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NUMERICAL MODELING OF SALINITY AND SEDIEMNT TRANSPORT IN LAKE PONTCHARTRAIN DURING THE BONNET CARRE SPILLWAY FLOOD RELEASE

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ABSTRACT

Lake Pontchartrain is a brackish estuary located in southeastern Louisiana with a mean depth of 4 meter and an area of 1630 square km. To protect the city of New Orleans from the Mississippi River flooding, the Bonnet Carré Spillway (BCS) was constructed to divert water from the river into Lake Pontchartrain and then into the Gulf of Mexico. This paper presents the application of a two-dimensional numerical model for simulating the flow circulations, salinity and sediment distributions in Lake Pontchartrain during the Bonnet Carré Spillway is opened for flood release. The numerical model was developed base on CCHE2D free surface hydrodynamic model. The salinity and sediment modules were coupled with flow model. The developed model was first verified against analytical solutions of mass transport in the open channel flow, and then it was applied to simulate the flow, salinity and sediment in Lake Pontchartrain during BCS was opened for flood release. The model was calibrated using field measured data provided by USGS, and then it was validated by simulating flow fields, sediment transport during BCS opening, and salinity recovery processes after BCS closed. The simulated results were compared with filed data provided by USGS, USACE and satellite imagery.

1. INTRODUCTION

In response to the high flood stage of the Mississippi River and to protect the city of New Orleans, the Bonnet Carré Spillway (BCS) was built to divert Mississippi River flood waters to the Gulf of Mexico via Lake Pontchartrain.

The construction of the spillway was completed in 1931. It is located in St. Charles Parish, Louisiana - about 19 km west of New Orleans. The spillway consists of two basic components: a 2.4 km long control structure along the east bank of the Mississippi River and a 9.7 km floodway that transfers the diverted flood waters to the lake. The design capacity of the spillway is 7080 m^3/s and will be opened when the Mississippi river levels in New Orleans approached the flood stage of 5.2 m. It was first operated in 1937 and nine times thereafter (1945, 1950, 1973, 1975, 1979, 1983, 1997, 2008 and 2011). The maximum flow discharges and days of opening for each event are listed in Table 1 (USACE 2011, GEC 1998).

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During the BCS opening, a large amount of fresh water and sediment discharged from the Mississippi River into Lake Pontchartrain and then into the Gulf of Mexico. The flow discharge over the spillway produces significant effects on the lake hydrodynamics. It also changes the distributions of salinity, nutrients and suspended sediment (SS) in the lake dramatically. During a flood releasing event, the fresh water dominated the whole lake and the lake salinity reduced significantly. A lot of sediment deposited into the lake or was transported into the Gulf of Mexico. The contaminated sediment from Mississippi River could bring a lot of pollutants, such as nutrients, Al, Cu, Cr, Hg, Pb, Zn, etc., to the lake, and caused a lot of environmental problems. The algal bloom occurred in a large area of the lake after a flood release event. The blooms produced high levels of heptatoxins and caused decreases of dissolved oxygen in the lake (Dortch et al., 1998; Penland et al., 2002).

Table 1 Information of Bonnet Carré Spillway opening for flood release

Year	Date opened	Date Closed	Days opened	Max. discharge m^3/s
1937	Jan28	Mar 16	48	5975
1945	Mar 23	May 18	57	9005
1950	Feb 10	Mar 19	38	6315
1973	Apr 8	Jun 21	75	5522
1975	Apr 14	Apr 26	13	3115
1979	Apr 17	May 31	45	5409
1983	May 20	Jun 23	35	7589
1997	Mar 17	Apr 18	31	6881
2008	Apr 11	May 8	28	4531
2011	May 9	June 20	42	8892

Due to a large amount of sediment discharged /deposited into the lake, the bed form of the lake changed. The BCS opening event produced significant changes in flow pattern, salinity and water temperature, which greatly affected the lake fish habitat, and caused negative impacts to oyster beds and fishery nursery grounds in the lake. In response to the dynamic changes in the salinity, temperature, water surface elevation, and bed form of the lake, it was observed that some species, particularly brown shrimp, shifted and moved. It may take a long time for the fisheries resources to recover from the flood release event.

