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Results from Salinity Intrusion Modeling of the Pascagoula River to Evaluate Water Withdrawal for the Strategic Petroleum Reserve Richton Expansion Site

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Executive Summary

The Department of Energy (DOE) is evaluating the development of new storage sites in the Gulf of Mexico region to increase the capacity of the Strategic Petroleum Reserve (SPR). Petroleum is stored in caverns formed by pumping fresh water into salt domes to dissolve the salt. Formation of the caverns involves pumping in fresh raw water to dissolve the salt, and pumping out the resultant brine. The proposed Richton SPR would withdraw freshwater from the Pascagoula River which empties into Mississippi Sound and ultimately the Gulf of Mexico. The effect of reducing the flow could result in salinity from Mississippi Sound traveling further up the Pascagoula River, potentially changing the salinity variation along the axis of the river.

The purpose of this study is to determine present environmental conditions in the Pascagoula River, particularly the salinity structure, and then to estimate how that structure is affected by the raw water intake (RWI) at Merrill. To determine potential changes in the salinity profile of the Pascagoula River, a one-dimensional (longitudinal) model was applied to the system. Salinity data from a period of low flow was used to calibrate the model, which was then validated with salinity data at various flows. The model calibration scenario has a root mean square error (RMSE) of 2.24 ppt which represents a good fit of the model to the data. Most of error can be attributed to the longitudinal variation of salinity, which is not consistent and in some cases increases at upstream stations. The model validations' RMSE ranged from 2.8 to 4.8 ppt indicating that the model is providing a good fit to the data under a variety of flow regimes.

To minimize the environmental impacts of the RWI, withdrawals will shut down when flows are less than 28.3 m^3/s (1000 cfs) at the Pascagoula gage at Merrill. To simulate worst case impacts at this flow rate, the model was applied using 95th percentile tidal amplitudes at the river mouth. It is expected that the RWI will pump 190,000 m^3/day (50 MGD) out of the river. Simulations at 28.3 m^3/s (1000 cfs) both with and without the RWI were compared using predicted salinities along the length of the river, from the mouth to Cumbest Bluff, as well as changes in the upstream extent of salinity intrusion. At Cumbest Bluff, the upstream extent of the model, a 0.04 ppt increase in salinity is expected with the RWI. It is also expected that the extent of salinity intrusion, defined as the river location where the salinity is 1% of river mouth salinity, will increase by up to 1.1 km (0.7 mi) from 36.8 to 37.9 km (22.9 to 23.5 mi) with the RWI.

In addition to the 28.3 m^3/s (1000 cfs) case, the model was also run for 7Q10 flow conditions on the Pascagoula River combined with 95th percentile tidal amplitudes. Under these conditions, at Cumbest Bluff, a 0.1 ppt increase in salinity is expected with the RWI. It is also expected that the extent of salinity intrusion will increase by up to 1.2 km (0.7 mi) from 38.6 to 39.8 km (24.0 to 24.7 mi) with the RWI.

While the model was run for two worst case conditions, 28.3 m^3/s (1000 cfs) and 7Q10, these are not representative of the average flow conditions on the Pascagoula River. The model was also run for three moderate flow conditions near or below mean annual flow at Merrill: 79 m^3/s (2790 cfs), 132.9 m^3/s (4695 cfs), and 298.7 m^3/s (10550 cfs). Mean annual flow at the Merrill gage is 281 m^3/s (9909 cfs) (USGS, 2009). Under these flow conditions, the model did not show any change in the salinity concentration at Cumbest Bluff. Differences in the extent of salinity intrusion with and without the RWI were also considerably less, ranging from 0 to 0.2 km (0 to 0.1 mi).

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The Department of Energy (DOE) is evaluating the development of new storage sites in the Gulf of Mexico region to increase the capacity of the Strategic Petroleum Reserve (SPR). Petroleum is stored in caverns formed by pumping fresh water into salt domes to dissolve the salt. Formation of the caverns involves pumping in fresh raw water to dissolve the salt, and pumping out the resultant brine. The proposed Richton SPR would withdraw freshwater from the Pascagoula River with empties into Mississippi Sound and ultimately the Gulf of Mexico. The effect of reducing the flow could result in salinity from Mississippi Sound traveling further up the Pascagoula River, potentially changing the salinity variation along the axis of the river.

To determine potential changes in the salinity profile of the Pascagoula River, a one-dimensional (longitudinal) model (Ippen and Harleman, 1961) was applied to the system. The application of the model builds on previous modeling studies of the Pascagoula River system using DYNHYD and TOXI5 documented by HARZA (1995 & 1995). Much of the same data used in the HARZA study, including the United States Geological Survey (USGS) cross-sections of the Pascagoula River, and annual USGS salinity profile surveys, were also used in applying the one-dimensional salinity intrusion model.

The purpose of this study is to determine present environmental conditions in the Pascagoula River, particularly the salinity structure. The salinity data was then used to calibrate the one-dimensional salinity intrusion model. After calibration, the model was tested in three validation runs which represented a variety of flow rates. Finally, the model was applied using 7Q10 low flows in the Pascagoula River to determine potential salinity intrusion under worst case conditions.

2.0 Description of the Study Area

The Pascagoula River, located in southeastern Mississippi, is about 130 km (80 mi) long and has a drainage area of about 23,000 km^2 (8,800 sq mi). It is one of the only undisturbed rivers to flow into the Gulf of Mexico and it provides abundant wildlife habitat as well as a variety of estuarine habitats along the southern portion where it is influenced by salt water intrusion from Mississippi Sound. Approximately 27.4 km (17 mi) from the river mouth, the Pascagoula splits into a west branch (the West Pascagoula River) and an east branch (main stem Pascagoula River).

The proposed Richton raw water intake (RWI) facility will be located near Merrill, MS approximately 130 km (80 mi) up the Pascagoula River, just south of the USGS Merrill gauging station (Figure 2.1-1) and near the confluence of the Leaf and Chickasawhay Rivers. The extent of tidal influence in the Pascagoula River ends approximately 68 km (42 mi) upstream from the Gulf of Mexico. The maximum extent of saltwater intrusion ever recorded occurred about 32 km (20 mi) upstream of the Gulf of Mexico during the 1963 drought (HARZA, 1994).

Tides at the mouth of the Pascagoula are generally diurnal with an average tidal range of approximately 0.5 m (1.6 ft); the 95^{th} tidal range percentile is about 0.9 m (2.8 ft) (NOAA, 2009). During the moon's quadrature, about once every 14 days, the tides become semi-diurnal with a smaller tidal range.

At the USGS Merrill gage, mean annual flow in the Pascagoula is 281 m^3/s (9,909 cfs). Extreme flows in the river range from 18.3 m^3/s (648 cfs) in October 2000 to 4,980 m^3/s (176,000 cfs) in February, 1961 (USGS, 2007). The most recently calculated 7Q10 value is 26.0 m^3/s (917 cfs) (HARZA, 1995). Salinity at the river mouth varies depending on actual tidal range and river flow, though it has been hypothesized that higher tides have a more significant effect on saltwater intrusion than low stream flows (HARZA, 1994).

