HYDRODYNAMIC AND SALINITY MODELING IN THE PONTCHARTRAIN BASIN:

ASSESSMENT OF FRESHWATER DIVERSIONS AT VIOLET WITH MRGO MODIFICATIONS

Final Report

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EXECUTIVE SUMMARY

The focus of this study was the response of salinity in Lake Borgne, the Biloxi Marshes and Mississippi, Chandeleur and Breton Sounds of the Pontchartrain Estuary, in response to freshwater diversions from the Mississippi River at Violet. Diversions in the range of 5,000 to 15,000 cubic feet per second (cfs) were investigated using the unstructured 3-D Finite Volume Coastal Ocean Model, FVCOM. Model runs simulated spring discharge conditions with representative tides and tributary flows. The spring period corresponds to the time when the Mississippi River is at it maximum annual stage, thus providing the greatest potential hydraulic gradient and highest flow through a given structure.

A base condition simulating existing conditions with no diversion was compared to diversion flows of 5,000, 10,000 and 15,000 cfs. In all of the diversion scenarios, the MRGO channel was constricted by approximately 90% at a location near Bayou La Loutre. Theoretical response times of Lake Borgne for the 5000, 10,000 and 15,000 cfs diversion flows were 4, 2 and 1.3 months, respectively. The corresponding response times for Lake Pontchartrain for the same diversions at the Bonnet Carré are 16, 8 and 5 months.

Model simulations show that salt water inflow along the channel and into Lake Borgne was significantly reduced when MRGO is constricted. Secondly, diversions in the range of 10,000 to 15,000 cfs were effective in lowering the mean salinity in the Biloxi Marsh area by 3 to 5 ppt after 60 days of the effective flow diversion. The influx of freshwater via the Violet Canal shifted the mean 10 and 15 ppt isohalines towards the Gulf of Mexico by approximately 12 miles (20 km). The model indicates that the salinity reduction at the north entrance of the Biloxi Marshes begin in as little as one month after the diversion is initiated. The model results indicate that modification of the MRGO and the introduction of freshwater at the Violet Diversion can significantly change the present salinity regime in Lake Borgne and eastern Lake Pontchartrain. Adaptive management of this and other proposed diversions will be needed to optimize the benefits of these diversions.

The results presented in this report show the feasibility of modifying the salinity regime in the Biloxi Marshes area by flow diversions of the order of 15,000 cfs from the Mississippi River at Violet. Our simulations do not include wind shear, atmospheric pressure or Gulf of Mexico water fluctuations, both of which would tend to increase mixing in the Estuary, resulting in short term upstream and seaward translations of the isohalines.

This study did not address availability of head in the Mississippi River for the diversion flows used in the simulations. The model domain did not include the interior wetlands, and therefore it does not address hydro-periods and flooding of the interior Violet wetlands and associated benefits/impacts. No attempt was made in this study, to assess the environmental impacts of introducing Mississippi River water to Lake Borgne via the Violet Diversion.

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INTRODUCTION AND BACKGROUND

The Lake Pontchartrain Basin is located north of New Orleans in southeastern Louisiana, USA, as shown in Figure 1. This complex estuarine ecosystem consists of three main water bodies that are interconnected by narrow passes, numerous freshwater rivers, as well as shipping canals, outfalls, and surrounding marshes and wetlands. The basin has formed in a shallow depression lying between the alluvial ridge of the Mississippi River to the west and the sloping uplands to the north. Lake Maurepas is located to the west, and is predominantly freshwater, receiving water from the Blind, Amite, and Tickfaw Rivers. Lake Maurepas is connected to Lake Pontchartrain, through a narrow passage called Pass Manchac. Lake Borgne is an estuary located east of Lake Pontchartrain; this estuary has an open boundary with an embayment of the Gulf of Mexico and is connected to Lake Pontchartrain through two natural tidal passes, Chef Menteur Pass and The Rigolets. In addition, the Inner Harbor Navigation Canal (IHNC), which enters into the southeastern corner of Lake Pontchartrain, serves as a third tidal pass. The Mississippi River is separated from the Lake Pontchartrain Basin by levees, but is connected at two locations, the Bonnet Carré Spillway and through a lock at the IHNC. The spillway is a component of the Mississippi River and Tributaries Flood 2 Control project, designed to operate as a relief valve during potential flooding conditions at New Orleans. Table 1 summarizes some of the important data on the physical and demographic characteristics of the Lake Pontchartrain System.

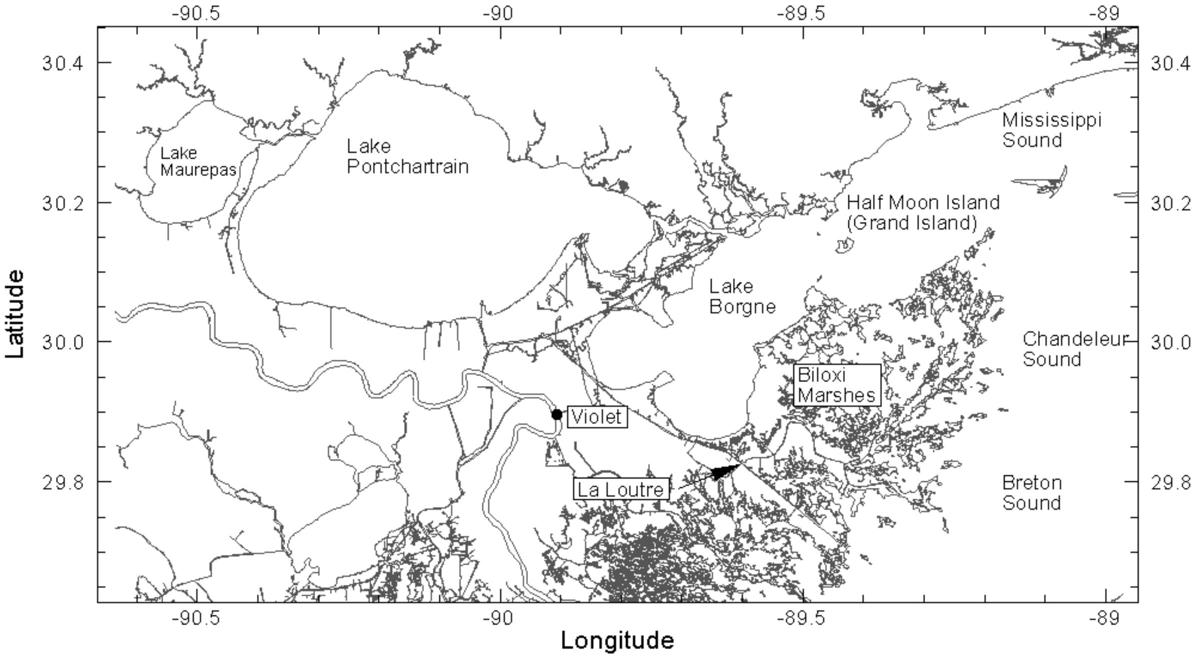

Figure 1 Map of the Pontchartrain Basin

Table 1 Basin Physical and Demographic Data

Basin mean annual rainfall	1.47 m
Basin population	1.5 million people
Lake Pontchartrain average depth	3.7 m
Lake Pontchartrain classification	brackish
Lake Pontchartrain north-south axis	40.2 km
Lake Pontchartrain east-west axis	64.4 km
Lake Pontchartrain surface area	1630 km^2
Lake Pontchartrain uses	fishing, crabbing, swimming, boating
Lake Pontchartrain tides	diurnal; mean range of 0.11 m
Lake Pontchartrain tidal prism	1.6x10^8 m^3
Lake Pontchartrain water column	generally well mixed
Lake Pontchartrain stratification	stronger at certain times near the IHNC
The Rigolets Pass total length average depth cross-sectional area	 14.5 km 8 m 7500 m^2
Chef Menteur Pass total length average depth cross-sectional area	 11.3 km 13 m 2422 m^2
IHNC-MRGO total length average depth cross-sectional area	 30 km 7.5 m 1125 m^2
Pass Manchac total length average depth cross-sectional area	 15 km 8 m 2924 m^2
Lake Maurepas surface area	233 km^2
Lake Maurepas average depth	3.0 m
Lake Borgne surface area	550 km^2
Lake Borgne average depth	2.7 m

* After Haralampides, 2000

STUDY OBJECTIVES

The main objectives of this study were to (using a hydrodynamic model) determine the amount of freshwater required to restore historic salinities in the Biloxi Marshes by diverting water from the Mississippi River at Violet, and assess the effectiveness (at the regional scale) of constricting the MRGO channel at Bayou La Loutre.

METHODOLOGY AND TECHNICAL APPROACH

Hydrodynamic and salinity modeling in the Pontchartrain estuary was performed using the Finite Volume Coastal Ocean Model (FVCOM) to establish baseline (present) conditions. The model was used to simulate water levels, velocity and salinity distributions resulting from tidal variations. Once baseline conditions were established, freshwater diversions from the Mississippi River were introduced at Violet, Louisiana and simulations were repeated to investigate the salinity reduction from each diversion in the Biloxi Marshes. The resulting salinity changes were then compared to proposed target salinities to benefit and enhance oyster productivity in the area. Proposed target salinities were obtained from the Comprehensive Habitat Management Plan (CHMP) by the Lake Pontchartrain Basin Foundation (LPBF, 2006). An image with the target salinities is shown in Appendix A.

MODELING

Model Description

FVCOM is a prognostic, unstructured-grid, finite-volume, free-surface, 3-D primitive equation coastal ocean circulation model developed by the University of Massachusetts at Dartmouth and the Woods Hole Oceanographic Institute (UMASSD-WHOI) joint efforts. The model consists of momentum, continuity, temperature, salinity and density equations and is closed physically and mathematically using turbulence closure sub-models (Burchard, 2002, Mellor and Yamada, 1984). The horizontal grid is composed of unstructured triangular cells and the irregular bottom is presented using generalized terrain-following coordinates or otherwise known as sigma coordinates. The General Ocean Turbulent Model (GOTM) developed by (Burchard, 2002) has been added to FVCOM to provide optional vertical turbulent closure schemes. FVCOM is solved numerically by a second-order accurate discrete flux calculation in the integral form of the governing equations over an unstructured triangular grid. This approach combines the best features of finite-element methods (grid flexibility) and finite-difference methods (numerical efficiency and code simplicity) and provides a much better numerical representation of both local and global momentum, mass, salt, heat, and tracer conservation. FVCOM is written with Fortran 90 with MPI parallelization, and runs efficiently on single and multi-processor machines. The model structure and available modules and sub-models are shown in Figure 2.

For a more detailed description and for information regarding the model’s governing equations, model parameterization, and details on turbulence, numerical methods, and the solution of the governing equations, the reader is directed to Chen et al, 2003.

