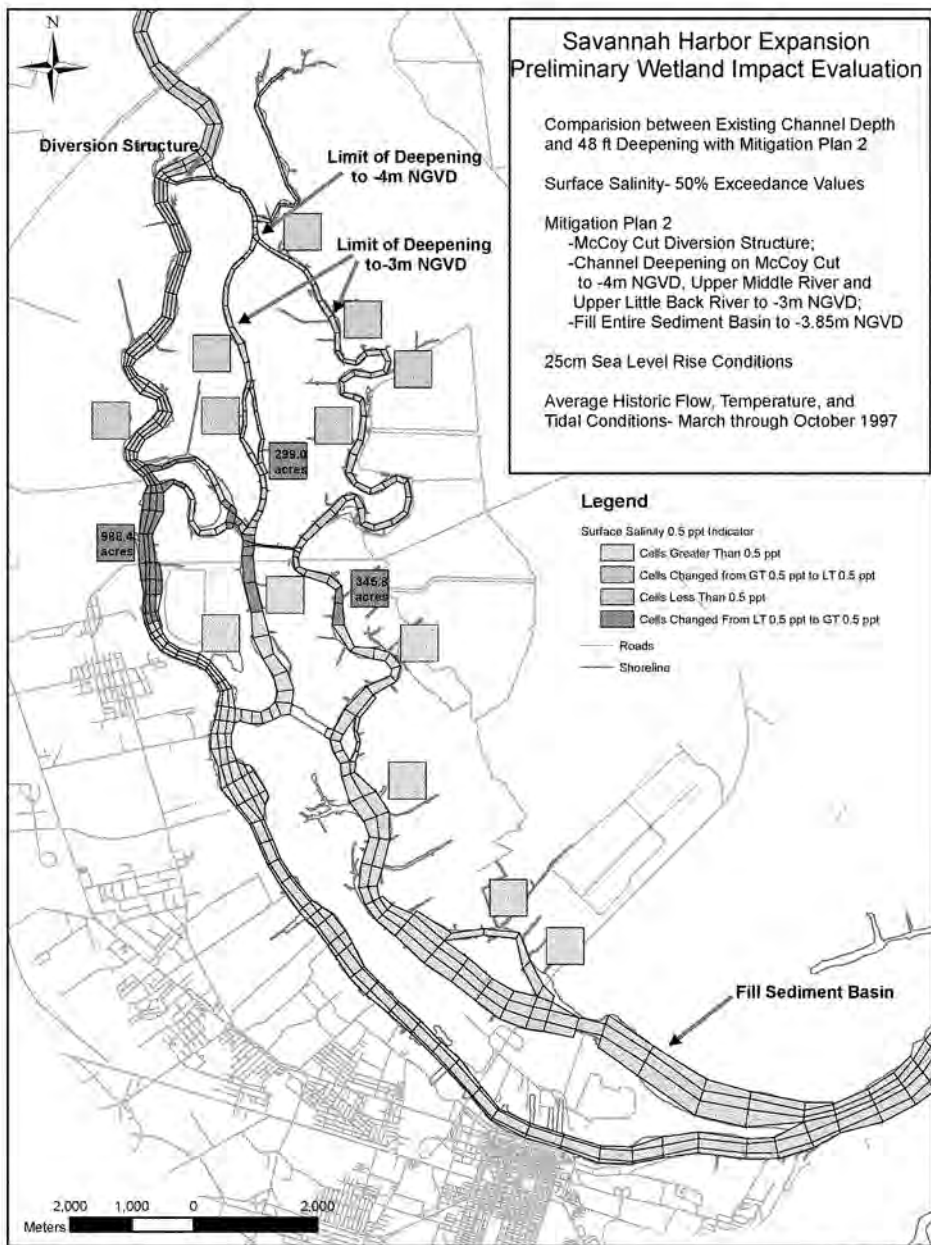


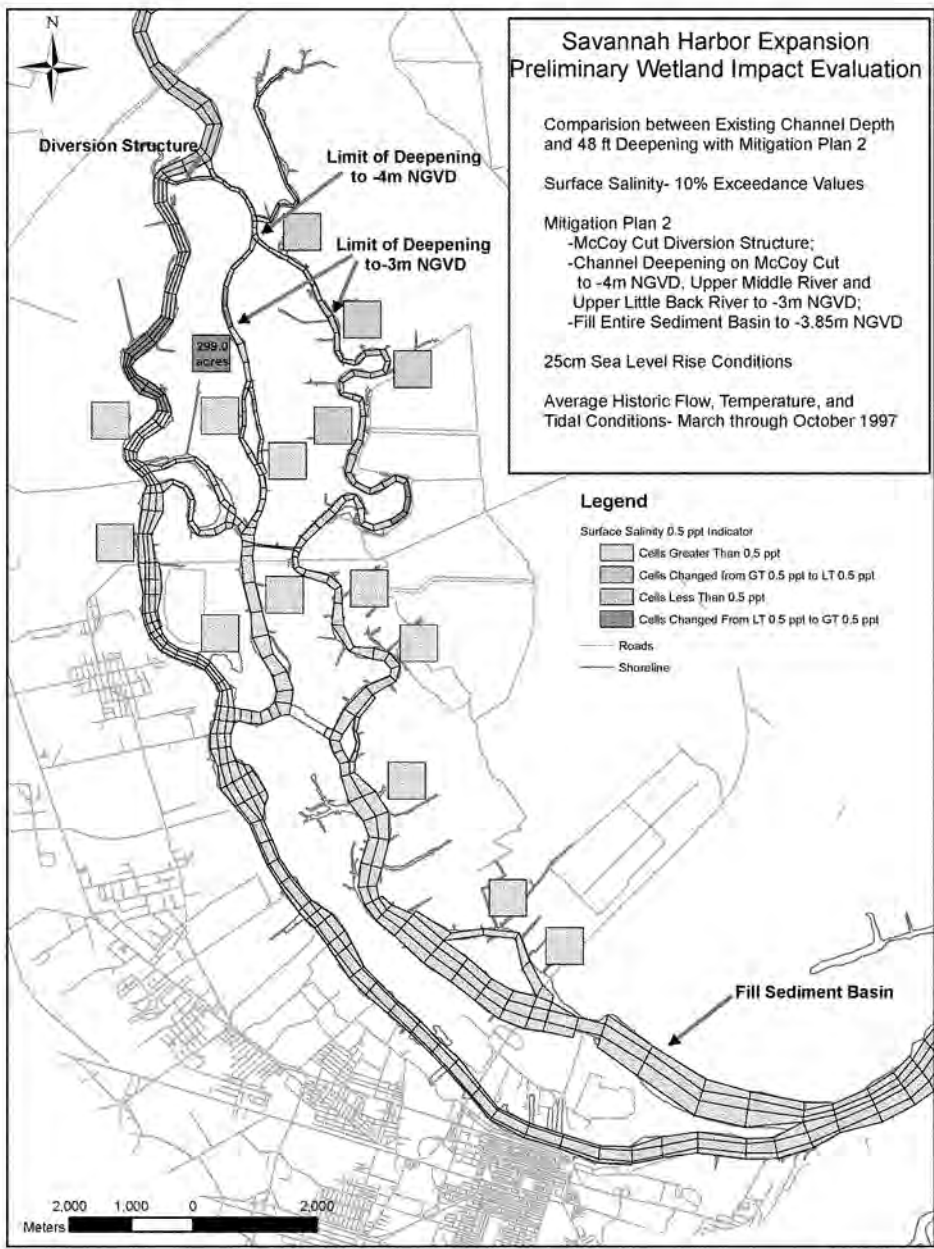


Sensitivity Analysis #2A

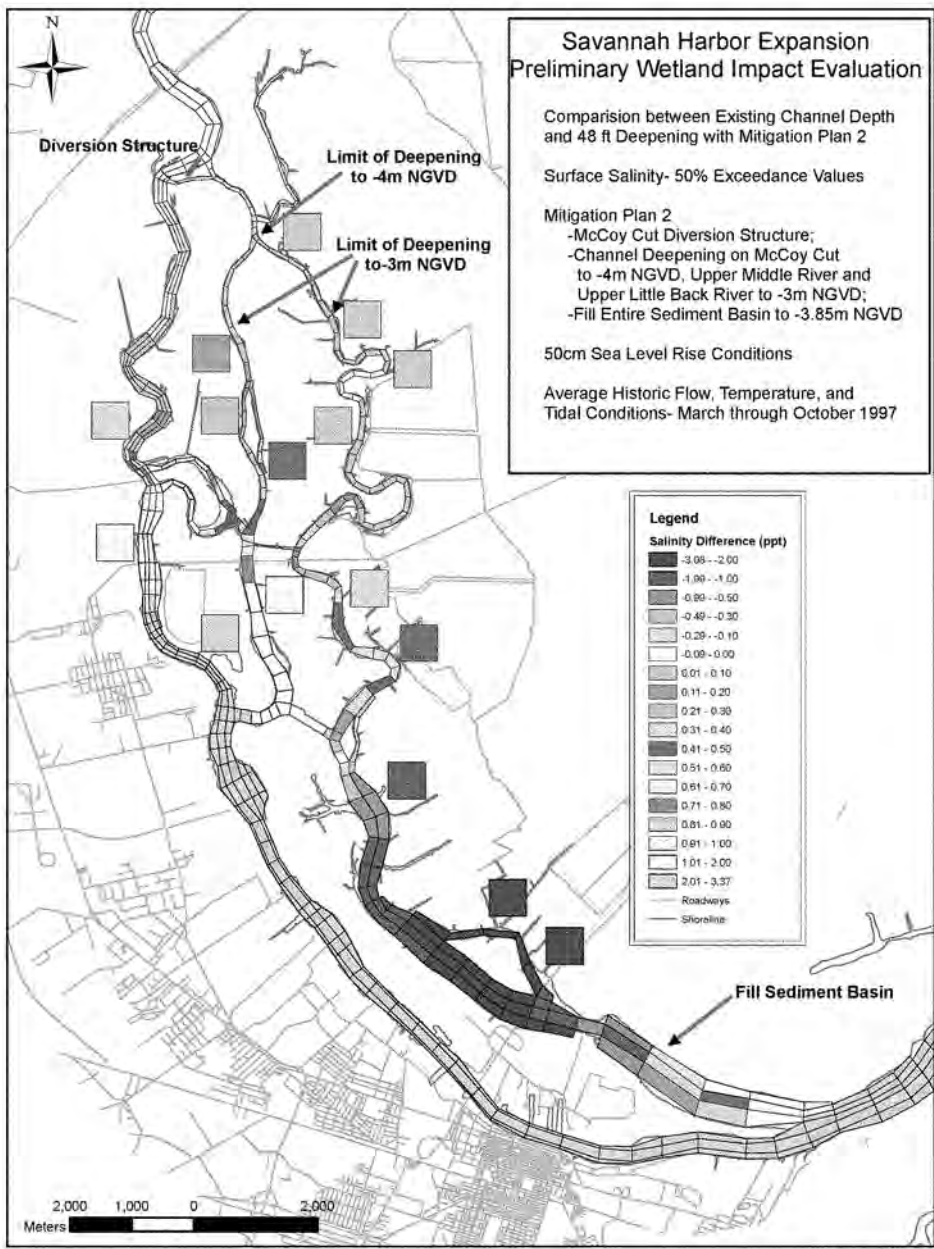


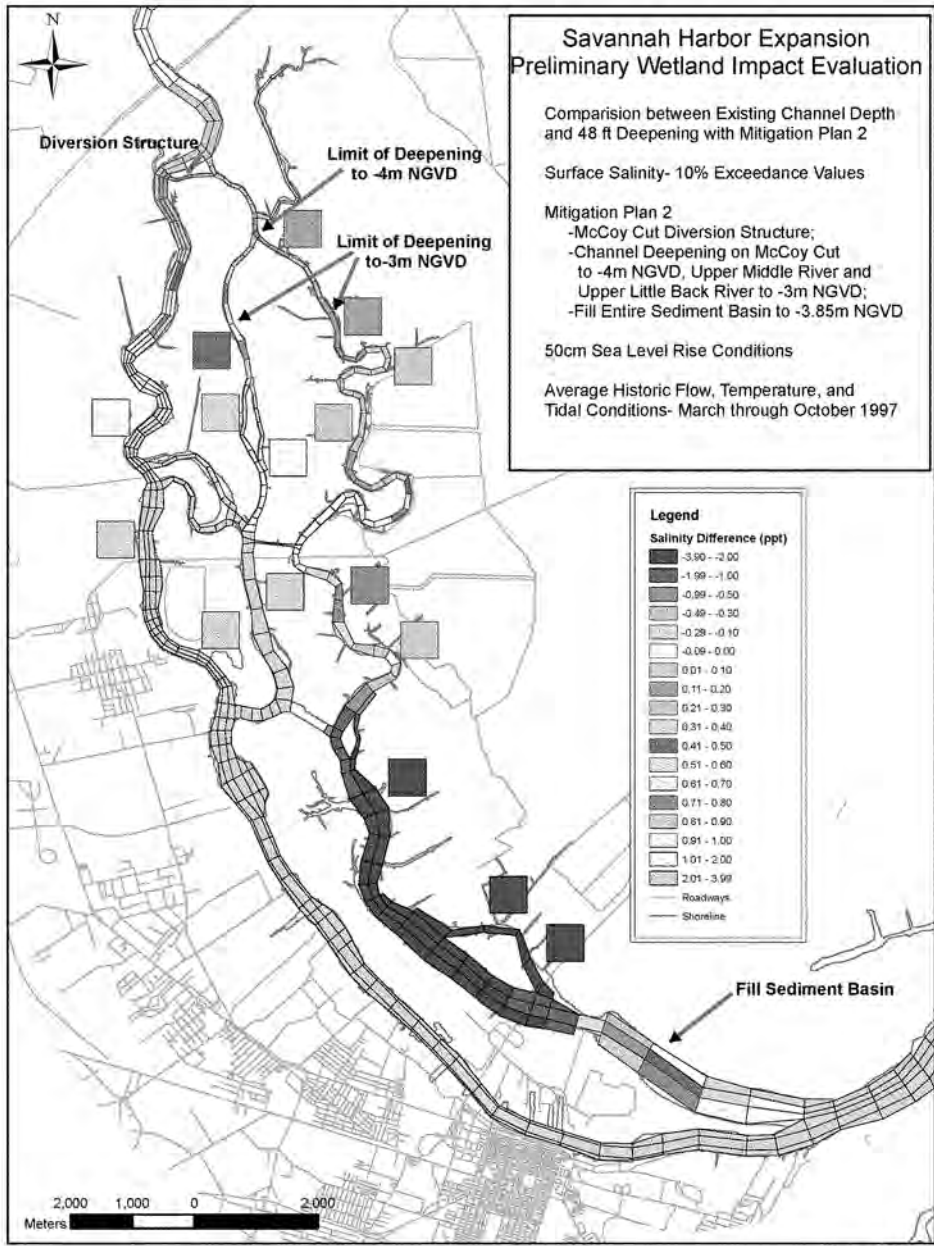


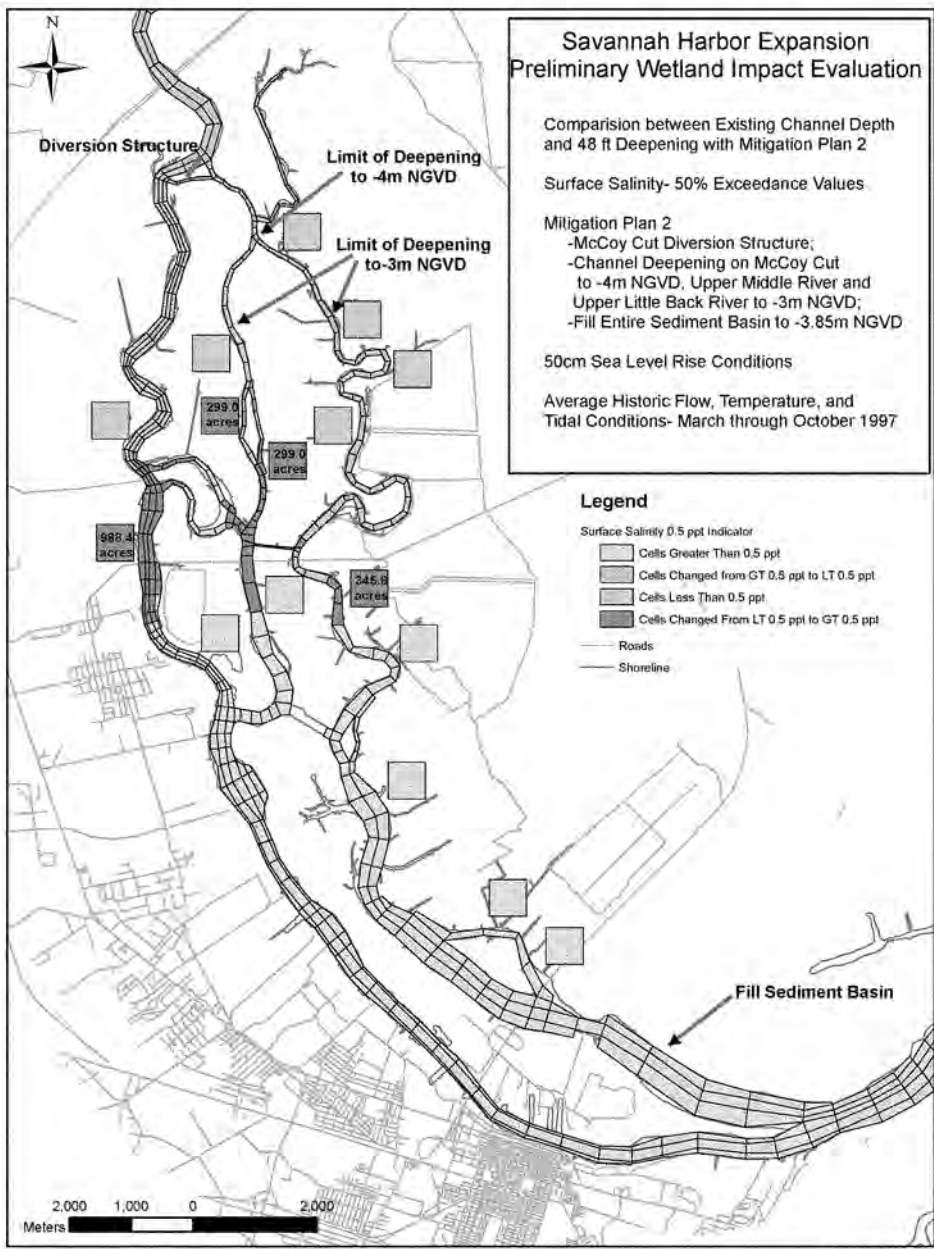


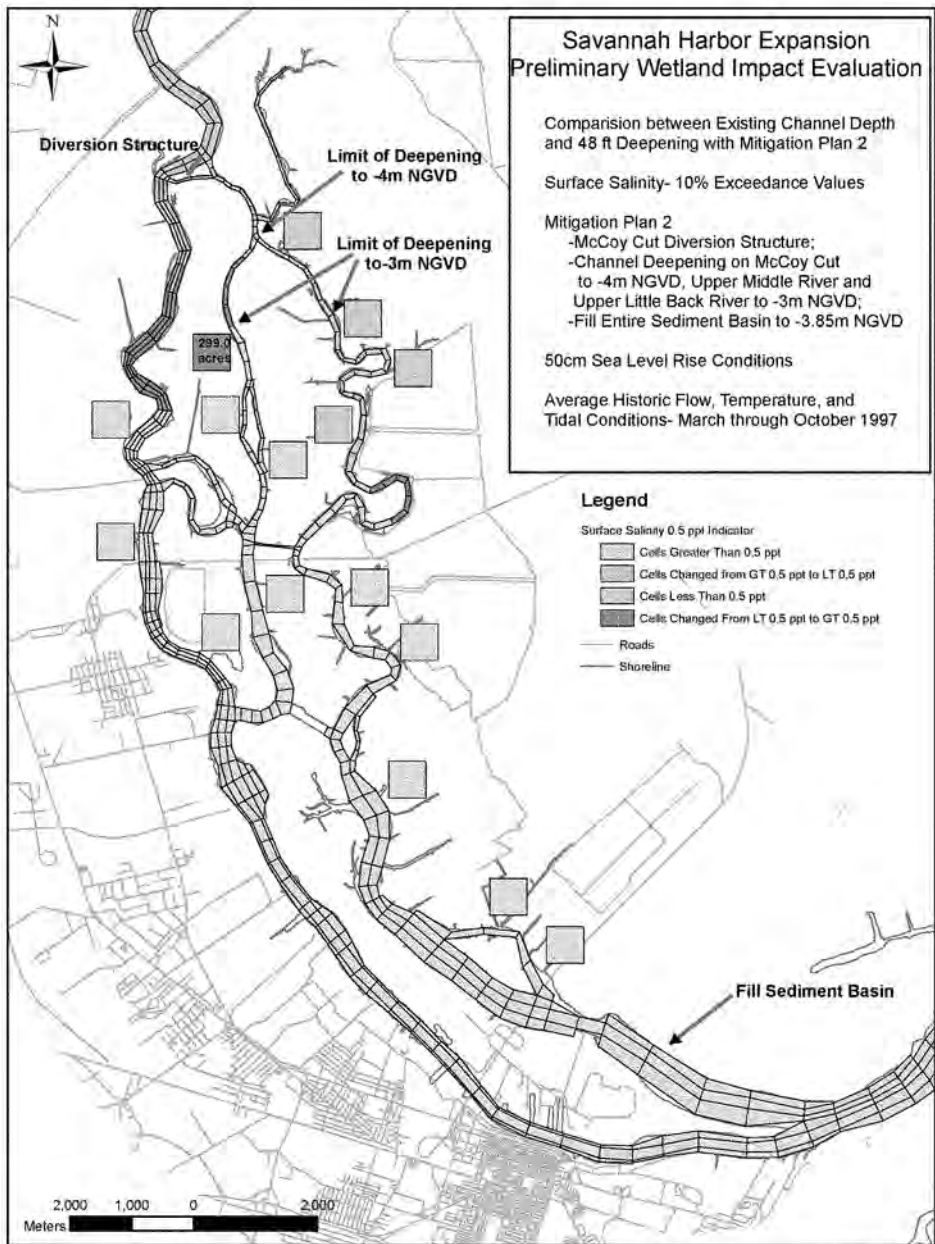


Sensitivity Analysis #2B







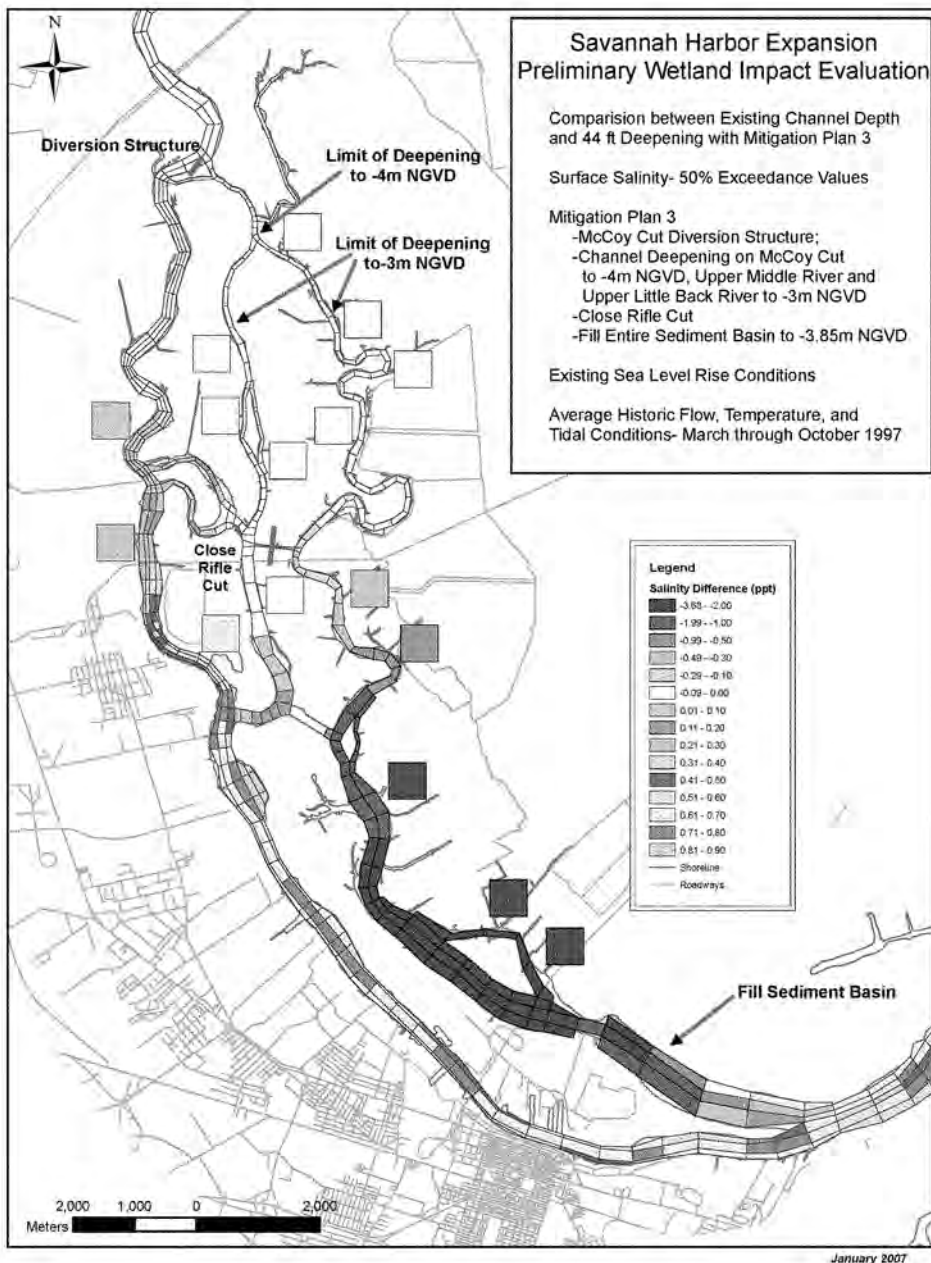


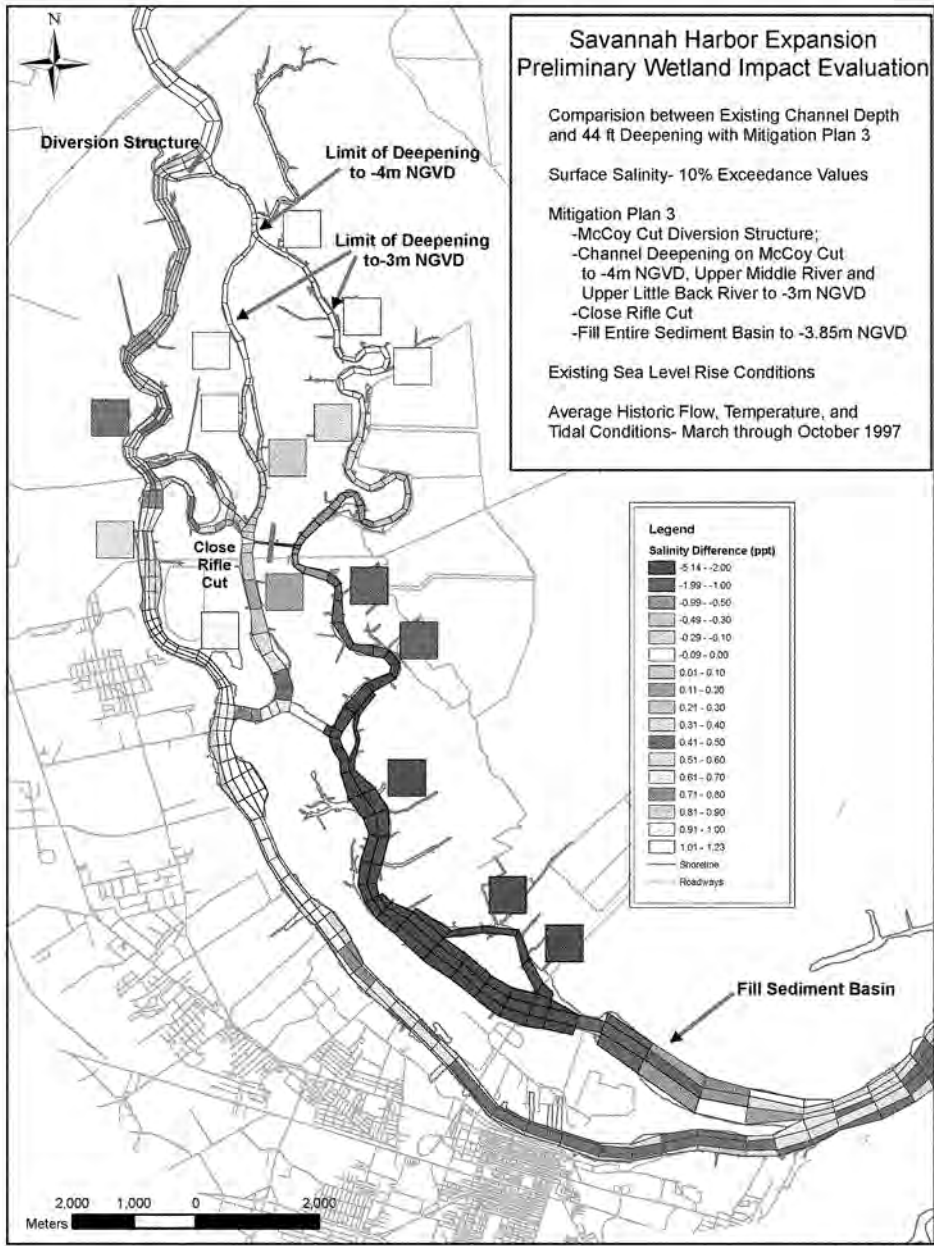
MITIGATION PLAN 3

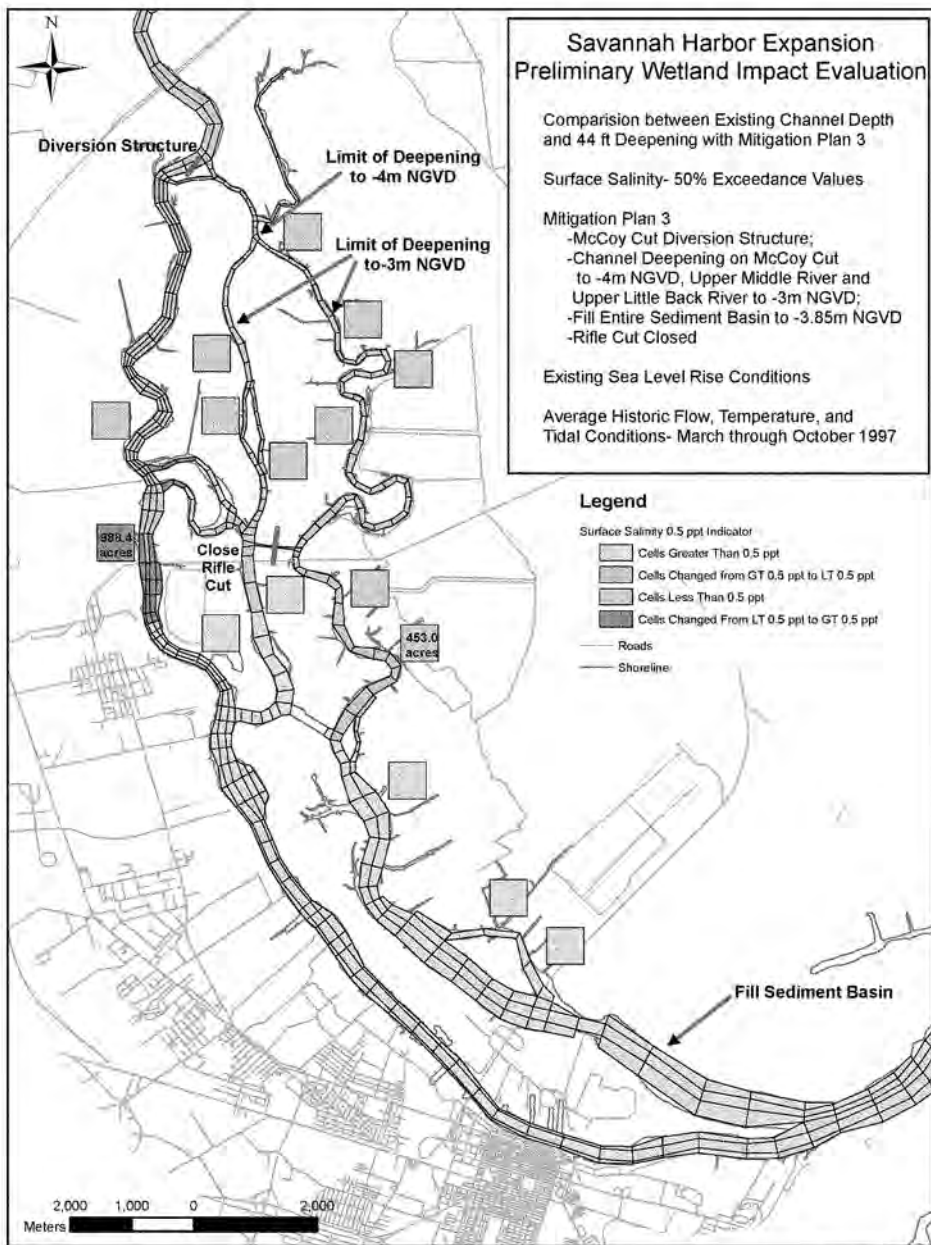
- *McCoy Cut Diversion Structure*
- *Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD*
- *Fill Entire Sediment Basin to -3.85m NGVD*
- *Close Rifle Cut*

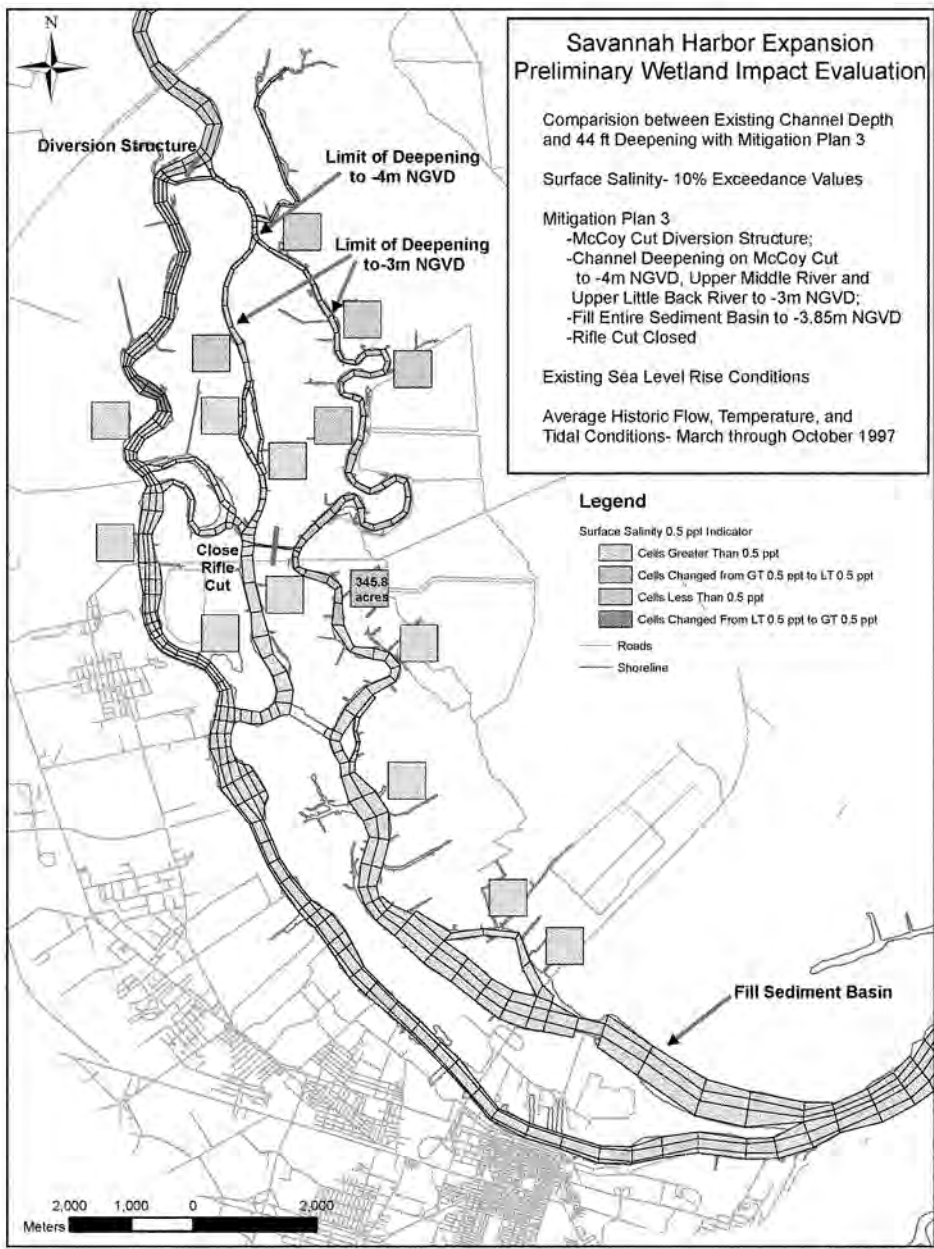
44-ft Deepening

Basic Evaluation

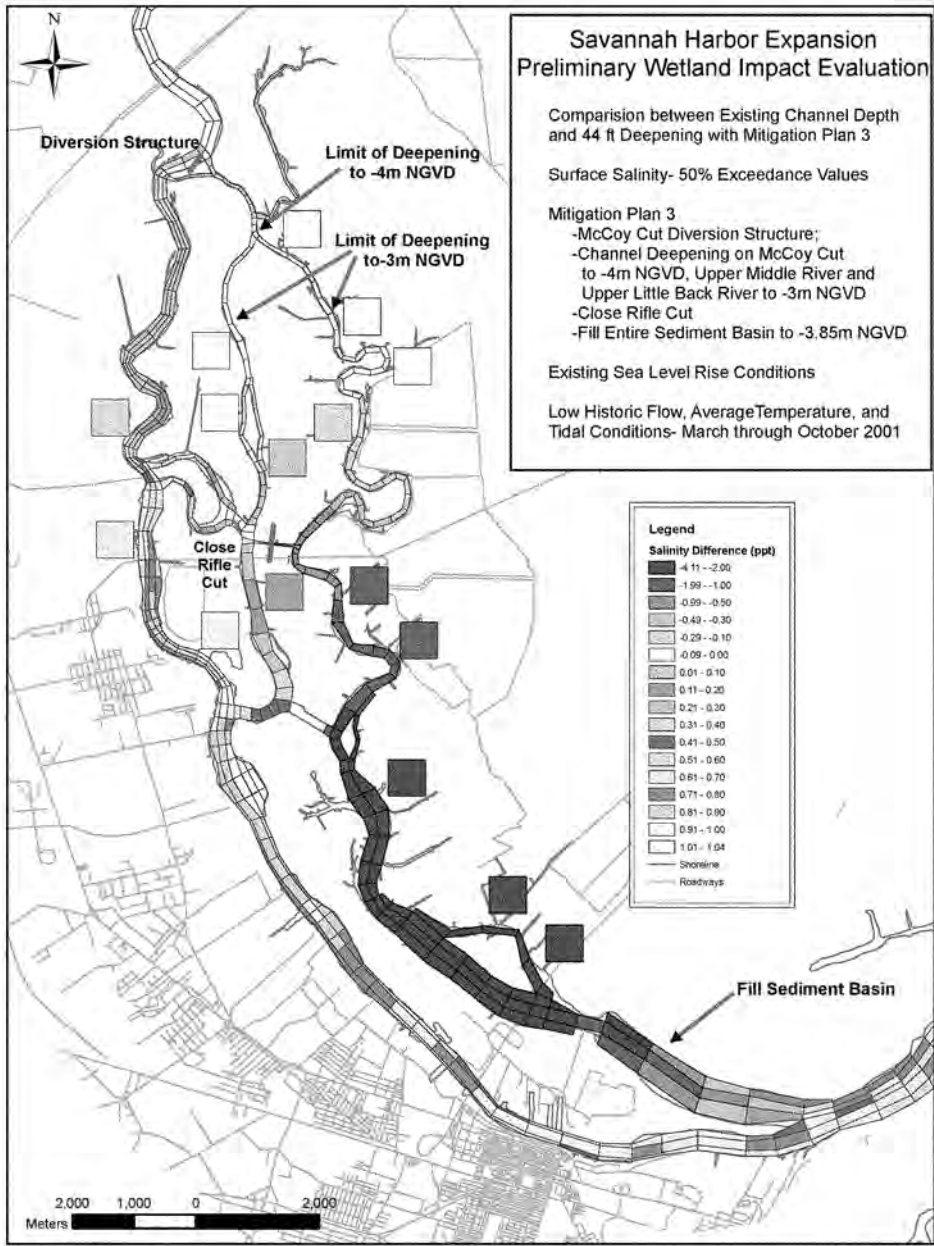


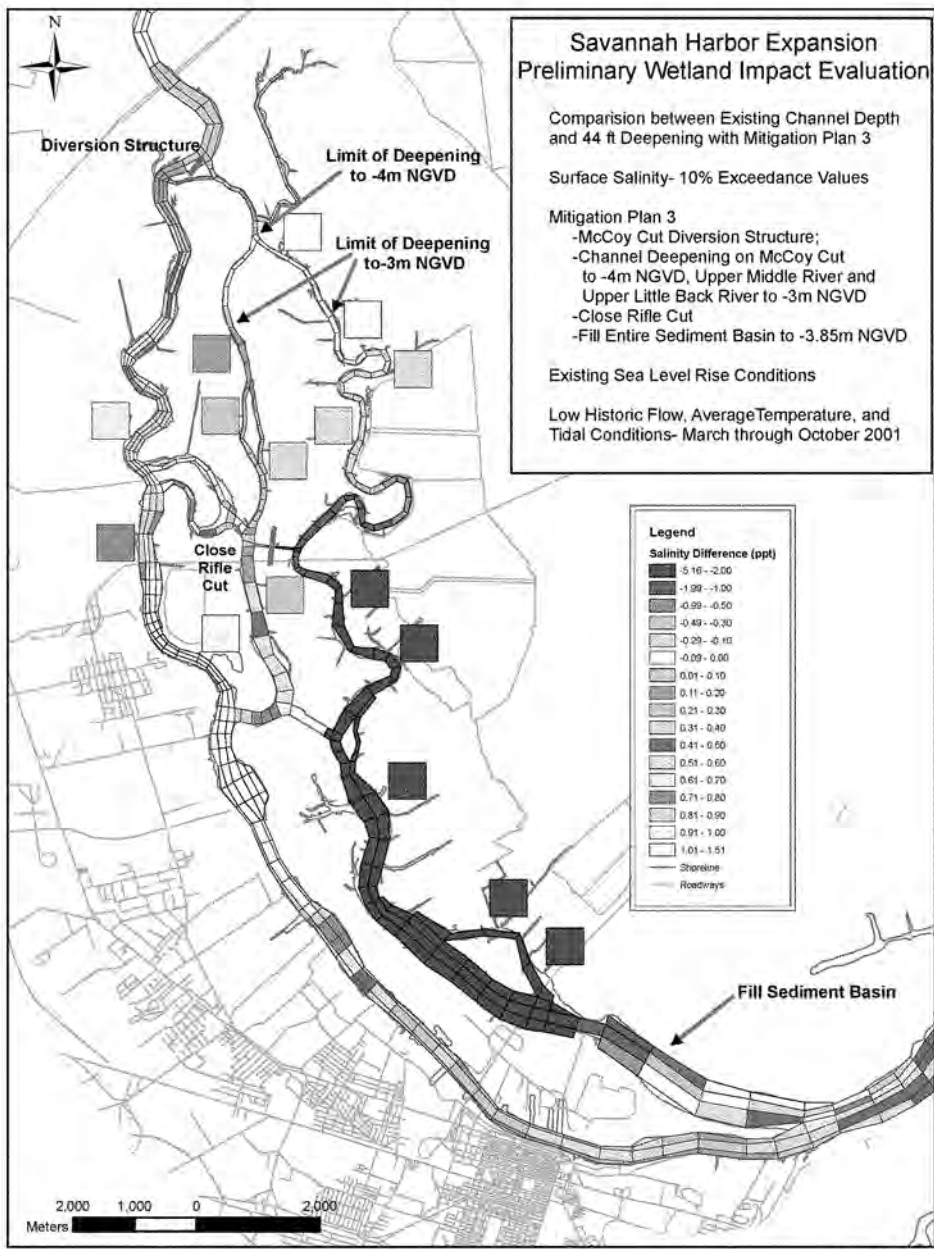


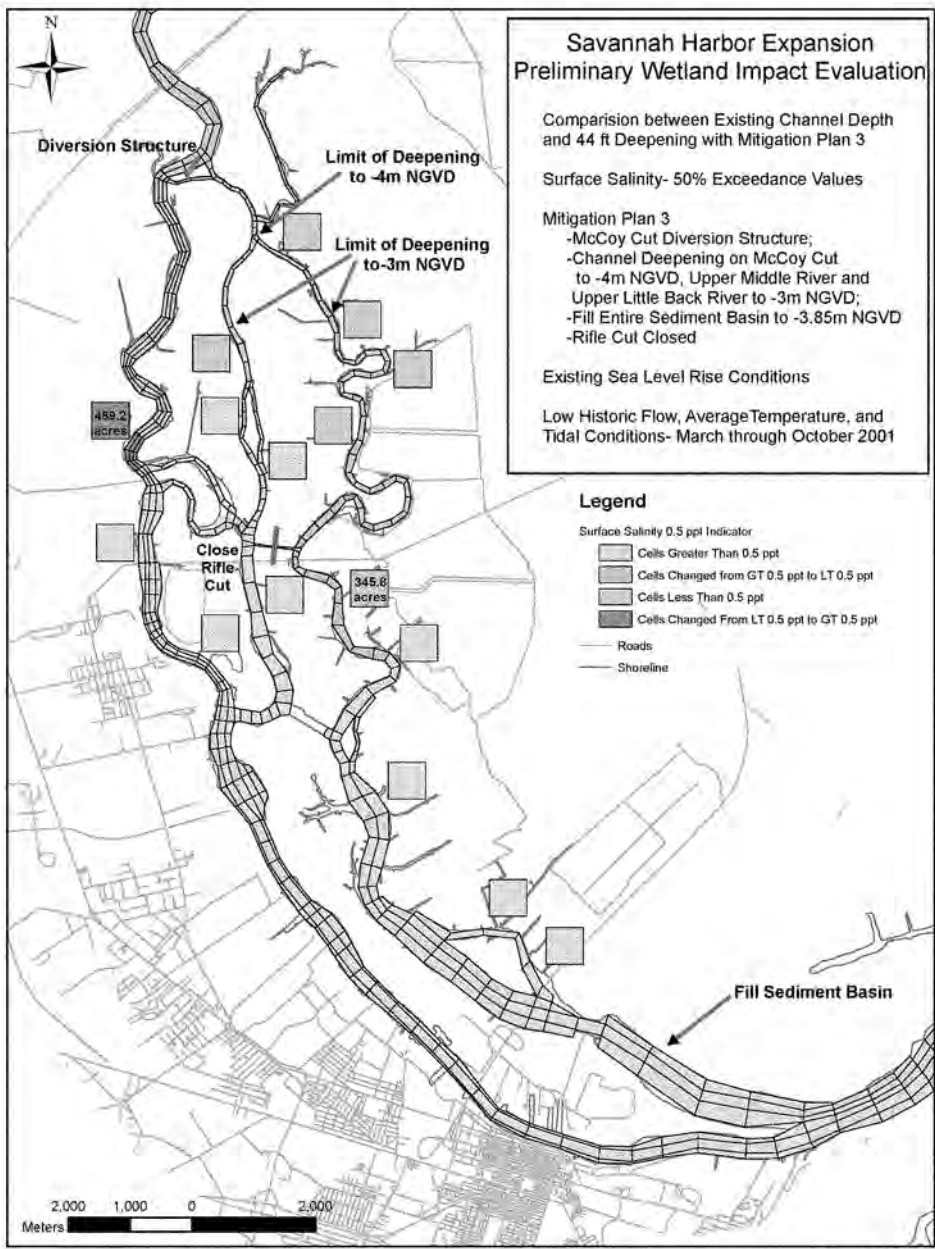


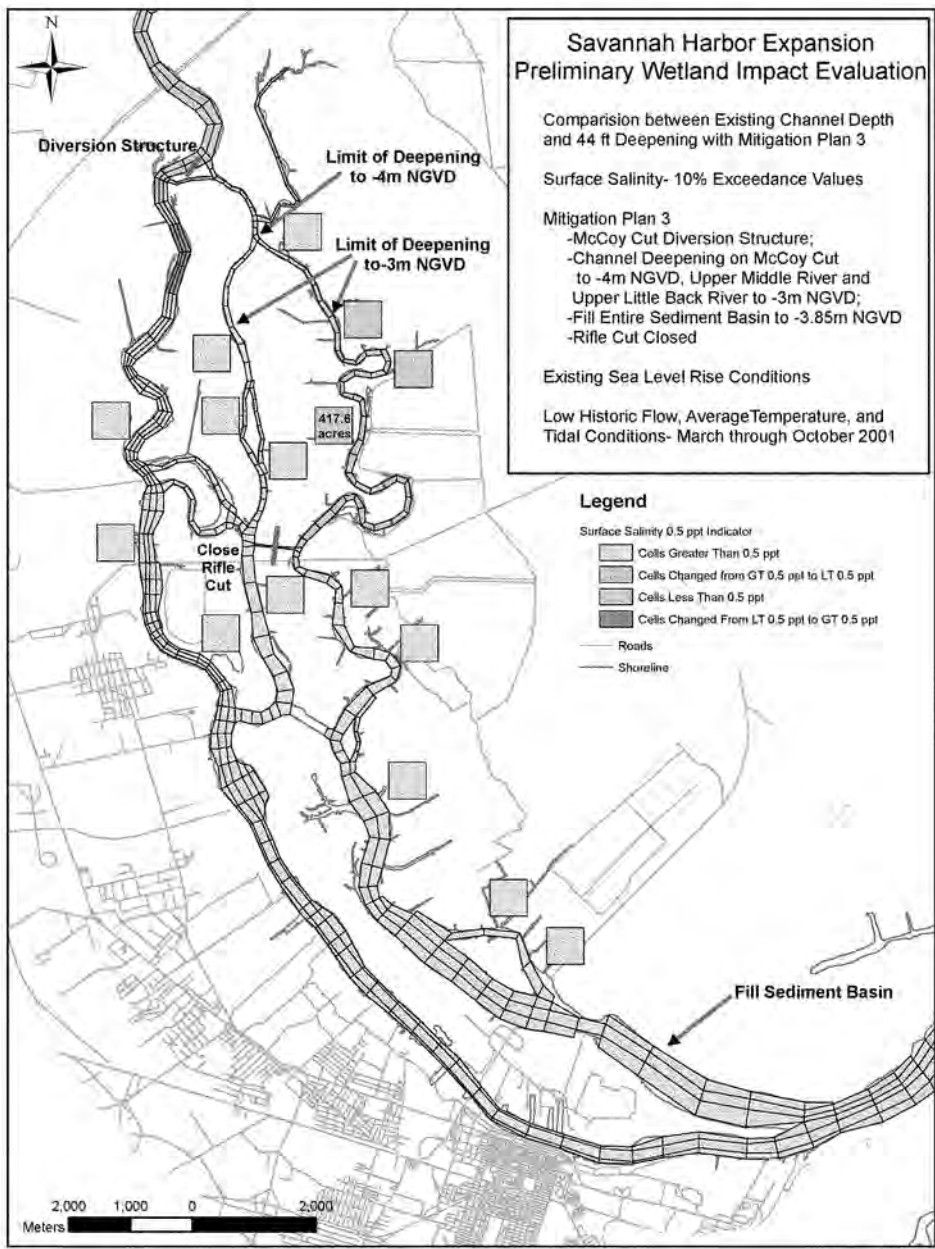


Sensitivity Analysis #1

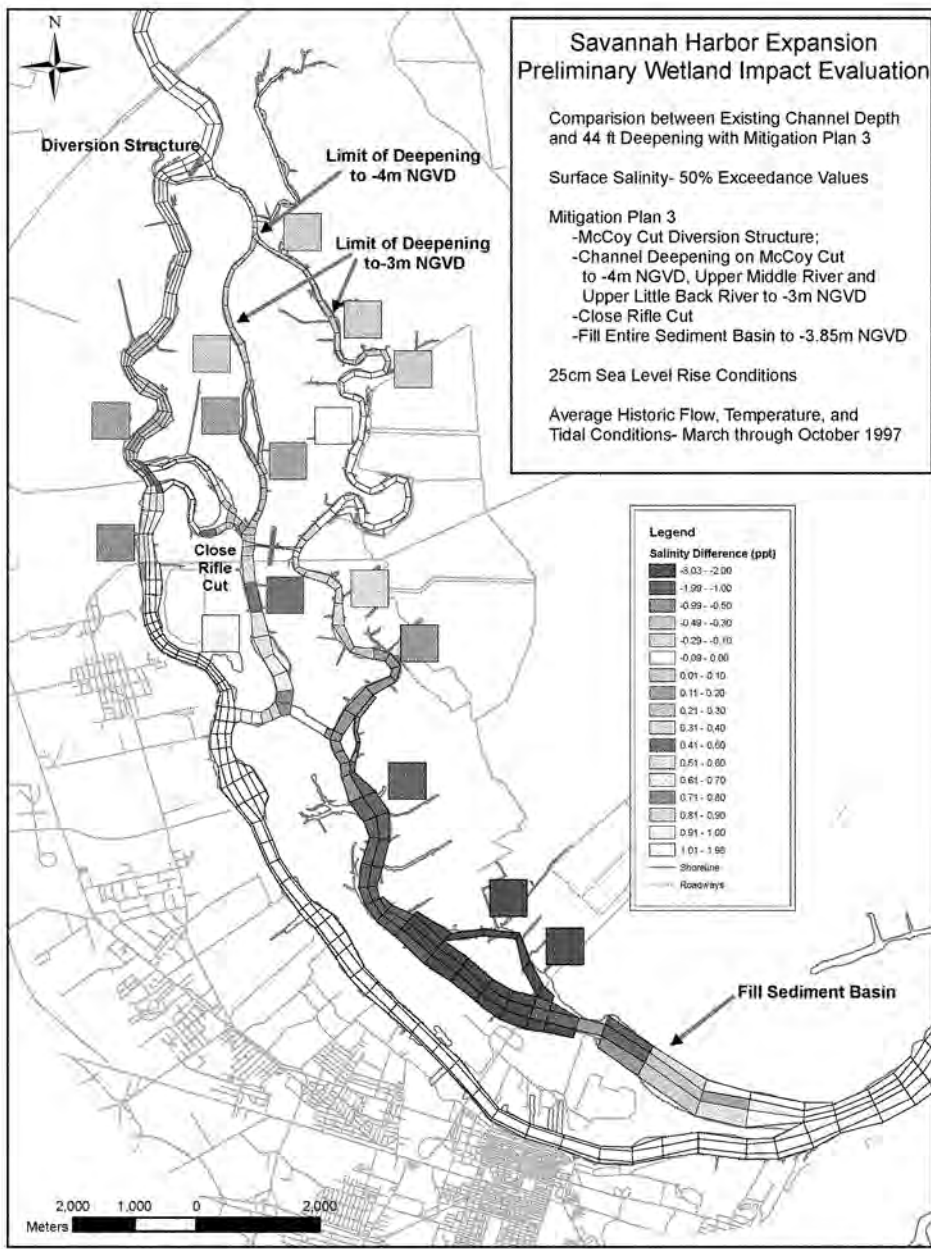


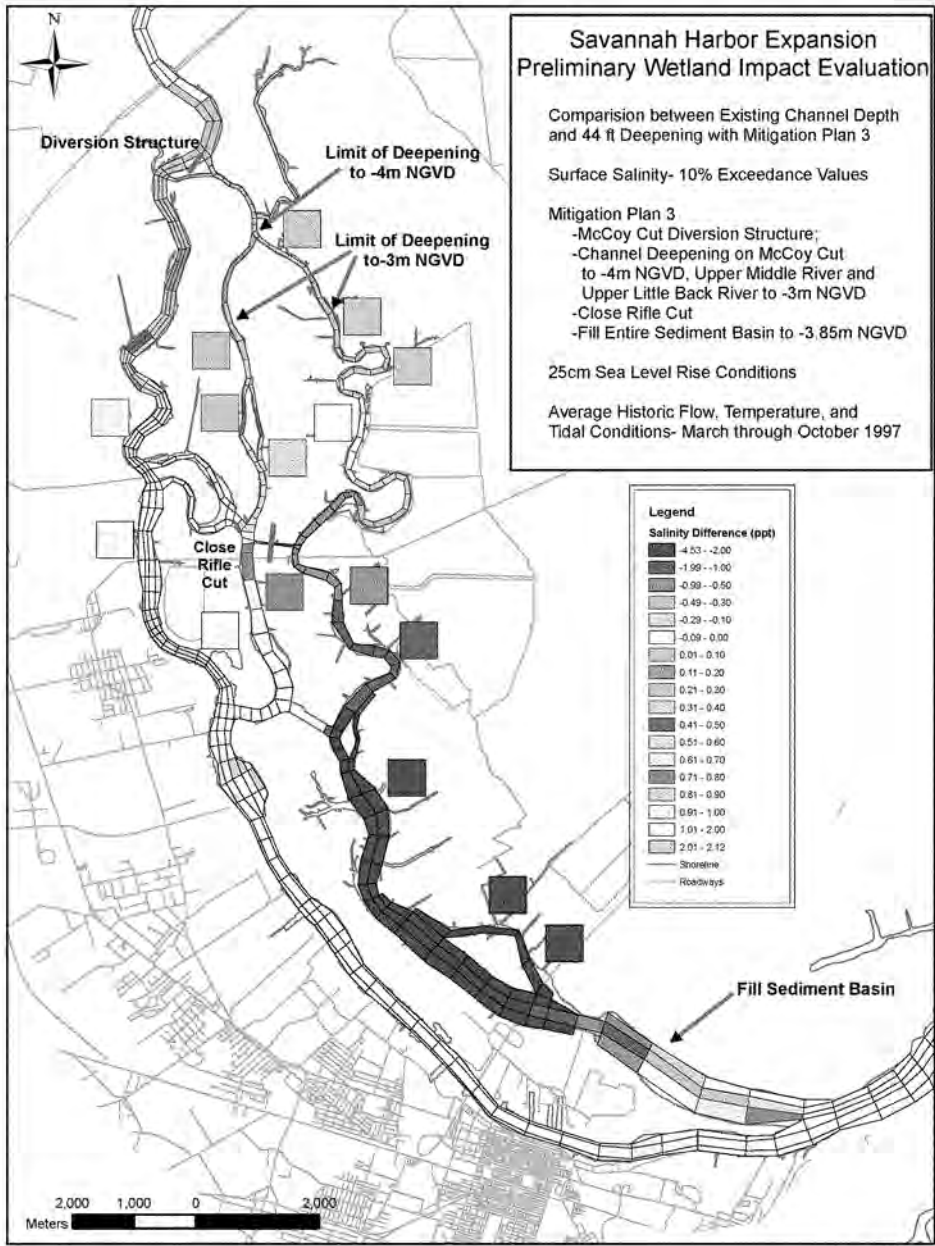


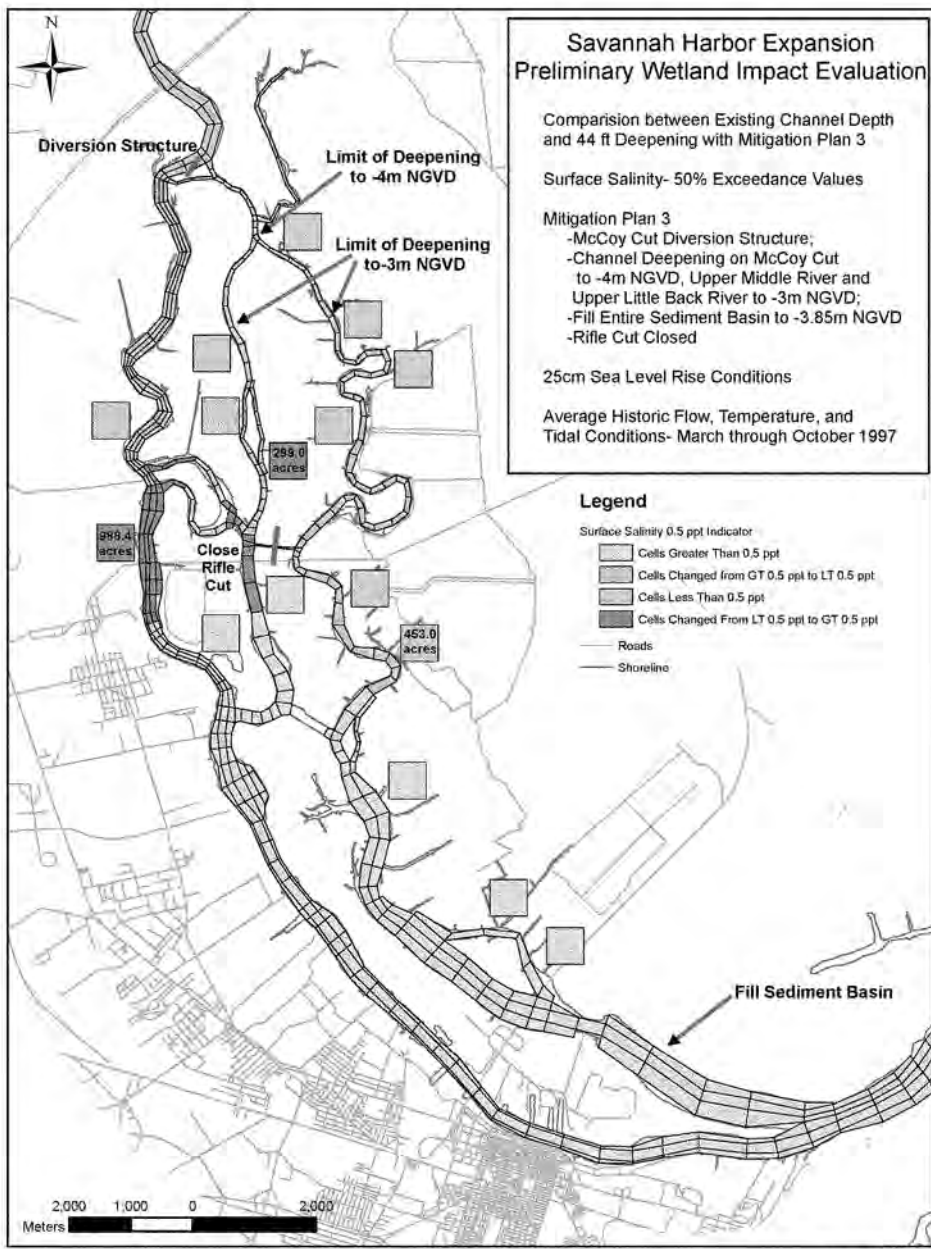


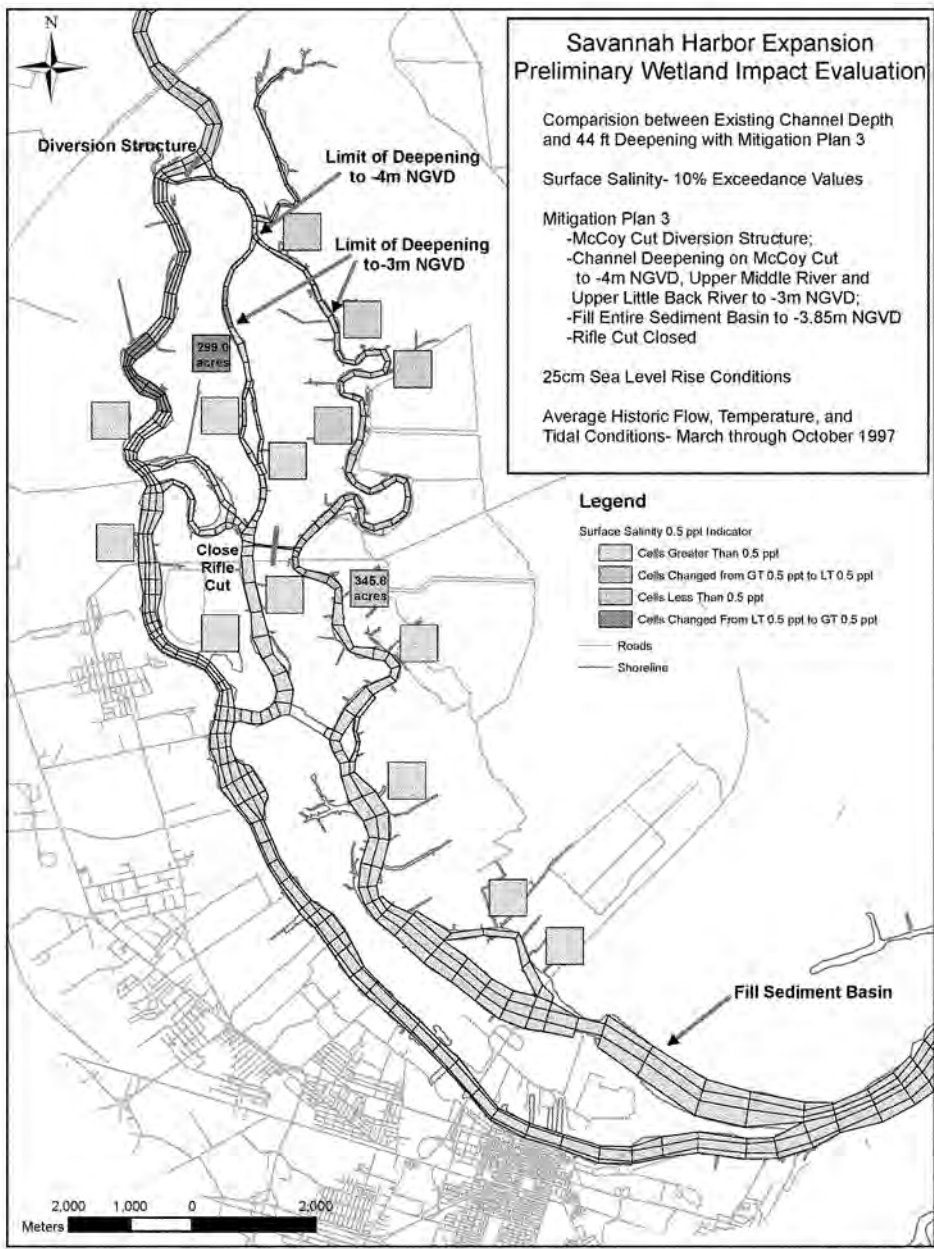


Sensitivity Analysis #2A

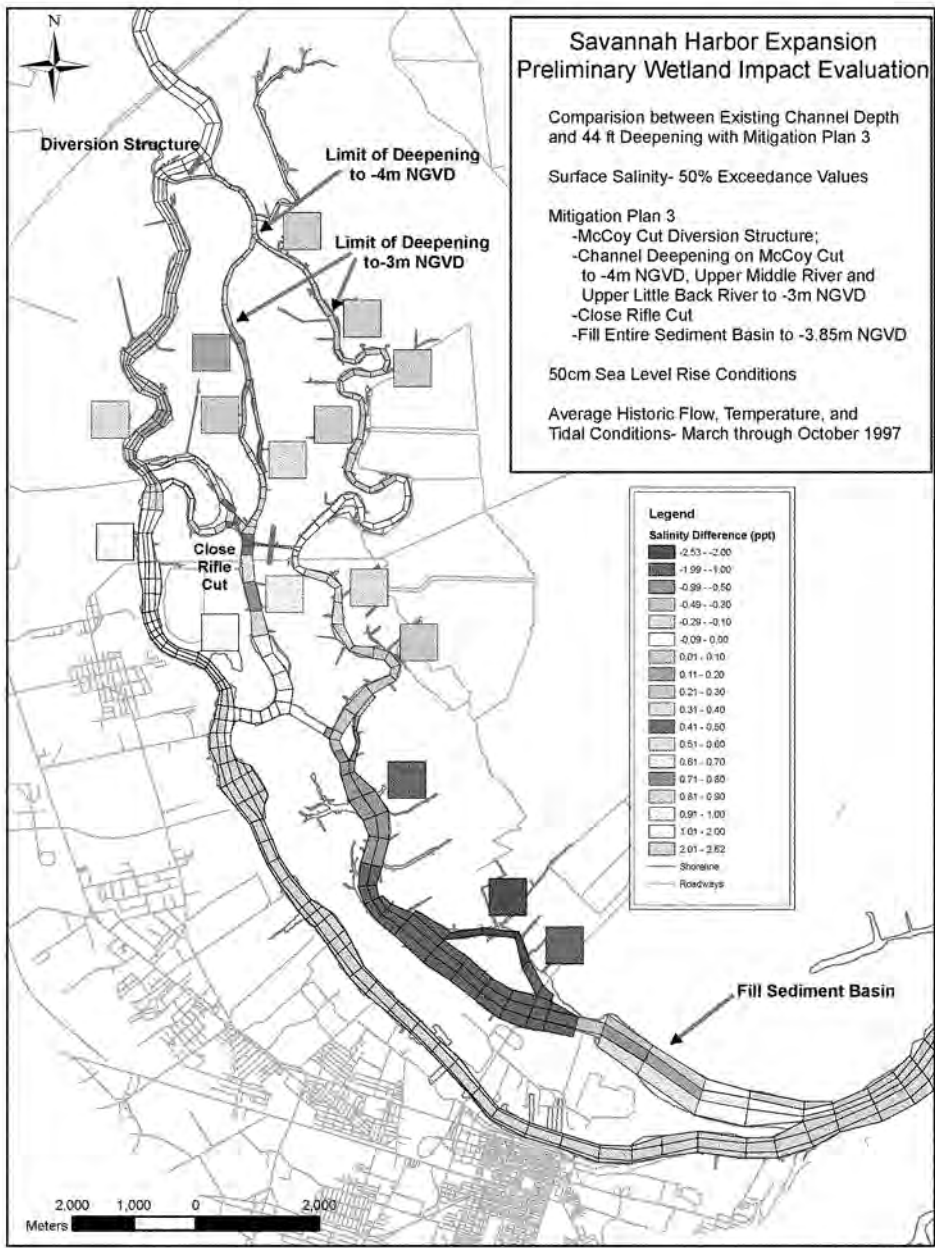


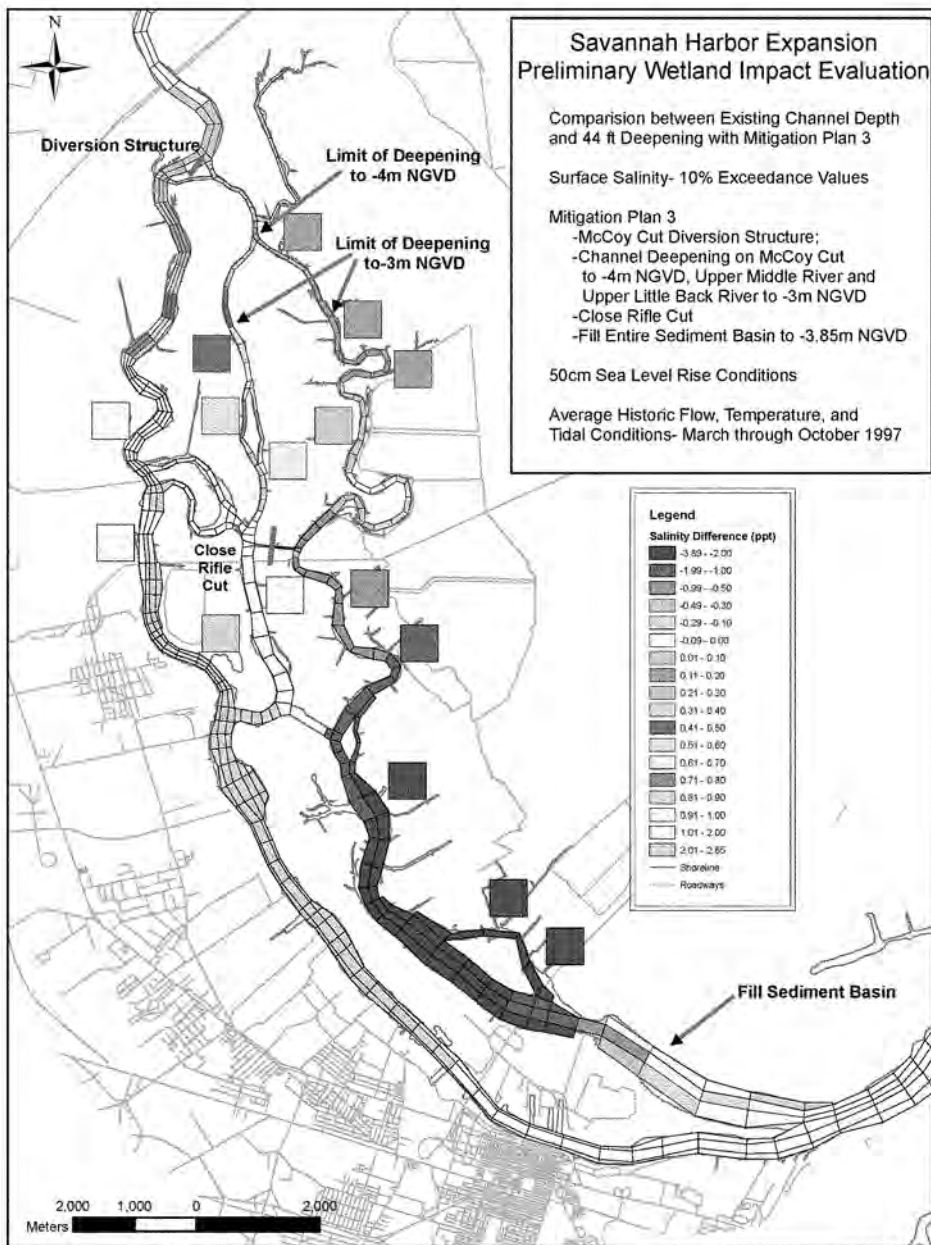




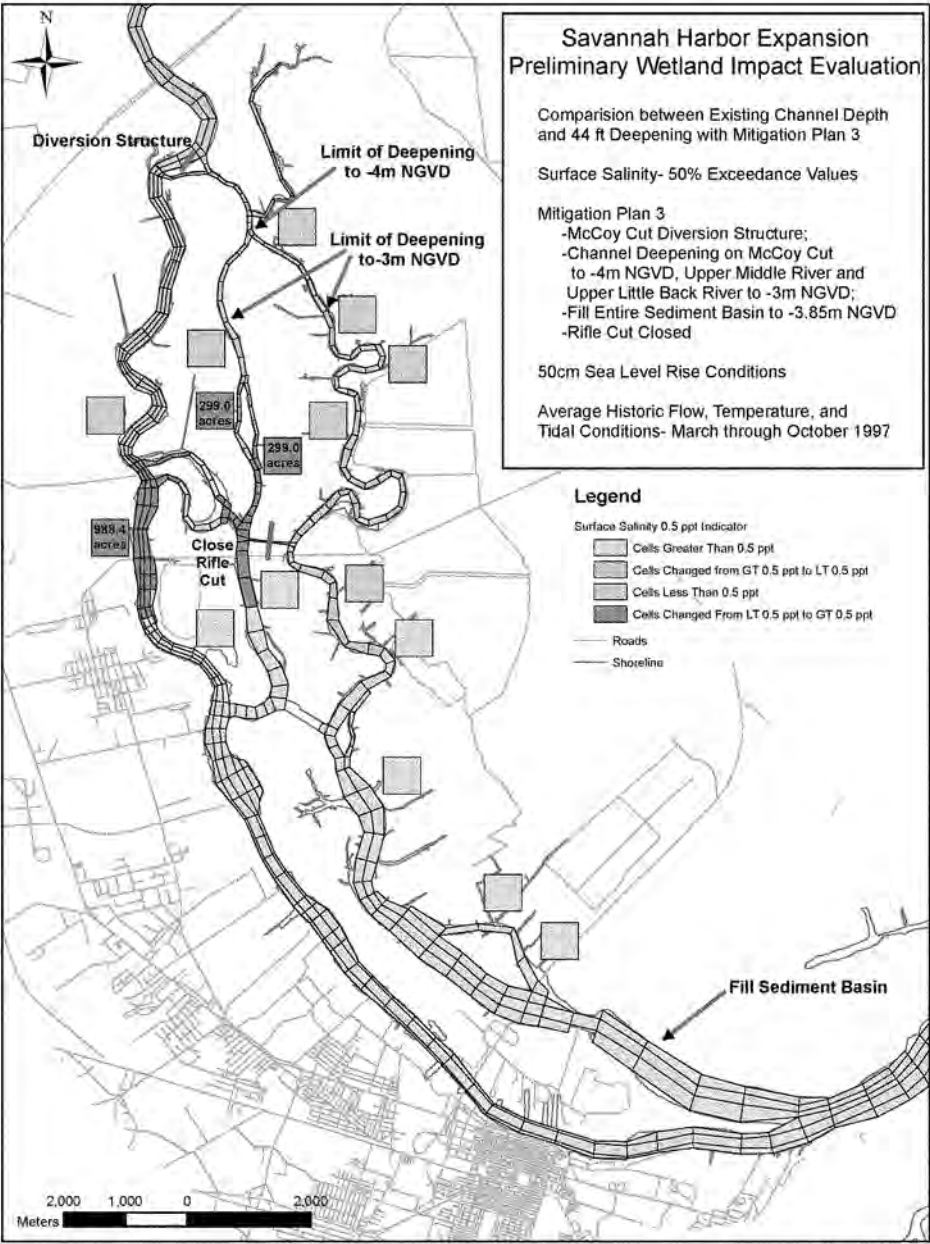


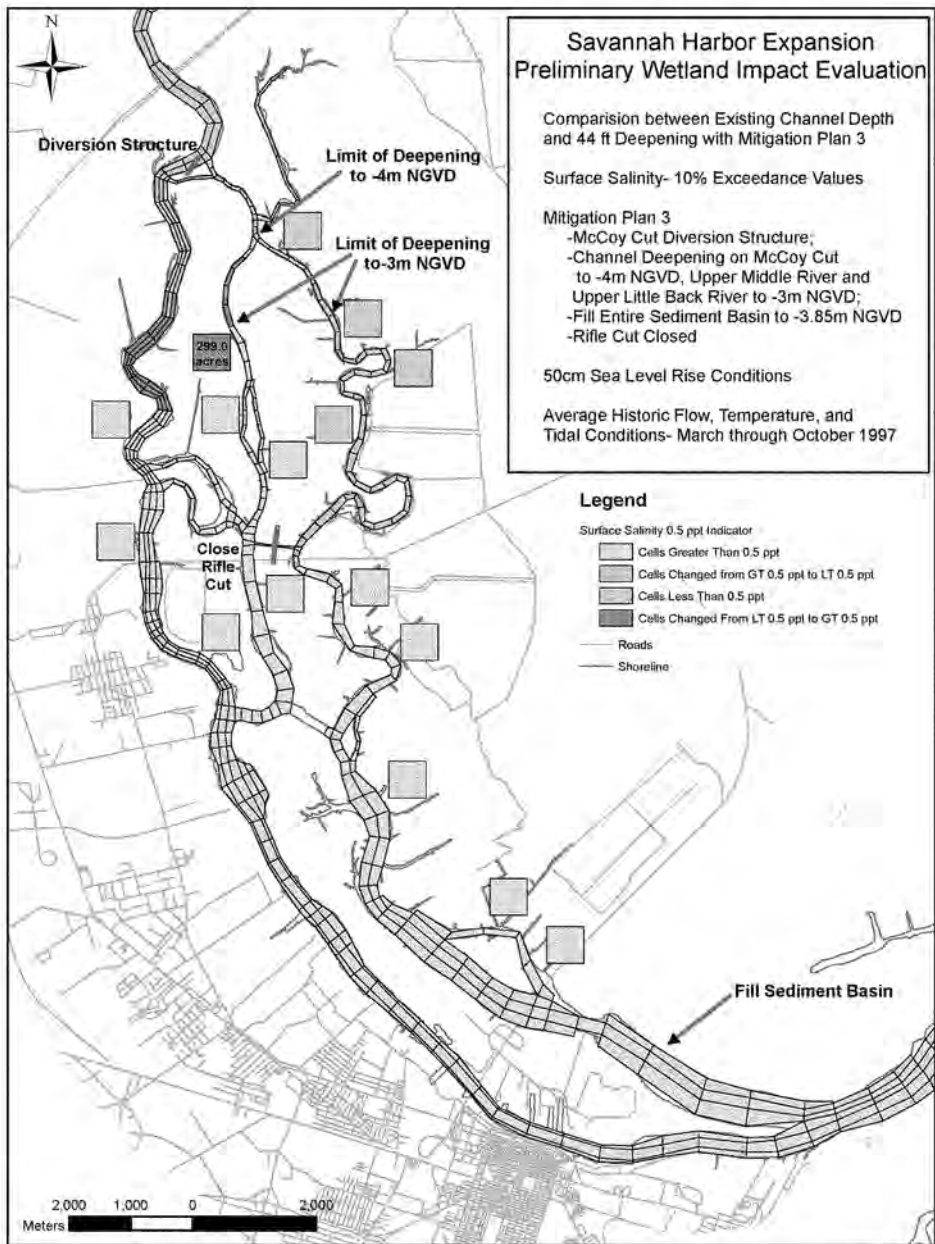
Sensitivity Analysis #2B





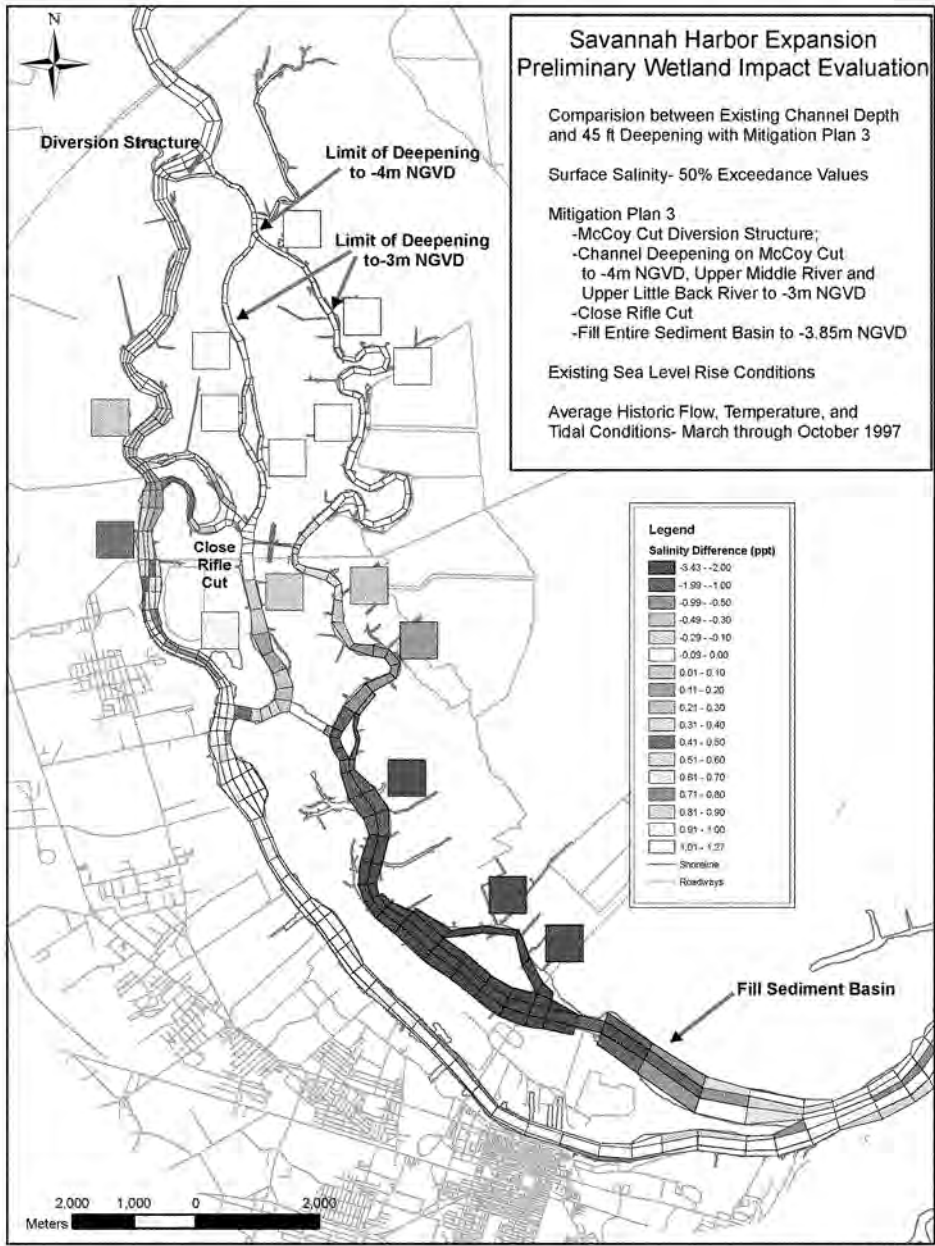
January 2007

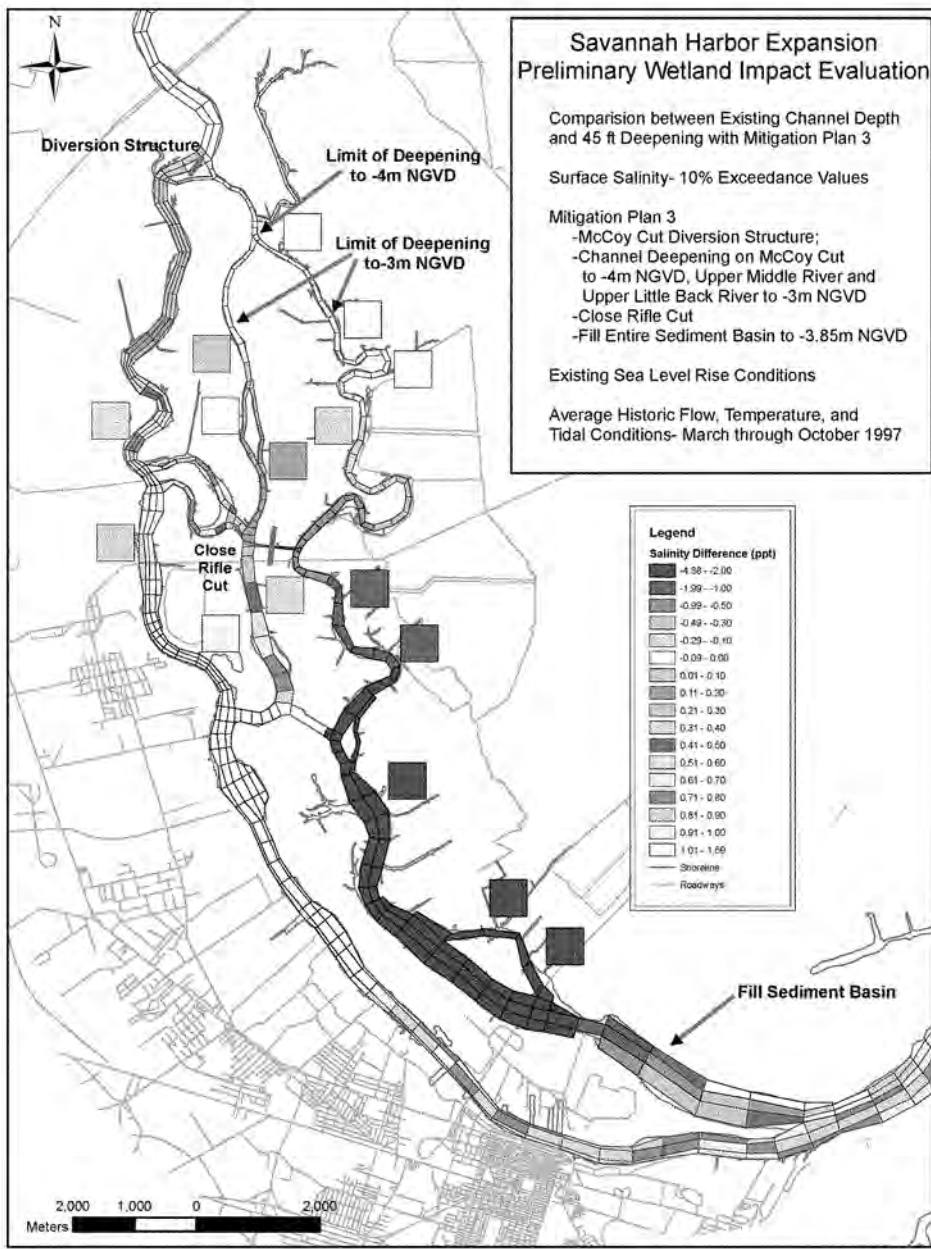


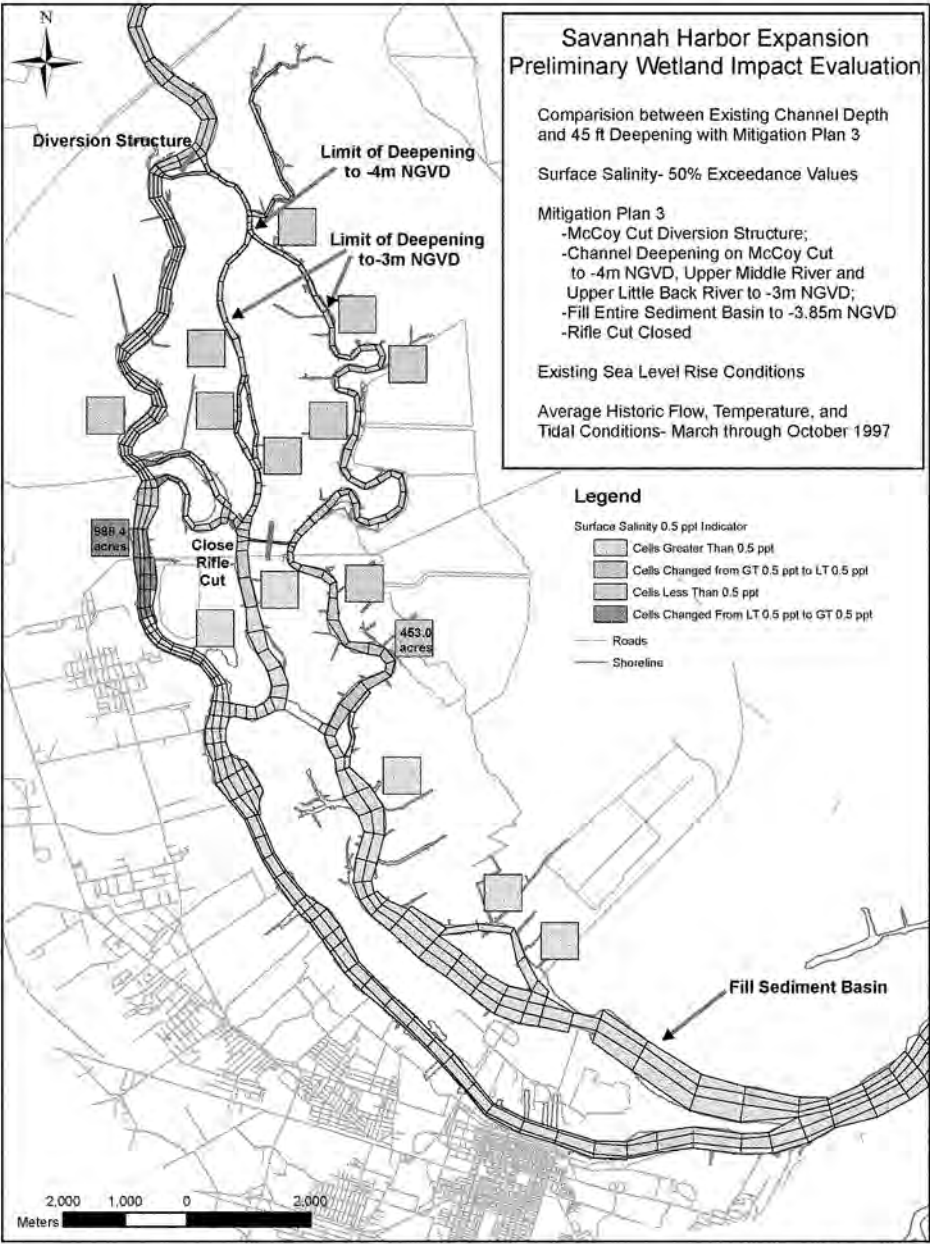


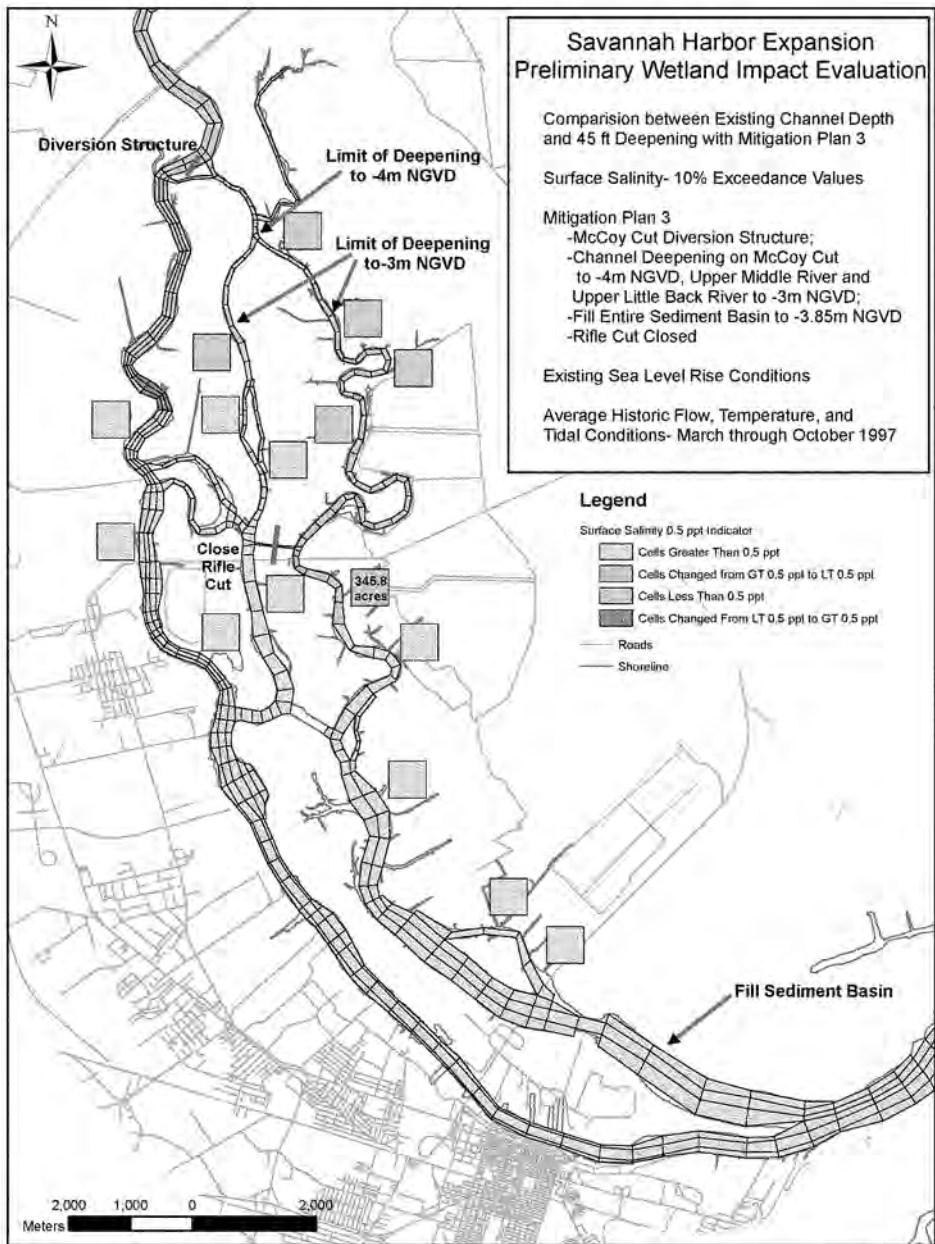
45-ft Deepening

Basic Evaluation

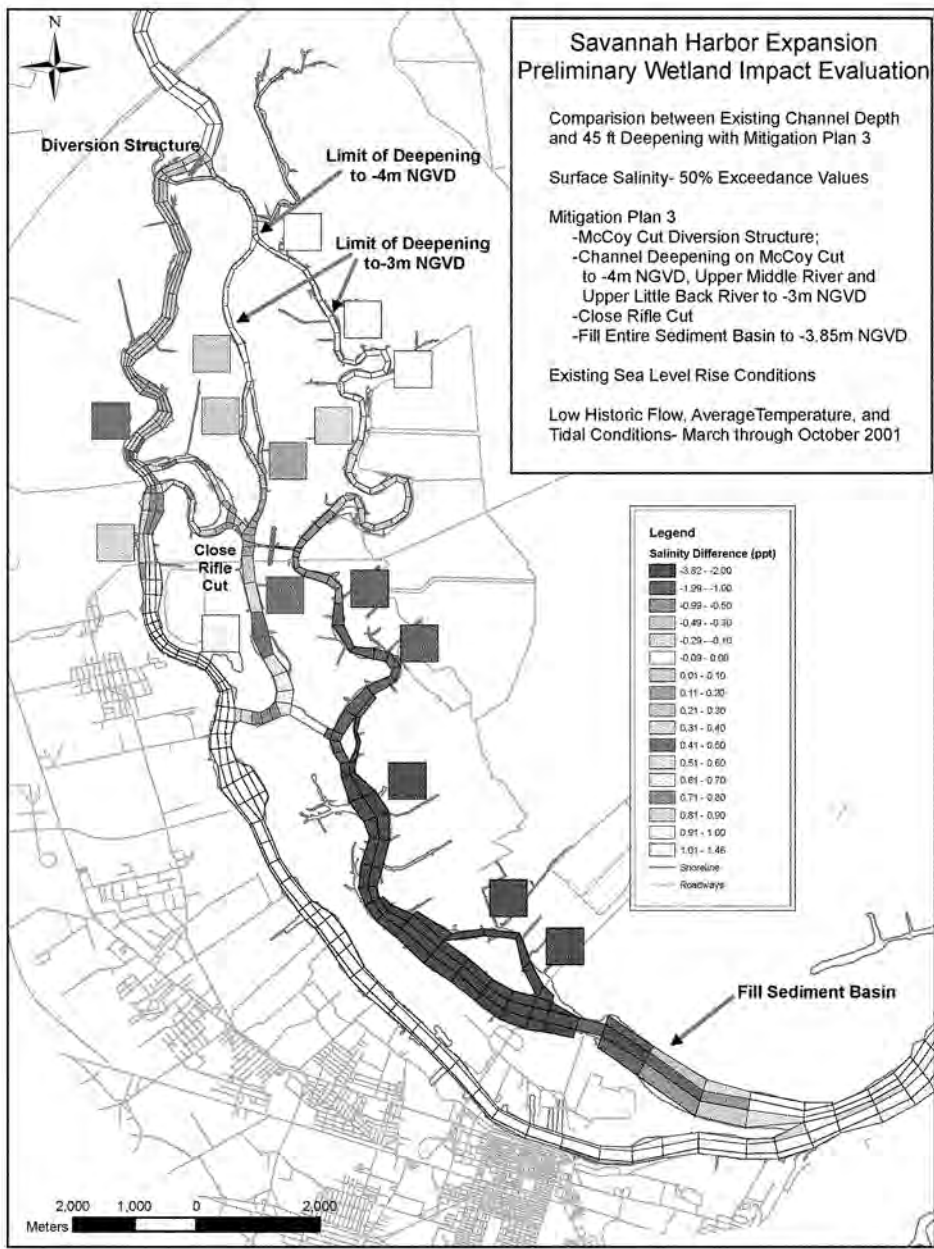


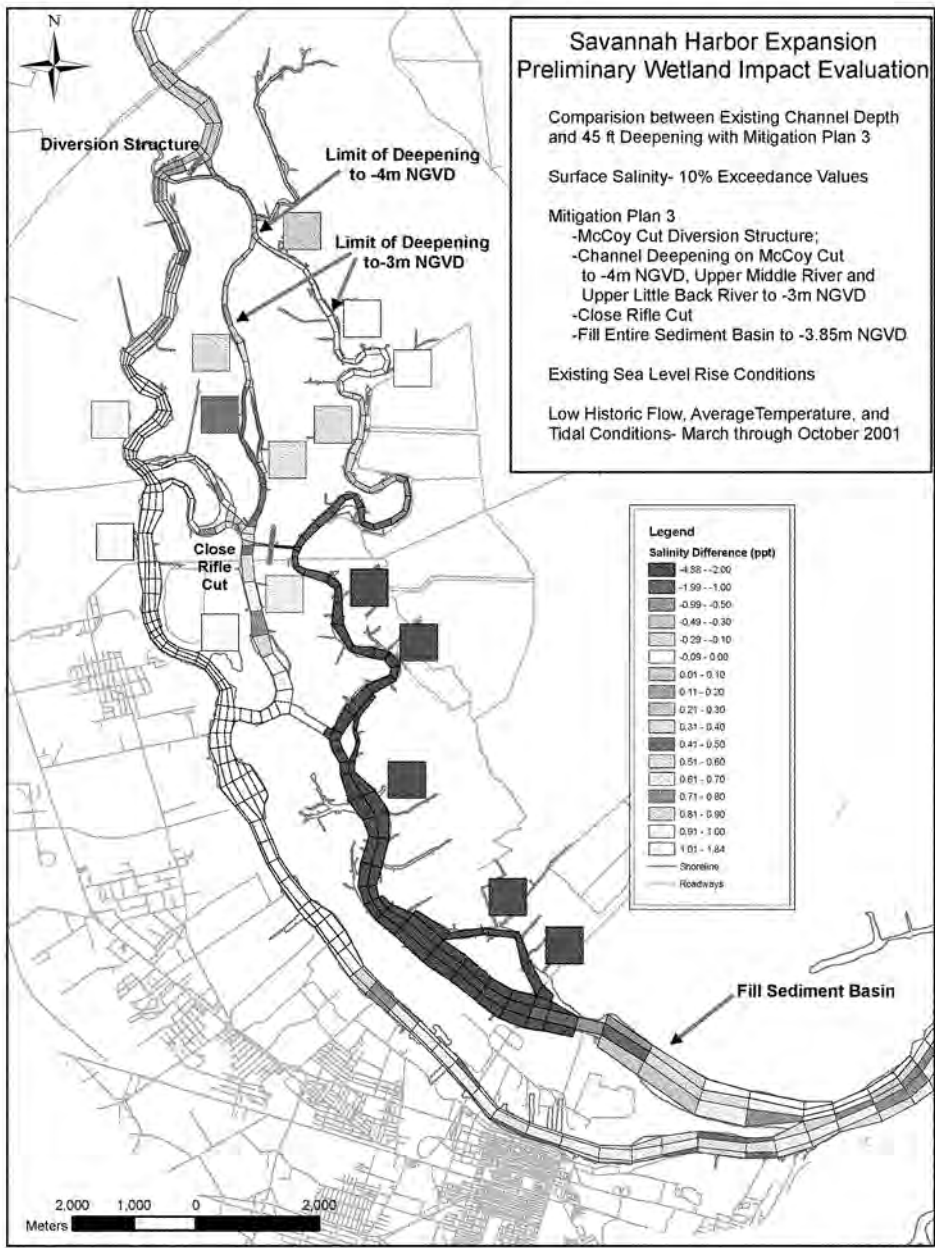


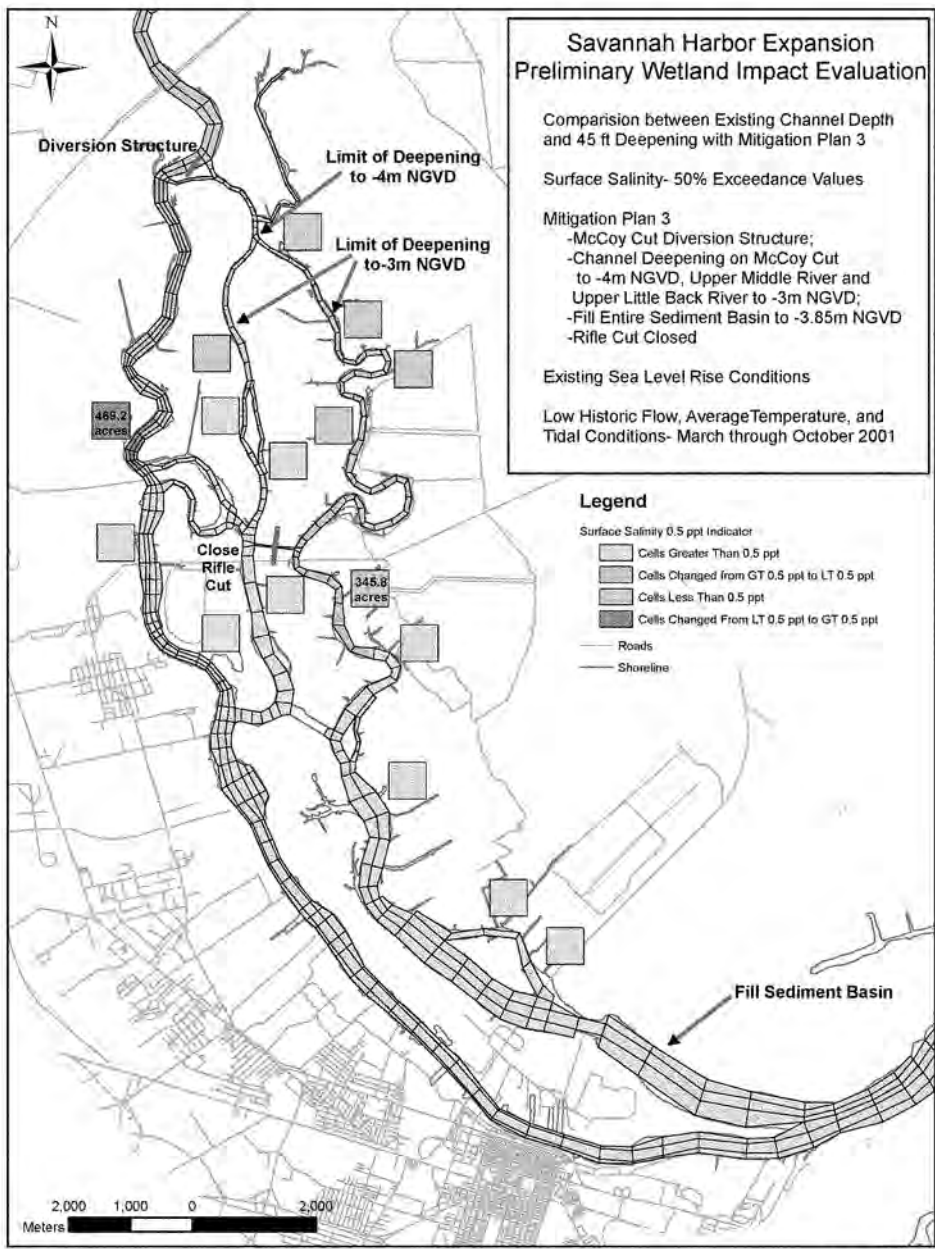


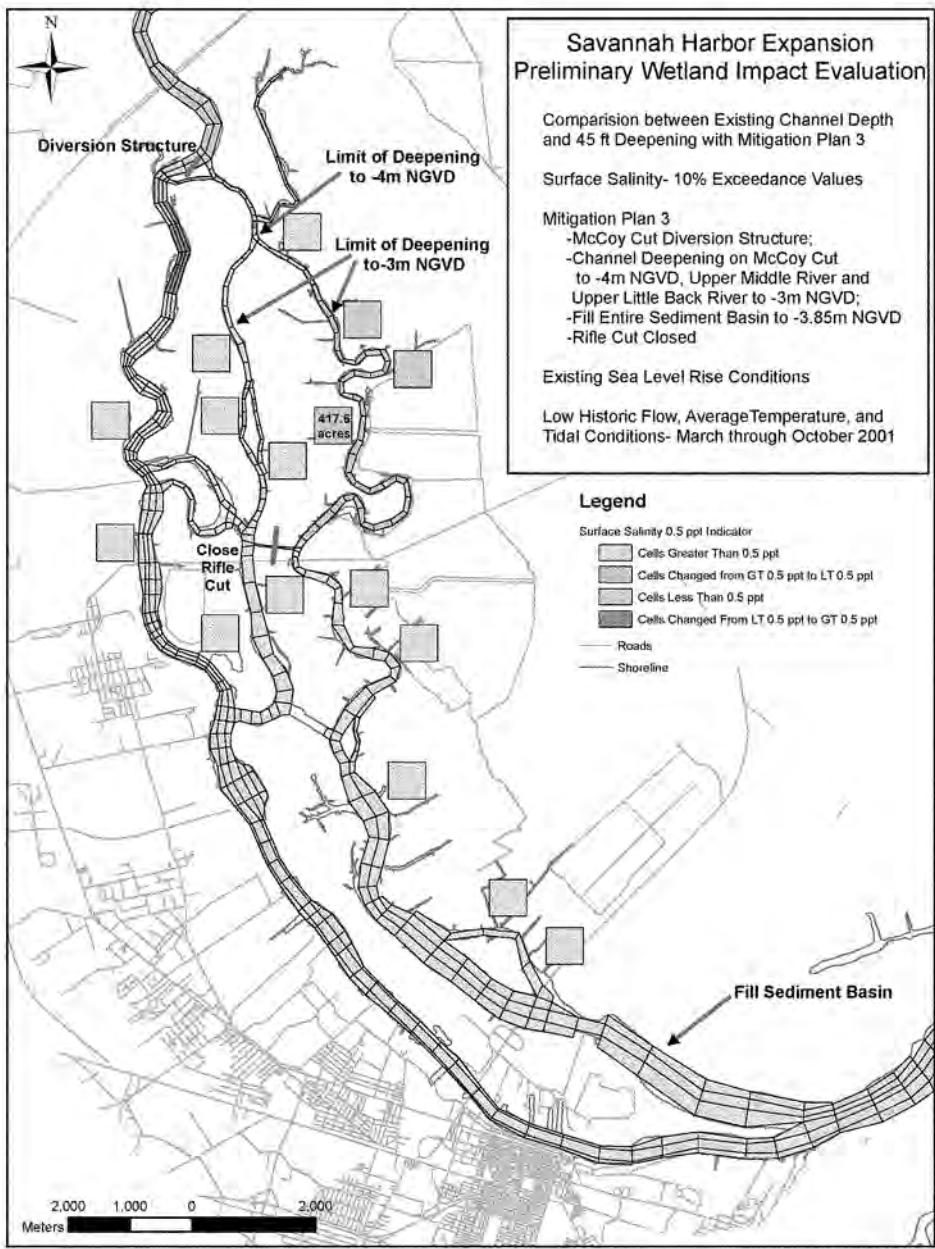


Sensitivity Analysis #1

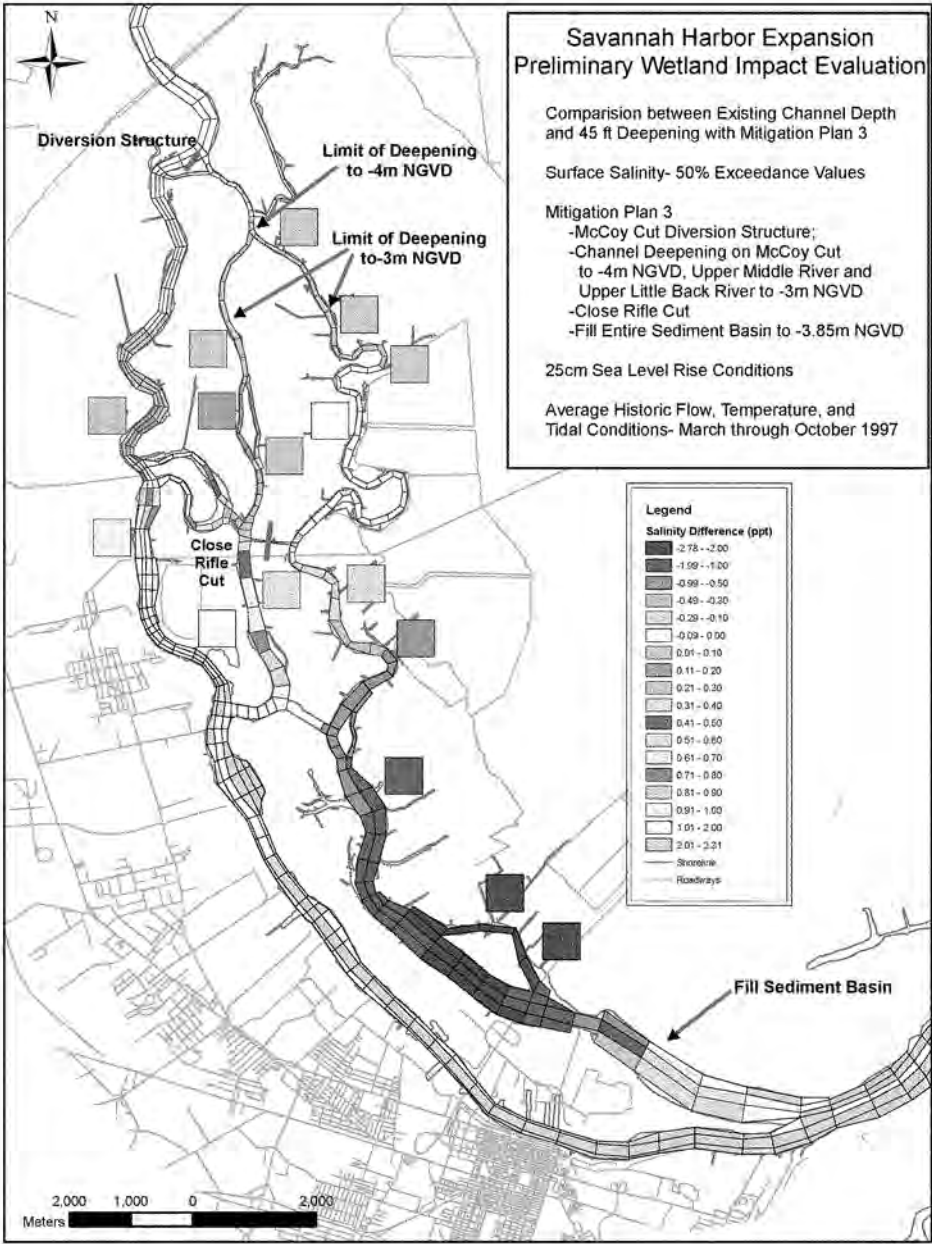


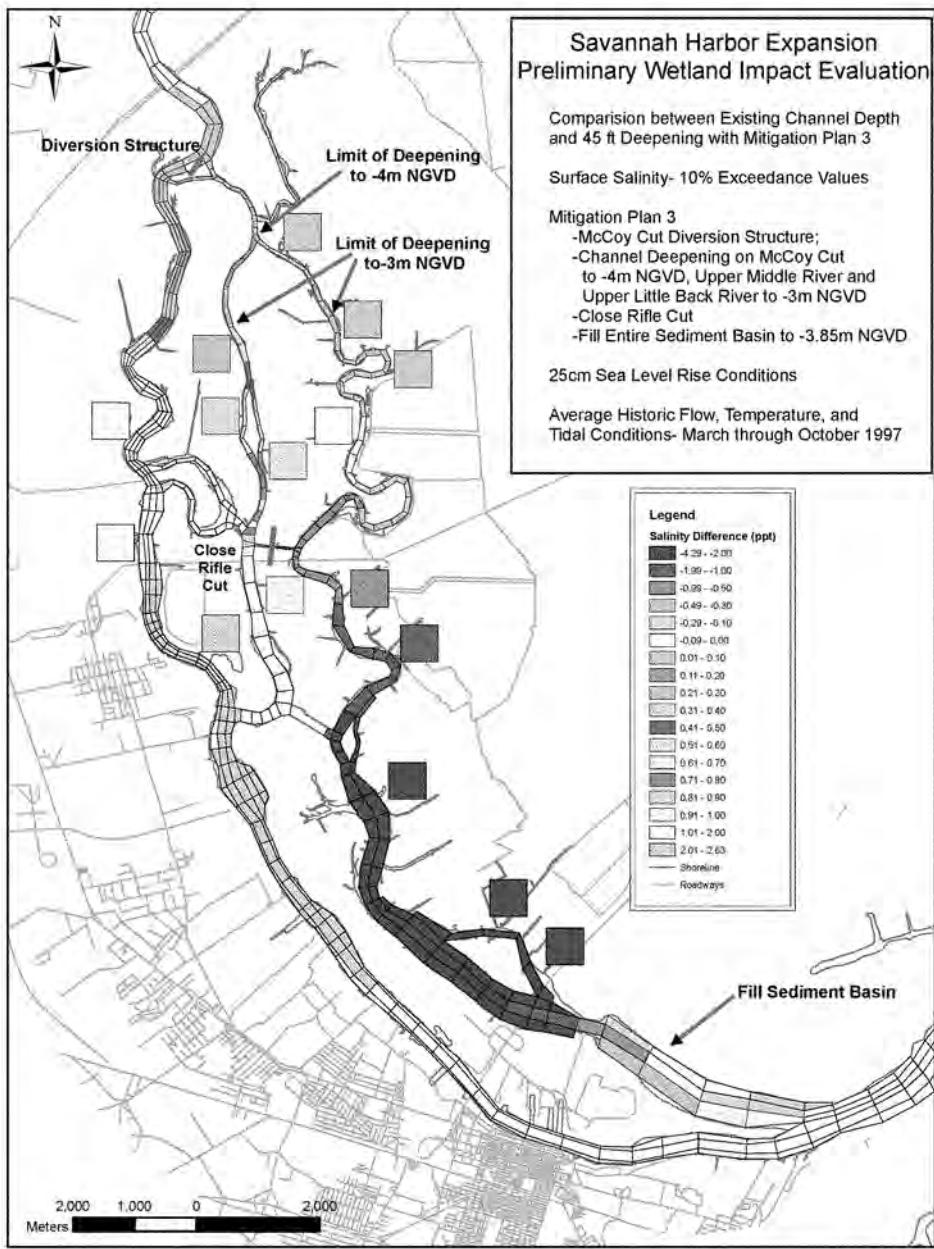


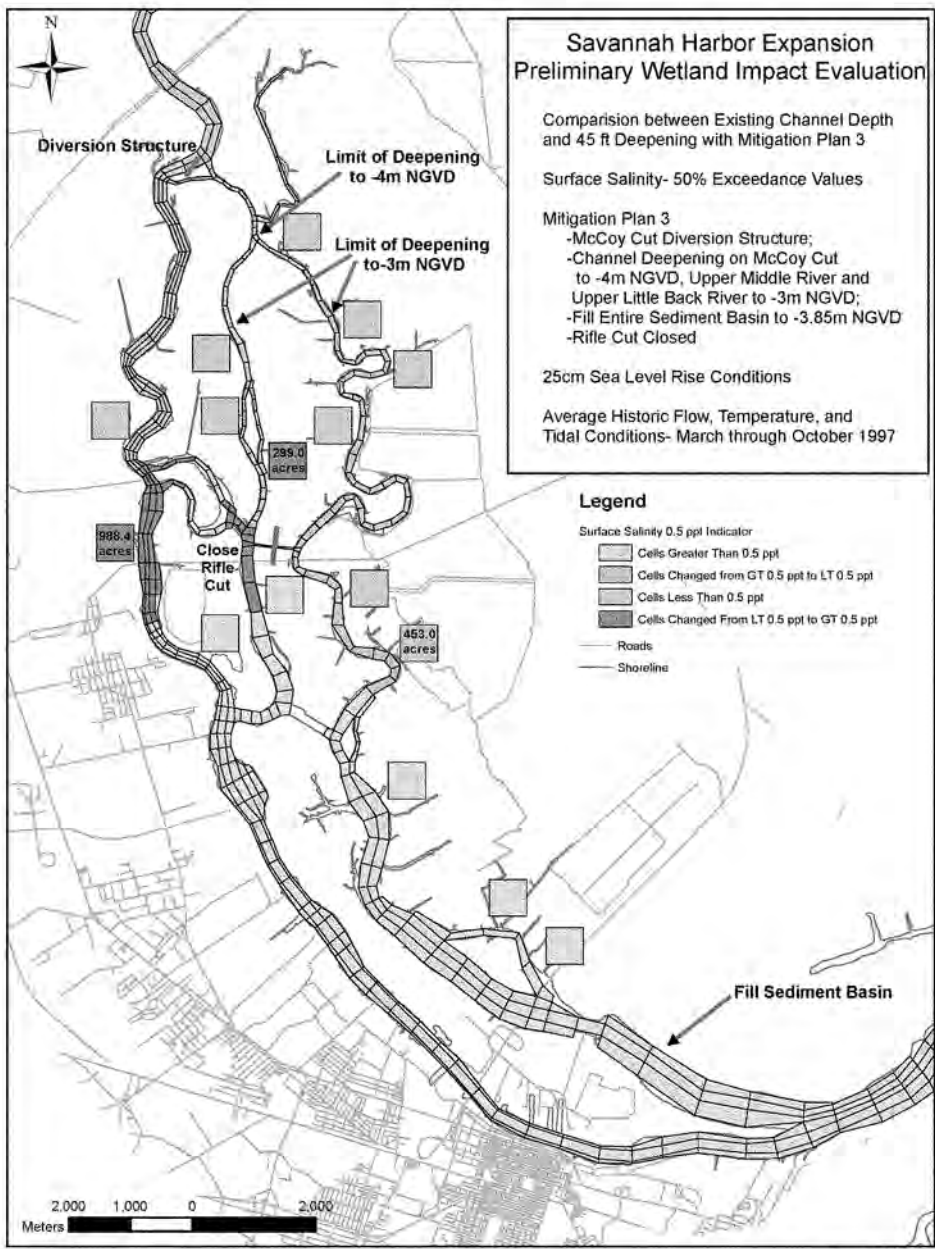


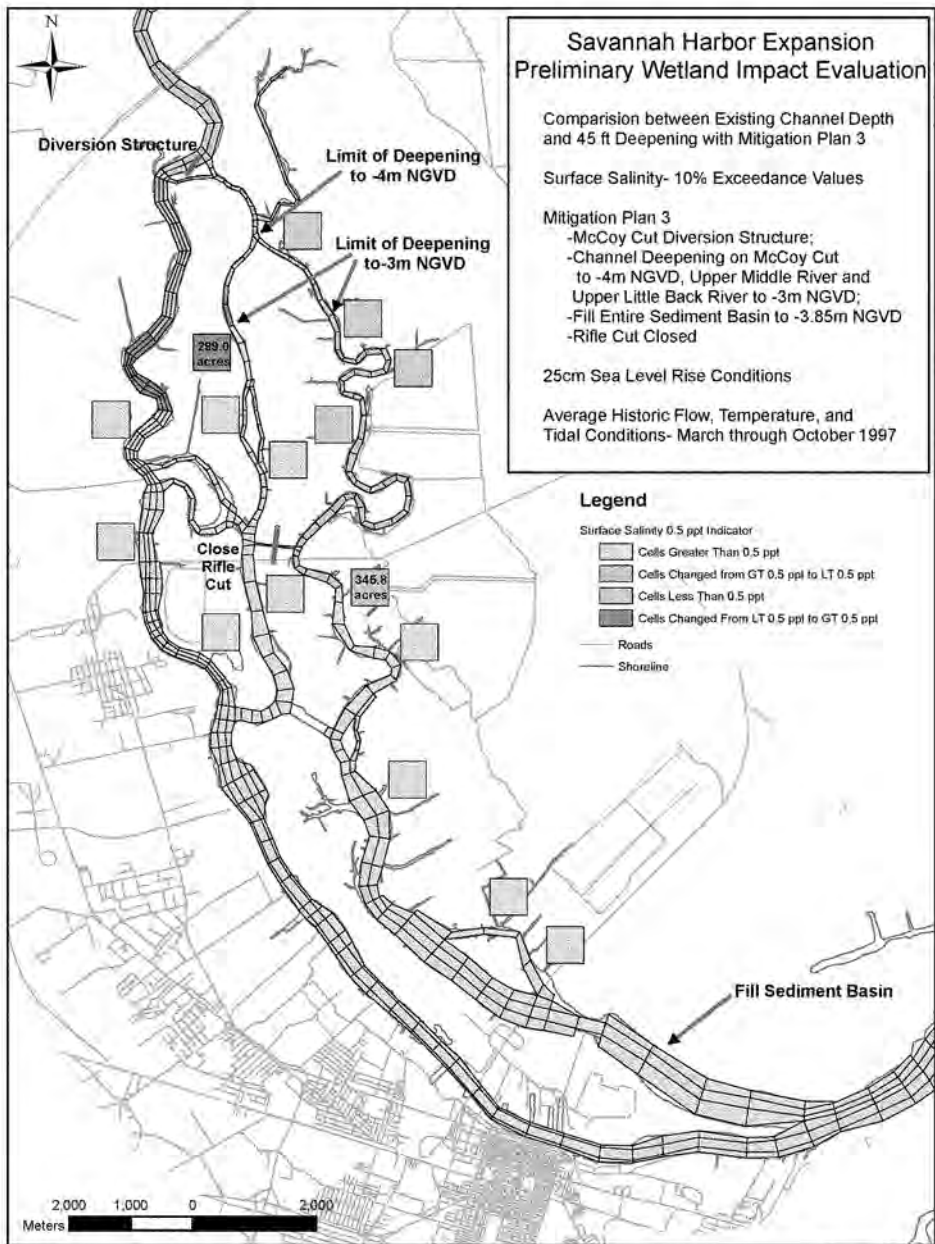


Sensitivity Analysis #2A

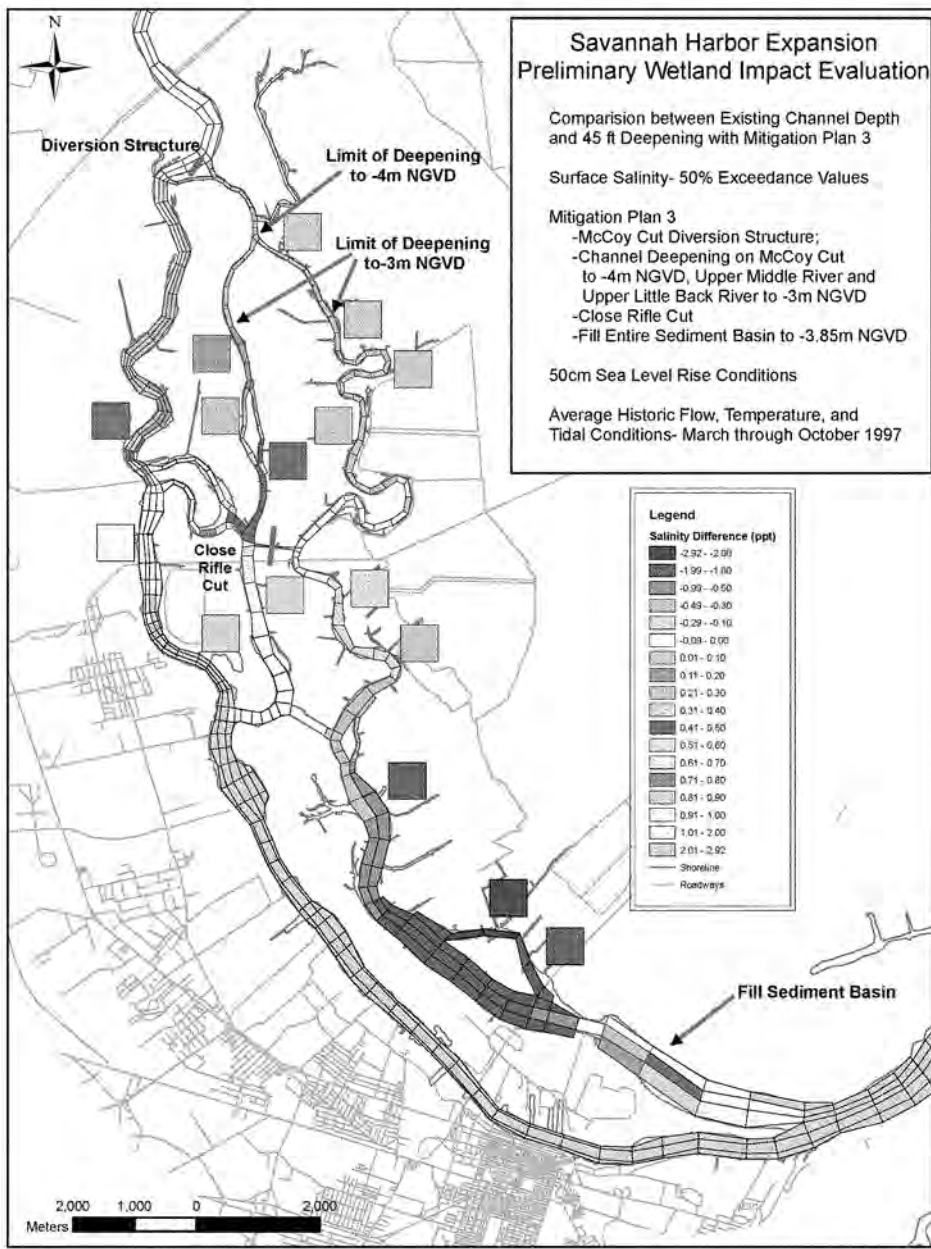


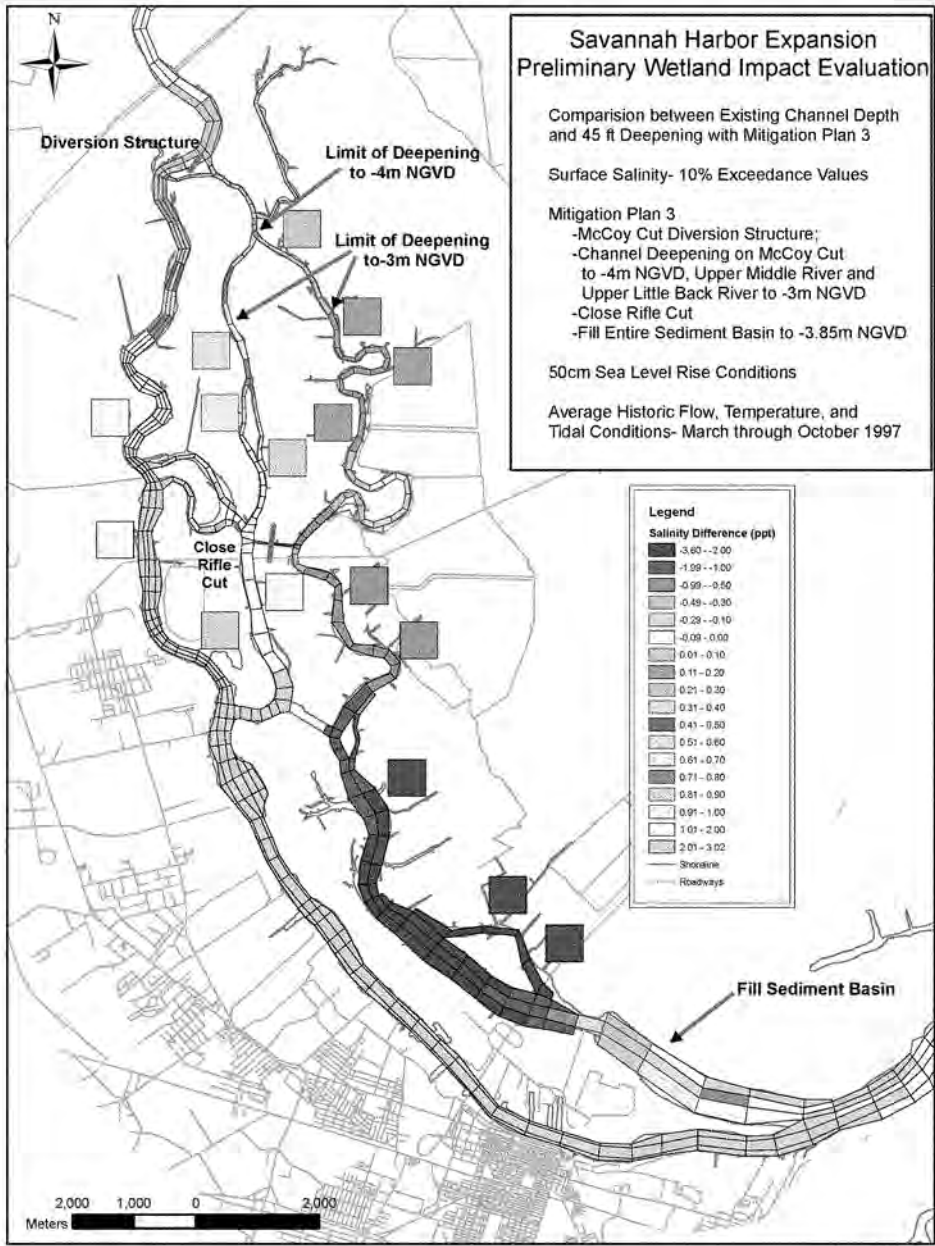


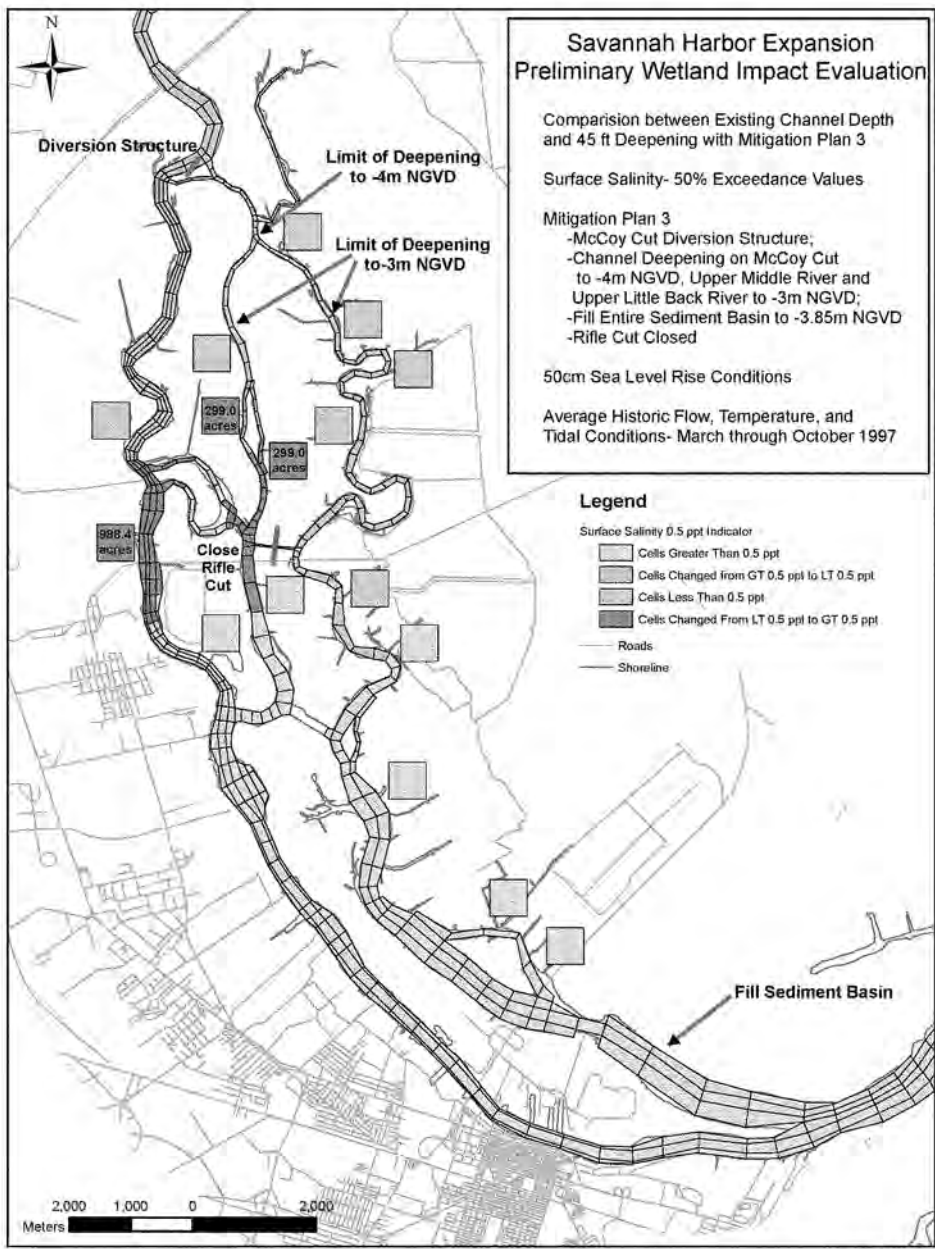


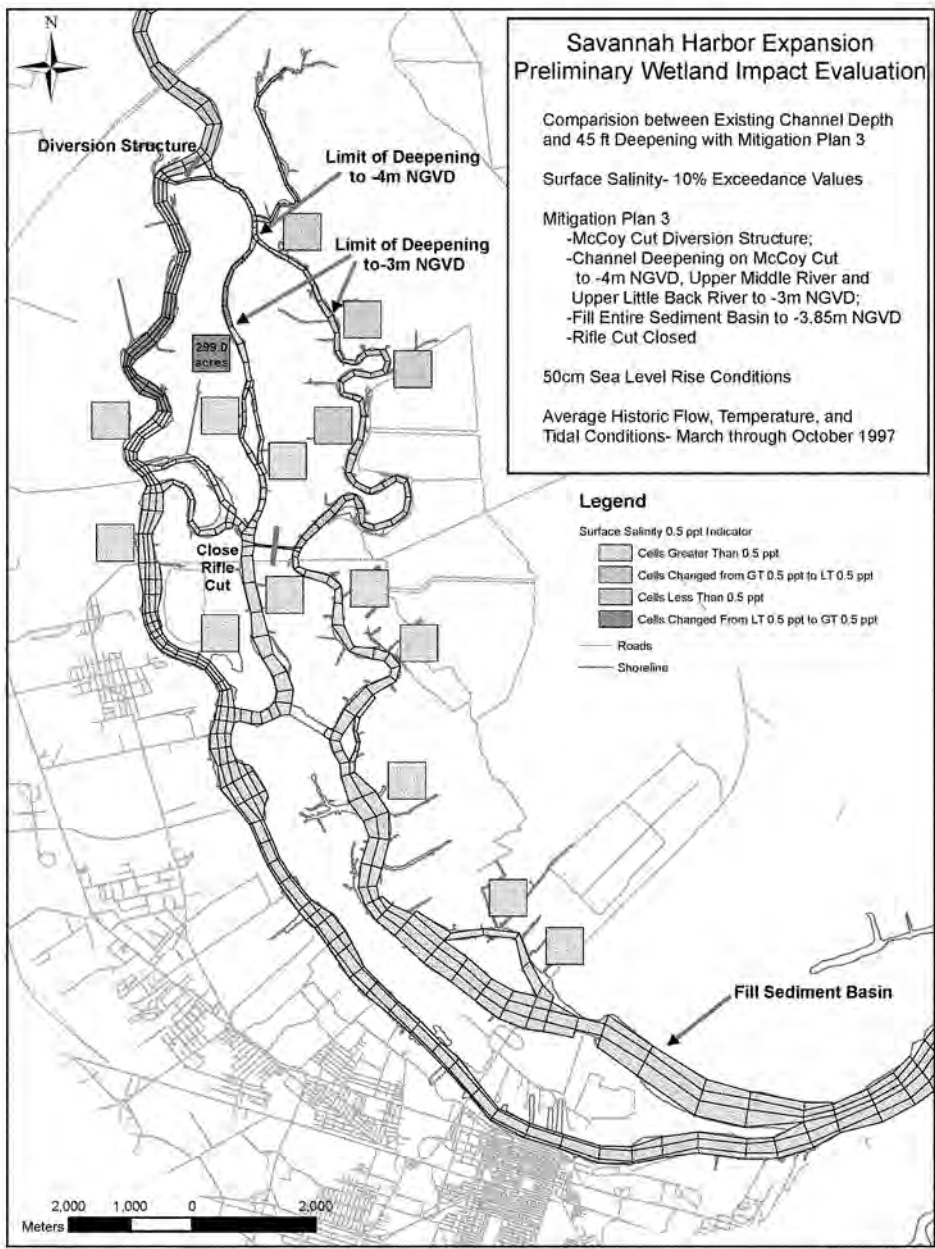


Sensitivity Analysis #2B



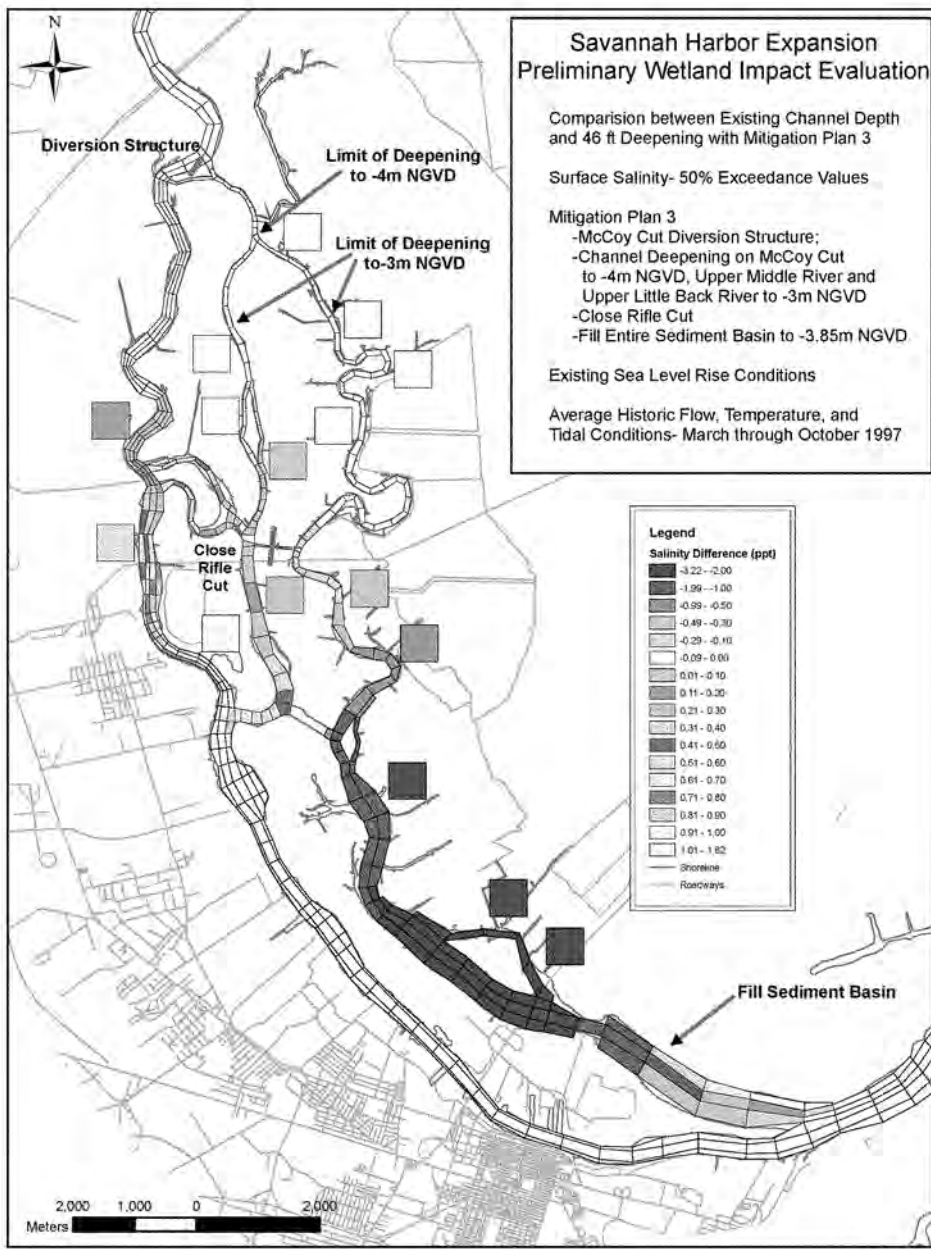


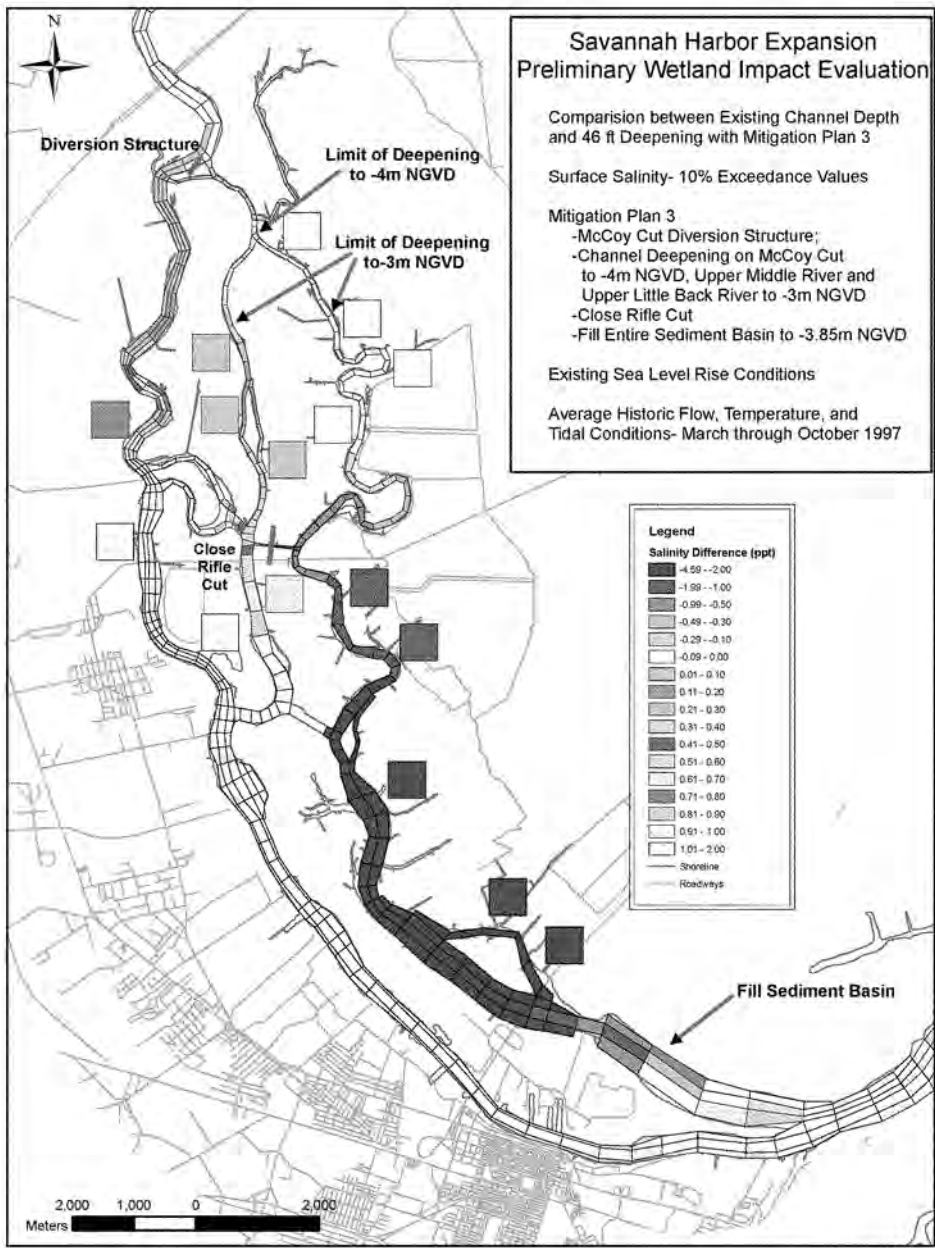


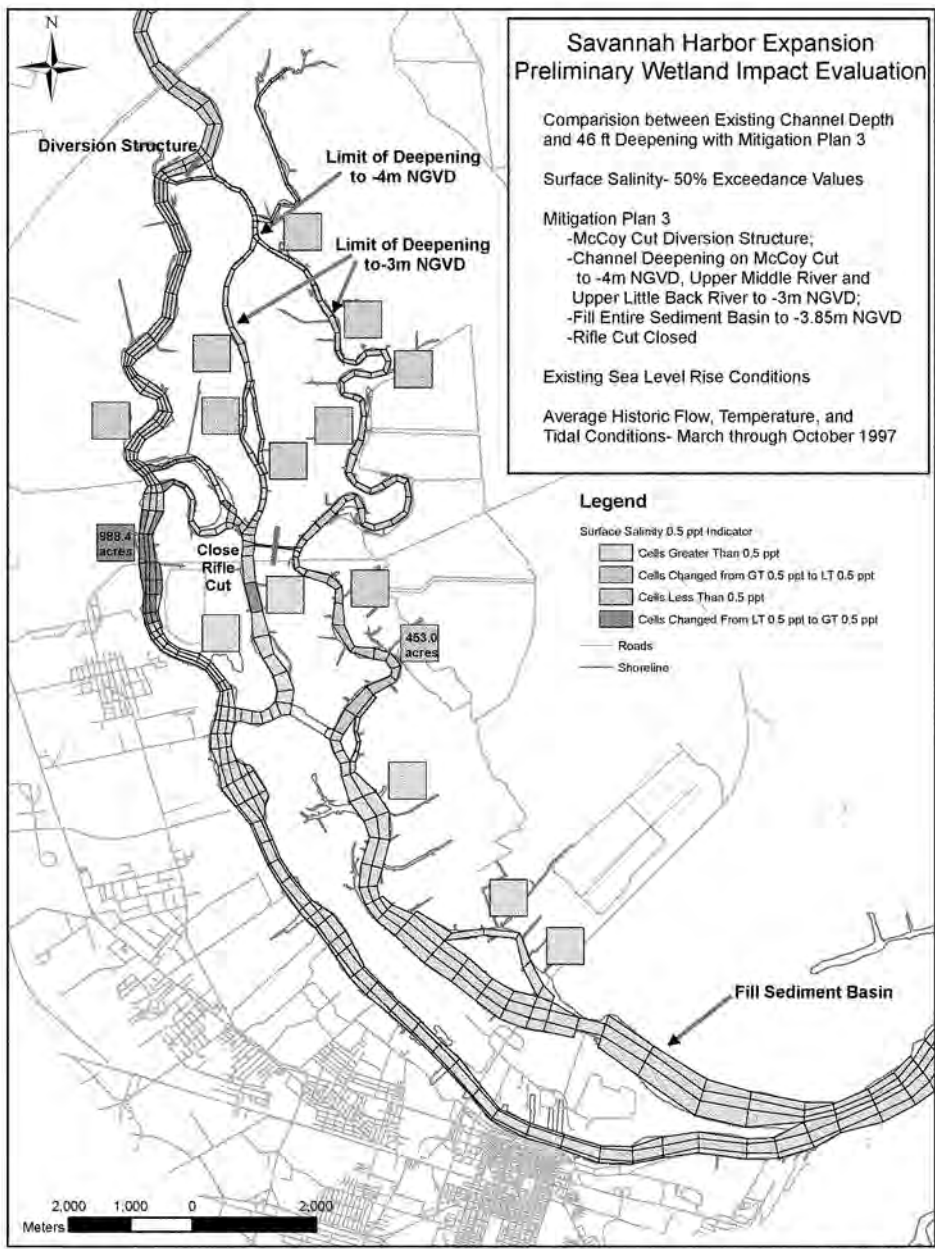


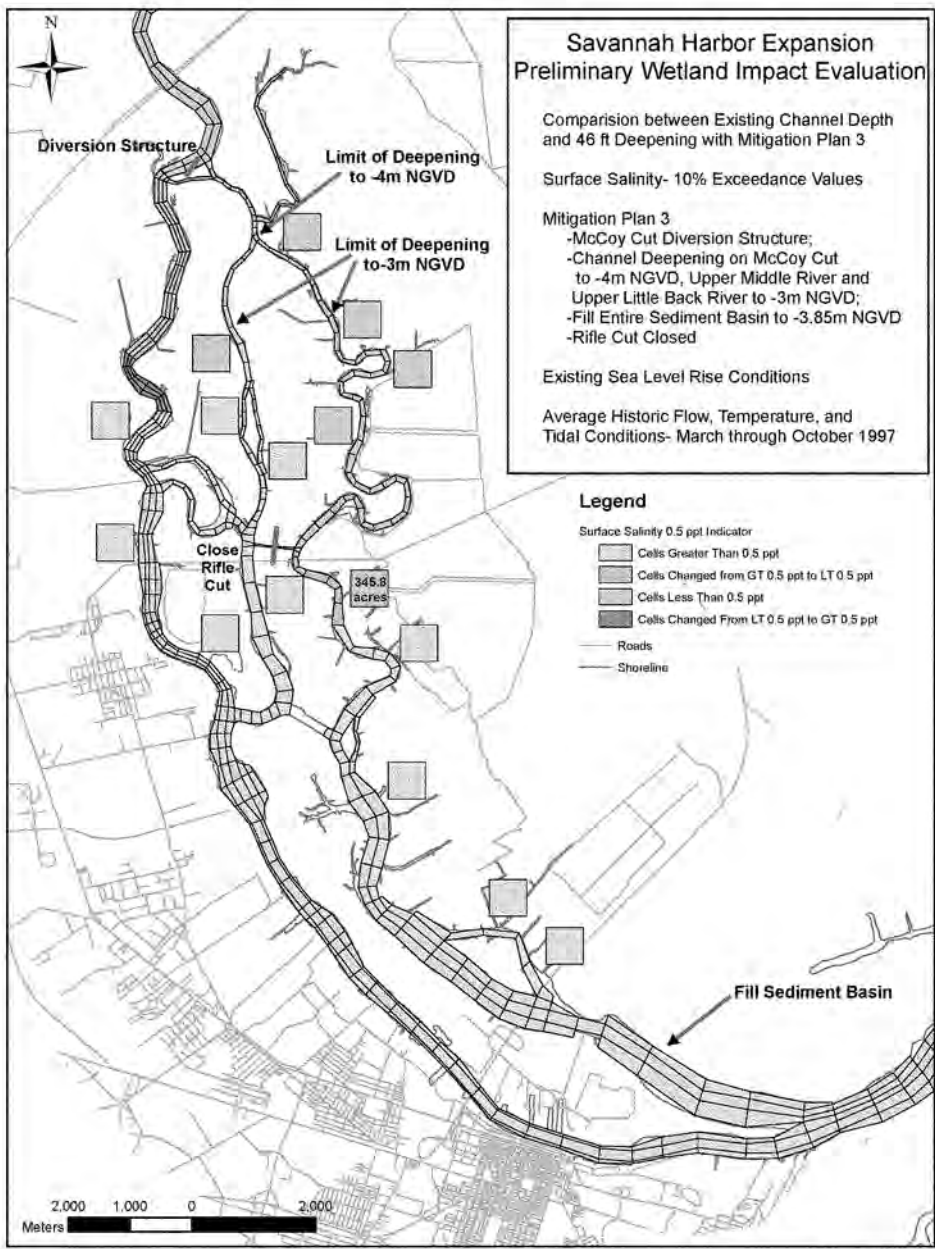
46-ft Deepening

Basic Evaluation

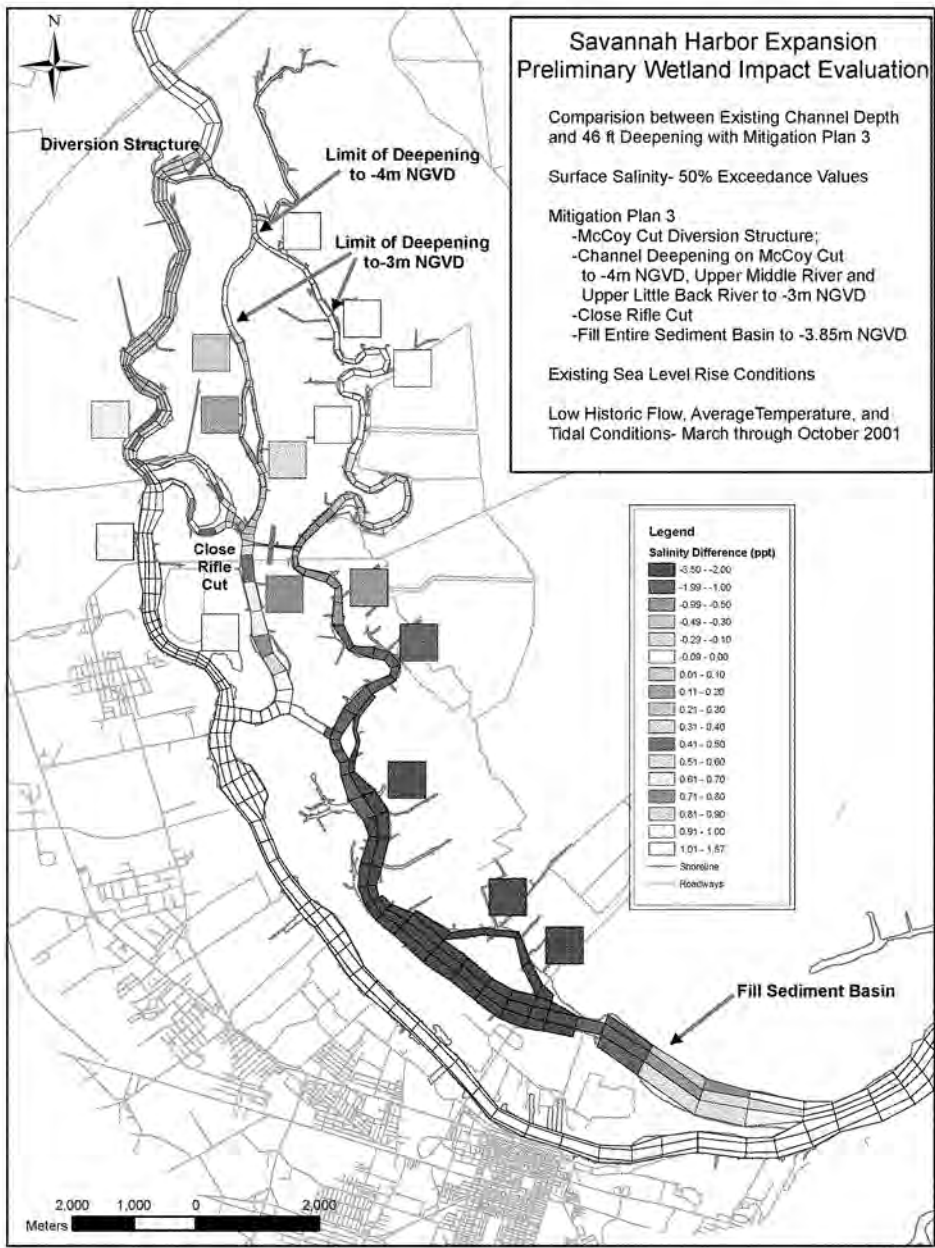


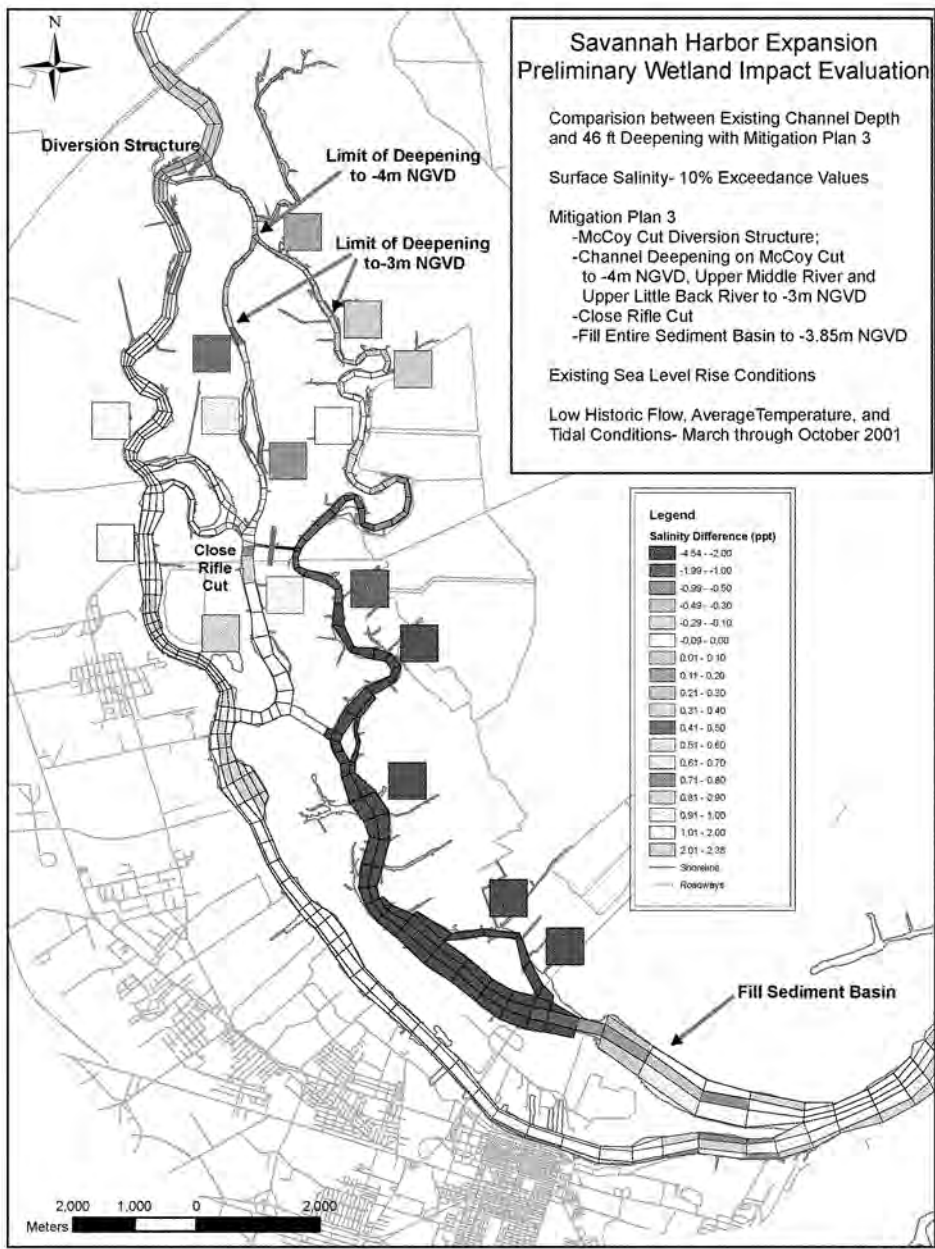


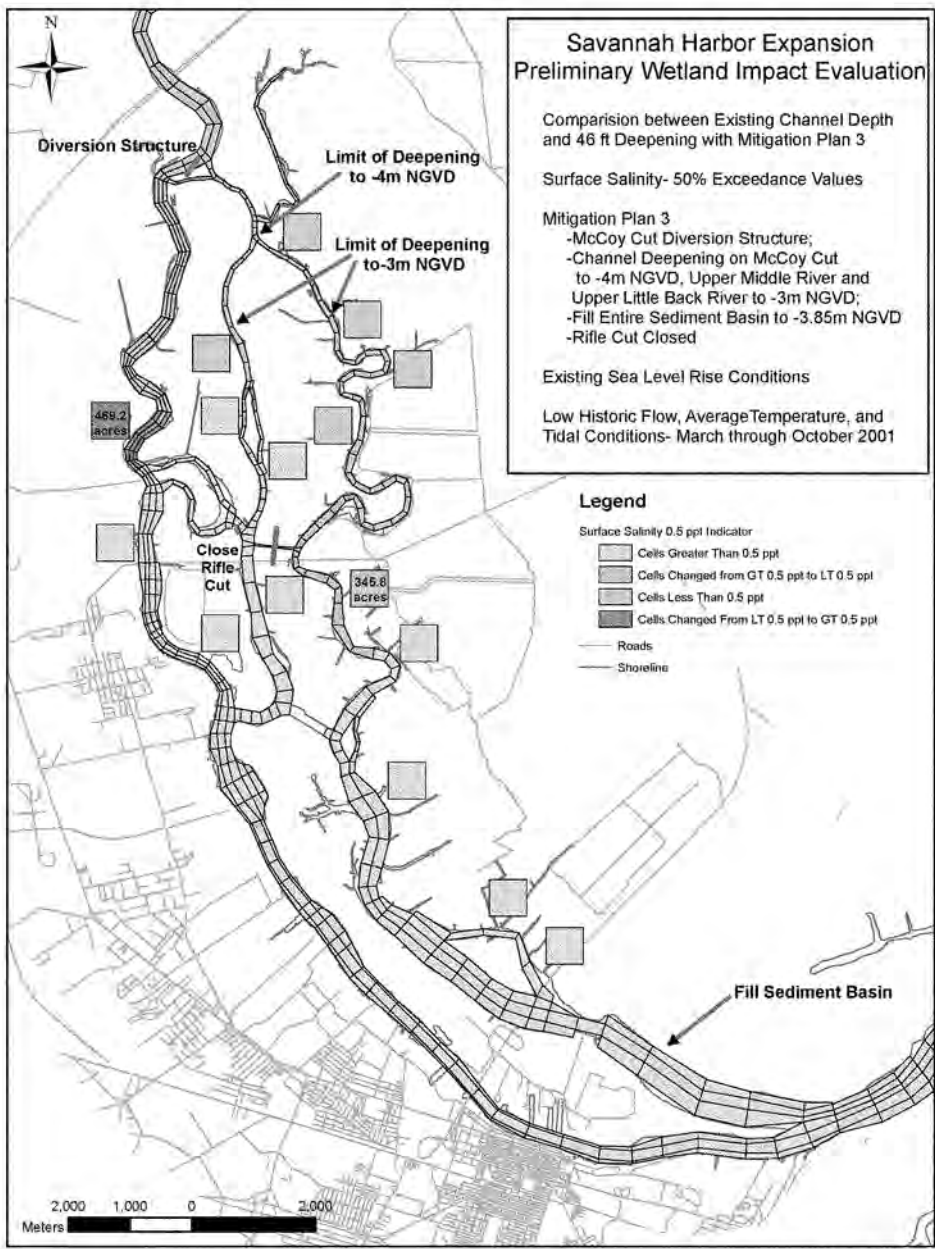


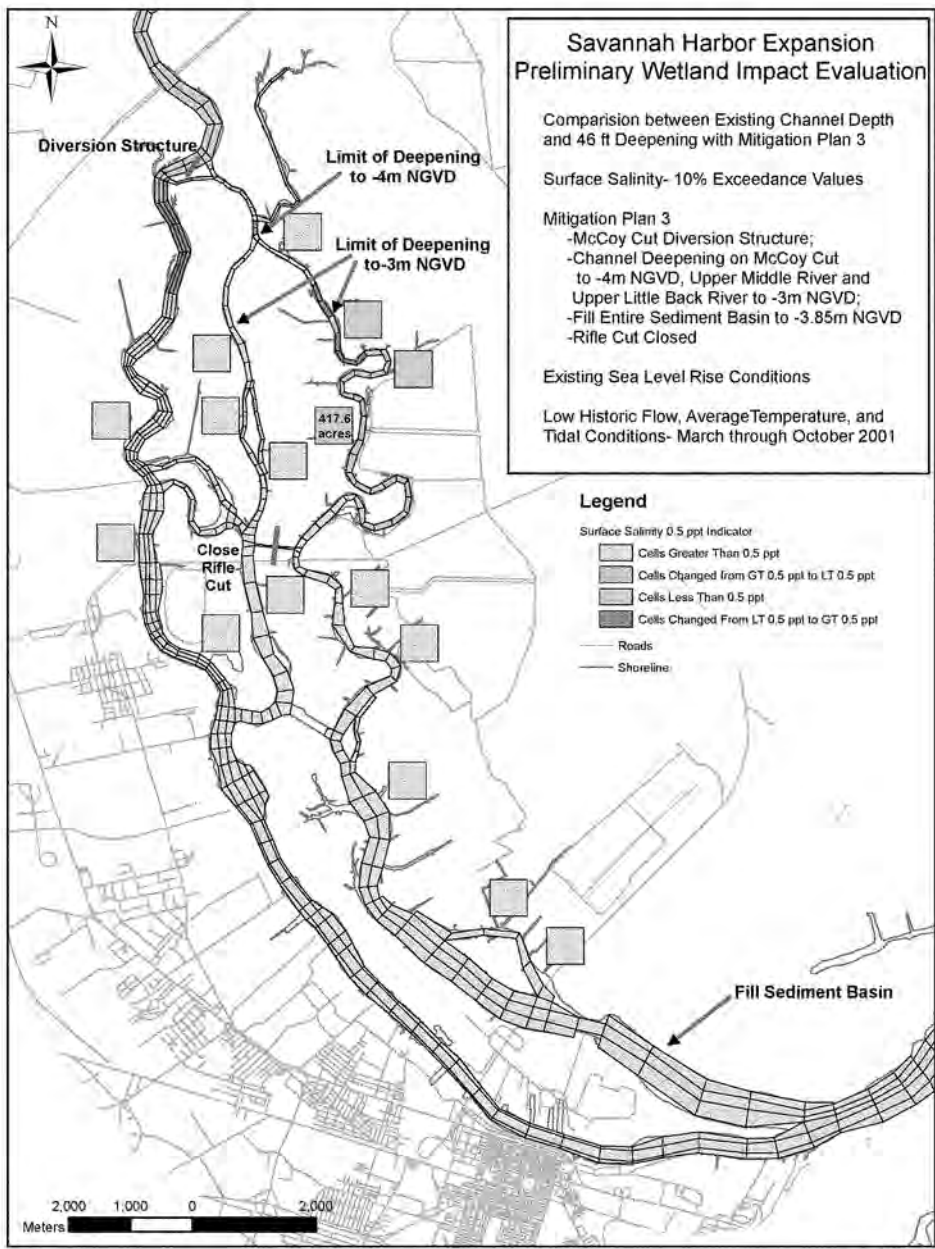


Sensitivity Analysis #1

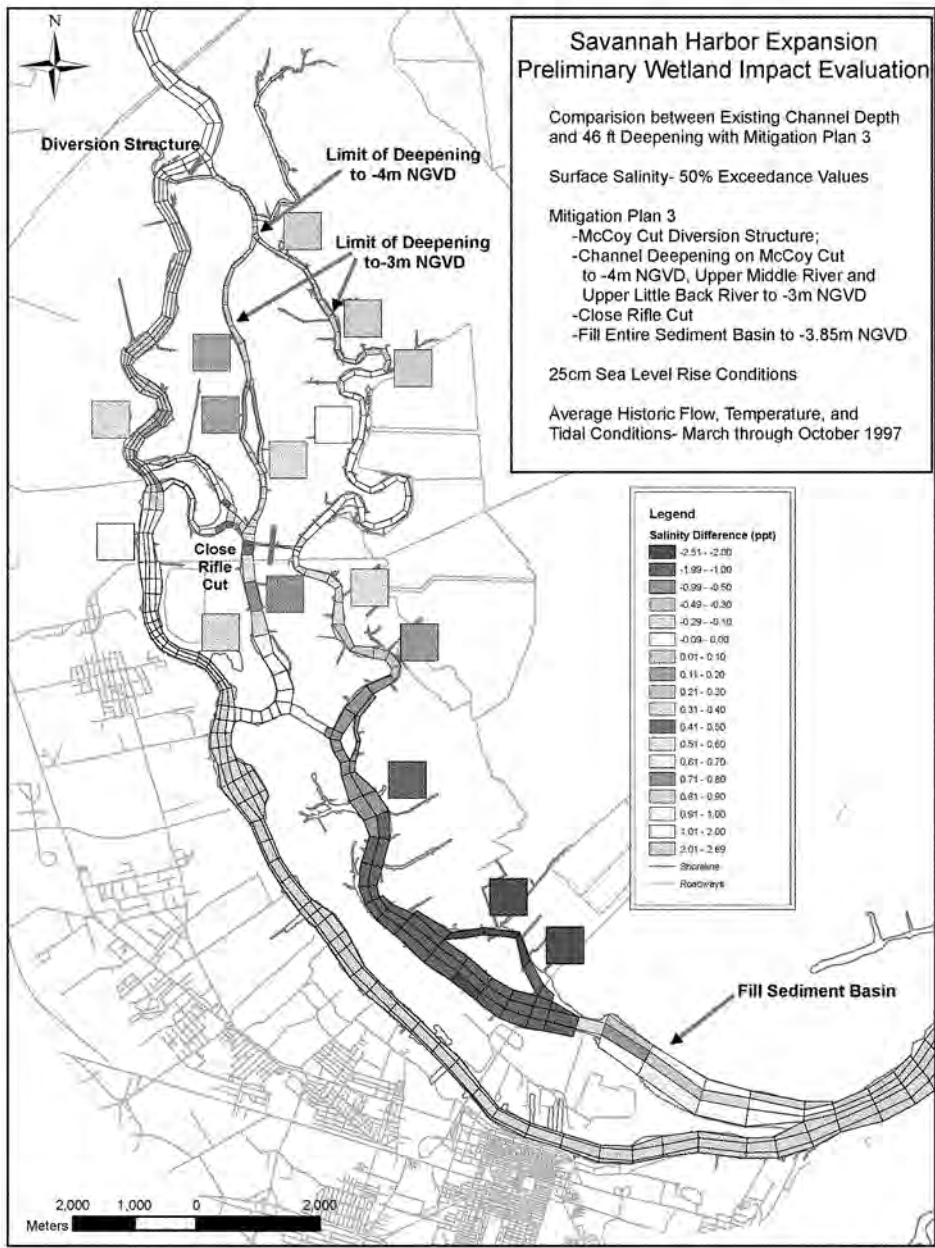


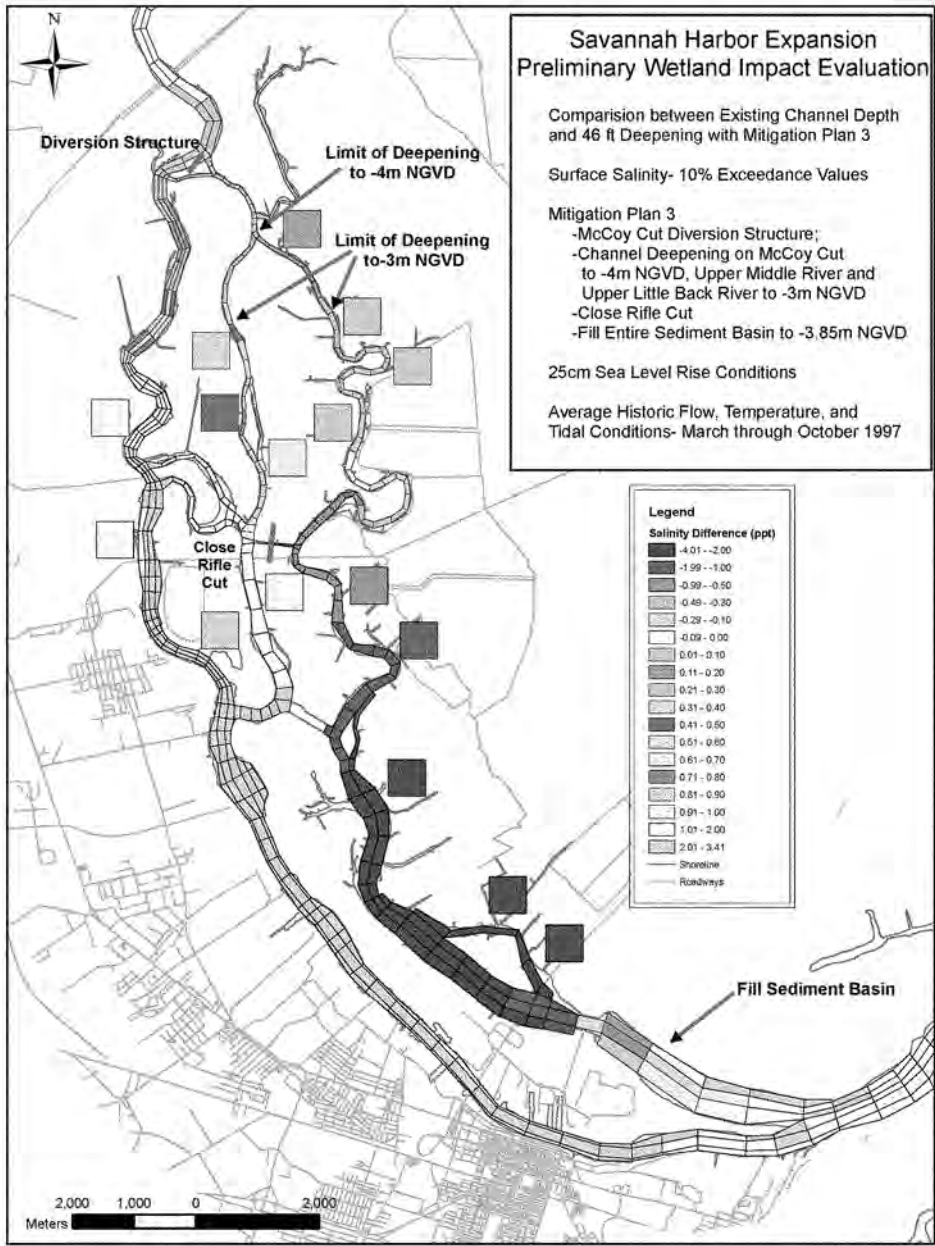


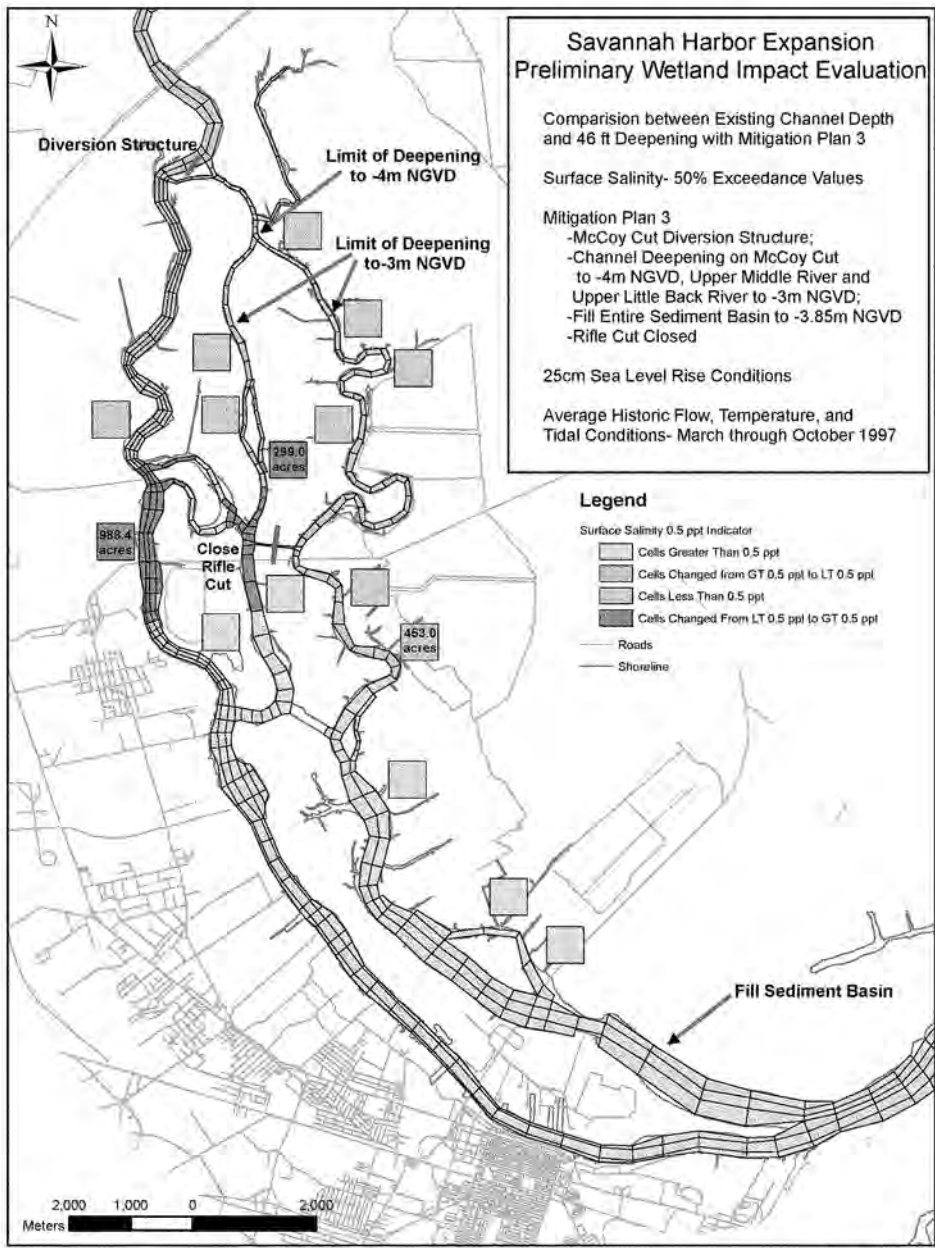


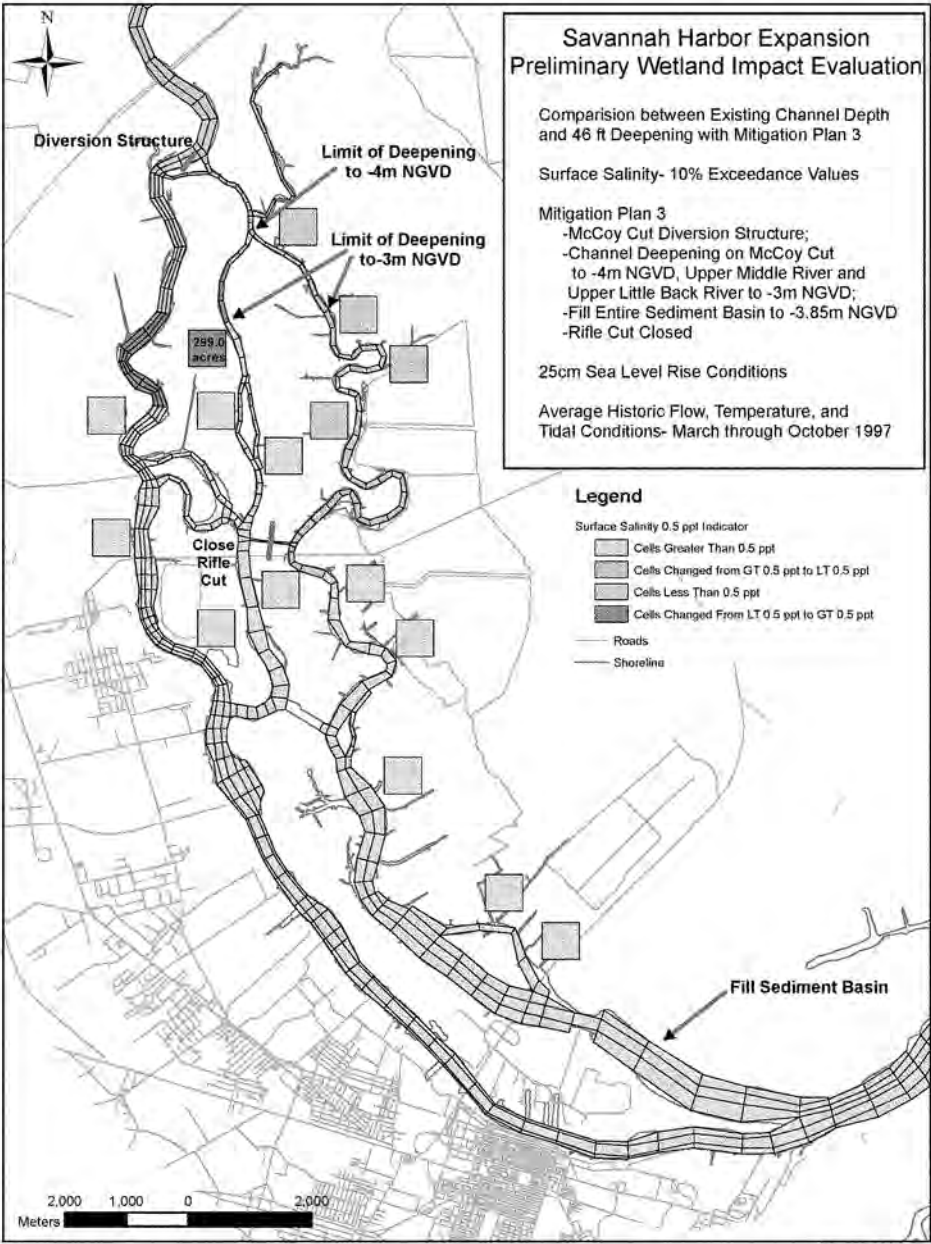


Sensitivity Analysis #2A

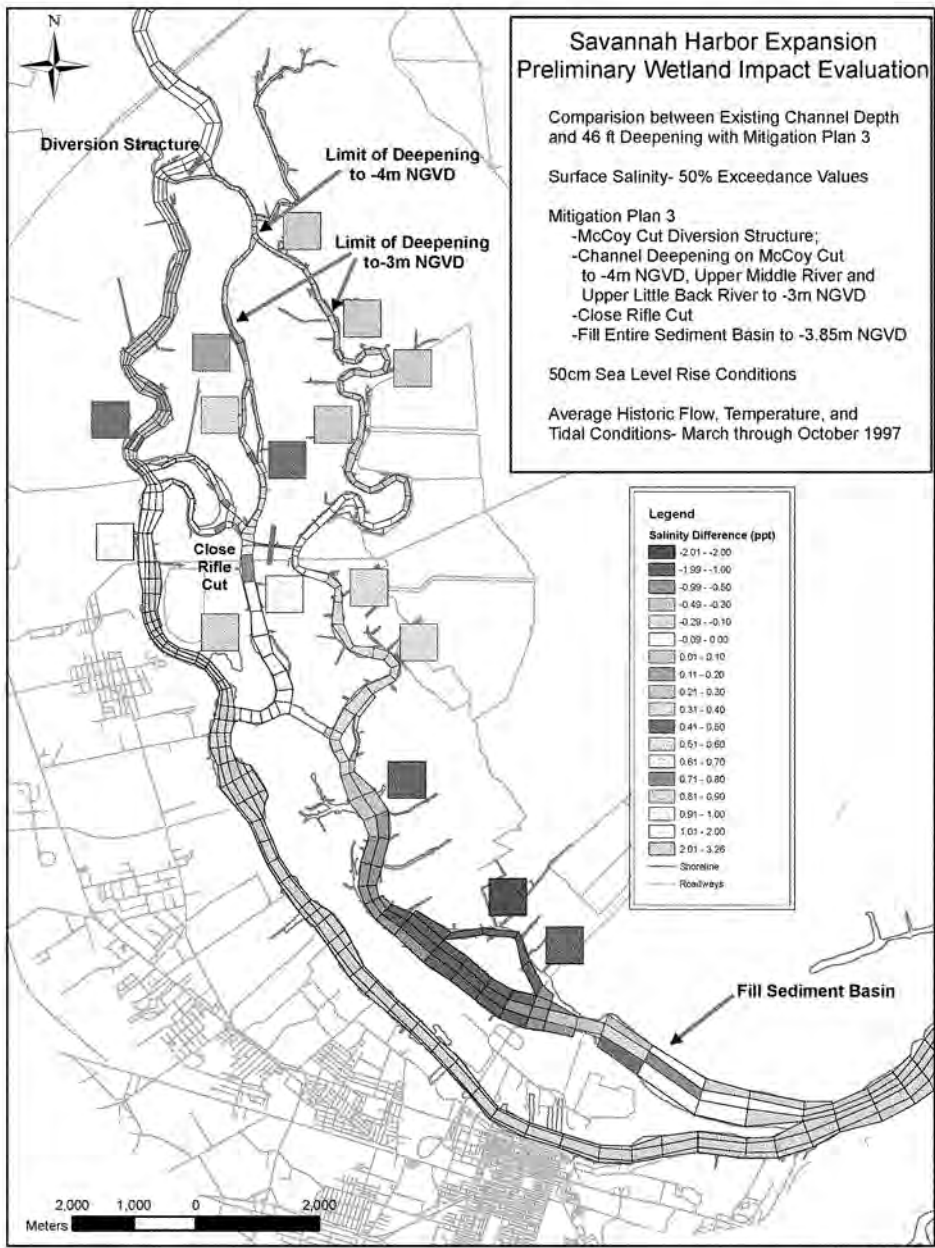


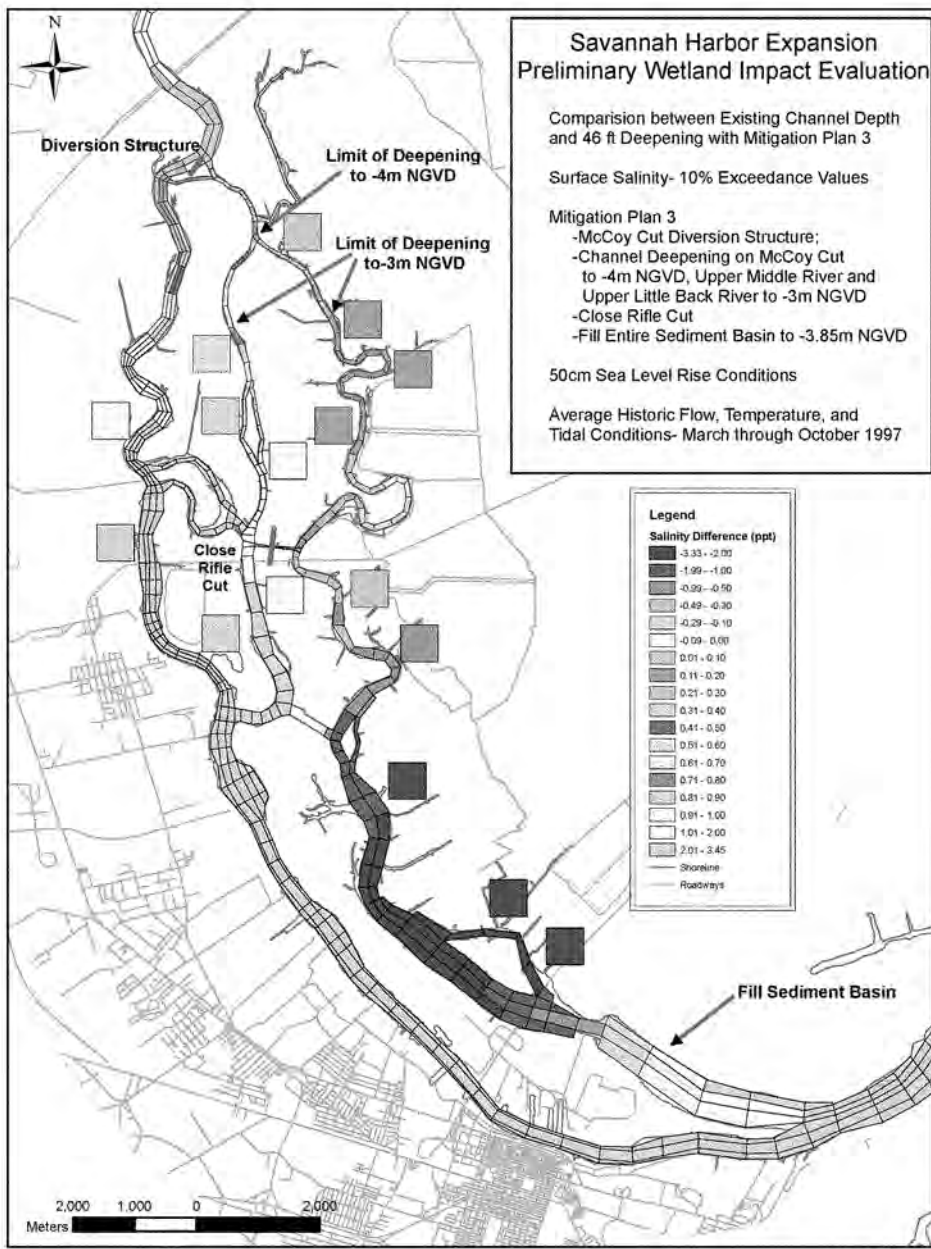


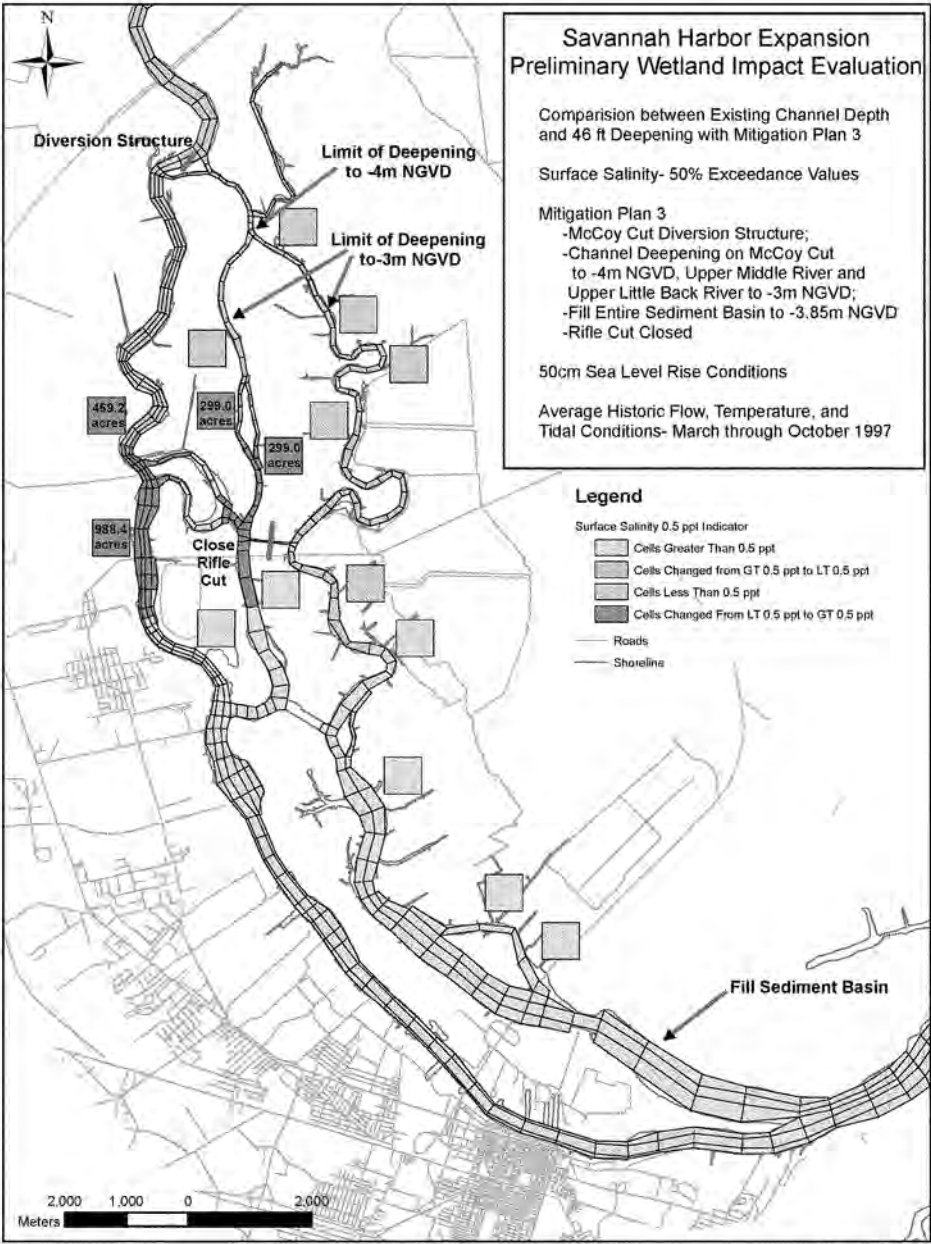


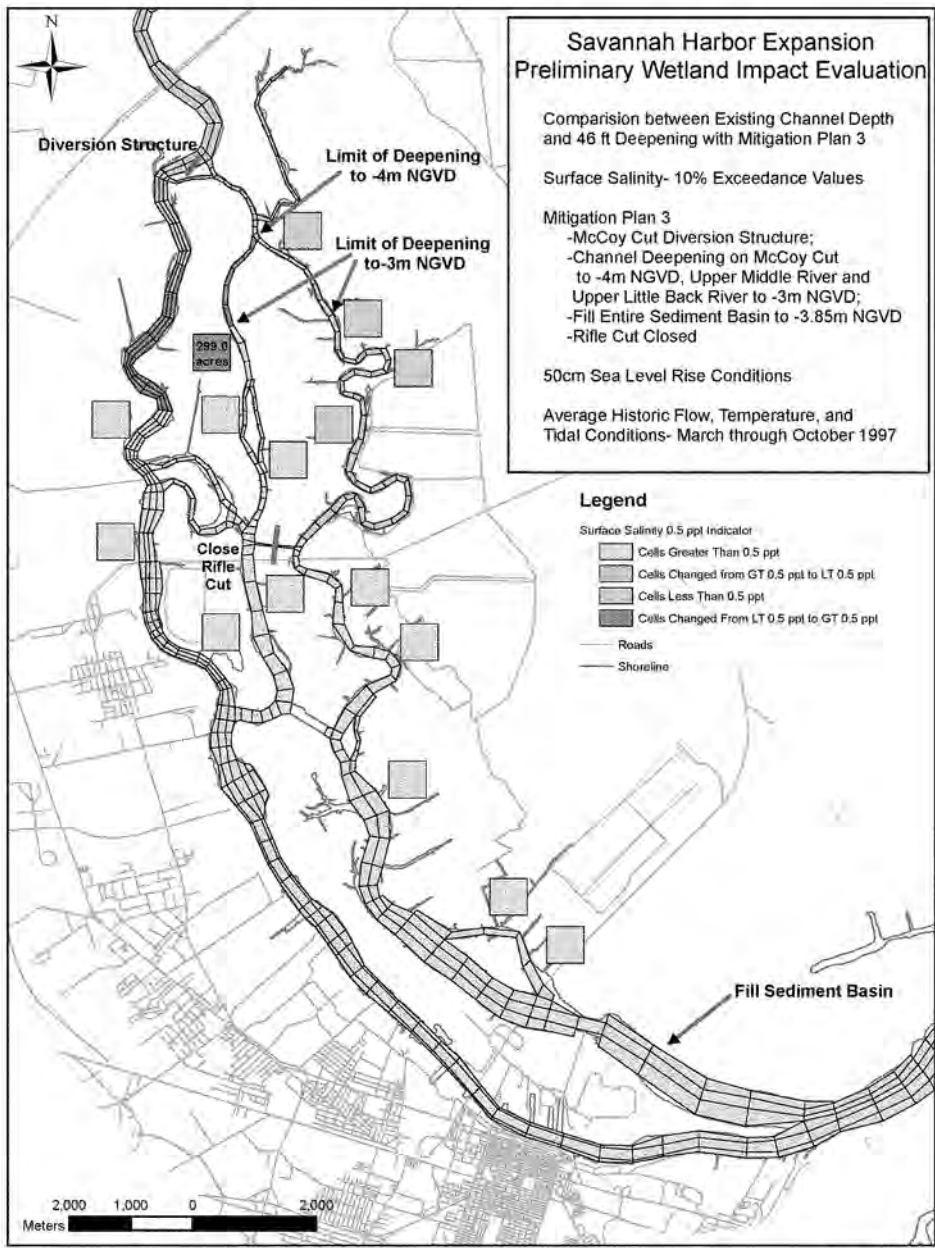


Sensitivity Analysis #2B



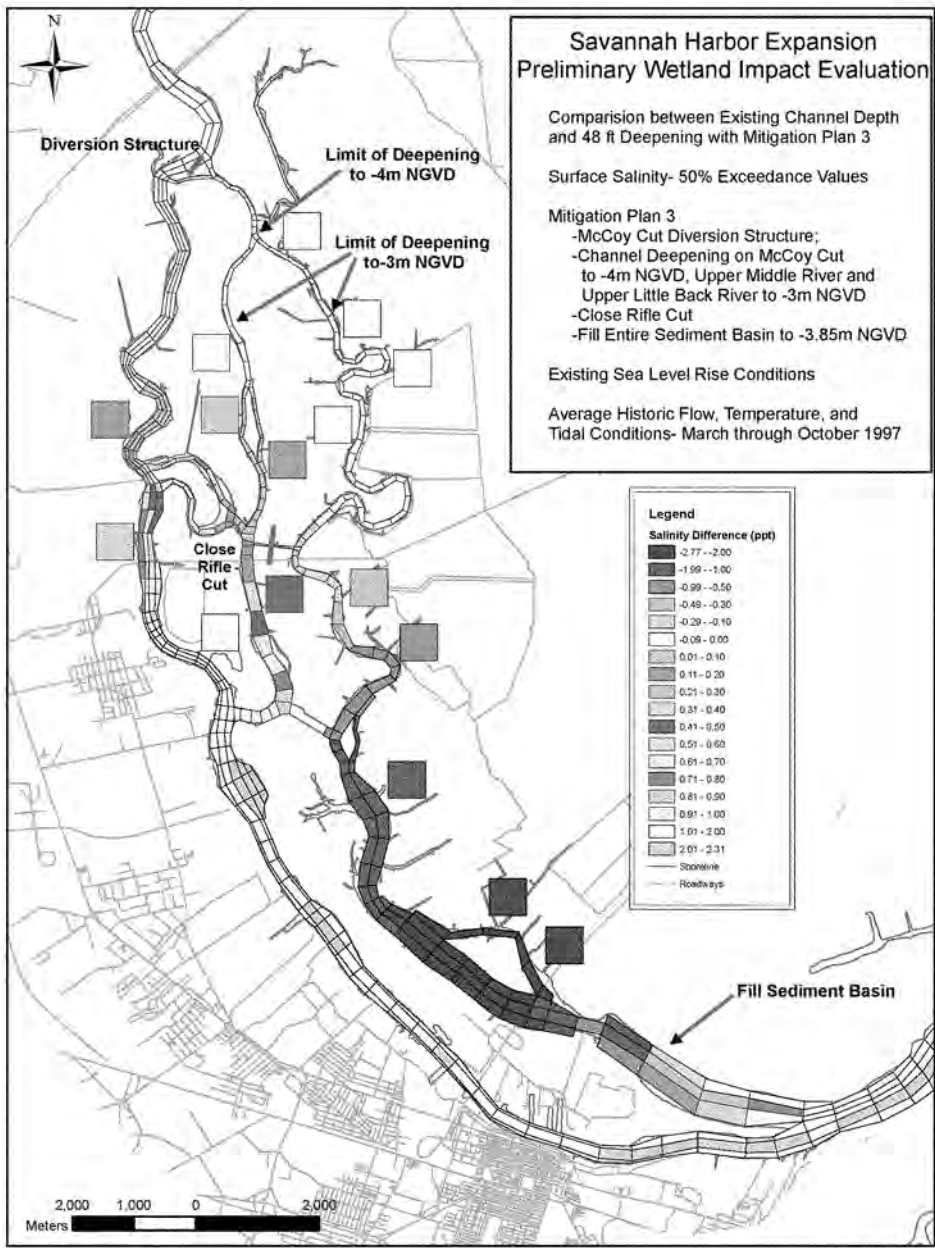


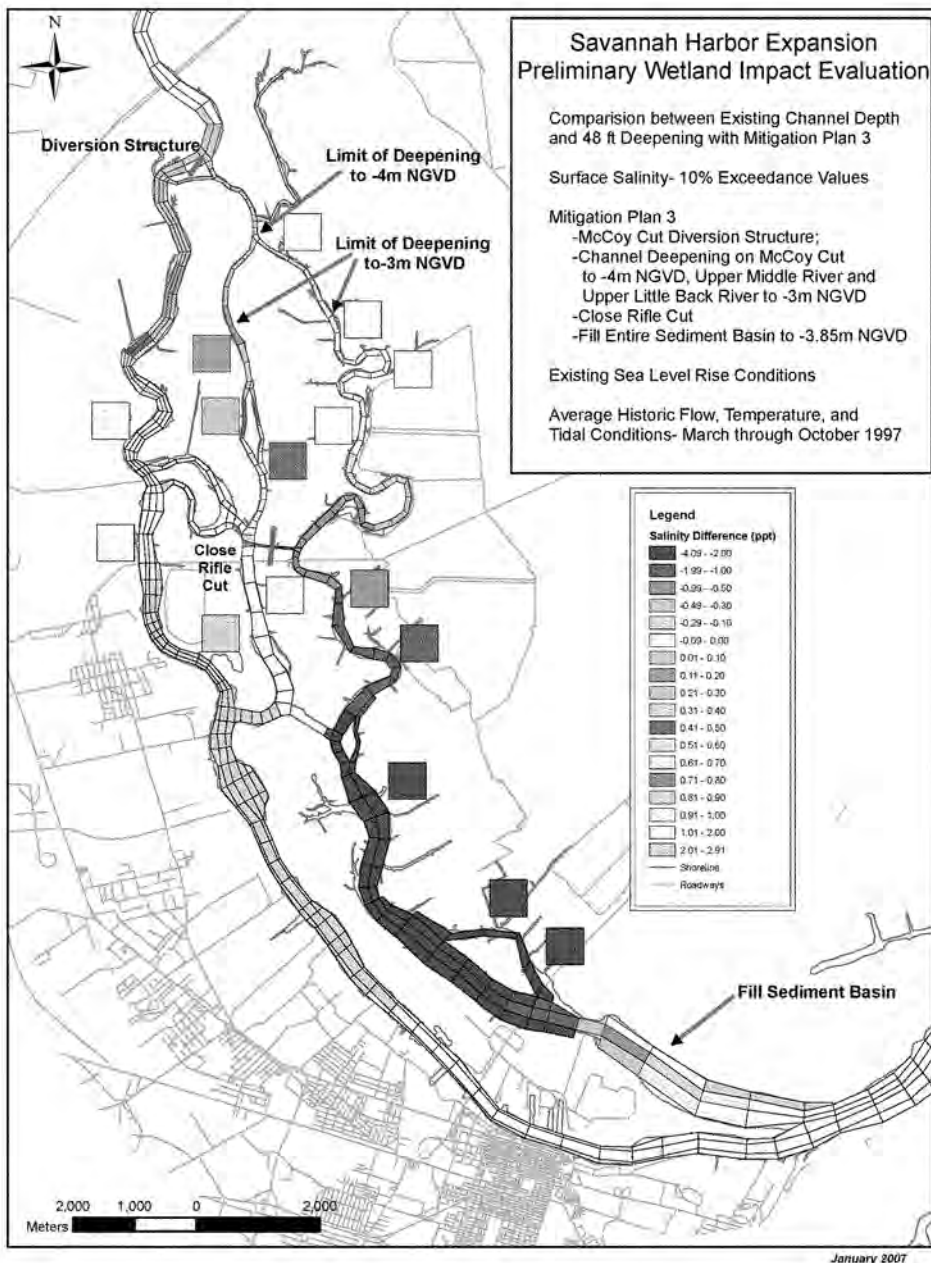


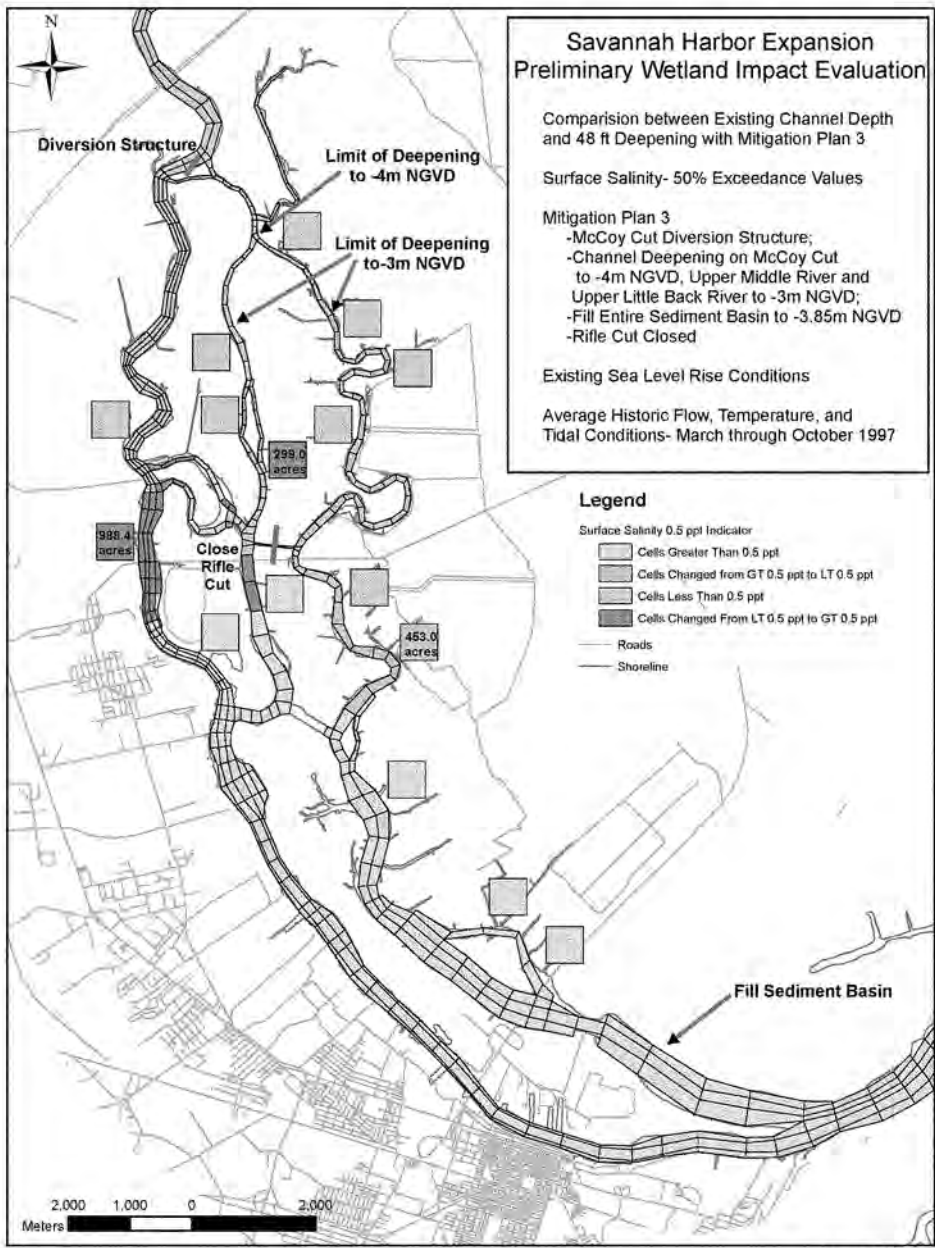


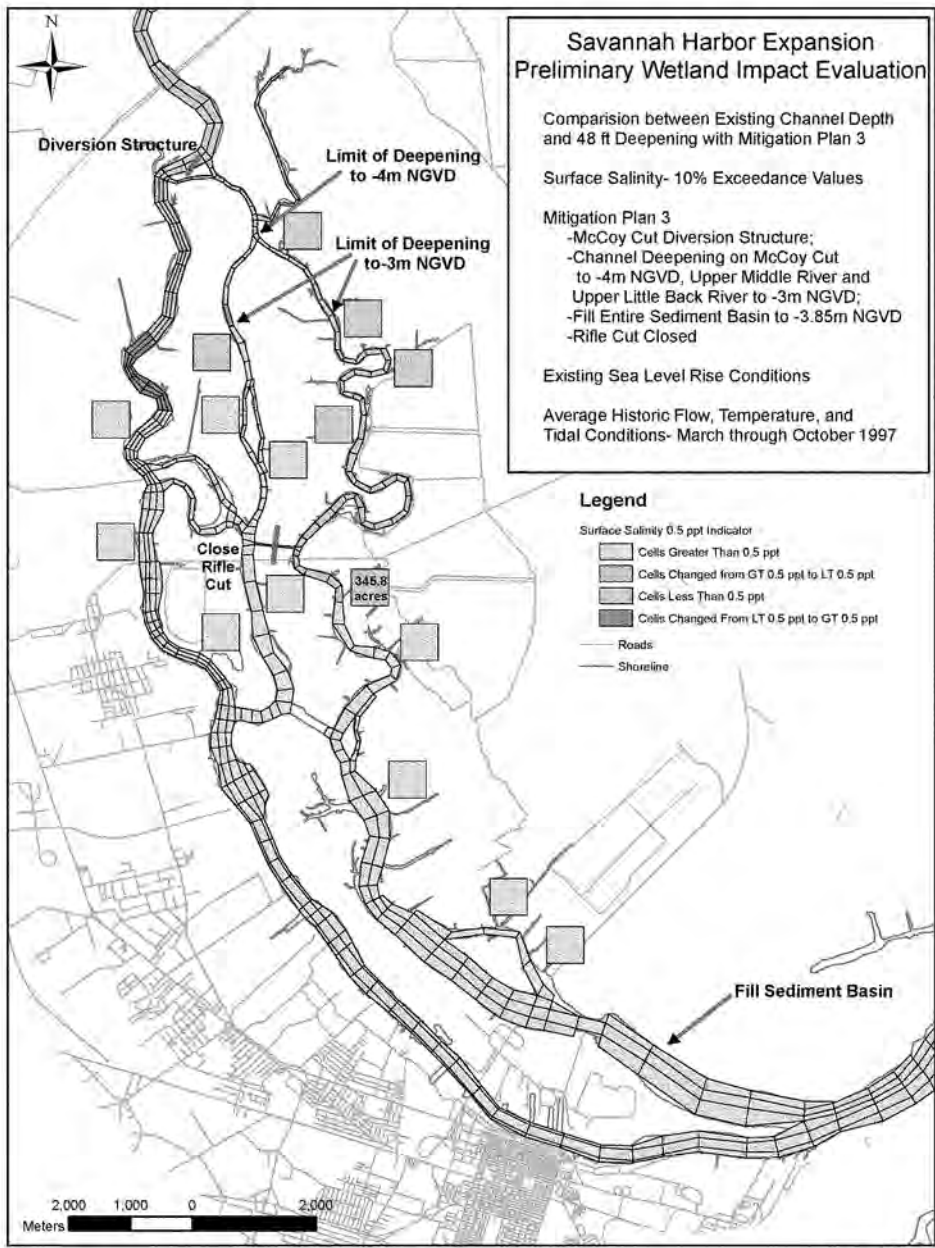
48-ft Deepening

Basic Evaluation

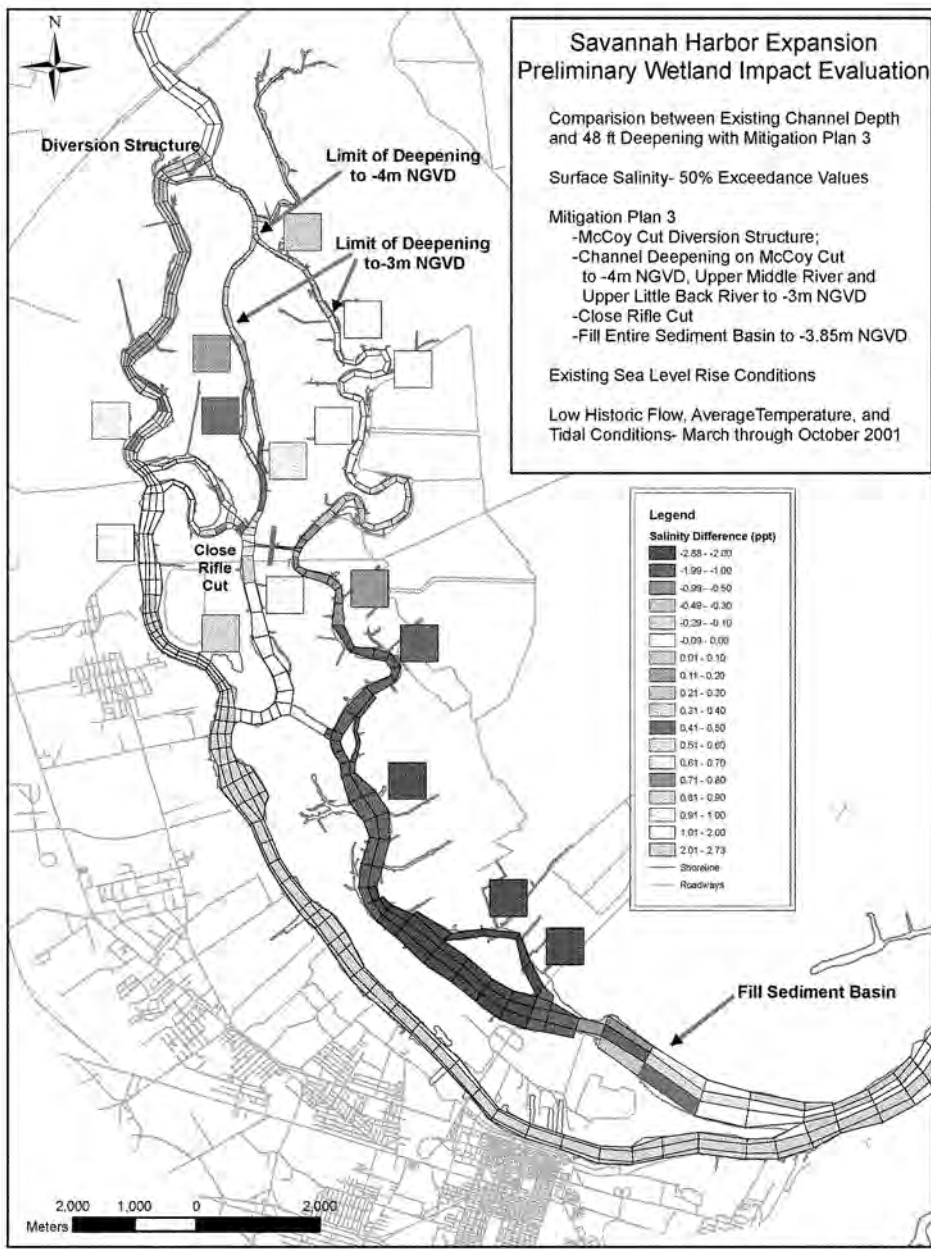


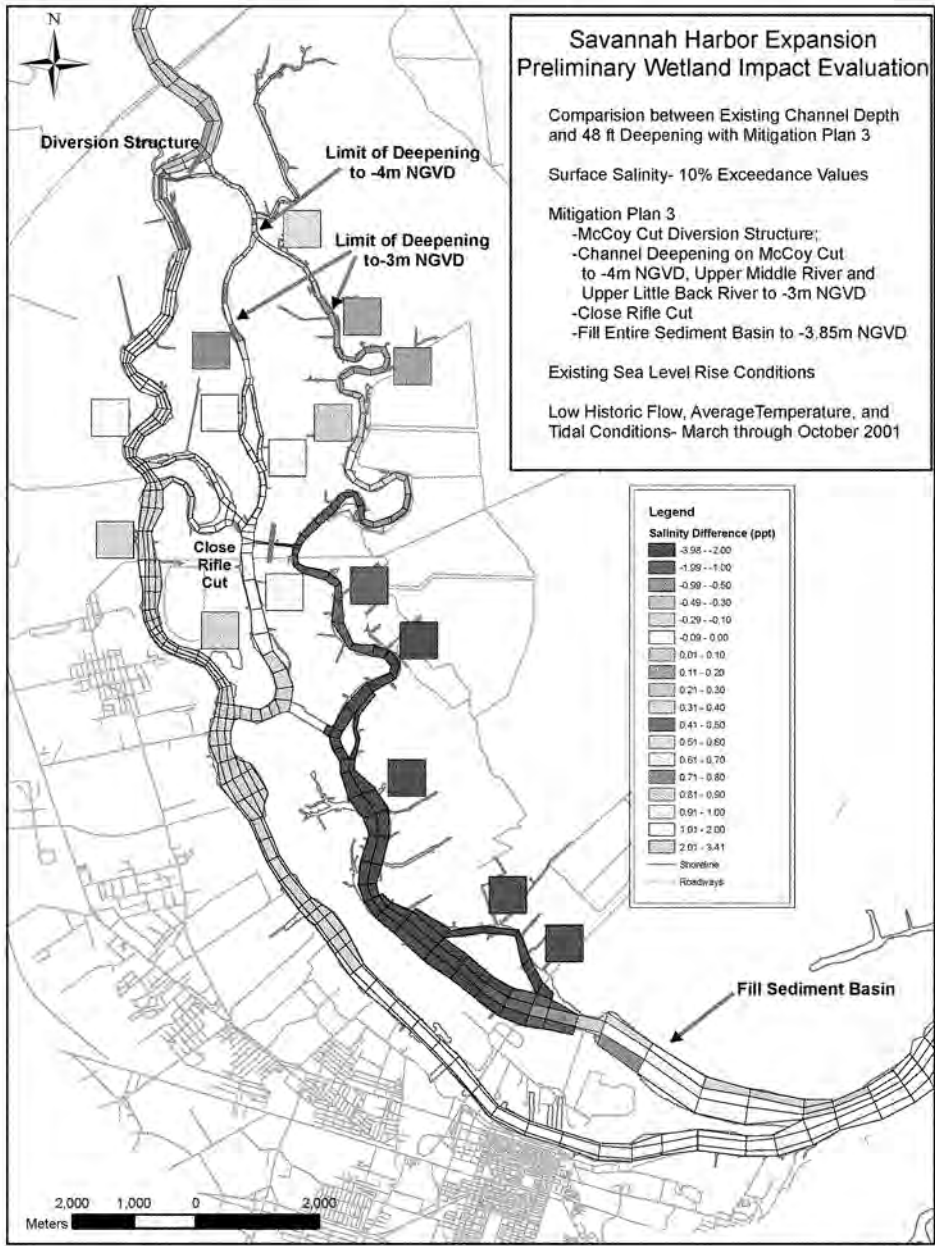


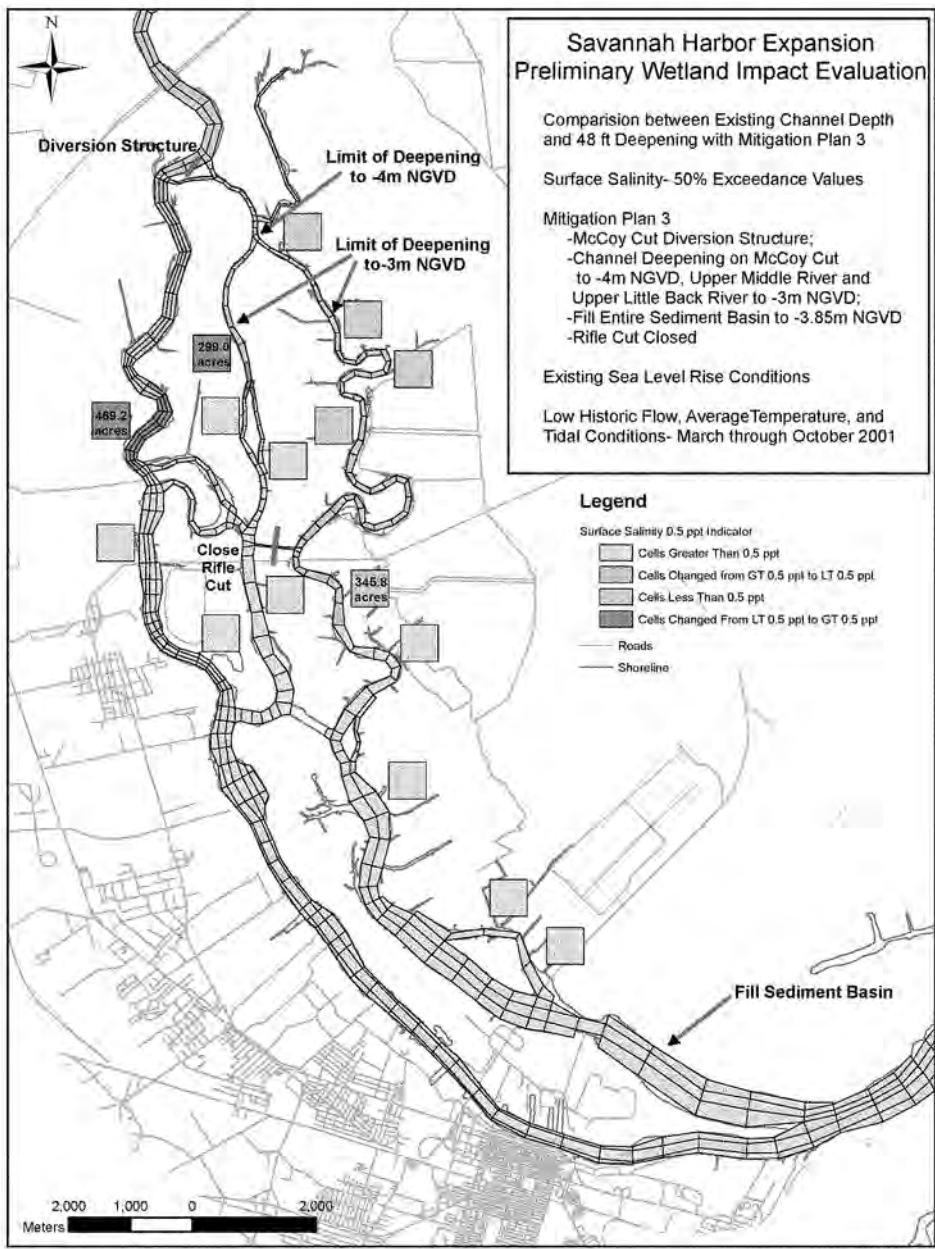


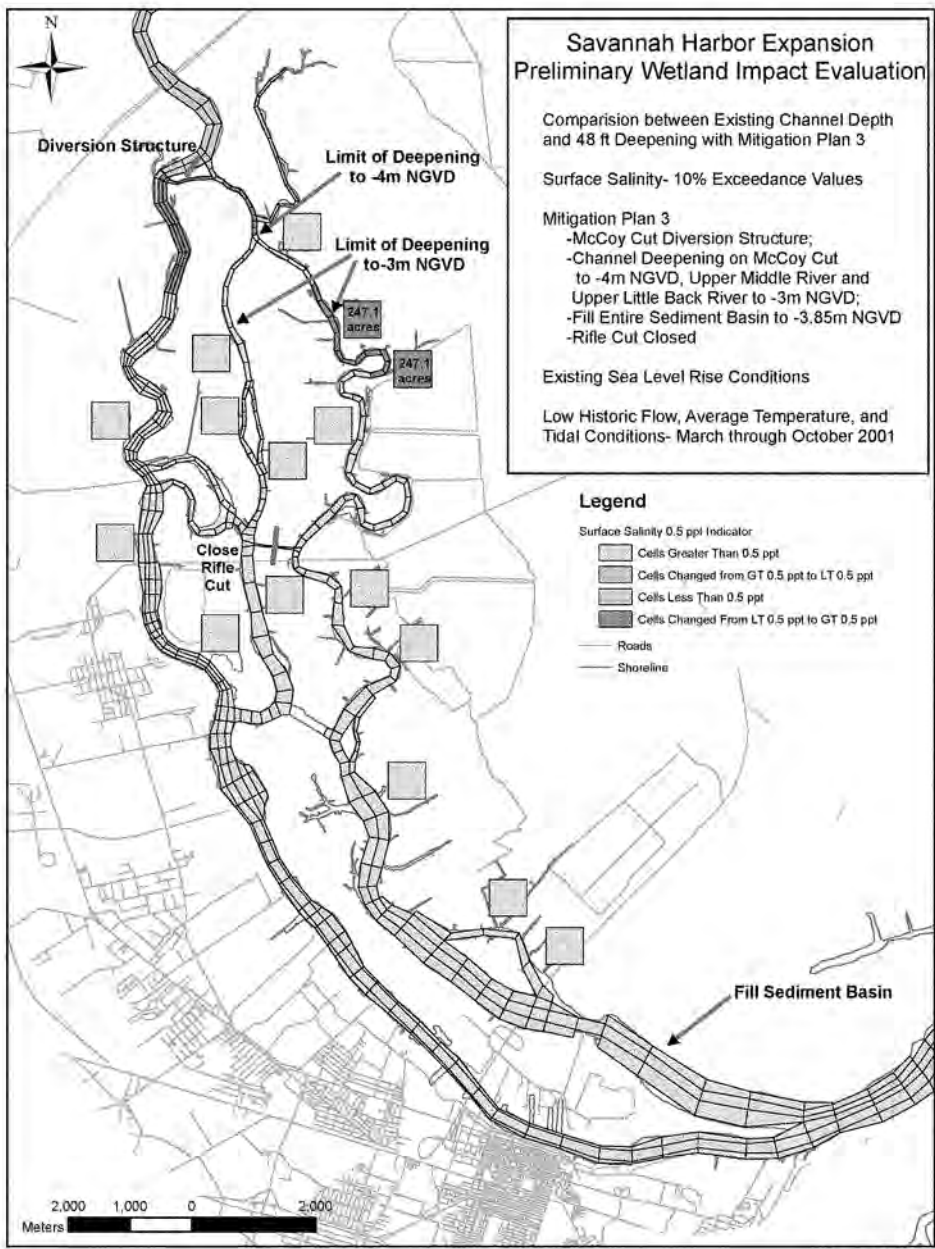


Sensitivity Analysis #1

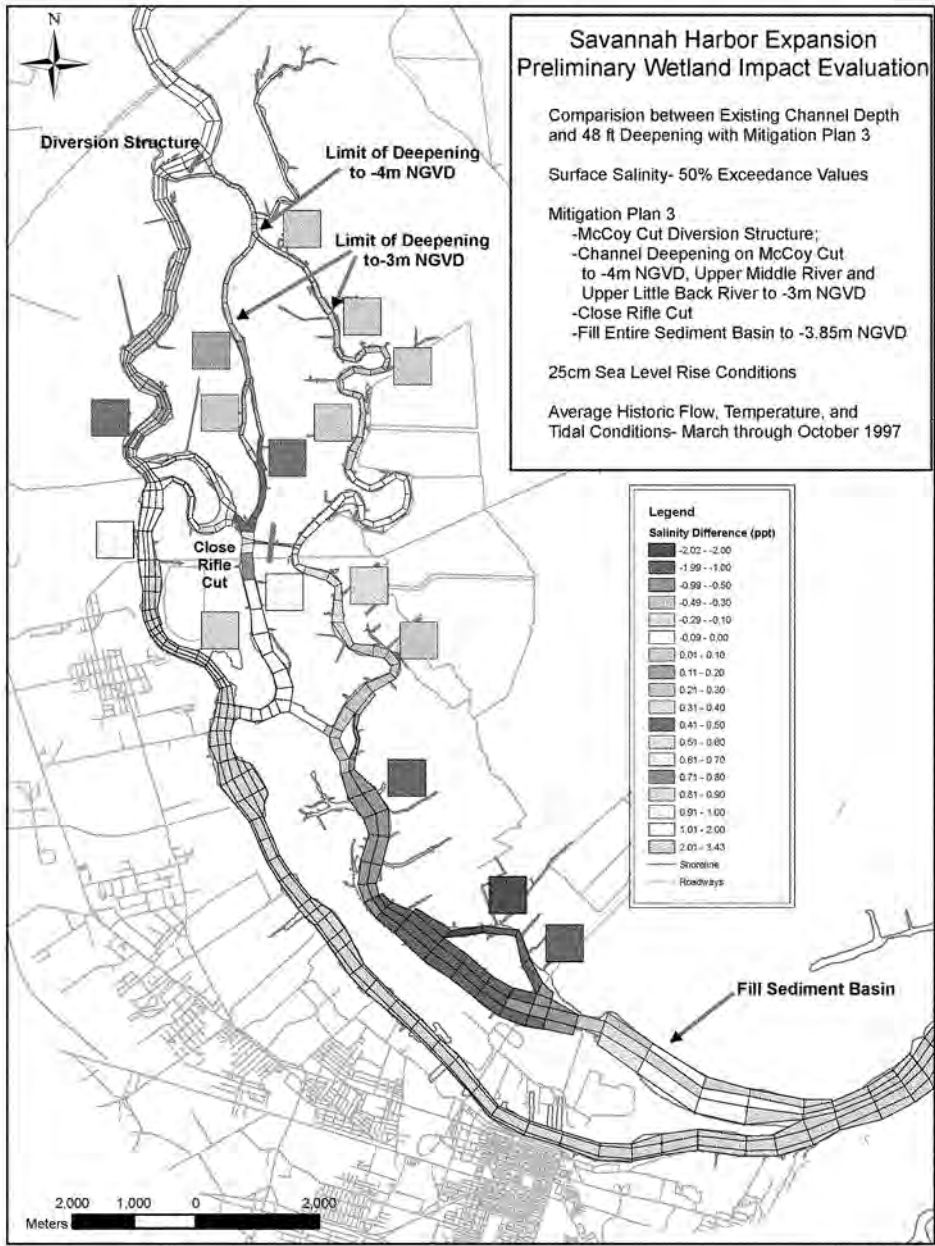


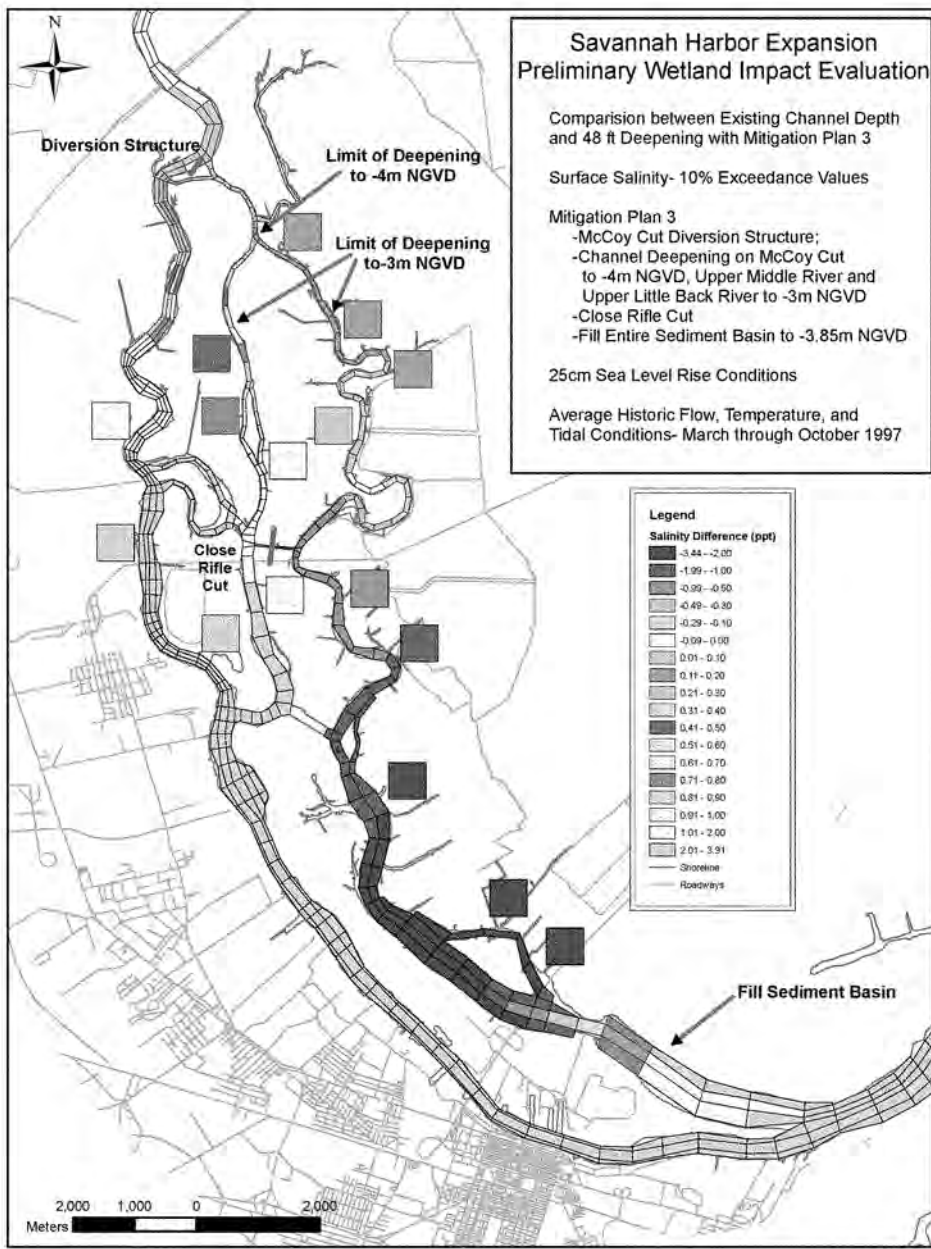


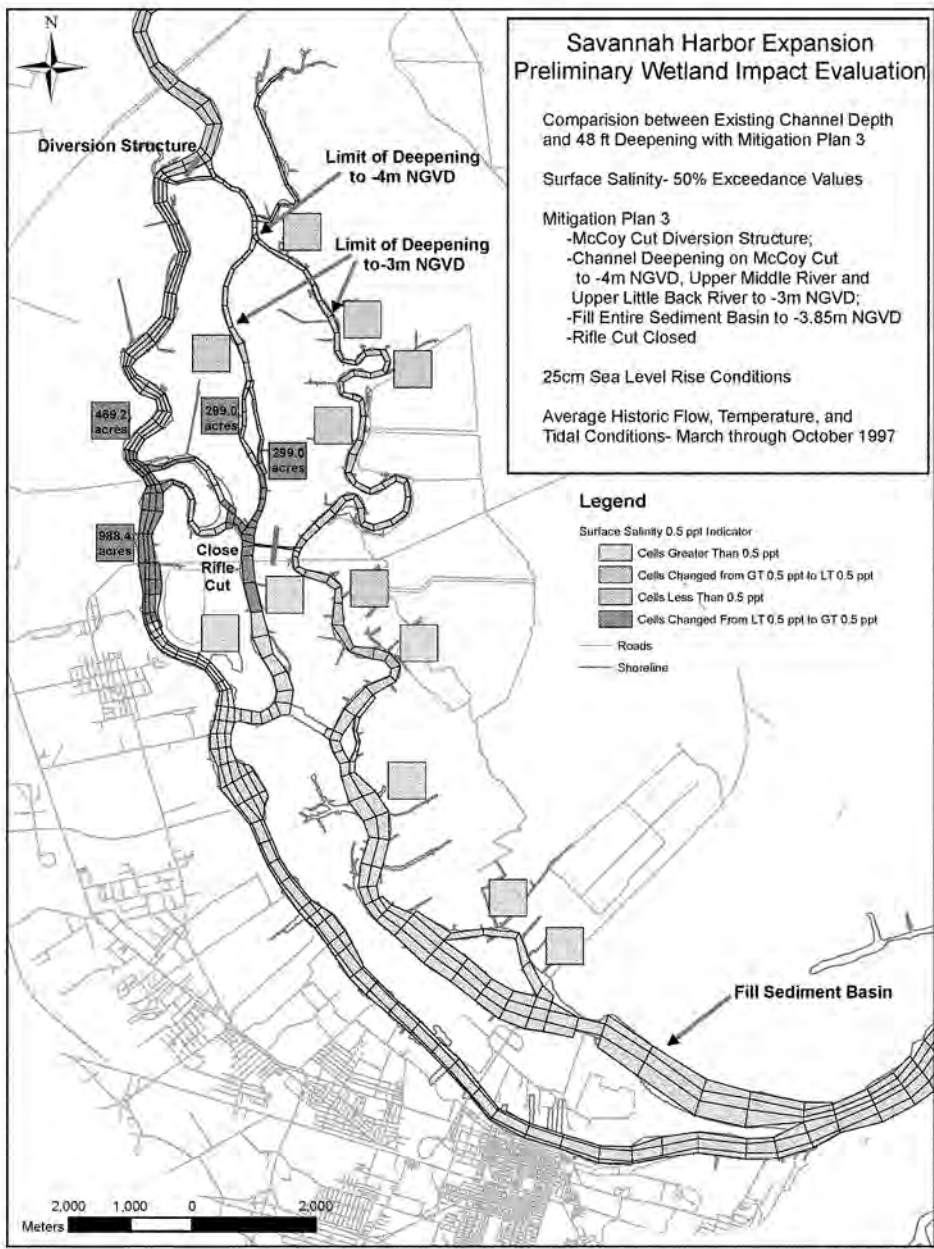


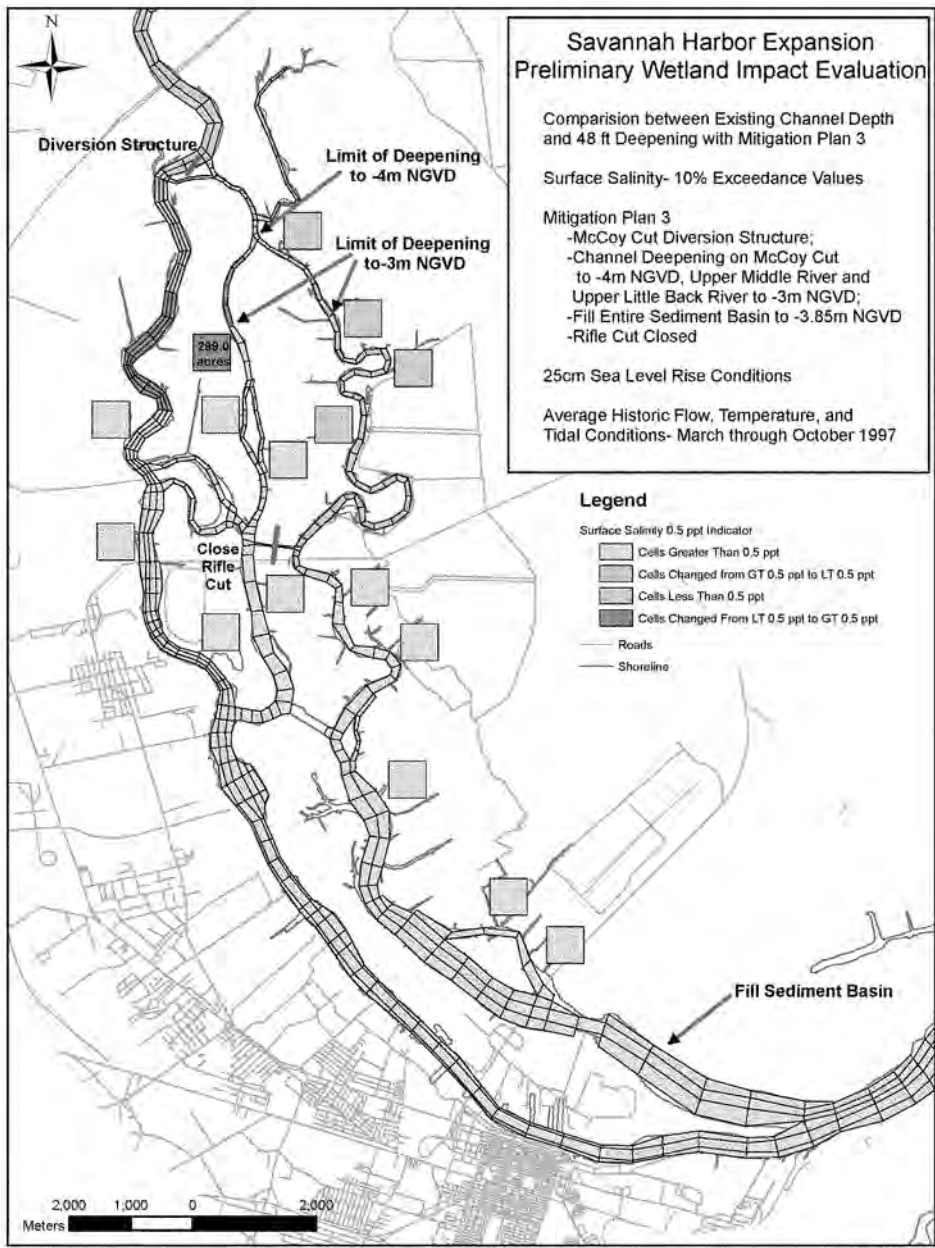


Sensitivity Analysis #2A

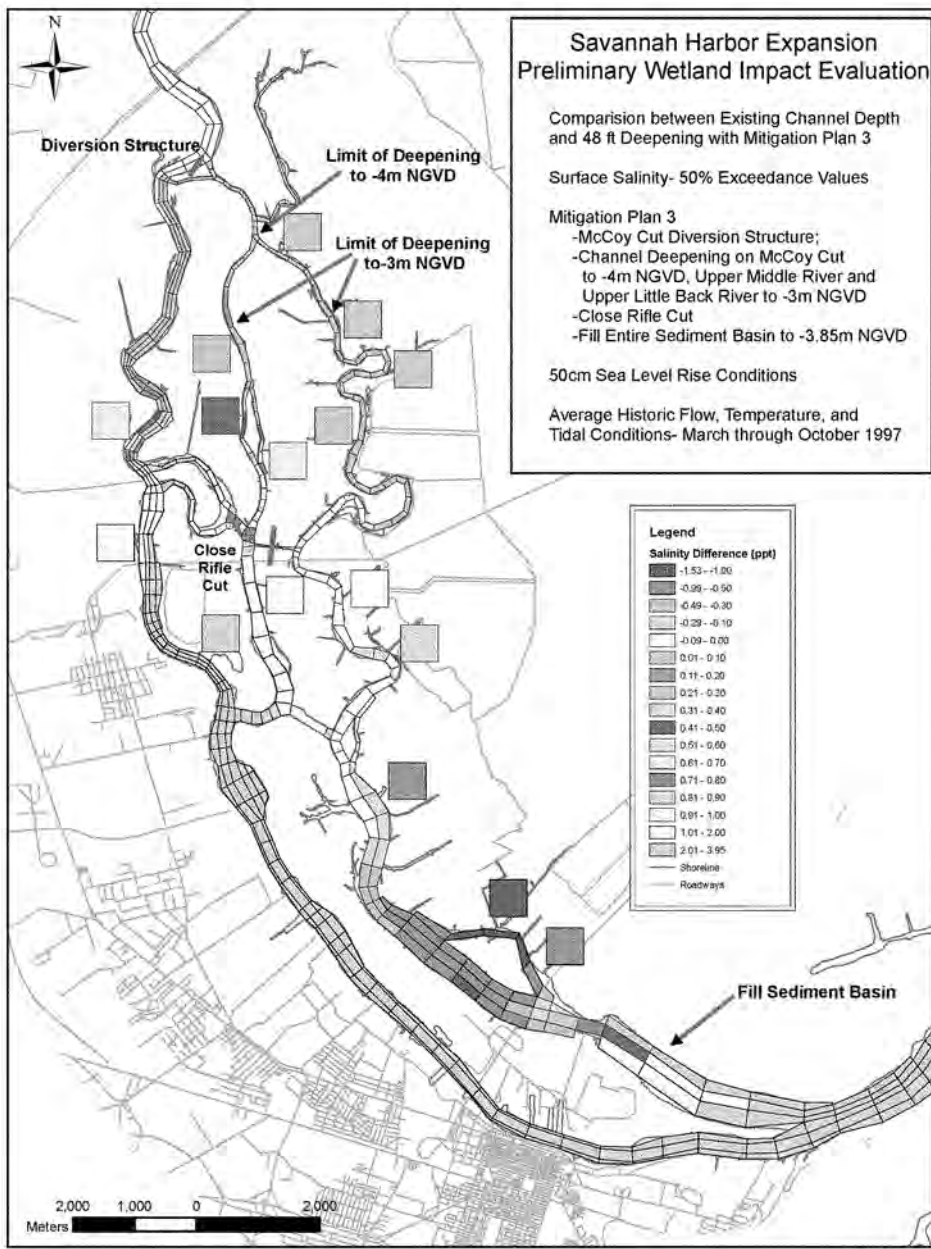


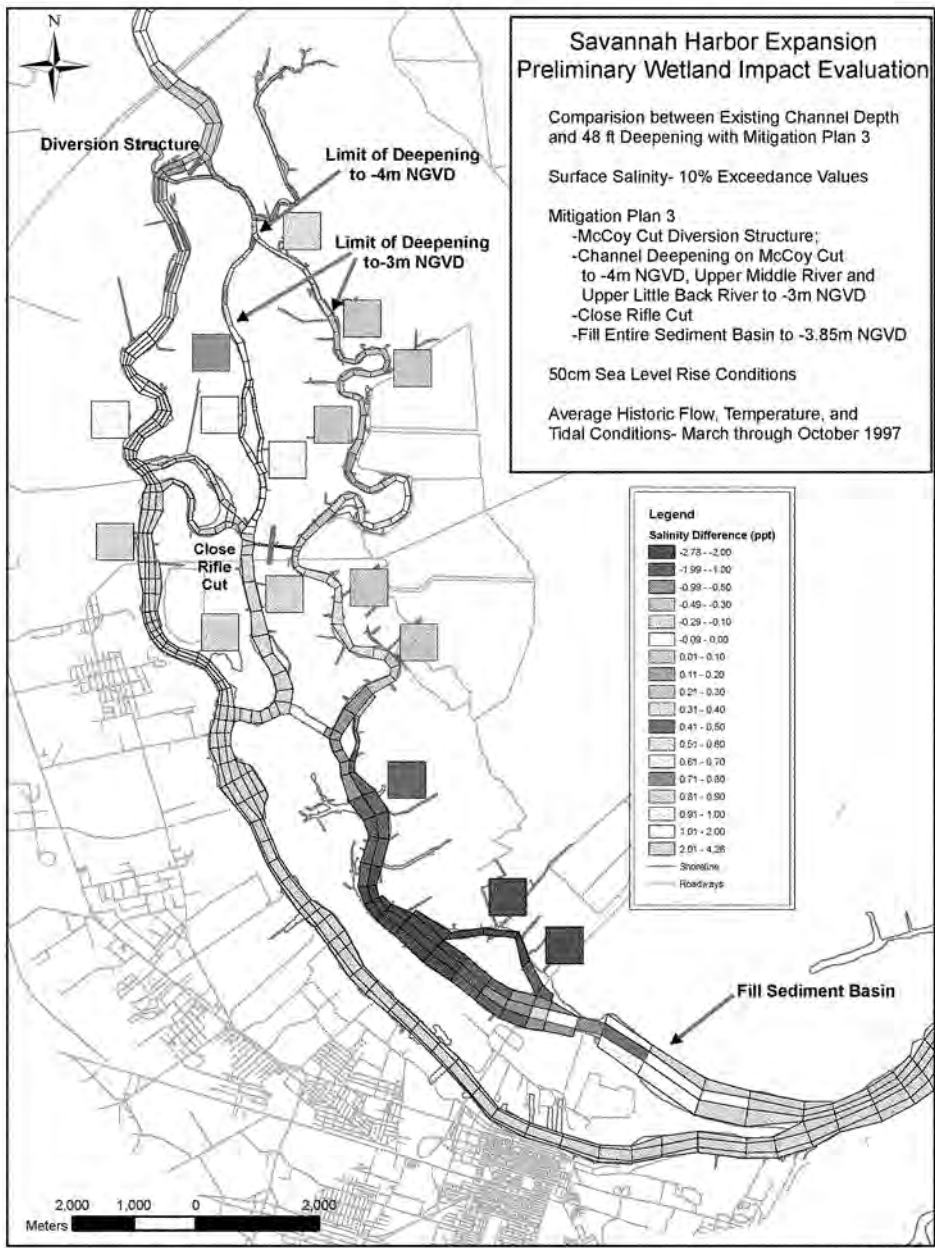


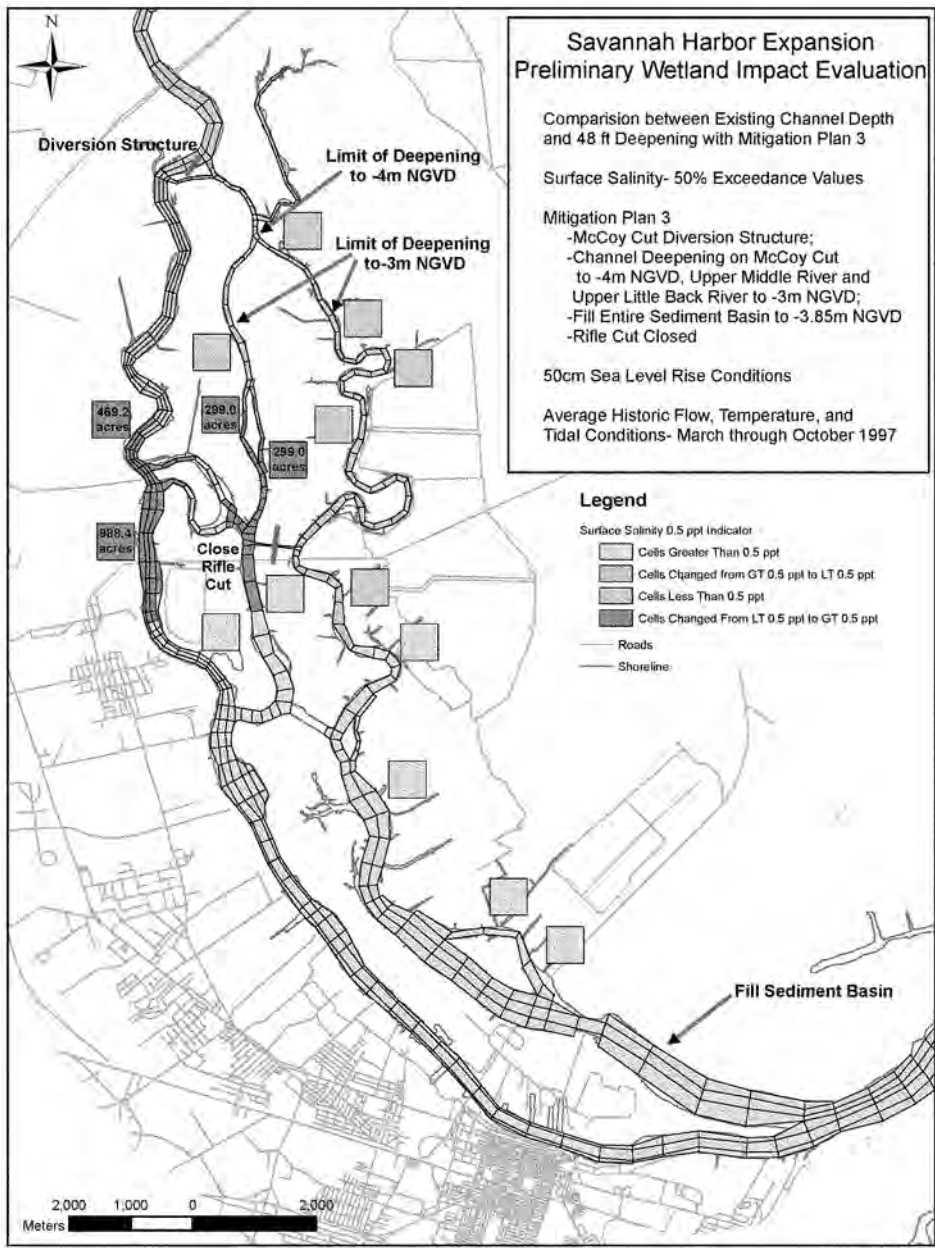


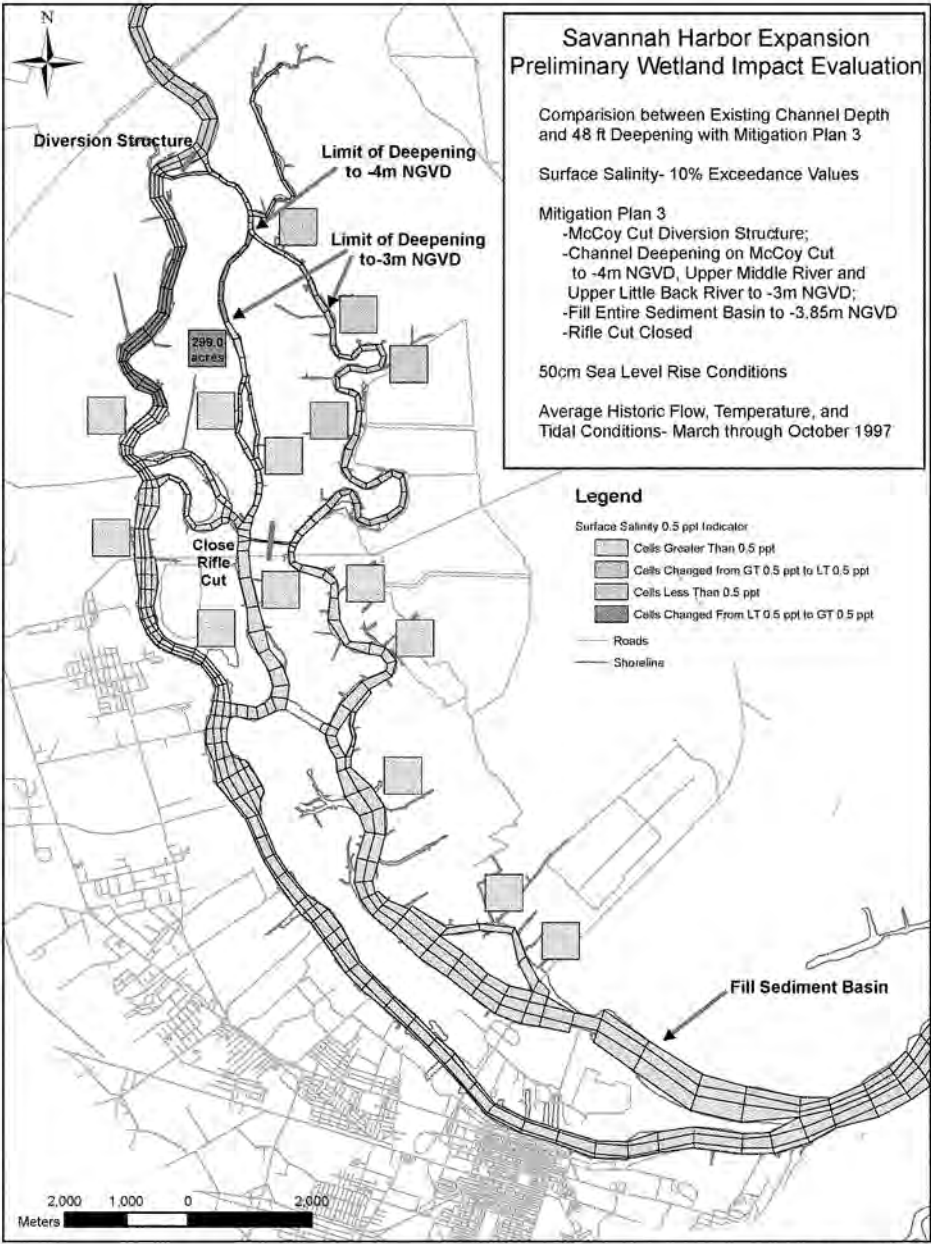


Sensitivity Analysis #2B







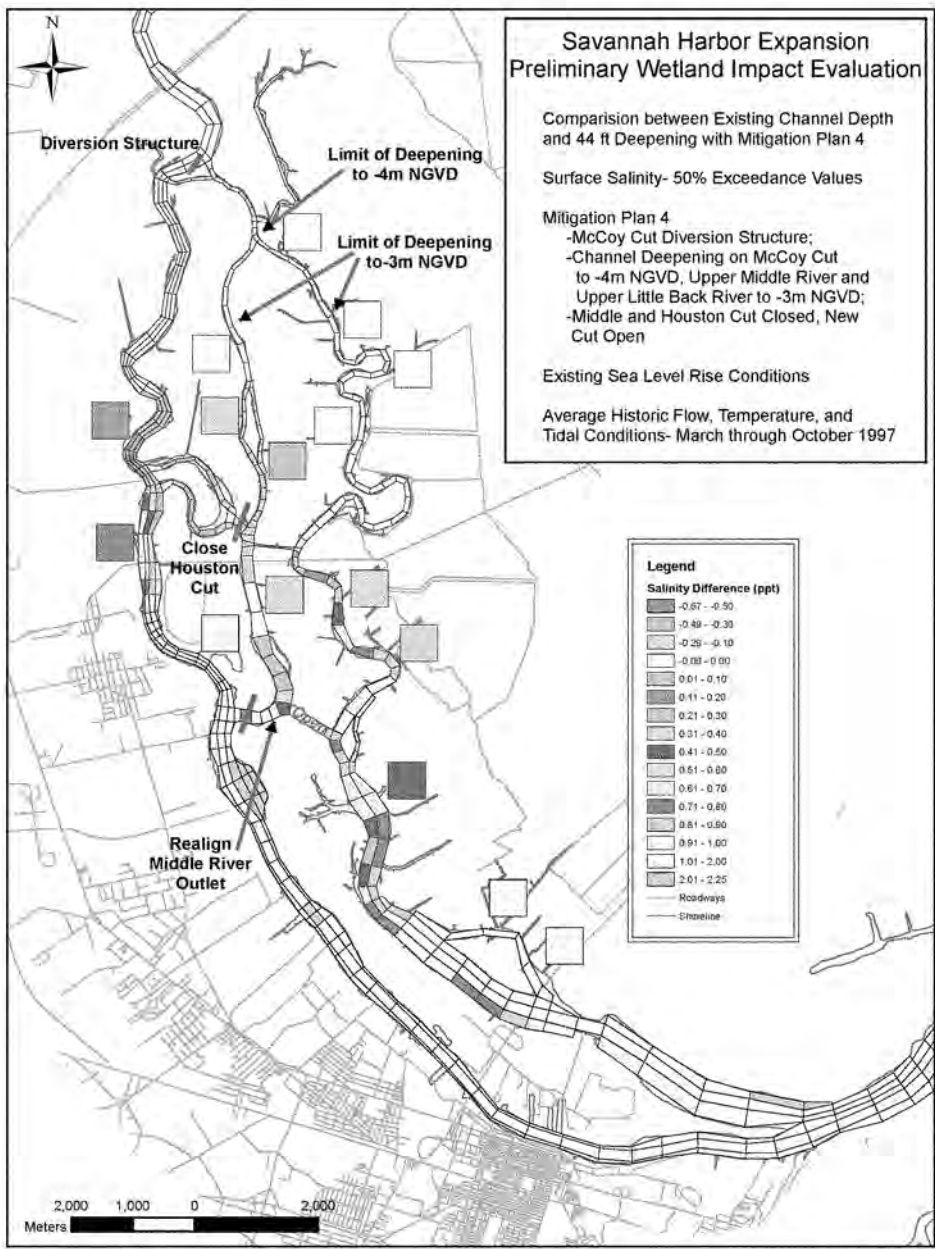


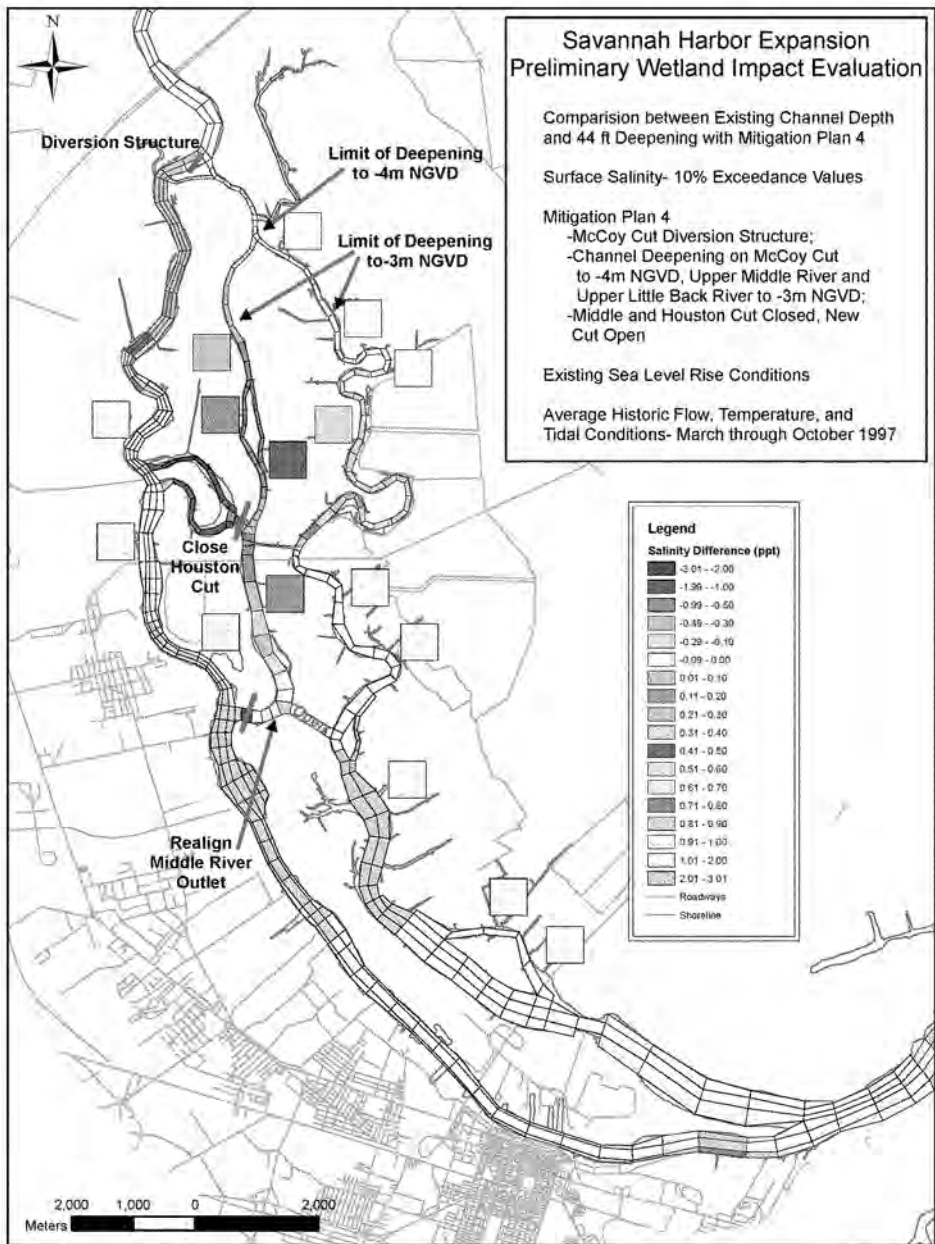
MITIGATION PLAN 4

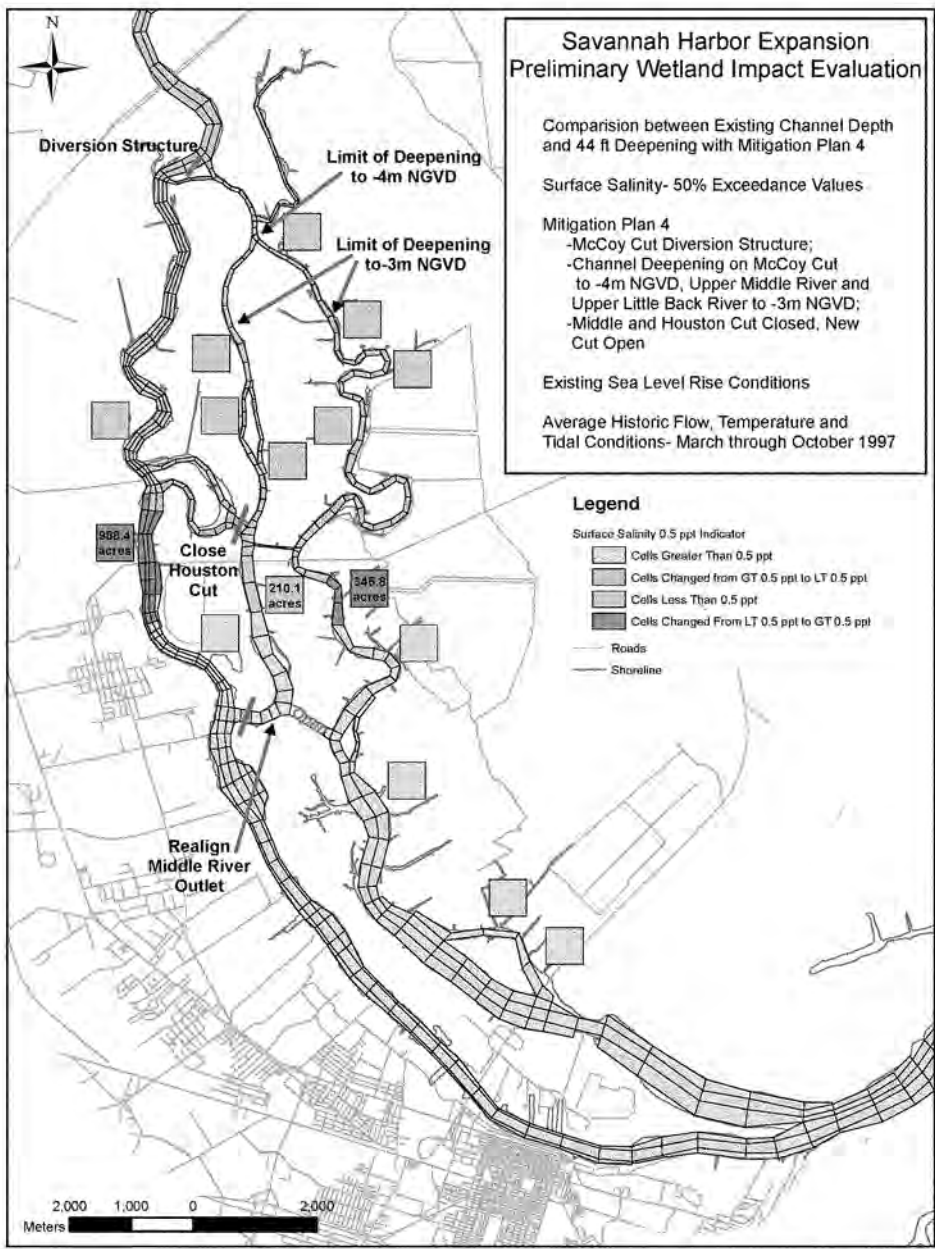
- *McCoy Cut Diversion Structure*
- *Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD*
- *Realign Middle River Outlet by Closing Middle River at Front River and Opening New Cut*
- *Close Houston Cut*