In April 1994, the USGS surveyed cross sections of the Pascagoula and West Pascagoula Rivers during a period of high flow when the banks were at full condition. The depth gradient of the channels is relatively flat, though there are also a large number of holes along the thalweg.

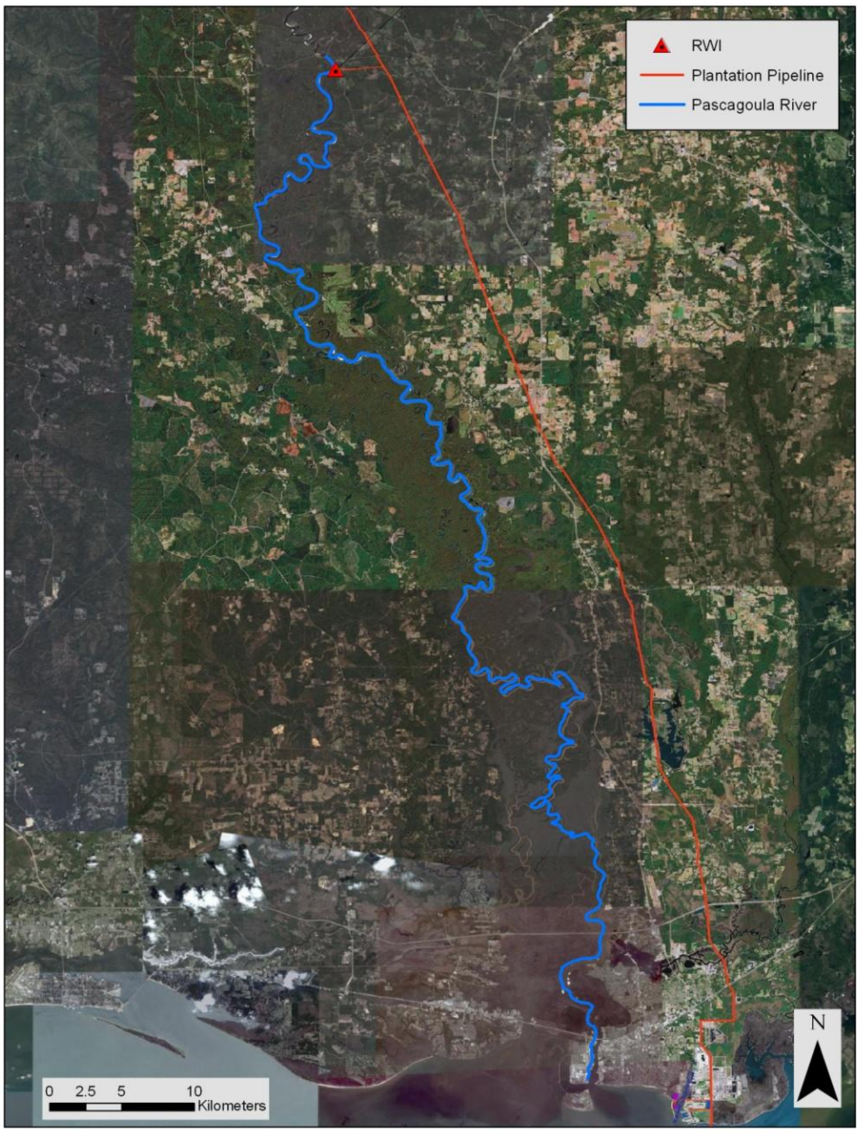

Figure 2.1-1. Area around the proposed Richton RWI along the Pascagoula River.

3.0 Modeling Approach

A salinity intrusion model was used to estimate the potential impacts of the RWI withdrawal on the salinity structure of the Pascagoula River. The model was calibrated to salinity data taken during annual USGS surveys at various stations along the river using actual flow and tide conditions during the survey. The model calibration uses a period of relatively low flows; it was then validated using three different flow conditions. Finally, the model was used to estimate impacts using a flow rate of 28.3 m^3/s (1000 cfs) at Merrill and using 7Q10 flow conditions. The 28.3 m^3/s (1000 cfs) flow condition represents the lowest flow rate at which the RWI would operate. The 7Q10 flow condition represents worst case conditions.

3.1 Model Description

The salinity intrusion model used was developed under U.S. Army Corps of Engineers (USACE) funding by Ippen and Harleman (1961) at the Massachusetts Institute of Technology. The model is a one-dimensional, time dependent, analytic model that predicts the longitudinal distribution of salinity over the tidal cycle. A series of experiments were conducted at the USACE Waterways Experiment Station in Vicksburg, MS which successfully validated the model. The model consists of a solution to the conservation of salt equation and a series of boundary conditions. The resulting equation for salinity as a function of distance up estuary and time is:

$$S(x,t) = S_o \exp\left\{-\frac{Q_f}{2bhD'_o B\delta^2}\left[1-(1-\delta x)\exp\left[\frac{a}{b}(1-\cos\sigma t)\right]+\delta B\right]^2\right\}$$

with

$$\delta = \frac{F\sigma}{h}$$

$$\sigma = \frac{2\pi}{T}$$

where

- b = width of estuary (m)
- h = depth of estuary (m)
- Q_f = freshwater discharge into estuary (m^3/s)
- a = tidal amplitude at estuary mouth (m)
- T = period of primary tidal constituent
- S_o = constant salinity at the estuary mouth (ppt)
- F = scale factor relating maximum tidal velocity at estuary mouth to tidal amplitude (1/s)
- B = seaward excursion from estuary mouth where salinity is constant (km)
- D'_o = apparent diffusion coefficient at estuary mouth (m^2/s)

The estuary width and depth were obtained from averages of the USGS cross sections. The length of the estuary was obtained from historical records of the maximum extent of saltwater intrusion. The freshwater discharge into the estuary and tidal amplitude at the ocean boundary vary by model scenario and were derived from USGS gaging stations (02479000 and 02479300) and the Tides and Currents software package (Nobeltec, 2000), respectively, for each salinity survey period. The estuary mouth salinity was obtained from annual USGS salinity surveys at the mouth of the Pascagoula River and also varies across model scenarios (USGS, 2009). The scale factor, F, was determined using tidal velocities and amplitudes at the river mouth. The final two parameters, the seaward excursion distance and the apparent diffusion coefficient were used to calibrate the model to the observed salinities.

3.2 Model Inputs

3.2.1 Estuary Width, b

The width of the Pascagoula estuary was determined from a series of USGS cross sections surveyed in April 1994 to provide data for the HARZA study. The cross sections included both the Pascagoula and West Pascagoula River, and were taken when the flow at the USGS Merrill gage was about 1400 m^3/s (50,000 cfs) and the river bank was at full condition.

Between the river mouth and Cumbest Bluff, at 40.9 km (25.4 mi), there are five cross-sections on the Pascagoula River upstream of the split, 14 cross-sections on the east branch of the Pascagoula River, and 14 cross-sections on the West Pascagoula River. Of the 14 cross-sections on each branch downstream of the split, 12 are at corresponding locations on the two branches. At these locations the sum of the widths of the two branches was used; an average was then taken of the widths along the river from the mouth upstream to Cumbest Bluff giving an estuary width input value of 284 m (932 ft).