To understand the impact of the BCS flood release event on the ecosystem of Lake Pontchartrain, the flow circulation, sediment transport and salinity distribution are most important key tasks to be studied. In this study, a numerical model was used to simulate the flow circulation, sediment transport and salinity distribution in Lake Pontchartrain due to the BCS opening for flood release.

2. MODEL DESCRIPTION

To simulate the flow field, sediment transport and salinity distribution in Lake Pontchartrain, a two-dimensional depth-averaged model, CCHE2D, was applied. CCHE2D is a 2D hydrodynamic and sediment transport model that can be used to simulate unsteady turbulent flows with irregular boundaries and free surfaces (Jia and Wang 1999, Jia et al. 2002). It is a finite element model utilizing a special method based on the collocation approach called the “efficient element method”. This model is based on the 2D Reynolds-averaged Navier-Stokes equations. By applying the

Boussinesq approximation, the turbulent stress can be simulated by the turbulent viscosity and time-averaged velocity. There are several turbulence closure schemes available within CCHE2D, including the parabolic eddy viscosity, mixing length, k–ε and nonlinear k–ε models. In this model, an upwinding scheme is adopted to eliminate oscillations due to advection, and a convective interpolation function is used for this purpose due to its simplicity for the implicit time marching scheme which was adopted in this model to solve the unsteady equations. The numerical scheme of this approach is the second order. The velocity correction method is applied to solve the dynamic pressure and enforce mass conservation. Provisional velocities are solved first without the pressure term, and the final solution of the velocity is obtained by correcting the provisional velocities with the pressure solution. The system of the algebraic equations is solved using the Strongly Implicit Procedure (SIP) method (Stone 1968).

2.1 Governing Equations

The free surface elevation of the flow is calculated by the continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \tag{1}$$

The momentum equations for the depth-integrated two-dimensional model in the Cartesian coordinate system are:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial \eta}{\partial x}+\frac{1}{h}\left(\frac{\partial h\tau_{xx}}{\partial x}+\frac{\partial h\tau_{xy}}{\partial y}\right)+\frac{\tau_{sx}-\tau_{bx}}{\rho h}+f_{Cor}v \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial \eta}{\partial x}+\frac{1}{h}\left(\frac{\partial h\tau_{yx}}{\partial x}+\frac{\partial h\tau_{yy}}{\partial y}\right)+\frac{\tau_{sy}-\tau_{by}}{\rho h}-f_{Cor}u \tag{3}$$

where u and v are the depth-integrated velocity components in x and y directions, respectively; t is the time; g is the gravitational acceleration; η is the water surface elevation; ρ is the density of water; h is the local water depth; f_{Cor} is the Coriolis parameter; τ_{xx}, τ_{xy}, τ_{yx} and τ_{yy} are depth integrated Reynolds stresses; and τ_{sx} and τ_{sy} are surface share stresses in x and y directions, respectively; and τ_{bx} and τ_{by} are shear stresses on the interface of flow and bed in x and y directions, respectively.

The turbulence Reynolds stresses in equations (2) and (3) are approximated according to the Bousinesq's assumption that they are related to the main rate of the strains of the depth-averaged flow field and an eddy viscosity coefficient ν_t which is computed using the Smagorinsky scheme (Smagorinsky 1993):

$$\nu_t=\alpha\Delta x\Delta y\left[\left(\frac{\partial u}{\partial x}\right)^2+\frac{1}{2}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2\right]^{1/2} \tag{4}$$

The parameter α ranges from 0.01 to 0.5. In this study, it was taken as 0.1.