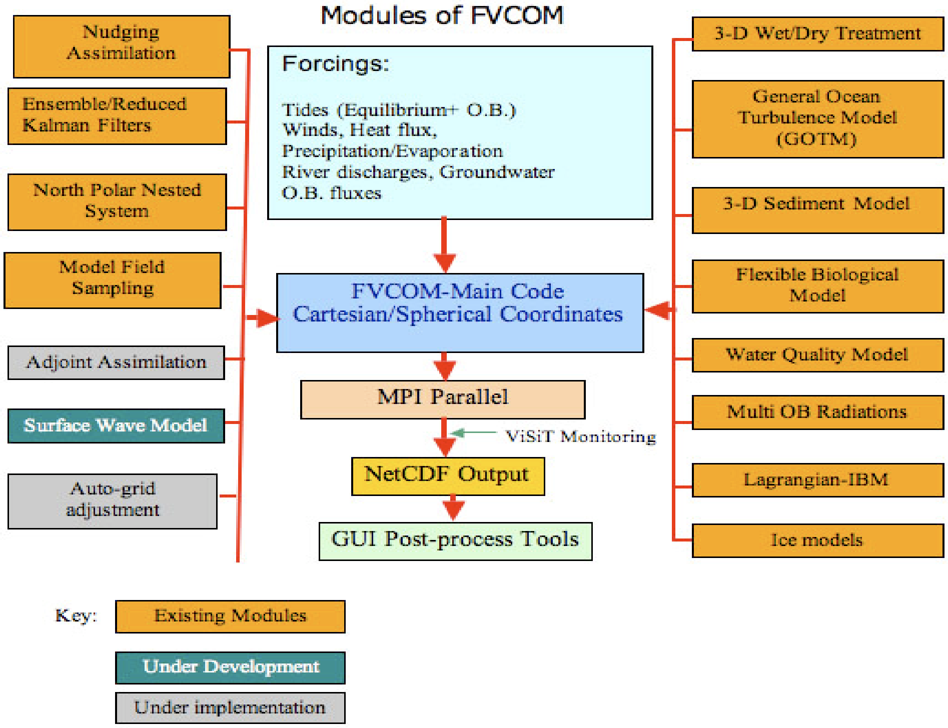

Figure 2 Model structure of FVCOM and available modules/sub-models (Chen et al, 2006)

Model Setup

The model was setup for an area of the Pontchartrain Basin that includes Lakes Maurepas, Pontchartrain and Borgne, the Biloxi Marshes, and the Mississippi, Breton and Chandeleur Sounds. The computational domain consists of 6893 computational nodes and 12780 elements (Figure 3). The horizontal grid resolution varies spatially from 75 m in the MRGO near Bayou La Loutre, to approximately 100 m in the tidal passes. The maximum grid resolution is near the open boundary and varies from 300 – 3000 m. The model consists of 3 vertical layers at this preliminary stage, although versions of the grid with 11 layers will be used in future simulations. Simulation times for the model were 12 hours per 30 day run on a single CPU processor. At the end of the 30 day simulation, the model was hot-started to continue the simulation for the next 30 days. This ensured that file sizes would be manageable for post-processing and analysis.

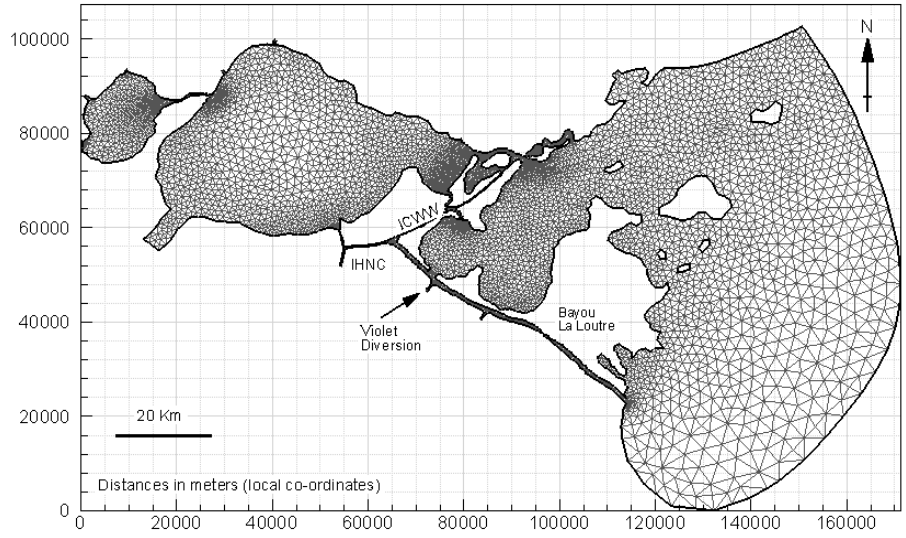

Figure 3 Model computational domain. Resolution varies from 800 m near the open boundary to 100 m in the tidal passes; for the scenarios were the MRGO was constricted, the local element size was 75 meters (similar to ICWW)

Initial Conditions

The model bathymetry for the model was obtained from a combination of sources; National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) hydrographic surveys, and supplements from the US Geological Survey in 1996. Additional data in Breton and Chandeleur Sound were obtained from the Advance Circulation Model grid ADCIRC version SL15v3. The model bathymetry is shown in Figure 4.

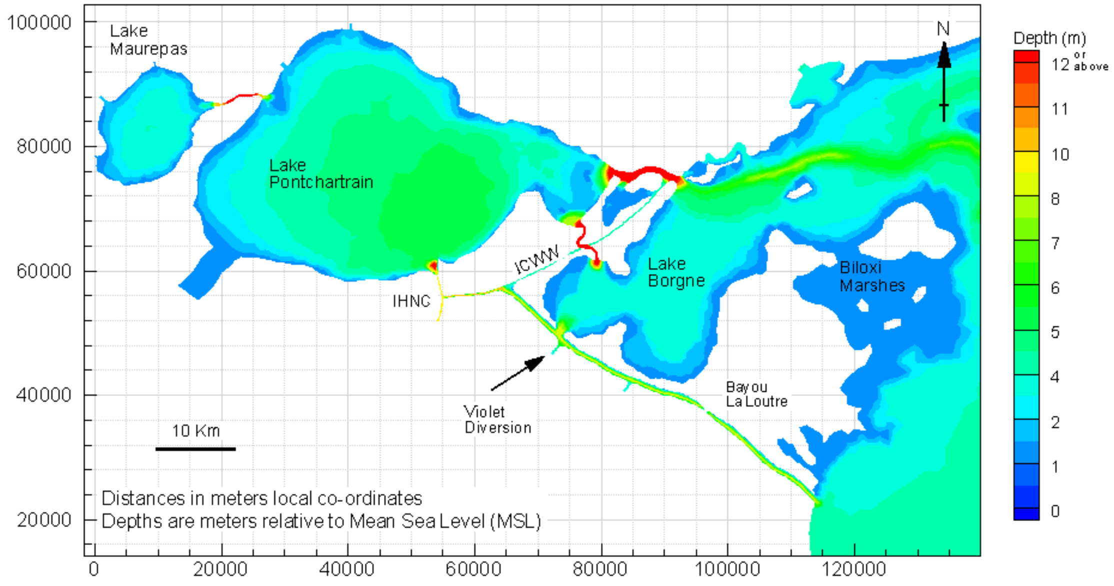

Figure 4 Model Bathymetry relative to Mean Sea Level.

Initial salinity conditions were generated using datasets collected from 1997 through 2002 by Haralampides (2000), Georgiou (2002) and Dr. Martin O'Connell from 2003 through 2006 (pers. comm.). These datasets were used to generate average conditions for a normal year. In areas with little or no data interpolation methods were used to fill the gaps, while maintaining a realistic estuarine salinity gradient. Once a uniform gradient was generated, the model was executed for 30 days with tidal forcing to bring the system to a dynamic equilibrium in the vicinity of freshwater inputs such as tributaries, and in areas with more dynamic conditions such as those near the tidal passes. During this simulation, mean monthly tributary flows were used representing the month of March. Figure 5 shows the distribution of salinities that were used as the initial condition for all simulations.

For all simulations, initial elevation was set to zero (relative to mean sea level – MSL). The model started each simulation from rest (still water surface) and the spin-up times for all boundary conditions (tributary flows and tidal elevations at open boundaries) were of the order of hours.

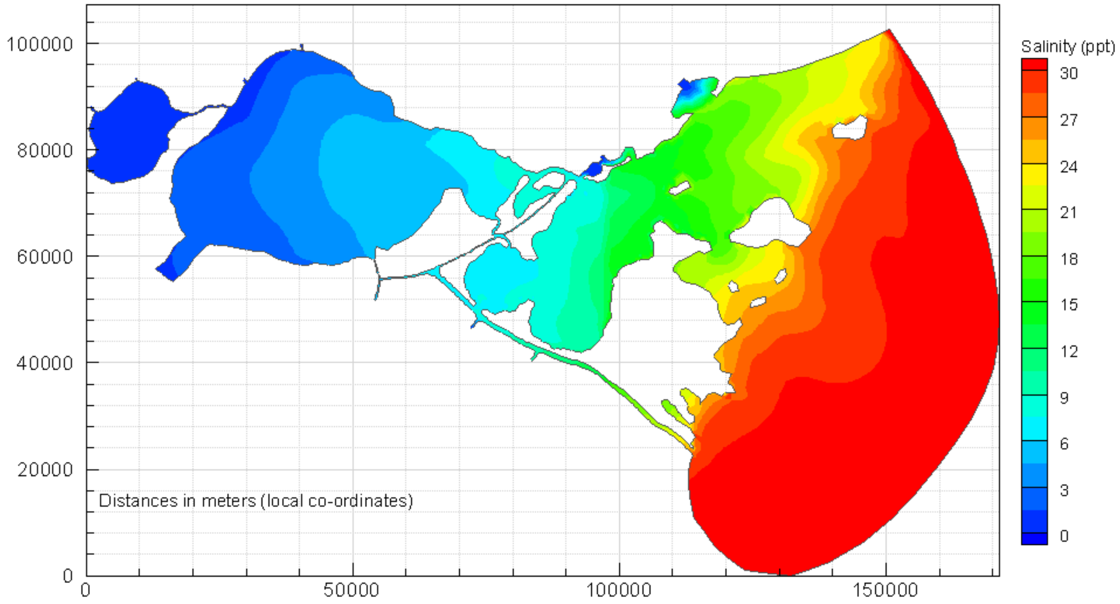

Figure 5 Initial condition for salinity used in the model. The salinity gradient represents average conditions for the last 10 years.

Boundary Conditions

At the open boundary, tides and salinity boundary conditions were used. Forecast tides were generated using a synthetic tide predictor with 4 tidal constituents. Amplitudes and phases of the main tidal constituents for the area were used. Tides in the area are mainly diurnal with varying ranges throughout the estuary. The tidal conditions at the open boundary were the same for all simulations.

Model salinities used at the open boundary represent typical historic seasonal values for the simulation period (spring season, April 1 through May 31th). These values were generated by combining:: (1) discrete measurements taken in the vicinity of the boundary over the last few years by Dr. Martin O'Connell (pers. comm.), (2) extracted values from Gulf of Mexico models and Mississippi Bight models in hindcast simulations performed by the Naval Research Laboratory, Ocean Dynamics and Prediction Branch and posted on their website http://www7320.nrlssc.navy.mil/projects.php. Similar to the tidal boundary conditions, salinity boundary conditions at the open boundary were the same for all simulations.

Tributary discharges were also applied for all major rivers flowing into the Pontchartrain Basin including the Amite, Blind, and Tickfaw in Lake Maurepas, the Tangipahoa and Tchefuncte Rivers in Lake Pontchartrain, the Pearl River near the Louisiana and Mississippi State line, and the Wolf and Jordan Rivers in Bay St. Louis. Monthly mean flows were used in the model and were based on a ten-year record from 1991 to 2001, except for the Wolf and Jordan Rivers, were seasonal median flows were used based on the record length. Tributary flows are shown in Figure 6.