3.2.2 Estuary Depth, h

The depth of the Pascagoula estuary was also determined from the USGS profiles for the HARZA study. The profiles include both the Pascagoula and West Pascagoula River, and were taken when the flow at the USGS Merrill gage was about 1400 m^3/s (50,000 cfs) and the river bank was at full condition.

Similar to the analysis performed for estuary width, the mean of the depths of the two branches was used; an average was then taken of the depths along the river from the mouth upstream to Cumbest Bluff giving an estuary depth input value of 3.5 m (11 ft).

3.2.3 Freshwater Discharge, Q_f

Freshwater discharge into the estuary was estimated independently for the calibration run and each of the three validation runs.

Flow rates at Cumbest Bluff were estimated using two USGS stream gages located in the Pascagoula River basin, the gage at Merrill (02479000) which has discharge records from 1930 to 2009 and the gage at Vestry (02479300), on the Red River, which has discharge records from 1958 to 2009. To transpose flows from Merrill to Cumbest Bluff the methodology outlined in the 1994 HARZA Pascagoula River Low Flow Management study was used. This study found that the flow rate at Cumbest Bluff was related to the flow rate at Merrill and the flow rate at Vestry in the following way (HARZA, 1994):

$$Q_{CB} = Q_{Merrill} + 3.63\, Q_{Vestry}$$

A summary of the freshwater flows for each model run is presented in Table 4-1.

3.2.4 Tidal Amplitude, a

Tidal amplitude at the estuary mouth was estimated independently for the calibration run and each of the three validation runs. The Tides and Currents software package (Nobeltec, 2000) was used to generate tidal predictions for the time period of each model run. The value used for each run is presented in Table 4-1.

3.2.5 Tidal Period, T

Tides at the mouth of the Pascagoula River are generally diurnal, meaning that the system usually experiences only one high tide and one low tide during each lunar day. At the moon's quadrature, which occurs approximately every 14 days, the tides become semi-diurnal (two high tides and two low tides per day); during this period the tidal amplitude is reduced. Diurnal tides have a period of 24.84 hrs.

3.2.6 Salinity at Estuary Mouth, S_o

The salinity at the estuary mouth was estimated independently for the calibration run and each of the three validation runs using the USGS annual salinity profile surveys. These annual surveys consist of salinity profiles taken at one mile intervals along the river from the mouth until the measured specific conductivity was below 500 µmhos/cm (approximately 0.3 ppt). Each annual survey provides salinities at various depths in the water column during both high and low tide. The survey results were vertically and tidally-averaged to provide a salinity value for model input.

The time period of the calibration run was defined by the salinity period with the lowest recorded flows. The three validation runs were defined using salinity periods with varying flows. The salinity values used for each model run are presented in Table 4-1.

3.2.7 Velocity Scale Factor, F

The velocity scale factor is a function of the tidal amplitude, the tidal frequency, the tidal velocity, and the mean water depth of the system. Since tidal frequency is a function of tidal period, tidal velocity is the only remaining input parameter needed to estimate F.

Tidal velocity was estimated from the 3-D baroclinic hydrodynamic model used for the far-field brine discharge modeling (ASA, 2009) and originally developed by the USACE Engineer Research and Development Center (ERDC) for the area of Mississippi Sound in support of a project to deepen the channels and port area of Gulfport, Mississippi (Bunch, et al, 2003). The model simulated hydrodynamics in the area using the CH3D model at 5 vertical levels for a period of 6 months (April through September) in 1997.

Time-varying velocity data for the period 15 April through 30 September 1997 was provided by the USACE ERDC. Time series at both the mouth of the main-stem Pascagoula River and the West Pascagoula River were extracted and analyzed to determine the 95^{th} percentile velocities. The mean of the 95^{th} percentile velocity at each river mouth was taken as the maximum tidal velocity at the estuary mouth, a value of 45.3 cm/s (1.5 ft/s).

3.2.8 Seaward Excursion Distance, B

The seaward excursion distance is the distance from the river mouth to a point where the salinity is constant at all times during the tidal cycle. This input parameter is one of two parameters used to calibrate the model to observed salinities.

3.2.9 Apparent Diffusion Coefficient, D'_o

The apparent diffusion coefficient is a combination of eddy diffusivity and gravitational convection. This input parameter is one of two parameters used to calibrate the model to observed salinities.

4.0 Salinity Model Results

The one dimensional model applied in this study predicts upstream variation of salinity. Thus the model is well suited to determine upriver displacement of the salt wedge. The model was calibrated and validated using the results of four USGS salinity profile surveys. The calibration run was based on salinity data from September 20 and 21, 2000, which is the period of lowest flow among all the salinity surveys. The model calibration scenario was used to determine appropriate values for the seaward excursion distance and apparent diffusion coefficient. The model calibration was performed using a low flow condition because the greatest risk of increased salt water intrusion occurs during low flow periods.

To test the possibility of a low flow bias from the model calibration, three validation cases were also run using the seaward excursion distance and apparent diffusion coefficient determined from the calibration run. These three runs also used USGS salinity profiles and correspond to a period of high flow, and two periods of mid flow, approximately 10 times, 3 times, and 4 times the flow during the September 2000 case.

Table 4-1 provides an overview of the input data used in each model run. As seen, the basic geometry of the river remains constant. River flows, tidal amplitudes, and salinity values vary based on historic conditions in the river.

Table 4-1. Summary of salinity intrusion model inputs.

Parameter	Model Run	Value	Source
Estuary Width, b	All	284 m (932 ft)	1994 USGS cross-sections (HARZA, 1994)
Estuary Depth, h	All	3.5 m (11.4 ft)	1994 USGS profiles (HARZA, 1994)
Estuary Length, L	All	40.9 km (25.4 mi)	Maximum recorded extent of salinity intrusion (HARZA, 1994)
Freshwater Flow, Q_f	September 2000	32.2 m^3/s (1138 cfs)	USGS Gages at Merrill and Vestry
	August 1997	100.3 m^3/s (3541 cfs)	USGS Gages at Merrill and Vestry
	August 1991	186.2 m^3/s (6577 cfs)	USGS Gages at Merrill and Vestry
	July 1989	422.6 m^3/s (14924 cfs)	USGS Gages at Merrill and Vestry
Tidal Amplitude, a	September 2000	0.58 m (1.9 ft)	Tides and Currents (Nobeltec, 2000)
	August 1997	0.52 m (1.7 ft)	
	August 1991	0.79 m (2.6 ft)	
	July 1989	0.64 m (2.1 ft)	
Tidal Period, T	All	89424 s	Diurnal Tide
Maximum Tidal Velocity	All	0.46 m/s (1.5 ft/s)	USACE Hydrodynamic Model Data
Maximum Tidal Salinity, S_o	September 2000	30.1 ppt	USGS Annual Salinity Profile Surveys
	August 1997	27.3 ppt	
	August 1991	26.8 ppt	
	July 1989	22.1 ppt	
Seaward Excursion	All	3822 m (12,539 ft)	Calibrated

Parameter	Model Run	Value	Source
Distance, B			
Apparent Diffusion Coefficient, D'_o	All	2274 m^2/s (24,480 ft^2/s)	Calibrated

4.1 Model Calibration

The model was calibrated using USGS salinity profiles from September 20 and 21, 2000. These profiles contain salinity from two distinct time periods, high tide and low tide. The final salinity value for input to the model was both vertically and tidally-averaged. This salinity profile was chosen for calibration because it corresponds to the lowest flow of all the annual profiles. The river flow at the Merrell gage for this period was only 23.5 m^3/s (831 cfs), which is approaching, the lowest daily mean value of 18.3 m^3/s (648 cfs) and is lower than 7Q10 value of 26.0 m^3/s (917 cfs) (HARZA, 1995).