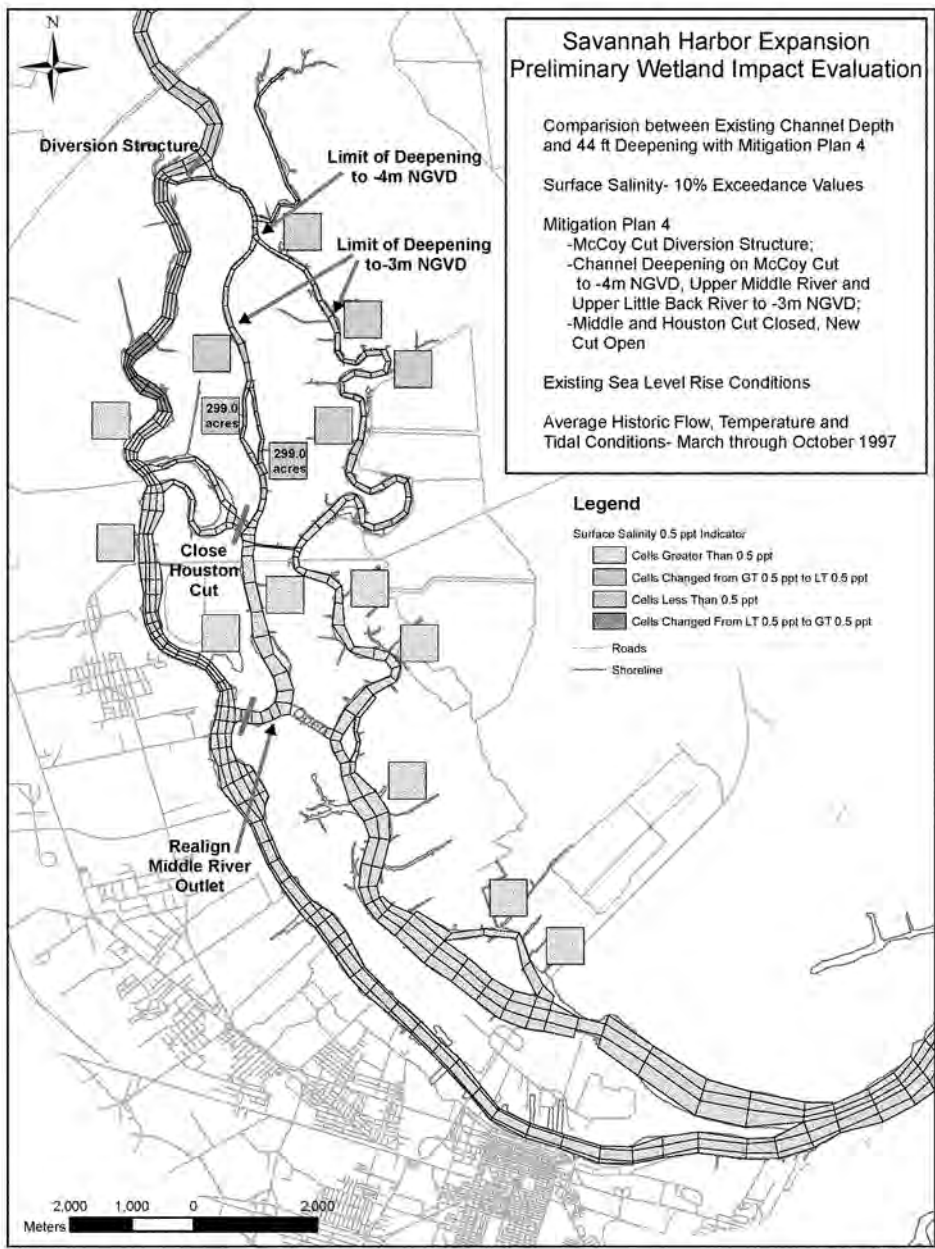
44-ft Deepening

Basic Evaluation

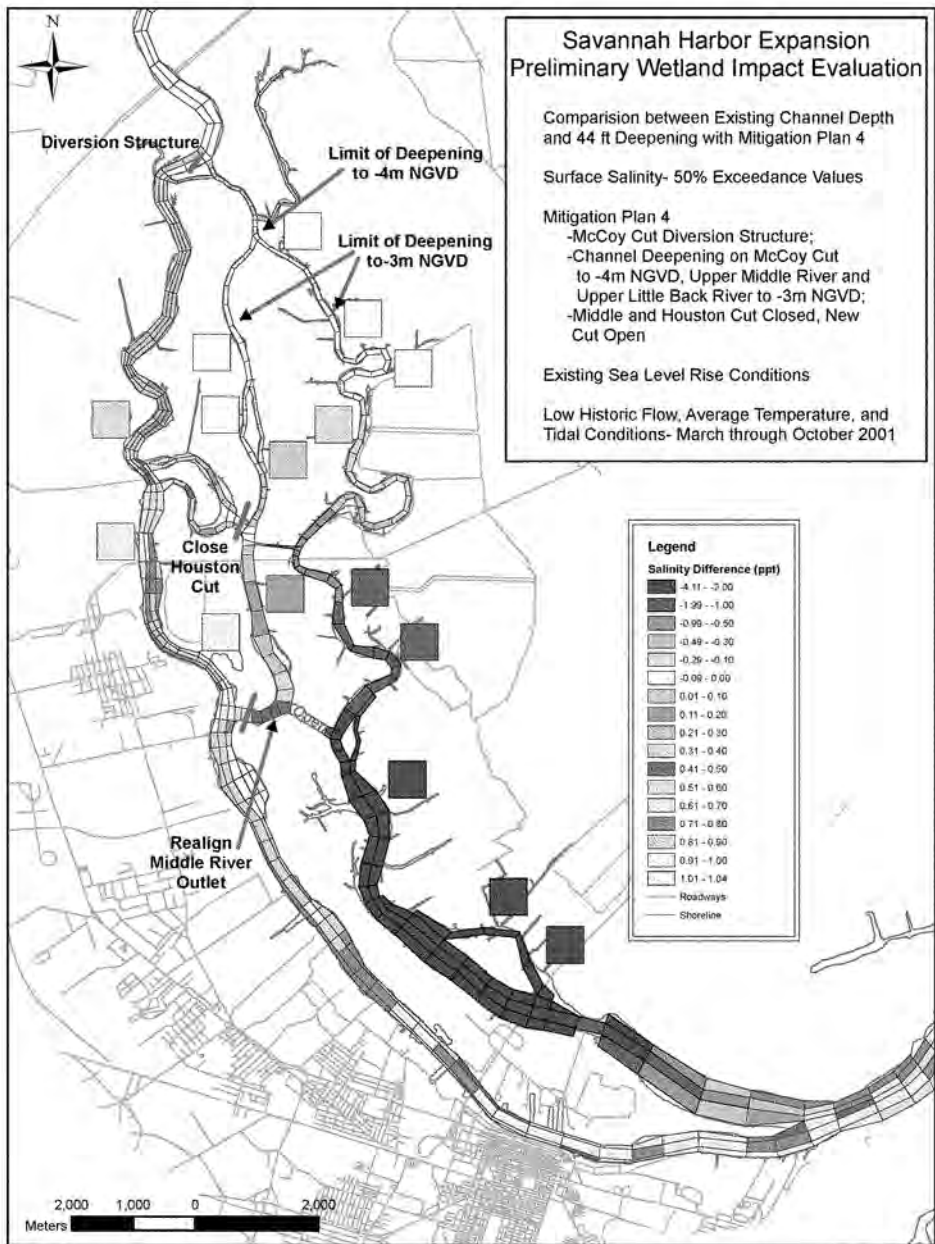


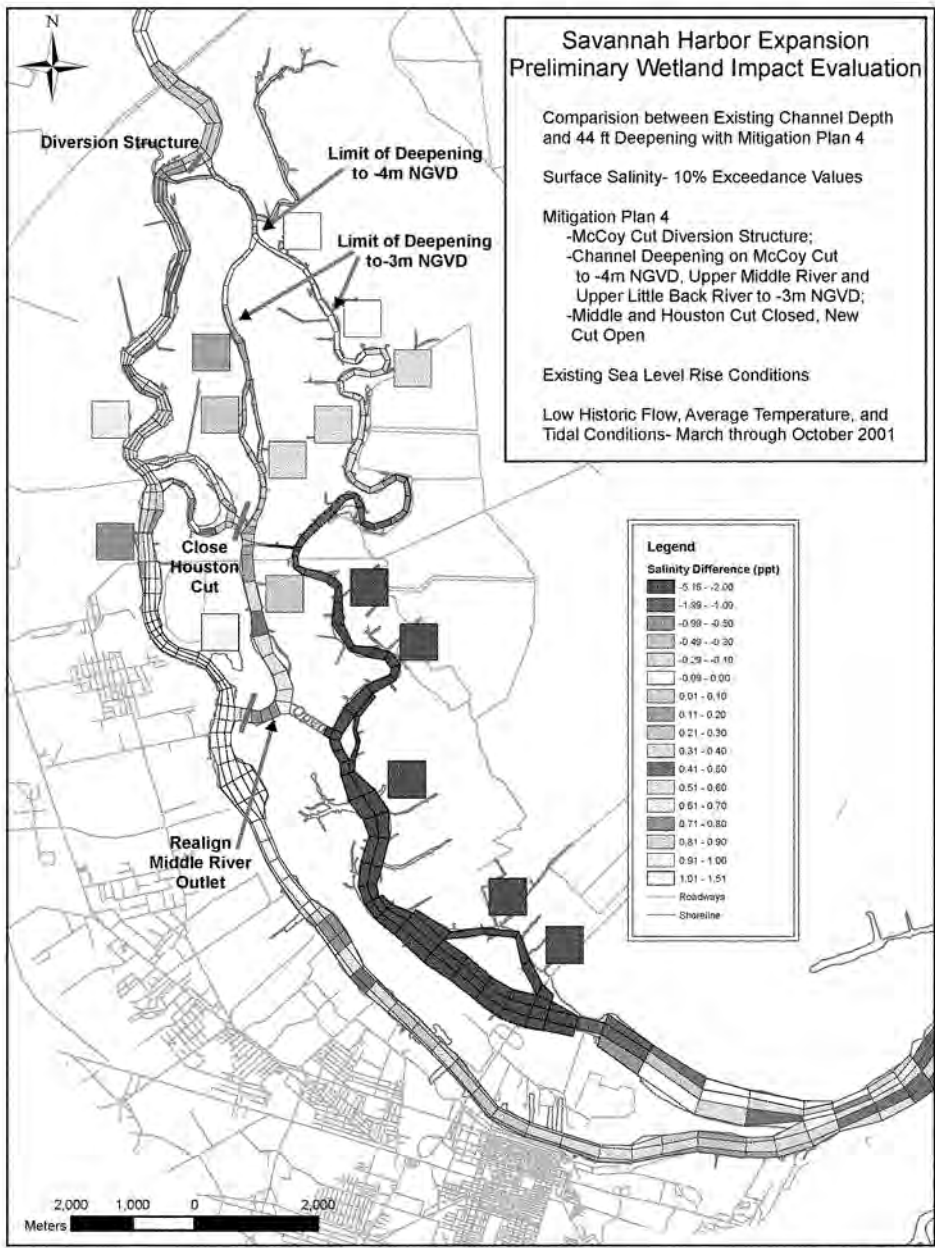


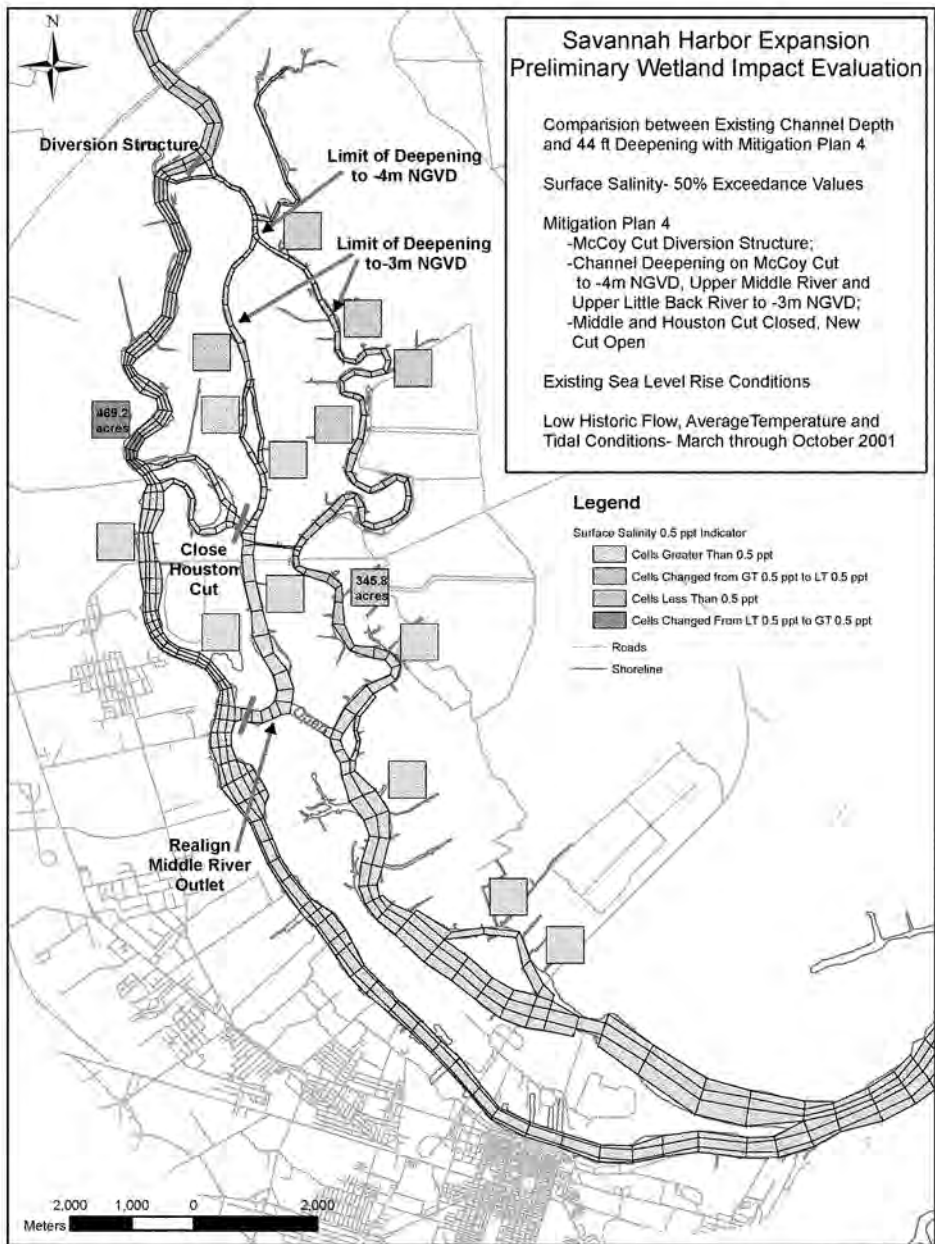


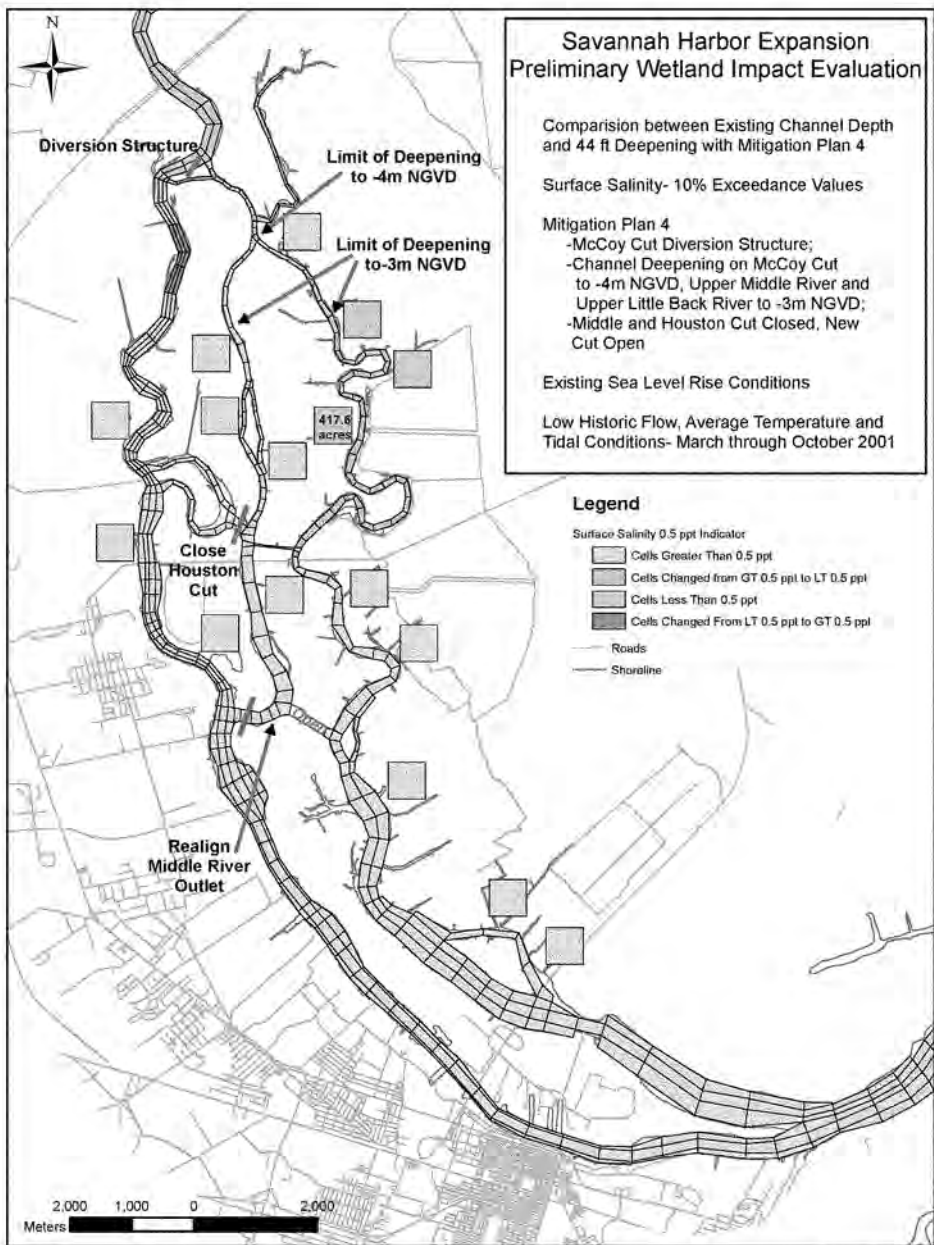


Sensitivity Analysis #1

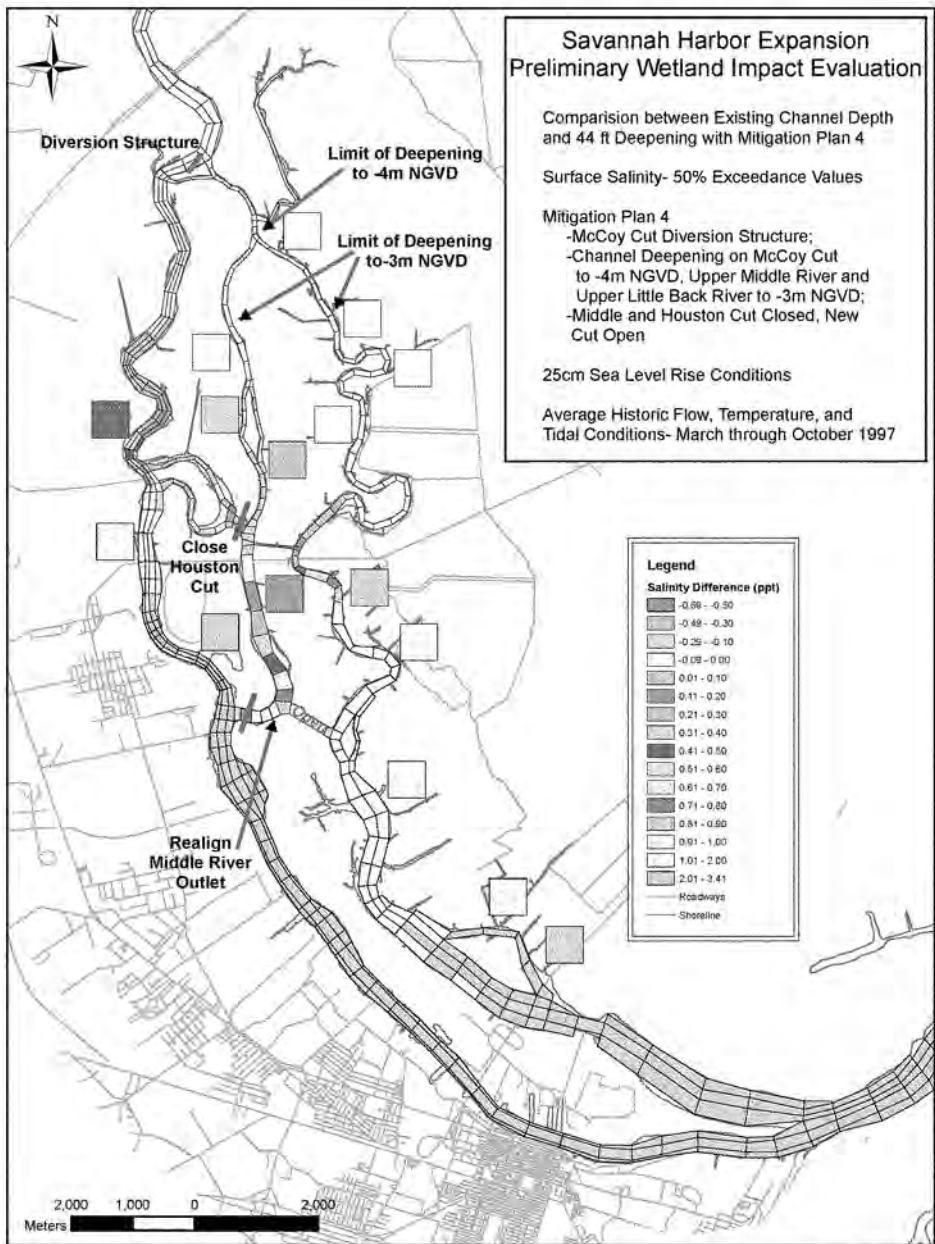


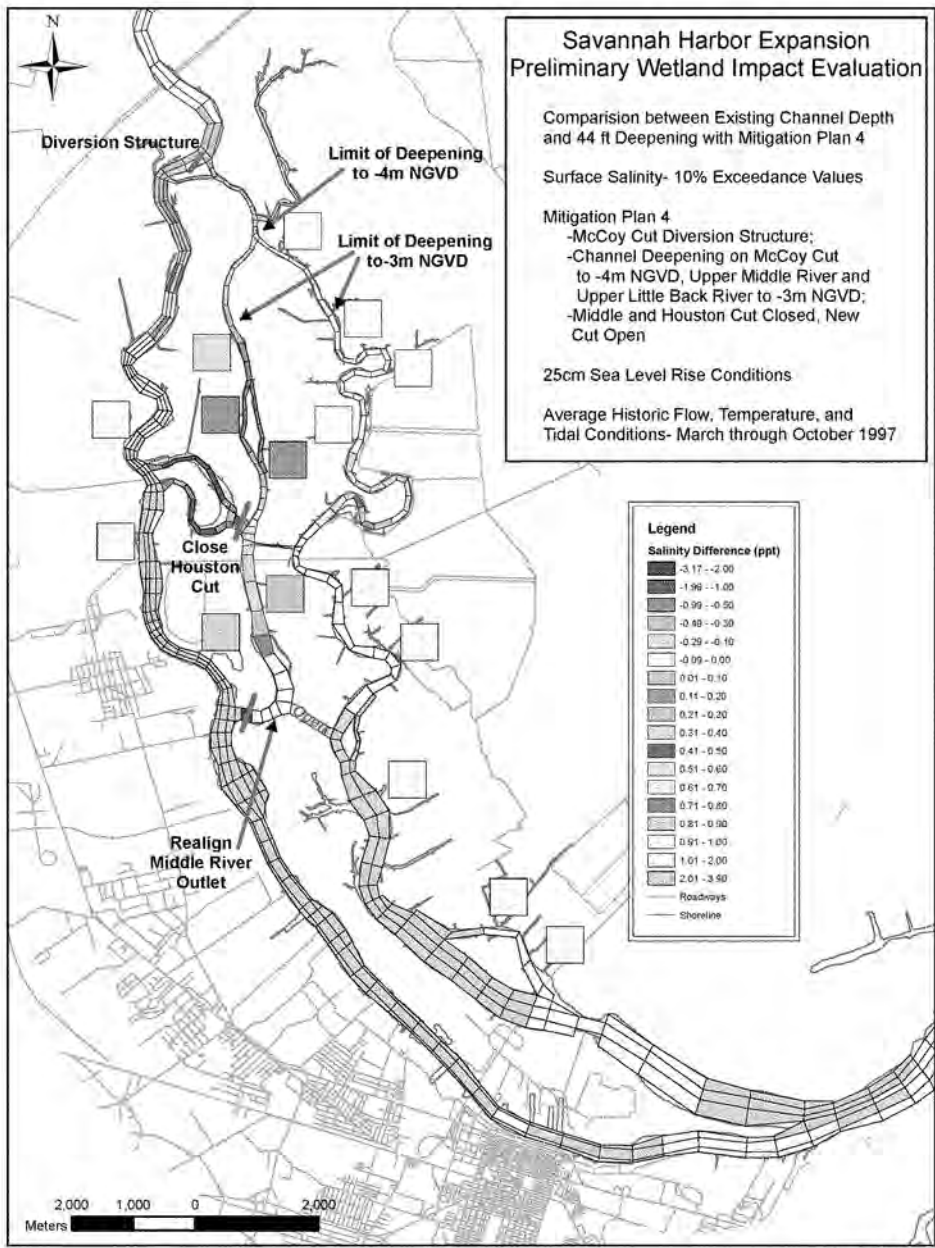


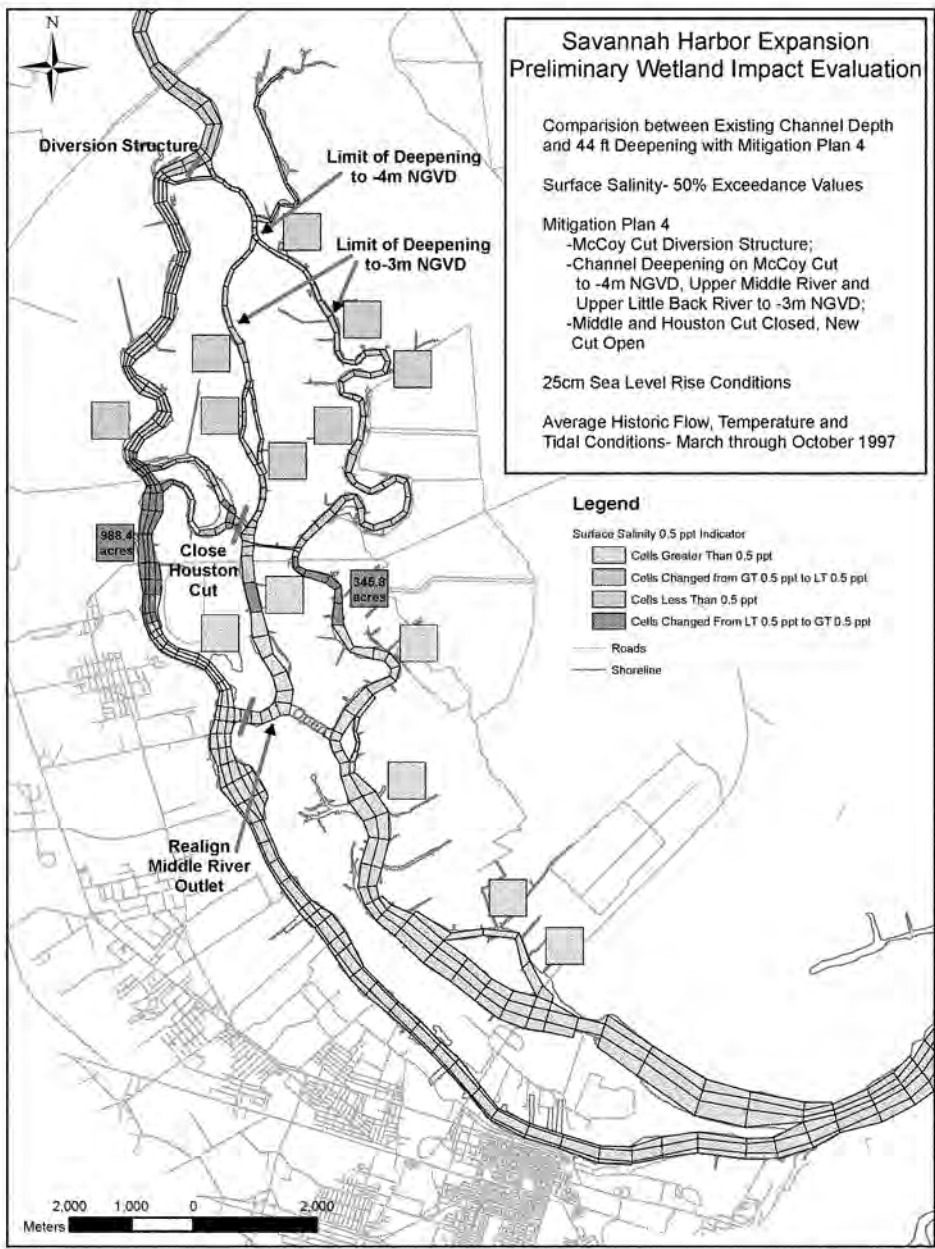


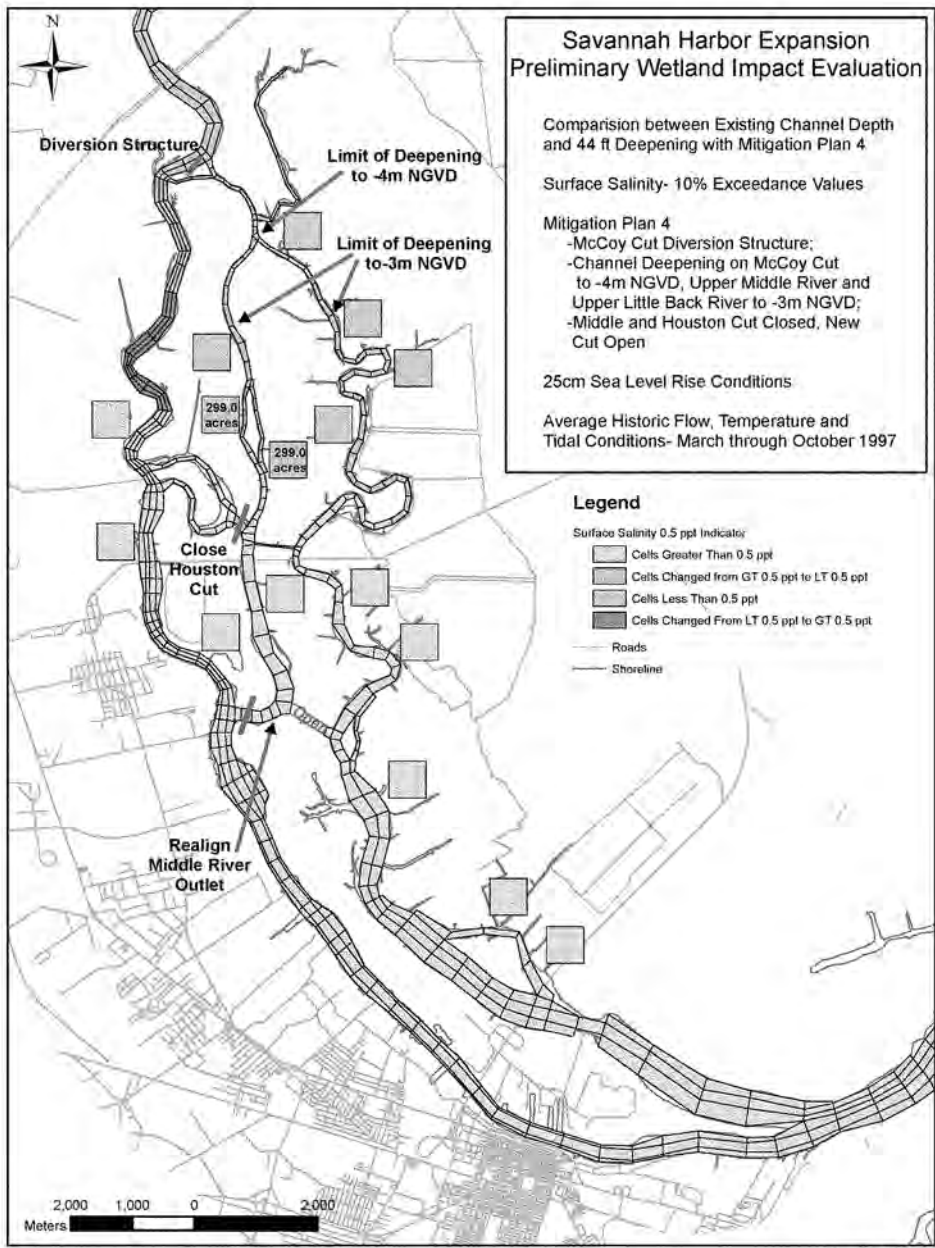


Sensitivity Analysis #2A

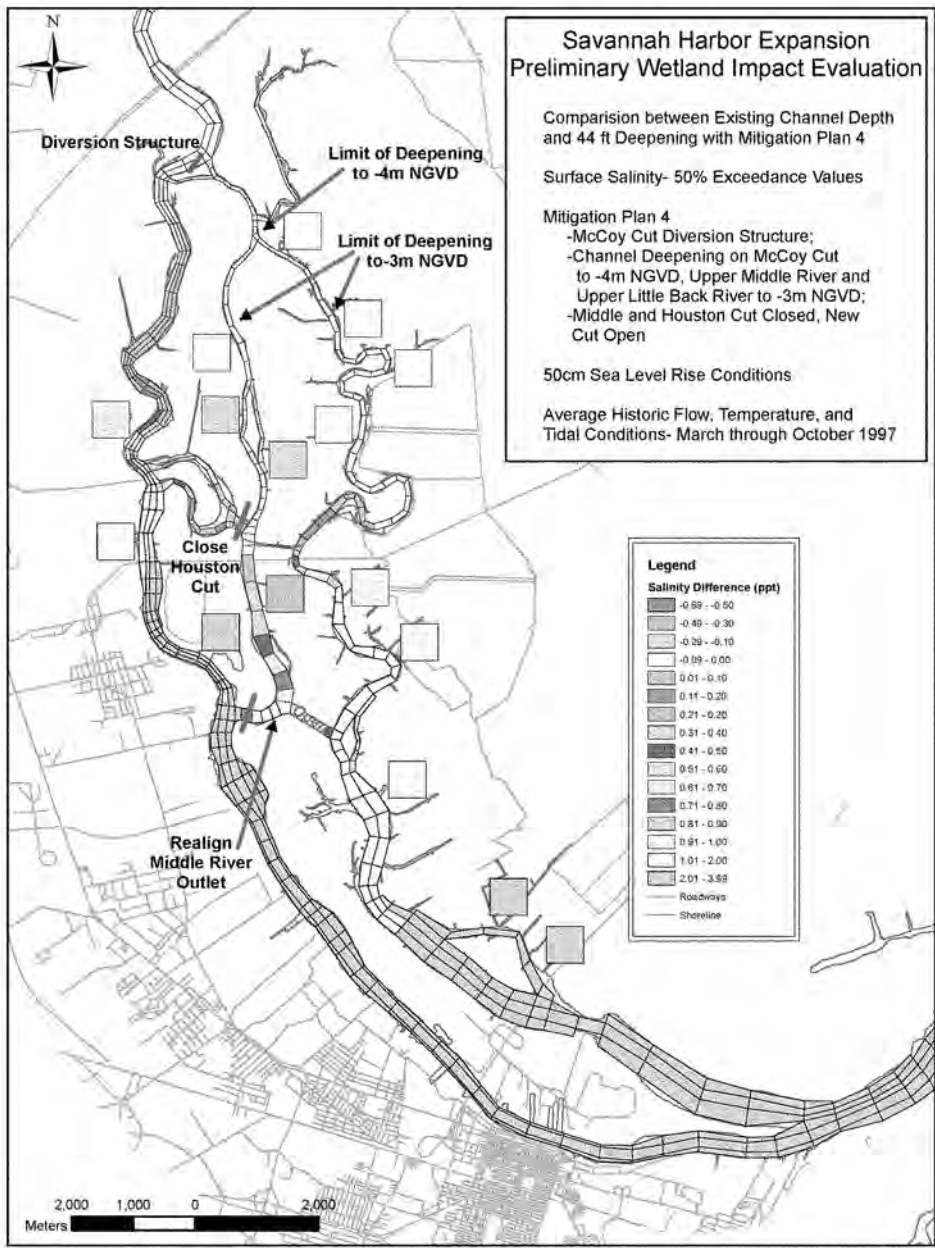


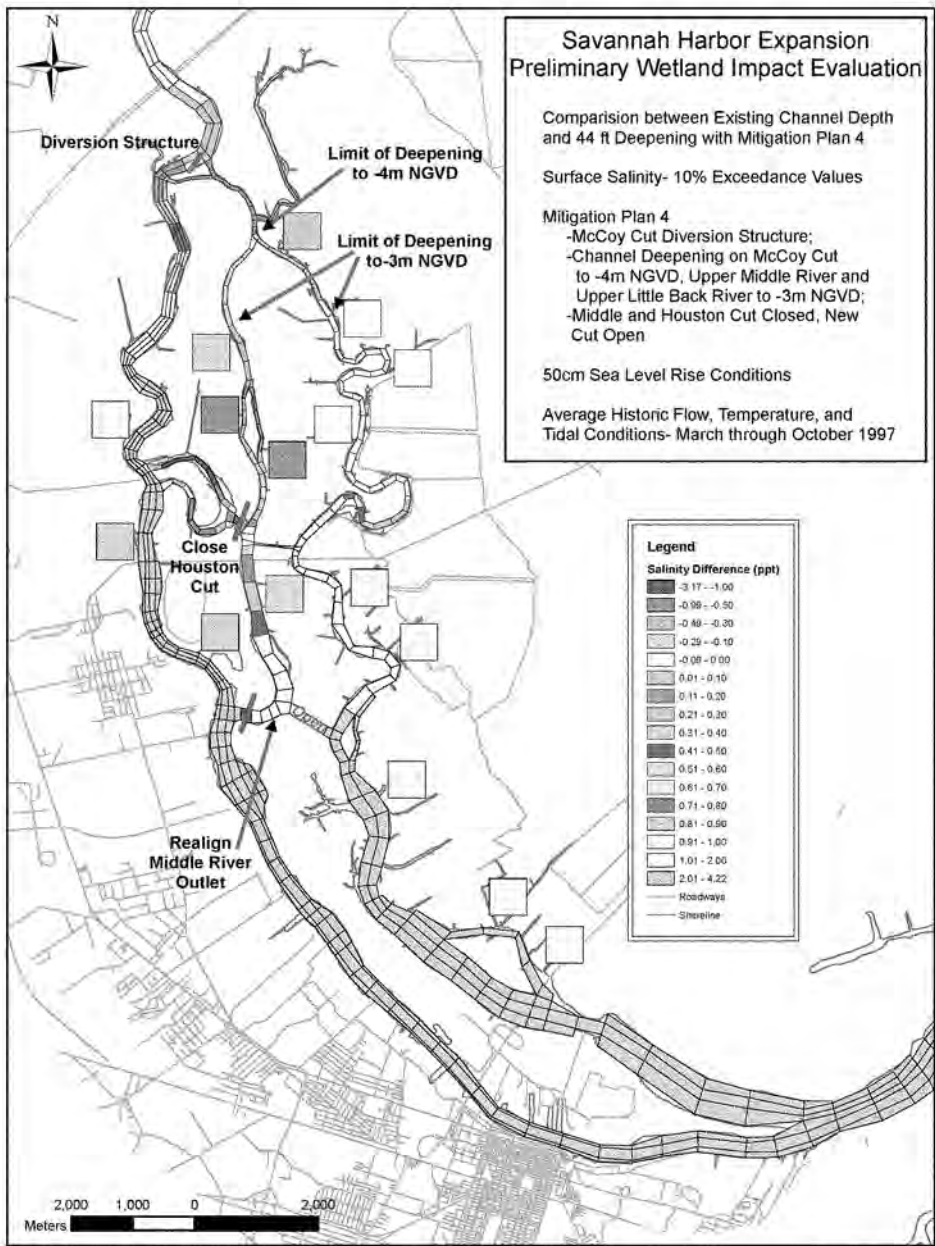


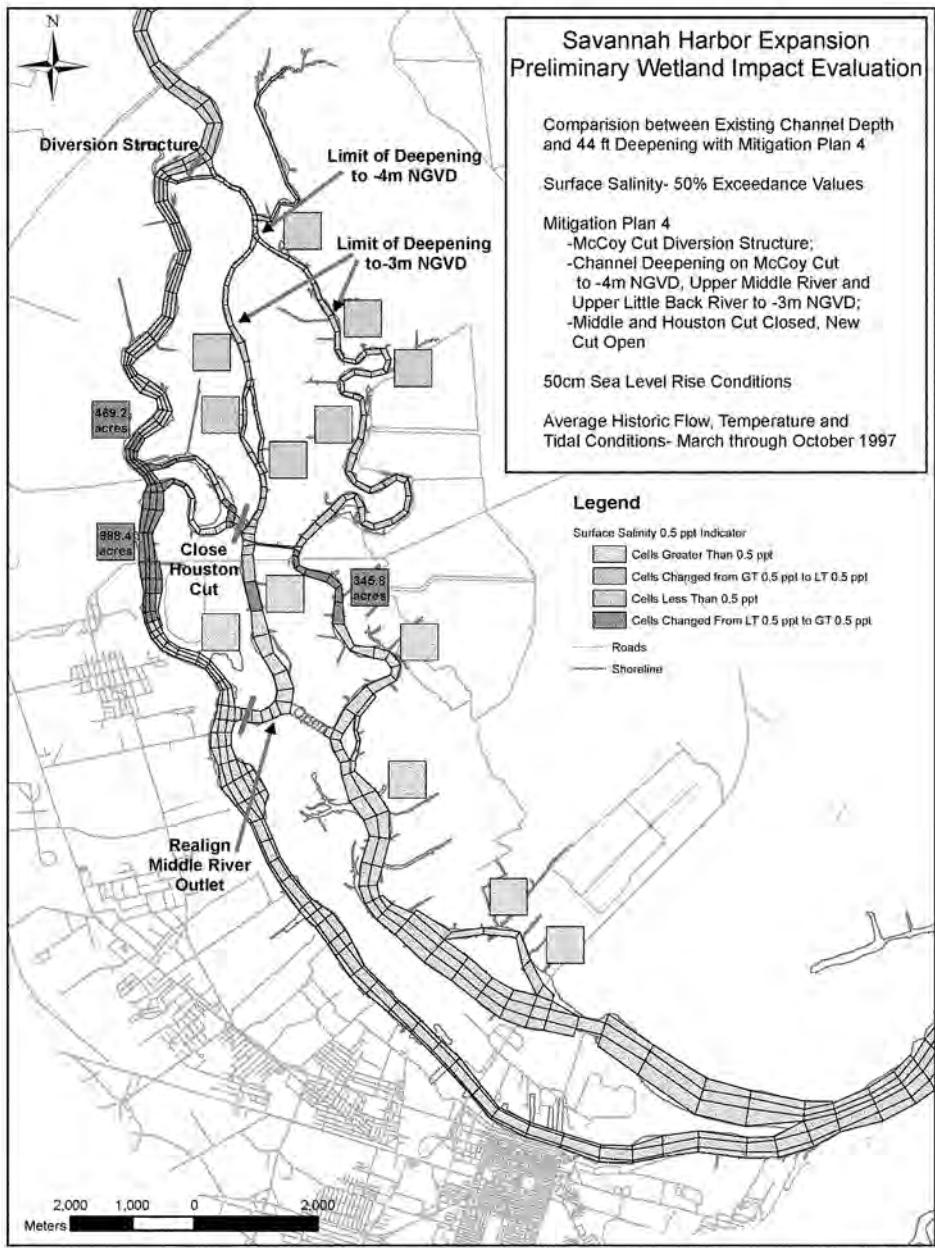


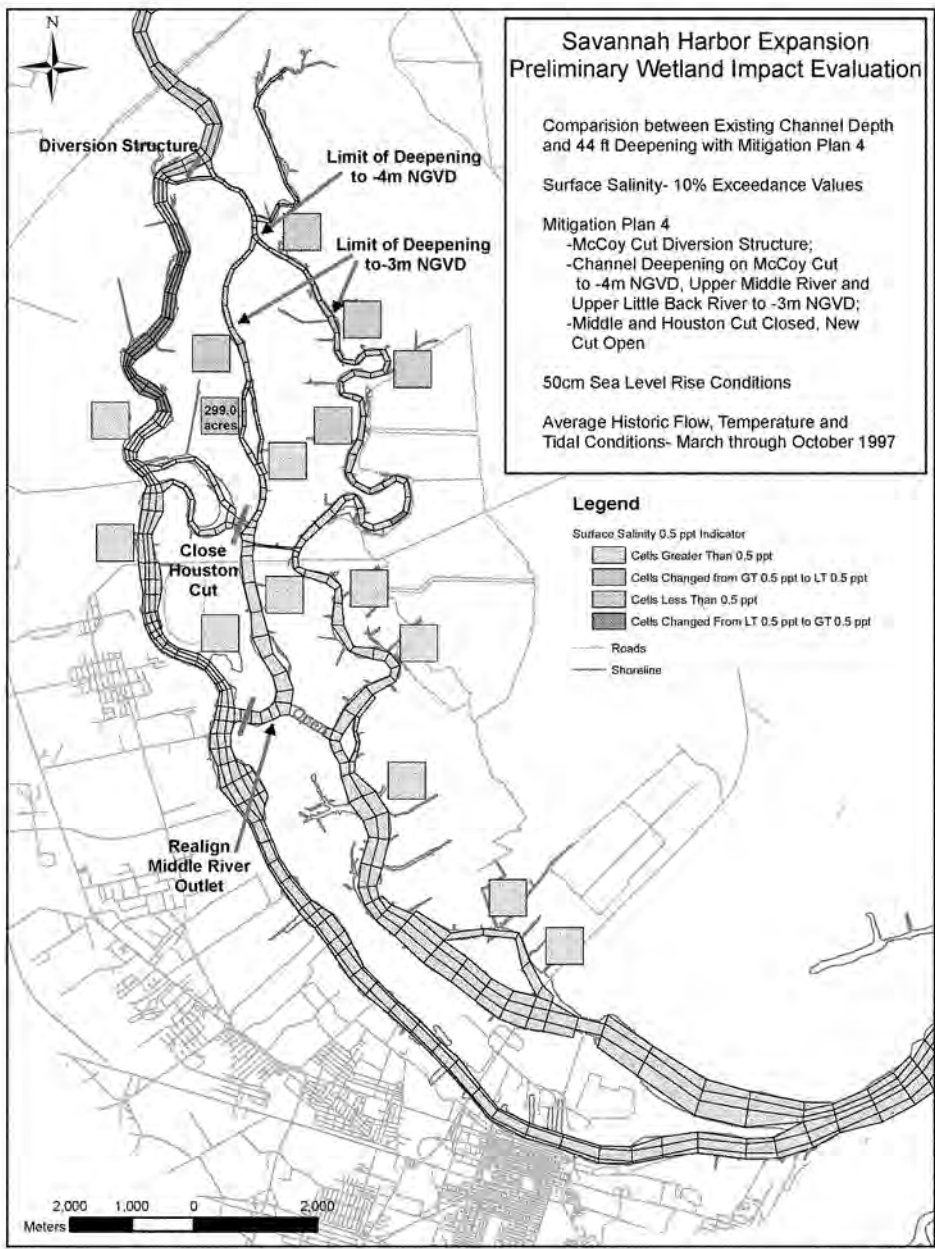


Sensitivity Analysis #2B



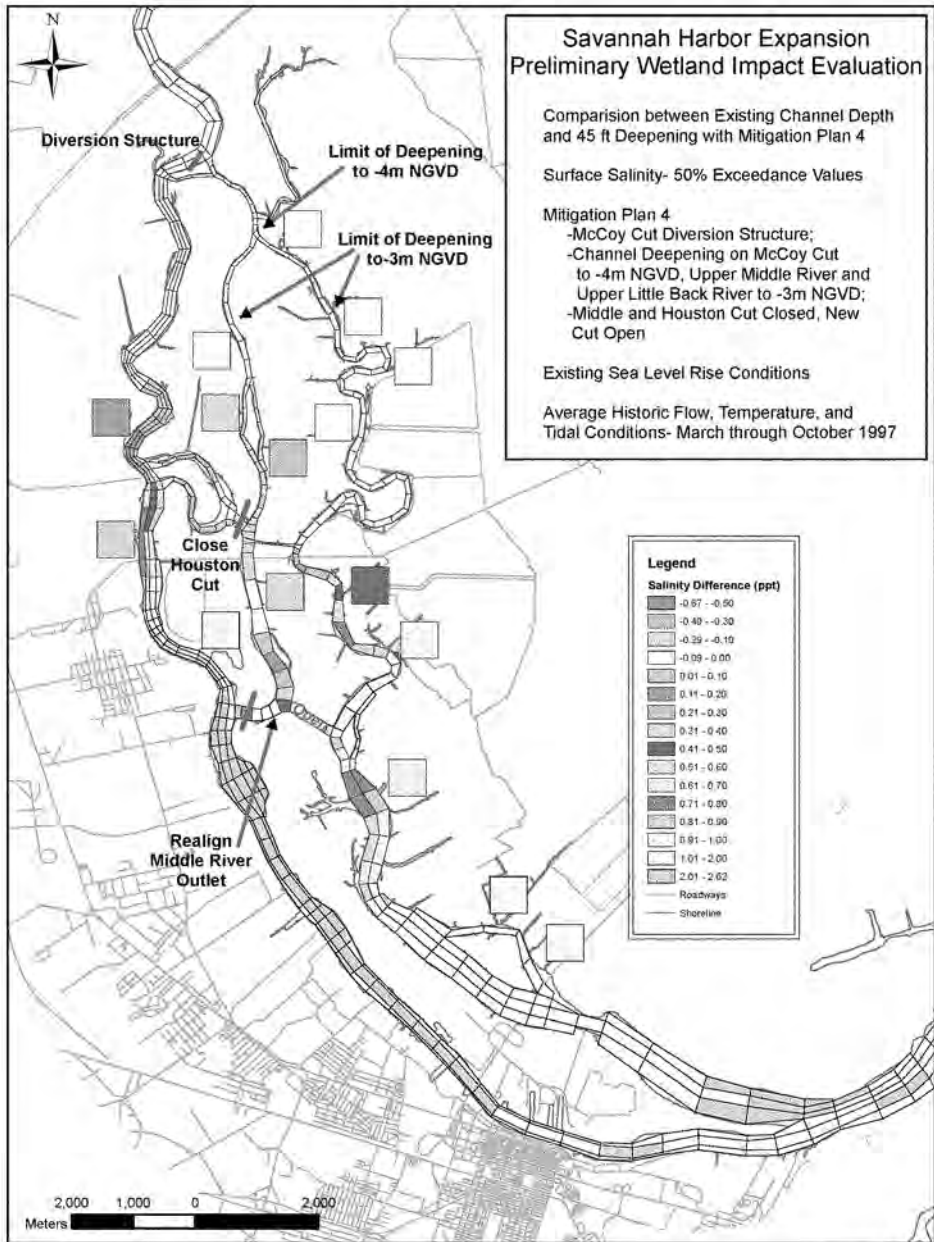


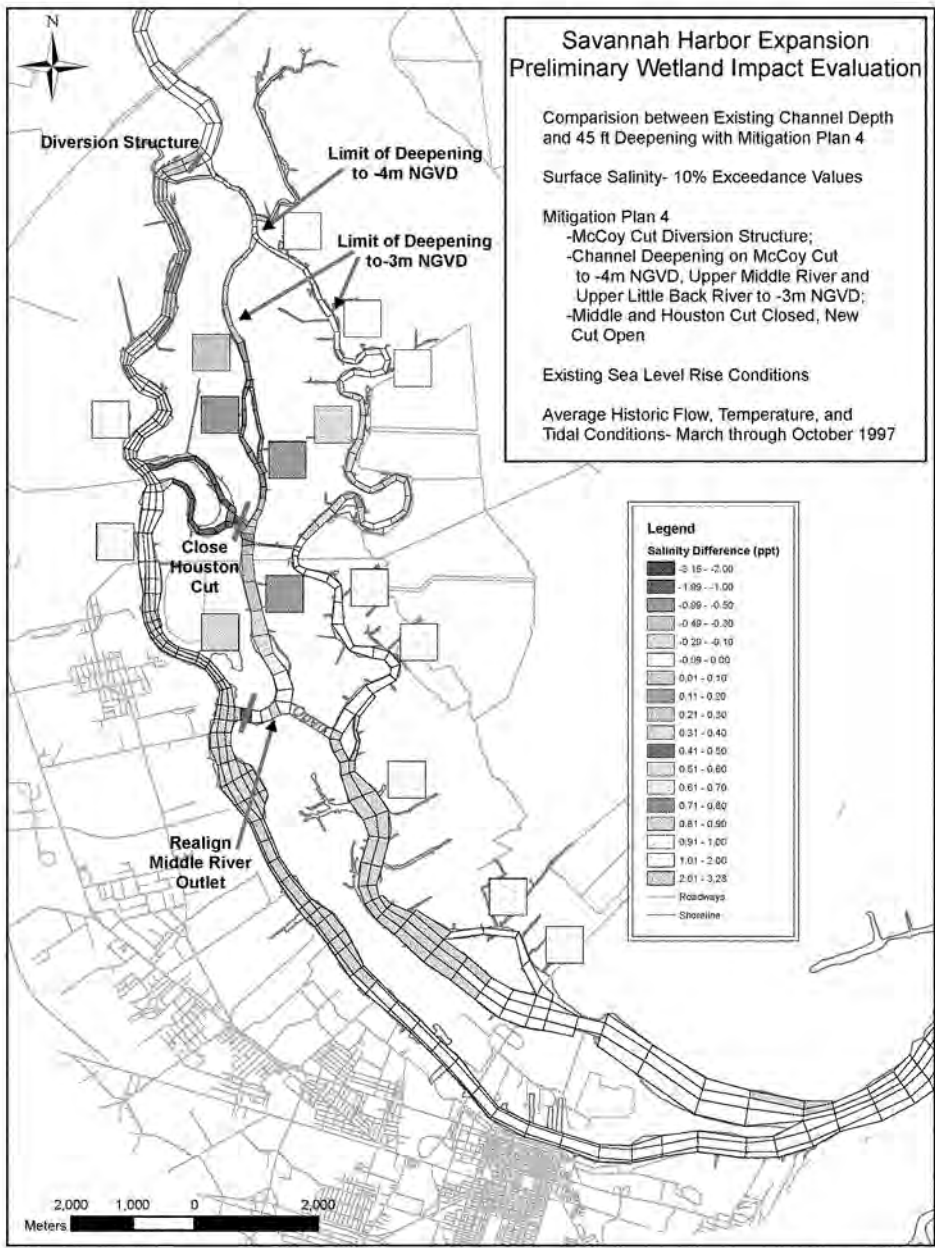


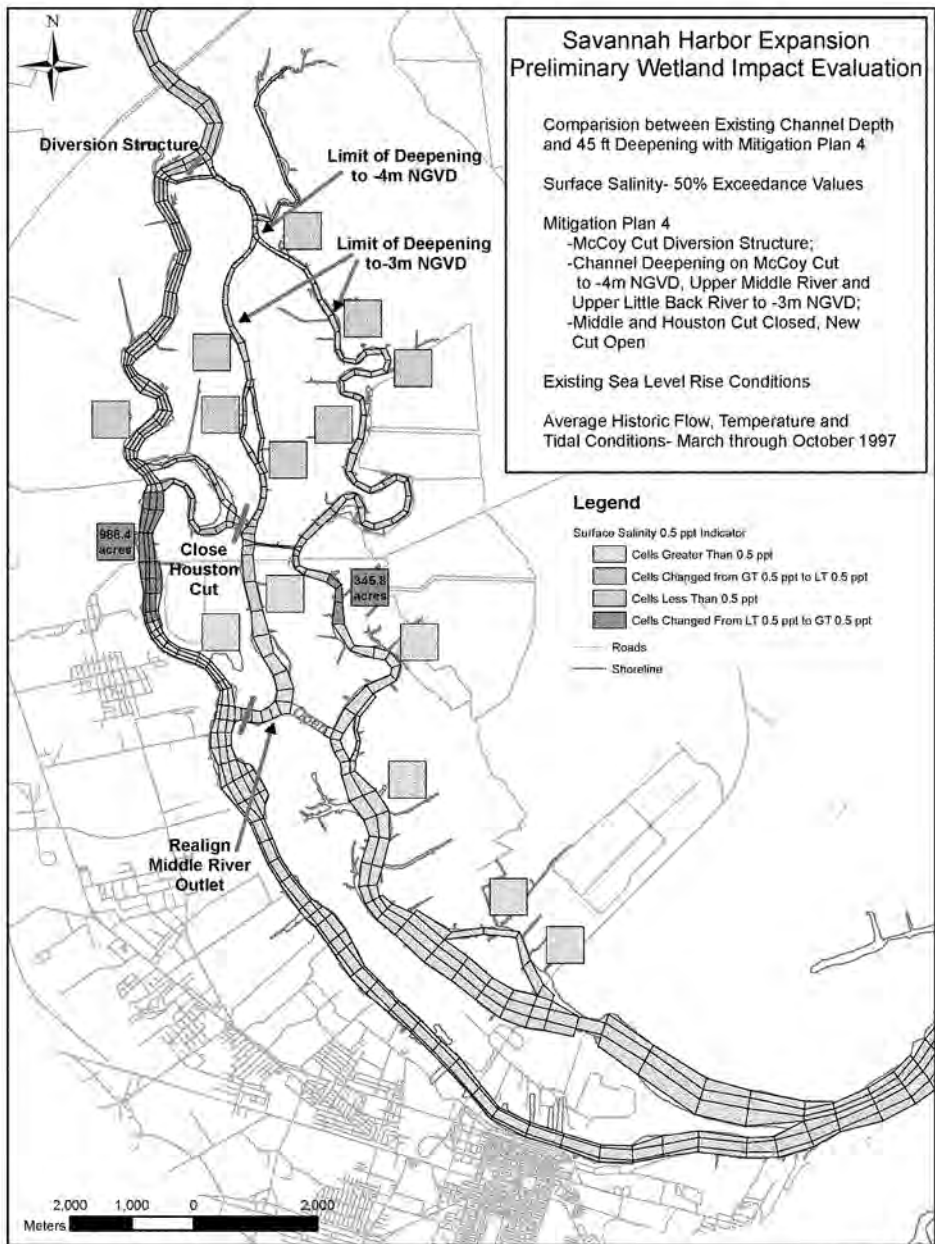


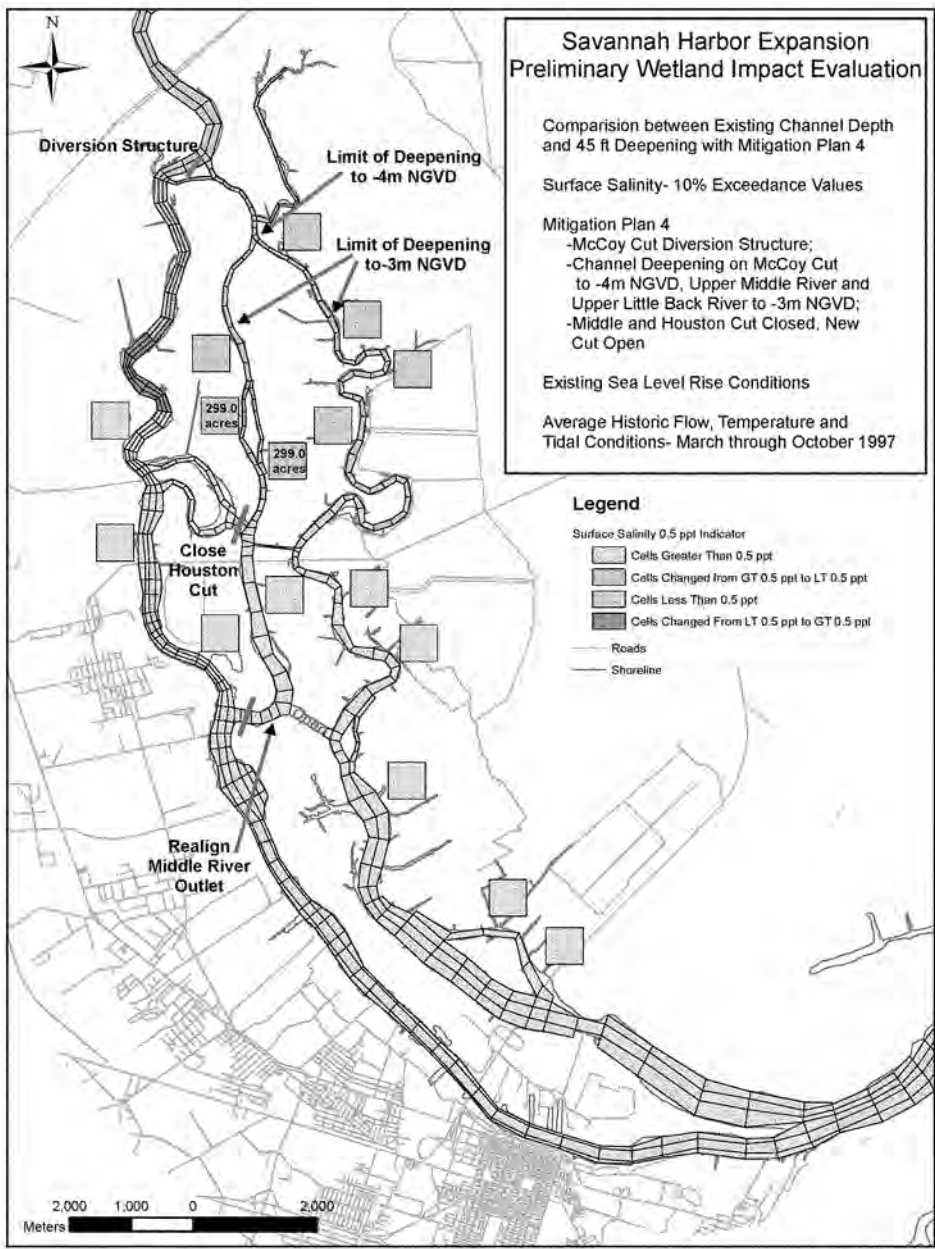
45-ft Deepening

Basic Evaluation

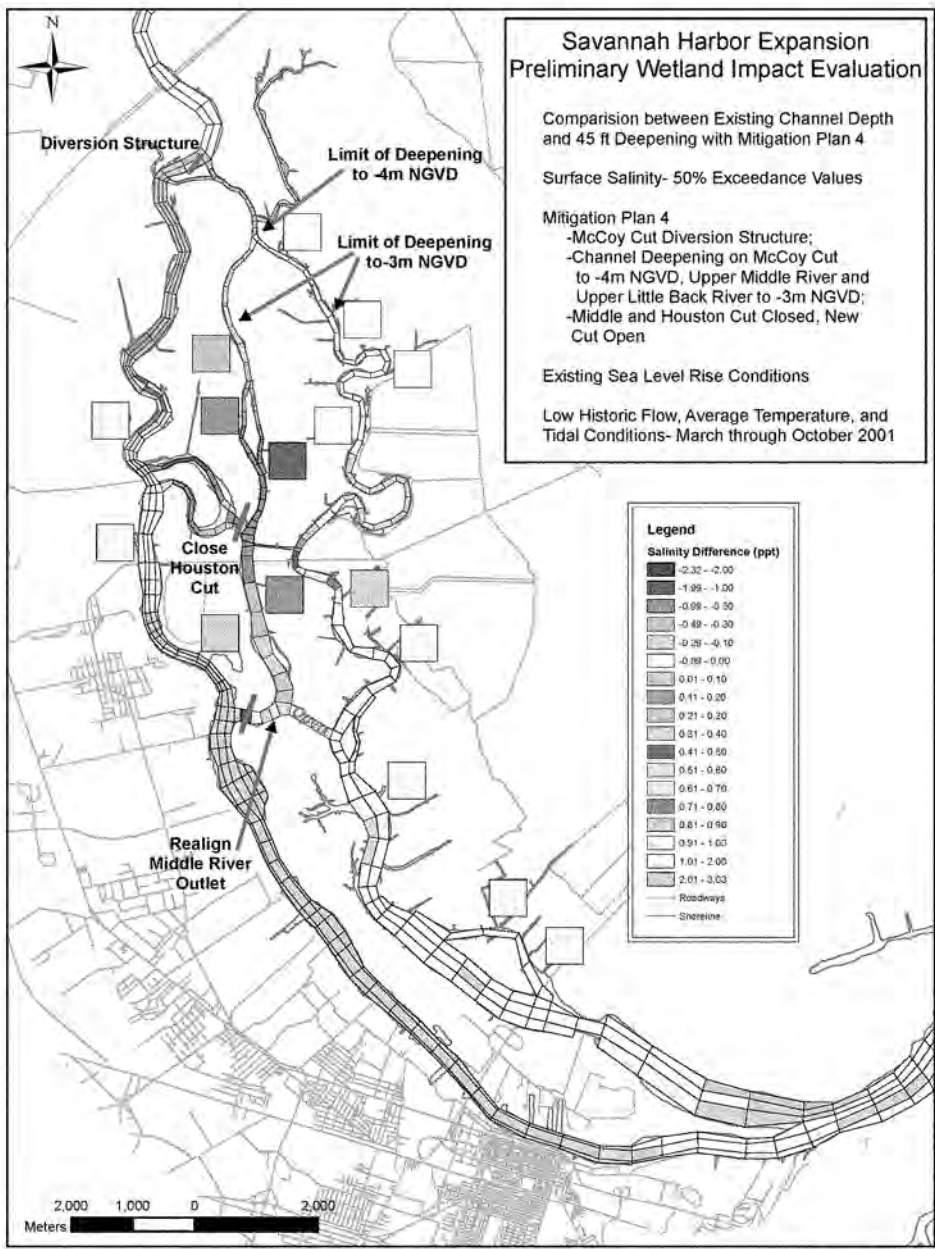


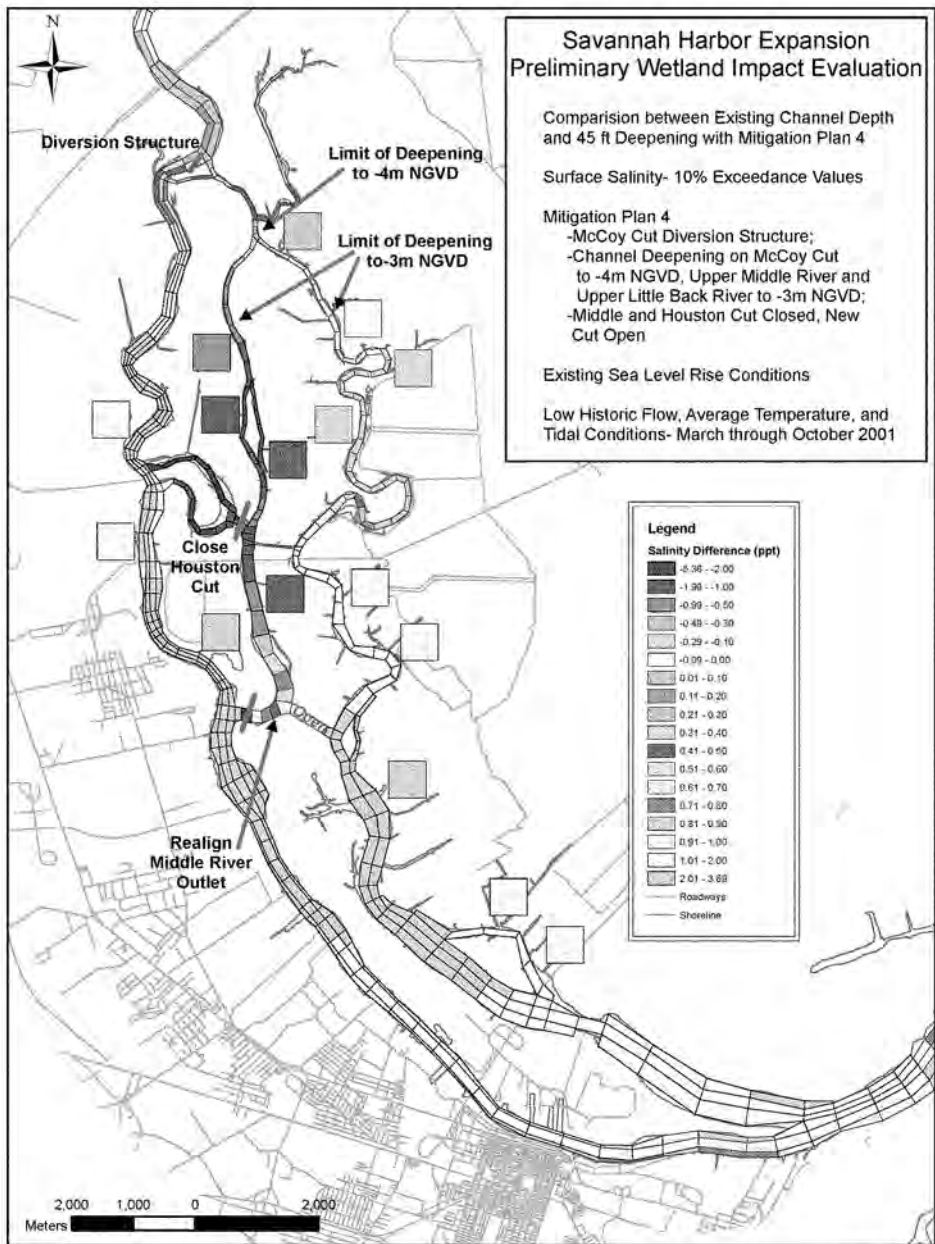


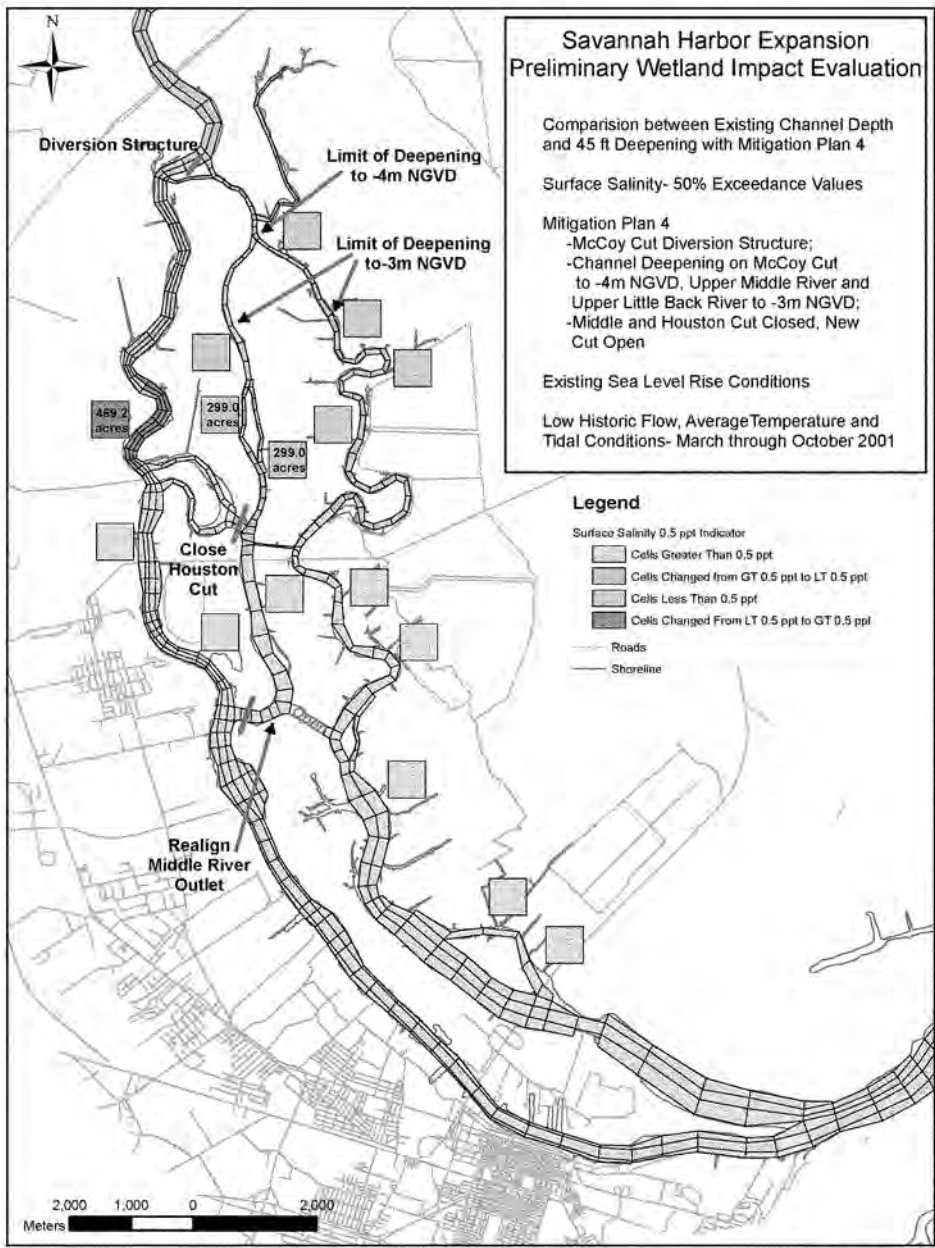


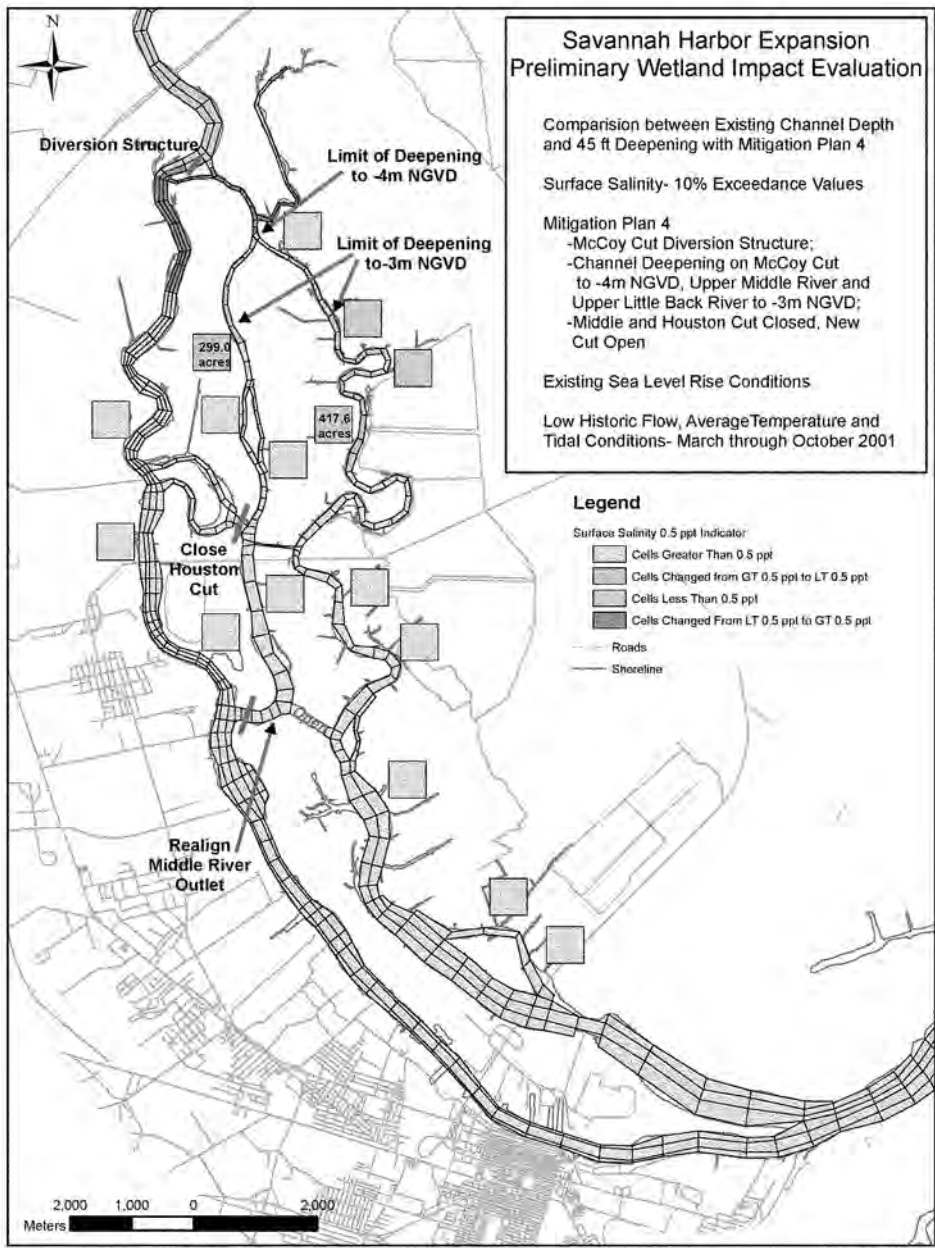


Sensitivity Analysis #1

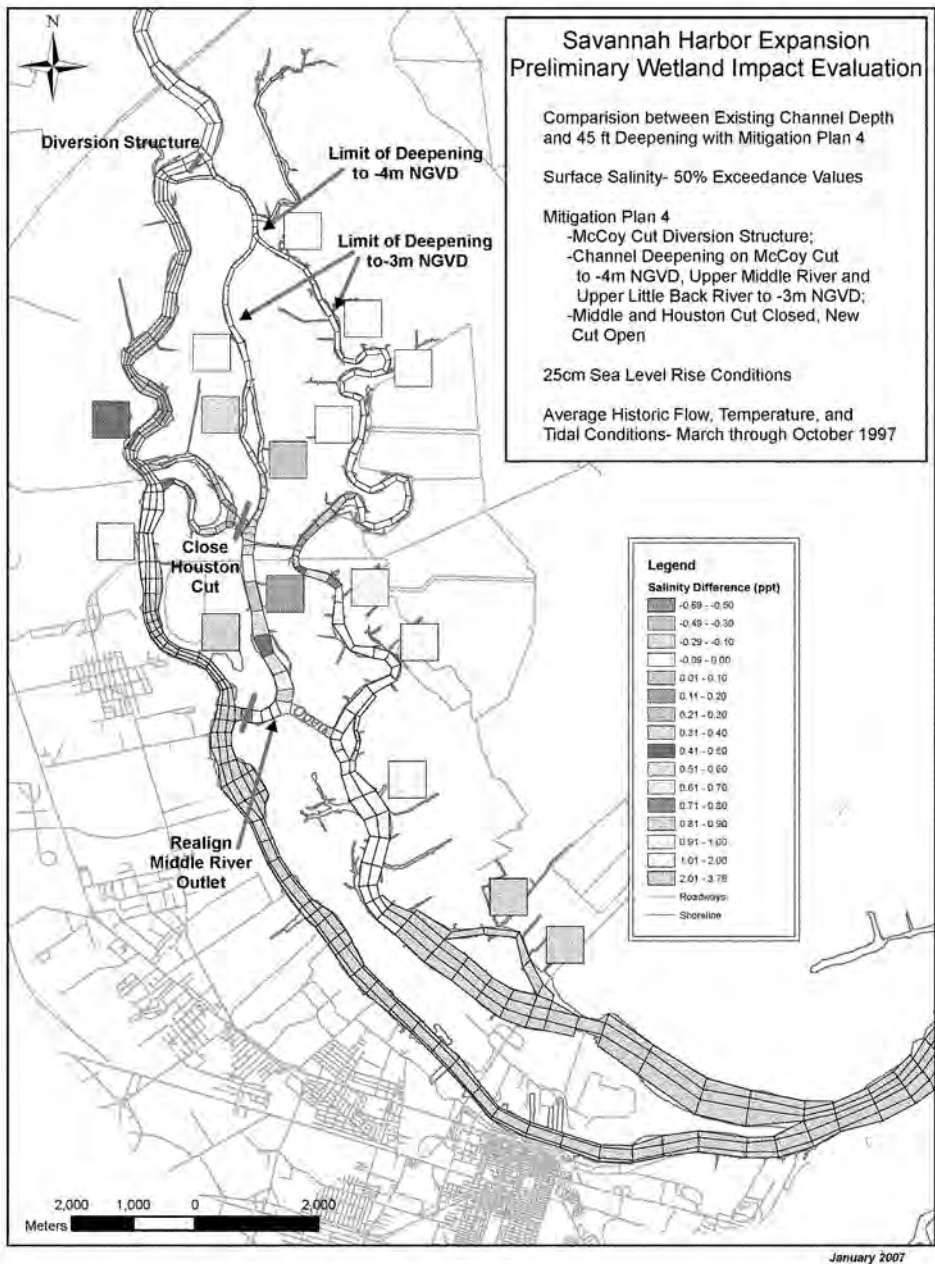


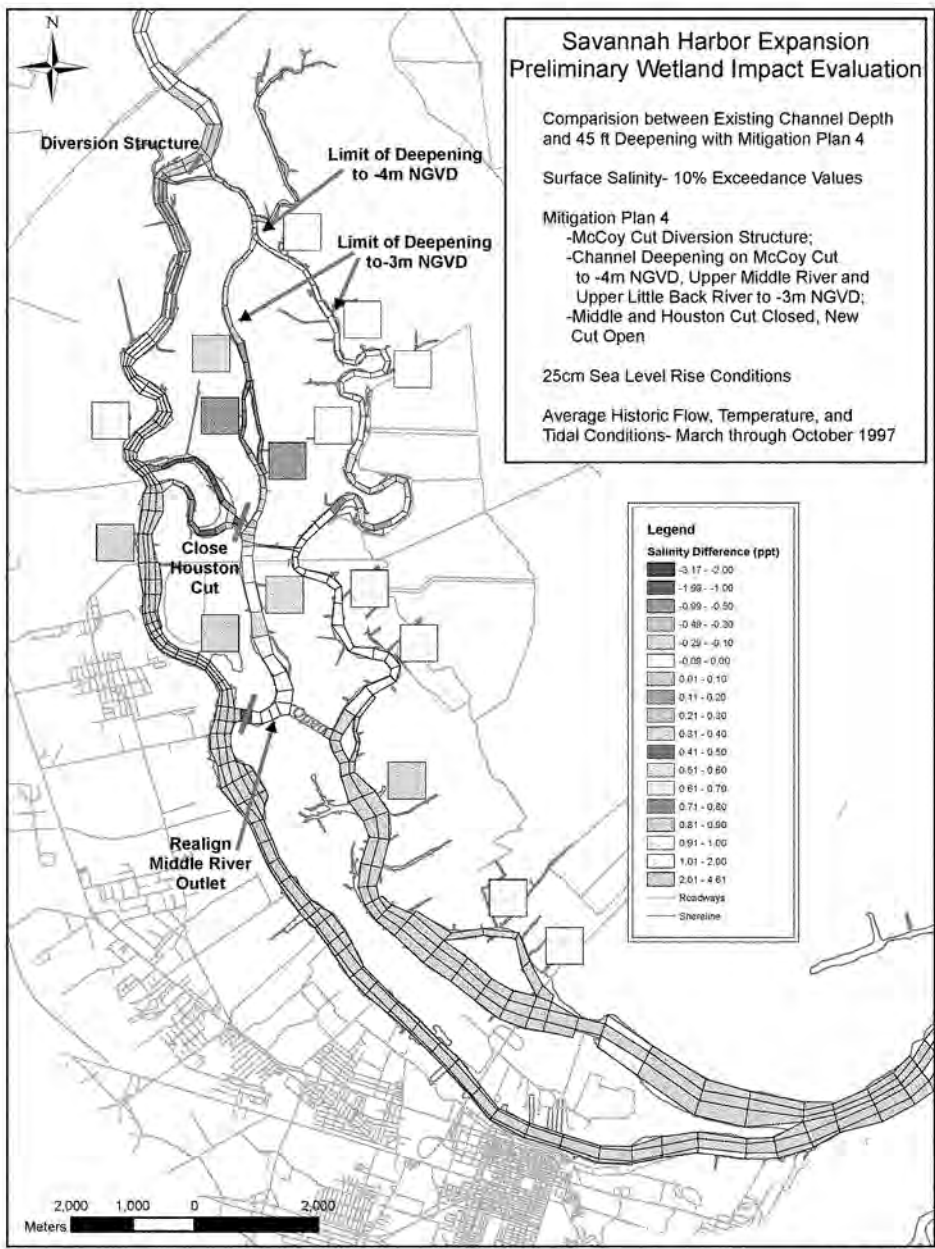


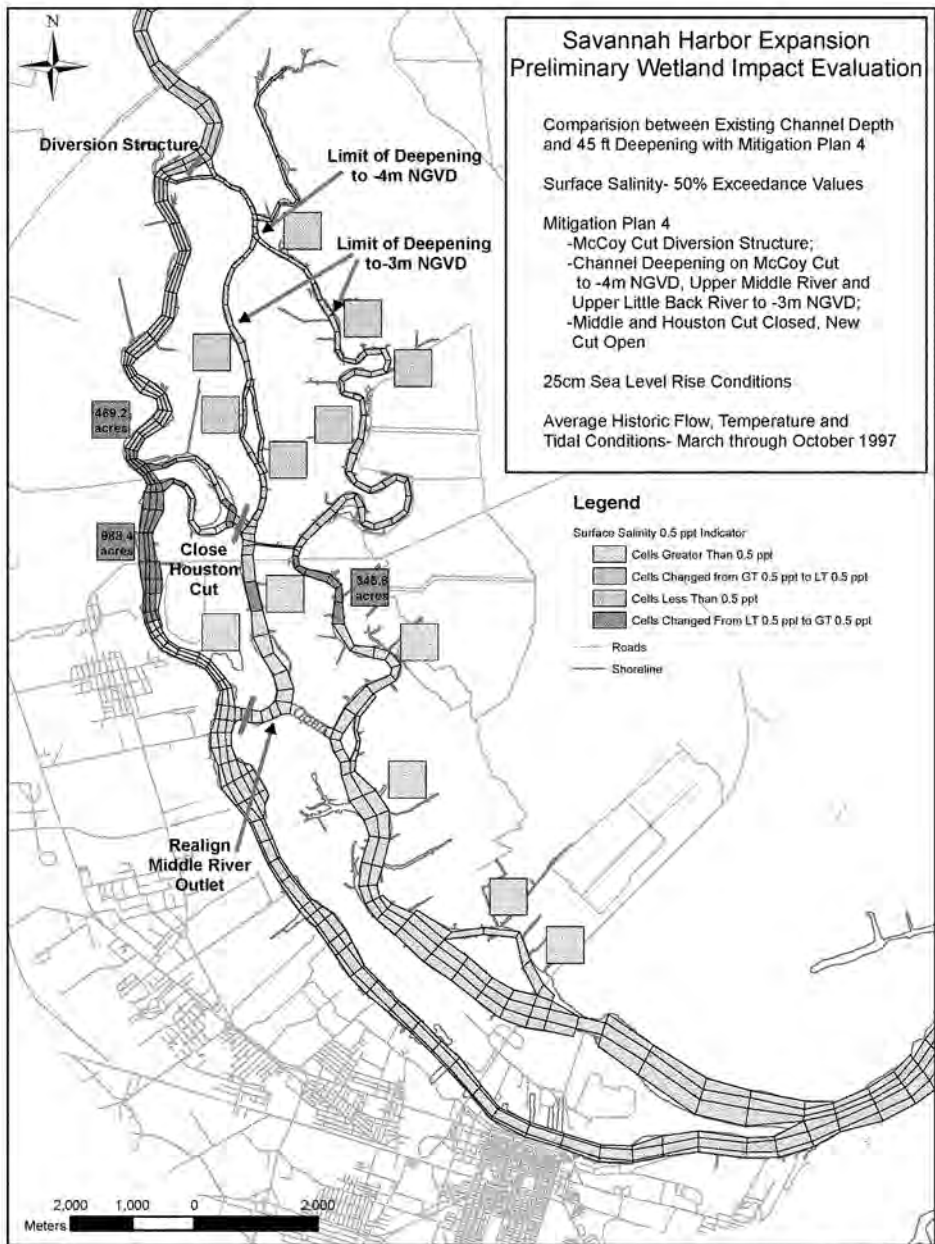


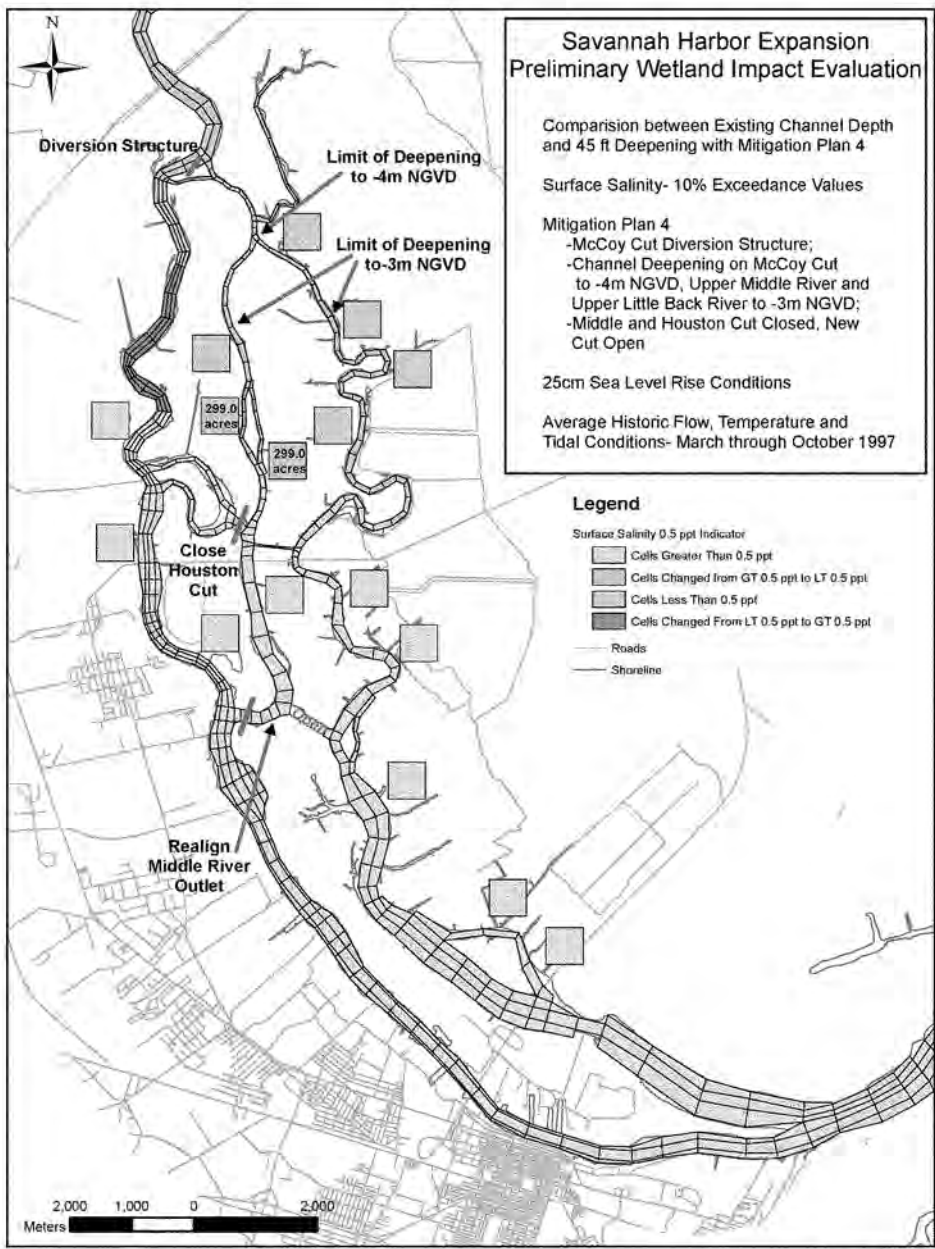


Sensitivity Analysis #2A

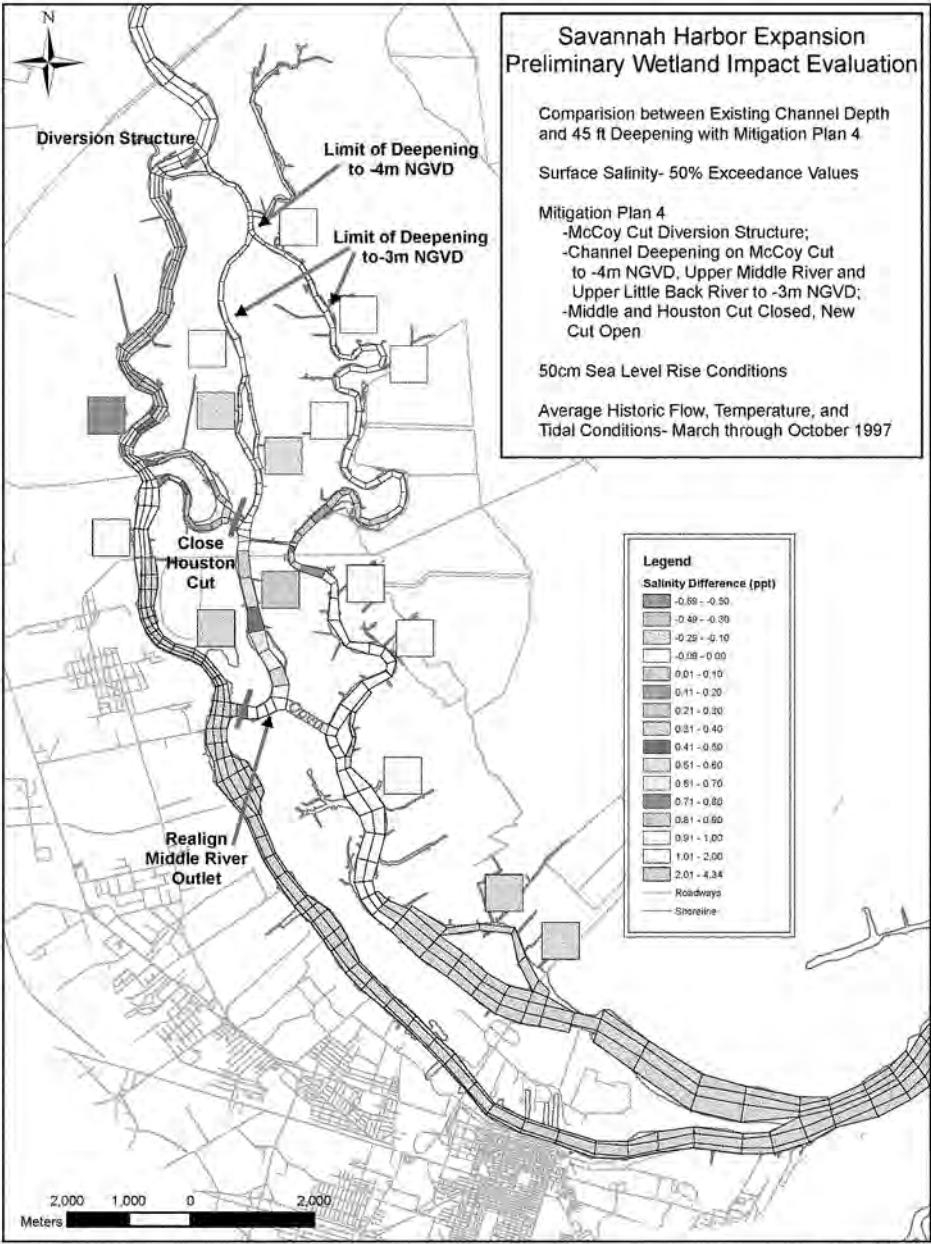


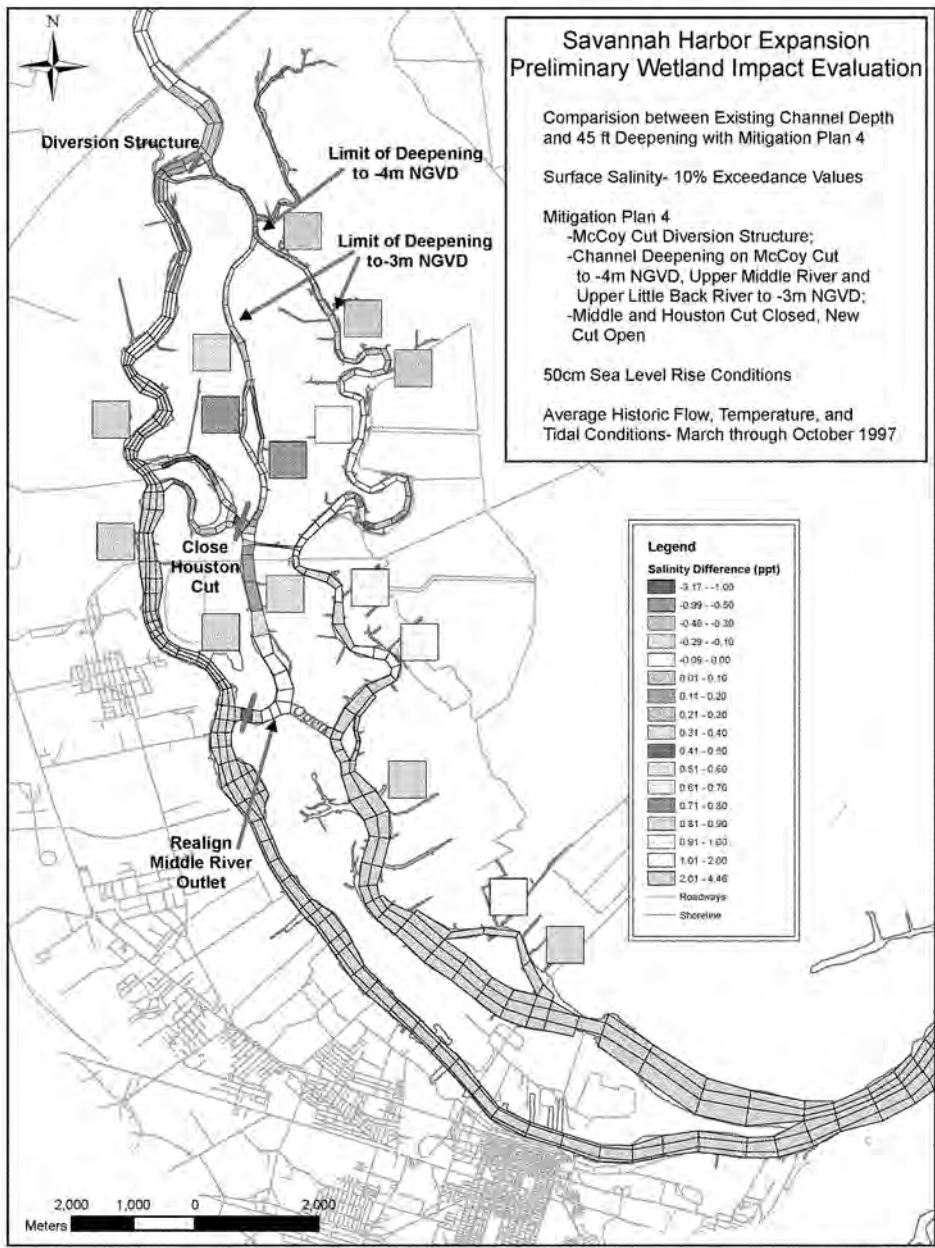


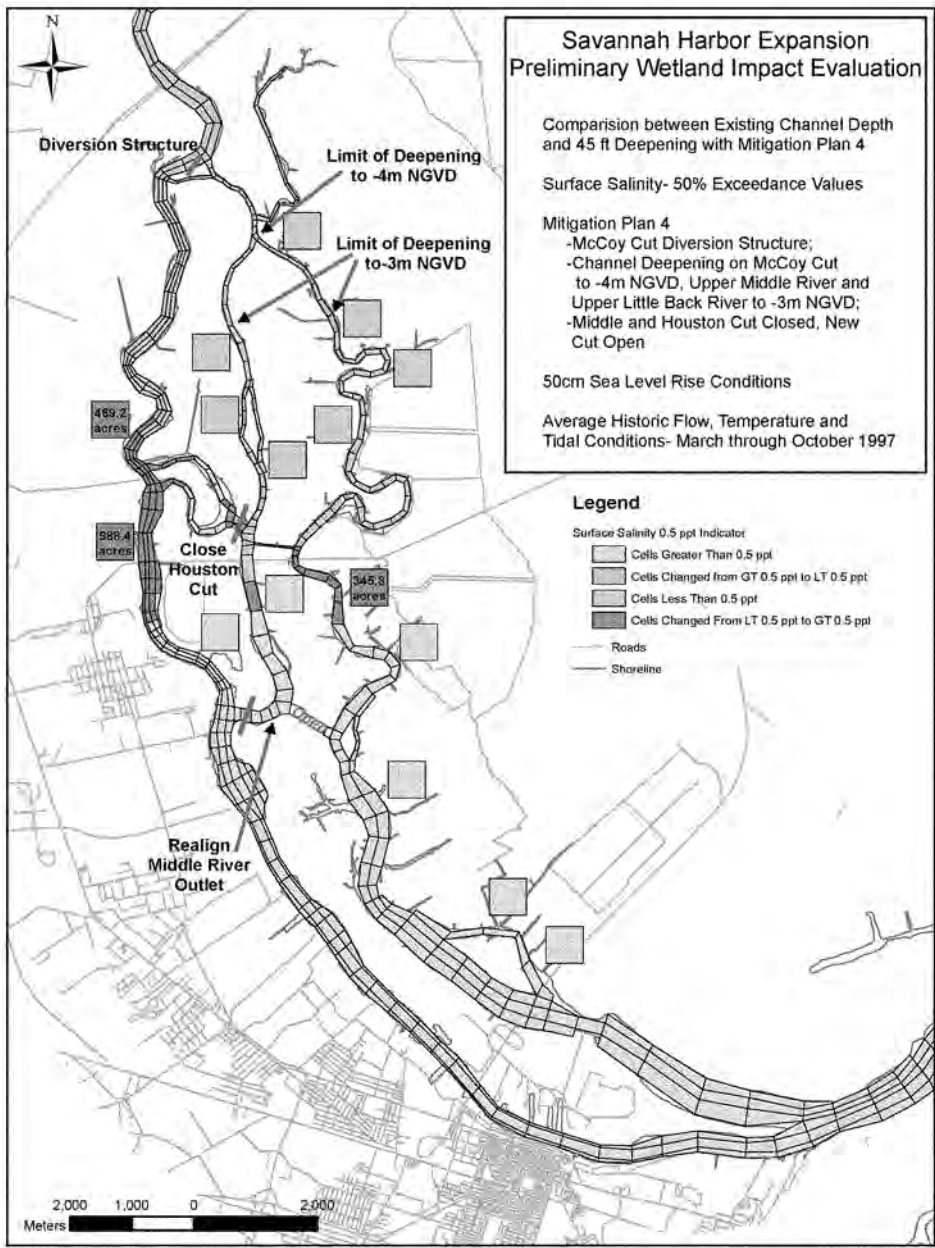


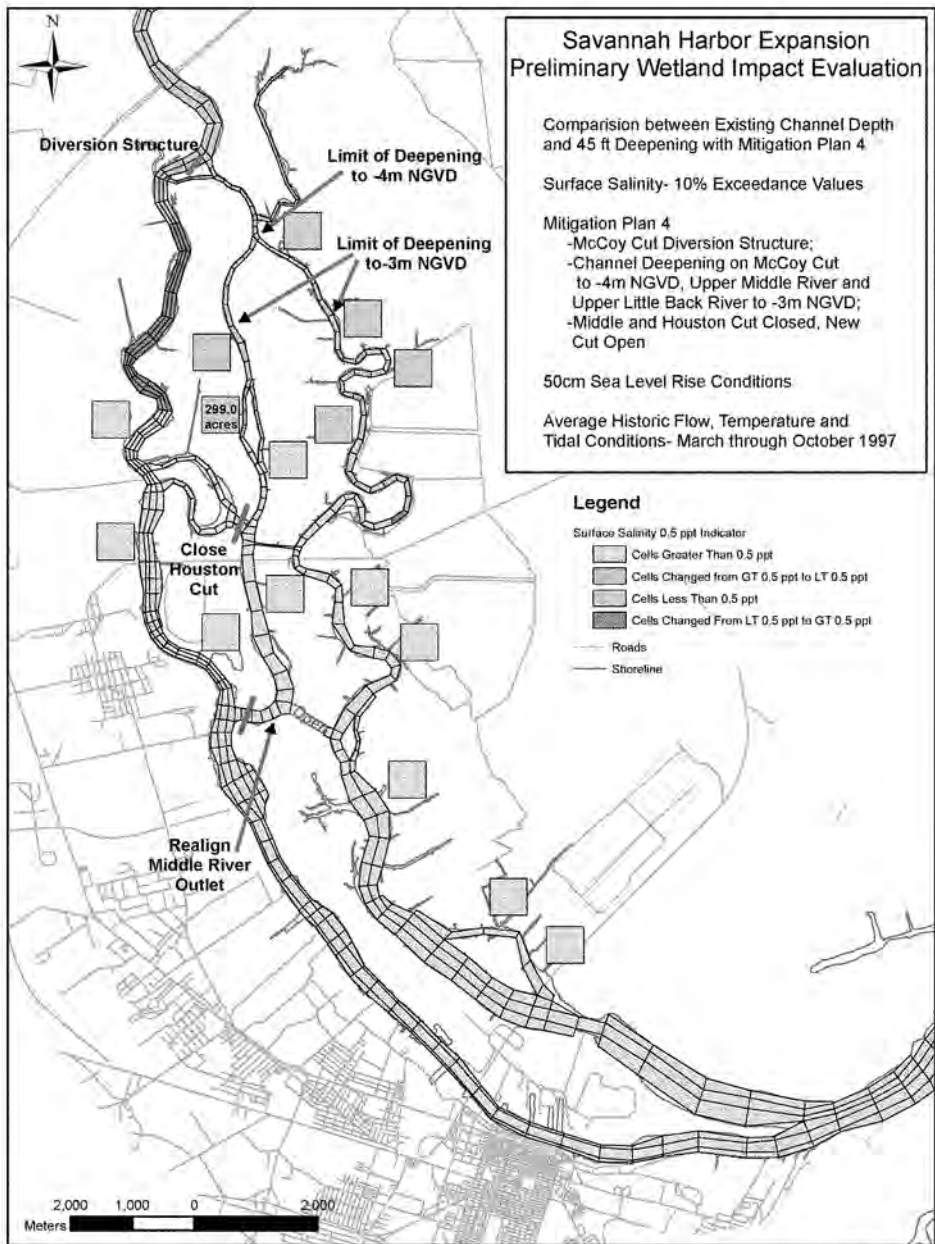


Sensitivity Analysis #2B



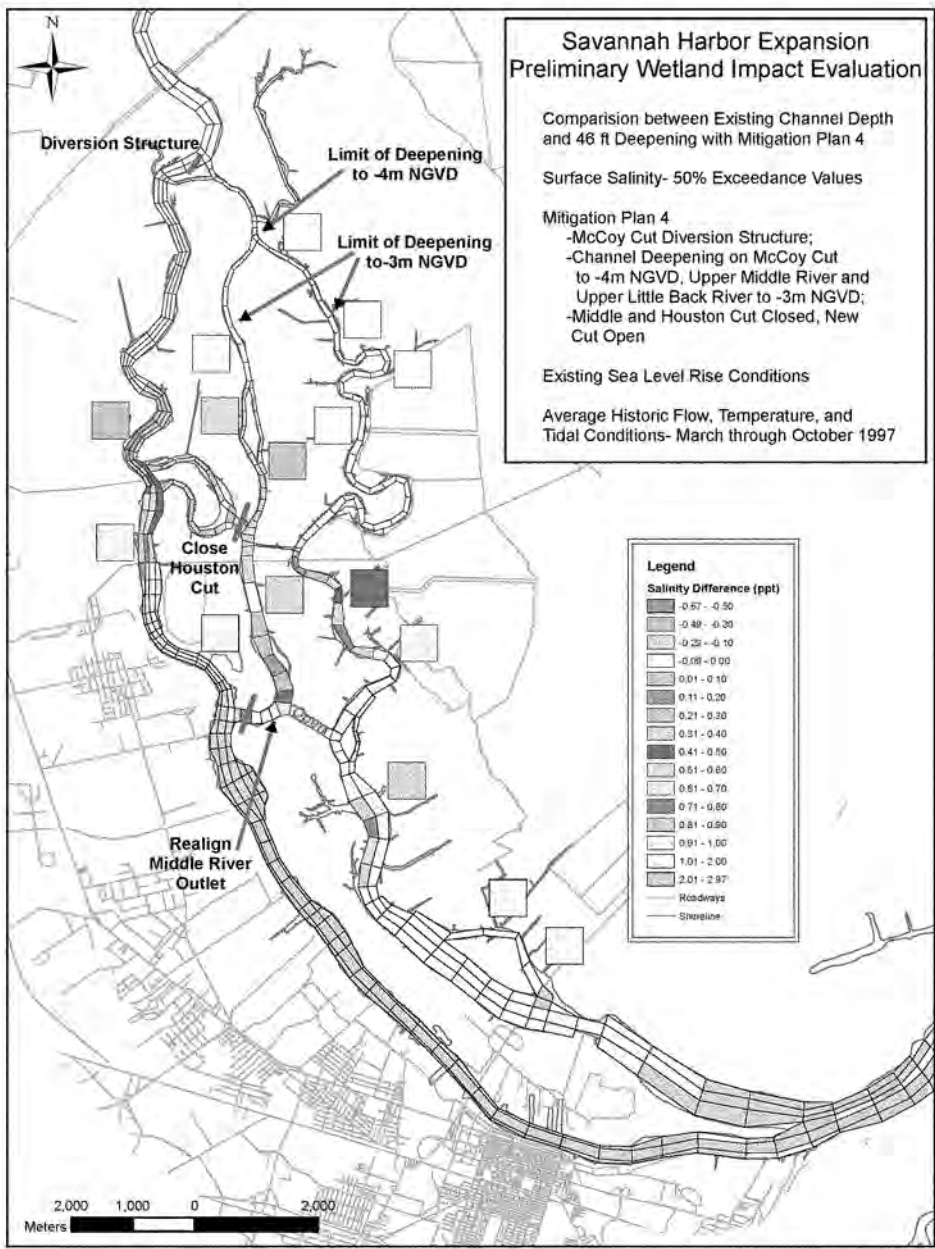


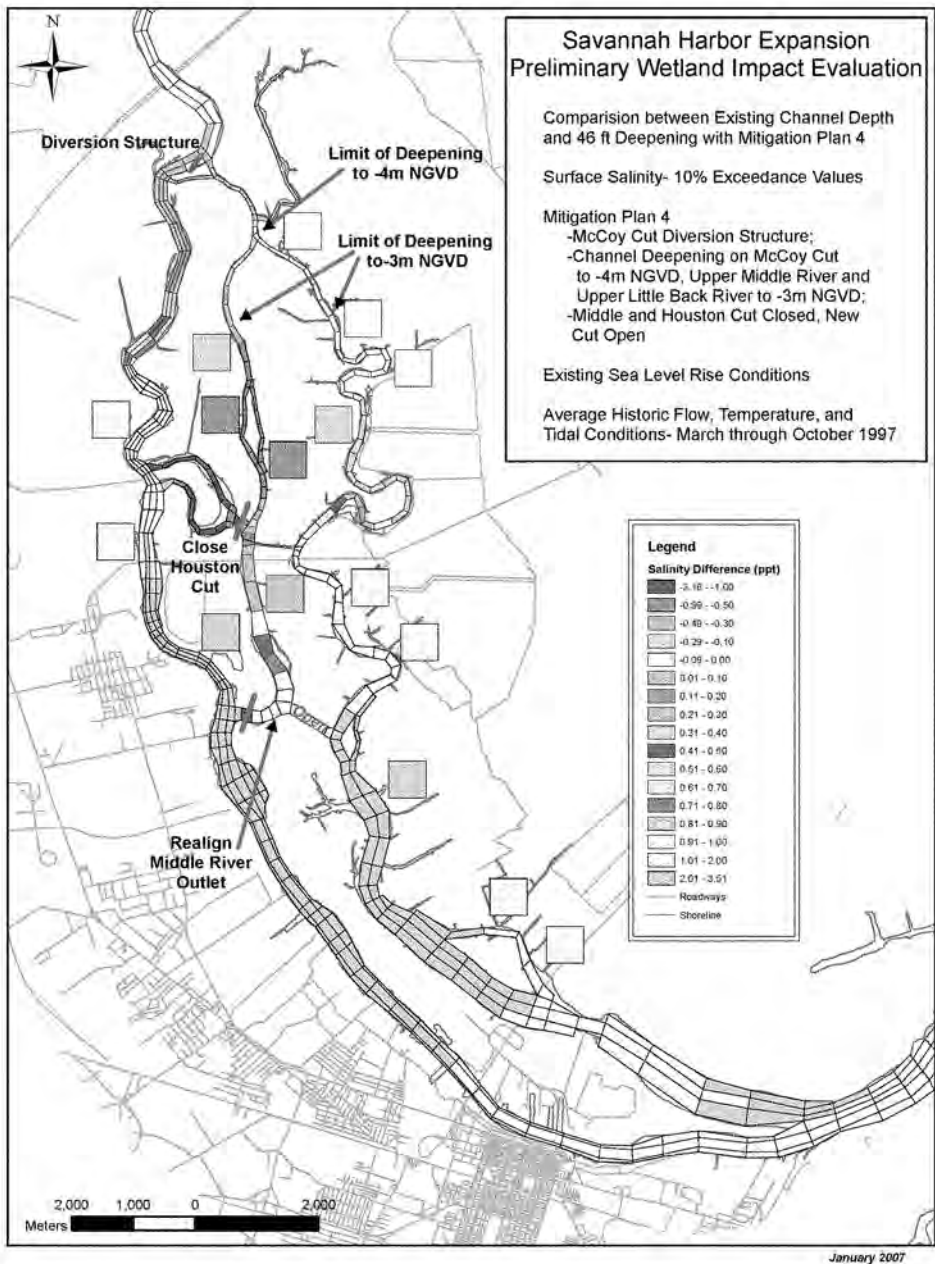


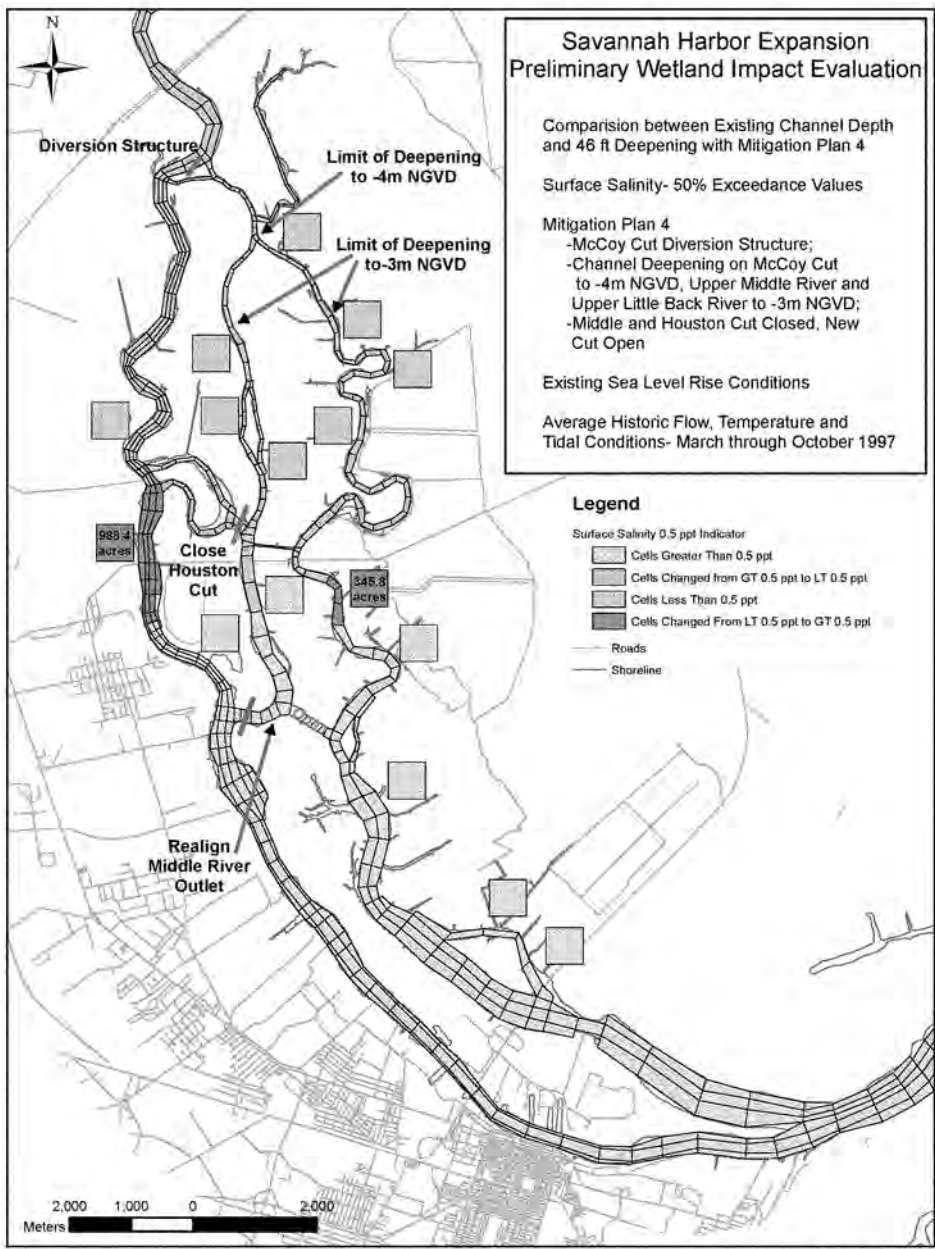


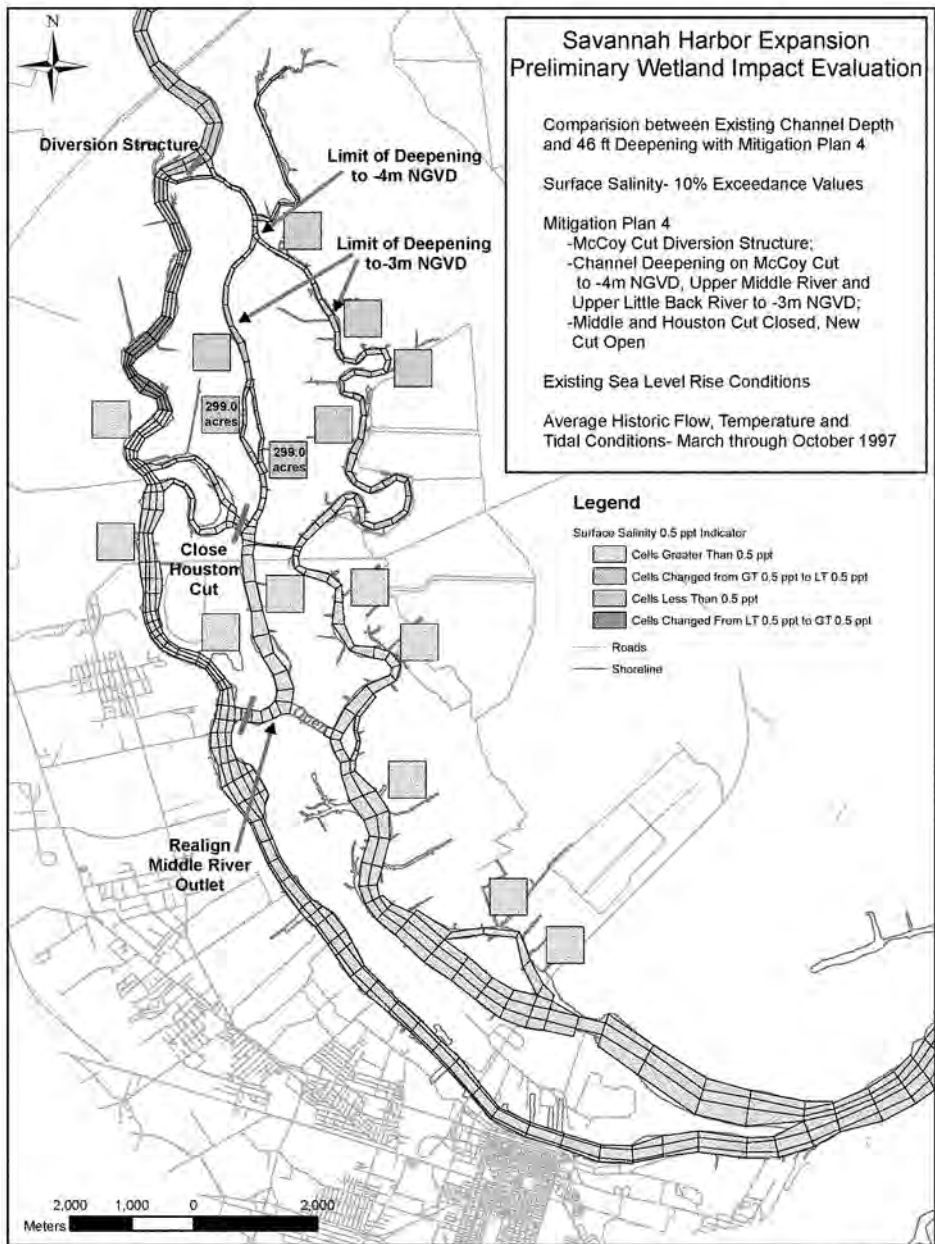
46-ft Deepening

Basic Evaluation

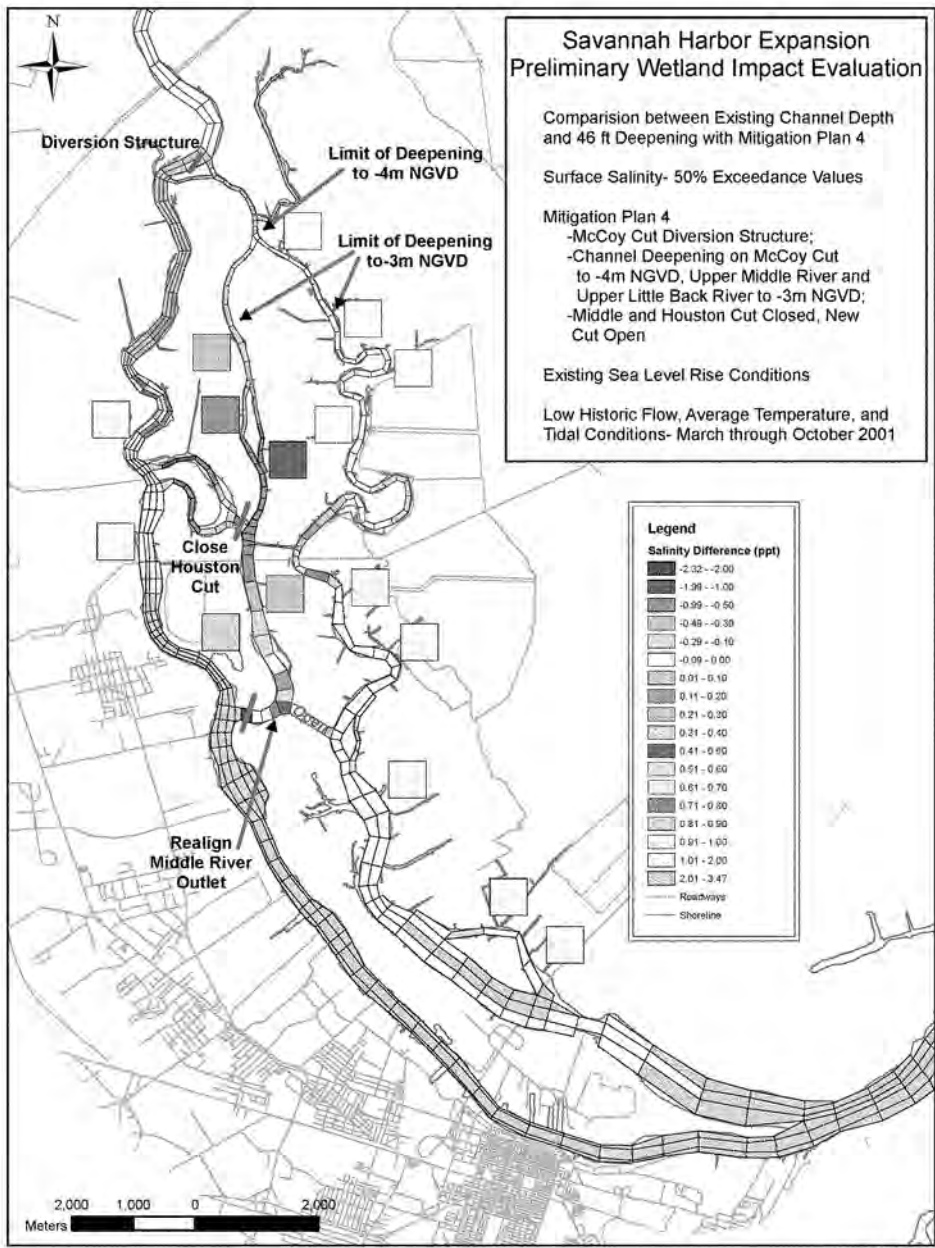


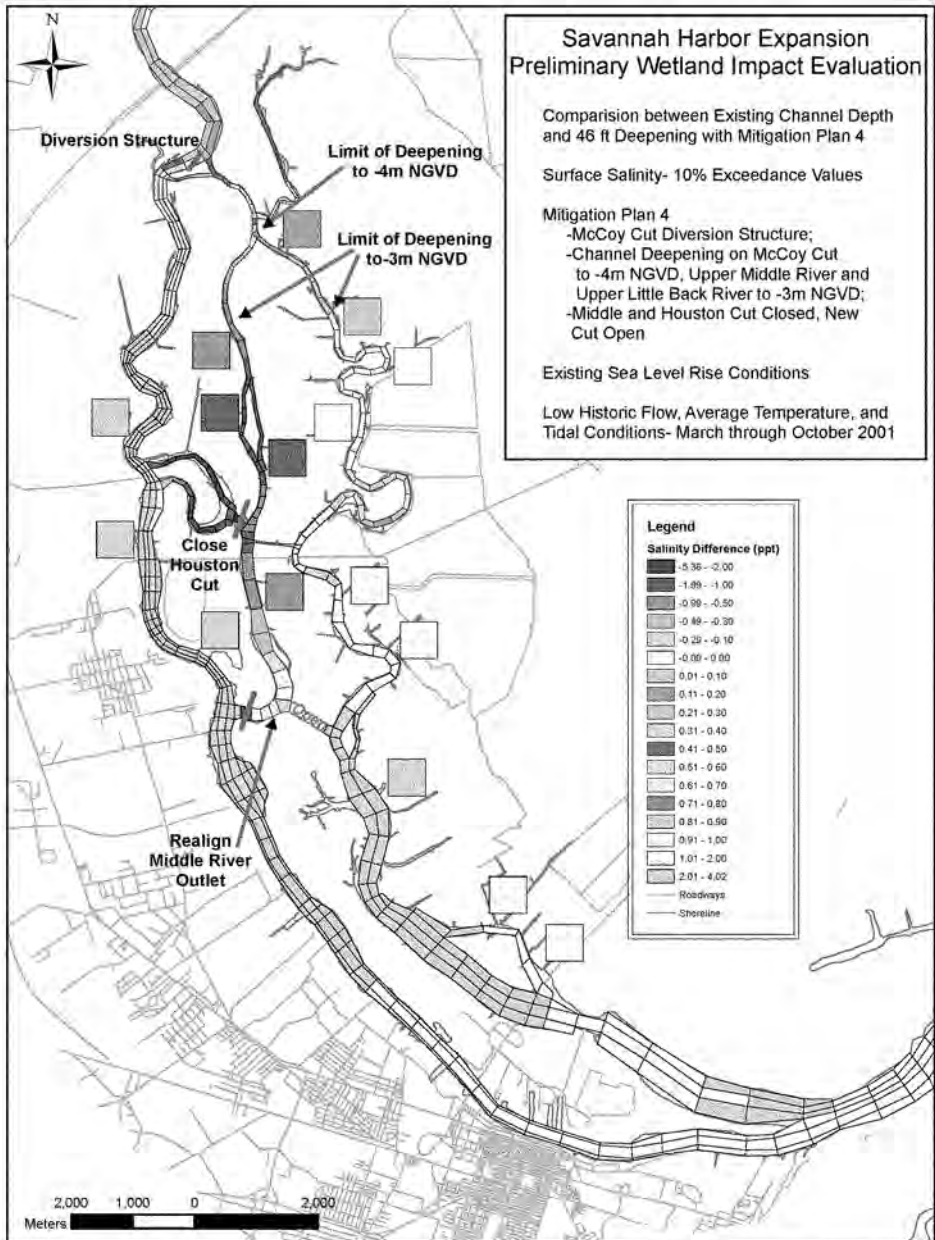




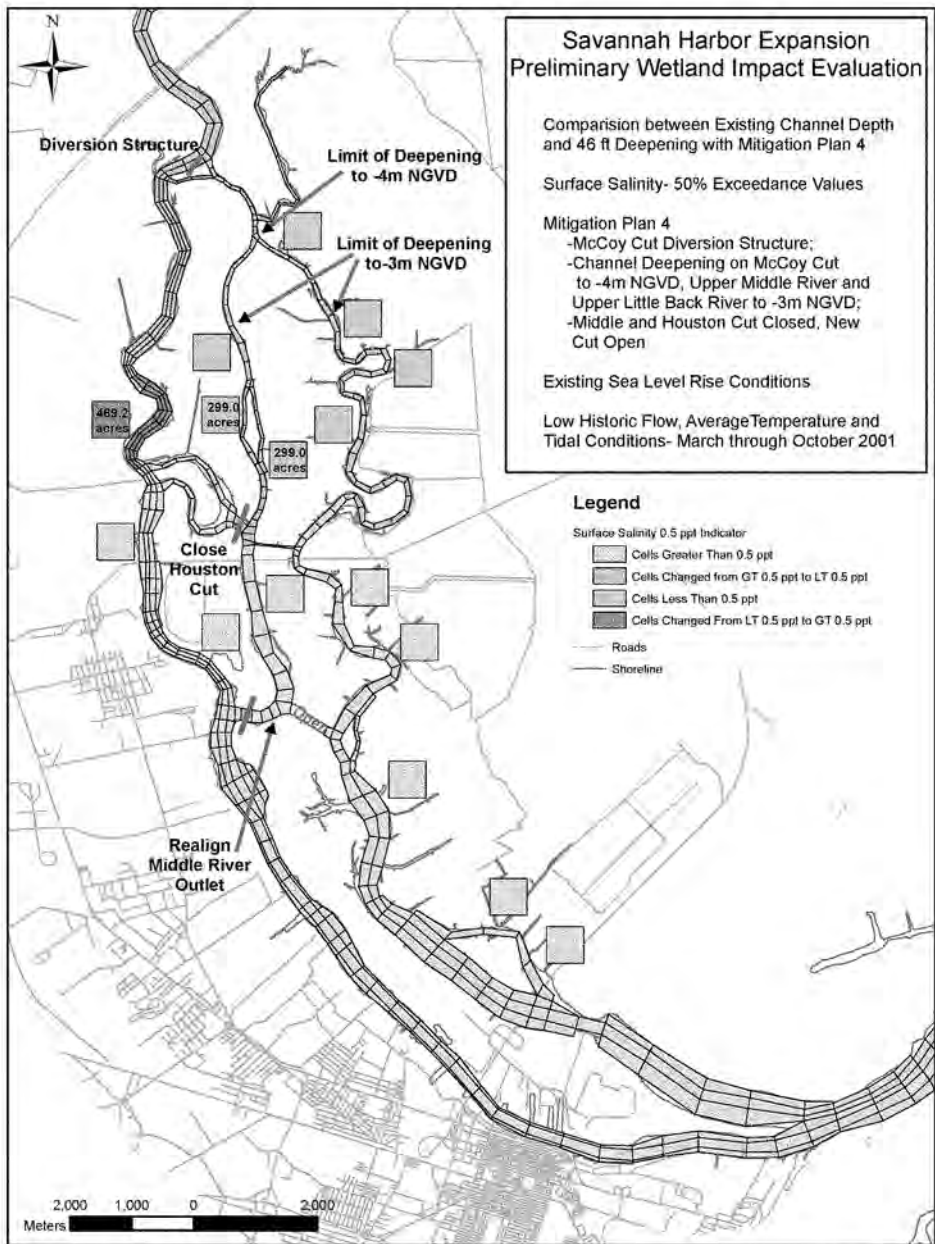


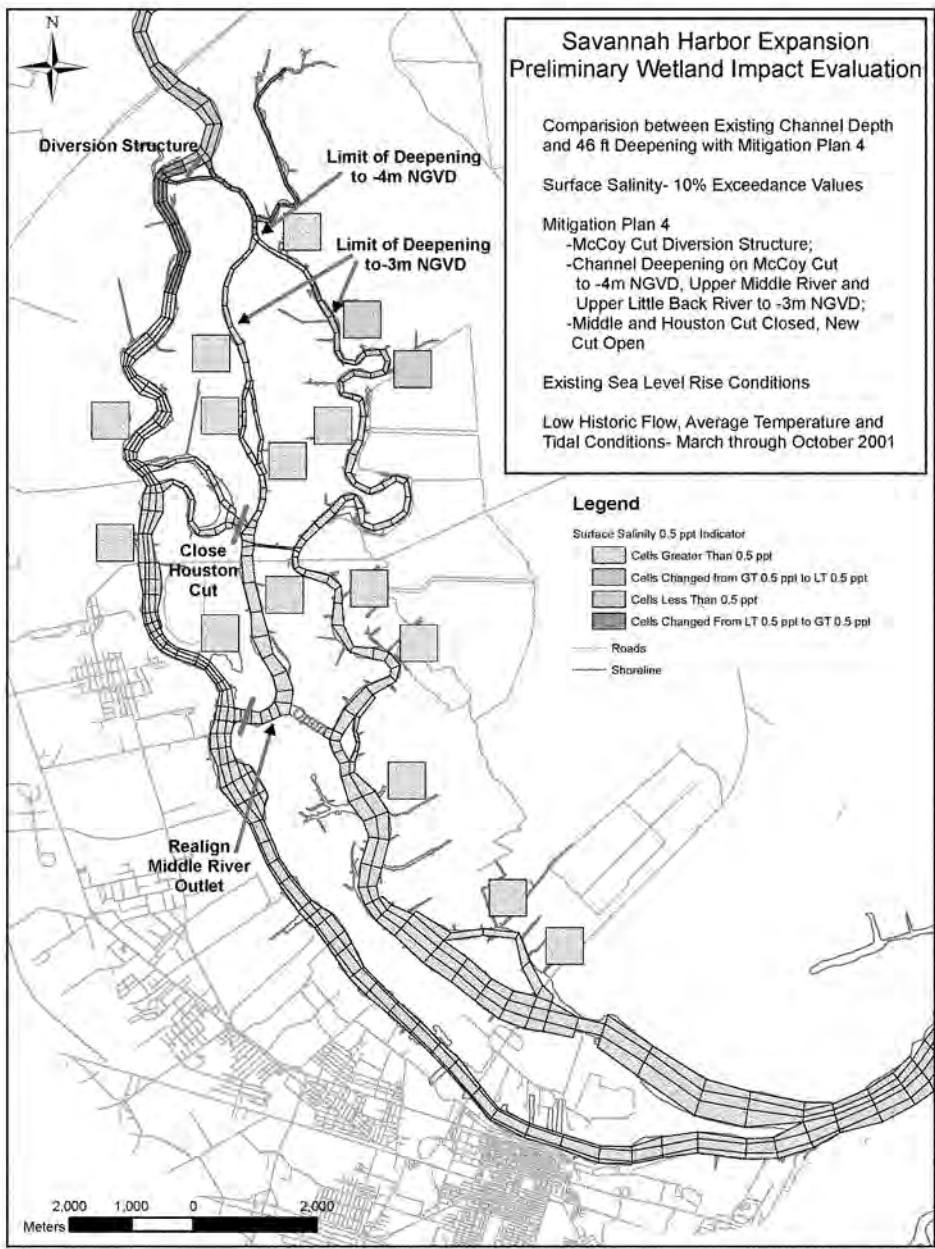
Sensitivity Analysis #1



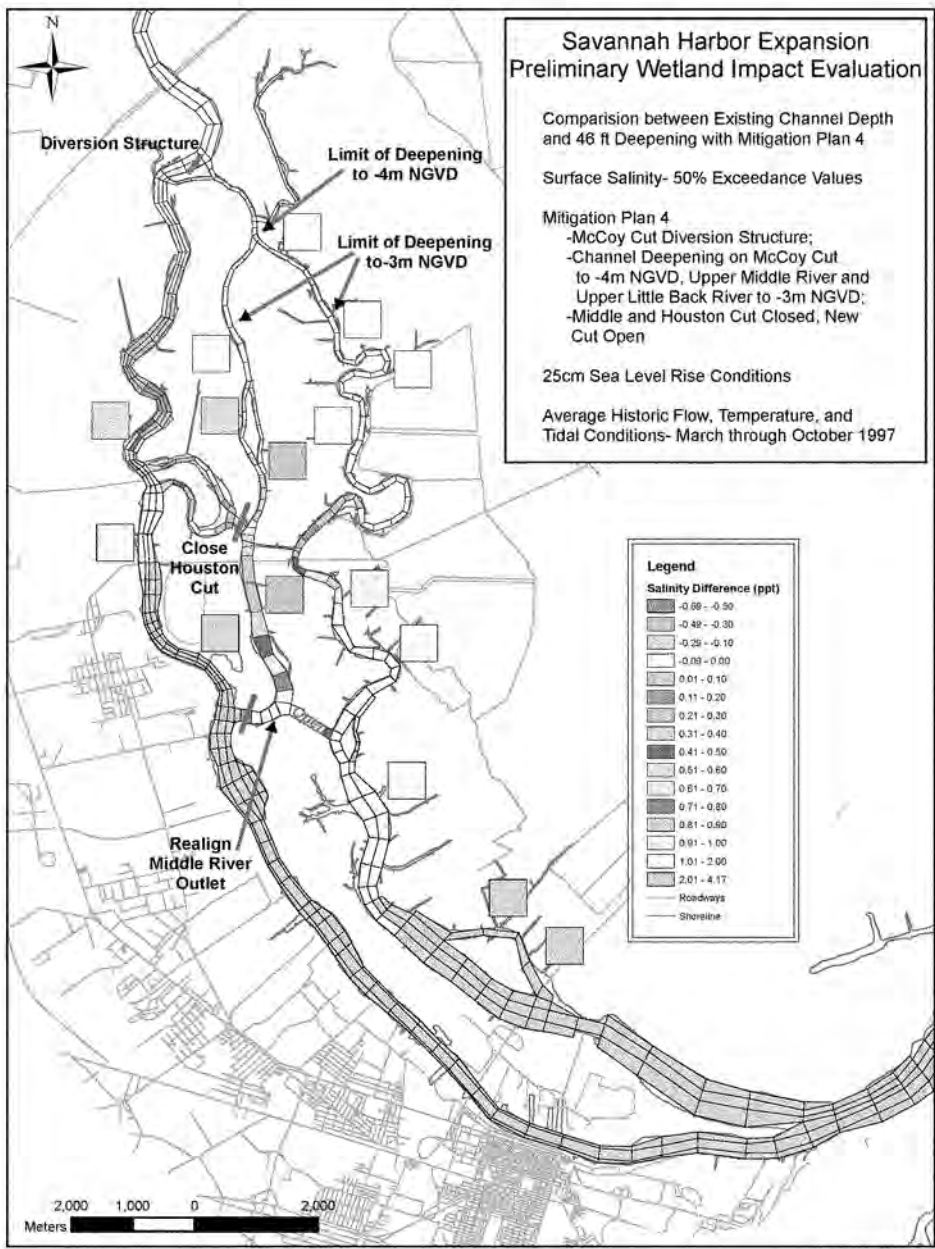


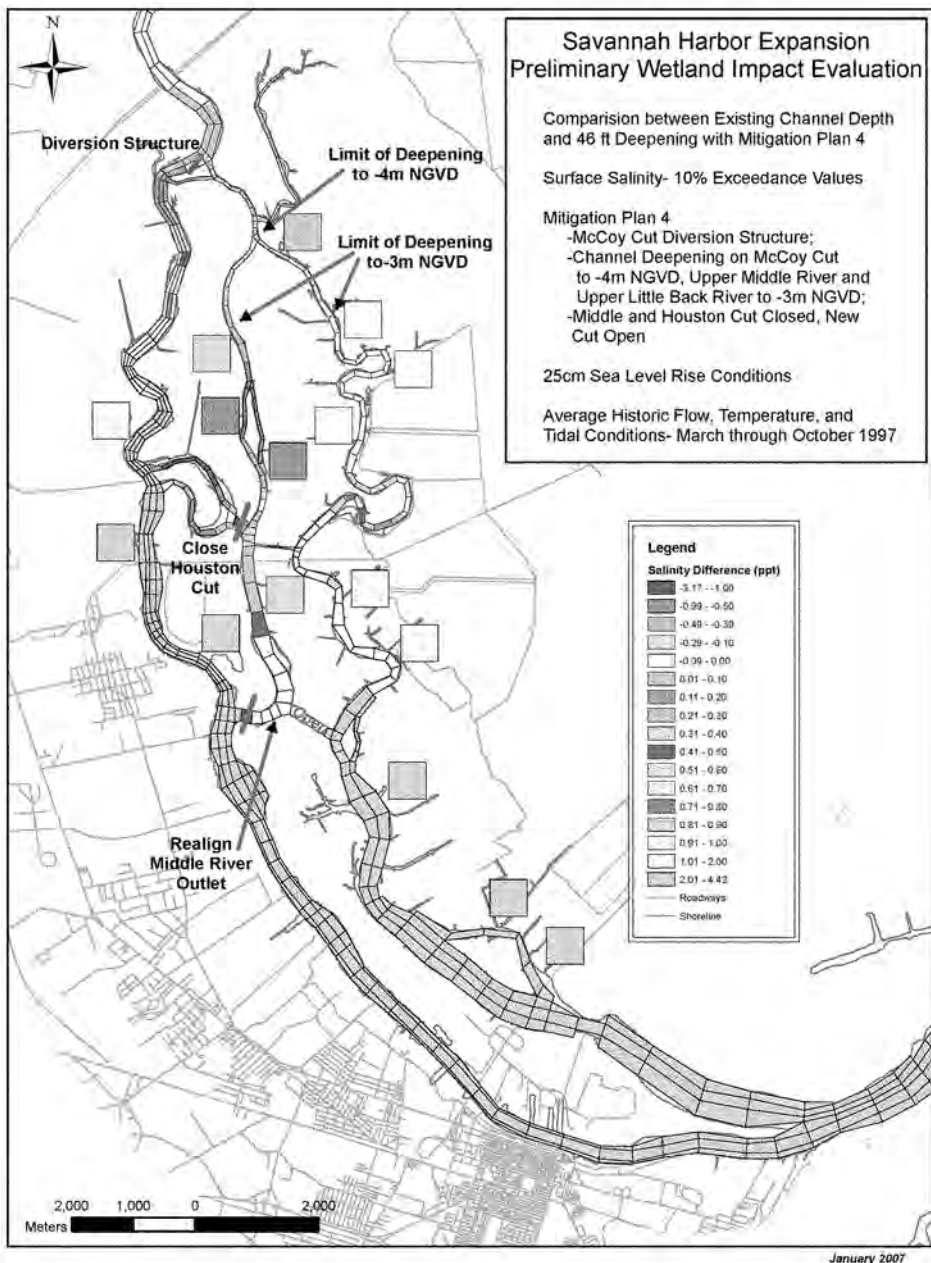
January 2007

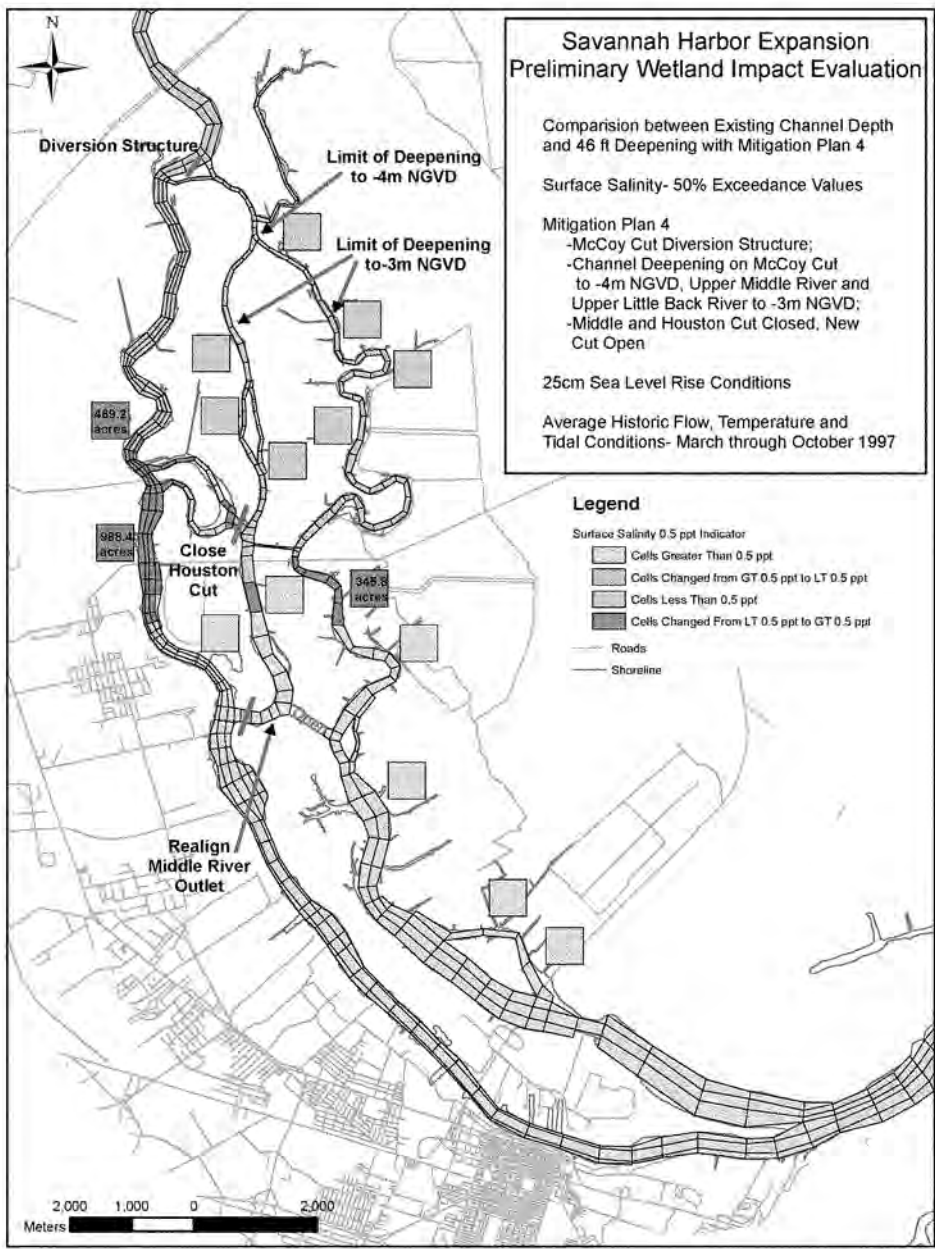


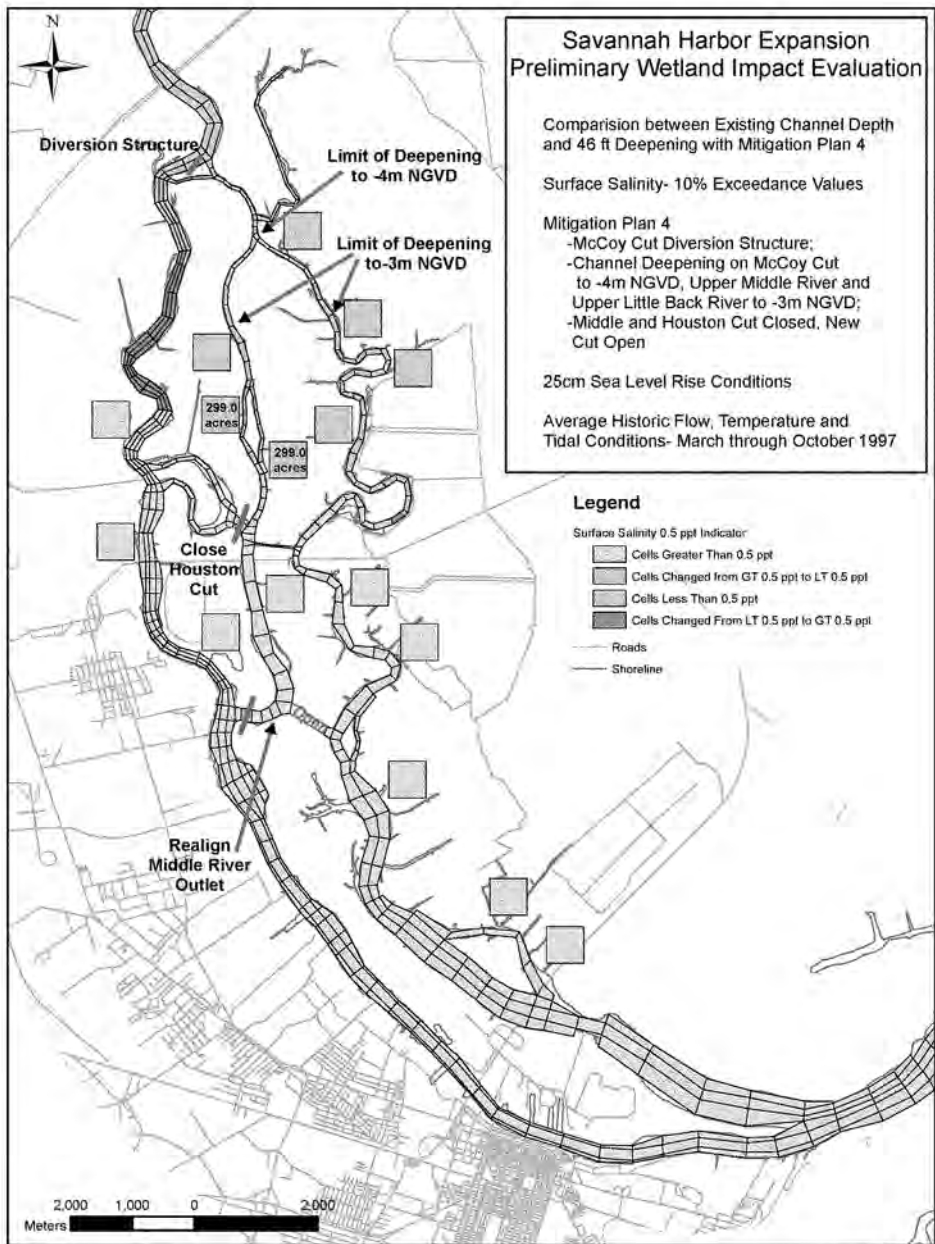


Sensitivity Analysis #2A

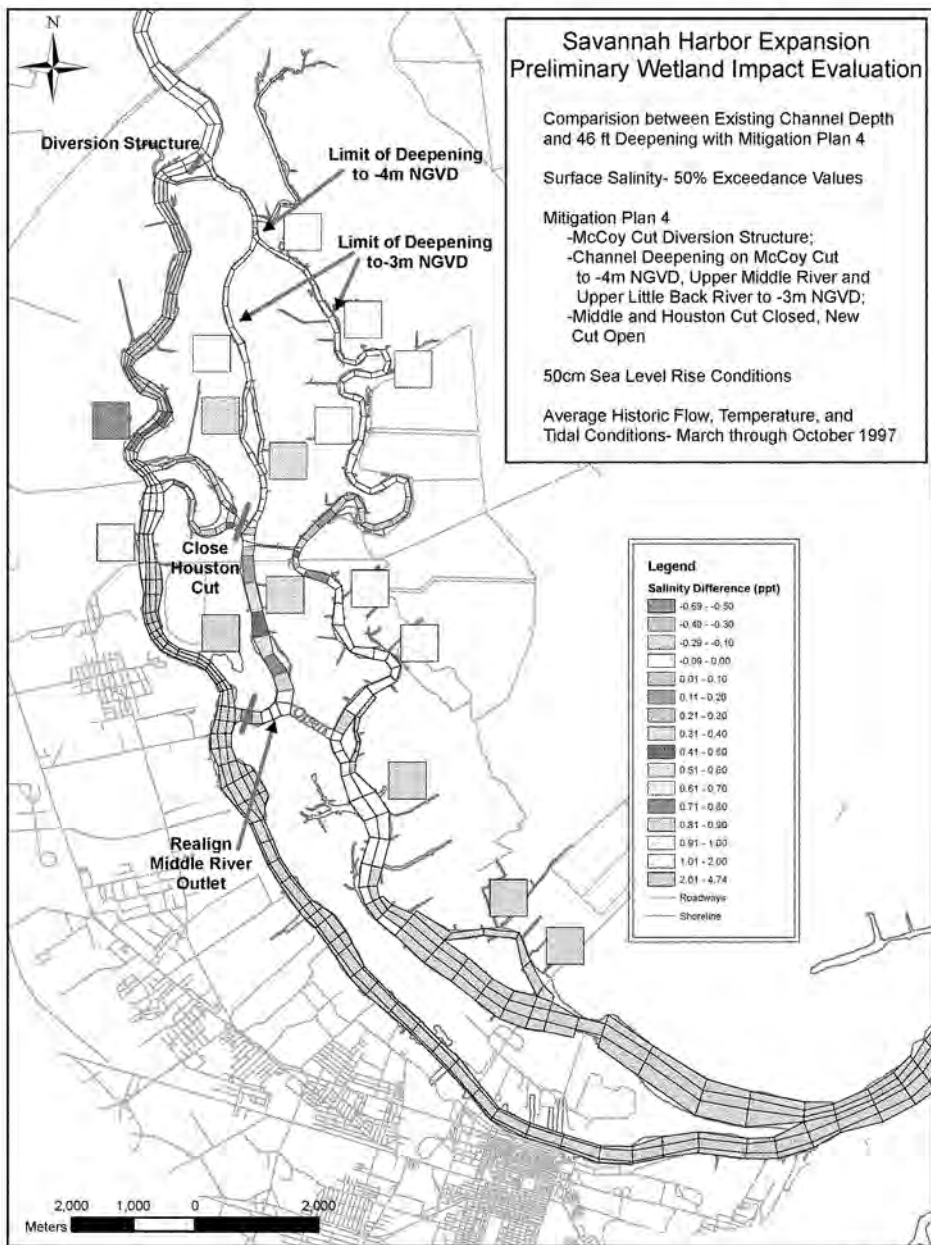


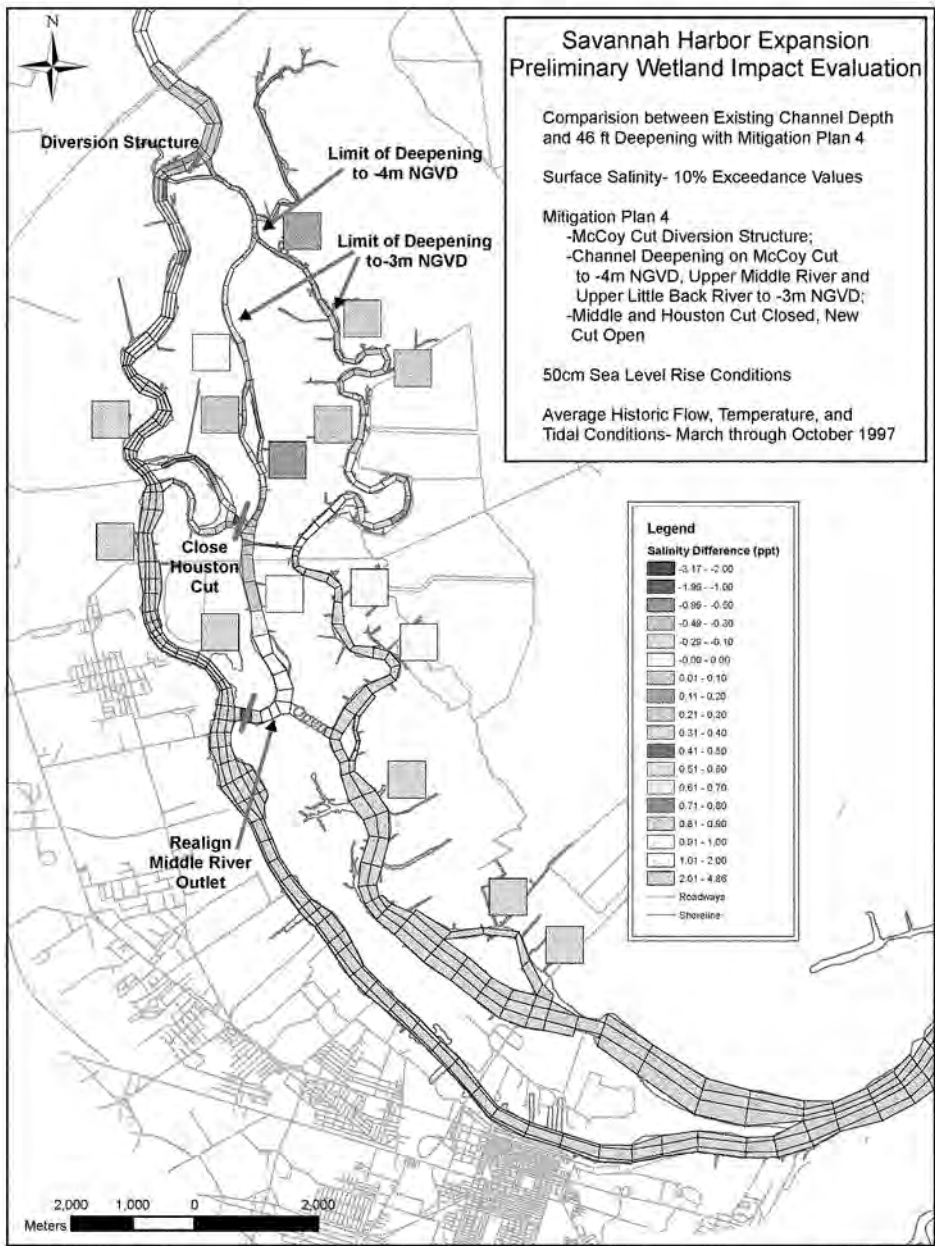


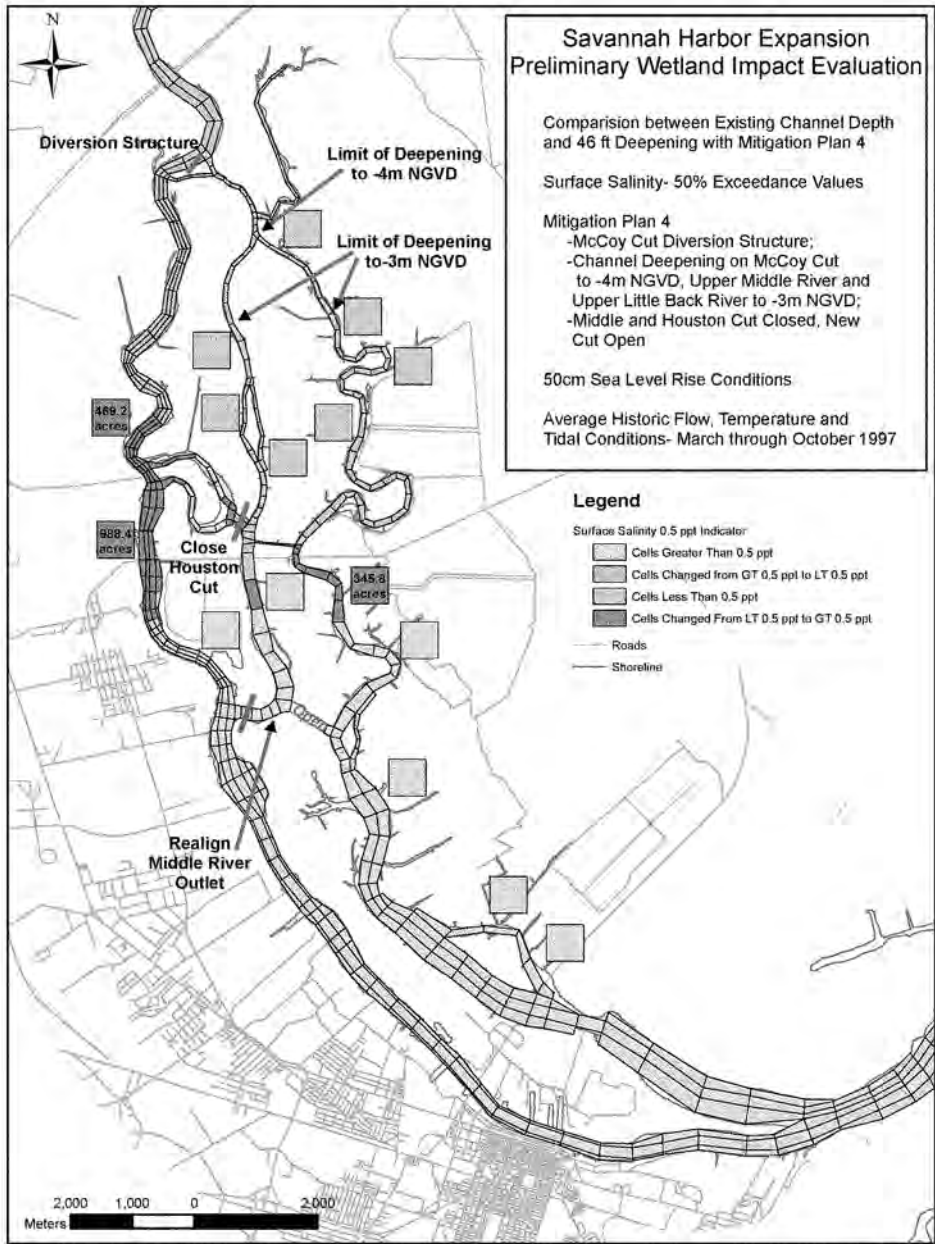


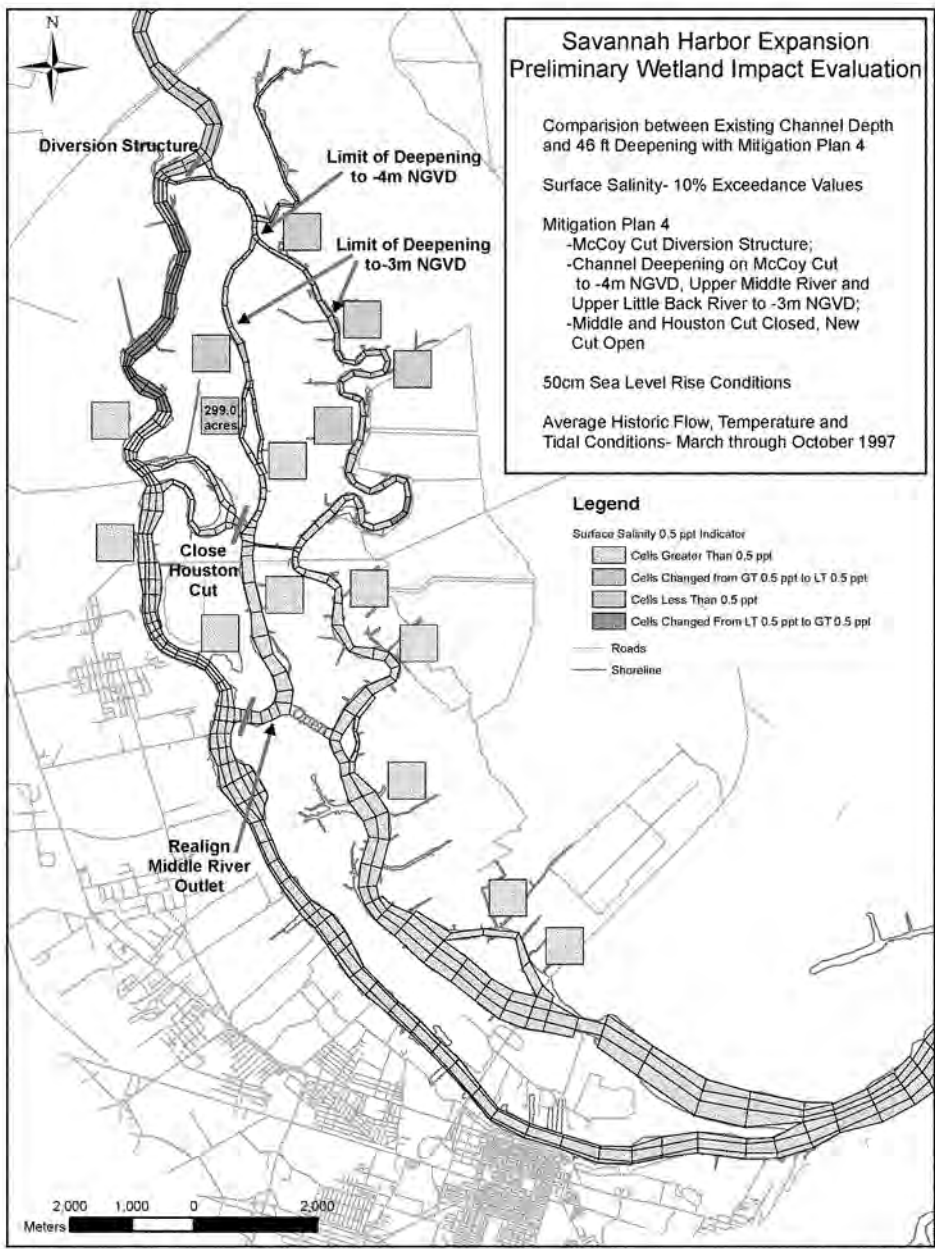


Sensitivity Analysis #2B



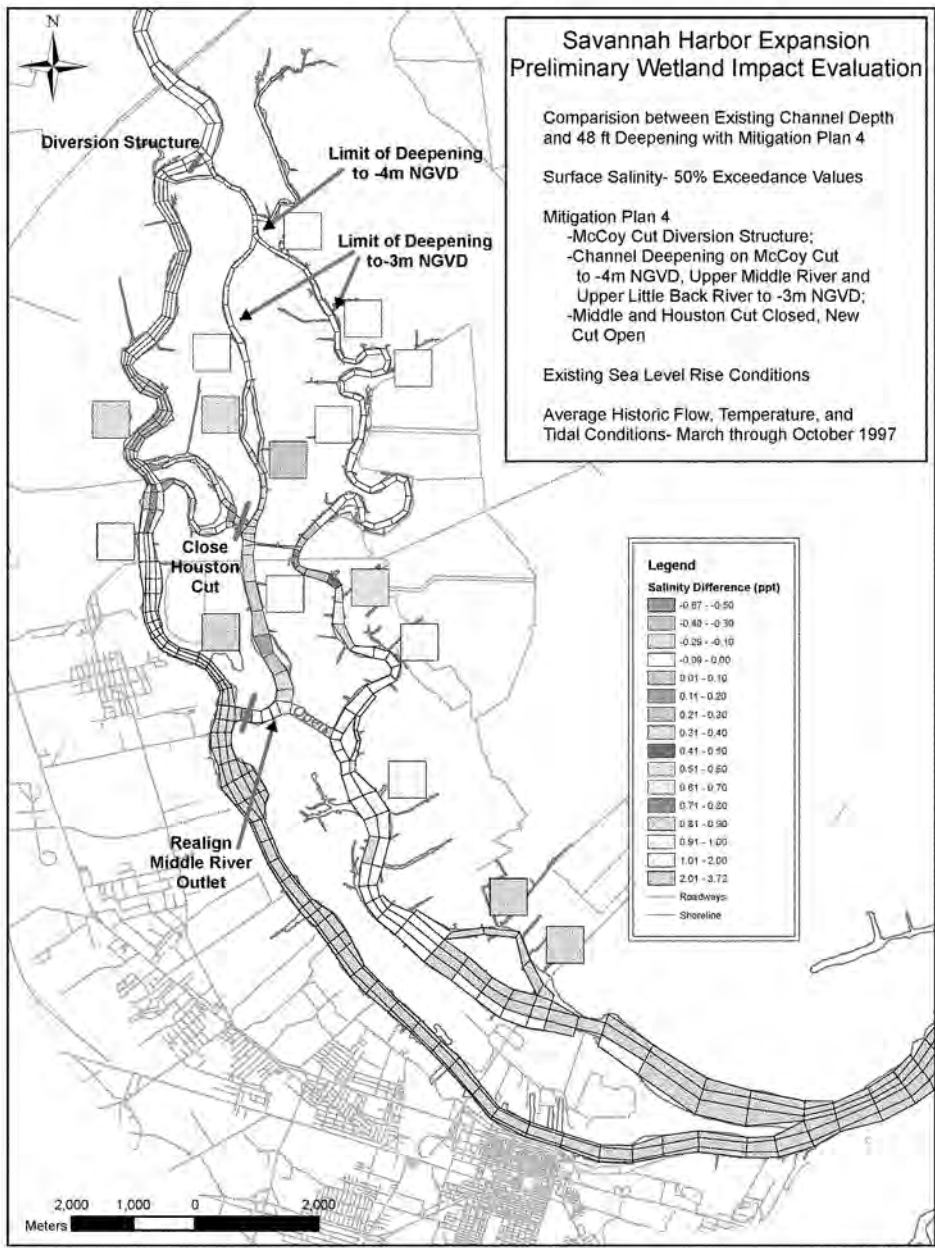


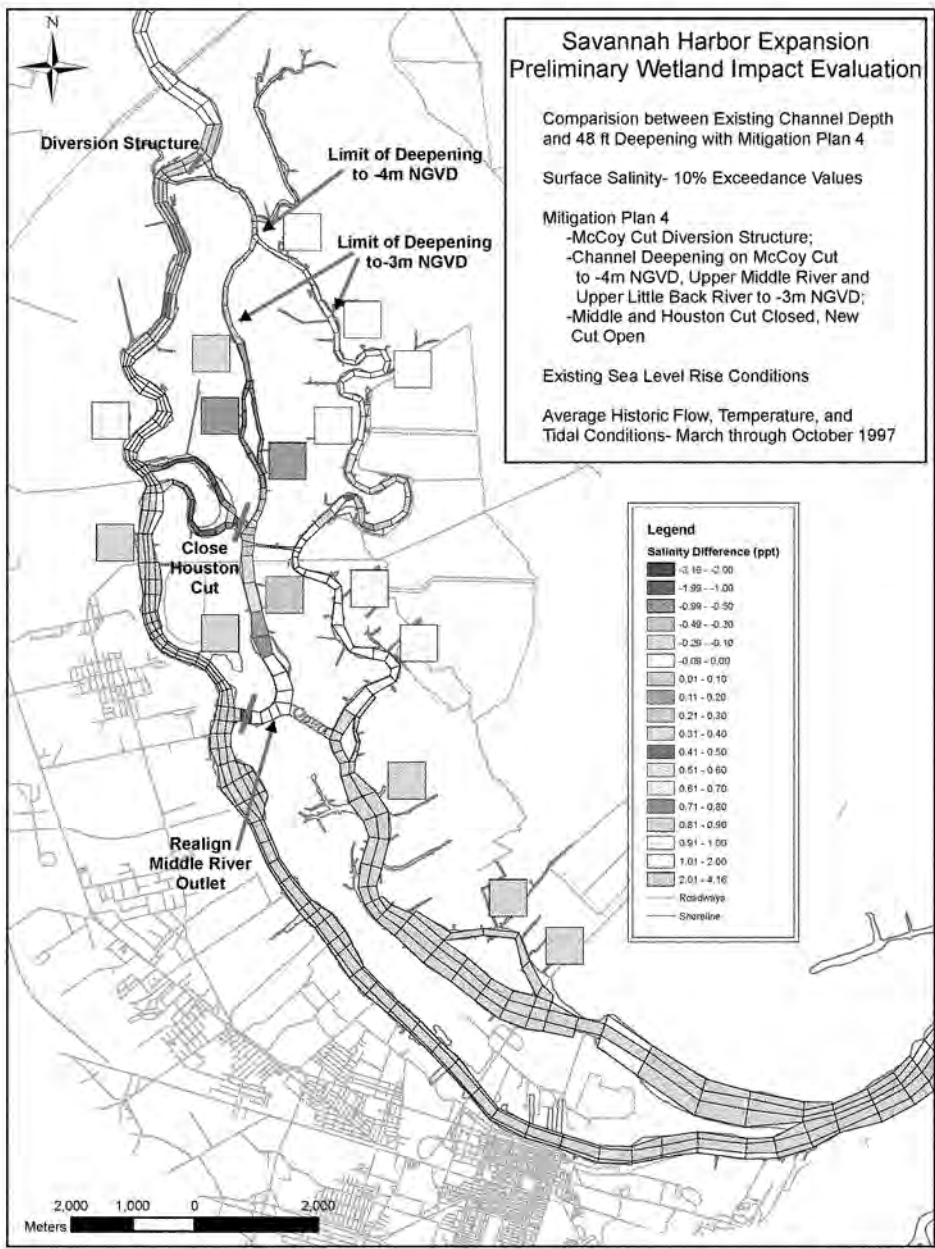


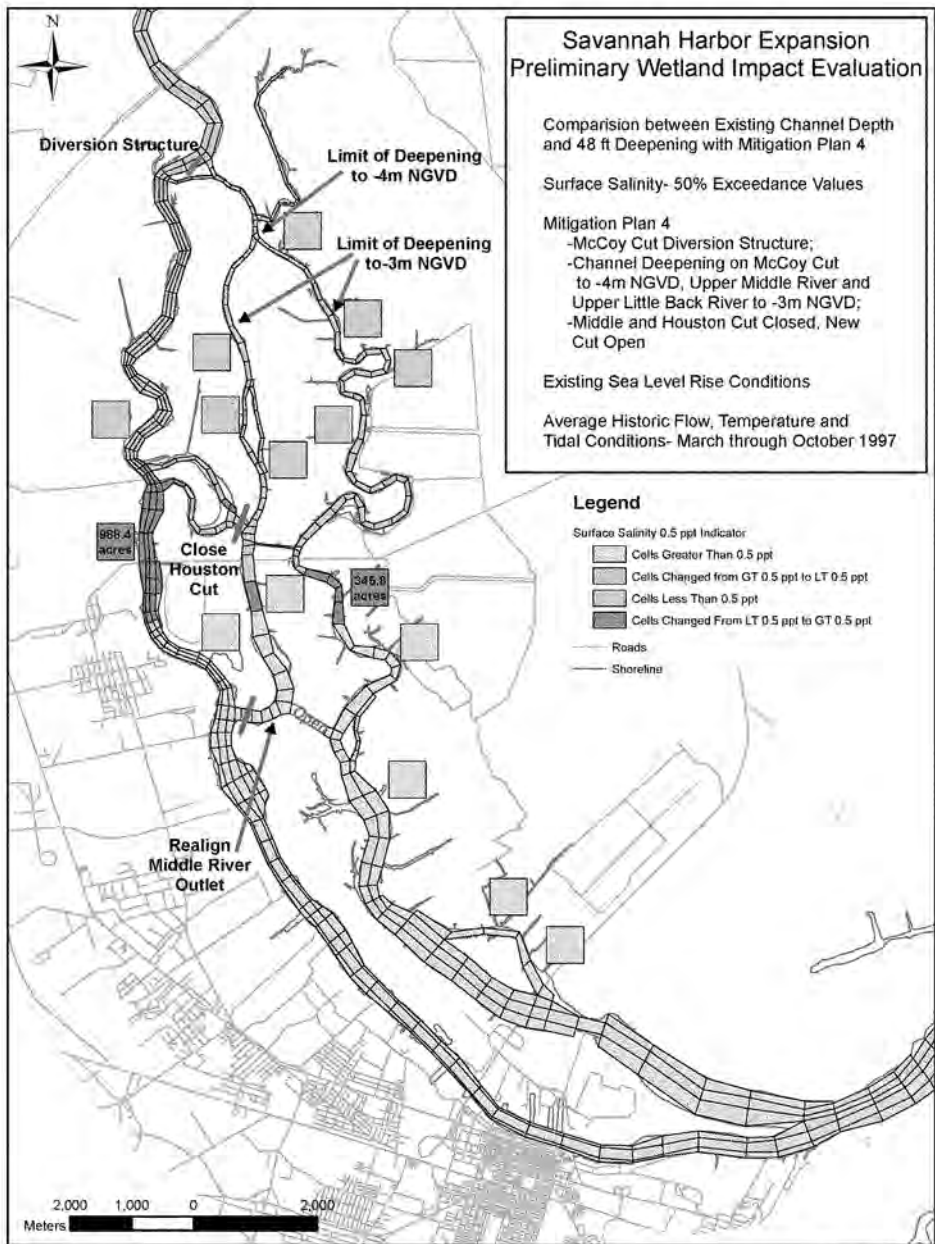


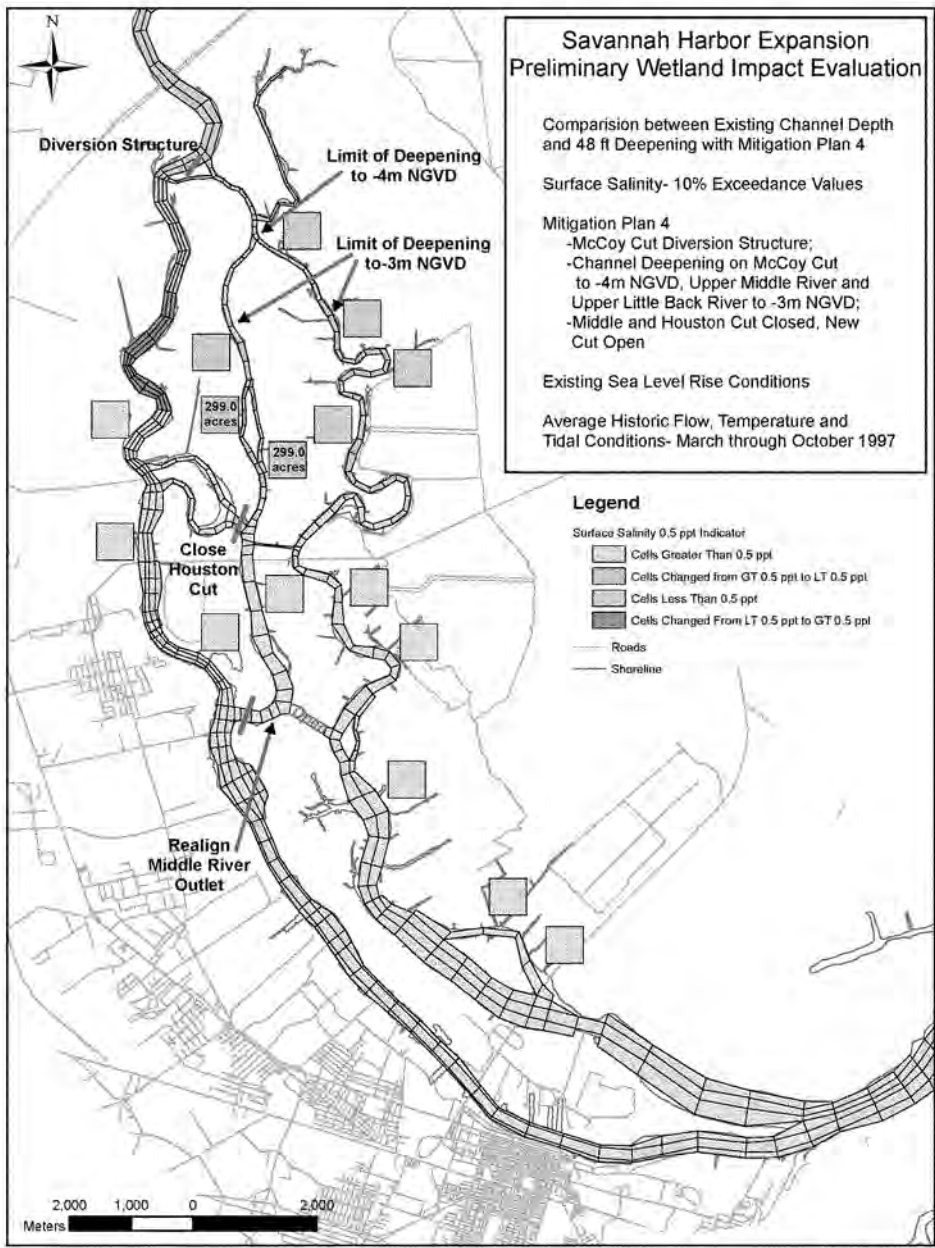
48-ft Deepening

Basic Evaluation

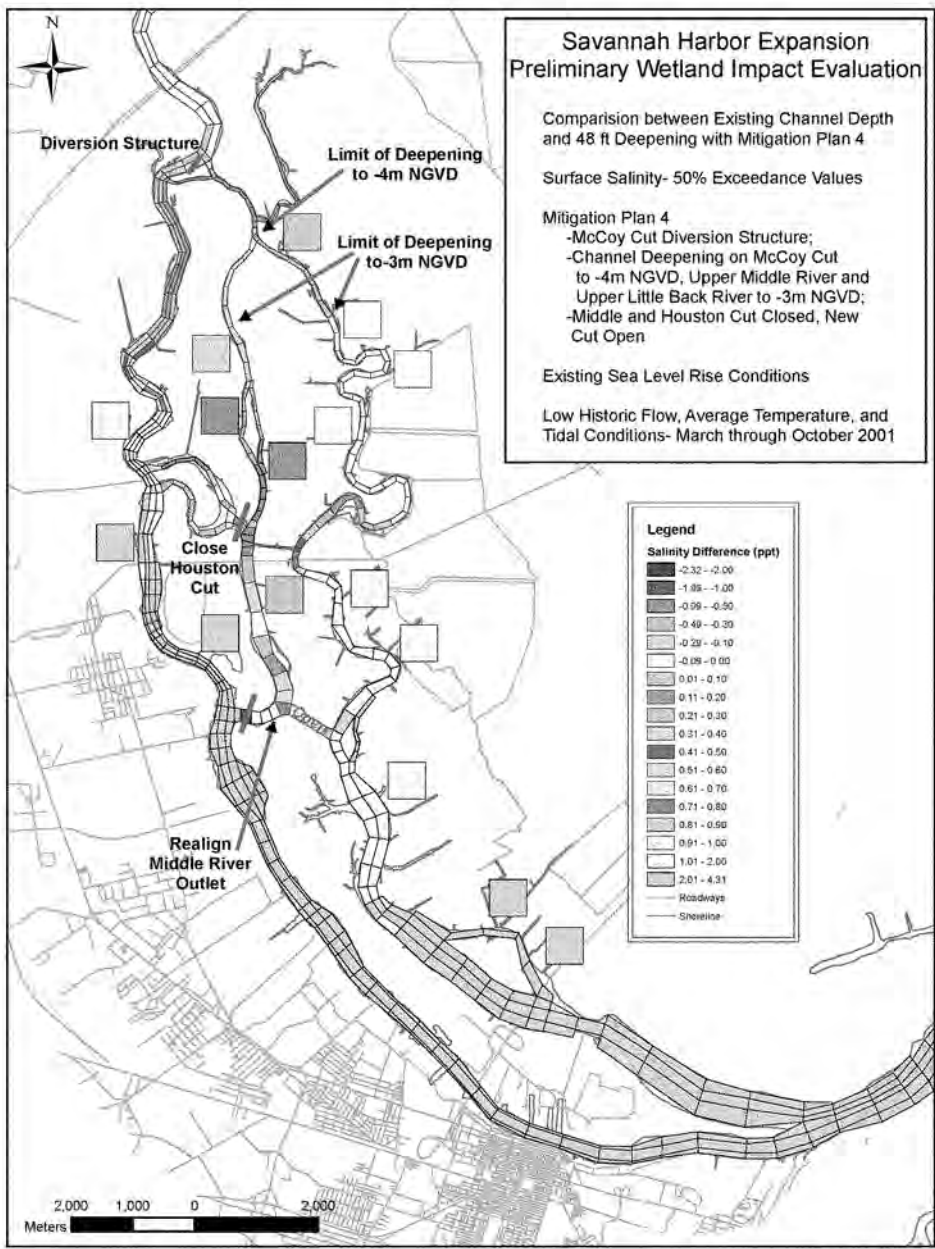


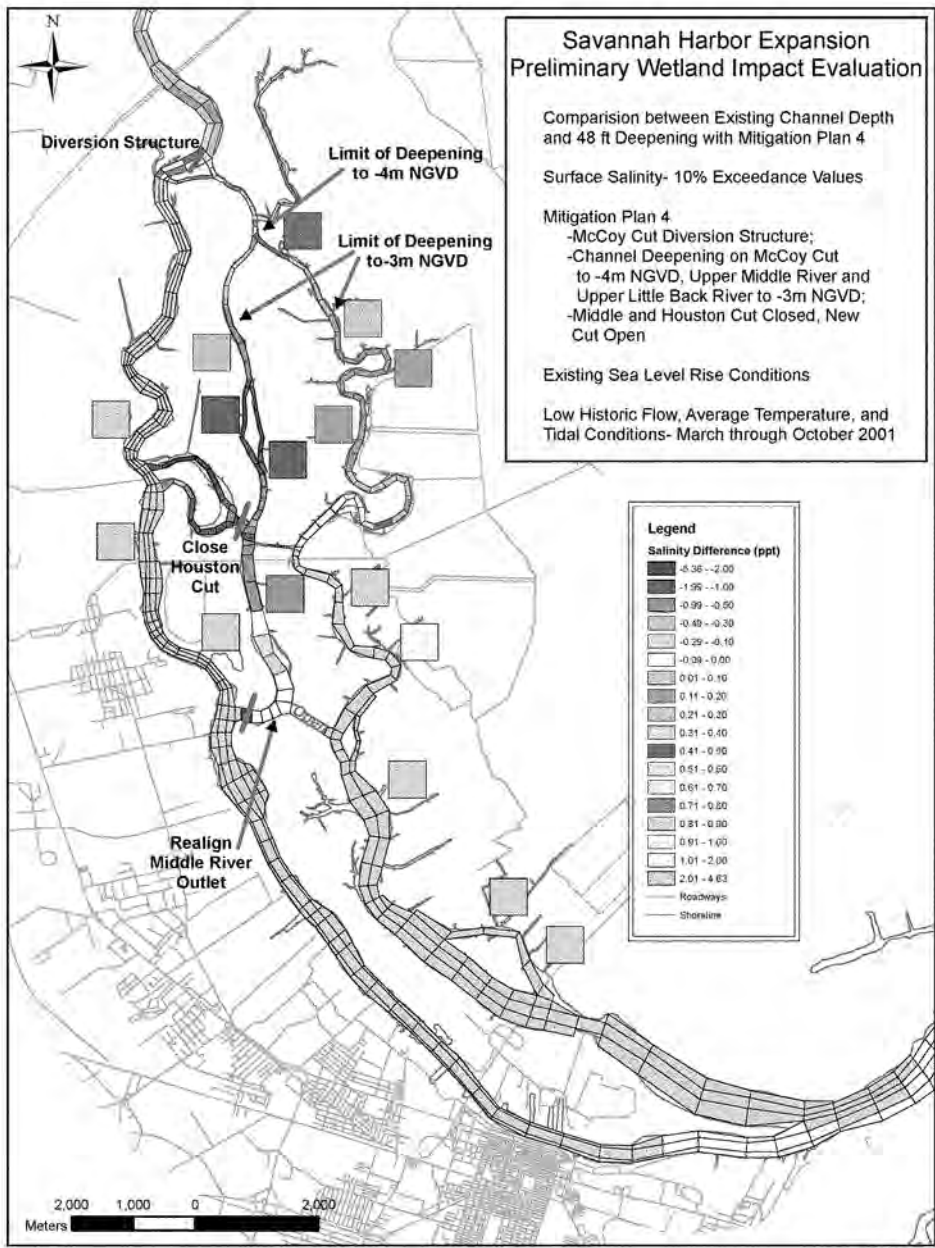


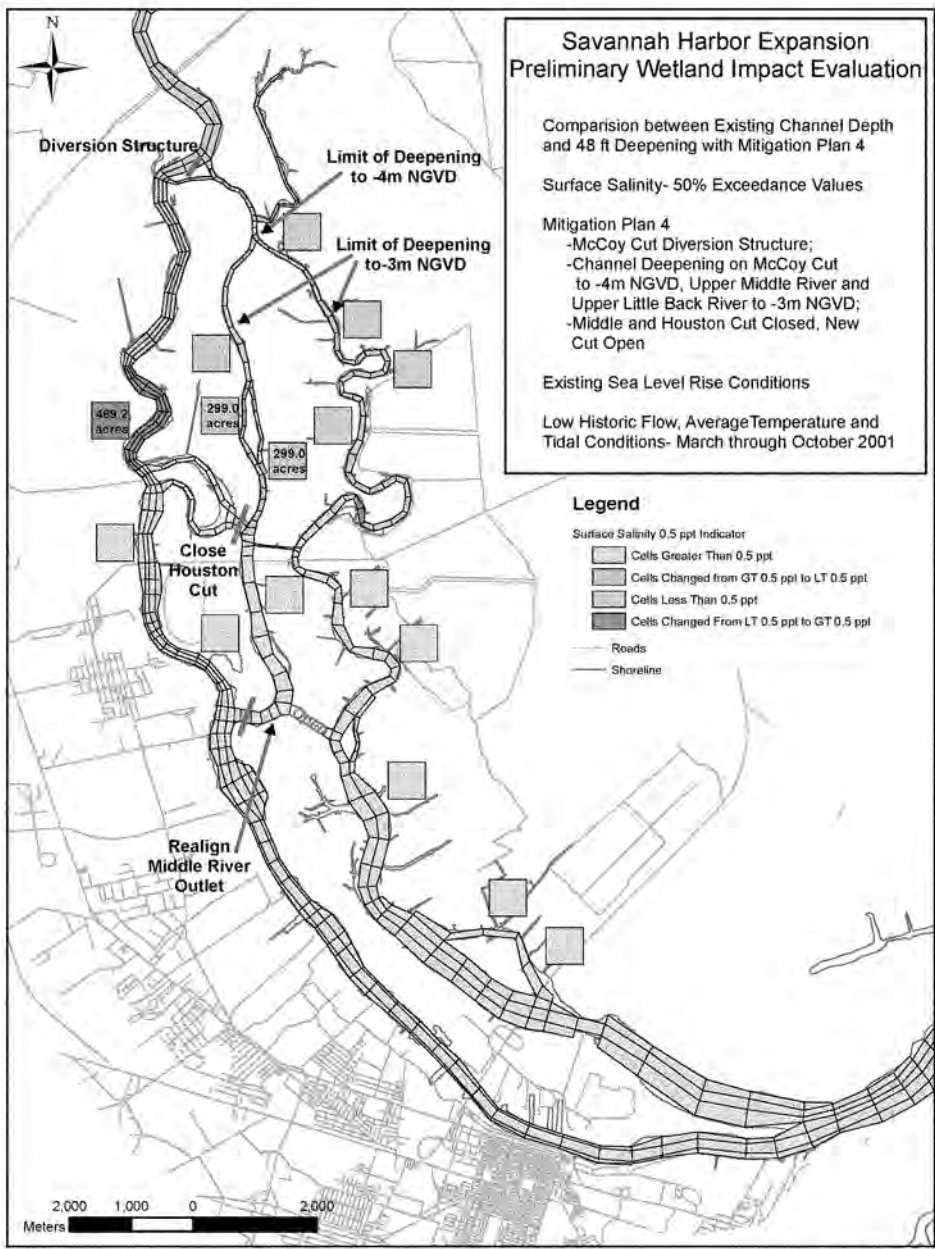


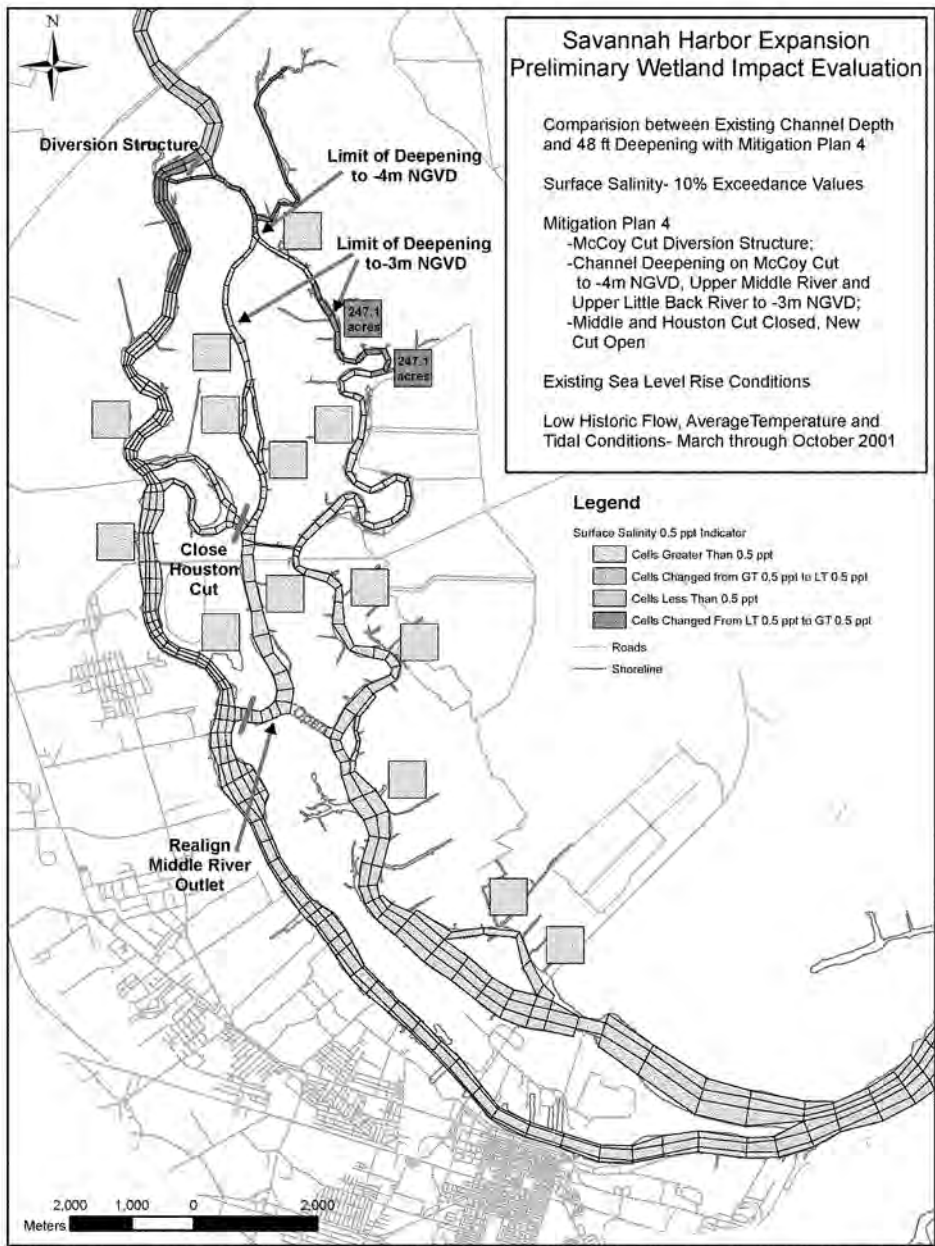


Sensitivity Analysis #1

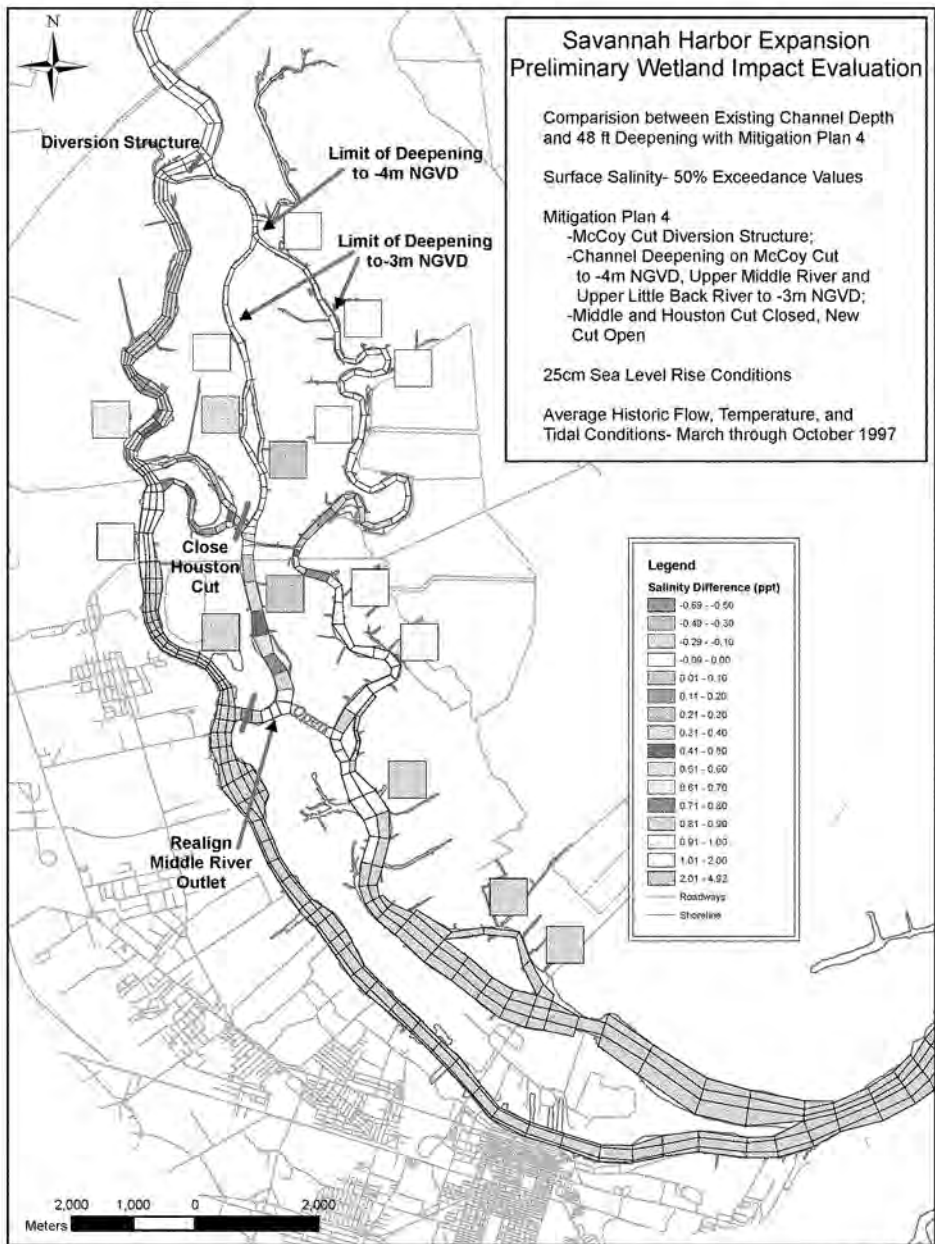


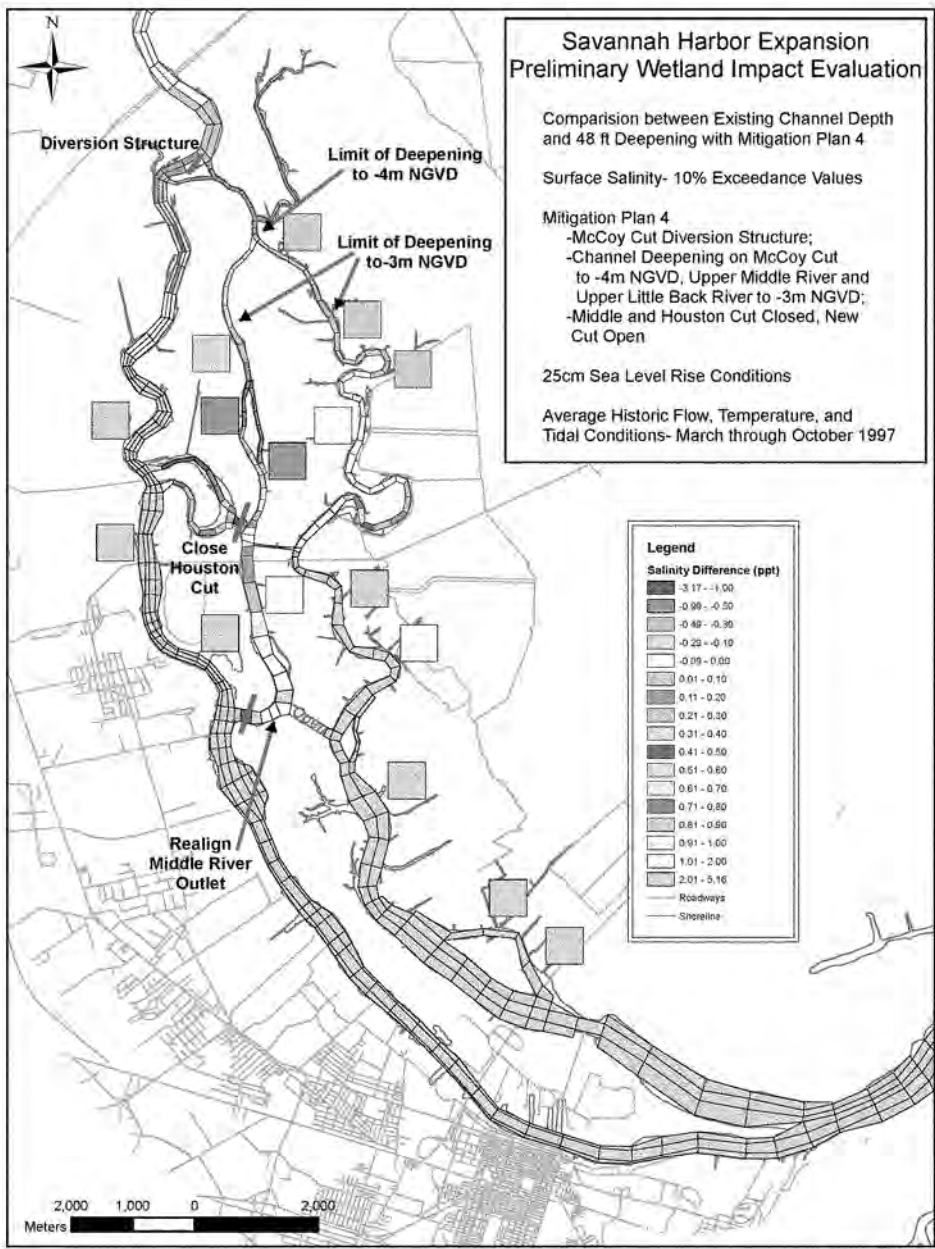


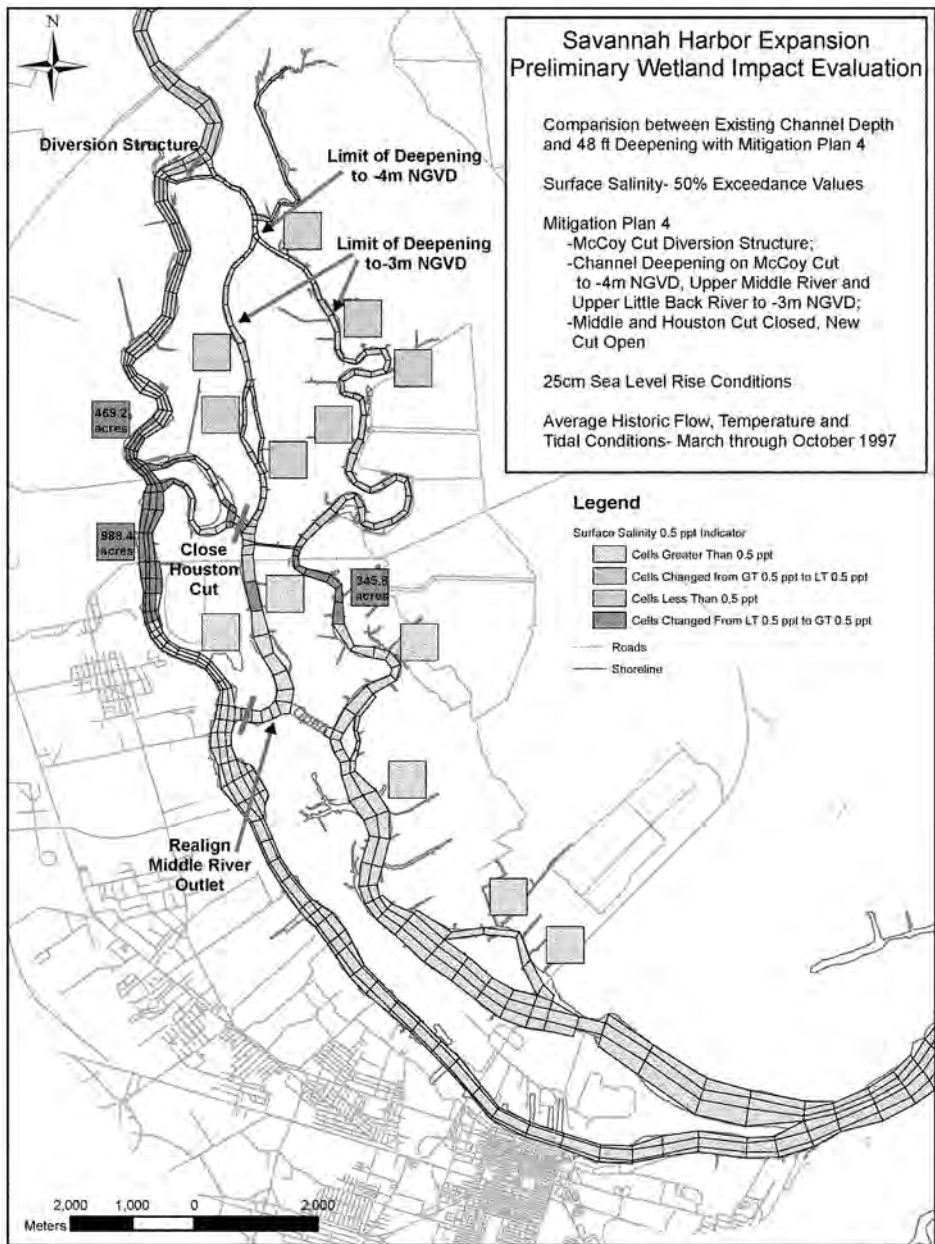


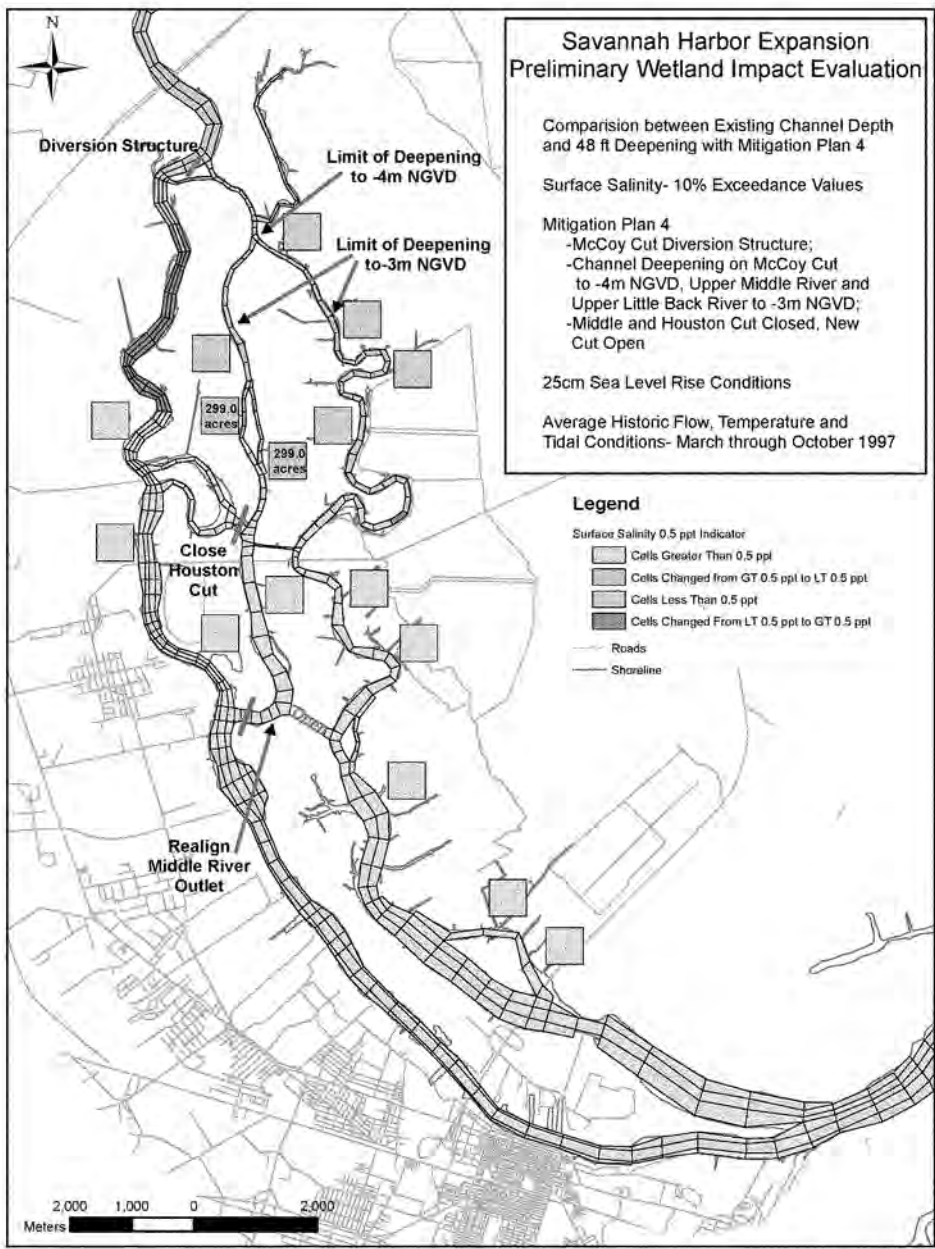


Sensitivity Analysis #2A

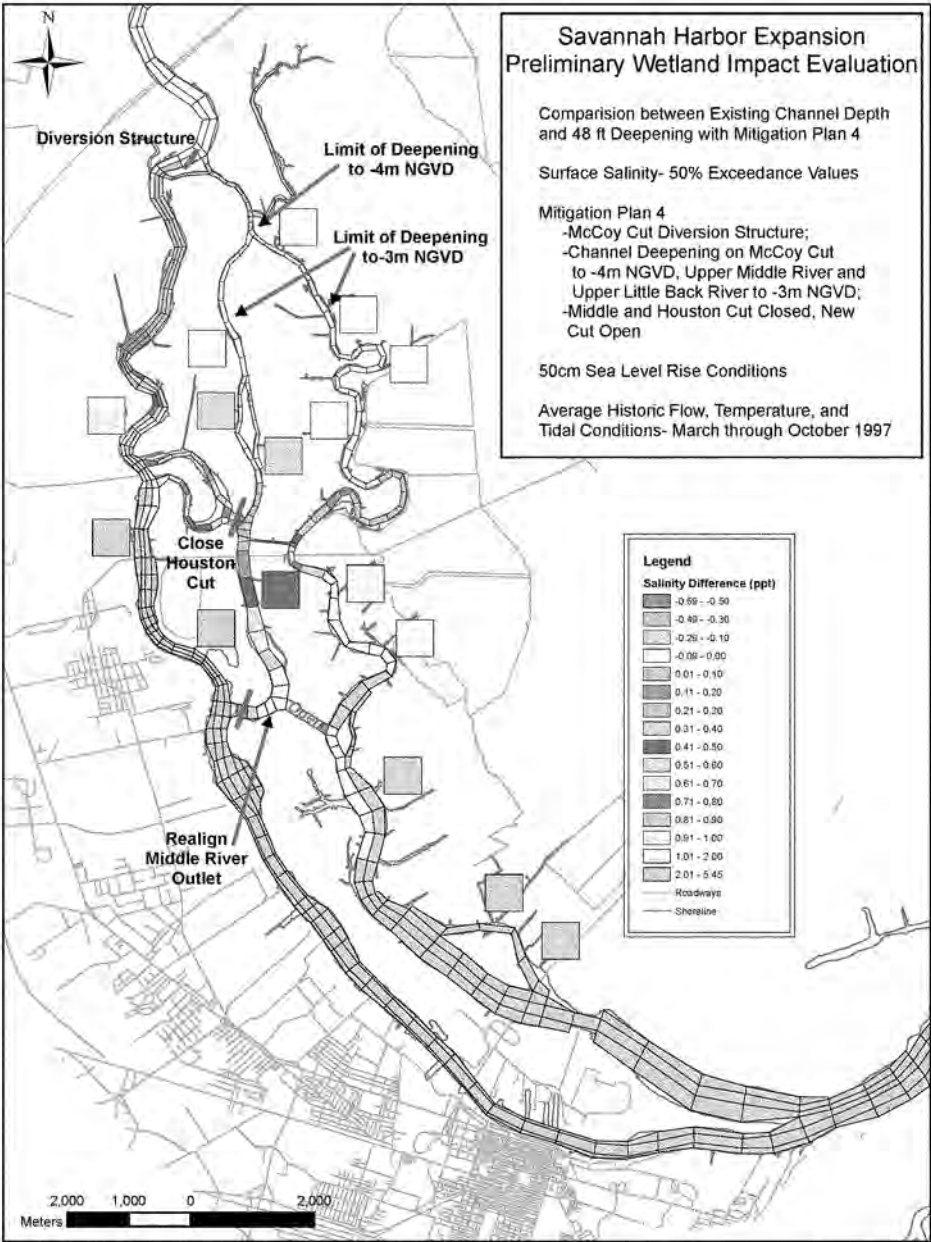


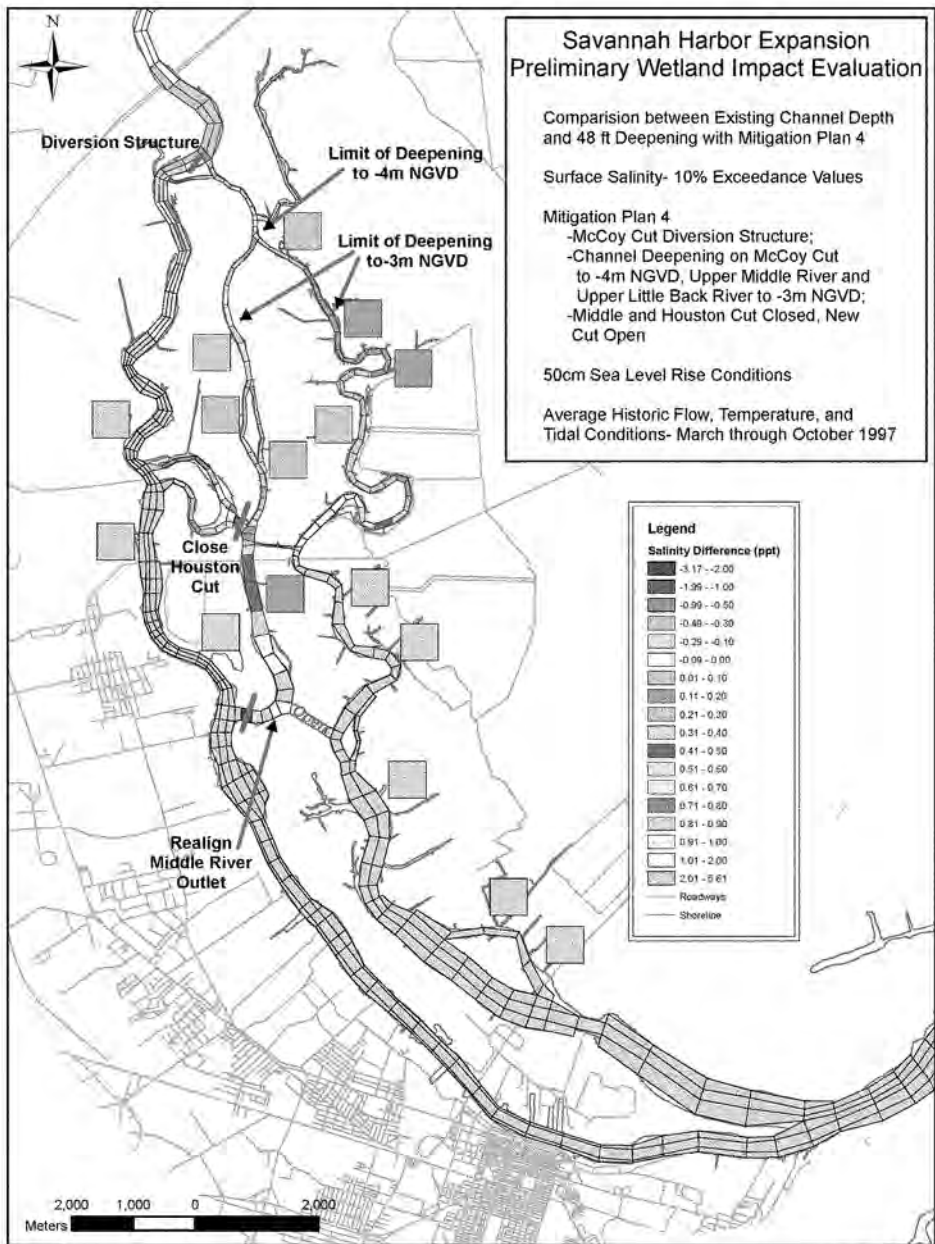


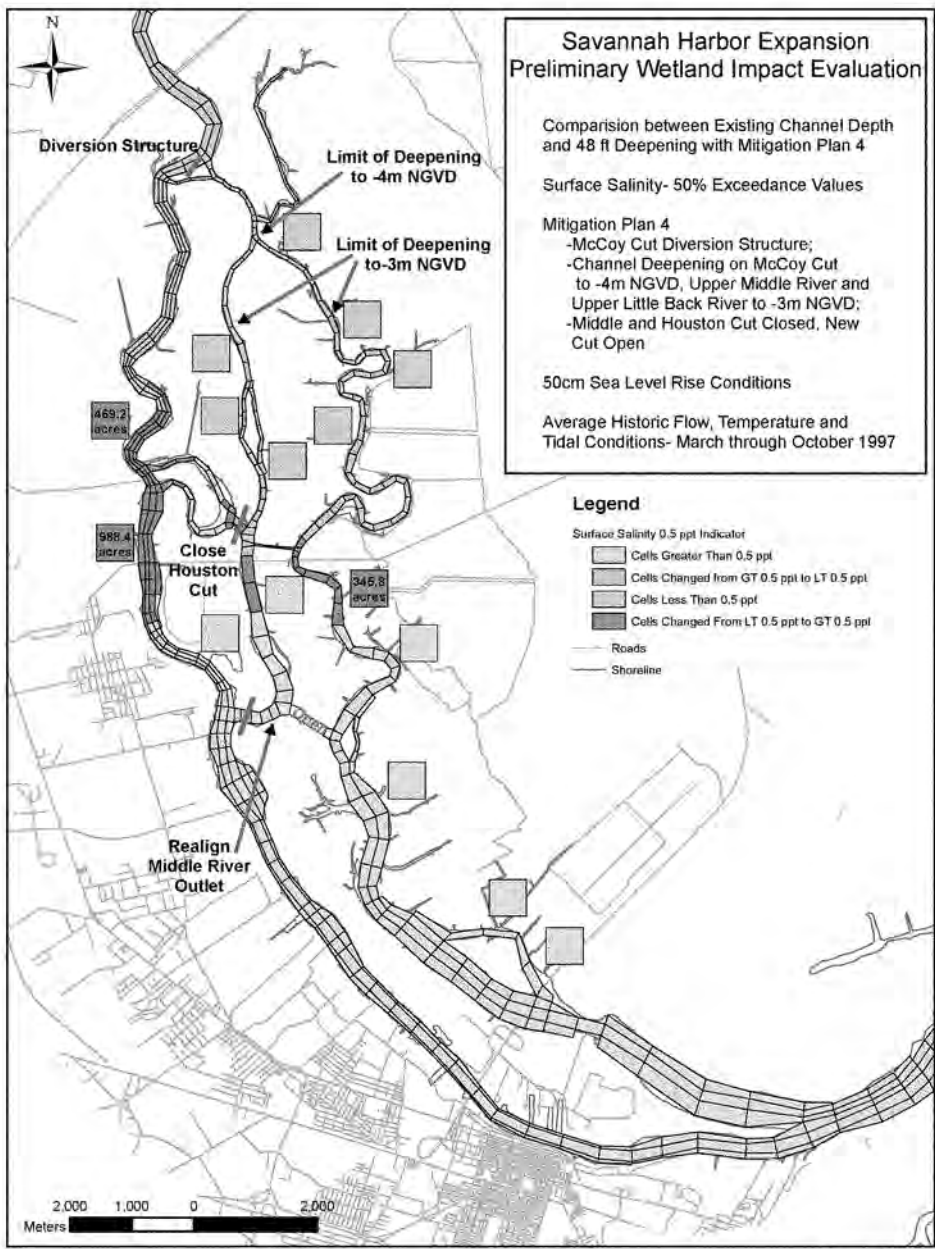


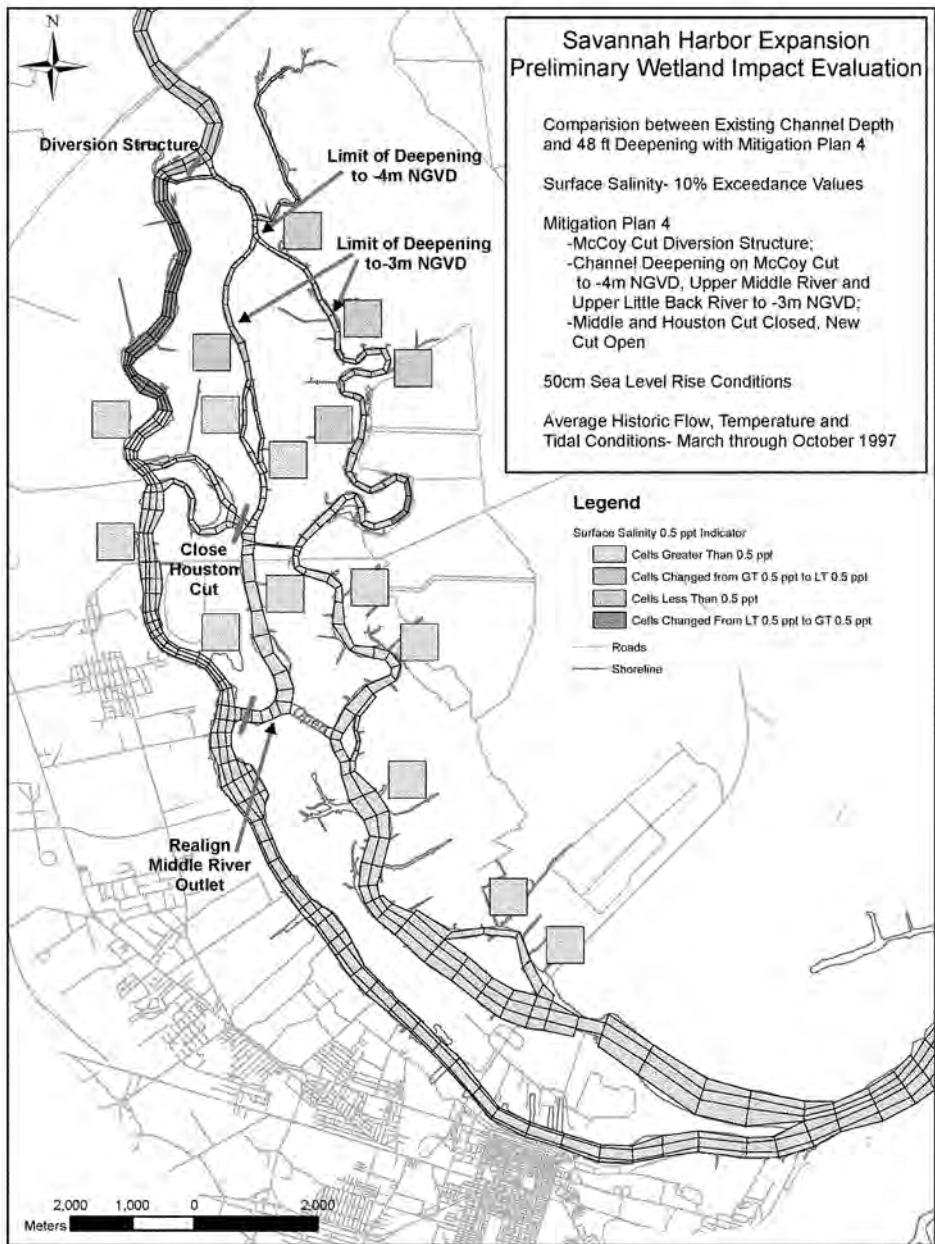


Sensitivity Analysis #2B







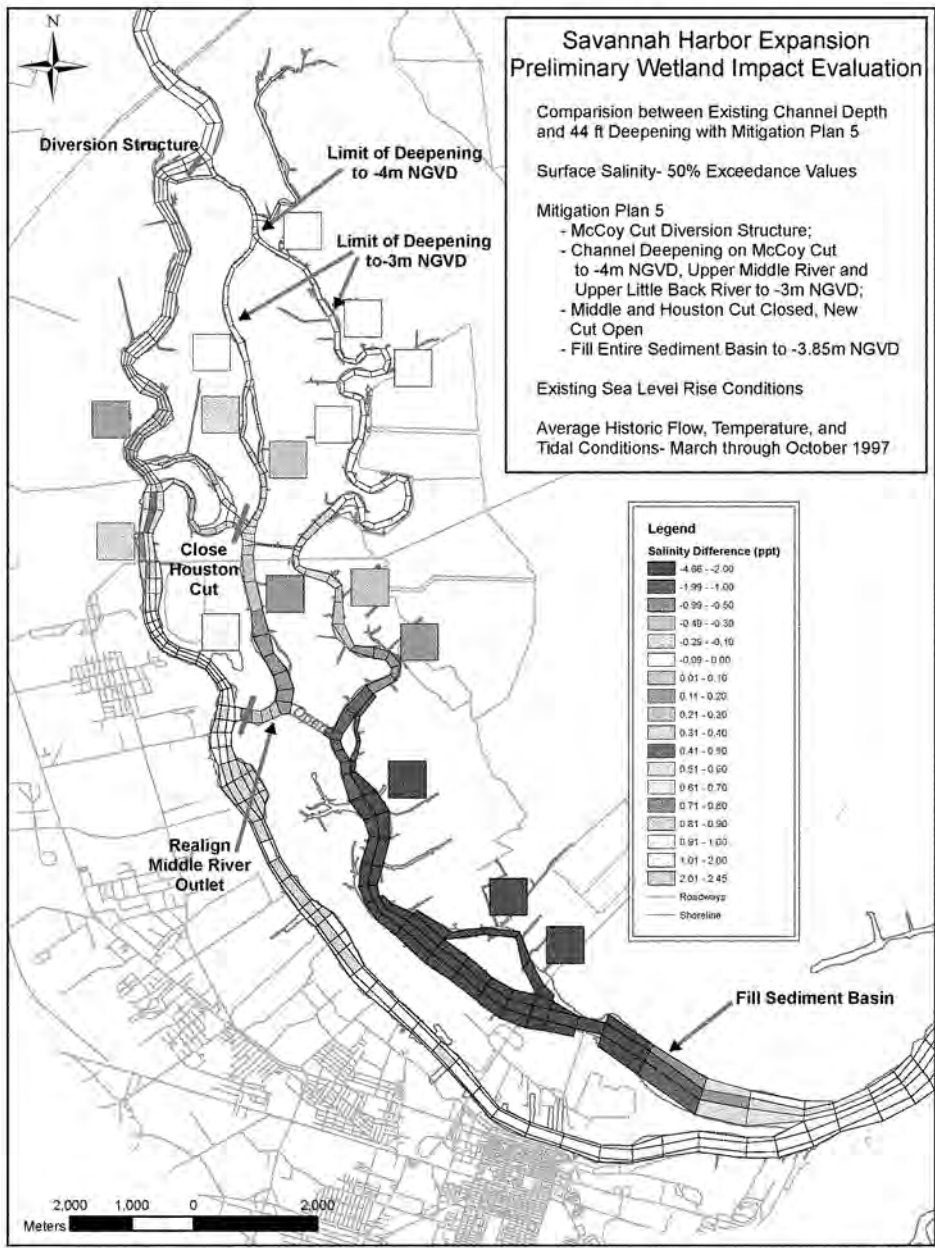


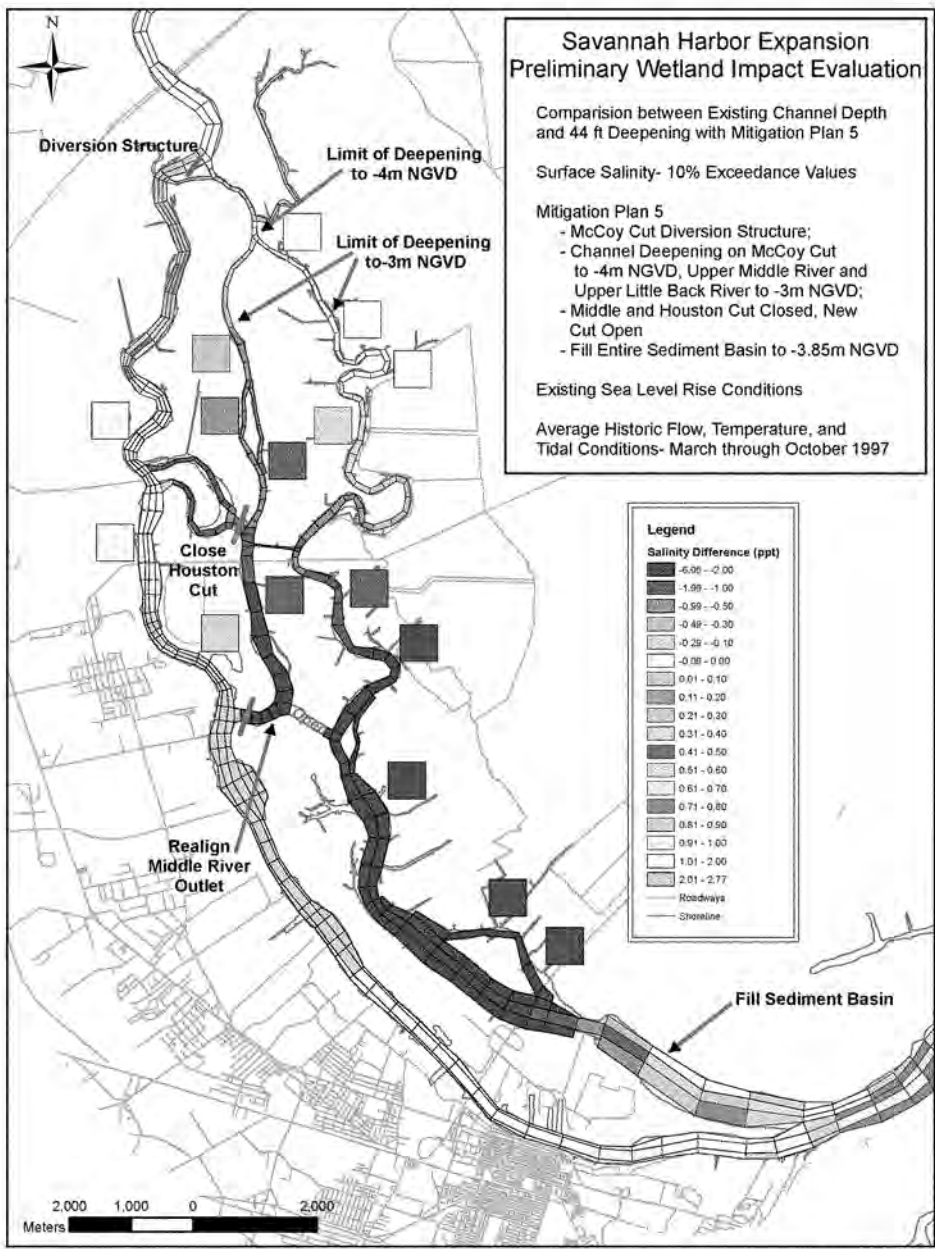
MITIGATION PLAN 5

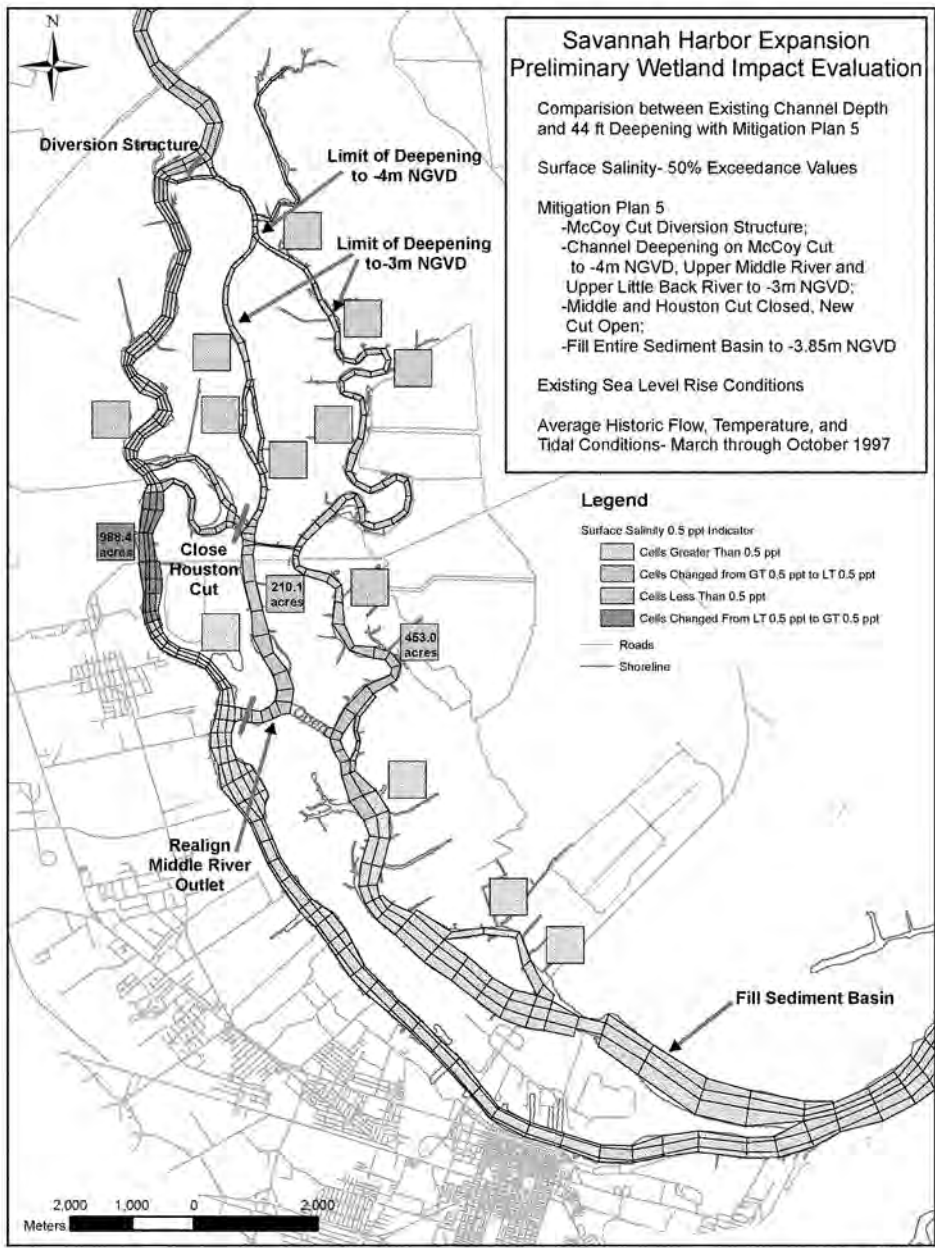
- *McCoy Cut Diversion Structure*
- *Channel Deepening on McCoy Cut to -4m NGVD and Upper Middle and Little Back River to -3m NGVD*
- *Realign Middle River Outlet by Closing Middle River at Front River and Opening New Cut*
- *Close Houston Cut*
- *Fill Entire Sediment Basin to -3.85m NGVD*

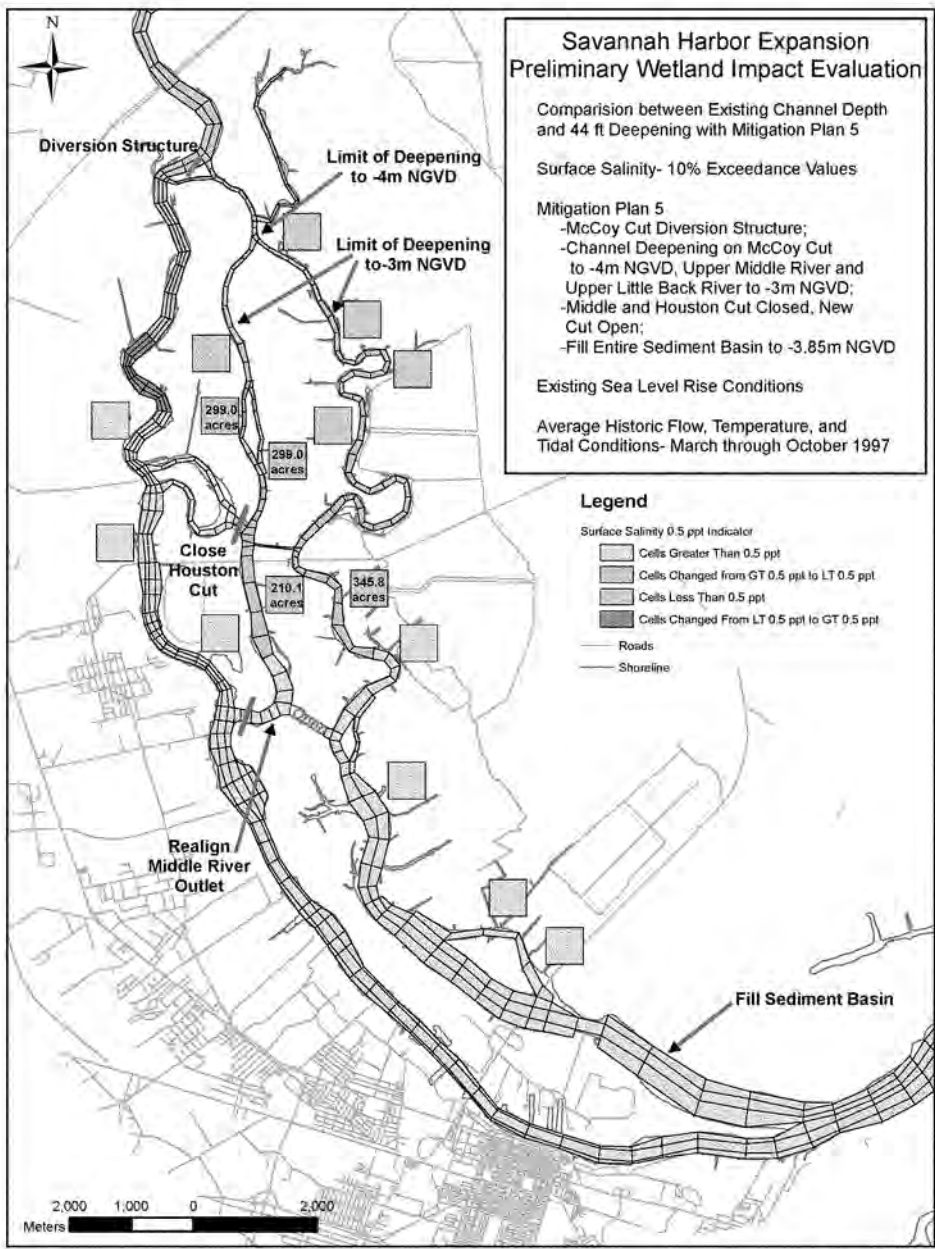
44-ft Deepening

Basic Evaluation

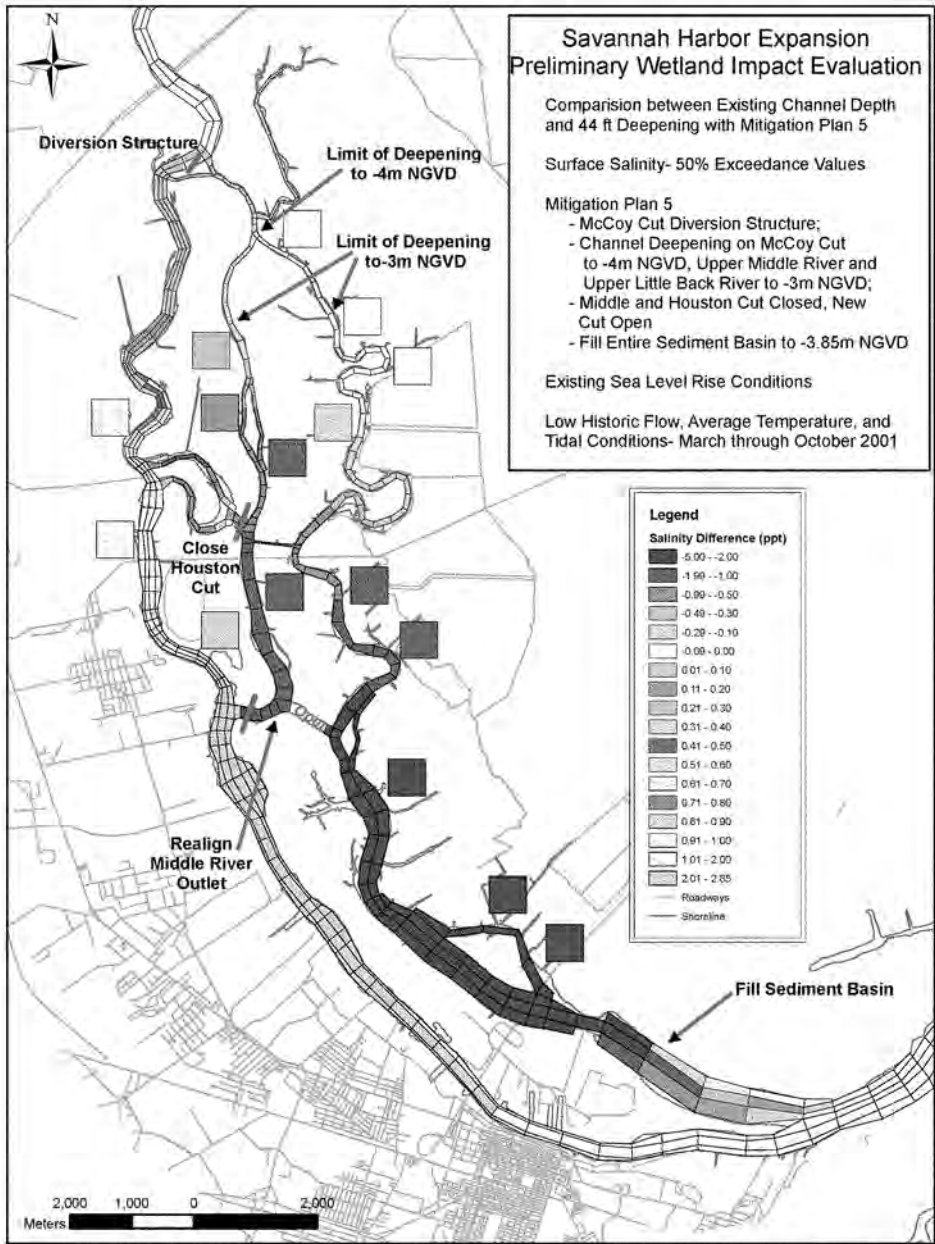


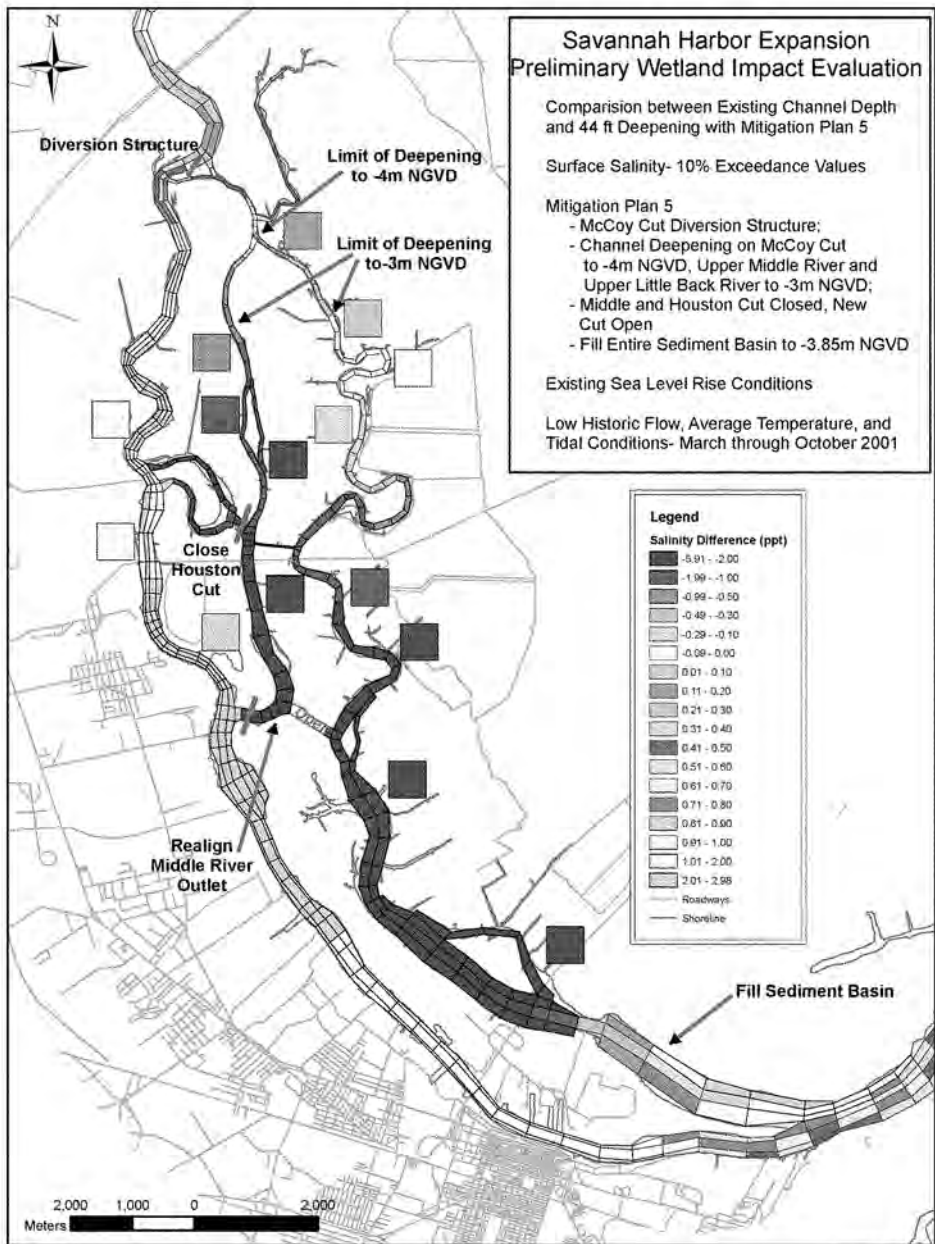


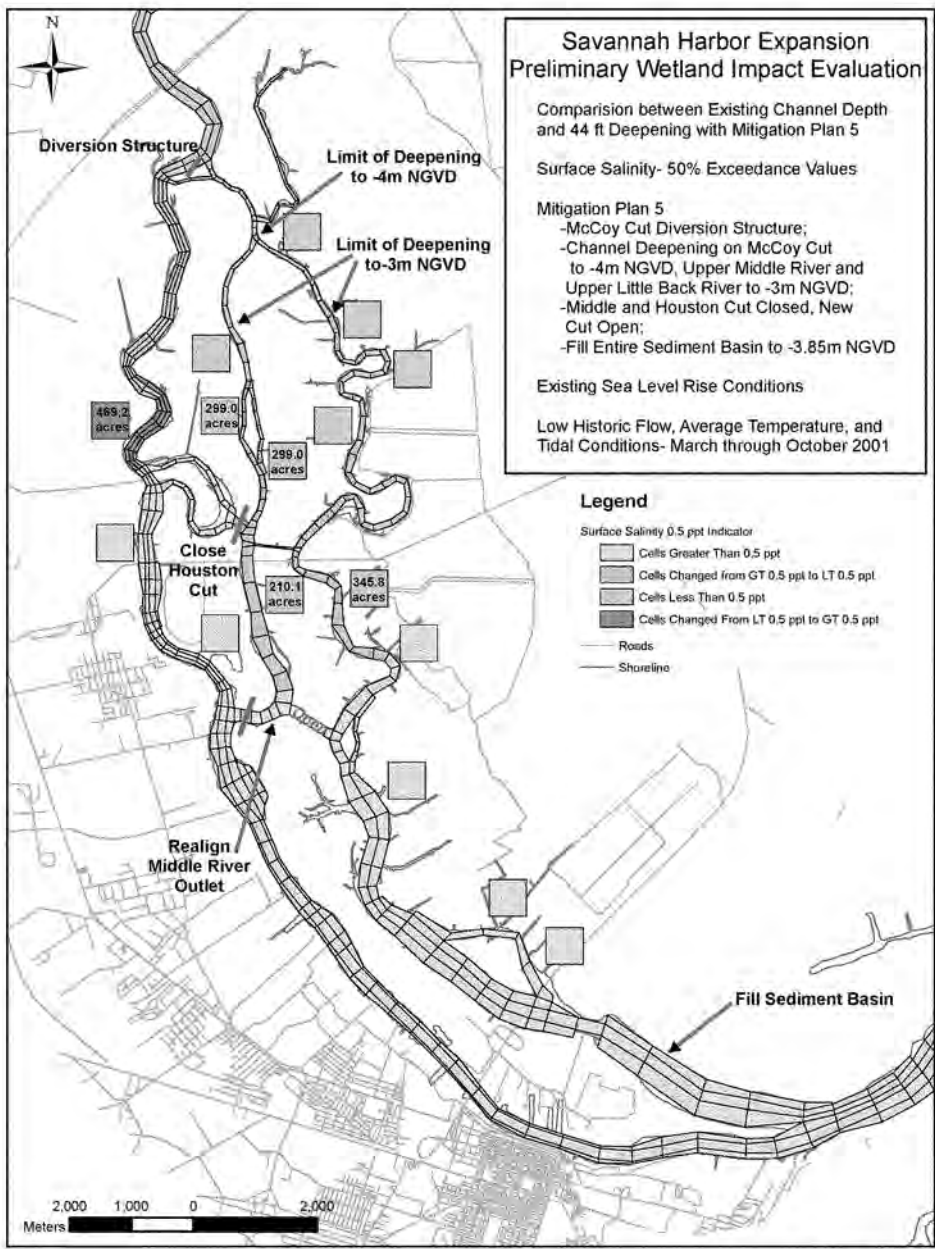


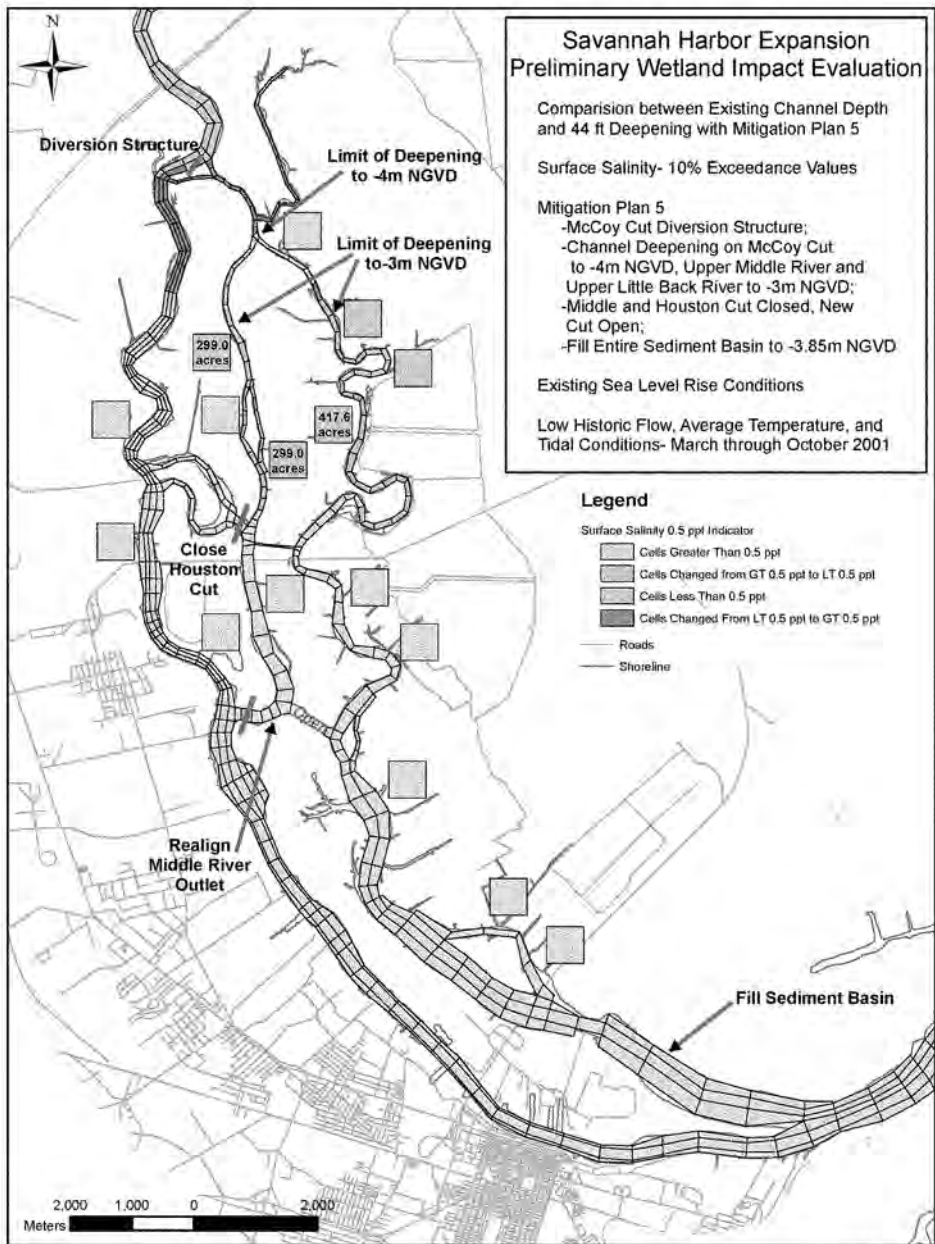


Sensitivity Analysis #1

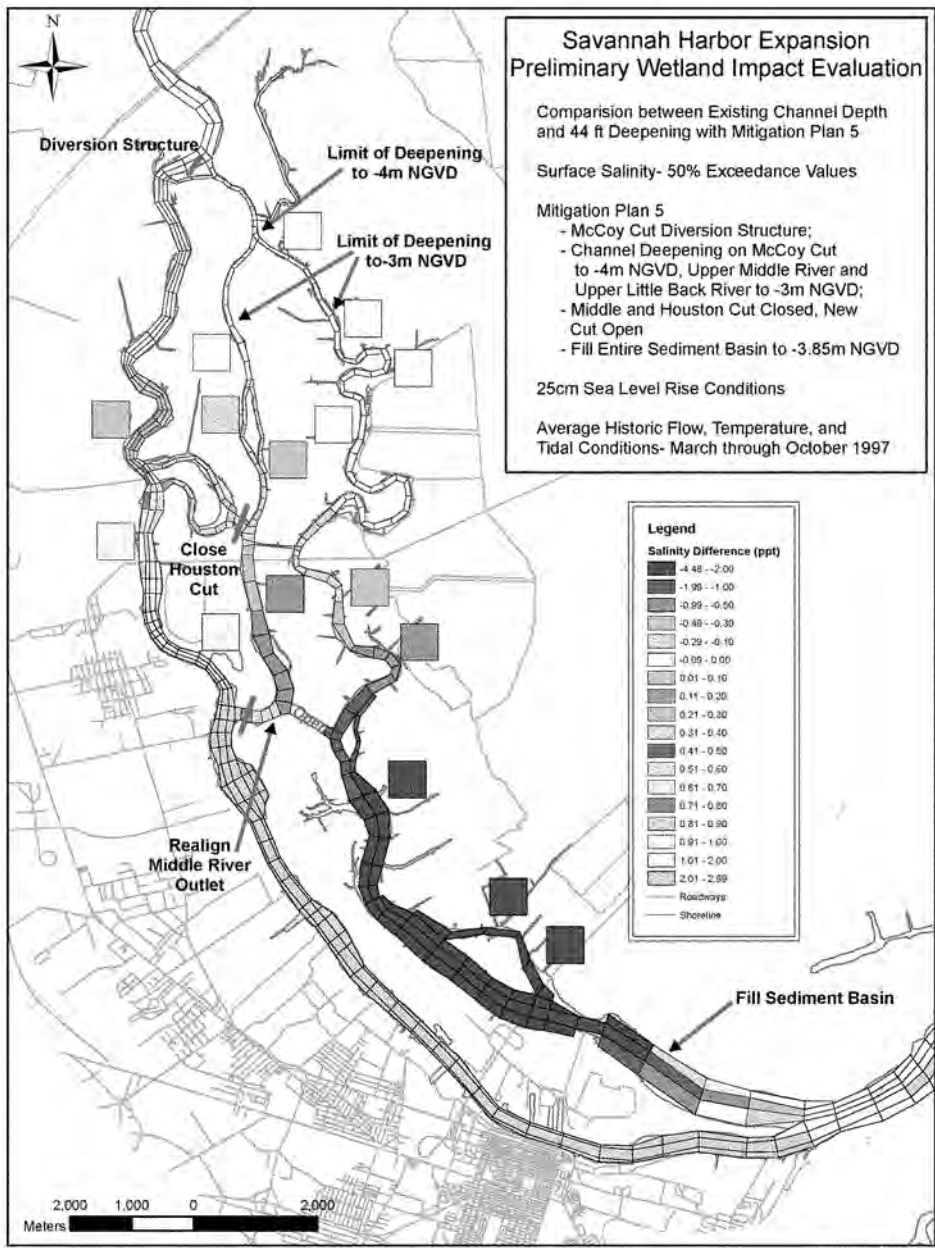


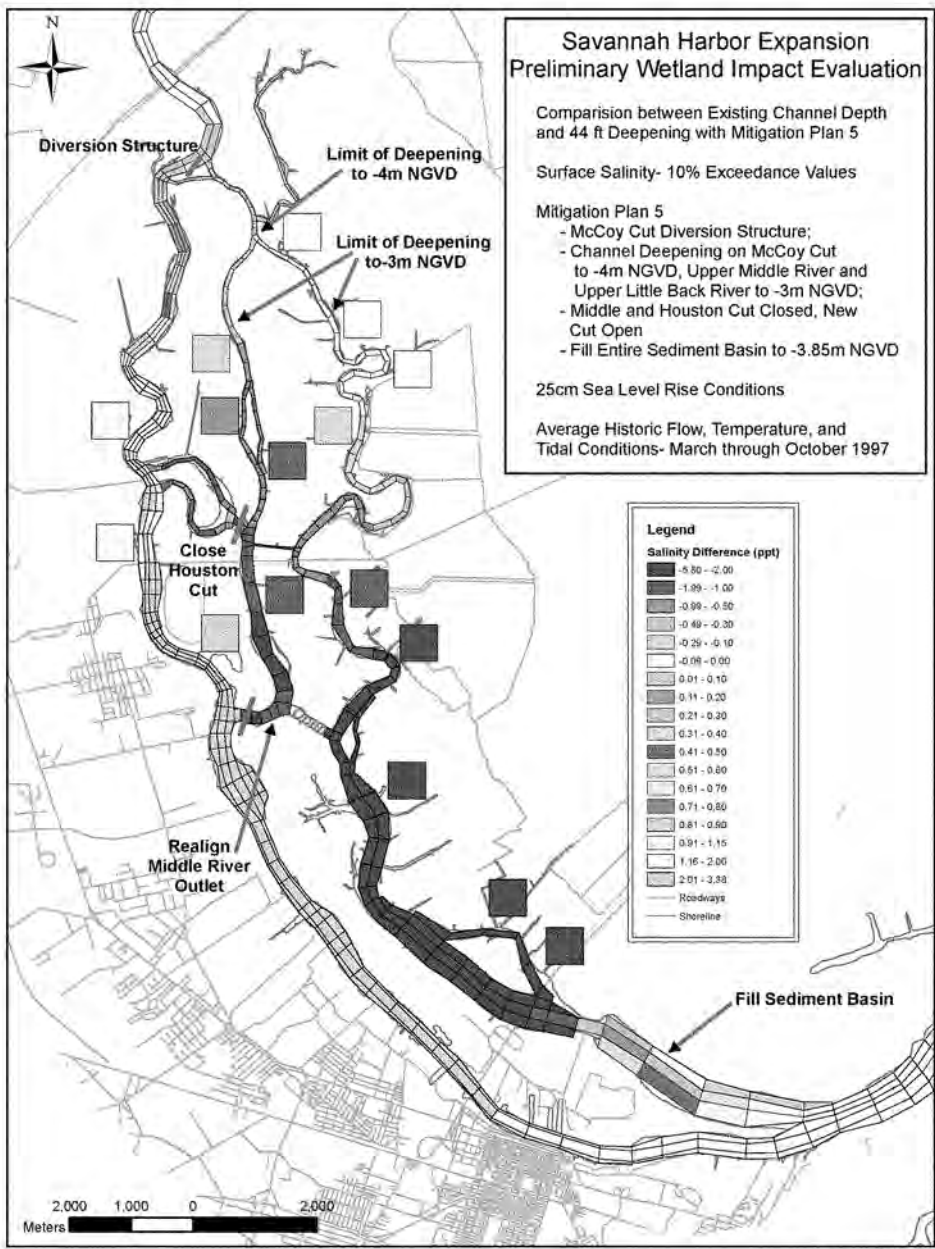


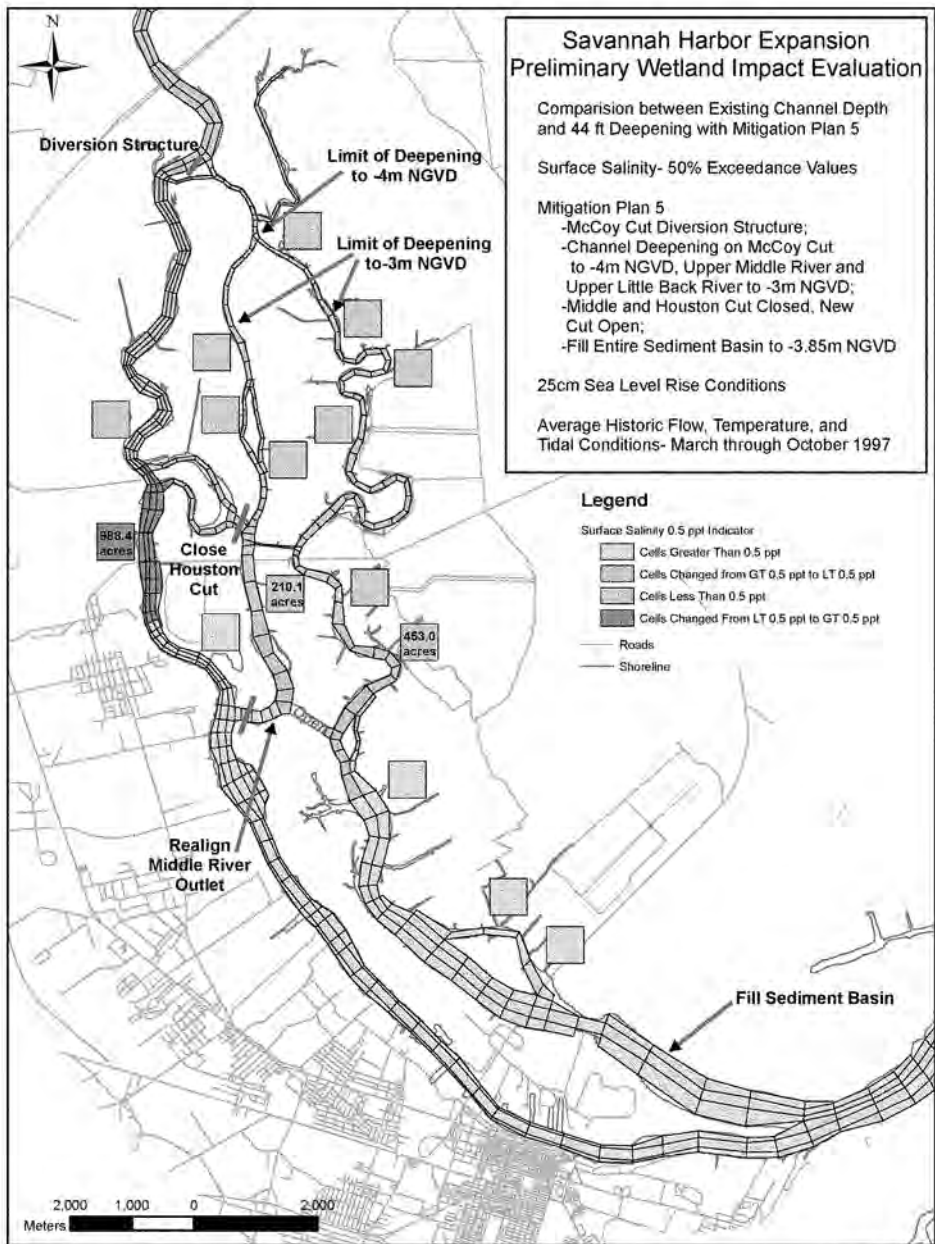


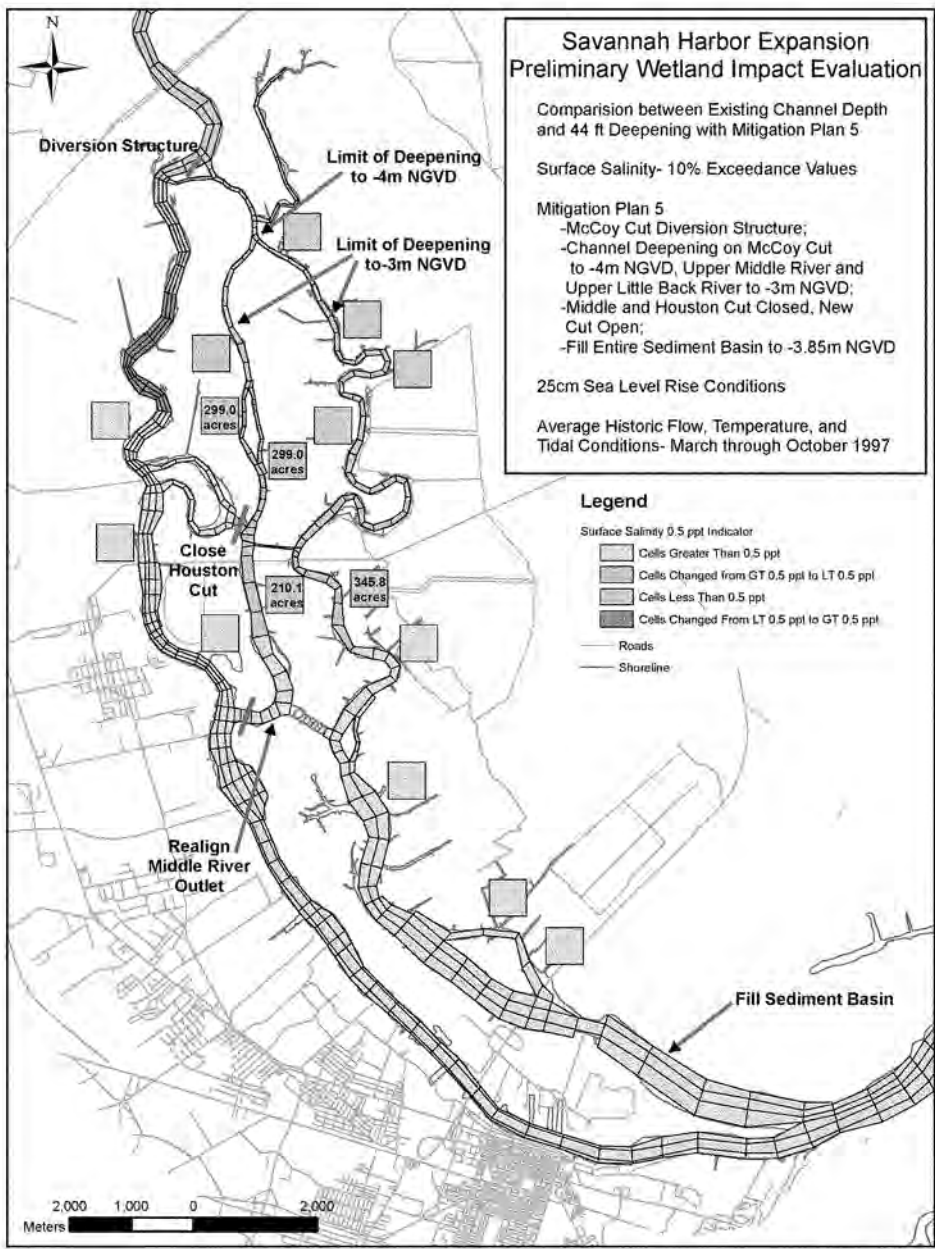


Sensitivity Analysis #2A

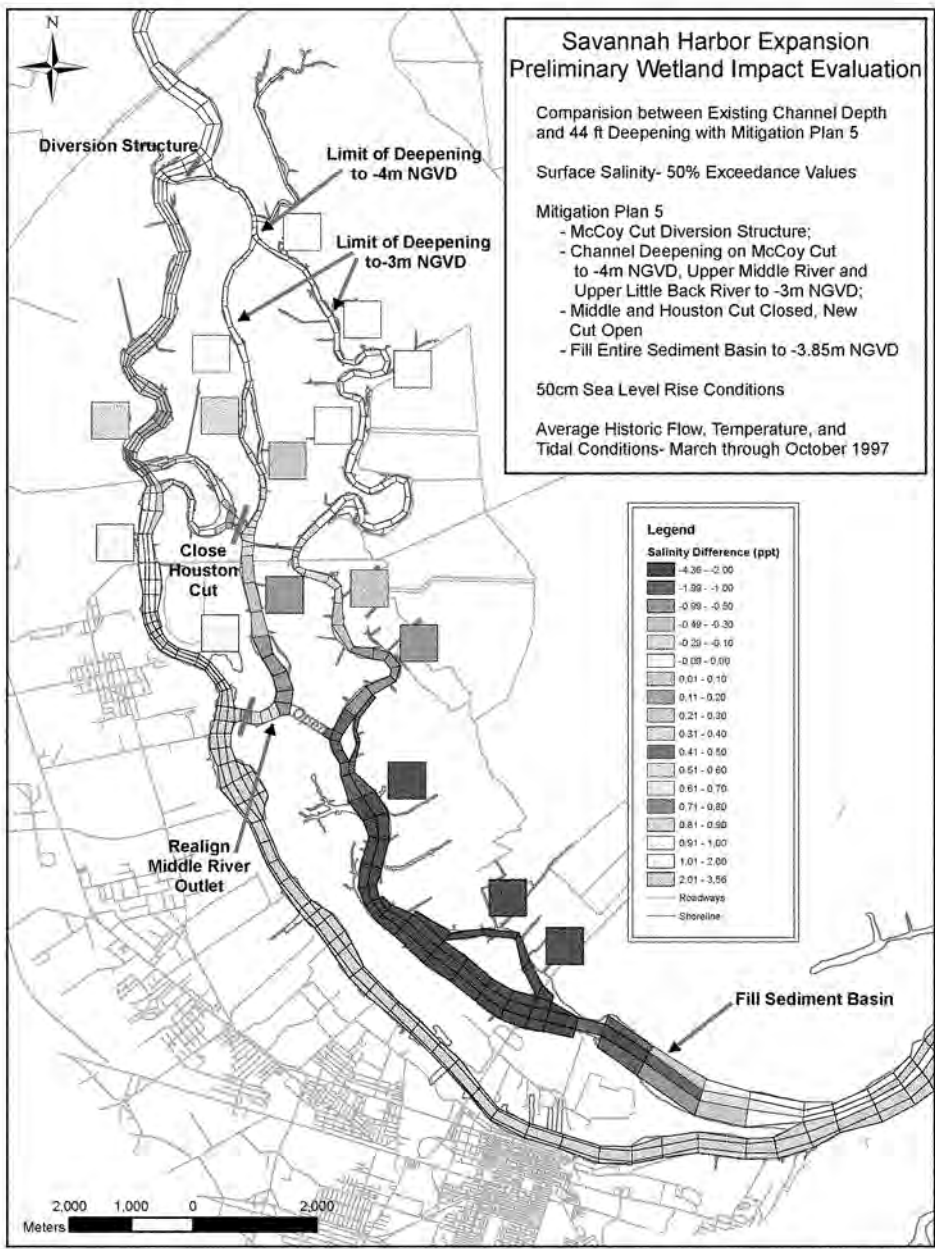


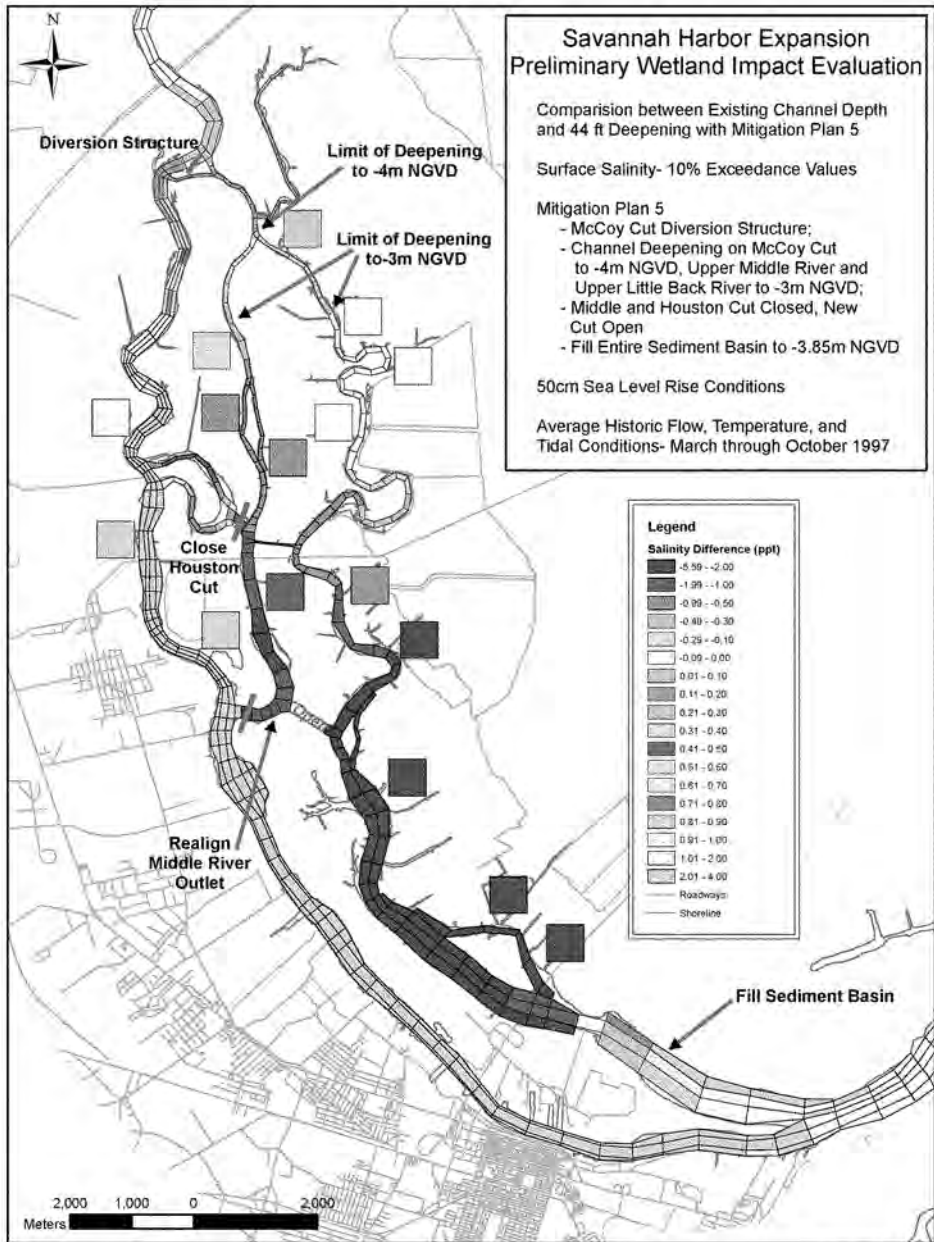


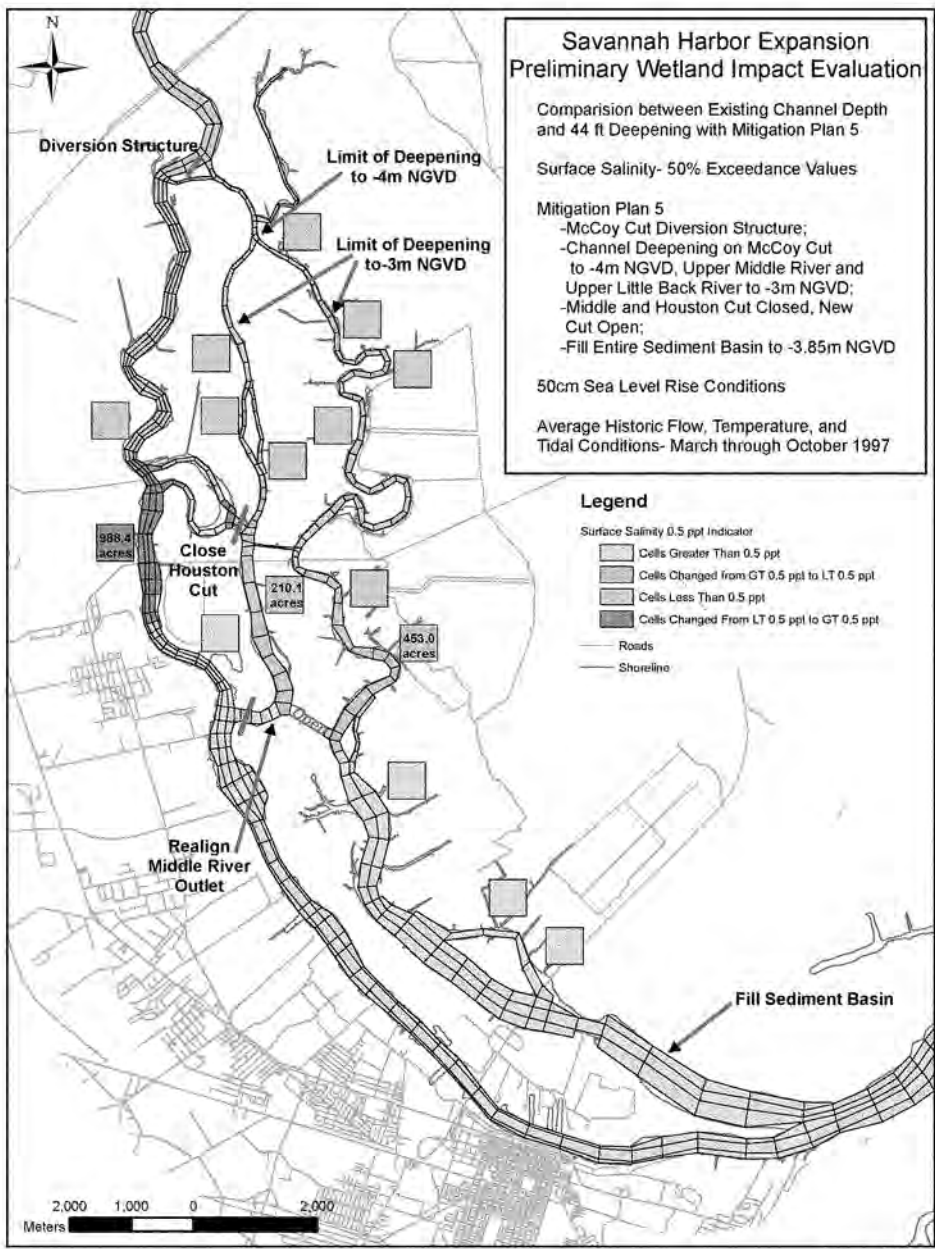


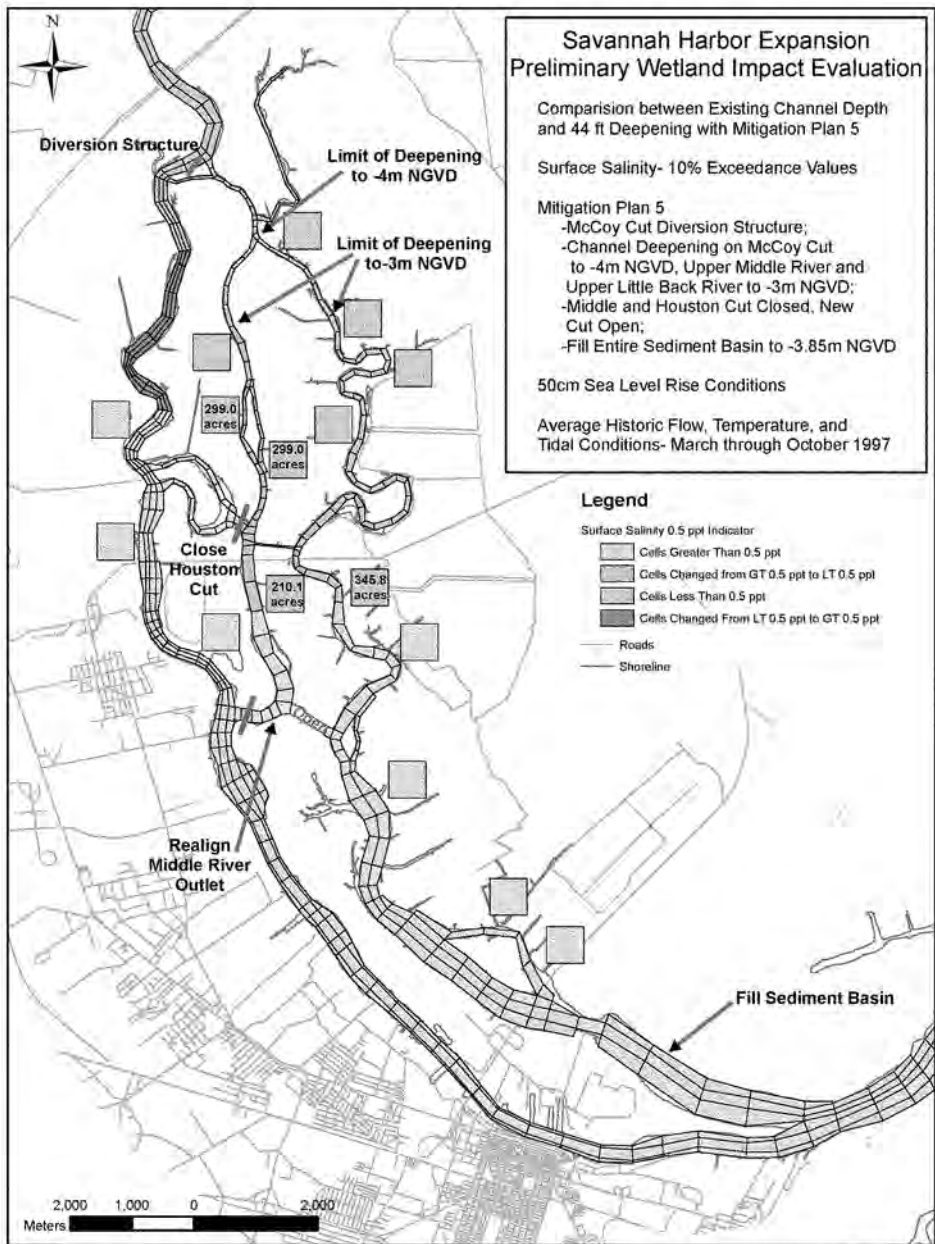


Sensitivity Analysis #2B



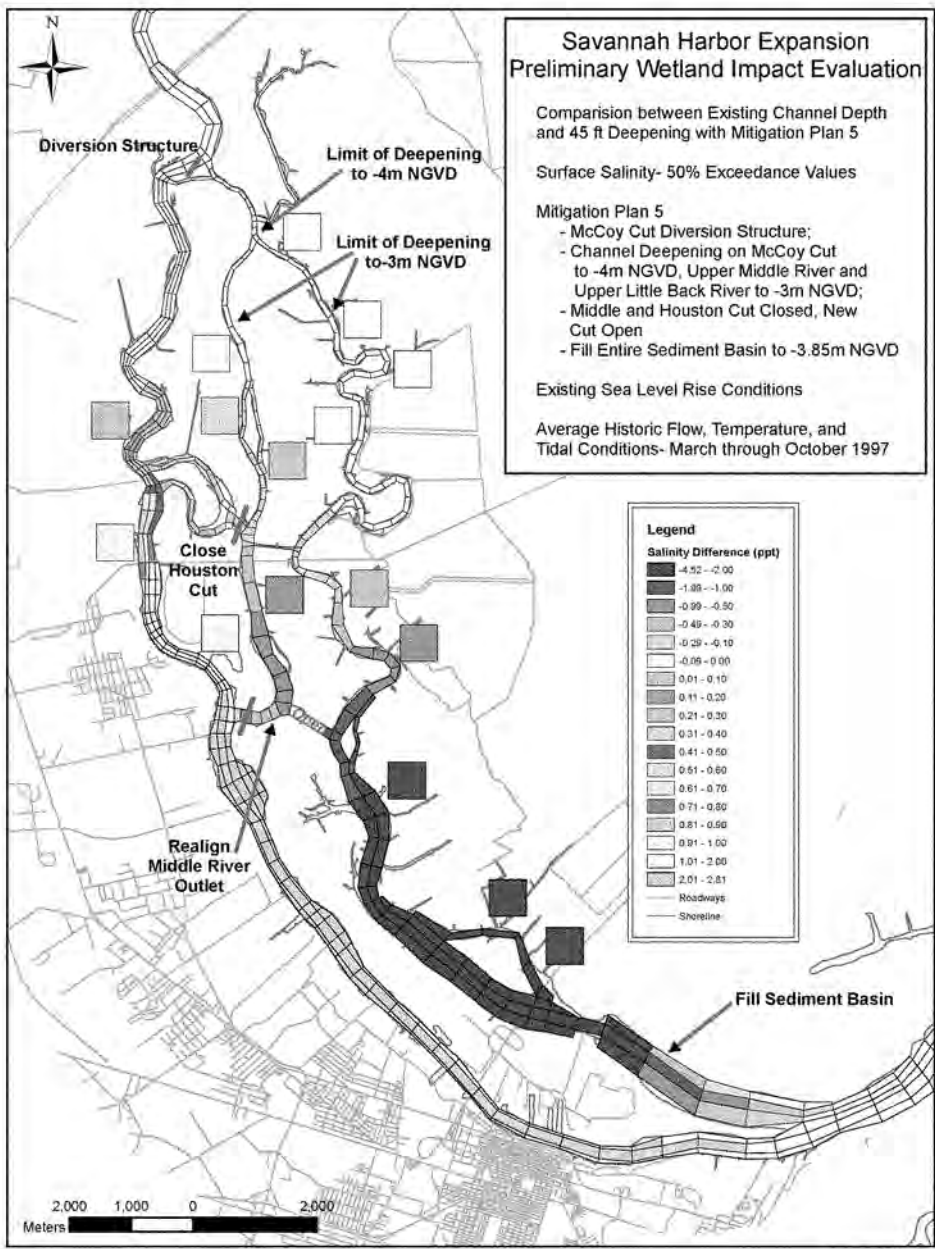


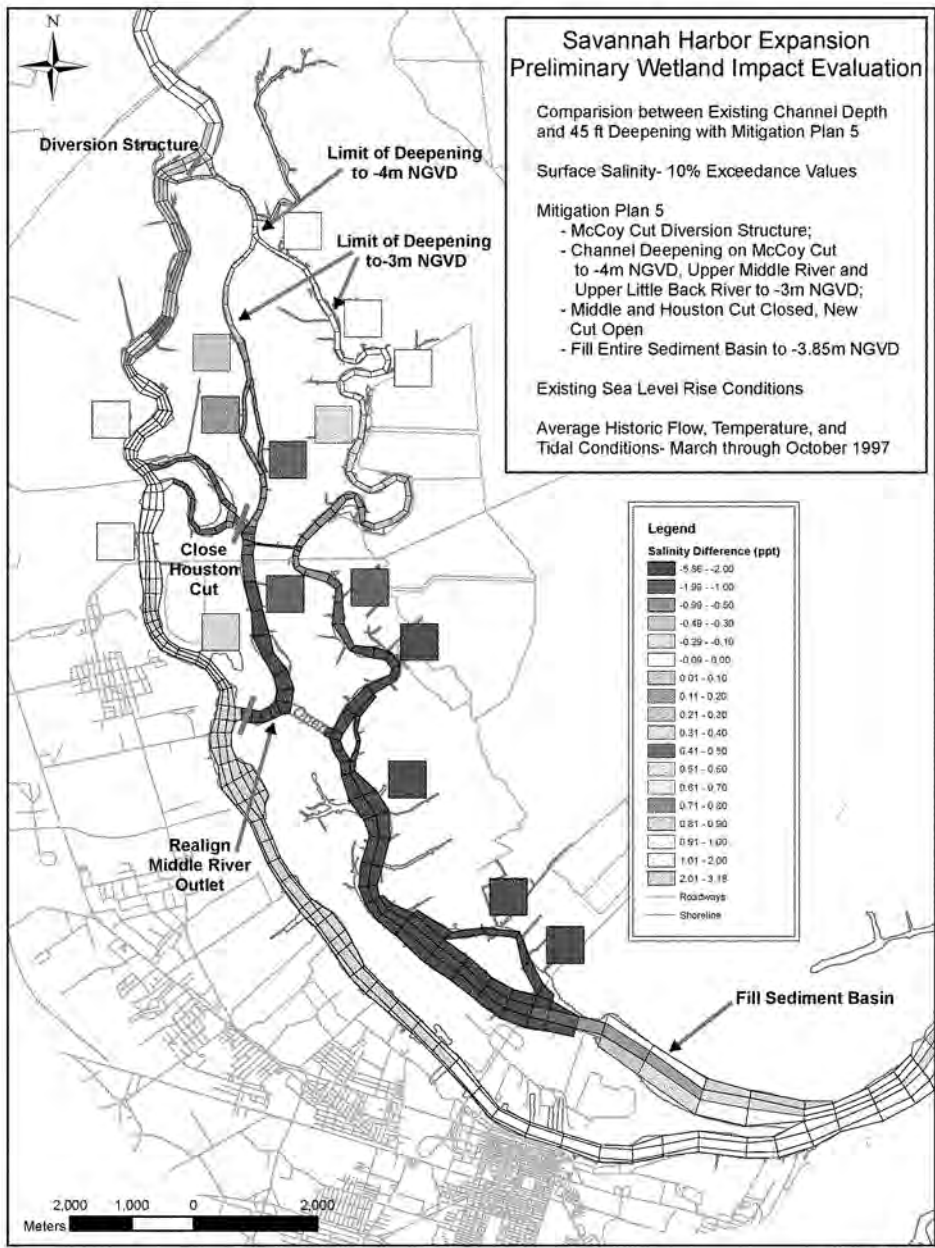


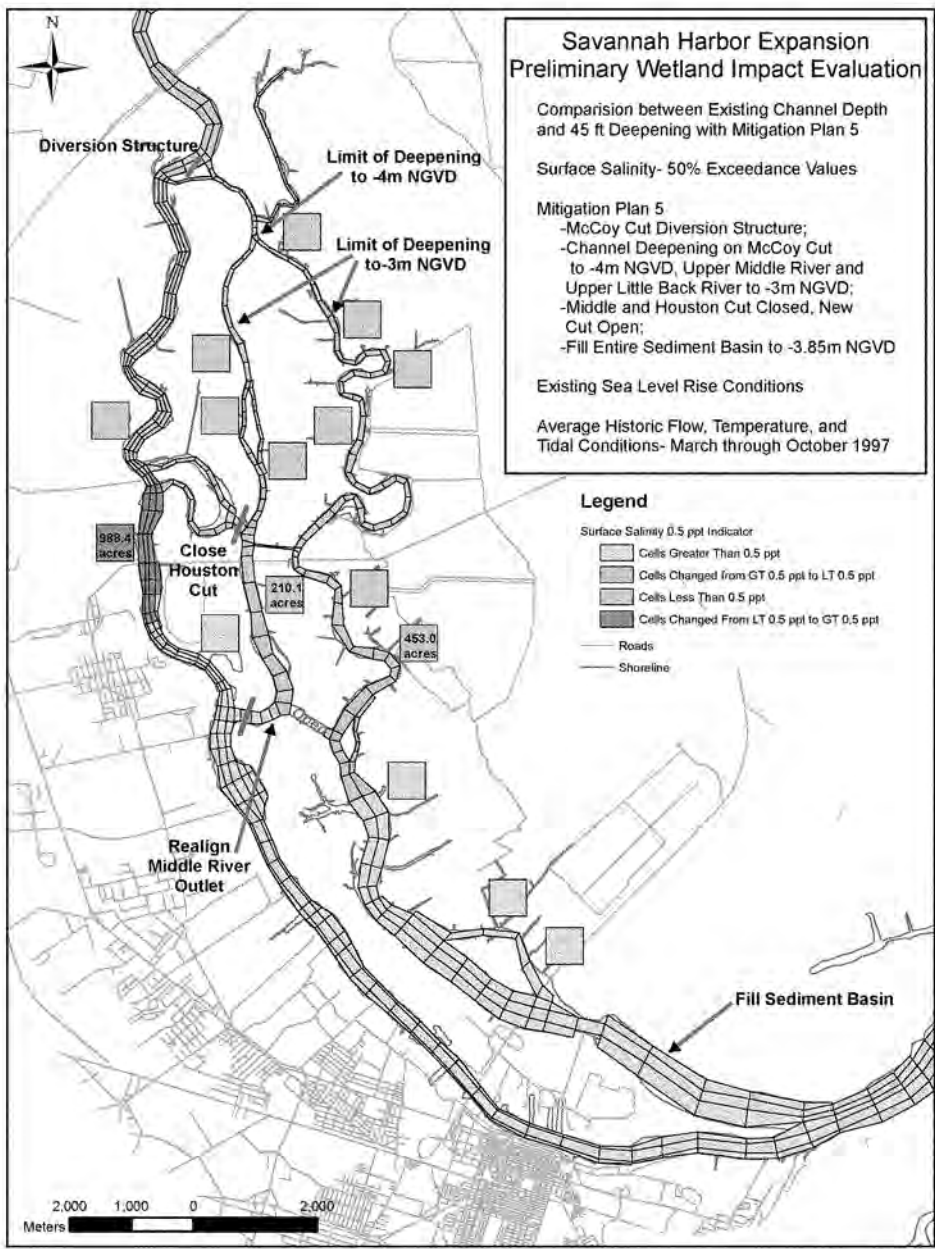


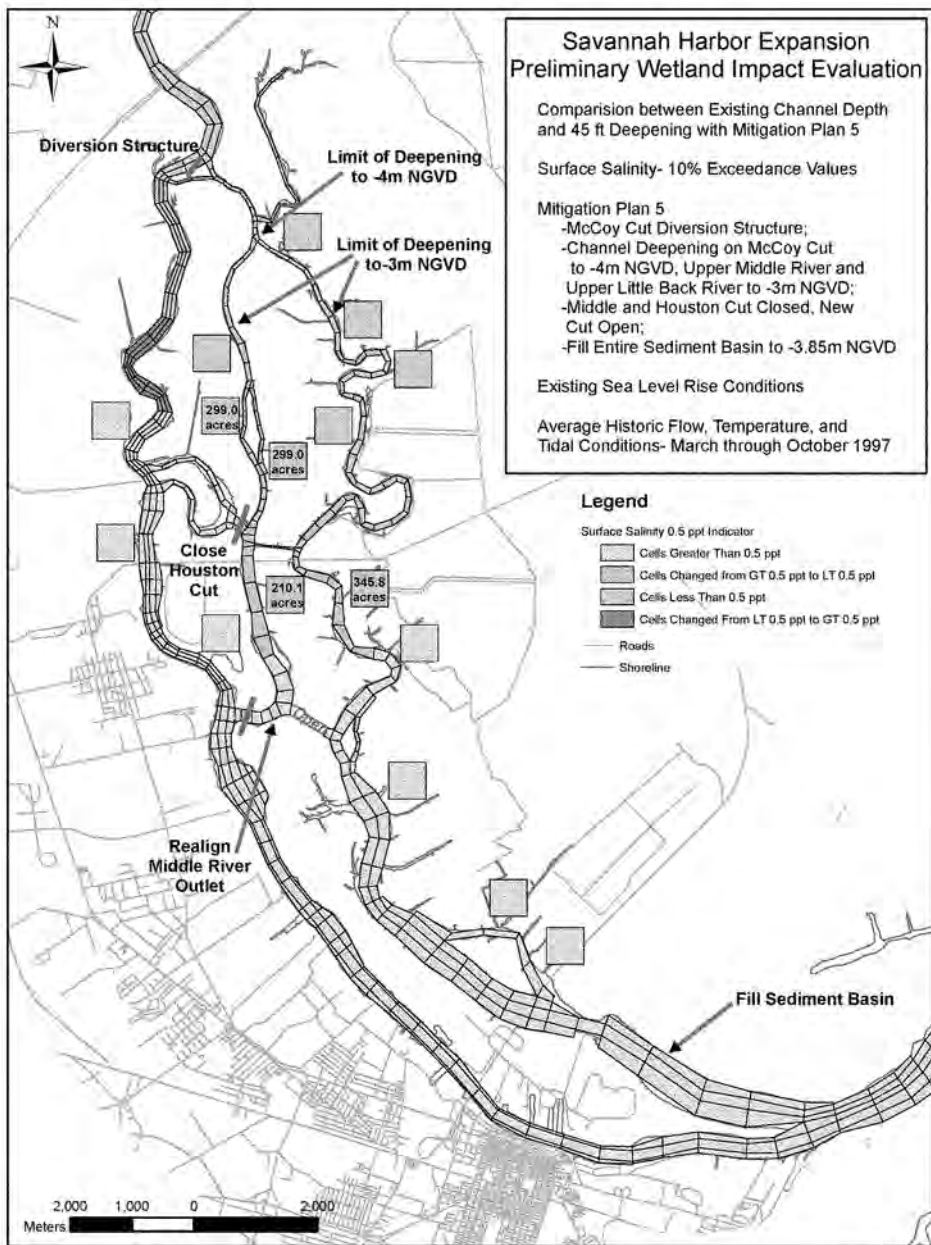
45-ft Deepening

Basic Evaluation

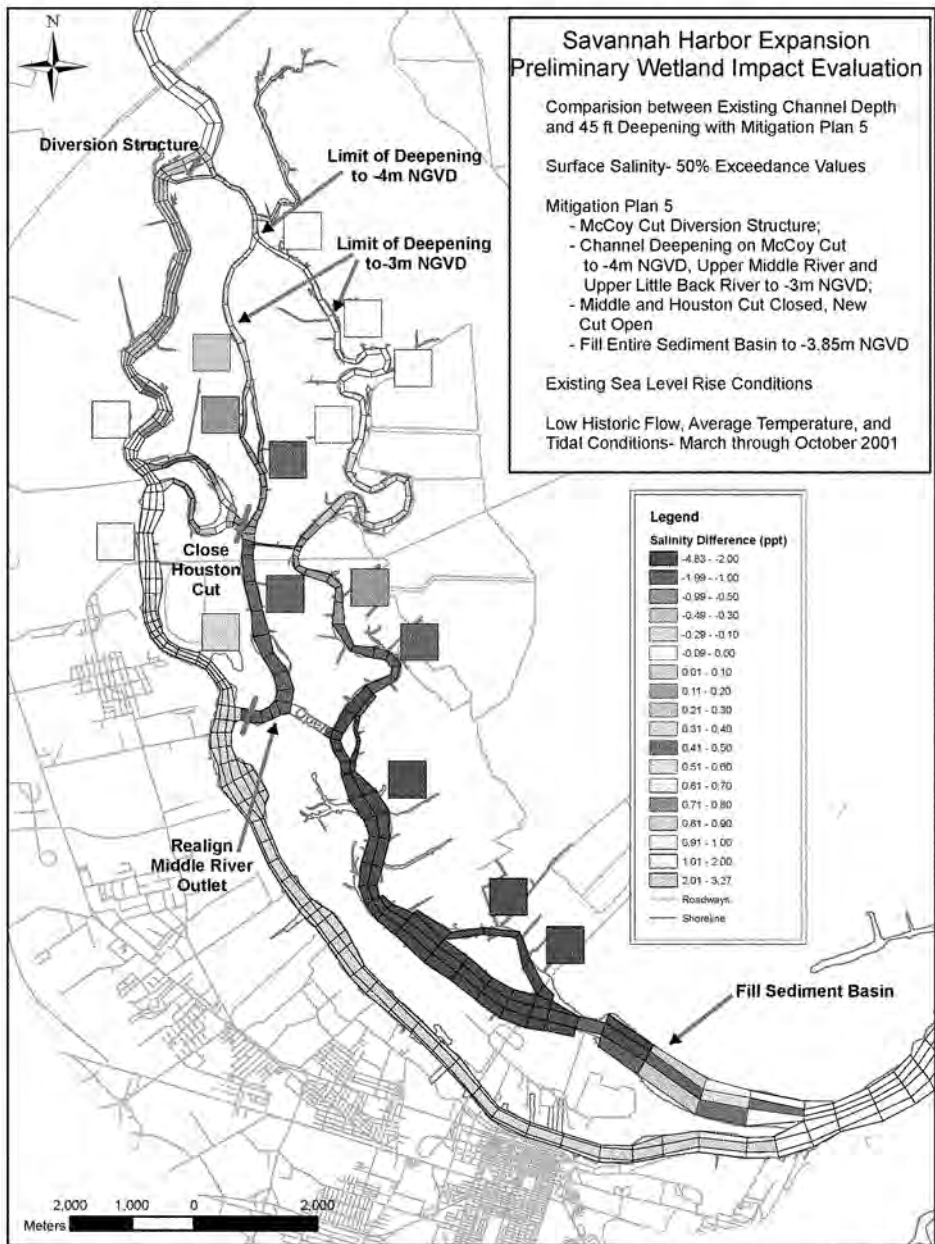


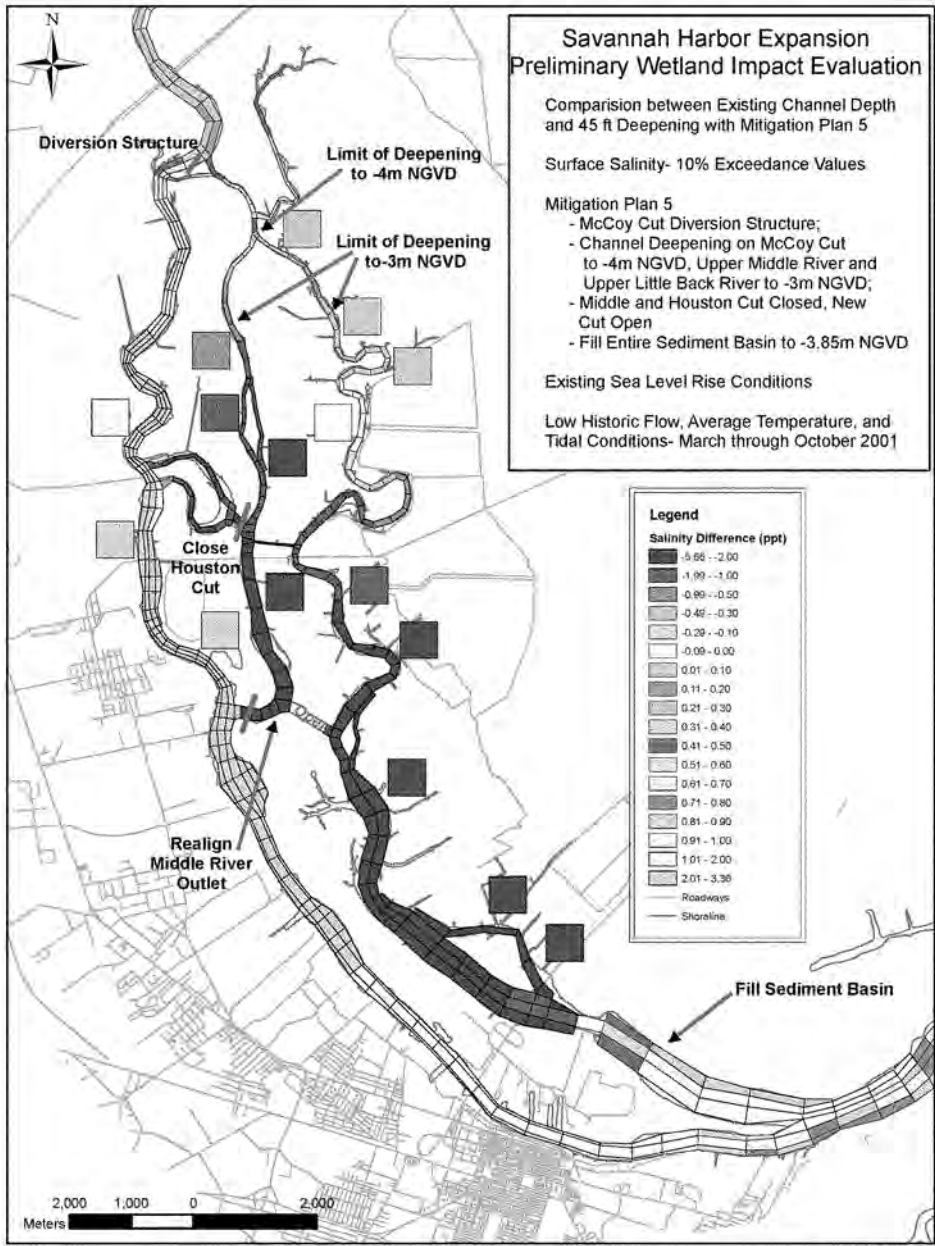


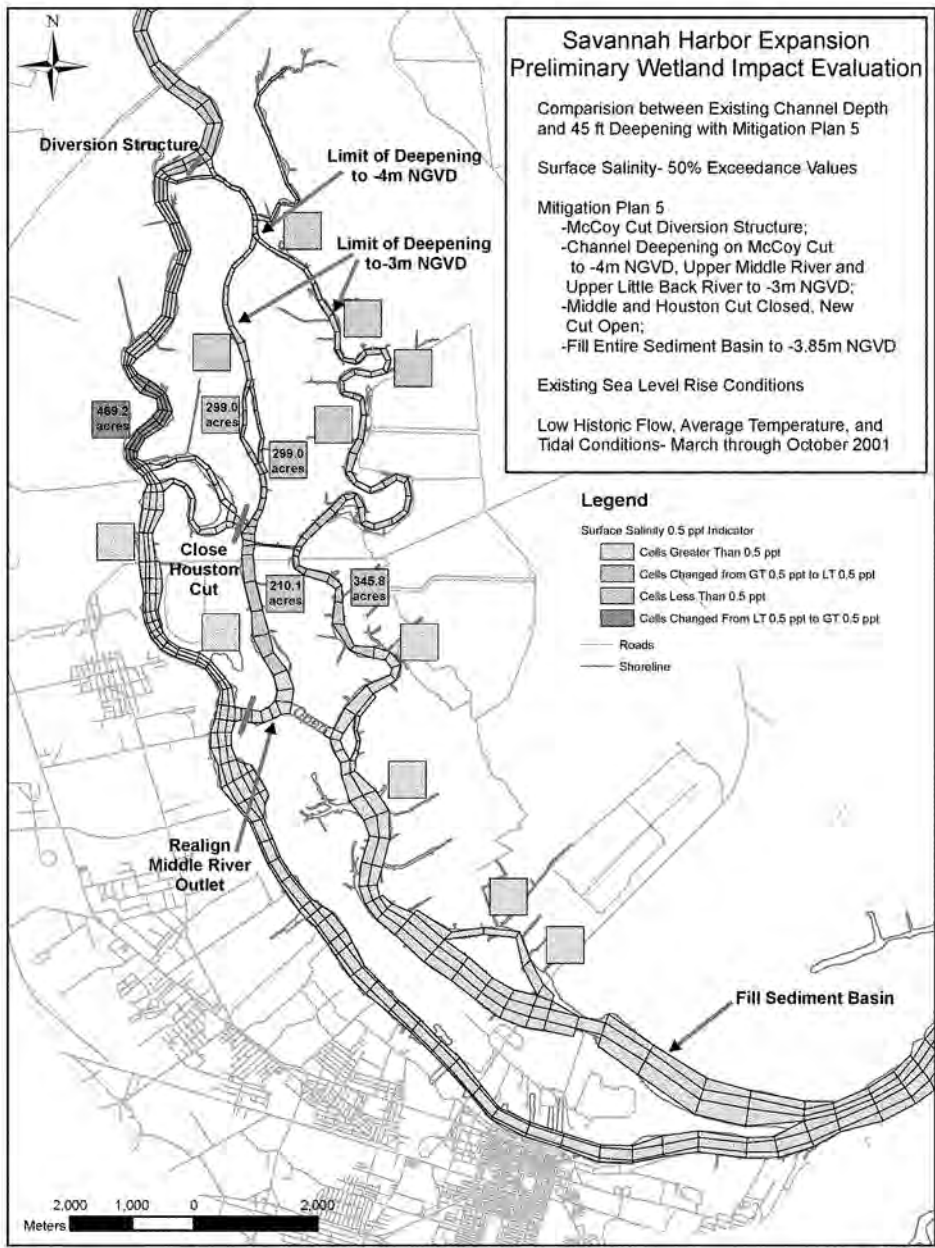


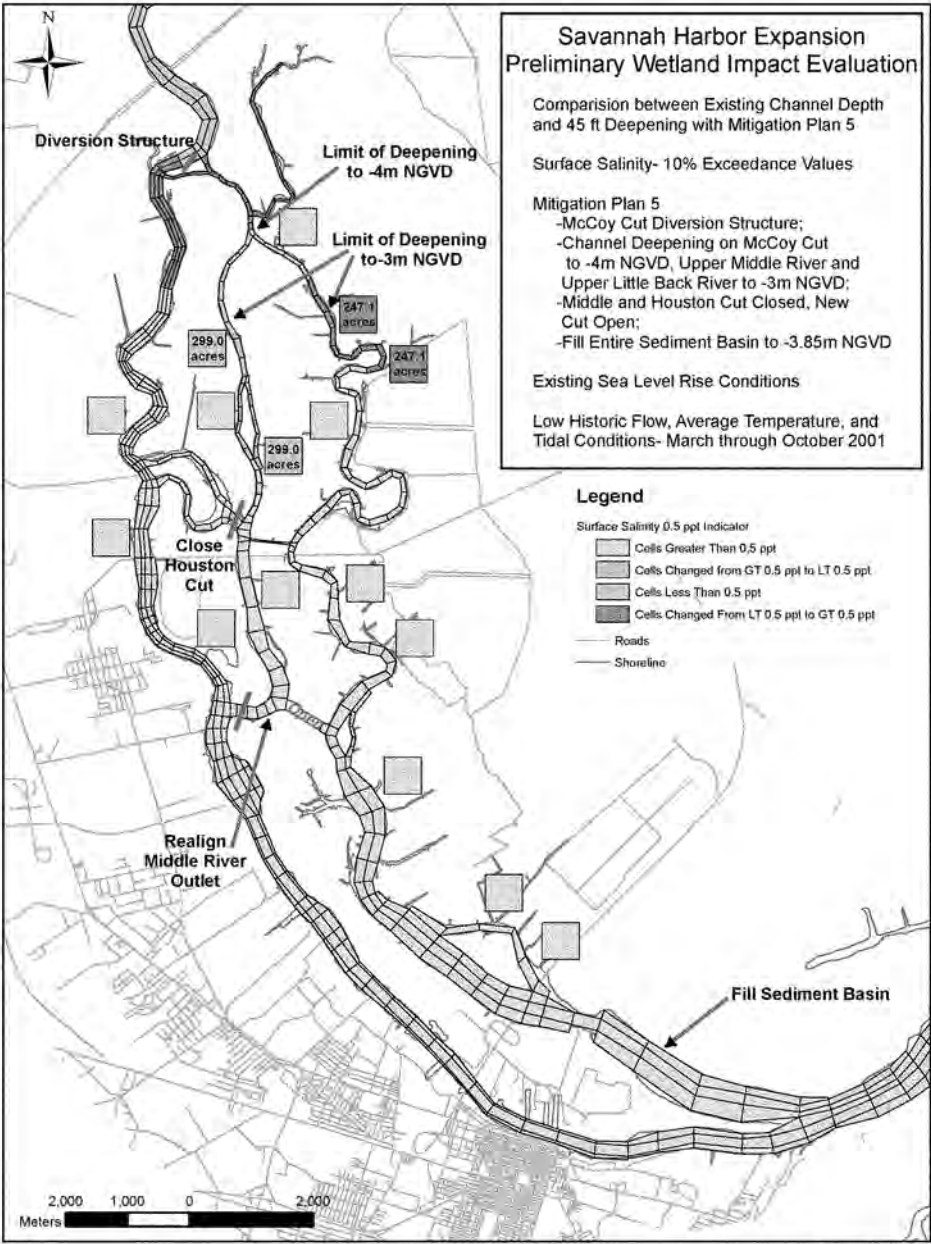


Sensitivity Analysis #1

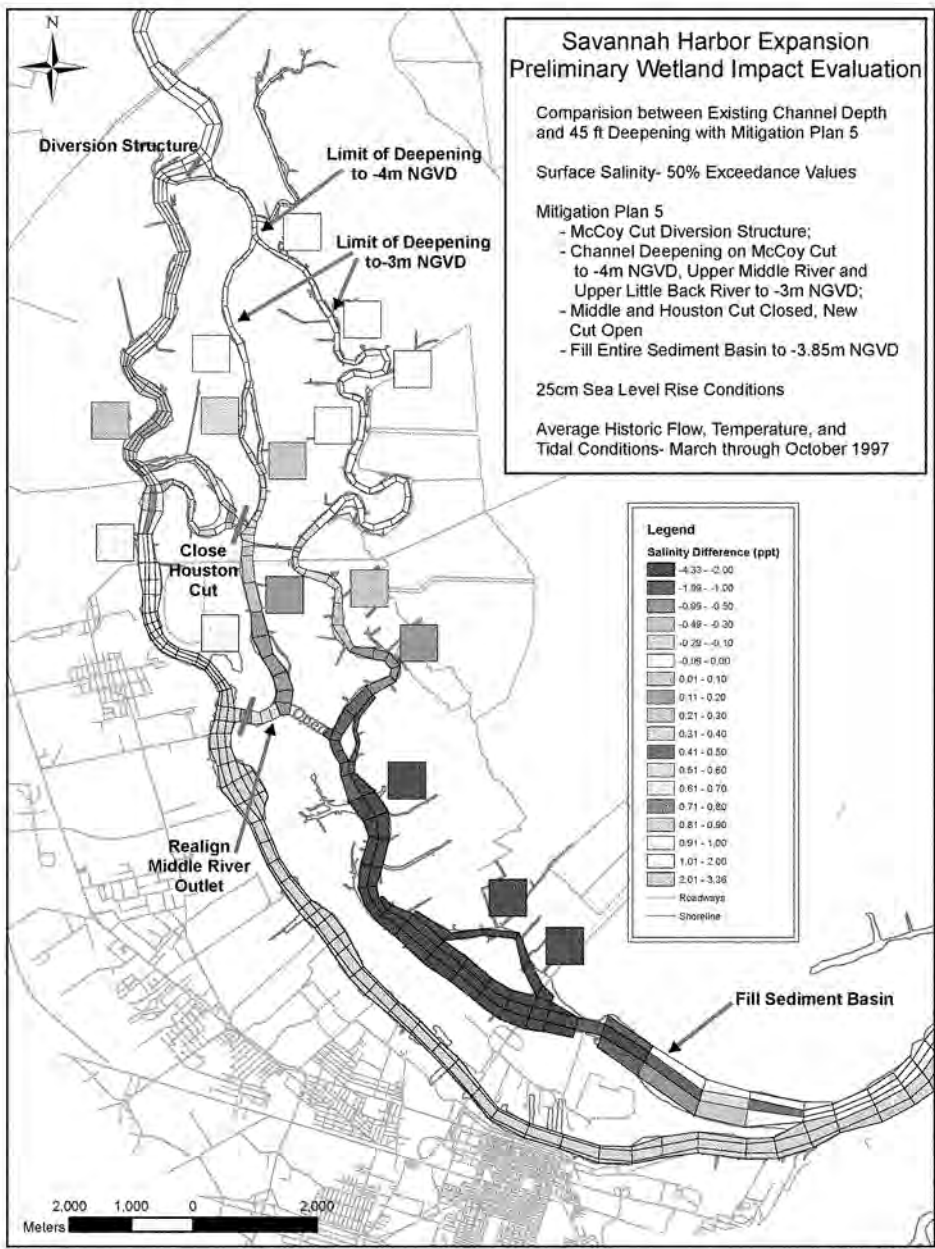


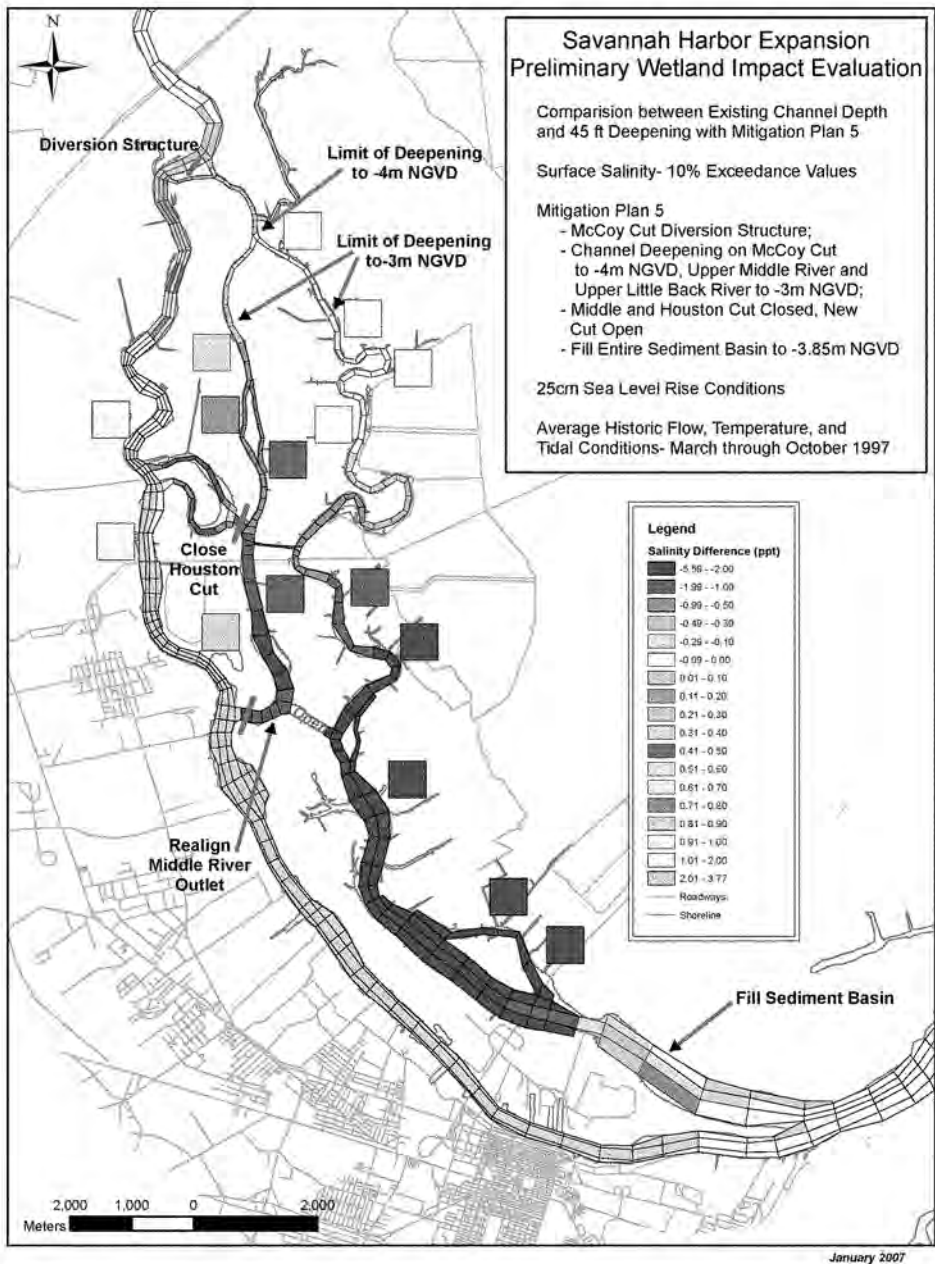


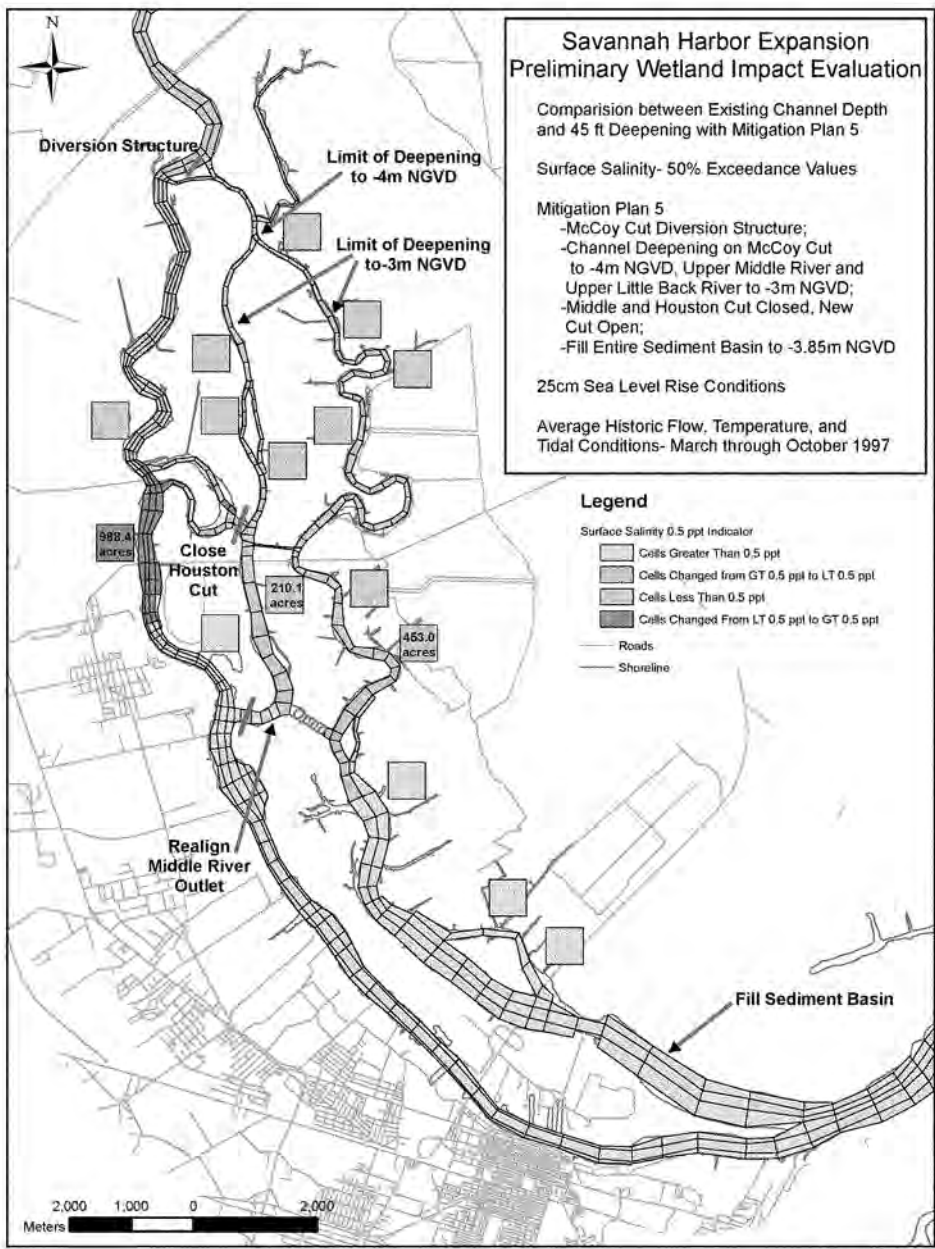


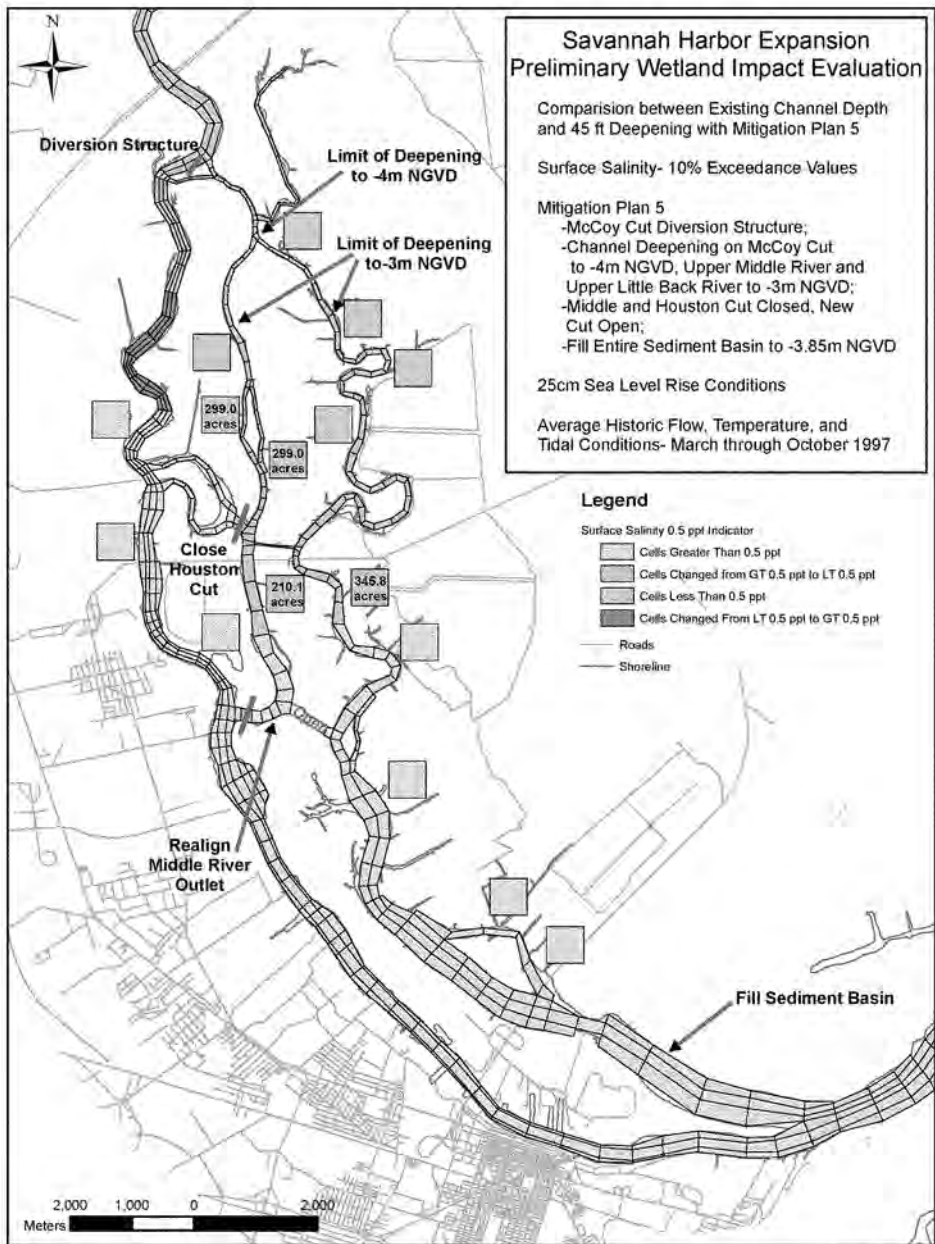


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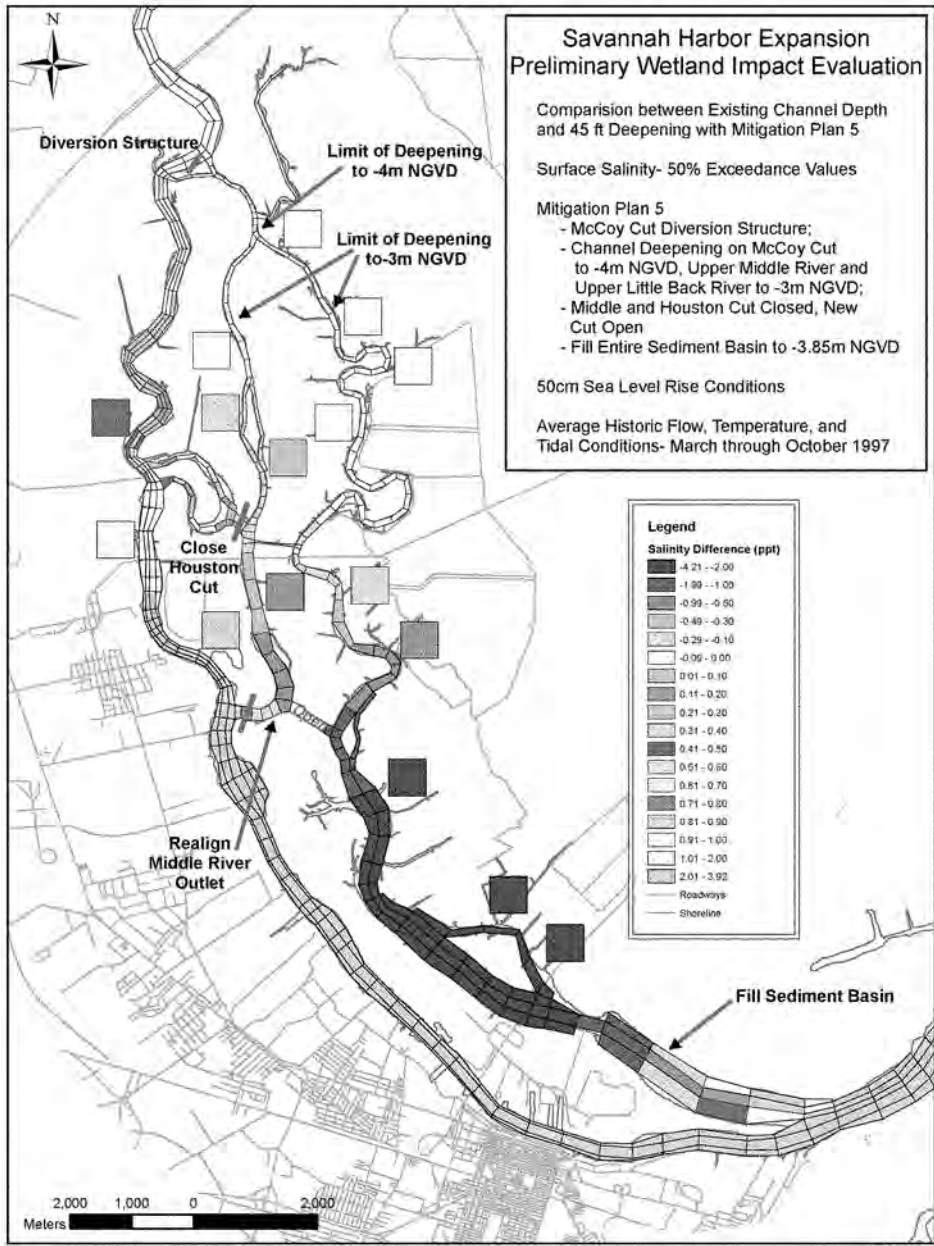


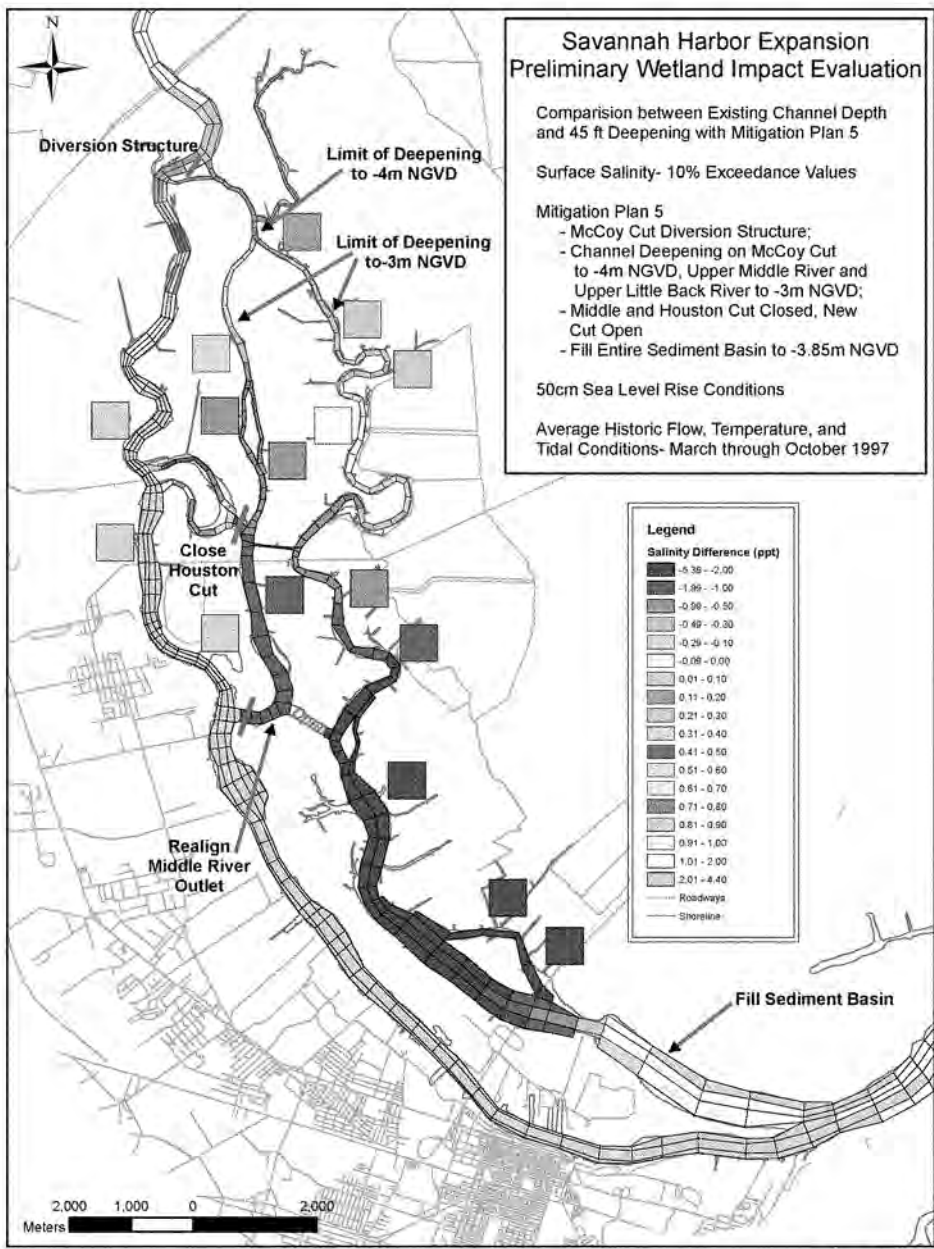


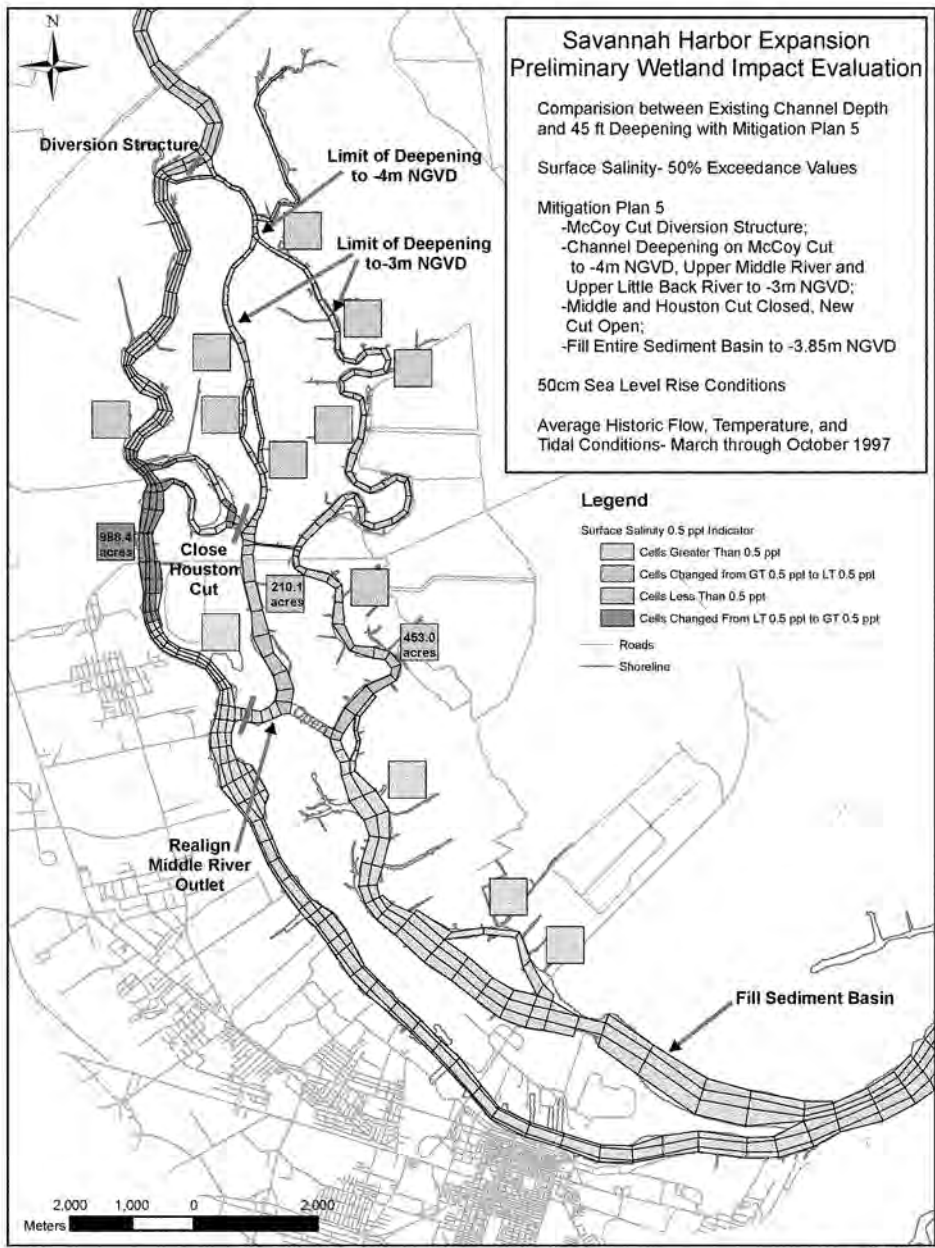


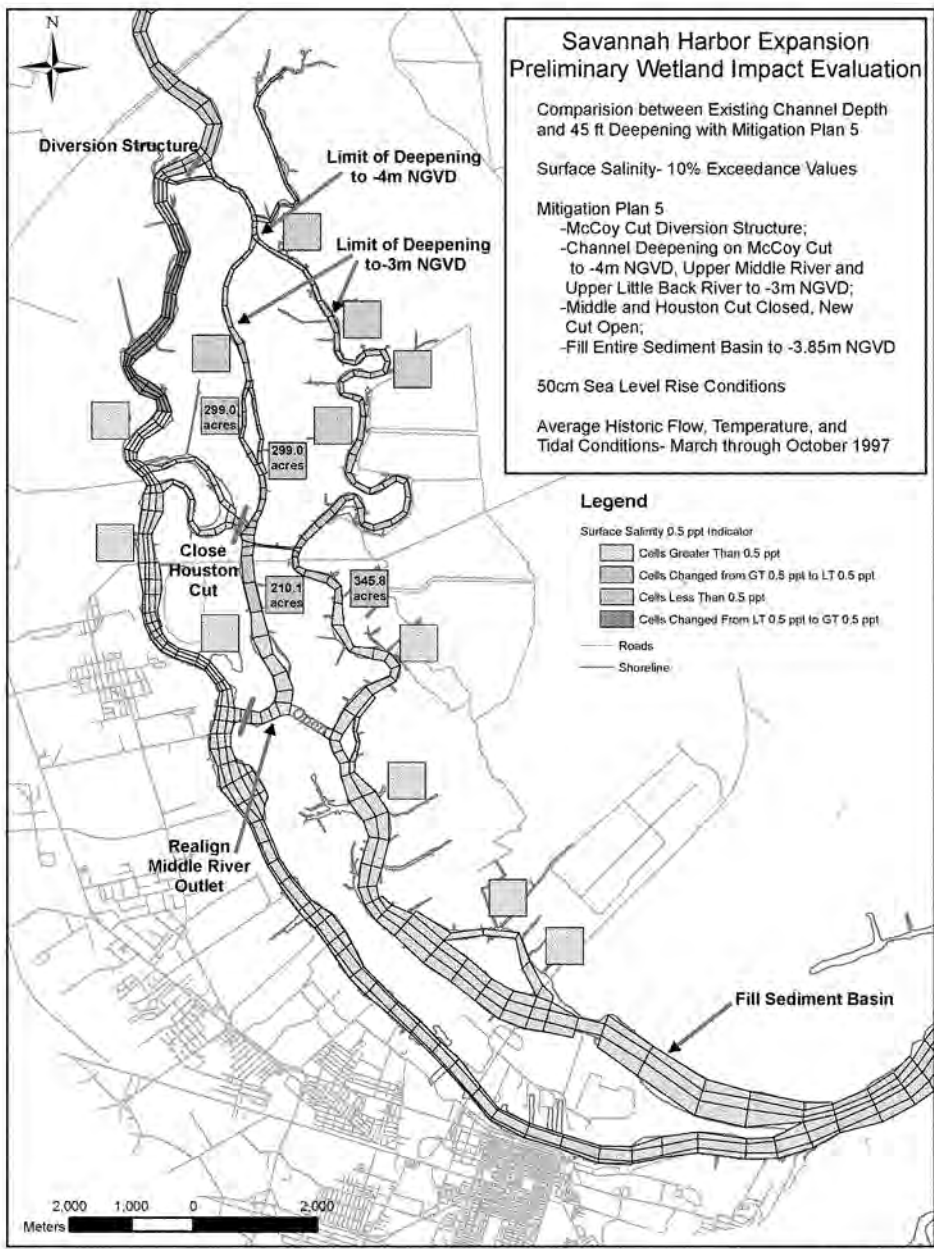


Sensitivity Analysis #2B



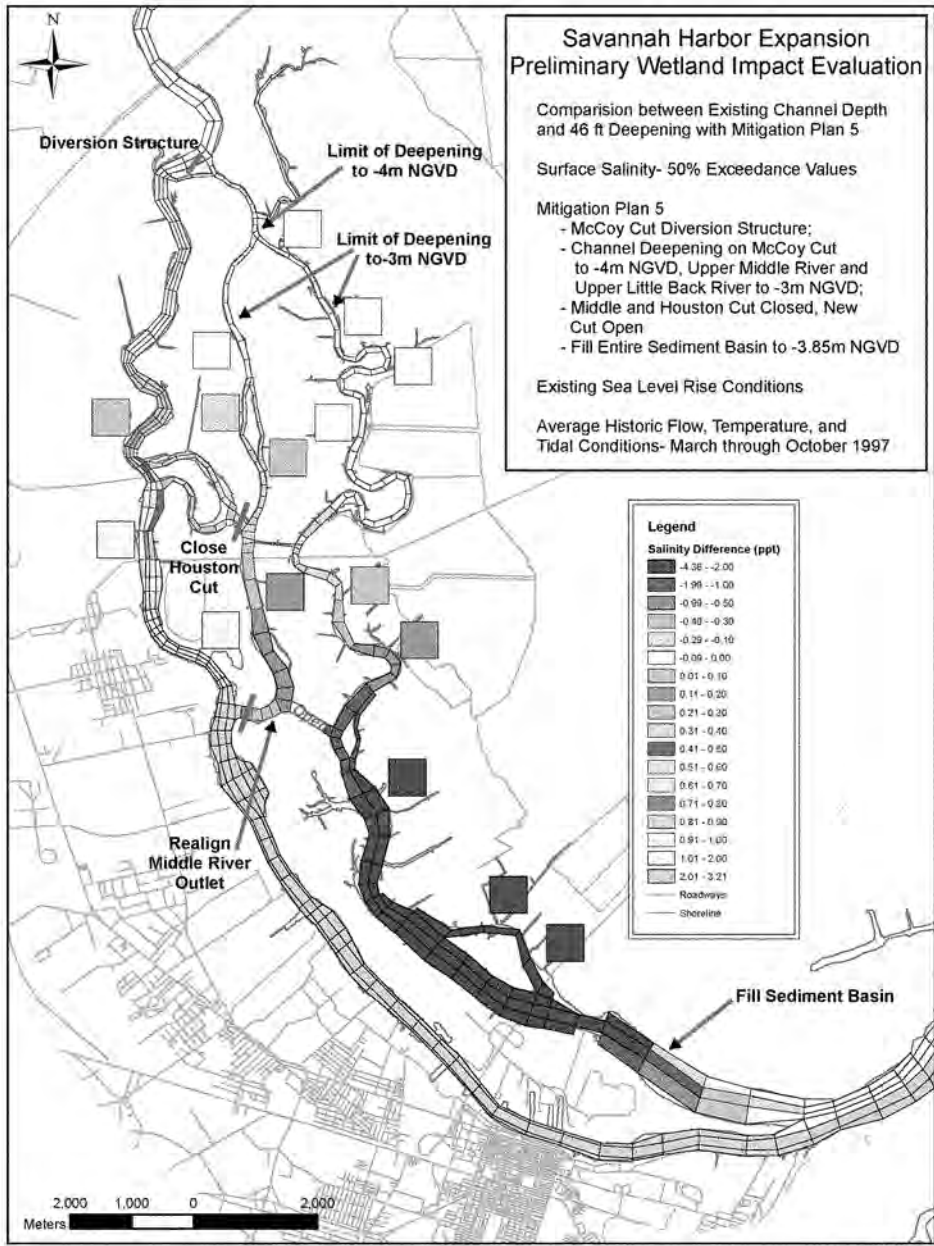


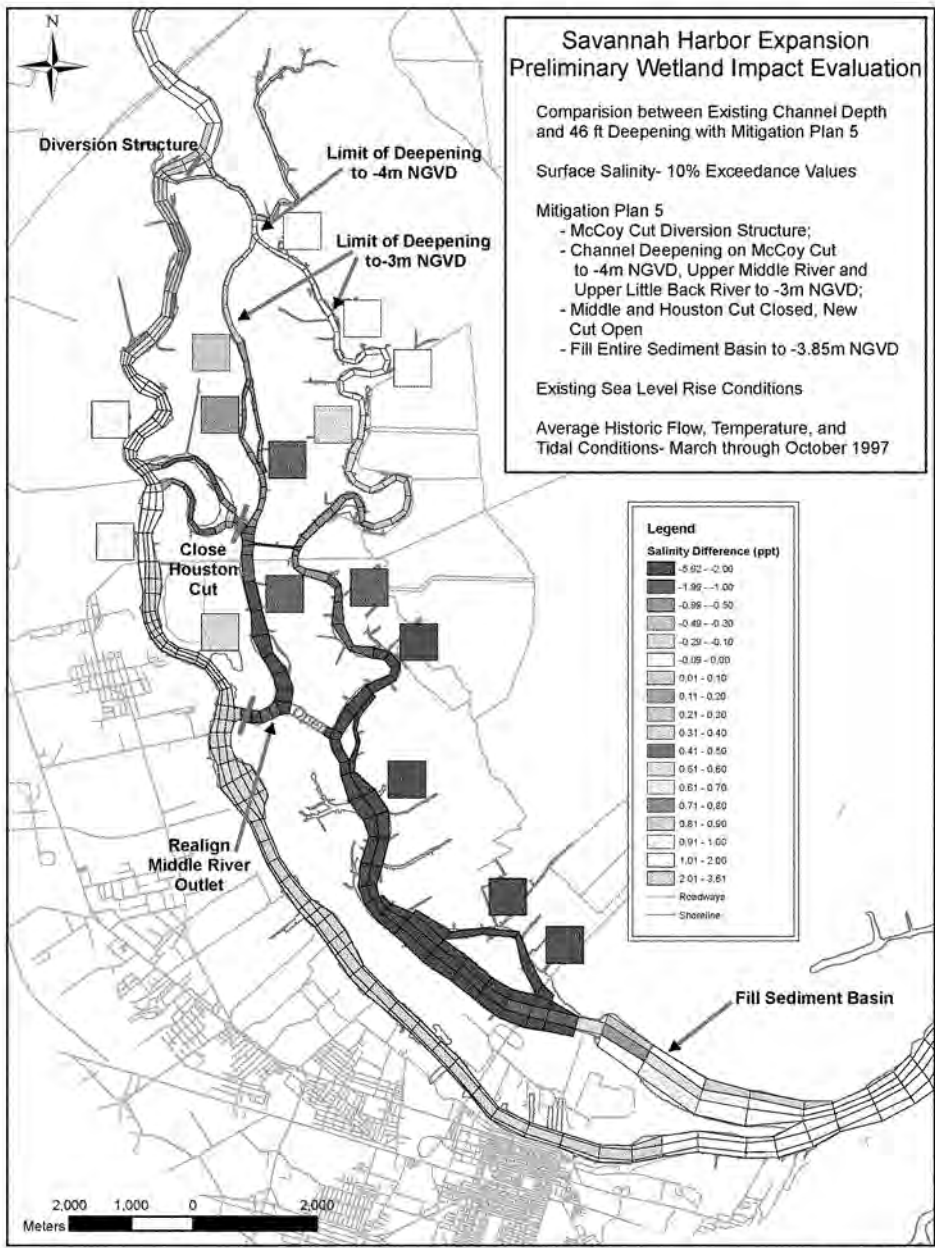


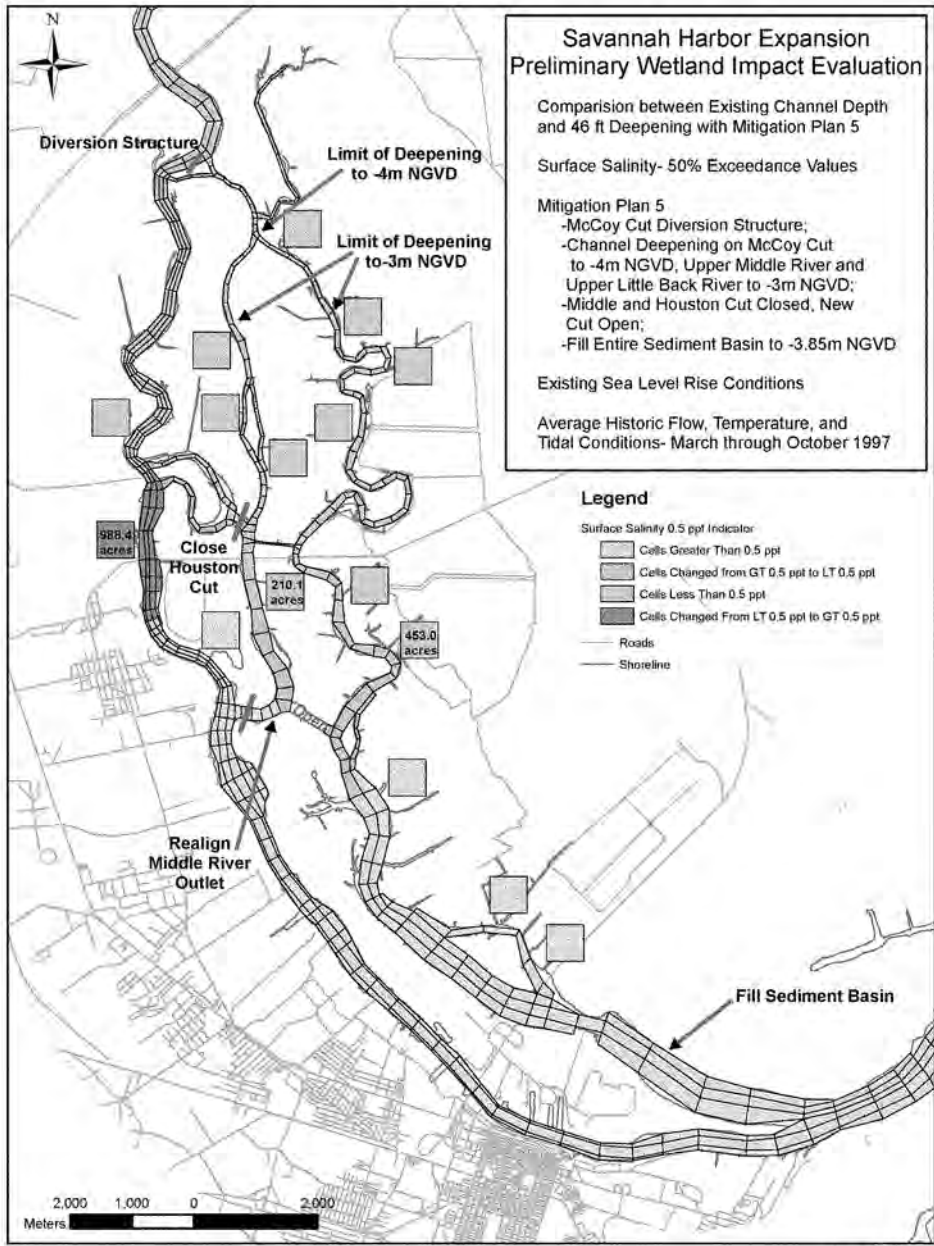


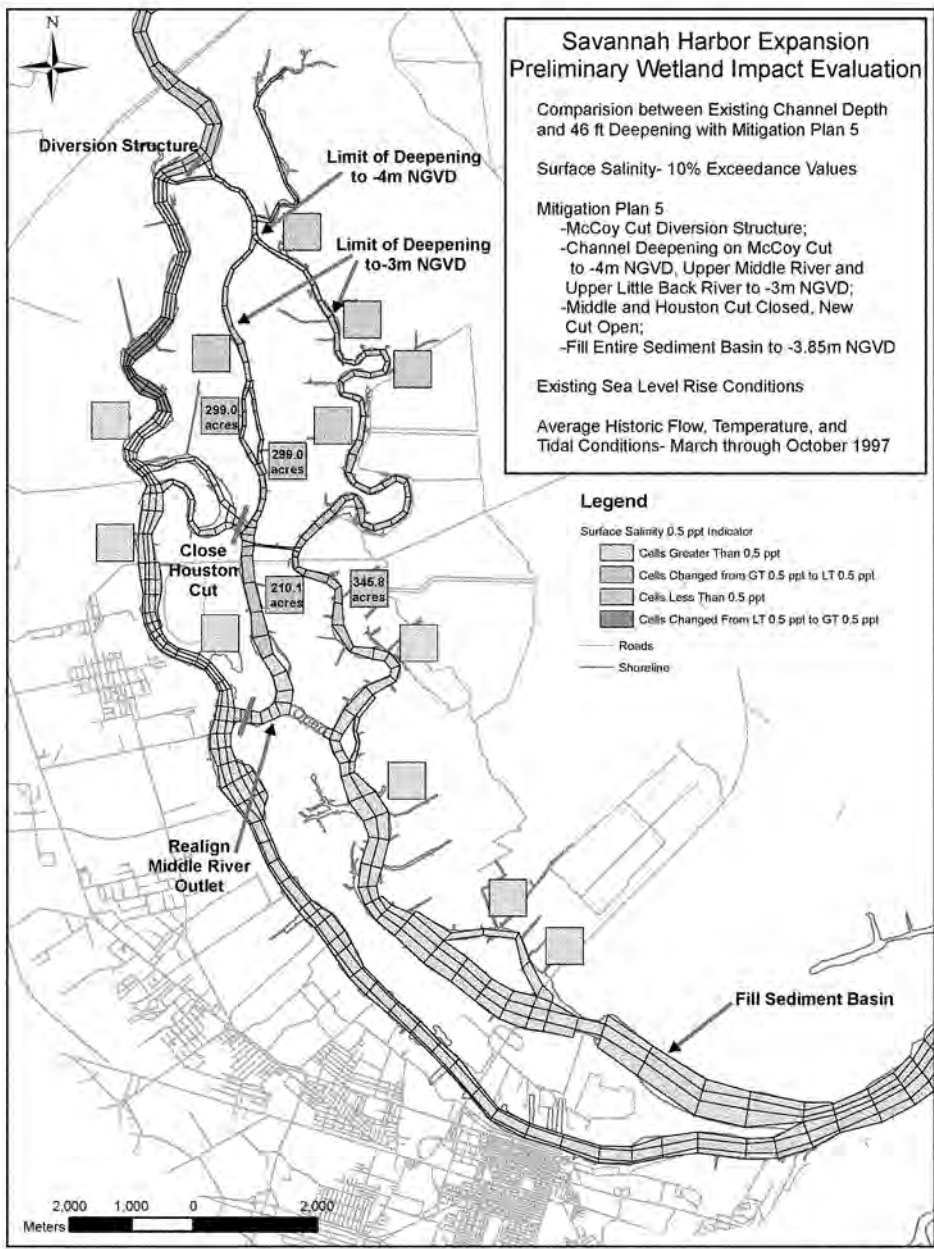
46-ft Deepening

Basic Evaluation

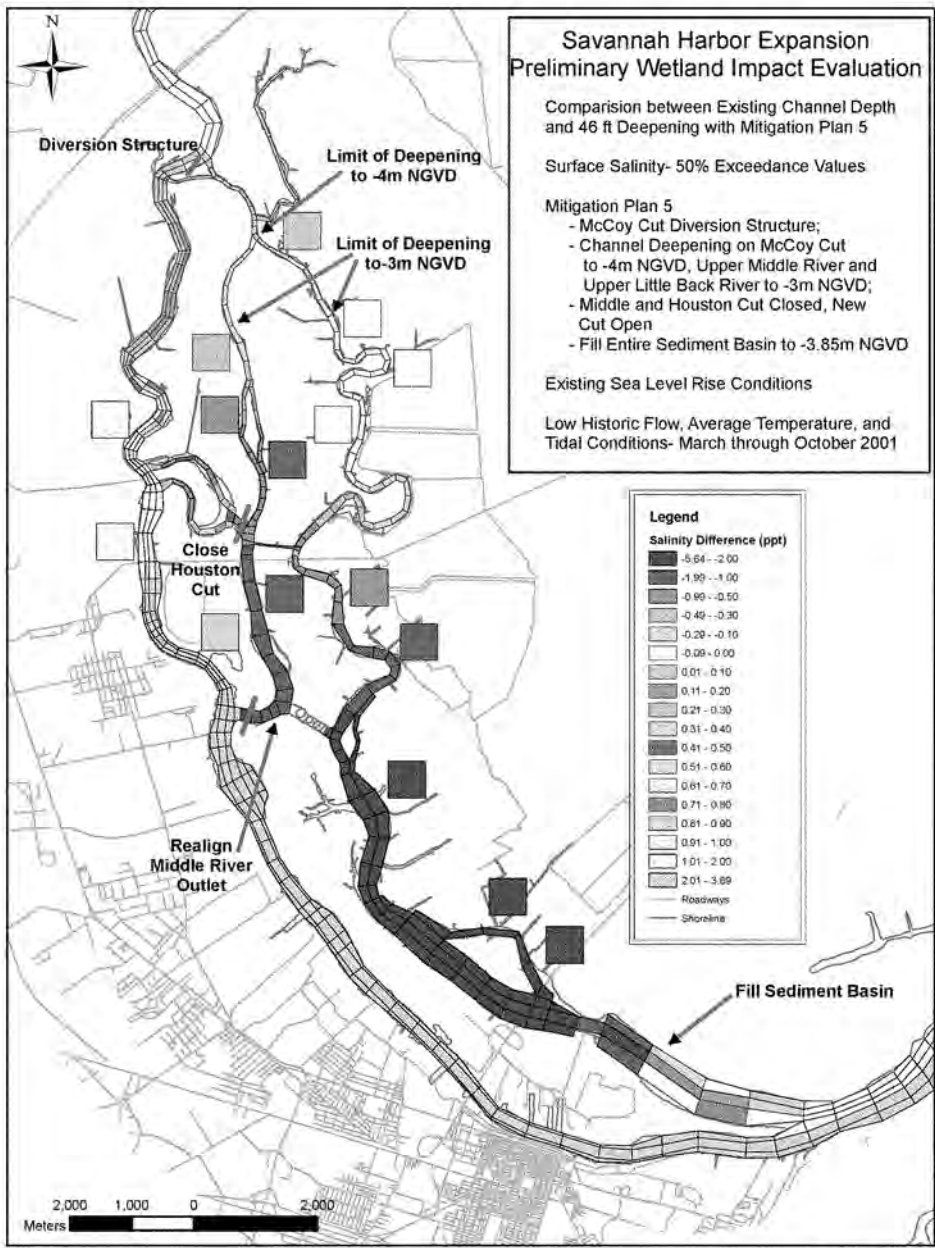


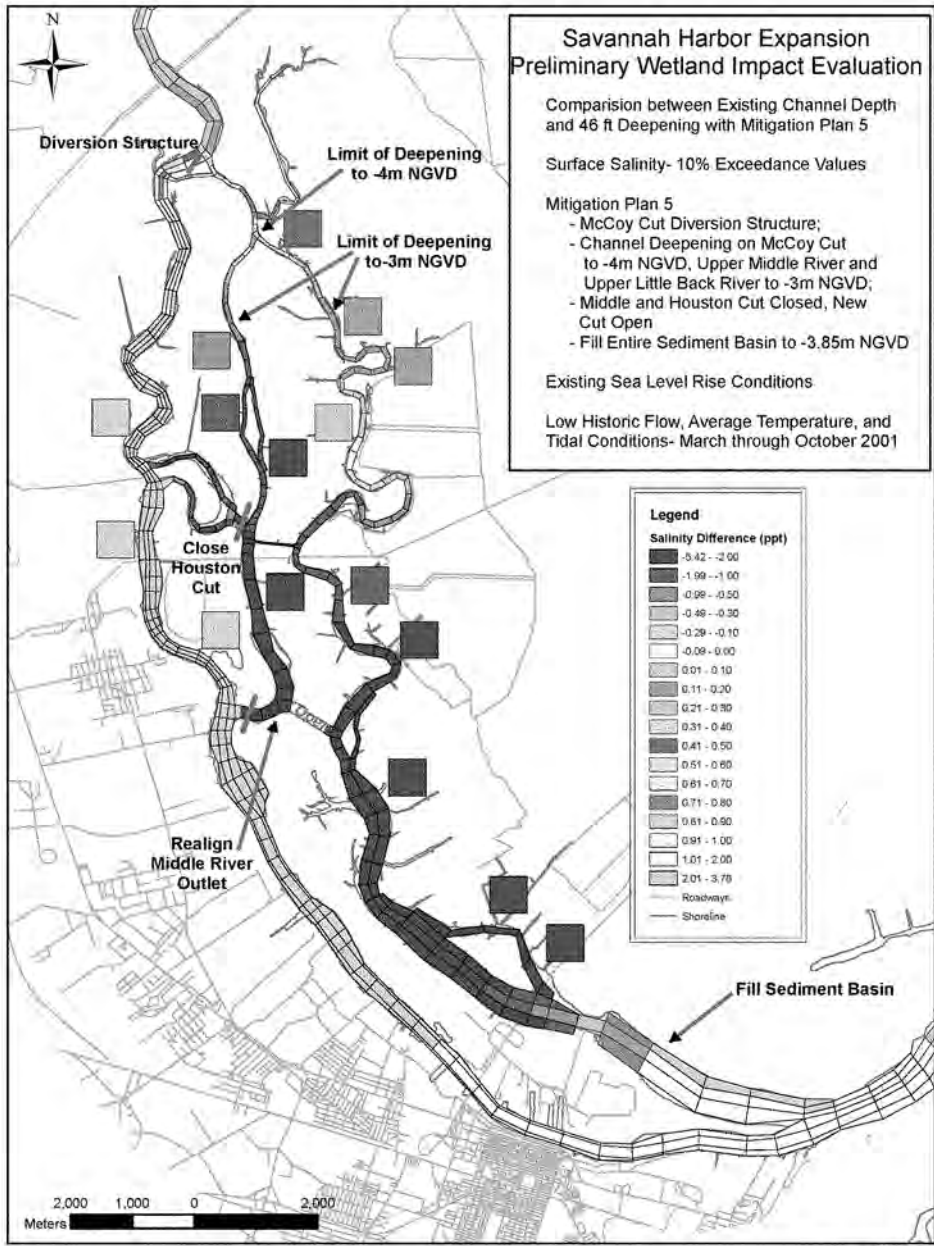


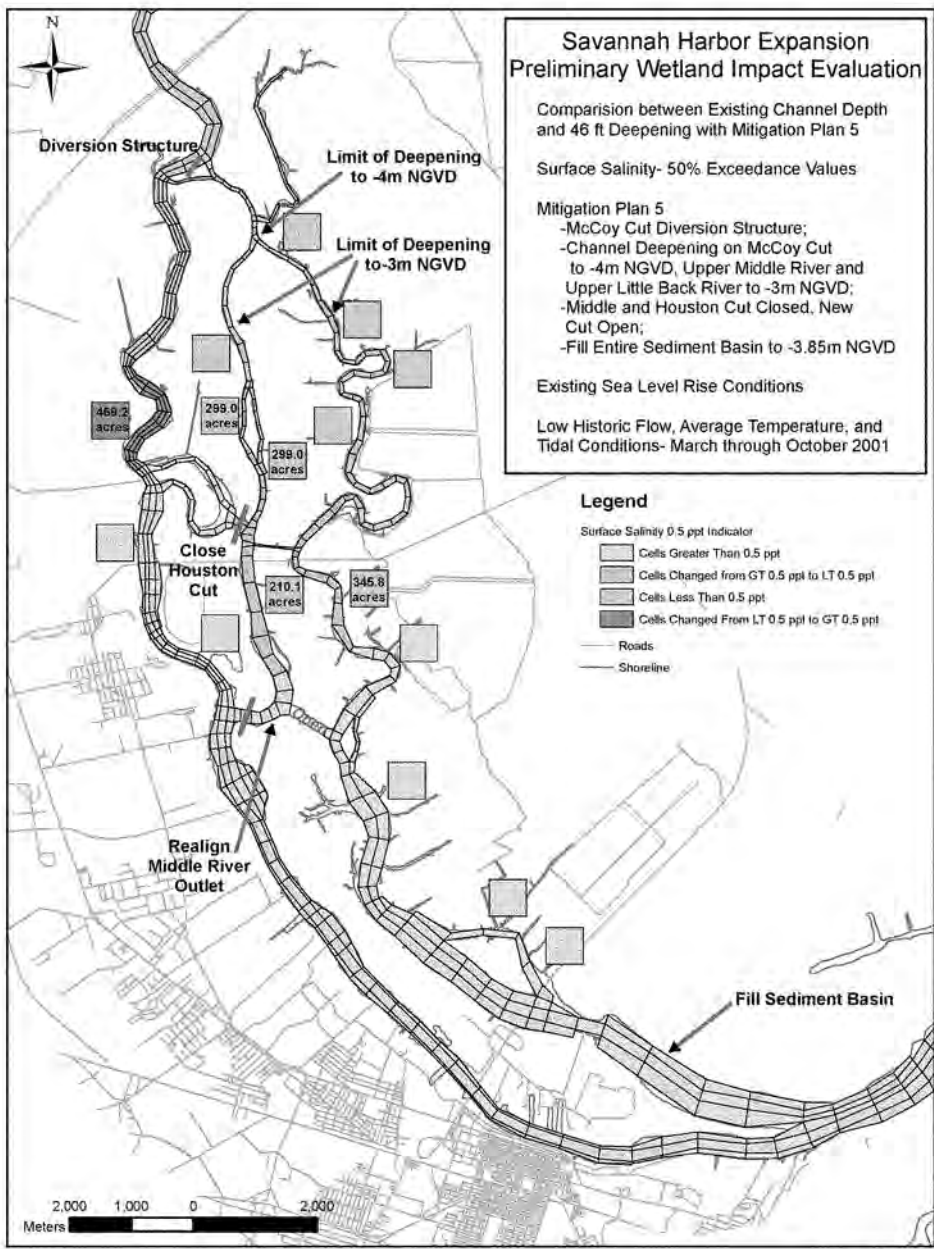


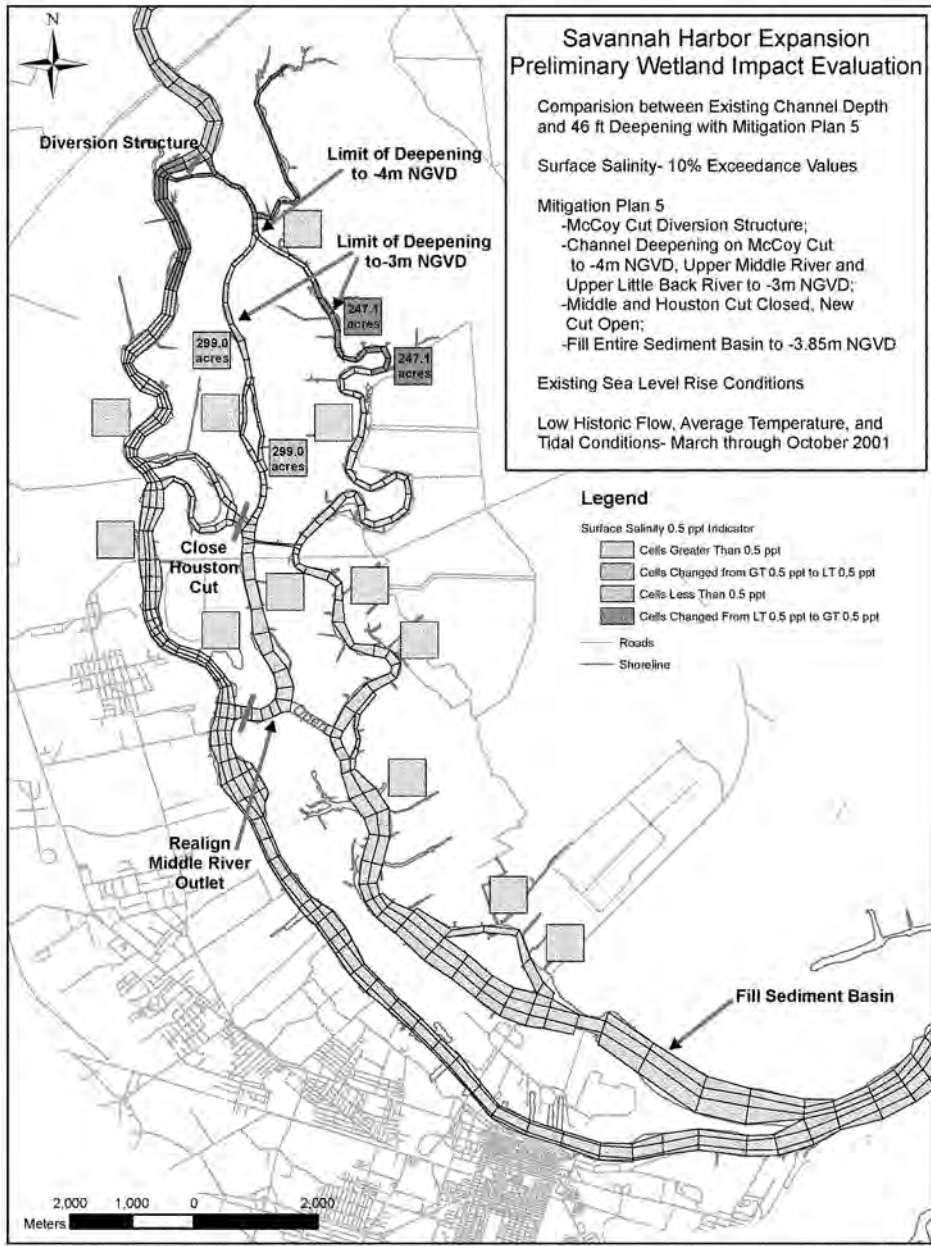


Sensitivity Analysis #1

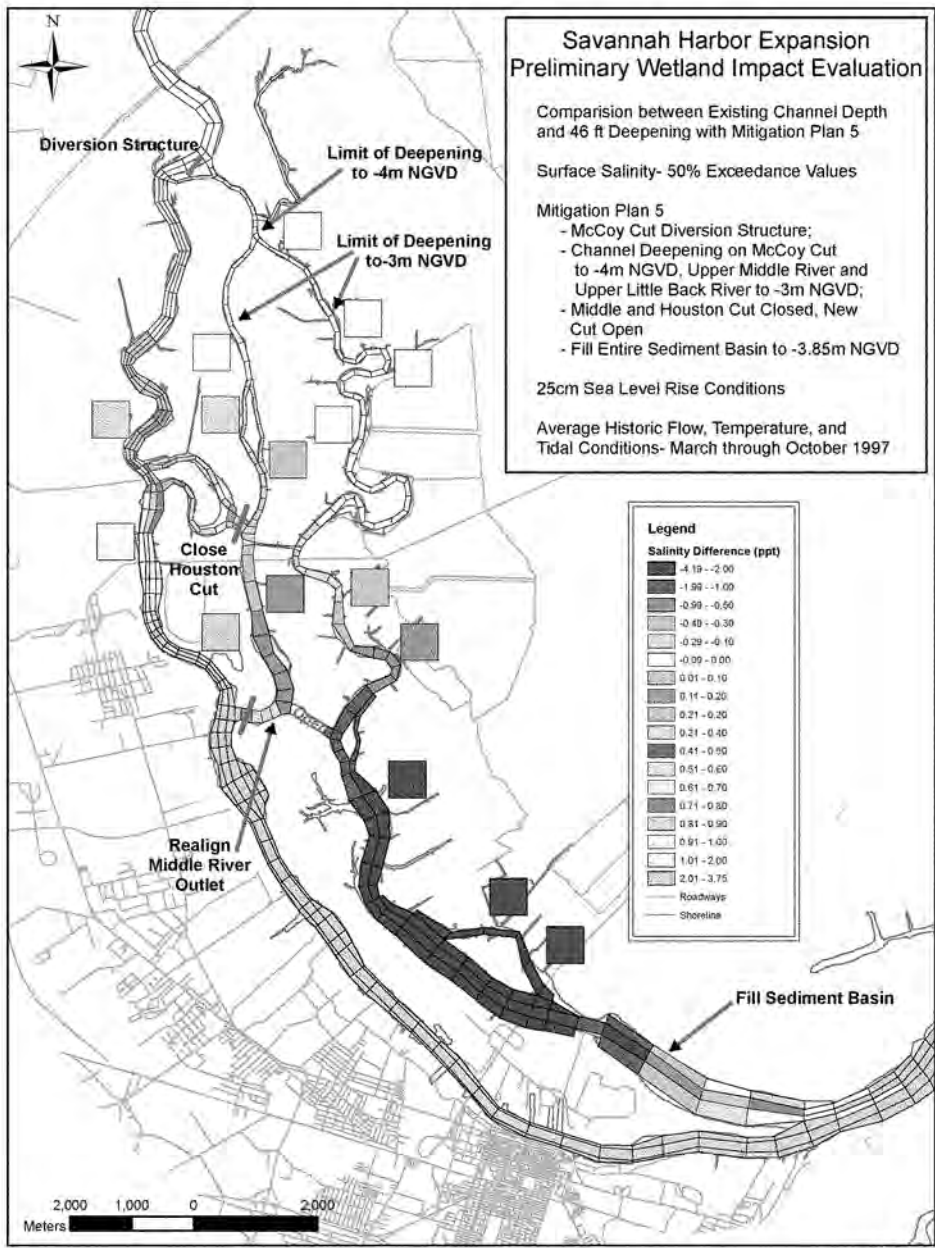


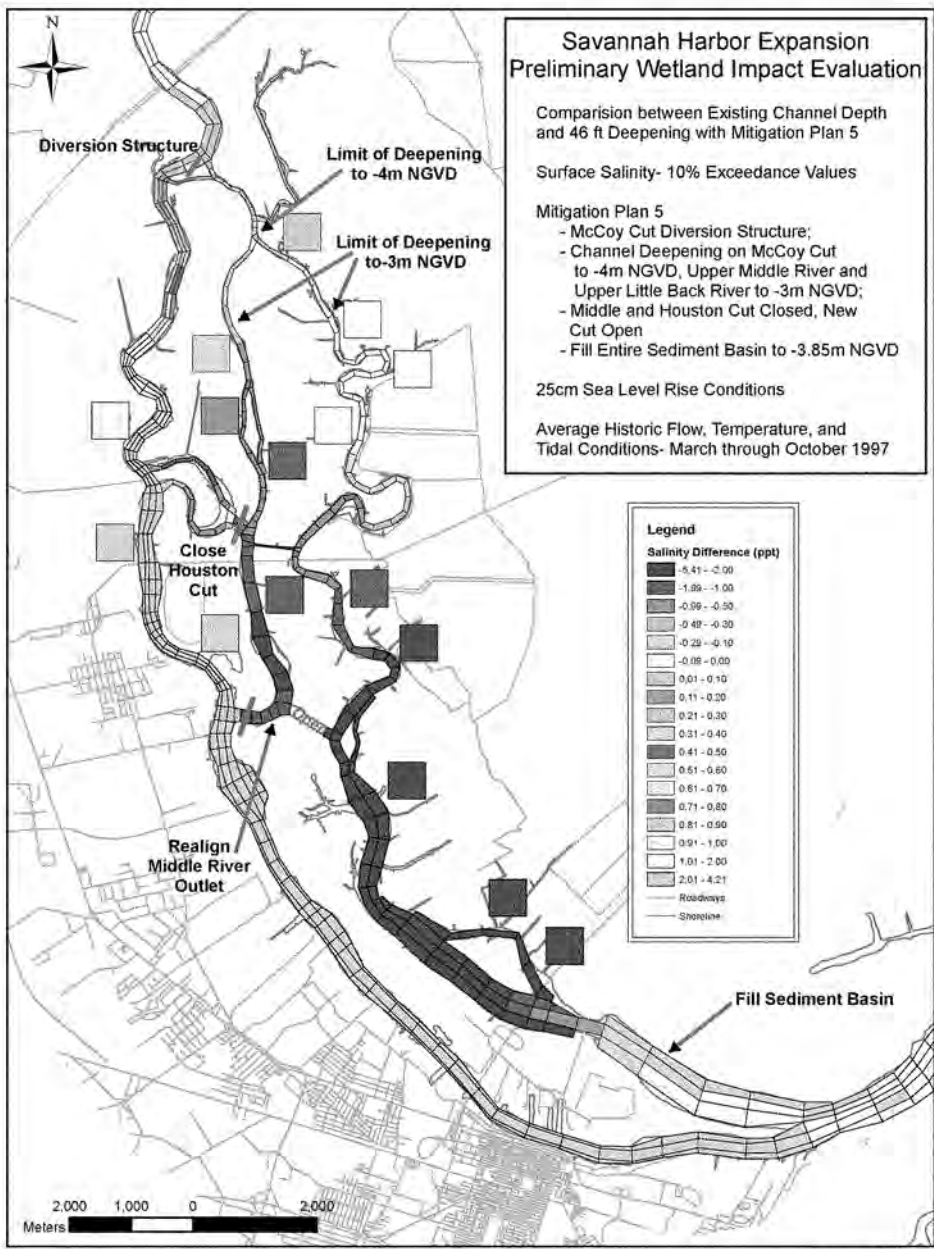


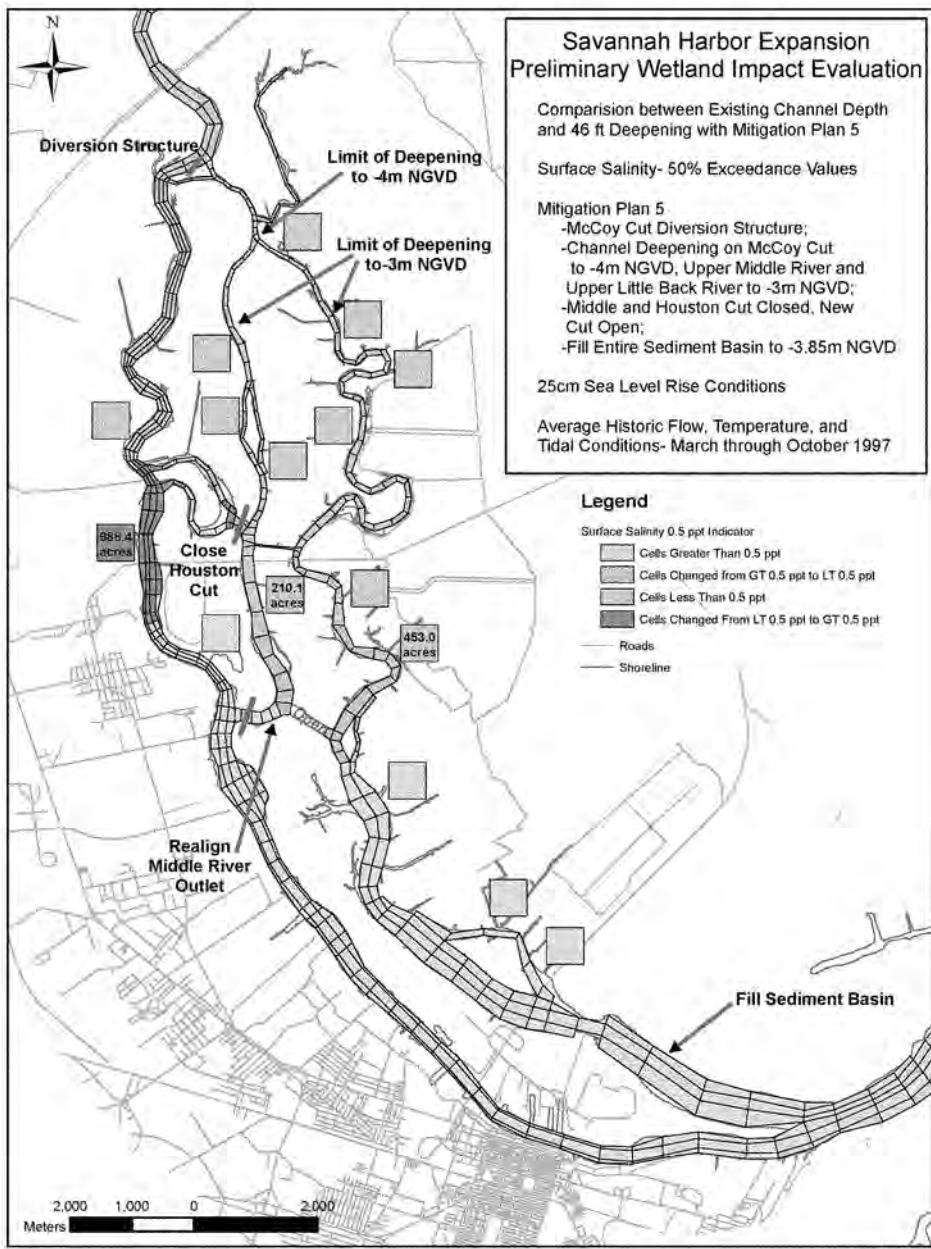


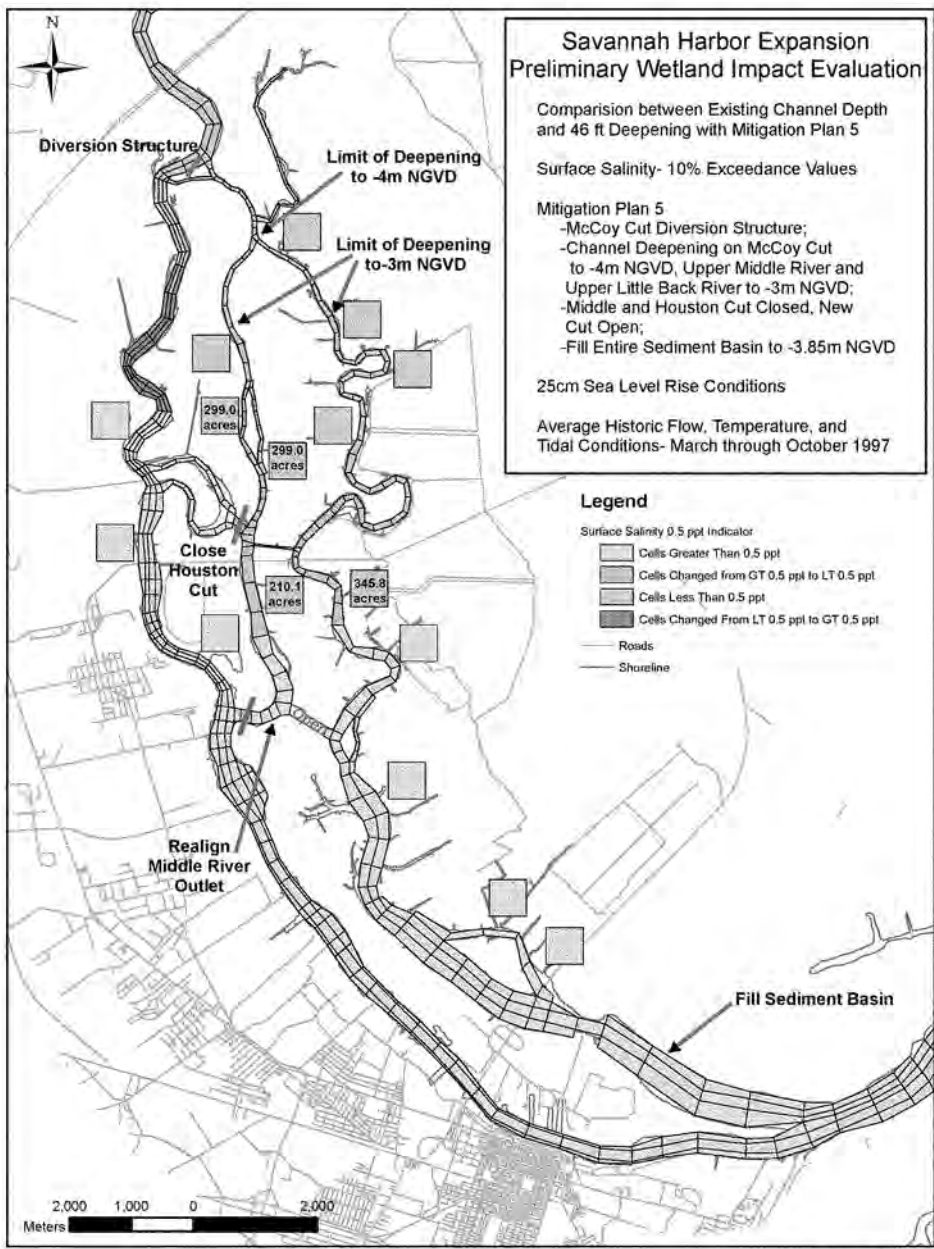


Sensitivity Analysis #2A

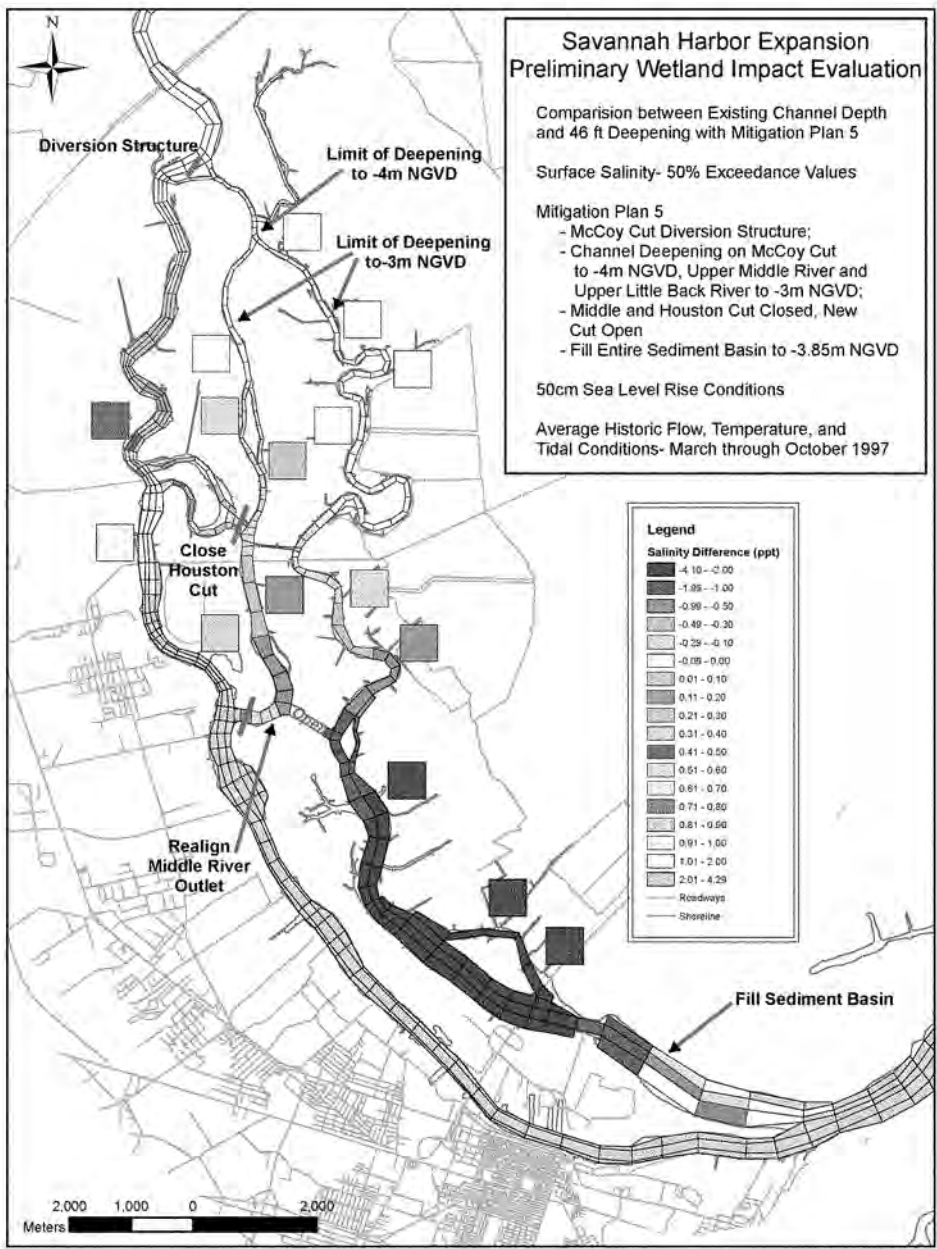


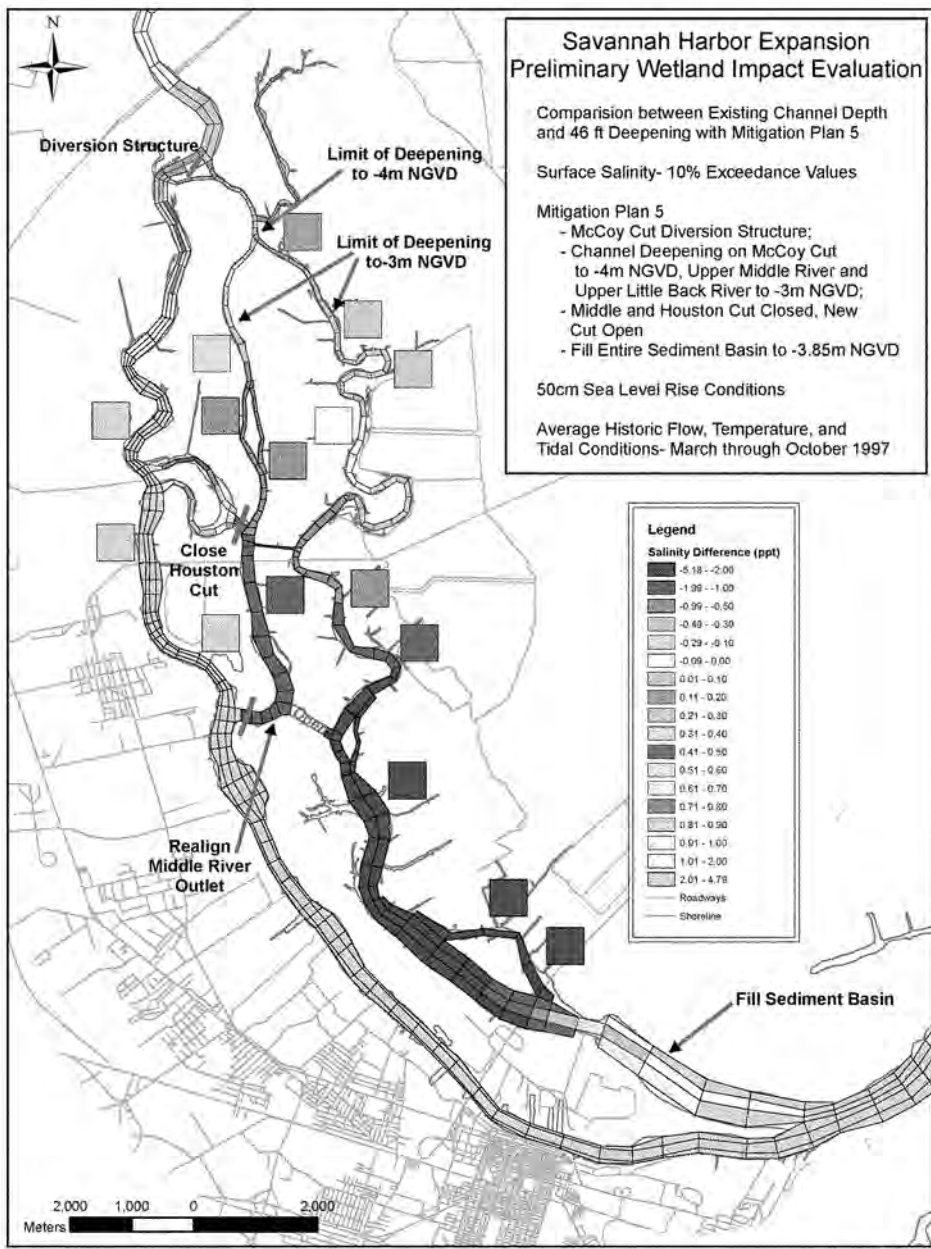


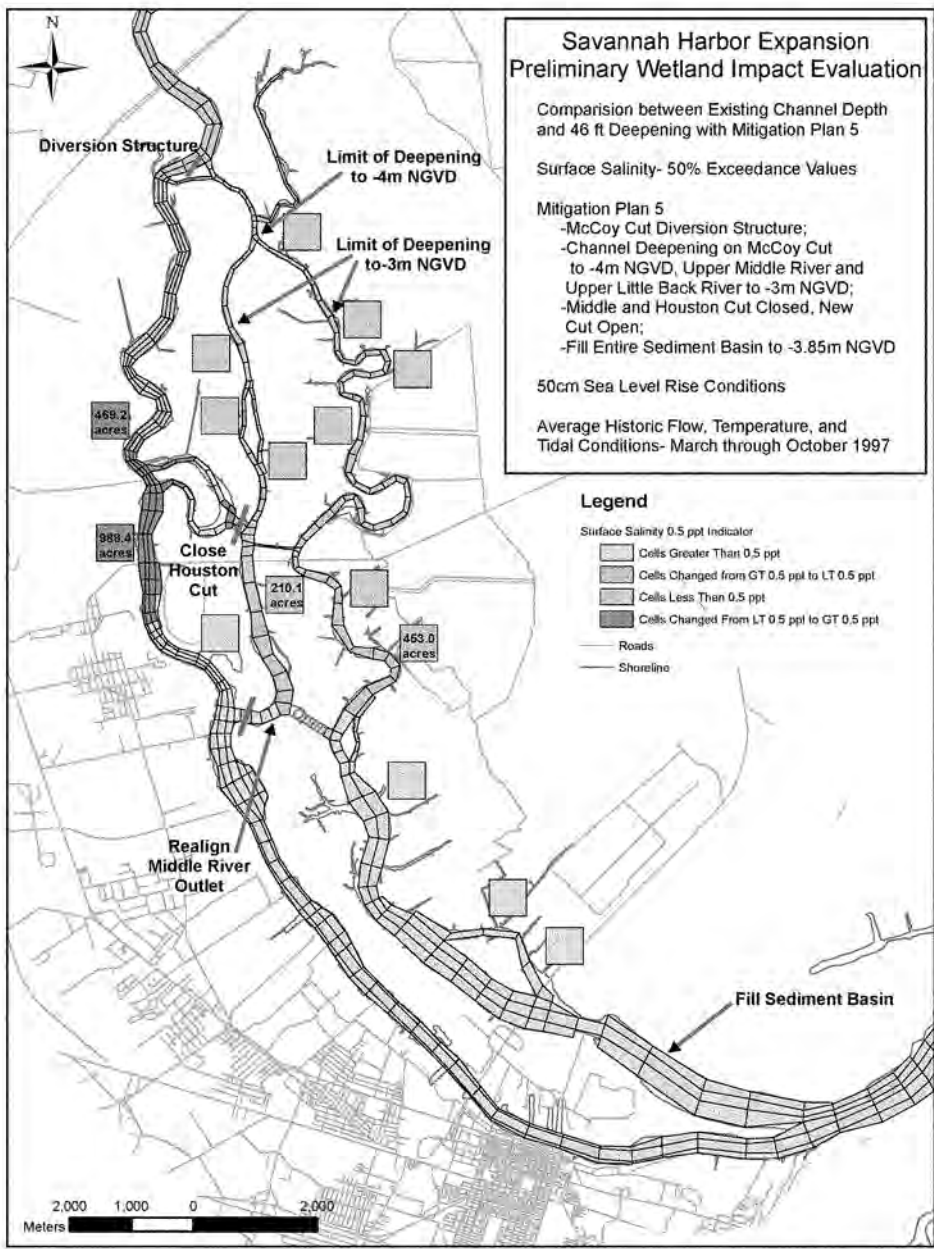


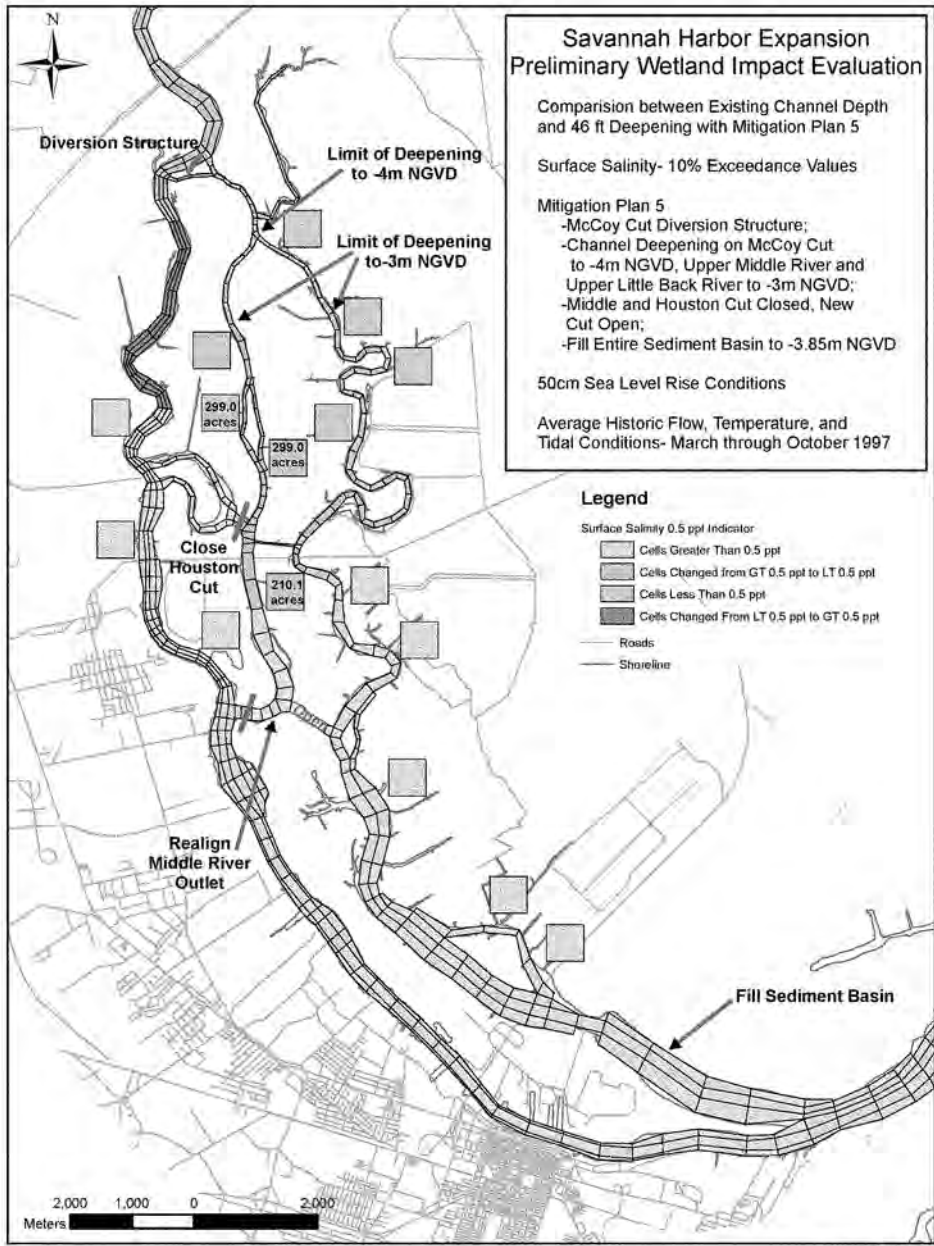


Sensitivity Analysis #2B



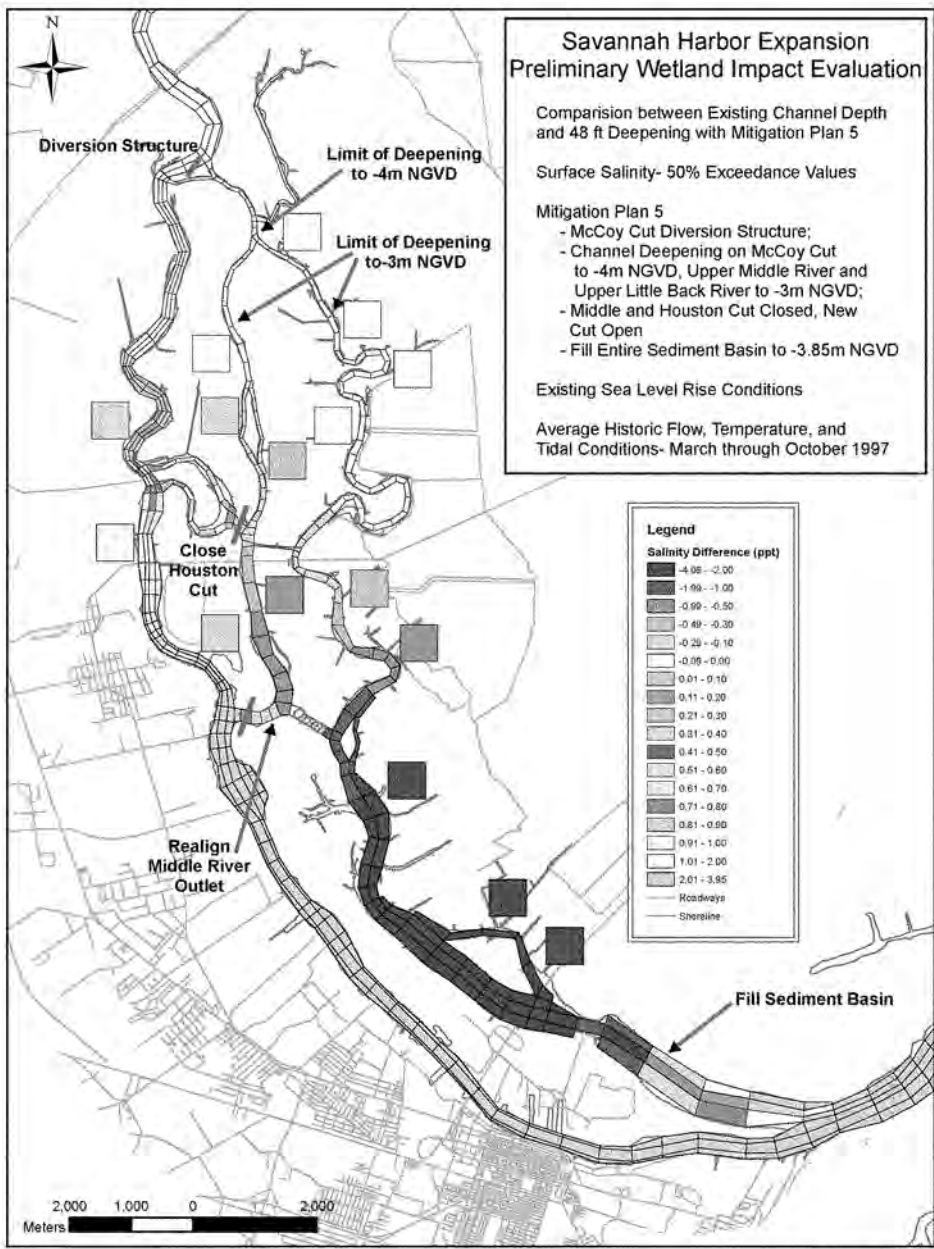


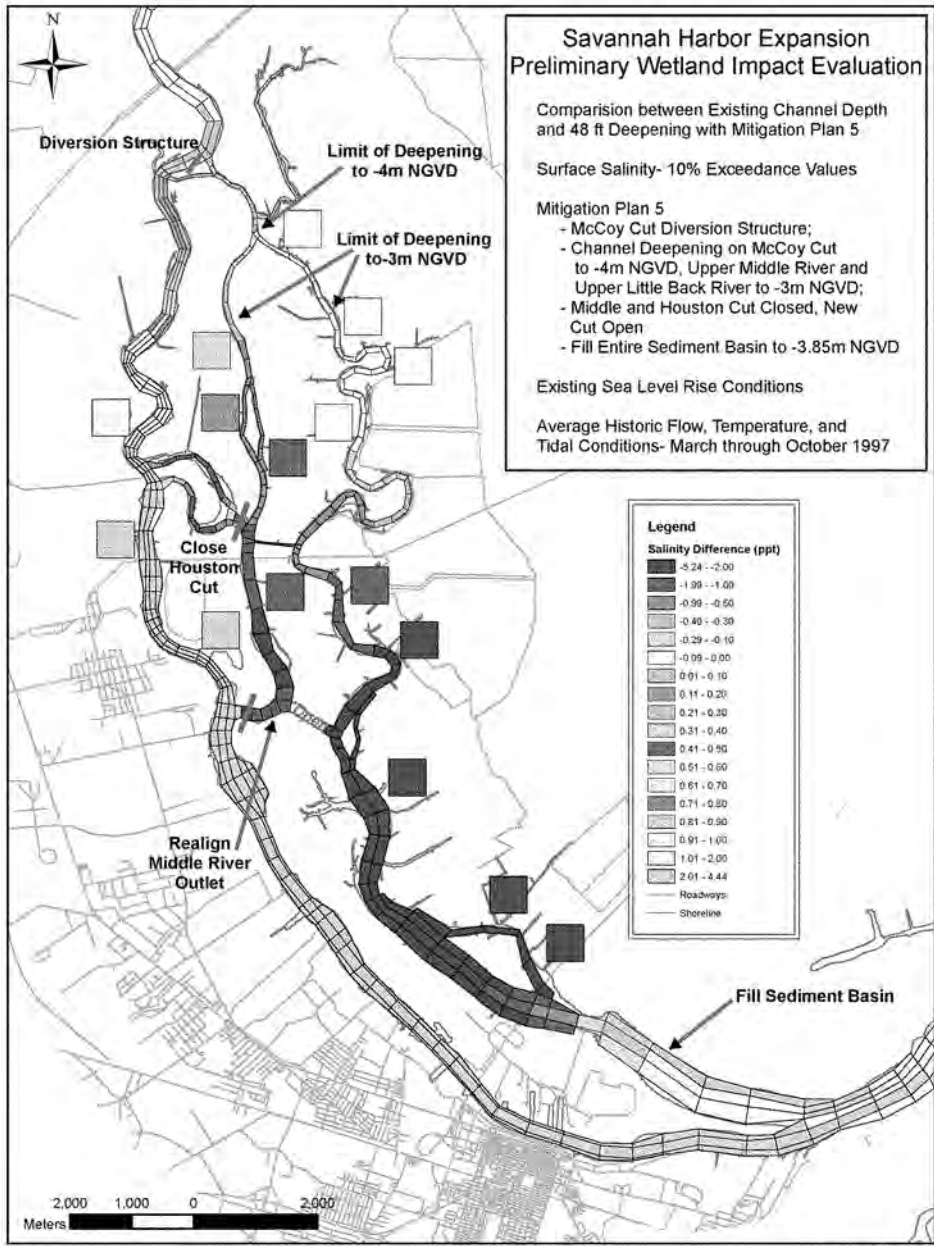


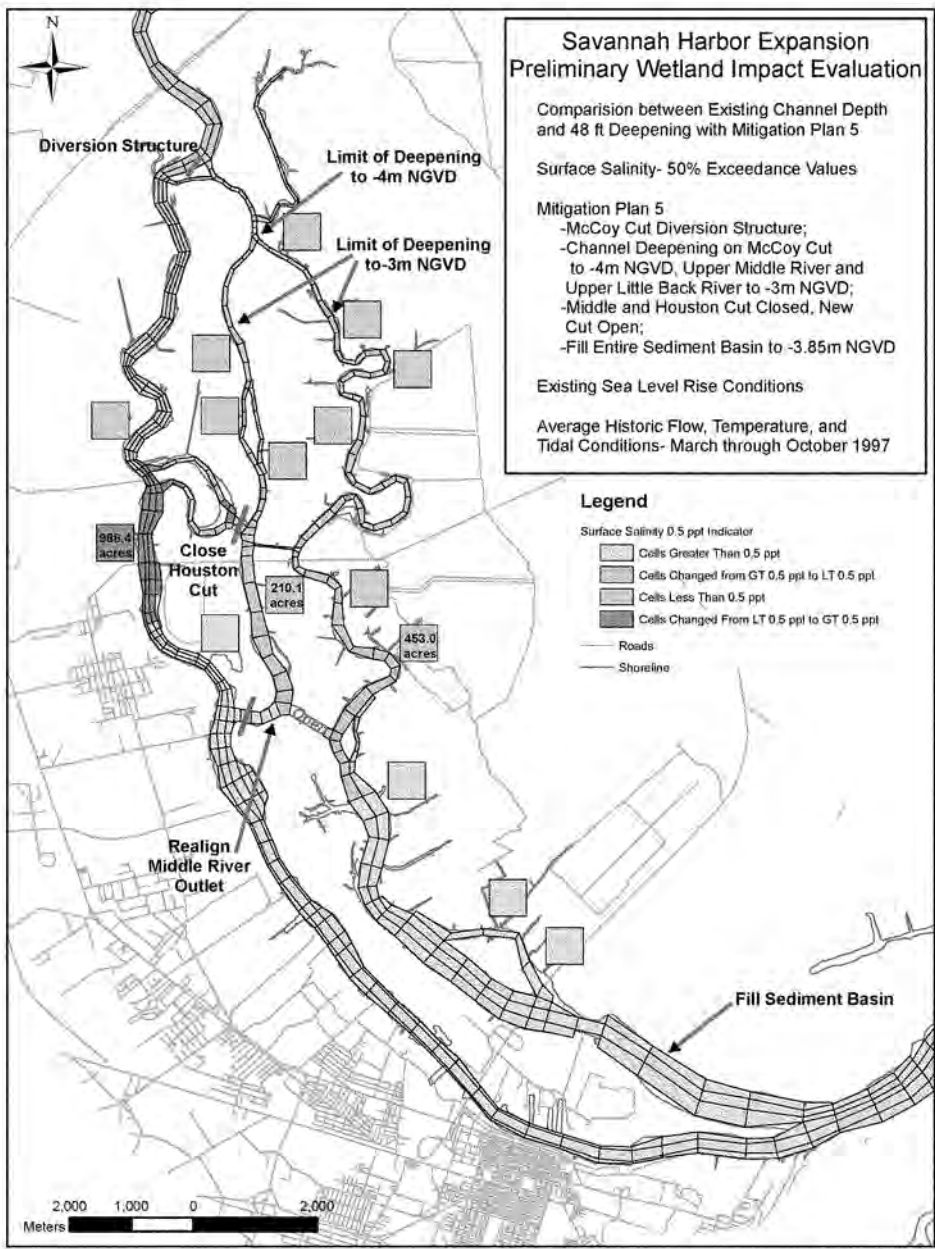


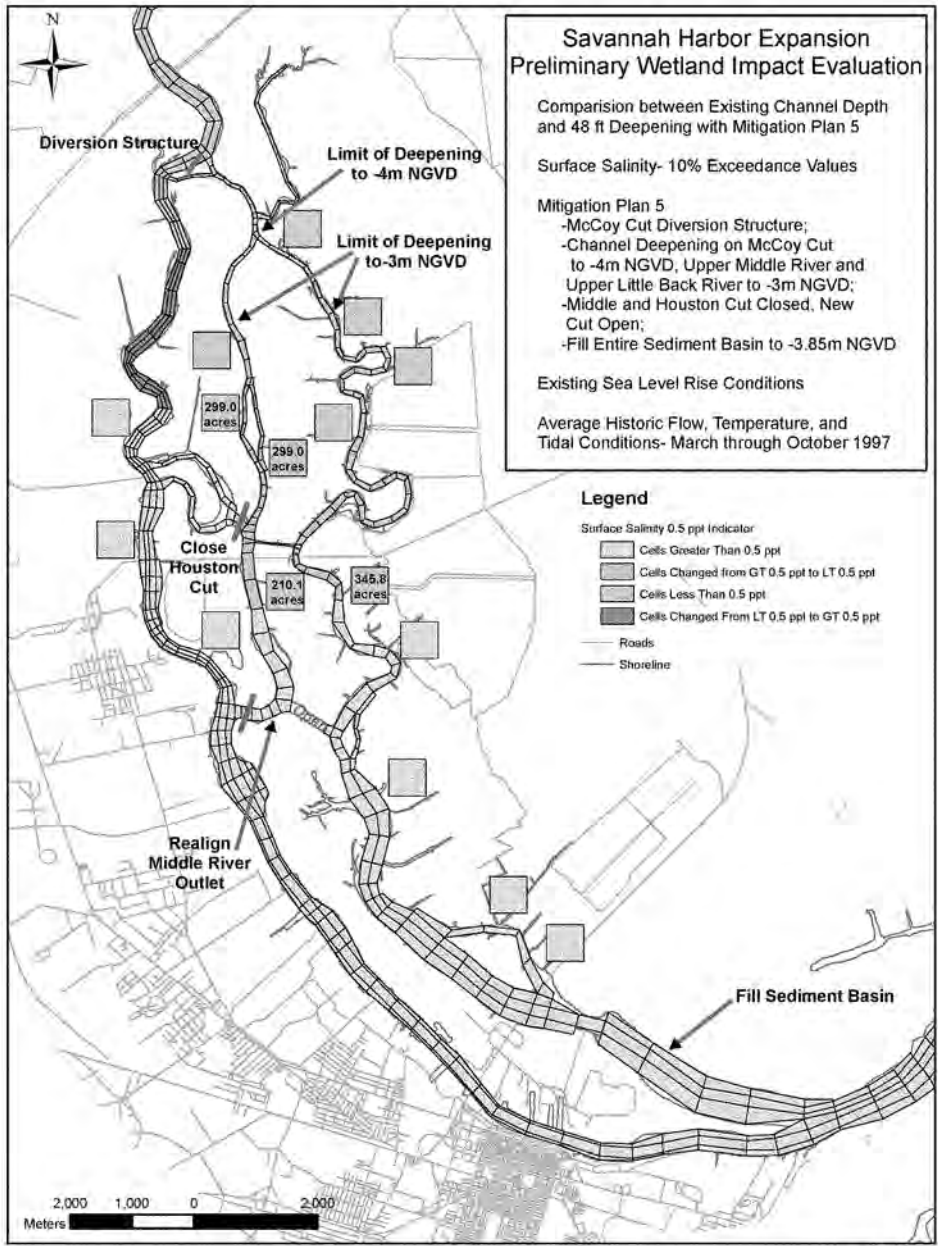
48-ft Deepening

Basic Evaluation

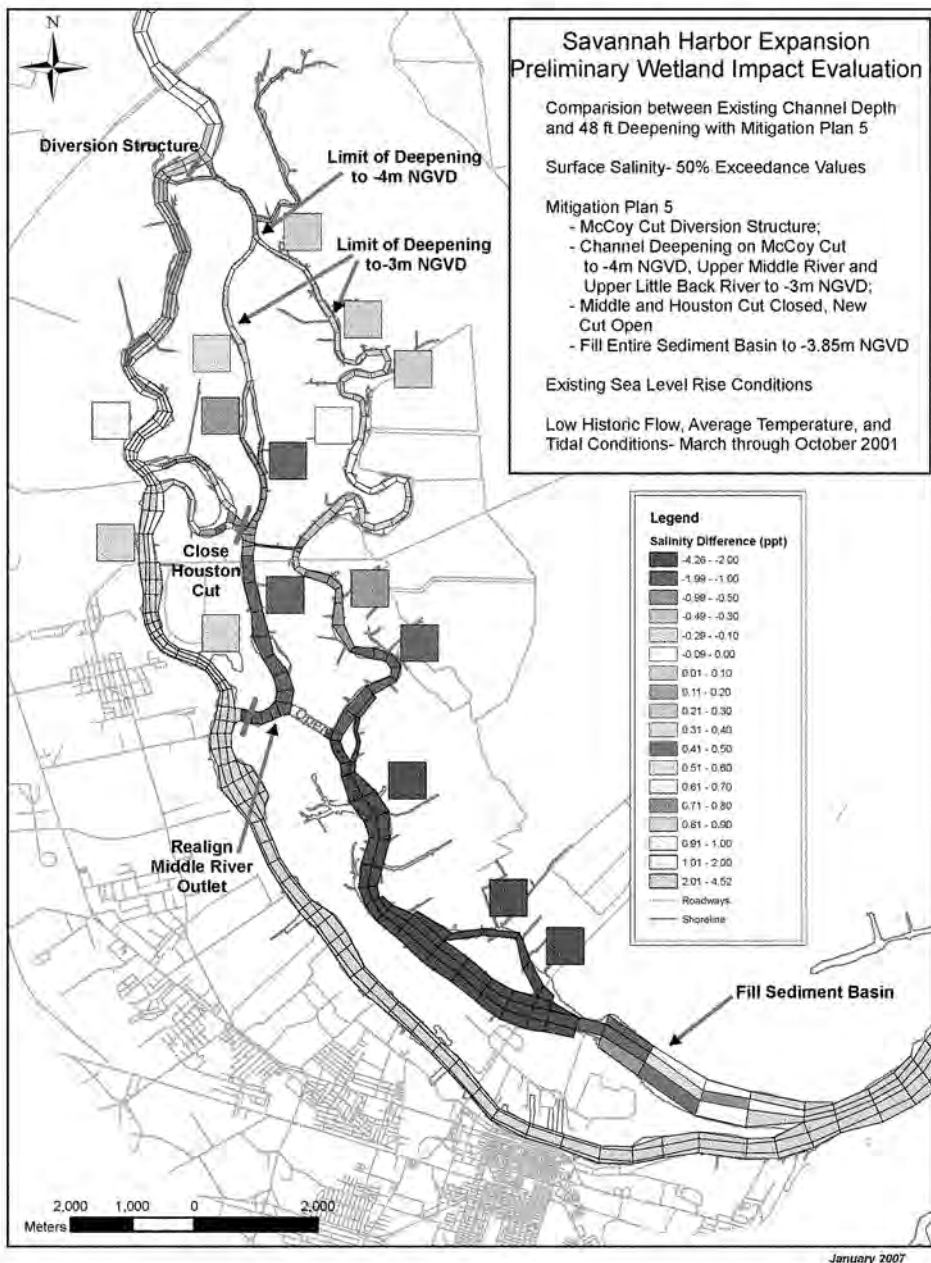


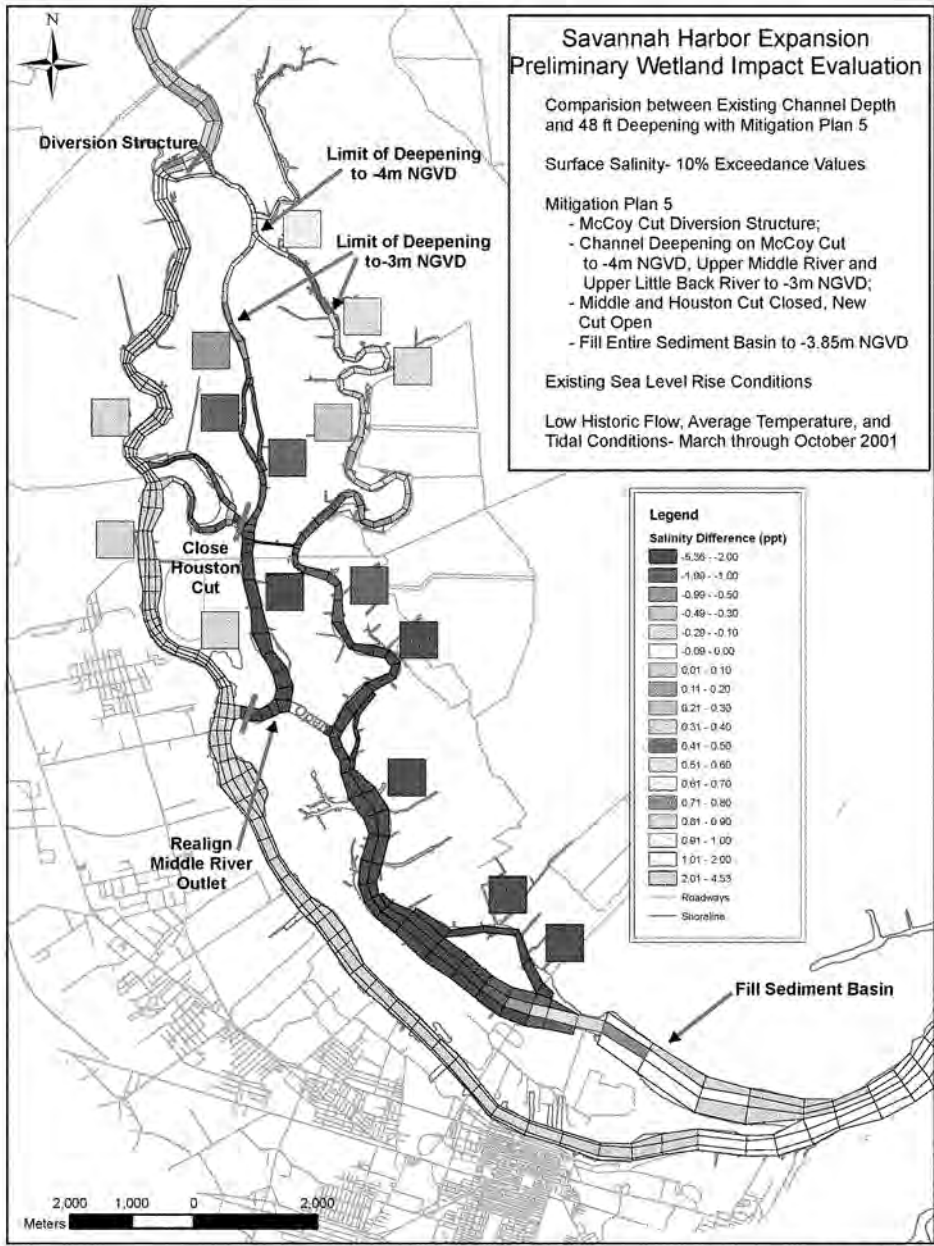


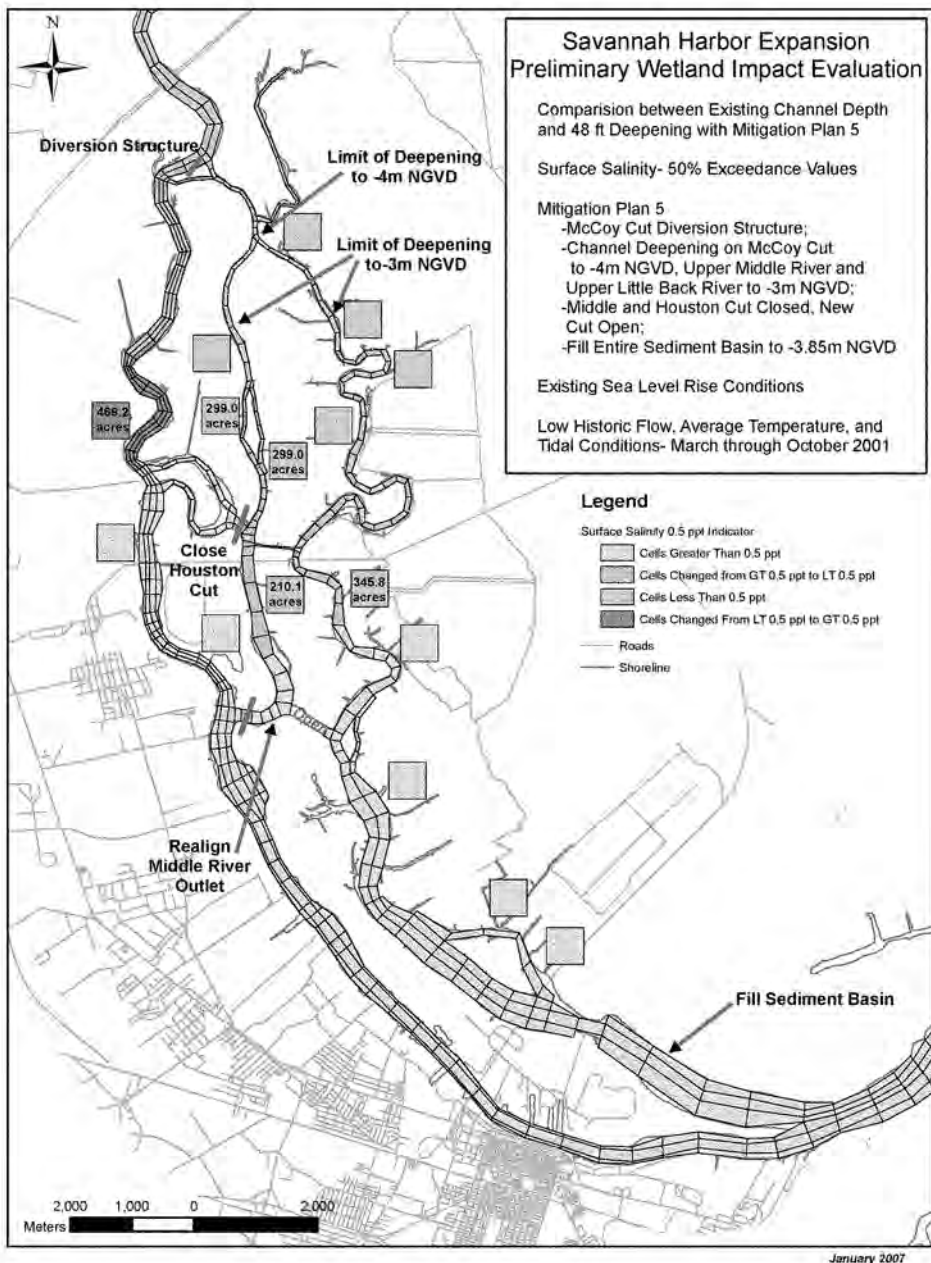


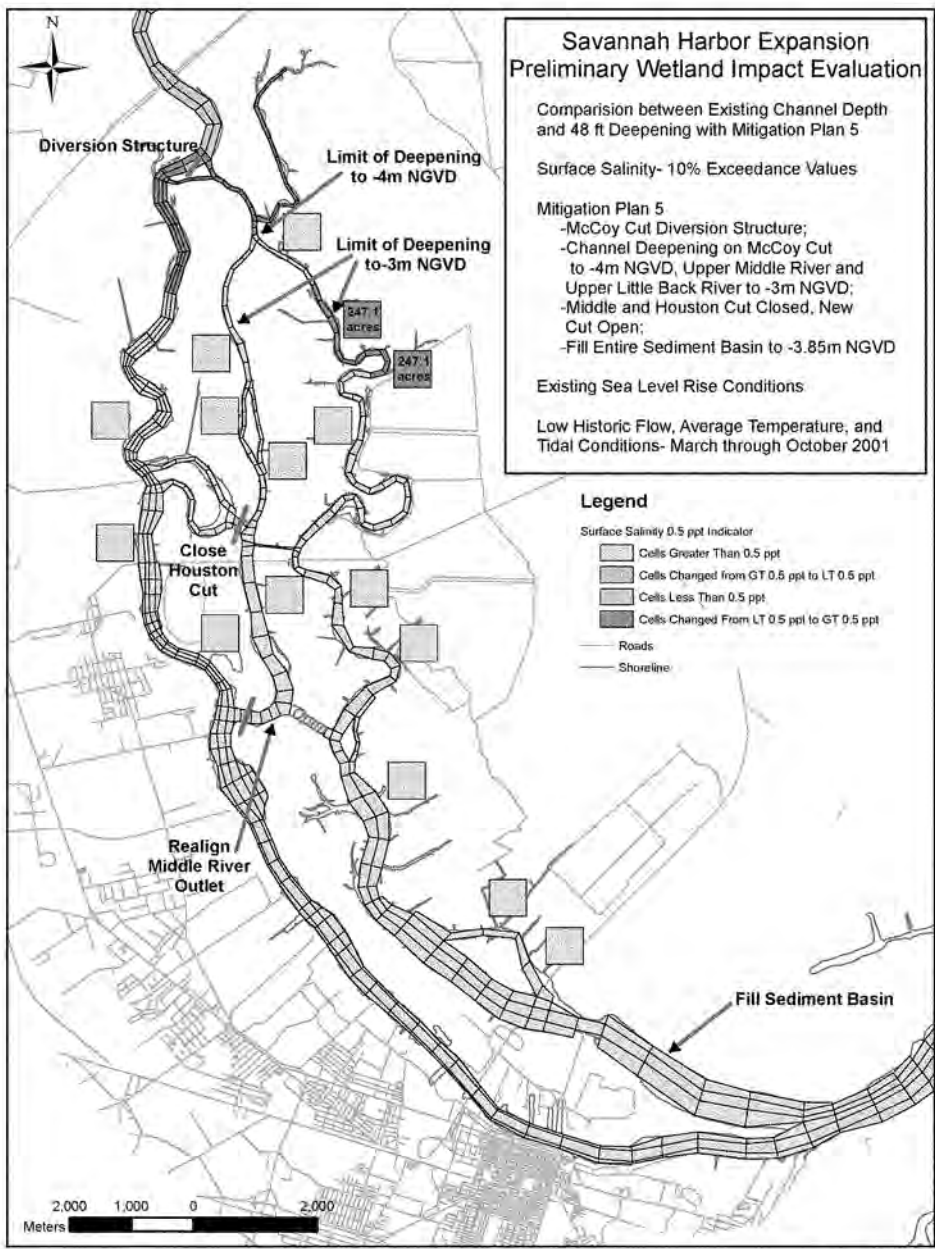


Sensitivity Analysis #1

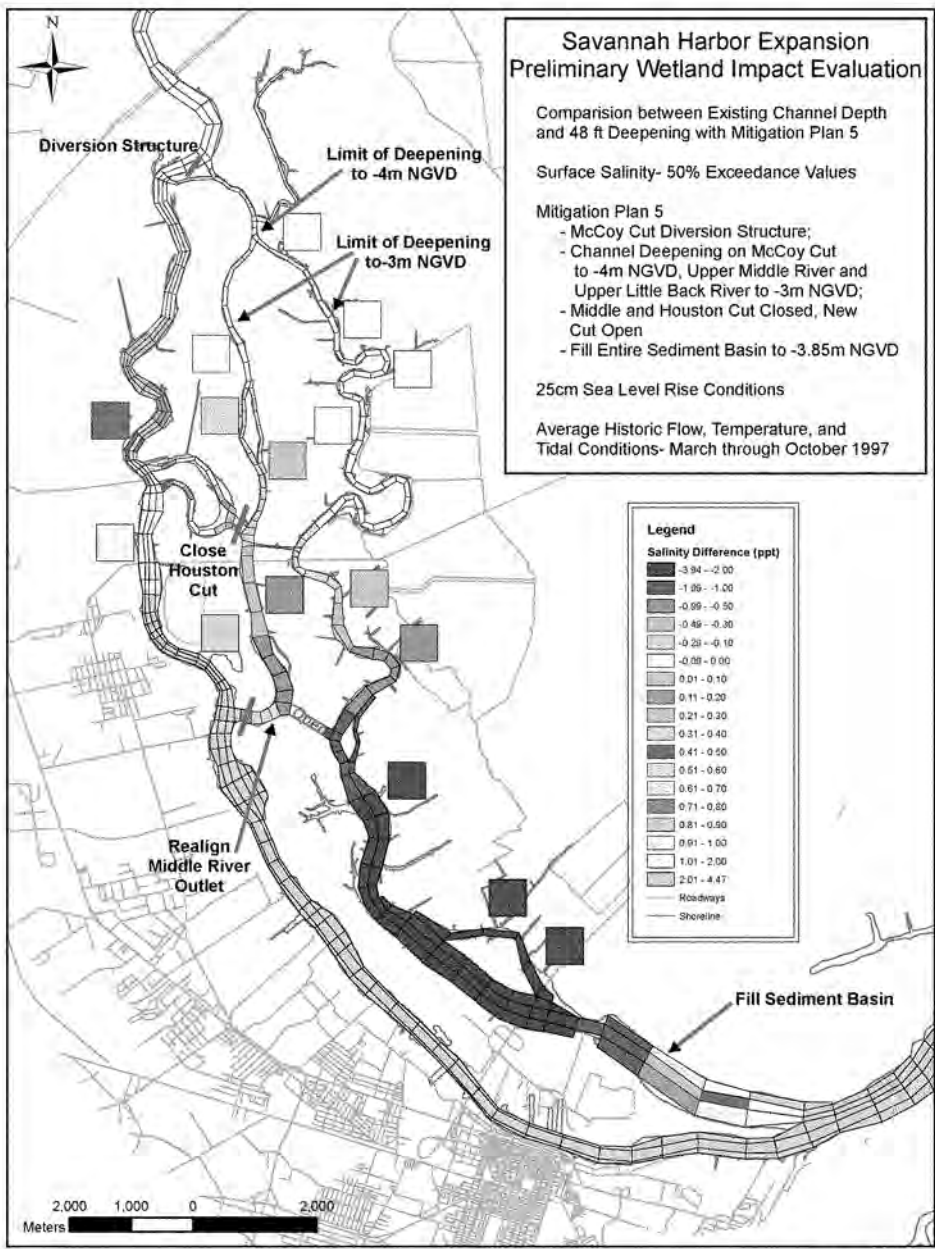


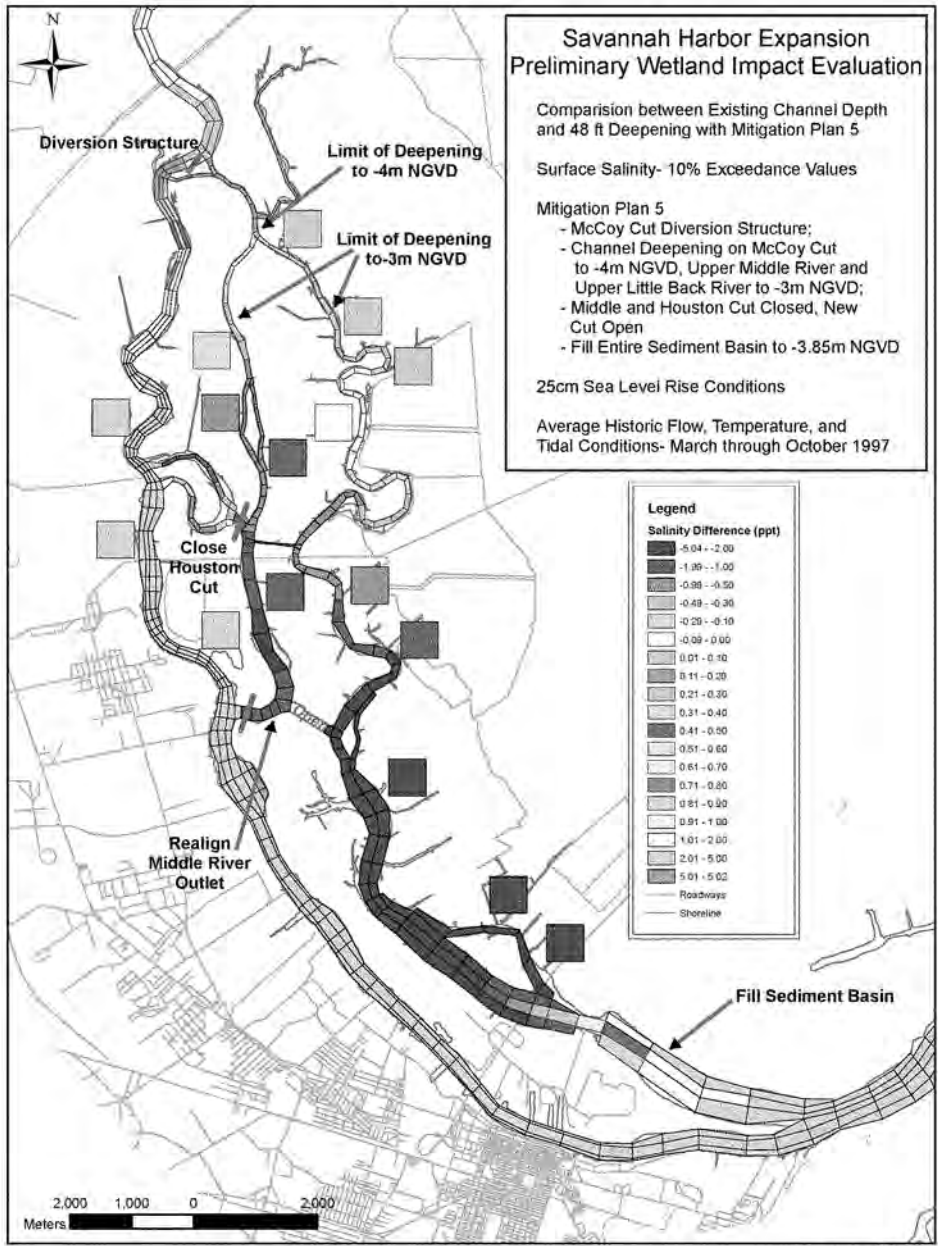


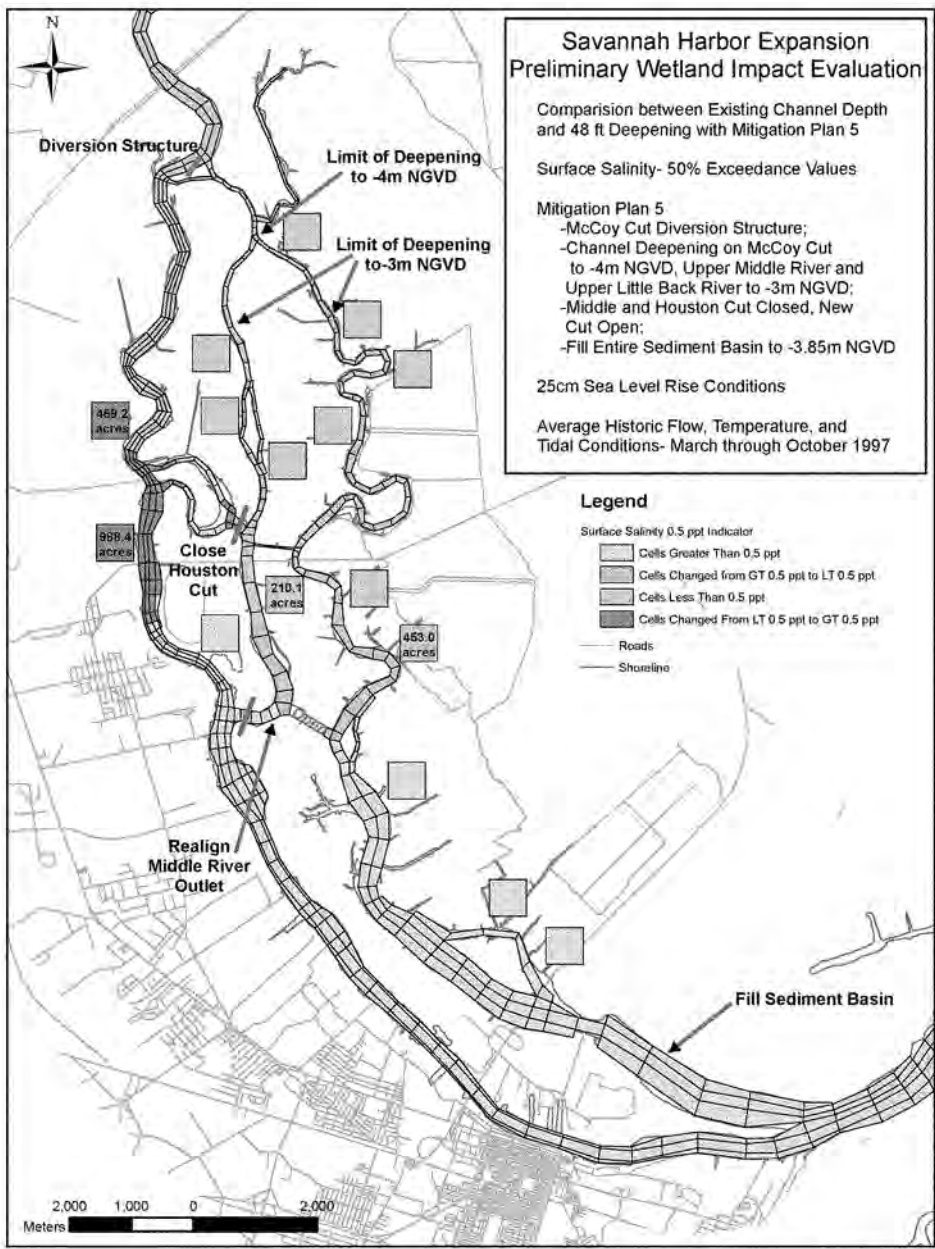


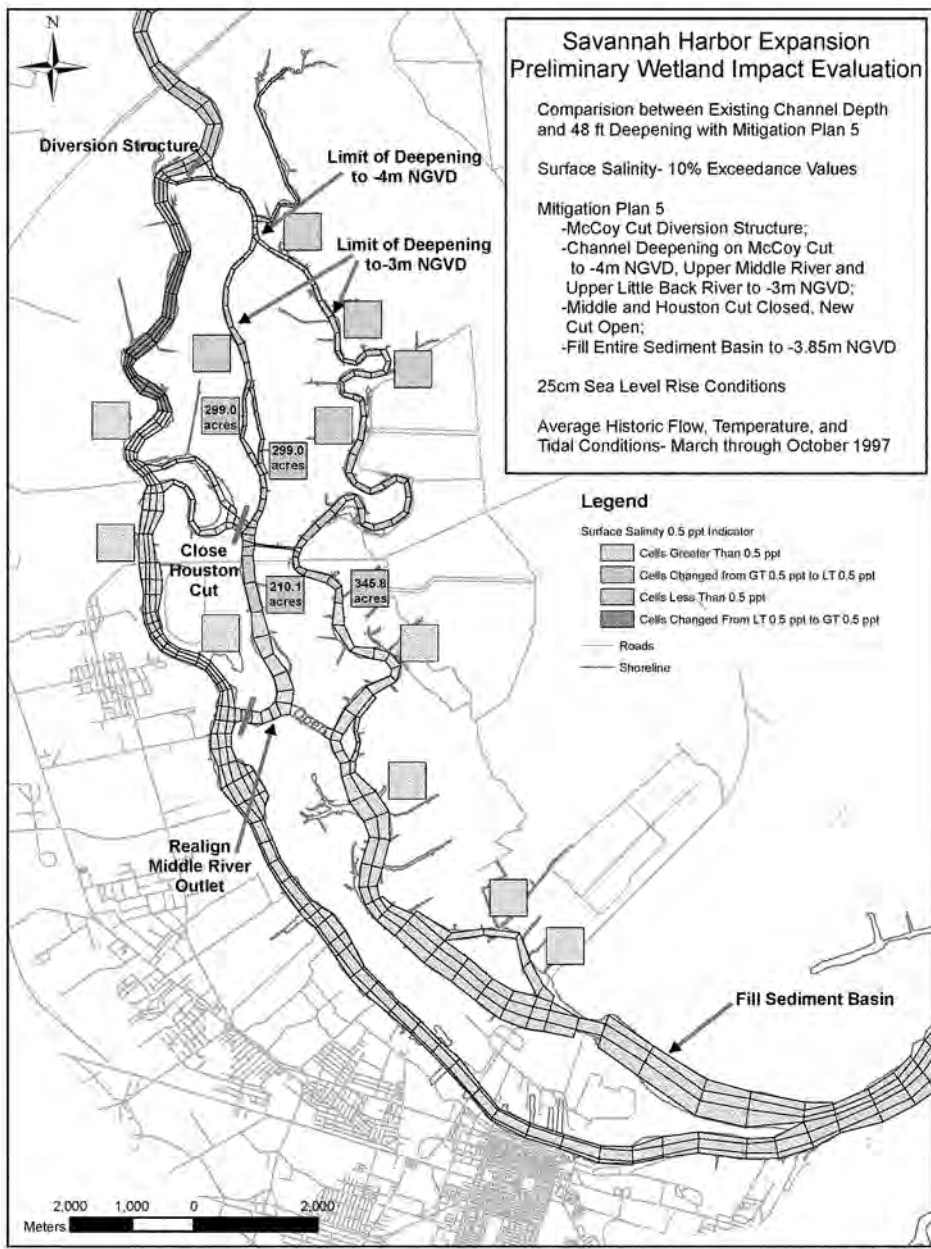


Sensitivity Analysis #2A

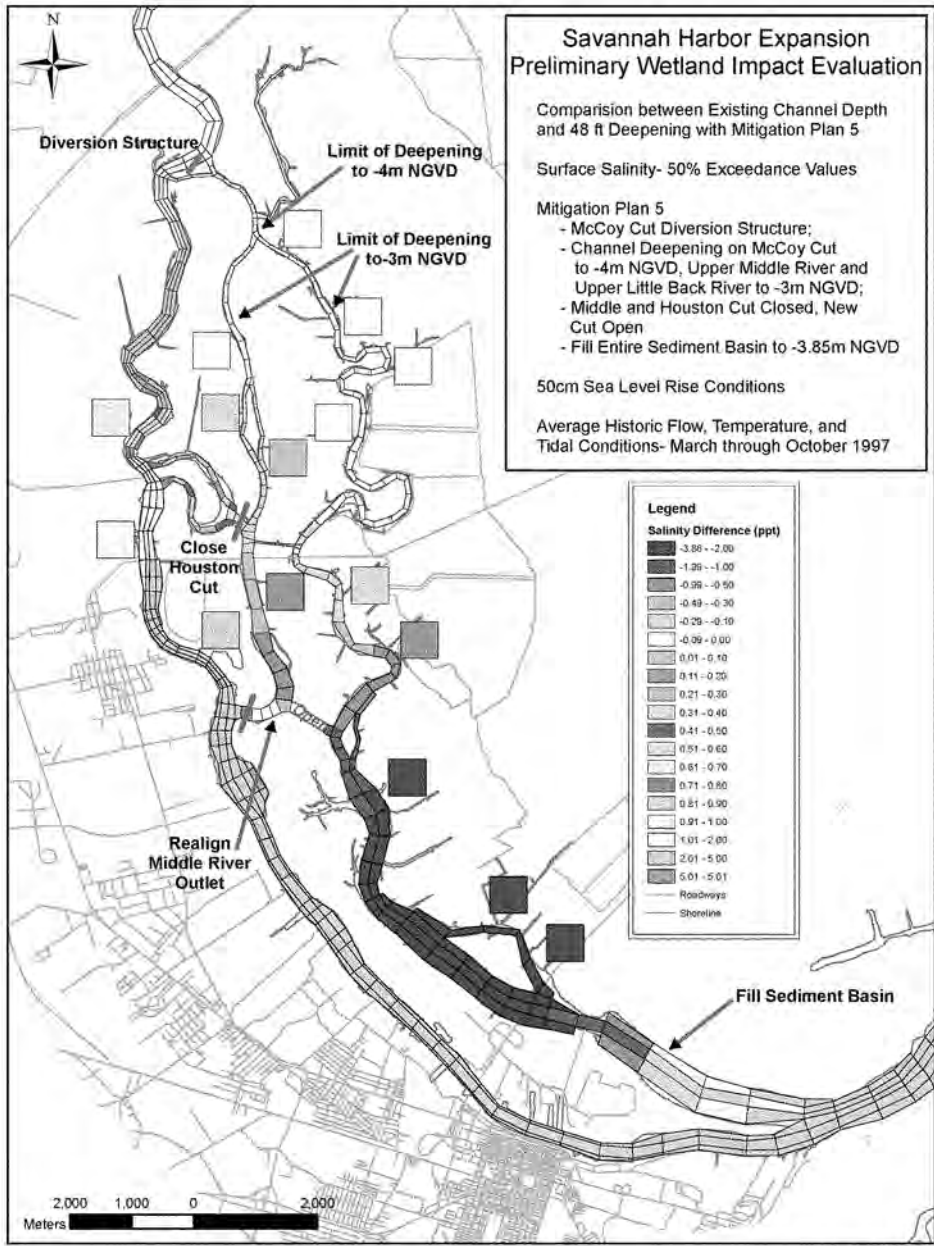


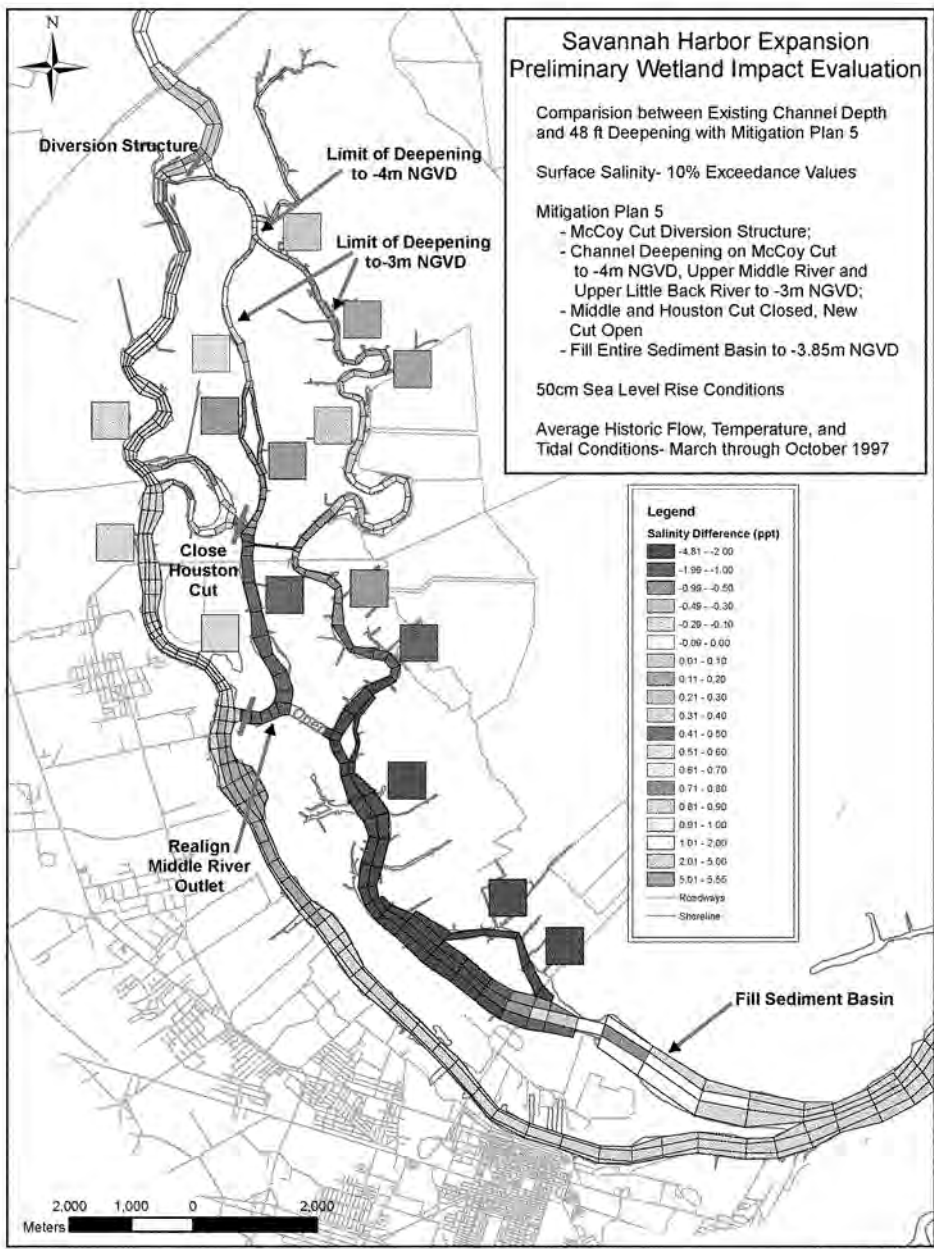


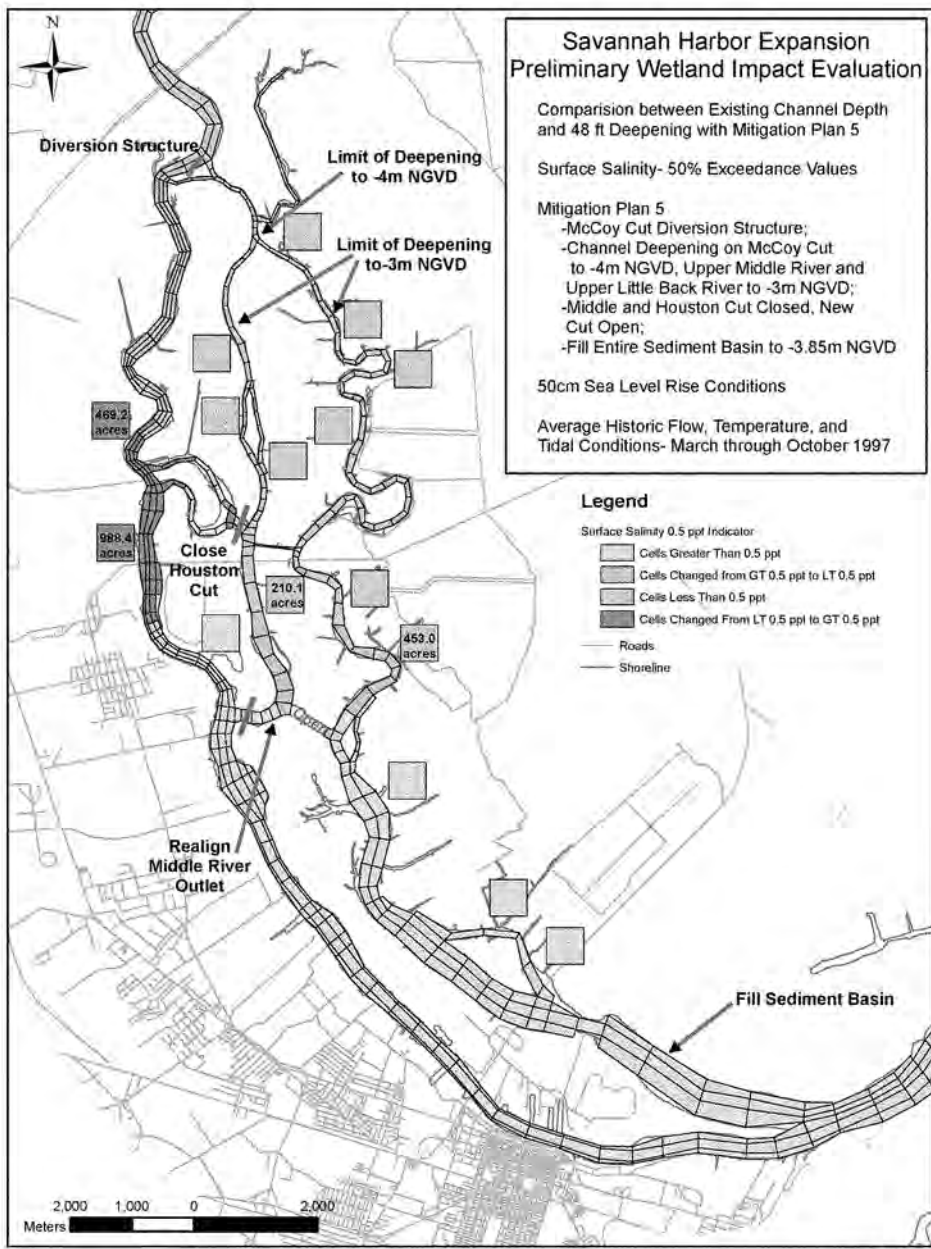


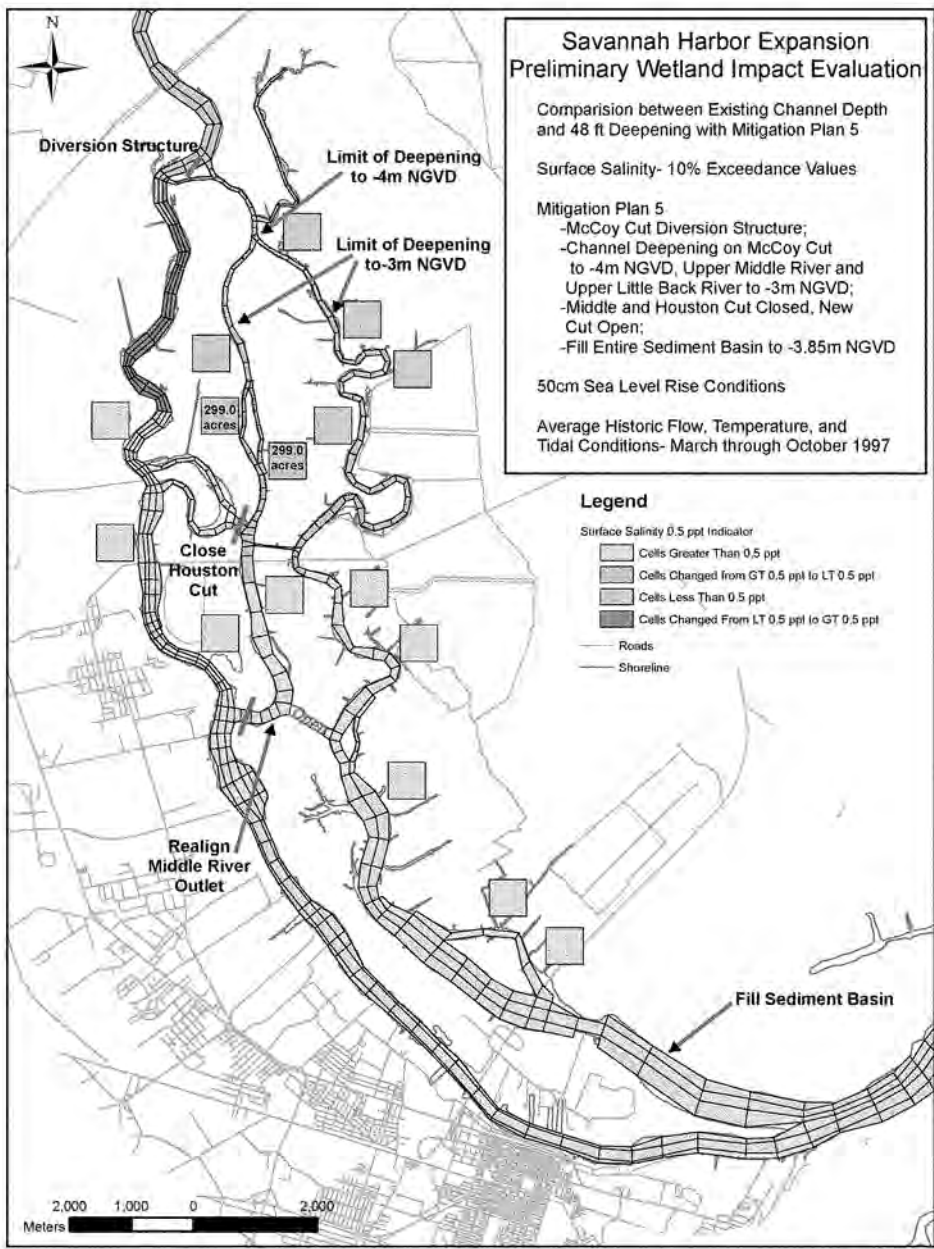


Sensitivity Analysis #2B











Savannah Harbor Expansion Project

Evaluation of Marsh/Wetland Impacts with Additional Mitigation Plans

August 2007

Introduction

This report summarizes the results of marsh impacts with implementation of mitigation alternatives and navigation channel deepening. Five additional mitigation alternatives are presented and have been evaluated under three possible navigation channel depths (48 ft, 46 ft, and 45 ft).

Each of the mitigation plans were evaluated using the 3D hydrodynamic model EFDC. The run period for each plan is March through October 1997. This time period is representative of average historic flow, temperature, and tidal conditions. The effects of sea level rise have *NOT* been evaluated in this report. The parameter evaluated is the 50 % exceedance surface salinity value throughout the model grid. The run period and parameters were specified by the Interagency Coordination Team.

Plan Description

Five additional mitigation plans were modeled to determine their effectiveness in reducing salinity impacts to freshwater marsh due to deepening the navigation channel. Mitigation Plans 1-5 were evaluated prior to the plans presented here. Evaluation of Plans 1-5 determined that Plan 3 showed the most potential at reducing impacts from harbor deepening. The additional mitigation plans presented here use Plan 3 as a basis for evaluation. Below is a brief description of Plan 3 and each of the five additional plans presented in this report. Also, on the following page is a graphic showing the features associated with each of the mitigation plans.

Plan 3 - <i>McCoys Cut Diversion Structure</i> - <i>Channel Deepening on McCoys, Upper Middle and Little Back River</i> - <i>Fill Entire Sediment Basin</i> - <i>Close Rifle Cut</i>	Plan 3c - <i>McCoys Cut Diversion Structure</i> - <i>Fill Entire Sediment Basin</i> - <i>Close Rifle Cut</i> - <i>Close Lower (western) Arm at McCoys Cut</i>
Plan 3a - <i>McCoys Cut Diversion Structure</i> - <i>Channel Deepening on McCoys, Upper Middle and Little Back River</i> - <i>Fill Entire Sediment Basin</i> - <i>Close Rifle Cut</i> - <i>Close Lower (western) Arm at McCoys Cut</i>	Plan 6 - <i>McCoys Cut Diversion Structure</i> - <i>Channel Deepening on McCoys, Upper Middle and Little Back River</i> - <i>Fill Entire Sediment Basin</i> - <i>Close Rifle Cut</i> - <i>Remove Tidegate Abutments and Piers</i>
Plan 3b - <i>McCoys Cut Diversion Structure</i> - <i>Fill Entire Sediment Basin</i> - <i>Close Rifle Cut</i>	Plan 6b - <i>McCoys Cut Diversion Structure</i> - <i>Fill Entire Sediment Basin to -3.85m NGVD</i> - <i>Close Rifle Cut</i> - <i>Remove Tidegate Abutments and Piers</i> - <i>Close Lower (western) Arm at McCoys Cut</i>

	McCoy Cut Diversion Structure	Channel Deepening on McCoy, Upper Middle and Little Back River	Fill Entire Sediment Basin	Close Rifle Cut	Close Lower (western) Arm at McCoy Cut	Remove Tidalgate Abutments and Piers	
Plan 3	x	x	x	x			Plan 3
Plan 3a	x	x	x	x	x		Plan 3a
Plan 3b	x		x	x			Plan 3b
Plan 3c	x		x	x	x		Plan 3c
Plan 6	x	x	x	x		x	Plan 6
Plan 6b	x		x	x	x	x	Plan 6b

Output Presented

There are three types of maps presented in this report:

- 1- **Predicted River Salinity from the Hydrodynamic Model (EFDC)-** The EFDC model grid is shown with 50% exceedance surface salinities broken into 5 categories: 0-0.5 ppt, 0.6-1.0 ppt, 1.1-2.0 ppt, 2.1-4.0 ppt, 4.0-32.5 ppt. Modeling is based on average historic flow, temperature, and tidal conditions- March through October 1997. The effects of sea level rise have NOT been evaluated in this report.
- 2- **Estimated Marsh Salinity Contour Lines-** Marsh salinity contour lines are shown that break the marsh into 5 categories: 0-0.5 ppt, 0.6-1.0 ppt, 1.1-2.0 ppt, 2.1-4.0 ppt, > 4.0 ppt. The first category 0-0.5 ppt represents freshwater marsh. The contour lines were extrapolated into the marsh from the riverine hydrodynamic model results shown in the maps described above 1- *Predicted River Salinity from the Hydrodynamic Model*.

Because of the subjectivity of developing the contour lines for this set of maps, two measures were taken to ensure the results are valid. First, all of the maps were developed by the same person to eliminate bias due to the possibility of different perspectives. Second, verification was done to determine a level of confidence in comparing the results. The verification was done by testing the repeatability of drawing the contour line for the freshwater zone (0-0.5 ppt) for three randomly selected maps. For the repeatability test, first the same person redrew the freshwater zone. Second a different person redrew the freshwater zone. Both of these tests produced acreages with less than a 2% difference from the original acreages. From this test, the results are considered valid within +/- 50 acres.

- 3- **Surface Salinity Difference Maps-** Maps show the change in riverine salinity at each EFDC grid cell between the existing condition and each mitigation plan. Salinity values are predicted using the hydrodynamic model (EFDC). The grid cells are color coded to show the salinity differences. The grey shading is used to show cells that have lower salinity values than the existing condition (i.e. deepening impacts have been reduced to 0, and, in fact, show improvement over the existing condition).

Results

Results from the modeling are presented in the following two tables. The two tables show estimated marsh salinity impacts based on the mapping described in **2-Estimated Marsh Salinity Contour Lines** above. The contour line verification described in the previous section suggests the acreages are valid within +/- 50 acres.

Table 1- Estimated Marsh Salinity Impacts- Plans 3, 3a, 3b and 3c

48 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 3a (acres)	Plan 3b (acres)	Plan 3c (acres)
0.0 – 0.5	4072	2860	3584	3531	3406	3383
0.6 – 1.0	864	830	766	949	871	784
1.1 – 2.0	555	1215	1587	1489	1221	1368
2.1 – 4.0	834	739	682	673	938	892
> 4	2506	3188	2213	2190	2396	2405

46 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 3a (acres)	Plan 3b (acres)	Plan 3c (acres)
0.0 – 0.5	4072	3015	3753	3840	3521	3599
0.6 – 1.0	864	1050	1298	1535	1195	1070
1.1 – 2.0	555	921	991	892	952	1066
2.1 – 4.0	834	789	616	774	860	762
> 4	2506	3057	2174	1790	2304	2335

45 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 3a (acres)	Plan 3b (acres)	Plan 3c (acres)
0.0 – 0.5	4072	3105	3718	3798	3572	3626
0.6 – 1.0	864	1319	1827	1733	1368	1347
1.1 – 2.0	555	630	732	726	816	783
2.1 – 4.0	834	906	763	780	855	856
> 4	2506	2873	1792	1794	2221	2219

Table 2- Estimated Marsh Salinity Impacts- Plans 3, 6 and 6b**48 ft Depth**

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 6 (acres)	Plan 6b (acres)
0.0 – 0.5	4072	2860	3584	3715	3610
0.6 – 1.0	864	830	766	1419	885
1.1 – 2.0	555	1215	1587	1141	1384
2.1 – 4.0	834	739	682	793	770
> 4	2506	3188	2213	1764	2183

46 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 6 (acres)	Plan 6b (acres)
0.0 – 0.5	4072	3015	3753	3817	3610
0.6 – 1.0	864	1050	1298	1677	1512
1.1 – 2.0	555	921	991	893	891
2.1 – 4.0	834	789	616	703	642
> 4	2506	3057	2174	1743	2177

45 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 6 (acres)	Plan 6b (acres)
0.0 – 0.5	4072	3105	3718	4038	3865
0.6 – 1.0	864	1319	1827	1835	1459
1.1 – 2.0	555	630	732	559	774
2.1 – 4.0	834	906	763	712	589
> 4	2506	2873	1792	1689	2145

Summary

In viewing and discussing the results of the mitigation plans it is important to remember the following:

- 1- The marsh impacts are evaluated by looking at the *net* acreage. This is especially important when discussing the impacts to freshwater marshes. The net acreage value is based on the conditions of the marsh after the project is in place. It does not take into consideration what the marsh salinity is under current conditions. For example, a mitigation plan may gain freshwater marsh on Back River and lose freshwater marsh on Front River. The net acreage may meet the impact criteria, but in reality, it may take some time for a marsh to convert from a brackish marsh to a freshwater marsh.
- 2- The model has a limited ability to evaluate specific design parameters of a true diversion structure. The diversion structure described in each of the plans was modeled by altering the Front River width just downstream of McCoys Cut. By narrowing the passage on Front River the water surface elevation at the mouth of McCoys Cut was increased. The rise in elevation encourages more water to go down McCoys Cut. EFDC does not have options for inserting a defined diversion structure but narrowing the River channel in this area is essentially what a diversion structure will do.

Several different "sizes" of diversion structures were evaluated during the development of the mitigation plans by varying the widths of the narrow passage on Front River. This allowed us to vary the amount of flow diverted down McCoys Cut. The structure modeled in Mitigation Plan 3, and each of the additional plans in this report, was found to be the most effective at diverting freshwater

flows through McCoys Cut of the several different "sizes" evaluated. A future design task will be required to develop specifications for a diversion structure that performs as in the model simulation.

The evaluation of each of the mitigation plans included review of the effects the plan has on the tide range and velocities. It was concluded that each of the additional plans do not reduce the tide range significantly in Back River, Little Back River, or Middle River. Velocities for all the additional plans are close to existing conditions. However, as expected, removing the abutments and piers in Plans 6 and 6b do increase velocities in Back River and Little Back River slightly above the existing condition.

Plan 3a

The results for Plan 3a are very similar to Plan 3. Little value to reducing salinity impacts seem to be added with the additional mitigation feature of closing the lower arm at McCoys Cut, although it does provide modest gains for some depths. Despite the limited mitigation potential for freshwater marshes, this feature does have the potential to provide fish habitat benefits and should be evaluated in that model framework. Another possible benefit to closing the lower arm at McCoys Cut is that it could provide a cost savings to the dredged material disposal cost for deepening McCoys Cut and the upper portions of Middle and Little Back Rivers by providing a nearby disposal area. Also,

Plan 3b

Plan 3b appears to have less benefits compared to Plan 3. Deepening the upper reaches of McCoys Cut, Middle River and Little Back River are critical in allowing more freshwater to flow down the Back River system.

Plan 3c

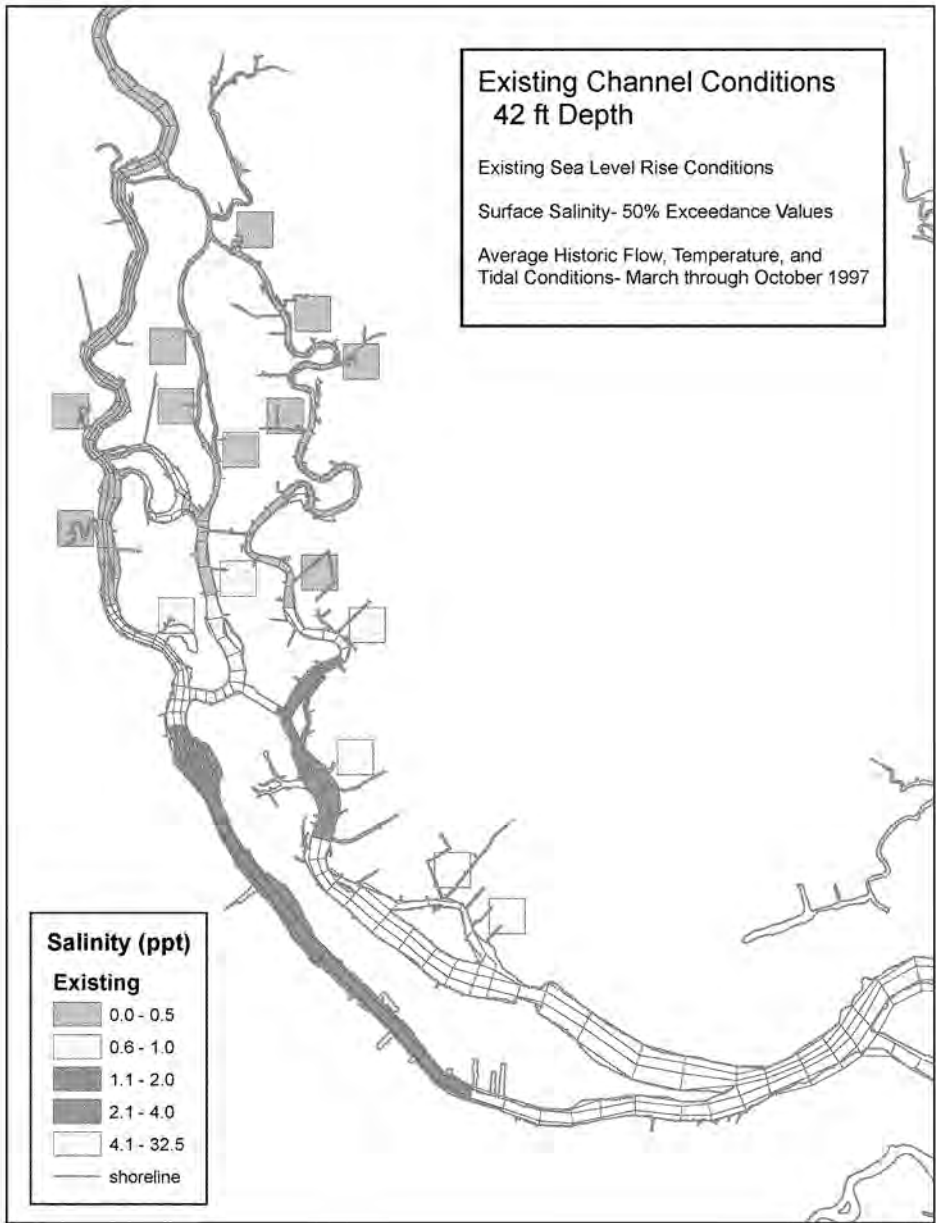
Plan 3c combines the two additional features of Plan a and b. The combination plan does not appear to have reduced salinity impacts greater than that of Plan 3 without the two additional features. These two combinations seem to add little value in reducing salinity impacts along the freshwater reaches of Front, Middle, Back and Little Back Rivers.

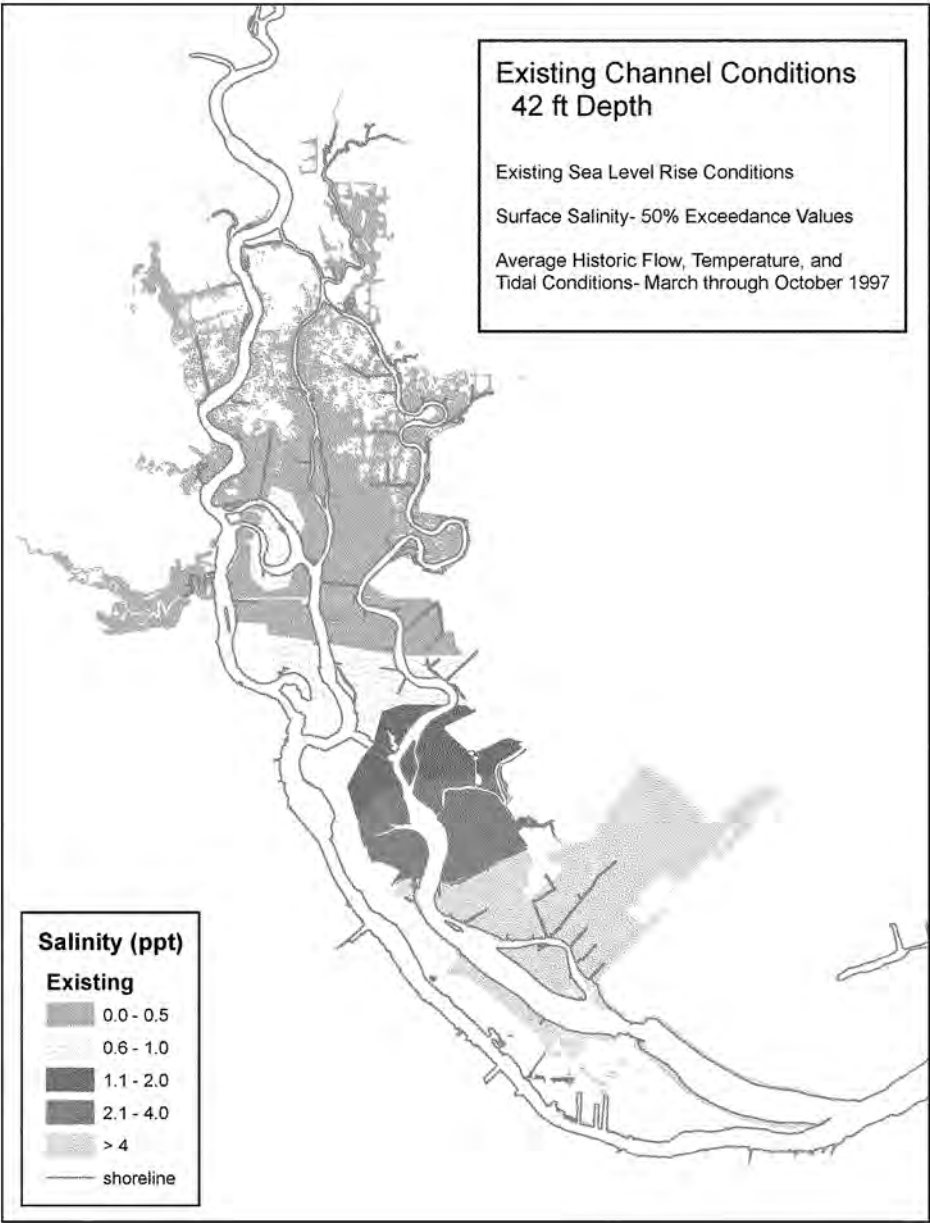
Plan 6

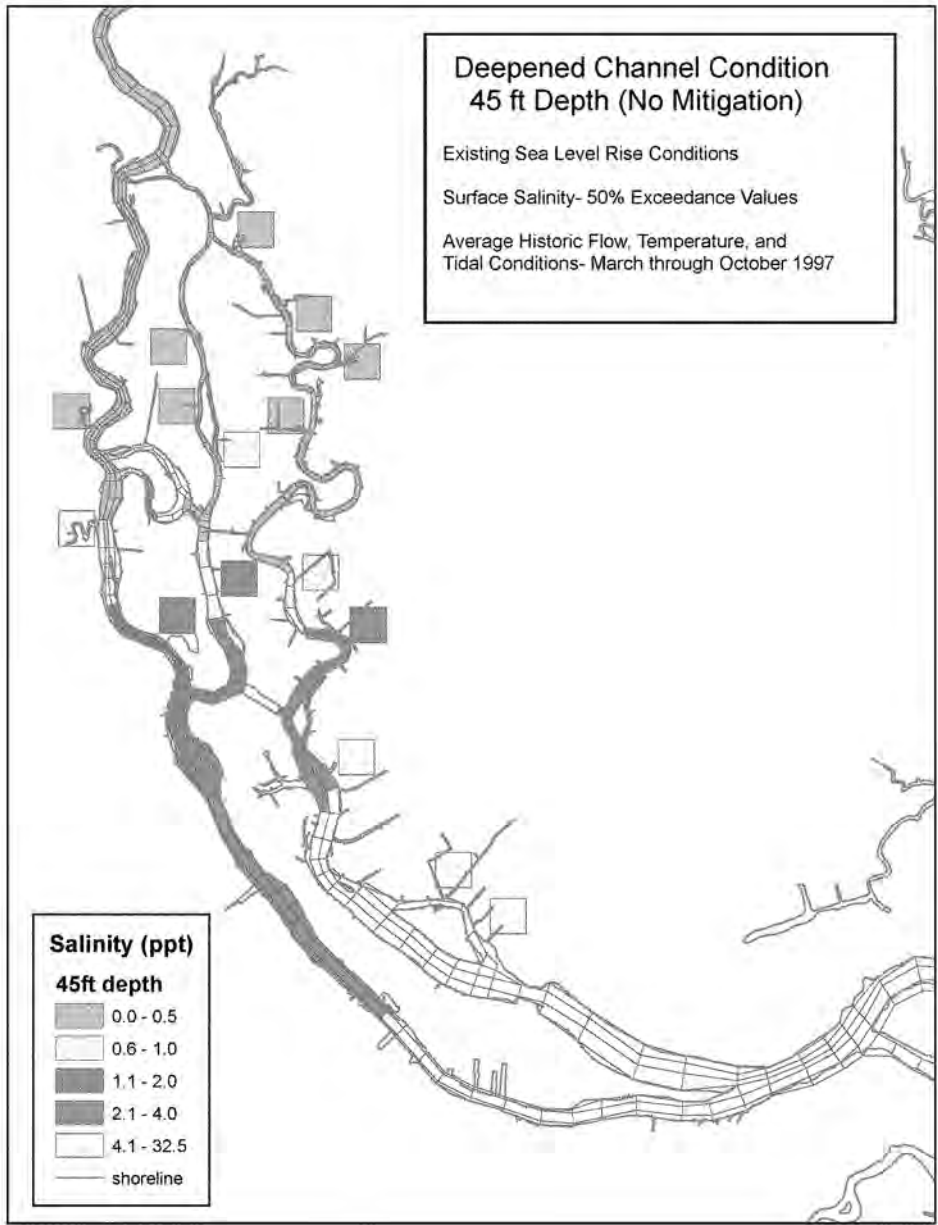
The results from Plan 6 appear to further reduce salinity impacts as compared to Plan 3. In all deepening scenarios the additional mitigation features provides more freshwater marsh area than that of Plan 3.

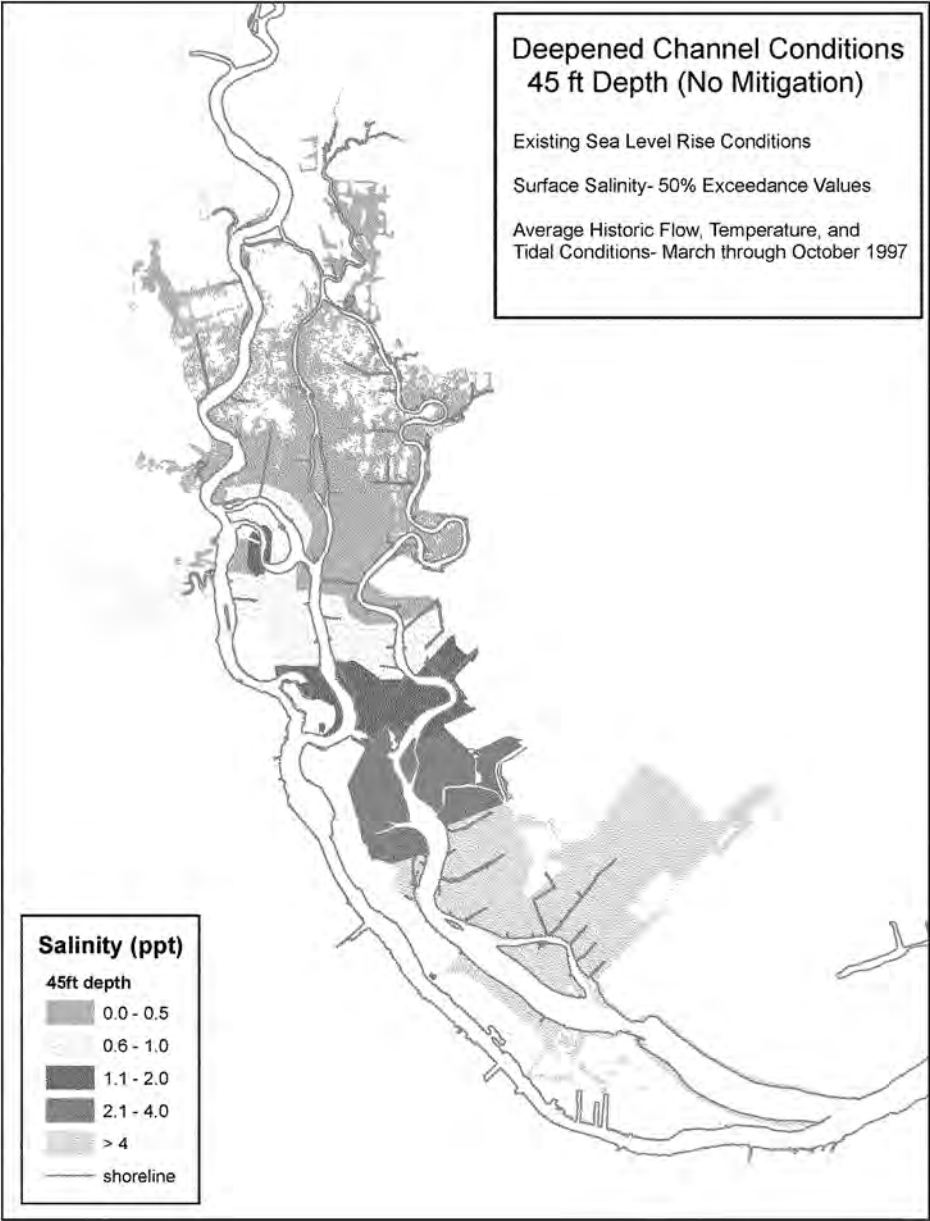
Plan 6b

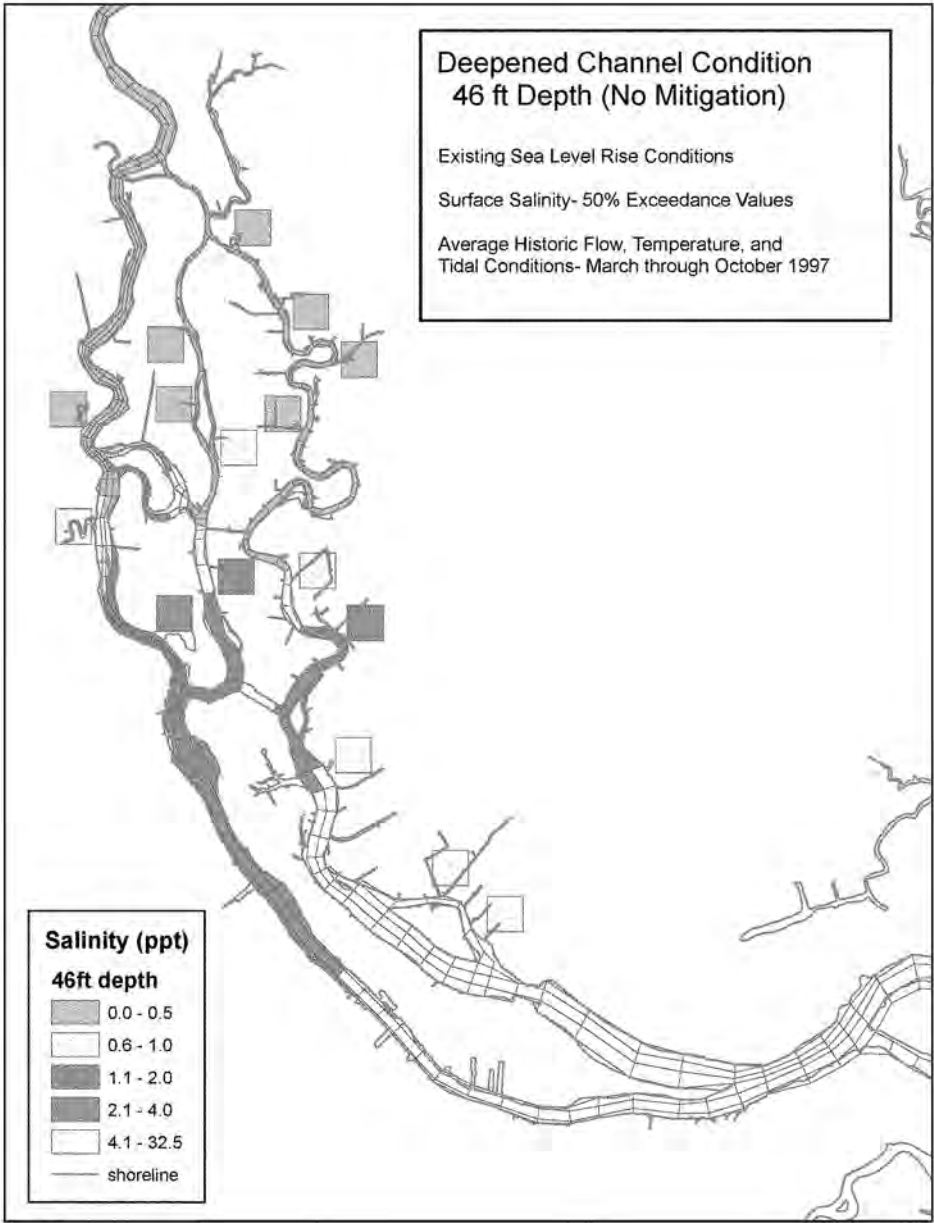
Plan 6b appears to further reduce salinity impacts on Front River over that of Plan 3. The increased flushing capacity due to opening the area at the tidegate in combination with closing the lower arm at McCoys Cut appears to combat salinity pushing further upstream due to deepening the navigation channel. Salinity impacts on Back, Little Back and Middle Rivers are similar to what they were in Plan 3.