In CCHE2D model, three approaches are adopted to simulate non-uniform sediment transport. One is the bed load transport, which is to simulate the bed load only without considering the diffusion of suspended load. The second approach is the suspended load transport, which simulates suspended load and treats bed -material load as suspended load. The third approach is to simulate bed load and suspended load separately (Jia and Wang 1999, Jia et al. 2002, Wu 2008).

In this study, CCHE2D was used to simulate sediment transport in Lake Pontchartrain during the BCS opening for flood release. In this period, sediment transport in the lake is primarily dominated by suspended sediment. So the second sediment transport approach, suspended load, was used for this study, and the non-uniform suspended sediment (SS) transport equation can be written as:

$$\frac{\partial c_k}{\partial t}+u\frac{\partial c_k}{\partial x}+v\frac{\partial c_k}{\partial y}=\frac{\partial}{\partial x}\left(D_{cx}\frac{\partial c_k}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_{cy}\frac{\partial c_k}{\partial y}\right)+S_{ck} \tag{5}$$

where c_k is the depth-averaged concentration of the kth size class of SS; D_{cx} and D_{cy} are the mixing coefficients of SS in x and y directions, respectively; S_{ck} is the source term and can be calculated by:

$$S_{ck}=-\frac{\alpha_t\omega_{sk}}{h}(c_k-c_{t*k}) \tag{6}$$

where c_{t*k} is the equilibrium sediment concentration of the kth size class of suspended load; ω_{sk} is the settling velocity of the kth size class; α_t is the adaptation coefficient of suspended load, and it can be estimated using the formula proposed by Wu (2008).

Settling velocity is calculated using Zhang's formula (Zhang and Xie 1993):

$$w_{sk}=\sqrt{\left(13.95\frac{\nu}{d_k}\right)+1.09\left(\frac{\gamma_s}{\gamma}-1\right)gd_k}-13.95\frac{\gamma}{d_k} \tag{7}$$

where ν is the kinematic viscosity; d_k is the diameter of the kth size class of sediment; γ_s and γ are the densities of water and sediment; g is the gravity acceleration.

The equilibrium sediment concentration c_{t*k} can be calculated based on sediment transport capacities of fractional suspended load and bed load (Wu et al, 2000).

The salinity transport equation can be written as:

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}=\frac{\partial}{\partial x}\left(D_{sx}\frac{\partial S}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_{sy}\frac{\partial S}{\partial y}\right) \tag{8}$$

in which S is the depth-averaged salinity; D_{sx} and D_{sy} the mixing coefficients of salinity in x and y directions, respectively.

In natural lakes, the wind shear stresses (τ_{sx} and τ_{sy}) at the free surface are expressed by

$$\tau_{sx}=\rho_a C_d U_{wind}\sqrt{U_{wind}^2+V_{wind}^2} \tag{9}$$

$$\tau_{sy}=\rho_a C_d V_{wind}\sqrt{U_{wind}^2+V_{wind}^2} \tag{10}$$

where ρ_a is the air density; U_{wind} and V_{wind} are the wind velocity components at 10 m elevation in x and y directions, respectively. Although the drag coefficient C_d may vary with wind speed (Koutitas and O'Connor 1980; Jin et al. 2000), for simplicity, many researchers assumed the drag coefficient was a constant on the order of 10^{-3} (Huang and Spaulding 1995; Rueda and Schladow 2003; Chao et al 2004; Kocyigit and Kocyigit 2004). In this study, C_d was taken as 1.5×10^{-3}.

In this study, the decoupled approach was used to simulate sediment concentration and salinity. At one time step, the flow fields, including water elevation, velocity components, and eddy viscosity parameters were first obtained using the hydrodynamic model, and then the suspended sediment concentration as well as salinity were solved numerically using Eqs. (5) and (8), respectively.