Transposing this flow rate downstream to Cumbest Bluff gives a model input value of 32.2 m^3/s (1138 cfs). This flow rate was calculated with flows from Merrill and Vestry using the HARZA methodology described in section 3.2.3. Tidal amplitude was estimated from the Tides and Currents software package. The river geometry, tidal period, and tidal velocity remain constant across all model runs.

The remaining parameters, seaward excursion distance and apparent diffusion coefficient, were adjusted until the root mean square error (RMSE) between model predictions and data was minimized. These values, which were used in the subsequent validation runs and RWI impact analysis, are given in Table 4-1. The RMSE for the calibration run is 2.24 ppt. This represents a very good fit of the model to the data. The vertically and tidally-averaged September 2000 survey is shown in Figure 4.1-1 plotted against the model results.

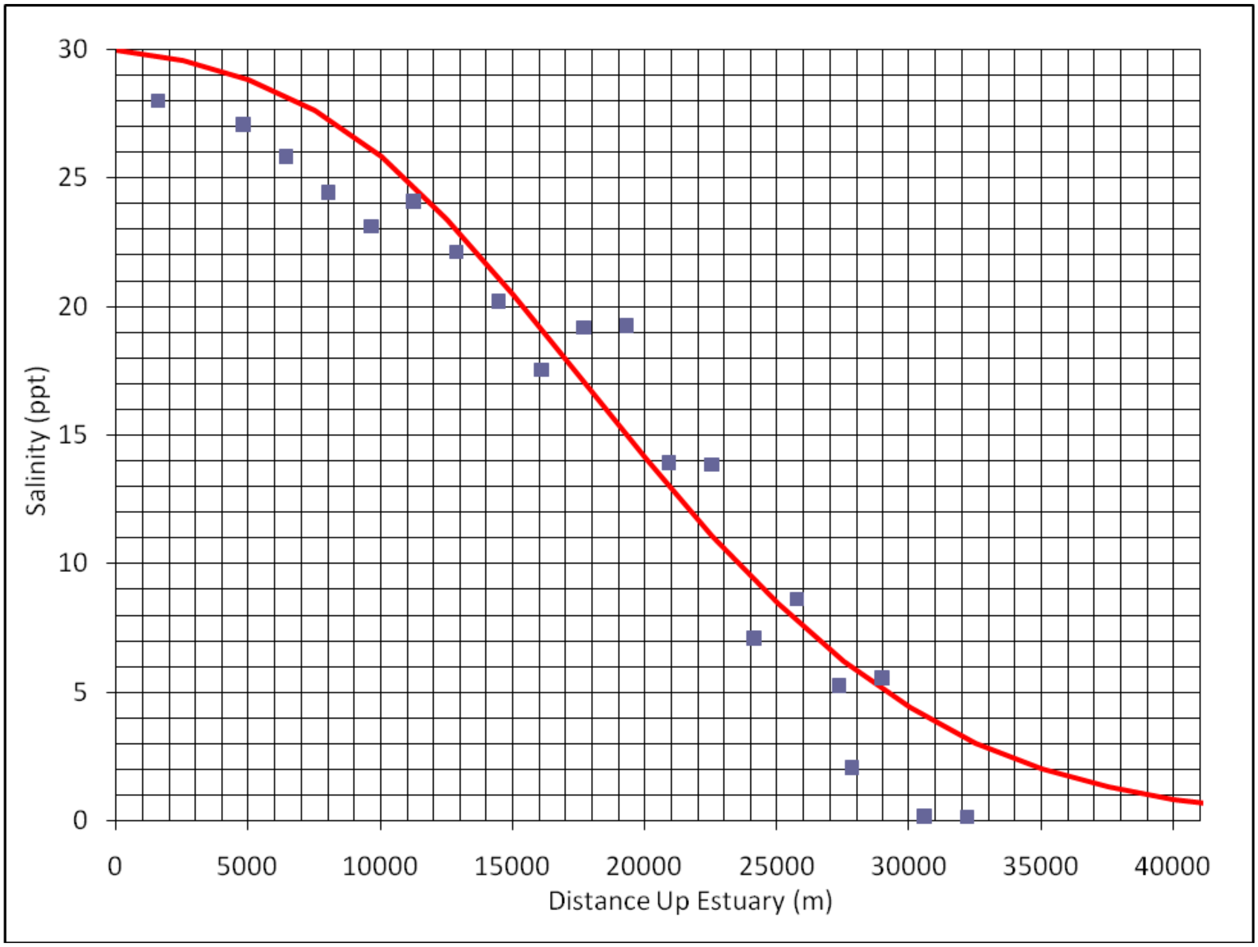

Figure 4.1-1. Model predicted salinity distribution in the Pascagoula River (red line) compared to vertically and tidally averaged salinity measurements for low flow conditions (September 2000). Data points indicate sampling locations.

Most of the RMSE is due to the fluctuation of salinity as the survey moved upstream. The survey does not show a consistent upstream variation, while the salinity values are generally decreasing; the variation is not smooth and even contains some increasing upstream values. Tides have a significant effect on salinity in the Pascagoula River, and because the salinity profiles were not taken instantaneously, the longitudinal salinity profile may have been affected. The river bottom geometry along the Pascagoula River is also complex; a series of holes exist along the thalweg and as saline water moves upstream it drops into these holes and must fill them before continuing upstream (HARZA, 1994). Tributaries and oxbow lakes connected to the river may also be influencing the longitudinal salinity profile.

4.2 Model Validation

After calibrating the model, it was run for different flow conditions corresponding to approximately 3, 6, and 15 times the low flow condition modeled with the calibration run. The parameters for each of these model runs are summarized in Table 4-1. The scenario specific freshwater flow, tidal amplitude, and maximum salinity parameters were all derived from the same sources used in the calibration run. Table 4.2-1 shows the RMSE for each of the validation runs; Figures 4.2-1 through 4.2-3 shows model predictions plotted against observed salinity values. Again, it is likely that most of the model discrepancy can be explained by the timing of the USGS salinity measurements and the complex channel geometry of the Pascagoula River.

Table 4.2-1. Model validation results.