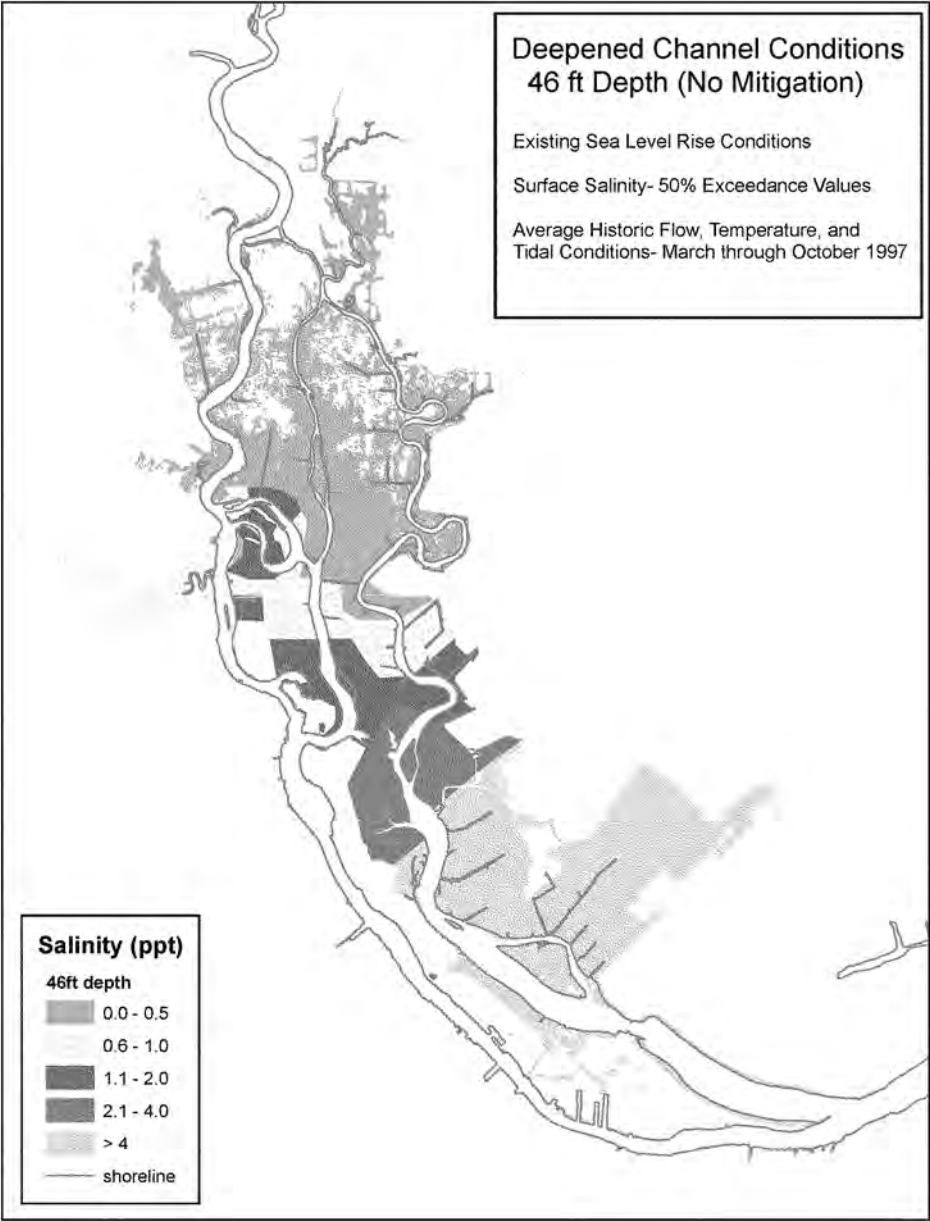


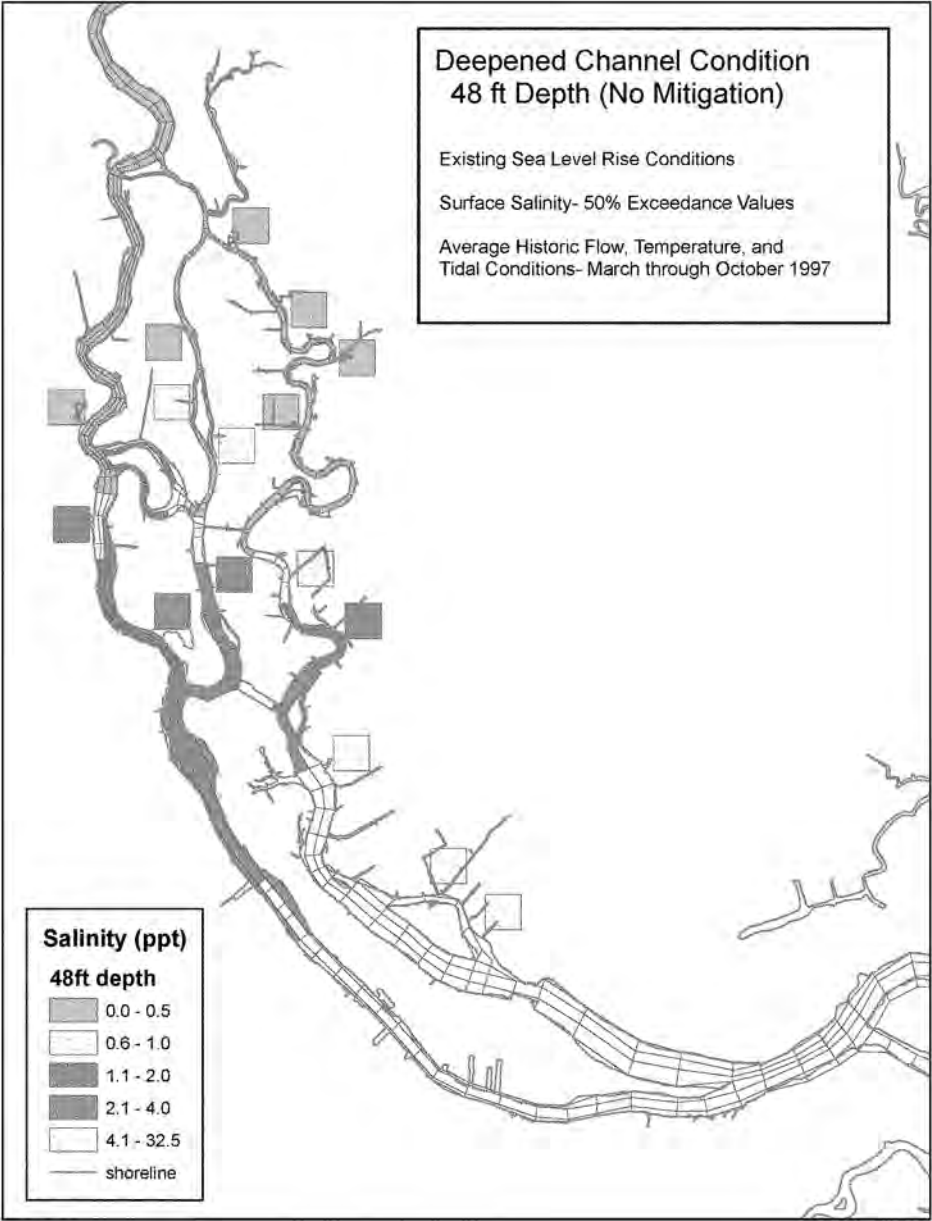


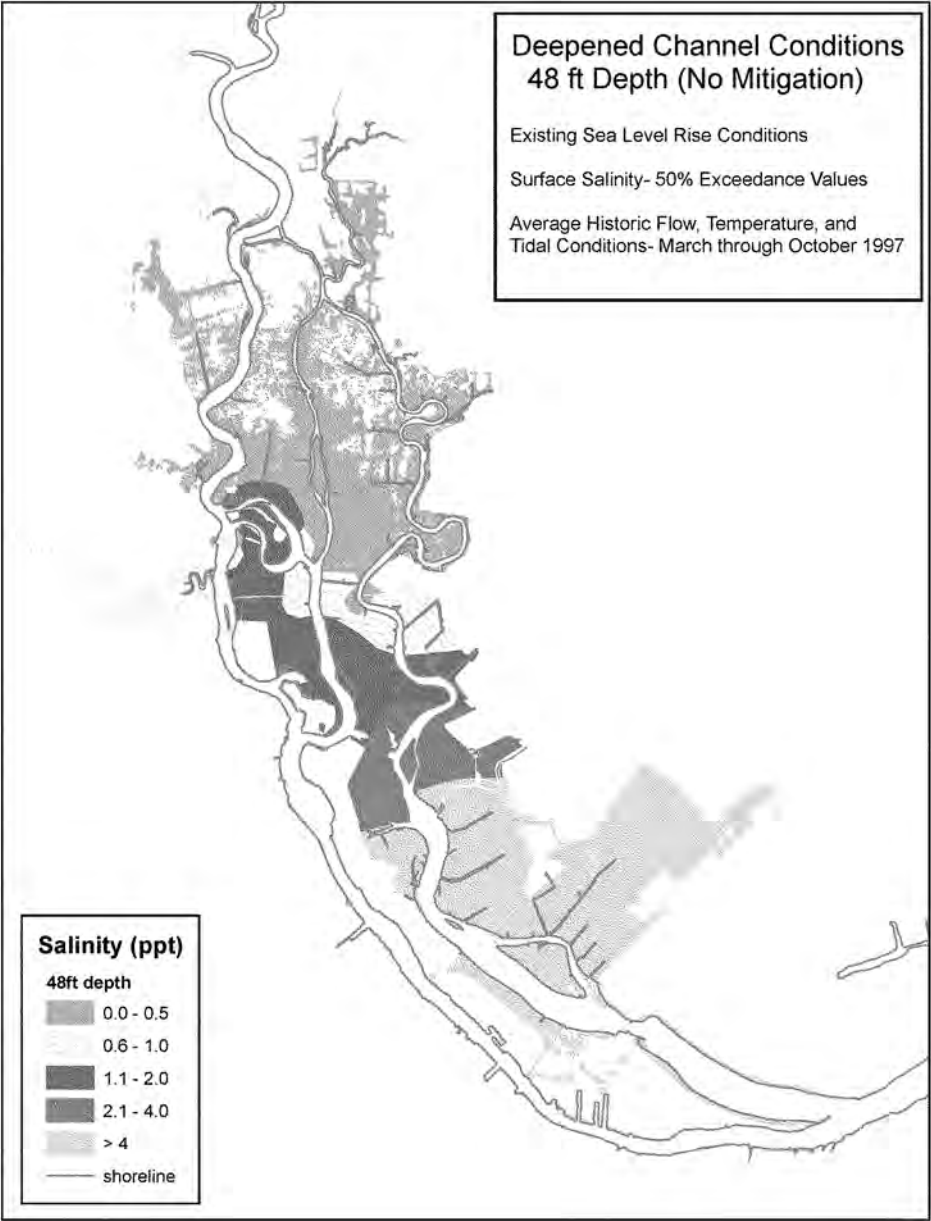


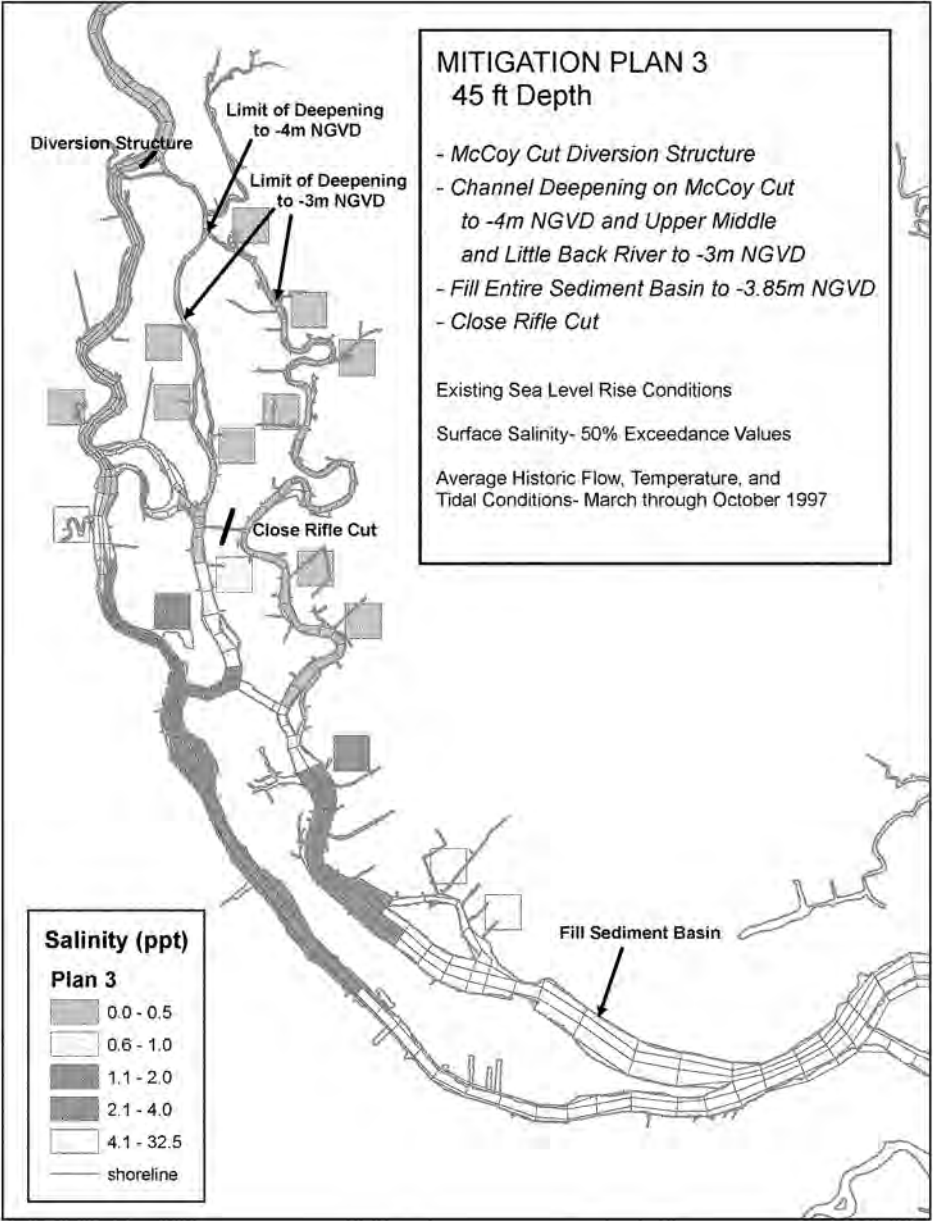


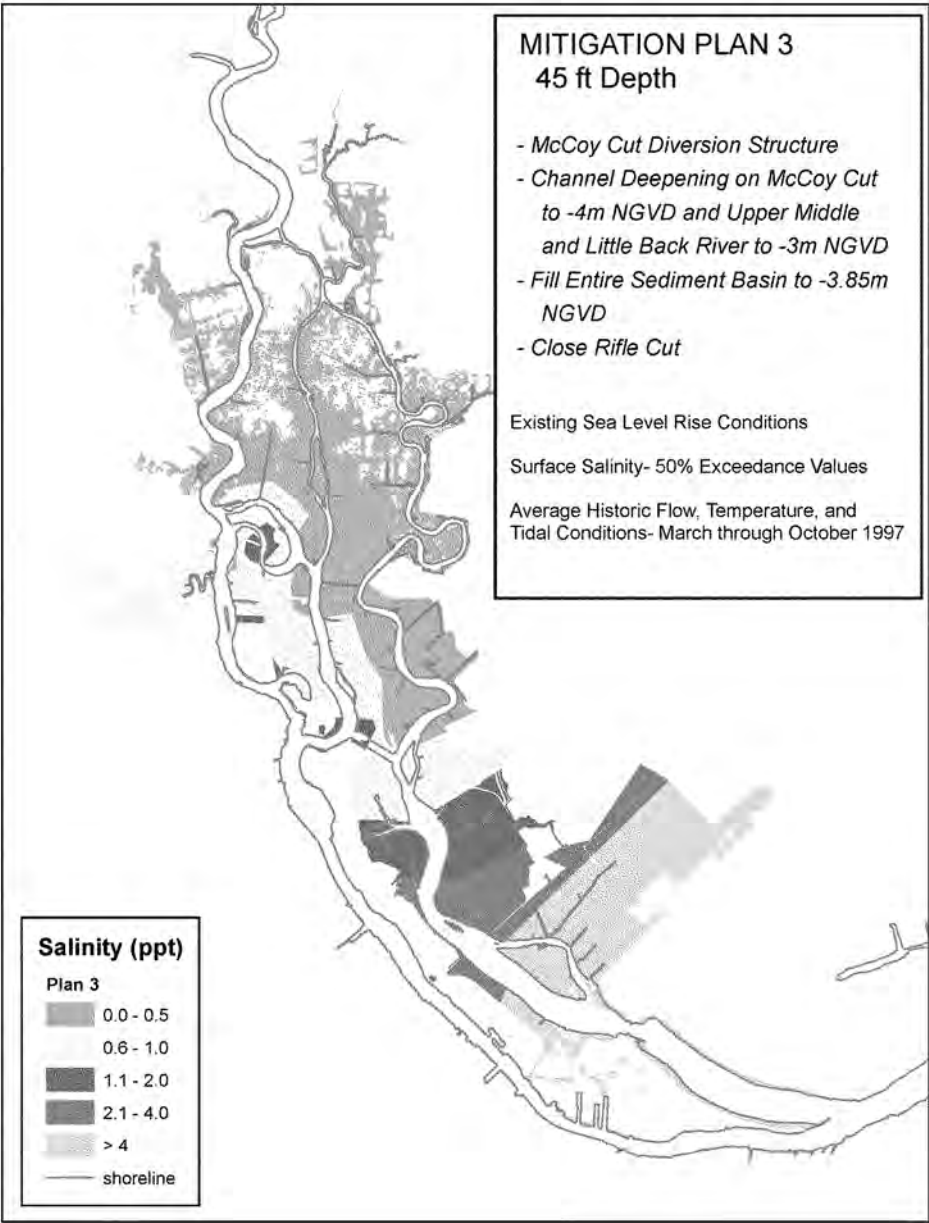


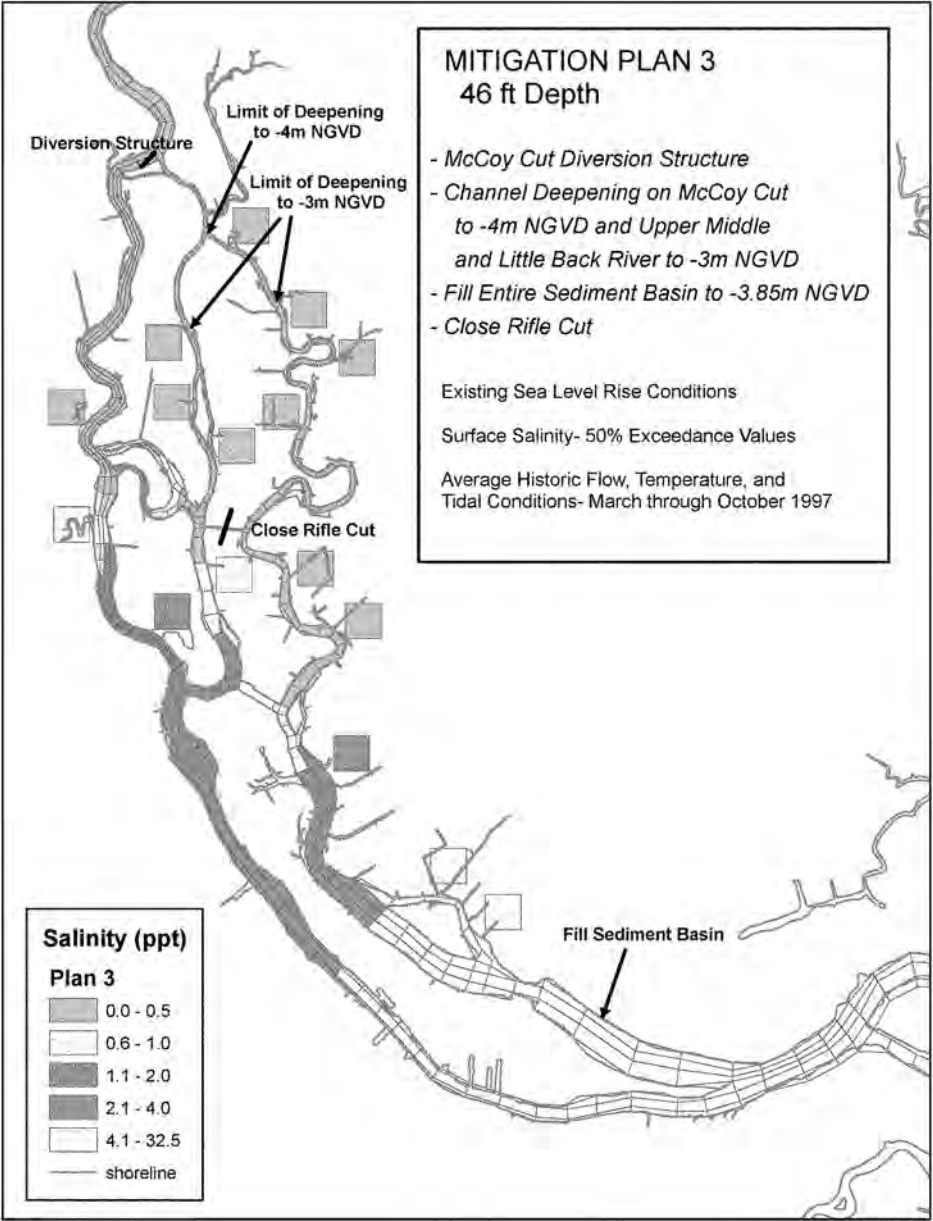


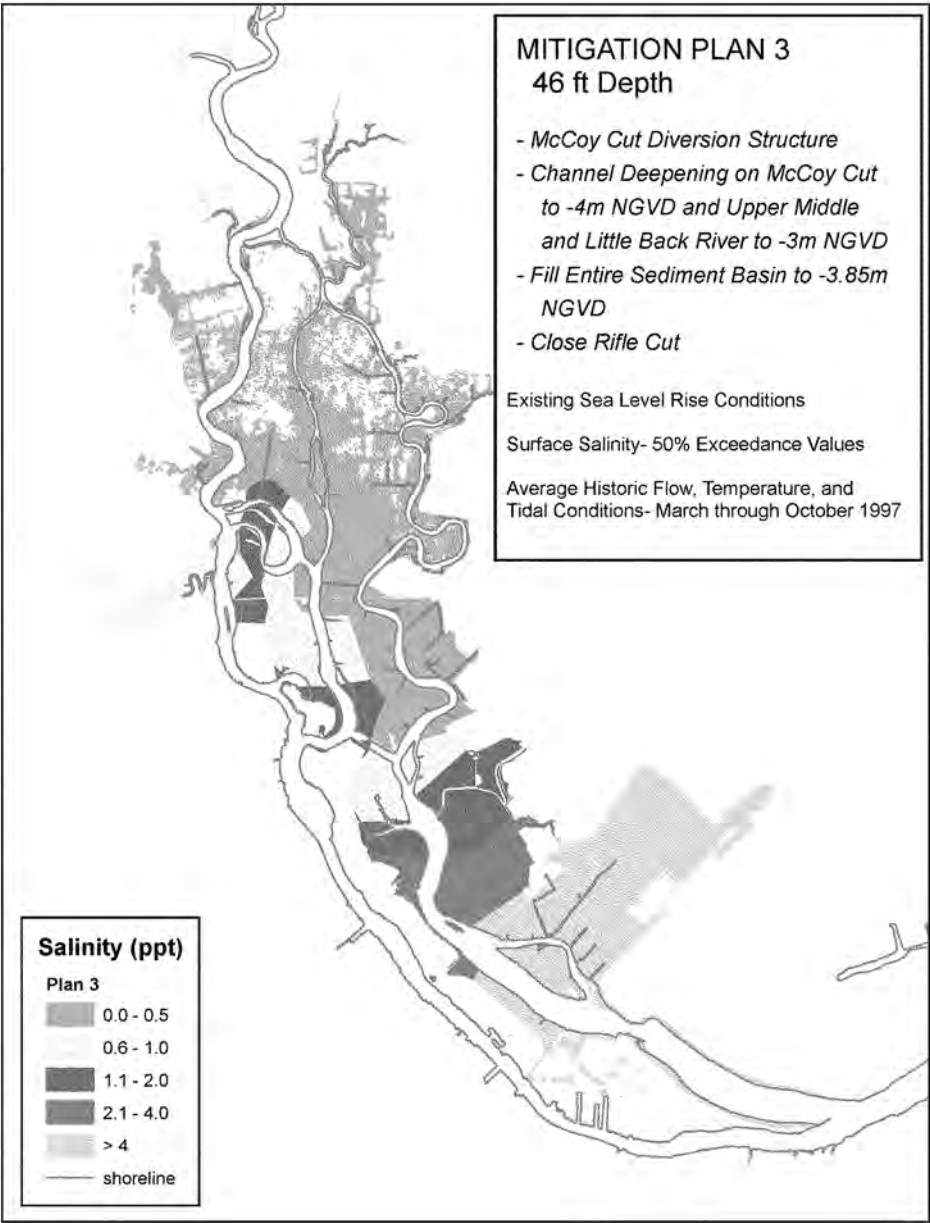


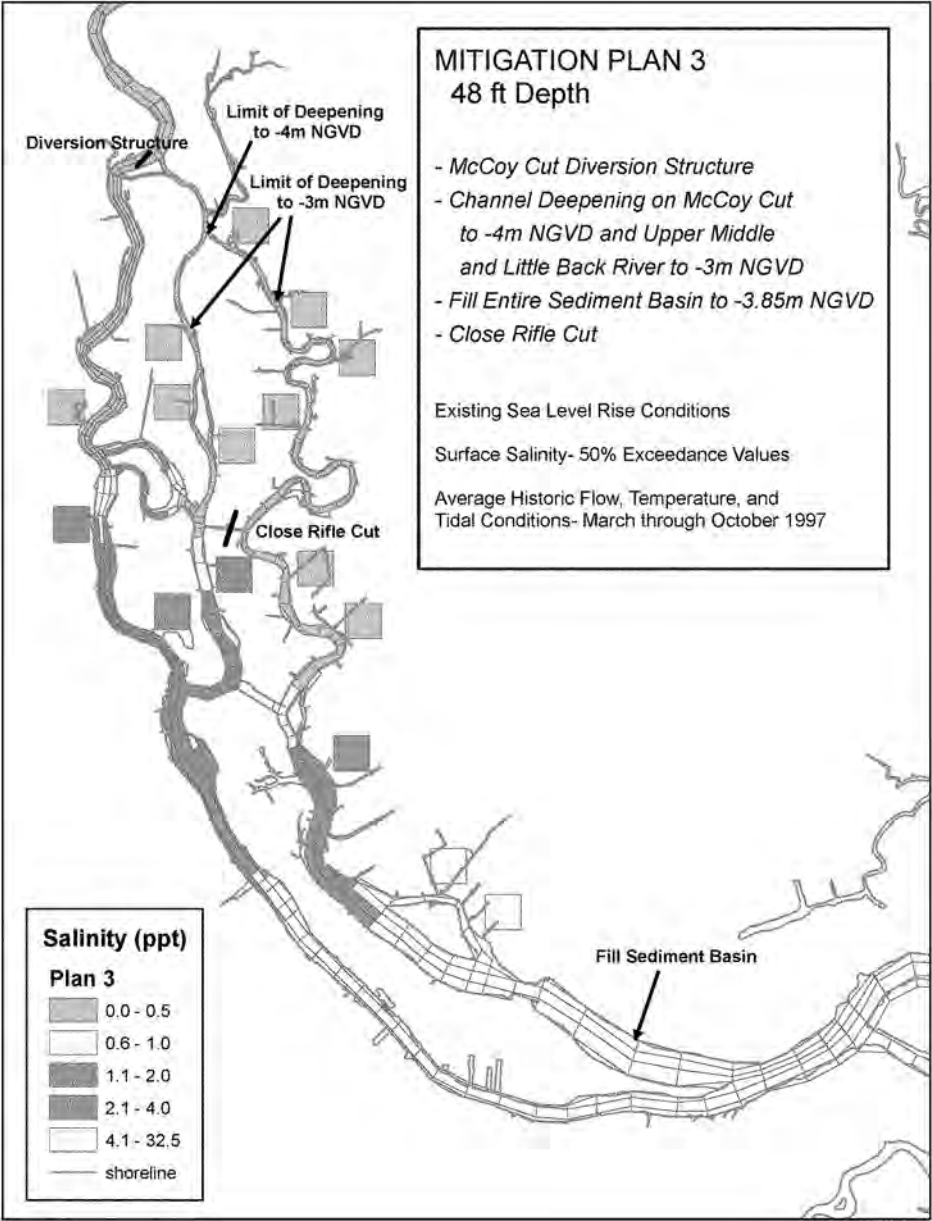


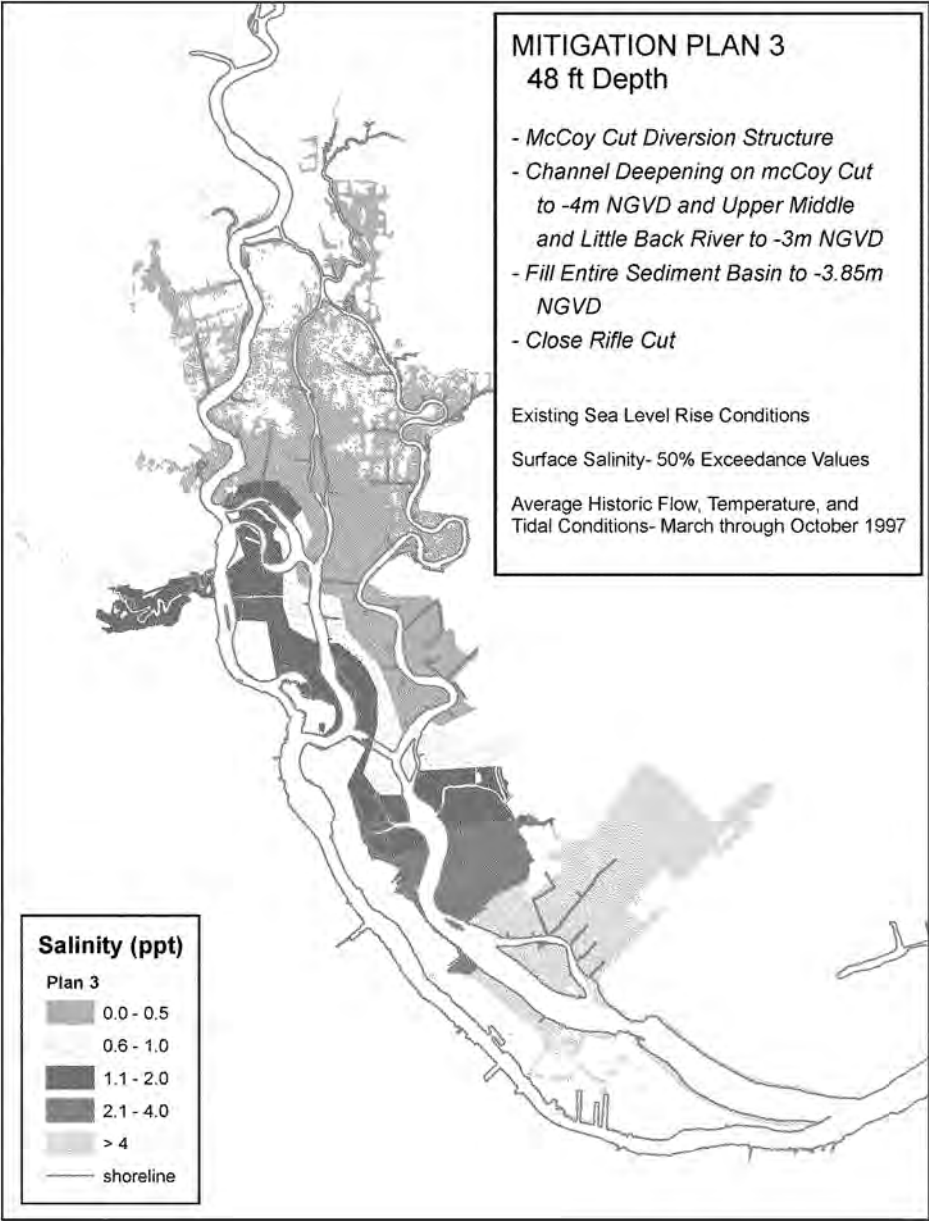


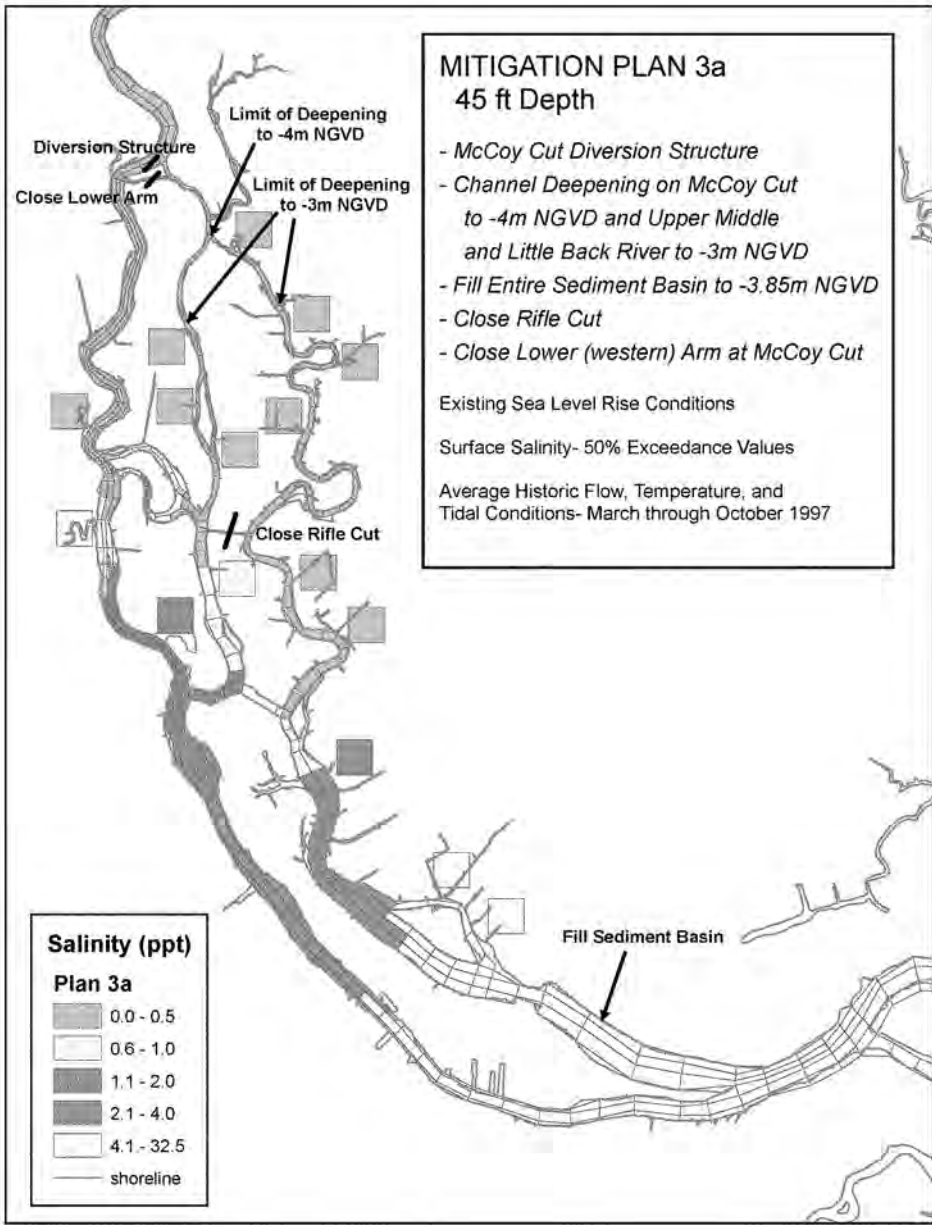


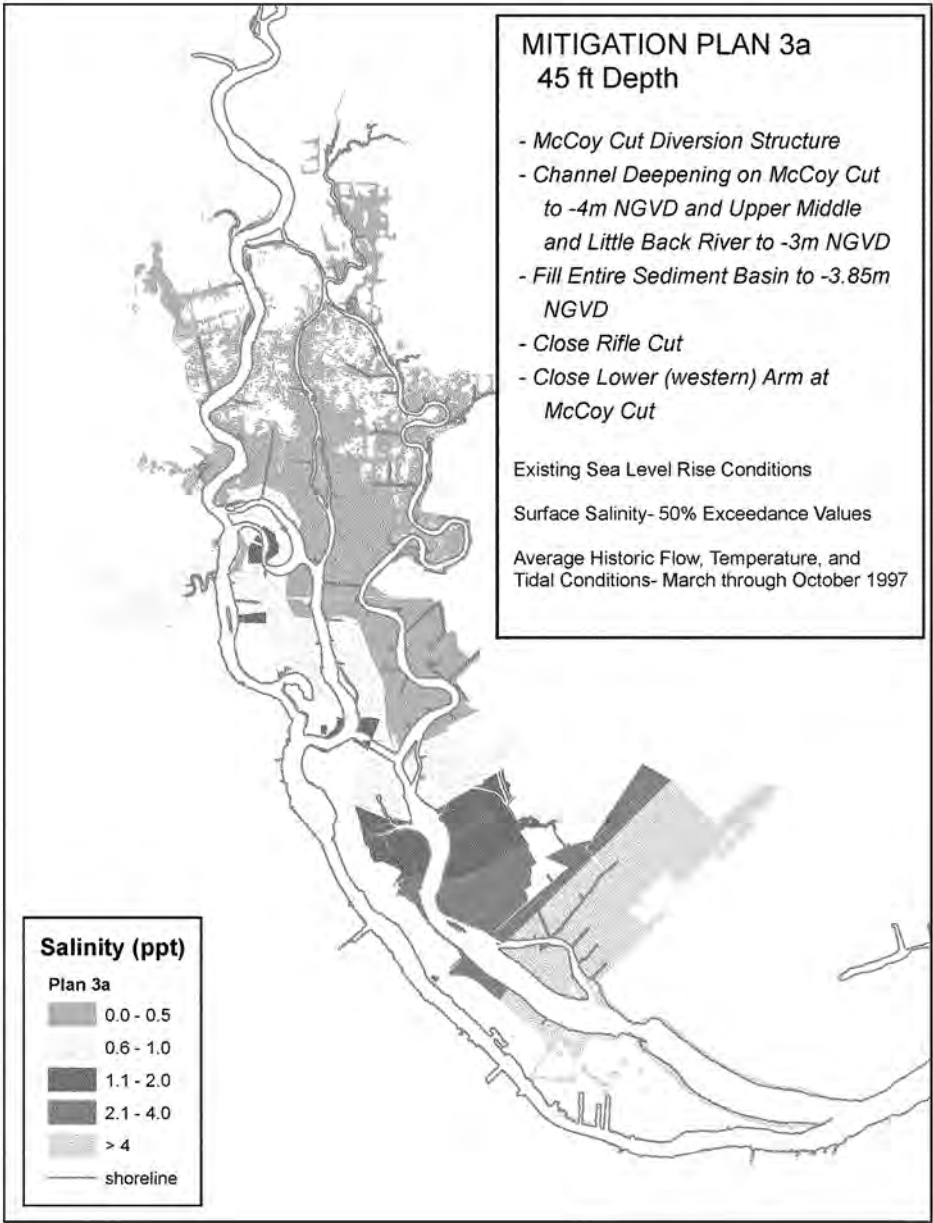


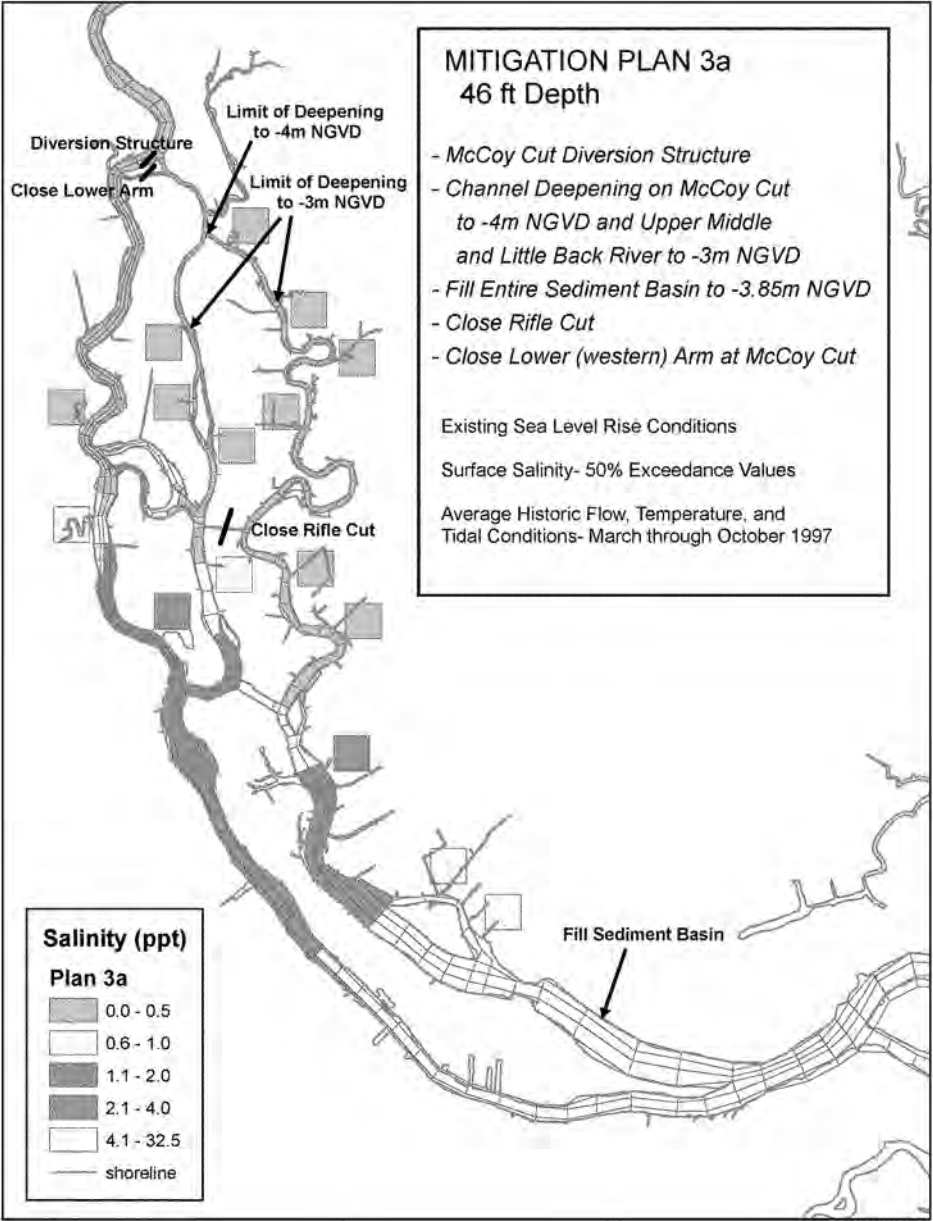


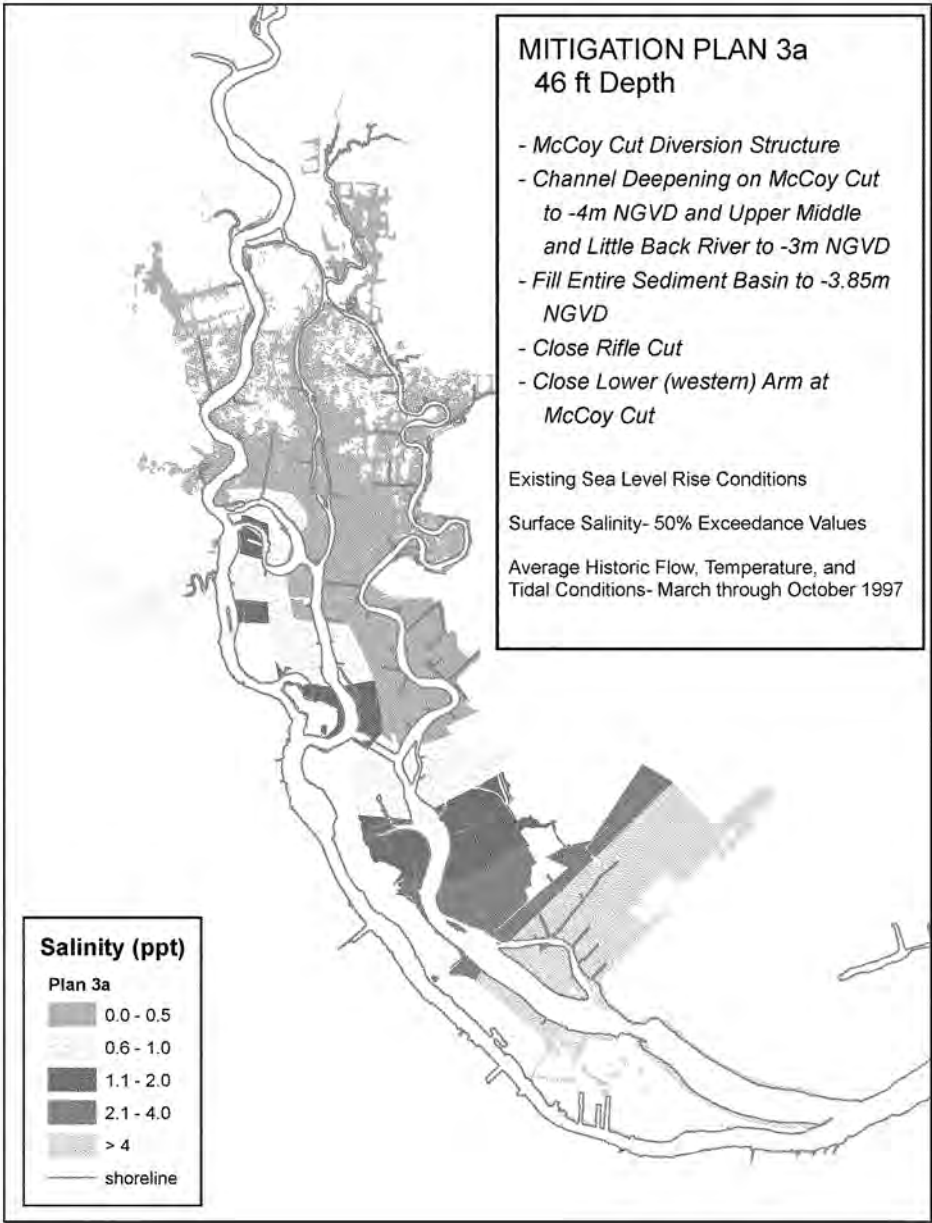


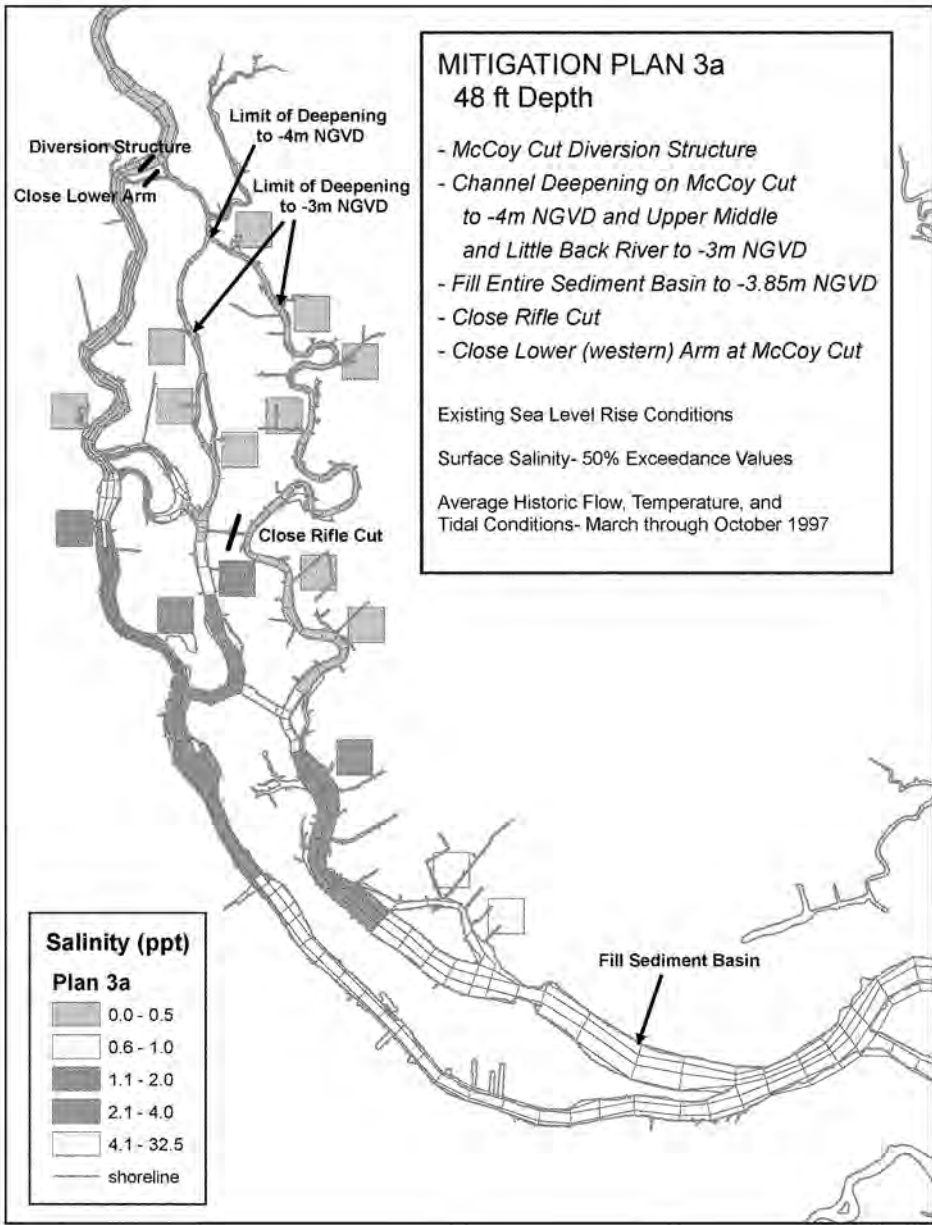


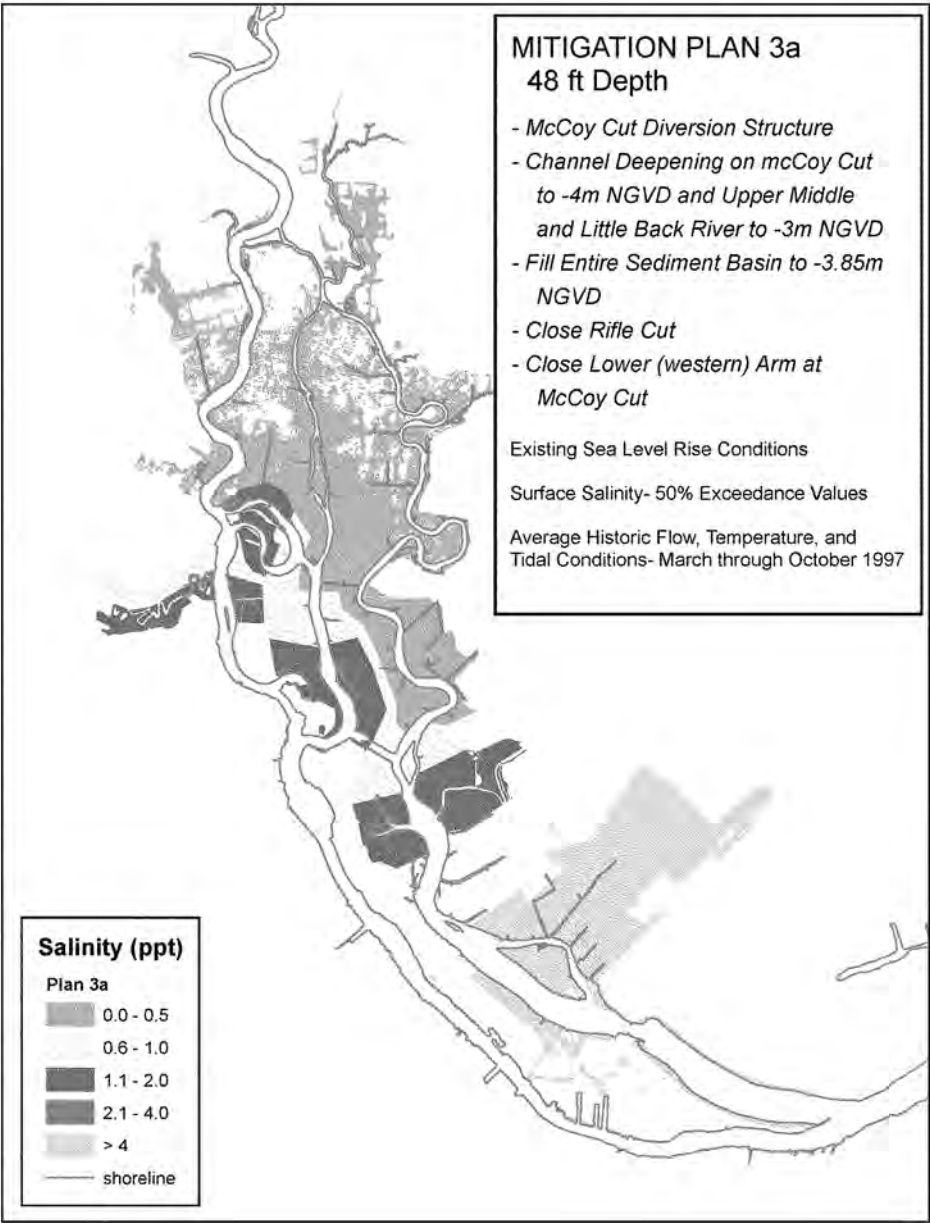


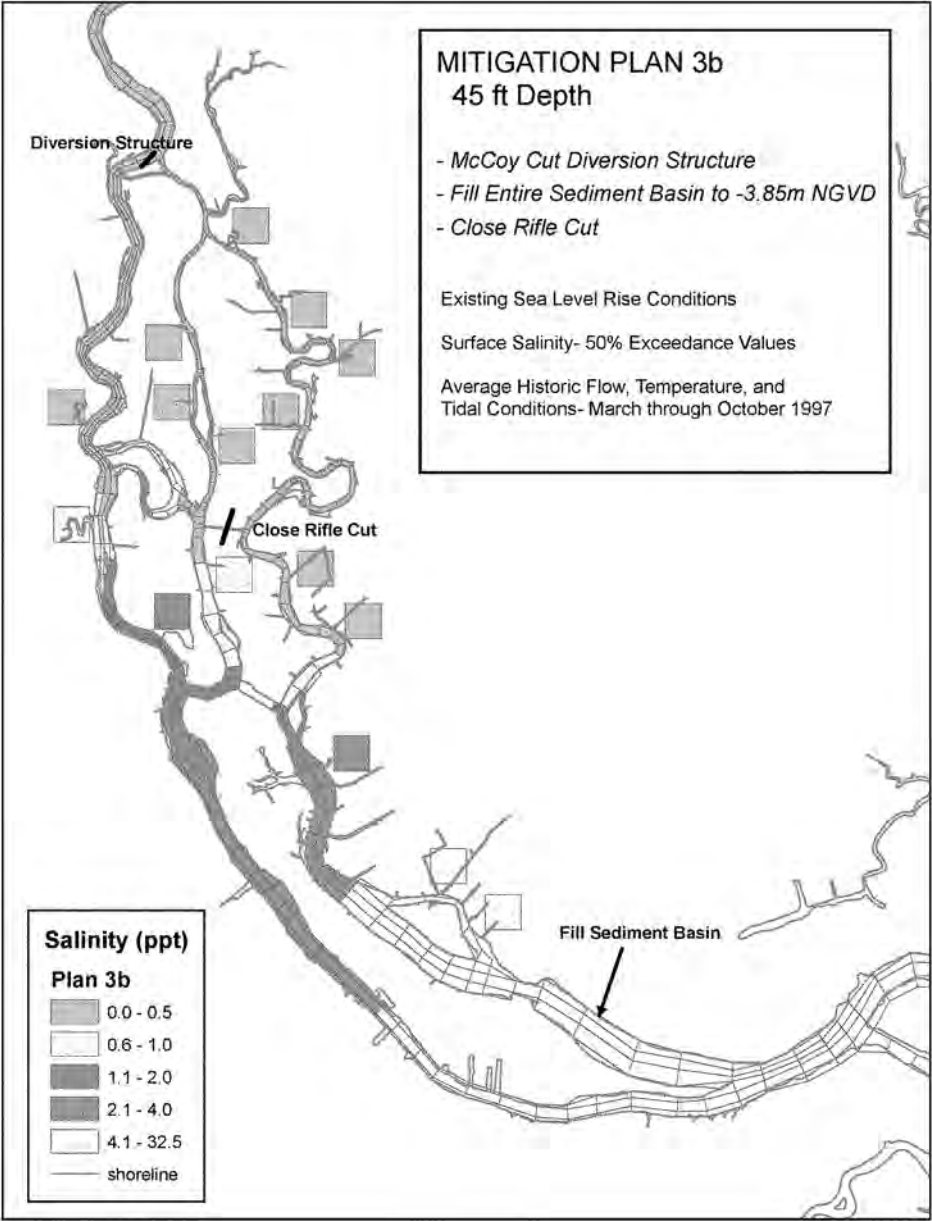


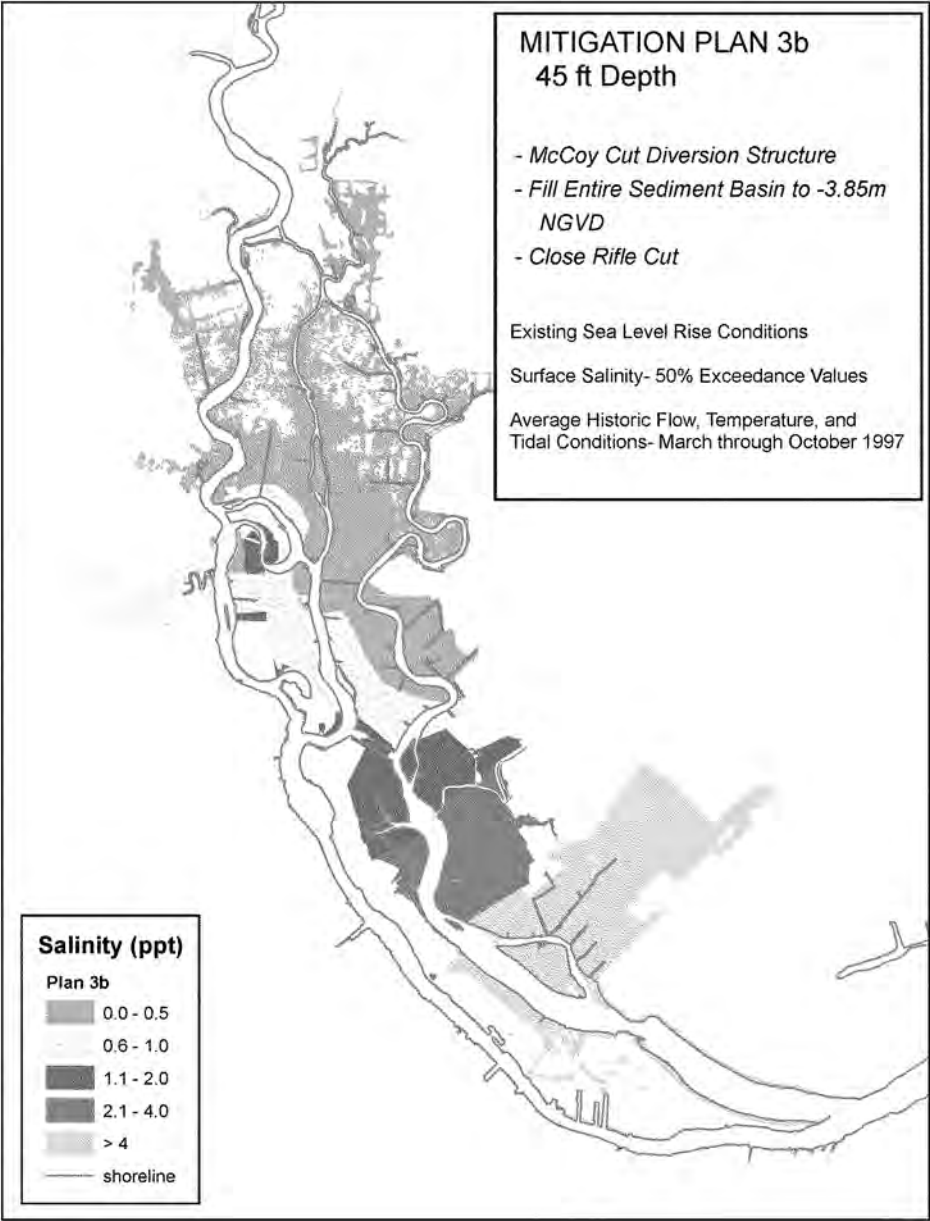


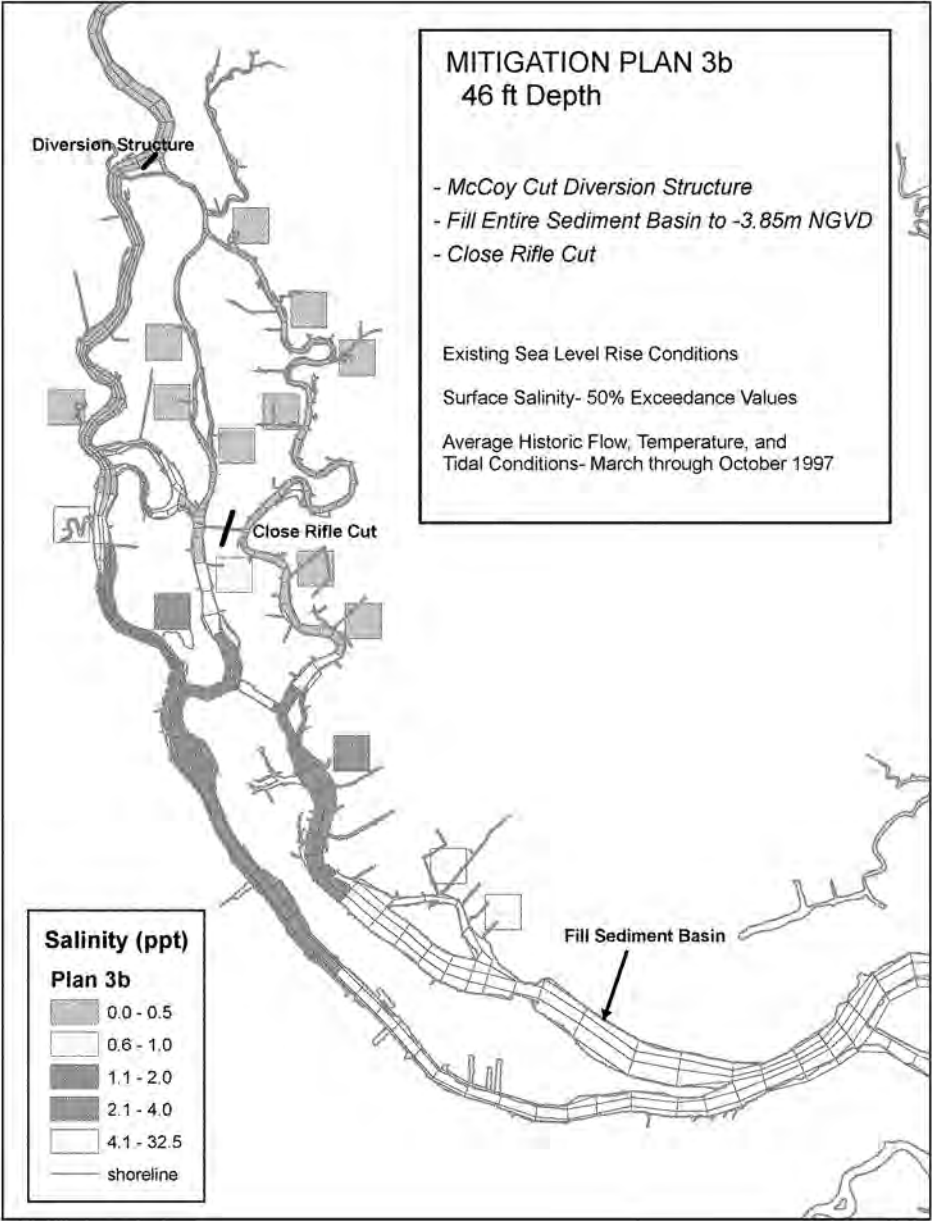


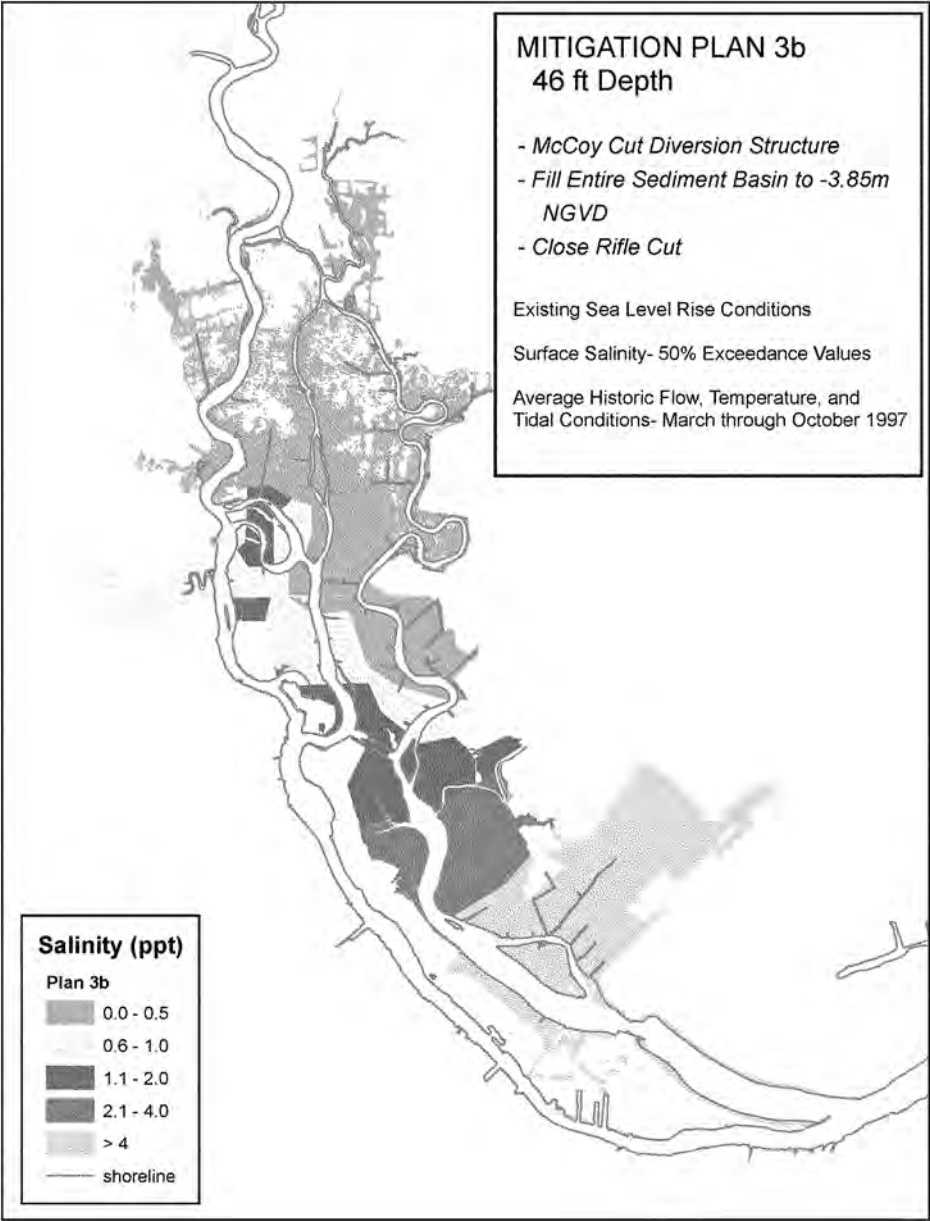


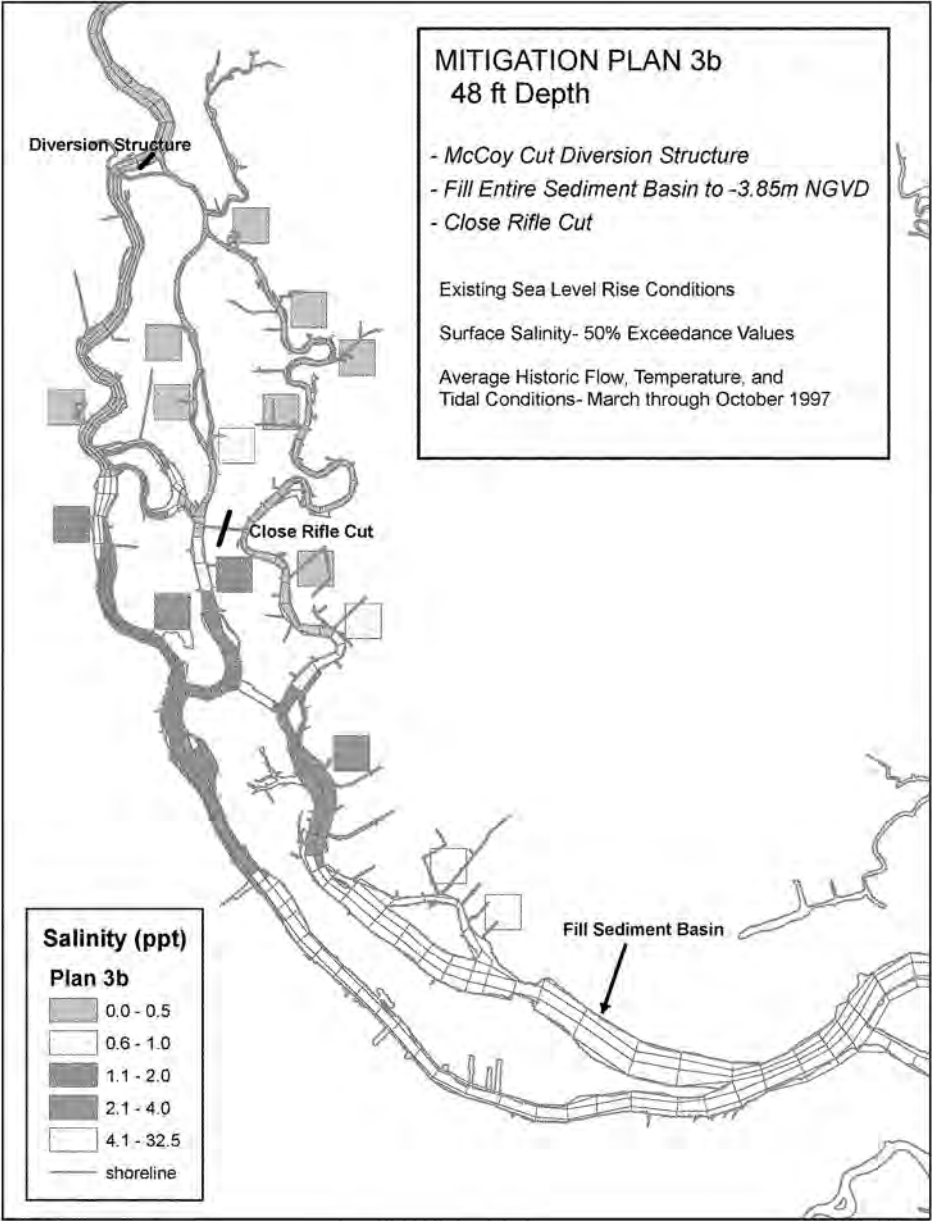


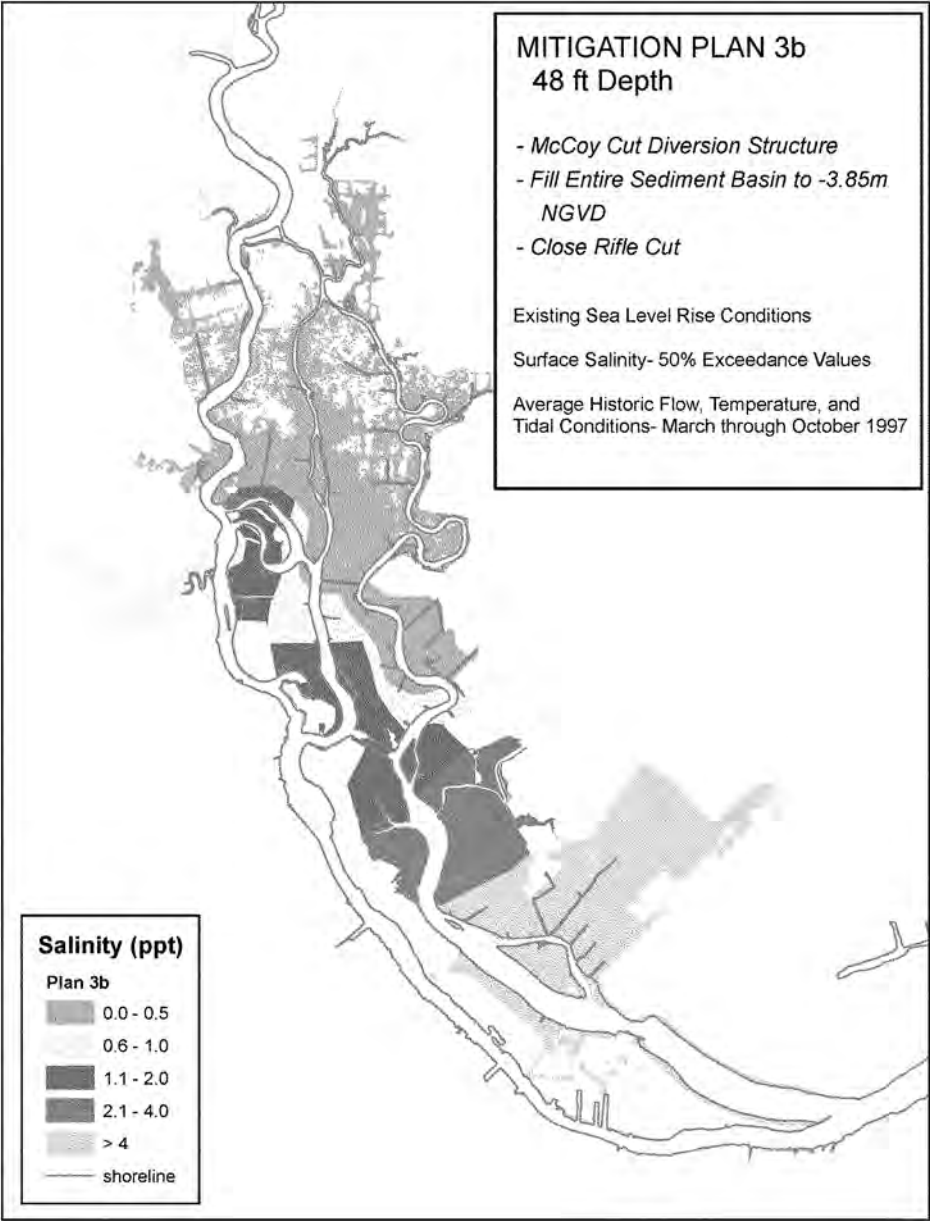


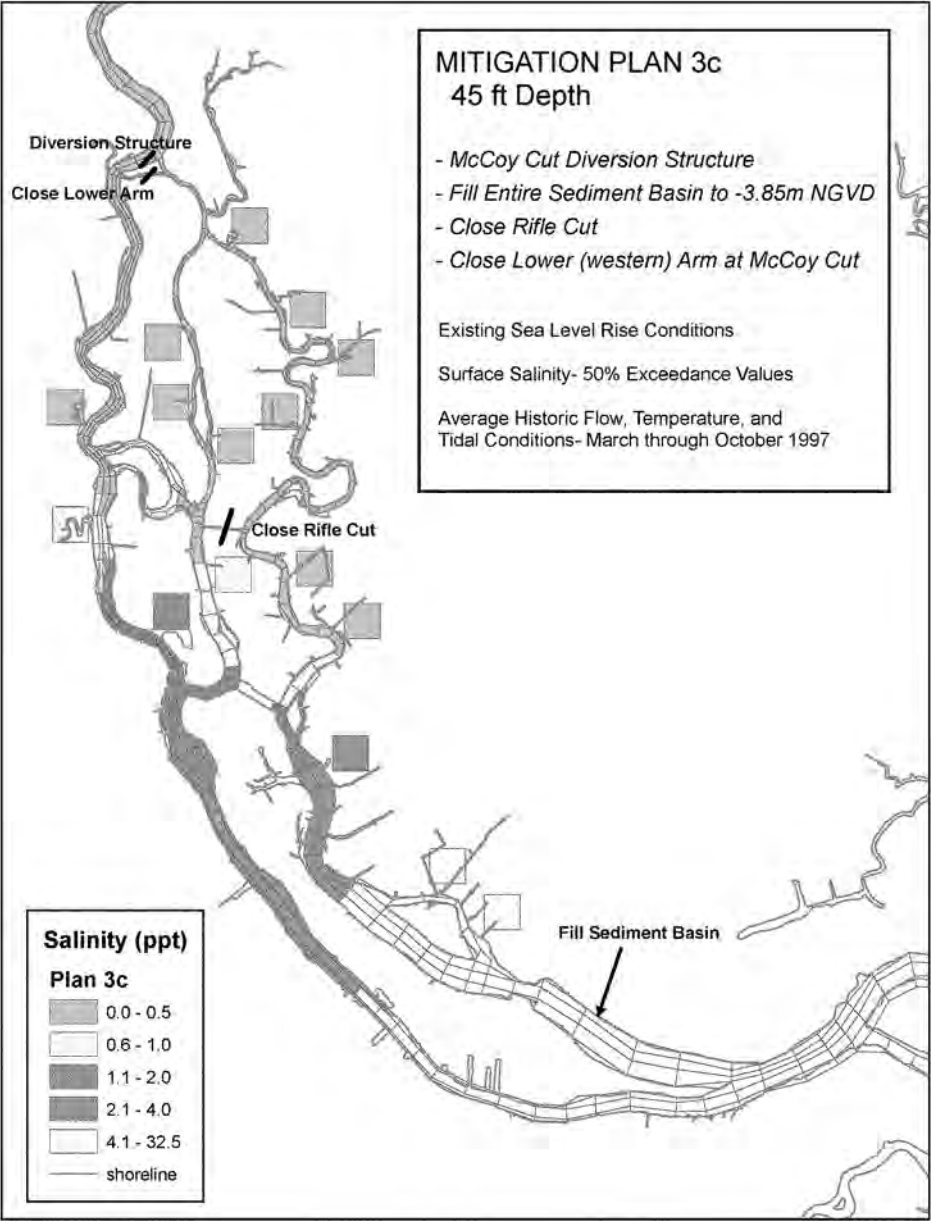


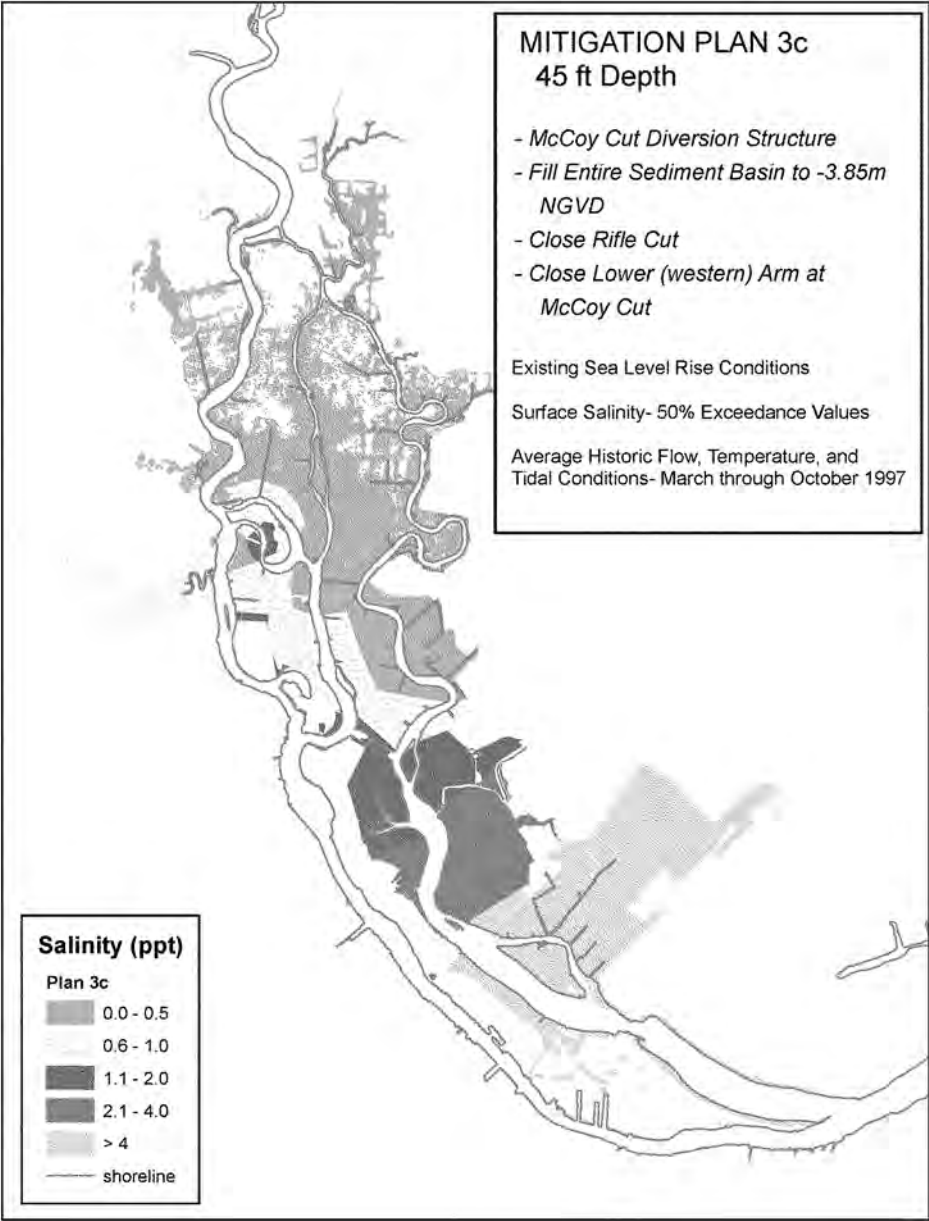


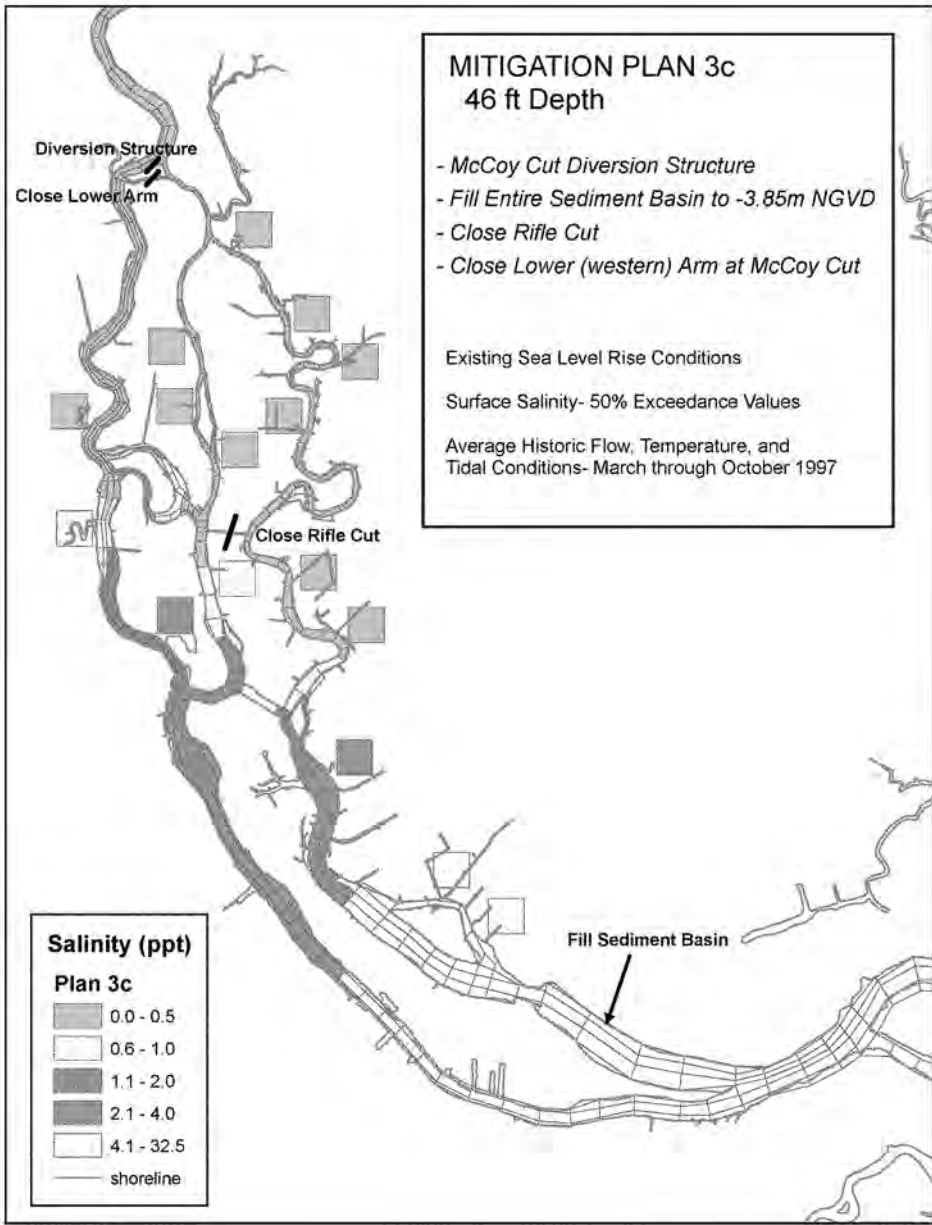


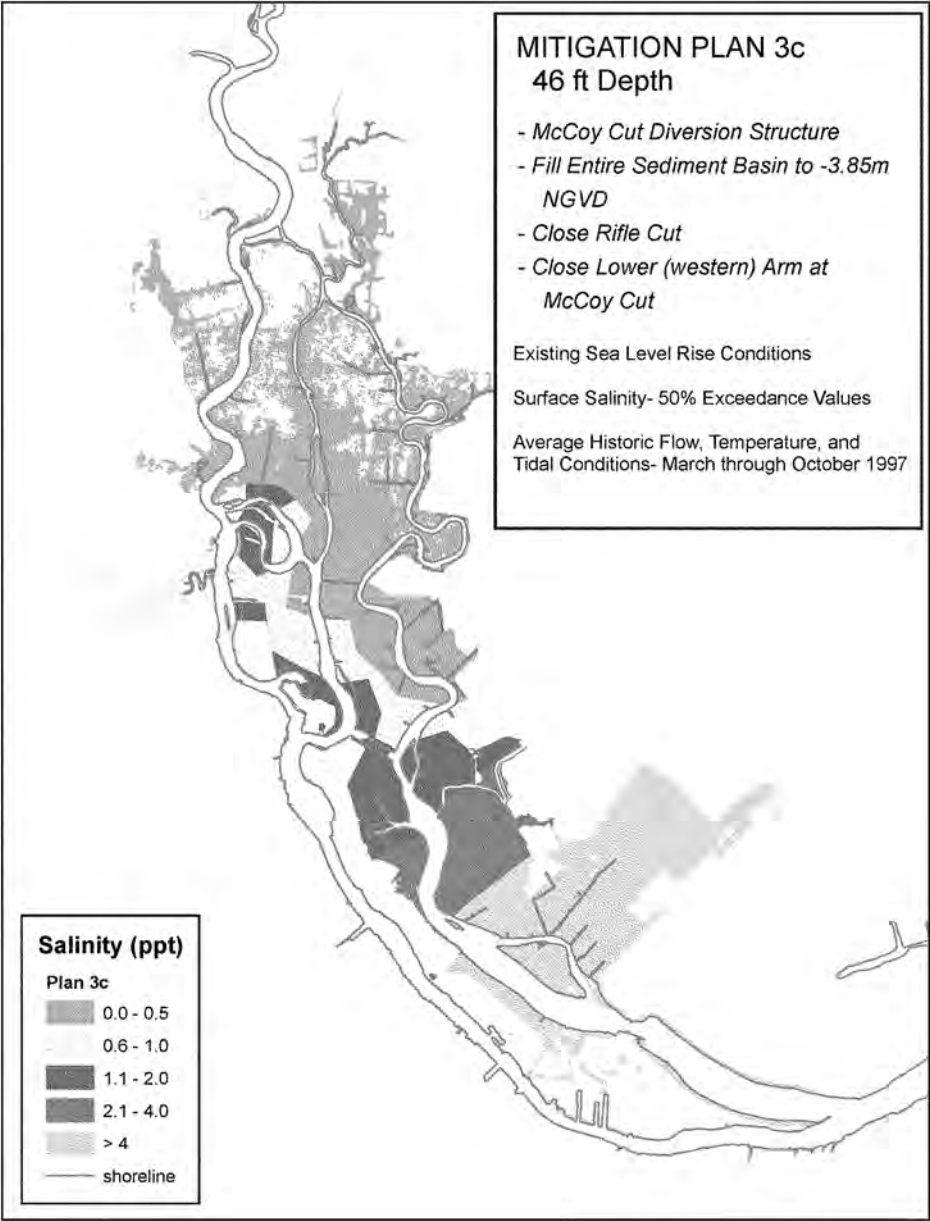


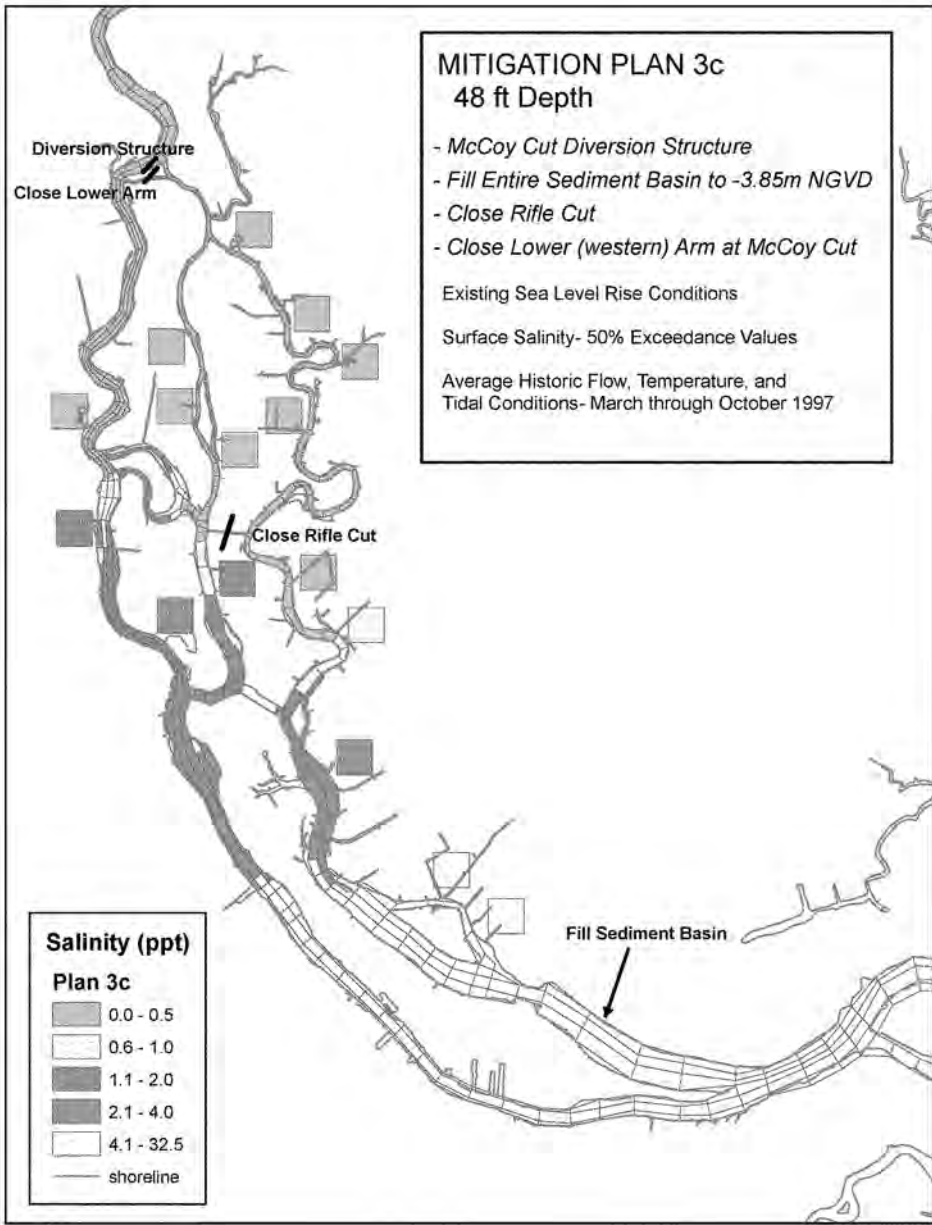


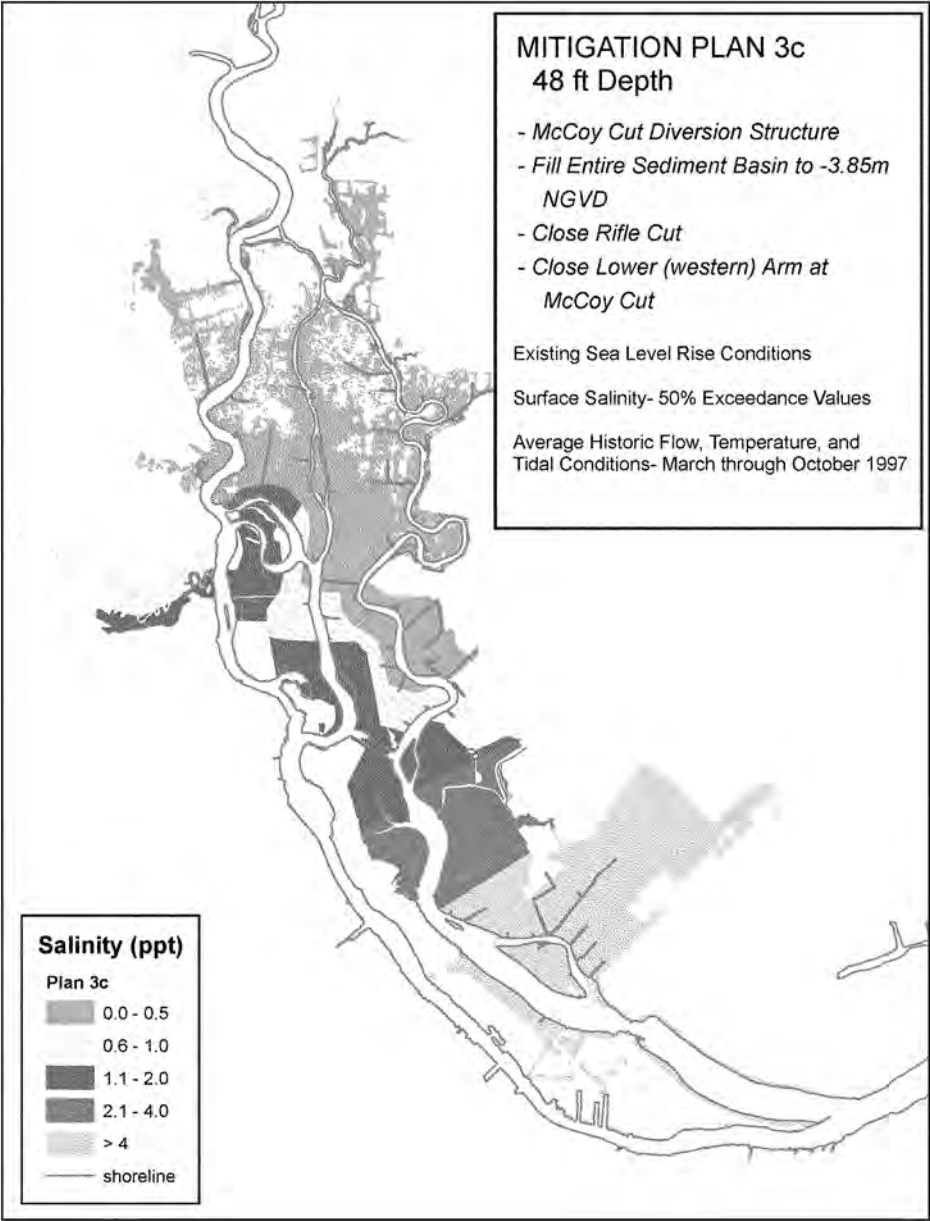


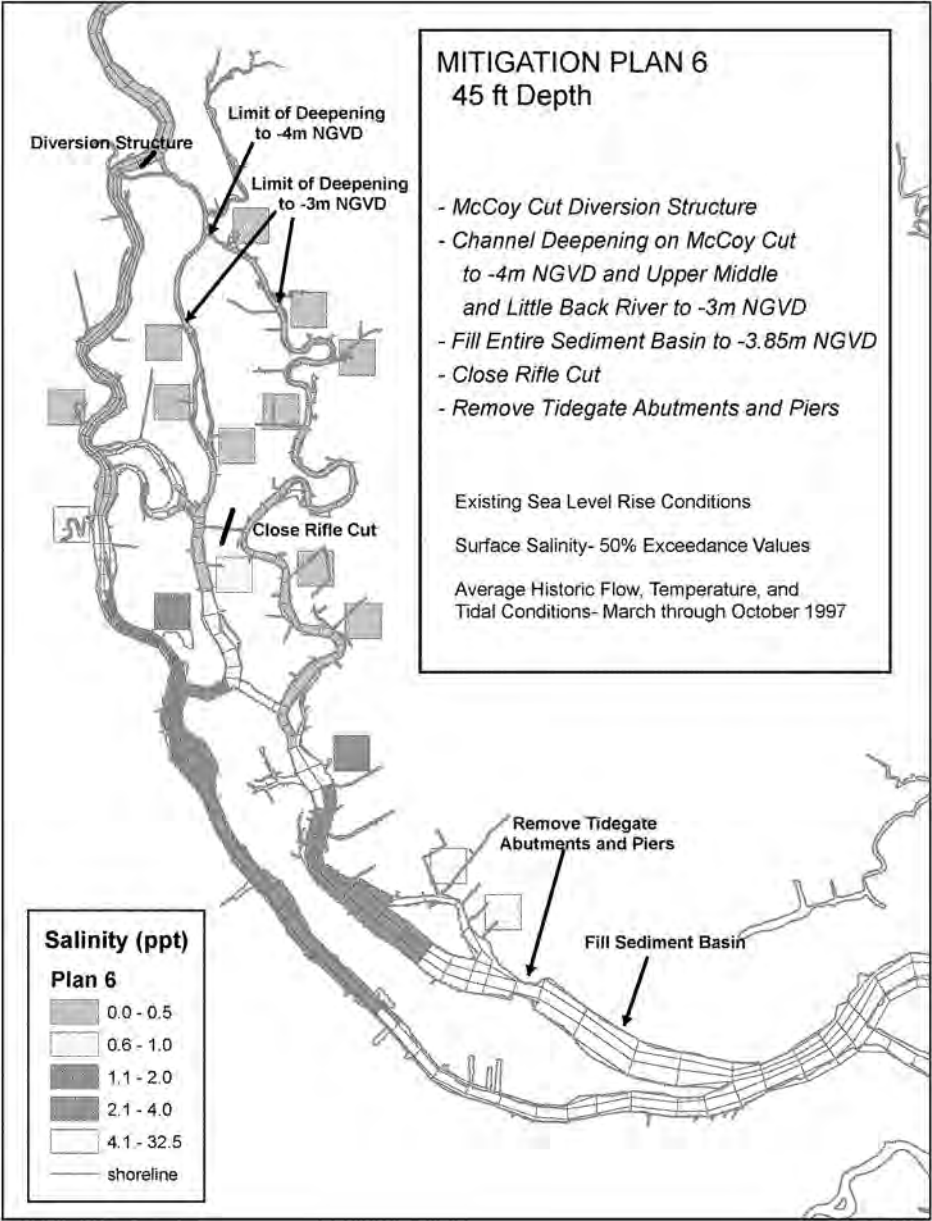


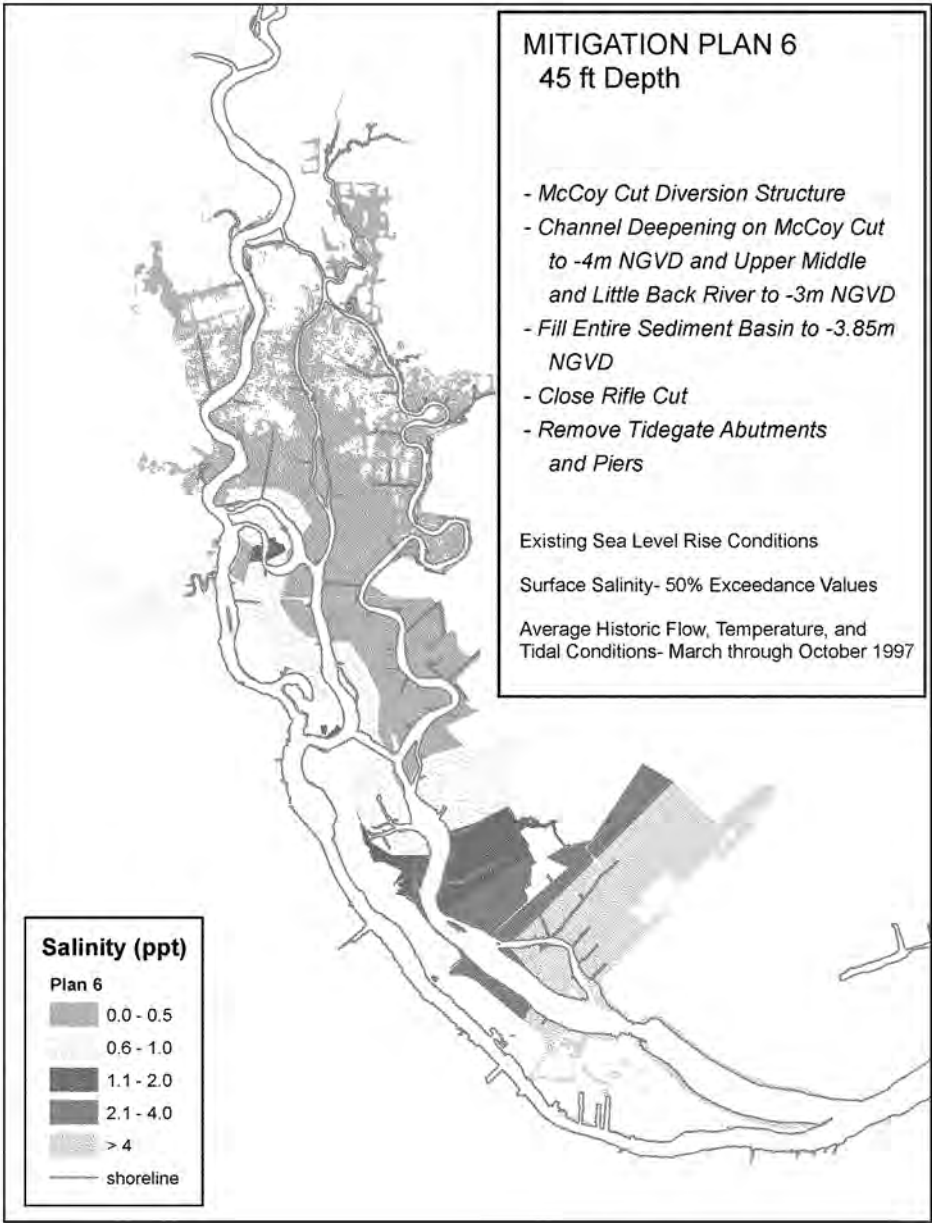


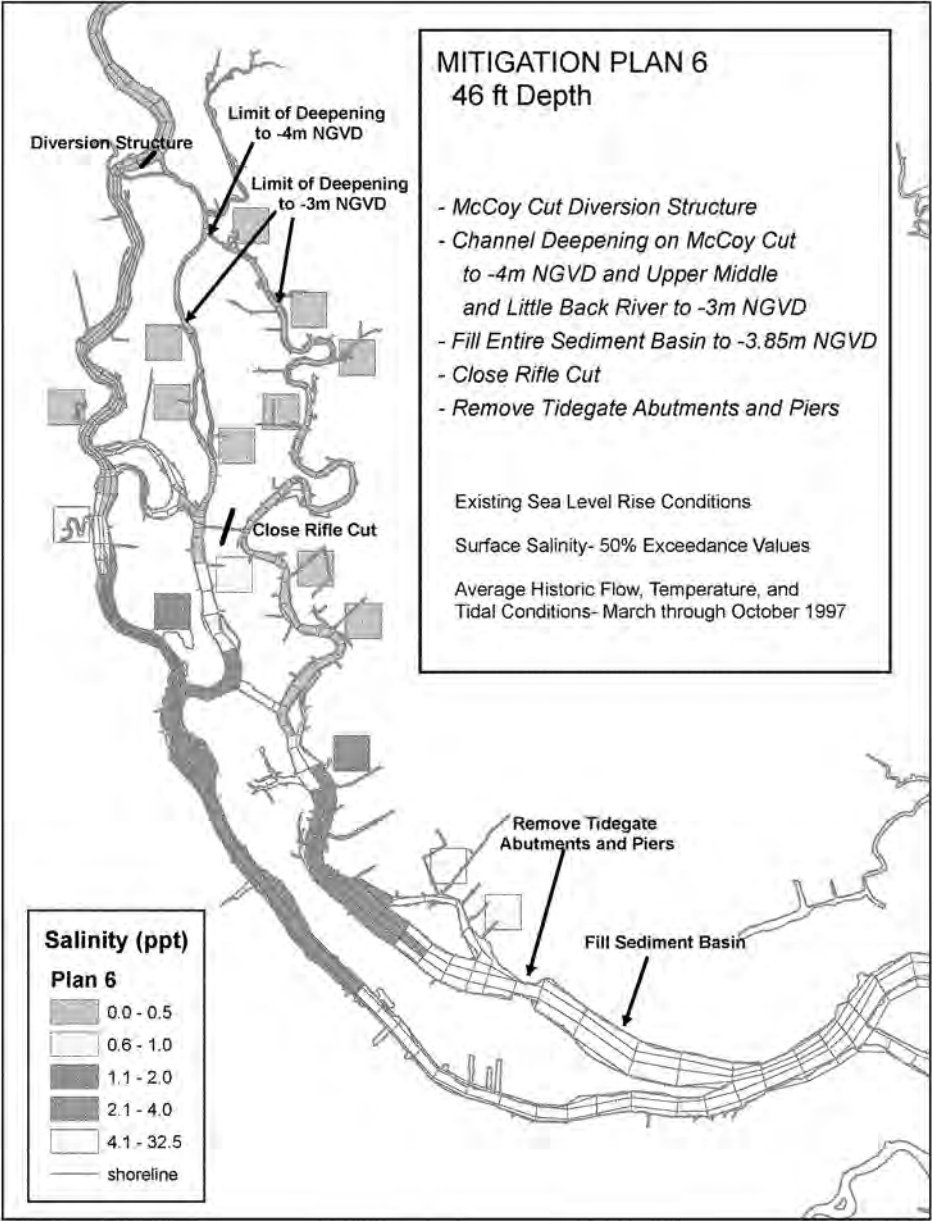


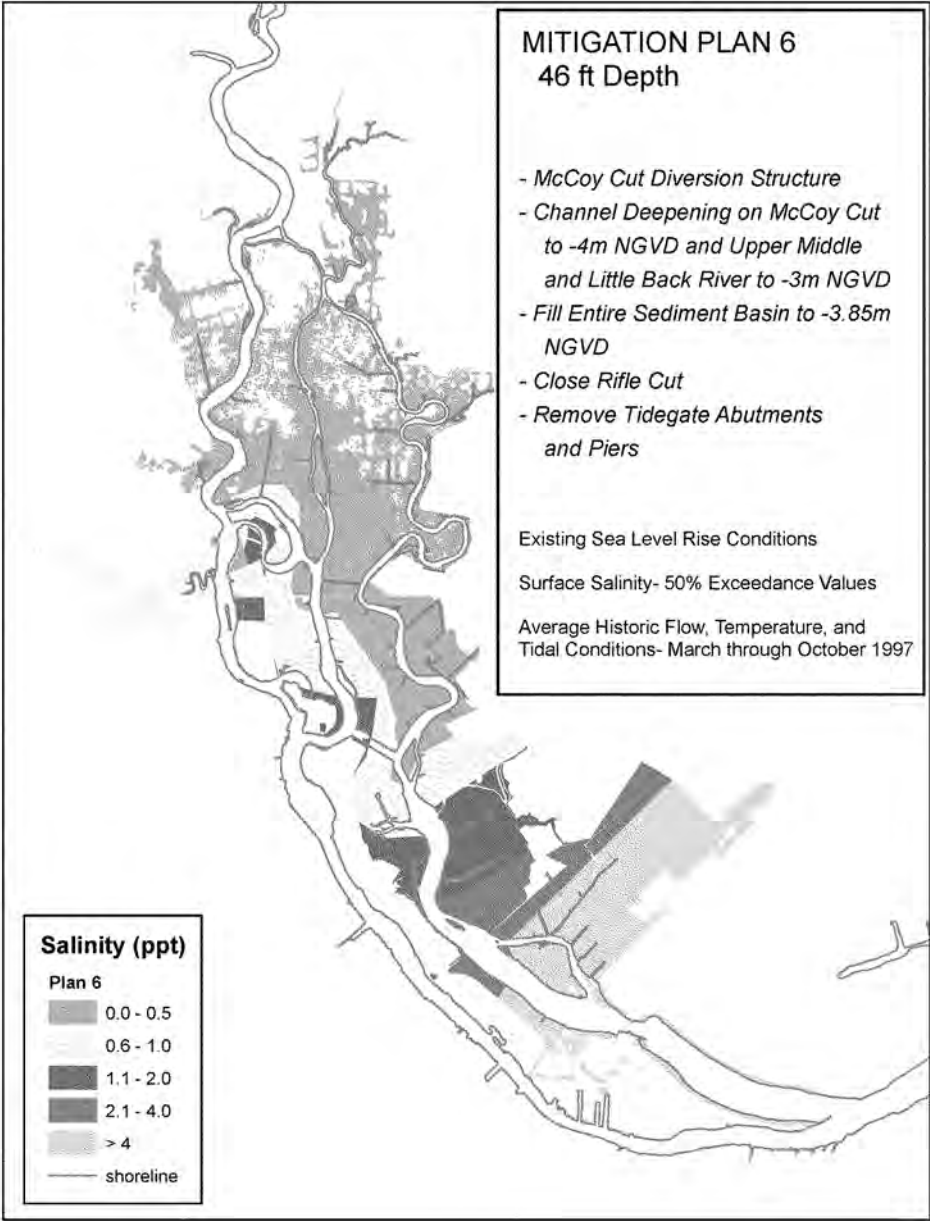


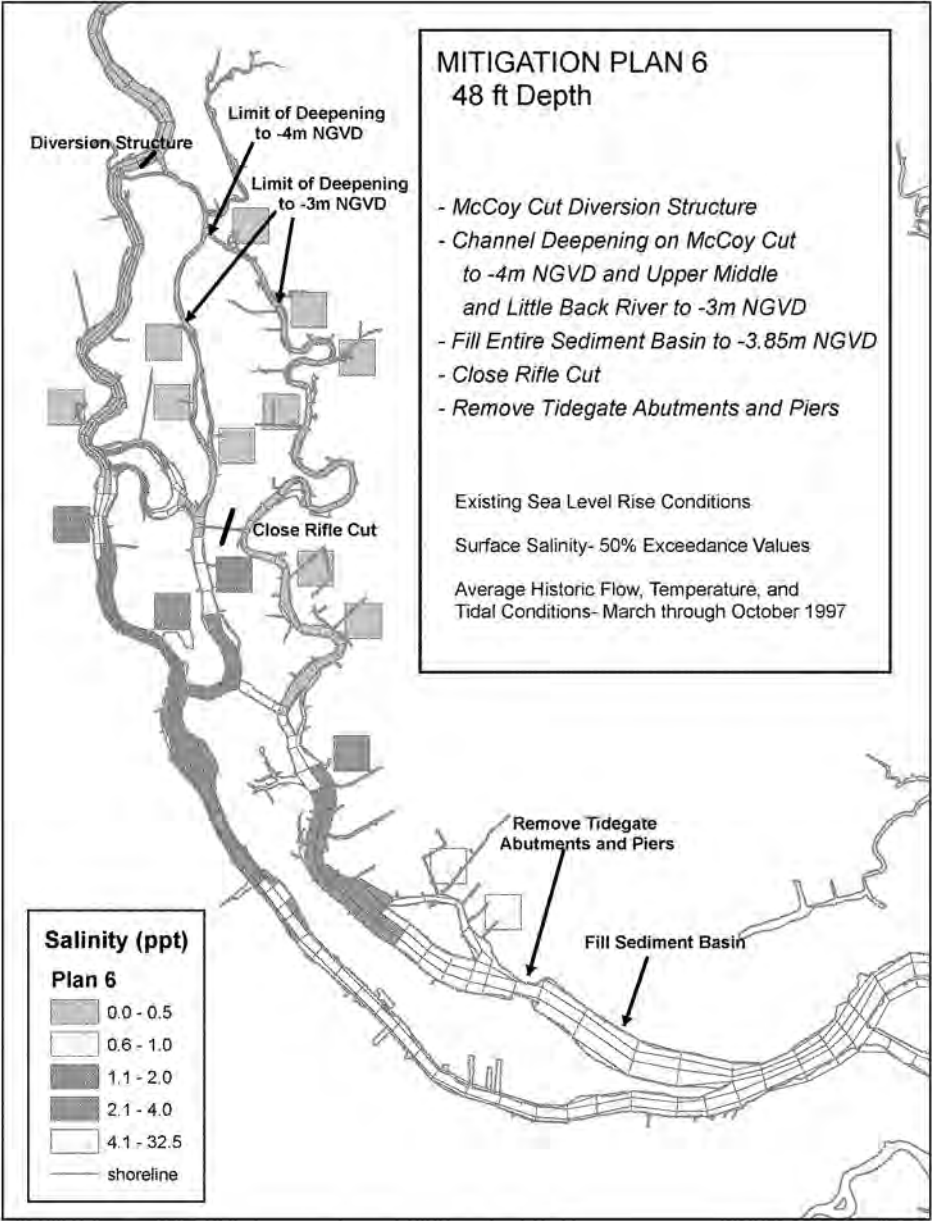


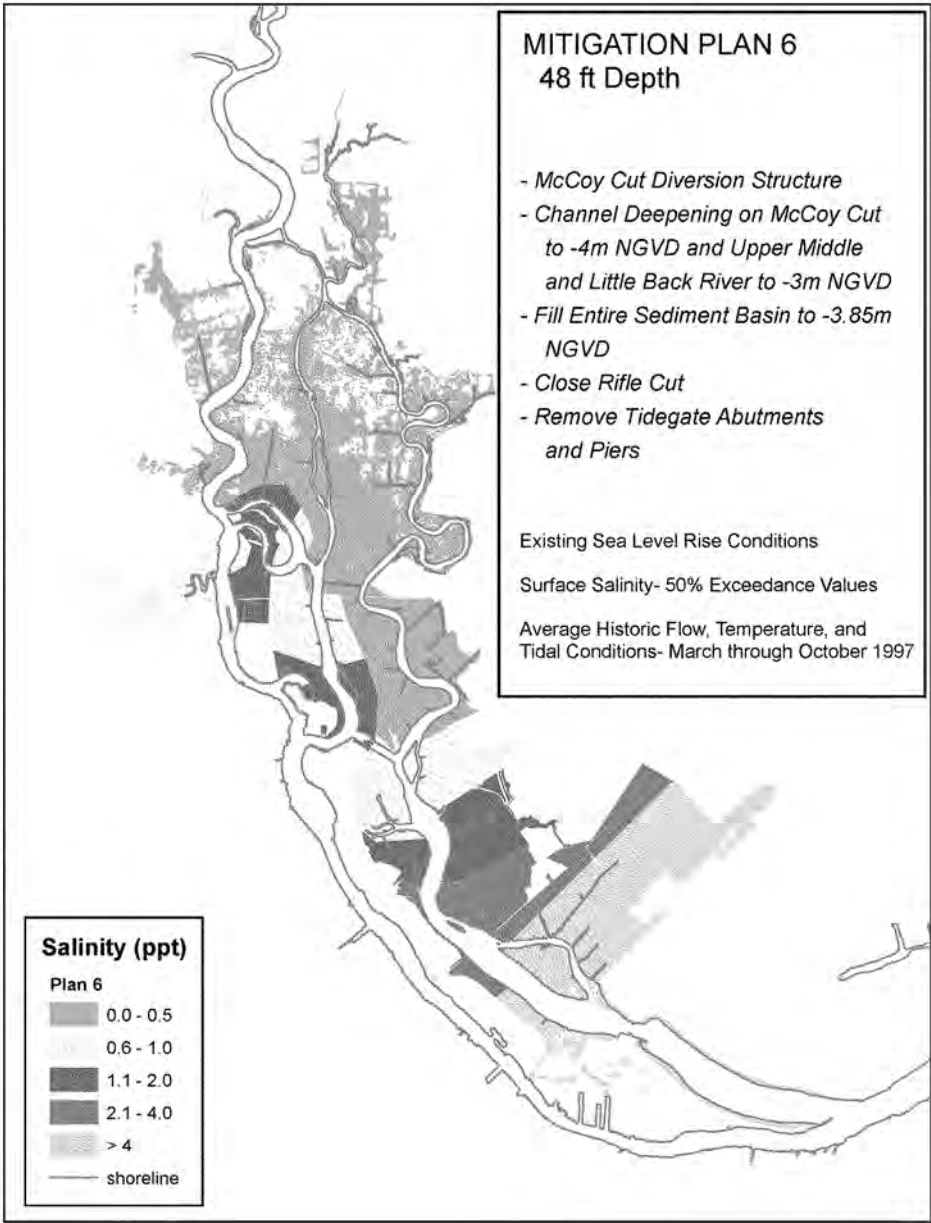


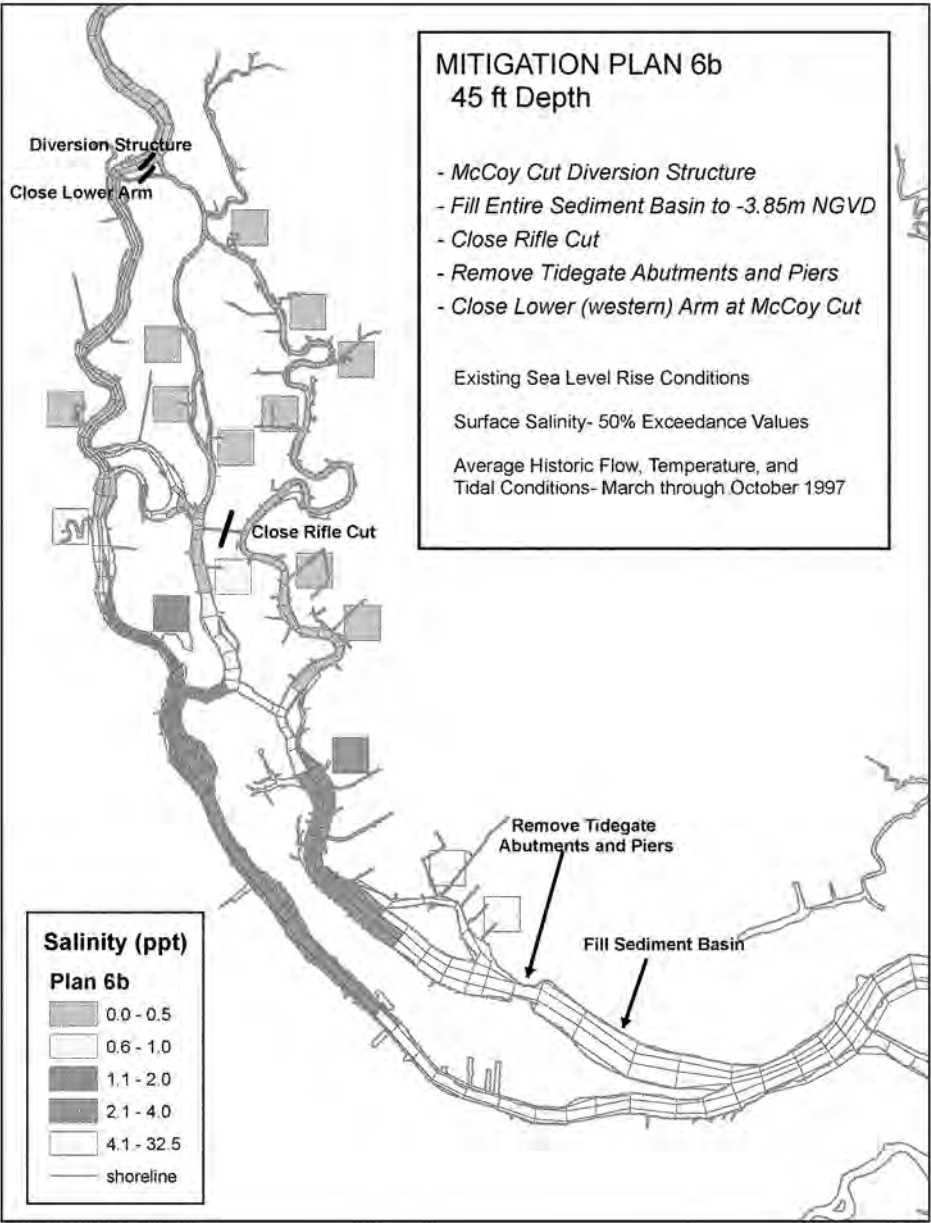


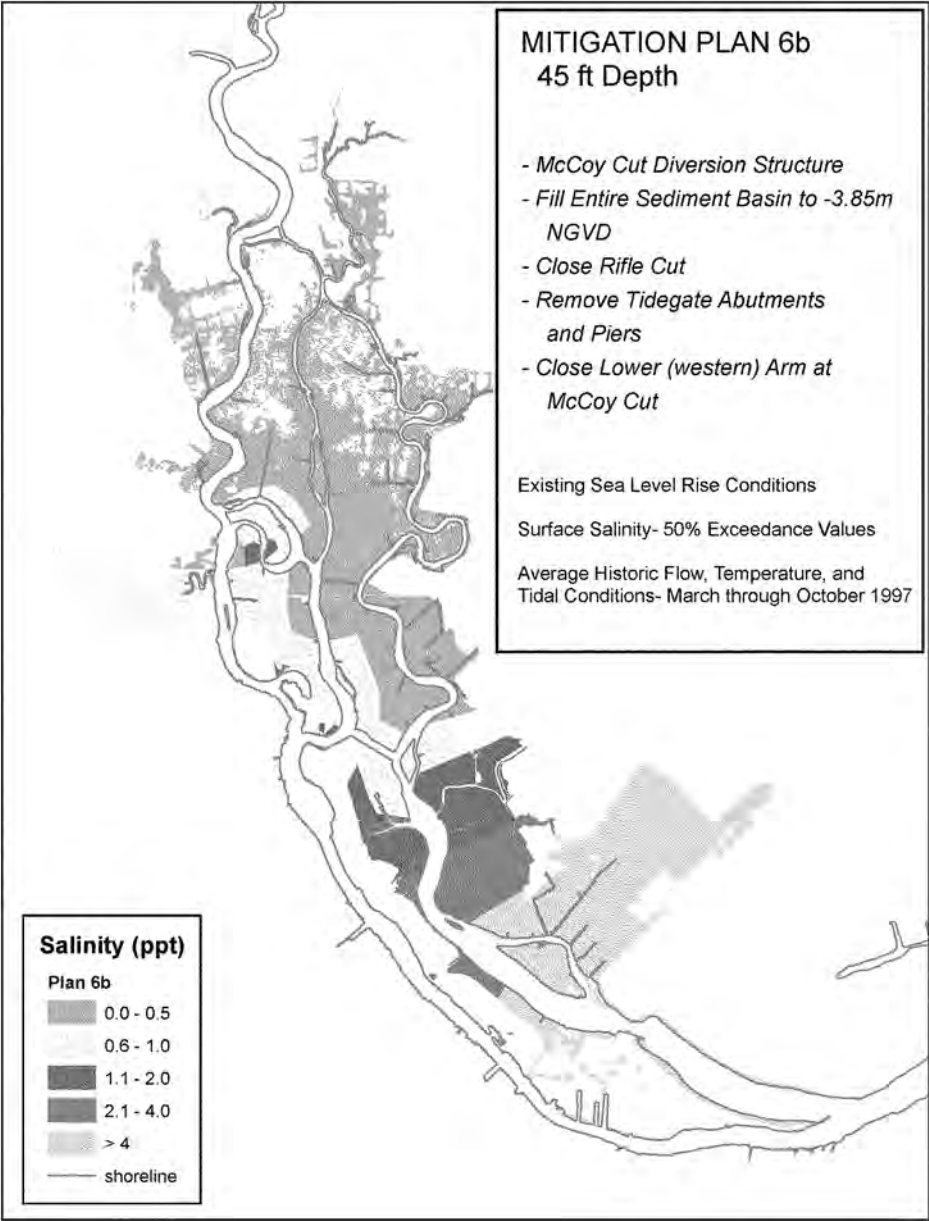


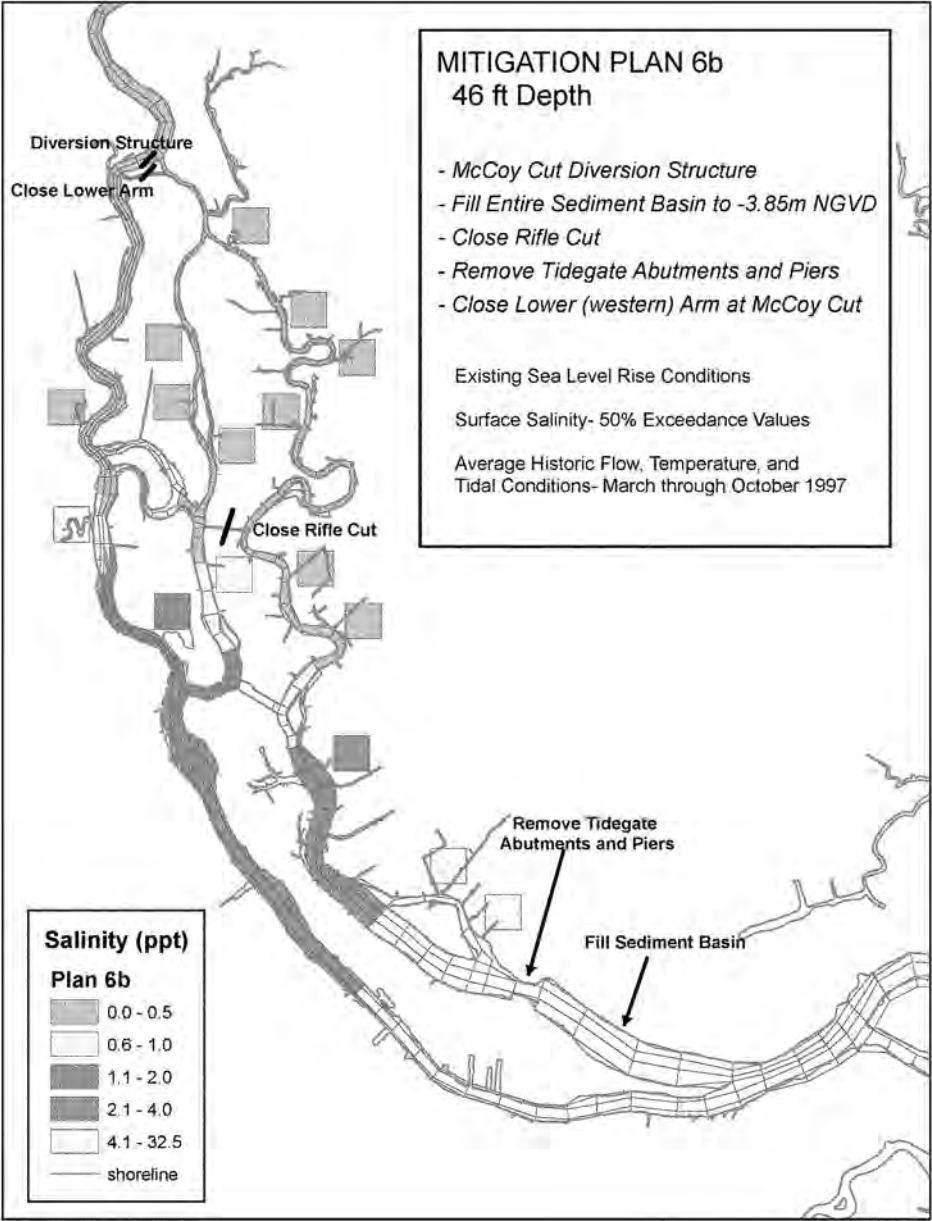


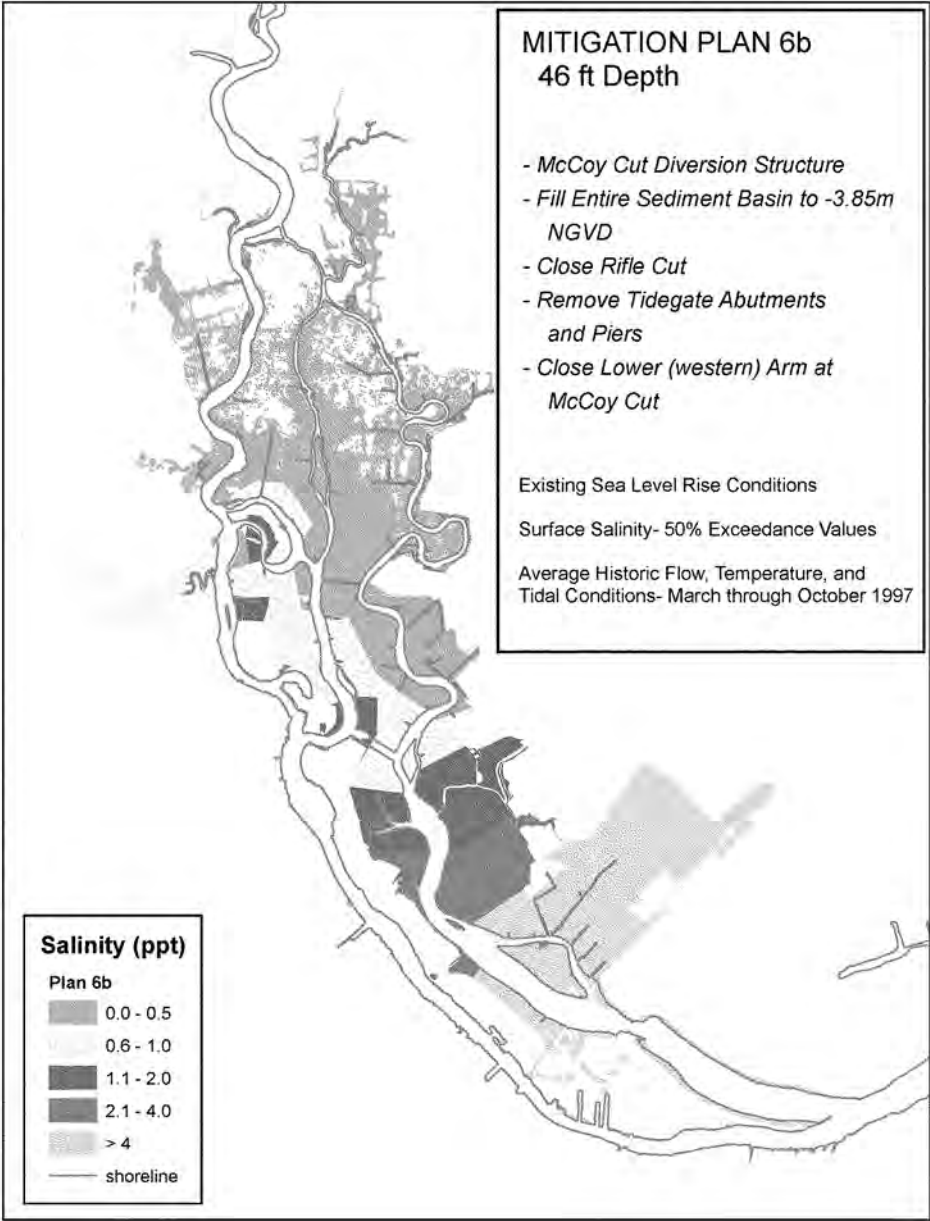


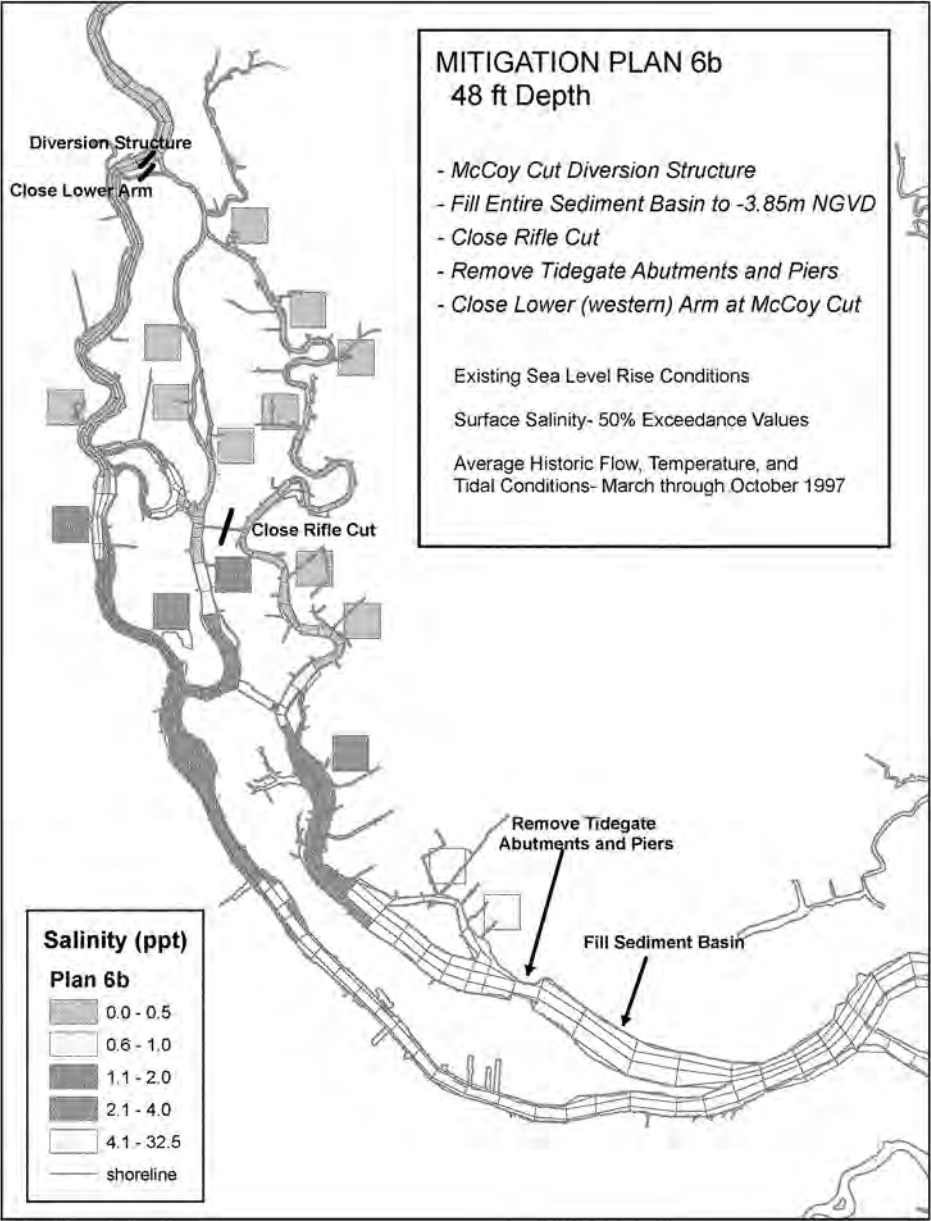


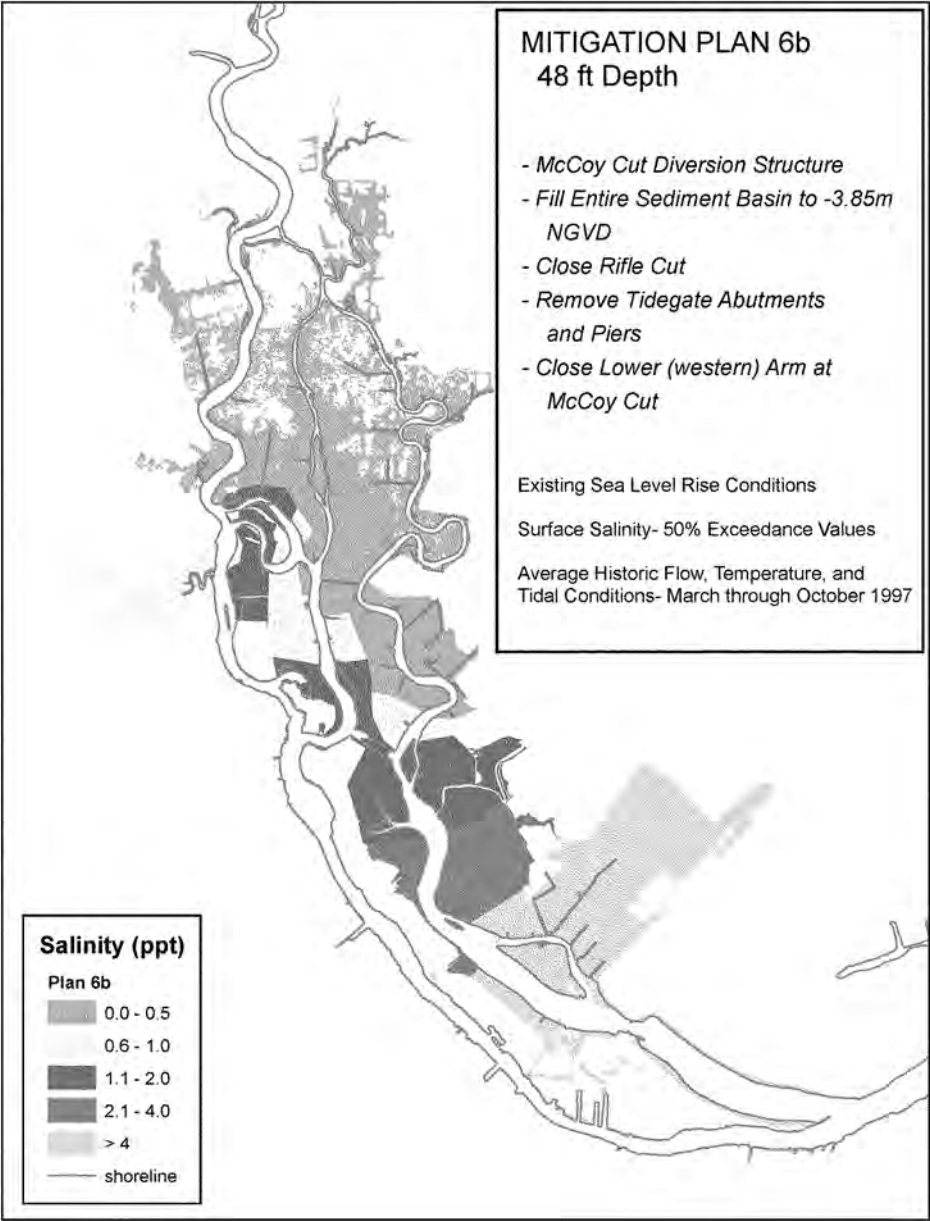


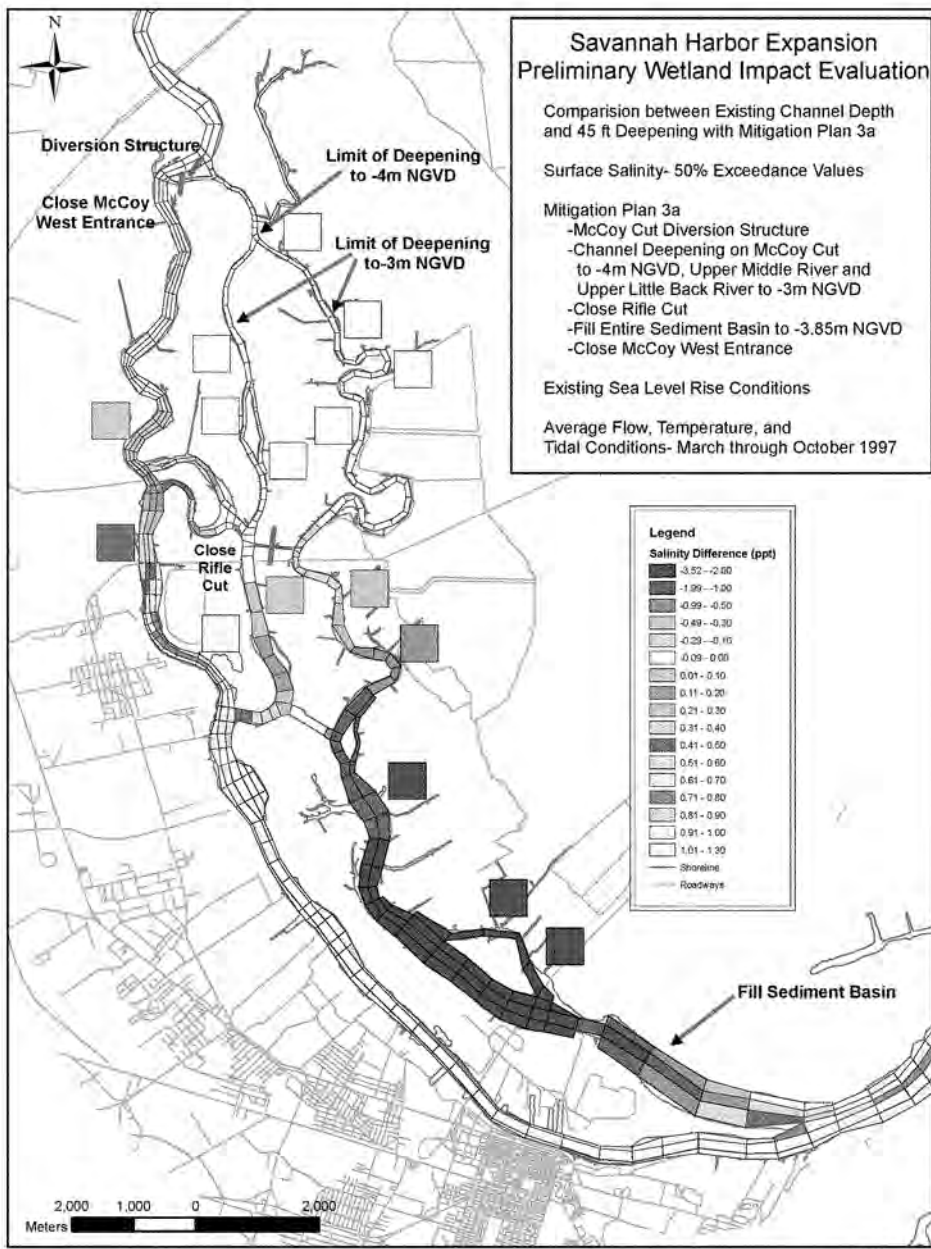


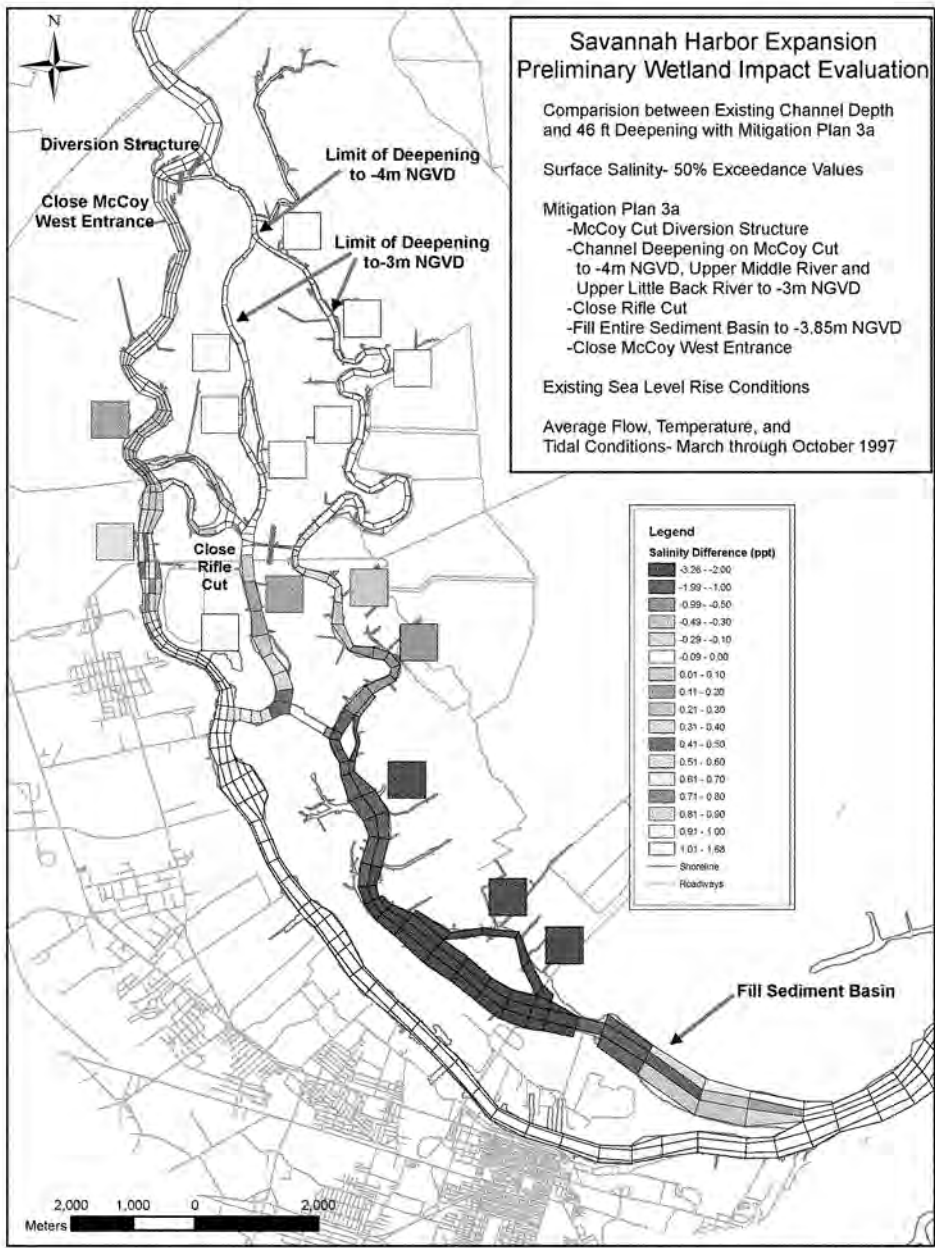


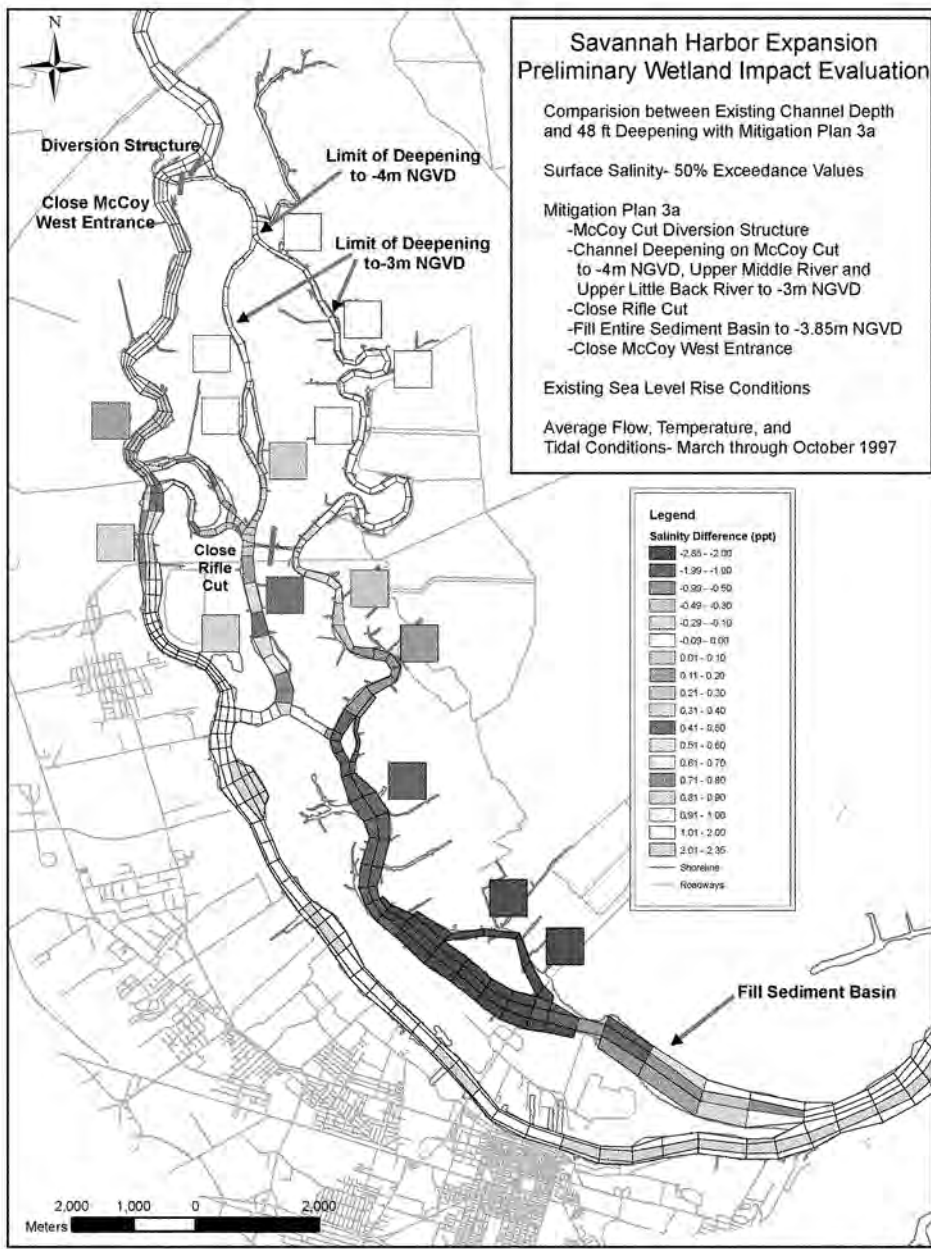


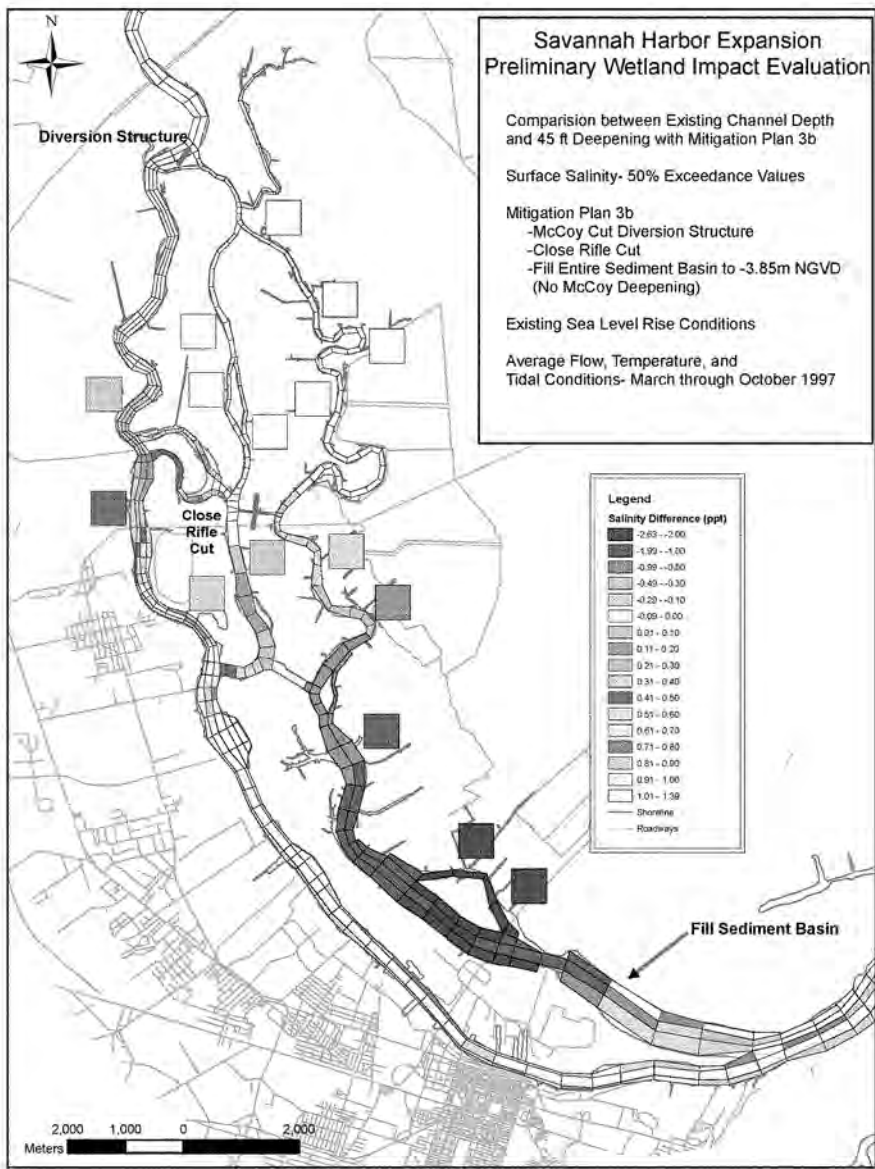




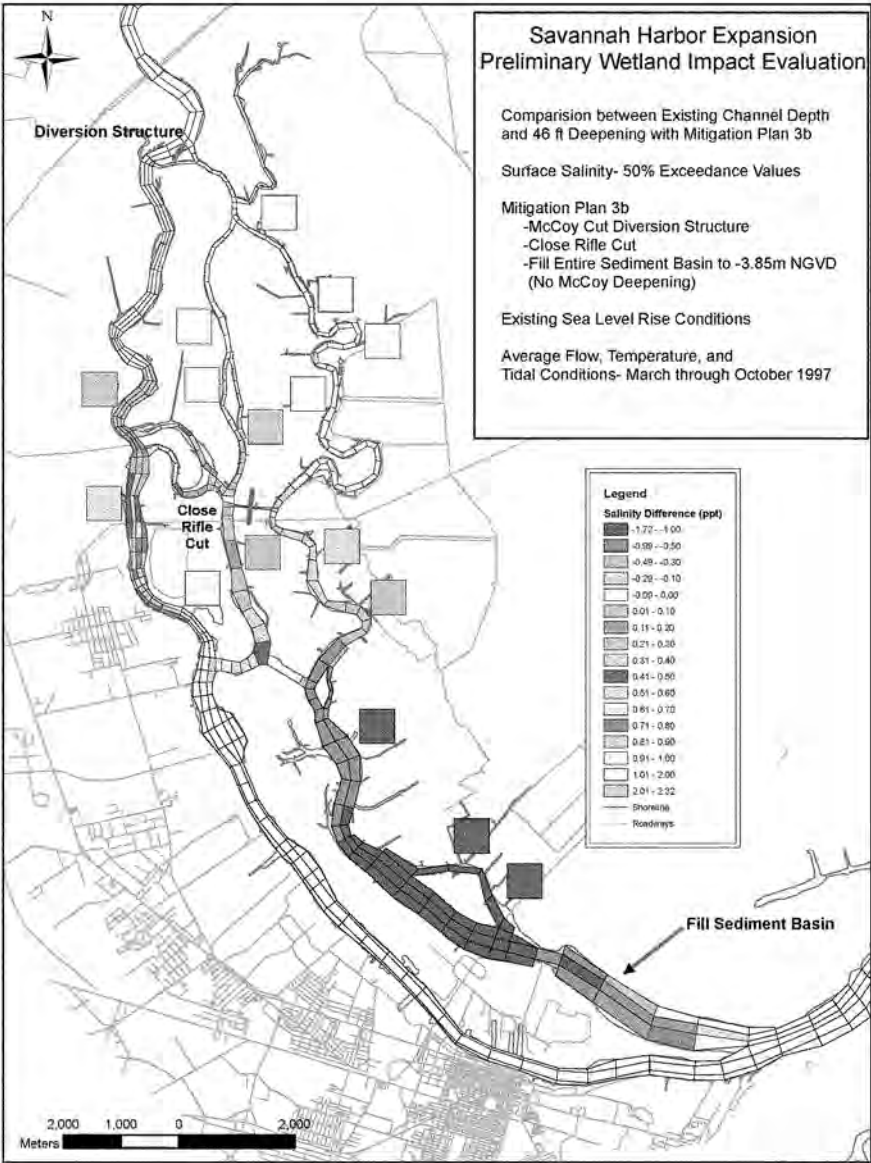


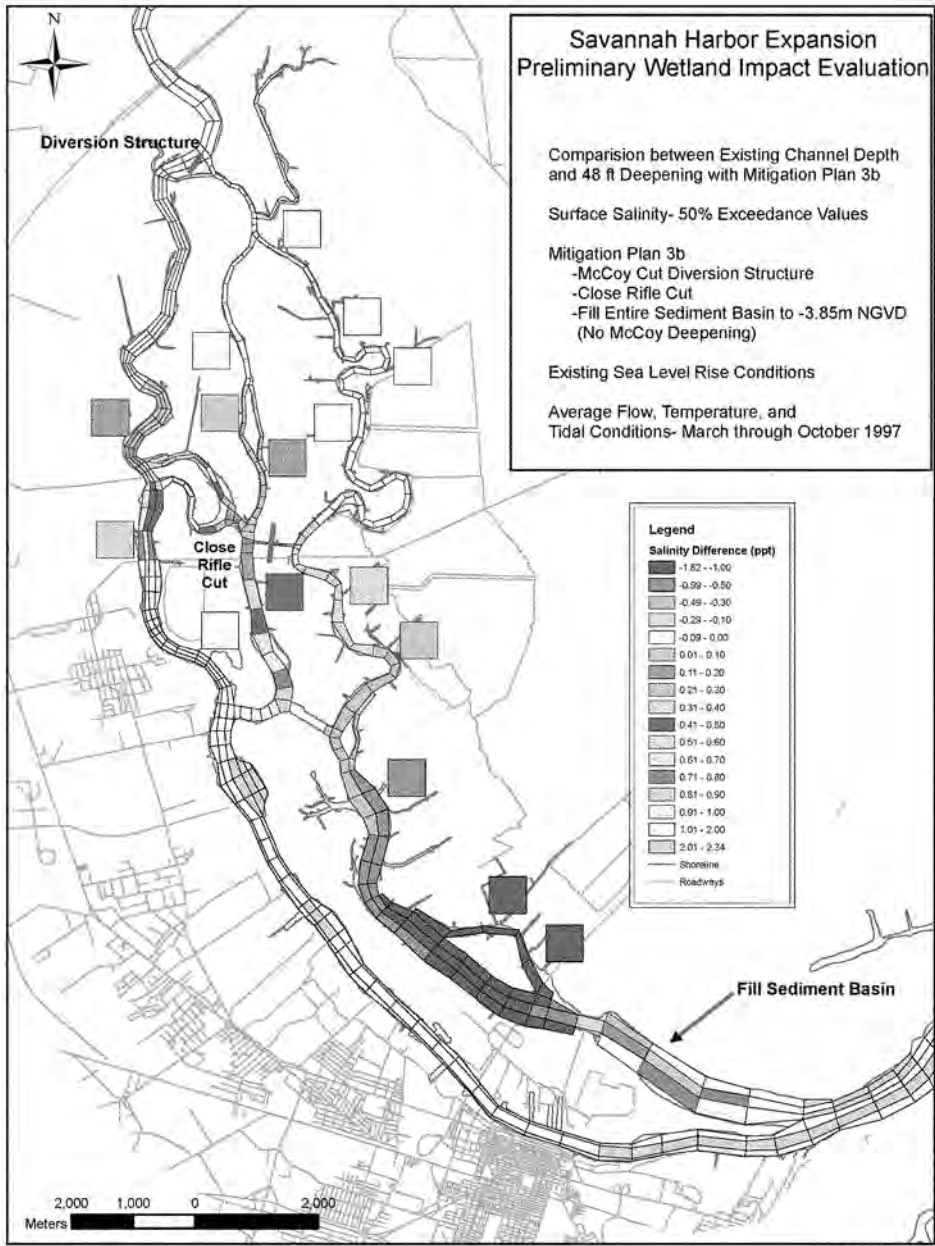


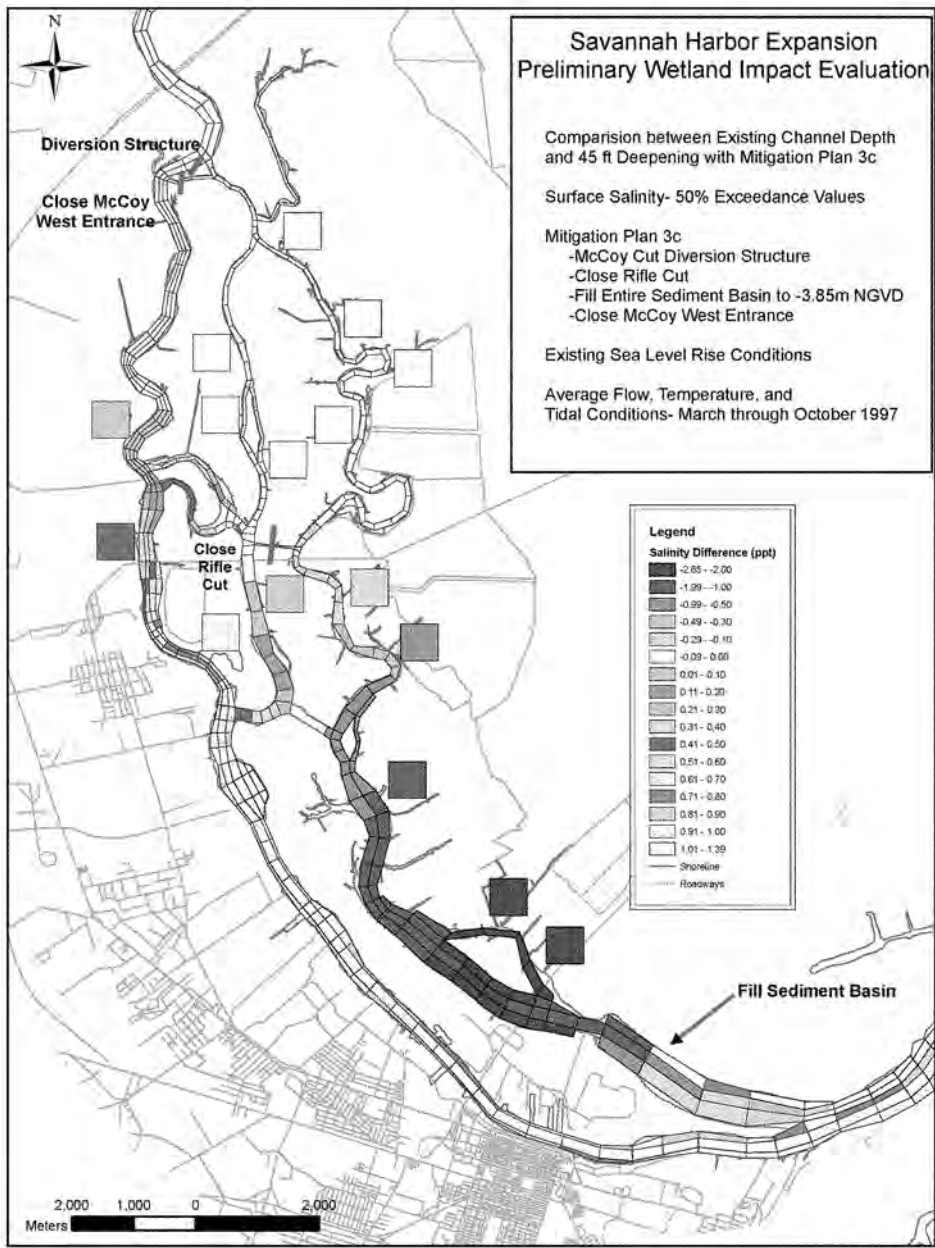


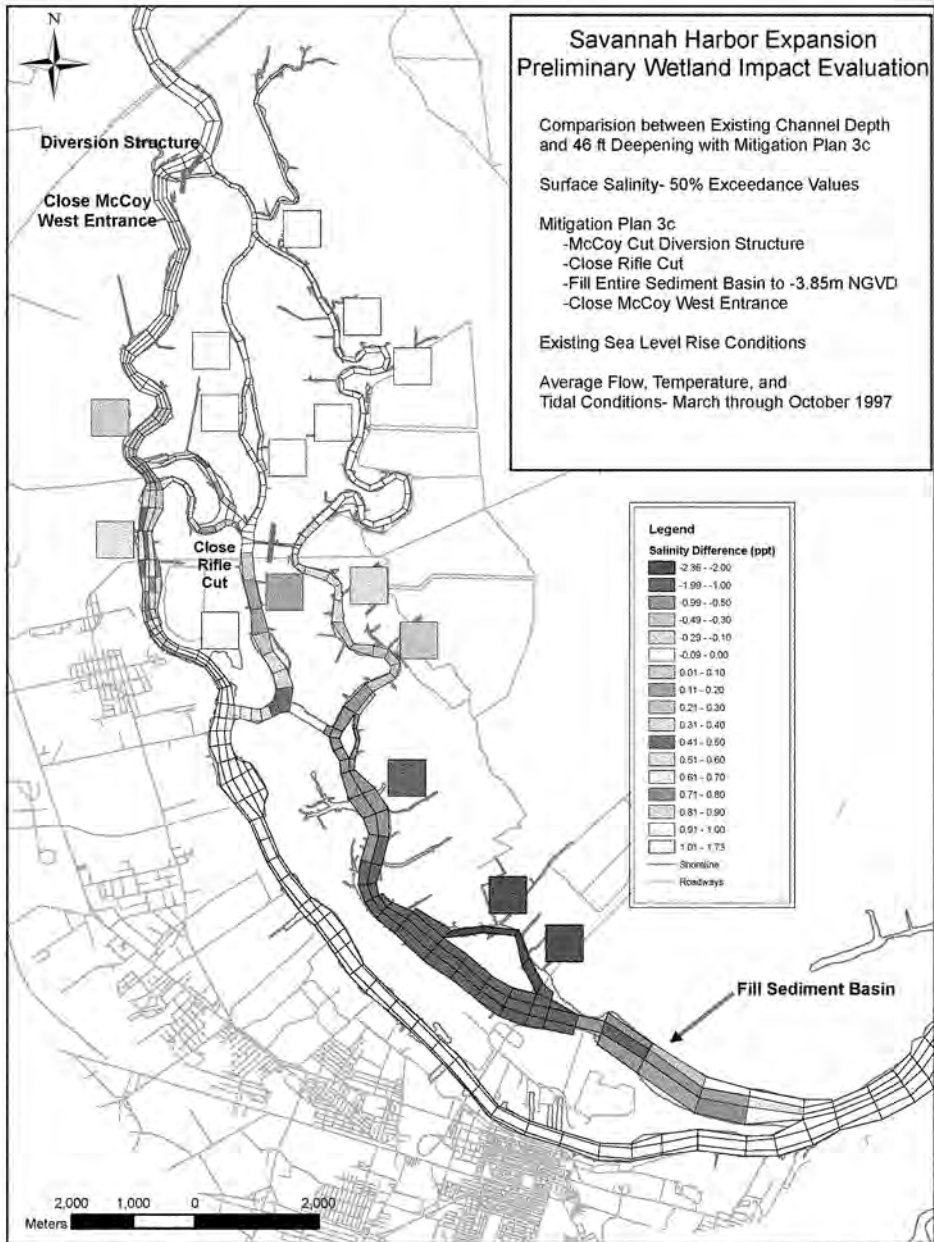


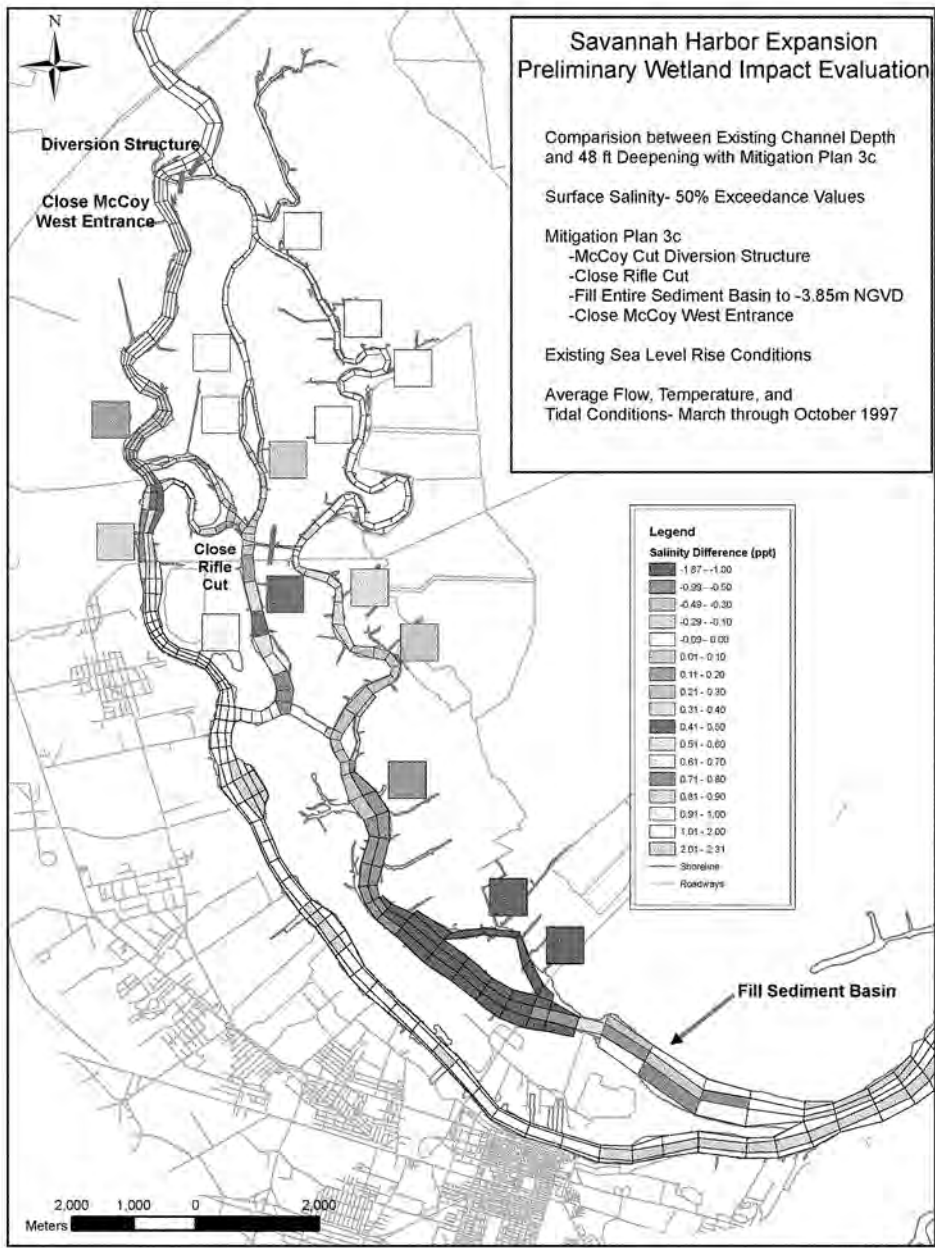
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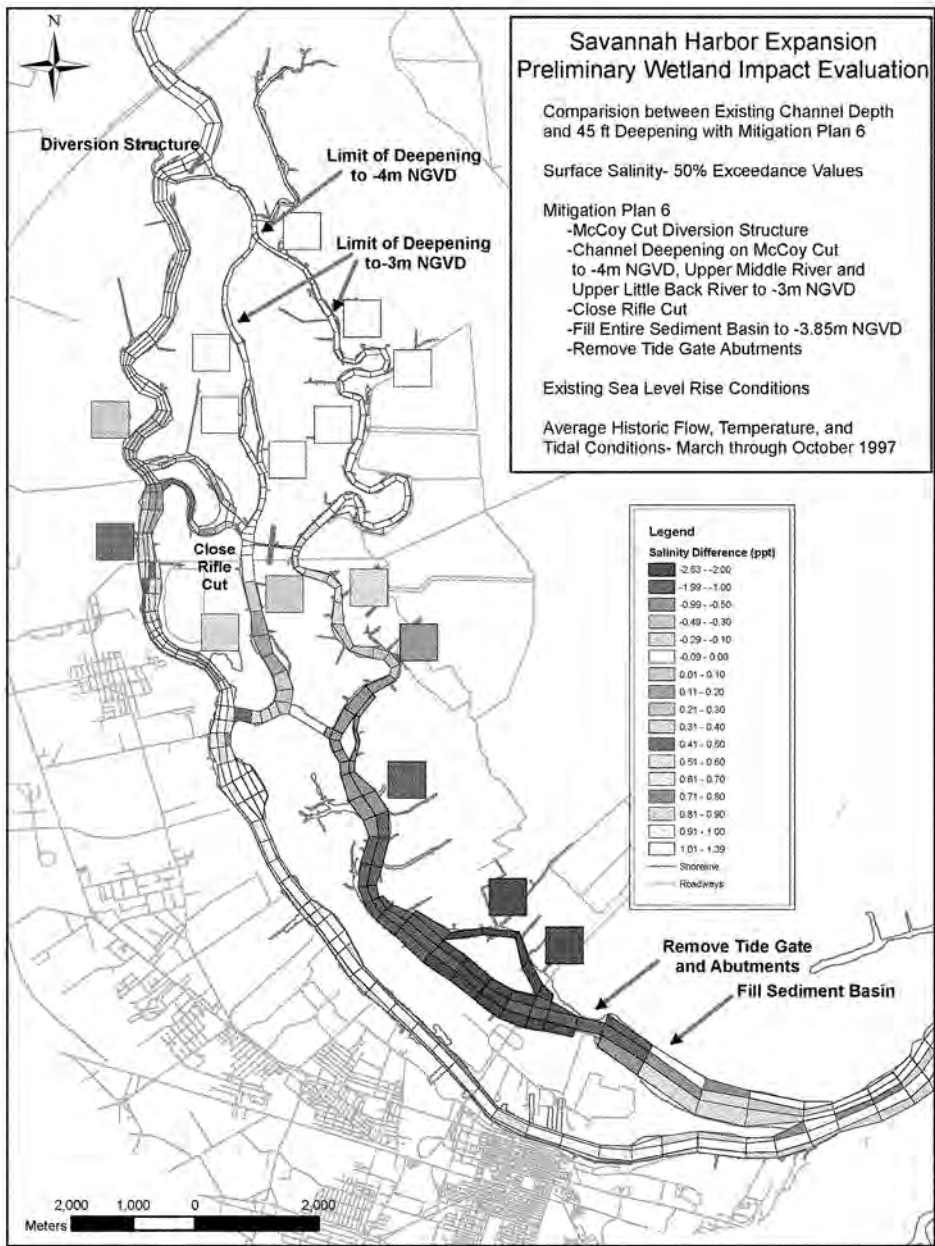




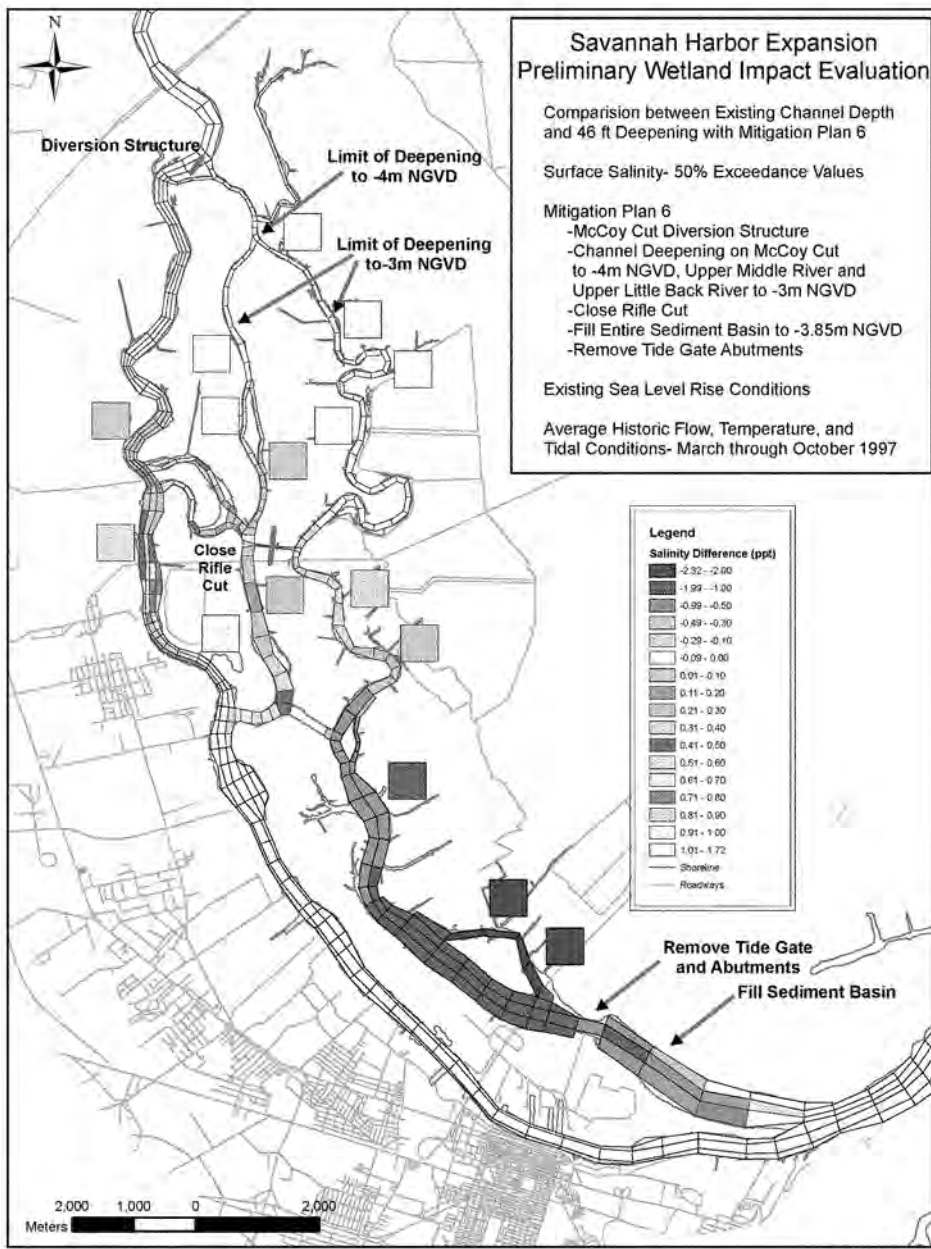


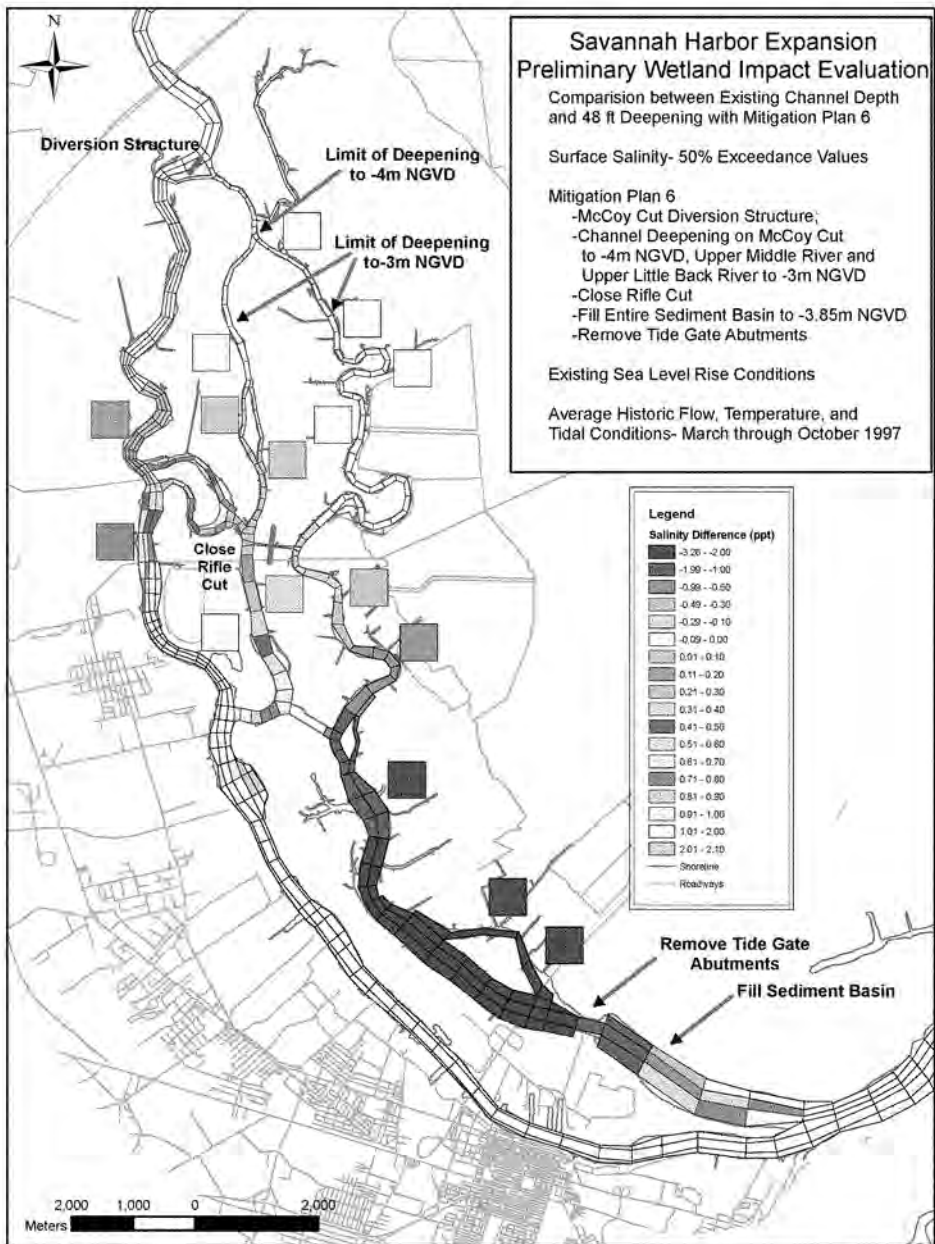




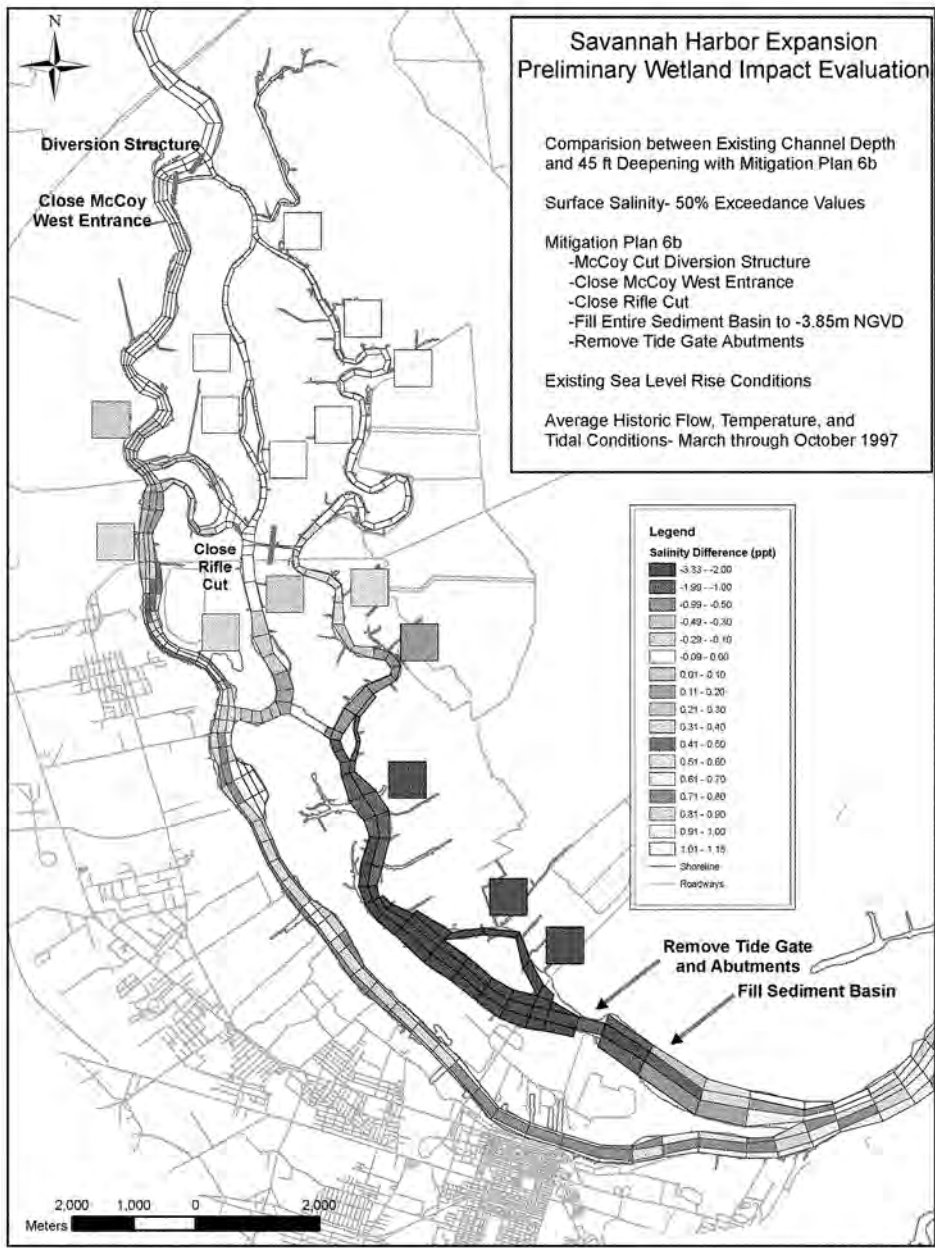


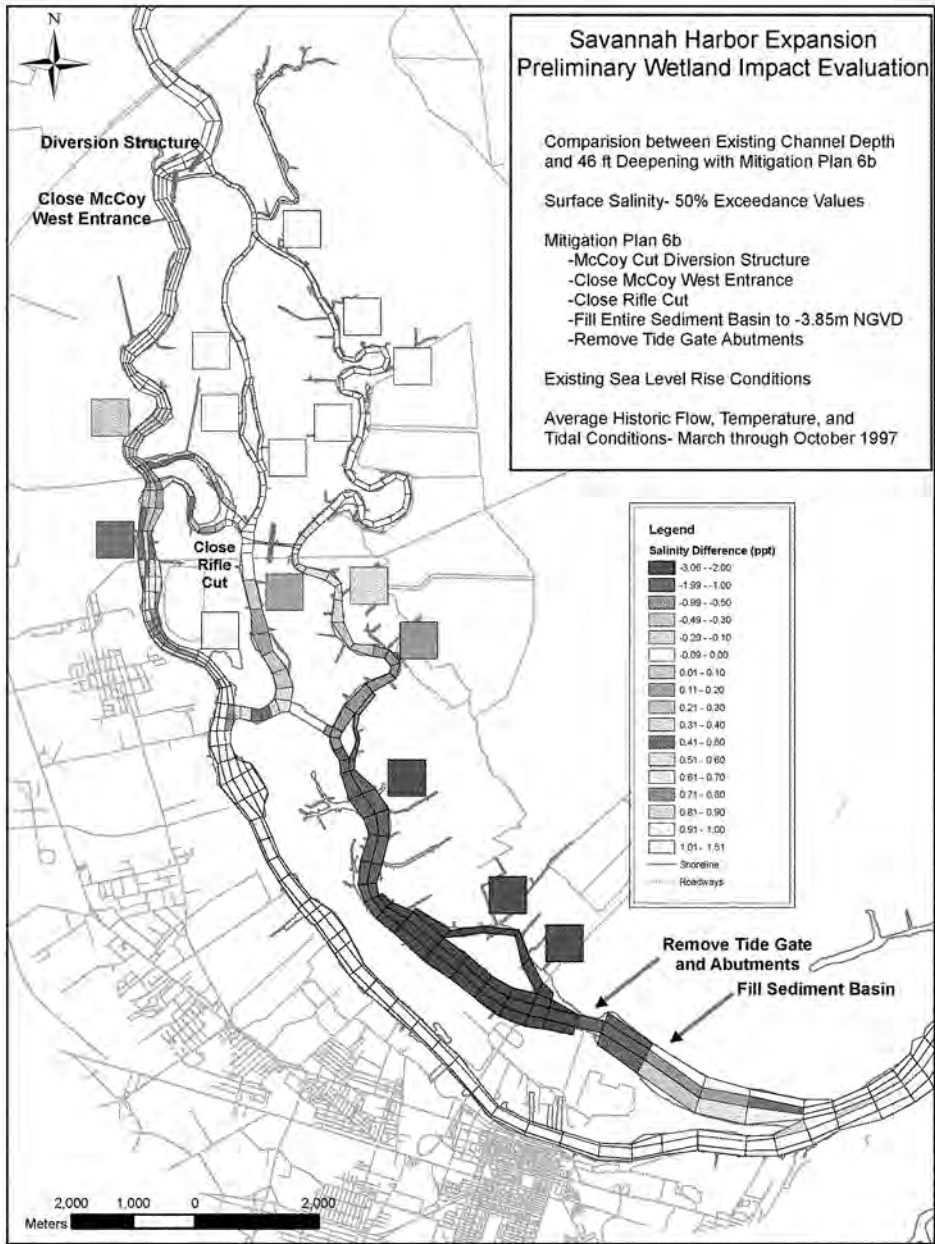
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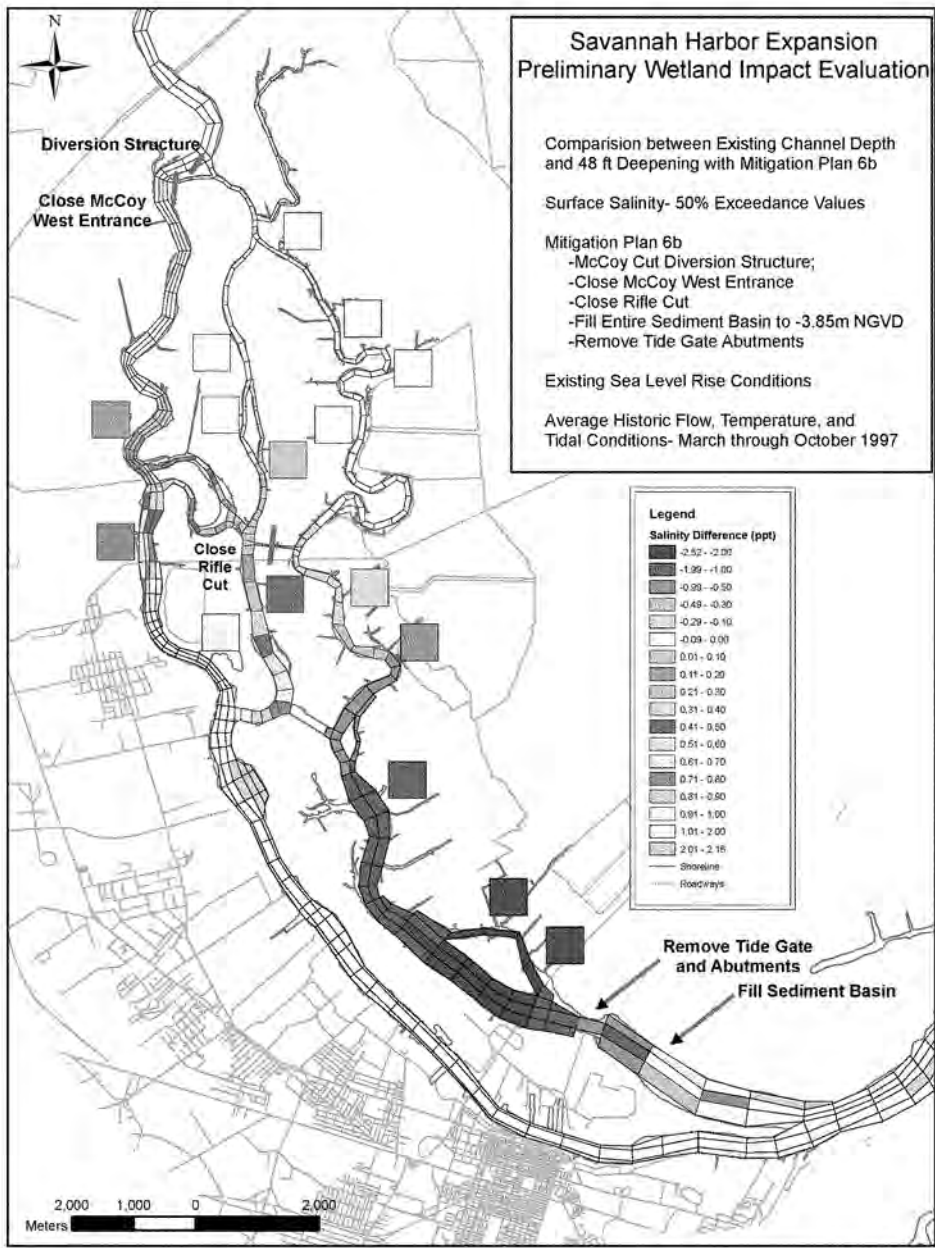




July 2007









Savannah Harbor Expansion Project

***Evaluation of Marsh/Wetland Impacts
Plan 6a ONLY***

August 2007

Introduction

This report summarizes the results of marsh impacts with implementation of one mitigation alternative and navigation channel deepening. One additional mitigation alternative is presented and has been evaluated under three possible navigation channel depths (48 ft, 46 ft, and 45 ft).

The mitigation plan was evaluated using the 3D hydrodynamic model EFDC. The run period is March through October 1997. This time period is representative of average historic flow, temperature, and tidal conditions. The effects of sea level rise have NOT been evaluated in this report. The parameter evaluated is the 50 % exceedance surface salinity value throughout the model grid. The run period and parameters were specified by the Interagency Coordination Team.

Plan Description

One additional mitigation plan was modeled to determine the effectiveness in reducing salinity impacts to freshwater marsh due to deepening the navigation channel. Mitigation Plans 1-6b were evaluated prior to the plan presented here. The additional mitigation plan presented here is Plan 6a. Below is a brief description of Plan 6a and a graphic showing the features of Plan 6a and several other mitigation plans evaluated prior to this report.

Plan 6a

- McCoy's Cut Diversion Structure
- Channel Deepening on McCoy's, Upper Middle and Little Back River
- Fill Entire Sediment Basin
- Close Rifle Cut
- Remove Tidegate Abutments and Piers
- Close Lower (western) Arm at McCoy Cut

	McCoy Cut Diversion Structure	Channel Deepening on McCoy's, Upper Middle and Little Back River	Fill Entire Sediment Basin	Close Rifle Cut	Close Lower (western) Arm at McCoy Cut	Remove Tidegate Abutments and Piers	
Plan 3	x	x	x	x			Plan 3
Plan 3a	x	x	x	x	x		Plan 3a
Plan 3b	x		x	x			Plan 3b
Plan 3c	x		x	x	x		Plan 3c
Plan 6	x	x	x	x		x	Plan 6
Plan 6a	x	x	x	x	x	x	Plan 6a
Plan 6b	x		x	x	x	x	Plan 6b

*For additional details about Plans 3a, 3b, 3c, 6 & 6b please refer to report Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts with Additional Mitigation Plans dated August 2007

Output Presented

There are three types of maps presented in this report:

- 1- **Predicted River Salinity from the Hydrodynamic Model (EFDC)**- The EFDC model grid is shown with 50% exceedance surface salinities broken into 5 categories: 0-0.5 ppt, 0.6-1.0 ppt, 1.1-2.0 ppt, 2.1-4.0 ppt, 4.0-32.5 ppt. Modeling is based on average historic flow, temperature, and tidal conditions- March through October 1997. The effects of sea level rise have NOT been evaluated in this report.
- 2- **Estimated Marsh Salinity Contour Lines**- Marsh salinity contour lines are shown that break the marsh into 5 categories: 0-0.5 ppt, 0.6-1.0 ppt, 1.1-2.0 ppt, 2.1-4.0 ppt, > 4.0 ppt. The first category 0-0.5 ppt represents freshwater marsh. The contour lines were extrapolated into the marsh from the riverine hydrodynamic model results shown in the maps described above 1- *Predicted River Salinity from the Hydrodynamic Model*.
- 3- **Surface Salinity Difference Maps**- Maps show the change in riverine salinity at each EFDC grid cell between the existing condition and each mitigation plan. Salinity values are predicted using the hydrodynamic model (EFDC). The grid cells are color coded to show the salinity differences. The grey shading is used to show cells that have lower salinity values than the existing condition (i.e. deepening impacts have been reduced to 0, and, in fact, show improvement over the existing condition).

Results

Results from the modeling are presented in the following table. The table shows estimated marsh salinity impacts based on the mapping described in 2-**Estimated Marsh Salinity Contour Lines** above. The acreages are valid within +/- 50 acres.

Table 1- Estimated Marsh Salinity Impacts- Plans 3, 6, 6a, and 6b

48 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 6 (acres)	Plan 6a (acres)	Plan 6b (acres)
0.0 – 0.5	4072	2860	3584	3715	3735	3610
0.6 – 1.0	864	830	786	1419	1340	885
1.1 – 2.0	555	1215	1587	1141	1191	1384
2.1 – 4.0	834	739	682	793	790	770
> 4	2506	3188	2213	1764	1776	2183

46 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 6 (acres)	Plan 6a (acres)	Plan 6b (acres)
0.0 – 0.5	4072	3015	3753	3817	3871	3610
0.6 – 1.0	864	1050	1298	1677	1650	1512
1.1 – 2.0	555	921	991	893	862	891
2.1 – 4.0	834	789	616	703	700	642
> 4	2506	3057	2174	1743	1749	2177

Table 1 (continued)- Estimated Marsh Salinity Impacts- Plans 3, 6, 6a, and 6b**45 ft Depth**

Estimated Marsh Salinity	Existing (acres)	Deepened Only —No Mitigation— (acres)	Plan 3 (acres)	Plan 6 (acres)	Plan 6a (acres)	Plan 6b (acres)
0.0 – 0.5	4072	3105	3718	4038	4040	3865
0.6 – 1.0	864	1319	1827	1835	1781	1459
1.1 – 2.0	555	630	732	559	588	774
2.1 – 4.0	834	906	763	712	745	589
> 4	2506	2873	1792	1689	1678	2145

Summary

In viewing and discussing the results of the mitigation plans it is important to remember the following:

- 1- The marsh impacts are evaluated by looking at the *net* acreage. This is especially important when discussing the impacts to freshwater marshes. The net acreage value is based on the conditions of the marsh after the project is in place. It does not take into consideration what the marsh salinity is under current conditions. For example, a mitigation plan may gain freshwater marsh on Back River and lose freshwater marsh on Front River. The net acreage may meet the impact criteria, but in reality, it may take some time for a marsh to convert from a brackish marsh to a freshwater marsh.
- 2- The model has a limited ability to evaluate specific design parameters of a true diversion structure. The diversion structure described in each of the plans was modeled by altering the Front River width just downstream of McCoys Cut. By narrowing the passage on Front River the water surface elevation at the mouth of McCoys Cut was increased. The rise in elevation encourages more water to go down McCoys Cut. EFDC does not have options for inserting a defined diversion structure but narrowing the River channel in this area is essentially what a diversion structure will do.

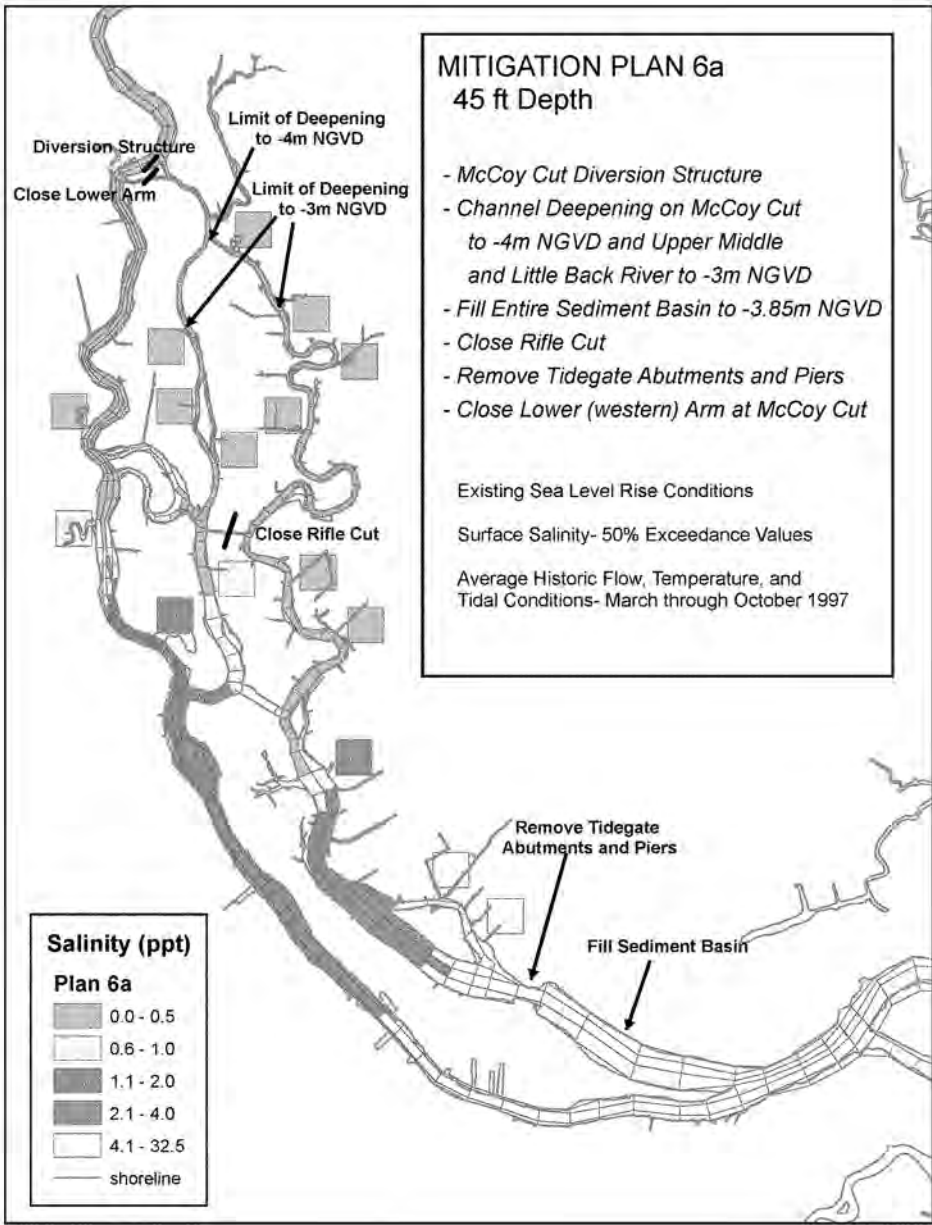
Several different "sizes" of diversion structures were evaluated during the development of the mitigation plans by varying the widths of the narrow passage on Front River. This allowed us to vary the amount of flow diverted down McCoys Cut. The structure modeled in Mitigation Plan 3, and each of the additional plans in this report, was found to be the most effective at diverting freshwater flows through McCoys Cut of the several different "sizes" evaluated. A future design task will be required to develop specifications for a diversion structure that performs as in the model simulation.

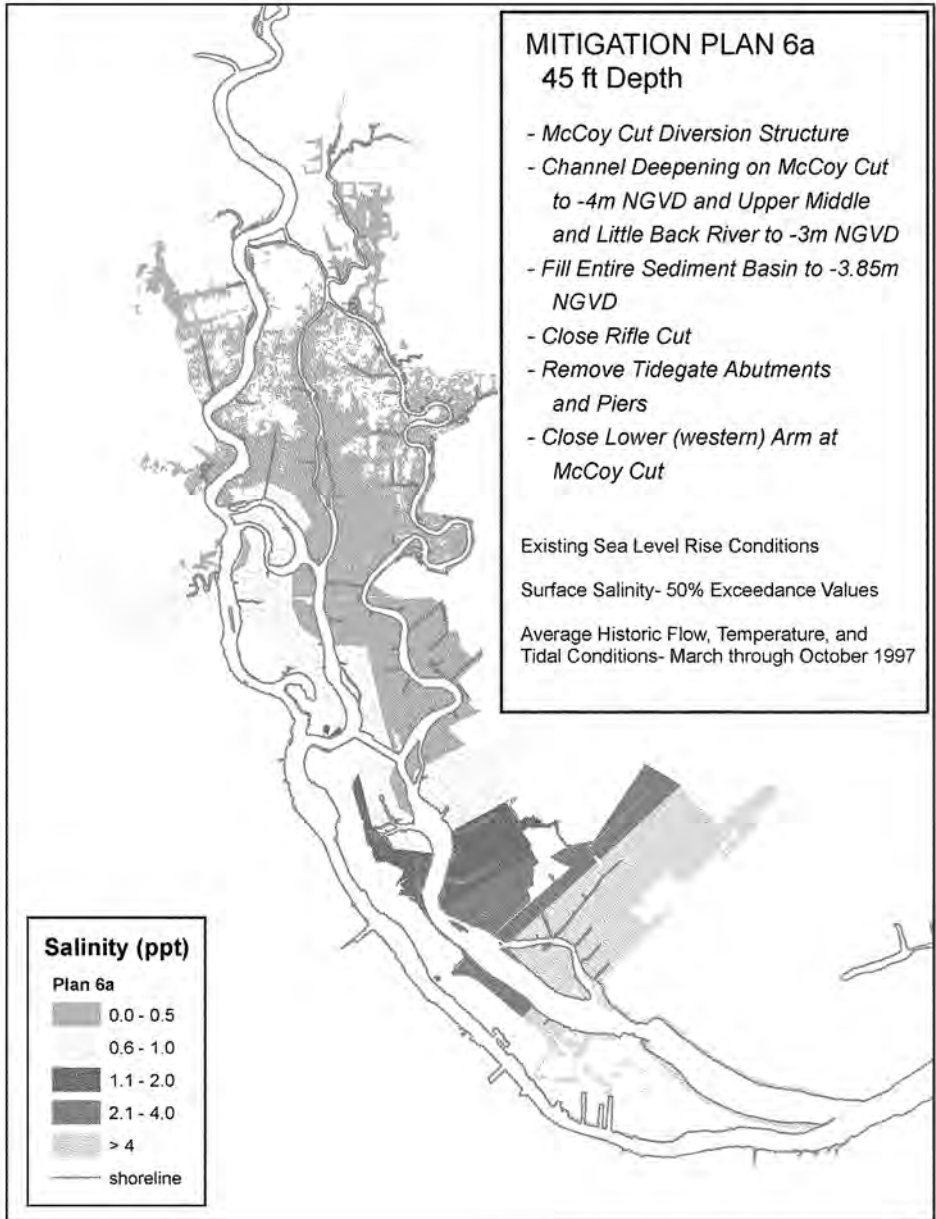
The evaluation of the mitigation plan included review of the effects the plan has on the tide range and velocities. It was concluded that each of the additional plan does not reduce the tide range significantly in Back River, Little Back River, or Middle River. Velocities for all the additional plans are close to existing conditions. However, as expected, removing the abutments and piers in Plans 6, 6a and 6b do increase velocities in Back River and Little Back River slightly above the existing condition.

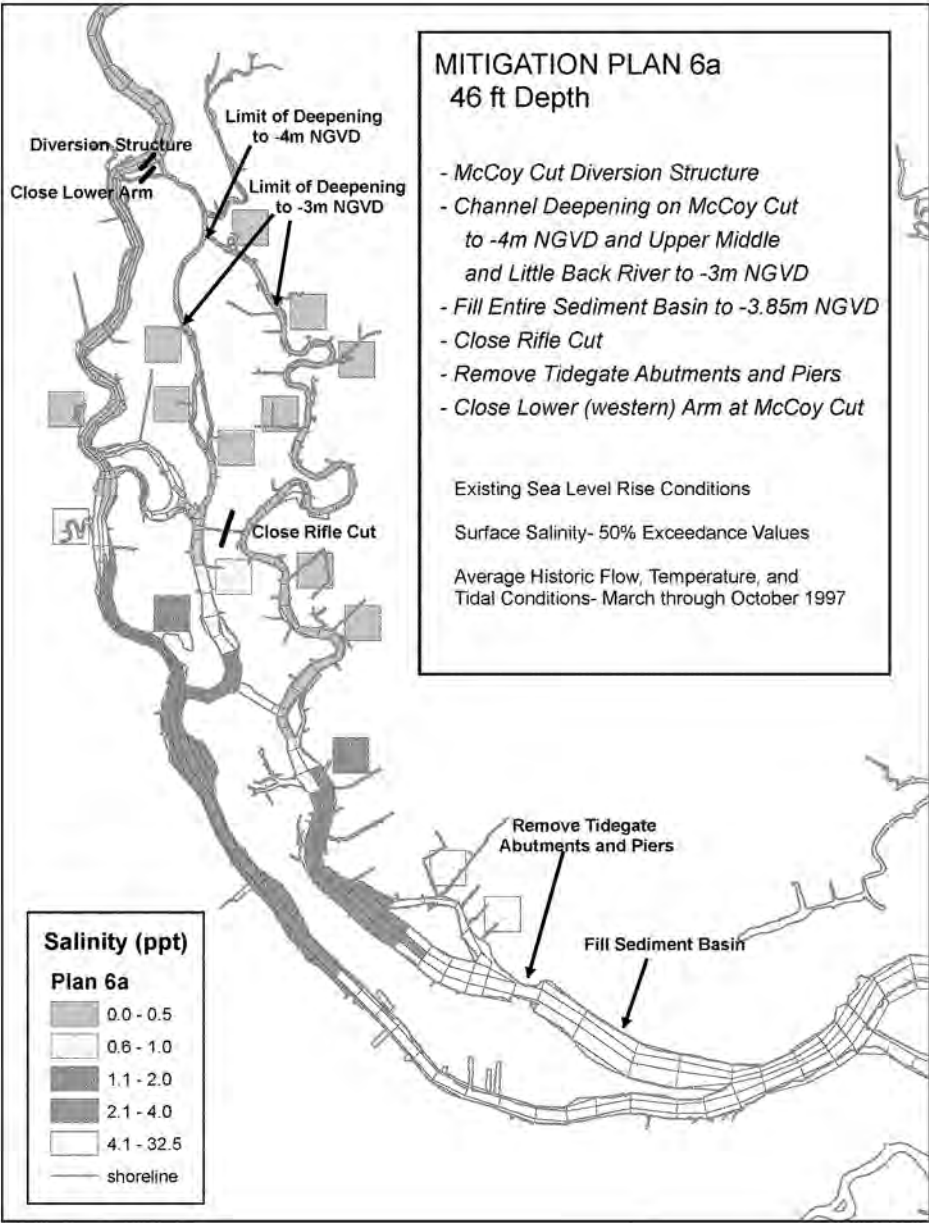
Plan 6a

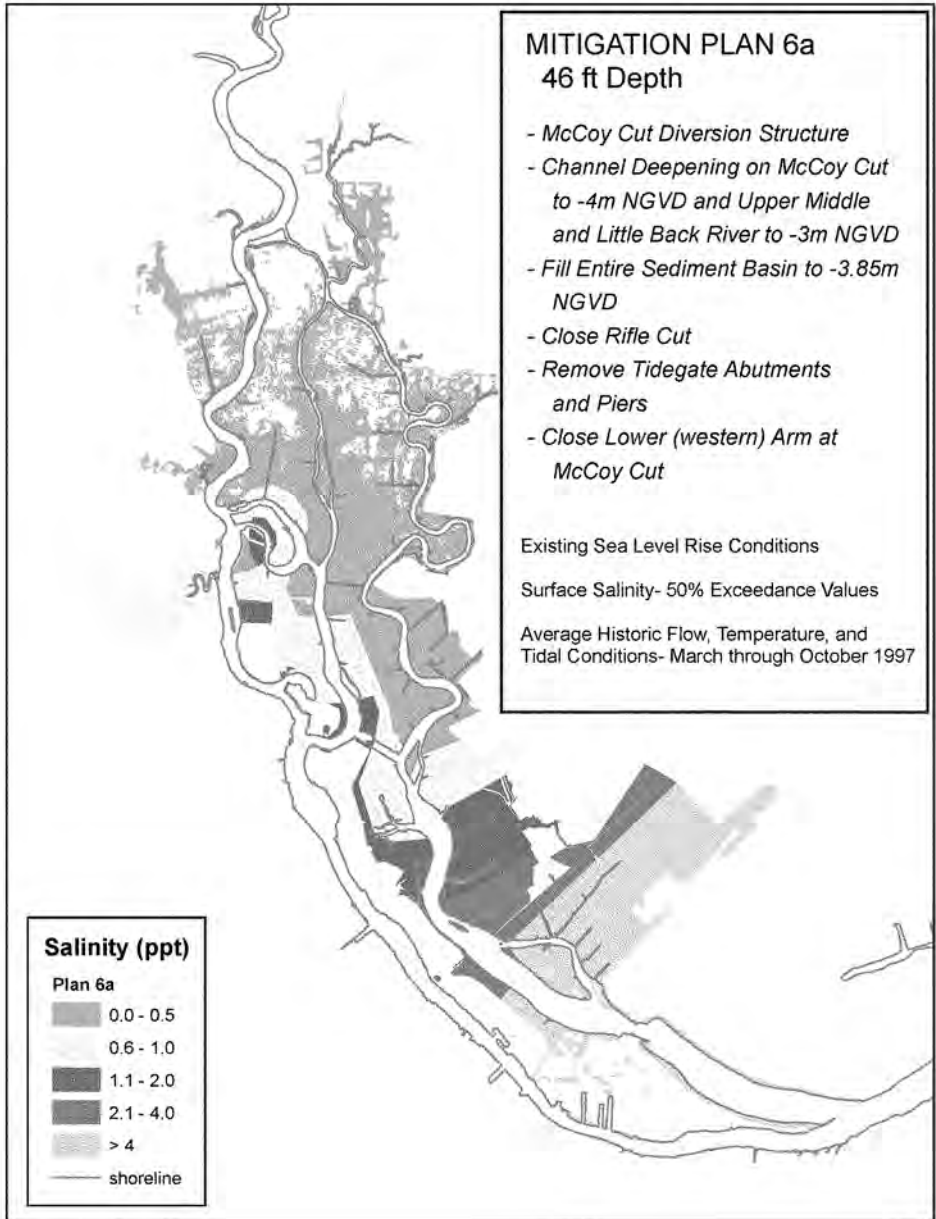
The results of Plan 6a are comparable to Plan 6. Salinity impacts are slightly reduced further than that of Plan 6. Closing the Lower (western) Arm at McCoy Cut does provided added benefits on Middle River, Back River and Little Back Rivers.

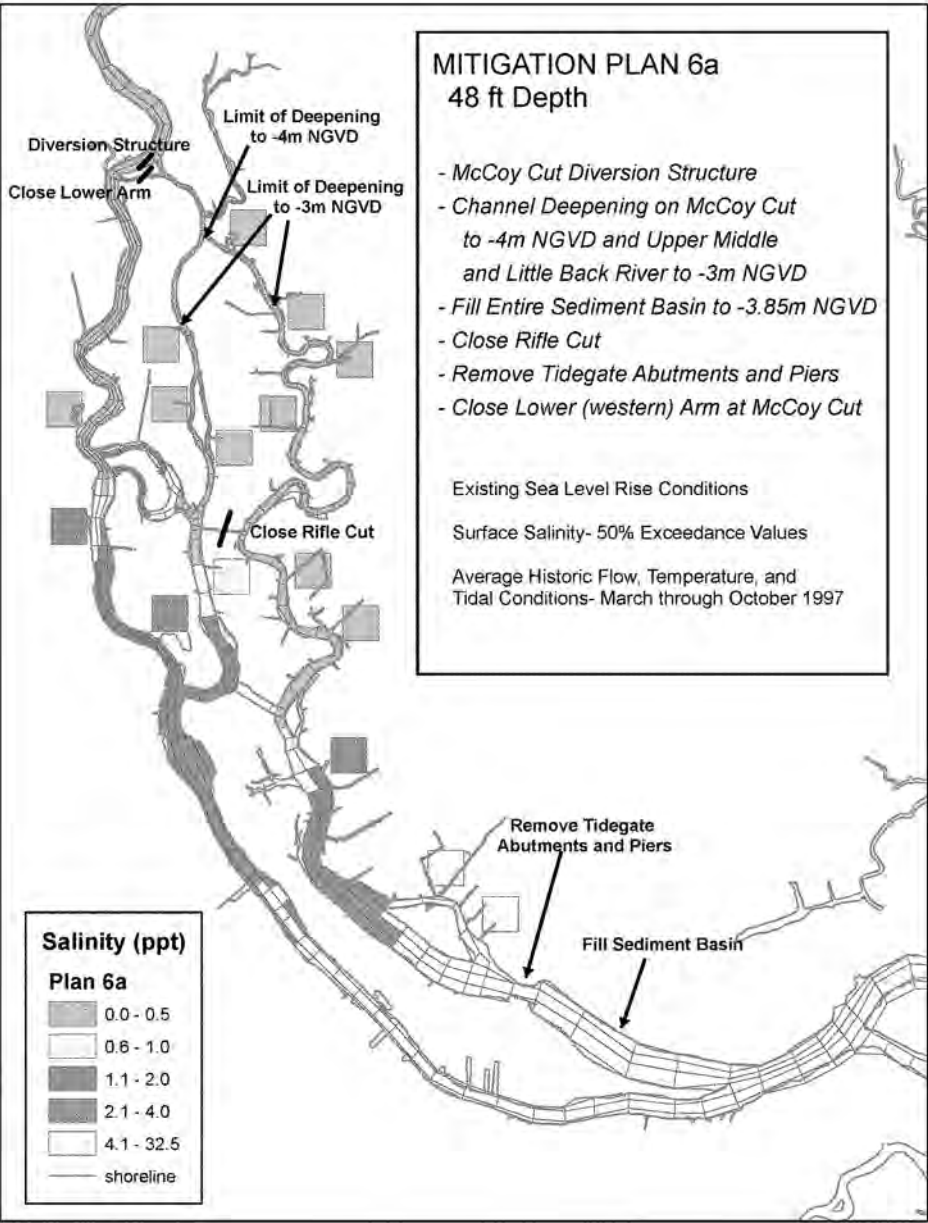
For additional details about Plans 3a, 3b, 3c, 6 & 6b please refer to report [Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts with Additional Mitigation Plans](#) dated August 2007.

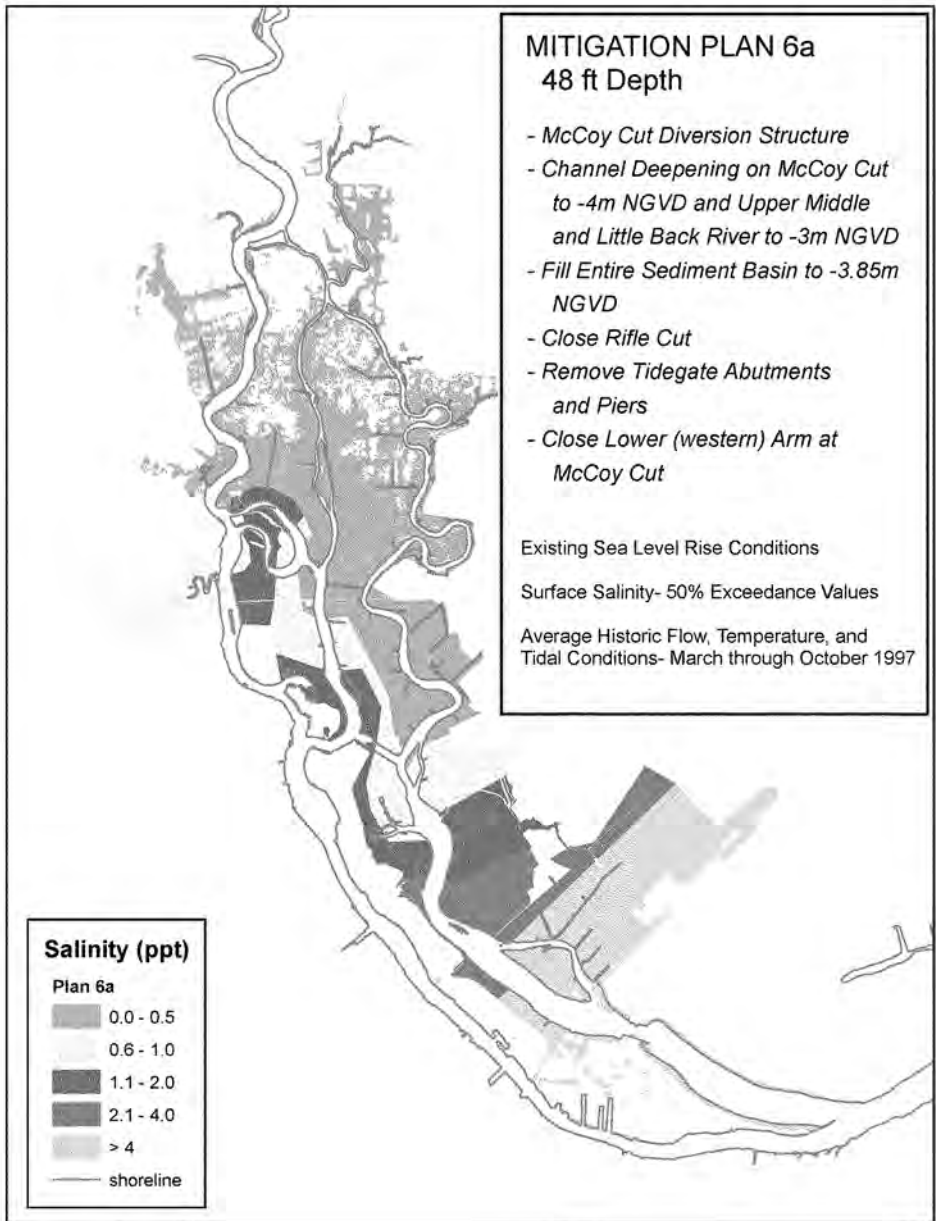


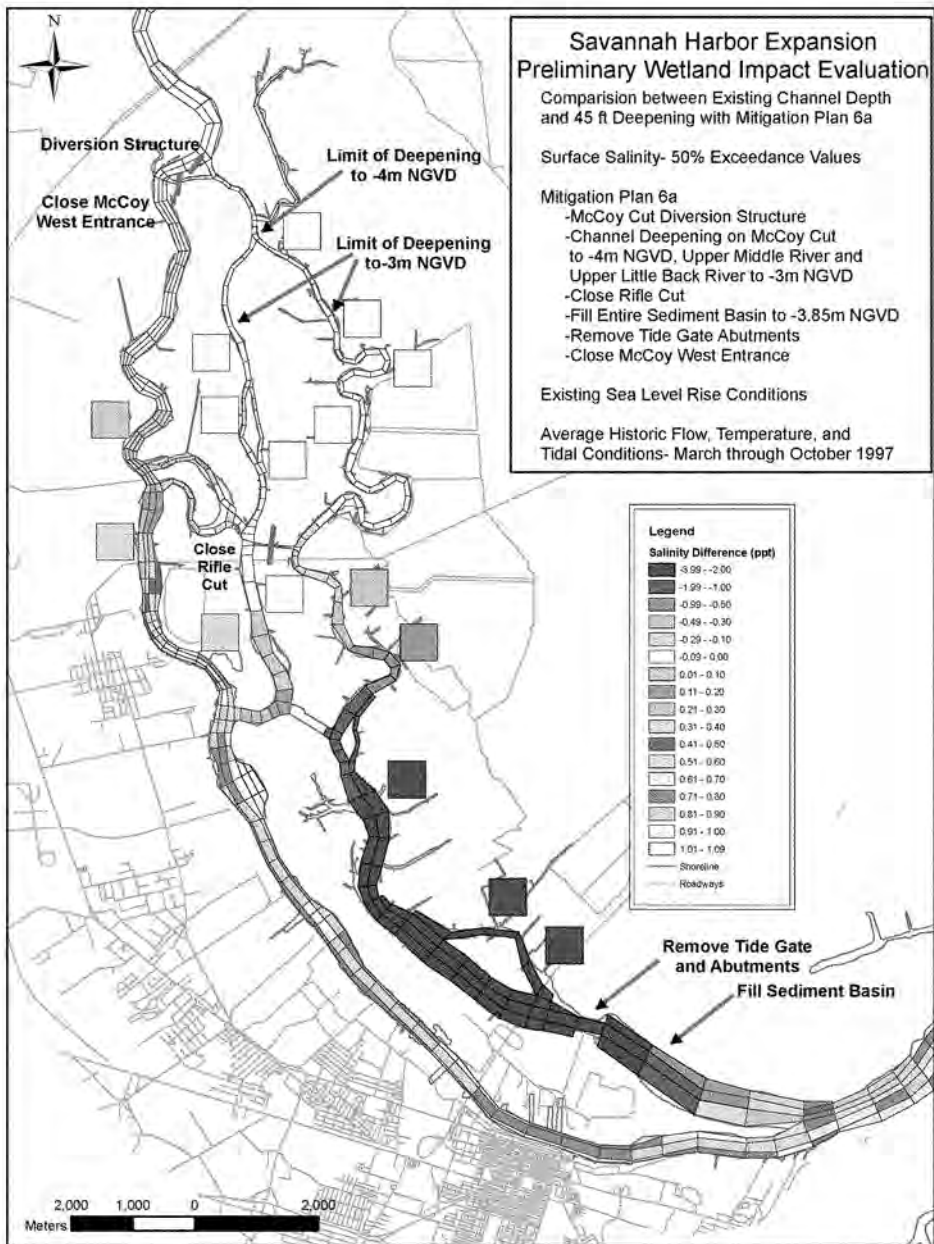


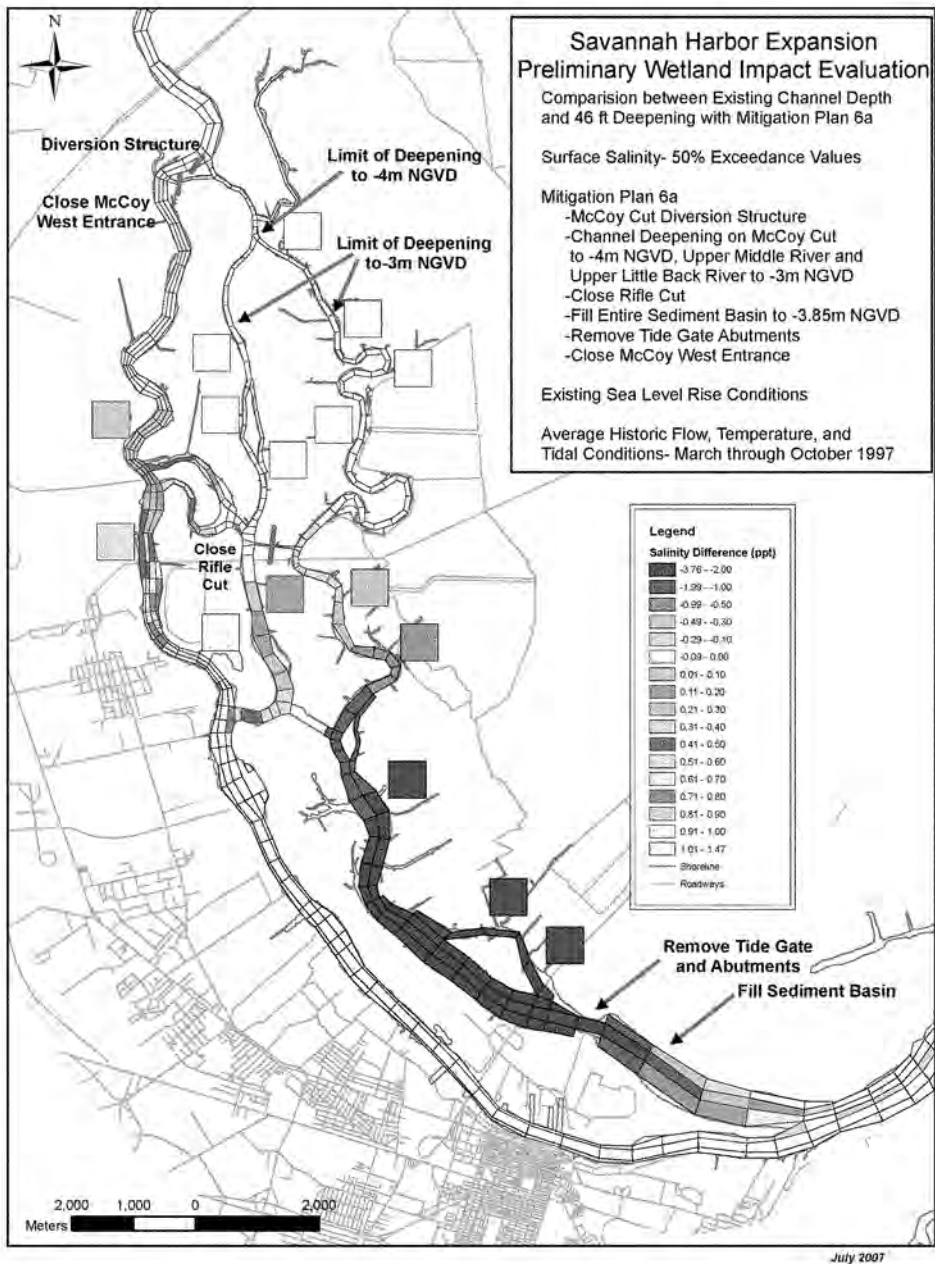


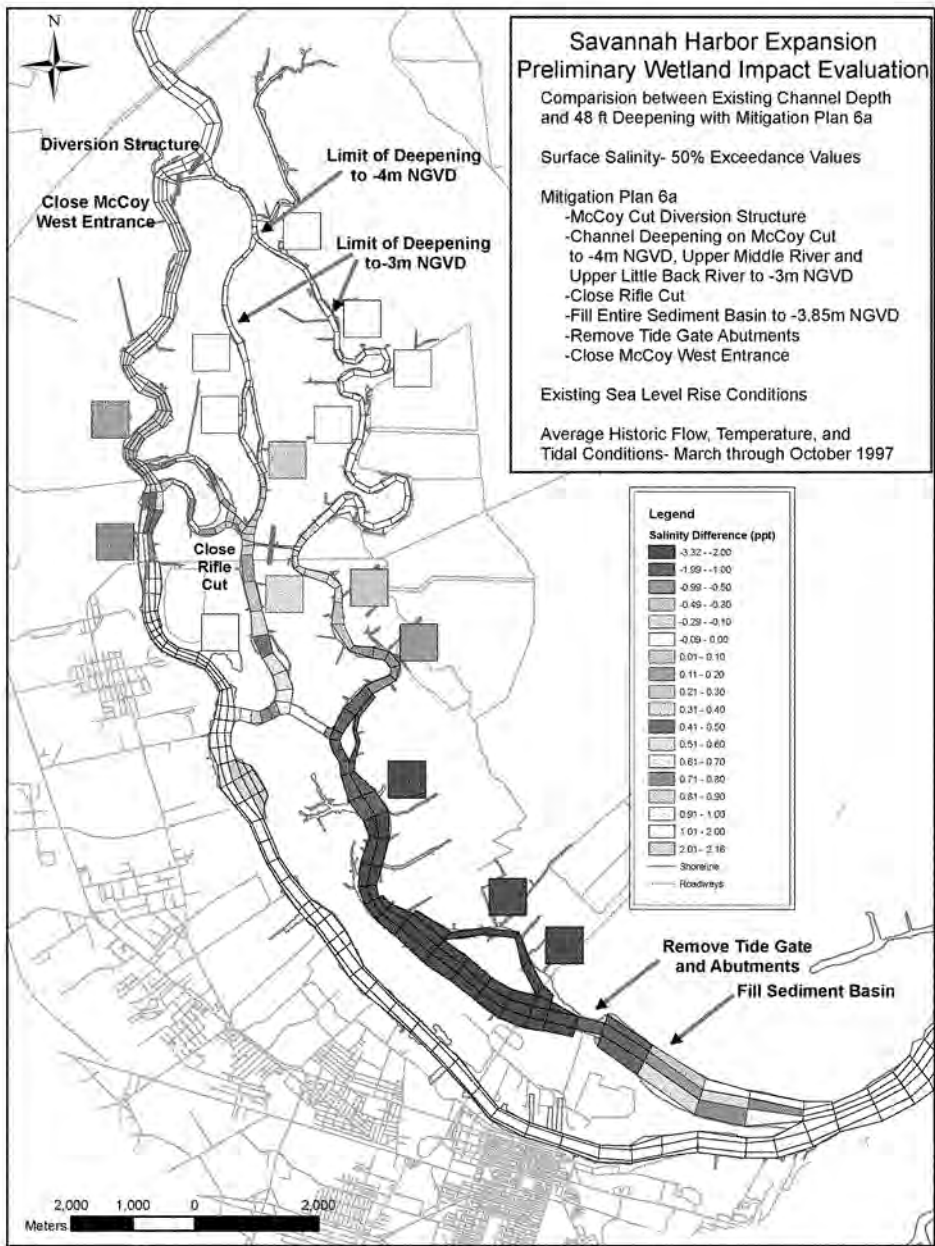












July 2007



Savannah Harbor Expansion Project

Evaluation of Marsh/Wetland Impacts

Plan 7 ONLY

October 2007

Introduction

This report summarizes the results of marsh impacts with implementation of Mitigation Plan 7 and its effects on reducing salinity impacts to marshes/wetlands due to navigation channel deepening. Plan 7 has been evaluated under two possible navigation channel depths (48 ft and 46 ft).

The mitigation plan was evaluated using the 3D hydrodynamic model EFDC. The run period is March through October 1997. This time period is representative of average historic flow, temperature, and tidal conditions. The effects of sea level rise have NOT been evaluated in this report. The parameter evaluated is the 50% exceedance surface salinity value throughout the model grid. The run period and parameters were specified by the Interagency Coordination Team.

Plan Description

One additional mitigation plan was modeled to determine the effectiveness in reducing salinity impacts to freshwater marsh due to deepening the navigation channel. Mitigation Plans 1-6b were evaluated prior to the plan presented here. Detailed results for Plans 1-6b can be found in the following reports:

Wetland/Marsh Mitigation Plan Evaluation dated April 2007

Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts with Additional Mitigation Plans dated August 2007

Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts Plan 6a Only dated August 2007

The additional mitigation plan presented here is Plan 7 which incorporates the mitigation features of Plan 3 plus rerouting Front River through Steamboat River. Below is a brief description.

Plan7

- McCoys Cut Diversion Structure
- Channel Deepening on McCoys, Upper Middle and Little Back River
- Fill Entire Sediment Basin
- Close Rifle Cut
- Reroute Front River through Steamboat River by Closing Drakies Cut

The adjustments made to the model to predict results of Plan 7 were complex and required close scrutiny to ensure the additional mitigation feature was modeled accurately. Front River was rerouted through Steamboat by closing off Drakies Cut, cells 13_100, 14_100 and 15_100, and widening and deepening the 17 cells along Steamboat River to represent the equivalent flow area currently found in Front River. Cells 24_100 and 25_100 represent Houstown Cut, the linkage between Steamboat and Middle River. These cells were not deepened or widened, their depths remained the same as they are in the existing channel conditions model. The sill at this cut is at elevation -2.2 m NGVD. See Figures 1 & 2.

Figure 1- EFDC Model Grid

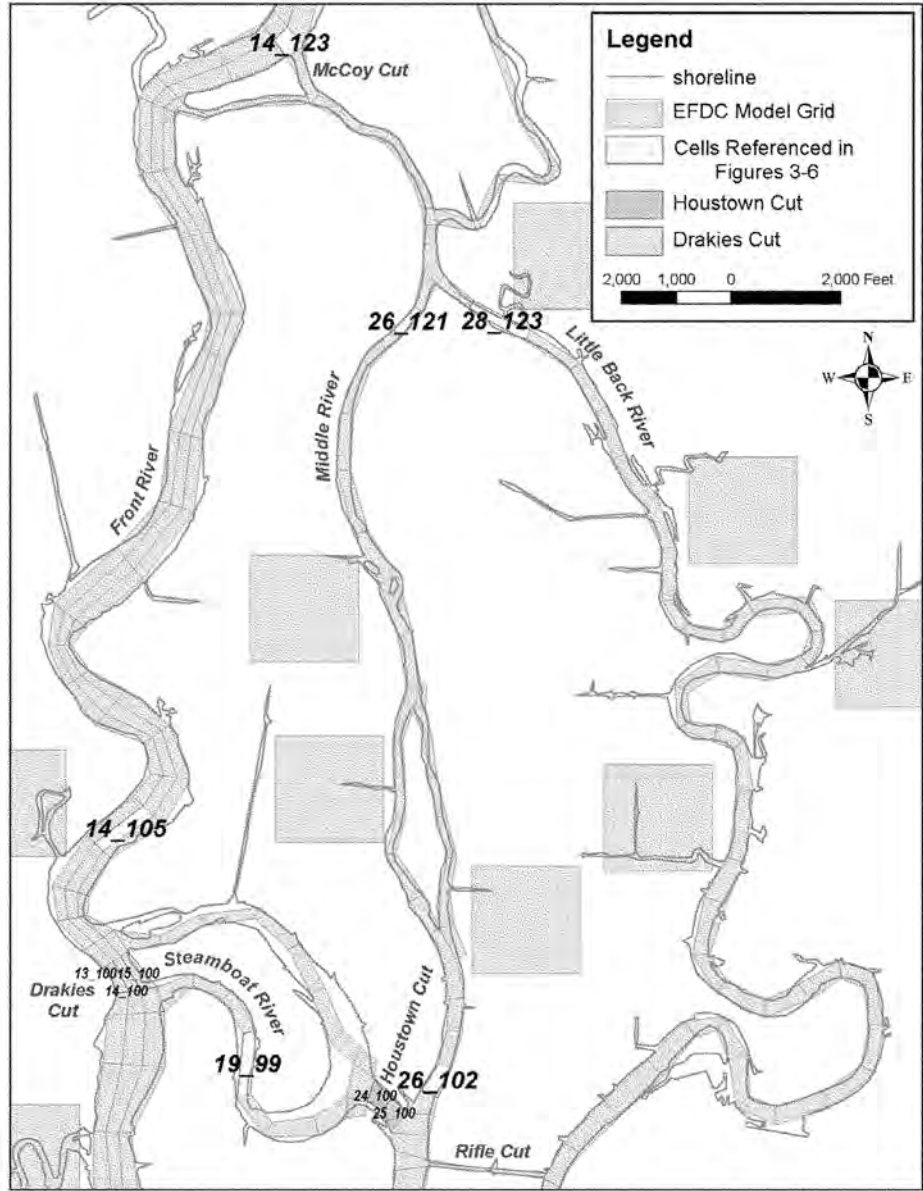


Figure 2- Steamboat River- Aerial View



Output Presented

There are three types of maps presented in this report:

- 1- **Predicted River Salinity from the Hydrodynamic Model (EFDC)-** The EFDC model grid is shown with 50% exceedance surface salinities broken into 5 categories: 0-0.5 ppt, 0.6-1.0 ppt, 1.1-2.0 ppt, 2.1-4.0 ppt, 4.0-32.5 ppt. Modeling is based on average historic flow, temperature, and tidal conditions- March through October 1997. The effects of sea level rise have NOT been evaluated in this report.
- 2- **Estimated Marsh Salinity Contour Lines-** Marsh salinity contour lines are shown that break the marsh into 5 categories: 0-0.5 ppt, 0.6-1.0 ppt, 1.1-2.0 ppt, 2.1-4.0 ppt, > 4.0 ppt. The first category 0-0.5 ppt represents freshwater marsh. The contour lines were extrapolated into the marsh from the riverine hydrodynamic model results shown in the maps described above 1- *Predicted River Salinity from the Hydrodynamic Model*.
- 3- **Surface Salinity Difference Maps-** Maps show the change in riverine salinity at each EFDC grid cell between the existing condition and each mitigation plan. Salinity values are predicted using the hydrodynamic model (EFDC). The grid cells are color coded to show the salinity differences. The grey shading is used to show cells that have lower salinity values than the existing condition (i.e.

deepening impacts have been reduced to 0, and, in fact, show improvement over the existing condition).

Results

Results from the modeling are presented in the following table. The table shows estimated marsh salinity impacts based on the mapping described in 2-**Estimated Marsh Salinity Contour Lines** above. The acreages are valid within +/- 50 acres. The numbers in Table 1 reflect all marsh acreages minus acreages that will be lost due to construction of Plan 7. Plan 7 construction will consist of both widening and deepening Steamboat River, which will impact approximately 100 acres of the adjacent marsh area.

Table 1- Estimated Marsh Salinity Impacts- Plans 3 and 7

48 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 7* (acres)
0.0 – 0.5	4072	2860	3584	3772
0.6 – 1.0	864	830	766	1145
1.1 – 2.0	555	1215	1587	1024
2.1 – 4.0	834	739	682	605
> 4	2506	3188	2213	2186

46 ft Depth

Estimated Marsh Salinity	Existing (acres)	Deepened Only --No Mitigation-- (acres)	Plan 3 (acres)	Plan 7* (acres)
0.0 – 0.5	4072	3015	3753	4285
0.6 – 1.0	864	1050	1298	1054
1.1 – 2.0	555	921	991	866
2.1 – 4.0	834	789	616	739
> 4	2506	3057	2174	1788

* acreages incorporate marsh loss due to construction of Plan 7 mitigation features

The model predictions for Plan 7 show that the additional mitigation feature, routing Front River through Steamboat, does provide additional mitigation benefits. For the 48 ft deepening, the mapping shows that the freshwater zone ends just below Steamboat as compared to Plan 3 where the freshwater zone ends above Steamboat. It may be counterintuitive to think that the freshwater zone around Steamboat would remain fresh with the Front River routed through it. However, what the modeling shows is that when Steamboat is widened and deepened the salinity becomes more stratified and the velocities increase. This change in geometry allows the less dense freshwater to stay on top of the water column and flush through the bend while providing freshwater to the marshes (See Figure 3). In Plan 3 and under existing conditions Steamboat is smaller and more shallow. Velocities are low and the water column is less stratified. This allows more saline water to be available in the surface layer of the water column, for a longer period of time, to interact with the marsh; thus causing the freshwater zone to move above Steamboat.

Despite the shallow depth of the sill at Houstown Cut (-2.2 m NGVD) saline water moves from Steamboat through Houstown Cut to Middle River and causes increases in surface salinity on Middle River (See Figure 4 and Table 2). However, surface salinities on Front River above Steamboat are greatly reduced by lengthening the path that the saline water has to travel during each tidal cycle (See Figure 5). Figure 6 shows that the predominate path for surface salinity to move through the upper portion of the river system is Middle River. Near McCoy's Cut the surface salinities on Middle River are much higher than that of Front River. The salinity movement on Middle River appears to supply salinity to the upper portion of Little Back River.

Figure 3- Salinity Comparison- Steamboat River

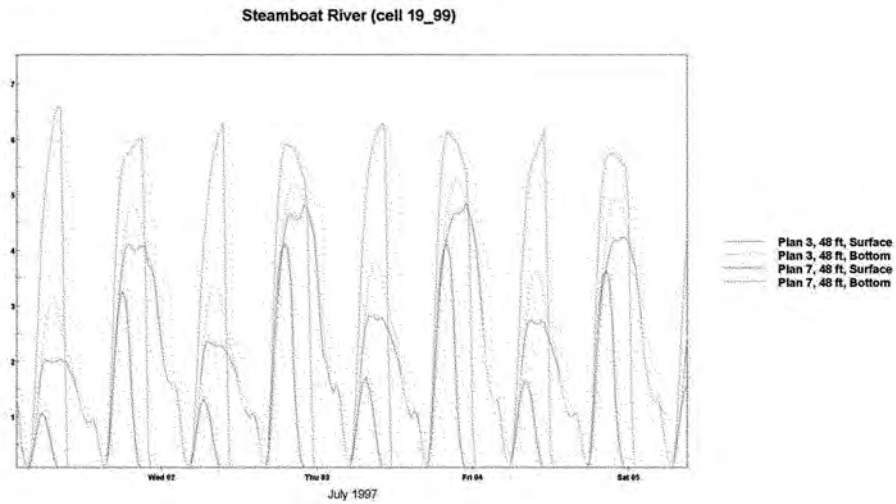


Figure 4- Surface Salinity Comparison- Middle River

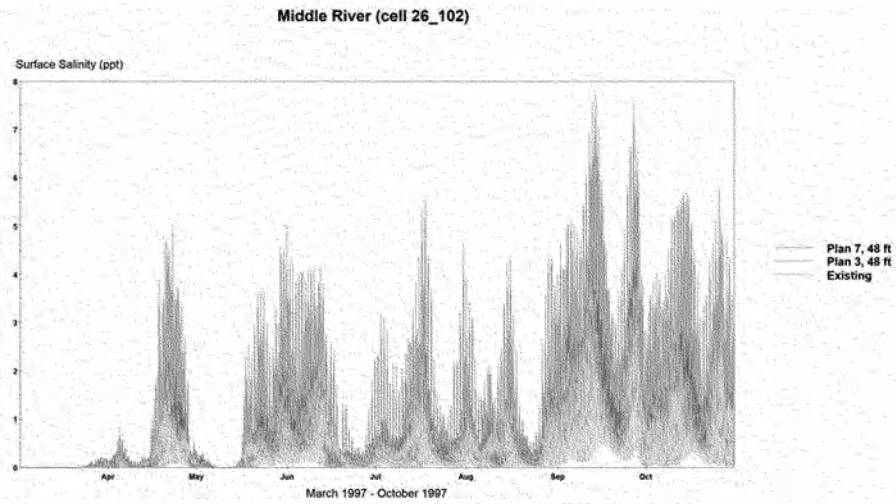


Table 2- Surface Salinity Percentile Value Comparison- Middle River (Cell 26_102)

Percentile*	Existing Conditions	Plan 3 48 ft	Plan 7 48 ft
10	0.00	0.00	0.00
20	0.01	0.02	0.01
30	0.05	0.06	0.04
40	0.11	0.14	0.11
50	0.20	0.27	0.24
60	0.33	0.45	0.48
70	0.48	0.68	0.82
80	0.68	1.06	1.42
90	1.00	1.63	2.54

*The percentile values were computed from the same datasets used to develop Figure 4.

Figure 5- Surface Salinity Comparison- Front River

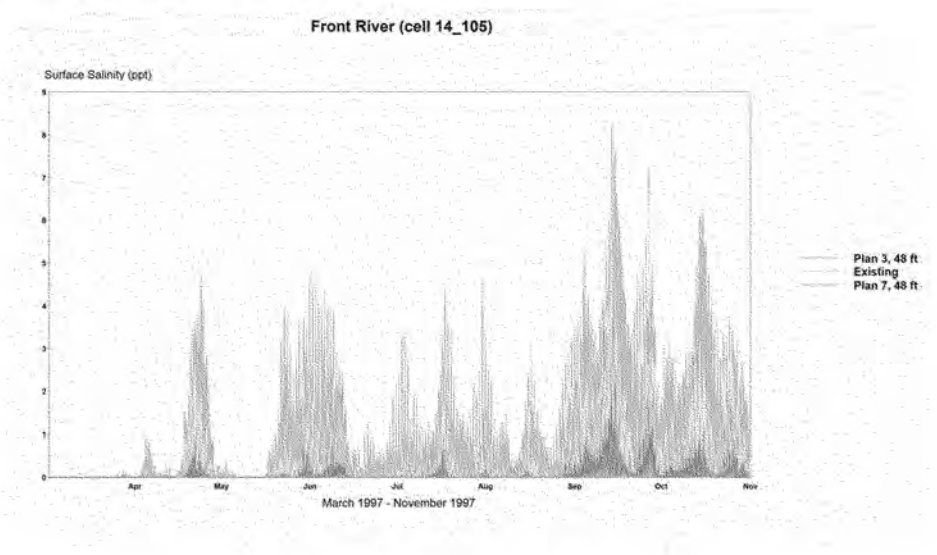
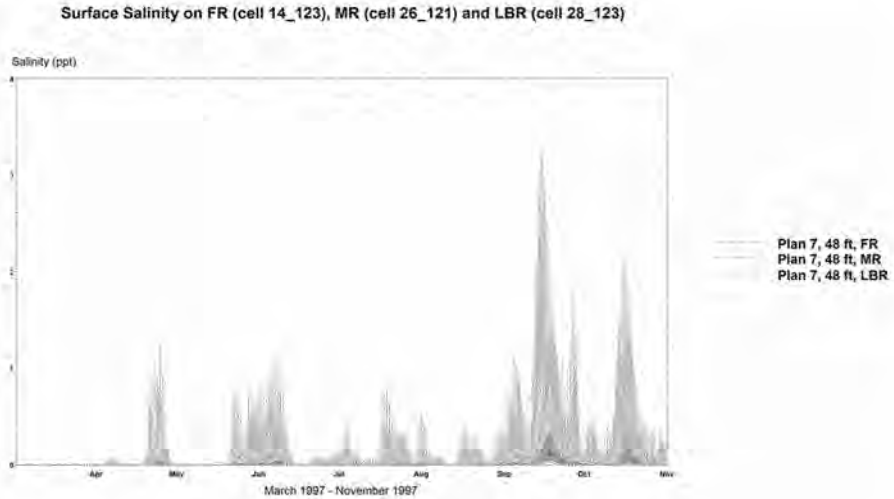


Figure 6- Surface Salinity Comparison- Front, Middle, and Little Back River



Summary

In viewing and discussing the results of the mitigation plans it is important to remember the following:

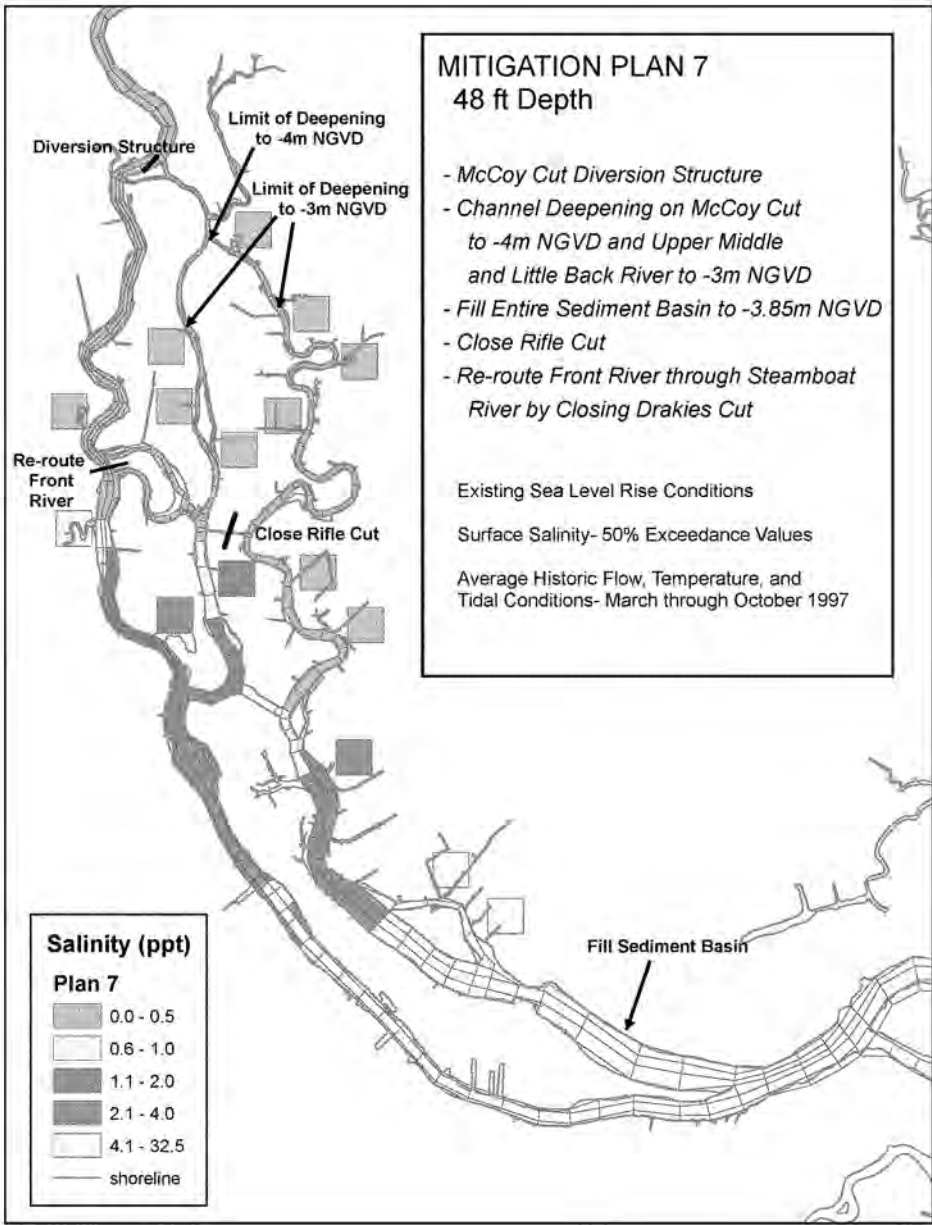
- 1- The marsh impacts are evaluated by looking at the *net* acreage. This is especially important when discussing the impacts to freshwater marshes. The net acreage value is based on the conditions of the marsh after the project is in place. It does not take into consideration what the marsh salinity is under current conditions. For example, a mitigation plan may gain freshwater marsh on Back River and lose freshwater marsh on Front River. The net acreage may meet the impact criteria, but in reality, it may take some time for a marsh to convert from a brackish marsh to a freshwater marsh.
- 2- The model has a limited ability to evaluate specific design parameters of a true diversion structure. The diversion structure described in each of the plans was modeled by altering the Front River width just downstream of McCoys Cut. By narrowing the passage on Front River the water surface elevation at the mouth of McCoys Cut was increased. The rise in elevation encourages more water to go down McCoys Cut. EFDC does not have options for inserting a defined diversion structure but narrowing the River channel in this area is essentially what a diversion structure will do.

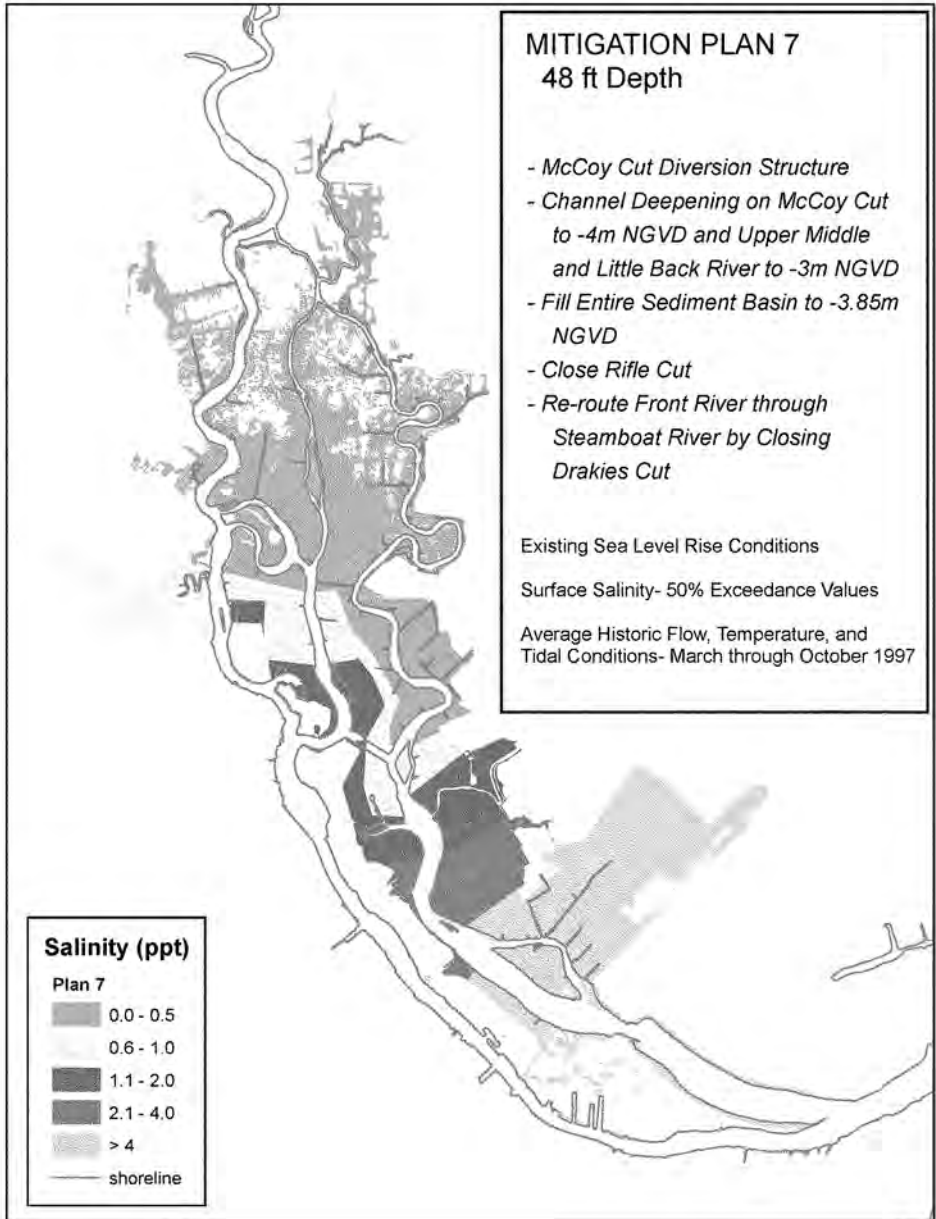
Several different "sizes" of diversion structures were evaluated during the development of the mitigation plans by varying the widths of the narrow passage on Front River. This allowed us to vary the amount of flow diverted down McCoys Cut. The structure modeled in Mitigation Plan 3 and Plan 7, was found to be the most effective at diverting freshwater flows through McCoys Cut of the several different "sizes" evaluated. A future design task will be required to develop specifications for a diversion structure that performs as in the model simulation.

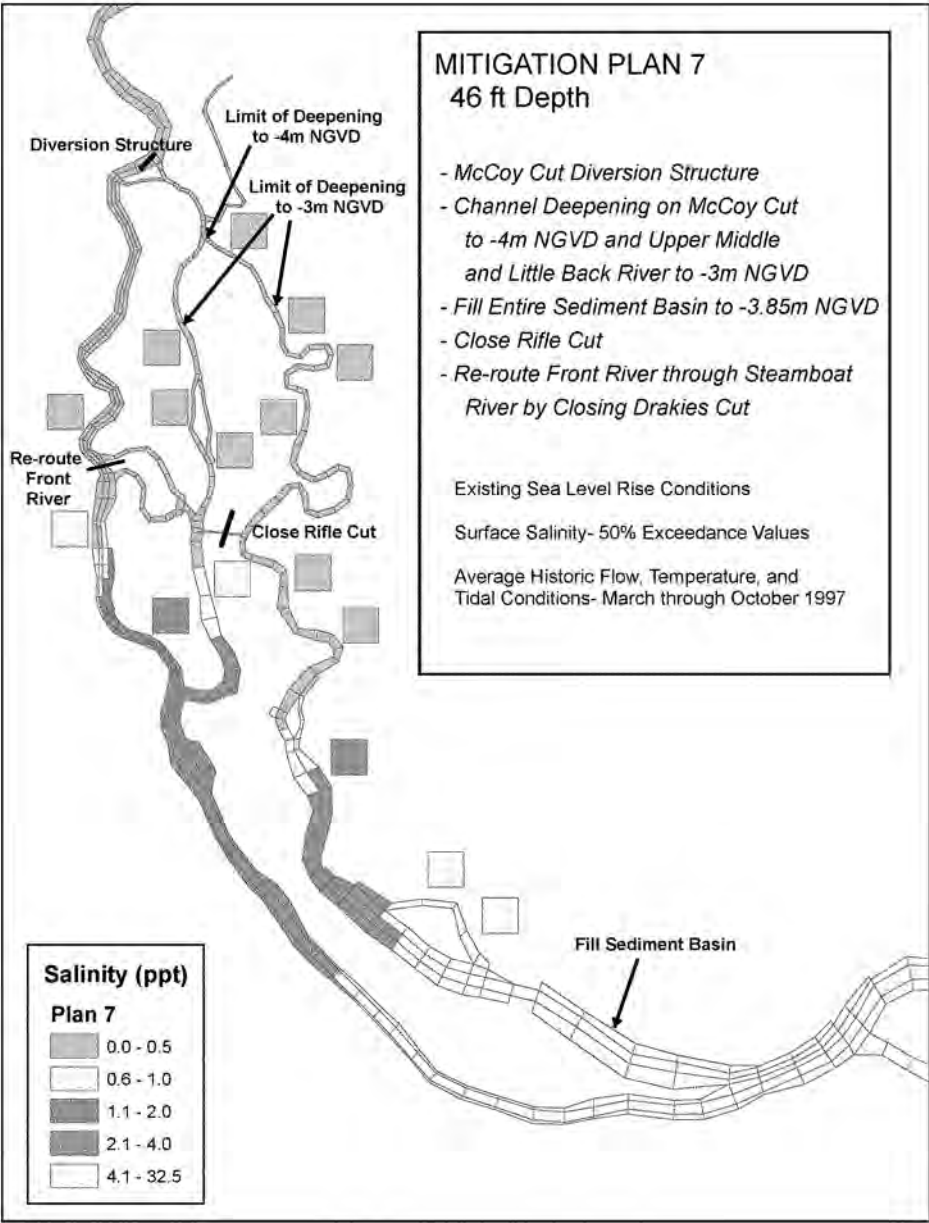
The evaluation of the mitigation plan included review of the effects the plan has on the tide range. It was concluded that Plan 7 does not reduce the tide range significantly in Front River, Back River, Little Back River, or Middle River. The maximum high tide range reduction on Front River is less than 3 inches.

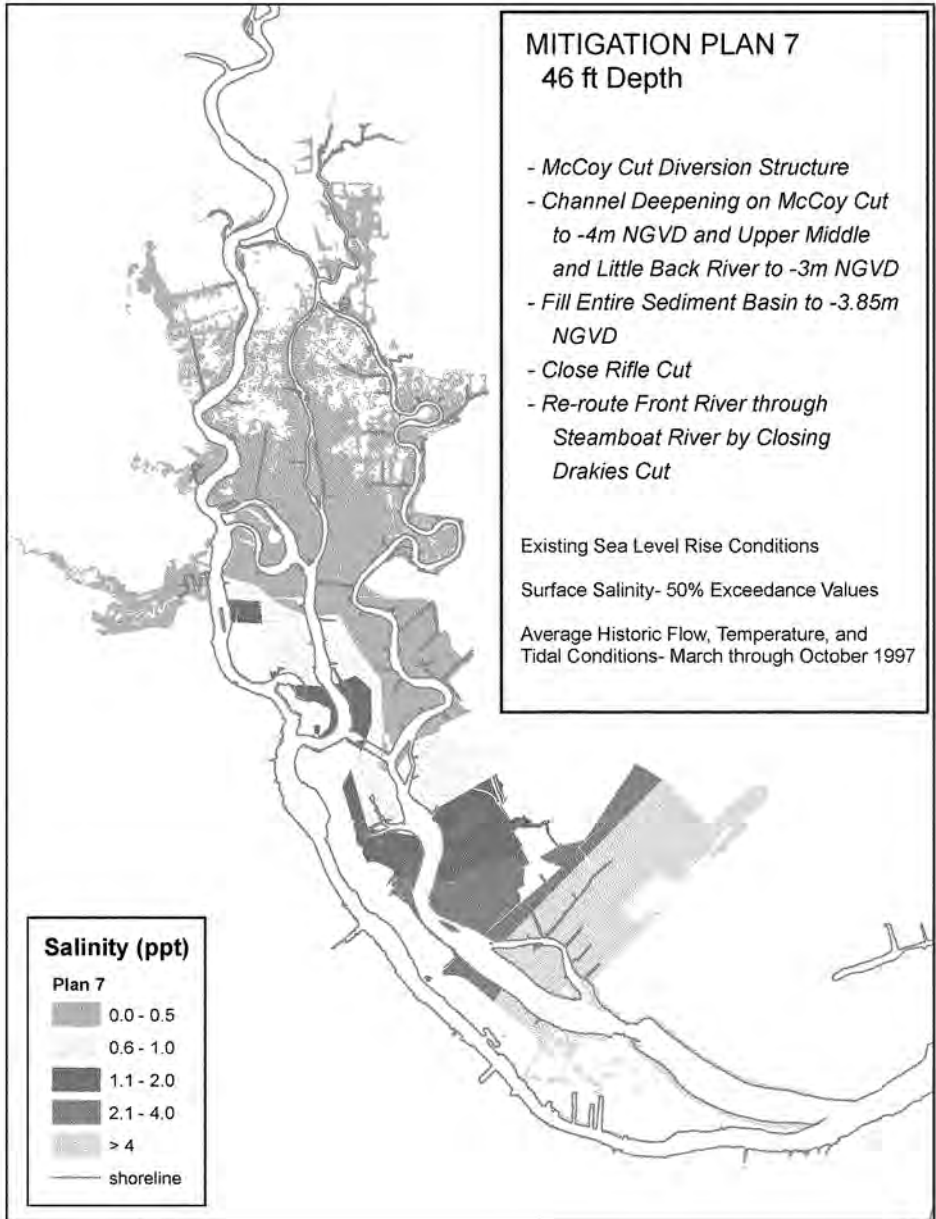
Plan 7 does appear to be more effective in mitigating the impacts due to deepening than Plan 3 when viewing the acreage impacts based on the 50th percentile salinity contours. For the 48 ft depth there is approximately 180 more freshwater marsh/wetland acres available. However, at the 48 ft depth, Plan 7 does not fully mitigate the impacts to freshwater marsh/wetlands and additional mitigation measures would likely be required.

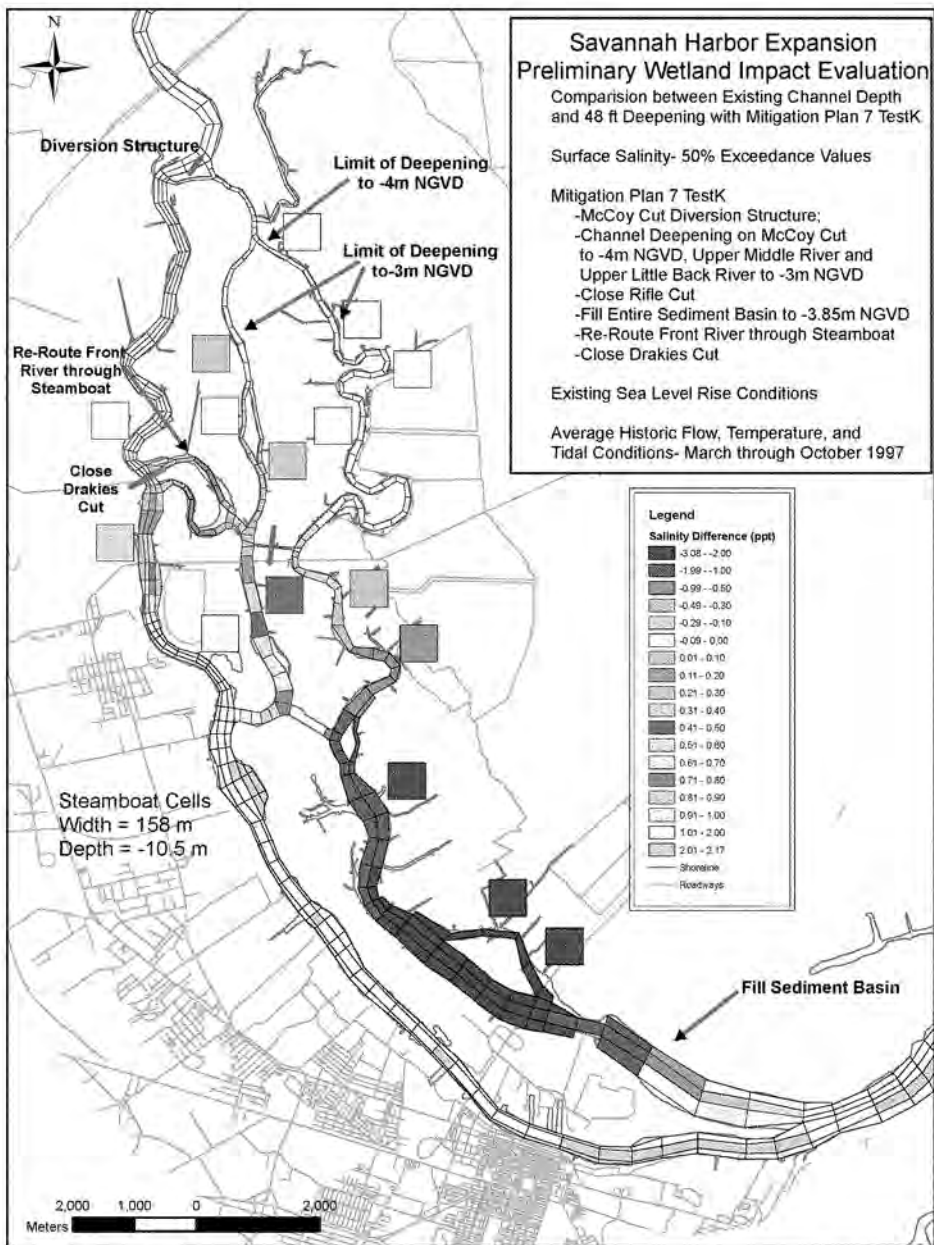
Despite the benefits shown by computing the 50th percentile surface salinities and subsequent marsh/wetland acreages impacted, Plan 7 does appear to increase surface salinity on Middle River. As shown in Figures 3 & 4 and Table 2, surface salinity on Middle River increases significantly for percentiles greater than 50. The increases on Middle River are more pronounced with drought flows. During those high tide periods Plan 7 has the potential to provide more saline water to wetlands than that of Plan 3.

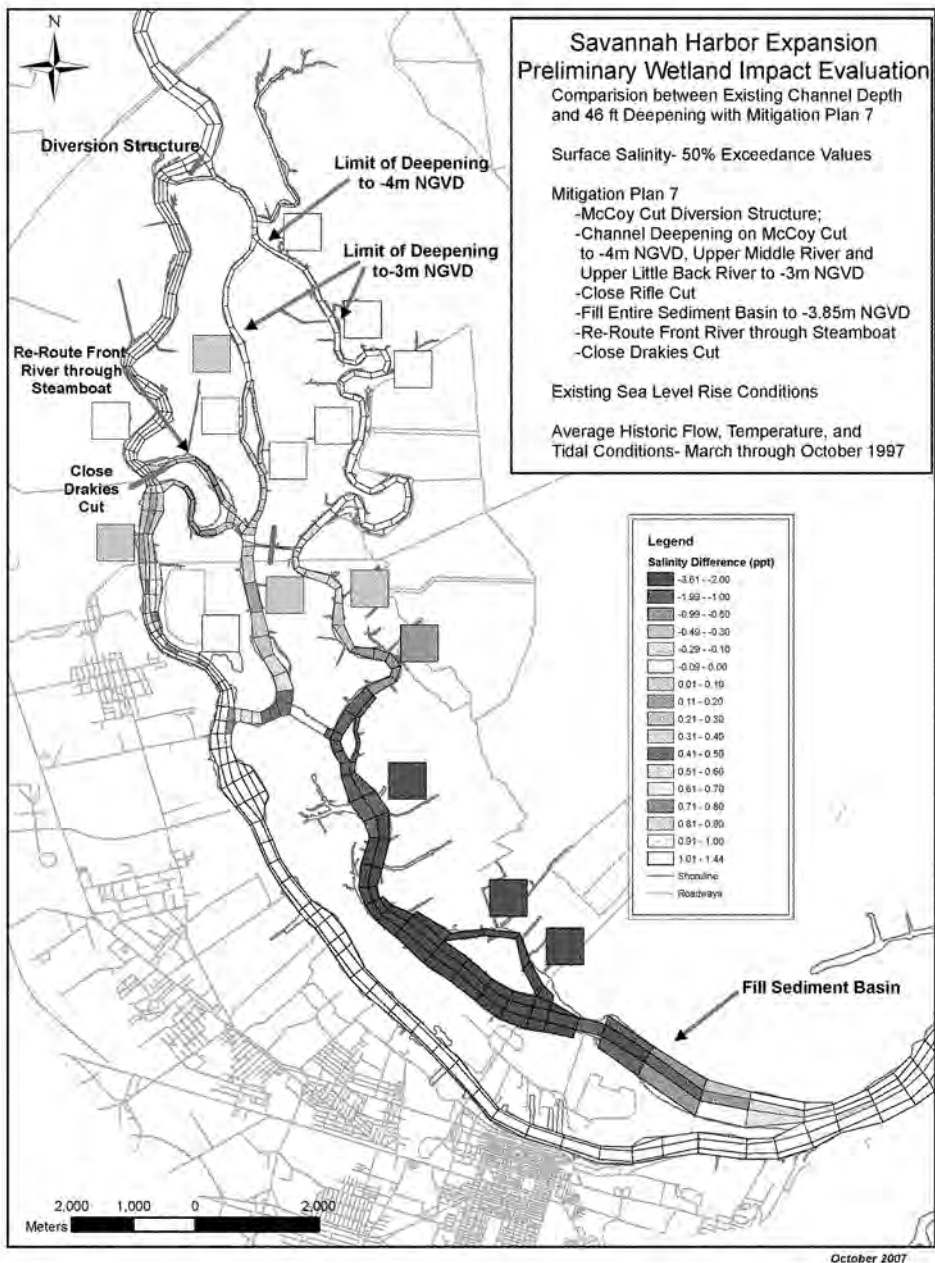














Savannah Harbor Expansion Project

Sensitivity Analysis of Proposed Navigation Meeting Areas

September 2009

Introduction

This report summarizes the results of impacts to freshwater marshes/wetlands and to water quality (dissolved oxygen, D.O.) within the Savannah River estuary due to two proposed navigation meeting areas. A meeting area is an area within the navigation channel that has been widened to allow two-way ship traffic to meet and pass safely. The two proposed areas are located in the Long Island Range and Oglethorpe Range (See Table 1 and Figure 1). They were evaluated using the ERDC Ship Simulator and economically justified using HarborSym. Results of those two analyses are provided separately. The ERDC Ship Simulator Meeting Areas Analysis dated March 31, 2009 is located in the Engineering Appendix, Digital Supplement, and the HarborSym results are located in the Economics Appendix.

Table 1: Meeting Area Dimensions and Locations

Meeting Area	Length (ft)	Width* (ft)	Stationing
Long Island	8,000	100	14+000 to 22+000
Oglethorpe	4,000	100	54+800 to 58+800

* Width is in addition to the width of the navigation channel at the toe.

Figure 1: Meeting Area Locations



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Hydrodynamic & Water Quality Model Input

The two meeting areas were incorporated into the EFDC and WASP model grids by adjusting the widths of several grid cells along the navigation channel. The cells that have been widened are representative channel cells; cells that have been reduced in width represent adjacent bank and sideslope transition cells. See Table 2.

Table 2: Meeting Area Model Parameters

Meeting Area	EFDC Model Grid Adjustments*
Long Island	widen cell 14_28 by 100 feet (30.5 m) -- from 153.75m to 184.25m reduce width of cell 13_28 by 100 feet (30.5m) -- from 265.81m to 235.31m widen cell 14_27 by 100 feet (30.5 m) -- from 154.4m to 184.9m reduce width of cell 13_27 by 100 feet (30.5m) -- from 245.15m to 214.65m widen cell 14_26 by 25 feet (7.62m) -- from 175.28m to 182.9m reduce width of cell 13_26 by 25 feet (7.62m) -- from 208.99m to 201.37m
Oglethorpe	widen cell 14_50 by 85 feet (25.9 m) -- from 163.43m to 189.33m reduce width of cell 15_50 by 85 feet (25.9 m) -- from 143.61m to 117.71m widen cell 14_49 by 100 ft (30.5 m) -- from 150.85m to 181.35m reduce width of cell 15_49 by 100 ft (30.5 m) -- from 94.36m to 63.86m widen cell 14_48 by 100 ft (30.5 m) -- from 165.93m to 196.43m reduce width of cell 15_48 by 100 ft (30.5 m) -- from 88.2m to 57.7m

*Adjustments made by changing the DX value in the dxdy.inp file.

Several model run scenarios were analyzed to determine if there are any additional impacts as a result of the two proposed meeting areas. Two scenarios for freshwater marsh/wetland impacts one during an average freshwater flow year, considered the "Basic Evaluation", and also one during a low freshwater flow year, considered "Sensitivity Analysis #1". See Table 3. For more information on how these run scenarios were developed see the report titled *Evaluation of Marsh/Wetland Impacts with Proposed Mitigation Plan* dated November 2007, which is included in the Engineering Appendix, Digital Supplement.

Table 3: Model Input Conditions for Freshwater Marsh/Wetland Impacts

Run Scenario	River Flow	Evaluation Period	Parameters Evaluated
Basic Evaluation	Average/Typical	1-March to 1-November	Surface & Bottom Salinity
Sensitivity Analysis #1	Low Flow/Dry	1-March to 1-November	Surface Salinity Only

In addition to the analysis performed for marsh/wetland impacts, an analysis was also done to determine water quality (i.e. D.O.) impacts. One time-period scenario was analyzed for this purpose. The run period is August of 1997, an average flow summer-month period.

All run scenarios incorporate the 48 ft project depth (considered a worse case scenario for the sensitivity analysis) along with the proposed mitigation plan for that depth (Plan 6a and D.O. injection). The details of Plan 6a are shown in Figure 2. Locations of the D.O. injection are selected to be at the former tide gate site and Mulberry Grove (near the confluence of Steamboat

River and Front River). See Figure 3. Details of the D.O. injection system can be found in the report titled *Design of Dissolved Oxygen Improvement Systems in Savannah Harbor* dated April 2008, which is included in the Engineering Appendix, Digital Supplement.

Figure 2: Mitigation Plan 6a

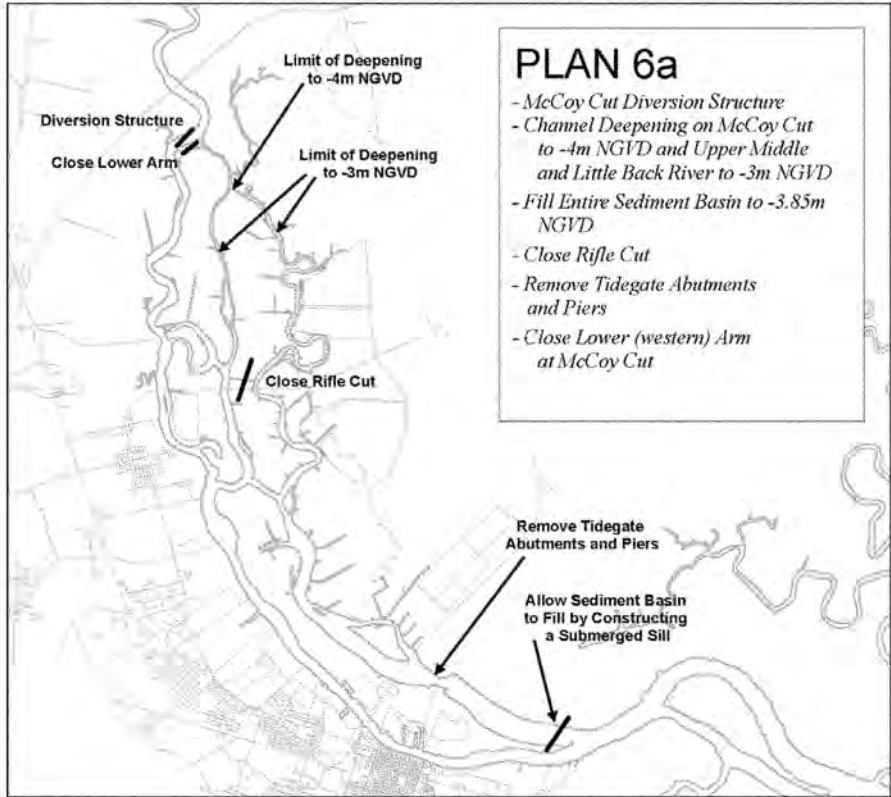


Figure 3: D.O. Mitigation Locations



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Results

Marsh/Wetland Impact Analysis

Impacts to Tidal Fluctuations

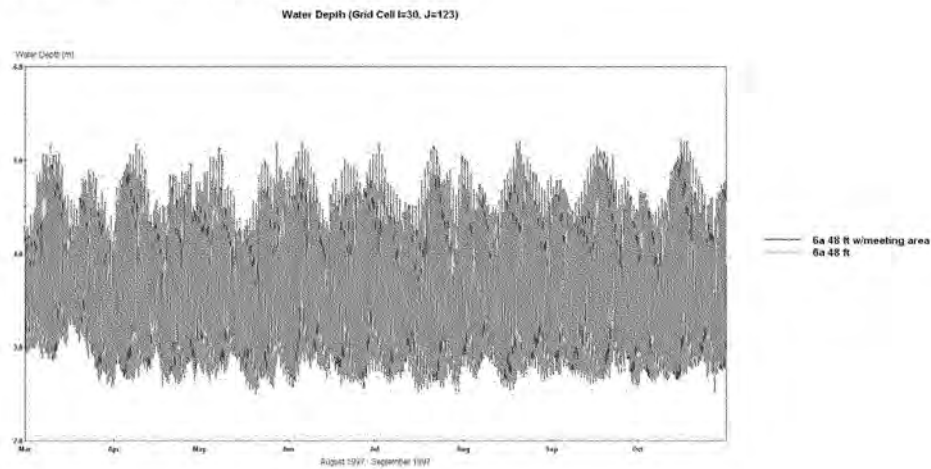
Impacts to tidal fluctuations within the estuary due to inclusion of the meeting areas were examined at several grid cell locations on Back and Middle Rivers, shown highlighted in Figure 4. Details of tidal variability are shown by water depth in Figures 5-11. None of these seven locations along Middle and Back River show an impact to tidal depth or timing as a result of inclusion of the meeting lanes within the model geometry. Comparisons are made between the 48 ft depth alternative with Mitigation Plan 6a in place with and without the meeting areas modeled.

Figure 4: EFDC Grid Cell Locations Examined for Impacts to Tidal Fluctuations



Figure 5: Water Depth Comparison at EFDC Grid Cell 30 123

A: full run period March through October 1997



B: zoomed run period August 1997

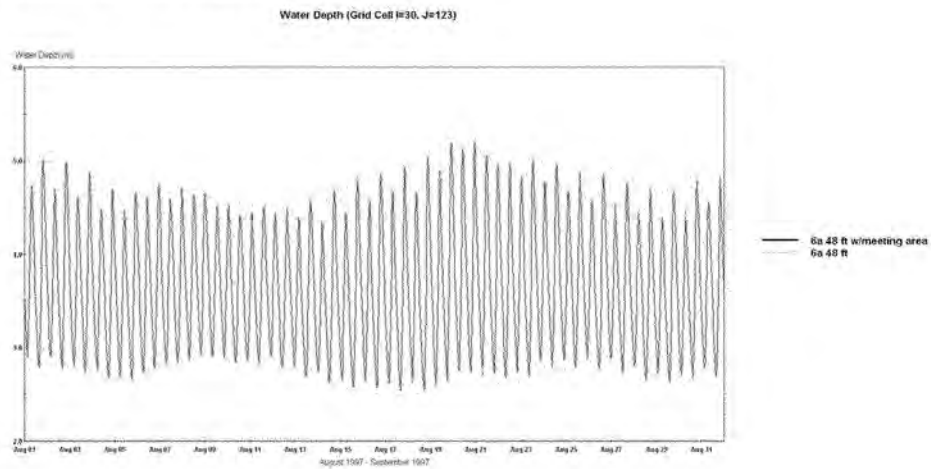
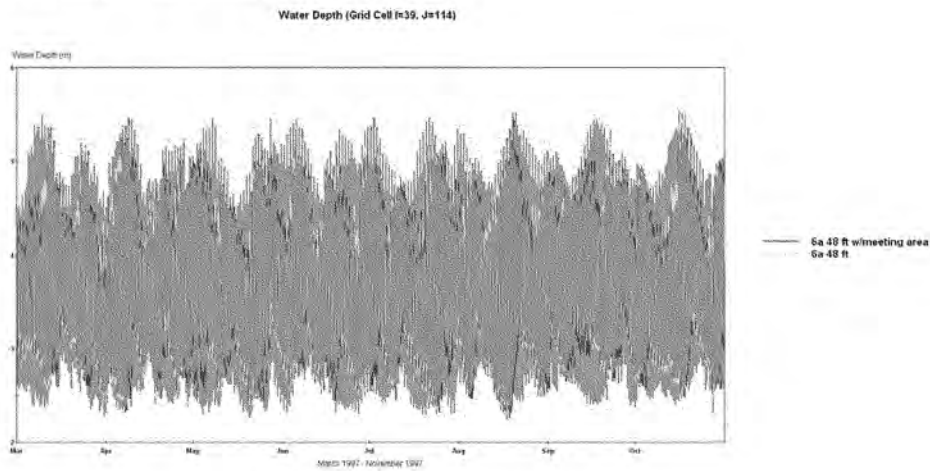


Figure 6: Water Depth Comparison at EFDC Grid Cell 39 114

A: full run period March through October 1997



B: zoomed run period August 1997

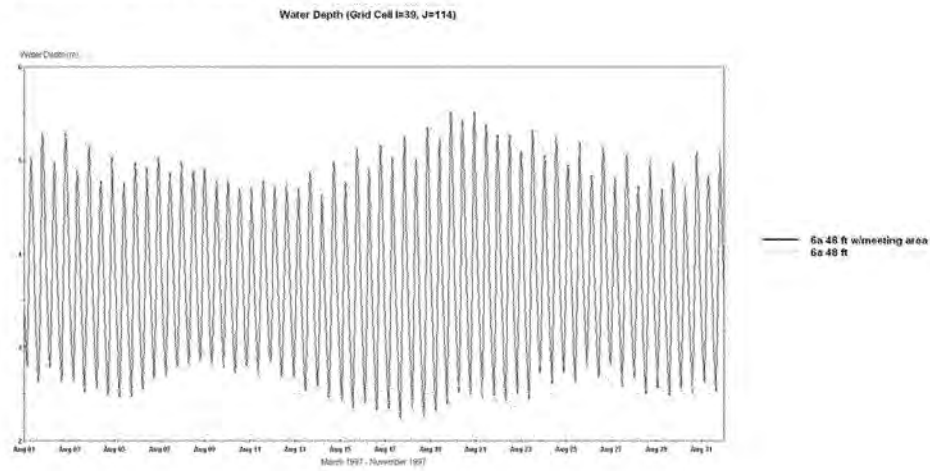
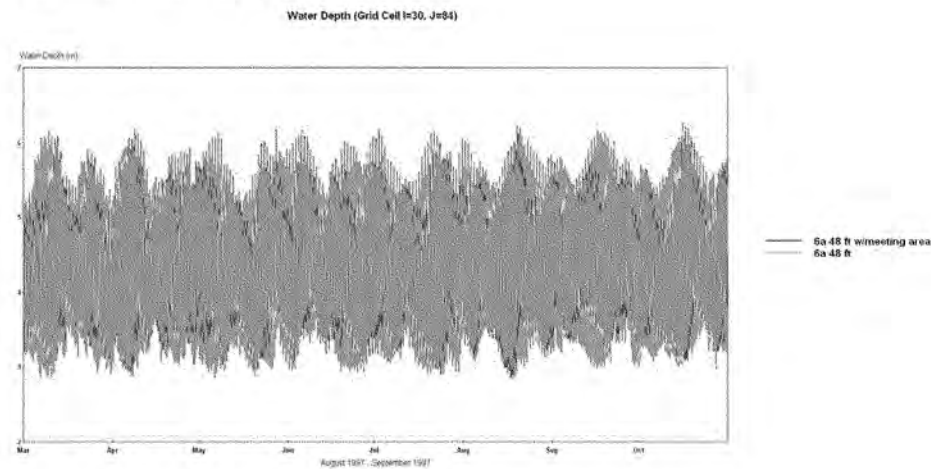


Figure 7: Water Depth Comparison at EFDC Grid Cell 30 84

A: full run period March through October 1997



B: zoomed run period August 1997

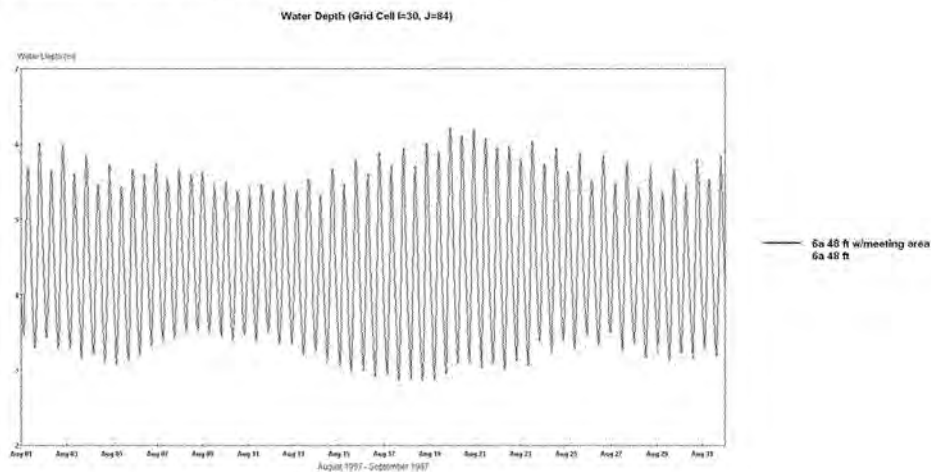
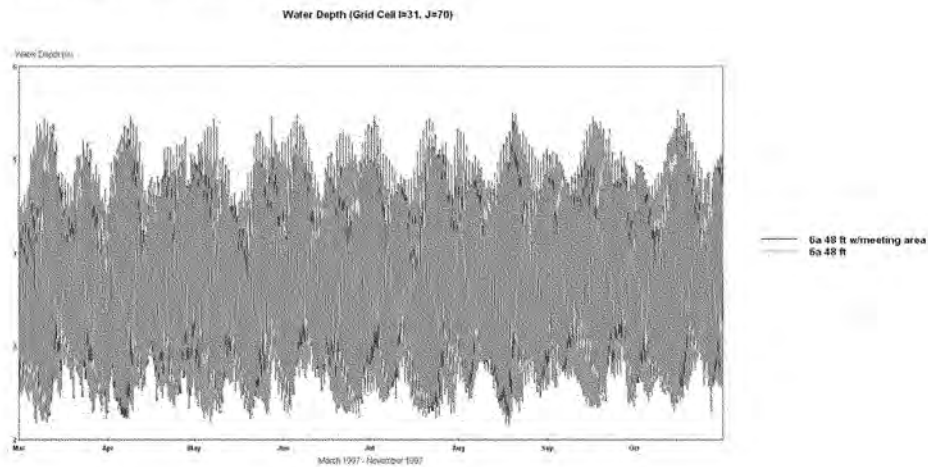


Figure 8: Water Depth Comparison at EFDC Grid Cell 31 70

A: full run period March through October 1997



B: zoomed run period August 1997

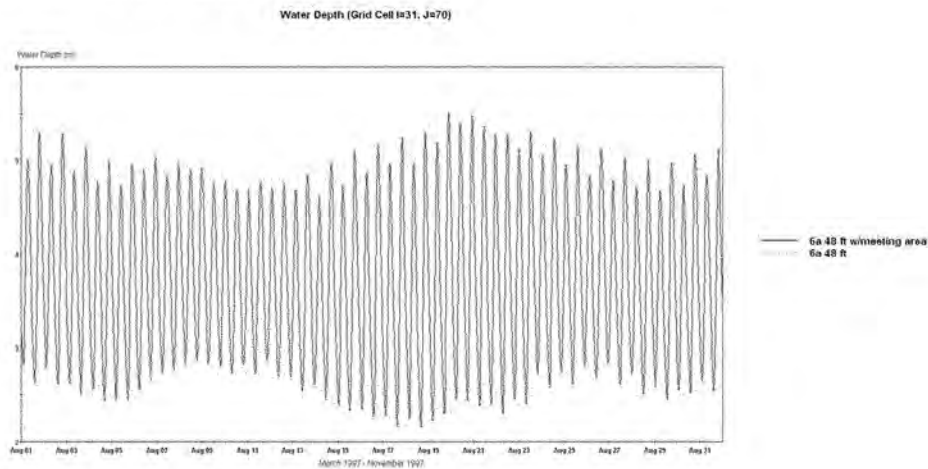
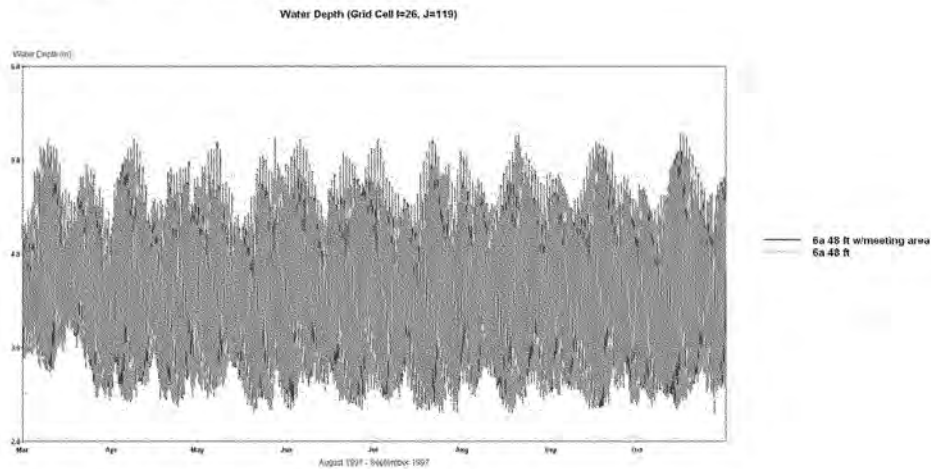


Figure 9: Water Depth Comparison at EFDC Grid Cell 26 119

A: full run period March through October 1997



B: zoomed run period August 1997

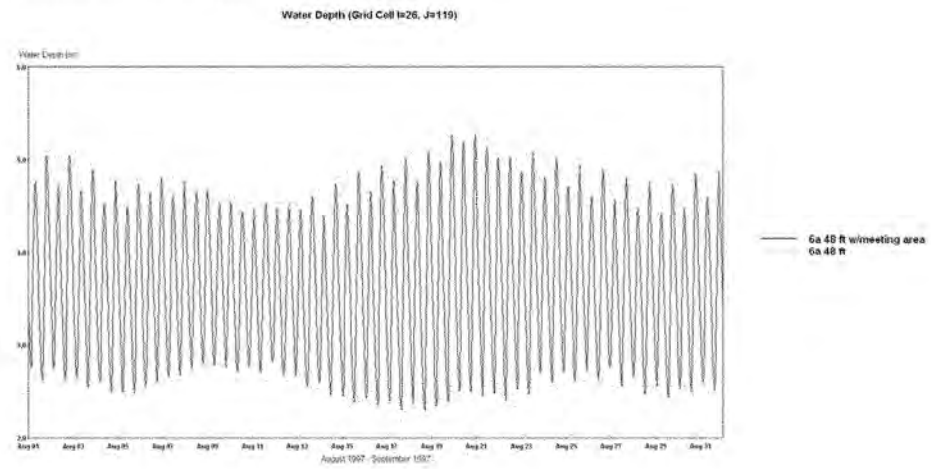
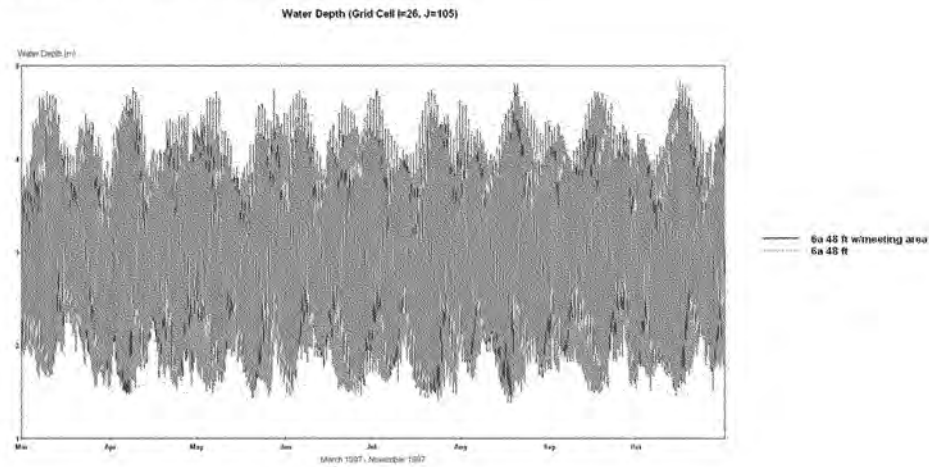


Figure 10: Water Depth Comparison at EFDC Grid Cell 26 105

A: full run period March through October 1997



B: zoomed run period August 1997

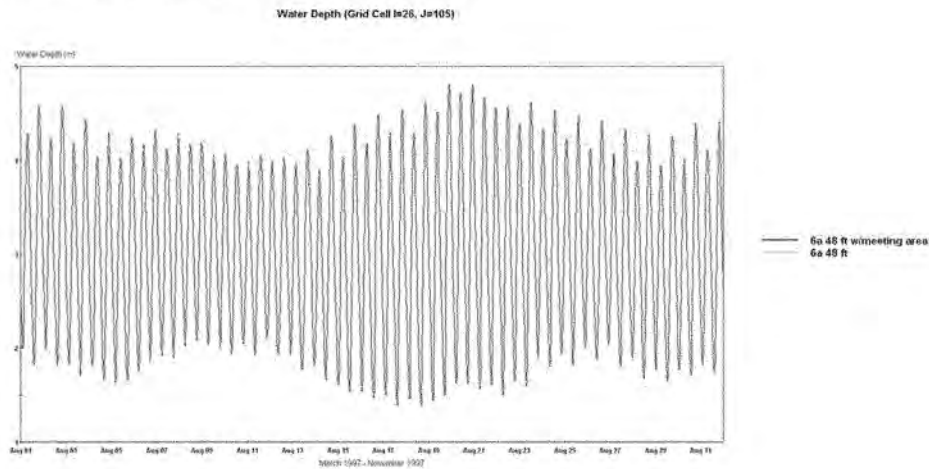
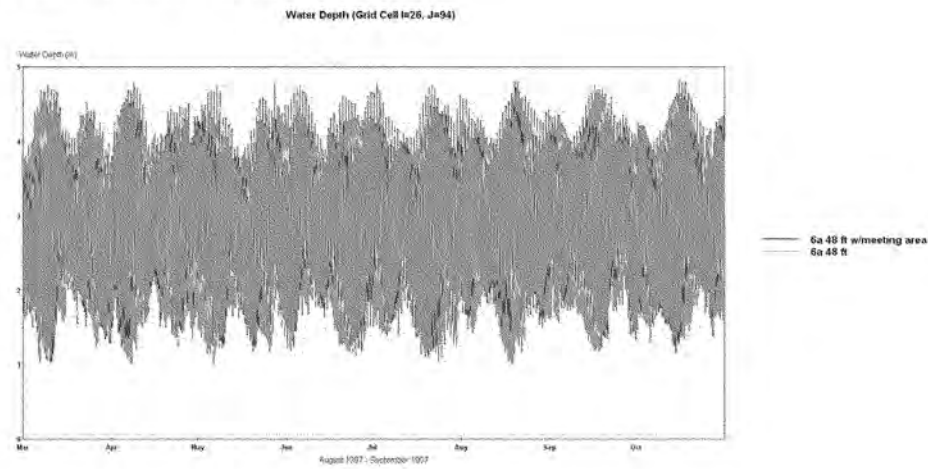
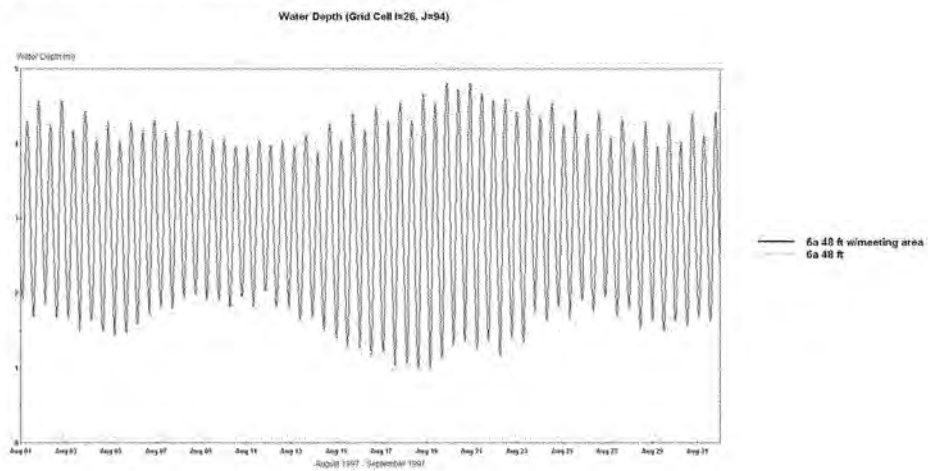


Figure 11: Water Depth Comparison at EFDC Grid Cell 26 94

A: full run period March through October 1997



B: zoomed run period August 1997



Impacts to Salinity Regime

Impacts to the salinity regime within the estuary due to inclusion of the meeting areas in the model grid geometry were examined and results are shown in Figures 12-14. Comparisons are made between the 48 ft depth alternative with Mitigation Plan 6a in place with and without the meeting areas modeled.

Figures 12 and 13 show the changes in salinity for both the model grids surface and bottom salinity predictions for the Basic Evaluation run period. The Basic Evaluation occurs from March through October in 1997 which is considered an average flow year. These would be conditions experienced within the estuary on an average basis.

The maximum change in the surface salinity prediction for the Basic Evaluation is 0.14 ppt. This change occurs just upstream of the tide gate on Back River and causes an increase in the salinity prediction from 5.88 ppt to 6.02 ppt. Surface salinity changes under the Basic Evaluation conditions extend up to New Cut on Back River. However, the increases in prediction values in that area are quite minor, 0.01 ppt. Additionally, the change in salinity regime causes a decrease in predicted surface salinity values on Front River up to 0.44 ppt.

Comparatively the maximum change in the bottom salinity prediction during Basic Evaluation conditions is 0.33 ppt and occurs on Front River just upstream of Elba Island. The addition of the meeting areas within the model cause the bottom salinity to increase from 19.25 ppt to 19.58 ppt. Changes in bottom salinity for the Basic Evaluation, although very small (less than 0.1 ppt) are seen as far upstream as New Cut on Back River. However, this change or shift in the salinity regime causes a decrease in predicted bottom salinity values on Front River up to almost 0.5 ppt.

Figure 14 shows surface salinity changes under the Sensitivity Analysis #1 (low flow/drought conditions). Increases are seen throughout Front, Middle and Back Rivers. However, the increases are minor (under 0.17 ppt).

Figure 12: Surface Salinity Difference Comparison – with and without meeting areas modeled

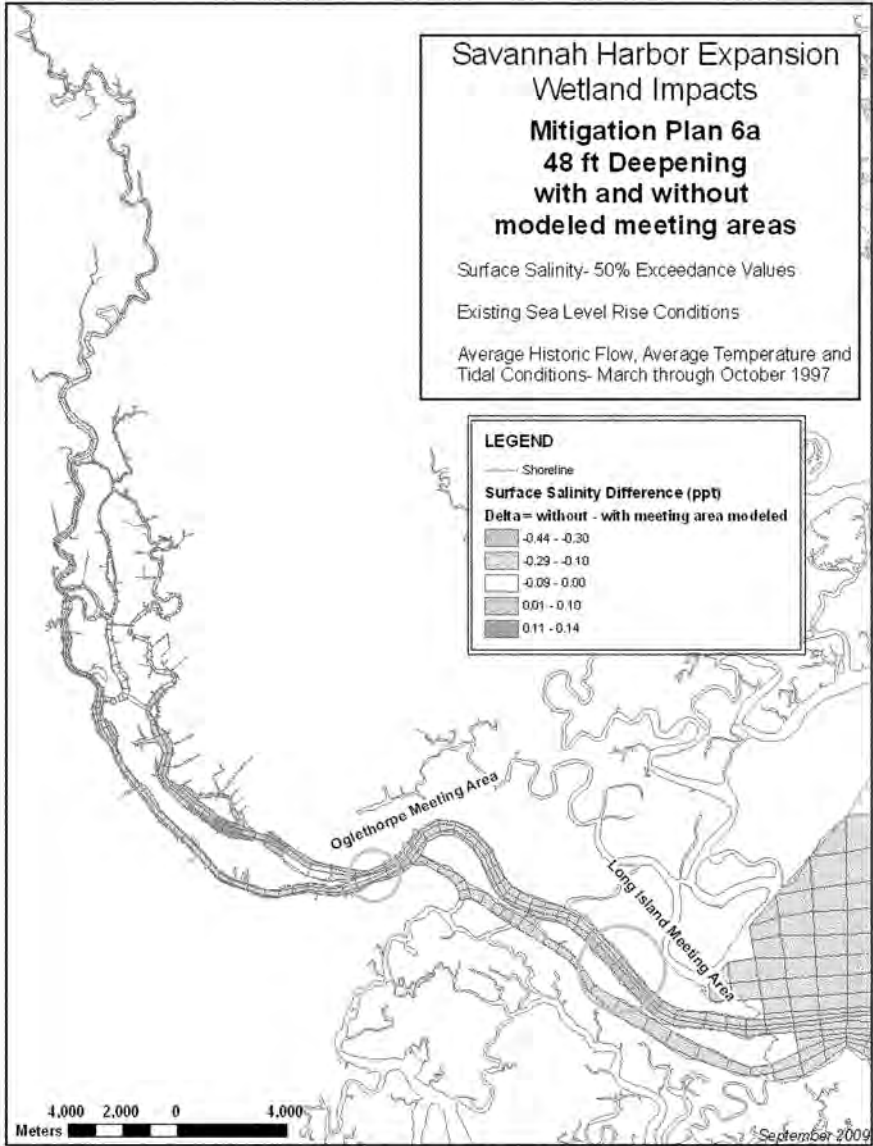


Figure 13: Bottom Salinity Difference Comparison – with and without meeting areas modeled

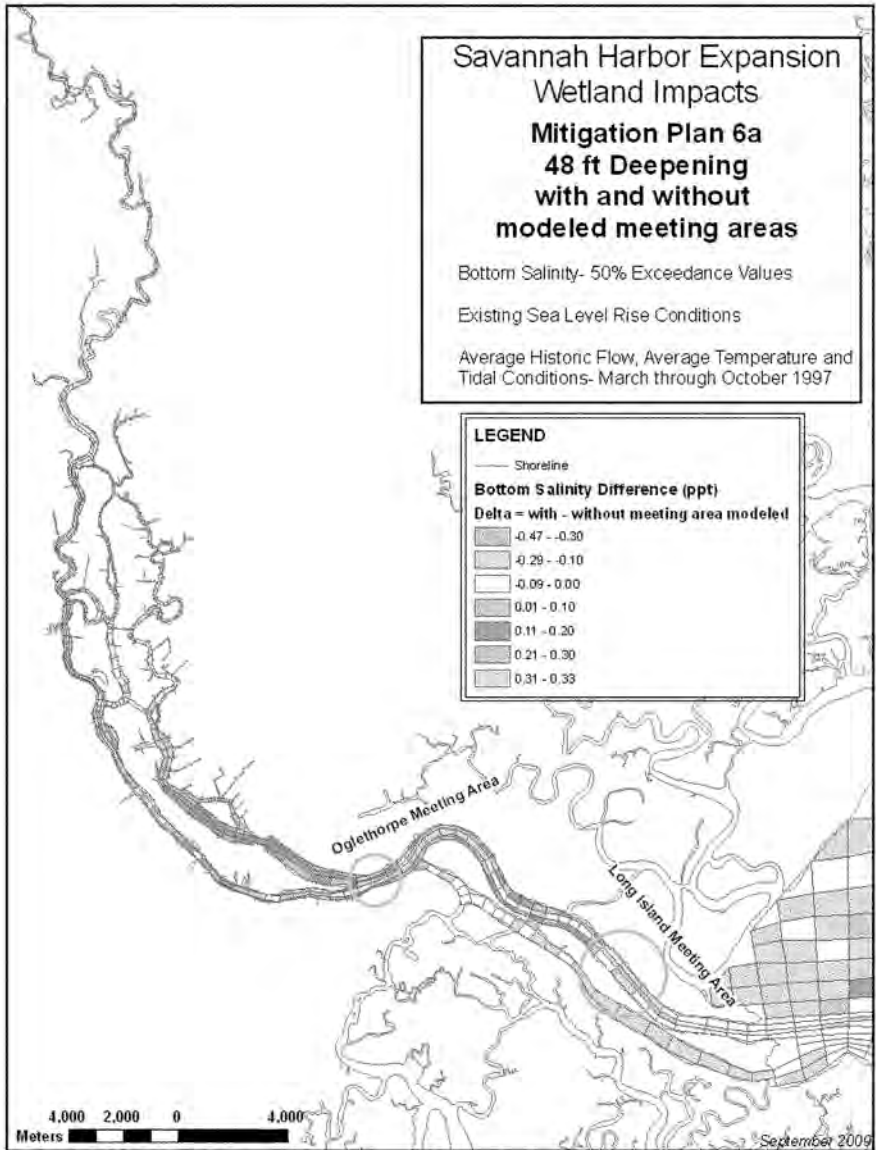
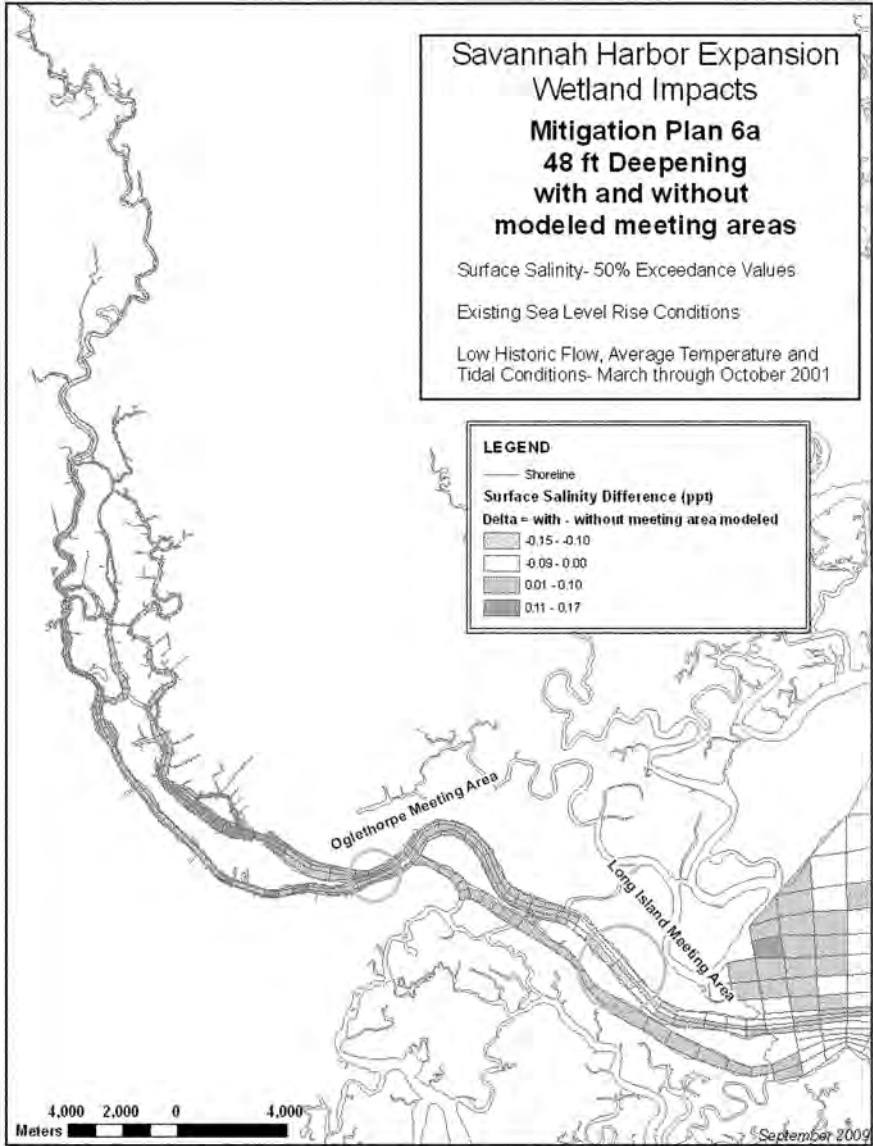


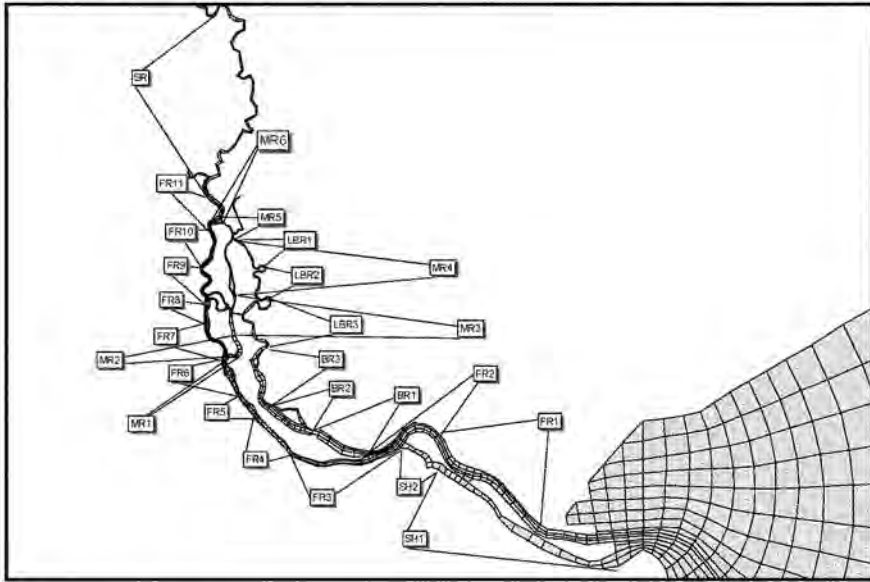
Figure 14: Surface Salinity Difference Comparison – with and without meeting areas modeled



Impacts to D.O.

Impacts to D.O. within the estuary due to inclusion of the meeting areas in the model grid are shown in Tables 4 and 5. Table 4 shows the change in D.O. percentiles for critical cells. A critical cell is the cell with the lowest D.O. concentrations during the simulation. The critical cell is found within each Zone. Table 5 shows the change in D.O. percentiles for each zone. A zone is an assemblage of cells that is limited by specified horizontal and vertical boundaries. The extents of each zone are shown in Figure 15.

Figure 15: Spatial Zones for D.O. Impact Evaluation



The maximum decrease in the critical cells for D.O. (shown in Table 4) as a result of modification to the model grid occurs on Back River in Zone BR3, which is located near New Cut. The change is 0.26 mg/L, which is a 7% decrease in the predicted D.O. value. Conversely, there are some increases in D.O. as a result of the model grid modification as well, which occurs on Front River in Zone FR9. The change is 1.47 mg/L, which is a 16.2% increase.

Table 5 shows that the maximum decrease in the zones for D.O. as a result of modification to the model grid occurs on Front River in Zone FR8 at the 95th percentile. The relative difference for this change in prediction is 1.2%. Comparatively, the maximum increase in D.O. as a result of modification to the grid is 0.13 mg/L for the 1st percentile and occurs on Back River in Zone BR1 and has a relative difference of 3%.

For both tables the 50th percentile differences are very minor with D.O. changes less than 0.1 mg/L.

Table 4: Changes in D.O. Percentiles for Critical Cells With and Without the Meeting Areas Included in the Model Grid.

Delta D.O. Percentiles for Critical Cells
Baseline: Scenario: 6A6ft-withD0mitigation
Project: Scenario: 6A6ftpasslane-withD0mitigation

Zone	Delta D.O. Percentile																	
	1%		5%		10%		25%		50%		75%		90%		95%		99	
	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%
FR1	0	0.0	-0.01	-0.2	0	0.0	-0.01	-0.2	-0.02	-0.4	-0.01	-0.2	-0.02	-0.4	-0.03	-0.6	-0.09	-1.9
FR2	-0.01	-0.3	-0.03	-0.8	-0.03	-0.7	-0.04	-0.9	-0.05	-1.1	-0.04	-0.9	0	0.0	0.01	0.2	0.02	0.4
FR3	-0.02	-0.5	-0.02	-0.5	-0.02	-0.5	-0.04	-1.0	-0.03	-0.7	-0.03	-0.7	-0.06	-1.2	0	0.0	-0.01	-0.2
FR4	-0.04	-1.1	-0.03	-0.8	-0.02	-0.5	-0.05	-1.2	-0.03	-0.7	-0.04	-0.9	-0.01	-0.2	-0.04	-0.7	0	0.0
FR5	-0.02	-0.5	-0.03	-0.7	-0.01	-0.2	-0.03	-0.7	-0.03	-0.6	-0.03	-0.6	-0.03	-0.6	-0.02	-0.4	-0.01	-0.2
FR6	-0.02	-0.5	-0.03	-0.7	-0.04	-1.0	-0.06	-1.4	-0.03	-0.7	-0.03	-0.6	-0.03	-0.6	-0.02	-0.4	-0.02	-0.3
FR7	-0.02	-0.5	-0.01	-0.2	-0.02	-0.4	-0.03	-0.6	-0.03	-0.6	-0.02	-0.4	-0.02	-0.3	-0.03	-0.4	-0.02	-0.3
FR8	-0.02	-0.4	-0.02	-0.4	-0.04	-0.8	-0.03	-0.5	-0.05	-0.7	-0.02	-0.2	-0.12	-1.3	-0.08	-0.8	-0.09	-0.9
FR9	0.23	4.1	0.05	0.8	0.05	0.8	0.02	0.3	0.09	1.2	0.81	9.9	1.1	12.5	1.47	16.2	0.94	8.8
FR10	-0.01	-0.2	-0.01	-0.2	0	0.0	0	0.0	0	0.0	-0.01	-0.2	0	0.0	0.01	0.1	0.01	0.1
MR1	-0.02	-0.5	0	0.0	0	0.0	-0.01	-0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
MR2	-0.02	-0.4	-0.03	-0.6	-0.03	-0.6	-0.02	-0.4	-0.02	-0.4	-0.02	-0.3	-0.01	-0.2	-0.01	-0.2	-0.04	-0.6
MR3	0	0.0	0	0.0	-0.01	-0.2	0	0.0	0	0.0	0.01	0.2	0.02	0.3	0	0.0	-0.01	-0.2
MR4	-0.01	-0.2	0.03	0.7	0.01	0.2	0	0.0	0	0.0	-0.01	-0.2	0.02	0.3	-0.01	-0.2	0	0.0
MR5	0	0.0	0.01	0.2	0.02	0.4	0	0.0	0.01	0.2	0.01	0.2	-0.01	-0.2	0	0.0	-0.01	-0.2
MR6	0	0.0	-0.02	-0.7	0	0.0	0.02	0.5	0	0.0	0	0.0	-0.01	-0.2	0	0.0	0	0.0
LBR1	0.03	0.7	-0.04	-0.8	-0.01	-0.2	0.01	0.2	0.01	0.2	0.01	0.2	0	0.0	0.01	0.1	0	0.0
LBR2	0.19	4.4	0.02	0.4	0.01	0.2	0.01	0.2	0.01	0.2	0.01	0.2	0.02	0.4	0.04	0.7	0.45	7.7
BR1	0.01	0.4	0.02	0.8	0	0.0	0	0.0	0	0.0	-0.02	-0.5	-0.01	-0.3	-0.03	-0.8	-0.01	-0.2
BR2	0.07	3.0	0.06	2.3	0.04	1.4	0.16	4.6	0.09	2.1	0.04	0.9	0.06	1.2	0.01	0.2	0.05	1.0
BR3	0.06	2.6	0.03	1.2	0	0.0	0.06	2.4	0.02	0.7	-0.01	-0.3	-0.17	-5.2	-0.2	-3.7	-0.26	-7.0
SCH1	-0.02	-0.8	-0.02	-0.7	-0.02	-0.7	-0.01	-0.3	-0.02	-0.6	0.02	0.5	0.02	0.5	-0.05	-1.1	-0.05	-1.1
SCH2	-0.01	-0.3	-0.05	-1.2	-0.01	-0.2	-0.03	-0.7	-0.02	-0.4	0	0.0	0.01	0.2	-0.04	-0.8	-0.01	-0.2
SR	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
SbR	-0.03	-0.7	-0.01	-0.2	0	0.0	0	0.0	-0.05	-0.7	-0.01	-0.1	-0.04	-0.5	0	0.0	-0.06	-0.7

Table 5: Changes in D.O. Percentiles for Zones With and Without the Meeting Areas Included in the Model Grid

Difference of D.O. %-tiles for zones of Savannah Estuary

Simulation Period: Year 1997 AUGUST 1 -AUGUST 31

Baseline ario: 6A6ft-withD0mitigation

Project 6A6ftpasslane-withD0mitigation

Zone Name	Project - Baseline Difference (mg/l)										Project - Baseline Relative Difference (%)									
	1%	5%	10%	25%	50%	75%	90%	95%	99%		1%	5%	10%	25%	50%	75%	90%	95%	99%	
FR1	-0.01	-0.02	-0.02	-0.05	-0.04	-0.01	0.01	-0.02	-0.05	-0.3	-0.4	-0.6	-1.2	-1.0	-0.2	0.2	-0.4	-1.0		
FR2	-0.01	-0.01	-0.02	-0.05	-0.04	-0.04	0.03	0.02	0.02	-0.2	-0.3	-0.4	-1.2	-0.8	-0.7	0.6	0.3	0.4		
FR3	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	0.00	0.02	0.02	-0.5	-0.4	-0.4	-0.8	-0.6	-0.6	0.0	0.3	0.3		
FR4	-0.02	-0.01	-0.01	-0.04	-0.03	-0.03	0.00	-0.01	-0.02	-0.5	-0.4	-0.3	-0.9	-0.7	-0.6	0.0	-0.2	-0.4		
FR5	-0.02	-0.02	-0.02	-0.03	-0.05	-0.03	-0.01	-0.01	-0.01	-0.5	-0.4	-0.4	-0.6	-1.1	-0.5	-0.2	-0.1	-0.2		
FR6	-0.02	-0.02	-0.03	-0.04	-0.03	-0.02	-0.02	-0.03	-0.02	-0.5	-0.4	-0.6	-1.0	-0.6	-0.4	-0.3	-0.4	-0.3		
FR7	-0.02	-0.03	-0.01	-0.02	-0.04	-0.02	-0.05	-0.02	0.01	-0.3	-0.4	-0.1	-0.5	-0.7	-0.4	-0.7	-0.3	0.1		
FR8	0.00	-0.03	-0.04	-0.02	-0.05	-0.03	-0.06	-0.11	-0.03	0.1	-0.6	-0.7	-0.4	-0.7	-0.4	-0.7	-1.2	-0.3		
FR9	0.05	0.04	-0.01	0.01	0.00	-0.01	0.00	0.02	0.02	0.8	0.6	-0.1	0.2	-0.1	-0.1	0.0	0.3	0.2		
FR10	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.00	0.00	-0.1	0.0	-0.1	0.0	0.0	0.0	0.1	0.1	0.2		
FR11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
MR1	-0.02	-0.01	-0.03	-0.03	-0.01	-0.02	0.01	-0.02	-0.01	-0.5	-0.3	-0.6	-0.6	-0.3	-0.3	0.2	-0.4	-0.1		
MR2	0.01	0.02	0.00	0.01	-0.01	-0.02	-0.03	-0.01	-0.01	0.2	0.4	0.1	0.1	-0.2	-0.4	-0.5	-0.2	-0.1		
MR3	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	-0.1	0.2	0.1	0.3	0.2	0.0	-0.1	0.1	-0.1		
MR4	0.01	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.3	0.0	0.3	0.2	0.2	0.1	0.0	0.0	0.0		
MR5	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.2	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0		
MR6	-0.01	0.01	-0.01	0.00	0.01	0.00	0.00	0.00	0.00	-0.3	0.2	-0.3	0.1	0.2	0.0	0.0	0.0	0.1		
LBR1	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	0.0	0.0	0.0	-0.1	0.0	-0.1	-0.1	0.0	-0.1		
LBR2	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.02	-0.02	0.0	0.0	0.0	-0.1	-0.3	0.0	0.1	0.3	-0.4		
LBR3	0.00	0.00	-0.01	-0.01	-0.02	-0.01	0.00	0.00	0.00	-0.1	0.0	-0.2	-0.2	-0.5	-0.2	0.0	0.0	0.1		
BR1	0.13	0.01	0.01	0.01	0.00	0.02	0.01	0.04	0.05	3.0	0.2	0.2	0.3	0.1	0.3	0.2	0.8	0.9		
BR2	0.07	0.05	0.04	0.07	0.08	0.03	0.02	0.02	0.02	2.7	1.8	1.2	1.9	1.8	0.7	0.4	0.5	0.4		
BR3	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.04	0.07	1.0	1.1	1.0	1.2	1.4	1.2	0.8	1.1	2.0		
SCh1	-0.05	-0.03	-0.03	-0.01	0.00	-0.02	-0.01	-0.02	-0.04	-1.5	-1.0	-0.7	-0.2	-0.1	-0.5	-0.3	-0.5	-0.9		
SCh2	0.01	-0.01	0.00	-0.02	-0.01	0.01	0.00	0.01	0.00	0.1	-0.2	0.0	-0.5	-0.3	0.2	0.1	0.1	0.1		
SR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
StbR	-0.01	0.00	-0.01	0.02	0.00	0.00	-0.03	-0.03	-0.04	-0.2	0.1	-0.2	0.3	0.0	0.0	-0.4	-0.4	-0.6		

Conclusions

In summary, the changes due to model grid modification with addition of the meeting area geometries are minor. The impacts to tidal fluctuations and the salinity regime as shown by Figures 5 through 15 are minor. The largest changes in salinity occur on the bottom of the river and are not expected to pose an impact to adjacent wetlands.

The largest impacts to D.O. as a result of the model grid occur at the extreme percentiles, 1st and 95th while the 50th percentile salinities changes are very minor.

For completeness, these features could be incorporated into the project conditions model grid. However, it is currently unknown whether these navigation features will be economically justified and incorporated into the final selected plan. Also, as shown by this sensitivity analysis, the changes are likely to have little to no impact on the previous estimates to freshwater marsh/wetland or water quality impacts and therefore no bearing on the mitigation plan or project cost estimates.



Savannah Harbor Expansion Project

Sensitivity Analysis of Proposed Sill on Middle River

September 2009

Introduction

This report summarizes the results of 1) impacts to Shortnose Sturgeon (SNS) habitat within the Savannah River estuary, 2) freshwater marshes/wetlands adjacent to the estuary and 3) water quality (dissolved oxygen, D.O.) due to the addition of a sill on Middle River to the mitigation plan. The sill on Middle River was proposed as a possible mitigation feature for protection of observed SNS habitat along a bend in lower Middle River. Evaluation of the new mitigation feature along with the feature's impacts to other resources is the focus of this report.

In addition to the impact analysis, the criteria for which SNS juvenile habitat is categorized as suitable or unsuitable has changed from previous reporting to better reflect observed SNS habitat in critical areas.

SNS Juvenile Habitat Research

Shortnose Sturgeon Research conducted in 1999-2000 by Collins et al.^(a) in the Lower Savannah River for the Georgia Ports Authority reported important findings, which are useful and pertinent to the SHEP. Based on discussions between the USACE and NOAA-Fisheries, the following findings from Collins et al research have become focal points for modeling analysis and defining SNS habitat.

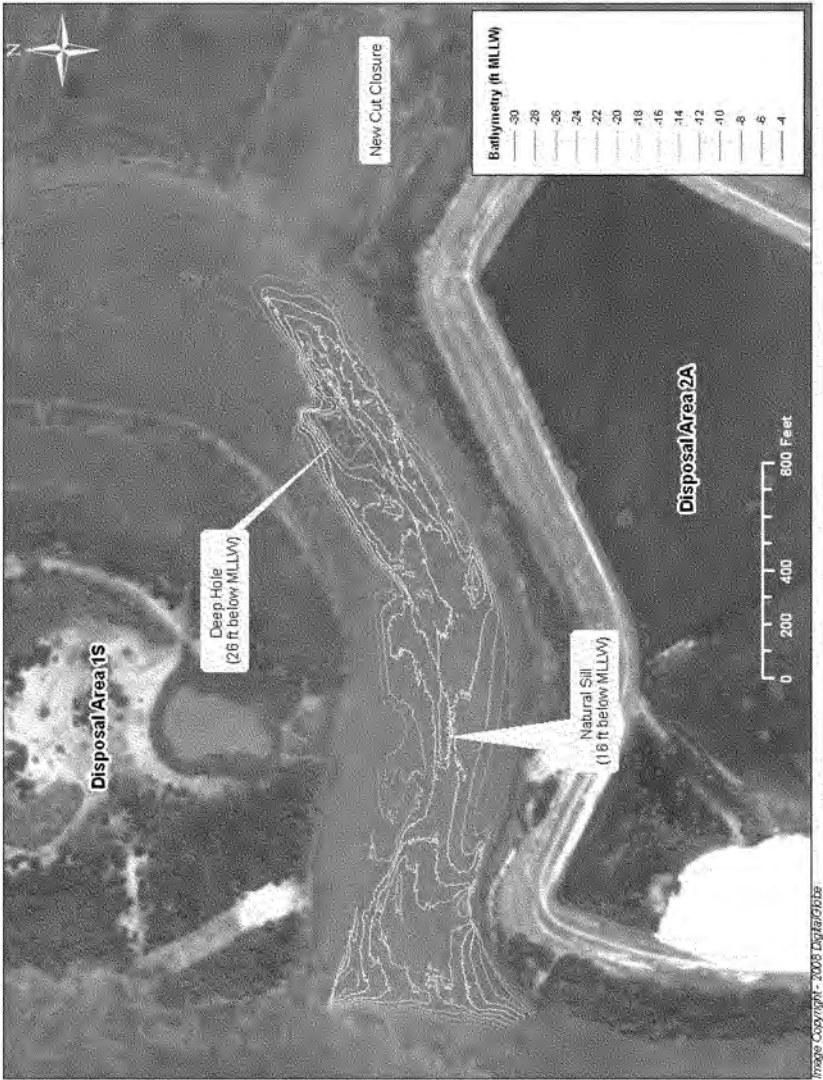
- SNS juveniles (defined as < 56 cm TL) occur in salinities up to 17.6 ppt
- During temperatures < 22°C, juveniles prefer a location inside the Middle River (river km 31.3) in a 7.9 meter deep hole.
- At river km 31.3, 9 juvenile fish were captured with 4 measuring < 40 cm TL, Collins suggested this area is critical nursery habitat for young SNS
- Water quality data suggest that the natural sill between the 7.9 meter deep hole and the confluence with the Front River may minimize salinity fluctuations associated with the tidal cycle.
- Using Collins salinity data (43 data points) for juvenile SNS captured during temperatures < 22°C adjacent to or within the deep hole, a max salinity tolerance of 14.9 ppt was identified.

Middle River Survey

To confirm the 7.9 m (approximately 26 ft) hole on Middle River and obtain more information about it's size and shape, a survey was completed in March 2009 of Middle River from the confluence with Front River to just upstream of the New Cut closure. See Figure 1. A large hole does exist within this area at a depth of approximately 26 ft below MLLW. There is also a sill 16 ft below MLLW between the deep hole and Front River that aids in protecting the area from high saline waters found on the bottom of Front River. There are some questions about how this hole and sill were formed, and if it is natural or man-made. There are some suggestions that the deep hole was man-made due to the steep side slope on the northeast edge of the hole. However, that is only speculation and has not been proven true or false.

(a) Collins, Mark R., William C. Post, Daniel C. Russ. *Distribution of Shortnose Sturgeon in the Lower Savannah River*. Report to Georgia Ports Authority.

Figure 1: Middle River Survey conducted March 2009



Sill Design and Model Input Parameters

Improving the sill on Middle River at the Front River confluence was proposed as a mitigation feature to protect SNS habitat. The idea is that the sill would be low enough to allow fish movement to the Middle River bend, but would be high enough to inhibit high concentrations of bottom salinity moving from Front River into the bend. Table 1 outlines the design parameters of this sill. These are considered the maximum height and length parameters for the sill. Anything higher could be undesirable for the SNS, could impact navigation on the Middle River and/or could impact the current geometry of the deep hole in the bend on Middle River.

The sill was modeled by changing the bottom elevation in EFDC/WASP grid cells 16_82, 17_82 and 18_82 to elevation -2.88 m NGVD (-6.4 ft MLLW) which is an increase of approximately 4 meters over the three cells average bottom elevations. See Figure 2 for a map showing the cell locations. Due to the change in grid cell geometry both the hydrodynamic (EFDC) and water quality (WASP) models were re-run for the analysis.

Table 1: Design Parameters of the Middle River Sill

Current Conditions at Middle River/Front River Confluence	
Bottom elevation	~20 ft below MLLW
Channel Width	~600 ft
Proposed Sill Design Parameters	
Top of Sill	6.4 ft below MLLW
Sill Length	~1500 ft long
Sill would have sloped sides tapering to existing bottom elevations.	
Constructed with sandy materials possibly coming from nearby disposal areas 1S & 2A.	
Total channel area on Middle River impacted with design is approximately 19 acres.	

Figure 2: EFDC/WASP Grid



SNS Habitat Impact Analysis

SNS Habitat Criteria

The SNS juvenile habitat evaluation criteria originally chosen for SHEP impact evaluation was decided upon by the Interagency Coordination Team. Details of this criteria are shown in Table 2. Figure 3 shows the results of the existing conditions model run with the original habitat suitability criteria.

A new set of SNS juvenile habitat criteria was suggested by NOAA-Fisheries in hopes that the existing conditions (basemaps) would better represent the observed SNS habitat patterns noted in research conducted by Collins et al in 1999-2000. See Table 3 for the new criteria. The change is shown in blue. The D.O. criteria does not change with the new evaluation, only the salinity criteria changes.

The area of interest in this analysis is the bend in Middle River just upstream of the confluence with Front River and on Front River below Houlihan Bridge to the Middle River confluence. SNS juveniles have been observed in this area during cool months of the year by Collins et al, however our initial impact basemaps used for SHEP impacts did not show this area to be suitable habitat for SNS Juveniles during January due to high salinity recordings. See Figure 3. Once the new criteria was established the existing conditions basemap better correlates the predicted SNS Juvenile habitat with the observed datasets. See Figure 4.

Table 2: SNS Criteria Developed by the Interagency Coordination Team

Species & Life Stage	Freshwater Flow Conditions	Simulation Period	Habitat Criteria
Shortnose Sturgeon (juvenile)	50%-ile of Long Term	January	Suitable habitat when DO >= 3.5 mg/l at 90% exceedance (10th %ile), >=3.0 at 95% (5th percentile), and >=2.0 at 99% (1 percentile) Suitable habitat when Max Salinity <= 4 ppt

Table 3: SNS Criteria Developed by National Marine Fisheries

Species & Life Stage	Freshwater Flow Conditions	Simulation Period	Habitat Criteria
Shortnose Sturgeon (juvenile)	50%-ile of Long Term	January	Suitable habitat when DO >= 3.5 mg/l at 90% exceedance (10th %ile), >=3.0 at 95% (5th percentile), and >=2.0 at 99% (1 percentile) AND Suitable habitat when 50%ile of Max Salinity <= 14.9 ppt

Figure 3: SNS Habitat Basemaps (Previously Approved Criteria)

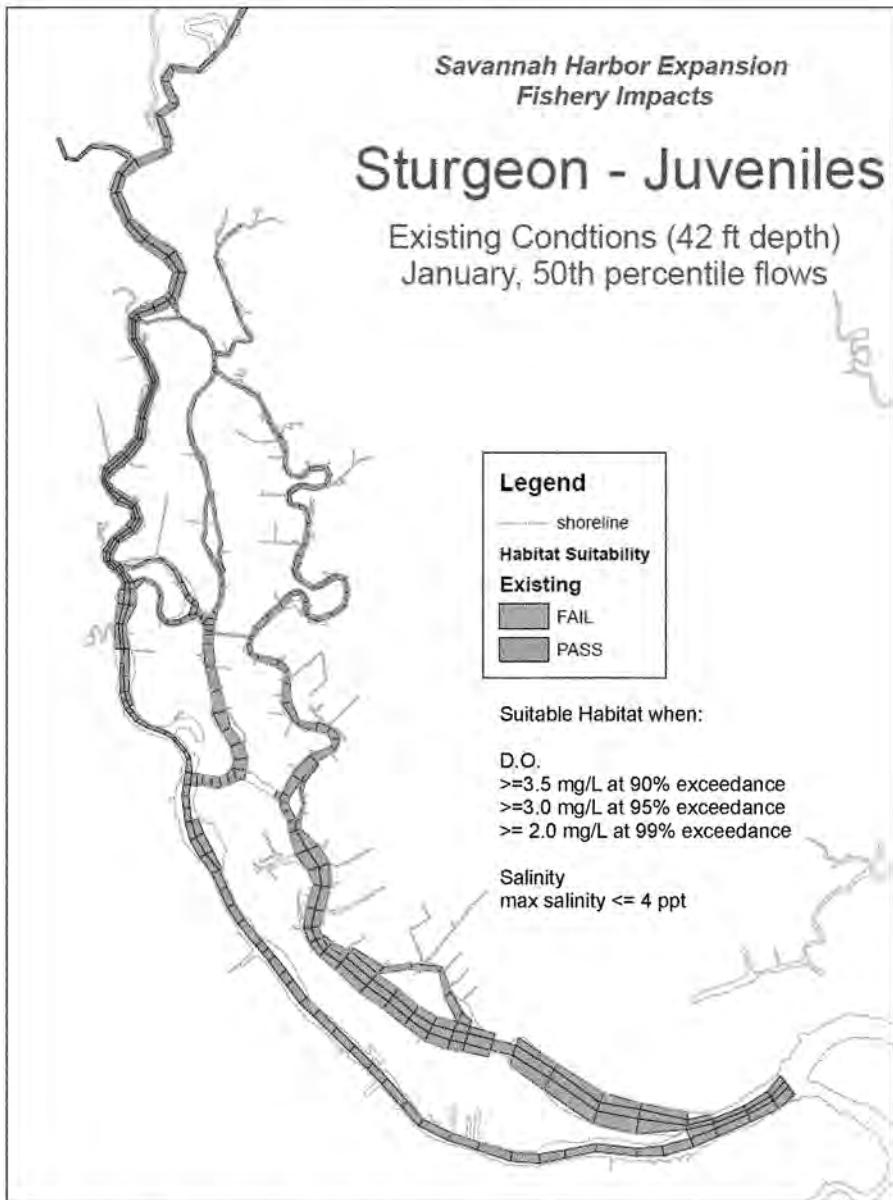
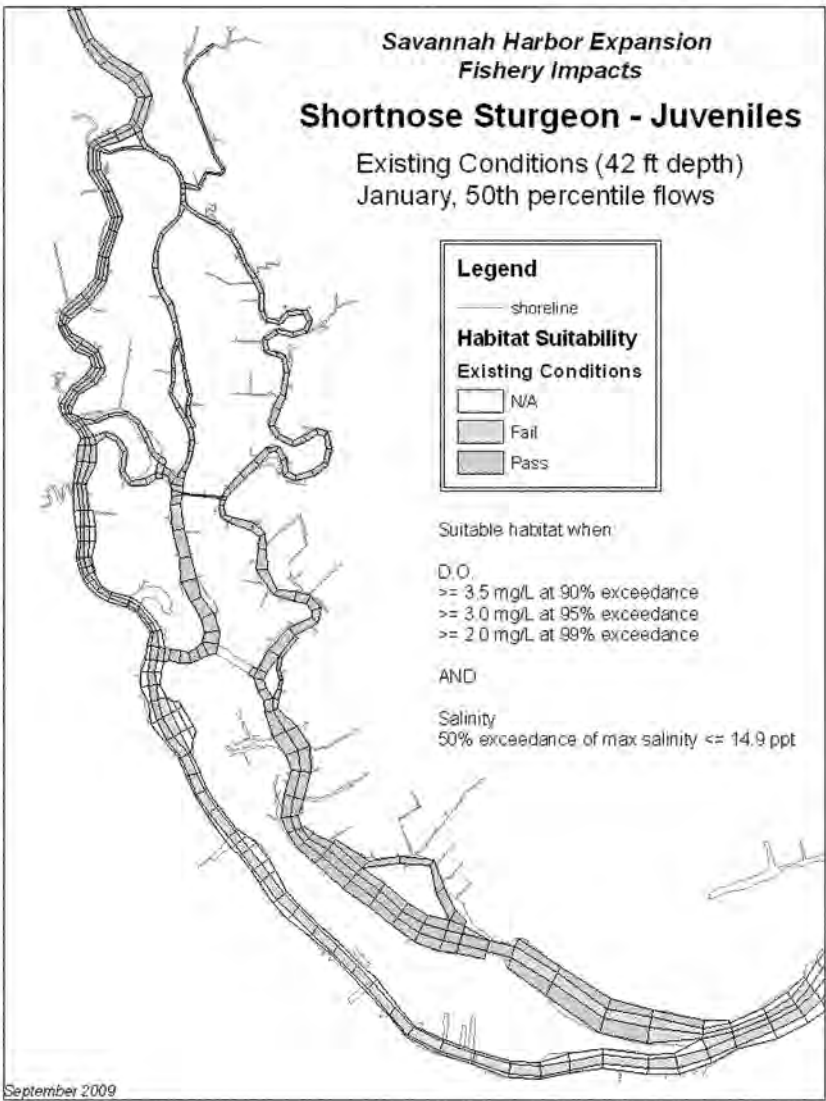


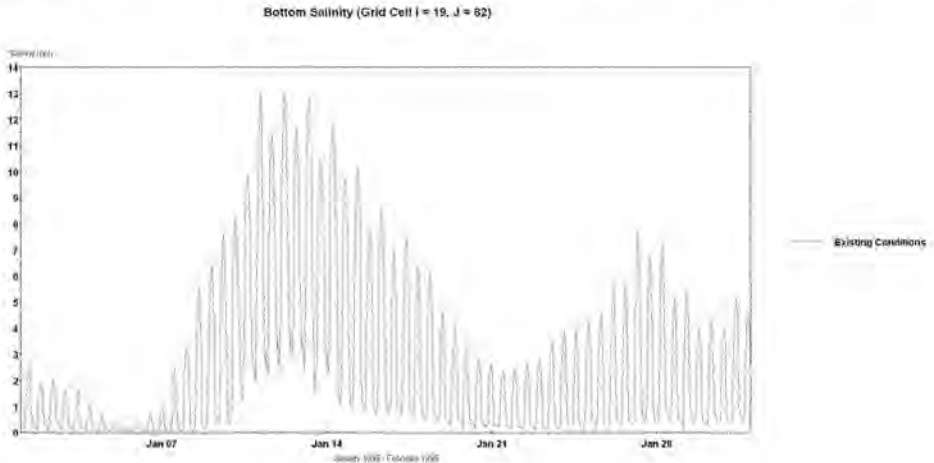
Figure is from the report titled *Evaluation of Fishery Habitat Impacts with Proposed Mitigation Plan* dated June 2008.

Figure 4: SNS Habitat Basemaps (New Approved Criteria)



In the area of interest maximum bottom salinities range from 9.6 to 14.9 ppt for the January run scenario with existing bathymetry conditions. This range of maximum bottom salinity satisfies both sets of the new habitat criteria, and failed the original criteria. At model grid cell 19_82 (on Middle River at site of deep hole) the maximum bottom salinity was 13.1 ppt which occurred during the spring high tide. The average bottom salinity throughout the run period within the bend was 2.6 ppt. Indicating the spring peak tides have a substantial impact on the salinity in Middle River. Outside of this tidal condition the salinity values are much lower. Figure 5 shows the salinity variation over the full month at model grid cell 19_82.

Figure 5: Modeled Bottom Salinity Output (Grid Cell 19_82 on Middle River at deep hole)



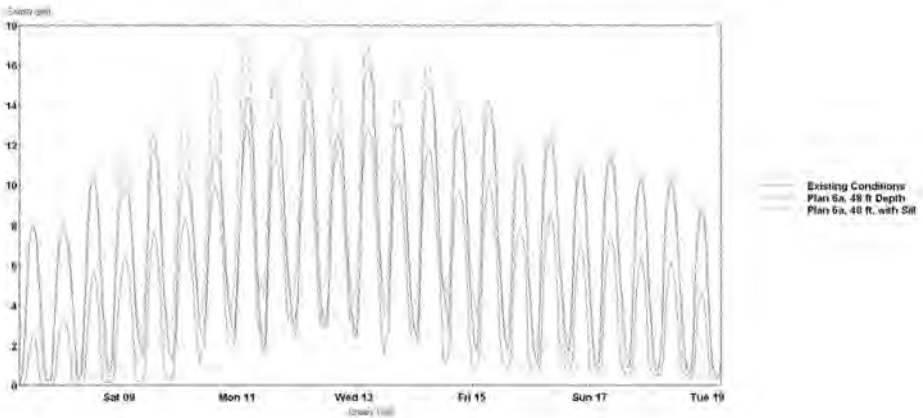
The new criteria appears to be more appropriate than the original for the Juveniles since they have been observed in the Middle River bend and the modeled salinity seems to be in line with Collins et al research.

SNS Habitat Feature Evaluation

To preserve the SNS Juvenile habitat on Middle River, especially within the deep hole at the bend, improvements to the sill on Middle River were suggested, modeled and incorporated into the mitigation plan. Figure 6 shows a comparison between the existing conditions, the 48 ft channel depth with mitigation plan 6a without the sill on Middle River and with the sill on Middle River. The comparison is zoomed to the week of the January spring tide event and shows bottom salinities within the Middle River bend. As shown in the figure, the sill in place on Middle River does reduce bottom salinities. However, it doesn't fully mitigate for the impact due to deepening the channel to 48 feet.

Figure 6: Bottom Salinity Comparison on Middle River Bend (Beyond Sill)

Bottom Salinity Comparison (Grid Cell i=19, j=82)



The following figures, 7 and 8, show the changes in habitat suitability due to the project. In Figure 7 the comparison is made between the existing conditions and the 48 ft channel depth with mitigation plan 6a. In Figure 8 the comparison is made between the existing conditions and the 48 ft channel depth with mitigation plan 6a and the sill at Middle River. Gains and losses in habitat are shown on the figures for the new approved habitat criteria. Since the run period is in January, the habitat suitability is based on the salinity criteria. The D.O. values predicted for this run period are high enough to meet the water quality criteria.

Both figures show a loss of habitat on Front River from Kings Island Turning Basin up to Steamboat River. Losses in this area are due to increases in salinity caused by the project, not water quality impacts to D.O. values. The habitat losses do not extend up Middle River through the area of interest in the bend. These figures do not definitively show the benefit of the sill for Juvenile SNS in the Middle River bend. However, comparing the bottom salinity over the full tidal run period as seen in Figure 6 does show a decrease in salinity due to the improvement of the sill.

In addition to salinity and D.O., the velocities were also evaluated within the Middle River bend (grid cell 19_82) to assess the potential for shoaling within the observed SNS habitat area due to improvements to the sill. The peak velocities were compared between the model runs with and without the sill in place. The sill showed a maximum difference in the daily peaks of 0.42 fps at mid-depth in the water column. The maximum differences on the bottom was 0.14 fps and the max difference on the surface was actually a slight increase with the sill. Averaging over the full water column a very minor difference was noted, and was not a significant change with the sill in place. However, looking at the velocity comparisons by depth show that there are decreases at mid-depth and at the bottom of the water column that could have an influence on shoaling in the area. Slower velocities would allow an opportunity for sediment to fall out of the water column behind the sill. The potential for increased shoaling in this area with the sill does exist, but can't be defined as great and is not expected to be significant.

Figure 7: SNS Habitat Impacts Comparison Between Existing Conditions and 48 ft Channel Depth, Mitigation Plan 6a ONLY - no Sill on Middle River (New Approved Criteria)

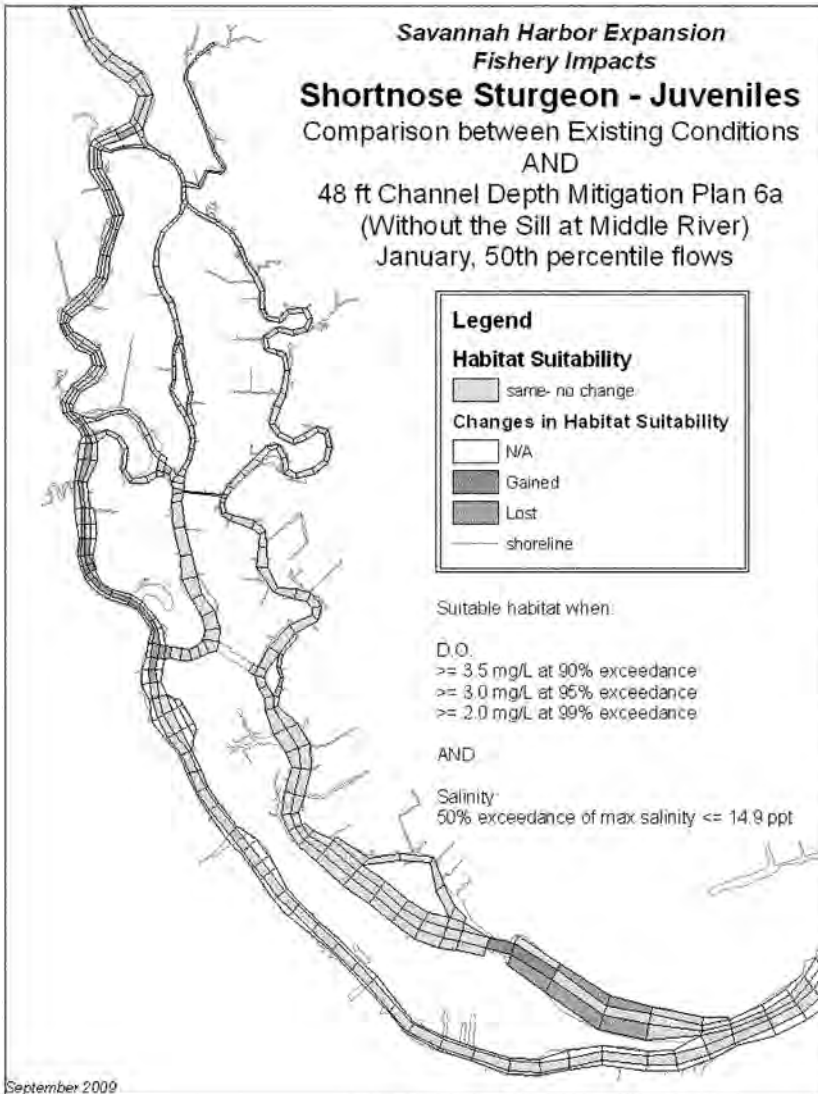
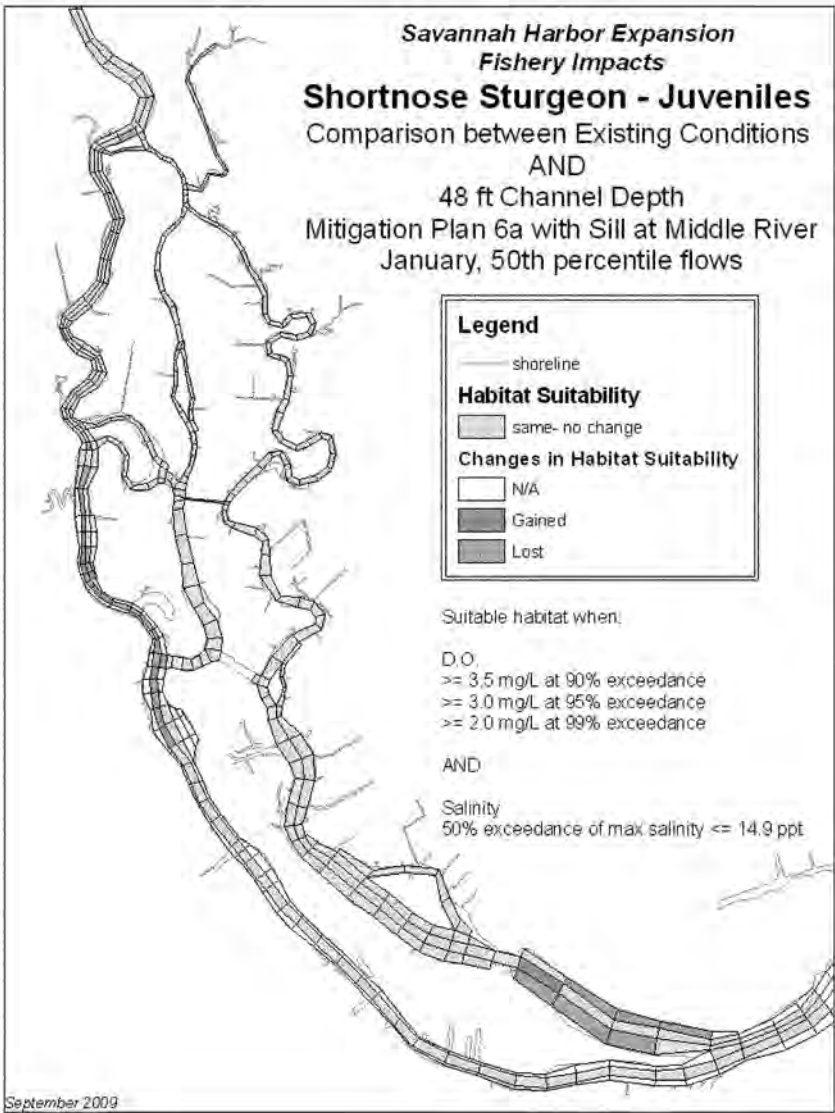


Figure 8: SNS Habitat Impacts Comparison Between Existing Conditions and 48 ft Channel Depth, Mitigation Plan 6a with the Sill on Middle River (New Approved Criteria)



Freshwater Marsh/Wetland Impact Analysis

Marsh/Wetland Impact Analysis

Impacts to Tidal Fluctuations

Impacts to tidal fluctuations within the estuary due to inclusion of a new mitigation feature (sill at the mouth of Middle River) were examined at several grid cell locations on Back and Middle Rivers. See Figure 4. Details of tidal variability are shown by water depth in Figures 5 through 11. None of these seven locations along Middle and Back River show an impact to tidal depth or timing as a result of inclusion of the new mitigation feature within the model geometry. Comparisons are made between the 48 ft depth alternative with Mitigation Plan 6a in place with and without the new mitigation feature modeled.

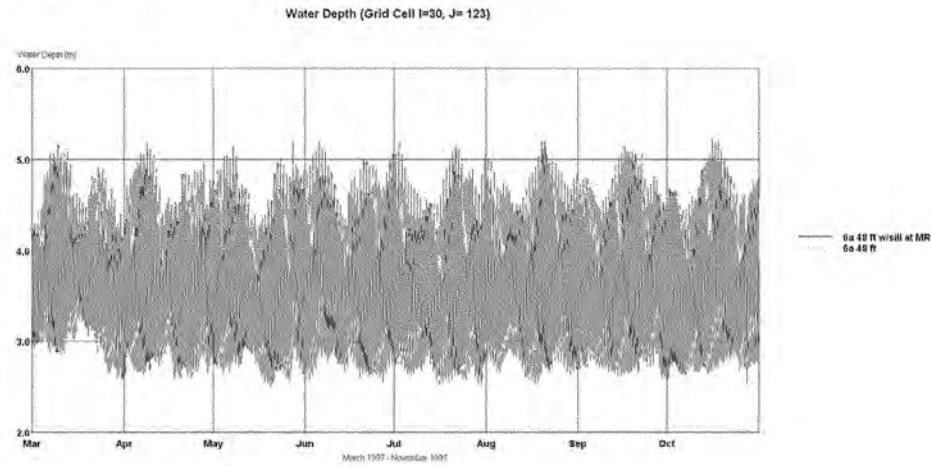
Figure 4: EFDC Grid Cell Locations Examined for Impacts to Tidal Fluctuations



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Figure 5: Water Depth Comparison at EFDC Grid Cell 30 123

A: full run period March through October 1997



B: zoomed run period August 1997

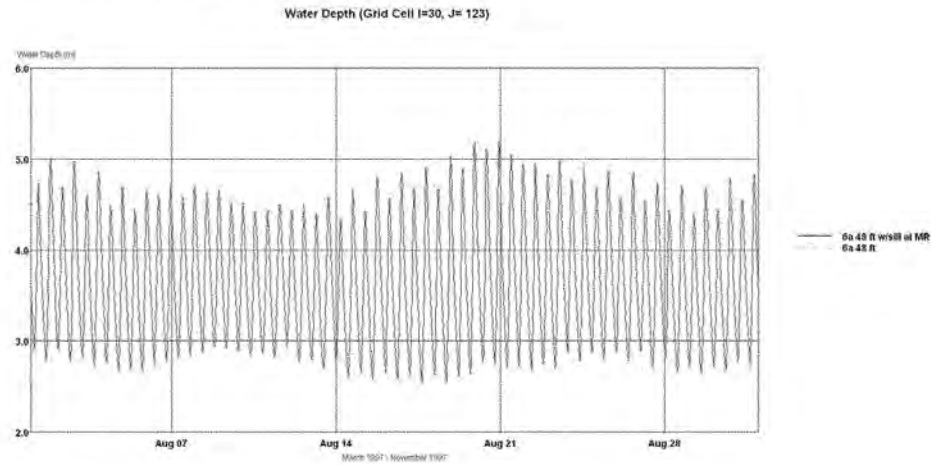


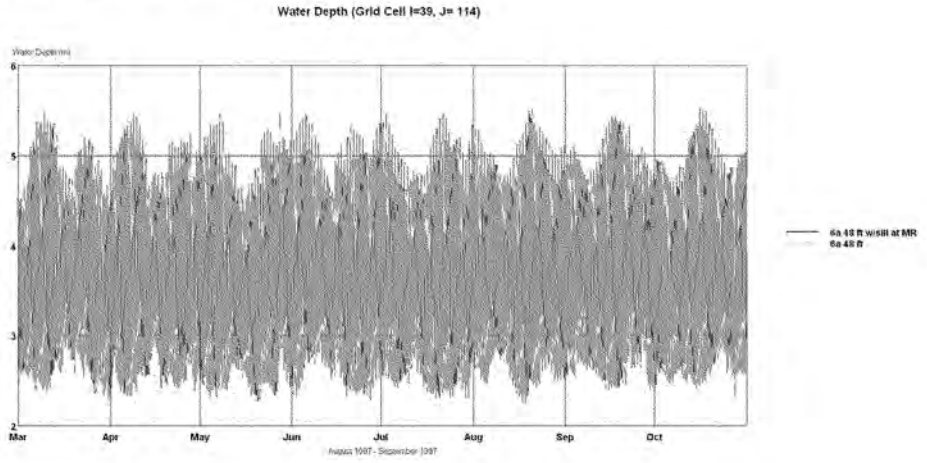
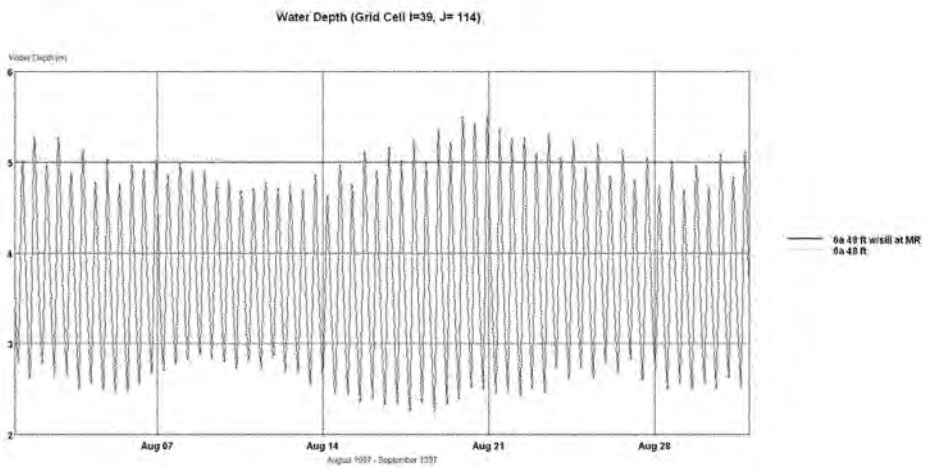
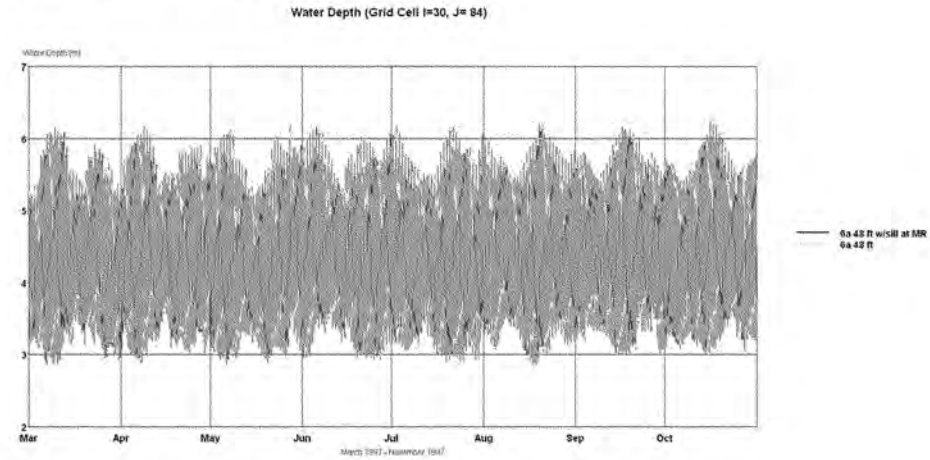
Figure 6: Water Depth Comparison at EFDC Grid Cell 39 114**A:** full run period March through October 1997**B:** zoomed run period August 1997

Figure 7: Water Depth Comparison at EFDC Grid Cell 30 84

A: full run period March through October 1997



B: zoomed run period August 1997

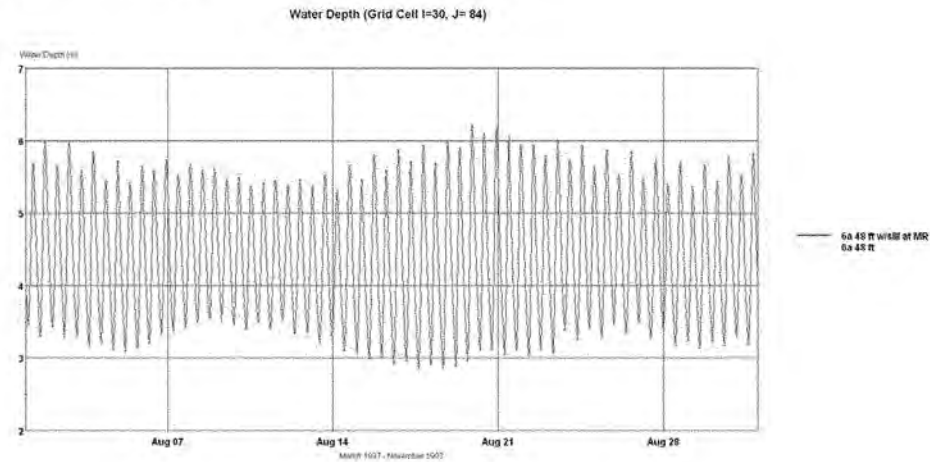
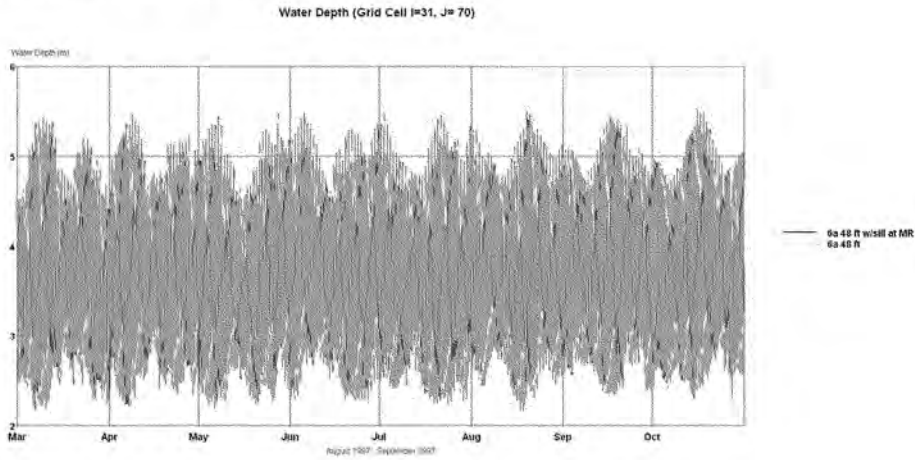


Figure 8: Water Depth Comparison at EFDC Grid Cell 31 70

A: full run period March through October 1997



B: zoomed run period August 1997

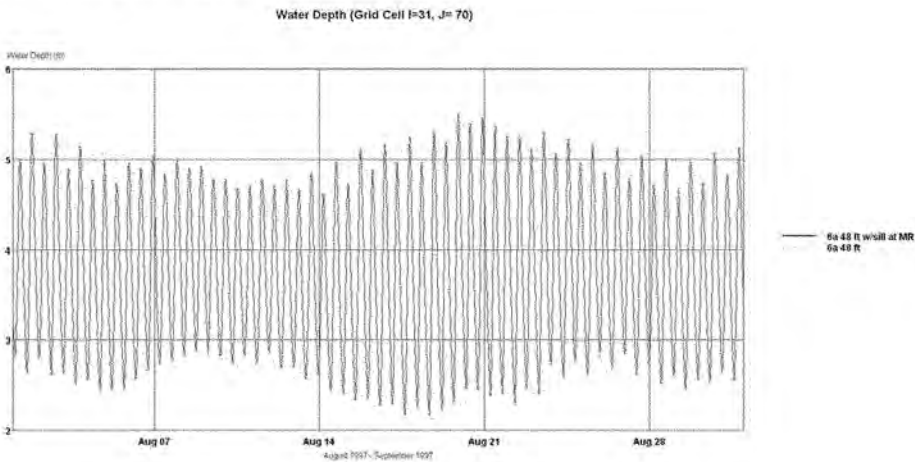
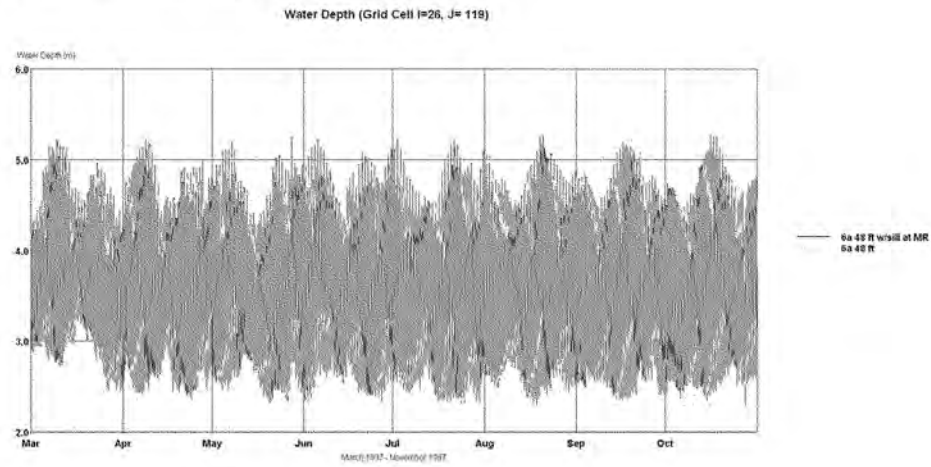


Figure 9: Water Depth Comparison at EFDC Grid Cell 26 119

A: full run period March through October 1997



B: zoomed run period August 1997

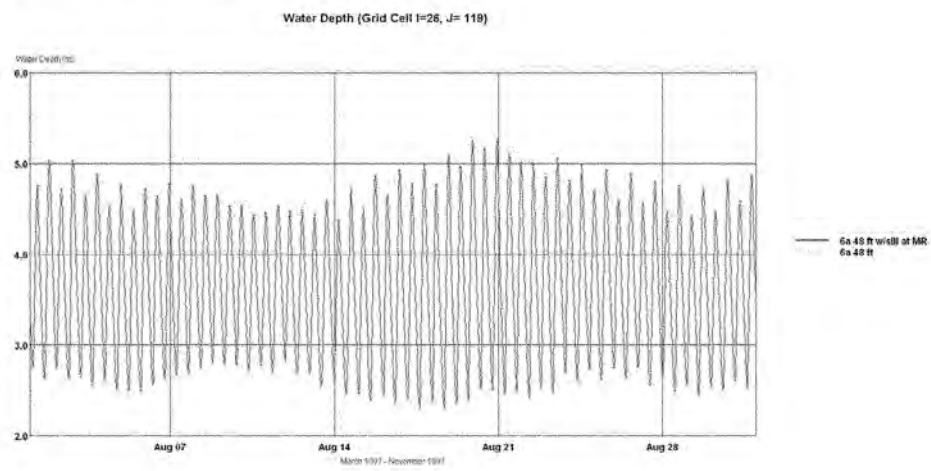
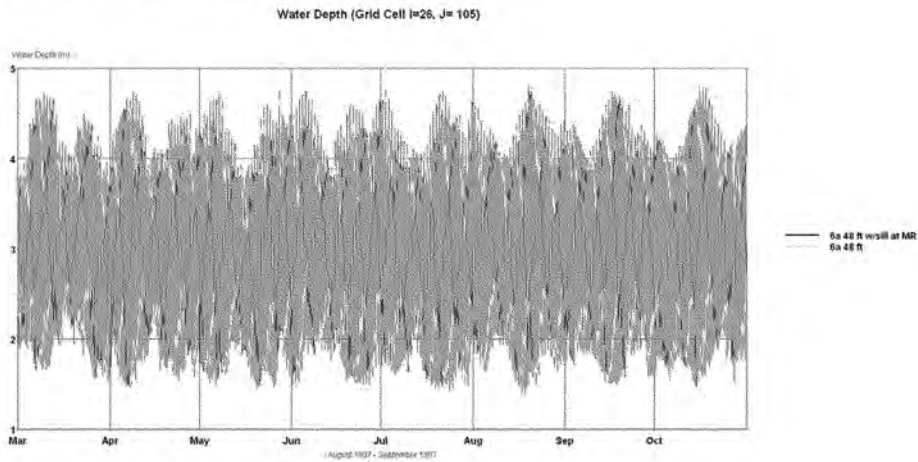


Figure 10: Water Depth Comparison at EFDC Grid Cell 26 105

A: full run period March through October 1997



B: zoomed run period August 1997

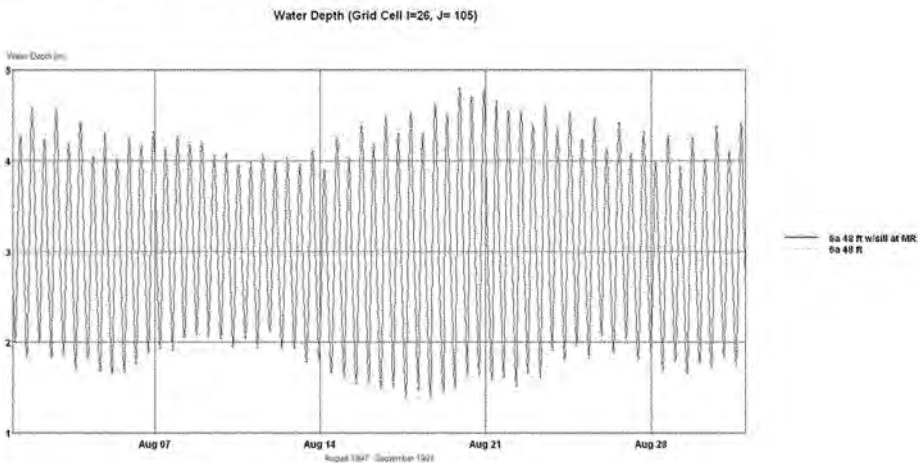
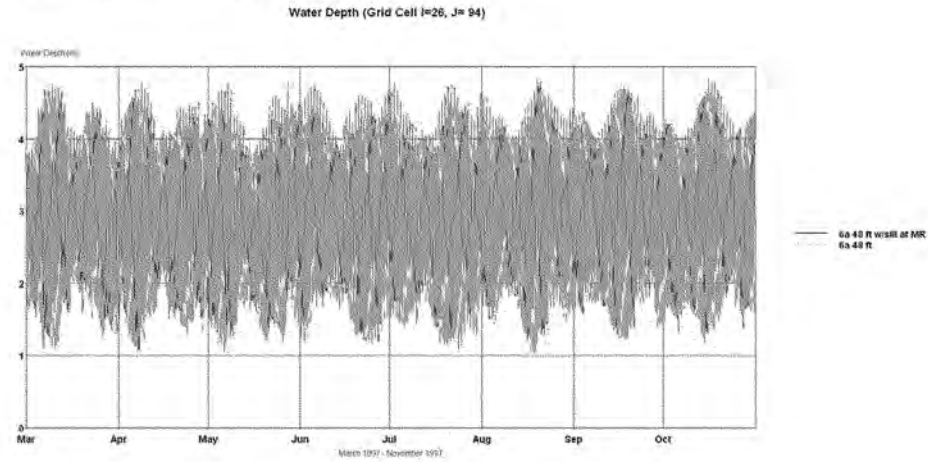
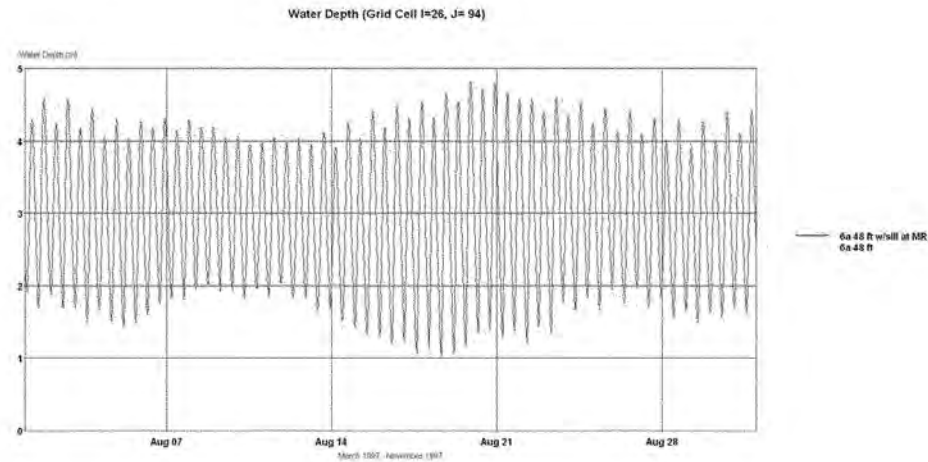


Figure 11: Water Depth Comparison at EFDC Grid Cell 26 94

A: full run period March through October 1997



B: zoomed run period August 1997



Impacts to Salinity Regime

Impacts to the salinity regime within the estuary due to inclusion of the new mitigation feature (sill at mouth of Middle River) in the model grid geometry were examined and results are shown in Figures 12 through 14. Comparisons are made between the 48 ft depth alternative with Mitigation Plan 6a in place with and without the mitigation feature modeled.

Figures 12 and 13 show the changes in salinity for both the model grids surface and bottom salinity predictions for the Basic Evaluation run period. The Basic Evaluation occurs from March through October in 1997 which is considered an average flow year. These would be conditions experienced within the estuary on an average basis.

Inclusion of the sill as a mitigation feature does cause a rise in predicted surface salinity values for the Basic Evaluation (average flow year). The maximum rise is 0.06 ppt. However, the predicted bottom salinity drops in the same location to values between 0.5 ppt and 0.99 ppt.

Figure 14 shows surface salinity changes under the Sensitivity Analysis #1 (low flow/drought conditions). Minor surface salinity increases are seen along Front River (less than 0.1 ppt). The peak increases are seen in the bend on Middle River. The maximum increase for surface salinity in this area is 0.28 ppt. Comparatively, Figure 15 shows the bottom salinity changes with the Sensitivity Analysis #1 low flow scenario. The decreases in bottom salinity prediction for this scenario on Middle River with the sill in place range from 0.1 ppt to 0.99 ppt.

For both run scenarios, average and low flow/drought conditions, the surface salinities increase slightly, while the bottom salinities are predicted to be lowered by a much larger amount.

Figure 12: Surface Salinity Difference Comparison – with and without meeting areas modeled

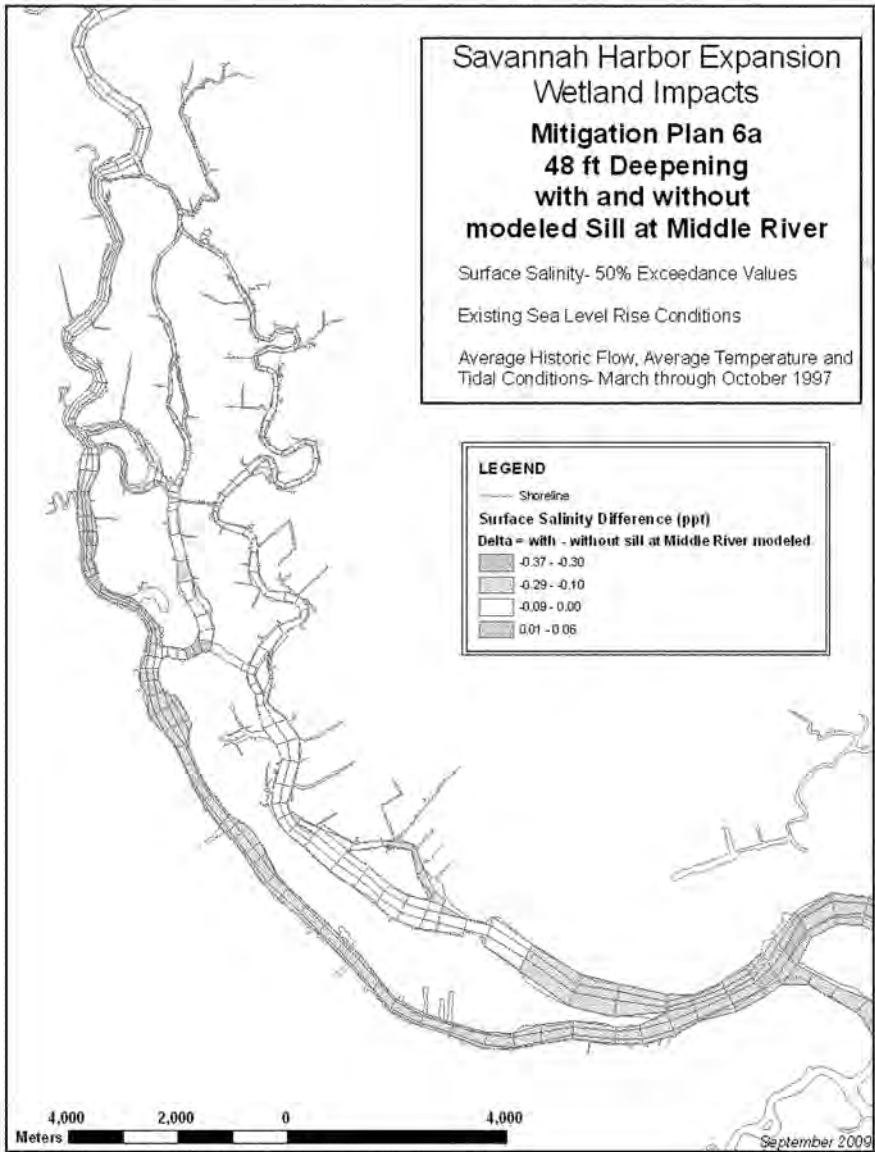


Figure 13: Bottom Salinity Difference Comparison – with and without meeting areas modeled

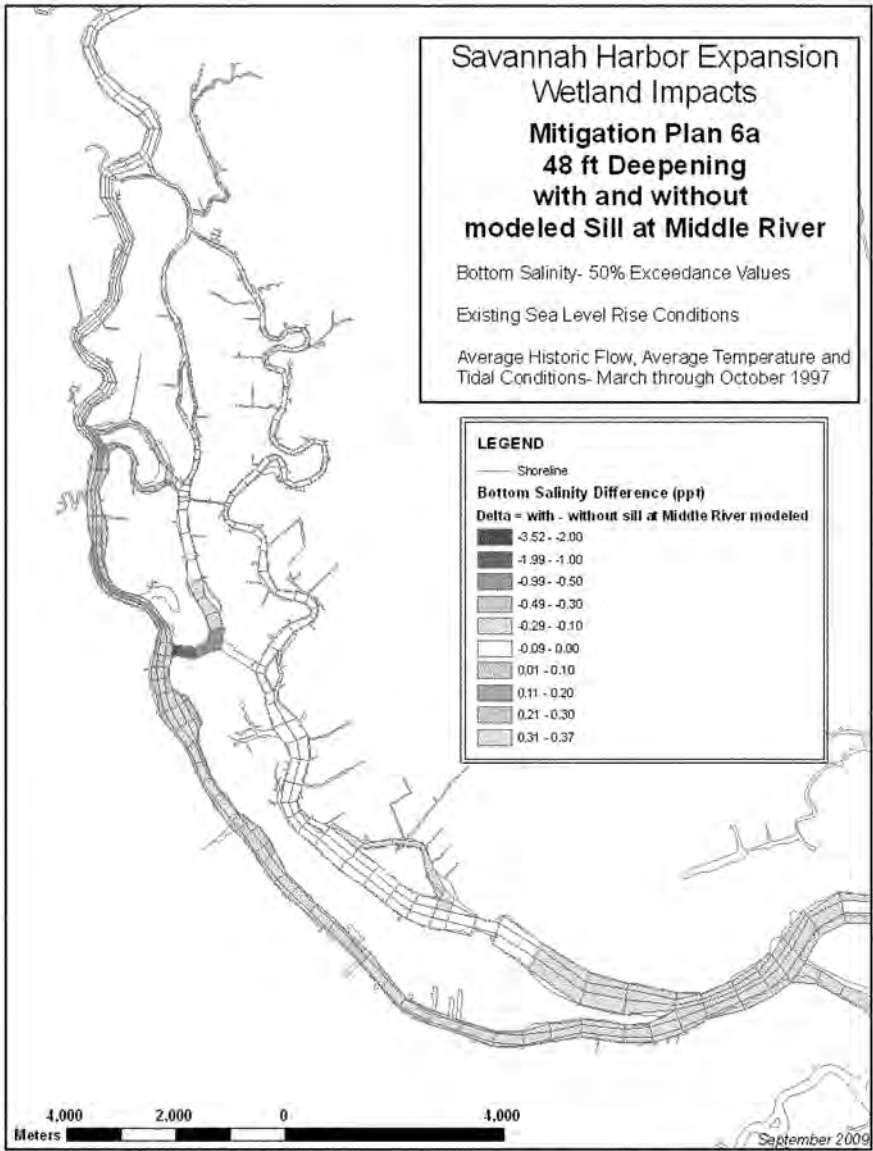


Figure 14: Surface Salinity Difference Comparison – with and without meeting areas modeled

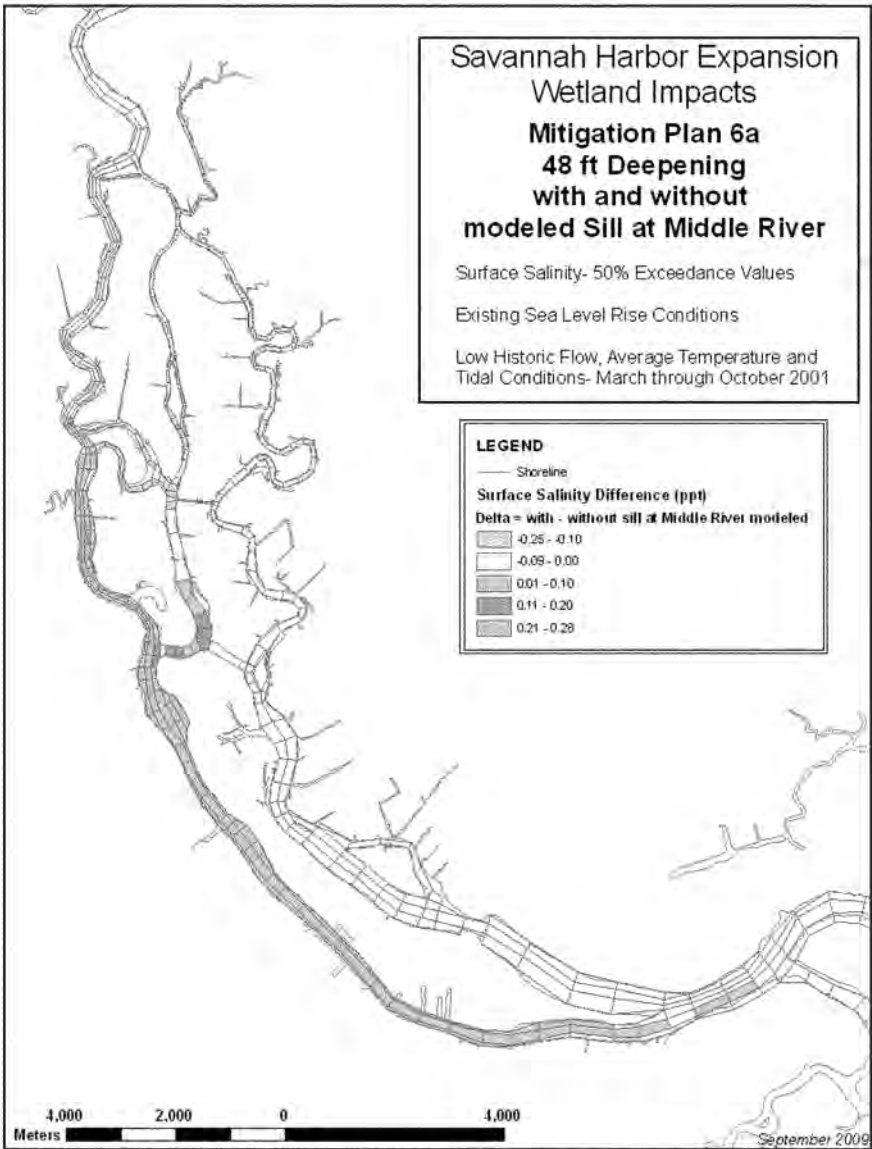
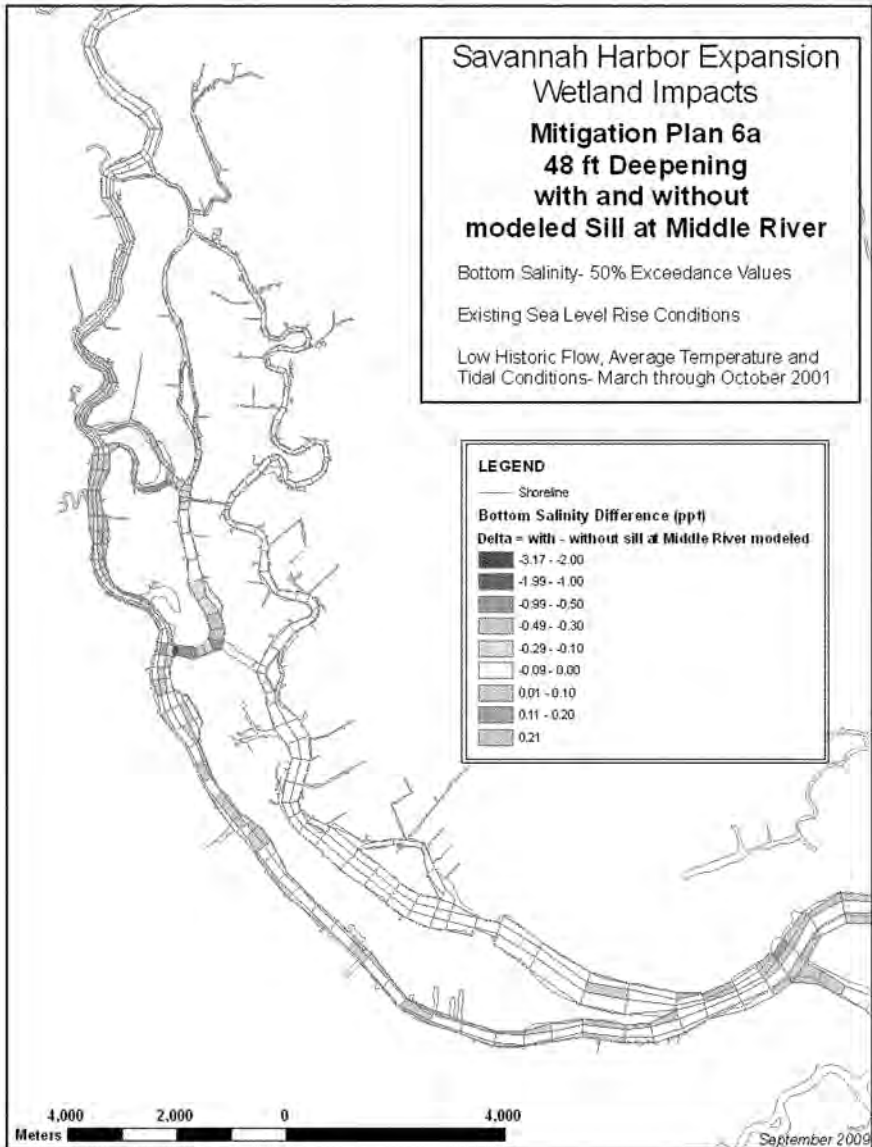


Figure 15: Bottom Salinity Difference Comparison – with and without meeting areas modeled



Water Quality (D.O.) Impact Analysis

Impacts to D.O. within the estuary due to inclusion of the Middle River sill in the model grid geometry are shown in Tables 4 and 5. Table 4 shows the change in D.O. percentiles for critical cells. A critical cell is the cell with the lowest D.O. concentrations during the simulation within each Zone. Table 5 shows the change in D.O. percentiles for each zone. A zone is an assemblage of cells that is limited by specified horizontal and vertical boundaries. The extents of each zone are shown in Figure 16.

The changes in D.O. in the critical cells (shown in Table 4) as a result of modification to the model are concentrated on Front River, zones FR7 and FR9. There are also some changes on Back River in zone BR3. The maximum decrease in D.O. is 1.06 mg/L which is a relative difference of 15.6% at the 25th percentile. Comparatively, there are some increases in D.O. as a result of the model grid modification as well, which mostly occur on Front River (FR9) with a maximum predicted increase in D.O. of 4.22 mg/L, which is a relative difference of 39.6%. The decreases in D.O. predicted values overall are minor with the exception of the maximums. The majority of the 50th percentile decreases are at or near zero.

The decreases in D.O. in the for the zones (shown in Table 5) as a result of modification to the model are minor. The maximum decrease is 0.13 mg/L which is a relative difference of only 2.3%. Comparatively, there are some increases in D.O. as a result of the model grid modification as well, which occurs on Middle River (MR1) with a maximum predicted increase in D.O. of 0.23 mg/L, which is a relative difference of 4.8%. Both of these maximum increases and decreases in D.O. occur at the 1st and 5th percentiles. It should be noted that the D.O. changes from the 50th percentile values are minor, many are zero. The maximum change is an increase in D.O. by only 1%.

Figure 16: Spatial Zones for D.O. Impact Evaluation

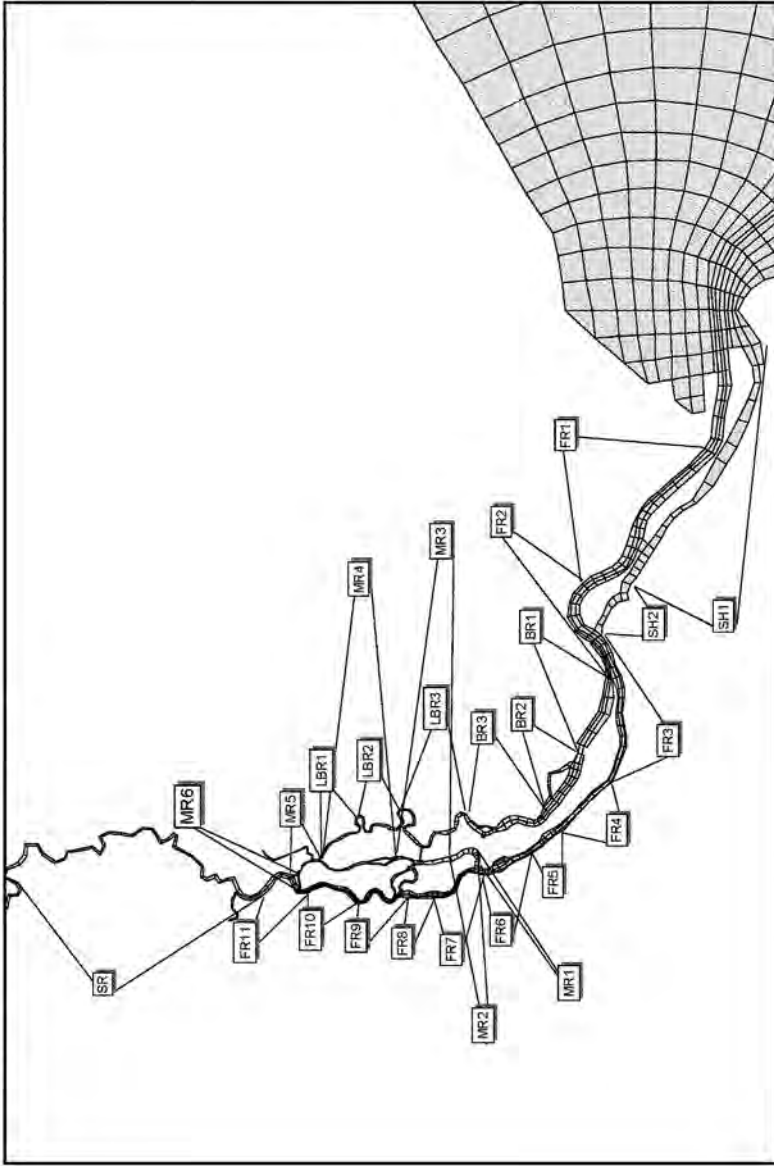


Table 4. Changes in D.O. Percentiles for Critical Cells With and Without the New Mitigation Feature Included in the Model Grid

Delta D.O. Percentiles for Critical Cells
Baseline: 6A6ft-withD0mitigation
Project: Scenario: DO_PlansPLUS-1997-6ftWASP

Zone	Delta D.O. Percentile																	
	1%		5%		10%		25%		50%		75%		90%		95%		99	
	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%
FR1	0	0.0	0.01	0.2	0	0.0	0.05	1.2	0.01	0.2	-0.01	-0.2	-0.01	-0.2	-0.02	-0.4	-0.09	-1.9
FR2	0	0.0	-0.02	-0.5	-0.01	-0.2	-0.01	-0.2	0	0.0	0.02	0.4	0	0.0	0	0.0	0	0.0
FR3	0.01	0.3	0	0.0	-0.01	-0.3	0	0.0	0	0.0	-0.01	-0.2	-0.01	-0.2	-0.05	-0.9	0.02	0.3
FR4	-0.02	-0.5	-0.01	-0.3	0	0.0	-0.01	-0.2	0	0.0	-0.02	-0.4	0	0.0	-0.01	-0.2	0.02	0.3
FR5	0	0.0	-0.02	-0.5	0	0.0	0.01	0.2	0	0.0	0	0.0	-0.01	-0.2	0.01	0.2	0.01	0.2
FR6	0	0.0	-0.02	-0.5	-0.02	-0.5	-0.02	-0.5	0.01	0.2	0.01	0.2	0	0.0	0	0.0	0	0.0
FR7	0.56	13.0	0.54	12.1	0.64	14.1	0.7	14.7	1.19	23.7	1.36	24.3	0.95	14.6	0.71	10.2	0.65	8.8
FR8	-0.02	-0.4	-0.03	-0.6	-0.04	-0.8	-0.03	-0.5	-0.04	-0.6	0.02	0.2	-0.06	-0.7	-0.02	-0.2	0.02	0.2
FR9	-0.57	-10.2	-1.02	-16.4	-1.02	-15.8	-1.06	-15.6	-0.11	-1.5	0.37	4.5	3.02	34.4	4.31	47.4	4.22	39.6
FR10	0	0.0	0	0.0	0	0.0	-0.01	-0.2	0	0.0	0	0.0	0.01	0.2	0.01	0.1	0.01	0.1
FR11	0	0.0	0	0.0	0.01	0.2	0	0.0	0.01	0.2	0.01	0.2	0	0.0	0	0.0	0.01	0.1
MR1	0.24	5.3	0.19	4.0	0.14	2.8	0.04	0.8	0.03	0.5	0.05	0.9	-0.06	-1.0	-0.02	-0.3	-0.07	-1.1
MR2	0.01	0.2	0.02	0.4	0.01	0.2	0.02	0.4	0.04	0.7	0.07	1.2	0.06	1.0	0.02	0.3	-0.02	-0.3
MR3	-0.04	-0.9	0.03	0.7	0.01	0.2	0	0.0	0.02	0.4	0.05	0.9	0.07	1.2	0.12	2.0	0.07	1.1
MR4	-0.02	-0.4	0.01	0.2	0	0.0	0.02	0.4	0.01	0.2	0.02	0.4	0.03	0.5	0	0.0	-0.01	-0.2
MR5	0.02	0.9	0.01	0.4	0.02	0.6	0.02	0.5	0	0.0	-0.01	-0.2	0.01	0.2	0	0.0	0	0.0
MR6	0.01	0.2	0	0.0	0	0.0	0.01	0.2	-0.01	-0.1	0	0.0	0	0.0	0	0.0	0	0.0
LBRI	-0.01	-0.2	-0.09	-1.9	-0.01	-0.2	0.02	0.4	0.02	0.3	0.01	0.2	0.01	0.2	0.02	0.3	0	0.0
LBRI2	0.19	4.4	0.02	0.4	0.01	0.2	0.01	0.2	0.01	0.2	0.02	0.4	0.01	0.2	-0.01	-0.2	0	0.0
LBRI3	0	0.0	0.01	0.4	0.02	0.7	0.01	0.3	0.02	0.6	0	0.0	0.02	0.5	-0.02	-0.5	-0.02	-0.5
BR1	-0.01	-0.3	0.03	0.8	0.02	0.5	-0.03	-0.7	0	0.0	0.02	0.4	0	0.0	-0.01	-0.2	0	0.0
BR2	0.03	1.3	0.02	0.8	0	0.0	0.02	0.6	0.02	0.5	0.02	-0.4	0.01	0.2	-0.01	-0.2	-0.04	-0.8
BR3	0.02	0.9	-0.01	-0.4	-0.03	-1.2	0	0.0	0	0.0	-0.04	-1.4	-0.23	-7.1	-0.27	-7.8	-0.37	-9.9
SCH1	0.01	0.4	0	0.0	0.03	1.0	0.03	1.0	0.01	0.3	0	0.0	0.03	0.7	-0.01	-0.2	-0.04	-0.9
SCH2	0.01	0.3	-0.05	-1.2	0	0.0	-0.03	-0.7	0	0.0	0	0.0	0.02	0.4	-0.02	-0.4	0.04	0.8
SR	0	0.0	0.01	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
SBR	-0.39	-9.5	-0.42	-8.6	-0.31	-5.8	-0.25	-4.1	-0.09	-1.3	0.05	0.6	0.16	1.9	0.15	1.7	0.23	2.5

Table 5: Changes in D.O. Percentiles for Zones With and Without the New Mitigation Feature Included in the Model Grid

Difference of D.O. %-tiles for zones of Savannah Estuary

Simulation Period: Year 1997 AUGUST 1 -AUGUST 31

Baseline ario: 6A5ft-withDmitigation

Project DO_Plan6aPLUS-1997-6ftWASP

Zone Name	Project - Baseline Difference (mg/l)										Project - Baseline Relative Difference (%)									
	1%	5%	10%	25%	50%	75%	90%	95%	99%		1%	5%	10%	25%	50%	75%	90%	95%	99%	
FR1	-0.01	0.00	-0.01	0.00	-0.01	0.00	0.02	0.00	0.00		-0.2	0.1	-0.1	0.0	-0.3	0.0	0.5	0.0	0.1	
FR2	-0.01	-0.01	-0.02	-0.01	-0.01	0.00	0.01	0.00	0.00		-0.2	-0.2	-0.4	-0.2	-0.3	0.0	0.3	0.1	0.1	
FR3	-0.01	-0.01	-0.01	-0.02	0.00	0.00	0.01	0.01	0.01		-0.2	-0.1	-0.2	-0.4	0.0	-0.1	0.1	0.2	0.2	
FR4	-0.01	-0.01	-0.01	0.00	0.00	0.01	0.01	0.00	0.01		-0.3	-0.3	-0.1	-0.3	0.0	0.1	0.2	0.0	0.3	
FR5	0.00	-0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02		-0.1	-0.2	0.0	0.0	0.0	0.0	0.2	0.2	0.3	
FR6	0.00	0.01	0.00	-0.01	0.01	0.00	0.01	0.00	0.01		0.0	0.1	0.0	-0.2	0.2	0.0	0.3	0.0	0.1	
FR7	0.01	0.01	0.01	0.00	0.03	0.04	0.03	0.06	0.06		0.2	0.2	0.3	0.1	0.4	0.6	0.4	0.7	0.8	
FR8	-0.02	-0.03	-0.03	-0.06	-0.01	-0.01	-0.05	0.00	0.02		-0.5	-0.6	-0.6	-1.0	-0.1	-0.2	-0.6	0.0	0.2	
FR9	0.04	0.04	-0.02	0.02	-0.02	-0.03	-0.02	-0.03	0.01		0.6	0.6	-0.3	0.2	-0.2	-0.3	-0.3	-0.3	0.1	
FR10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	-0.01	0.01		0.0	0.1	0.1	0.0	0.0	0.0	0.1	-0.2	0.1	
FR11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
MR1	0.23	0.13	0.04	0.04	0.05	0.04	0.04	-0.04	0.01		4.8	2.7	0.8	0.7	1.0	0.7	0.6	-0.7	0.1	
MR2	0.01	0.05	0.01	0.03	0.04	0.04	-0.04	-0.02	0.02		0.3	1.0	0.2	0.6	0.8	0.6	-0.7	-0.4	0.3	
MR3	-0.01	-0.01	0.00	0.02	0.03	0.04	0.10	0.07	0.11		-0.1	-0.3	0.1	0.3	0.5	0.7	1.7	1.2	1.8	
MR4	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01		0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	
MR5	0.00	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00		0.1	0.7	0.3	0.4	0.0	0.0	0.0	0.0	0.1	
MR6	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.1	0.6	-0.1	0.0	0.1	0.0	0.0	0.0	0.0	
LBR1	0.00	-0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01		-0.1	-0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.2	
LBR2	0.00	0.00	0.01	0.00	0.00	0.01	0.03	0.04	-0.01		0.1	0.1	0.2	-0.1	0.0	0.3	0.6	0.6	-0.2	
LBR3	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01		0.2	0.2	0.3	0.3	0.1	0.2	0.2	0.2	0.3	
BR1	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.02		0.1	0.0	0.0	0.2	0.1	0.1	0.0	0.3	0.4	
BR2	0.05	0.00	0.02	-0.02	0.00	0.00	0.02	0.00	0.00		1.7	0.0	0.6	-0.5	0.0	0.0	0.4	0.1	0.0	
BR3	0.00	-0.01	-0.01	0.00	0.02	-0.01	0.00	0.00	0.01		-0.1	-0.4	-0.4	0.1	0.6	-0.2	0.0	0.1	0.3	
SCH1	0.03	-0.02	-0.01	0.01	0.01	0.01	0.01	0.00	0.00		0.7	-0.6	-0.2	0.3	0.4	0.4	0.3	0.0	-0.1	
SCH2	0.00	-0.02	0.00	-0.01	0.00	0.01	0.01	0.01	0.01		0.1	-0.5	-0.1	-0.3	0.0	0.3	0.2	0.3	0.2	
SR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
StBr	-0.10	-0.13	-0.11	-0.06	0.01	0.04	0.04	0.09	0.08		-1.9	-2.3	-1.9	-0.9	0.1	0.5	0.6	1.1	1.0	

Conclusions

The new SNS habitat criteria with the existing channel bathymetry does seem to be a better representation of the observed Juvenile SNS locations by including the Middle River bend within the suitable habitat boundary as compared to the original criteria.

Based on the habitat suitability maps, the Middle River sill does not show benefits to SNS habitat in the Middle River bend over the maps created without the bend. However, when a closer look is taken with the raw datasets a decrease in bottom salinity in the bend is noted. Despite the lack of benefits shown in the habitat suitability maps, the mitigation feature does in fact provide some benefits in lowering predicted bottom salinity values. The model output shows that the benefits are largely concentrated during the spring tidal event. Outside of the spring tidal event, the sill does not offer a large amount of salinity protection to the area. It may be helpful to have more information about the tidal conditions during the research period conducted by Collins et al to have a better comparison between the maximum salinities observed and modeled. Specifically, it may be helpful to know if the maximum salinities readings observed by Collins in the Middle River bend were collected during high tide of the spring tidal cycle.

The hydrodynamic model shows only minor changes in velocities behind the sill, which were used to indicated possible shoaling areas. Since the changes are small and only found in the bottom layers of the water column, shoaling is not expected to rapidly impact the habitat on Middle River. However, the model is a predictive tool and does not guarantee that shoaling in this area will not occur.

In addition to completing the impact analysis for SNS, a sensitivity analysis was also completed for impacts to freshwater marshes/wetlands and to water quality (D.O). Overall and generally speaking the impacts to these two resources appear to be minor.

Impacts to tidal fluctuations and the salinity regime are minor. Surface salinities are impacted with inclusion of the feature in the model grid, however the impact is not significant and is not expected to alter the previously determined acreage amounts. The greatest impacts or changes are seen locally with the project feature and are not far reaching.

The largest negative impacts to D.O. as a result of altering the model grid occur in the critical cell differences along Front River (FR9) and Back River (BR3). The impacts categorized by zone are very minor, close to zero, with the largest changes actually benefiting the D.O. concentrations by raising them 4.8%.

For completeness, this proposed mitigation feature could be incorporated into the project conditions model grid. However, as shown by this sensitivity analysis, the changes are likely to have little to no impact on the previous estimates to freshwater marsh/wetland or water quality impacts and therefore no bearing on the mitigation plan or project cost estimates.

Alternatively, due to the lack of benefits shown in the habitat suitability maps along with the uncertainty of shoaling that may or may not occur behind the sill, this feature may be more appropriate as an adaptive management feature.

Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer

Savannah Harbor Expansion Project

FINAL REPORT

Prepared by:

US Army Corps of Engineers
Savannah District
Geology/Hydrogeology and HTRW Design Section
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June 2007

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EXECUTIVE SUMMARY

Supplemental studies conducted as part of the Tier II Environmental Impact Statement (EIS) were intended to expand upon previous studies and address comments from the *Potential Ground-Water Impacts* feasibility study (USACE, 1998). The current study was conducted according to several major tasks, each of which provided an array of information that, when combined, provided the most comprehensive picture of the geology and hydrogeology underlying the Savannah River navigation channel and surrounding area to date.

The field work entailed conducting a detailed subbottom seismic survey, performing marine and land drilling, and collecting porewater data, hydraulic conductivity data, and head data. Results from the field work were analyzed and incorporated into both a three-dimensional coupled flow and transport ground-water model and a comprehensive Geographic Information System (GIS).

The subbottom survey was performed from river station 30+000 to -30+000, where the Miocene confining unit is naturally thin and paleochannels are known to have further incised into the confining layer. Results of the survey provided detailed information about all major paleochannels within the area of concern. The location, attitude, and extent of all paleochannels were mapped and incorporated into the Miocene surfaces created for the GIS and the ground-water model.

The three-dimensional coupled flow and transport ground-water model simulated the specific effects of dredging the navigation channel on water quality in the Upper Floridan aquifer. The model outputs used two values of hydraulic conductivity and provided two sets of results that are believed to bracket true conditions, yielding a range of plausible responses under both dredging and no dredging conditions.

Model simulation results indicated that the proposed dredging activities would contribute a minimal amount of increased total downward flow through the confining

layer, and the resulting differences between the dredging and no dredging scenarios were minor. The simulations also projected that, regardless of dredging, chloride concentrations in the Upper Floridan aquifer are expected to increase significantly in the lower reaches of the Savannah River over the next 100 to 300 years if the present rate of aquifer withdrawal remains constant. Under current conditions, the maximum expected chloride concentrations in the Upper Floridan aquifer directly beneath the river ranged from 500 to 1,400 mg/L depending on the hydraulic conductivity of the confining layer, and the proposed dredging was projected to contribute an additional 10 to 200 mg/L to these concentrations.

Simulated chloride concentration time-histories were generated for Upper Floridan production wells located along or near the river from downtown Savannah to Tybee Island. The mid-range hydraulic conductivity simulations indicated that downward migration of chloride from the river would contribute 10 to 50 mg/L to total chloride concentrations in Savannah area production wells by the year 2200, and the difference between the dredging and no dredging scenarios ranged from negligible to less than 10 mg/L for each well location.

Model results showed that the impact of the proposed dredging activities on the change in chloride concentration through the confining layer is insignificant when compared with predicted concentrations that assume no dredging conditions. The simulated concentrations decrease significantly upon entering the Upper Floridan aquifer due to considerable horizontal flow of fresh water within the aquifer mixing with and diluting the relative very low volume of salt water migrating downward from the Savannah River.

The negative head gradient induced by pumping in Savannah appears to have caused limited breakthrough of chlorides to occur in the downstream reaches of the Savannah River. The porewater profiles and model results from this study indicated that both the increased salinity along the bottom of the Savannah River and the reduced thickness of the confining layer due to dredging will not significantly affect

the timing of breakthrough of chlorides along the navigation channel in the Upper Floridan aquifer. Furthermore, the study results showed that the proposed dredging would have negligible impacts on water quality in production wells that tap the Upper Floridan aquifer in and around the city of Savannah.

1. INTRODUCTION

The Savannah Harbor Expansion Project is a multi-faceted study to determine the feasibility of expanding and deepening the present Savannah Harbor and Ocean Bar Channel (Figure 1-1). The initial phase of the study was conducted under the authority of Section 203 of the Water Resources Development Act of 1986. Completed in 1998, the Savannah Harbor Expansion Feasibility Study and Tier I Environmental Impact Statement (EIS) recommended deepening Savannah Harbor from the Ocean Bar Channel upstream to the Georgia Ports Authority. Although authorized in 1999, the US Army Corps Chief of Engineers Report required additional analyses and approvals before commencement of expansion activities, namely a consensus mitigation plan, Tier II EIS, and General Reevaluation Report. The Geology/Hydrogeology and HTRW Design Section, US Army Corps of Engineers, Savannah District prepared this supplemental studies report as part of the Engineering Appendix of the Tier II EIS that will serve as a basis for future decisions concerning the expansion of Savannah Harbor.

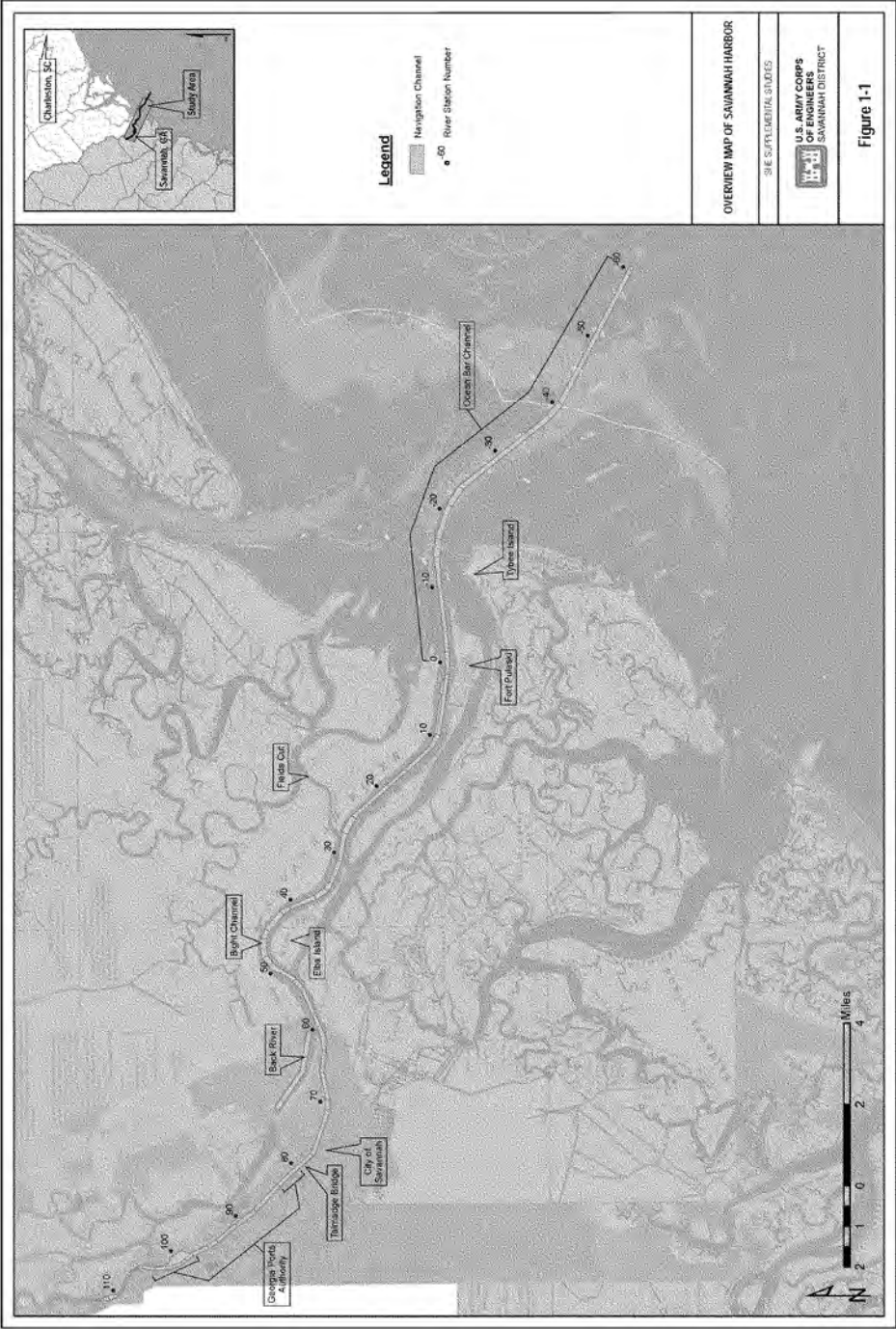


Figure 1-1

2. PROJECT OVERVIEW

2.1. PURPOSE AND SCOPE

The methods employed in this study were intended to build and expand on the information from previous studies, particularly the 1998 *Potential Ground-Water Impacts* for the Savannah Harbor Expansion Feasibility Study that was prepared as part of the Tier I EIS (USACE, 1998). Following the release of the 1998 study, the Savannah District, with input from the United States Geological Survey (USGS), Georgia Environmental Protection Division (GAEPD), South Carolina Department of Health and Environmental Control (SCDHEC), and the Stakeholders Evaluation Group (SEG), developed a conceptual plan and work outline to address comments from the 1998 report and establish new supplemental study objectives.

The principal objective of the current study was to determine how much proposed dredging activities (Table 2-1) would contribute to increased chloride levels in the Upper Floridan aquifer and evaluate the associated impacts on aquifer water quality. Based on the "6-foot improvement" option, the proposed dredging activities to deepen the navigation channel would impact materials contained between -42 feet and -58 feet Mean Low Water (MLW), which is comprised primarily of Miocene-aged sediments. Consequently, the study focused on the Miocene-aged upper confining unit (i.e. confining layer) along the navigation channel, especially from Fields Cut (Intra-Coastal Waterway) to approximately two miles offshore of Tybee Island, where the confining layer naturally thins and relict channels have cut further down into the confining layer (Figure 2-1).

The Savannah District evaluated the study objectives according to six major tasks that included completing additional seismic surveying, conducting additional land and marine drilling that incorporated porewater and hydraulic testing, developing a ground-water model, determining the feasibility of conducting an aquitard test, and incorporating data, past and present, into a comprehensive Geographic Information System (GIS).

Table 2-1. Proposed Dredging Depths for Savannah Harbor and Ocean Bar Channel

Location (River Station)	Current Project Depth (ft below MLW)	Advance Maintenance (ft)	Allowable Overdepth (ft)	Current Total O&M Dredging Depth (ft below MLW)	Proposed 6-Foot Improvement (ft below MLW)
-60+000 to -14+000	44	0	2	46	52
-14+000 to 0+000	42	2	2	48	52
0+000 to 24+000	42	2	2	46	52
24+000 to 35+000	42	4	2	48	54
35+000 to 37+000	42	6	2	50	56
37+000 to 70+000	42	4	2	48	54
70+000 to 102+000	42	2	2	46	52
102+000 to 103+000	42	0	2	44	50
103+000 to 105+500	36	2	2	40	N/A
105+500 to 112+500	30	2	2	34	N/A
Oyster Island Turning Basin	40	0	2	42	N/A
Fig Island Turning Basin	34	4	2	40	N/A
Marsh Island Turning Basin	34	0	2	36	N/A
Kings Island Turning Basin	42	8	2	52	58
Argyle Island Turning Basin	30	0	2	32	N/A
Port Wentworth Turning Basin	30	0	2	32	N/A
Sediment Basin (Back River)	40	0	2	42	N/A
0 to 13+300	38	0	2	40	N/A

2.2. PREVIOUS STUDIES

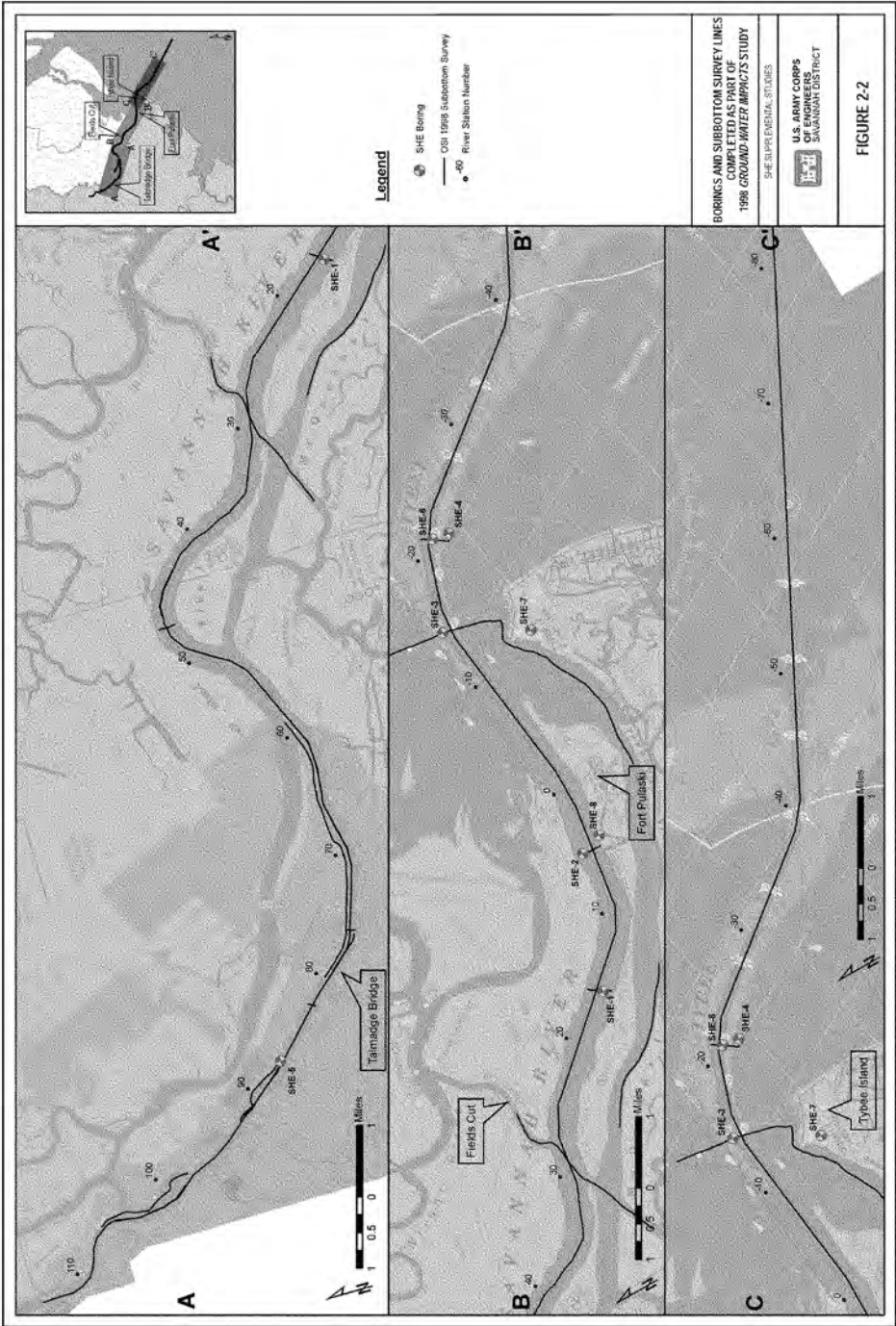
The Savannah District US Army Corps of Engineers first addressed potential impacts to the Upper Floridan aquifer due to dredging in 1980 (USACE, 1980). The report, completed as part of a larger long term planning document, was limited in scope and involved conducting a review of existing boring logs to outline the harbor stratigraphy on a large-scale basis. The Savannah Harbor Comprehensive Study (USACE, 1982) was the first study to contain detailed information as to potential ground-water effects in the Upper Floridan aquifer due to dredging. A field investigation completed as part of the report included drilling two deep core holes (SH-65 and SH-66) and performing a limited subbottom geophysical survey. The report concluded that the aquifer strata would not be impacted given the proposed project depth at that time.

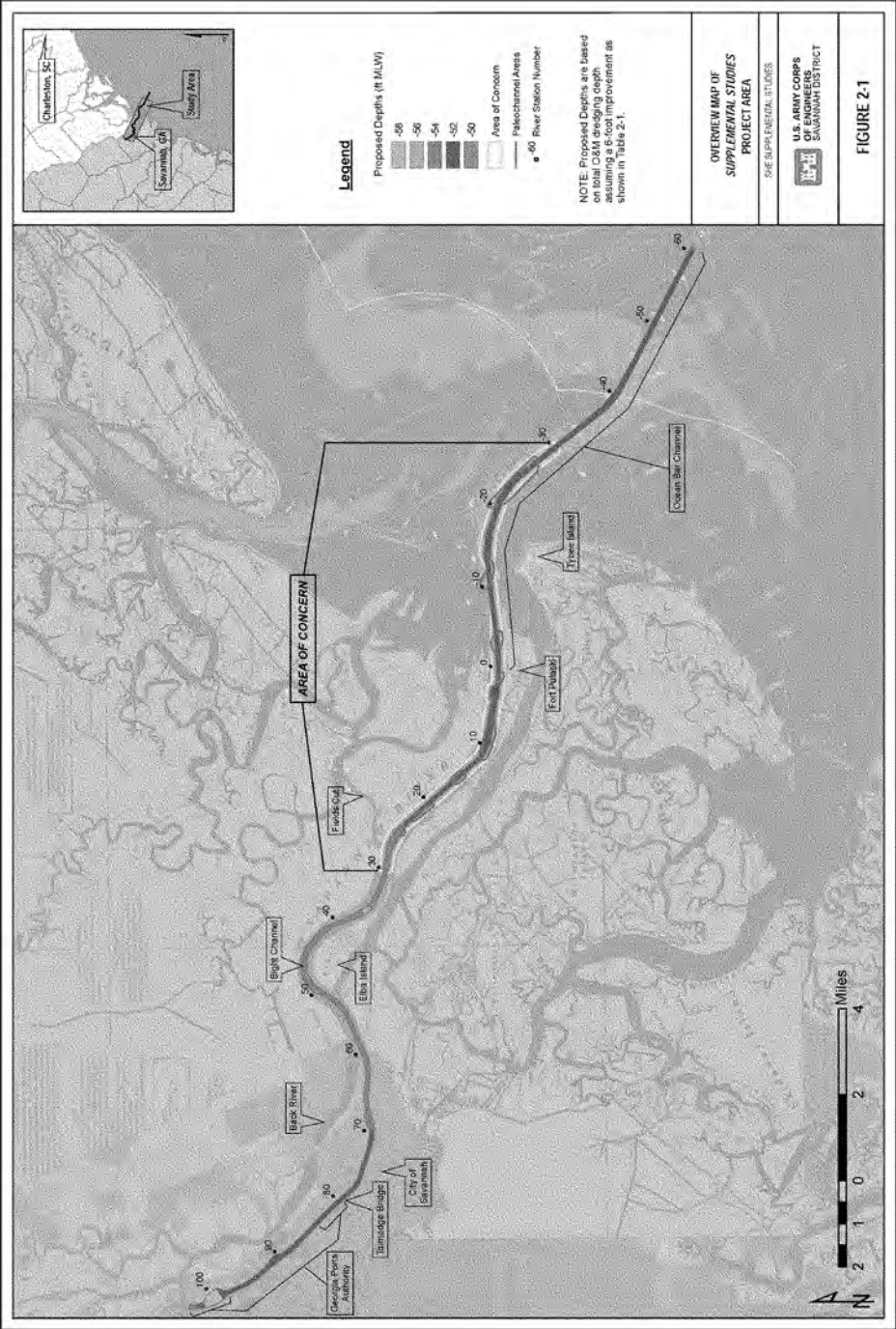
In 1992, the Savannah District issued a contract to Dr. Vernon J. Henry to further evaluate the potential for salt-water intrusion in the aquifer due to dredging. Henry

compiled and examined existing seismic reflection data and boring logs along the navigation channel. The investigation revealed several buried relict stream channels (i.e. paleochannels) had downcut into the Miocene confining unit and were later infilled with younger sediments of different lithology than that of the confining unit. The report concluded that dredging associated with a proposed -46.0 feet MLW project depth would not directly breach the confining layer, and seepage associated with paleochannels underlying the navigation channel would depend on the transmissivity of both the channel fill sediments and the confining unit. Furthermore, the report recommended drilling additional cores in the paleochannel material to determine hydraulic properties (Henry, 1992).

The findings of the 1992 report focused on paleochannels intersecting the navigation channel, and subsequent studies were conducted to evaluate their role in potential impacts to the Upper Floridan aquifer. Specifically, the studies aimed to evaluate the postulation that if the paleochannel in-fill material were more permeable than the underlying confining unit, then seawater would have a more direct path through the confining unit, thus increasing the rate of salt-water intrusion into the Upper Floridan aquifer. In 1998, the Savannah District US Army Corps of Engineers published the resulting efforts in a report entitled *Potential Ground-Water Impacts* as part of the Savannah Harbor Expansion Project Feasibility Study (USACE, 1998). The field investigation included drilling eight core borings (SHE-1 through SHE-8), conducting laboratory analyses on core samples, and examining well data to determine the physical properties of sediments underlying the proposed project area. In addition, the Savannah District conducted an extensive, site-specific subbottom geophysical survey to better determine the physical relationship between the various stratigraphic units below the existing Savannah River navigation channel (Figure 2-2). The resulting data were used to create a comprehensive profile of the geologic and hydrogeologic units underlying the navigation channel and to calculate a vertical leakage rate of seawater through the paleochannels and Miocene confining unit to the top of the Floridan aquifer. The 1998 feasibility study concluded that the volume of seawater moving vertically through the overlying stratigraphic units was

insignificant compared to the volume of freshwater moving laterally through the Upper Floridan aquifer; therefore, the proposed dredging would have no noticeable effect on the quality of ground water in the Upper Floridan aquifer.





3. DESCRIPTION OF THE STUDY AREA

3.1. GEOLOGIC SETTING

Eastern Chatham County is underlain by approximately 2,000 feet of sedimentary Coastal Plain sediments ranging in age from Holocene to Cretaceous (Miller, 1986). From land surface to a depth of about 500 feet, these sediments consist of unconsolidated to somewhat indurated beds of sand and clay of Recent (Holocene) age to indurated limestones of Oligocene and Eocene age (Table 3-1). The Oligocene and Eocene limestones comprise what is commonly referred to as the Upper Floridan aquifer. A regional west-east geologic cross-section (Figure 3-1) published by Clarke et al. (1990) illustrates the attitude and thickness of the Upper Floridan aquifer and overlying strata from updip in Bulloch County to downdip in eastern Chatham County.

Table 3-1. Geologic and Hydrogeologic Units in Eastern Chatham County

Age	Geologic Unit ¹	General Lithology	Hydrogeologic Unit ²	
Pleistocene-Recent	Satilla Formation	Fluvial sands, silts, and clays	Surficial Aquifer	
Upper Miocene	Hawthorne Group	Ebenezer Formation (Miocene Unit A)	Green-colored clays, silts, clayey silts, and sandy or silty clays	Upper Confining Unit
Middle Miocene		Coosawhatchie Formation (Miocene Unit B)	Green-colored clays, silts, clayey silts, and sandy or silty clays	Upper Confining Unit
Late Oligocene		Tiger Leap Formation	Buff-colored, porous limestone with foraminifera	Upper Floridan Aquifer
Early Oligocene	Lazaretto Creek Formation	Buff-colored, porous limestone with foraminifera	Upper Floridan Aquifer	
Late Eocene	Ocala Limestone	Massively bedded, fossiliferous limestone	Upper Floridan Aquifer	

¹ Modified from Veems and Edwards, 2001

² Clarke et al., 1990

In general, Tertiary strata in Chatham County dip 10 to 15 feet per mile to the south-southwest. However, the dips are locally controlled by structural "highs" and "lows" as illustrated in Figure 3-2. Prominent structures include the Beaufort arch, a domal

structure near Beaufort, South Carolina (Siple, 1960), the Tybee high, an anticlinal structure with a northwest-southeast trending axis near the mouth of the Savannah River (Furlow, 1969), and the Ridgeland trough, a structural low with a northeast-trending axis extending northeastward through northern Chatham County, Georgia into Jasper County, South Carolina (Heron and Johnson, 1966).

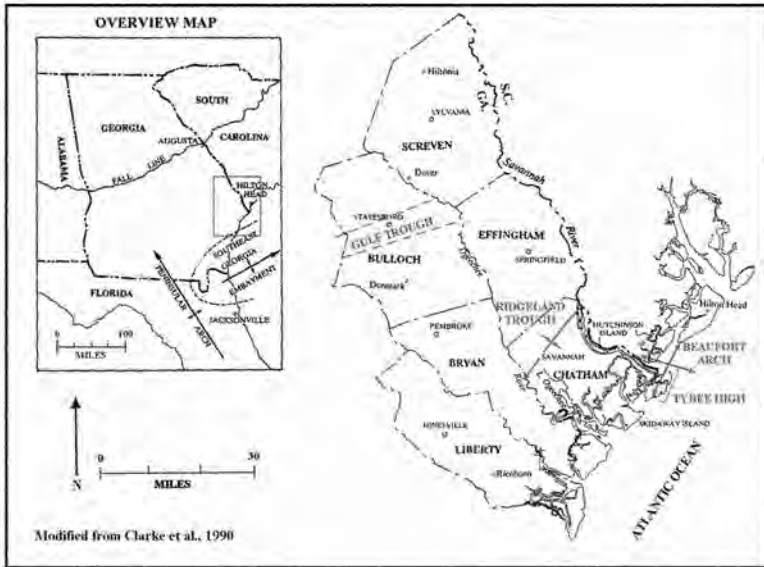


Figure 3-2. Structural features in the Chatham County area.

Within the study area, the elevation of the top of the Oligocene unit, the uppermost unit of the Upper Floridan aquifer, ranges from roughly -95 feet MLW near the Tybee high to approximately -200 feet MLW near downtown Savannah. The top of the Miocene unit occurs at an average of -45 feet MLW and is generally level within the study area, and unit thickness ranges from less than 30 feet near the Tybee high to 160 feet near downtown Savannah. The GIS analyses presented in Figures 3-3a and 3-3b show locations where the Miocene unit is exposed in the bottom of the

navigation channel through time based on historic bathymetric data. Notice that 1998 marks the first time that dredging activities exposed large stretches of Miocene along the Bight Channel (Elba Island) and near Kings Island Turning Basin.

In this study, the Tybee high is the structural feature of most importance, namely where the tops of the Miocene confining unit and the Oligocene unit are nearest land surface. Over the crest of the Tybee high, the elevations of the top of the Oligocene unit range from -95 feet MLW beneath Tybee Island to -115 feet MLW at the channel at Fields Cut, and the Miocene is generally exposed in the bottom of the navigation channel (Figure 3-3b). Proposed dredging operations associated with the Savannah Harbor Expansion Project would lower the channel depth to as much as -58 feet MLW. In the harbor vicinity, this stratigraphic horizon is composed of Pleistocene-Recent and Miocene sediments (Figure 3-4).

3.2. HYDROGEOLOGIC SETTING

The Floridan aquifer system underlies parts of Alabama, Georgia, South Carolina, and Florida and supplies approximately 50 percent of the ground water in Georgia (Kressler et al., 2001). Formerly known as the principal artesian system, the aquifer system is divided into two major aquifers: the Upper Floridan and Lower Floridan. Within Chatham County and the study area, the Upper Floridan aquifer is the primary source of ground water. Recharge to the confined aquifer system occurs to the northwest and west of the study area, and precipitation generally does not influence water levels within the study area. Instead, water levels in the Savannah area show direct response to pumping (Clarke et al., 1990).

Prior to development, the flow system was considered steady state, i.e. recharge was equal to natural discharge (artesian springs, streams, etc.), and water levels showed little fluctuation from year to year. However, development within the coastal region and the associated increased ground-water withdrawal rates has unbalanced the recharge and discharge rates. This increased pumping has lowered water levels,

induced additional recharge and reduced natural discharge, and increased total flow through the system (Krause and Randolph, 1989).

The long-term pumping of the Upper Floridan aquifer in the Savannah area and surrounding coastal areas has lowered ground-water levels and reversed the seaward hydraulic gradient that existed before development (Garza and Krause, 1996; Krause and Randolph, 1989) as shown in Figure 3-5. The increased withdrawal of water from the Upper Floridan aquifer has resulted in radial flow directed toward the center of pumping and a cone of depression beneath Savannah. Prior to development, heads in the Upper Floridan aquifer ranged from 20 to 150 feet above sea level in southeast Georgia and from 30 to 50 feet above sea level in Chatham County (Krause and Randolph, 1989). In contrast, in May of 1998 Peck et al. (1999) reported a maximum head of 60 feet above sea level occurring south of Brunswick and maximum drawdown occurring near the city of Savannah, where heads ranged from -10 feet to -100 feet below mean sea level (Figure 3-6).

This reversal in hydraulic gradient has resulted in lateral encroachment of seawater and downward vertical intrusion of salt water through the confining unit. The lateral encroachment of seawater is evidenced two ways. First, lateral encroachment is expressed by the westward movement of the freshwater / salt-water interface toward the center of pumping (Savannah) (Figure 3-5). Second, lateral encroachment is seen at Port Royal Sound where the confining unit is completely absent and the aquifer is directly overlain by seawater. Here, seawater enters the aquifer and moves southward (laterally) toward the center of pumping. The plumes associated with this lateral encroachment have been well documented as elevated chloride concentrations in Floridan wells at the north end of Hilton Head Island, South Carolina (Smith, 1988; Ransom et al., 2006).

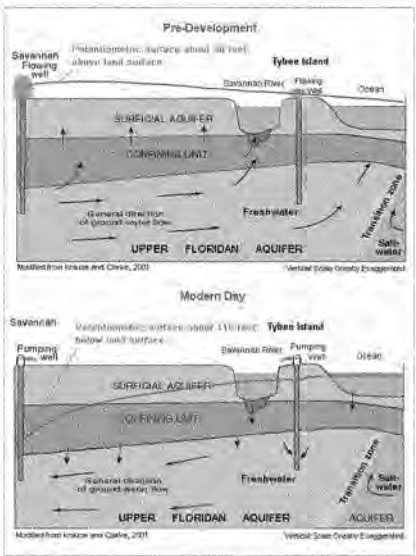


Figure 3-5. Schematic view of pre-development and modern day ground-water flow in the Savannah area.

The sustained pumping in the Savannah area has also resulted in a downward hydraulic gradient and induced significant head differences between the surficial aquifer and the confined Upper Floridan aquifer, with head differences ranging from – 60 to –120 feet in Chatham County (Clarke et al., 1990). Additionally, the Savannah District (1998) and Clarke et al. (1999) documented downward hydraulic gradients through the upper confining unit at four nested well locations in the Savannah area (SHE-9, SHE-10, Fort Pulaski, and Tybee Island). The results from these reports indicated that downward leakage of water through the confining unit contributes a significant amount of water to the flow system in the study area; in fact, the leakage through the upper confining unit has been estimated to represent nearly half the water budget for the Savannah area, or 40 million gallons per day (MGD) (Garza and Krause, 1996). This study examines the impact of the proposed dredging on the rate

of this vertical intrusion, which consists of both fresh and salt water, and the resulting ground-water impacts in the Upper Floridan aquifer.

3.3. GEOLOGIC AND HYDROGEOLOGIC UNITS

The stratigraphic intervals and general hydrogeologic framework of the Floridan aquifer and overlying geologic units were first described in the late 1950's and early 1960's by Herrick (1961), Siple (1960), Counts and Donsky (1963), and McCollum and Counts (1964), and numerous reports since have further detailed the lithologic and hydrologic properties (Clarke et al., 1990; Clarke, 2003; Weems and Edwards, 2001). The nomenclature and, in some cases, age of the various stratigraphic units vary from report to report according to location and data available. For the purposes of this study, geologic units are referred to according to nomenclature designated by Weems and Edwards (2001), and hydrogeologic units are referenced according to the framework set forth in Clarke et al. (1990) (Table 3-1).

The Upper Floridan aquifer system stretches from coastal South Carolina to northern Florida and includes Chatham County and Savannah Harbor. This study focused on the hydrogeology of sediments underlying the present navigation channel, specifically the upper 150 to 200 feet, which encompasses the Oligocene, Miocene, and Pleistocene-Recent units. In the Savannah Harbor area, the geologic formations can be grouped into three broadly defined hydrogeologic units: the Upper Floridan aquifer, the Miocene confining unit, and the surficial aquifer (Table 3-1). Past reports include descriptions of the upper and lower Brunswick aquifers, Miocene-aged aquifers that are productive in the Glynn County area and as far north as Bryan County (Krause and Clarke, 2001). In the past, the northern extent of these aquifers was determined using electrical logs, gamma logs, and well cuttings (Clarke et al., 1990), and it was surmised that these aquifers extended to the Savannah area. More recently, however, Clarke (2003) and Weems and Edwards (2001) reported that the upper and lower Brunswick aquifers are discontinuous or absent in Chatham County. In addition, the Savannah District collected numerous continuous core samples to the top of the Oligocene unit, and none of these cores indicated the

presence of such units underlying the navigation channel. As such, their descriptions were not included in this report.

3.3.1. Upper Floridan Aquifer

In the coastal area, the Upper Floridan aquifer consists of limestone of Late Eocene and Oligocene age and is characterized as vuggy and highly fossiliferous. The Late Eocene (Ocala Limestone) unit consists of massively bedded, fossiliferous limestone and dolomite that contains bryozoans, foraminifera, and mollusk shells. The Oligocene unit unconformably overlies the Late Eocene unit and consists of buff-colored, porous limestone with foraminifera, zones of micrite, and nonparticulate phosphate. The Oligocene unit is distinguished from the Late Eocene unit by its lack of bryozoans and its abundance of miliolid foraminifera (Clarke et al., 1990).

The elevation of the top of the Upper Floridan aquifer (Oligocene) is approximately -200 feet MLW under the city of Savannah, and the contact gently slopes upward to the east toward Tybee Island. Over the crest of the Tybee high, the top of the Upper Floridan aquifer is closer to land surface and is typically around -100 feet MLW in elevation. In the study area, the Upper Floridan aquifer is 150 to 250 feet thick, and the uppermost two zones, zone 1 and zone 2, are the most productive (McCollum and Counts, 1964; Krause and Randolph, 1989). Zone 1 and zone 2, approximately 44 feet and 35 feet thick, respectively (Clarke et al., 1990), combine to supply more than seventy percent of the water pumped from open holes tapping the entire aquifer (Krause and Randolph, 1989). Pumping reached a maximum of 88 MGD in 1990 (Fanning, 1999) and has since slightly declined due to a reduction in industrial pumping. In the year 2000, Chatham County withdrew approximately 72 MGD from the Upper Floridan aquifer (Fanning, 2002).

Transmissivity of the Upper Floridan aquifer is highly variable in the coastal area, and in the area between Port Royal Sound, South Carolina and Savannah, the transmissivity varies from 27,000 ft²/d to 80,000 ft²/d (Counts and Donsky, 1963; Hayes, 1979; Spigner and Ransom, 1979). The transmissivity in the Savannah area is low in comparison with other areas along the coast (27,000 ft²/d to 33,000 ft²/d).

The low transmissivity has resulted in a substantially deeper cone of depression as compared with other major pumping centers with similar withdrawal rates (Clarke et al., 1990).

3.3.2. Miocene Confining Unit

Strata of Miocene age in the coastal area have been differentiated into the Ebenezer Formation (upper Miocene), the Coosawhatchie Formation (middle Miocene), and the Marks Head and Parachula Formations (lower Miocene); three depositional sequences of similar lithology each bounded by unconformable contacts (McCollum and Herrick, 1964; Weems and Edwards, 2001). Hydrogeologists refer to the units collectively as the "confining bed" or "confining unit" overlying the Upper Floridan aquifer. In the Savannah area, the Miocene sediments unconformably overlie limestone of Oligocene age, a lithologically and geophysically distinctive contact.

The confining unit is a series of lithologically complex sequences of predominately clastic sediments containing low-permeability clays, silts, clayey silts and sands, and clayey or silty sands. Each sequence comprises a geologic unit that consists of a basal carbonate layer, a middle clay layer, and an upper sand layer and is bounded above and below by an unconformity. These units were each defined by persistent geophysical markers designated as A, B, and C and are basal contacts for each of the Miocene units. Clarke and others (1990) felt these three units best fit the stratigraphic framework of McCollum and Herrick (1964), whereby units A, B, and C correlate to upper, middle, and lower Miocene, respectively.

As illustrated on geologic cross-sections in reports by Counts and Donsky (1963), Hayes (1979), and Spigner and Ransom (1979), the Miocene confining unit both thins and lies progressively nearer land surface in the area from eastern Chatham County, Georgia into southern Jasper County, South Carolina and the Beaufort arch area in coastal Beaufort County, South Carolina. In the project area, Miocene units A and B occur, and Miocene unit C is generally absent or eroded such that only the basal carbonate layer remains and is indistinguishable from the basal contact of unit B. In the study area, Miocene units A and B consist of green-colored, silty clay and

clayey or silty sands underlain by a basal dense, phosphatic limestone or dolomite. Underneath the navigation channel, the basal contacts range in thickness from less than 1 foot to 10 feet thick and the overall thickness of the confining unit (units A, B, and C) ranges from about 30 feet thick near the Tybee high to over 150 feet thick near downtown Savannah.

Thin beds of fine-grained sands typically occur between two high gamma activity signatures within the Hawthorne Group (Table 3-1). In some areas, these zones are sufficiently permeable to yield significant quantities of water to wells and, thus, can be classified as aquifers. This "Hawthorne aquifer" (Hayes, 1979) is separated from the Upper Floridan aquifer by a phosphatic sandstone with high natural gamma activity. The USGS referred to the same stratigraphic interval in the Savannah area as the "upper Brunswick aquifer" (Clarke et al., 1990). In the project area, however, no permeable sands occur within the Miocene that could be considered aquifers. In addition, a water-use inventory failed to identify any Miocene (Hawthorne) wells in the area within several miles on either side of the Savannah River, as wells in the Savannah area generally tap either the underlying Upper Floridan aquifer or the overlying basal Pleistocene sands (surficial aquifer).