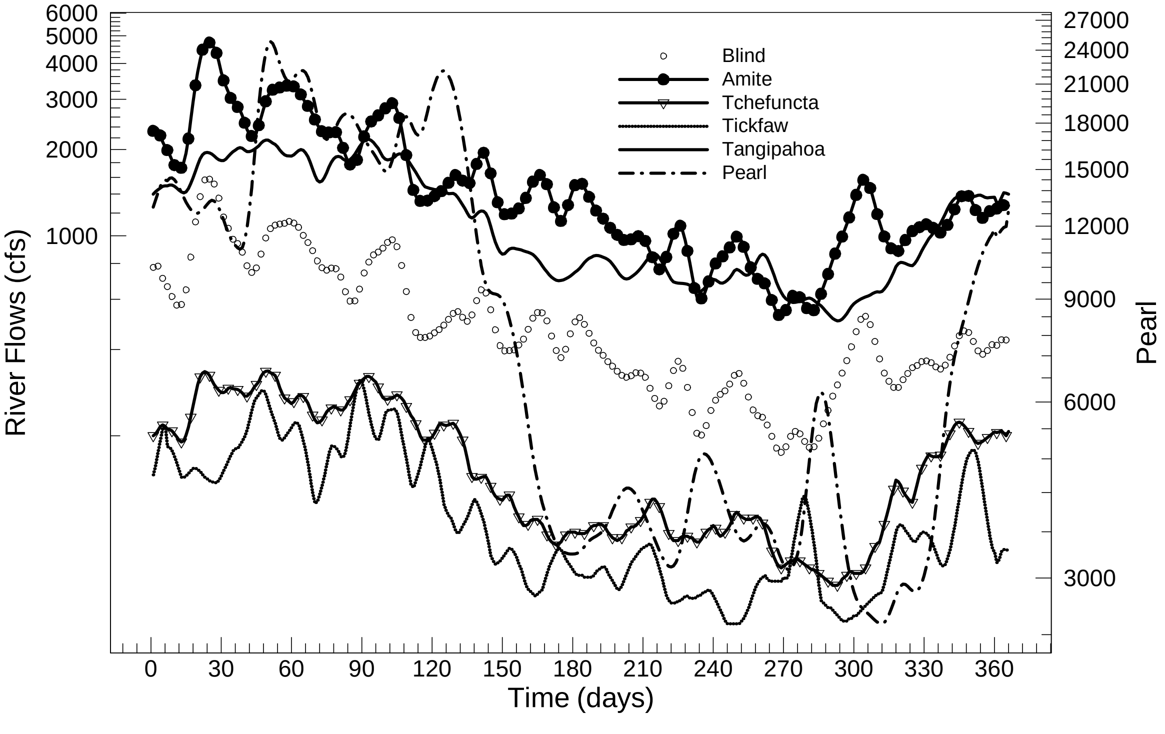

Figure 6 Tributary flows used in the model; Flows represent a 10 year average of the mean daily flow for each day. Spring flows from Jordan and Wolf Rivers are not shown here; median flows were used in the model simulations.

CALIBRATION AND VALIDATION

The model was calibrated to reproduce tidal variations throughout the basin and predicted tidal flow through the main tidal passes and the navigation complex (Intracoastal Waterway – ICWW, Inner Harbor Navigation Canal – IHNC). Discharge measurements in the tidal passes performed in August 1997 by the U.S. Geological Survey and the University of New Orleans were used to validate the model data. An Acoustic Doppler Current Profiler (ADCP) was used to collect synoptic data across the channel. Three-dimensional velocity profiles were integrated to calculate discharge across the channel with each boat pass. The survey was completed within 2 days. The discharge data were used to compute the tidal prism through one tidal cycle. Figure 7 shows the flow distribution in thousands of cfs per tidal pass.

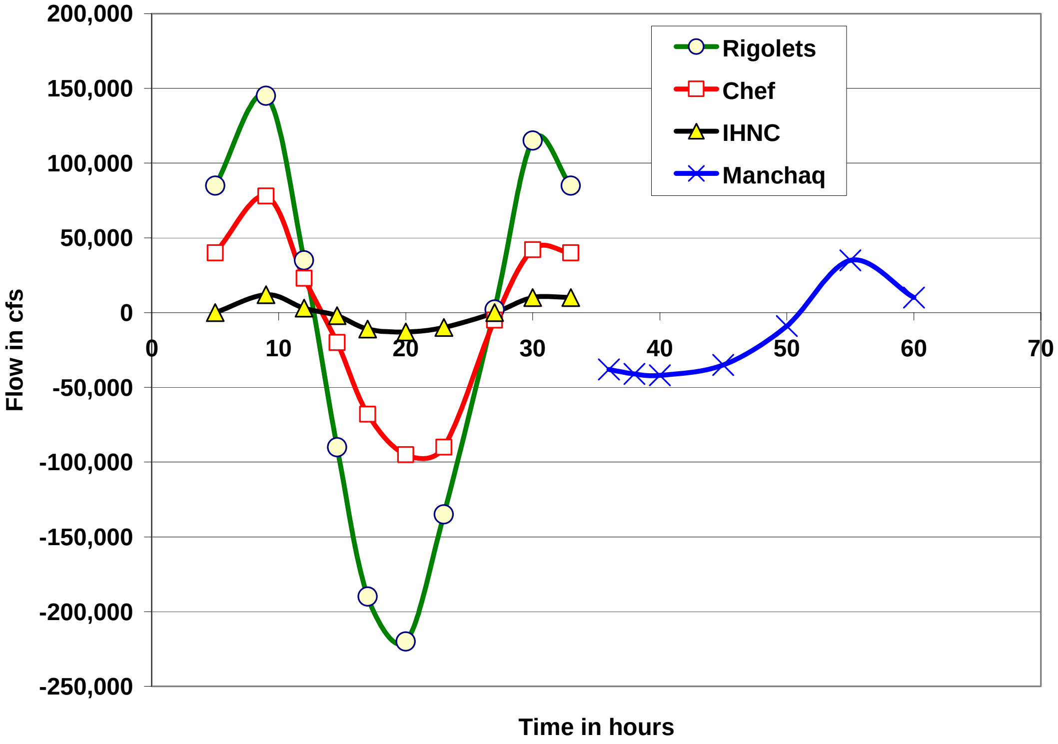

Figure 7 Tidal flow surveys through the Passes, August 1997 (after Haralampides, 2000)

The measured flows in the tidal passes were used to calibrate the model. Local depth, elevation and velocities were extracted from the model to compute tidal flows through the passes. Parameters such as bottom roughness were varied until the desired results were obtained. A summary of the flow comparisons is shown in Table 2. Table 3 shows the comparison of the observed and simulated tidal range and phase for four locations throughout the basin.

Table 2 Simulated and Observed flows for August 1997.

	flows in (cfs)	IHNC	Chef Menteur Pass	Pass Manchac	Rigolets	Total
Observed	Flood/Ebb	13,000	85,000	35,000	180,000	313,000
	Error (±4%)	(520)	(3,400)	(1,400)	(7,200)	(12,520)
Simulated	Flood/Ebb	15,500	82,000	36,500	175,000	309,500
	Difference	2,500	3,000	1,500	5,000	3,500

* A measurement error of less or equal to 4% of the total flow is assumed for ADCP measurements.

* Measured and simulated flow is the maximum during the tidal cycle, and is averaged for Flood and Ebb.

Table 3 Simulated and observed tidal ranges and phases for the spring tide

		Lake Pontchartrain	Rigolets Pass	Half Moon Island	Pass Manchac
Simulated	Range (m)	0.16	0.43	0.66	0.15
	Phase (hours)	23	23	24	23
Observed	Range (m)	0.17	0.31	0.65	0.16
	Phase (hours)	24	25	25	26

* Calibration for tides is based on diurnal signal.

MODEL RESULTS

Seasonal Simulations (Spring)

Surface salinity distributions for no diversion and constant diversions of 5,000 cfs, 10,000 cfs, and 15,000 cfs are presented in Figures 8, 9, 10, 11, respectively. In the baseline conditions, or no diversion case (Figure 8), some freshening occurs due to spring flows in the Pearl River in the vicinity of the Half Moon Island. This periodic effect is typical for the season but it will diminish with the approach of lower tributary flows and higher evaporation rates in the summer months. Figure 9 shows the results from a constant diversion of 5,000 cfs at Violet. The model shows an immediate response in the vicinity of the diversion in the southern part of Lake Borgne; however, isohalines in the vicinity of Half Moon Island and the north entrance to the Biloxi Marshes are only somewhat shifted after a period of 60 days. This indicates that the impact from such a diversion will be primarily local, primarily in the Lake Borgne area.

Figures 10 and 11 show the results from diversions of 10,000 cfs and 15,000 cfs respectively at the end of a 60-day simulation, corresponding to the period from April 1st through May 31th. Both simulations show a more pronounced freshening effect in the vicinity of the Biloxi Marshes. It is noted however, that in the absence of continued diversion flow the system is unable to maintain the freshening effect in the area and maintain gradients beyond Half Moon Island and the north entrance to the Biloxi Marshes diminishes rapidly. Freshwater that arrives from the diversion at Violet travels from Lake Borgne southward toward Half Moon Island across Malheureux Point and into the Biloxi Marshes. In a similar way, the effect of the Pearl River takes place north of the Island, and helps maintain a stable gradient with a south to north orientation. Tidal fluctuations during spring tides tend to retard the advance of the freshening effect; however, during neap tides the rate of advance is enhanced.

Typical locations of the seasonal mean 10 ppt and 15 ppt isohalines from no diversion and a diversion of 15,000 cfs are shown in Figure 12. The approximate shift of the 10 ppt isohaline is 20 km (12 miles) seaward. Table 4 shows the variability in the surface salinity relative to the mean 10 ppt and 15 ppt isohalines. This variability represents the temporal changes due to tidal forcing/pumping.

Table 4 Variability in the surface salinity relative to the mean location of the 10 ppt and 15 ppt isohalines.

	Diversion of 10,000 cfs Standard Deviation	Diversion of 15,000 cfs Standard Deviation
Mean 10 ppt Isohaline Position	1.2 – 1.7	1.4 – 2.2
Mean 15 ppt Isohaline position	1.3 – 2.0	1.5 – 2.5

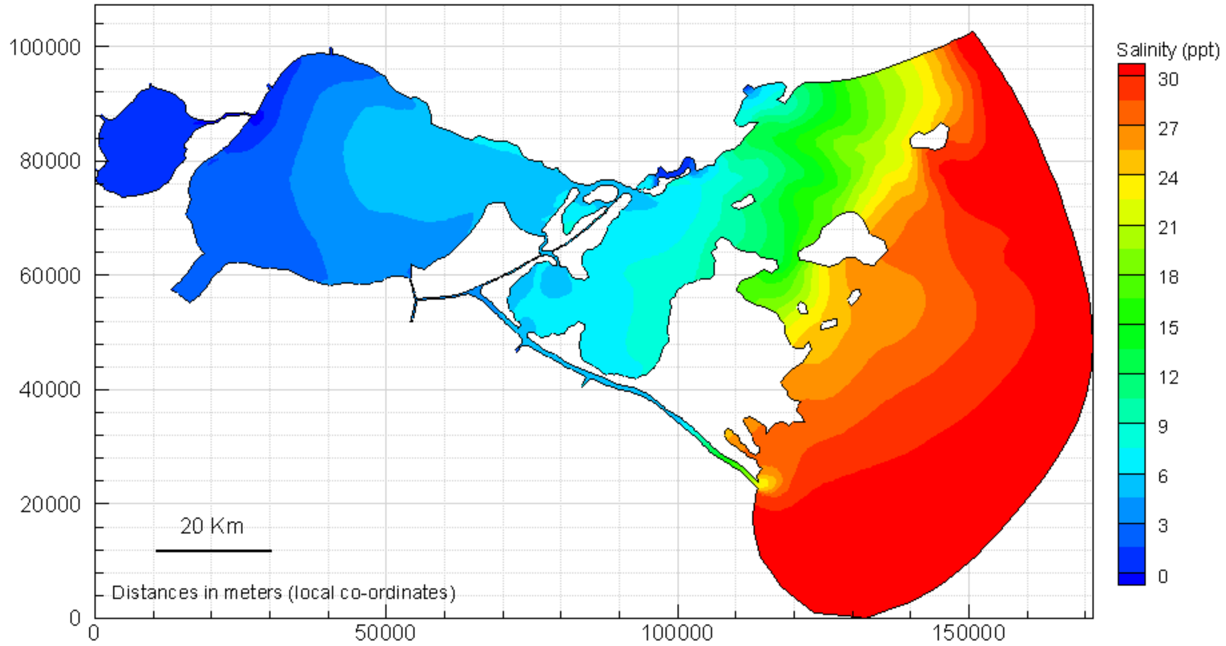

Figure 8 Simulated Salinity after 60 days of simulation without a diversion at Violet.