Scenario	Type	RMSE
September 2000	Calibration	2.2 ppt
August 1997	Validation (~3x calibration flow)	4.4 ppt
August 1991	Validation (~4x calibration flow)	4.8 ppt
July 1989	Validation (~10x calibration flow)	2.8 ppt

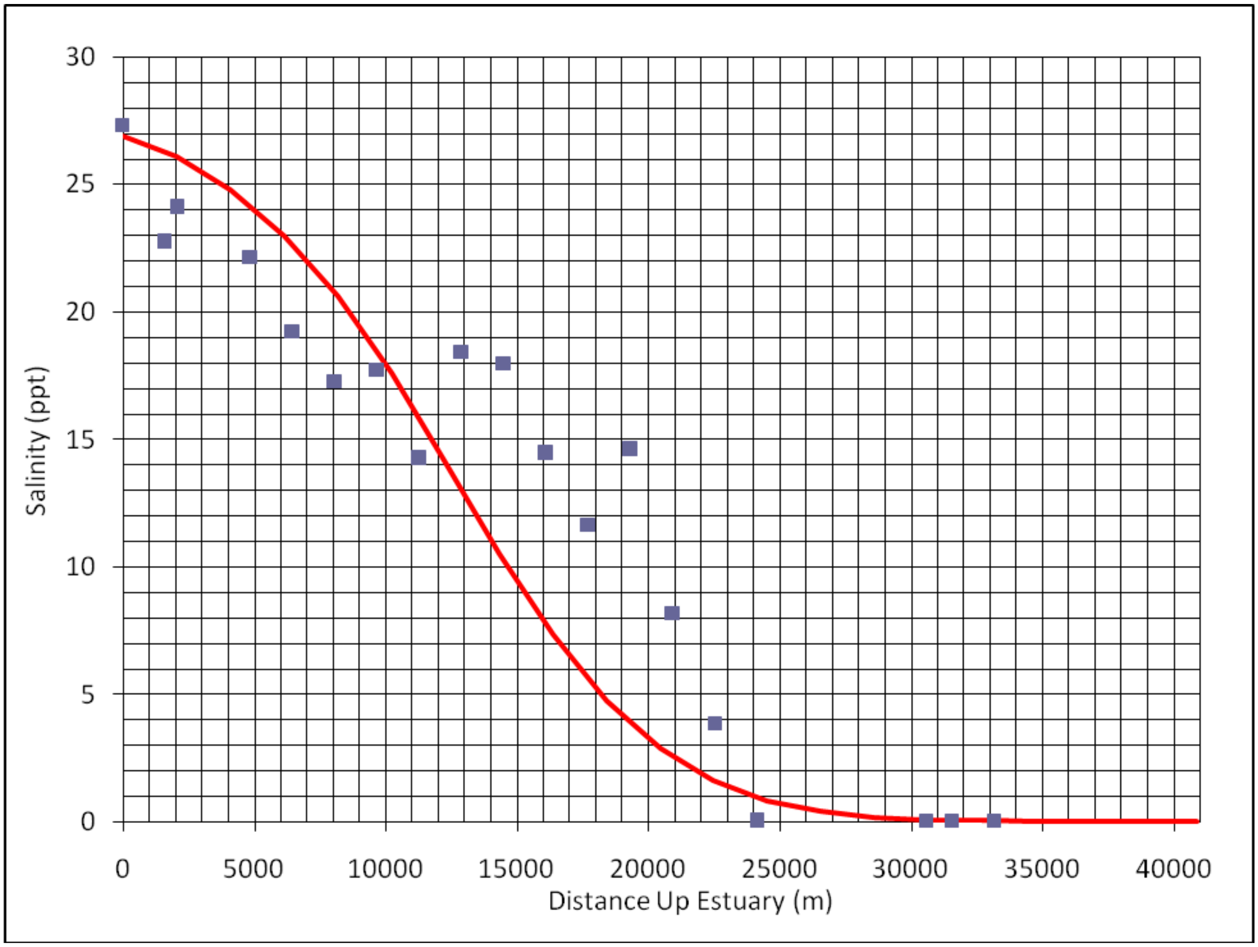

Figure 4.2-1. Model predicted salinity distribution in the Pascagoula River (red line) compared to vertically and tidally averaged salinity measurements (August 1997). Data points indicate sampling locations.

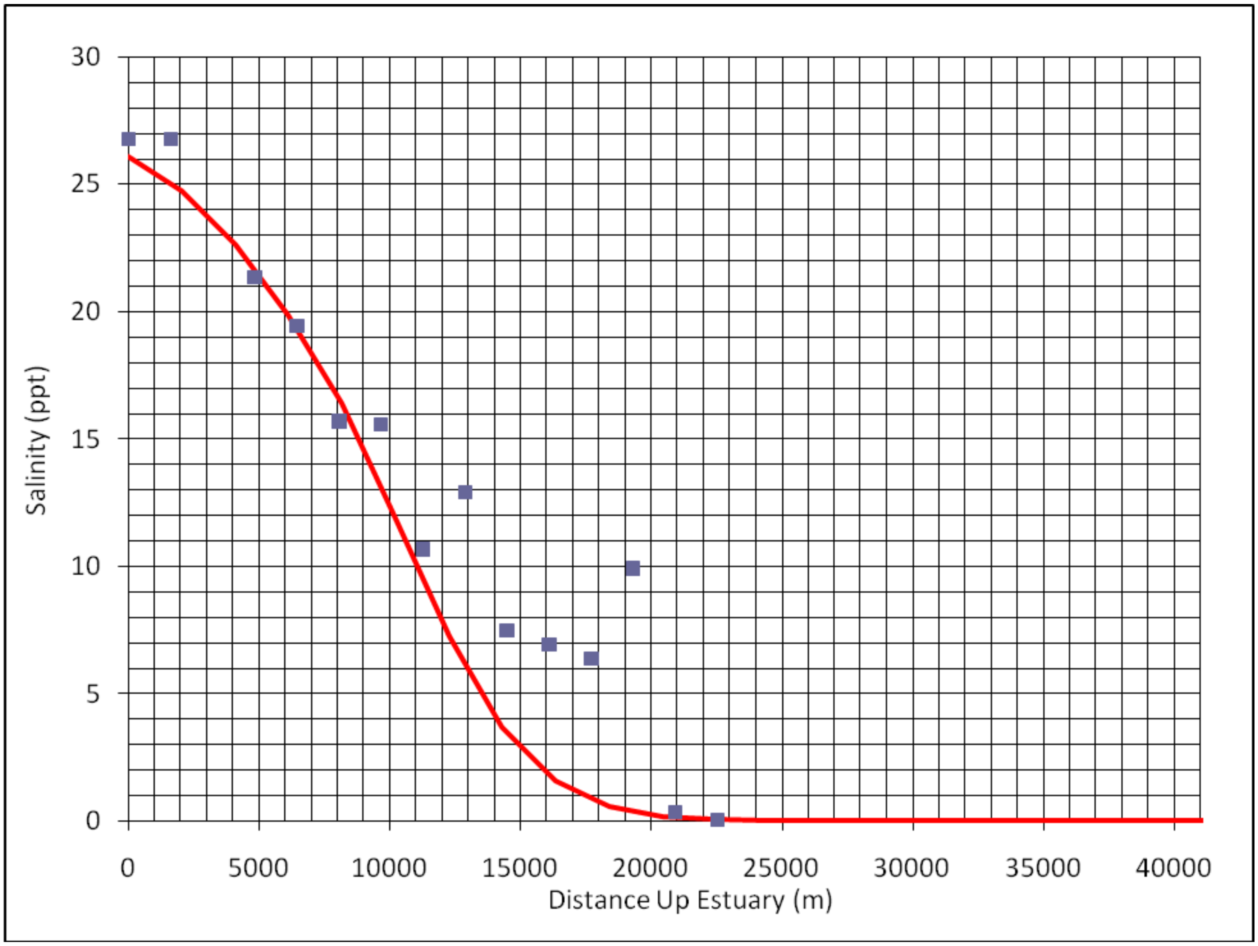

Figure 4.2-2. Model predicted salinity distribution in the Pascagoula River (red line) compared to vertically and tidally averaged salinity measurements (August 1991). Data points indicate sampling locations.