3.3.3. Pleistocene-Recent Unit

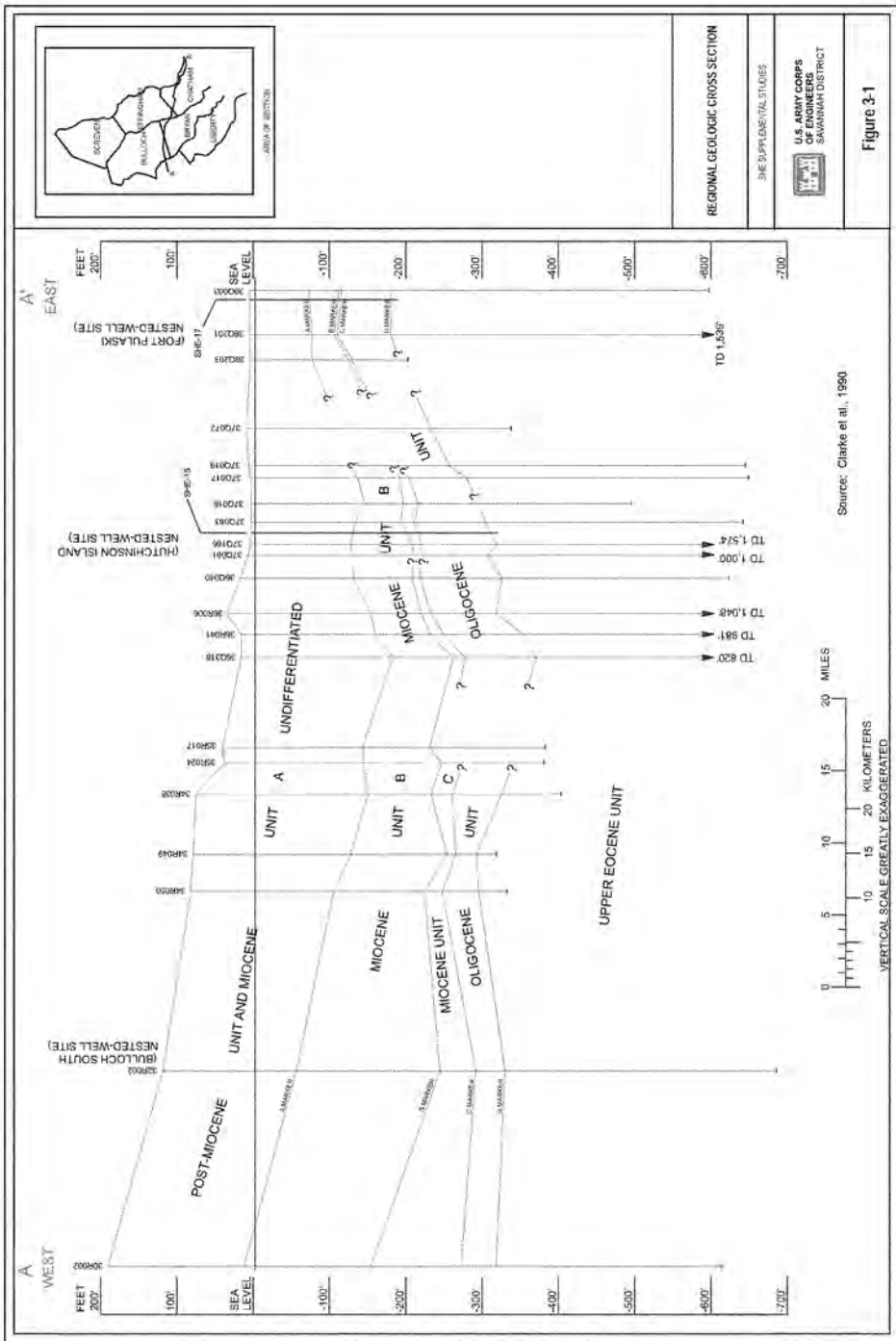
Herrick (1965) and Furlow (1969) first described the Pleistocene deposits in the Savannah area, and detailed lithology and geometry of the Pleistocene to Recent sediments were compiled as part of subsequent ground-water studies of the Floridan aquifer system, including those conducted by the Savannah District. The Pleistocene-Recent unit overlies the Miocene unit in the Savannah area, and the contact is marked by an erosional unconformity, which is sharp in some areas but gradational in others. The shallow sands and clays that occur from land surface to a depth of typically 60 to 75 feet, but locally as much as 130 feet, comprise the Pleistocene-Recent unit (Counts and Donsky, 1963 and Furlow, 1969).

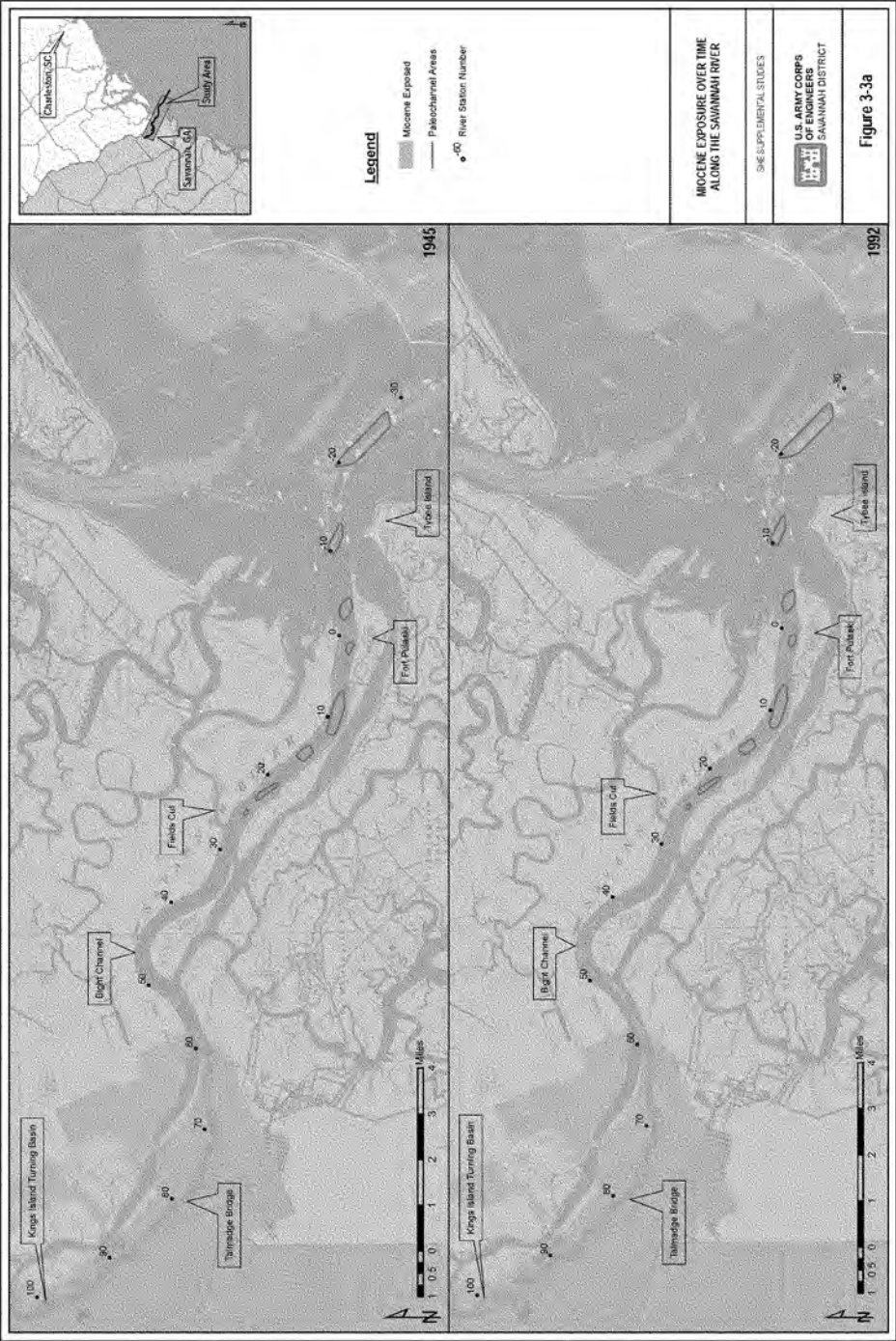
Pleistocene to Recent sediments in the Savannah area consist of phosphatic, micaceous, and clayey sand of Pliocene age; arkosic sand and gravel containing

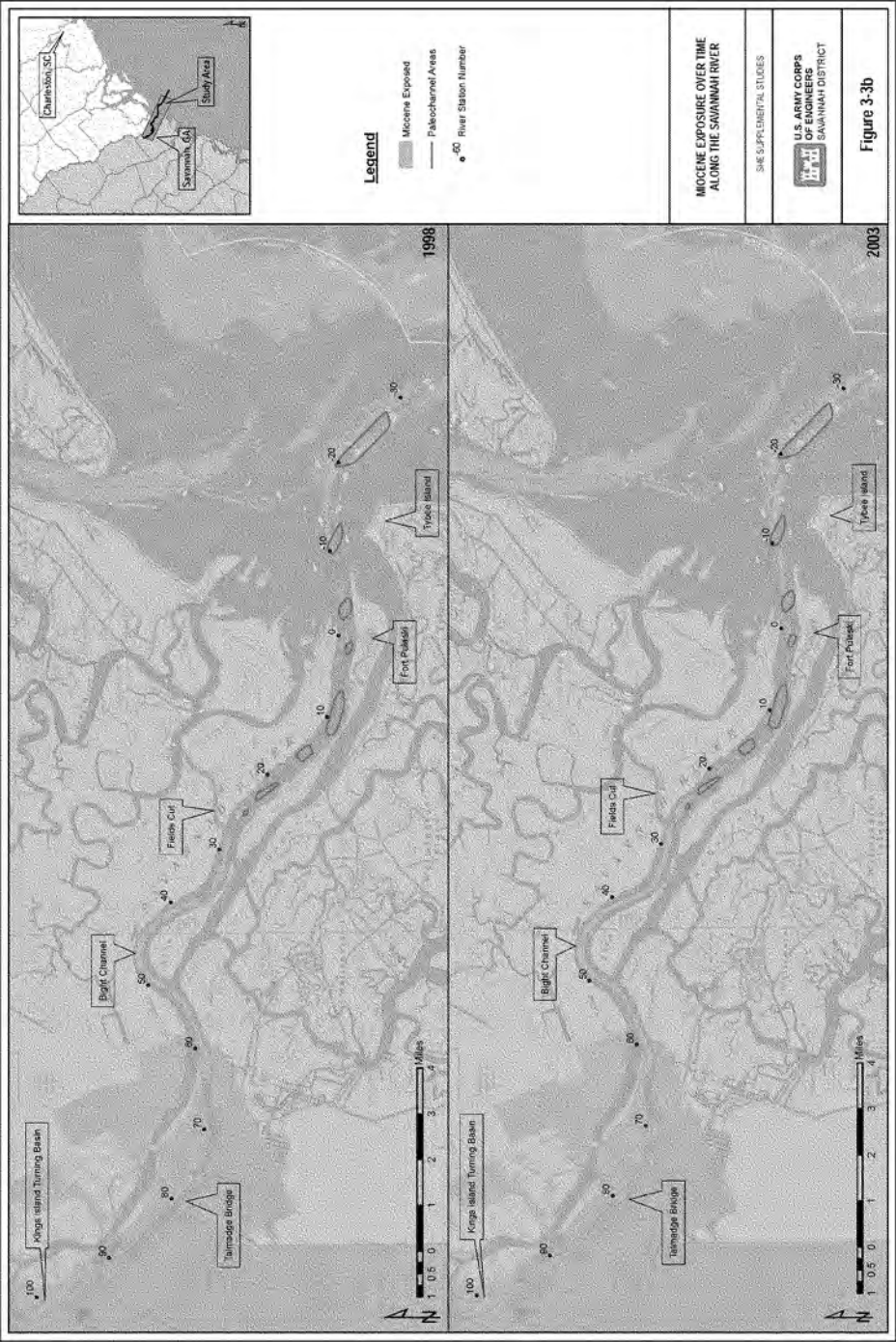
discontinuous clay beds of Pleistocene age; and mud, sand, and gravel of Holocene age (Clark et al., 1990). According to Miller (1986), post-Miocene sediments generally can be divided into a basal sequence of marginal to shallow marine beds overlain by a series of sandy, marine terrace deposits that are in turn capped by a thin layer of fluvial sand or residuum, or both. Although the geometry and lithologies of these Pleistocene-Recent sediments are geologically complex, with typically lenticular bodies of sand or clay, aquifer sands near the base of the Pleistocene are laterally persistent although not necessarily continuous throughout the coastal region.

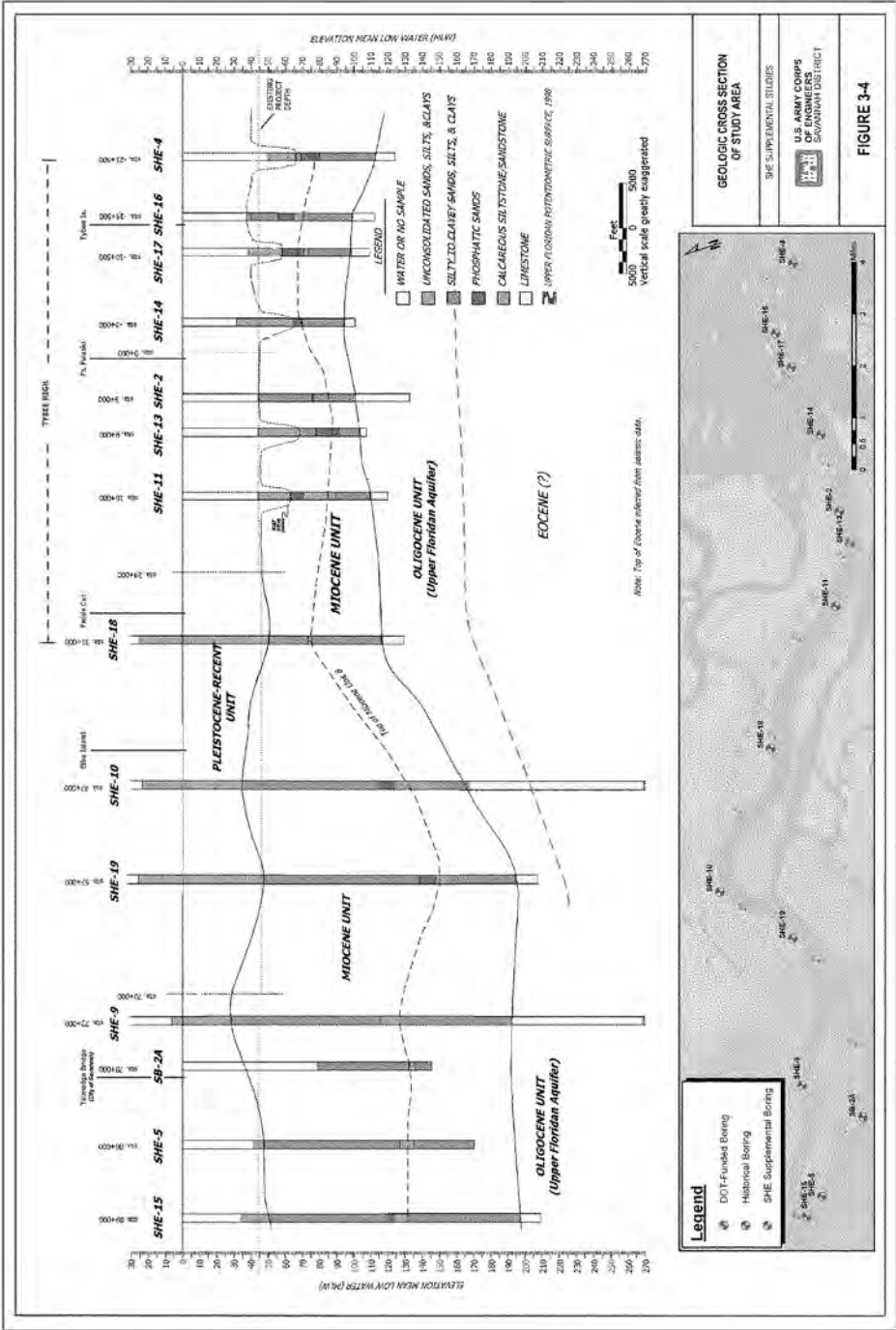
Within the study area, the Pleistocene to Recent sediments generally range in thickness from about 50 to 70 feet. Along the present day navigation channel, the Pleistocene-Recent sediments range from 0 to 30 feet thick and are predominantly composed of clays and silts. Depositional environments of the Pleistocene-Recent unit within the Savannah River corridor include off-channel deposits of sands and clays and in-channel deposits of fluvial sands, silts, and clays (paleochannels).

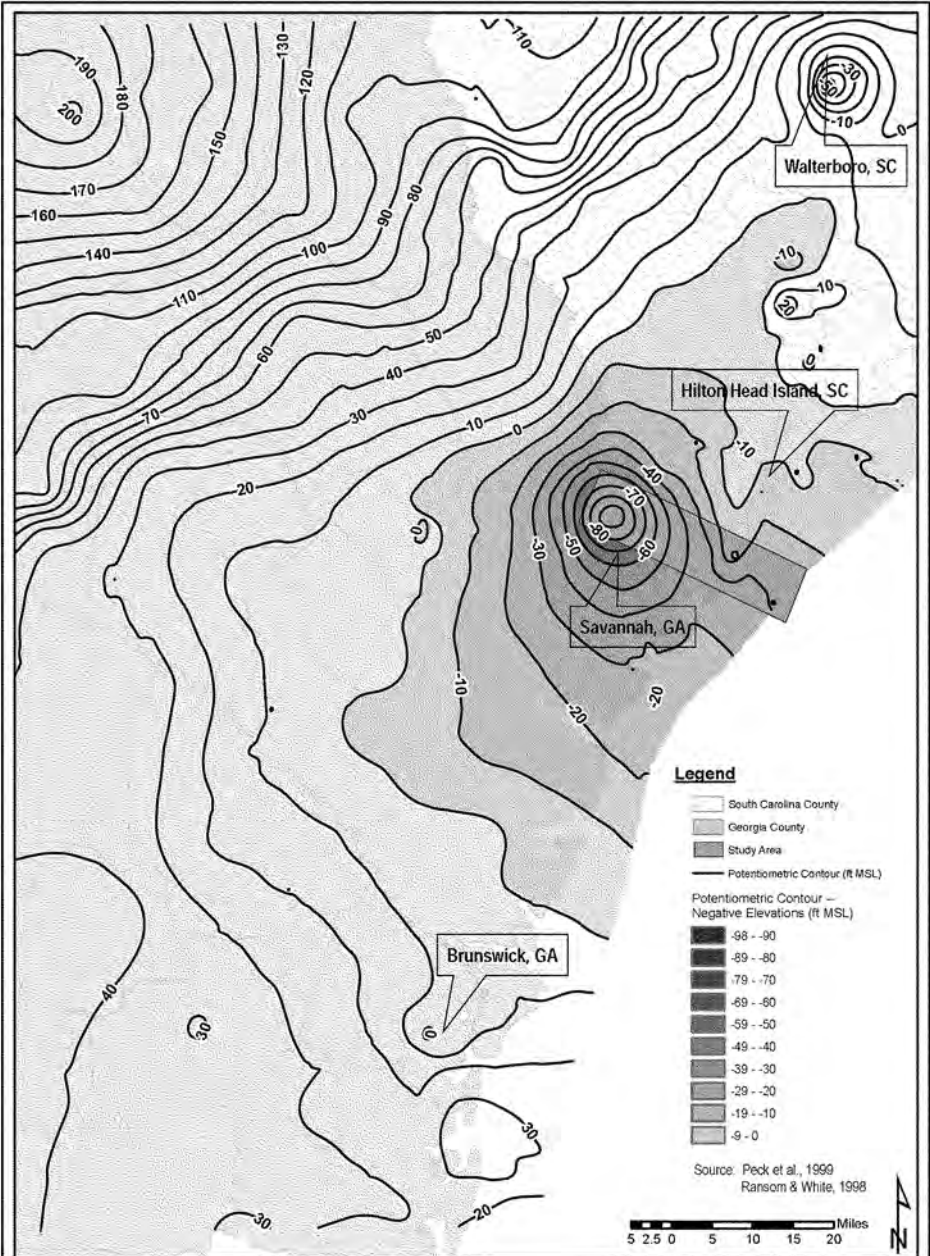
The Pleistocene sands, also known as the surficial aquifer, collectively constitute one of the most important sources of water for irrigation purposes in southeast Georgia. Ground water within the surficial aquifer occurs under both unconfined (water table) and confined (artesian) conditions in the coastal zone. In places, a basal Pleistocene sand, typically about 15 to as much as about 40 ft thick, is separated from an upper fine-grained sand by a low-permeability dark-gray clay. These sands are recharged by local rainfall, and ground water moves laterally with typically very low hydraulic gradients toward local streams and tidal water bodies. In the Savannah area, daily combined withdrawals from the upper and lower water-bearing zones range from 120,000 to 855,000 gallons per day (Clarke et al., 1990).











U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

POTENTIOMETRIC SURFACE
OF THE UPPER FLORIDAN AQUIFER
IN THE COASTAL AREA, 1998

SHE SUPPLEMENTAL STUDIES

Figure 3-6

4. STUDY METHODS

The methods employed in this study were intended to build and expand on the information from previous studies, particularly the internal studies done by the Savannah District (USACE, 1998) and USGS Bulletin 113 by Clarke et al. (1990). The Savannah District used input from various agencies including the USGS, GAEPD, SCDHEC, SEG, and Georgia Ports Authority to develop a scope of work for the supplemental studies. The study was implemented according to six tasks (Table 4-1), each of which is summarized below.

Table 4-1. Tasks Comprising Supplemental Studies

Task	Subject	Description
1	Subbottom Seismic Survey	Conduct additional subbottom seismic surveying with particular emphasis to better define paleochannel geometry and Upper Floridan confining unit thickness. All seismic data will be acquired in digital format to facilitate analysis and storage in the GIS.
2	Marine Drilling	Conduct additional marine continuous core borings to further characterize in-filled sediments of paleochannels and Miocene confining unit below paleochannels.
3	Land Drilling	Conduct additional continuous core borings on land adjacent to navigation channel to top of Upper Floridan aquifer at three strategic locations where geologic or hydrogeologic data is sparse.
4	GIS	Combine existing geologic, hydrogeologic, seismic, and engineering data from previous studies into the harbor-wide GIS being constructed for Savannah Harbor. Add future supplemental data to the GIS to allow enhanced analysis and visualization.
5	3-D Numerical Hydraulic Model	Develop 3-D coupled flow and transport model of the hydrologic system focused on the navigation channel, and use model to compare before and after dredging results as related to projected chloride changes in the Upper Floridan aquifer.
6	Aquiltard Test Feasibility	Conduct trial step-drawdown pumping test on two recently installed Upper Floridan wells located adjacent to river channel to determine feasibility of hydraulic testing of confining unit. If results indicate hydraulic testing of confining unit is feasible, estimate design parameters and assumptions for full aquiltard testing.

Ocean Surveys, Incorporated (OSI), acting as a contractor to the Savannah District, performed a supplemental subbottom geophysical survey to fulfill requirements outlined in Task 1.. The survey served as an addition to the extensive work completed in 1997, in which relict paleochannels and the underlying stratigraphy were defined along the centerline of the navigation channel. OSI conducted the supplemental survey along the sides of the navigation channel between river stations +30+000 to -30+000, where the majority of paleochannels cut across the navigation

channel, in an effort to better determine the orientation of the paleochannels and the thicknesses of the underlying units.

During the period 9 December 2003 to 6 May 2004, seven marine continuous core borings (SHE-11 through SHE-17) were drilled adjacent to the navigation channel, six of which were drilled in known paleochannels (Figure 4-1), to fulfill the requirements outlined in Task 2. The cores were drilled to the top of the Upper Floridan aquifer to further define the stratigraphy underlying Savannah harbor. Each core was drilled using freshwater and analyzed for porewater geochemistry, geophysical markers, grain size, porosity, and vertical hydraulic conductivity.

Similar to Task 2, Task 3 entailed drilling two additional land borings (SHE-18 and SHE-19) in an effort to complete the geologic transect along the entire length of the navigation channel. The borings were strategically drilled in areas where geologic or hydrogeologic data was sparse, and core samples were analyzed for porewater geochemistry, geophysical markers, grain size, porosity, and vertical hydraulic conductivity. In addition, the data from the borings will be used to install two sets of multi-level wells near existing Upper Floridan wells. Although right-of-entry issues have delayed well installation, the multi-level wells will be installed within the surficial aquifer and the Miocene confining unit and will be used to collect hydraulic head and ground-water data at discrete depth intervals over long periods of time.

Task 4 concerned the development of a comprehensive harbor-wide Geographic Information System (GIS). Specifically, the task aimed to compile existing geologic, hydrogeologic, seismic, and engineering data from available historical reports published by the Savannah District, USGS, GAEPD, SCDHEC, or otherwise into a comprehensive GIS for enhanced analysis and visualization.

Task 5 entailed developing a three-dimensional (3-D) numerical hydraulic coupled flow and transport model of the hydrologic system in the immediate vicinity of the navigation channel. The Savannah District issued a contract to CDM to perform this task. The model incorporated hydraulic properties, confining unit thickness, and historic and present pumping rates to determine a range of plausible aquifer

responses to deepening the navigation channel. Simulations were run according to a no dredging scenario and a worst-case dredging scenario, where "worst-case" refers to a maximum project depth of -48 feet MLW and the associated overdredging allowances. The outputs were compared to evaluate the potential effects of dredging on water quality in the Upper Floridan aquifer.

Task 6 was intended to be a trial pumping test on two existing Upper Floridan wells in order to determine the feasibility of performing an aquitard test on the confining unit. Prior to conducting this task, several model simulations were performed to evaluate the potential response in the Surficial aquifer and Miocene confining unit to a long-term pumping test conducted with a well in the Upper Floridan aquifer. Further details on the simulated pump tests are included in Section 4.5.

4.1. DRILLING

During the period 9 December 2003 to 27 August 2004, the Savannah District drilled nine additional borings along the present navigation channel to complete the work outlined in the supplemental studies work plan, and those boring locations are presented in Figure 4-1. Seven of the nine borings were marine borings drilled using the Savannah District's self-elevating barge, and the remaining two borings were drilled on land in close proximity to the Savannah River. Eight of the nine borings completed were located between approximate river stations 30+000 and -30+000, roughly between the Intra-Coastal Waterway (ICW) at Fields Cut and the area immediately offshore from Tybee Island, where the confining unit is thinned and paleochannels are known to cut across the navigation channel. An additional boring (SHE-15) was drilled near river station 89+000, about two miles upriver from the Talmadge Bridge and near the center of the cone of depression.

All borings were completed using traditional mud-rotary drilling with wire-line coring, with the exception of SHE-12 and part of SHE-19. The upper portions of these holes were advanced using splitspoon techniques in an effort to improve recovery of the Pleistocene-Recent material, which is generally more heterogeneous and

unconsolidated in nature than the Miocene confining unit material. An attempt was made to obtain continuous samples from river bottom (or land surface) to maximum hole depth, and core recovery was generally good, greater than 75% for all borings, with only occasional core losses due to soft unconsolidated sediments being washed away during coring. Cores were described and classified, and samples were collected and analyzed for porewater geochemistry, hydraulic conductivity, and triaxial shear properties. All borings were drilled from river bottom (or land surface) to the top of the Upper Floridan aquifer with the exception of SHE-12, which served as a test hole for locating boring SHE-13.

4.1.1. Marine Borings

The majority of marine borings were located between river stations +16+000 and -14+000, where paleochannels are known to cut across the navigation channel and the confining unit is closest to land surface (river bottom). Six of the seven marine borings were drilled within known paleochannels, and the remaining boring (SHE-16) was drilled outside any known paleochannel to serve as a control and comparison tool for porewater geochemistry and permeability samples. Several precautions were taken in order to prevent salt-water contamination of the porewater geochemistry samples. Before coring commenced, 6" steel casing was firmly seated in the river bottom. The salt water was then flushed out of the casing and replaced with freshwater that was stored in enclosed tanks on the drilling barge. In order to ensure the casing sealed out salt water, the conductivity, temperature, pH, and salinity were monitored using a Horiba U-22 water quality monitoring system. The water quality probe was used throughout the entire drilling process to ensure non-in situ salt water did not enter the core hole.

4.1.2. Land Borings

Two land borings were drilled adjacent to the navigation channel at strategic locations where geologic or hydrologic data was sparse. The locations of borings SHE-19 and SHE-18 corresponded to river stations +57+000 and +31+000, respectively. Land borings were drilled similarly to marine borings, and although salt-

water contamination was not a concern, water quality was monitored throughout the drilling process with the Horiba U-22 water quality monitoring system.

4.2. POREWATER PROFILES

Since the 1880's, increasing withdrawals of water from the Upper Floridan aquifer have caused a cone of depression to form in the Savannah area and lowered the water level in the aquifer to as much as 100 feet below sea level (Peck et al., 1999). The net effect of this lowering of water level has reversed the natural pre-development flow of ground water from the aquifer upward through the confining layer to a downward flow of water from above through the confining layer and toward the center of the area of pumping in Savannah. This downward flow accounts for a significant portion of the water budget contained within the cone of depression, and, since much of the area within the drawdown cone of depression is overlain by salt water, chloride levels in the Upper Floridan aquifer in the Savannah area are expected to increase. The porewater data collected for this study provided a means to better characterize the Miocene confining unit in terms of downward hydraulic gradient, intrusion rates, and effects of thinning the material due to dredging or paleochannel incisions.

In recent years, studies on low-permeability clayey aquitards (i.e. confining layers) have increased greatly due to the effects they have on the movement of contaminants in hydrogeologic systems. More specifically, several studies have addressed the use of porewater salinity data from aquitards to better understand the relationship between aquitards and adjoining aquifers in salt-water intrusion scenarios (Husain et al., 1998 and Lenahan et al., 2004). Van der Kamp (2001) stresses the importance of using solute-transport observations in conjunction with permeability measurements to increase confidence in the characterization of aquitards.

Ransom et al. (2006) first identified porewater salinity profiles as a helpful tool in assessing salt-water intrusion in the Savannah-Hilton Head coastal area. In 2001,

funded by SCDHEC as part of the Sound Science Initiative, a porewater profile was constructed from both Geoprobe screen point ground-water samples and rotosonic core samples taken at a site located in Chatham County near Bull River. As part of the supplemental studies, the Savannah District utilized the methods set forth by Dr. James Landmeyer (USGS) and Mr. Camille Ransom (SCDHEC) to collect porewater geochemical data to measure the extent to which salt water (i.e. chloride) has penetrated the confining unit along the navigation channel.

4.2.1. Sampling

For each boring, samples of porewater, water contained within the pore spaces of a geologic material, were collected at regular intervals from, at minimum, the top of the confining unit to the top of the Upper Floridan aquifer. Several sampling methods, each of which is described below, were employed to collect in-situ porewater at discrete depths throughout the confining unit. The porewater samples were then analyzed for concentration of several dissolved ions including chloride. The resulting concentrations were then plotted according to the depth at which they were collected, yielding profiles of chloride concentration within the confining unit versus elevation for each boring location.

4.2.1.1. Sample Integrity

Several steps were taken in order to ensure that the cores were not contaminated and were truly "undisturbed." As mentioned in Section 4.1.1, the drilling fluid was monitored throughout the drilling process to insure that salt water did not contaminate the drilling fluid in marine borings. When possible, porewater was extracted immediately following each core run in order to minimize evaporation of porewater within the core. Additionally, a procedure was performed during the drilling at SHE-9 to insure that drilling fluid did not permeate the entire cross section of any given core. Micron-sized polystyrene spheres that contain a fluorescent dye (Polysciences, Inc.) were added to drill mud during mixing at a final concentration of near 10^6 to 10^7 microspheres/mL of mud. After drilling was completed, an epifluorescent

microscope at the USGS Science Center in Columbia, South Carolina was used to check for the presence of microspheres in a given cross section of core.

The core material from a particular depth was split into two pieces. Following a transect from the exterior of the core to the interior, approximately 1 mg of sediment was removed every 5 mm. The sediment was added to 9 mLs of distilled water and then shaken, and approximately 1 mL of the supernatant was placed on a nucleopore membrane. The membrane was then placed on a standard microscope slide, and the density of microspheres was recorded using an epifluorescent microscope. No penetration of microspheres into the undisturbed core material recovered was observed.

4.2.1.2. Core Sampling

The Miocene confining unit typically contains a significant amount of fine sand, yet still contains enough clay to maintain cohesiveness and medium to high porosities. As a result, the Miocene material cores well and proved to be ideal for obtaining porewater samples. A typical ten-foot core run yields at least eight feet of recovery, and the core is well consolidated and virtually undisturbed (Figure 4-2). Likewise, a typical porewater sample yields over 2mLs of fluid.

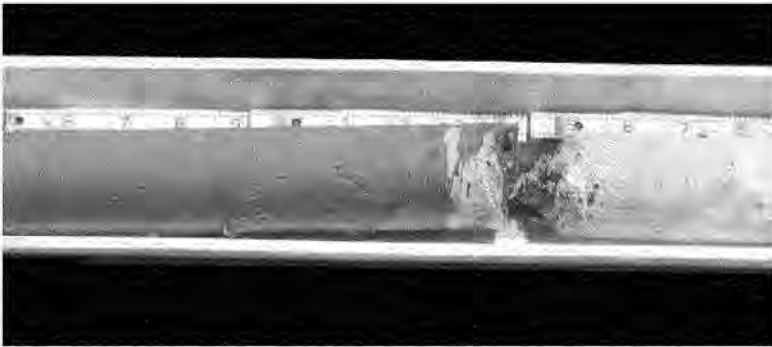


Figure 4-2. Core sample of Miocene confining unit (left) and underlying Oligocene limestone (right).

The Savannah District employed a method developed by Dr. James Landmeyer of the USGS to collect porewater samples from Miocene cores. After cores were extracted from the core barrel, measured, and described, a 0.5 to 0.7 foot interval of core was removed from the 8 to 10 foot section. The outside of the core was then cut away to ensure no drilling fluid contaminated the water sample. The remaining core sample, typically 40 to 50 grams in weight, was then loaded into a specially designed piston and cylinder chamber. The stainless steel chamber was constructed using three main components, a base with a small sampling port, a hollow cylinder that fit securely on the base, and a solid cylindrical piston that fit snugly into the hollow cylinder. In addition, a series of Teflon, polypropylene, stainless steel, and cellulose filter paper were placed in the bottom of the chamber to prevent the core sample from clogging the sample port in the base. The core sample was loaded into the hollow cylinder, and then solid discs of polypropylene and Teflon were placed on top of the sample to form a tight seal. The solid piston was then inserted into the hollow cylinder (Figure 4-3). The loaded chamber, or "bomb," was then placed in a Carver manual lab press equipped with a scale gauge. A 10mL syringe was then placed in the sampling port, and up to 3000 psi of pressure was applied. As the piston compressed the core sample, porewater was forced into the sample syringe. The sample, typically 2 to 4mLs, was then placed into a 5mL airtight scintillation vial and stored at room temperature until analyzed.

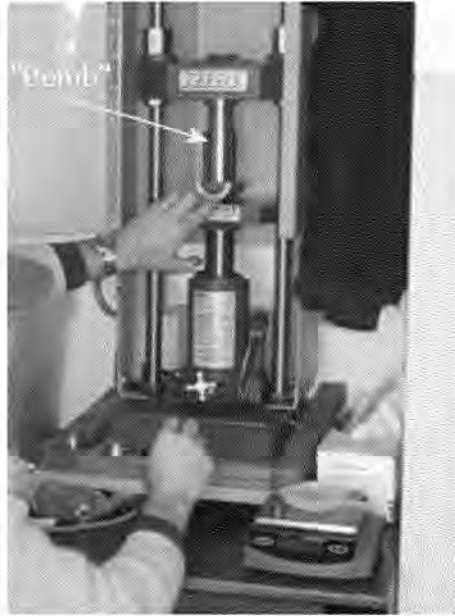


Figure 4-3. Porewater sampling chamber or "bomb."

4.2.1.3. *Geoprobe® Sampling*

The Miocene confining unit is well consolidated and cohesive; whereas, the surficial Pleistocene-Recent sediments typically consist of coarser grained, loose sands and silts. As a result, core recovery is usually poor, and core samples retained are disturbed and unconsolidated. Chloride penetration through these sediments is still of interest; however, and an alternative sampling technique was utilized at the land boring locations (SHE-18, SHE-19, SHE-9, and SHE-10) to obtain in-situ porewater samples. Using a Geoprobe direct-push rig, screen point samples were taken to obtain water from ground surface to the top of the Miocene confining unit. The screen point ground-water sampling system, used in conjunction with the Geoprobe, is a protected screen sampler that enables the user to collect representative ground-water samples from a discrete interval as small as a few inches or as much as three

feet. In any case, the smallest screen interval possible was used to obtain the necessary volume of water. A small check valve was inserted in Teflon tubing, and the tubing was then inserted inside the drill rods down to the screened interval to obtain a sample. The tubing was removed from the drill rods and the water sample was transferred to 5mL scintillation vials and stored at room temperature until analyzed.

4.2.2. Analysis

A field screening method was used prior to sending porewater samples to the laboratory for quantitative analysis. After extracting porewater from a given sample, a portable refractometer was used to measure bulk salinity (Figure 4-4). Based on the results, the screening interval could be refined or additional samples could be squeezed to verify or invalidate anomalous results.

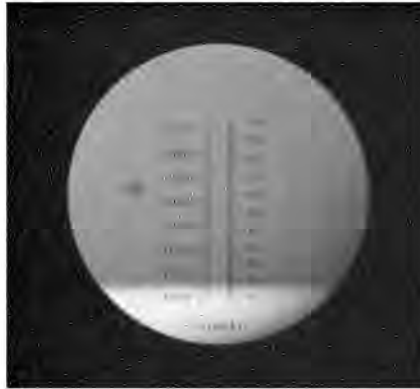


Figure 4-4. View of refractometer shadow line and corresponding salinity value in parts per thousand.

Upon drilling completion of each boring, porewater samples were securely packed and delivered by car to the USGS South Carolina District Office in Columbia. Dr. James Landmeyer of the USGS analyzed each sample for chloride, bromide, and

sulfate using established ion chromatograph methods, specifically US Environmental Protection Agency (EPA) Method 300.0 (Dionex, 2003).

4.3. GEOPHYSICAL SURVEY

Past subbottom geophysical surveys revealed the existence of buried relict stream channels (paleochannels) underlying the present day navigation channel. The survey performed as part of the scope of work for this report was designed to complement and expand upon subbottom data gathered in 1997. Specifically, the survey aimed to identify and profile all significant paleochannels underlying the navigation channel from river stations +30+000 to -30+000, where the confining unit is thinned and the aquifer is closest to ground surface. The data collected also provided a means for locating several of the marine borings completed as part of this study.

4.3.1. Location

During the period 11-17 February 2004, OSI performed a subbottom geophysical survey in the Savannah Harbor bar channel and entrance channel. Initially, data was acquired along each edge of the navigation channel from river station +30+000 to -30+000. Following a brief review of the survey data, representatives from OSI and the Savannah District established supplemental track lines in areas where prominent paleochannels occurred. The supplemental tracklines were oriented both parallel and perpendicular to the course of the present day navigation channel in an effort to better determine the orientation and attitude of the paleochannels. In total, the survey incorporated approximately 60 miles of tracklines and greater than 50 survey lines. Figure 4-5 shows the locations of the tracklines.

4.3.2. Field Survey

4.3.2.1. Equipment

OSI performed the subbottom survey using a 26-foot survey vessel equipped with an array of geophysical survey and support equipment. A Real Time Kinematic Differential Global Positioning System (RTK DGPS) was installed on the vessel and

interfaced with a radio link to a shoreside DGPS base station and onboard computer, which allowed the field team (OSI and Savannah District representatives) to navigate precisely along pre-determined tracklines and correct for tidal variations in real-time.

OSI employed a suite of geophysical equipment to conduct the subbottom survey, including a modified version of Coastal Oceanographic's HYPACK® MAX PC-based navigation and data-logging software package, an Innerspace Model 448 digital depth sounder, and an OSI 300-joule high resolution "boomer" subbottom profiling system. For further details and specifications, see Appendix A.

4.3.2.2. Data Processing

OSI generated a survey trackline plot and all-inclusive daily field log detailing survey lines investigated and their associated data file names immediately upon conclusion of the field survey. Subbottom profile data were then extensively reviewed and interpreted with the primary task of identifying the prominent relict channel features within the study area (river stations +30+000 to -30+000). The reconstructed survey tracklines, identified subbottom reflector "picks," and contoured hydrographic data are all incorporated in the final report furnished by OSI, which is included as Appendix A.

4.4. THREE-DIMENSIONAL GROUND-WATER MODEL

As part of the scope of work for this study, CDM developed a comprehensive three-dimensional (3-D) numerical hydraulic coupled flow and transport model of the hydrologic system in the immediate vicinity of the navigation channel. The model incorporated hydraulic properties, confining unit thickness, and historic and present pumping rates to determine a range of plausible aquifer responses to dredging. The model was run according to several scenarios, including no future dredging, dredging with a 6-foot improvement plus an additional 3-foot removal of confining material, and varying the hydraulic conductivity of the confining layer. The model assumed an additional three feet of confining material was removed in order to account for any additional material that may be disturbed by the dredge cutter-head during the deepening process. While the cutter-head would not necessarily remove the

additional material, any disturbance would alter the hydraulic properties of the material. For that reason, the model properties assumed the three additional feet were completely removed to insure the simulation results represented a conservative response. The model structure and simulations are summarized below, and a complete report is included as Appendix B.

4.4.1. Model Background

Siple (1957) first observed and reported seawater encroachment in coastal South Carolina. Over the past fifty years, the hydrogeology and ground-water flow system of the coastal area and Savannah have been studied extensively, and numerous papers have presented ground-water flow models (Bush, 1988; Clarke and Krause 2000; Garza and Krause, 1996; Krause and Randolph, 1989; Smith, 1988; Smith, 1994). Early ground-water flow models by Bush (1988) and Smith (1994) used a version of the USGS Saturated-Unsaturated Transport (SUTRA) model code to investigate the potential for lateral salt-water encroachment into the Upper Floridan aquifer. The models simulated ground-water flow and solute transport in 2-D vertical sections under various pumping schemes and predicted movement of the freshwater/salt-water transition zone in the Upper Floridan aquifer beneath Port Royal Sound near Hilton Head Island, South Carolina.

Krause and Randolph (1989) developed a Regional Aquifer-System Analysis (RASA) model that simulated 3-D ground-water flow using MODFLOW. The RASA model results provided a comprehensive picture of the steady-state ground-water flow regime in the coastal area and served as a basis for three more site-specific models: the Glynn model (Randolph and Krause, 1990), the coastal model (Randolph et al., 1991) and the Savannah model (Garza and Krause, 1996).

As part of the ongoing Sound Science Initiative, the USGS is updating the RASA MODFLOW model and applying a 3-D version of SUTRA to simulate both ground-water flow and density-dependent solute transport in coastal Georgia and adjacent parts of South Carolina and Florida. The model results will be used to evaluate

regional ground-water management issues, salt-water intrusion, and seawater encroachment in coastal Georgia.

The USGS regional ground-water flow model does not contain sufficient detail to evaluate potential changes in ground-water heads, gradients, and migration of saline water due explicitly to dredging of the Savannah River navigation channel.

Therefore, for this study, CDM developed a fully 3-D, finite element ground-water flow and salt-water intrusion model with a higher level of discretization in the Savannah area to specifically evaluate the potential effects of dredging on water quality in the Upper Floridan aquifer.

The early models, the RASA model, and its offspring models simulated ground-water flow influenced by pumping in Savannah and indicated fairly high vertical downward flows (leakage) through the upper confining unit to the Upper Floridan aquifer, but none of these models addressed vertical salt-water intrusion. Of these models, only Smith (1988) and Bush (1988) used SUTRA 2D to specifically simulate solute transport of chlorides; however, the simulations addressed only lateral seawater encroachment in two dimensions. The RASA model and its successors simulated regional ground-water flow in three dimensions but did not address seawater encroachment or salt-water intrusion. The proposed dredging, however, would not directly affect the rate of lateral seawater encroachment from the Atlantic Ocean or the regional ground-water flow regime. Instead, the removal of confining material along the navigation channel would affect the rate of downward leakage of water through the confining unit. As such, the CDM model focuses only on the vertical leakage mechanism and the effects of confining layer thickness and vertical hydraulic conductivity on water quality in the Upper Floridan aquifer in the Savannah area.

4.4.2. Study Approach

CDM adopted a five-step approach to develop the ground-water model: data review and analysis, development of ground-water flow and salt-water intrusion model, model refinement, model calibration, and model application.

CDM conducted a review of existing data and reports on aquifer studies and investigations for the proposed Savannah Harbor Expansion (SHE) project, including the studies published by the Savannah District. CDM then developed a ground-water flow model with salt-water intrusion simulation capabilities based on the existing USGS MODFLOW regional ground-water flow model. A finite element modeling code with a flexible grid structure was used so that the SHE model would have a sufficient level of detail along the Savannah River to evaluate the impact of the proposed dredging program. The model was specifically developed to simulate only intrusion of salt water from the Savannah River in the harbor area, with the focus on the stretch of river where dredging is proposed.

Following development of the model, CDM refined the model to accurately represent current flow conditions along the Savannah River navigation channel. The refinement involved increasing the discretization of the finite element grid along the Savannah River in the project area, improving the representation of the Miocene confining unit based on USACE boring and seismic data, and improving the channel and offshore bathymetry based on detailed USACE survey data and data available from the National Oceanographic and Atmospheric Association (NOAA). In order to verify the model, CDM tested the ability of the model to represent both steady state and transient ground-water head and flow conditions. Additionally, CDM tested the ability of the model to simulate saline water migration through the Miocene confining unit as measured in the USACE porewater profiles.

Once the model was tested and shown to be able to adequately reproduce observed ground-water heads, gradients, and chloride concentrations, it was applied to evaluate the potential impacts of the proposed dredging. The model was used to simulate the rate of migration of saline water from the Savannah River through the Miocene confining unit into the underlying Upper Floridan aquifer under a variety of input parameter assumptions. Chloride sources located outside the Savannah River channel (offshore, salt marshes, etc.) were not included in the simulations to ensure that simulation results represented the explicit effects of dredging on chloride concentration distributions in the Upper Floridan aquifer.

4.4.3. Model Structure

4.4.3.1. Model Codes

The modeling software utilized in this study included DYNFLOW (single phase ground-water flow), DYNTRACK (solute transport) and DYNCFD (dual-phase, density dependent ground-water flow). DYNFLOW is a fully three-dimensional, finite element ground-water flow model. CDM engineering staff has developed, tested, and documented DYNFLOW over the past 25 years, and the model is commonly used for both site-specific remedial design investigations and large-scale basin modeling projects. DYNFLOW uses a grid built with a large number of tetrahedral elements. These elements are triangular in plan view and allow for a wide flexibility in grid variation over the area of study. An identical grid is used for each level of the model, but the thickness of each model layer (the vertical distance between levels in the model) can vary at each point in the grid. In addition, two-dimensional elements can be inserted into the basic 3-D grid to simulate thin features such as faults. One-dimensional elements can be used to simulate the performance of wells that are perforated in several model layers. DYNFLOW has been applied to over 200 ground-water modeling studies in the United States and has been reviewed and tested by the International Groundwater Modeling Center (IGWMC) (van der Heijde, 1985, 1999).

CDM utilized DYNTRACK as the solute transport code, which was developed over the past 15 years by CDM engineering staff. DYNTRACK uses the random-walk technique to solve the advection-dispersion ground-water flow equation. In DYNTRACK, a solute source can be represented as an instantaneous input of solute mass (represented by a fixed number of particles), as a continuous source on which particles are input at a constant rate, or as a specified concentration at a node. The concentration within a particular zone of interest is represented by the total number of particles that are present within the zone multiplied by their associated solute mass then divided by the volume of water within the zone. DYNTRACK has also been reviewed and tested by the IGWMC (CDM, 2005; van der Heijde, 1985).

DYNCFT, a coupled flow and transport model, was used to fully simulate variable density effects on ground-water flow. DYNCFT combines the ground-water flow capabilities of DYNFLOW with the contaminant transport capabilities of DYNTRACK. Coupling flow and transport computations allows the effect on ground-water flow of fluid density gradients associated with solute concentration gradients to be incorporated into model simulations (i.e. density-dependent flow). In the SHE model, DYNCFT was applied to simulate the density-dependent flow component of saline water from the Savannah River navigation channel.

4.4.3.2. Model Domain and Finite Element Grid

The domain or geographic extent of the SHE project ground-water model was based on the USGS regional ground-water flow model. The SHE model domain covered approximately 42,250 square miles and was discretized into 16,362 triangular elements defined by 8,257 nodes at the vertices of the triangles (Figure 4-6). In order to represent the proposed dredging, discretization was finest in the area of the Savannah River to ensure the chloride source area (i.e. the river) was sufficiently defined. Node spacing was on the order of 125 feet within the river, which allowed any given transect across the width of the river to contain four nodes. The node spacing increased outside of the Savannah River area to typically 4.5 to 5 miles for inland nodes, and offshore nodal spacing is approximately 10.5 to 11 miles. Figure 4-7 shows a portion of the grid with detailed discretization near the city of Savannah.



Figure 4-7. Detailed view of finite element grid in the Savannah area.

4.4.3.3. Boundary Conditions

The boundary conditions assigned in the SHE model are based on the USGS regional ground-water flow model and modified to fit the finite-element model structure. Fixed head and no flow boundaries were used as the major types of ground-water flow boundary conditions, and fixed concentration boundary conditions were used for the seawater transport computations. Chloride concentrations in the Savannah River were obtained from the surface water modeling conducted by Tetra Tech NUS, Inc. (Tetra Tech) for the SHE project. Salinity values for both existing and post-dredging conditions were obtained from preliminary surface water model simulations and represent simulated average annual concentrations of river water at the bottom of the river. Salinity was converted to chloride concentration by

multiplying the salinity values by 0.37, a reasonable value for seawater. Chloride input concentrations ranged from a high of about 10,000 mg/L near the mouth of the river to below 3 mg/L in downtown Savannah. Both ground-water flow and transport boundary conditions are summarized in Table 4-2. See Appendix B, Section 2.4 for further discussion regarding boundary conditions.

Table 4-2. Boundary Conditions Assigned for Ground-water Model

Boundary Description	Type of Boundary Condition
Savannah River	Fixed Head = 0 for flow boundary; Constant Concentration for chloride seawater migration simulations (transport)
Upstream Savannah River	Rising Water
Ocean	Fixed Head
East (Ocean)	No Flow
Southeast (Ocean)	No Flow
Southwest	Fixed Head
Southern	Fixed Head
Northwest	No Flow
Northeast	No Flow
Water Table	Fixed Head
Base	No Flow

4.4.3.4. Stratigraphy/Layering

The conceptual layout of the aquifer and confining units was based on the USGS regional model. The units and their properties were defined according to the regional stratigraphic framework set forth by the USGS; however, not all the hydrogeologic units, namely the Miocene aquifers, are present in the project area. As such, the model utilized the generalized units in distal areas around the Savannah River, but in the immediate vicinity of the navigation channel, the model used the refined, site-specific stratigraphy shown in Table 3-1. To accommodate this refinement and to provide sufficient vertical discretization for chloride migration simulation beneath the river, the seven hydrogeologic units used in the model were divided into 12 levels and 11 layers, where levels are the planes containing nodes that bound the area contained within the layers. Table 4-3 below lists the seven basic hydrogeologic

units, the corresponding layer numbers represented in the model, and their equivalent units underlying the study area.

Table 4-3. Model Hydrogeologic Units and Layers and Their Equivalent Units in Eastern Chatham County

Model Layer	Regional Hydrogeologic Unit	Eastern Chatham County Equivalent Unit
11	Surficial Aquifer	Surficial Aquifer
10		
9	Miocene Confining Unit	Upper Confining Unit
8		
7	Miocene Aquifer	Not Present in Study Area
6		
5	Upper Floridan Confining	Upper Confining Unit
4		
3	Upper Floridan Aquifer	Upper Floridan Aquifer
2	Lower Floridan Confining	Lower Confining Unit
1	Lower Floridan Aquifer	Lower Floridan Aquifer

4.4.3.5. Ground-Water Pumping

The ground-water pumping specified in the model was taken directly from data files developed by the USGS for the regional MODFLOW model. Ground-water pumping data are available in two formats: well specific and distributed. The well specific pumping data are based on either individual well or facility permits. Typically, well specific data are available for 100,000 gallons per day permits or larger, and in most cases, the total permit capacity is known but the individual well production is not known. The distributed pumping data refer to the total ground-water pumping estimates for each of the Georgia counties located within the model domain. Additionally, for the historical simulation, ground-water pumping data were obtained from the USGS. Figure 4-8 shows the total ground-water pumping rates applied in the model for the historical period from 1900 to 2000. Note that for projection simulations, the 2000 pumping rate was projected to continue indefinitely into the future.

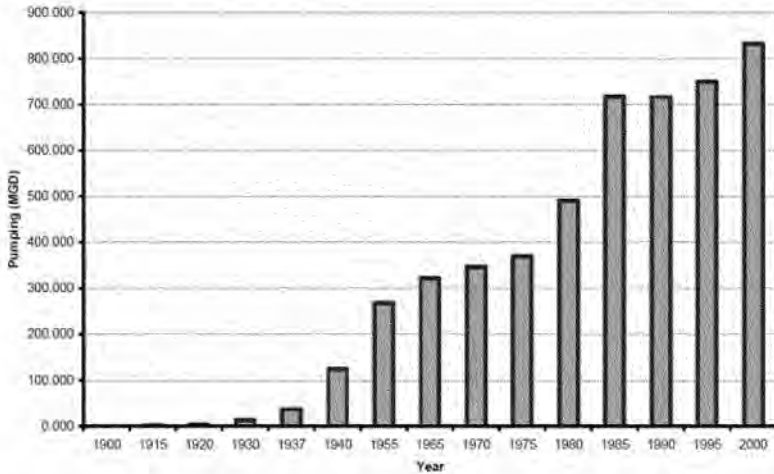


Figure 4-8. Applied ground-water pumping rates for historical simulations (1900-2000) across entire model domain.

4.4.4. Model Calibration

4.4.4.1. Steady-State Calibration

Model calibration is the process of making adjustments to model input parameters until the output from the model reasonably matches a set of measured data and the observed behavior of the ground water flow system. The USGS regional ground-water flow model was calibrated to steady-state year 2000 conditions, and the SHE model was calibrated to the same set of aquifer parameters to represent a best fit in terms of the observed and simulated ground-water heads and gradients. In steady-state calibrations, measured and model-computed heads (water levels) are compared, and the difference between the two, referred to as the residual, is calculated. According to ASTM Standard D 5918-96 *Standard Guide for Calibrating a Ground-Water Flow Model Application*, a calibration is considered adequate when there is no systematic head bias across the model and the standard deviation of

residuals is within 10 to 15% of the total measured head range across the model domain.

Figure 4-9 shows that no single area of the model had systematically high or low simulated ground-water heads relative to the measured heads, and the heads closely matched those reproduced by the USGS model. The measured heads in the Floridan aquifer system vary by 100 feet in the Savannah area alone, which is a difficult system to calibrate. However, the calculated standard deviation (11 feet) was significantly lower than 10 percent of the total measured head gradient across the model (200 to 300 feet). Based on this assessment, the SHE model was adequately calibrated to simulate steady state conditions.

4.4.4.2. Transient Testing

In addition to the steady-state calibration check, CDM tested the ability of the model to reproduce both the historical and temporal behavior of ground-water heads and the measured chloride levels in the Miocene confining unit below the Savannah River. Measured ground-water head data is only available for the model area from around the 1980s onward. However, to test the ability of the model to reproduce the measured levels of chloride in the Miocene confining unit, CDM developed a transient simulation starting with pre-development conditions (1900).

The transient testing was performed for the period from 1900 to 2000 using an annual time step. Surficial aquifer heads were kept constant from 1900 to 1960 and then changed every 10 years based on a linear interpolation between the 1900 and 2000 values. Pumping was varied every 5 to 10 years depending on the availability of data, and chloride concentrations in the Savannah River were kept constant using the chloride distribution set forth by the Tetra Tech surface water model simulations.

The model effectively reproduced the long-term behavior observed in the ground-water heads in the Upper Floridan aquifer as shown in CDM Figures 2-26 and 2-27 in Appendix B. The model accurately simulated the heads as well as the general

trends in heads, even though annual variations in pumping could not be simulated due to a lack of data.

In addition to testing the ability of the model to reproduce historical and temporal heads, the ability of the model to reproduce the measured values of chloride in the Miocene confining unit was also assessed. The simulated results represent the chloride concentrations resulting from the migration of saline water from the Savannah River over the 100-year (1900-2000) transient simulation period. CDM Figures 2-28 through 2-37 in Appendix B compare measured porewater chloride concentration profiles to simulated chloride concentration profiles. The simulated profiles generally resulted in deeper penetration of saline water than observed and higher chloride concentrations than measured porewater values. Furthermore, the transient test also indicated that the simulated penetration depths and chloride concentrations are most sensitive to the vertical hydraulic conductivity of the Miocene confining unit.

The calibrated value of vertical hydraulic conductivity (1.5×10^{-4} ft/day) for the Miocene confining unit is considered to represent the mid-range of reasonable values; however, given that the simulated results overestimated the rate of salt-water intrusion, this value is perhaps higher (more transmissive) than actual field conditions. A second set of simulations using a lower vertical hydraulic conductivity (1.5×10^{-5} ft/day) was also tested, and the simulated results slightly underestimated the rate of salt-water penetration. Therefore, the true system response lies somewhere between the two simulations. The model simulation runs that used the higher value (1.5×10^{-4} ft/day) ensured that the model results represented a conservative evaluation of possible dredging effects on the salt-water intrusion rate through the confining unit.

4.4.5. Model Simulations

4.4.5.1. Input Parameters

As mentioned above, the model application used two values of vertical hydraulic conductivity for the Miocene confining unit: the calibrated value, which represents the

mid-range of reasonable values, and a lower value. In doing so, the two sets of results bound true conditions. Table 4-4 shows the range of vertical hydraulic conductivity for the Miocene confining units in the project area. The lower value of vertical hydraulic conductivity results in chloride profiles at the SHE borehole locations that were in some ways more consistent with the measured values. However, the simulation produced heads in the cone of depression in the Upper Floridan aquifer that were approximately 25 feet too low when compared to field data. Conversely, the calibrated value of hydraulic conductivity produced accurate head distribution within the cone of depression, but the model results overestimated the rate of penetration when compared to the porewater sample data. Results of the sensitivity simulation are provided in Appendix B. With little data available, conservative storativity and specific yield values were used. Values of 0.00001 for storativity and 0.1 for specific yield were applied to all layers and hydrologic units in the model.

Table 4-4. Ground-Water Model Hydraulic Conductivity Input and Sensitivity Analysis Parameters

Sensitivity Parameters		Calibration Statistics		Upper Floridan Heads at Hutchinson Island Well (37Q185)	
Unit	Vertical Hydraulic Conductivity (ft/day)	Mean Difference (ft)	Standard Deviation (ft)	Simulated (ft MLW)	Observed Mean Year 2000 (ft MLW)
Miocene	1.50E-5	-5.5	12.4	-123.5	
Confining Unit	1.50E-4 (Calibrated)	-1.121	10.86	-97.6	-93.8

It should be noted that simulations of future conditions become less certain the farther one gets away from the calibrated data set and selected input parameters, and future pumping rates and boundary conditions will change over time. The projection simulations done for this study assume a continuation of current conditions for the next 200 years, making results beyond the 20-year time horizon less and less certain.

For this study, simulations were run forward in time with a 1-year time-step for a period of 200 years. The results were used to evaluate the potential impact of

dredging on ground-water flow and chloride concentrations in the Miocene confining layer and eventually chloride concentrations in the Upper Floridan aquifer.

Upon breakthrough, the salt water leaking downward through the Miocene confining layer will be diluted into the fresh-water Upper Floridan aquifer. However, assuming mixing of the salt water throughout the full thickness of the Upper Floridan aquifer would result in very low concentrations and would not be a conservative assumption. Therefore, an aquifer thickness of 50 to 60 feet was used to calculate the final concentration of chlorides in the Upper Floridan aquifer. The chosen aquifer thickness limited the chloride mixing to the upper, more conductive portion of the aquifer, resulting in higher and thus more conservative estimates of chloride concentration. The predictive simulations used the following input parameters:

Initial ground-water heads: The year 2000 steady state ground-water levels were used as the starting condition for the simulations.

Ground-water pumping: Future ground-water pumping was kept constant at year 2000 levels. Regulatory officials from both South Carolina and Georgia agree that future pumping from the Upper Floridan aquifer must decrease in order to limit the impacts of salt-water intrusion in the coastal area. A recently-released GAEPD document entitled *Coastal Georgia Water and Waste Water Permitting Plan for Managing Salt-Water Intrusion* (2006) indicates that Georgia will reduce withdrawals from the Upper Floridan aquifer by 5 MGD by the end of 2008; therefore, keeping the pumping rate constant provided a conservative assessment of future ground-water production in the area.

Chloride concentrations in the Miocene: The simulated 2000 distribution of chlorides in the Miocene unit (Figure 4-10) was used as the initial condition. Note that these figures represented significant penetration of chlorides into the Miocene confining units as of "today" (i.e. the start of the projection simulation). The starting chloride concentrations were generally an overestimate of chloride penetration, as discussed above, and, therefore, represented a conservative starting assumption.

Savannah River salinity: As discussed in Section 4.4.3.3, the Savannah River nodes were assigned a constant chloride concentration. The chloride concentrations used for the dredging simulations were obtained from the Tetra Tech surface water model and were higher than the no dredging scenario. For the dredging scenario, the higher values were applied at the beginning of the simulation (year 2000).

Miocene thickness and dredged depths: The dredging depths used in the model represent the "6-foot" improvement option at full maintenance depth plus three additional feet. The removal of three additional feet accounts for any additional material that may be disturbed by the dredge cutter-head. A disturbance would alter the hydraulic properties of the material; therefore, to insure model results represented a conservative response, the model properties assumed the three additional feet were completely removed.

Transport parameters: Table 4-5 shows the transport parameters utilized in the simulations. The applied values have generally provided reasonable dispersion results in other modeling studies and are not based on field data. Advective transport dominated chloride transport in the SHE model; therefore, variation of the dispersion transport parameters did not significantly affect results.

Table 4-5. Transport Modeling Input Parameters

Parameter	Value
Longitudinal Dispersion	30 feet
Transverse Dispersion	3 feet
Upper Floridan Vertical Dispersion Anisotropy	0.1 (dimensionless)
Effective Porosity	0.1 (dimensionless)
Retardation	1 = no retardation (dimensionless)

Salt-water density: The ratio of salt-water density to freshwater density was varied linearly from 1.0 for zero chloride concentration to 1.013 for a chloride concentration of 10,000 mg/L.

4.4.5.2. Conservative Assumptions

The model simulations intended to provide a bracketed range of results to evaluate the probable range of impacts following dredging activities. In order to accomplish this objective, several conservative assumptions were used in the input parameters as described above in Section 4.4.5.1. In summary, the conservative assumptions applied to the model simulations were:

- Pumping rates from the Upper Floridan aquifer in the Savannah area were assumed to remain as they are at present although withdrawal rates are expected to decrease in the future.
- The model utilized the simulated present-day chloride distributions in the Miocene confining unit. These values generally overestimated penetration concentrations when compared with measured porewater values.
- The model was sensitive to the porosity of the confining unit, with lower values increasing the rate of movement of salt downward. This was tested, but with little field data to adequately defend a "calibrated" value, a low end value (0.1) was selected to be conservative.
- Paleochannel in-fill material was assumed to have hydraulic properties comparable to that of surficial aquifer sands, although actual core permeability results indicate the paleochannels contain a significant amount of material that is less permeable.
- Three additional feet of confining layer material were assumed to have been removed throughout the project area to allow for possible disturbance by the cutter-head during dredging activities.
- Historical simulations were run using current-day navigation channel geometry and depths.

4.5. SIMULATED PUMPING TEST

CDM conducted several simulations to evaluate the potential response in the surficial aquifer and Miocene confining unit to a long-term pumping test conducted with a well in the Upper Floridan aquifer. The intent of the simulations was to evaluate the feasibility of performing full aquitard testing of the confining unit.

CDM simulated a pump test within the framework of the flow model described in Section 4.4 and applied the calibrated mid-range value of vertical hydraulic conductivity (1.5×10^{-4} ft/day).

The pumping well used in the simulation was located on the north end of Tybee Island at the approximate location of the Tybee Island Test Well Cluster. Three different pumping rates, 500, 1,000 and 2,000 gallons per minute (gpm), were evaluated, and the simulations were run for a period of one year. The simulated response in observations wells at distances of 750, 1,100 and 2,400 feet was recorded.

4.6. MISCELLANEOUS

4.6.1. Gamma Logging

Distinctive, characteristic natural gamma peaks occur within the Miocene sediments throughout coastal Georgia and South Carolina, and gamma logging has long been acknowledged as a useful tool for correlating strata between borings (McCollum and Counts, 1964; Weems and Edwards, 2001). As part of this study, natural gamma logs were obtained from all borings to aid in correlating and defining stratigraphic units within the project area. Specifically, two known gamma markers occur in the project area within the Miocene unit (known as "A" and "B"). These markers are found in stratigraphic layers that contain high natural gamma radiation. They are associated with highly phosphatic carbonate beds and are generally found a few feet

above the unconformities separating Miocene units A and B, and Miocene unit B and the Oligocene unit (Clarke et al., 1990).

A natural gamma probe and digital controller manufactured by Mount Sopris Instrument Company was employed to conduct all gamma logging. The probe, connected to a cable and a winch, measured natural gamma of the soil, and the data was detected, shaped, and transmitted up the cable line to the controller. The controller, an MGX II Console, then converted the data to a digital output and transmitted it to a laptop computer to provide a real-time continuous log as the probe was winched up or down the borehole.

4.6.2. Electrical Conductivity Logging

Soil conductivity is useful to help classify soils and qualitatively assess the amount of salt water present in pore spaces. Finer grained soils typically exhibit higher conductivities, while sand and gravels are characterized by distinctly lower conductivities. Soil conductivity logs were acquired at boring locations SHE-9, SHE-10, SHE-18, and SHE-19, and the results were checked for correlation with both boring logs and porewater chloride profiles. A Direct Image Electrical Conductivity (EC) System with a Wenner array in conjunction with a Geoprobe direct-push rig was used to obtain the logs. The EC probe measured approximately 15 inches long and contained four electrodes. The probe was installed on the end of drill rods and advanced into the subsurface using the percussion hammer and hydraulic slides from the Geoprobe (Butler et al., 1999). A current was applied to the two outside electrodes and voltage was measured on the two inside electrodes (Christy et al., 1994). The measurement was conveyed to a laptop computer via a pre-strung coaxial cable to provide a real-time continuous log as the probe advanced.

4.6.3. Ground-Water Gradient Data

The cone of depression in the Savannah area has induced a downward flow gradient, and while the gradient between the surficial aquifer and the Upper Floridan is well known, little is known about the corresponding downward gradient within the Miocene confining layer. The 1998 *Ground-Water Impacts* study (USACE, 1998)

presented the first measured evidence of a downward vertical hydraulic gradient through the Miocene confining layer in the Savannah area. As part of the supplemental studies, additional measurements were taken in an array of wells along the Savannah River from upstream near the center of the cone of depression to downstream on the north end of Tybee Island. Heads were measured using a water-level indicator or, where available, vibrating wire pressure transducers installed at various levels within the Miocene confining layer (SHE-9 and SHE-10). Gradients were then calculated based on the elevations of the water levels and screen intervals and the height difference between the measurement points.

4.6.4. Soils Laboratory Data

Sixty-five undisturbed core samples collected from December 2003 to August 2004 were submitted to the USACE Engineering and Materials Unit and analyzed to determine laboratory permeability and hydraulic conductivity as well as grain size distribution and other geotechnical parameters. In addition, two undisturbed core samples were submitted and analyzed for triaxial shear properties.

After cores were extracted from the core barrel, measured, and described, a 0.5 to 1.0 foot interval of core was removed from the 8 to 10 foot section. The samples were wrapped in plastic cling wrap, aluminum foil, and a covering of duct tape to prevent moisture loss, and, in addition, some samples were placed into rigid plastic tubing and sealed for added protection. The cores were refrigerated until completion of the boring, at which time they were packed in a foam-padded box and delivered by car to the USACE Engineering Materials Unit in Atlanta, Georgia. Overall, every effort was made to preserve the samples intact with minimal disturbance. Regardless of the received condition, some sample specimens required slight remolding in preparation of testing. Any specimen remolding was conducted with all efforts directed at preserving the as-received moisture condition and density prior to engineering properties testing.

Twenty-four samples collected from November 2001 to June 2002 (borings SHE-9 and SHE-10) were submitted to DLZ Engineering Laboratory. Sample preservation

and laboratory analyses were performed according to similar protocol as described above, and the sample results are included in the section below along with the results from samples submitted to the USACE Engineering Materials Unit.

4.6.4.1. Permeability, Porosity, and Hydraulic Conductivity

The hydraulic conductivity (K) of the geologic units overlying the aquifer, the Pleistocene-Recent unit and the Miocene unit, are of particular interest in this study. Specifically, the values determined by the lab analyses were applied to calculations and model simulations that evaluated the potential downward migration of seawater through the Miocene confining unit into the Upper Floridan aquifer.

Samples were tested for hydraulic conductivity using ASTM Method D5084. Various base and head platens were utilized during sample preparation to best match the diameter of each sample. All permeability specimens were properly back-pressure saturated and verified to meet the required minimum B value of 95% prior to conducting permeation. Porosity (n) was calculated using standard dry unit weight and specific gravity determination techniques and the relationship $n = e/(1+e)$, where e is the void ratio of the sample. The hydraulic conductivity was measured using a Mercury U-tube Manometer and the resultant values were reported at a target hydraulic gradient value of about 20.

4.6.4.2. Triaxial Compression

The strength of geological materials is generally expressed as the maximum resistance to deformation or fracture by applied shear or compressive stress. The strength characteristics of geological materials depend to an important degree on their previous history and on the conditions under which they will be stressed. Consequently, laboratory tests are designed to simulate the conditions under which the material will be stressed in the field. For this study, samples were analyzed for triaxial shear properties in order to better characterize the strength and deformation-specific properties of the Miocene confining unit under in-situ conditions.

Triaxial testing was conducted using ASTM Method D4767 Consolidated Undrained Triaxial Compression test with pore pressure measurements. The loading for specimens was selected at 0.5 and 1.0 tons per square foot (tsf) for each of the two sample locations. Specimens were prepared by carefully trimming them from the as-received samples to an approximate diameter of 1.4 inches and a height of 3 inches. Some sample specimens required slight remolding in preparation of testing, particularly for sample hole SHE-17 at depth 79.0 to 80.0, which was classified as clayey sand.

4.6.4.3. Unified Soil Classification

Core samples were classified according to the Unified Soil Classification system using grain-size analyses and Atterberg Limits results. Samples that were suspected to contain organic material were subjected to an oven-dried liquid limit testing method to verify the classification description. When oven-dried liquid limit results were found to be less than 75% of the results from moist prepared liquid limit samples, the soil was classified as an organic silt or organic clay. Some soil classification results were also visually identified when both the grain-size and Atterberg Limits tests were not performed. These sample classifications are identified as "Visual."

4.7. GEOGRAPHIC INFORMATION SYSTEM (GIS)

A geologic and hydrogeologic GIS was developed as part of this supplemental study in order to enhance visualization and analysis of both historical and newly collected data. Ultimately, the resulting maps and products included in this report will be incorporated into the larger harbor-wide GIS. ArcGIS 9 was used as the framework for the GIS. Data was compiled and entered into a Microsoft Access 2000 database, which, in turn, was linked and integrated with the GIS as a geodatabase. ArcInfo Desktop version 9 with Spatial Analyst and 3-D Analyst extensions was used to process and analyze the data. ArcMap version 9, a two-dimensional visualization tool, was used to produce maps and figures.

X, Y, Z data files containing locations and elevations of critical geologic contacts or features along the Savannah River were used to define raster surfaces. The data was used to define several base surfaces including the study area, the river bottom, and the stratigraphy of major geologic formations. The base surfaces were then used to create several calculated surfaces, which are discussed in the Section 5.7 of this report. The processes used to create them are detailed in Appendix C.

4.7.1. Data Sources

4.7.1.1. Geologic Data

As part of the objectives outlined in the supplemental studies, historical boring logs were compiled, digitized, and added to the GIS. Coordinates for each boring were converted to NAD83, Georgia State Plane Coordinate System, East Zone. The boring locations and corresponding digitized boring logs were plotted in the GIS to provide a clickable resource for quick reference. In addition, major formation elevations were identified for each boring log and entered into an integrated database, which served as the basis for creating various surfaces of the lithologic units underlying the navigation channel for both the ground-water model and GIS analyses. Over 400 boring logs and their interpretations were processed and mapped as part of this study.

The Savannah District compiled permeability and hydraulic conductivity, porewater, gamma, and soil conductivity data collected as part of the 1998 feasibility study as well as the data collected as part of the supplemental studies into a geodatabase that was integrated with the GIS. The tabular data was plotted according to location and elevation from which it was collected. In addition, where available, plotted data curves and lab reports including grain-size analyses and soil classifications were scanned, and the resulting image files were linked to the data location to allow quick access to the data source.

4.7.1.2. Hydrogeologic Data

Drawdown data of the Upper Floridan aquifer (Peck et al., 1999) was obtained from the USGS and incorporated into the GIS. The potentiometric contours generated by

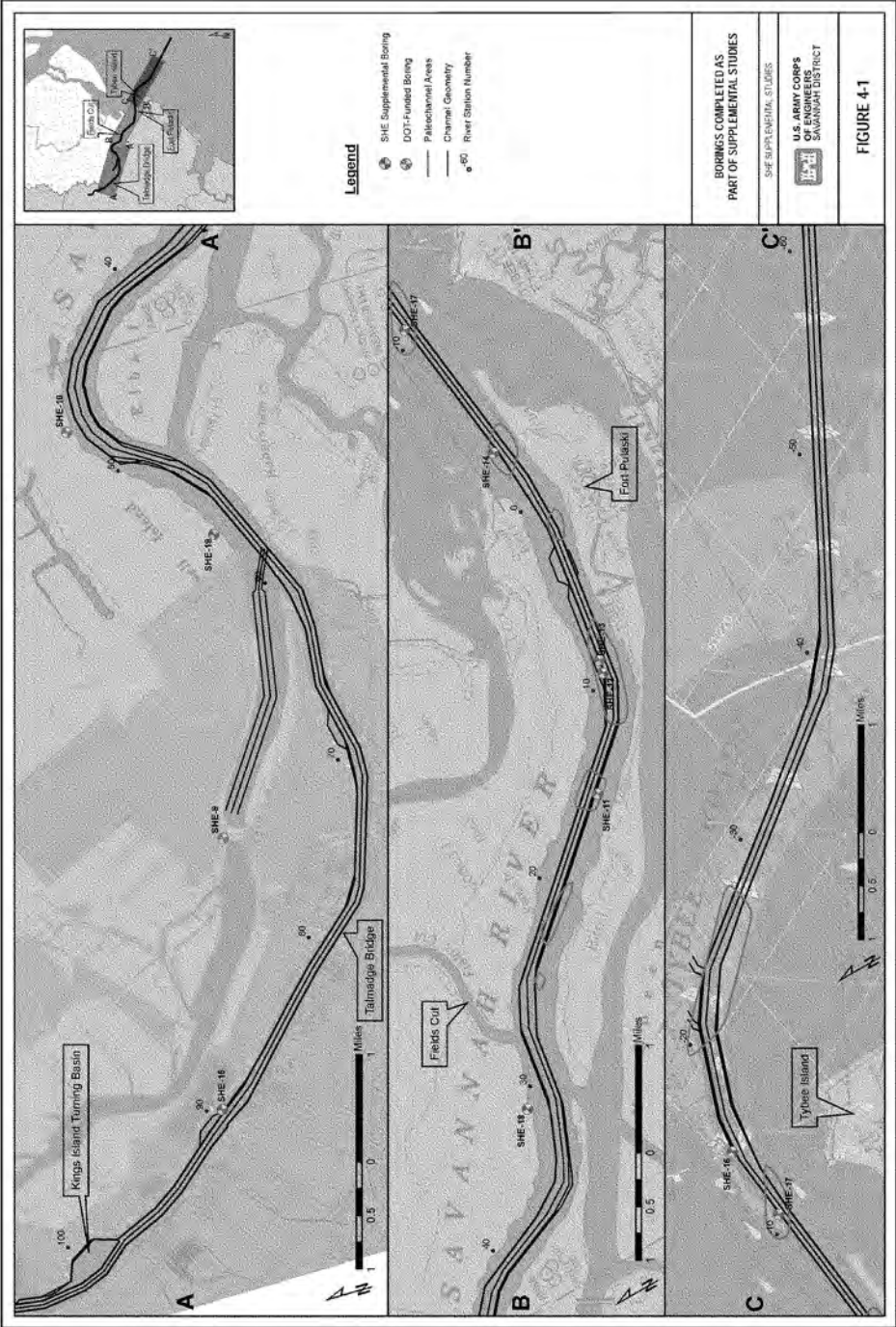
the well data cover the cone of depression around Savannah and coastal Georgia and limited areas of South Carolina and Florida. In order to illustrate a more complete view of the potentiometric heads in the Upper Floridan, SCDHEC data (Ransom and White, 1998) was included in the potentiometric surface calculation as well.

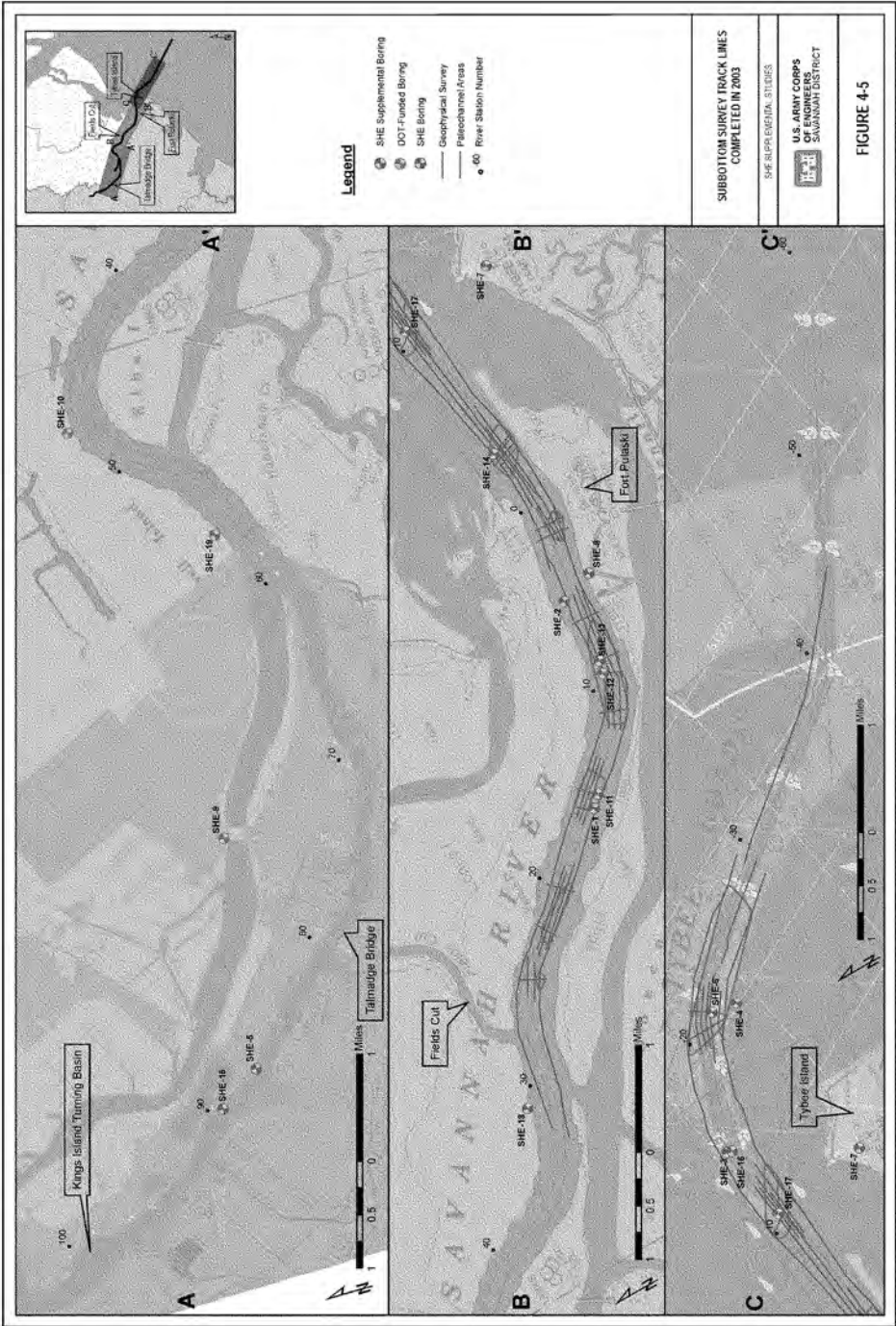
4.7.1.3. Seismic Data

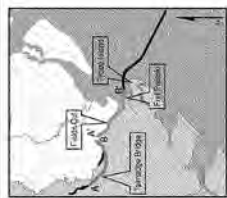
As detailed in Section 4.3, all seismic data collected as part of the supplemental studies was acquired in digital format to facilitate its inclusion in the GIS. OSI also provided all subbottom interpretation data in Microsoft Excel "pick files," X, Y, Z formatted data that included coordinates and elevations of each reflector along each survey trackline. The data was loaded into the geodatabase and used to create detailed surfaces of not only the major lithologic contacts but also of each major paleochannel as it intersected the navigation channel. Additionally, the tracklines were plotted and embedded with hyperlinks to image files of each interpreted cross section that included color-coded interpretations of each reflector.

4.7.1.4. Historical Dredging Records

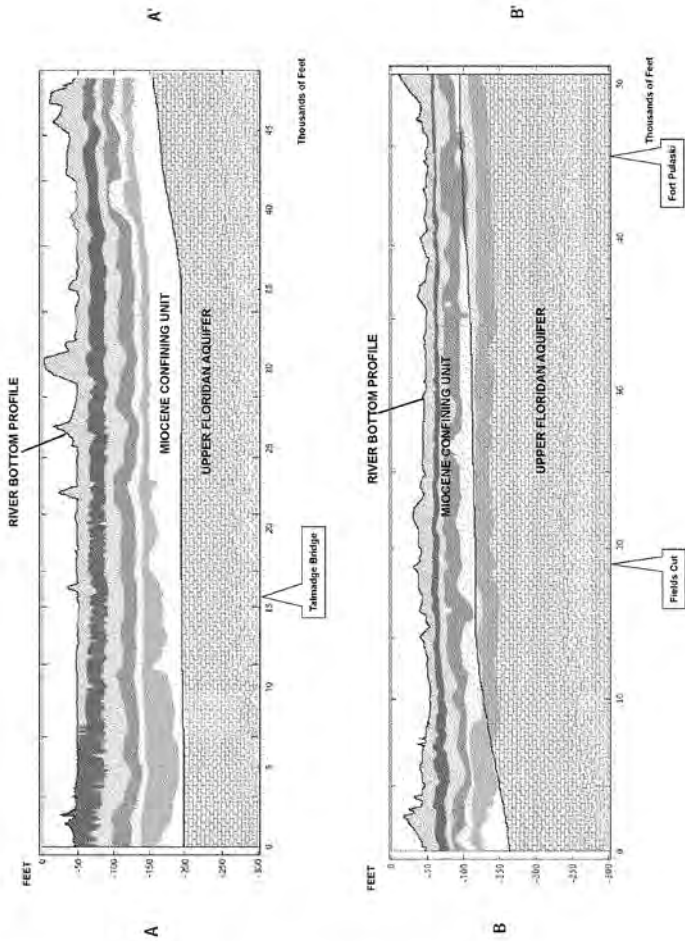
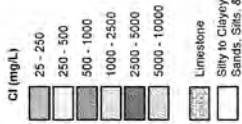
Historical dredging records were incorporated into the GIS to assess the location and amount of confining material removed through time. Internal historical documents including annual surveys, congressional authorizations, status reports, exam studies, and design memoranda were reviewed for information regarding channel depth and geometry. The resulting authorized depths and widths were used to interpolate coordinates and incorporated into the GIS. Whenever available, digitized bottom survey data (1986 and 2003) and geometry design files superseded information gathered from congressional authorizations or other text-based sources.







Legend



CROSS SECTIONS OF SIMULATED
CURRENT CHLORIDE DISTRIBUTIONS
ALONG THE SAVANNAH RIVER

ONE SUPERFICIAL STAGE

U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

CDM

FIGURE 4-11

5. STUDY RESULTS AND DISCUSSION

The study results and discussion presented below encompass data collected not only as part of this supplemental report but also from the initial 1998 *Ground-Water Impacts* study (USACE, 1998). Where appropriate, historical data was used to complement or verify findings associated with new data collected.

5.1. DRILLING

Core borings completed as part of the supplemental studies indicated presence of the lithological sequence typical of that associated with historical data, and contact elevations of geologic units encountered correlated well with those determined from historical borings. In general, the sediments underlying the navigation channel are laterally continuous sequences of heterogeneous Pleistocene to Recent sediments underlain by relatively homogenous Miocene units A and B (Table 3-1). The characteristic green-colored sediments of the Miocene units are underlain by Oligocene-aged porous limestone. Appendix D contains boring logs for borings completed as part of the supplemental studies.

Pleistocene to Recent sediments encountered consisted of poorly graded sands (SP), silty sands (SM), silt (ML), clayey silt (MH), low plasticity clays (CL), and high plasticity clays (CH). These sediments were typically tan to gray with occasional small gravel and organic debris. In some cases, particularly in marine borings located within paleochannels, the Pleistocene to Recent sediments contained green-colored fine-grained sediment, which is most likely Miocene-aged material that has been reworked or transported by historical channels.

The Pleistocene to Recent sediments varied in thickness depending upon whether or not the boring was located within a paleochannel. In borings located outside paleochannels, the lower boundary of the Pleistocene to Recent sediments generally ranged from -40 to -50 MLW (Figure 5-1). In contrast, borings located within the relict channels indicated Pleistocene to Recent sediments were present to lower

elevations where the paleochannel had cut down into the underlying Miocene unit. In these borings, the elevation of the Pleistocene to Recent/Miocene contact varied from -58 (SHE-17) to -71 MLW (SHE-12). Historically, the contact was observed as deep as -73 MLW at boring SH-318 (Figure 5-1).

Miocene sediments typically consisted of dark to light olive green silty sands (SM), clayey sands (SC), silt (ML), clayey silt (MH), and low plasticity clay (CL) and contained characteristic seams of calcareous clays, silts, and sands and limestone. Frequent thin partings of very fine micaceous sand and silt were found in cores throughout the Miocene sediments, as were trace fossils of burrows. No fractures were observed in any of the borings.

Miocene unit A, as described by Clarke et al. (1990), consisted of compacted, sometimes dense, clayey silt or sand, or silty, sandy clay and an abundance of small brown fish scales described by Huddleston (1988). Thicknesses ranged from 20 to 30 feet thick in borings outside paleochannels near the Tybee high (river stations 30+000 to -30+000). Historical borings indicate that the thickness progressively increases upriver, and the maximum thickness observed was 76 feet at SHE-15, upriver of the Talmadge Bridge (Figure 5-1). In all borings, the lowest approximately 10 feet contained a characteristic highly phosphatic zone (Tybee Phosphorite member of the Coosawhatchie Formation). The phosphatic zone was underlain by calcareous clay, sandstone, or dolomitic limestone that ranged in thickness from several tenths of a foot to 2.5 feet thick and was moderately hard to hard. The dark green to black phosphate-rich zone and the cream colored, hard to brittle calcareous clay/limestone seams were distinctly evident in each boring, as was the distinction between the lower carbonate of unit A and the mixed olive green clay, silt and sand material above. However, no distinction was apparent between a "middle clay and upper sand" as described by Clarke and others (1990) in any of the borings.

Miocene unit B typically consisted of 25 to 40 feet of materials similar to the A unit. The highest elevation of the top of unit B in the core borings occurred over the Tybee high at -70 MLW in boring SHE-14, and historical boring SHE-3 showed the contact

at -67 MLW (Figure 5-1). Miocene unit A and unit B soils were found to be very similar, but a few noticeable distinctions were noted. In hand sample, unit B materials appeared to contain a lower percentage of sand and a higher percentage of clay than unit A sediments, and phosphatic sand occurred not only in the bottom few feet of the unit similar to unit A, but also in the top few feet as well (SHE-4, SHE-9). Unit B material tended to become more dense and indurated with depth and often exhibited mottled light green to green bioturbated zones. As in unit A, the "lower carbonate, middle clay and upper sand" sequence was not apparent within unit B.

Bartholomew et al. (2000) observed fractures in Eocene and Pliocene to Holocene (but not specifically Miocene) sediments at outcrops from northwest of Charleston, South Carolina to Sapelo Island, Georgia that were associated with horizontal stresses produced by the Charleston earthquake of 1886. As noted above, no fractures were observed in Miocene-aged material during drilling activities conducted as part of this study or the 1998 report. Although nearly all core borings drilled for this or previous projects in the Savannah Harbor area have been near-vertical borings, no historical boring logs (out of approximately 300) indicated the presence of fractures within the Miocene.

The Oligocene unit, considered in this study to be the first occurrence of continuous limestone below Miocene unit B and the top of the Upper Floridan aquifer, was typically characterized by a light gray to white, highly fossiliferous limestone. The first few feet of the limestone was generally dense, moderately hard to hard, pitted, vuggy, somewhat phosphatic, and in several borings, very sandy. The contact between the limestone and the olive green Miocene unit B material immediately above was very distinct, with the first few tenths of a foot of limestone consisting of a very weathered, hard, gray to black cap. However, occasionally it was characterized by a transitional zone of a mixture of re-worked limestone and Miocene material or with Miocene material filling voids or burrows in the limestone. The highest occurrence of the top of the Oligocene limestone in the core borings was -94 MLW at SHE-14 (Figure 5-1).

5.2. POREWATER PROFILES

Porewater samples were first collected as part of the Savannah Harbor Expansion in 2001-2002 at borings SHE-9 and SHE-10. The resulting profiles of chloride concentration versus elevation are included as part of this report along with results from borings completed in 2003 and 2004 (Figure 5-1). All profiles indicated highest chloride concentrations occur nearer ground surface (or river bottom) and show an overall decrease in concentration with increased depth.

5.2.1. Profiles Outside Known Paleochannels

Porewater profiles constructed outside known paleochannel locations included two marine boring locations (SHE-15 and SHE-16) and all land boring locations (SHE-9, SHE-10, SHE-18, and SHE-19). Figure 5-1 and Table 5-1 show chloride concentration versus elevation. The profiles show highest chloride concentrations occur closest to land surface (or river bottom) and decrease with descending elevation. The highest chloride value occurred at boring SHE-16 (12,381 mg/L) at approximately 5 feet below the bottom of the riverbed (-42.0 ft MLW). The next sample, taken 10 feet below the bottom of the river (-46.8 ft MLW), indicated the concentration decreased more than 50 percent to 5,253 mg/L. The remainder of the porewater profile at SHE-16 showed decreasing chloride concentrations to the top of the Oligocene limestone, with no values above 100 mg/L below the Miocene A/B contact. The concentration of chloride in the Miocene porewater sample nearest the top of the aquifer (-99.8 ft MLW) was 16 mg/L. The high values recorded near the top of the boring were expected, as the boring is located in the Atlantic Ocean where the surface water undergoes decreased freshwater mixing from the Savannah River.

Table 5-1. Porewater Data Collected from 2001 to 2004

Boring	Sample	Geologic Unit	Elevation (MLW)	Chloride (mg/L)	Boring	Sample	Geologic Unit	Elevation (MLW)	Chloride (mg/L)
SHE-9	P-1	P/R	-1.8	4212	SHE-13	P-1	CF	-50.9	17423
SHE-9	P-2	P/R	-5.8	5421	SHE-13	P-2	CF	-52.4	19760
SHE-9	P-3	P/R	-9.8	4201	SHE-13	P-3	CF	-56.4	16516
SHE-9	P-4	P/R	-13.8	4871	SHE-13	P-4	CF	-62.9	9973
SHE-9	P-5	P/R	-20.1	901	SHE-13	P-5	A	-73.1	7676
SHE-9	P-7	P/R	-21.8	1212	SHE-13	P-6	A	-78.7	4485
SHE-9	P-8	P/R	-24.8	1264	SHE-13	P-7	A	-82.9	1760
SHE-9	P-9	P/R	-29.2	2154	SHE-13	P-8	A	-86.9	1062
SHE-9	P-10	A	-29.8	1296	SHE-13	P-9	B	-91.9	493
SHE-9	P-12	A	-44.4	1523	SHE-13	P-10	B	-97.6	281
SHE-9	P-14	A	-52.7	1542	SHE-13	P-11	B	-104.4	153
SHE-9	P-16	A	-71.1	910	SHE-14	P-1	CF	-45.2	14405
SHE-9	P-18	A	-87.7	917	SHE-14	P-2	A	-52.9	5199
SHE-9	P-20	A	-97.8	901	SHE-14	P-3	A	-56.6	6570
SHE-9	P-22	A	-112.7	967	SHE-14	P-4	A	-65.6	14687
SHE-9	P-24	A	-115.9	904	SHE-14	P-4a	A	-65.6	15916
SHE-9	P-25	A	-119.3	2189	SHE-14	P-4c	A	-66.1	13334
SHE-9	P-26	A	-126.2	1847	SHE-14	P-5	B	-71.6	2710
SHE-9	P-27	B	-130.9	910	SHE-14	P-6	B	-76.7	462
SHE-9	P-28	B	-149.2	961	SHE-14	P-7	B	-81.6	186
SHE-9	P-30	B	-164.7	910	SHE-14	P-8	B	-87.1	257
SHE-9	P-32	B	-175.8	480	SHE-14	P-9	B	-92.8	89
SHE-9	P-34	B	-184.6	310	SHE-14	P-10	O	-96.1	151
SHE-10	10SP1	P/R	13.5	5086	SHE-15	P-1	P/R	-41.3	4296
SHE-10	10SP2	P/R	3.5	4374	SHE-15	P-2	P/R	-48.9	3237
SHE-10	10SP3	P/R	-6.5	332	SHE-15	P-3	A	-52.5	7209
SHE-10	P-1	P/R	-10.5	1769	SHE-15	P-4	A	-53.3	3573
SHE-10	P-2	A	-40.5	820	SHE-15	P-5	A	-57.9	1406
SHE-10	P-3	A	-50.5	810	SHE-15	P-6	A	-64.3	280
SHE-10	P-4	A	-55.5	756	SHE-15	P-7	A	-74.9	130
SHE-10	P-6	A	-68.5	762	SHE-15	P-8	A	-89.2	92
SHE-10	P-7	A	-76.5	454	SHE-15	P-9	A	-101.8	45
SHE-10	P-8	A	-83.5	451	SHE-15	P-10	A	-111.7	192
SHE-10	P-9	A	-91.5	220	SHE-15	P-11	A	-114.3	173
SHE-10	P-10	A	-98.5	179	SHE-15	P-12	A	-120.8	51
SHE-10	P-11	A	-104.5	141	SHE-15	P-12a	A	-120.8	51
SHE-10	P-12	A	-112.5	130	SHE-15	P-13	A	-123.6	50
SHE-10	P-14	A	-128.5	76	SHE-15	P-14	B	-135.8	16
SHE-10	10-PW-1	B	-152.5	42	SHE-15	P-15	B	-145.2	12
SHE-10	10-PW-2	B	-161.2	34	SHE-15	P-16	B	-155.0	22
SHE-11	P-1	CF	-49.1	5196	SHE-15	P-17	B	-171.0	11
SHE-11	P-2	CF	-56.1	3573	SHE-15	P-18	B	-180.5	15
SHE-11	P-3	CF	-58.6	5218	SHE-15	P-19	B	-193.6	24
SHE-11	P-4	A	-66.6	7680	(Continued)				
SHE-11	P-5	A	-79.1	1418					
SHE-11	P-6	B	-90.6	971					
SHE-11	P-7	B	-97.3	936					
SHE-11	P-8	B	-100.6	762					
SHE-11	P-9	B	-106.3	501					

Boring	Sample	Geologic Unit	Elevation (MLW)	Chloride (mg/L)	Boring	Sample	Geologic Unit	Elevation (MLW)	Chloride (mg/L)
SHE-16	P-1	A	-41.8	12381	SHE-19	19SP1	P/R	11.0	811
SHE-16	P-2	A	-46.6	5253	SHE-19	19SP2	P/R	1.0	2390
SHE-16	P-3	A	-51.6	2810	SHE-19	19SP3	P/R	-9.0	1995
SHE-16	P-4	A	-56.6	1245	SHE-19	19SP4	P/R	-19.0	6316
SHE-16	P-5	A	-61.6	630	SHE-19	19SP5	P/R	-29.0	1145
SHE-16	P-6	A	-69.6	176	SHE-19	19SP6	P/R	-39.0	1171
SHE-16	P-7	B	-79.6	67	SHE-19	P-1	A	-62.3	554
SHE-16	P-8	B	-89.6	24	SHE-19	P-2	A	-68.8	338
SHE-16	P-9	B	-97.6	16	SHE-19	P-3	A	-77.5	292
SHE-16	P-10	O	-99.6	24	SHE-19	P-4	A	-81.8	209
SHE-18	18SP1	P/R	7.0	847	SHE-19	P-5	A	-91.9	143
SHE-18	18SP2	P/R	-3.0	3642	SHE-19	P-6	A	-102.0	82
SHE-18	18SP3	P/R	-13.0	9065	SHE-19	P-7	A	-112.0	58
SHE-18	18SP4	P/R	-23.0	4133	SHE-19	P-8	A	-121.6	57
SHE-18	18SP5	P/R	-33.0	5678	SHE-19	P-9	A	-132.1	47
SHE-18	18SP6	P/R	-43.0	4297	SHE-19	P-10	A	-146.6	26
SHE-18	P-1	A	-49.5	6185	SHE-19	P-11	B	-163.0	35
SHE-18	P-2	A	-56.5	3860	SHE-19	P-12	B	-167.5	31
SHE-18	P-3	A	-67.5	1601	SHE-19	P-13	B	-181.6	19
SHE-18	P-4	A	-72.5	945	SHE-19	P-14	B	-193.2	30
SHE-18	P-5	B	-90.7	110					
SHE-18	P-6	B	-91.8	42					
SHE-18	P-7	B	-96.6	23					
SHE-18	P-8	B	-107.0	15					

P/R = Pleistocene/Recent Unit

CF = Channel Fill

A = Miocene Unit A

B = Miocene Unit B

O = Oligocene

Boring SHE-15, in contrast to SHE-16, was located well upstream near the center of the cone of depression in downtown Savannah (Figure 5-1). The maximum chloride concentration (7,209 mg/L at -52.5 ft MLW) was observed approximately 18 feet below the bottom of the riverbed (-41.3 ft MLW), noting that the top 15 feet of the boring log indicated presence of soft, wet, fat silt, also called "fluff". Consolidated material, poorly graded sand in this case, was first encountered at -49.3 ft MLW. The remainder of the porewater data from SHE-15 showed a general decrease in chloride concentration with increasing depth, with 24 mg/L recorded closest to the top of the Oligocene unit at -193.6 ft MLW. No values above 50 mg/L were observed below the Miocene A/B contact.

All supplemental land borings were drilled in close proximity to the dredging disposal areas in Jasper County, South Carolina. Borings SHE-9 and SHE-10 were drilled in 2001 and 2002, respectively; whereas, the remainder of all borings were drilled sequentially throughout late 2003 and 2004. SHE-9, located near the tide gate structure, showed the same trend seen in the marine boring profiles outside paleochannels: decreasing chloride concentration with depth. The chloride concentrations fluctuated from 901 to 5,421 mg/L throughout the surficial material and from 310 to 2,189 mg/L in the Miocene confining layer. The profile within the Miocene material generally decreased with depth, with the exception of values from –119 and –128 ft MLW. The punctuated increase in chloride concentration at depth coincides with the Miocene A/B contact and a spike in the resistivity log and the gamma log.

Located across the Savannah River from Elba Island, SHE-10, similar to SHE-9, was drilled earlier than the majority of the borings in 2002. All porewater samples within the Miocene confining unit were taken at the time of drilling with the exception of 10-PW-1 and 10-PW-2 (Table 5-1). These samples were taken in 2005 in an effort to fill in data gaps and complete the profile to the top of the limestone as shown in Figure 5-1. The results show fluctuating chloride values throughout the surficial material, which is most likely related to the elevated chloride content contained in dredge spoils that are piped into the nearby disposal areas over long periods of time. In the Miocene confining layer, the chloride porewater profile showed a steady decrease in concentration from the top to the bottom elevation. Values ranged from 820 mg/L at –40.5 ft MLW to 76 mg/L at –128.5 ft MLW.

It is important to note the chloride concentrations within the Miocene in SHE-9 and to a lesser degree in SHE-10 are significantly higher than samples taken at similar elevations in other boreholes. For example, the SHE-9 sample taken closest to the Miocene/Oligocene contact has a concentration of 310 mg/L, an order of magnitude greater than similar samples in all other borings located outside known paleochannels. Similarly, the results from boring SHE-10 were inflated by approximately one-half an order of magnitude. Figure 5-2 shows a scatter plot of all

the porewater data collected as part of the supplemental studies. As depth increases, the majority of the samples are clustered tightly near the low end of the chloride concentration axis. The samples from SHE-9, however, show inflated values throughout the Miocene confining unit and do not fit the trend seen in the remainder of the samples.

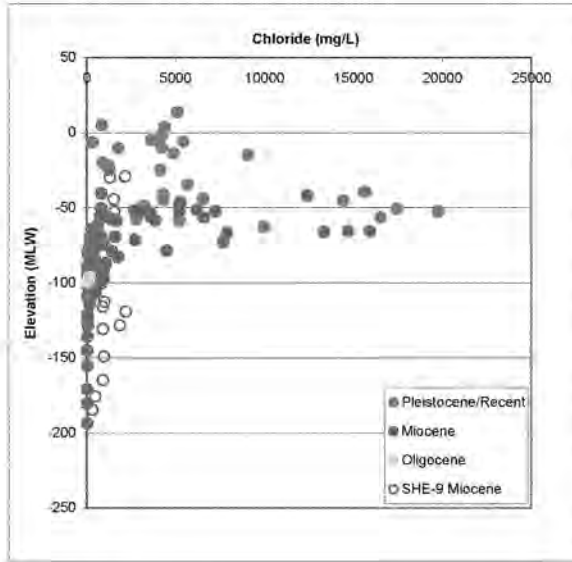


Figure 5-2. Scatter plot of porewater data collected from 2001 to 2004.

This difference is likely attributed to the sample collection technique. Borings SHE-9 and SHE-10 were drilled in 2001 and 2002, and the porewater core samples were not squeezed on site (with the exception of the two deepest samples at SHE-10, as described above). Instead, the core samples were logged, wrapped, sealed, and shipped to the USGS laboratory in Columbia, South Carolina. The cores were refrigerated for an extended period (over 30 days and 5 days, respectively) before being cut and squeezed for porewater. It is likely that evaporation of the porewater

falsely inflated the chloride concentrations. Furthermore, it was noted that several samples were not analyzed because "not enough water" could be squeezed from them; whereas, when the cores from borings SHE-11 through SHE-19 were squeezed on site at the time of drilling, every sample yielded at least 2mLs of water.

Land borings SHE-18 and SHE-19 were drilled in 2004, and core porewater samples were collected, logged, and squeezed on site according to the method described in Section 4.2 of this report. The resulting aqueous samples were then stored in airtight scintillation vials and transported to the USGS lab in Columbia, South Carolina for analysis. The chloride profiles indicated the same trends seen throughout other land and marine borings located outside known paleochannels: fluctuation of chloride concentration in surficial sediments underlain by a steady decrease in chloride concentration throughout samples taken from Miocene material. Values ranged from 811 to 9,065 mg/L in the surficial sediments and from 15 to 6,185 mg/L in the Miocene confining layer. No increases in chloride concentration were observed within the Miocene confining layer in either boring SHE-18 or SHE-19.

Porewater chloride profiles constructed from borings outside known paleochannels exhibited similar trends. Data from land borings indicated that chloride values fluctuate throughout the surficial sediments, which is most likely a result of the origin of the materials (dredge spoils). All borings showed a steady decrease in chloride concentration from the top of the Miocene sediments to the bottom with the exception of SHE-9, which showed increased chloride concentration from -119 to -128 ft MLW. SHE-16, a marine boring directly overlain by seawater, showed the maximum chloride concentration seen within the Miocene confining layer (12,381 mg/L), which was observed five feet below the bottom of the navigation channel. The average chloride concentration found within 10 feet of the top of the limestone aquifer was 24 mg/L, excluding SHE-9 (anomalous).

5.2.2. Profiles Within Paleochannels

Four marine borings were drilled (SHE-11, SHE-13, SHE-14, SHE-17) within known paleochannels adjacent to the present day navigation channel (Figure 4-1). All of the

borings were overlain by seawater and located within the area of concern, where the confining layer naturally thins and paleochannels have further downcut into the confining material.

Chloride profiles constructed from borings SHE-13 and SHE-17 showed a trend similar to that seen in borings outside paleochannels: a steady decrease in chloride concentration in the confining layer as elevation decreases (Figure 5-1). The maximum value observed at SHE-13 was 19,760 mg/L, which occurred eight feet below the bottom of the river channel in the paleochannel fill material, primarily composed of gray to green fine clayey sand. The paleochannel cut down to -67.1 ft MLW, marking the top of the Miocene confining layer. The first sample taken in the confining material contained a chloride concentration of 7,678 mg/L. The chloride concentrations decreased with elevation to the deepest sample, which was taken two feet above the top of the limestone and measured 153 mg/L chloride concentration.

The paleochannel material at boring SHE-17, located off the north end of Tybee Island, consisted primarily of gray fat silt and was present to a depth of -58.4 ft MLW. Four chloride samples were extracted from paleochannel material, and the maximum concentration was observed one foot below the bottom of the river channel (15,601 mg/L). The shallowest sample taken from Miocene material measured 1,663 mg/L (-58.9 ft MLW). The chloride concentration decreased with depth, and no values above 100 mg/L were observed below the Miocene A/B contact. The deepest sample was extracted less than one foot above the top of the aquifer, and the chloride concentration was 28 mg/L.

The boring log for SHE-11 showed the paleochannel/Miocene contact at a depth of -65.8 ft MLW, and three porewater samples were extracted from the paleochannel material overlying the confining layer. The porewater profile showed an overall decrease in chloride concentration with increasing depth, but the values did not sequentially decrease with depth as seen in other boreholes. Instead, two samples indicated higher chloride concentrations than the preceding samples taken at shallower depths. The chloride concentration found closest to the river bottom was

5,195 mg/L at -48.3 ft MLW. The profile then showed a decrease to 3,573 mg/L (-56.3 ft MLW); however, the next two samples, one of which was extracted from paleochannel material and one of which was extracted from Miocene material, both showed an increase in chloride concentration to 5,128 mg/L (-58.8 ft MLW) and 7,880 mg/L (-66.8 ft MLW), respectively. The sample containing 7,880 mg/L was taken one foot below the paleochannel/confining layer contact. The chloride concentration decreased throughout the remainder of the profile to 501 mg/L at -106.5 ft MLW, five feet above the top of the limestone.

The chloride profile from boring SHE-14 did not follow the trend of decreasing chloride with decreasing elevation. Similar to the profile from SHE-11, the overall concentration from the top to the bottom of the profile decreased; however, the profile showed a spike in concentration near the paleochannel/confining layer contact. A concentration of 14,405 mg/L was measured three feet below the river bottom. The chloride concentration then decreased to 5,199 mg/L (-53.1 ft MLW) before increasing again to a maximum value of 15,916 mg/L at -65.8 ft MLW. The concentration decreased throughout the remainder of the Miocene material to 69 mg/L, one foot above the top of the limestone.

5.2.3. Porewater Profile Summary

The porewater data derived from work completed as part of the supplemental studies indicate that, as expected, seawater is moving downward through the Miocene confining layer toward the Oligocene limestone, and, in some locations, low concentrations of chlorides appear to have migrated entirely through the confining layer and into the limestone. In addition, profiles constructed within known paleochannels differed significantly from those constructed outside paleochannels. In borings drilled outside paleochannels, the corresponding porewater profiles showed decreasing chloride concentration with decreasing elevation in samples throughout confining layer, and concentrations varied depending on the composition of overlying sediments and/or water. Profiles constructed within paleochannels showed punctuated increases in vertical migration of chloride through the paleochannel material, and the spikes in chloride concentration typically occurred at

the paleochannel/confining layer contact. Otherwise, the profiles illustrated the same trend seen outside paleochannels: in the confining layer, chloride concentration decreased with decreasing elevation. The punctuated increase of concentration at the base of the paleochannel material and the decreased thickness of the underlying confining layer resulted in higher chloride concentrations near the top of the limestone, with the exception of boring SHE-17.

5.3. GEOPHYSICAL SURVEY

Subbottom profiling records revealed evidence of numerous continuous and semi-continuous subsurface acoustic reflectors that could be confidently mapped, but only those reflectors correlative with the base of identified paleochannel (*RCCF*) features and the underlying sediments were mapped. In almost all cases, recent sediment deposits in the navigation channel were minimal or absent and therefore not mapped. It is believed that natural erosional processes in the river and/or dredging of the current navigation channel have removed the recent deposits.

Several survey tracklines were run directly over boring locations in an effort to "ground truth" the subbottom data set and accurately tie relevant reflectors to specific horizons/stratigraphic units. Subbottom data were reviewed and compared closely with USACE boring logs. Under ideal conditions, the expected resolution of the subbottom profiling system utilized during this investigation is approximately three feet; this margin of error was taken into account when comparing core data with subbottom records. Table 5-2 presents comparisons between contacts documented in the boring logs and acoustic reflectors observed on the subbottom records. Based on these comparisons, an average acoustical velocity of 5,300 feet per second best represented the sediments in the river overlying the Upper Floridan aquifer.

5.3.1. Subbottom Reflectors

Subbottom reflectors could be traced for appreciable distances along survey lines throughout the majority of the area investigated, and subbottom reflectors were correlated with specific horizons/stratigraphic units identified in USACE borings.

Figure 5-3 provides a section of a subbottom “boomer” profile record that exemplifies some of the more prominent reflectors and illustrates an area where a paleochannel incised the Miocene unit and was later filled in with younger sediments.

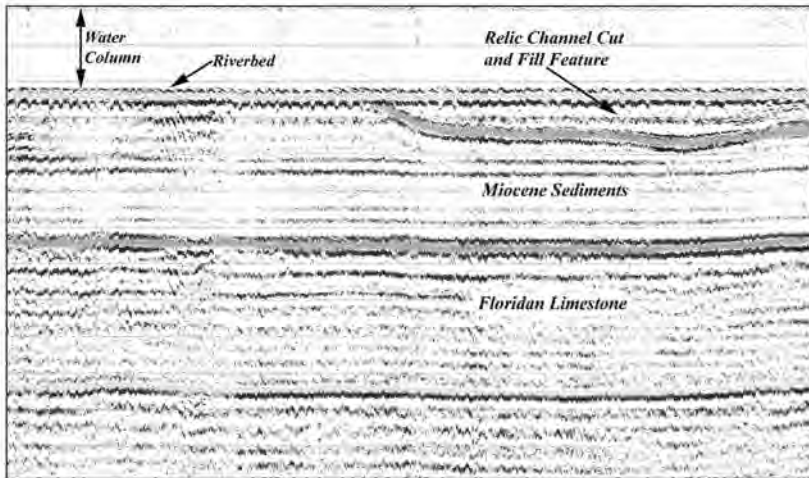


Figure 5-3. Typical subbottom profile with prominent reflectors.

Four prominent subbottom reflectors were identified and color-coded in Figure 5-3. The red and blue reflectors represented the base of the *RCCF* feature and the upper surface of the Upper Floridan aquifer (limestone), respectively. The yellow reflector was representative of the Miocene A/B contact, and the green reflector was believed to correlate with a deep (Eocene) contact within the Upper Floridan aquifer. In several sections of subbottom data, orange was used to differentiate reflectors correlative with the base of a younger *RCCF* feature identified adjacent to or traversing the primary or a red-coded *RCCF* feature (not illustrated in Figure 5-3).

Subbottom penetration was restricted or partially restricted along several segments of the tracklines investigated. In general, this restriction was intermittent and attributed to the presence of trapped gas bubbles within the near-surface sediments.

The gaseous manifestations, interpreted to be a by-product of the breakdown of organics originating in the sediments of paleo-estuarine environments, significantly reduced the level of acoustic signal propagation through the sediment. This reduction in signal propagation adversely affected the ability of the subbottom profiler to identify underlying subsurface acoustic reflectors. Other phenomena that might have been responsible for inhibiting the subbottom profiler from resolving reflectors at depth are changes in sediment type, compaction, lithification, and/or recent dredging/disturbance of the surficial sediments.

5.3.2. Paleochannels

Subbottom profiling data acquired during the current survey confirmed the existence of several *RCCF* features within the Savannah River entrance channel and revealed the presence of several additional *RCCF* features that had not yet been identified during previous investigations of the river. Eight of these features appear to be significant in size and underlie the navigation channel. The remaining *RCCF* features identified between river stations 30+000 and -30+000 were detected along only a single survey line and/or along survey lines located outside the navigation channel. The significant paleochannel features detected during the current investigation are referred to as *RCCF 1-8* and are centered on the following Savannah River stations as shown below in Table 5-2. Depths presented in the following table were based on the interpretation of subbottom profiling records. Considering the resolution of the boomer subbottom profiler and the assumptions made to convert raw subbottom data to depths referenced to the project vertical datum, the accuracy of the interpretation is approximately +/- 10% of the mapped depth of the correlative reflectors. Appendix A contains specific information regarding individual paleochannel features.

As summarized in Table 5-2, the *RCCF 4* feature appears to have incised more deeply into the Miocene confining layer than any of the other features detected in the entrance channel. This feature, detected between Savannah River stations 7+000 and 12+000, also takes up the largest spatial area.

Table 5-2. Paleochannel Locations and Formation Elevations

Feature Designation	Location (River Station)	Elevation of Paleochannel/Miocene Contact at Maximum Incision Depth (ft MLW)	Average Elevation of Miocene/Oligocene Contact (ft MLW)	Minimum Thickness of Miocene Confining Layer (ft)
RCCF 1	22+000	-80	-116	36
RCCF 2	20+000	-64	-116	55
RCCF 3	15+000	-74	-112	42
RCCF 4	9+000	-83	-108	26
RCCF 5	1+500	-70	-107	38
RCCF 6	-3+000	-70	-98	28
RCCF 7	-11+000	-67	-99	34
RCCF 8	-21+000	-73	-110	36

In general, subbottom data suggested that the *RCCF* features identified in the entrance channel are oblique to the present-day course of the river. These findings suggested that historic drainage patterns in the area differed significantly from present-day patterns and/or that survey trackline orientation may have played a role in the ability to detect the *RCCF* features. A large percent of survey tracklines (during the recent and past survey investigations of the river) were oriented parallel to the river's course. Survey tracklines oriented parallel to the river's course are more conducive to detecting features oriented perpendicular or oblique to the river's course. It is possible that *RCCF* features oriented parallel to the river's course and not within the boundaries of the limited cross-river survey tracklines investigated may not have been recognized or their presence may have been masked among other subsurface reflectors identified in the area. However, based on the combined trackline density of all historical surveys, the size and impact of any such feature would be minimal.

5.3.2.1. Correlation with Core Borings

Nine borings were used to verify the elevations of the subbottom reflectors. Of the nine borings, five coincided with survey tracklines, and the remaining four borings were located in the immediate vicinity of a survey trackline. Table 5-3 shows the elevations of contacts according to both the seismic data and USACE boring logs.

The elevations of contacts for both the top of the Miocene and the top of the Oligocene units reported by OSI correlated very well with USACE borings located either directly on a survey trackline or in the immediate vicinity of a trackline as illustrated in Figure 5-4. The elevation differences between the seismic picks and USACE boring logs for the top of the limestone varied from less than one foot at SHE-11 to 3.9 feet at SHE-17. In all cases, the two interpretations differed by less than 10 percent.

Table 5-3. Correlation of OSI Seismic Records with USACE Boring Logs

Location (River Station)	Boring	Seismic Feature	Contact	Seismic Reflector	USACE Boring Log Elevation (ft MLW)	Seismic Record Elevation (ft MLW)	Delta (ft)	Percent Difference
15+896	SHE-1	RCCF 3	Miocene Unit A	Red	-52.7	-51	1.7	3.3
15+896	SHE-1	RCCF 3	Oligocene	Blue	-116.0	-112	4.0	3.5
15+180	SHE-11	RCCF 3	Miocene Unit A	Red	-65.8	-64	1.8	2.8
15+180	SHE-11	RCCF 3	Oligocene	Blue	-111.8	-112	0.2	0.2
9+005	SHE-12	RCCF 4	Miocene Unit A	Red	-71.0	-73	2.0	2.8
8+626	SHE-13	RCCF 4	Miocene Unit A	Red	-67.1	-79	11.9	16.3
8+626	SHE-13	RCCF 4	Oligocene	Blue	-106.6	-109	2.4	2.2
-3+062	SH-327	RCCF 6	Miocene Unit A	Red	-69.2	-69	0.2	0.3
-3+324	SHE-14	RCCF 6	Miocene Unit B	Yellow	-67.9	-62	5.9	9.1
-3+324	SHE-14	RCCF 6	Oligocene	Blue	-94.2	-93	1.2	1.3
-10+675	SHE-17	RCCF 7	Miocene Unit A	Red	-58.4	-62	3.6	6.0
-10+675	SHE-17	RCCF 7	Oligocene	Blue	-98.1	-102	3.9	3.9
-21+922	SHE-4	RCCF 8	Oligocene	Blue	-112.5	-112	0.4	0.4
-21+383	SHE-6	RCCF 8	Miocene Unit A	Red	-70.1	-71	0.9	1.3

The seismic interpretation of the elevation of the top of the Miocene unit correlated well with existing boring log data. The elevations from the two data sets varied from 0.2 feet at SH-327 to 12 feet at boring SHE-13, and all interpretations, with the exception of SHE-13, differed by less than 10 percent. The elevation of the top of the Miocene unit is typically very distinct in both hand sample (boring log) and seismic reflection data. However, where the Miocene unit is overlain by paleochannel material, the distinction is typically less obvious. The paleochannel fill material consists mainly of fine-grained sands and silty sands that often contain reworked Miocene sediments. As a result, the paleochannel material is usually gray to grayish

green in color and closely resembles Miocene material. In borings located within paleochannels, the contact was sometimes marked by a thin bed of well-graded sand, but otherwise was indistinguishable. In these cases, the seismic subbottom data proved invaluable to determining the elevation of the Paleochannel/Miocene contact.

5.4. THREE DIMENSIONAL GROUND-WATER MODEL

Ground-water model simulations were evaluated using several sets of results as described below. For each set of results, two different values of vertical hydraulic conductivity for the Miocene (low and mid-range values) were used to bracket the range of potential impacts. "Breakthrough" is said to occur when the simulated chloride concentrations in the top 50 to 60 feet of the Upper Floridan aquifer initially exceeds 250 mg/L. Appendix B contains the complete report and figures furnished by CDM.

It is important to note that all chloride concentrations reported below are based on salt water input exclusively from the river and navigation channel. The concentrations both directly beneath the river and at production wells represent chloride contributions only from within the river and navigation channel and *do not represent total concentrations*. The model did not simulate chloride sources from nearby salt marshes or the Atlantic Ocean so that results would clearly document the effects of dredging and not the overall influence of pumping in the Savannah area. Consequently, simulation results represent the chloride contribution explicitly due to dredging.

5.4.1. Vertical Profiles of Simulated Chloride Concentrations after 200 Years

Figure 5-5 illustrates an example of the simulated chloride concentration as a function of depth in the Miocene confining unit for both no dredging and dredging scenarios in the year 2200. Note that all borehole locations showed a higher chloride concentration at the top of the Miocene for the dredging scenario, which was based on the simulation results from the Tetra Tech surface water model. The increased

chloride concentrations at the top of the Miocene generally resulted in higher concentrations at the bottom of the Miocene, and the expected impacts were most sensitive to the pumping gradient and vertical hydraulic conductivity of the Miocene confining unit. The charts labeled "A" show the results based on the calibrated (mid-range) hydraulic conductivity value for the Miocene unit, and charts labeled "B" illustrate the results with the lower hydraulic conductivity value.

The results also indicated that chloride concentrations decreased significantly from the bottom of the Miocene to the top of the Upper Floridan aquifer. This sharp decrease was attributed to the considerable horizontal flow of fresh water within the aquifer mixing with and diluting the relative very low volume of saltwater migrating downward through the confining unit. Overall, the difference in chloride concentration in the Upper Floridan aquifer between the results of the dredging scenario and no dredging scenario were small. Applying the lower hydraulic conductivity value further diminished the difference between the dredging and no dredging scenarios, and at upstream borehole locations where the Miocene confining unit is thicker, little or no breakthrough was observed (year 2200). The simulation results also indicated that total breakthrough did not occur throughout most of the study area, and the system would still be in transition after 200 years.

5.4.2. Time-History of Simulated Chloride Concentrations

5.4.2.1. Underlying Navigation Channel

Figure 5-6 illustrates an example of the simulated chloride concentrations beneath the dredged channel adjacent to each of the SHE borehole locations as a function of time. Both the no dredging and dredging scenarios are presented, and the concentrations shown are computed for the top 50 to 60 feet of the Upper Floridan aquifer. Similar to the previous figures, charts labeled "A" illustrate the results based on the mid-range hydraulic conductivity value for the Miocene unit and charts labeled "B" illustrate the results with the lower hydraulic conductivity value. The actual behavior of the system is expected to fall between the two sets of results.

All the figures represent maximum expected concentrations directly beneath or adjacent to the Savannah River. The concentrations shown are those only resulting from salt water moving through the Miocene confining unit directly below the river and navigation channel, and concentration impacts from all other areas overlain by other salt water sources (i.e. salt marshes, dredge spoils, etc.) are not simulated. Therefore, the predicted concentrations represent only the portion contributed from the navigation channel; they do not represent total expected concentrations.

In the upstream locations where the Miocene confining unit thickens (river stations 89+000 to 47+000), either chloride breakthrough into the Upper Floridan did not occur ("B" charts) or concentrations remained low, typically not exceeding 100 to 200 mg/L ("A" charts). Under all conditions in these locations, the dredging scenario showed no chloride concentration contributions in the Upper Floridan exceeding the EPA drinking water standard (250 mg/L).

In contrast, at locations further downstream (river stations 31+000 to -14+000), the mid-range hydraulic conductivity simulations ("A" charts) showed significantly higher chloride concentrations at the top of Upper Floridan aquifer directly below the river. After 200 years, chloride concentrations ranged from several hundred to greater than 1000 mg/L. For the low hydraulic conductivity simulation ("B" charts), concentrations were either significantly lower (SHE-18 and SHE-11), or simulated initial breakthrough in the Upper Floridan occurred much later than the year 2200.

In general, applying the dredging scenario did not appear to significantly change the timing of chloride breakthrough into the Upper Floridan aquifer. Figure 5-6 and CDM Figures 3-17 to 3-28 in Appendix B show very little separation between the dredging versus no dredging scenarios, which indicates the proposed dredging would not significantly increase the rate of vertical salt-water intrusion into the Upper Floridan aquifer. The maximum amount of time dredging decreased the initial breakthrough was 10 to 15 years at the location in the navigation channel adjacent to SHE-18. The remainder of the locations showed negligible time differences of initial breakthrough between the dredging and no dredging scenarios. The results indicate that,

regardless of dredging, as the system approached steady state (total breakthrough), the increased chloride concentration in the downward flux from Savannah River eventually resulted in slightly increased concentrations in the Upper Floridan aquifer.

5.4.2.2. Nearby Production Wells

Simulated chloride concentration time-histories were also generated for nearby Upper Floridan production wells located along or near the river from downtown Savannah to Tybee Island (Figure 5-7). An example of the simulated chloride concentrations is shown in Figure 5-8 for both the no dredging and the dredging scenarios utilizing the mid-range and low hydraulic conductivity values. The mid-range hydraulic conductivity simulations indicated that downward migration of chloride from the river would contribute 10 to 50 mg/L to total chloride concentrations in Savannah area production wells by the year 2200, and the difference between the dredging and no dredging scenarios ranged from negligible to less than 10 mg/L for each well location. These concentrations represent only the contribution from the river and navigation channel and do not represent total concentration in the wells. As such, the added impact from dredging (negligible to less than 10 mg/L) represents a small fraction of the much higher total concentration expected in a given production well. Simulations using the lower value of hydraulic conductivity showed that downward migration of chloride from the river would not contribute to any increase in total chloride concentration at most of the wells by the year 2200.

5.4.3. Simulated Chloride Concentration Distributions in the Upper Floridan Aquifer

Figure 5-9 shows plan view simulated chloride concentrations in the Upper Floridan aquifer for the years 2000, 2050, and 2200 for both dredging and no dredging scenarios. The distributions indicated that chloride plumes tend to move parallel to the river due to the ground-water flow direction induced by heavy pumping near downtown Savannah. Thus, the concentration results discussed above are relevant only for chloride concentrations directly below the river. Simulated impacts north or south of the river dissipated over a relatively short distance.

Simulated chloride concentrations in the Upper Floridan aquifer were significantly higher underlying the downstream reaches of the river; however, simulations using the mid-range value of hydraulic conductivity showed negligible difference between the dredging and no dredging scenarios (Figure 5-9).

5.4.4. Ground-Water Model Analysis and Conclusions

Increased ground-water pumping in Savannah has depressed ground-water heads in the Upper Floridan aquifer and induced downward flow of water from the surficial aquifer and Savannah River through the Miocene confining unit to the Upper Floridan aquifer. The resulting head gradients are the dominant force contributing to downward movement of salt water through the Miocene confining unit.

The expected increase in downward volume of flow of saline water from the area underlying the Savannah River due to dredging is small. The model results indicated that the area affected by dredging accounted for a total downward flow between 50 to 250 gallons per minute depending on the hydraulic conductivity assigned to the Miocene confining unit. Dredging the navigation channel increased the total downward flow between 2 to 7 gallons per minute, or 3 to 4 percent. The contribution is negligible when compared to ground-water production in the Savannah area from the Upper Floridan aquifer, which is on the order of 80 million gallons per day (55,555 gallons per minute).

The 200-year projection simulations were most sensitive to the aquifer thickness and vertical hydraulic conductivity of the Miocene confining unit, and the results showed salt water from the river potentially penetrating the Miocene and reaching the Upper Floridan aquifer. After 200 years, the upstream chloride concentrations in the Upper Floridan aquifer beneath the river were simulated to be approximately 0 mg/L for low-value hydraulic conductivity simulations and up to 100 mg/L for the mid-range hydraulic conductivity simulations. Downstream, where the Miocene is relatively thin, chloride concentrations directly beneath the river approached 500 mg/L after 200 years for the low-value hydraulic conductivity simulations. For the mid-range hydraulic conductivity simulations, total breakthrough occurred after approximately

100 years, and the maximum chloride concentration in the Upper Floridan aquifer occurred in the downstream portion of the project area (1,400 mg/L).

The increased river source concentrations assigned at the bottom of the river, values for which were obtained from the Tetra Tech surface water model, appeared to increase simulated chloride concentrations in the top of the Upper Floridan aquifer. In the upstream reaches of the river, where the surface water model predicted minimum increases in chloride concentrations, the differences in chloride concentrations in the top of the Upper Floridan aquifer between the dredging and no dredging scenarios were minor. Downstream, where higher surface water chloride concentrations were predicted to occur, the corresponding differences in concentrations in the Upper Floridan aquifer directly below the river ranged from 10 to 200 mg/L and were typically observed 50 or more years into the future.

5.5. SIMULATED PUMPING TEST

5.5.1. Effects of Pumping Test on Hydraulic Heads

All simulation results are based on applying the mid-range value of vertical hydraulic conductivity to the Miocene confining layer (1.5×10^{-4} ft/day). At the lowest pumping rate simulated (500 gpm), the simulated drawdown in the surficial aquifer at the pumping well location was less than 0.5 feet after 1 year of pumping. At the observation point located 1,100 feet from the pumping well, the simulated response was less than 0.25 feet in the surficial aquifer and less than 2 feet in the Miocene confining unit. At the observation point located 2,400 feet away negligible response in the surficial aquifer or Miocene confining unit was noted.

At the highest pumping rate simulated (2,000 gpm), the simulated drawdown at the pumping well location was approximately 1 foot in the surficial aquifer and approximately 12 feet in the Miocene confining unit. At the observation point located 1,100 feet from the pumping well, the simulated drawdowns in the surficial aquifer and Miocene confining unit were approximately 0.6 and 6 feet, respectively.

Response curves for the simulated pumping rate of 2,000 gpm at the observation

point located 1,100 feet away from the pumping well are shown in Figure 5-10. Additional response curves for each scenario are included in Appendix B.

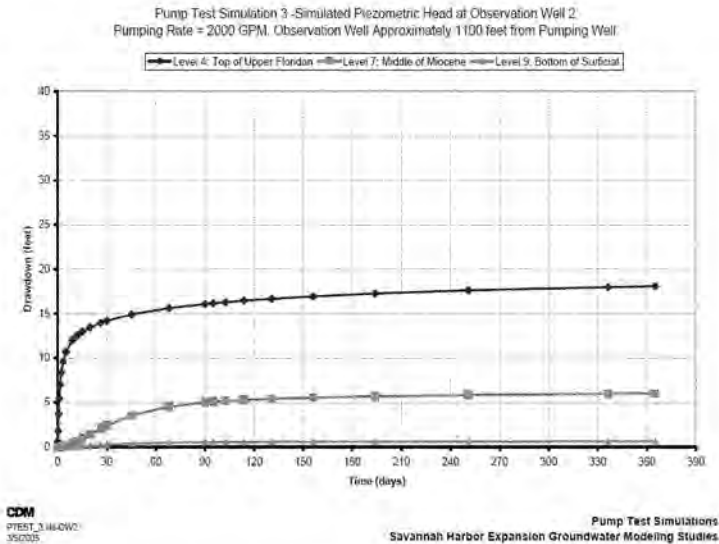


Figure 5-10. Response curves in the Upper Floridan aquifer, Miocene confining unit, and surficial aquifer for a simulated pumping rate of 2000 gallons per minute.

The simulation results are somewhat corroborated by results from a pump test conducted on wells at the Tybee Island Test Well Cluster by Clemson University in 1997. Although a misinterpretation of stratigraphy nullified the intended purpose, the results clearly indicated significant hydraulic separation between the Miocene confining layer and the Upper Floridan aquifer. The pump test was run using a pumping well completed in the uppermost 18 feet of the aquifer and an observation well 20 feet away that was completed in the Miocene confining layer 25 feet above the top of the aquifer. The pumping well was pumped for 72 hours at an average

pumping rate of approximately 100 gpm, and the observation well showed no response to pumping from the aquifer.

5.5.2. Implications

Results from the simulated pump tests indicate that response times in the surficial aquifer and Miocene confining unit would be relatively slow with heads gradually decreasing over a period of 30 to 60 days. The slow response times and expected drawdowns of only a few inches would make it difficult to perform a meaningful pump test. The test would have to be at least two months in duration and pump at least 1,000 gpm to develop sufficient data with which to assess the vertical hydraulic conductivity of the Miocene confining unit. In addition, numerous sources of interference including tidal variations, other local pumping wells, and regional pumping would mask the observation data, and further complicate interpreting any results. The small drawdowns at high pumping rates as seen in the simulation results, combined with the amount of background interference in the area of concern, indicated that this task was not practical.

5.6. MISCELLANEOUS

5.6.1. Gamma Logs

The gamma logs obtained from core borings as part of the supplemental studies were almost without exception uniquely characteristic of their associated strata (Figure 5-11). Specifically, the shapes of the gamma signatures for the two marker beds, Miocene A and B, differ significantly. The upper marker associated with the bottom of unit A (i.e. contact between unit A and unit B) was typically represented by a thick, multi-lobed, somewhat blunt peak. The lower marker associated with the bottom of unit B (i.e. contact between unit B and Oligocene unit) was characteristically a single, thin, very sharp peak. Typically, the peaks were located slightly above their corresponding contacts (SHE-19); however, in some borings, one or both gamma peaks bracketed the contact (SHE-18). The gamma log from boring SHE-13 represented the only exception. No upper marker was observed, which may indicate that the contact has been eroded by the overlying paleochannel. In addition,

the peak representing the lower marker was significantly smaller in magnitude than peaks observed in adjacent boreholes. With the exception of SHE-13, the gamma markers were particularly useful in determining the elevation of the contact between unit A and B when the associated phosphatic carbonate zone was not readily recognizable or missing in core samples.

5.6.2. Electrical Conductivity Logs

Soil conductivity varied according to soil type and salinity of the porewater fluid. Conductivity logs recorded at borings SHE-9, SHE-10, SHE-18, and SHE-19 showed higher conductivities in finer grained soils and lower conductivities in sandier soils. The resulting conductivity logs were used to verify depths of soils recorded on boring logs. The conductivity logs showed large scale curve shifts in addition to the peaks and valleys associated with soil type. These shifts indicate an overall increase or decrease in the salinity of the porewater fluid and correlated very well with chloride values derived from porewater sampling (Figure 5-12).

5.6.3. Ground-Water Gradient Data

Water levels recorded in well clusters on the north end of Tybee Island and at Fort Pulaski indicated that pumping the Upper Floridan aquifer has not only reduced heads in the aquifer, but also that the head differences have propagated through the overlying confining layer.

Data collected from additional wells along the Savannah Harbor navigation channel give a more complete picture of the vertical hydraulic gradient changes that occur from the surficial aquifer to the Upper Floridan aquifer over the distance from Tybee Island to downtown Savannah. Table 5-4 shows the hydraulic heads measured in wells set at various depths in the surficial aquifer, Miocene confining layer, and Upper Floridan aquifer. At several locations, the results indicated that the vertical hydraulic gradient across the entire confining layer is less than that of some intervals within the confining layer. These intervals within the confining layer, some of which exhibit gradients 2 to 3 times the average gradient of the entire confining layer, suggest that somewhat lower permeability zones exist within the confining layer.

Table 5-4. Measured Hydraulic Heads in Savannah Area Wells

Well	Date	Harbor Area	Approx River Station	Hydro-geologic Unit	Measuring Point Elevation	Head Elevation	Hydraulic Gradient	
							Interval	Overall
SHE-MW-1 (39Q029)	3/5/2005	Tybee	-10+000	S	2.0	2.32	-0.04	-0.22
Tybee-3 (39Q026)	3/5/2005		-10+000	M	-81.0	0.11	-0.47	
Tybee-2 (39Q025)	3/5/2005		-10+000	F	-108.0	-21.24		
SHE-MW-3 (38Q208)	3/5/2005	Ft. Pulaski	4+000	S	-9.0	-0.01	-0.03	-0.25
SHE-MW-4 (38Q209)	3/5/2005		4+000	M	-85.0	-2.07	-0.75	
USNPS (38Q002)	3/5/2005		4+000	F	-103.0	-23.13		
SHE-10A	4/30/2005	Elba Island	48+000	S	-24.0	4.10	-0.04	-0.26
SHE-10B	4/30/2005		48+000	U	-56.5	2.80	-0.22	
SHE-10C	4/30/2005		48+000	M	-86.5	-6.10	-0.24	
SHE-10D	4/30/2005		48+000	L	-151.5	-19.50	-0.14	
SHE-10	4/30/2005		48+000	F	-185.8	-33.10		
SHE-9A	4/30/2005	Tide Gate	75+000	S	2.7	2.70	-0.09	-0.33
SHE-9B	4/30/2005		75+000	U	-87.7	-5.60	-0.36	
SHE-9C	4/30/2005		75+000	L	-152.4	-28.80	-0.30	
SHE-9D	4/30/2005		75+000	F	-191.8	-60.90		
GG5-A (37Q185)	1/5/2005	Hutchinson	90+000	S	-0.65	-0.65		-0.40
GG5 (37Q185)	1/5/2005		90+000	F	-200.0	-80.55		

S = Surficial Aquifer
U = Upper Confining
M = Middle Confining
L = Lower Confining
F = Upper Floridan Aquifer
* Head derived from elevation of river according to tide table

Note: Confining layer head elevations at SHE-9 and SHE-10 derived from vibrating wire pressure transducers.

5.6.4. Soils Laboratory Data

Eighty-nine undisturbed core samples from ten borings were analyzed to determine grain size distribution, Atterberg Limits, porosity, and vertical hydraulic conductivity. The laboratory results for hydraulic conductivity, grain size distribution, and porosity are summarized in Table 5-5, and the complete laboratory report, including plasticity data, is attached as Appendix E.

5.6.4.1. Grain Size Distribution and Porosity

Samples were collected at regular intervals, usually five feet, throughout each of the ten borings. Samples were primarily collected from the Miocene confining material, and, when core recovery allowed, samples were collected from paleochannel in-fill material as well.

As illustrated in Table 5-5, the laboratory results for both paleochannel and Miocene sediments indicated high total fines content. The average fines content for paleochannel fill sediments was reported at 69.0 percent, and the average fines content for the Miocene sediments was 52.5 percent. More than 80% of the 67 samples tested contained high liquid limit (LL) plastic fines, and more than 80% of the samples had resultant saturations above 95%. Some of the samples that were not tested for liquid limit determination are believed to contain similar high liquid limit plastic fines characteristics. The laboratory data reported high porosities for both the paleochannel material and the Miocene units, which is typical of geologic materials containing high clay content. The average porosity of the relict channel fill samples was reported as 0.626, and the average porosity of the Miocene samples was reported as 0.593.

5.6.4.2. Permeability and Hydraulic Conductivity

Geologic materials with over 15 percent clay and nearly 30 percent total fines (material passing a number 200 sieve) typically contain correspondingly low permeabilities and hydraulic conductivities (Freeze and Cherry, 1979), as confirmed by the laboratory analyses performed on samples as part of this study (Table 5-5).

The hydraulic conductivity for Miocene sediments ranged from 1.12×10^{-4} cm/sec in

boring SHE-14 to 1.18×10^{-8} cm/sec in boring SHE-19 (3.17×10^{-1} to 3.34×10^{-5} ft/day, respectively). The average vertical hydraulic conductivity for all Miocene samples (units A and B) tested was 2.13×10^{-6} cm/sec (6.04×10^{-3} ft/day), which was very similar to results reported in the 1998 *Ground-Water Impacts* report (USACE, 1998). The median for all Miocene samples tested was 1.41×10^{-7} cm/sec (3.98×10^{-4} ft/day). As for the relict channel fill samples, the hydraulic conductivity ranged from 2.78×10^{-6} cm/sec in boring SHE-13 to 4.33×10^{-8} cm/sec in boring SHE-11 (7.88×10^{-3} to 1.23×10^{-4} ft/day, respectively). The average vertical hydraulic conductivity of the relict channel samples was reported at 3.72×10^{-7} cm/sec (1.05×10^{-3} ft/day), and the median value was 6.38×10^{-8} cm/sec (1.81×10^{-4} ft/day).

Table 5-5. Summary of Soils Laboratory Results from 2001 to 2004

Boring	Sample	Elevation	Geologic Unit	USCS Class	Grain Size Distribution			Porosity	Hydraulic Conductivity k_{arc} (cm/sec)	Hydraulic Conductivity k_{arc} (ft/day)
					% Gravel	% Sand	% Fines			
SHE-11	K-1	-30.3	CF	CH	0.0	12.3	87.7	0.692	4.79E-08	1.36E-04
SHE-11	K-2	-57.8	CF	CH	0.0	10.8	89.2	0.691	4.33E-08	1.23E-04
SHE-11	K-3	-80.3	CF	CH*	0.0	4.8	95.2	0.728	5.40E-08	1.53E-04
SHE-13	K-1	-51.6	CF	SC	0.0	81.2	18.8	0.412	2.78E-06	7.88E-03
SHE-13	K-2	-57.4	CF	CH*	0.0	47.4	52.6	0.633	1.46E-07	4.14E-04
SHE-14	K-1	-44.9	CF	CH*	0.0	3.2	96.8	0.662	7.90E-08	2.24E-04
SHE-17	K-1	-40.0	CF	CL	0.0	49.9	50.1	0.582	6.98E-08	1.98E-04
SHE-17	K-2	-44.7	CF	CH*	0.0	40.4	59.6	0.577	6.38E-08	1.81E-04
SHE-17	K-3	-52.3	CF	CH	0.0	26.6	71.4	0.655	6.18E-08	1.75E-04
Mean Values for Channel Fill Material:					0.0	31.0	69.0	0.626	3.72E-07	1.05E-03
SHE-9	K-1	-50.8	A	MH	0.3	13.0	86.7	0.683	1.80E-06	5.10E-03
SHE-9	K-2	-61.5	A	MH	0.0	35.3	64.7	0.711	3.10E-07	8.79E-04
SHE-9	K-3	-80.7	A	SM	0.0	65.2	34.8	0.587	1.50E-06	4.25E-03
SHE-9	K-4	-101.1	A	MH	13.6	22.6	63.8	0.680	4.80E-08	1.36E-04
SHE-9	K-5	-112.2	A	CH	1.3	30.0	68.7	0.684	9.40E-08	2.66E-04
SHE-10	HC-1	-55.1	A	SM	0.1	72.5	27.4	0.629	1.70E-07	4.82E-04
SHE-10	HC-2	-62.4	A	MH	0.0	23.9	76.1	0.747	1.10E-07	3.12E-04
SHE-10	HC-3	-69.5	A	MH	0.8	49.0	50.2	0.709	1.10E-06	3.12E-03
SHE-10	HC-4	-83.9	A	MH	0.0	16.3	81.7	0.688	5.50E-07	1.56E-03
SHE-10	HC-5	-92.5	A	MH	0.0	14.8	85.2	0.718	2.90E-07	8.22E-04
SHE-10	HC-6	-98.6	A	MH	0.0	33.8	66.2	0.709	1.70E-07	4.82E-04
SHE-10	HC-7	-104.5	A	SC	0.0	62.5	37.5	0.581	4.50E-07	1.28E-03

Boring	Sample	Elevation	Geologic Unit	USCS Class	Grain Size Distribution			Porosity	Hydraulic Conductivity k_{ave} (cm/sec)	Hydraulic Conductivity k_{ave} (ft/day)
					% Gravel	% Sand	% Fines			
SHE-10	HC-8	-112.0	A	SM	0.0	53.3	46.7	0.774	7.10E-07	2.01E-03
SHE-10	HC-9	-119.5	A	SM	0.0	84.7	15.3	0.504	2.40E-07	6.80E-04
SHE-10	HC-10	-128.5	A	SM	0.0	65.8	34.2	0.456	1.50E-06	4.25E-03
SHE-10	HC-11	-137.5	A	SM	0.0	72.5	27.5	0.464	3.20E-05	9.07E-02
SHE-10	HC-12	-144.4	A	SM	0.0	81.1	18.9	0.458	2.20E-07	5.24E-04
SHE-11	K-4	-70.1	A	SC-H	0.0	80.7	19.3	0.507	2.53E-07	7.17E-04
SHE-11	K-5	-79.6	A	MH	0.0	40.7	59.3	0.507	6.44E-08	1.83E-04
SHE-13	K-5	-74.3	A	CH*	0.0	3.8	96.2	0.662	1.69E-07	4.79E-04
SHE-13	K-6	-79.9	A	CH*	0.0	1.7	98.3	0.688	9.92E-08	2.81E-04
SHE-13	K-7	-83.9	A	MH	0.0	22.8	77.2	0.633	7.32E-08	2.07E-04
SHE-13	K-8	-88.1	A	MH*	0.0	34.3	65.7	0.629	8.81E-08	2.50E-04
SHE-14	K-2	-51.9	A	CH*	0.0	10.8	89.2	0.646	7.39E-08	2.09E-04
SHE-14	K-3	-56.3	A	CH*	0.0	2.1	97.9	0.650	1.58E-07	4.48E-04
SHE-14	K-4	-65.3	A	SP-SM	0.0	94.1	5.9	0.404	1.12E-04	3.17E-01
SHE-15	K-1	-55.0	A	MH	0.0	19.2	80.8	0.712	1.48E-07	4.20E-04
SHE-15	K-2	-63.3	A	MH*	0.0	27.8	72.2	0.636	4.74E-06	1.34E-04
SHE-15	K-3	-72.3	A	CH*	0.0	27.4	72.6	0.671	1.48E-07	4.14E-04
SHE-15	K-4	-83.0	A	SC*	0.0	68.2	31.8	0.572	3.34E-07	9.47E-04
SHE-15	K-5	-95.3	A	OH	0.0	5.3	94.7	0.647	2.44E-07	6.82E-04
SHE-15	K-6	-113.1	A	OH*	0.0	0.4	99.6	0.744	1.84E-08	5.22E-05
SHE-16	K-1	-42.8	A	SC-H	0.0	68	32.0	0.529	6.28E-07	1.78E-03
SHE-16	K-2	-53.8	A	SC*	0.0	83.6	16.4	0.469	7.09E-07	2.01E-03
SHE-17	K-4	-59.2	A	SC-H	0.0	78.6	21.4	0.478	1.04E-06	2.95E-03
SHE-17	K-5	-68.8	A	SP-SM	0.0	88.2	11.8	0.499	2.29E-07	6.49E-04
SHE-18	K-1	-64.5	A	OH	0.0	2.1	97.9	0.817	2.12E-07	6.01E-04
SHE-18	K-2	-70.2	A	SM*	0.0	79.8	20.2	0.494	9.95E-08	2.82E-04
SHE-19	K-1	86.2	A	CH	0.0	48.6	51.4	0.498	3.27E-06	9.27E-03
SHE-19	K-2	96.7	A	MH	0.0	4.4	95.6	0.599	2.61E-06	7.40E-03
SHE-19	K-3	118.5	A	SC-H	0.0	61.6	38.4	0.585	1.41E-07	4.00E-04
SHE-19	K-4	131.8	A	MH*	0.0	48.2	51.8	0.592	6.28E-08	1.78E-04
SHE-19	K-5	142	A	MH	0.0	12.7	87.3	0.638	3.10E-08	8.79E-05
SHE-19	K-6	152.5	A	MH*	0.0	8.5	91.5	0.671	2.58E-08	7.31E-05
SHE-19	K-7	162.3	A	OH	0.0	0.3	99.7	0.761	1.16E-08	3.34E-05
SHE-19	K-8	167.1	A	OH*	0.0	29.7	70.3	0.796	3.15E-08	8.93E-05
Mean Values for Miocene Unit A:					0.4	40.3	59.4	0.619	3.57E-06	1.01E-02
SHE-9	K-6	-129.4	B	SC	0.0	70.0	30.0	0.405	2.80E-07	7.94E-04
SHE-9	K-7	-148.4	B	SM	0.0	73.2	26.8	0.520	1.30E-07	3.69E-04
SHE-9	K-8	-164.2	B	SM	0.0	71.9	28.1	0.540	1.70E-07	4.82E-04
SHE-9	K-9	-175.3	B	SM	0.0	65.7	34.3	0.564	1.40E-07	3.97E-04
SHE-9	K-10	-188.5	B	SM	0.1	68.1	31.8	0.540	2.80E-07	7.94E-04
SHE-10	HC-13	-150.9	B	SM	0.0	77.3	22.7	0.469	2.50E-07	7.09E-04
SHE-10	HC-14	-160.9	B	SM	0.0	66.7	33.2	0.488	1.50E-06	4.25E-03
SHE-11	K-6	-91.1	B	CH*	0.0	0.0	100.0	0.489	6.12E-08	1.73E-04
SHE-11	K-7	-98.8	B	SM*	0.0	79.4	20.6	0.543	9.48E-08	2.69E-04

Boring	Sample	Elevation	Geologic Unit	USCS Class	Grain Size Distribution			Porosity	Hydraulic Conductivity k _{arc} (cm/sec)	Hydraulic Conductivity k _{arc} (ft/day)
					% Gravel	% Sand	% Fines			
SHE-11	K-8	-101.1	B	SM-H	0.4	86.0	13.6	0.508	2.37E-07	6.72E-04
SHE-11	K-9	-106.6	B	SM-H	0.0	51.9	48.1	0.663	3.92E-08	1.11E-04
SHE-13	K-9	-93.1	B	MH	0.0	19.2	80.8	0.686	5.44E-08	1.54E-04
SHE-13	K-10	-98.8	B	MH*	0.0	11.0	89.0	0.716	4.88E-08	1.38E-04
SHE-13	K-11	-105.6	B	SM-H	0.0	61.5	38.5	0.612	1.32E-07	3.74E-04
SHE-14	K-5	-71.3	B	MH*	0.0	22.9	77.1	0.582	3.40E-08	9.64E-05
SHE-14	K-6	-76.3	B	SM-H	0.0	51.1	48.9	0.590	1.05E-07	2.98E-04
SHE-14	K-7	-81.3	B	MH	0.0	40.0	60.0	0.634	5.69E-07	1.61E-03
SHE-14	K-8	-86.8	B	SM*	0.0	56.9	43.1	0.593	5.77E-08	1.64E-04
SHE-14	K-9	-92.5	B	SM*	0.0	68.1	31.9	0.616	1.13E-07	3.20E-04
SHE-15	K-7	-135.3	B	SC-H	0.0	68.4	31.6	0.511	6.55E-08	1.86E-04
SHE-15	K-8	-144.7	B	SM-H	0.0	81.9	18.1	0.433	5.74E-07	1.63E-03
SHE-15	K-9	-155.3	B	MH*	0.0	45.3	54.7	0.607	6.64E-08	1.88E-04
SHE-15	K-10	-171.0	B	SM-H	0.0	59.5	40.5	0.586	4.96E-08	1.41E-04
SHE-15	K-11	-181.3	B	SM*	0.0	50.1	49.9	0.611	6.33E-08	1.79E-04
SHE-15	K-12	-193.9	B	SM-H	0.0	66.5	33.5	0.567	4.95E-07	1.40E-03
SHE-16	K-3	-70.1	B	CH*	0.0	43.2	56.8	0.548	2.07E-08	5.87E-05
SHE-16	K-4	-80.1	B	SC-H	0.0	56.0	44.0	0.560	7.26E-08	2.06E-04
SHE-16	K-5	-91.8	B	SM-H	0.0	53.5	46.5	0.579	2.98E-08	8.45E-05
SHE-17	K-6	-86.7	B	MH	0.0	45.4	54.6	0.521	4.87E-08	1.38E-04
SHE-18	K-3	-93.9	B	SM-H	0.0	65.5	34.5	0.603	1.62E-07	4.59E-04
SHE-18	K-4	-106.3	B	SM*	0.0	75.4	24.6	0.541	5.09E-08	1.44E-04
SHE-19	K-9	188.8	B	SM-H	0.0	68.9	31.1	0.430	9.60E-08	2.72E-04
SHE-19	K-10	202.1	B	SM-H	0.0	57.4	42.6	0.565	1.58E-08	4.48E-05
SHE-19	K-11	213.7	B	SM-H	0.0	54.5	45.5	0.478	5.39E-08	1.53E-04
Mean Values for Miocene Unit B:					0.0	56.8	43.1	0.557	1.81E-07	5.14E-04
Mean Values for Miocene Confining Unit:					0.2	47.3	52.5	0.593	2.13E-06	6.04E-03

CF = Charrel Fill

A = Miocene Unit A

B = Miocene Unit B

* = Soils visually classified

In all cases, an arithmetic mean was used to compute average values because arithmetic means tend to emphasize the higher values of a given data set, which when applied in a model or calculations, represents a conservative assumption.

The average value of hydraulic conductivity measured from paleochannel material was less than that observed in the Miocene sediments, and the minimum value observed in paleochannel material was within the same order of magnitude as the

minimum values observed in samples collected from the Miocene units. Furthermore, the maximum value observed in relict channel samples was two orders of magnitude less than that observed in Miocene samples (Table 5-5). Therefore, the vertical hydraulic conductivity results of the paleochannel material indicate that, although the paleochannel sediments are variable in lithology, zones within them contain significant amounts low-permeability material. It should be noted that samples collected from paleochannel material are biased to the materials that contain higher percentage of clays, as these are the more cohesive samples that remain intact during coring and can be considered truly "undisturbed." Every attempt was made to sample a representative horizon, and boring logs indicate that while the channel fill sediments did include some sandy soils, they were predominantly fine-grained. The sandier sediments observed in the paleochannel sediments undoubtedly have higher hydraulic conductivities, but they are difficult or impossible to sample without disturbing their structural integrity. Regardless, in the vertical direction, the zones with lower hydraulic conductivity dominate downward flow.

Historical values of hydraulic conductivity of the Miocene units did not vary significantly from values indicated by samples collected as part of this study. Vertical hydraulic conductivities for Chatham County from one core sample in Miocene A and 18 samples in Miocene B discussed in Clarke and others (1990), including work done by Furlow (1969), indicated a value of 4.0×10^{-4} ft/day for Miocene A and a range of 1.3×10^{-2} to 5.3×10^{-5} ft/day for Miocene B.

An alternative statistical method was employed to further investigate the vertical hydraulic conductivity of the Miocene confining unit in the study area. Davis (1969) and Domenico and Schwartz (1998) both report that a log-transformed data analysis is often a more practical approach to viewing hydraulic conductivity data sets and may approximate the log-normal distribution. Figure 5-13 shows the frequency distribution of the log-transformed hydraulic conductivity samples from the Miocene confining unit. The distribution of the log-transformed values is approximately normally distributed with a standard deviation of 0.67 and a median of -3.4. The calibrated hydraulic conductivity from the ground-water model corresponds to a

logarithmic value of -3.82 , which falls well within the standard deviation of the frequency distribution.

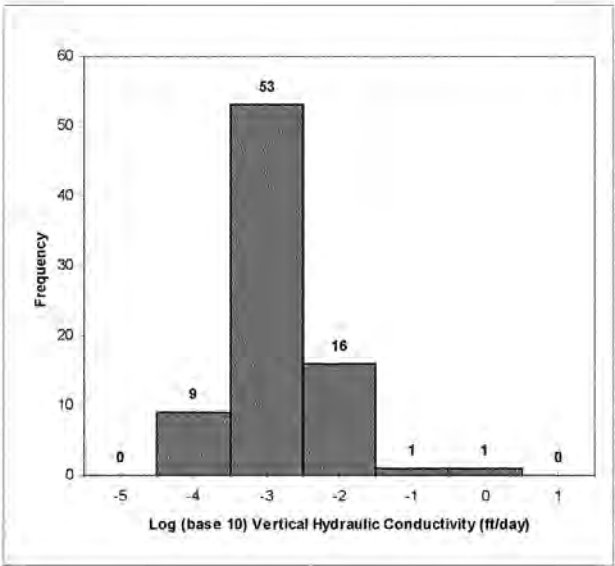


Figure 5-12. Frequency distribution of logarithmic (base 10) vertical hydraulic conductivity of the Miocene confining unit in the Savannah River area.

5.6.4.3. Triaxial Compression

In order to evaluate the possibility of open fractures existing in the confining layer underlying the navigation channel, the in-situ conditions under which the material is found must be considered. Two samples were submitted for triaxial compression testing to identify the strength and deformation-specific properties of such material given its inherent physical characteristics and in-situ conditions.

The samples submitted for triaxial testing had similar physical properties (grain-size, plasticity, void ratio, density, and saturation) as the core samples submitted for

general grain-size and permeability analyses (Appendix E). The soil classifications of the triaxial samples ranged from a fat clay (k6/282) with 29% sand to a clayey sand high LL (k6/283) with 22% plastic fines. Most samples contained occasional seams of silts and fine sands.

The results of the triaxial tests were used to determine the total stress parameter of "cohesion," which is customary in fine-grained soils. Generally, a fat clay and a clayey sand high LL have a saturated cohesion of 0.12 tsf (230 psf). The saturated cohesion values of the samples collected as part of this study were determined to be 0.56 tsf (1,120 psf) for the fat clay sample and 1.85 tsf (3,700 psf) for the clayey sand high LL sample.

Total stress parameters of soils also include the effect of pore pressure on the materials. Pore pressure effects were significant as evidenced by the test results (Appendix E) and are expected to be significant under in-situ conditions due to the confinement of soil layers and the appreciable amounts of saturated high LL plastic fines. The sample results from this study indicated high cohesion values and a high degree of saturation of in-situ soils that are indicative of materials that tend to deform easily.

5.6.5. Other Considerations

In the study area, the top of the Miocene occurs at approximately -40 feet MLW. Consequently, the confining unit occurs under fully saturated conditions and considerable lithostatic pressure; two conditions that do not favor development of joints or fractures (Carver, 2000). Although no cone penetrometer testing (CPT) was done specifically for this project, extensive CPT testing has been done for geotechnical considerations at various locations along the Savannah river front. These CPT tests typically penetrate into the Miocene confining layer and are used to aid in the design of pile foundations for structures.

As the CPT probe is advanced into the soil, the probe measures an array of geotechnical parameters within the soil strata encountered, including sleeve friction,

tip resistance, and pore pressure. It is common knowledge in the Savannah area geotechnical community that a distinctive in-situ pore pressure response is recorded when the CPT probe encounters the Miocene confining layer, namely a sudden high pore pressure kick that does not dissipate as the probe is advanced into the layer.

This response in the confining layer indicates that the pore pressure induced by the CPT probe as it is pushed is well-confined and has no avenue for the pore pressure to escape or dissipate as it would in a more granular, less tight soil such as sand.

The high pore pressure signature of the Miocene confining layer is not characteristic of materials that contain a significant amount of fractures or joints. If fractures existed in the confining layer, the high pore pressure response that is typical of Miocene sediments would not occur. Instead, the pore pressure measurements would be lower, as fractures allow avenues for pore pressure to escape and dissipate.

Furthermore, the historical decrease in aquifer pressure (piezometric head) has further increased net vertical and confining (lateral) pressure in the confining layer. Davis and others (1963, 1976) measured land subsidence in the Savannah area with several precise leveling surveys from 1918 to 1975 and found approximately 0.5 feet of subsidence had occurred in the Savannah area. The reports concluded that declining heads in the Upper Floridan aquifer had caused compaction of the Miocene confining unit, which, in turn, resulted in land subsidence. The compaction of the confining unit would tend to decrease the hydraulic conductivity and any secondary permeability caused by fracturing or jointing, which would further limit the possibility of open fractures occurring in the confining material underlying the navigation channel.

5.7. GIS

The GIS served not only as a repository for organizing and viewing raw data, but also as a helpful tool for enhanced visualization and advanced analysis of the compiled data sources. The analyses completed provided a comprehensive view of the navigation channel to aid in visualizing major changes to the Savannah River through

time. Selected analyses and figures completed as part of the supplemental studies are summarized below, and detailed calculations and flow charts illustrating the calculation steps for all surfaces are included as Appendix C.

5.7.1. Calculated Surfaces

5.7.1.1. *Miocene Removed from Dredging and Paleochannel Erosion*

The total thickness of feet of Miocene material removed (Figure 5-14) was calculated using the 2003 Annual Survey surface (which included supplemental data for Kings Island Turning Basin) and the Undisturbed Miocene with Paleochannels raster. It is important to note that the undisturbed surfaces were constructed by projecting the natural surface of the Miocene based on older marine borings and land borings, and the undisturbed surface was projected in the paleochannel areas to calculate the amount of material removed due to paleochannel incisions. The GIS analysis indicated that approximately 5 feet of confining material has been removed along the majority of length of the navigation channel as a result of dredging activities. The amount of material removed from natural paleochannel incisions is illustrated as well. As expected, natural erosion from paleochannels has removed the largest thickness of material, which in some places is up to 30 feet (Figure 5-14).

5.7.1.2. *Miocene (Current)*

A number of calculations were involved to create a refined surface representing the surface elevation of the Miocene. Boring log data, geophysical data, and bathymetry data were all combined to form a refined surface, which is shown in Figure 5-15. The elevation of the top of the Miocene ranged from -29 feet MLW near the Bight Channel to -80 feet MLW underlying the paleochannel centered at river station 9+000 (RCCF 4). The analysis indicated that the average elevation of the top of the Miocene along the majority of the river was between -45 to -50 feet MLW.

5.7.1.3. *Current Miocene Thickness*

The Limestone surface was subtracted from the Current Miocene surface in order to determine the thickness of the confining unit. The returned raster values indicated

thickness of Miocene material in feet underlying the navigation channel (Figure 5-16). The surface indicated that the Miocene confining unit is most thin where paleochannels have incised the contact. A minimum thickness of 23 feet was calculated underlying the paleochannel centered on river station 9+000 (RCCF 4), which correlates well with the seismic data interpretation (26 feet). The analysis showed a maximum thickness of 160 feet upstream near Kings Island Turning Basin.

5.7.1.4. Projected Miocene Thickness

The Undisturbed Miocene surface and the proposed dredging depths were combined to project the thickness of the Miocene based on a "6-foot improvement" as illustrated in Figure 5-17. The "6-foot improvement" incorporates the total maintenance dredge depths plus an additional 3 feet of material to account for any potential disturbance by the dredge cutter-head. The projected minimum thickness (23 feet) of the Miocene confining layer did not change, as the paleochannel material overlying this area would be dredged, but the underlying Miocene material would not be disturbed. The minimum thickness of confining material outside the paleochannel areas was projected as 38 feet near river station -5+000.

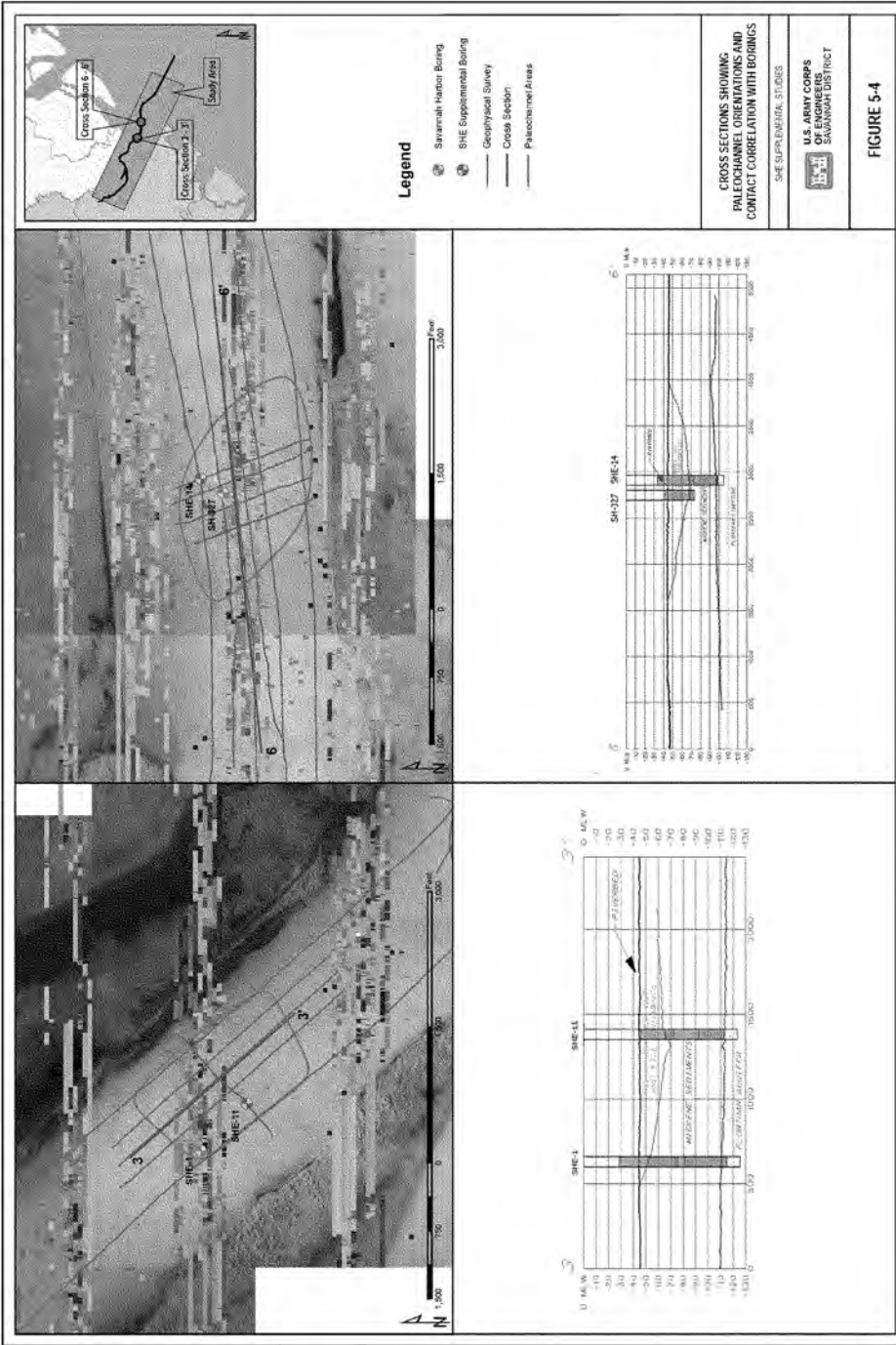
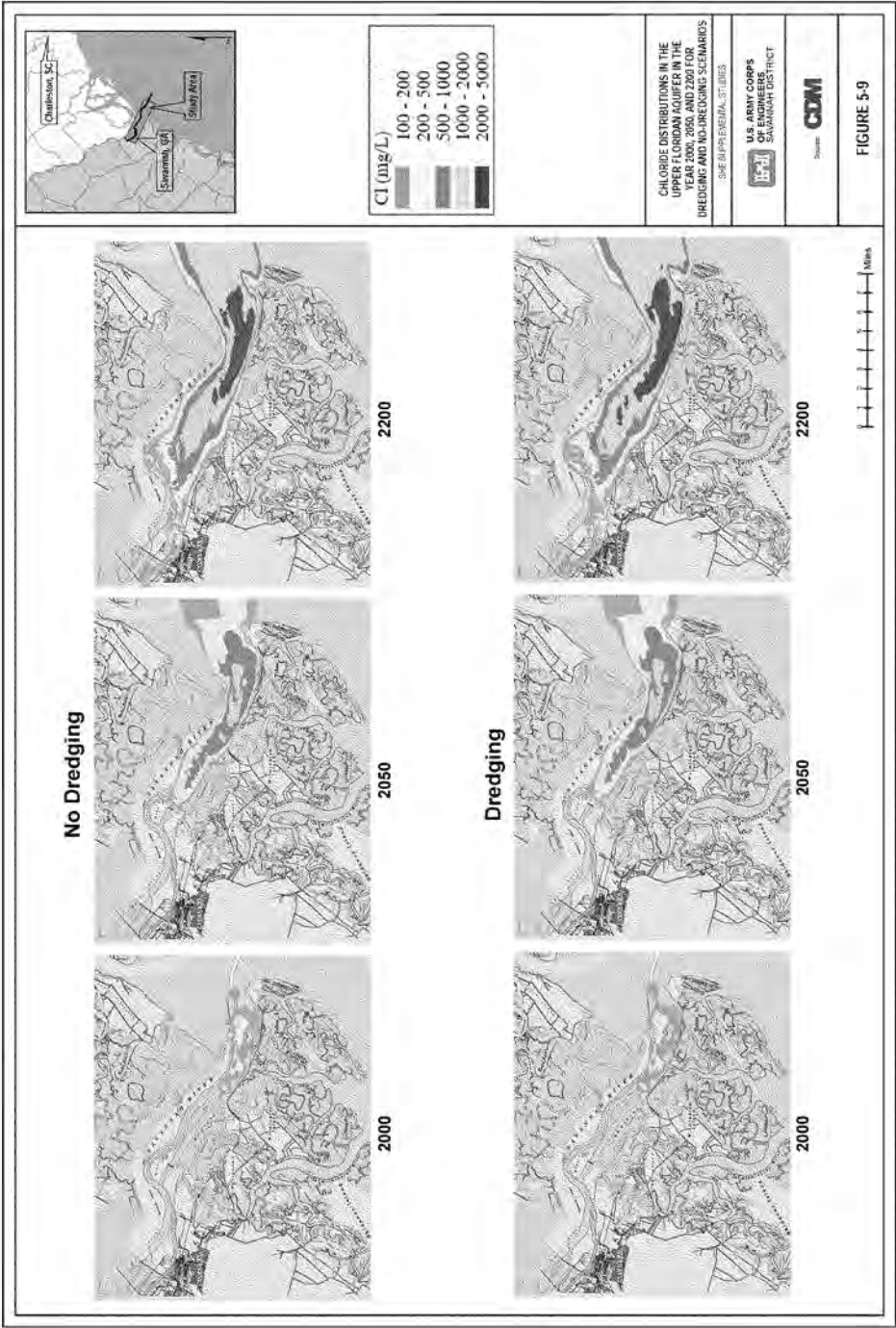


FIGURE 5-4



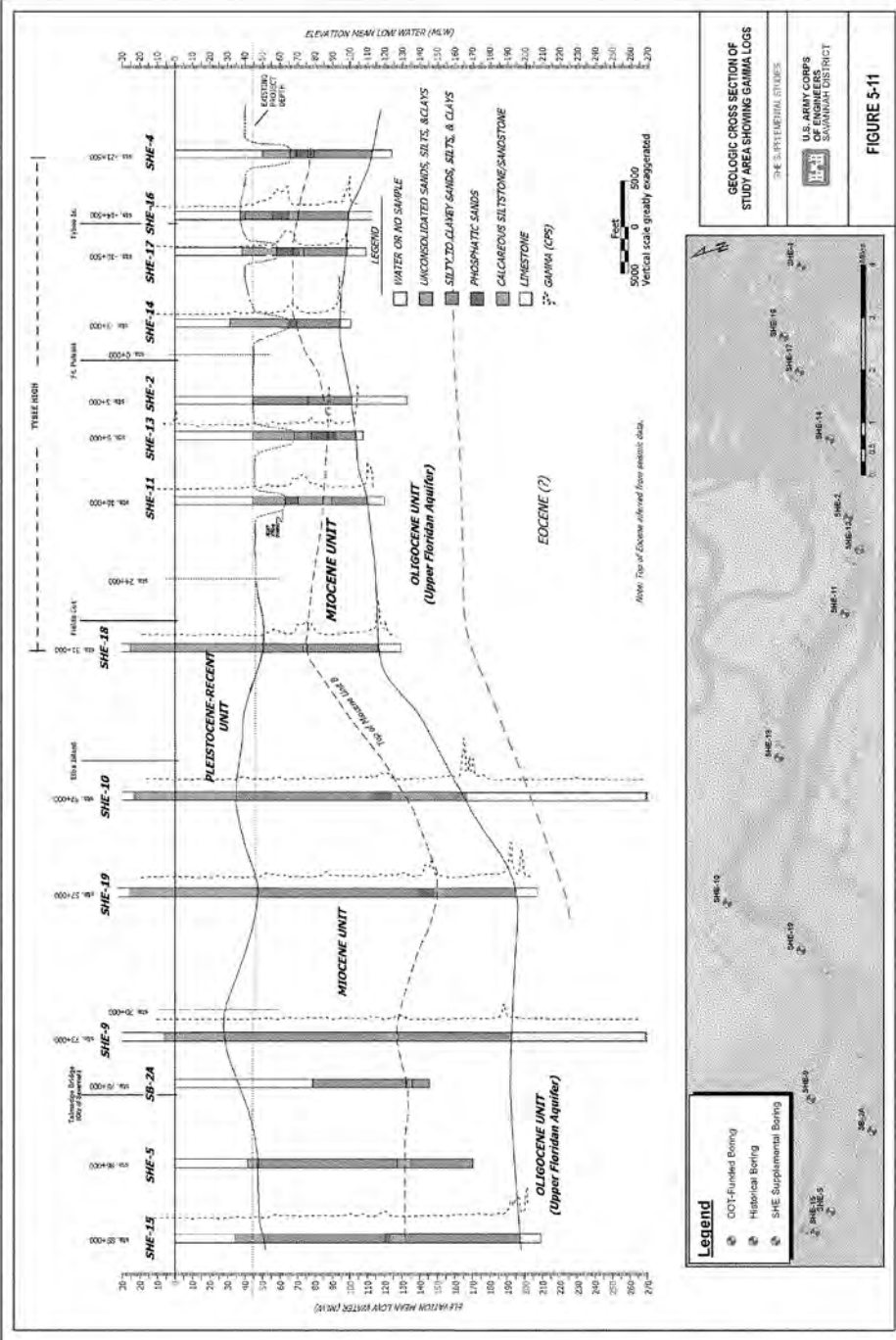
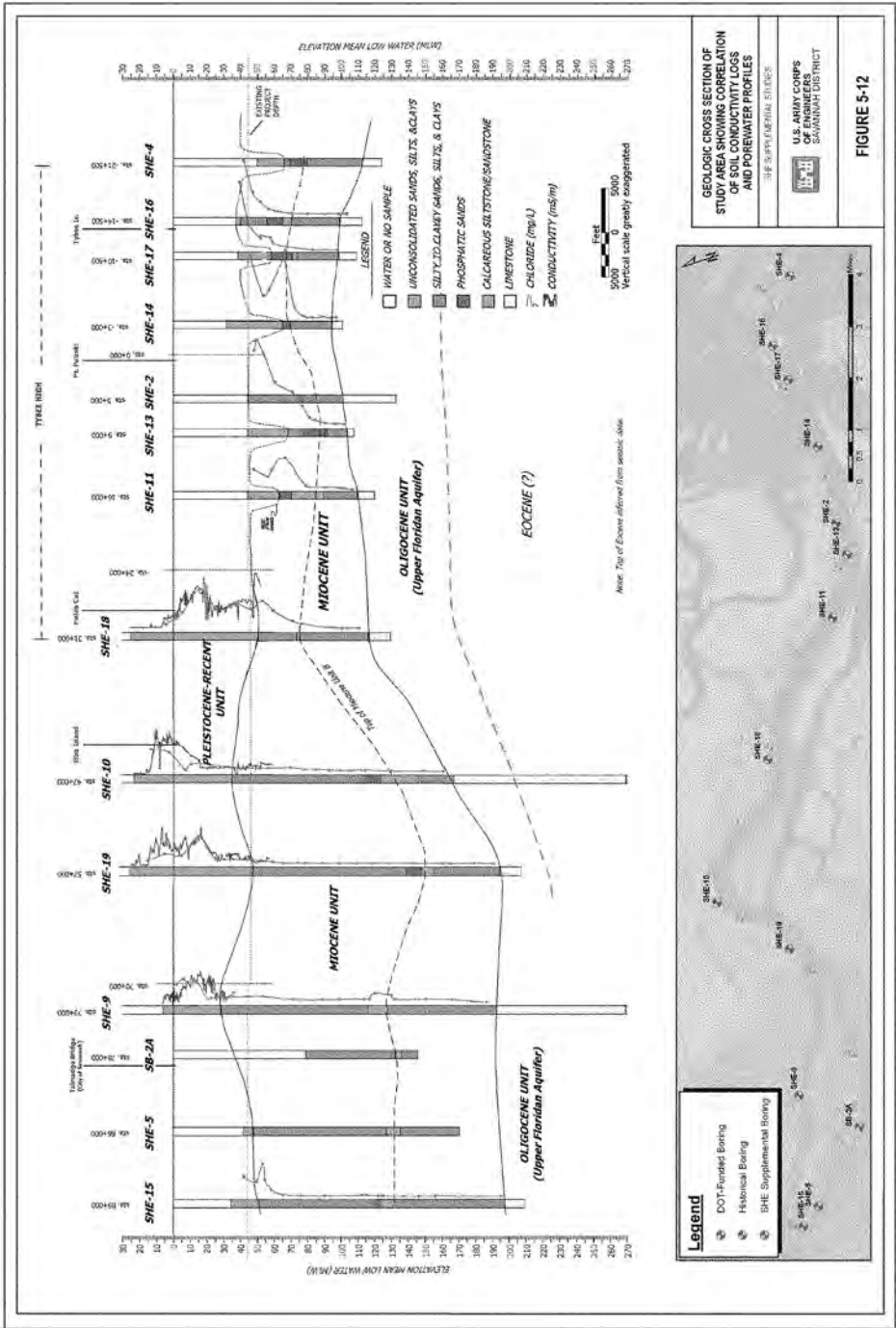
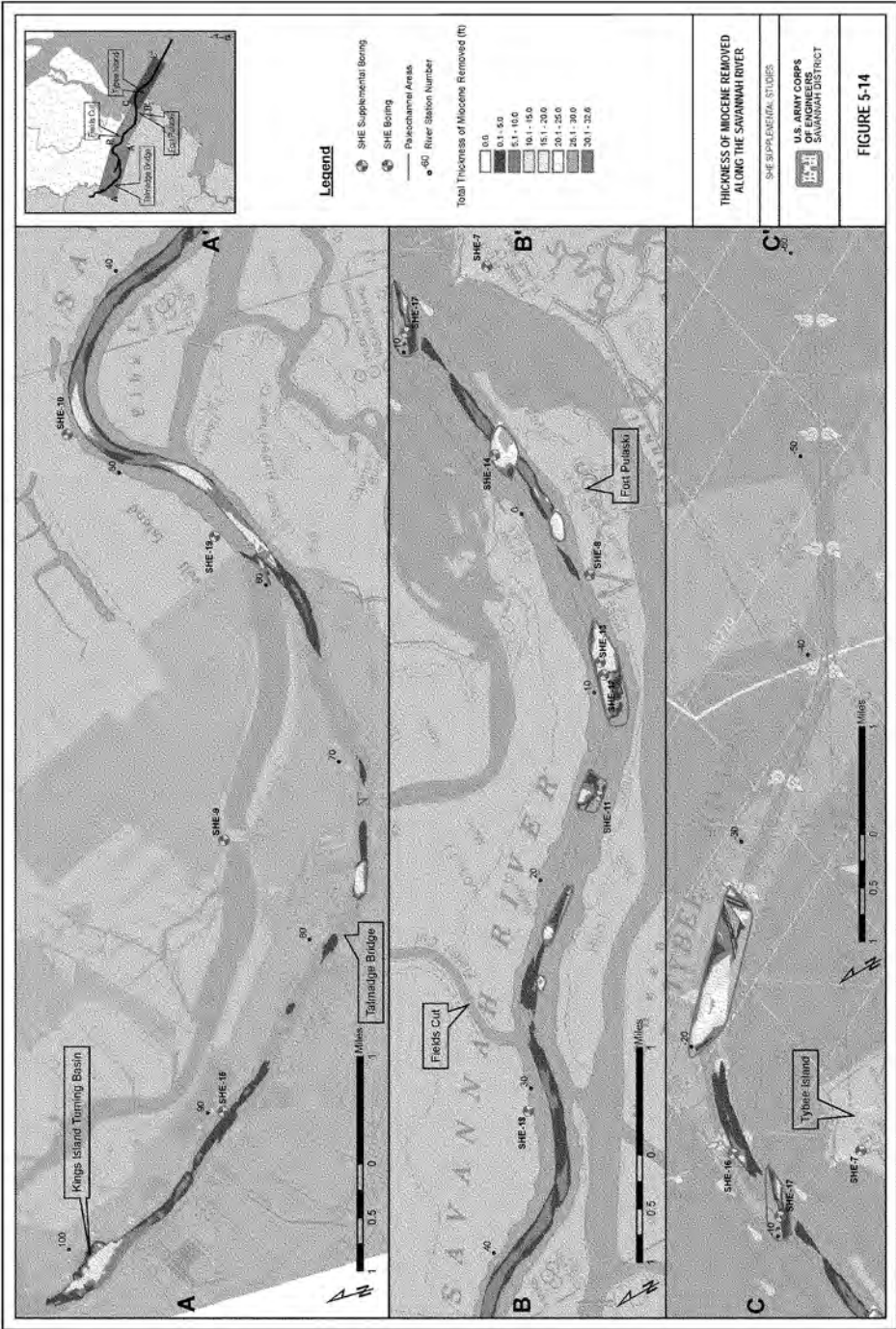
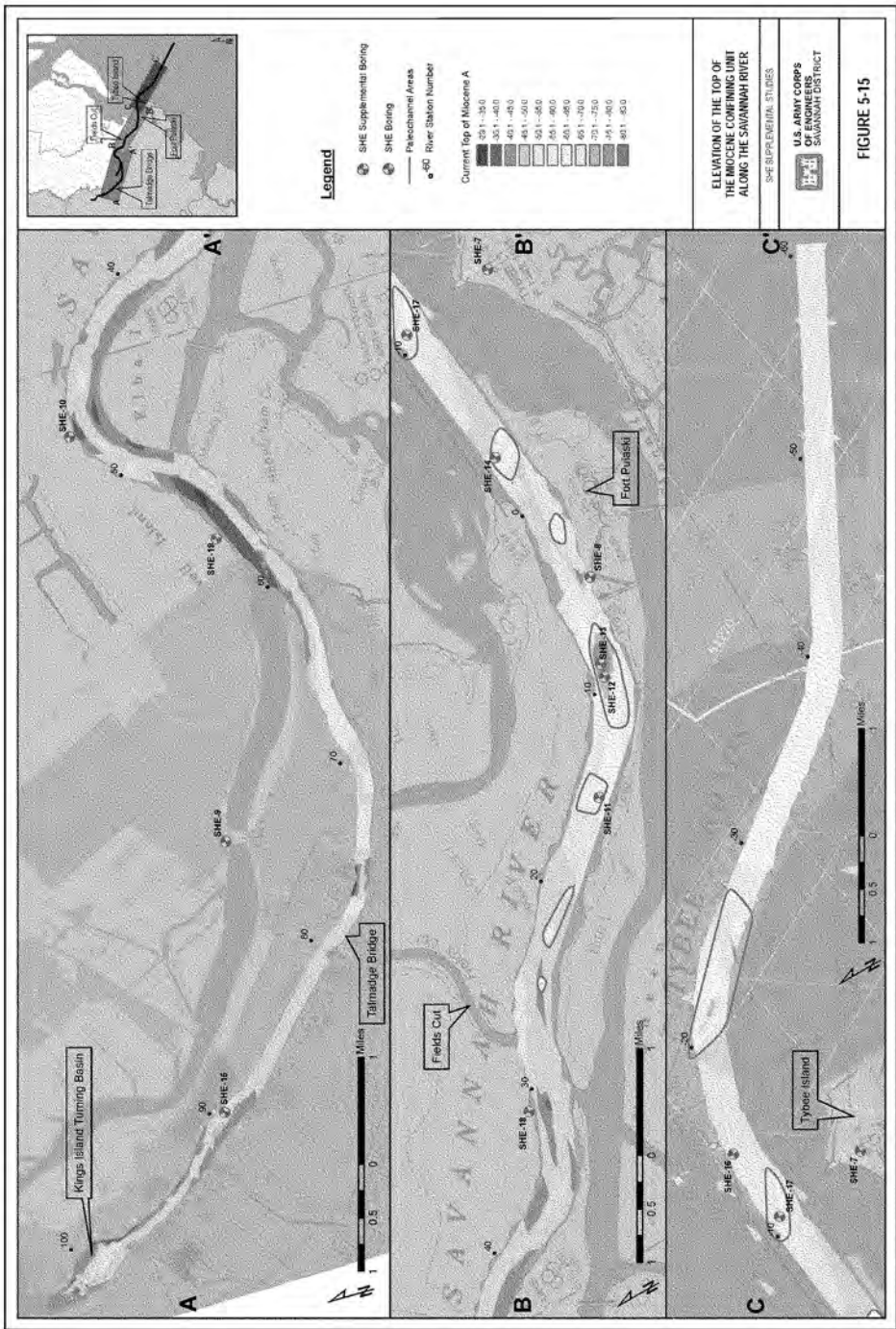
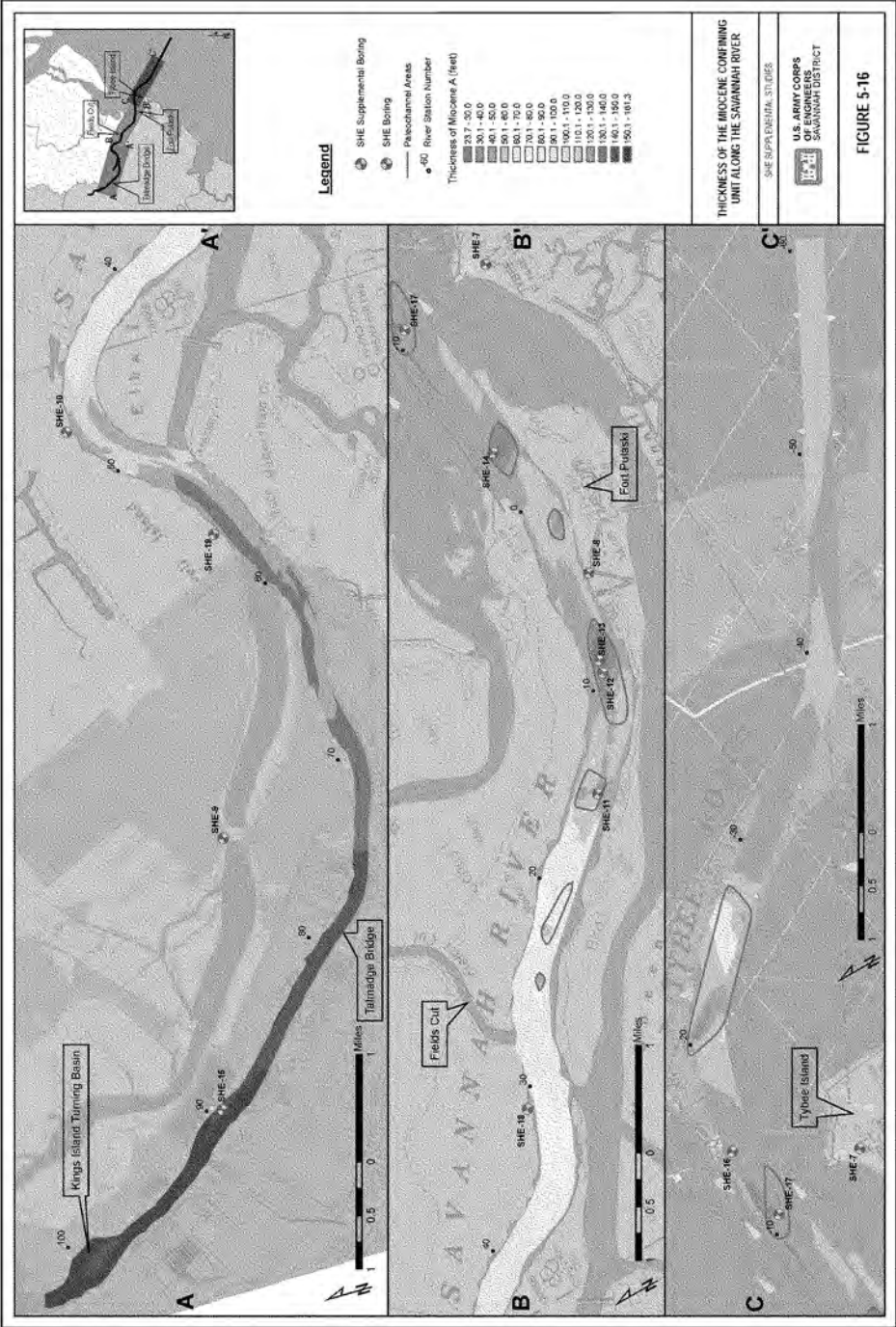


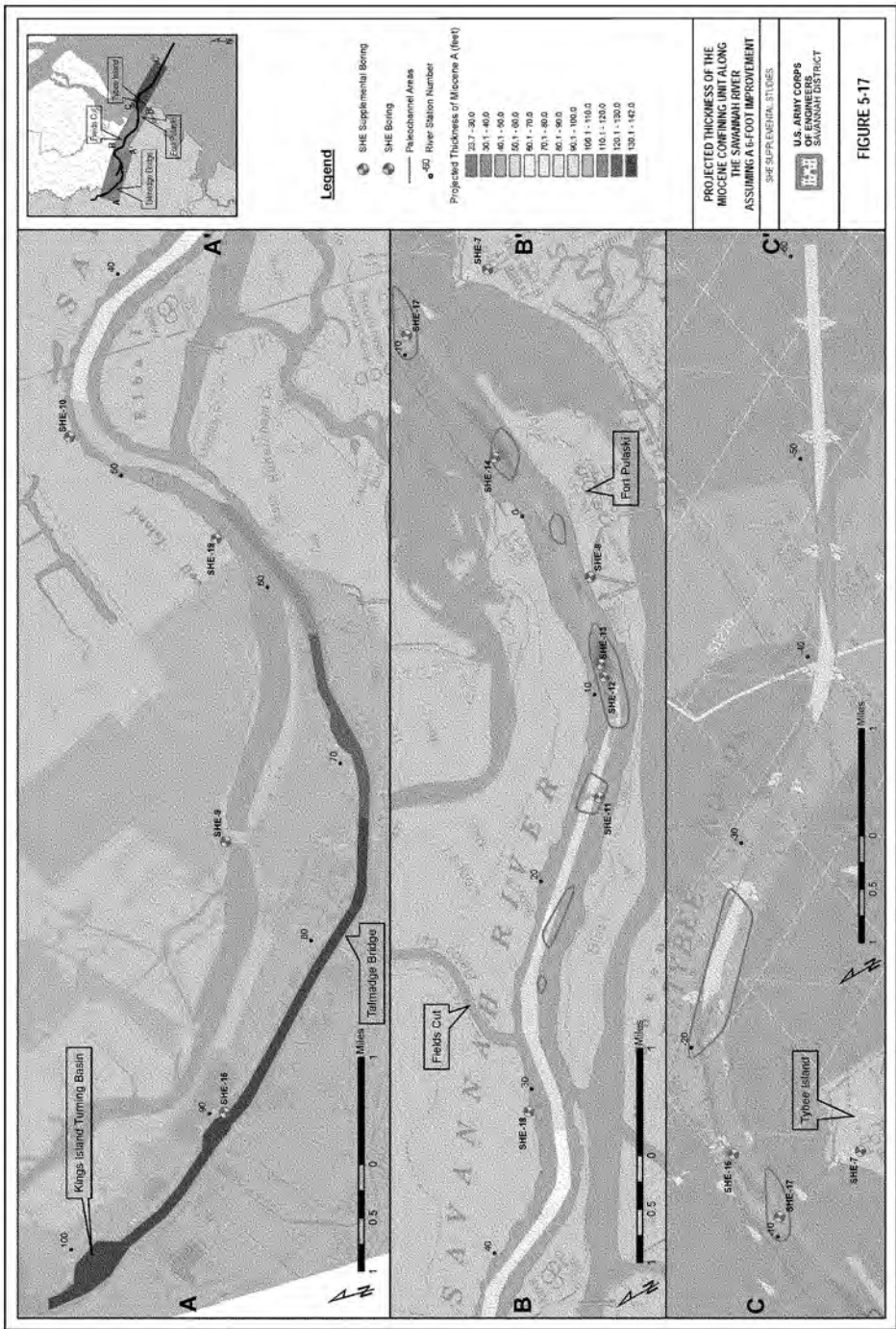
FIGURE 5-11











6. SUMMARY

The supplemental studies conducted as part of the Tier II EIS were intended to expand upon previous studies, particularly the 1998 USACE feasibility study entitled *Potential Ground-Water Impacts*. The study was conducted according to six major tasks outlined in Table 4-1. Each task provided a wealth of information that, when combined, form a comprehensive picture of the geology and hydrogeology underlying the navigation channel and surrounding area.

The detailed approach allowed for a greater understanding of the geologic and hydrogeologic framework underlying the navigation channel. Measured porewater data, hydraulic conductivity data, head data, seismic data, and confining layer thickness data were used to build upon a regional model built by USGS and refine it to address water quality issues specifically associated with dredging impacts. In order to ensure the model results were conservative, the dredging scenarios were run assuming an additional three feet of material would be removed below the proposed dredging depths. In addition, the model outputs used two values of hydraulic conductivity and provided two sets of results that bracketed true conditions, yielding a best-case and worst-case scenario for both dredging and no dredging conditions. Selected results are summarized below.

6.1. POREWATER PROFILES

The porewater data derived from this work indicate that, as expected, seawater is moving downward through the Miocene confining layer toward the Oligocene limestone (Upper Floridan aquifer), and, in some locations, low concentrations of chlorides appear to have migrated entirely through the confining layer and into the limestone. The pronounced profiles show that chloride concentration decreases with depth from the top to the bottom of the confining layer, and chloride values ranged from a high of 20,000 mg/L near the top of the layer to a low of 15 mg/L near the bottom of the layer. The data also suggest somewhat enhanced leakage of salt water in areas where deep paleochannels cut across the present navigation channel

that are underlain by punctuated decreases in chloride concentration below the Miocene unit A contact.

6.2. GEOPHYSICAL SURVEY

The subbottom seismic survey provided a comprehensive data set of the stratigraphy underlying the navigation channel within the area of concern (river stations 30+000 to -30+000). The seismic profiles generated from the survey were used to better understand the three dimensional relationship of the navigation channel, paleochannels, and the confining layer. In general, subbottom data indicated that the paleochannel features identified in the entrance channel are oriented oblique to the present-day course of the river. The subbottom data indicated that *RCCF 4* had downcut into the confining material more than any other paleochannel feature, and the minimum thickness of Miocene confining material underlying the navigation channel was 26 feet near boring SHE-13.

6.3. GROUND-WATER MODEL

The ground-water model indicated that the expected increase in downward volume of flow of saline water from the area underlying the Savannah River navigation channel due to dredging is small. The area affected by dredging accounted for a total downward flow between 50 to 250 gallons per minute depending on the hydraulic conductivity assigned to the Miocene confining unit. Dredging the navigation channel increased the total downward flow between 2 to 7 gallons per minute, or 3 to 4 percent. The contribution is negligible when compared to ground-water production in the Savannah area from the Upper Floridan aquifer, which is on the order of 80 million gallons per day (55,555 gallons per minute).

The concentrations presented represent only the contribution from the river and navigation channel. Other salt-water sources (salt marshes, offshore) were not simulated in order to simulate the explicit impacts of dredging.

In the year 2200, the upstream chloride concentrations in the Upper Floridan aquifer beneath the river were simulated to be approximately 0 mg/L for low-value hydraulic conductivity simulations and up to 100 mg/L for the mid-range hydraulic conductivity simulations. Downstream, chloride concentrations directly beneath the river approached 500 mg/L after 200 years for the low-value hydraulic conductivity simulations. For the mid-range hydraulic conductivity simulations, total breakthrough (equilibrium) occurred after approximately 100 years, and the maximum chloride concentration in the Upper Floridan aquifer occurred in the downstream portion of the study area (1,400 mg/L).

In the upstream reaches of the river, where the surface water model predicted minimum increases in chloride concentrations, the differences in chloride concentrations in the top of the Upper Floridan aquifer between the dredging and no dredging scenarios were minor. Downstream, where higher surface water chloride concentrations were predicted to occur, the corresponding differences in concentrations in the Upper Floridan aquifer directly below the river ranged from 10 to 200 mg/L and were typically observed 50 or more years into the future. These concentrations represent only a small percentage of the total concentrations expected in the aquifer, thereby yielding the contribution from dredging to the total concentration in the aquifer insignificant when compared with the combined chloride contributions from other salt-water sources.

6.4. SIMULATED PUMPING TEST

Results from the simulated pump tests indicate that it would be difficult to conduct a meaningful aquitard test. The simulations showed that response times in the surficial aquifer and Miocene confining unit would be relatively slow with expected drawdowns of only a few inches. In addition, an aquitard test would have to be at least two months in duration and pump at least 1,000 gpm to develop sufficient data with which to assess the vertical hydraulic conductivity of the Miocene confining unit. In addition, the interference expected from tidal variations, local pumping wells, and regional pumping trends would further obscure any meaningful results. The long

duration and sustained pumping rate required combined with the expected minimal and indistinct response make the task of performing an aquitard test impractical.

6.5. SOILS LABORATORY DATA

6.5.1. Hydraulic Conductivity

The vertical hydraulic conductivity results of the Miocene samples were very similar to those reported in the 1998 study, and the results from paleochannel material indicate that, although the paleochannel sediments are variable in lithology, portions of them contain properties similar to the confining material. The average value of hydraulic conductivity measured from paleochannel material 3.72×10^{-7} cm/sec (1.05×10^{-3} ft/day) was less than that observed in the Miocene sediments 2.13×10^{-5} cm/sec (6.04×10^{-3} ft/day). Additionally, the minimum value observed in paleochannel material was within the same order of magnitude as the minimum values observed in samples collected from the Miocene units, and the maximum value observed in relict channel samples was two orders of magnitude less than that observed in Miocene samples.

6.6. OTHER CONSIDERATIONS

Bartholomew et al. (2000) observed fractures in Eocene and Pliocene to Holocene (but not specifically Miocene) surface outcrops in the coastal area. It has been suggested that if similar vertical or near-vertical fractures exist in the Miocene confining layer in the lower reaches of the Savannah River, they may provide pathways for enhanced downward movement of salt water through the confining layer toward the Upper Floridan aquifer.

In the study area, the top of the Miocene confining unit occurs near -40 MLW under fully saturated conditions and considerable lithostatic pressure. CPT tests conducted along the Savannah River indicate the top of the Miocene confining layer is recognized by a distinctive high pore pressure signature. This high pore pressure is characteristic of well-confined, well-consolidated materials. If fractures existed in the

confining layer, the high pore pressure response that is typical of Miocene sediments would not occur. Instead, the pore pressure measurements would be lower, as fractures allow avenues for pore pressure to escape and dissipate.

7. CONCLUSIONS

The results from field work, ground-water modeling, and GIS analyses conducted as part of this study provided the most comprehensive picture of the geology and hydrogeology underlying the Savannah River to date. The conclusions and recommendations listed below are based on compiled historic data as well as data collected specifically for the supplemental studies. Whenever applicable, conservative assumptions were applied in order to ensure recommendations were based on a worst-case impact.

A site-specific seismic subbottom survey was performed from river station 30+000 to ~30+000, and the results of the survey provided detailed stratigraphy and information about all major paleochannels within the area of concern. The location, attitude, and extent of all paleochannels were mapped and incorporated into the Miocene surfaces created for the GIS and the ground-water model to determine their role in potential dredging impacts. Ground-water model results indicated that any additional contribution of chloride by the paleochannels is negligible when compared to the total contribution from other adjacent salt-water sources outside paleochannels along the river bottom. The impacts of dredging in the in-fill sediments of the paleochannels, which were simulated in the model to represent sand, were small when compared to the impacts of dredging elsewhere in the channel where Miocene confining unit is impacted. GIS analyses indicated that the minimum thickness of Miocene confining material occurs where paleochannels have incised into the top of the unit, and the proposed dredging activities would not further impact the Miocene confining layer in these areas.

Concern over the possible existence of fractures within the confining unit underlying the navigation channel was addressed. The in-situ conditions under which the confining layer exists in the project area (~40 feet MLW and under considerable lithostatic pressure), the nature of the confining material (considerable clay content and plasticity), and the lack of any physical evidence all indicate that fractures most likely do not exist in the project area. If they did exist in the past, the in-situ conditions

would not allow them to exist as open pathways for enhanced downward flow. Instead, the lithostatic pressure and plastic nature of the material would cause any open fractures to heal themselves. **The absence of observable vertical joints in Miocene-aged surface exposures and subsurface cores of the Miocene, as well as lack of any historical evidence (springs), reinforce the notion that fractures or joints are not a factor in the hydraulics of the confining layer in the Savannah area.**

Conducting a trial pumping test on two existing Upper Floridan wells was proposed in order to determine the feasibility of performing a full aquitard test on the confining unit. Initially, several model simulations were performed to evaluate the potential response in the surficial aquifer and Miocene confining unit to a long-term pumping test conducted with a well in the Upper Floridan aquifer. The inherent properties of the Miocene confining material (well-compacted, low hydraulic conductivity, and general "tight" nature) are characteristic of geologic units that would typically show very little response to pumping. The simulation results indicated slow response times (months) and small drawdowns (inches), which would make performing a meaningful aquitard test difficult at best. **The simulation results, as well as the response from previous tests conducted at the Tybee Island Test Well Cluster, led to a decision not to conduct the additional trial pumping test, and it is felt that full aquitard testing is not warranted.**

Since the 1880's, increasing withdrawals of water from the aquifer have lowered the water levels in the aquifer to as much as 100 feet below MLW. The net effect of this lowering of water level has reversed the natural pre-development flow of ground water from the aquifer upward through the confining layer to a downward flow of water through the confining layer toward the center of the area of greatest pumping from the aquifer (Savannah). **The ground-water model simulation results indicated that these head gradients are the dominant force contributing to downward movement of salt water through the Miocene confining unit.**

GIS analyses of removal of confining material through time and ground-water model results indicated that historic dredging has probably had minimal influence on the rate of salt-water intrusion. The GIS analyses indicated that the majority of confining material removed along the navigation channel has occurred since 1992, which, relative to ground-water flow rates, can be considered current conditions. Furthermore, the model simulations were run assuming up to nine feet of confining material were removed and showed very little difference between the dredging and no dredging projected impacts.

All model results and concentrations reported are based on chloride concentration effects specifically associated with dredging the navigation channel. They do not account for other salt-water sources including salt marshes or the Atlantic Ocean. As such, the values reported *do not* represent total concentrations or distributions expected; they represent the contribution from the river and navigation channel to the total concentration. This contribution is a small percentage when compared to the total concentration expected from other salt-water sources.

The location of the maximum negative head gradient, i.e. the center of the cone of depression, poses the largest potential for enhanced salt-water leakage through the confining layer. The porewater data and model results, however, showed that the thickness of the confining unit (>100 feet) and the lower salinity of the river water at this upstream location minimize this impact in the upstream reaches of the navigation channel and production wells located in and around Savannah.

The downstream areas, however, specifically near the Tybee high, showed a gradual increase in chloride concentrations in the Upper Floridan aquifer ranging from 500 to 1400 mg/L depending on hydraulic conductivity of the confining layer. The enhanced salt-water intrusion in this area is attributed to a combination of factors: the induced negative head gradient from pumping in Savannah; the overlying seawater or saline water with minimal freshwater input from the Savannah River; the naturally thin confining layer (40-60 feet); and the paleochannels that have further removed Miocene material.

Although lab results indicated that zones within the paleochannel fill material have comparable hydraulic conductivities to the Miocene material, porewater profiles constructed within paleochannels suggest that they still have some influence on the rate of salt-water intrusion. The porewater profiles also showed that chloride concentrations decrease rapidly below the Miocene contact. This punctuated reduction in concentration supports the notion that dredging paleochannel material would have minimal effect on the downward rate of salt-water intrusion. Additionally, if the paleochannel material were not considered "confining," then dredging in these areas would not reduce the thickness of the underlying confining unit. Instead, the potential impacts on water quality due to dredging should focus on the entire thickness of material overlying the aquifer and the amount of Miocene-aged material removed.

Near the Tybee high, the aquifer is predominantly overlain by seawater, and the Miocene confining layer is thin. These two naturally occurring factors significantly contribute to the enhanced salt-water intrusion in the area and locally affect water quality in the Upper Floridan aquifer. However, the model results showed that the proposed dredging would have little effect on this process. The ground-water model results showed that, in the year 2200, the concentration increase in the navigation channel due to dredging translated to only a small increase in the aquifer directly below the navigation channel (10-200 mg/L dependent on hydraulic conductivity). Production wells located in the downstream reaches of the river showed negligible differences between the dredging and no dredging scenarios, and the contribution to total chloride concentrations increased by a range of 0 to 50 mg/L after 200 years.

The ground-water model simulations were run 200 years into the future with a constant pumping rate in the Savannah area, and the results indicated that this rate of pumping would cause total breakthrough of seawater to occur regardless of dredging at some downstream locations in approximately 100 to 300 years depending on hydraulic conductivity of the confining layer.

In summary, the negative head gradient induced by pumping in Savannah has caused limited breakthrough of chlorides to occur in the downstream reaches of the Savannah River. The porewater profiles and model results from this study indicated that increased salinity in the Savannah River and the reduced thickness of the confining layer due to dredging will not significantly affect the timing of breakthrough of chlorides along the navigation channel in the Upper Floridan aquifer. Furthermore, the study results showed that the proposed dredging would have minimal impacts on water quality in production wells that tap the Upper Floridan aquifer in and around the city of Savannah.

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APPENDIX A

OSI Geophysical Survey Investigation Report



U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

**Geophysical Survey Investigation
Subbottom Profiling
Savannah River Entrance Channel
Savannah, Georgia**



OSI Report No. 04ES007
February 2004



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APPENDICES

- I. Equipment Specification Sheets
- II. Survey Field Log
- III. Summary Table Comparing ACOE Boring Units and Subbottom Reflectors
& Master Summary Table of Relic Channel Cut and Fill Features and Limestone
- IV. Interpretive Profiles

Digital Appendix (provided on CD included with report)

- Subbottom pick files (EXCEL format) for each subbottom data record that profiled a relic channel cut and fill feature
- Project Drawing Files (Microstation CADD format)

FINAL REPORT
Geophysical Survey Investigation
Subbottom Profiling
Savannah River Entrance Channel
Savannah, Georgia

1.0 INTRODUCTION

During the period 11-17 February 2004, Ocean Surveys, Inc. (OSI) conducted a geophysical survey investigation in the Savannah River Entrance Channel between River Stations 30+000 and -30+000 (Figure 1). The investigation, conducted for the Army Corps of Engineers (ACOE) - Savannah District, was completed under an Indefinite Delivery Contract OSI has with the ACOE - Philadelphia District (Contract Number DACW61-03-D-0003, Task Order Number 3). The investigation was specifically designed to complement and expand upon subbottom data acquired by OSI during a similar survey investigation of the river performed for the ACOE - Savannah District in 1997.

2.0 PROJECT SUMMARY

2.1 Project Background and Objectives

Contingent plans call for the expansion and deepening of the present-day Savannah Harbor and Entrance Channel to safely accommodate larger bulk and container ships than can presently use the river for commerce. The survey investigation described herein, is part of a multi-disciplinary comprehensive study designed by the ACOE to evaluate the feasibility of the proposed project.

Previous investigations have helped to identify the subsurface stratigraphy underlying the river that might be affected by dredging the channel to a deeper depth. The generalized sequence of geological formations identified in ascending order are: the upper Floridan Aquifer (a highly permeable limestone of mainly Oligocene and Late Eocene age and the primary source of fresh water in the Savannah area), a Miocene confining unit made up of a

complex sequence of clastics that mainly contain low-permeability clays, silts, clayey silts, and sand), and a Pleistocene-Recent sedimentary unit (principally composed of silts and clays).

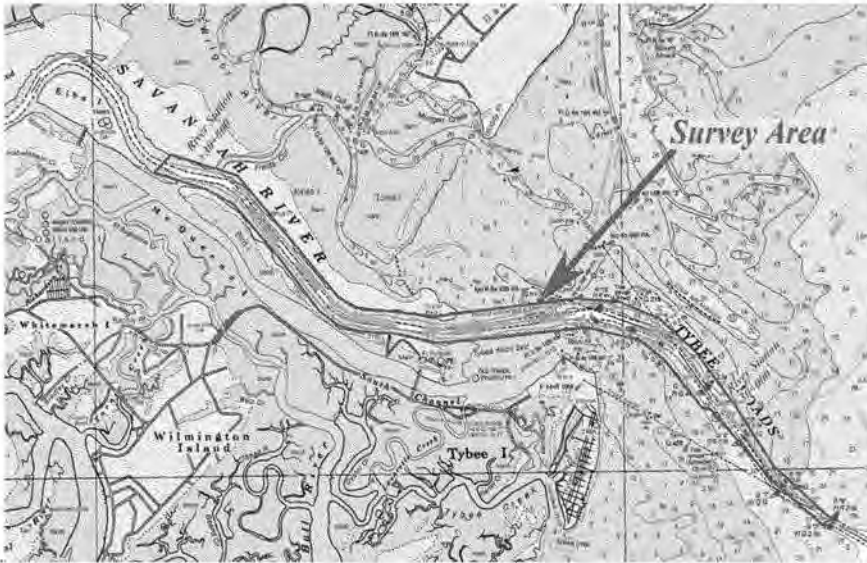


Figure 1 – Site Location map (taken from NOAA Chart No. 11513 entitled St. Helena Sound to Savannah River, 22nd Edition, 1997). Note: green lines in figure are representative of survey vessel tracklines.

Subbottom geophysical surveys, including the OSI subbottom investigation completed in October 1997 (OSI Report No. 97ES076), have revealed the existence of several buried relic stream channels (underlying the present-day navigation channel) which incise or cut into the Miocene confining unit and have been in-filled. It has been theorized by others, that if the relic stream channel cuts were in-filled by higher permeability sediments than those comprising the Miocene confining unit, then deepening the navigation channel might result in a more direct migration pathway for saltwater intrusion to the underlying aquifer system than currently exists (references cited in the U.S. Army Corps of Engineers, 1998, Savannah Harbor Expansion Feasibility Study).

The primary objective of the current survey investigation was to provide data to help the ACOE determine if deepening the Entrance Channel might have an adverse impact on the Upper Floridan Aquifer system. The OSI survey investigation was designed with the intent of identifying and profiling the significant Relic Channel Cut and Fill (*RCCF*) features underlying the navigation channel between Savannah River Stations 30+000 and -30+000, the area deemed most significant by the ACOE. These data will provide a means for locating future borings within the *RCCF* features to better understand their importance and to evaluate whether they provide a more direct migration pathway to the underlying aquifer. Separate studies, designed by the ACOE, conducted by others, are addressing other issues such as the composition and permeability of the fill sediments within the relic channel cut and fill features.

2.2 Summary of Field Survey & Equipment

Prior to OSI's mobilization and departure to Savannah, GA, a digital CAD drawing showing the proposed survey trackline layout was provided by the ACOE. This initial trackline layout consisted of two primary survey lines set along either edge of the navigation channel between Savannah River Stations 30+00 and -30+00. Upon arrival on-site, the OSI field team met with ACOE-Savannah District representative and project coordinator, Mr. Cardwell Smith. During this initial meeting, horizontal and vertical control stations were identified and project strategies and objectives were discussed. Mr. Smith remained with the OSI field team for the duration of the survey to provide direction and logistical support.

Following this meeting, the survey investigation was initiated by an OSI survey crew consisting of a geophysical specialist and navigator/geophysical technician. Survey operations were conducted from OSI's R/V "Parker", a 26-foot survey vessel equipped with an array of geophysical survey and support equipment. A Real Time Kinematic Differential Global Positioning System (RTK DGPS) receiver was installed on the survey vessel and interfaced with a radio link to a shoreside DGPS base station and an onboard computer. This

integrated 3-dimensional precision positioning system provided the field team with the ability to navigate the survey vessel precisely along tracklines throughout the survey area and to correct soundings for tidal variation in real-time. The accuracy of the positioning system was verified daily by occupying known survey control monuments within the survey area provided by the ACOE. Survey investigations were performed in feet and are referenced to the Georgia State Plane Coordinate System, East Zone, GA-1001 (NAD83). Vertical reference for the project is ACOE mean low water (MLW). The DGPS base station was established at the outset of the survey investigation by the OSI crew on Point "CARD" located on Oyster Bed Island. The site was secure and its location provided a clear line of site to the entire survey area. The geographical coordinates and elevation of the point, as provided by the ACOE, are as follows:

Point	Latitude (WGS84)	Longitude (WGS84)	ACOE MLW Elevation
"CARD"	32° 02' 24.0049"	080° 53' 49.38506"	33.17'

A summary of the primary equipment installed on the survey vessel and employed to complete this investigation and its capabilities is presented in the following table. Equipment specification sheets are included in Appendix I.

Equipment	Equipment Function
Trimble 7400 MSi "OTF" Differential Global Positioning System (DGPS)	Real-time kinematic GPS, capable of providing centimeter level positioning accuracy. The system consists of two 7400MSi GPS receivers, GPS volute antennas and cables, RS232 output data cables, and Pacific Crest radio links to transfer differential corrections. Fully automated with OTF (on-the-fly) initialization, the Trimble 7400 MSi provides means for 9-channel simultaneous satellite tracking of L1 C/A code, L1/L2 full cycle carrier. One 7400MSi unit is mounted on the survey vessel and continuously receives differential satellite correction factors via radio link from the other 7400MSi receiver set as a reference station on a known horizontal control point onshore. The Trimble 7400 MSi accepts the correction factors relayed to it via radio link and applies these corrections to obtain continuous, high accuracy, real time position updates. The Trimble system is interfaced with an onboard data logging and navigation system for trackline control.
Modified version of Coastal Oceanographic's HYPACK ® MAX PC-based navigation and data-logging software package	Survey vessel trackline control was accomplished by using a computer-based navigation software package (Coastal Oceanographic's HYPACK ® MAX) in conjunction with the Trimble 7400 GPS receiver onboard the vessel. Vessel position data obtained from the GPS receiver, updated at 1.0-second intervals, were input into the navigation

Equipment	Equipment Function
(software package cont.)	computer system, which in real-time processed these data into the desired coordinate system (Georgia State Plane, East Zone (1001), NAD 83). While surveying, the incoming raw and processed position data are continuously logged onto the computer hard drive and displayed on a video monitor enabling the vessel's helmsman to guide the survey vessel accurately along proposed tracklines. Proposed survey tracklines, along with NOAA charts for the area, the locations of project control monuments, and other targets of project significance are projected onto the video monitor relative to the location of the survey vessel to aid the helmsman in maneuvering throughout the area.
Innerspace Model 448 digital depth sounder	Water depth measurements were obtained by employing an Innerspace Model 448 depth sounder with a 200 kHz. - 8° beam over-the-side mounted transducer. The Model 448 recorder provides precise, high-resolution depth records using a solid-state thermal printer as well as digital data output, which allows integration with the navigation software. The Model 448 also incorporates both tide and draft corrections plus a calibration capability for local water mass sound speed.
OSI 300-joule high resolution "Boomer" subbottom profiling system interfaced with a TSS 360 series shallow seismic processor/data logger and an EPC model GSP-1086 gray scale thermal printer.	Subsurface profiler that generates a high-energy acoustic pulse in the water column in the range of 400 Hz. - 8 kHz via towed transducer. The acoustic pulse generated propagates downward to the riverbed where it is partially reflected at the water-sediment interface. The balance of this signal continues into the bottom and is partially reflected at each successive subsurface interface (e.g. changes in sediment characteristics or rock surfaces). The boomer system is interfaced with a multifunctional digital processor (that provides a means to filter, enhance, and log the subbottom data set in SEG-Y format) and thermal graphic printer. Under ideal conditions the resolution of the subbottom "boomer" profiling system as configured during this survey is expected to be approximately 3 feet.

Hydrographic data were acquired concurrently with subbottom profiling along all tracklines investigated. Initially, data were acquired along the proposed tracklines established along each edge of the navigation channel between Savannah River Stations 30+00 and -30+00. Following acquisition and a brief field review of these data by the OSI geophysical specialist and the ACOE representative, a supplemental set of tracklines was established within the survey area. Supplemental tracklines were established in areas where subbottom data revealed the presence of prominent *RCCF* features. Supplemental tracklines were oriented both parallel and perpendicular to the course of the existing navigation channel and were variably spaced. In total, more than 50 survey lines (greater than 60-statute miles of tracklines) were investigated. Near the conclusion of the survey and at the request of the ACOE representative, two-reconnaissance tracklines were investigated outside the pre-designated survey site near historic ACOE boring locations. The first line was located in the

Bull River near the Bull River Marina and the second line was located in the Savannah River in the vicinity of Elba Island.

The following table provides a general chronology of events for the survey investigation.

Task	Dates	Task Description
Mobilization	10-11 February 2003	Survey crew and vessel depart Old Saybrook, CT and transit to Savannah, GA. Afternoon of 11 February survey crew launches vessel, prepares survey vessel and equipment on-site and meets with ACOE representative.
Establish GPS Base Station, Testing/ Tuning Survey Gear On-site	12 February 2003	Survey crew establishes GPS base station on Oyster Bed Island and performs verification checks to prove accuracy of the GPS positioning system. Check, test/tune survey gear on-site for operation and perform necessary calibrations.
Survey Operations	13-16 February 2003	Conduct survey operations. Acquire sounding and subbottom "boomer" profiling data along proposed and supplemental survey lines.
Survey Operations and Demobilization	17 February 2003	Survey investigation completed. Recover GPS base station, haul survey vessel, and demobilize vessel on-site for travel. Survey crew and vessel departs Savannah, GA and returns to OSI office Old Saybrook, CT.

2.3 Data Processing and Products

Following completion of the survey investigation, the acquired data sets were brought back to OSI's Old Saybrook, CT office for processing, interpretation and construction of data deliverables. Immediately upon return, an all-inclusive daily field log (presented in Appendix II) detailing survey lines investigated and their associated data file names (both HYPACK[®] MAX and SEG-Y formats), and a survey trackline plot (Microstation CADD format) were generated. This log and plot were forwarded to the ACOE along with all project HYPACK[®] MAX survey data files (raw and edited formats) and subbottom records (paper and SEG Y formats) as an interim deliverable prior to submittal of this report.

Subbottom profile data were reviewed and interpreted with the primary task of identifying the prominent *RCCF* features existing within the project area. Final data are presented in both plan and profile formats on OSI Drawing 04ES007.1-2. Drawing 04ES007.1 presents

an overview of investigated survey tracklines highlighting areas where the *RCCF* features were identified and representative profile sections were constructed. Included on this drawing are the limits of the existing navigation channel, Savannah River Stationing, the location of recent ACOE borings obtained in support of the project, and an aerial photograph of the project area. This drawing is presented at a horizontal scale of 1"=2,000'. OSI Drawing 04ES007.2, Sheets 1-3 are panel drawings which provide sets of profiles and plan view contour plots of: the riverbed, the *RCCF* features, and the upper surface of limestone, for each area where the *RCCF* features were identified. These latter drawing sheets are presented at a horizontal scale of 1"=600' and a vertical scale of 1"=60'. All project drawings are included in full scale in sleeves at the end of this report. A digital drawing file of each sheet, which is in Microstation CADD format, is presented in a digital appendix on a compact disc (CD) included with this report.

The following table summarizes the processing steps and deliverables associated with each of the acquired data sets.

Table of Data Processing Tasks and Project Deliverables

DATA SET	DATA PROCESSING TASK PERFORMED	DATA DELIVERABLE
Survey Tracklines	Survey tracklines were reconstructed and computer plotted from the x-y coordinates logged at each "fix" point using the HYPACK [®] MAX software package. Once reconstructed on the computer, these tracklines were used for the subsequent task of interpretation and review of the acquired sounding and subbottom data. To aid in review, tracklines on which an <i>RCCF</i> feature was detected have been assigned an interpretive line number.	OSI Drawing 04ES007.1 presents an overview of survey tracklines investigated. Interpretive line number labels are included in the digital CADD drawing. These labels are presented on a separate layer, which has been turned off on the paper plot for display purposes.
Hydrographic	Hydrographic data were first checked against the sounding strip charts for verification of depth quality and then processed and corrected to project datum (based on correctors obtained via the kinematic GPS system) using the HYPACK [®] MAX software package. These data were computer contoured at a 2-foot interval using the software package "QuickSurf" Version 3.1 (Schreiber Instruments, Inc.) and used to construct continuous profiles along survey lines that identified <i>RCCF</i> features. Hydrographic data were also used in the task of referencing subbottom reflectors to project datum.	Processed hydrographic data for all survey tracklines are included in the digital OSI Drawing 04ES007.1 on a layer turned off for display purposes. Plan view hydrographic contours and constructed profile sections for areas where <i>RCCF</i> features were identified are included on OSI Drawing 04ES007.2, Sheets 1-3.

DATA SET	DATA PROCESSING/TASK PERFORMED	DATA DELIVERABLE
Subbottom Reflection	Subbottom "Boomer" reflection data (SEG Y files) were processed and enhanced using ReflexW, version 3.0 - a Windows based, modular software package by Sandmeier Software (Karlsruhe, Germany). Subbottom records revealed evidence of numerous continuous and semi-continuous subsurface acoustic reflectors that could be confidently mapped and tied directly to horizons/stratigraphic units identified in ACOE borings. An overview table was constructed to summarize comparisons made between subbottom reflectors and units identified in the ACOE borings. Subbottom reflectors correlative with the base of the <i>RCF</i> features and the upper surface of the limestone (Floridan Aquifer) have been interpreted and traced (picked) for each subbottom profile using the ReflexW program. Reflector "picks" were adjusted for sensor offsets (relative to the GPS antennae), converted to thickness (based on an average acoustical velocity of 5,300 ft/sec for the nearsurface sediments), pasted into an EXCEL format spreadsheet and referenced to the project vertical datum. Considering the resolution of the boomer subbottom profiler and the ability to accurately reference reflectors to the project vertical datum (based on an assumed average acoustic velocity), the accuracy of the presented "picks" is approximately $\pm 1-10\%$ the mapped depth of the reflectors. A master table was constructed that summarizes the subbottom interpretation on an area and line-by-line basis. Included in this master summary table are: field run and interpretive line designations, the SEG-Y and interpretive "pick" file names, summaries of the base depth of the <i>RCF</i> features and upper limestone surface, ACOE boring tie information, and thickness estimates of sediment between the base of the <i>RCF</i> features and the top of the limestone. Similar to hydrographic data, depths to the base of the <i>RCF</i> features and the top of limestone (relative to MLLW) have been computer contoured at a 2-foot interval using the QuickSurf program. (In some cases, data acquired along cross-river survey tracks were removed from the data set prior to computer contouring, in order to generate a more aesthetically pleasing contour plot). Based on this information representative subbottom profiles have been constructed for each of the prominent <i>RCF</i> features identified.	Summary table comparing ACOE boring units and subbottom reflectors (Appendix III). Interpretive subbottom profiles highlighting subbottom reflector "picks" correlative with <i>RCF</i> features and the upper surface of limestone (Appendix IV). Subbottom "pick" files constructed in EXCEL format are presented in the digital appendix included on a CD presented with this report. Master summary table of relic channel cut and fill features and limestone (Appendix III). Depth to the base of the <i>RCF</i> features and the top of limestone are included in the digital CADD Drawing 04ES007.1. These depths are presented on separate layers, which have been intentionally turned off on the paper plot for display purposes. Plan view contours of the <i>RCF</i> features and the top of limestone and representative subbottom profiles are included on OSI Drawing 04ES007.2, Sheets 1-3.

Data acquired in the Bull River and in the Savannah River near Elba Island were included in the interim deliverable. These data have not been processed or interpreted and subsequently are not discussed herein as it is beyond the scope of this current analysis.

3.0 SUBBOTTOM DATA ANALYSIS AND DISCUSSION

3.1 Overview

Subbottom profiling records revealed evidence of numerous continuous and semi-continuous subsurface acoustic reflectors that could be confidently mapped. Since the primary focus of the investigation was to identify the significant *RCCF* features in the survey site and provide data to help the ACOE evaluate the impact that deepening the navigation channel might have on the Upper Floridan Aquifer system, only those reflectors correlative with the base of the *RCCF* features and the upper surface of the aquifer (limestone) have been mapped. In almost all cases, the thickness of recent sediment deposits in the channel was minimal or absent, and therefore was not included in the mapping. It is believed that natural erosional processes in the river and/or maintenance dredging of the current navigation channel have removed the recent deposits.

Several survey tracklines were run directly over historic ACOE boring locations in an effort to groundtruth the subbottom data set and accurately tie relevant reflectors to specific horizons/stratigraphic units. Subbottom data were reviewed and compared closely with ACOE boring logs. (Boring logs provided by the ACOE are not included with this report). Under ideal conditions, the expected resolution of the subbottom profiling system utilized during this investigation is approximately three feet. This margin of error was taken into account when comparing core data with subbottom records. A table provided in Appendix III presents comparisons between contacts documented in the borings and acoustic reflectors observed on the subbottom records. Based on these comparisons an average acoustical velocity of 5,300 feet/second was found to best represent the sediments in the river overlying the Upper Floridan Aquifer.

Subbottom reflectors could be traced for appreciable distances along survey lines throughout the majority of the area investigated. Therefore, correlations between subbottom reflectors and specific horizons/stratigraphic units identified in the ACOE borings could be confidently correlated over large areas. Figure 2 provides a section of a subbottom “boomer” profile record that exemplifies some of the more prominent reflectors observed during the investigation and illustrates an area where a relic stream had incised the Miocene sediment

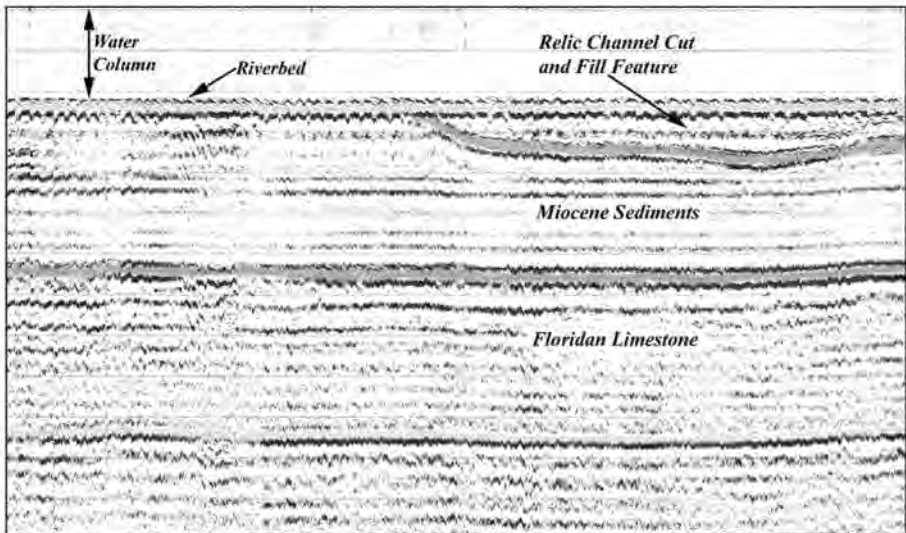


Figure 2 – Figure 2, a reproduced section of subbottom “boomer” profile record acquired during the investigation that exemplifies some of the more prominent reflectors observed.

sequence and was later filled in. The reflectors identified in the profile could be confidently traced back to an ACOE boring, based on ties with intersecting survey lines. Four prominent subbottom reflectors have been identified and color-coded on Figure 2. The red and blue reflectors represent the base of the *RCCF* feature and the upper surface of the Floridan Aquifer (limestone), respectively. The yellow reflector appears to relate to a contact within the Miocene sediments and the green reflector is believed to correlate with a deep contact within the Floridan Aquifer. In several sections of subbottom data, orange has been used to

differentiate reflectors correlative with the base of a younger *RCCF* feature identified adjacent to or traversing the primary or red-coded *RCCF* feature detected in an area (not illustrated in figure 2). The color scheme of reflectors and their relationship to specific horizons/stratigraphic units mentioned above are consistent in the figures and profile sections presented throughout this report and in the project drawings.

3.2 Summary of Identified Relic Channel Cut and Fill Features

Subbottom profiling data acquired during the current survey confirmed the existence of several *RCCF* features within the Savannah River Entrance Channel previously identified and revealed the presence of several additional *RCCF* features that had not yet been identified during previous investigations of the river. Eight of these features appear to be significant in size, underlie the navigation channel, and warrant further discussion regarding their potential impact to the project. The remaining *RCCF* features identified between Savannah River Station 30+000 and -30+000 were detected along only a single survey line and/or along survey lines located outside the navigation channel. The significant *RCCF* features detected during the current investigation are referred to as *RCCF 1-8* and are centered on the following Savannah River Stations summarized below:

- *RCCF 1* - Station 22+000
- *RCCF 2* - Station 20+000
- *RCCF 3* - Station 15+000
- *RCCF 4* - Station 9+000
- *RCCF 5* - Station 1+500
- *RCCF 6* - Station -3+000
- *RCCF 7* - Station -11+000
- *RCCF 8* - Station -21+000

Appendix III provides a master summary table, which presents the maximum depths (relative to MLW) that the *RCCF* features have incised into the Miocene sediments, the interpreted depth of the upper surface of limestone underlying the identified features, and the calculated thickness of sediment between the two interfaces on a survey line-by-line basis. These summaries are provided for each identified *RCCF* feature and are based on the subbottom "pick files" included in the digital appendix of this report. Refer to the "pick files" (EXCEL format) for a more detailed data presentation. Note in the "pick files" and on the project drawings, red and orange-coded *RCCF* features have not been differentiated from one another.

Subbottom penetration was restricted or partially restricted along several segments of the tracklines investigated during the current survey. In general, this restriction was intermittent and attributed to the presence of trapped gas bubbles within the nearsurface sediments. The gaseous manifestations, interpreted to be a by-product of the breakdown of organics originating in the sediments of paleo-estuarine environments, significantly reduce the level of acoustic signal propagation through the sediment. This reduction in signal propagation adversely affects the ability of the subbottom profiler to identify underlying subsurface acoustic reflectors. Other phenomena that might have been responsible for inhibiting the subbottom profiler from resolving reflectors at depth are changes in sediment type, compaction, lithification and/or recent dredging/disturbance of the surficial sediments.

The following sections present a synopsis of findings for the significant *RCCF* features identified underlying the Savannah River Entrance Channel (progressing from up-to-downriver). Refer to the associated OSI project drawings, interpretive profiles, tables, and digital "pick" files presented with this report while reviewing the following sections.

3.2.1 RCCF 1 and RCCF 2 (OSI Drawing 04ES007.2, Sheet 1)

Two *RCCF* features were detected between River Stations 22+000 and 20+000 (*RCCF 1 and RCCF 2*, respectively). The detected *RCCF* features appear to be related as subbottom data acquired along a survey trackline that passed through both areas traced a common subbottom reflector at the base of both *RCCF* features. Both features are primarily located along the southern side of the navigation channel and do not appear to span across the navigation channel. *RCCF 1* appears to extend further into the channel than *RCCF 2* and is better defined. Nearsurface gaseous sediments encountered on the downriver side of *RCCF 2* made it difficult to assess whether the feature actually extends underneath the navigation channel. Neither of the features incise very deeply into the Miocene sediment sequence (-80' and -64' MLW for *RCCF 1 and RCCF 2*, respectively). Minimum thickness of sediment recorded below the *RCCF* features and above the upper surface of limestone was 36 and 55 feet, respectively. Figure 3 shows three sections of subbottom data that represent the two detected *RCCF* features, the reflector that ties the two features together, and identifies the area of nearsurface gaseous sediments that hindered the mapping near Station 20+000. Note the reflector correlative with the upper surface of limestone underlying both of these areas is generally weak and flat-lying and exists at approximately -116' MLW. The reflectors association with the upper limestone surface is based on information obtained downriver from ACOE boring 11 (located near Station 15+000).

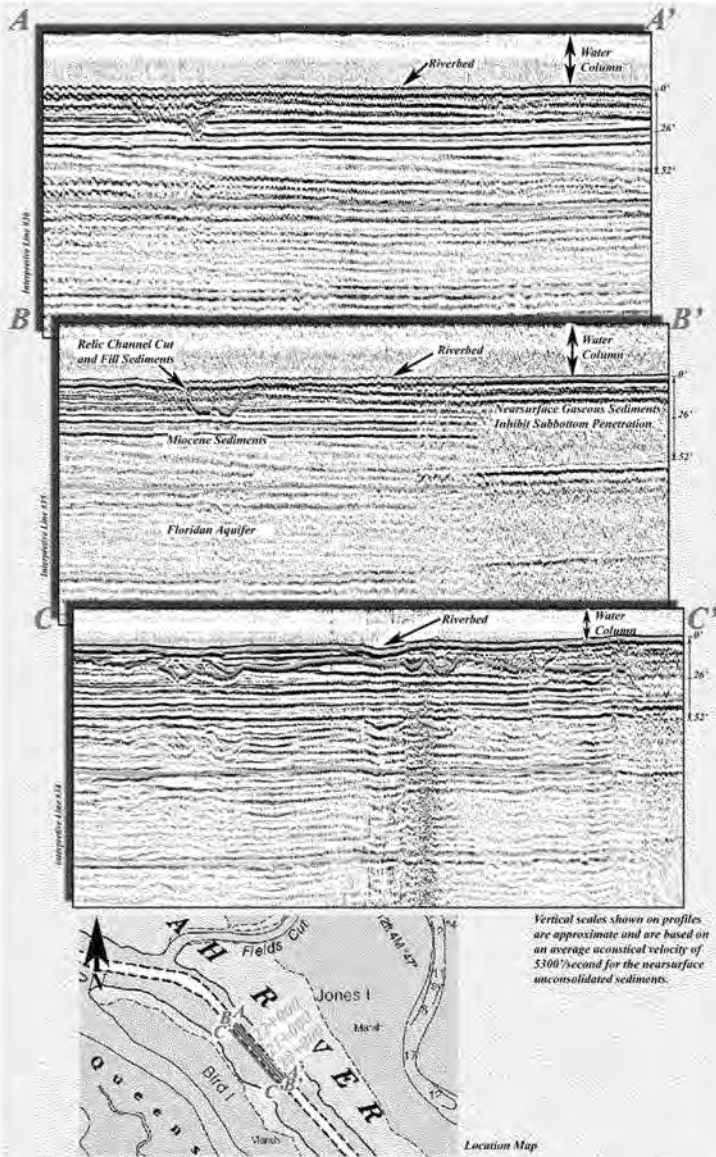


Figure 3 – Representative subbottom profiles of *RCCF* features identified between Savannah River Stations 22+000 and 20+000.

3.2.2 RCCF 3 (OSI Drawing 04ES007.2, Sheet 1)

RCCF 3 detected in the vicinity of Station 15+000, is one of the better examples of a cut and fill feature recognized during the investigation. The *RCCF* feature detected in this area extends across the channel and was profiled along both the north and south offset survey lines and all lines in-between. ACOE borings SHE-11 and SHE-1, located within and nearby the *RCCF* feature, respectively, correlated well with the presented interpretation. This *RCCF* feature appears to reach approximately -74' MLW, although in the channel it appears to be closer to -70' MLLW. The minimum thickness of Miocene sediments observed between the base of the *RCCF* feature and the top of limestone is 42 feet. The upper surface of limestone was detected at approximately -112 MLW throughout the area. Figure 4 provides three examples of subbottom data which best represent the detected *RCCF* feature in the vicinity of Station 15+000.

3.2.3 RCCF 4 (OSI Drawing 04ES007.2, Sheet 2)

RCCF 4, detected between Stations 7+000 and 12+000, extends over a much larger area than any of the other *RCCF* features identified during this investigation. The feature, somewhat complex in shape, underlies most of the navigation channel in this area, but appears to have incised most deeply (approximately -83' MLW) on the north side of the channel in the vicinity of Station 8+500. The minimum thickness of Miocene sediments observed below the base of this *RCCF* feature and above the top of limestone is approximately 26 feet. In the area where the *RCCF* feature was detected, the upper surface of limestone appears to fluctuate around -108' MLW. Nearsurface gaseous sediments inhibited subbottom penetration along sections of the north and south offset survey lines in this area. ACOE borings SHE-12, SHE-13, and SH-318 were all acquired within the area where the *RCCF* feature was detected. Unfortunately, SHE-12 and SH-318 were shallow borings and did not penetrate deep enough to sample sediments and/or the limestone below the *RCCF* feature. Fortunately SHE-13 penetrated through the *RCCF* feature and encountered the upper limestone surface. Horizon depths correlate well with the subbottom profiler data. In figure 5, two representative sections of subbottom data acquired between Stations 7+000 and 12+000 best represent the identified feature.

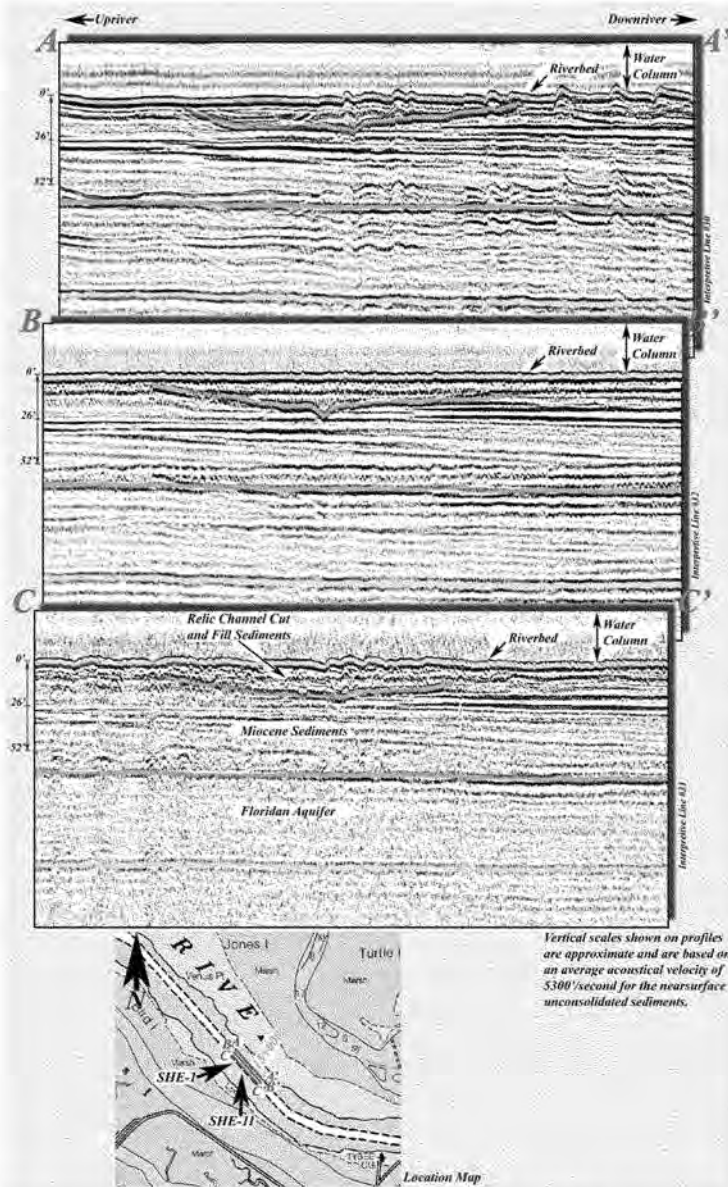


Figure 4 – Representative subbottom profiles of RCCF feature identified in the vicinity of Savannah River Station 15+000.

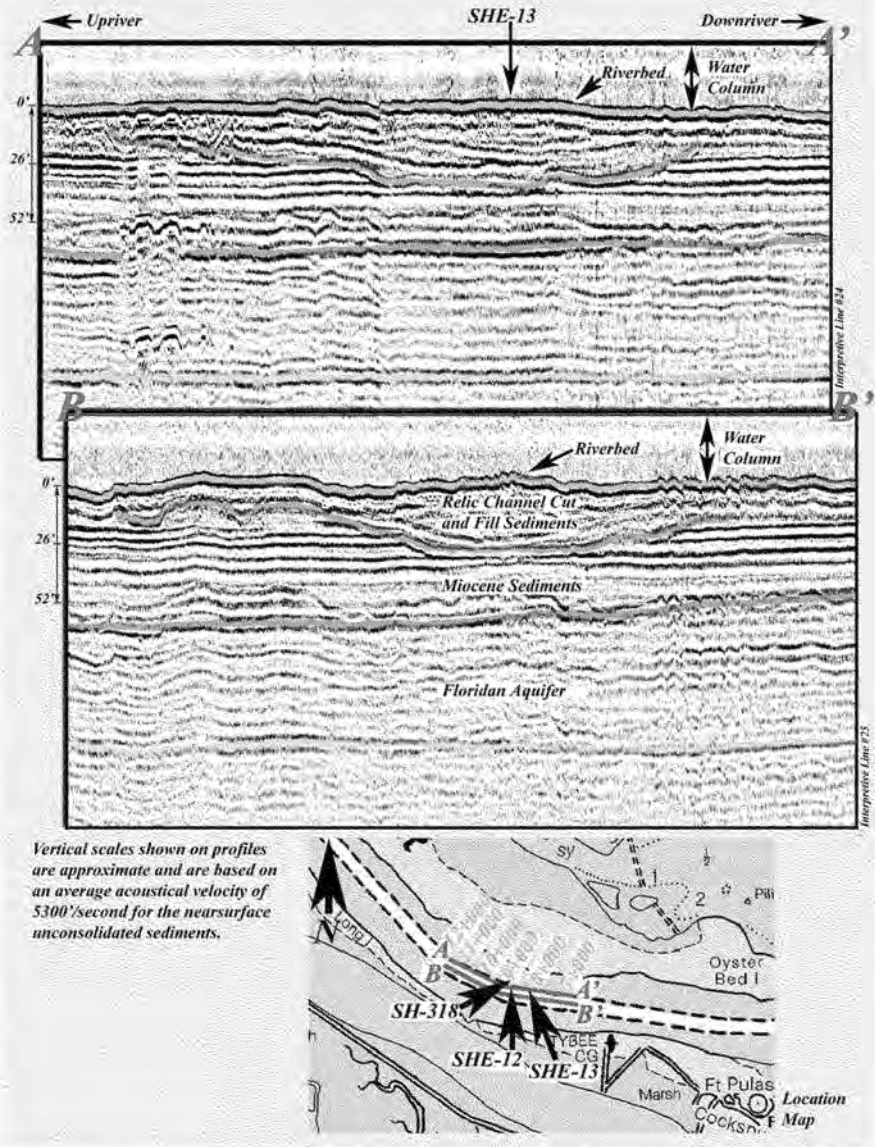


Figure 5 – Representative subbottom profiles of RCCF feature identified in between Savannah River Stations 7+000 and 12+000.

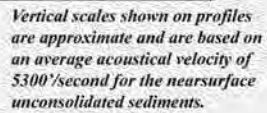
3.2.4 RCCF 5 (OSI Drawing 04ES007.2, Sheet 2)

The *RCCF* feature detected between Stations 1+000 and 2+000 is one the smallest significant *RCCF* features profiled during the investigation. The feature appears to extend across much of the navigation channel but is most pronounced along its southern edge. This *RCCF* feature has incised in this area to approximately -70' MLW. The minimum thickness of Miocene sediments observed below the base of the *RCCF* feature and above the top of limestone is 38 feet. The upper surface of limestone (based on correlations made with ACOE boring SHE-14) was detected at approximately -107' MLW. Figure 6 illustrates subbottom data that best represent the detected *RCCF* feature in this area. Note that the two subbottom sections representing the feature were acquired along the southern side of the navigation channel.

3.2.5 RCCF 6 (OSI Drawing 04ES007.2, Sheet 2)

The *RCCF* feature detected at Station -3+000 is a well-defined subsurface feature that extends across the river and was mapped on all survey lines collected in the area. This feature, in comparison with all other *RCCF* features detected during the current investigation, is probably the best example of a preserved relic channel cut and fill feature imaged by the subbottom profiler. On the southern side of the navigation channel subbottom profiler data show a younger relic channel incising the primary *RCCF* feature identified. Figure 7, a fence diagram that was constructed based on subbottom data acquired along a longitudinal and a cross-river survey track in the area, identifies both the primary (shaded red) and younger *RCCF* features (shaded orange).

The subbottom profiler revealed numerous flat-lying reflectors underlying the *RCCF* feature. ACOE boring SHE-14, drilled on the northern side of the navigation channel within the *RCCF* feature, provided the necessary information to identify which reflector correlates with the upper surface of limestone. A second ACOE boring, SH-327, was also drilled within this



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RCCF feature. However, SH-327 was a shallow boring and did not penetrate deep enough to sample sediments and/or the limestone below the *RCCF* feature.

The maximum the *RCCF* feature appears to have incised in this area is to approximately -70' MLW. The minimum thickness of Miocene sediments observed below the base of the *RCCF* feature and above the top of limestone is approximately 28 feet. Subbottom data suggest that the upper surface of limestone lies at approximately -98' MLW in this area.

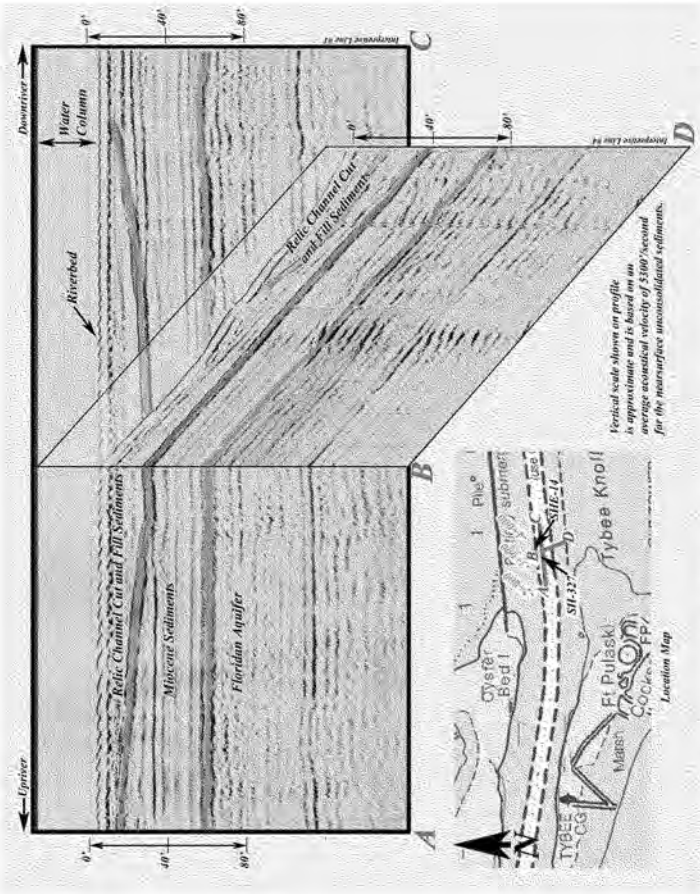


Figure 7 – Constructed subbottom profile sections of RCCF features identified between Savannah River Stations -2+000 and -4+000. Note the second RCCF feature incising the primary RCCF feature in the B to D profile.

3.2.6 RCCF 7 (OSI Drawing 04ES007.2, Sheet 3)

The *RCCF* feature detected between Stations -9+000 and -13+000 is a complex feature that extends across the river between the north and south offset tracklines. On the north side of the channel, the feature is actually comprised of two cut and fill features juxtaposed on one another. Figure 8, a representative profile constructed from three subbottom profile sections acquired in the area, illustrates the relationship between the two identified *RCCF* features. Note that it appears that the *RCCF* feature shaded orange in the figure, identified on the north side of the channel, has actually incised the *RCCF* feature shade red that extends across the river from the south.

Nearsurface gaseous sediments reduced subbottom penetration and made it difficult to trace reflectors along several survey tracklines in the area. However, successful subbottom penetration attained on adjacent tracklines provided the data necessary to construct the representative contour plots of the *RCCF* feature and top of limestone. Figure 9, provides the four primary sections of subbottom data used as the basis to construct the contour plots and representative profile of the area.

The maximum the *RCCF* feature appears to have incised in this area is to approximately -67' MLW. The minimum thickness of Miocene sediments observed below the base of the *RCCF* feature and above the top of limestone is 34 feet. The upper surface of limestone in the area was detected between approximately -94 and -105' MLW. ACOE boring SHE-3, located downriver from the identified *RCCF* feature (near Station -14+500), was the principal boring used to reference subsurface reflectors to specific horizons. Since the current survey investigation did not have any tracklines that passed over the SHE-3 boring location, subbottom data acquired during the 1997 OSI survey of the river was used to make this cross-correlation.

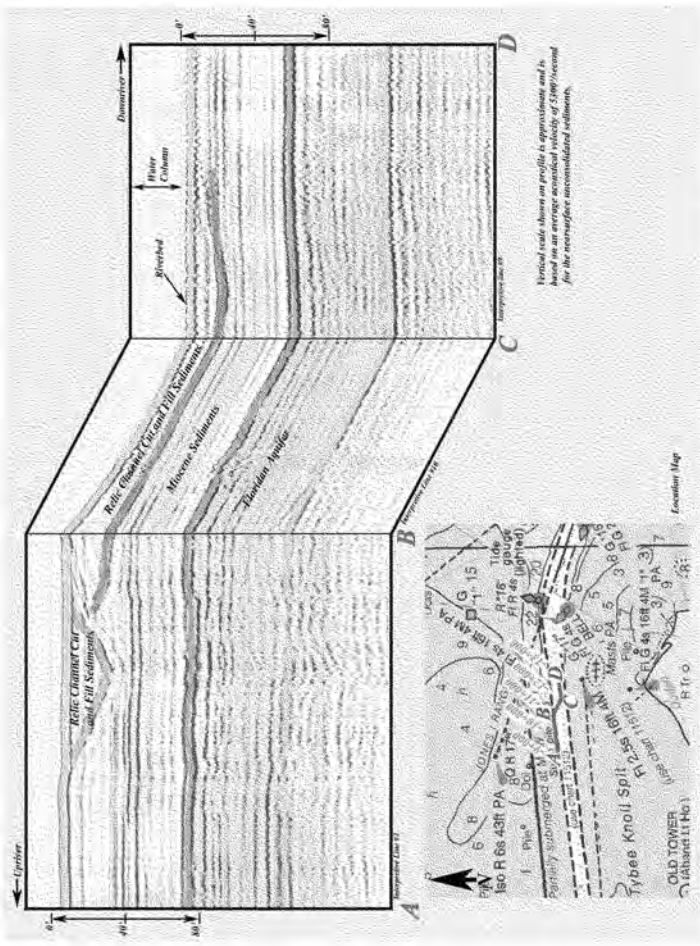


Figure 8 – Constructed subbottom profile sections of *RCCF* features identified between Savannah River Stations -9+000 and -13+000. Note the second *RCCF* feature incising the primary *RCCF* feature in the A to B section.

3.2.7 RCCF 8 (OSI Drawing 04ES007.2, Sheet 3)

The *RCCF* feature detected between Stations -19+000 and -23+000 is the second largest *RCCF* feature identified during this investigation (second only to *RCCF 4* identified between Stations 7+000 and 12+000). The feature appears to extend across the river and was detected underlying both the north and south offset survey lines and all lines between. A review of subbottom data suggests a reworking of the nearsurface sediments in the area. This reworking is more pronounced in an offshore direction and in some areas appears to have masked detection or removed the downriver side of the *RCCF* feature. Several minor pockets of nearsurface gaseous sediments were also observed in the area where the *RCCF* feature was detected, but their presence did not adversely impact the interpretation.

Two ACOE borings were drilled in the vicinity of the *RCCF 8* feature. ACOE boring SHE-4 was located just outside the southern edge of the navigation channel and was drilled to the underlying limestone. This boring formed the basis for identifying the reflector correlative with the upper limestone surface in the area. A second ACOE boring, SHE-6, located just inside the southern edge of the navigation channel and within the *RCCF* feature, provided data to characterize the sediments in the feature, but was a shallow boring and did not penetrate deep enough to sample sediments and/or the limestone below the *RCCF* feature. Figure 10, a representative fence diagram constructed from three subbottom profile sections acquired in the area, illustrates the *RCCF 8* feature and identifies the location of the two ACOE borings drilled in the area.

The maximum the *RCCF* feature appears to have incised in this area is to approximately -73' MLW. The minimum thickness of Miocene sediments observed below the base of this *RCCF* feature and the top of limestone is 36 feet. In the area where the *RCCF* feature was detected, the upper surface of limestone appears to fluctuate around -110' MLW.

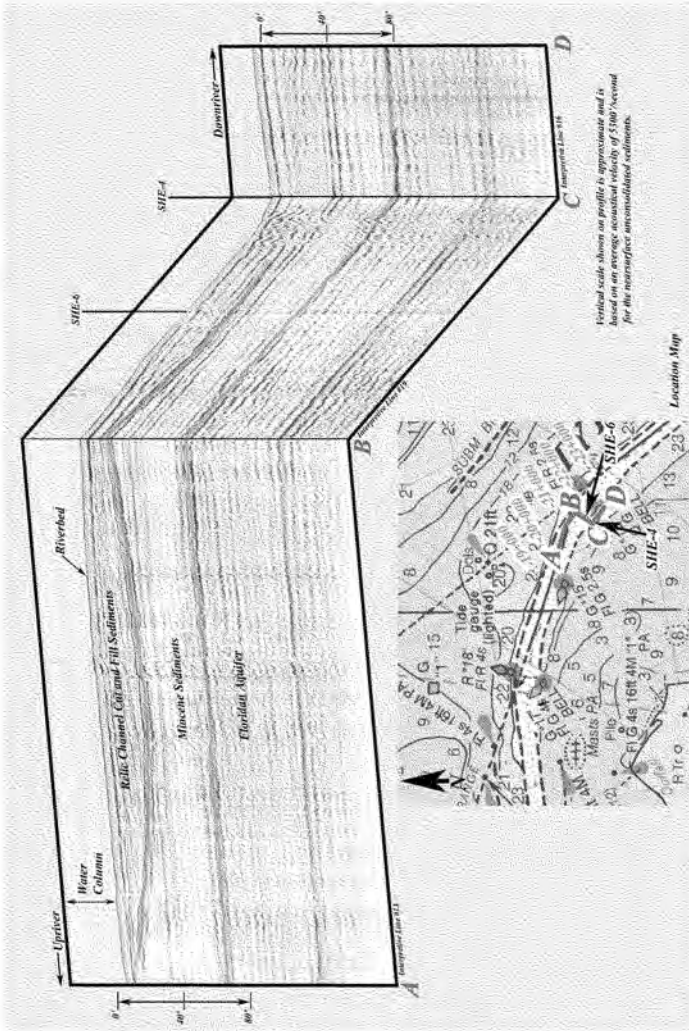


Figure 10 – Constructed subbottom profile sections of RCCF features identified between Savannah River Stations -19+000 and -23+000. Note the locations of the two ACOE borings accomplished in the area, SHE-4 was used to identify the limestone reflector.

4.0 SUMMARY

A major source of fresh water for the Savannah area is the Floridan Aquifer. The Aquifer is a porous limestone that underlies a sequence of unconsolidated sediments in the Savannah River. The ACOE-Savannah District is charged with maintaining the Savannah River Entrance Channel and is considering deepening the channel. As part of the overall project the ACOE needs to assess the impact dredging would have on the Aquifer underlying the river.

Previous geophysical surveys have identified relic stream channels located beneath the Savannah River. These features, underlying the entrance channel (between Savannah River Stations 30+000 and -30+000), incise a sequence of Miocene-age sediments that serve as the Floridan Aquifer's confining unit. If these relic stream channel cuts were in-filled by higher permeability sediments (than those comprising the confining unit), then deepening the channel might result in a more direct migration pathway for saltwater intrusion to the underlying aquifer system than currently exists. The geophysical survey described herein was designed to identify (by means of a high-resolution subbottom profiler) all of the significant relic stream channel features within the survey area. Separate studies, designed by the ACOE, conducted by others, are addressing other issues such as the composition and permeability of the fill sediments within the relic channel features. Detailed comparison of sedimentary composition is therefore not included in this report.

Subbottom profiling data acquired during the current investigation confirmed the presence of several previously identified relic channel cut and fill (*RCCF*) features in the entrance channel and identified several new features, which until this survey had not yet been recognized. In total, eight *RCCF* features that appeared significant were identified in the Savannah River Entrance Channel. The significant *RCCF* features detected during the current investigation are referenced as *RCCF 1-8*. For each of these areas, subbottom reflectors, correlative with the base of the *RCCF* features and the upper surface of the

underlying limestone surface (Floridan Aquifer), have been referenced to project datum (MLW). These data formed the basis to construct the plan view contour plots and profiles included with this report. The thickness of recent sediment deposits overlying the *RCCF* features was minimal and/or not discernable by the subbottom profiler utilized during this investigation and hence is not represented on the contour plots or profiles. It is believed that natural erosional processes in the river and/or maintenance dredging of the current navigation channel have removed these deposits. The following table identifies the location of each of the *RCCF* features and summarizes the maximum incision depths of the features into the Miocene sediment sequence, the average depth at which limestone exists below the identified features, and the minimum thickness of sediment detected between the base of the *RCCF* features and the upper surface of the underlying limestone. Depths presented in the following table are based on the interpretation of subbottom profiling records. Considering the resolution of the boomer subbottom profiler and the assumptions made to convert raw subbottom data to depths referenced to the project vertical datum, the accuracy of the interpretation is approximately +/- 10% of the mapped depth of the correlative reflectors. This accuracy should be taken into account when reviewing the project and comparing depths in the following table.

<i>Feature Designation</i>	<i>Feature centered on approximate Savannah River Station</i>	<i>Maximum Incision depth of RCCF feature (MLW)</i>	<i>Average depth of upper limestone surface (MLW)</i>	<i>Minimum thickness of sediment detected between base of RCCF feature and upper limestone surface (Floridan Aquifer)</i>
<i>RCCF 1</i>	Station 22+000	-80'	-116'	36'
<i>RCCF 2</i>	Station 20+000	-64'	-116'	55'
<i>RCCF 3</i>	Station 15+000	-74'	-112'	42'
<i>RCCF 4</i>	Station 9+000	-83'	-108'	26'
<i>RCCF 5</i>	Station 1+500	-70'	-107'	38'
<i>RCCF 6</i>	Station -3+000	-70'	-98'	28'
<i>RCCF 7</i>	Station -11+000	-67'	-99'	34'
<i>RCCF 8</i>	Station -21+000	-73'	-110'	36'

As summarized in the preceding table, the *RCCF 4* feature appears to have incised more deeply into the Miocene confining unit than any of the other features detected in the entrance channel. This feature, detected between Savannah River Station 7+000 and 12+000, also impacts a much larger area than any of the other *RCCF* features identified.

In general, subbottom data suggest that the *RCCF* features identified in the entrance channel are oriented perpendicular to the present-day course of the river and maintain a general north-south orientation. These findings suggest that historic drainage patterns in the area differed significantly from present-day patterns and/or that survey trackline orientation may have played a role in the ability to detect the *RCCF* features. A large percent of survey tracklines (during the recent and past survey investigations of the river) were oriented parallel to the river's course. Survey tracklines oriented parallel to the river's course are more conducive to detecting features oriented perpendicular or oblique to the river's course. It is possible that *RCCF* features oriented parallel to the river's course and not within the boundaries of the limited cross-river survey tracklines investigated may not have been recognized or their presence may have been masked among other subsurface reflectors identified in the area. Future surveys might consider acquisition of subbottom data along a series of evenly spaced cross-river survey transects lines to supplement data acquired during this investigation.

Historic ACOE boring logs provided lithological descriptions for correlation with subbottom reflectors identified during the survey and enhanced the geophysical interpretation. Since the completion of this survey investigation, OSI has been in communication with the ACOE-Savannah District and has helped to identify areas where additional borings may be most useful to support the objectives of the project and further groundtruth the acquired subbottom data set. It is recommended that the results of any additional boring programs be reviewed with the subbottom data to further confirm the interpretation presented herein.

5.0 REFERENCES

- Foyle, A.M., Henry Jr., V.J., and Alexander, C.R., 2001. The Miocene Aquitard and the Floridan Aquifer of the Georgia / South Carolina Coast: Geophysical Mapping of Potential Seawater Intrusion Sites, Georgia Department of Natural Resources Bulletin 132.
- Ocean Surveys, Inc., 1998. Final Report Submitted to the U.S. Army Corps Of Engineers – Savannah District” Entitled “Geophysical Investigation, Savannah Harbor, Savannah, Georgia, OSI Report No. 97ES076.
- U.S. Army Corps of Engineers, 1998. Savannah Harbor Expansion Feasibility Study, <http://www.sysconn.com/harbor/Study%20Reports/1998%20Aquifer/98Aquifer.html>.

APPENDIX I**EQUIPMENT SPECIFICATION SHEETS**



SURVEYING AND MAPPING PRODUCTS

7400MSi

High precision real-time GPS receiver for dynamic control systems

Real-time centimeter guidance for a wide range of applications.

The 7400MSi is Trimble's fourth generation real-time kinematic (RTK) GPS system, representing major technological breakthroughs. It offers low-latency, fast-update centimeter accuracy positioning. Designed specifically for dynamic machine control applications, it is the most advanced GPS receiver available today.

Based on Trimble's field-proven RTK technology, the 7400MSi features fully automatic (fly-the-fly) initialization. Centimeter-level position updates are computed five times per second with a latency of less than 2/10ths of a second. This ensures the response and accuracy necessary for precise dynamic applications on moving equipment.

The 7400MSi delivers both performance and simple interfacing. The receiver is designed for reliable operation in construction, mining and other precise positioning environments. Trimble's Supertrak™ multi-bit GPS signal technology provides superior satellite tracking in the most adverse environments, including the presence of radio interference. Trimble's Maxwell GPS chip architecture enables the 7400MSi to provide sub-meter accuracy positions prior to initialization and rapid reliable initialization for centimeter accuracy on the move.

The 7400MSi provides a simple interface to PC-computer, external processing devices, or control systems via any one of its four serial ports. An easy-to-use application file interface enables a user to completely program the receiver operations with a single command. Real-time kinematic

operation, the active coordinate system and all other receiver operations can be set using the application file interface or by the included Remote Controller software. The 7400MSi can be configured as an autonomous reference station or a moving unit. Streamlined outputs are sent from the receiver to give detailed information which includes position, quality assurance data and GPS satellite information. Coordinates can be output in user-defined or pre-loaded datum and map projection reference frames. The receiver also includes a one pulse per second (PPS) output for precise timing of other interfaced equipment.

The 7400MSi addresses a vast range of applications that include construction and mining equipment positioning, robotic equipment control, marine construction and hydrographic surveying.



7400MSi

Standard Features

- Centimeter accuracy, real-time positioning
- 9Hz position updates
- Automatic OTF/on-the-fly initialization while moving
- Super-trak™ signal processing technology
- 4 serial I/O ports
- Outputs local coordinates direct from receiver
- 1 PPS output
- Remote Controller™ software
- Rugged, lightweight, power efficient
- One year hardware warranty
- Quickplan™ software for mission planning

Options and Accessories

- Rugged L1/L2 Antenna
- Compact L1/L2 antenna
- Permanent mount L1/L2 Antenna
- Removable Antenna Groundplane
- Antenna weather dome
- Office support module: OSM or OSMII
- Receiver transport case
- 6Ah, 10Ah, or camcorder batteries
- External frequency input
- 30m antenna cable
- 10m antenna cable
- Extended hardware warranty
- Firmware and Software update service
- Site training

Ordering Information

7400MSi Part Number 27755-00
Includes 7400 MSi receiver, Remote Controller software, Configuration (pdf), Operating manual, 5-pin Lemo to DB9 cable, 7-pin Lemo to DB9 cable, Power input cable

Physical Characteristics

GPS Receiver	
Size:	28cm x 28cm x 8cm
Weight:	2.8kg
Power:	Nominal 10.5-35 VDC, 9 watts
Operating temp:	-25° to +55°C
Storage temp:	-40° to +75°C
Humidity:	100% fully sealed

Technical Specifications

Tracking:	9 channels L1 C/A code, L1/L2 full cycle carrier. Fully operational during V code encryption.	
Signal processing:	Multi-bit Maxwell architecture, very low noise C/A code processing, multipath suppression	
Positioning:		
Mode	Latency	Accuracy
L1C	0.4 second	3cm ± 3ppm (from baseline length) Horizontal 3cm ± 3ppm (from baseline length) Vertical
L1E	<0.2 second	3cm ± 3ppm (from baseline length) Horizontal 3cm ± 3ppm (from baseline length) Vertical
1. Depend on radio link latency		
2. 1 ppm/100m, worse with 50 cm/s and satellite geometry		
Initialization:	Automatic while moving or static	
Time required:	Typically <1 minute	
Range:	Up to 10km	
Start-up:	± 2 minutes from power on to accuracy start ± 30 seconds with recent ephemeris	
Communications:	4 x RS232 ports. Band runs up to 38,400	
Configuration:	Configuration of modules via user definable application files	
Remote Control:	Full control & display of receiver operations via graphical user interface software running remotely under Microsoft Windows	
Output Formats:	NMEA-0183 (GPRMC, GGA, ZDA) Trimble Binary Streamed Output	

ADVISORY NOTICE: This receiver uses the GPS P-code signal, which by U.S. policy may be restricted or withdrawn without notice.

Specifications and descriptions subject to change without notice.



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Coastal Oceanographics, Inc.



Hydrographic Survey Software

HYPACK® is PC-based Windows software for planning, conducting, editing and publishing hydrographic surveys. Read on for additional information about each of HYPACK®'s software modules.

Design

HYPACK® MAX contains powerful tools that let you quickly design your survey and display your results. Its powerful drawing engine can display background files in DXF, DGN, TIF, S-57, BSB raster, C-Map, and VPF files at any rotation and scale. Design tools allow you to quickly create planned lines. HYPACK® MAX automatically stores your information to a project directory, allowing you to set up new surveys or to quickly switch to an existing survey. All of this in the easy drag-and-drop environment of Windows® 95, 98, or NT.



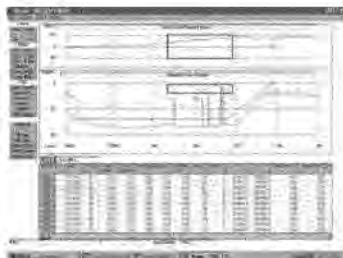
Survey

HYPACK® MAX's SURVEY program allows the flexibility and power needed to perform your work. It supports GPS, Range-Azimuth, and Range-Range navigation systems. It supports single beam, dual frequency, multiple transducer, and multibeam echosounders, along with gyros, magnetometers, telemetry tide gauges, and other survey devices. The SURVEY program can be configured to display and track single vessels, multiple vessels, or the main vessel and ROVs or towfish. Users can display the vessel positions against background files of DXF, DGN, TIF, S-57, BSB, C-Map, or VPF file format.



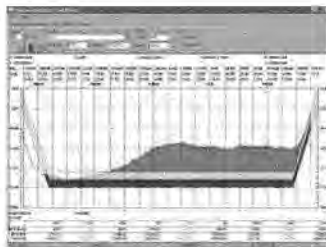
Editing

HYPACK® MAX's graphical editing routines allow you to quickly edit your survey data. Water level corrections can be automatically determined using RTK GPS water level techniques, telemetry tide gauges, manual observations, or downloaded from NOAA web sites. Sound velocity corrections can be applied. Users can quickly review and edit individual points or blocks of data. HYPACK® MAX's new "Field to Finish" process now allows you to automatically remove data spikes, perform final sounding selection, and generate smooth sheets or export info to CAD before you hit the dock.



Final Products

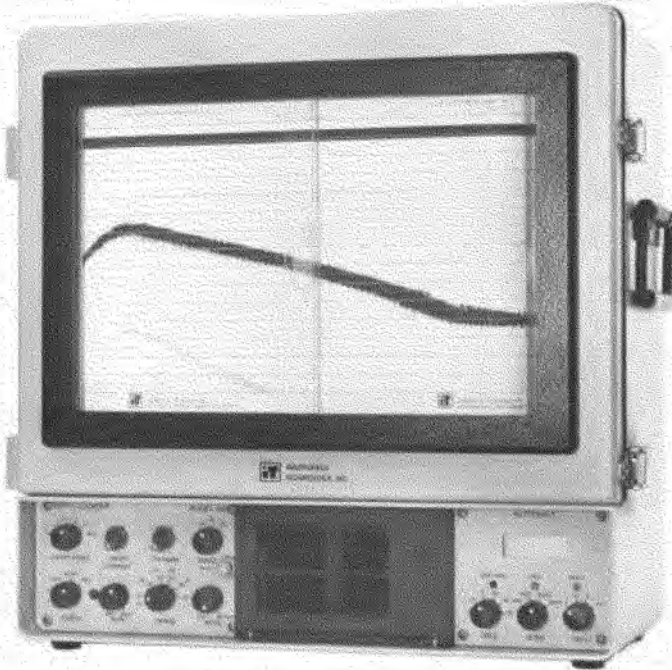
What really puts HYPACK® MAX above the other hydrographic packages is the variety of final product programs. The Cross Section and Volume program is the standard used by the U.S. Army Corps of Engineers for calculation of dredge volume quantities throughout the USA. The Surface Modeling program generates 3-D models, contours, and also computes volumes between surfaces for beach erosion studies. The Export program allows users to import HYPACK® MAX data into CAD and GIS packages in either DXF or DGN format.



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INNERSPACE

THERMAL DEPTH SOUNDER RECORDER MODEL 448



DESCRIPTION

The Innerspace Technology Model 448 Thermal Depth Sounder Recorder provides survey precision, high resolution depth recordings using SOLID STATE THERMAL PRINTING. The lightweight, portable unit is designed for use in small boat surveying as required for nautical chart production, engineering surveys, harbor and channel maintenance, pre and post dredge surveys, etc. The Model 448 TDSR uses a thermal printing technique pioneered by Innerspace for depth sounding which provides the high resolution and accuracy required by groups such as the U.S. Army Corps of Engineers, dredging companies, survey companies, port administrations, etc. The state of the art design allows integration into portable hydrographic survey systems.



INNERSPACE TECHNOLOGY, INC.

OPERATION

The Model 448 TDSR utilizes the highest resolution, solid state, fixed thermal print head available for depth sounding. Blank white, high contrast thermal paper is used to print the selected range scale along with the depth. The depth is always read directly from the scale printed, thereby avoiding the possible confusion encountered when examining out-moded, preprinted, multi-scaled charts. Built-in chart annotation is standard and includes printing of numerical values for Speed of Sound, Tide and Draft. Time and event marks are numerically annotated and the chart is automatically labeled FEET or METERS as determined by the MODE switch.

Operator controls are provided on a gasketed, splashproof front panel. Thumbwheel switch settings are behind a splashproof access cover on the front panel, and the digitizer controls and display are provided on a front panel plug in module.

The microprocessor controlled sounder/recorder utilizes plug in printed circuit boards, a modular plug in power supply and plug in modular digitizer. Minimum wiring connections help provide an extremely reliable and serviceable unit. A preprogrammed test routine and diagnostic LED indicators provide valuable assistance for the operator and/or electronics technician. The single package portable unit may be used vertically or horizontally and can be powered from either an AC or DC source.

FEATURES

- **LOW COST**
- **RELIABLE**
- **THERMAL PRINTING** fixed head—no stylus to replace
- **CLEAN** operation—no carbon dust residue
- **QUIET** operation—no rotating stylus, no arcing
- **ODORLESS** operation—no burned paper
- **LARGE VIEWING** area with sliding window
- **LARGE CHART** standard format—high resolution
- **BLANK PAPER** is high contrast black on white and low in cost
- **PORTABLE** and lightweight for small boat operation
- **MICROPROCESSOR** controlled
- **SCALE SELECTED** is the only one printed
- **FEET or METERS** operation—switch selectable
- **THUMBWHEEL SETTINGS** for speed of sound, tide and draft
- **ANNOTATION** of all parameters appear on recordings in chart margin
Speed of Sound, Tide, Draft, Event, Time and Mode of Operation
- **TVG** (time varied gain) minimizes gain adjustments
- **INTERNAL** micro controlled depth digitizer
- **EXTERNAL** depth digitizer connector on rear panel
- **NO ADJUSTMENTS** for zero line or call line are required

OPTIONS

CUSTOM LOGO—Programs recorder to repetitively print, in the lower chart margin, customer specified information such as user's logo, name, address, etc.

SPECIFICATIONS—SINGLE FREQUENCY TDSR MODEL 448

PRINTING	Thermal solid state fixed head thick film
CHART PAPER	8- $\frac{3}{4}$ inches x 200 feet
PAPER SPEEDS	.5, 1, 2, 4 or 8 inches/min. (Depends on scale selected)
DEPTH RANGES	0 to 335 feet or 0 to 80 meters. 6 overlapping phases of 60 feet or 15 meters A x 2 SWITCH multiplies each range by a factor of 2 and A x .5 SWITCH multiplies each range by a factor of .5
ACCURACY	$\pm$.1 foot or meter timing and printing resolution
SPEED OF SOUND	Thumbwheel switch selectable 4550 to 5050 feet/sec. or 1350 to 1550 meters/sec. Precision crystal referenced frequency synthesizer using a phase locked loop provides exact calibration.
TIDE	Thumbwheel switch selectable from 0 to $\pm$ 25.0 feet or meters
DRAFT	Thumbwheel switch selectable from 0 to + 99.9 feet or meters
EVENT MARK	Front panel switch or remote, increments internal counter
TIME	Internal clock with battery backup
SOUNDER FREQUENCY	208 kHz or 125 kHz standard or others optional
TRANSDUCERS	208 kHz 8 degree beamwidth at -3db 208 kHz 3 degree beamwidth at -3db (optional) 125 kHz 14 degree beamwidth at -3db (optional)
PULSE LENGTH	.15 to .6 ms. Automatically determined by frequency and depth range selected
PULSE POWER	250 watts RMS
SOUNDING RATE	1,200 soundings per minute max
TIME VARIED GAIN (TVG)	Automatically compensates for spreading loss and attenuation over depth range
GAIN CONTROL	Provides manual gain adjustment
STANDBY MODE	Allows transceiver and digitizer (if used) to operate without running chart paper
OUT OF PAPER SENSOR	Indicated by blinking front panel light. Paper motion stops, but sounding continues.
RAPID PAPER ADVANCE	Front panel switch allows for the rapid advance of blank paper
ANNOTATION	The numerical value of Speed of Sound, Tide, Draft, Time and Event are permanently recorded above the chart record periodically.

DIGITIZER OUTPUT	In addition to the built in depth digitizer, Start/Stop pulses are available for use with external digitizers such as Inner-space Models 410, 412 and 445.
POWER	Either 12, 24 V DC or 120, 240 V AC (Must be specified AC or DC)
DIMENSIONS	17 in. W x 17 1/4 in. H x 9 1/4 in. D
WEIGHT	45 pounds
ENCLOSURE	Coated aluminum, corrosion resistant and splashproof. Sliding window for chart access and settings door for easy access to thumbwheel switches.

SPECIFICATIONS—INTERNAL MICROPROCESSOR DIGITIZER

OPERATING MODES	Either a DIRECT, GATED, AUTO or MANUAL mode may be chosen <table> <tr> <td>DIRECT</td><td>— No gate present</td></tr> <tr> <td>GATED</td><td>— Gate width doubles, then quadruples automatically to reacquire the bottom reply</td></tr> <tr> <td>AUTO</td><td>— Gate width doubles, quadruples then goes to non-gated automatically to reacquire the bottom reply</td></tr> <tr> <td>MANUAL</td><td>— Fixed gate as preset on initial depth thumbwheel</td></tr> </table>	DIRECT	— No gate present	GATED	— Gate width doubles, then quadruples automatically to reacquire the bottom reply	AUTO	— Gate width doubles, quadruples then goes to non-gated automatically to reacquire the bottom reply	MANUAL	— Fixed gate as preset on initial depth thumbwheel
DIRECT	— No gate present								
GATED	— Gate width doubles, then quadruples automatically to reacquire the bottom reply								
AUTO	— Gate width doubles, quadruples then goes to non-gated automatically to reacquire the bottom reply								
MANUAL	— Fixed gate as preset on initial depth thumbwheel								
GATE WIDTH	Selectable 2, 4, 8, 20, 40 or 80 via rotary switch. Gate width in feet or meters, determined by the recorder MODE switch setting								
MISSED REPLIES	REPLY switch selects 2, 4, 8 or 16 missed replies, before reacquisition of bottom reply, in AUTO mode.								
DISPLAY	Four digit LCD 7 segment. Resolution to 0.1 feet or meters, determined by the recorder MODE switch setting.								
INDICATORS	Three LED's representing BAD DATA, REPLY and depth GATE								
INITIAL DEPTH	Three station thumbwheel switch allows entry of an initial depth gate position								
ALARM	A switched audible alarm indicates loss of track								
OUTPUTS	BCD—8421 TTL compatible 5V positive logic. Buffered outputs with data hold, inhibit, strobe and flag lines. IEEE488 GPIB—4 digits with proper protocol and selectable address switches (optional) EIA RS232C—4 digits with selectable baud rates (optional). A bad data flag is available and can optionally set the output number to all zeros.								

**INNERSPACE TECHNOLOGY, INC.**

SEISMIC REFLECTION PROFILING "BOOMER" SYSTEM

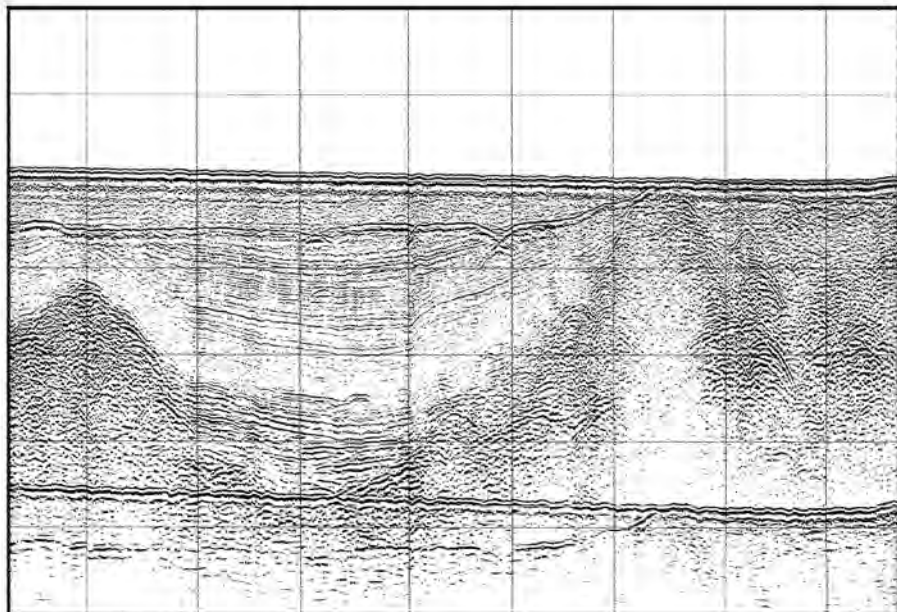
The 100-1000 joule Boomer is a moderate to deep penetration, moderate resolution sound transducer utilized for widely varied seismic profiling applications. The electromechanical sound transducer is mounted on a catamaran and is designed to operate with the capacitance energy sources, and matching hydrophone streamer array. This system is typically interfaced with a digital seismic processor for signal amplification, filtering, and TVG controls, and a thermal graphic recorder for displaying the seismic profiles.



The "Boomer's" unique electromechanical assembly consists of an insulated metal plate and rubber diaphragm adjacent to a flat-wound electrical coil. A short duration, high power electrical pulse discharges from the separate energy sources into the coil and the resultant magnetic field explosively repels the metal plate. The plate motion in the water generates a single broadband acoustic pressure pulse.

The elimination of the strong cavitation or ringing pulse associated with the Sparkers, combined with the broadband frequency spectrum, (1) permits the bottom echo to appear as a fine line; and (2) provides a clear cross-sectional record of subbottom materials to depths exceeding 250 feet (given appropriate site conditions). The system operates equally well in salt or fresh water.

Applications for the Boomer include reconnaissance geological surveys, mineral exploration, foundation studies for offshore platforms, harbor development, and cable/pipeline crossing surveys.



SPECIFICATIONS

Pulse Character Energy Level	@300 watt-seconds
Duration	0.2 milliseconds
Source Level	107 db ref. 1 microbar at 1 meter
Spectrum	400 Hz to 8 kHz
Repetition Rate	1-4 pulses/second
Dimensions	84 cm (W) x 59 cm (H) x 158 cm (L) (33 in x 23 in x 62 in)
Weight	90 kg (200 lbs)
Cable Length	25 meters (80 ft)
Towing Speed	2-5 knots

OCEAN SURVEYS, INC.

Specialists in Marine & Freshwater Site Surveys



Corporate Headquarters:
91 Sheffield Street
Old Saybrook, CT 06475

Tel: 860/388-4631
Fax: 860/388-5879
www.oceansurveys.com



product data sheet

TSS 360 series 360 Shallow Seismic Processor

The cost-effective solution to shallow seismic processing

Many shallow seismic survey operations such as pre-drilling, dredging, sewage outfall, construction, pipeline route and aggregate surveys are degraded by the distorting effects of attenuation, noise interference, motion distortion and seabed absorption.

Specifically designed for use anywhere from the shoreline up to the edge of the continental shelf, the TSS 360 Shallow Seismic Processor employs sophisticated processing to improve data quality, offering flexibility in a compact easy-to-use survey instrument.



Seismic profile before
and after 360 processing



The unit accepts data from any single channel hydrophone and provides high quality information for hard copy, analogue and digital storage for translation by interpretation workstations.

- Pre-drilling
- Dredging
- Sewage outfall
- Pipeline route and aggregate surveys

Features

- Multifunctional processing:
 - time variant gain/trim
 - pass filtering
 - time period blanking
 - lateral swell filter
 - enhanced resolution facility
- User friendly
- 8001T built-in logging option
- Service facilities

Benefits

- Enables cost-effective upgrade of existing equipment:
 - improves edges
 - enhances signal to noise ratio
 - extends weather window
 - accurate and cost-effective event recording
- Ease of use in all survey conditions
- Meets industry standard for data storage
- Enables on-line quality control

Confidence in retrieval of survey data

EPC

MODEL GSP-1086 SERIES GRAY SCALE PRINTER



The EPC Model GSP-1086 is an all purpose, continuous image printer. Photographic quality images are printed using a 2048 pixel thermal printhead with a dot density of eight dots/millimeter. Pixel depth is selectable up to eight bits.

Two LCD displays and a sealed membrane control panel provide the operator with a simple user interface which displays system status at all times. Because the control panel is software defined, the printer can easily be configured for a wide range of custom applications.

Sonar and imaging applications are easily accommodated by the 1086's standard interface suite: Dual Channel Analog, Centronics Compatible Parallel, and RS-232 Serial I/O.

Keeping with EPC tradition, the 1086 is packaged in a rugged, field-ready sheet metal case. An optional transport case and rack mount kit are available for ship-of-opportunity and fixed based operations, respectively.

The 500 Series incorporates exciting new features like Bandpass Filtering and Time Varied Gain. Data throughput, system diagnostics, and reliability have also been improved in the 500 Series. A mini keyboard, tie-down loops and enhanced documentation are included.

EPC LABORATORIES INC., 42A Cherry Hill Drive, Danvers, MA 01923 USA. PHONE: (978) 777-1996
FAX: (978) 777-3955 EMAIL: sales@epclabs.com WEB: <http://www.epclabs.com>

HARDWARE

Host Processor:
486DX2 /66 MHz
CPU Bus:
16 Bit Industry Standard Architecture (ISA)
Control Panel:
Sealed membrane type, software defined
Displays:
Twin 2x40 LCD displays with LED backlights

POWER

Power Supply:
350 Watt, auto-sensing, universal input
84-265 VAC, 50-60 Hz
Power Consumption:
80 Watts non-printing
130 Watts Peak

PHYSICAL

Dimensions & Weight:
17.6"W x 19.3"H x 6.7"D
50 LBS.
Media:
Heat sensitive thermal paper or high grade
plastic film - 234dB dynamic range
Paper Length: 150 feet
Film Length: 120 feet
Temperature (non-condensing):
0°C to 65°C - Operating
-28°C to 65°C - Storage

PRINTING

Gray Levels & Resolution:
Selectable: 8, 16, 32, 64 Levels
Printhead: 2048 Pixels @ 203 DPI
Maximum Line Speeds (normal):
@ 8 Shades: 15 ms
@ 16 Shades: 18 ms
@ 32 Shades: 26 ms
@ 64 Shades: 43 ms
Chart Speeds (Lines Per Inch):
Fixed: 75, 80, 100, 120, 150, 200, 240, 300
Variable: 1.6 kHz max clock, BNC input
1 / 1200 lines per inch

Warranty: One Year Limited Parts & Labor

ANALOG INTERFACE

Dual Signal Inputs:
0V to 10V SIGNAL BNC inputs
(2KW input impedance)
External Trigger Input (pulse):
TTL EXT TRIG BNC input with slope sense
Internal Key Output (master)
TTL KEY OUT BNC with polarity selection
(62.5us pulse width)
Gain, Threshold, Polarity:
Independent controls for each channel
Minimum printable signal 150 mV
Time Bases:
1.5 MHz A/Ds with 8 Bit resolution
Scan - 5 ms to 10 secs, 1 ms resolution
Key - 5 ms to 10 secs, 1 ms resolution
Delay - 0 secs to 8 secs, 1 ms resolution

PARALLEL INTERFACE

Interconnect:
25 Pin Sub D, metal shell
Data Input (Lines 2-9):
Eight Bit Centronics Compatible
2048 bytes per raster line
White = 0300; Black = selectable
Handshakes:
Low Active host/STB on Pin 1
Low Active printer/ACK on Pin 10
High Active printer BUSY on Pin 11
BUSY cycles on end of line (2048 bytes)
/ACK cycles on every /STB
Burst Rate Bandwidth: Over 250 kHz
Sustained Bandwidth: Based on gray level

COMMAND INTERFACE

QWERTY Keyboard
Jack for commands and annotation
RS-232 Serial Data Input (DCE)
9 Pin Sub "D" for commands & GPS

NEW FEATURES

Time Varied Gain:
255 Logarithmic curves to choose from.
Band Pass Filtering:
LOW PASS: 1kHz, 1.2kHz, 2kHz, 2.4kHz, 3kHz,
4kHz, 6k and 12kHz
HIGH PASS: 83Hz, 100Hz, 166Hz, 200Hz, 250Hz,
333Hz, 500Hz and 1kHz.

Specifications subject to change



EPC LABORATORIES INC., 42A Cherry Hill Drive, Danvers, MA 01923 USA PHONE: (978) 777-1996
FAX: (978) 777-3955 EMAIL: sales@epclabs.com WEB: <http://www.epclabs.com>

APPENDIX II

SURVEY FIELD LOG

OCEAN SURVEYS, INC.

Date	Run	Line	BOL event	EOL event	HYPACK* MAX File Name	SEG Y file	Event SEG Y file opened	Survey line river direction	ACOE boring accomplished on survey line	Comment
2/13/2004	1	2	132	277	002_1340.044	13020400 SEG	149	up-down		Recon offset south - end @ Sta -11, actual begin event 149
						13020401 SEG	189			
						13020402 SEG	229			
						13020403 SEG	272			
2/13/2004	2	1	278	372	001_1451.044	13020404 SEG	278	down-up		Recon offset north
						13020405 SEG	331			
2/13/2004	3	1	373	455	001_1533.044	13020406 SEG	373	down-up	SHE-14	
						13020407 SEG	438			
2/13/2004	4	1	456	774	001_1638.044	13020408 SEG	456	down-up	SHE-2	SHE-2 boring offline
						13020409 SEG	526		SHE-12	
						13020410 SEG	587			
						13020411 SEG	647			
						13020412 SEG	700			end of line lost kinematic GPS / diff mode
2/13/2004	5	2	775	984	002_1852.044	13020413 SEG	775	up-down		
						13020414 SEG	847			
						13020415 SEG	909			
2/13/2004	6	1	985	1170	001_2006.044	13020416 SEG	985	down-up		begin of line lost kinematic GPS / diff mode
						13020417 SEG	1034			
						13020418 SEG	1073			
2/14/2004	7	2	1172	1299	002_1540.045	13020419 SEG	1109	up-down	SHE-3	SHE-3 boring offline
						14020400 SEG	1171			Recon offset

Geophysical Survey Investigation, Subbottom Profiling
Savannah River Entrance Channel, Savannah, Georgia

Appendix II-1

OCEAN SURVEYS, INC.

Date	Run	Line	BOL event	EOL event	HYPACK * MAX File Name	SEG Y file	Event SEG Y file opened	Survey line river direction	ACOE boring accomplished on survey line	Comment
						14020401 SEG	1226			south
						14020402 SEG	1280			
2/14/2004	7 continue	2	1300	1518	002_1630.045	14020403 SEG	1326	up-down	SHE-1	SHE-1 boring offline
						14020404 SEG	1379			
						14020405 SEG	1444			
2/14/2004	8	1	1519	1672	001_1806.045	14020406 SEG	1519	up-down		
						14020407 SEG	1586			
2/14/2004	9	1	1673	1800	001_1908.045	14020408 SEG	1673	down-up	SH-327	
						14020409 SEG	1755			lost kinematic GPS, need to correct file for tide
2/14/2004	10	1	1801	1860	001_1955.045	14020410 SEG	1801	up-down		SH-327 boring offline
2/14/2004	11	2	1861	1878	002_2029.045	14020411 SEG	1861	north- south		
2/14/2004	12	3	1879	1895	003_2037.045	14020412 SEG	1879	south		
2/14/2004	13	4	1896	1905	004_2050.045	14020413 SEG	1896	south- north		448 paper off on- line
2/14/2004	14	4	1906	1920	004_2103.045	14020414 SEG	1906	south- north		448 paper off on- line
2/15/2004	15	1	1921	2027	001_1459.046	15020400 SEG	1921	south- north		Bull River survey line
2/15/2004	16	1	2028	2059	001_1636.046	15020401 SEG	1981			
2/15/2004	17	2	2069	2102	002_1653.046	15020402 SEG	2028	up-down		
2/15/2004	18	1	2103	2131	001_1712.046	15020403 SEG	2069	down-up		
						15020404 SEG	2103	up-down		
2/15/2004	19	4	2134	2164	004A1730.046	15020405 SEG	2134	south- north		

OCEAN SURVEYS, INC.

Date	Run	Line	BOL event	EOL event	HYPACK * MAX File Name	SEG Y file	Event SEG Y file opened	Survey line river direction	ACOE boring accomplished on survey line	Comment
2/15/2004	20	5	2165	2212	005 1800.046	15020406 SEG	2165	up-down		Lost kinematic GPS, end of file RTK float mode
2/15/2004	21	5	2213	2273	005 1830.046	15020407 SEG	2213	up-down		
2/15/2004	22	6	2274	2429	006 1857.046	15020408 SEG	2274	up-down		Offshore channel modification (Sta -30), adverse wx conditions affect data, end of line GPS in stand- alone mode
2/15/2004	23	2	2430	2462	002 2025.046	15020410 SEG	2430	down-up		
2/15/2004	24	1	2463	2495	001 2043.046	15020411 SEG	2463	up-down		
2/15/2004	25	3	2496	2534	003 2100.046	15020412 SEG	2496	down-up	SHE-4, SHE- 6	
2/15/2004	26	1	2535	2560	001 2125.046	15020413 SEG	2535	up-down		
2/15/2004	27	5	2561	2591	005 2136.046	15020414 SEG	2561	down-up		
2/15/2004	28	3	2592	2616	003 2156.046	15020415 SEG	2592	north- south		
2/15/2004	29	2	2617	2637	002 2208.046	15020416 SEG	2617	north- south	SHE-4, SHE- 6	
2/16/2004	30	23	2638	2655	023 1425.047	16020400 SEG	2638	north- south		
2/16/2004	31	23	2656	2672	024 1436.047	16020401 SEG	2656	north- south		
2/16/2004	32	21	2673	2694	021 1447.047	16020402 SEG	2673	down-up		lost kinematic GPS, need to correct file for tidal reference
2/16/2004	33	22	2695	2720	022 1522.047	16020403 SEG	2695	up-down		

Geophysical Survey Investigation, Subbottom Profiling
Savannah River Entrance Channel, Savannah, Georgia

OCEAN SURVEYS, INC.

Date	Run	Line	BOL event	EOL event	HYPACK [®] MAX File Name	SEG Y file	Event SEG Y file opened	Survey line river direction	ACOE boring accomplished on survey line	Comment
2/16/2004	34	26	2721	2764	026 1330.047	16020404 SEG	2721	up-down		
2/16/2004	35	25	2765	2781	025 1551.047	16020405 SEG	2765	north- south	SHE-14	
2/16/2004	36	14	2782	2859	014 1611.047	16020406 SEG	2782	down-up		
2/16/2004	37	16	2860	2932	016 1637.047	16020407 SEG	2860	up-down	SHE-12	SHE-12 boring offline
2/16/2004	38	15	2933	3008	015 1708.047	16020408 SEG	2933	down-up	SHE-13	
2/16/2004	39	17	3009	3025	017 1740.047	16020409 SEG	3009	north- south		
2/16/2004	40	18	3026	3040	018 1754.047	16020410 SEG	3026	south- north	SHE-12, SH- 318	
2/16/2004	41	19	3041	3055	019 1803.047	16020411 SEG	3041	north- south	SHE-13	
2/16/2004	42	20	3056	3071	020 1816.047	16020412 SEG	3056	south- north		
2/16/2004	43	11	3072	3105	011 1834.047	16020413 SEG	3072	down-up		
2/16/2004	44	10	3106	3139	010 1846.047	16020414 SEG	3106	up-down		
2/16/2004	45	13	3140	3173	013 1902.047	16020415 SEG	3140	down-up		
2/16/2004	46	12	3174	3189	012 1919.047	16020416 SEG	3174	south- north	SHE-11	lost kinematic GPS, need to correct file for tidal reference
2/16/2004	47	5	3190	3235	005 1935.047	16020417 SEG	3190	down-up		lost kinematic GPS, need to correct file for tidal reference
2/16/2004	48	6	3236	3279	006 1949.047	16020418 SEG	3236	up-down		
2/16/2004	49	9	3280	3324	009 2011.047	16020419 SEG	3280	down-up		
2/16/2004	50	7	3325	3337	007 2032.047	16020420 SEG	3325	north- south		
2/16/2004	51	8	3338	3352	008 2045.047	16020421 SEG	3338	South-		

Geophysical Survey Investigation, Subbottom Profiling
Savannah River Entrance Channel, Savannah, Georgia

OCEAN SURVEYS, INC.

Date	Run	Line	BOL event	EOL event	HYPACK * MAX File Name	SEG Y file	Event SEG Y file opened	Survey line river direction	ACOE boring accomplished on survey line	Comment
2/16/2004	52	4	3353	3374	004_2058.047	16020422 SEG	3353	down-up		
2/16/2004	53	1	3375	3395	001_2108.047	16020423 SEG	3375	up-down		
2/16/2004	54	3	3396	3410	003_2122.047	16020424 SEG	3396	north- south		
2/16/2004	55	1	3411	3475	001_2149.047	16020425 SEG	3411	down-up		Survey near Elba Island, very end of line GPS non- differential mode

APPENDIX III**SUMMARY TABLE COMPARING ACOE BORING UNITS
AND SUBBOTTOM REFLECTORS
&
MASTER SUMMARY TABLE OF RELIC CHANNEL
CUT AND FILL FEATURES AND LIMESTONE**

Summary Table Comparing ACOE Boring Units and Subbottom Reflectors

Field Run	Interpretive line designation	RCCF feature reference	Approximate navigation event # in vicinity of boring (adjusted for layback)	Boring on-line	Overburden thickness based on core	time to river bed (ms)	time to reflector (ms)	Overburden thickness based on assumed velocity @ core location	Comment
3	North Offset	6	388.7	SHE-14	60.0	14.638	38.372	62.8	Match with limestone contact (Blue reflector)
9	2	6	1769	SHE-127	27.7	20.938	30.587	25.5	Match with A/B contact (yellow reflector), which lies just below relic channel cut, difficult pick since relic channel cut slightly masks underlying reflector
15	4A	6	2768.3	SHE-14	60.0	13.65	37.028	26.5	Match with limestone contact (Blue reflector)
26	16	8	2545	SHE-4	73.2	18.942	45.969	71.6	Match with limestone contact (Blue reflector)
29	19	8	2625.5, 2622	SHE-6, SHE-4	73.2	17.934	45.922	74.2	SHE-6 not deep enough / SHE-4 outside RCCF detectors A/B and limestone contacts (yellow and blue reflectors), match shown on this line with limestone contact (Blue reflector) SHE-4
					37.2	17.934	32.860	39.4	Match shown on this line with A/B contact (yellow reflector) SHE-4

OCEAN SURVEYS, INC.

Field Run	Interpretive line designation	RCCF feature reference	SEG-Y file	Approximate navigation event # in vicinity of boring (adjusted for layback)	Boring on-line	Overburden thickness based on core	time to river bed (ms)	time to reflector (ms)	Overburden thickness based on assumed velocity @ core location	Comment
37	24	4	16020407 SEG	2896.5	SHE-13	62.0	18.816	43.074	64.3	Match with limestone contact (Blue reflector)
						33.0	18.37	31.929	35.0	Match with base of relic channel cut (red reflector)
41	28	4	16020411 SEG	3044.7	SHE-13	62.0	19.404	43.988	65.1	Match with limestone contact (Blue reflector)
						33.0	19.404	32.775	35.4	Match with base of relic channel cut (red reflector)
46	33	3	16020416 SEG	3179	SHE-11	79.8	15.624	45.912	80.3	Match with limestone contact (Blue reflector)
						33.3	15.624	27.948	32.7	Match with base of relic channel cut (red reflector)

Master Summary Table of Relic Channel Cut and Fill Features and Limestone

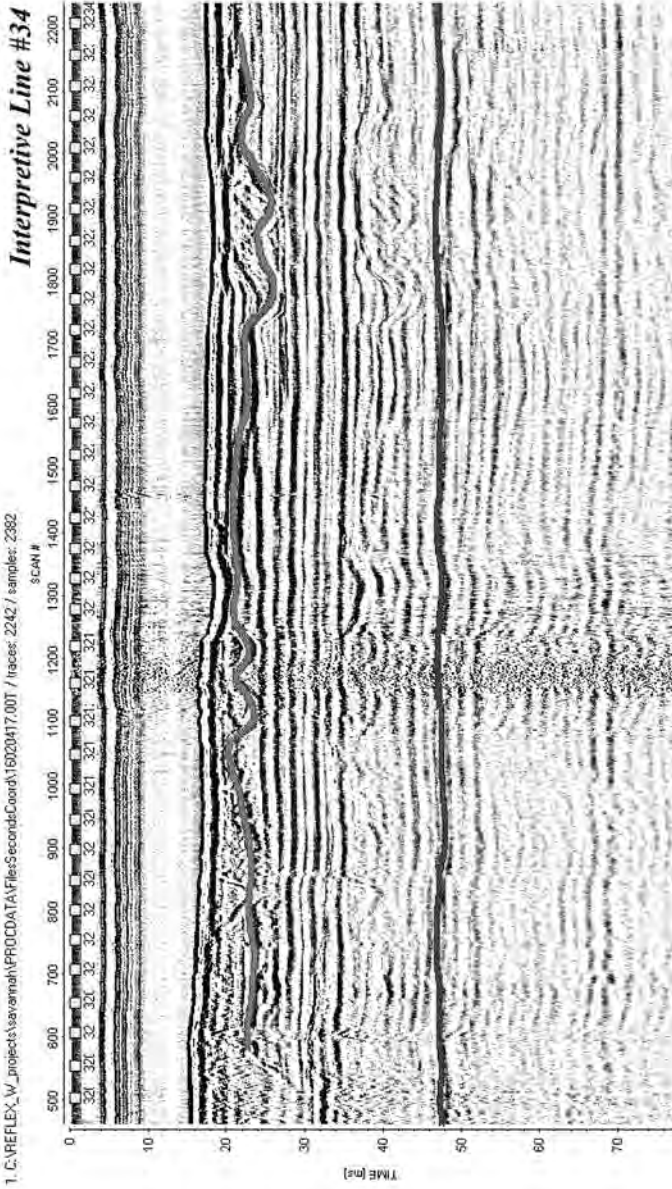
Field No.	Interpretive line designation	RCC/F Feature Relic Channel Cut and Fill Features Deemed Significant	SFG, Y file	Interpretive file name ("_Sheet.X")	Navigation event # in vicinity of relic channel cut feature	Boring acquired on-line	Maximum base depth of relic channel cut feature based on subbottom data (MLW, feet)	Depth of upper limestone surface based on subbottom data & maximum depth of relic channel cut feature (MLW, feet)	Thickness of sediment below maximum depth of relic channel cut feature and top of limestone (feet)	Core Tie	Comment
4	North Offset	1	13020411	Not represented	658				NA	SHE-11 /offsite	
5	South Offset	1	14020401 SEG	Not represented	1277				NA	SHE-11 /offsite	
46	34	1	16020417 SEG	16020417	3228		-58	-115	56	SHE-11 /offsite	
48	35	1	16020418 SEG	16020418	3245.5		-69	-116	47	SHE-11 /offsite	
49	36	1	16020419 SEG	16020419	3313		-80	-116	36	SHE-11 /offsite	
50	37	1	16020420 SEG	16020420	3330		-71	-119	49	SHE-11 /offsite	
4	North Offset	2	13020410 SEG	Not represented	646				NA	SHE-11 /offsite	RCC not detected
7	South Offset	2	14020402 SEG	14020402	1300		-84	-119	55	SHE-11 /offsite	
47	34	2	16020417 SEG	16020417	3204		-58	-115	56	SHE-11 /offsite	
48	35	2	16020418 SEG	Not represented	3270				NA	SHE-11 /offsite	Gaseous sediments
49	36	2	16020419 SEG	Not represented	3300				NA	SHE-11 /offsite	RCC not detected
51	38	2	16020421 SEG	16020421	3342		-56	-115	59	SHE-11 /offsite	
4	North Offset	3	13020409 SEG	13020409(15+000)	601		-74	-117	43	SHE-11	
8	South Offset	3	14020410 SEG	14020410	1536		-89	-116	47	SHE-11	
43	30	3	16020413 SEG	16020413	3091		-67	-113	46	SHE-11	
44	31	3	16020414 SEG	16020414	3123		-67	-111	44	SHE-11	
45	32	3	16020415 SEG	16020415	3158		-71	-113	42	SHE-11	
46	33	3	16020416 SEG	16020416	3163	SHE-11	-70	-115	45	SHE-11	
			13020408 /	13020408 /							
4	North Offset	4	13020408 SEG	13020409	534		-83	-109	28	SHE-13	
7	South Offset	4	14020404 SEG	14020404 (7612+000)	1427		-71	-106	35	SHE-13	
7	South Offset	4	14020404 SEG	14020404	1366		-56	-114	58	SHE-13	
36	23	4	16020406 SEG	16020406	2814		-78	-110	32	SHE-13	
37	24	4	16020407 SEG	16020407	2893	SHE-13	-82	-106	27	SHE-13	
38	25	4	16020408 SEG	16020408	2912		-91	-107	26	SHE-13	
39	26	4	16020409 SEG	16020409	3015		-86	-112	46	SHE-13	
40	27	4	16020410 SEG	16020410	3035		-75	-109	34	SHE-13	
41	28	4	16020411 SEG	16020411	3045	SHE-13	-81	-110	29	SHE-13	
3	North Offset	5	13020408 SEG	Not represented	439					SHE-14 /offsite	No RCC observed

Field Run	Interpretive line designation	RCCF Feature Reference	SFG-Y file	Interpretive file name (* .sheet (b))	Navigation event # in vicinity of relic channel cut feature	Boring acquired on-line	Maximum base depth of relic channel cut feature based on subbottom data (MLW, feet)	Depth of upper limestone surface based on subbottom data @ maximum depth of relic channel cut feature (MLW, feet)	Thickness of sediment below maximum depth of relic channel cut feature and top of limestone (feet)	Core Tie	Comment
7	South Offset	5	14020405 SEG	14020405	1487		-70	-110	40	SHE-14 /offsite	RCC not resolved
24	1A	5	16020403 SEG	Not represented	2703					SHE-14 /offsite	
31	1	5	14020406 SEG	14020406 (1to2)	1525		-66	-105	40	SHE-14 /offsite	
30	21	5	16020401 SEG	16020401	2659		-67	-105	38	SHE-14 /offsite	
30	21	5	16020400 SEG	16020400	2651		-87	-110	43	SHE-14 /offsite	
32	22	5	16020402 SEG	16020402	2667					SHE-14 /offsite	No RCC observed LS only
3	North Offset	6	13020406 SEG	13020406	199	SHE-14	-65	-56	31	SHE-14	
1	South Offset	6	13020401 SEG	13020401	199		-70	-59	29	SHE-14	
34	1	6	14020406 SEG	14020406	1573		-68	-87	28	SHE-14	
8	1A	6	16020404 SEG	16020404	2745.5		-69	-88	29	SHE-14	
9	2	6	14020409 SEG	14020409	1769	SHE-327	-70	-69	29	SHE-14	
10	3	6	14020410 SEG	14020410	1834		-68	-100	32	SHE-327, SHE-14	
11	4	6	14020411 SEG	14020411	1869		-70	-103	32	SHE-14	
35	4A	6	16020405 SEG	16020405	2773	SHE-14	-70	-102	32	SHE-14	
12	5	6	14020412 SEG	14020412	1867		-69	-98	29	SHE-14	
14	6	6	14020414 SEG	14020414	1910		-65	-96	31	SHE-14	
2	North Offset	7	13020404 SEG	13020404	307		-42	-85	34	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	RCC coded orange included in red contour
5	South Offset	7	13020413 SEG	13020413	821		-65	-104	39	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	
8	1	7	14020407 SEG	14020407	1652.5		-63	-102	39	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	
9	2	7	14020408 SEG	14020408	1663		-62	-104	42	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	Has two relic channel cut features (coded red and orange) modified to single pick
16	7	7	15020402 SEG	15020402	2043.5		-58	-102	44	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	
17	8	7	15020403 SEG	15020403	2050		-67	-102	35	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	
18	9	7	15020404 SEG	15020404	2125		-67	-103	36	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	
19	10	7	15020405 SEG	15020405	2148		-67	-105	38	SHE-3 /offsite, reflectors traced by examining intersecting 97' survey data and the north offset survey line	Has two relic channel cut features (coded red and orange) modified to single pick

Field Run	Interpretive line designation	RCCP Feature Reference	SEG-Y file	Interpretive file name ("_Abst.bk")	Navigation event # in vicinity of relic channel cut feature	Boring acquired on-line	Maximum base depth of relic channel cut feature based on subbottom data (MLW, feet)	Depth of upper incision surface based on maximum depth of relic channel cut feature (MLW, feet)	Thickness of sediment below maximum depth of relic channel cut feature and top of limestone (feet)	Cure Tie	Comment
6	North Offset	8	13020418 SEG	13020418	1086		-86	-111	46	SHE-4	
5	South Offset	8	13020414 SEG	13020414	918		-86	-113	45	SHE-4	13020415 use mod file for red picks
20	11	8	13020406 SEG	13020415	2192		-73	-112	39	SHE-4	
23	13	8	13020410 SEG	15020410	2450		-72	-110	38	SHE-4	
24	14	8	13020411 SEG	15020411	2477		-72	-109	37	SHE-4	
25	15	8	13020412 SEG	15020412	2522		-71	-108	37	SHE-4	
26	16	8	13020413 SEG	15020413	2543	SHE-4	-60	-110	50	SHE-4	
27	17	8	13020414 SEG	15020414	2578		-72	-113	41	SHE-4	
28	18	8	13020415 SEG	15020415	2601		-70	-106	38	SHE-4	SHE-6 not deep enough / SHE-4 outside RCCP. SHE-6 year 2000 data does not match with blue LS reflector
29	19	8	15020416 SEG	15020416	2626	SHE-4	-73	-113	40	SHE-4	
Navigation Channel Cut and Fill Features											
4	North Offset	Sta. 25+000	13020411 SEG	Not represented	699					SHE-11 offshore	
7	South Offset	Sta. 25+000	14020401 SEG	14020401	1251		-74	-116	42	SHE-11 offshore	
52	39	Sta. 25+000	16020422 SEG	Not represented	3365					SHE-11 offshore	RCC not detected
53	40	Sta. 25+000	16020423 SEG	Not represented	3368					SHE-11 offshore	RCC not detected
54	41	Sta. 25+000	16020424 SEG	16020424	3407		-70	-114	44	SHE-11 offshore	
6	North Offset	Sta. 27+500	13020416 SEG	13020416	1004		-72	-112	40	SHE-4 offshore	
5	South Offset	Sta. 27+000	13020415 SEG	13020415	957		-77	-115	38	SHE-4 offshore	same file
5	South Offset	Sta. 23+000 to Sta. 27+000	13020415 SEG	13020415	940.5		-49	-119	70	SHE-4 offshore	same file

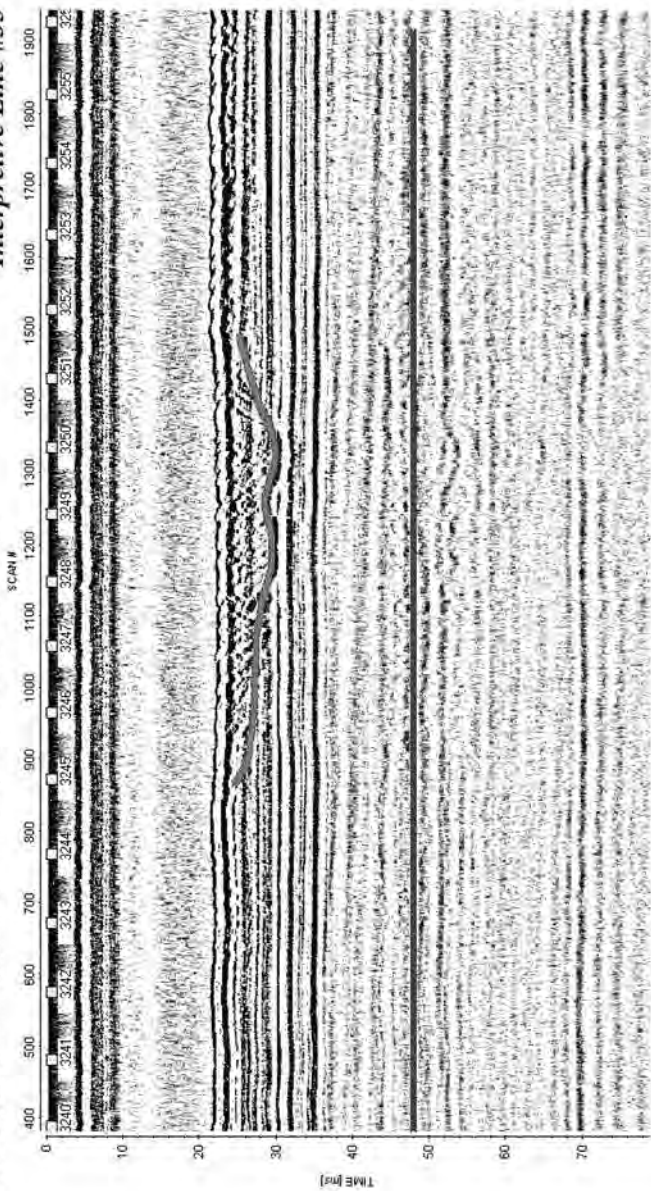
APPENDIX IV**INTERPRETED SUBBOTTOM PROFILES**

*Note: subbottom profiles presented in this appendix are oriented based on the direction in which they were surveyed and are not always presented north up.



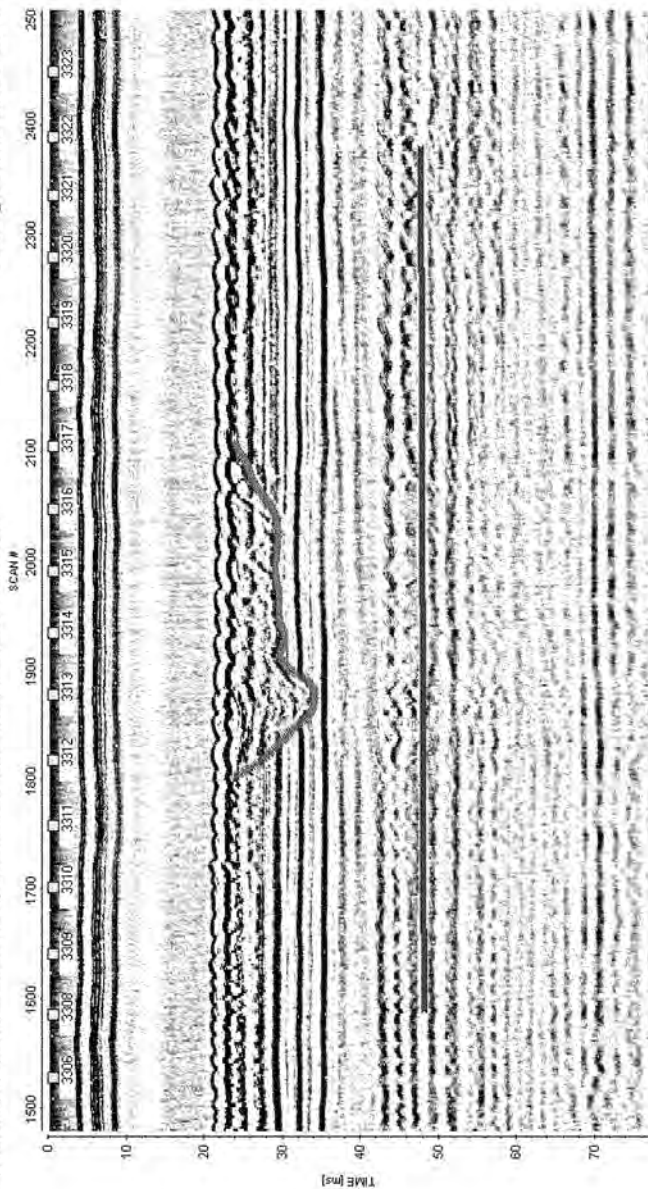
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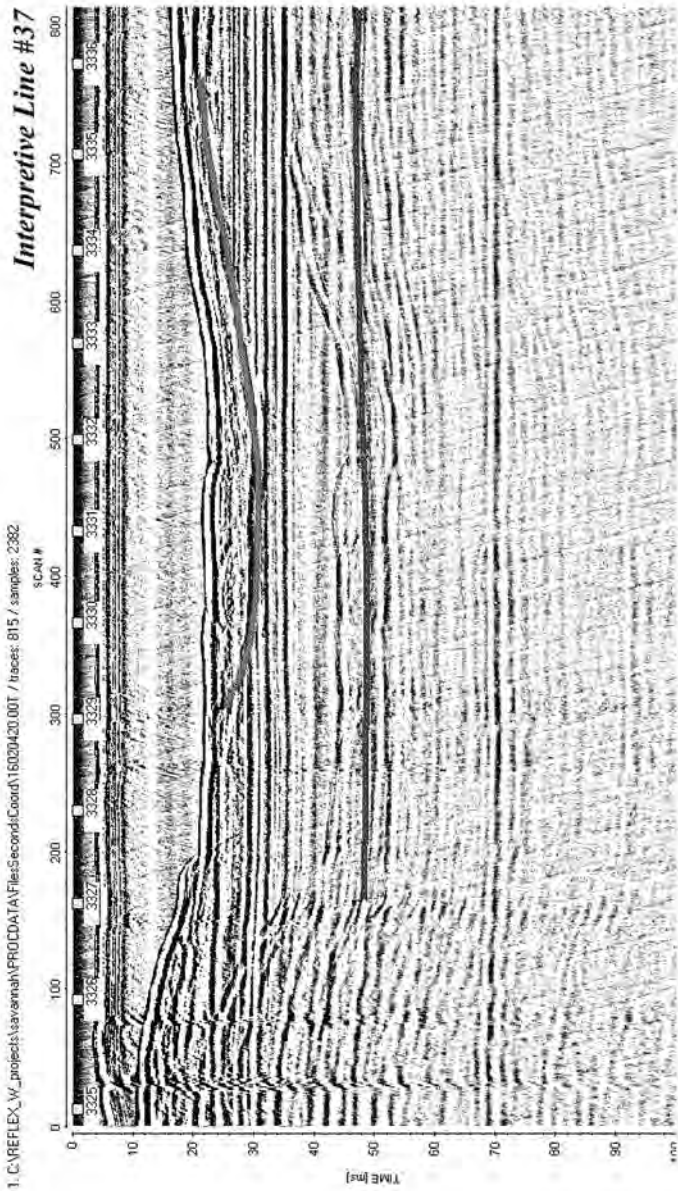
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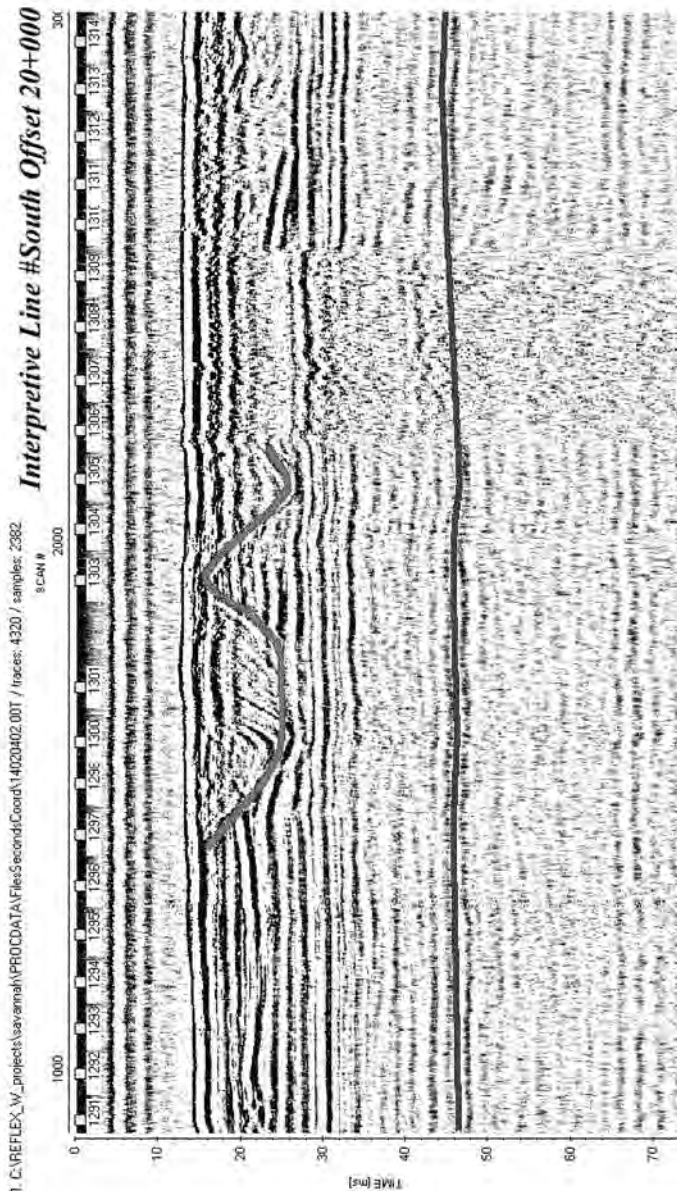


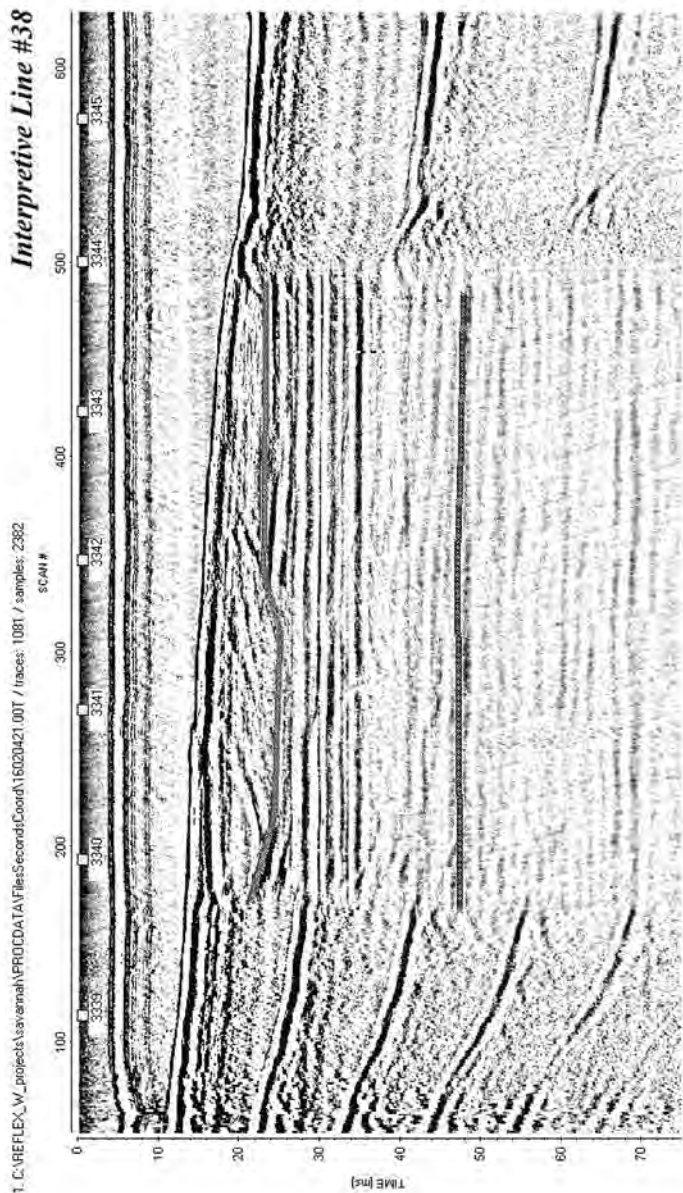
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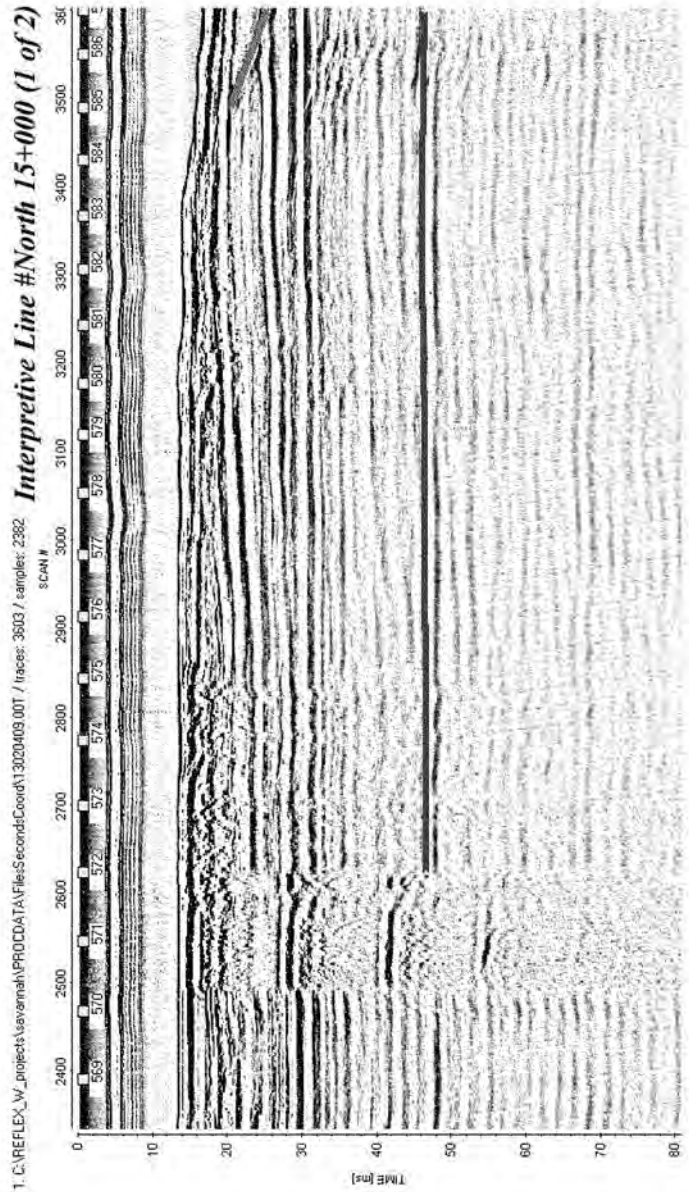
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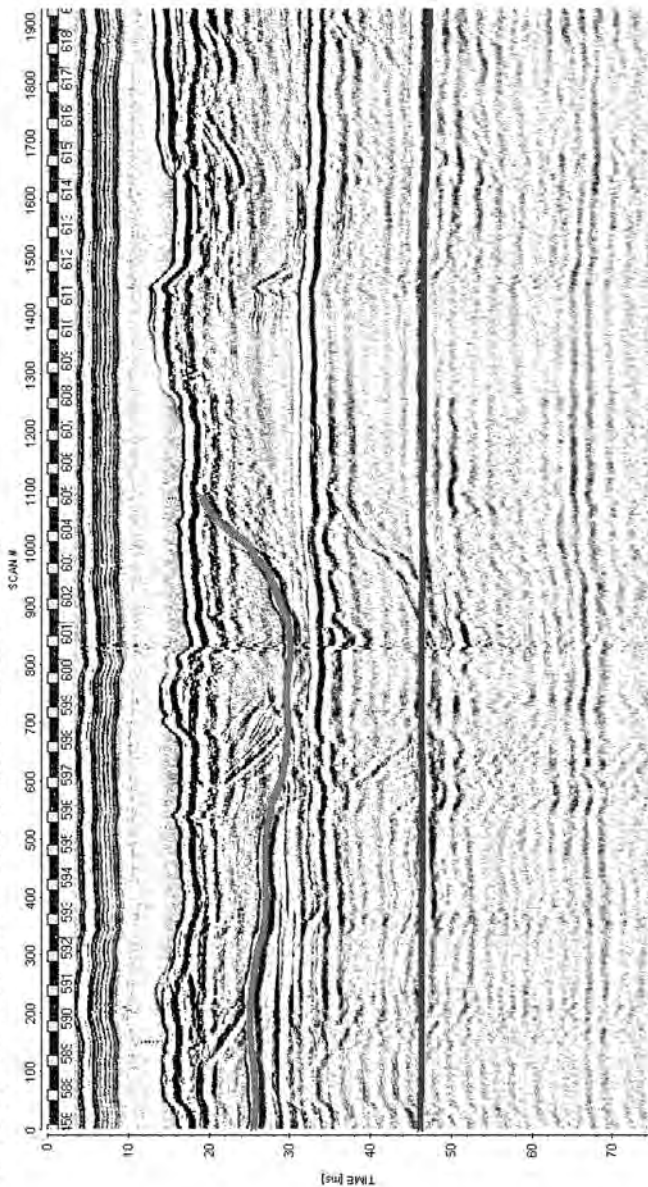




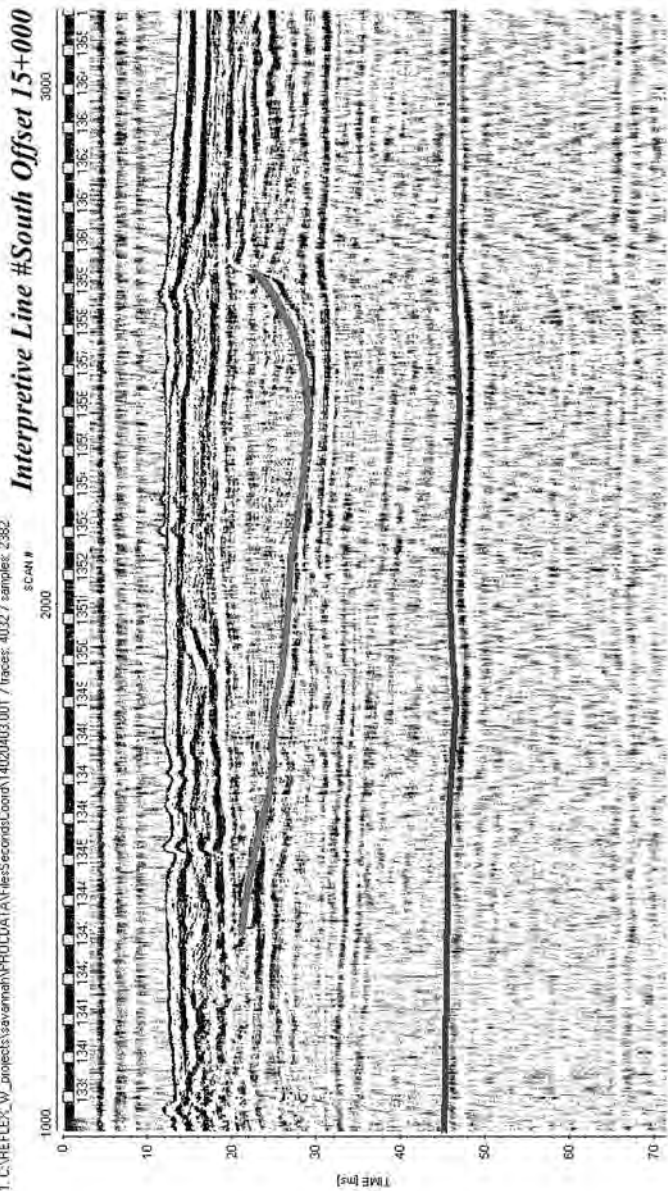


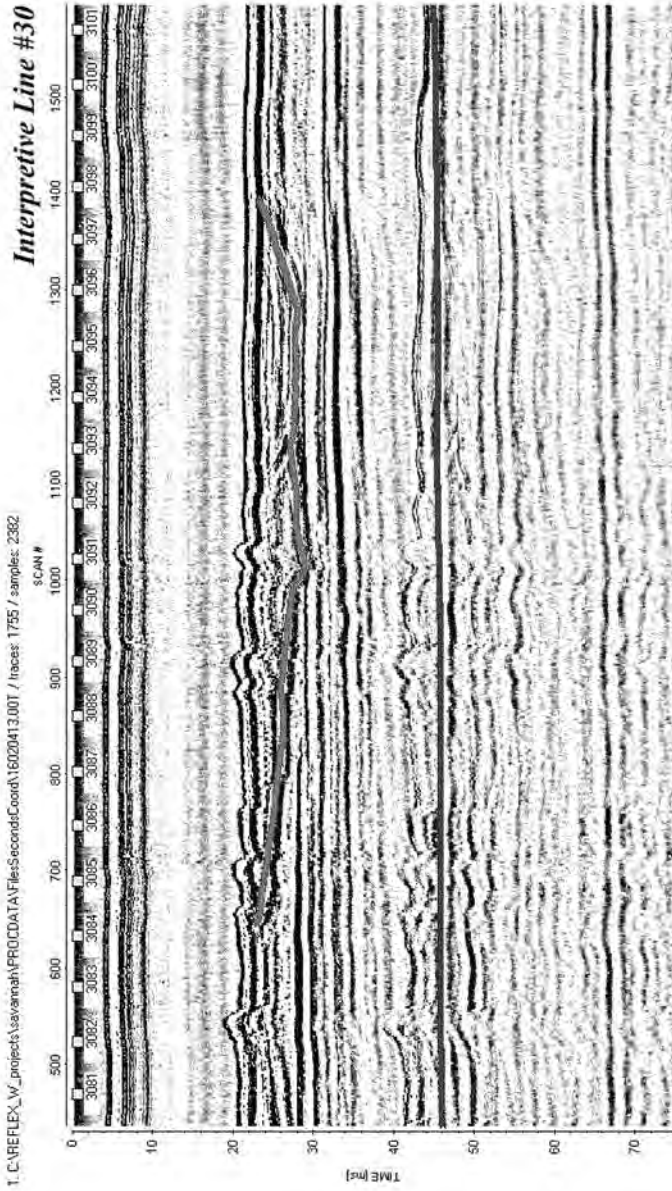
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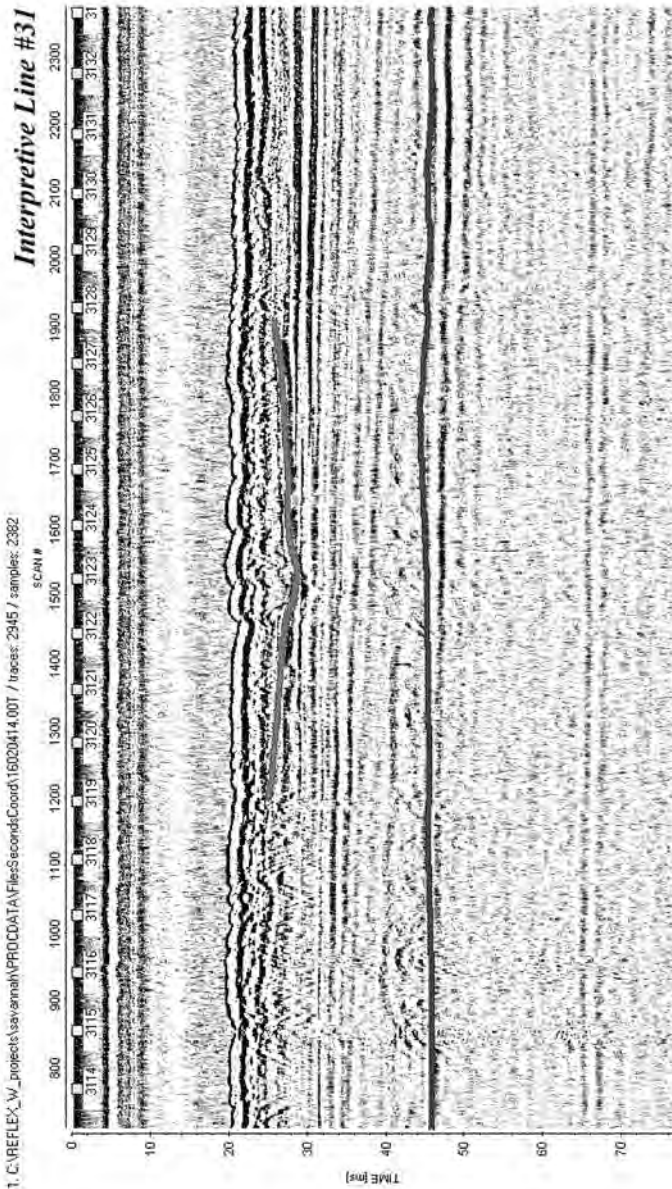
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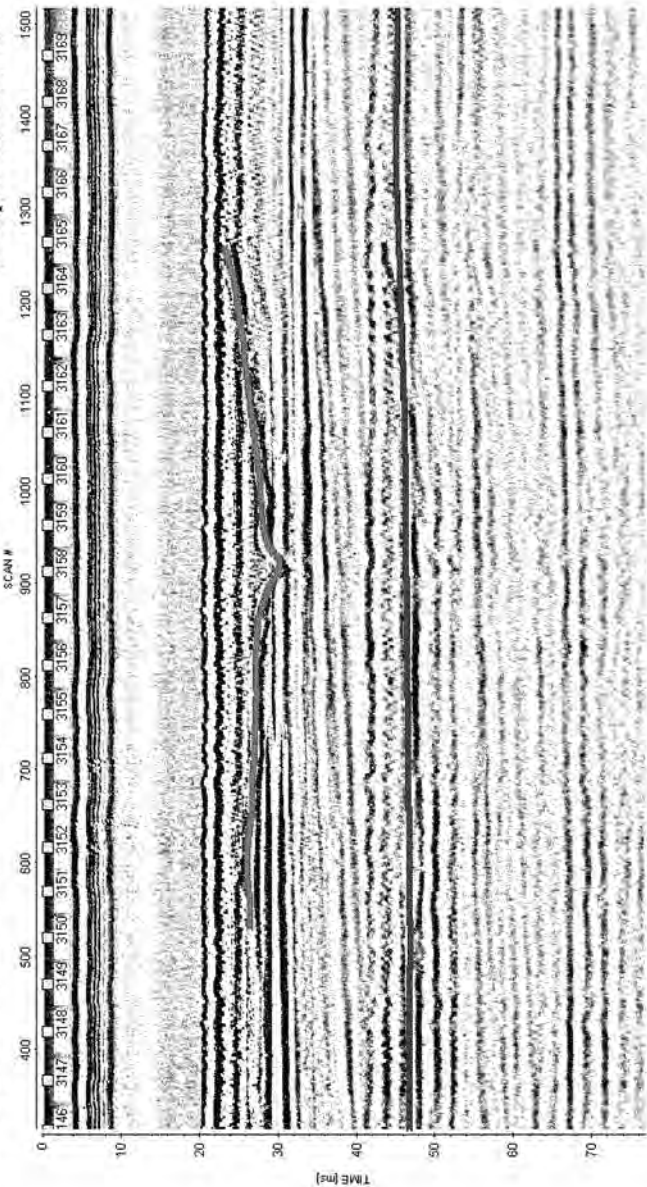


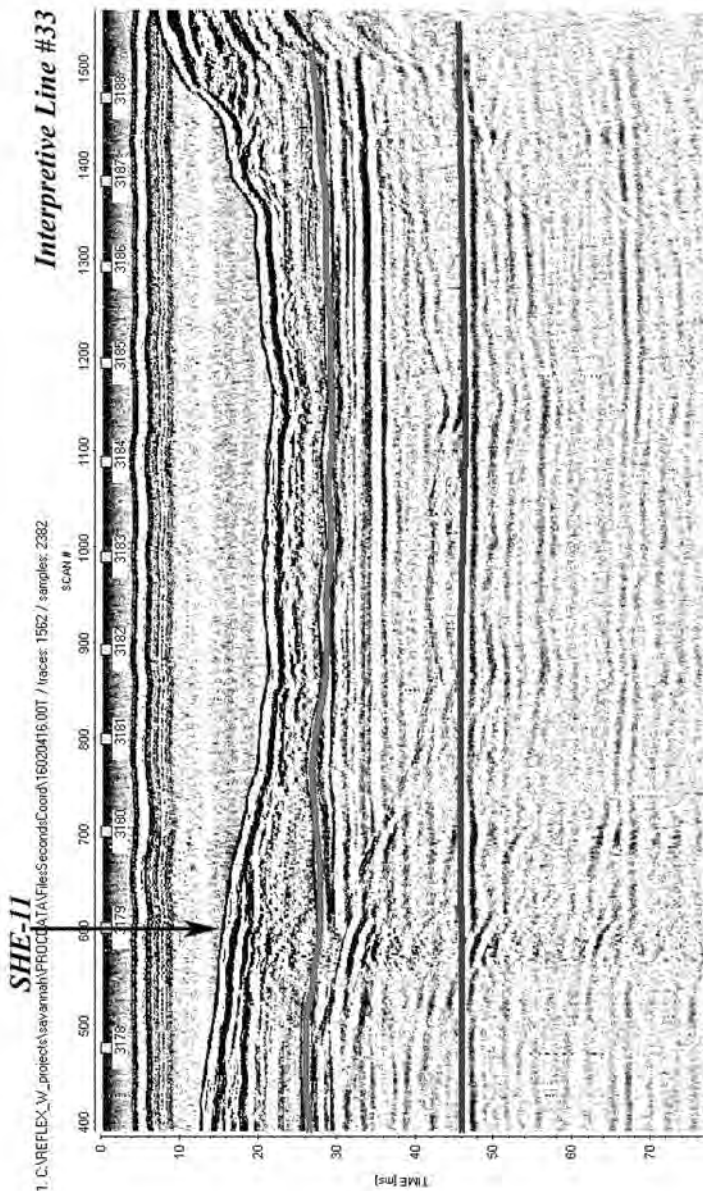




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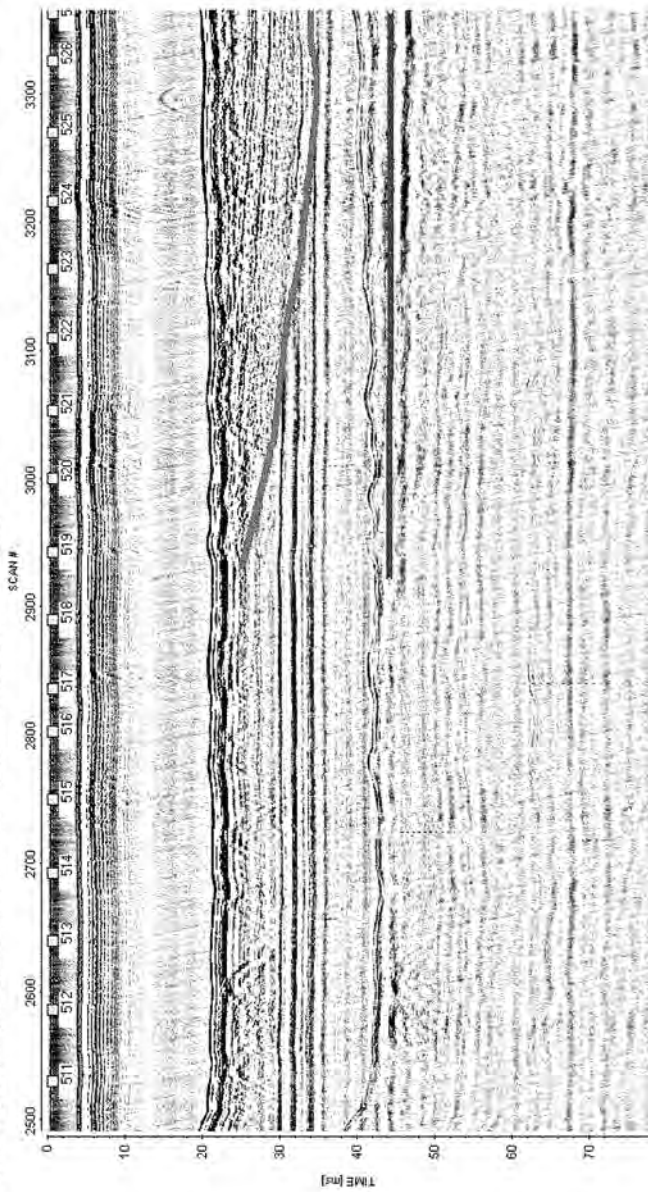
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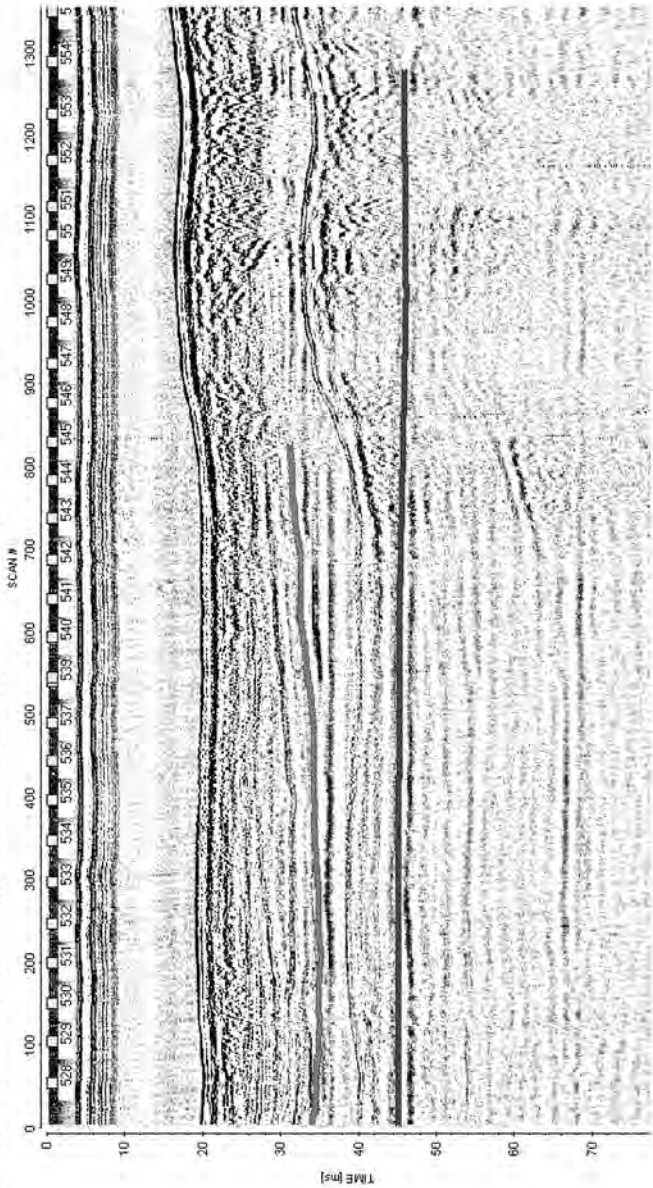
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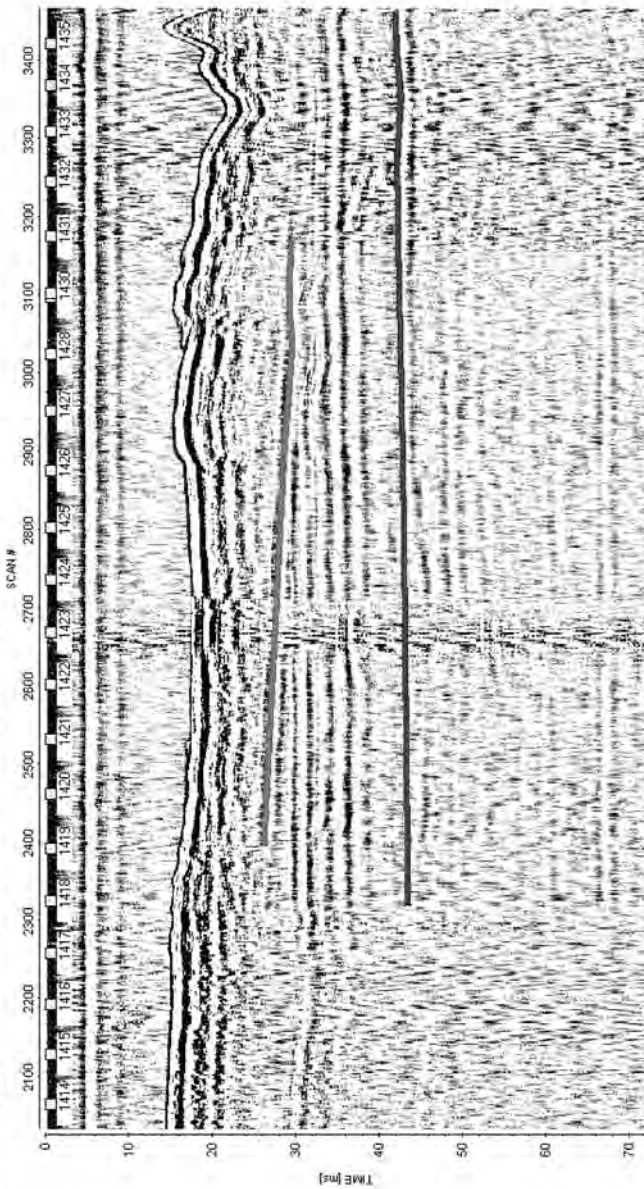
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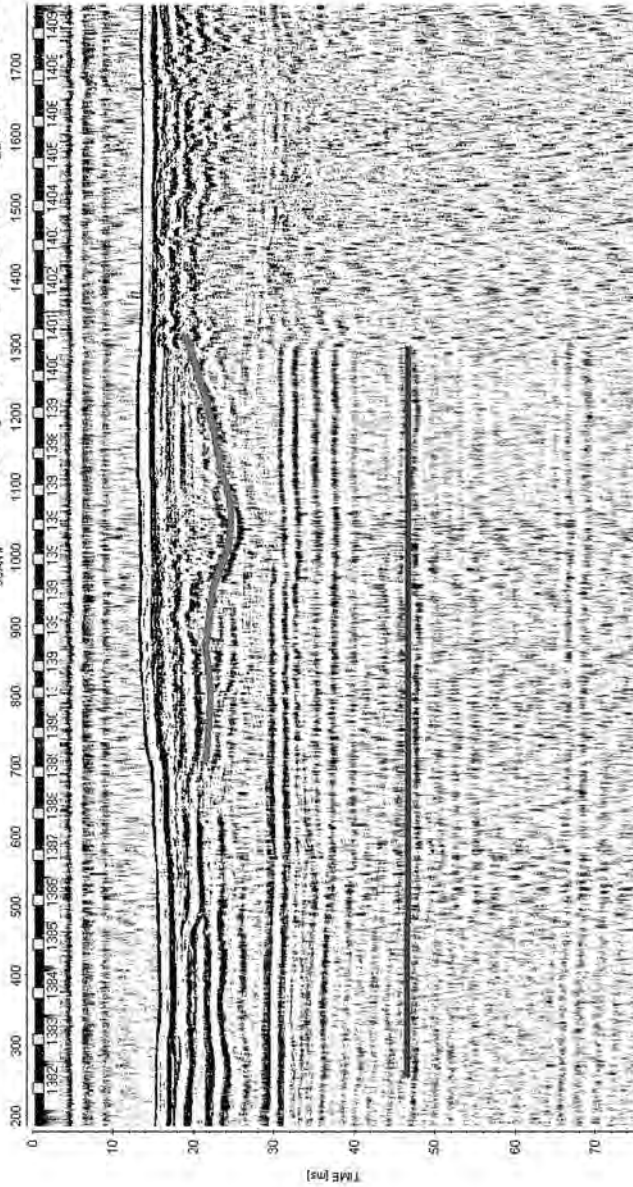
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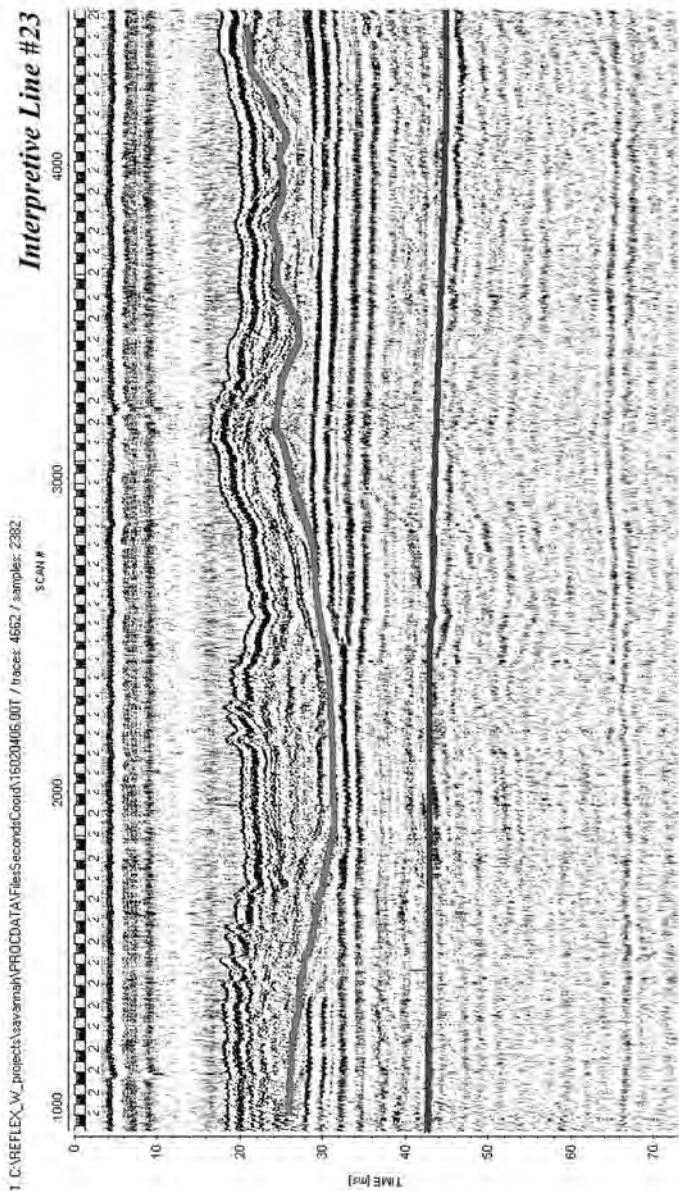
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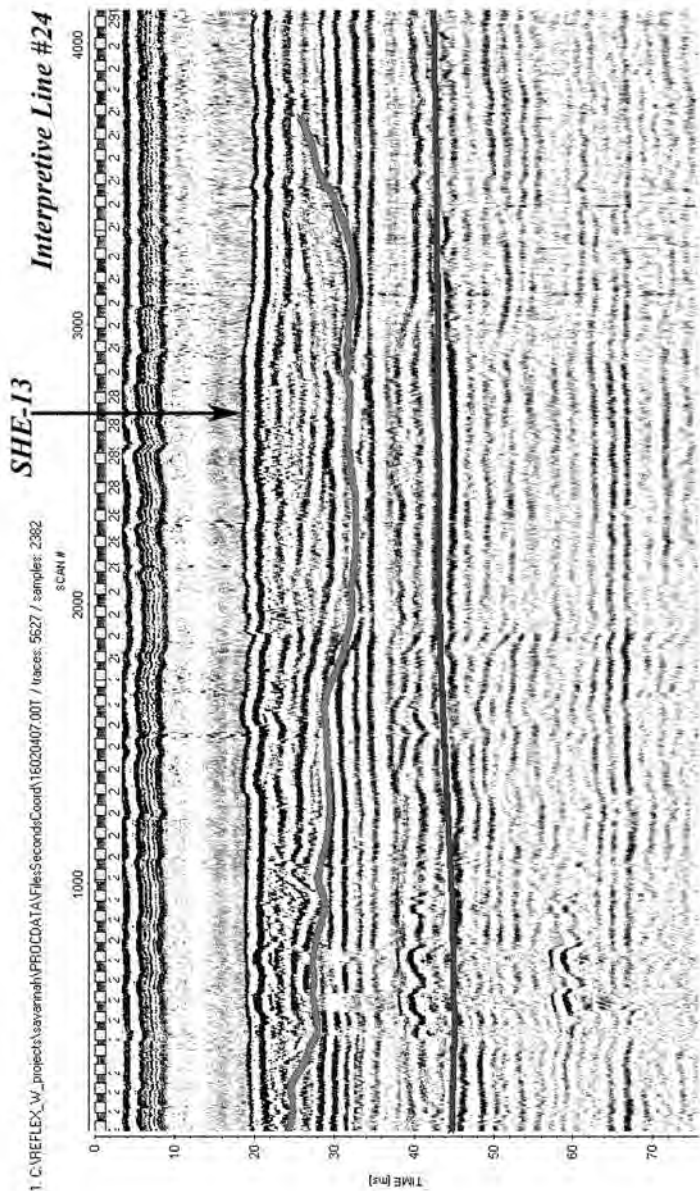


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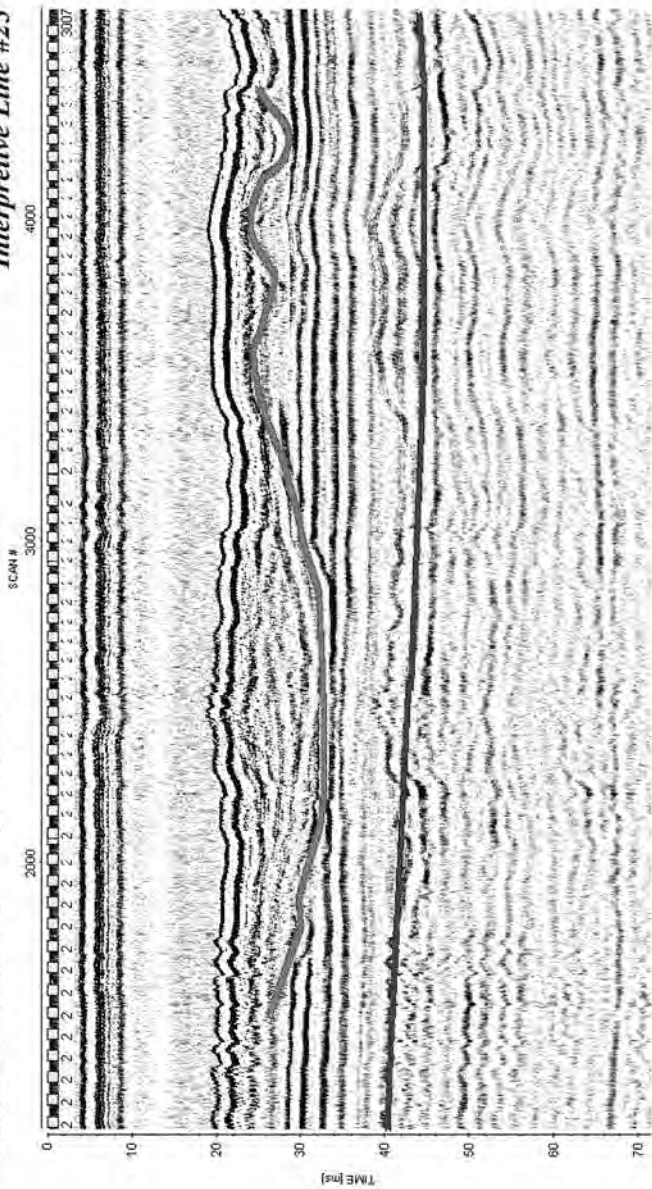


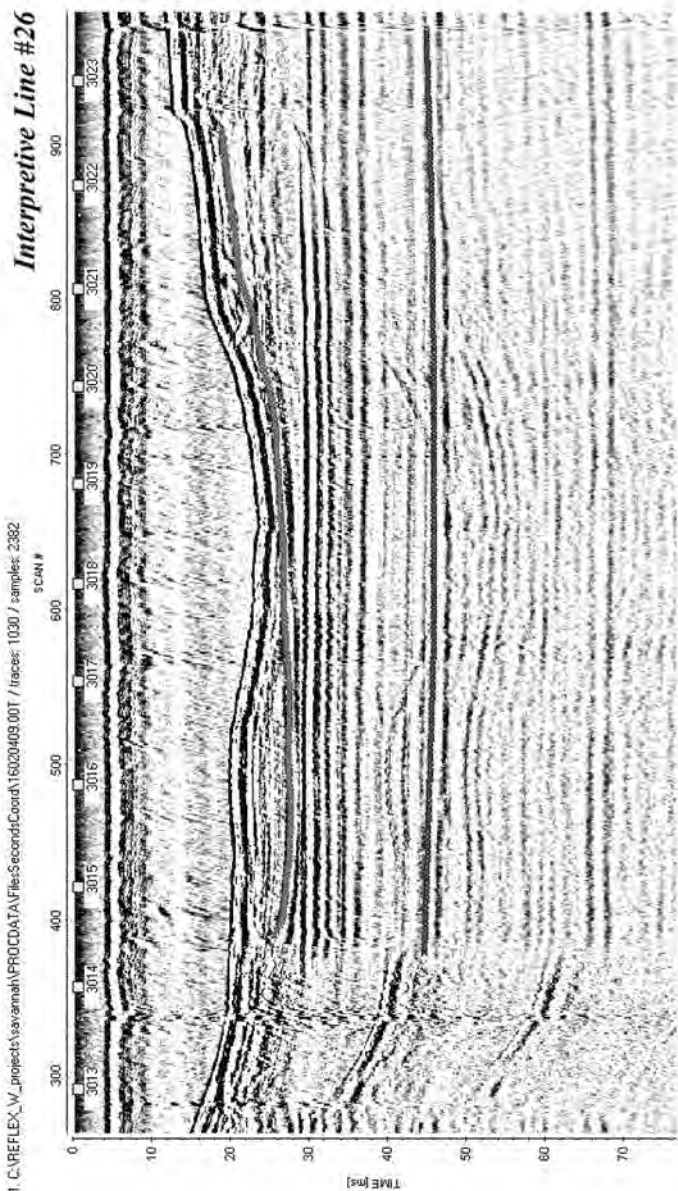


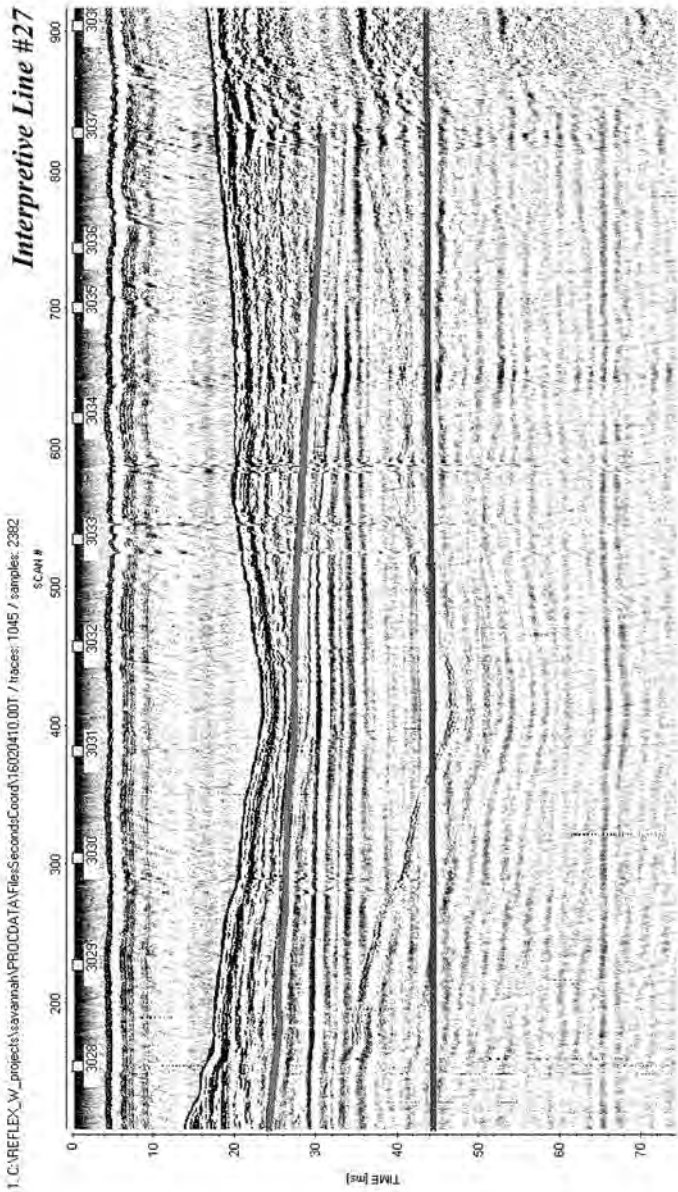


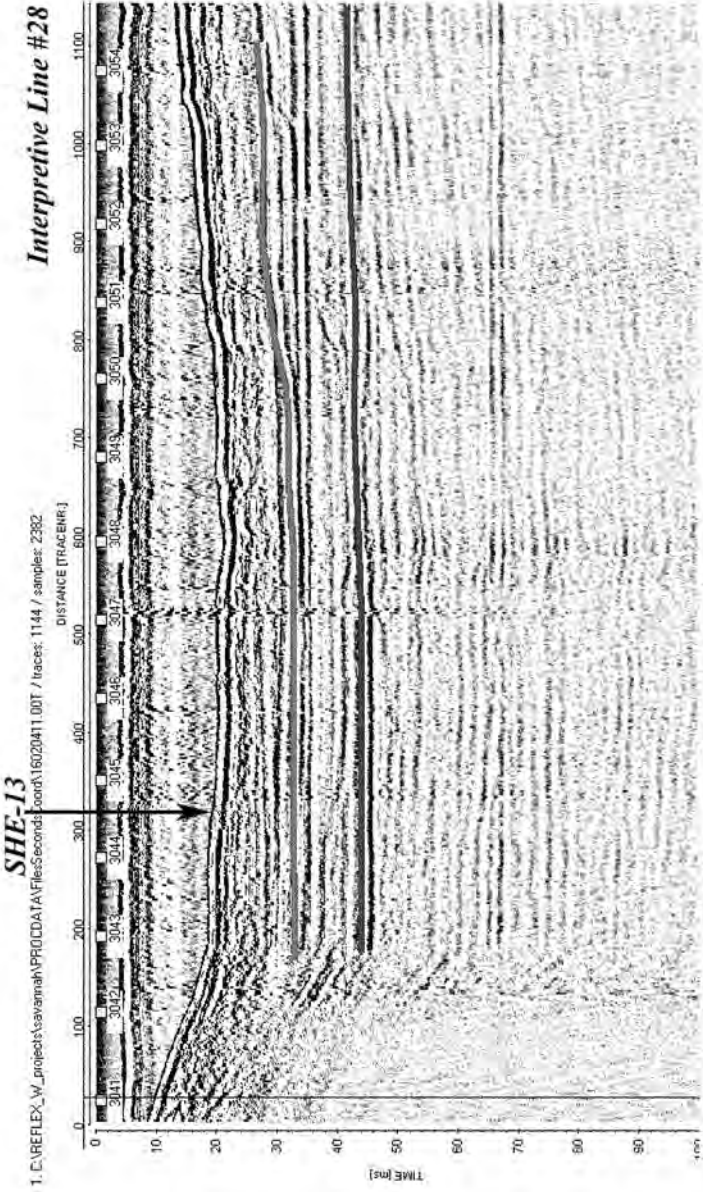
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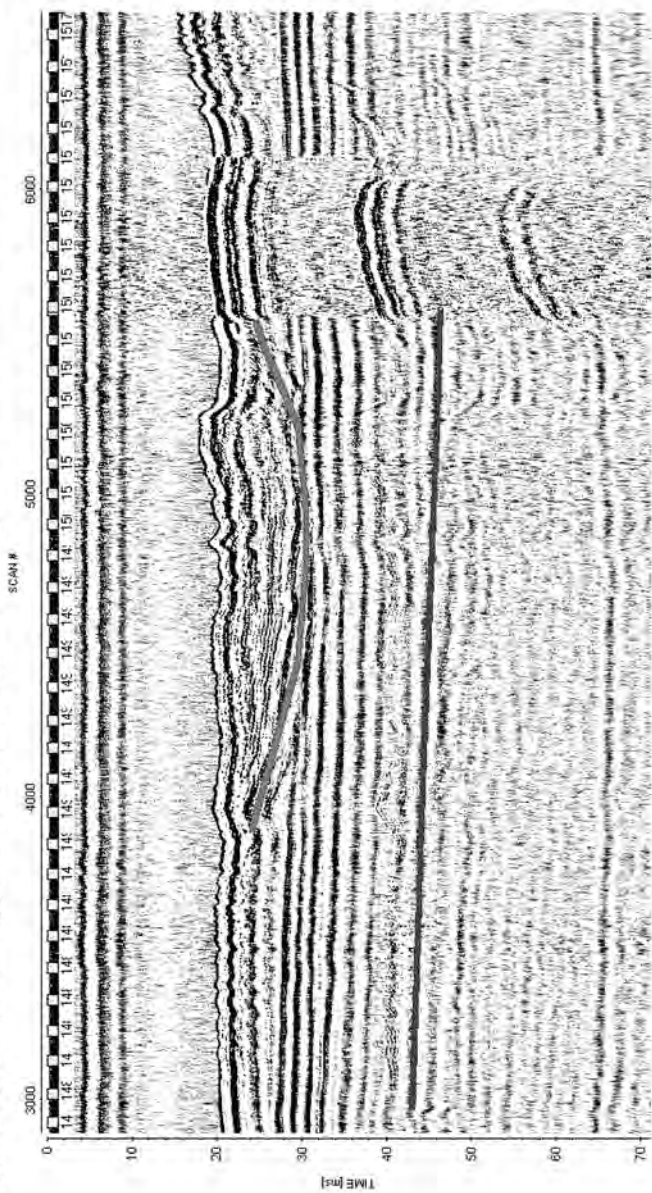






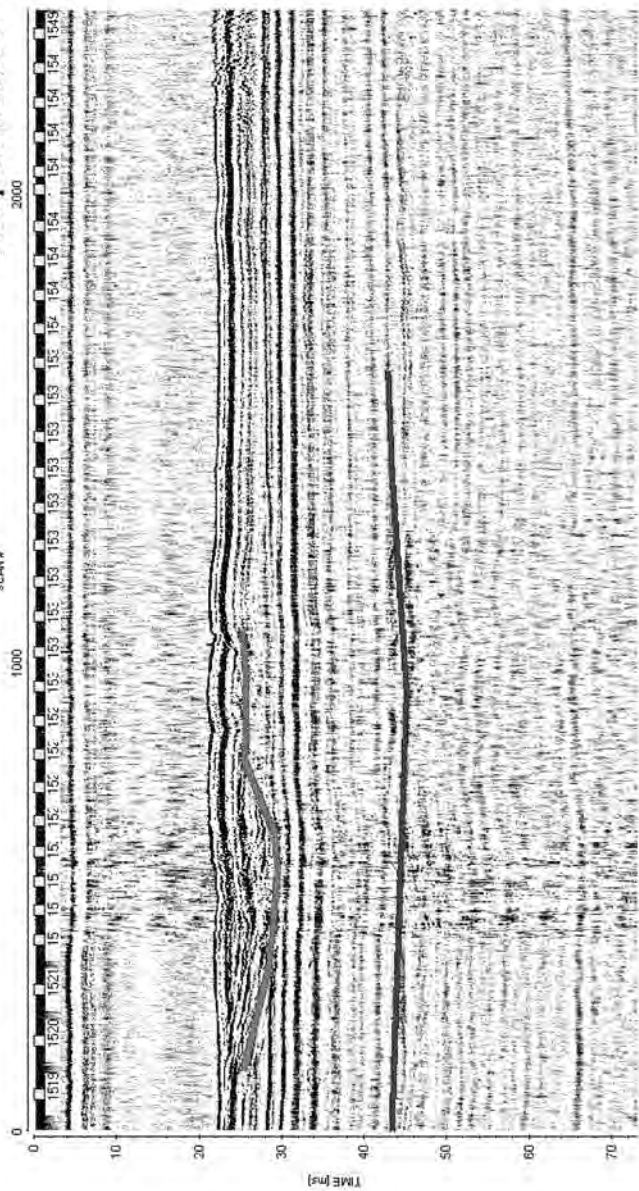
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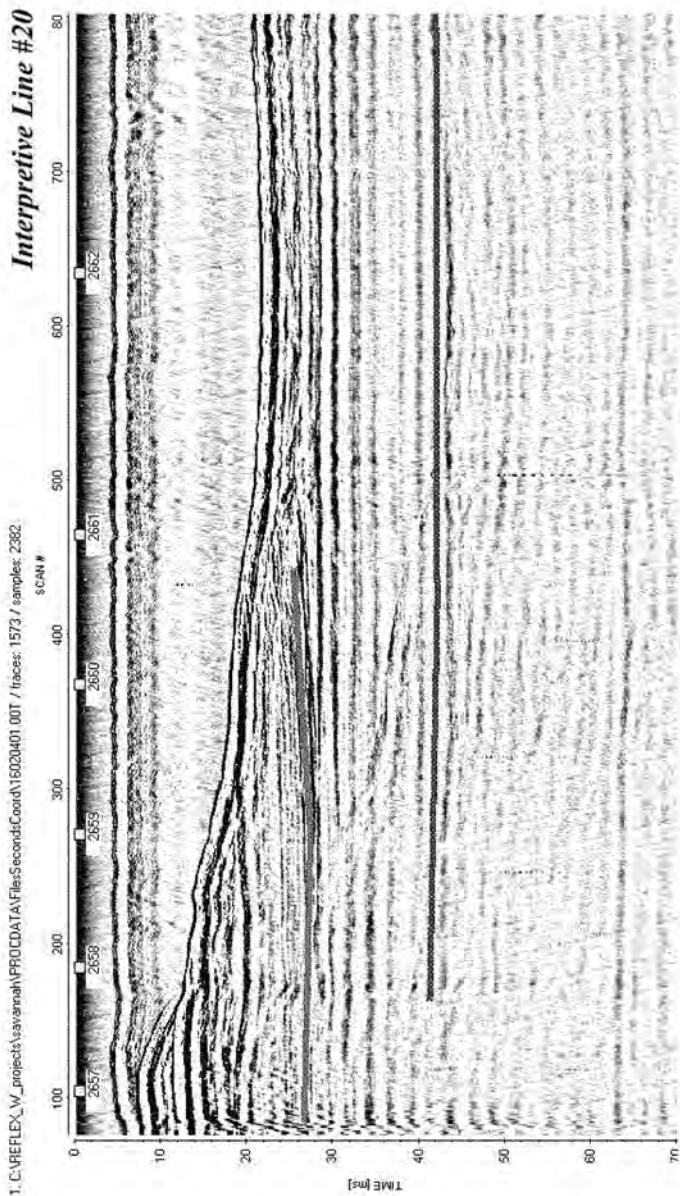


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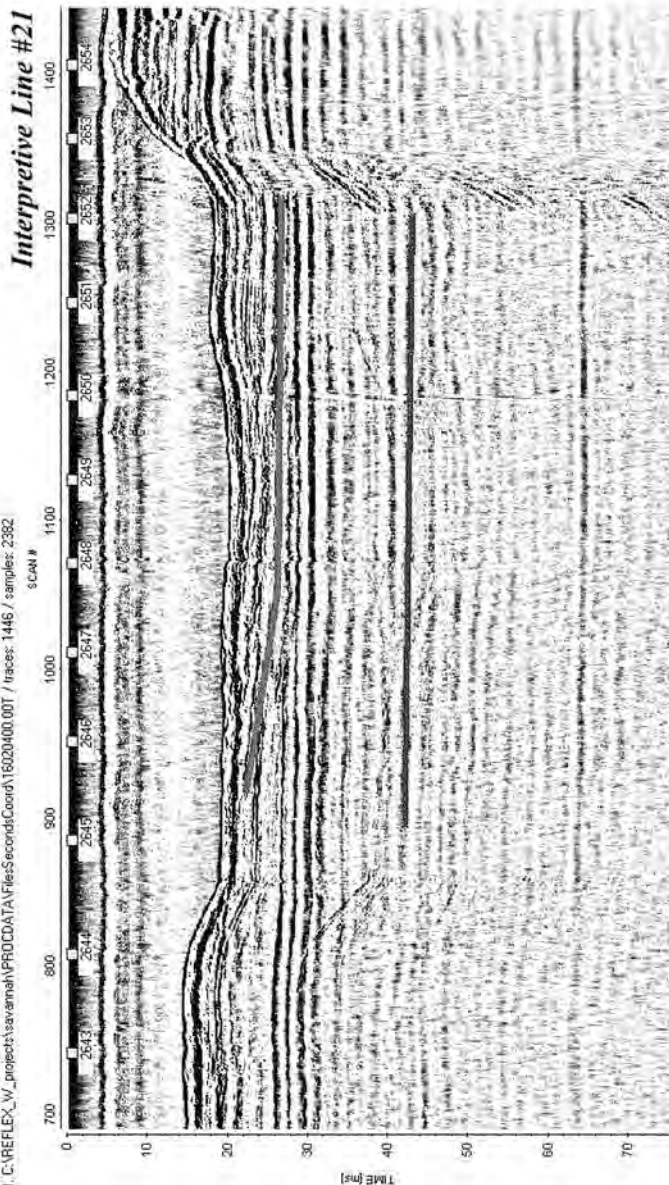
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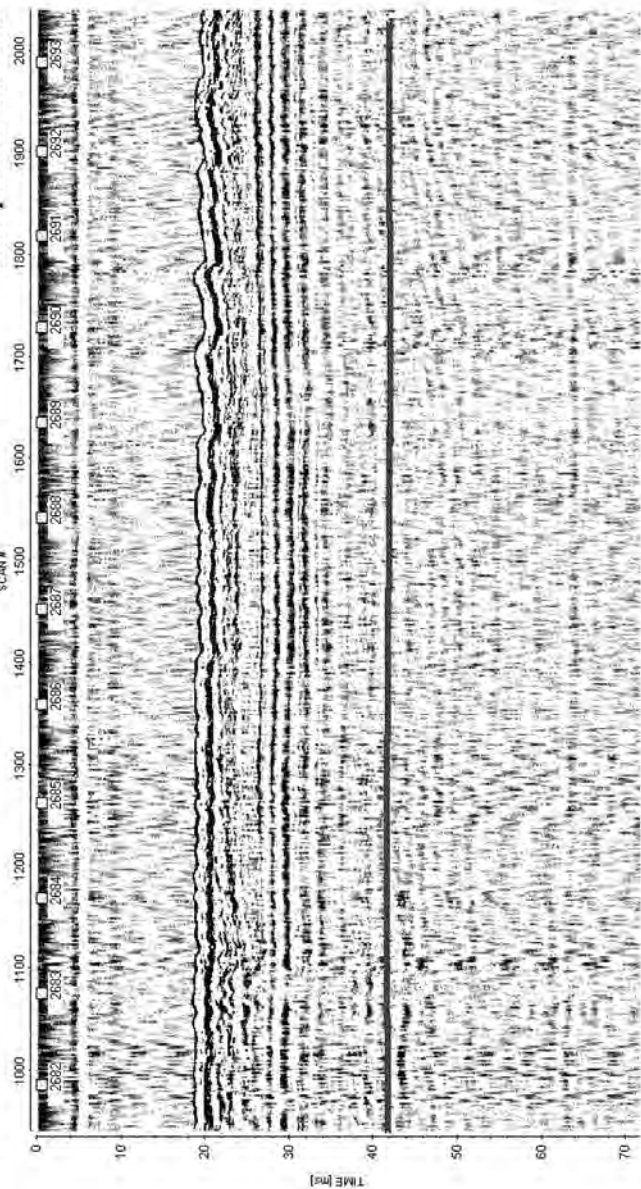


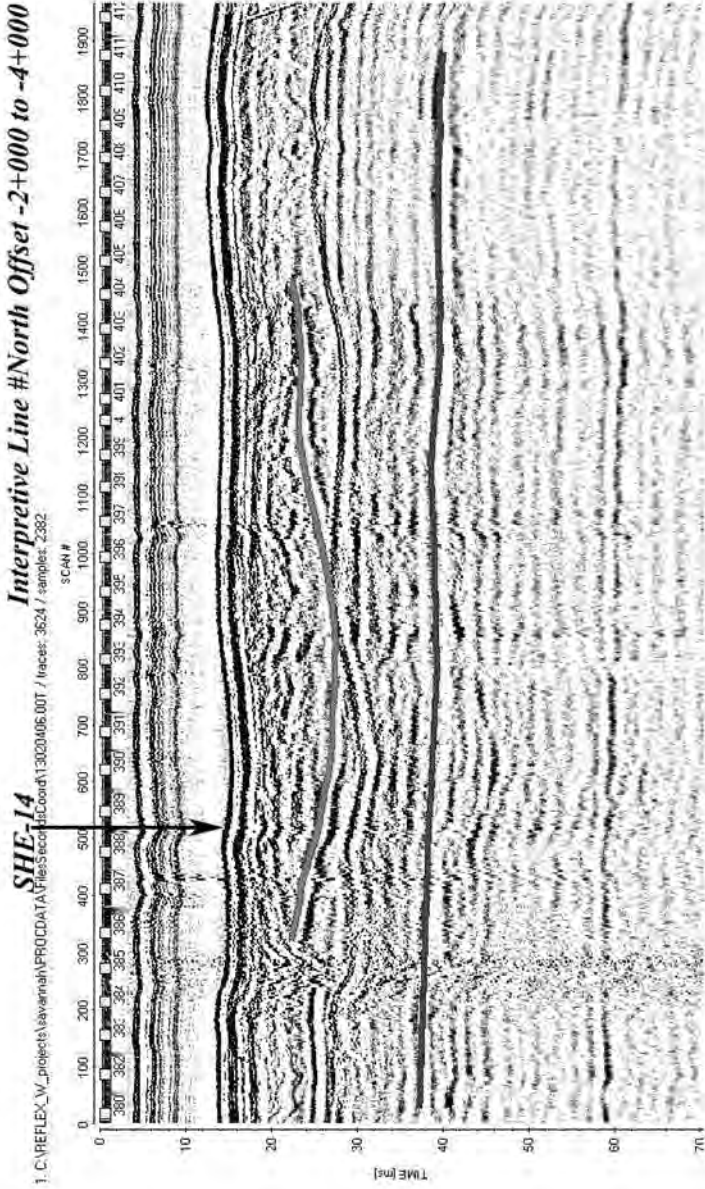
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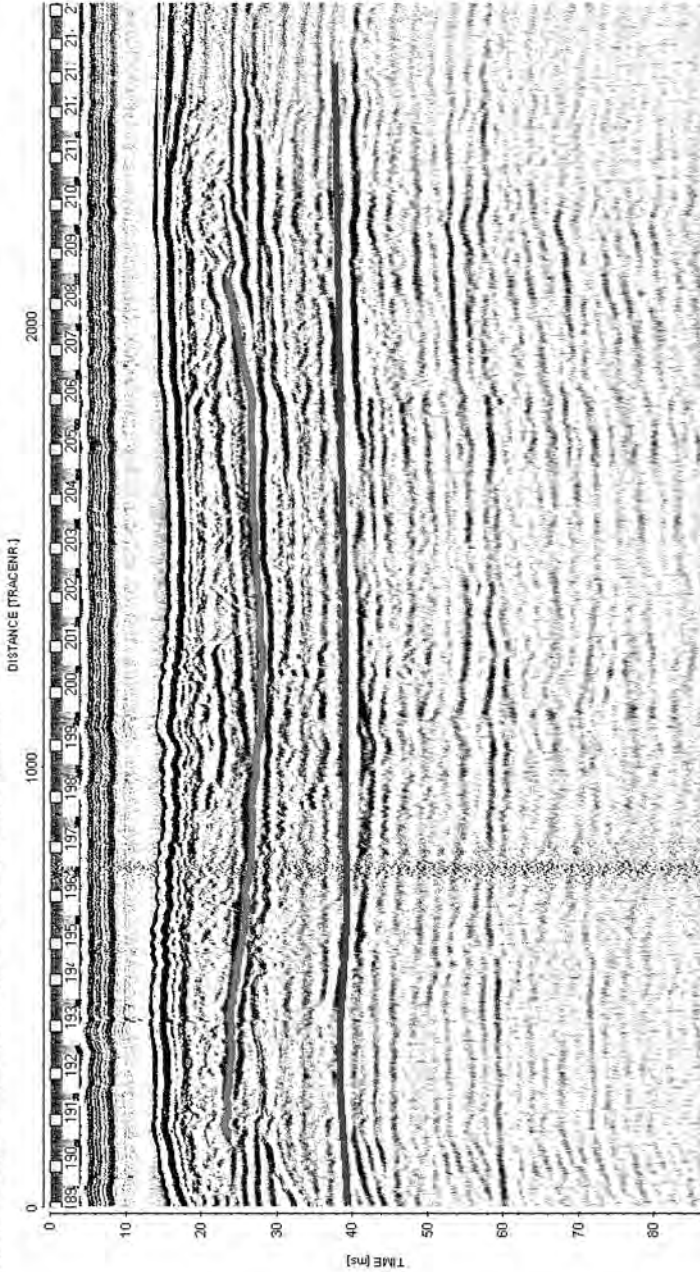
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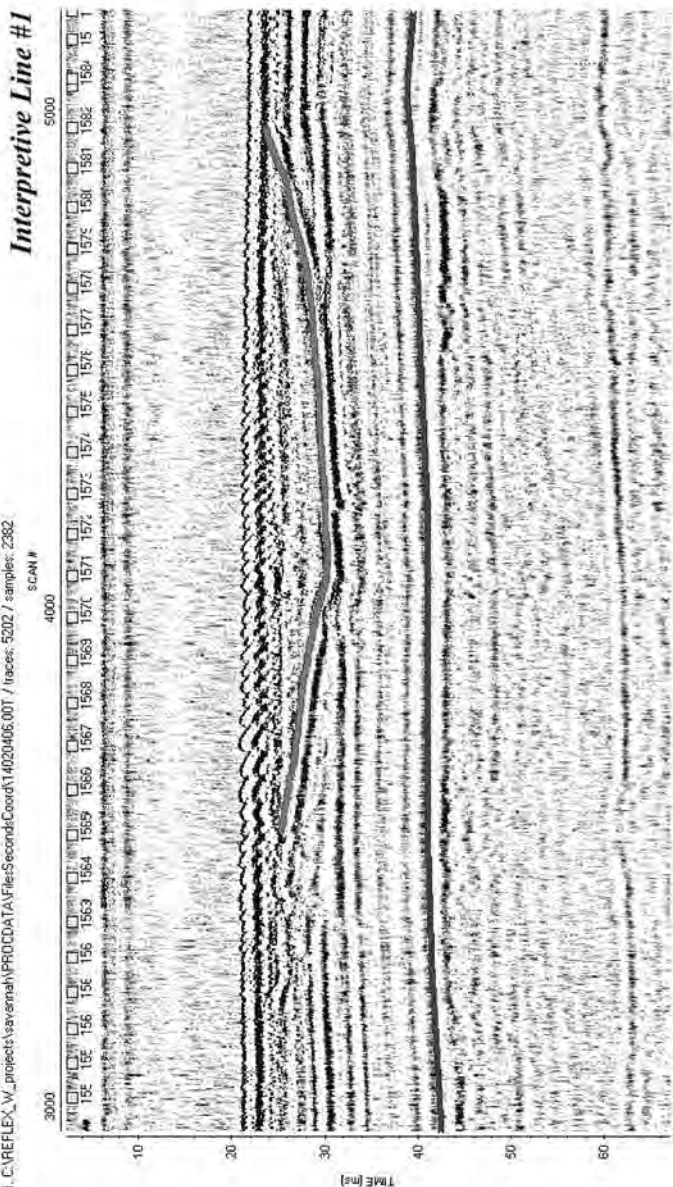


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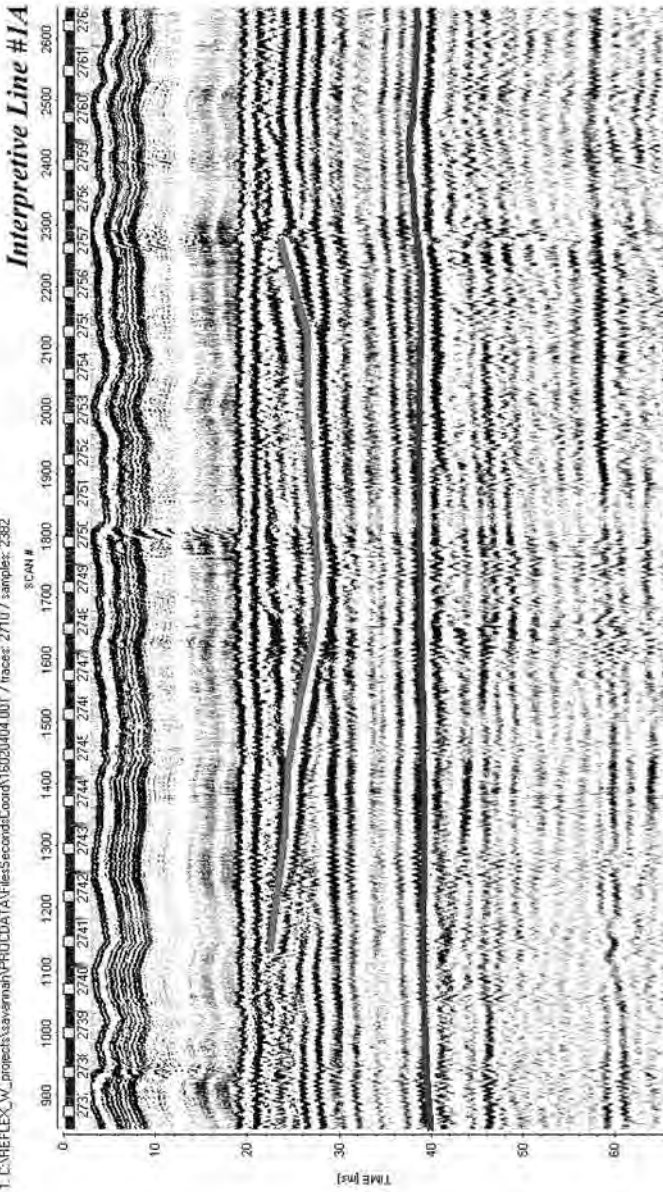
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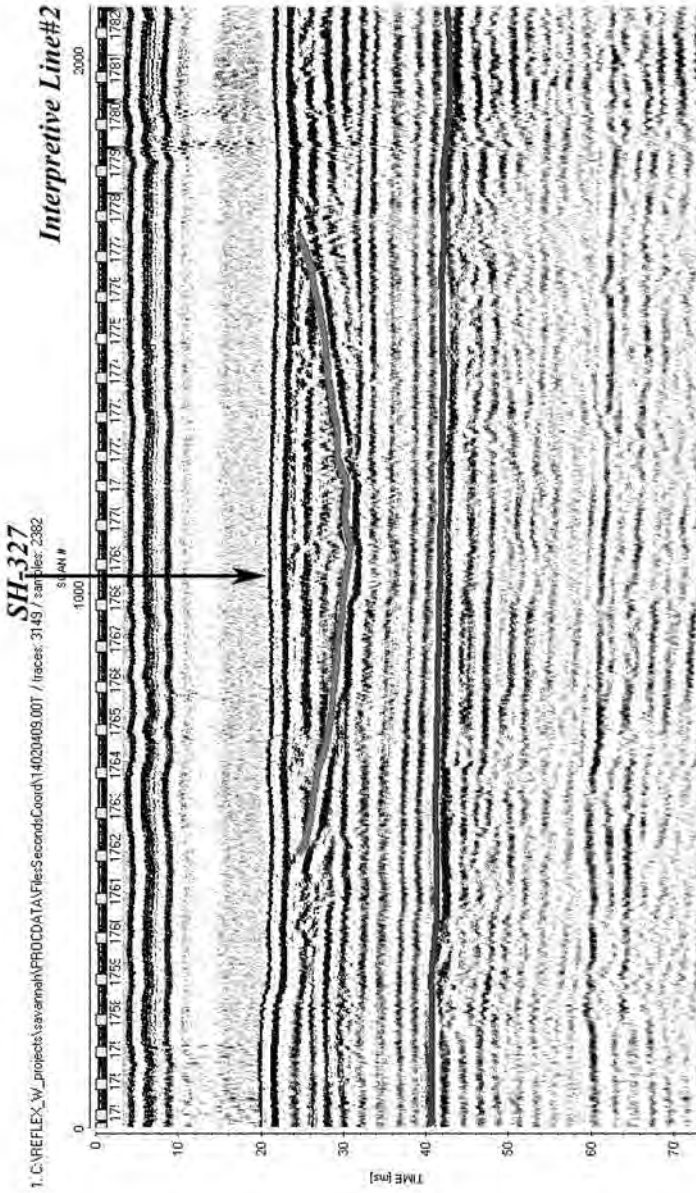


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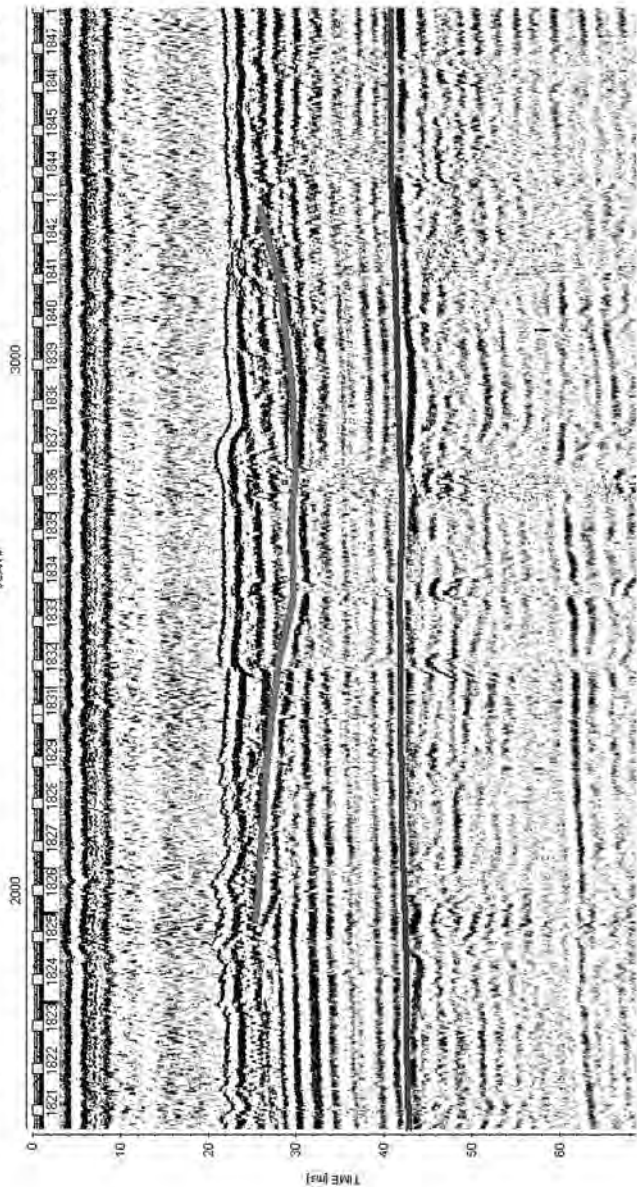
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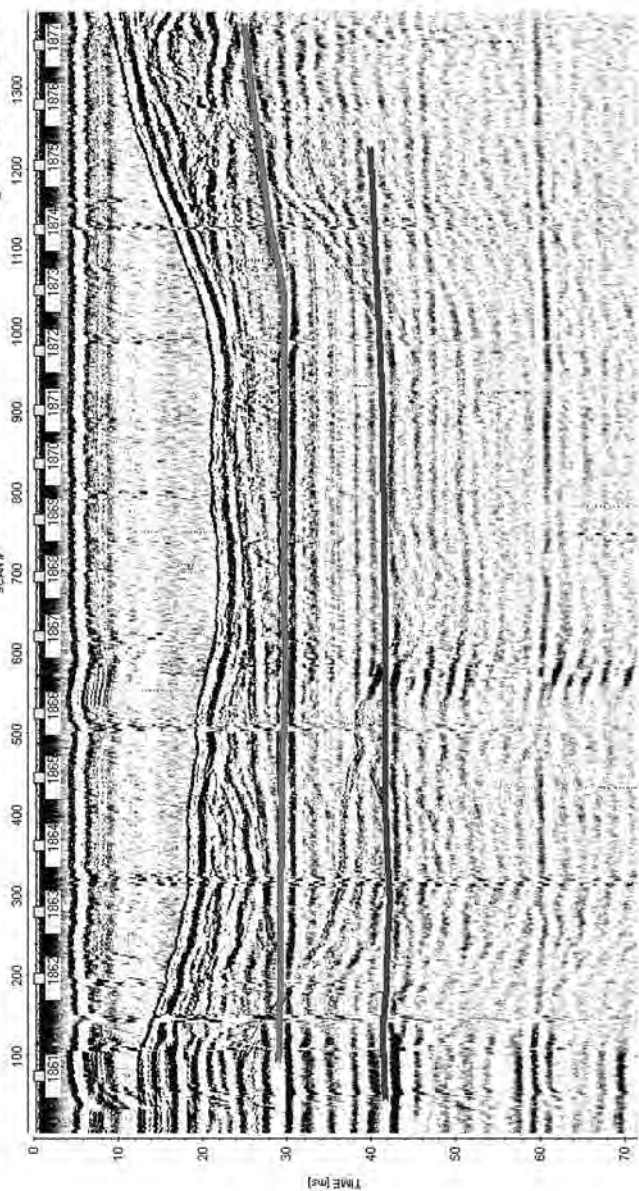
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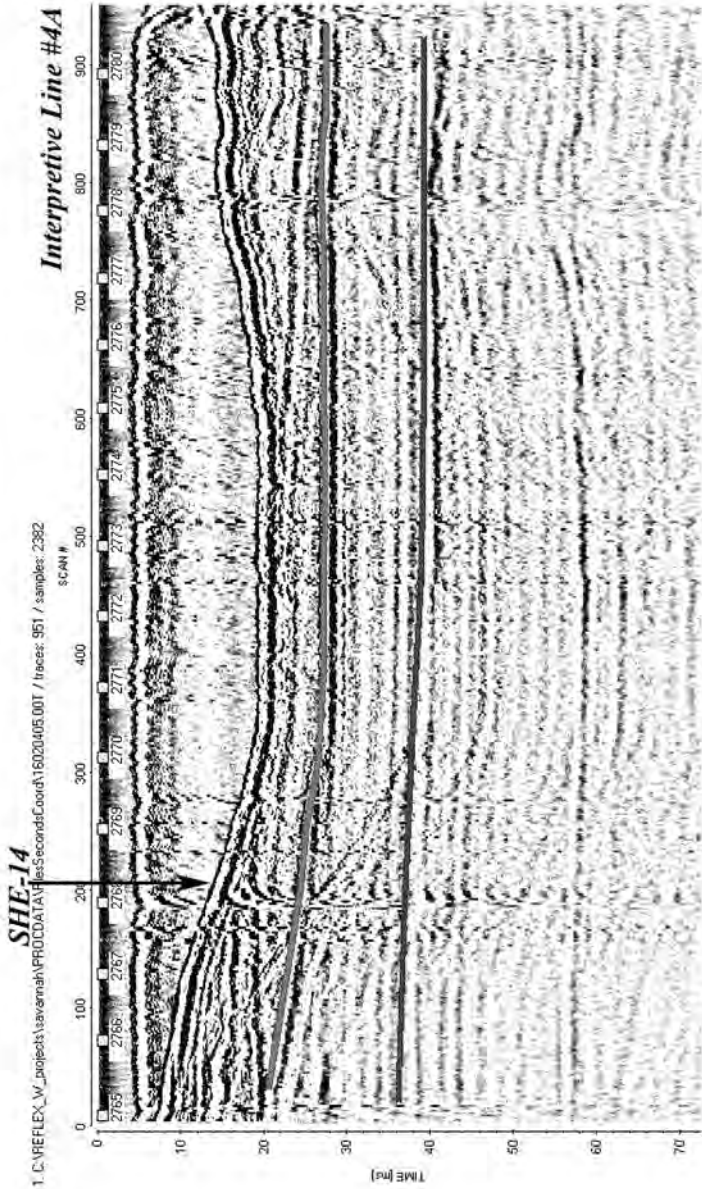
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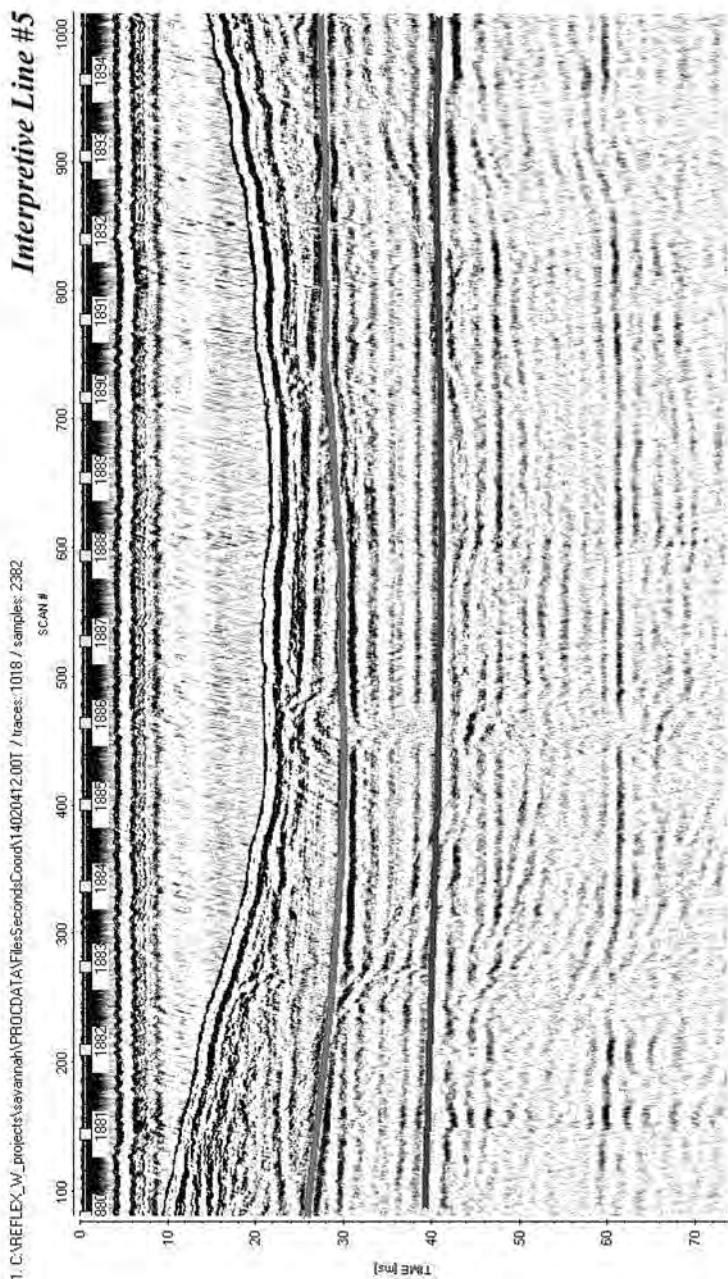


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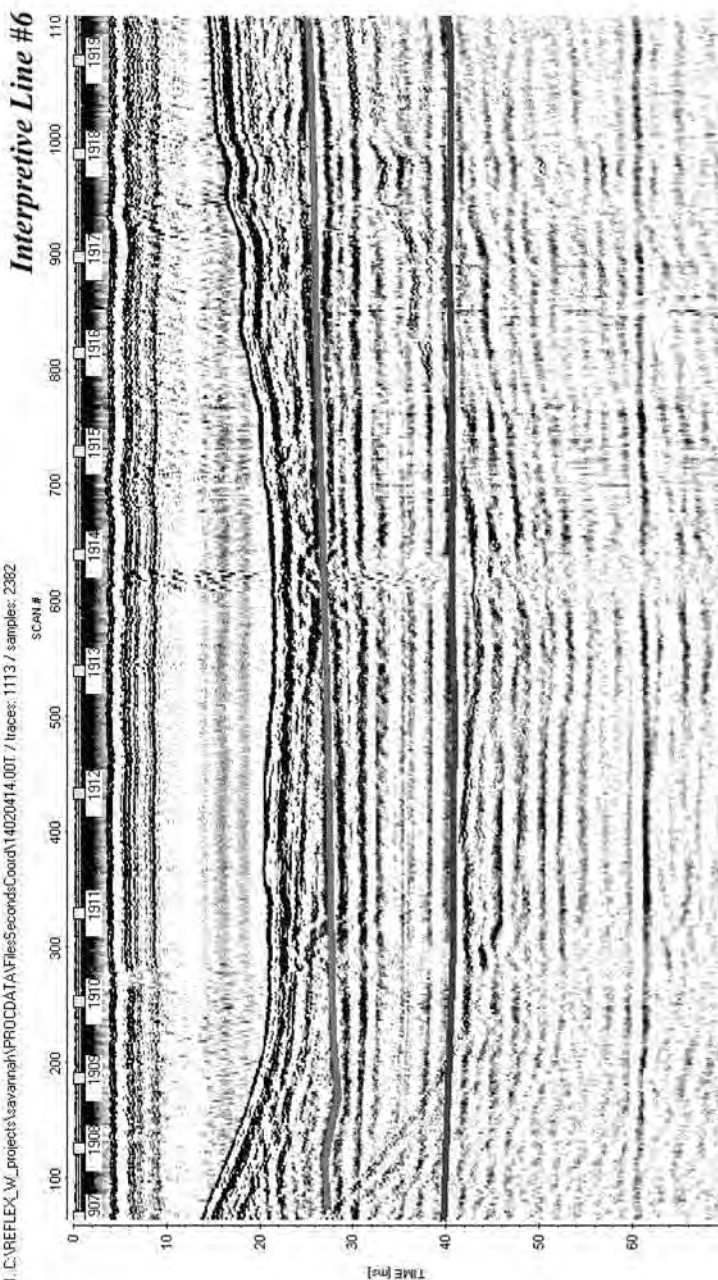
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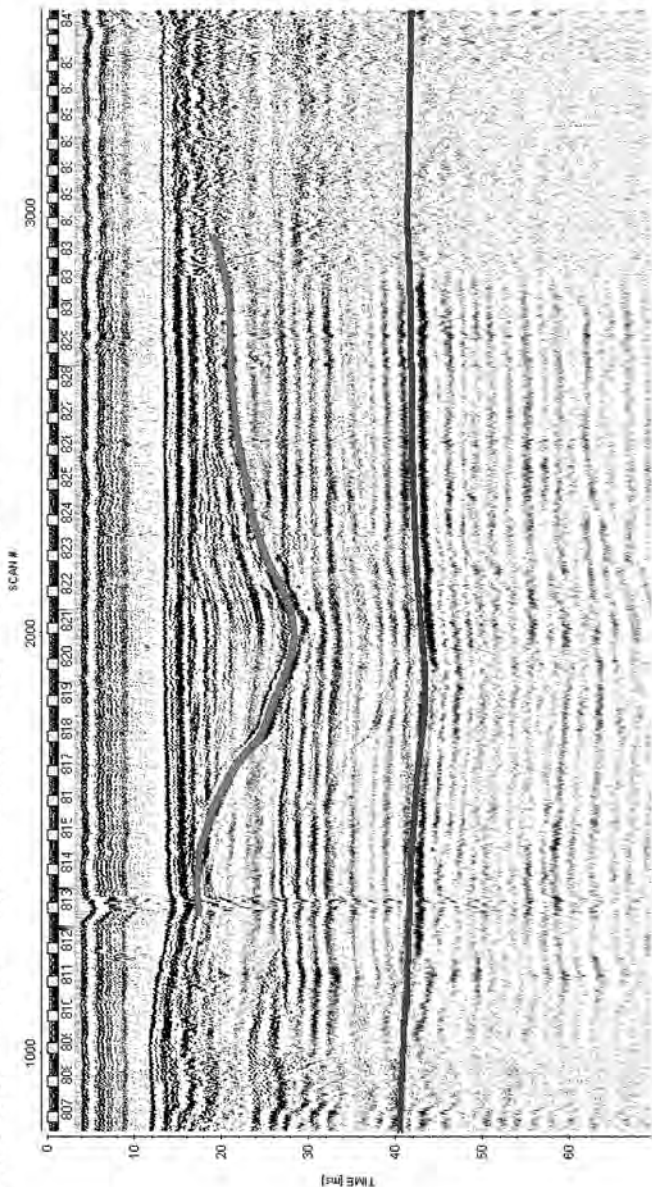


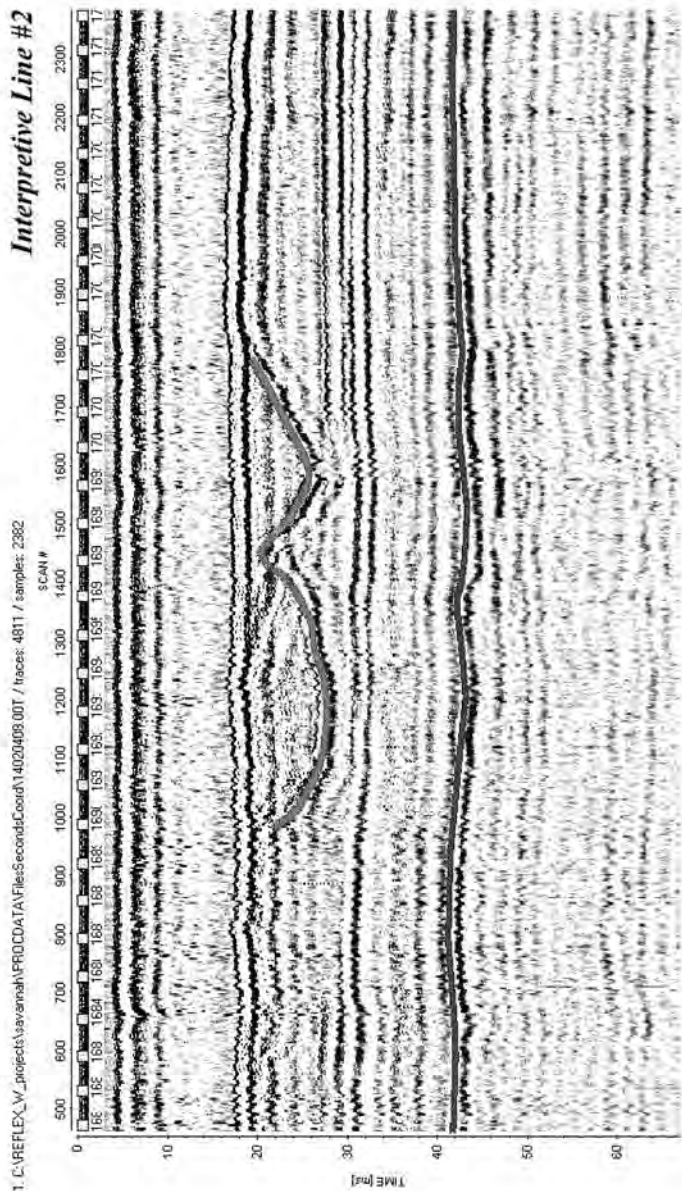
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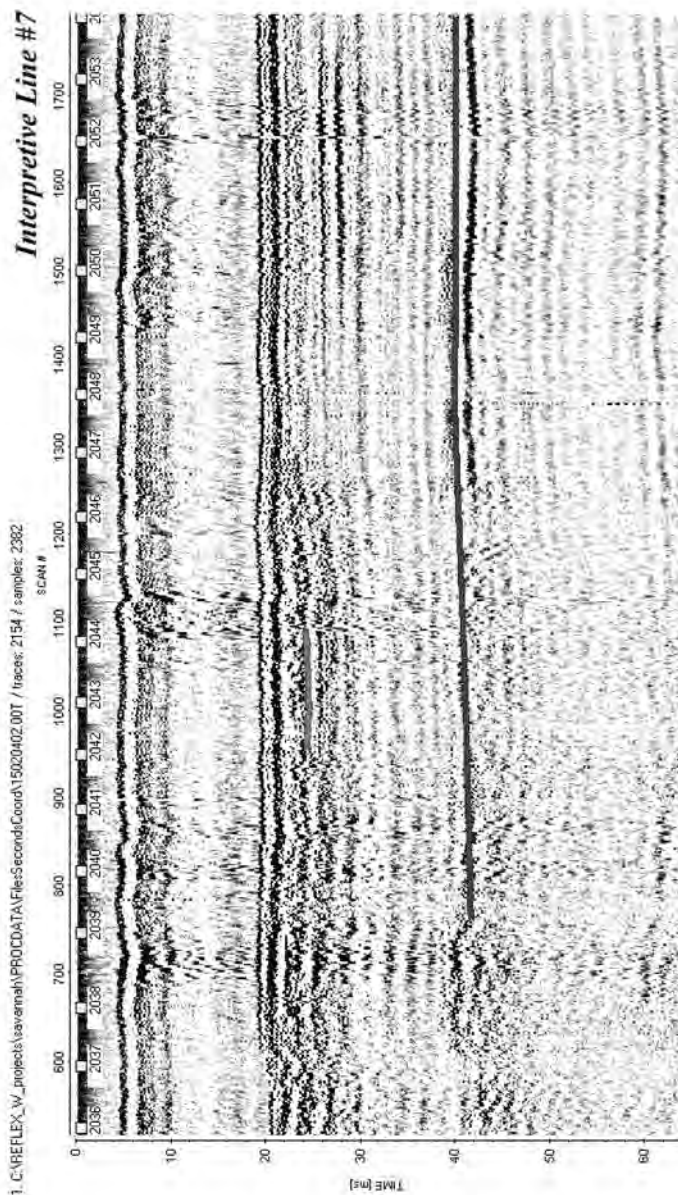


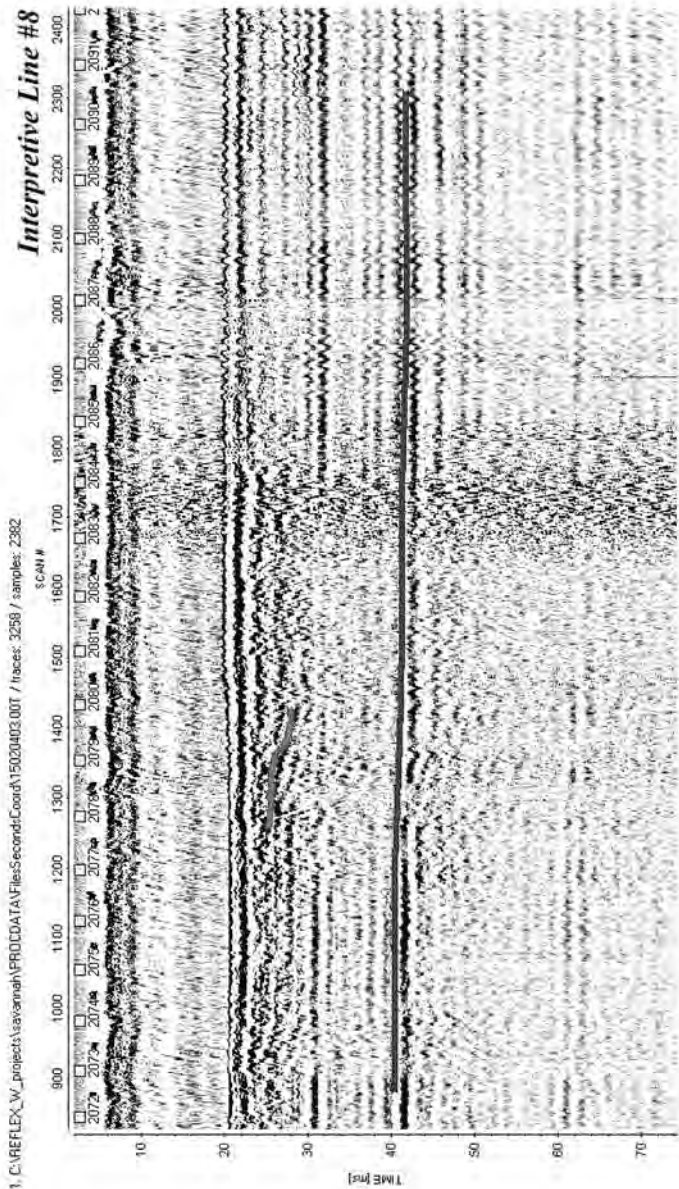
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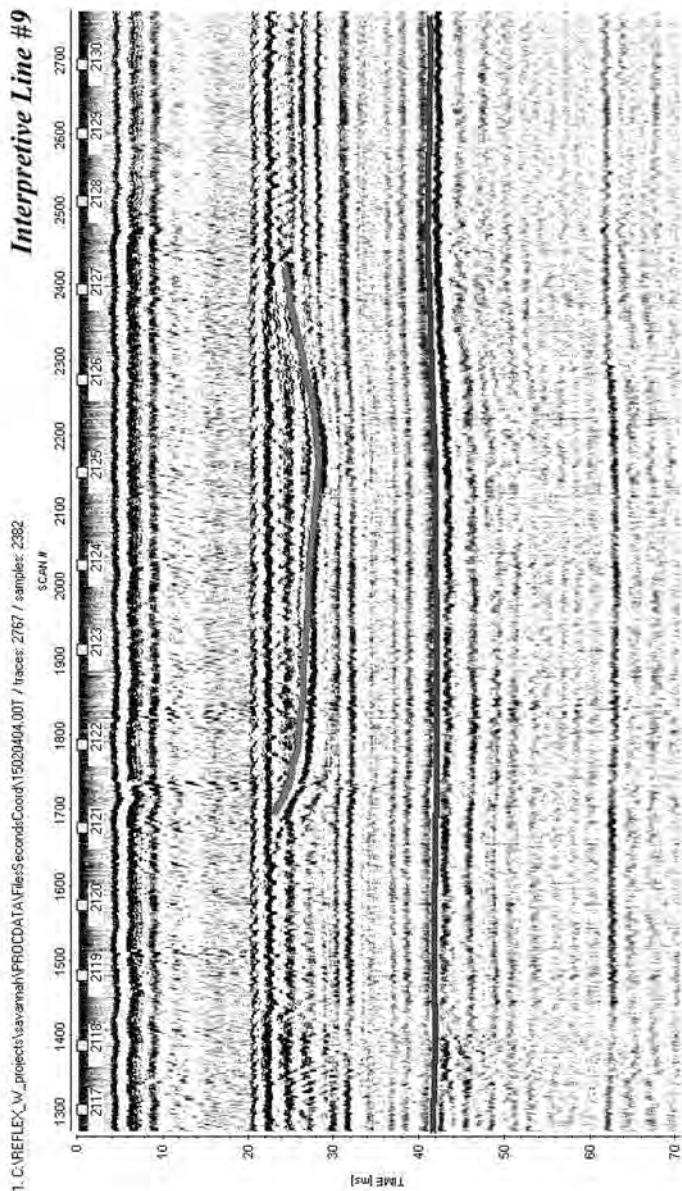
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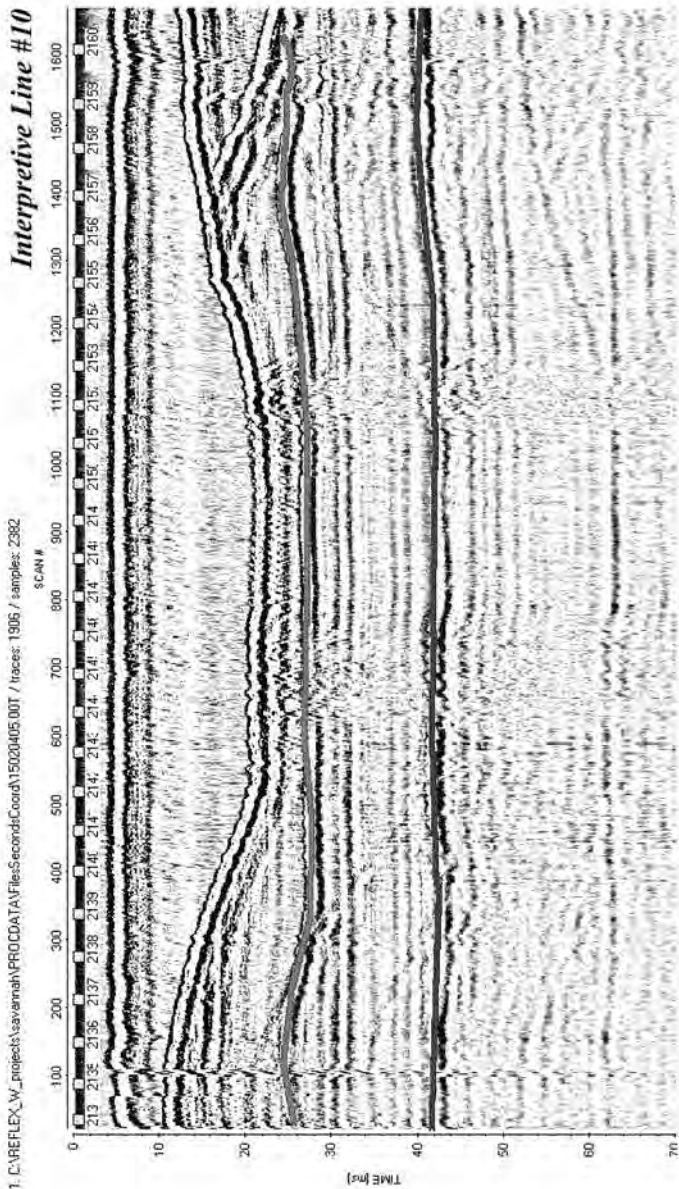






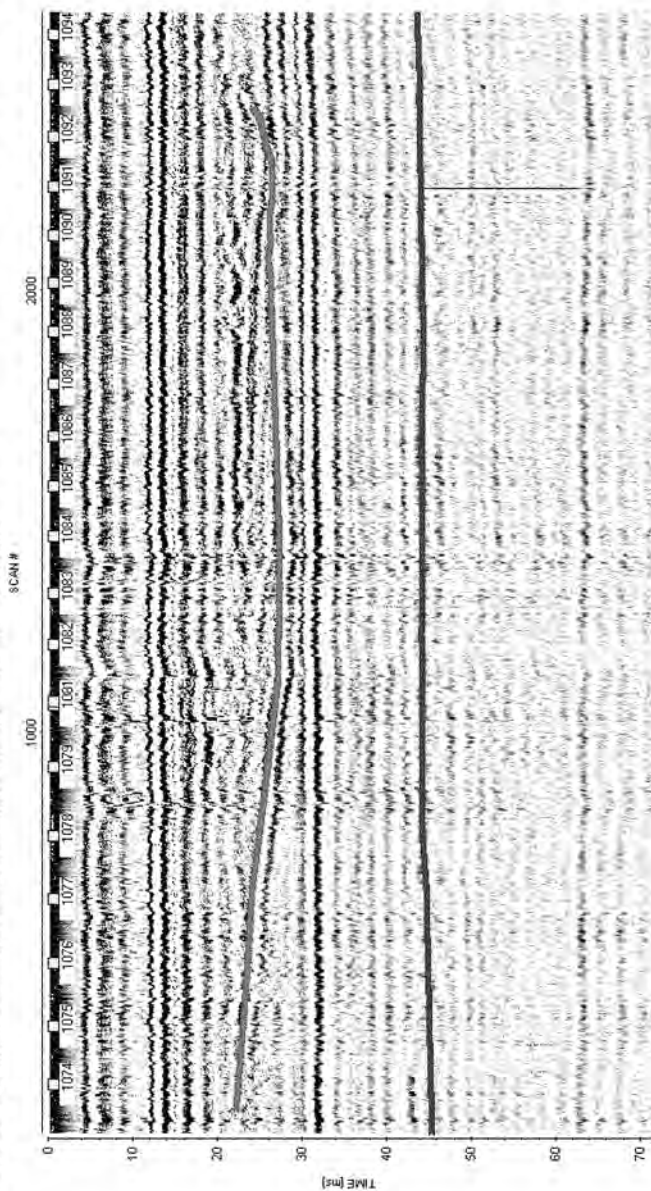






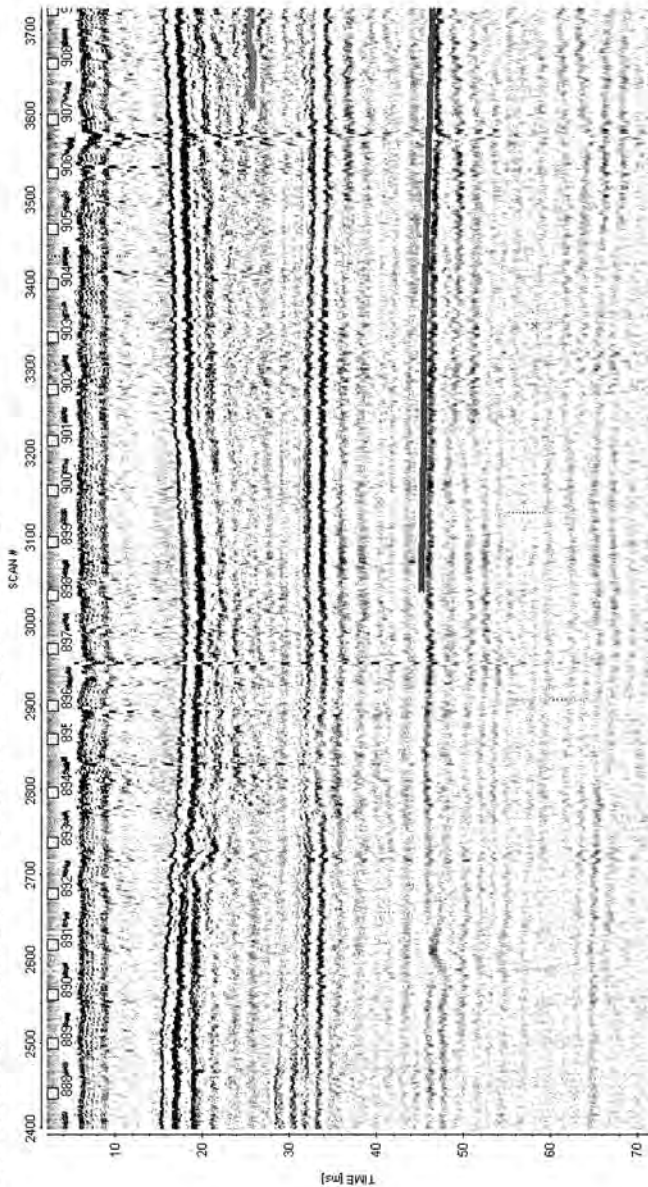
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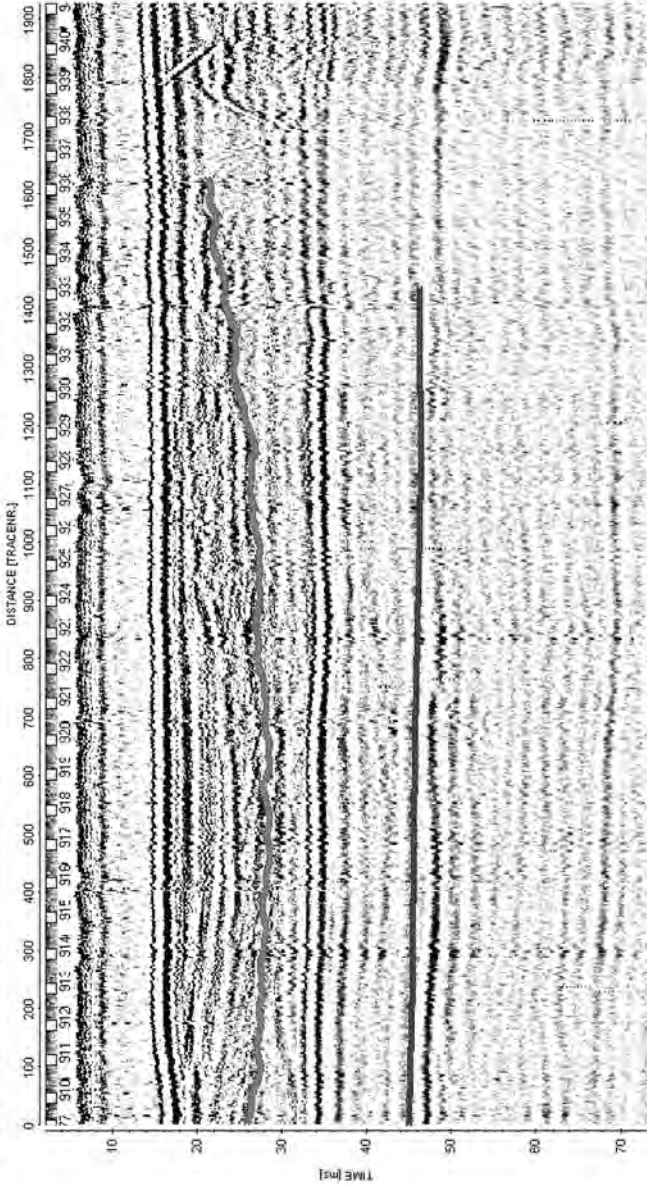
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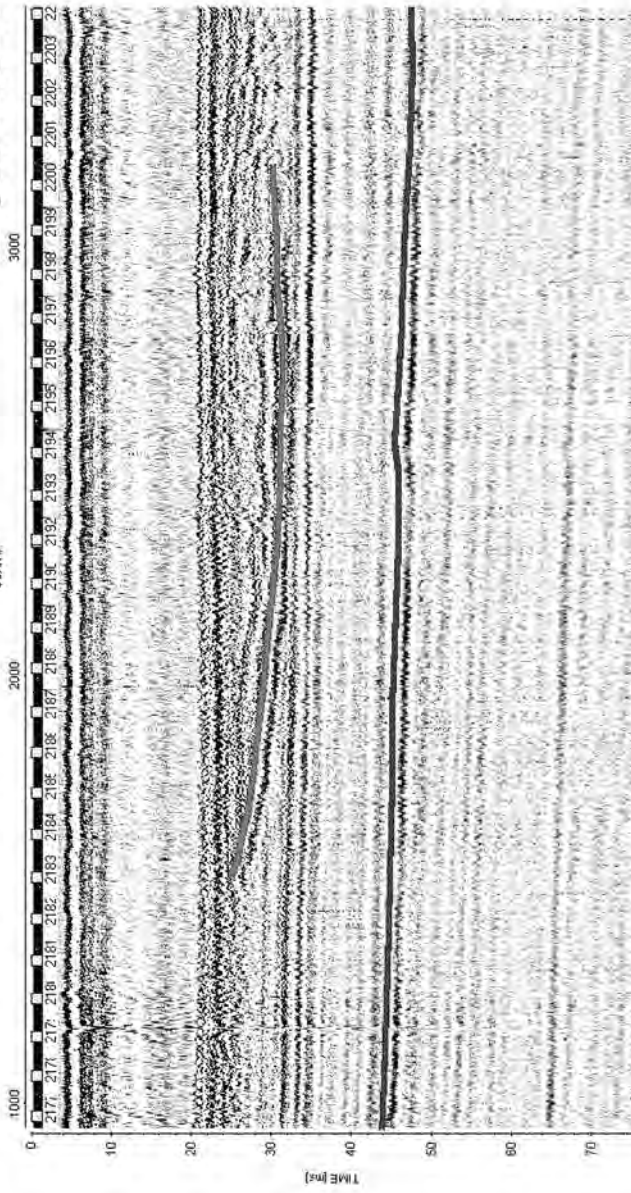
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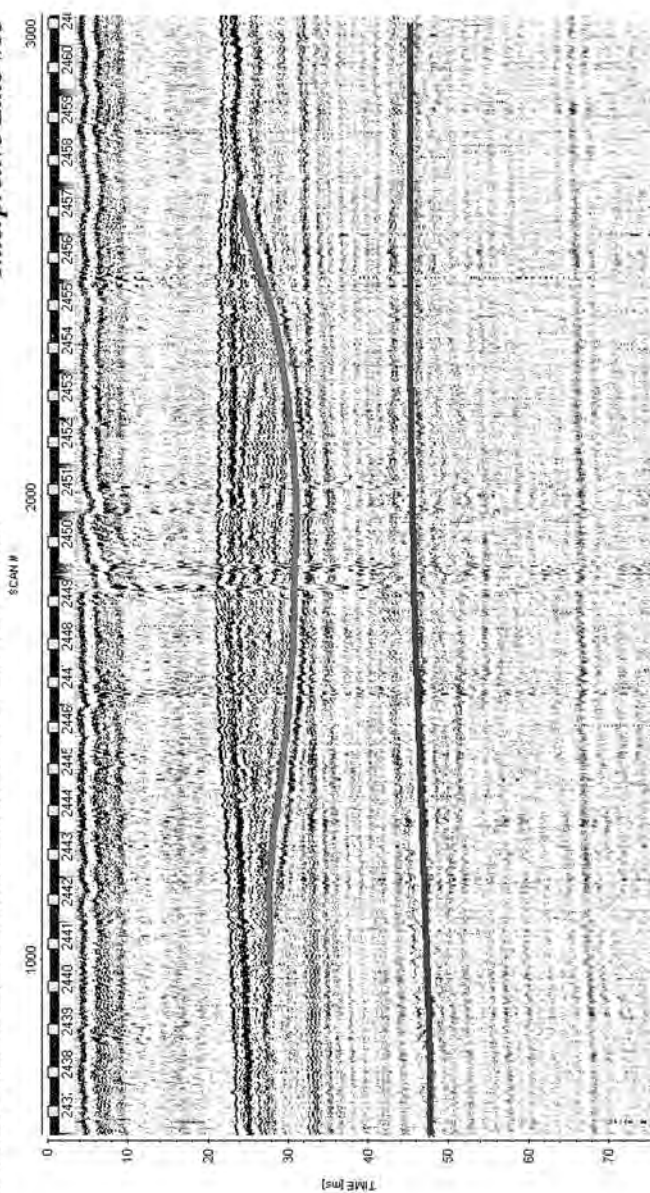
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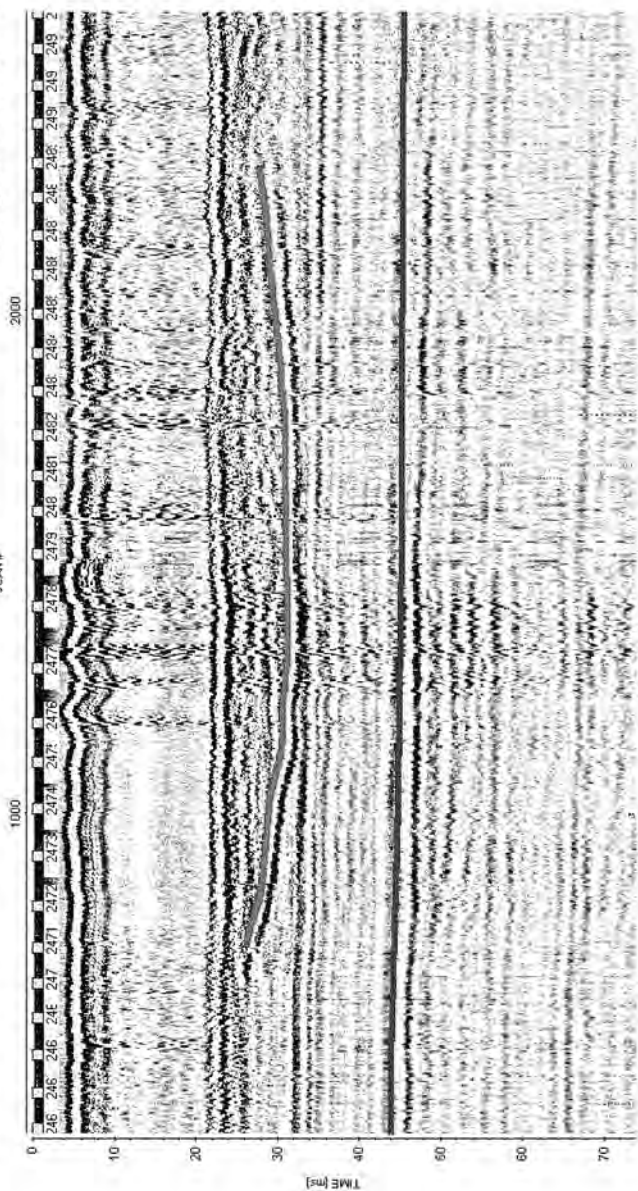
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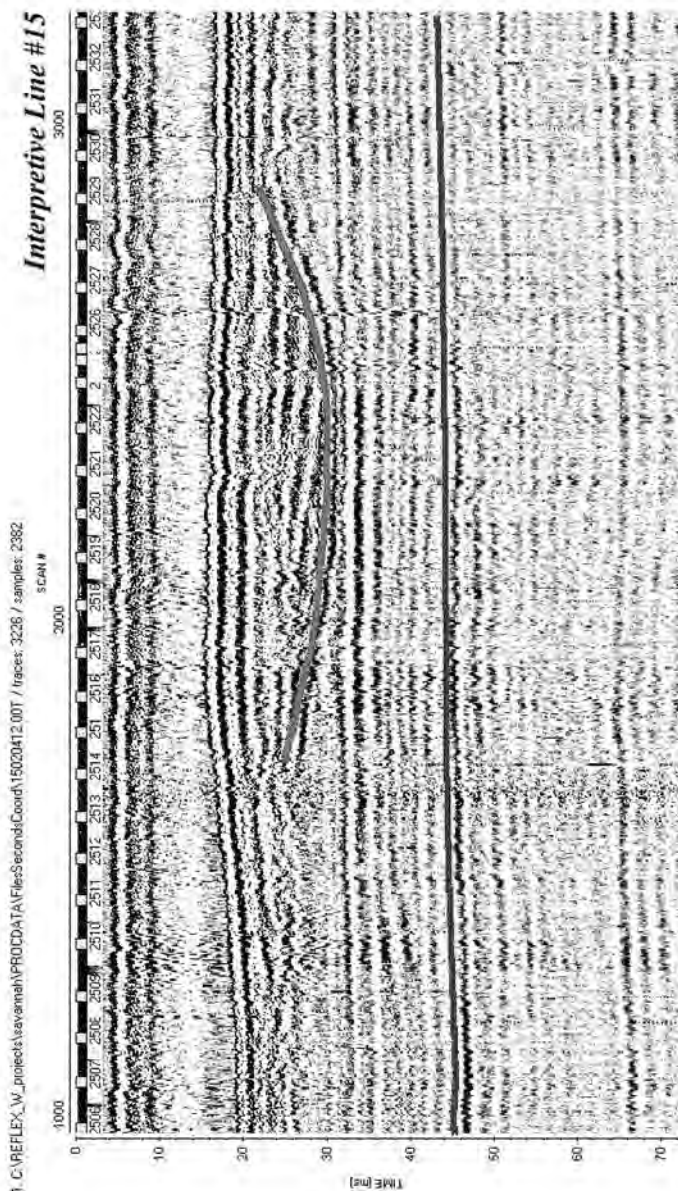
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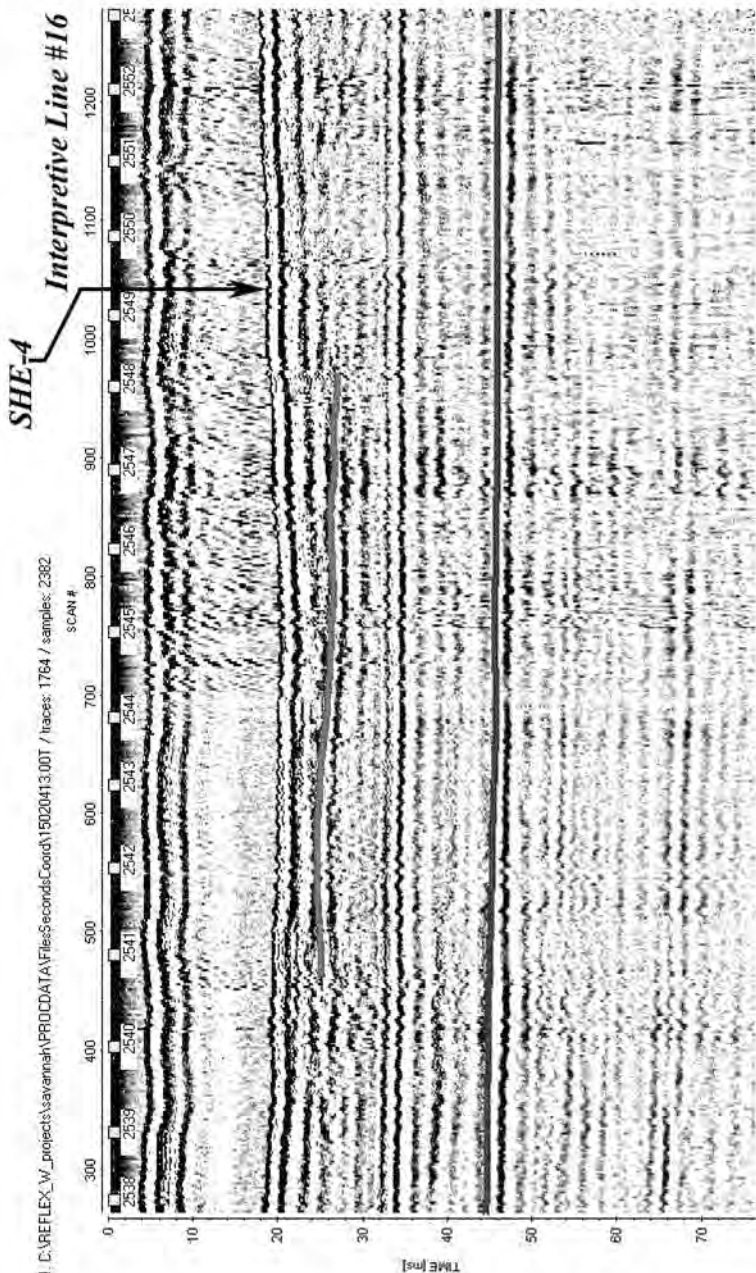


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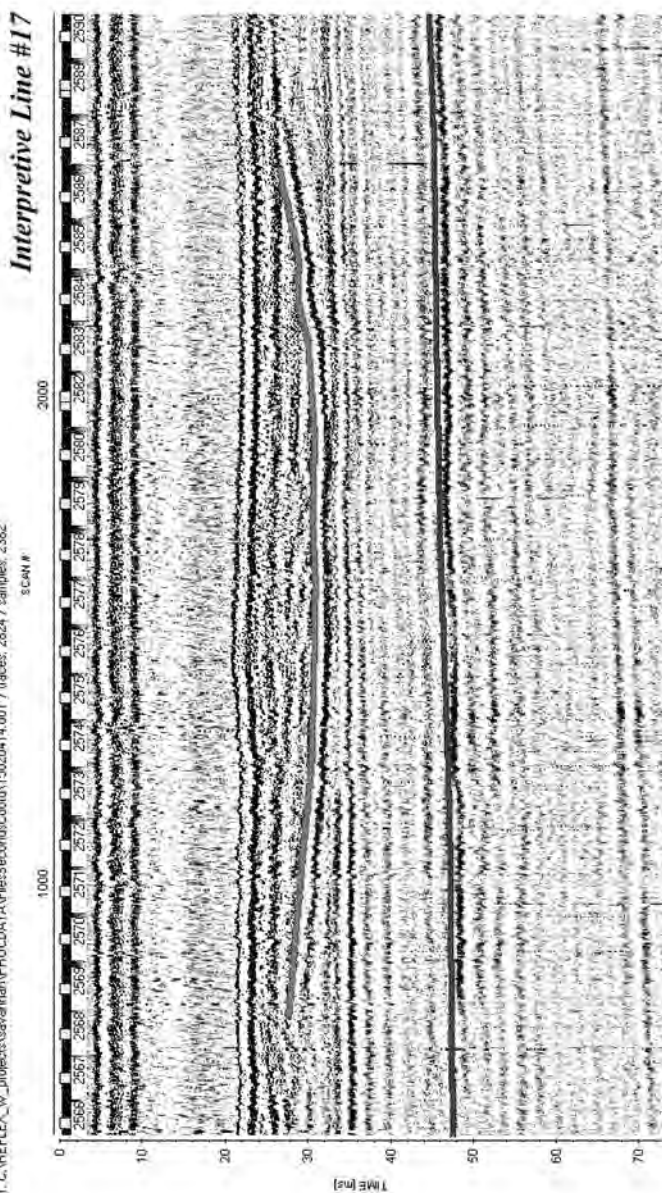
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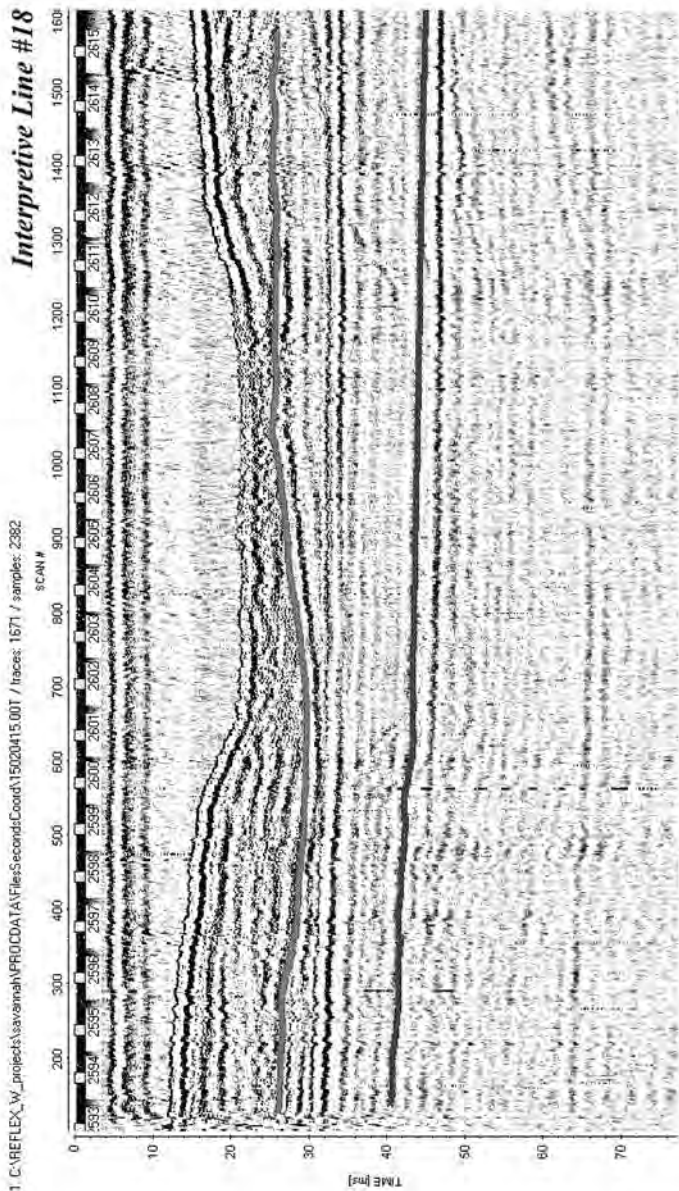


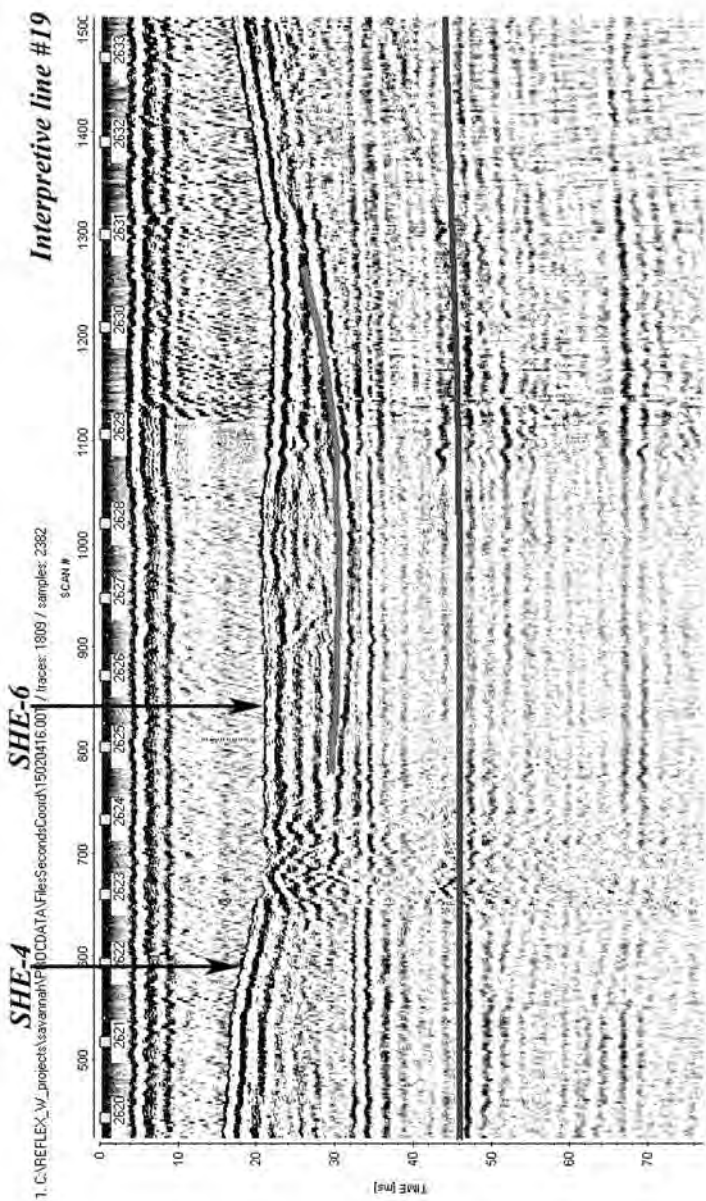


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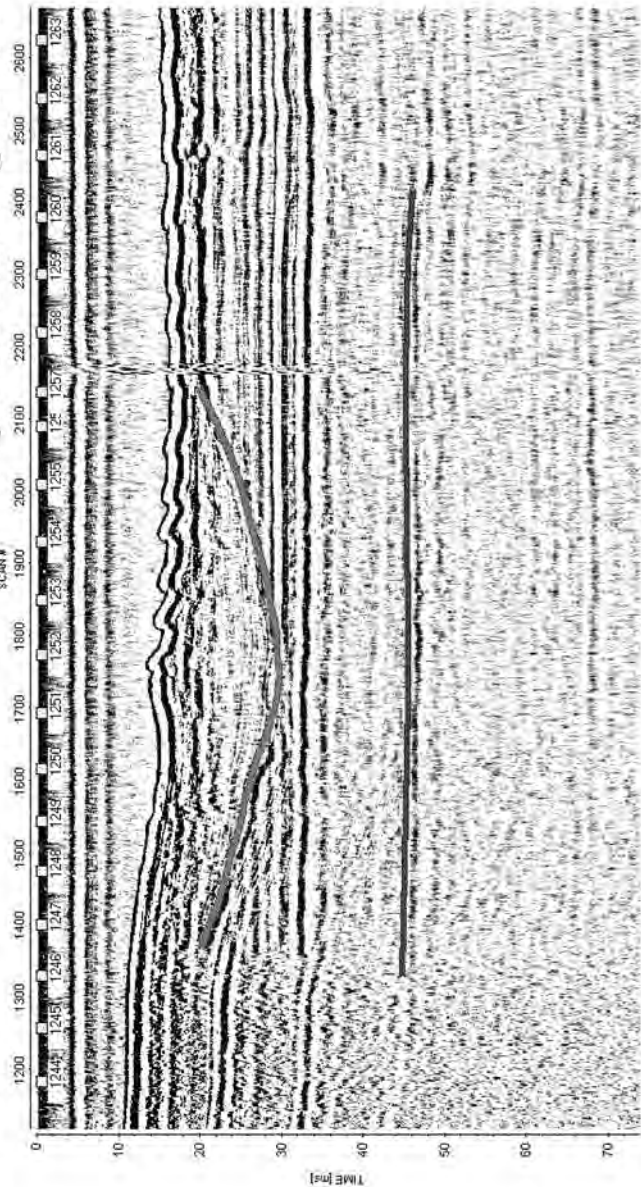
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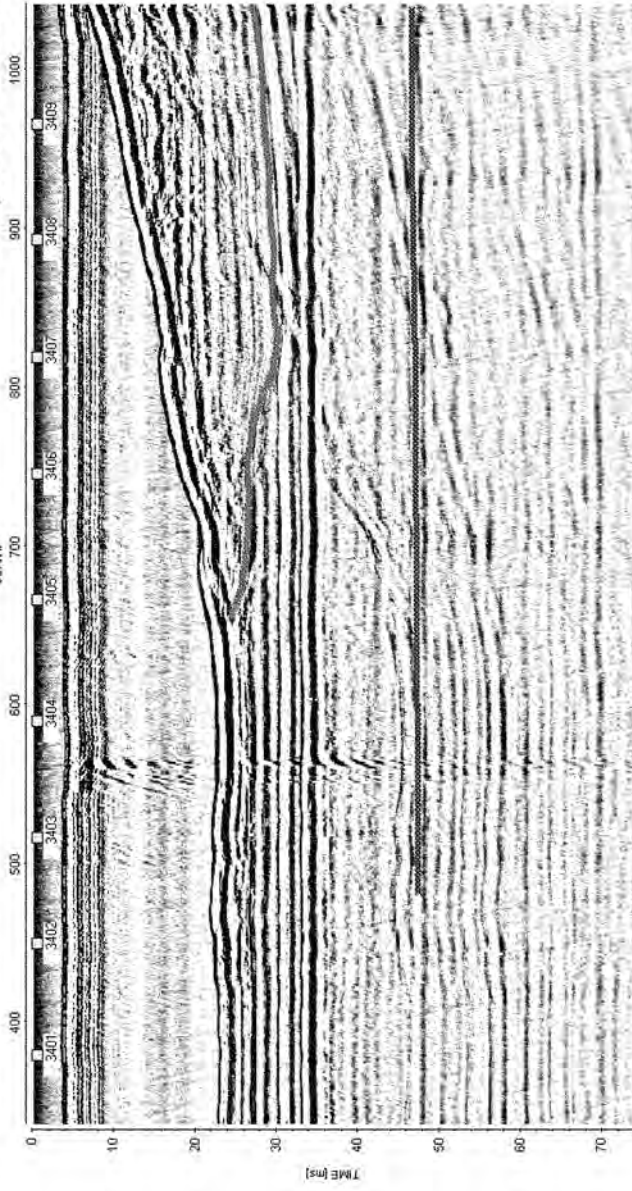
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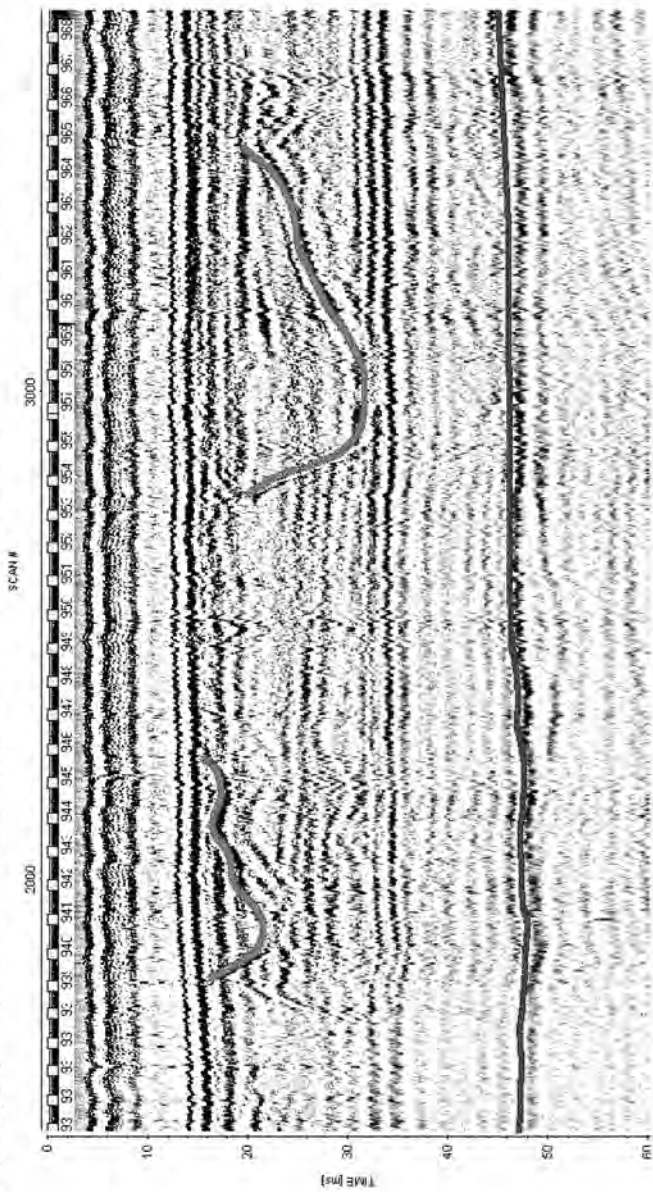
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APPENDIX B

CDM Ground-Water Model Studies Technical Memorandum



US ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT



United States Army Corps
of Engineers
Savannah District

Savannah Harbor Expansion
Three-Dimensional Salt Water Intrusion
Modeling

September 27, 2005

*Technical
Memorandum*

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Section 1

Introduction

1.1 Purpose and Scope

This technical memorandum documents the groundwater flow model developed to evaluate the potential impacts to the Upper Floridan aquifer by the proposed dredging of the Savannah Harbor channel. The work was completed under Contract No. DACW17-01-D-0013 - 3-Dimensional Salt Water Intrusion Modeling, Savannah Harbor Expansion Project.