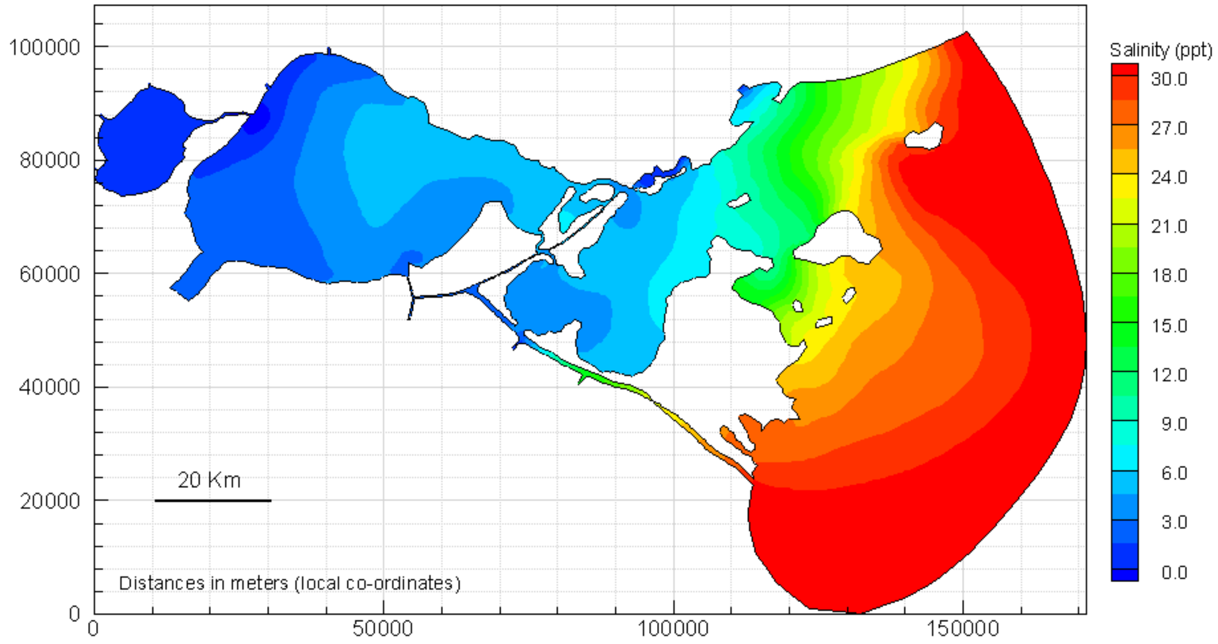

Figure 9 Simulated Salinity after 60 days of 5,000 cfs diversion at Violet.

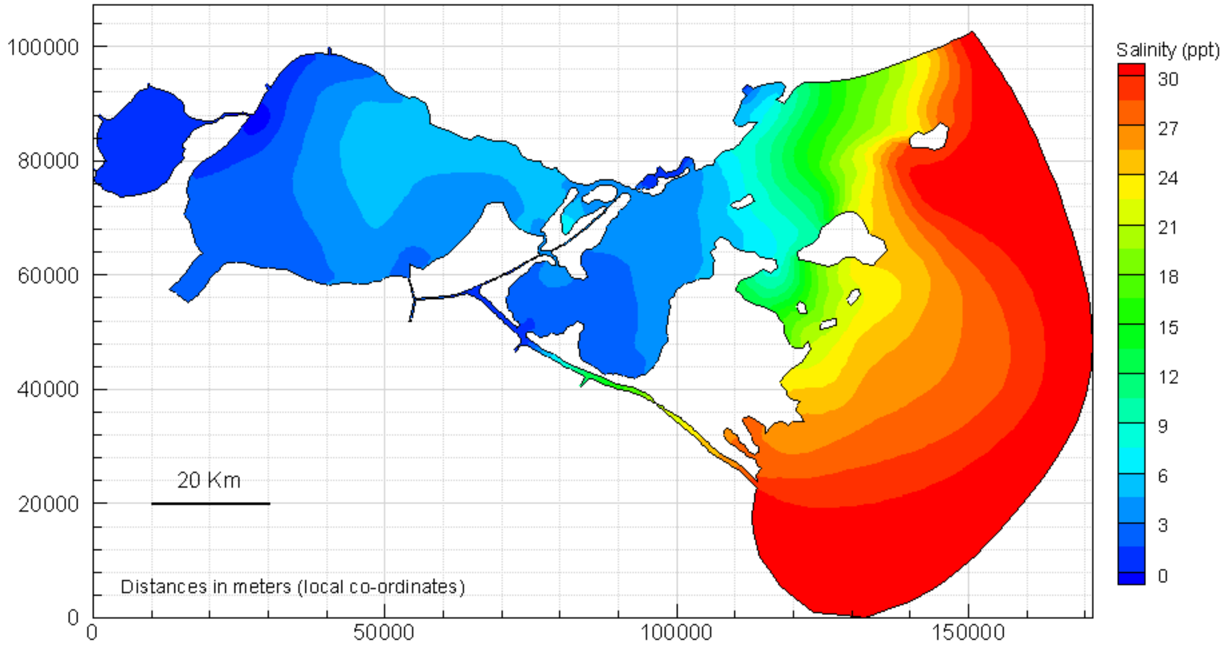

Figure 10 Simulated Salinity after 60 days of 10,000 cfs diversion at Violet

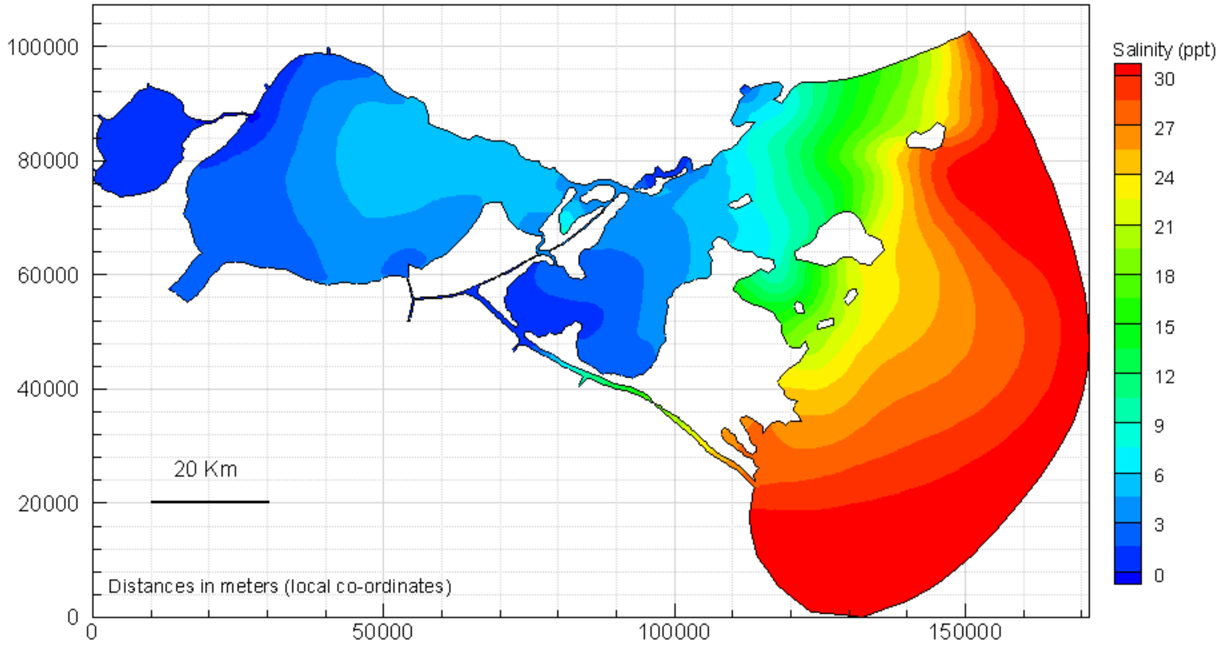

Figure 11 Simulated Salinity after 60 days of 15,000 cfs diversion at Violet.

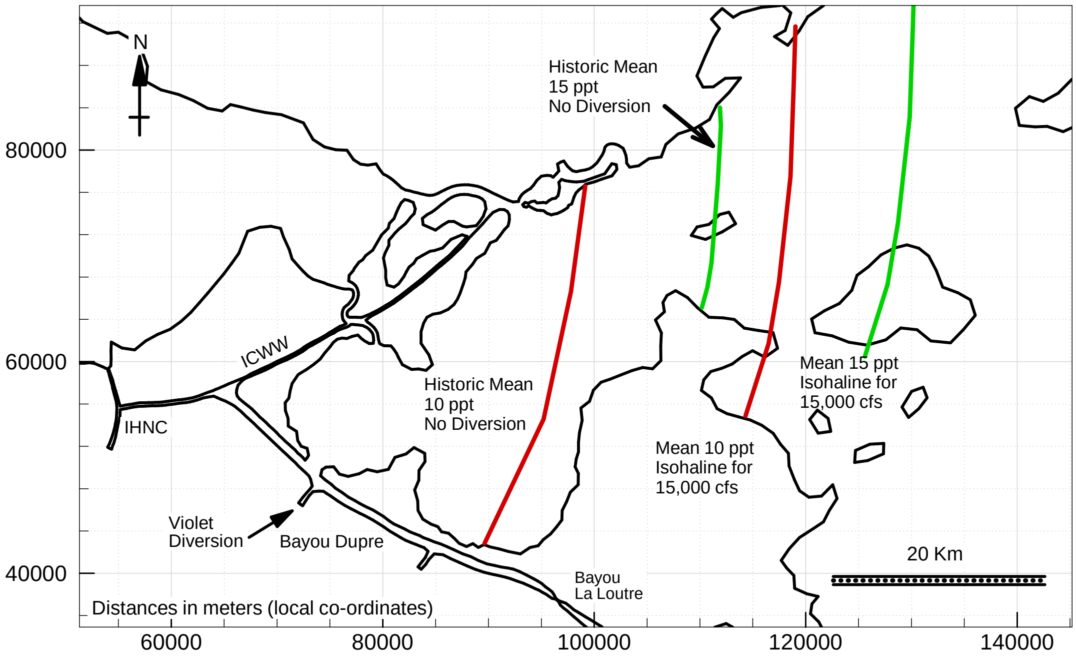

Figure 12 Comparison of 10 ppt isohalines for no diversion, and for a diversion of 15,000 cfs at Violet after 60 days of operation at the specified flow.

Annual Simulations

In addition to seasonal 60 day simulations during the spring season, where diversion flows can be generally higher than any other season due to the higher stage in the Mississippi River, simulations for the entire year were also performed. These simulations were conducted with more realistic boundary conditions for the diversion and tributary flows. For instance, a run-of-the-River hydrograph was used for two simulations one with 5,000 and one with 15,000 cfs. Both signals in the model follow the Mississippi River seasonal flow fluctuations and peak during spring at 5,000 cfs and 15,000 cfs respectively. The remaining season, flows are generally lower and hence allow salt fluxes from the Gulf to be diffused and mixed into the Estuary. Other boundary conditions during these simulations were kept constant to simplify the comparison between the simulations. Figure 13 shows the Violet diversion flows used in these annual simulations. Despite the use of monthly mean flows, the model internally uses a flow value interpolated onto the model time step, which is of the order of seconds. Tributary flows from Figure 6 were also used for these simulations. Tidal characteristics were kept the same as in previous simulations. Figures 14 through 17 show the annual average salinity distribution from all simulations, including 2 existing cases (no diversion), one with constriction and one without constriction of the MRGO.