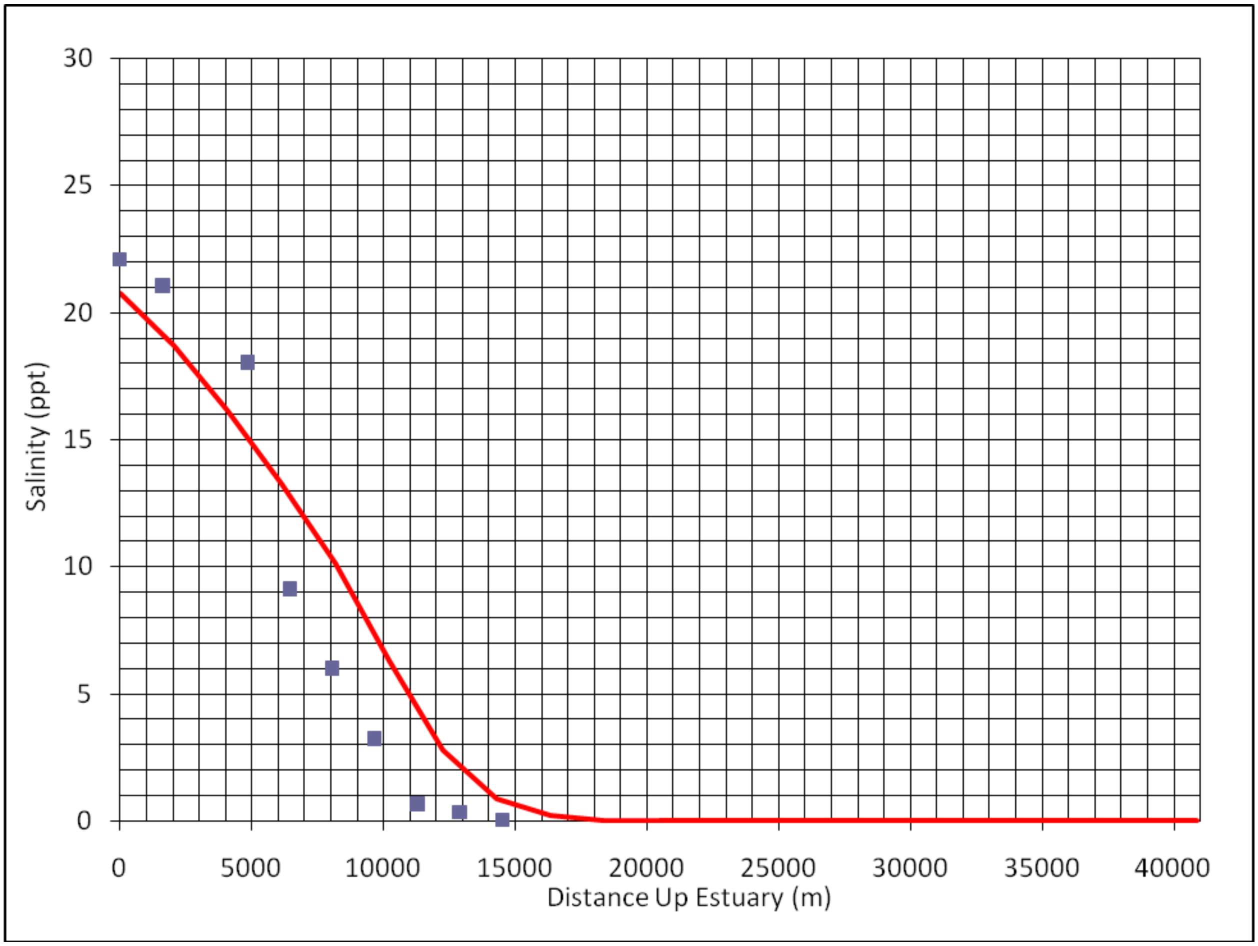

Figure 4.2-3. Model predicted salinity distribution in the Pascagoula River (red line) compared to vertically and tidally averaged salinity measurements (July 1989). Data points indicate sampling locations.

4.3 RWI Impact Analysis

The Richton RWI is expected to remove approximately 190,000 m^3/day (50 MGD) from the Pascagoula River at Merrill. This volume represents about 8% of the 7Q10 flow rate at Merrill. Due to the increase in drainage area size and contribution of freshwater flow from tributaries, the RWI represents only about 6% of the estimated 7Q10 value at Cumbest Bluff, 40.9 km (25.4 mi) from the Gulf of Mexico.

To simulate the worst case effects of the RWI on salinity intrusion in the Pascagoula River, the model was applied to two low flow conditions, 7Q10 and 28.3 m^3/s (1000 cfs), the lowest flow rate at which the RWI will operate. The 7Q10 flow rate of 26.0 m^3/s (917 cfs) at the Merrill gage was transposed to Cumbest Bluff using the 7Q10 flow rate at Vestry, 3.4 m^3/s (121.1 cfs)(MDEQ, 1999), and the methods described in section 3.2.3, giving a 7Q10 flow rate of 38.4 m^3/s (1357 cfs). The 95th percentile tidal amplitude of 0.9 m (2.8 ft) was also used in the model. Salinity at the river mouth was assumed to be equal to the September 2000 scenario, 30.1 ppt.

Figure 4.3-1 provides a comparison of modeled salinities, both with and without the RWI at various locations along the river under the 28.3 m^3/s (1000 cfs) flow condition at Merrill. Figure 4.3-2 provides a comparison of modeled salinities, both with and without the RWI at various locations along the river under 7Q10 flow conditions. The RWI does not have a significant impact on salinity values at the river mouth, however towards the upper reaches of the model domain, the salinity concentration increases by about 0.1 ppt. The model also estimates that the RWI will cause the salt wedge (distance to reach 1% of river mouth salinity) to migrate approximately 1 km (0.6 mi) further upstream.

The HARZA Pascagoula River Low Flow Management studies' salinity intrusion results provide a means for comparing the results of this study. The Phase 4 report (HARZA, 1995) concludes that "under both the 7dayQ_{10} and the 1963 inflows, the maximum upstream occurrence of column averaged salinities above 500 mg/L is RM19…threshold column averaged salinity readings indicate a likely maximum upstream movement of the bottom of the salt water wedge of from one to two miles farther upstream, placing the farthest upstream extent of the salt water wedge between RM 20 and RM21…simulation of the maximum upstream movement of salinity is not appreciable influenced by pumping rates at Cumbest Bluff up to 100 MGD". It is difficult to tell from their description of salt wedge movement, whether the one to two mile change was the result of pumping at Cumbest Bluff; data or plots to support this conclusion were not found in the report. If in fact the movement of the salt wedge calculated in HARZA was due to pumping, then their results are consistent with the conclusions of this study, that the salt wedge is expected to move 1 km (0.6 mi) under low flow conditions.