1.2 Project Background

The Savannah Harbor Expansion (SHE) Project was conceived to deepen the Savannah Harbor and entrance channel to various depths below Mean Low Water (MLW) (ACOE, 2002). The 3-Dimensional Salt Water Intrusion Modeling Study was conducted as part of a series of investigations to determine if deepening of the Savannah Harbor channel has the potential to impact the water quality in Upper Floridan aquifer within the project area. The Floridan aquifer is the largest source of freshwater in the coastal area of Georgia and the potential for saltwater intrusion is a growing concern among the coastal communities and State and Federal agencies.

To evaluate regional groundwater management issues and the saltwater intrusion problem in coastal Georgia, the USGS has developed a regional MODFLOW model. The USGS groundwater model covers the entire 24-county coastal Georgia area, and extends north into Jasper County, South Carolina, and south into Nassau County, Florida. USGS's regional model does not have sufficient detail to effectively evaluate potential changes in groundwater heads, gradients, and migration of saline water due to dredging of the Savannah channel. Therefore, for this project a fully 3-dimensional, finite element groundwater flow and saltwater intrusion model with a higher level of discretization in the Savannah area was developed. The regional hydrogeologic structure, including model layering, aquifer properties and boundaries conditions of the SHE groundwater model were based on the USGS groundwater model. In the Savannah area detailed bathymetric and lithologic data were incorporated to refine the river channel geometry and the underlying hydrogeologic conditions.

1.3 Study Approach

The overall approach adopted by CDM for this study consisted of the following steps:

- **Data Review and Analysis:** CDM conducted a review of existing data and reports on aquifer studies and investigations for the proposed SHE Project, including the ACOE Savannah District's studies.
- **Development of Groundwater Flow and Saltwater Intrusion Model:** CDM developed a groundwater flow model with saltwater intrusion simulation capabilities based on the existing USGS groundwater model. A finite element

modeling code with a flexible grid structure was used so that the SHE groundwater model would have a sufficient level of detail along the Savannah River to evaluate the relative impact of the proposed dredging program. The model was specifically developed to simulate intrusion of salt water from the Savannah River in the harbor area, with the focus on the stretch of the river channel where dredging is proposed.

- **Refinement of the model:** The refinement involved: increasing the discretization of the finite element grid along the Savannah River in the project area; improving the representation of the Miocene confining unit based on ACOE boring data; improving the channel and offshore bathymetry based on detailed ACOE survey data and data available from NOAA.
- **Model Calibration:** The SHE groundwater model's ability to represent both steady-state and transient groundwater head and flow conditions was tested. Additionally, the model's ability to simulate saline water migration through the Miocene unit as measured in SHE boreholes was tested.
- **Model Application.** Once the model was tested and was shown to be able to adequately reproduce observed groundwater heads, gradients, and chloride concentrations, it was applied to evaluate the potential impacts of the proposed dredging by simulating the rate of migration of saline water from the Savannah River into the underlying groundwater system under a variety of input parameter assumptions. Potential migration of seawater through the offshore portion of the navigation channel was simulated. Other chloride sources such as salt marshes and the migration of seawater through undredged areas were not included in the simulations.

Section 2

Model Development

2.1 Model Background

The numerical groundwater flow and transport model used to evaluate the potential impacts of the SHE project is based on the regional USGS groundwater model. This section provides an overview of the SHE groundwater model structure and input parameters derived from the USGS groundwater model. Detailed information on the USGS groundwater model will be available in a report to be published in 2005.

2.2 Modeling Codes

The modeling software utilized in this study includes DYNFLOW (single phase groundwater flow), DYNTRACK (solute transport) and DYNCFIT (dual-phase, density dependent groundwater flow).

2.2.1 DYNFLOW

DYNFLOW is a fully three-dimensional, finite element groundwater flow model. This model has been developed over the past 25 years by CDM engineering staff, and is in general use for large scale basin modeling projects and site specific remedial design investigations. It has been applied to over 200 groundwater modeling studies in the United States. The DYNFLOW code has been reviewed and tested by the International Groundwater Modeling Center (IGWMC) (van der Heijde 1985). The code has been extensively tested and documented by CDM.

The governing equation for three-dimensional groundwater flow that is solved by DYNFLOW is:

$$S_s \frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x_i} K_{ij} \frac{\partial \phi}{\partial x_j}; i, j = 1, 2, 3$$

where the state variable ϕ represents the potentiometric head [L]; K_{ij} represents the hydraulic conductivity [LT^{-1}] tensor; S_s is the specific storativity (volume/volume/length), [L^{-1}]; x_j is a Cartesian coordinate and t is time.

DYNFLOW uses a grid built with a large number of tetrahedral elements. These elements are triangular in plan view, and give a wide flexibility in grid variation over the area of study. An identical grid is used for each level of the model, but the thickness of each model layer (the vertical distance between levels in the model) can vary at each point in the grid. In addition, 2-dimensional elements can be inserted into the basic 3-dimensional grid to simulate thin features such as faults. One-dimensional elements can be used to simulate the performance of wells which are perforated in several model layers.

2.2.2 DYNTRACK

The solute transport code used in this study is DYNTRACK. DYNTRACK uses the random-walk technique to solve the advection-dispersion equation. DYNTRACK has been developed over the past 15 years by CDM engineering staff. The partial differential equation describing transport of conservative solutes in a groundwater flow field is:

$$n_e \frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i} n_e D_{ij} \frac{\partial C}{\partial x_j} - q_i \frac{\partial C}{\partial x_i}; i, j = 1, 2, 3$$

where C is the concentration at any x_i location, n_e is the effective porosity, q_i is the specific discharge vector, and D_{ij} is the dispersion tensor. The first term on the right hand side of the equation represents the dispersive flux as embodied by Fick's Law; the second term represents the advective flux of solute mass.

DYNTRACK uses a Lagrangian approach to approximate the solution of the partial differential equation of transport. This process uses a random walk method to track a statistically significant number of particles, wherein each particle is advected with the mean velocity within a grid element and then randomly dispersed according to specified dispersion parameters.

In DYNTRACK, a solute source can be represented as an instantaneous input of solute mass (represented by a fixed number of particles), as a continuous source on which particles are input at a constant rate, or as a specified concentration at a node. The concentration within a particular zone of interest is represented by the total number of particles that are present within the zone multiplied by their associated solute mass, divided by the volume of water within the zone. DYNTRACK has also been reviewed and tested by the IGWMC (van der Heijde 1985).

2.2.3 DYNCFT

To fully simulate variable density effects on groundwater flow, the coupled flow and transport model DYNCFT was used. DYNCFT combines the groundwater flow capabilities of DYNFLOW, with the contaminant transport capabilities of DYNTRACK. Coupling flow and transport computations allows the effect on groundwater flow of fluid density gradients associated with solute concentration gradients to be incorporated into model simulations (i.e., density-dependent flow). In DYNCFT the flow and transport computations are loosely coupled. At each time step, the flow computations are completed first, holding densities constant, then the transport computations are completed. The computed heads are then re-adjusted to account for the effects of the fluid density. The main transport-related application for

the SHE groundwater model is the migration of saline water from the Savannah River.

2.3 Model Domain and Finite Element Grid

The domain or geographic extent of the SHE groundwater model is based on the USGS groundwater model. The extent of active cells within the USGS groundwater model was used as the basis in determining the domain of the SHE groundwater model. The SHE groundwater model domain has an area of approximately 42,250 square miles, and is discretized into 16,362 triangular elements defined by 8,257 nodes at the vertices of the triangles. **Figure 2-1** illustrates two typical finite elements and

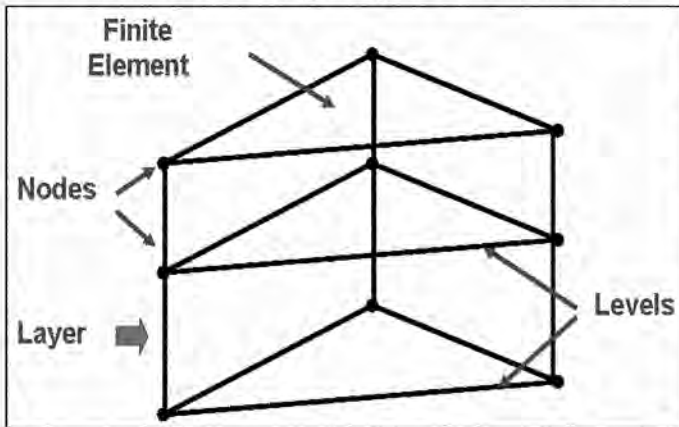


Figure 2-1: Typical Finite Element Structure and Terminology

the associated terminology.

Figure 2-2 shows the domain of the SHE groundwater model's finite-element grid. In order to represent the proposed dredging, discretization is finest in the area of the Savannah River. Within the river, node spacing is on the order of 125 feet. **Figure 2-3** shows a portion

of the grid with detailed discretization near the city of Savannah. The node spacing increases outside of the Savannah River area. The typical inland node spacing is 4.5 to 5 miles. Offshore nodal spacing is approximately 10.5 to 11 miles.

2.4 Boundary Conditions

DYNFLOW accepts various types of boundary conditions on the groundwater flow system including:

- Specified head boundaries (where the piezometric head is known, such as at rivers, lakes, ocean, or other points of known head). These boundaries maintain the specified head, and adjust the flow into or out of the model to maintain that head.
- Specified flux boundaries (such as rainfall infiltration, well pumpage, and no-flow "streamline" boundaries). These boundaries specify the amount of water into or out of the model (including specifying no flow), and vary the head to maintain the specified flux.

- Rising water boundaries; these are hybrid boundaries (specified head or specified flux boundary) depending on the system status at any given time. Generally used at the ground surface to simulate streams, wetlands, and other areas of groundwater discharge. This boundary allows the head to rise to the land surface elevation, after which it acts as a fixed head, discharging water to the surface. Some of the river nodes were assigned rising water boundaries.
- Head-dependent flux (3rd type) boundaries including “River” and “General Head” boundary conditions. This boundary was not used in the model.

The boundary conditions assigned in the SHE groundwater model are based on the USGS groundwater model and modified as described below to fit the finite-element model structure. The types of groundwater flow boundary conditions used for the model are fixed heads and no flow boundary conditions. Fixed concentration boundary conditions are used for the seawater transport computations. **Figure 2-4** shows the location of the boundary condition nodes in the model. Both groundwater flow and transport boundary conditions are described in more detail below.

2.4.1 Savannah River Boundary Condition

A fixed head boundary condition was applied to nodes within the Savannah River at the top water level in the area of interest of the Savannah Harbor. Heads were assigned a value of zero to represent the long-term average water level in the river. Further upstream, the Savannah River nodes were assigned either fixed heads based on the estimated elevation of the water surface in the river or a rising node boundary to allow the surficial aquifer to discharge to the river. For the saline water migration simulations, the Savannah River nodes were assigned a constant chloride concentration. The chloride concentrations in the Savannah River were obtained from the surface water modeling conducted for the SHE by Tetra Tech (Tetra Tech, November, 2004). **Figure 2-5** illustrates the simulated mean salinity for the Savannah River for both dredging and no dredging conditions generated by the Tetra Tech surface water model. These salinity values represent simulated average annual concentrations of river water at the bottom of the river from preliminary surface water model simulations. Salinity was converted to chloride concentration by multiplying the salinity values by 0.37, a reasonable value for sea water (Harrey, 1969).

2.4.2 Ocean Boundary Condition

Offshore nodes located within the Atlantic Ocean (see **Figure 2-4**) were assigned an equivalent freshwater head at the top level (free water surface) of the model. The equivalent freshwater head is computed as shown below.

$$\text{Equivalent Freshwater Head} = \text{Depth of Seawater} * \text{Relative Seawater Density}$$

For example, if the depth of seawater at the ocean boundary node is 100 feet, the equivalent freshwater head is $100 * 0.025 = 2.5$ feet. The relative density of seawater compared to freshwater was obtained from The Chemistry and Fertility of Sea Waters (Harvey, 1969). Only the migration of seawater through the navigation channel is

simulated, the inland migration of seawater in other areas is not simulated, and therefore no concentration boundary condition is required. The east and southeast boundaries of the model (located in the ocean) are modeled as no flow boundaries consistent with the USGS groundwater model.

2.4.3 Southwest and Southern Boundaries

A fixed head boundary condition was assigned to nodes along the southwest boundary of the model (see Figure 2-4). The values assigned as fixed heads were interpolated onto the grid from computed values in the USGS groundwater model.

2.4.4 Northwest and Northeast Boundaries

The northwest and northeast boundaries of the model are no-flow boundaries consistent with USGS groundwater model.

2.4.5. Base of the Model

A no-flow boundary condition is assigned at the base of the model consistent with the USGS groundwater model.

2.4.6 Water Table

Consistent with the representation in the USGS groundwater model and using the assumption that pumping in the Upper Floridan aquifer is the driving force of the downward gradient, the water table is represented as fixed head values within the surficial aquifer unit throughout the model.

2.5 Model Layering and Stratigraphy

The conceptual layout out of the aquifer and confining units in the model is based on the USGS groundwater model. Table 2-1 lists the seven basic hydrogeologic units represented in the model.

Table 2-1
Hydrogeologic Units Represented in the Model

Regional Hydrogeologic Unit	Savannah Harbor Area Hydrogeologic Unit	Relative Depth
Surficial Aquifer	Surficial Aquifer	Shallow ↓ Deep
Miocene Confining Units	Miocene Confining Units	
Miocene Aquifer	Not Present	
Upper Floridan Confining Unit	Upper Floridan Confining Unit	
Upper Floridan Aquifer	Upper Floridan Aquifer	
Lower Floridan Confining Unit	Lower Floridan Confining Unit	
Lower Floridan Aquifer	Lower Floridan Aquifer	

Figures 2-6 through 2-10 show cross sections through the model layering showing the hydrogeologic units listed above. Thicknesses of the hydrogeologic units were interpolated from the USGS groundwater model. To provide sufficient vertical discretization to simulate chloride migration beneath the river, these seven

hydrogeologic units of the SHE groundwater model were divided into 12 levels and 11 layers as summarized in Table 2-2.

Table 2-2: Model Layering and Hydrogeologic Units

Layer	Regional Hydrogeologic Unit	Savannah Harbor Area Hydrogeologic Unit
11	Surficial Aquifer	
10	Miocene Confining	Miocene Confining
9	Miocene Confining	Miocene Confining
8	Miocene Confining	Miocene Confining
7	Miocene Aquifer	Not Present
6	Upper Floridan Confining	
5		
4		
3	Upper Floridan Aquifer	Upper Floridan Aquifer
2	Lower Floridan Confining	Lower Floridan Confining
1	Lower Floridan Aquifer	Lower Floridan Aquifer

Figures 2-11 through 2-17 illustrate the thickness of each of the seven hydrogeologic units for the entire model domain.

2.6 Aquifer Properties

Figures 2-11 through 2-17 illustrate the distribution of the major aquifer hydraulic properties. The aquifer properties were derived from the USGS groundwater model.

2.7 Groundwater Recharge

Groundwater recharge is not explicitly simulated. The fixed heads in the surficial aquifer generate groundwater flux either into, or out of the model depending on the simulated heads in the model levels below the surficial aquifer.

2.8 Groundwater Pumping

The groundwater pumping specified in the model was taken directly from data files developed by the USGS for the regional MODFLOW model. Groundwater pumping data are available in two formats - well specific and distributed. The well specific pumping data are based on individual well, or facility permits. Typically, well specific data are available for 1 MGD permits or larger, and in most cases the total permit capacity is known but not the individual well production. The distributed pumping data refer to the total groundwater pumping estimates for each of the 24 Georgia counties located within the model domain. For the historical simulation, groundwater pumping data were obtained from the USGS. Figure 2-18 illustrates the total groundwater pumping applied in the model for the historical period from 1900 to 2000. Note that for projection simulations, the 2000 pumping was projected to continue indefinitely into the future.

Well Specific Pumping

Within the Georgia counties, in many cases, the locations and pumping rates for specific wells are known. At these locations a pumping rate is specified at the horizontal location of the wells. The pumping is assigned vertically to the appropriate aquifer unit (e.g. Upper or Lower Floridan) based on information about the screened interval of each well. **Figure 2-19** shows the specified pumping well locations within the Upper and Lower Floridan aquifers.

Distributed Pumping

The difference in pumping volumes between the individual county total and the known permit specific pumping is distributed equally to the nodes that fall within that county. This approach is similar to the USGS's methodology. The distributed pumping is allocated to the appropriate aquifer unit according to the vertical distribution developed by the USGS for the regional model. **Figure 2-20** shows the allocation of county-based distributed pumping for the year 2000.

2.9 Model Calibration

2.9.1 Steady State Calibration

Model calibration is the process of making adjustments to model input parameters until the output from the model reasonably matches a set of measured data and the observed behavior of the ground water flow system. The USGS groundwater model is calibrated to steady-state year 2000 conditions, and input data sources are referenced in Sections 2-6 through 2-8. In steady-state calibrations, measured and model-computed heads (water levels) are compared, and the difference between the two, referred to as the residual, is calculated.

This modeling study was not designed to seek a fully calibrated model of the Savannah area aquifer system, but rather to test the plausible range of input parameters and their effect on results. Nevertheless, the model results were examined against data to test whether the SHE groundwater model adequately represents the observed conditions and is consistent with the USGS representation. To do this, the simulated steady-state heads for the year 2000 were compared to both the calibration targets used by the USGS and the actual simulated USGS groundwater model heads. **Figure 2-21** shows a comparison between the simulated SHE groundwater model heads and the measured groundwater heads in the Upper and Lower Floridan aquifers for the year 2000 by plotting the location and magnitude of water level residuals. The figure also shows the simulated head contours for the Upper Floridan aquifer. Typically, a calibration is considered adequate when there is no systematic head bias across the model, and the standard deviation of residuals should be within 10-15% of the total measured head gradient across the model domain.

Figure 2-21 shows that no single area of the model has systematically high or low simulated groundwater heads relative to the measured values. Additionally, the standard deviation of 11 feet is significantly lower than 10 percent of the total measured head gradient across the model which is 200 to 300 feet. Within the Savannah area alone the range of measured heads in the Floridan aquifer system is

approximately 100 feet. Based on this assessment the SHE groundwater model is adequately calibrated to simulate steady conditions.

Figure 2-22 and **2-23** show a comparison between the simulated SHE groundwater model heads and the USGS groundwater model heads for the Upper and Lower Floridan aquifers. The figures illustrate that both models produce comparable results, which is as expected because the overall hydrogeologic structure, aquifer properties and applied hydraulic stresses are consistent.

2.9.2 Transient Testing

In addition to the steady-state calibration check, the SHE groundwater model's ability to reproduce both the historical temporal behavior of groundwater heads and the measured chloride levels in the Miocene confining unit below the Savannah River was tested. Measured groundwater head data is available for the model area from around the 1980s onward. However, to test the model's ability to reproduce the measured levels of chloride in the Miocene confining unit, a transient simulation starting with pre-development conditions (1900) was developed.

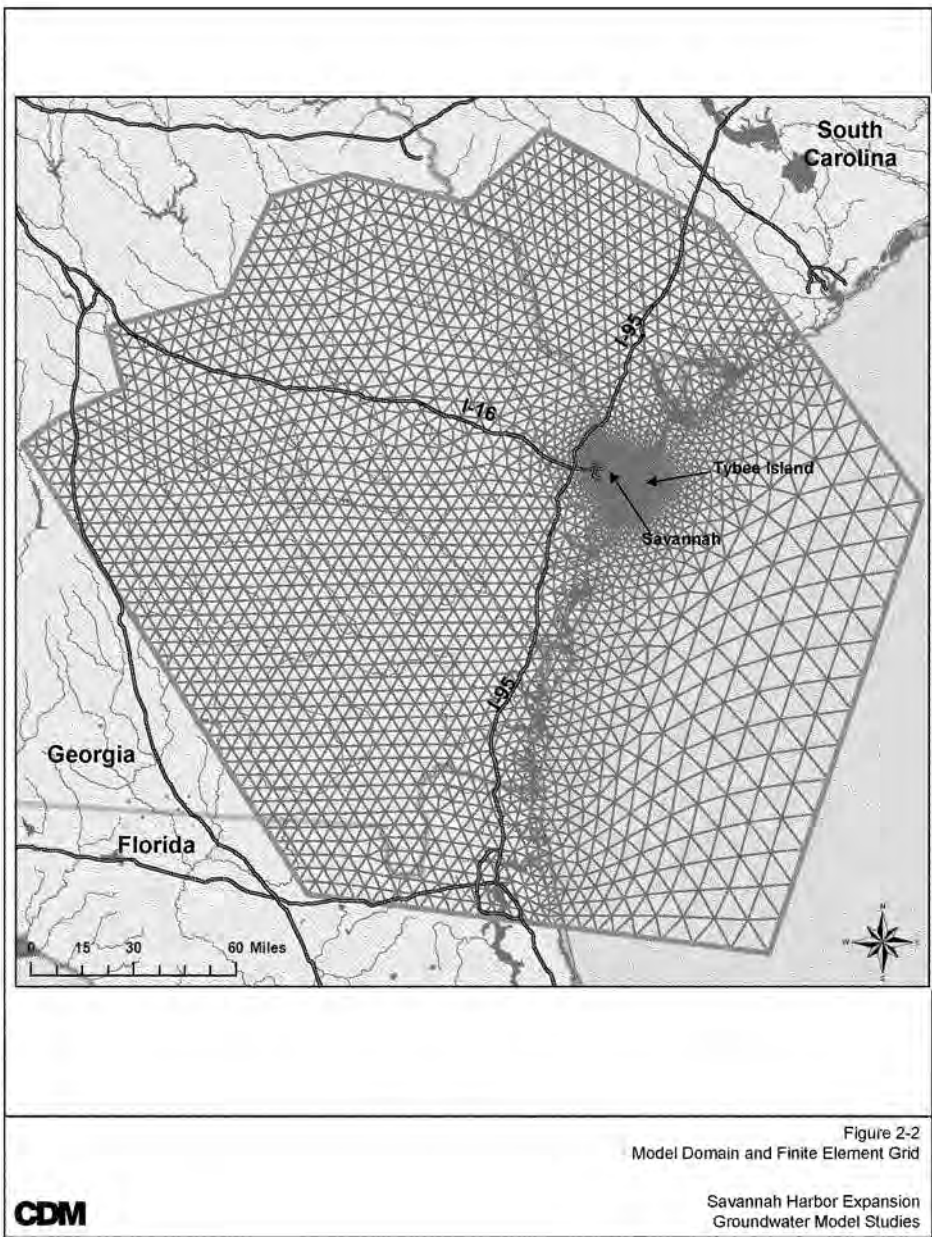
The transient testing was performed for the period of 1900 to 2000, using an annual time step. Surficial aquifer heads were kept constant from 1900 to 1960, and then changed every 10 years based on a linear interpolation between the 1900 and 2000 values. Pumping was varied every 5 to 10 years depending on the availability of data as shown in Figure 2-18. Chloride concentrations in the Savannah River were kept constant using the chloride distribution described in Section 2.4.1. Figures 2-24 through 2-26 illustrate the pre-development heads in the surficial, Upper and Lower Floridan aquifers respectively. Primary interest is in the heads simulated in the area of interest. No attempt was made to estimate changes to fixed head boundary conditions along the southern boundary, because they had no impact on results near Savannah.

The resulting simulated groundwater heads in selected wells in the Savannah area are shown Figures 2-27 and 2-28. Although in most cases, data were available for only a limited period within the 100 years simulated these graphs show that the model can effectively reproduce the long-term behavior observed in the groundwater heads in the Upper Floridan aquifer. The model accurately simulated the heads, as well as the general trends in heads, even though annual variations in pumping could not be simulated due to a lack of data.

Figures 2-29 through 2-40 illustrate the measured (from pore water samples) and simulated chloride concentration profiles at the SHE boreholes along the Savannah River. Concentrations of chlorides at the bottom of the river were taken from the TetraTech surface water model. The simulated results represent the chloride concentrations resulting from the migration of saline water from the Savannah River over the 100 year transient simulation period. These figures illustrate that the aquifer properties from the USGS groundwater model generally result in an overall depth of penetration of saline water somewhat deeper than observed, and chloride concentrations higher than measured. The simulated depth of penetration and chloride concentrations is most sensitive to the vertical hydraulic conductivity of the

Miocene confining unit. Therefore, for the model application the calibrated value of the vertical hydraulic conductivity for the Miocene confining unit is considered to represent the mid-range of reasonable values, but is perhaps somewhat more transmissive than it actually is. In this sense, the model results represent a conservative (i.e. too rapid) penetration of salt water. Several additional comments are in order

- Note that in most cases, the assumption of the starting concentration taken from the Tetra Tech surface water model results appears to reasonably match the data (e.g. Figures 2-29, 2-30, 2-31, 2-35, and 2-38). In one case, it appears to be slightly too high (Figure 2-34). In some cases, it might be somewhat too low (e.g. 2-36).
- The model simulates the Miocene confining units as a homogeneous unit, in which the total vertical hydraulic conductivity is conservatively estimated at about 1.5×10^{-4} feet per day. In reality, the rate of penetration and concentration is greatly affected by local heterogeneities in the unit (including small sandy layers). Thus the pore sample data is quite variable, while model results are expected to show smooth curves of decreasing concentration. The intent was to accurately simulate (or slightly overestimate) the depth of penetration, and use as accurate as possible surface chloride concentrations, but not to try to simulate local heterogeneity. In this way, projection simulations at steady state, when the actual concentration curves will eventually smooth out, will be reasonably projected.
- A second set of simulations, using a lower vertical hydraulic conductivity, was also tested, which underestimated the rate of salt water penetration. The true system response lies somewhere in between the two simulations.



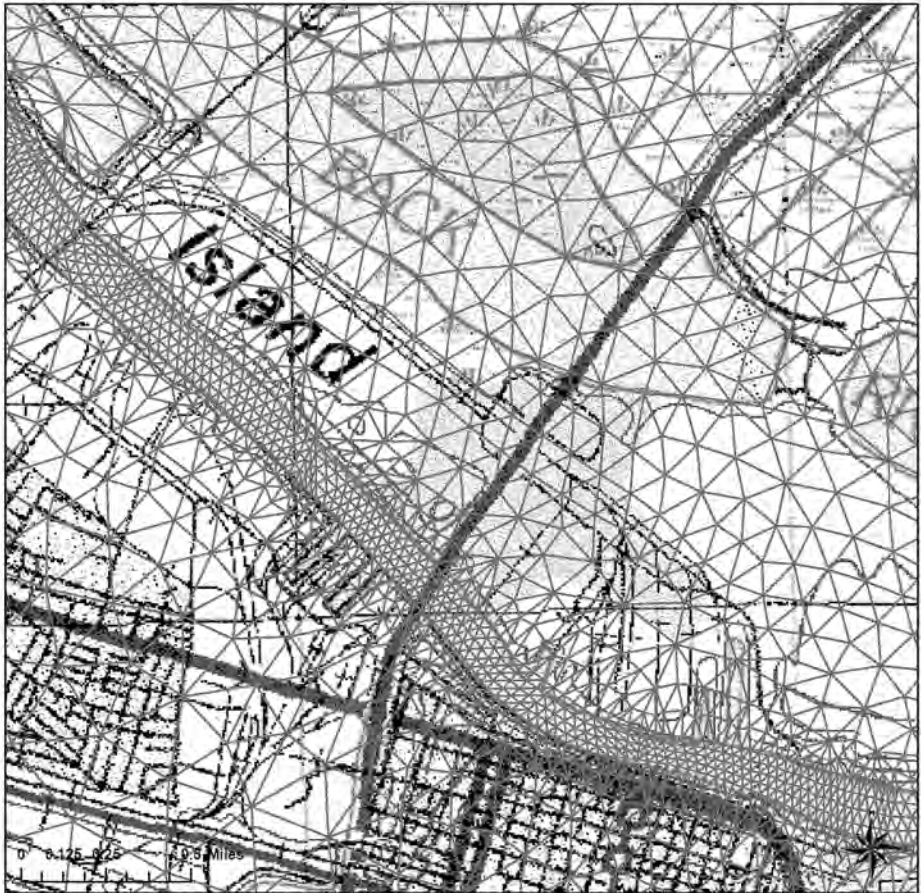
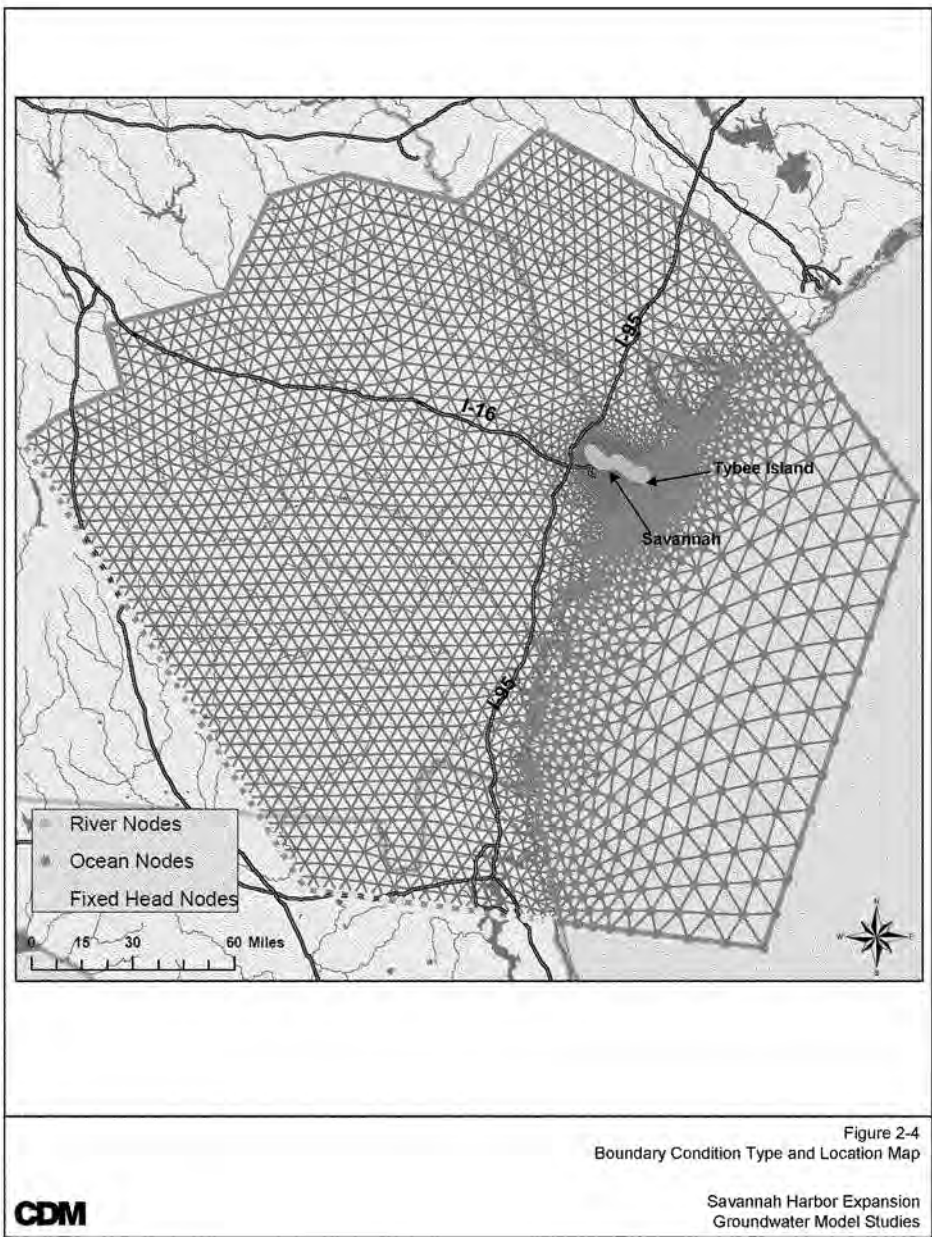
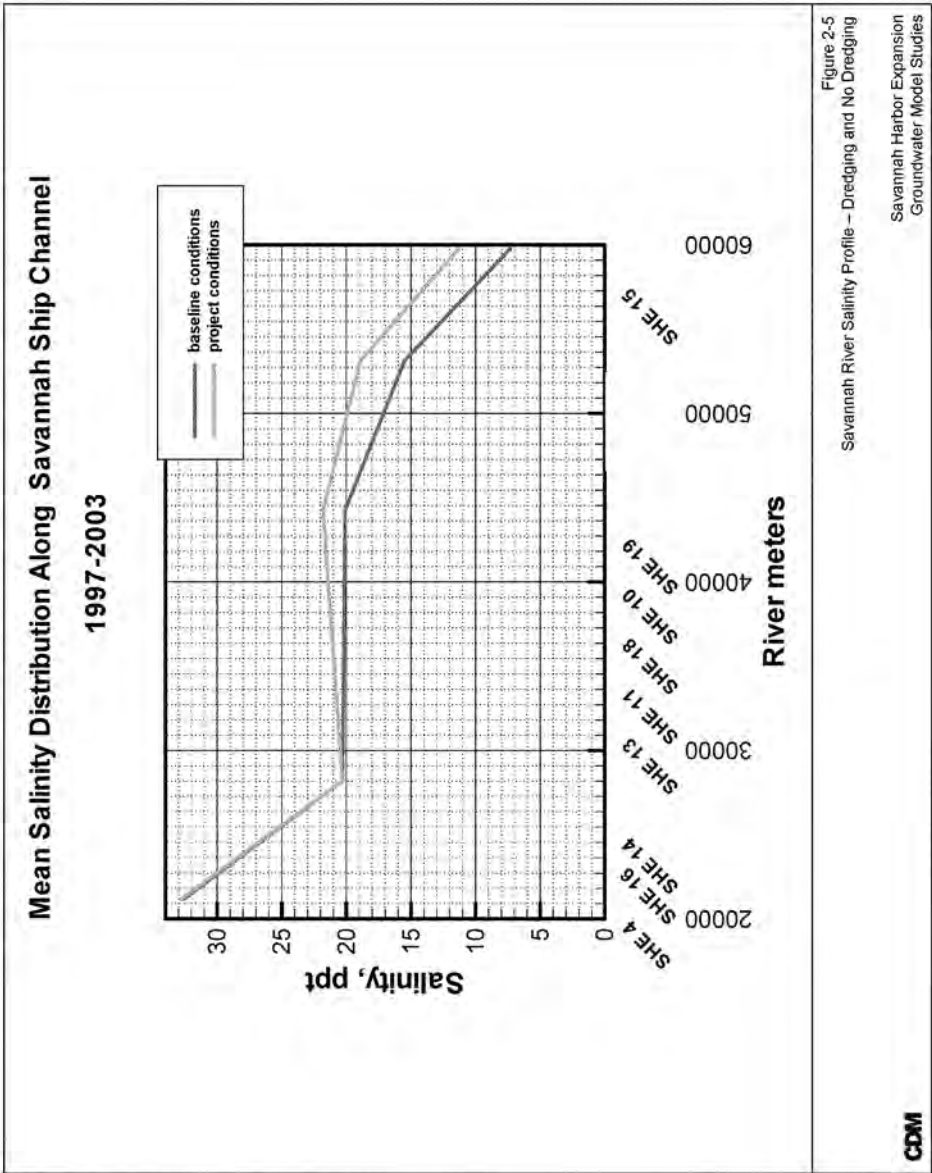
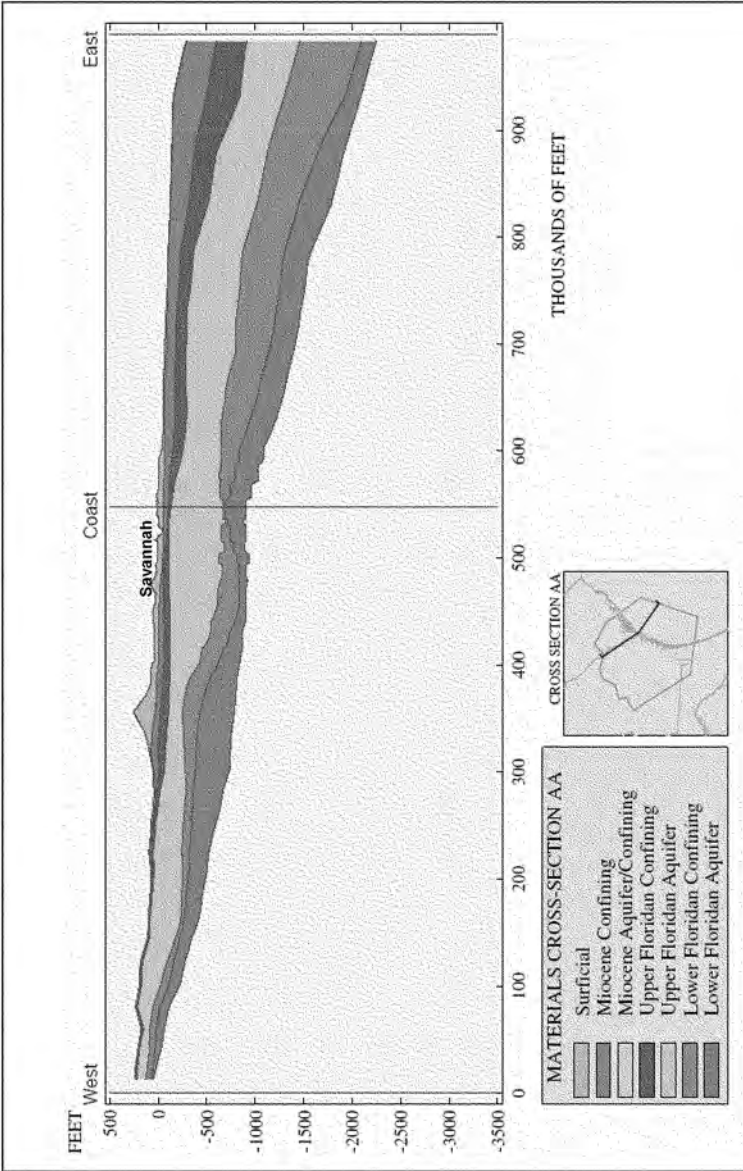


Figure 2-3
Detailed View of Finite Element Grid in Savannah Area

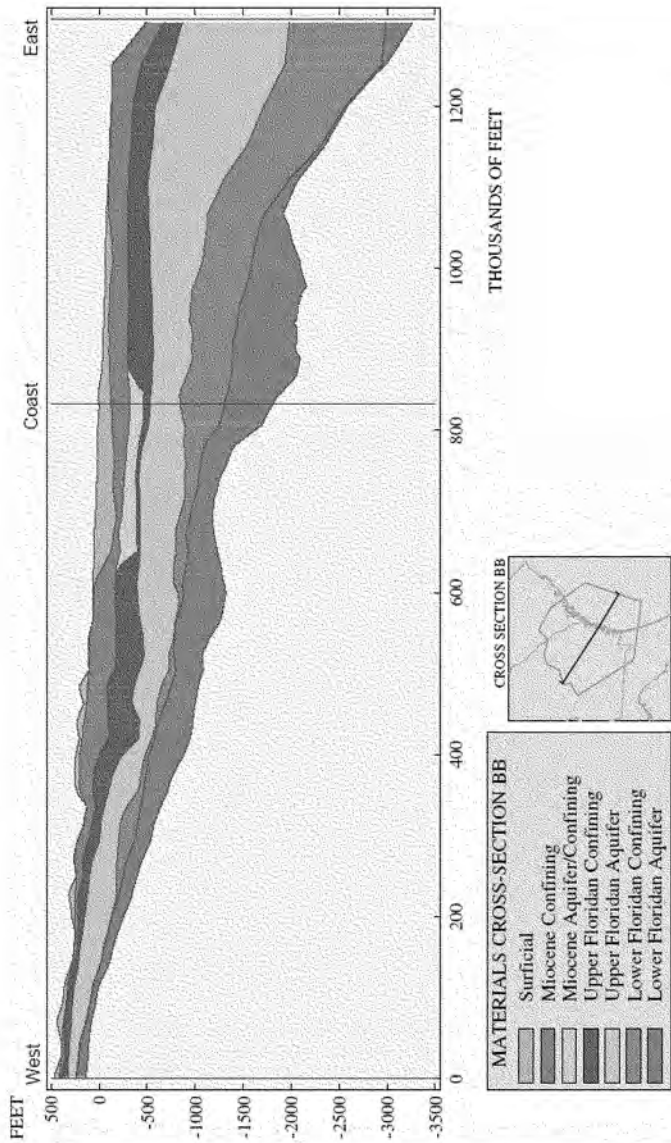






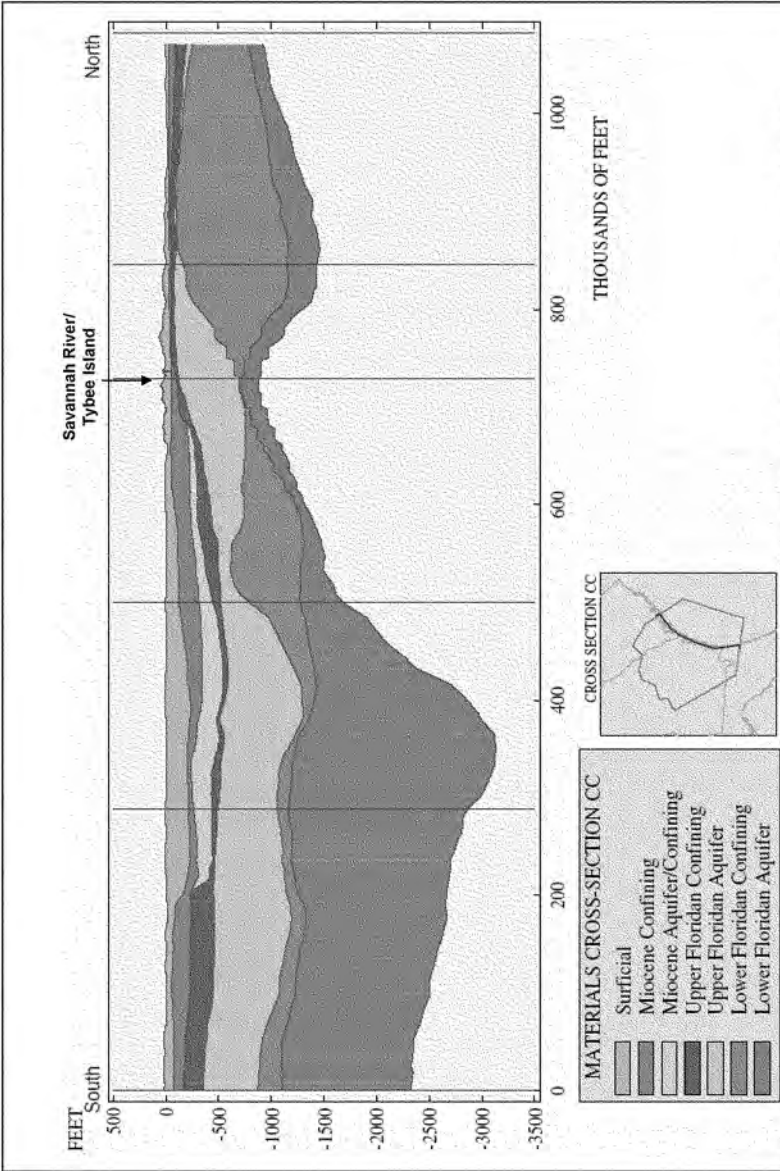
The Miocene Aquifer is not present in this cross-section which runs through Savannah.

Figure 2-6
Cross Section through Model
Normal to Coastline through Savannah Area
Savannah Harbor Expansion
Groundwater Model Studies



The Miocene Unit in this cross-section has aquifer properties in some areas and confining unit properties in others.

Figure 2-7
Cross Section through Model
Normal to Coastline through Center of Model
Savannah Harbor Expansion
Groundwater Model Studies



The Miocene unit in this cross-section has aquifer properties in some areas and confining unit properties in others.

Figure 2-8
Cross Section Along Coastline
Savannah Harbor Expansion
Groundwater Model Studies

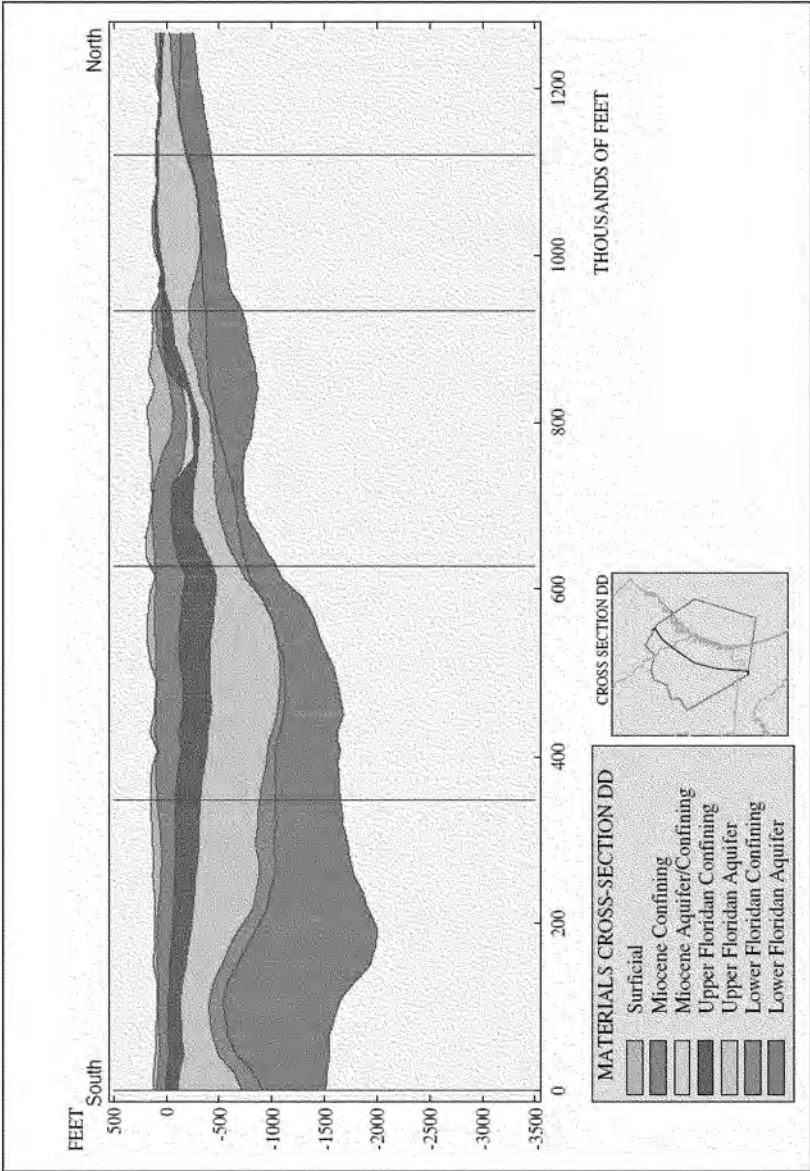
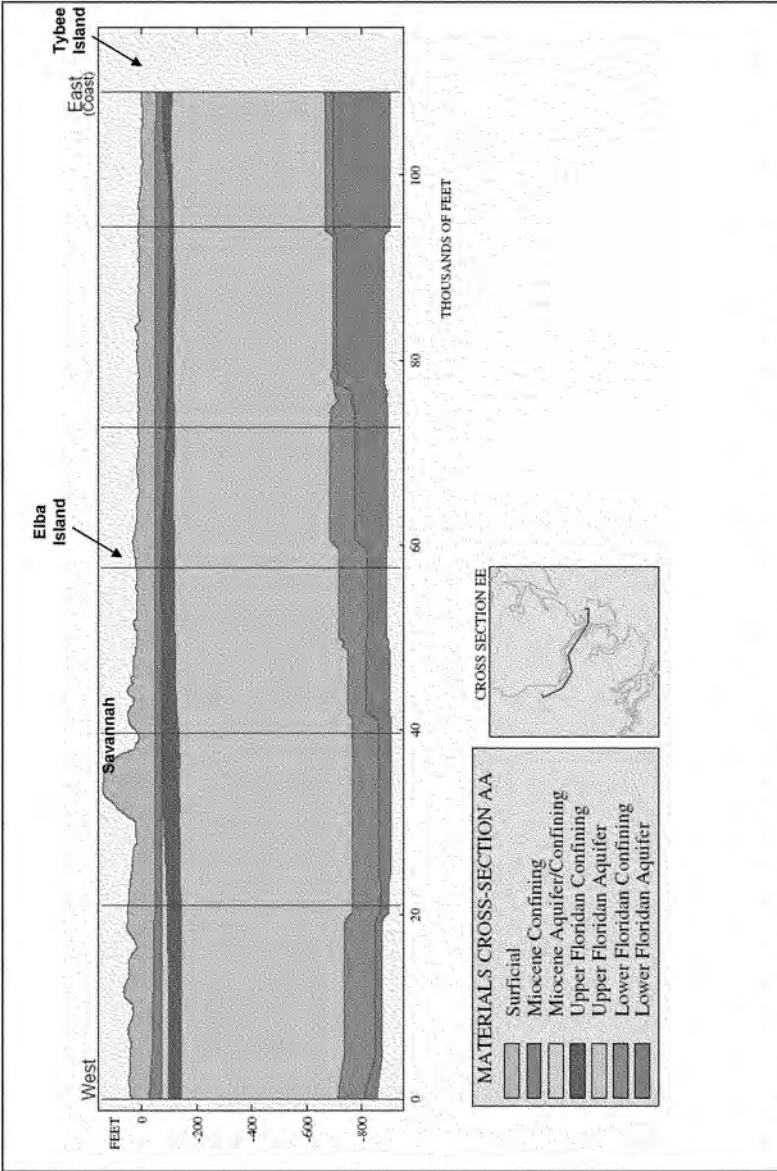


Figure 2-9
Cross Section Parallel to Coastline Inland of Savannah

Savannah Harbor Expansion
Groundwater Model Studies



In the Savannah area the Miocene Unit has confining unit properties; further upgradient the unit has aquifer properties.

Figure 2-10
Cross Section Along Savannah River in Project Area
Savannah Harbor Expansion
Groundwater Model Studies

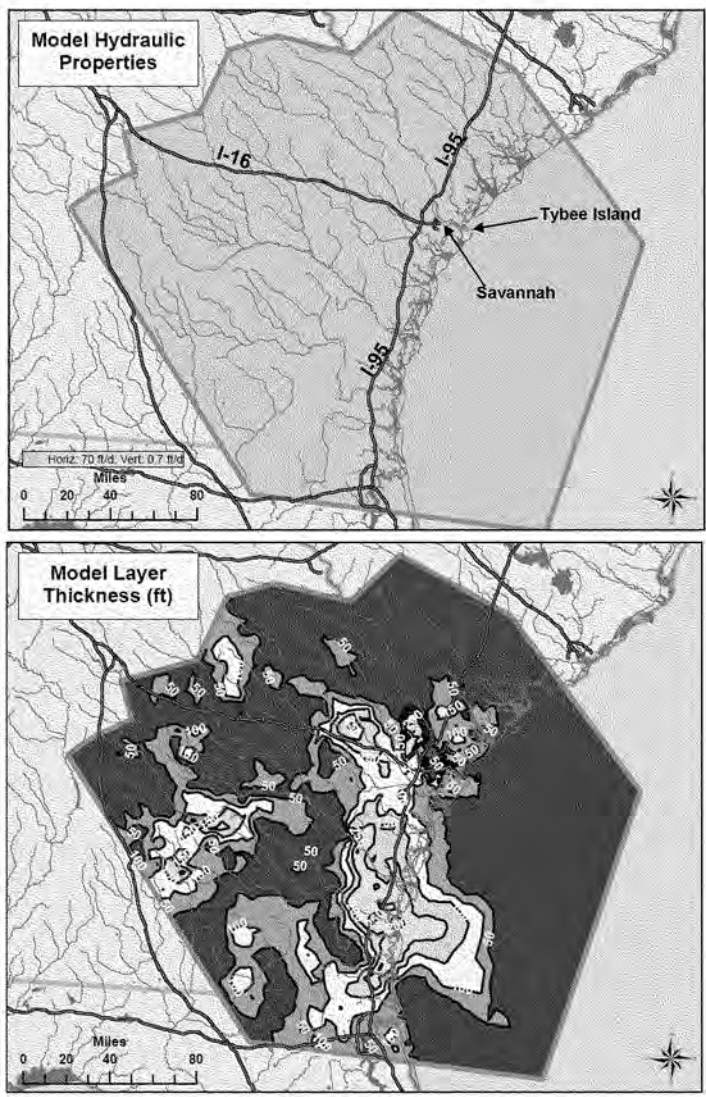


Figure 2-11
Hydraulic Properties and Thickness of Surficial Aquifer

Savannah Harbor Expansion
Groundwater Model Studies

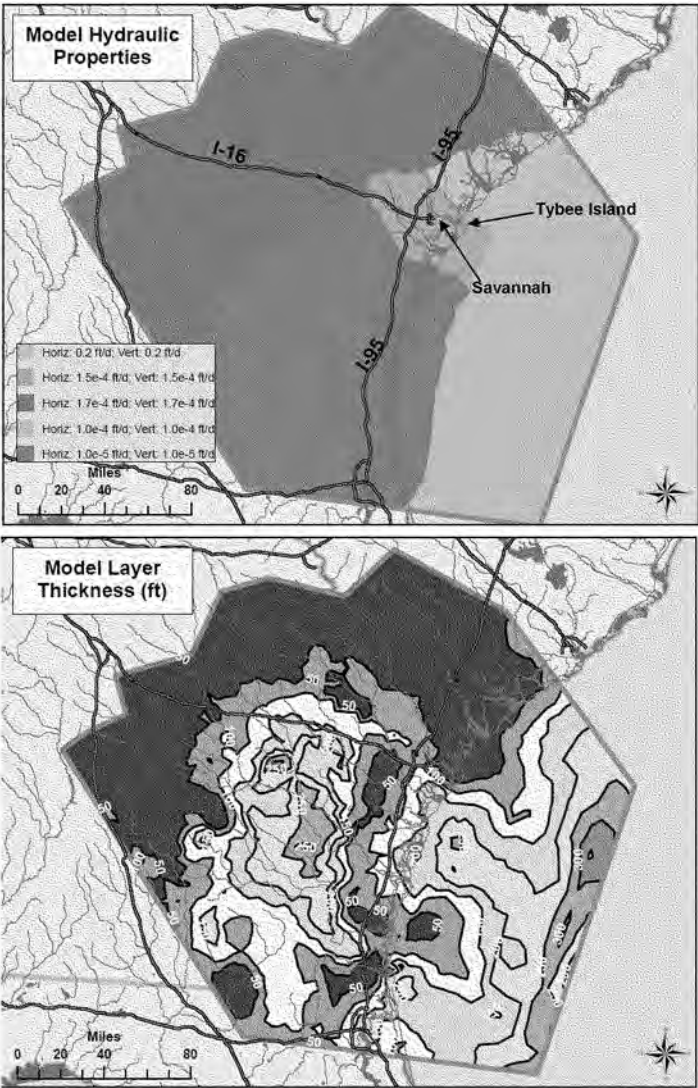


Figure 2-12
Hydraulic Properties and Thickness of Miocene Confining Unit

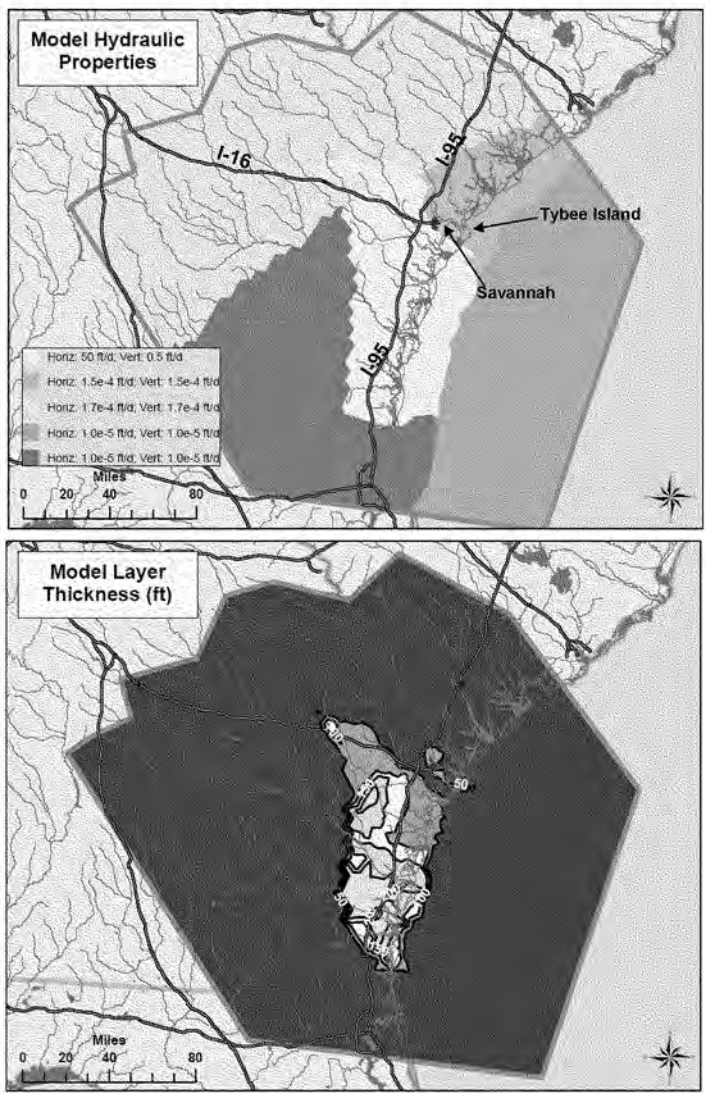


Figure 2-13
Hydraulic Properties and Thickness of Miocene Aquifer/Confining Units

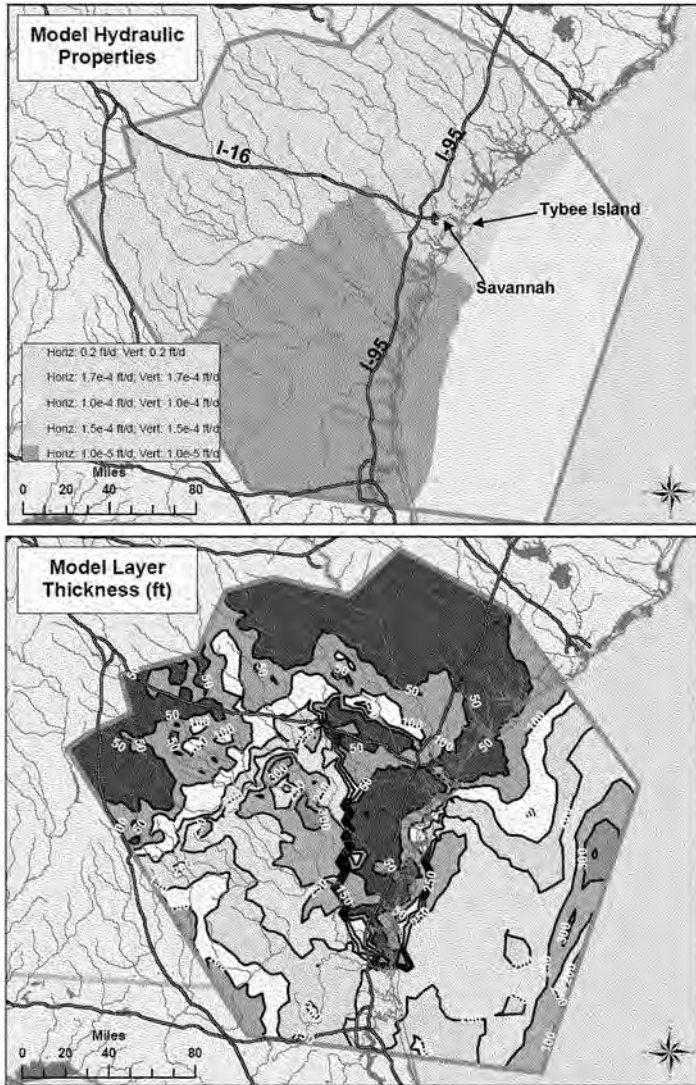


Figure 2-14
Hydraulic Properties and Thickness of Upper Floridan Confining Unit

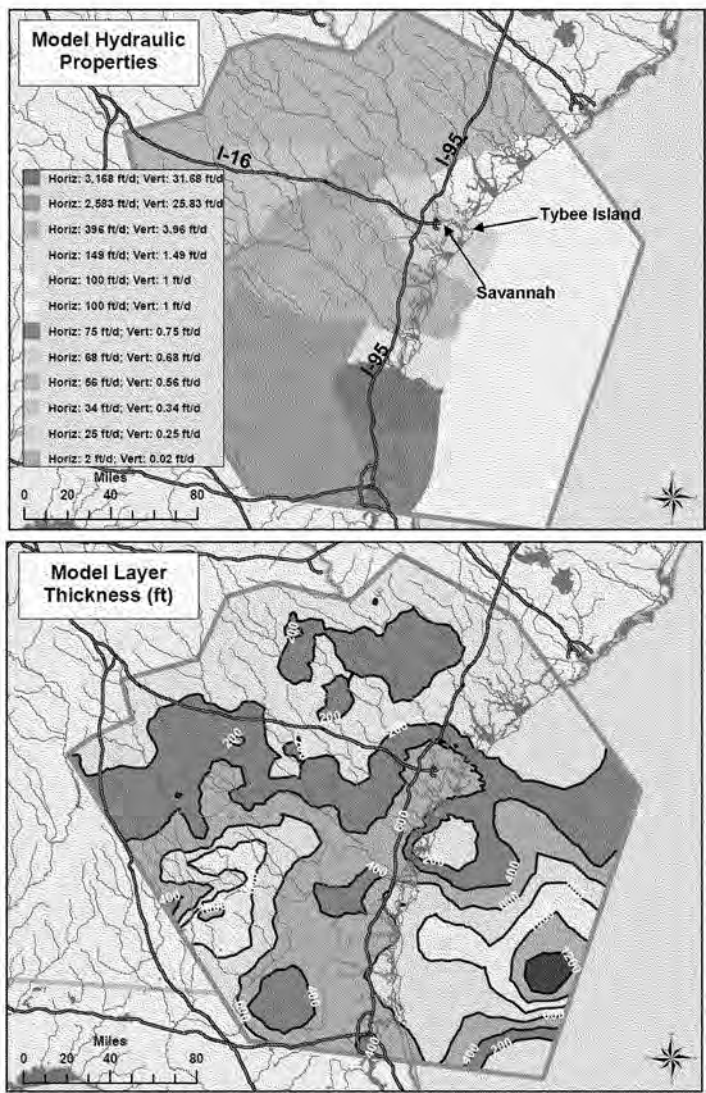


Figure 2-15
Hydraulic Properties and Thickness of Upper Floridan Aquifer

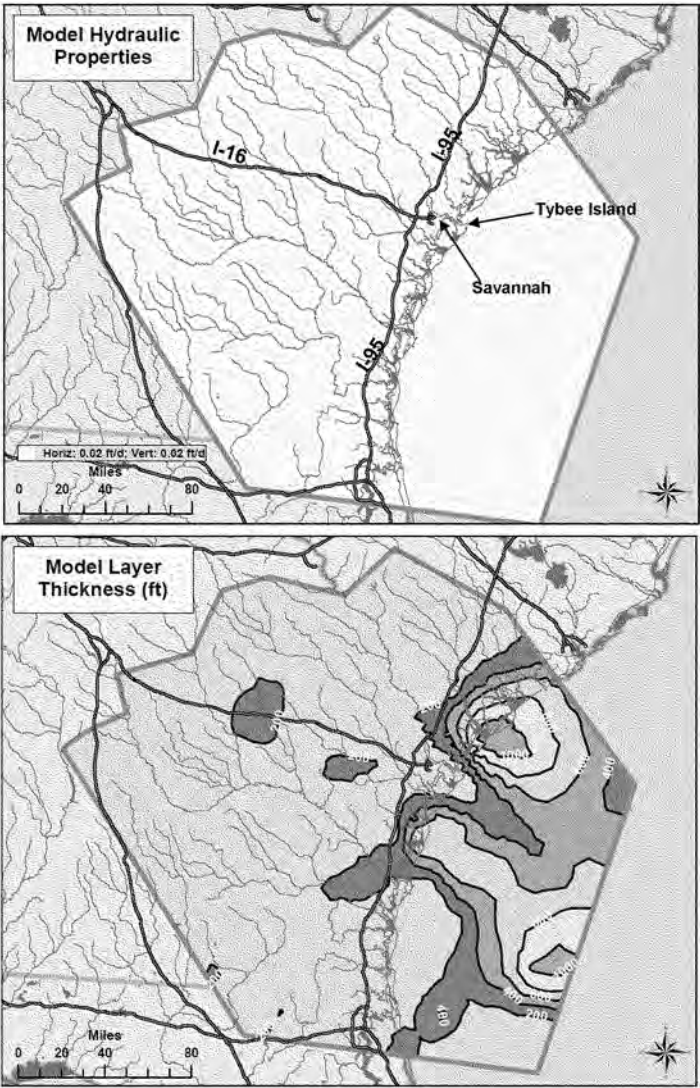


Figure 2-16
Hydraulic Properties and Thickness of Lower Floridan Confining Unit

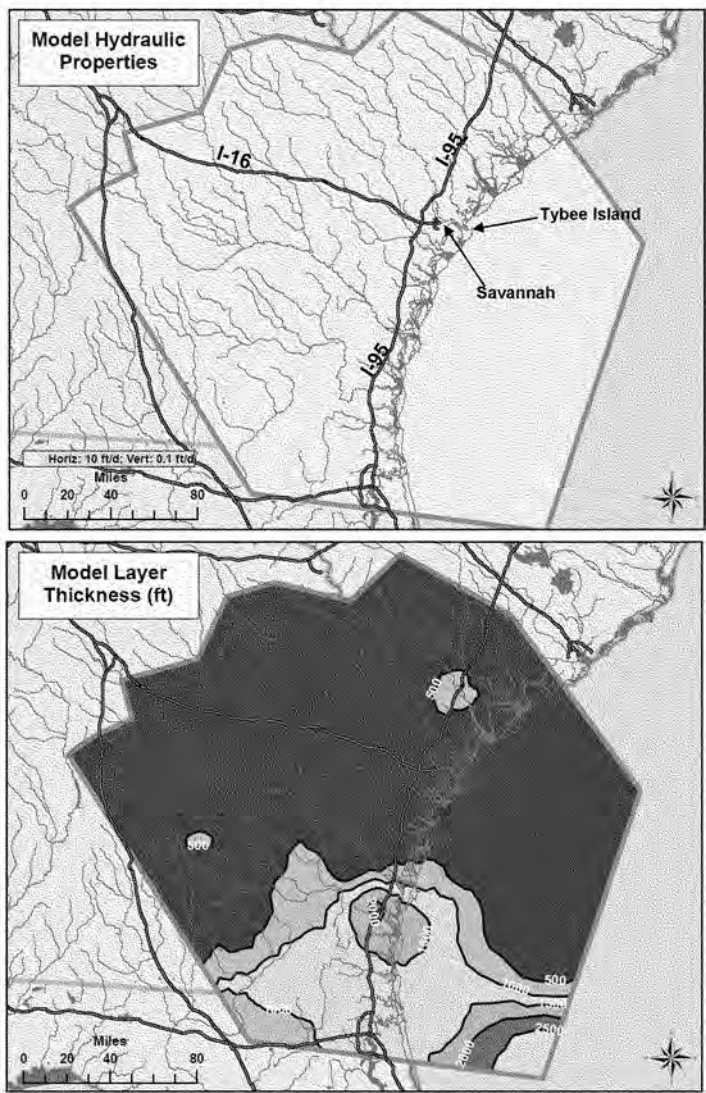


Figure 2-17
Hydraulic Properties and Thickness of Lower Floridan Aquifer

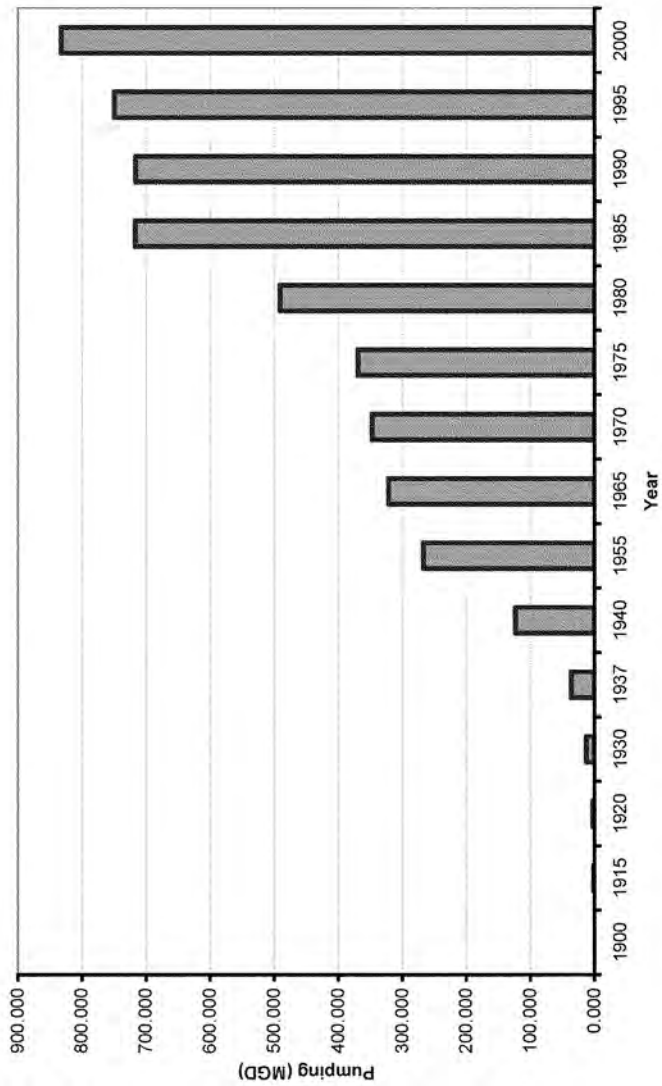


Figure 2-18
Applied Groundwater Pumping for Historical Simulation (1900 to 2000)
Savannah Harbor Expansion
Groundwater Model Studies

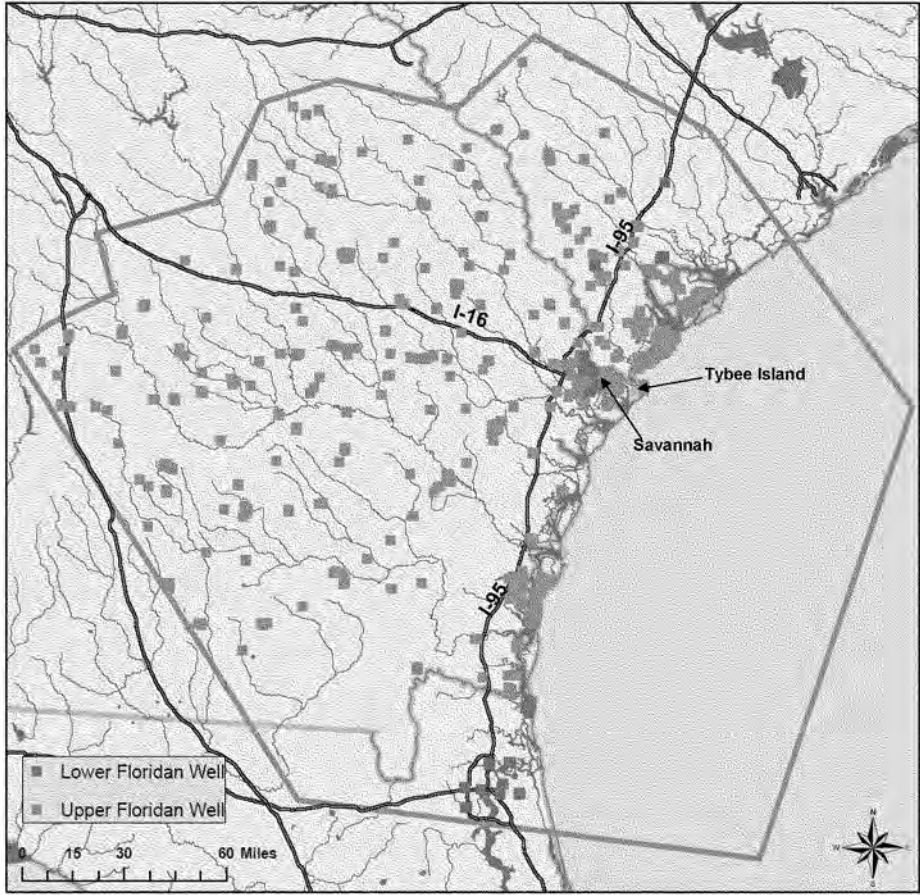
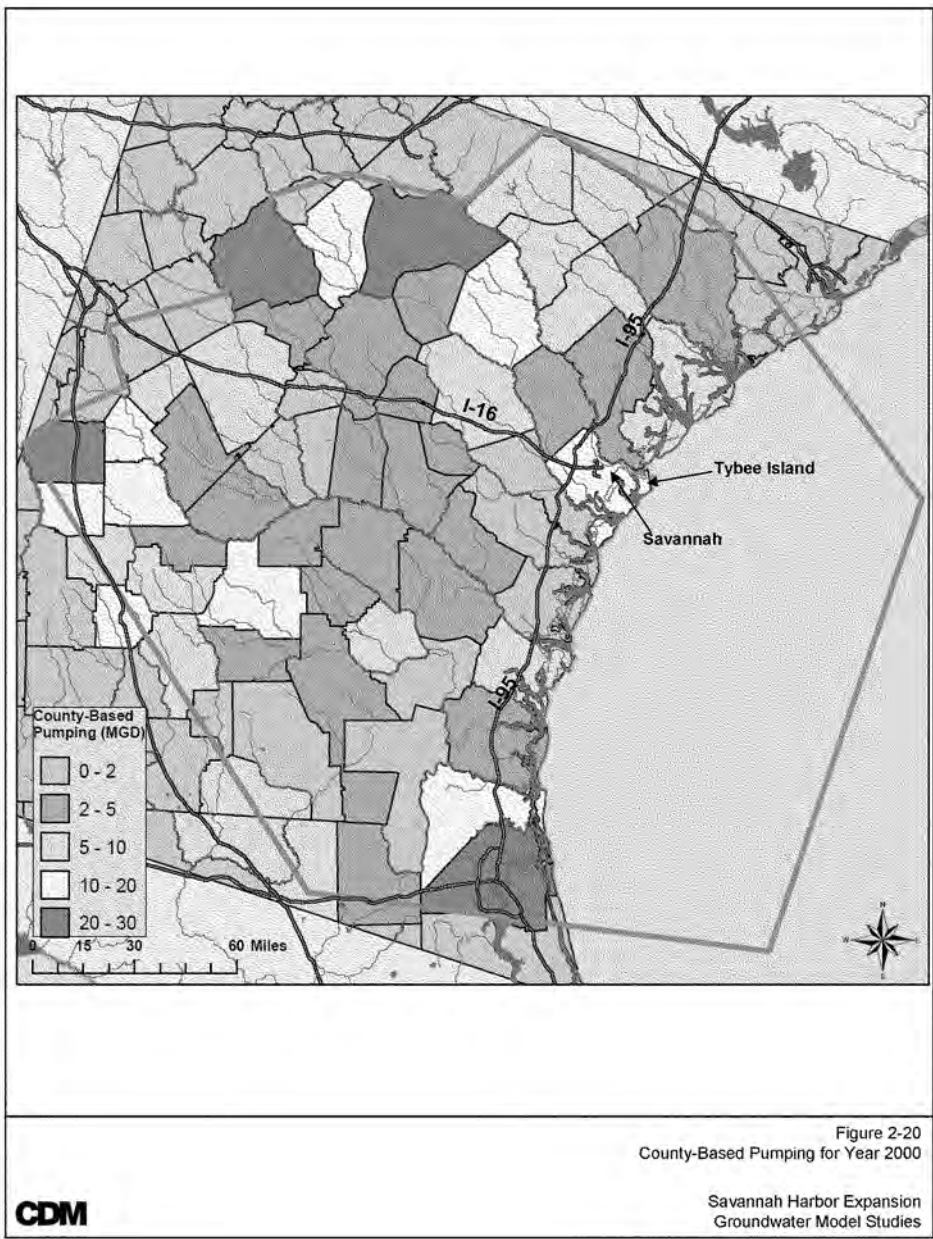


Figure 2-19
Well Pumping Locations for Year 2000



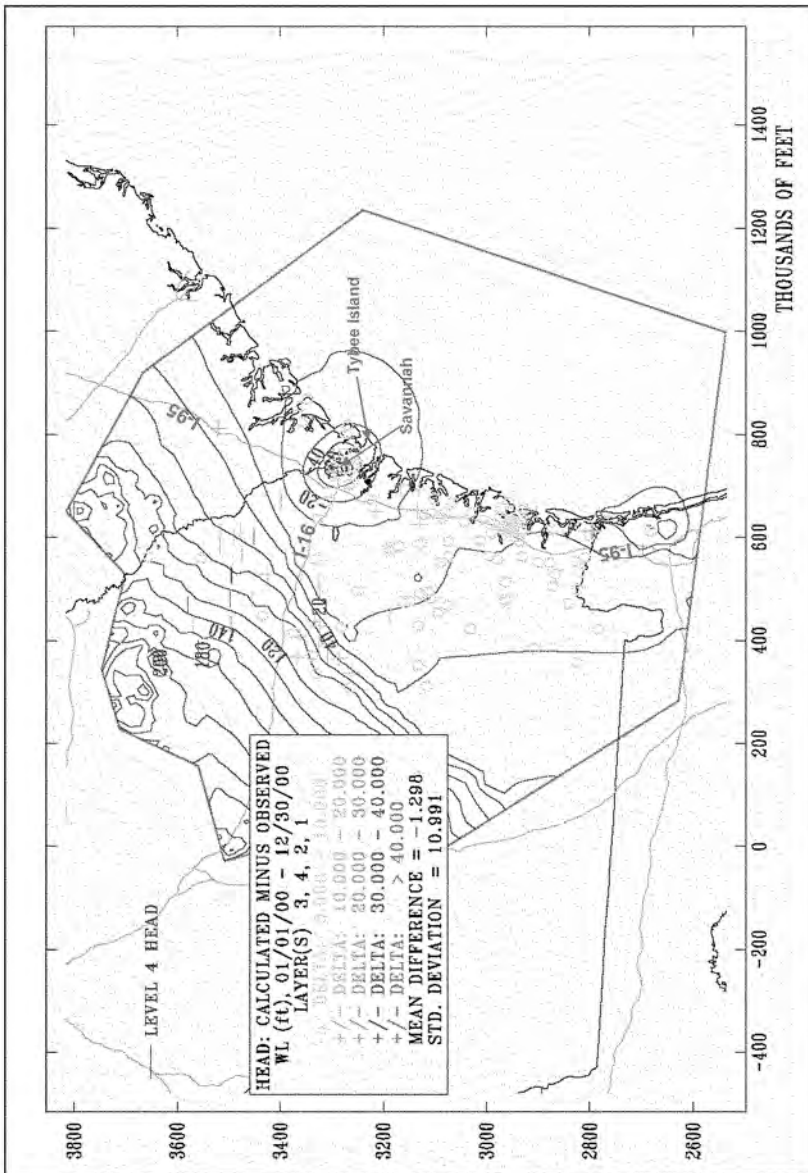
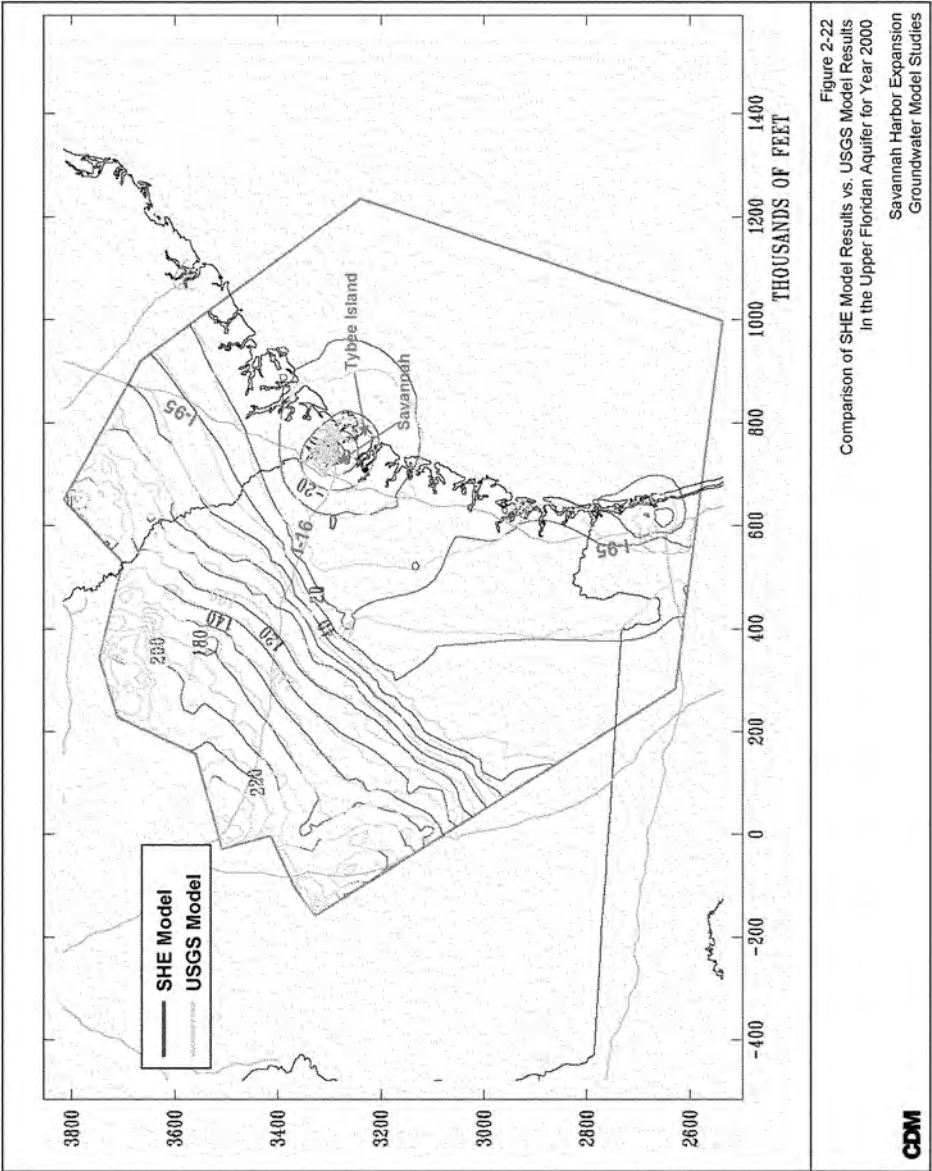


Figure 2-21
Steady State Calibration for Year 2000

Savannah Harbor Expansion
Groundwater Model Studies

CDM



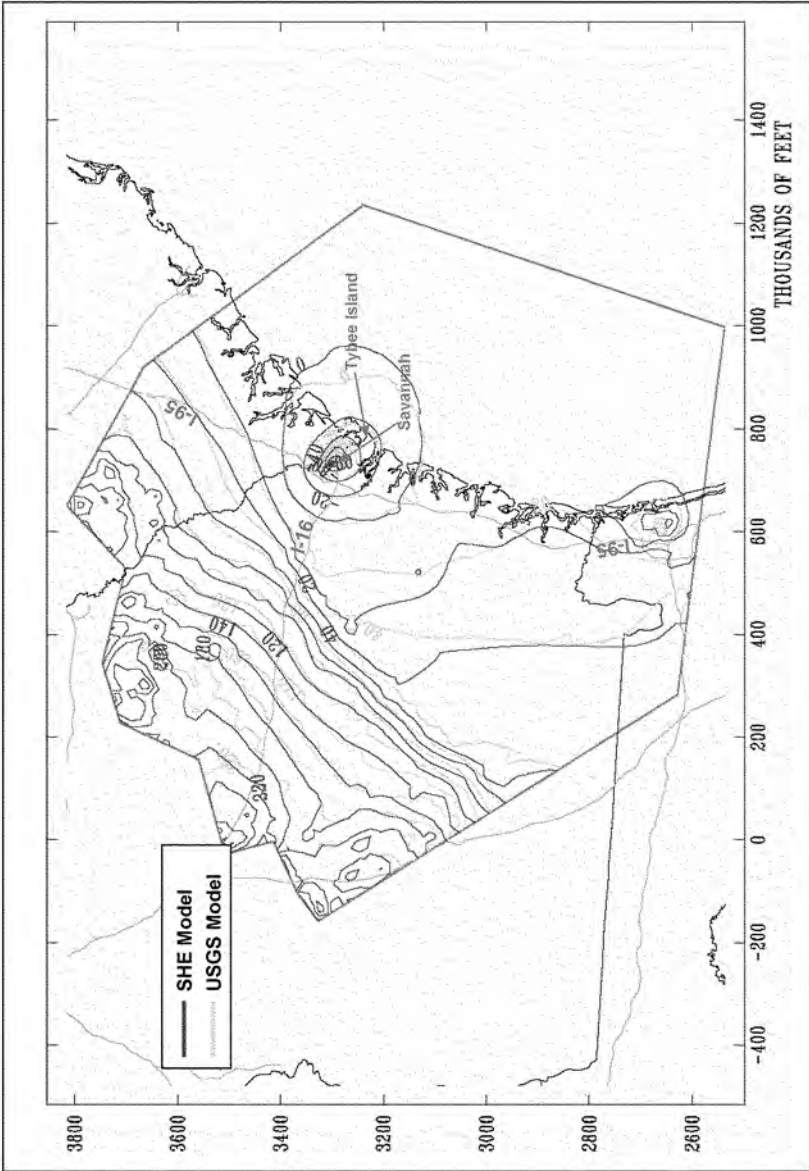
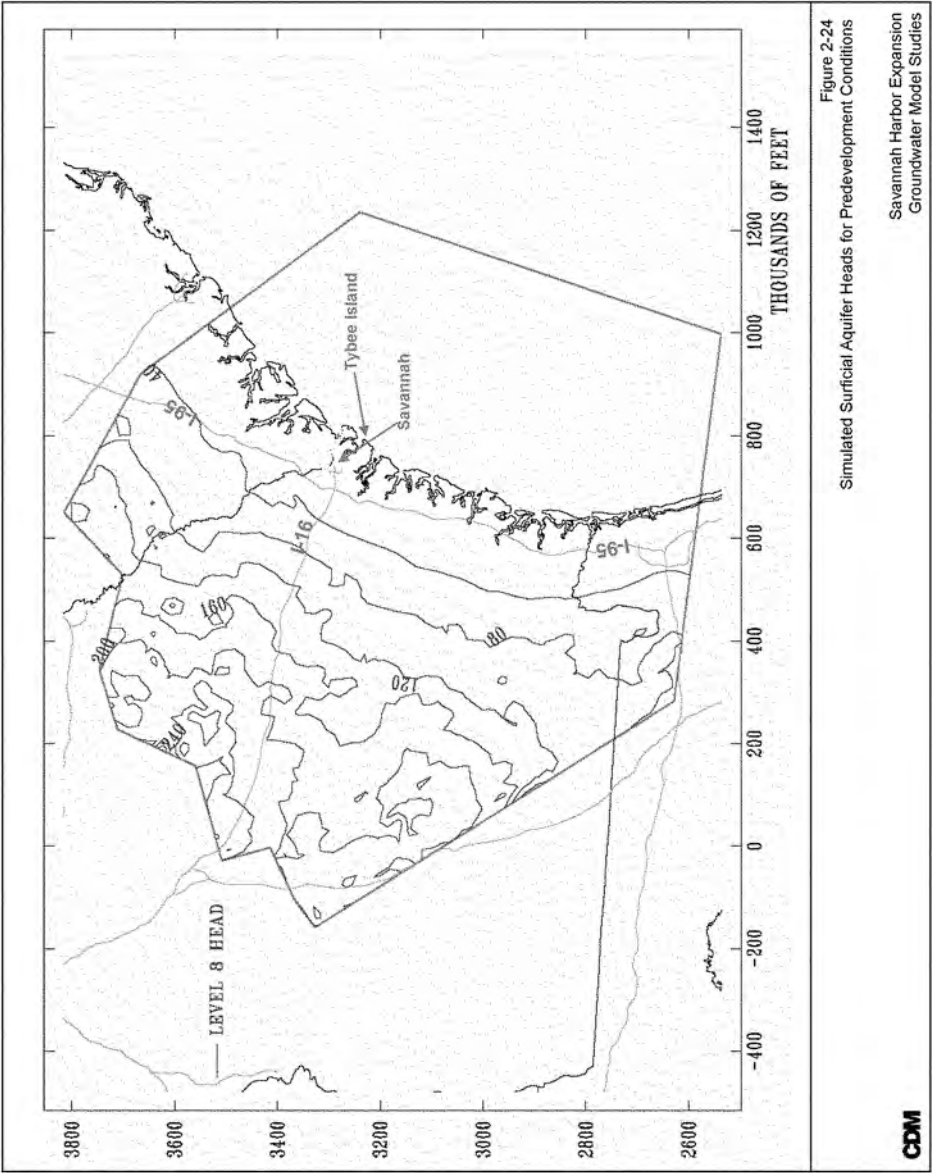


Figure 2-23
Comparison of SHE Model Results vs. USGS Model Results
in the Lower Floridan Aquifer for Year 2000
Savannah Harbor Expansion
Groundwater Model Studies



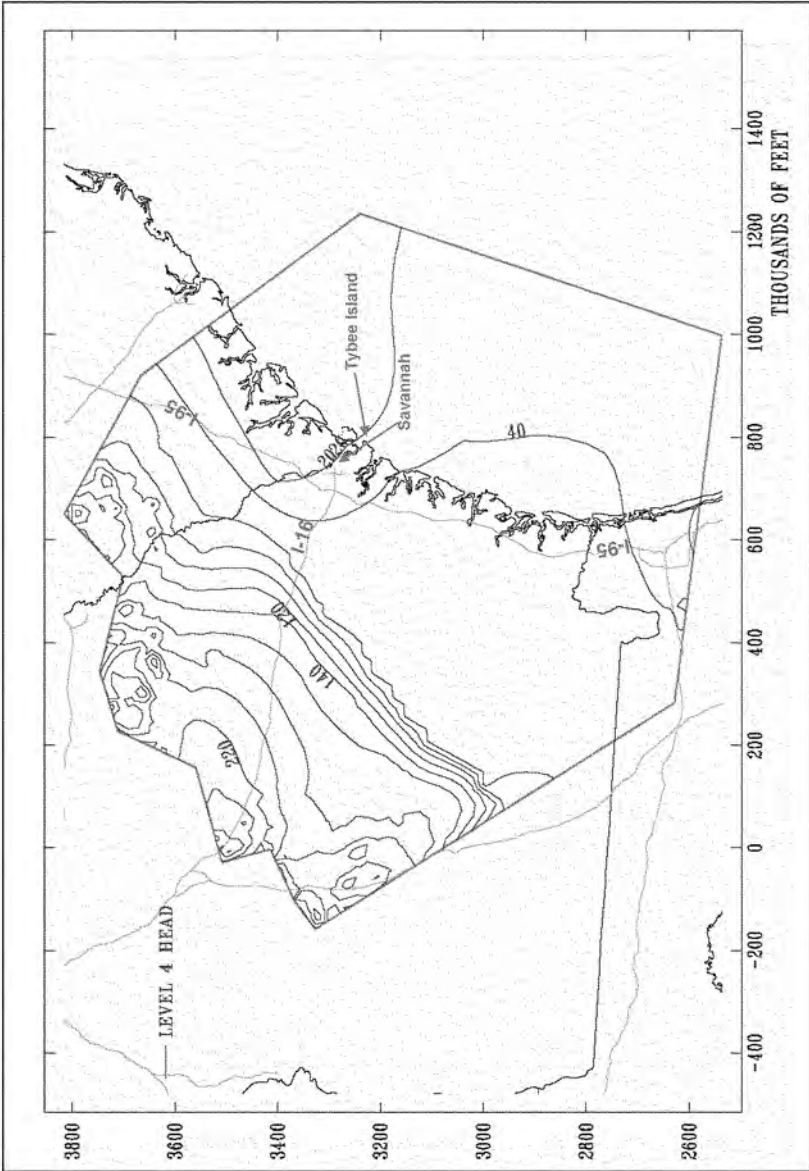


Figure 2-25
Simulated Upper Floridan Aquifer Heads for Predevelopment Conditions

Savannah Harbor Expansion
Groundwater Model Studies

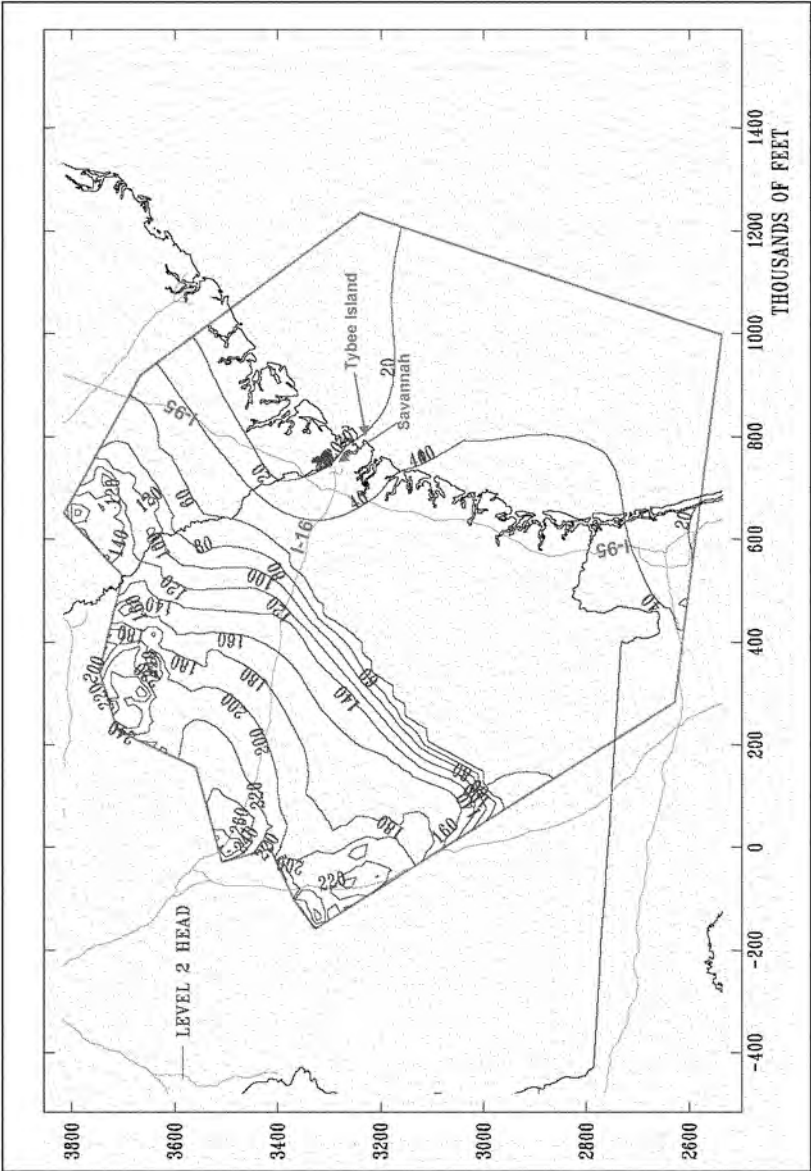


Figure 2-26
Simulated Lower Floridan Aquifer Heads for Predevelopment Conditions
Savannah Harbor Expansion
Groundwater Model Studies

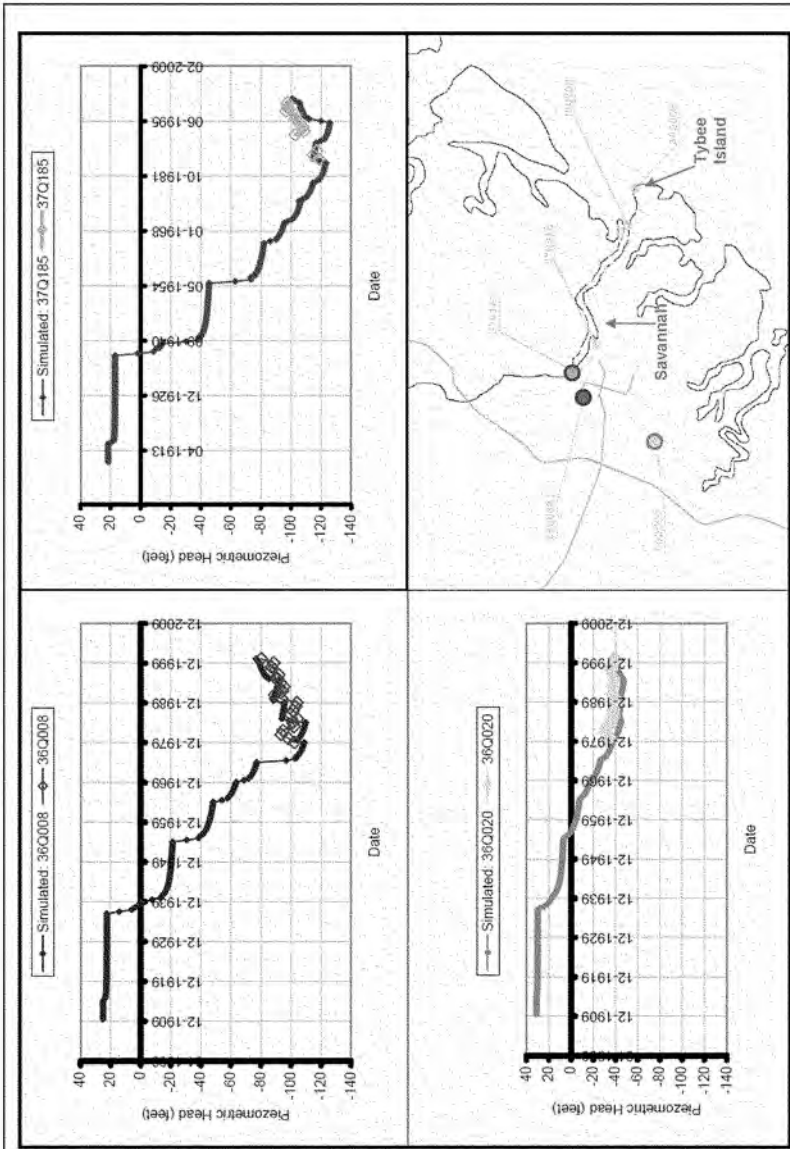


Figure 2-27
Comparison of Historical Simulated and Measured Heads in Upper Floridan Aquifer
Savannah Harbor Expansion
Groundwater Model Studies

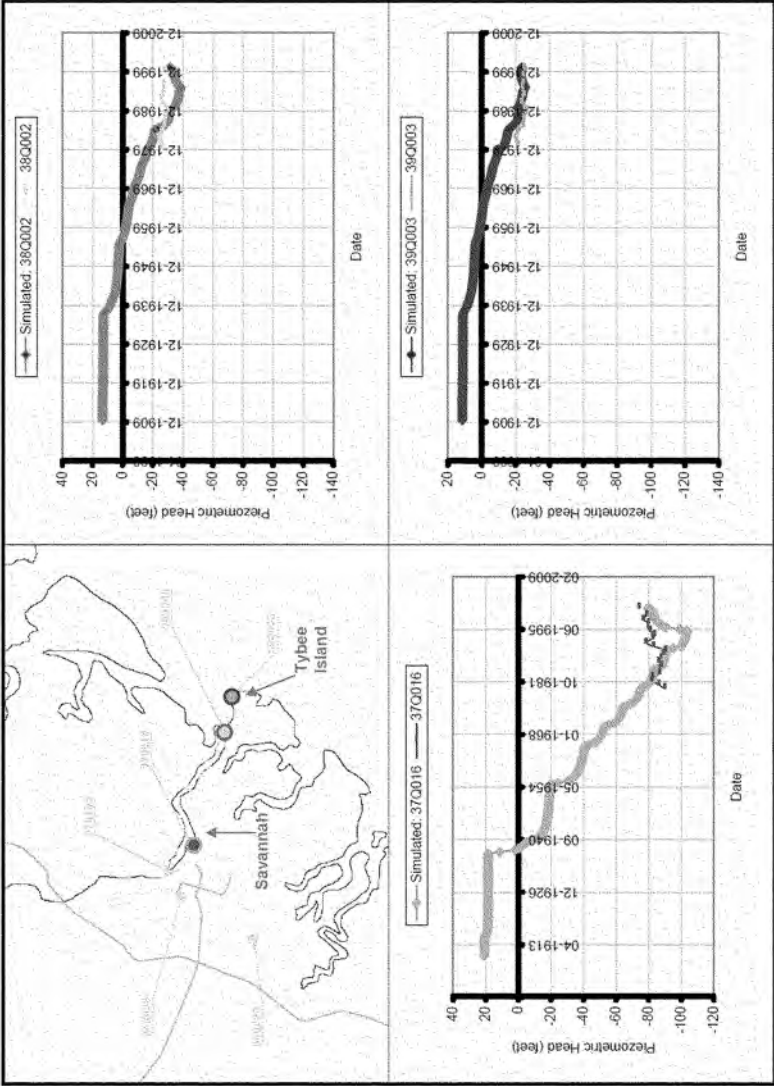


Figure 2-28
Comparison of Historical Simulated and Measured Heads in Upper Floridan Aquifer
Savannah Harbor Expansion
Groundwater Model Studies

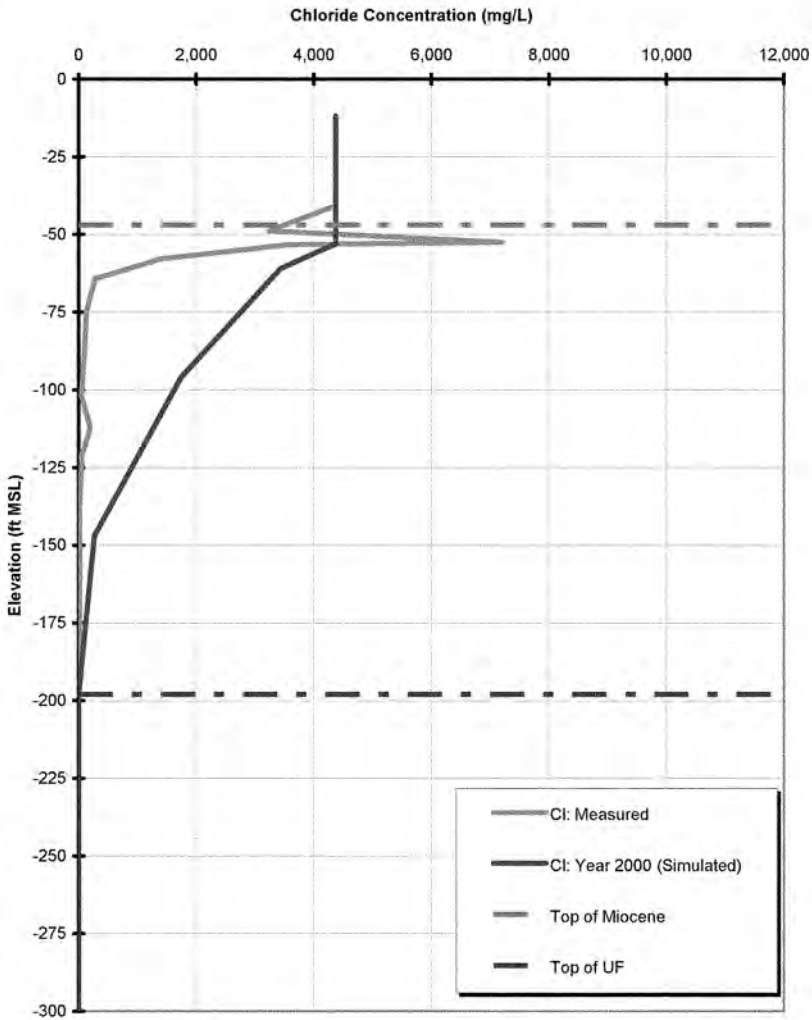


Figure 2-29
Measured and Simulated Chloride Measurements at SHE-15 Borehole

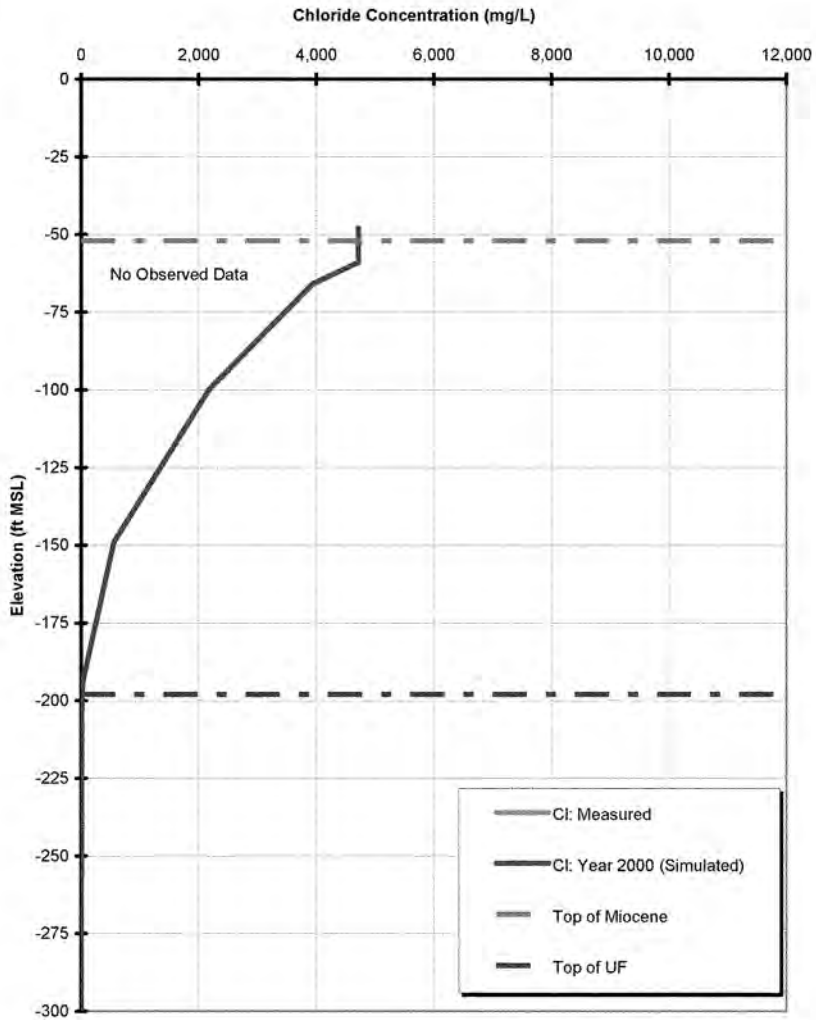


Figure 2-30
Measured and Simulated Chloride Measurements at SHE-5 Borehole

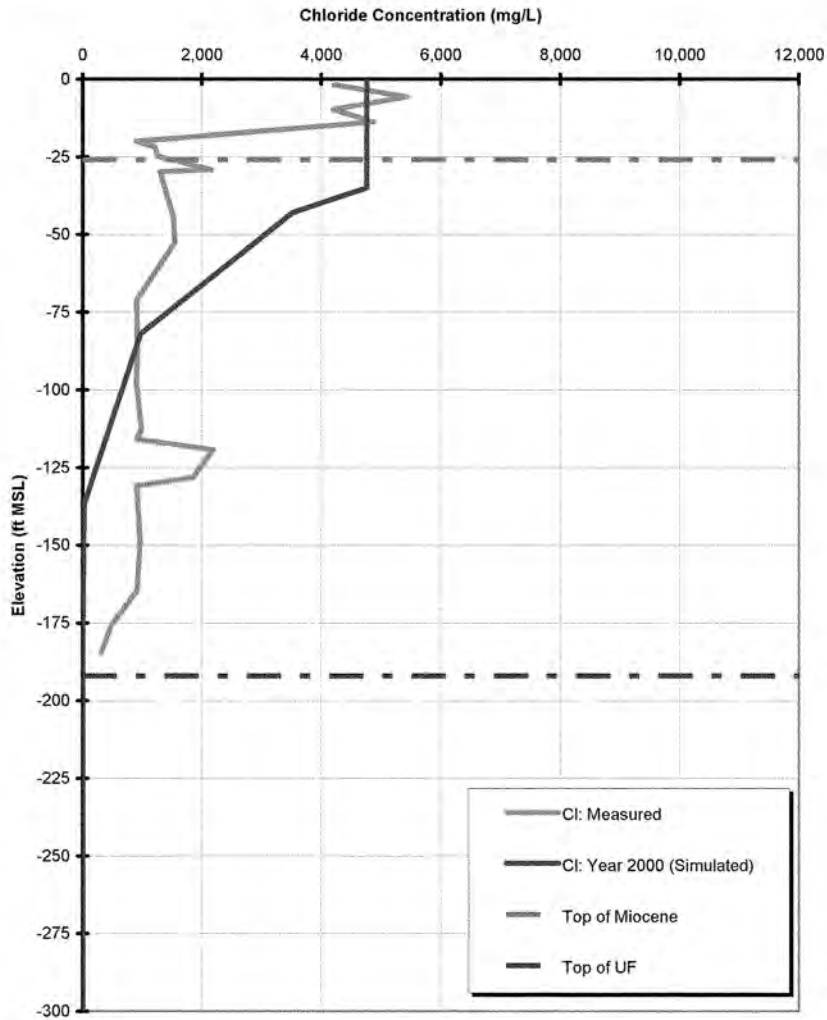


Figure 2-31
Measured and Simulated Chloride Measurements at SHE-9 Borehole

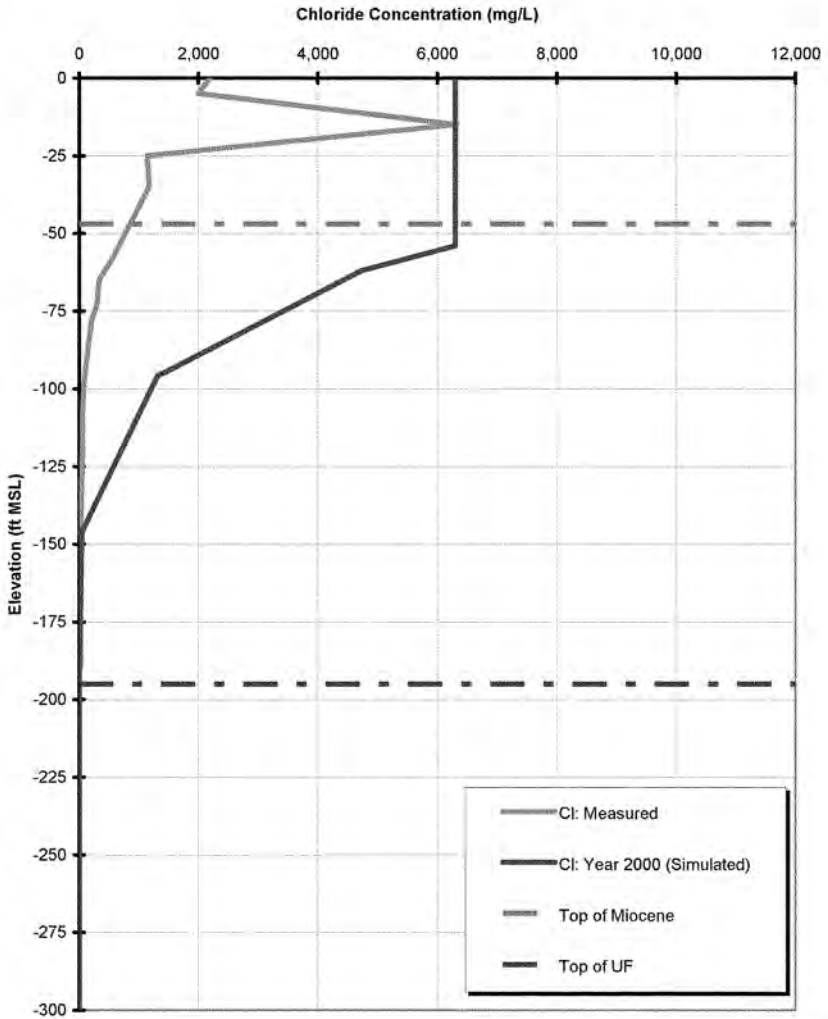


Figure 2-32
Measured and Simulated Chloride Measurements at SHE-19 Borehole

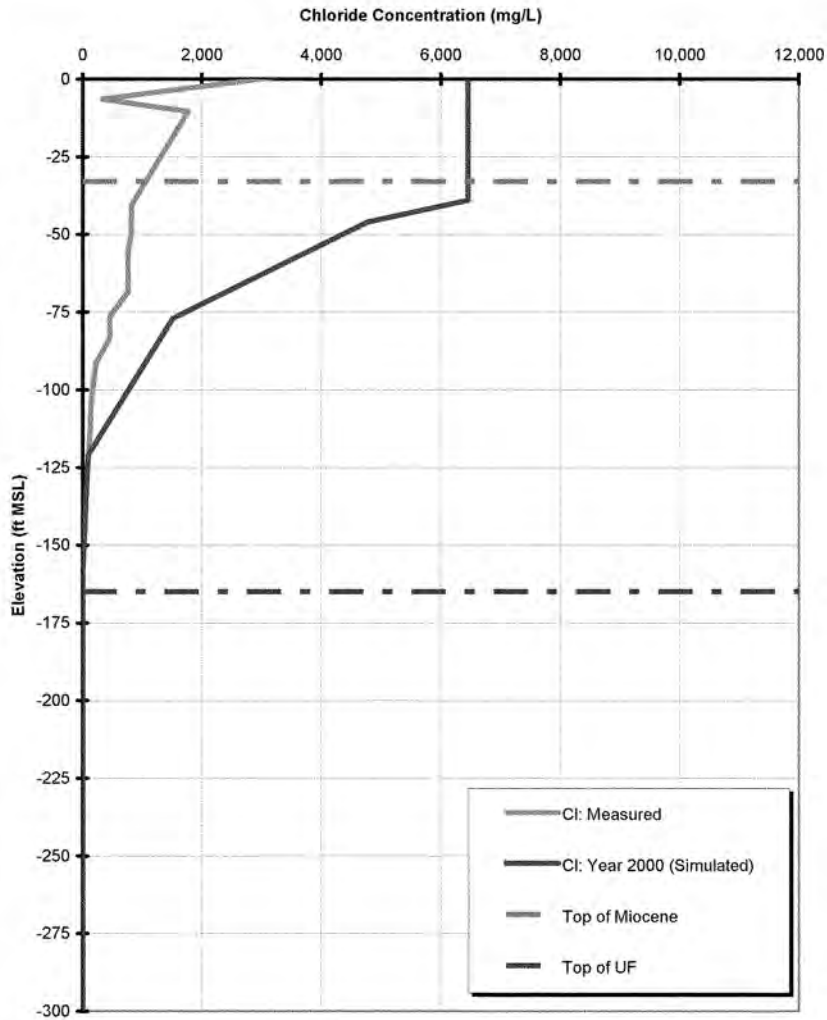


Figure 2-33
Measured and Simulated Chloride Measurements at SHE-10 Borehole

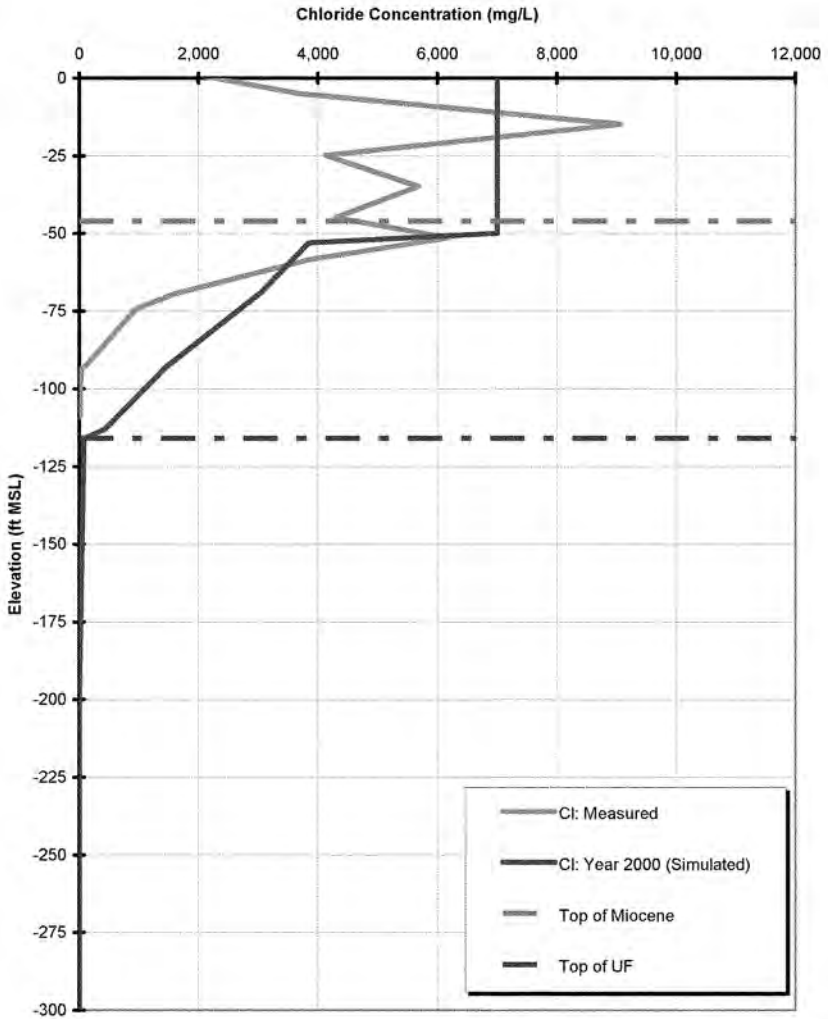


Figure 2-34
Measured and Simulated Chloride Measurements at SHE-18 Borehole

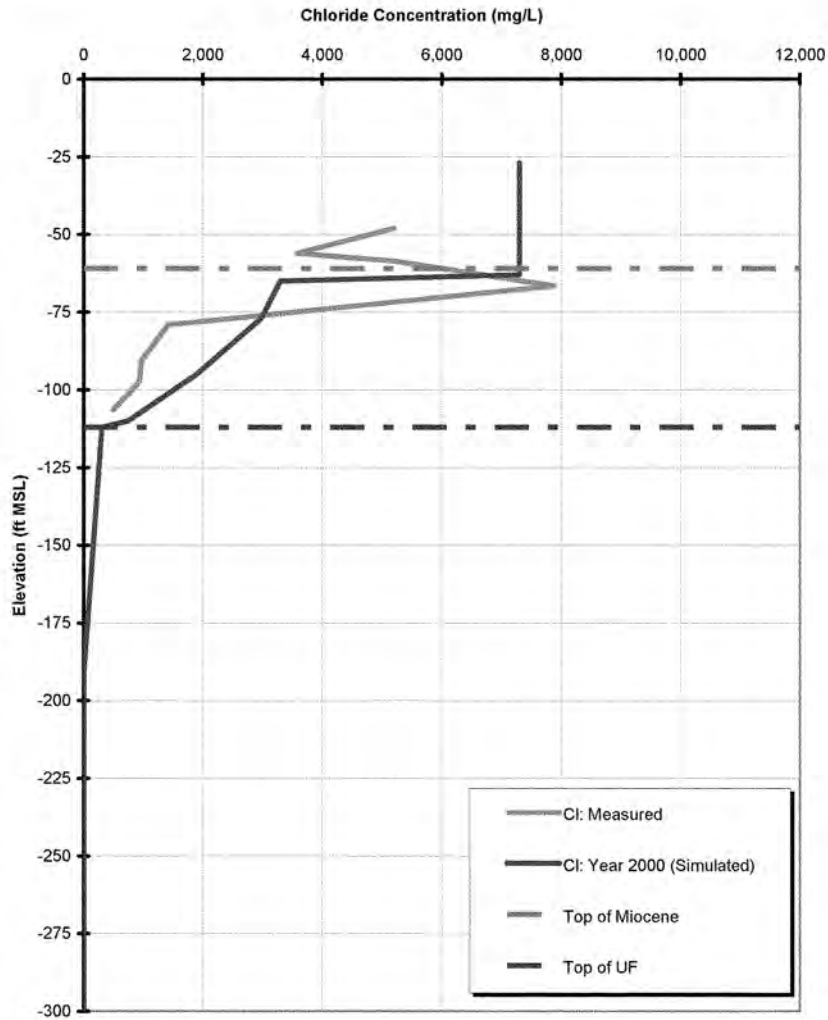


Figure 2-35
Measured and Simulated Chloride Measurements at SHE-11 Borehole

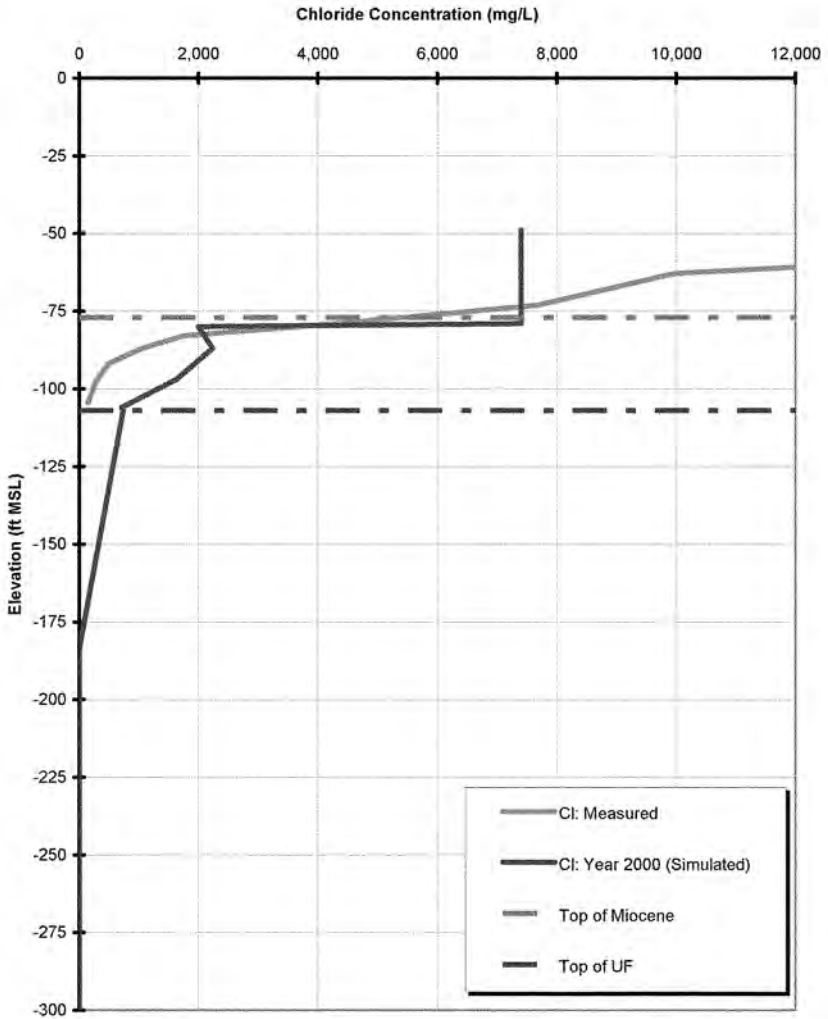


Figure 2-36
Measured and Simulated Chloride Measurements at SHE-13 Borehole

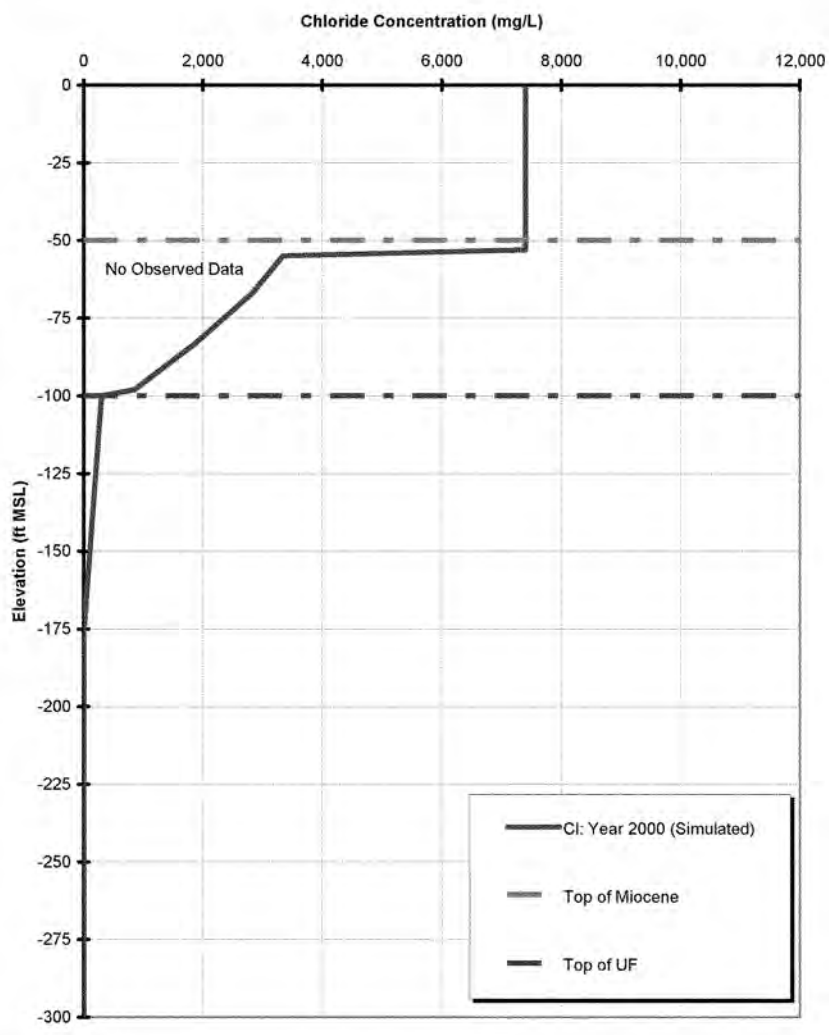


Figure 2-37
Measured and Simulated Chloride Measurements at SHE-2 Borehole

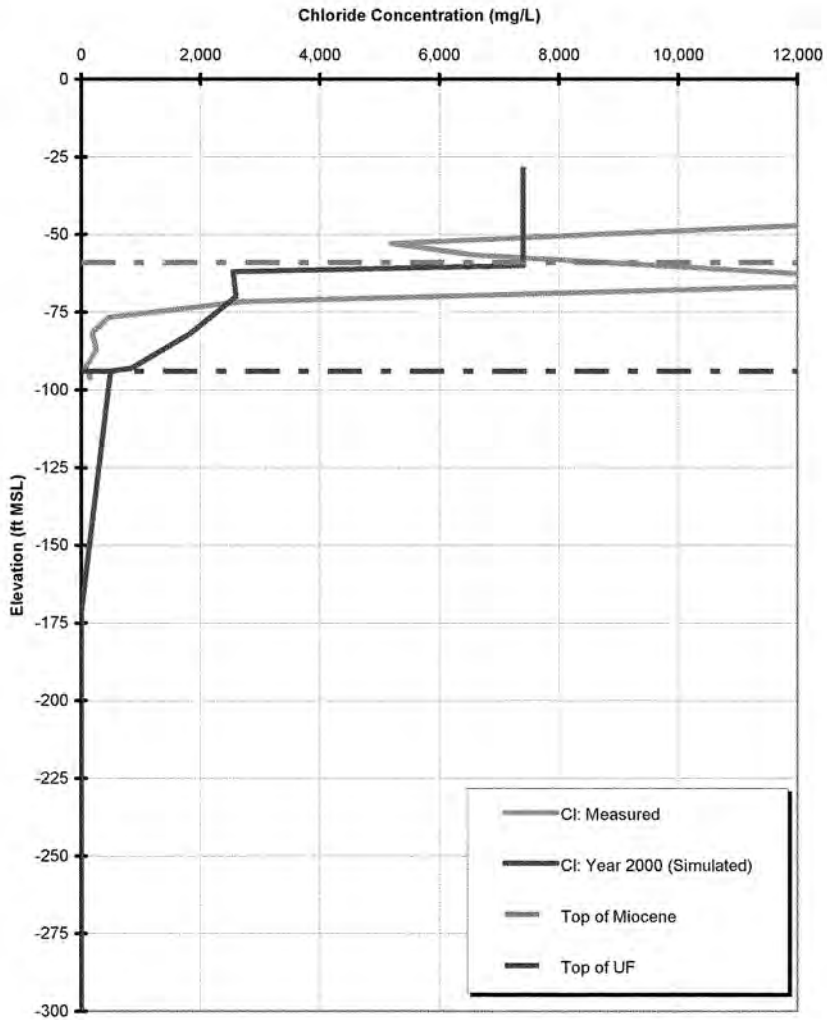


Figure 2-38
Measured and Simulated Chloride Measurements at SHE-14 Borehole

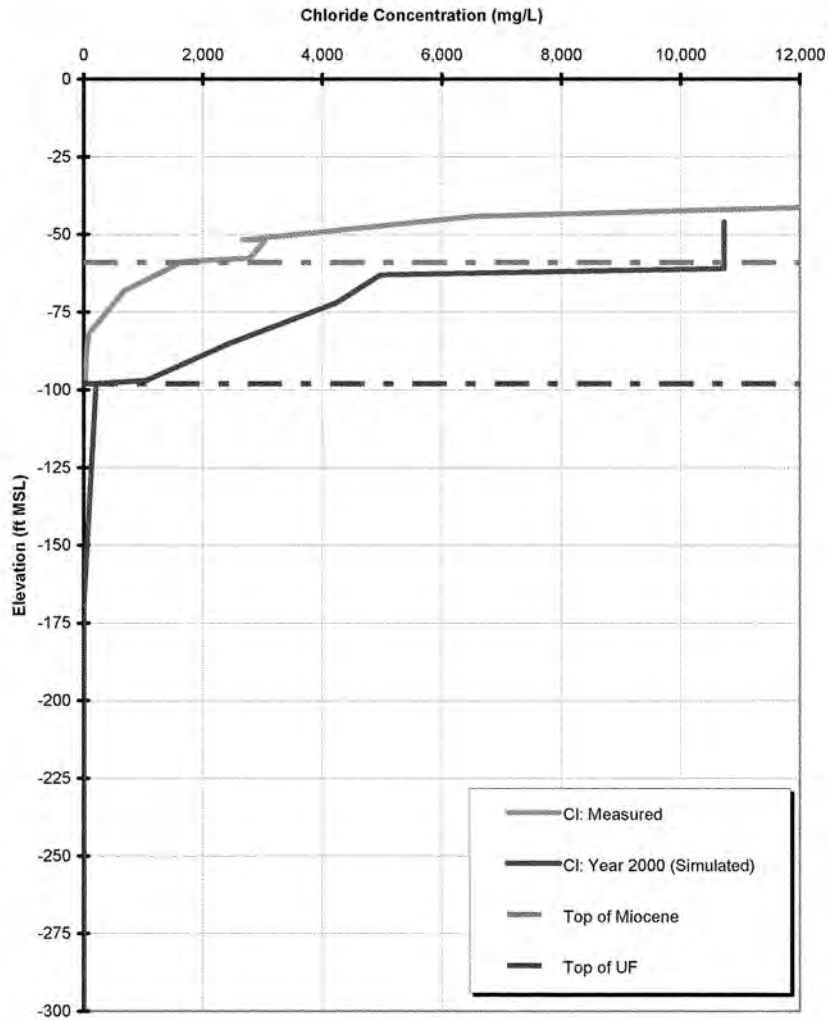


Figure 2-39
Measured and Simulated Chloride Measurements at SHE-17 Borehole

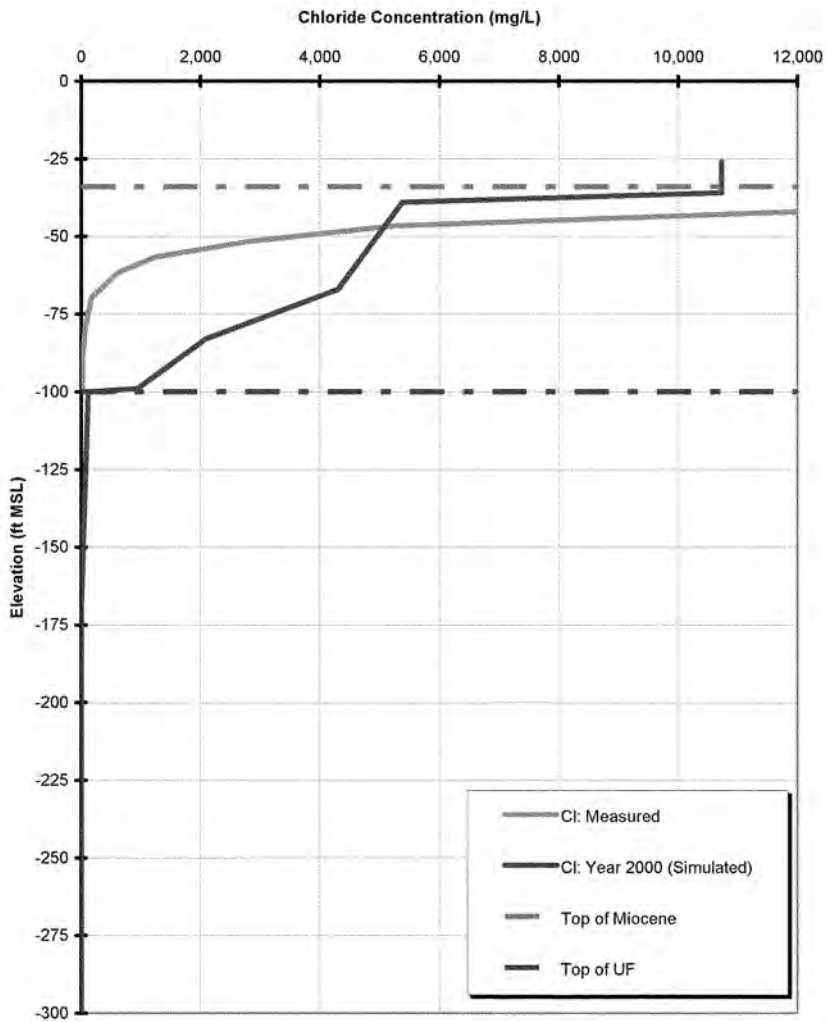


Figure 2-40
Measured and Simulated Chloride Measurements at SHE-16 Borehole

Section 3

Model Application

3.1 Methodology

The focus of the modeling study was to assess the impacts of dredging the Savannah River navigation channel on groundwater flow and saltwater migration into the Upper Floridan aquifer. The potential impacts of the proposed dredging program were evaluated in terms of the relative increase in simulated future chloride concentrations and the change in the rate of chloride penetration as a result of migration of saline water from the area of the navigation channel through Miocene confining unit into the Upper Floridan aquifer. Seawater intrusion from the Atlantic Ocean or nearby salt marshes was not simulated. Using this approach the impacts of dredging are more clearly documented and are not obscured by the impact that Savannah area pumping has in drawing water from all areas with overlying salt water.

The SHE groundwater model discussed in Section 2 was calibrated to a single set of aquifer parameters based on the calibrated USGS groundwater model. These parameters provide the overall 'best fit' in terms of the observed and simulated groundwater heads and gradients. In terms of the simulated chloride concentrations in the Miocene confining unit, the calibrated aquifer parameters generally result in an overall depth of penetration somewhat deeper than observed, and chloride concentrations higher than measured. Simulated migration through the Miocene confining unit is most sensitive to the vertical hydraulic conductivity assigned to the unit. Therefore, for the model application two different values of vertical hydraulic conductivity for the Miocene unit were used: the calibrated value, which represents the mid range of reasonable values, and a lower value. In this way, the true conditions are bounded by the two sets of results.

Table 3-1 illustrates the range of vertical hydraulic conductivity for the Miocene confining units in the area of interest utilized for the predictive simulations. On the low end of the range, a reduction in the vertical hydraulic conductivity by an order of magnitude results in simulated heads in the cone of depression in the Upper Floridan aquifer to be about 30 feet too low when compared to field data. However, the resulting chloride profiles at the SHE borehole locations using the lower value of Miocene vertical hydraulic conductivity were generally more consistent with the measured values. Using the calibrated value, the head distribution was accurate in the cone of depression, but the model somewhat overestimated the rate of penetration when compared to the pore water sample data.

CDM also evaluated increasing the vertical hydraulic conductivity of the Miocene unit approximately 5 fold. The groundwater flow results indicated that using a vertical hydraulic conductivity significantly higher than the calibrated value would

result in simulated heads in the Upper Floridan aquifer being approximately 30 feet too high.

Table 3-1 Sensitivity Analysis Parameters

Sensitivity Parameters		Calibration Statistics		Upper Floridan Head at Well 37Q185	
Unit	Vertical Hydraulic Conductivity (feet/day)	Mean Difference (ft)	Standard Deviation (ft)	Simulated (feet, MSL)	Observed Mean Year 2000 (feet, MSL)
Miocene Confining Unit	Low-Value 1.50E-05	-5.5	12.4	-126.7	-96.8
	Mid-Value 1.50E-04	-1.121	10.86	-100.8	

The higher vertical hydraulic conductivity value also resulted in the simulated chlorides concentration significantly different than those measured in the SHE boreholes. Using a vertical hydraulic conductivity for Miocene higher than the calibrated value results in unrealistic Miocene and Upper Floridan chloride concentrations, and therefore for this analysis, the hydraulic conductivity values shown in Table 3-1 represent the appropriate range of expected conditions in the Miocene confining unit.

3.2 Predictive Simulations

To evaluate the potential impact of the dredging on flow and chloride concentrations in the Miocene, and eventually chloride levels in the Upper Floridan, simulations were run forward in time with a 1-year time-step for a period of 200 years. These predictive simulations used the following input parameters:

- Initial groundwater heads: The year 2000 steady-state groundwater levels were used as the starting condition for the simulation.
- Groundwater pumping: Groundwater pumping was kept constant at year 2000 levels. This provides a conservative assessment of future groundwater production in the area, since there is general consensus that pumping will not be allowed to increase in the future
- Chloride concentrations in the Miocene: The simulated 2000 distribution of chlorides in the Miocene Unit, as shown in **Figures 3-1** and **3-2** were used as the initial condition (**Figure 3-3** shows the location of the cross-sections). Note that these figures represent significant penetration of chlorides into the Miocene confining units as of “today”, or the start of the projection simulation. These starting chlorides are generally an overestimate of chloride penetration, as discussed above, and therefore represent a conservative starting assumption.
- Savannah River salinity. As discussed in Section 2, the Savannah River nodes were assigned a constant chloride concentration. The chloride concentrations

used for the dredging simulations are higher than the no dredging scenario and were obtained from the surface water modeling conducted for the SHE by Tetra Tech (Tetra Tech, November 2004). For the dredging scenario, the higher values were applied at the beginning of the simulation (year 2000).

- **Miocene thickness and dredged depths.** Data provided by the ACOE was used to determine the change in elevation of the top of the Miocene confining unit as a result of the dredging. For the groundwater modeling it was assumed that dredging would occur as described by the “6-foot” improvement option, plus an additional 3 feet of material which is simulated as removed, but is actually only disturbed as part of the dredging process. Dredging depths range from 55 to 59 feet below MLW, or elevations range from -58 to -62 feet MSL. These depths are considered the maximum depths that could occur.
- **Transport parameters.** Table 3-2 shows the transport parameters utilized in the simulations.

Table 3-2 Transport Modeling Parameters

Parameter	Value
Longitudinal Dispersivity	30 feet
Transverse Dispersivity	3 feet
Upper Floridan Vertical Dispersion Anisotropy	0.1 (dimensionless)
Effective Porosity	0.1 (dimensionless)
Retardation	1 = no retardation (dimensionless)

- **Salt water density.** The ratio of salt water density to fresh water density was varied linearly from 1.0 for zero chloride concentration to 1.013 for a chloride concentration of 10,000 mg/L.

3.3 Simulations Results

The simulations were evaluated using several sets of results as described below. For each set of results, two different values of vertical hydraulic conductivity of the Miocene (mid and low-values) are used to bracket the range of potential impacts.

- Vertical profiles of simulated chloride concentrations at the SHE borehole locations for the year 2200 for no dredging and dredging scenarios.
- Simulated time history of chloride concentrations beneath the dredged channel adjacent to the SHE borehole locations from the year 1990 to 2200 for no dredging and dredging scenarios.
- Simulated time history of chloride concentrations at selected Upper Floridan production wells from the year 1990 to 2200 for no dredging and dredging scenarios.

In addition to the three types of results described above, figures are presented showing simulated chloride plumes in the Upper Floridan aquifer and chloride concentrations in cross-sections through the Savannah River. These concentration contour plots provide a broader, more qualitative view of the modeling results.

Vertical Profiles of Simulated Chloride Concentrations after 200 years

Using the boreholes shown location map shown in **Figure 3-4**, results in **Figures 3-5** through **3-16** illustrate the simulated chloride concentration as a function of depth through the Miocene confining unit for the year 2200 for the no dredging and dredging scenarios and two different values of vertical hydraulic conductivity of the Miocene confining unit. The charts labeled “A” illustrate the results based on the calibrated (mid-range) hydraulic conductivity value for the Miocene unit which, based on the simulated chloride profiles. Charts labeled “B” illustrate the results with the lower hydraulic conductivity value. Several observations can be made based on these results.

- At all borehole locations, the chloride concentration at the top of the Miocene is higher for the dredging scenario. This increase in salinity is based on the Savannah River salinity modeling results provided by Tetra Tech. This is one of the primary reasons for slightly higher chloride concentrations in the Miocene and Upper Floridan after dredging.
- The figures illustrate the shift in concentration that will take place in the next 200 years as water with higher chloride concentrations migrates downward due to the vertical groundwater head gradients.
- For the dredging conditions, the increased chloride concentrations at the top of the Miocene results in higher concentrations at the bottom of the Miocene, and generally higher concentrations in the Upper Floridan.
- In terms of the impact study, the change in concentration in the Upper Floridan aquifer is of primary importance. The results show that the simulated chloride concentrations drop off significantly in the Upper Floridan aquifer due to the higher flow within the aquifer and the consequent dilution effect.
- The difference between the dredging and no dredging chloride concentrations in the Upper Floridan aquifer at the SHE borehole locations is generally small in all the profiles, suggesting that the dredging will not significantly alter the expected chloride concentration in the Upper Floridan, which is primarily a function of the downward groundwater gradient caused by pumping.

The difference between no dredging and dredging simulated chloride concentrations in the upper part of the Upper Floridan is more easily visualized in the time history plots shown in **Figures 3-17** through **3-28** discussed below.

Time-History of Simulated Chloride Concentrations

Figures 3-17 through **3-28** illustrate the simulated chloride concentrations as a function of time beneath the dredged channel adjacent to each of the SHE borehole

locations for both the no dredging, and the dredging scenarios, using the range of hydraulic conductivity values for the Miocene confining unit. The concentrations shown are computed for the top 50 to 60 feet of the Upper Floridan aquifer. Similar to the previous figures, charts labeled “A” illustrate the results based on the mid-range hydraulic conductivity value for the Miocene unit and charts labeled “B” illustrate the results with the lower hydraulic conductivity value. It is expected that the actual behavior of the system will fall between the two sets of results.

Several conclusions can be drawn from these figures:

- All the figures represent expected concentrations directly beneath or adjacent to the river. These are the maximum concentrations to be expected, and they drop off as you move away from the river to the north or south.
- The concentrations shown are those only resulting from salt water coming through the Miocene confining units directly below the river channel. Concentration impacts from all other areas overlain by salt water are not simulated.
- In the upstream locations (represented by SHE-15 through SHE-10 - from river station 89+00 to 47+00) either breakthrough¹ into the Upper Floridan does not occur (“B” charts) or concentrations remain relatively low, typically not exceeding 100 to 200 mg/L as seen in the “A” charts. The Miocene Confining Unit is thicker at these upstream borehole locations than at the locations farther downstream. Under all conditions at these locations there is no appreciable increase in Upper Floridan chloride concentrations as a result of the dredging.
- For the mid hydraulic conductivity simulations (“A” charts) in locations further downstream, starting with SHE-18 (river station 31+00) simulated concentrations at SHE-13, SHE-2, and SHE-14 are significantly higher than locations further upstream. Concentrations at the top of Upper Floridan aquifer directly below the river after 200 years range from several hundred to greater than 1000 mg/L. For the low hydraulic conductivity simulation, concentrations are either significantly lower such as at SHE-18 and SHE-11, or breakthrough in the Upper Floridan is simulated to occur much later than the year 2200 – by as much as 100 years.
- Even after 200 years, the system is still in transition in most of the study area.
- In general, the dredging appears to have limited impact on the timing of breakthrough into the Upper Floridan aquifer. In the upper reaches since breakthrough is not simulated to occur during the 200 year simulation period, the dredging does not appear to speed up the occurrence of breakthrough. In the lower reaches, where the Miocene is thinner, in some cases the dredging does appear to speed up the occurrence of breakthrough by as much as 10 to 15 years

¹ For this study, “breakthrough” is said to occur when the simulated chloride concentrations in the top 50 to 60 feet of the Upper Florida Aquifer initially exceeds 250 mg/L.

(Figure 3-22), however earlier breakthrough is not generally discernable in the majority of the locations (Figures 3-24, 3-25 and 3-26).

- As the system approaches steady state, the increased chloride concentration in the downward flux from Savannah River eventually results in slightly increased concentrations in the Upper Floridan aquifer (see Figures 3-24, 3-25 and 3-26).

Simulated chloride concentration time-histories are also generated for nearby Upper Floridan production wells shown on **Figure 3-29**. The simulated chloride concentrations are shown **Figures 3-30 through 3-48** for both the no dredging and the dredging scenarios utilized the mid and lower hydraulic conductivity values. These results illustrate that with the mid-value of hydraulic conductivity for the Miocene, chloride concentrations in Savannah area production wells could increase by 10 to 50 mg/L by the year 2200 as a result of downward migration from the river. Using the lower value of hydraulic conductivity, concentrations are effectively zero at most of the wells. For the mid-value of hydraulic conductivity for the Miocene, the difference between the dredging and no dredging in the simulated production well chloride concentrations ranges from negligible to less than 10 mg/L. **Figure 3-48** illustrates the simulated chloride concentrations in the Upper Floridan at the Tybee Island well. For the mid-value of hydraulic conductivity in the Miocene, breakthrough is simulated to occur in the next 20 to 30 years, with concentrations increasing steadily through the 200 year simulation period. However, the difference between no dredging and dredged appears to be imperceptible at this location. For the low-value hydraulic conductivity in the Miocene, breakthrough appears to be considerably further into the future, with practically no increase in simulated chloride concentrations over the 200 year period.

Simulated Chloride Concentrations Distributions

Figures 3-49 and 3-52 show plan view simulated chloride concentrations in the Upper Floridan aquifer for the years 2000, 2050, and 2200, with and without dredging. Note that, because of the flow direction caused by the heavy pumping in the area of downtown Savannah, chloride plumes tend to move parallel to the river. Thus, the concentration results discussed above are relevant only for concentrations directly below the river. Impacts north or south of the river disappear over a relatively short distance.

These figures illustrate how concentrations in the Upper Floridan vary spatially with time. Along the downstream reaches of the river, concentrations are significantly higher than those in the upstream areas. Nonetheless, for the mid value of hydraulic conductivity simulations in which breakthrough is simulated to occur, the difference between the dredging and no dredging scenarios is not significant.

3.4 Study Conclusions

- A fully 3-dimensional groundwater flow model with saltwater intrusion simulation capabilities was developed and applied to evaluate the relative impact of the proposed SHE dredging program.

- Depressed groundwater heads in the Upper Floridan aquifer due to Savannah area pumping induces downward flow from the river through the Miocene to Upper Floridan aquifer. These vertical head gradients are the dominant force in causing downward movement of salt water through the Miocene confining unit.
- An analysis of the downward volume of flow of saline water from the area of the Savannah River impacted by the dredging shows that the total volume of downward moving salt water is small. The model simulates downward flow from the area of river affected by dredging to be between 50 to 250 gallons per minute under existing conditions, depending on the hydraulic conductivity of the Miocene. With dredging, this value increases by between 2 to 7 gallons per minute – approximately 3 to 4 percent. When compared to total groundwater production in Chatham County, which is on the order of 70 to 80 million gallons per day (49,000 to 56,000 gpm), this is relatively insignificant.
- The 200 year projection simulations show salt water from the river potentially penetrating the Miocene and reaching the Upper Floridan aquifer. The simulated concentrations in the top of the Upper Floridan aquifer are very sensitive to the hydraulic conductivity of the Miocene, and ultimately the thickness of the Upper Floridan over which the concentrations are calculated. In this analysis, the concentrations were computed for the top 50 to 60 feet of the Upper Floridan aquifer only.
- In the upper reaches of the river near the center of the cone of depression, where the Miocene is thicker, localized concentrations in the Upper Floridan aquifer beneath the river are simulated to be approximately 0 mg/L for low-value hydraulic conductivity simulations and up to 100 mg/L for the mid-value hydraulic conductivity simulations after 200 years.
- Downstream, where the Miocene is relatively thin, chloride concentrations directly beneath the river approach 500 mg/L after 200 years in some areas for the low-value hydraulic conductivity simulations. For the mid-value hydraulic conductivity simulations, equilibrium is reached after approximately 100 years, with some concentrations as high as 1400 mg/L in some areas.
- The simulated maximum chloride concentrations in the top of the Upper Floridan aquifer for the dredging conditions appear to increase mainly due to increased river source concentration assigned at the bottom of the river. In the upstream reaches of the river, the differences due to the dredging are minor. Downstream, where higher river concentrations occur, the increase in concentrations in the Upper Floridan aquifer directly below the river due to dredging ranges from 10 to 200 mg/L. These differences are typically observed 50 or more years into the future.
- The increased salinity in the Savannah River and the reduced thickness of the Miocene confining unit due to dredging do not appear to significantly affect the timing of breakthrough of chlorides into the Upper Floridan aquifer. Model results and pore water sample results suggest that limited breakthrough of salt

water into the Upper Floridan aquifer may occur very soon in the downstream area, but may not occur for decades further upstream.

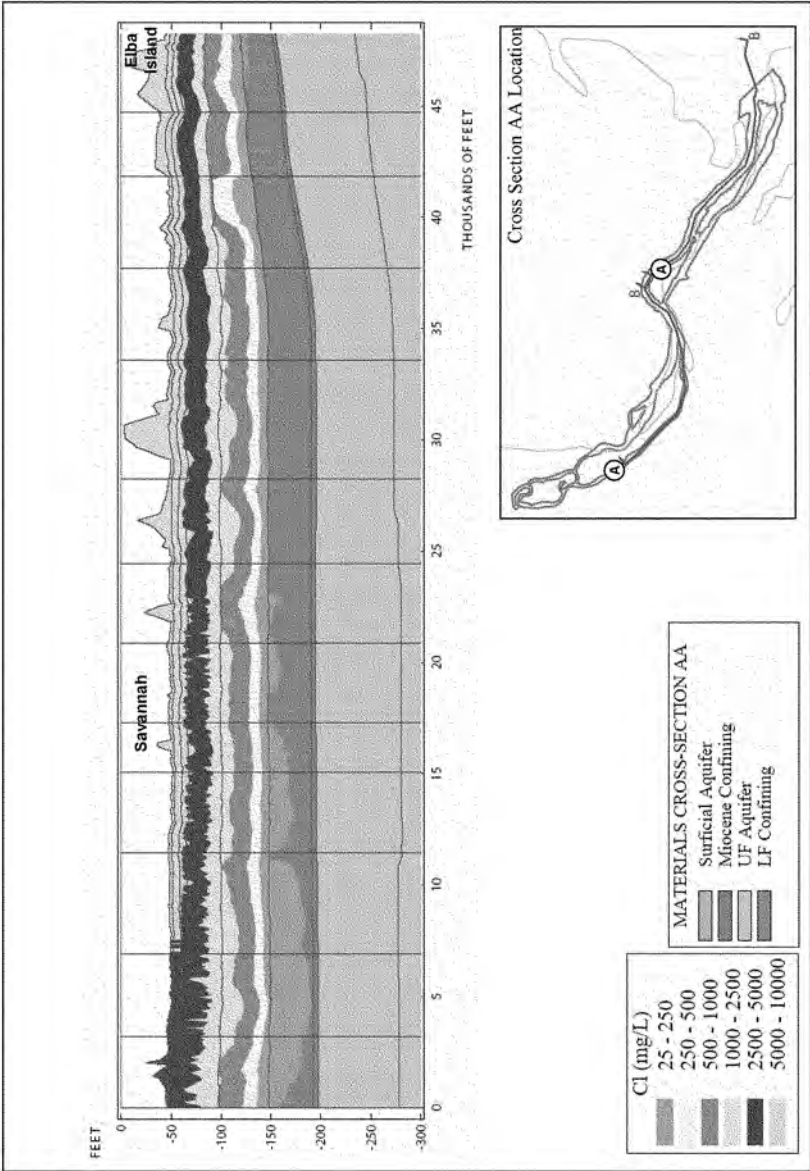
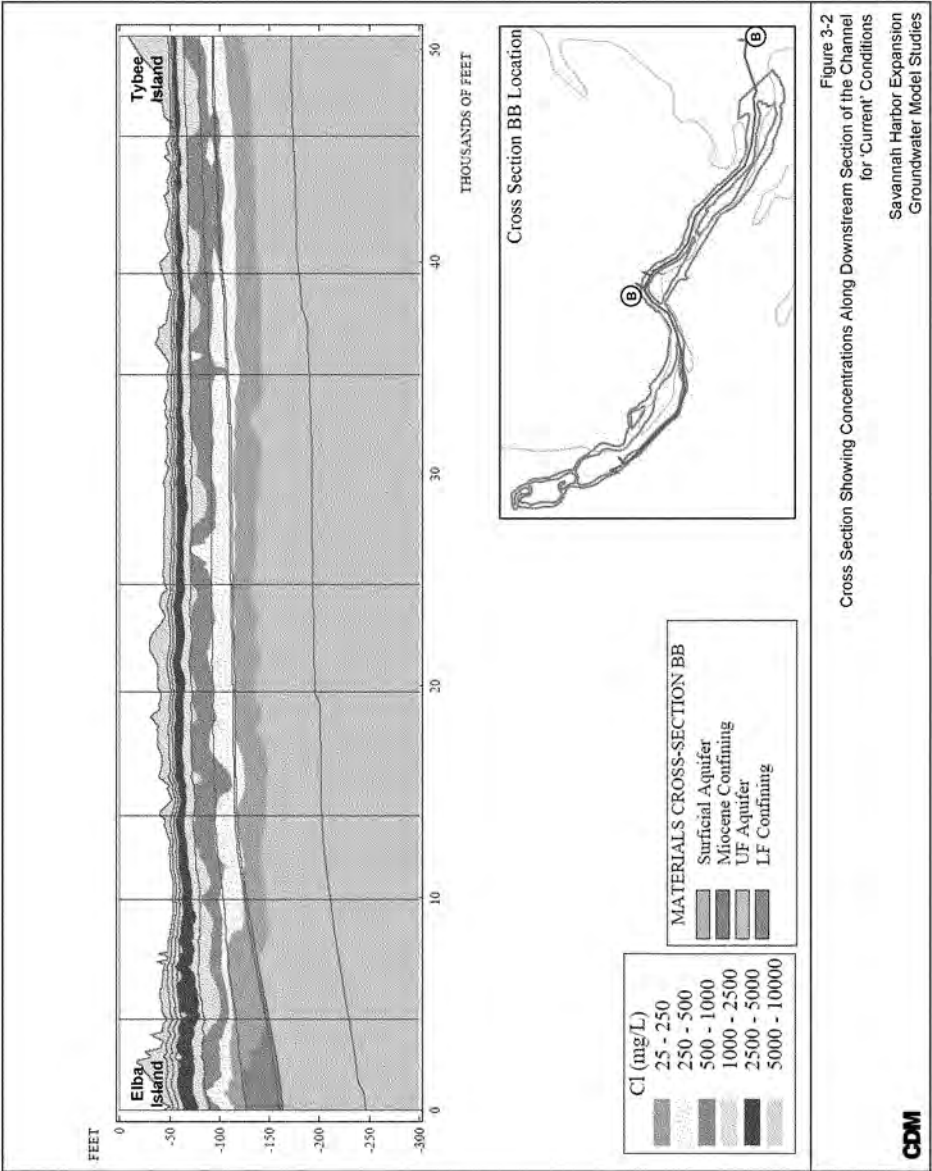


Figure 3-1
Cross Section Showing Concentrations Along Upstream Section of the Channel
for 'Current' Conditions
Savannah Harbor Expansion
Groundwater Model Studies



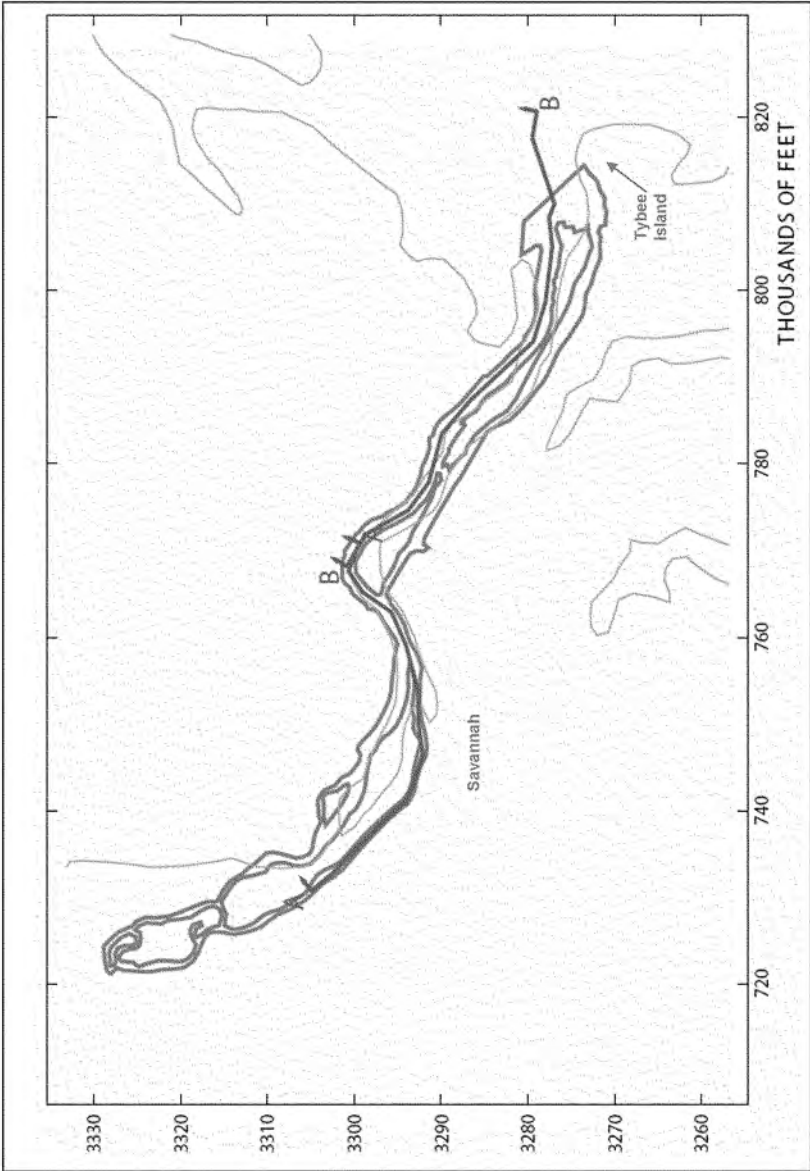


Figure 3-3
Cross Section Location Map
Savannah Harbor Expansion
Groundwater Model Studies



Source:
U.S. Army Corps of Engineers, Savannah District
Geology/Hydrogeology Section

Figure 3-4
Borehole Location Map
Savannah Harbor Expansion
Groundwater Model Studies

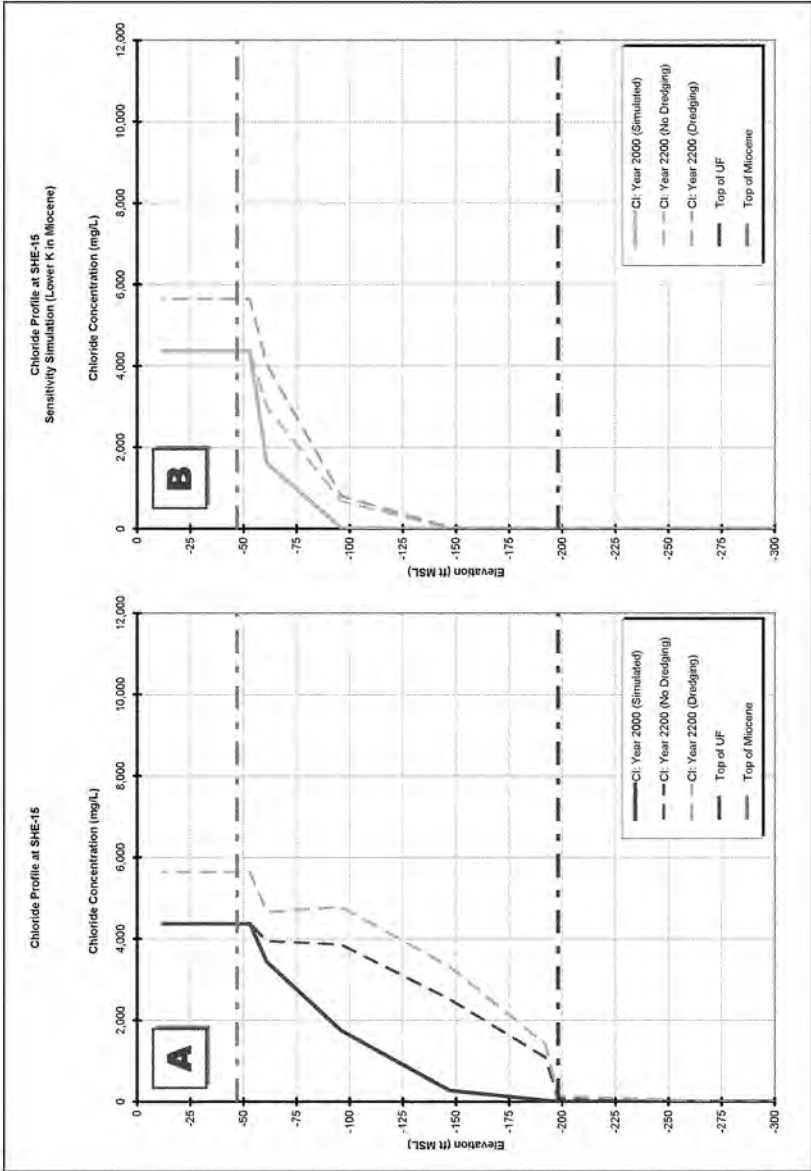


Figure 3-5
Comparison of Simulated Concentration Profiles at SHE-15 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

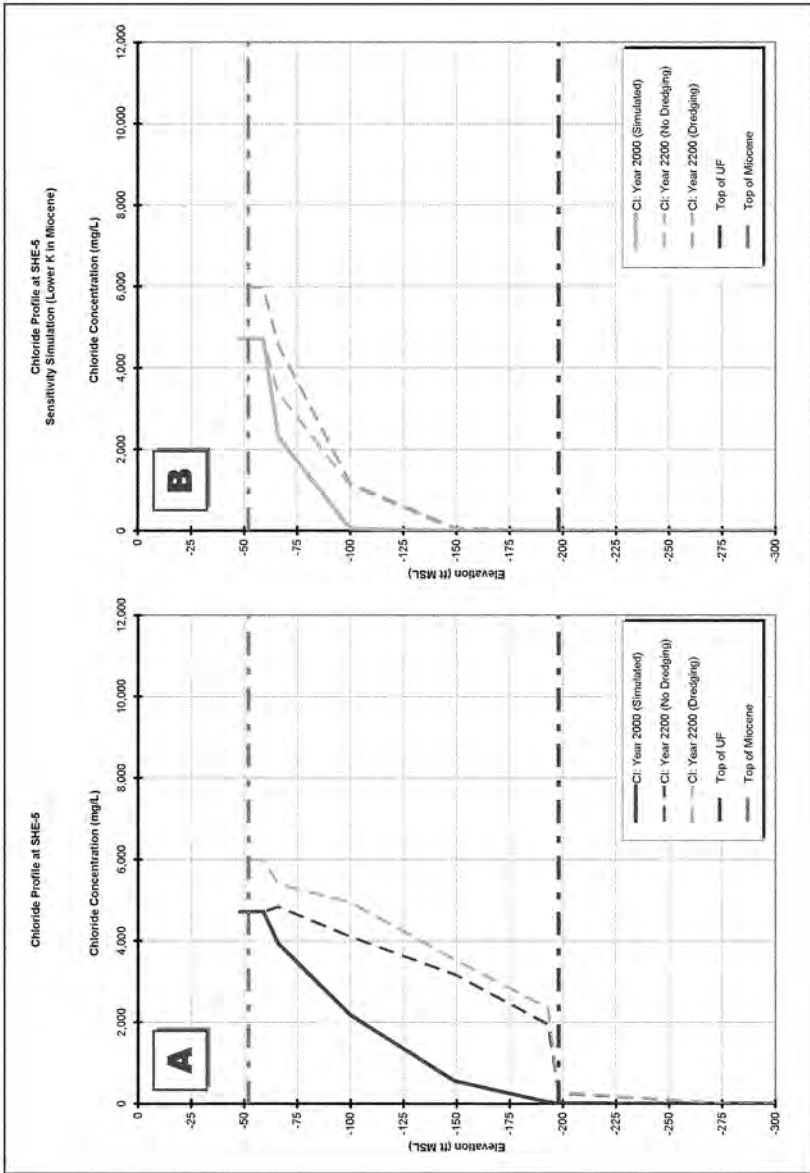


Figure 3-6
Comparison of Simulated Concentration Profiles at SHE-5 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

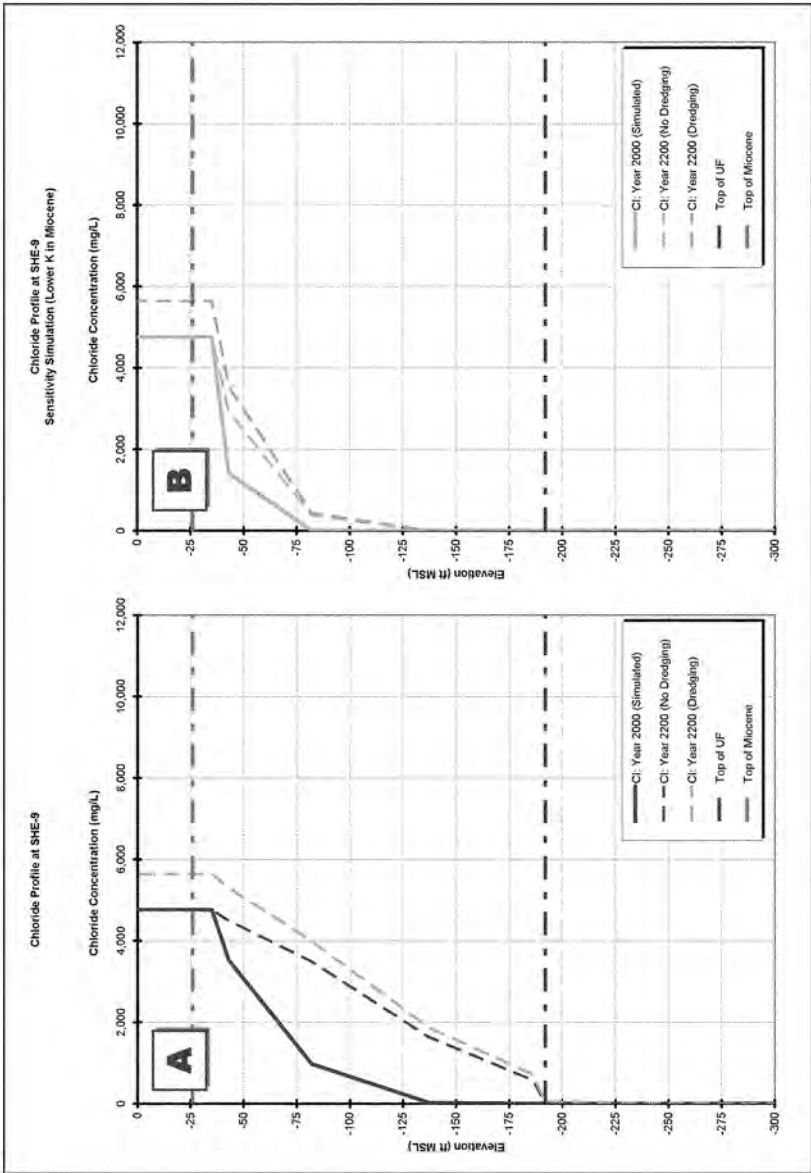


Figure 3-7
Comparison of Simulated Concentration Profiles at SHE-9 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

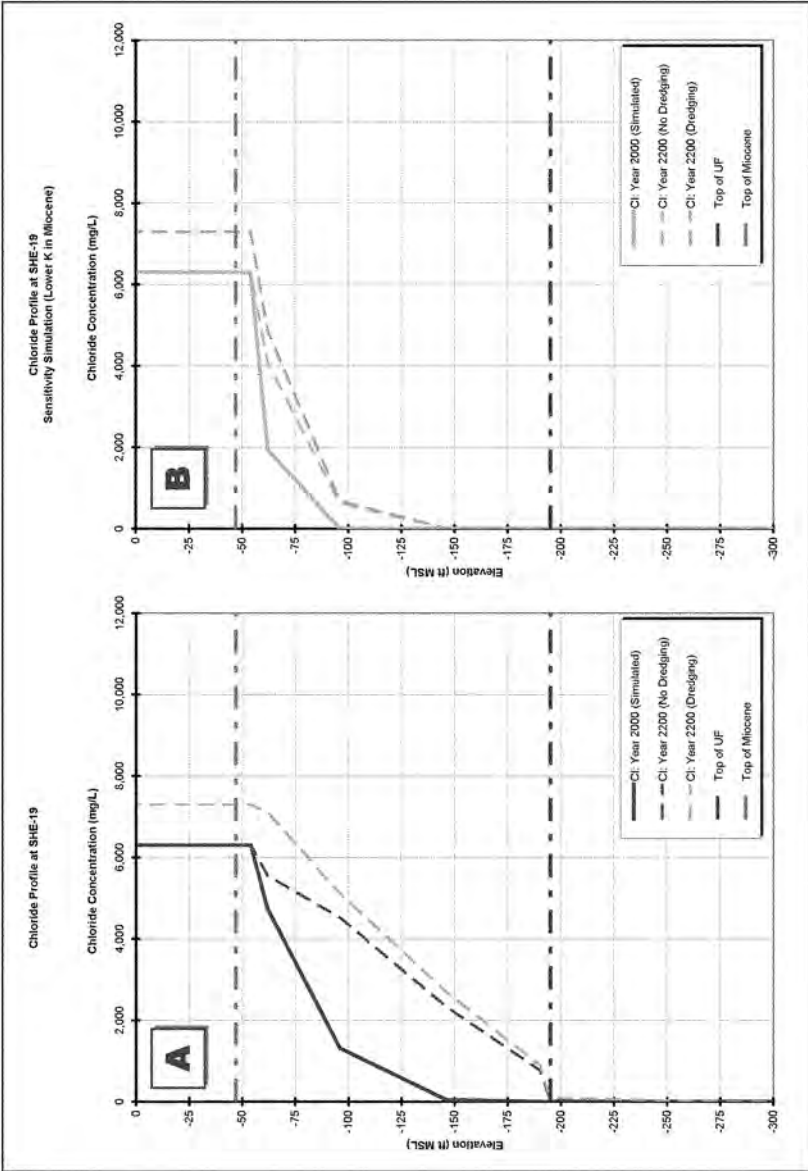


Figure 3-8
Comparison of Simulated Concentration Profiles at SHE-19 for No Dredging and Dredging
Savannah Harbor Expansion
Groundwater Model Studies

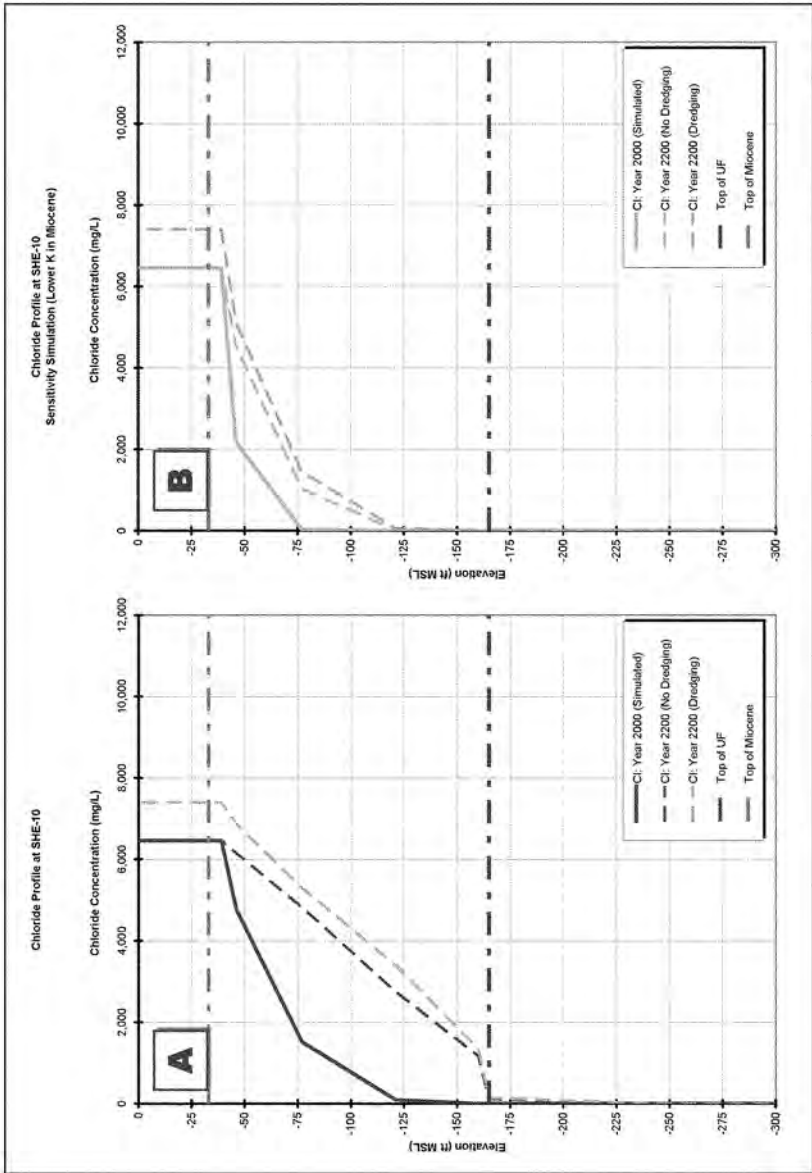


Figure 3-9
Comparison of Simulated Concentration Profiles at SHE-10 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

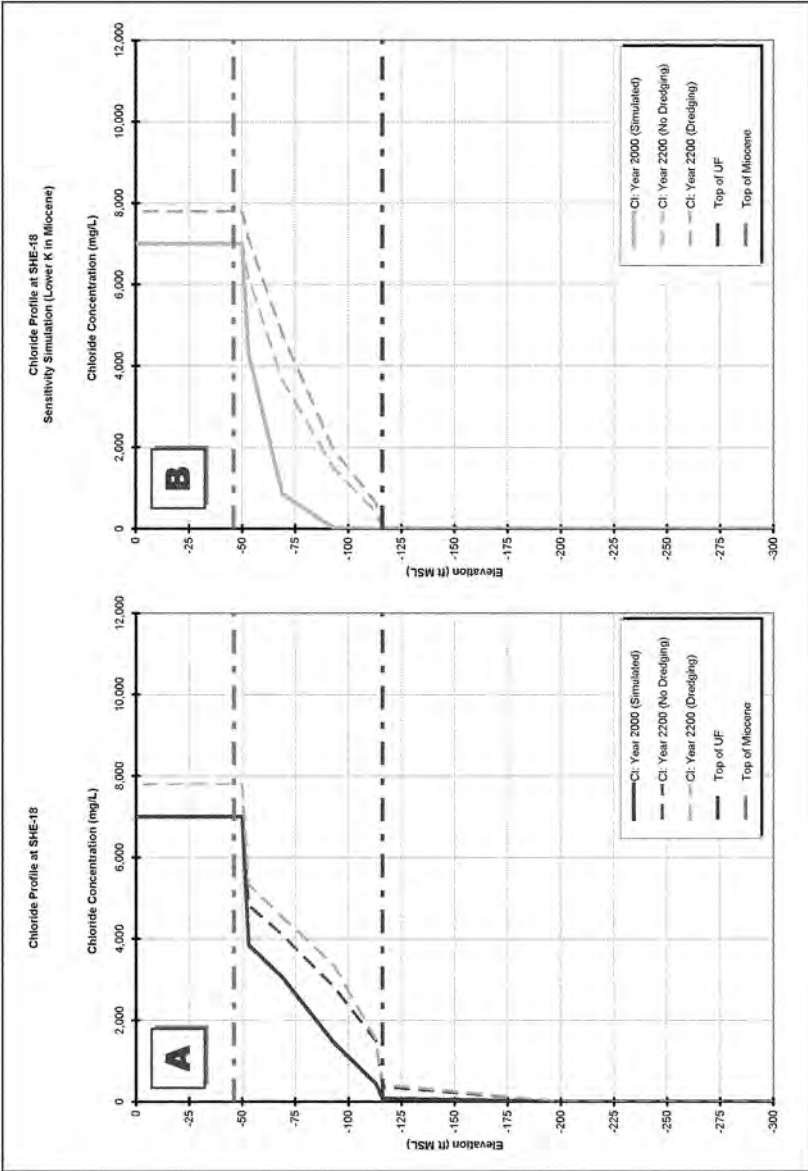


Figure 3-10
Comparison of Simulated Concentration Profiles at SHE-18 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

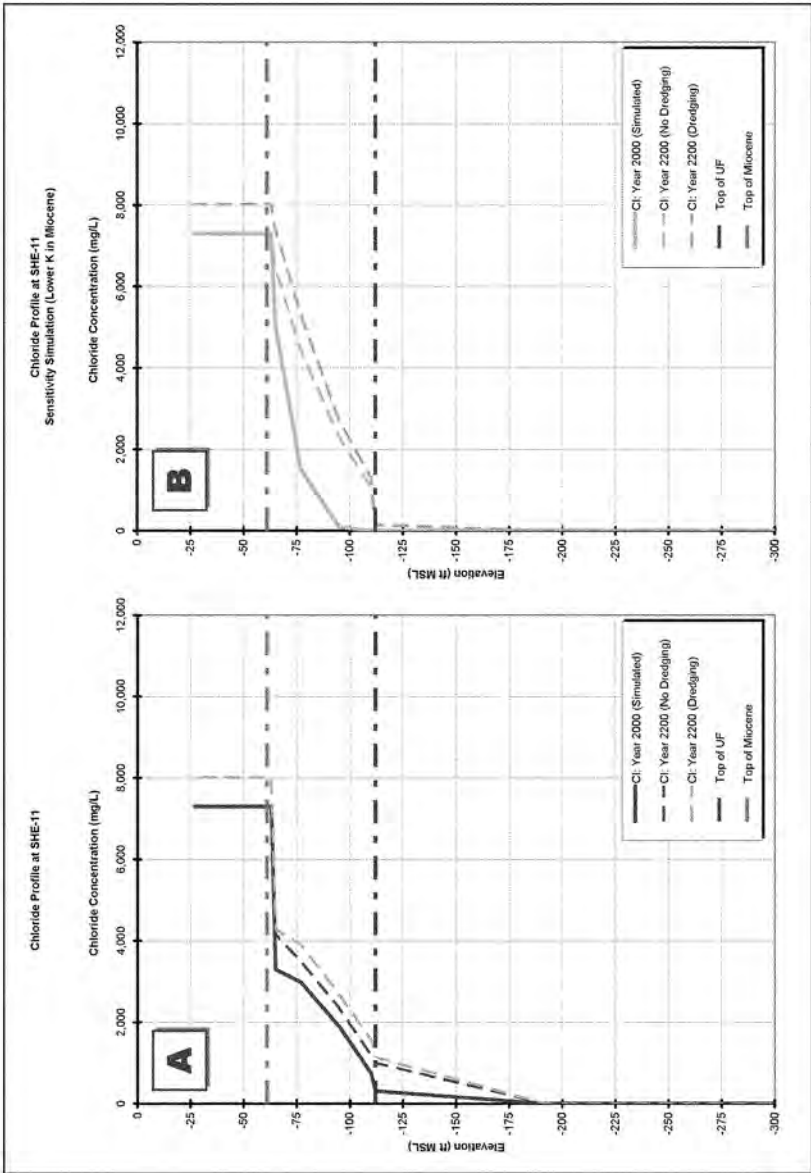


Figure 3-11
Comparison of Simulated Concentration Profiles at SHE-11 for No Dredging and Dredging

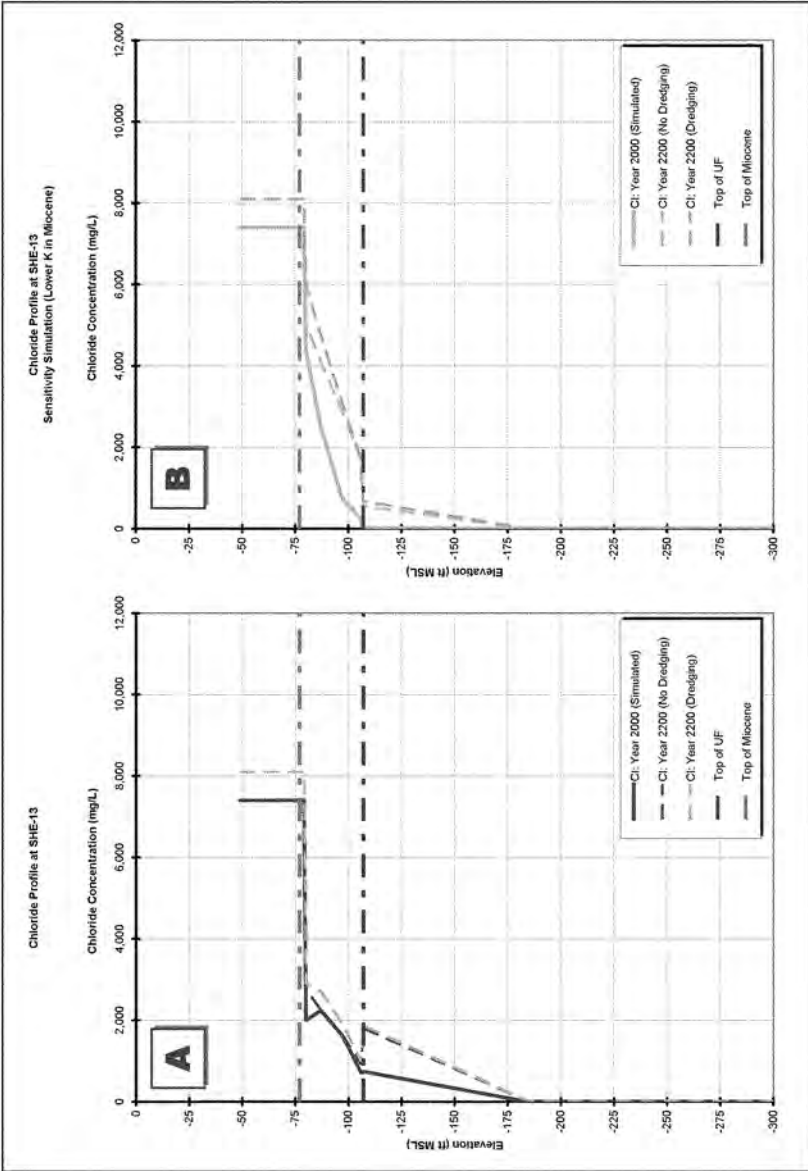


Figure 3-12
Comparison of Simulated Concentration Profiles at SHE-13 for No Dredging and Dredging

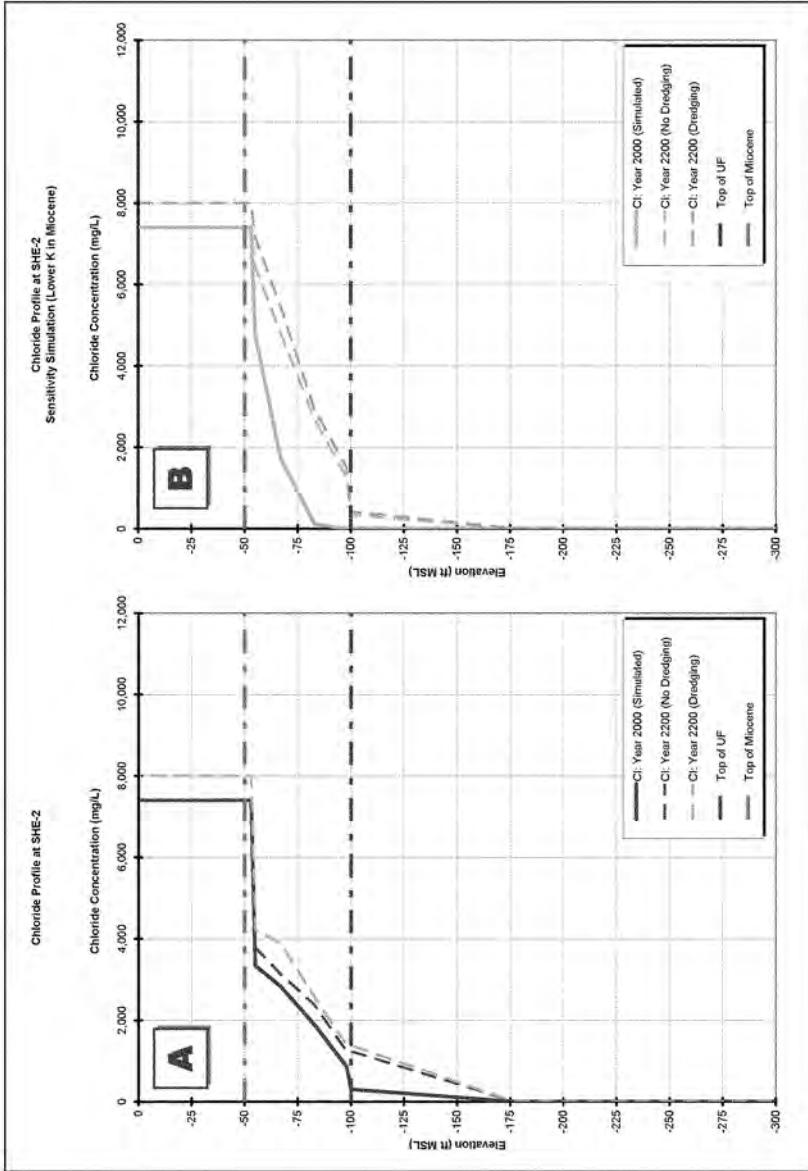


Figure 3-13
Comparison of Simulated Concentration Profiles at SHE-2 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

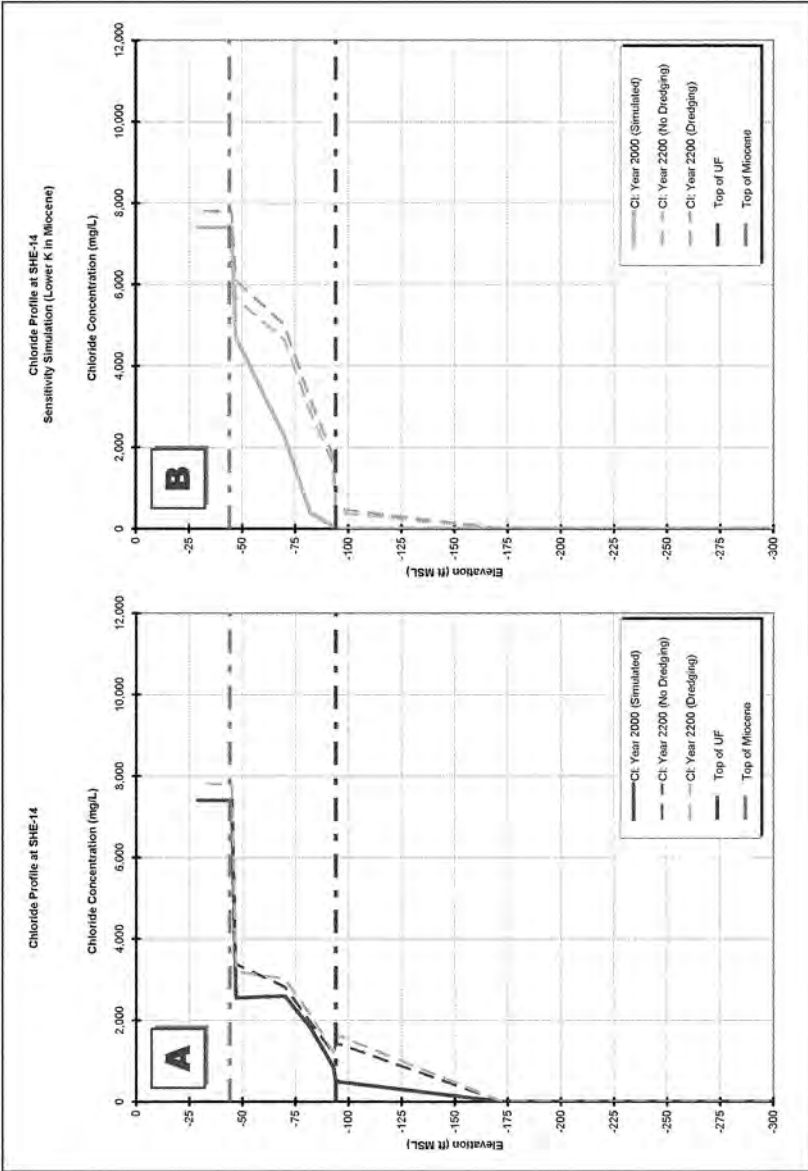


Figure 3-14
Comparison of Simulated Concentration Profiles at SHE-14 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

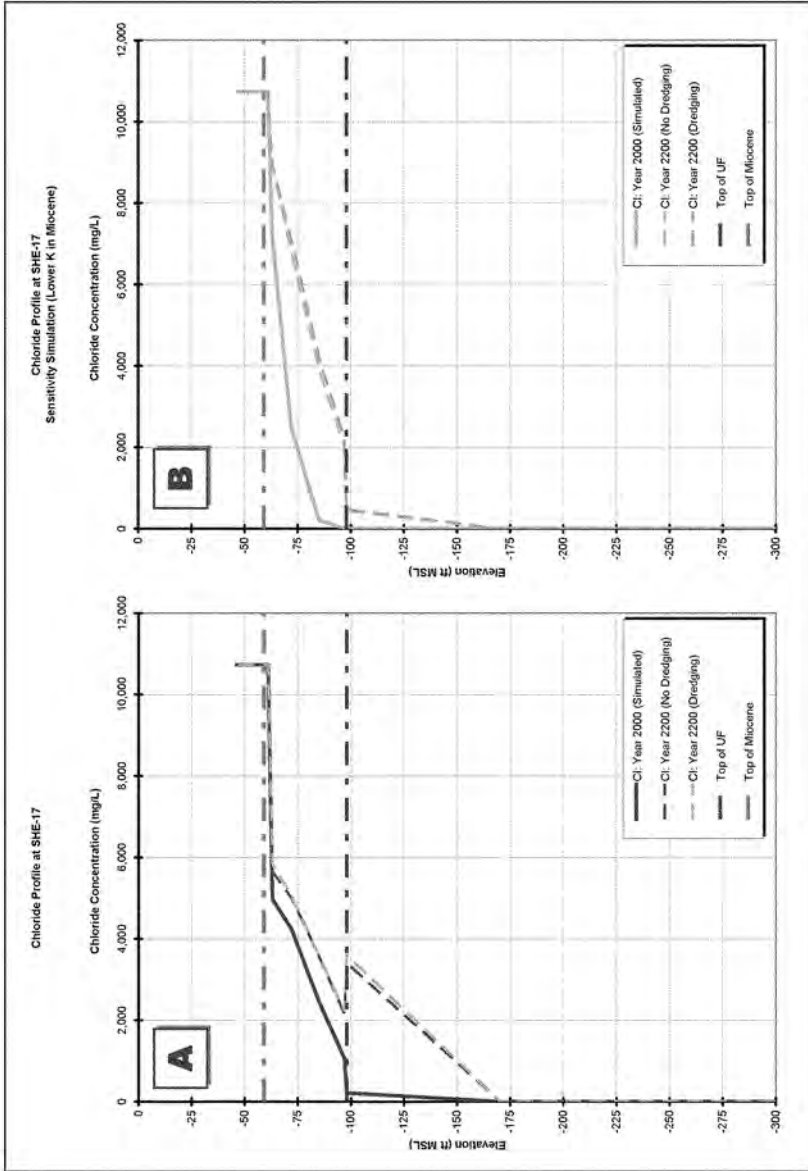


Figure 3-15
Comparison of Simulated Concentration Profiles at SHE-17 for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

Groundwater Model Studies

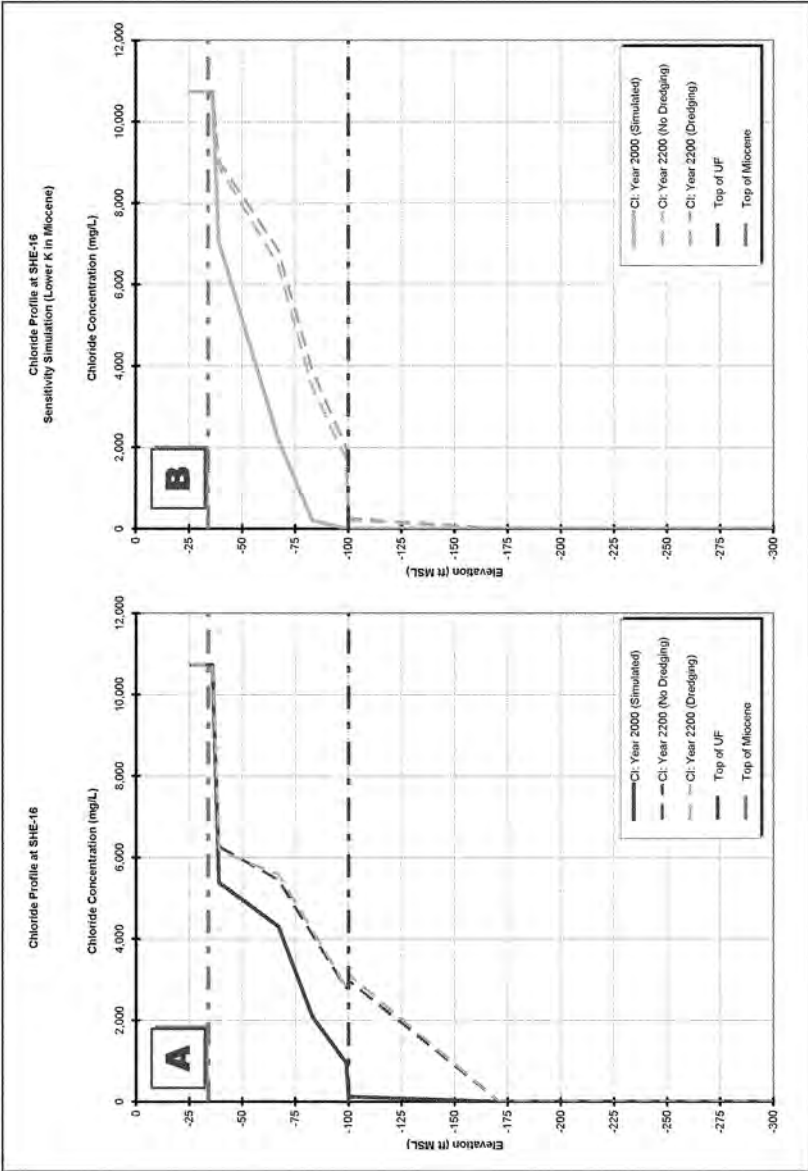


Figure 3-16
Comparison of Simulated Concentration Profiles at SHE-16 for No Dredging and Dredging

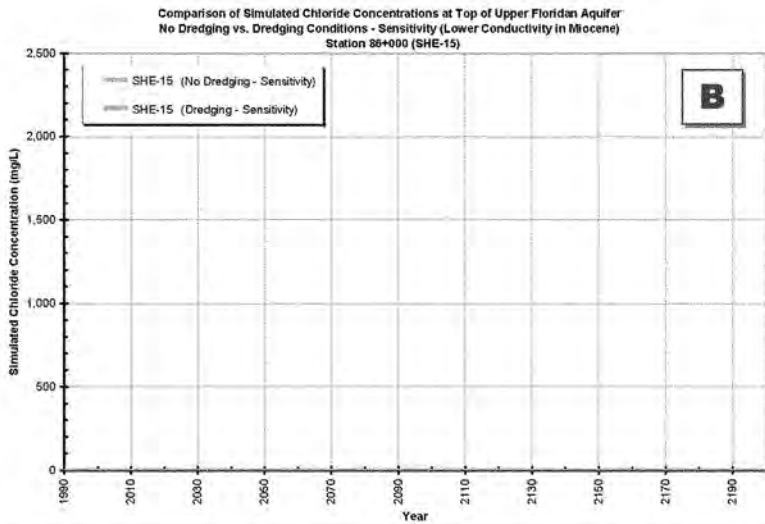
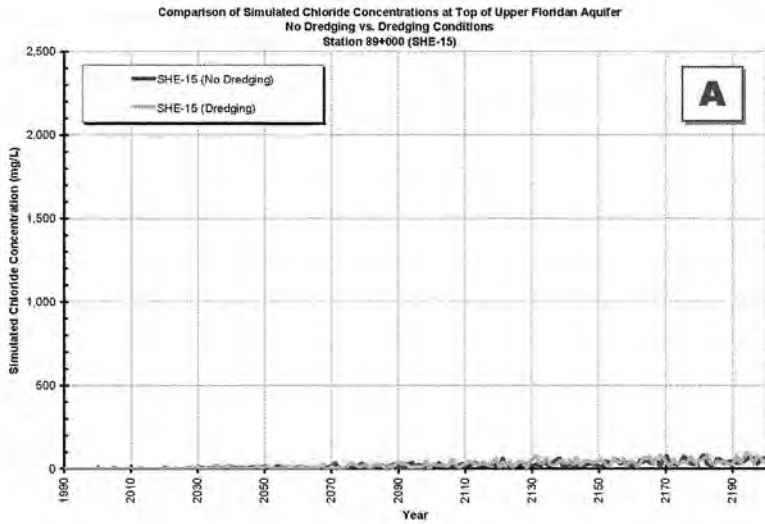


Figure 3-17
Comparison of Simulated Concentration Time Histories at SHE-15
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

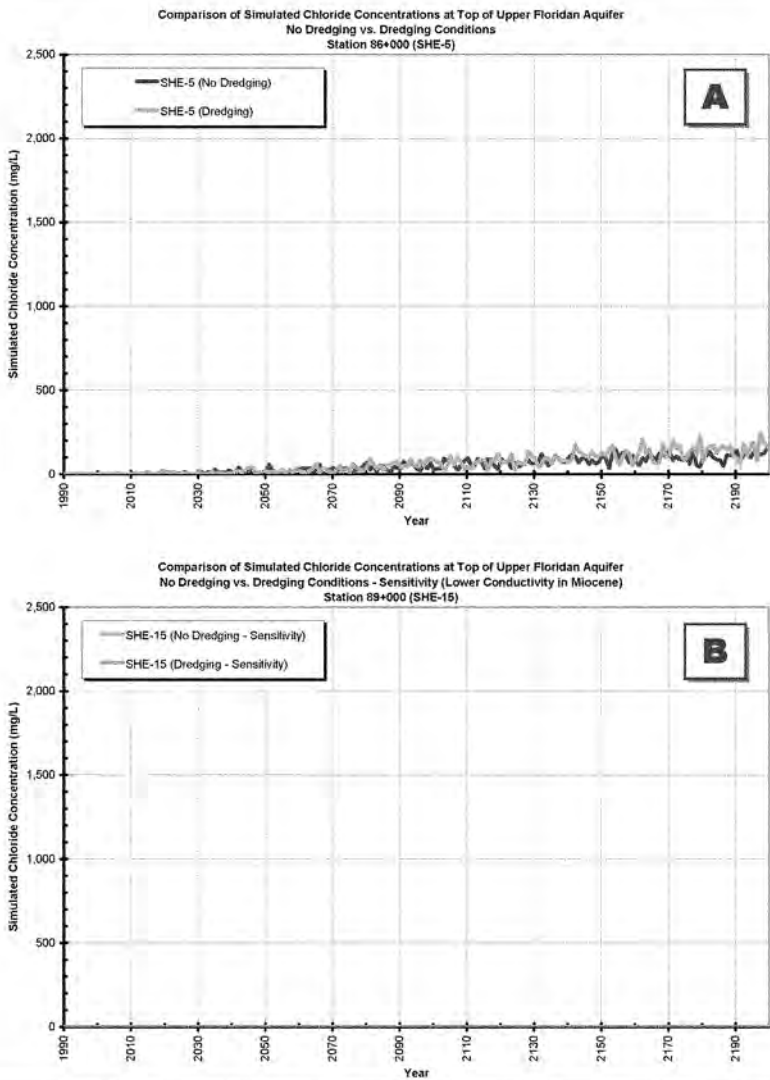


Figure 3-18
Comparison of Simulated Concentration Time Histories at SHE-5
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

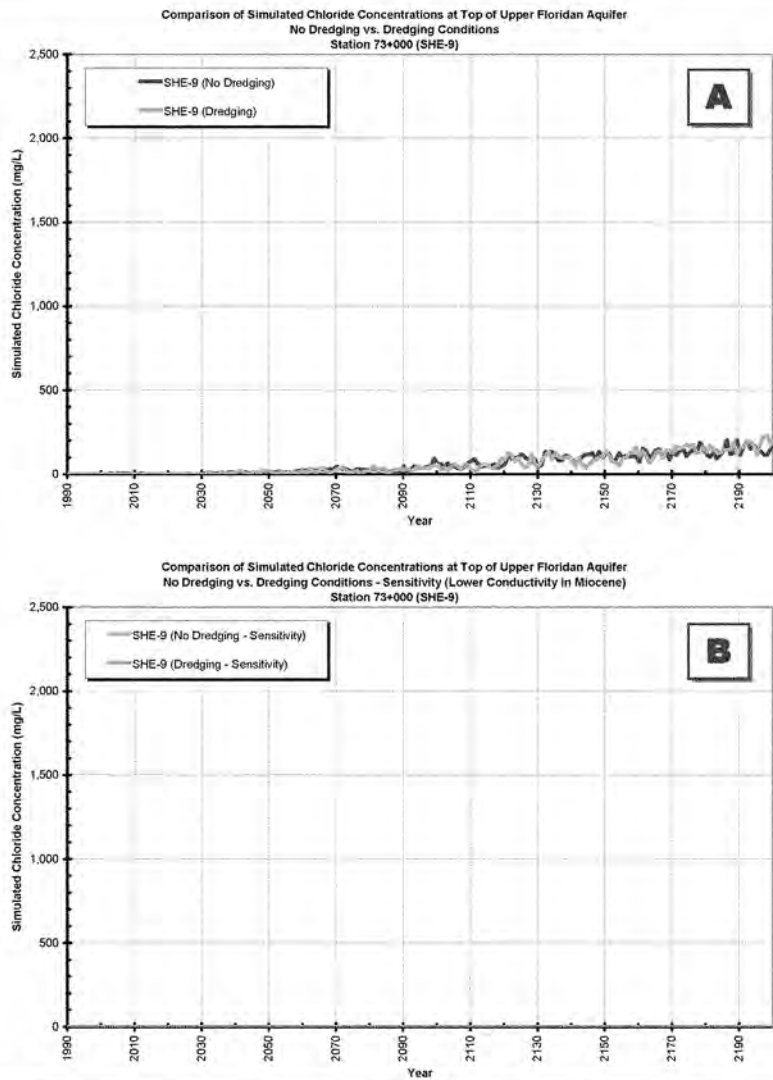


Figure 3-19
Comparison of Simulated Concentration Time Histories at SHE-9
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

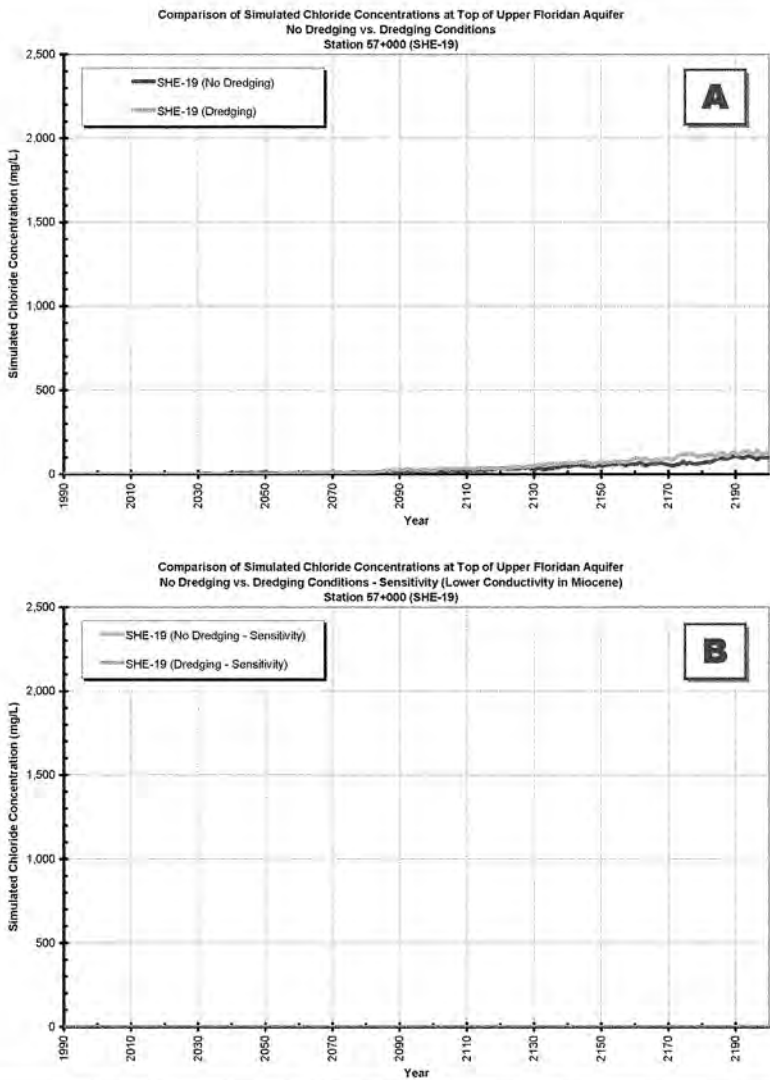


Figure 3-20
Comparison of Simulated Concentration Time Histories at SHE-19
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

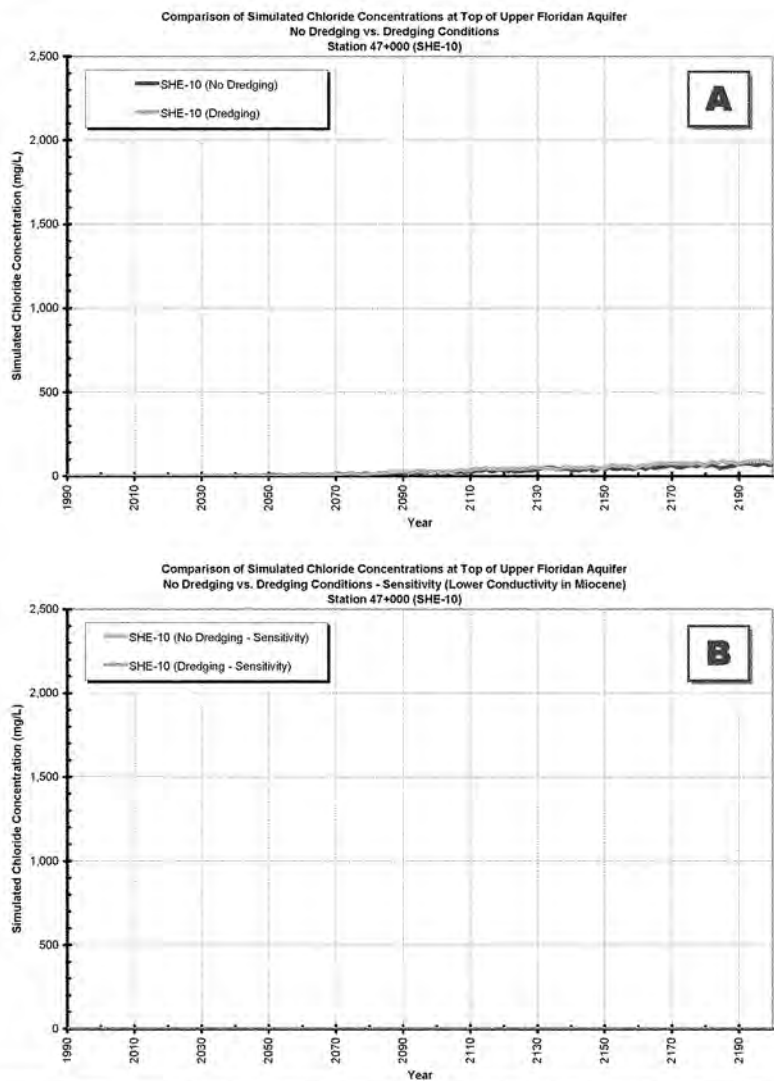


Figure 3-21
Comparison of Simulated Concentration Time Histories at SHE-10
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

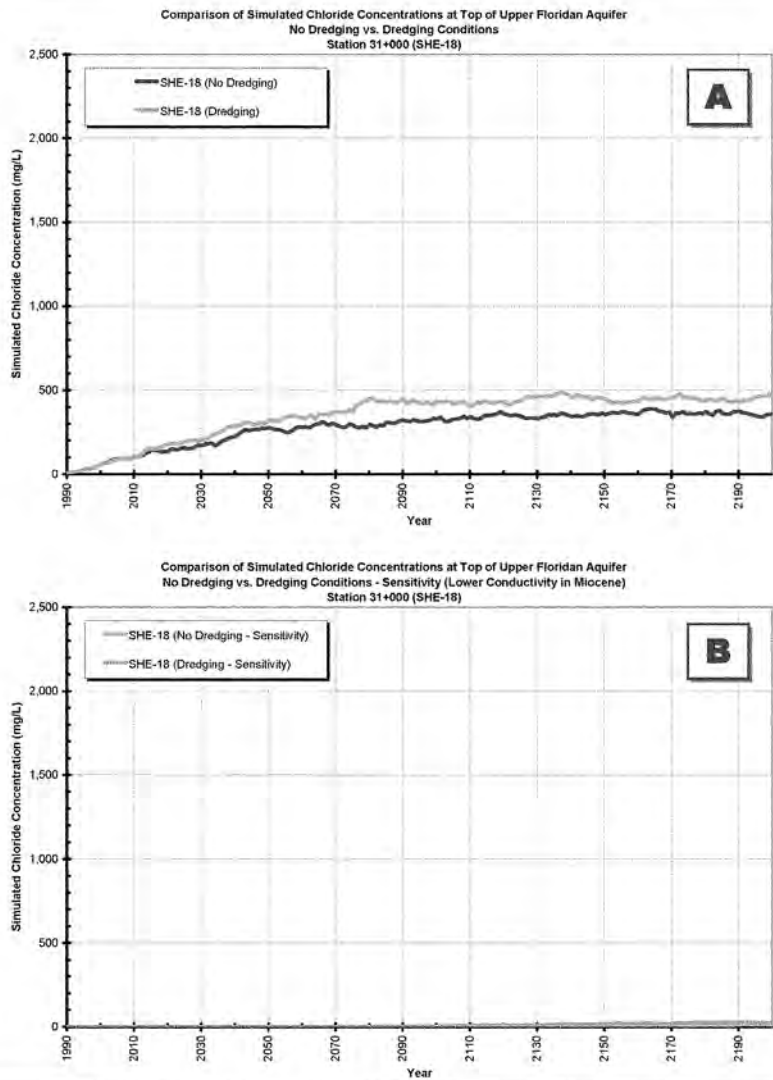


Figure 3-22
Comparison of Simulated Concentration Time Histories at SHE-18
for No Dredging and Dredging
Savannah Harbor Expansion
Groundwater Model Studies

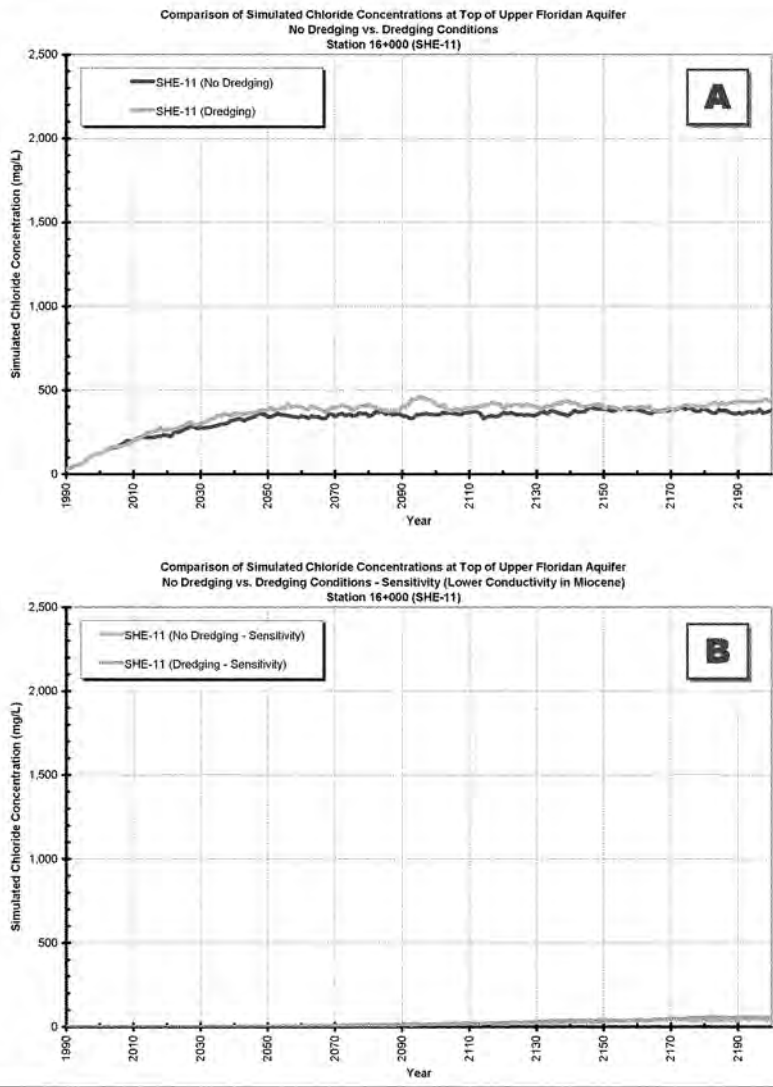


Figure 3-23
Comparison of Simulated Concentration Time Histories at SHE-11
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies

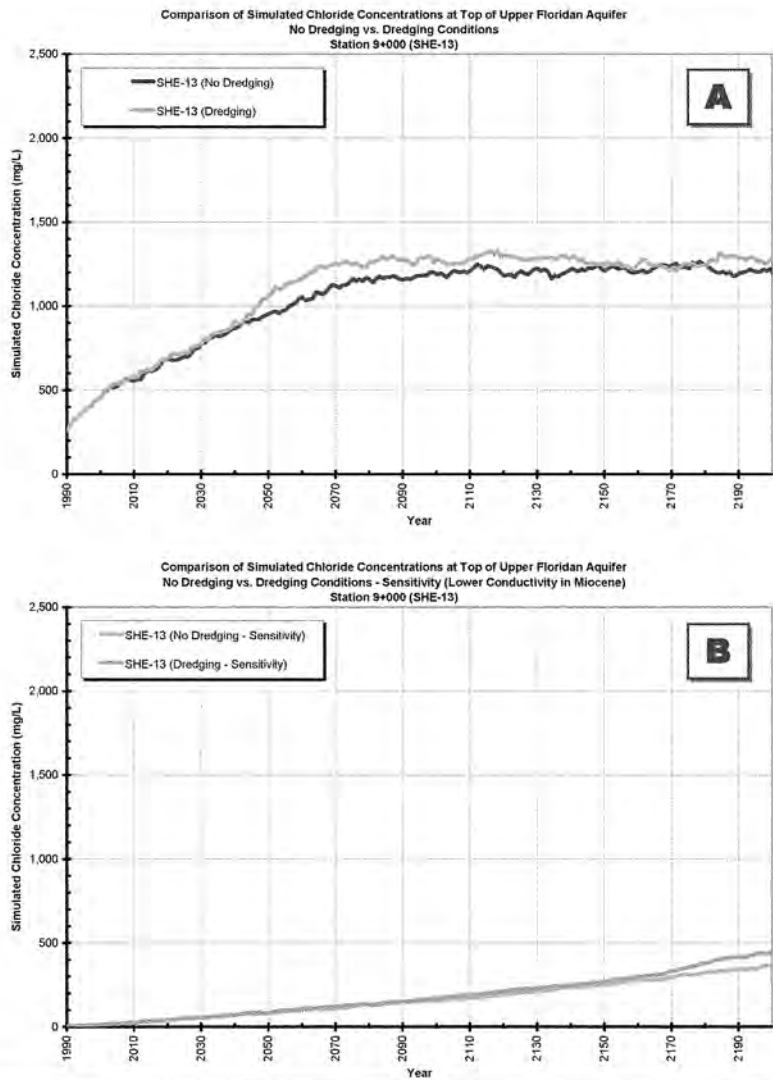


Figure 3-24
Comparison of Simulated Concentration Time Histories at SHE-13
for No Dredging and Dredging
Savannah Harbor Expansion
Groundwater Model Studies

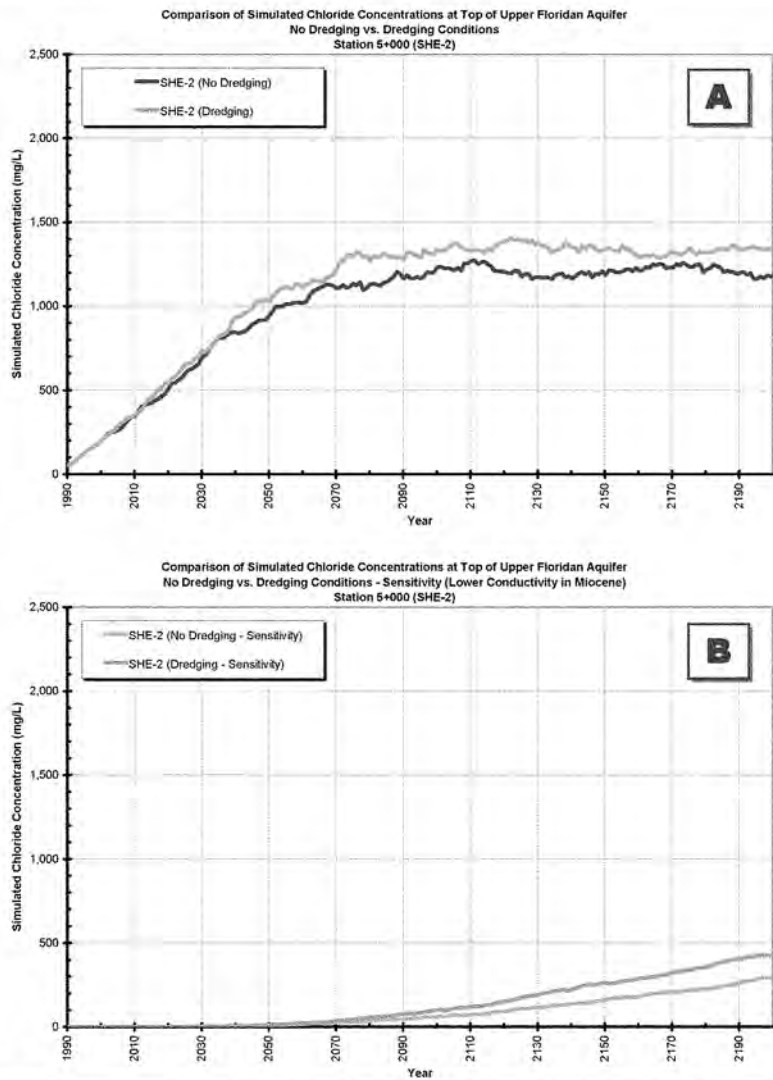


Figure 3-25
Comparison of Simulated Concentration Time Histories at SHE-2
for No Dredging and Dredging
Savannah Harbor Expansion
Groundwater Model Studies

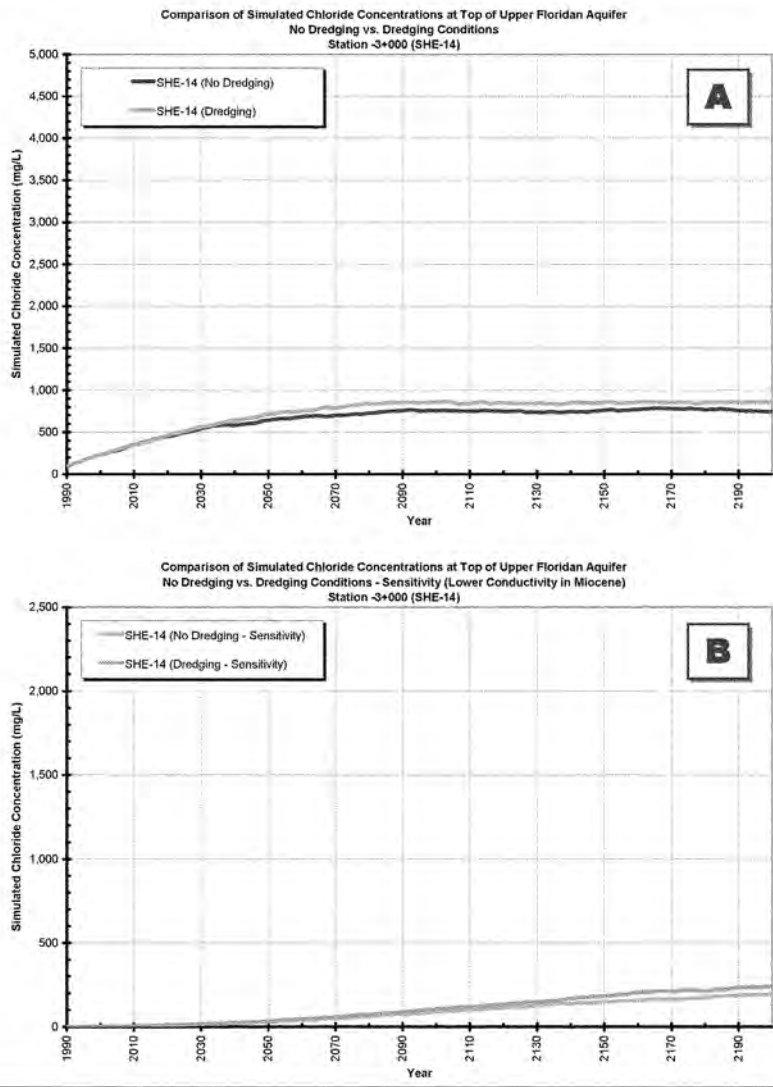


Figure 3-26
Comparison of Simulated Concentration Time Histories at SHE-14
for No Dredging and Dredging
Savannah Harbor Expansion
Groundwater Model Studies

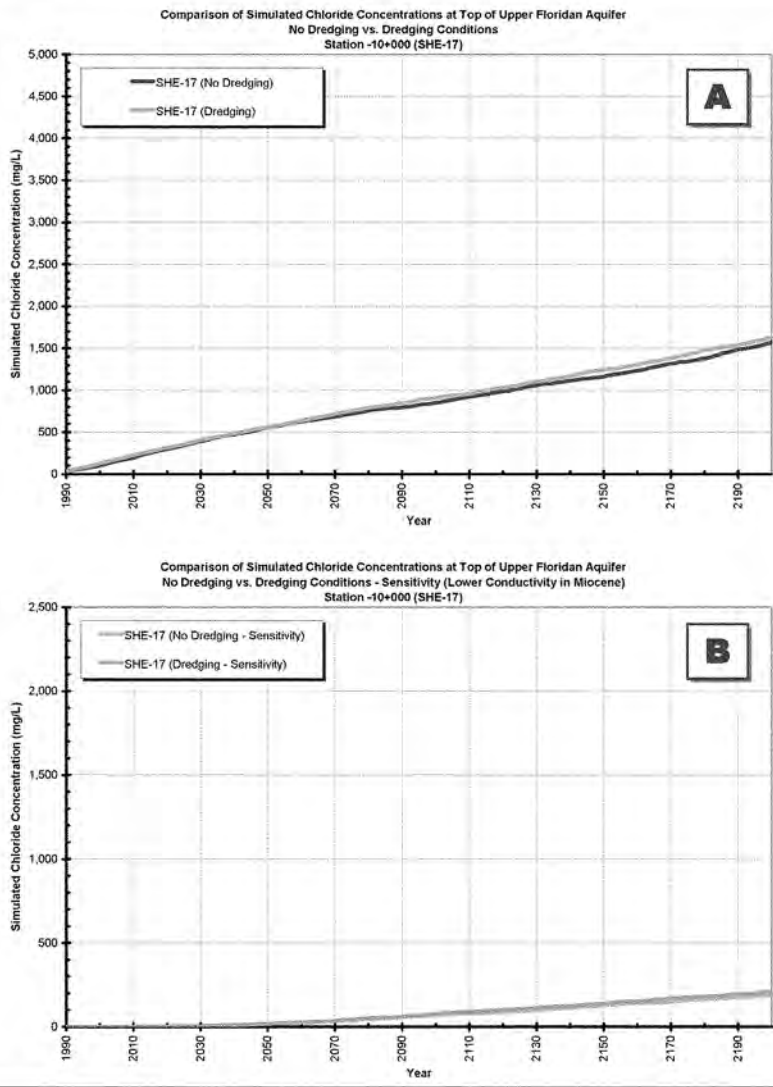


Figure 3-27
Comparison of Simulated Concentration Time Histories at SHE-17
for No Dredging and Dredging
Savannah Harbor Expansion
Groundwater Model Studies

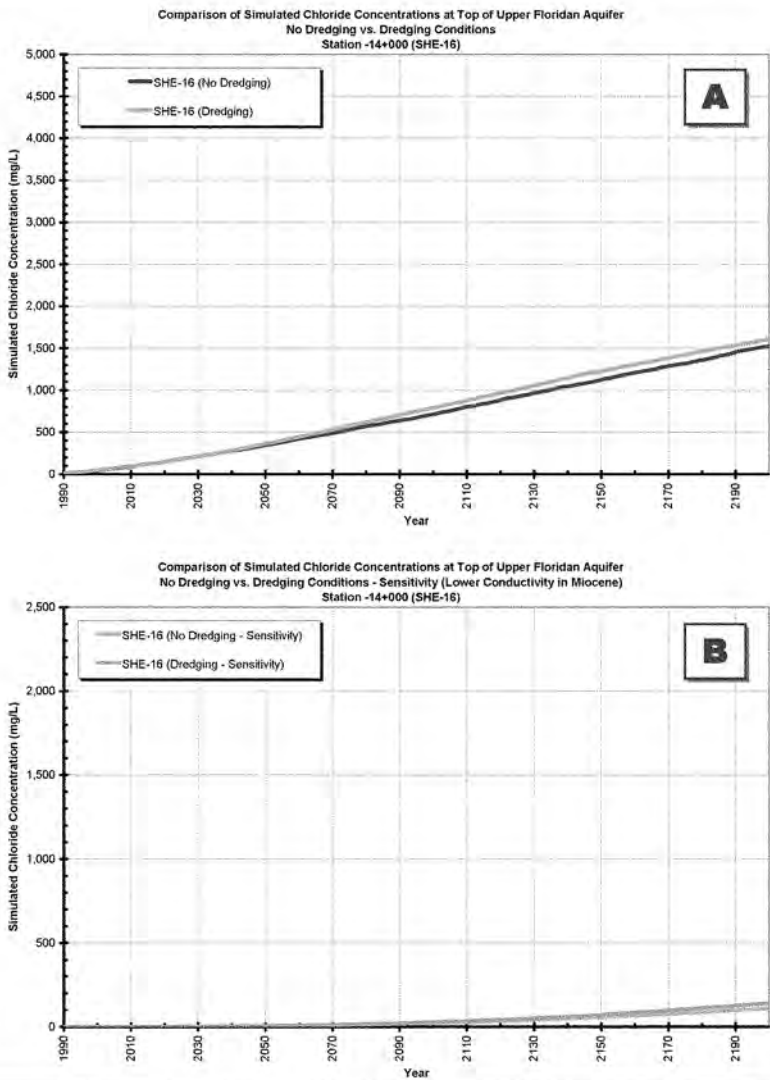


Figure 3-28
Comparison of Simulated Concentration Time Histories at SHE-16
for No Dredging and Dredging

Savannah Harbor Expansion
Groundwater Model Studies



ID	Name	ID	Name
1	Savannah Sugar Refinery Well (025I2901)	10	SEPCO - Riverside Thermo Plant Well (025T0301)
2	GAF Corp. Well (025I3501)	11	SEPCO - Riverside Thermo Plant Well (025T0302)
3	Gold Bond Building Products Well (025I3301)	12	SEPCO - Riverside Thermo Plant Well (025T0303)
4	International Paper Well #1	13	Southern States Phosphate Well (025I3101)
5	International Paper Well #2	14	Savannah Main Well #11
6	International Paper Well #5	15	City of Garden City Well (025M0101)
7	Hunt Wesson Well (025I2801)	16	Kemira Well (025I3001)
8	Hunt Wesson Well (025I2802)	17	Kemira Well (025I3002)
9	Hunt Wesson Well (025I2803)	18	Whitemarsh Island Well #28
		19	Tybee Island Well (025M0602)

Figure 3-29
Location of Selected Pumping Wells

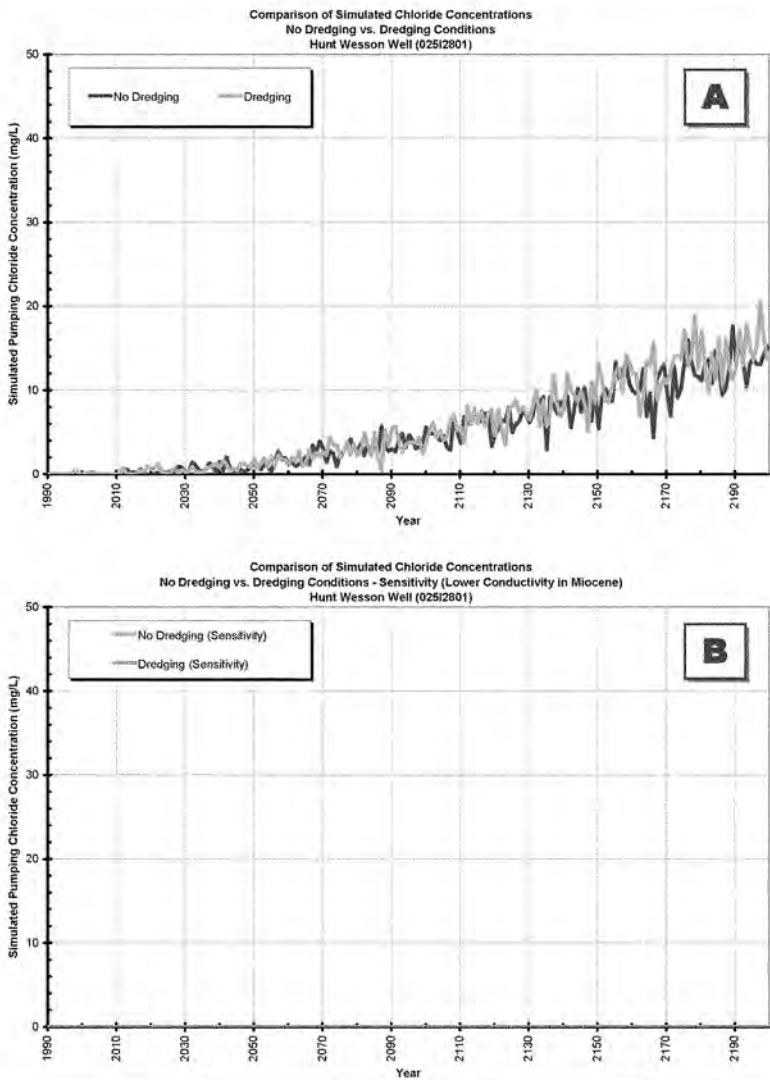


Figure 3-30
Pumping Well Concentrations for No Dredging and Dredging
At Hunt Wesson Well (025E2801)

Savannah Harbor Expansion
Groundwater Model Studies



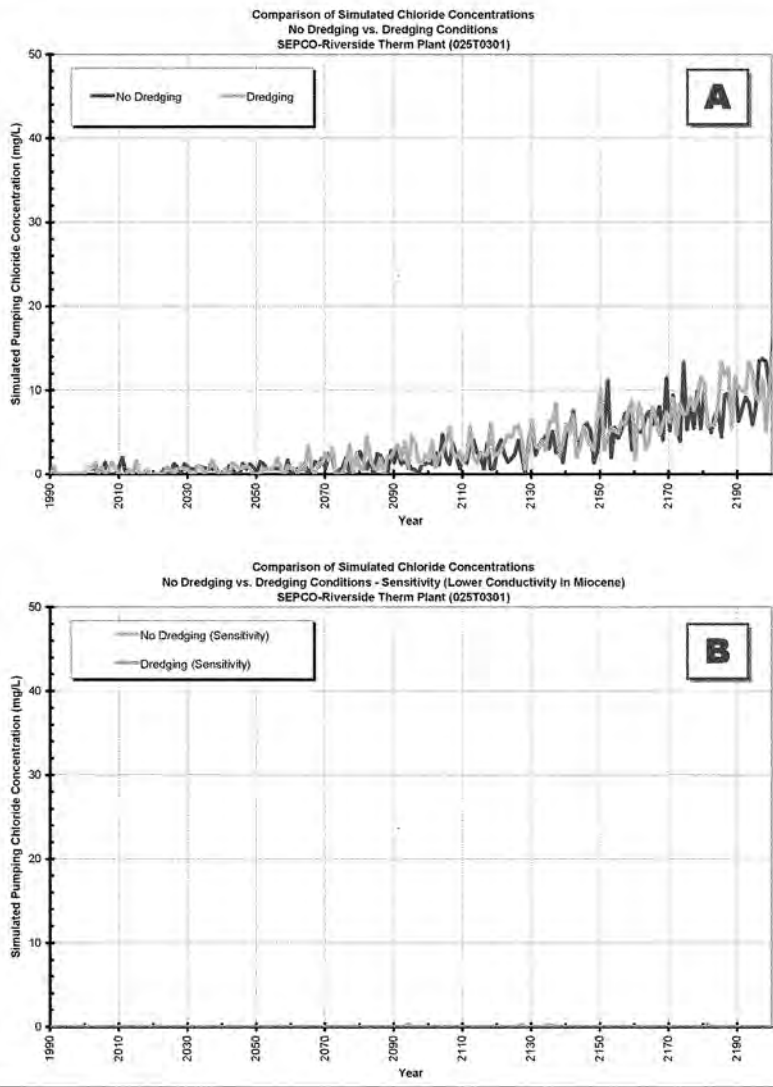


Figure 3-31
Pumping Well Concentrations for No Dredging and Dredging
At SEPCO-Riverside Therm. Plant (025T0301)

Savannah Harbor Expansion
Groundwater Model Studies



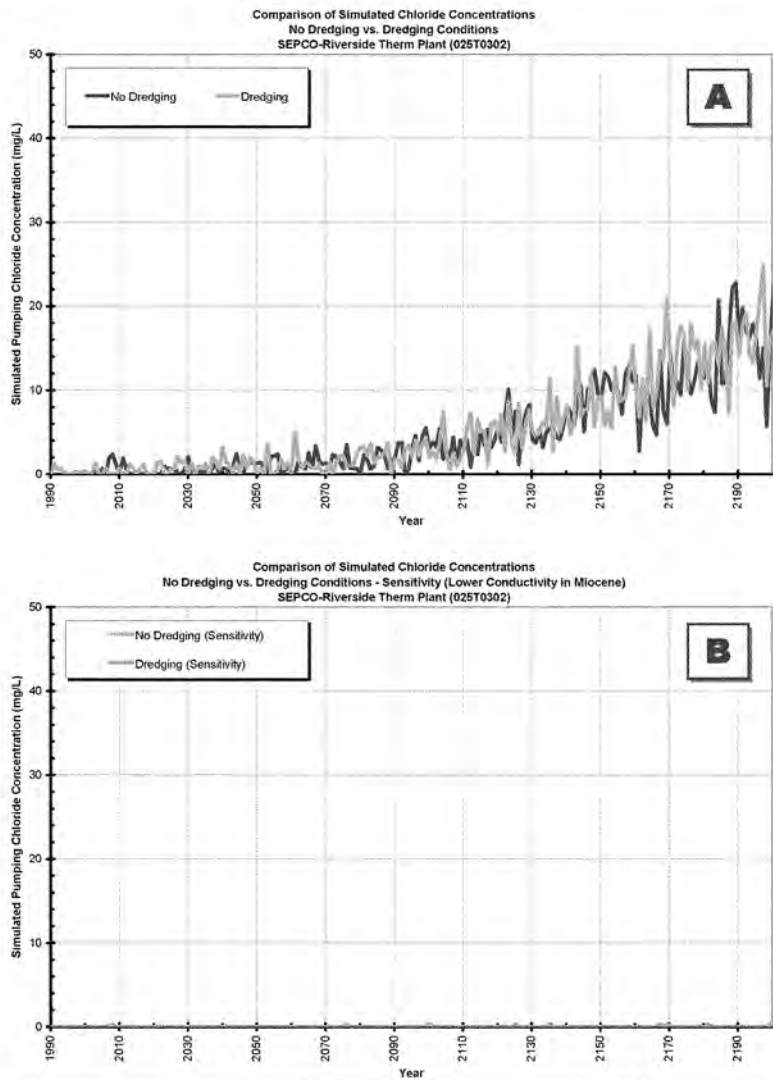


Figure 3-32
Pumping Well Concentrations for No Dredging and Dredging
At SEPCO-Riverside Therm. Plant (025T0302)

Savannah Harbor Expansion
Groundwater Model Studies

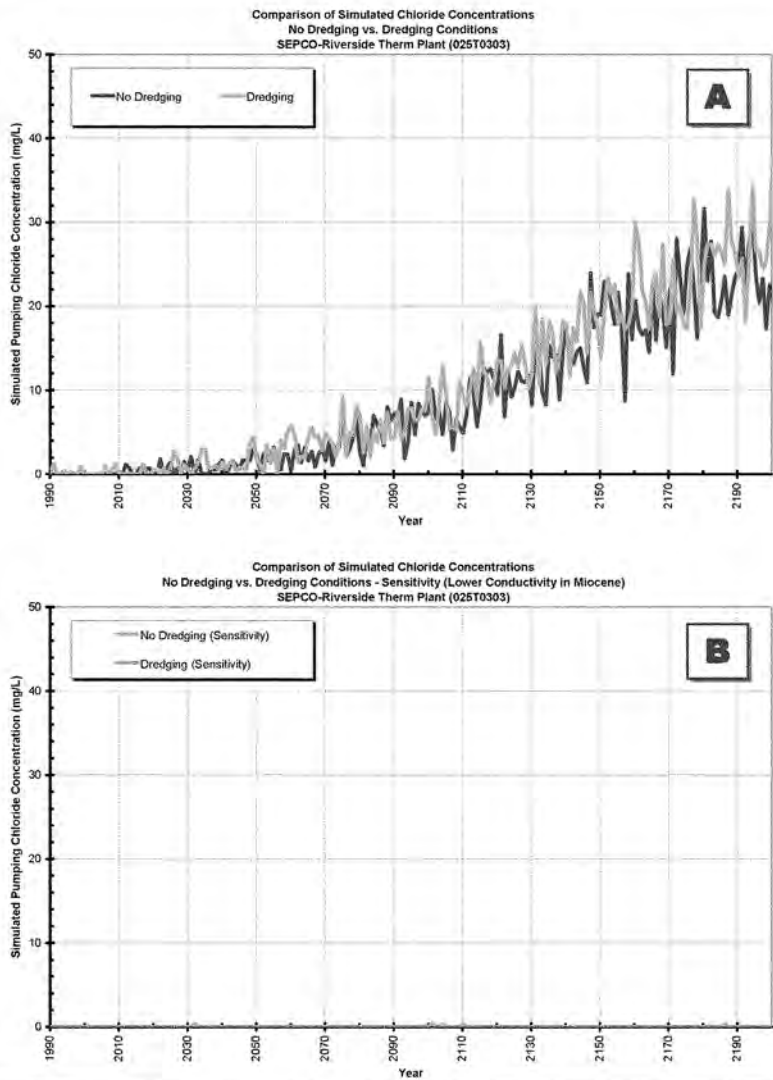


Figure 3-33
Pumping Well Concentrations for No Dredging and Dredging
At SEPCO-Riverside Therm. Plant (025T0303)

Savannah Harbor Expansion
Groundwater Model Studies

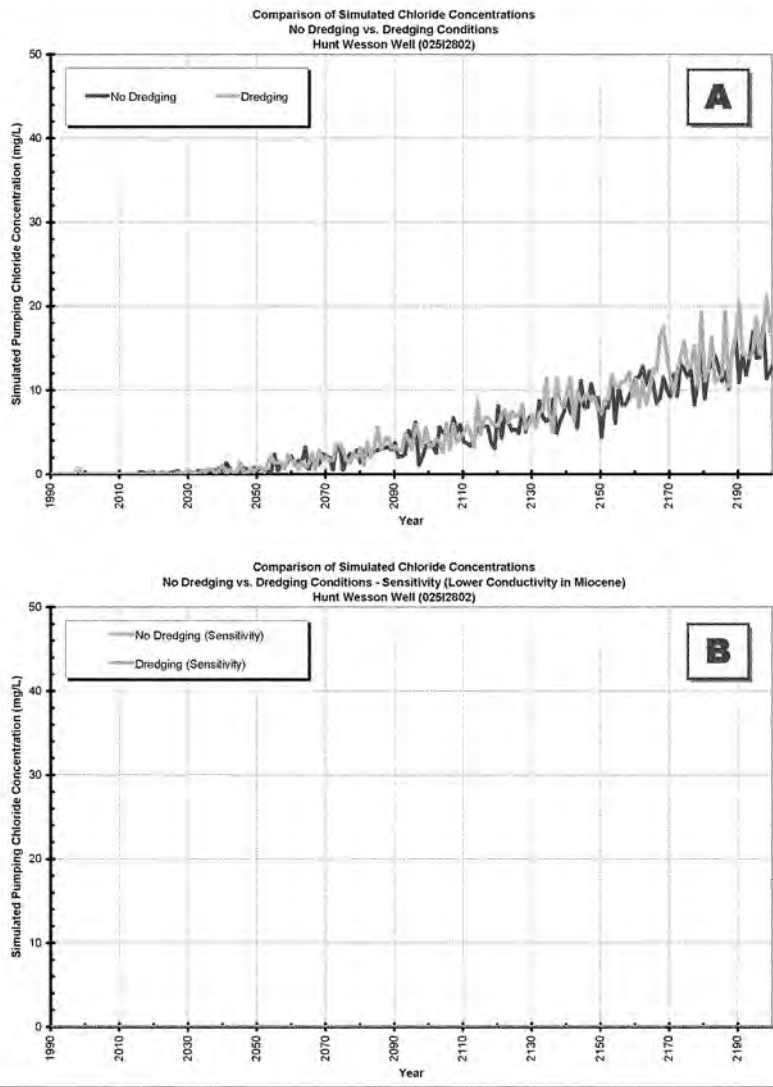


Figure 3-34
Pumping Well Concentrations for No Dredging and Dredging
At Hunt Wesson Well (028E2802)

Savannah Harbor Expansion
Groundwater Model Studies



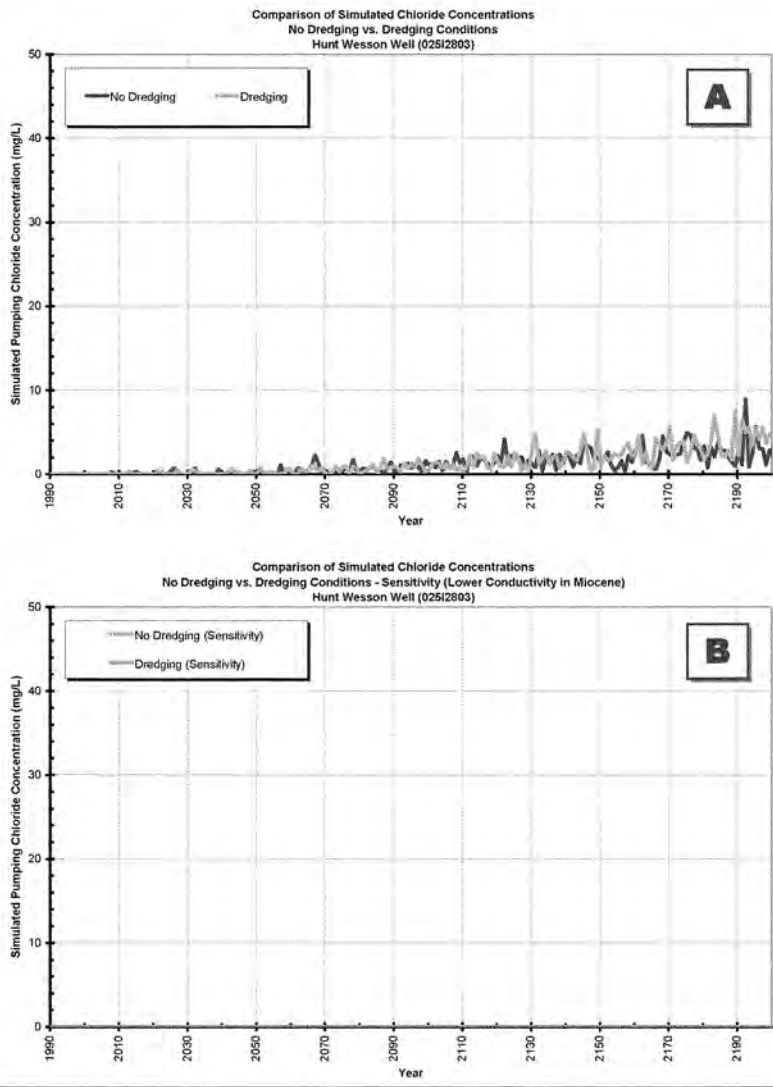


Figure 3-35
Pumping Well Concentrations for No Dredging and Dredging
At Hunt Wesson Harbor (02512803)

Savannah Harbor Expansion
Groundwater Model Studies

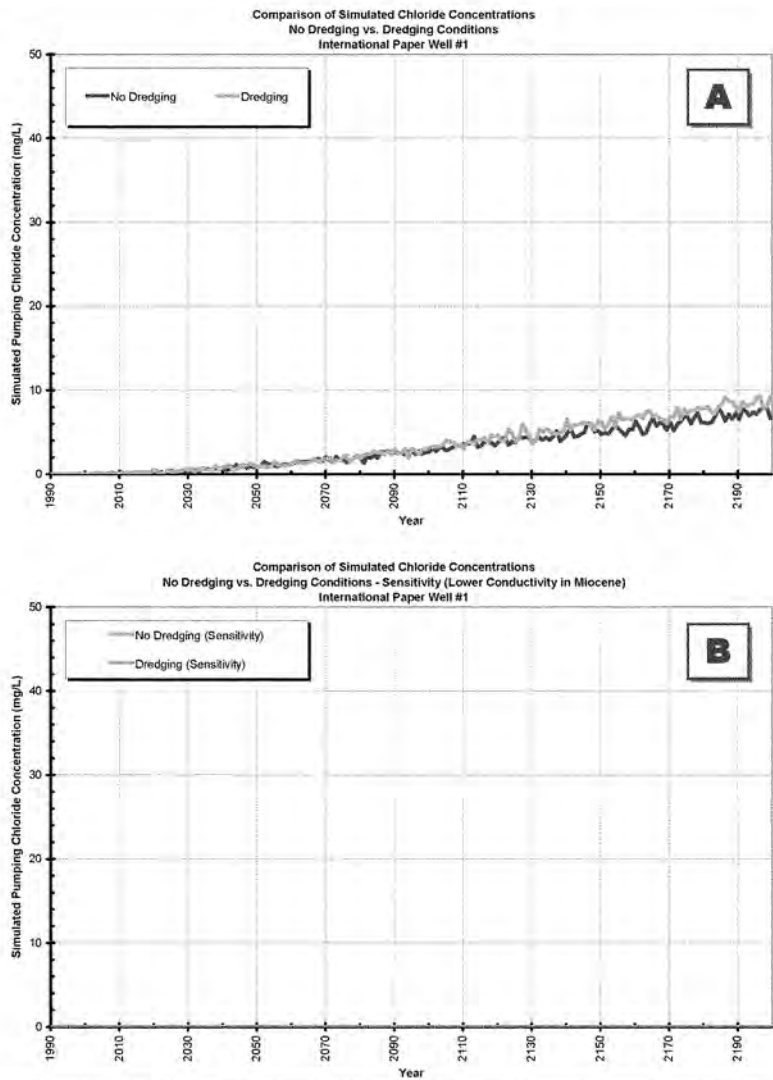


Figure 3-36
Pumping Well Concentrations for No Dredging and Dredging
At International Paper Well #1
Savannah Harbor Expansion
Groundwater Model Studies

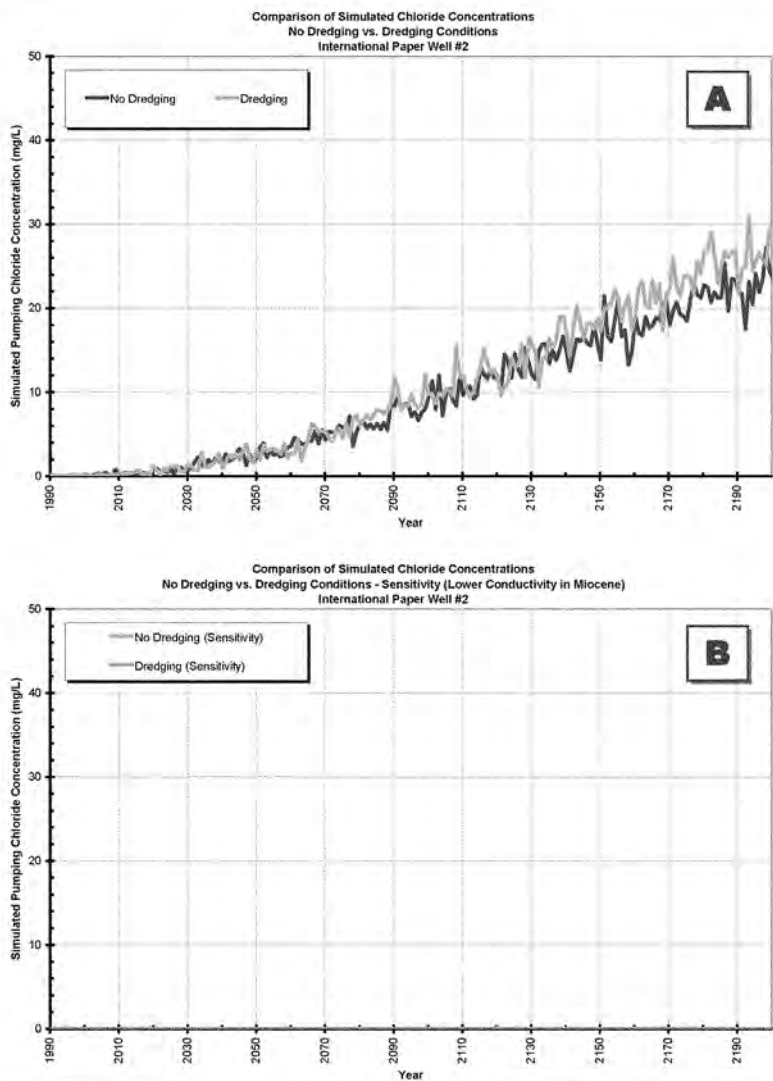


Figure 3-37
Pumping Well Concentrations for No Dredging and Dredging
At International Paper Well #2
Savannah Harbor Expansion
Groundwater Model Studies

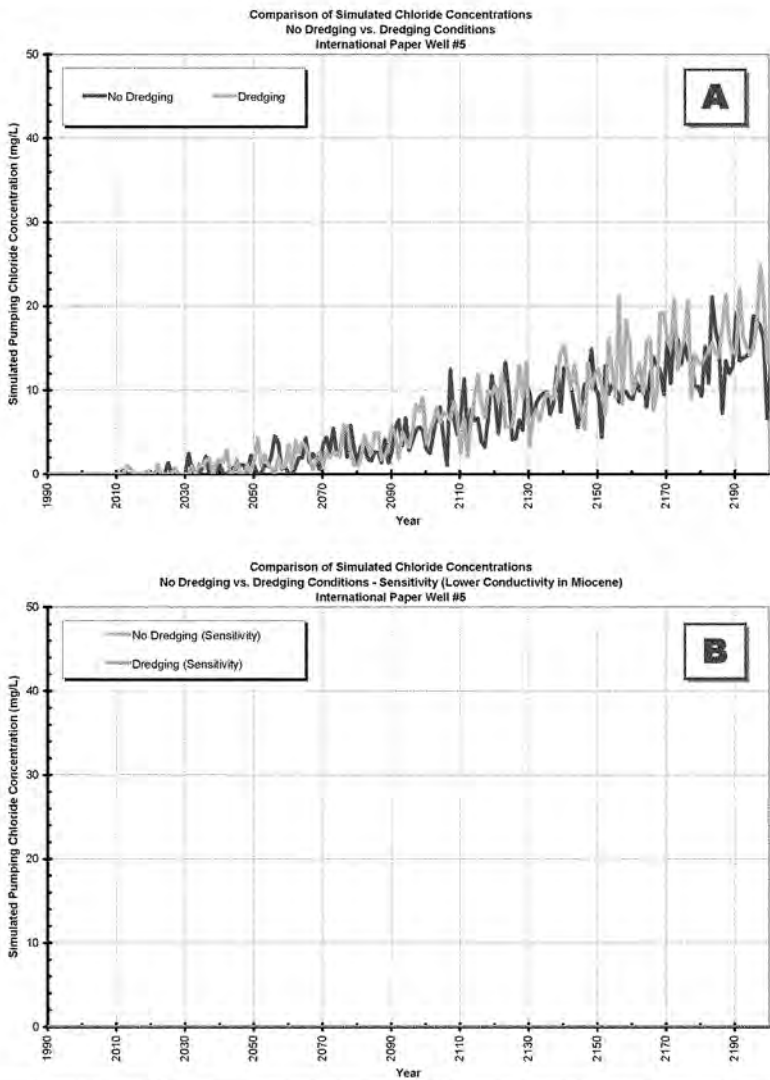


Figure 3-38
Pumping Well Concentrations for No Dredging and Dredging
At International Paper Well #5
Savannah Harbor Expansion
Groundwater Model Studies

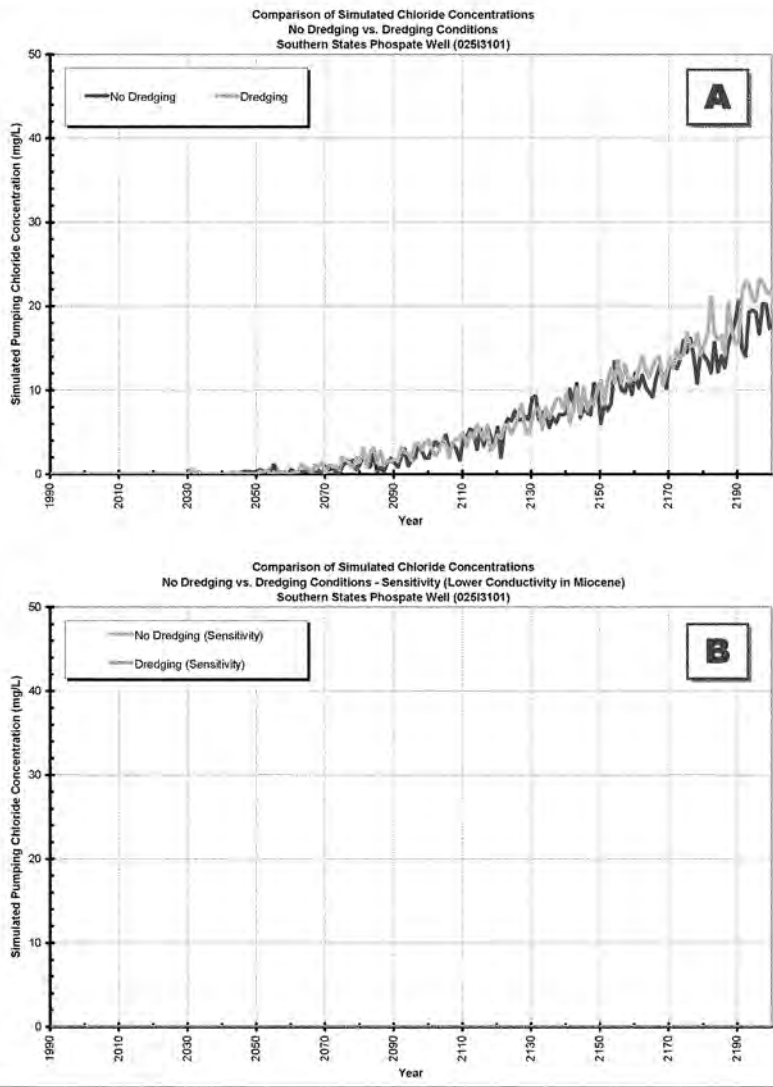


Figure 3-39
Pumping Well Concentrations for No Dredging and Dredging
At Southern States Phosphate Well (02513101)

Savannah Harbor Expansion
Groundwater Model Studies

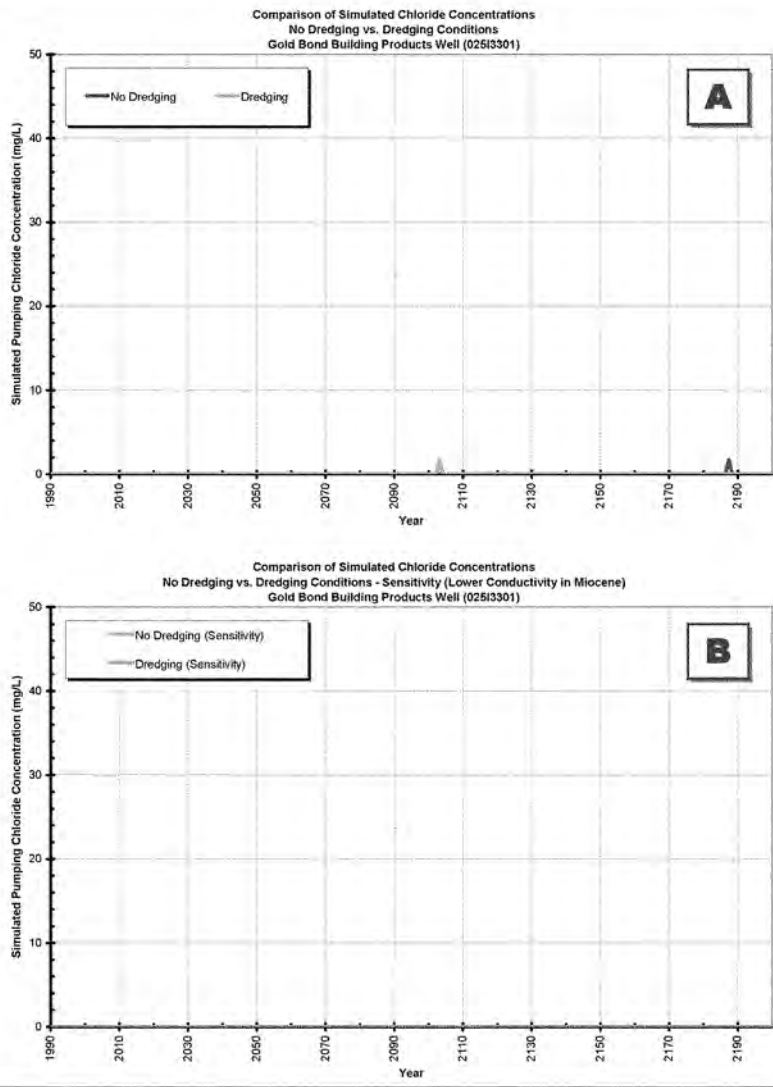


Figure 3-40
Pumping Well Concentrations for No Dredging and Dredging
At Gold Bond Building Products Well (025I3301)

Savannah Harbor Expansion
Groundwater Model Studies



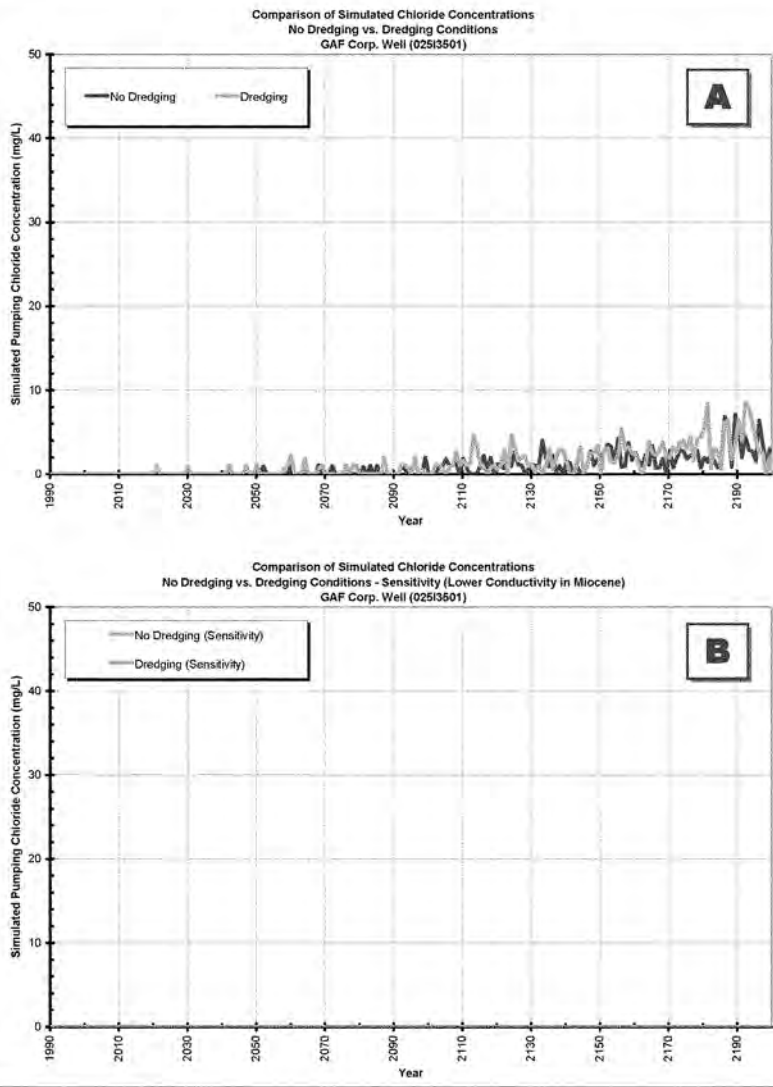


Figure 3-41
Pumping Well Concentrations for No Dredging and Dredging
At GAF Corp. Well (02513501)

Savannah Harbor Expansion
Groundwater Model Studies

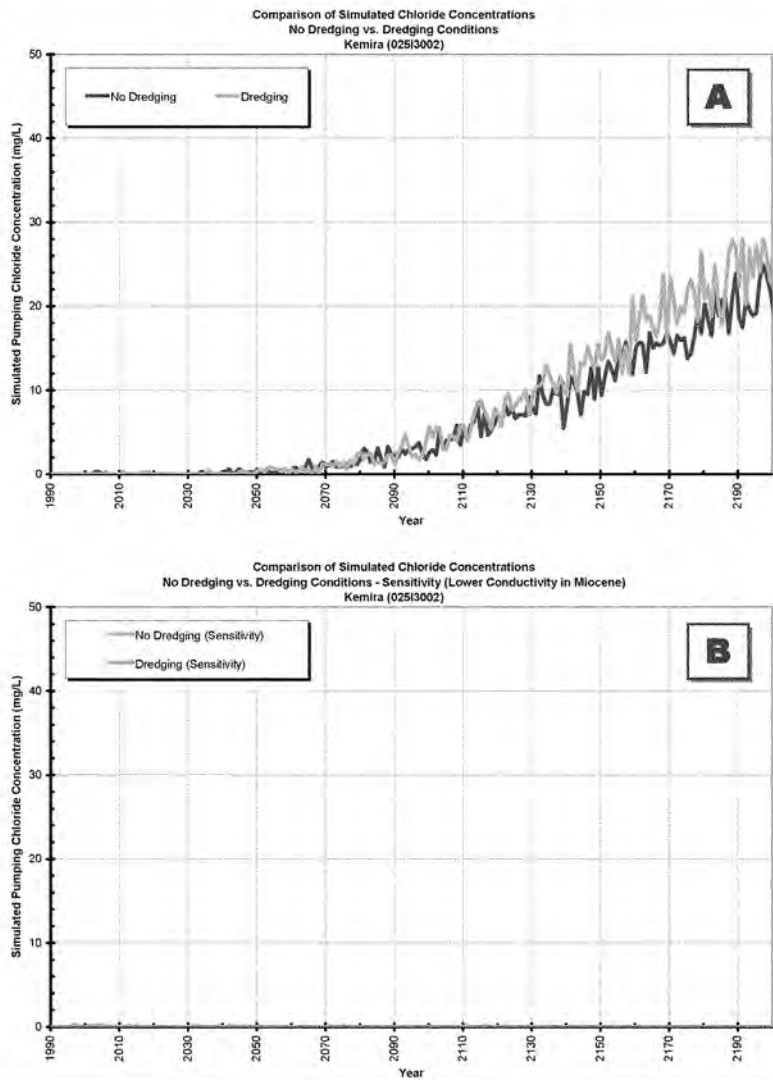


Figure 3-42
Pumping Well Concentrations for No Dredging and Dredging
At Kemira Well (025E3002)
Savannah Harbor Expansion
Groundwater Model Studies

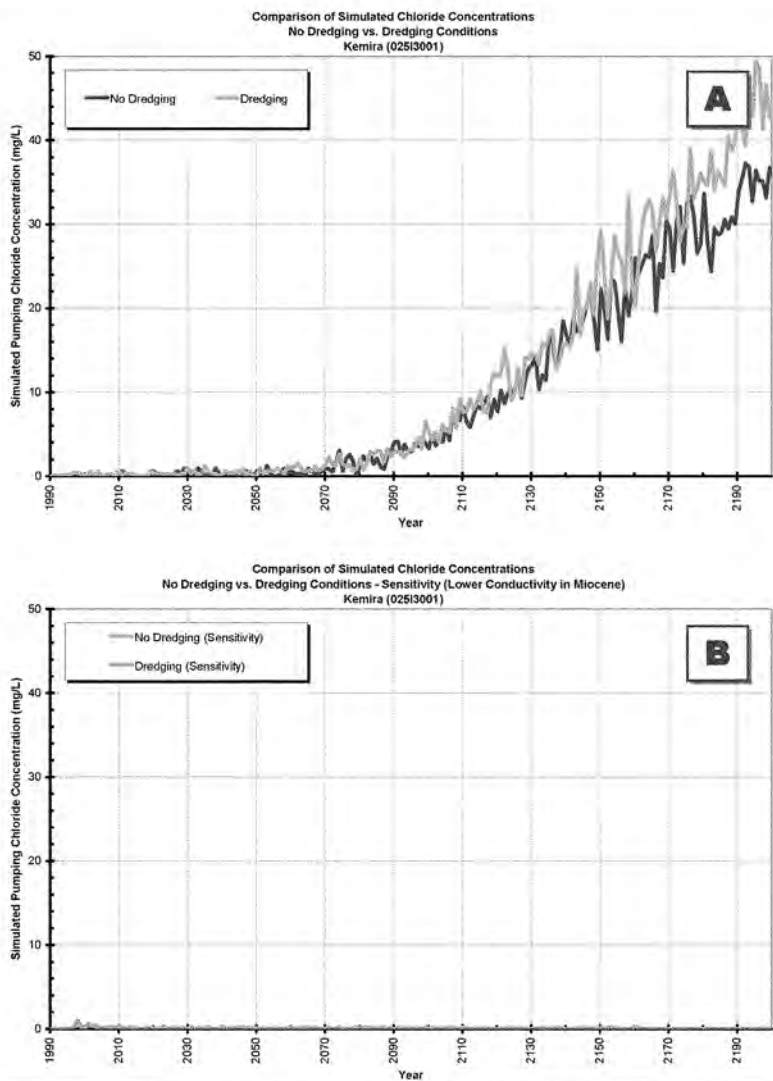


Figure 3-43
Pumping Well Concentrations for No Dredging and Dredging
At Kemira Well (02513001)

Savannah Harbor Expansion
Groundwater Model Studies

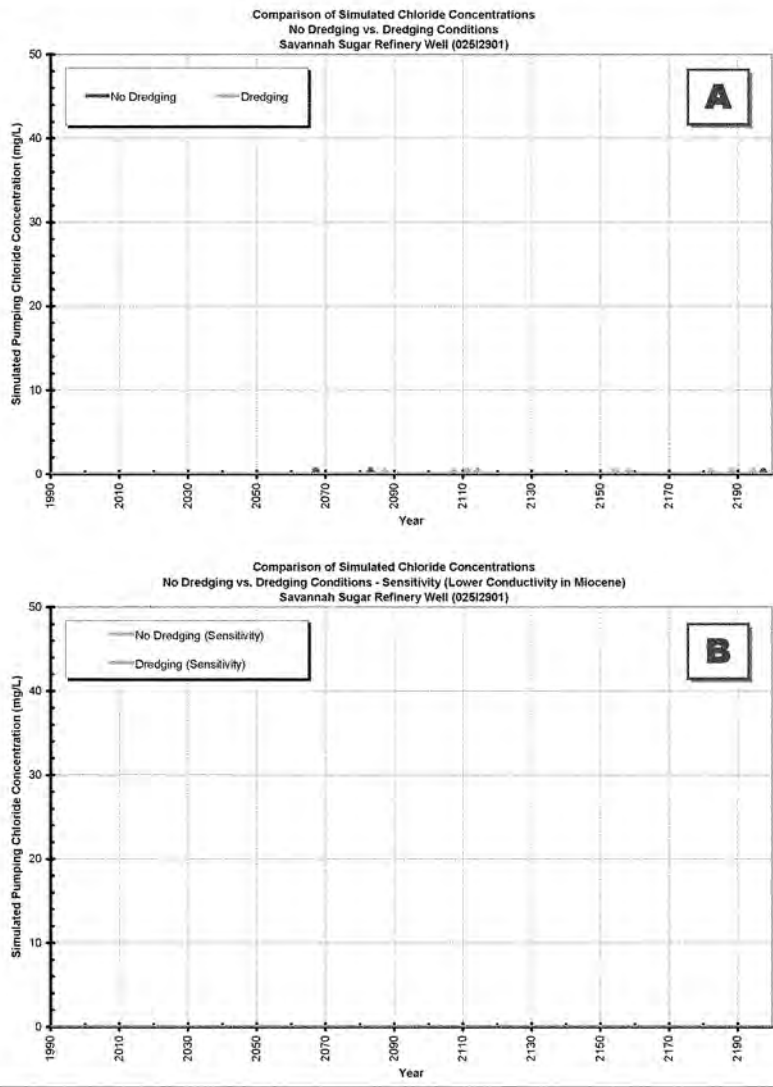


Figure 3-44
Pumping Well Concentrations for No Dredging and Dredging
At Savannah Sugar Refinery Well (025I2901)
Savannah Harbor Expansion
Groundwater Model Studies

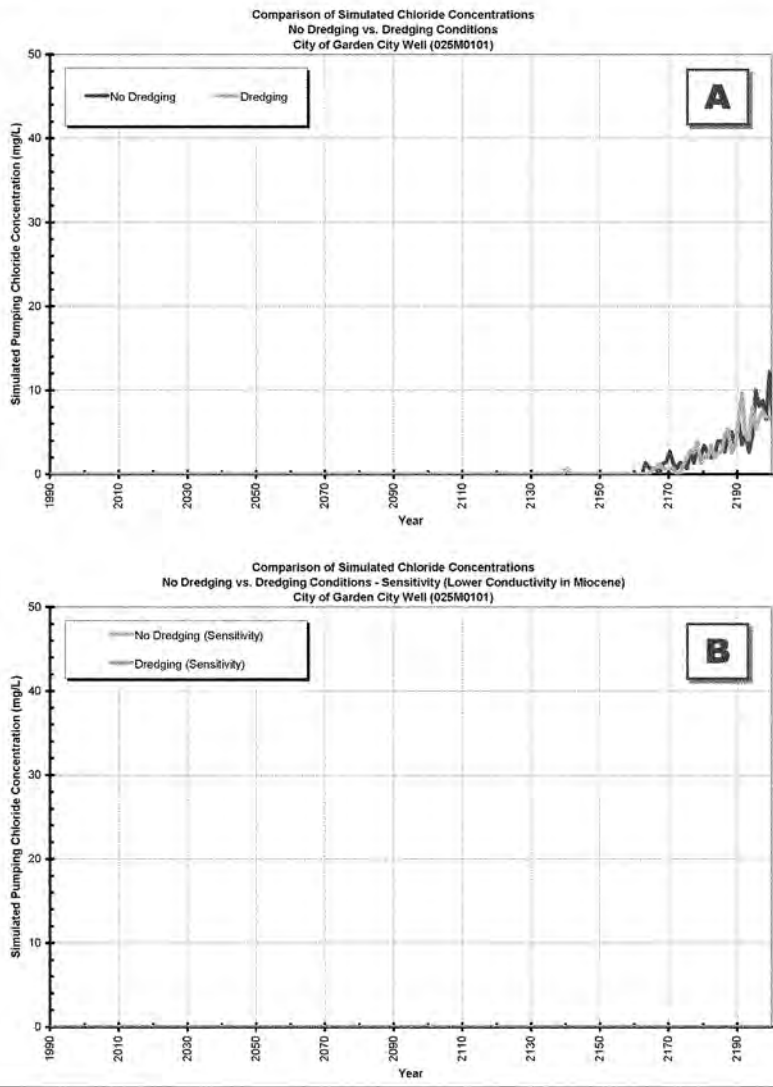


Figure 3-45
Pumping Well Concentrations for No Dredging and Dredging
At City of Garden City Well (025M0101)

Savannah Harbor Expansion
Groundwater Model Studies



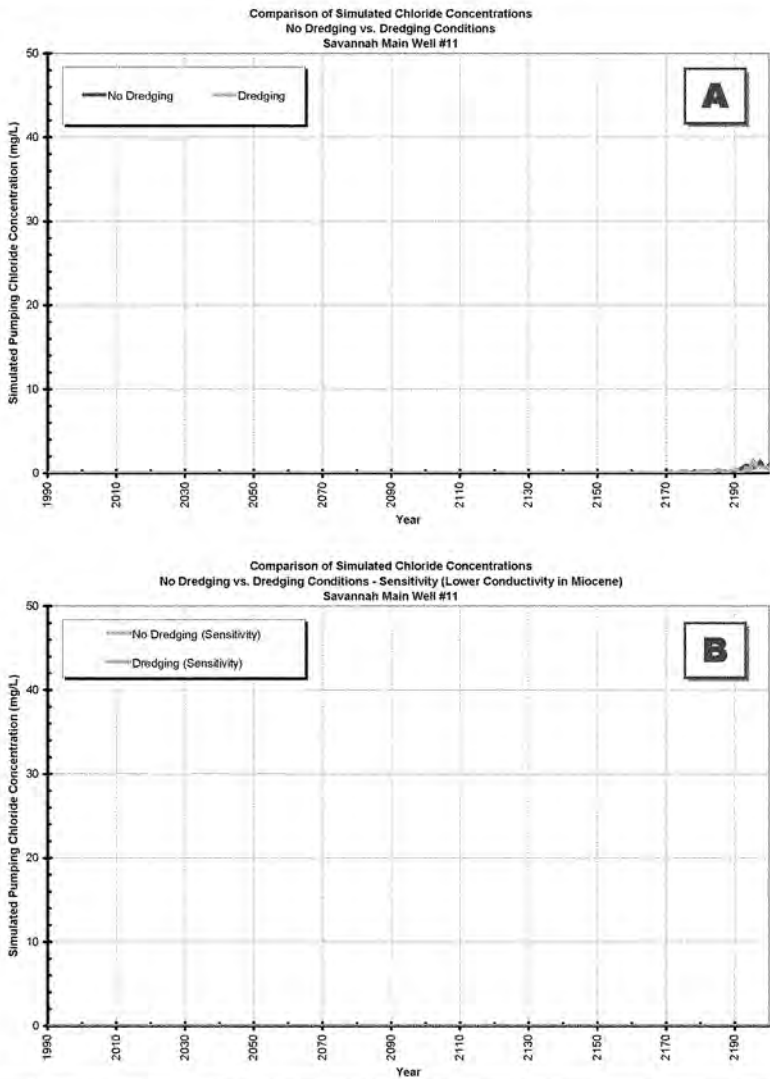


Figure 3-46
Pumping Well Concentrations for No Dredging and Dredging
At Savannah Main Well #11
Savannah Harbor Expansion
Groundwater Model Studies



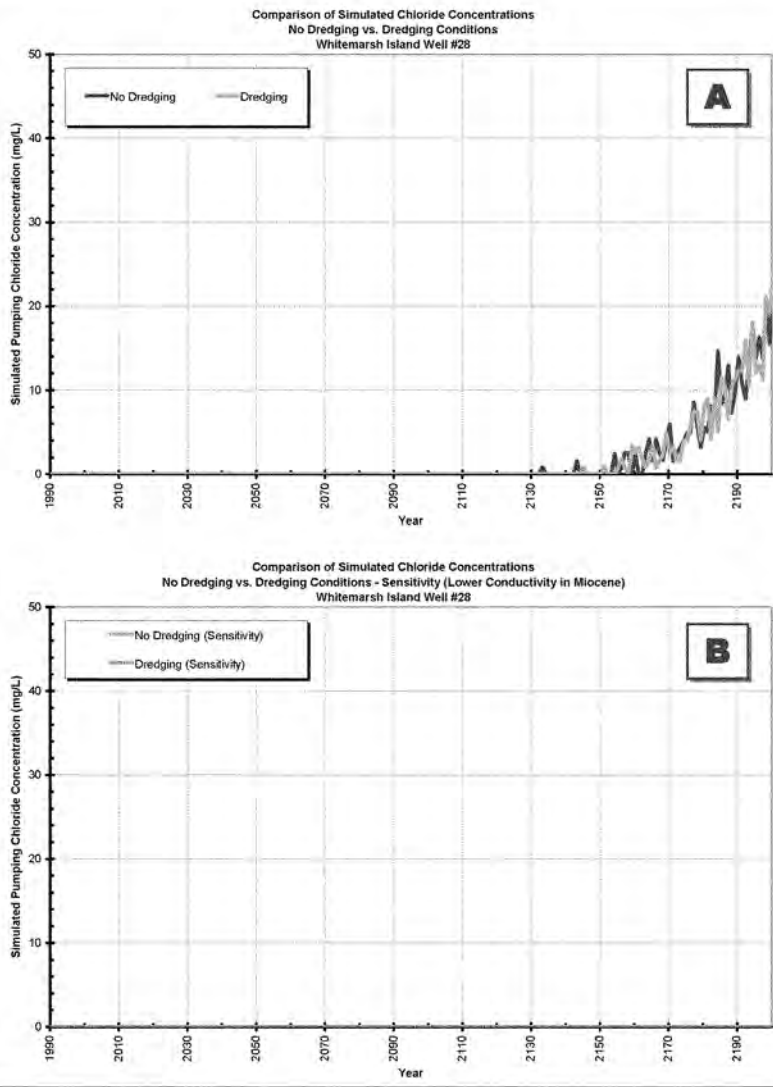


Figure 3-47
Pumping Well Concentrations for No Dredging and Dredging
At Whitemarsh Island Well #28

Savannah Harbor Expansion
Groundwater Model Studies

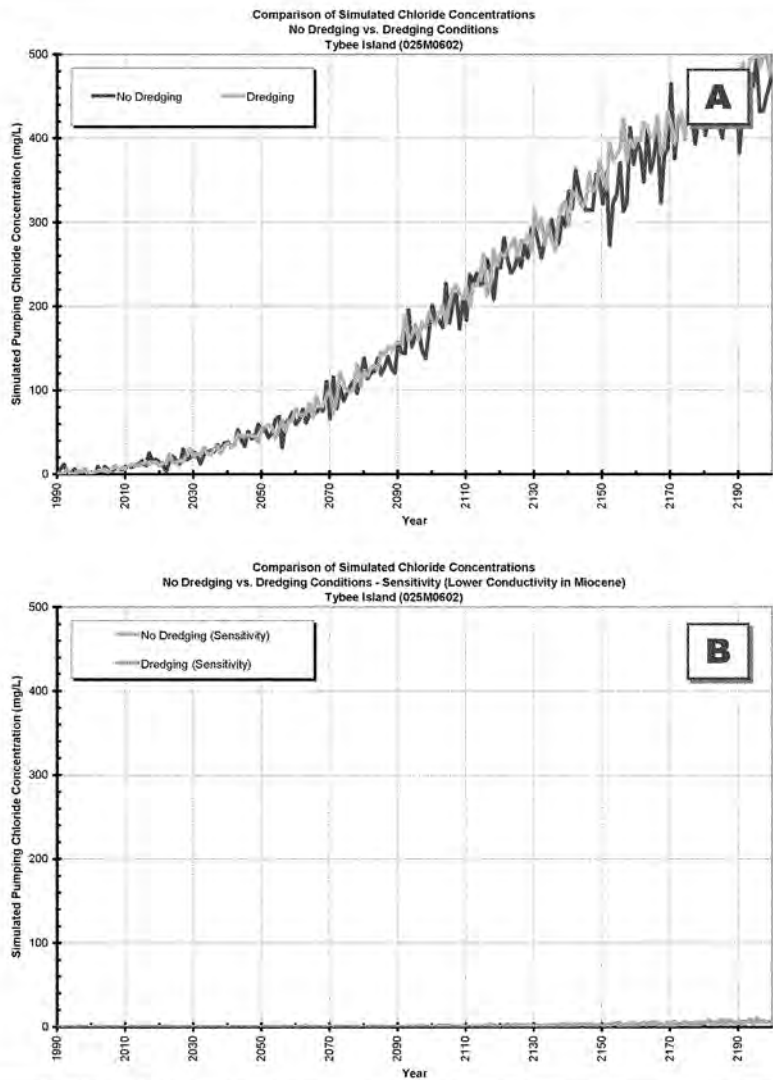


Figure 3-48
Pumping Well Concentrations for No Dredging and Dredging
At Tybee Island (025M0602)
Savannah Harbor Expansion
Groundwater Model Studies

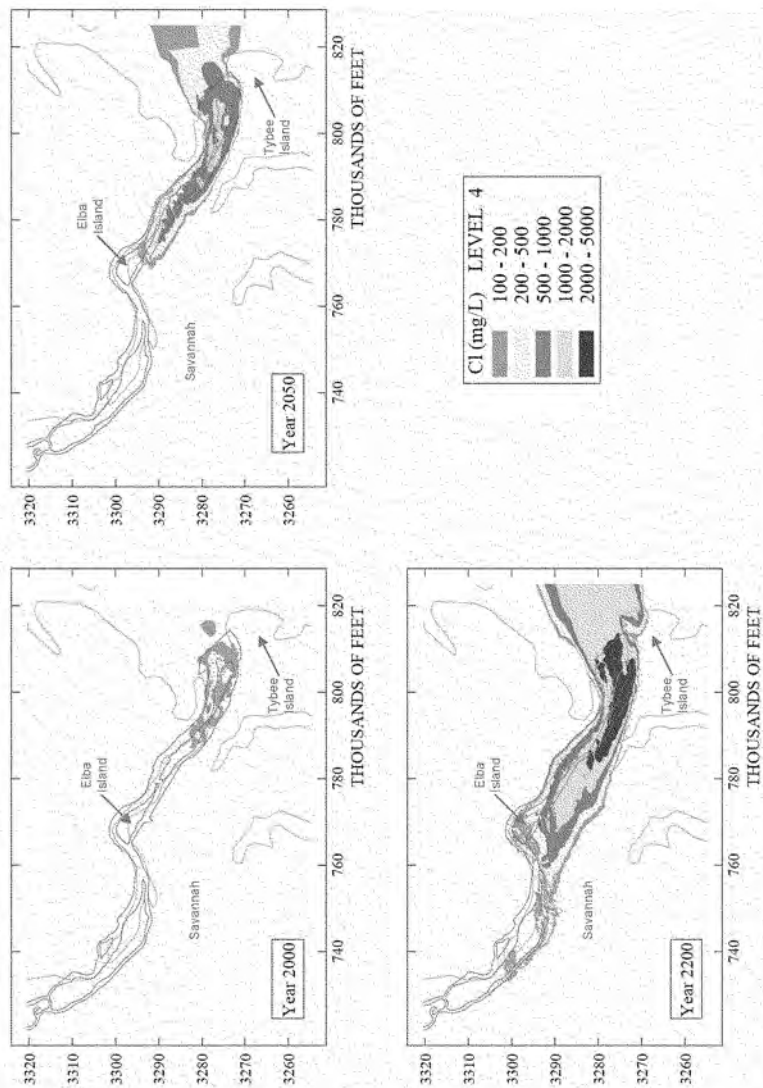


Figure 3-49
Plan View of Concentrations in the Upper Floridan – Year (2000, 2050 and 2200) No Dredging

Savannah Harbor Expansion
Groundwater Model Studies

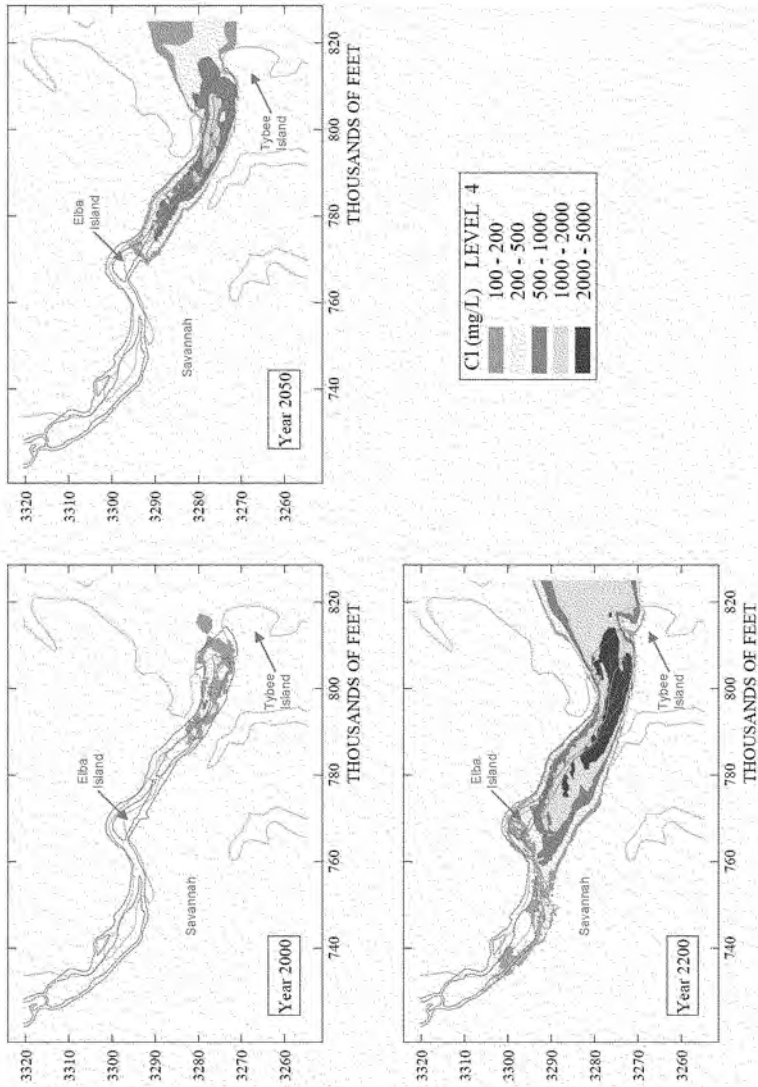


Figure 3-50
Plan View of Concentrations in the Upper Floridan – Year (2000, 2050 and 2200) Dredging

Savannah Harbor Expansion
Groundwater Model Studies

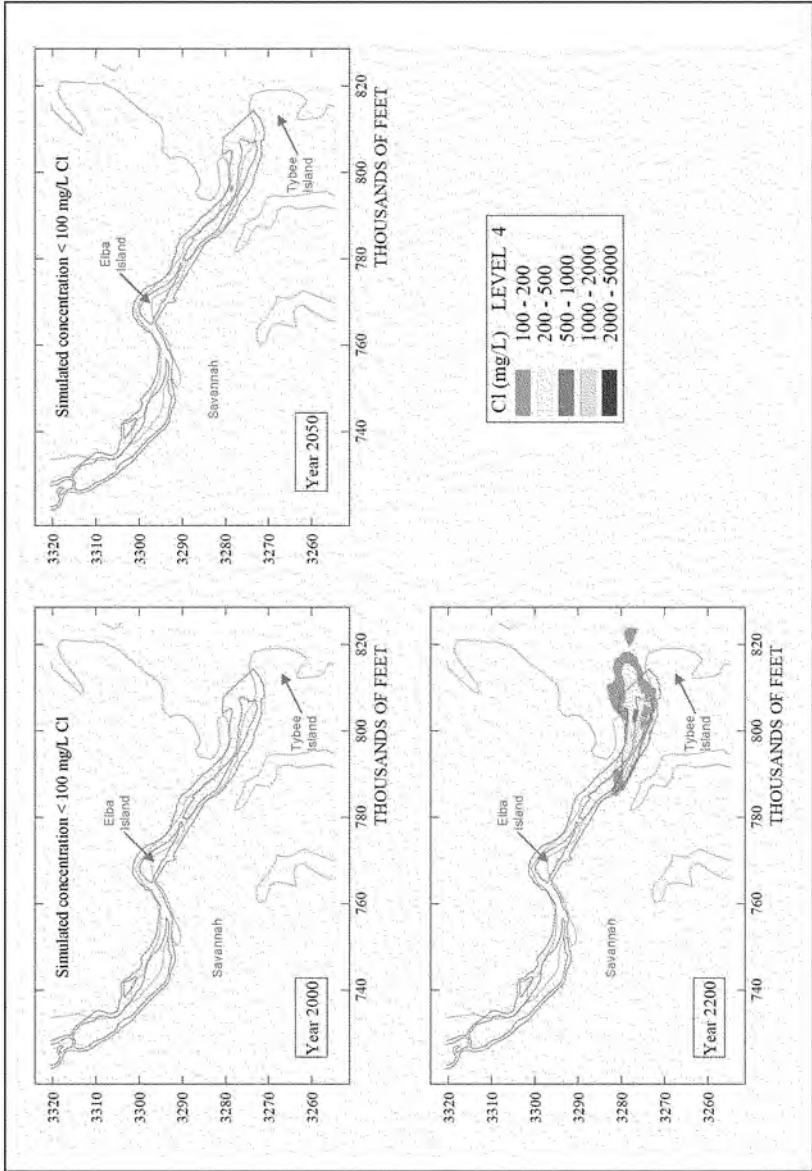


Figure 3-51
Plan View of Concentrations in the Upper Floridan – Year (2000, 2050 and 2200) No Dredging
Sensitivity Simulation – Lower Conductivity in Miocene
Savannah Harbor Expansion
Groundwater Model Studies

Savannah Harbor Expansion Groundwater Modeling Studies Aquifer Performance Test Simulations

CDM conducted several simulations to evaluate the potential response in the Surficial Aquifer and Miocene Confining Unit to a long-term pumping test conducted with a well screened in the Upper Floridan Aquifer.

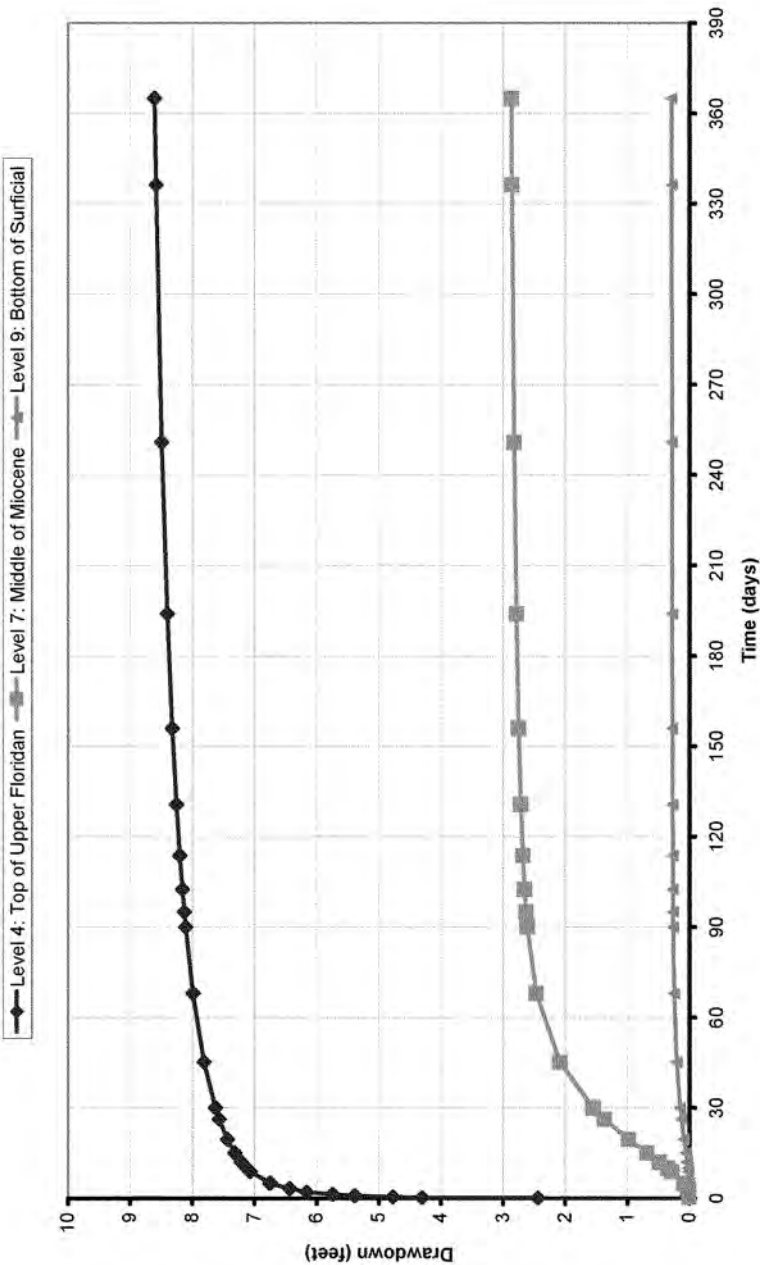
The pumping well used in the simulation was located on Tybee Island at the approximately location of the Tybee Island Test Well Cluster. Three different pumping rates (500, 1000 and 2000 gpm) were evaluated, and the simulations were run for a period of 1 year. The simulated response in observations wells at distances of 750, 1100 and 2400 feet was recorded.

At the lowest pumping rate simulated (500 gpm) the simulated drawdown in the Surficial Aquifer at the pumping well location was less than 0.5 feet after 1 year of pumping. At the observation point located 1100 feet from the pumping well the simulated response in the Surficial Aquifer was less than 0.25 feet, and in the Miocene Confining Unit the simulated response was less than 2 feet. At the observation point located 2400 feet away practically no response in the Surficial Aquifer or Miocene Confining Unit was noted.

At the highest pumping rate simulated (2000 gpm) the simulated drawdown at the pumping well location in the Surficial Aquifer was approximately 1 foot, and approximately 12 feet in the Miocene Confining Unit. At the observation point located 1100 feet from the pumping well the simulated drawdown in the Surficial Aquifer and Miocene Confining Unit was approximately 0.6 and 6 feet respectively.

Response time in the Surficial Aquifer and Miocene Confining Unit was relatively slow, with heads gradually decreasing over a period of 30 to 60 days. The slow response time and expected drawdowns of only a few inches would make it difficult to perform a pump test. The test would have to be at least two months in duration, and pump at least 1000 gpm over this period of time to develop sufficient data with which to assess the vertical hydraulic conductivity of the Miocene units.

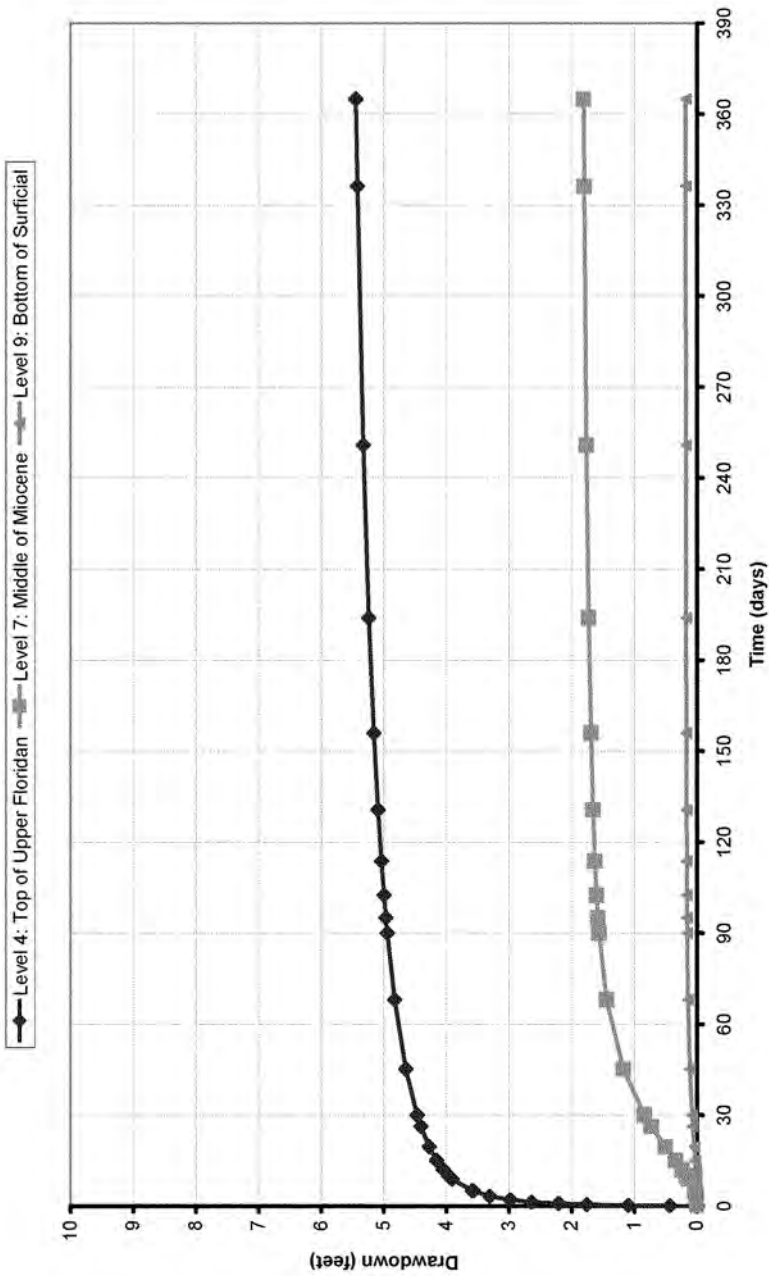
Pump Test Simulation 1 - Simulated Piezometric Head at Pumping Well
Pumping Rate = 500 GPM



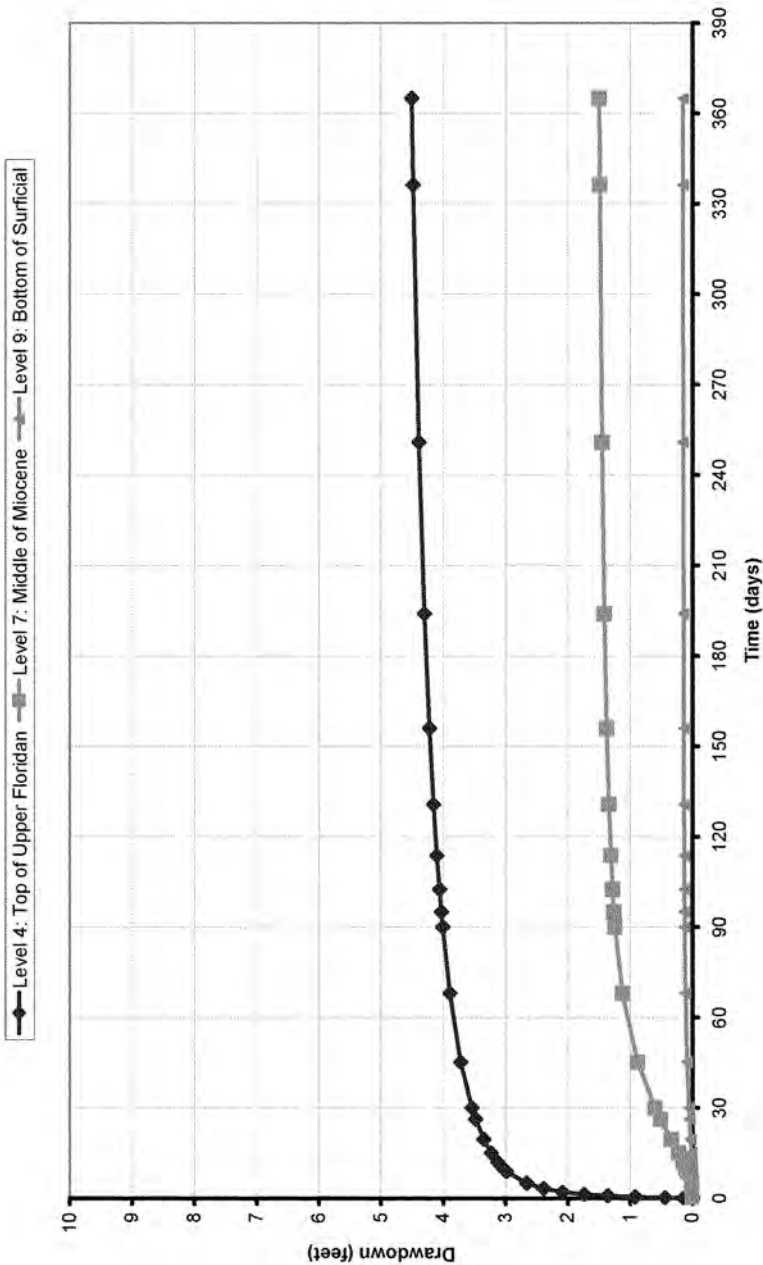
CDM

PTTEST_1_new.xls-PW
3/5/2005

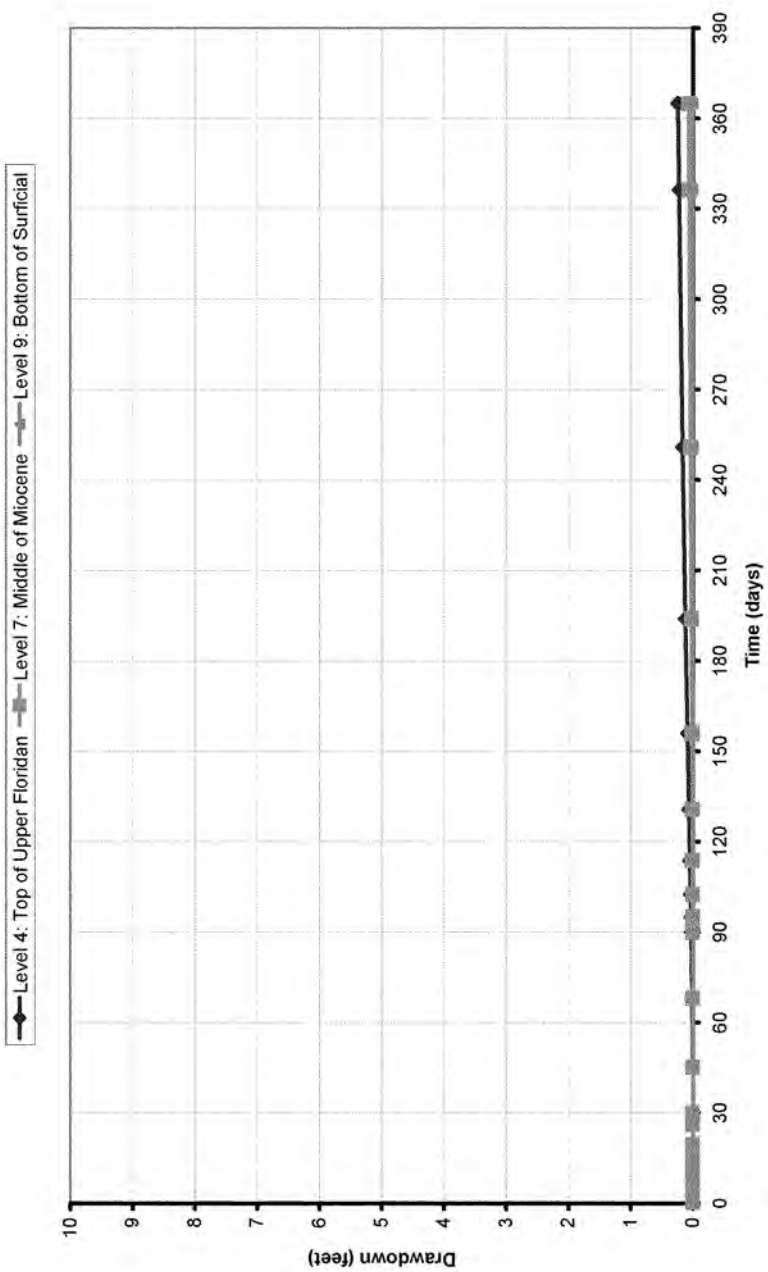
Pump Test Simulation 1 -Simulated Piezometric Head at Observation Well 1
Pumping Rate = 500 GPM. Observation Well Approximately 750 feet from Pumping Well



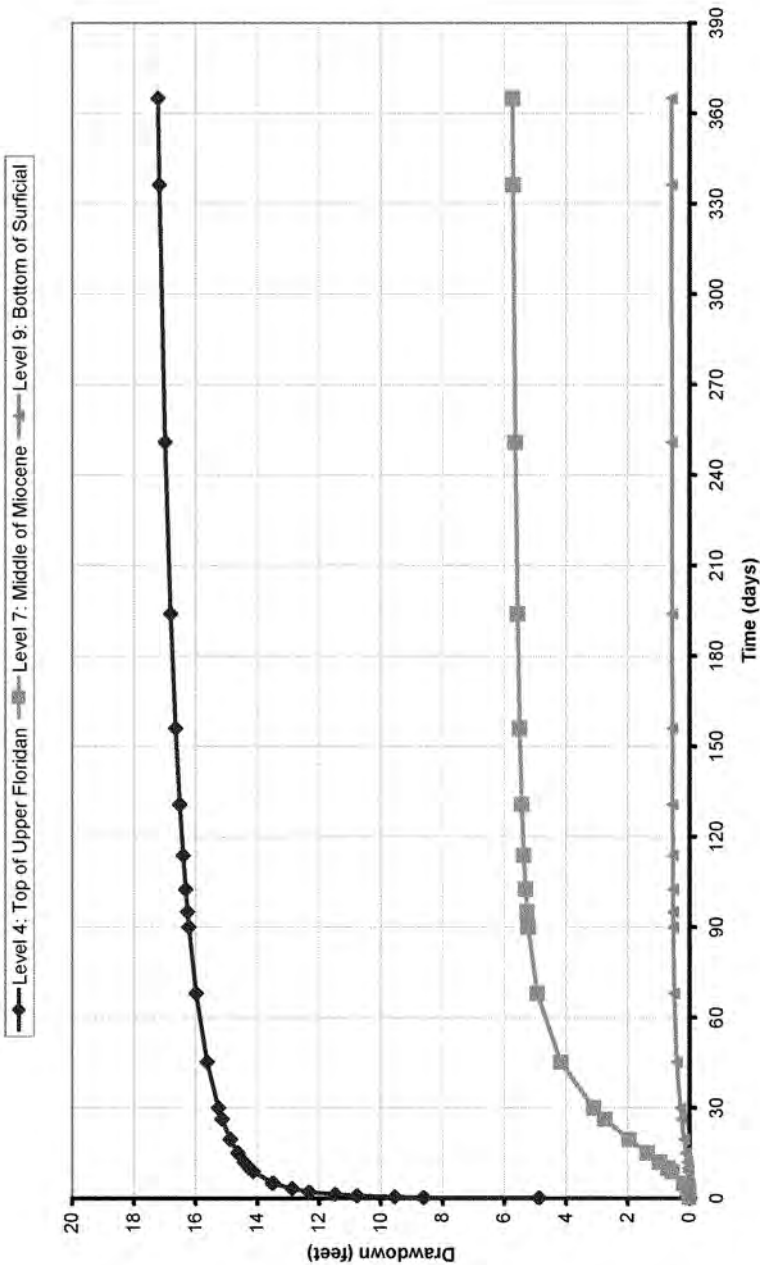
Pump Test Simulation 1 - Simulated Piezometric Head at Observation Well 2
Pumping Rate = 500 GPM. Observation Well Approximately 1100 feet from Pumping Well



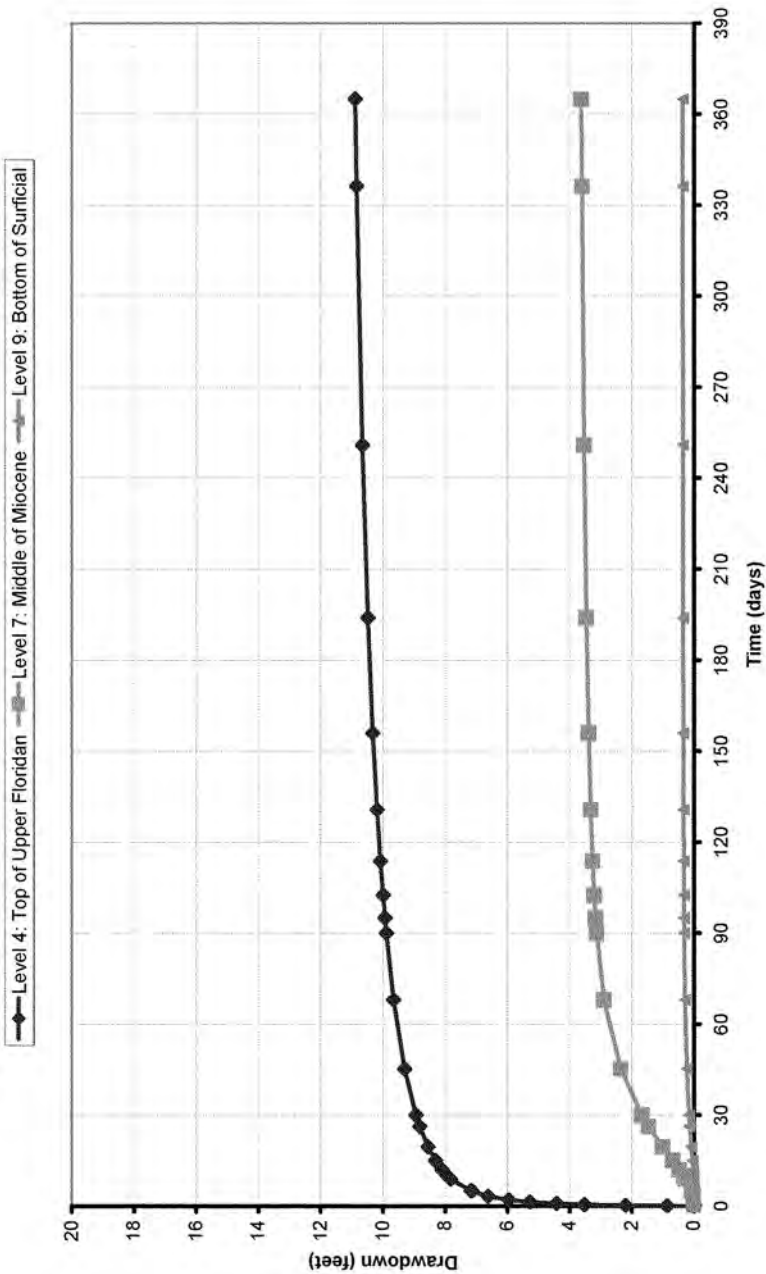
Pump Test Simulation 1 -Simulated Piezometric Head at Observation Well 3
Pumping Rate = 500 GPM. Observation Well Approximately 2400 feet from Pumping Well



Pump Test Simulation 2 - Simulated Piezometric Head at Pumping Well
Pumping Rate = 1000 GPM

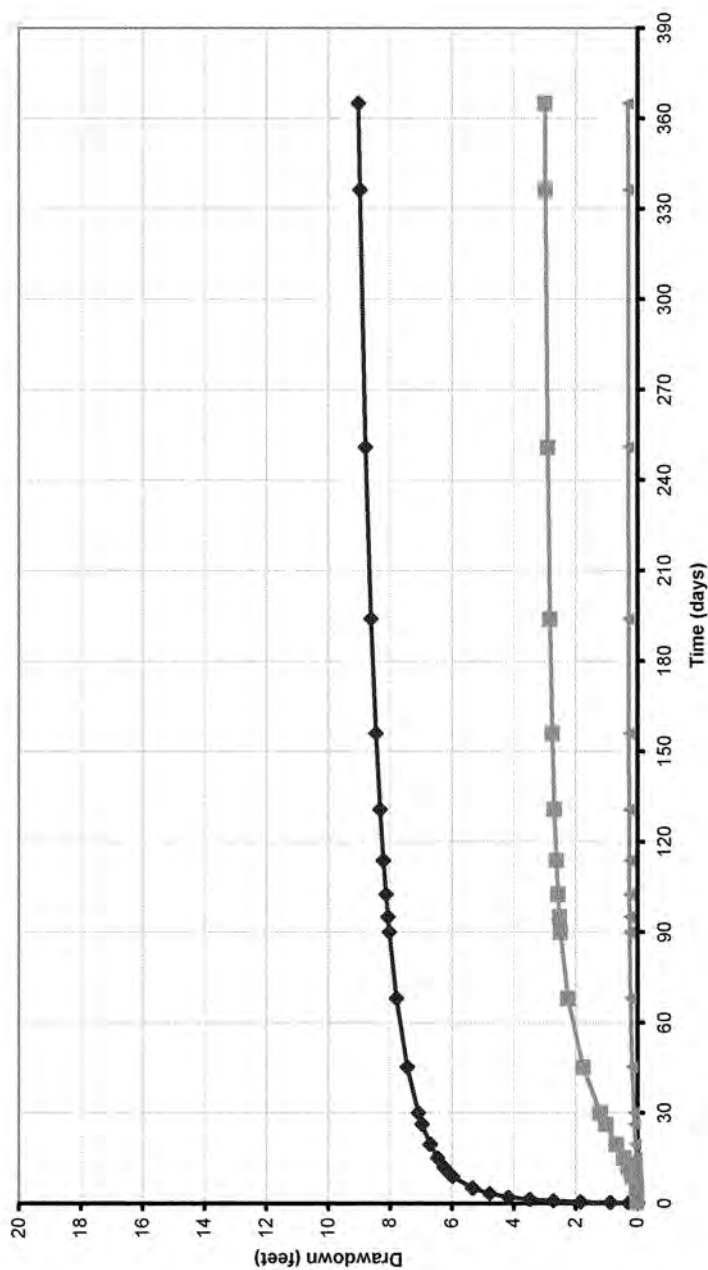


Pump Test Simulation 2 -Simulated Piezometric Head at Observation Well 1
Pumping Rate = 1000 GPM. Observation Well Approximately 750 feet from Pumping Well

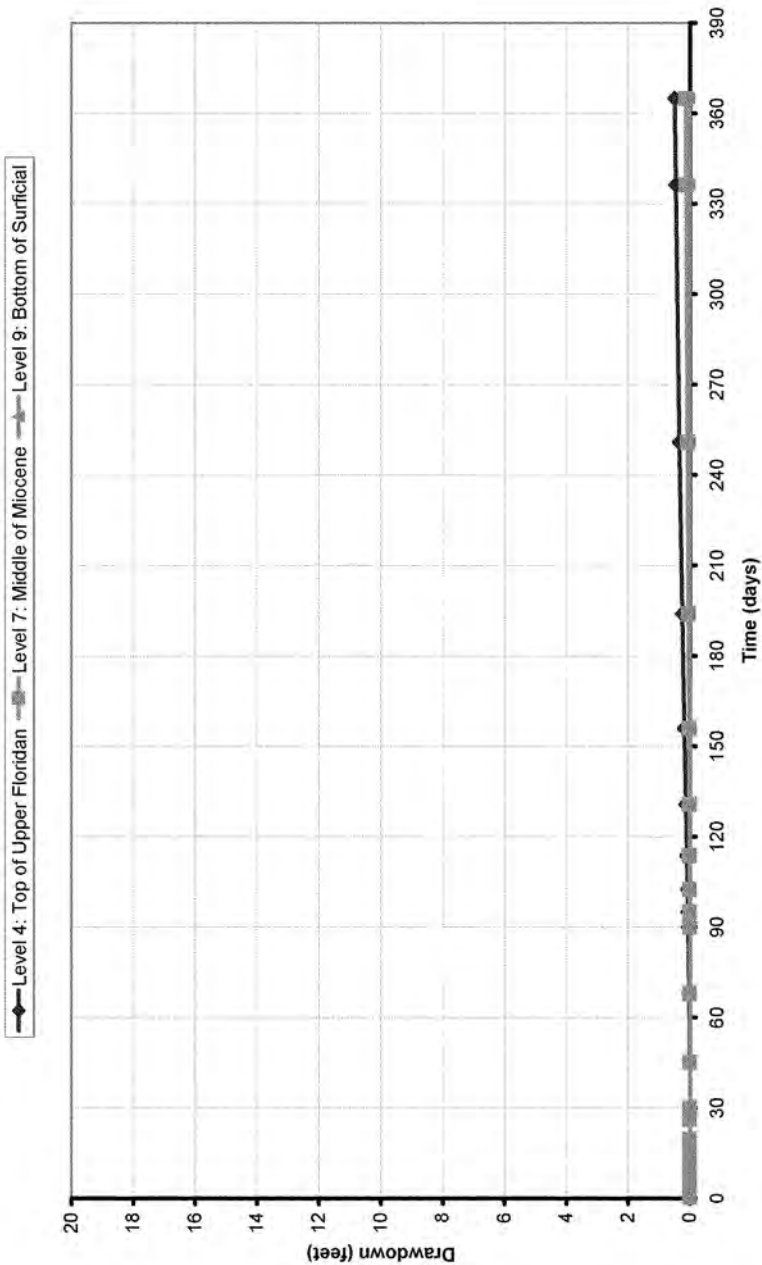


Pump Test Simulation 2 - Simulated Piezometric Head at Observation Well 2
Pumping Rate = 1000 GPM. Observation Well Approximately 1100 feet from Pumping Well

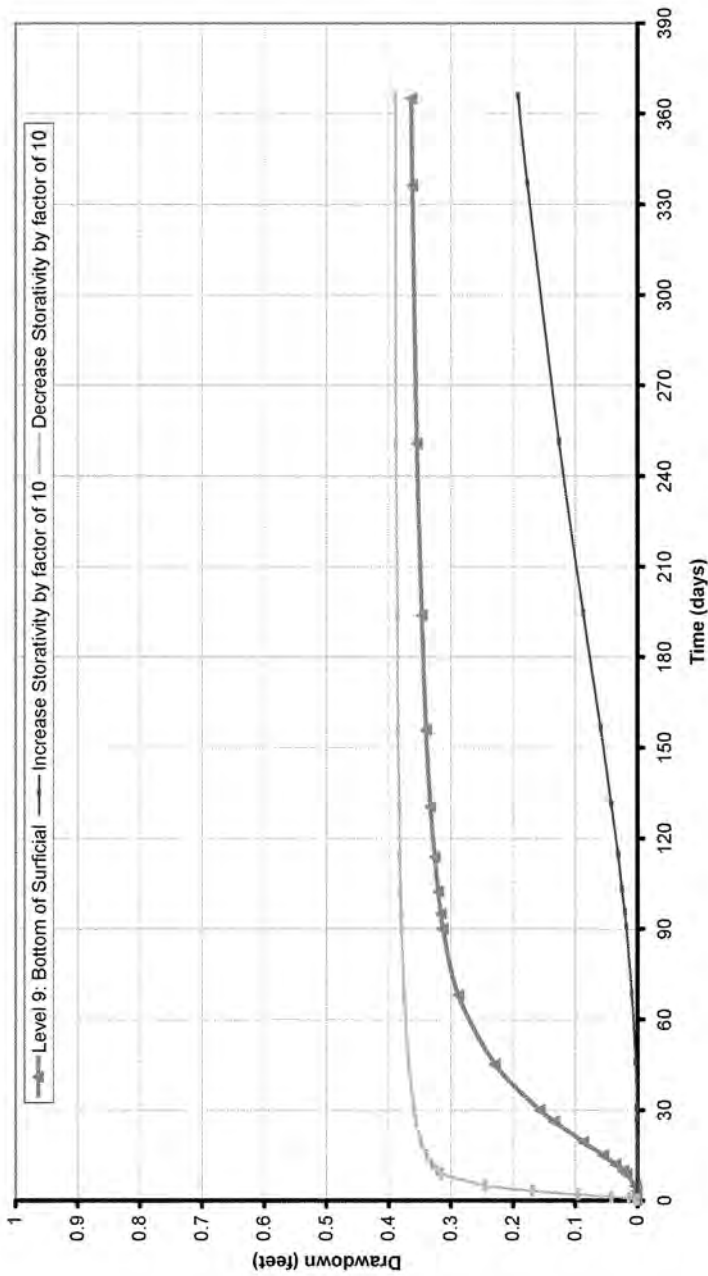
◆ Level 4: Top of Upper Floridan ■ Level 7: Middle of Miocene ▲ Level 9: Bottom of Surficial



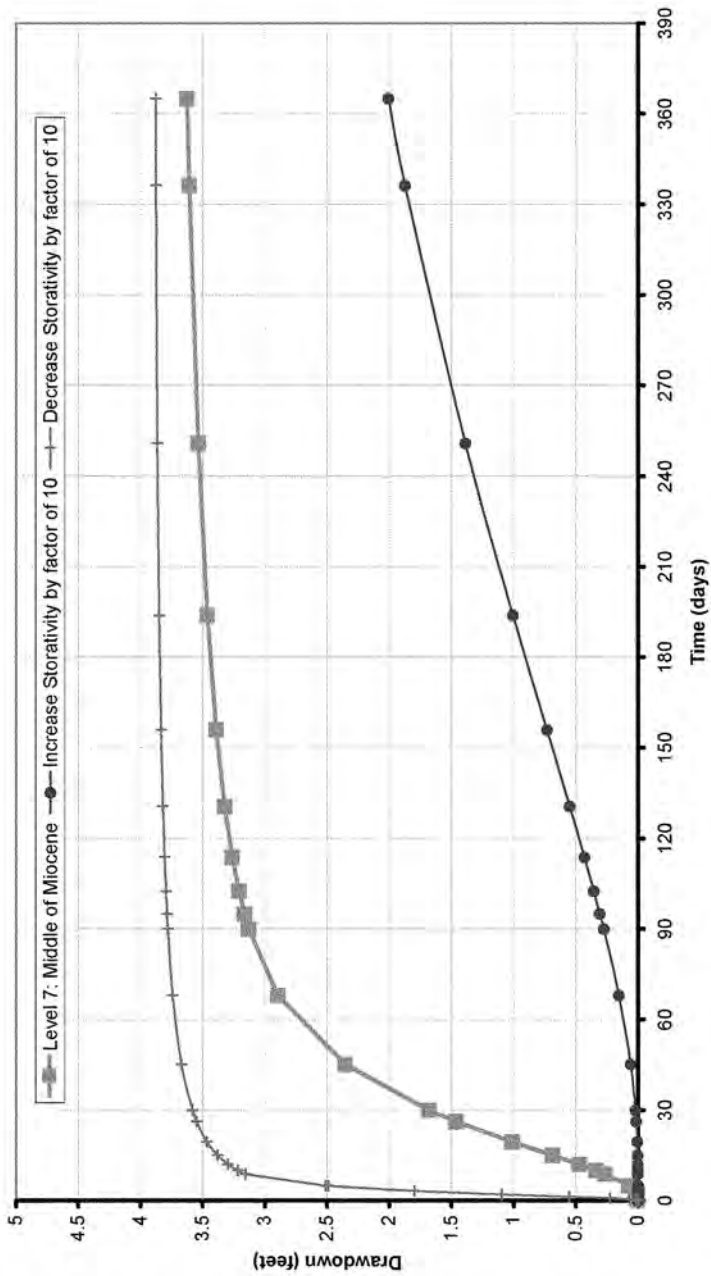
Pump Test Simulation 2 -Simulated Piezometric Head at Observation Well 3
Pumping Rate = 1000 GPM. Observation Well Approximately 2400 feet from Pumping Well



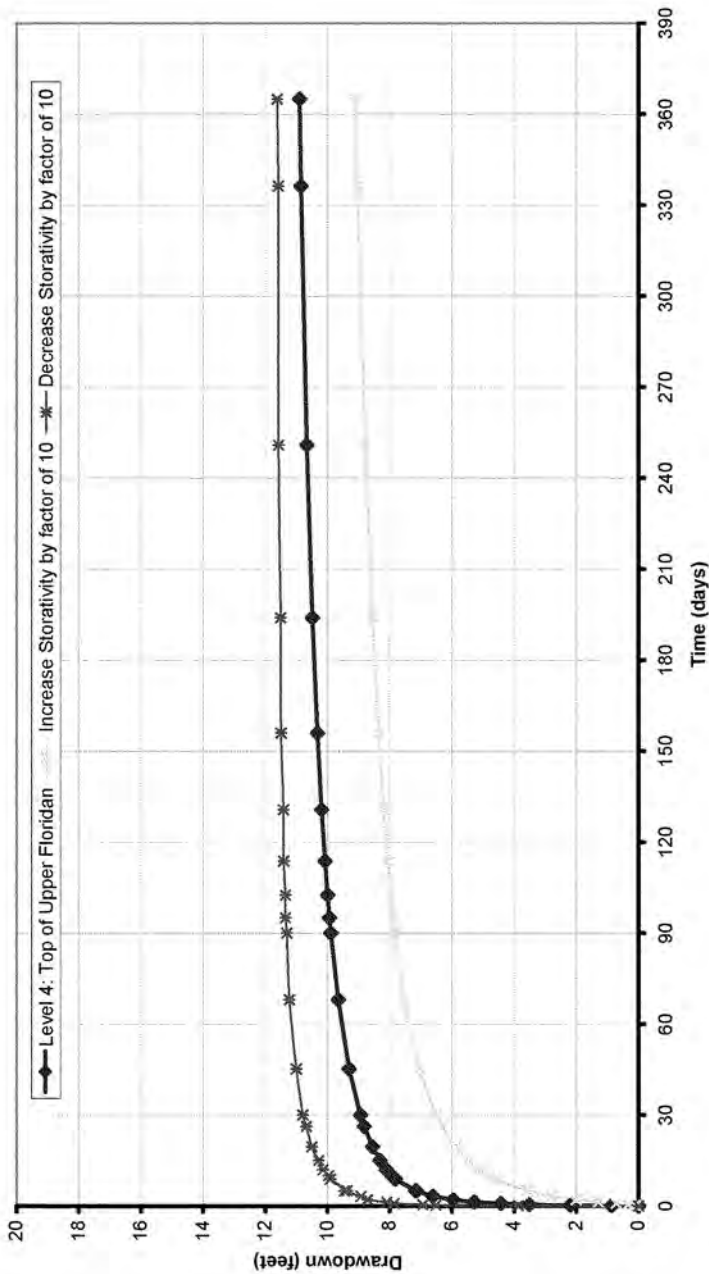
Pump Test Simulation 2 and Sensivity Simulations
Simulated Piezometric Head at Observation Well 1 - Model Level 9 - Base of Surficial Aquifer
Pumping Rate = 1000 GPM. Observation Well Approximately 750 feet from Pumping Well



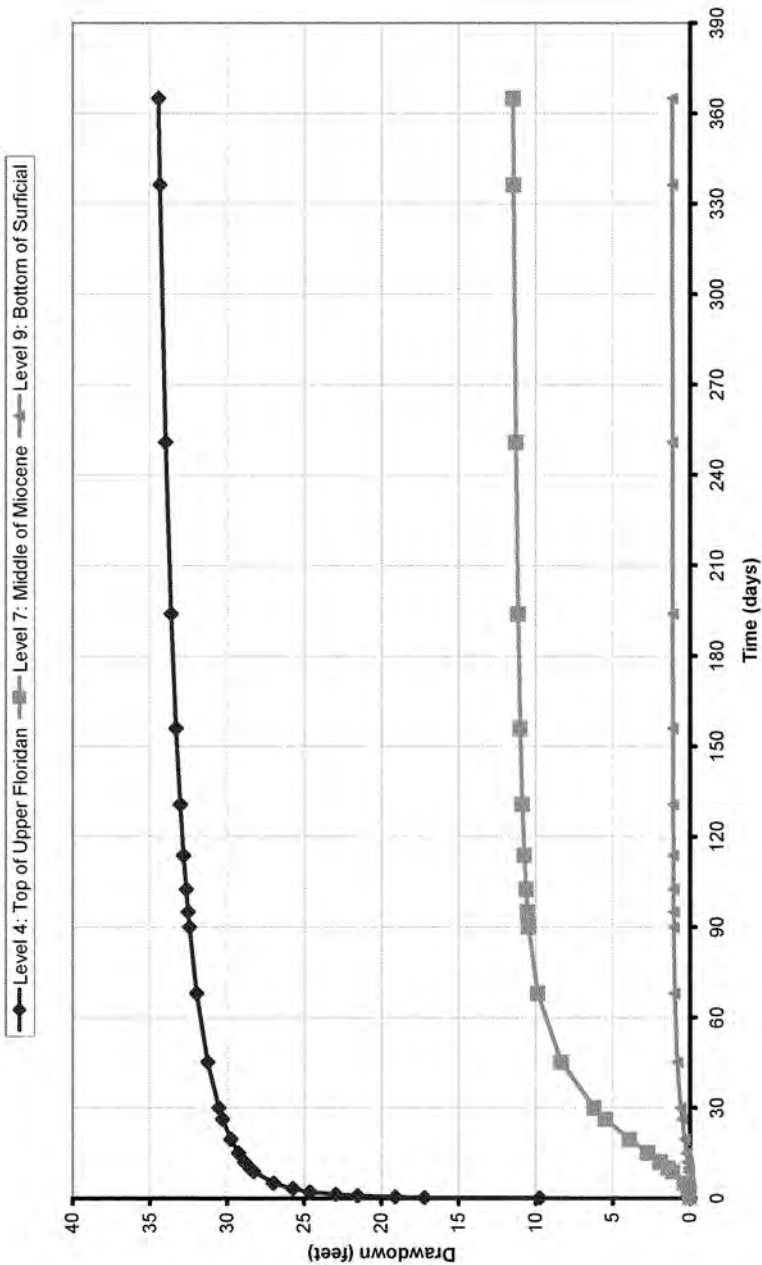
Pump Test Simulation 2 and Sensivity Simulations
Simulated Piezometric Head at Observation Well 1 - Model Level 7 - Middle of Miocene Confining
Pumping Rate = 1000 GPM. Observation Well Approximately 750 feet from Pumping Well



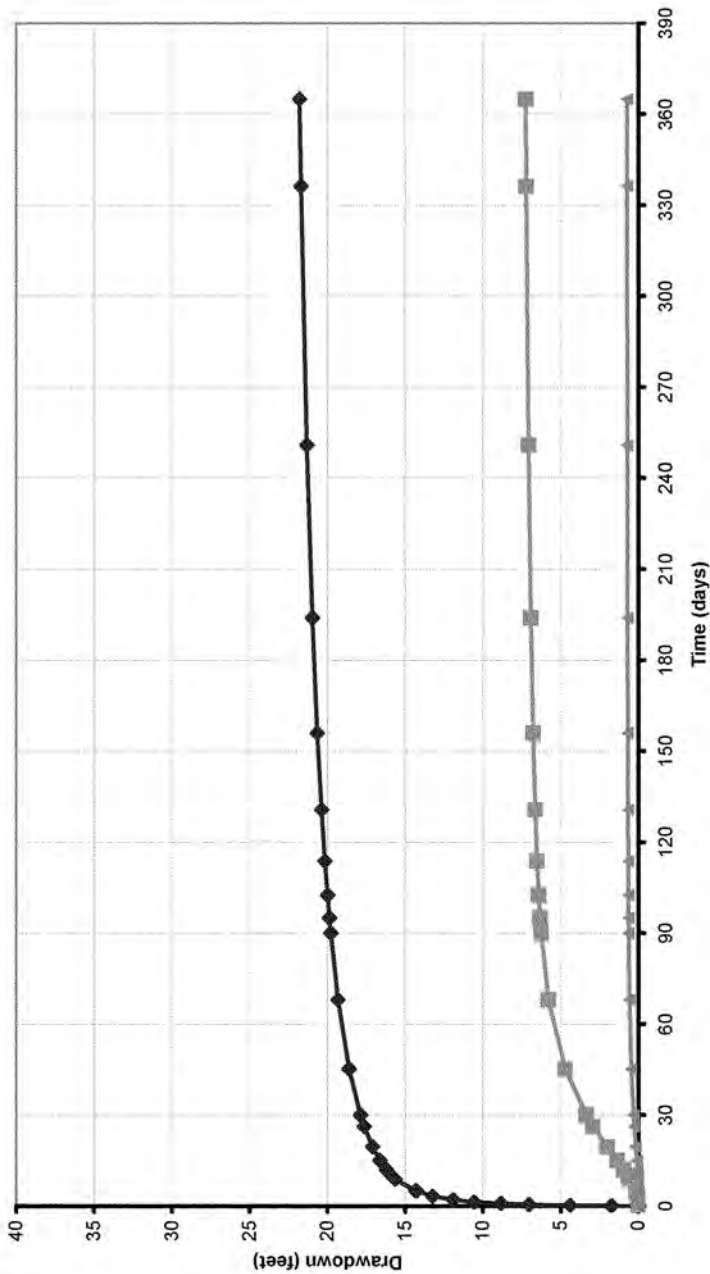
Pump Test Simulation 2 and Sensivity Simulations
Simulated Piezometric Head at Observation Well 1 - Model Level 4 - Upper Floridan
Pumping Rate = 1000 GPM. Observation Well Approximately 750 feet from Pumping Well



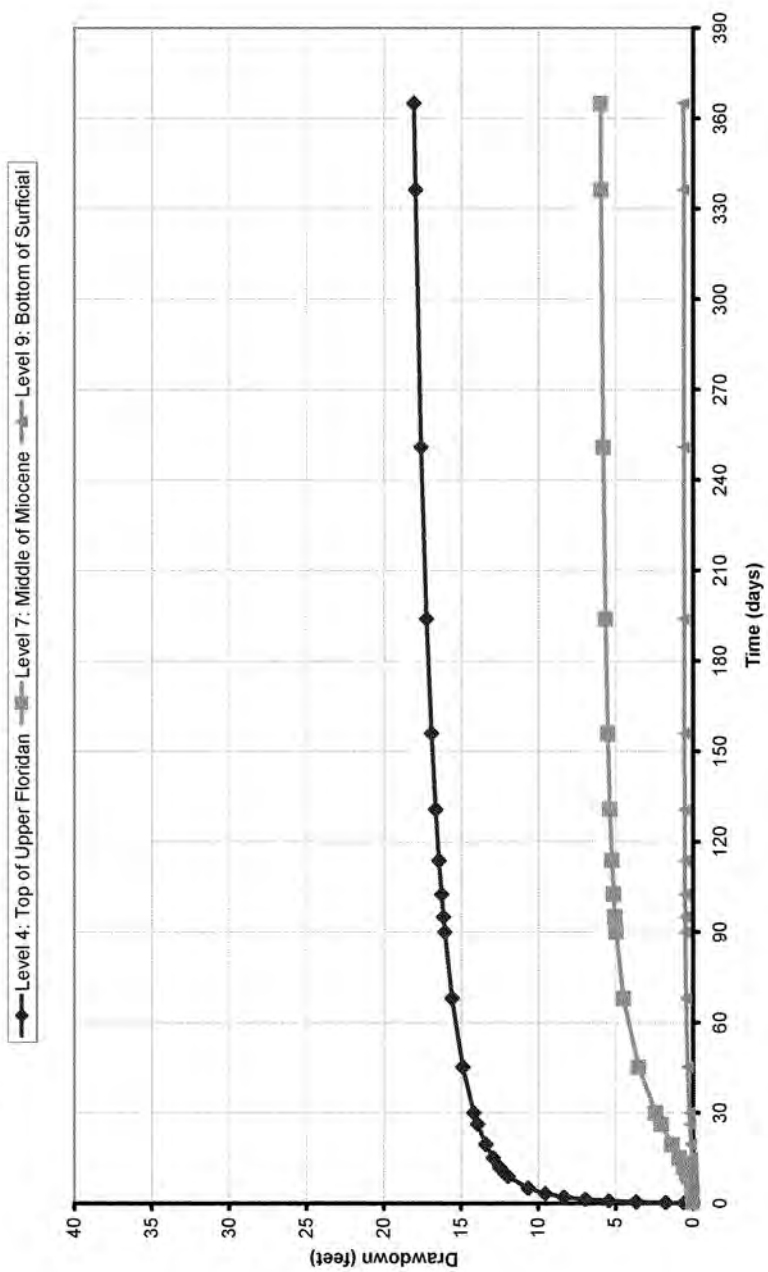
Pump Test Simulation 3 - Simulated Piezometric Head at Pumping Well
Pumping Rate = 2000 GPM



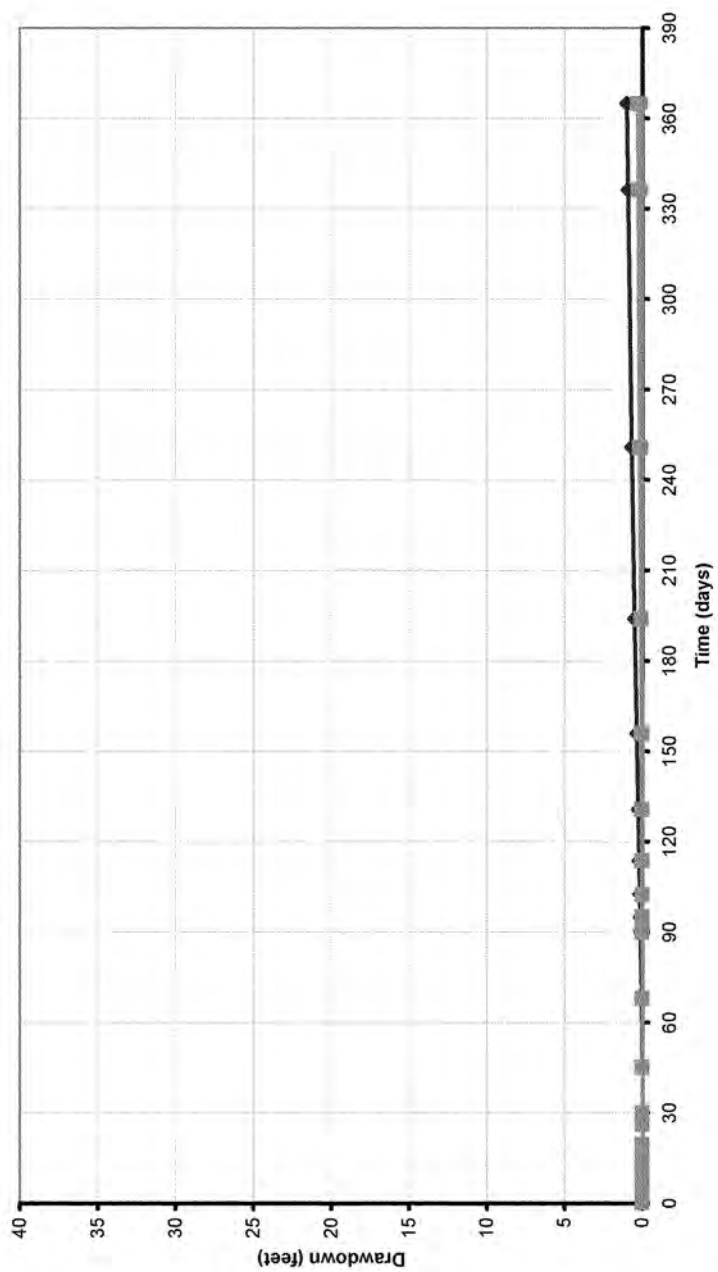
Pump Test Simulation 3 - Simulated Piezometric Head at Observation Well 1
Pumping Rate = 2000 GPM. Observation Well Approximately 750 feet from Pumping Well



Pump Test Simulation 3 - Simulated Piezometric Head at Observation Well 2
Pumping Rate = 2000 GPM. Observation Well Approximately 1100 feet from Pumping Well



Pump Test Simulation 3 - Simulated Piezometric Head at Observation Well 3
Pumping Rate = 2000 GPM. Observation Well Approximately 2400 feet from Pumping Well



APPENDIX C

GIS ANALYSES



U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

Geologic and Hydrogeologic GIS Analyses Performed as Part of the Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer

1. OVERVIEW

A geologic and hydrogeologic GIS was developed as part of the *Supplemental Studies* in order to enhance visualization and analysis of both historical and newly collected data. Ultimately, the resulting maps and products included in this report will be incorporated into the larger harbor-wide GIS. ArcGIS 9 was used as the framework for the GIS. Data was compiled and entered into a Microsoft Access 2000 database, which, in turn, was linked and integrated with the GIS as a geodatabase. ArcInfo Desktop version 9 with Spatial Analyst and 3-D Analyst extensions was used to process and analyze the data. ArcMap version 9, a two-dimensional visualization tool, was used to produce maps and figures.

The GIS served not only as a repository for organizing and viewing raw data, but also as a helpful tool for enhanced visualization and advanced analysis of the compiled data sources. The analyses completed provided a comprehensive view of the navigation channel to aid in visualizing major changes to the Savannah River through time. Detailed calculations are outlined below, and the model builder flow chart illustrating the calculation steps for all surfaces is included as Figure 1.

2. DATA SOURCES

2.1. GEOLOGIC DATA

As part of the objectives outlined in the supplemental studies, historical boring logs were compiled, digitized, and added to the GIS. Coordinates for each boring were converted to NAD83, Georgia State Plane Coordinate System, East Zone. The boring locations and corresponding digitized boring logs were plotted in the GIS to provide a clickable resource for quick reference. In addition, major formation elevations were identified for each boring log and entered into an integrated database, which served as the basis for creating various surfaces of the lithologic units underlying the navigation channel for both the ground-water model and GIS analyses. Over 400 boring logs and their interpretations were processed and mapped as part of this study.

The Savannah District compiled permeability and hydraulic conductivity, porewater, gamma, and soil conductivity data collected as part of the 1998 feasibility study as well as the data collected as part of the supplemental studies into a geodatabase that was integrated with the GIS. The tabular data was plotted according to location and elevation from which it was collected. In addition, where available, plotted data curves and lab reports including grain-size analyses and soil classifications were scanned, and the resulting image files were linked to the data location to allow quick access to the data source.

2.2. HYDROGEOLOGIC DATA

Drawdown data of the Upper Floridan aquifer (Peck et al., 1999) was obtained from the USGS and incorporated into the GIS. The potentiometric contours generated by the well data cover the cone of depression around Savannah and coastal Georgia, and limited areas of South Carolina and Florida. In order to illustrate a more complete view of the potentiometric heads in the Upper Floridan, SCDHEC data

(Ransom and White, 1998) was included in the potentiometric surface calculation as well.

2.3. SEISMIC DATA

As detailed in task 3, all seismic data collected as part of the supplemental studies was acquired in digital format to facilitate its inclusion in the GIS. OSI also provided all subbottom interpretation data in Microsoft Excel "pick files," X, Y, Z formatted data that included coordinates and elevations of each reflector along each survey trackline. The data was loaded into the geodatabase and used to create detailed surfaces of not only the major lithologic contacts, but also of each major paleochannel as it intersected the navigation channel. Additionally, the tracklines were plotted and embedded with hyperlinks to image files of each interpreted cross section that included color-coded interpretations of each reflector.

2.4. HISTORICAL DREDGING RECORDS

Historical dredging records were incorporated into the GIS to assess the location and amount of confining material removed through time. Internal historical documents including annual surveys, congressional authorizations, status reports, exam studies, and design memoranda were reviewed for information regarding channel depth and geometry. The resulting authorized depths and widths were compiled into a spreadsheet with interpolated coordinates and incorporated into the GIS. Whenever available, digitized bottom survey data (1986 and 2003) and geometry design files superseded information gathered from congressional authorizations or other text-based sources.

3. BASE SURFACES

X, Y, Z data files containing locations and elevations of critical geologic contacts or features along the Savannah River were used to define raster surfaces. ESRI defines a raster as "a spatial data model that defines space as an array of equally sized cells arranged in rows and columns. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent geographic features."

3.1. STUDY AREA

The study area domain for the GIS was defined using a combination of raster surfaces with a 20-foot cell size. The coverage areas were defined by annual surveys, seismic data, and geologic formation elevations interpreted from boring logs. Areas where data was present were defined as "true" and given a value of "1," and areas where all values were not 1 were reclassified as "0." The resulting domain was used in the calculation to trim subsequent raster surfaces. When any created raster is divided by the study area domain, values located outside the domain are divided by 0. The undefined value is then eliminated from the raster, resulting in a trimmed surface that matches the area of the study area domain.

3.2. ANNUAL SURVEYS

Three-D Analyst was used to process the X, Y, Z values from the 1986 and 2003 annual surveys and create 3-D topographic surfaces of the navigation channel and turning basins. Two rasters, one of the 1986 annual survey and one of the 2003 survey, were created. The 2003 annual survey did not cover Kings Island Turning Basin; for that reason, in order to create a complete bottom survey, 2004 exam study data from Kings Island Turning Basin was spliced with the 2003 annual survey data. The data was converted to a Triangular Irregular Network (TIN) surface model of the data points, where a TIN is a vector data structure used to store and display surface

models. A TIN partitions geographic space using a set of irregularly spaced data points, each of which has an X, Y, and Z value. These points are connected by edges into a set of contiguous, non-overlapping triangles, creating a continuous surface that represents the terrain. The resulting surface model was then converted to a raster surface with a 20-foot cell size. The raster calculator within Spatial Analyst was then utilized to trim the raster surface to match that of the study area domain.

3.3. MIOCENE EXPOSURE TIME STEPS

Several surfaces were created to approximate the exposure of the Miocene in the bottom of the navigation channel through time. Historical surveys and documents were used to define depths along the channel through time. The depths and locations were combined into an X, Y, Z format in an effort to examine the historical evolution of the navigation channel. The X, Y, Z data was used to create a series of 3-D polygons in ArcScene representing the depth and width of a given stretch of the channel in time. The 3-D polygons were exported as 2-D tiffs with world files for each surface and year. The tiff was then displayed in ArcMap and georeferenced to correct for 3-D distortion. The tiff was then reclassified with exposed areas equal to "1" and all other values equal to "0." The reclass values equal to "1" were then converted to a 2-D polygon. The resulting images were combined with the trimmed Pre-Dredging Miocene surface to represent areas where the Miocene confining unit was exposed in the bottom of the navigation channel (Figures 2 and 3).

3.4. MIOCENE (UNDISTURBED)

A surface was created to represent the top of the Miocene underlying the navigation channel before paleochannel incisions and erosional processes (including dredging activities) impacted the surface. "Natural" Miocene values were extracted from the boring log interpretations by using those values where the contact occurred at least ten feet below the elevation of the river bottom at the time of drilling. Ten feet was used in order to eliminate including points where the contact was buried only by "fluff," or recent deposits that collect in between maintenance dredging events. The data was also supplemented with several "estimated" values of the elevation of the

contact in order to create a complete coverage for the Miocene surface. The estimated values were created by examining cross sections and interpreting reasonable values where boring data was sparse or absent.

The X, Y, Z data points determined from the process described above were converted to a TIN surface, and the resulting TIN surface was converted to a raster surface with a 20-foot cell size. The raster calculator was then utilized to trim the surface to match that of the study area domain.

Similarly, "All" Miocene values were extracted from boring log interpretations and used to create another intermediary raster. These two factor surfaces ("Natural" and "All") were then mosaicked for maximum values, yielding the Undisturbed Miocene surface.

3.5. MIOCENE (PRE-DREDGING)

Two rasters were combined to create a raster surface representing the elevation of the top of the confining unit before dredging activities and minor natural erosional processes impacted the contact. Subbottom seismic data from the survey performed as part of the supplemental studies was used to create a trimmed raster surface of each of the eight major paleochannels identified between river stations +30+000 to -30+000. The X, Y, Z data was converted to TIN surfaces of each paleochannels, and the TINs were converted to raster surfaces. The resulting eight rasters were then "mosaicked" together to create one paleochannel raster ("Paleos_only"). The Undisturbed Miocene raster was mosaicked with the paleochannel raster using the "minimum" values mosaic method. The resulting raster values corresponded to the lowest elevation of the two surfaces and represented the erosion of the contact specifically by paleochannel incisions ("mio_undis_pal").

3.6. MIOCENE (CURRENT)

A number of calculations were involved to create a refined surface representing the surface of the Miocene as it appears today. Boring log data, geophysical data, and bathymetry data were all combined to form a refined surface.

Two rasters were combined in order to create a raster representing the current approximate surface of the top of the Miocene confining unit. First, all boring logs that contained the elevation of the top of the Miocene, including those where the contact occurred within ten feet of the river bottom at the time of drilling, were combined with several "estimated" values as described above to create a raster surface of the top of the Miocene ("MioceneALL"). This surface was then mosaicked with *mio_nat* for minimum values. The X, Y, Z data was used to create a TIN surface and then converted to a raster surface with a 20-foot cell size, and the raster calculator was used to trim the raster to match the domain of the study area. The "MioceneALL" raster and the paleochannel raster were combined using the "minimum" values mosaic method to create a raster representing the approximate elevation of the top of the Miocene confining unit ("Mio_min_pal").

An intermediary raster surface ("Mmp_as_neg") was created in order to refine the elevation of the top of the Miocene confining unit as it appears underneath the navigation channel. The intermediary surface represented additional thickness of Miocene material removed that was not accounted for in the *Mio_min_pal* surface described above. The raster calculator was used to add the approximated Miocene surface to the *Mmp_as_neg* surface account for additional material removed by the most recent dredging event (2003 Annual Survey). The returned values represented the current elevation of the Miocene confining unit after the most recent dredging event (Figure 4).

3.7. MIOCENE (PROPOSED)

Three surfaces were used to create a surface representing the elevation of the Miocene confining unit after the proposed 6-foot improvement. First, a raster surface representing the proposed dredge depths was created. The study area domain was combined with polygons of the proposed depths by station number. The 3-D polygons were converted to a raster and then trimmed to match the domain of the study area ("pd_area") using a reclass surface. The final surface ("prop_depth") represented proposed depths within the navigation channel.

The Pre-Dredging Miocene surface was then multiplied by the pd_area surface to trim the proposed depth coverage to the navigation channel coverage area (Mio_ud_pda). Next, the Proposed Depth surface was subtracted from the undisturbed Miocene surface within the navigation channel ("pd_mio"). The returned values were then reclassified where negative values were equal to "1" and all other values were equal to "0." The reclass surface was then multiplied by the pd_mio surface, and the negative return values were added to the prop_depth surface, yielding a raster that represented the elevation of the top of the Miocene confining layer following the proposed dredging activities ("mio_prop").

3.8. LIMESTONE

Subbottom seismic data from both the 1997 and 2002 surveys and boring log data were combined to create a surface representing the elevation of the top of the Oligocene limestone (Upper Floridan aquifer). Cross section interpretations were used to create several "estimated" values where data was sparse or absent in order to provide complete coverage of the study area domain. The resulting X, Y, Z data were converted to a TIN surface, and the TIN surface was then converted to a raster surface with a 20-foot cell size. The raster calculator was utilized to trim the raster to match the domain of the study area.