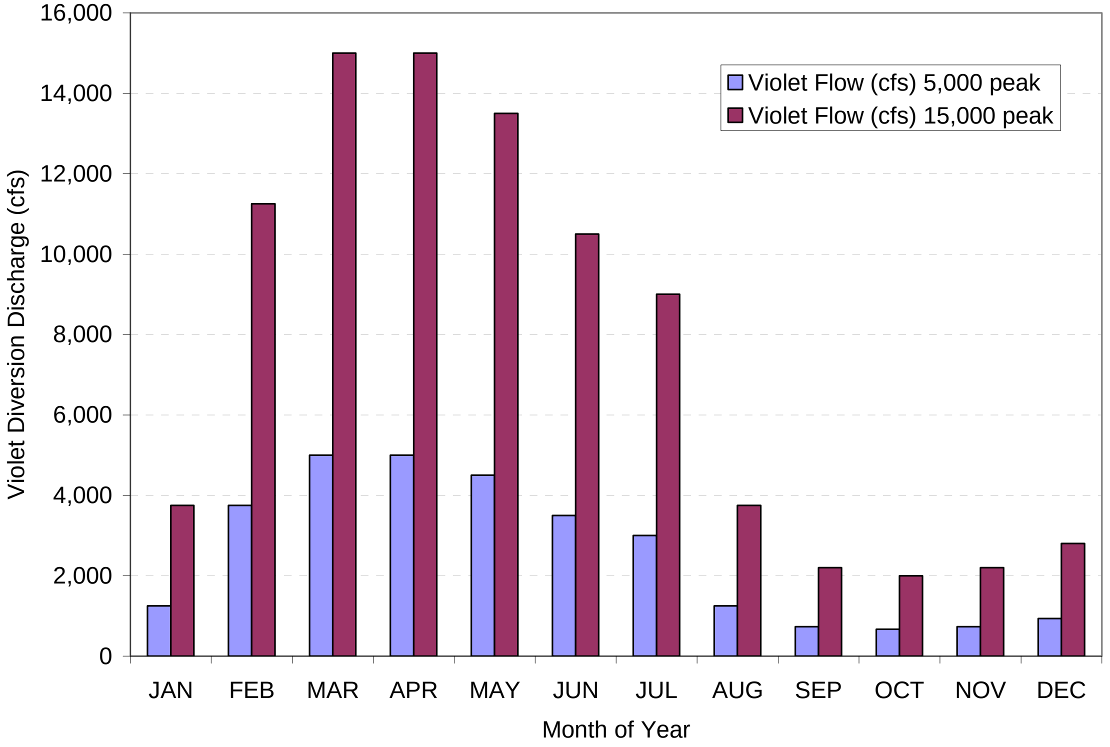

Figure 13 Run-of-the-River hydrographs used to simulate a typical year of Diversion at Violet. The Flows peak at 5,000 cfs and 15,000 cfs respectively in the spring, and follow the Mississippi River signal and stage availability for the remaining seasons as observed historically.

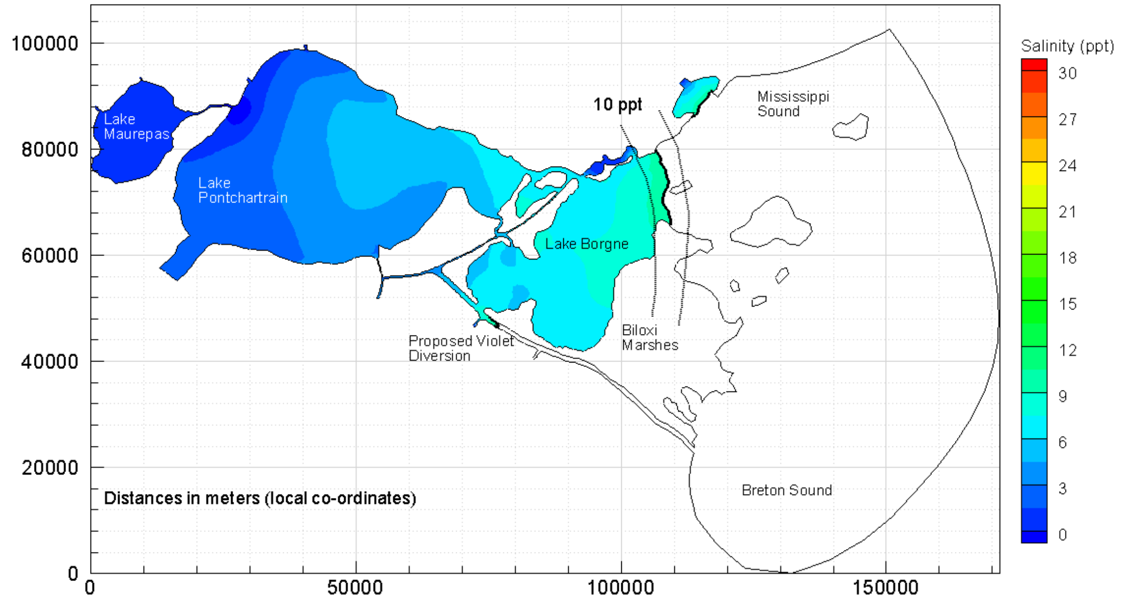

Figure 14 Distribution of average salinity and location of the 10 ppt isohaline after 1 year simulation with average monthly tributary flows; normal year conditions; MRGO is open at Bayou LaLoutre; precipitation was assumed to be equal to evapo-transpiration; Base 1.

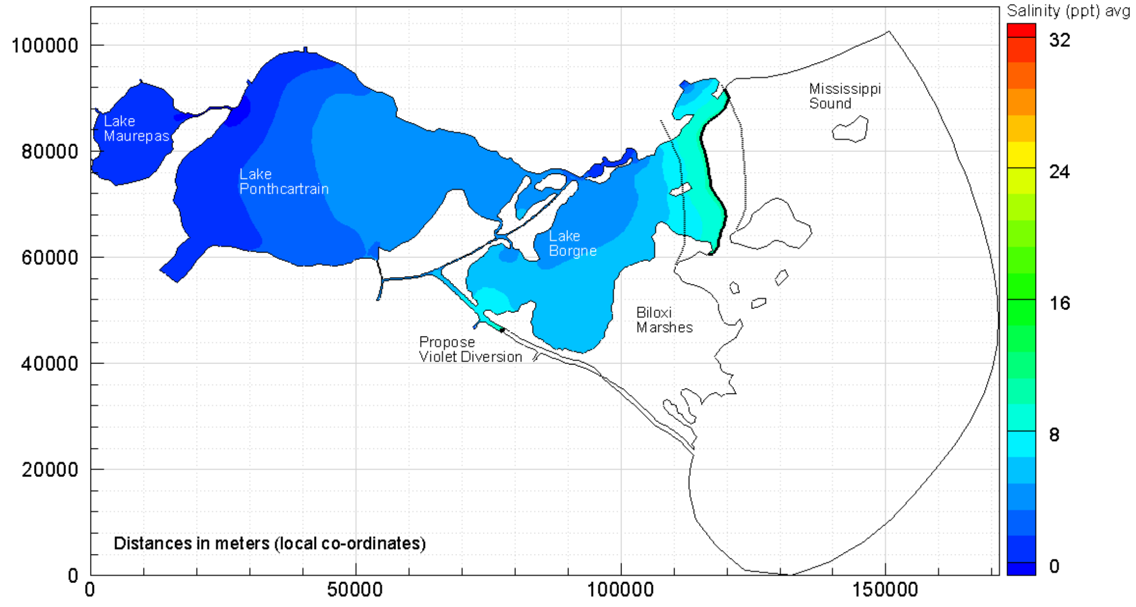

Figure 15 Distribution of average salinity and location of the 10 ppt isohaline after 1 year simulation with average monthly tributary flows; normal year conditions; MRGO is constricted at Bayou LaLoutre; precipitation was assumed to be equal to evapo-transpiration; Base 2.

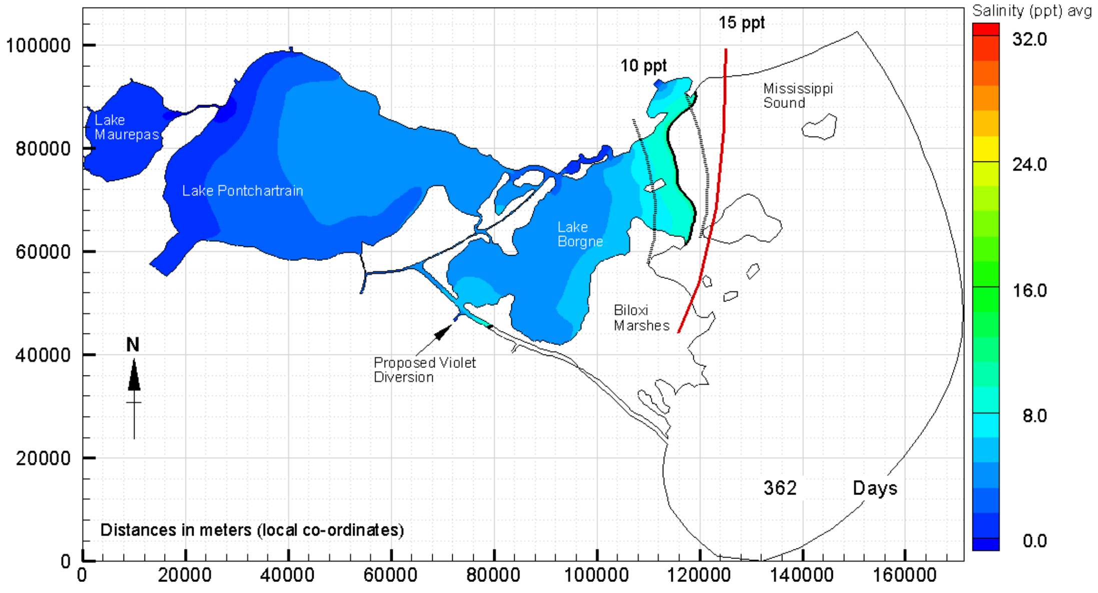

Figure 16 Average salinity distribution after one year simulation with a run-of-the-river hydrograph at Violet with a peak flow of 5,000 cfs. The solid line indicates the location of the 10 ppt isohaline; dotted lines indicate the uncertainty in the simulation; MRGO is constricted at Bayou LaLoutre; precipitation was assumed to be equal to evapo-transpiration.

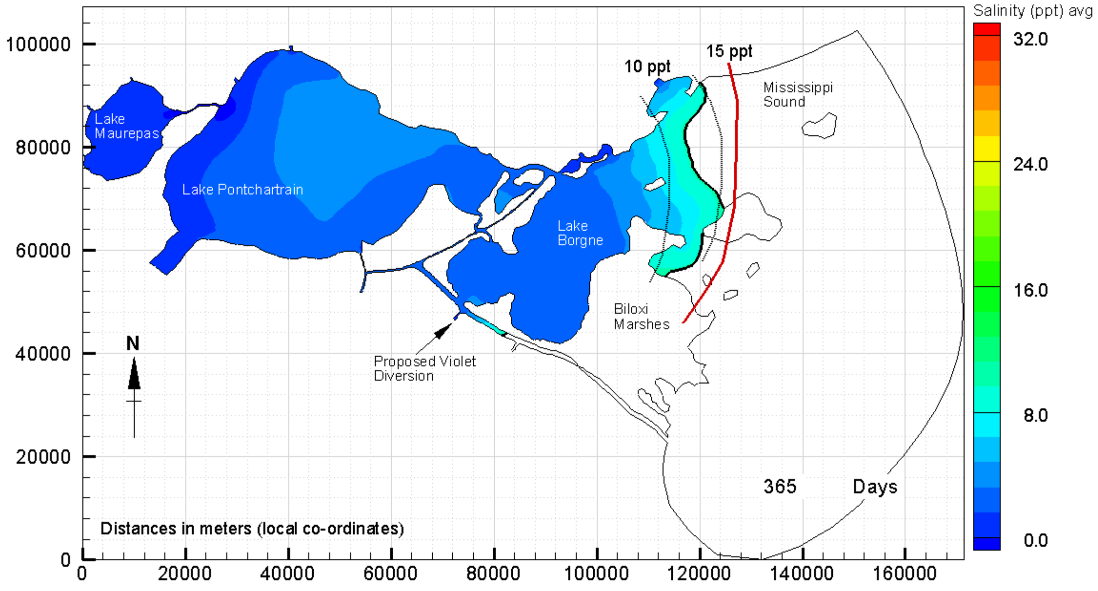

Figure 17 Average salinity distribution after one year simulation with a run-of-the-river hydrograph at Violet with a peak flow of 15,000 cfs. The solid line indicates the location of the 10 ppt isohaline; dotted lines indicate the uncertainty in the simulation; MRGO is constricted at Bayou LaLoutre; precipitation was assumed to be equal to evapo-transpiration.