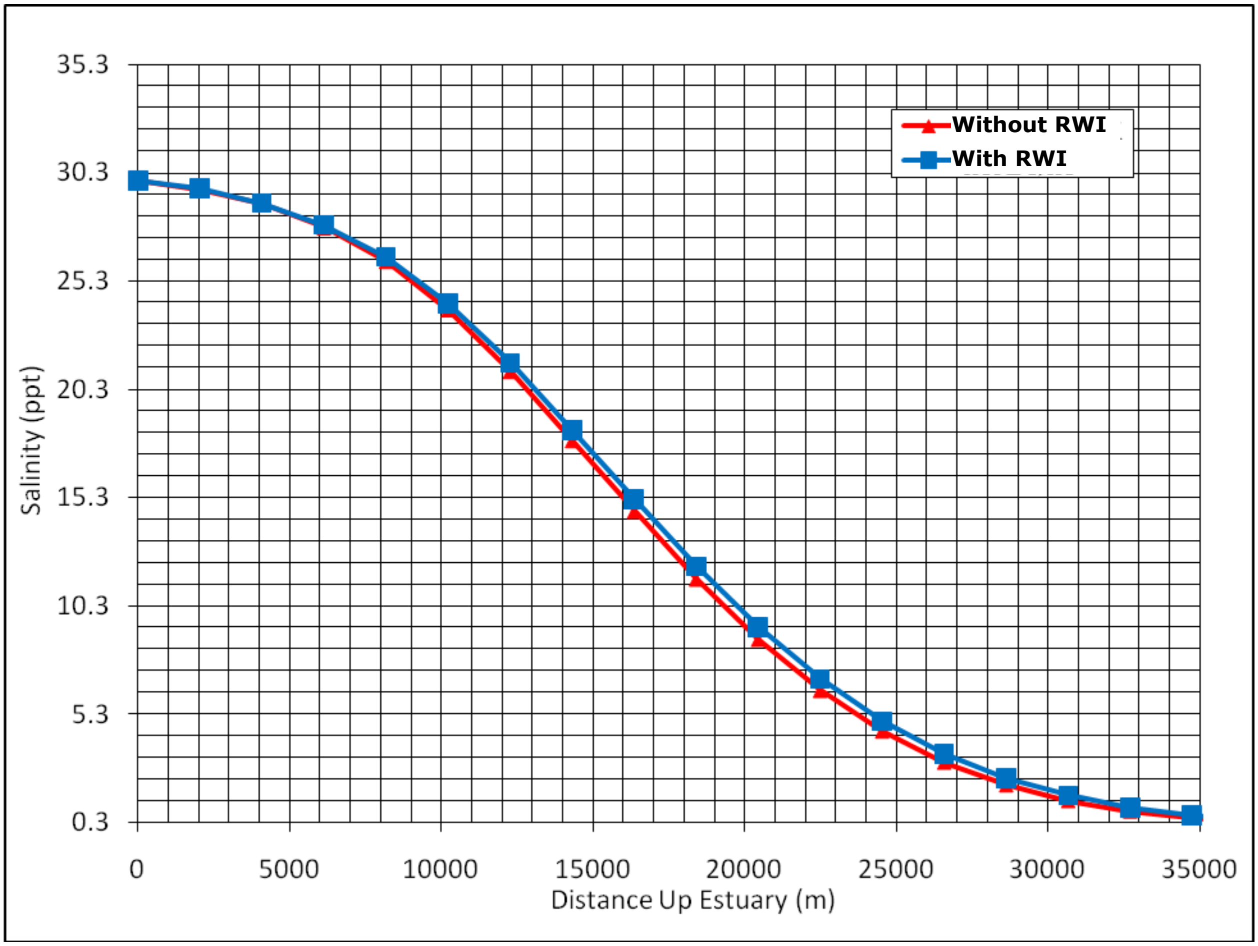

Figure 4.3-1. Model predicted salinity distribution under 28.3 m^3/s (1000 cfs) flow conditions in the Pascagoula River at Merrill both with and without the proposed RWI intake at Merrill.