4. CALCULATED THICKNESS SURFACES

4.1. MIOCENE REMOVED (PALEOCHANNELS)

The Undisturbed Miocene raster and the Pre-dredging Miocene raster were used to calculate the thickness of material removed within the paleochannels. The Pre-dredging Miocene surface was subtracted from the Undisturbed Miocene surface using the raster calculator. The resulting positive values represented the thickness of material (feet) removed by paleochannels incising the Miocene surface (Figure 5)

4.2. MIOCENE REMOVED (DREDGING)

The 2003 Annual Survey surface and the Pre-dredging Miocene surfaces were subtracted in order to calculate the thickness of Miocene removed due to dredging and natural erosional processes other than the paleochannel incisions (Figure 6). The returned negative values represented thickness of Miocene removed. A reclass surface of the returned raster was created to convert the values to a positive thickness where the raster value equaled "1" when the surface was less than zero and the raster value equaled "0" when the surface was greater than zero. The reclass surface was then multiplied by the original returned calculated surface, yielding a surface where negative values represented thickness of Miocene removed and zero values indicated no Miocene material had been removed.

4.3. MIOCENE REMOVED (DREDGING; PALEOCHANNELS)

The total thickness of feet of Miocene material removed was created by combining the data from Miocene removed by dredging and Miocene removed by paleochannels surface. First, using map algebra, the Miocene removed by dredging raster was multiplied by -1. Then, the Miocene removed by paleochannels raster was mosaicked with the Miocene removed by dredging raster for maximum values. The output surface represented total thickness of Miocene removed due to natural erosion in the paleochannel areas and dredging along the remainder of the course of the river (Figure 7).

4.4. PLEISTOCENE/RECENT MATERIAL THICKNESS (DEPTH TO MIOCENE)

The 2003 Annual Survey surface and the Current Miocene surface were used to identify where the Miocene unit is exposed in the bottom of the navigation channel and calculate the thickness of material remaining above the Miocene contact. The depth to Miocene was calculated by subtracting the Current Miocene surface from the 2003 Annual Survey surface. The resulting raster yielded no negative values; returned positive values represented current Pleistocene/Recent material remaining on top of the Miocene and zero values indicated that Miocene material had already been removed and is thus exposed in the bottom of the navigation channel (Figure 8).

4.5. NATURAL MIOCENE THICKNESS

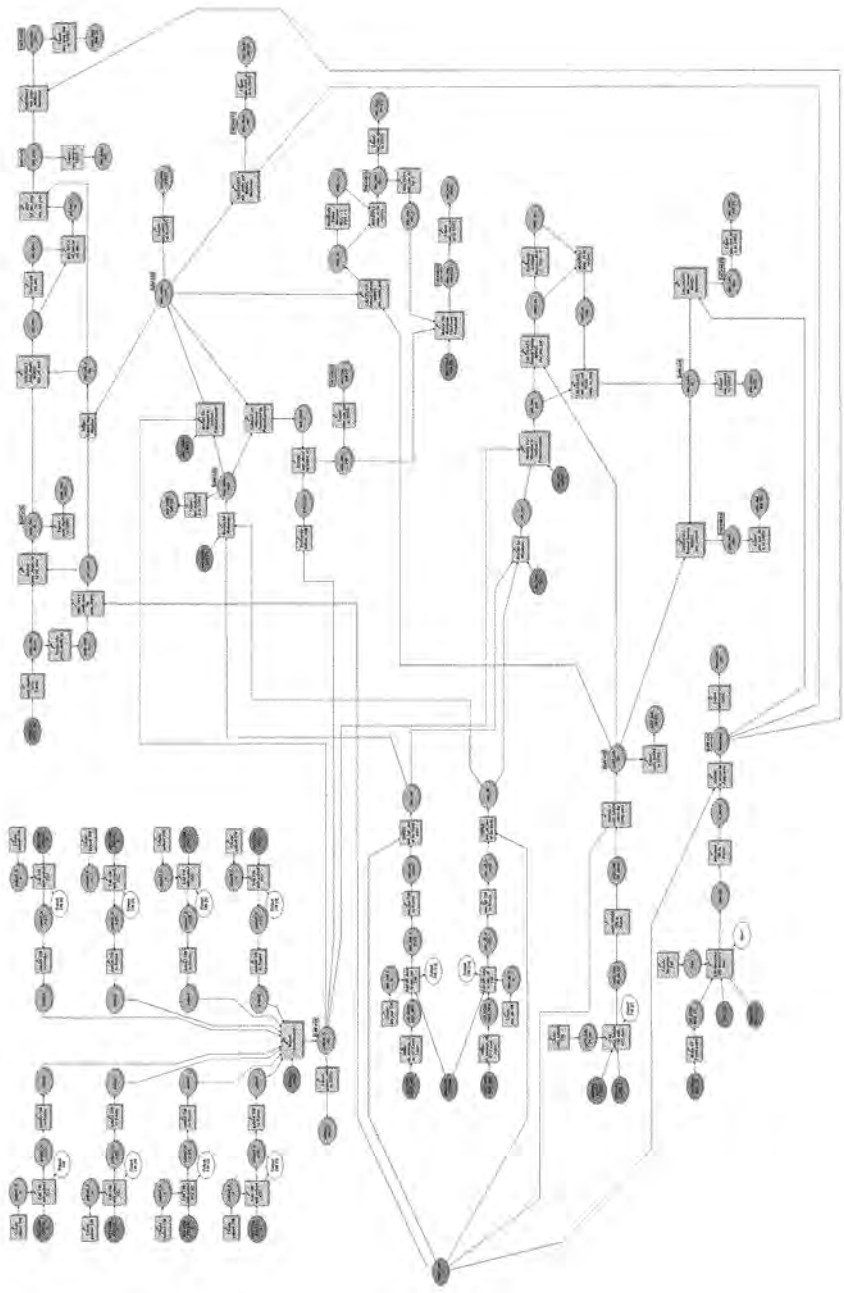
The Pre-dredging Miocene surface ("mio_undis_pal") and the Limestone surface were used to create a surface representing the thickness of the confining unit prior to modern dredging activities. Using the raster calculator, the Limestone surface was subtracted from the Pre-dredging Miocene surface, and all returned values represented the natural thickness (feet) of the Miocene confining unit ("mio_thik_nat").

4.6. CURRENT MIOCENE THICKNESS

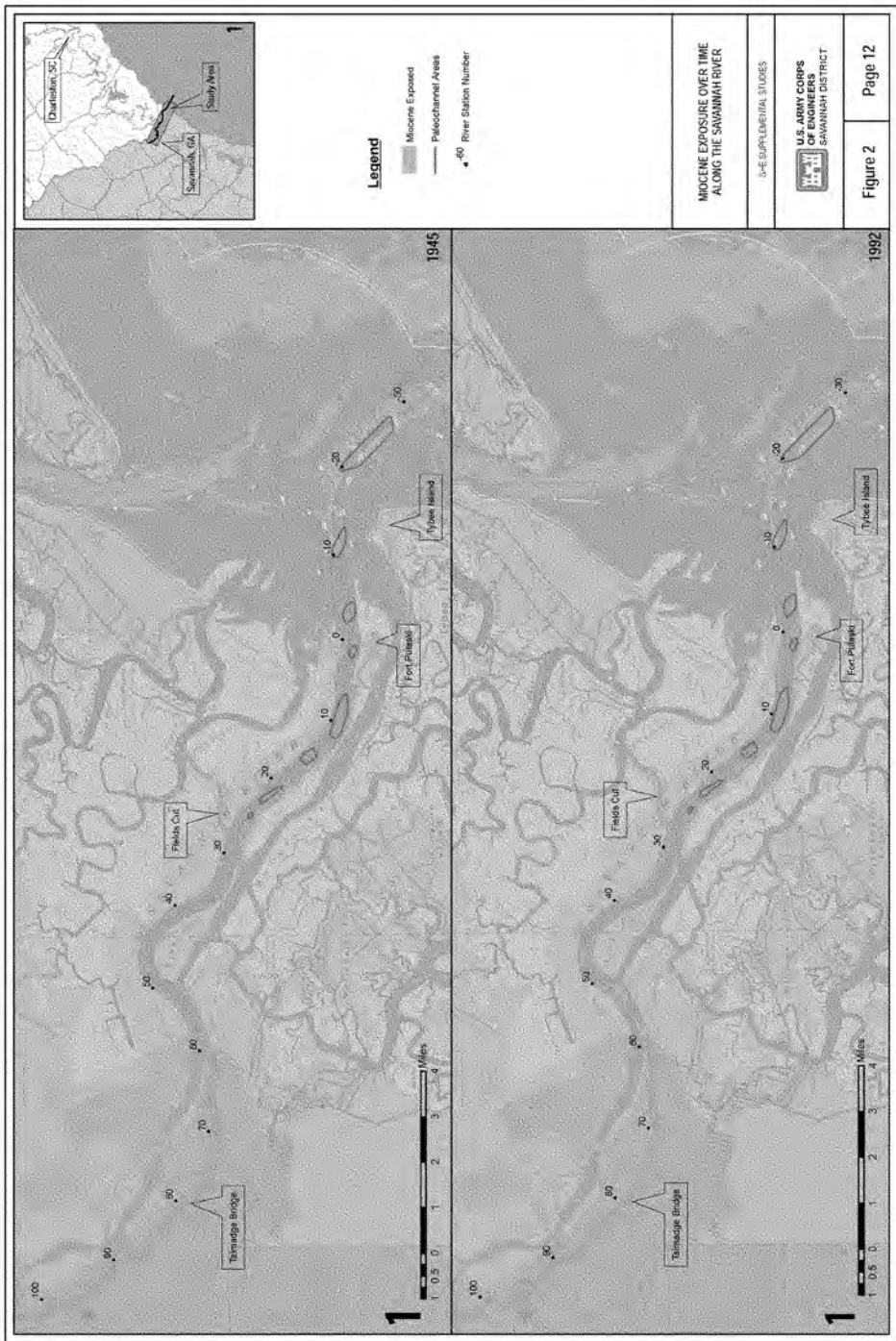
The Limestone surface was subtracted from the Current Miocene surface in order to determine the thickness of the confining unit. The returned raster values indicated thickness of Miocene material in feet underlying the navigation channel (Figure 9).

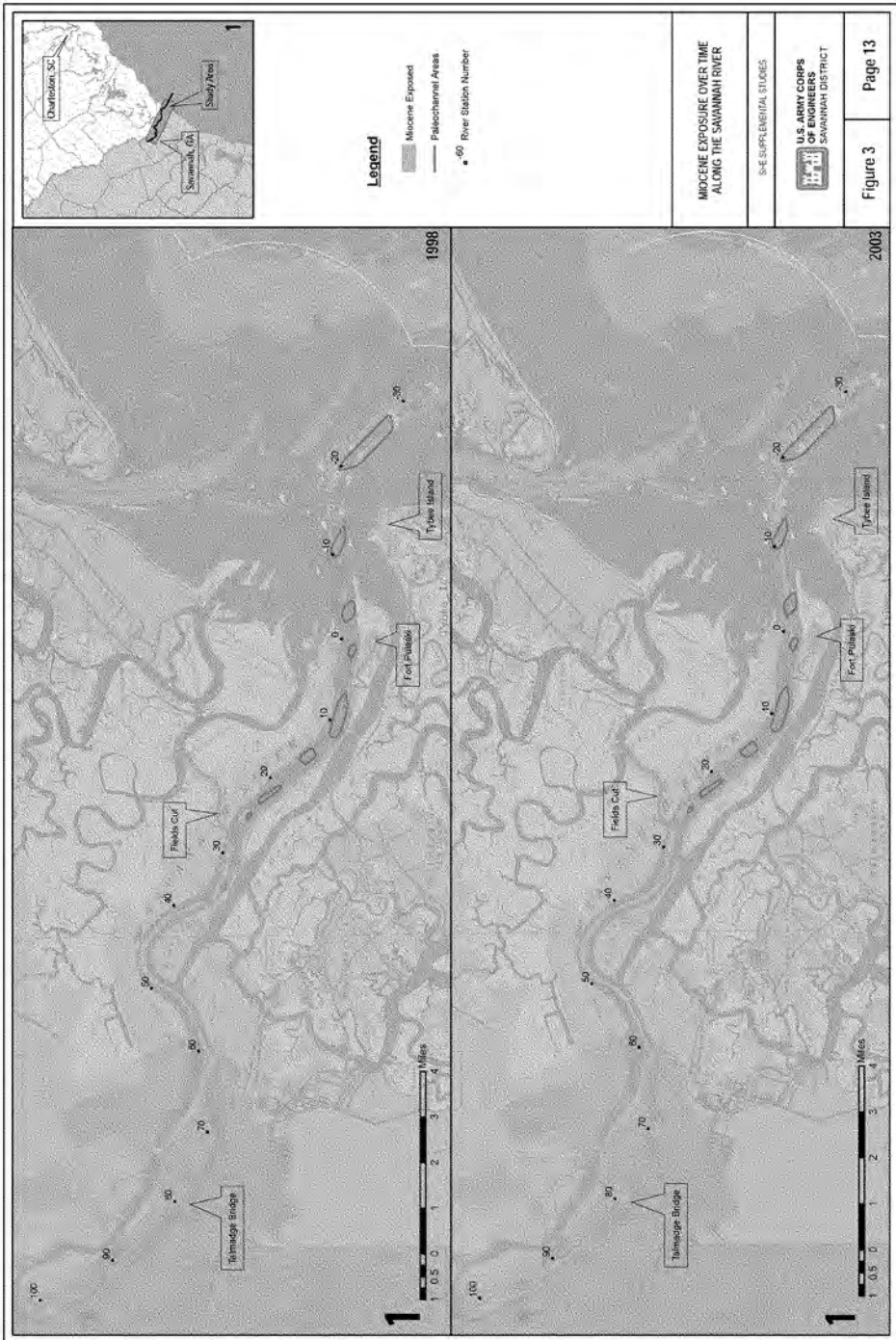
4.7. PROPOSED MIOCENE THICKNESS

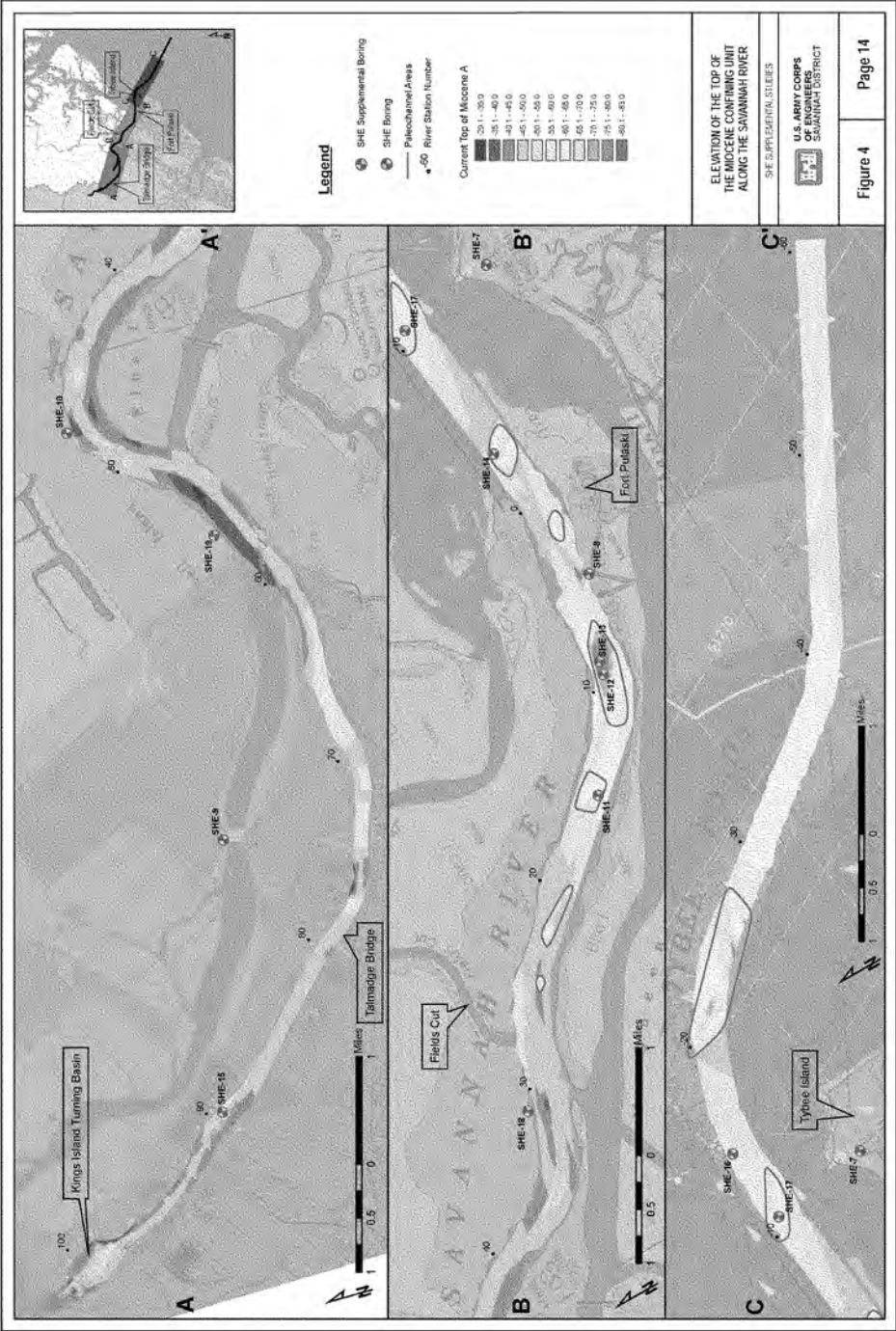
Similar to the two Miocene thicknesses described above, a surface was created to represent the thickness of the Miocene following the proposed dredging activities. The raster calculator was used to subtract the Limestone surface from the proposed Miocene surface ("mio_prop"). The returned values represented a projected thickness of the confining unit after the proposed dredging (Figure 10).

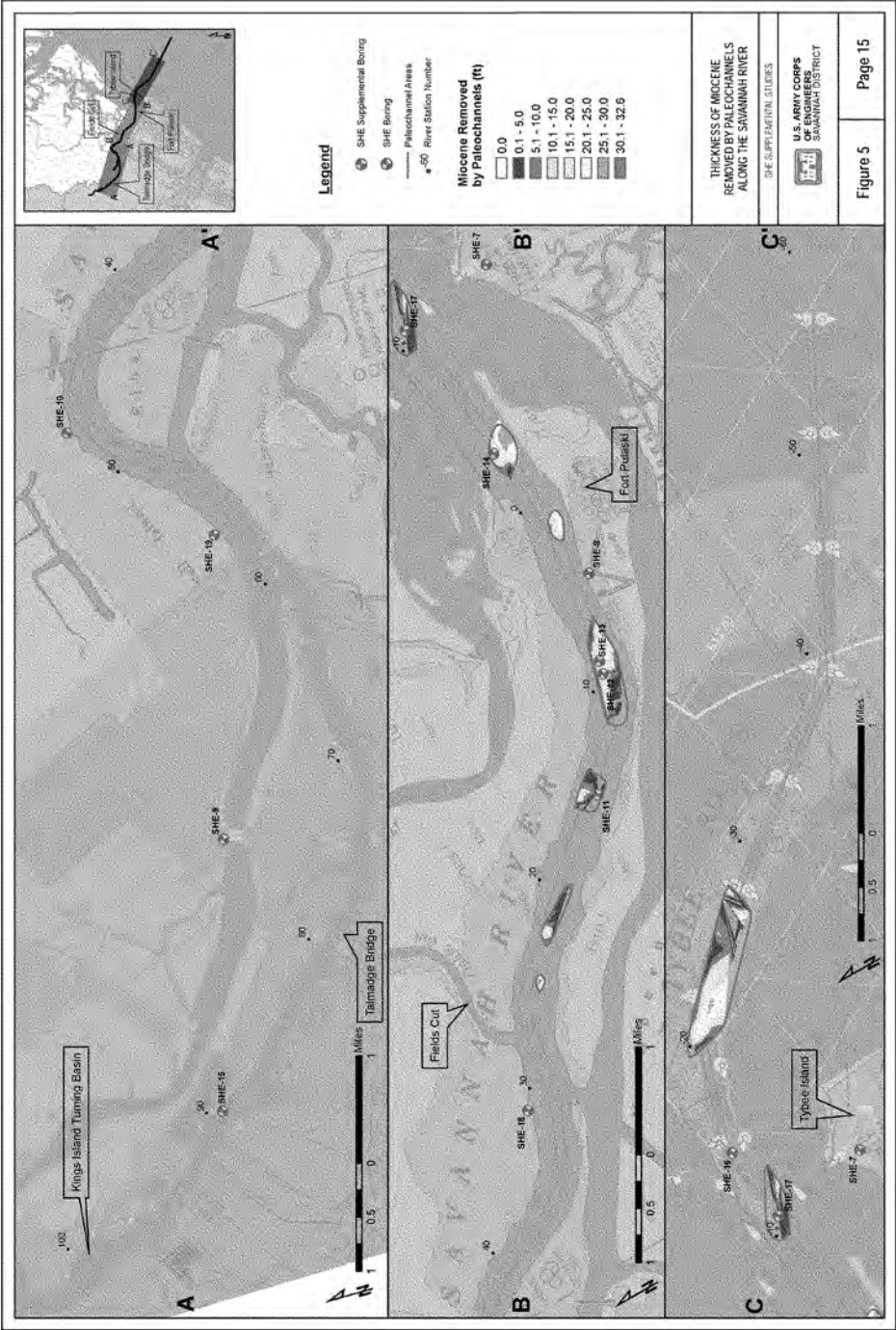


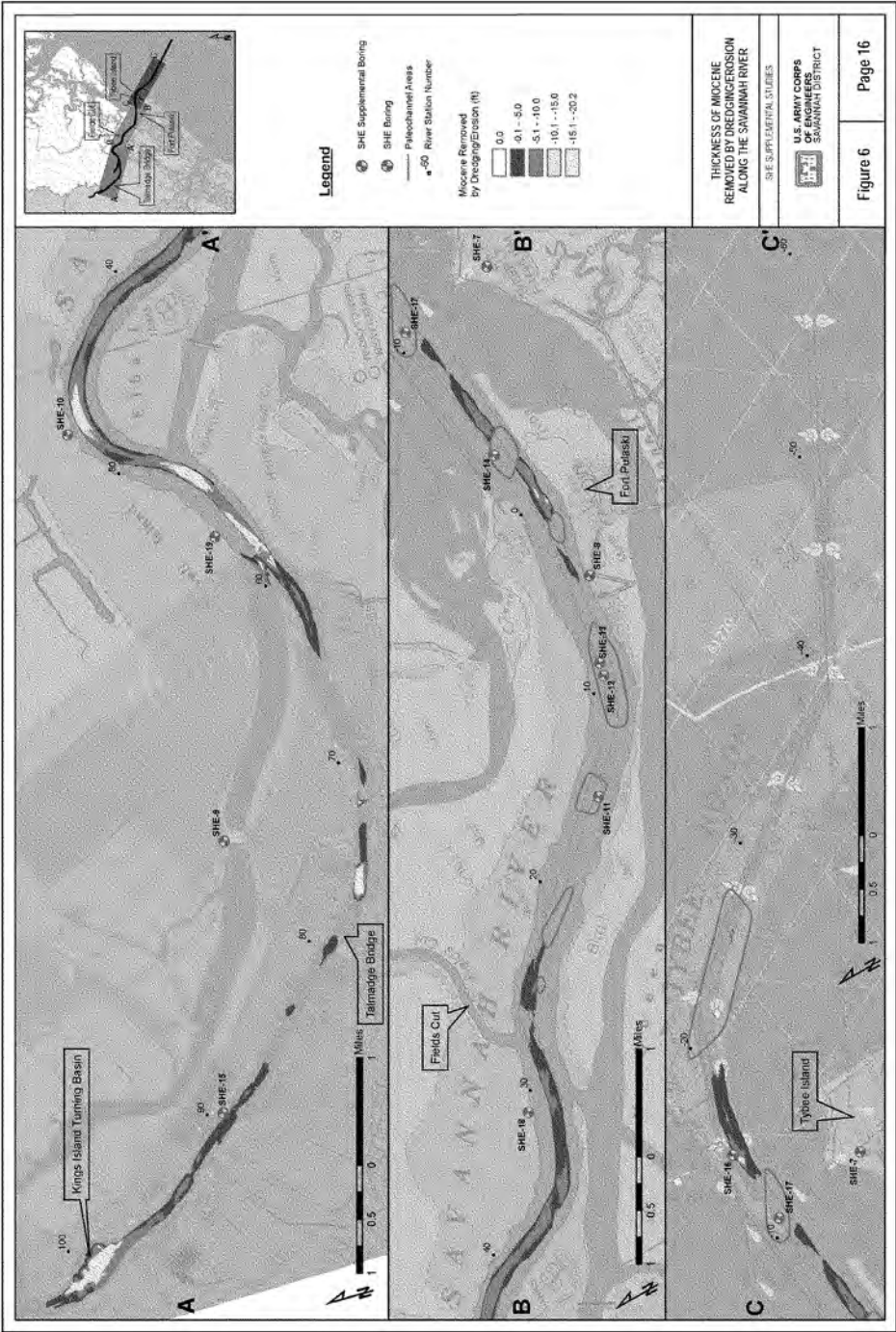
GIS Analyses Performed as Part of the Supplemental Studies to Determine Potential Ground Water Impacts to the Upper Floridan Aquifer

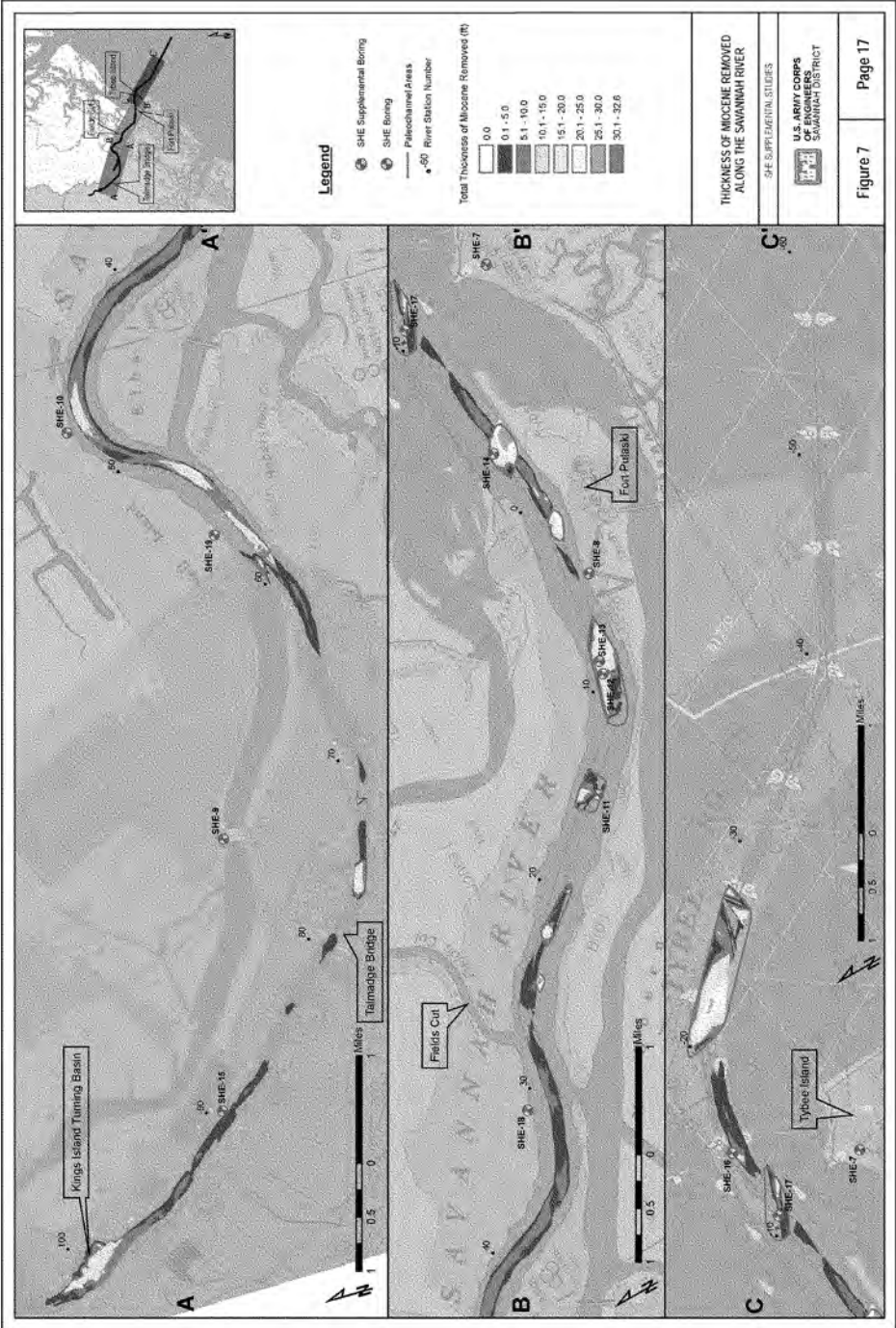


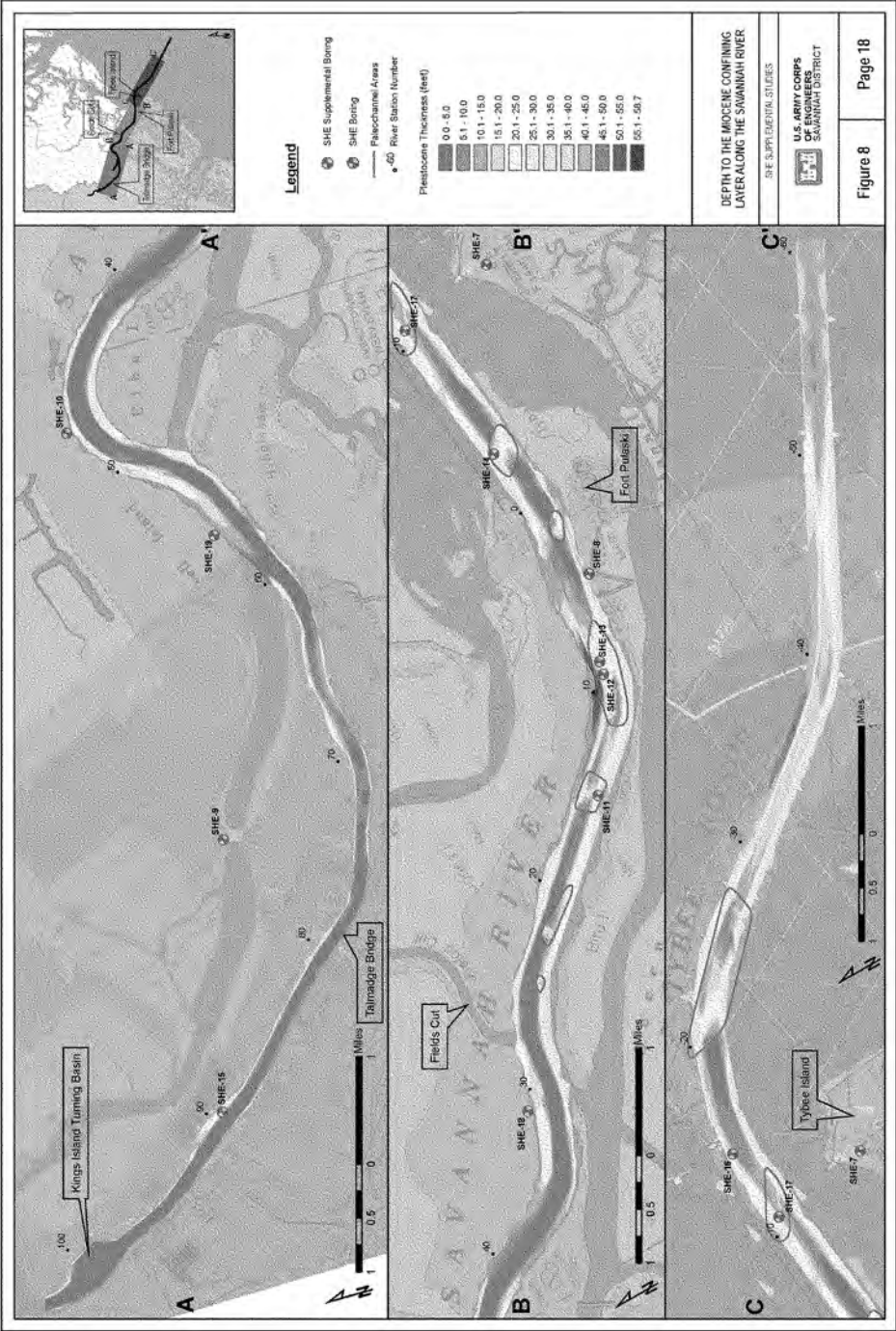


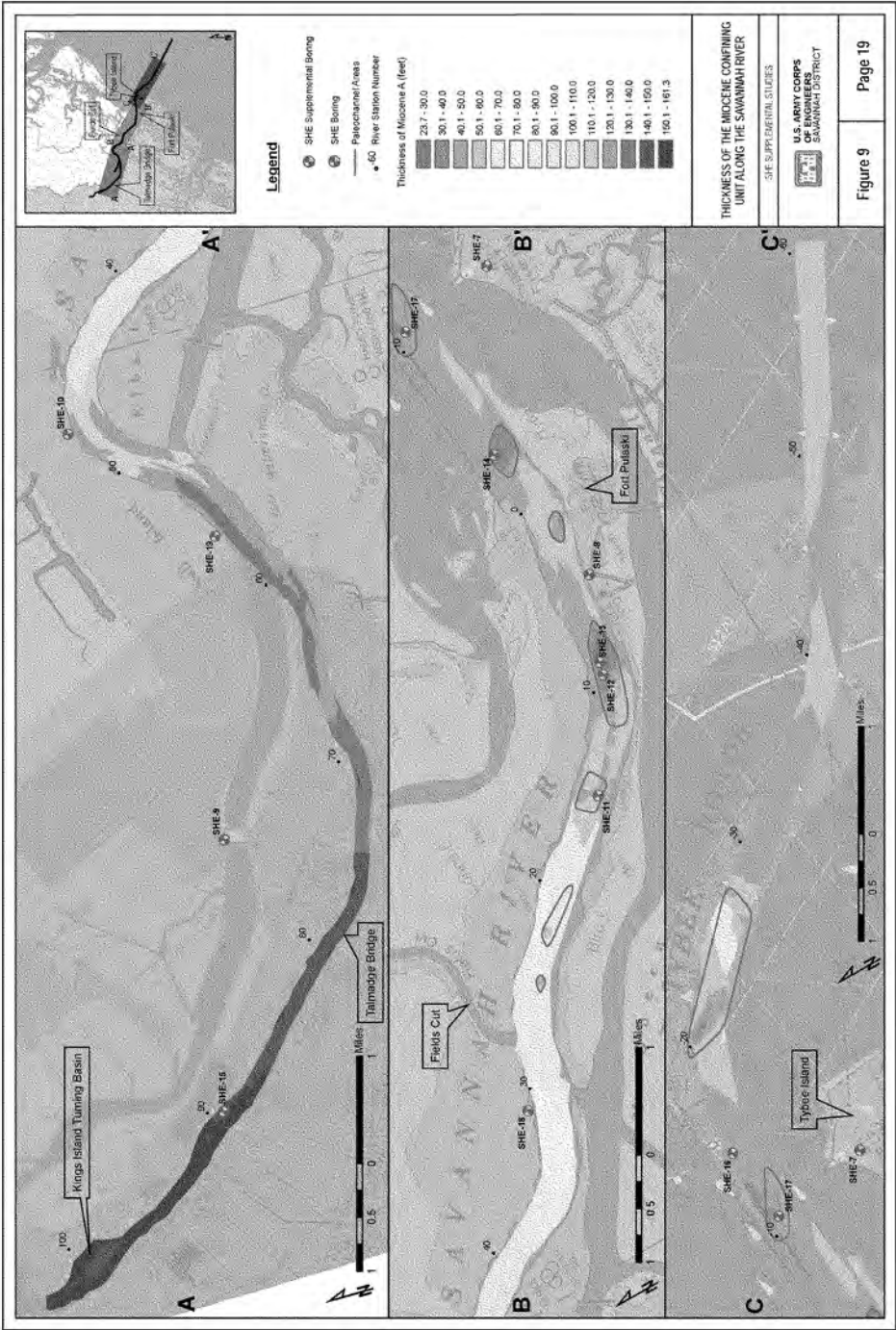


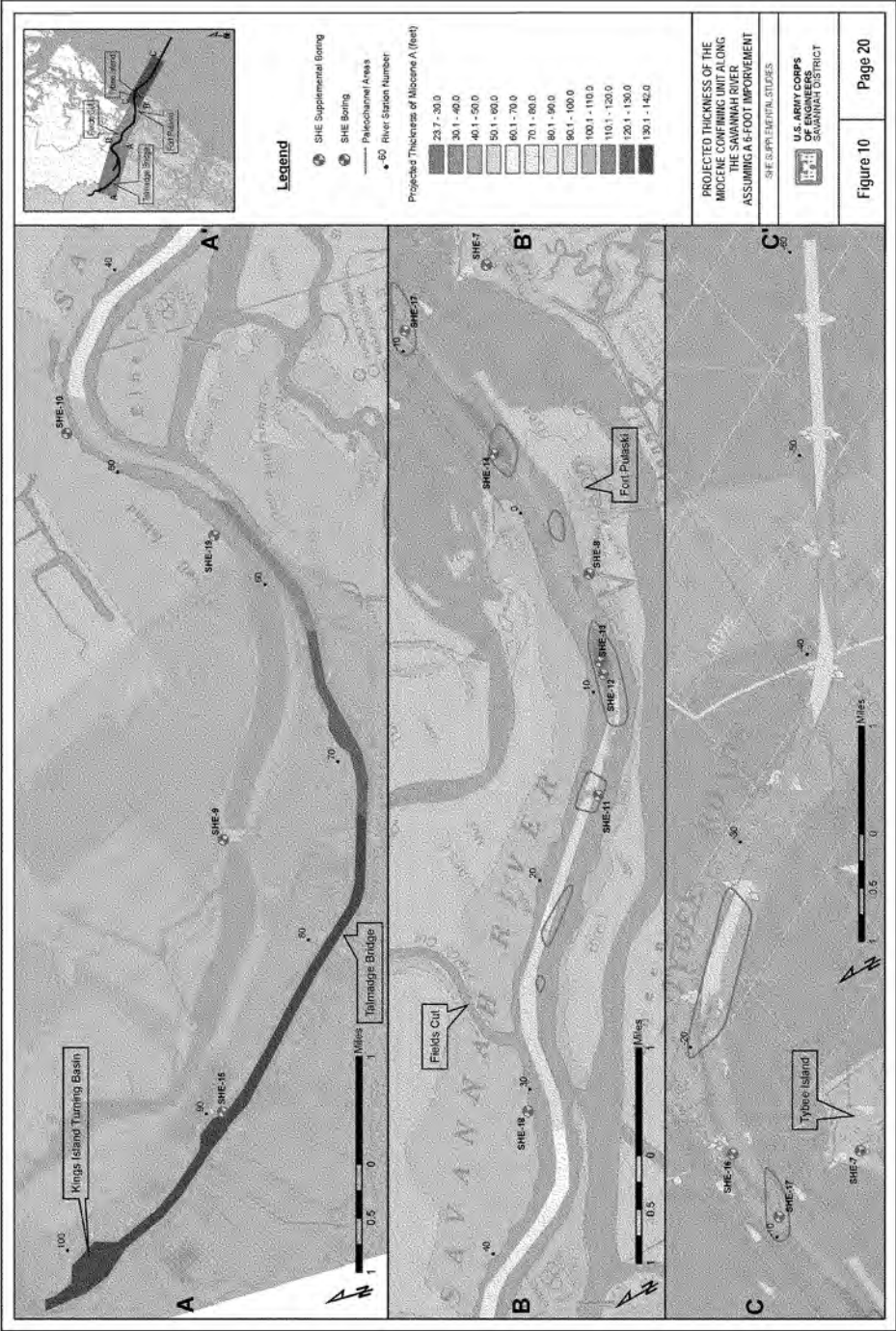












APPENDIX D

Boring Logs



U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

Hole No. SHE-9

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 OF 8 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) N-765318.998 E-992787.271 GA EAST				11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500			
4. HOLE NO. (As shown on drawing title and file number) SHE-9				13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 0 UNDISTURBED : 0			
5. NAME OF DRILLER P. ROUNTREE				14. TOTAL NUMBER CORE BOXES 18			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >373.0'				16. DATE HOLE : STARTED : 15 Sept 2001 : COMPLETED : 4 Oct 2001			
8. DEPTH DRILLED INTO ROCK 10.0'				17. ELEVATION TOP OF HOLE 15.2' MLW			
9. TOTAL DEPTH OF HOLE 373.0'				18. TOTAL CORE RECOVERY FOR BORING 86 %			
				19. SIGNATURE OF INSPECTOR C. SMITH			
ELEVATION (FT) # 0	DEPTH (FT) # 0	SYMBOLS #	CLASSIFICATION OF MATERIALS (Description) #	PERCENT CORE RECOVERY #	SAMPLE NO. #	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) #	
15.2'	0		Wash.			NOTE: Change of scale to 1" = 5' at 10.0'. Elevation to top of casing = 16.2 MLW	
5.2'	10		(SM) Tan to brown fine silty SAND, trace dark mineral grains, trace mica, wet.	Pull 1 Run=10.0 Rec=6.0			
-0.2'	15		(SW) Gray wellgraded SAND, little fines, little shell fragments up to 0.3 inches, trace fine to coarse gravel.				
-4.8'	20		(SP) Gray fine poorly graded SAND, little mica, little shell fragments up to 0.1 inches, trace dark mineral grains.	Pull 2 Run=5.3 Rec=1.0			
	25		Little fines, trace organic material. Laminated.				
	30		Trace fine gravel.	Pull 3 Run=10.0 Rec=1.0			
	35						
CONTINUED ON SHEET No. 2						NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.	

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 8 SHEETS	
ELEVATION (FT) e	DEPTH (FT) d	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) a	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if signif/cant) g Chloride (mg/L)
			SP (Continued).		P-1	0 1000 2000
	40		Zone of medium subangular quartz sand.	Pull 4 Run=6.5 Rec=1.5		
-25.6'			(SC) Tan to brown fine clayey SAND, trace dark mineral grains, trace fine gravel, trace mica.	Pull 5 Run=3.5 Rec=1.8		
-28.3'	45		(SM) MIOCENE A-Green fine silty SAND, little fine mica, trace dark mineral grains.		P-2	RECENT MIOCENE A
	50			Pull 6 Run=10.0 Rec=1.5		
	55		Trace mica.		P-3	
	60		Partings of fine quartz sand.	Pull 7 Run=10.0 Rec=7.0	P-4	
-49.1'	65		Tan to light olive green, increased fines.		P-5	
			(ML) Light olive green low plasticity SILT, little fine sand, not cemented. Green, laminated, trace mica.		K-1	
-52.2'			(SM) Green fine silty SAND, little clay, trace mica, trace dark mineral grains. Light olive green to yellow, decreased clay content, rare horizons of gray fine quartz sand, laminated.	Pull 8 Run=10.0 Rec=10.0	P-6	
	70					
	75		CONTINUED ON SHEET No. 3			

DRILLING LOG (Cont Sheet)		ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9		
PROJECT SAVANNAH HARBOR DEEPENING		INSTALLATION SAVANNAH, GA		SHEET 3 OF 8 SHEETS		
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if slight/cont.) Chloride (mg/L)
	75		SM (Continued).		P-7	
			Green, sand partings every 0.3 feet.		K-2	
	80		Partings less common.	Pull 9 Run=10.0 Rec=10.0		
			Trace medium subangular sand.			
	85				P-8	
			Increased fines.			
-73.0'	90		(SC) Green fine clayey SAND, trace dark mineral grains, partings of fine sand.	Pull 10 Run=10.0 Rec=10.0		
-73.7'			(SM) Green fine silty SAND, trace mica, trace dark mineral grains, laminated.			
	95		Partings of fine sand occurring every 0.3 feet.		P-9 K-3	
	100			Pull 11 Run=10.0 Rec=10.0		
					P-10	
	105		Partings occur every 0.5 feet.			
			3" layer of fine quartz sand.		P-11	
-93.6'	110		Decreased sand, partings frequent, laminated.	Pull 12 Run=10.0 Rec=10.0		
			(ML) Green low plasticity SILT, some fine sand, not cemented, laminated, rare partings of fine sand.			
			0.2 foot thick horizon of fine sand.		P-12	
	115					

CONTINUED ON SHEET No. 4

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 4 OF 8 SHEETS	
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
-99.1'	115		ML (Continued). (SM) Green fine silty SAND, trace mica, trace dark mineral grains.		K-4 P-13 Pull 13 Run-6.7 Rec-6.7	0 1000 2000
	120		Gradational color change from green to light olive green to cream. Cream colored horizons are indurated.		Pull 14 Run-3.3 Rec-3.3	
	125		Dark olive green, finely laminated. Little mica, increased fines.		P-14	
			Trace mica.			
			Decreased fines, medium to fine sand. Partings of fine sand throughout.		Pull 15 Run-6.6 Rec-7.6	
	130		Trace shell fragments up to 0.01". laminae less pronounced, very stiff.		P-15 K-5	
-115.4'			(ML) Gray to dark gray indurated SILT, little fine sand, trace phosphatic grains, highly cemented.		P-16	
-117.5'			Some fine sand with trace dark mineral grains, moderately cemented.		Pull 16 Run-2.4 Rec-2.0	
-118.0'	135		(SM) Olive green silty medium to fine SAND, little phosphatic grains, laminated.		P-17	
			(ML) Gray to tan low plasticity SILT, trace fine sand, laminated, moderately cemented.			
	140				Pull 17 Run-9.6 Rec-2.2	
			Indurated.			
			Moderately to highly cemented, increased sand content.			
-127.4'	145		(SM)-MIOCENE B-Dark olive green to black fine phosphatic SAND, trace fine gravel.		P-18 K-6 P-19	MIOCENE A MIOCENE B
			Some silt.			
-132.1'	150		(ML) Gray, low plasticity SILT, little fine sand with trace dark mineral grains, trace phosphatic grains, hard.		Pull 18 Run-7.4 Rec-4.8	
					Pull 19 Run-3.6 Rec-0.0	
-138.7'	155		(SM) Gray silty fine SAND, little dark mineral grains, trace phosphatic grains.			

CONTINUED ON SHEET No. 5

DRILLING LOG (Cont Sheet)		ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9		
PROJECT SAVANNAH HARBOR DEEPENING		INSTALLATION SAVANNAH, GA		SHEET 5 OF 8 SHEETS		
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water logs, depth of weathering, etc. If significant) g Chloride (mg/L)
	155		SM (Continued):			0 1000 2000
	160		Olive green, no phosphatic grains. Decreased fines. Moderately cemented. Medium to fine sand.	Pull 20 Run=10.0 Rec=4.5	K-7 P-20	
	165			Pull 21 Run=8.5 Rec=1.3	P-21	
	170			Pull 22 Run=1.5 Rec=0.5	P-22	
	175		Fine sand, trace mica. Partings of fine sand with trace dark mineral grains occurring every 0.3 feet, not cemented.	Pull 23 Run=10.0 Rec=10.0	K-8 P-23	
-165.2'	180		(SC) Green fine clayey SAND, some dark mineral grains, laminated.		P-23	
	185			Pull 24 Run=10.0 Rec=6.8	K-9 P-24	
	190		Little dark mineral grains.		P-25	
	195		Some dark mineral grains.			

CONTINUED ON SHEET No. 6

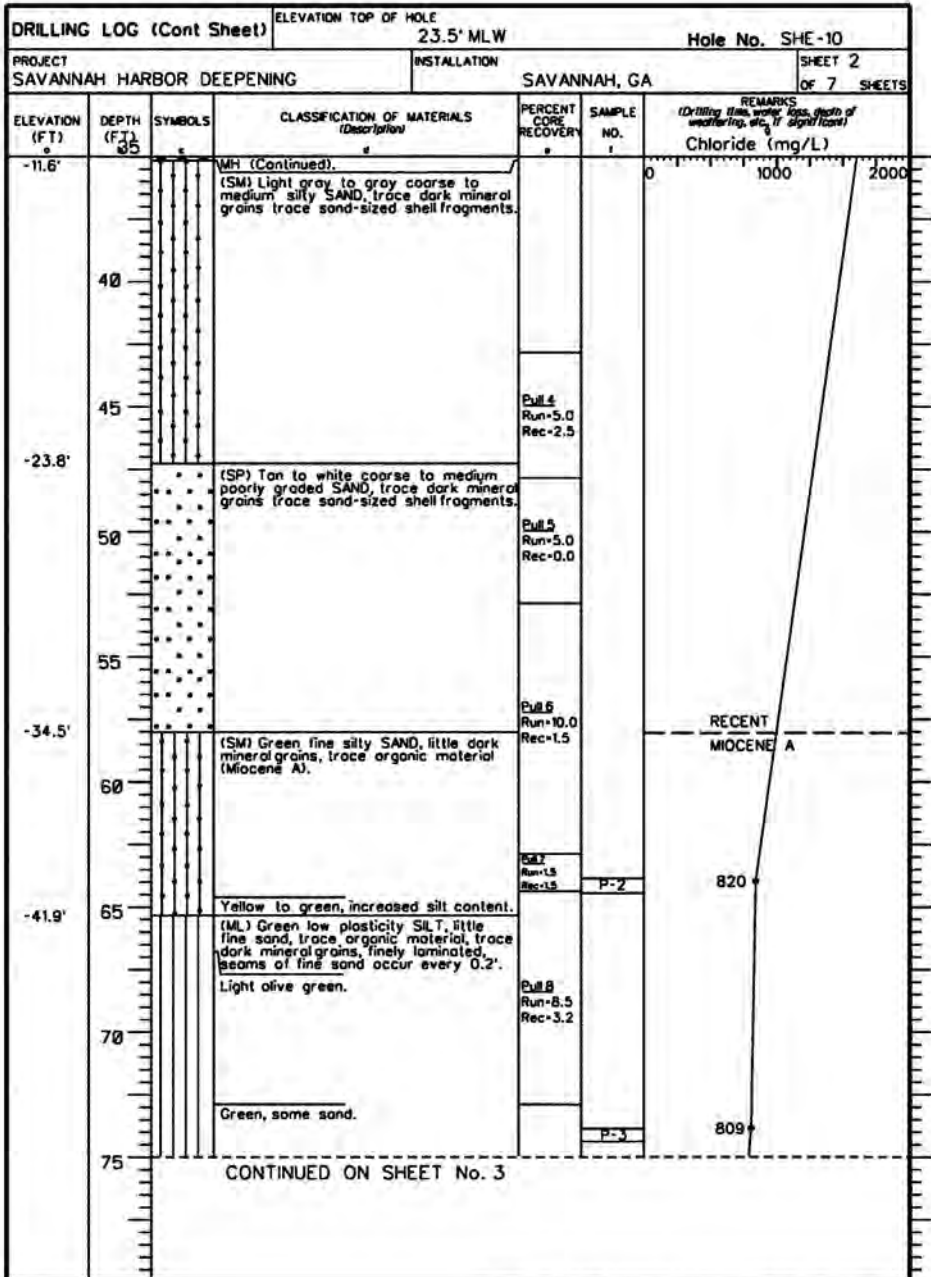
DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 6 OF 8 SHEETS	
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g Chloride (mg/L)
-180.6'	195		SC (Continued).			0 1000 2000
	200		(SM) Green fine silty SAND, some dark mineral grains, laminated. Occasional partings of fine sand with little dark mineral grains.	Pull 25 Run=8.8 Rec=7.6	P-26	
	205			Pull 26 Run=3.2 Rec=2.4	K-10 P-27	
-191.8'	210		(LS) Limestone, hard, slightly weathered, fine grained, gray to white, 15% dark phosphatic grains, HCl rxn.	Pull 27 Run=8.5 Rec=0.5		MIOCENE B LIMESTONE
	215		0.2' thick horizon of olive green high plasticity clay with trace fine quartz sand, trace phosphatic grains up to 0.25".	Pull 28 Run=1.5 Rec=0.2		
	220		0.2' thick horizon of olive green high plasticity clay with trace fine quartz sand, trace phosphatic grains up to 0.25".	Pull 29 Run=10.0 Rec=9.5	P-28	
	225		Burrow infilled with olive green silty fine to medium quartz SAND, trace phosphatic grains up to 0.3", trace shell fragments up to 0.25".			
	230		Moderately weathered, fossils present, moderately hard, burrow present at 220.6 infilled with silty, shelly sand same as above.			
	235		Slightly weathered.			
	240		Mottled red to green to gray, highly fossiliferous, very soft.			
	245		Cream with trace of green, vuggy, soft.			
	250		Horizons of mottled green to white to gray sandy material, very soft.			
	255		Cream, small vugs up to 0.1" fossiliferous, soft.	Pull 30 Run=10.0 Rec=10.5	P-29	
	260		Vuggy, vugs infilled with olive green silty material.			
	265		Vugs up to 0.25".			
	270		Very vuggy, highly fossiliferous, hard.			
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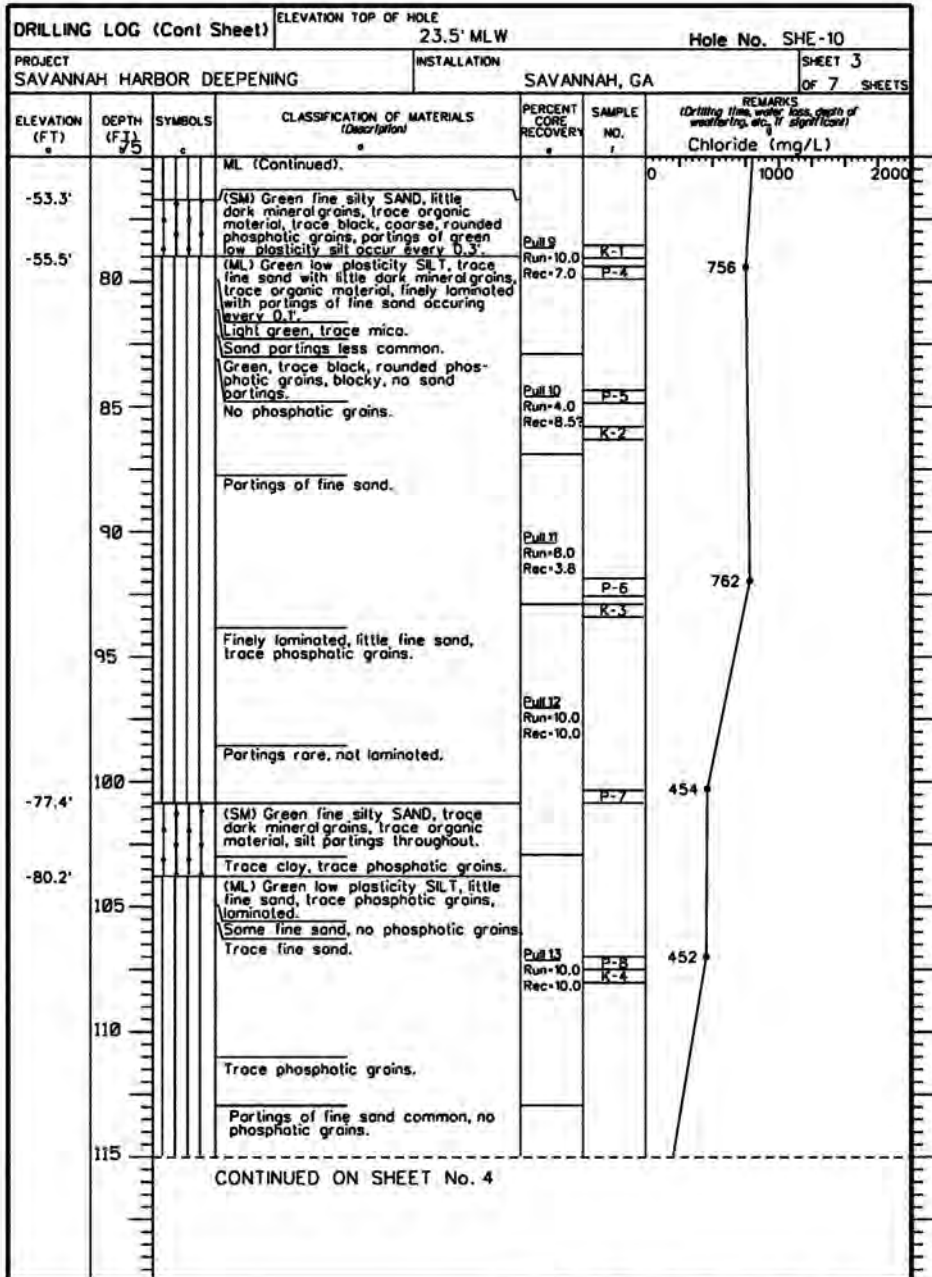
DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 7 OF 8 SHEETS	
ELEVATION (FT) e	DEPTH (FT) f	SYMBOLS g	CLASSIFICATION OF MATERIALS (Description) h	PERCENT CORE RECOVERY i	SAMPLE NO. j	REMARKS (Drilling time, water loss, depth of weathering, etc. if significant) k Chloride (mg/L)
	235		LS (Continued).			0 1000 2000
			Highly weathered, no vugs, some sand sized shell fragments, very soft.			
			Cream, vuggy, very fossiliferous, hard.			
	240		Highly weathered, no vugs, some shell fragments up to 0.25".	Pull 31 Run=10.0 Rec=10.0	P-30	
			Cream to white, hard, moderately weathered, small vugs.			
			Soft, highly weathered, 0.5" diameter burrow infilled with olive green silty material.			
	245					
	250		Very soft.	Pull 32 Run=10.0 Rec=4.9		
	255		Hard, vugs up to 0.5 inches, highly fossiliferous.		P-31	
			Very soft, cream to tan, no vugs.			
			1" horizon of hard, vuggy, fossiliferous material.			
	260		Moderately hard.	Pull 33 Run=10.0 Rec=9.3		
			Soft.			
	265		Moderately hard.		P-32	
			Soft.			
			Hard.			
	270		Soft.	Pull 34 Run=10.0 Rec=9.3		
-254.8'			Vuggy, hard, very fossiliferous.			
	275		Less vugs, moderately hard.			
CONTINUED ON SHEET No. 8						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 16.2' MLW		Hole No. SHE-9	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 8 OF 8 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
-269.7'	275	c	LS (Continued).	Full 35 Run=10.0 Rec=4.5		
	280					
	285					NOTE: Change of scale to 1" = 20' at 290.0'.
	290					Core logging stopped at 284.9'. Hole was advanced using 4" rock bit with no sample collection to final depth.
	310					
	330					
	350					
	370					
BOTTOM OF BORING AT 373.0'						

Hole No. SHE-10

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 OF 7 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) N-767200 E-1014100 GA EAST				11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500			
4. HOLE NO. (As shown on drawing title and file number) SHE-10				13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 0 UNDISTURBED : 0			
5. NAME OF DRILLER P. ROUNTREE				14. TOTAL NUMBER CORE BOXES 12			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >243.0'				16. DATE HOLE STARTED : 30 Jan 2002 COMPLETED : 15 Feb 2002			
8. DEPTH DRILLED INTO ROCK 10.0'				17. ELEVATION TOP OF HOLE 23.5' MLW			
9. TOTAL DEPTH OF HOLE 243.0				18. TOTAL CORE RECOVERY FOR BORING 74 %			
				19. SIGNATURE OF INSPECTOR C. SMITH			
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g	
23.5'	0					NOTE: Change of scale to 1"=5' at 10.0'.	
			Wash.			Chloride (mg/L) 0 1000 5100 5084	
11.5'			(SM) Gray to green fine silty SAND, trace dark mineral grains, trace mica, trace sand-sized shell fragments; mottled with gray to green low plasticity silt (dredge spoils).	Pull 1 Run=10.0 Rec=0.5		4374	
				Pull 2 Run=10.9 Rec=1.0		332	
-8.4'			(SW) Gray well graded SAND, trace fine gravel, trace fine dark mineral grains, trace sand-sized shell fragments, trace organic material.	Pull 3 Run=10.0 Rec=2.2		1769	
-9.0'			(MH) Gray to brown fat SILT, trace fine sand, trace fine gravel. Seams of fine sand with little mica. Organic material, soft, seams of lean silt and fine silty sand.		P-1		
	35		CONTINUED ON SHEET No. 2				NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.





DRILLING LOG (Cont Sheet)		ELEVATION TOP OF HOLE 23.5' MLW		Hole No. SHE-10		
PROJECT SAVANNAH HARBOR DEEPENING		INSTALLATION SAVANNAH, GA		SHEET 4 OF 7 SHEETS		
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY %	SAMPLE NO. I	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
	115		ML (Continued).		P-9 P-5	0 220 1000 2000
	120			Pull 14 Run=10.0 Rec=10.0		
	125			K-8 P-10		179
-103.5'			(SC) Green fine clayey SAND, some dark mineral grains.	Pull 15 Run=10.0 Rec=10.0	K-7 P-11	141
-106.6'	130		(CH) Green high plasticity CLAY, finely laminated partings of white calcareous material.			
	135		Trace organic material.		K-8 P-12	130
-114.1'			(SC) Green fine clayey SAND, trace organic material, laminated partings of fine sand.	Pull 16 Run=10.0 Rec=10.0		
-114.7'			(ML) Green low plasticity SILT, little fine sand, trace organic material, occasional partings of fine sand.			
-114.7'	140		Finely laminated with partings of white calcareous material, trace mica, trace dark mineral grains.		K-9 P-13	
-116.2'			(SP) Dark olive green fine poorly graded SAND, some dark mineral grains, trace organic material, trace rounded phosphatic grains.	Pull 17 Run=3.7 Rec=3.7		
	145		(SM) Dark olive green fine phosphatic silty SAND, some dark mineral grains, trace organic material.		K-10 P-14	475
-123.2'			Trace fine phosphatic gravel, silt partings.	Pull 18 Run=3.0 Rec=0.6		
	150		(LS) Limestone, fine grained, cream to gray little dark mineral grains, trace fine gravel, very hard.			
	155		Occasional partings of olive green silt up to 1" thick.	Pull 19 Run=3.3 Rec=3.5		

CONTINUED ON SHEET No. 5

CONTINUED ON SHEET No. 5

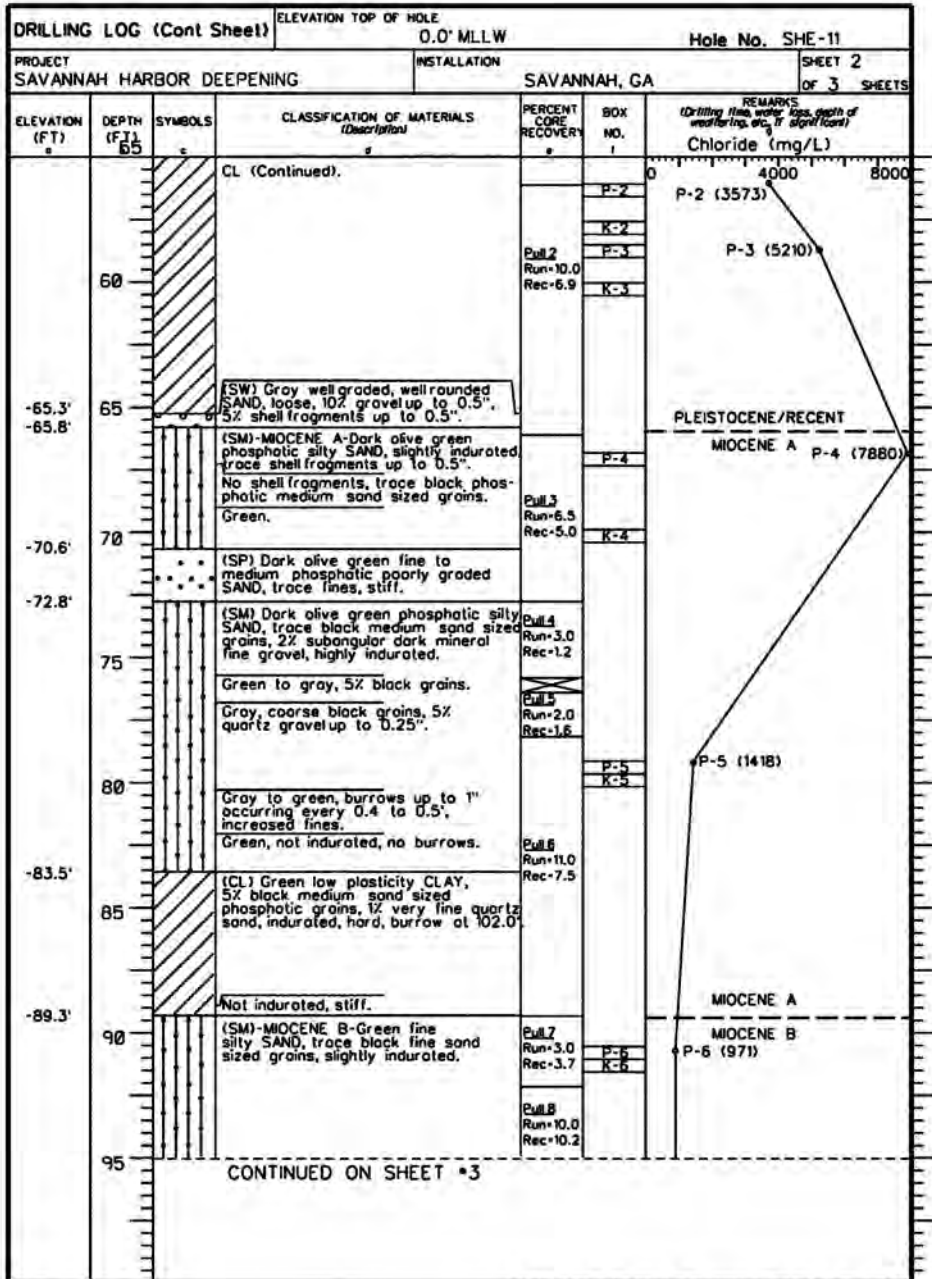
DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 23.5' MLW		Hole No. SHE-10	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 5 OF 7 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc. if significant) Chloride (mg/L)
	155	c	Limestone (Continued).			0 4000 8000
	160			Pull 20 Run=10.0 Rec=8.4	K-1 P-5	
	165				K-2 P-6	
	170		(SM) Green fine silty SAND, little dark mineral grains, trace clay, hard. Cream to green, very hard, trace mica. Partings of green silt up to 0.1" thick.	Pull 21 Run=10.0 Rec=10.0		MIOCENE A MIOCENE B
	175				P-7 K-3	
	180		Burrow present, concentric inclusion.			
	185			Pull 23 Run=6.3 Rec=6.3	K-4 P-8	
	190		(LS) Limestone, very hard, cream to black, fossiliferous, vuggy with coarse to medium sand filling in voids. Cream, less vugs. Mottled with black phosphatic coloration, less fossils. Little phosphatic fine gravel, voids are common and up to 1/8", silty sand filling in voids.	Pull 24 Run=3.7 Rec=2.0		MIOCENE B LIMESTONE
	195				P-19	
CONTINUED ON SHEET No. 6						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 23.5' MLW		Hole No. SHE-10	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 6 OF 7 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
	195	c	LS (Continued). Cream to gray, phosphatic zoning common, very fossiliferous, no fine gravel. Gray, vugs increase in size. Dissolution cavities, fine gravel filling in voids. No fine gravel, vuggy.	Pull 26 Run=8.6 Rec=8.0		
	200					
	205		Fine to medium grained, hard, voids are smaller, fossils are smaller and broken.	Pull 27 Run=10.0 Rec=10.0		
	210					
	215		Voids are up to 1/4" and common.	Pull 28 Run=10.0 Rec=8.2		
	220					
	225		Zones of grayish green silty material. Cream fossils are up to 1", vuggy. Not vuggy, fine grained, no large fossils. Vuggy with voids up to 1/2".	Pull 29 Run=10.0 Rec=9.1		
	230		Soft. Hard.			
	235		CONTINUED ON SHEET No. 7			

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 23.5' MLW		Hole No. SHE-10																																																																						
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 7 OF 7 SHEETS																																																																						
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc. if significant) g																																																																					
-219.5'	235		LS (Continued).	Pull 30 Run=10.0 Rec=9.5		NOTE: Change of scale to 1"=30' at 250.0'. Core logging stopped at 243.0'. Hole advanced to 270' using 9 7/8" rock bit in order to set 6" SS casing. Hole further advanced using 5 7/8" rock bit to final depth of 370.0'.																																																																					
240	Voids up to 1/4", fossils up to 1/2", soft. Voids less common, hard.																																																																										
245																																																																											
250																																																																											
280	280					<table border="1"> <thead> <tr> <th>Sample</th> <th>Top Depth</th> <th>Chloride (mg/L)</th> </tr> </thead> <tbody> <tr><td>10SP1</td><td>10.0</td><td>5086</td></tr> <tr><td>10SP2</td><td>20.0</td><td>4374</td></tr> <tr><td>10SP3</td><td>30.0</td><td>332</td></tr> <tr><td>P-1</td><td>33.5</td><td>1769</td></tr> <tr><td>P-2</td><td>63.8</td><td>820</td></tr> <tr><td>P-3</td><td>73.9</td><td>810</td></tr> <tr><td>P-4</td><td>79.4</td><td>756</td></tr> <tr><td>P-5</td><td>84.3</td><td>NV</td></tr> <tr><td>P-6</td><td>92.2</td><td>762</td></tr> <tr><td>P-7</td><td>100.4</td><td>454</td></tr> <tr><td>P-8</td><td>107.0</td><td>452</td></tr> <tr><td>P-9</td><td>115.6</td><td>220</td></tr> <tr><td>P-10</td><td>122.6</td><td>179</td></tr> <tr><td>P-11</td><td>128.5</td><td>141</td></tr> <tr><td>P-12</td><td>136.0</td><td>130</td></tr> <tr><td>P-13</td><td>143.5</td><td>NV</td></tr> <tr><td>P-14</td><td>152.5</td><td>76</td></tr> <tr><td>P-15</td><td>161.5</td><td>NV</td></tr> <tr><td>P-16</td><td>168.5</td><td>NV</td></tr> <tr><td>P-17</td><td>174.0</td><td>NV</td></tr> <tr><td>P-18</td><td>184.9</td><td>NV</td></tr> <tr><td>P-19</td><td>193.0</td><td>NV</td></tr> </tbody> </table> SP = Screen point sample NV = No value reported	Sample	Top Depth	Chloride (mg/L)	10SP1	10.0	5086	10SP2	20.0	4374	10SP3	30.0	332	P-1	33.5	1769	P-2	63.8	820	P-3	73.9	810	P-4	79.4	756	P-5	84.3	NV	P-6	92.2	762	P-7	100.4	454	P-8	107.0	452	P-9	115.6	220	P-10	122.6	179	P-11	128.5	141	P-12	136.0	130	P-13	143.5	NV	P-14	152.5	76	P-15	161.5	NV	P-16	168.5	NV	P-17	174.0	NV	P-18	184.9	NV	P-19	193.0	NV
Sample	Top Depth	Chloride (mg/L)																																																																									
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-346.5'	370	BOTTOM OF BORING AT 370.0'																																																																									
275																																																																											

Hole No. SHE-11

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 OF 3 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) X-1038083.3, Y-747009.2 GA EAST				11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500 CD-3			
4. HOLE NO. (As shown on drawing title and file number) SHE-11				13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 0 UNDISTURBED : 0			
5. NAME OF DRILLER D. HEWETT				14. TOTAL NUMBER CORE BOXES 5			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >140.0'				16. DATE HOLE STARTED : 09 Dec 2003 COMPLETED : 12 Dec 2003			
8. DEPTH DRILLED INTO ROCK 10.0'				17. ELEVATION TOP OF HOLE 0.0' MLLW			
9. TOTAL DEPTH OF HOLE 140.0'				18. TOTAL CORE RECOVERY FOR BORING 86 %			
				19. SIGNATURE OF INSPECTOR C. SMITH, G. TAYLOR, M. McINTOSH			
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	BOX NO.	REMARKS (Drilling time, water loss, depth of weathering, etc. if significant)	
0.0'	0						
-32.8'	30		Water.			NOTE: Change of scale to 1" = 5' at 30.0'. Set 73' of 6" casing to a depth of -54.8'. Began using Super Gel-X freshwater drilling mud at -32.0'. Grouted hole after completion of boring.	
-47.8'	35		Wash.				
-48.9'	40						
	45						
	50		(SM) Gray to green fine silty SAND, trace dark mineral grains, firm to stiff. (CL) Gray to green low plasticity CLAY, trace fine quartz sand, stratified structure, firm to stiff.	(Full) Run-8.5 Rec-8.5	P-1 K-1	Chloride (mg/L) 0 4000 8000 P-1 (5195)	
	55						
CONTINUED ON SHEET #2						NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.	



DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-11		
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA			SHEET 3 OF 3 SHEETS	
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	BOX NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)	
			SM (Continued).			0 4000 8000	
			Not indurated.	Pull 8 Run=10.0 Rec=10.2	P-7 K-7	P-7 (936)	
	100				P-8 K-8	P-8 (783)	
			Slightly indurated.				
	105			Pull 9 Run=9.5 Rec=9.7	P-9 K-9	P-9 (501)	
	110			Pull 10 Run=2.0 Rec=2.1		MIOCENE B	
-111.8'			(LS) Limestone, highly weathered, very fine to fine grained, few vugs up to 0.25", black, fossiliferous, weak HCl rxn.	Pull 11 Run=1.5 Rec=1.3		LIMESTONE	
			Moderately weathered, less vugs, gray, strong HCl rxn.	Pull 12 Run=1.5 Rec=1.2		Sample	Top Elev Mud Cond. (mS/cm)
	115		Slightly weathered, cream colored, 0.1" lens of slightly weathered, green to brown, moderate HCl rxn at 131.9'.	Pull 13 Run=2.0 Rec=2.3		P-1	-48.3 4.45
			Moderately weathered, gray to white, highly fossiliferous, strong HCl rxn.	Pull 14 Run=5.0 Rec=4.9		P-2	-56.3 5.83
	120					P-3	-58.8 6.14
						P-4	-66.8 6.22
						P-5	-79.3 5.98
						P-6	-90.8 7.82
						P-7	-97.5 7.93
						P-8	-100.8 5.43
						P-9	-106.5 6.50
-121.8'			BOTTOM OF BORING AT -121.8'				
	125						

Hole No. SHE-12

DRILLING LOG		DIVISION SOUTH ATLANTIC	INSTALLATION SAVANNAH, GA		SHEET 1 OF 2 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING			10. SIZE AND TYPE OF BIT 1 1/8" I. D. SPLITSPOON			
2. LOCATION (Coordinates or Station) X-1043110.36, Y-743816.9 GA EAST			11. DATUM FOR ELEVATION SHOWN (FSM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT			12. MANUFACTURER'S DESIGNATION OF DRILL FALLING 1500 CD-3			
4. HOLE NO. (As shown on drawing title and file number) SHE-12			13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 20 UNDISTURBED : 0			
5. NAME OF DRILLER D. HEWETT			14. TOTAL NUMBER CORE BOXES NONE			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.			15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >92.3'			16. DATE HOLE STARTED : 16 DEC 2003 COMPLETED : 17 DEC 2003			
8. DEPTH DRILLED INTO ROCK 0.0'			17. ELEVATION TOP OF HOLE 0.0' MLLW			
9. TOTAL DEPTH OF HOLE 92.3'			18. TOTAL CORE RECOVERY FOR BORING NONE			
			19. SIGNATURE OF INSPECTOR C. SMITH, M. MCINTOSH			
ELEVATION (FT) 0.0	DEPTH (FT) 0	SYMBOLS e	CLASSIFICATION OF MATERIALS (Description) e	PERCENT MOISTURE CONTENT e	JAR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g BLOWS/FT.
			Water.			NOTE: Change of scale to 1" = 5' at 60.0'. Set 65' of casing to a depth of -46.9'. Began using Super Gef-X freshwater drilling mud at -45.9'. Grouted hole after completion of boring.
-45.9			(SP) Tan fine poorly graded SAND, trace dark mineral grains, trace shell fragments up to 0.5", wet.		1	
-47.4			(SC) Dark gray medium to fine clayey SAND, trace dark mineral grains, moderate HCl rxn, moist.		2	Switch to saltwater drilling mud.
-47.9			(SP) Dark gray fine poorly graded SAND, little dark mineral grains, trace shell fragments up to 0.25", not cemented, strong HCl rxn, wet.		3	
			No shells, trace well rounded fine gravel, trace fines.		4	
			No fine gravel, little fines.		5	
			Lens of dark gray low plasticity clay, trace very fine quartz sand.		6	
-55.1			(SM) Dark gray fine silty SAND, trace dark mineral grains, not cemented, partings of white fine calcareous material, stiff.		7	
			No white partings, finely laminated.		8	
-57.9			(ML) Gray to green low plasticity SILT, silt, not cemented, blocky, strong HCl rxn, dry. Burrow and partings present filled with medium to fine sand, trace dark mineral grains, trace shell fragments up to 0.25".		9	
			No burrows, trace medium to fine sand, moist.		10	
-60.6			(SM) Gray to green fine silty SAND, little dark mineral grains, strong HCl rxn, not cemented, moist.		11	
			Partings of white calcareous material.		12	
					13	
CONTINUED ON SHEET #2						
NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASS- IFICATION SYSTEM.					BLOWS PER FOOT: NUMBER REQUIRED TO DRIVE 1 1/8" I. D. SPLITSPOON W/140 LB. HAMMER FALLING 30".	

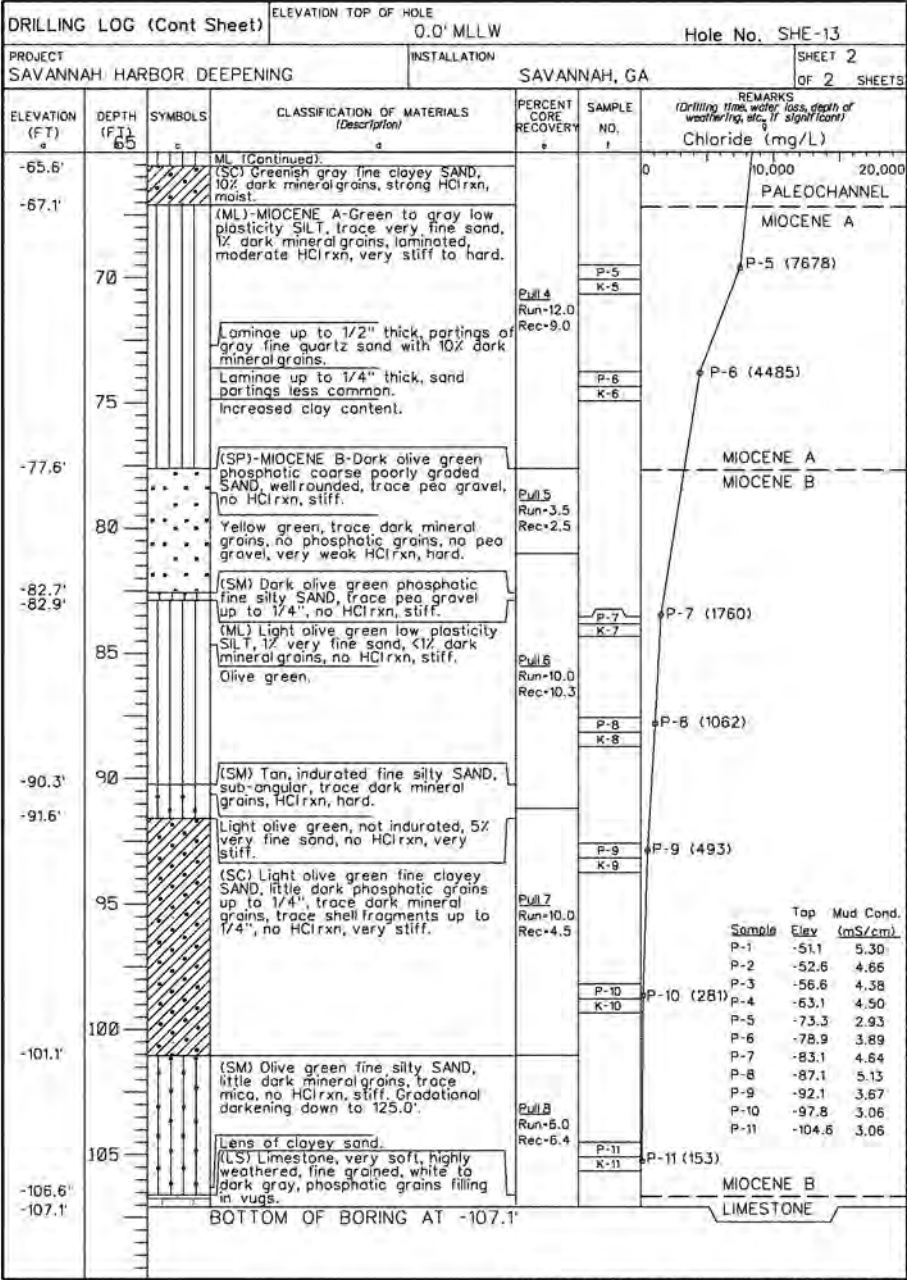
DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-12	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 2 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT MOISTURE CONTENT	JAR SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
-65.4	65		SM (Continued). (SP) Gray, fine to medium poorly graded SAND, trace mica, trace dark mineral grains, trace shell fragments up to 1/16". Little shell fragments, little fines.		13	
					14	
					15	
	70		(ML) Grayish green low plasticity SILT, trace very fine sand, no cementation, blocky, moderate HCl rxn, dry (MIOCENE A). Some fine sand, trace heavy mineral grains.		16	PALEOCHANNEL
-71.0			Partings of fine quartz sand occurring every 0.3 inches. Orange colored partings at 90.8'.		17	MIOCENE A
					18	
					19	
-74.2	75				20	
BOTTOM OF BORING AT 74.2'						

Hole No. SHE-13

DRILLING LOG		DIVISION SOUTH ATLANTIC	INSTALLATION SAVANNAH, GA	SHEET 1 OF 2 SHEETS
1. PROJECT SAVANNAH HARBOR DEEPENING			10. SIZE AND TYPE OF BIT HQ CORE BARREL	
2. LOCATION (Coordinates or Station) X-1043732, Y-743660 GA EAST			11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLLW	
3. DRILLING AGENCY SAVANNAH DISTRICT			12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500 CD-3	
4. HOLE NO. (As shown on drawing title and file number) SHE-13			13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 0 UNDISTURBED :	
5. NAME OF DRILLER D. HEWETT			14. TOTAL NUMBER CORE BOXES 5	
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.			15. GROUND WATER ELEVATION N/A 0	
7. THICKNESS OF OVERBURDEN >125.5'			16. DATE HOLE STARTED : 12 Jan 2004 COMPLETED : 14 Jan 2004	
8. DEPTH DRILLED INTO ROCK 0.5'			17. ELEVATION TOP OF HOLE 0.0' MLLW	
9. TOTAL DEPTH OF HOLE 125.5'			18. TOTAL CORE RECOVERY FOR BORING 80 %	
19. SIGNATURE OF INSPECTOR C. SMITH, G. TAYLOR, M. McINTOSH				

ELEVATION (FT) 0.0	DEPTH (FT) 0	SYMBOLS E	CLASSIFICATION OF MATERIALS (Description) e	PERCENT CORE RECOVERY e	SAMPLE NO. i	REMARKS (Drilling time, water loss, depth of weathering, etc., if slight loss) e
			Water.			NOTE: Change of scale to 1" = 5' at 60.0'. Set 73' of 6" casing to a depth of -54.6'. Began using Super Gel-X freshwater drilling mud @ -44.6'. Grouted hole after completion of boring.
-44.6'	45		BOTTOM OF RIVER AT -44.6'			Chloride (mg/L) 0 10,000 20,000
			(SC) Gray, fine clayey SAND, 3% shell fragments up to 1/4", 2% dark mineral grains, HClrxn, wet, sulfur odor.	Bull 1 Run-10.0 Rec-4.5	P-1 K-1 P-2	NOTE: Samples K-3, and K-4 do not exist.
-51.1'	50		(SM) Gray, medium to fine silty SAND, 10% shell fragments up to 1/8", 10% dark mineral grains, 1% micaceous material, HClrxn, moist.			P-1 (17,423) P-2 (19,760)
-54.6'	55		(SC) Gray, fine clayey SAND, 3% shell fragments up to 1/4", 2% dark mineral grains, HClrxn, wet, sulfur odor. Occasional interbedded clayey sand and laminated silt in layers from 1/2" to 2" thick. Greenish gray, clay layers thicker.	Bull 2 Run-5.0 Rec-5.0	P-3 K-2	P-3 (16,518)
-59.9'	60		(ML) Greenish gray low plasticity SILT, 2% very fine sand, not cemented, laminated, strong HClrxn, dry.			
-62.6'			(SC) Gray fine clayey SAND, 3% shell fragments up to 1/8" inches, 1% dark mineral grains, weak HClrxn, wet.	Bull 3 Run-5.5 Rec-3.0	P-4	P-4 (9973)
-64.6'	65		Trace gravel up to 1", 1" calcareous shell fragment at 81.7'. (ML) Greenish gray low plasticity SILT, 2% very fine sand, not cemented, blocky, strong HClrxn, dry.			NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

CONTINUED ON SHEET #2



Hole No. SHE-14

DRILLING LOG		DIVISION SOUTH ATLANTIC	INSTALLATION SAVANNAH, GA		SHEET 1 OF 2 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING			10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) X-1055157, Y-743062 GA EAST			11. DATUM FOR ELEVATION SHOWN (ITM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT			12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500 CD-3			
4. HOLE NO. (As shown on drawing title and file number) SHE-14			13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED 0 UNDISTURBED 0			
5. NAME OF DRILLER D. HEWETT			14. TOTAL NUMBER CORE BOXES 5			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.			15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >119.0'			16. DATE HOLE STARTED 21 Jan 2004 COMPLETED 24 Jan 2004			
8. DEPTH DRILLED INTO ROCK 0.5'			17. ELEVATION TOP OF HOLE 0.0' MLLW			
9. TOTAL DEPTH OF HOLE 119.0'			18. TOTAL CORE RECOVERY FOR BORING 82 %			
			19. SIGNATURE OF INSPECTOR C. SMITH, G. TAYLOR, M. McINTOSH			
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			Water.			
			BOTTOM OF RIVER AT -34.3'			
-34.3'	35		(SM) Tan to black, medium to coarse silty SAND, little oyster shells up to 0.1", trace fine gravel, trace fine dark mineral grains, not cemented, no HCl rxn, wet.	Pull 1 Run=10.0 Rec=2.0		NOTE: Change of scale to 1" = 5' at 30.0'. Set 68' of 6" casing to a depth of -49.3'. Began using Super Gel-X freshwater drilling mud at -34.3'. Grouted hole after completion of boring.
-42.8'	40					
-43.3'	45		(SP) Tan fine to medium well rounded poorly graded SAND.			Chloride (mg/L)
-44.3'			(SW) White to black well rounded well graded SAND, 5% gravel up to 1", trace fines.		K-1 P-1	P-1 (14,405)
-47.1'	50		(ML) Greenish gray, stiff, medium plasticity SILT, trace very fine sand, finely laminated, moist.			PALEOCHANNEL MIOCENE A
			(SM) MIOCENE A-Greenish gray fine quartz silty SAND, trace dark mineral grains, trace mica, weak HCl rxn, moist.	Pull 2 Run=10.0 Rec=10.6		
			Partings of gray very fine quartz sand, trace dark mineral grains, no HCl rxn, moist.			
			Finely laminated.		K-2 P-2	P-2 (5199)
			Laminated, trace dark mineral grains.			
			Finely laminated.			
	55		Decreased fines, wet, not laminated, no partings.			
			Laminated, moist.	Pull 3 Run=10.0 Rec=5.9	K-3 P-3	P-3 (6570)
	60					
CONTINUED ON SHEET *2						NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-14	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 2 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if signif/cont) Chloride (mg/L)
	60		SM (Continued).			0 10,000 20,000
-62.9'			(SW) Gray to green wellgraded SAND, little medium to fine dark mineral grains, trace shell fragments up to 0.01", trace fines, weak HClrxn, soft, wet.			
-64.3'	65		(SP) Tan to black and dark olive green mottled fine poorly graded wellrounded phosphatic SAND, trace coarse grains, trace shell fragments, no HClrxn, wet.		K-4 P-4 P-4c	P-4 (14,688) P-4c (13,334) P-4c (15,916)
-67.9'			(SM)-MIOCENE B-Dark olive green fine phosphatic silty SAND, trace fine gravel, wet.	Pull 4 Run=10.0 Rec=10.0		MIOCENE A MIOCENE B
-69.8'	70		(SC) Light olive green fine clayey quartz SAND, trace dark mineral grains, blocky, very stiff, dry.		K-5 P-5	P-5 (2710)
			Olive green.			
	75		Decreased clay content.		K-6 P-6	P-6 (462)
-77.4'			(SM) Olive green fine silty SAND, trace dark mineral grains, blocky, very stiff, dry.	Pull 5 Run=10.0 Rec=10.2		
	80				K-7 P-7	P-7 (186)
			Layers of olive green very stiff silt up to 1".			Top Mud Cond. Sample Elev (mS/cm)
	85		No silt layers.			P-1 -45.4 4.00
			Some dark mineral grains.			P-2 -53.1 4.00
						P-3 -56.8 2.30
						P-4 -65.8 3.10
						P-4c -65.8 3.10
						P-4c -66.3 3.10
						P-5 -71.8 3.10
						P-6 -76.9 3.66
						P-7 -81.8 3.66
						P-8 -87.3 3.66
						P-9 -93.0 3.66
						P-10 -96.3 2.38
	90		Decreased silt content, hard.	Pull 6 Run=10.0 Rec=10.2	K-8 P-8	P-8 (257)
			Finely laminated.			
-93.5'			(SP) Dark olive green fine phosphatic SAND, some rounded dark mineral grains, little fines, very stiff, moist.		K-9 P-9	P-9 (69)
-94.2'	95		(LS) Limestone, highly weathered, aphanitic black, HClrxn, shattered.			MIOCENE B LIMESTONE
			Very soft, fine grained, white, little dark mineral grains, little shell fragments up to 0.25", strong HClrxn.	Pull 7 Run=8.0 Rec=5.5	P-10	P-10 (151)
			Tan.			
-100.3'	100		BOTTOM OF BORING AT -100.3'			

Hole No. SHE-15

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 OF 5 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) E-979959.61, N-769041.05 GA EAST				11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500			
4. HOLE NO. (As shown on drawing title and file number) SHE-15				13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 0 UNDISTURBED : 0			
5. NAME OF DRILLER D. HEWETT				14. TOTAL NUMBER CORE BOXES 14			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >224.5'				16. DATE HOLE STARTED : 13 APR 2004 COMPLETED : 16 APR 2004			
8. DEPTH DRILLED INTO ROCK 10.2'				17. ELEVATION TOP OF HOLE 0.0' MLLW			
9. TOTAL DEPTH OF HOLE 224.5'				18. TOTAL CORE RECOVERY FOR BORING 83 %			
				19. SIGNATURE OF INSPECTOR C. SMITH/M. MCINTOSH			
ELEVATION (FT) 0.0	DEPTH (FT) 0	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)	
						NOTE: Change of scale to 1" = 5' at 30.0'. Set 71' of 6" casing to a depth of -37.6'. Began using Super Gel-X freshwater drilling mud at -34.3'. Grouted hole upon completion of boring.	
			Water.				
			BOTTOM OF RIVER AT -34.3'			Chloride (mg/L)	
			(MH) Dark gray to black fat SILT, soft, wet.	Pull 1 Run-5.0 Rec-0.0		0 4000 8000	
			Brown to gray.				
				Pull 2 Run-5.0 Rec-2.0	P-1	P-1 (2710)	
				Pull 3 Run-5.0 Rec-1.5			
			(SP) Gray to brown medium to fine poorly graded SAND, trace black grains, soft, mottled with gray fat silt from above.		P-2	P-2 (3237)	
			(SW) Gray to brown well graded SAND, trace black grains, trace mica, trace fine gravel, soft.	Pull 4 Run-5.0 Rec-4.2		RECENT	
			(ML) Gray to green lean SILT laminated, blocky texture, stiff (Miocene A).		P-3	P-3 (7209)	
			Clayey, silt laminated, soft.		P-4	P-4 (3573)	
			CONTINUED ON SHEET No. 2			NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.	

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-15	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 5 SHEETS	
ELEVATION (FT) e	DEPTH (FT) 65	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
-55.6'			ML (Continued). (SC) Green fine clayey sand, soft.	Pull 5 Run-5.0 Rec-5.0	K-1	0 4000 8000 P-5 (1400)
-59.3'	60		(SM) Green to gray fine silty SAND, trace organic matter, laminated, firm to stiff. Gray, very stiff.	Pull 6 Run-5.0 Rec-5.3	K-2 P-6	P-6 (280)
	65		Green, firm.			
	70		Hard.	Pull 7 Run-10.0 Rec-10.0		
-74.3'			Occasional partings of gray fine sand.		K-3	
	75		(ML) Green lean SILT, laminated, hard, partings of fine sand occur every ~0.5'.		P-7	P-7 (130)
-77.5'			(SM) Green fine silty SAND, laminated, firm to stiff. Very stiff to hard.	Pull 8 Run-10.0 Rec-10.0		
	80					
-83.7'			(ML) Greenish gray lean SILT, little organic matter, laminated, hard.		K-4	
	85		Clayey. Trace clay.	Pull 9 Run-10.0 Rec-8.0		
-89.5'	90		(SM) Green fine silty SAND, little organic matter, little mica, laminated, stiff.		P-8	P-8 (92)
			Partings of gray fine sand.			
	95		CONTINUED ON SHEET No. 3			

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-15	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 3 OF 5 SHEETS	
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g Chloride (mg/L)
			SM (Continued).		K-5	0 4000 8000
-97.3'	100		(SC) Gray fine clayey SAND, trace mica, trace organic matter, HClrxn, firm.	Pull 10 Run=8.0 Rec=8.2		
-101.4'			(SM) Green fine silty SAND, little black grains, trace organic matter, HClrxn, stiff.		P-9	P-9 (45)
-103.1'			Clayey, weak HClrxn, hard.			
	105		(ML) Green lean SILT, laminated, HClrxn, hard.	Pull 11 Run=10.0 Rec=5.0		
-107.1'			(SM) Green fine silty SAND, trace organics, weak HClrxn, hard.		P-10	P-10 (192)
	110				K-6	
					P-11	P-11 (173)
-115.8'	115		(SC) Green fine clayey SAND, trace mica, finely laminated, weak HClrxn, firm to stiff.	Pull 12 Run=10.0 Rec=9.0		
	120		Phosphatic, medium to fine.		P-12	P-12 (51)
-122.1'			(SP) Tan fine poorly graded SAND, little dark grains, indurated.	Pull 13 Run=2.0 Rec=2.0		
-123.6'			Partings of green clayey sand every 0.5'		P-13	P-13 (51)
-124.4'	125		(SC) Tan to yellow fine clayey SAND, trace fine phosphatic grains, HClrxn, stiff to hard.	Pull 14 Run=1.0 Rec=1.0		
			Green.			
-127.3'			(SP) Tan fine poorly graded SAND, trace dark grains, weak HClrxn very stiff, partings of green clayey sand throughout.	Pull 15 Run=2.0 Rec=0.5		
-128.5'			No partings, hard.			
-131.0'	130		(SM) Brown to green fine silty SAND, laminated, firm.	Pull 16 Run=9.0 Rec=6.8		
			(SP) Gray medium to fine poorly graded SAND, some dark grains, soft to firm, 0.1' horizons of green lean clay occur every ~0.4'.			
-134.1'	135		(CL) Green lean CLAY, finely laminated, stiff, partings of gray fine sand every ~0.5' (Miocene B). Tan colored parting. Tan colored parting. (SC) Grayish green fine clayey SAND, laminated, weak HClrxn, stiff to hard.			
CONTINUED ON SHEET No. 4						
MIOCENE A						
MIOCENE B						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-15	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 4 OF 5 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, grade of weathering, etc., if significant) Chloride (mg/L)
	135		SC (Continued).			
			Trace phosphatic grains, firm.			
			Partings of tan lean clay occur throughout, very stiff.			
			Partings every ~0.5'.			
	140		No partings, medium to fine sand, hard.			
				Pull 17 Run=10.0 Rec=9.5		
	145		Green, fine sand.			
				K-8 P-15	P-15 (12)	
	150		Increased silt content.			
-150.5'			(SM) Green fine silty SAND, weak HCl rxn, hard.			
-152.0'			(SC) Green fine clayey SAND, laminated, weak HCl rxn, hard.			
-152.9'			(SM) Green fine silty SAND, trace mica, blocky, very stiff to hard.			
	155					
					P-16 K-9	P-16 (22)
	160					
				Pull 19 Run=6.0 Rec=6.0		
	165					
	170					
					K-10 P-17	P-17 (11)
	175					
CONTINUED ON SHEET No. 5						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-15																																																													
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 5 OF 5 SHEETS																																																													
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling fluid, water loss, depth of weathering, etc., if significant) Chloride (mg/L)																																																												
	175		SM (Continued).			0 4000 8000																																																												
-178.8'	180		(CL) Green sandy lean CLAY, weak HCl rxn, hard, sand is fine grained with some dark grains.	Pull 21 Run=9.5 Rec=9.3	P-18 (15)																																																													
-184.8'	185		(SC) Green fine clayey SAND, some black grains, trace phosphatic grains, HCl rxn, hard.	Pull 22 Run=6.0 Rec=6.0																																																														
-191.5'	190		Parting of green lean clay, very stiff. Interbedded ~0.4' thick layers of stiff lean clay and hard fine clayey sand from above.																																																															
-194.4'	195		(SM) Green fine silty SAND, some black grains, trace phosphatic grains, hard. (SC) Green fine clayey SAND, trace phosphatic grains, very stiff to hard, 0.1' horizon of tan sandy lean clay, tan to green. Little coarse sand sized phosphatic grains. Interbedded tan lean clay and green silty sand. Tan, trace shell fragments, strong HCl rxn, hard.	Pull 23 Run=10.0 Rec=10.0	P-19 (24)																																																													
-197.6'	200		(LS) Limestone, highly weathered, ophanitic, block, very hard. Hard, slightly weathered, fine grained, tan, pitted, coarse sand to fine gravel sized phosphatic grains throughout. Soft, slightly fossiliferous. Moderately hard, pitted, burrow infilled with green, shelly, phosphatic lean clay.			MIOCENE B LIMESTONE																																																												
	205		Porous.	Pull 24 Run=10.0 Rec=5.0																																																														
-207.8'	210		0.2' layer of green, shelly, phosphatic lean clay, soft. Moderately hard, tan. Highly weathered, ophanitic, block, very hard. Slightly weathered, fine grained, tan, soft, some coarse sand sized phosphatic grains, slightly fossiliferous.																																																															
	215		BOTTOM OF BORING AT -207.8'																																																															
						<table><tr><th>Sample</th><th>Top Elev.</th><th>Mud Cond.</th></tr><tr><td>p-1</td><td>-41.3</td><td>2.70</td></tr><tr><td>p-2</td><td>-48.9</td><td>2.66</td></tr><tr><td>p-3</td><td>-52.5</td><td>2.66</td></tr><tr><td>p-4</td><td>-57.0</td><td>2.28</td></tr><tr><td>p-5</td><td>-64.4</td><td>2.85</td></tr><tr><td>p-6</td><td>-74.9</td><td>2.15</td></tr><tr><td>p-7</td><td>-89.2</td><td>1.23</td></tr><tr><td>p-8</td><td>-101.8</td><td>1.07</td></tr><tr><td>p-9</td><td>-111.7</td><td>1.00</td></tr><tr><td>p-10</td><td>-114.3</td><td>1.00</td></tr><tr><td>p-11</td><td>-120.8</td><td>1.00</td></tr><tr><td>p-12</td><td>-120.8</td><td>1.00</td></tr><tr><td>p-13</td><td>-123.6</td><td>2.42</td></tr><tr><td>p-14</td><td>-135.8</td><td>2.43</td></tr><tr><td>p-15</td><td>-145.2</td><td>2.15</td></tr><tr><td>p-16</td><td>-152.0</td><td>1.36</td></tr><tr><td>p-17</td><td>-171.0</td><td>0.95</td></tr><tr><td>p-18</td><td>-180.5</td><td>1.01</td></tr><tr><td>p-19</td><td>-193.6</td><td>0.93</td></tr></table>	Sample	Top Elev.	Mud Cond.	p-1	-41.3	2.70	p-2	-48.9	2.66	p-3	-52.5	2.66	p-4	-57.0	2.28	p-5	-64.4	2.85	p-6	-74.9	2.15	p-7	-89.2	1.23	p-8	-101.8	1.07	p-9	-111.7	1.00	p-10	-114.3	1.00	p-11	-120.8	1.00	p-12	-120.8	1.00	p-13	-123.6	2.42	p-14	-135.8	2.43	p-15	-145.2	2.15	p-16	-152.0	1.36	p-17	-171.0	0.95	p-18	-180.5	1.01	p-19	-193.6	0.93
Sample	Top Elev.	Mud Cond.																																																																
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Hole No. SHE-16

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 OF 3 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) E-1066369, N-744241 GA EAST				11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500			
4. HOLE NO. (As shown on drawing title and file number) SHE-16				13. TOTAL NO. OF SOIL SAMPLES TAKEN : DISTURBED : 0 : UNDISTURBED : 0			
5. NAME OF DRILLER D. HEWETT				14. TOTAL NUMBER CORE BOXES 7			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >112.3'				16. DATE HOLE : STARTED : 27 APR 2004 : COMPLETED : 28 APR 2004			
8. DEPTH DRILLED INTO ROCK 13.5'				17. ELEVATION TOP OF HOLE 0.0' MLLW			
9. TOTAL DEPTH OF HOLE 112.3'				18. TOTAL CORE RECOVERY FOR BORING 87 %			
				19. SIGNATURE OF INSPECTOR C. SMITH/M. McINTOSH			
ELEVATION (FT)	DEPTH (FT)	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) #	PERCENT CORE RECOVERY %	SAMPLE NO. I	REMARKS (Drilling time, water loss, depth of weathering, etc. If significant)	
0.0	0						
	30		Water.			NOTE: Change of scale to 1" = 5' at 30.0'. Set 63' of 6" casing to a depth of -43.8'. Began using Super Gel-X freshwater drilling mud at -37.3'. Grouted hole upon completion of boring.	
	35						
	-37.3'		BOTTOM OF RIVER AT -37.3'			Chloride (mg/L) 0 3000 6000 13000	
	40		(SC) Green fine shelly clayey SAND, trace rounded, coarse sand-sized phosphatic grains, strong HClrxn, very stiff (Miocene A). Trace sand sized shell fragments.	Full Run=5.5 Rec=4.0		P-1 (12,381)	
	-43.4'				P-1		
	45		(SM) green fine silty SAND, trace phosphatic grains, trace sand sized shell fragments, strong HClrxn, stiff.	Full Run=5.0 Rec=5.0		K-1	
	50		Some phosphatic grains. Very stiff.		P-2	P-2 (5252)	
	-52.7'		(SC) Green fine clayey SAND, little phosphatic grains, strong HClrxn, stiff.	Full Run=5.0 Rec=4.8		P-3	
	55		Phosphatic. 0.1 lens of shelly clayey sand.	Full Run=5.0 Rec=5.0		P-3 (2810)	
	-55.0'				K-2		
CONTINUED ON SHEET No. 2				NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.			

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-16	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 3 SHEETS	
ELEVATION (FT) ±	DEPTH (FT) ±	SYMBOLS ±	CLASSIFICATION OF MATERIALS (Description) ±	PERCENT CORE RECOVERY ±	SAMPLE NO. ±	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) ±
-55.8'	55		SC (Continued).			Chloride (mg/L)
-57.2'			Dark green to brown to black, highly phosphatic, very stiff.			0 3000 6000 13000
			(ML) Gray to tan lean SILT, hard, mottled with phosphatic clayey sand from above		P-4	P-4 (1245)
			(SM) Green to black phosphatic fine silty SAND, hard.			
			Very stiff.			
	60		Trace coarse sand sized rounded phosphatic grains.	Pull 5 Run=5.0 Rec=5.0		
			Hard.			
			Some coarse sand sized rounded phosphatic grains.		P-5	P-5 (630)
			Soft, trace coarse sand sized rounded phosphatic grains.	Pull 5 Run=2.5 Rec=2.5		
			Very stiff.			
-64.9'	65		Trace shell fragments.			
			(ML) Tan lean SILT, trace fine sand is phosphatic, weak HCl rxn, indurated.	Pull 7 Run=3.5 Rec=1.7		
			0.1" diameter burrow infilled with green to black silty sand.			
	70		Green, hard. Partings of tan and black fine sand occurring ~1.0' (Miocene B).		P-6 K-3	P-6 (176) MIOCENE A MIOCENE B
				Pull 8 Run=8.0 Rec=8.0		
	75		Sand partings occurring every ~0.5'.			
	80		Sand partings throughout.		P-7 K-4	P-7 (66)
-80.5'			(SM) Green fine silty SAND, finely laminated, rare partings of lean silt, hard.	Pull 9 Run=10.0 Rec=10.0		
	85					
-87.9'			(ML) Green lean SILT, trace fine sand is black, hard.			
-90.0'	90		(SM) Green fine silty SAND, finely laminated, rare partings of lean silt, hard.	Pull 10 Run=10.0 Rec=10.0	P-8 K-5	P-8 (24)
-94.4'	95		(ML) Green lean SILT, trace fine sand is black, hard.			
			CONTINUED ON SHEET No. 3			

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-16	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 3 OF 3 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
			ML (Continued).			Chloride (mg/L) //
			0.5' horizon of green sandy fat clay.			0 3000 6000 13000
-96.7'			(SM) green fine silty SAND, laminated, hard.	P-11 Run-4.0 Rec-4.0	P-9 (17)	MIOCENE B
-98.8'	100		(LS) Limestone, soft, fine grained, gray to white, friable, slightly weathered.	P-12 Run-1.5 Rec-1.5	P-10 (24)	LIMESTONE
			0.5% phosphatic grains.			
			0.2' lens of green lean silt.			
			Hard, 50% coarse grains, white to gray, rare vugs.			
			Burrow infilled with shelly phosphatic silty sand.			
	105		Aphanitic, white, highly fossiliferous.	P-13 Run-10.0 Rec-4.0		
	110					
-112.3'			BOTTOM OF BORING AT -112.3			
	115					Sample Top Mud Cond. Elev. (mS/cm)
					P-1	-42.0 1.98
					P-2	-46.8 2.25
					P-3	-51.8 2.25
					P-4	-56.8 2.31
					P-5	-61.8 1.20
					P-6	-69.8 1.75
					P-7	-79.8 1.77
	120				P-8	-89.8 1.77
					P-9	-97.8 0.72
					P-10	-99.8 0.72
	125					
	130					
	135					

Hole No. SHE-17

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 OF 3 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinates or Station) X-1062567, Y-743811 GA EAST				11. DATUM FOR ELEVATION SHOWN (FSM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500 CD-3			
4. HOLE NO. (As shown on drawing title and file number) SHE-17				13. TOTAL NO. OF SOIL SAMPLES TAKEN DISTURBED : 0 UNDISTURBED : 0			
5. NAME OF DRILLER D. HEWITT				14. TOTAL NUMBER CORE BOXES 6			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >128.0'				16. DATE HOLE : STARTED : 05 May 2004 : COMPLETED : 06 May 2004			
8. DEPTH DRILLED INTO ROCK 0.5'				17. ELEVATION TOP OF HOLE 0.0' MLLW			
9. TOTAL DEPTH OF HOLE 128.0'				18. TOTAL CORE RECOVERY FOR BORING 67 %			
				19. SIGNATURE OF INSPECTOR C. SMITH, M. MCINTOSH			

ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
0.0	0		Water.			NOTE: Change of scale to 1" = 5' at 37.5'.
-38.4'	40		BOTTOM OF RIVER AT -38.4'			Chloride (mg/L) 0 8,000 16,000 P-1 (15,601)
	45		(MH) Gray, fat SILT, trace mica, trace sand sized shell fragments, stiff, partings of fine sand occur every ~1.0'.	Pull 1 Run=5.0 Rec=4.2	P-1	Set 71' of 6" casing to a depth of -52.9'. Began using Super Gel-X freshwater drilling mud @ -38.4'. Grouted hole after completion of boring.
	50		Sand partings every ~0.5', blocky texture. Partings of white calcareous material occur every ~1.0'. Laminated.	Pull 2 Run=5.0 Rec=4.0	P-2	P-2 (6548)
-52.9'	55		(SM) Gray, silty fine SAND, slightly calcareous, soft.	Pull 3 Run=5.0 Rec=5.4	P-3	P-3 (2666)
-53.4'	60		(MH) Gray fat SILT, partings of calcareous fine sand occur every ~1.0'.	Pull 4 Run=10.0 Rec=6.6	P-4	P-4 (2791) RECENT MIOCENE A P-5 (1663)
-58.4'	65		(SM)-MIOCENE A-Dark green to black silty fine phosphatic SAND, slightly calcareous, hard, phosphate grains range in size from fine to coarse. Burrow present, infilled with tan silt.			

CONTINUED ON SHEET #2

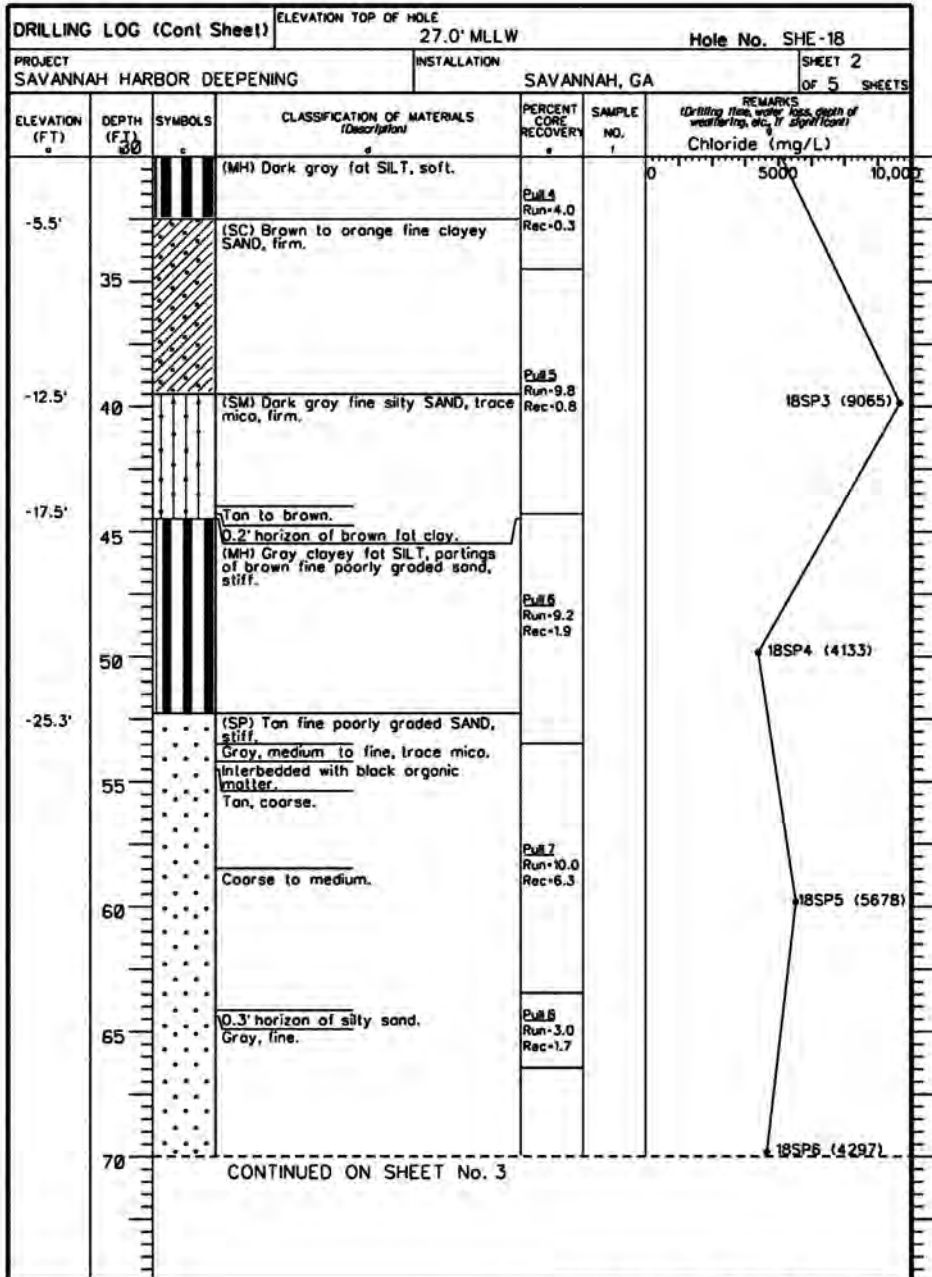
NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

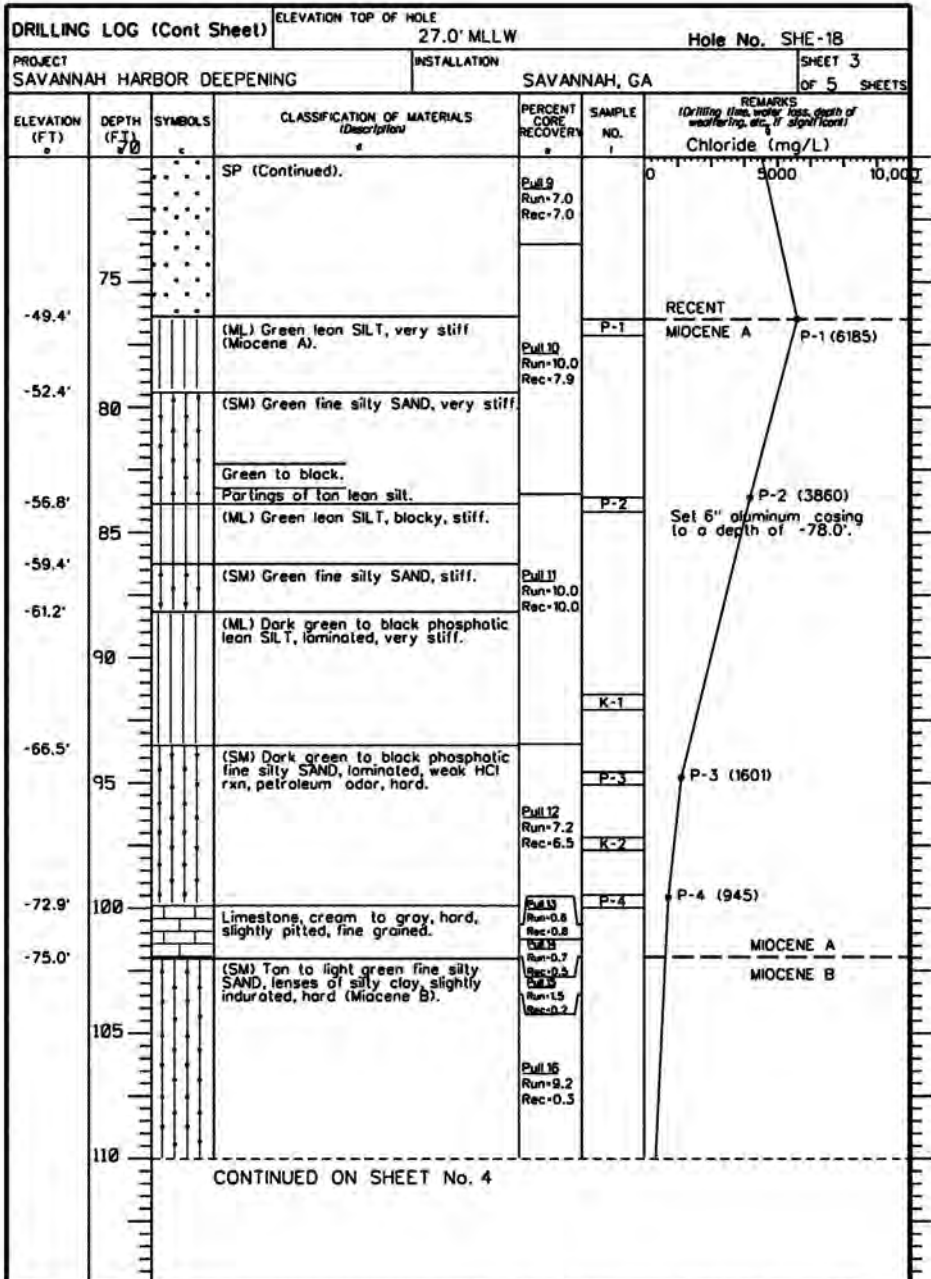
DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-17	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 3 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
			SM (Continued).			0 8,000 16,000
-70.7'	70		(ML)-Cream lean SILT, trace very fine sand, slight HCl rxn, hard; mottled with dark olive green to black silty sand from above. 0.4' horizon of dark olive green silty sand. Cream, stiff. (SC)-MIOCENE B-Green fine clayey SAND, stiff. (SM) Green fine silty SAND, stiff to very stiff.	Pull 5 Run=10.0 Rec=7.2	P-6 K-5	P-6 (680)
-73.4'						MIOCENE A
-74.3'	75			Pull 6 Run=10.0 Rec=0.5		MIOCENE B
	80		Portions of gray fine sand occur every ~0.1'. Gray to tan, weak HCl rxn. Green, hard.		P-7	P-7 (74)
	85			Pull 7 Run=9.5 Rec=9.5	K-6	
	90				P-8	P-8 (39)
	95		Burrow present, infilled with black silt.			
-98.1'	100		(LS) Limestone, soft, moderately weathered, fine grained, gray to tan, slightly porous, some phosphatic grains. Trace phosphatic grains. Vug infilled with green silty sand. Gray to cream. Some vugs, some fossils, hard. Vuggy, fossiliferous.	Pull 8 Run=6.0 Rec=7.8	P-9	P-9 (28) MIOCENE B LIMESTONE
	105					

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 0.0' MLLW		Hole No. SHE-17																																					
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 3 OF 3 SHEETS																																					
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water logs, depth of weathering, etc. if significant) g																																				
-109.9'	105		LS (Continued).	Pull 9 Run 10.0 Rec 3.2																																						
	Little vugs, slightly weathered, trace fossils.																																									
	110		BOTTOM OF BORING AT -109.9'																																							
						<table><thead><tr><th>Sample</th><th>Top Elev</th><th>Mud Cond. (mS/cm)</th></tr></thead><tbody><tr><td>P-1</td><td>-39.7</td><td>1.46</td></tr><tr><td>P-1a</td><td>-39.7</td><td>1.46</td></tr><tr><td>P-2</td><td>-44.4</td><td>1.55</td></tr><tr><td>P-3</td><td>-52.0</td><td>1.55</td></tr><tr><td>P-3a</td><td>-52.0</td><td>1.55</td></tr><tr><td>P-4</td><td>-57.8</td><td>2.30</td></tr><tr><td>P-5</td><td>-58.9</td><td>2.78</td></tr><tr><td>P-6</td><td>-68.4</td><td>4.54</td></tr><tr><td>P-7</td><td>-82.4</td><td>2.49</td></tr><tr><td>P-8</td><td>-91.1</td><td>2.49</td></tr><tr><td>P-9</td><td>-97.4</td><td>2.49</td></tr></tbody></table>	Sample	Top Elev	Mud Cond. (mS/cm)	P-1	-39.7	1.46	P-1a	-39.7	1.46	P-2	-44.4	1.55	P-3	-52.0	1.55	P-3a	-52.0	1.55	P-4	-57.8	2.30	P-5	-58.9	2.78	P-6	-68.4	4.54	P-7	-82.4	2.49	P-8	-91.1	2.49	P-9	-97.4	2.49
Sample	Top Elev	Mud Cond. (mS/cm)																																								
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P-7	-82.4	2.49																																								
P-8	-91.1	2.49																																								
P-9	-97.4	2.49																																								

Hole No. SHE-18

DRILLING LOG		DIVISION SOUTH ATLANTIC		INSTALLATION SAVANNAH, GA		SHEET 1 of 5 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING				10. SIZE AND TYPE OF BIT HQ CORE BARREL			
2. LOCATION (Coordinate or Station) E-1026349.8, N-757753.3 GA EAST				11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500			
4. HOLE NO. (As shown on drawing title and file number) SHE-18				13. TOTAL NO. OF SOIL SAMPLES TAKEN : DISTURBED : 0 : UNDISTURBED : 0			
5. NAME OF DRILLER D. HEWETT				14. TOTAL NUMBER CORE BOXES 8			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.				15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >153.5'				16. DATE HOLE : STARTED : 22 JUN 2004 : COMPLETED : 30 JUN 2004			
8. DEPTH DRILLED INTO ROCK 12.0'				17. ELEVATION TOP OF HOLE 27.0' MLLW			
9. TOTAL DEPTH OF HOLE 153.5'				18. TOTAL CORE RECOVERY FOR BORING 56 %			
				19. SIGNATURE OF INSPECTOR C. SMITH/M. MCINTOSH			
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc. if significant)	
27.0'	0					Began using Super Gel-X freshwater drilling mud at 7.0'. Grouted hole upon completion of boring.	
	5					Chloride (mg/L) 0 5000 10,000	
20.0'			(SM) Tan to brown medium to fine silty SAND, trace roots, weak HCl rxn, stiff.				
16.7'	10		(SP) Tan coarse to medium poorly graded SAND, trace mica, soft. 0.1' lens of red to tan silty sand. Fine.	Pull 1 Run=5.0 Rec=2.1			
14.3'			Coarse to medium. (ML) Tan to red to brown sandy lean SILT, sand is fine grained, trace mica, soft. Little organic matter.	Pull 2 Run=10.0 Rec=5.6			
7.4'	20		(SP) Tan to orange coarse to medium poorly graded SAND, trace organic matter, trace fine gravel. 0.3' horizon of medium clayey sand. Fine. Coarse to medium. 0.1' lens of organic sandy clay. Fine.	Pull 3 Run=8.5 Rec=0.3		18SP1 (B47)	
-3.0'	30					18SP2 (J364)	
CONTINUED ON SHEET No. 2							
NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.							





DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 27.0' MLLW		Hole No. SHE-18	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 4 OF 5 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	SAMPLE NO.	REMARKS (Drilling time, water logs, depth of weathering, etc., if significant) Chloride (mg/L)
	110		SM (Continued).			0 5000 10,000
	115			Pull 17 Run=5.6 Rec=0.6		
	120		Green with lenses of gray fine poorly graded sand, not indurated. No sand lenses.		P-5 P-6	P-5 (110) P-6 (42)
	125		Very hard.	Pull 18 Run=6.0 Rec=6.0	K-3 P-7	P-7 (23)
	130			Pull 19 Run=10.0 Rec=9.6		
	135		Very stiff, 0.2' horizon of soft lean silt.		K-4 P-8	P-8 (15)
	140			Pull 20 Run=7.0 Rec=7.8		
-114.5'				Pull 21 Run=0.5 Rec=0.6		MIocene B
	145		Limestone, phosphatic, dark gray to black, very hard, highly weathered, ophinitic. Gray, fossiliferous, vuggy, fine grained moderately hard.	Pull 22 Run=1.5 Rec=0.2		LIMESTONE
	150		0.1' lens of black phosphatic, very hard, ophinitic material. Gray, slightly vuggy.			
CONTINUED ON SHEET No. 5						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 27.0' MLLW		Hole No. SHE-18	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 5 OF 5 SHEETS	
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	SAMPLE NO. f	REMARKS (Drilling time, water loss, grade of weathering, etc., if significant) Chloride (mg/L)
-126.5'	150		Limestone (continued).	Pull 23 Run=10.0 Rec=4.5		0 5000 10,000
			Sandy, fossiliferous, vuggy, hard.			
	155	BOTTOM OF BORING AT -153.5'				

Hole No. SHE-19

DRILLING LOG		DIVISION SOUTH ATLANTIC	INSTALLATION SAVANNAH, GA		SHEET 1 OF 7 SHEETS	
1. PROJECT SAVANNAH HARBOR DEEPENING			10. SIZE AND TYPE OF BIT 1 3/8" SS, HQ CORE BARREL			
2. LOCATION (Coordinates or Station) E-1007278.7, N-761688.5 GA EAST			11. DATUM FOR ELEVATION SHOWN (FSM or MSL) MLLW			
3. DRILLING AGENCY SAVANNAH DISTRICT			12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500			
4. HOLE NO. (As shown on drawing title and file number) SHE-19			13. TOTAL NO. OF SOIL :DISTURBED :UNDISTURBED SAMPLES TAKEN : 52 : 0			
5. NAME OF DRILLER D. HEWETT			14. TOTAL NUMBER CORE BOXES 13			
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED _____ DEG. FROM VERT.			15. GROUND WATER ELEVATION N/A			
7. THICKNESS OF OVERBURDEN >233.5'			16. DATE HOLE :STARTED :COMPLETED : 6 JUL 2004 : 27 JUL 2004			
8. DEPTH DRILLED INTO ROCK 14.7'			17. ELEVATION TOP OF HOLE 21.0' MLLW			
9. TOTAL DEPTH OF HOLE 233.5'			18. TOTAL CORE RECOVERY FOR BORING 69 %			
			19. SIGNATURE OF INSPECTOR C. SMITH/M. McINTOSH			
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT RECOVERY	JAR/ SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
21.0	0					
18.7'			(SC) Tan to brown medium to fine clayey SAND, trace organic matter, stiff.		1	Grouted hole upon completion of boring.
					2	
			(ML) Gray to brown lean SILT, little fine sand, very stiff.		3	
					4	
16.5'	5		(SM) Gray fine silty SAND, stiff.		5	
					6	
14.2'			(SP) Gray medium poorly graded SAND, medium.		7	Chloride (mg/L)
					8	0 4000 8000
11.3'	10		(MH) Gray fat SILT, trace fine gravel, very soft.		9	19SP1 (811)
					10	
					11	
					12	
6.3'	15		(SM) Tan to gray fine silty SAND, finely laminated, very loose.		13	
5.3'			(SP) Tan to brown medium to fine poorly graded SAND, loose.		14	
3.0'			(SM) Gray fine silty SAND, occasional lenses of gray fat silt up to 0.2', loose.		15	
1.5'	20		(CH) Gray to black sandy fat CLAY, sand is fine, trace mica, soft.		16	19SP2 (2390)
					17	
					18	
					19	
-2.7'	25		0.3' horizon of gray fine clayey sand. (SM) Gray fine silty SAND, loose.		20	
-6.2'			(MH) Gray to black sandy fat SILT, sand is fine, soft.			
-7.5'			(CL) Gray lean CLAY, finely laminated, sulfur odor, medium stiff.			
	30					19SP3 (1995)

CONTINUED ON SHEET No. 2

NOTE: SOILS VISUALLY FIELD CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM.

BLOWS PER FOOT:
NUMBER REQUIRED TO DRIVE
1 3/8" ID SPLITSPOON W/ 140 LB.
HAMMER FALLING 30".

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 21.0' MLLW		Hole No. SHE-19	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 2 OF 7 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	JAR/ SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
-12.5'	30		CL (Continued). Little sand, trace organics. Trace sand.		21	0
-13.5'	35		(SC) Brown fine clayey SAND, trace mica, loose. Medium sand. (SP) Brown coarse to medium poorly graded SAND, loose. Gray.		22	
					23	
					24	
					25	4000
					26	
					27	
					28	
-18.0'	40		(CH) Gray fat CLAY, roots throughout, medium stiff.		29	5
			No organic matter, partings of fine sand occur every ~0.5'.		30	
			0.2' seam of gray fine silty SAND, some mica, medium.		31	
			Trace organic matter, partings of fine sand occur every ~0.5', stiff.		32	
	45		Partings more common.		33	12
-28.7'	50		(SP) Gray medium to fine poorly graded SAND, medium.		34	
			Fine, two 0.1' lenses of silty clay.		35	
			Medium to fine, trace fine gravel.		36	
-33.0'	55		(CH) Gray sandy fat CLAY, medium stiff.		37	7
			Trace sand, occurs in partings.		38	
			Sand partings throughout.		39	
					40	
-40.0'	60		(SC) Gray medium to fine clayey SAND, medium.		41	17
-40.5'			(CH) Gray fat CLAY, organic matter throughout, partings of medium to fine sand occur every ~0.5', medium stiff.		42	
			0.4' horizon of gray medium poorly graded SAND, dense.		43	
-43.5'	65		(SC) Gray medium clayey SAND, clay occurs as mottled with sand from above, medium.		44	
			Trace fine gravel.		45	14
-46.5'			(SP) Gray medium to fine poorly graded SAND, trace fine gravel, dense.		46	
-48.0'	70		(SM) Gray fine silty SAND, trace coarse gravel, medium.		47	
					48	

CONTINUED ON SHEET No. 3

DRILLING LOG (Cont Sheet)		ELEVATION TOP OF HOLE 21.0' MLLW		Hole No. SHE-19		
PROJECT SAVANNAH HARBOR DEEPENING		INSTALLATION SAVANNAH, GA		SHEET 3 OF 7 SHEETS		
ELEVATION (FT) ±	DEPTH (FT) ±	SYMBOLS ±	CLASSIFICATION OF MATERIALS (Description) ±	PERCENT CORE RECOVERY ±	JAR/ SAMPLE NO. ±	REMARKS (Drilling fluid, water logs, depth of weathering, etc. if significant) Chloride (mg/L)
-50.2'	70		SM (Continued).		49	0 4000 8000 9
-51.6'			(CH) Gray sandy fat CLAY, little shell fragments up to 0.25", medium stiff		50	RECENT
			(SM) Grayish green fine silty SAND, little mica, trace white calcareous partings, dense (Miocene A).		51	MIocene A 44
			Trace coarse gravel, very dense. No gravel.		52	Set 75' of 6" aluminum casing. 84/0.8 Began coring with HQ core barrel.
	75					
	80			Pull 1 Run=10.0 Rec=3.2		
					P-1	P-1 (554)
	85					
				Pull 2 Run=10.0 Rec=10.9	K-1	
	90					
					P-2	P-2 (338)
	95					
			Finely laminated.	Pull 3 Run=10.0 Rec=10.0	K-2	
	100				P-3	P-3 (292)
	105		Partings of fine sand occur every ~0.3'.		P-4	P-4 (209)
				Pull 4 Run=10.0 Rec=10.5		
-87.7'			(ML) Greenish yellow lean SILT, laminated, very stiff.			
-88.9'	110		(SM) Green fine silty SAND, laminated, partings of fine sand occur every ~0.3', very stiff.			
CONTINUED ON SHEET No. 4						

CONTINUED ON SHEET No. 4

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 21.0' MLLW		Hole No. SHE-19	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 4 OF 7 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	JAR/ SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc. if significant) Chloride (mg/L)
			SM (Continued).			0 4000 8000
-91.2'			(ML) Cream to green lean SILT, very stiff.		P-5	P-5 (143)
-92.5'	115		(SC) Green fine clayey SAND, finely laminated, stiff.			
	120			P-1.5 Run=10.0 Rec=10.4	K-3	
	125		Partings of fine sand throughout.	P-1.6 Run=0.4 Rec=0.4	P-6	P-6 (82)
	130			P-1.7 Run=9.6 Rec=9.6		
-111.4'			(CL) Green lean CLAY, partings of fine sand throughout, very stiff.		K-4	
-112.5'	135		(SC) Green fine clayey SAND, finely laminated, very stiff.		P-7	P-7 (58)
	140		(SM) Green fine silty SAND, finely laminated, very stiff.	P-1.8 Run=10.0 Rec=10.3		
-118.9'			Trace sand sized phosphatic grains.		K-5 P-8	P-8 (57)
	145					MIOCENE B LIMESTONE
-126.2'	150		(SC) Green fine clayey SAND, finely laminated, stiff.	P-1.9 Run=10.0 Rec=10.5		
			Decreased clay content.			
CONTINUED ON SHEET No. 5						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 21.0' MLLW		Hole No. SHE-19	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 5 OF 7 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	JAR/ SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
	150		SC (Continued).			0 4000 8000
	155		Increased clay content.		K-6 P-9	P-9 (47)
			0.9' vertical seam of gray fine sand.	Run-10.0 Rec-10.0		
-138.8'	160		(CL) Green lean CLAY, finely laminated, very stiff.		K-7 P-10	P-10 (NV)
	165		Sandy.			
				Run-10.0 Rec-7.5	K-8 P-11	P-11 (26)
-148.1'	170		(SM) Dark green to black medium to fine phosphatic silty SAND, firm.			
	175		Limestone, moderately hard, fine grained, gray to black, phosphatic, some vugs.	Run-5.0 Rec-2.0		
			Soft, cream colored, sandy with lean silt intermixed in matrix, little phosphatic grains present.			
-152.5'	180		(ML) Gray to green sandy lean SILT, hard, partings of gray fine sand throughout, partially indurated.	Run-5.0 Rec-0.0 Run-0.5 Rec-2.0		
	185		Green.	Run-2.5 Rec-3.2	P-12	P-12 (35)
						MIocene A
-165.1'			(SM) Yellowish green fine silty SAND, sand is primarily dark mineral grains, very stiff (Miocene B).	Run-2.0 Rec-2.0		MIocene B
	190		Hard, partings of gray fine sand throughout.		P-13 K-9	P-13 (32)
CONTINUED ON SHEET No. 6						

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 21.0' MLLW		Hole No. SHE-19	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 6 OF 7 SHEETS	
ELEVATION (FT)	DEPTH (FT)	SYMBOLS	CLASSIFICATION OF MATERIALS (Description)	PERCENT CORE RECOVERY	JAR/ SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) Chloride (mg/L)
	190	c	SM (Continued).	Pull 17 Run=5.0 Rec=5.0		0 4000 8000
	195		Green, partings less common, increased clay content.			
	200		Sand partings throughout.	Pull 18 Run=10.0 Rec=10.0		
	205		Partings are rare.		K-10 P-14	P-14 (20)
	210			Pull 19 Run=10.0 Rec=0.3		
	215		Light green, decreased clay content.	Pull 20 Run=1.5 Rec=1.5	K-11 P-15	P-15 (30)
	220		Green with slight mottling of light green, very stiff, increased clay content. Trace phosphatic grains. Light green, mottled with cream lean silt and black phosphatic sand.	Pull 21 Run=8.5 Rec=8.2		MIOCENE B LIMESTONE
-197.8'	225		Limestone, soft, fine grained, cream to black, black material is hard. Moderately hard, cream, fossiliferous, vuggy, phosphatic inclusion at 220'. Soft, not fossiliferous, porous, ophinitic zones throughout. Moderately hard, fine grained. Burrow infilled with sandy mixture of phosphatic grains and shell fragments. Fossiliferous, vuggy. Hard, tan to black, phosphatic. Tan, not phosphatic. Moderately hard to soft, sandy. Soft.	Pull 22 Run=2.0 Rec=2.3		
	230		CONTINUED ON SHEET No. 7			

DRILLING LOG (Cont Sheet)			ELEVATION TOP OF HOLE 21.0' MLLW		Hole No. SHE-19	
PROJECT SAVANNAH HARBOR DEEPENING			INSTALLATION SAVANNAH, GA		SHEET 7 OF 7 SHEETS	
ELEVATION (FT) a	DEPTH (FT) b	SYMBOLS c	CLASSIFICATION OF MATERIALS (Description) d	PERCENT CORE RECOVERY e	JAR/ SAMPLE NO. f	REMARKS (Drilling time, water level, depth of weathering, etc., if significant) g
-212.5'	230		Limestone (Continued).	Full 23 Run=8.0 Rec=8.0		
	235		BOTTOM OF BORING AT 233.5'			
					Sample	Top Depth Chloride (mg/L)
					19SP1	10 811
					19SP2	20 2390
					19SP3	30 1995
					19SP4	40 6316
					19SP5	50 1145
					19SP6	60 1171
					P-1	83.3 554
					P-2	89.8 338
					P-3	98.5 292
					P-4	102.8 209
					P-5	112.9 143
					P-6	123.0 82
					P-7	133.0 58
					P-8	142.6 57
					P-9	153.1 47
					P-10	162.9 NV
					P-11	167.6 26
					P-12	184.0 35
					P-13	188.5 32
					P-14	202.6 20
					P-15	214.2 30
					SP = Screen Point sample NV = No Value reported	

APPENDIX E

Soils Laboratory Analytical Results



U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

CESAS-EN-GGe

1 August 2005

MEMORANDUM THRU

EN-GG

EN-G

FOR EN-GG (Card Smith)

SUBJECT: Savannah Harbor Expansion Permeability Study, Savannah, Georgia Requisition No. W33SJG40168635 and W33SJG41536745, Work Order No.'s 0330e & 0344e

1. Enclosed is our report of test results for the subject permeability study conducted throughout the year in 2004. The test results include flexible wall permeability data, grain-size distribution, Atterberg Limits, moisture content as-received, specific gravity, Unified Soil Classification, and triaxial testing.
2. The samples were received at various times throughout 2004, and were generally delivered in a foam padded box. Samples were typically wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss. Some of the final samples received were also placed into rigid plastic tubing and sealed for added protection. Overall, every effort was made to preserve the samples intact with minimal disturbance. Regardless of the received condition, some sample specimens required slight remolding in preparation of testing. Any specimen remolding was conducted with all efforts of preserving the as-received moist condition and density prior to engineering properties testing.
3. As the samples were received and prepared for permeability testing by ASTM D5084, some variations in the diameters of specimens required the utilization of various base and head platens. This was conducted in order to best match the diameters of the samples received. All permeability specimens were properly back-pressure saturated and verified to meet the required minimum B value of 95% prior to conducting permeation. The hydraulic conductivity was measured using a Mercury U-tube Manometer and the resultant values were reported at a target hydraulic gradient value of about 20. The reports are provided on EMU Form D5084-4.
4. Triaxial testing was also requested for a couple of samples. This was conducted using ASTM D4767 Consolidated Undrained Triaxial test with pore pressure measurements. The loading for specimens was selected at 0.5 and 1.0 tsf for each of two sample locations. Specimens were prepared by carefully trimming them from the as-received samples to an approximate diameter of 1.4 inches and height of 3 inches. Some sample specimens required slight remolding in preparation of testing, particularly for sample hole SHE-17 at depth 79.0 to 80.0 which classified as clayey sand.

CESAS-EN-GGe

22 February 2005

SUBJECT: Savannah Harbor Expansion Permeability Study, Savannah, Georgia Requisition No. W33SJG40168635 and W33SJG41536745, Work Order No.'s 0330e & 0344e

5. The soil classification for the samples was reported from grain-size and Atterberg Limits results. When samples displayed characteristics of possible organics, oven-dried liquid limit testing was conducted in order to verify the classification description. When oven-dried liquid limit results were found to be less than 75% of the results from moist prepared liquid limit samples, then the soil was classified as an organic silt or organic clay. Some soil classification results were also visually identified when both the grain-size and Atterberg Limits tests were not performed. These sample classifications are identified as "Visual" within the reports. The reports are provided on ENG Form 2087.

6. If there are any questions or additional information is required, please contact me at (678) 354-0310.

Encl

MICHAEL P. WIELPUTZ, P.E.
Environmental & Materials Unit

CF: EN-ESF

8/1/2005

CE3AS-ENGG

SUMMARY OF MATERIAL PROPERTIES

PROJECT: Savannah Harbor Expansion Portability Study, Savannah, GA
 REQUISITION NO. W03SJ4016835 WORK ORDER: 3306

LAB Number	Hole No.	Sample	Depth		ASTM D2002/D140		ASTM D4318			ASTM D2216		ASTM D854	Dry Density (g/cc)	Void Ratio	Porosity	Hydraulic Gradient	Hydraulic Conductivity k _{sat} (cm/sec)	Color	ASTM D2487 Unified Soil Classification System
			start (ft)	end (ft)	No. 4	No. 200	LL	PL	PI	MC%, Spd									
K6/005	SHE-11	K-1	48.5	48.0	100.0	87.7	84	24	60	75.7	2.66	0.817	2.250	0.692	22.4	4.79E-08	Off-white clay (CH), with a little sand, a trace of mica and wood fragments	ASTM D2487 Unified Soil Classification System	
K6/006	SHE-11	K-2	76.0	76.5	100.0	89.2	---	---	---	96.2	2.66	0.794	2.239	0.691	20.6	4.35E-08	Off-white clay (CH), with a little sand		
K6/007	SHE-11	K-3	78.5	79.0	100.0	95.2	---	---	---	65.5	2.70	0.725	2.672	0.728	21.7	5.40E-08	Off-white clay (CH), with a trace of sand		
K6/008	SHE-11	K-4	88.3	88.8	100.0	19.3	87	30	37	34.4	2.80	1.372	1.030	0.507	22.7	2.53E-07	Dark olive clay (SH), with a trace of sand		
K6/009	SHE-11	K-5	97.8	98.3	100.0	59.3	76	39	37	38.0	2.74	1.338	1.030	0.507	23.8	6.44E-08	Dark olive clay (SH), with a trace of sand		
K6/010	SHE-11	K-6	109.3	109.8	100.0	100.0	---	---	---	38.8	2.67	1.366	0.957	0.859	23.5	6.12E-08	Dark olive clay (SH), with a trace of sand		
K6/011	SHE-11	K-7	117.0	117.5	100.0	20.6	---	---	---	38.2	2.65	1.205	1.186	0.943	22.7	9.48E-08	Dark olive clay (SH), with a trace of sand		
K6/012	SHE-11	K-8	118.3	118.8	99.6	13.6	64	34	30	40.9	2.70	1.319	1.034	0.506	23.6	2.37E-07	Dark olive clay (SH), with a trace of sand		
K6/013	SHE-11	K-9	125.0	125.5	100.0	46.1	144	71	73	72.3	2.65	0.880	1.963	0.693	23.1	3.92E-08	Dark olive clay (SH), with a trace of sand		
K6/014	SHE-13	K-1	70.0	70.5	100.0	18.8	---	---	---	31.6	2.70	1.498	0.702	0.612	17.0	2.78E-08	Dark olive clay (SH), with a trace of sand		
K6/015	SHE-13	K-2	75.8	76.3	100.0	52.8	67	22	45	35.0	2.68	0.849	1.728	0.633	20.6	1.48E-07	Dark olive clay (SH), with a trace of sand		
K6/016	SHE-13	K-5	92.7	93.2	100.0	98.2	---	---	---	85.6	2.83	0.879	1.955	0.682	21.7	1.09E-07	Dark olive clay (SH), with a trace of sand		
K6/017	SHE-13	K-6	98.3	98.8	100.0	98.3	---	---	---	75.4	2.70	0.839	2.208	0.688	21.0	9.92E-08	Dark olive clay (SH), with a trace of sand		
K6/018	SHE-13	K-7	102.3	102.8	100.0	77.2	122	53	79	68.2	2.71	0.991	1.727	0.633	22.3	7.32E-08	Dark olive clay (SH), with a trace of sand		
K6/019	SHE-13	K-8	106.5	107.0	100.0	65.7	---	---	---	62.1	2.68	0.974	1.893	0.629	22.2	8.61E-08	Dark olive clay (SH), with a trace of sand		
K6/020	SHE-13	K-9	111.5	112.0	100.0	30.8	158	74	84	82.4	2.67	0.826	2.189	0.686	23.8	5.44E-08	Dark olive clay (SH), with a trace of sand		
K6/021	SHE-13	K-10	117.2	117.7	100.0	89.0	---	---	---	92.8	2.66	0.727	2.516	0.716	23.1	4.88E-08	Dark olive clay (SH), with a trace of sand		
K6/022	SHE-13	K-11	124.0	124.5	100.0	38.5	151	67	84	49.5	2.69	1.037	1.577	0.612	22.9	1.32E-07	Dark olive clay (SH), with a trace of sand		
K6/023	SHE-14	K-1	83.6	84.1	100.0	96.8	---	---	---	74.7	2.75	0.876	1.962	0.692	23.9	7.99E-08	Dark olive clay (SH), with a trace of sand		
K6/024	SHE-14	K-2	70.6	71.2	100.0	89.2	130	38	92	76.3	2.72	0.970	1.827	0.648	23.1	7.39E-08	Dark olive clay (SH), with a trace of sand		
K6/025	SHE-14	K-3	75.0	75.5	100.0	97.9	---	---	---	76.7	2.77	0.955	1.899	0.650	22.0	1.89E-07	Dark olive clay (SH), with a trace of sand		
K6/026	SHE-14	K-4	84.0	84.5	100.0	5.9	41	26	15	30.9	2.73	1.617	0.677	0.404	6.3	1.12E-04	Dark olive clay (SH), with a trace of sand		
K6/027	SHE-14	K-5	90.0	90.5	100.0	77.1	---	---	---	49.9	2.75	1.120	1.393	0.582	21.3	3.40E-08	Dark olive clay (SH), with a trace of sand		
K6/028	SHE-14	K-6	95.0	95.8	100.0	48.9	110	48	62	63.3	2.74	1.109	1.441	0.560	20.3	1.05E-07	Dark olive clay (SH), with a trace of sand		
K6/029	SHE-14	K-7	100.0	100.5	100.0	60.0	156	59	97	72.0	2.71	0.984	1.731	0.634	21.9	5.69E-07	Dark olive clay (SH), with a trace of sand		
K6/030	SHE-14	K-8	105.5	106.0	100.0	43.1	---	---	---	61.2	2.69	1.063	1.457	0.593	22.4	5.77E-08	Dark olive clay (SH), with a trace of sand		
K6/031	SHE-14	K-9	111.2	111.7	100.0	31.9	---	---	---	61.1	2.73	1.037	1.607	0.616	20.6	1.13E-07	Dark olive clay (SH), with a trace of sand		
K6/032	SHE-14	K-10	117.2	117.7	100.0	80.6	186	73	112	105.0	2.64	0.717	2.469	0.712	23.4	1.48E-07	Dark olive clay (SH), with a trace of sand		
K6/033	SHE-15	K-1	71.7	72.3	100.0	73.2	---	---	---	65.5	2.66	0.984	1.745	0.606	22.7	4.74E-08	Dark olive clay (SH), with a trace of sand		
K6/034	SHE-15	K-2	80.0	80.5	100.0	72.2	---	---	---	79.5	2.71	0.890	2.043	0.671	22.4	1.48E-07	Dark olive clay (SH), with a trace of sand		
K6/035	SHE-15	K-3	89.0	89.6	100.0	72.5	108	34	74	79.5	2.71	0.890	2.043	0.671	22.4	1.48E-07	Dark olive clay (SH), with a trace of sand		

8/1/2005

CEASAS-ENG05e

SUMMARY OF MATERIAL PROPERTIES															
PROJECT: Savannah Harbor Expansion Permeability Study, Savannah, GA															
WORK ORDER: 3306															
LAB Number	Hole No.	Sample No.	Depth start (ft)	Depth end (ft)	ASTM D422/D140 Percent Passing No.4	ASTM D422/D140 No. 200	ASTM D4318 Atterberg Limits LL	ASTM D4318 PI	ASTM D2216 MC%	Dry Density (g/cc)	Void Ratio	Porosity	Hydraulic Gradient	Hydraulic Conductivity, k_{vc} (cm/sec)	
K6/262	SHE-15	K-4	99.7	100.3	100.0	31.6	---	---	50.8	2.71	1.162	0.572	23.7	3.34E-07	
K6/263	SHE-15	K-5	112.0	112.6	100.0	94.7	144	59	74.8	2.58	0.906	0.847	22.6	2.44E-07	
K6/264	SHE-15	K-6	129.8	130.2	100.0	99.6	---	---	115.5	2.57	0.656	0.744	22.0	1.84E-08	
K6/265	SHE-15	K-7	152.0	162.5	100.0	31.6	94	35	59	42.0	1.301	0.611	20.3	0.85E-08	
K6/266	SHE-15	K-8	161.4	161.9	100.0	18.1	66	35	31	30.6	2.66	0.764	0.433	21.4	5.74E-07
K6/267	SHE-15	K-9	172.0	172.5	100.0	54.7	---	---	60.5	2.64	1.033	0.543	0.607	22.1	6.44E-08
K6/268	SHE-15	K-10	187.7	188.2	100.0	40.5	137	55	82	54.9	2.69	1.112	0.586	22.5	4.96E-08
K6/269	SHE-15	K-11	198.0	198.5	100.0	49.9	---	---	59.6	2.70	1.020	0.571	0.611	22.1	6.33E-08
K6/270	SHE-15	K-12	210.6	211.1	100.0	33.5	122	52	70	49.7	2.73	1.167	1.368	0.567	22.3
K6/271	SHE-16	K-1	62.0	62.6	100.0	32.0	60	28	53	2.68	1.178	1.124	0.529	21.3	6.28E-07
K6/272	SHE-16	K-2	73.0	73.5	100.0	16.4	---	---	37.5	2.68	1.351	0.884	0.469	22.4	7.09E-07
K6/273	SHE-16	K-3	89.3	89.8	100.0	56.3	---	---	46.7	2.70	1.225	1.203	0.546	23.2	2.07E-08
K6/274	SHE-16	K-4	99.3	99.8	100.0	44.0	110	41	69	51.0	2.72	1.239	1.222	0.550	23.1
K6/275	SHE-16	K-5	111.0	111.5	100.0	46.5	89	44	55	49.7	2.71	1.150	1.376	0.579	19.0
K6/276	SHE-17	K-1	58.1	65.6	100.0	50.1	46	21	25	47.1	1.072	0.582	22.3	6.69E-08	
K6/277	SHE-17	K-2	82.8	83.4	100.0	59.6	---	---	44.4	2.69	1.083	1.368	0.577	20.5	6.38E-08
K6/282	SHE-17	T-1	89.1	70.1	100.0	73.0	87	30	57	50.5	2.71	---	---	---	---
K6/278	SHE-17	K-3	70.4	71.0	100.0	71.4	82	24	58	64.3	2.69	0.914	1.901	0.655	22.9
K6/279	SHE-17	K-4	77.3	77.9	100.0	21.4	64	26	39	34.9	2.77	1.386	0.916	0.478	23.3
K6/283	SHE-17	T-2	79.0	80.0	100.0	22.0	82	23	39	38.3	2.79	---	---	---	---
K6/280	SHE-17	K-5	96.9	87.4	100.0	11.8	---	---	33.3	2.81	1.419	0.995	0.499	22.6	2.29E-07
K6/281	SHE-17	K-6	104.8	105.2	100.0	54.6	106	46	60	42.9	2.71	1.280	1.089	0.821	20.8
K6/284	SHE-18	K-1	91.5	92.2	100.0	97.9	328	108	220	79.7	2.52	0.454	4.454	0.817	22.8
K6/285	SHE-18	K-2	97.2	97.9	100.0	20.2	---	---	37.3	2.77	1.407	0.975	0.844	23.9	9.15E-08
K6/286	SHE-18	K-3	120.9	121.5	100.0	34.5	131	53	78	51.1	2.67	1.045	1.519	0.603	22.0
K6/287	SHE-18	K-4	133.3	134.0	100.0	21.8	---	---	43.1	2.68	1.218	1.181	0.541	23.3	5.09E-08
K6/288	SHE-19	K-1	85.2	87.0	100.0	51.4	72	31	41	43.9	2.72	1.362	0.992	0.693	22.4
K6/289	SHE-19	K-2	96.7	97.5	100.0	96.6	156	63	93	85.1	2.71	1.081	1.483	0.999	23.5
K6/290	SHE-19	K-3	118.5	119.2	100.0	38.4	84	31	53	51.1	2.68	1.133	1.410	0.585	22.5
K6/291	SHE-19	K-4	131.8	132.4	100.0	51.8	---	---	52.4	2.70	1.092	1.451	0.592	21.2	6.28E-08
K6/292	SHE-19	K-5	142.0	142.6	100.0	87.3	135	55	80	63.5	2.70	0.972	1.762	0.838	22.5

SUMMARY OF MATERIAL PROPERTIES

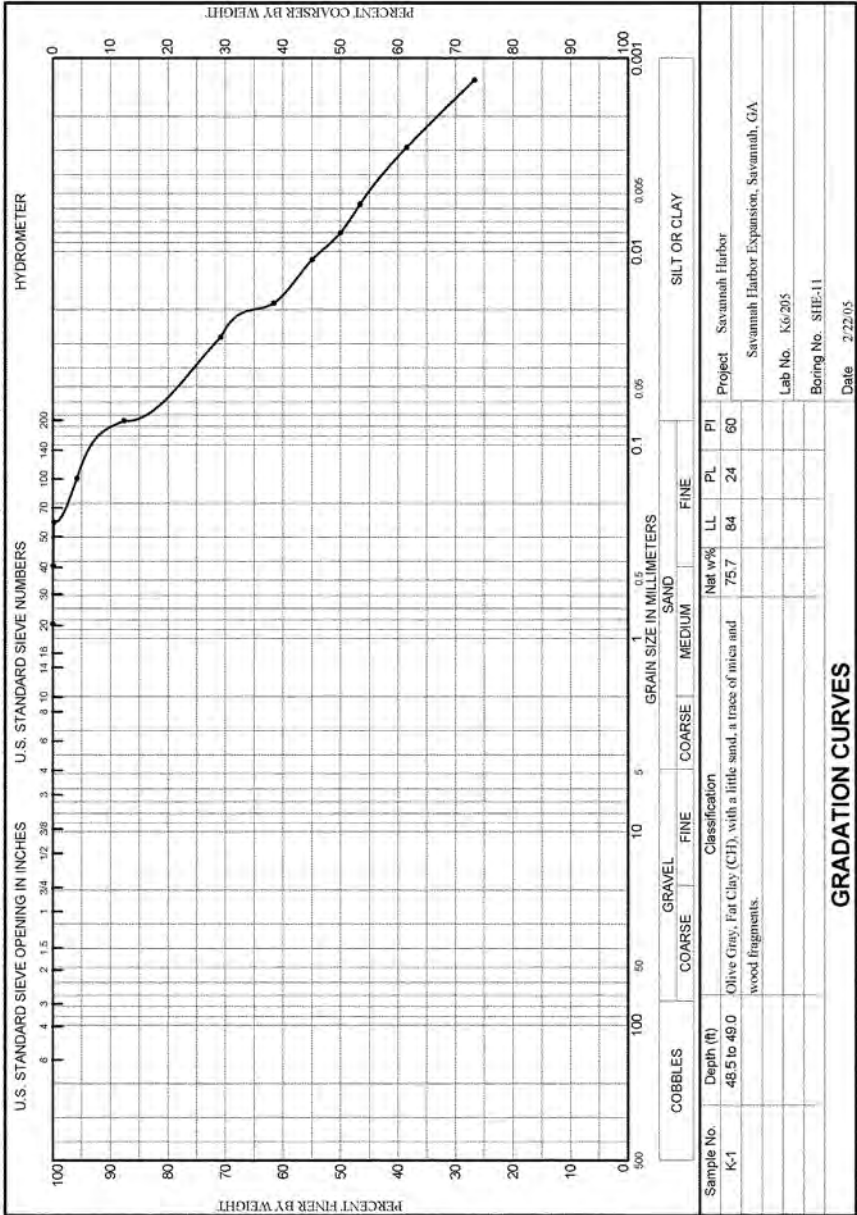
PROJECT: Savannah Harbor Expansion Permeability Study, Savannah, GA
REQUISITION NO: WQ3SJ240168935 WORK ORDER: 3306

LAB Number	Hole No.	Sample No.	Depth start (ft)	Depth end (ft)	ASTM D422/D1140 No. 4 Percent Passing	ASTM D4318 Atterberg Limits LL	PL	PH	ASTM D2216 MC%	ASTM D854 Spd	Dry Density (g/cc)	Void Ratio	Porosity	Hydraulic Gradient	Hydraulic Conductivity, K _{sat} (cm/sec)	Color	ASTM D2487 Unified Soil Classification System
K6/293	SHE-19	K-6	152.5	153.1	100.0	91.5	—	—	81.7	2.68	0.850	2.037	0.671	23.1	2.58E-08	Yellow clay	U ₁ (Silty) Clay (organic: Silty High LL)
K6/294	SHE-19	K-7	162.3	162.9	100.0	99.7	259	83	124.7	2.69	0.618	3.191	0.761	24.3	1.18E-08	Yellow clay	U ₁ (Silty) Clay (organic: Silty High LL)
K6/295	SHE-19	K-8	167.1	167.6	100.0	70.3	—	—	155.7	2.56	0.512	3.903	0.796	22.2	3.15E-08	Yellow clay	U ₁ (Silty) Clay (organic: Silty High LL)
K6/296	SHE-19	K-9	186.8	189.3	100.0	31.1	69	37	28.5	2.68	1.497	0.755	0.430	21.9	9.60E-08	Yellow clay	U ₁ (Silty) Sand (SM), well (High LL) Plastic
K6/297	SHE-19	K-10	202.1	202.6	100.0	45.6	132	55	52.0	2.66	1.151	1.268	0.565	24.1	1.98E-08	Yellow clay	U ₁ (Silty) Sand (SM), well (High LL) Plastic
K6/298	SHE-19	K-11	213.7	214.2	100.0	46.5	97	47	38.1	2.69	1.461	0.915	0.473	23.5	5.39E-08	Yellow clay	U ₁ (Silty) Sand (SM), well (High LL) Plastic



DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

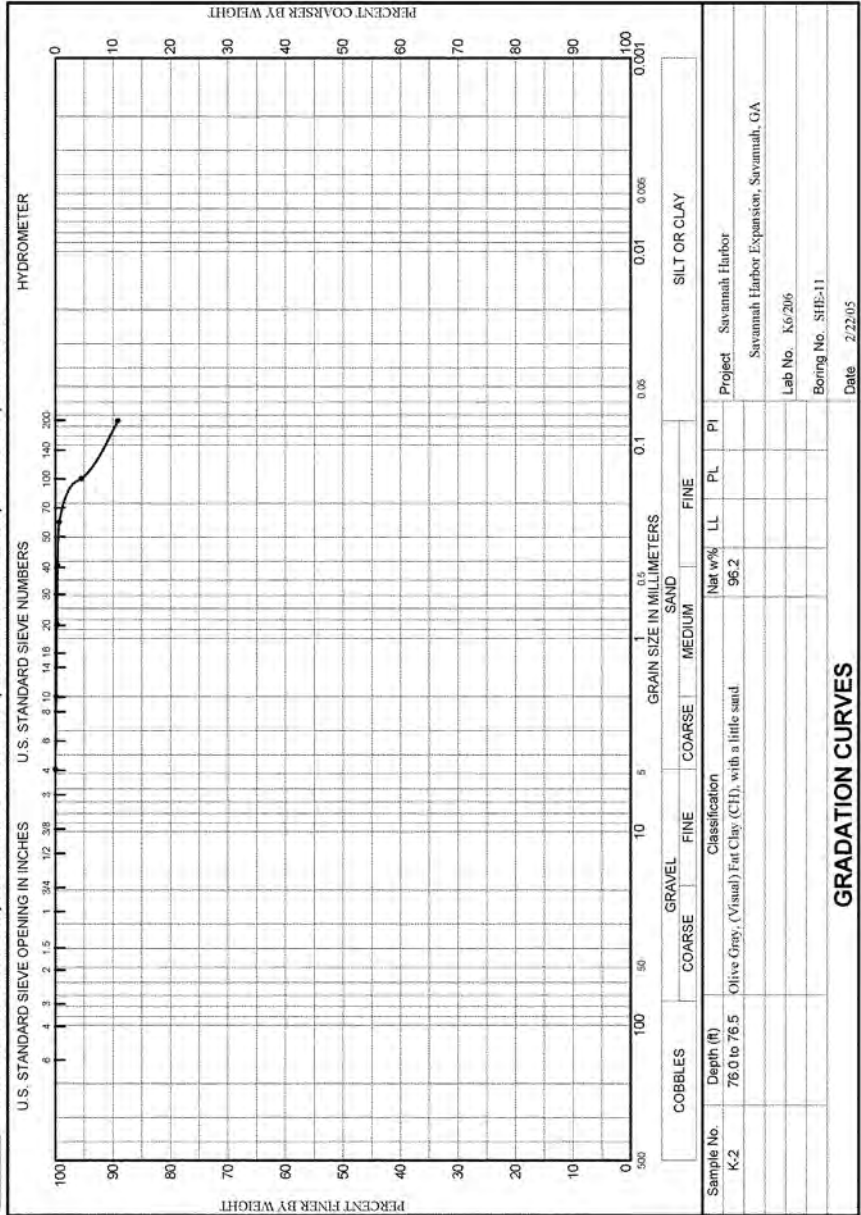
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

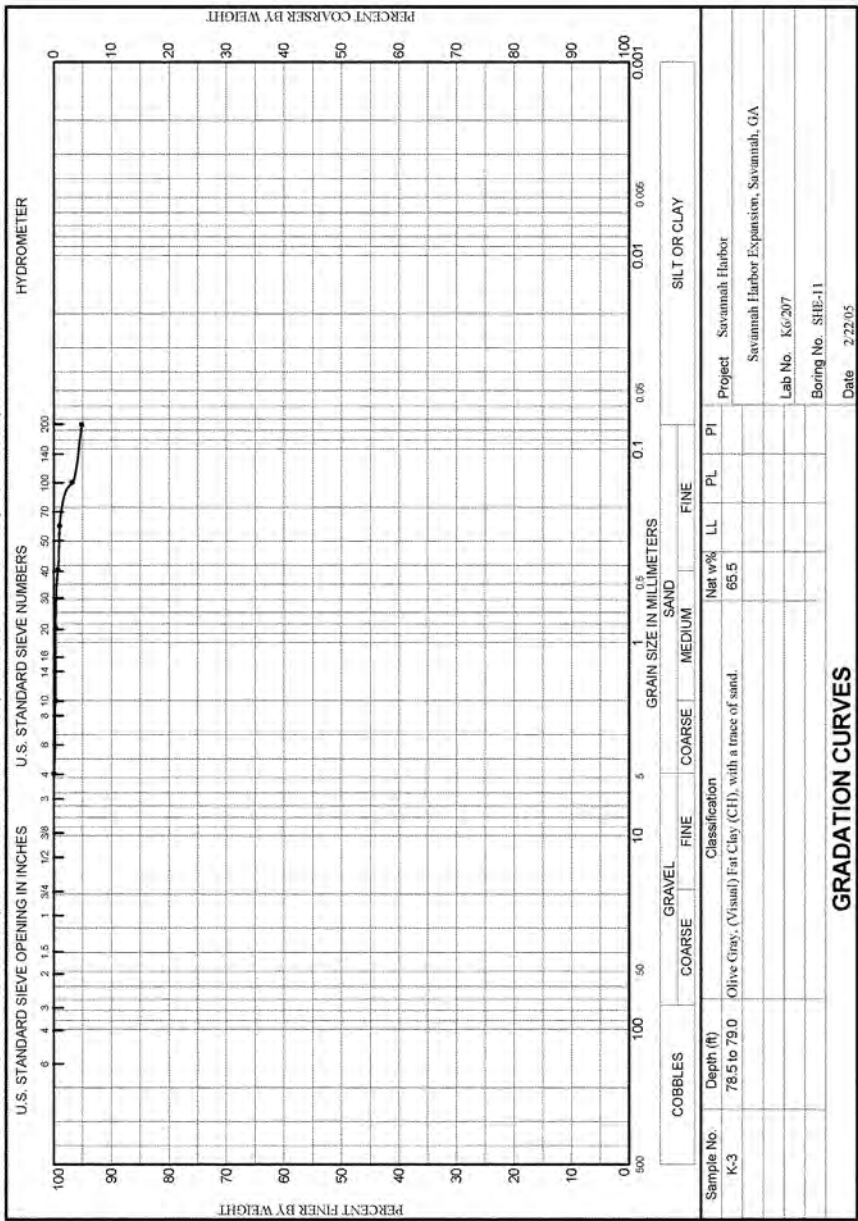
WORK ORDER: 330e
REQUISITION: W33SJG40168635



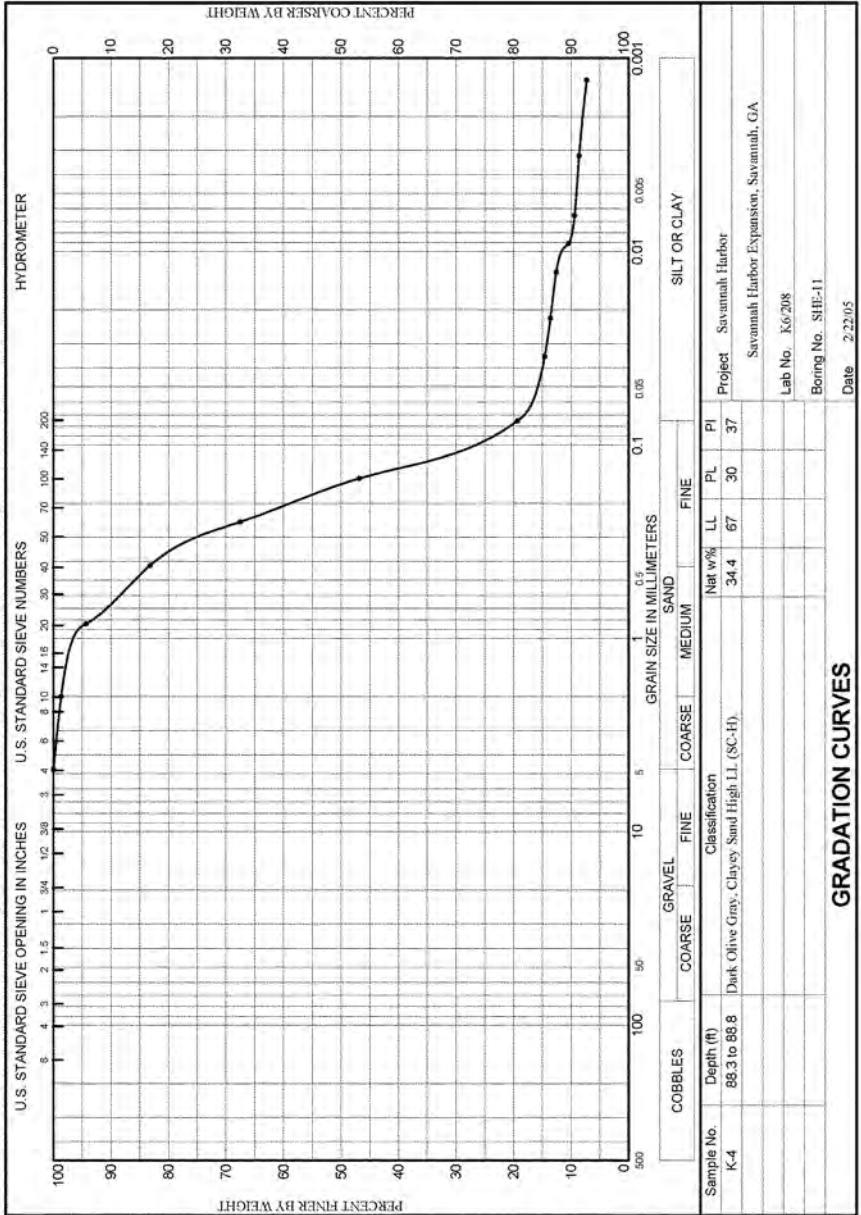


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



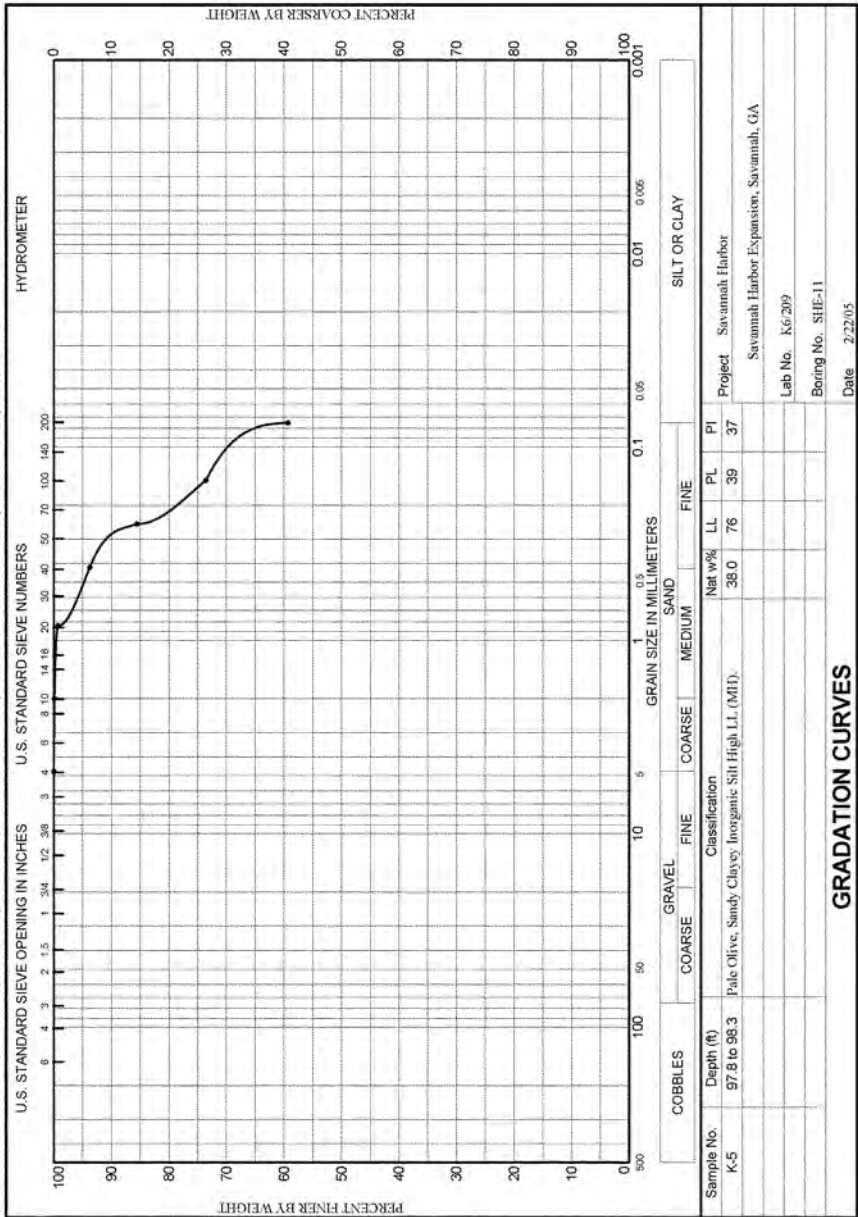
WORK ORDER: 330e
REQUISITION: W33SJG40168635



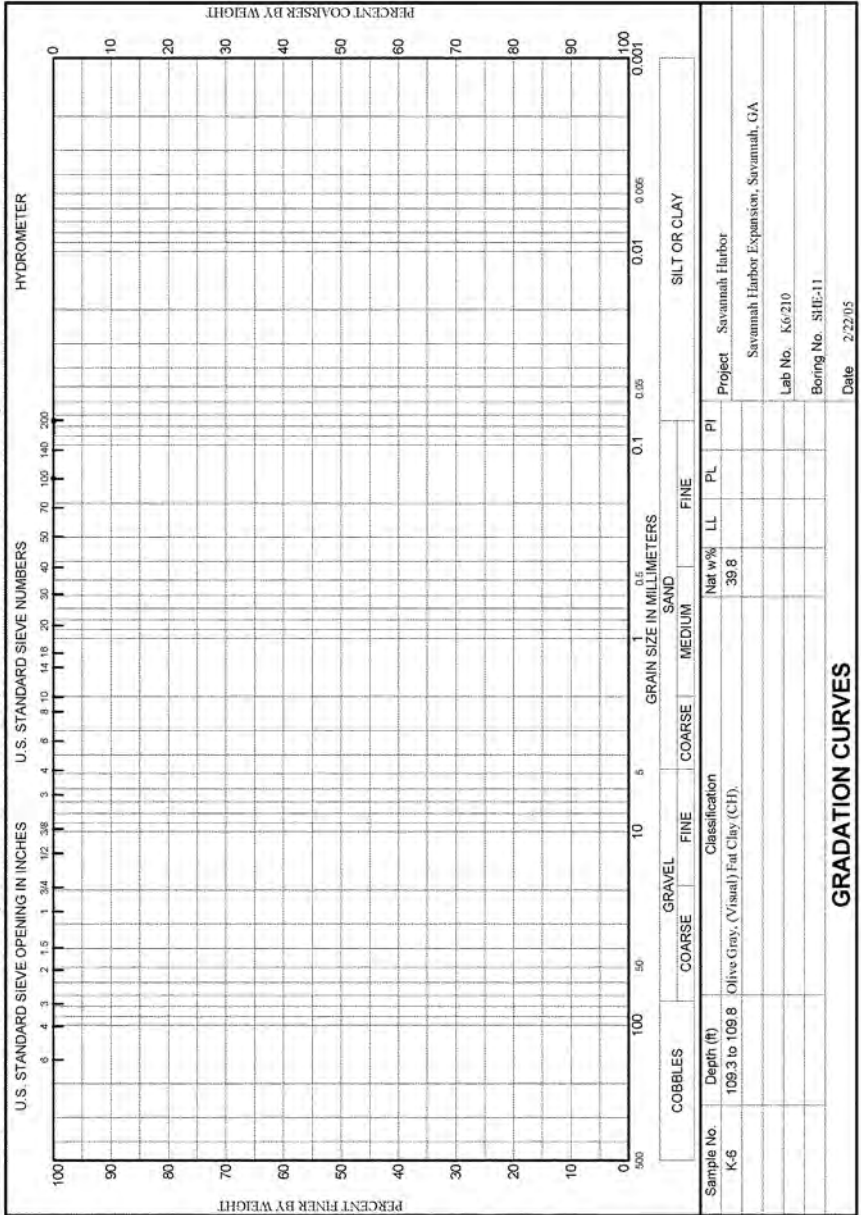


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635

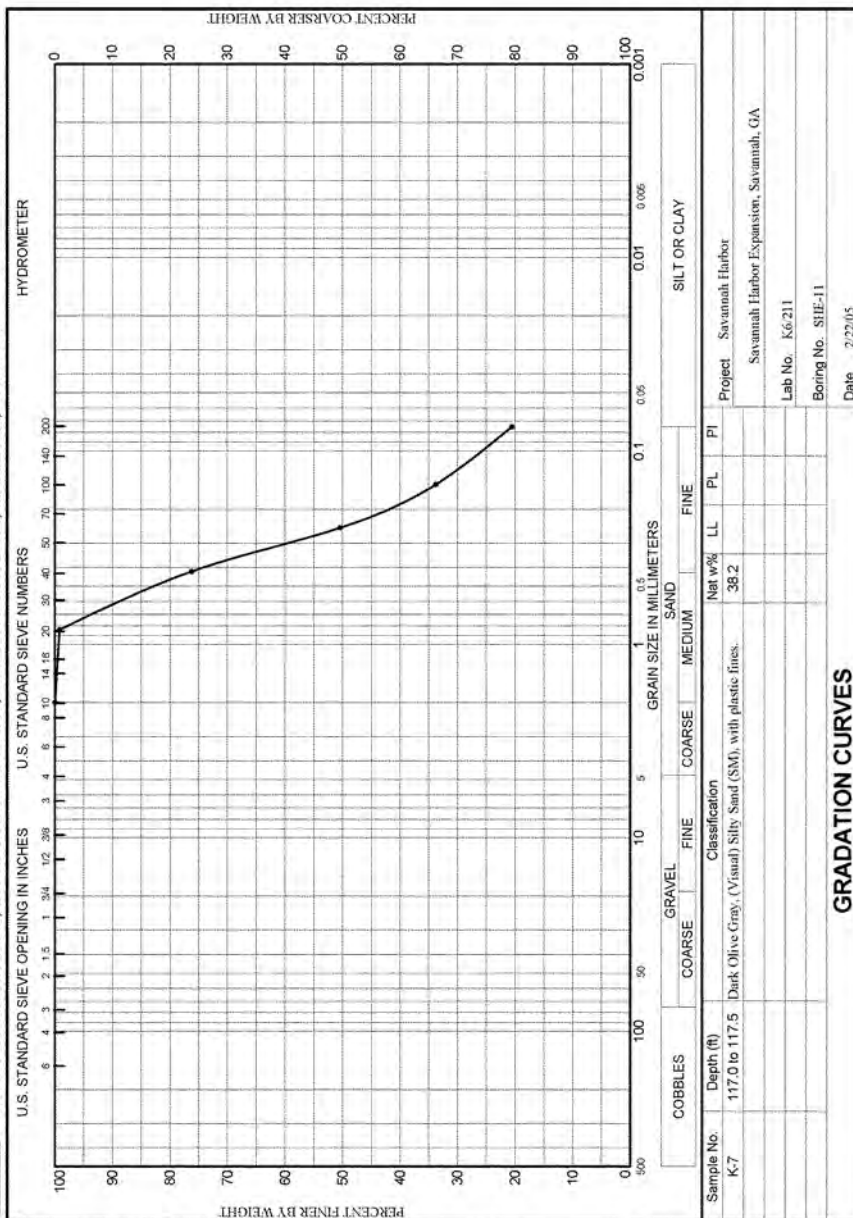


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REQUISITION: W33SJG40168635

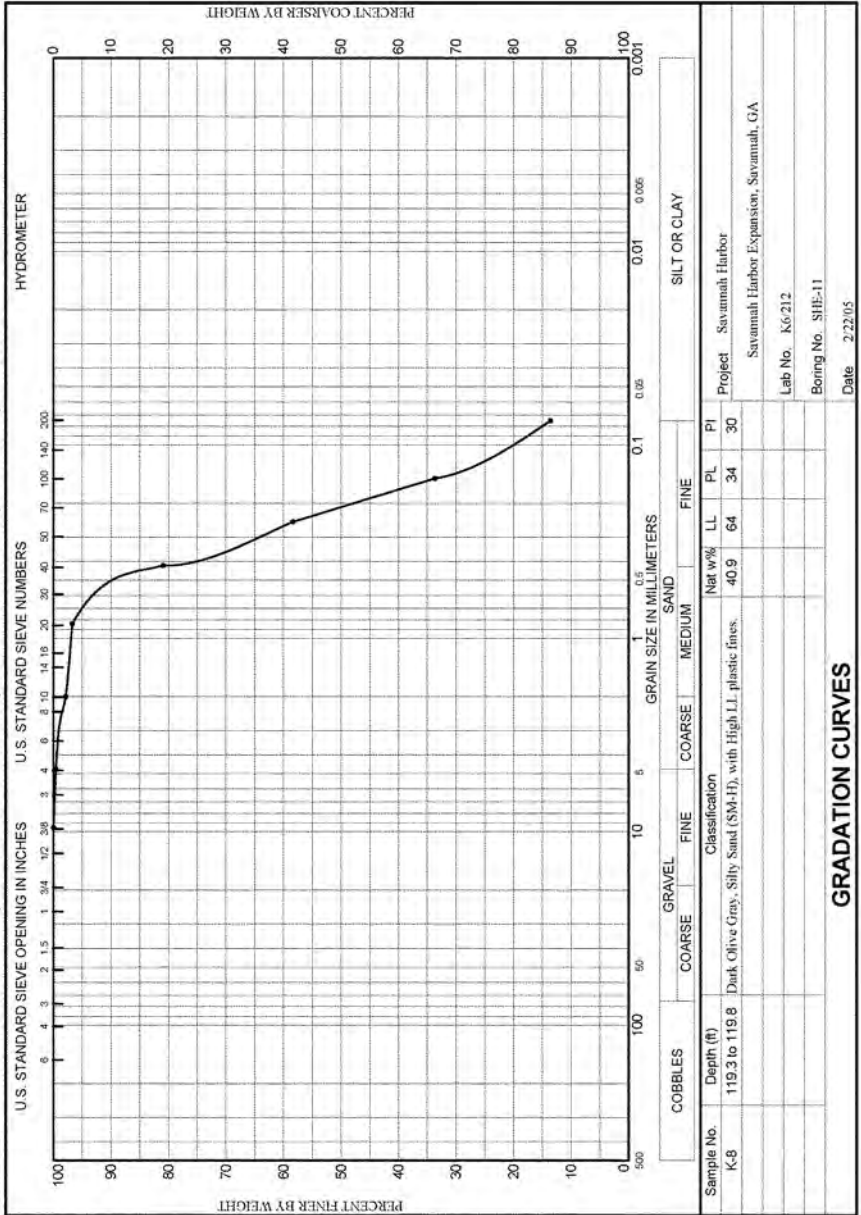




DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062



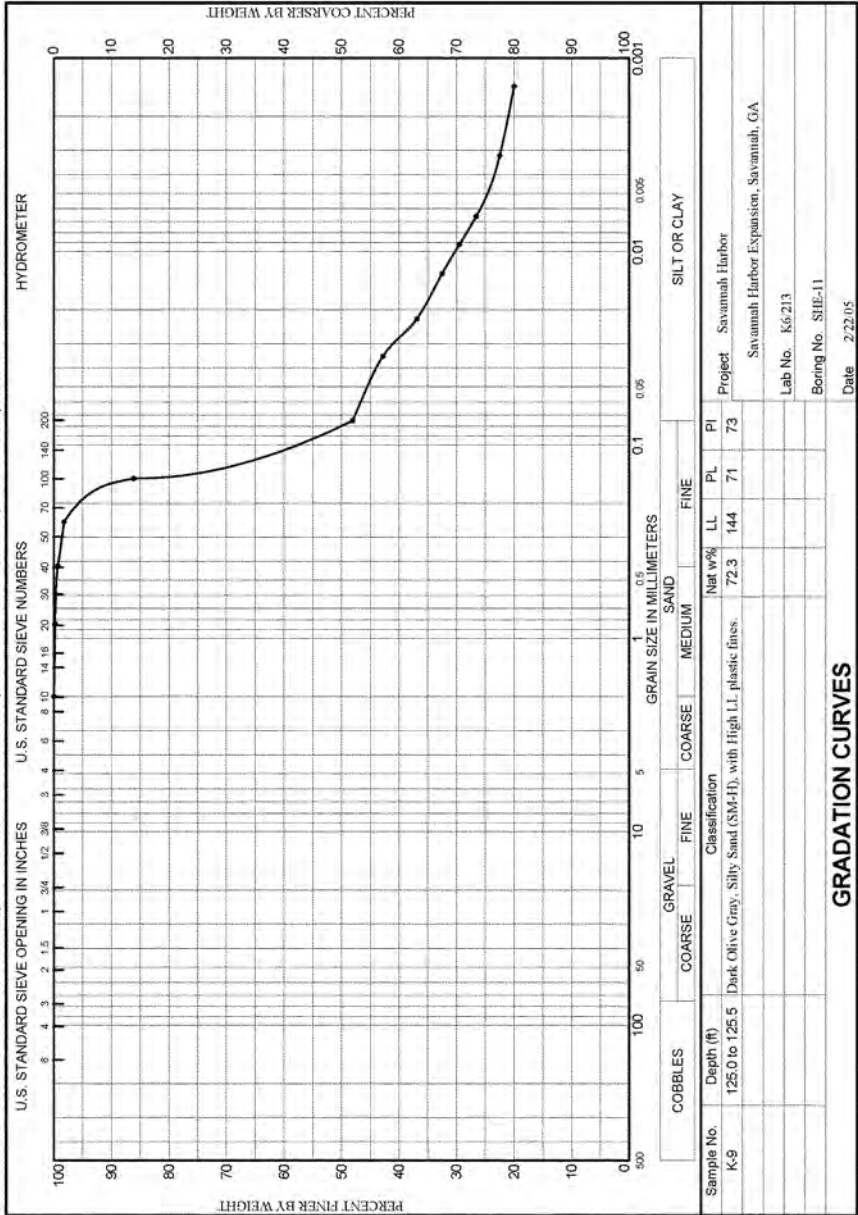
WORK ORDER: 330e
REQUISITION: W335JG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

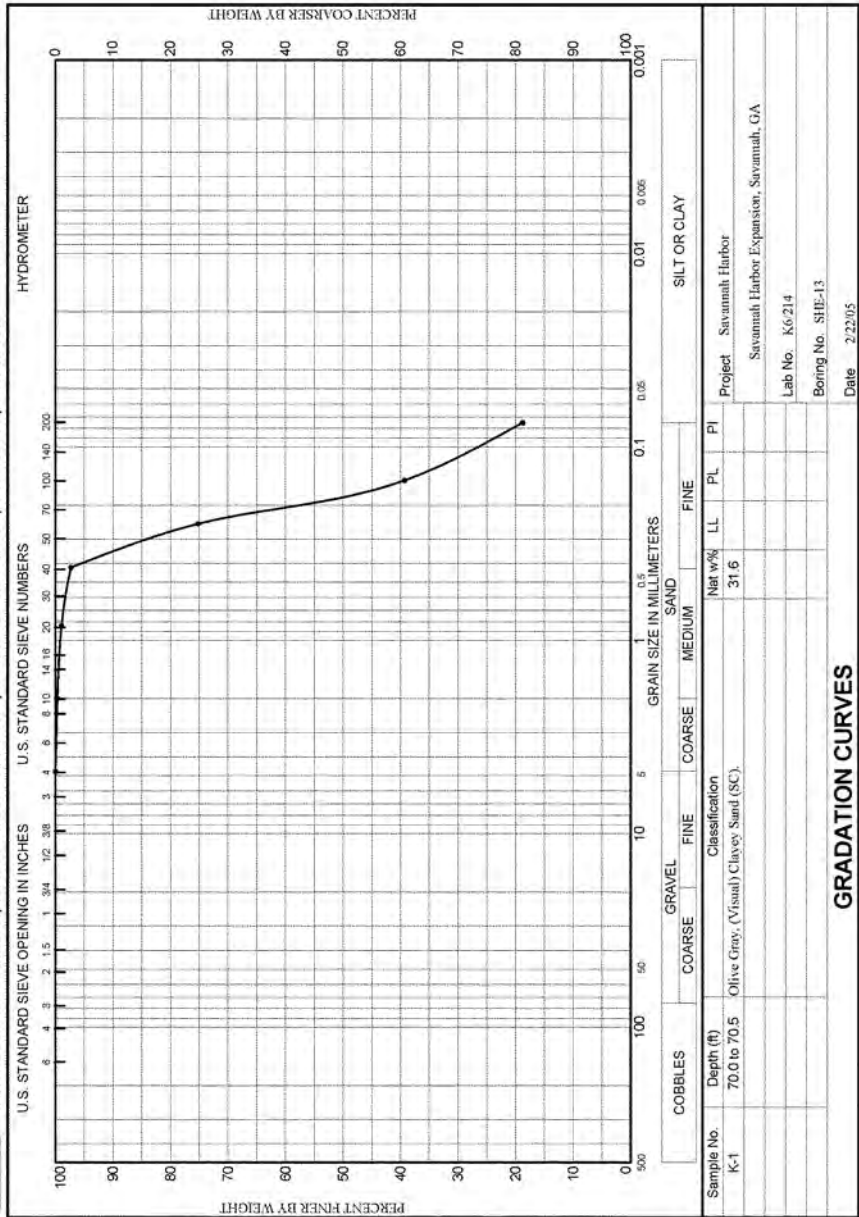
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

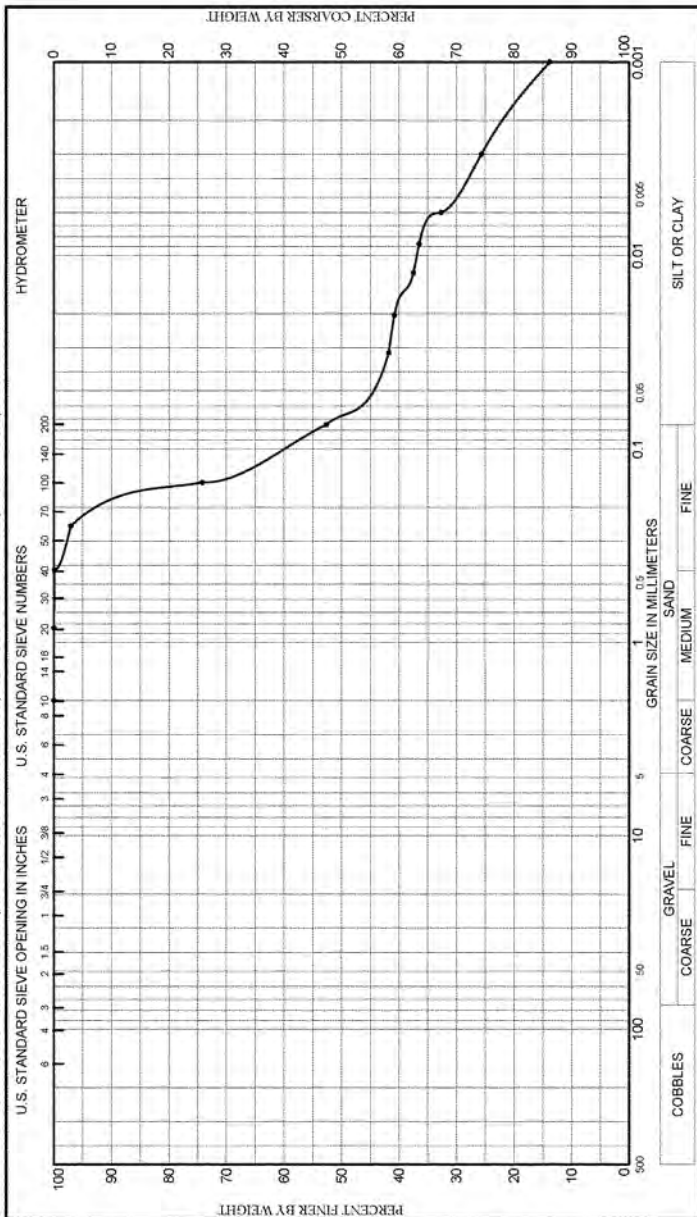
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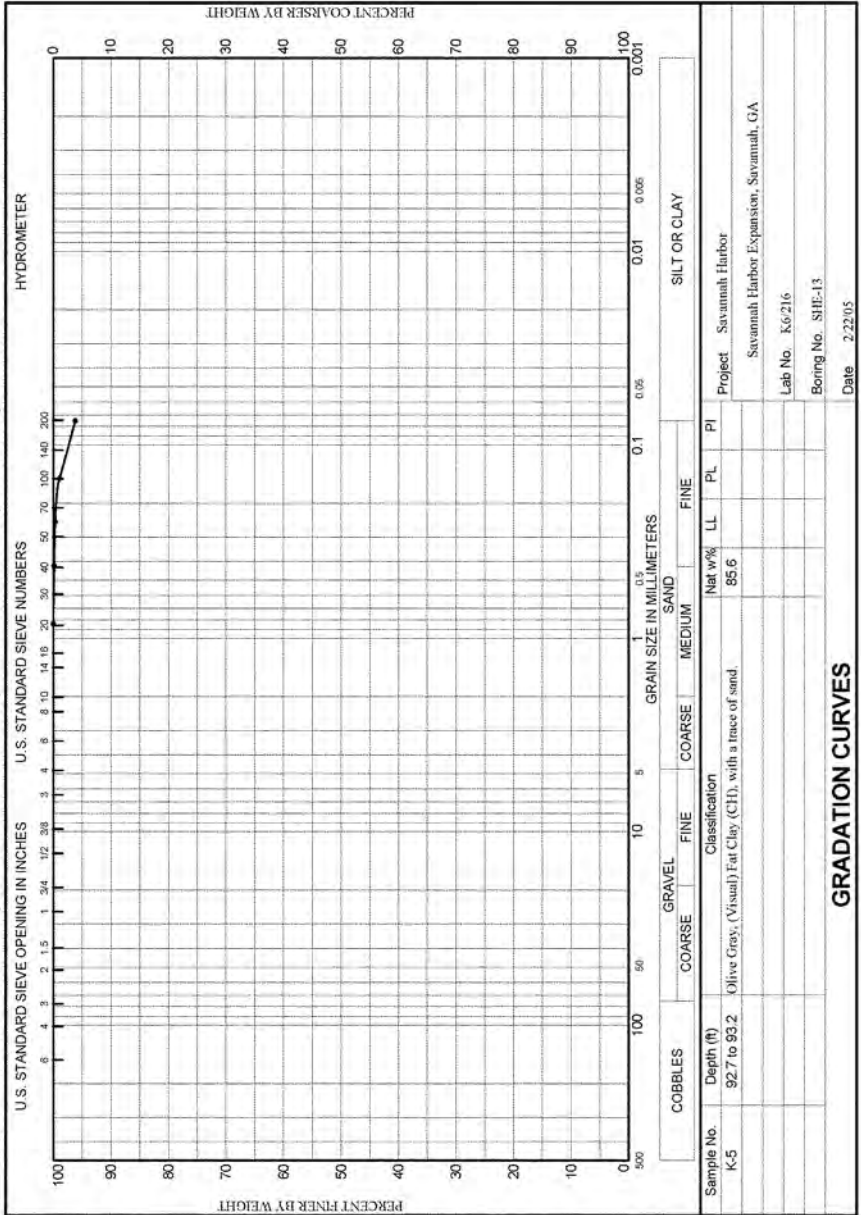


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 3306
REQUISITION: W3SSJG40168635



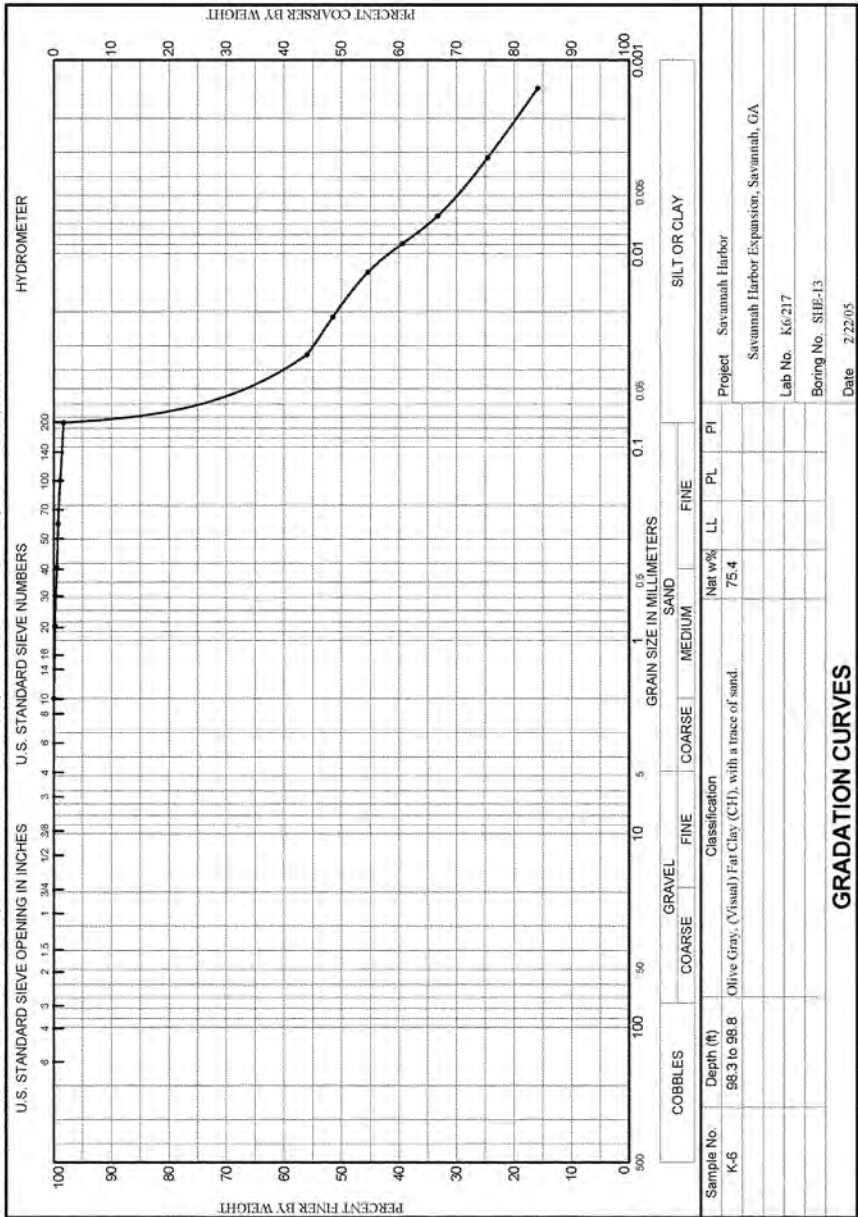
WORK ORDER: 330e
REQUISITION: W33SJG40168635



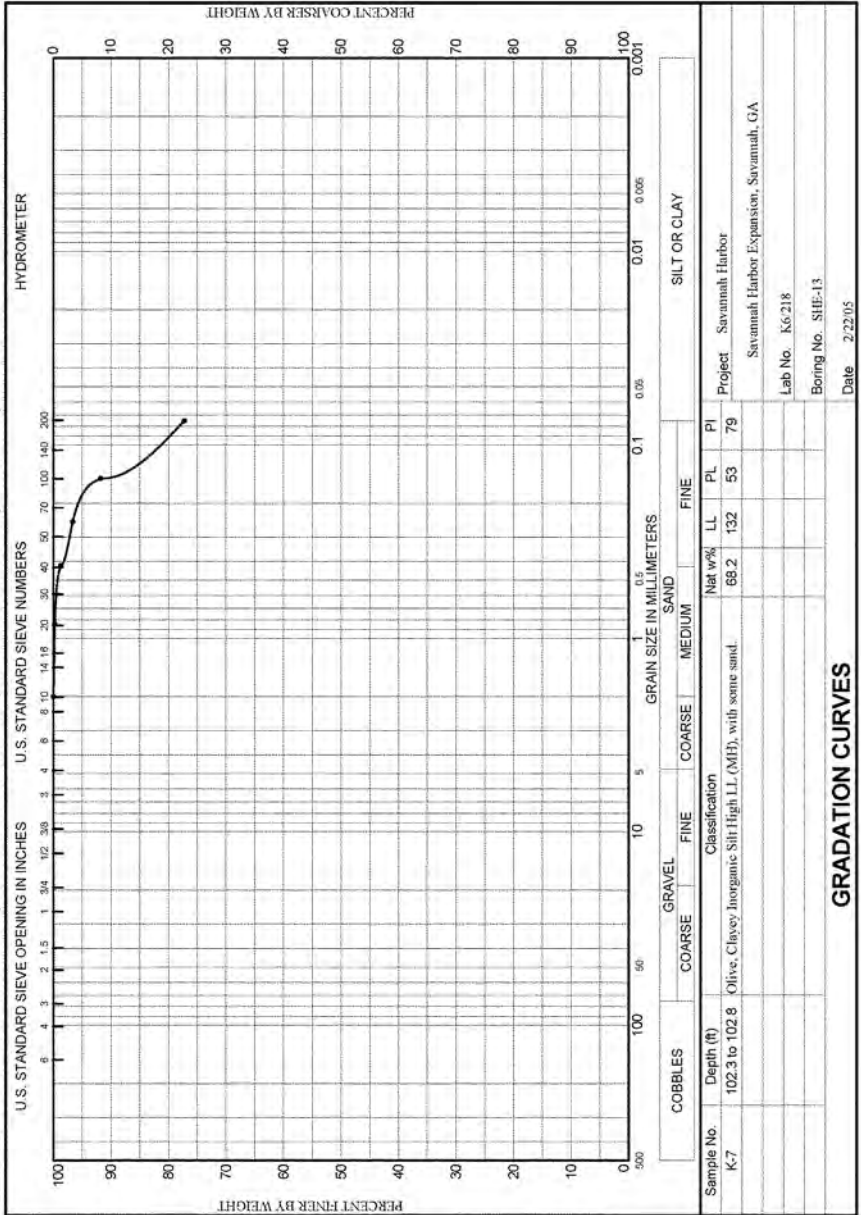


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SJG40168635



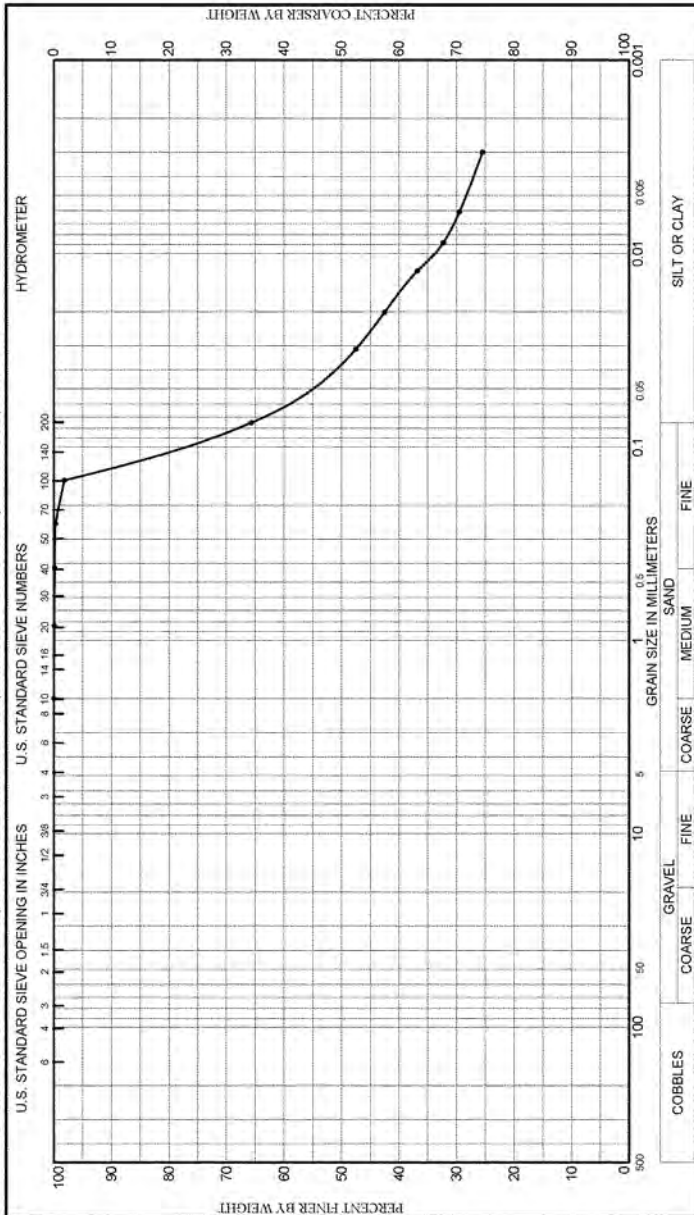
WORK ORDER: 330e
REQUISITION: W335JG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



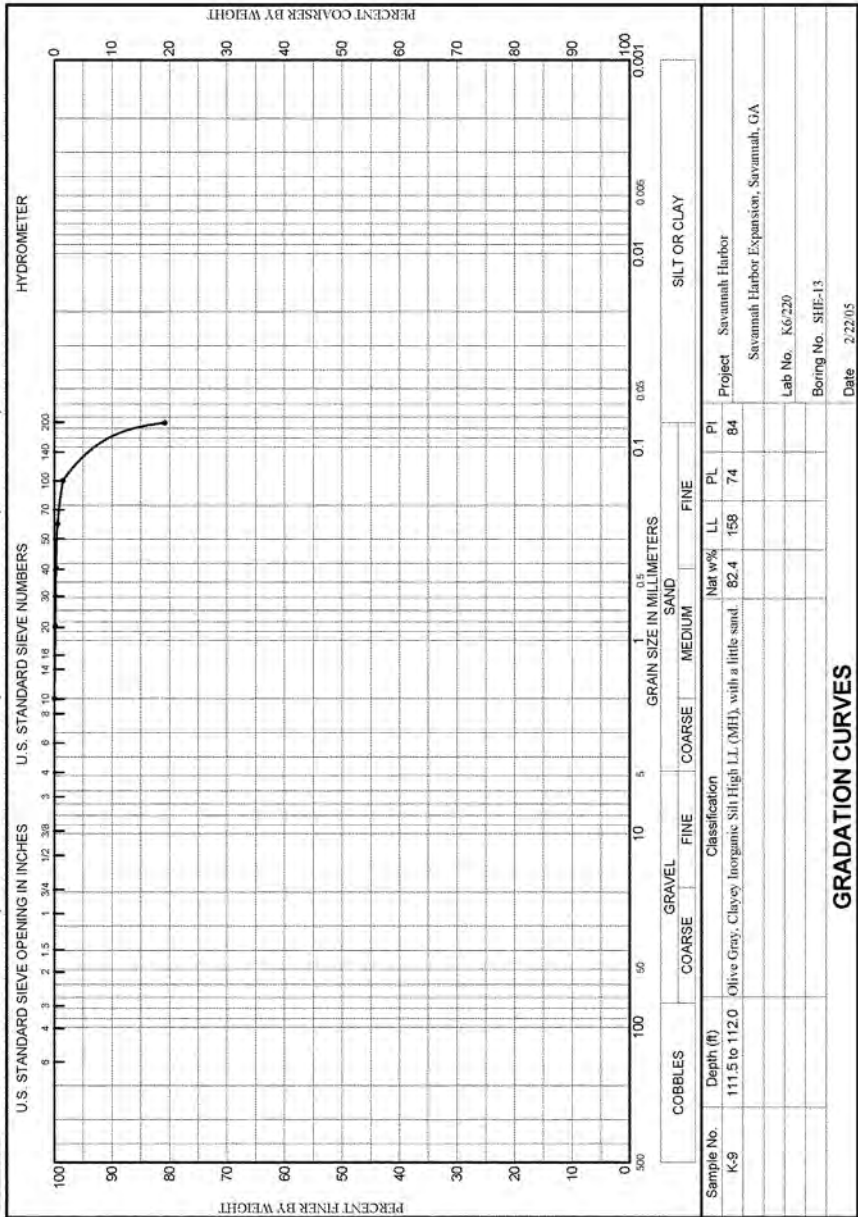
GRADATION CURVES

Project Savannah Harbor
Savannah Harbor Expansion, Savannah, GA
Lab No. K6219
Boring No. S11F-13
Date 2/22/05



DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

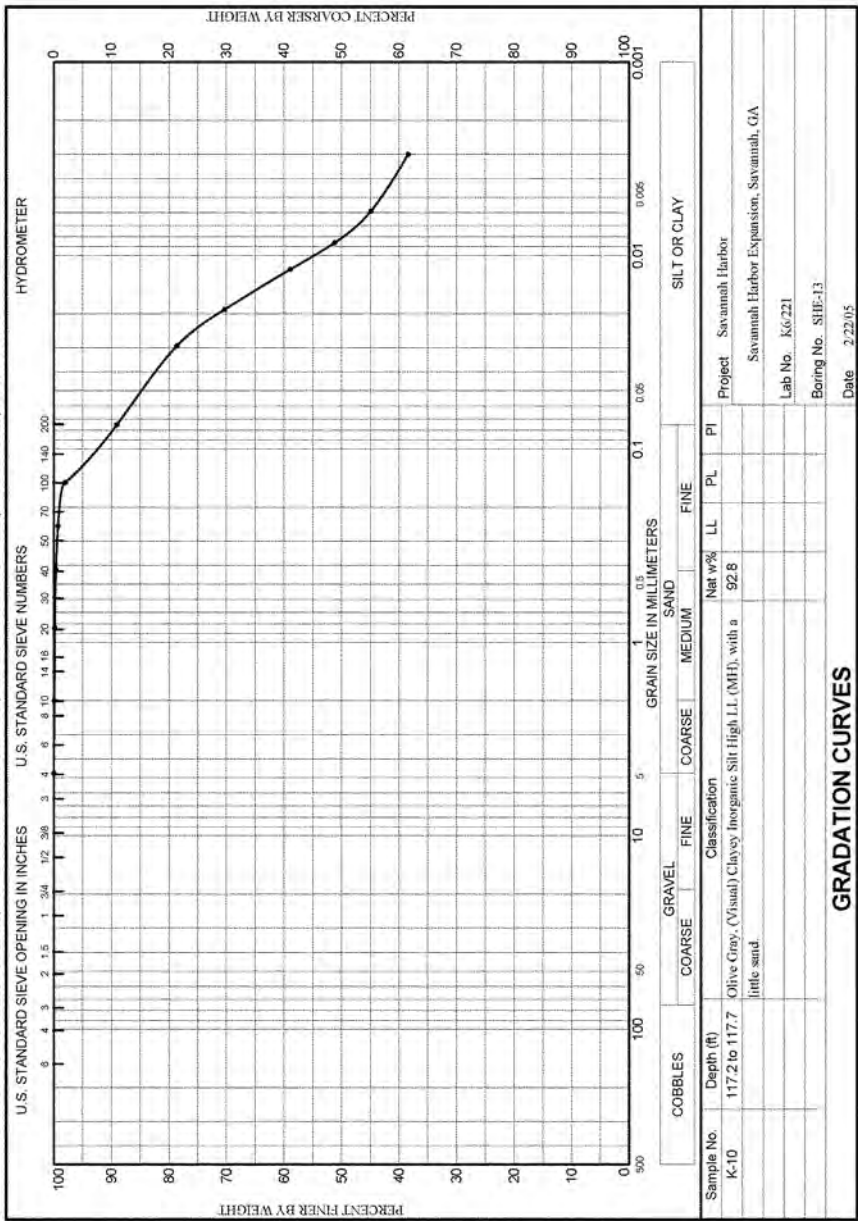
WORK ORDER: 330e
REQUISITION: W33SJG40168635



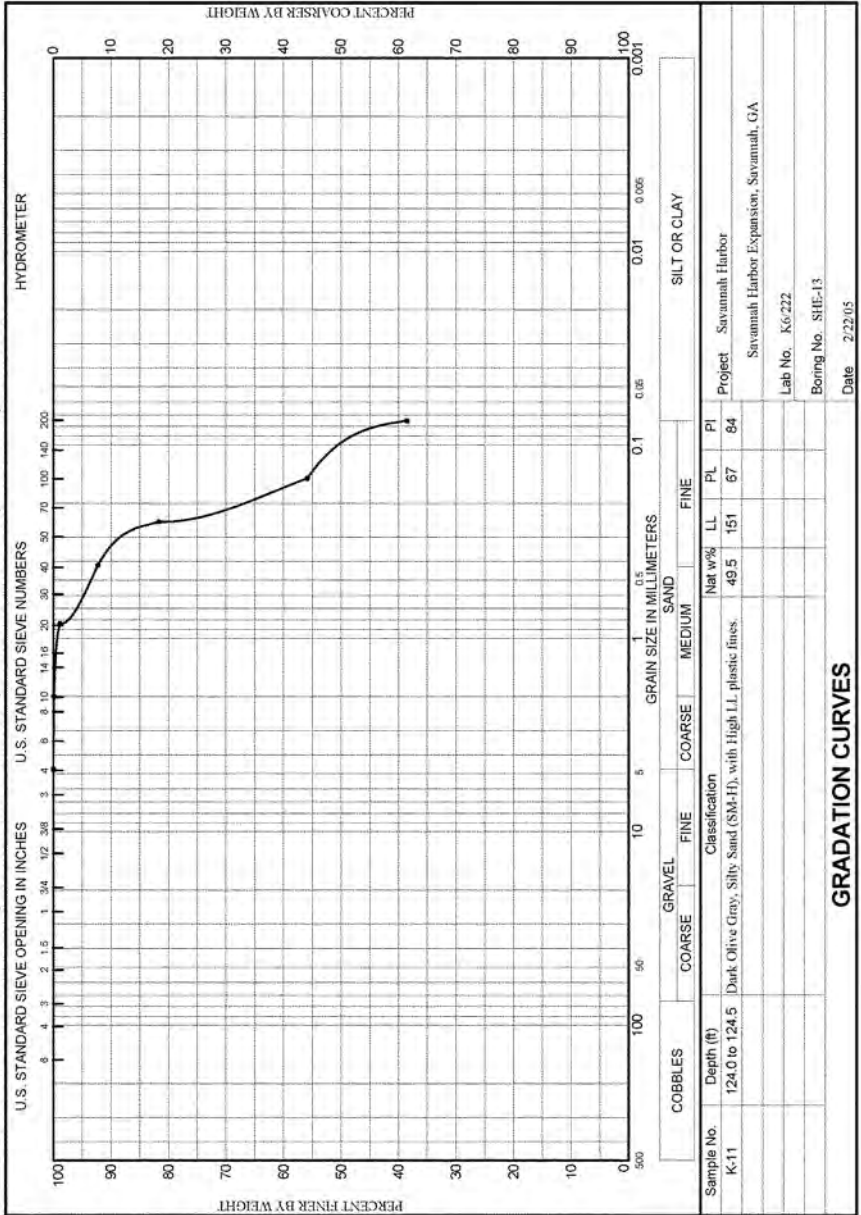


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



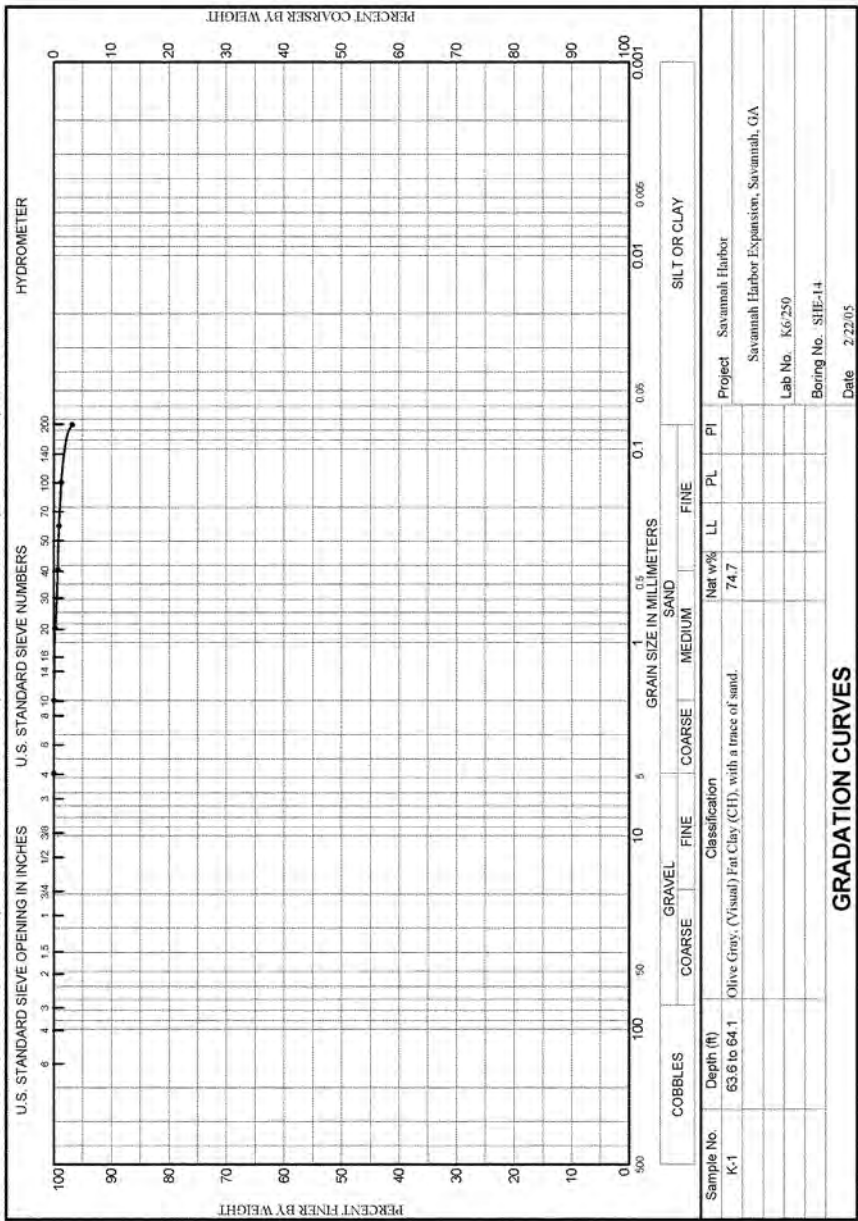
WORK ORDER: 330e
REQUISITION: W335JG40168635





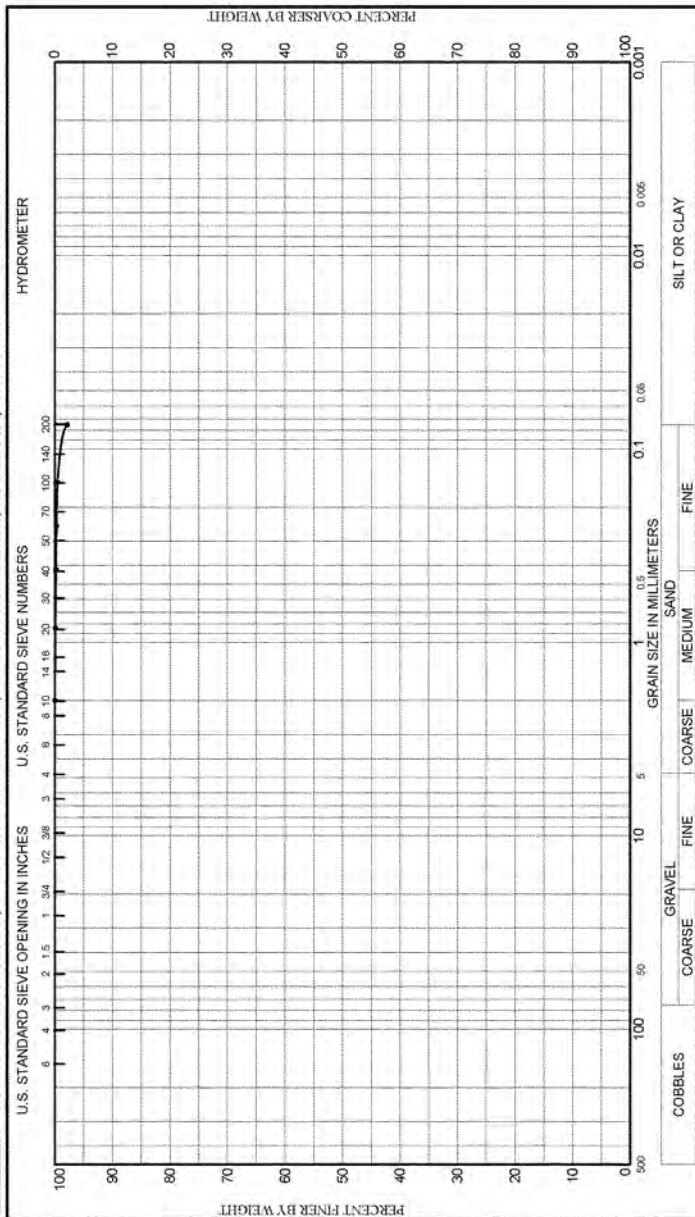
DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635





REQUISITION: W33S.JG40168635

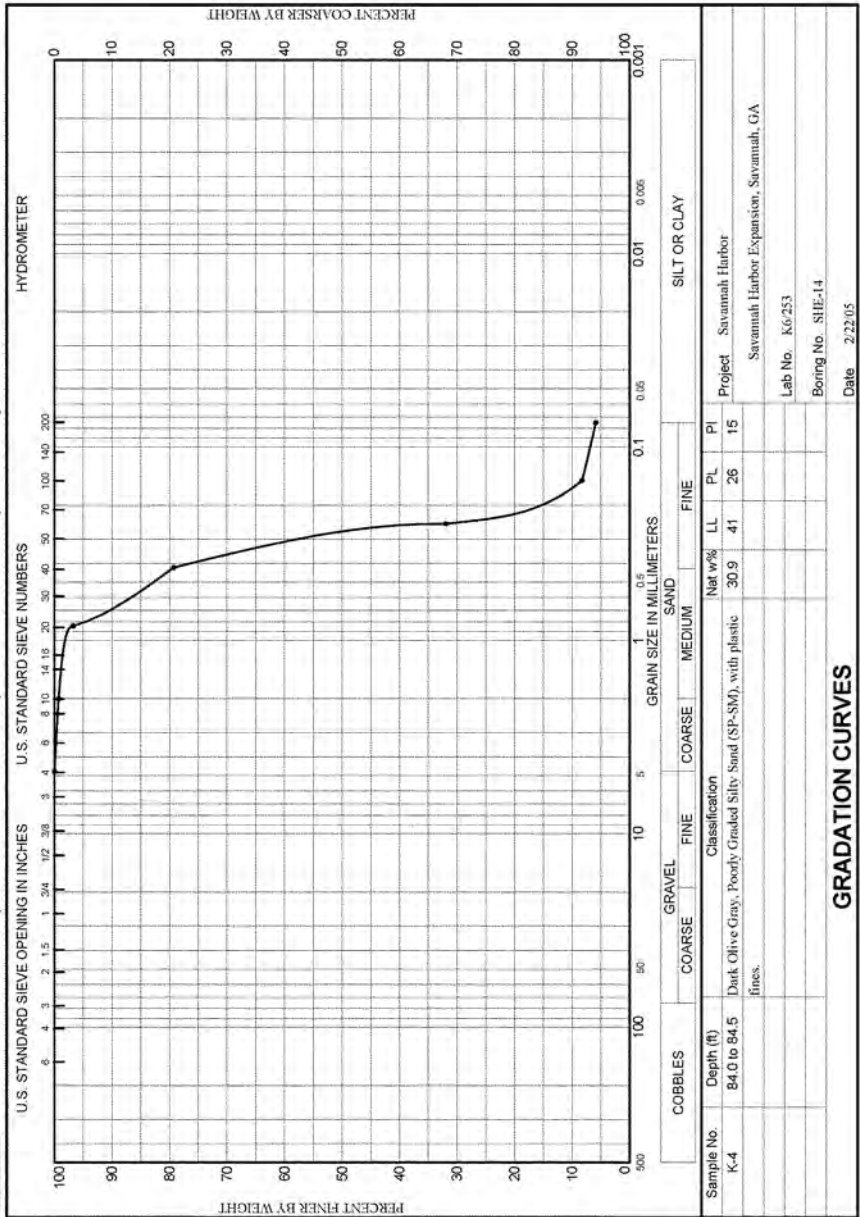


Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	Project
K-3	75.0 to 75.5	Olive Gray, (Visual) Fat Clay (CH), with a trace of sand.	76.7			Savannah Harbor
						Savannah Harbor Expansion, Savannah, GA
						Lab No. K6-252
						Boring No. SHE-14
						Date 2/22/05



DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

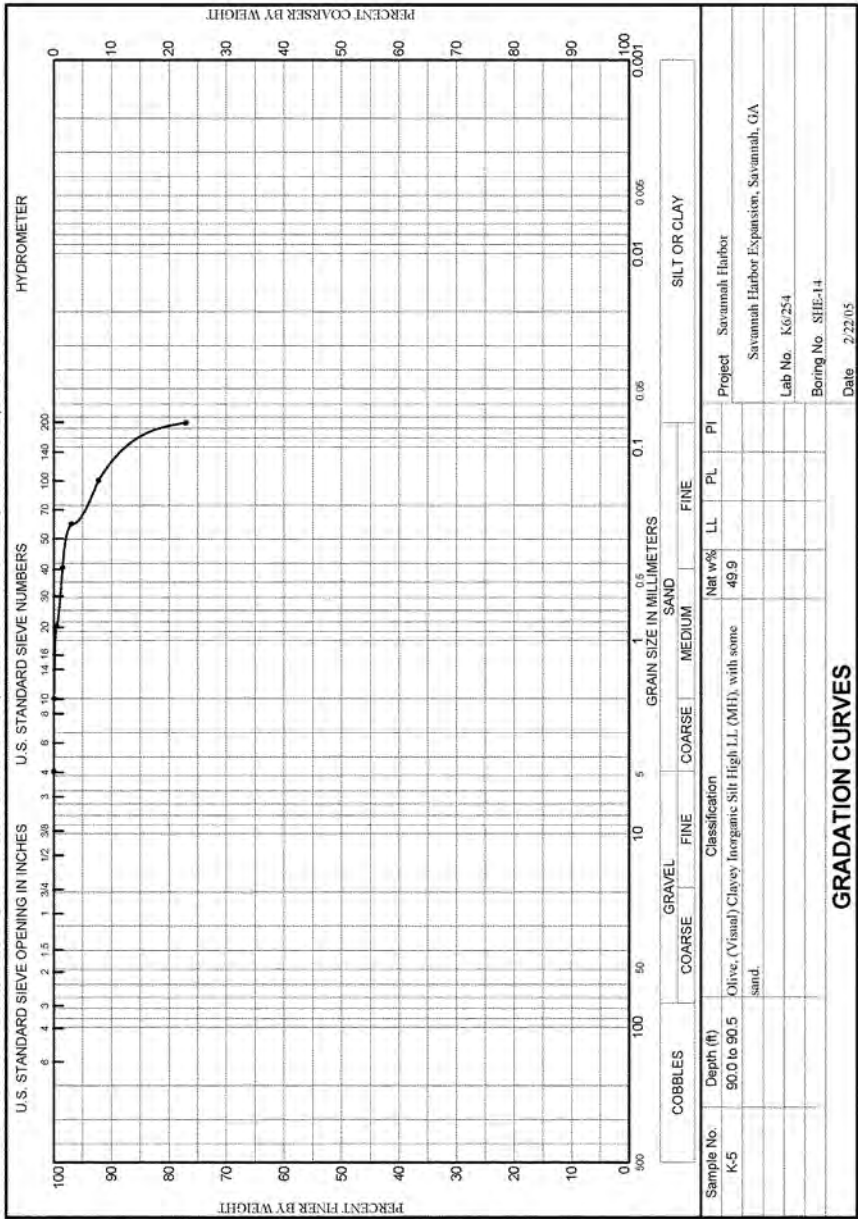
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

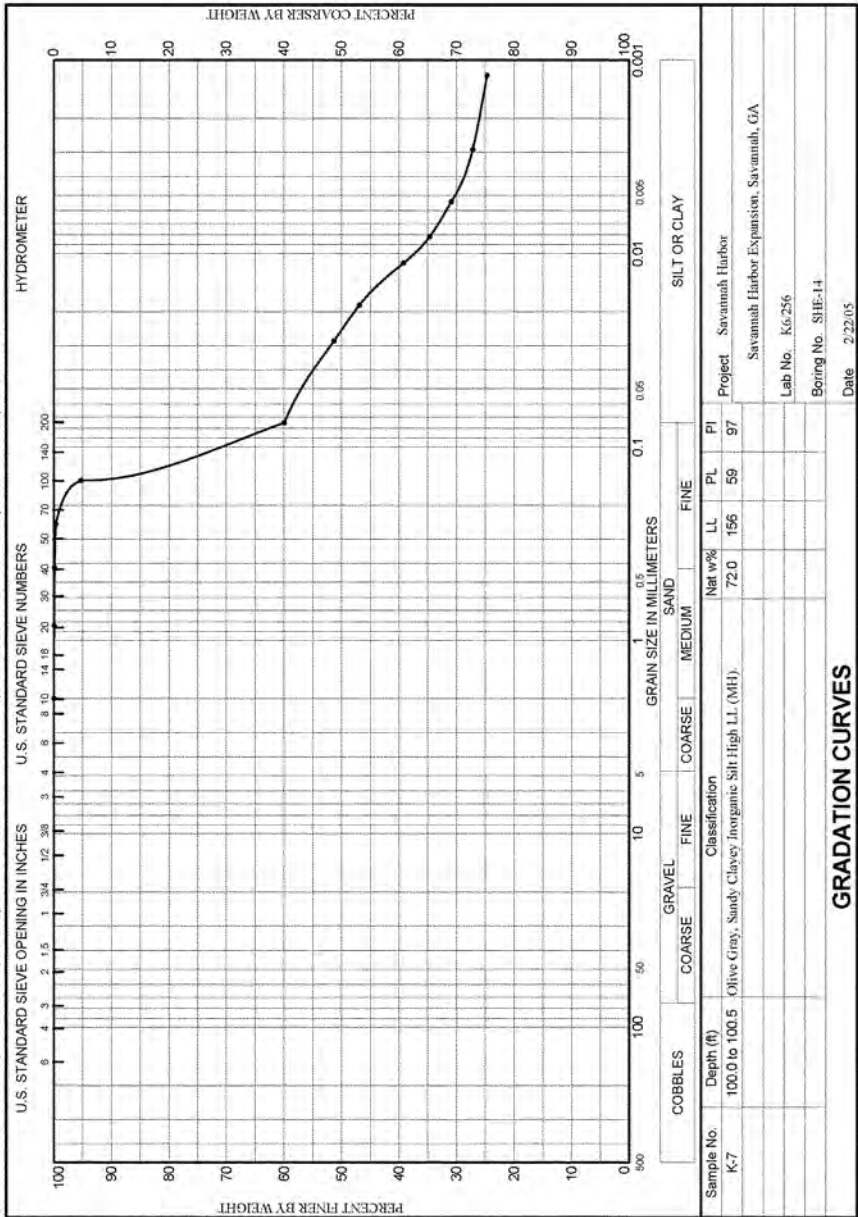
WORK ORDER: 330e
REQUISITION: W33SUG40168635



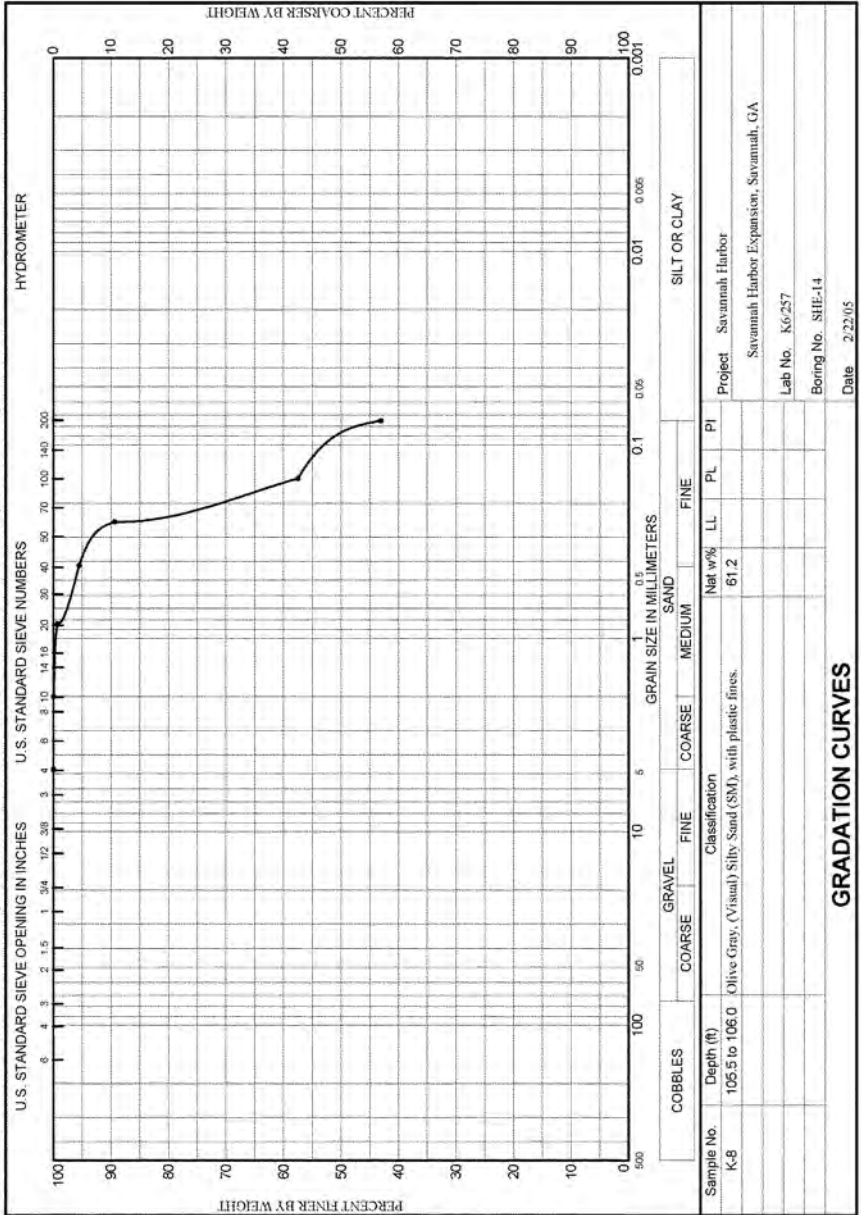


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 3306
REQUISITION: W33SJG40168635



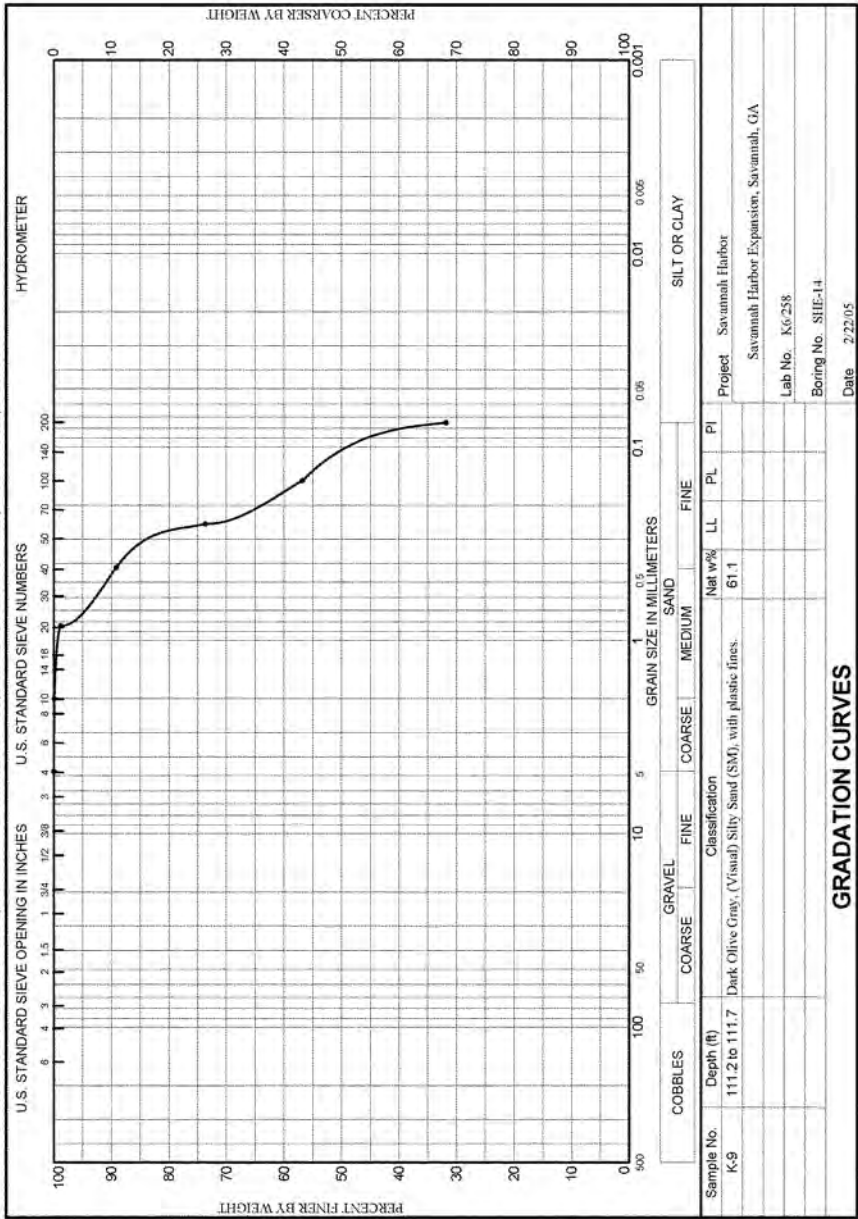
WORK ORDER: 330e
REQUISITION: W335JG40168635



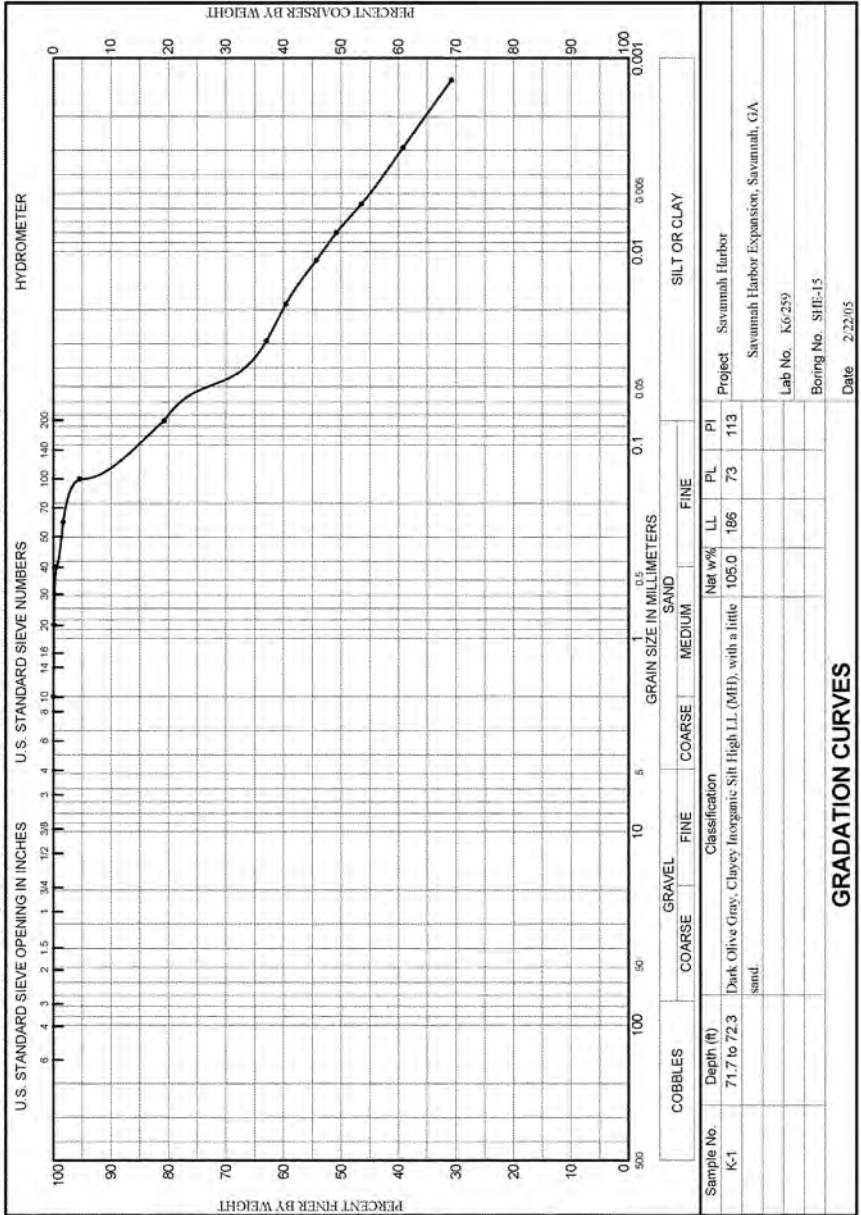


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



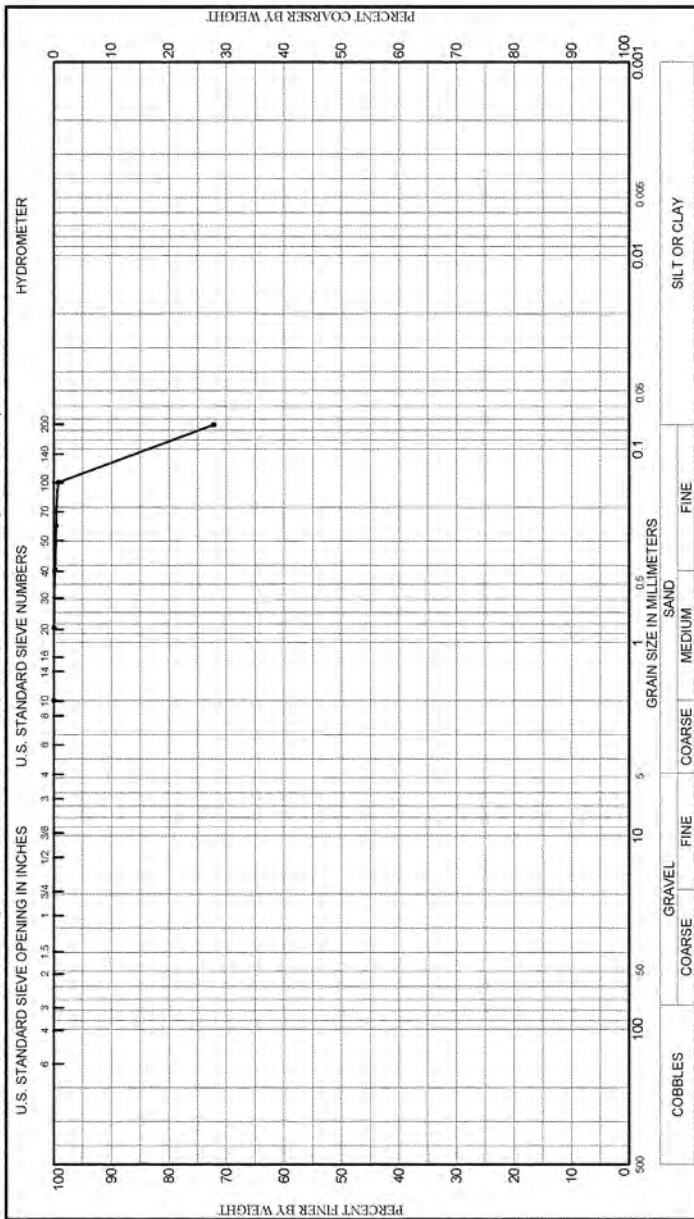
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635

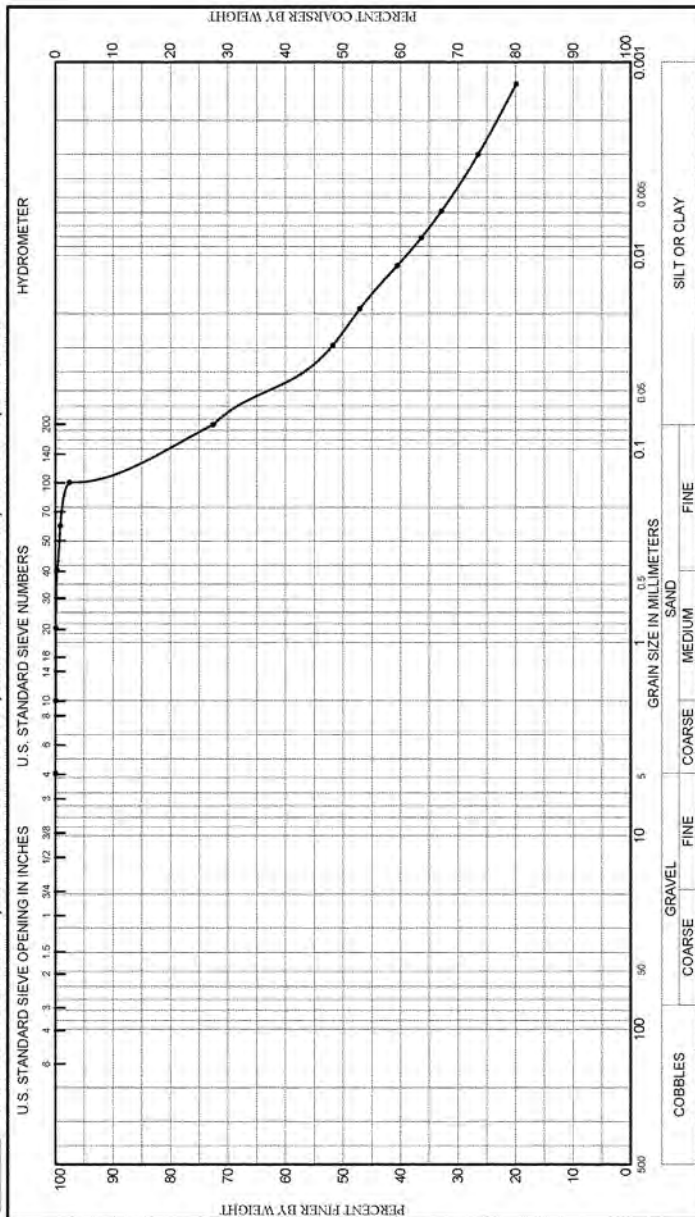


Sample No.	Depth (ft)	Classification	Nat w% LL (MHT)	PL	PI	Project
K-2	80.0 to 80.5	Dark Olive Gray, (Visual) Clayey Inorganic Silt High LL (MHT) with some sand.	65.5			Savannah Harbor
						Savannah Harbor Expansion, Savannah, GA
						Lab No. K-260
						Boring No. SHE-15
						Date 2/22/05

GRADATION CURVES



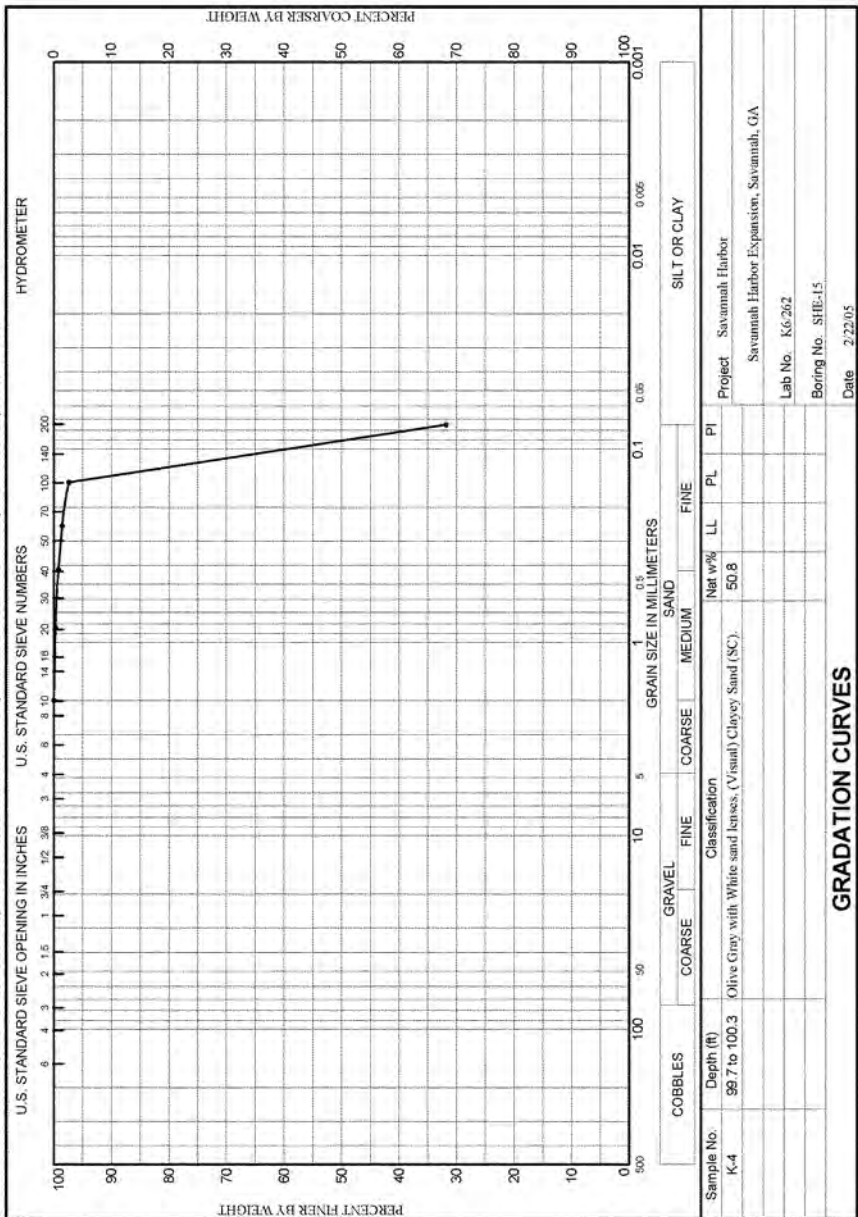
REQUISITION: W33SJG40168635

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DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

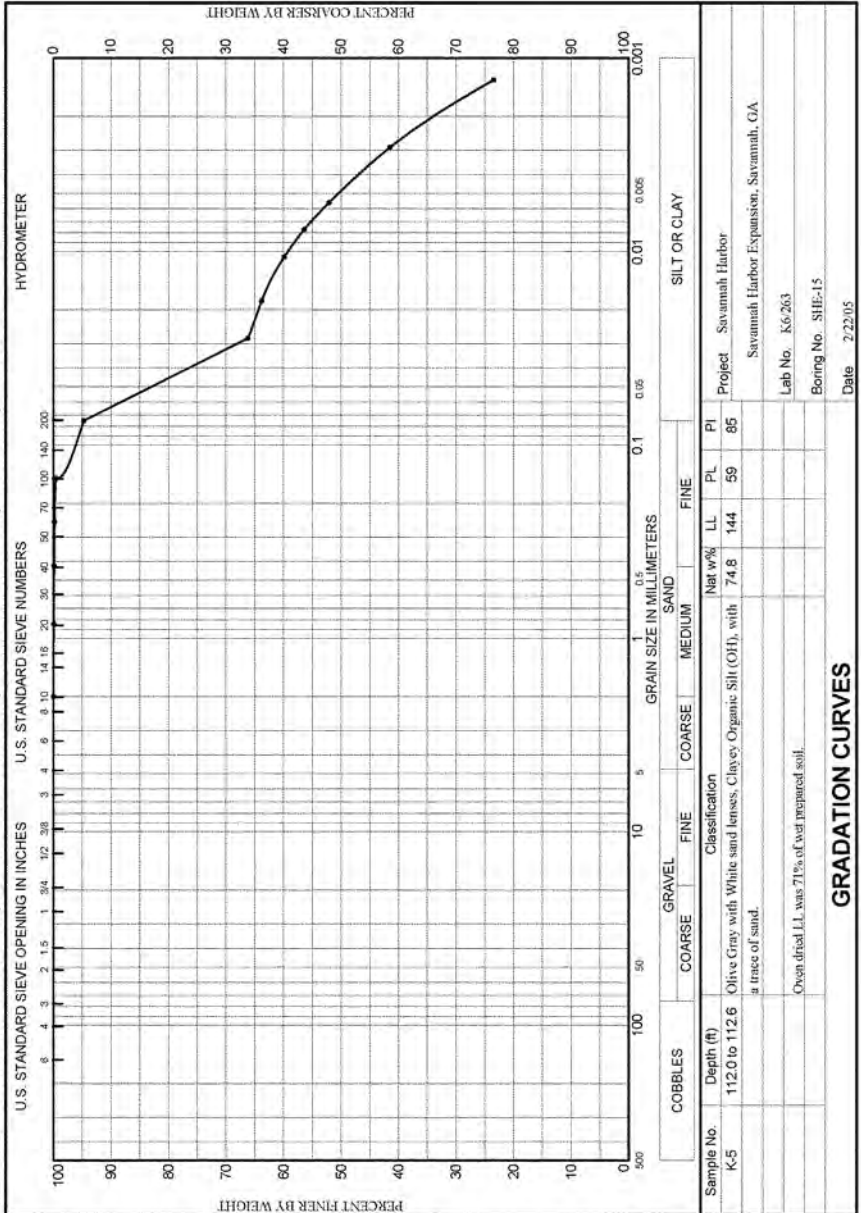
WORK ORDER: 330e
REQUISITION: W33SUG40168635



DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

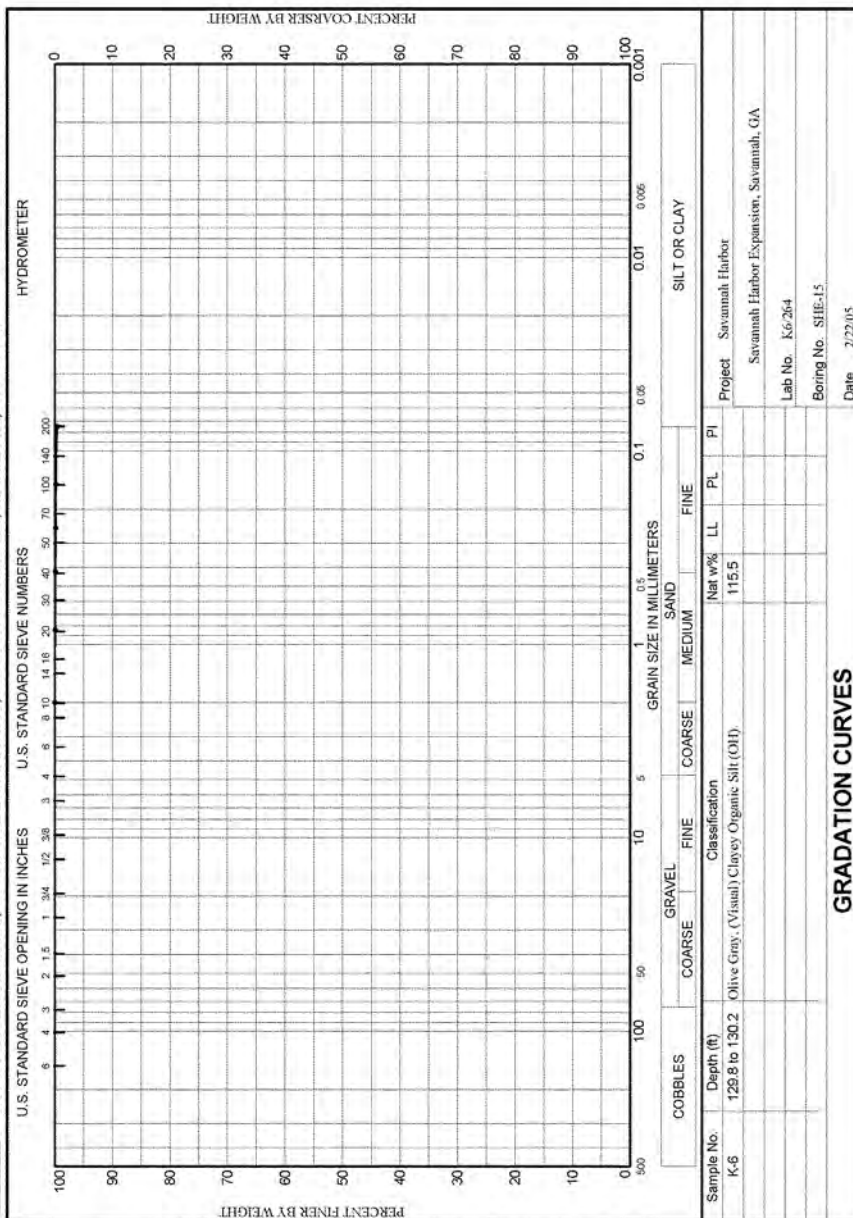
WORK ORDER: 330e

REQUISITION: W33SJG40168635

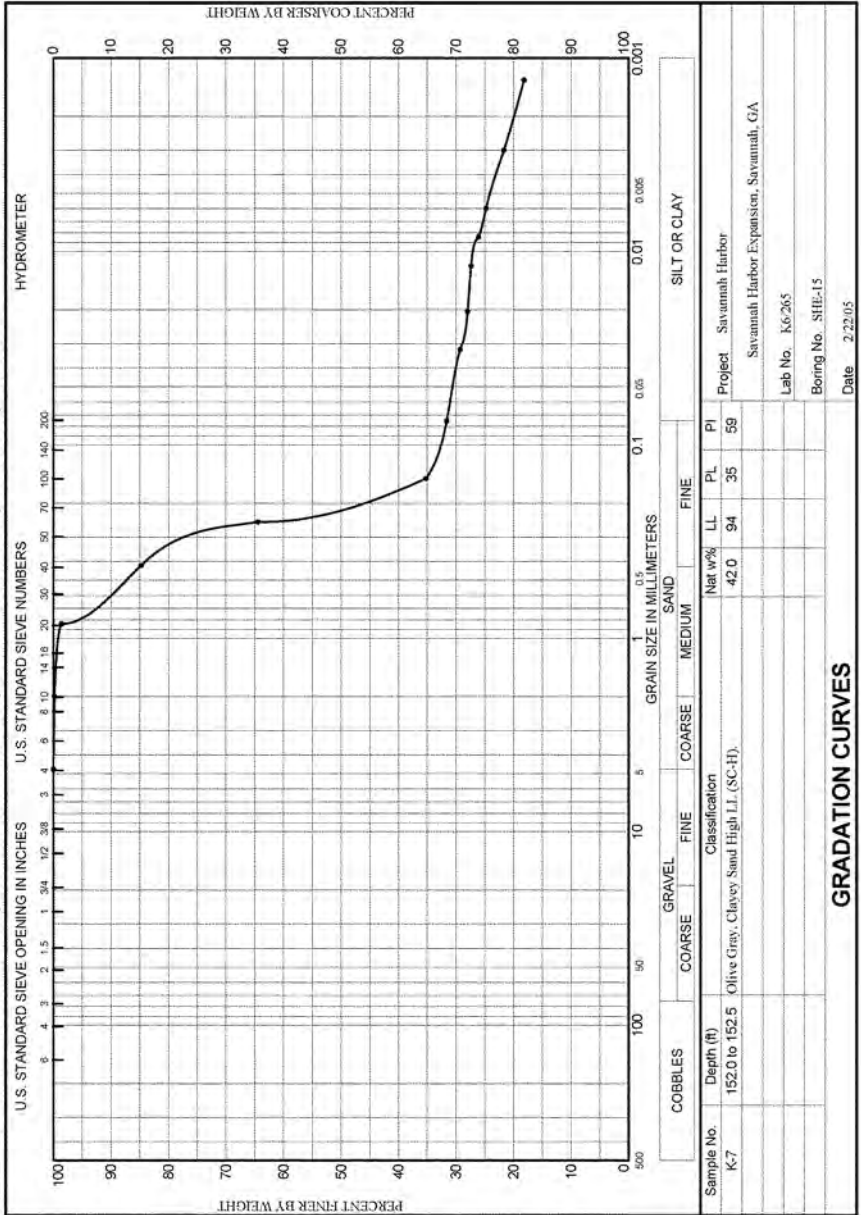


WORK ORDER: 330e
REQUISITION: W33SJG40168635

DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062



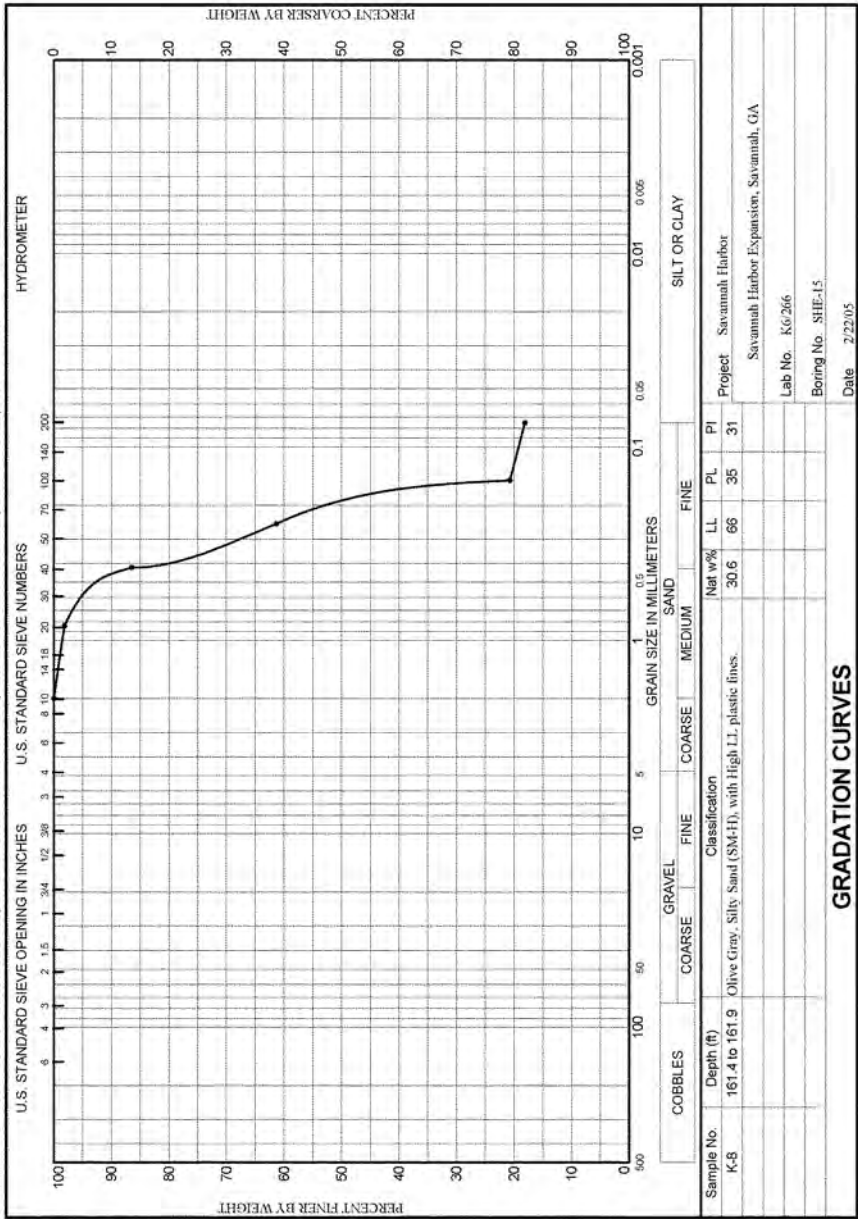
WORK ORDER: 3309
REQUISITION: W33SJG40168635



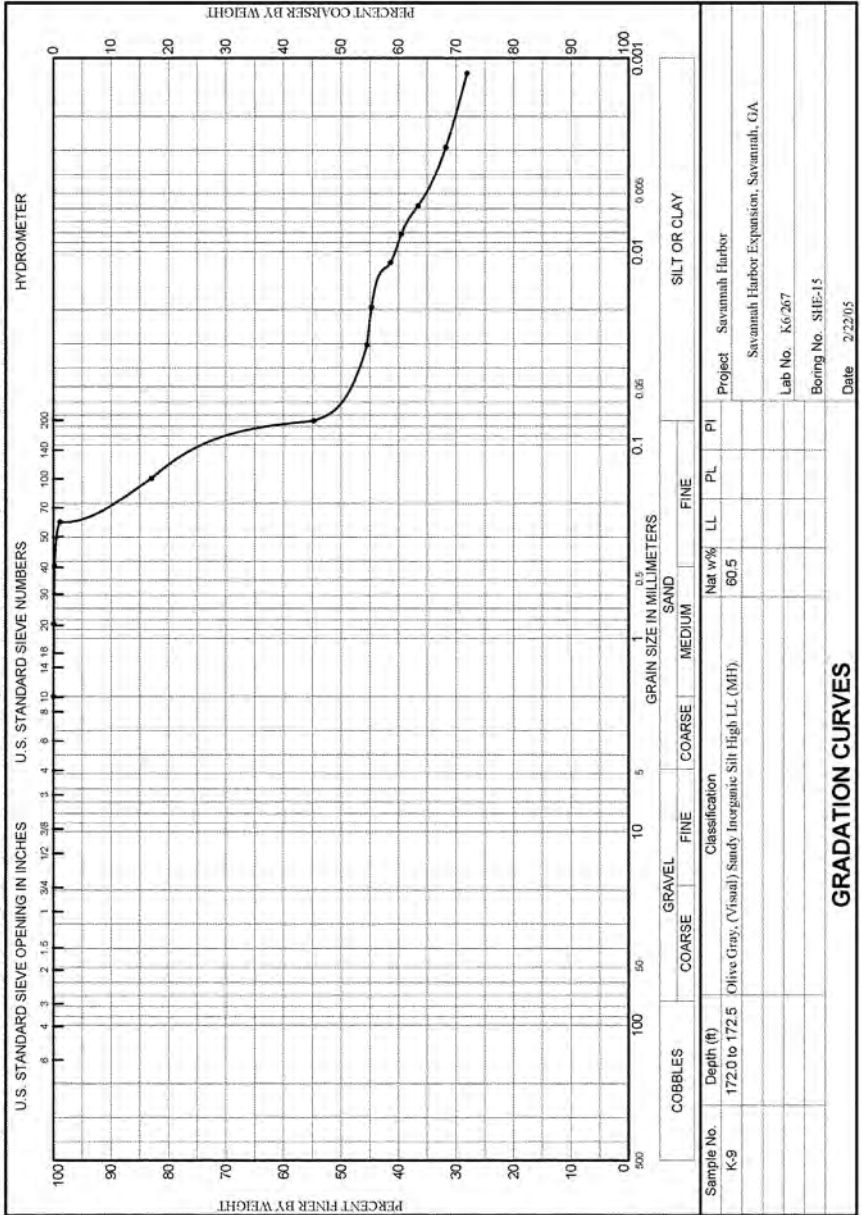


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



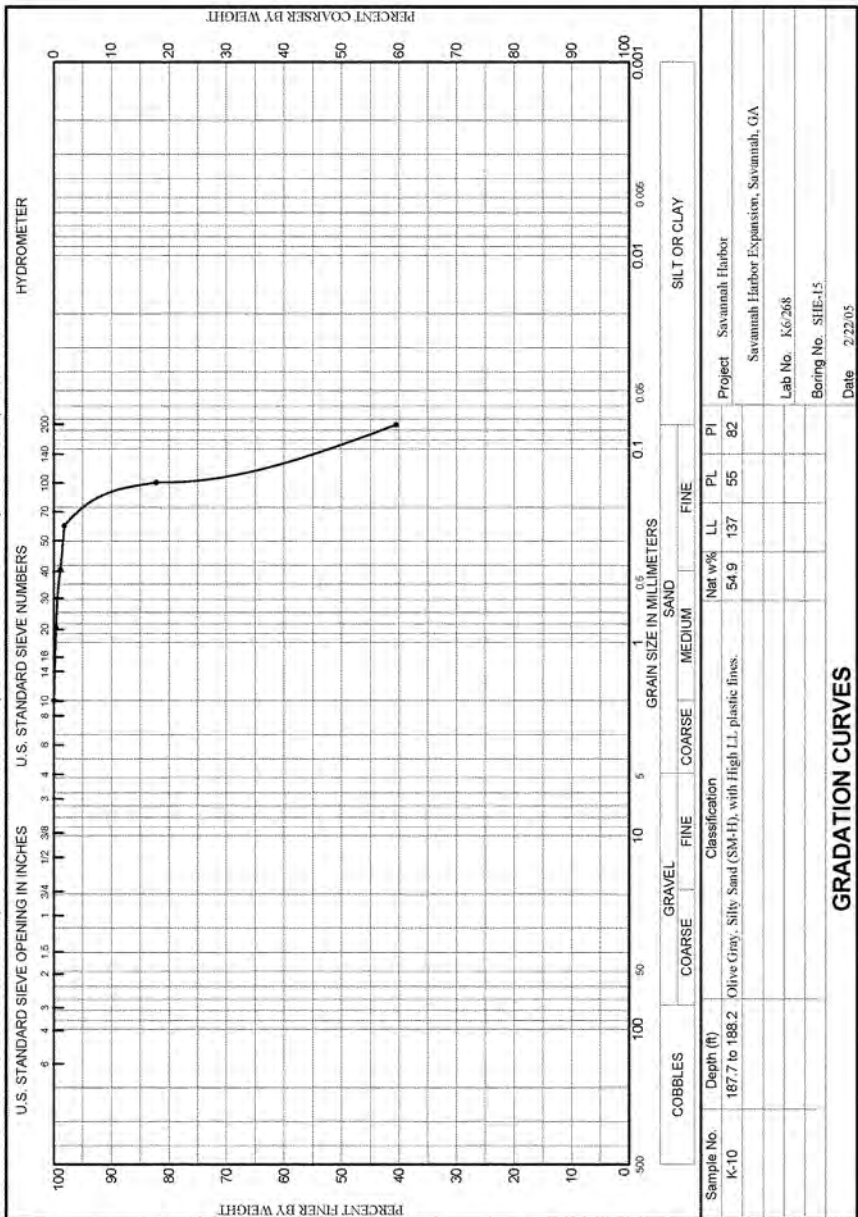
WORK ORDER: 330e
REQUISITION: W33SJG40168635



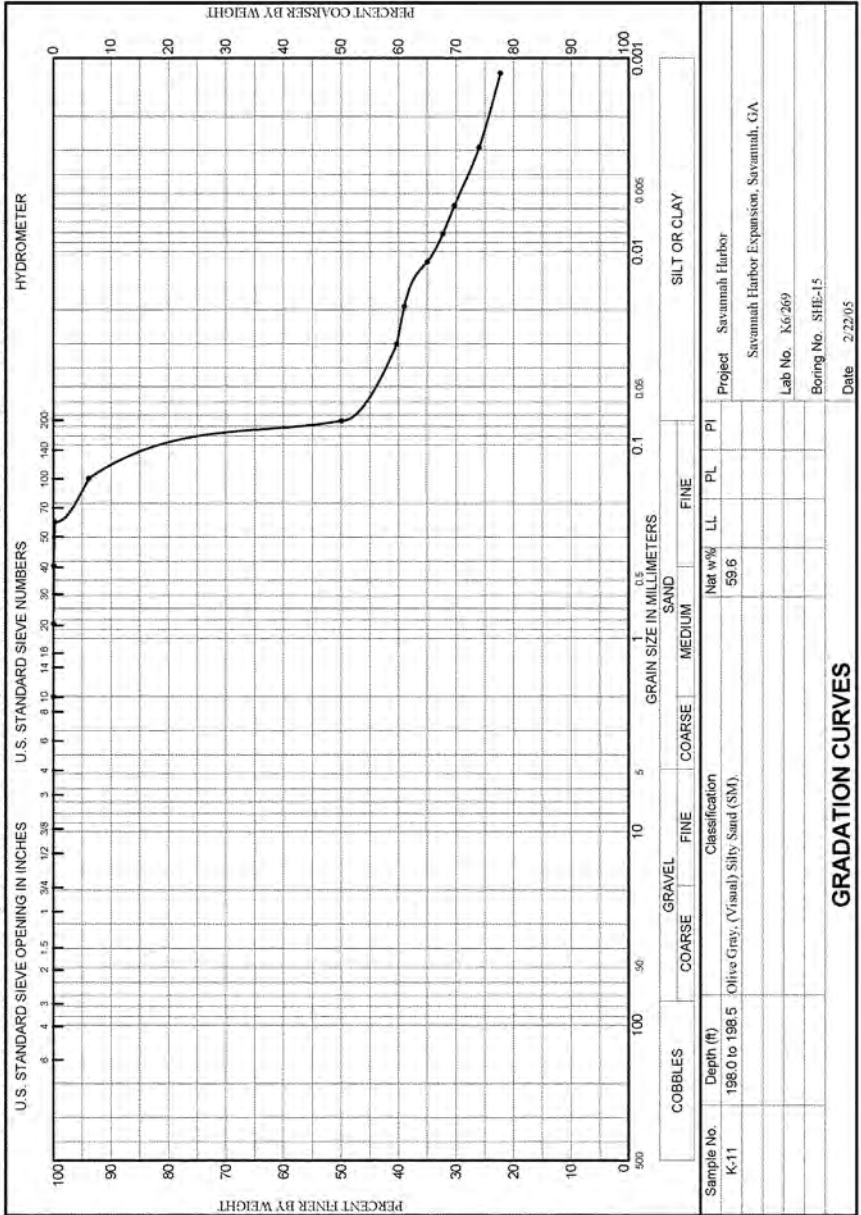


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



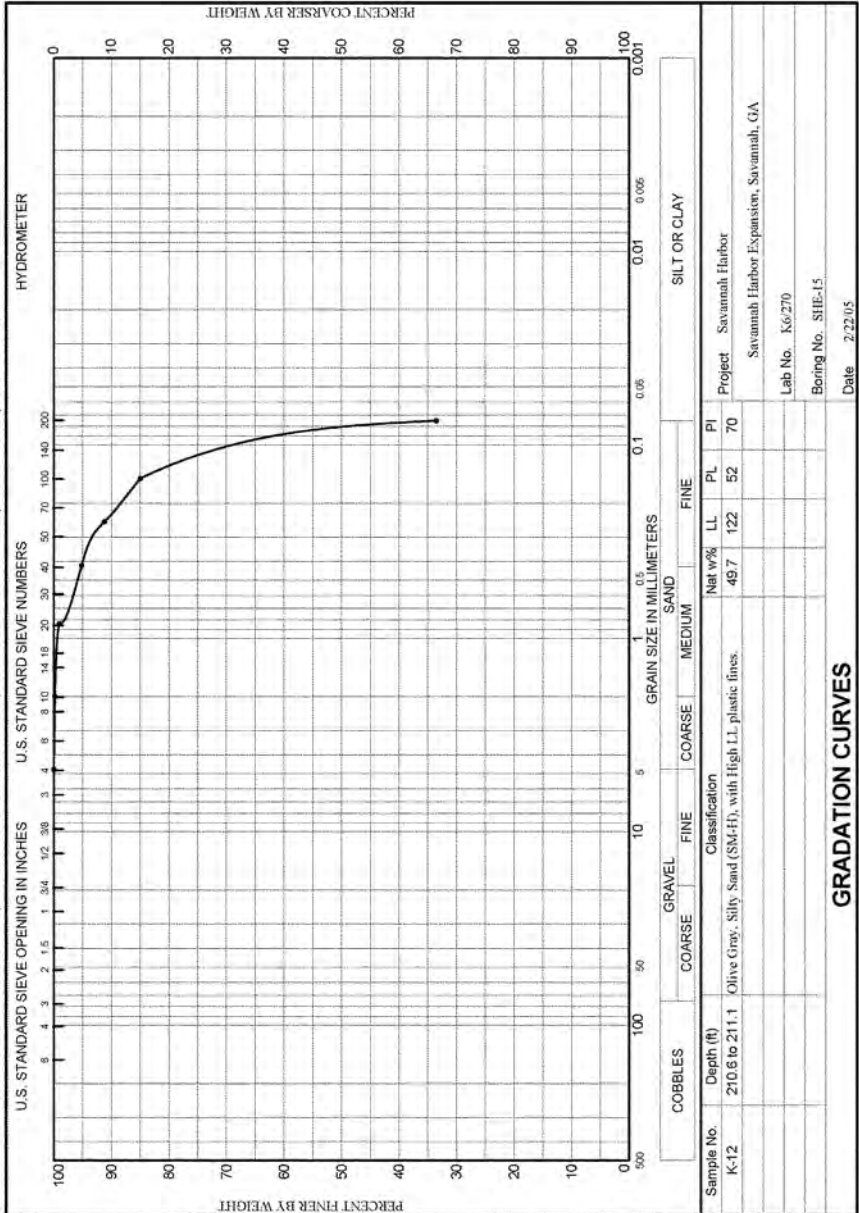
WORK ORDER: 330e
REQUISITION: W33SJG40168635





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CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

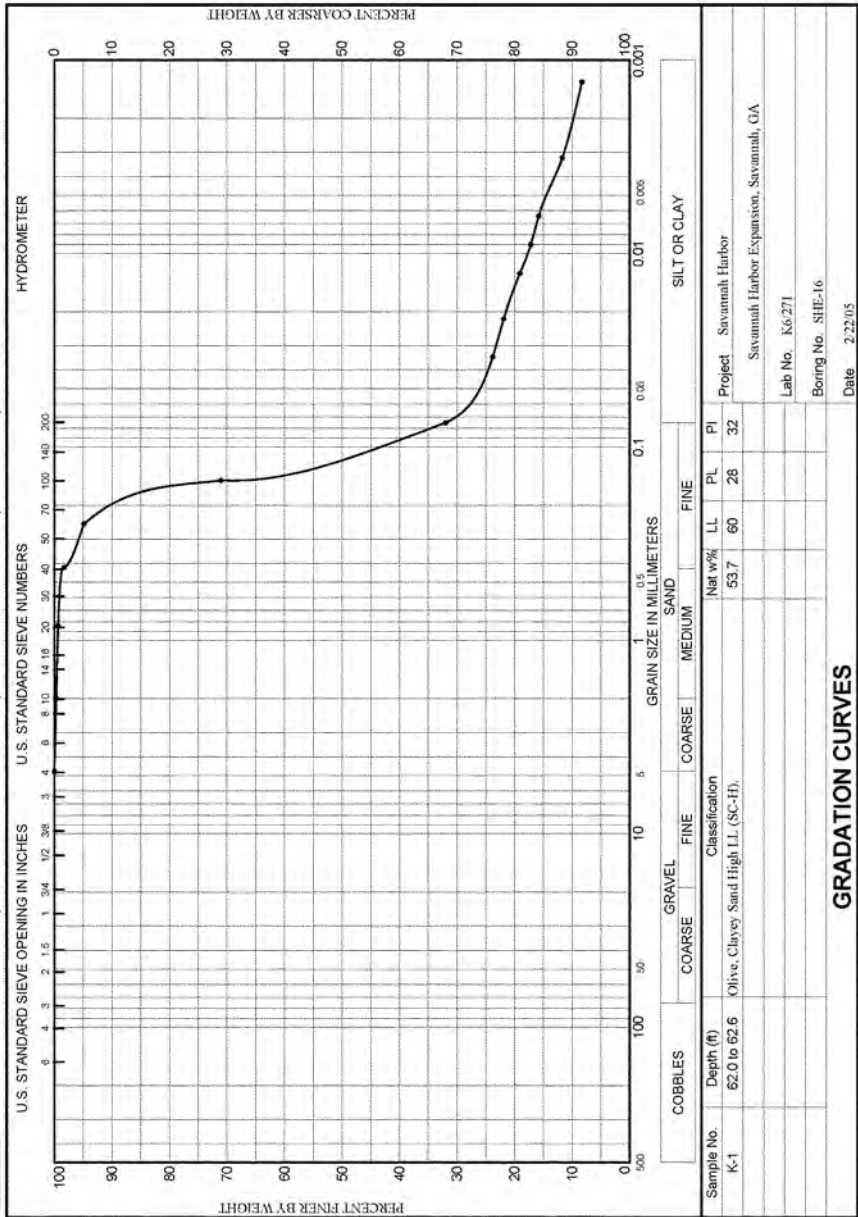
WORK ORDER: 330e
REQUISITION: W33SUG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

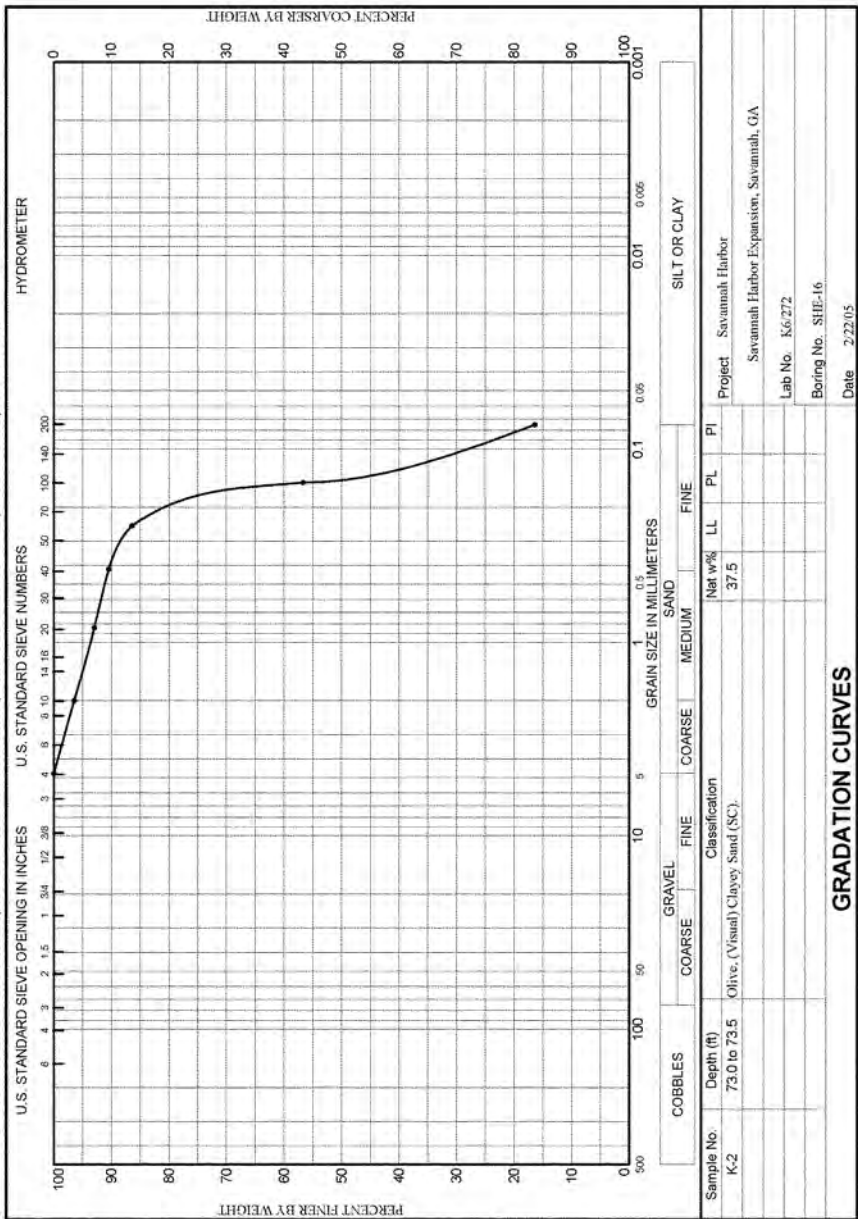
WORK ORDER: 330e
REQUISITION: W33S/JG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

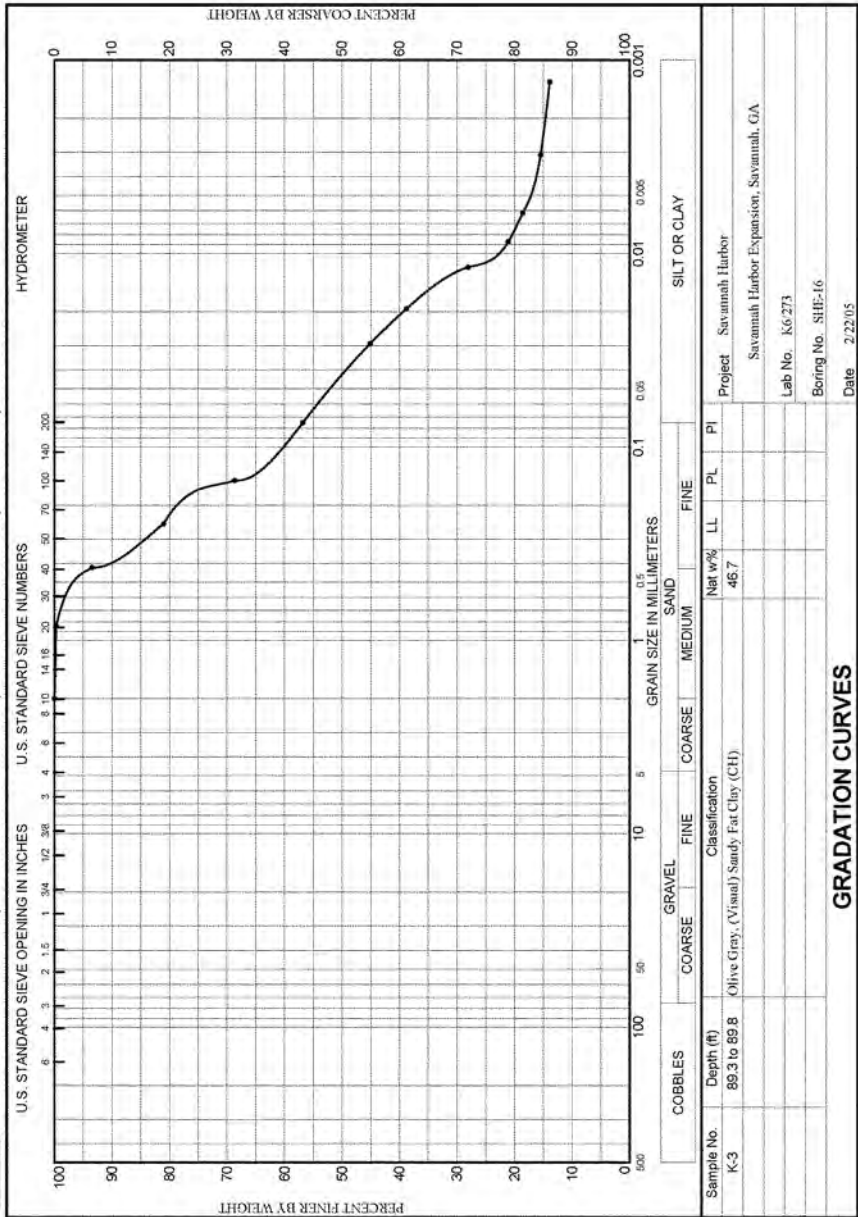
WORK ORDER: 330e
REQUISITION: W33SUG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

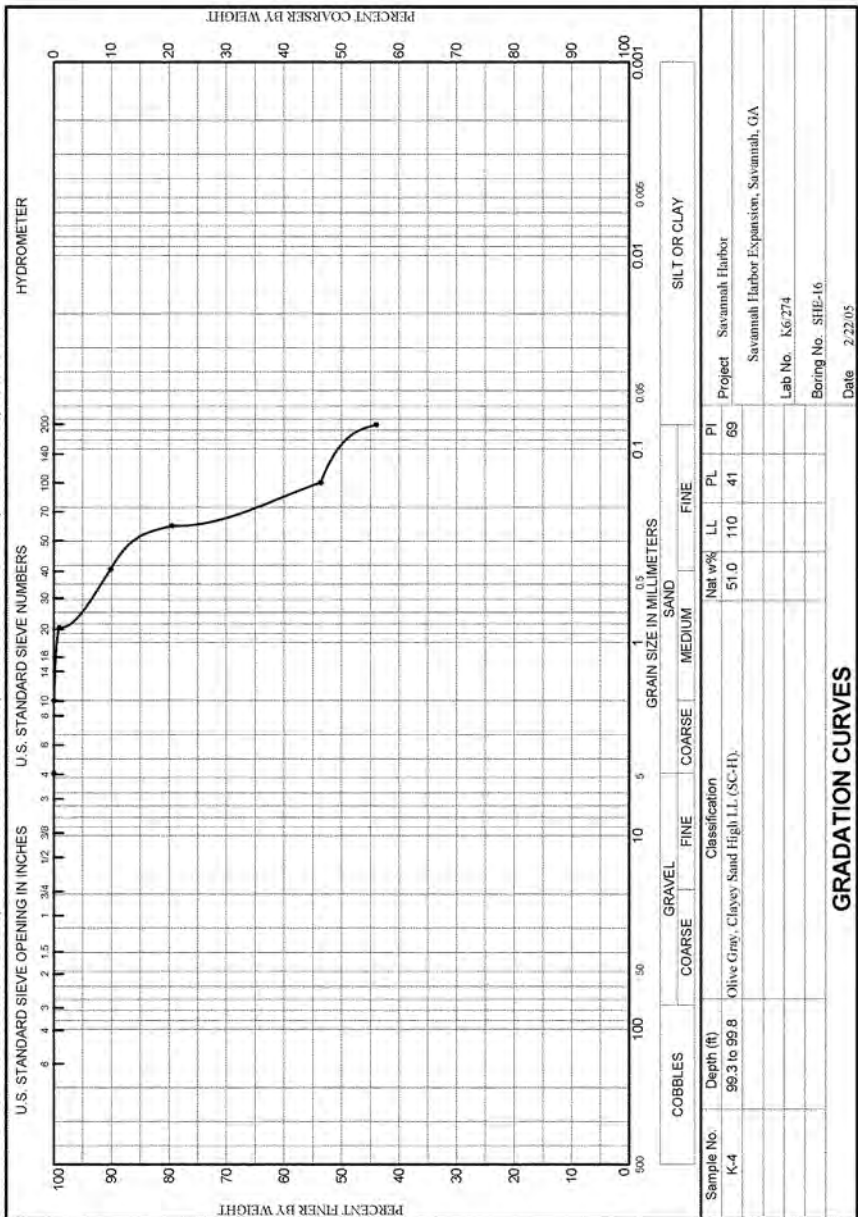
WORK ORDER: 330e
REQUISITION: W33S/JG40168635



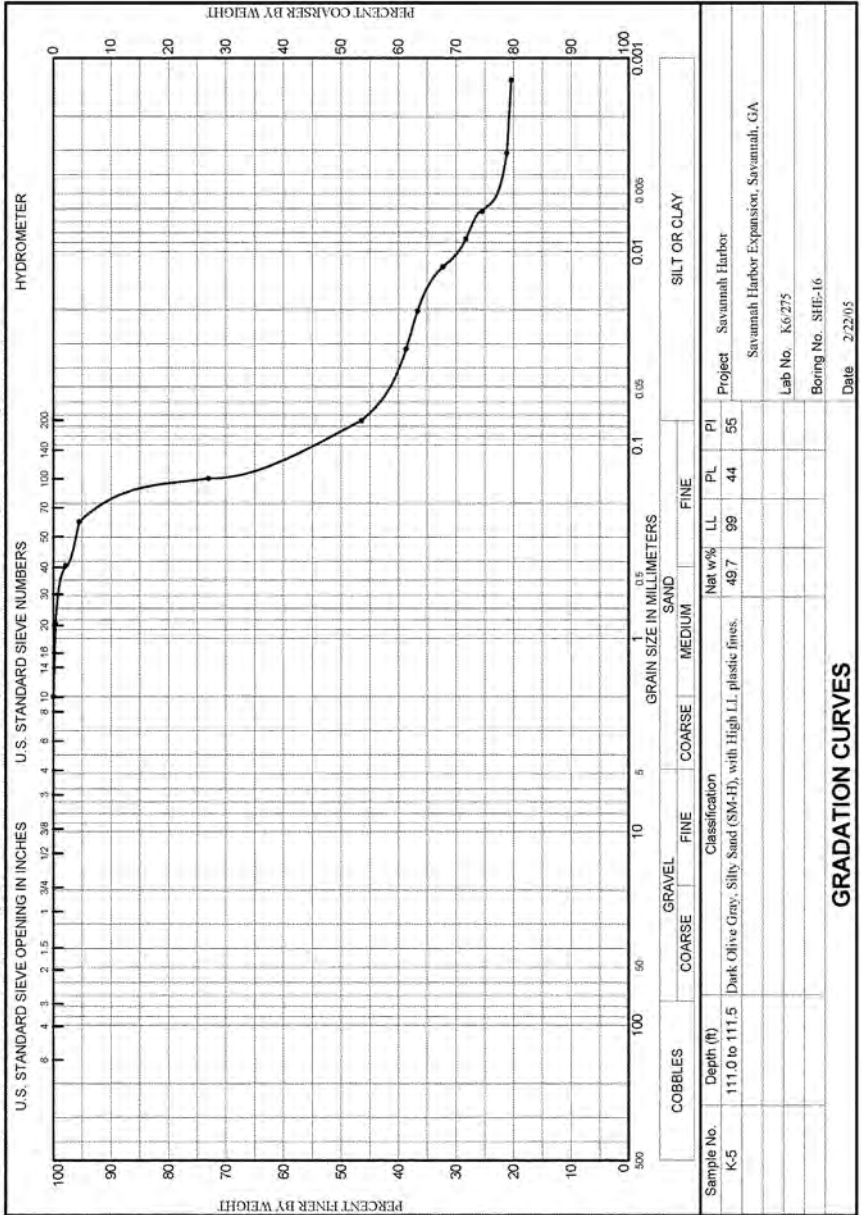


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SUG40168635



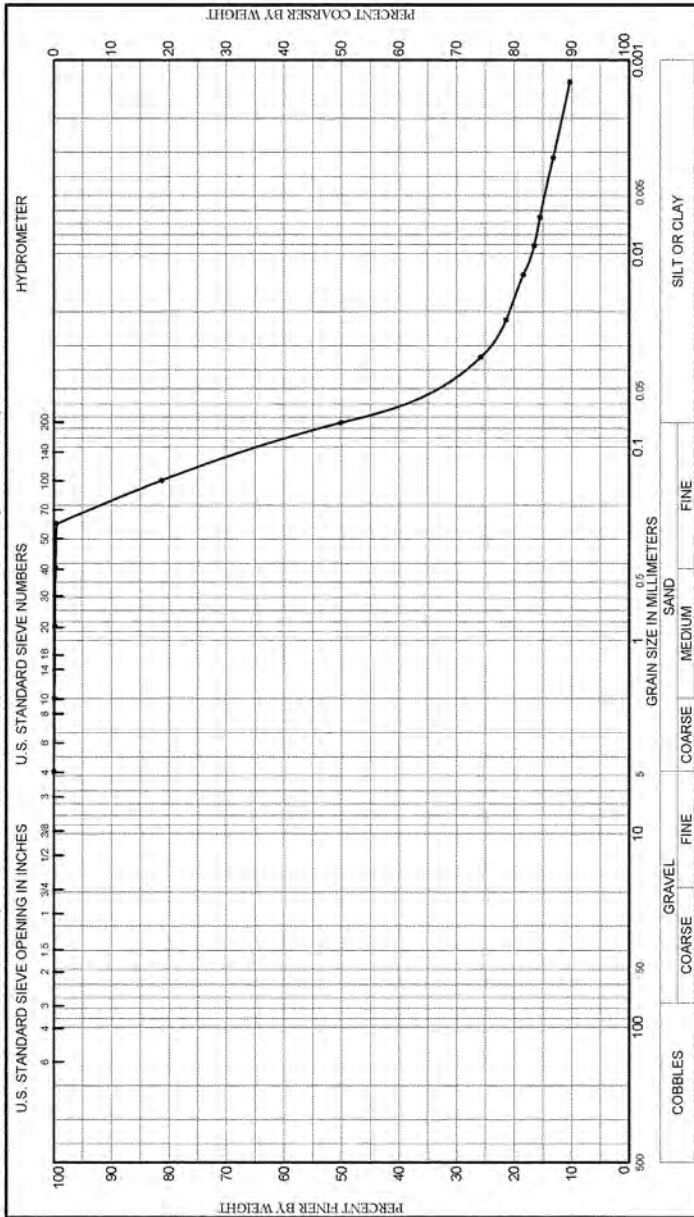
WORK ORDER: 3300
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SJG40168635



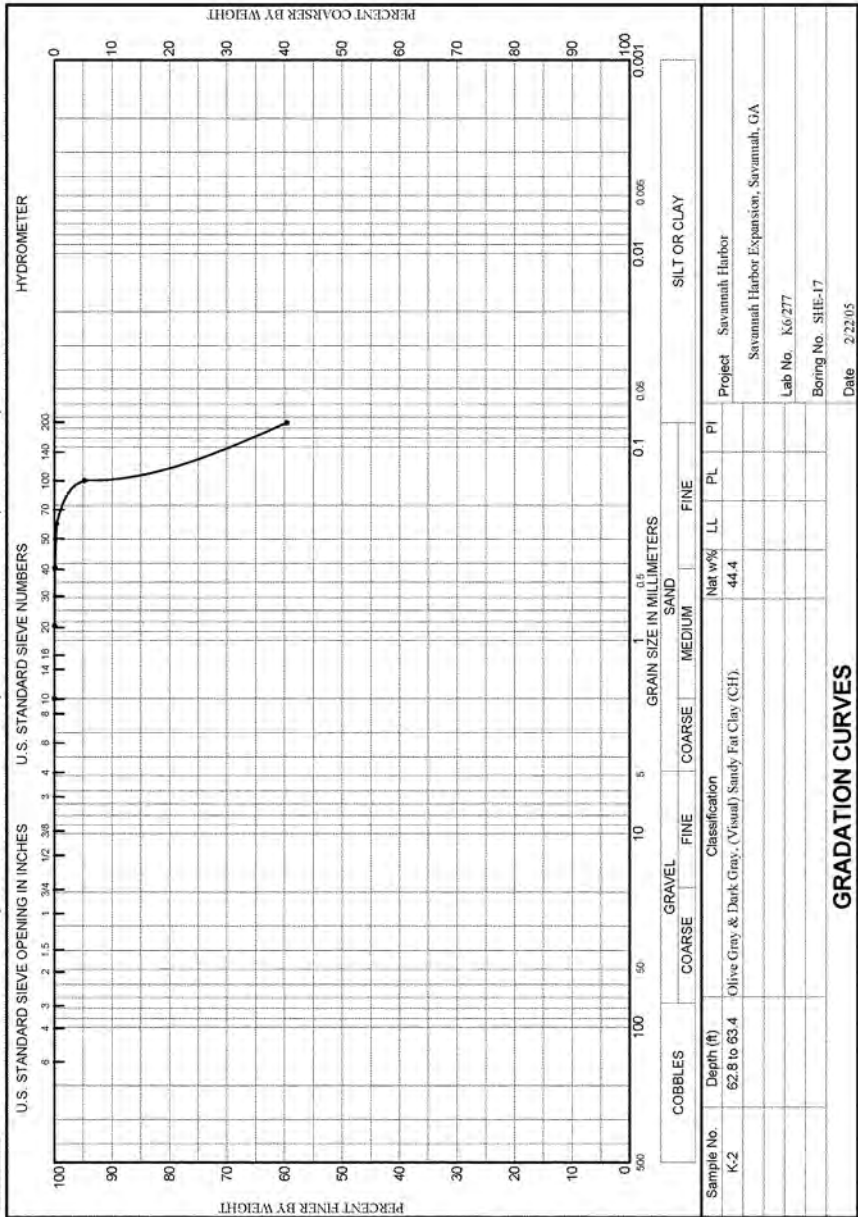
COBBLES		GRAVEL		FINE SAND		MEDIUM SAND		FINE SILT OR CLAY	
COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE
Classification		Classification		Classification		Classification		Classification	
Olive Gray & Dark Gray, Sandy Lean Clay (CL)		Olive Gray & Dark Gray, Sandy Lean Clay (CL)		Olive Gray & Dark Gray, Sandy Lean Clay (CL)		Olive Gray & Dark Gray, Sandy Lean Clay (CL)		Olive Gray & Dark Gray, Sandy Lean Clay (CL)	
Nat w% LL 46 21 25		Nat w% LL 46 21 25		Nat w% LL 46 21 25		Nat w% LL 46 21 25		Nat w% LL 46 21 25	
PI		PI		PI		PI		PI	
25		25		25		25		25	
Project Savannah Harbor		Project Savannah Harbor		Project Savannah Harbor		Project Savannah Harbor		Project Savannah Harbor	
Savannah Harbor Expansion, Savannah, GA		Savannah Harbor Expansion, Savannah, GA		Savannah Harbor Expansion, Savannah, GA		Savannah Harbor Expansion, Savannah, GA		Savannah Harbor Expansion, Savannah, GA	
Lab No. K-6 276		Lab No. K-6 276		Lab No. K-6 276		Lab No. K-6 276		Lab No. K-6 276	
Boring No. SJIE-17		Boring No. SJIE-17		Boring No. SJIE-17		Boring No. SJIE-17		Boring No. SJIE-17	
Date 2/22/05		Date 2/22/05		Date 2/22/05		Date 2/22/05		Date 2/22/05	

GRADATION CURVES



DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

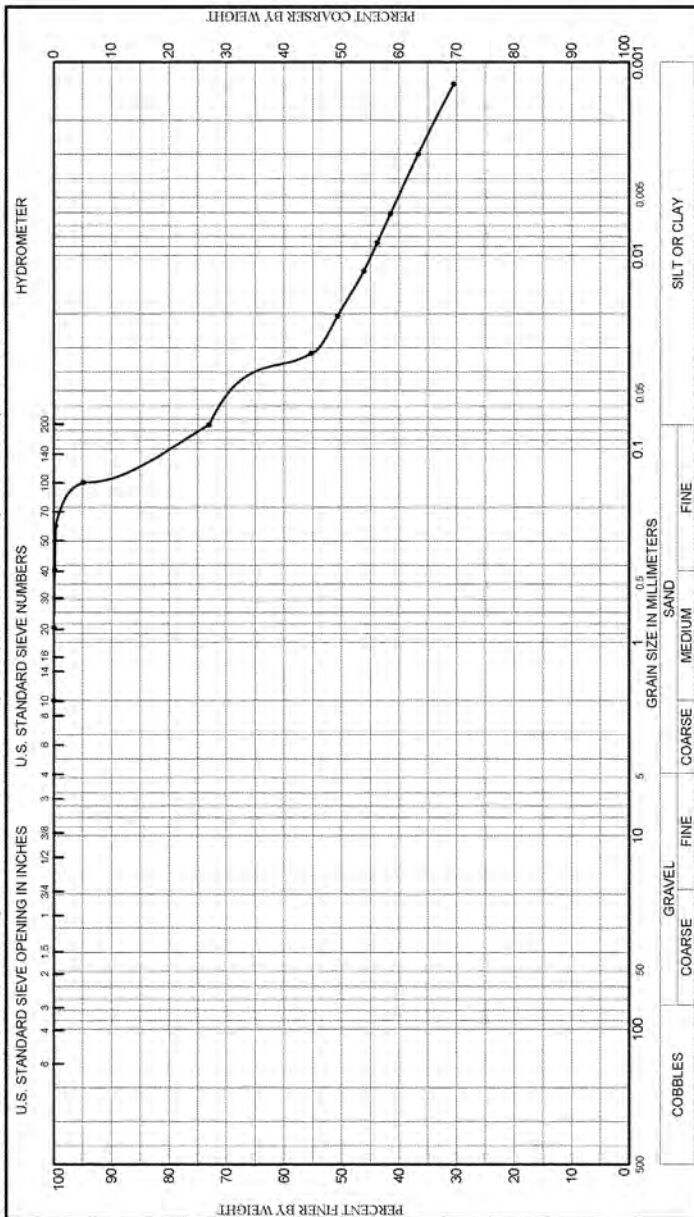
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

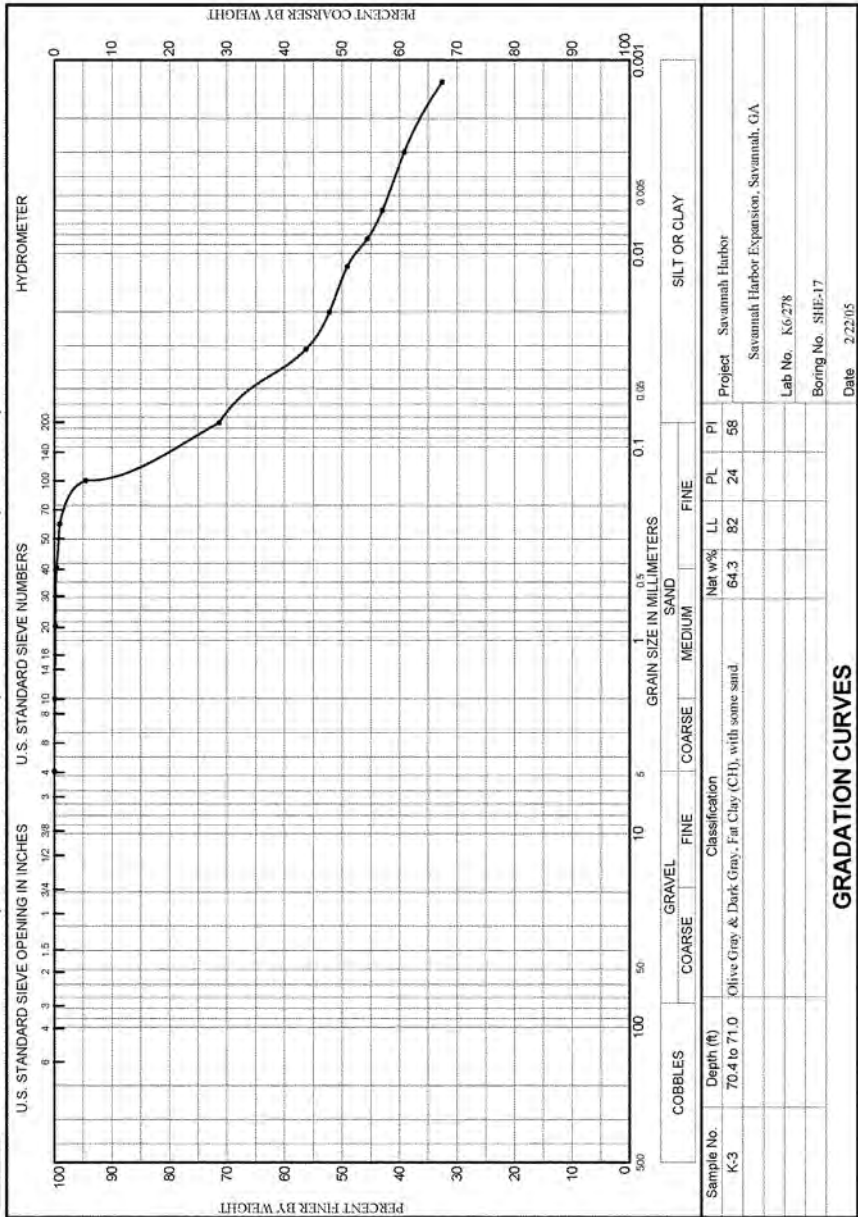
WORK ORDER: 330e
REQUISITION: W33S/JG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

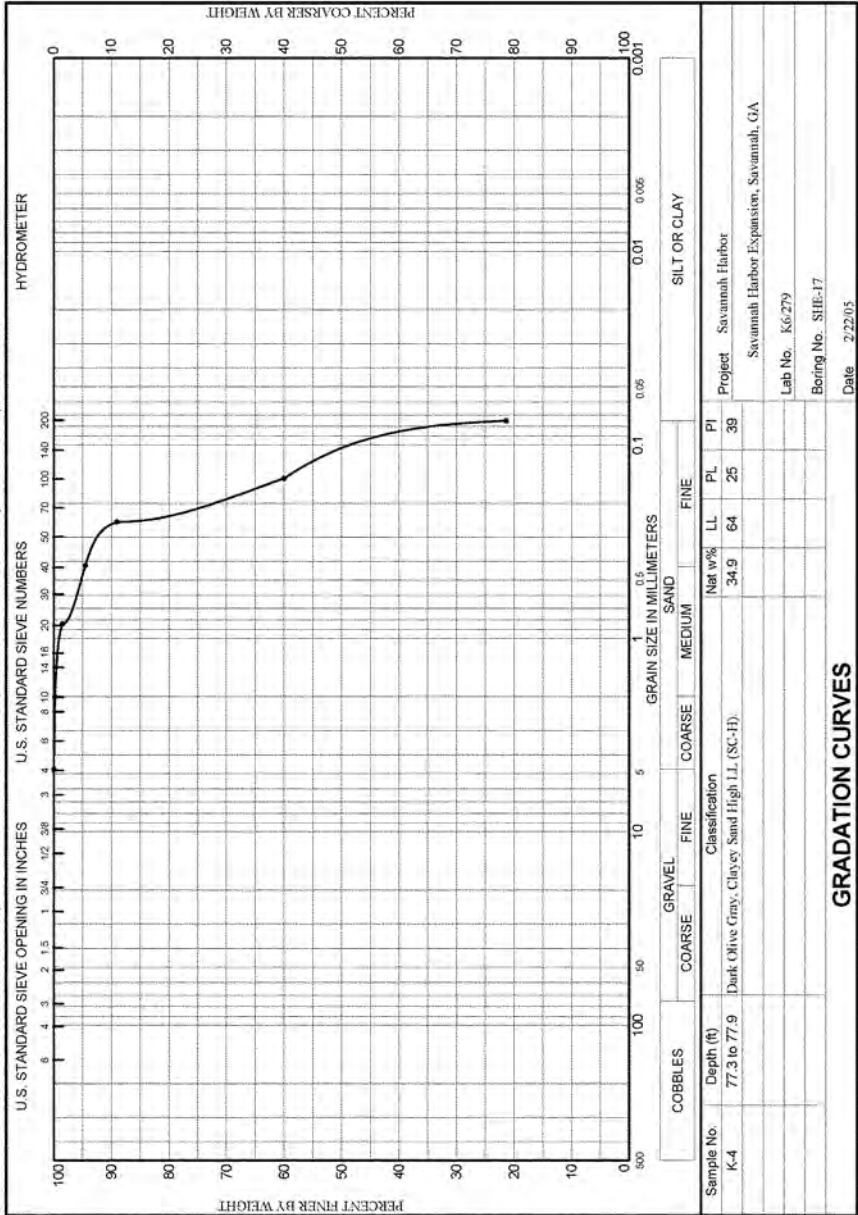
WORK ORDER: 330a
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

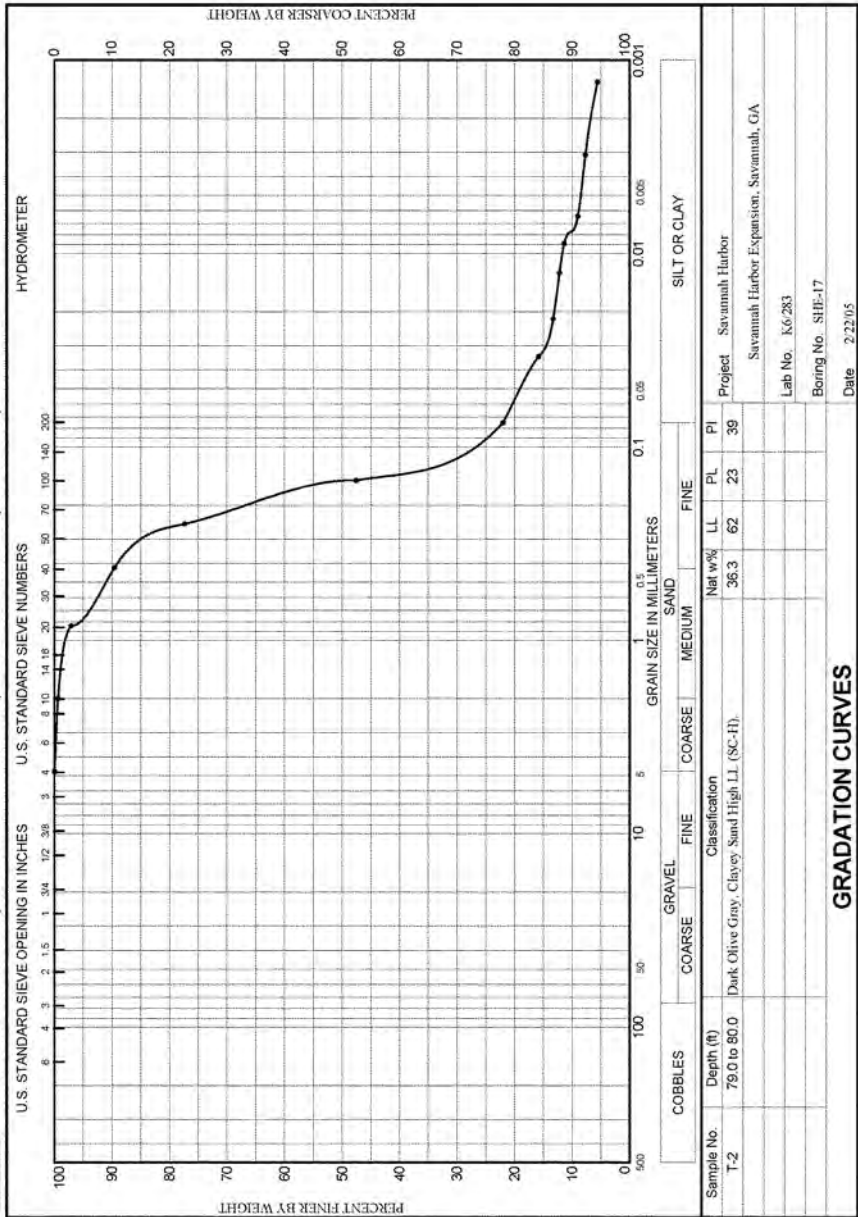
WORK ORDER: 330e
REQUISITION: W33SUG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

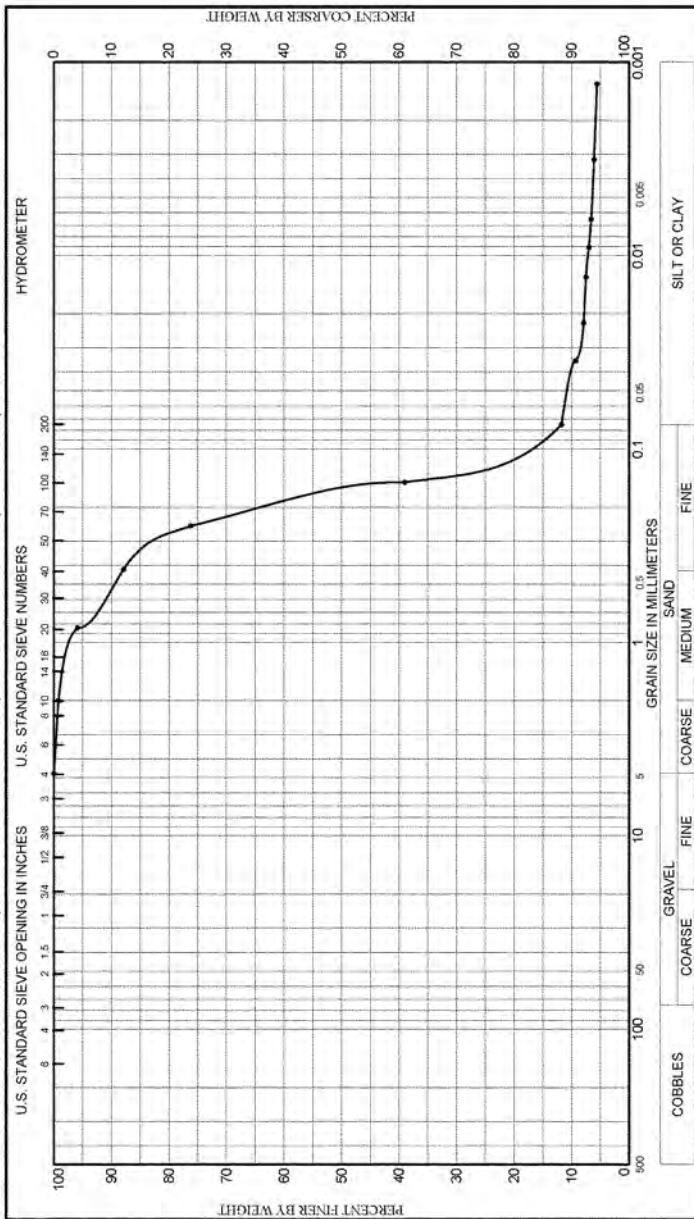
WORK ORDER: 330e
REQUISITION: W33SJG40169535





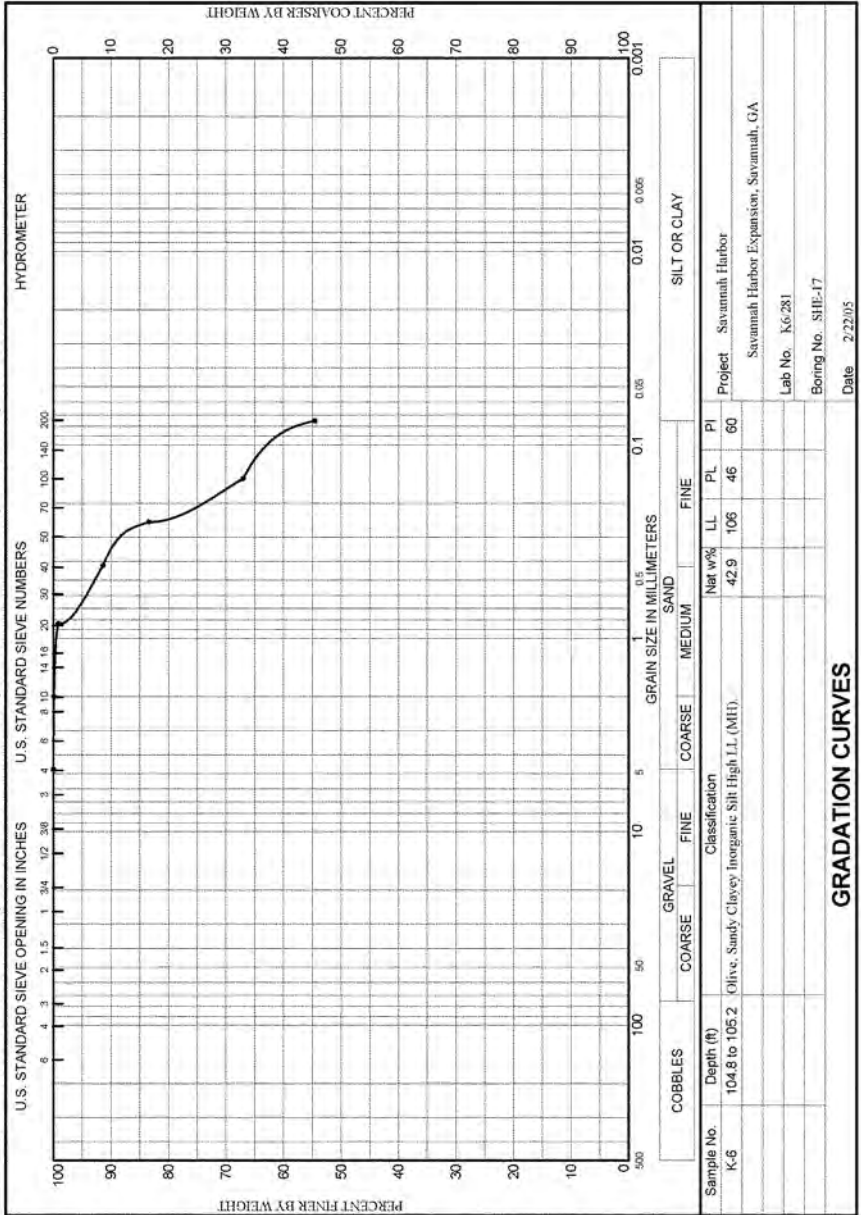
DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SJG40168635



Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
K-5	86.9 to 87.4	Dark Olive Gray, (Visual) Poorly Graded Silty Sand (SP-SM)	33.3			

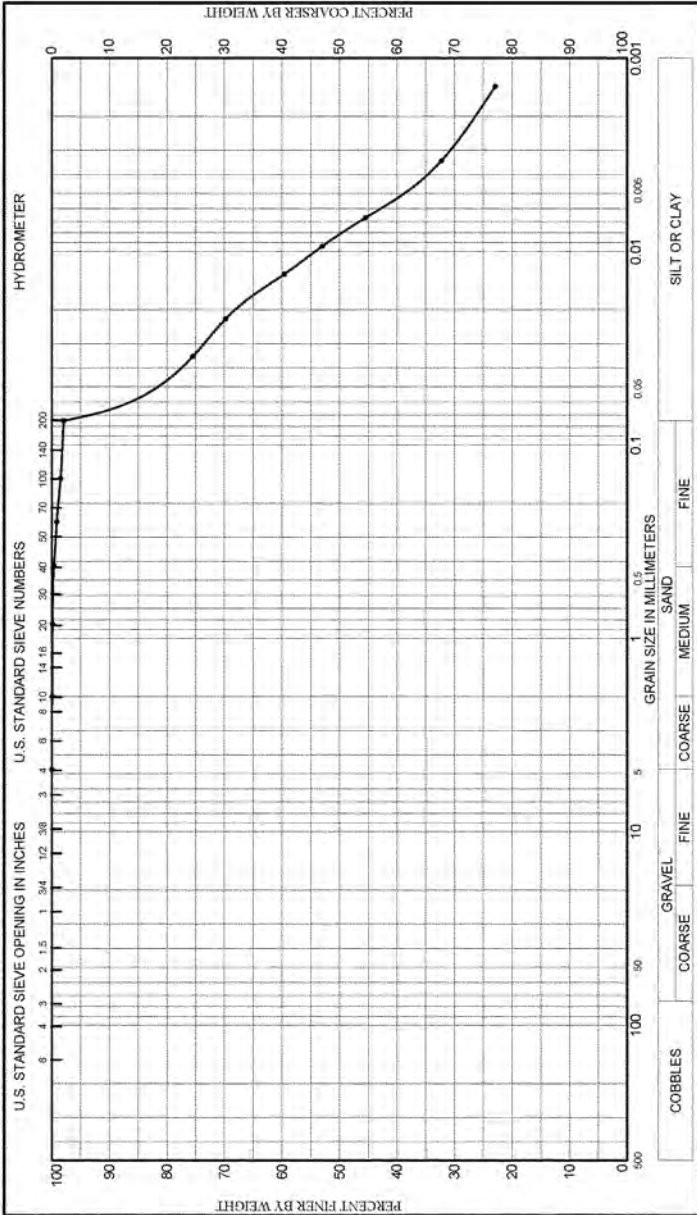
WORK ORDER: 330e
REQUISITION: W335JG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SJG40168635



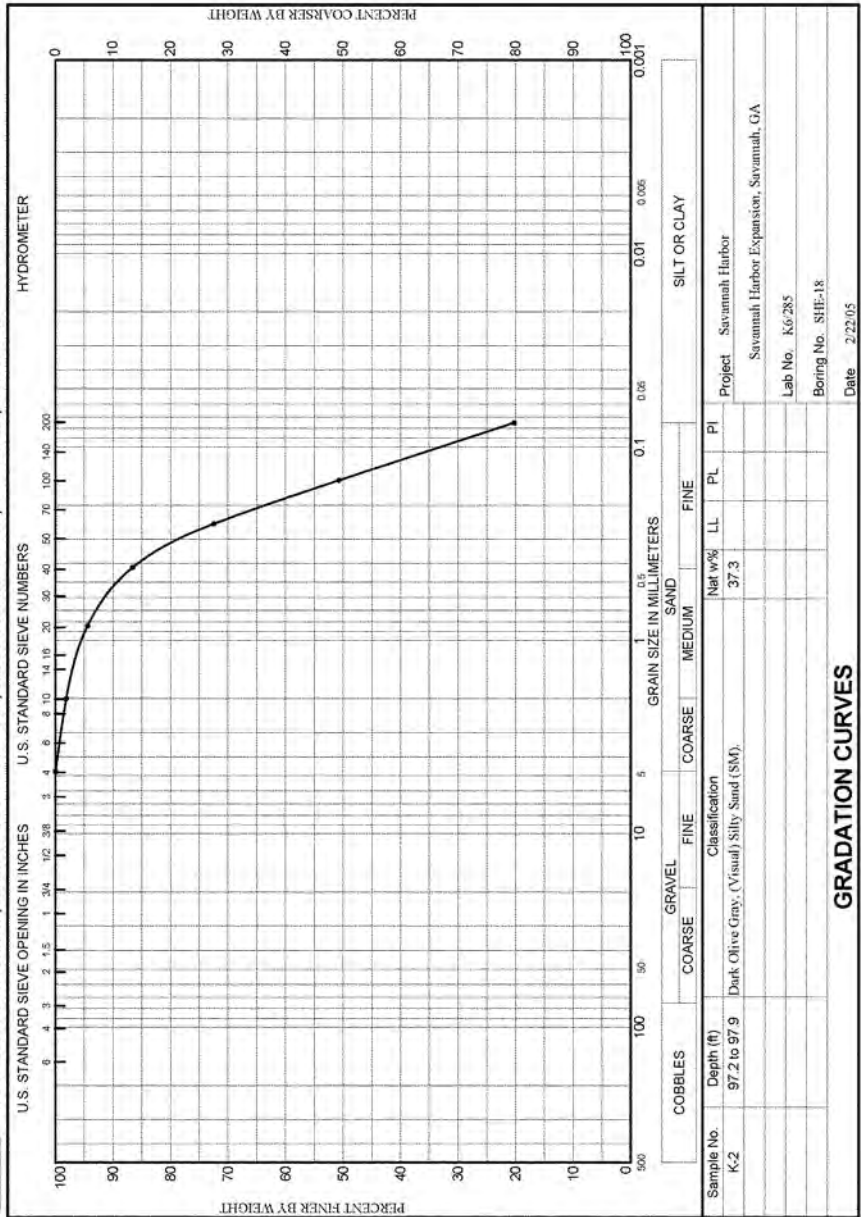
Sample No.		Depth (ft)	Classification	Nat w%	LL	PL	PI	Project	Savannah Harbor
K-1		91.5 to 92.2	Dark Olive Gray, Clayey Organic Silt (OH), with a trace of sand.	179.7	328	108	220	Savannah Harbor Expansion, Savannah, GA	
								Lab No.	KC 284
			Oven dried 1 L was 30% of wet prepared soil.					Boring No.	SHE-18
								Date	2/22/05

GRADATION CURVES



DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
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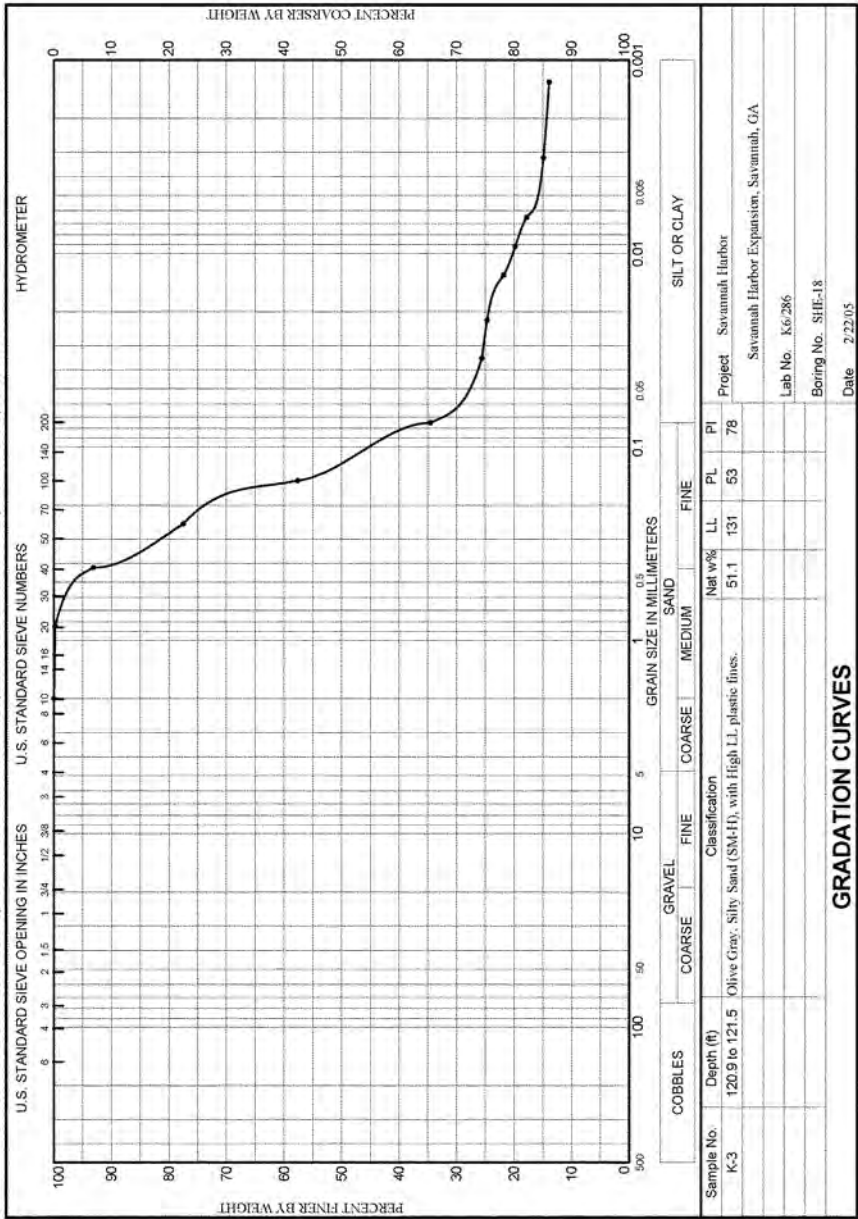
WORK ORDER: 330e
REQUISITION: W33SJG40168635



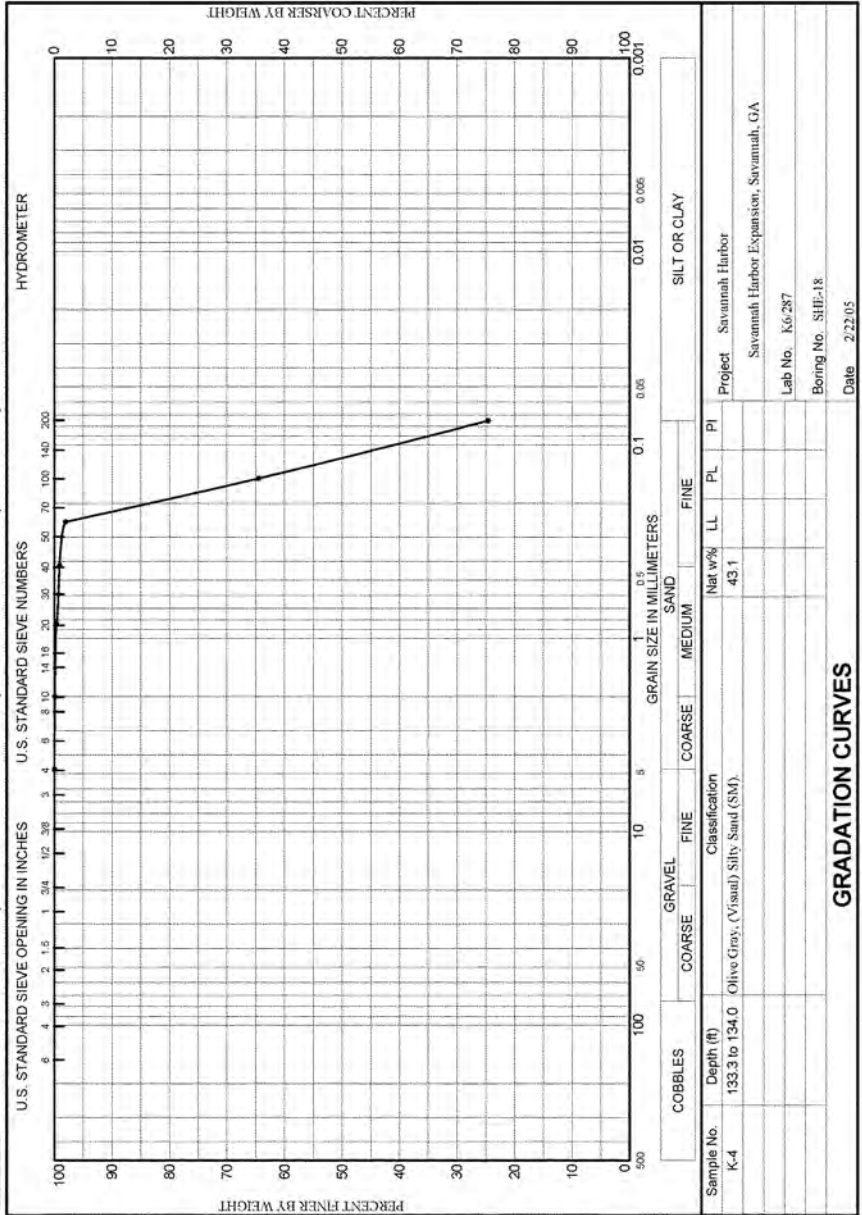


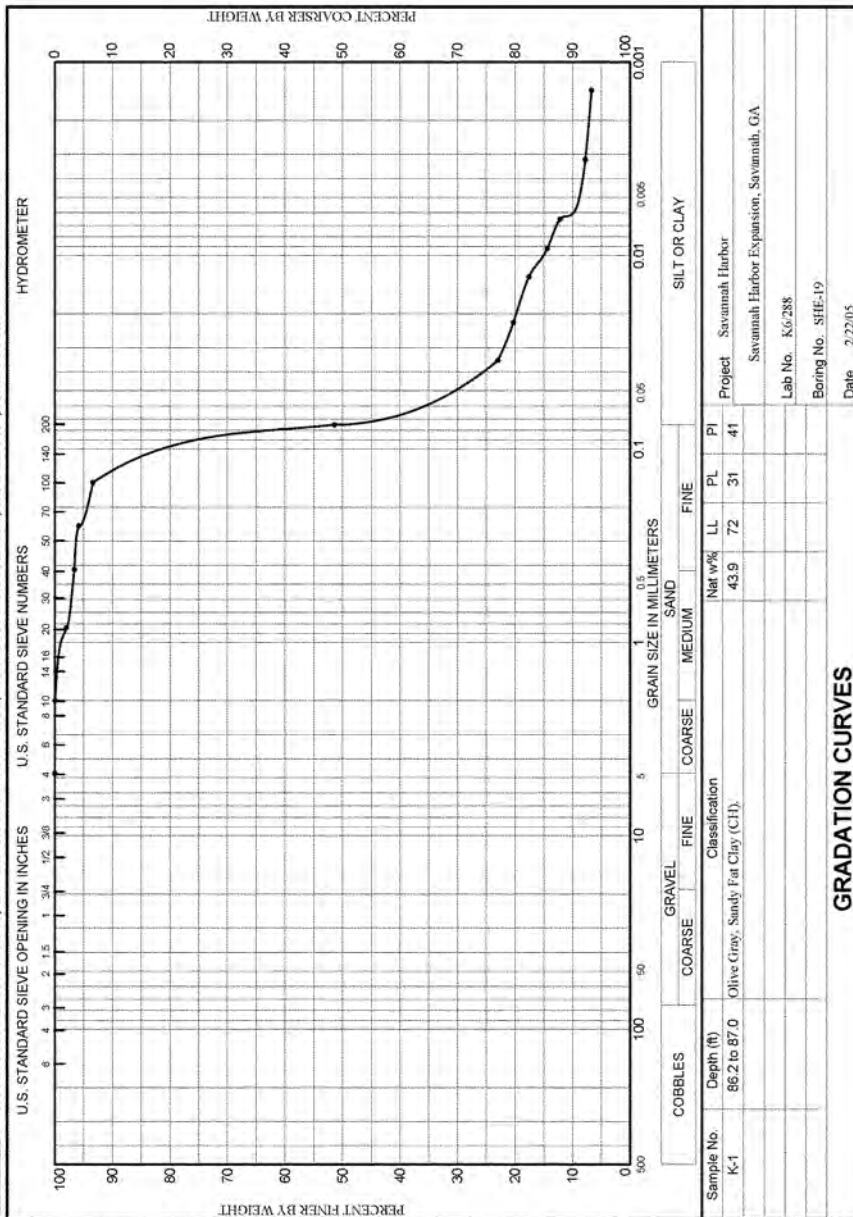
DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33S/JG40168635

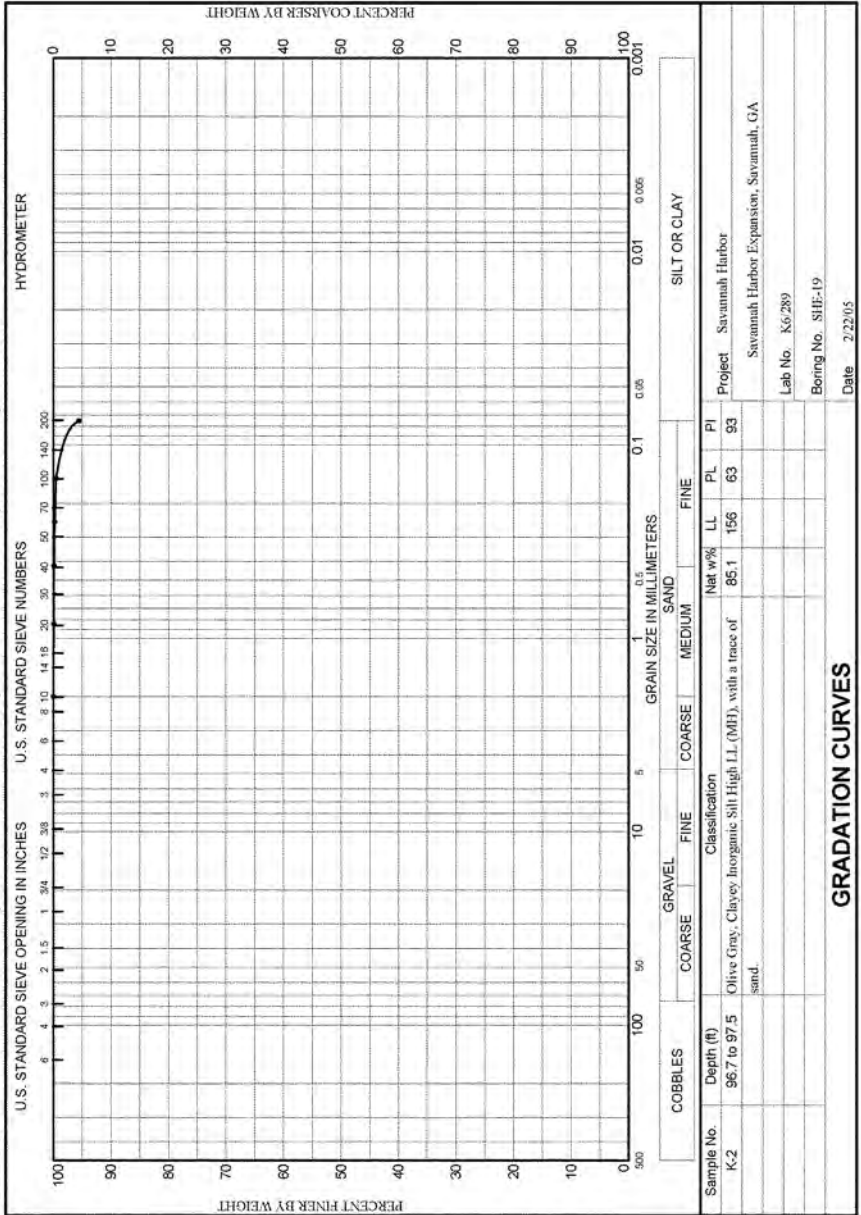


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062
WORK ORDER: 330a
REQUESTION: WQ35JG40168635





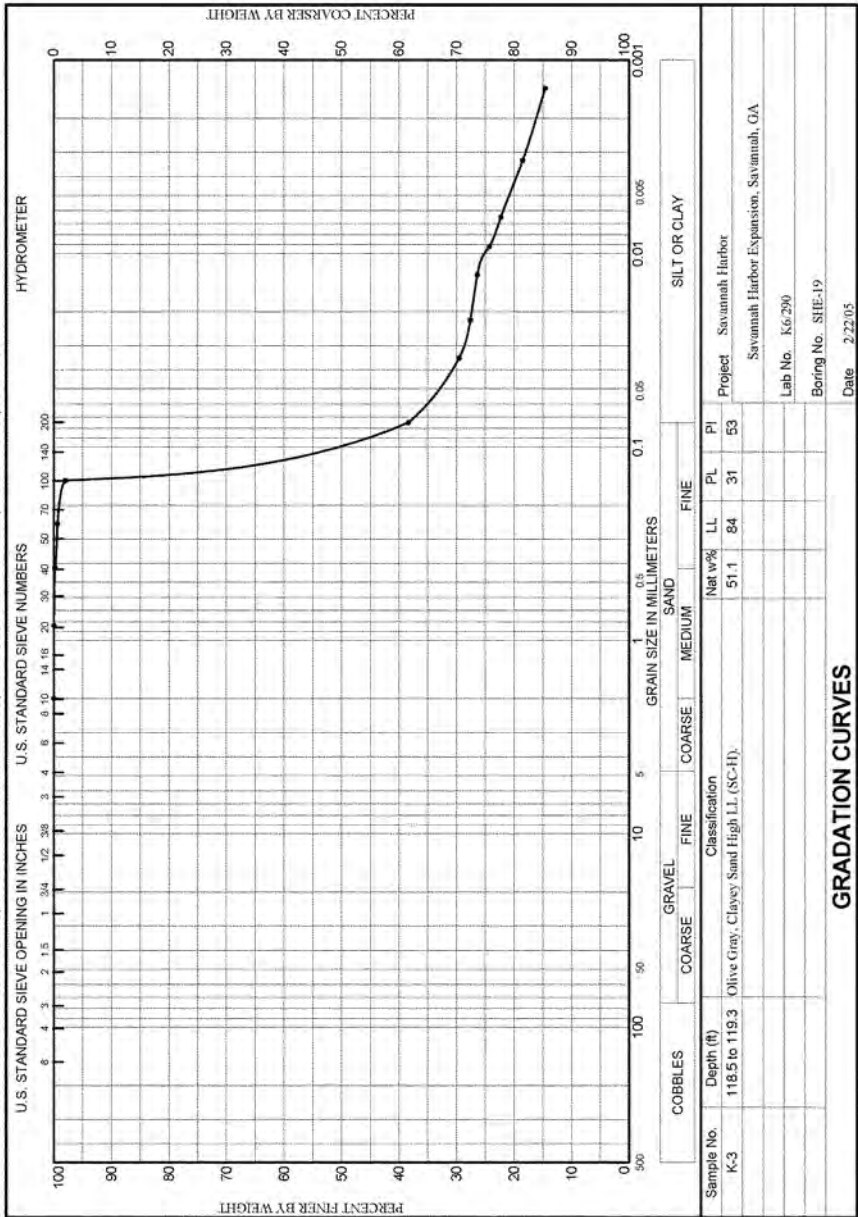
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

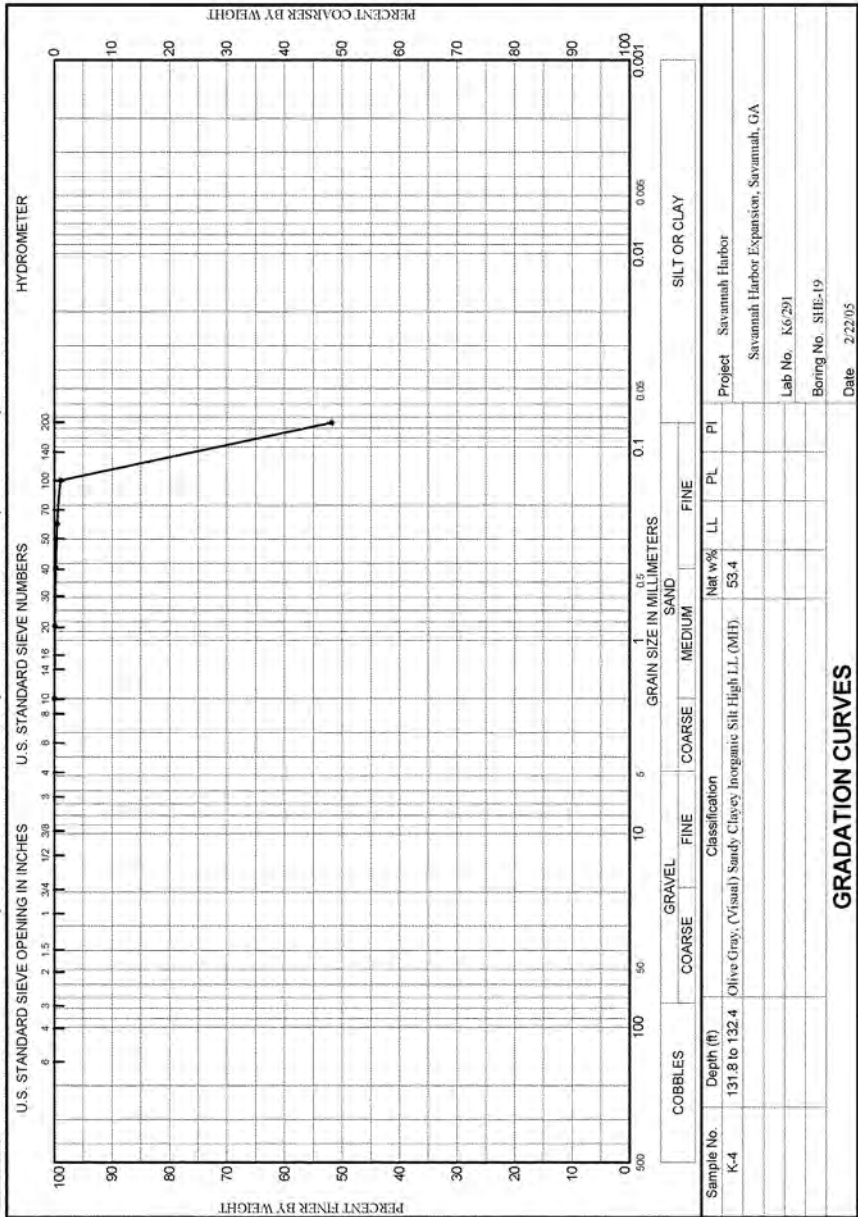
WORK ORDER: 3306
REQUISITION: W33SJG40168635





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CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

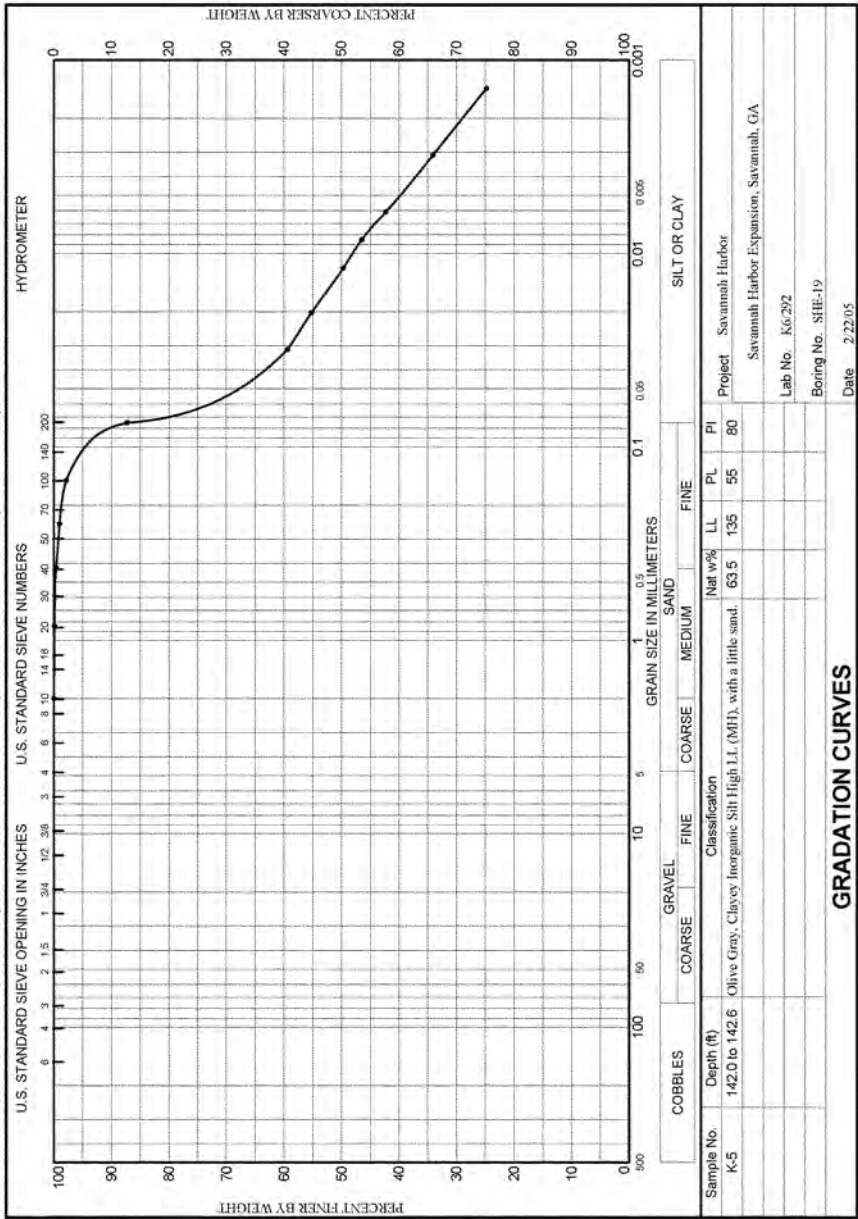
WORK ORDER: 330e
REQUISITION: W33SJG40168635



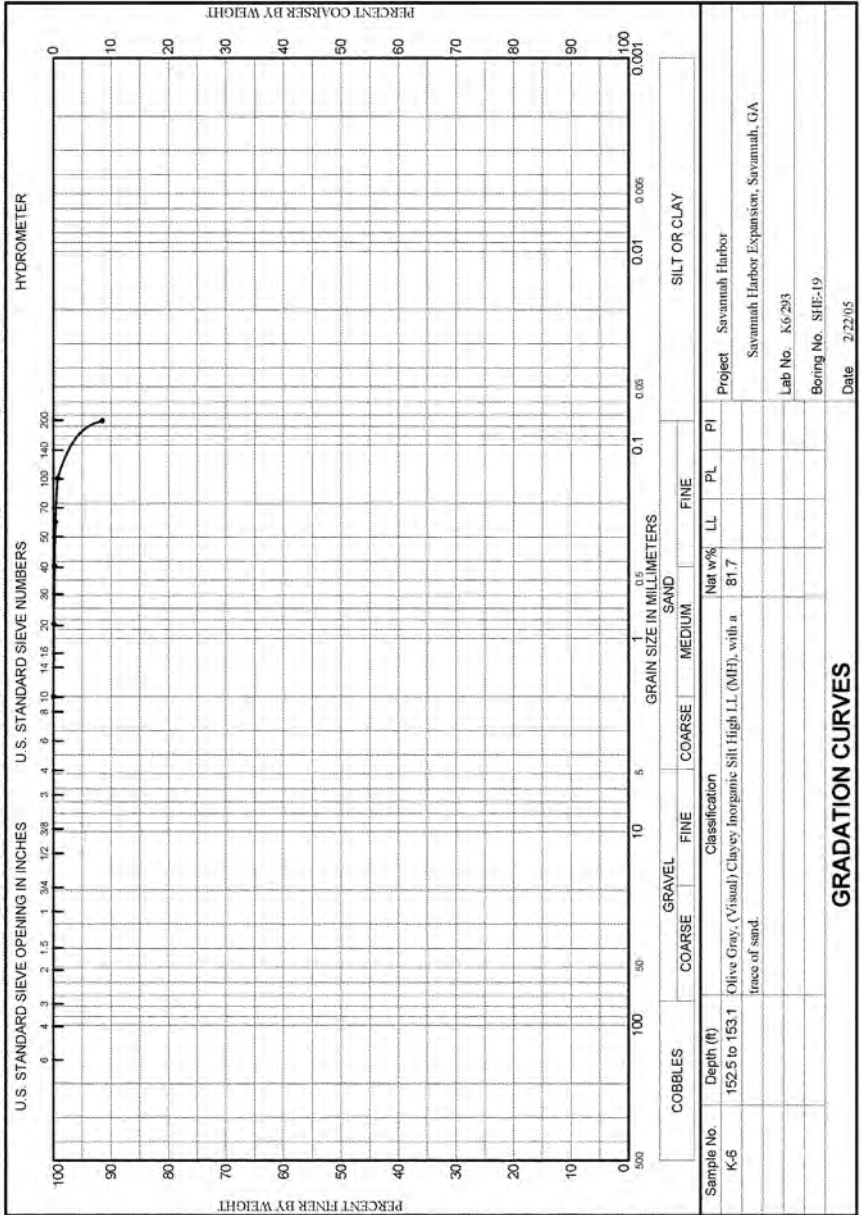


DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SJG40168635



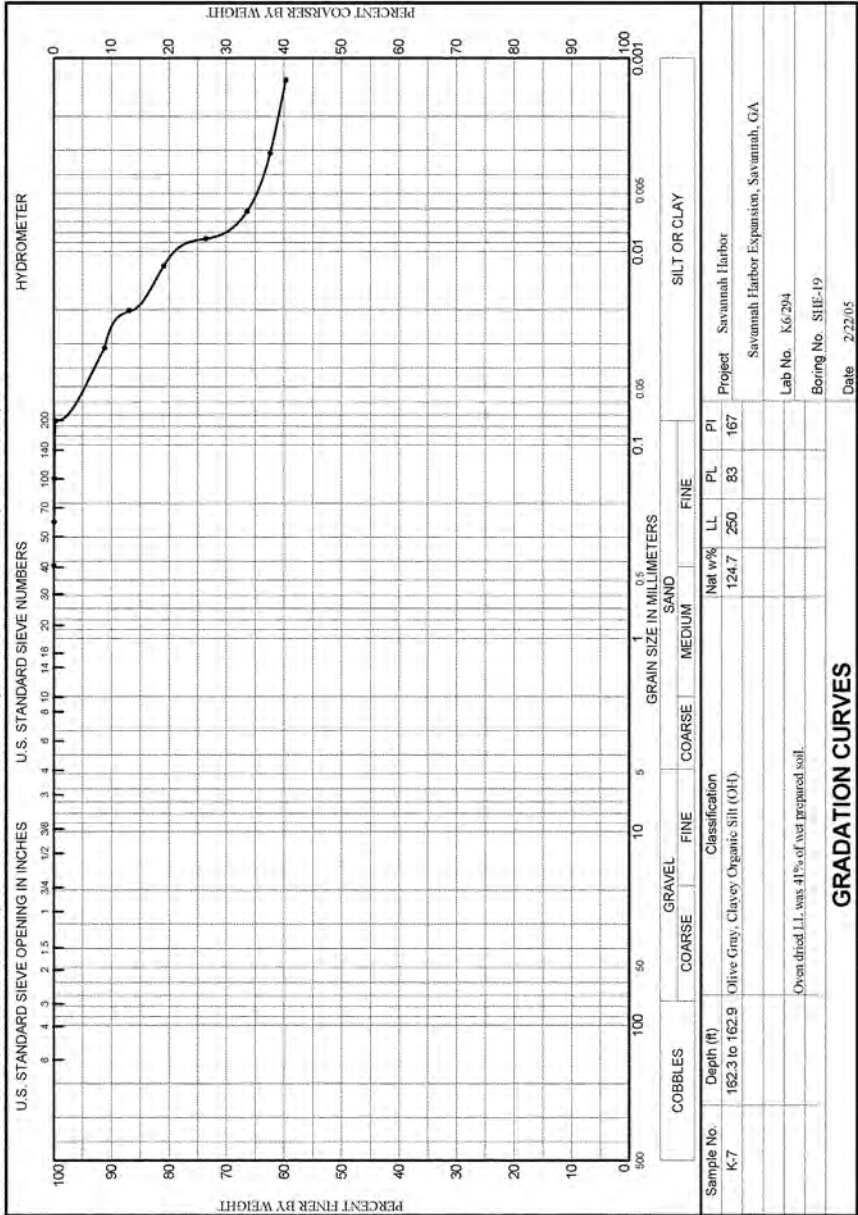
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

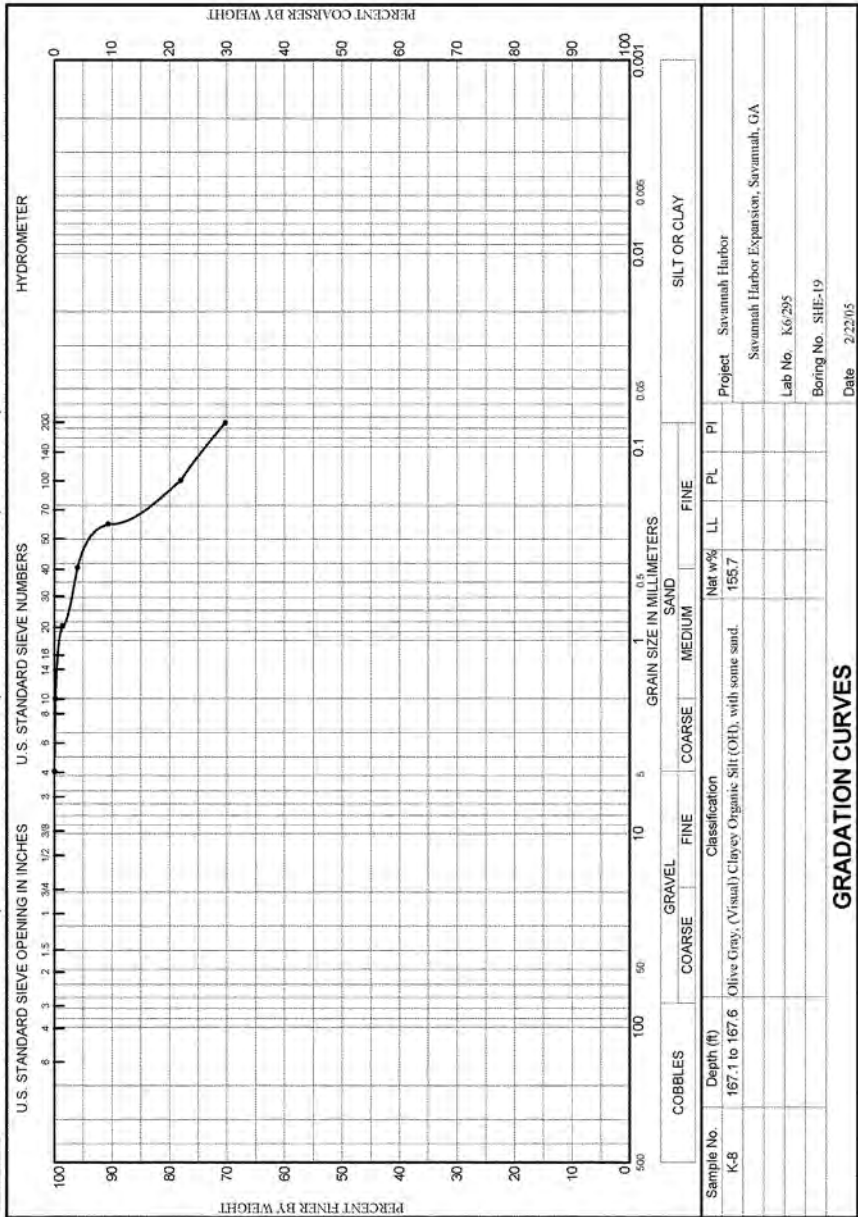
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

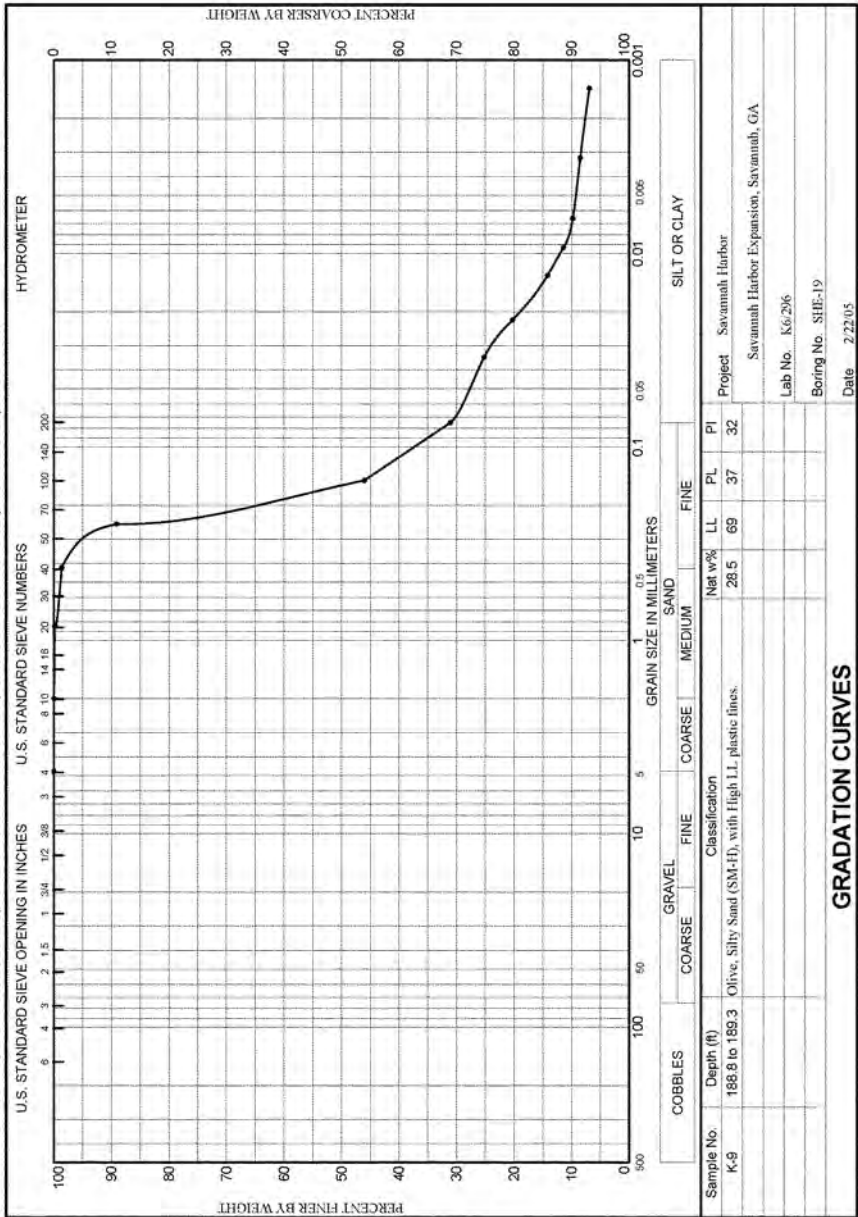
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

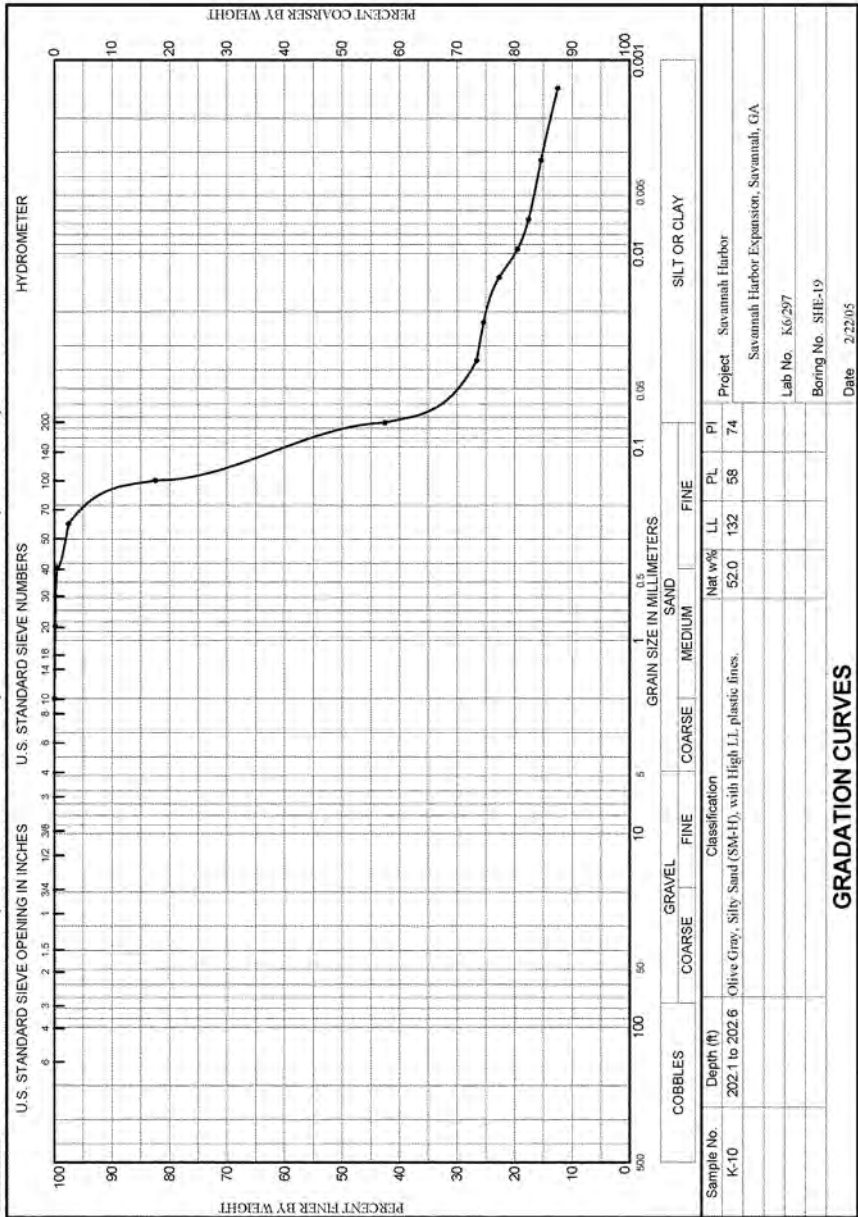
WORK ORDER: 330e
REQUISITION: W33SJG40168635





DEPARTMENT OF THE ARMY, SAVANNAH DISTRICT, ENVIRONMENTAL AND MATERIALS UNIT
CORPS OF ENGINEERS, 200 N. COBB PARKWAY, BLDG 400 SUITE 404, MARIETTA, GA. 30062

WORK ORDER: 330e
REQUISITION: W33SJG40169535





GRADATION CURVES



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

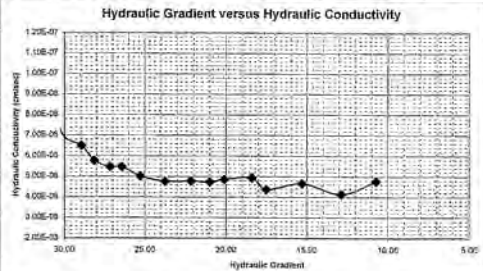
Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/205	Olive Gray	Fat Clay (CH), with a little sand, a trace of mica and wood fragments.	2.68	84	24	60	100.0	87.7

Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.459	23.408	7.461	174.638	265.5
Final	5.487	23.648	7.329	173.307	265.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	75.7%	0.823	0.817	2.275	94%
Final	84.1%	0.824	0.817	2.250	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)		Consolidation Stress (psi)
64.0		
Back Pressure (psi)		4.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW



Specimen Permeability Results

Start Time:		Permometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sp-c} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
1/27/2004	~Start~	20.3	16.0	1.2					
1/27/2004	960	20.3	15.1	1.2	14.8	13.9	25.3	23.7	4.77E-08
1/27/2004	1080	20.3	14.2	1.3	13.9	12.9	23.7	22.1	4.79E-08
1/27/2004	840	20.3	13.6	1.3	12.9	12.3	22.1	21.0	4.73E-08
1/27/2004	660	20.3	13.1	1.3	12.3	11.7	21.0	20.1	4.86E-08
Averages:					22.4		4.79E-08		

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-1
Depth (ft)	48.5 to 49.0	Lab No.	K6/205
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/206	Olive Gray	(Visual) Fat Clay (CH), with a little sand.	2.65				100.0	89.2

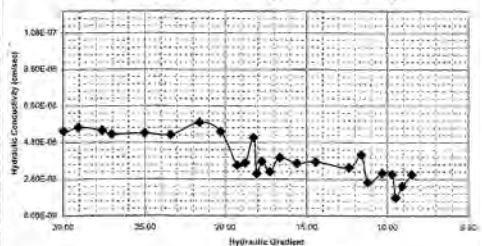
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.472	23.521	6.727	158.228	241.0
Final	5.479	23.579	6.492	153.065	235.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	90.3%	0.801	0.794	2.348	100%
Final	84.3%	0.800	0.794	2.239	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sec} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
1/27/2004	~Start~	20.2	14.2	1.3					
1/27/2004	840	20.2	13.4	1.3	12.9	12.1	25.0	23.4	5.22E-08
1/27/2004	780	19.8	11.9	1.4	11.2	10.5	21.6	20.3	5.33E-08
1/27/2004	480	19.5	11.1	1.4	10.0	9.7	19.3	18.8	3.70E-08
1/27/2004	240	19.5	10.8	1.4	9.4	9.3	18.3	18.1	3.09E-08
					Averages:		20.6		4.33E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-2
Depth (ft)	76.0 to 76.5	Lab No.	K6/206
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/207	Olive Gray	(Visual) Fat Clay (CH), with a trace of sand.	2.70				100.0	95.2

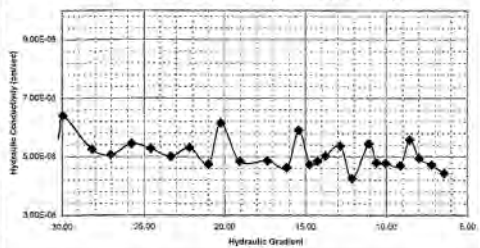
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.461	23.419	6.932	162.332	240.9
Final	5.498	23.743	6.732	159.846	236.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	78.4%	0.730	0.725	2.730	89%
Final	98.9%	0.732	0.725	2.672	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)		Consolidation Stress (psi)
75.0		
Back Pressure (psi)		
70.0		5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sec} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/2/2004	~Start~	19.9	15.1	1.2					
2/2/2004	600	19.9	14.5	1.3	13.8	13.2	25.8	24.6	5.27E-08
2/2/2004	660	19.9	13.2	1.3	12.5	11.9	23.3	22.2	5.31E-08
2/2/2004	420	19.8	12.2	1.3	11.3	10.9	21.0	20.2	6.15E-08
2/2/2004	1320	19.7	10.7	1.4	10.2	9.3	19.1	17.4	4.86E-08
					Averages:		21.7		5.40E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-3
Depth (ft)	78.5 to 79.0	Lab No.	K6/207
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/208	Dark Olive Gray	Clayey Sand High LL (SC-H)	2.80	67	30	37	100.0	19.3

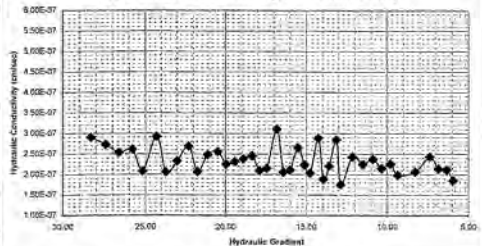
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	6.613	34.346	7.284	250.177	472.5
Final	6.599	34.201	7.283	249.078	473.2
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	37.5%	1.377	1.372	1.038	100%
Final	36.8%	1.377	1.372	1.030	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
1/30/2004	~Start~	20.3	15.8	1.2					
1/30/2004	60	20.3	15.3	1.2	14.6	14.1	25.2	24.3	2.92E-07
1/30/2004	60	20.3	14.6	1.2	13.8	13.4	23.7	23.0	2.60E-07
1/30/2004	60	20.3	13.9	1.3	12.9	12.6	22.3	21.8	2.07E-07
1/30/2004	60	20.3	13.2	1.3	12.3	11.9	21.1	20.5	2.55E-07
Averages:							22.7		2.53E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-4
Depth (ft)	88.3 to 88.8	Lab No.	K6/208
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/209	Pale Olive	Sandy Clayey Inorganic Silt High LL (MH)	2.74	76	39	37	100.0	59.3

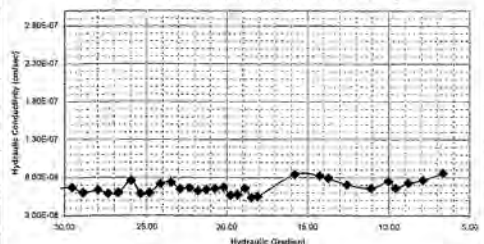
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.769	26.141	6.818	178.228	330.5
Final	5.748	25.946	6.806	176.583	331.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	38.0%	1.343	1.338	1.049	100%
Final	37.6%	1.343	1.338	1.030	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	64.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	4.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
1/30/2004	~Start~	20.3	15.3	1.2					
1/30/2004	240	20.3	15.0	1.2	14.1	13.8	26.0	25.4	5.86E-08
1/30/2004	240	20.3	14.4	1.3	13.5	13.1	24.8	24.1	7.17E-08
1/30/2004	240	20.3	13.7	1.3	12.7	12.4	23.5	22.9	6.49E-08
1/30/2004	240	20.3	13.1	1.3	12.1	11.8	22.3	21.8	6.25E-08
					Averages:		23.8		6.44E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40169635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-5
Depth (ft)	97.8 to 98.3	Lab No.	K6/209
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/210	Olive Gray	(Visual) Fat Clay (CH)	2.67				100.0	100.0

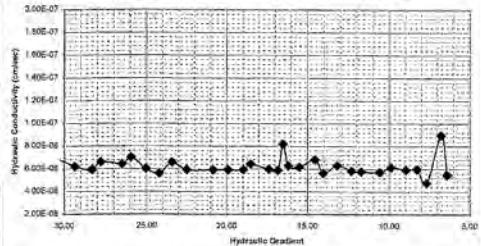
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.299	22.052	7.180	158.335	293.8
Final	5.307	22.118	7.163	158.451	294.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	36.8%	1.371	1.366	0.956	100%
Final	35.8%	1.371	1.366	0.957	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)		Consolidation Stress (psi)
65.0		
Back Pressure (psi)		5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{30°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/2/2004	~Start~	18.4	16.3	1.2					
2/2/2004	240	18.4	16.0	1.2	15.1	14.8	26.5	26.0	7.05E-08
2/2/2004	480	18.6	15.1	1.2	14.3	13.8	25.0	24.2	5.60E-08
2/2/2004	540	18.8	14.1	1.3	13.4	12.8	23.4	22.5	5.91E-08
2/2/2004	600	19.2	12.7	1.3	11.9	11.4	20.8	19.9	5.93E-08
					Averages:		23.5		6.12E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-6
Depth (ft)	109.3 to 109.8	Lab No.	K6/210
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

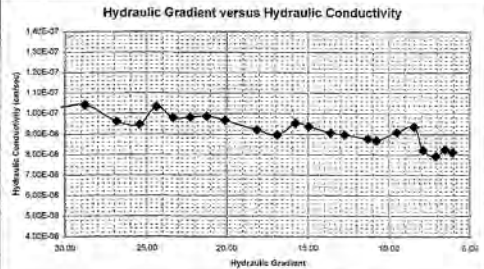
Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/211	Dark Olive Gray	(Visual) Silty Sand (SM), with plastic fines.	2.65				100.0	20.6

Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.445	23.285	7.323	170.525	298.2
Final	5.436	23.205	7.297	169.323	299.2
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	38.2%	1.210	1.205	1.201	89%
Final	44.7%	1.211	1.205	1.186	100%

Permeameter Conditions

Permeant	Mercury Permeameter	
Fluid	Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)		Consolidation Stress (psi)
64.0		
Back Pressure (psi)		4.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{SEC} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/3/2004	~Start~	20.4	16.8	1.2					
2/3/2004	420	20.4	16.0	1.2	15.6	14.8	26.8	25.4	9.48E-08
2/3/2004	360	20.4	14.8	1.2	14.2	13.6	24.4	23.3	9.37E-08
2/3/2004	360	20.3	13.6	1.3	12.9	12.3	22.3	21.2	9.87E-08
2/3/2004	840	20.3	11.9	1.4	11.7	10.5	20.1	18.1	9.21E-08
					Averages:		22.7		9.48E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330a
Hole No.	SHE-11	Sample No.	K-7
Depth (ft)	117.0 to 117.5	Lab No.	K6/211
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/212	Dark Olive Gray	Silty Sand (SM-H), with High LL plastic fines	2.70	64	34	30	99.6	13.6

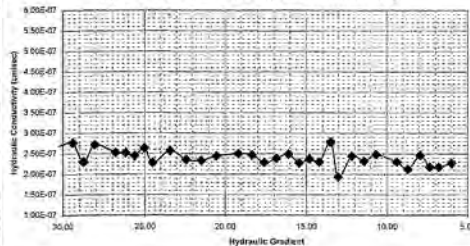
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.634	24.931	7.163	178.594	330.7
Final	5.684	25.375	6.998	177.569	329.6
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	38.9%	1.324	1.319	1.046	100%
Final	38.3%	1.324	1.319	1.034	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	64.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	4.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, $k_{20^\circ\text{C}}$ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/4/2004	~Start~	20.1	15.8	1.2					
2/4/2004	60	20.1	15.5	1.2	14.6	14.3	26.2	25.6	2.38E-07
2/4/2004	60	20.2	14.9	1.2	14.0	13.7	25.0	24.5	2.28E-07
2/4/2004	120	20.2	13.8	1.3	13.0	12.5	23.4	22.4	2.36E-07
2/4/2004	120	20.2	12.8	1.3	12.0	11.5	21.5	20.5	2.45E-07
					Averages:		23.6		2.37E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-8
Depth (ft)	119.3 to 119.8	Lab No.	K6/212
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

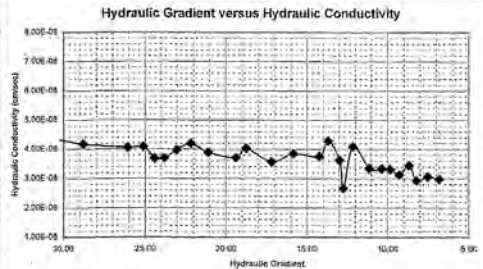
Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Limits			Atterberg		ASTM D422
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200	
K6/213	Dark Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.65	144	71	73	100.0	48.1	

Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.523	23.956	7.096	169.993	262.1
Final	5.483	23.615	7.090	167.428	262.8
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	77.1%	0.887	0.880	2.009	100%
Final	74.2%	0.886	0.880	1.963	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	64.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	4.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{50°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/5/2004	~Start~	20.4	15.9	1.2					
2/5/2004	660	20.4	15.4	1.2	14.7	14.2	26.1	25.1	4.09E-08
2/5/2004	480	20.4	14.7	1.2	13.8	13.5	24.4	23.8	3.69E-08
2/5/2004	660	20.4	13.8	1.3	13.0	12.5	23.0	22.2	4.19E-08
2/5/2004	1620	20.4	12.3	1.3	11.9	11.0	21.1	19.4	3.71E-08
					Averages:		23.1		3.92E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W335JG40168635	Work Order No.	330e
Hole No.	SHE-11	Sample No.	K-9
Depth (ft)	125.0 to 125.5	Lab No.	K6/213
Sample Received	16-Dec-03	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/214	Olive Gray	(Visual) Clayey Sand (SC)	2.70				100.0	18.8

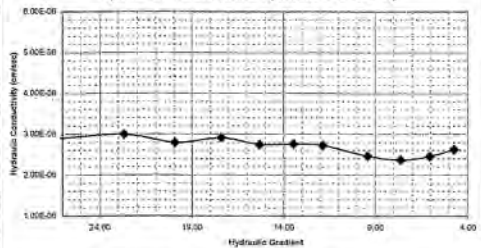
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.634	24.931	7.133	177.834	346.4
Final	5.617	24.782	6.718	166.491	337.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	30.4%	1.491	1.486	0.818	100%
Final	26.0%	1.490	1.486	0.702	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{sec} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/6/2004	~Start~	20.6	15.2	1.2					
2/6/2004	30	20.6	13.5	1.3	14.0	12.2	26.1	22.7	2.99E-06
2/6/2004	30	20.6	10.7	1.4	10.7	9.3	19.9	17.4	2.91E-06
2/6/2004	30	20.6	8.7	1.5	8.2	7.2	15.3	13.5	2.76E-06
2/6/2004	60	20.6	6.6	1.6	6.3	5.0	11.8	9.4	2.46E-06
Averages:							17.0		2.78E-06

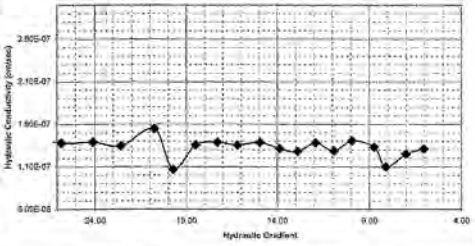
Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-1
Depth (ft)	70.0 to 70.5	Lab No.	K6/214
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C

		U.S. Army Corps of Engineers, Savannah District Environmental & Materials Unit, Marietta, Georgia									
Sample Results											
		ASTM D2087		ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422			
Lab No.	Color	USCS Classification		SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200		
K6/215	Olive Gray	Sandy Fat Clay (CH)		2.68	67	22	45	100.0	52.6		
Specimen Results											
Trial	Diameter, D (cm)	Area, A (cm ²)		Length, L (cm)	Volume (cm ³)		Moist Mass (gms)				
Initial	5.597	24.603		6.427	158.118		265.5				
Final	5.560	24.284		6.305	153.107		262.8				
	Water Content, %	Wet Density (g/cc)		Dry Density (g/cc)	Void Ratio		Saturation, %				
Initial	35.0%	0.953		0.949	1.818		67%				
Final	64.6%	0.955		0.949	1.728		100%				
Permeameter Conditions					Hydraulic Gradient versus Hydraulic Conductivity						
Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)										
De-aired tap water	pipet 0.0314		annulus 0.7671								
Chamber Pressure (psi)	65.0		Consolidation Stress (psi)								
Back Pressure (psi)	80.0		5.0								
Conducted By	Sample Testing By: MW		Report Preparation By: MW								
Specimen Permeability Results											
Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sec} (cm/sec)		
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final			
2/7/2004	~Start~	19.9	14.2	1.3							
2/7/2004	300	19.9	13.4	1.3	12.9	12.1	25.8	24.1	1.39E-07		
2/7/2004	300	19.9	11.8	1.4	11.3	10.4	22.6	20.8	1.75E-07		
2/7/2004	300	19.9	10.7	1.4	9.9	9.3	19.7	18.5	1.36E-07		
2/7/2004	300	19.9	9.6	1.5	8.7	8.1	17.3	16.2	1.35E-07		
					Averages:		20.6		1.46E-07		
Remarks:					Project Information						
(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.					Project		Savannah Harbor Expansion				
					Location		Savannah, Georgia				
					Requisition No.		W33SJG40168635		Work Order No.		330e
					Hole No.		SHE-13		Sample No.		K-2
					Depth (ft)		75.8 to 76.3		Lab No.		K6/215
					Sample Received		21-Jan-04		Report Date		3-Feb-05
Permeability Test Report - ASTM D5084 Method C											



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/216	Olive Gray	(Visual) Fat Clay (CH), with a trace of sand.	2.63				100.0	96.2

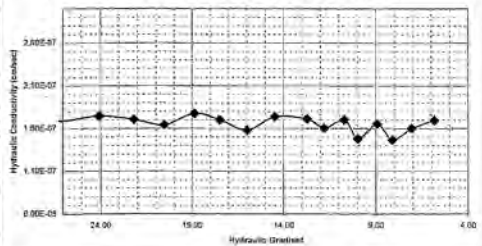
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.513	23.868	6.349	151.529	236.0
Final	5.493	23.696	6.313	149.595	234.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	75.8%	0.885	0.879	1.993	100%
Final	74.3%	0.885	0.879	1.955	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, $k_{20^\circ\text{C}}$ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/9/2004	~Start~	20.4	15.5	1.2					
2/9/2004	300	20.4	14.4	1.3	14.2	13.1	28.3	26.1	1.69E-07
2/9/2004	300	20.4	12.5	1.3	12.1	11.2	24.1	22.2	1.70E-07
2/9/2004	300	20.4	10.9	1.4	10.3	9.5	20.5	18.9	1.78E-07
2/9/2004	360	20.4	9.5	1.5	8.8	8.0	17.5	16.0	1.58E-07
					Averages:		21.7		1.69E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-5
Depth (ft)	92.7 to 93.2	Lab No.	K6/216
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/217	Olive Gray	(Visual) Fat Clay (CH), with a trace of sand.	2.70				100.0	98.3

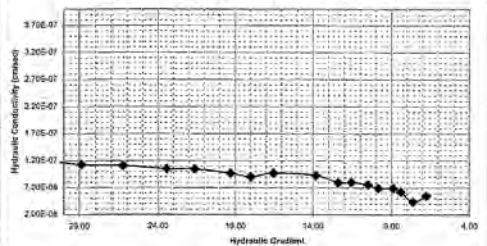
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.479	23.575	6.335	149.344	232.3
Final	5.507	23.820	6.240	148.641	230.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	82.3%	0.845	0.838	2.221	100%
Final	81.7%	0.845	0.838	2.206	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/10/2004	~Start~	20.8	15.6	1.2					
2/10/2004	540	20.8	14.3	1.3	14.3	13.0	28.8	26.2	1.09E-07
2/10/2004	480	20.8	12.1	1.4	11.7	10.7	23.4	21.6	1.05E-07
2/10/2004	480	20.8	10.4	1.4	9.6	9.0	19.3	18.0	9.04E-08
2/10/2004	1200	20.8	8.4	1.5	8.2	6.9	16.5	13.8	9.27E-08
					Averages:		21.0		9.92E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-6
Depth (ft)	98.3 to 98.8	Lab No.	K6/217
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2057	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/218	Olive	Clayey Inorganic Silt High LL (MH), with some sand.	2.71	132	53	79	100.0	77.2

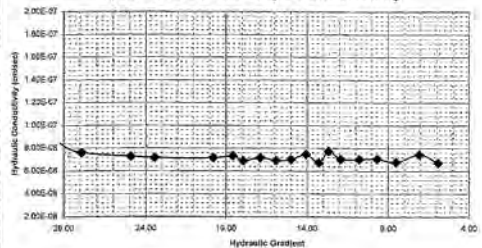
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.506	23.809	7.127	169.678	276.8
Final	5.511	23.853	7.085	169.007	276.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	64.1%	0.997	0.991	1.738	100%
Final	63.7%	0.997	0.991	1.727	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/11/2004	~Start~	20.6	17.5	1.1					
2/11/2004	360	20.6	16.9	1.1	16.4	15.8	29.0	27.9	7.61E-08
2/11/2004	600	20.6	14.5	1.2	14.1	13.3	24.9	23.5	7.16E-08
2/11/2004	600	20.6	11.9	1.4	11.2	10.5	19.8	18.6	7.34E-08
2/11/2004	600	20.6	10.9	1.4	10.1	9.5	17.9	16.9	7.16E-08
					Averages:		22.3		7.32E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-7
Depth (ft)	102.3 to 102.8	Lab No.	K6/218
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/219	Olive Gray	(Visual) Clayey Inorganic Silt High LL (MH), with some sand.	2.68				100.0	65.7

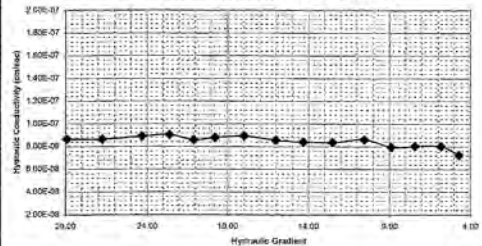
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.527	23.992	6.756	162.088	259.7
Final	5.490	23.674	6.704	158.702	258.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	64.5%	0.981	0.974	1.751	99%
Final	63.2%	0.980	0.974	1.693	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/12/2004	~Start~	20.6	16.6	1.2					
2/12/2004	600	20.6	15.5	1.2	15.4	14.3	28.9	26.8	8.63E-08
2/12/2004	540	20.6	13.4	1.3	13.0	12.1	24.3	22.6	9.05E-08
2/12/2004	480	20.6	11.9	1.4	11.3	10.6	21.1	19.8	9.01E-08
2/12/2004	900	20.6	10.0	1.4	9.6	8.6	18.0	16.0	8.57E-08
					Averages:		22.2		8.81E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-8
Depth (ft)	106.5 to 107.0	Lab No.	K6/219
Sample Received	21-Jan-04	Report Date	3-Feb-05
Permeability Test Report - ASTM D5084 Method C			



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087 USCS Classification	ASTM D854 SpGr	ASTM D4318 Atterberg Limits			ASTM D422 %Pass No. 4	ASTM D422 %Pass No. 200
K6/220	Olive Gray	Clayey Inorganic Silt High LL (MH), with a little sand.	2.67	158	74	84	100.0	80.8

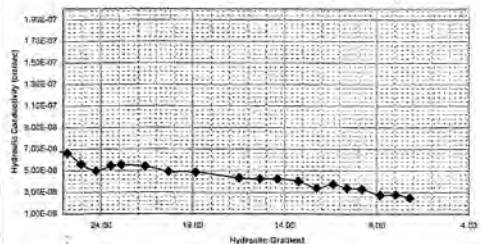
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.499	23.751	7.129	169.321	261.5
Final	5.539	24.099	6.918	166.726	256.7
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	83.7%	0.833	0.826	2.238	100%
Final	81.9%	0.832	0.826	2.189	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7671
<u>Chamber Pressure (psi)</u>		<u>Consolidation Stress (psi)</u>
65.0		5.0
<u>Back Pressure (psi)</u>		
60.0		
<u>Conducted By</u>	<u>Sample Testing By:</u>	<u>Report Preparation By:</u>
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, $k_{20^\circ\text{C}}$ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/14/2004	~Start~	20.6	16.1	1.2					
2/14/2004	480	20.6	15.4	1.2	14.9	14.2	27.0	25.8	6.35E-08
2/14/2004	420	20.7	14.6	1.2	13.8	13.4	25.0	24.3	4.96E-08
2/14/2004	300	20.7	13.9	1.3	12.9	12.6	23.5	22.9	5.53E-08
2/14/2004	840	20.7	12.6	1.3	11.9	11.2	21.8	20.3	4.91E-08
					Averages:		23.8		5.44E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-9
Depth (ft)	111.5 to 112.0	Lab No.	K6/220
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/221	Olive Gray	(Visual) Clayey Inorganic Silt High LL (MH), with a little sand.	2.66				100.0	89.0

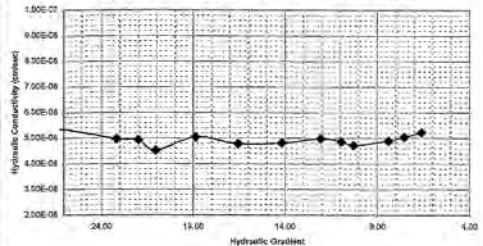
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.579	24.447	7.150	174.796	259.9
Final	5.547	24.166	6.959	168.167	254.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	100.0%	0.734	0.727	2.655	100%
Final	94.7%	0.734	0.727	2.516	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k_{syc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/16/2004	~Start~	20.4	17.2	1.1					
2/16/2004	540	20.4	16.6	1.2	16.1	15.4	29.0	27.8	5.24E-08
2/16/2004	1680	20.4	14.1	1.3	14.5	12.9	26.2	23.2	4.97E-08
2/16/2004	660	20.5	13.0	1.3	12.2	11.7	22.0	21.1	4.52E-08
2/16/2004	1860	20.5	10.6	1.4	10.5	9.2	18.9	16.6	4.78E-08
					Averages:		23.1		4.88E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-10
Depth (ft)	117.2 to 117.7	Lab No.	K6/221
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087 USCS Classification	ASTM D854 SpGr	ASTM D4318 Atterberg Limits LL PL PI			ASTM D422 %Pass No. 4	ASTM D422 %Pass No. 200
K6/222	Dark Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.69	151	67	84	100.0	38.5

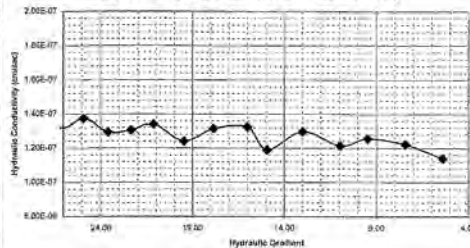
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.420	23.075	7.107	163.994	272.1
Final	5.420	23.068	7.061	162.873	272.1
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	59.2%	1.044	1.037	1.595	100%
Final	58.6%	1.043	1.037	1.577	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/17/2004	~Start~	20.6	16.8	1.1					
2/17/2004	360	20.6	15.9	1.2	15.7	14.7	27.8	26.1	1.32E-07
2/17/2004	300	20.6	14.5	1.2	14.0	13.3	24.9	23.6	1.29E-07
2/17/2004	300	20.6	13.2	1.3	12.6	11.9	22.3	21.1	1.34E-07
2/17/2004	480	20.6	11.4	1.4	11.0	10.0	19.5	17.9	1.31E-07
					Averages:		22.9		1.32E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-13	Sample No.	K-11
Depth (ft)	124.0 to 124.5	Lab No.	K6/222
Sample Received	21-Jan-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/250	Olive Gray	(Visual) Fat Clay (CH), with a trace of sand.	2.75				100.0	96.8

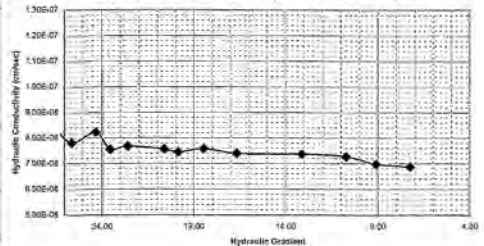
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.595	24.584	7.278	178.932	280.7
Final	5.516	23.893	7.060	168.685	275.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	77.8%	0.883	0.876	2.142	100%
Final	71.3%	0.882	0.876	1.962	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k_{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/21/2004	~Start~	21.2	16.7	1.2					
2/21/2004	300	21.2	16.2	1.2	15.5	15.0	27.6	26.7	8.23E-08
2/21/2004	420	21.2	14.9	1.2	14.4	13.7	25.6	24.3	8.22E-08
2/21/2004	360	21.2	14.0	1.3	13.3	12.7	23.6	22.6	7.68E-08
2/21/2004	360	21.2	12.5	1.3	11.6	11.2	20.6	19.8	7.45E-08
					Averages:		23.9		7.90E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-1
Depth (ft)	63.6 to 64.1	Lab No.	K6/250
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/251	Olive Gray	Fat Clay (CH), with a little sand	2.72	130	38	92	100.0	89.2

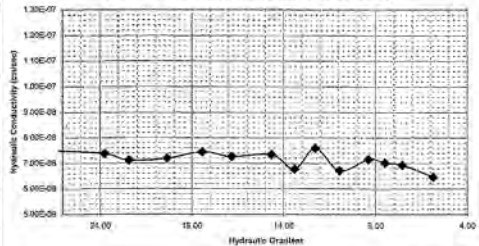
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.474	23.532	7.087	166.759	276.4
Final	5.550	24.195	6.946	168.050	272.8
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	66.4%	0.976	0.970	1.805	100%
Final	67.2%	0.976	0.970	1.827	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
2/20/2004	~Start~	21.0	17.3	1.1					
2/20/2004	540	21.0	16.4	1.2	16.2	15.2	29.2	27.5	7.66E-08
2/20/2004	960	21.0	14.4	1.3	14.6	13.1	26.4	23.8	7.38E-08
2/20/2004	900	21.0	12.6	1.3	12.4	11.3	22.4	20.4	7.25E-08
2/20/2004	840	21.0	10.7	1.4	10.2	9.3	18.4	16.8	7.28E-08
					Averages:		23.1		7.39E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-2
Depth (ft)	70.6 to 71.2	Lab No.	K6/251
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/252	Olive Gray	(Visual) Fat Clay (CH), with a trace of sand.	2.77				100.0	97.9

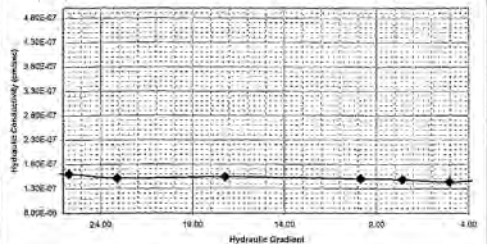
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.539	24.099	7.004	168.792	278.0
Final	5.538	24.092	6.913	166.553	276.3
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	68.6%	0.961	0.955	1.898	100%
Final	67.2%	0.961	0.955	1.859	100%

Permeameter Conditions

Permeant Fluid	Mercury Permometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
4/5/2004	~Start~	19.7	18.8	1.1					
4/5/2004	120	19.7	18.3	1.1	17.7	17.2	32.1	31.2	1.73E-07
4/5/2004	540	19.7	15.4	1.2	16.0	14.1	29.1	25.7	1.60E-07
4/5/2004	1320	19.7	10.9	1.4	12.7	9.5	23.1	17.2	1.54E-07
4/5/2004	1260	19.7	5.8	1.6	5.4	4.2	9.9	7.6	1.44E-07
					Averages:		22.0		1.58E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-3
Depth (ft)	75.0 to 75.5	Lab No.	K6/252
Sample Received	4-Feb-04	Report Date	3-Feb-05
Permeability Test Report - ASTM D5084 Method C			



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/253	Dark Olive Gray	Poorly Graded Silty Sand (SP-SM), with plastic fines.	2.73	41	26	15	100.0	5.9

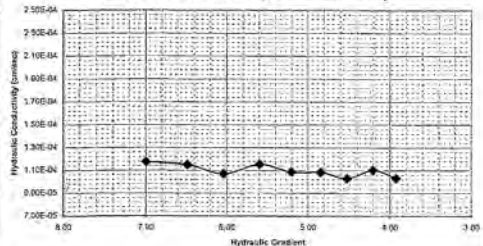
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.395	22.863	7.617	174.159	366.3
Final	5.533	24.048	7.188	172.859	354.2
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	25.2%	1.621	1.617	0.689	100%
Final	24.8%	1.621	1.617	0.677	100%

Permeameter Conditions

Permeant Fluid	Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet 0.3184	
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By:	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Head (cm)	Tail (cm)	Start	Final	Start	Final	
4/22/2004	~Start~	22.2	57.4	5.1					
4/22/2004	30	22.2	56.4	6.1	52.3	50.3	7.3	7.0	1.17E-04
4/22/2004	120	22.2	48.9	14.1	40.2	34.8	5.6	4.8	1.08E-04
4/22/2004	420	23.1	46.9	15.2	52.5	31.7	7.3	4.4	1.06E-04
4/22/2004	90	22.2	54.5	7.9	52.3	46.6	7.3	6.5	1.16E-04
Averages:							6.3		1.12E-04

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-4
Depth (ft)	84.0 to 84.5	Lab No.	K6/253
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/254	Olive	(Visual) Clayey Inorganic Silt High LL (MH), with some sand.	2.75				100.0	77.1

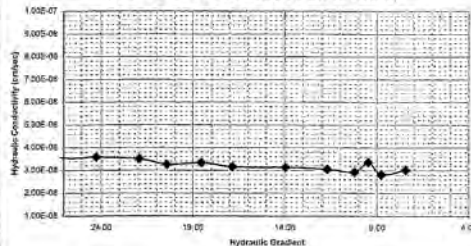
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.645	25.029	7.092	177.497	308.4
Final	5.644	25.018	6.922	173.159	303.7
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	52.9%	1.125	1.120	1.453	100%
Final	50.7%	1.125	1.120	1.393	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7671
<u>Chamber Pressure (psi)</u>	64.0	<u>Consolidation Stress (psi)</u>
<u>Back Pressure (psi)</u>	60.0	4.0
<u>Conducted By</u>	<u>Sample Testing By:</u>	<u>Report Preparation By:</u>
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
4/21/2004	~Start~	22.2	16.9	1.1					
4/21/2004	1560	22.2	15.6	1.2	15.8	14.4	28.6	26.2	3.56E-08
4/21/2004	1800	22.2	13.4	1.3	13.4	12.1	24.3	21.9	3.51E-08
4/21/2004	1800	22.2	11.6	1.4	11.3	10.2	20.4	18.5	3.40E-08
4/21/2004	3780	22.2	9.2	1.5	9.3	7.7	16.8	14.0	3.13E-08
Averages:							21.3		3.40E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-5
Depth (ft)	90.0 to 90.5	Lab No.	K6/254
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/255	Olive	Silty Sand (SM-H), with High LL plastic fines.	2.74	110	48	62	100.0	48.9

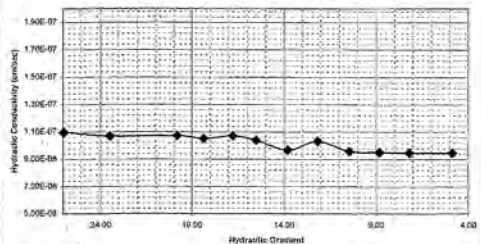
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.547	24.166	7.116	171.973	299.1
Final	5.551	24.202	7.026	170.053	296.8
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	53.6%	1.115	1.109	1.469	100%
Final	52.6%	1.115	1.109	1.441	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	64.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	4.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, $k_{20^\circ\text{C}}$ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
4/23/2004	~Start~	23.4	17.2	1.1					
4/23/2004	600	23.4	15.7	1.2	16.1	14.5	28.7	25.9	1.10E-07
4/23/2004	1020	23.4	12.4	1.3	13.1	11.1	23.5	19.8	1.07E-07
4/23/2004	540	23.5	10.8	1.4	10.3	9.4	18.4	16.8	1.07E-07
4/23/2004	780	23.6	9.2	1.5	8.7	7.7	15.5	13.8	9.66E-08
					Averages:		20.3		1.05E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-6
Depth (ft)	95.0 to 95.6	Lab No.	K6/255
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/256	Olive Gray	Sandy Clayey Inorganic Silt High LL (MH)	2.71	156	59	97	100.0	60.0

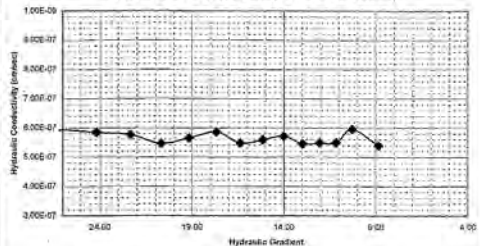
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.534	24.055	4.927	118.518	196.4
Final	5.569	24.361	4.822	117.460	193.1
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	64.7%	0.991	0.984	1.755	100%
Final	63.8%	0.991	0.984	1.731	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipe	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k ₂₀ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
4/26/2004	~Start~	23.9	12.3	1.3					
4/26/2004	60	23.9	11.5	1.4	10.9	10.1	28.4	26.2	5.92E-07
4/26/2004	60	23.9	10.0	1.4	9.3	8.6	24.2	22.3	5.69E-07
4/26/2004	60	23.9	8.9	1.5	8.0	7.4	20.7	19.2	5.66E-07
4/26/2004	60	23.9	7.8	1.5	6.8	6.3	17.7	16.4	5.47E-07
					Averages:		21.9		5.69E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-7
Depth (ft)	100.0 to 100.5	Lab No.	K6/256
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/257	Olive Gray	(Visual) Silty Sand (SM), with plastic fines.	2.69				100.0	43.1

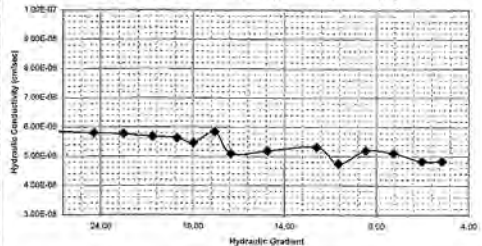
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.458	23.401	7.078	165.624	280.0
Final	5.467	23.473	6.986	163.977	277.8
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	55.1%	1.089	1.083	1.482	100%
Final	54.2%	1.089	1.083	1.457	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7871
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
4/28/2004	~Start~	19.9	16.8	1.2					
4/28/2004	780	19.9	15.9	1.2	15.6	14.7	28.1	26.3	5.85E-08
4/28/2004	840	19.9	14.0	1.3	13.6	12.7	24.4	22.8	5.76E-08
4/28/2004	840	19.9	12.4	1.3	11.8	11.1	21.2	19.9	5.64E-08
4/28/2004	780	19.9	11.3	1.4	10.6	9.9	19.0	17.8	5.84E-08
Averages:							22.4		5.77E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-8
Depth (ft)	105.5 to 106.0	Lab No.	K6/257
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/258	Dark Olive Gray	(Visual) Silty Sand (SM), with plastic fines.	2.73				100.0	31.9

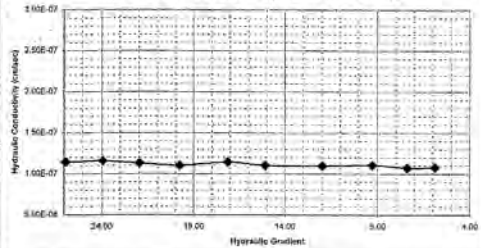
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.444	23.281	6.167	143.578	238.9
Final	5.461	23.426	6.079	142.419	238.7
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	59.7%	1.044	1.037	1.628	100%
Final	58.9%	1.044	1.037	1.607	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
5/3/2004	~Start~	19.9	15.1	1.2					
5/3/2004	540	19.9	13.8	1.3	13.9	12.5	28.6	25.9	1.17E-07
5/3/2004	480	19.9	12.0	1.4	11.6	10.6	24.0	22.0	1.13E-07
5/3/2004	780	19.9	9.8	1.5	9.6	8.3	19.8	17.1	1.15E-07
5/3/2004	1320	19.9	7.4	1.6	7.3	5.8	15.1	12.0	1.10E-07
					Averages:		20.6		1.13E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-14	Sample No.	K-9
Depth (ft)	111.2 to 111.7	Lab No.	K6/258
Sample Received	4-Feb-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/259	Dark Olive Gray	Clayey Inorganic Silt High LL (MH), with a little of sand.	2.64	186	73	113	100.0	80.8

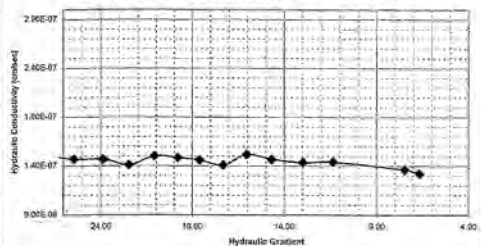
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.209	21.312	7.090	151.109	223.7
Final	5.245	21.604	6.582	142.190	215.3
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	101.6%	0.724	0.717	2.687	100%
Final	93.4%	0.724	0.717	2.469	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By:	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, $k_{20^\circ\text{C}}$ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
5/20/2004	~Start~	21.6	16.3	1.2					
5/20/2004	300	21.6	15.4	1.2	15.1	14.2	28.8	27.1	1.50E-07
5/20/2004	300	21.6	13.8	1.3	13.3	12.5	25.4	23.9	1.47E-07
5/20/2004	300	21.6	12.4	1.3	11.8	11.1	22.5	21.1	1.50E-07
5/20/2004	300	21.6	11.2	1.4	10.4	9.8	19.8	18.6	1.46E-07
					Averages:		23.4		1.48E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-1
Depth (ft)	71.7 to 72.3	Lab No.	K6/259
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/260	Dark Olive Gray	(Visual) Clayey Inorganic Silt High LL (MH), with some sand.	2.66				100.0	72.2

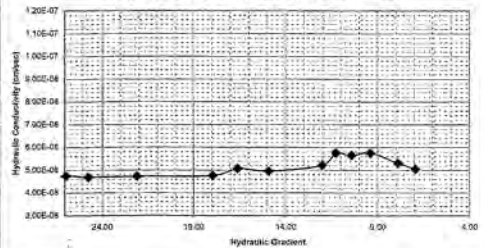
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.415	23.032	7.010	161.464	260.8
Final	5.414	23.018	6.984	160.749	260.6
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	66.1%	0.970	0.964	1.757	100%
Final	65.6%	0.970	0.964	1.745	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
5/24/2004	~Start~	21.3	18.2	1.1				
5/24/2004	1080	21.3	17.1	1.1	17.1	16.0	30.7	28.7
5/24/2004	720	21.5	15.0	1.2	14.4	13.7	25.9	24.7
5/24/2004	3060	21.7	11.4	1.4	12.3	10.0	22.1	18.0
5/24/2004	1500	21.9	9.8	1.5	9.2	8.3	16.6	14.9
Averages:					22.7		4.74E-08	

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-2
Depth (ft)	80.0 to 80.5	Lab No.	K6/260
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087 USCS Classification	ASTM D854 SpGr	ASTM D4318 Atterberg Limits LL PL PI			ASTM D422 %Pass No. 4	ASTM D422 %Pass No. 200
K6/261	Dark Olive Gray	Fat Clay (CH), with some sand.	2.71	108	34	74	100.0	72.6

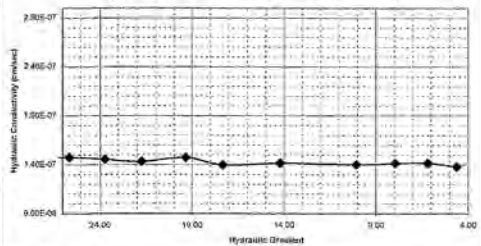
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.497	23.736	7.114	168.855	263.0
Final	5.504	23.791	7.104	169.003	263.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	75.0%	0.896	0.890	2.040	100%
Final	75.4%	0.897	0.890	2.043	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
5/21/2004	~Start~	22.0	17.6	1.1					
5/21/2004	240	22.0	16.8	1.1	16.5	15.7	29.2	27.7	1.48E-07
5/21/2004	360	22.0	14.7	1.2	14.5	13.4	25.6	23.7	1.45E-07
5/21/2004	540	22.1	12.3	1.3	12.3	11.0	21.8	19.4	1.47E-07
5/21/2004	960	22.1	9.5	1.5	9.8	8.0	17.3	14.2	1.42E-07
					Averages:		22.4		1.46E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-3
Depth (ft)	89.0 to 89.6	Lab No.	K6/261
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/262	Olive Gray	(Visual) Clay Sand (SC)	2.71				100.0	31.8

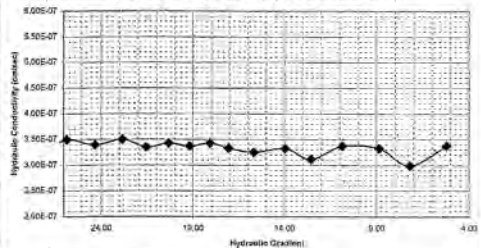
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.444	23.278	7.104	165.372	287.3
Final	5.451	23.339	7.102	165.765	286.6
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	49.1%	1.168	1.162	1.328	100%
Final	49.1%	1.168	1.162	1.334	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
5/26/2004	~Start~	22.2	17.1	1.1					
5/26/2004	60	22.2	16.7	1.2	16.0	15.5	28.2	27.4	3.25E-07
5/26/2004	120	22.2	15.0	1.2	14.6	13.8	25.8	24.3	3.40E-07
5/26/2004	120	22.2	13.5	1.3	12.9	12.2	22.9	21.6	3.35E-07
5/26/2004	120	22.2	12.2	1.3	11.5	10.9	20.3	19.2	3.37E-07
					Averages:		23.7		3.34E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-4
Depth (ft)	99.7 to 100.3	Lab No.	K6/262
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/263	Olive Gray	Clayey Organic Silt (OH), with a trace of sand.	2.58	144	59	85	100.0	94.7

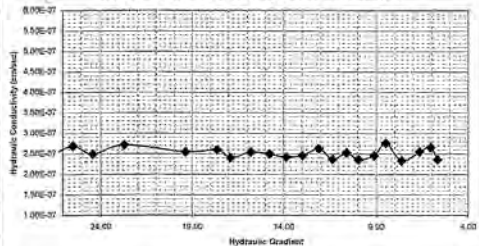
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.525	23.970	7.083	169.778	264.8
Final	5.525	23.970	7.050	169.001	264.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	71.6%	0.913	0.906	1.849	100%
Final	71.1%	0.913	0.906	1.836	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By:	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
5/26/2004	~Start~	22.1	16.5	1.2					
5/26/2004	60	22.1	16.2	1.2	15.3	15.0	27.3	26.7	2.50E-07
5/26/2004	120	22.1	15.0	1.2	14.3	13.7	25.4	24.4	2.29E-07
5/26/2004	420	22.1	12.2	1.3	12.8	10.9	22.7	19.4	2.54E-07
5/26/2004	120	22.1	10.9	1.4	9.9	9.5	17.6	16.9	2.40E-07
					Averages:		22.6		2.44E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-5
Depth (ft)	112.0 to 112.6	Lab No.	K6/263
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2067	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/264	Olive Gray	(Visual) Clayey Organic Silt (OH).	2.57				100.0	99.6

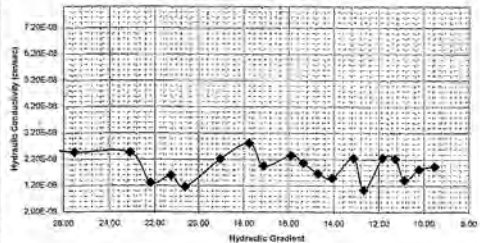
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.488	23.652	7.095	167.822	236.4
Final	5.491	23.685	7.085	167.799	236.6
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	113.6%	0.663	0.656	2.913	100%
Final	113.5%	0.663	0.656	2.912	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
6/1/2004	~Start~	22.3	16.0	1.2					
6/1/2004	1920	22.3	15.3	1.2	14.8	14.0	26.2	24.9	1.92E-08
6/1/2004	2100	22.5	13.9	1.3	13.0	12.6	23.1	22.4	1.05E-08
6/1/2004	1800	22.6	13.0	1.3	12.0	11.6	21.3	20.6	1.16E-08
6/1/2004	1740	21.9	11.5	1.4	11.0	10.1	19.4	17.9	3.22E-08
					Averages:		22.0		1.84E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-6
Depth (ft)	129.8 to 130.2	Lab No.	K6/264
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087 USCS Classification	ASTM D854 SpGr	ASTM D4318 Atterberg Limits			ASTM D422 %Pass No. 4	ASTM D422 %Pass No. 200
K6/265	Olive Gray	Clayey Sand High LL (SC-H)	2.65	94	35	59	100.0	31.6

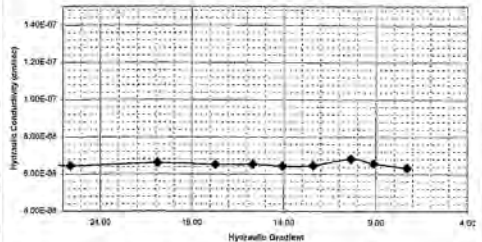
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.442	23.256	7.097	165.041	299.7
Final	5.453	23.354	7.079	165.320	301.0
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	39.2%	1.306	1.301	1.041	100%
Final	39.3%	1.306	1.301	1.045	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
6/2/2004	~Start~	21.1	17.5	1.1					
6/2/2004	780	21.1	16.4	1.2	16.4	15.2	29.0	27.0	6.60E-08
6/2/2004	2160	21.1	13.1	1.3	14.4	11.8	25.6	20.9	6.61E-08
6/2/2004	1320	21.1	10.3	1.4	10.0	8.8	17.7	15.7	6.54E-08
6/2/2004	1380	21.1	8.5	1.5	7.9	7.0	14.1	12.4	6.46E-08
					Averages:		20.3		6.55E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-7
Depth (ft)	152.0 to 152.5	Lab No.	K6/265
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/266	Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.66	66	35	31	100.0	18.1

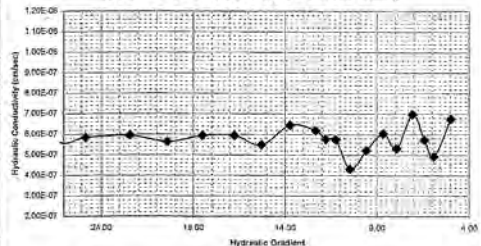
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.436	23.212	7.117	165.205	320.7
Final	5.428	23.137	7.115	164.621	322.1
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	29.0%	1.504	1.500	0.771	100%
Final	28.8%	1.504	1.500	0.764	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
6/3/2004	~Start~	21.2	16.6	1.2				
6/3/2004	60	21.2	16.0	1.2	15.5	14.8	27.3	26.0
6/3/2004	120	21.2	14.0	1.3	14.1	12.7	24.8	22.5
6/3/2004	120	21.2	11.9	1.4	11.6	10.5	20.4	18.5
6/3/2004	120	21.2	10.1	1.4	9.5	8.7	16.8	15.3
					Averages:		21.4	5.74E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-8
Depth (ft)	161.4 to 161.9	Lab No.	K6/266
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/267	Olive Gray	(Visual) Sandy Inorganic Silt High LL (MH)	2.64				100.0	54.7

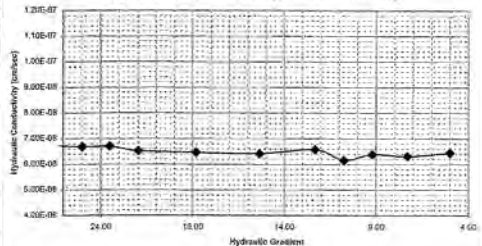
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.531	24.029	7.115	170.957	281.4
Final	5.531	24.026	7.080	170.107	282.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	58.9%	1.039	1.033	1.555	100%
Final	58.5%	1.039	1.033	1.543	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
6/4/2004	~Start~	21.4	18.5	1.1					
6/4/2004	540	21.4	17.6	1.1	17.4	16.5	30.9	29.3	6.81E-08
6/4/2004	600	21.6	14.5	1.2	14.1	13.3	25.0	23.5	6.71E-08
6/4/2004	1620	21.7	12.0	1.4	12.4	10.6	22.0	18.8	6.47E-08
6/4/2004	2280	21.8	8.5	1.5	8.7	6.9	15.4	12.3	6.58E-08
					Averages:		22.1		6.64E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-9
Depth (ft)	172.0 to 172.5	Lab No.	K6/267
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/268	Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.69	137	55	82	100.0	40.5

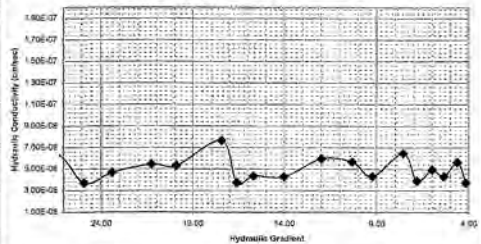
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.518	23.915	7.130	170.526	289.7
Final	5.522	23.945	7.103	170.082	290.3
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	52.7%	1.118	1.112	1.420	100%
Final	52.5%	1.118	1.112	1.414	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{perc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
6/7/2004	~Start~	21.4	17.9	1.1					
6/7/2004	1140	21.4	16.2	1.2	16.7	15.0	29.6	26.5	6.56E-08
6/7/2004	900	21.4	14.5	1.2	14.2	13.3	25.1	23.4	5.24E-08
6/7/2004	900	21.4	12.6	1.3	12.1	11.3	21.3	19.9	5.13E-08
6/7/2004	900	21.5	10.8	1.4	9.8	9.4	17.2	16.6	2.91E-08
					Averages:		22.5		4.96E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-10
Depth (ft)	187.7 to 188.2	Lab No.	K6/268
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/269	Olive Gray	(Visual) Silty Sand (SM).	2.70				100.0	49.9

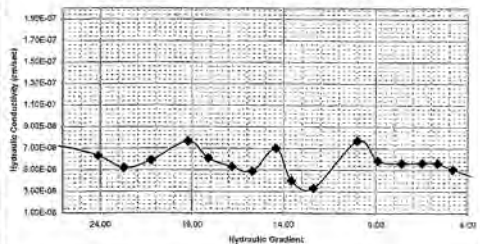
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.582	24.476	7.116	174.185	287.1
Final	5.544	24.140	7.086	171.053	288.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	60.0%	1.036	1.030	1.618	100%
Final	58.2%	1.036	1.030	1.571	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7671
<u>Chamber Pressure (psi)</u>	65.0	<u>Consolidation Stress (psi)</u>
<u>Back Pressure (psi)</u>	60.0	5.0
<u>Conducted By</u>	<u>Sample Testing By:</u>	<u>Report Preparation By:</u>
	MVV	MVV

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
6/8/2004	~Start~	21.1	17.1	1.1					
6/8/2004	780	21.1	15.9	1.2	16.0	14.7	28.3	26.1	7.18E-08
6/8/2004	780	21.1	14.1	1.3	13.6	12.8	24.1	22.7	5.20E-08
6/8/2004	900	21.1	12.2	1.3	12.0	10.9	21.3	19.2	7.66E-08
6/8/2004	960	21.1	10.9	1.4	10.2	9.5	18.1	16.8	5.29E-08
					Averages:		22.1		6.33E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-11
Depth (ft)	198.0 to 198.5	Lab No.	K6/269
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/270	Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.73	122	52	70	100.0	33.5

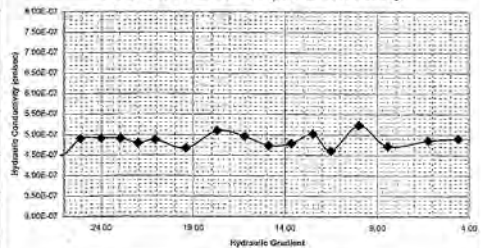
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.546	24.154	7.083	171.096	298.7
Final	5.540	24.103	6.954	167.609	296.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	49.7%	1.163	1.157	1.356	100%
Final	48.0%	1.163	1.157	1.308	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{avg} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
6/9/2004	~Start~	21.4	15.7	1.2					
6/9/2004	60	21.4	15.1	1.2	14.5	13.9	26.2	25.1	4.91E-07
6/9/2004	60	21.4	14.0	1.3	13.3	12.7	24.0	23.0	4.92E-07
6/9/2004	60	21.4	13.0	1.3	12.2	11.7	22.0	21.1	4.87E-07
6/9/2004	120	21.4	11.2	1.4	10.7	9.8	19.4	17.7	5.10E-07
					Averages:		22.3		4.95E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-15	Sample No.	K-12
Depth (ft)	210.6 to 211.1	Lab No.	K6/270
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/271	Olive	Clayey Sand High LL (SC-H)	2.68	60	28	32	100.0	32.0

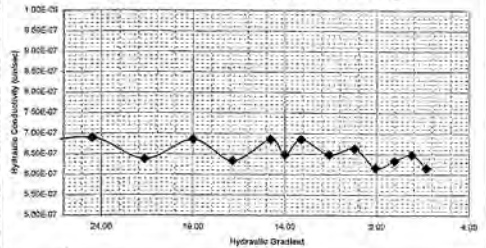
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.664	25.198	6.817	171.784	308.8
Final	5.544	24.143	6.649	160.532	290.7
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	47.6%	1.183	1.178	1.272	100%
Final	42.0%	1.183	1.178	1.124	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By:	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
9/2/2004	~Start~	22.1	17.9	1.1					
9/2/2004	120	22.1	16.0	1.2	16.8	14.8	31.7	27.9	6.67E-07
9/2/2004	120	22.1	12.8	1.3	13.0	11.5	24.5	21.7	6.38E-07
9/2/2004	120	22.1	10.4	1.4	10.1	8.9	19.0	16.8	6.33E-07
9/2/2004	60	22.1	8.9	1.5	7.8	7.4	14.8	14.0	5.74E-07
					Averages:		21.3		6.28E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-16	Sample No.	K-1
Depth (ft)	62.0 to 62.6	Lab No.	K6/271
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/272	Olive	(Visual) Clayey Sand (SC)	2.68				100.0	16.4

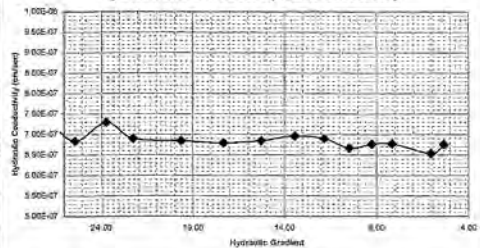
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.624	24.842	7.162	177.919	337.6
Final	5.565	24.324	6.951	169.072	330.7
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	36.7%	1.356	1.351	0.982	100%
Final	33.0%	1.355	1.351	0.884	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{avg} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
9/2/2004	~Start~	22.1	17.2	1.1					
9/2/2004	60	22.1	16.2	1.2	16.0	15.0	28.9	27.0	7.32E-07
9/2/2004	60	22.1	14.4	1.3	14.1	13.1	25.4	23.7	7.29E-07
9/2/2004	120	22.1	12.2	1.3	12.3	10.9	22.3	19.6	6.84E-07
9/2/2004	120	22.1	9.9	1.4	9.6	8.5	17.3	15.3	6.91E-07
					Averages:		22.4		7.09E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-16	Sample No.	K-2
Depth (ft)	73.0 to 73.5	Lab No.	K6/272
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/273	Olive Gray	(Visual) Sandy Fat Clay (CH)	2.70				100.0	56.8

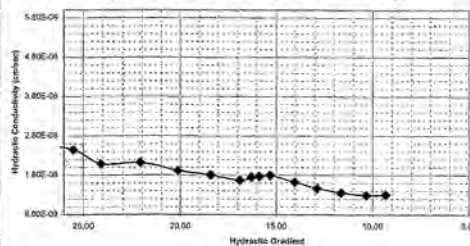
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.444	23.278	7.118	165.698	294.5
Final	5.451	23.335	7.098	165.636	294.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	44.6%	1.230	1.225	1.204	100%
Final	44.6%	1.230	1.225	1.203	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By: MW	Report Preparation By: MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
9/7/2004	~Start~	22.1	18.0	1.1					
9/7/2004	1080	22.1	17.3	1.1	16.9	16.2	29.9	28.6	2.74E-08
9/7/2004	1860	22.0	14.9	1.2	14.4	13.6	25.5	24.1	2.09E-08
9/7/2004	3420	22.0	12.7	1.3	12.5	11.4	22.1	20.1	1.91E-08
9/7/2004	3900	21.9	11.0	1.4	10.4	9.6	18.4	16.9	1.54E-08
					Averages:		23.2		2.07E-08

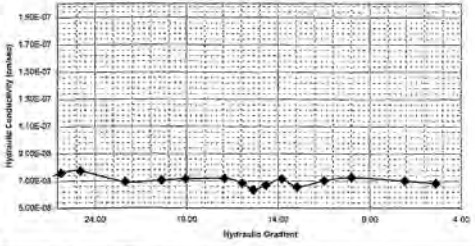
Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-16	Sample No.	K-3
Depth (ft)	89.3 to 89.8	Lab No.	K6/273
Sample Received	5-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C

		U.S. Army Corps of Engineers, Savannah District Environmental & Materials Unit, Marietta, Georgia										
Sample Results												
		ASTM D2087		ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422				
Lab No.	Color	USCS Classification		SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200			
K6/274	Oliva Gray	Clayey Sand High LL (SC-H)		2.72	110	41	69	100.0	44.0			
Specimen Results												
Trial	Diameter, D (cm)	Area, A (cm ²)		Length, L (cm)	Volume (cm ³)		Moist Mass (gms)					
Initial	5.404	22.935		7.110	163.069		293.1					
Final	5.451	23.339		7.080	165.232		292.6					
	Water Content, %	Wet Density (g/cc)		Dry Density (g/cc)	Void Ratio		Saturation, %					
Initial	43.9%	1.244		1.239	1.192		100%					
Final	44.9%	1.244		1.239	1.222		100%					
Permeameter Conditions					Hydraulic Gradient versus Hydraulic Conductivity 							
Permeant Fluid		Mercury Permeameter Area of Tubes (cm ²)										
De-aired tap water	pipet	annulus										
	0.0314	0.7671										
Chamber Pressure (psi)		65.0	Consolidation Stress (psi)									
Back Pressure (psi)		60.0	5.0									
Conducted By	Sample Testing By:	Report Preparation By:										
	MW	MW										
Specimen Permeability Results												
Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{vc} (cm/sec)			
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final				
9/9/2004	~Start~	22.1	17.1	1.1								
9/9/2004	300	22.1	16.6	1.2	15.9	15.4	28.2	27.4	6.92E-08			
9/9/2004	360	22.1	15.2	1.2	14.6	14.0	25.8	24.8	7.74E-08			
9/9/2004	900	22.0	12.8	1.3	12.6	11.5	22.4	20.4	7.17E-08			
9/9/2004	1140	22.0	11.0	1.4	10.7	9.6	19.1	16.9	7.20E-08			
					Averages:		23.1		7.26E-08			
Remarks:					Project Information							
(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminium foil, and a covering of duct tape to prevent moisture loss.					Project		Savannah Harbor Expansion					
					Location		Savannah, Georgia					
					Requisition No.		W33SJG40168635		Work Order No.		330e	
					Hole No.		SHE-16		Sample No.		K-4	
					Depth (ft)		99.3 to 99.8		Lab No.		K6/274	
					Sample Received		5-May-04		Report Date		14-Feb-05	
					Permeability Test Report - ASTM D5084 Method C							



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/275	Dark Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.71	99	44	55	100.0	46.5

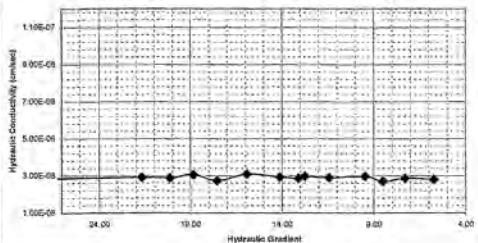
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.455	23.368	7.106	166.046	287.4
Final	5.479	23.575	7.093	167.219	288.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	50.1%	1.156	1.150	1.360	100%
Final	50.7%	1.156	1.150	1.376	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{SPC} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
9/10/2004	~Start~	21.9	18.3	1.1					
9/10/2004	8040	21.9	13.6	1.3	17.2	12.3	30.5	21.7	2.91E-08
9/10/2004	1500	21.9	12.0	1.4	11.4	10.8	20.1	18.8	3.05E-08
9/10/2004	2160	21.9	10.4	1.4	9.9	9.0	17.5	15.9	3.09E-08
9/10/2004	1800	21.9	8.9	1.5	8.0	7.4	14.1	13.1	2.86E-08
Averages:							19.0		2.98E-08

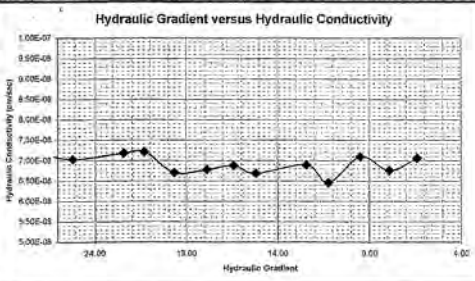
Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-16	Sample No.	K-5
Depth (ft)	111.0 to 111.5	Lab No.	K6/275
Sample Received	5-May-04	Report Date	14-Feb-05

Permeability Test Report - ASTM D5084 Method C

 U.S. Army Corps of Engineers, Savannah District Environmental & Materials Unit, Marietta, Georgia											
Sample Results											
		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422				
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200			
K6/276	Olive Gray & Dark Gray	Sandy Lean Clay (CL).	2.70	46	21	25	100.0	50.1			
Specimen Results											
Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)						
Initial	5.407	22.964	7.276	167.080	283.8						
Final	5.461	23.426	6.767	158.515	273.4						
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %						
Initial	56.3%	1.078	1.072	1.521	100%						
Final	51.5%	1.077	1.072	1.392	100%						
Permeameter Conditions											
Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)										
De-aired tap water	pipet	annulus									
	0.0314	0.7671									
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)									
Back Pressure (psi)	60.0	5.0									
Conducted By	Sample Testing By:	Report Preparation By:									
	MW	MW									
											
Specimen Permeability Results											
Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)			
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final			
11/16/2004	~Start~	20.8	16.4	1.2							
11/16/2004	480	20.8	15.7	1.2	15.3	14.5	28.3	26.9	7.21E-08		
11/16/2004	1080	20.8	13.4	1.3	13.6	12.1	25.2	22.4	7.18E-08		
11/16/2004	840	20.7	12.0	1.4	11.5	10.6	21.3	19.6	6.70E-08		
11/16/2004	840	20.7	10.3	1.4	9.6	8.8	17.9	16.4	6.87E-08		
					Averages:		22.3		6.99E-08		
Remarks:					Project Information						
(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.					Project		Savannah Harbor Expansion				
					Location		Savannah, Georgia				
					Requisition No.		W33JG40168635		Work Order No.		330e
					Hole No.		SHE-17		Sample No.		K-1
					Depth (ft)		58.1 to 58.6		Lab No.		K6/276
					Sample Received		18-May-04		Report Date		3-Feb-05
Permeability Test Report - ASTM D5084 Method C											



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/277	Olive Gray & Dark Gray	(Visual) Sandy Fat Clay (CH)	2.69				100.0	59.6

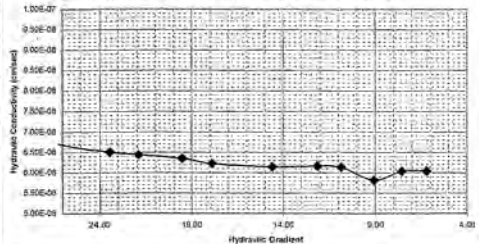
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.510	23.846	7.054	168.197	291.3
Final	5.463	23.437	6.827	160.002	277.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	55.2%	1.089	1.083	1.487	100%
Final	50.7%	1.089	1.083	1.366	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)		Consolidation Stress (psi)
65.0		
Back Pressure (psi)		5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
11/17/2004	~Start~	20.8	16.5	1.2					
11/17/2004	720	20.8	15.5	1.2	15.3	14.3	28.2	26.3	6.71E-08
11/17/2004	720	20.8	13.2	1.3	12.8	11.9	23.4	21.9	6.44E-08
11/17/2004	960	20.8	11.1	1.4	10.6	9.7	19.5	17.9	6.22E-08
11/17/2004	2040	20.8	8.1	1.5	7.9	6.6	14.6	12.1	6.16E-08
					Averages:		20.5		6.38E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-17	Sample No.	K-2
Depth (ft)	62.8 to 63.4	Lab No.	K6/277
Sample Received	18-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/278	Olive Gray & Dark Gray	Fat Clay (CH), with some sand.	2.69	82	24	58	100.0	71.4

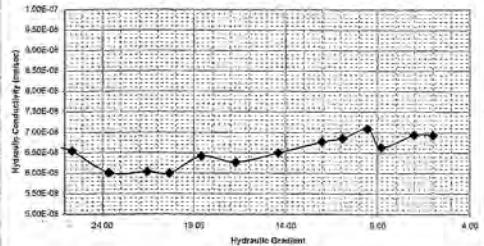
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.550	24.191	7.063	170.866	272.8
Final	5.538	24.084	7.007	168.765	269.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	72.1%	0.921	0.914	1.937	100%
Final	70.8%	0.921	0.914	1.901	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{30°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
11/17/2004	~Start~	21.1	17.4	1.1				
11/17/2004	660	21.1	16.4	1.2	16.3	15.2	29.1	27.3
11/17/2004	900	21.2	14.5	1.2	14.3	13.3	25.6	23.7
11/17/2004	660	21.3	12.7	1.3	12.1	11.4	21.6	20.4
11/17/2004	1140	21.4	10.8	1.4	10.4	9.3	18.6	16.7
					Averages:		22.9	6.18E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-17	Sample No.	K-3
Depth (ft)	70.4 to 71.0	Lab No.	K6/278
Sample Received	18-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/279	Dark Olive Gray	Clayey Sand High LL (SC-H)	2.77	64	25	39	100.0	21.4

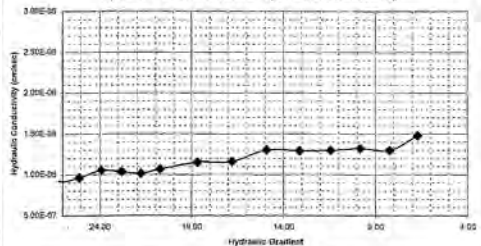
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.651	25.081	7.106	178.236	341.2
Final	5.627	24.864	6.938	172.506	334.1
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	35.4%	1.403	1.398	0.979	100%
Final	33.1%	1.402	1.398	0.915	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)		Consolidation Stress (psi)
65.0		
Back Pressure (psi)		5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
11/18/2004	~Start~	20.9	16.3	1.2					
11/18/2004	30	20.9	15.7	1.2	15.1	14.5	27.4	26.2	9.23E-07
11/18/2004	30	20.9	14.5	1.2	13.9	13.2	25.1	23.9	1.05E-06
11/18/2004	30	20.9	13.4	1.3	12.6	12.1	22.8	21.8	1.02E-06
11/18/2004	60	20.9	11.7	1.4	11.5	10.3	20.8	18.7	1.15E-06
					Averages:		23.3		1.04E-06

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40188635	Work Order No.	330e
Hole No.	SHE-17	Sample No.	K-4
Depth (ft)	77.3 to 77.9	Lab No.	K6/279
Sample Received	18-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2057	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/280	Dark Olive Gray	(Visual) Poorly Graded Silty Sand (SP-SM).	2.81				100.0	11.8

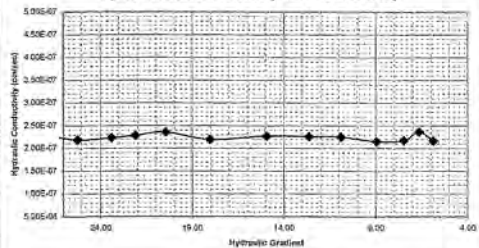
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.376	22.698	7.118	161.575	311.7
Final	5.400	22.903	7.104	162.694	311.2
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	34.9%	1.424	1.419	0.982	100%
Final	35.4%	1.424	1.419	0.995	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{avc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
11/18/2004	~Start~	21.1	18.0	1.1				
11/18/2004	300	21.1	16.5	1.2	16.9	15.3	29.8	27.1
11/18/2004	240	21.1	14.5	1.2	14.3	13.3	25.2	23.4
11/18/2004	240	21.1	12.9	1.3	12.5	11.6	22.1	20.5
11/18/2004	600	21.1	9.9	1.4	10.2	8.5	18.0	14.9
Averages:							22.6	2.29E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-17	Sample No.	K-5
Depth (ft)	86.9 to 87.4	Lab No.	K6/280
Sample Received	18-May-04	Report Date	3-Feb-05
Permeability Test Report - ASTM D5084 Method C			



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/281	Olive	Sandy Clayey Inorganic Silt High LL (MH)	2.71	106	46	60	100.0	54.6

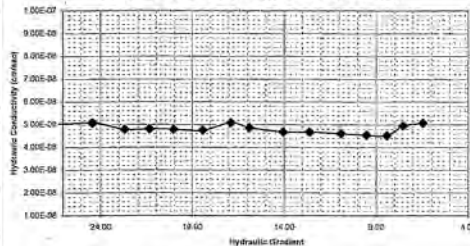
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.423	23.097	7.121	164.470	298.8
Final	5.418	23.054	7.092	163.489	299.2
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	40.6%	1.295	1.290	1.101	100%
Final	40.2%	1.295	1.290	1.089	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, $k_{20^\circ\text{C}}$ (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
11/19/2004	~Start~	21.4	16.3	1.2					
11/19/2004	1320	21.4	15.0	1.2	15.2	13.8	26.8	24.4	5.07E-08
11/19/2004	900	21.5	13.4	1.3	12.8	12.1	22.7	21.4	4.81E-08
11/19/2004	1260	21.6	11.8	1.4	11.3	10.4	20.0	18.4	4.73E-08
11/19/2004	900	21.8	10.4	1.4	9.6	9.0	16.9	15.9	4.87E-08
					Averages:		20.8		4.87E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-17	Sample No.	K-6
Depth (ft)	104.8 to 105.2	Lab No.	K6/281
Sample Received	18-May-04	Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/284	Dark Olive Gray	Clayey Organic Silt (OH), with a trace of sand.	2.52	328	108	220	100.0	97.9

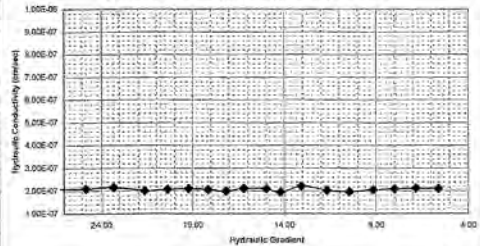
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.637	24.958	7.094	177.039	228.3
Final	5.617	24.782	7.015	173.840	225.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	180.7%	0.462	0.454	4.555	100%
Final	176.7%	0.462	0.454	4.454	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sw} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
11/20/2004	~Start~	22.1	17.0	1.1				
11/20/2004	180	22.1	16.2	1.2	15.9	15.0	28.4	26.8
11/20/2004	180	22.1	14.3	1.3	13.9	13.0	24.8	23.3
11/20/2004	180	22.1	12.7	1.3	12.1	11.4	21.7	20.4
11/20/2004	180	22.1	11.5	1.4	10.7	10.1	19.2	18.2
Averages:					22.8		2.12E-07	

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-18	Sample No.	K-1
Depth (ft)	91.5 to 92.2	Lab No.	K6/284
Sample Received		Report Date	3-Feb-05
Permeability Test Report - ASTM D5084 Method C			



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/285	Dark Olive Gray	(Visual) Silty Sand (SM)	2.77				100.0	20.2

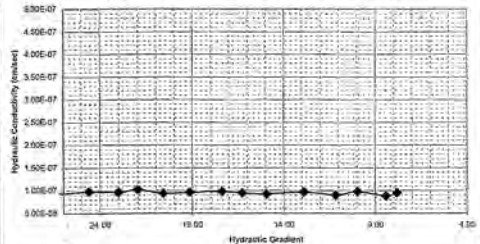
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.094	20.383	7.179	146.338	282.0
Final	5.109	20.499	7.163	146.841	281.0
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	35.0%	1.412	1.407	0.968	100%
Final	35.2%	1.412	1.407	0.975	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
11/20/2004	~Start~	22.4	17.4	1.1				
11/20/2004	360	22.4	16.7	1.2	16.3	15.5	28.5	27.2
11/20/2004	480	22.4	15.3	1.2	14.9	14.0	26.1	24.6
11/20/2004	360	22.5	13.8	1.3	13.1	12.5	23.0	22.0
11/20/2004	600	22.6	12.3	1.3	11.8	10.9	20.6	19.1
				Averages:		23.9		9.95E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-18	Sample No.	K-2
Depth (ft)	97.2 to 97.9	Lab No.	K6/285
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

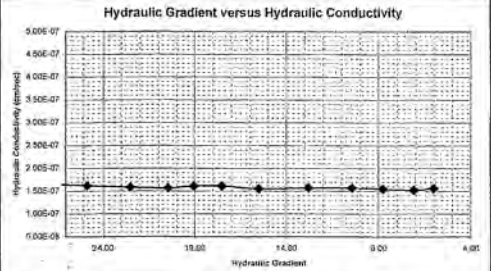
Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/286	Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.67	131	53	78	100.0	34.5

Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.478	23.564	7.104	167.410	275.5
Final	5.466	23.463	7.031	164.958	275.0
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	57.4%	1.051	1.045	1.556	99%
Final	56.8%	1.051	1.045	1.519	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW



Specimen Permeability Results

Start Time:		Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k_{sarc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
11/22/2004	~Start~	21.6	17.4	1.1				
11/22/2004	300	21.6	16.3	1.2	16.2	15.1	29.0	27.0
11/22/2004	420	21.6	13.9	1.3	13.9	12.6	24.8	22.5
11/22/2004	300	21.7	12.0	1.4	11.5	10.7	20.5	19.0
11/22/2004	540	21.7	10.1	1.4	9.8	8.7	17.5	15.5
				Averages:		22.0		1.62E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-18	Sample No.	K-3
Depth (ft)	120.9 to 121.5	Lab No.	K6/286
Sample Received		Report Date	3-Feb-05
Permeability Test Report - ASTM D5084 Method C			



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/287	Olive Gray	(Visual) Silty Sand (SM).	2.68				100.0	24.6

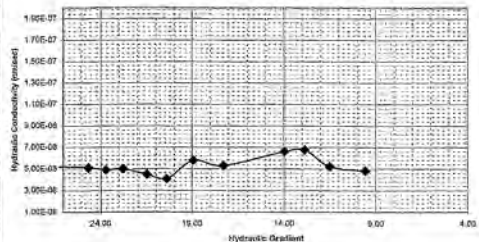
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.478	23.564	7.151	168.518	296.7
Final	5.464	23.444	7.126	167.064	298.4
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	44.6%	1.223	1.218	1.200	100%
Final	44.1%	1.223	1.218	1.181	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
11/22/2004	~Start~	21.9	16.9	1.1					
11/22/2004	660	21.9	16.2	1.2	15.8	15.0	27.7	26.4	5.20E-08
11/22/2004	540	21.9	14.7	1.2	14.0	13.5	24.6	23.7	4.91E-08
11/22/2004	900	21.9	13.5	1.3	12.9	12.2	22.8	21.5	4.49E-08
11/22/2004	900	22.0	12.1	1.4	11.6	10.7	20.4	18.9	5.78E-08
					Averages:		23.3		5.09E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-18	Sample No.	K-4
Depth (ft)	133.3 to 134.0	Lab No.	K6/287
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/288	Olive Gray	Sandy Fat Clay (CH)	2.72	72	31	41	100.0	51.4

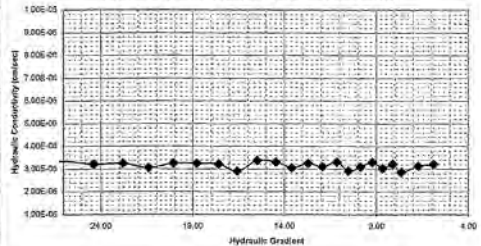
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.393	22.845	7.166	163.708	314.2
Final	5.406	22.953	7.114	163.284	310.8
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	36.7%	1.367	1.362	0.997	100%
Final	36.5%	1.367	1.362	0.992	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipe	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
12/2/2004	~Start~	20.6	17.0	1.1				
12/2/2004	15	20.6	16.0	1.2	15.8	14.8	27.9	26.0
12/2/2004	15	20.6	14.2	1.3	13.8	12.9	24.4	22.8
12/2/2004	15	20.6	12.7	1.3	12.2	11.4	21.4	20.1
12/2/2004	15	20.6	11.4	1.4	10.6	10.0	18.8	17.6
Averages:					22.4		3.27E-06	

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-1
Depth (ft)	86.2 to 87.0	Lab No.	K6/288
Sample Received		Report Date	3-Feb-05

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**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/289	Olive Gray	Clayey Inorganic Silt High LL (MH), with a trace of sand.	2.71	156	63	93	100.0	95.6

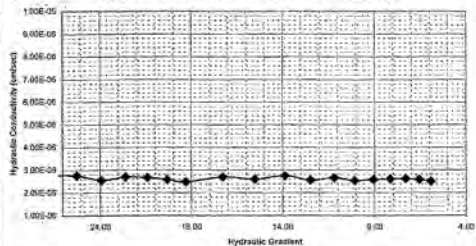
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.413	23.014	7.132	164.143	286.7
Final	5.420	23.072	7.087	163.514	282.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	55.5%	1.087	1.081	1.502	100%
Final	55.2%	1.087	1.081	1.493	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/2/2004	~Start~	20.6	17.1	1.1					
12/2/2004	15	20.6	16.3	1.2	16.0	15.1	28.3	26.7	2.77E-06
12/2/2004	15	20.6	14.8	1.2	14.2	13.5	25.2	23.9	2.55E-06
12/2/2004	15	20.6	13.4	1.3	12.8	12.1	22.6	21.4	2.64E-06
12/2/2004	15	20.6	12.3	1.3	11.5	10.9	20.3	19.3	2.49E-06
					Averages:		23.5		2.61E-06

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-2
Depth (ft)	96.7 to 97.5	Lab No.	K6/289
Sample Received		Report Date	3-Feb-05

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**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/290	Olive Gray	Clayey Sand High LL (SC-H).	2.68	84	31	53	100.0	38.4

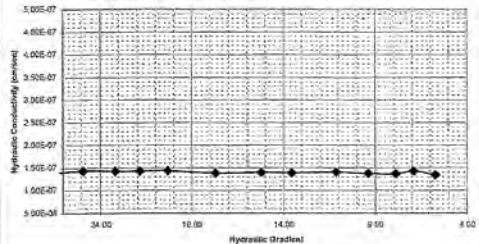
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.375	22.691	7.137	161.956	277.2
Final	5.416	23.036	7.099	163.537	276.2
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	51.1%	1.128	1.123	1.387	100%
Final	51.9%	1.128	1.123	1.410	99%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{sc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/6/2004	~Start~	21.0	17.7	1.1					
12/6/2004	360	21.0	16.7	1.2	16.6	15.5	29.3	27.4	1.37E-07
12/6/2004	360	21.0	14.4	1.3	14.1	13.1	24.9	23.2	1.42E-07
12/6/2004	360	21.1	12.8	1.3	12.4	11.5	21.9	20.3	1.45E-07
12/6/2004	780	21.1	10.1	1.4	10.0	8.6	17.7	15.2	1.40E-07
					Averages:		22.5		1.41E-07

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-3
Depth (ft)	118.5 to 119.3	Lab No.	K6/290
Sample Received		Report Date	3-Feb-05

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**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/291	Olive Gray	(Visual) Sandy Clayey Inorganic Silt High LL (MH)	2.70				100.0	51.8

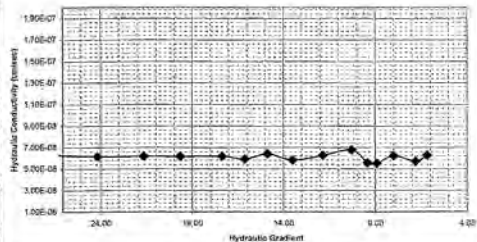
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.485	23.455	7.140	167.469	280.9
Final	5.440	23.241	7.131	165.735	280.9
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	53.6%	1.098	1.092	1.477	98%
Final	53.6%	1.098	1.092	1.451	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeometer Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k_{DPC} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/6/2004	~Start~	21.1	17.4	1.1					
12/6/2004	480	21.1	16.8	1.2	16.3	15.6	28.6	27.4	6.36E-08
12/6/2004	1260	21.1	13.6	1.3	13.7	12.3	24.1	21.7	6.17E-08
12/6/2004	1440	21.1	11.3	1.4	11.2	9.9	19.6	17.4	6.19E-08
12/6/2004	900	21.0	9.9	1.4	9.2	8.5	16.1	14.9	6.39E-08
					Averages:		21.2		6.28E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-4
Depth (ft)	131.8 to 132.4	Lab No.	K6/291
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/292	Olive Gray	Clayey Inorganic Silt High LL (MH), with a little sand.	2.70	135	55	80	100.0	87.3

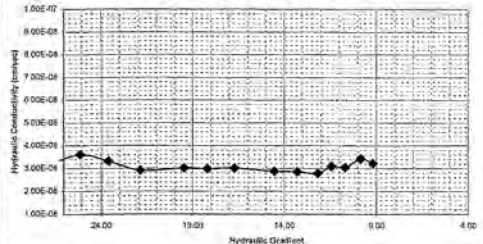
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.469	23.492	7.131	167.520	272.2
Final	5.482	23.601	7.055	166.515	271.0
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	65.8%	0.979	0.972	1.779	100%
Final	65.2%	0.979	0.972	1.762	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/7/2004	~Start~	20.6	17.1	1.1					
12/7/2004	1380	20.6	16.2	1.2	16.0	15.0	28.4	26.6	3.28E-08
12/7/2004	1380	21.3	14.5	1.2	14.1	13.3	25.1	23.6	3.07E-08
12/7/2004	2700	21.1	12.3	1.3	12.3	11.0	21.9	19.5	3.02E-08
12/7/2004	1980	21.0	10.8	1.4	10.2	9.4	18.2	16.7	3.01E-08
					Averages:		22.5		3.10E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-5
Depth (ft)	142.0 to 142.6	Lab No.	K6/292
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2987	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/293	Olive Gray	(Visual) Clayey Inorganic Silt High LL (MH), with a trace of sand.	2.69				100.0	91.5

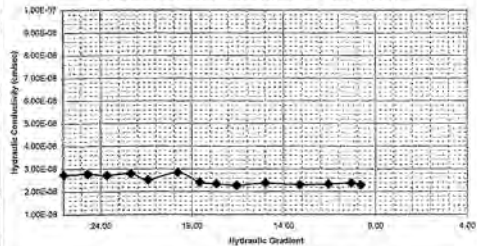
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.447	23.303	7.126	166.056	260.8
Final	5.444	23.274	7.083	164.859	259.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	76.5%	0.886	0.880	2.059	100%
Final	75.7%	0.886	0.880	2.037	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{apc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/8/2004	~Start~	20.8	17.0	1.1					
12/8/2004	2100	20.8	15.9	1.2	15.9	14.7	28.1	26.0	2.74E-08
12/8/2004	1140	20.8	14.6	1.2	13.9	13.4	24.7	23.7	2.65E-08
12/8/2004	1200	20.8	13.4	1.3	12.6	12.1	22.4	21.4	2.52E-08
12/8/2004	1860	20.7	11.9	1.4	11.2	10.5	19.8	18.6	2.42E-08
					Averages:		23.1		2.58E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-6
Depth (ft)	152.5 to 153.1	Lab No.	K6/293
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

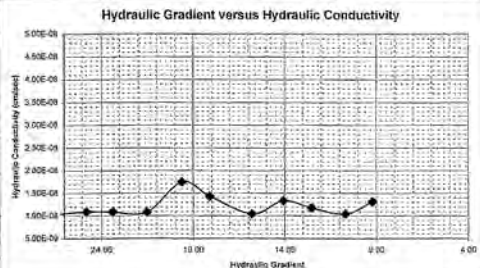
Lab No.	Color	ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/294	Olive Gray	Clayey Organic Silt (OH)	2.59	250	83	167	100.0	99.7

Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.492	23.688	7.134	168.983	234.1
Final	5.500	23.758	7.111	168.951	234.1
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	123.2%	0.626	0.618	3.191	100%
Final	123.2%	0.626	0.618	3.191	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW



Specimen Permeability Results

Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sec} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
12/13/2004	~Start~	20.6	18.7	1.1				
12/13/2004	3900	20.6	17.5	1.1	17.6	16.4	31.1	28.9
12/13/2004	6180	20.6	15.3	1.2	15.4	14.0	27.2	24.8
12/13/2004	5340	20.7	13.5	1.3	13.3	12.2	23.4	21.5
12/13/2004	4860	20.3	11.6	1.4	11.1	10.3	19.6	18.1
Averages:							24.3	1.18E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-7
Depth (ft)	162.3 to 162.9	Lab No.	K6/294
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2087 USCS Classification	ASTM D854 SpGr	ASTM D4318 Atterberg Limits			ASTM D422 %Pass No. 4	ASTM D422 %Pass No. 200
K6/295	Olive Gray	(Visual) Clayey Organic Silt (OH), with some sand.	2.55				100.0	70.3

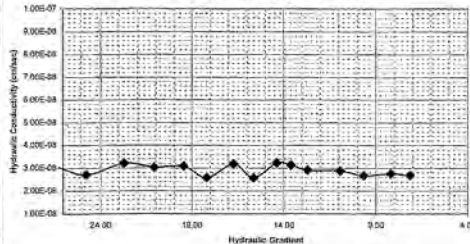
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.489	23.666	7.256	171.712	223.9
Final	5.472	23.517	7.200	169.329	223.8
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	154.7%	0.520	0.512	3.972	99%
Final	153.3%	0.520	0.512	3.903	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeometer Reading			Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k_{spc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/21/2004	~Start~	16.6	17.2	1.1					
12/21/2004	1380	16.6	16.4	1.2	16.1	15.2	28.0	26.5	3.10E-08
12/21/2004	2100	16.6	14.3	1.3	14.2	13.0	24.7	22.7	3.22E-08
12/21/2004	2100	16.6	12.5	1.3	12.1	11.2	21.1	19.5	3.08E-08
12/21/2004	2100	16.6	11.0	1.4	10.4	9.6	18.2	16.7	3.18E-08
					Averages:		22.2		3.15E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-8
Depth (ft)	167.1 to 167.6	Lab No.	K6/295
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/296	Olive	Silty Sand (SM-H), with High LL plastic fines.	2.68	69	37	32	100.0	31.1

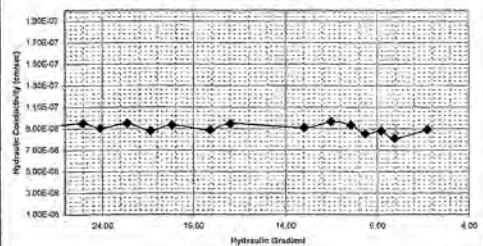
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.525	23.974	7.193	172.452	333.3
Final	5.480	23.586	7.170	169.123	333.5
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	29.1%	1.502	1.497	0.790	99%
Final	28.2%	1.502	1.497	0.755	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	<u>pipet</u>	<u>annulus</u>
	0.0314	0.7671
<u>Chamber Pressure (psi)</u>	65.0	<u>Consolidation Stress (psi)</u>
<u>Back Pressure (psi)</u>	60.0	5.0
<u>Conducted By</u>	<u>Sample Testing By:</u>	<u>Report Preparation By:</u>
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:		Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{sec} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final
1/6/2005	~Start~	20.1	16.5	1.2				
1/6/2005	540	20.1	15.5	1.2	15.3	14.3	26.8	25.0
1/6/2005	480	20.1	14.2	1.3	13.8	12.9	24.1	22.6
1/6/2005	420	20.1	12.9	1.3	12.2	11.5	21.4	20.2
1/6/2005	480	20.1	11.1	1.4	10.3	9.7	18.1	17.0
Averages:							21.9	9.60E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

<u>Project</u>	Savannah Harbor Expansion		
<u>Location</u>	Savannah, Georgia		
<u>Requisition No.</u>	W33SJG40168635	<u>Work Order No.</u>	330e
<u>Hole No.</u>	SHE-19	<u>Sample No.</u>	K-9
<u>Depth (ft)</u>	188.8 to 189.3	<u>Lab No.</u>	K6/296
<u>Sample Received</u>	2-Nov-04	<u>Report Date</u>	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

Lab No.	Color	ASTM D2067	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
		USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/297	Olive Gray	Silty Sand (SM-H), with High LL plastic fines.	2.66	132	58	74	100.0	42.6

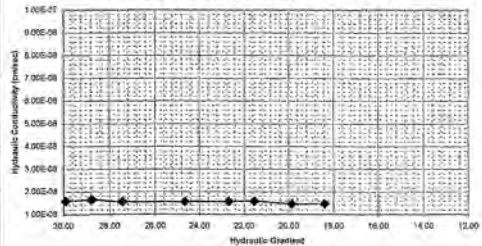
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.523	23.959	7.187	172.195	296.1
Final	5.517	23.908	7.158	171.142	296.7
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	49.3%	1.156	1.151	1.312	100%
Final	48.8%	1.156	1.151	1.298	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeameter Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, k _{20°C} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
12/23/2004	~Start~	18.9	18.2	1.1					
12/23/2004	1740	18.9	17.5	1.1	17.1	16.4	29.9	28.8	1.65E-08
12/23/2004	5040	19.0	15.3	1.2	15.7	14.1	27.4	24.6	1.57E-08
12/23/2004	2340	19.9	13.6	1.3	12.9	12.3	22.7	21.5	1.59E-08
12/23/2004	3600	20.6	11.9	1.4	11.3	10.5	19.8	18.4	1.51E-08
					Averages:		24.1		1.58E-08

Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-10
Depth (ft)	202.1 to 202.6	Lab No.	K6/297
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C



**U.S. Army Corps of Engineers, Savannah District
Environmental & Materials Unit, Marietta, Georgia**

Sample Results

		ASTM D2087	ASTM D854	ASTM D4318 Atterberg Limits			ASTM D422	
Lab No.	Color	USCS Classification	SpGr	LL	PL	PI	%Pass No. 4	%Pass No. 200
K6/298	Olive	Silty Sand (SM-H), with High LL plastic fines.	2.69	97	47	50	100.0	45.5

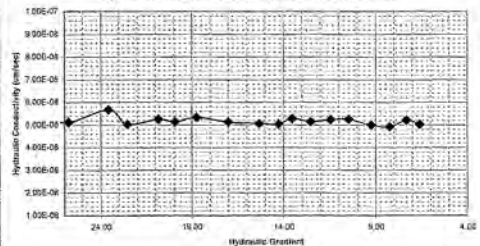
Specimen Results

Trial	Diameter, D (cm)	Area, A (cm ²)	Length, L (cm)	Volume (cm ³)	Moist Mass (gms)
Initial	5.523	23.956	7.169	171.727	324.4
Final	5.521	23.941	7.164	171.515	325.0
	Water Content, %	Wet Density (g/cc)	Dry Density (g/cc)	Void Ratio	Saturation, %
Initial	34.1%	1.406	1.401	0.917	100%
Final	34.1%	1.406	1.401	0.915	100%

Permeameter Conditions

Permeant Fluid	Mercury Permeameter Area of Tubes (cm ²)	
De-aired tap water	pipet	annulus
	0.0314	0.7671
Chamber Pressure (psi)	65.0	Consolidation Stress (psi)
Back Pressure (psi)	60.0	5.0
Conducted By	Sample Testing By:	Report Preparation By:
	MW	MW

Hydraulic Gradient versus Hydraulic Conductivity



Specimen Permeability Results

Start Time:			Permeometer Reading		Head Loss		Hydraulic Gradient		Hydraulic Conductivity, K _{svc} (cm/sec)
Date	Time Elapsed (sec)	Temp. (°C)	Pipet (cm)	Annulus (cm)	Start	Final	Start	Final	
1/7/2005	~Start~	19.4	17.6	1.1					
1/7/2005	600	19.4	17.0	1.1	16.5	15.8	28.9	27.7	5.29E-08
1/7/2005	1140	19.4	14.7	1.2	14.7	13.5	25.8	23.6	5.68E-08
1/7/2005	1080	19.4	13.2	1.3	12.9	11.9	22.5	20.8	5.26E-08
1/7/2005	840	19.4	12.1	1.4	11.4	10.7	19.9	18.7	5.33E-08
					Averages:		23.5		5.39E-08

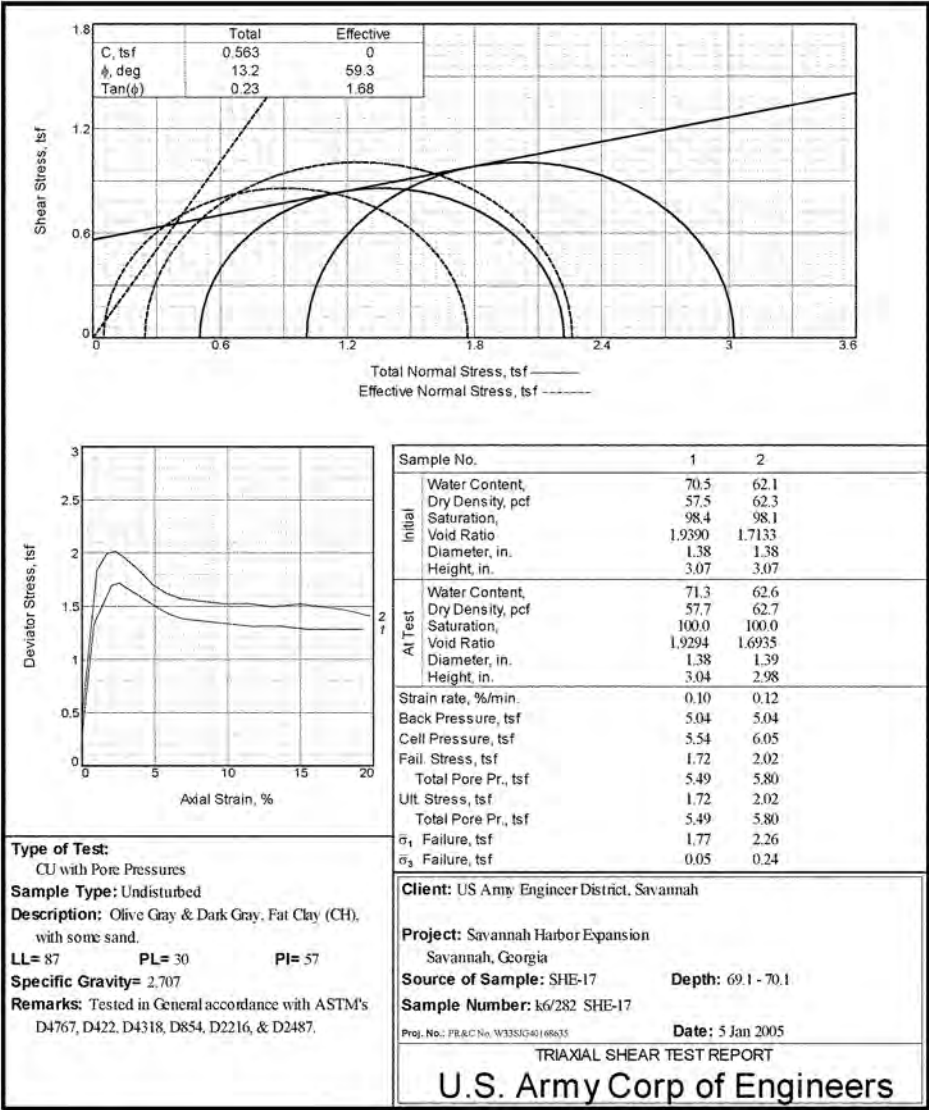
Remarks:

(1) Other tests were conducted in General Accordance with ASTM's D422, D4318, D2216, and D2487. (2) Specific Gravity value was determined from testing per ASTM D854. (3) Samples were received in a foam padded box. Samples were wrapped in suran wrap, aluminum foil, and a covering of duct tape to prevent moisture loss.