Figure 14 shows the distribution of the salinity with typical tributary flows, existing MRGO and no diversion after one year simulation. It is noted that despite the fact that there is no diversion some freshening does occur, and an eastward displacement of the 10 ppt isohaline can be noted, shown here as a solid black line. Salt fluxes into the estuary are primarily tidally depended, but large transport of salt in the estuary can be attributed to small surges from barometric systems, sustained easterly winds, and tropical activity during the summer months. Except for tidal flows, the other modes of transport during these simulations were neglected. Figure 14 also shows the fluctuations about the 10 ppt isohaline. An uncertainty was computed using standard deviation analysis, to delineate a region of uncertainty for the results. Dotted lines show the limit of the uncertainty in the simulation, which is noted here as ±1 standard deviation. Standard deviations in the estuary, computed for the entire year using a 12 hr temporal sampling scale, vary widely from near 0.2 ppt in the upper estuary to nearly 3.5 ppt near and west of Cat Island, in Mississippi Sound.

The selection of the capacity of the diversion structure is critical to avoid high costs associated with higher than necessary capacity; however, the capacity must be adequate to ensure that the diversion objectives can be met during critical seasons of high salinity such as droughts. Time series plots of salinity from both simulations are shown in Figures 18 through 22. These plots represent locations of interest in the estuary, and help identify the main differences between the two proposed diversion hydrographs with peaks of 5,000 and 15,000 cfs respectively.

Figure 18 shows the time histogram of the near surface salinity in ppt for a location near the LUMCON weather station, located near the mouth of the Tangipahoa River. We note that while no significant change exists between the two diversion signals for the first few months of operation, after approximately five months, the 15,000 cfs signal appears to produce freshening in the western part of the Lake by approximately 0.3 – 0.5 ppt. Similarly, Figure 21 shows some freshening of the eastern part of Lake Pontchartrain in the range of 0.8 – 1.2 ppt. Figures 20 and 22 show that the major difference between the two proposed diversions signals, in that the effect of the 15,000 diversion is far more pronounced during the flow peak, producing additional reduction in salinity of the order of 4 ppt near Half moon island and at the entrance to the Biloxi Marshes; the effective reduction however is reduced in the summer and fall seasons where flow is lower and the signals converge. As expected, the effect of the diversion becomes smaller as we move east to the Sound. This is clearly shown in Figure 19. The north tip of the Marsh where data were extracted is southwest of Cat Island just inside the main pass. This area opens to Chandeleur Sound, and is the main pathway for tidal currents into the Pontchartrain Estuary. Figure 19 shows that during the start of the spring season, and during the end of the year, the difference that the two diversion flows (5,000 and 15,000) produce is less than 0.5 – 0.7 ppt, while during the spring peak flows the signals mean appears to have been sifted by as much as 2 ppt. This indicates that the effect of a high diversion flow in this area is rather minimal during the end of summer and fall season, but more effective clearly during the spring. Based on Figures 18 through 22, the appropriate flow to meet the objectives appears to be a combination of the two proposed flows with reduced diversion flows during periods when the Pearl River flow is high.

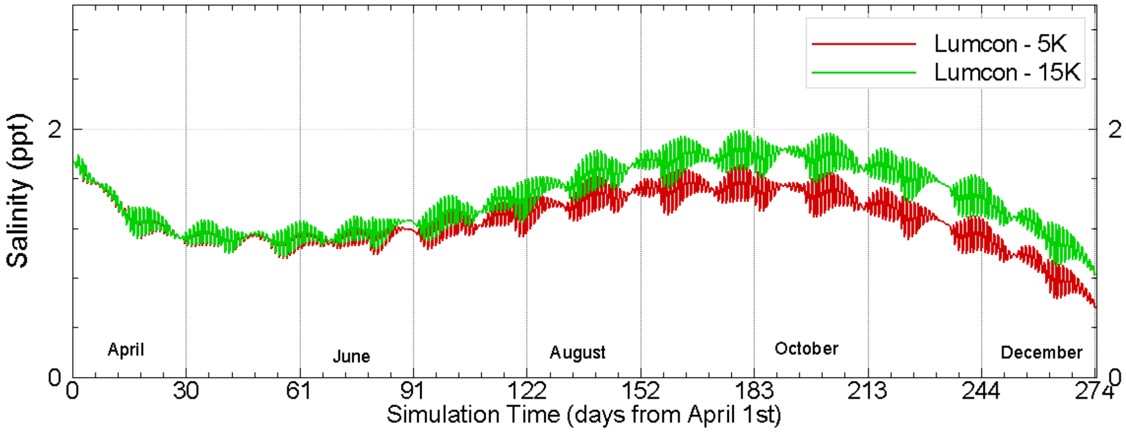

Figure 18 Simulated near surface salinity near the LUMCON station with a run-of-the-River hydrograph signal at Violet (Solid green and red lines represent the 5,000 cfs and 15,000 cfs flow peak respectively)

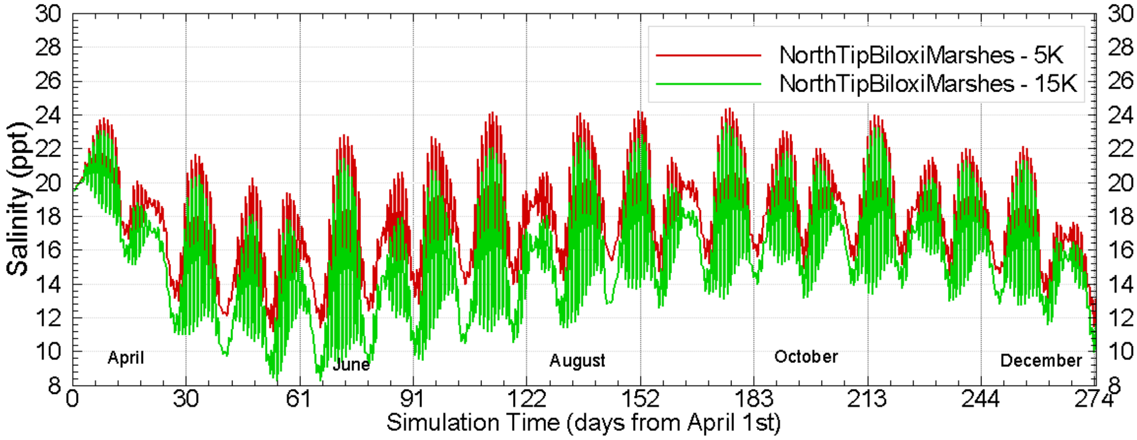

Figure 19 Simulated near surface salinity near the North tip of the Biloxi Marshes with a run-of-the-River hydrograph signal at Violet (Solid green and red lines represent the 5,000 cfs and 15,000 cfs flow peak respectively)

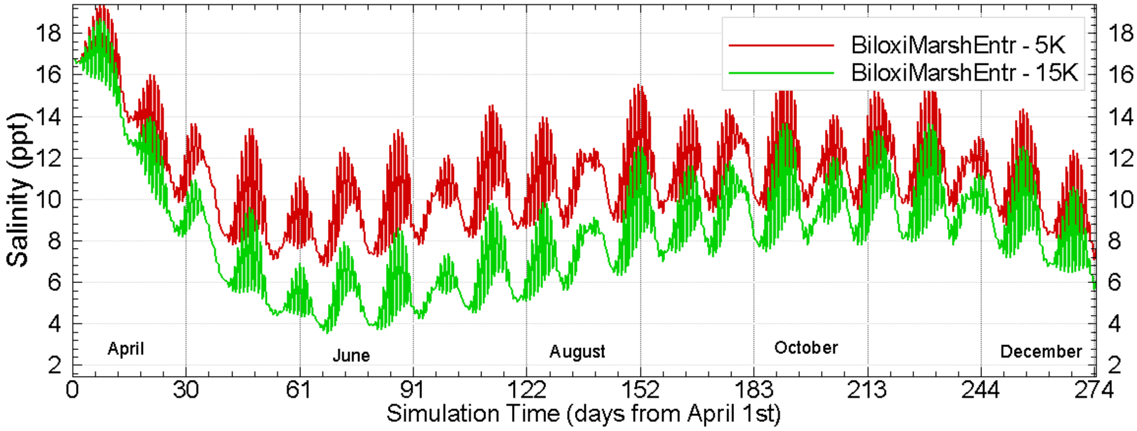

Figure 20 Simulated near surface salinity near the entrance to the Biloxi Marshes east of Lake Borgne station with a run-of-the-River hydrograph signal at Violet (Solid green and red lines represent the 5,000 cfs and 15,000 cfs flow peak respectively)

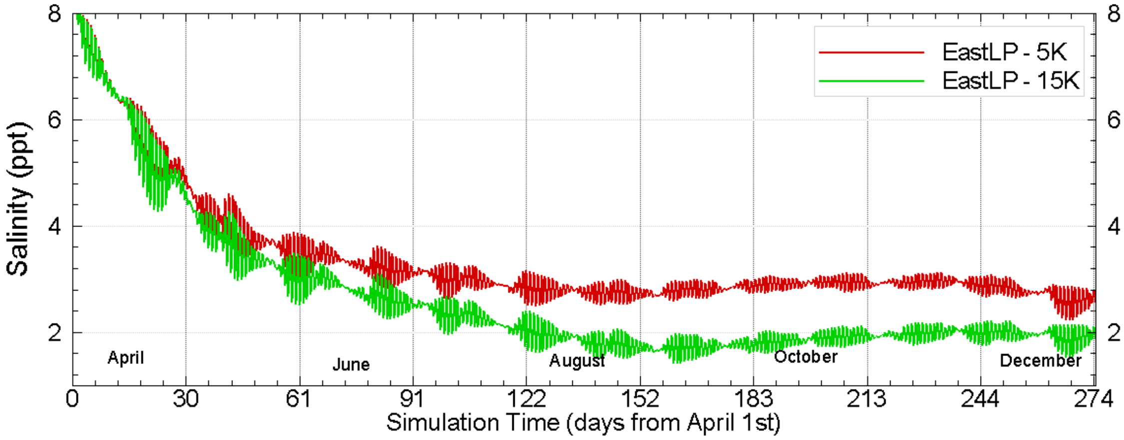

Figure 21 Simulated near surface salinity near eastern Lake Pontchartrain with a run-of-the-River hydrograph signal at Violet (Solid green and red lines represent the 5,000 cfs and 15,000 cfs flow peak respectively)

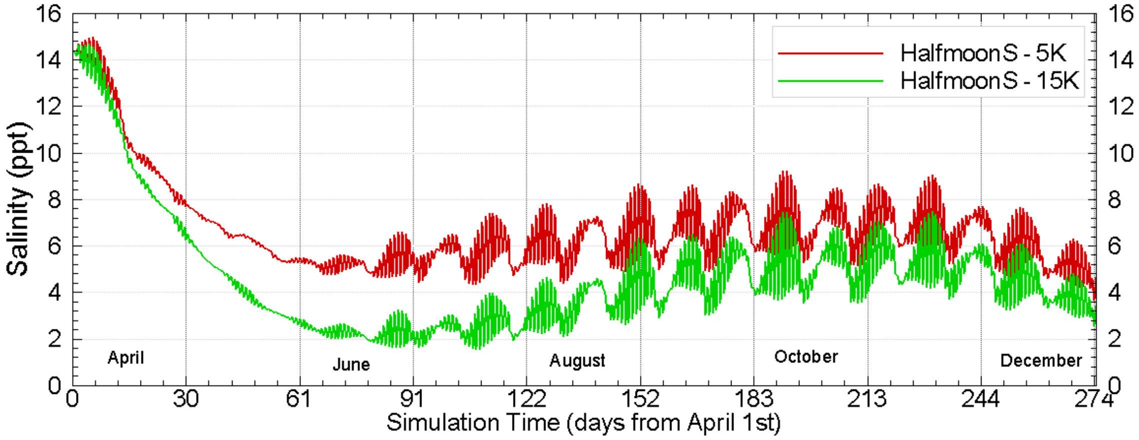

Figure 22 Simulated near surface salinity near Half moon Island south with a run-of-the-River hydrograph signal at Violet (Solid green and red lines represent the 5,000 cfs and 15,000 cfs flow peak respectively).