3. MODEL VERIFICATION

To verify the transport simulation model, the numerical results were tested against an analytical solution for predicting salinity intrusion in a one-dimensional river flow with constant depth. It was assumed that the downstream end of the river is connected with the ocean with salt water. At the end of the river reach (x=0), there is a point source with a constant salinity, S_0, from the ocean, and the salt water may intrude into the river due to dispersion (Figure 1). Under the steady-state condition, the salinity in the river can be expressed as:

$$U\frac{\partial S}{\partial x} = D_x\frac{\partial^2 S}{\partial x^2} \tag{11}$$

where U is the velocity (no tidal effect); S is the salinity in river; D_x is the dispersion coefficient; and x is the displacement from downstream seaward boundary (point O). An analytical solution given by Thomann and Mueller (1988) is:

$$S(x) = S_0 \exp(\frac{Ux}{D_x}) \tag{12}$$

in which S_0 is the salinity at downstream seaward boundary. In this test case, it was assumed that the water depth = 10 m, U=0.03m/s, D_x=30 m^2/s, and S_0 = 30 ppt. Figure 2 shows the salinity concentration distributions obtained by the numerical model and analytical solution. The maximum error between the numerical result and analytical solution is less than 2%.

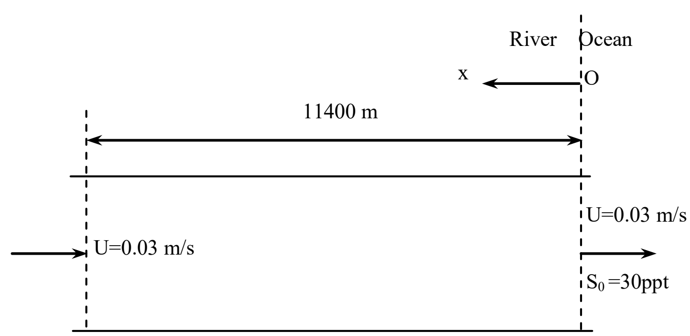


Figure 1 Test river for model verification

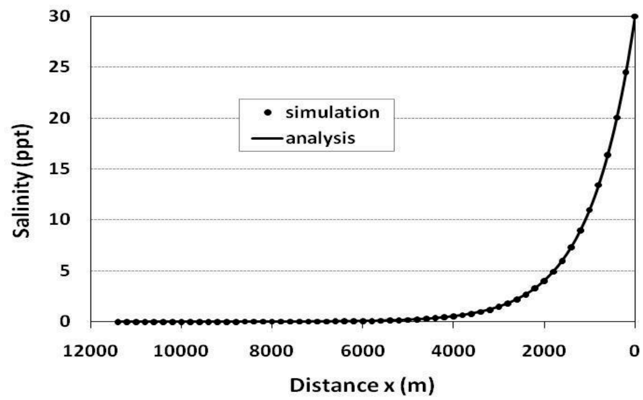


Figure 2 Salinity distribution along the river

4. MODEL CALIBRATION FOR LAKE PONTCHARTRAIN

4.1 Study Area

Figure 3 shows the bathymetry and locations of field measurement stations of the study site — Lake Pontchartrain. The circulation in Lake Pontchartrain is an extremely complicated system. It is affected by tide, wind, fresh water input, etc. The lake has a diurnal tide with a mean range of 11 cm. Higher salinity waters from the Gulf of Mexico can enter the lake through three narrow tidal passes: the Rigolets, Chef Menteur, and a man-made Inner Harbor Navigation Canal (IHNC). Freshwater can discharge into the lake through the Tchefuncte and Tangipahoa Rivers, the adjacent Lake Maurepas, and from other watersheds surrounding the lake. The Bonnet Carré Spillway (BCS) is located at the southwest of the lake.

Based on the bathymetric data, the computational domain was descritized into an irregular structured mesh with 224×141 nodes using the NCCHE Mesh Generator (Zhang and Jia, 2009).