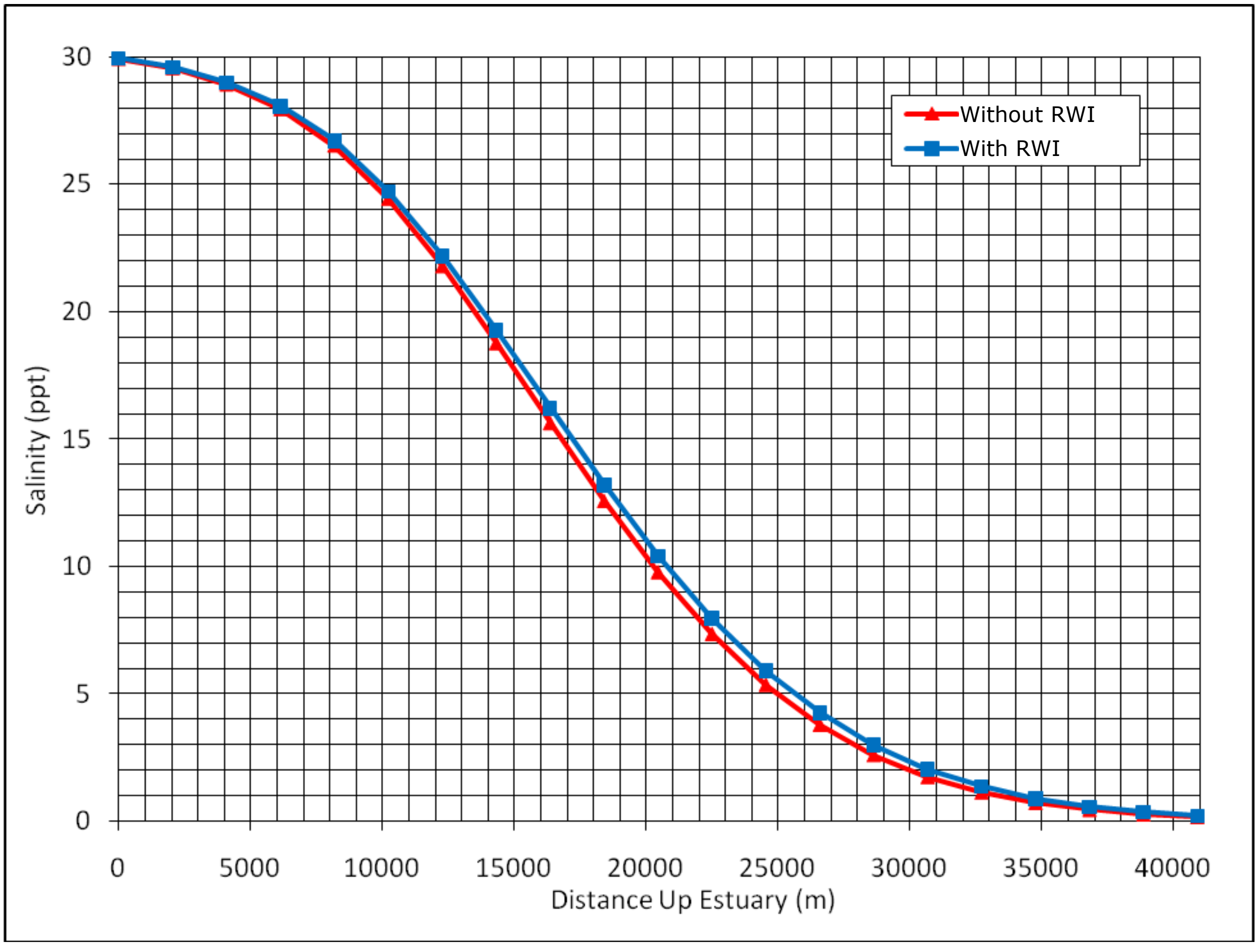

Figure 4.3-2. Model predicted salinity distribution under 7Q10 flow conditions in the Pascagoula River both with and without the proposed RWI intake at Merrill.

Since the 28.3 m^3/s (1000 cfs) and 7Q10 simulations both represent rare low flow conditions, the effects of the RWI were also evaluated at more moderate flow conditions, which are more representative of average flows on the Pascagoula River. Since the flows used in the model validation cases represent 3, 6, and 15 times the 7Q10 flows at Cumbest Bluff, the effects of the RWI were simulated with these cases.

In these three cases, the model did not show any change in the salinity concentration at Cumbest Bluff. Differences in the extent of salinity intrusion with and without the RWI were insignificant, ranging from 0 to 0.2 km (0 to 0.1 mi).

5.0 Summary and Conclusions

A one-dimensional salinity intrusion model (Ippen and Harleman, 1961) was set up and calibrated for the Pascagoula River system. Model inputs included estuary geometry, river flow data, tidal amplitude, period, and velocity, and salinity at the river mouth.

Estuary geometry, tidal period, and tidal velocity were held constant for the calibration, validation, and RWI analysis scenarios. Estuary geometry was determined from USGS cross sections of the Pascagoula and West Pascagoula rivers (HARZA, 1994). Tidal period was set to 24.84 hours, that of a diurnal system. Tidal velocity was derived from the 3-D baroclinic hydrodynamic model of Mississippi Sound that was developed by the USACE ERDC.

Tidal amplitude, river flow, and salinity were determined for each model scenario. Tidal amplitude was extracted from the Tides and Currents software package (Nobeltec, 2000). River flow was taken from USGS gage data at two stations on the Pascagoula River, Merrill (02479000) and Vestry (02479300) and transposed to Cumbest Bluff using the HARZA methods. Salinity data was determined by vertically and tidally averaging the annual USGS salinity profiles (USGS, 2009).

The model calibration was performed using a USGS salinity profile taken during low flow conditions (USGS, 2009). The calibration was necessary to determine two unknown model parameters, seaward excursion distance, B, and apparent diffusion coefficient D'_o. The model calibration has an RMSE of 2.24 ppt which indicates a very good fit to the data.

Three model validations were performed using USGS salinity profiles taken during various flow conditions on the Pascagoula River. The validations used the excursion distance, B, and apparent diffusion coefficient D'_o determined from the model calibration. The RMSE of these scenarios ranges from 2.8 to 4.8 ppt; indicating a good fit to the data under varying flow conditions.

After calibrating and validating the model, it was used to analyze the impacts of the RWI. The model was applied using 28.3 m^3/s (1000 cfs) at Merrill (the minimum flow rate at which the RWI would operate) and 7Q10 flow conditions with the 95^{th} percentile tidal amplitude to ensure simulation of worst case conditions. The differences in salinity between these scenarios with and without the RWI increase with distance up the estuary. At the upper reaches of the estuary, the salinity varies by about 0.1 ppt between the cases with and without the RWI. The upstream extent of the salt wedge, defined as the river location where the salinity is 1% of river mouth salinity, also increases about 1 km (0.6 mi) when the RWI is in use.

Since the 28.3 m^3/s (1000 cfs) and 7Q10 simulations both represent rare low flow conditions, the effects of the RWI were also evaluated at more moderate flow conditions, which are more representative of average flows on the Pascagoula River. Since the flows used in the model validation cases represent 3, 6, and 15 times the 7Q10 flows at Cumbest Bluff, the effects of the RWI were simulated with these cases. For these simulations, the model did not show any change in the salinity concentration at Cumbest Bluff. Differences in the extent of salinity intrusion with and without the RWI were insignificant, ranging from 0 to 0.2 km (0 to 0.1 mi).

6.0 References

Bunch, B. W., M. Channell, W. D. Corson, B. A. Ebersole, L. Lin, D. J. Mark, J. P. McKinney, S. A. Pranger, P. R. Schroeder, S. J. Smith, D. H. Tillman, B. H. Tracy, M. W. Tubman, and T. L. Welp. 2003. *Evaluation of island and nearshore confined disposal facility alternatives, Pascagoula River Harbor dredged material management plan*. ERDC TR-03-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

HARZA, 1994. Pascagoula river low flow management study, Phase 1 through 3 Report, Final. Prepared for the Mississippi Department of Environmental Quality. December, 1994.

HARZA, 1995. Pascagoula River low flow management study, Phase 4 Report, Final. Prepared for the Mississippi Department of Environmental Quality. July, 1995.

Ippen, A.T and D.R.F Harleman, 1961. One-dimensional analysis of salinity intrusion in estuaries. Technical Bulletin No. 5, Committee on Tidal Hydraulics, Corps of Engineers, U.S. Army, June, 1961.

Mississippi Department of Environmental Quality (MDEQ), 1999. Fecal Coliform TMDL forRed Creek Pascagoula River Basin George and Jackson Counties, Mississippi. Mississippi Department of Environmental Quality Office of Pollution Control TMDL/WLA Section of the Water Quality Assessment Branch, Jackson, MS.

Nobeltec, 2000. Tides and Currents for Windows, Version 3.0e, 2000.

Swanson, J.C, C. Galagan, T. Isaji, D. Stuebe, C. Reynolds, 2009. Results from brine discharge modeling for the proposed strategic petroleum reserve Richton expansion site, February, 2009.

United States Geological Survey (USGS), 2007. Water-Data Report 2007: 02479000 Pascagoula River at Merrill, MS, http://wdr.water.usgs.gov/wy2007/pdfs/02479000.2007.pdf, Date accessed: January 29, 2009.

United States Geological Survey (USGS), 2009a. USGS Surface-Water Annual Statistics for Mississippi: USGS 02479000 Pascagoula River at Merrill, MS, http://waterdata.usgs.gov/ms/nwis/annual/?search_site_no=02479000&agency_cd=USGS&referred_module=sw&format=sites_selection_links, Date accessed: February 23, 2009.

United States Geological Survey (USGS), 2009b. Water Quality Samples for Mississippi: Sample Data, http://nwis.waterdata.usgs.gov/ms/nwis/qwdata/, Date accessed: January 29, 2009.