Previous Figures 14 through 17 show that despite the eastward movement of the 10 and 15 ppt isohalines for the 5,000 and 15,000 cfs proposed diversion hydrographs, there are other notable differences. The first difference is the salinity reduction in Lake Borgne though which most of the freshwater is conveyed; the second difference is the freshening of the eastern portion of Lake Pontchartrain. Figure 23 shows the difference in salinity between the 5,000 and 15,000 cfs hydrographs in key locations of the system namely the eastern portion of Lake Pontchartrain, the middle of Lake Borgne, the entrance to the Biloxi Marshes, and south of Half Moon Island. Notable differences between the two signals are the increasing trend of freshening in the eastern Lake Pontchartrain versus the other locations where some recovery appears to be taking place during the summer and fall seasons. This can be attributed to the changes in salt flux through the tidal passes as a result of the lower salinity water in Lake Borgne. In other words, under existing conditions and prior to the diversion, Lake Borgne exchanges higher salinity water to Lake Pontchartrain. With the diversion and the constriction of the MRGO however, the water available for tidal exchange between the two lakes would be fresher, and hence will slowly reduce the salinities in eastern Lake Pontchartrain. In addition, this trend makes the tributary flows more effective in reducing the ambient salinity in Lake Pontchartrain due to the large residence time of the Lake and due to the effective mixing produced by wind shear.

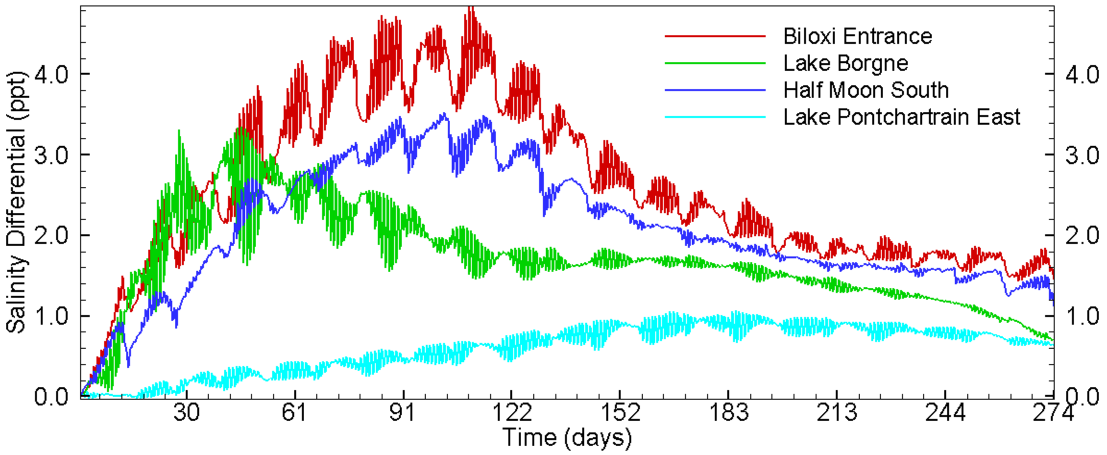

Figure 23 Salinity difference for four locations in the Estuary from a run-of-the-River hydrograph at Violet; values shown are computed as simulated salinity from a 5,000 cfs signal minus the simulated salinity from a 15,000 cfs signal).

Frequency analysis was performed at selected locations from the diversion site near Bayou Dupre to the entrance to the Biloxi Marshes. One year time series signals for four locations, namely Bayou Dupre, middle of Lake Borgne, south Half Moon Island and at the entrance to the Biloxi Marshes were sampled at 12 hr frequency and were ranked to produce exceedence plots. Figure 24 shows the frequency analysis for the 5,000 cfs diversion flow and Figure 25 shows the frequency analysis for the 15,000 cfs diversion flow. Figure 24 shows that with a 5,000 cfs diversion 80% of the time salinities in the middle of Lake Borgne would be less than 4 ppt, 10% of the time the salinity at the entrance to the Biloxi marshes would be less than 14 ppt, and 50% of the time less than 10 ppt. Similarly, Figure 25 shows that with a diversion of 15,000 cfs, 80% of the time salinities in the middle of Lake Borgne would be less than 4 ppt, 90% of the time the salinity at the entrance to the Biloxi marshes would be less than 12 ppt, and 50% of the time less than 8 ppt.

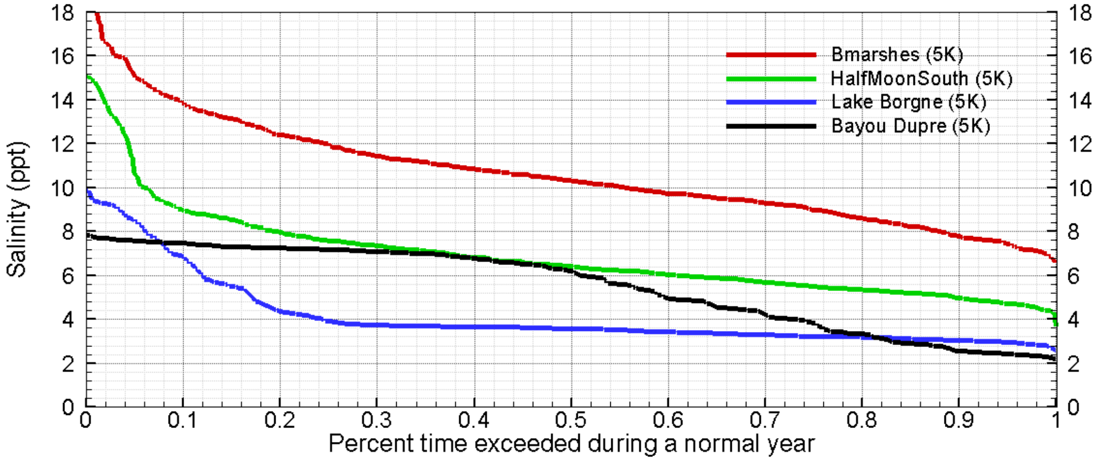

Figure 24 Frequency analysis of near surface salinity in areas of interest in Lake Borgne and the Biloxi Marshes for the 5,000 cfs diversion.

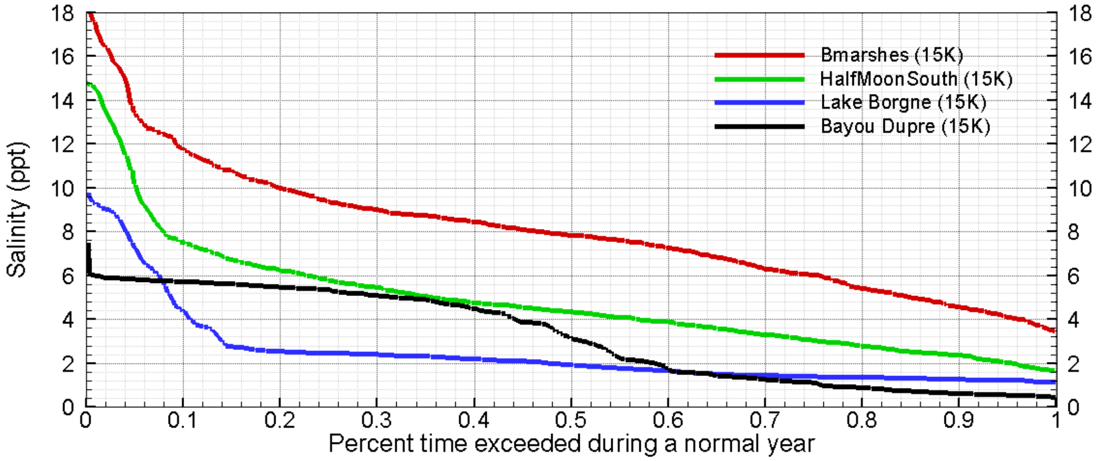

Figure 25 Frequency analysis of near surface salinity in areas of interest in Lake Borgne and the Biloxi Marshes for the 15,000 cfs diversion.

Figure 26 shows the comparison of the temporal salinity distribution at selected locations for the base case with no constriction and the 5,000 and 15,000 cfs hydrographs. Figure 26 indicates that the mean salinity reduction for the fall season is 1 ppt for the 5,000 cfs hydrograph and 3 ppt for the 15,000 cfs hydrograph at the entrance to the Biloxi Marshes. Similarly, south of Half Moon Island, the corresponding salinity reductions are less than 1 ppt and less than 3 ppt respectively.

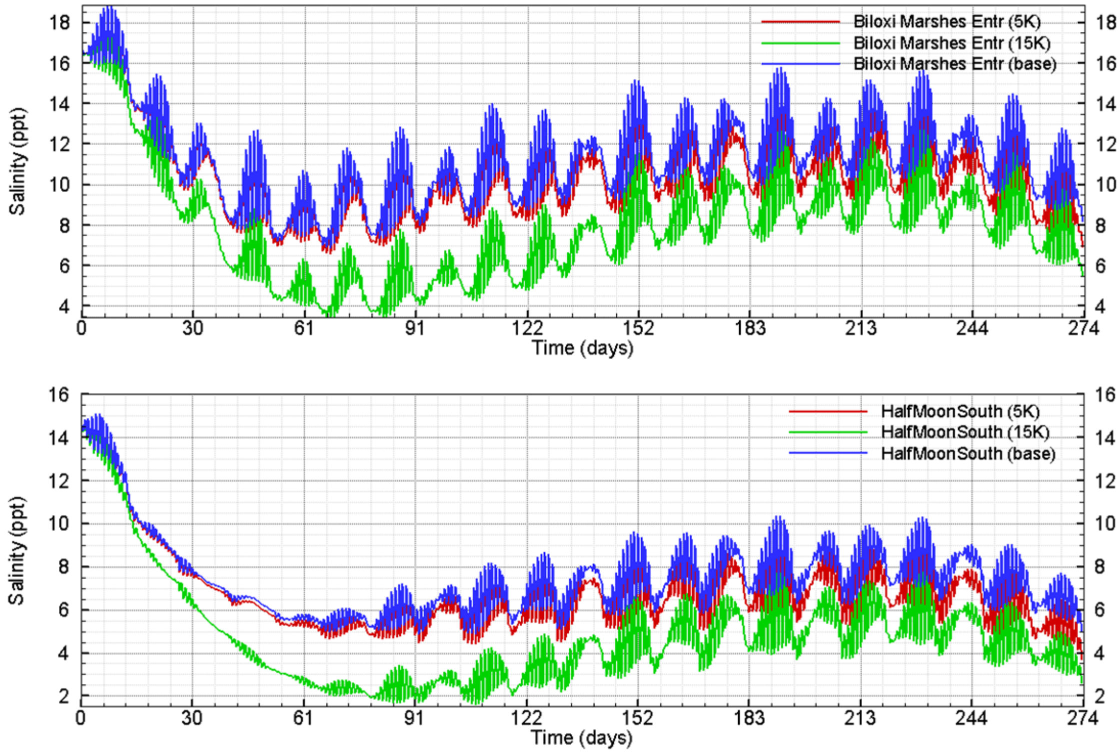

Figure 26 Simulated near surface salinity near eastern Lake Pontchartrain with a run-of-the-River hydrograph signal at Violet (green and red lines represent the 5,000 cfs and 15,000 cfs flow peak respectively, and blue line represents the existing no diversion ca case without constriction)

DISCUSSION AND CONCLUSIONS

There were three diversion scenarios for the Violet option: a) 5000 cfs, b) 10,000 cfs and c) 15,000 cfs. The model assumed that there would be a 90 % constriction in the MRGO south of the Violet Diversion for all of the diversion scenarios. This constriction severely reduces the salt intrusion into Lakes Borgne and Pontchartrain and forces most of the diversion flow into Lake Borgne. This enhances the freshening effect of the diversion on Lake Borgne. Two base cases were simulated: a) existing MRGO without the Violet Diversion and b) 90% restricted MRGO channel without the Violet Diversion.