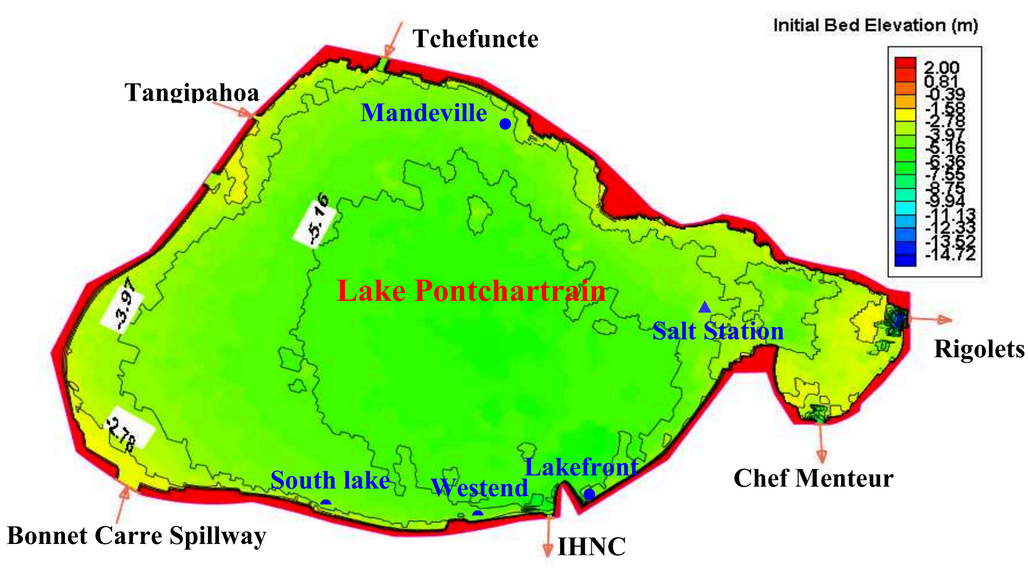


Figure 3 The bathymetry and field measurement stations in Lake Pontchartrain

4.2 Boundary Conditions

As shown in Figure 3, there are two inlet boundaries located at the northwest of the lake, and three tidal boundaries located at the south and east of the lake. The flow discharges at Tchefuncte and Tangipahoa Rivers obtained from USGS were set as two inlet boundary conditions. The hourly water surface elevation data at the Rigolets Pass obtained from USGS was set as a tidal boundary. Due to the lack of measured surface elevation data at Chef Menteur Pass, the Rigolets data was used (McCorquodale et al., 2005). After the BCS was opened for flood release, the flow discharge at BCS was set as inlet boundary conditions.

The other tidal pass, IHNC, is a man-made canal which connects the Lake Pontchartrain and Mississippi River with a lock structure. It is also connected with both the Gulf Intracoastal Waterway and the Mississippi River Gulf Outlet (MRGO). The measured daily water surface elevation data is the only available data at IHNC. In general, the daily water surface elevation data can not represent the variations of tidal boundary. It would cause problems if the measured daily data was directly set as tidal boundary conditions at IHNC. To resolve this problem, the relationship between measured daily water surface elevations at Rigolets and IHNC tidal passes were established and adopted to convert the hourly data at Rigolest to the hourly data at IHNC. Since both IHNC and Rigolets tidal passes are connected with the Gulf of Mexico, the tide effects at these two places are assumed to be similar. By comparing the measured daily water surface elevations at Rigolets and IHNC, no obvious phase differences were observed (McCorquodale et al., 2005). Figure 4 shows the comparison of measured daily water surface elevations at Rigolets and IHNC tidal passes.