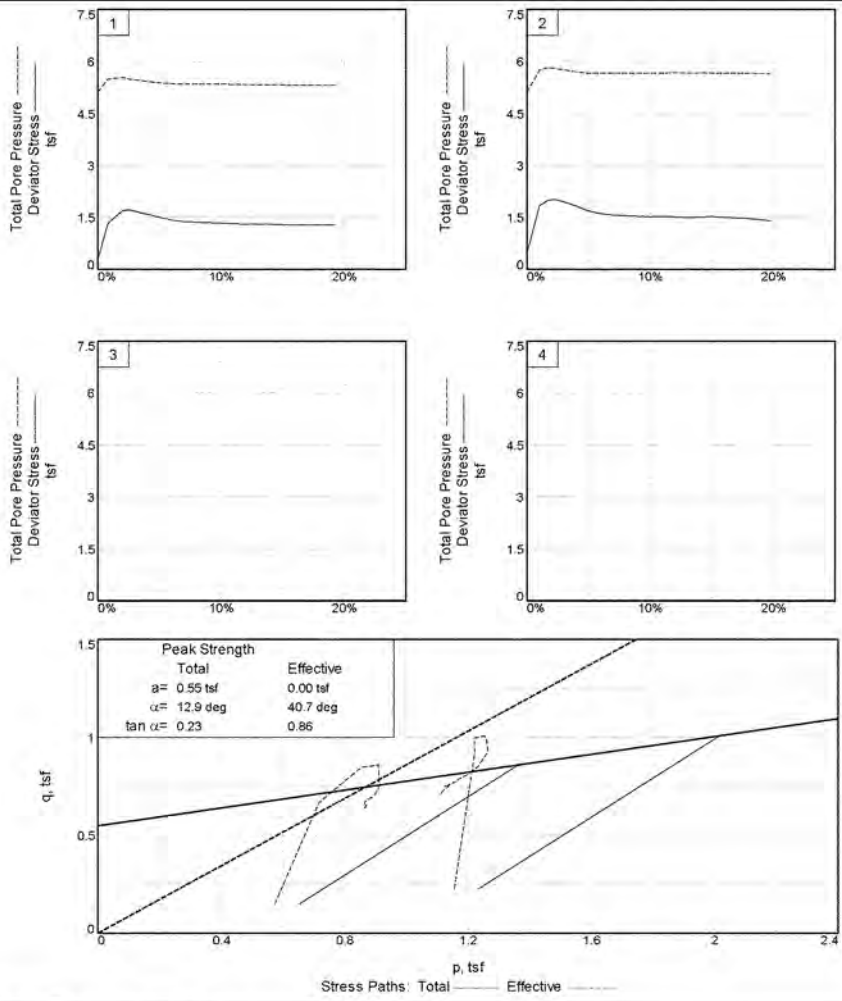
Project Information

Project	Savannah Harbor Expansion		
Location	Savannah, Georgia		
Requisition No.	W33SJG40168635	Work Order No.	330e
Hole No.	SHE-19	Sample No.	K-11
Depth (ft)	213.7 to 214.2	Lab No.	K6/298
Sample Received		Report Date	3-Feb-05

Permeability Test Report - ASTM D5084 Method C

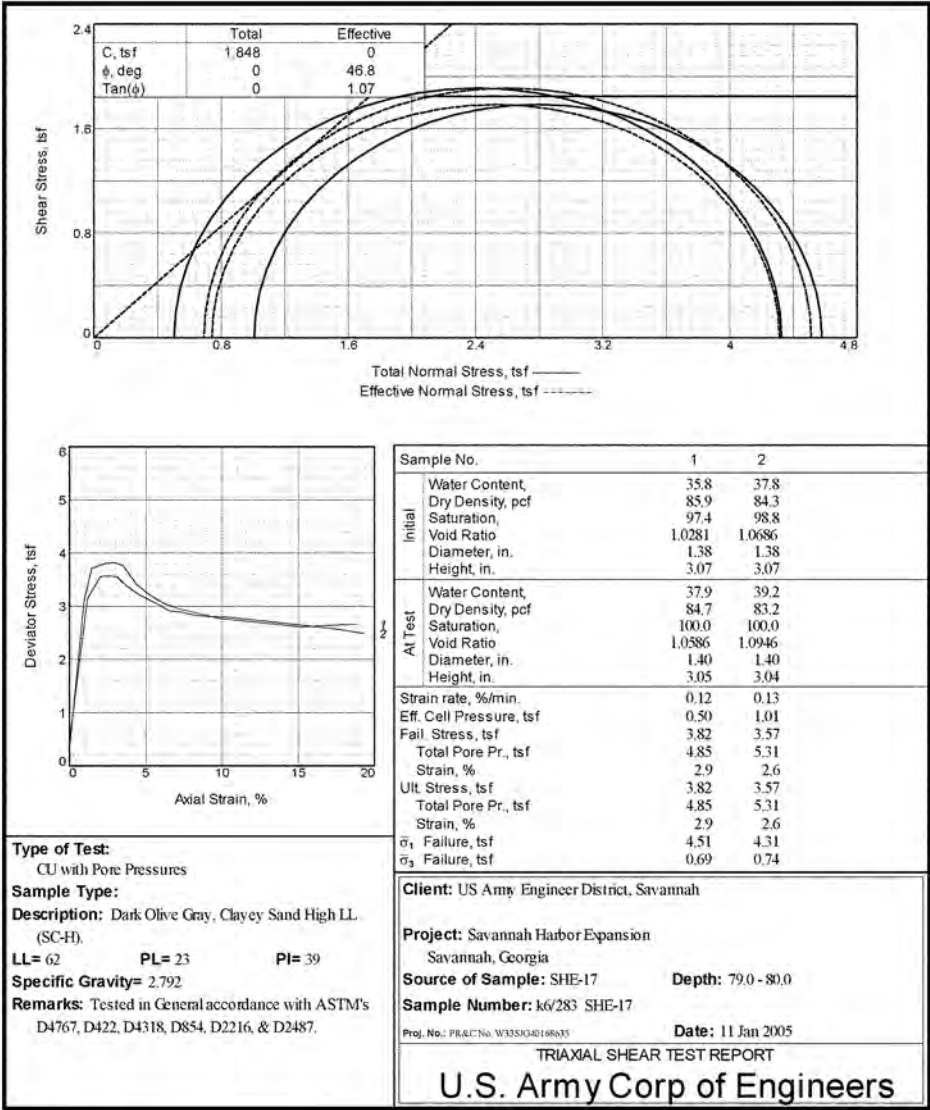


Tested By: MW Checked By: MW

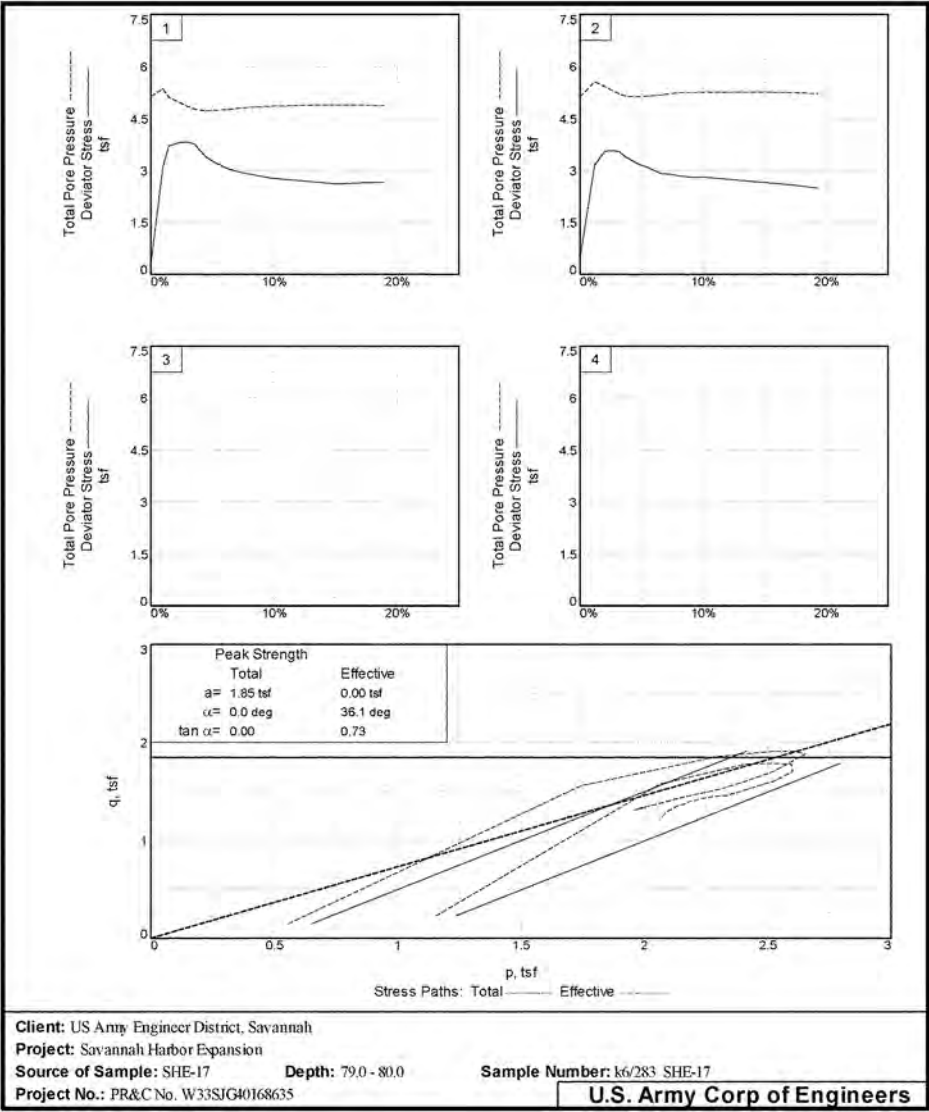


Client: US Army Engineer District, Savannah
Project: Savannah Harbor Expansion
Source of Sample: SHE-17 Depth: 69.1 - 70.1 Sample Number: k6/282 SHE-17
Project No.: PR&C No. W33SJ/G40168635 **U.S. Army Corp of Engineers**

Tested By: MW Checked By: MW



Tested By: MW Checked By: MW



Client: US Army Engineer District, Savannah

Project: Savannah Harbor Expansion

Source of Sample: SHE-17

Depth: 79.0 - 80.0

Sample Number: k6/283 SHE-17

Project No.: PR&C No. W33SJ/G40168635

U.S. Army Corp of Engineers

Tested By: MW

Checked By: MW

APPENDIX F

Independent Technical Review Documentation



U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

Peer Review Process for Aquifer Evaluation Portion of the Proposed Savannah Harbor Expansion Project

The Aquifer Evaluation, i.e. the Supplemental Studies report, was prepared as part of the Tier II Environmental Impact Statement for the proposed Savannah Harbor Expansion Project. It is a detailed technical report, the findings and recommendations of which will be used to support project decision documents requiring authorization by the U. S. Congress, and therefore is subject to peer review. The intent of this review process follows that of EC 1105-2-408 which provides guidance for peer review of Corps of Engineers water resource decision documents.

1. Independent Technical Review (ITR). The ITR portion of the review process consisted of two simultaneous reviews. One review was performed by the three cooperating agencies that reviewed and provided input to the initial scope of work. The agencies were not involved in the day-to-day technical work; however, representatives from each agency have attended several update meetings and given input throughout the data collection and reporting process. The following individuals served as technical experts for their respective agency and were given the opportunity to provide technical comments on the final work products:

USGS – GA District
USGS – SC District
GA DNR-EPD
SCDHEC

Mr. John Clarke
Dr. James Landmeyer
Dr. William McLemore (State Geologist)
Mr. Camille Ransom

The second simultaneous review was performed by the Corps of Engineers Hydrologic Engineering Center (HEC) in Davis, CA. HEC is the Corps designated Center of Expertise for a number of hydrological-related technical subjects, including ground-water hydrology. The representatives from HEC were not involved in the day-to-day technical work. The following individuals reviewed the work, in particular the 3-D numerical hydraulic model, and provided technical comments on the final work products:

HEC
HEC

Mr. Jon Fenske
Mr. Stan Gibson

2. External Peer Review (EPR). Upon completion of the ITR, an EPR of the Aquifer Evaluation will be performed by a panel of three to four independent experts who have been recommended by either the cooperating agencies listed above or the Aquifer Committee of the Stakeholders Evaluation Group. These technical experts will have no affiliation with the Corps of Engineers or any previous involvement with the proposed Savannah Harbor Expansion Project.

A peer review leader from the Corps of Engineers Center of Expertise for deep draft navigation planning (DDCX) in Mobile, AL will organize and conduct the external review. The peer review leader will also be responsible for maintaining the review records and formulating the charge to reviewers including specific questions as well as a broad evaluation of the final work product.

Comments and recommendations that resulted from the ITR (included in this appendix) have been incorporated into the present draft version of the Aquifer Evaluation report. Comments and recommended actions that result from the EPR will also be included in this appendix and incorporated into the final Aquifer Evaluation report.

Independent Technical Review

Savannah Harbor Expansion Project

Aquifer Evaluation

Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer

Reviewer	Agency	Date Received
Mr. John Clarke	USGS Georgia Water Science Center	15-Jun-05
Mr. Stan Gibson	USACE Hydrologic Engineering Center	18-Jul-05
Mr. Jon Fenske	USACE Hydrologic Engineering Center	18-Jul-05
Dr. James Landmeyer	USGS South Carolina Water Science Center	23-Aug-05
Dr. William McLemore	Georgia Environmental Protection Division	No response received.
Mr. Camille Ransom	South Carolina Department of Health and Environmental Control	No response received.

Response Author	Agency	Date Completed
Ms. Mackie McIntosh	USACE Savannah District	27-Sep-05
Mr. Mark Maimone	CDM	27-Sep-05
Mr. Paul Hossain	CDM	27-Sep-05

USACE Comment #	Reviewer	Report Section	Page, Figure	Comment	Response Author	Response/Action
1	John Clarke	Study Area	3-1	Provide references for cited thickness of sedimentary deposits in Chatham County (4,000 ft).	Hackie McIntosh	Miller (1986) shows 2000 feet underlying Chatham County. Edited text following to read: "In general, Tertiary strata in Chatham County dip 10 to 15 feet per mile to the west-southwest. However, the dips are locally controlled by structural 'high' and 'low' trends. Structures include Bear Creek, a strike-slip fault, and the Savannah River Channel (Spillie, 1950). The strike-slip fault is oriented roughly with a north-south-southeast trend and has a right-lateral offset of the Savannah River (Furber, 1982) and the Bear Creek trough, a structural low with a north-south-trending axis extending north-southward through northern Chatham County. Geology into Jasper County, South Carolina (Hoson and Johnson, 1963)." Added modified structural map from Clarke et al. (1990). Changed last sentence in paragraph to read "formerly known as..."
2	John Clarke	Study Area	3-2	Provide reference for Ridgeback Trough. Suggest that all structural features mentioned by shown on a map because you use these as points of reference in your text discussion. The Floridan aquifer system was formerly known as the principal artesian aquifer.	Hackie McIntosh	
3	John Clarke	Study Area	3-2	Exposure history of Miocene—be sure to mention this was delineated using GIS.	Hackie McIntosh	Inserted clause in sentence "The GIS analysis presented in Figures 3-2a and b..."
4	John Clarke	Study Area	3-4	Suggest cite Krause and Randolph (1989) for predevelopment head estimates. Discuss this relative to Chatham County, where head was between +30 and +50 ft above sea level.	Hackie McIntosh	Added "and from 10 to 50 feet above sea level in Chatham County (Krause and Randolph, 1989)" in discussion and changed inset citation according to Figure 6 of Krause and Randolph (1989).
5	John Clarke	Study Area	3-4	For 1998 map, also discuss in terms relative to Chatham County (range is -10 to deeper than -100 ft).	Hackie McIntosh	Edited sentence to read: "In contrast, in flow of 1988 Beck et al. reported the maximum head as 60 feet above sea level occurring south of Brunswick with maximum drawdown occurring near the city of Savannah, where heads ranged from -10 feet to -100 feet below sea level (Figure 3-3)." Added to references.
6	John Clarke	Study Area	3-5	Clarke and others (1992) not listed in references.	Hackie McIntosh	Added to references.
7	John Clarke	Study Area	3-6	Definition of Upper Floridan vs. Lower Floridan aquifer is somewhat controversial—Krause and Randolph (1989) assign zones 1&2 to Upper Floridan; Miller (1986) and Falk (2003) assign zones 1-4 to Upper Floridan. Suggest state that Floridan aquifer system has been subdivided into 5 zones, the upper two of which are most productive and assigned to the Upper Floridan.	Hackie McIntosh	Unlimited definition of 3 zones and mentioned only the ones relevant to the current study. Edited sentence to read: "In the study area, the Upper Floridan aquifer is 150 to 250 feet thick, and the uppermost two zones, zone 1 and zone 2, are the most productive (McCollum and Counts, 1994; Krause and Randolph, 1989)."
8	John Clarke	Study Area	3-6	upper and lower Brunswick are lower case (not Upper/Lower).	Hackie McIntosh	Nonconformity is documented both ways in Weems and Edwards (2001). Lower case in Clarke and Krause (2000), and upper case in Clarke et al. (2001). Edited text using lower case nonconformity.
9	John Clarke	Study Area	3-7	Zones 1&2 combine to provide 70% of flow based on McCollum and Counts flowmeter tests (not 30% as stated on top of page).	Hackie McIntosh	30% refers to total (surface and ground) freshwater usage as seen in Fanning, 2002. Perhaps more relevant to discuss as a percentage of ground-water flow, in which case, the correct figure would be 70% (taken from McCollum and Counts, but adapted from Krause and Randolph's verbiage). Edited sentence to read: "combine to supply more than seventy percent of the water pumped from open holes tapping the entire aquifer (Krause and Randolph, 1989)."
10	John Clarke	Study Area	3-7	try and limit discussion of transmissivity to Chatham County area. Also, not sure if you were aware of recent report on this subject: http://water.usgs.gov/pubs/sir/2004/5264/ .	Hackie McIntosh	Eliminated last sentence of paragraph and reworked remaining sentences to cover only area between Fort Royal Sound and Savannah.
11	John Clarke	Study Area	3-5	Problems with shading patterns—the blue shade is not identified. Suggest limit shading to areas where head is below sea level. Don't state states, simply label states along Savannah River border.	Hackie McIntosh	Added color ramp to distinguish the contours less than 0 ft MSL. Kept the shading in the states and ocean to keep consistent with all other figures in report that have an overlay map. Too crowded in Savannah River area to add any labels.
12	John Clarke	Methods	4-1	Suggest mention (describe how the scope of work was developed by the aquifer committee and working group.	Hackie McIntosh	Added: "The Savannah District used input from various agencies including the USGS, GAOEP, SCDEMC, SEC, and Georgia Ports Authority to develop a scope of work for the supplemental studies."

USACE Comment #	Reviewer	Report Section	Page Figure	Comment	Response Author	Response/Action
13	John Clarke	Methods	4-14	The only models that evaluated saltwater encroachment were the Smith and Bush models that used SUTRA 2D. Other models simulated flow only.	Hackie McIntosh	<i>Edited text to read: "The early models, the BASA model, and its offspring models simulated ground water flow influenced by pumping in Savannah and indicated fairly high vertical downward flows (leakage) through the upper confining unit to the Upper Floridan aquifer, but none of these models addressed vertical salt-water intrusion. Of these models, only Smith (1988) and Bush (1988) used SUTRA 2D to specifically simulate solute transport of chlorides; however, the simulations addressed only lateral seawater encroachment in two dimensions. The BASA model and its successors simulated regional ground water flow in three dimensions but did not address seawater encroachment or salt-water intrusion."</i>
14	John Clarke	Methods	4-19	Range of chloride concentration in the river are low relative to chloride profile levels. The maximum level of 10,000 mg/L is lower than the maximum observed in the prewarwater profiles at SHE-13 (19,760), SHE-14 (14,405), SHE-17 (15,601), SHE-16 (12,381).	Mark Malmone	<i>We are aware of this. The chloride concentrations were, of necessity, taken from the surface water model for existing conditions, and not interpolated from the profiles. This was done because the primary goal of the simulations was to compare pre- and post-dredging conditions. Chloride concentrations for post-dredging conditions required the use of the model, of course, so a comparison was only possible by modeling both conditions. The impact of consequence is the difference between pre- and post-dredging.</i>
15	John Clarke	Methods	4-19	Table 4-2: I'm not familiar with a "rising water boundary"? Is this a specified head boundary that varies over time?	Mark Malmone	<i>This is a boundary that allows the head to rise to the land surface elevation, after which it acts as a fixed head, discharging water to the surface. Added definitions of all boundary conditions to text in Appendix B.</i>
16	John Clarke	Methods	4-20	Table 4-3: Table states that Lower Floridan is absent in the area of concern (not according to my knowledge of area).	Hackie McIntosh	<i>Corrected table.</i>
17	John Clarke	Methods	4-20	Well specific data are available for many permits, but are certainly not limited to >1 MGD level. GSEP requires permits for withdrawals above 100,000 gpd. Many of the smaller permits are well specific. In fact, problems with separating by well often arise from larger permittees who do not subdivide by well.	Hackie McIntosh	<i>Edited text to read: "The well specific pumping data are based on either individual well or facility permits. Typically, well specific data are available for 100,000 gallons per day, permits or larger, and in most cases, the total permit capacity is known but the individual well production is not known."</i>
18	John Clarke	Methods	4-20	Pumping data are for the entire model domain, which includes many more counties in Georgia than the 24 coastal counties.	Mark Malmone	<i>The model contained pumping from the entire model domain. Text corrected.</i>
19	John Clarke	Methods	4-22	surface head change: on what basis were water table heads varied over time? There are no long-term declines/changes documented in this layer, yet it is stated that the period 1900-1960 was head constant, followed by changes every 10 years based on linear interpolation between 1900 and 2000 values. (relates to comment #15).	Mark Malmone and Paul Hisslin	<i>The surficial aquifer head data from the USGS model calibrated to 2000 conditions indicated somewhat lowered heads in the Savannah area. CDF had originally utilized the 2000 surficial head conditions for the historical simulation, however, based on a comments from the Aquifer Committee, CDF developed a very simple a pre-development surficial aquifer head condition that eliminated some of the lowered heads within Savannah. This was primarily for presentation reasons. The water table elevation changes between the more recent values and the pre-1900 elevations were minimal. The small changes had no impact on the simulations results in the underlying aquifers.</i>
20	John Clarke	Methods	4-24	Model calibration: Perhaps the model calibration of head could have been achieved by locking in the lower Kv values and adjusting boundary conditions and/or aquifer transmissivity to raise heads in the Floridan. Your approach; however, would result in a more conservative estimate of rates of saltwater movement (more rapid), which may be appropriate for regulatory evaluations.	Mark Malmone	<i>Our intent was to consistently try to be conservative with our parameter estimates to address the question of non-intrusiveness of the model. Thus, we believe we have bounded the problem without attempting to fully calibrate the model. The relevant simulations, focusing on the change from pre- to post-dredging are likely to be conservative in that they exaggerate the impacts.</i>
21	John Clarke	Methods	4-24	Table 4-4: should include observed head at Hutchinson Island and also list for what time period.	Hackie McIntosh	<i>Added head data to table.</i>

USACE Comment #	Reviewer	Report Section	Page	Figure	Comment	Response Author	Response/Action
22	John Clarke	Methods	4-24		Need to describe why analysis was limited to upper 50-60 ft of Upper Floridan. I assume this was to include the most permeable portion of the aquifer?	Mark Haimone and Mackie McIntosh	Added to text: "Upon breakthrough, the salt water leaked downward through the Mixzone confining layer will be diluted into the fresh water Upper Floridan aquifer. However, assuming mixing of the salt water throughout the full thickness of the Upper Floridan aquifer would result in very low concentrations and would not be a conservative assumption. Therefore, an aquifer thickness of 50 to 60 feet was used to calculate the final concentration of chlorides in the Upper Floridan aquifer. The chosen aquifer thickness limited the chloride mixing to the upper, more conductive portion of the aquifer, resulting in higher and thus more conservative estimates of chloride concentration."
23	John Clarke	Methods	4-25		There is no discussion regarding the sensitivity of the model to porosity of the confining unit. Was this ever tested? The effective porosity of 0.1 listed in table 4-5 is low given the values reported from the borehole sample analysis (around 0.6). (Again, you utilized a conservative value that would result in more rapid transport times).	Mark Haimone	Added to text under Conservative Assumptions: "The model was sensitive to the porosity of the confining unit, with lower values increasing the rate of movement of salt downward. This was tested, but with little field data to adequately defend a "calibrated" value, a low and value was selected to be conservative. " This was consistent with the overall approach to modeling taken for the study.
24	John Clarke	Methods	4-24		Pages 4-24 through 4-26, input parameters: Suggest refer reader to appropriate sections for more complete discussion of values and how they were derived.	Mark Haimone and Mackie McIntosh	Most of the parameters listed mention the source of the data. Only the K _f value for the Mixzone Confining Unit could be explained further. The bounding values selected came from the calibration process, followed by an order of magnitude change in either direction. All values fell within the range of core samples as described in section 5.6.4.2. The text refers the reader to Appendix B both on p. 4-23 and 4-24 for a more complete discussion of input parameters and results of the K _f sensitivity analysis. The main body of the report sufficiently summarizes the input parameters; CDW's report contains more detail for those readers who need additional background information.
25	John Clarke	Methods	4-25		Table 4-5: Various transport modeling input parameters are listed, yet no discussion of the justification for assigning these values is offered. Are these "textbook" values, or was field data used for some of the values?	Mark Haimone and Mackie McIntosh	The transport parameters are not based on field data, but are values that have generally provided reasonable dispersion results in most modeling studies. Dispersion of the chloride front was a fairly minor aspect of the overall transport in comparison to the advective transport downward, and varying these parameters would not result in any significant changes in the results. Added to text: "The applied values have generally provided reasonable dispersion results in other modeling studies and are not based on field data. Advective transport dominated chloride transport in the 5HE model; therefore, variation of the dispersion transport parameters did not significantly affect results."
26	John Clarke	Methods	4-29		No discussion of laboratory determination of porosity, yet these values are later discussed.	Mackie McIntosh	Added sentence to 4.6.4.1: "Porosity (α) was calculated using standard dry unit weight and specific gravity determination techniques and the relationship $\alpha = e/(1+e)$, where e is the void ratio of the sample."
27	John Clarke	Methods	4-10		It is very difficult to distinguish hydrogeologic units by color since the chloride distribution is also in color. Suggest eliminate color for units and simply use labeled lines. What does the line at the top of the green pattern represent? Is this the river bottom?	Mackie McIntosh	Figure edited for clarity as suggested by reviewer.
28	John Clarke	Results	5-4		...and show an overall decrease in concentration as elevation decreases" is somewhat confusing—suggest say, "...and show an overall decrease in concentration with increased depth."	Mackie McIntosh	Edited sentence to read as suggested.

USACE Comment #	Reviewer	Report Section	Page Figure	Comment	Response/Author	Response/Action
29	John Clarke	Results	5-4	Suggests that all land borings were made outside of paleochannels; however, what about the Bull River site? This site, completed in a paleochannel, seems to have been omitted from this report. Also—the supply well completed on Hutchinson Island that was used for wellbore transducer experiments—is not described in this report. Both of these sites provide important information and should be included in the evaluation.	Mackie McIntosh	<i>The Bull River site was not included in this evaluation because it was not located in the immediate vicinity of the navigation channel. It is discussed briefly in the methods section to credit C. Ransom and J. Landreger as first using the method to measure chloride intrusion in the confining unit. As for the supply well on Hutchinson Is., that was used for wellbore transducer experiments "... it appears to be SHE-9, which is located in the disposal areas (Jasper County). The wellbore transducer data from this well is included in the methods (9.6-3) and results (5.6-3) of this study. No supply well with wellbore transducers was installed on Hutchinson Island to my knowledge.</i>
30	John Clarke	Results	5-7	Discussion of sample anomalies in 10-PW-1 and 10-PW-2 are offered, yet these sites are never described in terms of location, nor are the profiles ever shown.	Mackie McIntosh	<i>Second paragraph on p. 5-7 states origin of samples at SHE-10. "... All porewater samples within the Miocene confining unit were taken at the time of drilling with the exception of 10-PW-1 and 10-PW-2. These samples were taken in 2005 in an effort to fill in data gaps and complete the profile to the top of the limestone." Anomally discussed again on p. 5-8. Also, values are listed in table at location SHE-10 and values are included in cross section (figure 5-1). Added references to Table 5-1 and Figure 5-1 in discussion of sample origin on p. 5-7.</i>
31	John Clarke	Results	5-9	The terms "punctuated increases" and "punctuated spike" are used in the section. Why not simply say, "increased."	Mackie McIntosh	<i>Adjusted suggested verbiage.</i>
32	John Clarke	Results	5-10	Not clear what you mean by "sequentially decreased." Why not just say, "decreased."	Mackie McIntosh	<i>"Sequentially" refers to sample by sample. The overall trend line shows a decrease in concentration; however, some samples indicated that higher chloride concentrations than the preceding sample taken at a shallower depth. Added a sentence for clarification.</i>
33	John Clarke	Results	5-1	Confusing mix of color patterns showing lithology and unit. Suggest show color pattern for lithology and lines for unit tops/bottoms. The green for Miocene unit should be converted to a lithology—I assume this unit includes the calcareous siltstone/sandstone, phosphatic sand, and the sandy clay. Oligocene yellow and Pleistocene recent grey also need to be converted to lithologies.	Mackie McIntosh	<i>Revised all cross sections (figs. 3-3, 5-1, 5-11, 5-12) according to reviewer's suggestions.</i>
34	John Clarke	Results	5-5	Lines showing top of Miocene and top of Upper Floridan should be reversed.	Mackie McIntosh	<i>Corrected figure.</i>
35	John Clarke	Results	5-20	"Simulations using the lower value of hydraulic conductivity showed no increase in concentration at most of the wells." This statement seems unnecessary—why would you expect an increase in concentration with decreased Kv? Statement seems to imply that some wells did show an increase?	Mackie McIntosh	<i>The statement was made with respect to line, not the higher Kv value. Eventually, breakthrough will occur at all the wells regardless of Kv. The smaller value increases the amount of time it takes for breakthrough to occur. Clarified sentence to read: "Simulations using the lower value of hydraulic conductivity showed that downward migration of chloride from the river would not contribute to any increase in total chloride concentration at most of the wells by the year 2200."</i>
36	John Clarke	Results	5-9	Plots shown out of chronological order	Mackie McIntosh	<i>Switched graphs (W:\projects\SHE_QA\FIGURES\WELL_PLOTS\SHE_5-9a.mxd).</i>
37	John Clarke	Results	5-22	I assume the simulated pumping test was run with the "mid-range" Kv? Need to explicitly state which Kv value was used.	Mark Maimone and Mackie McIntosh	<i>The simulated pumping test was performed using the mid-range Kv value, representing the simulation that most closely represented a calibrated value based on the USGS water table calibration hydraulic properties. The value is explicitly stated in Methods Section 4.5. Added sentence to Results section: "2) Simulation results are shown for applying the mid-range value of vertical hydraulic conductivity to the Miocene confining layer (1.5x10⁻⁴ to/day)."</i>

USACE Comment #	Reviewer	Report Section	Page Figure	Comment	Response Author	Response/Action
38	John Clarke	Results	5-22 5-10	Figure 5-10: All of your discussion in the 2 nd paragraph of section 5.5.1 relates to the 2000 ppm pumping rate yet you show a plot for 2000 gpm. This is confusing—should replace graph with 2000 example.	Mackie McIntosh	Revised figure with 2000 gpm at observation point 100 feet away from pumping well.
39	John Clarke	Results	5-24	Suggest mention problems related to interference from lakes, nearby and regional pumpage as other factors making pumping test less feasible.	Mackie McIntosh	<i>Added sentence:</i> "In addition, numerous sources of interference including tidal variations, other local pumping wells, and regional pumping would mask the observation data, and further complicate interpreting any results. The small drawdowns at high pumping rates as seen in the simulation results, combined with the amount of background interference in the area of concern, indicated that this task was not practical."
40	John Clarke	Results	5-25	Rather than use term "reduced potential" suggest use "head." Not clear what you mean by reduced potential.	Mackie McIntosh	<i>Revised sentence to read:</i> "Water levels recorded in well clusters on the north end of Tybee Island and at Fort Pulaski indicated that pumping the Upper Floridan aquifer has not only reduced heads in the aquifer, but also that the head differences have propagated through the overlying confining layer."
41	John Clarke	Results	5-26	Porosity is mentioned in section 5.6.4, but is not mentioned in the earlier methods section.	Mackie McIntosh	See USACE comment #35 above.
42	John Clarke	Results	5-8	What is the "noise" shown on the chloride trend plots? If average annual pumpage is used and kept constant into the future, then patterns of head change (and solute transport) should be constant.	Mark Mainwaring	The noise or small, random fluctuations in chloride concentration are primarily the result of two factors. One is the models use of the random walk method of imparting random displacement of particles to simulate local dispersion. Each particle represents a discrete amount of "chloride." Because of the area of the model covered and the relatively wide range of concentrations that had to be simulated, the addition or subtraction of only a few particles result in relatively large changes in concentration at the lower end of the concentration range. Thus, the seemingly random small fluctuations in concentration in an otherwise steady flow system.
43	John Clarke	Summary	6-3	There is no mention of the simulated chloride concentrations in production wells.	Mackie McIntosh	<i>The conclusions presented represented the bigger picture -- increased concentration in production wells goes hand in hand with the increased concentrations in the aquifer, which are discussed at length. The simulation results discussed as overall trends as opposed to one point along the river and is more appropriate for drawing conclusions about the entire study.</i>
44	John Clarke	Summary	6-3	Section 6.4: Suggest mention interference problems (see comment 39).	Mackie McIntosh	<i>Added:</i> "In addition, the interference expected from tidal variations, local pumping wells, and regional pumping trends would further obscure any meaningful results. The long duration and sustained pumping rate required combined with the expected minimal and transient response make the task of performing an aquifer test impractical."
45	John Clarke	Conclusions	7-1	"Ground-water model results indicated that any addition contribution of chloride by paleochannels is negligible when compared to the total contribution along the river." I did not see discussion of this in earlier modeling section (5-9) and am unclear of what it meant by "is negligible when compared to the total contribution along the river."	Mackie McIntosh and Mark Mainwaring	<i>Edited sentence to read:</i> "Ground-water model results indicated that any additional contribution of chloride by the dredging of the paleochannels is negligible when compared to the total contribution from dredging of the river outside paleochannels along the river bottom. The impacts of dredging in the in-fill sediments of the paleo-channels, which were simulated in the model to represent sand, are small when compared to the impacts of dredging in the channel where Maceys confining unit is located."
46	John Clarke	Conclusions	7-3	3 rd paragraph: "Low contribution of saline water from the river." The low contribution might be due to a variety of factors (including K _r gradient, porosity), but I think what you intended to say was "lower salinity of river water."	Mackie McIntosh	<i>Adopted suggested verbiage:</i>

USACE Comment #	Reviewer	Report Section	Page Figure	Comment	Response Author	Response/Action
47	John Clarke	Appendix B	2-4	I am unclear about "rising water boundary" (see comment 15 above).	Mark Malmone	See USACE comment #13 above.
48	John Clarke	Appendix B	2-4	maximum chloride concentrations in river are 10,000 mg/L, yet porewater profiles show maximum concentrations are nearly 20,000 mg/L (see comment 14 above).	Mark Malmone	See USACE comment #14 above.
49	John Clarke	Appendix B	2-5	Section 2.4.6: implies that water table heads are fixed, yet a "rising head boundary" is mentioned elsewhere (page 2-8) and page 4-22 of main report indicates that head was changed over time. (see comments 15 and 19 above).	Mark Malmone and Paul Hossain	The surficial nodes were all assigned a fixed head. Only in the upstream portion of the Savannah river within the study area were some of the river nodes assigned a rising node boundary to allow the surficial aquifer to discharge to the river.
50	John Clarke	Appendix B	2-29 through 2-40	The lines representing top of Miocene and Upper Floridan should be reversed.	Mark Malmone and Paul Hossain	Corrected figures.
51	John Clarke	Appendix B	3-2	suggest add observed values at Hutchinson Island and add date of simulation/observation.	Mackie McIntosh	Added values to table.
52	John Clarke	Appendix B	3-5 through 3-16	The lines representing top of Miocene and Upper Floridan should be reversed.	Mark Malmone and Paul Hossain	Corrected figures.
53	John Clarke	Appendix B	3-17 through 3-48	need to explain "noise" on trend plots (see comment 42 above).	Mark Malmone	See USACE comment #42 above.
54	Stan Gibson	Appendix C		The GIS was well conceived and remarkably well documented. It has been constructed as a valuable interactive tool to organize the copious data and help maximize its usefulness. The latest technology was utilized to develop a powerful conceptual tool. It appears very well done. Please include more documentation on the groundwater code used. Proprietary, in-house code will always be viewed with more skepticism than public domain code (or at least widely used products). 25 years of development and experience is not nearly as impressive as a few solid peer reviewed references. If these references do not exist, then include significant references for the specific methodologies employed (e.g. the use of random walk algorithms for salinity dispersion). Additionally, include a citation of the IGWA report in which the model was reviewed so a reader could track down their thoughts.	Mackie McIntosh	No response needed.
55	Stan Gibson	Appendix B		The model outcome is the result of a long string of strongly conservative assumptions. While the conservatism often seemed excessive, it achieved its objective of demonstrating that dredging would not adversely affect ground water chloride levels.	Mark Malmone and Mackie McIntosh	Added citations in Section 4.1.3.1 and appropriate references
56	Stan Gibson	Appendix B			Mark Malmone	No response really required to this observation.

USACE Comment #	Reviewer	Report Section	Page	Figure	Comment	Response Author	Response/Action
57	Jon Fenske	Appendix B			It is clear that many conservative assumptions were used in developing the model and interpreting model results. However, to fully assess the model, a complete justification for all input values must be provided. The overriding concern from reviewing this study is the uniqueness of the calibrated solution. For example, it may be possible to match steady-state and transient aquifer heads by increasing the vertical hydraulic conductivity (Kv) in the Miocene confining unit, and decreasing the horizontal hydraulic conductivity (Kh) in the Upper Floridan aquifer. The calibration of the solute model to measured chloride levels in the confining unit are not as reliable since only one measuring date was available; furthermore, a similar replication of the chloride front may be possible by raising both vertical hydraulic conductivity and porosity values. Documentation should be provided which addresses these concerns. Specific comments are listed below. The value of simulated porosity assigned to the Miocene confining layer governs the velocity of vertical flow (i.e. how fast the chloride front moves. In the report (p. 5-27), a laboratory value of 0.5 % measured. In the model (App B, p.3-3, Table 3-2), a value of 0.1 for effective porosity is used. Although this value appears reasonable, more explanation is needed. A sensitivity analysis should be performed where the value of porosity is varied by factors of 0.5 and 2, and the resulting effect on the chloride plume discussed.	Mark Maimone	In fact, the model could not be calibrated by increasing the Kv of the confining unit and decreasing the Kh of the Upper Floridan aquifer without creating a serious mismatch of data vs. simulation in the cone of depression. Kh values from pump tests in the Upper Floridan unit, limiting our options in that regard as well. Our intent was to consistently try to be conservative with our parameter estimates to avoid the question of non-uniqueness of the model. Thus, we believe we have bounded the problem without attempting to fully calibrate the model. The relevant simulations, focusing on the change from pre- to post-dredging are likely to be conservative in that they exaggerate the impacts.
58	Jon Fenske	Appendix B			The model was sensitive to the porosity of the confining unit, with lower values increasing the rate of movement of salt downward. This was tested, but with little field data to adequately defend a "calibrated" value, a low end value was selected to be conservative. This was consistent with the overall approach to modeling taken for the study.	Mark Maimone	The modeling approach selected was designed to avoid as much as possible issues of the adequacy of calibration and the potential for non-uniqueness affecting the results. This was done for two reasons. One, because it is difficult to obtain adequate, representative field data for several important parameters such as Kv and porosity of the Miocene confining unit. Second, to present a very conservative set of results to focus attention on the relatively limited impacts of dredging even with overly conservative assumptions, thereby avoiding a discussion on the accuracy of the model. For this reason, residual statistics for the various simulations are generally not provided.
59	Jon Fenske	Appendix B			In the model document (App B, p.3-2, Table 3-1), results of a sensitivity analysis on the Kv of the Miocene confining unit are documented. Statistics for using a high Kv value should be included. Additionally, mean absolute residual should be included.	Mark Maimone	This represents a conservative assumption, and is therefore in line with our overall modeling approach. Drawdown of the surficial aquifer would decrease the gradient, and thus slow the rate of salt water penetration. Maintaining fixed water table elevations maintains the gradient as it now exists into the future. Also, it should be noted that after 50 to 75 years of significant pumping in the Savannah area, no impacts to the water table elevation have been documented. Although this might still occur, significant drawdowns would not be expected considering the length of time already elapsed.
60	Jon Fenske	Appendix B			More justification is needed, for simulating the surficial aquifer as a constant head boundary. A constant head boundary represents an infinite source of water. With simulated groundwater pumping continuing for 200 yrs in the Upper Floridan, it may be possible for a drawdown from the wells to eventually affect the water table.	Mark Maimone	This represents a conservative assumption, and is therefore in line with our overall modeling approach. Drawdown of the surficial aquifer would decrease the gradient, and thus slow the rate of salt water penetration. Maintaining fixed water table elevations maintains the gradient as it now exists into the future. Also, it should be noted that after 50 to 75 years of significant pumping in the Savannah area, no impacts to the water table elevation have been documented. Although this might still occur, significant drawdowns would not be expected considering the length of time already elapsed.
61	Jon Fenske	Appendix B			The model was simulated under transient conditions for 200 yr predictive runs. There are no figures or tables that list the values of storage (specific yield and specific storage) required as input for transient runs.	Mark Maimone and Paul Hossain	Added text to end of section 4.3.5.1: "With little data available, conservative storativity and specific yield values were used. The values, applied to all layers and hydrologic units in the model, are 0.00001 for storativity, and 0.1 for the specific yield."

USACE Comment #	Reviewer	Report Section	Page Figure	Comment	Response Author	Response/Action
62	Jon Fenske	Appendix B		A more complete listing of calibration statistics would be helpful. Values to include are: mean residual, mean absolute residual, root mean square residual, standard deviation, maximum and minimum residual, head range, and residual standard deviation over head range. Additionally, a histogram of model residuals, and a 45-degree line plot of measured vs. simulated heads would be instructive.	Mark Maimone	<i>The modeling approach selected was designed to avoid as much as possible issues of the adequacy of calibration and the potential for non-uniqueness affecting the results. This was done for two reasons. One, because it is difficult to obtain adequate, representative field data for several important parameters such as RV and porosity of the floccine confining unit. Second, to present a very conservative set of results to focus attention on the relatively limited impacts of dredging even with overly conservative assumptions, thereby avoiding a discussion on the accuracy of the model. For this reason, an extensive discussion of calibration was purposely avoided.</i>
63	Jon Fenske	Appendix B		It would be very useful if the model calibration could focus on residual disconnector data alone and below the confining layer.	Mark Maimone	<i>See USACE comment #62 above.</i>
64	Jon Fenske	Appendix B		The term "verification" implies an unrealistic level of certainty in groundwater models.	Mark Maimone and Mackie McIntosh	<i>Agreed. Edited Headings to read "Calibration" instead of "Verification."</i>
65	Jon Fenske	Appendix B		The domain of the finite-element model was based on the USGS regional flow model and covered 42,250 square miles with 16,362 triangular elements. Please provide justification for the grid spacing at the river of 125 ft. What is the approximate width of the river?	Mark Maimone and Mackie McIntosh	<i>The spacing was designed to place at least two nodes within the river in addition to nodes at either bank. In this way, the arching of water between the river and the groundwater system could be adequately simulated. Added: "In order to represent the proposed dredging, discretization was finest in the area of the Savannah River to ensure the chloride source area (i.e. the river) was sufficiently defined. Node spacing was on the order of 125 feet within the river, which allowed any given transect across the width of the river to contain four nodes."</i>
66	Jon Fenske	Methods	4-21	Page 4-21 of the report states: "Typically, a calibration is considered adequate when there is no systematic head bias across the model, and the standard deviation of residuals should be within 10-15% of the total measured head gradient across the model domain". What is the reference for this? Replace the word "gradient" with "range".	Mark Maimone and Mackie McIntosh	<i>Agreed. The guideline was contained in the discussion during the development of ASTM, Standard Guide for Calibrating a Ground-Water Flow Model Application. ASTM Standard D 5918-96, CDM has generally used this as a guidance for model acceptability. Edited text to read: "According to ASTM Standard D 5918-96 Standard Guide for Calibrating a Ground-Water Flow Model Application, a calibration is considered adequate when there is no systematic head bias across the model and the standard deviation of residuals is within 10 to 15% of the total measured head range across the model domain."</i>
67	Jon Fenske	General		Model results clearly indicated that the proposed dredging does not represent a significant hazard to the Upper Florida aquifer. The model included many conservative assumptions, and the model simulations provided a bracketed range of results to evaluate the probable range of impacts following dredging activities. However, future reviewers may question the reliability of porosity and K values. Additional information should be provided that provides full justification for all parameters and interpretation of model results.	Mark Maimone	<i>At this point, we believe that the approach of using conservative assumption is a more robust approach than trying to justify parameter selection.</i>
68	Jim Landmeyer	Executive Summary	II	Page II, last paragraph, the statement "...that increased salinity in the Savannah River..." What caused the increase of salinity in the River? If you are referring to this at one location, does the deepening of the channel cause the saltwater wedge at the bottom of the channel to move landward? This needs to be made more clear.	Mackie McIntosh	<i>Edited sentence to read: "The porewater profiles and model results from this study indicated that both the increased salinity along the bottom of the Savannah River and the reduced thickness of the confining layer due to dredging will not significantly affect the timing of breakthrough of chlorides along the navigation channel in the Upper Florida aquifer."</i>
69	Jim Landmeyer	General	Most Figures	The most study map has coastal SC looking rather odd; no Hilton Head Island, and Charleston, SC looks like a secured backwater. Pay heed a higher resolution map, since it is used repeatedly.	Mackie McIntosh	<i>Edited overview maps on all applicable figures.</i>
70	Jim Landmeyer	Overview	2-3	Last paragraph, where it says "...including eight core borings..." you might want to add (SHE-1 to SHE-8), since they are located on the Figure 2-2.	Mackie McIntosh	<i>Added SHE-1 to SHE-8 in parentheses.</i>

USACE Comment #	Reviewer	Report Section	Page Figure	Comment	Response Author	Response/Action
71	Jim Landmeyer	Study Area	3-3	the Peck et al. reference should have the date (1999).	Mackie McLittosh	Added 1999 in parentheses.
72	Jim Landmeyer	Study Area	3-4	there was one plume (Smith 1988), but there are now 3 separate saltwater plumes identified in this area (the Ransom et al. reference is OK).	Mackie McLittosh	Edited sentence to read: "The plumes associated with this lateral encroachment have been well documented as elevated chloride concentrations in Floridan wells at the north end of Hilton Head Island, South Carolina (Smith, 1988; Ransom et al., in press)."
73	Jim Landmeyer	Study Area	3-3	the Legend contains items not yet shown on this graph - just delete the ones not shown (i.e., chloride).	Mackie McLittosh	See USACE comment #33 above.
74	Jim Landmeyer	Methods	4-4	section 4.1.1., the last sentence is awkward; do you mean "...to ensure in-situ salt water..." (i.e. drop the non).	Mackie McLittosh	The "in-situ" salt water is what we are trying to capture. Non in-situ refers to all waters not associated with the porewater at any given depth, i.e. the overlying river or ocean water.
75	Jim Landmeyer	Methods	4-6	Page 4-6 and throughout, our office is now called the "USGS Water Science Center".	Mackie McLittosh	"USGS" is sufficient for this report.
76	Jim Landmeyer	Methods	4-24	below Table 4-4, there should be a statement regarding the limitations that result when any numerical model simulation is run far out into the future; basically, the farther one gets away from the calibrated data set, the more uncertain and non-unique the results can become. Adding this caveat will provide some degree of liability insurance.	Mark Halmone	Added text: "Simulations of future conditions become less certain the farther one gets away from the calibrated data set and selected input parameters. Future pumping rates and boundary conditions will change over time. The projection simulations done for this study assume a continuation of current conditions for the next 200 years, making results beyond the 20-year time horizon less and less certain."
77	Jim Landmeyer	Results	5-9	the left-to-right order of the simulations is out of order (2000-2200- 2050) and needs to be changed.	Mackie McLittosh	See USACE comment #36 above.

APPENDIX G

External Peer Review Documentation



US ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

External Peer Review Documentation

Proposed Savannah Harbor Expansion Project
Aquifer Evaluation
Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer

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Attachment 1: High-Value Kv Simulation Results

Attachment 2: Model Certification Documentation

1. Overview of External Peer Review Process

An external peer review (EPR) of the Aquifer Evaluation was performed by a panel of three independent experts upon completion of the independent technical review (ITR) process. The three appointed experts were recommended either by cooperating governmental agencies or the Aquifer Committee of the Stakeholders Evaluation Group as noted below and have no affiliation with the U.S. Army Corps of Engineers or any previous involvement with the proposed Savannah Harbor Expansion Project.

Nominating Agency	Reviewer	Reviewer Affiliation
SEG	Dr. Thomas Burbey	Virginia Polytechnic Institute and State University, Department of Hydrogeosciences
SCDHEC	Mr. Larry Hayes	Private Consultant (USGS South Carolina, Retired)
USGS	Ms. Eve Kuniansky	USGS Georgia Water Science Center

The reviewers were issued a copy of the Aquifer Evaluation report entitled *Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer*, dated 27 September 2005, which had been revised to incorporate comments from the ITR. The reviewers were also provided with a charge (see Section 4) to provide them with a basic study background and to facilitate their responses. The charge contained six questions, and the reviewers were given the option to use them as a guide or respond specifically to each question. One reviewer responded to the charge questions and provided additional comments, one reviewer responded only to the charge questions, and one reviewer provided comments to the report but did not respond to the charge questions. The original transcripts of comments are included as Section 5 of this Appendix.

A number of comments were broad in nature and/or focused on several overlapping themes, including the chosen conceptual approach for the modeling portion of the study. Responding to such comments in a matrix format was deemed impractical and insufficient; therefore, a general response was prepared in order to adequately address these concerns (Section 3.1). Responses to individual comments, including responses to comments that specifically answered the six charge questions, are summarized in a comment/response matrix (Section 3.2). The individual responses also include a summary of revisions that were incorporated into the Final Report.

Once responses were complete and revisions were incorporated into the Final Report, the appropriate functional chiefs, in this case Chiefs of Engineering in both Savannah and Wilmington Districts, were briefed as to the conclusions of the report and the nature of the comments provided. An EPR review package consisting of the documents that comprise this Appendix was then forwarded to the peer review leader at the National Deep Draft Planning Center of Expertise (DDNPCX) in Mobile District. The peer review leader, acting as a liaison, transmitted the package to the EPR reviewers along with a request for feedback regarding whether or not the responses adequately addressed their concerns. The peer review leader then added any feedback provided by the reviewers to the EPR review package and transmitted the package back to the authors. As of the publishing date of the Final Report, none of the peer reviewers had responded to the package of comment responses and revisions (see Memorandum for Record in Section 2 of this Appendix). Finally, the authors reviewed the EPR reviewer feedback and determined if any comment resolutions were disputed. The authors then briefed the functional chiefs with a summary of the feedback and made recommendations. For disputed comments/responses, the functional chiefs decided whether or not further action was required to resolve the comments and documented the decision in writing. The written response is included in Section 2 of this Appendix.

2. USACE Memorandums for Record

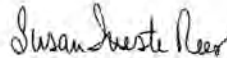
CESAM-PD

28 February 2007

MEMORANDUM FOR RECORD

SUBJECT: External Peer Review, *Supplemental Studies to determine Potential Ground-Water Impacts to the Upper Floridan Aquifer*

1. Subject document was provided to Mr. Larry R. Hayes (retired), Ms. Eve Kunianski (USGS), and Dr. Thomas J. Burbey (VPI) for review on 3 January 2006. The Charge to Reviewers is attached (attachment 1). Following their review the comments (attachment 2) were provided to the Savannah Harbor Improvements Team for response and revision of the report. The District responses are attached (attachment 3).
2. A copy of these responses was provided to the reviewers as a courtesy on 14 December 2006 with the request that if they wished to comment further based on the responses that we would be happy to consider these comments as well. No additional responses have been received.
3. Based on the fact that no additional comment has been made relative to the responses to original comments or revisions to the report, the External Peer Review is considered complete.



Susan Ivester Rees, Ph.D.
Program Manager, Mississippi
Coastal Improvements Program

COMPLETION OF EXTERNAL PEER REVIEW

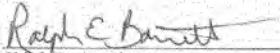
Proposed Savannah Harbor Expansion Project
Potential Aquifer Impact Study

Savannah District has completed the report *Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer* for the proposed Savannah Harbor Expansion Project. In accordance with USACE ER 1110-2-1150, ENGINEERING AND DESIGN FOR CIVIL WORKS PROJECTS, notice is hereby given that an independent external peer review, appropriate to the level of risk and complexity inherent in the project, has been conducted. Compliance with established policy principles and procedures, utilizing justified and valid assumptions, was verified during the external peer review process. This included: review of assumptions; methods, procedures, and material used in analyses; alternatives evaluated; the appropriateness of data used and level of data obtained; and reasonableness of the results, including whether the product meets the customer's needs consistent with existing Corps' policy. The external peer review was accomplished by a team of three independent experts in the field of ground-water hydrogeology.

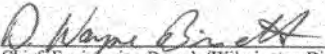
CERTIFICATION OF EXTERNAL PEER REVIEW:

External peer review of this study resulted in minor revisions and strengthened the report; however, the comments provided did not result in revision of any of the report's major conclusions or recommendations. Comments not related to the modeling portion of the study generally concerned clarification and formatting and were addressed as revisions to the body of the final report. Comments concerning the overall approach, those pertaining to the conceptual model, or those that were broad in scope were addressed in a general response or alongside the original comment in a comment/response matrix included in the report's external peer review documentation (Appendix G).

As noted above, all concerns resulting from external peer review of the project have been considered.


Chief, Engineering Division (Savannah District)

11 Sep 2007
(Date)


Chief, Engineering Branch (Wilmington District)

14 Sept. 2007
(Date)

3. Response to External Peer Review Comments

Proposed Savannah Harbor Expansion Project

Aquifer Evaluation

Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer

Reviewer	Agency	Date Received
Dr. Thomas Burbey	Virginia Polytechnic Institute and State University, Department of Hydrogeosciences	07-Feb-06
Ms. Eve Kuniarsky	USGS Georgia Water Science Center	07-Mar-06
Mr. Larry Hayes	Private Consultant (USGS South Carolina, Retired)	21-Mar-06

Response Author	Agency	Date Completed
Ms. Mackie McIntosh	USACE Savannah District	24-Oct-06
Dr. Mark Maimone	CDM	24-Oct-06

3.1 General Response to External Peer Review Comments

The Savannah District wishes to express thanks and gratitude to the external peer reviewers for their time and effort providing feedback regarding the draft report *Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer* (supplemental studies). The comments provided were instrumental in determining weaknesses, identifying areas of the report that needed clarification, and strengthening the document for final publication. The three appointed reviewers provided different backgrounds and experience in the field of hydrogeology, and their comments proved invaluable in gaining insight to how individuals from different perspectives may interpret the findings of the report. While the comments did not affect the conclusions or recommendations, the suggestions provided allowed the authors to refine the arguments presented and ultimately strengthen the Final Report.

Most of the comments were specific in nature and referred to individual pages or figures in the document. After compiling the comments from all three reviewers it became apparent, however, that a significant number of comments were broad in scope and focused on several recurring themes. Responding to these comments on an individual basis would not only be impractical but also insufficient; therefore, it was determined that a general response clarifying the original scope of work and study approach would be the most effective way of addressing the concerns presented by the three reviewers. This general response to comments addresses concerns related to these broad, overlapping comments. Specific responses to individual comments and requested revisions that were incorporated into the Final Report are included as Section 3.2 of this Appendix.

A number of the comments concerned the ground-water modeling approach (EPR comments 2, 3, 17, 33, 63, 68, 94, 124, C-1), and in particular, why the chosen model was not rigorously calibrated (EPR comments 2, 6, 25, 26, 84). The authors agree that the approach taken is somewhat unorthodox, and, in order to understand why this approach was chosen, it is

important that reviewers know the history of the aquifer studies and how the authors arrived at the chosen conceptual model. The authors initially did not feel it was appropriate to include such information in the main body of report, and the tone of comments provided during the independent technical review (ITR), which were provided by reviewers who generally were familiar with the aquifer studies since their inception in the mid 1990's, supported this notion. Instead, the model objectives were clearly stated in the charge to reviewers (p. 35 of this Appendix). Upon receipt of the external peer review (EPR) comments, however, it became apparent that the chosen modeling approach should have been more thoroughly explained for readers who are unfamiliar with the project.

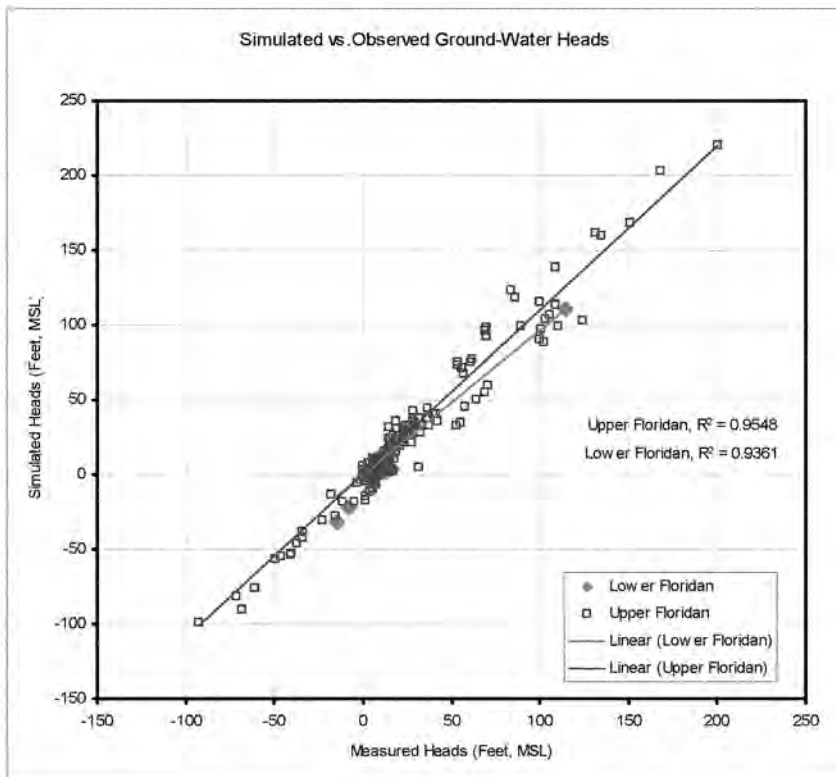
As noted in the Project Overview section of the report, the supplemental studies were commissioned following the release of the 1998 report *Potential Ground-Water Impacts*, which was completed as part of the Savannah Harbor Expansion Feasibility Study and the Tier I Environmental Impact Statement (EIS). The 1998 report concluded that the quantity of water moving vertically through the confining unit within the navigation channel was insignificant when compared to the quantity of water moving laterally through the Upper Floridan aquifer; therefore, the proposed dredging would have no noticeable effect on the quality of ground water within the Upper Floridan aquifer. The scope of the initial aquifer studies was small, however, and field data presented in the report was somewhat limited. Following the release of the report, it was determined that expanded field studies and data analysis were needed to ascertain the validity of the report conclusions. In order to outline a proposed plan of study, the SEG formed an Aquifer Committee and a Working Group sub-committee. The Working Group, which consisted of ten technical representatives from various public and private agencies, developed a plan of ten potential study tasks with specific objectives, including a scope of work (SOW) for the ground-water model portion of the study. A series of iterative discussions took place from 2001 to 2002 between members of the Working Group plus a number of technical experts and vested parties who were familiar with the area and the project, including representatives from the SEG, U.S.

Geological Survey (USGS), South Carolina Department of Health and Environmental Control (SCDHEC), Georgia Environmental Protection Department (GAEPD), and Georgia Ports Authority (GPA) and U.S. Army Corps of Engineers (USACE). The Working Group held several meetings and participated in an online forum to discuss potential study tasks and eventually narrowed the scope to the six major tasks that comprised the supplemental studies, including the 3-D coupled flow and transport ground-water model. The Working Group submitted their recommendations and proposed SOW to the Aquifer Committee, who then submitted a final proposed study plan to the SEG in June of 2002.

In October of 2002, a small group of agency representatives outlined a specific technical proposal for the supplemental studies ground-water model. Using the SEG final proposed study plan as guidance, the representatives agreed that the ground-water model was intended to act as a screening tool to verify the conclusions from the 1998 report. The recommendations from the meeting, as summarized from 2002 and 2003 correspondence with CDM, indicated that the results would be presented as a difference in downward flow of salt water through the channel for the pre- and post-dredging scenarios. The focus of the model structure "should not be on whether the correct set of values can be estimated through rigorous calibration, but rather what the results from the range of values are saying about the significance of the (dredging) impacts."¹⁰ The memo also stated that the input properties should be conservative, and "if results with conservative assumptions when translated into chloride concentration changes in the Upper Floridan were shown to be minimal, that should suffice." The model, as agreed upon, was not intended to "establish pre- and post-project rates of intrusion everywhere, only through the (navigation) channel." Instead, the model would focus on a range of values and the significance of any dredging impacts, not the absolute chloride concentrations in the Upper Floridan aquifer. Furthermore, the memo specifically states that the model should not be designed to answer the larger questions of salt-water intrusion in the Savannah area.

Using the model as a screening tool rather than performing a full-blown modeling study allowed the authors to shift emphasis to a bracketed range of reasonable responses to dredging impacts instead of one unique solution. The authors implicitly recognized the non-uniqueness of the model; this was intended from the outset. All realistic scenarios are included in the bracketed range of results, and the impact of the results was the same regardless of which end of the range is closer to the most likely outcome. The model results indicated that dredging would not significantly impact the rate of salt-water intrusion at either end of the range of results, thereby affirming the unimportance of finding a unique solution.

Provided this background, it is reasonable to question that, if the model was not intended to simulate regional salt-water intrusion, then why was a regional domain applied? At the time the supplemental studies objectives were being formulated, the Georgia Coastal Sound Science Initiative (SSI) was initiated. The SSI workplan, published in February 2000, tasked the USGS with developing a regional ground-water flow and solute transport model to characterize salt-water intrusion in the coastal Georgia region. The USGS implemented a multi-million dollar data collection and analysis program applied over several years and made the data available for use by outside parties, and the data in and around the Savannah area was detailed enough to allow for evaluating impacts solely along the navigation channel. At the time the supplemental studies model objectives were being refined, the USGS had already completed a working conceptual model and a fully-calibrated, documented flow model that encompassed the supplemental studies project area. It follows logically that the technical experts and vested parties, both as a cost savings and as an acknowledgement of the tremendous and thorough efforts of the USGS, would incorporate the existing data and flow model into the supplemental studies approach. Upon gaining technical approval of the modeling approach, CDM replicated the USGS flow model (layering, boundaries, properties, pumping, etc.) and refined the grid structure in the supplemental studies project area. Using their proprietary code, they were able to reproduce and match simulated versus observed heads very well as shown in the graph below.



It is important to reiterate that the refined grid structure incorporated USACE historical and recent geological, geophysical, and porewater data along the navigation channel to ensure sufficient resolution and model accuracy. During the development process, the CDM model was able to closely replicate the small scale data very well when superimposed on the larger scale regional flow model as shown in Table 3-1 of Appendix B (see below).

A number of the EPR comments focused on the chosen value of vertical hydraulic conductivity (Kv) for the Miocene confining layer (EPR comments 29, 43, 45, 47, 50, 122, 123, C-3, C-4, C-5, C-10, C-11). Based on the comments received, the authors realize that the discussion in

Appendix B should have been broadened to include the results of all Kv values (low, mid, and high). As such, the model simulations were run using the high-value Kv ($1.50\text{E-}03$ ft/day), and the results are included as Attachment 1.

Table 3-1 from Appendix B is expanded below to include the simulated heads and calibration statistics of all three Kv values compared to USGS Well 37Q185, located near the center of the cone of depression:

Sensitivity Parameters		Calibration Statistics		Upper Floridan Head At Well 37Q185	
Unit	Vertical Hydraulic Conductivity (ft/day)	Mean Difference (ft)	Standard Deviation (ft)	Simulated (ft MSL)	Observed Mean Year 2000 (ft MSL)
Miocene Confining Layer	Low-Value $1.50\text{E-}05$	-5.5	12.4	-126.7	-96.8
	Mid-Value $1.50\text{E-}04$	-1.121	10.86	-100.8	-96.8
	High-Value $1.50\text{E-}03$	4.49	14.5	-66.7	-96.8

As shown above, the simulated head distribution using the mid-value Kv was the most accurate when compared to field data. On the low end of the range, a reduction in the Kv by an order of magnitude resulted in simulated heads in the cone of depression in the Upper Floridan aquifer to be about 30 feet too low when compared to field data. Using the high-value Kv, the cone of depression was simulated 30 feet too high. An expanded list of sensitivity runs is summarized below, each of which indicates that the chosen low, mid, and high-value Kv values best represented a broad range of plausible results:

Miocene Confining Unit Sensitivity Runs			Simulated Head At Well 37Q185	Comparison to Field Data At Well 37Q185 (-96.8 ft MSL)	
Description	Property	Vertical Hydraulic Conductivity (ft/day)	Upper Floridan (ft MSL)	Mean Difference (ft)	Standard Deviation (ft)
Sensitivity Analysis Run 4	44,52, &64, Kv=0.15E-5	1.50E-6	-144.1	-8.42	16.145
Sensitivity Analysis Run 3	44,52, &64, Kv=0.15E-4	1.50E-5	-126.7	-5.5	12.4
Baseline, Recalibration of Miocene Confining in Savannah Area	44,52, &64, Kv=0.15E-3	1.50E-4	-100.8	-1.121	10.86
Sensitivity Analysis Run 5	44,52, &64, Kv=0.15E-1	8.25E-4	-76.8	2.96	13
Sensitivity Analysis Run 2	44,52, &64, Kv=0.15E-2	1.50E-3	-66.7	4.49	14.5
Sensitivity Analysis Run 1	44,52, &64, Kv=0.15E-1	1.50E-2	-31.8	8.133	19.171

The calibration statistics also indicated that the mid-value Kv is more accurate than either the low or high-value, and both the high-value and the mid-value vertical hydraulic conductivities resulted in simulated chloride concentrations at the bottom of the confining unit that were significantly higher than those measured in the SHE boreholes. In fact, the high-value Kv simulation results (see Attachment 1 Figures 1-12) showed initial salt water concentrations completely penetrating the Miocene confining unit, which is clearly not indicated by field observations. Based on the results of the tables and plots above and comparison with measured porewater values, the data suggests that the actual Miocene confining layer properties are probably bracketed between the low and mid-value Kv.

A number of EPR comments indicated that the reviewers did not feel the model results were representative of a "worst-case scenario" or even conservative, and most comments referenced the choice of Kv for the Miocene confining unit to support this notion (EPR comments 43, 45, 47, 50, 122, 123, C-3, C-4, C-5, C-10). The reviewers generally thought that the model results were

closer to a most-likely or expected response. The authors concede that the mid-value K_v may be close to the real value and not necessarily conservative. Applying the mid-value K_v in the flow model, however, overestimated the depth of chloride penetration in the solute transport model; therefore, the authors feel that applying the mid-value K_v yielded conservative results.

Regardless, simulations were also run forward in time with a 1-year time-step for a period of 200 years using the high-value K_v . The year 2000 simulated distribution of chlorides in the Miocene unit was used as the initial condition (Figures 1-12 in Attachment 1) despite the fact that using the high-value K_v showed significant penetration of chlorides into the Miocene confining units as of "today" (i.e. the start of the projection simulation). Figures 13-24 in Attachment 1 show the simulated chloride profile results for both the no-dredging and dredging scenarios, and figures 25-55 show individual time histories at selected borehole locations and production wells. Overall, the simulation results and the figures support the same conclusions drawn in the main report: the difference in chloride concentration in the Upper Floridan aquifer between the results of the dredging scenario and no-dredging scenario were small, and dredging the channel would not significantly impact the rate at which vertical salt-water intrusion is occurring.

There were, in addition, a number of other conservative assumptions built in to the model (see Section 4.4.5.2 and excerpt below) that, when combined, indicate that the range of model results for the low and mid-value K_v were indeed conservative:

The model simulations intended to provide a bracketed range of results to evaluate the probable range of impacts following dredging activities. In order to accomplish this objective, several conservative assumptions were used in the input parameters as described above in Section 4.4.5.1. In summary, the conservative assumptions applied to the model simulations were:

- *Pumping rates from the Upper Floridan aquifer in the Savannah area were assumed to remain as they are at present although withdrawal rates are expected to decrease in the future.*
- *The model utilized the simulated present-day chloride distributions (as opposed to observed porewater values). These values generally overestimated penetration concentrations when compared with measured porewater values.*
- *The model was sensitive to the porosity of the confining unit, with lower values increasing the rate of movement of salt downward. This was tested, but with little field data to adequately defend a "calibrated" value, a low end value (0.1) was selected to be conservative.*
- *Paleochannel in-fill material was assumed to have hydraulic properties comparable to that of surficial aquifer sands, although actual core permeability results indicate the paleochannels contain a significant amount of material that is less permeable.*
- *Three additional feet of confining layer material were assumed to have been removed throughout the project area to allow for possible disturbance by the cutter-head during dredging activities.*
- *Historical simulations were run using current-day navigation channel geometry and depths.*

The EPR reviewers also expressed concern about the choice of modeling only the chloride sources within the navigation channel (4 square miles) instead of modeling the entire chloride source area (1,200 square miles), or about half the entire area contained within the zero contour

of the cone of depression (2,300 square miles) (EPR comments 17, 63, 124, C-1). The authors agree that modeling the entire source area would further dwarf the impacts of dredging on water quality in the Upper Floridan aquifer. In fact, it is reasonable to state that had the entire source area been modeled, it would have been very difficult or impossible to discern impacts specifically due to thinning the confining layer along the navigation channel (i.e. dredging). However, the SOW for the supplemental studies was very clear: to examine dredging impacts, not pumping impacts, on water quality in the Upper Floridan aquifer. The USGS was tasked with modeling regional pumping impacts at a refined scale; whereas, the objectives of the supplemental studies were much narrower. The authors felt that eliminating other source areas was the most effective way to evaluate impacts specifically due to dredging and potentially the only way to isolate and discern the enhanced chloride intrusion specifically due to dredging. In addition, the data available along the navigation channel was very detailed, but there was very little to no data available in other areas. The available data may not be representative of areas outside the navigation channel and within the cone of depression, i.e. in areas overlain by salt marshes.

Both the ITR and the EPR reviewers provided valuable input, and the revisions resulting from their comments will significantly strengthen the aquifer studies Final Report. It should again be noted that the comments provided did not result in revision of any of the major conclusions or recommendations set forth in the Draft Report. Comments not related to the modeling portion of the study generally concerned sentence clarification, typographical errors, or figure formatting, and the authors intend to address the majority of these comments as revisions to the main body of the Final Report. Comments concerning the overall approach, conceptual model, or those that were broad in scope are addressed either in this general response or alongside the original comment in the comment/response matrix included in Section 3.2 of this Appendix.

3.2 Comment/Response Matrix

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
1	1 (General)	General			Throughout the report I was wanting to see a map view illustration showing the saline concentration of the channel and bay areas. This gives the reader a framework to understand where the source of the saline water may originate from.	<i>The Atlantic Ocean, rivers and creeks, and salt water marshes, all of which are shown in maps throughout the report, are sources of salt water. In the Savannah area, this accounts for approximately 1,200 square miles, or about half the area of the cone of depression (as noted in Section 3.2.). The average bottom salinity of the Savannah River is provided in cross section format in Appendix B. Generally speaking, the surface salt-water wedge extends well beyond the upstream extent of the navigation channel (Fig. 109-1000).</i>
2	2 (General)	General			My biggest concern has to do with the modeling investigation. I don't think it's good to assume that what's good at a regional scale works at a small scale. The objectives of the USGS regional model are quite different than the objectives and goals of this investigation. It is the objectives around which a conceptual model is built. Thus, for different objectives one should assume that a potentially very different conceptual and ultimately numerical model will ensue. My point being that your key objective (the navigation canal and its potential for desalination) is not the focus of the USGS model. The objectives of the USGS model are to simulate the flow and transport of the Moccasin aquifer. This is the focus and your model should have more adequately detailed this unit instead of using the layering of the regional model. More layers should have been used to simulate this unit. However, this was not by biggest concern. I was more concerned that you never discussed your method of calibration. You simply state what the model was calibrated to without stating your method. (Continued)	<i>We used the USGS model as a basis for a number of reasons. Using their extensive research and calibration efforts lends credibility to our model, and avoids duplication of effort and wasted funds. Our modeling objectives are different, as you note, and we have changed the grid and added additional detail in the area of the navigation canal. This is not the focus of the USGS model, but we have added detail above, however, we added many additional layers for contaminant transport, as needed, to get more detail on the movement of chlorides through the Moccasin. The response on calibration is provided in the General Response.</i>
3	3 (General)	General			Related to the modeling effort, the layering within the Moccasin should be more refined. I believe at least 5 layers should be used to better simulate the chloride movement through the unit. Table 2-2 of Appendix B is confusing to me. You're relating the model units between the regional model and the Savannah Harbor model and layer 7 is listed as "not present" in your model. Well what is layer 7 simulated as then? Also related to layering, what was the justification for one model layer for the Upper Floridan? The only real justification is if all the pumping wells are fully penetrating and the layer is dominated by horizontal flow. However, if pumping in the Savannah area induces vertical flow in this unit, then you must consider using additional layers to simulate the potential for vertical flow components that could enhance vertical flow through the Moccasin confining unit. (Continued)	<i>Layer 7 of the USGS model did not have the advantage of the local boring data along the river. In their model, the Moccasin aquifer was assumed to occur beneath the river. We corrected the USGS model assumptions by removing the Moccasin aquifer in the area of Savannah, replacing it with Moccasin confining unit as shown in the borings. Using one layer for the flow system in the Upper Floridan matched the USGS model. Flow is dominated by horizontal flow in the Upper Floridan aquifer, and most supply wells are effectively acting as fully penetrating of the upper permeable zone. We do use additional layers in the contaminant transport runs, but not in the flow simulations. Other than these changes to the model, the model is the same. The parameter distribution is the calibrated distribution of USGS publications.</i>

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
4	1	Introduction	1-1		There are numerous references to places in the text that do not show up in an illustration. According to the USGS publication "Suggestions to Authors", every final figure in a manuscript must be clearly labeled and shown on the map. In the introduction, Coastal Bar and the Georgia Ports Authority are used as the beginning and end of the study area channel, yet neither are shown on a map. There were several other occurrences where places or data points were provided in the text without a location reference via illustration.	Figure 1-1 revised to include the text references.
5	2	Study Area	3-5		On Figure 3-5, water level is used in the top figure where potentiometric surface should be used instead. Water level typically refers to an unconfined aquifer or water table. On the same illustration, I would recommend using one color for seawater. In the illustration you have the saltwater wedge as pink and the ocean as green.	Figure 3-5 was taken from a USGS publication, and we feel it adequately illustrates the regional hydrogeologic setting. The color differences are used to distinguish between surface water and ground water, which, in this study is an important distinction in order for the reader to understand both the lateral and vertical mechanisms that contribute to salt-water intrusion. Changed "water level" to "potentiometric surface" as suggested and updated source citation.
6	3	Methods	4-3		On the top of page 4-3, "worst case dredging scenario" is extremely vague at this point of the report. I suggest a better description of what you mean here.	"Worst-case" refers to a maximum project depth of 48 feet below MLW and the associated overdepth dredging allowances. Edited text on page 4-3 to include definition.
7	4	Results	5-3		On page 5-3, first and last line on the page refers to figure 5-3. In both cases it should be figure 5-1.	Corrected text to refer to figure 5-1, which is a cross section along the length of the navigation channel.
8	5	Results			Many of your linear plots of concentration would be much better represented as log plots. For example Figure 5-2 would more accurately represent the data if the Chloride concentration was plotted as Log Cl.	The point is noted and will be taken into account in future publications. The authors felt that, for this study, it was important to point out the fluctuation in values, especially within paleochannel material. Log plots would tend to minimize these fluctuations, therefore, in order to present the data in the most transparent manner, linear plots were more appropriate.
9	6	Results			On page 5-13, in referring to the seismic interpretation, you mention the "yellow reflector", yet there is no yellow in figure 5-3, which the statement is referring to.	Replaced figure with section showing all four prominent reflectors.
10	7	Results	5-1		Many of the boreholes shown in figure 5-1 are not shown in plan view. It would be helpful if these were shown in plan view.	Edited cross sections and maps appropriately to show all boring locations in both plan view and cross section.
11	1	Appendix A			Well written, documented, and defended. Congratulations to the authors.	No response needed.
12	2	Appendix A	2		It has been ... than currently exists. It seems to me the issue of concern is not removal of "higher permeability sediments", which are insignificant in regarding the downward movement of saltwater relative to the much lower permeability of the Miocene confining unit, but would removal of the lower permeability Miocene confining unit. Would removal of the lower permeability Miocene confining unit, which is the sediments, you have an opportunity to show that natural erosion has a much greater impact on saltwater intrusion than dredging would.	The authors agree that the impact of removing paleochannel material is to some degree not significant when compared to the removal of confining layer material. In the past, however, the SEG and local media have focused on the paleochannels and their potential impacts on the rate of salt-water intrusion. As such, it was deemed necessary to perform a more detailed investigation and explicitly address these concerns.
13	3	Appendix A	28		If these reflectors currently exist. Same comment as above. Your statement is only true if deepening the channel would reduce the thickness of the lower-permeability Miocene confining unit.	See response to EPR comment #12.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
14	4	Appendix A			Should include a "defense" of software programs used to analyze data to justify that software is appropriate and valid for intended usage.	HYPACK MAX is a proprietary software package developed by Coastal Oceanographics to perform exactly the types of analyses that were completed as part of OSI's deliverables. It is the industry standard for marine surveying and subbottom profiling, and OSI was instrumental in its development and implementation. HYPACK MAX is also the Corps-wide standard survey software package for marine surveying and subbottom profiling.
15	5	Appendix B	1-1		Should spell "CDM" out the first time it is used.	CDM is no longer referred to as "Camp, Dresser, and McKee, Inc." in their publications. Edited text in main report to eliminate reference to "Camp, Dresser, and McKee, Inc."
16	6	Appendix B	1-2		In Section 3, authors discuss potential increase in chlorides in various wells due to dredging and consequent migration of saltwater moving downward through the sediments underlying the Savannah River and the migration to the wells. Yet no discussions occur in the section on "Model Calibration" and "Model Application" about lateral flow and solute transport. Why not?	Horizontal transport to the wells is not the focus of this investigation, and no data were available to calibrate transport of chlorides within the Upper Floridan aquifer. We believe that, by providing relative changes between dredging and non-dredging conditions, we have addressed the proper objectives of the study, even if the absolute concentrations and timing of impact are not accurate. We do list the flow parameters for the Upper Floridan aquifer in section 2, however, without data, our ability to simulate accurately the concentrations reaching supply wells and the length of time it takes for chlorides to reach the wells cannot be tested or calibrated.
17	7	Appendix B	1-2		Other chloride sources... in the simulations" These "other chloride sources" may be the more significant source of high chlorides into the Upper Floridan Aquifer, with chlorides due to dredging being relatively insignificant. I understand your intent to try to show that part of the saltwater is being transported by the aquifer, but you could have missed the opportunity to show the relative insignificance of dredging versus natural sources of saltwater contamination. Your approach also puts you in the position of having to provide a rigorous defense that your model can simulate point to point flow and transport of chlorides through a limestone aquifer with considerable variations in vertical and lateral flow characteristics. If your model is "truly" calibrated, you should be able to simulate the "real world conditions" of natural recharge/discharge impacts and dredging impacts to a composite saltwater contamination scenario. (Continued)	Although it is clear that including all the other sources would emphasize even more the marginal impact of dredging on chlorides in the Moccasin and Upper Floridan aquifer, modeling other sources would have greatly added to the complexity of the simulations and opened the discussion up to a larger question not relevant to the study. As for point to point flow through limestone, the model results and conclusions are based on simulated transport within the Moccasin confining unit as opposed to absolute concentrations in the Upper Floridan aquifer. See the General Response for discussion related to calibration.
18	8	Appendix B	2-1		You say the DYNFLOW code has been reviewed and tested and documented, but omit any discussion of results. You should discuss strengths and weaknesses identified in the testing and results that would support use of the code as it applied in this report.	DYNFLOW has been reviewed and tested, and the appropriate documentation is referenced. In addition, certification documentation for each code is included in the appendix. The SHE aquifer studies were never intended to be a full blown modeling study; therefore, discussion of strengths and weaknesses and general background information on modeling codes was not included. See General Response for discussion regarding development of the conceptual model and modeling objectives.
19	9	Appendix B	2-2		Same comment as above, but perhaps even more so since solute transport codes by their very nature may be more difficult to validate for specific uses.	See response to EPR comment #18.
20	10	Appendix B	2-4	2-4	No head boundaries are given for north boundary of model.	See Appendix B, page 2-5, section 2.4.4. All boundaries are no flow boundaries except for those indicated in Figure 2-4 as fixed head boundaries.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
21	11	Appendix B	2-4		Tetra Tech, November, 2004 is not included in list of references.	Added Tetra Tech, unpublished data, 2004, to References Section 8.
22	12	Appendix B	2-4	2-5	Suggest you be consistent with rest of report and give chlorides in mg/L.	Consistent units are used throughout the Main Report. As backup documentation, the current text is sufficient.
23	13	Appendix B	2-4		Harvey, 1969 is not included in list of references.	Added reference to report.
24	14	Appendix B	2-4		You say "This (rising water boundary) was not used in the model." Yet in replying to ITR comment 49 (John Clarke) you say "some of river nodes [were] assigned a rising node" and Table 4-2 of main report shows rising nodes being used.	Added Text to Appendix B, page 2-5, section 2.4.6.
25	15	Appendix B	2-5		You need to defend use of fixed heads for the water table (2.4.6). See ITR comment 19 (Clarke).	The use of fixed heads for the surficial aquifer was a useful simplification. Long term data has shown that surficial aquifer heads have not changed appreciably despite the large increase in pumping in the Upper Floridan aquifer. The surficial aquifer heads were calculated from Tetra Tech data by the USGS and adjusted using more local wells available. The USGS used the Tetra Tech data for the historical simulation, with intermediate values used for the historic simulation. Changes were small in the Savannah area, and the changes in head in the surficial aquifer were less than 5% of the change in the Upper Floridan between 1900 and 2000. Thus, the leakage from the surficial aquifer to the Upper Floridan across the Miocene confining unit is largely unaffected by small changes in the surficial aquifer heads.
26	16	Appendix B		2-6 through 2-10	You need to give a zero reference for the vertical scale, i.e. MLW or MSL or whatever. Also, the scale should be expanded to more clearly show thicknesses of units of importance, i.e. the Surficial Aquifer, Miocene units, and Upper Floridan Aquifer.	All figures in Appendix B are referenced to MSL. Edited figure and added an inset map of the Savannah area.
27	17	Appendix B	2-6		No levels are shown in Table 2-2; also layers 5 and 6 are not given a Savannah Harbor Area Hydrologic Unit name. Why not?	Levels are the boundaries of layers. See Figure 2-1 of Appendix B for a graphical explanation. Since the Miocene aquifers are known to be missing along the channel area, there is no separate Upper Floridan confining unit, it is simply an extension of the Miocene confining unit. This was discussed with the USGS once it was apparent that the Miocene aquifer was absent beneath the river.
28	18	Appendix B		2-11 through 2-17	You say "Figures 2-11 through 2-17...entire model domain". You must describe the basis upon which these figures were developed, including reasons for differences in horizontal and vertical hydraulic properties, and regional differences. In using both lines of equal thickness and colors, neither of which is defined on the thickness maps, some of the maps become cluttered and barely readable. Suggest that either color or lines of equal thickness be used but not both. Also, whatever you use must be clearly defined on the map using a standard legend format.	We believe that the figures are adequate to display the general pattern of hydraulic conductivities and thicknesses. We have chosen to base our model on the extensively researched USGS regional model. Our mid-Kv model is identical in most cases to the USGS regional model (see Payne et al, 2005), and information on hydraulic properties and distribution is available from the USGS. In addition, USACE field data along the Savannah River was used to adapt the regional model to a localized scale appropriate for the Study Area.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
34	24	Appendix B		2-21	the small scale and clutter of Figure 2-21 makes it difficult to decipher comparisons, especially in the deep cone of depression surrounding Savannah. This figure does not meet acceptable graphic standards, and should be redrawn at a larger scale to acceptable graphic standards.	Edited figure and added an inset map of the Savannah area.
35	25	Appendix B	2-7	2-21	"Typically a calibration...the model domain." Need to provide the basis for this statement, especially the part about "10 to 15% of the total measured head gradient across the model domain" where an extremely deep cone of depression exists due to pumping.	Keeping the standard deviations within 10 percent of the range of values found in the model is a general guideline found in ASTM standards. A cone of depression makes it more difficult to match heads, but also increases the range of values, making the impact on the percentage difficult to assess. In any event, whether we consider the -100 MSL heads as part of the range or not, we are within 10%.
36	26	Appendix B	2-7	2-21	Section 2.9.1: Need to describe hydraulic and geohydrologic input data used in this steady state calibration. A reader can assume these data are those discussed in Sections 2.6 through 2.8, but one should not have to make an assumption of this type.	Correct. Model accuracy tests used the parameters described in sections 2.6 through 2.8.
37	27	Appendix B		2-22 through 2-23	Because of the small scale, it is very difficult, if not impossible, to clearly compare results between the two models in the area of most interest, i.e. areas adjacent to the Savannah River where dredging may occur. This figure should be reconstructed at a larger scale.	Edited figure and added an inset map of the Savannah area.
38	28	Appendix B	2-8	2-17	Section 2.9.2: Figure 2-17 shows hydraulic properties and thicknesses of the Lower Floridan, do you mean Figure 2-18?	Edited text to include correct figure reference (figure 2-18).
39	29	Appendix B		2-24 through 2-26	Need to discuss basis of construction for these figures.	Pre-development is represented by a steady state simulation with all pumping removed from the modeled area. The same aquifer system is used for the pre-development and the development. And effect on the results in the area of interest. Surficial heads are listed for each decade, and are varied by decade as discussed in Appendix B on page 2-8.
40	30	Appendix B		2-24 through 2-28	All of these figures fail to meet standard graphic standards and are in need of improvement (explanations of features shown or figures incomplete, missing, or unclear).	We feel the figures are of sufficient quality to convey the intended message.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
41	31	Appendix B	2-8	2-27 through 2-28	These figures are difficult to analyze because the measured and simulated heads overlap and run together in the latter years. The importance of these figures warrant their reconstruction at a larger scale showing clear definition between measured and simulated heads. On figure 2-28, well 37Q016, the simulated heads show a large dip that is not shown by the measured heads. This discrepancy should be explained.	The scale of the graphics was selected to provide an impression of the model's ability to reproduce long term trends (1900 through 2000) in response to changes in pumping. Calibration was not the focus, and thus more detailed figures were not considered to be useful. The model used 10-year averages for pumping, missing year to year changes in the actual pumping. Thus the response of the model is not always matching the data. It is most likely that the dip is caused by inaccurate representation of pumping in the model. This would not affect the results of the projection simulations nor the conclusions of the report in any significant way.
42	32	Appendix B		2-29 through 2-40	"Illustrate the measured and simulated chloride..." But figures 2-30 and 2-37 have no measured values. You should acknowledge this or delete the figures. Top of Micene and top of Upper Floridan (Should spell UF out in all figures.) should be solid lines to be consistent with symbol explanations. Chloride concentration and penetration differences between simulated and observed values should be explained. Observed chloride value data points should be shown on figures. Simulated values are based on the year 2000; are measured values from the year 2000? If not, use of data from a different year should be acknowledged and justified.	We recognize that on several figures, no field data were available, but we included the figures to complete the run of the river simulation results. We believe the figures are of sufficient quality to make the point of a general match between simulated chloride concentrations and measured chloride concentrations in the Mixene, taking into account the extreme variability of the data based on local heterogeneity. Additionally, as explained in the report, the year 2000 simulated chloride values from the "Erm Tech Model" were used as the initial condition, not observed values. This was necessary in order to incorporate the projected surface-water bottom salinities after dredging. Because the project is to protect the future fish, we do want to encourage the use of field data to calibrate the future fish. We believe that the use of wrong thing (focus on calibration, not on our overall approach). Note also that our model is aimed at matching decade long pumping and transport trends. To this end, we found it acceptable and logical to use 2000 as the start of the projections, as opposed to 2001 - 2005 when data were collected.
43	33	Appendix B	2-9		but is perhaps... of saltwater. The case has not been made that 1.5E-4 is a conservative conductivity value. Report data and analysis suggest 1.5E-4 is the expected or most likely conductivity value. If by conservative the author means a higher conductivity value than expected, which would result in greater than expected saltwater intrusion, a conductivity value on the order of E-3 would be conservative, likely resulting in simulated saltwater penetration to be deeper and chloride concentrations to be greater than would realistically be expected. A value in the E-3 range as conservative is supported in data contained in Section 3 of the main report.	We agree that the mid-Kv is the most likely hydraulic conductivity, but because of the other conservative assumptions and the fact that simulated values were consistently higher than observed values at the bottom of the Mixene confining unit, we believe that the mid-Kv simulation still represents an over-prediction or rate of chloride penetration. Additional information, including the simulation results of the high Kv, is provided in the General Response to strengthen the case.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
44	34	Appendix B	2-9		Note that in ... 2-35 and 2-38. A careful look at these figures does not support the above quoted statement. Figure 2-30 does not contain any measured data, and Figures 2-29, 2-31, 2-35, and 2-38 do not show reasonable matches between observed and simulated chloride concentrations until near the top of the Upper Floridan. Chloride concentration differences between observed and simulated values throughout the Miocene confining unit should be explained.	The modeled chloride concentrations of the mid-Kv and low-Kv were intended to show the actual chloride concentrations in the Miocene confining unit. The actual data shows the effects of many local heterogeneities in the system such as paleochannels and variation in hydraulic properties. These localized variations, however, tended to follow the same consistent trend once the porewater hit the Miocene confining unit. These could not be simulated with averaged properties, so an exact match was not attempted. Discrepancies between the concentration at the top of the Miocene taken from the surface water model, and those measured near the top of the Miocene pore water occur as well, but in most cases, the model was somewhat higher. We needed to use model values rather than measured because we needed the surface water model to provide projected concentrations of chloride at the bottom of the river for designed conditions.
45	35	Appendix B	2-9		"A second set... the two simulations." Data and analyses form the main report and supporting appendices do not support saying "The true system response lies somewhere in between the two simulations." The preponderance of evidence presented in the report and supporting appendices suggest that 1SE-4 is a reasonable or most likely value for the vertical conductivity of the Miocene confining unit, not a conservative value, and simulations made using 1.5E-4 would unlikely show results decidedly skewed towards either underestimates or overestimates of saltwater penetration - assuming the model is adequately calibrated for its intended use. To bound probable system responses, three simulations are needed: a simulation using 1.5E-4 (most likely case), a simulation using 1.5E-3 (worst or nonconservative case), and a simulation using 1.5E-5 (best case or nonconservative case) resulting in at least saltwater intrusion). (Continued)	A third simulation was run with the high Kv value. Results are provided in the General Response.
46	36	Appendix B	3-1		"generally result in ... higher than measured." Data and analyses contained in Section 2 do not fully support the above statement. Figures 2-31, 2-35, and 2-38 show that in parts of the Miocene confining bed observed values of chloride are higher than simulated values. The authors should discuss possible alternate reasons for these differences within the Miocene, and then select and defend their preferred explanation for the differences. Also, no observed chloride values are available for the Upper Floridan; consequently, no comparison can be made between simulated and observed chloride values in the Upper Floridan, which leads to questions about how can one defend model calibration, and it's ability to simulate with reasonable fidelity chlorides in the Upper Floridan.	In most of the plots, the simulated salt water penetration is deeper, and at higher concentrations, than the data show for the mid-Kv, and even for some of the low-Kv plots. For some shallow data, especially within the paleochannels, the reverse is true. This is probably due to local sand lenses which are not adequately modeled by our lumped parameters. We could not attempt to model all the local heterogeneities present in the Miocene confining unit and did not expect to match local fluctuations. The samples taken deeper into the confining unit at lower elevations are the focus of the comparison, and the model's conservative nature is generally demonstrated.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
47	37	Appendix B	3-1		"The calibrated value...sets of results." Data and analyses do not support that "the true conditions are bounded by the two sets of results." Data and analyses support using 1.5E-4 (calibrated value) to represent "true conditions". This "true condition" is bounded on the "best case" level (value of conductivity that is likely to show saltwater penetration to be less than would be expected under "true conditions"), but is not bounded on the "worst case" level (use of a value of conductivity that is likely to show saltwater penetrations to be more than would be expected under "true conditions").	See response to EPR comment #43 and General Response.
48	39	Appendix B	3-2		Table 3-1 shows simulated head 30 feet too low, not 25.	Corrected text to read 20 ft.
49	39	Appendix B	3-2		"But the model somewhat overstated the rate of penetration." As discussed above, if penetration into the Upper Floridan is being modeled, no observed data are supported by the model. The model is not consistent with depth than observed chlorides. It should be acknowledged that chloride comparisons are available only for the Moccasin confining unit.	The report is clear that data are available from pore water only from the Moccasin confining unit. The expectation that chloride concentrations in the Upper Floridan would be overestimated seems reasonable if the model is overestimating the breakthrough concentration at the bottom of the Moccasin. That is the basis of the statement.
50	40	Appendix B	3-2		Table 3-1: See USACE (11R) comment 59 (Fenske). For reasons presented in my above comments, I fully support Fenske's comment, and urge the authors to implement his suggestion. The authors' response to Fenske's comment and discussion on page 3-7 and 3-2 do not adequately address the concerns.	See General Response.
51	41	Appendix B	3-2		"The higher vertical... Floridan chloride concentrations." Since no observed chloride data were shown for the Upper Floridan in the SHE boreholes (figures 2-29 through 2-40), what is the basis for saying the higher conductivity value results in "unrealistic Upper Floridan chloride concentrations"? Also, it may be that higher simulated chloride concentrations in the Moccasin result from the model ignoring dilution effects since it is not unreasonable to expect that low chloride water moving horizontally through relatively permeable sands in the Moccasin unit is mixing with high chloride water moving downward from the overlying saltwater sources. Until various reasons for chloride differences between simulated and observed values are identified and discussed, no sound basis exists for simply assuming the differences exist because "conservative" conductivity values are used as model input. Remember, the chloride concentration difference also exists even when using the calibrated value, "which represents the mid range of reasonable values".	We do not believe that horizontal flow in the Moccasin confining unit is a major factor. Beneath the river, there is no Moccasin aquifer, and every core taken showed a plane, homogeneous, clay-like material. We believe that it is unlikely that horizontal flow in the confining unit would have a major effect on chloride concentrations with only small, thin, dead end pockets of water in a clay/silt matrix present. It is true that some of the model results show the potential for downward leakage of chlorides due to downward leakage of salt water through the Moccasin confining unit. However, our contention that we would overestimate future chloride concentrations in the Upper Floridan is based on our belief that we are overestimating the rate of salt water penetration of the Moccasin confining unit (See also Main Report section 5.2.). Either way, the focus is on the difference between dredging and non-dredging simulations, which are not affected much by the discussion of the proper Kv value for the Moccasin (See also General Response).
52	42	Appendix B	3-2	3-1 through 3-3	These figures are very difficult to decipher because of too many similar colors. These figures would be improved if colors were used only for chloride concentrations, and if geologic units were defined by a different color. A reference needs to be made to the vertical scale. A white B&B grid is also needed. Tiles should include "simulated chloride" before "concentrations" and "current" should be defined. No explanations of blue and red lines and of vertical and horizontal scales are given. These figures should be reconstructed to standard graphic requirements.	We agree but will not attempt to change this in the backup documentation of Appendix B. This problem was addressed in Figure 4-10 of the Main Report.
53	43	Appendix B	3-3		Two different values... potential impacts, as discussed before, "range of potential impacts" may not be bracketed.	See General Response for simulation results using the high Kv value.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
54	44	Appendix B	3-3		On page 3-2, it is stated that initial model input is based on the year 2000 (Figures 3-1 and 3-2), but in Section 3-1, 1990 is shown as start of simulations. The results were documented and analyzed starting in 2000, so we prefer to refer to it as a 200 year simulation.	We started the simulation in 1990 to avoid initial condition instability. The results were documented and analyzed starting in 2000, so we prefer to refer to it as a 200 year simulation.
55	45	Appendix B	3-4		Concentration after 200 years after 210 years in 1990 was starting year.	See response to EPR comment #54.
56	46	Appendix B	3-4		Should include in narrative and in Figures 3-5 through 3-16 actual conductivity values (1.5E-4 and 1.5E-5) used in the simulations (Don't leave reader guessing).	We feel the figures are of sufficient quality to convey the intended message. Figures presented in the main report will be updated to include K values.
57	47	Appendix B		3-5 through 3-16	Include actual conductivity values for "A" (1.5E-4 ft/d). As presently presented, titles for "A" are incomplete. A possible title for "A" could be "Simulated Chloride Profiles at SHE [Borehole number] using a vertical conduction value of 1.5E-4 for the Miocene Confining Unit". A similar title should be used for the "B" graphs. Color lines for top of Upper Floridan and Miocene should be consistent with Legend (Legend shows "unbroken" lines, whereas the lines on the graph are "broken").	See response to EPR comment #56.
58	48	Appendix B	3-4		"The results show...consequent dilution effect." For clarity suggest wording to read "due to considerable horizontal flow of fresh water within the aquifer mixing with and diluting the relative very low volume of saltwater migrating downward from the Savannah River".	Adapted suggested verbiage in main report. As backup documentation, wording in Appendix B is adequate.
59	49	Appendix B		3-7 through 3-28	Chloride scales for these figures should be expanded to more clearly show differences between dredging and no-dredging simulations. I.e. 0-100 mg/L or (0-250mg/L) or... as appropriate based on upper chloride levels. Reasons for "fluctuations" embedded in chloride trends should be discussed. As mentioned before, graph titles should give conductivity values used for "A" and "B" plots (1.5E-4 ft/d and 1.5E-5 ft/d respectively). For the reasons given in a number of my previous comments, a third plot using 1.5E-3 ft/d is needed to truly bound expected chloride concentrations.	Focusing attention on the chloride concentration does not match the intent of this approach (see also the General Response). This places too much emphasis on absolute concentrations, which will be inaccurate because other sources are ignored. Also, although the mid-KV is the most likely value for the vertical hydraulic conductivity of the Miocene confining unit, the assumed porosity is low. Thus the results are generally overpredicting depth of penetration and the timing of breakthrough. For these reasons, we believe the figures adequate to make the point that dredging will not significantly alter the rate of salt water movement. Results for the mid-KV are still representative of an upper bound, but this is further supported by the high KV simulation results shown in the tables in the General Response.
60	50	Appendix B		3-17	Title and Legend on "B" give SHE-5. Should title and legend read SHE-15?	Corrected figure.
61	51	Appendix B		3-18	Similar problem as above. Either the "B" plots are on the wrong figure or are labeled incorrectly.	Corrected figure.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
62	52	Appendix B	3-5	3-17 through 3-28	The concentrations shown are computed for the top 50 to 60 feet of the Upper Floridan Aquifer. Yet, the figures titles read "Concentrations at the top of Upper Floridan Aquifer". Figure titles should be revised to show concentrations at the top of the aquifer. The concentrations shown for the top 50 to 60 feet should be explained. If the top 10 feet of the Upper Floridan would have been selected, would simulated chloride concentration plots have differed significantly from those given in this report?	The top 50 to 60 feet of the Upper Floridan aquifer was the depth to which particles tended to penetrate, prior to lateral movement toward the pumping center in Savannah. It is probable that flow is concentrated in discrete permeable zones within the Upper Floridan aquifer, and the model does not attempt to simulate these zones. According to USGS, in most cases the upper permeable zone is considered the top 200 feet of the Upper Floridan aquifer. In the absence of data, we believed that 60 feet was a reasonable assumption. If we used a larger depth of penetration, simulated concentrations would decrease. We do not believe that the absolute concentrations simulated in the Upper Floridan aquifer are all that accurate because of the difficulty of simulating high and low flow zones, and of course, because only the dredged area of the river is simulated as a source. However the main concern is the comparison between dredging and non-dredging, not the expected concentrations (See also General Response).
63	53	Appendix B	3-5		Should explain why 250mg/L was selected as "breakthrough" value and its significance. I really don't see the justification for ignoring the importance of the composite effects of all sources of saltwater contamination (amount due to both the Savannah River and other sources of saltwater) that could cause chlorides to exceed 250mg/L (the EPA limit). If the composite effects of all sources of saltwater are ignored, then why would anyone be drinking chlorides less than 250 mg/L from the Upper Floridan. Even a small increase in chlorides due to dredging could be significant if chloride concentrations without dredging are close to 250 mg/L.	250 mg/l is simply the EPA drinking water standard, and thus a convenient value to use. The authors disagree that even small contributions from dredging are significant if concentrations are close to 250 mg/l; if Savannah area pumping rates remain the same, total chloride concentrations in nearby production wells are expected to exceed the drinking water standard regardless of whether or not the proposed dredging is negligible when compared with the contributions from other chloride sources (i.e. the Atlantic Ocean). See also General Response.
64	54	Appendix B		3-30 through 3-52	Should give actual Moreene confining unit vertical conductivities used for simulations "A" (1.5E-4 ft/d) and "B" (1.5E-5 ft/d). As said before, a third case using a Moreene confining unit vertical hydraulic conductivity of 1.5E-3 ft/d should be presented as a bound for the worst case.	See response to EPR comment #56.
65	55	Appendix B		3-30 through 3-53	Reasons for the fluctuations imposed on the chloride trends should be explained.	The fluctuations are primarily caused by the modeling method. We use particles of a certain "weight", representing a discrete amount of chloride. These particles are summed and divided by the amount of water in the aquifer where the particles occur. Because of the large number of particles required to simulate the entire river, the particles have a certain size, which means that taking a concentration at a particular time step will be subject to some variation depending on whether an additional particle just enters the layer or falls just short. More particles would smooth out the results but result in uneconomical simulation time requirements.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
66	58	Appendix B	3-5 and 3-6	3-30 through 3-48	I assume from the statement made on page 3-5 ("for the top 50 to 60 feet of the Upper Floridan aquifer") that model simulations are based on the top 50 to 60 feet of the aquifer. The model simulations have been given by various investigators, however, that show much of the flow through the Upper Floridan may take place through high-permeability zones consisting of only a small percentage of total aquifer thickness. Could this "preferred flow" occur between the Savannah River and the wells used in Figures 3-30 through 3-48 and, if so, what would the impact be to breakthrough times and chloride values?	We don't believe the simulated concentration of chloride at wells would be appreciably different if the total flow reaching the wells occurred through a few high permeability zones, or as simulated using our distributed flow through a matrix approximation. It is likely, however, that the time of travel could be less if these zones flow faster than our equivalent hydraulic capacity. Unfortunately there are no data to test these conclusions. Aside from the change in timing, the change with and without dredging would not be significantly different, so the conclusion that dredging has little significant impact would not change.
67	57	Appendix B	3-6	3-49 through 3-52	These are important figures and should be expanded in scale to more clearly show differences between dredging and no dredging. All the expanded figures should include lines of equal head showing the potentiometric surface of the Upper Floridan Aquifer. The "Year 2000" maps should include any available field measurements of head and chlorides allowing the reader to compare simulated and measured values. These figures as drawn do not meet normal graphic standards (no explanation of vertical and horizontal scales; no statement of conductivity values used for Figures 3-45 and 3-52 - reader should not have to assume what conductivity values were used).	The importance of these figures should not be overstated. We are not showing the cause of the chloride penetration of the Moccasin confining unit to the Upper Floridan aquifer, which we know to be the steep gradient between the surficial aquifer and the Upper Floridan aquifer. Because only the river is included as a source, the distribution and concentrations are not really relevant or realistic. The figures are meant to convey a side by side overview showing the minimal difference between dredging and non-dredging scenarios. These figures, placed side by side in Figure 5-9 in the Main Report, make this point adequately.
68	58	Appendix B			USACE [TR] comments 54, 57, 60, 62, 67 bring out important weaknesses in the modeling approach that have not been adequately resolved. This along with concerns expressed in my review comments lead me to question the validity, conservation, and defensibility of simulation results and analyses presented in Appendix B and in various sections of the main report, "Supplemental Studies to Determine Potential Ground-Water Impact to the Upper Floridan Aquifer". It is clear to me that the model has been adequately calibrated for its intended purpose - simulation of transient flow and chloride transport through the Moccasin confining unit and then horizontally through the upper 50-60 feet of the Floridan Aquifer.	See General Response. We disagree that the model approach selected does not adequately address the question of dredging impacts. We believe that the model results, as presented, already demonstrate that dredging impacts on Upper Floridan water quality will not be significant. Suggestions to broaden the modeling effort and to focus on model calibration, although it might strengthen our arguments, would merely enhance an adequately documented conclusion at great expense and parallel a study already being carried out by the USGS.
69	59	Appendix C			Insufficient documentation is provided to show that the GIS Analysis is valid for intended use. How would an independent reader know that the software and subroutines perform as intended in constructing Moccasin thickness maps and other maps?	The ArcGIS Desktop suite and its extensions are the industry standard for creating, inserting, editing, querying, analyzing, mapping, and publishing geographic information. The intended purpose of this report was to provide a visually-enhanced representation of the history of the navigation channel and the underlying geologic framework. In this report, the GIS analyses are used to qualitatively assess the exposure of the Moccasin confining layer through time and examine the geologic framework underlying the navigation channel. The Arc extension applications, although capable of doing so, were not intended in this report to be used for quantitative channel design applications.
70	60	Executive Summary			For reasons given in review of Appendix B, I am not convinced "true conditions" are bracketed. For this and other concerns raised in my review, additional analyses based on realistic simulations presented herein, in Section 63 of the Summary, and in the conclusion.	The authors disagree that true conditions are not bracketed. Conservative assumptions and comparison of field data with simulated flow and transport indicate that the model overpredicted the rate of salt-water intrusion. In order to further support these conclusions, simulation results using the high-Kv value are included in the General Response.
71	61	Overview	2-1		"MLW" should be defined the first time used.	Corrected text on page 2-1.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
72	62	Study Area	3-2		Heron and Johnson, 1966 not given date on list of figures.	Added date to citation in References. Heron and Johnson is used as a text reference on page 3-2. Figure 3-2 is adapted from Clarke et al., 1980 as noted on the figure, not Heron and Johnson.
73	63	Study Area	3-2	3-1	The elevation of... roughly - 95 feet MLLW Figure 3-1 shows the top of the Oligocene at about -120. If you don't wish to reference the bottom paragraph on page 3-2 to Figure 3-1, some other reference should be given.	Filled text to indicate this is a specific reference to the study area along the navigation channel. Figure 3-1 is a generalized regional cross section; Figure 3-4 shows a more site-specific cross section that shows the specific elevations mentioned in the text.
74	64	Study Area	3-3		Should provide reference for unit elevation given in discussion at top of page.	The geologic framework was previously presented in sections 3.1 and 3.2; the documentation and references provided in those sections apply here as well. Unit thicknesses in study area determined from USACE boring data. The data was collected and/or analyzed during this study; therefore, there is no outside reference.
75	65	Study Area	3-5		Can significant be qualified, i.e. percentage amount?	As noted in the next clause, nearly half the water budget, or 40 MGD. Added "40 MGD" to text.
76	66	Study Area	3-7		Should provide reference of unit elevations.	See response to EPR comment #74.
77	67	Study Area	3-7		Date for "[Fanning, 1990]" is 1999 in list of references.	Corrected text citation to read "[Fanning, 1999]." See response to EPR comment #74.
78	68	Study Area	3-9		Should provide reference for unit thicknesses given in top paragraph.	See response to EPR comment #74.
79	69	Study Area	3-10		Should provide a reference for unit thicknesses given in middle paragraph.	See response to EPR comment #74.
80	70	Study Area		3-4	Should define genesis of all boreholes (SHE boreholes in dark type and SHE boreholes under these contained within parenthesis) in Legend. All symbols used in a figure should be defined in the figure legend.	See response to EPR comment #7. Simplified figure and expanded legend to eliminate confusion.
81	71	Study Area		3-6	Normally, contour numbers are included within a break on the contour line. This avoids guessing what contour value goes with what contour line. Can this be done in this figure where contour spacing allows?	Edited figure and contour labels as suggested.
82	72	Study Area			Congratulations for a well written section.	No response needed.
83	73	Methods	4-2		seven marine continuous borings and "two additional land borings" give boring numbers so a reader can go to Figure 4-1 and locate the borings.	Added "(SHE-11 through SHE-17)" and "(SHE-18 and SHE-19)" to text.
84	74	Methods	4-3	4-1	Section 4.1: "nine additional borings" Figure 4-1 shows 11 not 9 borings.	GADOT sponsored the drilling and porewater sampling conducted at SHE-9 and SHE-10 in 2001-2002. Technically, they are not part of the supplemental studies, but the data is meaningful and is included in this report. Clarified legend on Figure 4-1 and added sentence to methods section 4.1.2 to indicate genesis of borings SHE-9 and SHE-10. Their origin is also mentioned in the porewater results section 5.2.
85	75	Methods	4-4		occasional core losses can occasional be quantified, i.e. percentage of losses?	Added core recovery percentage (greater than 75% for all borings) to text.
86	76	Methods	4-4		Section 4.1.2: "Two land borings" Figure 4-1 shows four land borings (SHE 19, SHE 10 and SHE 18) and these same land borings are discussed on page 4-9. Why are SHE 9 and SHE 10 not discussed in Section 4.1.2?	See response to EPR comment #81.
87	77	Methods	4-4		Section 4.2: "downward flow accounts" Should acknowledge the importance of other "portion(s) of the water budget" which are considerably more significant than vertical flow through the Miocene confining bed.	The authors agree. See General Response regarding overlapping regional studies versus isolating effects specifically due to dredging.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
88	78	Methods	4-6		Section 4.2.1.1: "a procedure was... at SHE-97" Why was this procedure done only at SHE-97? Since this procedure was done only at SHE-97, how can one be assured that fresh water in the drilling fluid did not migrate into the core samples (especially into the more permeable zones), thus "contaminating" core samples with relatively fresh water? What were the selection criteria for the "given cross section"? Was this the only section tested or were other sections tested?	The procedure was performed as a method validation check, and it was not possible to perform this procedure on each individual boring. Water was only monitored in the uppermost 100 ft of the borehole. The core samples chosen for the procedure were visually inspected and visually unconsolidated. Free water was generally not visible on any given cross section of core, and only structurally intact cores were chosen for analysis. The consistency and homogeneity of Miocene cores within the study area indicated that repeating this procedure was not necessary. All these indications suggest that fluids did not migrate through the entire cross section of core; the "procedure" referenced was simply a way to validate that this indeed was the case.
89	79	Methods	4-13		Garra and Krause, 1994. Date is 1996 in References, Section 8. "model was tested.... and chloride concentrations" compelling evidence has not been presented confirming that the model can "adequately reproduce" chloride concentrations. Data shown in Appendix B, Figures 2-29 through 2-40 show that the model simulated chloride values differ considerably from observed chloride values, and no data are presented that show flow well, or flow poorly, the model is able to simulate chloride values in the Upper Floridan Aquifer. Thus, in using the model to simulate chloride transport through the Upper Floridan, the model is being used to simulate a set of conditions outside the conditions for which the model has been calibrated.	Corrected text citation to read "Garra and Krause, 1996)." The model was not intended to predict Upper Floridan well chloride concentrations. The model results and conclusions are based on simulated transport within the Miocene confining unit as opposed to absolute concentrations in the Upper Floridan aquifer. See also General Response regarding overlapping regional studies, isolating effects specifically due to dredging, and the development of the SHE conceptual model.
91	81	Methods	4-16 through 4-17		Section 4.4.3.1: See my comments given in Appendix B.	See General Response.
92	82	Methods			Table 4-2: Boundary conditions should be defined here, or reader should be pointed to where these boundary conditions are described in Appendix B.	Added text: "See Appendix B, Section 2-4, for further discussion regarding boundary conditions."
93	83	Methods	4-20		Section 4.4.3.5: "the 2000 pumping... into the future". See my comments given in Appendix B.	See response to EPR comment #31.
94	84	Methods	4-22 through 4-27		Section 4.4.4.2 and 4.4.5: See my comments given in Appendix B.	See EPR comment #33 and General Response.
95	85	Methods	4-25		"general consensus among ... in the areas." A "general consensus" is not the same as a "consensus." The differences between the year 2000 pumping to the year 2005 should be compared. Also, can you really ignore the increases in pumping taking place in nearby Jasper and Beaufort Counties, South Carolina?	See response to EPR comment #31.
96	86	Methods	4-27		"Withdrawal rates are expected to decrease in the future." What evidence exists for this statement?	See response to EPR comment #31.
97	87	Methods	4-33		(Ransom and White, 1998) No date for this reference provided in Section 8, References.	Corrected text in References Section 8.
98	88	Results	5-1		Miocene units A and B suggest insert "Table 3.1" to help reader put these units into a framework relative to other sediments.	Inserted reference to Table 3-1.
99	88	Results	5-1		lower boundary of... from -40 to -50 MLY. Suggest you insert Figure 3-4.	Inserted reference to Figure 3-1.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
100	90	Results	5-1		relict channels the Pleistocene. Seismic wording is incomplete.	Added "indicated" to complete sentence (turns over to page 5-2).
101	91	Results	5-2		Boring SHE 318 (Figure 3-3): Do you mean Figure 3-4? There is no Figure 3-3, and figure 3-3a and 3-3b do not show any contacts.	Corrected figure reference (Figure 5-1).
102	92	Results	5-2		"Huddleston (1998)" is not included in Section 8, References.	Added reference to Section 8: Huddleston, P. F., A Revision of the Lithostratigraphic Units of the Coastal Plain of Georgia. Georgia Department of Natural Resources, Environmental Protection Division, Georgia Geologic Survey, Bulletin 104, 1988, 162p.
103	93	Results	5-2		Tainidge Bridge (Figure 3-3). Is the correct reference Figure 3-4?	Corrected figure reference (Figure 5-1).
104	94	Results	5-2		What is the meaning of "historically"?	In this case, historically refers to borings that were not completed as part of the supplemental studies. Clarified sentence to better convey point.
105	95	Results	5-3		contact at 67 MLW (Figure 3-3). Is the correct reference Figure 3-4?	Corrected figure reference (Figure 5-1).
106	96	Results	5-3		Bartholomew et al. (2000) is not included in Section 8, References.	Added reference to Section 8: Bartholomew, M.J., Rich, F.E., Whitaker, A.E., Lewis, S.F., Broffie, B.M., and Hill, A.A., Neotectonic features of the Lower Coastal Plain of Georgia and South Carolina. In: Abate, C., and Maybin, R. (eds.), A Compendium of Field Trips of South Carolina Geology with Emphasis on the Charleston, South Carolina Area, South Carolina Department of Natural Resources, Geological Survey, 2000, p. 19-30.
107	97	Results	5-3		at SHE-14 (Figure 3-3). Is the correct reference 3-4?	Corrected figure reference (Figure 5-1).
108	98	Results	5-4		"The resulting profiles" If these are the profiles shown in Figures 2-29 through 2-40, Appendix B, these figures should be referenced.	The profiles referenced here are the observed porewater values as the title of the section implies and as discussed in the sections following, not the simulated profiles in Appendix B.
109	99	Results	5-4		Section 5.2: "All profiles indicated... with increased depth." Consider the in profile fluxes... with depth." Table 5-1, Figure 5-1, SHE-10, 2-34(SHE-15), 2-3(SHE-19), 2-32(SHE-19), 2-32(SHE-10), 2-34(SHE-18), 2-35(SHE-11), and 2-38(SHE-14), this statement is somewhat misleading and should be revised to acknowledge and discuss chloride concentrations fluctuations with depth.	The section includes a discussion of the fluctuations on page 5-9. The statement is true, and fluctuations above and below the water table are discussed. We have to no way tried to hide the data or indicate that the fluctuations are not significant. The fluctuations are discussed twice in Section 5.2.2, and again in the porewater profile summary (Section 5.2.3).
110	100	Results	5-4		Section 5.2.1: "The profiles show...with descending elevations." See above comment.	See response to EPR comment #108.
111	101	Results	5-4		50 percent to 5,252 mg/L. Table 5-1 gives 5,253 mg/L as the highest value.	Corrected text to read "5,251 mg/L."
112	102	Results	5-4		no values above 100 mg/L below the Miocene A/B contact. Table 5-1 gives a chloride value of 176 below the Miocene A/B contact (first sample in the Miocene B unit).	Sample P-6 (167 mg/L) was taken from Miocene unit A. Corrected table to reflect correct geologic unit.
113	103	Results			Table 5-1: SHE-16 shows a chloride concentration in the top of the Oligocene (top of Upper Floridan) of 24 mg/L, and borehole SHE-14 shows a chloride concentration in the top of the Oligocene of 151 mg/L. It should be explained why these chloride values significantly exceed the chloride values at the bottom of the Miocene B unit.	The aquifer may have higher background chloride concentrations at those locations (which would result in higher porewater concentrations), but there is no data exists to determine if that is the case. It could also potentially be related to sample integrity. The occurrence of soft, pliable limestone was rare (hence only two samples) and tended to be relatively unconsolidated when compared with the Miocene material. The lack of data and lack of confidence in the data led us to not use the results in any sort of significant decision-making process, hence the lack of discussion.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
114	104	Results		2-29 through 2-40	Because of the close tie to Table 5-1 and Figures 2-29 through 2-40, a common elevation reference should be used.	Appendix B (Figures 2-29 through 2-40) is back-up documentation for arguments presented in the main report, and the authors believe it would be preferable to place them in Appendix B. The main report would be prepared to the same standard. Editing all elevations in Appendix B, however, would require a significant effort that is outside the scope of the existing contract with CDM.
115	105	Results			Table 5-1: Why, for SHE-15, are P-1 and P-2 shown at the bottom of the table instead of on page 5-5 with the other SHE-15 samples?	The table is set up by boring name as two columns, and the incidental location of the page break separated the data from the remainder of the values at that boring location. Reformatted the table to allow the reader to more easily navigate the data.
116	106	Results	5-6		concentration (7260 mg/L) was observed... the inverted (-41.3ft MLW). Table 5-1 shows this sample at a depth of -52.5'. Which is correct?	The -41.3 ft MLW refers to the elevation of the bottom of the river. The sample was collected at -52.5, up, 18 feet below the river bottom, as noted in Table 5-1 and in text. Added sample elevation to text to clarify.
117	107	Results	5-7		fluctuated from 1.264. Table 5-1 gives low chloride value as 901 mg/L not 1.264.	Corrected text to read "901 mg/L."
118	108	Results	5-13		the yellow reflector. There is no yellow reflector shown on Figure 5-3.	See response to EPR comment #9.
119	109	Results	5-17 through 5-22		Ground Water Model: See comments made in Appendix B.	See General Response.
120	110	Results	5-23		Can a reference be given for the Clemson University test conducted in [sic] 1997?	Added reference to text and Section B: Sharp, W., Watson, S., and Hughes, A.A., Aquifer Performance Test Report: Upper Saluda Reservoir (Unconsolidated Aquifer), Clemson County, Georgia, March 1997, 23, 1997. Clemson University Department of Geological Sciences, 1997, 189.
121	111	Results	5-27		Section 5.6.4.1 Suggestions in USACE comment 38 (Fenske) should be implemented.	We tested the effects of porosity on the rate of chloride penetration early in the modeling effort. Porosity and transport rate are linearly related. Presenting additional results based on porosities higher than the low end one used (0.1) would not add to the presentation any vital additional information (See also General Response).
122	112	Results	5-27 through 5-32		Table 5-5: See comments provided in Appendix B. All of the data shown herein seem to support the use of about 1.5E-4 as a realistic average values for the vertical hydraulic conductivity of the Niocene confining unit (a "realistic or expected" value, not a "conservative" value).	See response to EPR comment #43 and General Response.
123	113	Summary	6-1		In addition, the model... and no dredging conditions. Data and analysis does not support that true conditions have been bracketed yielding a best-case and worst-case scenario". Data and analysis support using 1.5E-4 ft/d for the "true conditions" scenario and 1.5E-5 ft/d for the "best case" scenario. To bracket "true conditions" a worst-case scenario needs to be provided. A vertical hydraulic conductivity of around 1.5E-3 is reasonable for the worst-case scenario.	See response to EPR comment #43 and General Response.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
124	114	Conclusions	7-1		The pore water profiles...city of Savannah. Authors provide some evidence and analyses in support of the above conclusion. But, this reviewer believes that weaknesses exist in data analysis and model development and use that could be used to challenge to the final conclusion. Also your case is weakened by omitting years 2000 to 2200 simulations in the Savannah area showing (1) chlorides due to existing sources without dredging, (2) expected chlorides due to existing sources and dredging, and (3) a large-scale map showing differences between dredging and non-dredging simulations, with a statistical analysis included in the discussion of differences quantifying to the extent reasonable the significance of dredging to total chloride concentrations. After all, the proposed dredging area is relatively insignificant compared to presently existing sources of chloride. I suggest that the document conclusion could be strengthened by including years 2000 to 2200 simulations in the Savannah area showing three cases: (1) chlorides due to existing sources without dredging; (2) a composite of chlorides due to existing sources and those chlorides resulting from dredging; and (3) a large-scale map showing differences between dredging and non-dredging simulations, with a statistical analysis included in the discussion of differences, quantifying to the extent reasonable the significance of dredging to total chloride concentrations. Also, the authors should provide a large-scale map. These analyses might clearly show that, since the proposed dredging area is relatively insignificant compared to presently existing sources of chloride, the relative significance of additional chlorides due to dredging is also insignificant. Also, see review comments 1, 2, 7, and 53. Also, many of the figures, especially those in the modeling sections, do not meet normal graphic standards and should be redrawn.	See response to EPR comment #17 and General Response.
C-1	C-1					See response to EPR comment #17 and General Response.
C-2	C-2				No, the authors have done a commendable job of including relevant studies.	No response needed.
C-3	C-3				No, see reply to question 4.	See General Response.
C-4	C-4				No, see attached specific review comments on modeling section and below general comment. Data and analyses do not convincingly support the statement that "True conditions" have been bracketed "yielding a best-case and worst-case scenario". In fact, data and analysis appear to support using 1.5E-4 1/d for the expected true impacts of dredging, with 1.5E-5 1/d representing the best case (conservative) scenario. To bracket "True conditions" a worst-case (non-conservative) scenario needs to be provided using a worst-case hydraulic conductivity of around 1.5E-3. See review comments 33, 35, and 37.	See response to EPR comment #43 and General Response.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
C-5	C-5				Data and analyses do not convincingly support the statement that "true conditions" have been bracketed "yielding a best-case and worst-case scenario." In fact, the analyses appear to support the best-case scenario (1-SE-1 #1) for the best case (conservative) scenario. To bracket "true conditions" a worst-case (non-conservative) scenario needs to be provided using a vertical hydraulic conductivity of around 1-SE-3. See review comments 33, 35, and 37.	See response to EPR comment #41 and General Response.
C-6	C-6				No, see above comments and specific review comments.	See response to EPR comment #43 and General Response.
C-7	C-1				The document does not indicate that the DYNCFIT part of the simulation code has been tested or verified by an independent group, such as the International Ground-Water Modeling Institute. This is the part of the simulation code that approximates the variable density component of the hydrodynamics. The other two components of the code DYNFLOW and DYNTRACK had referenced documentation that the codes had been verified to work correctly. Since the simulation code applied for the SNE supplemental study appears to be a proprietary code developed by CDH it is important that the code have independent verification as no such verification is contained within the document. Additionally, the documentation for the variable density approximation incorporated in the DYNCFIT part of the simulation code is minimal and no other reference to code documentation is provided.	The JMWI was no longer in existence when DYNCFIT was developed; therefore, there is no third party verification documentation available. The code was tested by CDH personnel and compared to standard solutions as noted in the certification documentation that is included as part of this appendix.
C-8	C-2				Dorothy F. Payne, Malek Abu Rumman, and John S. Clarke, 2005, Simulation of Ground-Water Flow in Coastal Georgia and Adjacent Parts of South Carolina and Florida-Preface, 1980, and 2000: U.S. Geological Survey Scientific Investigations Report 2005-5099, 81 pages, John S. Clarke, David C. Leeth, D'Wette Taylor-Harris, Jaime A. Painter, and James L. Labovskiy, 2005, Summary of Hydraulic Properties of the Floridan Aquifer System in Coastal Georgia and Adjacent Parts of South Carolina and Florida: U.S. Geological Survey Scientific Investigations Report 2004-5264, 54 pages, Michael F. Peck and Keith W. McFadden, 2004, Potentiometric Surface of the Upper Floridan Aquifer in the Coastal Area of Georgia, September 2000: U.S. Geological Survey Open-File Report 2004-1030, 1 sheet.	The authors are aware of these studies, all of which went to press after we completed our most recent draft with the exception of the updated potentiometric surface (Peck and McFadden). We examined this dataset and found that the data for one well in Savannah (near the center of the cone) appeared erroneous (~180 feet MSL). In addition, we did not have access to updated data from South Carolina in order to create a composite surface of the two states. As such, it was more accurate to use two datasets that were collected during similar timeframes as opposed to splicing the updated Georgia data with the 1998 South Carolina data. As for the other studies, the authors were generally aware of these publications from the data collection stages to final publication through participation in various regional TAC meetings and advisory sessions. The conclusions presented in the aforementioned studies do not impact any conclusions in the report.

EPR Comment #	Reviewer Comment #	Report Section	Page	Figure	Comment	Response/Action
C-9	C-3				There seemed to be a backwards thought process, in that, the conclusions indicate that the two simulations represented what was thought to be actual case and then the worse case scenario. When in fact the "sensitivity" simulation or "worse case" simulation was accomplished with a reduced conductance of the Miocene confining unit. This is a best case scenario, in that the transport of saline water through the confining unit would be reduced if the confining unit hydraulic conductivity is reduced. For a worst case scenario one would have an increased vertical hydraulic conductivity of the Miocene confining unit. Additionally, no runs were accomplished with changes in the porosity or storage parameters. A decrease in porosity would result in an increase in the velocity in the solute transport simulation. So a worst case scenario would have increased hydraulic conductivity of the Miocene confining unit and decreased porosity and for transient runs a decrease in storage parameters. (Continued) No, this is not conservative and is probably close to the correct choice and may not overpredict the impacts. In general, most geologic materials have heterogeneity and the transport occurs through the more permeable units, thus picking the mid-level Kv is appropriate and given the observed data provided a reasonable fit between simulated and observed data was achieved. A true worst case scenario as discussed above would be a conservative simulation to overpredict impacts.	See response to EPR comment #13 and General Response.
C-10	C-4					See response to EPR comment #13 and General Response.
C-11	C-5				Aside from perhaps using a higher Kv for the Miocene confining unit and decreased porosity as the worse case scenario, the approach is good.	See response to EPR comment #13 and General Response.
C-12	C-6				Aside from documentation of the code verification for DYNQFT and doing a true worst case scenario simulation rather than a best case simulation, there is ample documentation to support the conclusions.	See response to EPR comment #C-7.

4. Charge to Reviewers

**Charge to Reviewers
for
*Supplemental Studies to Determine Potential Ground-Water
Impacts to the Upper Floridan Aquifer
Proposed Savannah Harbor Expansion Project***

Background

The U.S. Army Corps of Engineers is studying the potential effects on the Upper Floridan aquifer due to a proposed harbor expansion of the Port of Savannah. The proposed Savannah Harbor Expansion Project consists of deepening approximately 35 miles of navigation channel. The initial phase of the study was conducted under the authority of Section 203 of the Water Resources Development Act of 1986. Completed in 1998, the Savannah Harbor Expansion Feasibility Study and Tier I Environmental Impact Statement (EIS) recommended deepening Savannah Harbor from the Ocean Bar upstream to the Georgia Ports Authority. Although authorized in 1999, the U. S. Army Chief of Engineers Record of Decision required additional analyses and approvals before commencement of expansion activities, namely a consensus mitigation plan, Tier II EIS, and General Reevaluation Report. The Geology/Hydrogeology and HTRW Design Section, U.S. Army Corps of Engineers, Savannah District prepared this supplemental studies report as part of the Tier II EIS that will serve as a basis for future decisions concerning the expansion of Savannah Harbor.

The intent of the current study was to determine if deepening the Savannah Harbor channel has the potential to impact water quality in the Upper Floridan aquifer, the primary source of drinking water in the coastal area. The study focuses on the Miocene-age upper confining unit of the Floridan aquifer, which in some areas of the present harbor is exposed in the bottom of the navigation channel. Special emphasis was placed on the role of buried paleochannels that have cut into the confining layer.

The clay-rich, low permeability confining layer protects the underlying porous limestone strata. Prior to the 1880's, wells drilled into the artesian aquifer would yield a head of water up to 35 feet above mean sea level (MSL) in the Savannah-Hilton Head, South Carolina area. However, since the 1880's, due to increasing withdrawals of water from the aquifer, a resulting cone of depression in the Savannah area has lowered the water level in the aquifer to as much as 130 feet below MSL. The net effect of this lowering of water level has reversed the natural pre-development flow of ground water from the aquifer upward through the confining layer to a downward flow of water through the confining layer toward the center of the area of greatest pumping from the aquifer (Savannah). Since much of the area within the drawdown cone of depression is overlain by saltwater, chloride levels in the Upper Floridan aquifer in the Savannah area are expected to increase.

Removing additional confining layer material during the dredging process would effectively reduce the thickness of the layer; therefore, it is necessary to determine what effect this may have on the level of chlorides in the Upper Floridan aquifer due to any potential increase in the rate of downward leakage of saltwater.

The methods employed in this study were intended to build and expand on the information from previous studies, particularly the 1998 Potential Ground-Water Impacts for the Savannah Harbor Expansion Feasibility Study that was prepared as part of the Tier I EIS (USACE, 1998). Following the release of the 1998 study, the Savannah District, with input from the United States Geological Survey (USGS), Georgia Environmental Protection Division (GAEPD),

South Carolina Department of Health and Environmental Control (SCDHEC), and the project Stakeholders Evaluation Group (SEG), developed a conceptual plan and work outline to address comments from the 1998 report and establish new supplemental study objectives.

The principal objective of the current study was to determine how much proposed dredging activities would contribute to increased chloride levels in the Upper Floridan aquifer and evaluate the associated impacts on aquifer water quality. The proposed dredging activities to deepen the navigation channel would typically impact materials contained between -42 feet MLW and -58 feet MLW, which is comprised primarily of Miocene-aged sediments. Consequently, the study focused on the Miocene-aged upper confining unit along the navigation channel, especially in an area from about river station 30+000 to -30+000, where the confining layer naturally thins and relict channels have cut further down into the confining layer.

A 3-dimensional coupled flow and transport ground-water model was used to simulate the effects of dredging the navigation channel on water quality in the Upper Floridan aquifer.

The objectives of the 3-dimensional ground-water model were:

- 1) Develop a modeling tool which focused on aquifer system response due only to dredging the Savannah River navigation channel as proposed.
- 2) Assess a range of plausible aquifer responses to harbor dredging by varying input parameters.
- 3) Provide information on expected impacts of dredging on Upper Floridan aquifer water quality (worst case, most likely case).

Please find enclosed a copy of the draft study and appendices for your review. This version of the report reflects comments received on an earlier draft. Your comments will be greatly appreciated and will benefit the preparation of the final version of the report.

Charge Questions

To assist in your review of the report, we ask that you pay particular attention to the following questions:

- 1) Are there any elements you feel could be included in the framework of the report which would strengthen the document?
- 2) Are you aware of any other significant data/studies that are relevant and should be included or referenced in the report?
- 3) Do you feel that the two model simulations likely bracket the expected true impacts of dredging?
- 4) Do you feel that the model assumptions are consistently and sufficiently conservative to overpredict impacts using the mid-level Kv?
- 5) Do you feel that the combination of field data and model framework adequately address the impacts of dredging?
- 6) Do you feel the report contains sufficient documentation to adequately support the conclusions?

5. Original Comment Transcripts from External Peer Reviewers

To: Susan Ivester Rees, PhD.
Coastal Environment Team
Planning and Environmental Division
Mobile District, Army Corps of Engineers
P.O. Box 2288
Mobile, Alabama 36628-0001

Subject: Review of Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer

I want to thank the Corps of Engineers for allowing me the opportunity to review this extensive and thorough scientific investigation aimed at assessing the potential for increased chloride concentrations in the Upper Floridan Aquifer resulting from dredging the Savannah River navigation channel. It is clear that significant time and resources were involved in evaluating these potential impacts and that a well coordinated team of scientists and engineers helped reach your conclusion that dredging will have negligible affect on the underling potable aquifer.

The focus of my review is on the hydrogeology and ground-water flow modeling activities. Although I read the entire supplemental report, I will only comment on these components of the overall investigation. For a large part, the investigation covered the essential elements to address the problem of concern. Your description of methods and analysis are well documented and written. For that I commend the team.

General Comments:

1. Throughout the report I was waiting to see a map view illustration showing the saline concentration of the channel and bay areas. This gives the reader a framework to understand where the source of the saline water may originate from.
2. My biggest concern has to do with the modeling investigation. I don't think it's good to assume that what's good at a regional scale works at a small scale. The objectives of the USGS regional model are quite different than

the objectives and goals of this investigation. It is the objectives around which a conceptual model is built. Thus, for different objectives one should assume that a potentially very different conceptual and ultimately numerical model will ensue. My point being that your key objective is the navigation canal and its potential connection with the underlying Upper Floridan Aquifer by way of the Miocene confining unit. This is the focus and your model should have more adequately detailed this unit instead of using the layering of the regional model. More layers should have been used to simulate this unit. However, this was not by biggest concern. I was more concerned that you never discussed your method of calibration. You simply state what the model was calibrated to without stating your method. In other words, did you use a parameter estimation code such as UCODE, PEST, or MODFLOW? Or did you simply use trial and error? Based on the discussion I assumed you used a trial and error calibration procedure.

I don't believe in this day of fast computers and sophisticated PE codes that trial and error is an acceptable form of calibration, particularly for sophisticated models such as this. It is extremely difficult to adequately calibrate a model such as this using trial and error without greatly oversimplifying parameterization (both number of parameters and zones), which is what was done with regard to the vertical hydraulic conductivity, porosity and storage properties of the confining unit where a single values were assumed for the entire Miocene unit (page 4-23) (and sensitivity testing was done with another single value). In addition, you selected Storage values were selected without discussion. This is where a parameter estimation code such as UCODE could make your model so much more powerfully convincing because it can evaluate multiple parameters simultaneously AND it can help to evaluate the conceptual model used and assumed to be correct. It would allow you to be able to use specific zones within the confining unit (for example where paleochannels exist) where possible differences in Kv may be occurring. The truly great advantage of using the parameter estimation model is that you have some great observation data that will allow for accurate calibration. The types of observational data, steady state and transient head values, and estimated advective transport velocities (which you can get from your pore water samples) provide invaluable data for proper calibration of the possible heterogeneous Kv and storage values of the aquifer and confining unit. I simply don't trust simplified parameterization for convenience, particularly when this is the key to the entire investigation. You even mention that your Kv data are biased toward the low values (pg 5-31), so why trust these in the model? I've seen many cases where trial and error calibrations appear good and produce good head representations, but when a new conceptualization was produced with UCODE, an entirely different hydraulic conductivity distribution results and the head match is even better. The bottom line is, if you want to convince people that the dredging operations won't affect the saline

concentrations of the Floridan aquifer, you better have confidence in your model and use PE, not trial and error.

3. Related to the modeling effort, the layering within the Miocene should be more refined. I believe at least 5 layers should be used to better simulate the chloride movement through the unit. Table 2-2 of Appendix B is confusing to me. You're relating the model units between the regional model and the Savannah Harbor model and layer 7 is listed as "not present" in your model. Well what is layer 7 simulated as then? Also related to layering, what was the justification for one model layer for the Upper Floridan? The only real justification is if all the pumping wells are fully penetrating and the layer is dominated by horizontal flow. However, if pumping in the Savannah area induces vertical flow in this unit, then you must consider using additional layers to simulate the potential for vertical flow components that could enhance vertical flow through the Miocene confining unit.

I will say that based on the observational data, it appears that your conclusions are correct regarding the dredging operations. However, I don't believe your modeling effort yields further convincing proof of this conclusion. I'm skeptical of the results of the model based on the simplicity of the parameter value distribution and the lack of parameter estimation used.

Specific Comments:

1. There are numerous references to places in the text that do not show up on an illustration. According to the USGS publication "Suggestions to Authors", every formal place that is discussed in the text must be shown on an illustration. On page 1.1 in the introduction Oceans Bar and the Georgia Ports Authority are used as the beginning and end of the study area channel, yet neither are shown on a map. There were several other occurrences where places or data points were provided in the text without a location reference via illustration.
2. On Figure 3-5, water level is used in the top figure where potentiometric surface should be used instead. Water level typically refers to an unconfined aquifer or water table. On the same illustration, I would recommend using one color for seawater. In the illustration you have the saltwater wedge as pink and the ocean as green.
3. On the top of page 4-3, "worst case dredging scenario" is extremely vague at this point of the report. I suggest a better description of what you mean here.

4. On page 5-3, first and last line on the page refers to figure 5-3. In both cases it should be figure 5-4.
5. Many of your linear plots of concentration would be much better represented as log plots. For example Figure 5-2 would more accurately represent the data if the Chloride concentration was plotted as Log Cl.
6. On page 5-13, in referring to the seismic interpretation, you mention the "yellow reflector", yet there is no yellow in figure 5-3, which the statement is referring to.
7. Many of the boreholes shown in figure 5-1 are not shown in plan view. It would be helpful if these were shown in plan view.

To: Susan Ivester Rees, Ph.D
Lead Oceanographer
Costal Environment Team

Subject: Peer Review of *Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer*

A short answer to reviewer **Charge Questions** are provided below. More specific and detailed answers are provided in my attached review comments.

1) Are there any elements you feel could be included in the framework of the report which would strengthen the document?

I suggest that the document conclusion could be strengthened by including years 2000 to 2200 simulations in the Savannah area showing three cases: (1) chlorides due to existing sources without dredging; (2) a composite of chlorides due to existing sources and those chlorides resulting from dredging; and (3) a large-scale map showing differences between dredging and non-dredging simulations, with a statistical analysis included in the discussion of differences, quantifying to the extent reasonable the significance of additional chlorides resulting from dredging to total chloride concentrations. These analyses might clearly show that, since the proposed dredging area is relatively insignificant compared to presently existing sources of chloride, the relative significance of additional chlorides due to dredging is also insignificant. Also, see review comments 1, 2, 7, and 53.

Also, many of the figures, especially those in the modeling sections, do not meet normal graphic standards and should be redrawn.

2) Are you aware of any other significant data/studies that are relevant and should be included or referenced in the report?

No, the authors have done a commendable job of including relevant studies.

3) Do you feel that the two model simulations likely bracket the expected true impacts of dredging?

No, see reply to question 4.

4) Do you feel that the model assumptions are consistently and sufficiently conservative to over predict impacts using the mid-level K1?

No, see attached specific review comments on modeling section and below general comment.

Data and analyses do not convincingly support the statement that "true conditions" have been bracketed "yielding a best-case and worst-case scenario". In fact,

data and analysis appear to support using $1.5\text{E-}4$ ft/d for the expected true impacts of dredging, with $1.5\text{E-}5$ ft/d representing the best case (conservative) scenario. To bracket "true conditions" a worst-case (non-conservative) scenario needs to be provided using a vertical hydraulic conductivity of around $1.5\text{E-}3$. See review comments 33, 35, and 37.

5) Do you feel that the combination of field data and model framework adequately address the impacts of dredging?

No data or analyses were shown in the report that could be used to calibrate and verify the ability of the model to reasonably simulate solute transport in the Upper Floridan Aquifer. Also, see above comments and specific review comments. Also, see comments 8, 9, 39, 41, 58, and 80.

6) Do you feel the report contains sufficient documentation to adequately support the conclusions?

No, see above comments and specific review comments.

Comment Number. Report Section, page and/or figure number (s): Comment

1. Appendix A: Well written, documented, and defended. Congratulations to the authors.

2. Appendix A, page 2: "It has been . . . than currently exists." It seems to me the issue of concern is not removal of "higher-permeability sediments", which are insignificant in retarding the downward movement of saltwater relative to the much lower permeability of the Miocene confining unit, but possible removal of the lower-permeability Miocene confining unit. Where dredging would remove only the higher permeability fill sediments, you have an opportunity to show that natural erosion has a much greater impact on saltwater intrusion than dredging would.

3. Appendix A, page 28: "If these relie... than currently exists." Same comment as above. Your statement is only true if deepening the channel would reduce the thickness of the lower-permeability Miocene confining unit.

4. Appendix A: Should include a "defense" of software programs used to analyze data to justify that software is appropriate and valid for intended usage.

5. Appendix B, page 1-1: Should spell "CDM" out the first time it is used.

6. Appendix B, page 1-2: In Section 3, authors discuss potential increase in chlorides in various wells due to dredging and consequent migration of saltwater moving downward through the sediments underlying the Savannah River and the migration to the wells. Yet no discussions occur in the section on "Model Calibration" and "Model Application" about lateral flow and solute transport. Why not?

7. Appendix B, page 1-2: "Other chloride sources... in the simulations" These "other chloride sources" may be the more significant source of high chlorides into the Upper Floridian Aquifer, with chlorides due to dredging being relatively insignificant. I understand your intent to try to show that part of the saltwater contamination due only to dredging, but in doing this you have missed the opportunity to show the relative insignificance of dredging versus natural sources of saltwater contamination. Your approach also puts you in the position of having to provide a rigorous defense that your model can simulate point to point flow and transport of chlorides through a limestone aquifer with considerable variations in vertical and lateral flow characteristics. If your model is "truly" calibrated, you should be able to simulate the "real world conditions" of natural recharge/discharge impacts and dredging impacts to a composite saltwater contamination scenario. A comparison of this scenario to your "impacts from dredging only" might support your conclusion that relative to all possible sources of chlorides dredging is insignificant. Also, one could make the case that a single chloride source is not in itself significant; what matters is that all combined sources do not result in water from a well having total chlorides exceeding the EPA limit of 250 mg/L. A last point is that if in salt marshes or other areas in which saltwater is present you are using freshwater

heads as model inputs, you are overestimating dilution of saltwater moving from the river channel towards nearby wells.

8. Appendix B, page 2-1: You say the DYNFLOW code has been reviewed and tested and documented, but omit any discussion of results. You should discuss strengths and weaknesses identified in the testing and results that would support use of the code as it applied in this report.

9. Appendix B, page 2-2: Same comment as above, but perhaps even more so since solute transport codes by their very nature may be more difficult to validate for specific uses.

10. Appendix B, page 2-4 and Figure 2-4: No head boundaries are given for north boundary of model.

11. Appendix B, page 2-4: Tetra Tech, November, 2004 is not included in list of references.

12. Appendix B, page 2-4 and Figure 2-5: Suggest you be consistent with rest of report and give chlorides in mg/L.

13. Appendix B, page 2-4: Harvey, 1969 is not included in list of references.

14. Appendix B, page 2-4: You say "This (rising water boundary) was not used in the model." Yet in replying to ITR comment 49 (John Clarke) you say "some of river nodes [were] assigned a rising node" and table 4-2 of main report shows rising nodes being used.

15. Appendix B, page 2-5: You need to defend use of fixed heads for the water table (2.4.6). See ITR comment 19 (Clarke).

16. Appendix B, Figure 2-6 thru 2-10: You need to give a zero reference for the vertical scale, i.e. MLW or MSL or whatever. Also, the scale should be expanded to more clearly show thicknesses of units of importance, i.e. the Surficial Aquifer, Miocene units, and Upper Floridian Aquifer.

17. Appendix B, page 2-6 and Table 2-2: No levels are shown in Table 2-2; also layers 5 and 6 are not given a Savannah Harbor Area Hydrologic Unit name. Why not?

18. Appendix B, Figures 2-11 through 2-17: You say "Figures 2-11 through 2-17... entire model domain", You must describe the basis upon which these figures were developed, including reasons for differences in horizontal and vertical hydraulic properties, and regional differences. In using both lines of equal thickness and colors, neither of which is defined on the thickness maps, some of the maps become cluttered and barely readable. Suggest that either color or lines of equal thickness be used but not

both. Also, whatever you use must be clearly defined on the map using a standard legend format.

19. Appendix B, Figure 2-12: This is perhaps the most important figure of the seven. Yet the thickness layer is difficult, if not impossible, to decipher because of the problems mentioned above. This "Model Layer Thickness" part should be expanded in scale to more clearly show the confining layer thickness over the Savannah River area. Also, in Appendix B, figure 2-12, do the hydraulic properties and thicknesses shown in these figures represent values used in the model's river and nearby nodes? Statements on page 2-9 indicate a "yes" to this question. Thus, the use of $1.5E-4$ appears to be the "expected or most likely value" not a "conservative" value as stated on page 2-9. Lastly, it is surprising to see that the vertical and horizontal conductivity are the same in a unit consisting of layers of sand and clay as presented in Appendices D and E. Do you have any evidence to support that vertical and horizontal conductivities are the same in the Miocene Confining unit?

20. Appendix B, page 2-6: Ground Water Recharge Section 2.7: Need to present a defense for use of fixed heads in the surficial aquifer considering the importance of recharge from the surficial aquifer to the Upper Floridian Aquifer in those areas where pumpage has considerably lowered the Floridian heads.

21. Appendix B, page 2-6: Need to defend using the year 2000 pumping for future pumping. It is hard to accept it is a "conservative" approach to limit pumping to the 2000 rate considering the present and future population growth in southern Beaufort and Jasper counties and in the coastal area of Georgia. As a check what differences exist between 2005 to 2000 pumping rates?

22. Appendix B, page 2-7, Section 2.9.1: Refer to USAC comments 62 & 63 by Jim Fenske. I agree with these comments, and do not believe the author has adequately addressed these comments.

23. Appendix B, page 2-7: "This modeling study... effect on results". If the model is uncalibrated, one may be able to test model sensitivity to various input parameters, but cannot relate results to actual (real world) flow in transport conditions. Also, isn't the real design of the modeling study to construct and calibrate a flow and transport model that can be used to simulate with reasonable accuracy the potential intrusion of seawater (chlorides) into the Upper Floridian Aquifer?

24. Appendix B, Figure 2-21: the small scale and clutter of Figure 2-21 makes it difficult to decipher comparisons, especially in the deep cone of depression surrounding Savannah. This figure does not meet acceptable graphic standards, and should be redrawn at a larger scale to acceptable graphic standards.

25. Appendix B, page 2-7: "Typically a calibration...the model domain." Need to provide the basis for this statement, especially the part about "10 to 15% of the total

measured head gradient across the model domain" where an extremely deep cone of depression exists due to pumping.

26. Appendix B, page 2-7, Section 2.9.1 and Figure 2-21: Need to describe hydraulic and geohydrologic input data used in this steady state calibration. A reader can assume these data are those discussed in Sections 2.6 through 2.8, but one should not have to make an assumption of this type.

27. Appendix B, Figures 2-22 and 2-23: Because of the small scale, it is very difficult, if not impossible, to clearly compare results between the two models in the area of most interest, i.e. areas adjacent to the Savannah River where dredging may occur. This figure should be reconstructed at a larger scale.

28. Appendix B, page 2-8, Section 2.9.2: Figure 2-17 shows hydraulic properties and thicknesses of the Lower Floridian, do you mean Figure 2-18?

29. Appendix B, Figures 2-24 through 2-26: Need to discuss basis of construction for these figures.

30. Appendix B, Figures 2-24 through 2-26: All of these figures fail to meet standard graphic standards and are in need of improvement (explanations of features shown or figures incomplete, missing, or unclear).

31. Appendix B, page 2-8 Figures 2-27 and 2-28: These figures are difficult to analyze because the measured and simulated heads overlap and run together in the latter years. The importance of these figures warrant their reconstruction at a larger scale showing clear definition between measured and simulated heads. On figure 2-28, well 37Q016, the simulated heads show a large dip that is not shown by the measured heads. This discrepancy should be explained.

32. Appendix B, Figures 2-29 through 2-40: "illustrate the measured and simulated chloride" But figures 2-30 and 2-37 have no measured values. You should acknowledge this or delete the figures. Top of Miocene and top of Upper Floridian (Should spell UF out in all figures.) should be solid lines to be consistent with symbol explanations. Chloride concentration and penetration differences between simulated and observed values should be explained. Observed chloride value data points should be shown on figures. Simulated values are based on the year 2000; are measured values from the year 2000? If not, use of data from a different year should be acknowledged and justified.

33. Appendix B, page 2-9: "but is perhaps...of saltwater." The case has not been made that $1.5E-4$ is a conservative conductivity value. Report data and analysis suggest $1.5E-4$ is the expected or most likely conductivity value. If by conservative the author means a higher conductivity value than expected, which would result in greater than expected saltwater intrusion, a conductivity value on the order of $E-3$ would be conservative, likely resulting in simulated saltwater penetration to be deeper and chloride concentrations to be

greater than would realistically be expected. A value in the E-3 range as conservative is supported in data contained in Section 3 of the main report.

34. Appendix B, page 2-9: "Note that in ... 2-35 and 2-38". A careful look at these figures does not support the above quoted statement. Figure 2-30 does not contain any measured data, and Figures 2-29, 2-31, 2-35, and 2-38 do not show reasonable matches between observed and simulated chloride concentrations until near the top of the Upper Floridian. Chloride concentration differences between observed and simulated values throughout the Miocene confining unit should be explained.

35. Appendix B, page 2-9: "A second set... the two simulations". Data and analyses form the main report and supporting appendices do not support saying "The true system response lies somewhere in between the two simulations." The preponderance of evidence presented in the report and supporting appendices suggest that $1.5E-4$ is a reasonable or most likely value for the vertical conductivity of the Miocene confining unit, not a conservative value, and simulations made using $1.5E-4$ would unlikely show results decidedly skewed towards either underestimates or overestimates of saltwater penetration - assuming the model is adequately calibrated for its intended use. To bound probable system response, three simulations are needed - a simulation using $1.5E-4$ (most likely case), a simulation using $1.5E-3$ (worst or "conservative" case resulting in greatest saltwater intrusion), and a simulation using $1.5E-6$ (best case resulting in least saltwater intrusion). Such a set of simulations would provide both upper and lower bounds, and the most likely case for discussing saltwater penetration due to water moving into the Upper Floridian through the Miocene confining bed from overlying saltwater sources.

36. Appendix B, page 3-1: "generally result in... higher than measured". Data and analyses contained in Section 2 do not fully support the above statement. Figures 2-31, 2-35, and 2-38 show that in parts of the Miocene confining bed observed values of chloride are higher than simulated values. The authors should discuss possible alternate reasons for these differences within the Miocene, and then select and defend their preferred explanation for the differences. Also, no observed chloride values are available for the Upper Floridian; consequently, no comparison can be made between simulated and observed chloride values in the Upper Floridian, which leads to questions about how can one defend model calibration, and its ability to simulate with reasonable fidelity chlorides in the Upper Floridian.

37. Appendix B, page 3-1: "the calibrated value...sets of results." Data and analyses do not support that "the true conditions are bounded by the two sets of results". Data and analyses support using $1.5E-4$ (calibrated value) to represent "true conditions". This "true condition" is bounded on the "best case" level (value of conductivity that is likely to show saltwater penetration to be less than would be expected under "true conditions"), but is not bounded on the "worst case" level (use of a value of conductivity that is likely to show saltwater penetrations to be more than would be expected under "true conditions").

38. Appendix B, page 3-2: Table 3-1 shows simulated head 30 feet too low, not 25.

39. Appendix B, page 3-2: "but the mode somewhat overstated the rate of penetration" As discussed above, if penetration into the Upper Floridian is being implied, no observed data are shown to support that simulated chlorides are greater with depth than observed chlorides. It should be acknowledged that chloride comparisons are available only for the Miocene confining unit.

40. Appendix B, page 3-2, Table 3-1: See UAACE comment 59 (Fenske). For reasons presented in my above comments, I fully support Fenske's comment, and urge the authors to implement his suggestion. The authors' response to Fenske's comment and discussion on page 3-7 and 3-2 do not adequately address the concerns.

41. Appendix B, page 3-2: "the higher vertical... Floridian chloride concentrations". Since no observed chloride data were shown for the Upper Floridian in the SHE boreholes (figures 2-29 through 2-40), what is the basis for saying the higher conductivity value results in "unrealistic Upper Floridian chloride concentrations"? Also, it may be that higher simulated chloride concentrations in the Miocene result from the model ignoring dilution effects since it is not unreasonable to expect that low chloride water moving horizontally through relatively permeable sands in the Miocene unit is mixing with high chloride water moving downward from the overlying saltwater sources. Until various reasons for chloride differences between simulated and observed values are identified and discussed, no sound basis exists for simply assuming the differences exist because "conservative" conductivity values are used as model input. Remember, the chloride concentration difference also exists even when using the calibrated value, "which represents the mid range of reasonable values".

42. Appendix B, page 3-2, Figures 3-1 through 3-3: These figures are very difficult to decipher because of too many similar colors. These figures would be improved if colors were used only for chloride concentrations, and if geohydrologic units were defined by another method. A reference needs to be given for the vertical scale. A-A and B-B should be labeled as A-A' and B-B' to clearly show relation of cross sections to location maps. Titles should include "simulated chloride" before "concentrations" and "current" should be defined. No explanations of blue and red lines and of vertical and horizontal scales are given. These figures should be reconstructed to standard graphic requirements.

43. Appendix B, page 3-3: "two different values... potential impacts." as discussed before, "range of potential impacts" may not be bracketed.

44. Appendix B, page 3-3: On page 3-2, it is stated that initial model input is based on the year 2000 (figures 3-1 and 3-2), but in Section 3.3 1990 is shown as start of simulations. What is correct? Is a 200 or 210 year simulation used?

45. Appendix B, page 3-4: "Concentrations after 200 years" After 210 years if 1990 was starting year as presented on page 3-3. Need to resolve confusion about "starting year".

46. Appendix B, page 3-4: Should include in narrative and in Figures 3-5 through 3-16 actual conductivity values (1.5E-4 and 1.5E-5) used in the simulations (Don't leave reader guessing.).

47. Appendix B, Figures 3-5 through 3-16: Include actual conductivity values for "A" (1.5E-4 ft/d). As presently presented, titles for "A" are incomplete. A possible title for "A" could be "Simulated Chloride Profiles at SHE [borehole number] using a vertical conduction value of 1.5E-4 for the Miocene Confining Unit". A similar title should be used for the "B" graphs. Color lines for top of Upper Floridian and Miocene should be consistent with Legend (Legend shows "unbroken" lines, whereas the lines on the graph are "broken").

48. Appendix B, page 3-4: "The results show... consequent dilution effect." For clarity suggest wording to read "due to considerable horizontal flow of fresh water within the aquifer mixing with and diluting the relative very low volume of saltwater migrating downward from the Savannah River".

49. Appendix B, figures 3-17 through 3-28: Chloride scales for these figures should be expanded to more clearly show differences between dredging and no-dredging simulations, i.e. 0-100 mg/L, or 0-250mg/L or... as appropriate based on upper chloride levels. Reasons for "fluctuations" embedded in chloride trends should be discussed. As mentioned before, graph titles should give conductivity values used for "A" and "B" plots (1.5E-4 ft/d and 1.5E-5 ft/d respectively). For the reasons given in a number of my previous comments, a third plot using 1.5E-3 ft/d is needed to truly bound expected chloride concentrations.

50. Appendix B, Figures 3-17: Title and Legend on "B" give SHE-5. Should title and legend read SHE-15?

51. Appendix B, Figure 3-18: Similar problem as above. Either the "B" plots are on the wrong figure or are labeled incorrectly.

52. Appendix B, page 3-5 and figure 3-17 through 3-28: "The concentrations shown are computed for the top 50 to 60 feet of the Upper Floridian". Yet, the figures' titles read "Concentrations at the top of Upper Floridian Aquifer". Figure titles should be revised to show agreement with the text wording. The rationale for selecting the "top 50 to 60 feet" should be explained. If the top 10 feet of the Upper Floridian would have been selected, would simulated chloride concentration plots have differed significantly from those given in this report?

53. Appendix B, page 3-5: Should explain why 250mg/L was selected as "breakthrough" value and its significance. I really don't see the justification for ignoring the importance of the composite effects of all sources of saltwater contamination (amount due to both the Savannah River and other sources of saltwater) that could cause chlorides to exceed 250mg/L (the EPA limit). It is the composite sources of chlorides that are of importance to those who wish to obtain fresh drinking water supplies (chlorides less than

250 mg/L) from the Upper Floridian. Even a small increase in chlorides due to dredging could be significant if chloride concentrations without dredging are close to 250 mg/L.

54. Appendix B, figures 3-30 through 3-52: Should give actual Miocene confining unit vertical conductivities used for simulations "A" ($1.5\text{E-}4$ ft/d) and "B" ($1.5\text{E-}5$ ft/d). As said before, a third case using a Miocene confining unit vertical hydraulic conductivity of $1.5\text{E-}3$ ft/d should be presented as a bound for the worst case.

55. Appendix B, Figures 3-30 through 3-48: Reasons for the fluctuations imposed on the chloride trends should be explained.

56. Appendix B, page 3-5 and 3-6, Figures 3-30 through 3-48: I assume from the statement made on page 3-5 ("for the top 50 to 60 feet of the Upper Floridian Aquifer.") that model simulations are based on flow through the "top 50 to 60 feet of the aquifer". Evidence has been given by previous investigations, however, that show much of the flow through the Upper Floridian may take place through high-permeability zones consisting of only a small percentage of total aquifer thickness. Could this "preferred flow" occur between the Savannah River and the wells used in Figures 3-30 through 3-48 and, if so, what would the impact be to breakthrough times and chloride values?

57. Appendix B, page 3-6 and Figures 3-49 through 3-52: These are important figures and should be expanded in scale to more clearly show differences between dredging and no dredging. All the expanded figures should include lines of equal head showing the potentiometric surface of the Upper Floridian Aquifer. The "Year 2000" maps should include any available field measurements of head and chlorides allowing the reader to compare simulated and measured values. These figures as drawn do not meet normal graphic standards (no explanation of vertical and horizontal scales, no statement of conductivity values used for Figures 3-45 and 3-52 - reader should not have to assume what conductivity values were used).

58. Appendix B, General: USACE comments 54, 57, 60, 62, 67 bring out important weaknesses in the modeling approach that have not been adequately resolved. This along with concerns expressed in my review comments lead me to question the validity, conservatism, and defensibility of simulation results and analyses presented in Appendix B and in various sections of the main report, "Supplemental Studies to Determine Potential Ground-Water Impact to the Upper Floridian Aquifer". Nor is it clear to me that the model has been adequately calibrated for its intended purpose - simulation of transient flow and chloride transport vertically through the Miocene confining unit and then horizontally through the upper 50-60 feet of the Floridian Aquifer.

59. Appendix C: General Comment: Insufficient documentation is provided to show that the GIS Analysis is valid for intended use. How would an independent reader know that the software and subroutines perform as intended in constructing Miocene thickness maps and other maps?

60. Executive Summary, General Statement: For reasons given in review of Appendix B, I am not convinced "true conditions" are bracketed. For this and other concerns raised in my review, I question conclusions based on model simulations presented herein, in Section 63 of the Summary, and in the conclusion.
61. Overview, page 2-1: "MLW" should be defined the first time used.
62. Study Area, page 3-2: "Heron and Johnson, 1966" not given date on list of figures.
63. Study Area, page 3-2 and Figure 3-1: "The elevation of... roughly - 95 feet MLW" Figure 3-1 shows the top of the Oligocene at about -120. If you don't wish to reference the bottom paragraph on page 3-2 to Figure 3-1, some other reference should be given.
64. Study Area, page 3-3: Should provide reference for unit elevation given in discussion at top of page.
65. Study Area, page 3-5: Can significant be qualified, i.e. percentage amount?
66. Study Area, page 3-7: Should provide reference of unit elevations.
67. Study Area, page 3-7: Date for "(Fanning, 1990)" is 1999 in list of references.
68. Study Area, page 3-9: Should provide reference for unit thicknesses given in top paragraph.
69. Study Area, page 3-10: Should provide a reference for unit thicknesses given in middle paragraph.
70. Study Area, Figure 3-4: Should define genesis of all boreholes (SHE boreholes in dark type and SHE boreholes under these contained within parenthesis) in Legend. All symbols used in a figure should be defined in the figure legend.
71. Study Area, Figure 3-6: Normally, contour numbers are included within a break on the contour line. This avoids guessing what contour value goes with what contour line. Can this be done in this figure where contour spacing allows?
72. Study Area, Congratulations for a well written section.
73. Methods, page 4-2: "seven marine continuous borings" and "two additional land borings" give boring numbers so a reader can go to Figure 4-1 and locate the borings.
74. Methods, page 4-3, Section 4.1, Figure 4-1: "nine additional borings" Figure 4-1 shows 11 not 9 borings.
75. Methods, page 4-4: "occasional core losses" can occasional be quantified, i.e. percentage of losses?

76. Methods, page 4-4, Section 4.1.2: "Two land borings" Figure 4-1 shows four land borings (SHE 19, SHE 10 and SHE 18) and these same land borings are discussed on page 4-9. Why are SHE 9 and SHE 10 not discussed in Section 4.1.2?

77. Methods, page 4-5, Section 4-2: "downward flow accounts" Should acknowledge the importance of other "portion[s] of the water budget" which are considerably more significant than vertical flow through the Miocene confining bed.

78. Methods, page 4-6, Section 4.2.1.1: "a procedure was... at SHE-9" Why was this procedure done only at SHE-9? Since this procedure was done only at SHE-9, how can one be assured that fresh water in the drilling fluid did not migrate into the core samples (especially into the more permeable zones), thus "contaminating" core samples with relatively fresh water? What were the selection criteria for the "given cross section"? Was this the only section tested or were other sections tested?

79. Methods, page 4-13: "Garza and Krause, 1994" Date is 1996 in References, Section 8.

80. Methods, page 4-15: "model was tested... and chloride concentrations" compelling evidence has not been presented confirming that the model can "adequately reproduce" chloride concentrations. Data shown in Appendix B, Figures 2-29 through 2-40 show that the model simulated chloride values differ considerably from observed chloride values, and no data are presented that show how well, or how poorly, the model is able to simulate chloride values in the Upper Floridian Aquifer. Thus, in using the model to simulate chloride transport through the Upper Floridian, the model is being used to simulate a set of conditions outside the conditions for which the model has been calibrated.

81. Methods, pages 4-16 and 4-17, Section 4.4.3.1: See my comments given in Appendix B.

82. Methods, Table 4-2: Boundary conditions should be defined here, or reader should be pointed to where these boundary conditions are described in Appendix B.

83. Methods, page 4-20, Section 4.4.3.5: "the 2000 pumping... into the future". See my comments given in Appendix B.

84. Methods, pages 4-22 through 4-27, Section 4.4.4.2 and 4.4.5: See my comments given in Appendix B.

85. Methods, page 4-25: "general consensus among ... in the areas." A "general consensus" is not the same as in-place regulations or restrictions. To check this "consensus", differences between the years 2000 pumping to the year 2005 should be compared. Also, can you really ignore the increases in pumping taking place in nearby Jasper and Beaufort Counties, South Carolina?

86. Methods, page 4-27: "withdrawal rates are expected to decrease in the future." What evidence exists for this statement?
87. Methods, page 4-33: "(Ranson and White, 1998)". No date for this reference provided in Section 8, References.
88. Results, page 5-1: "Miocene units A and B" suggest insert "Table 3.1" to help reader put these units into a framework relative to other sediments.
89. Results, page 5-1: "lower boundary of... from +40 to -50 MLW." Suggest you insert Figure 3-4.
90. Results, page 5-1: "relict channels the Pleistocene" Seems wording is incomplete.
91. Results, page 5-2: "boring SHE 318 (Figure 3-3): Do you mean Figure 3-4? There is no Figure 3-3, and Figure 3-3a and 3-3b do not show any contacts.
92. Results, page 5-2: "Huddleston (1988)" is not included in Section 8, References.
93. Results, page 5-2: "Talmidge Bridge (Figure 3-3)." Is the correct reference Figure 3-4?
94. Results, page 5-2: What is the meaning of "historically"?
95. Results, page 5-3: "contact at 67 MLW (Figure 3-3)." Is the correct reference Figure 3-4?
96. Results, page 5-3: "Bartholomew et. al. (2000)" is not included in Section 8, References.
97. Results, page 5-3: "at SHE-14(figure 3-3)." Is the correct reference 3-4?
98. Results, page 5-4: "The resulting profiles" If these are the profiles shown in Figures 2-29 through 2-40, Appendix B, these figures should be referenced.
99. Results, page 5-4, Section 5.2: "All profiles indicated...with increased depth." Considering the chloride fluxuations with depth given in Table 5-1, Figure 5-1, shown in Figures 2-29(SHE-15), 2-31(SHE-19), 2-32(SHE-19), 2-33(SHE-10), 2-34(SHE-18), 2-35(SHE-11), and 2-38(SHE-14), this statement is somewhat misleading and should be revised to acknowledge and discuss chloride concentrations fluxuations with depth.
100. Results, page 5-4, Section 5.2.1: "The profiles show...with descending elevations," See above comment

101. Results, page 5-4: "50 percent to 5,252 mg/L". Table 5-1 gives 5,253 mg/L as the highest value.
102. Results, page 5-4: "no values above 100 mg/L below the Miocene A/B contact". Table 5-1 gives a chloride value of 176 below the Miocene A/B contact (first sample in the Miocene B unit).
103. Results, Table 5-1: SHE-16 shows a chloride concentration in the top of the Oligocene (top of Upper Floridian) of 24 mg/L, and borehole SHE-14 shows a chloride concentration in the top of the Oligocene of 151 mg/L. It should be explained why these chloride values significantly exceed the chloride values at the bottom of the Miocene B unit.
104. Results, Table 5-1 and Figures 2-29 through 2-40: Because of the close tie to Table 5-1 and Figures 2-29 through 2-40, a common elevation reference should be used.
105. Results, Table 5-1: Why, for SHE-15, are P-1 and P-2 shown at the bottom of the table instead of on page 5-5 with the other SHE-15 samples?
106. Results, page 5-6 and Table 5-1: "concentration (7209 ms/L) was observed... the riverbed (-41.3ft MLW)". Table 5-1 shows this sample at a depth of -52.5. Which is correct?
107. Results, page 5-7: "fluctuated from 1,264". Table 5-1 gives low chloride value as 901 mg/L not 1,264.
108. Results, page 5-13 and 5-3: "the yellow reflector". There is no yellow reflector shown on Figure 5-3.
109. Results, pages 5-17 through 5-22, Ground Water Model: See comments made in Appendix B.
110. Results, page 5-23: Can a reference be given for the Clemson University test conducted in 1977?
111. Results, page 5-27, Section 5.6.4.1 Suggestions in USACE comment 58 (Fenske) should be implemented.
112. Results, pages 5-27 through 5-32, and Table 5-5: See comments provided in Appendix B. All of the data shown herein seem to support the use of about $1.5E-4$ as a realistic average values for the vertical hydraulic conductivity of the Miocene confining unit (a "realistic or expected" value, not a "conservative" value).
113. Summary, page 6-1: "In addition, the model, and no dredging conditions. Data and analysis does not support that "true conditions" have been bracketed" yielding a best-case and worst-case scenario". Data and analysis support using $1.5E-4$ ft/d for the "true

conditions" scenario and $1.5E-5$ ft/d for the "best case" scenario. To bracket "true conditions" a worst-case scenario needs to be provided. A vertical hydraulic conductivity of around $1.5E-3$ is reasonable for the worst-case scenario.

114. Conclusions, page 7-5: "The pore water profiles...city of Savannah." Authors provide some evidence and analyses in support of the above conclusion. But, this reviewer believes that weaknesses exist in data analysis and model development and use that could be used to challenge to the final conclusion. Also your case is weakened by omitting years 2000 to 2200 simulations in the Savannah area showing (1) chlorides due to existing sources without dredging, (2) expected chlorides due to existing sources and dredging, and (3) a large-scale map showing differences between dredging and non-dredging simulations, with a statistical analysis included in the discussion of differences quantifying to the extent reasonable the significance of dredging to total chloride concentrations. After all, the proposed dredging area is relatively insignificant compared to presently existing sources of chloride.

TO: Susan Ivester Rees, Lead Oceanographer
 Coastal Environmental Team, Planning and Environmental Division
 U.S. Army Corp of Engineers
 Mobile District
 P.O. Box 2288
 MOBILE AL 36629-0001

SUBJECT: Requested Review of "Review of Supplemental Studies to Determine Potential Ground-Water Impacts to the Upper Floridan Aquifer, Proposed Savannah Harbor Expansion Project"

Charge Questions

Question 1) Are there any elements you feel could be included in the framework of the report which would strengthen the document?

Answer: The document does not indicate that the DYNCFIT part of the simulation code has been tested or verified by an independent group, such as the International Ground-Water Modeling Institute. This is the part of the simulation code that approximates the variable density component of the hydrodynamics. The other two components of the code DYNFLOW and DYNTRACK had referenced documentation that the codes had been verified to work correctly. Since the simulation code applied for the SHE supplemental study appears to be a proprietary code developed by CDM it is important that the code have independent verification as no such verification is contained within the current document. Additionally, the documentation of the variable density approximation implemented in the DYNCFIT part of the simulation code is minimal and no other reference to code documentation is provided.

Question 2) Are you aware of any other significant data/studies that are relevant and should be included.

See new references

Dorothy F. Payne, Malek Abu Rumman, and John S. Clarke, 2005, Simulation of Ground-Water Flow in Coastal Georgia and Adjacent Parts of South Carolina and Florida—Predevelopment, 1980, and 2000: U.S. Geological Survey Scientific Investigations Report 2005-5089, 81 pages

John S. Clarke, David C. Leeth, DeVette Taylor-Harris, Jaime A. Painter, and James L. Labowski, 2005, Summary of Hydraulic Properties of the Floridan Aquifer System in Coastal Georgia and Adjacent Parts of South Carolina and Florida: U.S. Geological Survey Scientific Investigations Report 2004-5264, 54 pages

Page 1 of 2

Michael F. Peck and Keith W. McFadden, 2004, Potentiometric Surface of the Upper Floridan Aquifer in the Coastal Area of Georgia, September 2000: U.S. Geological Survey Open-File Report 2004-1030, 1 sheet

Question 3) Do you feel that the two model simulations likely bracket the expected true impacts of dredging?

Answer: There seemed to be a backwards thought process, in that, the conclusions indicate that the two simulations represented what was thought to be actual case and then the worse case scenario. When in fact the "sensitivity" simulation or "worse case" simulation was accomplished with a reduced conductance of the Miocene confining unit. This is a best case scenario, in that the transport of saline water through the confining unit would be reduced if the confining unit hydraulic conductivity is reduced. For a worst case scenario one would have an increased vertical hydraulic conductivity of the Miocene confining unit. Additionally, no runs were accomplished with changes in the porosity or storage parameters. A decrease in porosity would result in an increase in the velocity in the solute transport simulation. So a worst case scenario would have increased hydraulic conductivity of the Miocene confining unit and decreased porosity and for transient runs a decrease in storage parameters. Because the calibrated parameter values are assumed to be the correct values, then the increases or decreases in parameters for a worst case scenario should reflect the uncertainty in the parameter. The standard deviation of parameter information from observed data could be used, for example, for the increase perturbation of the hydraulic conductivity of the Miocene confining unit.

Question 4) Do you feel that the model assumptions are consistently and sufficiently conservative to overpredict impacts using the mid-level Kv?

Answer No, this is not conservative and is probably close to the correct choice and may not overpredict the impacts. In general, most geologic materials have heterogeneity and the transport occurs through the more permeable units, thus picking the mid-level Kv is appropriate and given the observed data provided a reasonable fit between simulated and observed data was achieved. A true worst case scenario as discussed above would be a conservative simulation to overpredict impacts.

Question 5) Do you feel that the combination of field data and model framework adequately address the impacts of dredging?

Answer: Aside from perhaps using a higher Kv for the Miocene confining unit and decreased porosity as the worse case scenario, the approach is good.

Question 6) Do you feel the report contains sufficient documentation to adequately support the conclusions?

Answer: Aside from documentation of the code verification for DYNCFIT and doing a true worst case scenario simulation rather than a best case simulation, there is ample documentation to support the conclusions.

ATTACHMENT 1

High-Value K_v Simulation Results



United States Army Corps of
Engineers
Savannah District

Savannah Harbor Expansion
Three-Dimensional Salt Water Intrusion
Modeling

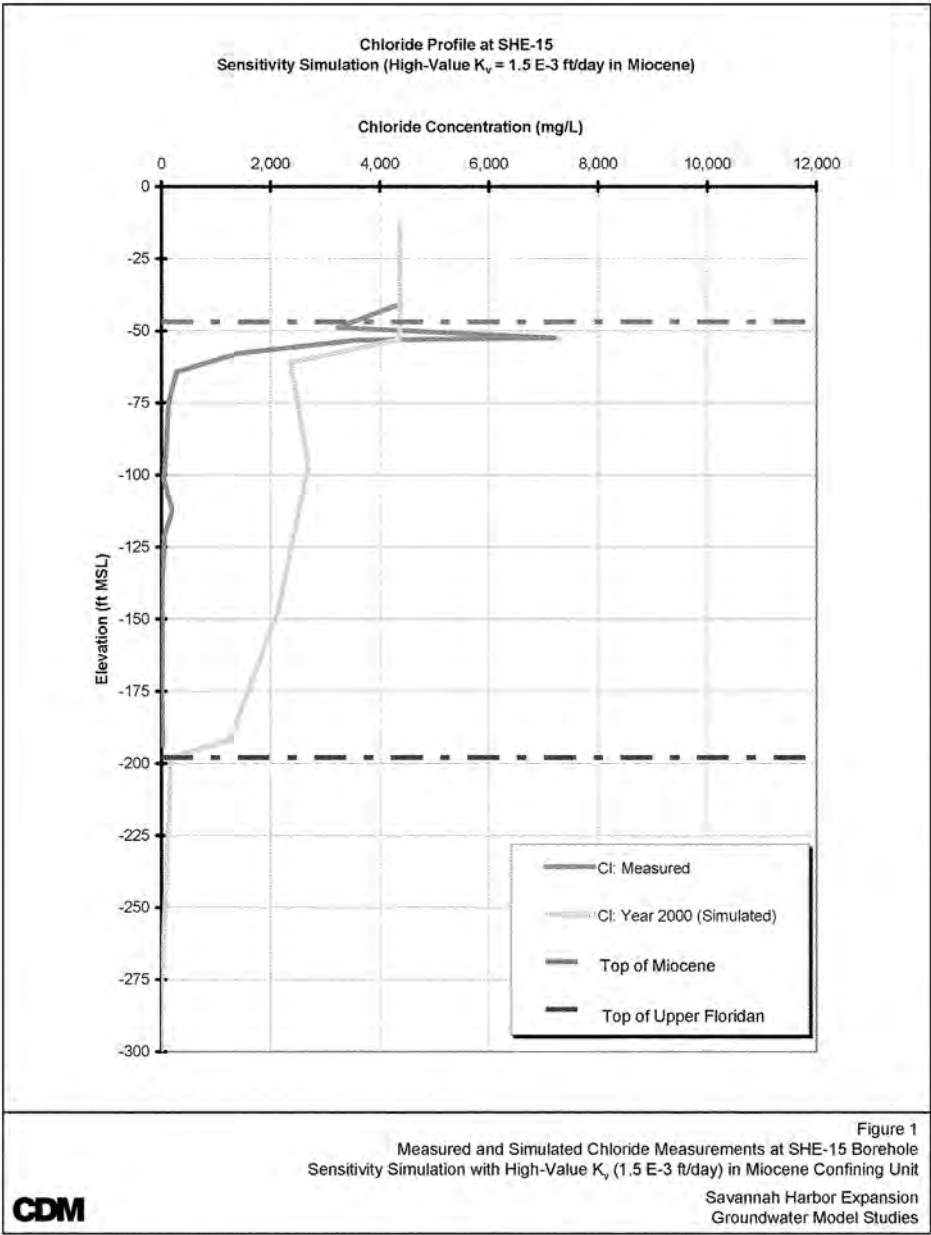
October 24, 2006

*Technical
Memorandum
Addendum #1*

High-Value Kv Model Simulation Results

The model application used two values of vertical hydraulic conductivity (Kv) for the Miocene confining unit: the calibrated value, which represents the mid-range of reasonable values, and a lower value. In doing so, the two sets of results appeared to bound true conditions. In response to reviewer questions, a third simulation was performed to check the impact of a higher Kv value for the Miocene confining unit, this time assigning a value of 1.5×10^{-3} ft/day, an order of magnitude higher than the calibrated value. This value appears to be too high based on the calibration statistics of the well readings within the pumping cone of depression. The simulation produced heads in the cone of depression in the Upper Floridan aquifer that were more than 20 feet too high when compared to field data. The calibrated value of hydraulic conductivity produced accurate head distribution within the cone of depression, but the model results overestimated the rate of penetration when compared to the porewater sample data. This overestimation of the rate of penetration was even more exaggerated when the high Kv parameter was used. Results of the high Kv sensitivity simulation are provided in figures 1 through 12. The figures clearly show that at every boring location, the projected concentration at the bottom of the Miocene confining unit is overestimated. In fact, with this high Kv value, the model simulates that salt water would have fully penetrated the Miocene confining unit entered the Upper Floridan aquifer. This is not supported by field data.

Despite the fact that this Kv value is clearly too high, simulations were also run forward in time with a 1-year time-step for a period of 200 years. The simulated 2000 distribution of chlorides in the Miocene unit was used as the initial condition. Note that these figures represented significant penetration of chlorides into the Miocene confining units as of "today" (i.e. the start of the projection simulation). Figures 13-24 show the simulated chloride profile results for both the no-dredging and dredging scenarios, and figures 25-55 show individual time histories at selected borehole locations and production wells. Overall, the same conclusions hold. The difference in chloride concentration in the Upper Floridan aquifer between the results of the dredging scenario and no dredging scenario were small.



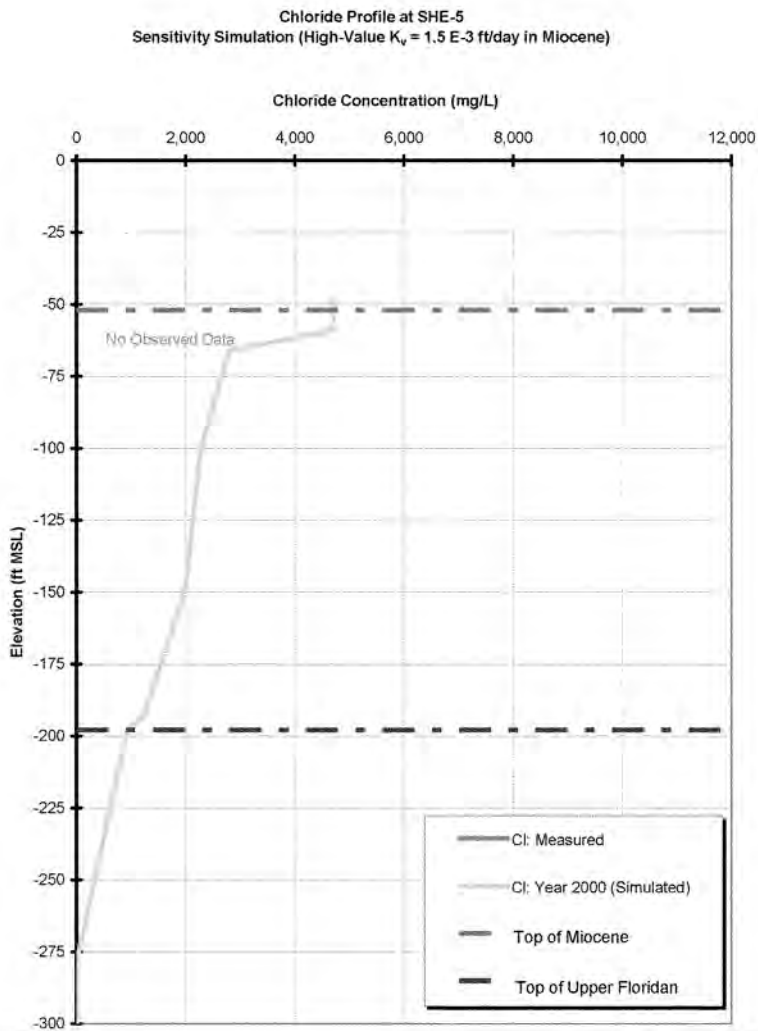


Figure 2

Measured and Simulated Chloride Measurements at SHE-5 Borehole
Sensitivity Simulation with High-Value K_v (1.5 E-3 ft/day) in Miocene Confining Unit

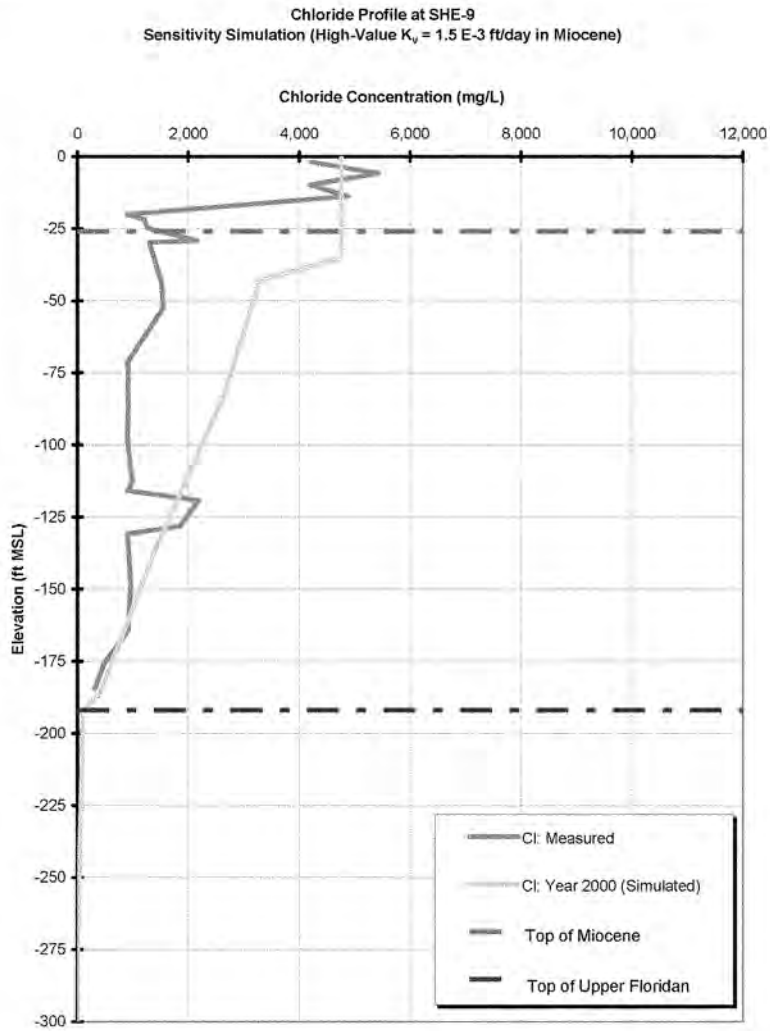


Figure 3
Measured and Simulated Chloride Measurements at SHE-9 Borehole
Sensitivity Simulation with High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in Miocene Confining Unit

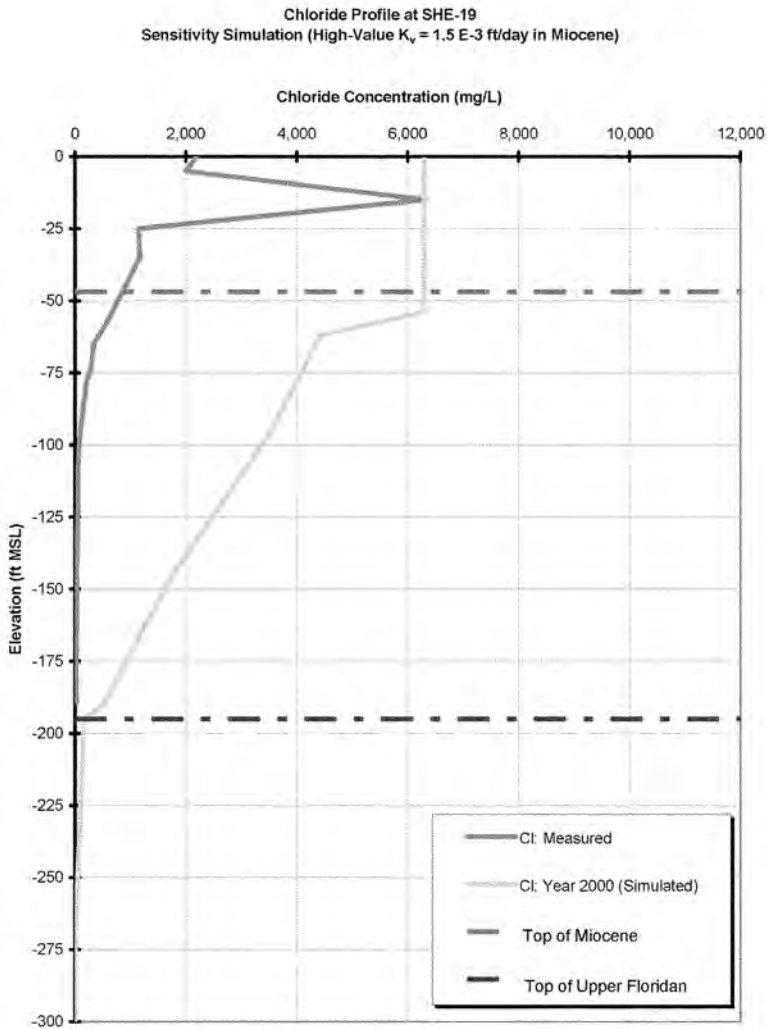
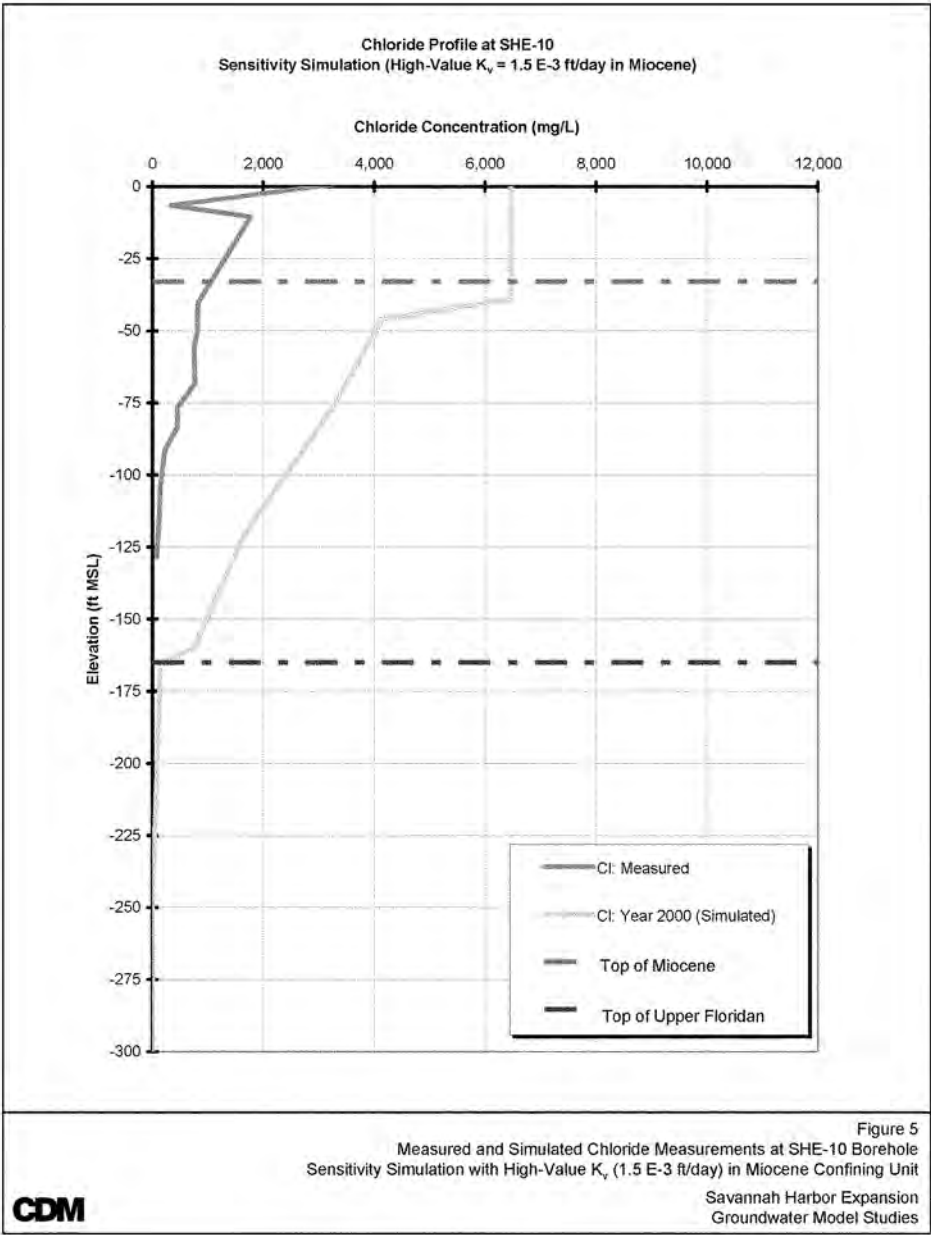


Figure 4

Measured and Simulated Chloride Measurements at SHE-19 Borehole
Sensitivity Simulation with High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in Miocene Confining Unit

Savannah Harbor Expansion
Groundwater Model Studies



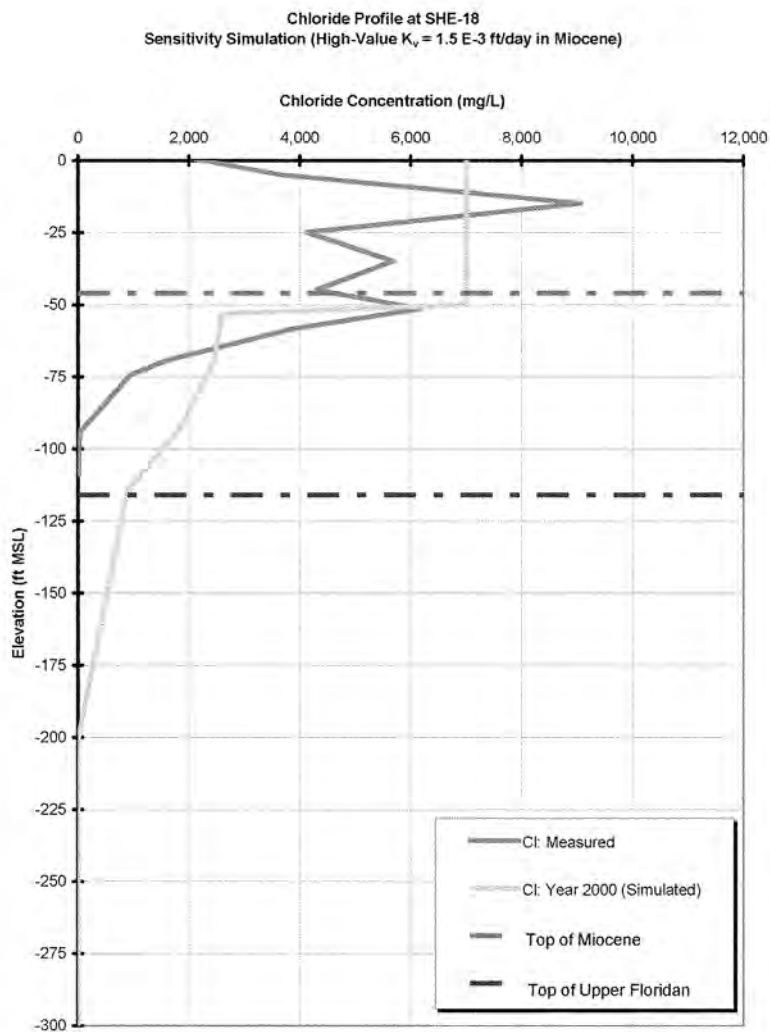


Figure 6

Measured and Simulated Chloride Measurements at SHE-18 Borehole
Sensitivity Simulation with High-Value K_v (1.5 E-3 ft/day) in Miocene Confining Unit

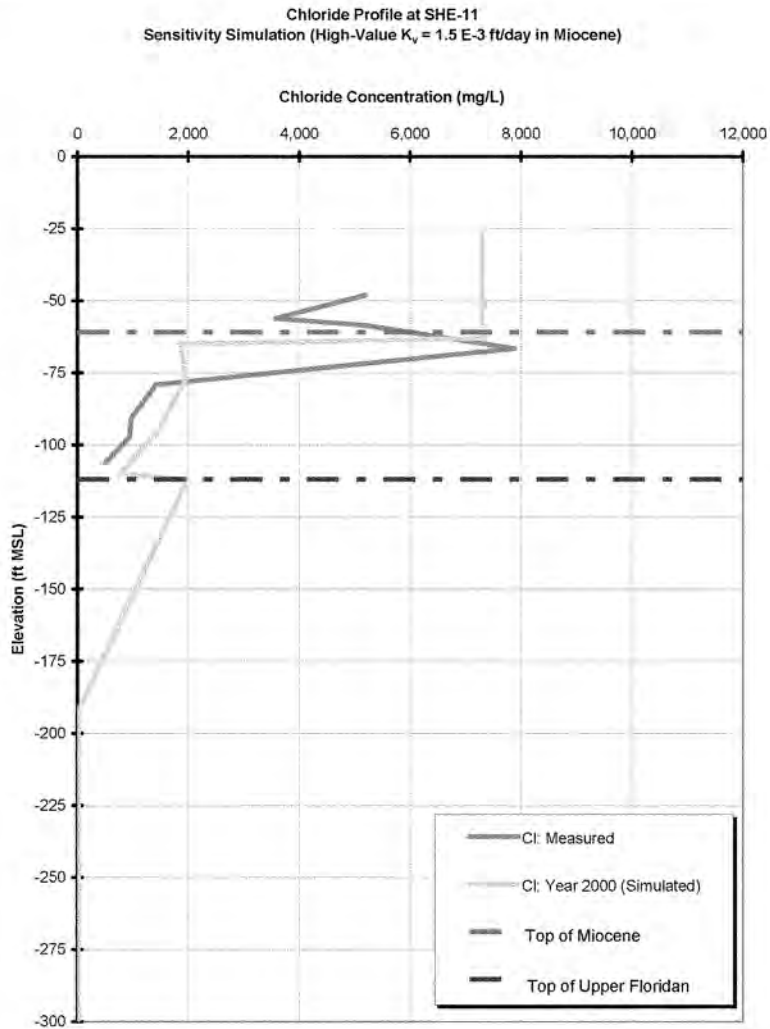


Figure 7

Measured and Simulated Chloride Measurements at SHE-11 Borehole
Sensitivity Simulation with High-Value K_v (1.5 E-3 ft/day) in Miocene Confining Unit

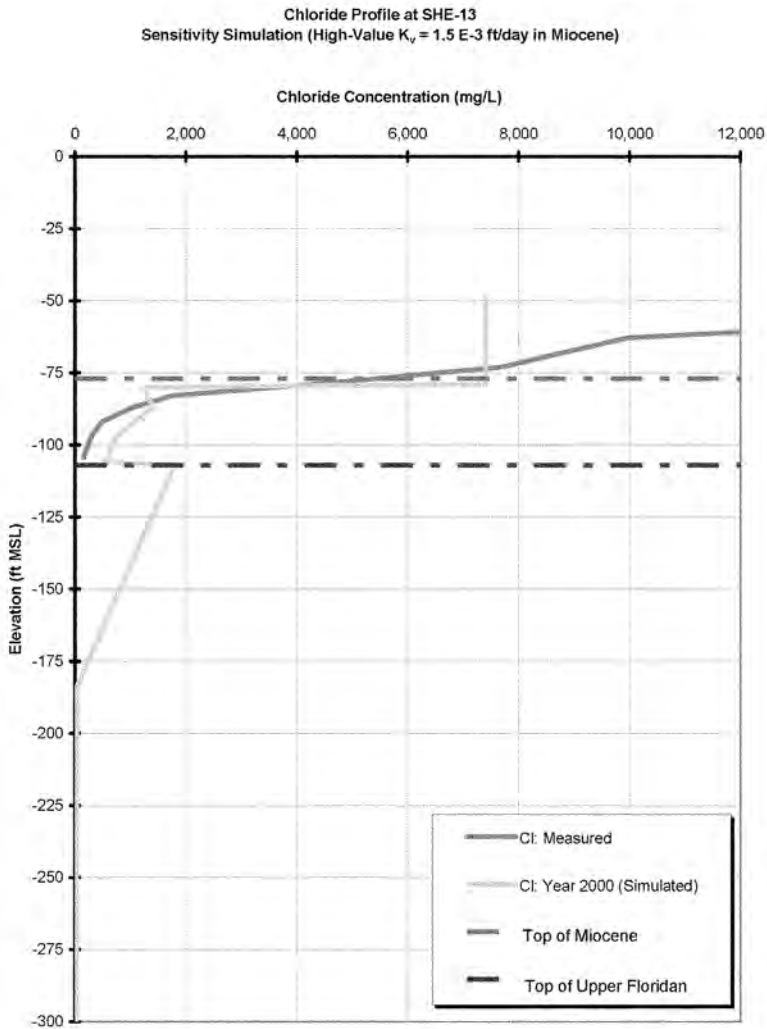


Figure 8

Measured and Simulated Chloride Measurements at SHE-13 Borehole
Sensitivity Simulation with High-Value K_v (1.5 E-3 ft/day) in Miocene Confining Unit

Savannah Harbor Expansion
Groundwater Model Studies

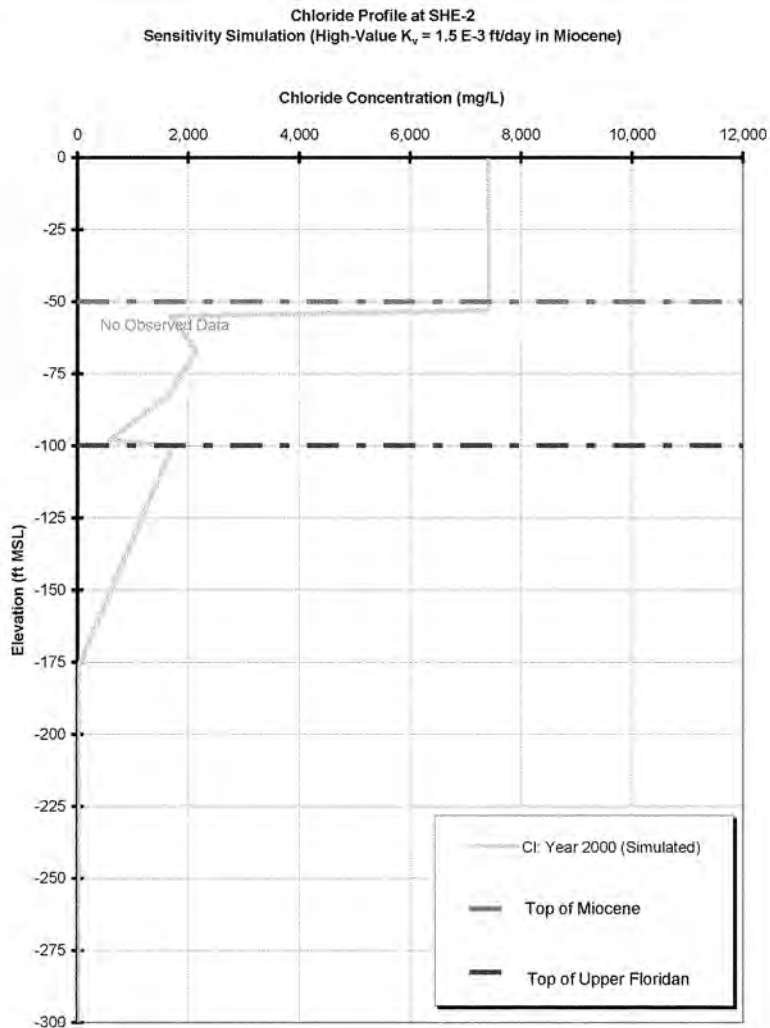


Figure 9

Measured and Simulated Chloride Measurements at SHE-2 Borehole
Sensitivity Simulation with High-Value K_v (1.5 E-3 ft/day) in Miocene Confining Unit

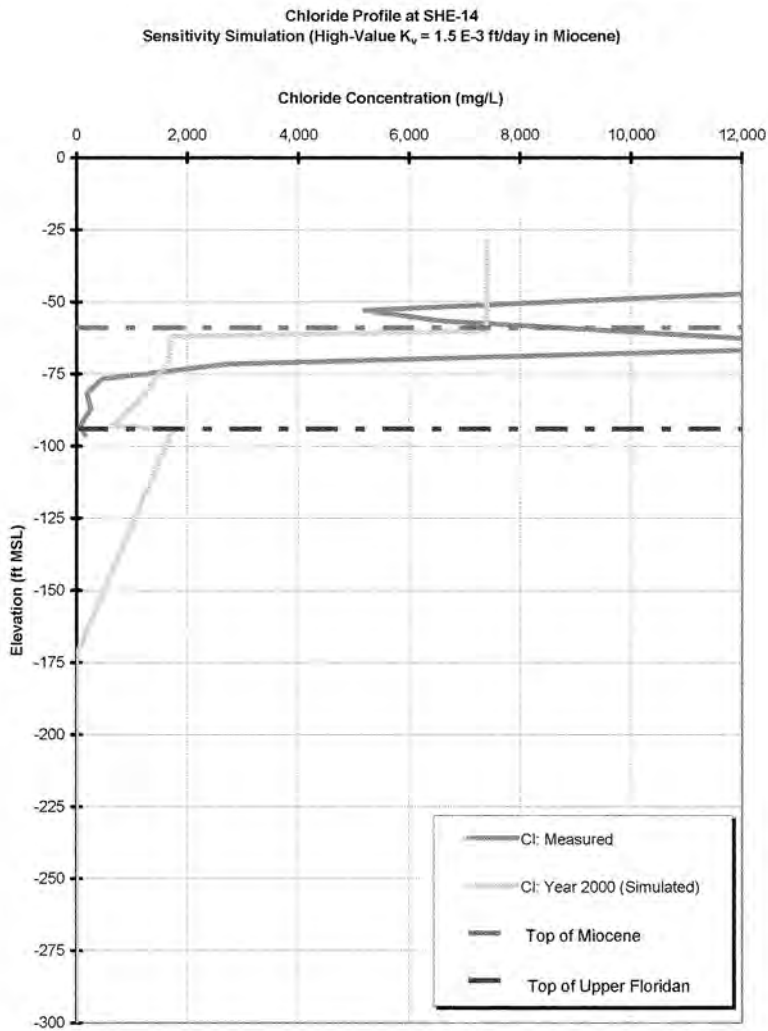
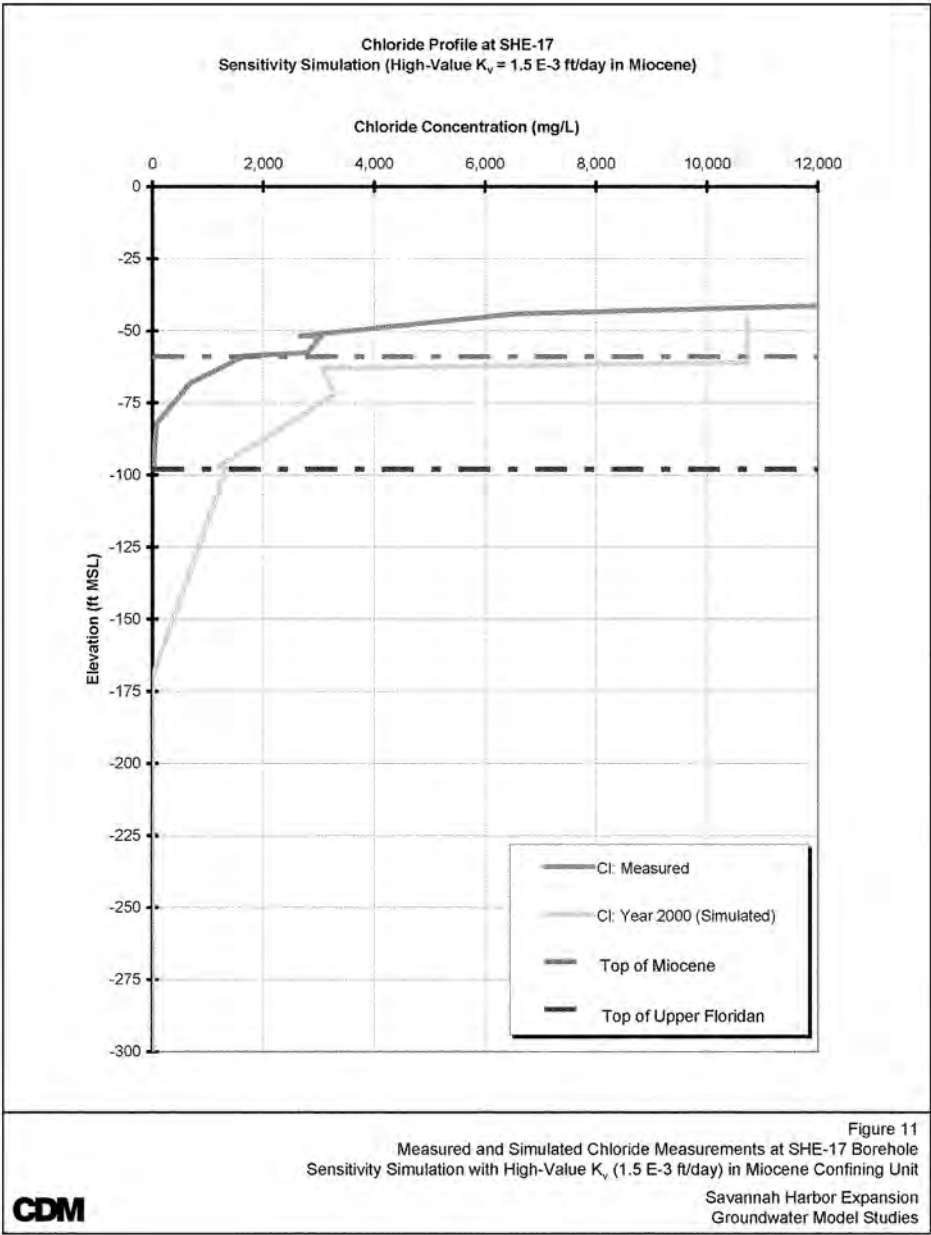


Figure 10

Measured and Simulated Chloride Measurements at SHE-14 Borehole
Sensitivity Simulation with High-Value K_v (1.5 E-3 ft/day) in Miocene Confining Unit

Savannah Harbor Expansion
Groundwater Model Studies



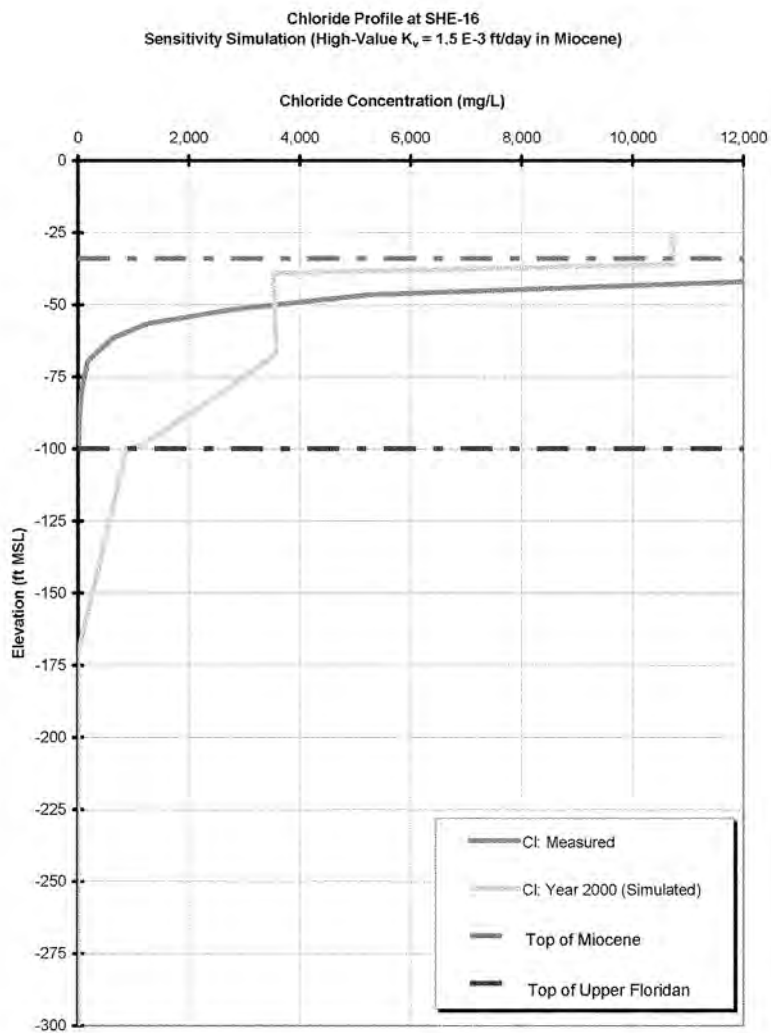
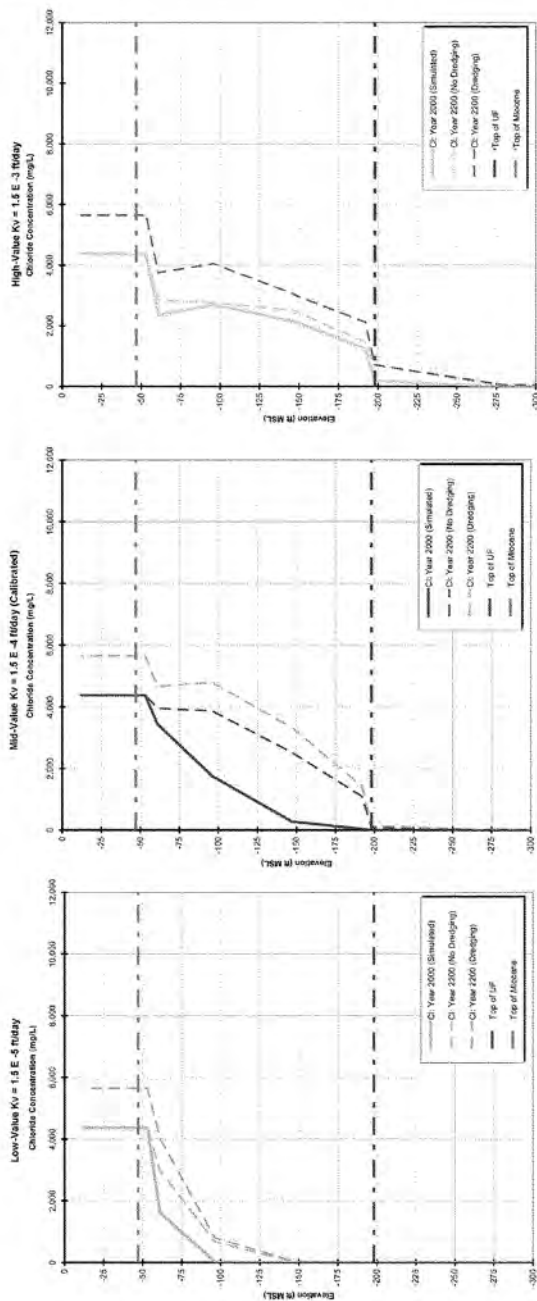


Figure 12

Measured and Simulated Chloride Measurements at SHE-16 Borehole
Sensitivity Simulation with High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in Miocene Confining Unit

Comparison of Simulated Chloride Concentrations Profiles at SHE-15
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



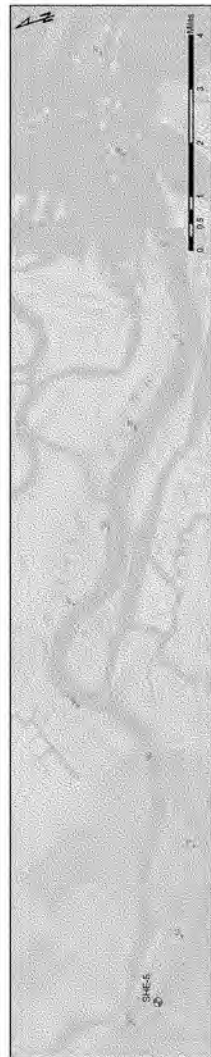
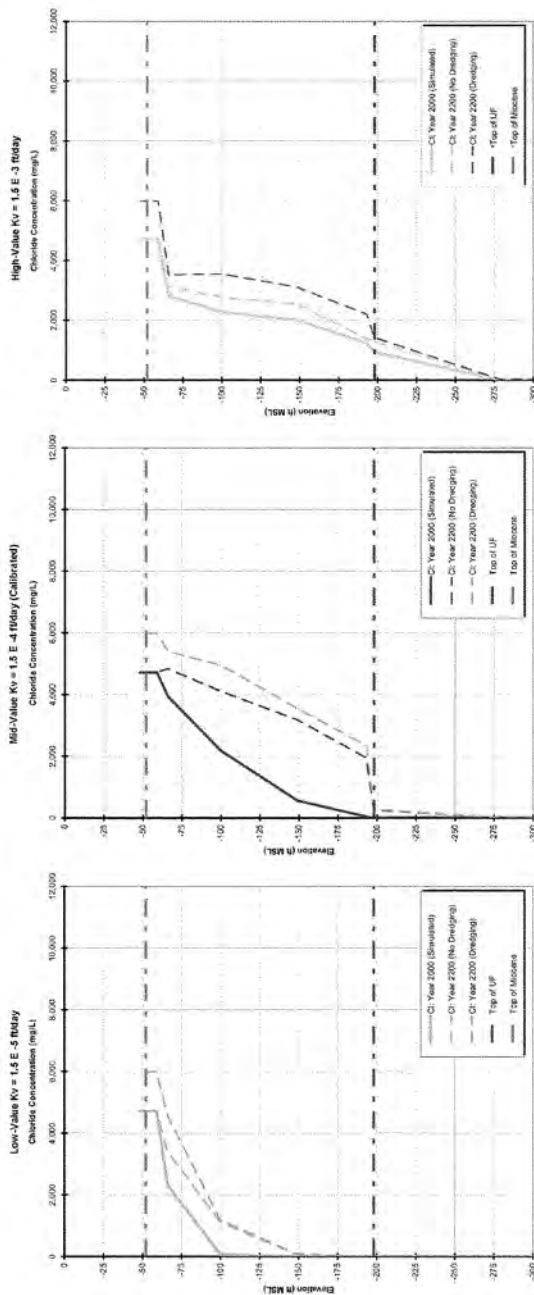
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-15

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Figure 13

Comparison of Simulated Chloride Concentrations Profiles at SHE-5
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



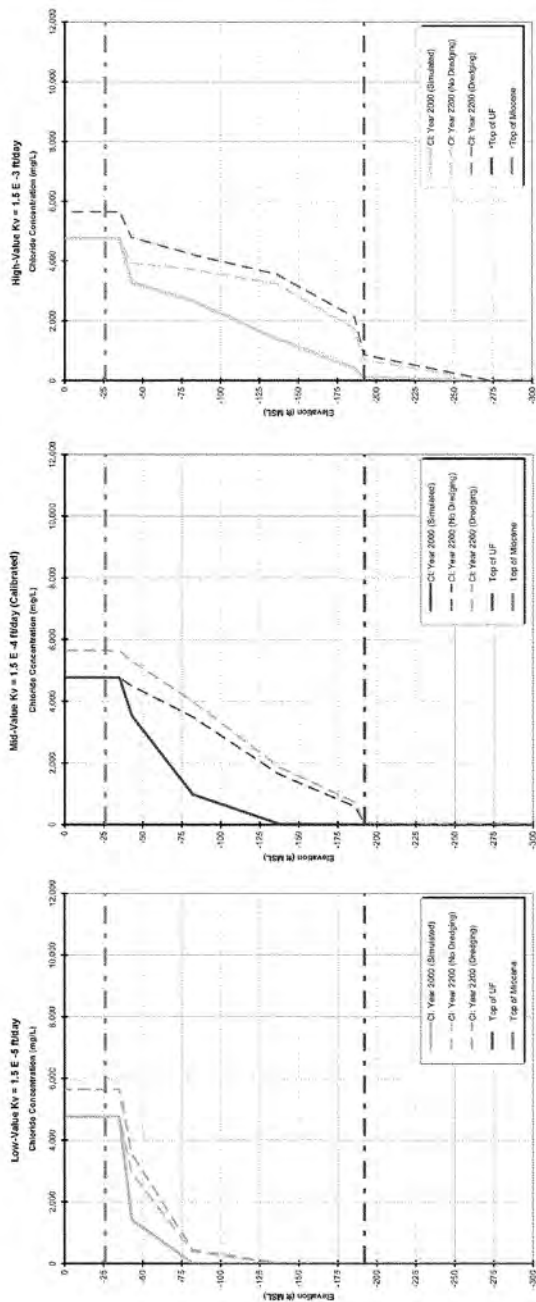
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-5

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OF ENGINEERS
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Figure 14

Comparison of Simulated Chloride Concentrations Profiles at SHE-9
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



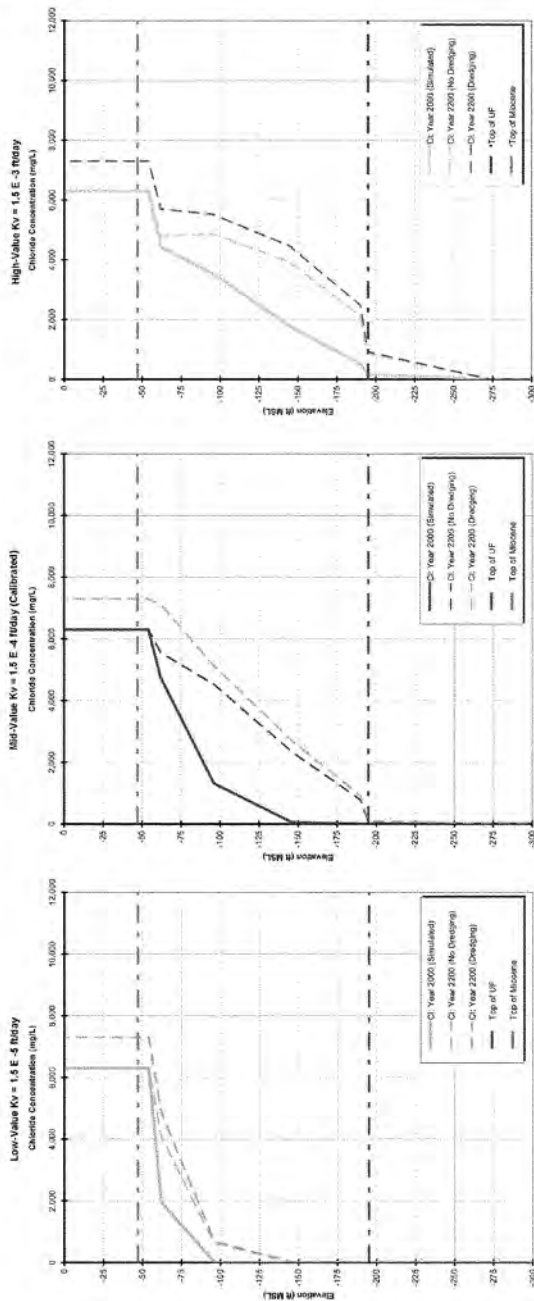
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-9

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Figure 15

Comparison of Simulated Chloride Concentrations Profiles at SHE-19
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



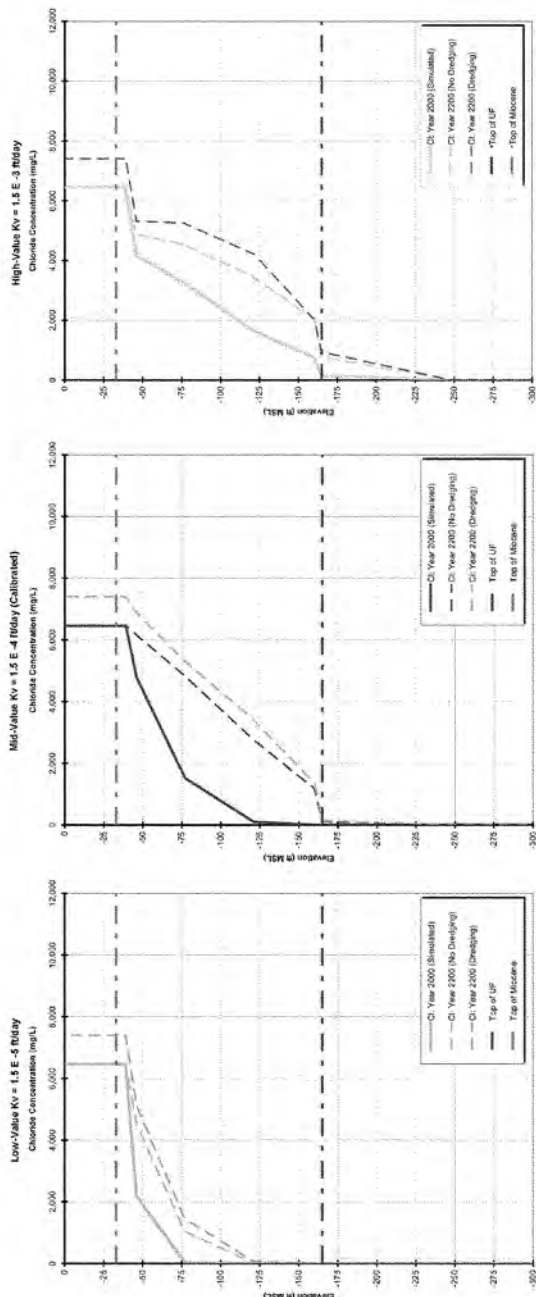
Comparison of Simulated Chloride Concentrations Profiles at SHE-19

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Figure 16

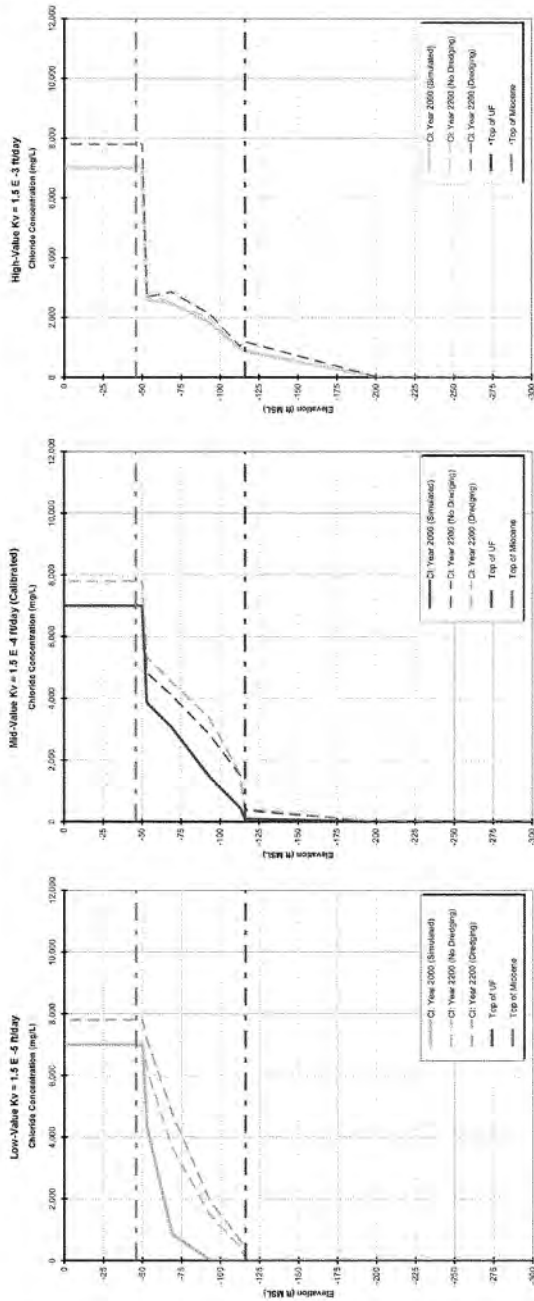
Comparison of Simulated Chloride Concentrations Profiles at SHE-10
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



Comparison of Simulated Chloride Concentration Profiles at SHE-10	
SHE SUPPLEMENTAL STUDIES	
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Figure 17

Comparison of Simulated Chloride Concentrations Profiles at SHE-18
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



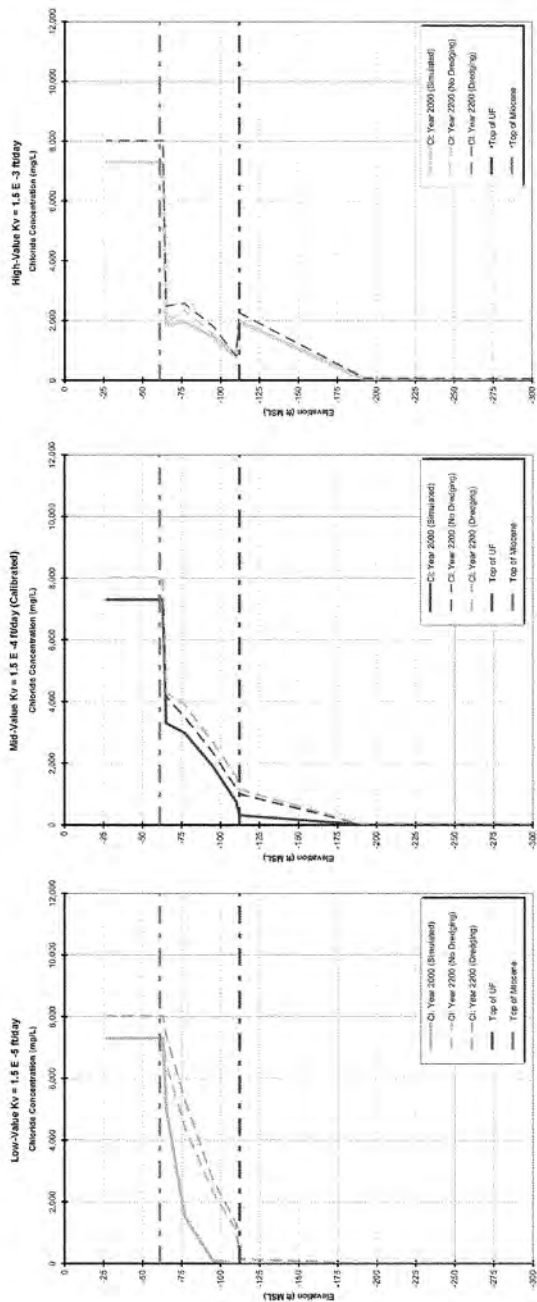
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-18

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Figure 18

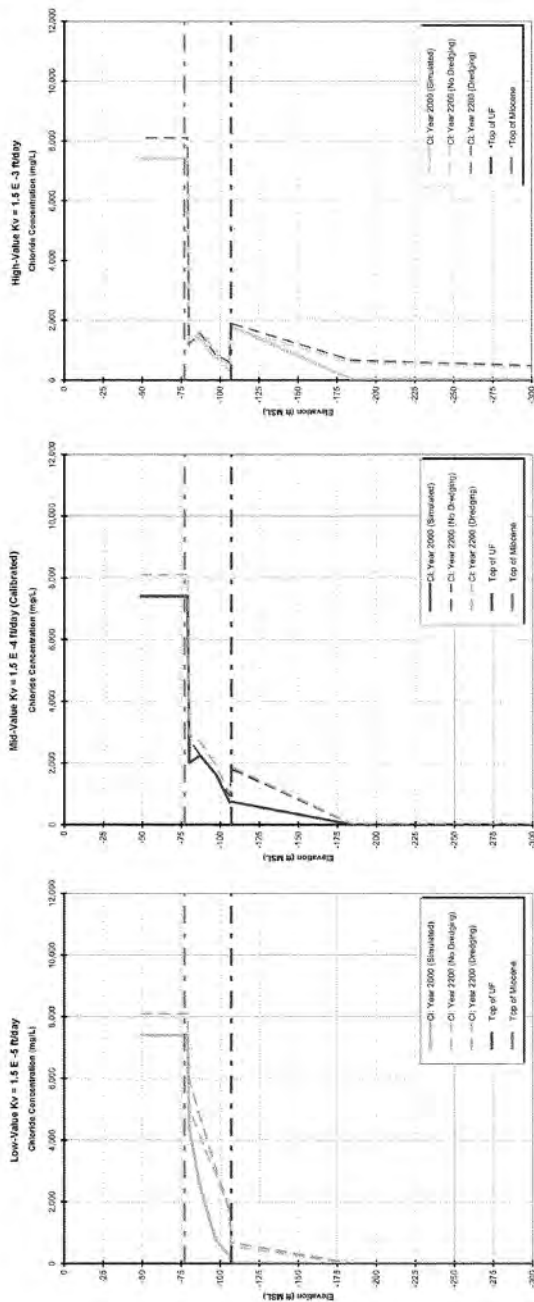
Comparison of Simulated Chloride Concentrations Profiles at SHE-11
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



Comparison of Simulated Chloride Concentrations Profiles at SHE-11	
SHE SUPPLEMENTAL STUDIES	
U.S. ARMY CORPS OF ENGINEERS SAVANNAH DISTRICT	

Figure 19

Comparison of Simulated Chloride Concentrations Profiles at SHE-13
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



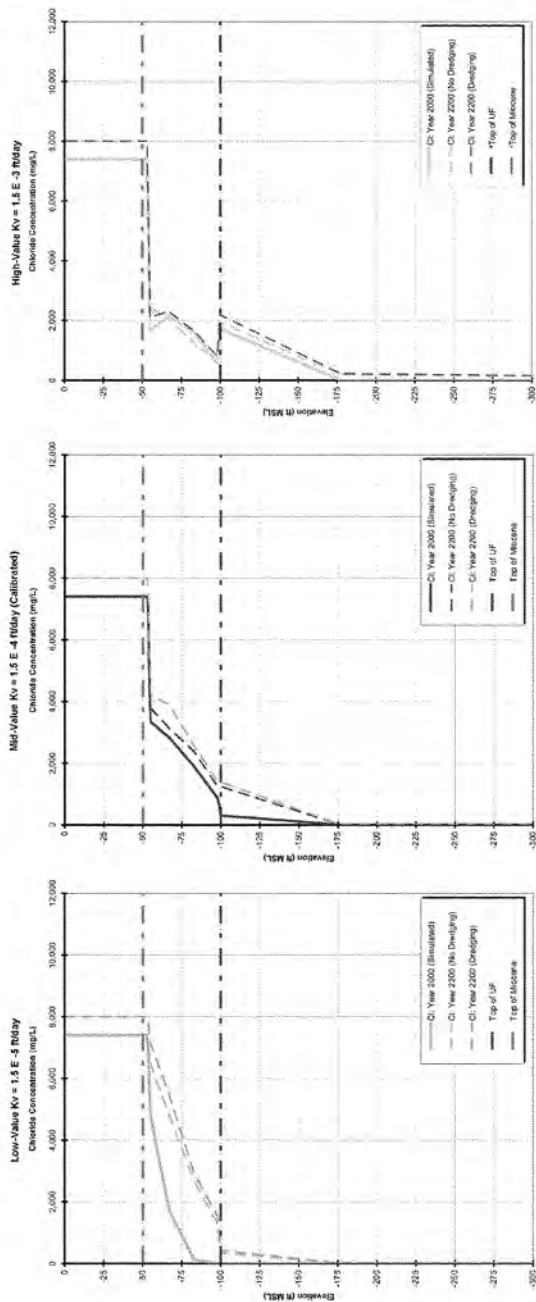
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-13

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OF ENGINEERS
SARASOTA DISTRICT

Figure 20

Comparison of Simulated Chloride Concentrations Profiles at SHE-2
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



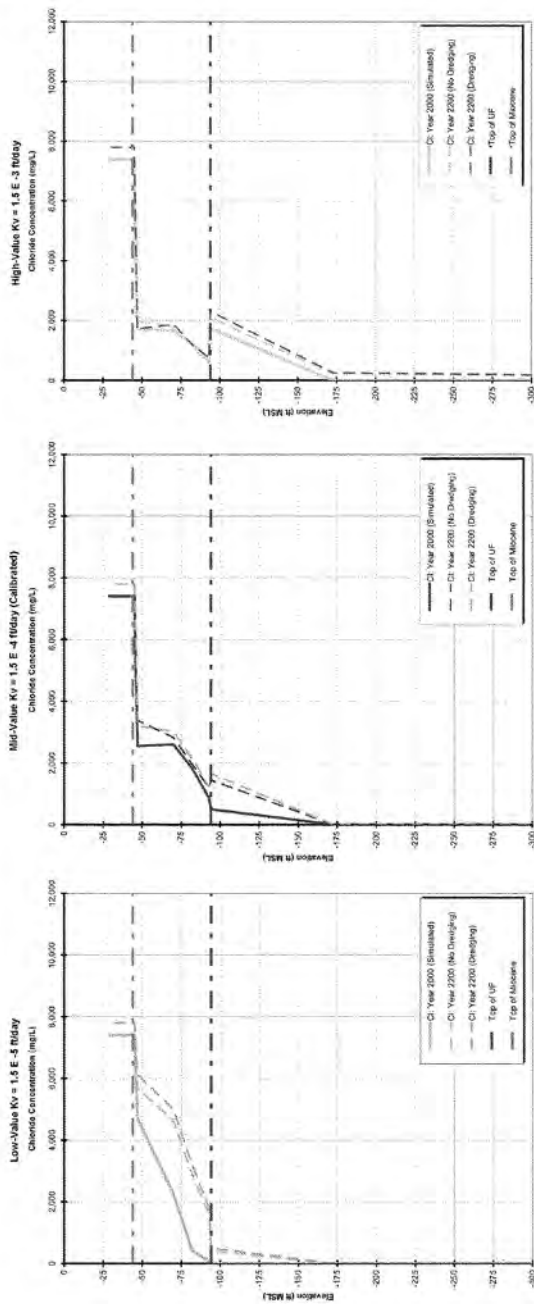
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-2

SHE SUPPLEMENTAL STUDIES

U.S. ARMY CORPS
OF ENGINEERS
SAVANNAH DISTRICT

Figure 21

Comparison of Simulated Chloride Concentrations Profiles at SHE-14
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



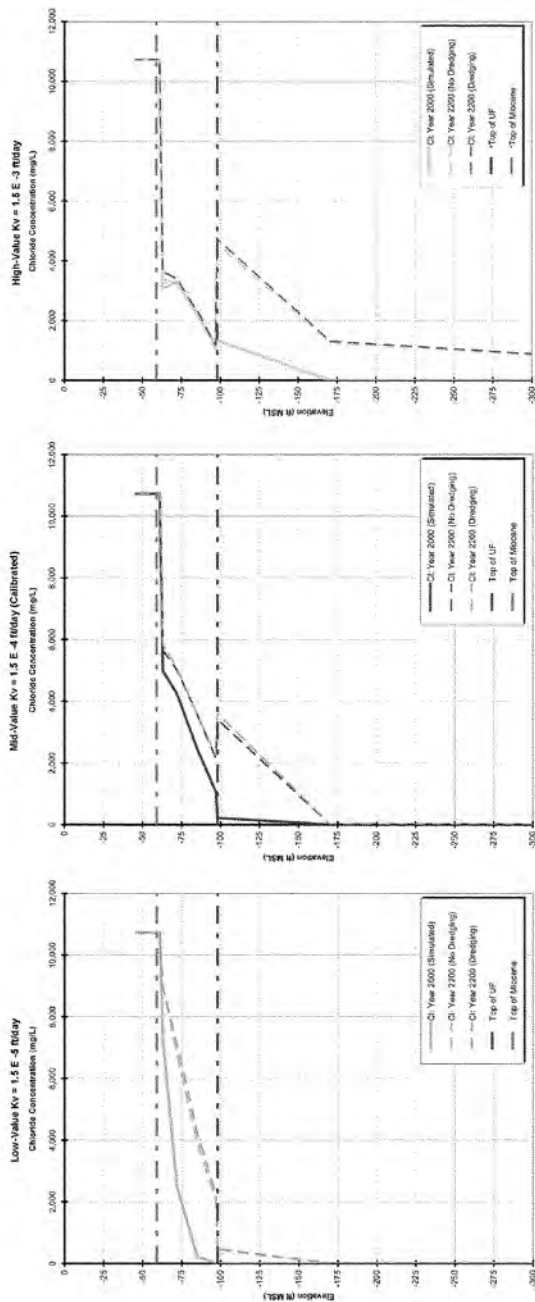
Comparison of Simulated
Chloride Concentrations
Profiles at SHE-14

SHE SUPPLY-ENGINEERING STUDIES

U.S. ARMY CORPS
OF ENGINEERS
SARASOTA DISTRICT

Figure 22

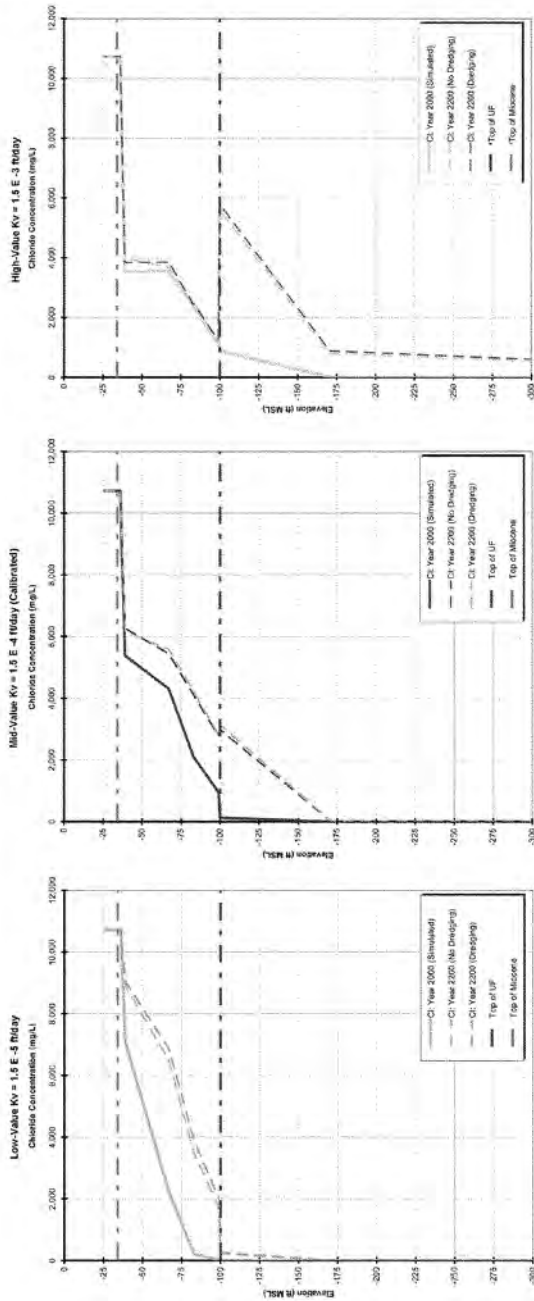
Comparison of Simulated Chloride Concentrations Profiles at SHE-17
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



Comparison of Simulated Chloride Concentrations Profiles at SHE-17	
SHE SUPPLEMENTAL STUDIES	
U.S. ARMY CORPS OF ENGINEERS SAVANNAH DISTRICT	

Figure 23

Comparison of Simulated Chloride Concentrations Profiles at SHE-16
for Dredging and No Dredging Conditions
Using the Low, Mid, and High-Value Vertical Hydraulic Conductivities in the Miocene Confining Unit



Comparison of Simulated
Chloride Concentrations
Profiles at SHE-16

SHE SUPPLEMENTAL STUDIES

U.S. ARMY CORPS
OF ENGINEERS
SARASOTA DISTRICT

Figure 24

Comparison of Simulated Chloride Concentrations at Top of Upper Floridan Aquifer
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)

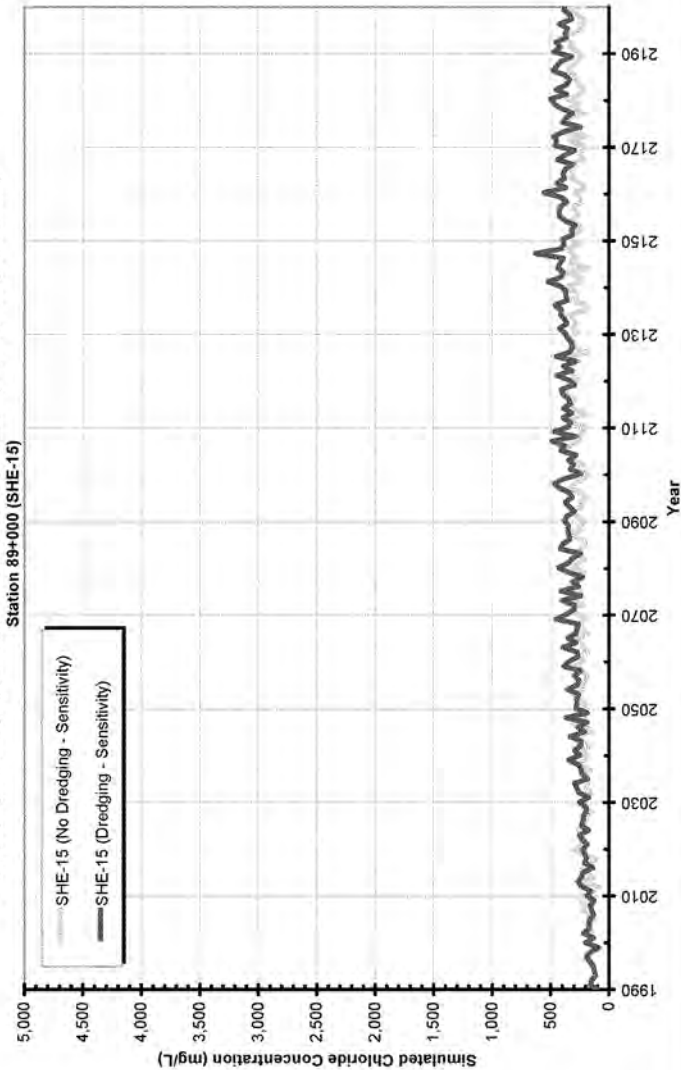


Figure 25
Comparison of Simulated Concentration Time Histories at SHE-15 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations at Top of Upper Floridan Aquifer
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)

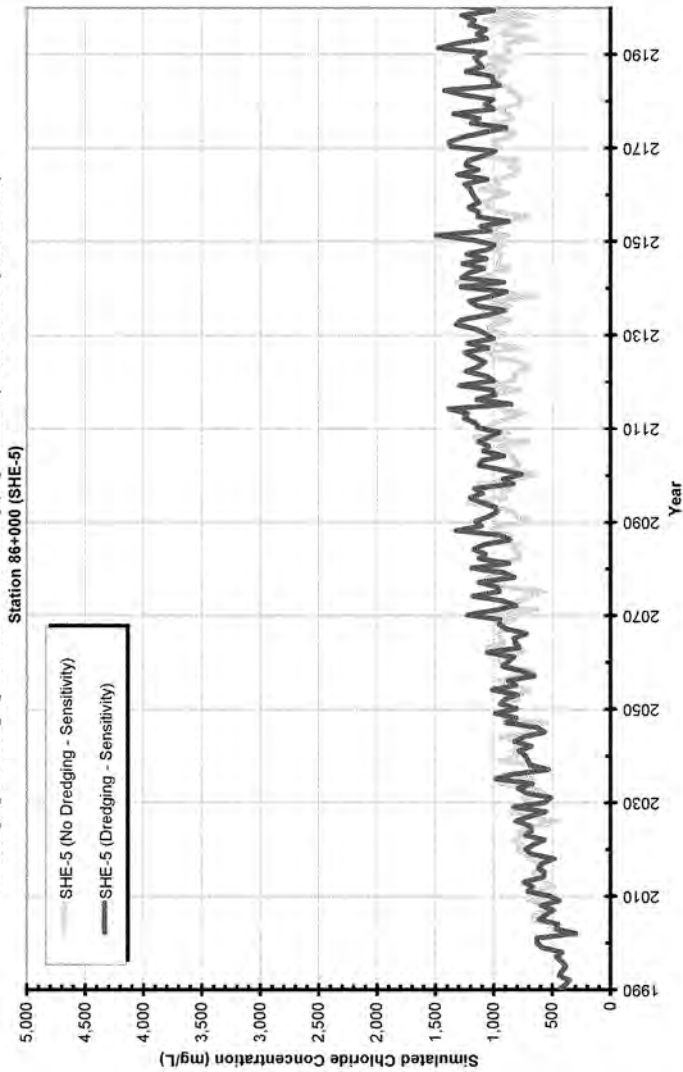


Figure 26
Comparison of Simulated Concentration Time Histories at SHE-5 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations at Top of Upper Floridan Aquifer
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)

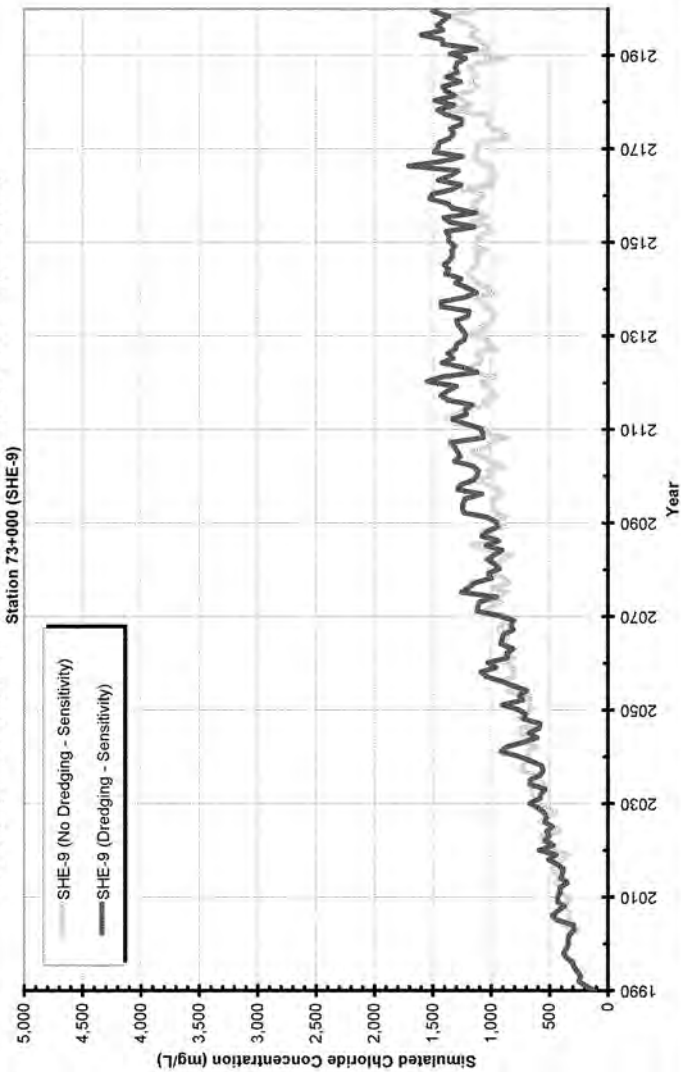


Figure 27
Comparison of Simulated Concentration Time Histories at SHE-9 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

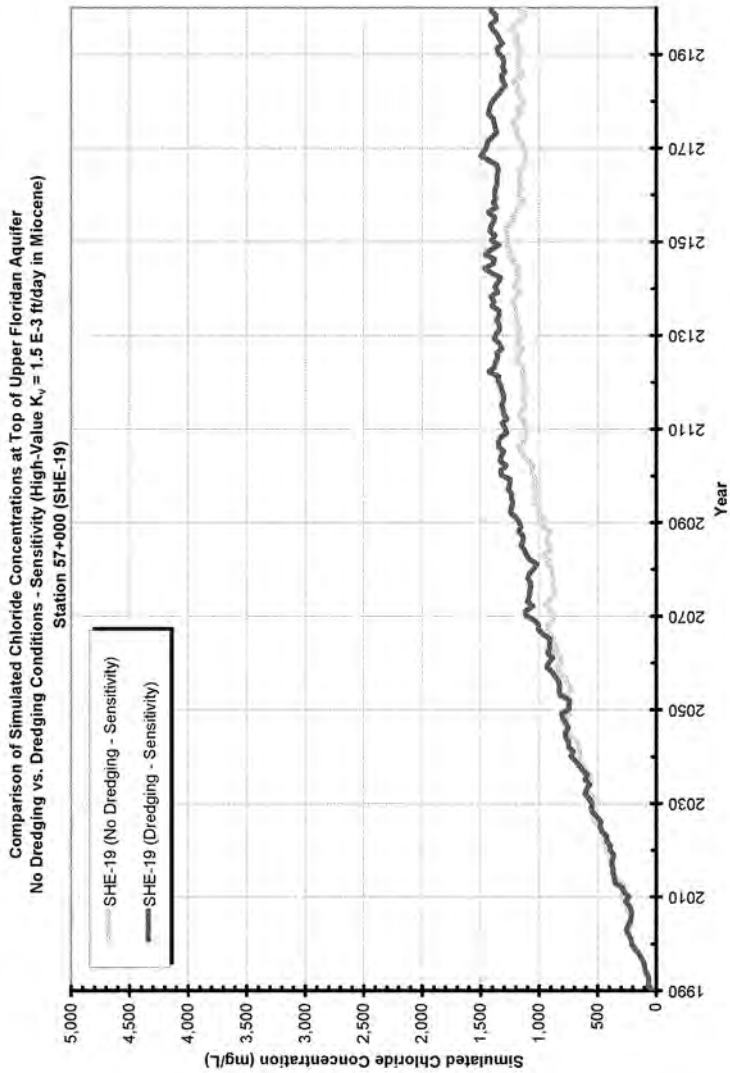


Figure 28
Comparison of Simulated Concentration Time Histories at SHE-19 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

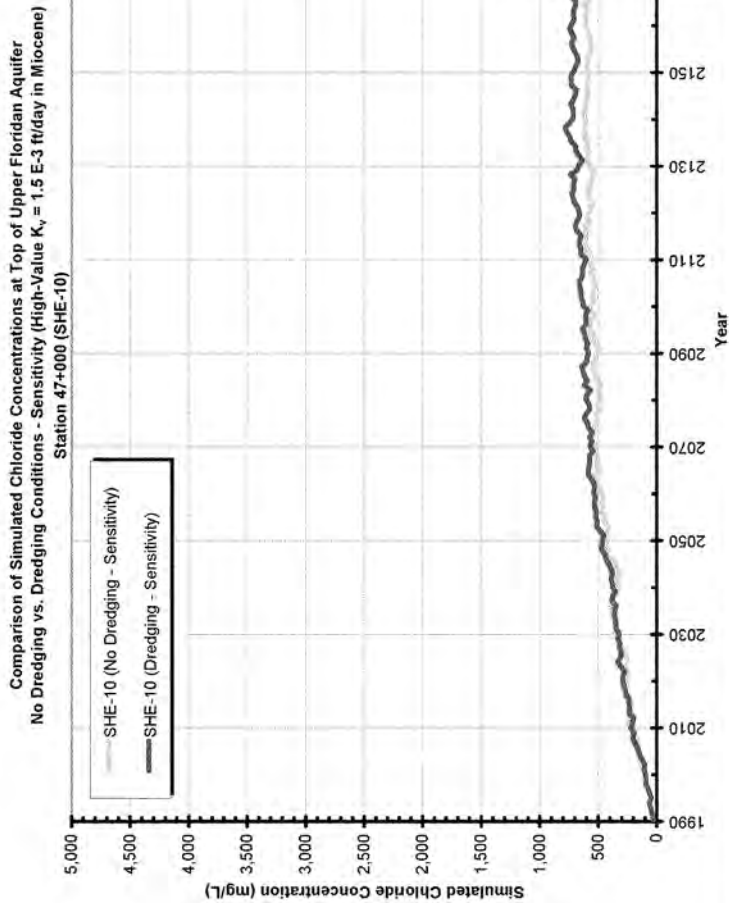


Figure 29
Comparison of Simulated Concentration Time Histories at SHE-10 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

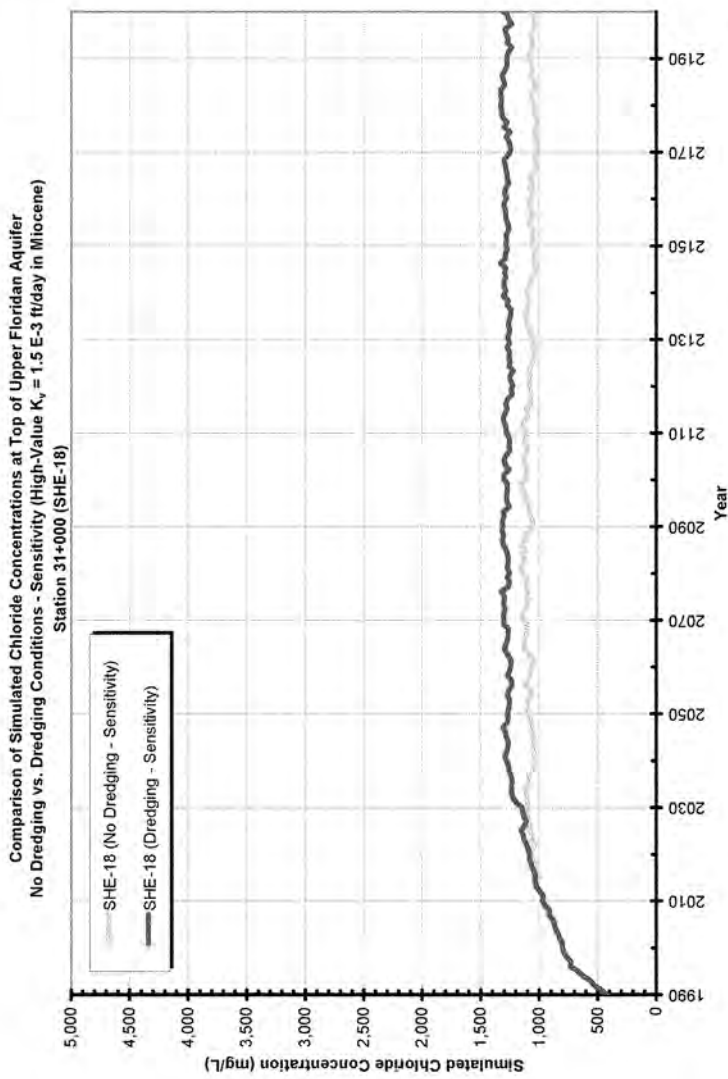


Figure 30
Comparison of Simulated Concentration Time Histories at SHE-18 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations at Top of Upper Floridan Aquifer
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Station 16+000 (SHE-11)

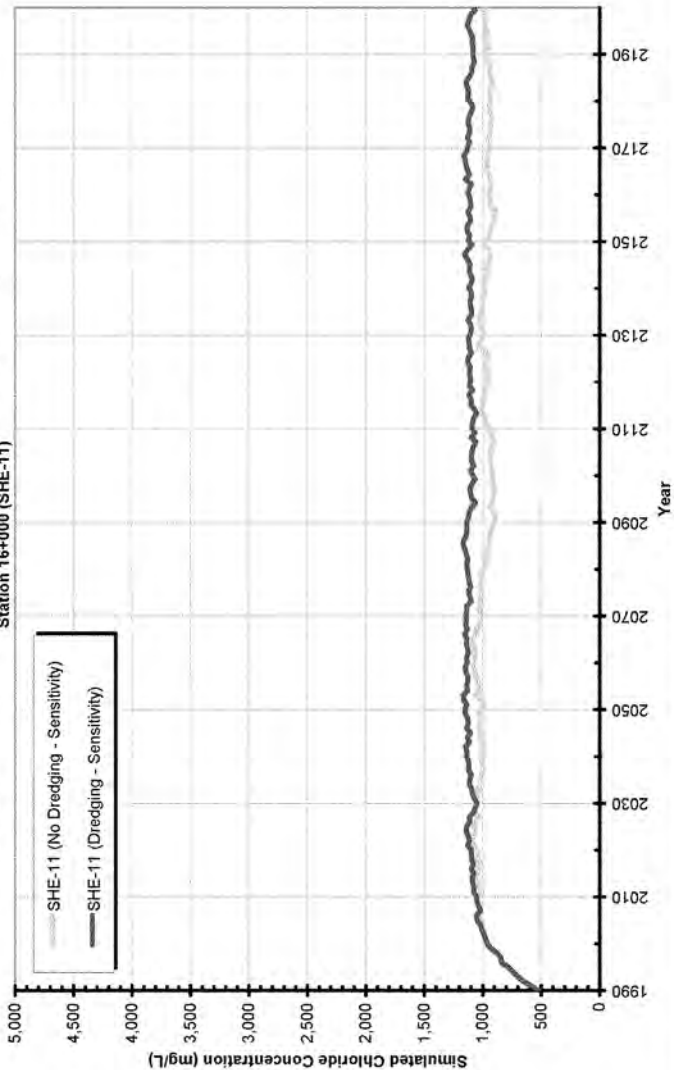


Figure 31
Comparison of Simulated Concentration Time Histories at SHE-11 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

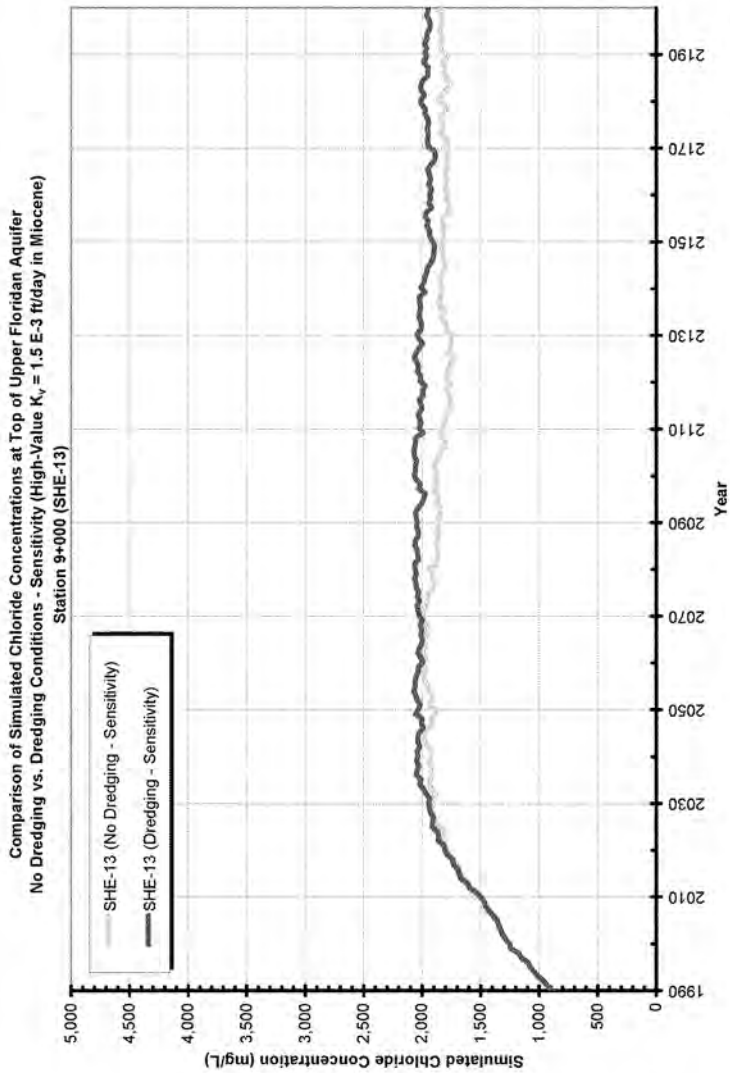


Figure 32
Comparison of Simulated Concentration Time Histories at SHE-13 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations at Top of Upper Floridan Aquifer
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Station 5+000 (SHE-2)

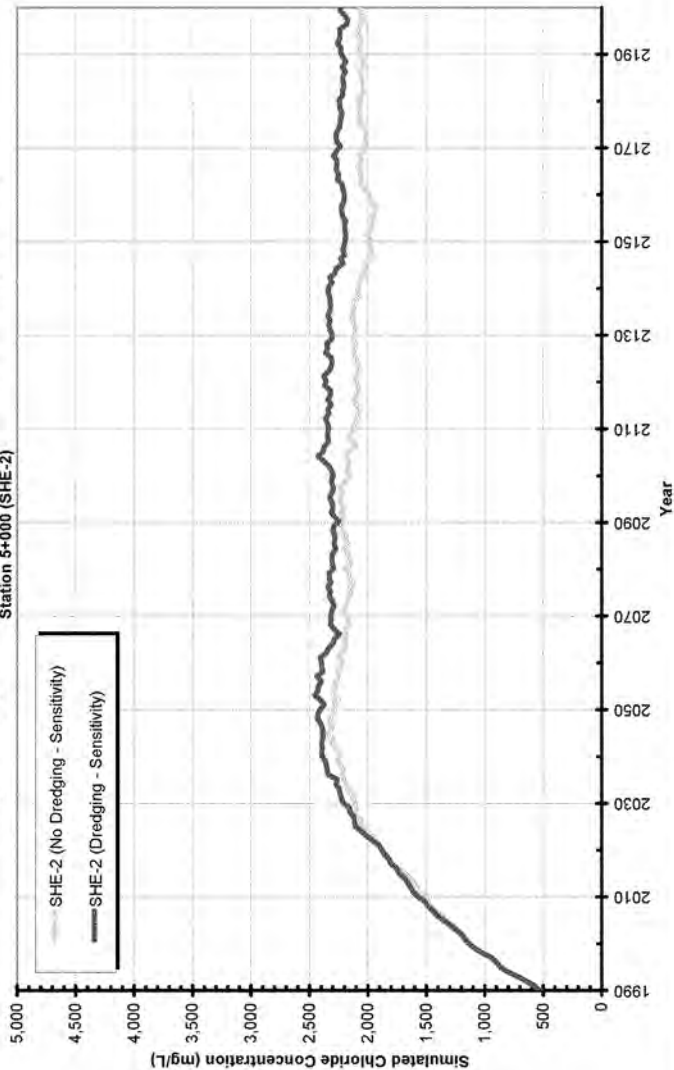


Figure 33
Comparison of Simulated Concentration Time Histories at SHE-2 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

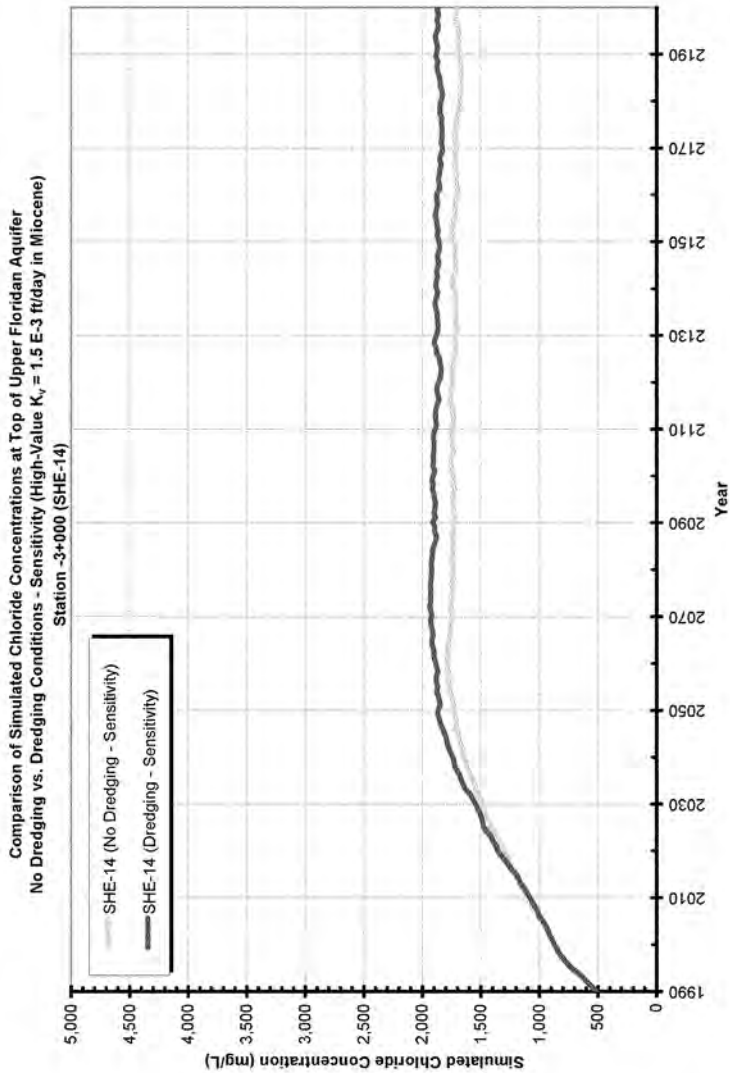


Figure 34
Comparison of Simulated Concentration Time Histories at SHE-14 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations at Top of Upper Floridan Aquifer
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Station -10+000 (SHE-17)

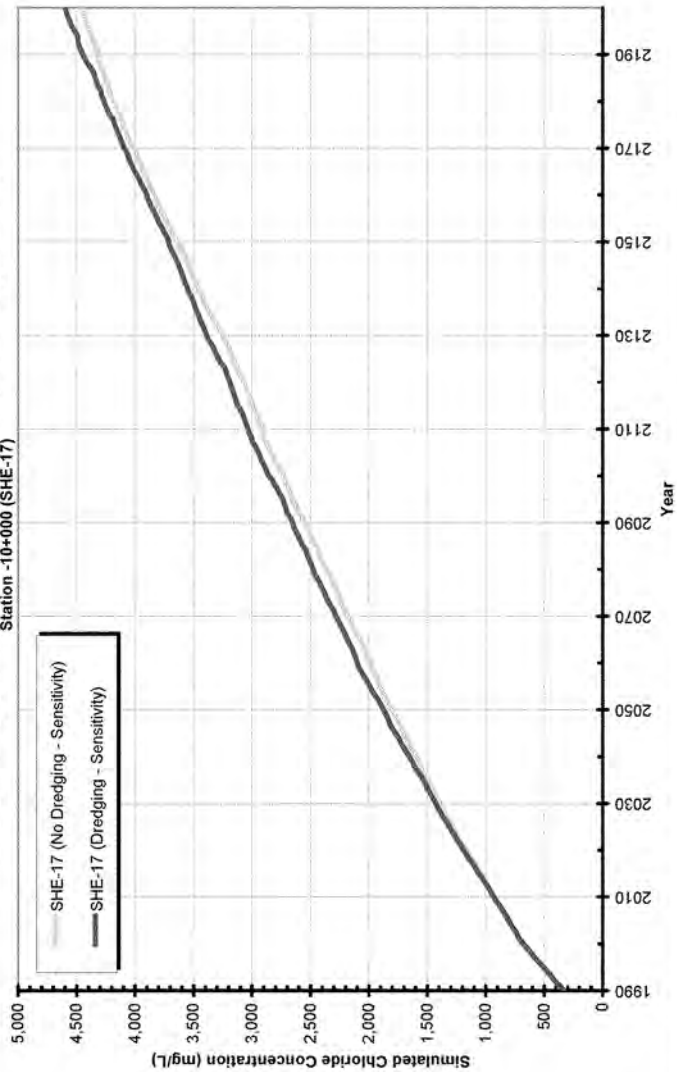


Figure 35
Comparison of Simulated Concentration Time Histories at SHE-17 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

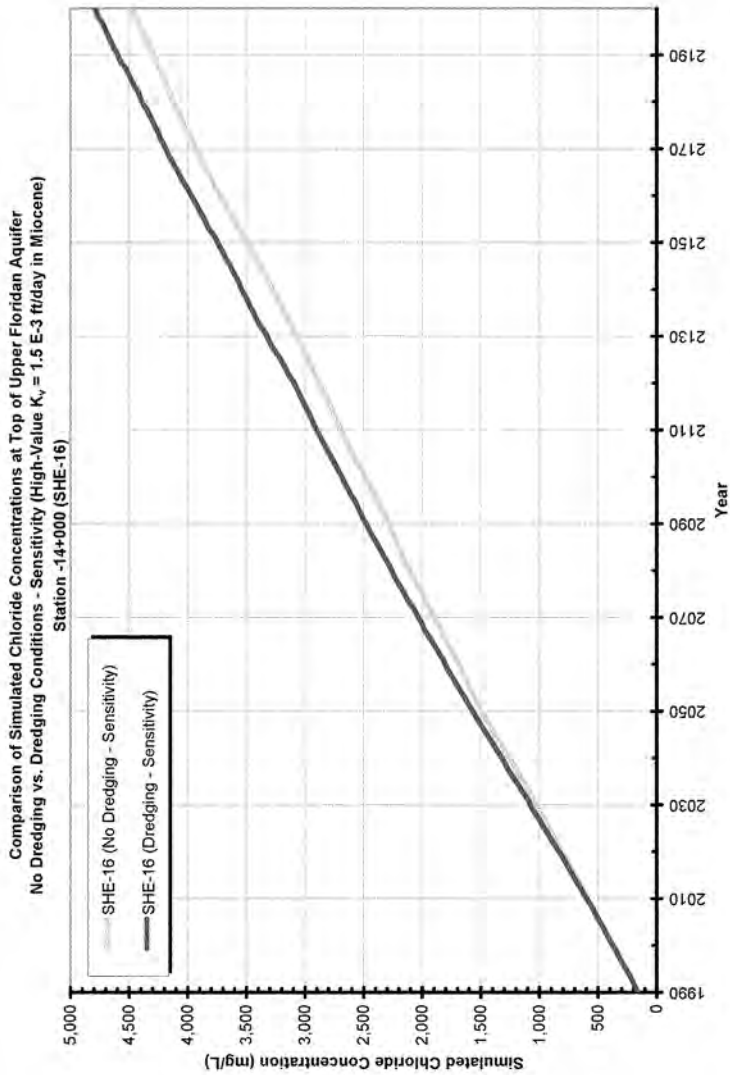


Figure 36
Comparison of Simulated Concentration Time Histories at SHE-16 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies



ID	Name	ID	Name
1	Savannah Sugar Refinery Well (025I2901)	10	SEPCO - Riverside Thermo Plant Well (025T0301)
2	GAF Corp. Well (025I3501)	11	SEPCO - Riverside Thermo Plant Well (025T0302)
3	Gold Bond Building Products Well (025I3301)	12	SEPCO - Riverside Thermo Plant Well (025T0303)
4	International Paper Well #1	13	Southern States Phosphate Well (025I3101)
5	International Paper Well #2	14	Savannah Main Well #11
6	International Paper Well #5	15	City of Garden City Well (025M0101)
7	Hunt Wesson Well (025I2801)	16	Kemira Well (025I3001)
8	Hunt Wesson Well (025I2802)	17	Kemira Well (025I3002)
9	Hunt Wesson Well (025I2803)	18	Whitemarsh Island Well #28
		19	Tybee Island Well (025M0602)

Figure 37
Location of Selected Pumping Wells

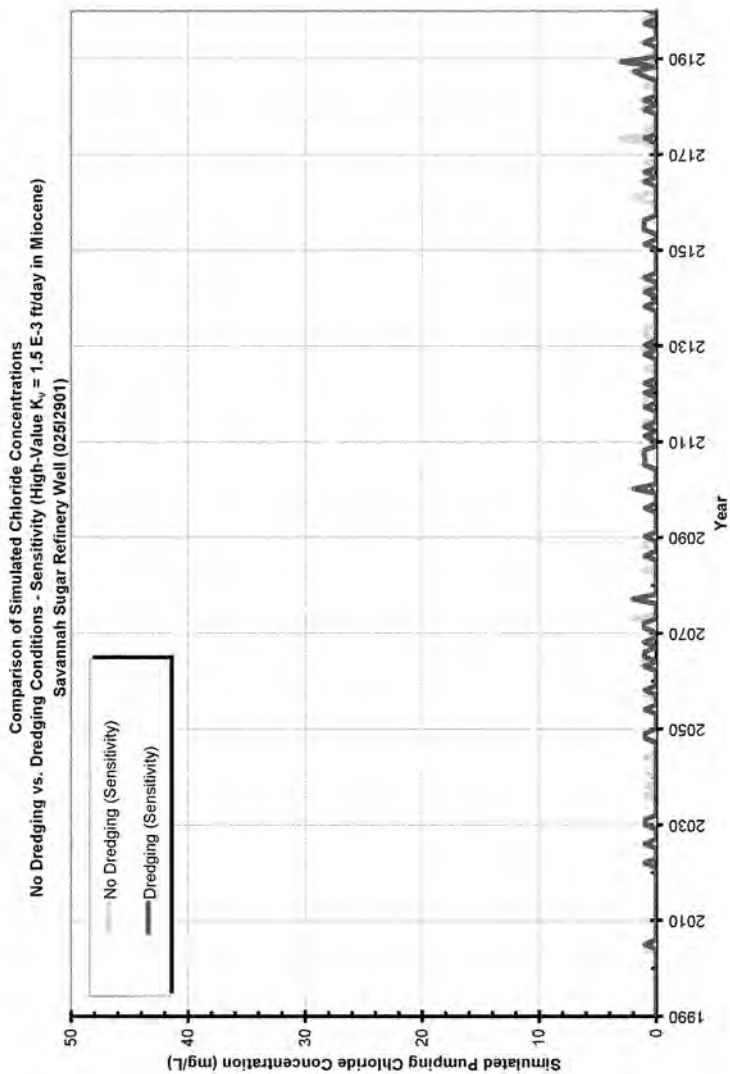


Figure 38
Comparison of Simulated Concentration Time Histories at Savannah Sugar Refinery Well for No Dredging vs. Dredging Conditions
Using the High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

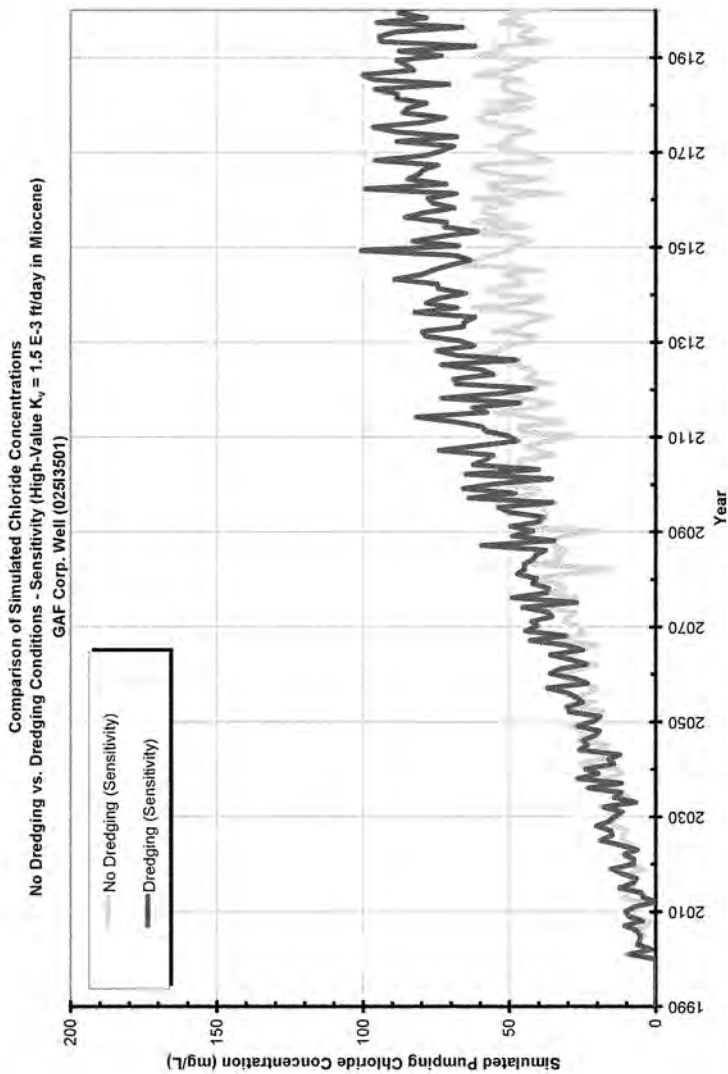


Figure 39
Comparison of Simulated Concentration Time Histories at GAF Corporation Well for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Gold Bond Building Products Well (02533301)

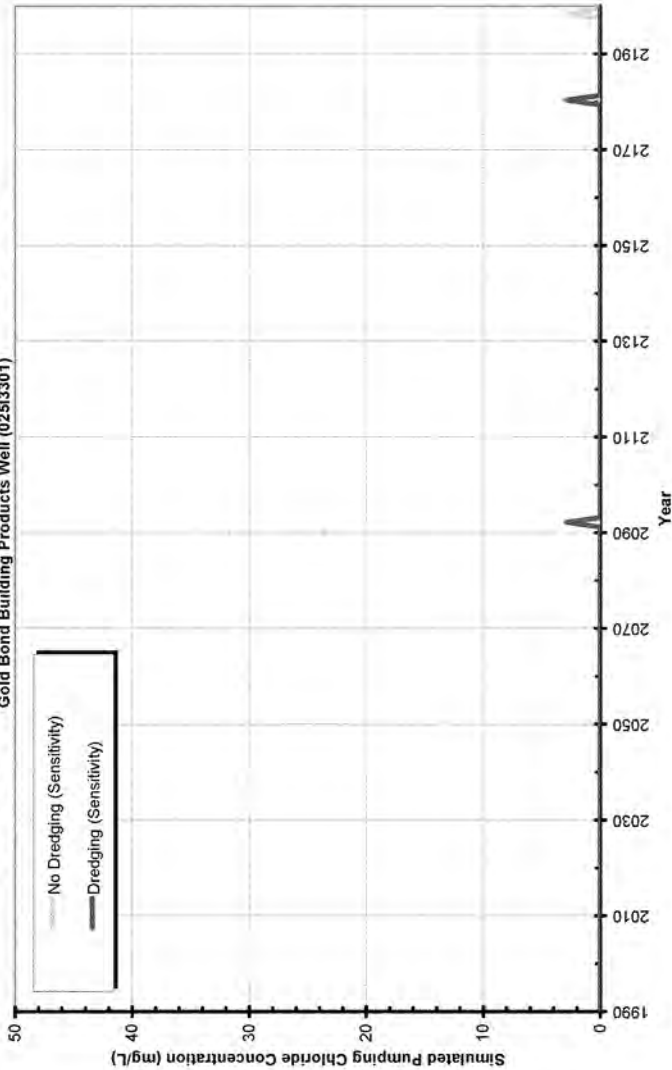


Figure 40
Comparison of Simulated Concentration Time Histories at Gold Bond Building Products Well for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

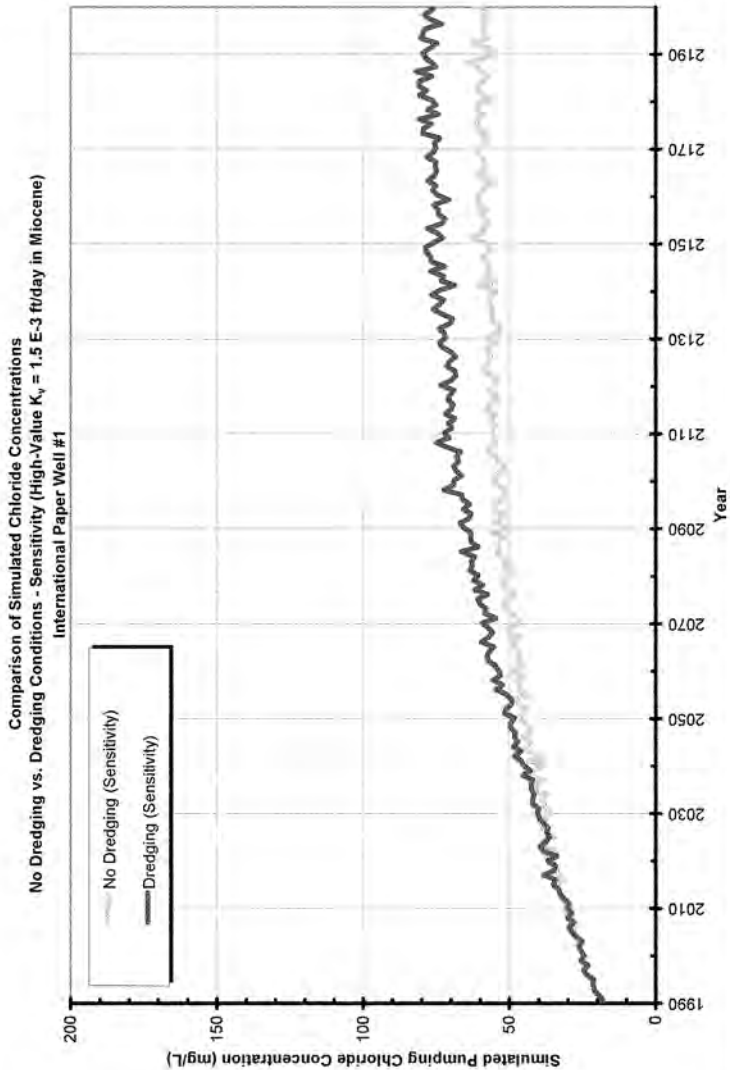


Figure 41
Comparison of Simulated Concentration Time Histories at International Paper Well #1 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

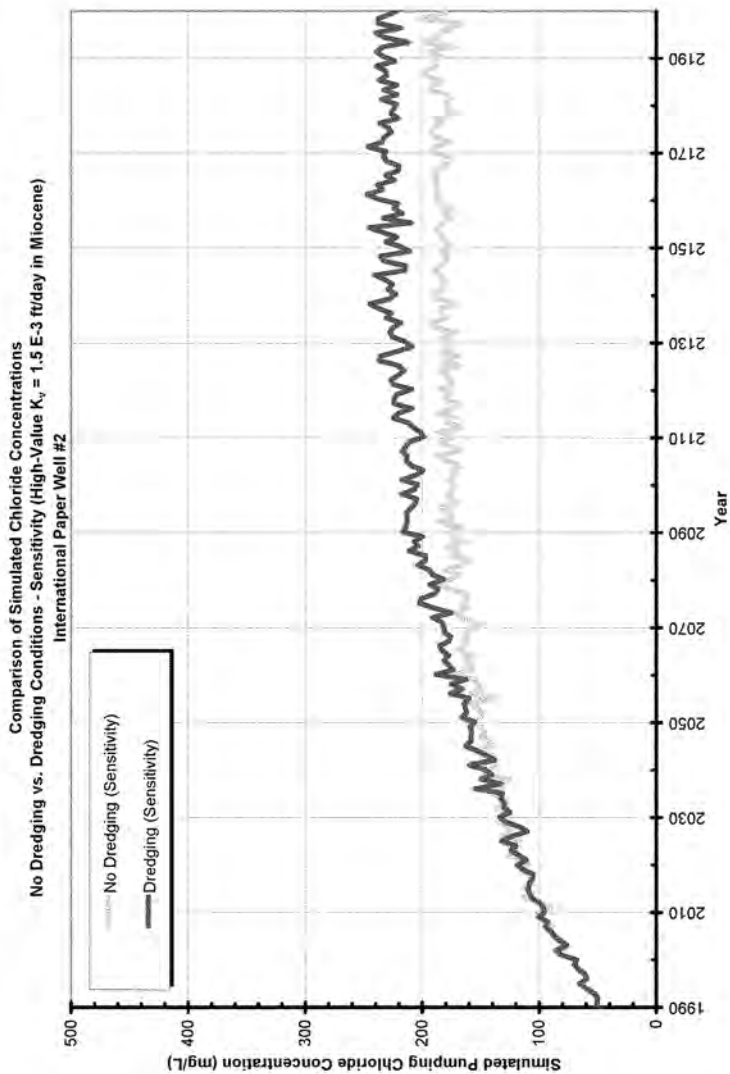


Figure 42
Comparison of Simulated Concentration Time Histories at International Paper Well #2 for No Dredging vs. Dredging Conditions
Using the High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
International Paper Well #5

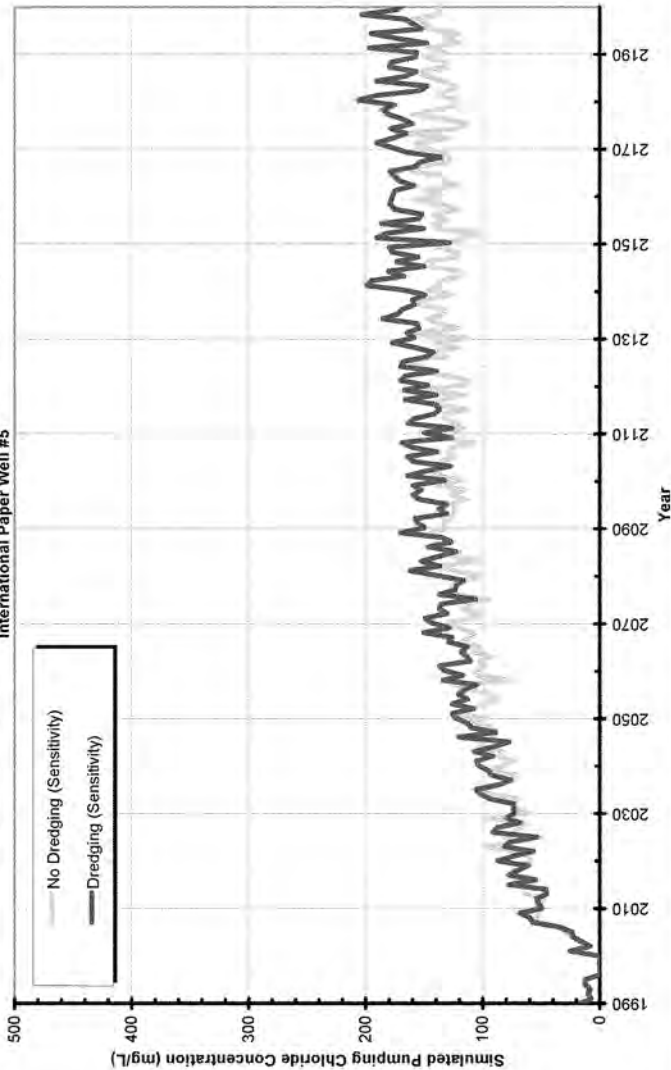


Figure 43
Comparison of Simulated Concentration Time Histories at International Paper Well #5 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

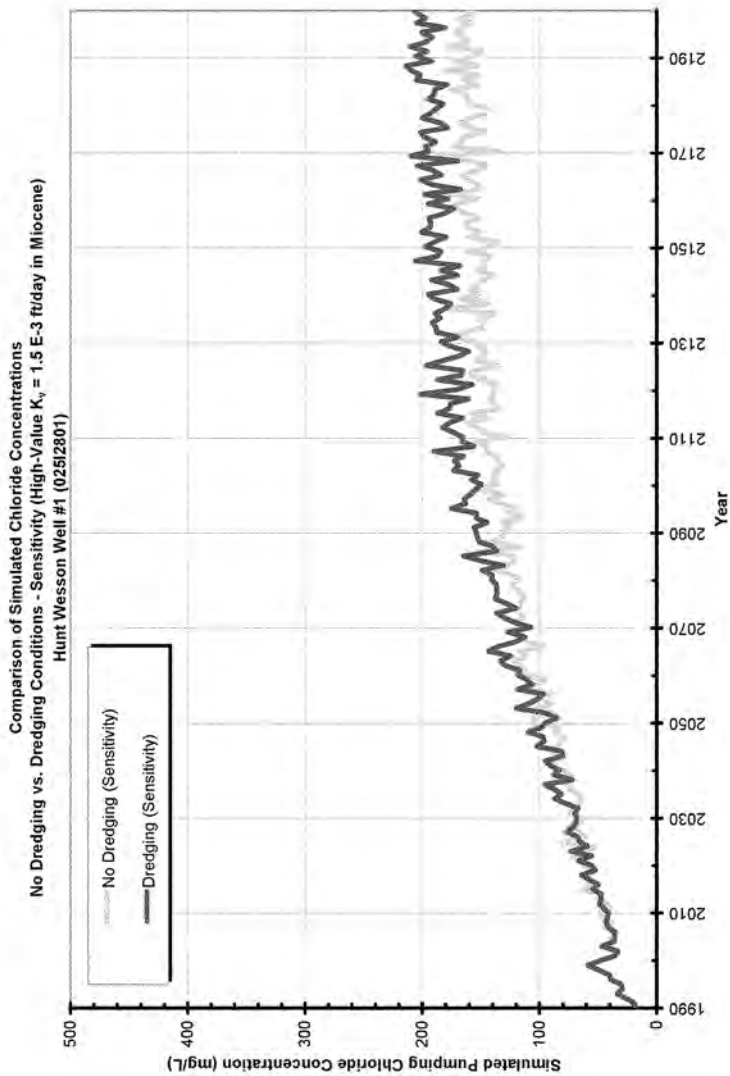


Figure 44
Comparison of Simulated Concentration Time Histories at Hunt Wesson Well #1 for No Dredging vs. Dredging Conditions
Using the High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Hunt Wesson Well #2 (02512802)

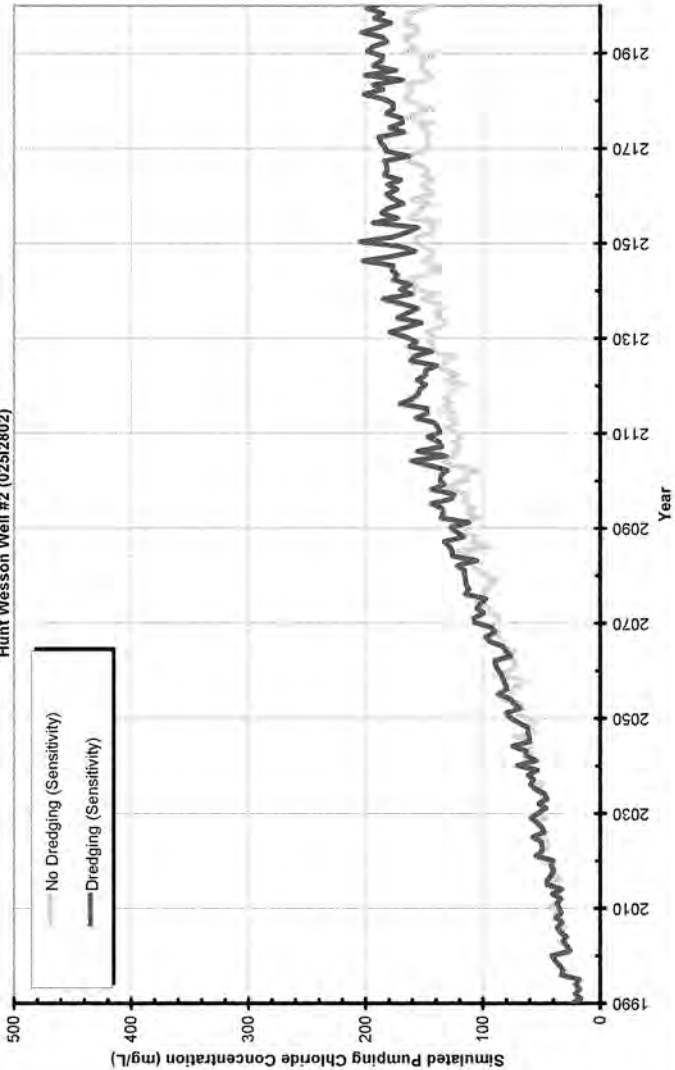


Figure 45
Comparison of Simulated Concentration Time Histories at Hunt Wesson Well #2 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

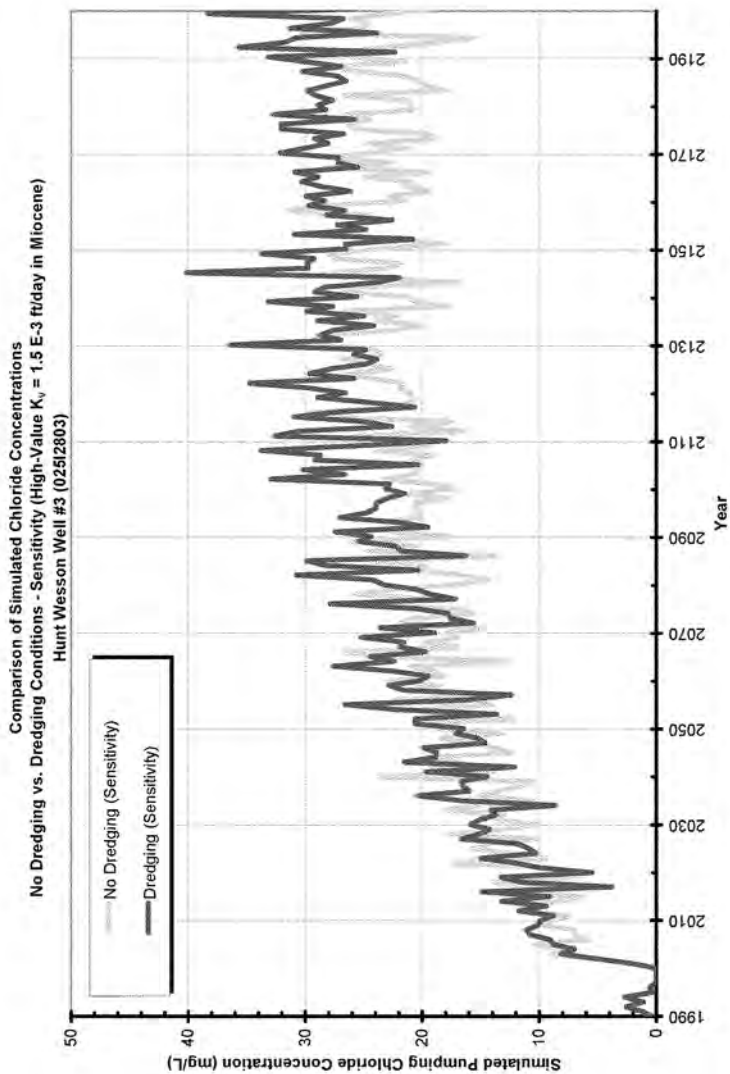


Figure 46
Comparison of Simulated Concentration Time Histories at Hunt Wesson Well #3 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
SEPCO-Riverside Therm Plant Well #1 (025T0301)

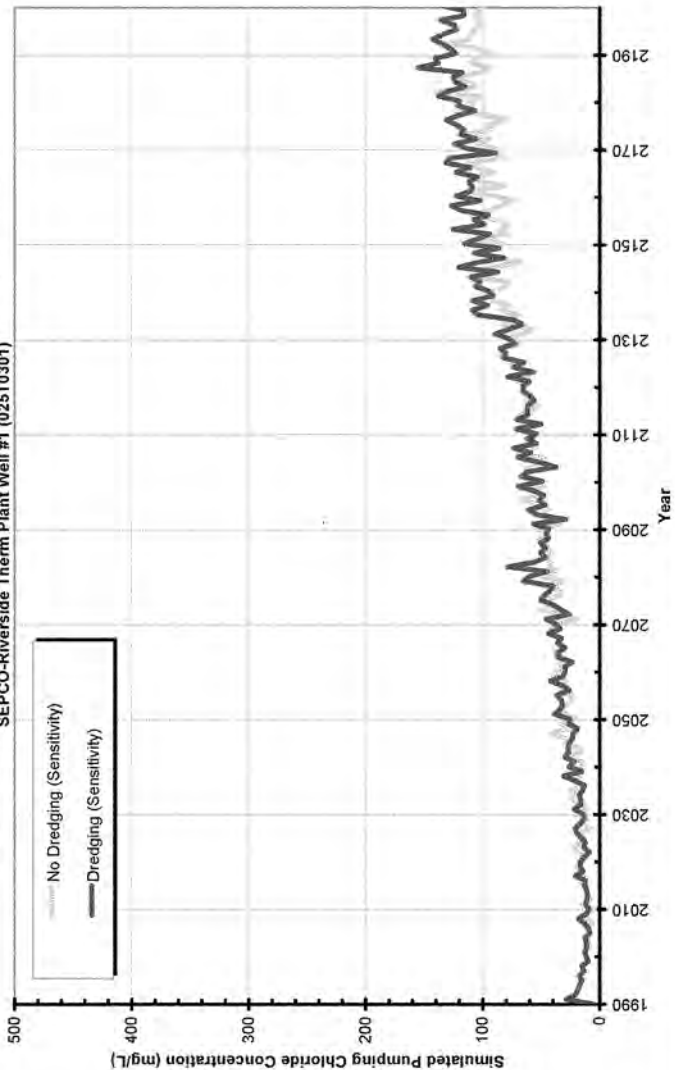


Figure 47
Comparison of Simulated Concentration Time Histories at SEPCO-Riverside Thermal Plant Well #1 for No Dredging vs. Dredging Conditions Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

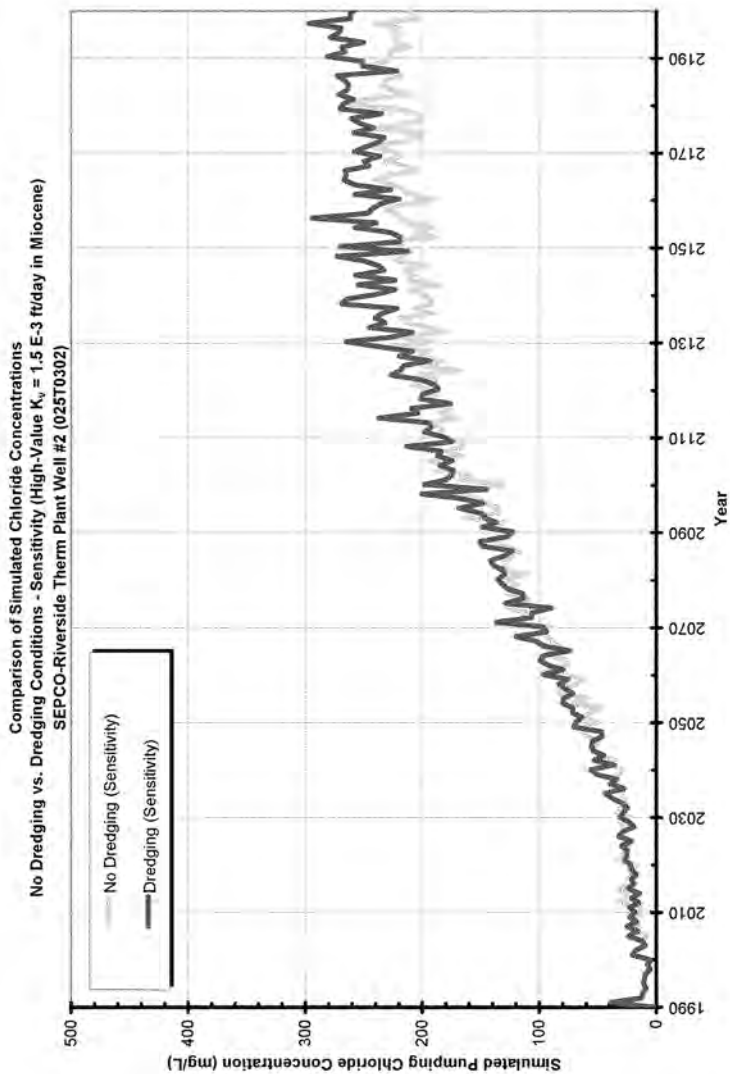


Figure 48
Comparison of Simulated Concentration Time Histories at SEPCO-Riverside Thermal Plant Well #2 for No Dredging vs. Dredging
Conditions Using the High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

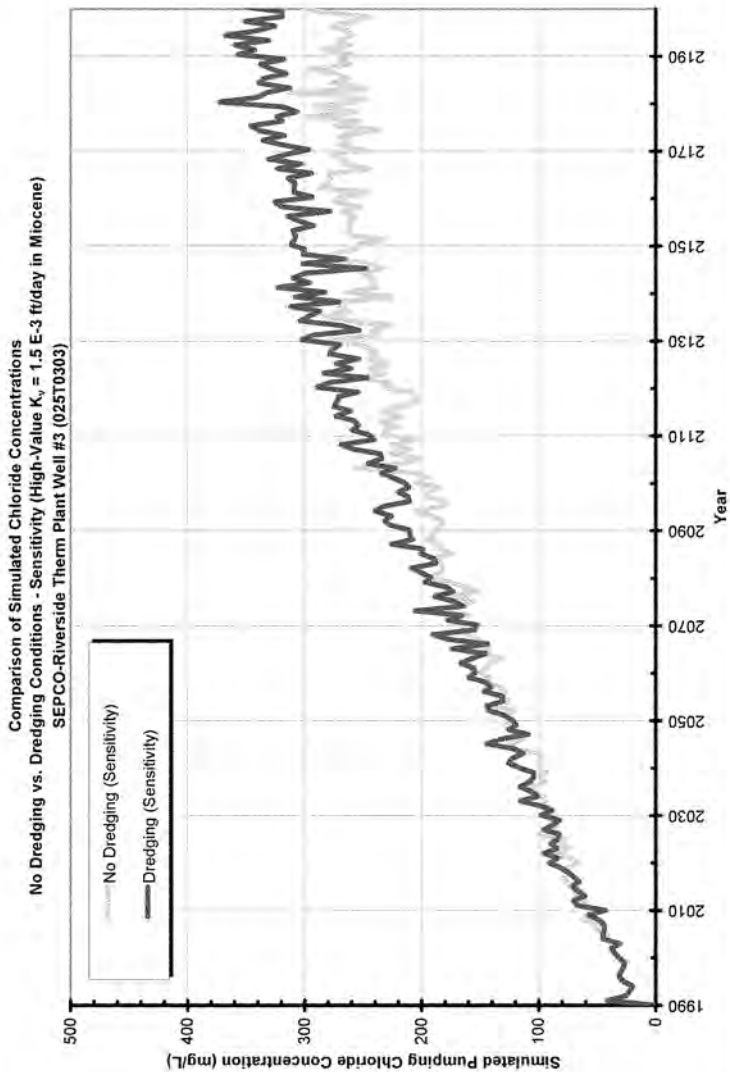


Figure 49
Comparison of Simulated Concentration Time Histories at SEPCO-Riverside Thermal Plant Well #3 for No Dredging vs. Dredging
Conditions Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

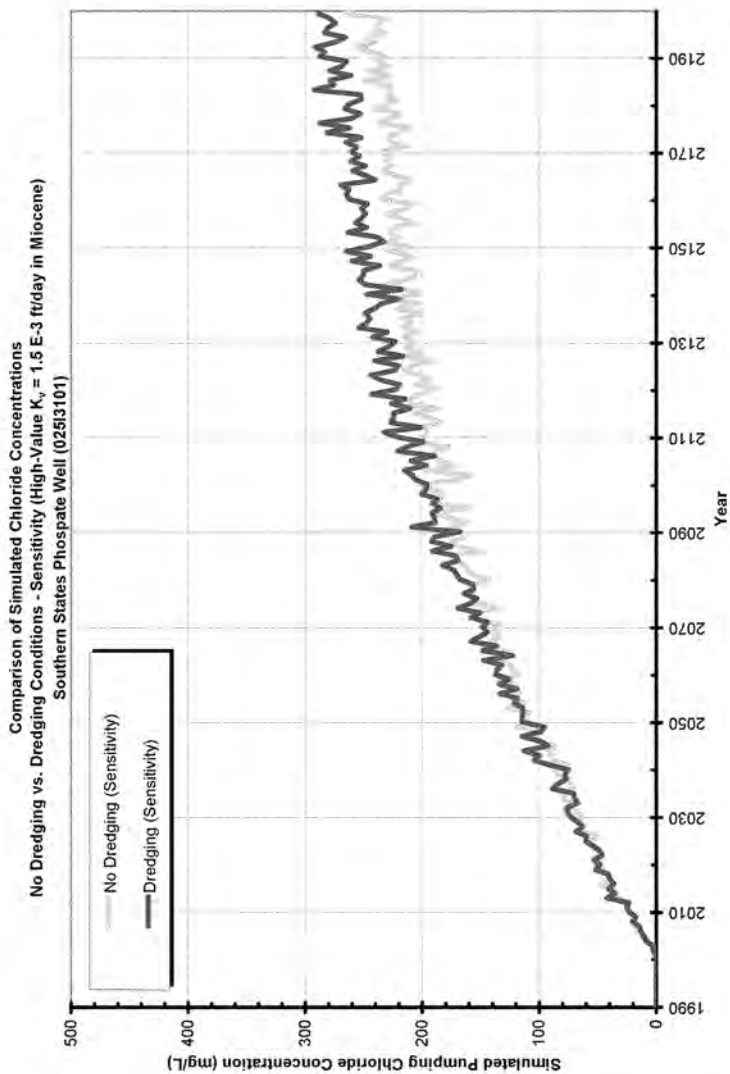


Figure 50
Comparison of Simulated Concentration Time Histories at Southern States Phosphate Well for No Dredging vs. Dredging Conditions
Using the High-Value K_v ($1.5 \text{ E-}3 \text{ ft/day}$) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

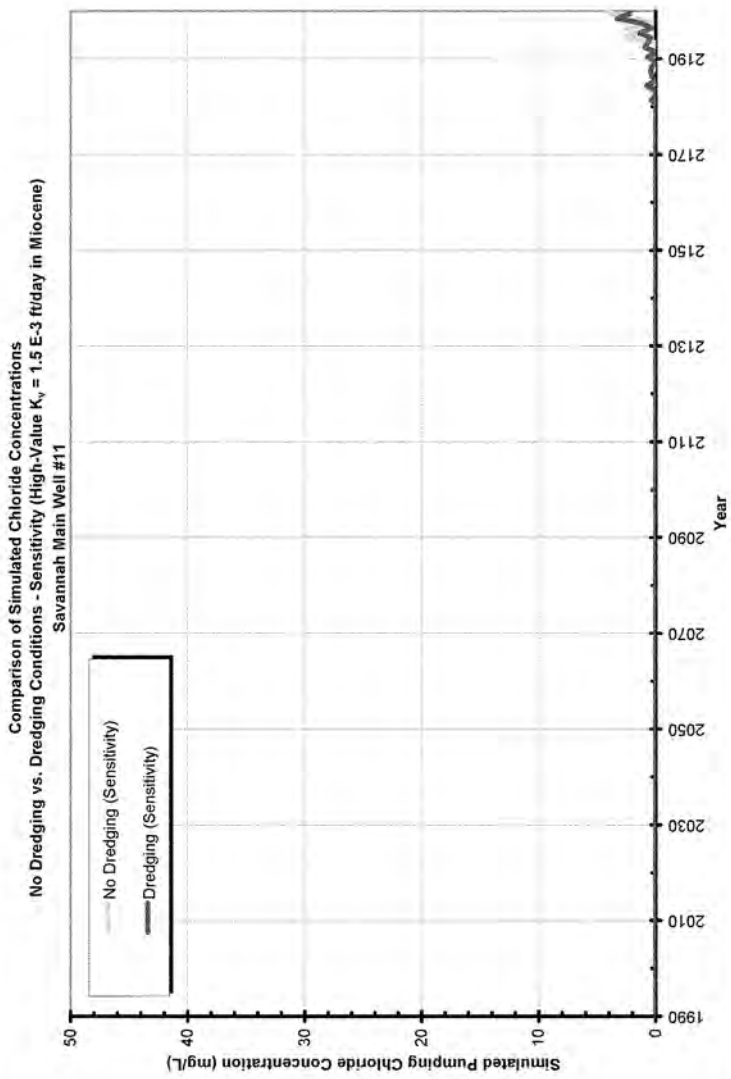


Figure 51
Comparison of Simulated Concentration Time Histories at Savannah Main Well #11 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

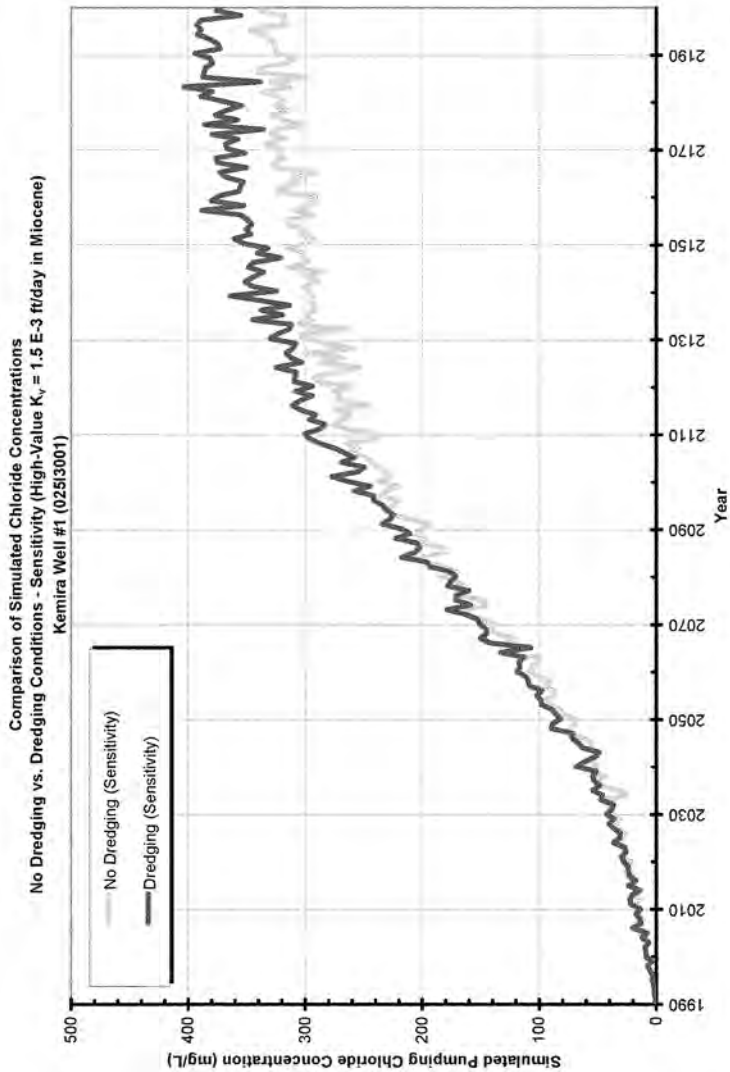


Figure 52
Comparison of Simulated Concentration Time Histories at Kemira Well #1 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Kemira Well #2 (025/3002)

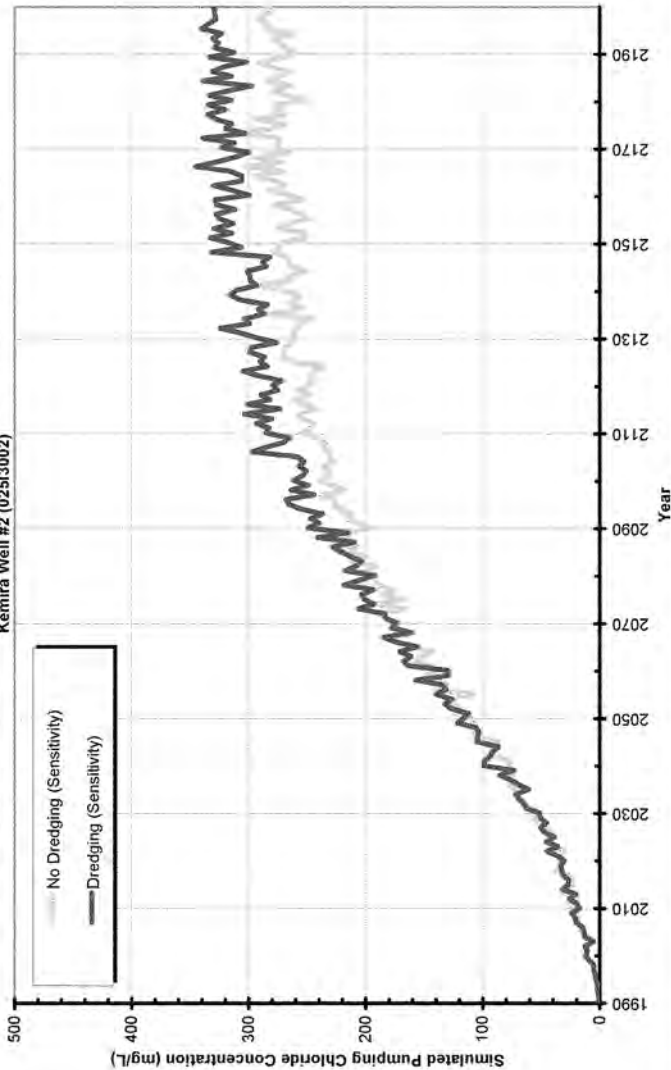


Figure 53
Comparison of Simulated Concentration Time Histories at Kemira Well #2 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

Comparison of Simulated Chloride Concentrations
No Dredging vs. Dredging Conditions - Sensitivity (High-Value $K_v = 1.5 \text{ E-3 ft/day}$ in Miocene)
Whitemarsh Island Well #28

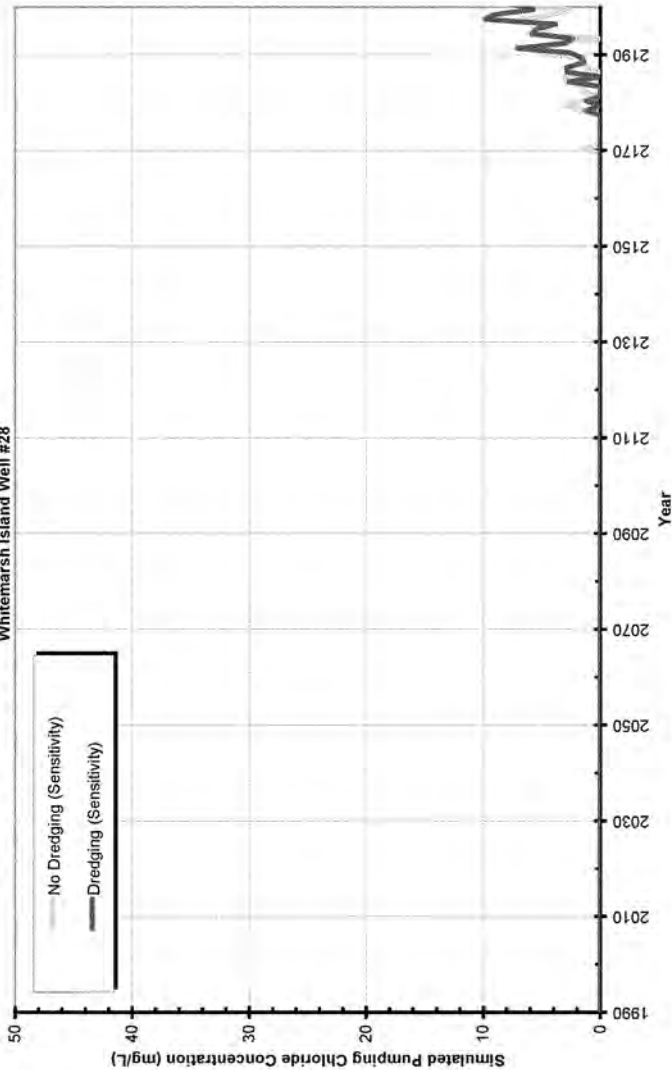


Figure 54
Comparison of Simulated Concentration Time Histories at Whitemarsh Island Well 28 for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

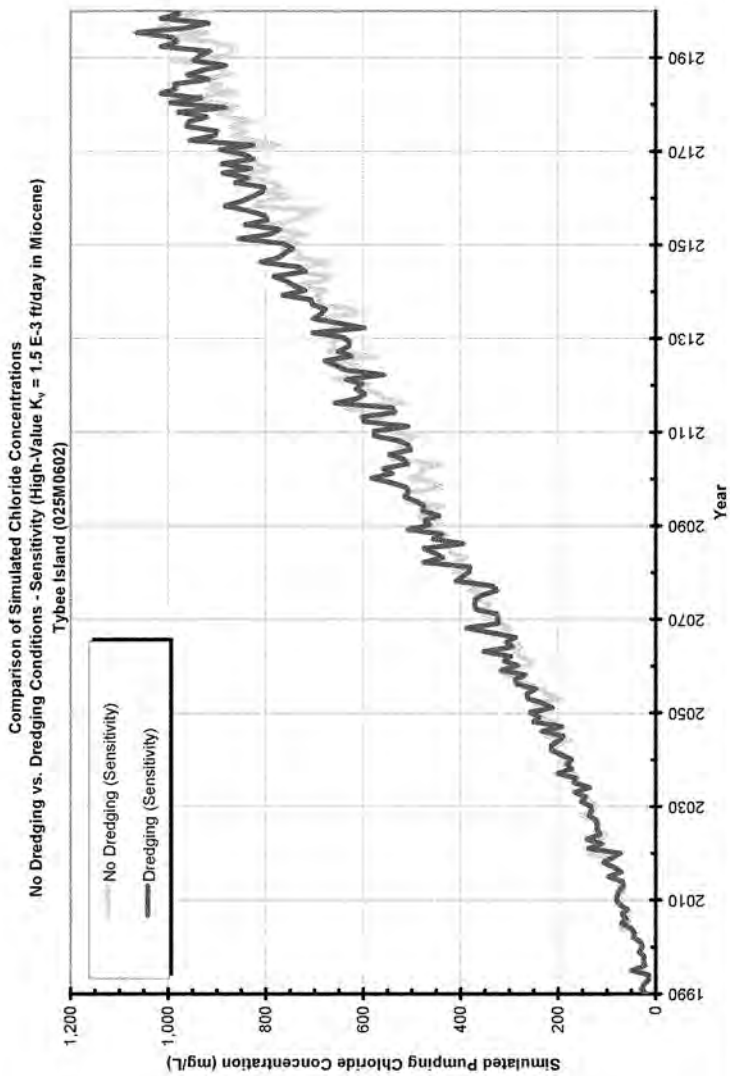


Figure 55
Comparison of Simulated Concentration Time Histories at Tybee Island Well for No Dredging vs. Dredging Conditions
Using the High-Value K_v (1.5 E-3 ft/day) in the Miocene Confining Unit
Savannah Harbor Expansion
Groundwater Model Studies

ATTACHMENT 2

Model Certification Documentation

Model Name: DYNFLOW

Model Description & Use: DYNFLOW is a fully three-dimensional, finite element groundwater flow model. This model has been developed over the past 25 years by CDM engineering staff, and is in general use for large scale basin modeling projects and site specific remedial design investigations. DYNFLOW uses a grid built with a large number of tetrahedral elements. These elements are triangular in plan view, and give a wide flexibility in grid variation over the area of study. An identical grid is used for each level of the model, but the thickness of each model layer (the vertical distance between levels in the model) can vary at each point in the grid. In addition, 2-dimensional elements can be inserted into the basic 3-dimensional grid to simulate thin features such as faults. One-dimensional elements can be used to simulate the performance of wells which are perforated in several model layers.

DYNFLOW accepts a variety of boundary conditions on the groundwater flow system including specified heads, specified fluxes, rivers, drains, and general head boundaries.

Peer Review: The DYNFLOW code has been reviewed and tested by the International Groundwater Modeling Center (IGWMC, 1985) and Dr. Paul van der Heijde(1999). DYNFLOW was evaluated by the ASCE Groundwater Quality Technical Committee (Pandit, 1997) as part of a study that summarized the capabilities, limitations and user assessment of widely used groundwater model codes. The code has been extensively tested and documented by CDM. It has been applied in hundreds of groundwater modeling studies by CDM and others.

Documentation / Support: DYNFLOW User's Manual and support are provided by CDM. DYNFLOW features and example applications are presented at www.dynsystem.com.

Points of Contact: Robert Fitzgerald, CDM, fitzgeraldrh@cdm.com
 Brian Heywood, CDM, heywoodbj@cdm.com
 Brendan Harley, CDM, harleybm@cdm.com

Applicable Projects: Regional water supply studies, pumping test evaluations, hazardous waste remediation studies, dewatering projects, integrated groundwater-surface water studies, ASR.

Model Name: DYNTRACK

Model Description & Use: DYNTRACK is a solute transport code that represents advective, dispersive, adsorptive and decay processes in groundwater flow fields (steady state or transient) computed by DYNFLOW. DYNTRACK has been developed over the past 20 years by CDM engineering staff.

A Lagrangian approach is used to approximate the solution of the partial differential equation of transport (advection-dispersion equation). This process uses a random walk method to track a statistically significant number of particles, wherein each particle is advected with the mean velocity within a grid element and then randomly dispersed according to specified dispersion parameters. Adsorption computations may be based on linear, Langmuir or Freundlich isotherms. First order constituent decay may also be computed.

In DYNTRACK, a solute source can be represented as an instantaneous input of solute mass (represented by a fixed number of particles), as a continuous source from which mass is input at a constant rate, or as a specified concentration at a node. The concentration within a particular zone of interest is represented by the total number of particles that are present within the zone multiplied by their associated solute mass, divided by the volume of water within the zone.

Peer Review: The DYNTRACK code has been reviewed and tested by the International Groundwater Modeling Center (IGWMC, 1985). DYNTRACK was evaluated by the ASCE Groundwater Quality Technical Committee (Pandit, 1997) as part of a study that summarized the capabilities, limitations and user assessment of widely used groundwater model codes. The code has been extensively tested and documented by CDM. It has been applied in numerous of groundwater modeling studies by CDM and others.

Documentation / Support: DYNTRACK User's Manual and support are provided by CDM. DYNTRACK features and example applications are presented at www.dynsystem.com.

Points of Contact: Robert Fitzgerald, CDM, fitzgeraldrh@cdm.com
 Brian Heywood, CDM, heywoodbj@cdm.com
 Brendan Harley, CDM, harleybm@cdm.com

Applicable Projects: Hazardous waste remediation studies, regional water quality studies.

Model Name: DYNCFT

Model Description & Use: The DYNFLOW groundwater flow code and the DYNTRACK solute transport code can be combined to simulate variable density effects on groundwater flow. The combined code is called DYNCFT. Coupling flow and transport computations allows the effect on groundwater flow of fluid density gradients associated with solute concentration gradients to be incorporated into model simulations (i.e., density-dependent flow). In DYNCFT the flow and transport computations are loosely coupled. At each time step, the flow computations are completed first, holding densities constant, then the transport computations are completed. The computed heads are then re-adjusted to account for the effects of the fluid density.

Since DYNCFT uses the DYNFLOW and DYNTRACK codes, all of the capabilities included in DYNFLOW and DYNTRACK (described previously) may be applied in DYNCFT simulations.

Peer Review: The DYNFLOW and DYNTRACK codes utilized by DYNCFT have been extensively tested and documented by CDM, reviewed and tested by the International Groundwater Modeling Center (IGWMC, 1985) and evaluated by the ASCE Groundwater Quality Technical Committee (Pandit, 1997). Coupled flow-transport computations have been tested using common benchmark solutions, and DYNCFT simulations of groundwater flow, heads and salt water intrusion in the Gaza Strip coastal aquifer were consistent with field measured conditions.

Documentation / Support: DYNCFT documentation and support are provided by CDM. DYNCFT features and an example application are presented at www.dynsystem.com

Point of Contact(s): Robert Fitzgerald, CDM, fitzgeraldrh@cdm.com
 Brian Heywood, CDM, heywoodbj@cdm.com
 Brendan Harley, CDM, harleybm@cdm.com

Applicable Projects: Salt water intrusion studies, regional ASR studies.

References

International Ground Water Modeling Center, 1985. *Review of DYNFLOW and DYNTRACK Groundwater Simulation Computer Codes*. Report of Findings by Paul K.M. van der Heijde for U.S. Environmental Protection Agency. IGWMC 85-17

van der Heijde, Paul K.M., 1999. *DYNFLOW Version 5.18: Testing and Evaluation of Code Performance*.

Pandit, Ashok, Panigrahi, Bijay, Peyton, Lee, Redi, Lakshmi, Sayed, Sayed and Emmett, H., 1997. *Ground-Water Flow and Contamination Models: Description and Evaluation*. Report of the activities of the ASCE Groundwater Quality Committee in Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management.

Wetland/Marsh Impact Evaluation

February 2007

Wetland/Marsh EFDC Modeling

Purpose:

The purpose of the wetland/marsh EFDC modeling is to determine the impacts of deepening the navigation channel; specifically, the effect on the salinity values throughout the marshes linked to the estuary. The EFDC modeling was used:

- (1) to provide estimates of salinity at gaged locations throughout the Back, Middle, and Front Rivers; which was used to provide input to the Model to Marsh (M2M) neural network model to provide a porewater salinity input grid to the Marsh Succession Models; and
- (2) to independently estimate salinity values for marsh cells under various deepening conditions.

The results of (1) are documented elsewhere. This report focuses on the results of (2).

Model Input Conditions:

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

<i>Run Scenario</i>	<i>River Flow</i>	<i>Sea Level Rise*</i>	<i>Evaluation Period</i>
Basic Evaluation	<i>Average/Typical</i>	<i>Existing Sea Level</i>	<i>1-March to 1-November</i>
Sensitivity Analysis #1	<i>Low Flow/Dry</i>	<i>Existing Sea Level</i>	<i>1-March to 1-November</i>
Sensitivity Analysis #2A	<i>Average/Typical</i>	<i>25 cm Sea Level Rise</i>	<i>1-March to 1-November</i>
Sensitivity Analysis #2B	<i>Average/Typical</i>	<i>50 cm Sea Level Rise</i>	<i>1-March to 1-November</i>

**25 and 50 cm sea level rise conditions were specified by the Interagency Coordination Team and are based on EPA and NOAA 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 Clio, 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 (See Table 2).

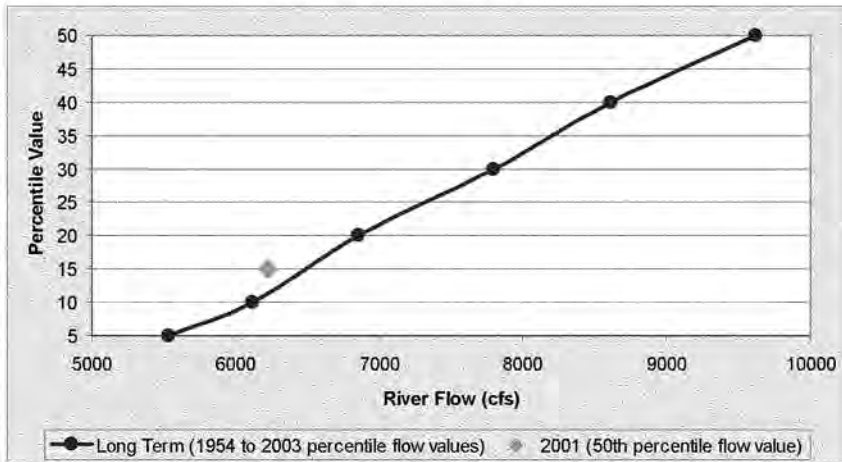
Table 2- Average River Flows from USGS gaging station at Clio, GA

<i>Period of Record</i>	<i>Mar.</i>	<i>Apr.</i>	<i>May</i>	<i>June</i>	<i>July</i>	<i>Aug.</i>	<i>Sept.</i>	<i>Oct.</i>	<i>Overall</i>
	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(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 Clio, 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 Clio, GA



The long term Clio 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 Clio 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. 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 this modeling effort.

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

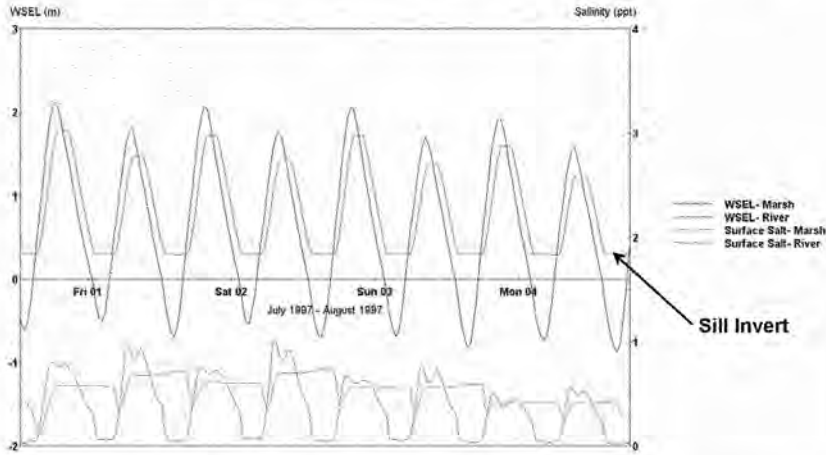
Model Limitations:

The EFDC model has undergone extensive calibration as outlined in the report titled *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project* and dated May 20, 2005. The model has been confirmed with additional datasets and is considered appropriate for making salinity predictions throughout the river system. However, model calibration was performed using data comparisons between grid cells and gages within the river system. No calibration points were located within the wetlands/marshes.

The marshes are simulated in the EFDC model grid using a marsh grid cell and a hydraulic structure. The hydraulic structure links the marsh grid cell to a riverine grid cell with a rating table and a small sill (.1 m high). In reality there is not a structure linking the marsh to the river, however, for modeling purposes the structure allows interaction between the marsh and river while maintaining stability. The rating curve specifies the exchange flow rates between the river and the marsh over time. The sill allows the marsh to maintain a very small pool of water in the cell at all times. By keeping the marsh cells wet and not allowing them to dry out, the model remains stable. The wetlands interact with the river during times when the flood tide is rising above the elevation of the sill, and when the ebb tide is falling but is elevated above the sill. The sill prevents interaction between the marsh and the river during low tide. This would be expected because marshes are typically shallower than the surrounding rivers and creeks that furnish tide water. When comparing 50th percentile marsh salinity to adjacent river cells, this explains why the marsh cells sometimes show higher salinity values.

The water carried during high tide is typically more saline than water carried at low tide. Once the tide is flushed from the marsh and the water surface has dropped below the elevation of the sill a small amount of water is left in the marsh cell to keep it wet. This small amount of water has a sustained high concentration of salinity from the flood tide, however the cell should actually be dry during this period of the tidal cycle (See Figure 2).

Figure 2- Water Surface Elevations and Surface Salinity for Marsh-Riverine Interaction



While the sill is necessary to maintain model stability, this method may predict higher salinity readings in the wetlands/marshes for a small portion of the tidal cycle than would actually occur. We do not, however, believe this to be significant.

Output Generated:

Three types of maps were generated to aid in evaluation of the impacts of deepening on the wetland/marshes.

Salinity Value Maps- Used as a baseline to evaluate the impacts. Maps show surface salinity values ranging from 0 to 32.5 ppt. These maps were only generated for the existing deepened channel condition for the two run periods of interest (1997 and 2001). They were not generated for each deepening scenario.

Salinity Difference Maps- Maps show salinity difference values (ppt) and compare changes in surface salinity values between the existing channel depth and each proposed deepened channel.

Threshold Salinity Maps- Maps show the boundary between fresh and salt water using 0.5 ppt salinity value as an indicator. Cells that are less than 0.5 ppt are pink and cells that are greater than 0.5 ppt are blue. The cells that change from less than to greater than 0.5 ppt with deepening are green.

All of the maps show the surface salinity values for both the 50% exceedance and the 10% exceedance values based on the run period (1 March to 1 November). The 10% exceedance values represents a salinity that is exceeded only 10% of the time. Statistics were done using the Post Processor developed by Tetra Tech.

In addition to the salinity maps there are tables showing marsh acreages impacted due to deepening. The acreages are based on the Threshold Salinity Maps and show the net impact (10% and 50% exceedance values) for marsh areas changing from less than 0.5 ppt to greater than 0.5 ppt or fresh to salt.

Findings:

The Salinity Value Base Maps for 1997 used in comparison to the Basic Evaluation and Sensitivity Analysis #2A & #2B show salinity values throughout the estuary system and the marshes. The salinity values are highest and reach the furthest upstream on Front River due to the deeper channel conditions than that of Middle, Back and Little Back Rivers. The 50% exceedance surface salinities on the Front River around River Street range from 3.01 to 5.00 ppt. Upstream of the tidegate on Back River the maximum salinity values are in the 7.01 to 9.00 ppt range. Between New Cut and Rifle Cut on Middle River the maximum surface salinity is 0.71 to 0.80 ppt. The salinity values in this area are directly related to those on Front River. The saline water is carried into Middle River through the entrance located just North of the Kings Island Turning Basin. There is also a connection from Middle River to the saline waters on Front River through Houston Cut and Steamboat River.

The Little Back River is mostly fresh water. Rifle Cut supplies both fresh and saline water from Middle River to Little Back River. Large volumes of water move very swiftly through Rifle Cut with the incoming and outgoing tides.

The 10% exceedance surface salinity values show a more drastic picture of salinity values throughout the system. The 10% exceedance values represents a salinity that is exceeded only 10% of the time. The 10% exceedance surface salinities on the Front River around River Street range from 7.01 to 9.00 ppt. Upstream of the tidegate on Back River the maximum salinity values are in the 11.01 to 15.00 ppt range. Between New Cut and Rifle Cut on Middle River the maximum surface salinity is 3.01 to 5.00 ppt. The Little Back River may still be considered mostly fresh water, however most salinity values are less than 0.20 ppt.

The Salinity Value Base Maps for 2001 used in comparison to Sensitivity Analysis #1 show salinity values throughout the estuary system and the marshes. The salinity values are highest and reach the furthest upstream on Front River due to the deeper channel conditions than that of Middle, Back and Little Back Rivers. The saline waters intrude further upstream during the dryer conditions of 2001 than during the average conditions of 1997 due to less freshwater flow coming downstream into the estuary during 2001 than there is in 1997. Also, the salinity values for 2001 increase throughout the system as compared to 1997, which would be expected due to the lower freshwater flow condition in 2001.

The 50% exceedance surface salinities on the Front River around River Street range from 5.01 to 7.00 ppt. Upstream of the tidegate on Back River the maximum salinity values are in the 11.01 to 15.00 ppt range. Between New Cut and Rifle Cut on Middle River the maximum surface salinity is 2.01 to 3.00 ppt. The 10% exceedance surface salinities on the Front River around River Street range from 9.01 to 11.00 ppt. Upstream of the tidegate on Back River the maximum salinity

values are in the 11.01 to 15.00 ppt range. Between New Cut and Rifle Cut on Middle River the maximum surface salinity is 5.01 to 7.00 ppt. The Little Back River has salinity values from 0.41 ppt and up.

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 run are average/typical river flow and existing sea level. The evaluation period is 1 March to 1 November 1997.

The Salinity Difference Maps for the Basic Evaluation show changes/differences in salinity throughout the estuary. The impacts with deepening just an additional 2 ft extend above Steamboat River on Front River and throughout Middle, Back and Little Back Rivers. The maximum increase in salinity for the 44-ft deepening is 0.80 and 0.84 ppt, 50% and 10% exceedance respectively (See Table 3). As the channel is deepened to 48-ft, the maximum proposed, the maximum increase in salinity jumps to 2.19 and 2.54 ppt, 50% and 10% exceedance respectively.

Table 3- Maximum Salinity Differences- Basic Evaluation

Depth	Maximum Salinity Difference	
	10% Exceedance	50% Exceedance
44-ft	0.84	0.80
45-ft	1.24	1.15
46-ft	1.73	1.49
48-ft	2.54	2.19

The increase in maximum salinity differences with the increase in channel depth appears to be a linear relationship. However, the maximum increases are generally found on the Front River where the deepening is occurring. A quick view of Table 3 doesn't tell the full story of salinity impacts with deepening. The Salinity Difference Maps provide a clearer picture of what is happening in the areas of greatest concern: Middle, Little Back, and Back Rivers.

The Threshold Maps for the Basic Evaluation show the boundary lines in the estuary between fresh (salinity less than 0.5 ppt) to salt (salinity greater than 0.5 ppt) water. These maps are comparisons between the baseline and a deepened condition, which allows the change from fresh to salt water to be shown on the plots. The marsh acreages associated with the changes are noted on the maps (also, See Table 4).

Table 4- Marsh Acreages Impacted- Basic Evaluation

Depth	Acreages Negatively Impacted		Acreages Positively Impacted		Net Impact Net Positive, (Net Negative)	
	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance
44-ft	0	1633.2	0	0	(0)	(1633.2)
45-ft	0	1633.2	0	0	(0)	(1633.2)
46-ft	0	1633.2	0	0	(0)	(1633.2)
48-ft	299.0	1932.2	0	0	(299.0)	(1932.2)

All of the deepening scenarios show an impact on marsh acreages becoming more salty. The range of acreages impacted is from 299 acres for the 10% exceedance value and 1932.2 acres for the 50% exceedance value. The 10% exceedance maps show only one marsh to be negatively impacted for the 48-ft deepening, which is located north of Steamboat River between Front and Middle Rivers. The 50% exceedance maps show several marshes to be negatively impacted for each deepening. The impacted marshes are located in the vicinity of Steamboat River and Rifle Cut on Front, Middle and Little 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 run are low flow/dry river flow and existing sea level. The evaluation period is 1 March to 1 November 2001.

The Salinity Difference Maps for the Sensitivity Analysis #1 show changes/differences in salinity throughout the estuary. The maximum increase in salinity for the 44-ft deepening is 0.80 and 0.92 ppt, 50% and 10% exceedance respectively (See Table 5). As the channel is deepened to 48-ft, the maximum proposed, the maximum increase in salinity jumps to 2.39 and 2.75 ppt, 50% and 10% exceedance respectively.

Table 5- Maximum Salinity Differences- Sensitivity Analysis #1

Depth	Maximum Salinity Difference	
	10% Exceedance	50% Exceedance
44-ft	0.92	0.80
45-ft	1.42	1.19
46-ft	1.93	1.61
48-ft	2.75	2.39

The Threshold Maps for the Sensitivity Analysis #1 show the boundary lines in the estuary between fresh (salinity less than 0.5 ppt) to salt (salinity greater than 0.5 ppt) water. These maps are comparisons between the baseline and a deepened condition, which allows the change from fresh to salt water to be shown on the plots. The marsh acreages associated with the changes are noted on the maps (also, See Table 6).

Table 6- Marsh Acreages Impacted- Sensitivity Analysis #1

Depth	Acreages Negatively Impacted		Acreages Positively Impacted		Net Impact Net Positive, (Net Negative)	
	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance
44-ft	494.2	469.2	0	0	(494.2)	(469.2)
45-ft	494.2	768.2	0	0	(494.2)	(768.2)
46-ft	494.2	768.2	0	0	(494.2)	(768.2)
48-ft	494.2	768.2	0	0	(494.2)	(768.2)

Each deepening scenario for the Sensitivity Analysis #1 shows negative impacts on the marshes. The number of acres effected ranges from 469.2 to 768.2. The 10% exceedance maps show two marshes negatively impacted for the each deepening. The impacted marshes are located on Little Back River between Rifle Cut and McCoy Cut. The 50% exceedance maps show one marsh on Front River north of Steamboat River negatively impacted for the 44-ft deepening. Two marshes are negatively impacted for the 45-ft, 46-ft and 48-ft deepenings, located north of Steamboat River, one on Front River and one on Middle River.

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 run are average/typical river flow and a 25 cm sea level rise. The evaluation period is 1 March to 1 November 1997.

The Salinity Difference Maps for the Sensitivity Analysis #2A show changes/differences in salinity throughout the estuary. The maximum increase in salinity for the 44-ft deepening is 1.39 and 1.47 ppt, 50% and 10% exceedance respectively (See Table 7). As the channel is deepened to 48-ft, the maximum proposed, the maximum increase in salinity jumps to 2.67 and 3.16 ppt, 50% and 10% exceedance respectively.

Table 7- Maximum Salinity Differences- Sensitivity Analysis #2A

Depth	Maximum Salinity Difference	
	10% Exceedance	50% Exceedance
Existing	0.89	0.86
44-ft	1.47	1.39
45-ft	1.87	1.70
46-ft	2.28	2.05
48-ft	3.16	2.67

The 25 cm sea level rise boundary condition causes further salinity intrusion in the estuary. The 48-ft deepening, 10% exceedance map shows the salinity changes reach as far upstream as the I-95 bridge crossing.

The Threshold Maps for the Sensitivity Analysis #2A show the boundary lines in the estuary between fresh (salinity less than 0.5 ppt) to salt (salinity greater than 0.5 ppt) water. These maps are comparisons between the baseline and a deepened condition, which allows the change from fresh to salt water to be shown on the plots. The marsh acreages associated with the changes are noted on the maps (also, See Table 8).

Table 8- Marsh Acreages Impacted- Sensitivity Analysis #2A

Depth	Acreages Negatively Impacted		Acreages Positively Impacted		Net Impact Net Positive, (Net Negative)	
	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance
Existing	299	1287.4	0	0	(299)	(1287.4)
44-ft	299	1932.2	0	0	(299)	(1932.2)
45-ft	299	1932.2	0	0	(299)	(1932.2)
46-ft	299	1932.2	0	0	(299)	(1932.2)
48-ft	299	1932.2	0	0	(299)	(1932.2)

Each deepening scenario for the Sensitivity Analysis #2A shows a negative impact on the marshes. The number of acres effected ranges from 299 to 1932.2. The 10% exceedance maps show one marsh negatively impacted for all the deepenings, which is located north of Steamboat River between Front and Middle Rivers. The 50% exceedance maps show several marshes negatively impacted for each deepening in and around Steamboat River and Rifle Cut.

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 run are average/typical river flow and a 50 cm sea level rise. The evaluation period is 1 March to 1 November 1997.

The Salinity Difference Maps for the Sensitivity Analysis #2B show changes/differences in salinity throughout the estuary. The maximum increase in salinity for the 44-ft deepening is 2.09 and 2.13 ppt, 50% and 10% exceedance respectively (See Table 9). As the channel is deepened to 48-ft, the maximum proposed, the maximum increase in salinity jumps to 3.22 and 3.64 ppt, 50% and 10% exceedance respectively.

Table 9- Maximum Salinity Differences- Sensitivity Analysis #2B

Depth	Maximum Salinity Difference	
	10% Exceedance	50% Exceedance
Existing	1.74	1.60
44-ft	2.13	2.09
45-ft	2.48	2.33
46-ft	2.87	2.62
48-ft	3.64	3.22

As expected, the 50 cm sea level rise boundary condition causes further salinity intrusion in the estuary. The 48-ft deepening, 10% exceedance map shows the salinity changes reach upstream to the I-95 bridge crossing. The trend with increasing sea level is an increase in salinity values throughout the estuary.