To judge the significance of these flows relative to the volume of Lake Borgne, it is estimated it would take four months for a flow of 5,000 cfs to fill Lake Borgne while it would take over 16 months to fill Lake Pontchartrain. Similarly it would take about two months and 1.3 months respectively to fill Lake Borgne for flows of 10,000 and 15,000 cfs. These relative filling times are a guide to the response times of Lake Borgne and Lake Pontchartrain to various sizes of freshwater diversions. Thus, we can expect the full effect on the Biloxi Marshes area of a diversion of 10,000 to 15,000 cfs in one to two months after the start of the diversion. Once the system reaches dynamic equilibrium, response times maybe smaller due to the presence of smaller salinity gradients. The actual response of the system depends on the Lake bathymetry, the tides, saltwater fluxes and the natural freshwater inflows from the tributaries and net rainfall-evaporation. Numerical modeling is able to address these factors and map their response in terms of sequential changes in position of the isohalines.

The first series of simulations were completed to determine the system response to a 2 month diversion at Violet. This period was the period that was expected to result in a change in salinity in the vicinity of the Biloxi Marshes for diversion flows of the order 10,000 to 15,000 cfs. The model showed that target salinities could be met within 2 months with a diversion in the range of 10,000 to 15,000 cfs. It also appears from the model that the diversion flow reduces the mixing of the Pearl River Plume with highly saline water; as a result even after one month there is a significant salinity reduction in Lake Borgne. The response time for salinity reductions at the Biloxi Marshes is faster than the theoretical fill times would suggest. These simulations indicate that it will take approximately one month before a change in the diversion flow at Violet produces a change in the salinity at the Biloxi Marshes; a computer forecast model could provide guidance for the operation of the Diversion under the prevailing hydrologic and salinity conditions at any particular time.

Another series of simulations were completed to determine the long term response of the Estuary to annual diversions at Violet. The diversion flows varied seasonally according to the mean monthly stage available in the Mississippi River. The two operational hydrographs were assumed to have peak monthly flows of 5,000 and 15,000 cfs (March-April) and minimum monthly flows of 2,000 and 650 cfs (Fall) respectively (Figure 13). The simulation period of 12 months permitted an estimate to be made on the effect of various Violet diversion options on the salinity in Lakes Pontchartrain and Borgne in addition to the Biloxi Marshes.

The extended simulations showed (Figure 15) that solely reducing the cross-section of a portion of the MRGO could reduce the system salinity over a 12 month diversion by approximately 20% in eastern Lake Pontchartrain, Lake Borgne and the Biloxi Marshes compared to the base case with no restriction in the MRGO.

The combination of the restriction of the MRGO and a diversion hydrograph with a peak flow of 5,000 cfs produced annual average salinities that were slightly less than the case with only the restriction (Figure 16); this is probably due to the very low fall diversion flows for this hydrograph as shown in Figure 13.

Figure 17 shows the annual average salinity distribution for the combination of a restriction of the MRGO and a diversion hydrograph with a peak flow of 15,000 cfs. As indicated in Figure 17 this hydrograph would result in significant freshening of Lake Borgne and the eastern Lake Pontchartrain. For example, in the vicinity of Bayou Dupre the 5,000 cfs hydrograph indicated that the salinities would be in the range of 3 – 8 ppt while for the 15,000 cfs hydrograph the range was <1 to 6 ppt as shown respectively in Figures 24 and 25. The implications for fisheries and habitat due to this change in the salinity patterns need to be studied.

The results presented here are for actual tidal conditions and natural freshwater inputs. The 10 ppt and the 15 ppt isohalines represent a mean position for the spring period; however, wind effects and Gulf of Mexico fluctuations have not been modeled and could result in large translations of the isohalines. This will generally alternate between upstream and seaward movement with respect to a given mean isohaline.

The reduction in the mean salinity in the vicinity of the Biloxi Marshes (north entrance) is directly related to the magnitude of the diversion. After 30 days of simulation the 5,000 cfs diversion reduces the salinity by about 1 ppt while 10,000 cfs and 15,000 cfs diversions result in approximately 2 and 3.5 ppt reductions in the mean salinity for the spring period. By 60 days, the respective effects are 1.5 ppt, 3.5 ppt and 5.5 ppt. At about 60 days of a 15,000 cfs diversion the location of the mean 10 ppt isohaline reaches equilibrium with the saltwater flux from the Gulf of Mexico. The salinity then oscillates about this location as indicated by Table 4. The spatial translation due to the temporal variations is of the order of ± 2 km (1.2 miles).

The capacity of a diversion structure will vary seasonally with the stage of the Mississippi River (Department of Civil and Environmental Engineering, University of New Orleans, et. al. 1997). The monthly median high stage at New Orleans is 11.9 ft ± 5 ft and occurs in April. Typically the lowest median monthly stages of approximately 3.1 ft ± 1 ft occur in September-October. If a submerged sluice type structure is designed to discharge 15,000 cfs at the high stage, its maximum capacity at the low stage will be reduced to about 7,000 cfs. During very low river flows the monthly low stage could be reduced by 1-ft and the flow would be only 6,000 cfs. Furthermore, if there are drought conditions in the Pontchartrain Estuary and its tributaries, it may be necessary to compensate for deficiencies in the natural fresh water inputs, by increasing the diversion flows. Consideration should be given to installing greater hydraulic capacity than that required for median conditions in the Estuary and the Mississippi River. This may also help manage salinities during extreme events such as droughts. All presentations of salinity in this report are surface salinity. This provides a good indication of the advance of the freshwater plume, and it is also representative of the mixed salinity in the shallower marsh areas. In general, the model indicated that the salinity within the region of interest would be nearly uniform throughout the water column.

This study did not address availability of head in the Mississippi River for the diversion flows used in the simulations. The model domain did not include the interior wetlands near Violet, and therefore it does not address hydro-periods and flooding of the interior Violet wetlands and associated benefits/impacts. No attempt was made in this study to assess the environmental impacts of introducing Mississippi River water to Lake Borgne via the Violet Diversion.

Long term modeling indicates that continuous operation of a Violet diversion at high flows could freshen Lake Borgne and Lake Pontchartrain. Salinity control throughout the estuary will require innovative management of this and other freshwater inputs. For example this may require pulsing of the Violet flow with compensation with input from the Pearl River. The management plan should include continuous monitoring of the salinity distribution through the estuary along with a forecasting model to provide guide decisions on increasing or decreasing diversions flows.

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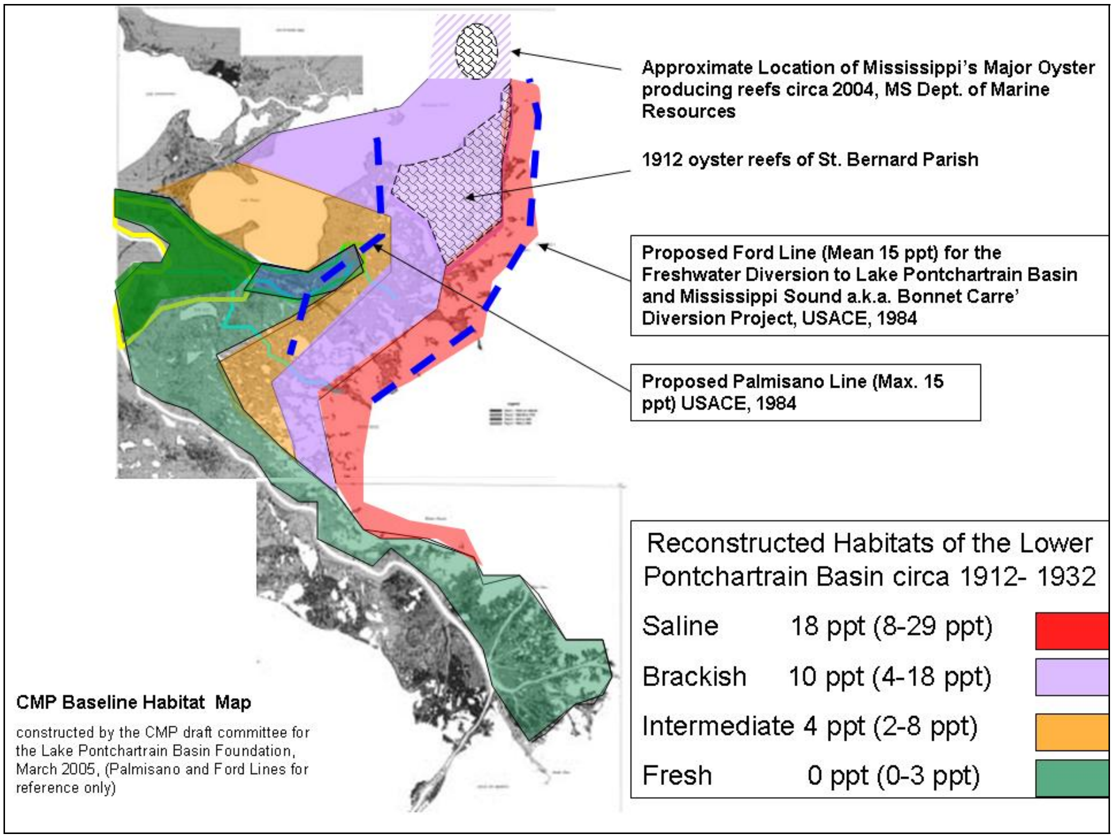
APPENDIX A



Approximate Location of Mississippi's Major Oyster producing reefs circa 2004, MS Dept. of Marine Resources

1912 oyster reefs of St. Bernard Parish

Proposed Ford Line (Mean 15 ppt) for the Freshwater Diversion to Lake Pontchartrain Basin and Mississippi Sound a.k.a. Bonnet Carre' Diversion Project, USACE, 1984

Proposed Palmisano Line (Max. 15 ppt) USACE, 1984

Reconstructed Habitats of the Lower Pontchartrain Basin circa 1912- 1932

Saline	18 ppt (8-29 ppt)	🟥
Brackish	10 ppt (4-18 ppt)	🟪
Intermediate	4 ppt (2-8 ppt)	🟧
Fresh	0 ppt (0-3 ppt)	🟩

CMP Baseline Habitat Map

constructed by the CMP draft committee for the Lake Pontchartrain Basin Foundation, March 2005, (Palmisano and Ford Lines for reference only)

Figure A1 Map of Re-constructed habitats for the Lake Pontchartrain Basin Estuary. Historic maps of oyster reefs (*Crassostrea virginica*), forests, and other information were utilized (after LPBF, 2006).