The Threshold Maps for the Sensitivity Analysis #2B show the boundary lines in the estuary between fresh (salinity less than 0.5 ppt) to salt (salinity greater than 0.5 ppt) water. These maps are comparisons between the baseline and a deepened condition, which allows the change from fresh to salt water to be shown on the plots. The marsh acreages associated with the changes are noted on the maps (also, See Table 10).

Table 10- Marsh Acreages Impacted- Sensitivity Analysis #2B

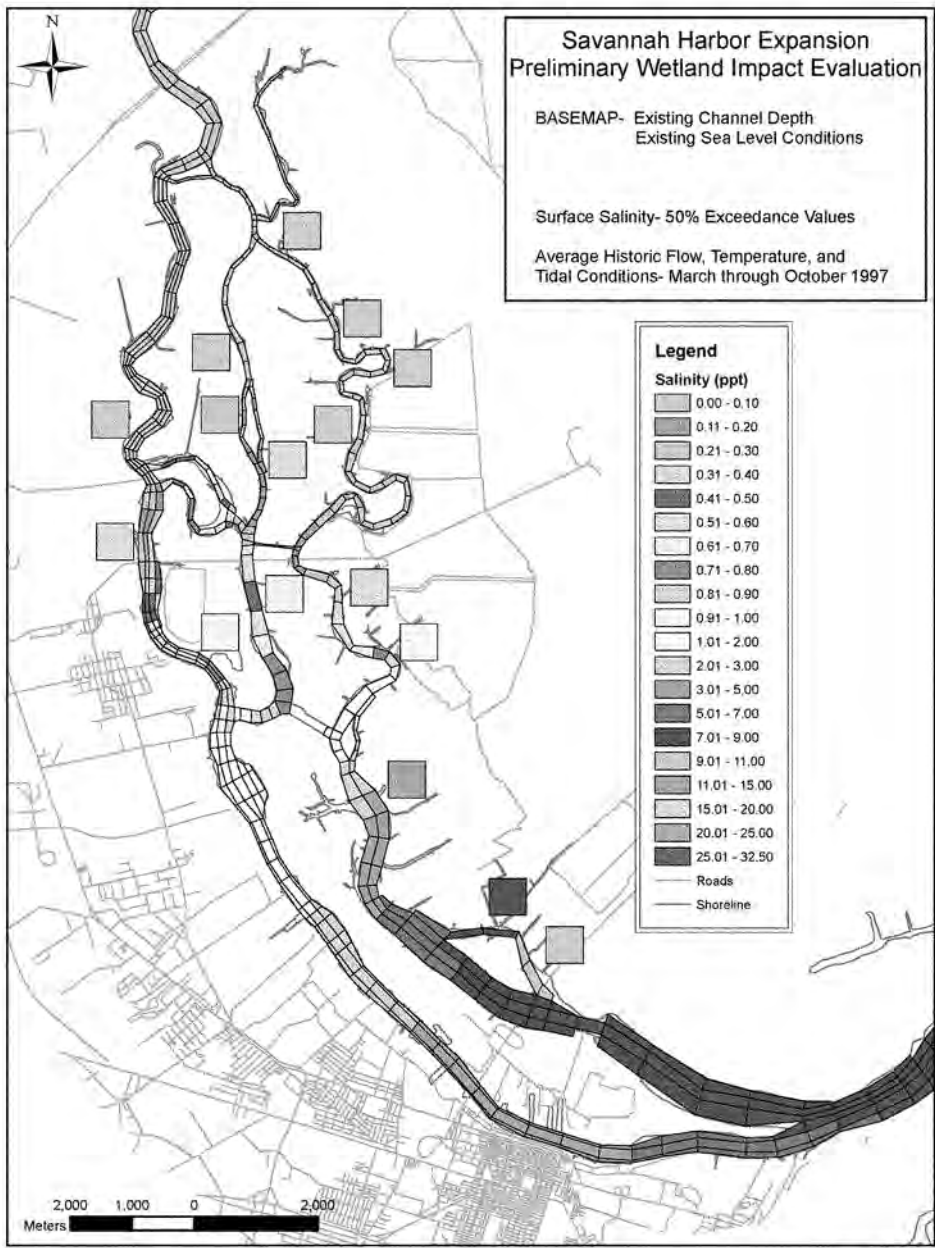
Depth	Acreages Negatively Impacted		Acreages Positively Impacted		Net Impact Net Positive, (Net Negative)	
	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance	10% Exceedance	50% Exceedance
Existing	299	1932.2	0	0	(299)	(1932.2)
44-ft	1210.8	1932.2	0	0	(1210.8)	(1932.2)
45-ft	1457.9	1932.2	0	0	(1457.9)	(1932.2)
46-ft	1457.9	1932.2	0	0	(1457.9)	(1932.2)
48-ft	1457.9	1932.2	0	0	(1457.9)	(1932.2)

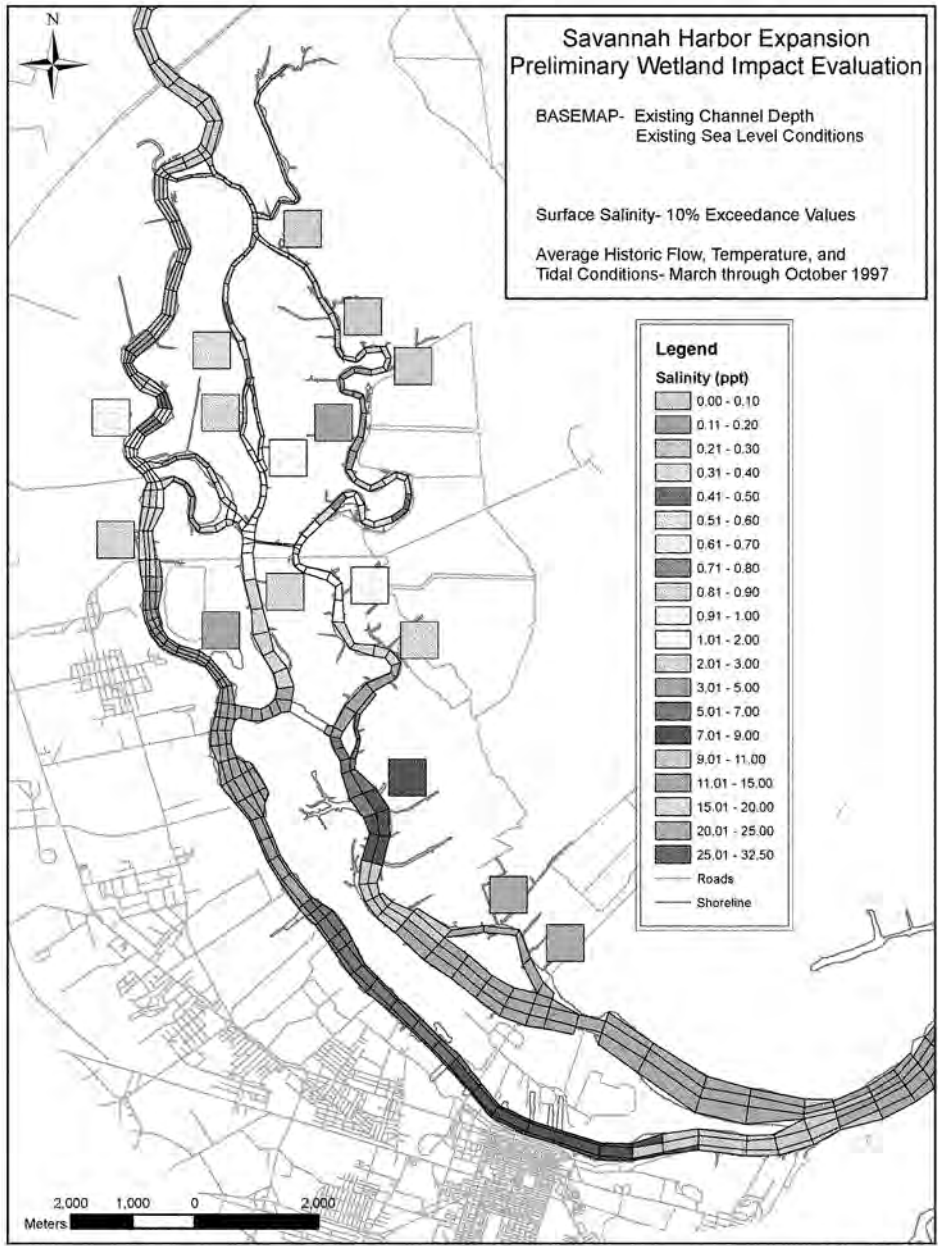
Each deepening scenario for the Sensitivity Analysis #2B shows a negative impact on the marshes. The number of acres effected ranges from 1210.8 to 1932.2. The 10% exceedance maps show five marshes negatively impacted for the 45-ft, 46-ft, and 48-ft. Four are located on Little Back River and one is located on Middle River between Front and Middle Rivers. The 50% exceedance maps show four marshes negatively impacted for each deepening, located in the vicinity of Steamboat River and Rifle Cut.

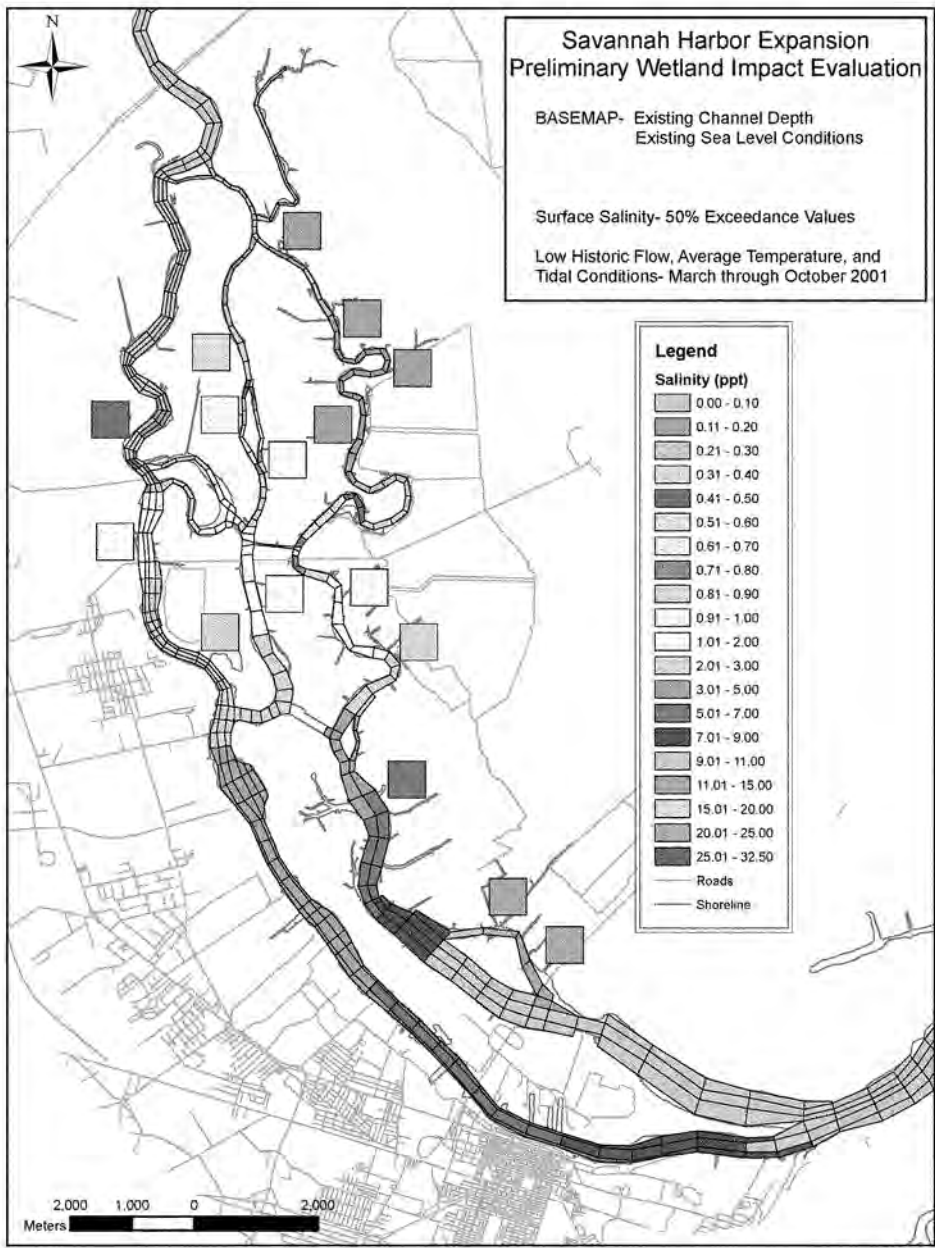
Conclusion:

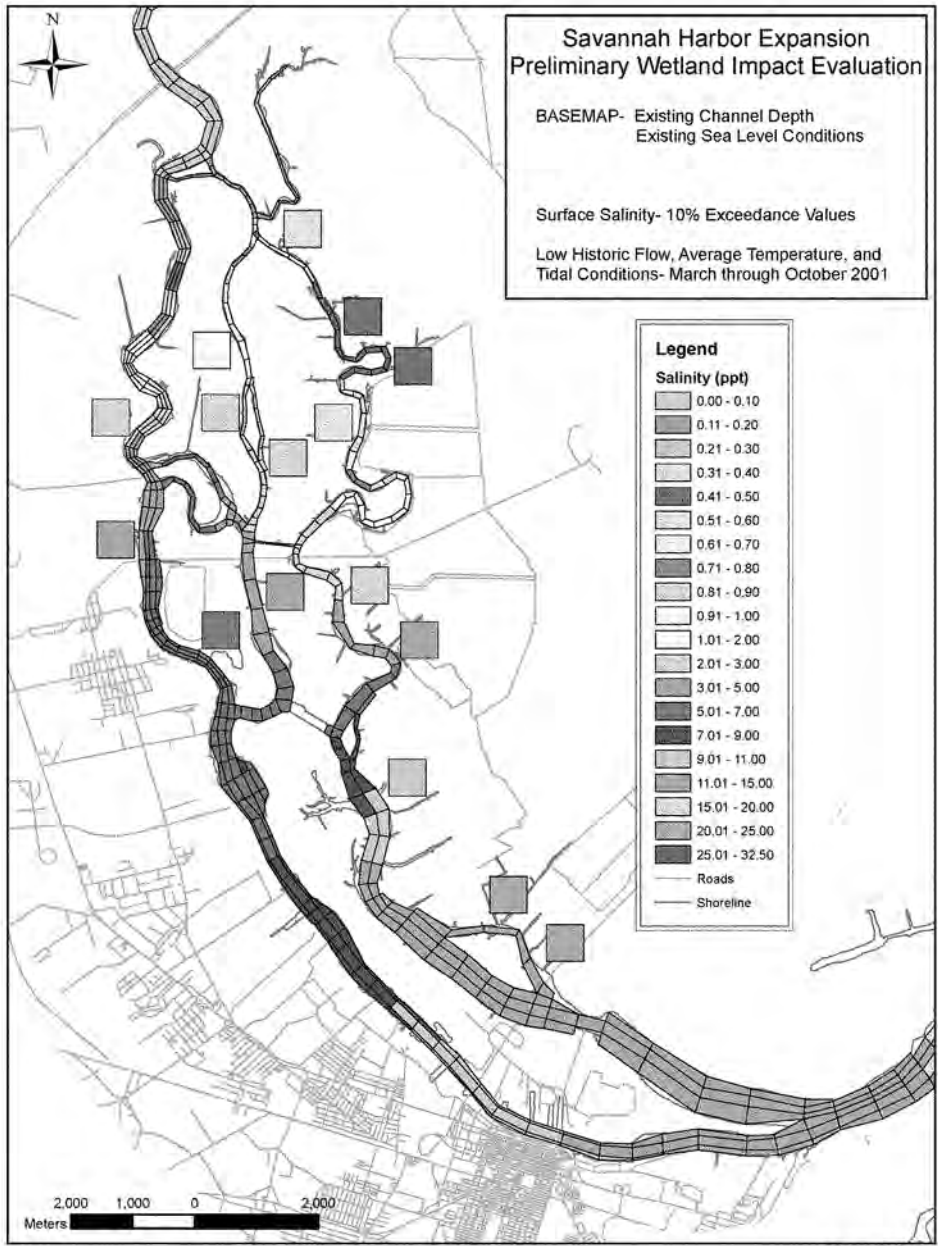
The EFDC modeling predicts that there will be impacts on the marshes/wetlands with each deepening. The level of impact depends directly on the proposed depth of the navigation channel. The trends indicate that as the navigation channel is deepened salinity intrudes further and further upstream. Also, salinity is propagated even further upstream with the rising sea level.

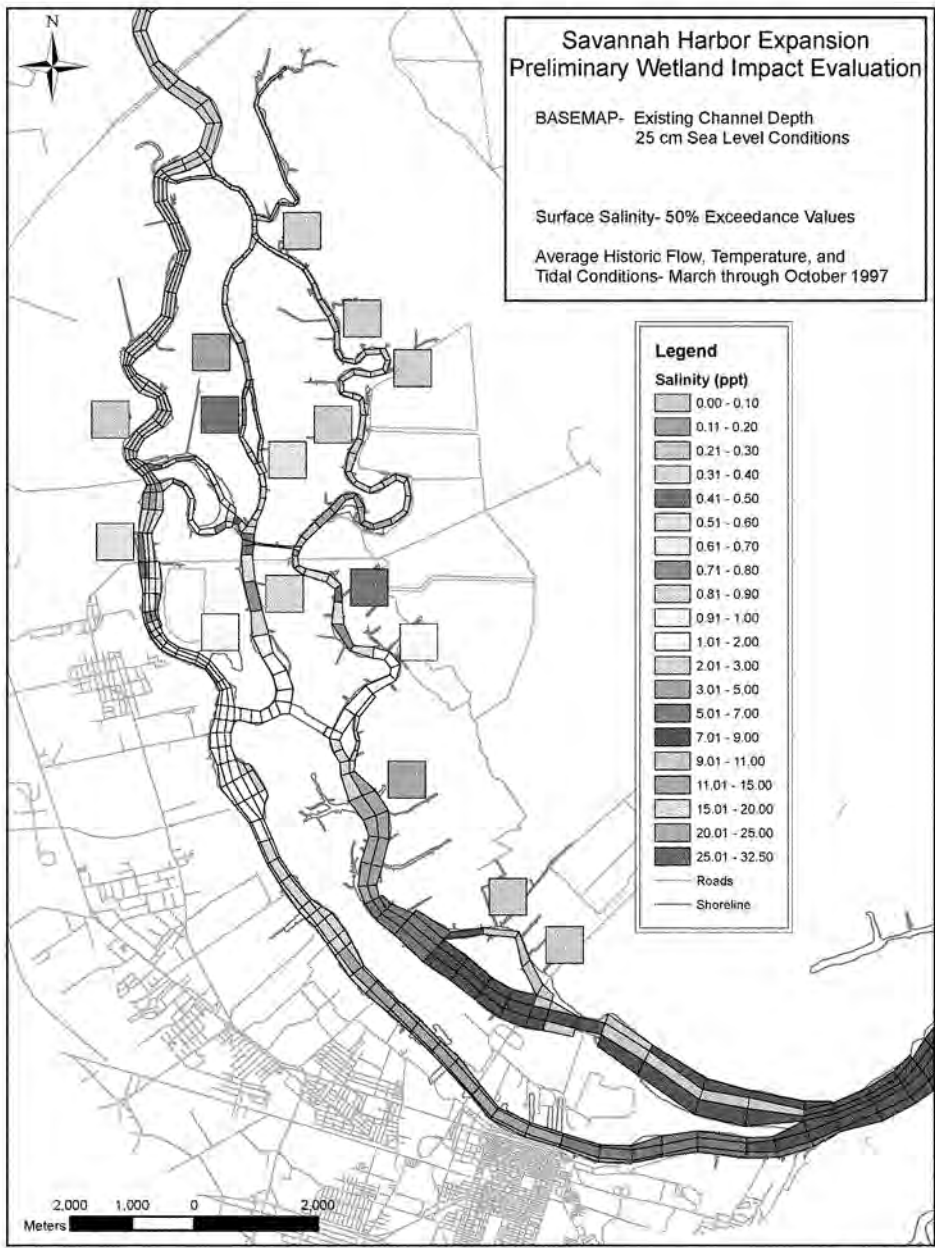
Base Maps

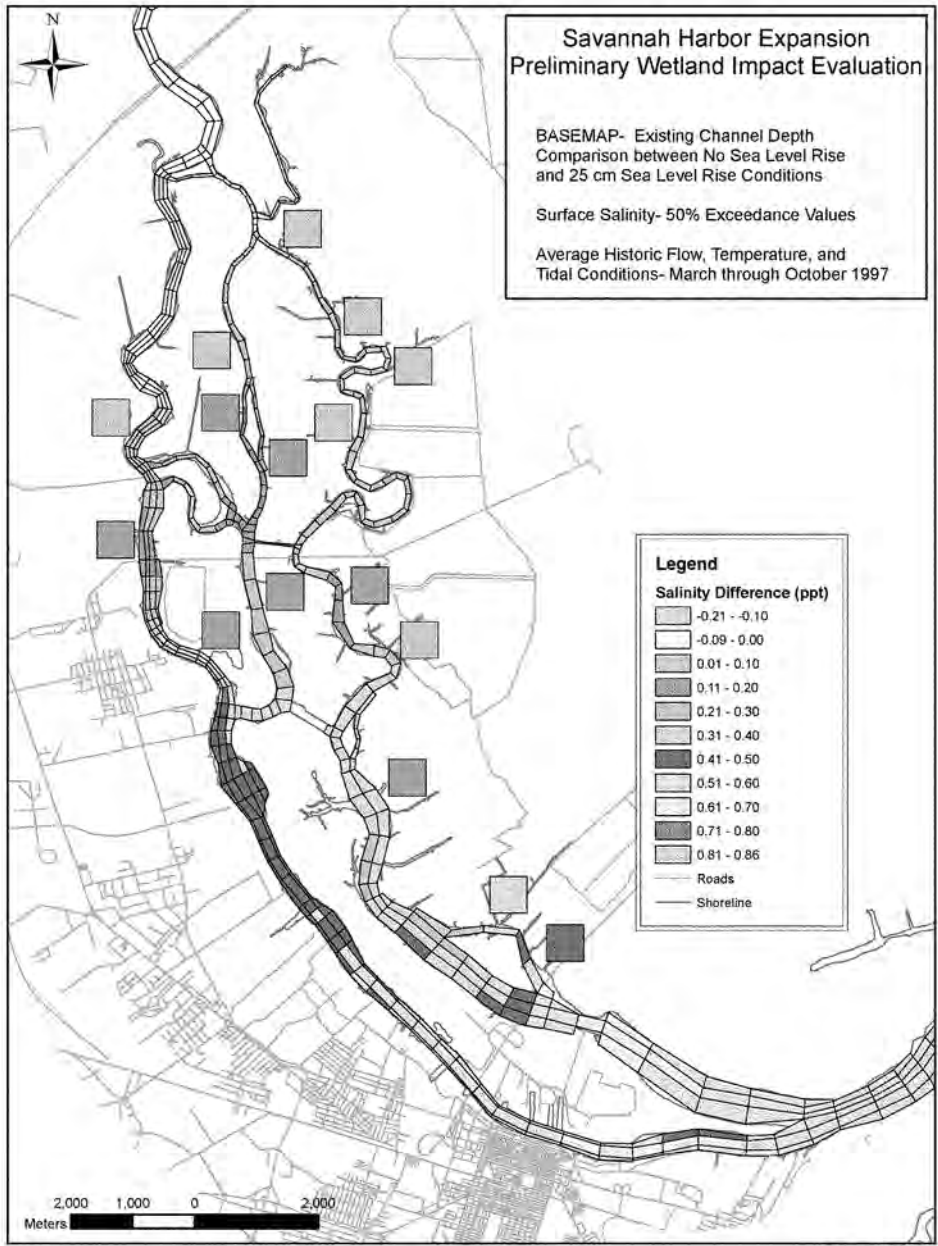


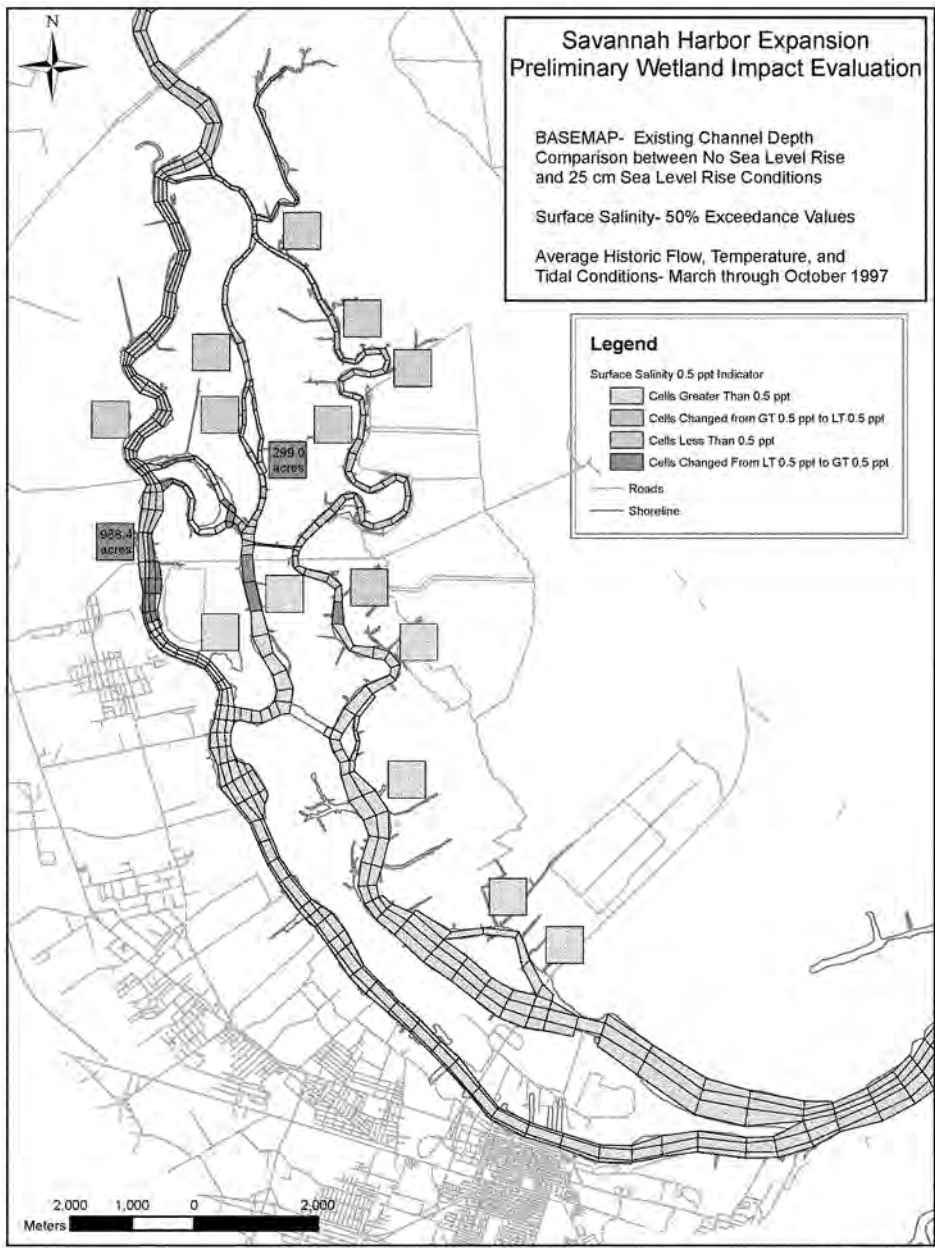


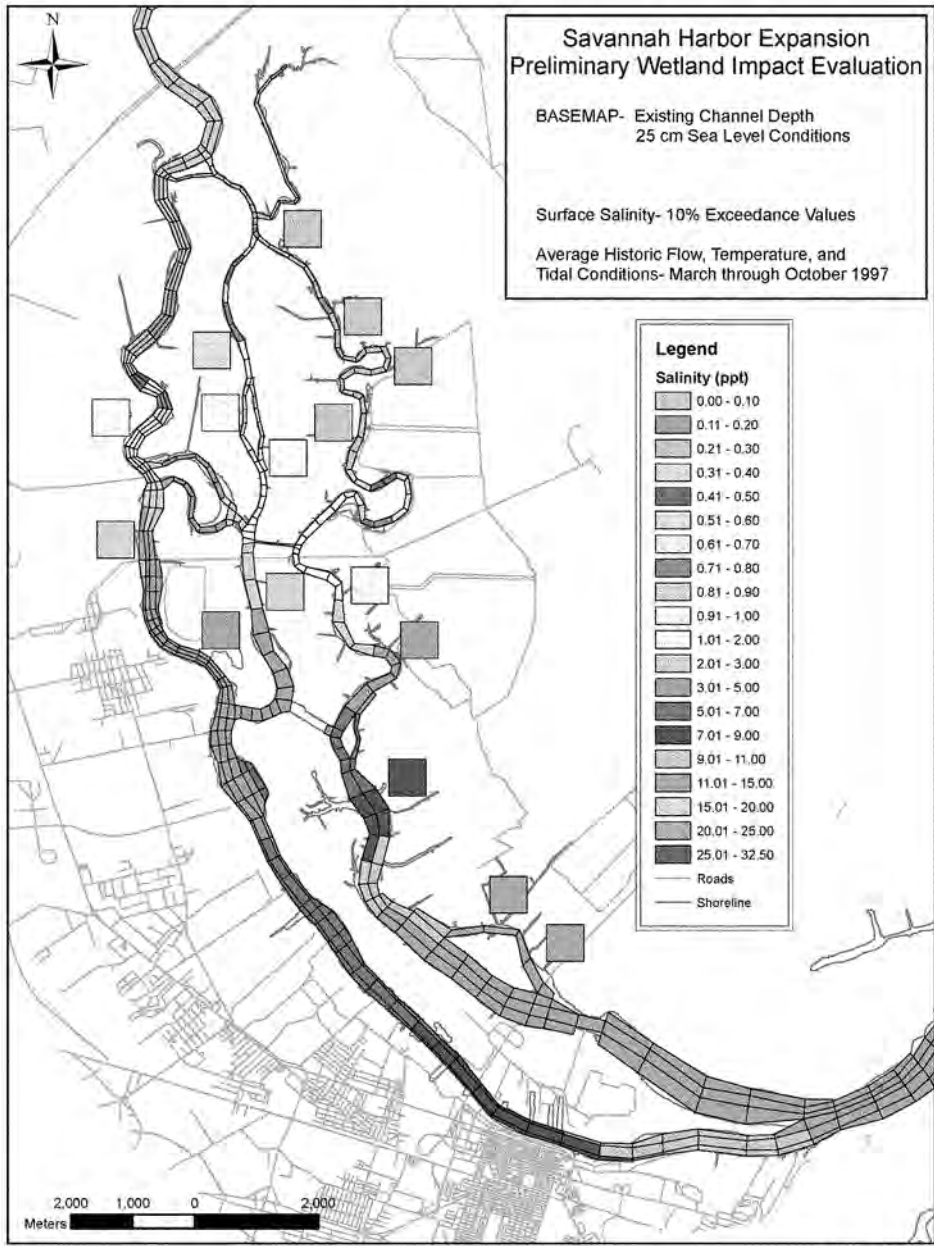


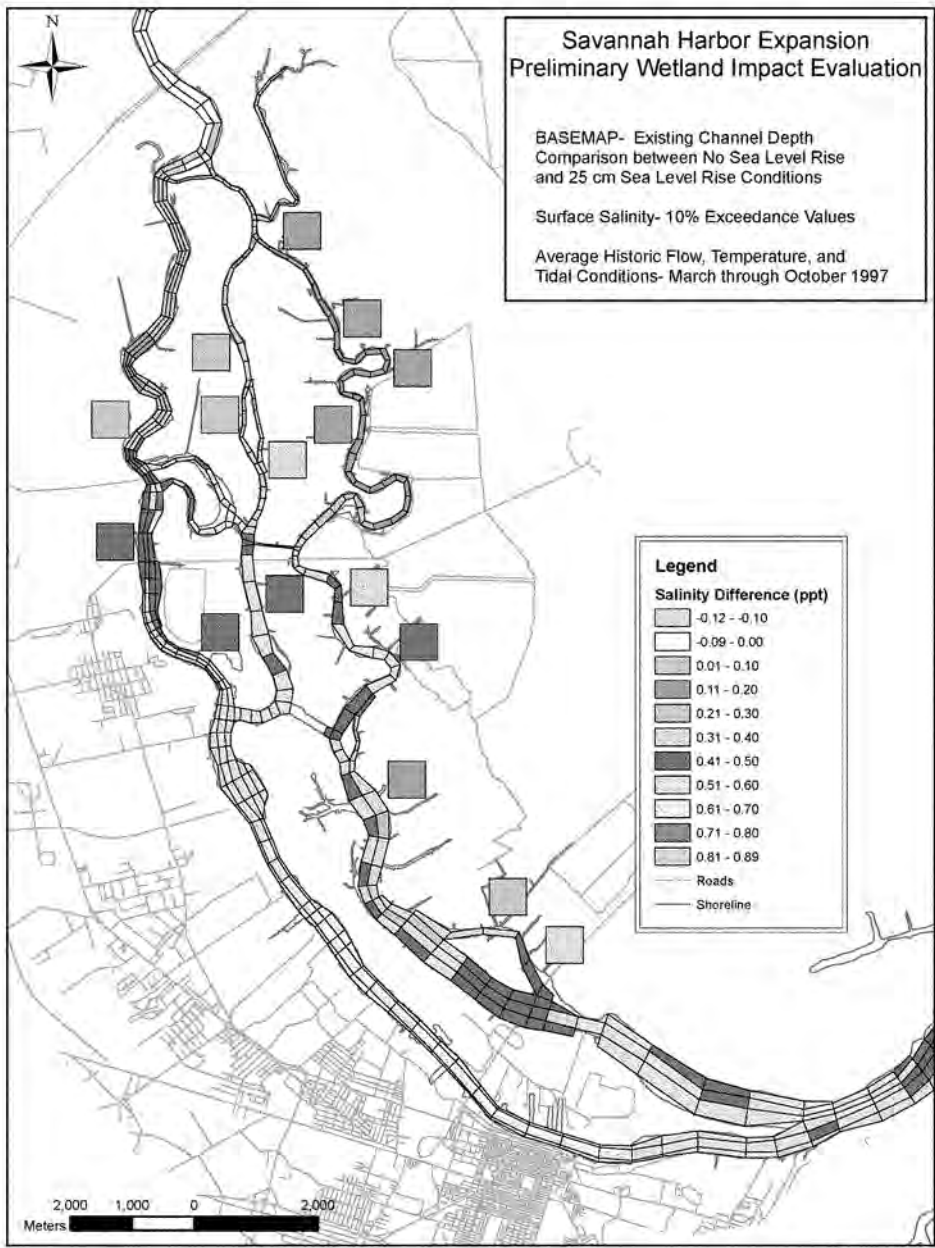


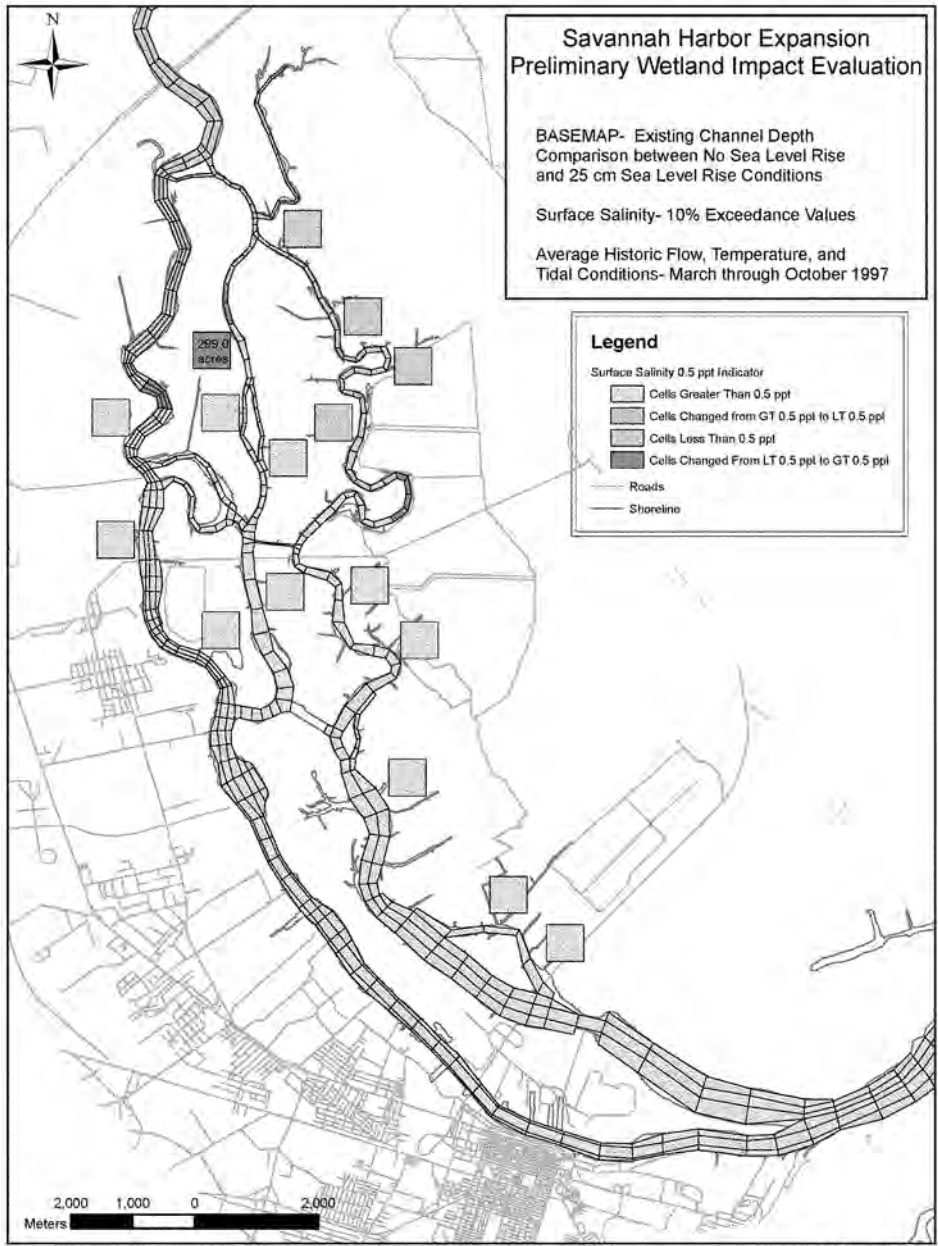


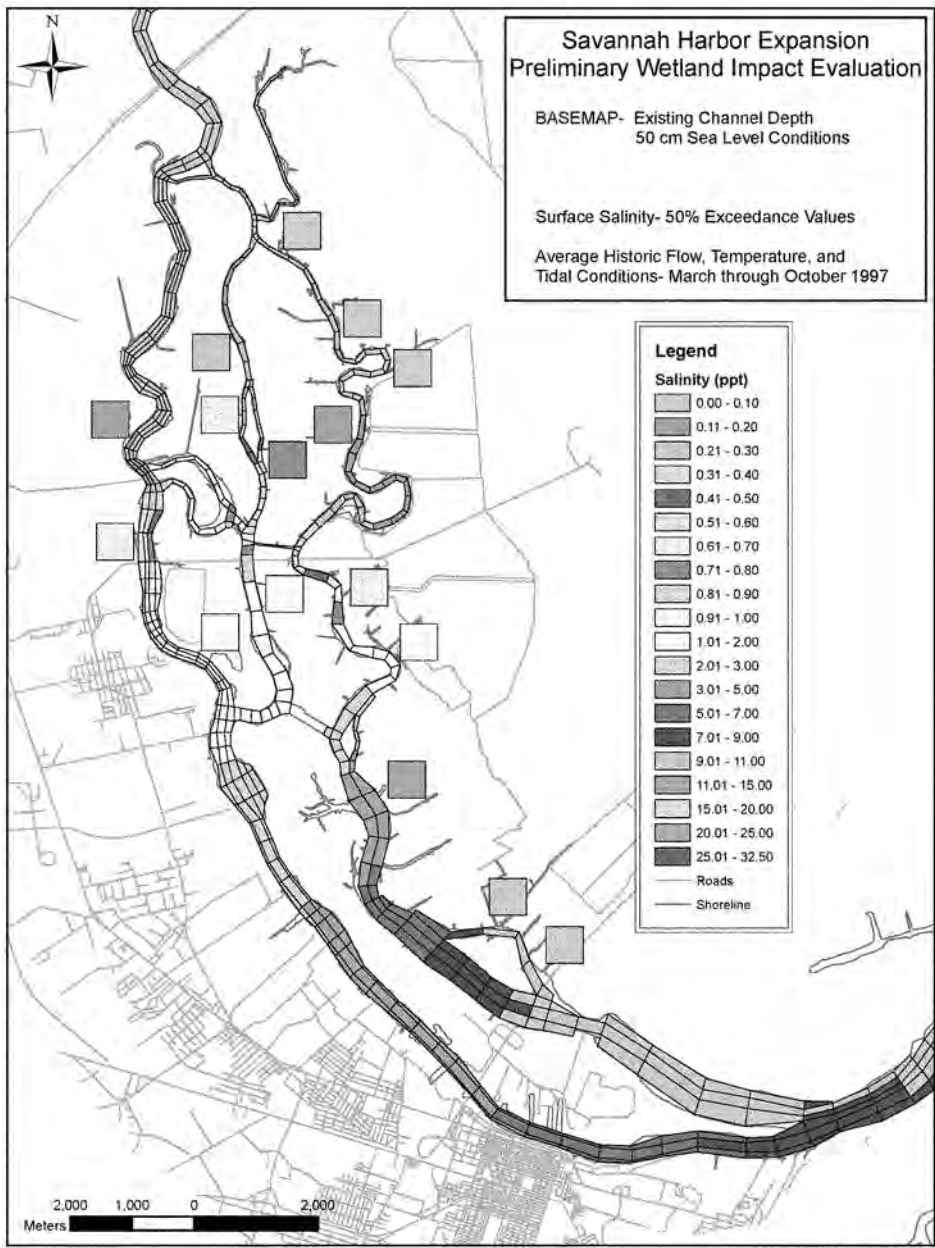


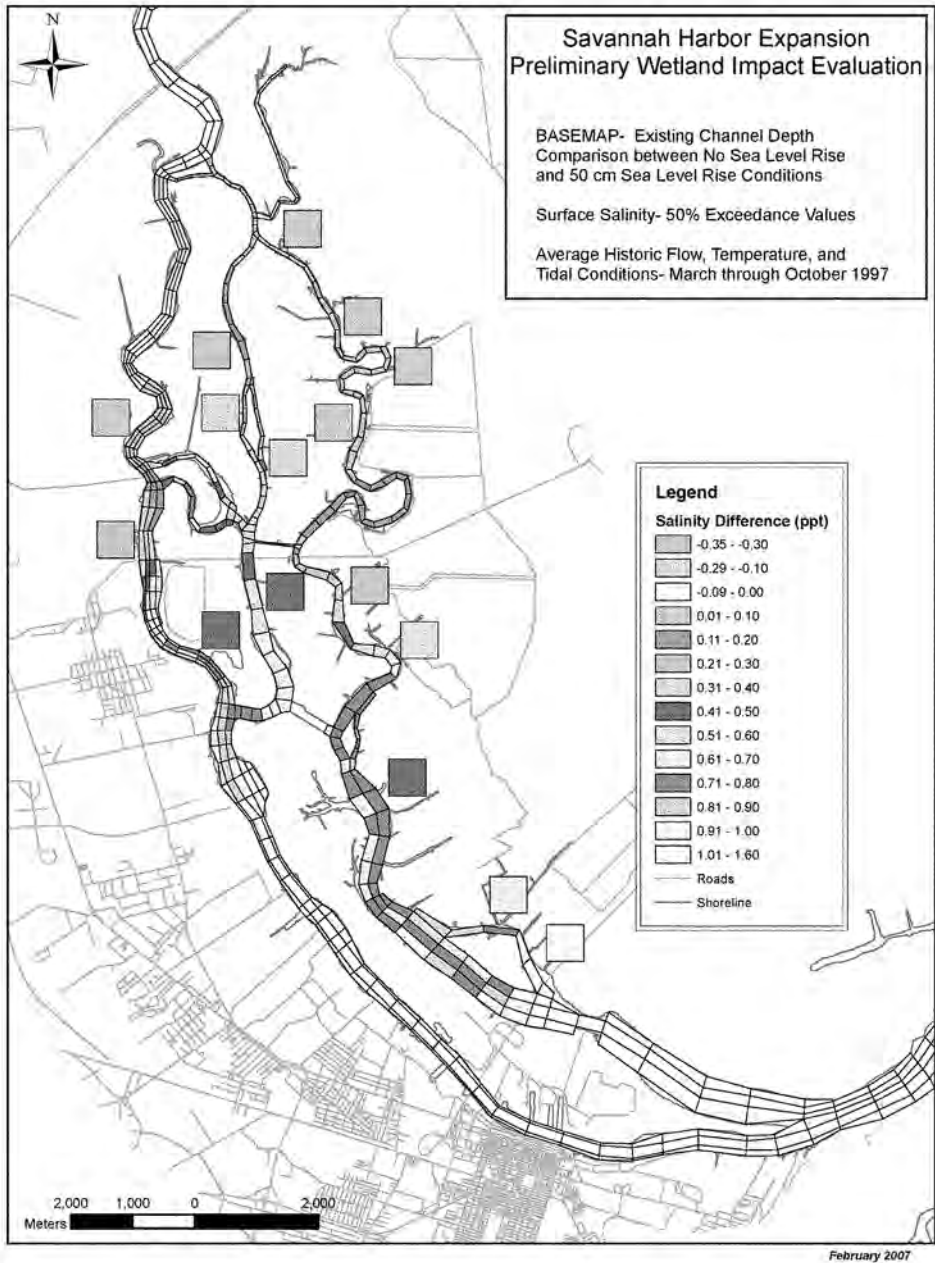


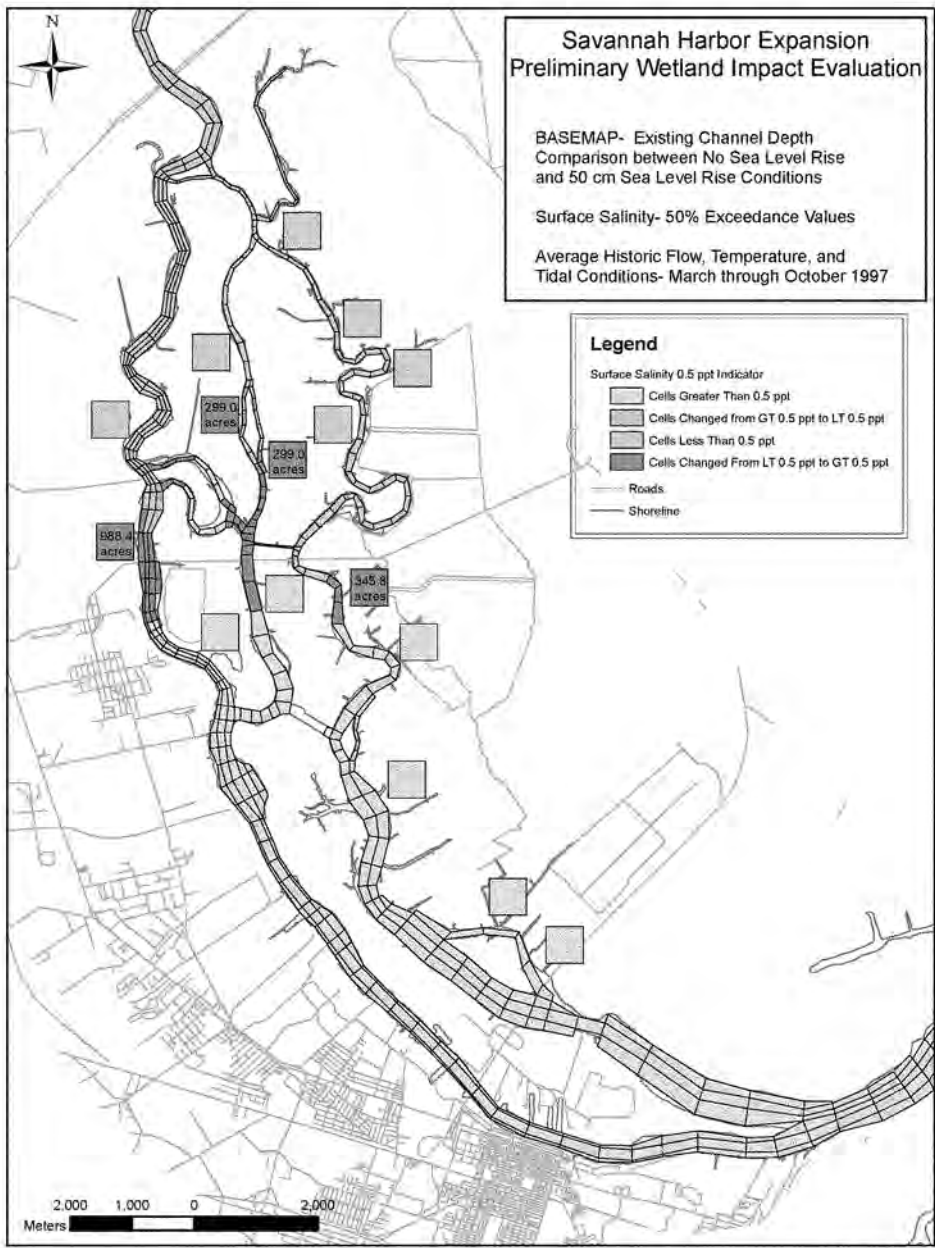


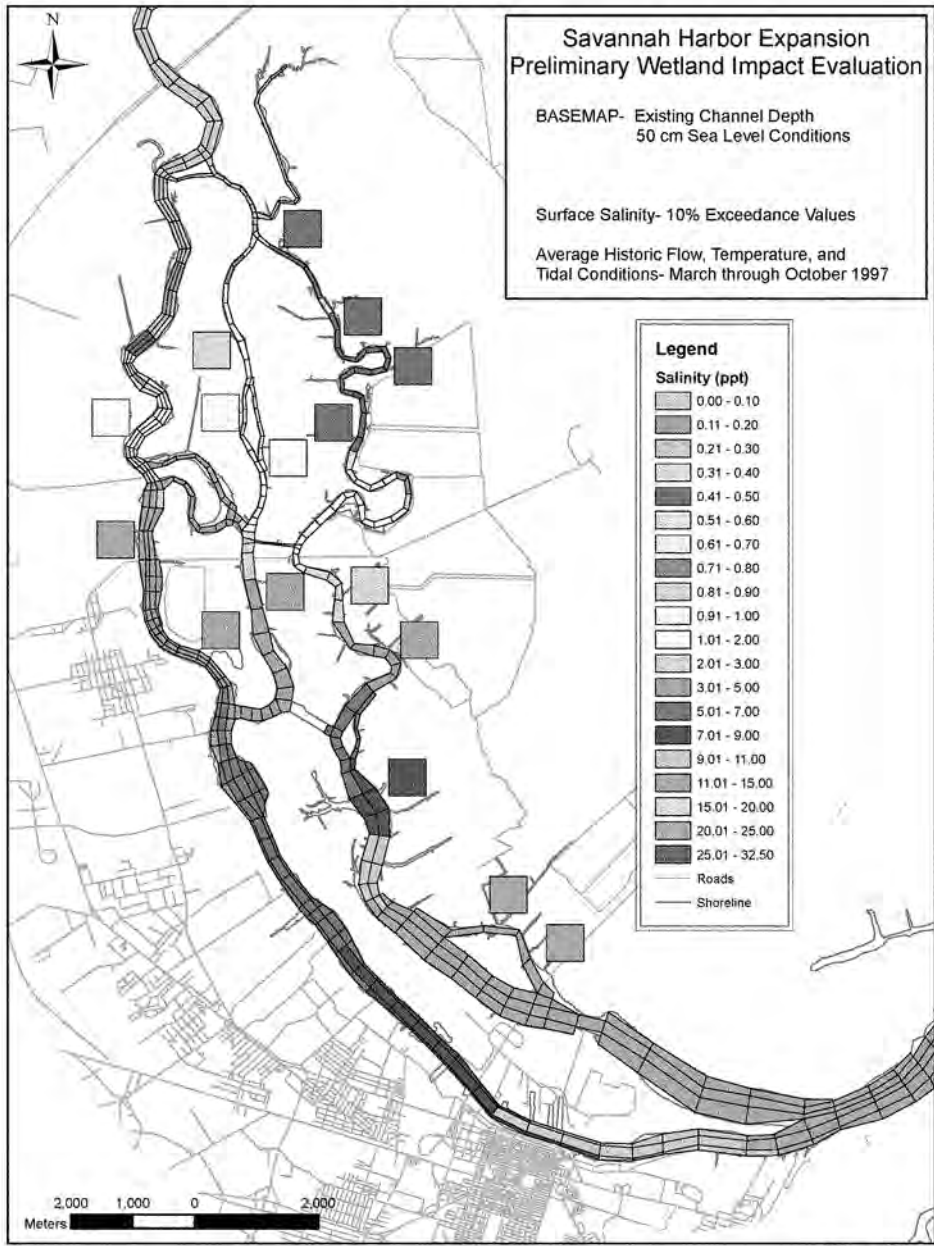


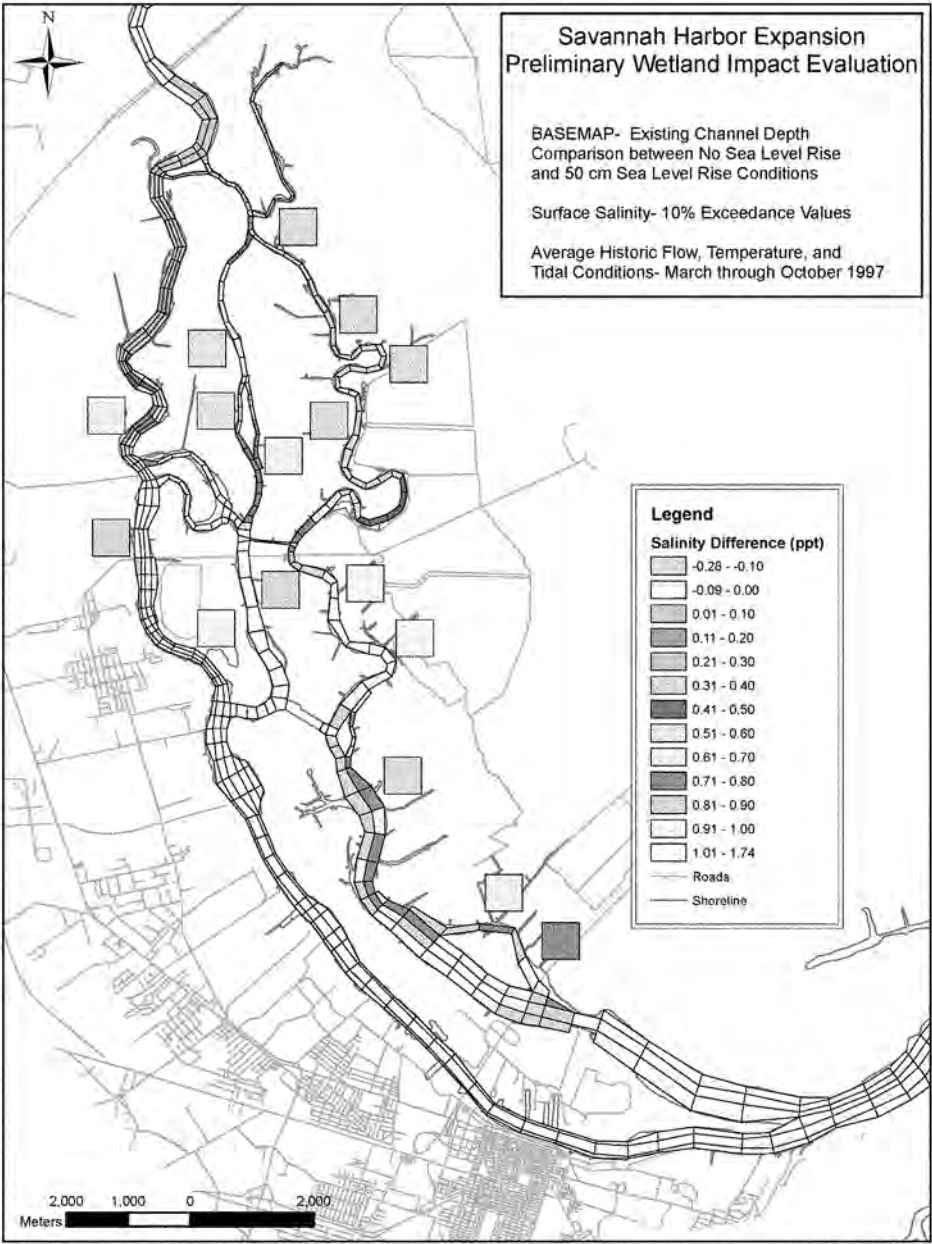


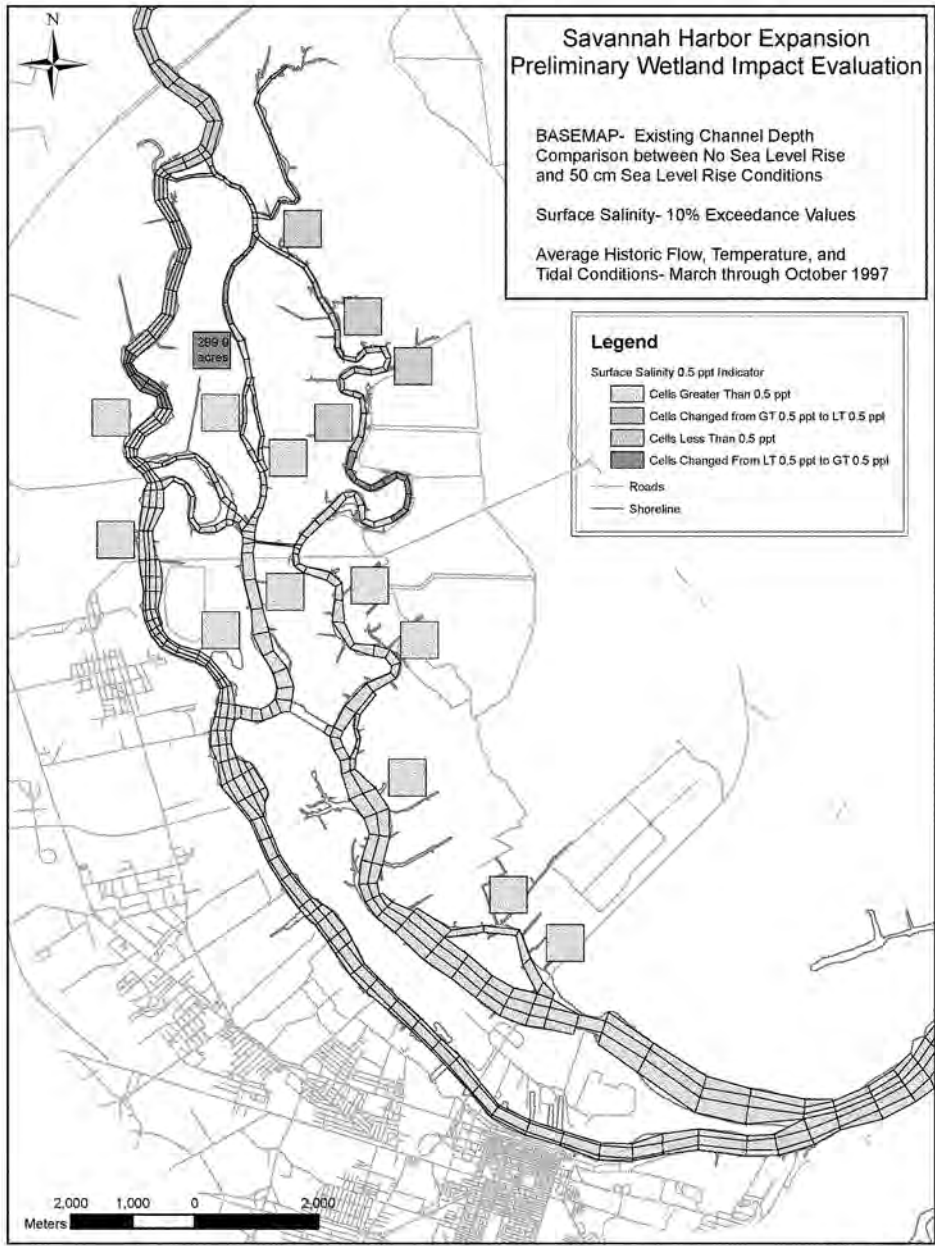




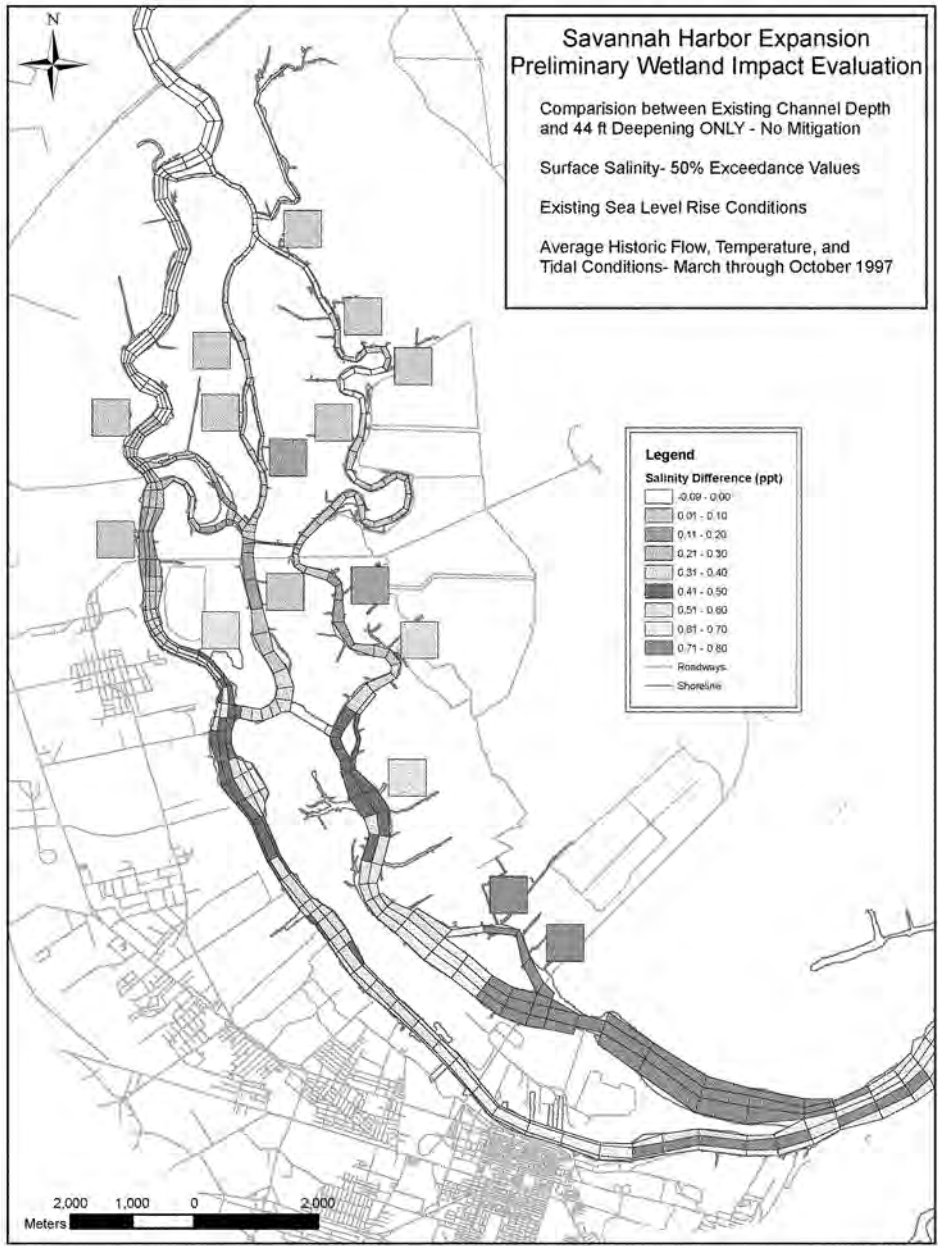


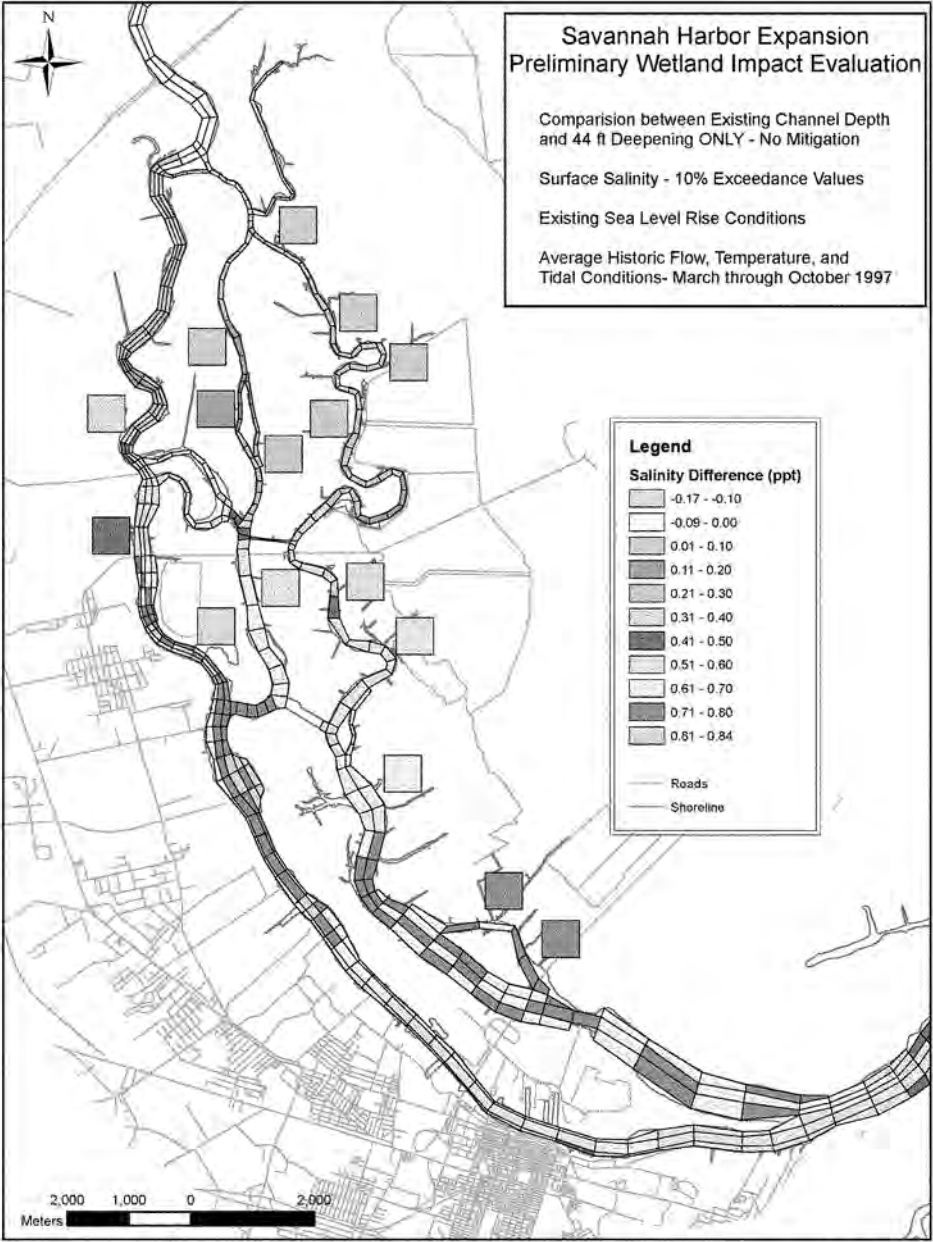


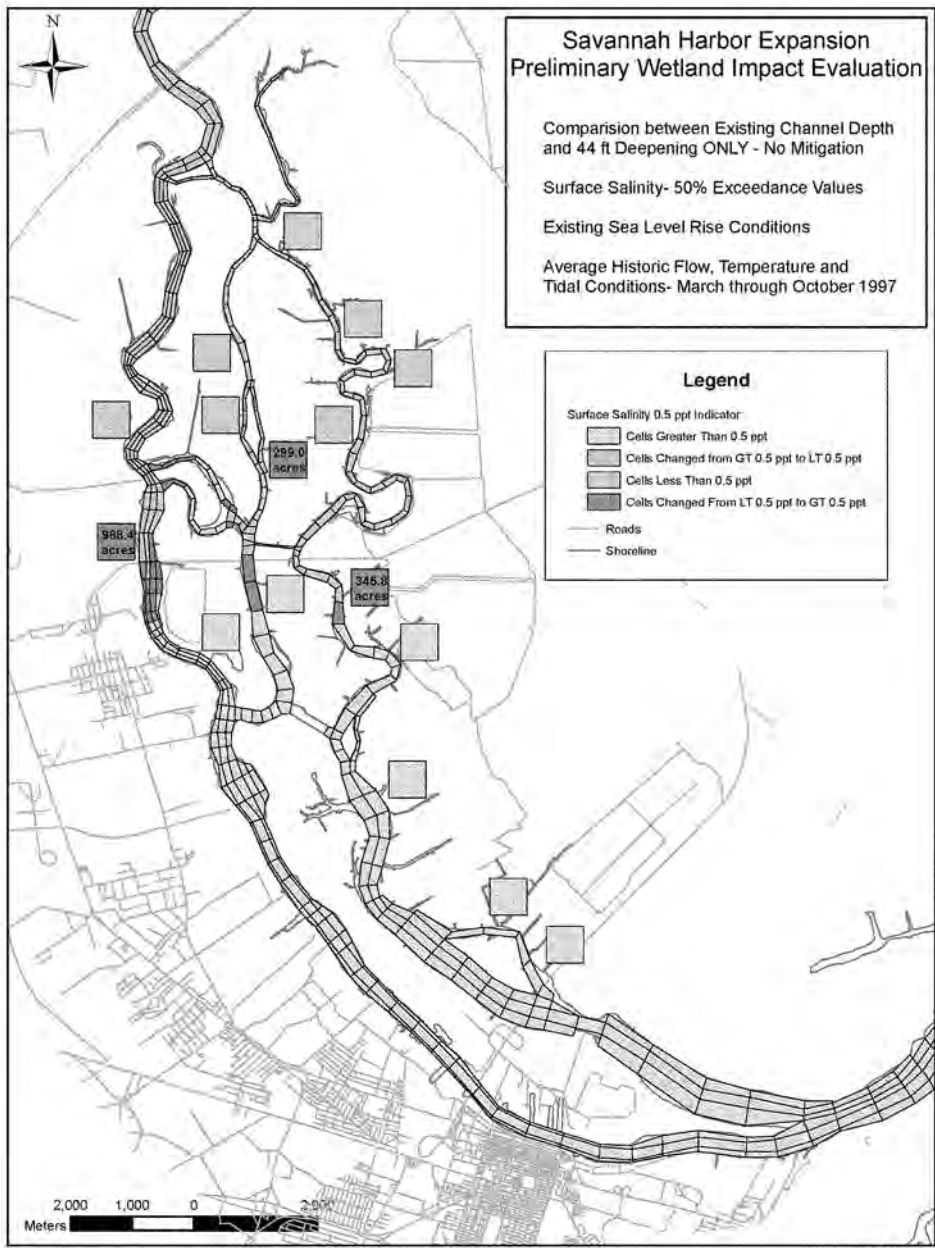


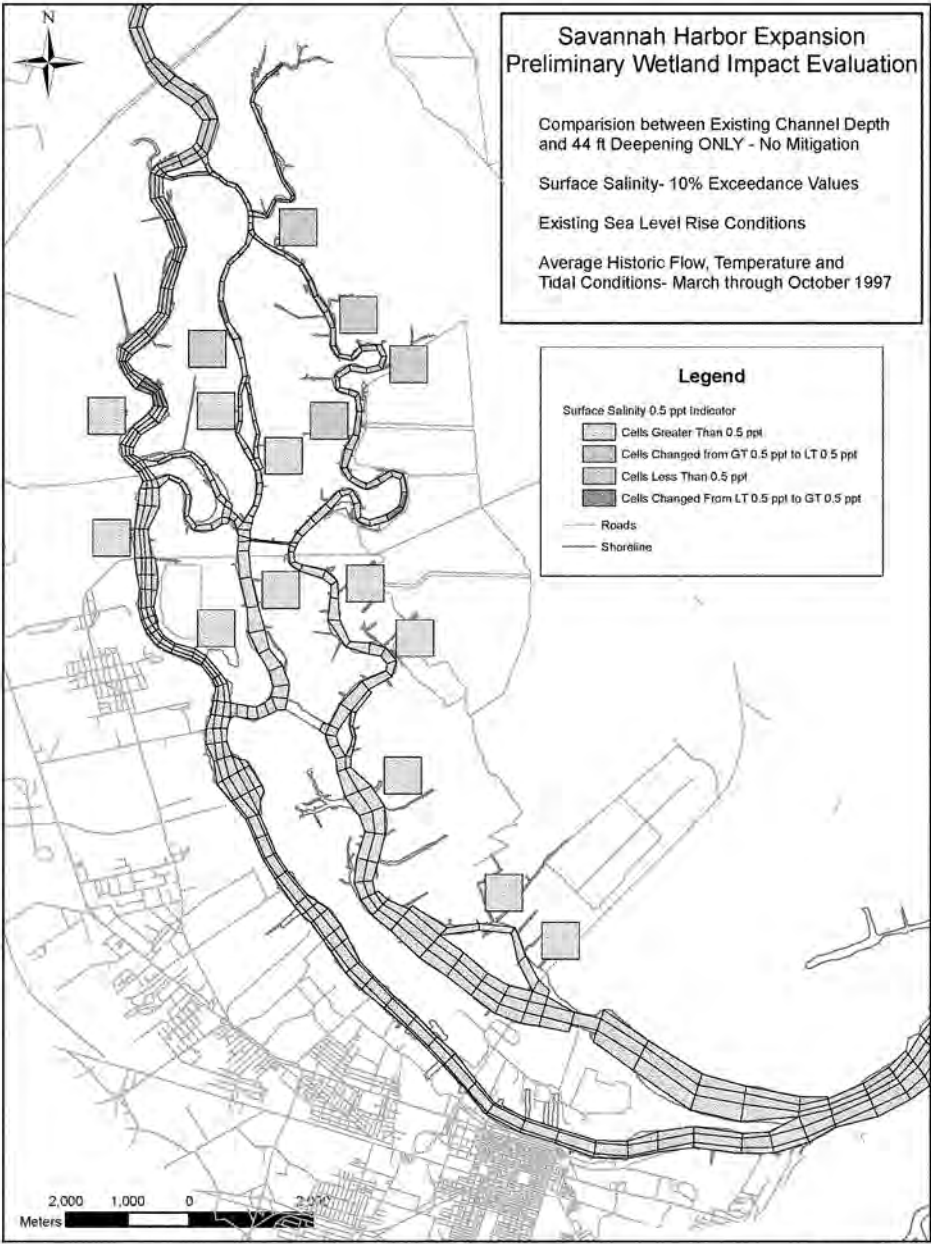


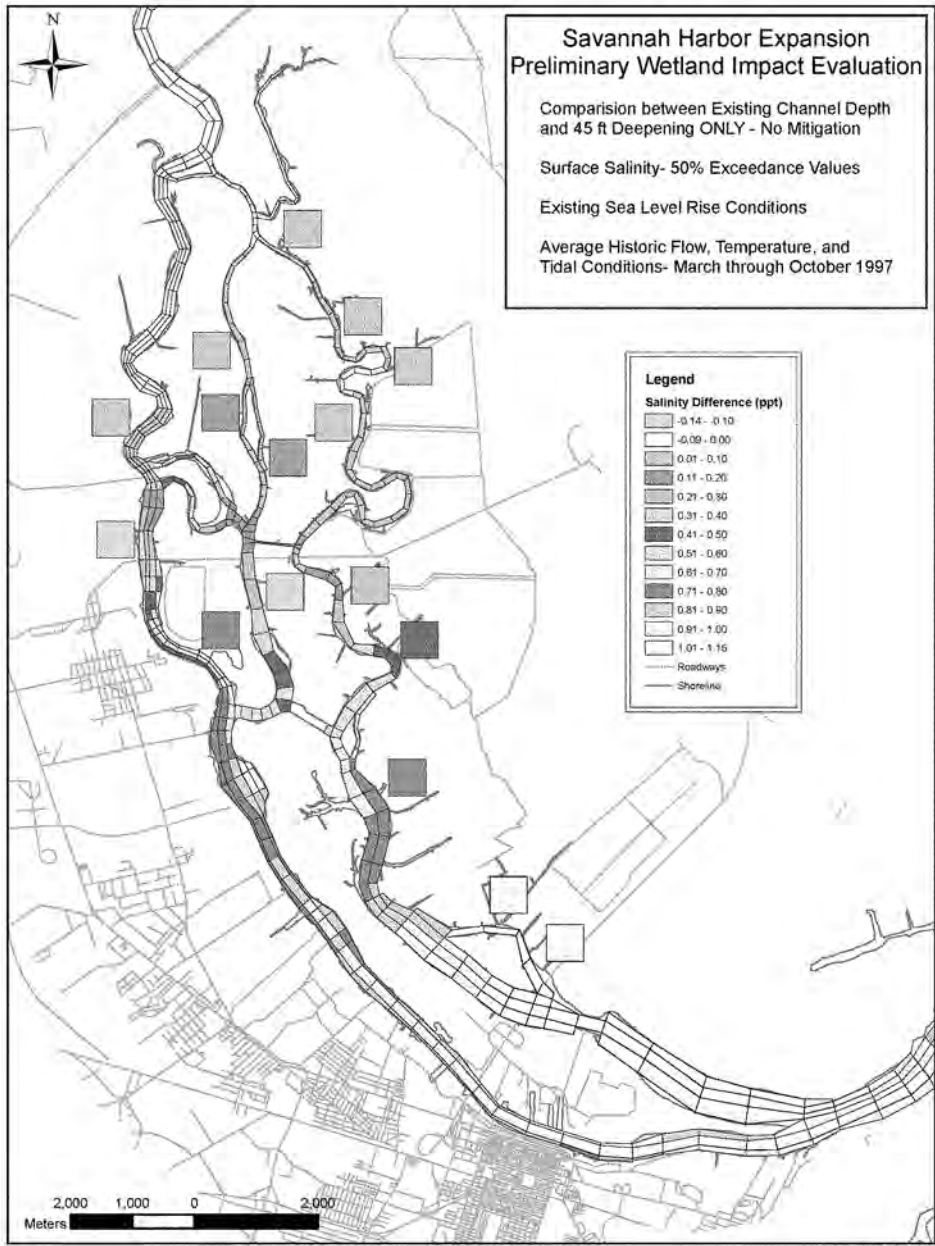
Basic Evaluation

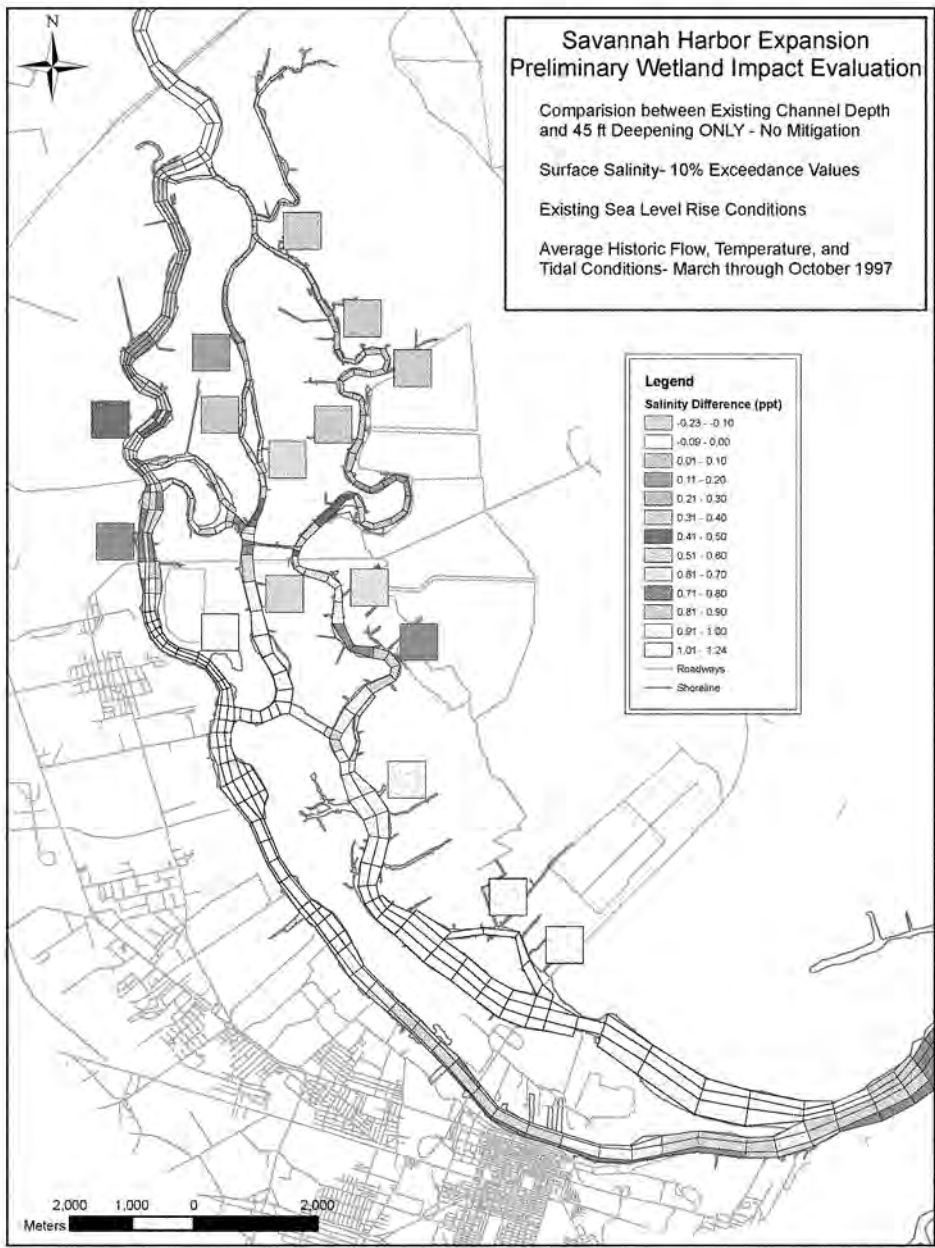


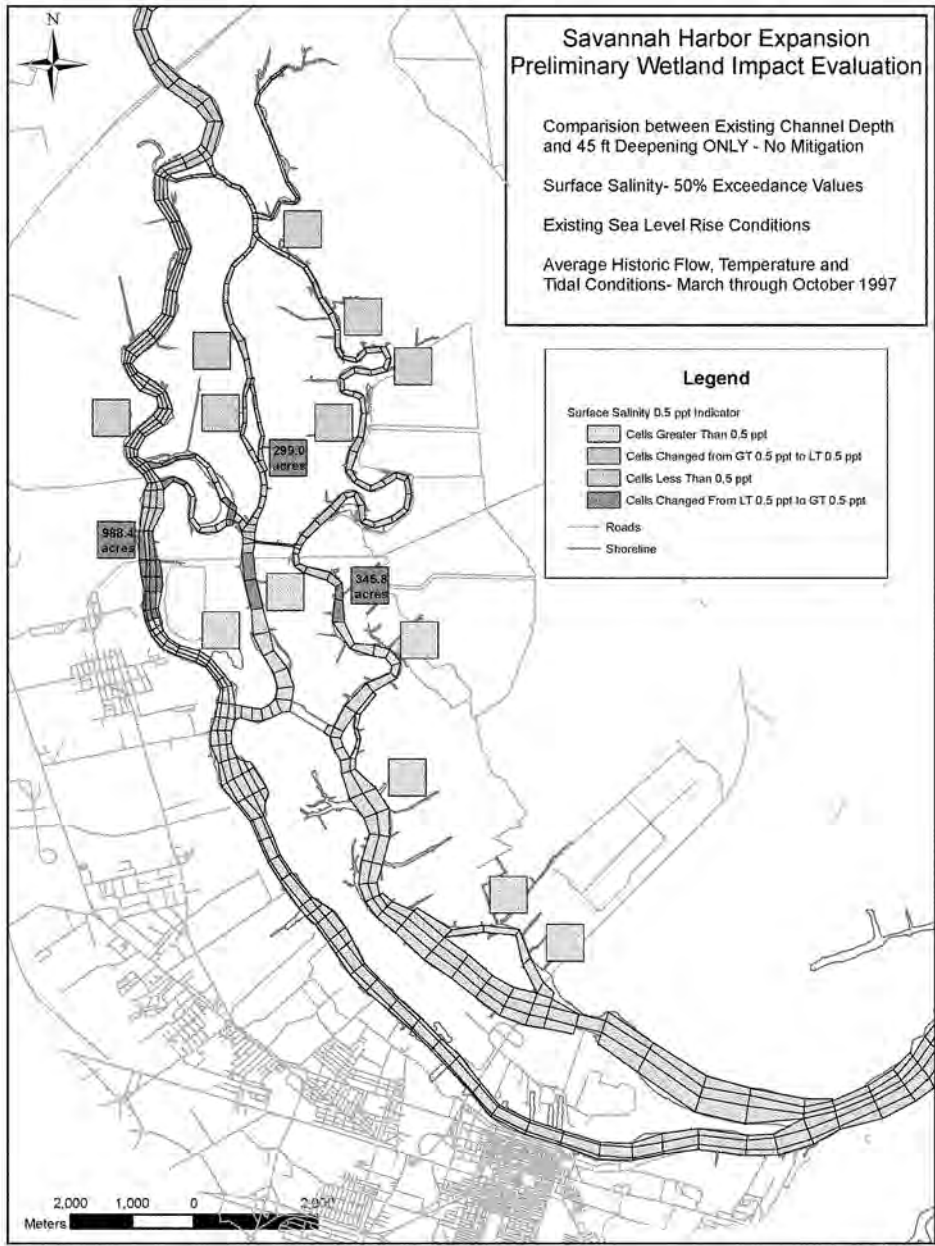


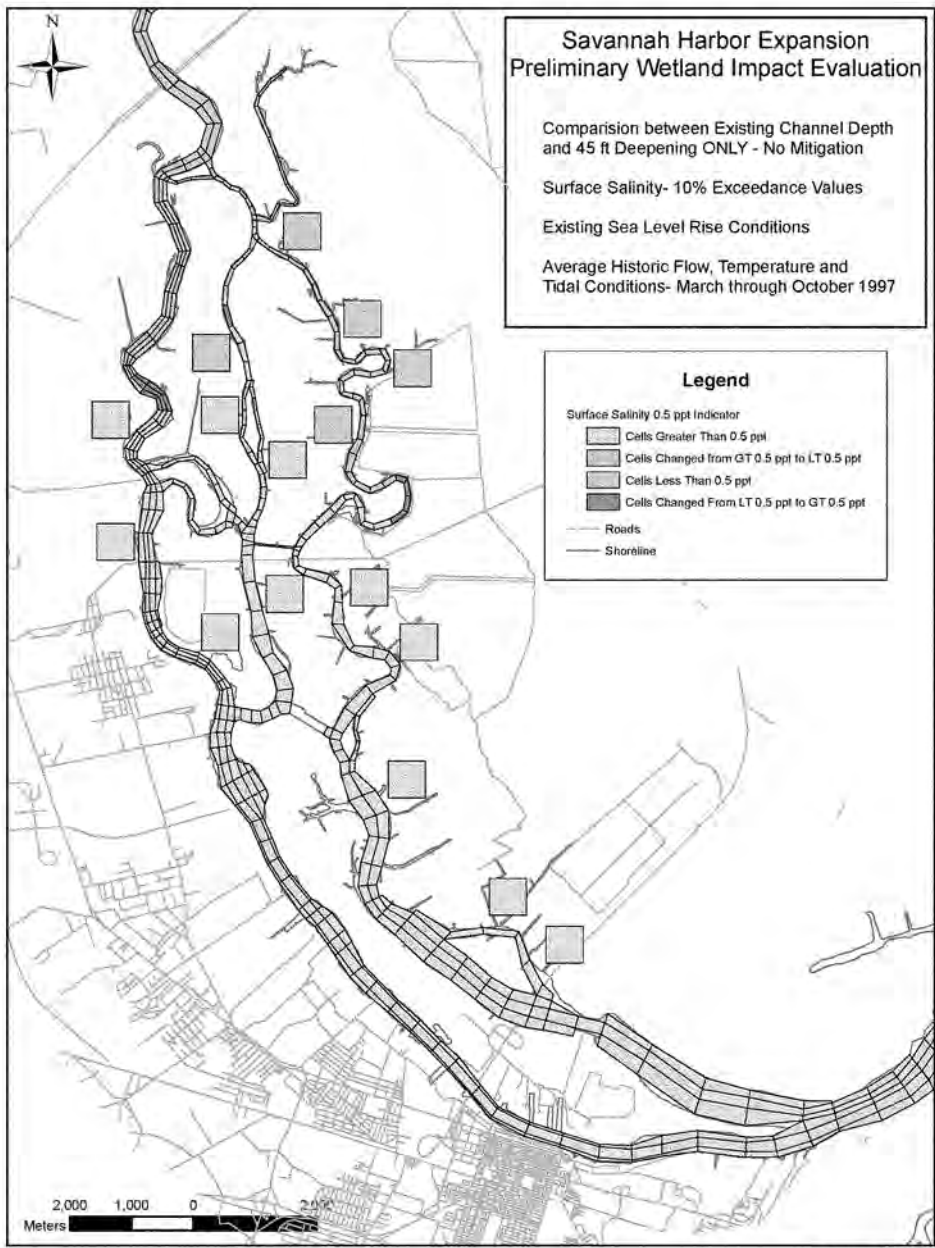


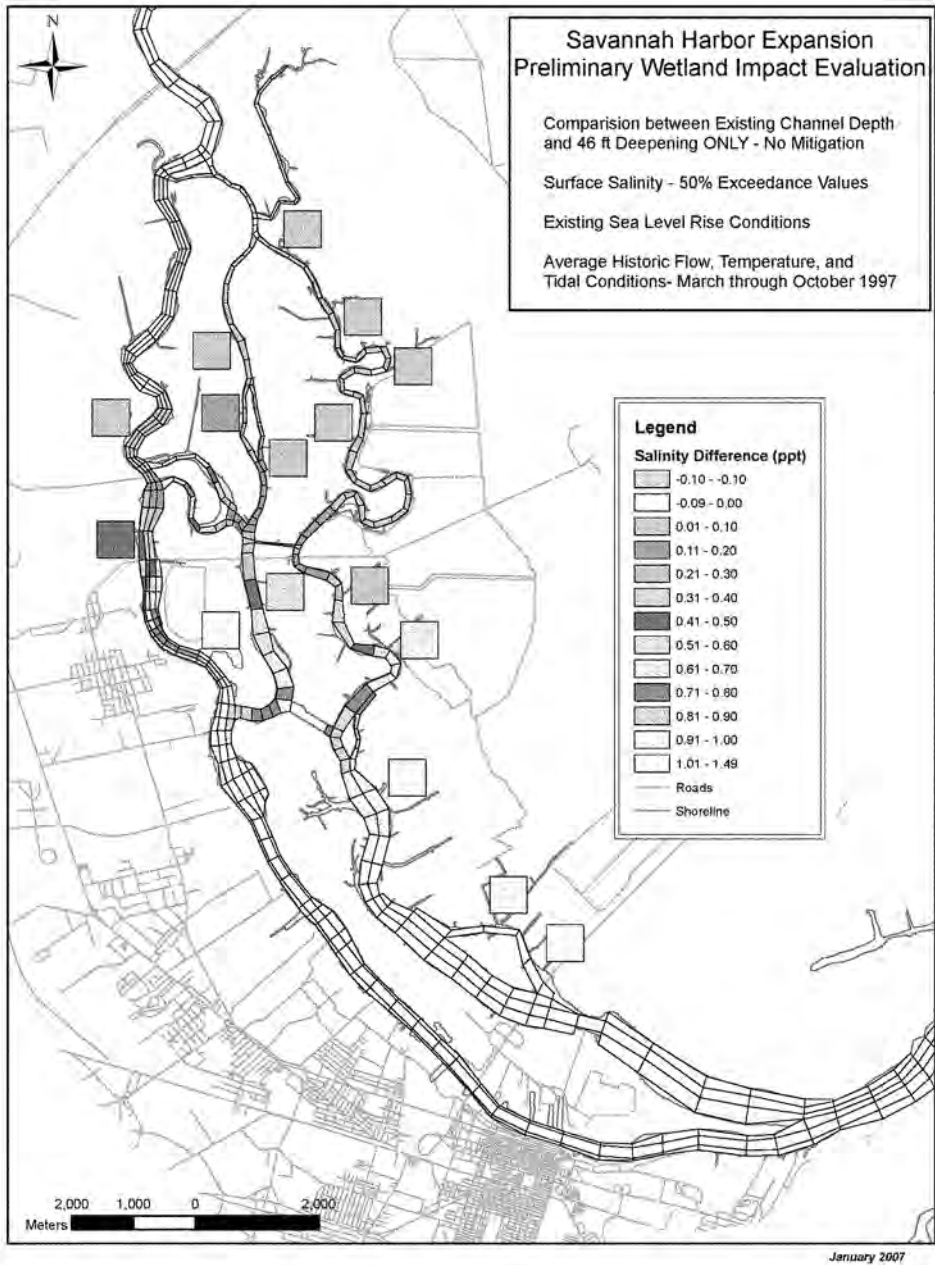


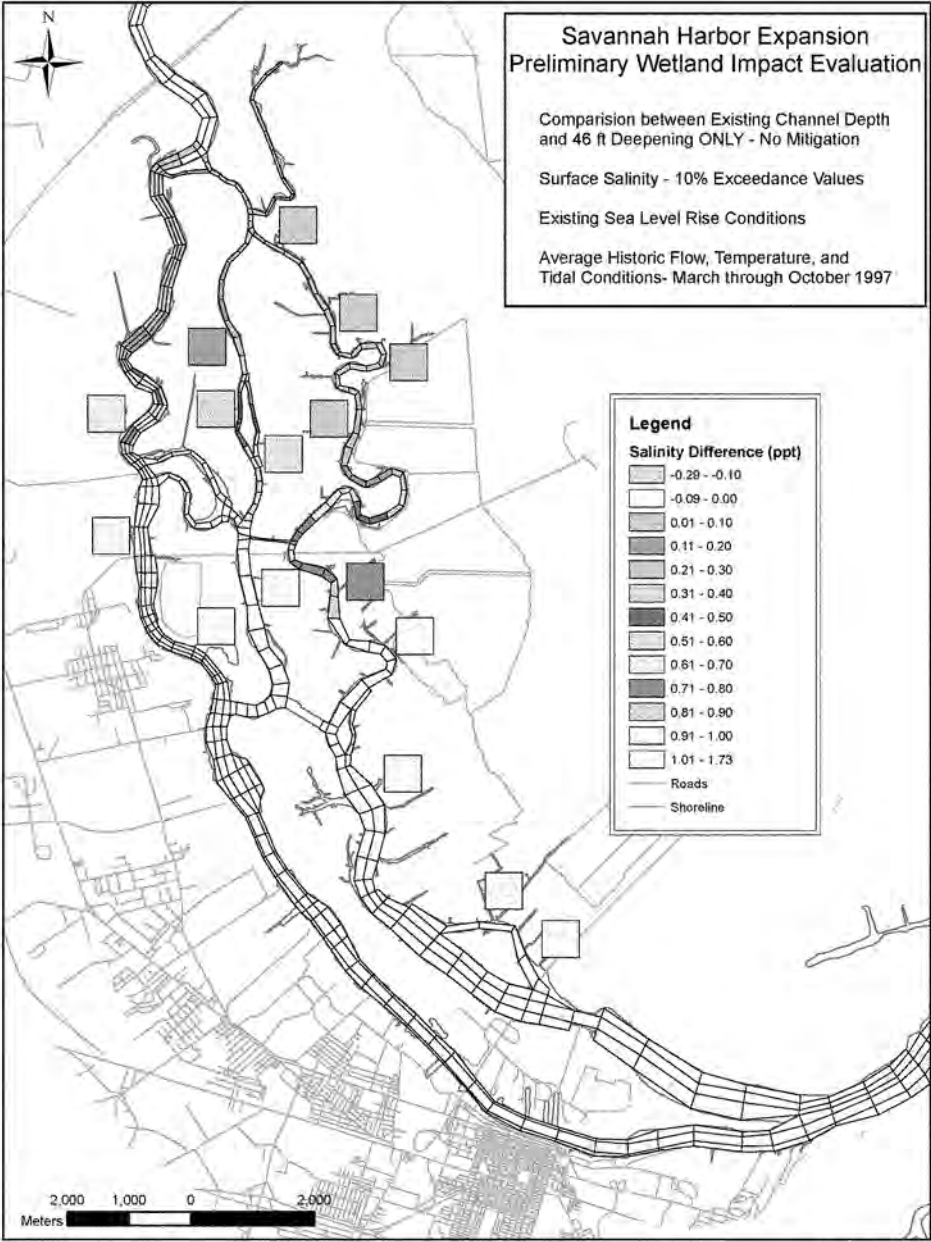


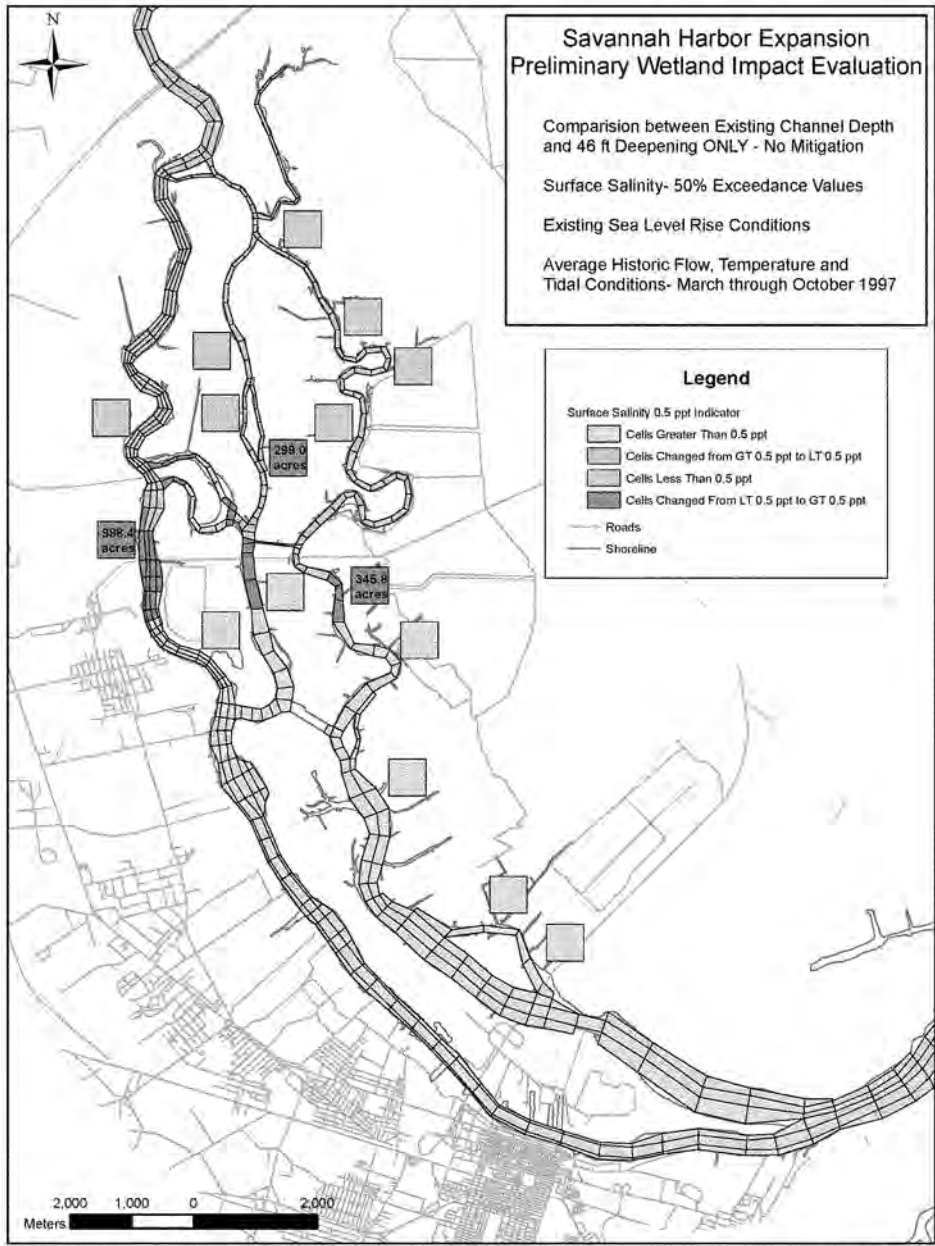


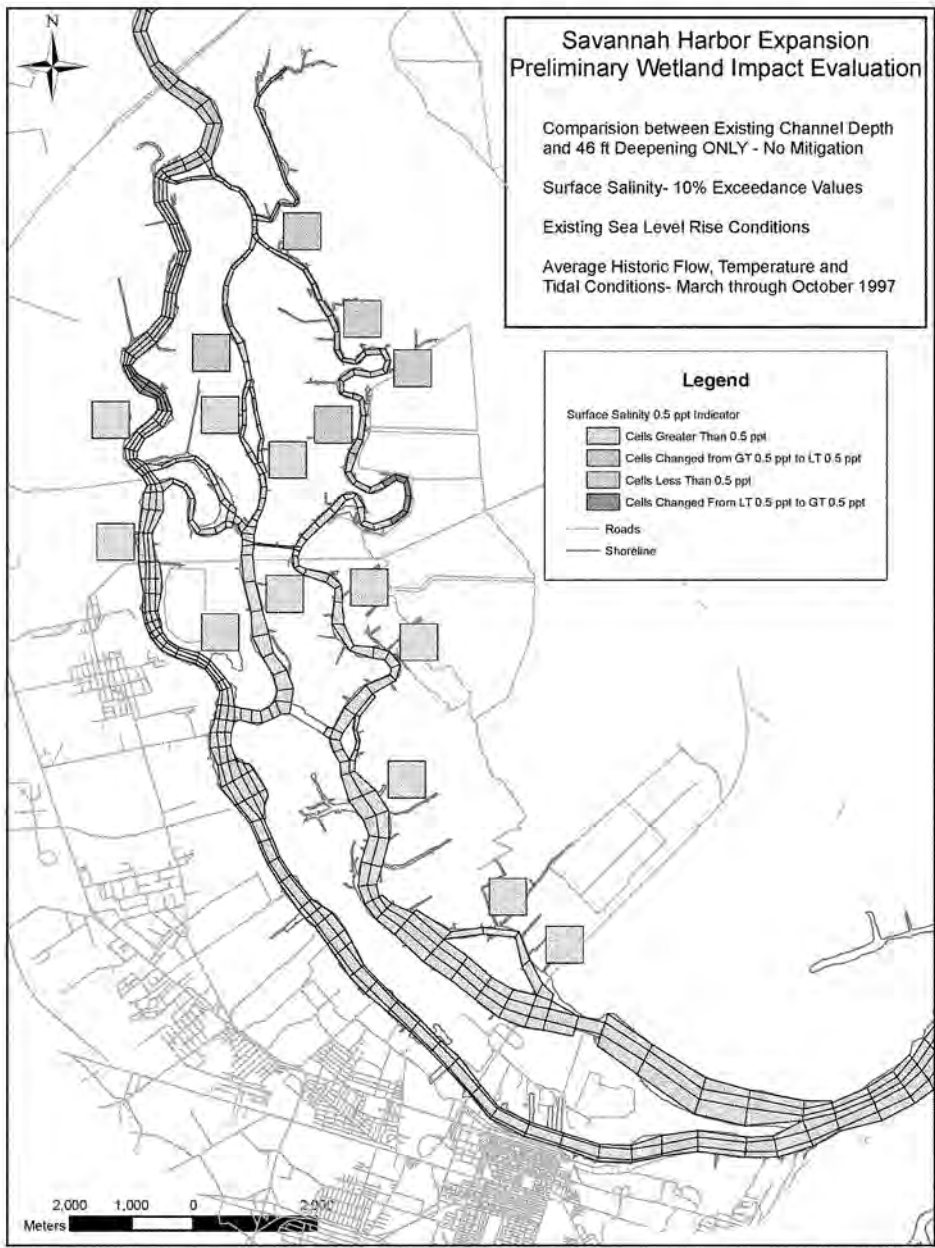


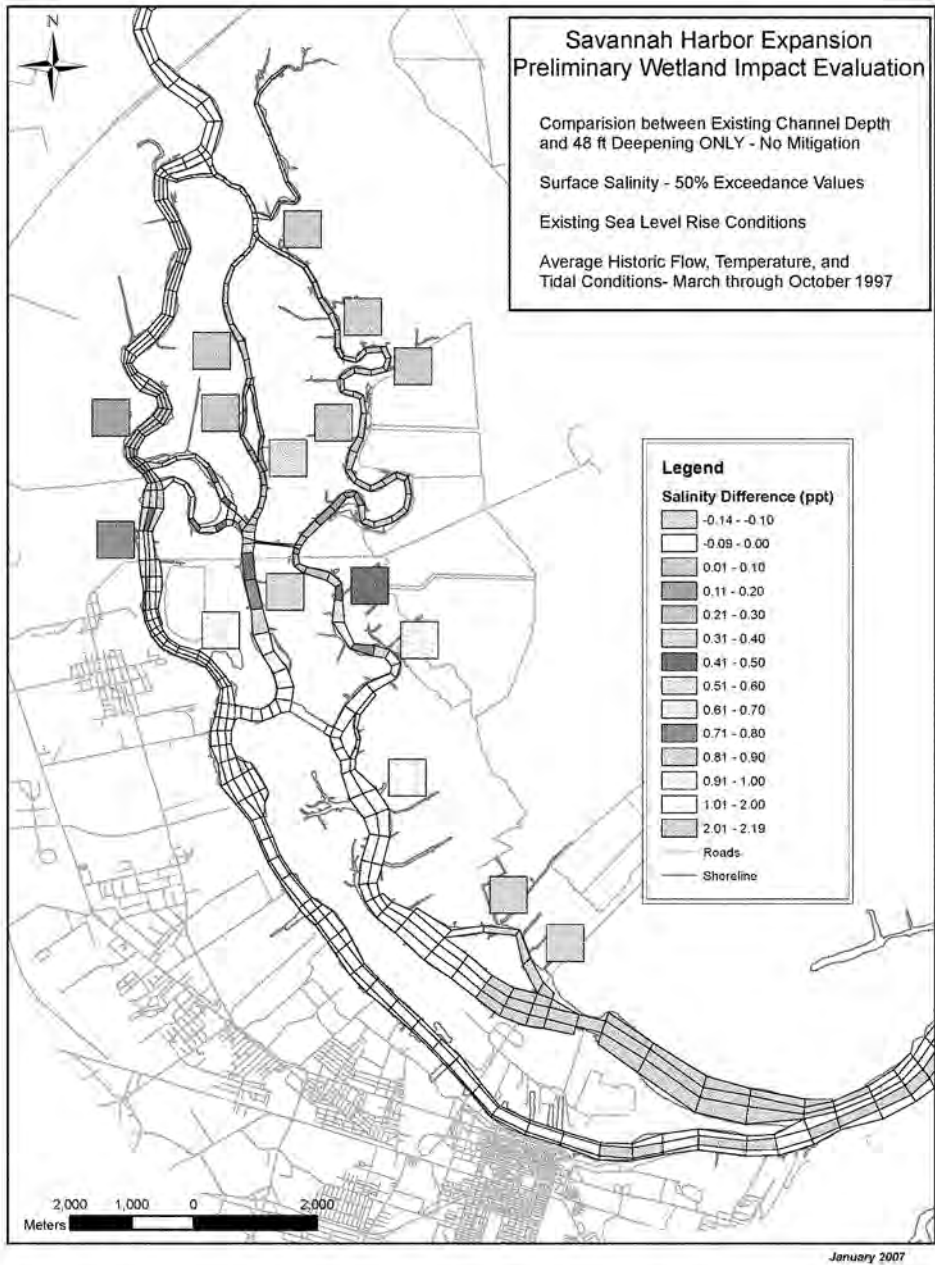


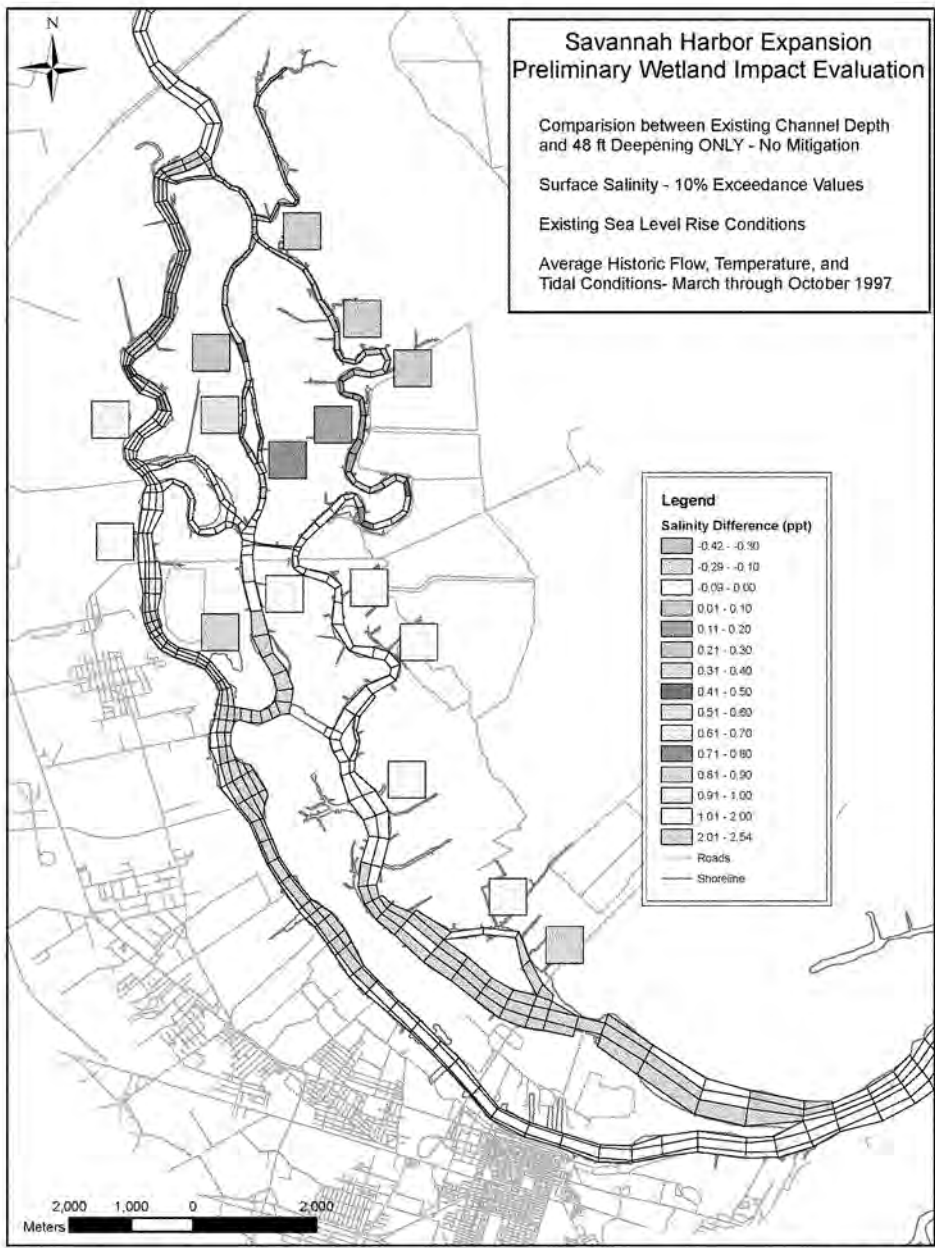


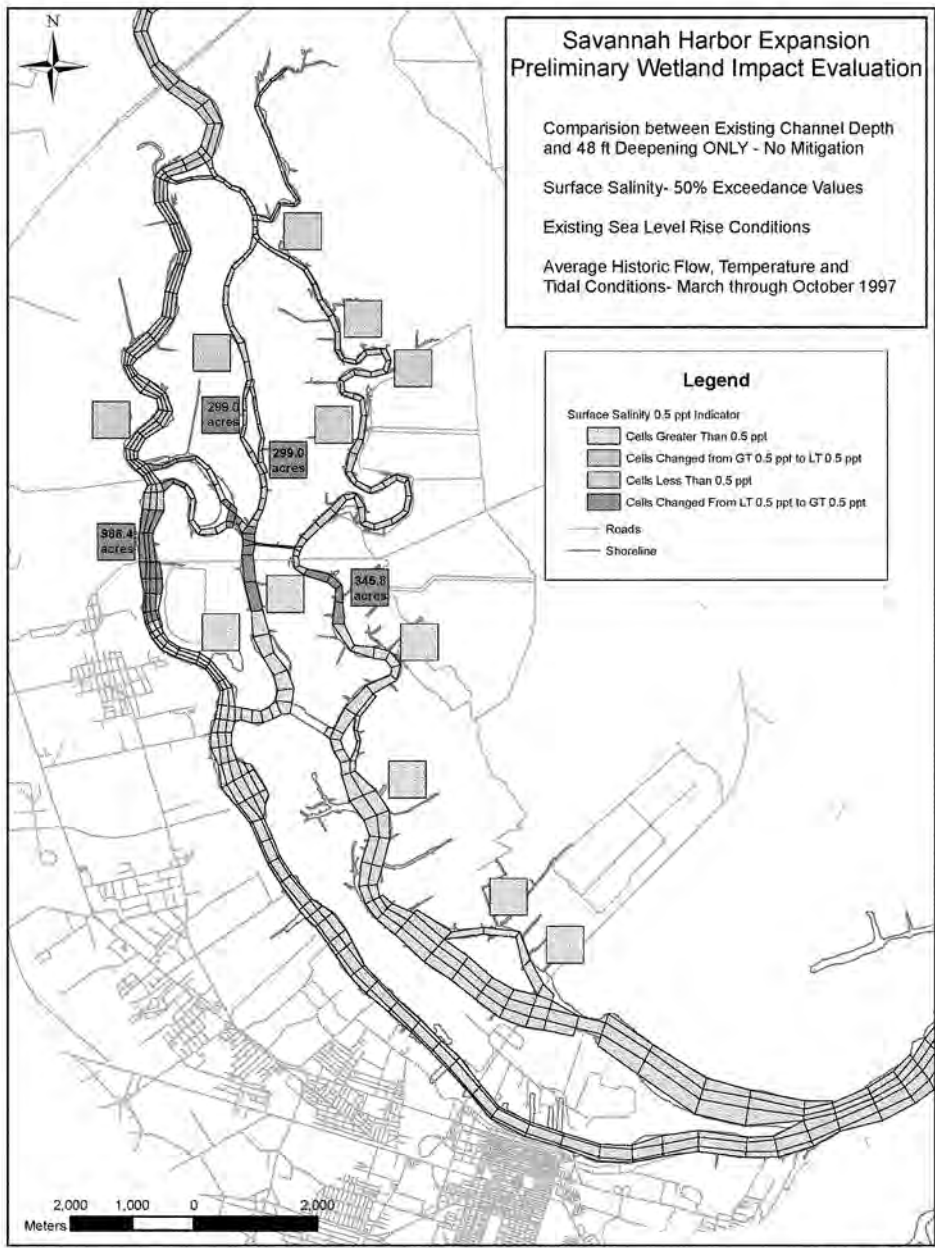


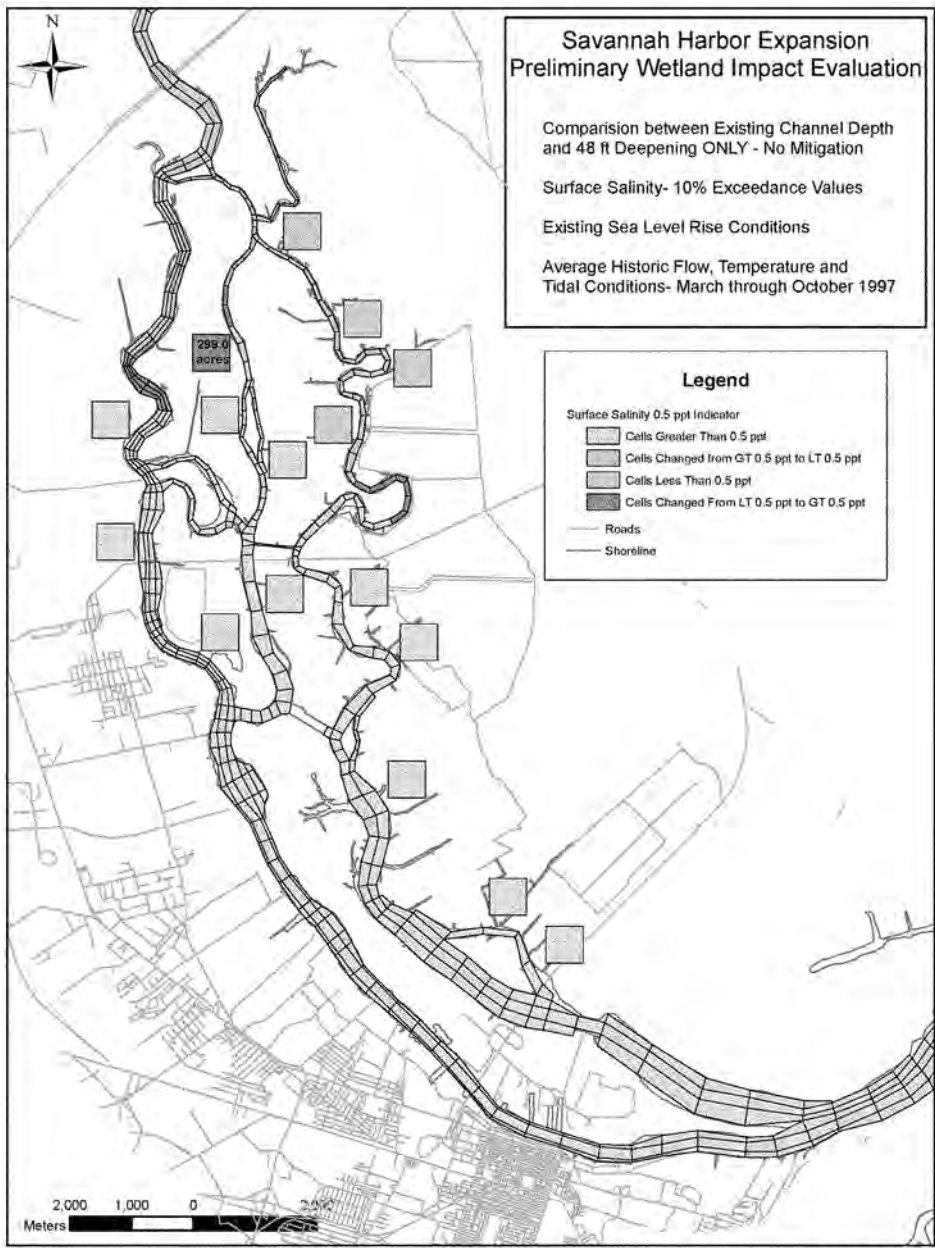




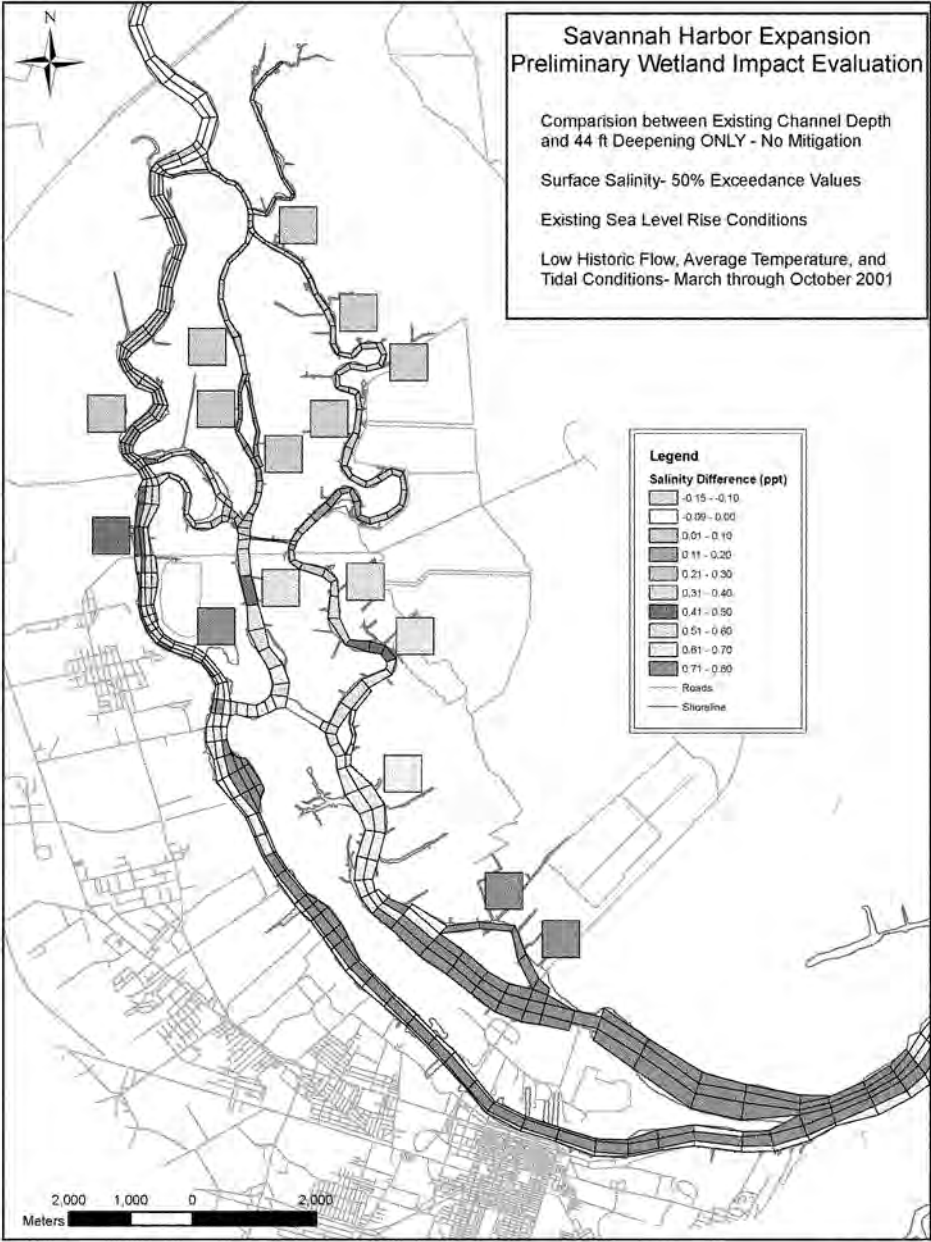


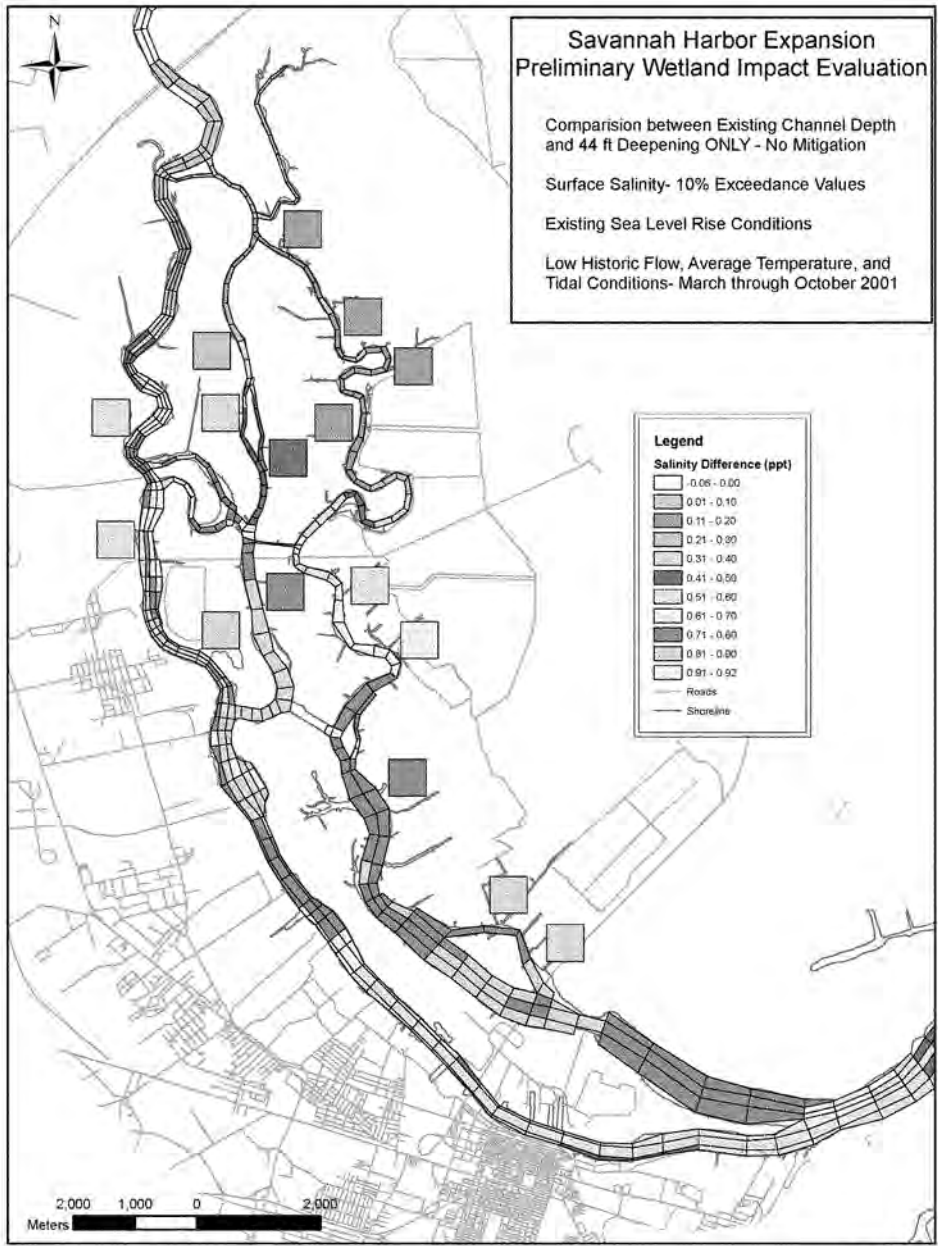


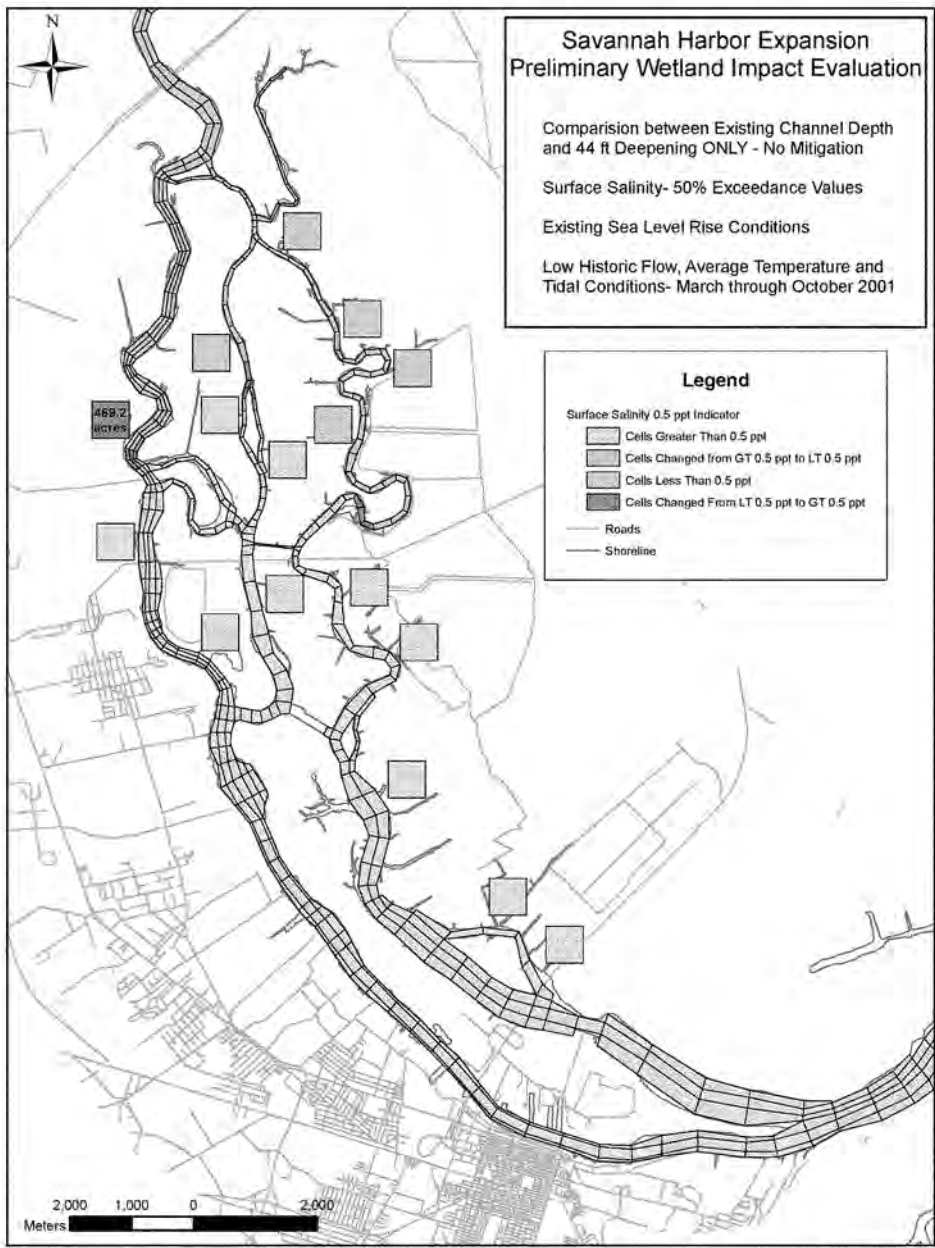


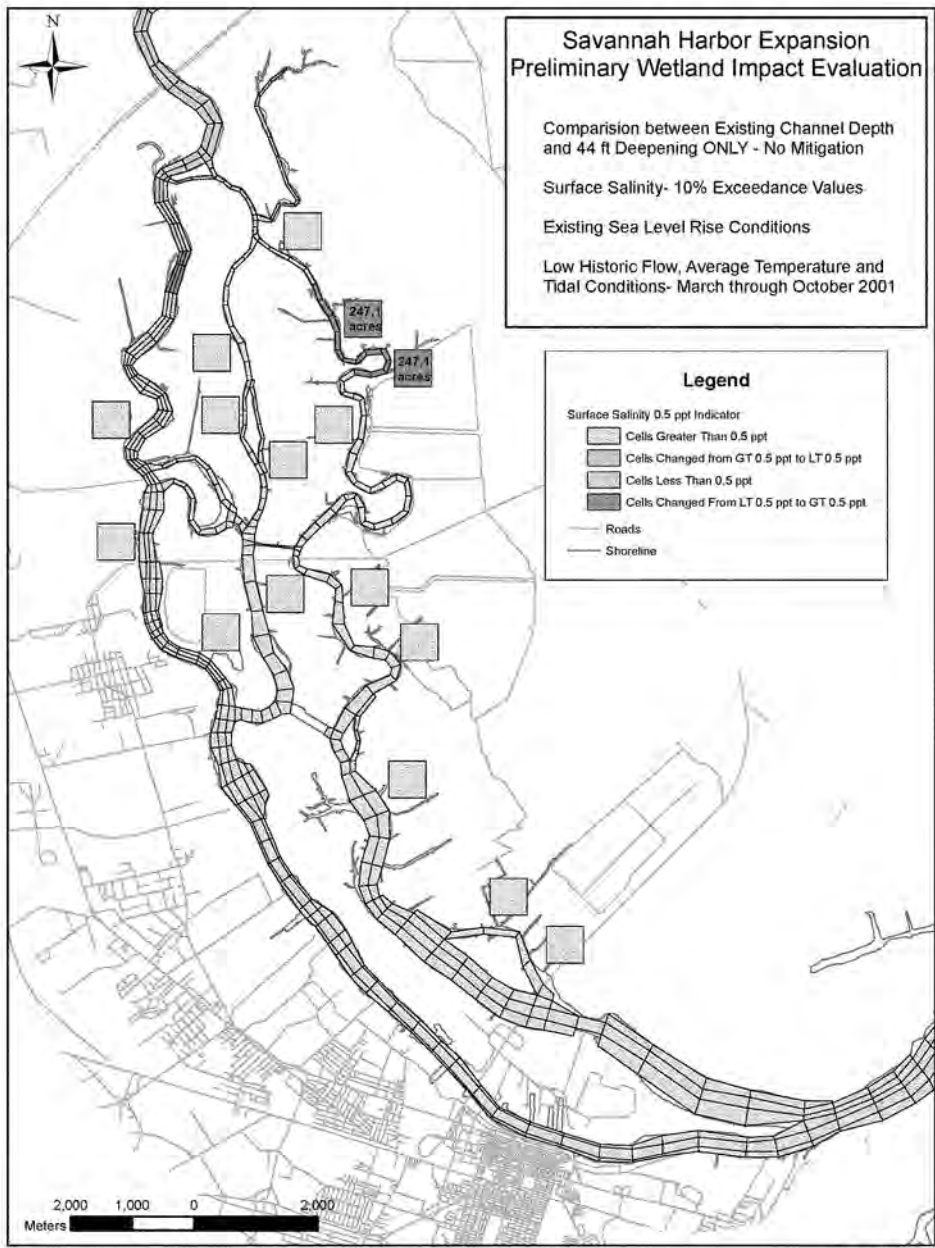


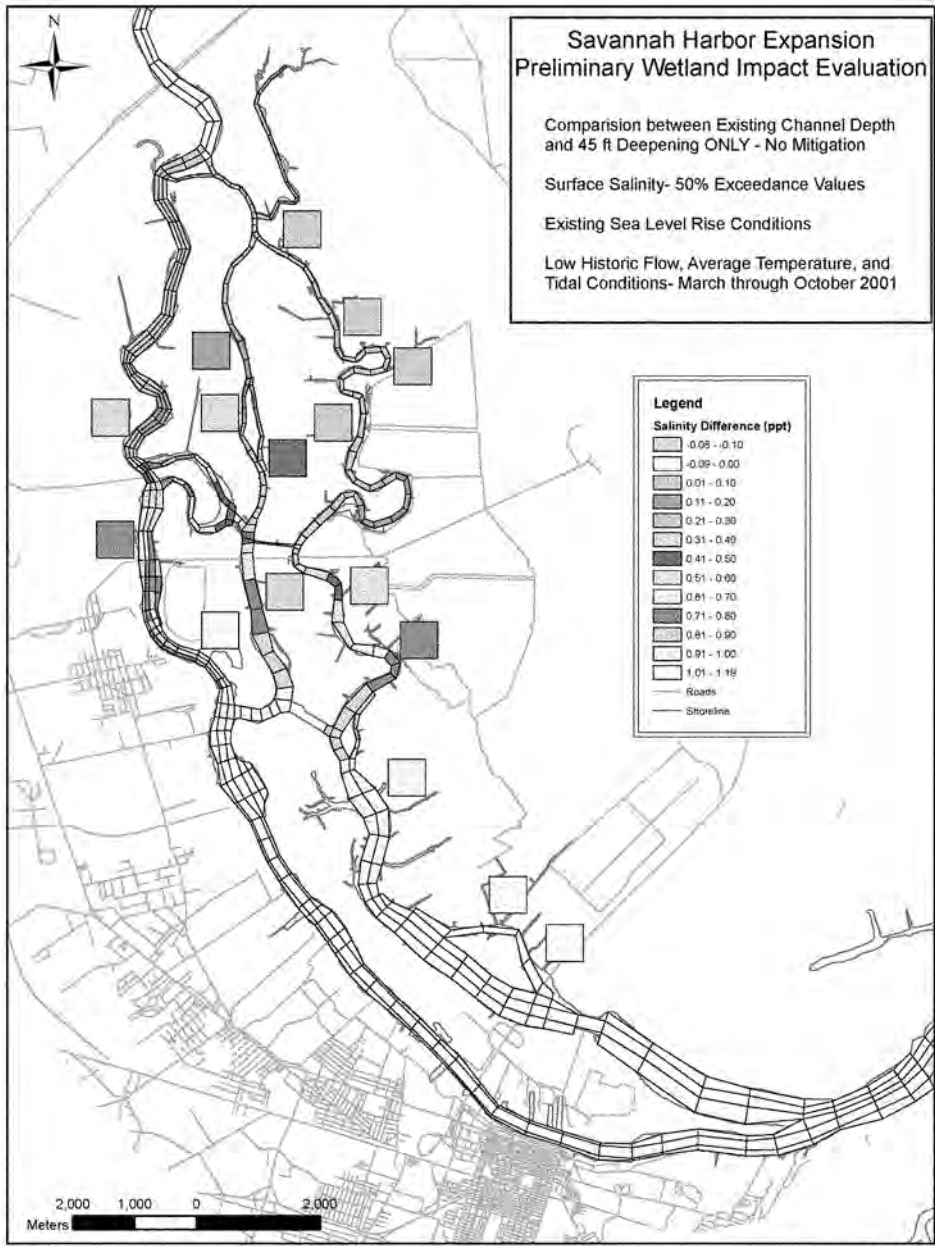
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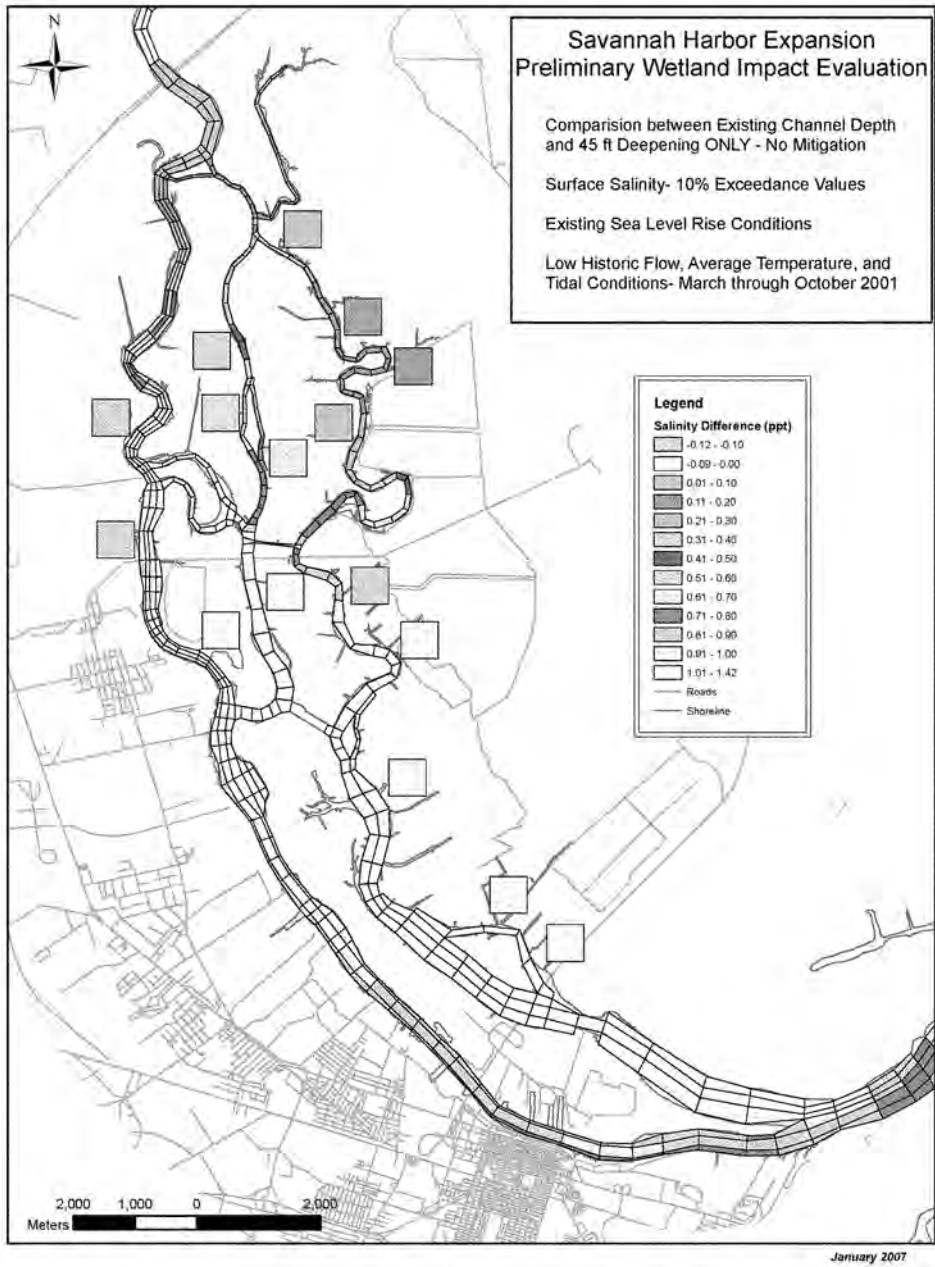


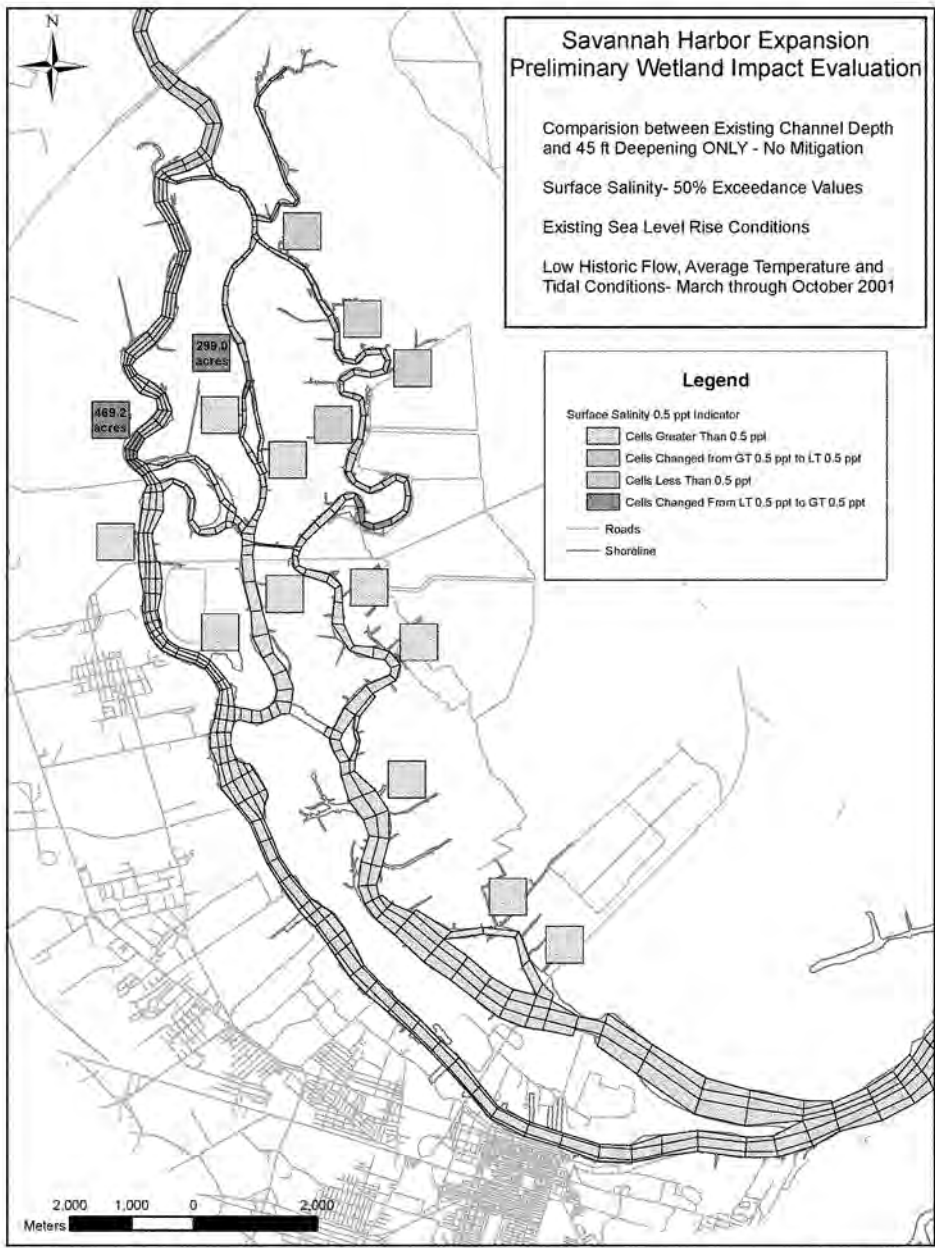


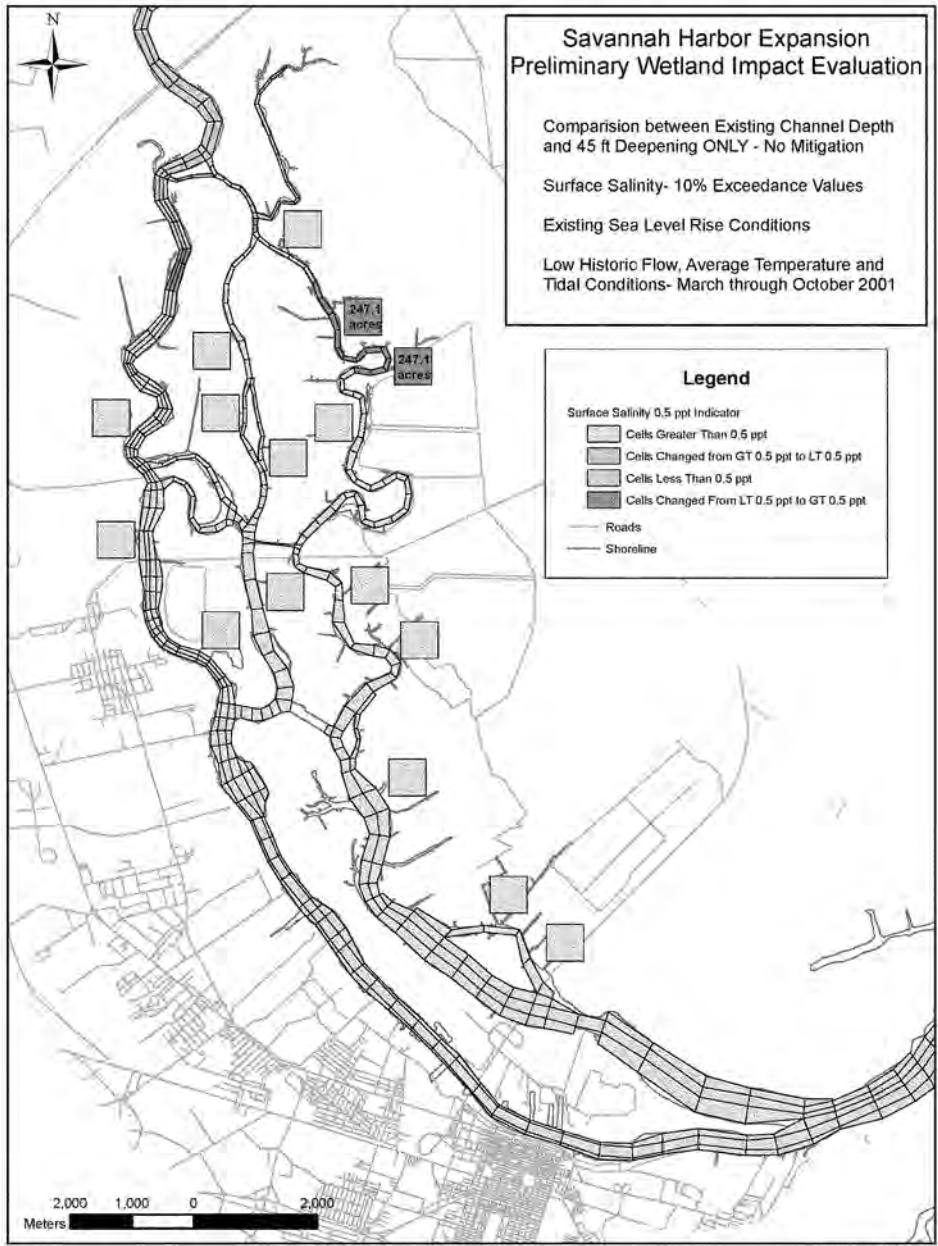


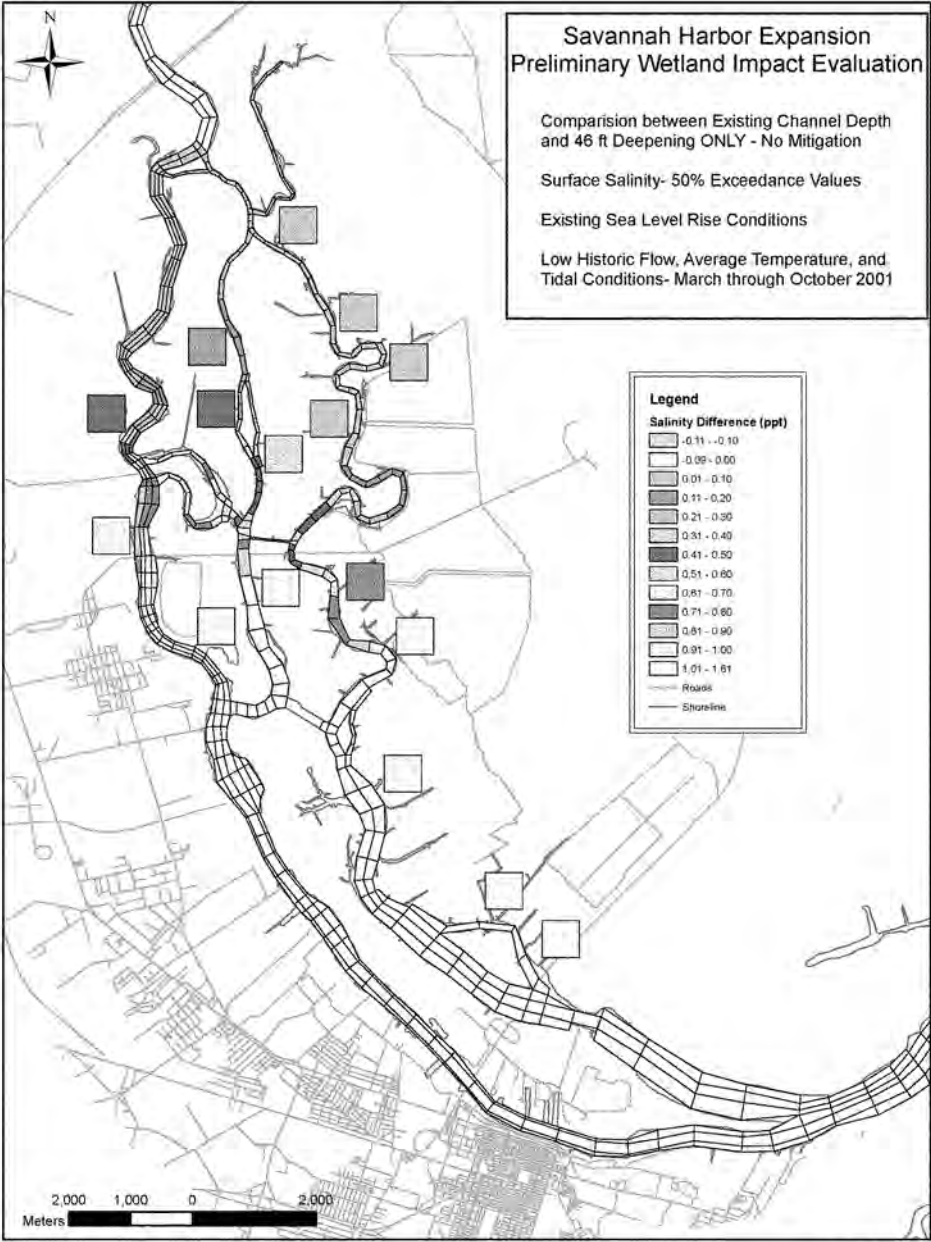


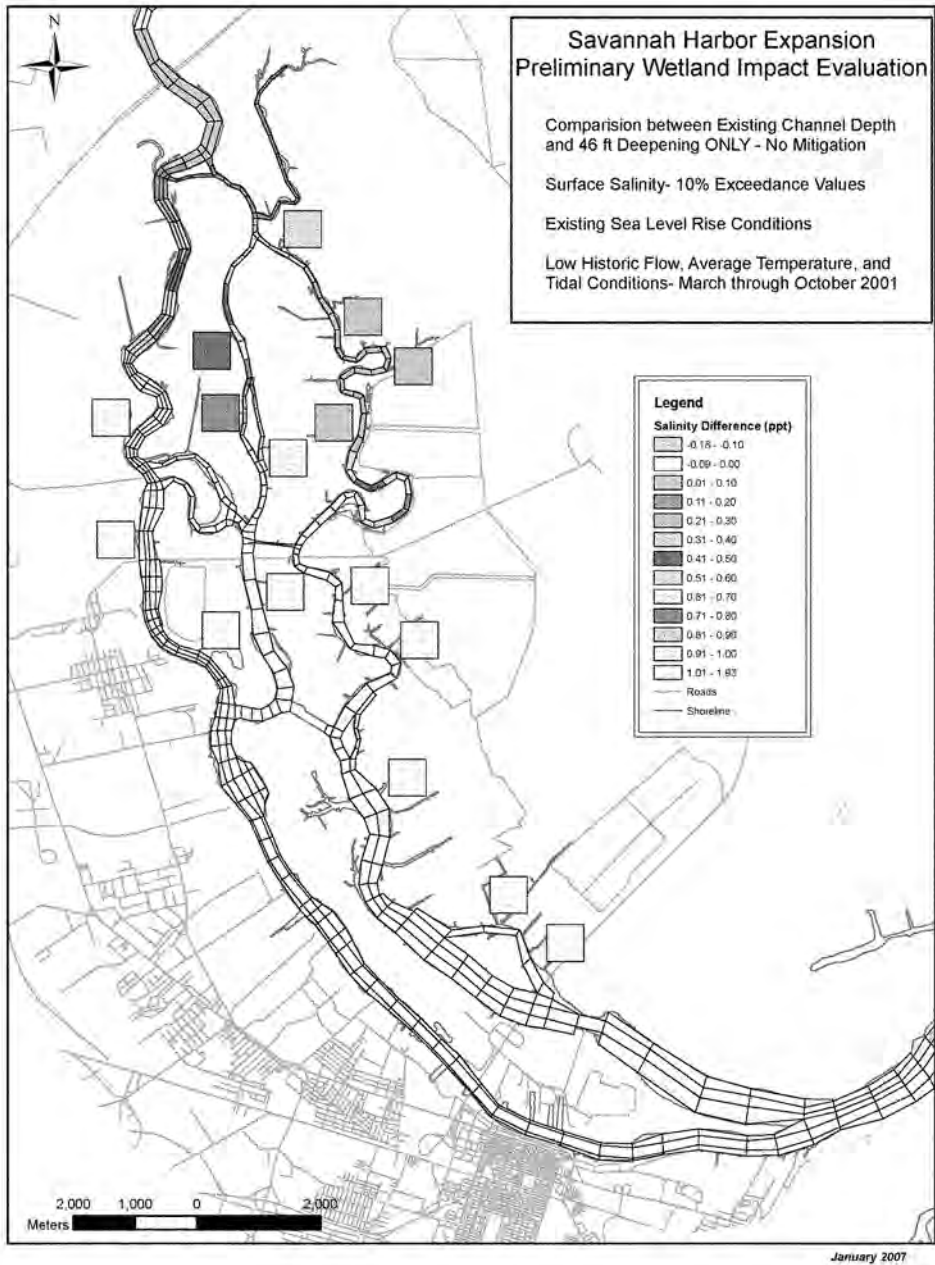


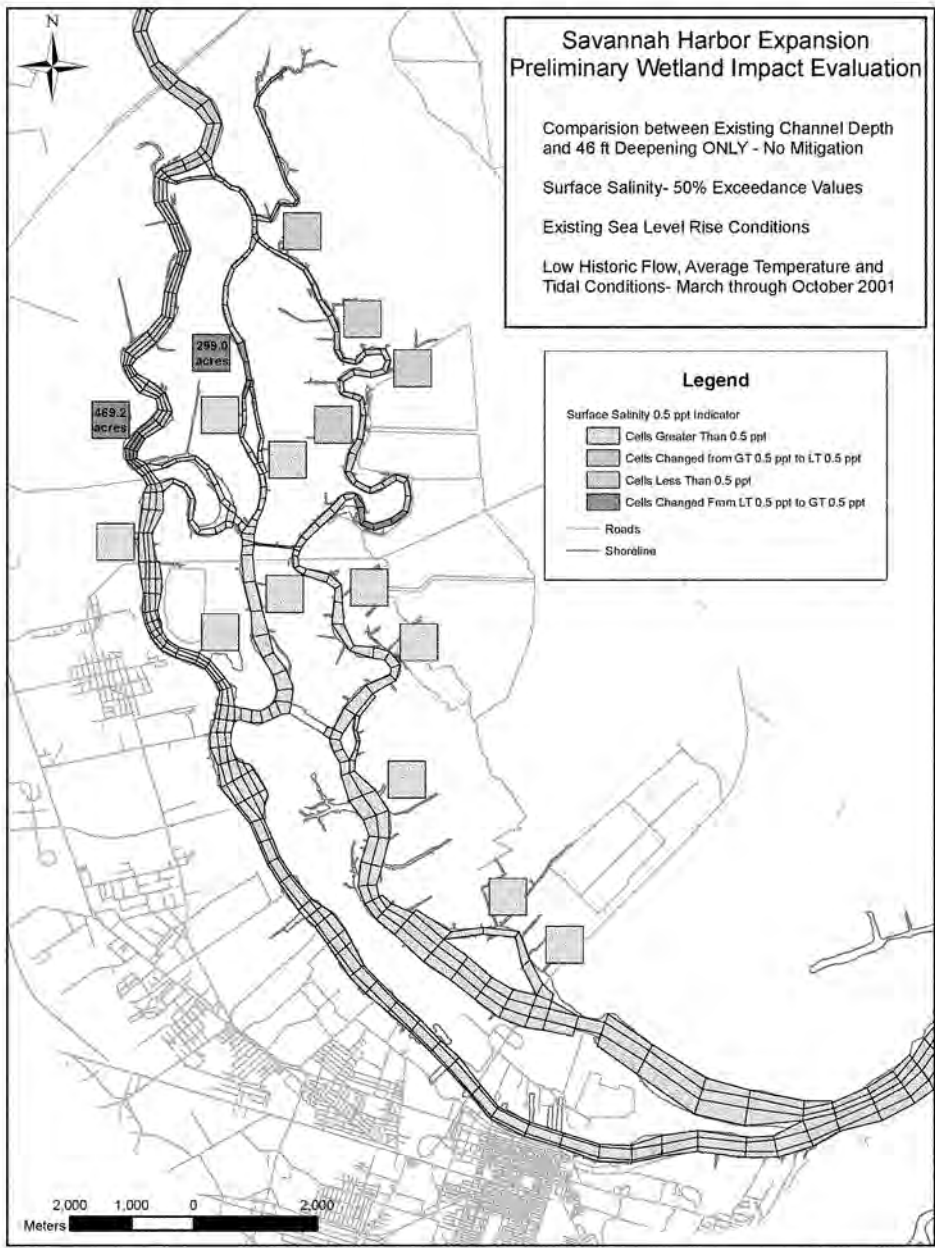


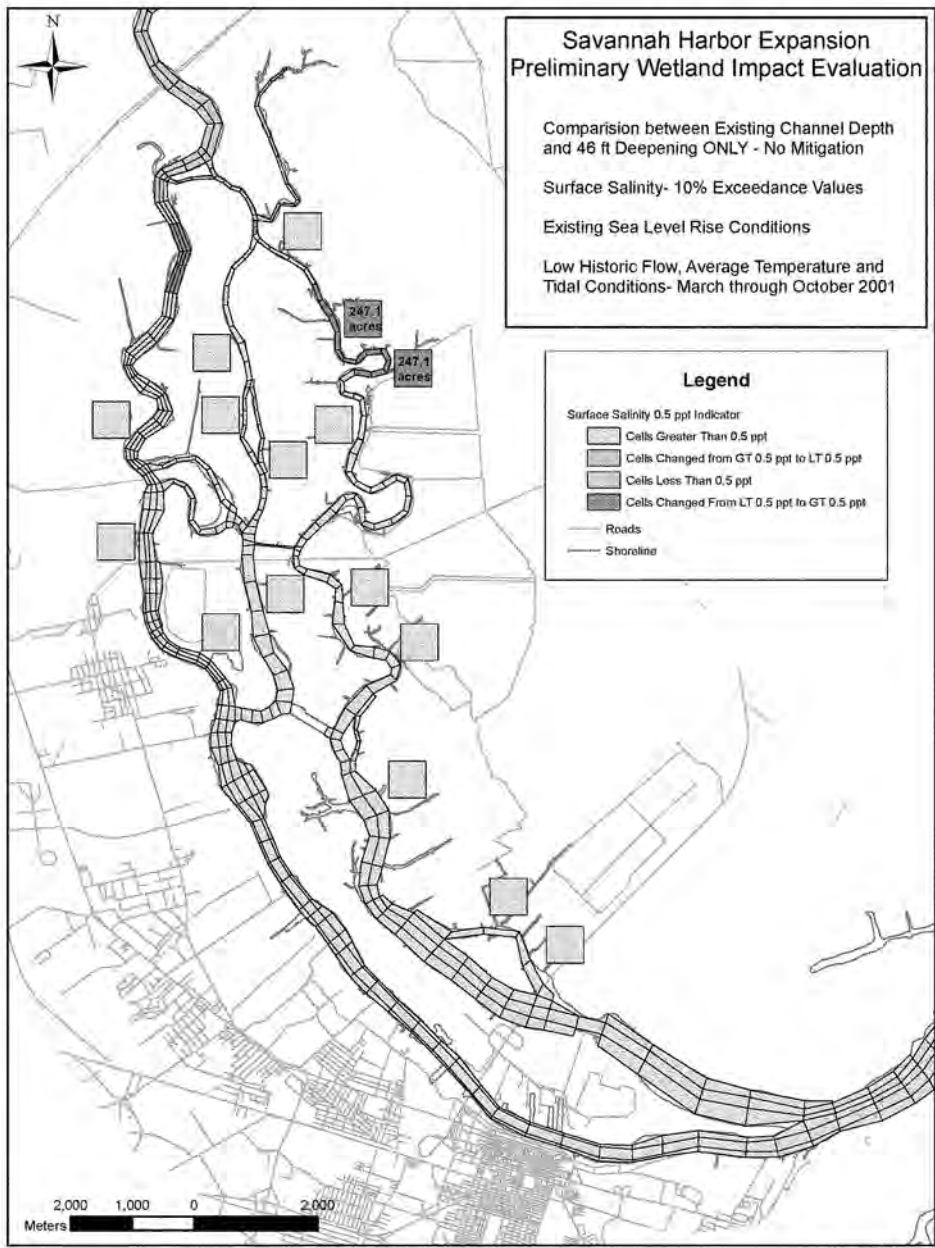


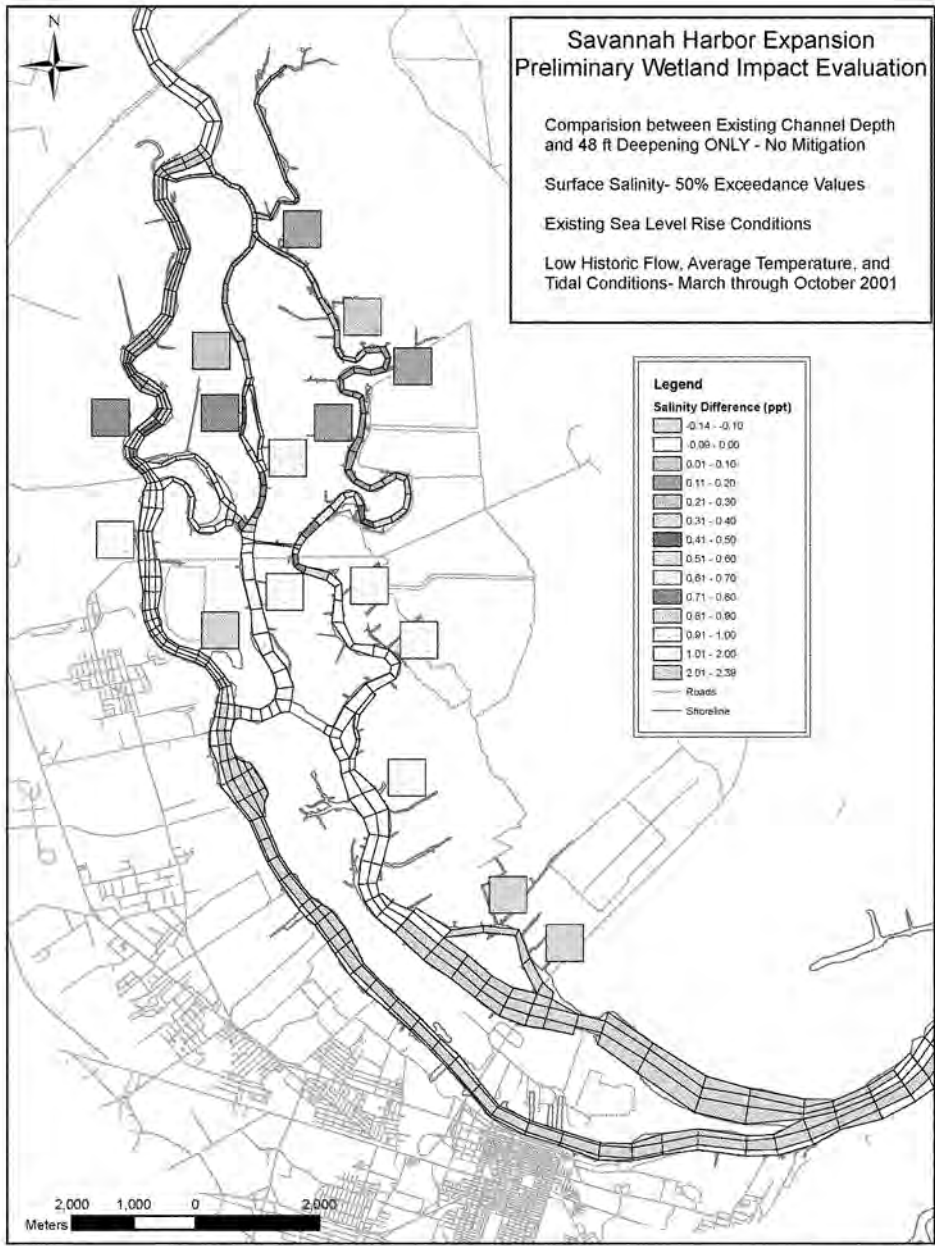


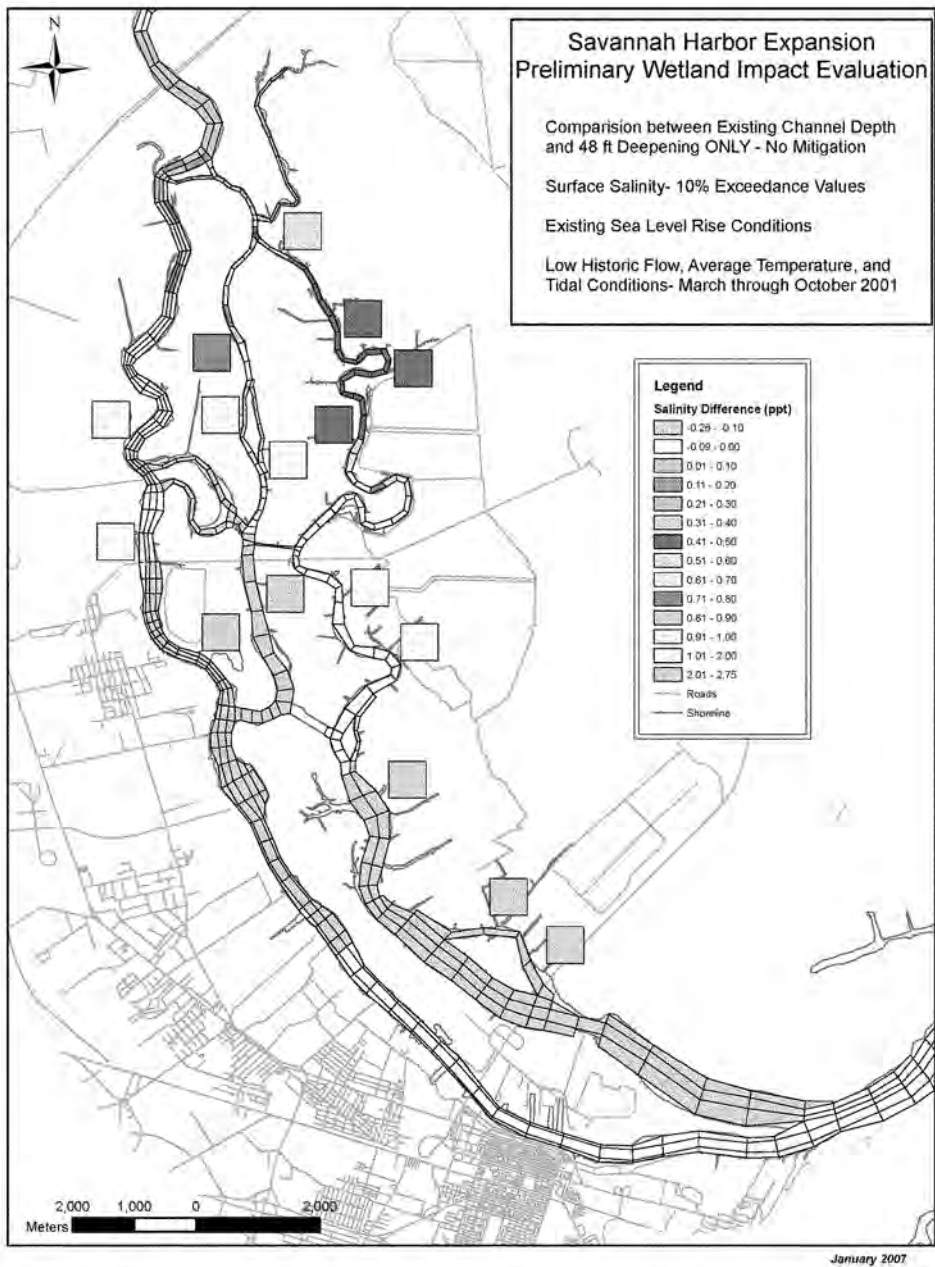


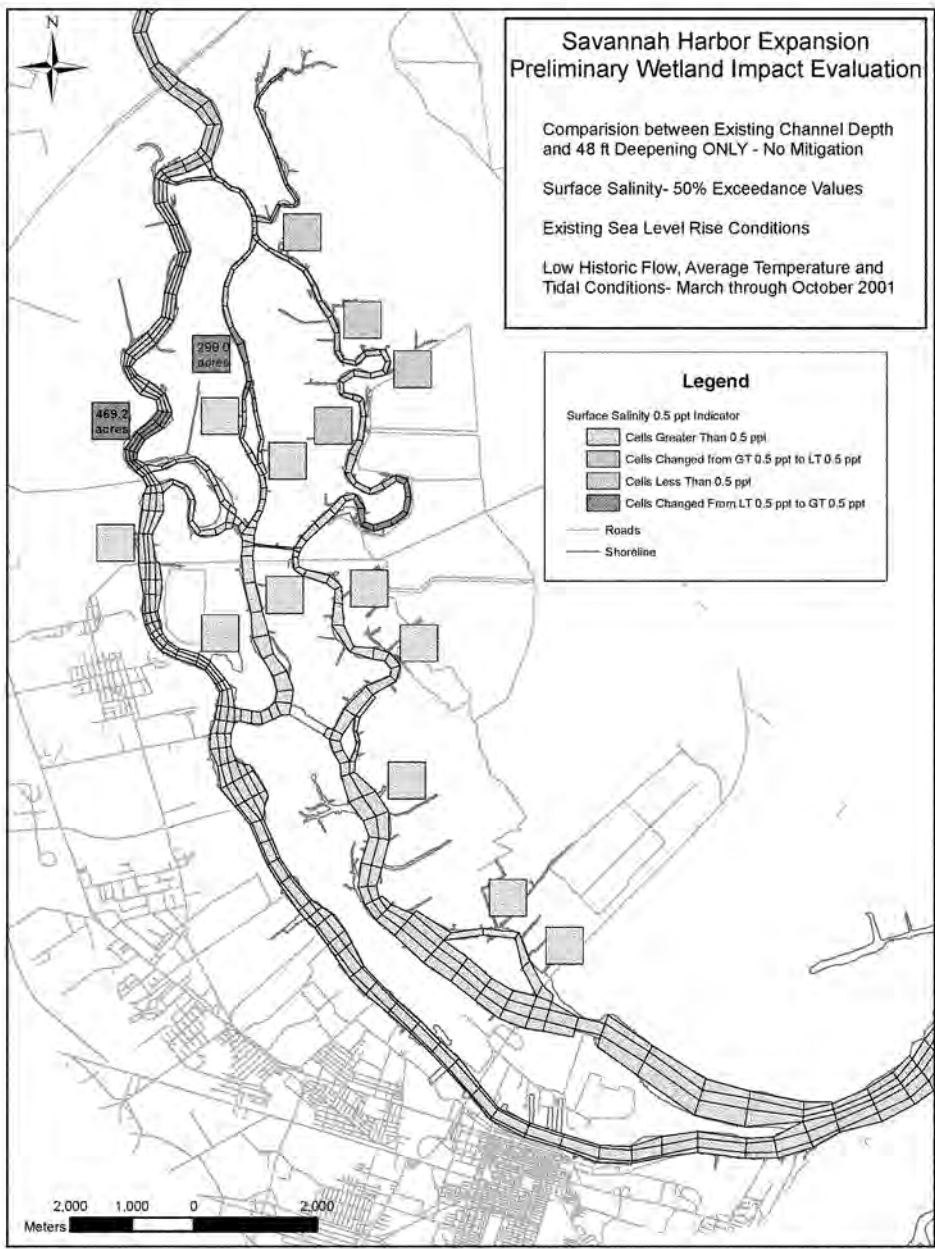


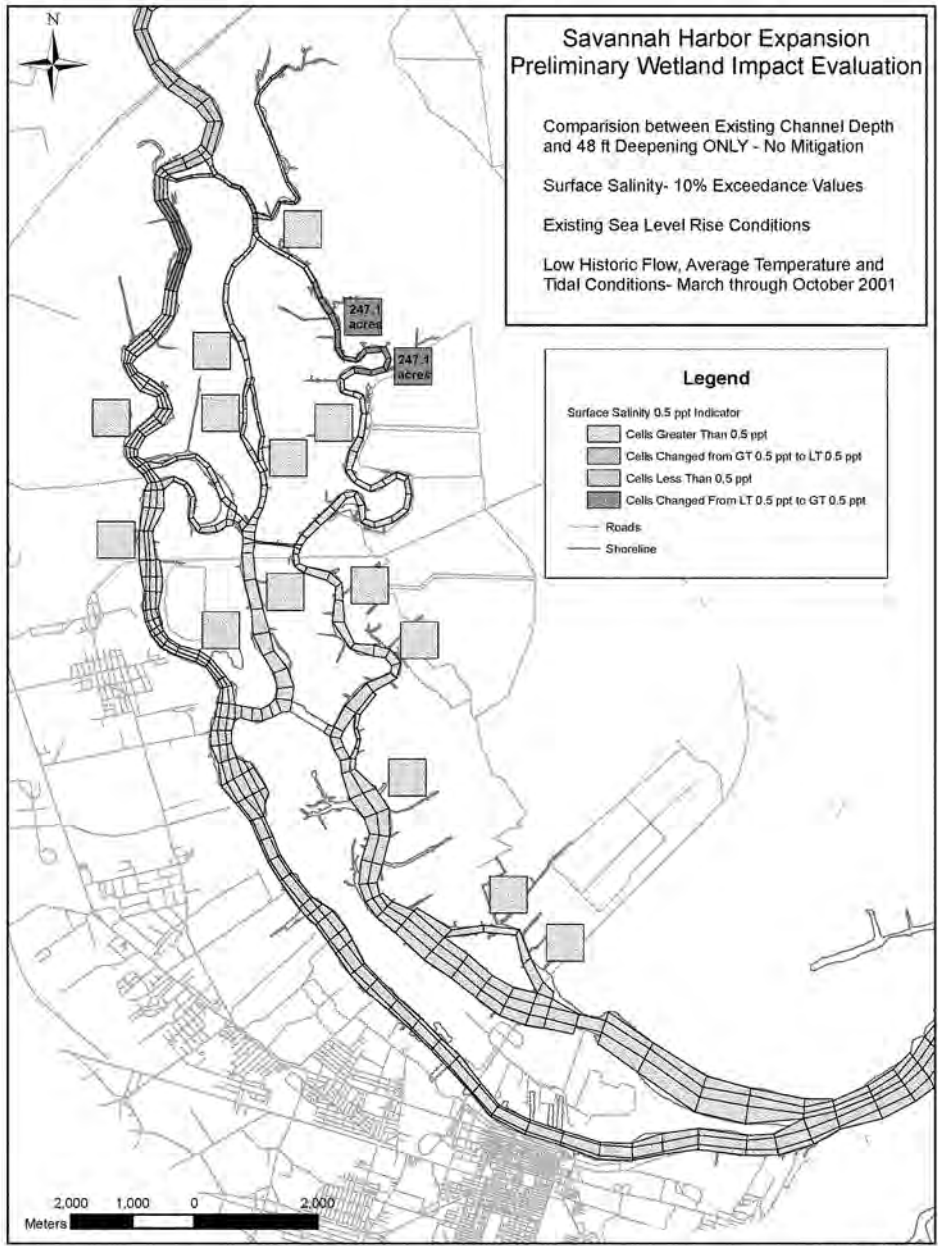




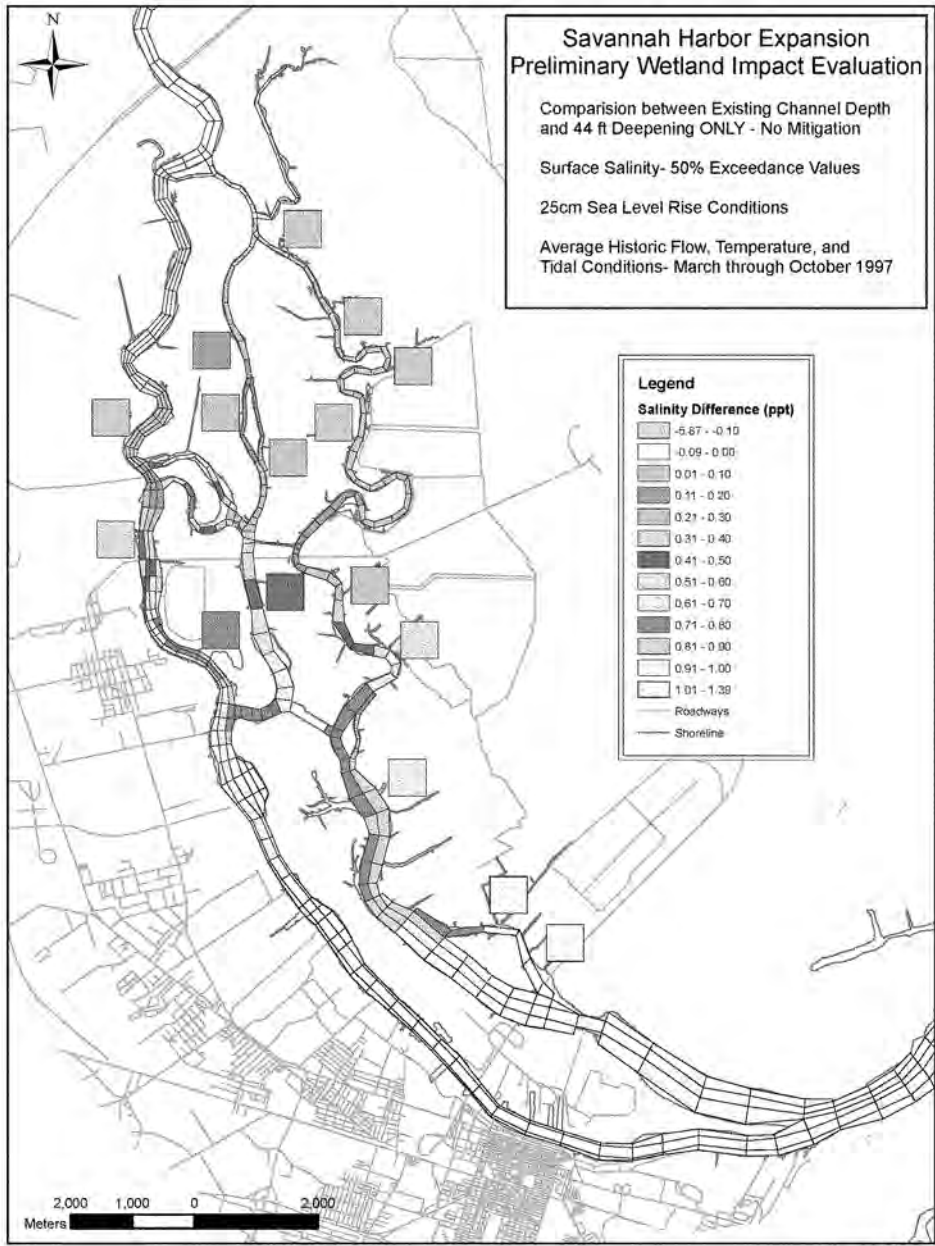


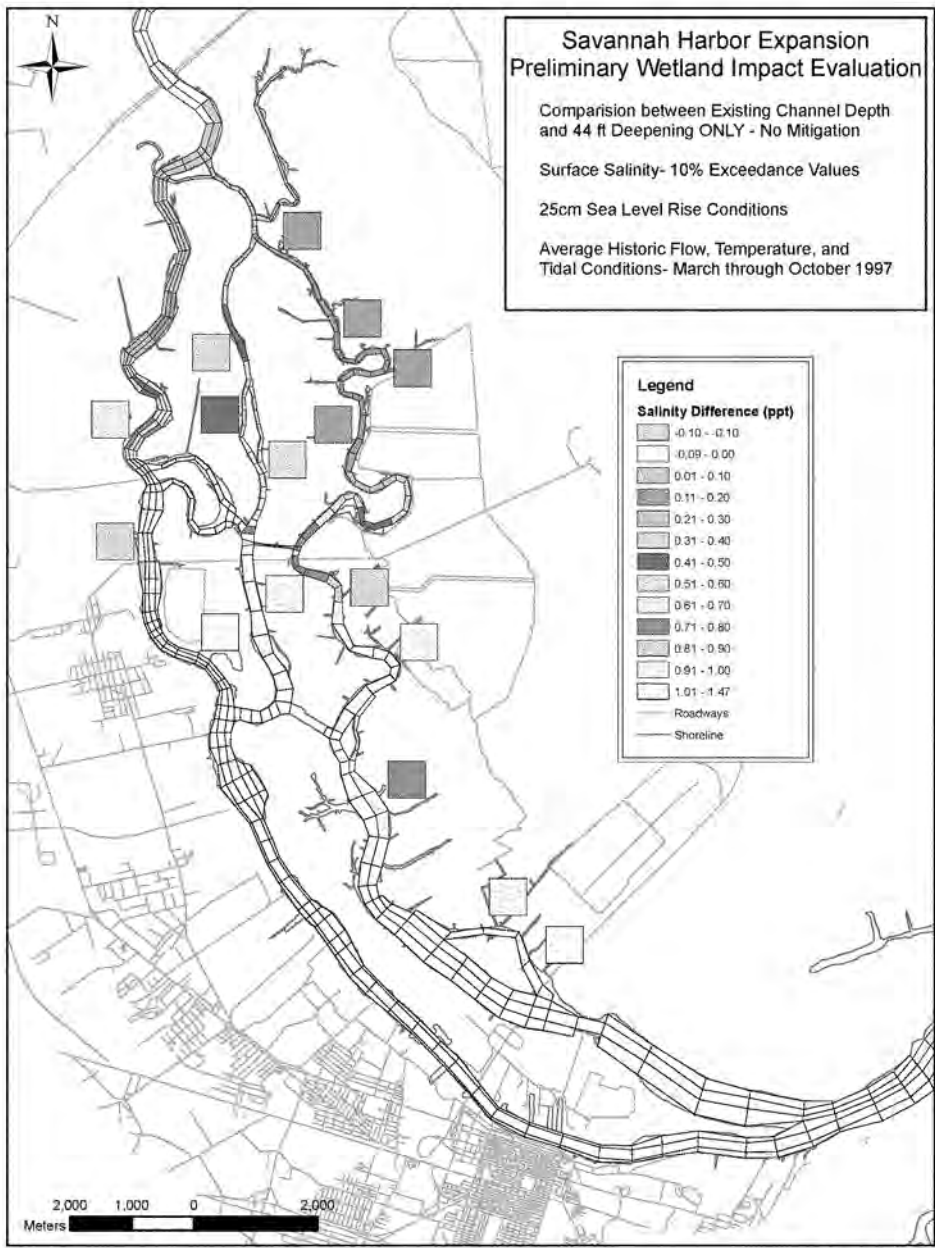


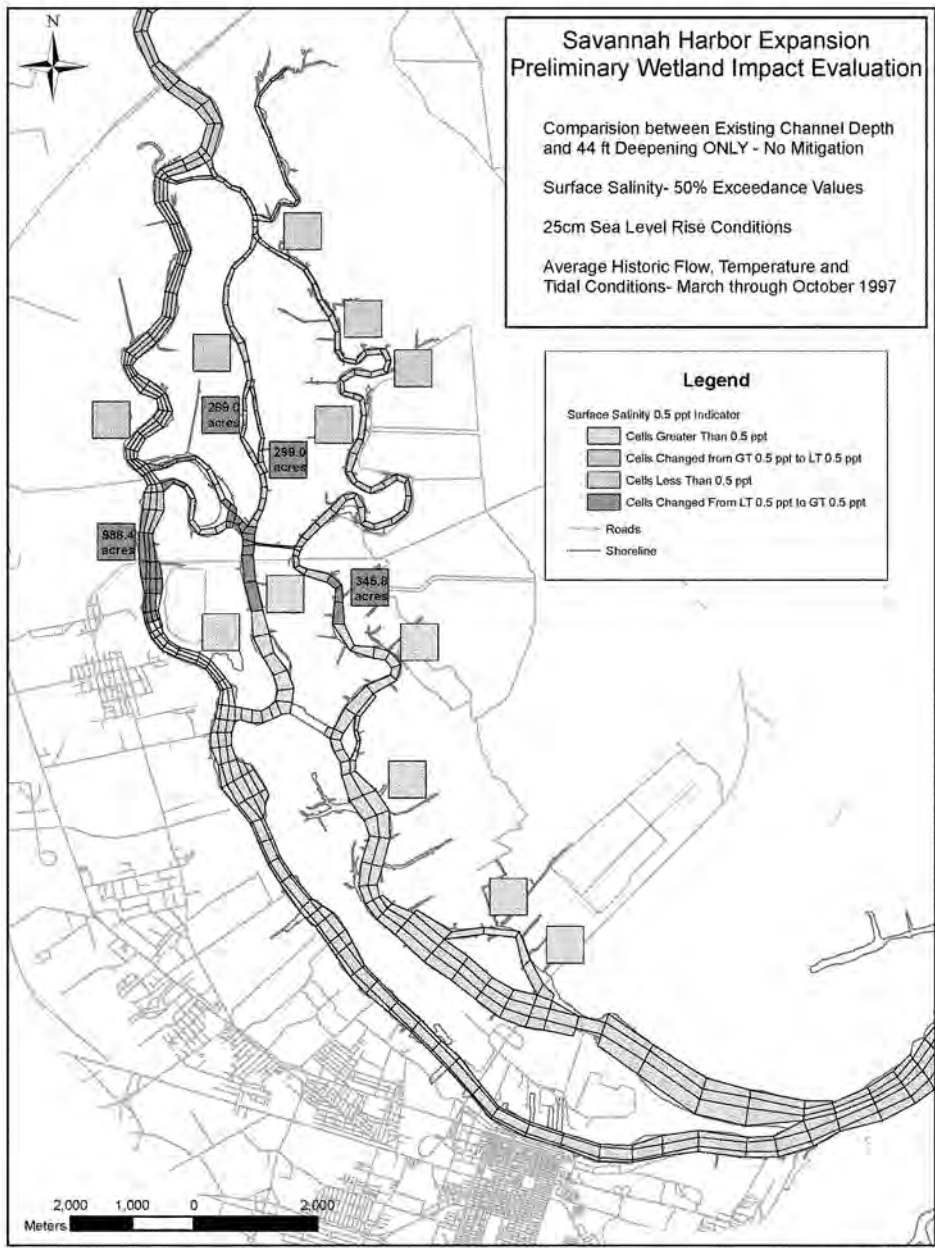


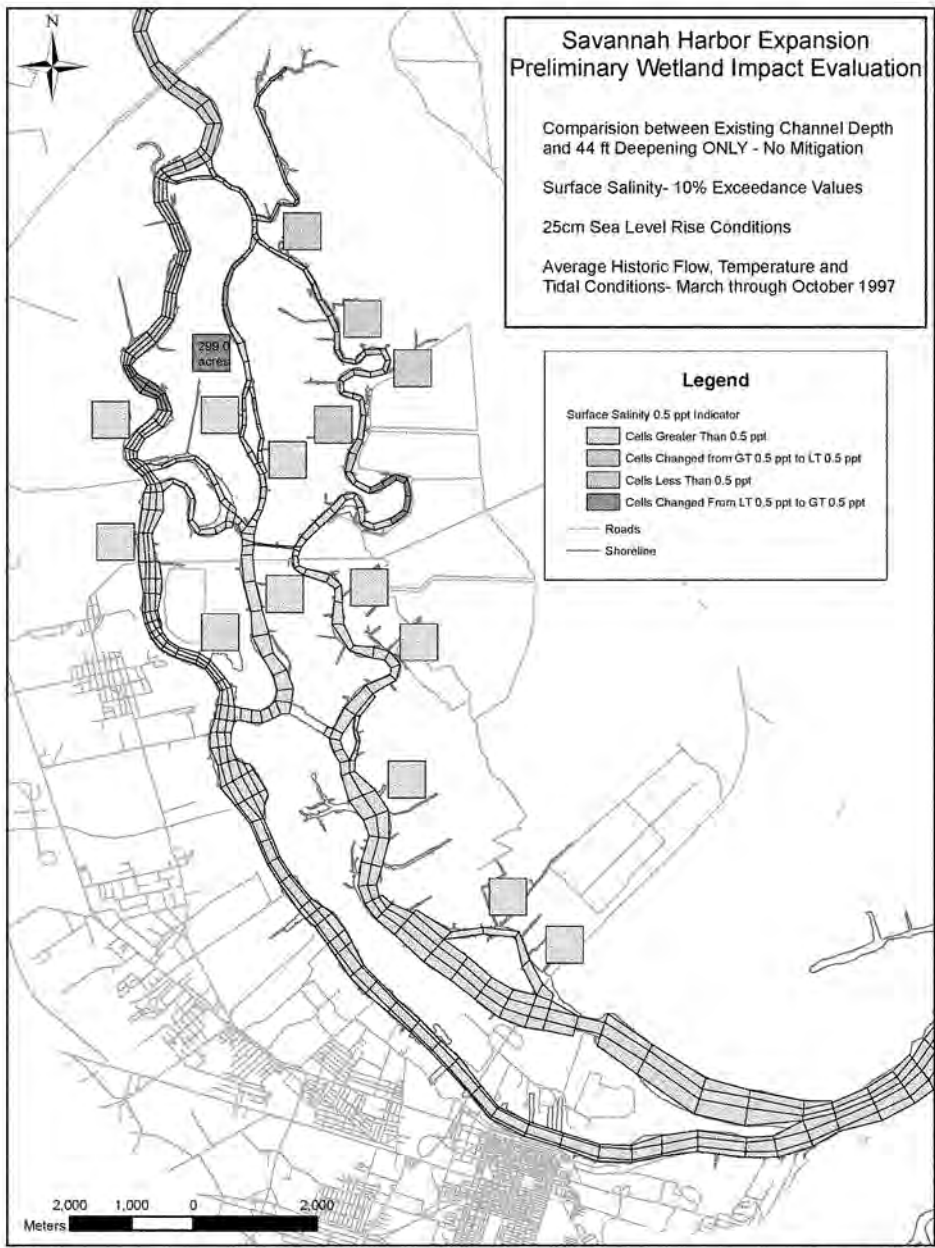


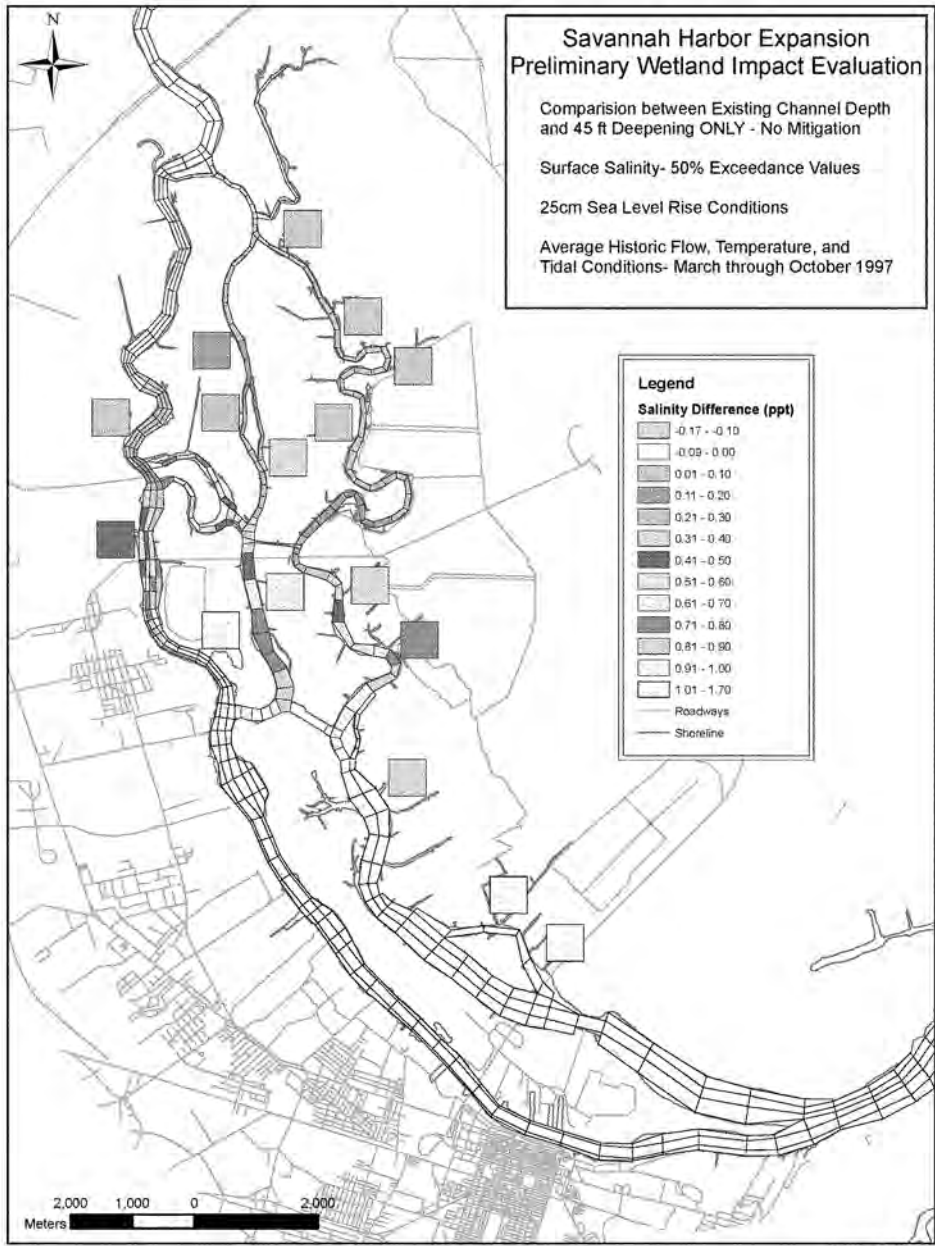
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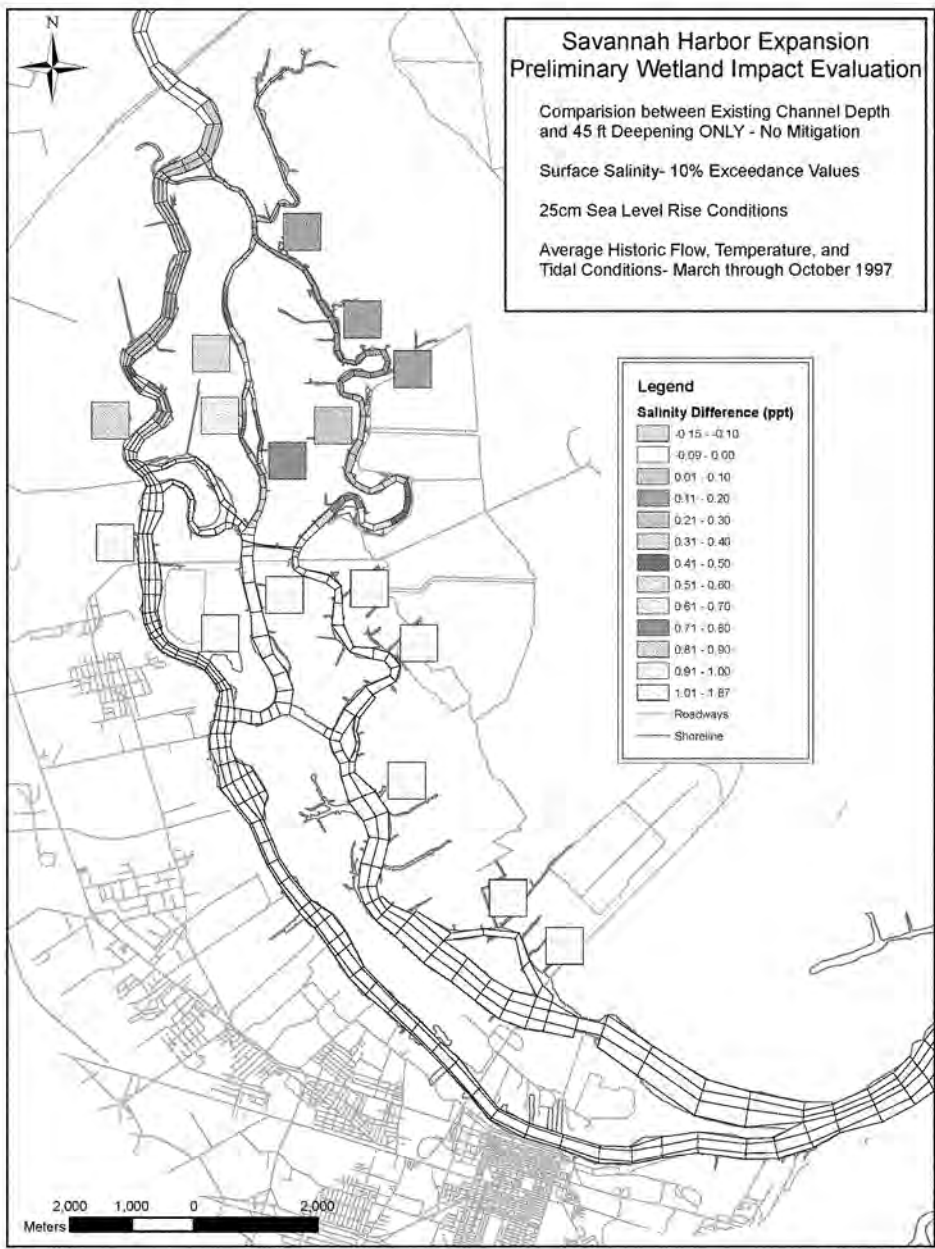


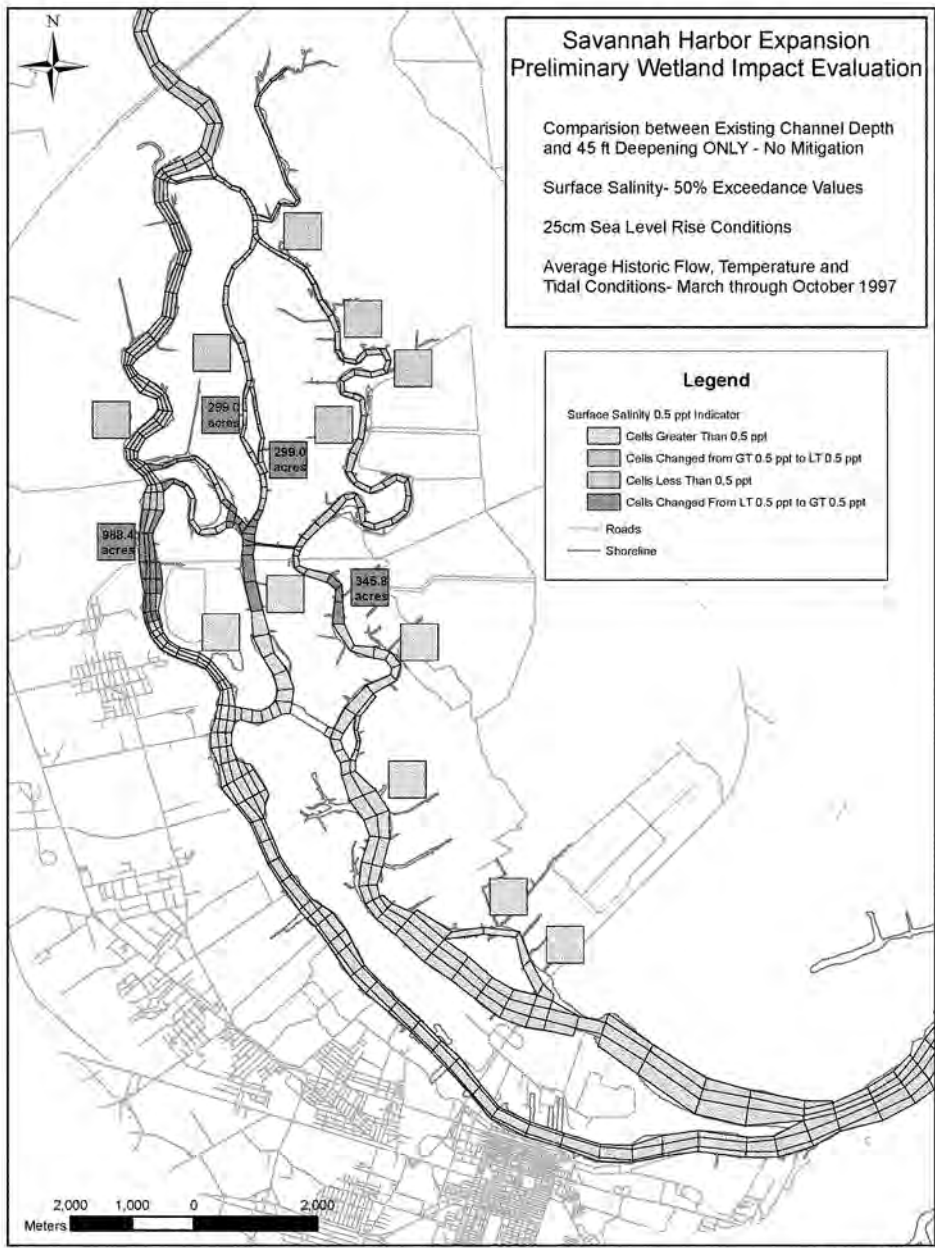


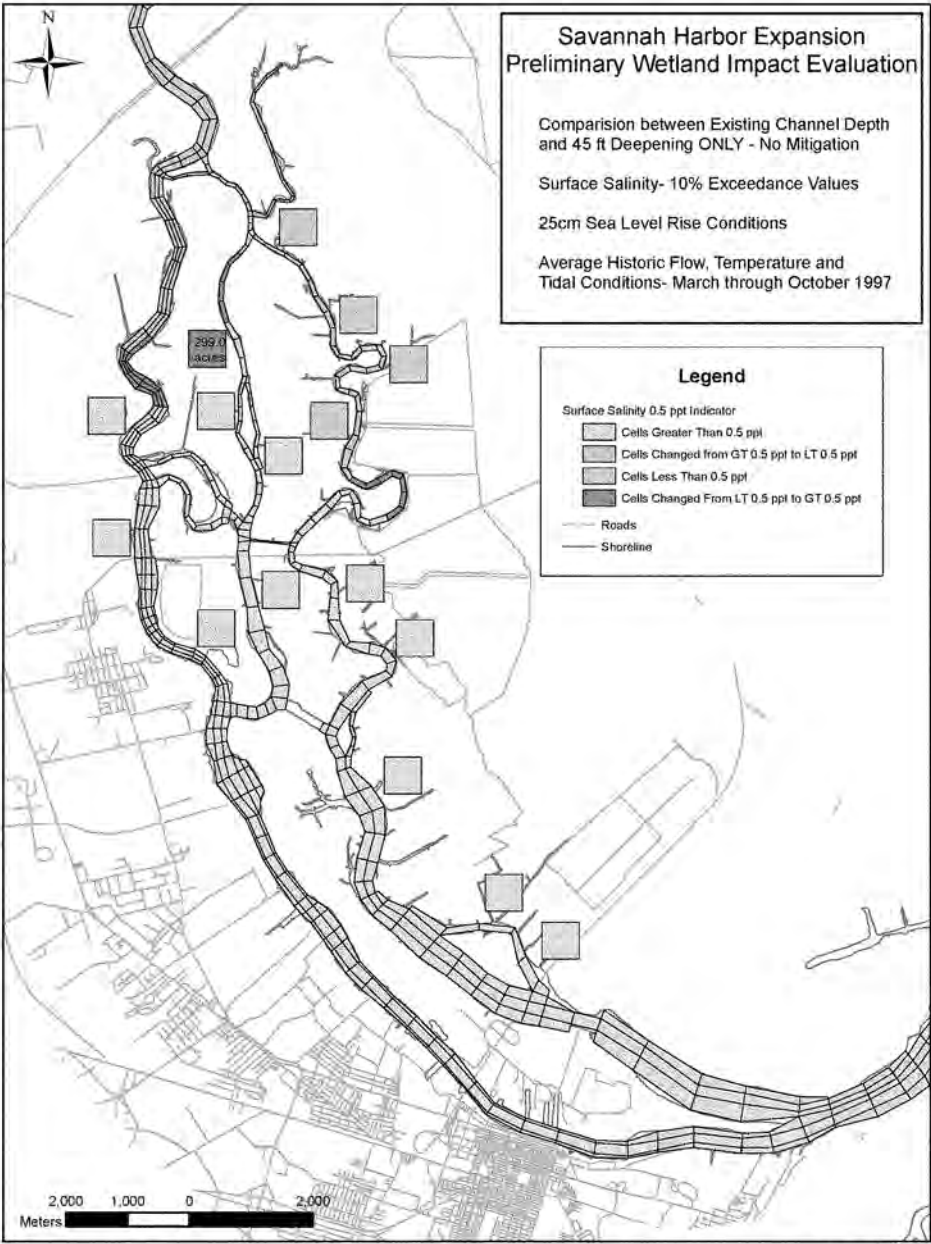


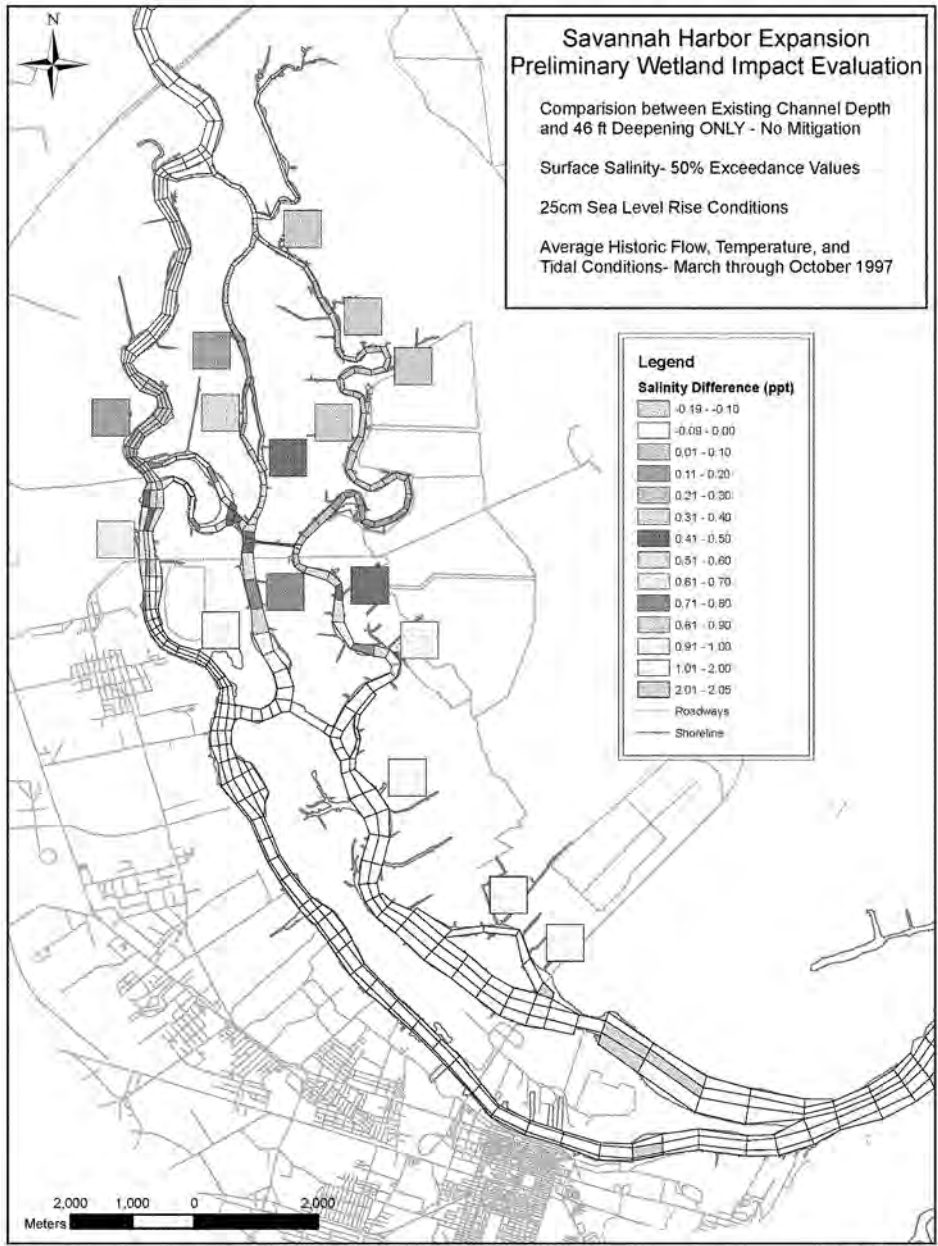


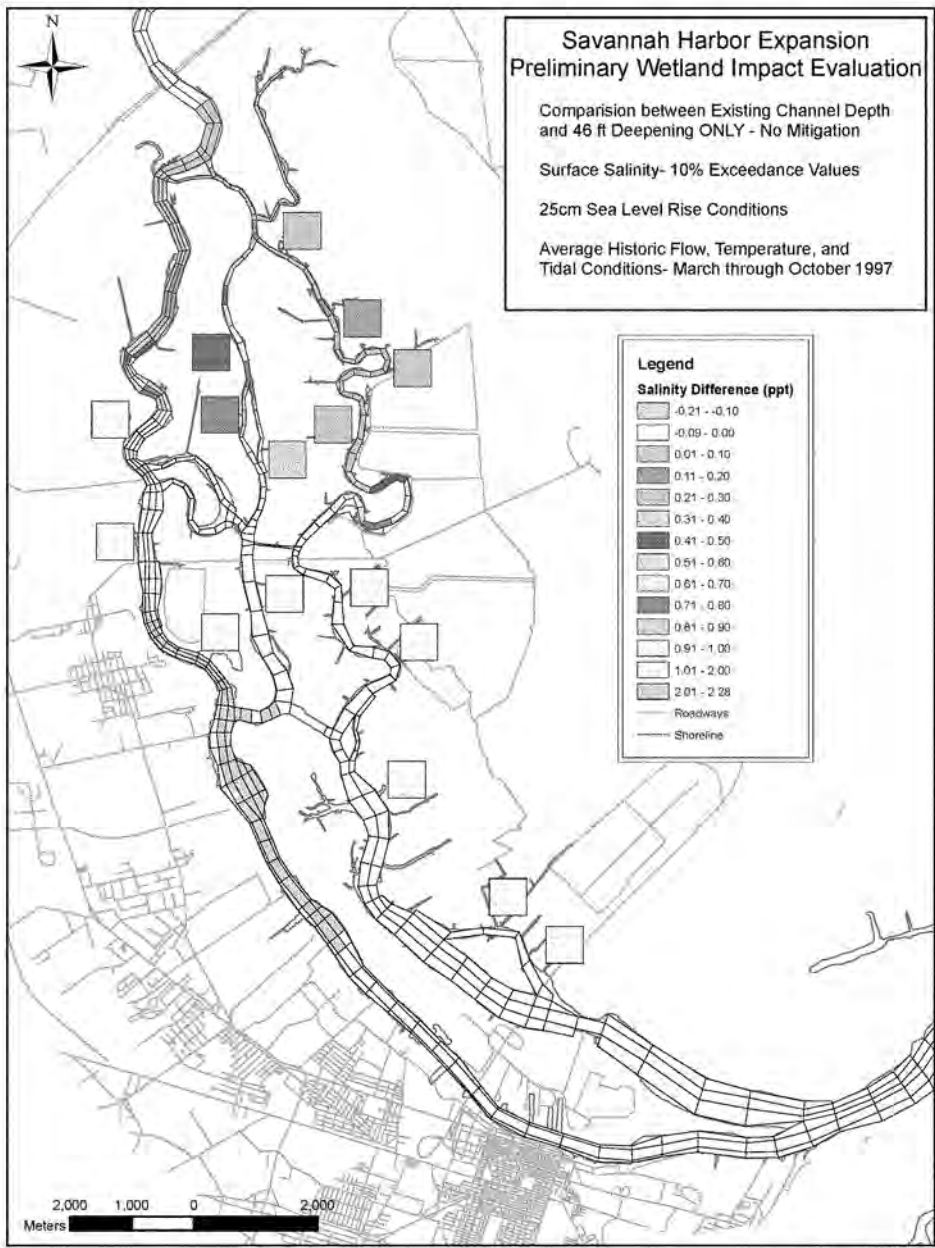


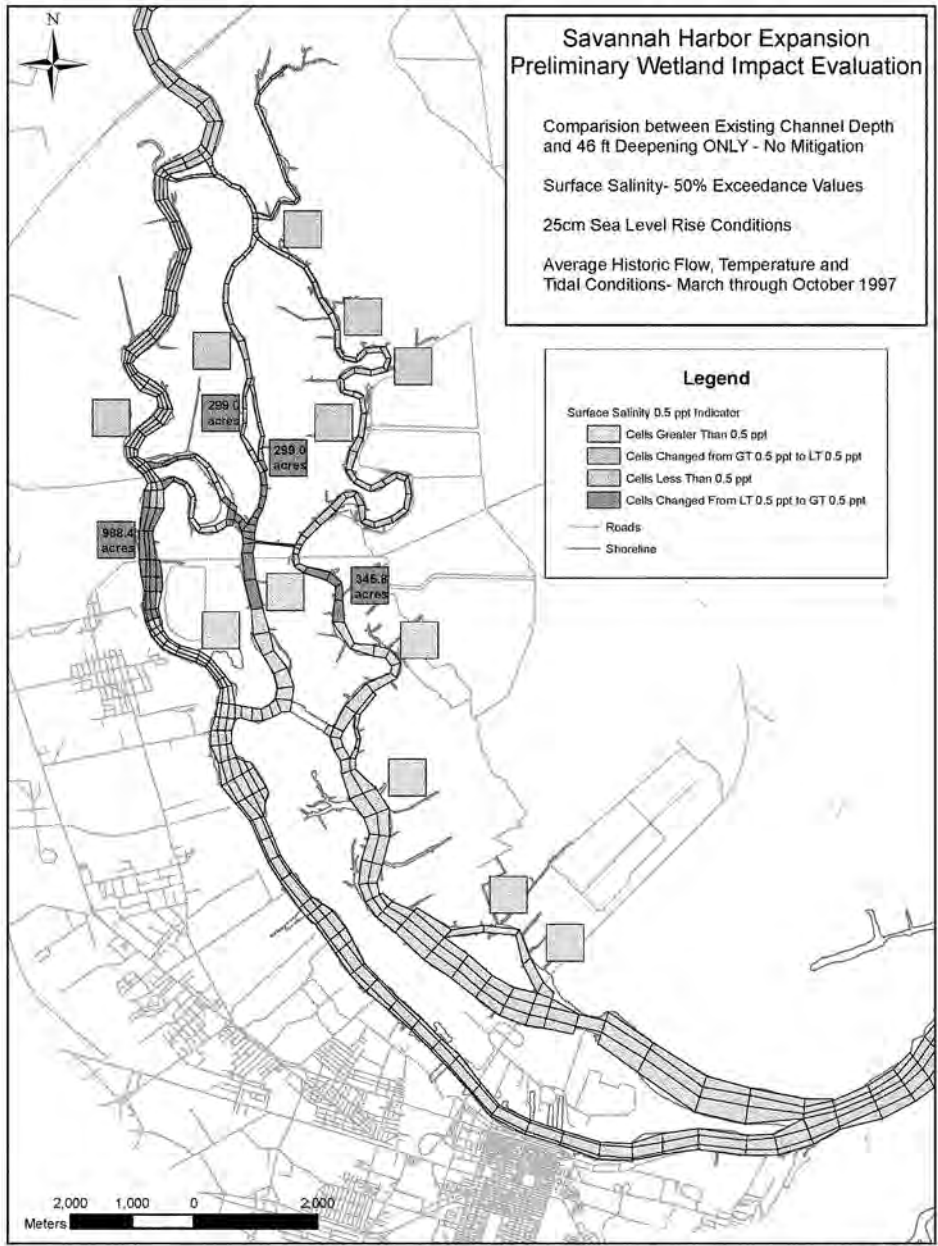


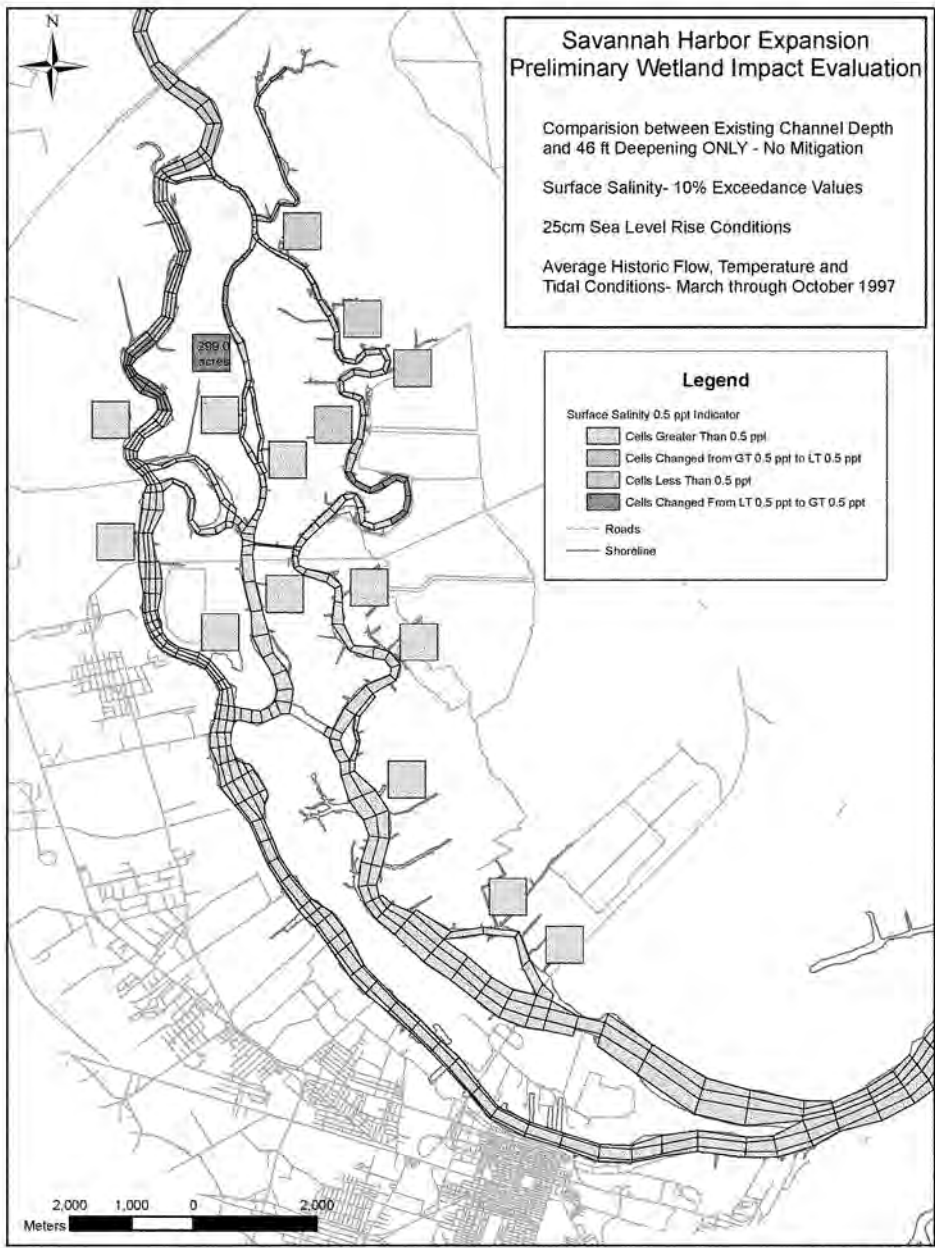


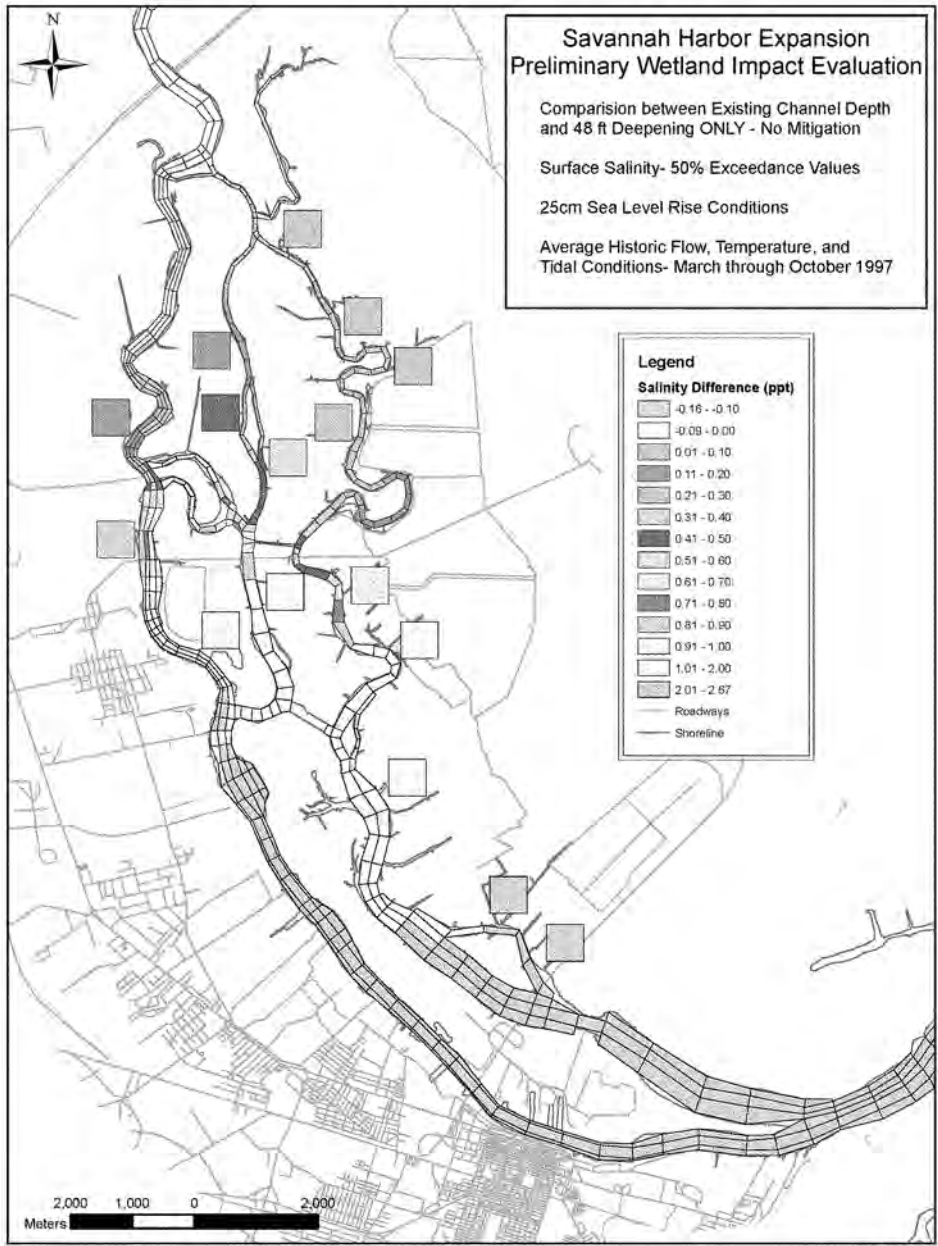


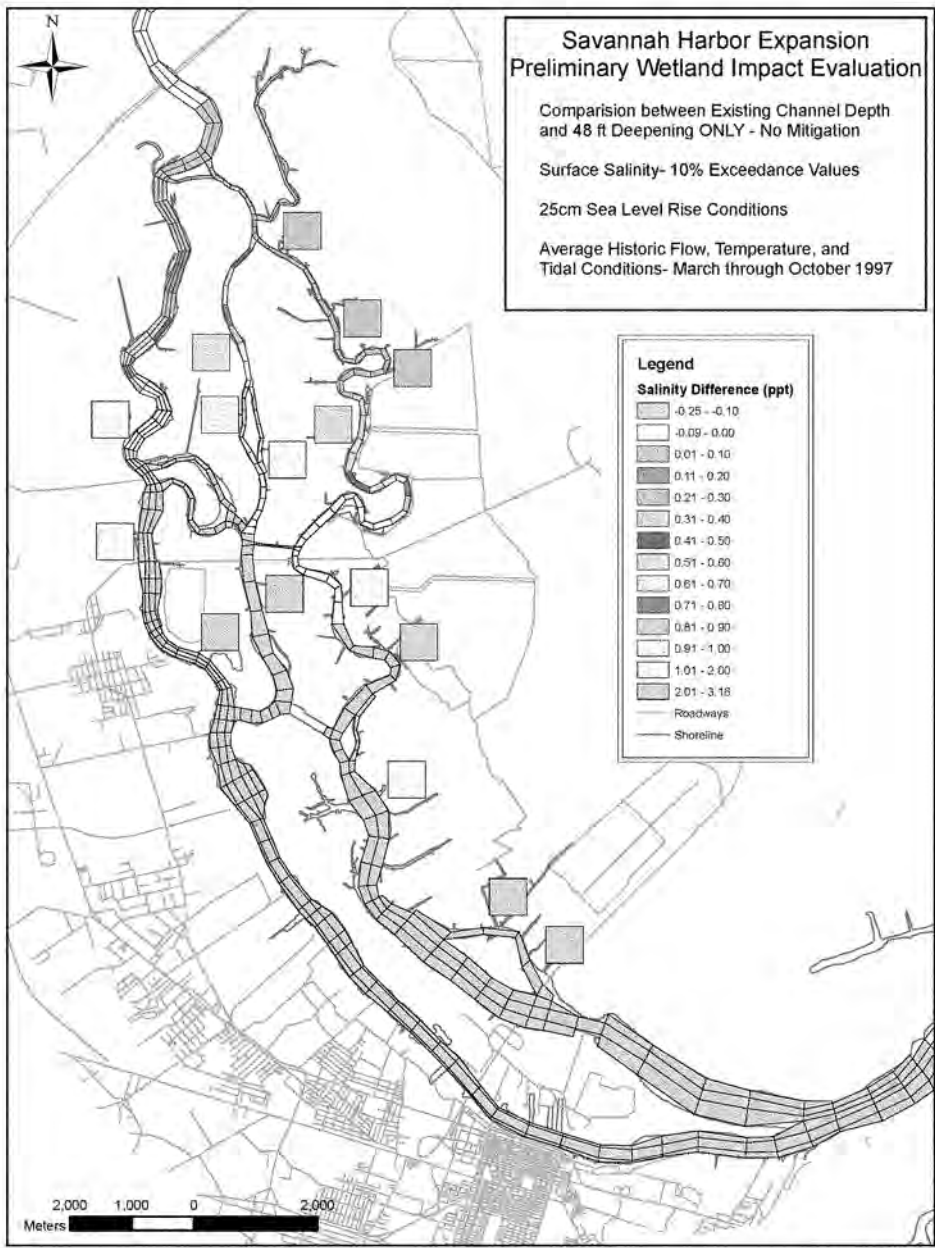


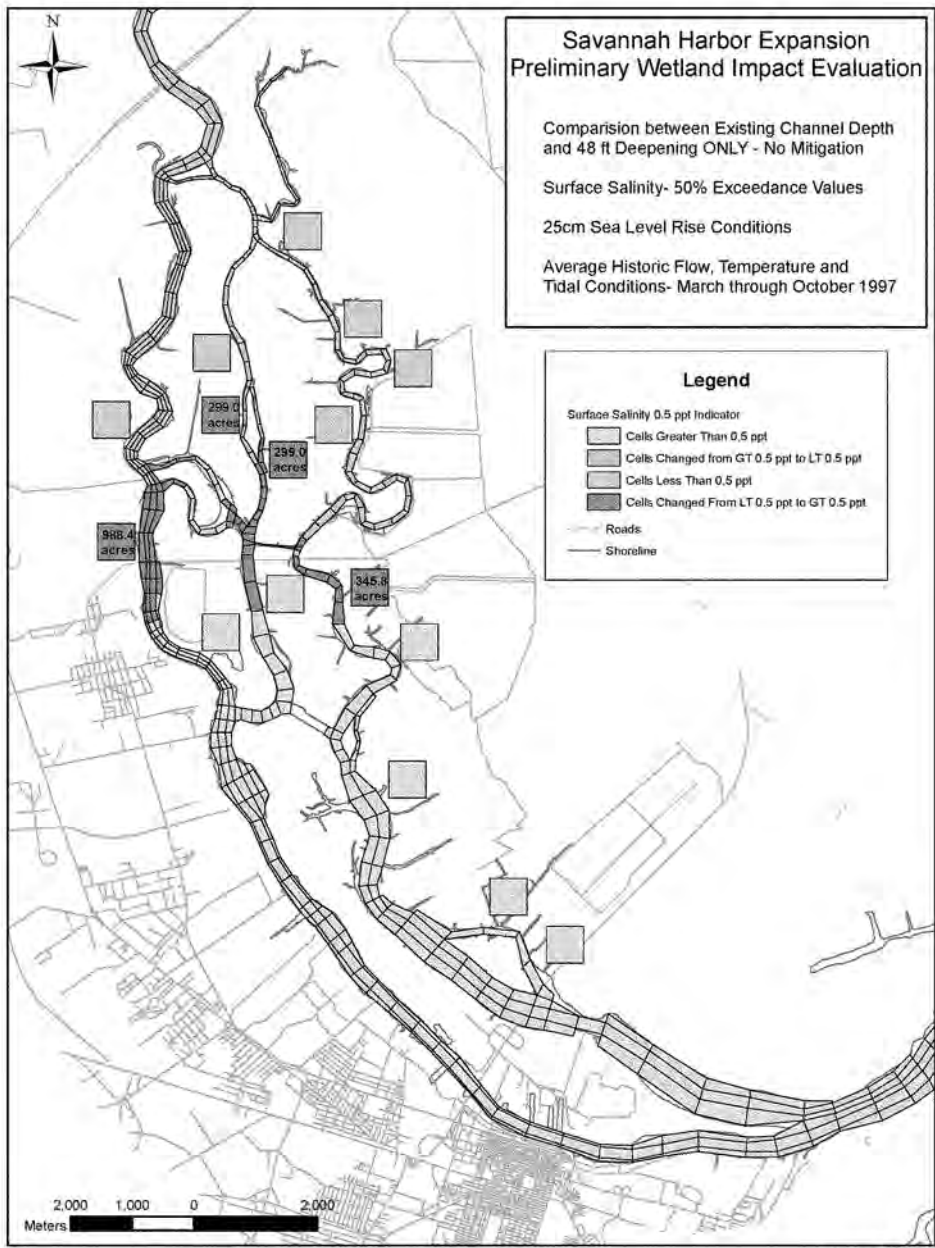


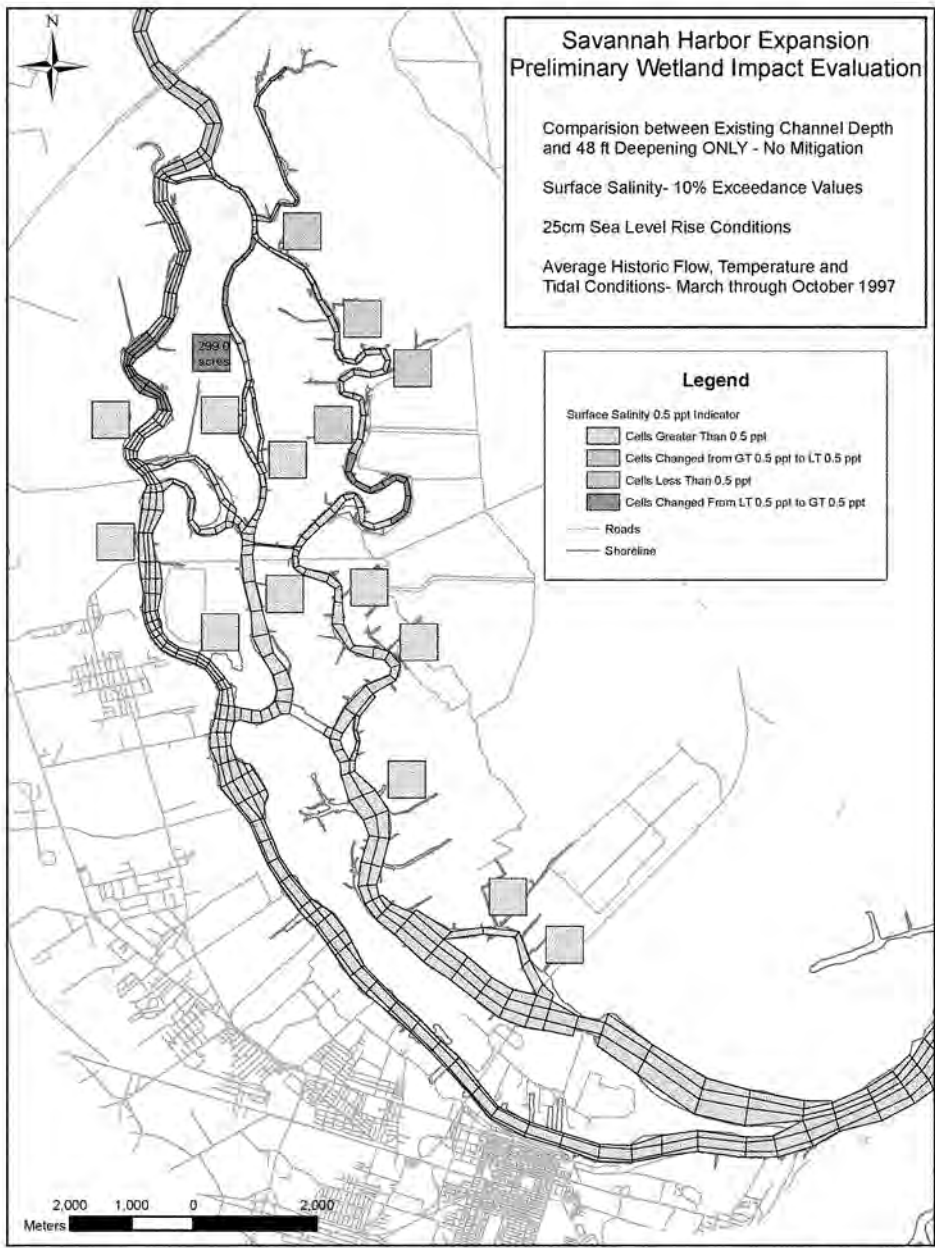




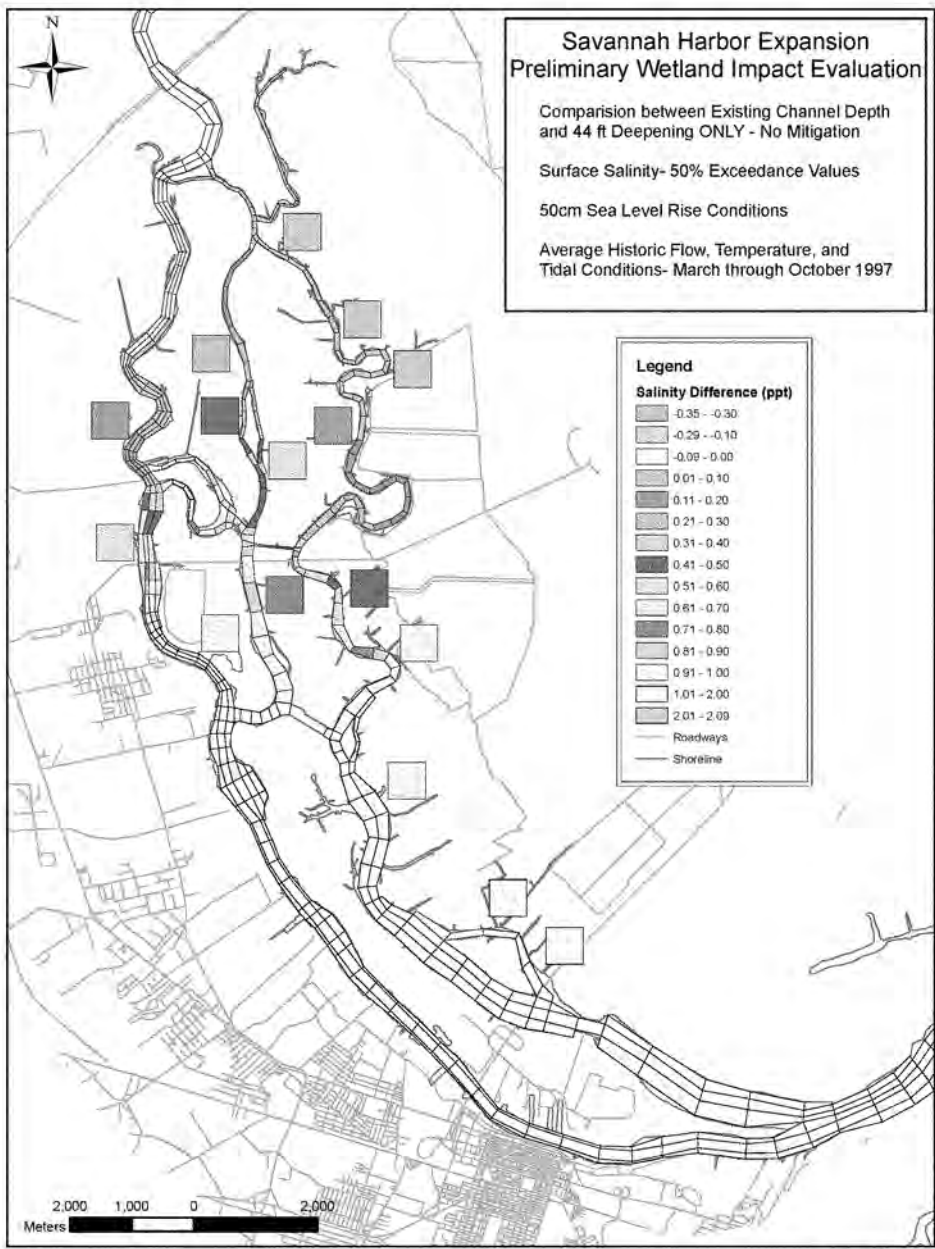


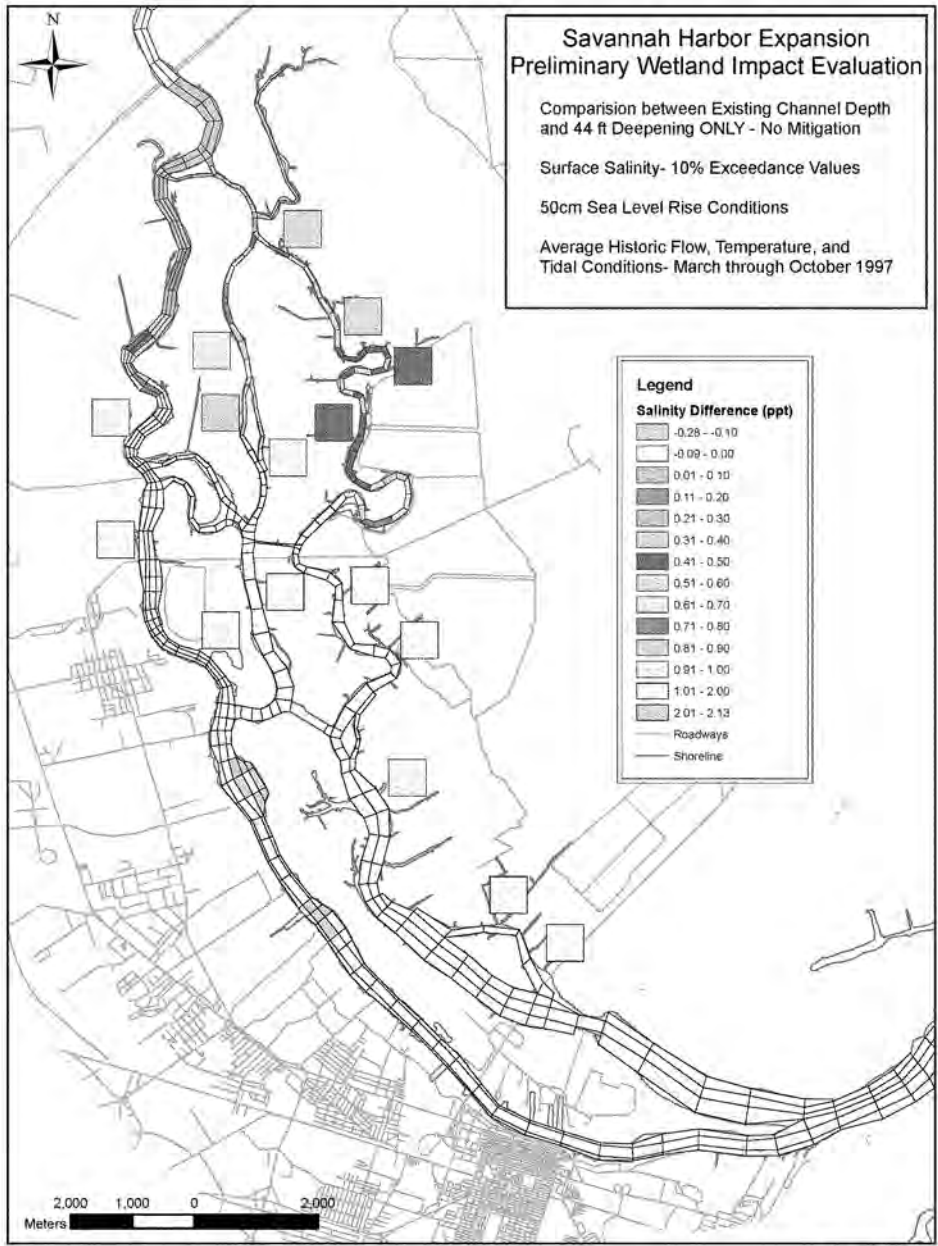


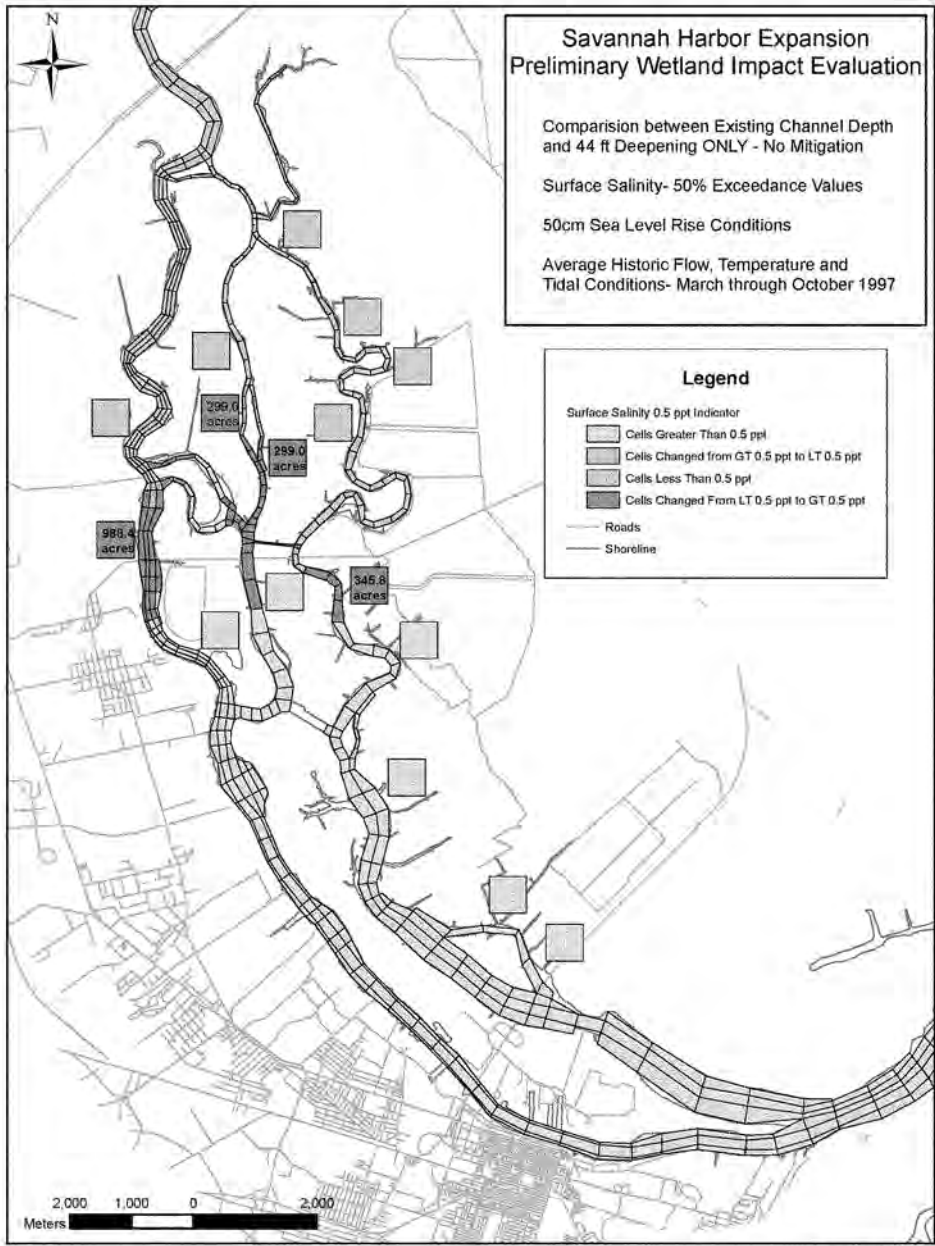


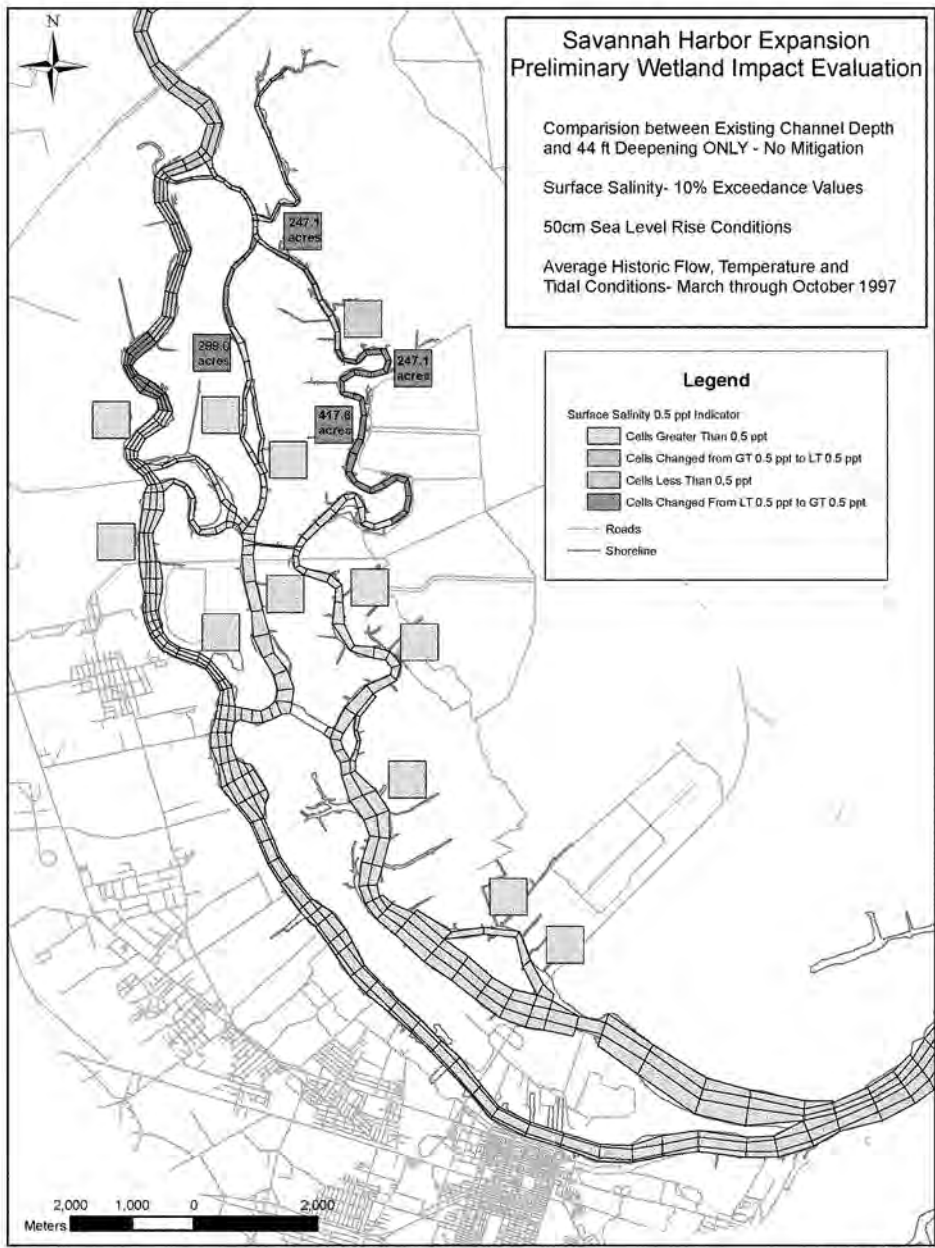


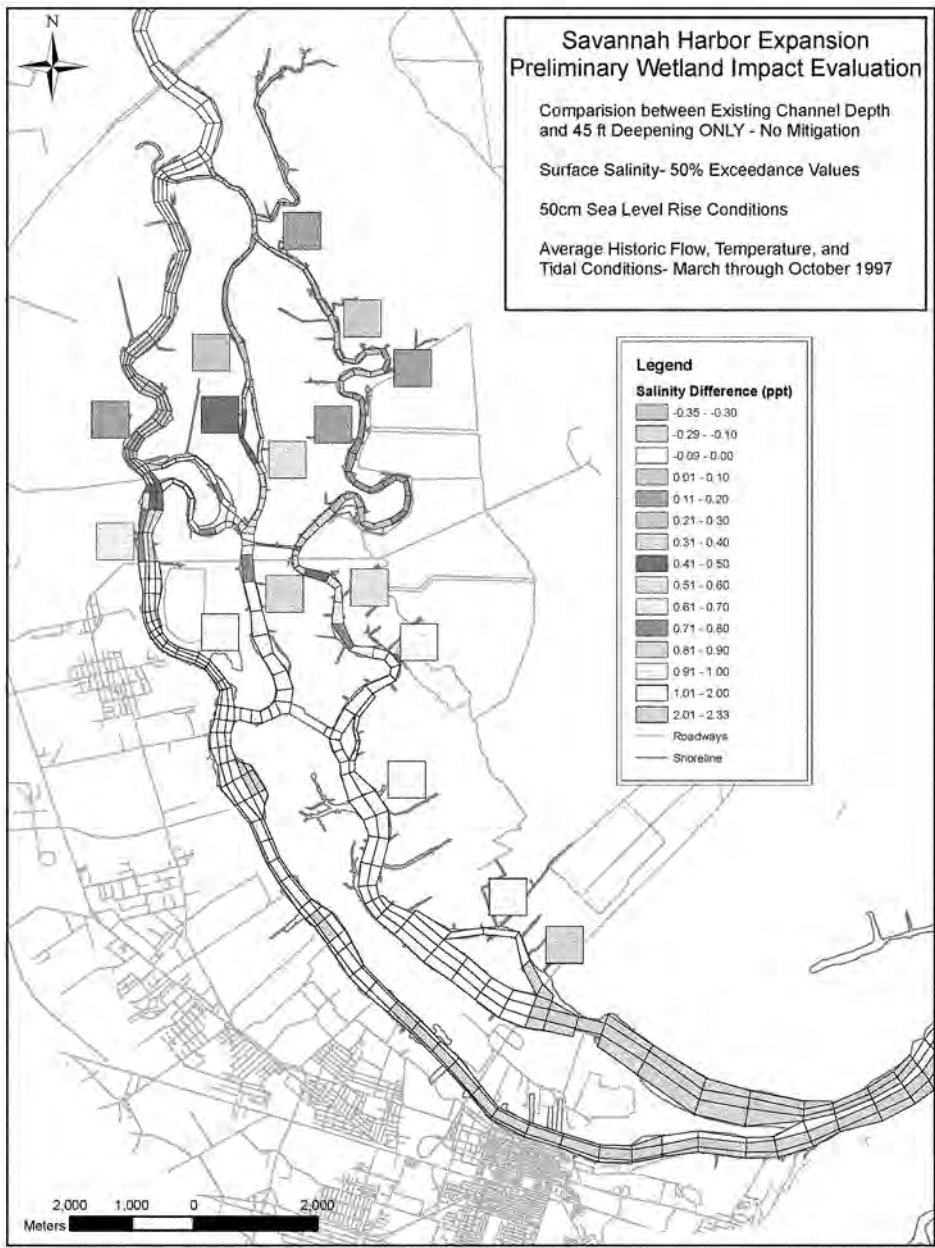
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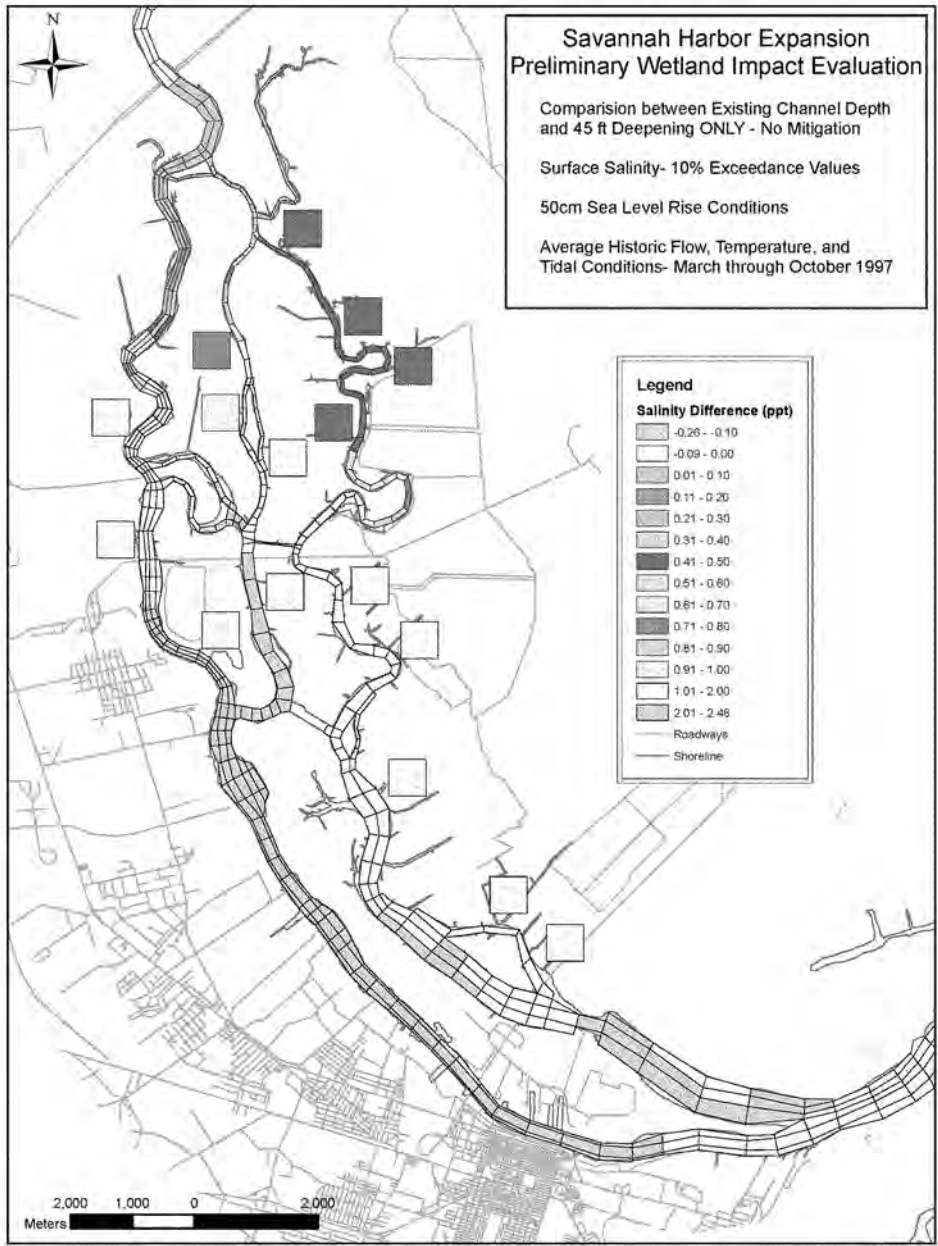


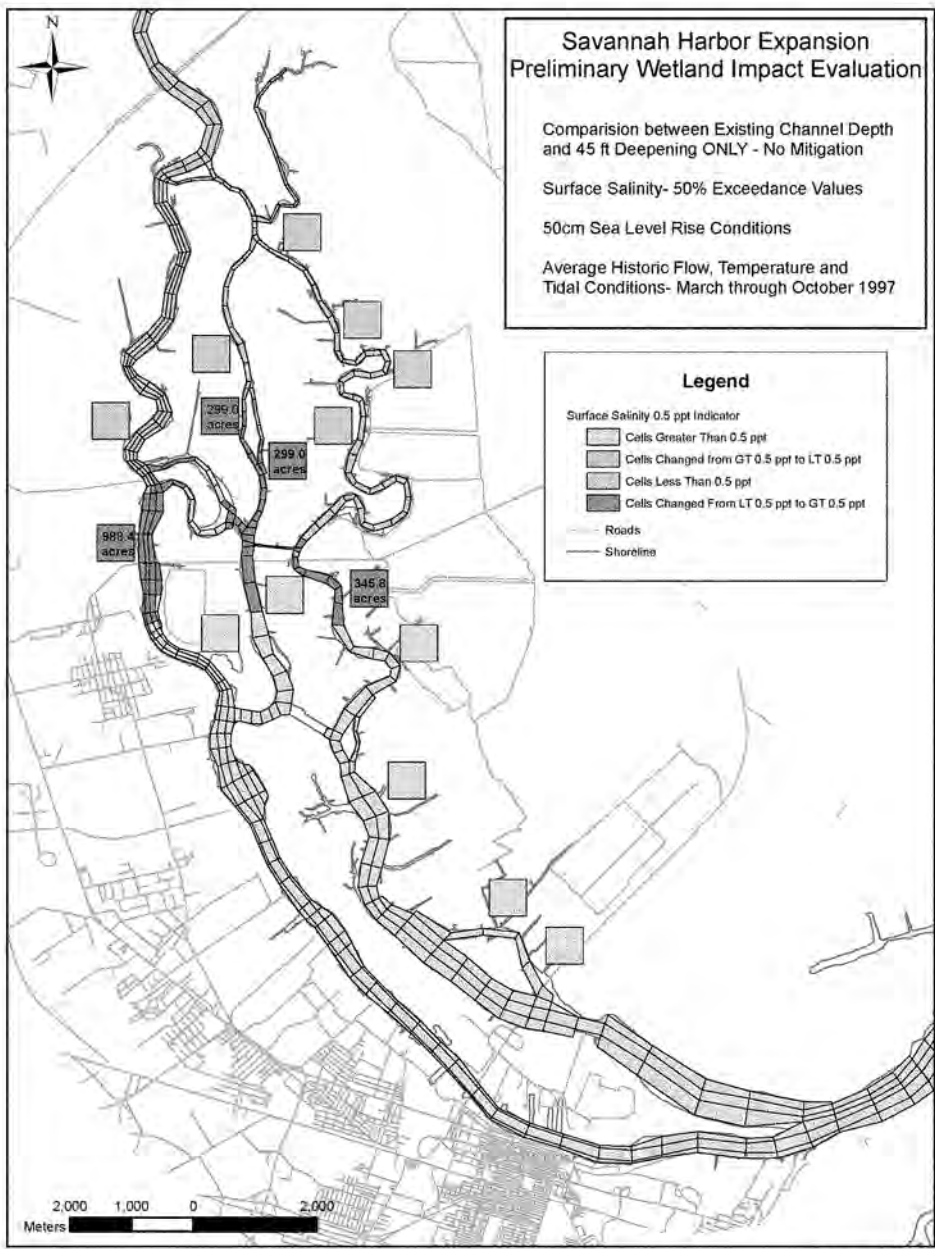


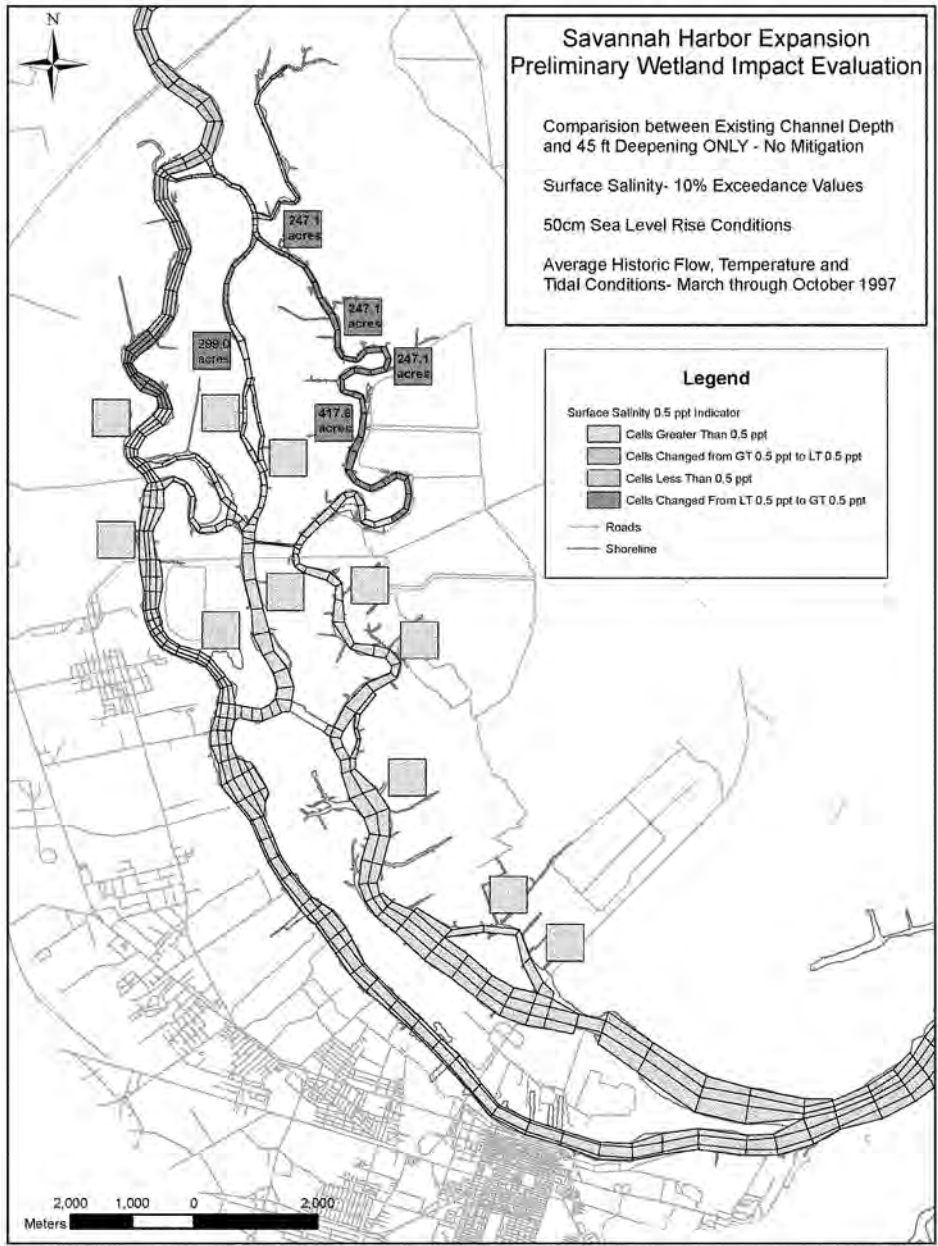


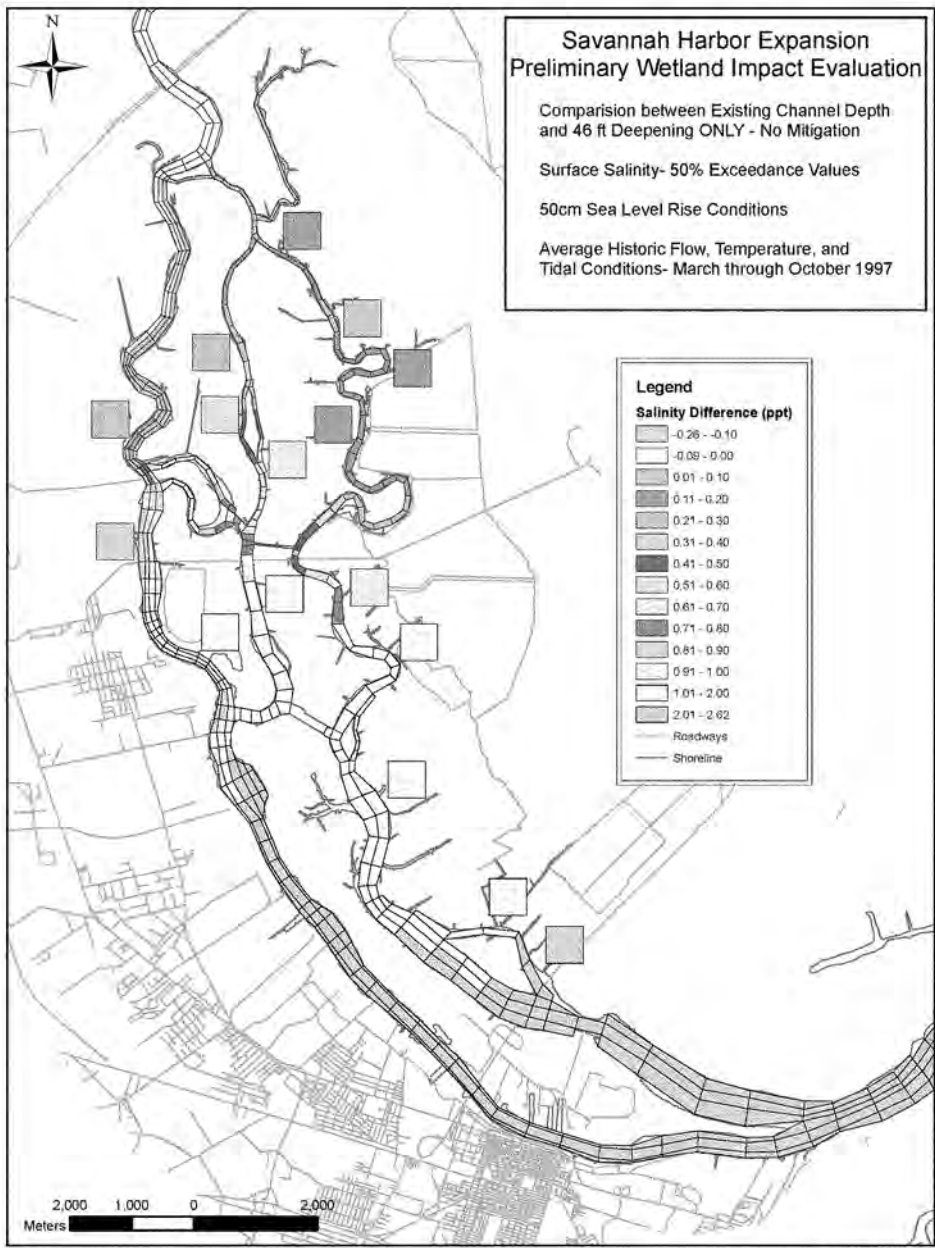


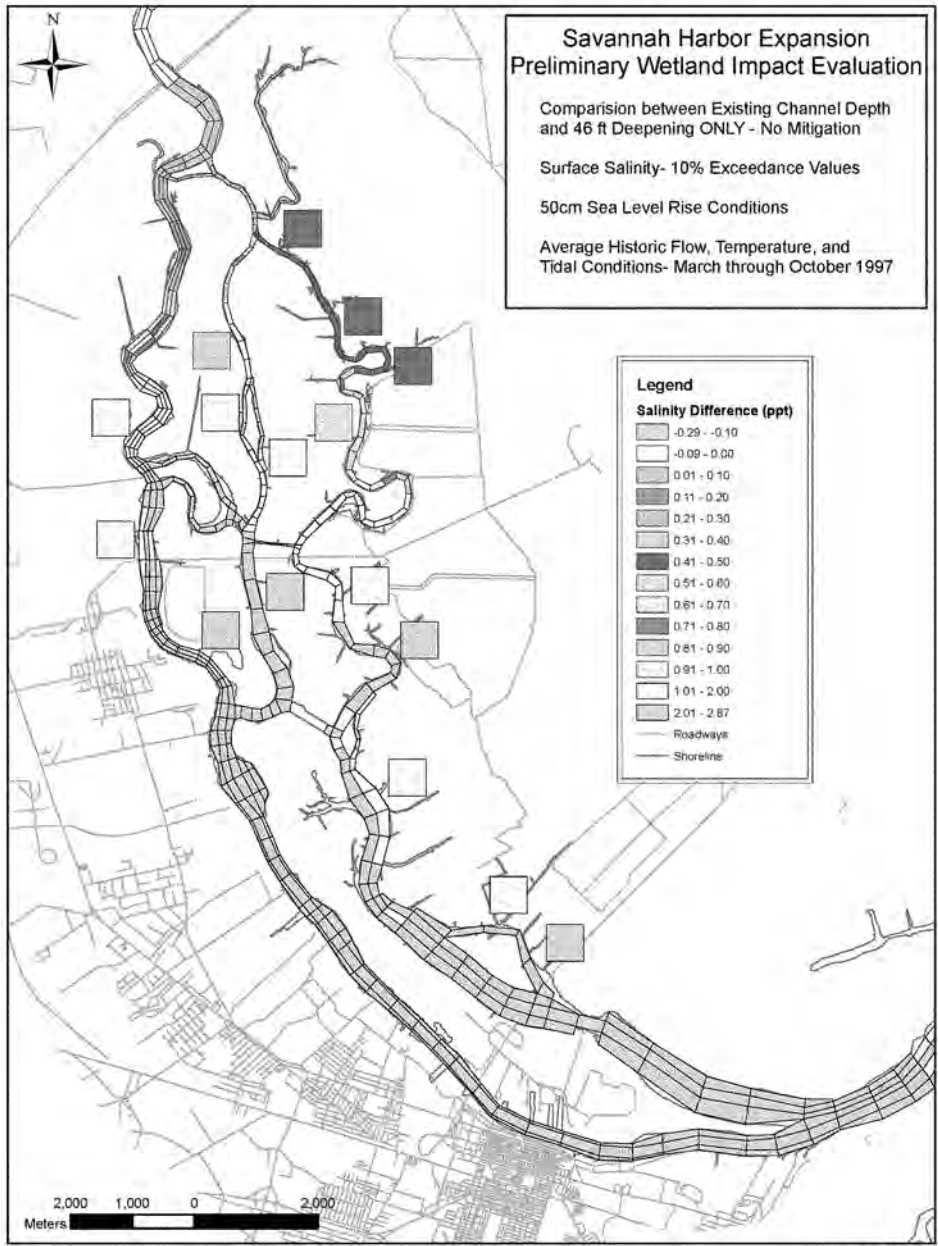


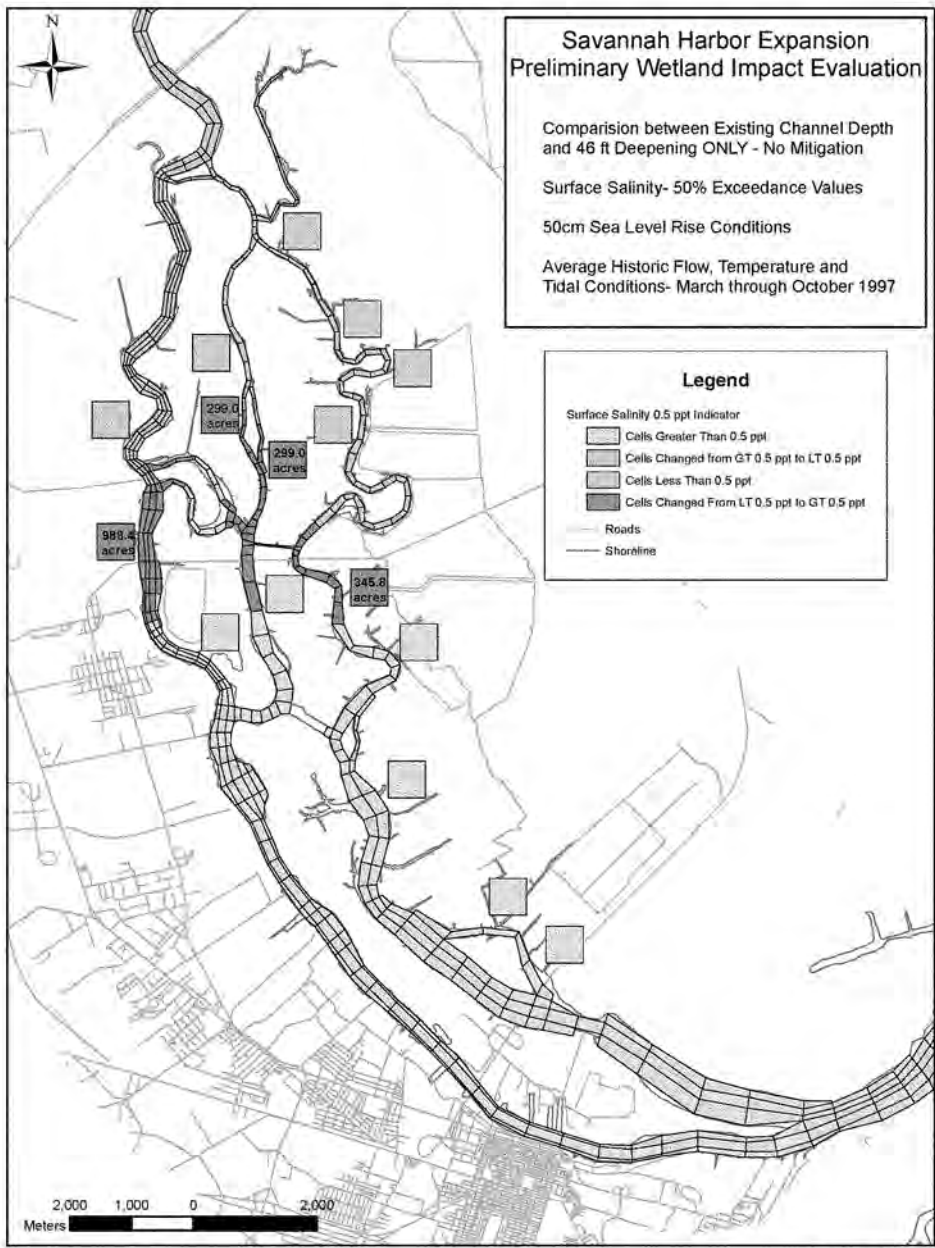


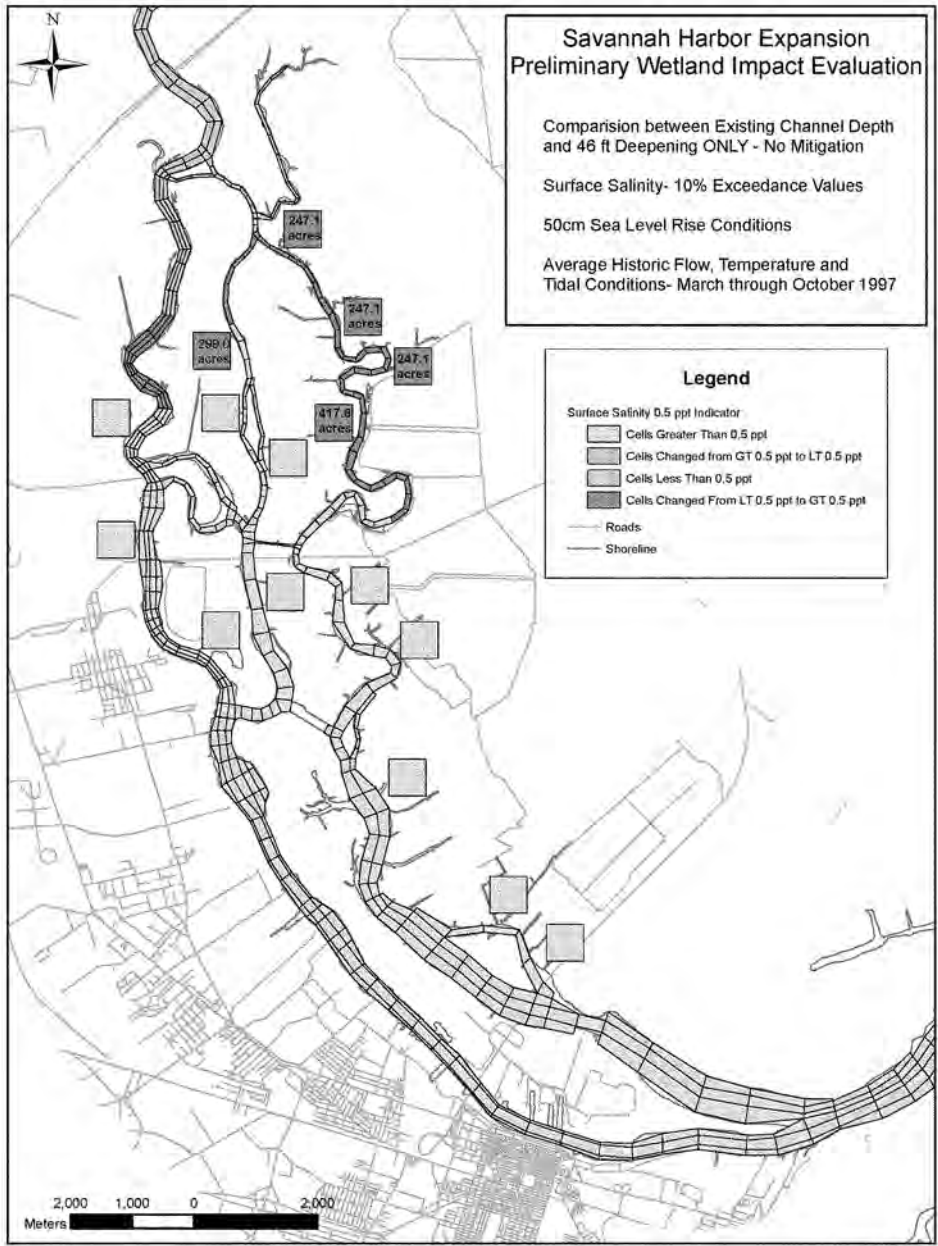


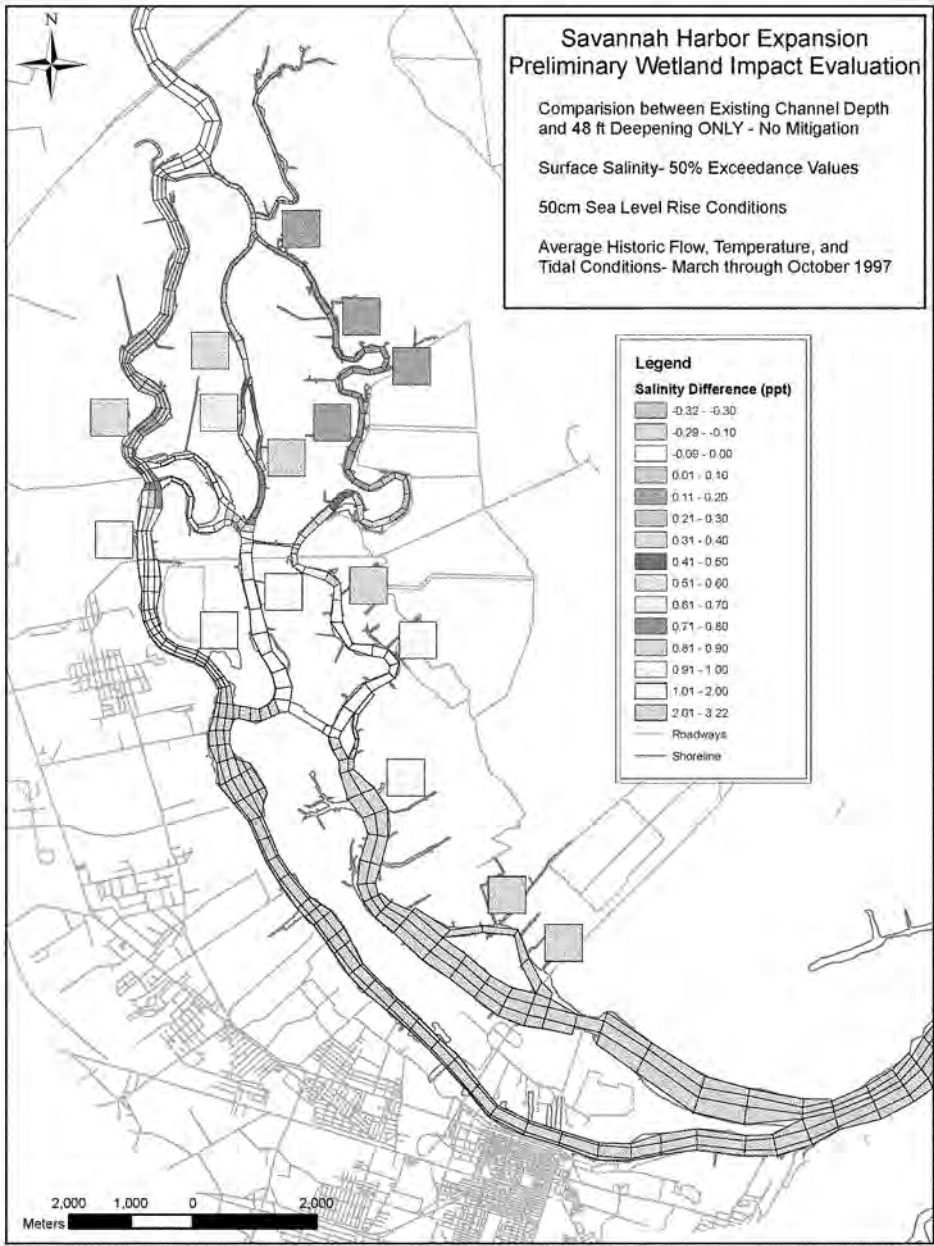


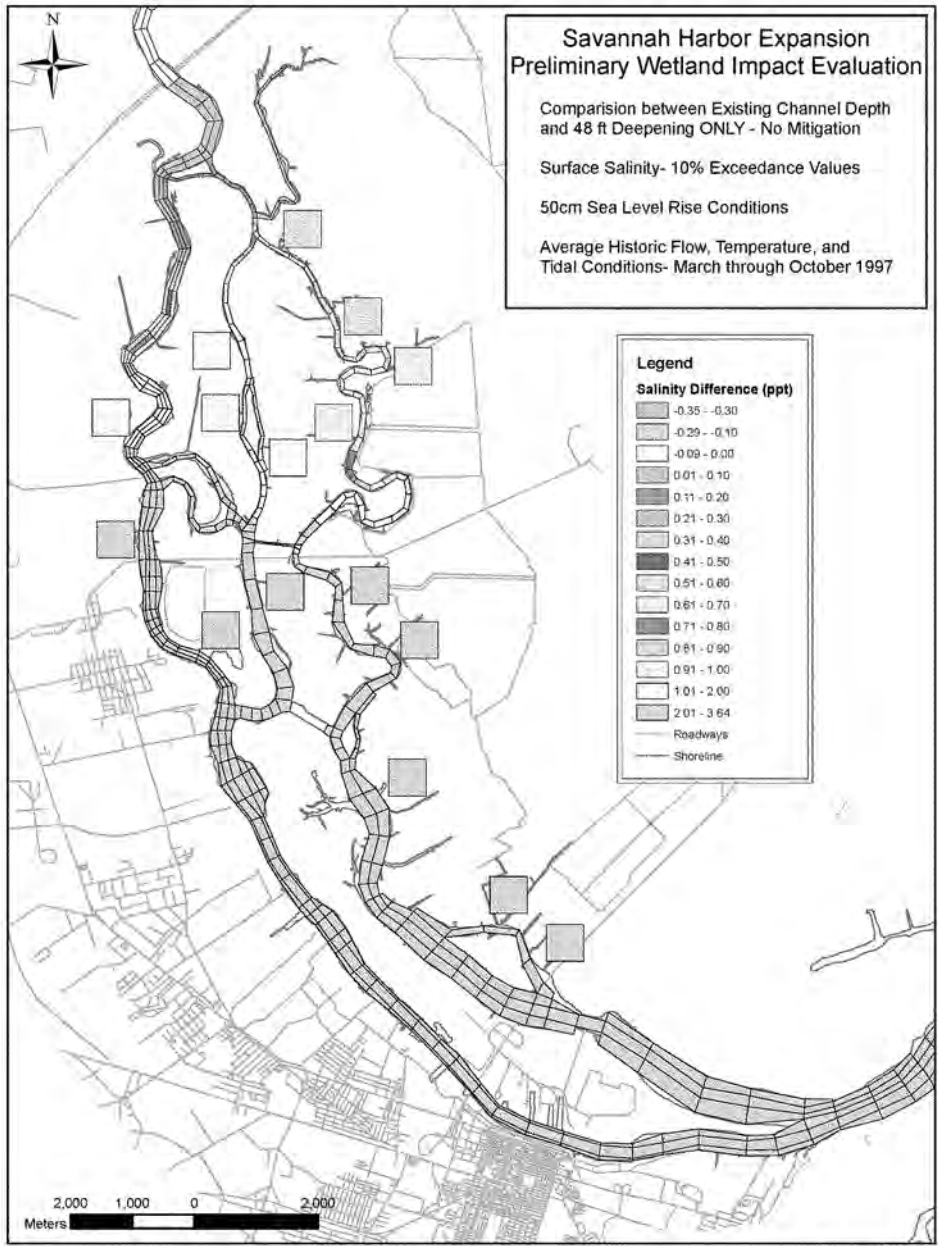


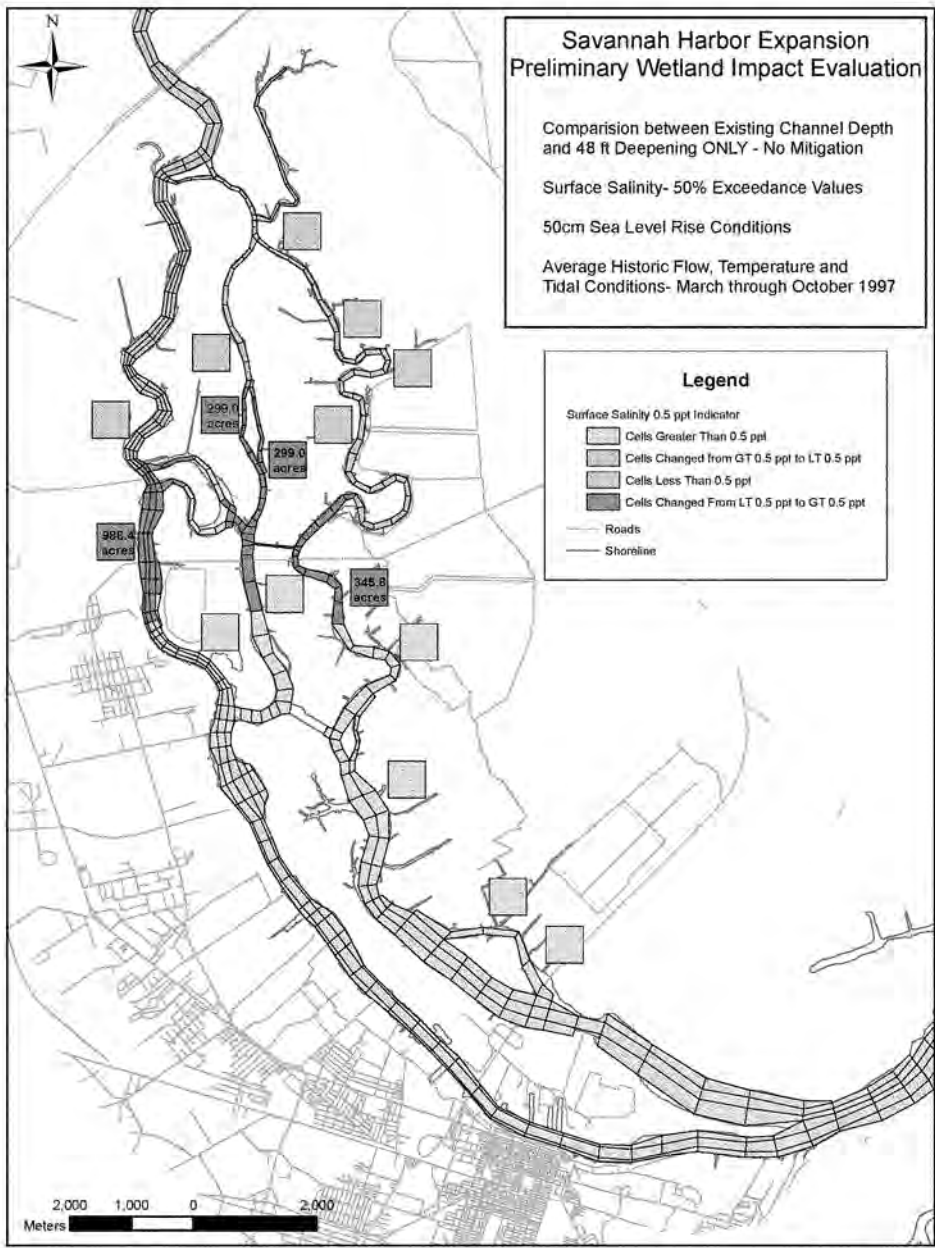


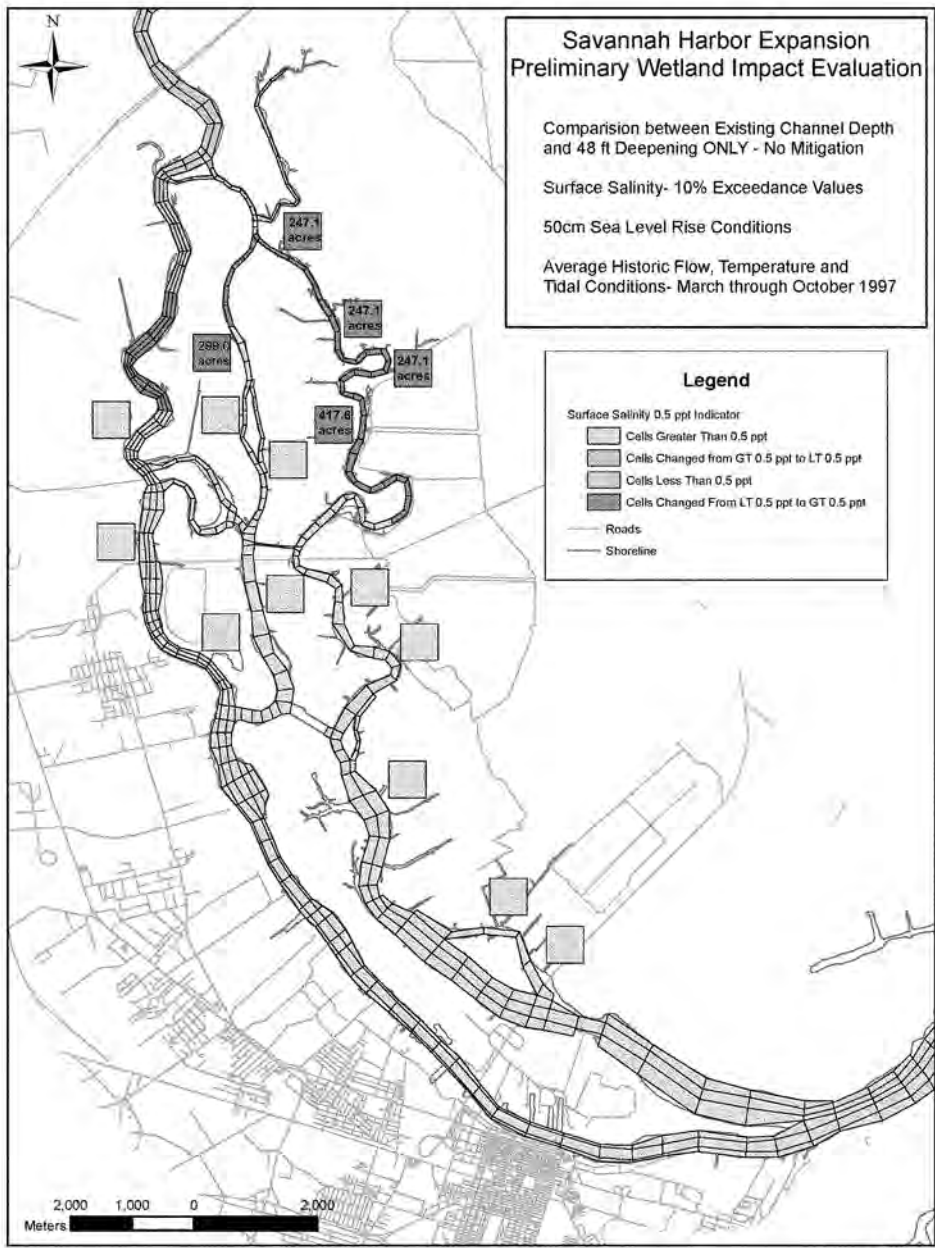












Savannah Harbor Data Analysis and Modeling Expectations of Federal Agencies

The purpose of this memorandum is to establish criteria (guidelines) by which to evaluate the performance of the hydrodynamic and water-quality models and post-processing routines used to predict impacts associated with the proposed Savannah Harbor Deepening Project. This memo provides a brief background of the modeling effort to date, a description of the resource areas of concern, a description of the modeling approach, and a guide for the evaluation of the model performance.

Background:

The purpose of the 1997 Savannah Harbor data collection and subsequent modeling activities was to provide a hydrodynamic and water-quality model to analyze impacts of deepening on circulation, salinity, and dissolved oxygen. The aquatic resources in the system are sensitive to small changes in water level, salinity, and dissolved-oxygen concentration. Additional understanding of the system and its behavior, beyond the 1997 data set and model calibration was recommended in order to make the necessary absolute predictions of water-level, salinity, and dissolved oxygen necessary to evaluate the mitigation issues associated with the potential deepening of the harbor.

The purpose of the 1999 Savannah Harbor data collection and modeling effort was to better understand and quantify the processes affecting circulation and water quality in the system, and to develop a defensible hydrodynamic and dissolved-oxygen model. These models are then to be used in conjunction with the extensive monitoring data and other tools to make the necessary absolute predictions for the evaluation of impact and mitigation issues. The 1999 data set provides the detailed data to develop this defensible hydrodynamic and water quality model.

Areas of Concern:

There are four resources of concern for federal agencies. These are:

1. Shortnose sturgeon
2. Striped bass
3. Tidal Wetlands
4. Dissolved oxygen

DRAFT -- Model calibration and validation criteria—DRAFT
Revised Nov 5, 2001

The federal agencies believe that accurate prediction of the following parameters and time scales at specific locations are necessary for evaluating project related impacts for each of the resources of concern:

Sturgeon:

- Critical parameters and statistic
 - Bottom DO --10th and 50th percentile
 - Bottom salinity – 50th and 90th percentile
- Critical time scale – hours for durations of DO concentrations below 3 mg/L
- Important stations- GPA8 and GPA22

Striped Bass:

- Critical parameter and statistics
 - High-tide surface salinities -- 90th percentile
 - Ebb and Flood velocity of top 2 meters
- Critical time scale – hours (maximum duration of salinity excursion)
- Important stations – GPA 5, 6, 7, 8, 9,10, 11R, 12R, 15, 22 and USGS Stations 02198840 (I-95), 02198920 (Houlihan Bridge), 02198979 (Limehouse), and 021989791 (USFW Dock).

Tidal Wetlands:

- Critical parameter—high tide water levels and salinities over 60 days
- Critical time scale – daily, weekly to monthly
- Important stations -- GPA 5, 6, 7, 8, 9,10, 11R, 12R, 15, and USGS Stations 02198840 (I-95), 02198920 (Houlihan Bridge), 02198979 (Little Back River nr Limehouse), and 021989791 (USFW Dock).

Dissolved-Oxygen:

- Critical parameter--10th and 50th percentiles
- Critical time scale – hourly to daily
- Important stations -- GPA 2, 4, 6, 8, 9,10, 11R, 14, 21, and 22.

Based on the resources of concern, the model calibration should focus on the following stations:

- Elevation and Salinity: GPA 5, 6, 7, 8, 9,10, 11R, 12R, 15, 22 and USGS Stations 02198840 (I-95), 02198920 (Houlihan Bridge), 02198979 (Limehouse), and 021989791 (USFW Dock).
- Temperature: GPA 2, 4, 6, 8, 9,10, 11R, 14, 21, and 22.
- Dissolved oxygen: GPA 2, 4, 6, 8, 9,10, 11R, 14, 21, and 22.

Description of Modeling Approach:

A key issue for the Resource Agencies, researchers and managers is the need for the model calibration to be capable of accurately predicting extreme conditions that are expected to occur less than 5 to 10 percent of the time. The reason for this request is the desire to have the full range of values (peak or minimum), "absolute numbers", regardless of the duration, for various conditions that might, in later analysis, be found to be important in the evaluation of impacts. The agencies conclude that the numbers for the long-term effects alone of post-project conditions being predicted by the hydrodynamic/salinity model (e.g., change in 50th percentile values only) would be necessary, but may not be sufficient to fulfill their needs for identifying all likely project effects.

The approach for meeting these expectations incorporates a hydrodynamic model that is being calibrated for predicting long-term trends (the mean) for all of the selected parameters. However, because of the need to model absolute values for hypothesis testing purposes, the calibrated model will be supplemented with adjunct data based interfaces (such as transfer functions based on neural networking methods, system identification methods, relative change techniques, or other acceptable approaches). These adjunct models utilize the extensive field data to develop the relationship between the model simulation output and the measured absolute values. If the hydrodynamic model is well calibrated to the mean, then its performance will be consistent and a translation of model predictions to provide absolute value predictions is possible.

Modeling Expectations:

The following provides the federal agencies' viewpoint on the necessary statistical analyses and the performance goals of the modeling results for selective parameters.

Statistical Analyses:

Statistical analysis should include calculation of the mean error, root mean square error, absolute mean error and relative error. Additionally, comparison of selected percentiles should be used to evaluate model performance.

Statistical analysis should be performed on the 1997 and 1999 data sets. For the 1997 validation data set, analysis should be performed on each of the 6 spring/neap tidal cycles between July 9, 1997 and Oct 5, 1997. The Julian dates for the six periods are: 191-204, 205-219, 220-234, 235-249, 250-263, 264-279. For the 1999 calibration data set, analysis should be performed on each of the five spring/neap tidal cycles between July 31 and October 13, 1999. The Julian dates for the five periods are: 213-226, 227-241, 242-255, 256-270, and 271-285.

DRAFT -- Model calibration and validation criteria—DRAFT
Revised Nov 5, 2001

Evaluation Criteria:

This memorandum puts forward a number of criteria for salinity, dissolved oxygen, water levels, circulation, and temperature based on resources of concern, namely, shortnose sturgeon, striped bass, tidal wetlands and dissolved oxygen. No actual physical or biological evidence is discussed herein, whether in terms of literature citation or data, to support that the tolerance in the criteria listed is appropriate for the evaluation of impacts on resources in the study domain. These criteria are therefore viewed as performance goals to which model predictions will be compared and evaluated for strengths and weaknesses and by which an understanding of their uncertainties may be developed. The stated criteria will not be used individually (by station and parameter) for "pass/fail" evaluation of the model calibration and/or post-processing routine.

The Federal agencies recently received the water quality database from ATM and need to evaluate the data in order to finalize the proposed model criteria. The preliminary criteria for the model performance are tabulated below:

Parameter		Percentiles					Timing of Maxima (Min)
		5 %	10 %	50 %	90 %	95 %	
Elevation (cm)		+/- 2	-	+/- 2	-	+/- 2	+/- 30
Salinity (ppt)	50% > 5 ppt	-	+/- 10%	-	+/- 10%	-	+/- 30
	50% < 5 ppt	-	-	+/- 0.5	+/- 0.5	-	+/- 30
DO (mg/L)		-	+/- 0.2	+/- 0.2	-	-	+/- 30
DO Deficit (mg/L)		-	+/- 0.2	+/- 0.2	-	-	+/- 30
Temperature (°C) *		-	-	+/- 1	-	-	-
Surface Currents (m/s) **		+/- 25%	-	-	-	+/- 25%	+/- 30
Volume Flows (m/s) **		+/- 25%	-	-	-	+/- 25%	-

* 50% represent Absolute Mean Error for temperature

** 5% and 95% represent the max. ebb and flood conditions for current and flow

Model Defensibility:

The federal agencies believe that the following analyses should be completed to ensure that the model is defensible:

Convergence testing:

- Convergence testing of the model must be performed on the application to the Savannah Harbor.

Sensitivity Analysis: Sensitivity analysis needs to be performed on the following model parameters and boundary inputs:

- Turbulence scheme coefficients
- Offshore salinity concentration
- Freshwater inflow rate and timing
- Bottom friction
- Horizontal eddy viscosity
- Selected water-quality rate kinetics

Data Description and Analysis:

- For the 1999 data set, some time periods are missing due to equipment failure and an approaching hurricane. Data analysis and descriptions are needed that describe boundary stations and critical internal stations. Descriptions should include a general statistical summary and a narrative outlining over data quality and, for boundary stations, techniques used to fill period of missing record.

Savannah Harbor Expansion Project Dredged Material Management Plan Update

January 2012
Updated March 2012

This report will be broken down into two parts, the inner harbor and the outer harbor or bar channel. This disposal plan report covers both operations and maintenance material and new work material.

1.0 INNER HARBOR SEDIMENT PLACEMENT PLAN

1.1 DISPOSAL AREAS

Based on the observed long term average, approximately 6,225,000 cubic yards (CY) of sediments are available to be removed each year from the inner harbor of the Savannah Harbor Navigation Project by the Corps. However, due to funding constraints, only 5,900,000 CY are actually removed. The dredged material is placed in nine dredged material containment areas (DMCA) located throughout the project (Table 1) which have been designated by the non-Federal sponsor for use for the Project. The DMCA's with their station location and acreage are listed in Table 1.

Table 1: Dredged Material Containment Areas (DMCA)

DMCA	Location(Station)	Acreage
2A	93+000 to 103+000	240
12A	6+500BR to 10+500BR*	1040
13A	47+800 to 57+000 (2+000BR)	1307
13B	42+000 to 47+800	540
14A	37+000 to 42+000	647
14B	28+000 to 37+000	703
Jones/Oysterbed (JOI)	10+000 to 27+000	890

*BR refers to Back River or that portion of the channel located in the Back River

DMCA 14B receives dredged material from both the Savannah Harbor Navigation Project and the Atlantic Intracoastal Waterway (AIWW), another waterway managed by the US Army Corps of Engineers. The non-Federal sponsor for the Georgia portion of the AIWW project is the Georgia Department of Transportation (GDOT). The South Carolina Department of Health and Environmental Control Office of Ocean and Coastal Resource Management (SC DHEC-OCRM) is the sponsor for the South Carolina portion of the AIWW. The other confined disposal areas only receive material from the Savannah Harbor Navigation Project, including the navigation channel, turning basins, the Sediment Basin, and berthing areas.



Figure 1 – Savannah Harbor Dredged Material Containment Areas

1.2 O&M SEDIMENT CHARACTERIZATION

The sediment dredged from the Savannah Harbor is a mixture of sands, silts, and clays. Sands are dredged from the lower and upper reaches of the project, while the predominant material removed from the middle harbor and Sediment Basin is silt. The inner harbor sediments are primarily silts and clays from Station 56+000 to 103+000. The reach from Station 28+000 to 56+000 is a transition reach that has a higher percentage of sand in its distributions than the sediment distributions of the upstream reach. A notable exception is in the vicinity of Station 36+000, which has a high percentage of silts and clays and almost no sand. This location is near the confluence of the inner harbor channel and both Elba Island and Fields Cut. The inner channel sediment distributions from Station 28+000 to the mouth of the Savannah River are primarily sand, which indicates that the source of sediment from this reach is offshore. A breakdown of sediment characteristics by dredging reach is shown in Table 2.

Table 2: Sediment Characterization by Reach

Stations	O&M (CY)	Sand (%)	Sand (CY)	Fines (%)	Fines (CY)
0+000 to +4+000	76,000	90%	68,400	10%	7,600
4+000 to 24+000	225,000	92%	207,000	8%	18,000
24+000 to 40+000	364,000	15%	54,600	85%	309,400
40+000 to 50+000	900,000	30%	270,000	70%	630,000
50+000 to 70+000	2,076,000	23%	477,480	77%	1,598,520
70+000 to 79+000	294,000	8%	23,520	92%	270,480
79+000 to 97+750	605,000	16%	96,800	84%	508,200
97+750 to 102+000	1,456,000	54%	786,240	46%	669,760
102+000 to 103+0000	51,000	64%	32,640	36%	18,360
103+000 to 112+000	178,000	80%	142,400	20%	35,600
TOTAL	6,225,000		2,159,080		4,065,920

1.3 DISPOSAL AREA ROTATION FOR O&M MATERIAL

Tables 3 through 5 detail the disposal area rotation for the disposal of O&M dredged material for the next 50-years for Savannah Harbor. The schedule is based on the channel reaches (station to station) and quantities described in Table 2. O&M dredging will be performed in conjunction with the new work dredging and will not impact the required 20-year capacity required by the DMMP. Dike construction (raising) requirements associated with this rotational schedule are included in Table 6. Any loss in sediment storage capacity to new work material will be replaced by the new work project. Deposition of the new work sediments is shown beginning in 2014 and ending in 2016 (background color = burnt orange).

Table 3: Inner Harbor New Work & Annual Maintenance Material Disposal Plans 2010 - 2026 (47 ft MLW Project Depth)

Fiscal Year*	Confined Disposal Area							TOTALS		
	2A	12A	13A	13B	14A	14B	J/O	O&M	New Work	O&M & New Work
2010	229,000	4,431,000	BUILD DIKE Breach X dike	782,500	BUILD DIKE	782,500	DRYING	6,225,000		
2011	229,000	DRYING	4,431,000	1,565,000	BUILD DIKE	DRYING	BUILD DIKE	6,225,000		
2012	229,000	DRYING	4,431,000	1,565,000	BUILD DIKE	BUILD DIKE	BUILD DIKE	6,225,000		
2013	229,000	BUILD DIKE	4,431,000	782,500	DRYING	DRYING	782,500	6,225,000		
2014	DRYING	4,828,500	DRYING	782,500	DRYING	2,299,000	248,815	5,611,000	2,547,815	8,158,815
2015	DRYING	1,685,000	DRYING	26,719	4,575,780	2,364,278	0	1,711,719	9,263,142	10,974,861
2016	DRYING	2,370,000	BUILD DIKE	DRYING	DRYING	DRYING	1,489,000	3,859,000	9,020,235	12,879,235
2017	FULL	DRYING	4,660,000	DRYING	DRYING	BUILD DIKE	1,565,000	6,225,000		
2018		DRYING	4,660,000	DRYING	BUILD DIKE	BUILD DIKE	1,565,000	6,225,000		
2019		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	6,225,000		
2020		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	6,225,000		
2021		4,660,000	DRYING	DRYING	782,500	782,500	BUILD DIKE	6,225,000		
2022		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	6,225,000		
2023		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	6,225,000		
2024		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	6,225,000		
2025		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	6,225,000		
2026		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	6,225,000		

Table 4: Inner Harbor New Work & Annual Maintenance Material Disposal Plans 2027 - 2050 (47 ft MLLW Project Depth)

Fiscal Year ^a	Confined Disposal Area										TOTALS		
	2A	12A	13A	13B	14A	14B	J/O	O&M	New Work	O&M & New Work			
2027		4,660,000	DRYING	DRYING	782,500	DRYING	782,500	DRYING	6,225,000				
2028		4,660,000	DRYING	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2029		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2030		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2031		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2032		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2033		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2034		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2035		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2036		DRYING	4,660,000	782,500	BUILD DIKE	DRYING	782,500	782,500	6,225,000				
2037		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2038		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2039		4,660,000	DRYING	BUILD DIKE	782,500	782,500	DRYING	DRYING	6,225,000				
2040		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2041		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2042		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2043		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2044		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2045		4,660,000	DRYING	DRYING	782,500	782,500	BUILD DIKE	6,225,000					
2046		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2047		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	782,500	6,225,000				
2048		DRYING	4,660,000	782,500	DRYING	BUILD DIKE	782,500	782,500	6,225,000				
2049		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				
2050		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	DRYING	6,225,000				

Table 5: Inner Harbor New Work & Annual Maintenance Material Disposal Plans 2051 - 2066 (47 ft MLW Project Depth)

	Confined Disposal Area							TOTALS		
Fiscal Year*	2A	12A	13A	13B	14A	14B	J/O	O&M	New Work	O&M & New Work
2051		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	6,225,000		
2052		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	6,225,000		
2053		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	6,225,000		
2054		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	6,225,000		
2055		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	6,225,000		
2056		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	6,225,000		
2057		4,660,000	DRYING	BUILD DIKE	782,500	782,500	DRYING	6,225,000		
2058		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	6,225,000		
2059		DRYING	4,660,000	782,500	DRYING	DRYING BUILD	782,500	6,225,000		
2060		DRYING	4,660,000	782,500	DRYING	DIKE	782,500	6,225,000		
2061		BUILD DIKE	4,660,000	DRYING	782,500	782,500	DRYING	6,225,000		
2062		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	6,225,000		
2063		4,660,000	DRYING	DRYING	782,500	782,500	DRYING	6,225,000		
2064		4,660,000	BUILD DIKE	782,500	DRYING	DRYING	782,500	6,225,000		
2065		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	6,225,000		
2066		DRYING	4,660,000	782,500	DRYING	DRYING	782,500	6,225,000		
Reach	Maintenance Volume									
0 to 50	1,565,000			JOI, 14B, 14A, 13B: Split Annual Volume in half to two available areas each year						
50 to 102	4,431,000			12A, 13A: Use Area Available						
102 to 112	229,000			2A or 12A, 13A: Use 2A when available						
Total	6,225,000									

* Based on Federal Fiscal Year 1 October to 30 September.

** 2A will be full in FY 2017 and no longer Available for use.

Table 6: Dike Construction Schedule

Dredged Material Containment Area (DMCA)	Dikes Construction Years
2A	2017 Area Full
12A	2013, 2019, 2025, 2031, 2037, 2043, 2049, 2055, 2061
13A	2010, 2016, 2022, 2034, 2040, 2046, 2052, 2058, 2064
13B	2039, 2057
14A	2010, 2011, 2012, 2018, 2036
14B	2012, 2018, 2048, 2060
Jones/Oysterbed	2011, 2012, 2045

1.4 NEW WORK DREDGING

The total amount of New Work material for all depths (alternatives) considered to be dredged from the Inner Harbor by reach is shown in Table 7 below. The volume to be dredged is based the required additional navigation depth for each alternative, plus 100% of the 2-foot overdepth below the authorized depth. Under normal conditions the new work dredged material would be placed in the same available site used for O&M based on which DMCA's are available at the time and the 3-year rotation shown in Tables 3 through 5. Identification of elevated levels of cadmium during sediment testing and analyses of new work sediments in 1997 and 2001 changed the scenarios for the placement of that material.

Table 7: Total New Work Material by Depth Evaluated and by Reach

Stations	48-ft New Work (CY)	47-ft New Work (CY)	46-ft New Work (CY)	45-ft New Work (CY)	44-ft New Work (CY)
4+000 to 6+375	217,263	174,073	130,559	87,346	48,128
6+375 to 30+000	2,775,041	2,308,262	1,840,479	1,372,897	913,871
30+000 to 45+000	2,181,609	1,802,866	1,426,462	1,052,928	684,583
45+000 to 51+000	1,088,128	892,307	699,013	508,740	324,752
51+000 to 57+000	1,025,450	883,874	743,122	602,960	464,032
57+000 to 67+000	1,242,896	1,035,585	828,620	621,905	415,297
67+000 to 80+125	1,446,786	1,196,291	944,611	691,727	444,210
80+125 to 90+000	1,132,066	946,436	759,169	570,368	380,724
90+000 to 103+000	2,895,175	2,533,434	2,169,594	1,803,823	1,438,457
Channel Subtotal CY	14,004,414	11,773,128	9,541,629	7,312,694	5,114,054
Long Island Meeting Area	484,231	450,941	417,783	384,096	350,859
Oglethorpe Meeting Area	446,541	426,336	405,461	384,089	362,348
Passing Lane Subtotal	930,772	877,277	823,244	768,185	713,207
Total New Work (CY)	14,935,186	12,650,405	10,364,873	8,080,879	5,827,261

1.4.1 Placement of Cadmium-Laden Material

1.4.1.1 Initial Cadmium Issue

Sediment testing and analyses in 1997 and 2001 for the Savannah Harbor Expansion Project indicated a potential for elevated levels of naturally-occurring cadmium associated with the Miocene clay layer. Because of this potential, Phase 2 sediment testing was performed in 2005, to examine the concentration and distribution of cadmium within new work sediments. Approximately 350 sediment samples were taken at 2-foot intervals from 45 cores distributed throughout the harbor but concentrating in areas believed to contain Miocene clays. This core data was initially analyzed and used to estimate the potential average cadmium concentration in new work sediment by station. This resulted in Stations 17+000 to 45+000 having an average cadmium concentration of 21.45 mg/kg. None of the other ranges had an average cadmium concentration of greater than 6.89 mg/kg, which is well below the Effects Range Median (ERM) of 9.6 mg/kg indicating little potential for environmental impact. It was determined that this reach between Stations 17+000 and 45+000 would be treated differently from the other harbor new work sediments. The criteria established for the treatment of this sediment was to place it all in one DMCA, and to cover it with a 2-foot layer of other new work sediment. The 2-foot covering layer was determined to be sufficient for biological purposes and also sufficient to ensure that underlying sediment would not be disturbed during future dike raisings.

The amount of cadmium laden new work material in this reach is 3,429,575 CY. This material plus a 2-foot cap of approximately 1,860,000 CY, yields a total of 5,289,575 CY must be able to fit into a single DMCA.

With the location of the cadmium being between Stations 17+000 to 45+000, DMCAs 14A, 14B, and Jones/Oysterbed were evaluated for placement of the material due to their proximity to that reach. Characteristics of the three DMCAs considered are shown in Table 8. All of these DMCAs met the initial requirements of being close to the reach containing the cadmium laden material and being able to contain all of the cadmium in one disposal site.

Table 8: DMCA Characteristics

DMCA	Acres	Current Capacity(CY)	Dike Raising Schedule
14A	647	7,000,000	2010/2012
14B	703	6,800,000	2012
Jones/Oysterbed (JOI)	550	5,340,000	2011

DMCA 14A was selected over the other two areas as the best site for the following reasons:

- Its elevation was lower than the adjacent disposal sites, allowing the cadmium-laden material to be placed at a lower elevation;

- After covering, there would be greater future potential to extend the life of the disposal area by subsequent dike raisings than the other disposal areas that were at a higher elevation; and
- This area would afford greater protection as the entire front side of the dike has erosion protection in the form of rip rap, already in place.

1.4.1.2 Finding of Additional Areas of Higher Cadmium Concentration

The initial review of the “Savannah Harbor Expansion Project, Cadmium Report (August 2006)” on cadmium within the navigation channel was based on average cadmium (mg/kg) per reach and identified the reach between stations 17+000 and 45+000 with 3,429,575 cubic yards (CY) of cadmium laden material as the only area in the harbor that needed special handling. That amount, plus the cover amount of 1,860,000 CY produce a total volume for cadmium-laden material of 5,289,575 CY, which could easily fit in DMCA 14A (7,000,000 CY capacity). A later review of cadmium concentration taking into account individual high points of concentration as well as average cadmium concentration per reach resulted in additional reaches being designated as having high concentrations of cadmium and, therefore, special handling requirements. Table 9 contains this information.

Table 9: Reaches with Elevated Cadmium Levels

Range	Material (CY)
Station 6+375 to 45+000	4,562,069 CY
Station 51+000 to 57+000	1,101,114 CY
Station 80+125 to 90+000	946,436 CY
TOTAL	6,609,619 CY

The resultant increase in the amount of material and differing locations meant that all of the material could not be placed in DMCA 14A; therefore, another site for the placement of the excess cadmium (beyond what was to be placed in 14A) needed to be identified

The initial re-evaluation of DMCAs resulted in DMCAs 12A, 13A, and 13B being eliminated due to having underdrains to aid in the drying out of the disposal area (cadmium stays bonded to clay when in a wet/moist state). That left DMCAs 14B, and Jones/Oysterbed to be further evaluated for placement of the cadmium-laden new work sediments.

The initial re-evaluation of DMCA’s 14B and Jones/Oysterbed (Jones Island portion) indicated that the Jones Island Site best met the engineering requirements for the placement of the cadmium sediments due to the ability to place the cadmium at a lower elevation and the DMCA being closer to the reach containing the cadmium. However, a major drawback to its use was the high erosion rate along the dikes on the Savannah River side of this DMCA. These dikes would need to be armored before the cadmium-laden material could be placed here. Armoring the dikes for this DMCA would cost approximately \$20.5M. The dikes along DMCA 14B have recently been armored to

protect against existing erosion problems, making it a viable site for placement of cadmium-laden sediments. Based on the available technical information and the costs for use, DMCA 14B was selected as the second site to receive the cadmium laden material.

Additional investigations would be performed during the PED phase of the project. Those studies could identify a way that all cadmium-laden sediments (and the covering sediment) could be contained in a single DMCA. Should the detailed engineering analyses lead to that conclusion, the Corps would deposit all the cadmium-laden sediments in a single DMCA.

1.4.1.3 Dike Raising Considerations

The decision to use DMCA 14B for the placement of cadmium laden material created another problem. This DMCA contains approximately 2,000,000 CY of good quality dike raising material which is needed for the dike raisings at DMCAs 14A (2010/2012) and 14B (2012). This material was used to raise the dikes on DMCA 14A (FY2010 with Stimulus funds). The timing of the dike raising on DMCA 14A and the subsequent use of DMCA 14B for the placement of excess cadmium laden material is important because the Corps is expected to begin raising dikes on DMCAs 14A/14B in Mar 2012 and will complete that work in Oct 2013. Outside of the Expansion Project, the Corps intends to begin raising the dikes on Jones/Oysterbed FY 2012(contract 2011/construction 2012). If after these dike raisings there is material remaining in DMCA 14B, it could be used to raise the dikes on DMCA 13B to recapture the capacity lost to new work material. Table 10 contains the quantities of dike raising materials required for the following projects:

Table 10: Dike Raising Scenarios

Description	Quantity (CY)	Begin Construction
Current 14A Dike Raising	500,000	FY 2010 (Comp 2011)
Next 14A Dike Raising (Begin SHEP)	700,000	FY 2012
14B Dike Raising (for cadmium-laden sediments)	600,000	FY 2012
TOTAL	1,800,000	

1.4.2 Dredging Sequence for the 47-Foot Project

For all Project depths considered: 44-, 45-, 46-, and 47-foot; except for the 48-foot project, all of the material, new work and O&M, could be placed in DMCA's 14A and 14B without having to remove the O&M material first.

For the 47-foot depth alternative, all of the material including the cadmium-laden material between Stations 6+375 and 30+000 would be placed in DMCA 14B. The coverage for this material will come from the reach between Stations 90+000 and 103+000. The cadmium-laden material between Stations 30+000 and 45+000 overage for this material will also come from the reach between Stations 90+000 and 103+000. The material in both DMCAs, 14A and 14B, would be allowed to consolidate for at least 9 months before the cover material is placed. Table 11 lays out the sequencing for the dredging process for all alternatives considered.

Table 11: Project Dredging Sequence using DMCA 14A and 14B for Cadmium Disposal

48-Foot Project				
Description	Stations	CY Material	DMCA	Notes
O&M Dredging	4+000 to 57+000	3,563,754	13A	
New Work Dredging	4+000 to 6+375	217,263	JOI	
New Work Dredging	6+375 to 30+000	3,259,272	14B	Cadmium
New Work Dredging	30+000 to 45+000	2,181,609	14A	Cadmium
New Work Dredging	51+000 to 57+000	1,251,494	14A	Cadmium
New Work Dredging	80+125 to 90+000	1,555,112	14A	Cadmium
New Work Dredging	45+000 to 51+000	1,088,128	13A	
New Work Dredging + O&M	57+000 to 67+000	2,631,872	13A	
New Work Dredging + O&M	67+000 to 80+125	2,387,645	13A	
New Work Dredging + O&M	90+000 to 93+280	1,259,825	13A	
New Work Dredging + O&M	93+280 to 98+140	1,860,000	14B	Cap for DMCA 14B
New Work Dredging + O&M	98+140 to 103+000	1,860,000	14A	Cap for DMCA 14A
Total		23,115,974		

47-Foot Project				
Description	Stations	CY Material	DMCA	Notes
New Work Dredging + O&M	4+000 to 6+375	248,815	JOI	
New Work Dredging + O&M	6+375 to 36+000	4,663,278	14B	Cadmium
New Work Dredging + O&M	36+000 to 45+000	1,825,726	14A	Cadmium
New Work Dredging + O&M	51+000 to 57+000	1,857,054	14A	Cadmium
New Work Dredging + O&M	80+125 to 90+000	1,369,482	14A	Cadmium
New Work Dredging + O&M	45+000 to 51+000	1,698,443	13A	
New Work Dredging + O&M	57+000 to 67+000	2,021,557	13A	
New Work Dredging + O&M	67+000 to 80+125	2,528,753	13A	
New Work Dredging + O&M	90+000 to 103+000	898,084	13A	
New Work Dredging + O&M	90+000 to 103+000	1,860,000	14B	Cap for DMCA 14B
New Work Dredging + O&M	90+000 to 103+000	1,860,000	14A	Cap for DMCA 14A
Total		20,831,192		

46-Foot Project				
Description	Stations	CY Material	DMCA	Notes
New Work Dredging + O&M	4+000 to 6+375	205,301	JOI	
New Work Dredging + O&M	6+375 to 30+000	2,972,789	14B	Cadmium
New Work Dredging + O&M	30+000 to 45+000	2,638,870	14A	Cadmium
New Work Dredging + O&M	51+000 to 57+000	1,707,141	14A	Cadmium
New Work Dredging + O&M	80+125 to 90+000	1,182,215	14A	Cadmium
New Work Dredging + O&M	45+000 to 51+000	1,505,149	13A	
New Work Dredging + O&M	57+000 to 67+000	2,214,851	13A	
New Work Dredging + O&M	67+000 to 80+125	1,865,100	13A	
New Work Dredging + O&M	90+000 to 103+000	534,244	13A	
New Work Dredging + O&M	90+000 to 103+000	1,860,000	14B	Cap for DMCA 14B
New Work Dredging + O&M	90+000 to 103+000	1,860,000	14A	Cap for DMCA 14A
Total		18,545,660		

Table 11(cont'd): Project Dredging Sequence using DMCAs 14A and 14B for Cadmium Disposal

45-Foot Project				
Description	Stations	CY Material	DMCA	Notes
New Work Dredging + O&M	4+000 to 6+375	162,088	JOI	
New Work Dredging + O&M	6+375 to 30+000	2,482,781	14B	Cadmium
New Work Dredging + O&M	30+000 to 45+000	2,254,075	14A	Cadmium
New Work Dredging + O&M	51+000 to 57+000	1,557,444	14A	Cadmium
New Work Dredging + O&M	80+125 to 90+000	993,414	14A	Cadmium
New Work Dredging + O&M	45+000 to 51+000	1,314,876	14B	Cap for DMCA 14B
New Work Dredging + O&M	57+000 to 67+000	545,124	14B	Cap for DMCA 14B
New Work Dredging + O&M	57+000 to 67+000	1,860,000	14A	Cap for DMCA 14A
New Work Dredging + O&M	67+000 to 80+125	1,563,391	13A	
New Work Dredging + O&M	90+000 to 103+000	3,888,473	13A	
Total		16,621,666		

44-Foot Project				
Description	Stations	CY Material	DMCA	Notes
New Work Dredging + O&M	4+000 to 6+375	122,870	JOI	
New Work Dredging + O&M	6+375 to 30+000	2,003,174	14B	Cadmium
New Work Dredging + O&M	30+000 to 45+000	1,873,074	14A	Cadmium
New Work Dredging + O&M	51+000 to 57+000	1,408,733	14A	Cadmium
New Work Dredging + O&M	80+125 to 90+000	803,770	14A	Cadmium
New Work Dredging + O&M	45+000 to 51+000	1,130,888	14B	Cap for DMCA 14B
New Work Dredging + O&M	57+000 to 70+000	729,112	14B	Cap for DMCA 14B
New Work Dredging + O&M	57+000 to 70+000	1,612,556	14A	Cap for DMCA 14A
New Work Dredging + O&M	70+000 to 73+100	247,444	14A	Cap for DMCA 14A
New Work Dredging + O&M	73+100 to 80+125	553,320	13A	
New Work Dredging + O&M	90+000 to 103+000	3,523,107	13A	
Total		14,008,048		

1.4.3 Capacity Replacement

The Savannah Harbor Expansion Project will place 12,650,405 CY of new work material in DMCAs established by the project sponsor for the placement of sediments for the Savannah Harbor Navigation Project. As part of that placement, the Expansion Project would replace the sediment storage capacity that it used to place the new work material.

1.4.3.1 New Work Dike Raising Considerations

The costs for the recently completed dike raisings at DMCAs 14A and 14B are reflected in Table 12. The amount of cadmium-laden new material to be dredged required the use of more than one DMCA, so the decision was made to use both DMCAs 14A and 14B. This also requires that the Corps raise those dikes before it begins dredging for SHEP.

Currently, there is approximately 2,000,000 CY of good quality material in DMCA 14B that can be used for this dike raising. As shown in the Table 13 below, 1,800,000 CY would be used in the actual dike raisings, which would leave 200,000 CY remaining. This material would be used to raise the dikes on DMCA 13B to recapture the capacity lost to new work material. The cost for moving this remaining material from DMCA 14B to DMCA 13B was calculated as follows.

- The average one-way haul distance is 15,000 feet (use 3 miles) (the distance from middle of DMCA 14B to the middle of DMCA 13B),
- The average speed of a tractor/pan is 8 mph, the time for a round trip is 45 minutes (0.75 hr).
- It costs \$65/ hour to operate a tractor with 2 pans (each hauling 7 CY each),
- This results in a haul cost of \$3.48/ CY ($\$65 \times 0.75/14$),
- This yields a total cost to move the excess material (200,000cy X \$3.48) of \$696,000 in additional costs above the dike raising costs at DMCA 14A and 14B (Table 12 – other).

Table 12: Costs for Dike Raisings at DMCA 14A and 14B

Dike	Contract	Contract			Contingencies
Raised	Back Dike	All Dikes	S&A	Total	25%
14A	\$399,845.00	\$2,777,283.00	\$220,182.00	\$3,397,310.00	\$4,246,637.50
14B		\$2,741,322.00	\$221,305.00	\$2,962,627.00	\$3,703,283.75
*Other				\$696,000.00	\$870,000.00
Total Cost					\$8,819,921.25

* the cost to move the remaining material from 14B to 13B.

Table 13: Dike Raising Scenarios

Description	Quantity (CY)	Begin Construction
Current 14A Dike Raising	500,000	FY 2010(comp 2011)
Next 14A Dike Raising (Begin SHEP)	700,000	FY 2012
14B Dike Raising (for cadmium placement)	600,000	FY 2012
TOTAL	1,800,000	

As stated above, DMCA 14B contained approximately 2,000,000 CY of good quality dike raising material which is being used for the dike raisings at DMCA 14A (2010/2012) and 14B (2012). This material was used to raise the dikes on DMCA 14A (FY2010 with stimulus funds). The timing of the dike raising on DMCA 14A and the subsequent use of DMCA 14B for the placement of excess cadmium-laden material is important because the Corps intends to begin raising dikes on DMCA 14A/14B in Dec 2011 with completion in Mar 2012. As an O&M requirement the dikes would be raised on Jones/Oysterbed starting in FY 2011.

1.4.3.2 Replacement of DMCA Sediment Storage Capacity used by SHEP

The Savannah Harbor Expansion Project would place 12,650,405 CY of new work material in existing DMCA's that are presently used for placement of O&M sediments for the Savannah Harbor Navigation Project. As part of the SHEP, the Expansion Project will replace the sediment storage capacity that it uses to deposit new work material.

To more accurately capture the costs for capacity replacement the most recent dike raising costs were used from the dike raising project at DMCA 14B. For that project the dikes were raised 6-feet at a cost of \$5,600,000 (included both dikes and weirs). The total amount of dike construction material required was 499,000 cubic yards (CY). Dividing the project cost by the amount of material (CY) to build the project yields a cost of \$11.22/CY for dike construction (including embankment, weirs, silt fence, etc.). This construction created 6,805,040 CY of capacity (6-feet x 703 acres x 43,560 ft²/acre / 27ft³/CY). This cost equates to \$5,600,000 / 6,805,040 CY = \$0.83/CY of capacity. This equates to the following cost to replace the capacity lost to new work material for each depth considered for the Savannah Harbor Expansion project (Table 14).

Table 14: Capacity Replacement Costs for Depths Considered

Dredged Material	48-foot Project	47-foot Project	46-foot Project	45-foot Project	44-foot Project
Total	23,115,974	20,831,192	18,545,660	16,621,666	14,008,048
New Work	14,935,186	12,650,405	10,364,873	8,080,879	5,827,261
Cost to Provide 1 CY of Capacity	\$0.83	\$0.83	\$0.83	\$0.83	\$0.83
Total Cost to Provide Lost Capacity	\$12,396,204.38	\$10,499,836.15	\$8,602,844.59	\$6,707,129.57	\$4,836,626.63

The majority of the material is associated with cadmium concentrations and cap for the cadmium-laden sediment. A summary of the material is in Table 15 below:

Table 15: Cadmium and Cadmium Cap Placement

Disposal Area	Cadmium Volume (CY)	Cover Volume (CY)	Non-Cadmium New Work (CY)	Total (CY)
JOI	0	0	174,073	174,073
14A	3,960,517	1,860,000	0	5,820,517
14B	2,649,102	673,434	0	3,322,536
12A	0	0	3,333,279	3,333,279
Total	6,609,619	2,533,434	3,507,352	12,650,405

The capacity consumed is initially compensated by multiplying the total yards by \$0.83/CY as defined in the DMMP. This yields a cost of \$12,396,000.

The secondary impact of SHEP on DMCA's 14A&B is the requirement to raise the dike after deepening is completed to restore the used storage capacity. The cadmium-laden sediments and cover material cannot be used in the crust method for borrow in future

dike raisings. Sediments to construct the dike embankment would need to be hauled from DMCA 12A, 13A or 13B. The cost of the increased haul distance needs to be included.

For DMCA 14B, assume a 6-foot dike raising uses 499,000 cubic yards of embankment to create 6,805,040 cubic yards of capacity. For DMCA 14A, assume a 6-foot dike raising (front and back dikes only) uses 250,000 cubic yards of embankment and creates 6,088,720 cubic yards of capacity. Therefore, a total of 749,000 cubic yards of material needs to be hauled resulting in 12,893,760 cubic yards of capacity.

Using an average one-way haul distance of 25,000 feet (use 5 miles) (the distance from the middle of DMCA 13A front to the front of dike between DMCA 14A and 14B for an average), an average speed of a tractor/pan of 8 mph, the time for a round trip is 75 minutes (1.25 hr). If a contractor charges \$65/ hour to operate a tractor with 2 pans (each hauling 7 CY each) the additional haul cost is \$5.80/CY. This yields 749,000 CY X \$5.80 = \$4,344,200 additional funds for the 12,893,760 CY capacity created, which results in \$0.34 added cost for DMCA 14A&B embankment fill. This results in \$0.34 times 11,952,788 cubic yards (cadmium-laden and cover quantities above) equals \$4,063,947.92 additional dollars. The total cost for capacity consumed is \$12,396,204.38 + \$4,063,947.92 = \$16,460,152.

For each alternative depth, the added haul cost is the same. The dikes would need to be raised 6 feet for maintenance needs in accordance with the O&M DMMP and dike raising schedule. The SHEP impact would vary for each depth based only on the volume of new work at the \$0.83/cy value. Finally, after adding in the haul cost, to get the capacity replacement cost you must subtract out the costs to initially raise DMCA at the beginning of the project as shown in Table 16 under capacity replacement.

Table 16: Capacity Replacement Costs

	48 Foot	47 Foot	46 Foot	45 Foot	44 Foot
New Work CY	14,935,186	12,650,405	10,364,873	8,080,879	5,827,261
Value @\$0.83/CY	\$12,396,204	\$10,499,836	\$8,602,844	\$6,707,129	\$4,836,626
Add Haul Cost	\$4,063,947	\$4,063,947	\$4,063,947	\$4,063,947	\$4,063,947
Total	\$16,460,152	\$14,563,784	\$12,666,792	\$10,771,077	\$8,900,574
14A/14B Dike Raising	\$7,949,921	\$7,949,921	\$7,949,921	\$7,949,921	\$7,949,921
Capacity Replacement	\$8,510,231	\$6,613,862	\$4,716,871	\$2,821,156	\$950,653

1.4.4 Risk and Uncertainty

The initial disposal plan developed in 2008 assumed that funding for the dike raising for DMCA 14A in 2009 and the dike raising for the DMCA 12B/13A combination site in 2009 would be available and the construction implemented. This was accomplished with ARRA funds.

1.5 BENEFICIAL USE

Beneficial use opportunities pursued by this new work project are:

- Covering cadmium-laden sediments;
- Material for future dike raisings; and
- Building and maintaining the bird islands now in the disposal areas

New work dredged material from Stations 90+000 to 103+000 are to be placed in DMCA 14A and 14B as the clean cover for the cadmium-laden sediments.

Those sediments in Stations 67+000 to 80+125 and Stations 90+000 to 103+000 that are scheduled to be placed in DMCA 12A are good quality sediments (suitable for dike-building) and will be used in the future for dike raising and/or maintenance.

1.6 JASPER TERMINAL - IMPACT ON DMCAs

In 2007, the Governors of South Carolina and Georgia agreed to work together to develop a new container terminal on lands that are presently used for the Savannah Harbor Navigation Project. The ports authorities of South Carolina and Georgia are working together (through their Joint Project Office) on the engineering and environmental studies that would be needed to apply for construction permits to build such a facility.

As the non-Federal sponsor for the Savannah Harbor Navigation Project, in 2007 the Georgia DOT asked that the Corps of Engineers release its perpetual dredged material disposal easements on portions of DMCAs 14A and 14B. Since the Corps previously identified those sites as being necessary for the continued maintenance of the Savannah Harbor Navigation Project, if the Corps released its easements, its costs to maintain the Navigation Project would increase as a result of increases in the pumping distances and costs of maintenance dredging. The Corps is working with Georgia DOT and the Joint Project Office to identify how the costs of the Federal Government would not increase (the Government would be made whole) if it released its disposal easements to the sites. If a suitable method is identified and agreed to by the Georgia DOT, the Corps would be willing to release its easements to those properties. The sites would then be available for future use by others, potentially for development of a new container terminal.

The placement of new work sediments on the sites by the Expansion Project would not prohibit the later use of the sites for development of a new container terminal. Instead, such placement would decrease the cost of developing the sites by the placement of a substantial volume of fill, which would raise the elevation of the sites to one more suitable for development as a container terminal.

2.0 OUTER HARBOR SEDIMENT PLACEMENT

2.1 O&M DREDGED MATERIAL DISPOSAL

O&M dredged material removed from the Bar Channel (Stations 0+000 to 60+000B) is placed in the EPA-approved Savannah Ocean Dredged Material Disposal Site (ODMDS). This 4.26 square mile site is centered at 31° 56' 54" N and 80° 45' 34" W. The site is used for placement of the 1 million cubic yards of material removed by hopper dredges each year from that channel reach. The final designation of the site as an ODMDS was made by EPA on August 3, 1987. A Management Plan for this site is included in the Long Term Management Strategy (1996).

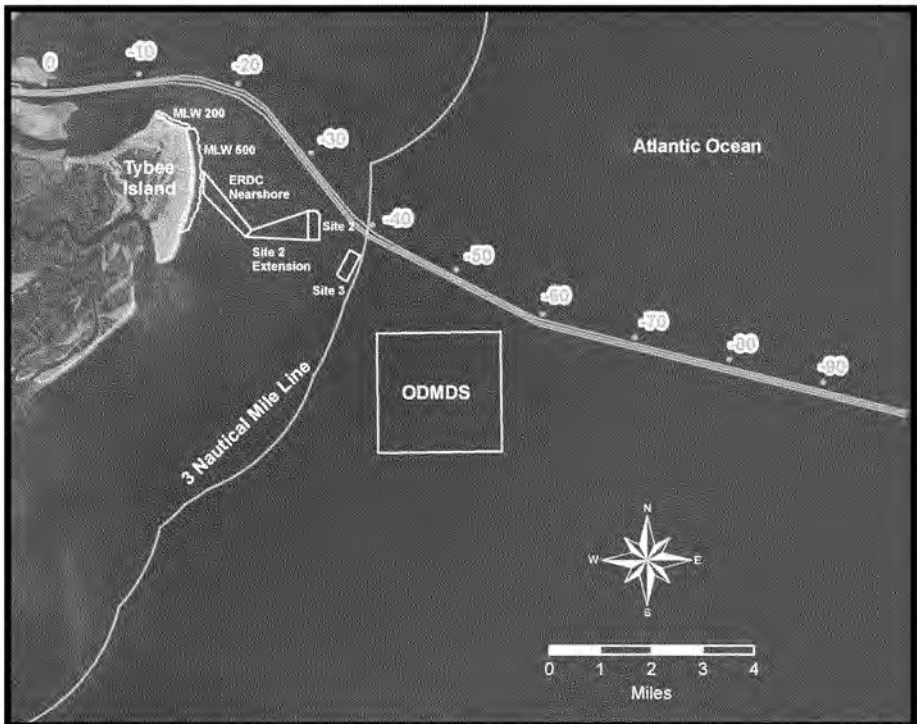


Figure 2: Unconfined Placement Areas for Maintenance Material

In addition to the ODMDS, there were seven sites where maintenance material could be deposited to construct submerged feeder berms which were developed as part of the LTMS pursuant to Section 404 of the Clean Water Act. These sites were located on the south side of the entrance channel at least 2,000 feet away from the channel, in water averaging 15 feet deep. These sites would effectively serve as nearshore disposal areas for use by dredges working in the bar channel. These sites would provide a cost effective

place for the dredges to deposit the dredged material since they are located relatively close to the channel. If constructed, the berms would be constructed with 200,000 to 300,000 CY of material to provide a berm that is elliptical in shape and oriented away from the channel so that tidal currents which converge and diverge away from the channel are not significantly restricted. Sediment placed on these berms would replenish littoral drift.

After the SHEP DEIS was published, the EPA informed the Corps that they consider any dredged material disposal site beyond the 3-mile line to be an ocean dredged material disposal site which requires their authorization pursuant to Section 103 of the Marine Protection, Research and Sanctuaries Act. Consequently, any sites beyond the 3-mile line would require the appropriate Section 103 site designation studies and EPA approval as ocean dredged material disposal sites. Based on this determination from the EPA, only the ODMDS, Sites 2 and 3, and other designated areas (See Figure 2 above) can be used for maintenance material from the entrance channel.

In addition to the disposal sites adjacent to the entrance channel, the LTMS also authorized suitable maintenance material to be placed into the nearshore off Tybee Island. As shown in Figure 2, suitable maintenance material can also be placed into the nearshore off Tybee Island in areas designated as MLW 200, MLW 500, ERDC Nearshore and Site 2 extension. Material placed into these sites would be used to construct feeder berms to benefit the Tybee Island beach. The LTMS also authorized the placement of suitable maintenance material directly onto the beach at Tybee Island.

The Base Plan (most cost effective and environmentally acceptable) for maintenance of the Savannah Harbor entrance channel is to place the material into the Jones-Oysterbed Island CDF, the ODMDS, or Sites 2 and 3. Consequently, any placement of maintenance material into the nearshore sites off Tybee Island or directly onto the beach at Tybee Island would require a non-Federal sponsor willing to pay the additional costs of placing material into these areas.

Maintenance sediments from the bar channel may be placed in these sites. Maintenance sediments from Stations 0+000 to 28+000 may also be placed in these sites when the average fines content does not exceed 15 percent. Maintenance material from the area of the bar channel extension (Station -60+000B to -97+680B) may also be suitable for these sites.

2.2 NEW WORK SEDIMENT PLACEMENT PLAN

The initial plan developed for the placement of new work material from the Bar Channel was for in-water placement in the nearshore zone which would be a beneficial use of the dredged materials. That plan was described in the November 2010 Draft GRR and Draft EIS. However, the Georgia Department of Natural Resources, Coastal Resources Division and the City of Tybee Island expressed concern about the quality of sediments that the Corps proposed to place nearshore. As a result of those concerns, the District revised the sediment placement plan for the entrance channel. The final design now

includes deposition of all new work sediments from the entrance channel into existing disposal areas (either the ODMDS or the Jones/Oysterbed Island CDF). Table 17 depicts the quantity of new work material to be removed by alternative depth evaluated and channel reach.

Table 17: Entrance Channel Placement of Material (cy) for all Project Depths

Station	Disposal Site	Alternative Depths Considered				
		44-foot	45-foot	46-foot	47-foot	48-foot
(-)98+600 to -57+000	ODMDS	1,667,123	2,242,371	2,925,432	3,736,308	4,613,909
(-)57+000 to -53+500	ODMDS	156,623	235,127	313,391	391,437	469,252
(-)53+500 to -40+000	ODMDS	646,796	975,843	1,304,385	1,632,346	1,959,186
(-) 40+000 to -30+000	ODMDS	505,693	771,105	1,038,620	1,305,921	1,573,800
(-)30+000 to -20+000	ODMDS	529,910	801,974	1,076,638	1,352,115	1,628,379
(-)20+000 to -10+000	ODMDS	473,047	746,614	1,028,399	1,311,222	1,594,871
(-) 10+000 to 0+000	ODMDS	346,997	532,621	723,394	917,064	1,110,713
0+000 to +4+000	ODMDS/JOI	101,482	166,705	235,626	305,674	375,403

2.2.1 Ocean Dredged Material Disposal Site (ODMDS) Capacity Analysis

Two approaches were taken to determine future capacity of the ODMDS after placement of materials from the Savannah Harbor Expansion offshore dredging.

- The first analysis assumed that dredged material would primarily consist of sands (with no bulking factor) and that all deposited material would remain in the ODMDS area after placement.
- The alternative approach was to examine the last period of time when the ODMDS was used consistently and compare the dredged volumes removed from the channel that were placed in the ODMDS with the change in capacity of the ODMDS based on placement surveys over the same time period.

Differences in capacity were determined by using software in Bentley InRoads to determine surface areas and to make volume computations. Actual dredging volumes were obtained from dredging reports maintained in the Savannah District office.

The ODMDS boundary is shown in pink on **Figure 3**. To comply with 40 CFR §227.28 disposal shall occur no less than 330 feet (100 meters) inside the site boundaries. The ODMDS footprint (shown in yellow) for placement of material is 3,242 acres.

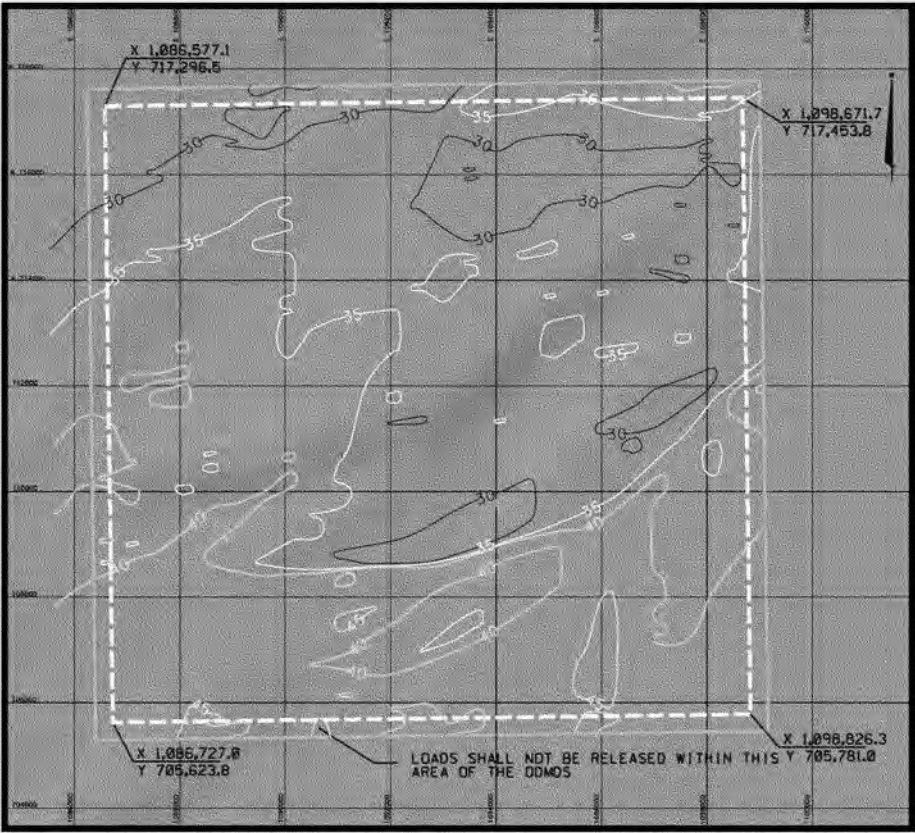


Figure 3: ODMDS Boundary and Bathymetry

Table 18 shows the quantity of material dredged from the entrance channel from 2002 to 2007 as well as the change in capacity of the ODMDS based on placement surveys made over the same time period. Results show that roughly 93% of the material dredged from the channel remains in the ODMDS after placement, possibly because of the presence of fines in the dredged material that do not settle out or may leave the area before settling or losses during the dredging process.

Table 18: Material Dredged versus ODMDS Change in Capacity

Year	Quantity Dredged (cy)	ODMDS Capacity* (cy)	
2002	186,537	57,836,270	
2003	635,163		
2004	620,642		
2005	888,101		
2007	973,463	54,766,930	
Total Dredged	3,303,906		
Change in Capacity		3,069,340	
percentage placed			93%

*ODMDS capacity is determined from the surface to -25 ft MLLW

Tables 19 and 20 shows results of the remaining capacity of the ODMDS for existing conditions and assuming the material placed from the Savannah Harbor Expansion is either 1) the volume placed is equivalent to the volume dredged or 2) volume placed is equivalent to 93% of the material dredged, based on the results from **Table 18**. Results of both methods are based on the upper limit for material placement in the ODMDS as 25 ft below MLLW. Table 20 shows results for both the 47 ft and 48 ft project. The capacity/life is reduced for a deeper project because of the greater volume of material required to be removed/placed and increased maintenance as the deeper project requires a longer channel to reach naturally-deep water in the ocean. The average annual Operations and Maintenance (O&M) dredge material volumes were developed previously based on historical dredging records. The volume of available undredged material that remains after dredging (primarily due to funding constraints) is also considered.

Table 19: ODMDS Capacity (Existing Conditions)

ODMDS capacity (2012)	57,087,926 cy
Average Annual O&M Dredge Volume	1,057,721 cy
Years Remaining until Capacity is Exceeded (without deepening)	55

Table 20: ODMDS Capacity (with project)

	49 ft depth (47 ft project)	49 ft depth (47 ft project)
Percentage of Dredged Material on ODMDS Floor	100% placed	93% placed
2014 Capacity (after 2 yrs of existing O&M)	54,972,484	54,972,484
New Work Quantity	10,646,413	10,646,413
2017 Capacity (after new work material)	44,326,071	45,071,320
Average Annual O&M Dredging Volume (after expansion)	1,066,778	1,066,778
O&M Dredging Volume (3 yrs during expansion)	3,200,333	3,200,333
2017 Capacity (after expansion new work and O&M)	41,125,738	42,095,010
Years Remaining until Capacity is Exceeded	39	42

Given the constraints for the Savannah ODMDS of a surface area of 3,242 acres and upper height limit of 25 feet below MLLW, with materials added from the offshore channel for the 47 foot project depth, the remaining capacity for the ODMDS would last between 39 and 42 years depending on the volume of material placed for the 47 foot project. Without material from the Savannah Harbor Expansion Project, the ODMDS capacity to hold annually dredged O&M material would last 55 years.

3.0 UPDATE OF THE DMMP

This DMMP Update was prepared to identify the expected effects of the proposed harbor deepening on the existing DMMP for the Savannah Harbor Navigation Project. If the SHEP is constructed, some events will not occur as expected, even though they have been predicted using the best practices available. Savannah District will conduct a detailed and lengthy post-construction monitoring program to identify how the estuary responds to the harbor deepening.

As part of the post-construction monitoring, the Corps will assess the maintenance patterns and identify if any changes in the shoaling patterns occurred as expected. If those patterns are sufficiently different from what is expected, the District may seek approval for changes to the advance maintenance program to allow it to maintain the harbor more efficiently.

As another part of the post-construction monitoring, the District will assess the volume of sediment storage capacity remaining in the Savannah ODMDS. If the storage capacity is substantially less than the predicted 42 years after deepening, the District would likely begin work to modify the ODMDS to restore a 50-year capacity. Modification of an ODMDS or designation of a new site is a complicated process which can take several years. The District would begin the required physical and biological studies no later than when data indicates the ODMDS will not provide the harbor's sediment disposal needs for the next 20 years.

Savannah District expects to develop a full DMMP that addresses all dredging and sediment placement issues in the harbor (to replace the DMMP developed as part of the 1996 LTMS) after data become available from a reasonable portion of the 10-year post-construction monitoring period.

Savannah Harbor Expansion Project Impacts to O&M

Background. In evaluating the proposed deepening of the Savannah Harbor, uppermost on the minds of the PDT was the necessity to examine the possible impacts to the District's Operations and Maintenance (O&M) Program. This report is an attempt to quantify the initial (one time) impacts to the O&M program as well as the annual (re-occurring) impacts to the program. The annual impacts include increased dredging costs for the Inner Harbor, Bar Channel, and Mitigation Areas; O&M costs for the fish passage, operating costs for the Oxygen Injection System; long term monitoring; and curation costs for the CSS *Georgia* (removal of the CSS *Georgia* from the project area will be accomplished with construction funds from the SHE project, and the cost will be counted in the project B/C ratio).

Annual Impacts to the O&M program

1. Inner Harbor Advance Maintenance

Current Dredging Market. Past dredging work in Savannah and Brunswick Harbors was performed by as many as 4 different small business contractors; however, current plans advertise this work in the unrestricted category, since the competitive field of dredging contractors capable of dredging Savannah Harbor has been reduced. Currently, we are working near the limit of the small dredges (18 inch cutterhead.) capability due to the depth of the channel, the length of the dredge pipeline to the dredged material containment areas, and the height of containment areas. It is the District's contention that using larger dredges will be more cost effective (22 to 30 inch cutterhead) to perform this work. Starting in FY08 Savannah Harbor maintenance dredging work has been advertised in the unrestricted category.

Current Project Conditions. In order to project shoaling conditions after the Savannah Harbor Expansion project is completed, CESAW-EN conducted an investigation of historical Inner Harbor shoaling rates and dredging volumes per river reach both With and Without the project (harbor deepening and mitigation features) in existence. With authorization and implementation of the Savannah Harbor Expansion Project the Sediment Basin would be filled. The filling of the Sediment Basin is a critical feature in mitigation planning for the Savannah Harbor Expansion Project as it restricts further upstream saltwater incursion.

Mitigation Planning. The selected mitigation plan as depicted in Table 1 includes, among other things, demolition of the Tidegate structure, removal of the northern and southern earthen abutments and construction of a sill across the throat of the Sediment Basin which will permit the Basin to fill with sediment to pre-harbor improvement conditions, thus reducing impacts to wetlands in the Back River by creating a partial barrier to saltwater intrusion up that river. The end result of this mitigation action will be a return of the Inner Harbor shoaling regime to Pre-Tidegate conditions. The deepening of McCoy's Cut and the construction of a diversion channel at the top end of that cut while allowing more freshwater into the area of the Savannah National Wildlife Refuge will also impact O&M in that 70,763

cubic yards of O&M material will have to be dredged from this area every 10-years. It is estimated that the dredging costs for this effort will be \$1,415,000 every 10 years (\$141,500/year or \$7,075,000 for the 50-year life of the project). Also the Fish Passage will need clearing and snagging every 2-3 years to maintain the flow. Say \$50,000/year. The only four elements in this table that incur an O&M obligation are (1) the deepening of McCoy's Cut, (2) the Fish Passage at New Savannah Bluff, (3) the Dissolved Oxygen Injection System, and (4) long-term mitigation monitoring.

Table 1: SHEP Mitigation Plan (47-Foot Project Depth)

Mitigation Element	Cost	Contingency	Total Cost
Real Estate	\$10,158,500	\$2,539,625	\$12,698,125
Fish Passage - New Savannah Bluff	\$23,661,976	\$5,915,494	\$29,577,470
CSS Georgia	\$11,131,500	\$2,782,875	\$13,914,375
McCoy's Cut Diversion Channel	\$2,324,082	\$581,021	\$2,905,103
Deepen McCoy's Cut, Upper Middle & Little Back	\$7,287,980	\$1,821,995	\$9,109,975
ROCK Berm at Mouth of Back River	\$16,824,049	\$4,206,012	\$21,030,061
Close Rifle Cut	\$663,131	\$165,783	\$828,914
Removal Tide Gate Pier and Abutments 10	\$2,860,514	\$715,129	\$3,575,643
Embankment at Tide Gate Removal	\$14,375,866	\$3,593,917	\$17,969,583
Close Lower McCoy's Cut Western Arm	\$1,137,557	\$284,389	\$1,421,946
Construct Dissolved Oxygen Injection Sys - On site	\$56,643,000	\$14,160,750	\$70,803,750
Construct Marsh at Disposal Site 1S	\$14,075,959	\$3,518,990	\$17,594,949
Boat Ramp	\$499,962	\$124,991	\$624,953
Broad Berm Basin - Back River	\$6,690,000	\$1,672,500	\$8,362,500
Water Impoundment	\$20,150,000	\$5,037,500	\$25,187,500
Mitigation Costs for Striped Bass	\$2,621,000	\$655,250	\$3,276,250
Mitigation Sub Totals	\$191,104,876	\$47,776,219	\$238,881,095
Pre-construction Monitoring	\$2,893,000	\$723,250	\$3,616,250
During Construction Monitoring	\$8,734,000	\$2,183,500	\$10,917,500
Post Construction Monitoring	\$16,828,000	\$4,207,000	\$21,035,000
Adaptive Management	\$16,701,000	\$4,175,250	\$20,876,250
Monitor After Adaptive Management	\$3,000,000	\$750,000	\$3,750,000
Mitigation Monitoring Sub Totals	\$48,156,000	\$12,039,000	\$60,195,000
Total	\$239,260,876	\$59,815,219	\$299,076,095

Project History. To understand the impact of these mitigation actions the history and purpose of the Sediment Control Works is important. In the early 20th Century, the Corps of Engineers maintained a fleet of hydraulic and mechanical dredges. Several of these dredges were maintained by the Savannah District and were based in the harbor. Historical records indicate that the Middle Harbor, between Stations 40+000 and 70+000 was the highest shoaling area of the harbor and the one to which the Savannah District dedicated the majority of its dredging plant. Hydraulic cutterhead dredges toiled 24/7 to keep this section of channel clear for passing vessels. In the late 1960's, engineering analyses using physical models identified an efficient way to capture the silts and redirect them to other areas outside

the shipping channel where they might be more easily removed at less cost. The result was the Sediment Control works, a three-part system consisting of a 2-mile long sediment basin, a tide gate consisting of 13 massive steel gates across the Back River, and a diversion canal cut through marsh in the upper Back River estuary which connected the Back and Front Rivers. The system was simple, yet effective. The gates closed with the ebb tide and materials in suspension settled out in the basin. The increased velocity caused by the tidal gradient, forced the upstream flow through the upper cut and into the Front River. The increased water volume and velocity flushed silty sediments through the City Front reach to below the Sediment Basin. Through a succession of tidal cycles, these silt materials were ultimately captured in the Sediment Basin and removed from circulation in the channel. In the mid-eighties, volumes as high as five million cubic yards of sediment have been dredged from the Sediment Basin on an annual basis. The system worked as designed and reduced cost to the taxpayer.

Impacts to Wetlands. As the harbor was improved through the 1980's and 1990's concerns over increased salinity levels were expressed by the US Fish and Wildlife Service (USFWS). Ultimately, the District concluded that the existence of the Tidegate structure prolonged the periods where higher salinity levels existed in the upper estuary's freshwater wetlands. The result was a conversion of freshwater to saltwater marshes which was inconsistent with the mission of the Savannah National Wildlife Refuge. On March 15, 1991, the Tidegate was taken out of service. As a result, the efficiency of the Sediment Basin at trapping sediments was reduced by forty to fifty percent. However,, removal of silts from the basin was more cost effective and less disruptive to shipping than allowing the Basin to completely fill.

Post-Project Channel Conditions. CESA-EN conducted a hydraulic analysis of channel conditions expected to occur after the Savannah Harbor Expansion Project is completed. They predict that shoaling will return to pre-Sediment Control Work conditions. Figure 1 below demonstrates this as the green area, which represents the inner harbor shoaling patterns since the decommissioning of the Tidegate has begun to mimic the shoaling pattern depicted in blue which represents the shoaling patterns of the inner harbor prior to constructing the Tidegate. Table 2 below compares historic average annual dredging quantities and costs for the middle harbor (Station 24+000 through Station 70+000) to projected quantities using the same removal costs. The total volume of sediment removed in the inner harbor is not expected to change with a harbor deepening, but the location of the shoaling will be different. Future maintenance costs for the middle harbor, using recent average annual costs will be almost two and a half times greater than existing costs based purely on a different distribution of the sediments. This is a direct result of having to dredge 1,932,000 cubic yards of materials from the channel instead of the Sediment Basin. The difference in cost results from the increased pumping distances to disposal areas and the loss of dredge efficiency due to reduced effective working time caused by passing vessels. There is also a loss of dredge efficiency related to the decreased dredging bank height in the channel (6-8 feet) as compared to 16-20 feet in the Sediment Basin. It should also be noted that if this area experiences periods of above normal precipitation costs could rise considerably.

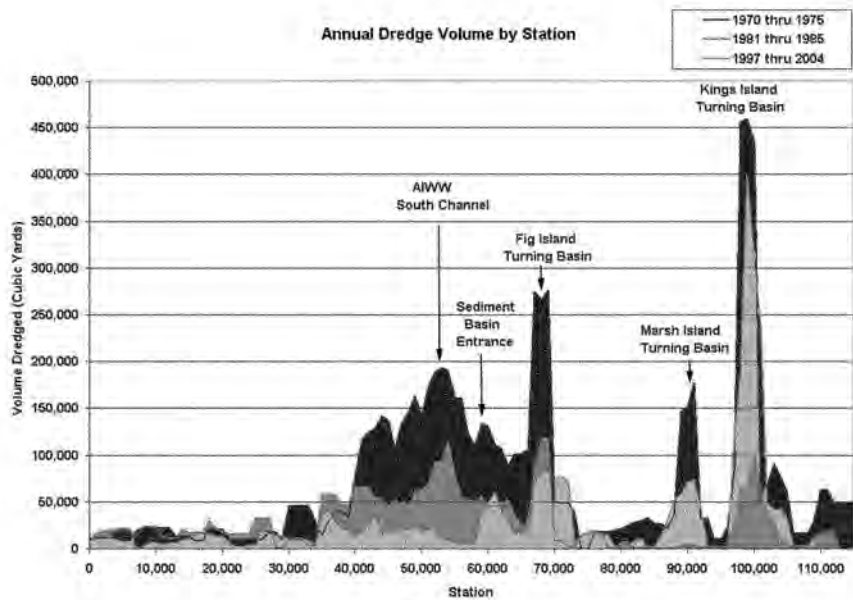


Figure 1

Table 2 – Historic vs. Projected Sediment Volumes and Associated Costs

Stations	Historic Volume w/Sediment Basin	Cost	Projected Volume	Cost
24 to 40+000	328,000	\$734,720	364,000	\$815,360
40 to 50+000	260,000	\$624,000	900,000	\$2,160,000
50 to 70+000	820,000	\$2,328,800	2,076,000	\$5,895,840
Totals	1,408,000	\$3,687,520	3,340,000	\$8,871,200

Present Concerns. The major concerns, as relates to maintenance of the authorized navigation depth in the inner harbor after deepening are the recent low O&M funding levels, the change in shoaling locations anticipated, the availability of dredging plant capable of dredging in the Savannah Harbor, and the available dredging time allotted between environmental windows. The historical solution to all four of these concerns has been the systematic application of what is termed “advanced maintenance” to the O&M of the harbor and concentrating dredging on the middle half of the channel. Since the 1970’s, the Savannah District has justified the need to dredge below the congressionally-authorized navigation depth in nearly every reach of the harbor to better maintain the authorized depth for shipping.

Advance maintenance is necessary in Savannah because of the high shoaling rate. The District Engineer, through discretionary authority, has authority to “over dredge” in fast

shoaling areas to extend the duration of the authorized navigation template. This allows the channel to provide its authorized depths for a period of time and prevent the need for repeated dredge mobilizations. Through a series of justifications and approvals based on shoaling rates and dredging records, the District demonstrated that advanced maintenance was both an environmentally and economically sound method of extending the duration of the authorized depths.

Recommendations. The District's advance maintenance program covered under the "Existing Project Depth" portion of Table 3 below was recently re-justified (June 2010). For the Recommended Project this table also contains three sections (identified by an asterisk and highlighted in yellow) where additional material would accumulate and advance maintenance could possibly be needed to maintain existing levels of service assuming the same level of dredge plant requirements. These three sections are the same impacted reaches identified in the sedimentation analysis and shown in Table 2. These predicted shoaling changes may require changes to the advance maintenance program. However, since the future shoaling cannot be determined precisely by modeling, the PDT believes that it would be better to allow the harbor to stabilize after the deepening to obtain a better understanding for the shoaling patterns before the District recommends any adjustment to the advanced maintenance program. If adjustments would be helpful, the District will seek approval to implement them through the normal business process, which would include an economic justification and environmental assessment.

Table 3 – Existing and Recommended Project Depths (feet below MLLW)

Station Limits		Existing Project Depths			Recommended Project Depths		
Lower	Upper	Channel	Advance Maint	Maint. Dredging	Channel	Advance Maint	Maint. Dredging
97+680B	60+000B	Not applicable			49	0	49
60+000B	14+000B	44	0	44	49	0	49
14+000B	24+000	42	2	44	47	2	49
24+000	35+000	42	4	46	47	4	51
35+000	37+000	42	6	48	47	6	53
37+000	50+500	42	4	46	47	4	51
50+500	52+750	42	4	46	47	4 *	51
52+750	54+000	42	4	46	47	4	51
54+000	60+250	42	4	46	47	4 *	51
60+250	66+750	42	4	46	47	4	51
66+750	70+000	42	4	46	47	4 *	51
70+000	102+000	42	2	44	47	2	49
102+000	103+000	42	0	42	47	0	47
103+500	105+500	36	2	38	36	2	38
105+500	112+500	30	2	32	30	2	32
Kings Island Turning Basin		42	8	50	48	8	56

NOTE: * indicates which reaches may require additional advance maintenance. Savannah District will request additional advance maintenance if post-project monitoring reveals it would be warranted.

2. Bar Channel Maintenance

Current Annual Maintenance Cycle. Maintenance dredging is presently performed on an annual basis. The annual cost of maintenance dredging in the outer bar channel is currently \$5.5 million (Table 4). This annual dredging process entails hopper dredges removing the dredged material from the bar channel and placing it in the ocean dredged material disposal site (ODMDS). The SHEP will require the extension of the Bar Channel from Station -60+000B to -97+680B. This will result in an increase in annual maintenance for the Bar Channel of \$46,600 (see Table 4, below).

Coastal Zone Management Act (CZM). The proposed project would comply with all elements of the South Carolina and Georgia Coastal Management Programs. The new work sediments associated with dredging the entrance channel will be placed in the ODMDS and an existing upland DMCA.

Due to their cost effectiveness, hopper dredges are expected to be the primary equipment used to maintain depths in the entrance channel. Those dredges would generally deposit maintenance sediments in the ODMDS because the nearshore placement areas are too shallow for direct access to hopper dredges. The Corps could place the maintenance sediments in the nearshore placement areas if a non-Federal interest paid the incremental cost for the additional equipment and time that would be required for such an operation.

Table 4 –Bar Channel Maintenance Costs

Range	Disposal Site	Average Annual O&M Costs	Projected Annual Maintenance Yards	Projected O&M Cost
(-)60+000 to -57+000	ODMDS	\$4.35	10,000	\$43,500
(-)57+000 to -53+500	ODMDS	\$4.35	3,000	\$13,050
(-)53+500 to -40+000	ODMDS	\$4.35	54,000	\$234,900
(-) 40+000 to -30+000	ODMDS	\$4.35	325,000	\$1,413,750
(-)30+000 to -20+000	ODMDS	\$4.35	281,000	\$1,222,350
(-)20+000 to -10+000	ODMDS	\$4.35	163,000	\$709,050
(-) 10+000 to 0+000	ODMDS	\$4.35	155,000	\$674,250
0+000 to +4+000	ODMDS	\$4.35	76,000	\$330,600
			1,067,000	\$4,641,450
			Mob & Demob	\$690,000
			Multiple Mobs	\$40,000
			Total Mob & Demob	\$730,000
			PED	\$40,000
			S&A	\$100,000
	TOTAL COSTS			\$5,511,450
Bar Channel Maintenance after Expansion				
Range	Disposal Site	Average Annual O&M Costs	Projected Annual Maintenance Yards	Projected O&M Cost
(-)98+600 to -57+000	ODMDS	\$4.35	21,580	\$93,873
(-)57+000 to -53+500	ODMDS	\$4.35	3,000	\$13,050
(-)53+500 to -40+000	ODMDS	\$4.35	54,000	\$234,900
(-) 40+000 to -30+000	ODMDS	\$4.35	325,000	\$1,413,750
(-)30+000 to -20+000	ODMDS	\$4.35	281,000	\$1,222,350
(-)20+000 to -10+000	ODMDS	\$4.35	163,000	\$709,050
(-) 10+000 to 0+000	ODMDS	\$4.35	155,000	\$674,250
0+000 to +4+000	ODMDS	\$4.35	76,000	\$330,600
			1,078,580	\$4,691,823
			Mob & Demob	\$690,000
			Multiple Mobs	\$40,000
			Total Mob & Demob	\$730,000
			PED	\$40,000
			S&A	\$100,000
	TOTAL COSTS			\$5,561,823
	Impacts to O&M			(\$50,373)

3. Summary of Annual O&M Dredging Impacts:

Currently, Savannah District annually receives approximately \$13M for O&M dredging and maintenance of the upland disposal areas. This does not include funds for dike raising which are described in Table 5 below. With these funds, the District maintains the center two quadrants of the Federal channel. However, under current conditions, with the Sediment Basin operational, if the entire channel prism were to be maintained the cost would be \$24,368,190 (Current price levels) an increase of approximately \$11.4 million (59%) over the present O&M funding (Table 6). This information is based on a Sedimentation Analysis done on the Savannah Harbor Expansion Project in June 2007. If/when the project is deepened (-42 feet to -47 feet) the sill constructed at the lower end of the Sediment Basin will cause it to fill. This will result in the sediment currently being captured in the Sediment Basin (~1,932,000CY) to instead deposit in the navigation channel mainly in the range from Station 24+000 to 70+000. This will result in a total increase of O&M dredging and maintenance costs to \$27,415,490 or an increase attributable to the project of \$3,047,773. Of this total \$2,997,400 was attributed to the Inner Harbor while \$50,373 was attributed to the Bar Channel.

Year	Project	Est Cost	Fed\$	Non-Fed\$
2010	12B/13A Dikes Raising	\$3,078,880	\$2,001,272	\$1,077,608
	Dike Maintenance	\$590,000	\$560,000	\$30,000
	Mosquito Control	\$300,000	\$300,000	\$0
	Bird Island Construction	\$900,000	\$600,000	\$300,000
2011	JOI Dike Raising	\$11,950,000	\$7,767,500	\$4,182,500
	Dike Maintenance	\$597,000	\$567,000	\$30,000
	Mosquito Control	\$300,000	\$300,000	\$0
2012	Dike Maintenance	\$615,000	\$615,000	\$0
	Mosquito Control	\$300,000	\$300,000	\$0
2013	12A Dike Raising	\$9,000,000	\$5,850,000	\$3,150,000
	Dike Maintenance	\$633,000	\$633,000	\$0
	Mosquito Control	\$300,000	\$300,000	\$0
2014	Dike Maintenance	\$640,000	\$640,000	\$0
	Mosquito Control	\$300,000	\$300,000	\$0
2015	Dike Maintenance	\$650,000	\$650,000	\$0
	Mosquito Control	\$300,000	\$300,000	\$0

* The raising of dikes is coordinated with the rotation schedule of the Dredged Material Containment Areas (DMCA) which is included in the DMMP Annual Work Plan.

Table 6 - Current O&M Costs vs. Projected O&M Costs after Deepening

Range	Avg Ann Cost O&M Dredge	Current Ann Maint Yards	Current O&M Costs	Projected Ann Maint Yards	Projected O&M Costs
(-)98+600 to -57+000	\$4.35	10,000	\$43,500	21,580	\$93,873
(-)57+000 to -53+500	\$4.35	3,000	\$13,050	3,000	\$13,050
(-)53+500 to -40+000	\$4.35	54,000	\$234,900	54,000	\$234,900
(-) 40+000 to -30+000	\$4.35	325,000	\$1,413,750	325,000	\$1,413,750
(-)30+000 to -20+000	\$4.35	281,000	\$1,222,350	281,000	\$1,222,350
(-)20+000 to -10+000	\$4.35	163,000	\$709,050	163,000	\$709,050
(-) 10+000 to 0+000	\$4.35	155,000	\$674,250	155,000	\$674,250
0+000 to +4+000	\$4.35	76,000	\$330,600	76,000	\$330,600
Bar Channel (Hopper) Total		1,067,000	\$4,641,450	1,078,580	\$4,691,823
4+000 to 24+000	\$5.95	225,000	\$1,338,750	225,000	\$1,338,750
24+000 to 40+000	\$3.25	328,000	\$1,066,000	364,000	\$1,183,000
40+000 to 50+000	\$2.93	260,000	\$761,800	900,000	\$2,637,000
50+000 to 70+000	\$2.80	820,000	\$2,296,000	2,076,000	\$5,812,800
70+000 to 79+000	\$2.40	294,000	\$705,600	294,000	\$705,600
79+000 to 97+750	\$4.06	605,000	\$2,456,300	605,000	\$2,456,300
97+750 to 102+000	\$3.67	1,456,000	\$5,343,520	1,456,000	\$5,343,520
102+000 to 103+000	\$3.67	51,000	\$187,170	51,000	\$187,170
Inner Harbor (Pipeline) Total		4,039,000	\$14,155,140	5,971,000	\$19,664,140
Sediment Basin	\$1.30	1,932,000	\$2,511,600	0	\$0
Project Total without Mob & Demob		7,038,000	\$21,308,190	7,049,580	\$24,355,963
MOB & DEMOB Ocean Bar - One Hopper			\$690,000		\$690,000
MOB & DEMOB Ocean Bar - Two Pipeline Dredges			\$2,200,000		\$2,200,000
MULTIPLE MOBS			\$40,000		\$40,000
MULTIPLE MOBS			\$40,000		\$40,000
Total MOBS & DEMOBS			\$2,970,000		\$2,970,000
PED			\$40,000		\$40,000
S&A			\$50,000		\$50,000
Projected Total for All Costs			\$24,368,190		\$27,415,963
			Impacts to O&M		\$3,047,773

4. Mitigation – Dissolved Oxygen System

Background. The Savannah District of the United States Army Corps of Engineers (USACE) partnered with the Georgia Ports Authority to evaluate the feasibility of deepening the navigation channel in the Savannah Harbor. This effort is called the Savannah Harbor Expansion (SHE) Project. The project is intended to identify whether deepening the harbor from its presently authorized 42-foot depth, up to a depth of 48-feet is warranted and environmentally acceptable. It will also identify the most appropriate depth within that range.

Hydrodynamic and water quality models were developed and determined to be acceptable in March 2006 by the EPA, United States Fish and Wildlife Service (USFWS), Georgia Department of Natural Resources, Environmental Protection Division (GA DNR-EPD), and South Carolina Department of Health and Environmental Control (SC DHEC) to identify dissolved oxygen levels throughout Savannah Harbor. Studies identified a dissolved oxygen injection system as being the most cost effective method to improve dissolved oxygen levels in the harbor. The Savannah Harbor Expansion Project examined ways to mitigate for potential adverse effects on dissolved oxygen levels resulting from the proposed harbor deepening alternatives. The Savannah Harbor Expansion Project intends to use a dissolved oxygen injection system for that mitigation. To meet these mitigation requirements, designs for a dissolved oxygen injection system were evaluated to size and locate the system components and ensure the dissolved oxygen effectively mixes throughout the portions of the harbor that would have experienced dissolved oxygen impacts.

Dissolved Oxygen Injection System. Deepening the navigation channel would adversely impact dissolved oxygen levels in the harbor if no mitigation is included. Since this is a critical resource in the harbor, the Corps has included a feature in the mitigation plan for each depth alternative that minimizes that adverse effect.

The Corps' studies indicate that oxygen injection is the most cost-effective method for raising D.O. levels in the harbor. Due to site-specific requirements, the Corps believes that a land-based injection system would be the most effective solution. It identified the use of Speece cones as the specific technique to inject oxygen into the water, although another land-based technique could be found to be more cost-effective. A different injection technique could be substituted at the time of construction without further NEPA coordination if impacts to wetlands, water quality or fisheries remain the same as with the Speece cones. The hydrodynamic and water quality modeling indicate that a system of injection locations would be needed, as summarized in Table 7. These systems would remove the incremental effects of the channel deepening alternatives.

Table 7: Number of Injection Locations based on Project Depth

Depth Alternative	Number of Injection Locations	Capacity to Increase D.O. (lb/day)
44-foot	3	36,000
45-foot	3	32,000
46-foot	3	36,000
47-foot	3	40,000
48-foot	3	44,000

The locations identified for these systems are shown in Figure 2. All three locations (near Georgia Pacific, Hutchinson Island – west, Hutchinson Island –east) would be needed for each channel depth alternative. The systems would be land-based, with water being withdrawn from the river through pipes, then super-saturated with oxygen and returned to the river. The water intake structure would include screens to reduce the intake of trash and other suspended solids. The screens would be sized to keep flow velocities from exceeding 0.5 foot per second to minimize entrainment of fish larvae. The intake and discharge would be located along the side of the river and not extend out into the authorized navigation channel. Figure 3 shows a typical layout for the oxygen injection facility. The systems would be operated at full capacity during the months of July/August/September. The Corps would begin to operate the systems on 15 June to allow the dissolved oxygen to be fully distributed throughout the estuary by 1 July.

With all oxygen injection designs, dissolved oxygen levels are higher near the injection site and taper off to lower levels as distance from the site increases. Removing the incremental project effect at a great distance from injection site requires substantially greater amounts of oxygen. A tradeoff results between the amount of oxygen required and the distance from the injection site. This becomes a tradeoff between the amount of oxygen required (operating expense) and the number of injection locations (capital expense). As the number of injection locations increases, the complexity of maintaining numerous systems also increases. The overall D.O. system configuration is designed to remove the incremental effect of a deeper channel in 95 percent of the cells in the hydrodynamic model. The minor impact that would remain at a distance away from the injection location is balanced by the higher dissolved oxygen levels that would occur close to where the oxygen is added. The District and the natural resource agencies believe the 95 percent level of performance recognizes both the higher D.O. levels close to the injection sites and the limitations of the model at distinguishing small differences between different run conditions.

**MODELED LOCATIONS
FOR DISSOLVED OXYGEN INJECTION SYSTEMS**

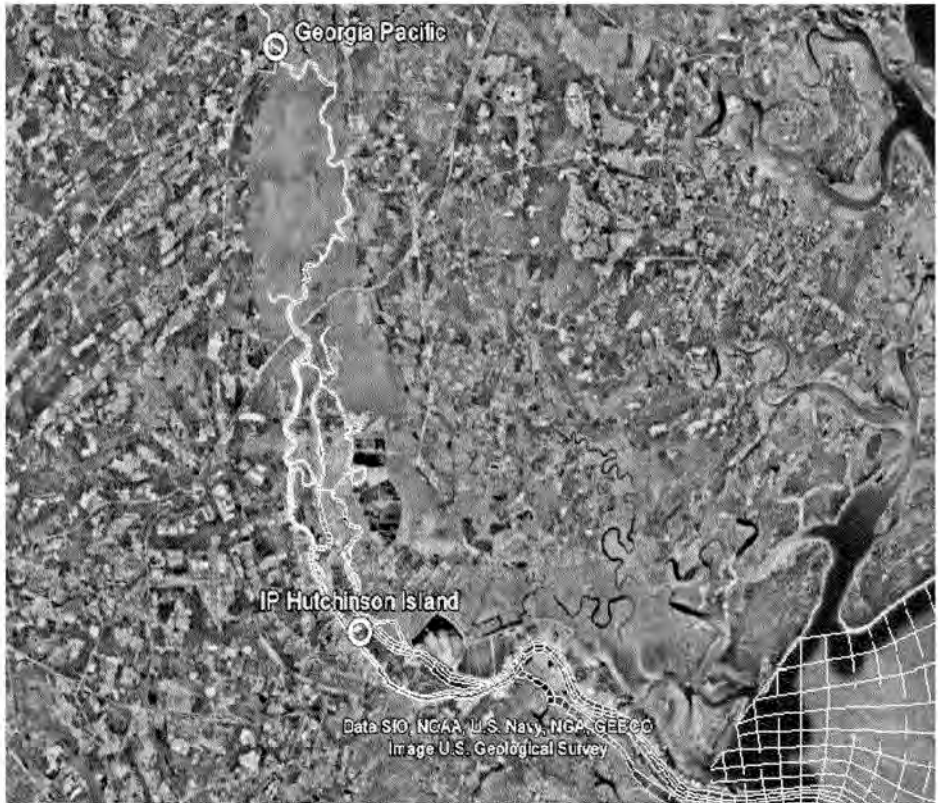


Figure 2

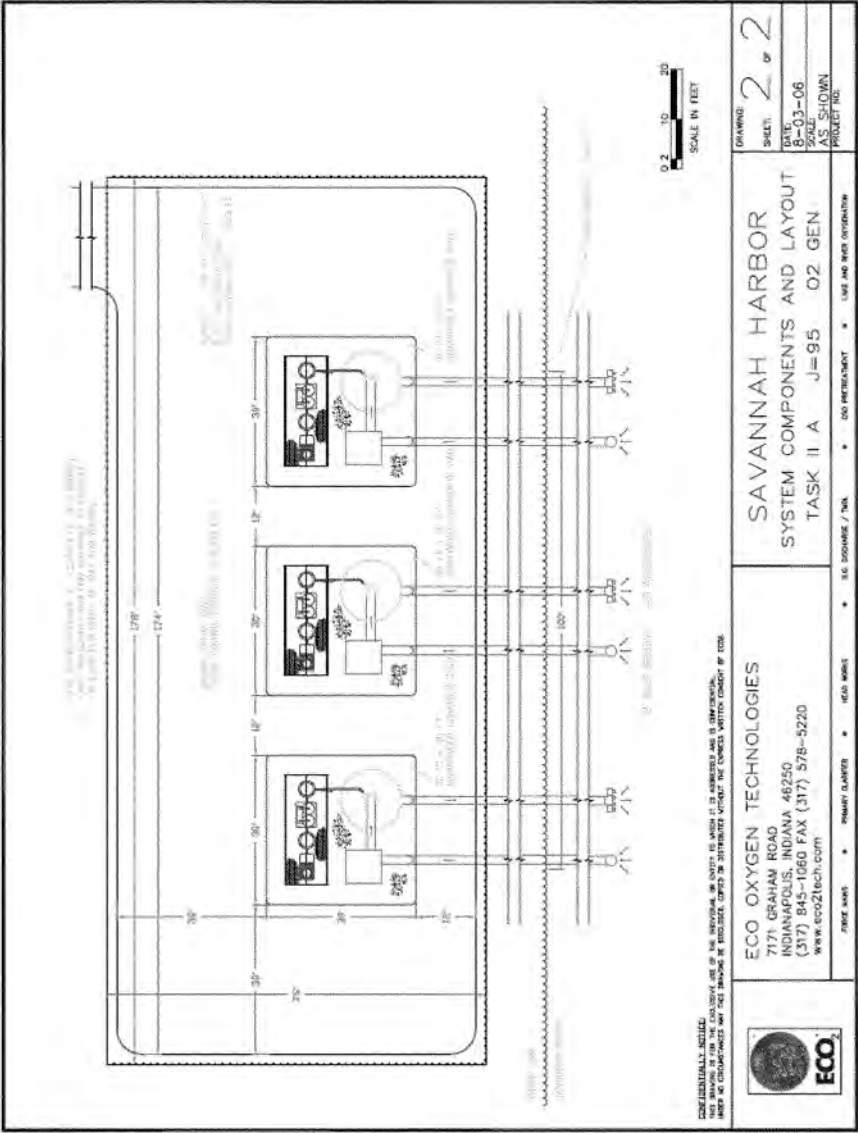


Figure 3

Since dissolved oxygen levels would be higher near the injection site and taper off away from the site, the Corps analyzed the model outputs and found that the systems would increase dissolved oxygen levels above their present levels over much of the harbor. Such improvements are a secondary benefit of a system that is designed to remove the incremental effect of a deeper channel in 95 percent of the bottom cells. The following information shows the extent of the improvements that would occur:

**Table 8: Percent of Cells
with Improvement in D.O. Levels
Over Existing Conditions
With the D.O. Improvement Systems**

Vertical Layer	DEPTH ALTERNATIVE				
	44-foot	45-foot	46-foot	47-foot	48-foot
Surface	99.3	98	98	98.4	99.2
Mid-Depth	94	94.5	94.5	96.2	95.1
Bottom	96.9	93.9	92.3	95.1	96.4
Water Column	98	99.9	99.8	99.8	99.7

The proposed system designs provide the best balance of system spacing, size and effectiveness, when the issues of operating complexity, existing land uses, and over-compensation of impacts are considered. The systems are also scalable so that it could be expanded in the future if desired to produce net improvements in harbor D.O. levels.

The costs for operating the dissolved oxygen injection system are based on their continued operation for a period of 180 days per year. Adjustments should be made to those operating costs if the systems would be operated for shorter or longer durations. Once the Oxygen Injection systems are installed, they will be the responsibility of the Federal Navigation Project to operate and maintain. Since the Corps considers mitigation features as "General Navigation Features", the Federal Government would be responsible for the costs to operate and maintain them.

Impacts to O&M. The annual impacts to O&M by the Dissolved Oxygen Injection System are for upkeep of the landside facilities to house the system and for the operating costs to produce the oxygen. These costs are shown by project depth in Table 9. Also included in the annual O&M costs are the replacement costs for the Speece cone and intake and discharge lines at 40-year intervals; and replacement of the oxygen flow control, oxygen generator and side stream pump at 20 year intervals.

Table 9: Dissolved Oxygen Injection System Annual Impact to O&M

Project Depth	Annual O&M Costs
44-foot	\$1,110,000
45-foot	\$908,500
46-foot	\$1,110,000
47-foot	\$1,210,400
48-foot	\$1,311,000

5. Project Impacts to O&M

Annual Savannah Harbor Expansion Project impacts to O&M are shown in Table 10, while Table 11 contains the annual impacts to O&M for the NED Plan (47-ft) and the annual O&M project costs after expansion. Cost sharing is 100-percent Federal above 45 feet and 50/50 Federal/non-Federal below 45 feet.

Table 10: Expansion Project Annual Impacts to O&M by Depth			
	44-ft Project		
Description	Cost	Federal Cost	Non-Federal Cost
Oxygen Injection System	\$1,110,000.00	\$1,110,000.00	\$0.00
Inner Harbor O&M Dredging	\$2,672,080.00	\$2,672,080.00	\$0.00
Channel Extension	\$46,589.00	\$46,589.00	\$0.00
Mitigation Features Dredging	\$114,000.00	\$114,000.00	\$0.00
CSS Georgia Curation	\$20,000.00	\$20,000.00	\$0.00
Fish Passage O&M	\$50,000.00	\$50,000.00	\$0.00
Long Term Monitoring	\$428,400.00	\$428,400.00	\$0.00
Total	\$4,441,069.00	\$4,441,069.00	\$0.00
	45-ft Project		
Oxygen Injection System	\$908,500.00	\$908,500.00	\$0.00
Inner Harbor O&M Dredging	\$2,672,080.00	\$2,672,080.00	\$0.00
Channel Extension	\$48,155.00	\$48,155.00	\$0.00
Mitigation Features Dredging	\$114,000.00	\$114,000.00	\$0.00
CSS Georgia Curation	\$20,000.00	\$20,000.00	\$0.00
Fish Passage O&M	\$50,000.00	\$50,000.00	\$0.00
Long Term Monitoring	\$428,400.00	\$428,400.00	\$0.00
Total	\$4,241,135.00	\$4,241,135.00	\$0.00
	46-ft Project		
Oxygen Injection System	\$1,110,000.00	\$1,009,250.00	\$100,750.00
Inner Harbor O&M Dredging	\$2,672,080.00	\$2,672,080.00	\$0.00
Channel Extension	\$48,938.00	\$48,546.50	\$391.50
Mitigation Features Dredging	\$114,000.00	\$114,000.00	\$0.00
CSS Georgia Curation	\$20,000.00	\$20,000.00	\$0.00
Fish Passage O&M	\$50,000.00	\$50,000.00	\$0.00
Long Term Monitoring	\$428,400.00	\$428,400.00	\$0.00
Total	\$4,443,418.00	\$4,342,276.50	\$101,141.50
	47-ft Project		
Oxygen Injection System	\$1,210,400.00	\$1,059,450.00	\$150,950.00
Inner Harbor O&M Dredging	\$2,672,080.00	\$2,672,080.00	\$0.00
Channel Extension	\$49,199.00	\$48,677.00	\$522.00
Mitigation Features Dredging	\$114,000.00	\$114,000.00	\$0.00
CSS Georgia Curation	\$20,000.00	\$20,000.00	\$0.00
Fish Passage O&M	\$50,000.00	\$50,000.00	\$0.00

Long Term Monitoring	\$428,400.00	\$428,400.00	\$0.00
Total	\$4,544,079.00	\$4,392,607.00	\$151,472.00
48-ft Project			
Oxygen Injection System	\$1,311,000.00	\$1,109,750.00	\$201,250.00
Inner Harbor O&M Dredging	\$2,672,080.00	\$2,672,080.00	\$0.00
Channel Extension	\$50,373.00	\$49,264.00	\$1,109.00
Mitigation Features Dredging	\$114,000.00	\$114,000.00	\$0.00
CSS Georgia Curation	\$20,000.00	\$20,000.00	\$0.00
Fish Passage O&M	\$50,000.00	\$50,000.00	\$0.00
Long Term Monitoring	\$428,400.00	\$428,400.00	\$0.00
Total	\$4,645,853.00	\$4,443,494.00	\$202,359.00

For Tables 11 - 13 cost indexing was accomplished using EM 1110-2-1304 (31 March 2000) Civil Works Construction Cost Index System (CWCCIS) (CWBS Code = 12 – Navigation Ports & Harbors).

Table 11: Impacts to O&M for NED Plan and O&M Program (47-Foot Project)

ANNUAL O&M INCREASE COST DUE TO EXPANSION

	Year										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Inner Harbor O&M Dredging	\$2,672,080	\$2,709,489	\$2,752,841	\$2,799,639	\$2,847,233	\$2,895,636	\$2,944,862	\$2,994,925	\$3,045,838	\$3,097,618	
Bar Channel O&M Dredging	\$49,199	\$49,888	\$50,686	\$51,548	\$52,424	\$53,315	\$54,222	\$55,143	\$56,081	\$57,034	
Oxygen Injection System	\$1,210,400	\$1,227,346	\$1,246,983	\$1,268,182	\$1,289,741	\$1,311,667	\$1,333,963	\$1,356,642	\$1,379,705	\$1,403,160	
Mitigation Features O&M Dredging	\$114,000	\$115,596	\$117,446	\$119,442	\$121,473	\$123,538	\$125,638	\$127,774	\$129,946	\$132,155	
Fish Passage O&M	\$50,000	\$50,700	\$51,511	\$52,387	\$53,277	\$54,183	\$55,104	\$56,041	\$56,994	\$57,963	
CSS Georgia Curator	\$20,000	\$20,280	\$20,604	\$20,955	\$21,311	\$21,673	\$22,042	\$22,416	\$22,798	\$23,185	
Long Term Monitoring	\$428,400	\$434,398	\$441,348	\$448,851	\$456,481	\$464,242	\$472,134	\$480,160	\$488,323	\$496,624	
	\$4,544,079	\$4,607,696	\$4,681,419	\$4,761,003	\$4,841,940	\$4,924,253	\$5,007,966	\$5,093,101	\$5,179,684	\$5,267,738	

ANNUAL O&M PROJECT COST AFTER EXPANSION

	Year										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Inner Harbor O&M Dredging	\$21,487,100	\$21,787,919	\$22,136,526	\$22,512,847	\$22,895,565	\$23,284,790	\$23,680,631	\$24,083,202	\$24,492,617	\$24,908,991	
Bar Channel O&M Dredging	\$3,416,423	\$3,464,253	\$3,519,681	\$3,579,516	\$3,640,367	\$3,702,254	\$3,765,192	\$3,829,200	\$3,894,297	\$3,960,500	
Oxygen Injection System	\$1,210,400	\$1,227,346	\$1,246,983	\$1,268,182	\$1,289,741	\$1,311,667	\$1,333,965	\$1,356,642	\$1,379,705	\$1,403,160	
Mitigation Features O&M Dredging	\$114,000	\$115,596	\$117,446	\$119,442	\$121,473	\$123,538	\$125,638	\$127,774	\$129,946	\$132,155	
Fish Passage O&M	\$50,000	\$50,700	\$51,511	\$52,387	\$53,277	\$54,183	\$55,104	\$56,041	\$56,994	\$57,963	
CSS Georgia Curator	\$20,000	\$20,280	\$20,604	\$20,955	\$21,311	\$21,673	\$22,042	\$22,416	\$22,798	\$23,185	
Long Term Monitoring	\$428,400	\$434,398	\$441,348	\$448,851	\$456,481	\$464,242	\$472,134	\$480,160	\$488,323	\$496,624	
Estimated \$ to Fully Maintain	\$26,726,323	\$27,100,492	\$27,534,099	\$28,002,179	\$28,478,216	\$28,962,346	\$29,454,706	\$29,955,436	\$30,464,678	\$30,982,578	
Current Funding Appropriation	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	
Additional Need to Fully Maintain	\$13,726,323	\$14,100,492	\$14,534,099	\$15,002,179	\$15,478,216	\$15,962,346	\$16,454,706	\$16,955,436	\$17,464,678	\$17,982,578	

* All costs are totals assuming a 47-foot project. No breakout of Federal vs. Sponsor cost has been applied.
(100% Fed to 45%, 50/50 Fed/Non-Fed from 45' to NED).

Table 12: Impacts to O&M for NED Plan and O&M Program (46-Foot Project)

ANNUAL O&M INCREASE COST DUE TO EXPANSION

	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Inner Harbor O&M Dredging	\$2,672,080	\$2,709,489	\$2,752,841	\$2,799,639	\$2,847,233	\$2,895,636	\$2,944,862	\$2,994,925	\$3,045,838	\$3,097,618
Bar Channel O&M Dredging	\$48,938	\$49,623	\$50,417	\$51,274	\$52,146	\$53,032	\$53,934	\$54,851	\$55,783	\$56,732
Oxygen Injection System	\$1,110,000	\$1,125,540	\$1,143,549	\$1,162,989	\$1,182,760	\$1,202,867	\$1,223,315	\$1,244,112	\$1,265,262	\$1,286,771
Mitigation Features O&M Dredging	\$114,000	\$115,596	\$117,446	\$119,442	\$121,473	\$123,538	\$125,638	\$127,774	\$129,946	\$132,155
Fish Passage O&M	\$50,000	\$50,700	\$51,511	\$52,387	\$53,277	\$54,183	\$55,104	\$56,041	\$56,994	\$57,963
CSS Georgia Curriton	\$20,000	\$20,280	\$20,604	\$20,955	\$21,311	\$21,673	\$22,042	\$22,416	\$22,798	\$23,185
Long Term Monitoring	\$428,400	\$434,398	\$441,348	\$448,851	\$456,481	\$464,242	\$472,134	\$480,160	\$488,323	\$496,624
	\$4,443,418	\$4,505,626	\$4,577,716	\$4,655,537	\$4,734,681	\$4,815,171	\$4,897,029	\$4,980,278	\$5,064,943	\$5,151,047

ANNUAL O&M PROJECT COST AFTER EXPANSION

	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Inner Harbor O&M Dredging	\$21,487,100	\$21,787,919	\$22,136,526	\$22,512,847	\$22,895,565	\$23,284,790	\$23,680,631	\$24,083,202	\$24,492,617	\$24,908,991
Bar Channel O&M Dredging	\$3,416,423	\$3,464,253	\$3,519,681	\$3,579,516	\$3,640,367	\$3,702,254	\$3,765,192	\$3,829,200	\$3,894,297	\$3,960,500
Oxygen Injection System	\$1,110,000	\$1,125,540	\$1,143,549	\$1,162,989	\$1,182,760	\$1,202,867	\$1,223,315	\$1,244,112	\$1,265,262	\$1,286,771
Mitigation Features O&M Dredging	\$114,000	\$115,596	\$117,446	\$119,442	\$121,473	\$123,538	\$125,638	\$127,774	\$129,946	\$132,155
Fish Passage O&M	\$50,000	\$50,700	\$51,511	\$52,387	\$53,277	\$54,183	\$55,104	\$56,041	\$56,994	\$57,963
CSS Georgia Curriton	\$20,000	\$20,280	\$20,604	\$20,955	\$21,311	\$21,673	\$22,042	\$22,416	\$22,798	\$23,185
Long Term Monitoring	\$428,400	\$434,398	\$441,348	\$448,851	\$456,481	\$464,242	\$472,134	\$480,160	\$488,323	\$496,624
Estimated \$ to Fully Maintain	\$26,625,923	\$26,998,686	\$27,430,665	\$27,896,986	\$28,371,235	\$28,853,546	\$29,344,056	\$29,842,905	\$30,350,235	\$30,866,189
Current Funding Appropriation	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000
Additional Need to Fully Maintain	\$13,625,923	\$13,998,686	\$14,430,665	\$14,896,986	\$15,371,235	\$15,853,546	\$16,344,056	\$16,842,905	\$17,350,235	\$17,866,189

* All costs are totals assuming a 46-foot project. No breakout of Federal vs. Sponsor cost has been applied.
(100% Fed to 45%, 50/50 Fed/Non-Fed from 45' to NED).

Table 13: Impacts to O&M for NED Plan and O&M Program (48-Foot Project)

ANNUAL O&M INCREASE COST DUE TO EXPANSION

	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Inner Harbor O&M Dredging	\$2,672,080	\$2,709,489	\$2,752,841	\$2,799,639	\$2,847,233	\$2,895,636	\$2,944,862	\$2,994,925	\$3,045,838	\$3,097,618
Bar Channel O&M Dredging	\$50,373	\$51,078	\$51,895	\$52,778	\$53,675	\$54,587	\$55,515	\$56,459	\$57,419	\$58,395
Oxygen Injection System	\$1,311,000	\$1,329,354	\$1,350,624	\$1,373,584	\$1,396,935	\$1,420,683	\$1,444,835	\$1,469,397	\$1,494,377	\$1,519,781
Mitigation Features O&M Dredging	\$114,000	\$115,596	\$117,446	\$119,442	\$121,473	\$123,538	\$125,638	\$127,774	\$129,946	\$132,155
Fish Passage O&M	\$50,000	\$50,700	\$51,511	\$52,387	\$53,277	\$54,183	\$55,104	\$56,041	\$56,994	\$57,963
CSS Georgia Curator	\$20,000	\$20,280	\$20,604	\$20,955	\$21,311	\$21,673	\$22,042	\$22,416	\$22,798	\$23,185
Long Term Monitoring	\$428,400	\$434,398	\$441,348	\$448,851	\$456,481	\$464,242	\$472,134	\$480,160	\$488,323	\$496,624
	\$4,645,853	\$4,710,895	\$4,786,269	\$4,867,636	\$4,950,386	\$5,034,542	\$5,120,129	\$5,207,172	\$5,295,694	\$5,385,720

ANNUAL O&M PROJECT COST AFTER EXPANSION

	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Inner Harbor O&M Dredging	\$21,487,100	\$21,787,919	\$22,136,526	\$22,512,847	\$22,895,565	\$23,284,790	\$23,680,631	\$24,083,202	\$24,492,617	\$24,908,991
Bar Channel O&M Dredging	\$3,416,423	\$3,464,253	\$3,519,681	\$3,579,516	\$3,640,367	\$3,702,254	\$3,765,192	\$3,829,200	\$3,894,297	\$3,960,500
Oxygen Injection System	\$1,311,000	\$1,329,354	\$1,350,624	\$1,373,584	\$1,396,935	\$1,420,683	\$1,444,835	\$1,469,397	\$1,494,377	\$1,519,781
Mitigation Features O&M Dredging	\$114,000	\$115,596	\$117,446	\$119,442	\$121,473	\$123,538	\$125,638	\$127,774	\$129,946	\$132,155
Fish Passage O&M	\$50,000	\$50,700	\$51,511	\$52,387	\$53,277	\$54,183	\$55,104	\$56,041	\$56,994	\$57,963
CSS Georgia Curator	\$20,000	\$20,280	\$20,604	\$20,955	\$21,311	\$21,673	\$22,042	\$22,416	\$22,798	\$23,185
Long Term Monitoring	\$428,400	\$434,398	\$441,348	\$448,851	\$456,481	\$464,242	\$472,134	\$480,160	\$488,323	\$496,624
Estimated \$ to Fully Maintain	\$26,826,923	\$27,202,500	\$27,637,740	\$28,107,581	\$28,585,410	\$29,071,362	\$29,565,576	\$30,068,190	\$30,579,350	\$31,099,198
Current Funding Appropriation	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000	\$13,000,000
Additional Need to Fully Maintain	\$13,826,923	\$14,202,500	\$14,637,740	\$15,107,581	\$15,585,410	\$16,071,362	\$16,565,576	\$17,068,190	\$17,579,350	\$18,099,198

* All costs are totals assuming a 48-foot project. No breakout of Federal vs. Sponsor cost has been applied.
(100% Fed to 45', 50/50 Fed/Non-Fed from 45' to NED).

FOR CONTINUATION OF HOUSE DOCUMENT 112-153

**SAVANNAH HARBOR EXPANSION PROJECT
CHATMAN CO., GEORGIA & JASPER CO., S. CAROLINA:
FINAL GENERAL RE-EVALUATION REPORT AND
ENVIRONMENTAL IMPACT STATEMENT**

SEE PART 7