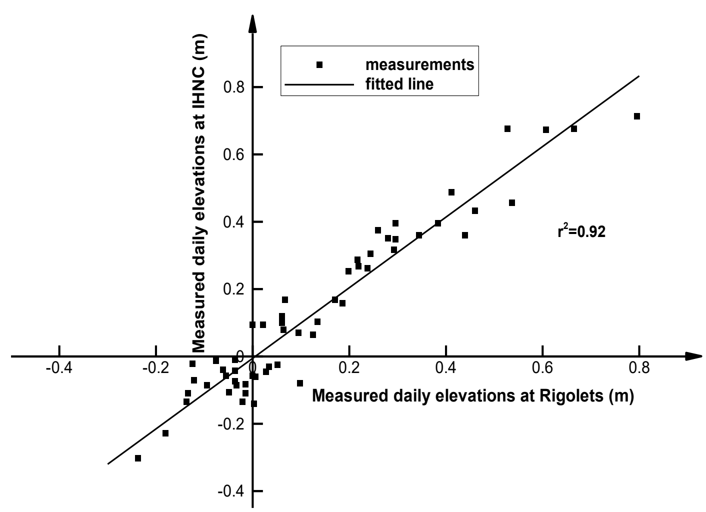


Figure 4 Comparison of measured daily water surface elevations at Regolets and IHNC

The measured results show that the surface elevations at the two locations have a close linear relation with the correlation coefficient r^2 being 0.92:

$$\eta_i = 1.0484\eta_r - 0.0055 \quad (13)$$

where η_i and η_r are the daily surface elevations at IHNC and Regolets, respectively. It was assumed that the hourly water surface elevations at IHNC and Regolets have the similar relationships, and Eq.

(13) was adopted to calculate the hourly water surface elevations at IHNC from the measured hourly surface elevation at Rigolets.

4.3 Model Calibration

After obtaining the inlet boundaries, outlet boundaries, and wind speeds and directions, the developed model was applied to simulate the flow circulation and sediment transport in Lake Pontchartrain. Some field measured data sets were used for model calibration and validation.

A period from March 1 to 31, 1998, was selected for model calibration. For calibration runs, several parameters, such as drag coefficient C_d, Manning's roughness coefficient, and the parameter α in Smagorinsky scheme (Eq.4), were adjusted to obtain a reasonable reproduction of the field data. In this study, $C_d = 0.0015$, Manning's roughness coefficient = 0.025, and $\alpha = 0.1$. Simulated water surface elevations and depth-averaged velocities were compared with the field measured data. Figure 5 shows the simulated and measured water surface elevations at the Mandeville. Figure 6 and Figure 7 show the simulated and measured depth-averaged velocities in x and y directions at the South Lake Site, respectively.

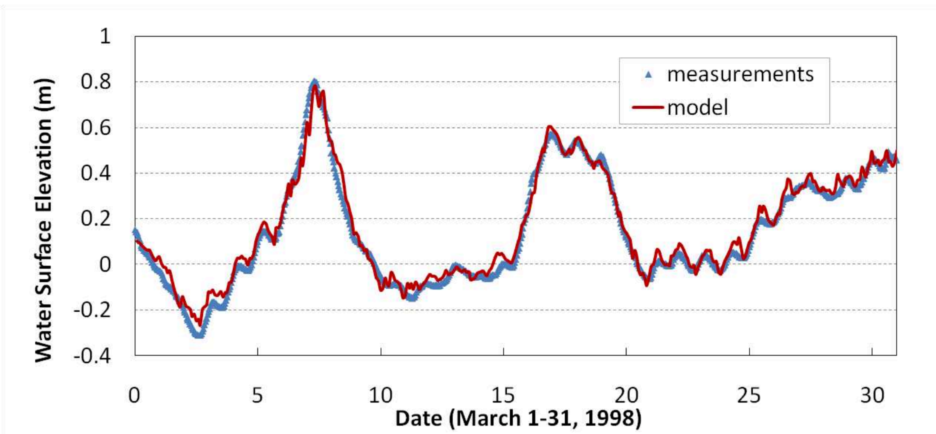


Figure 5 Simulated and measured water surface elevations at the Mandeville Station

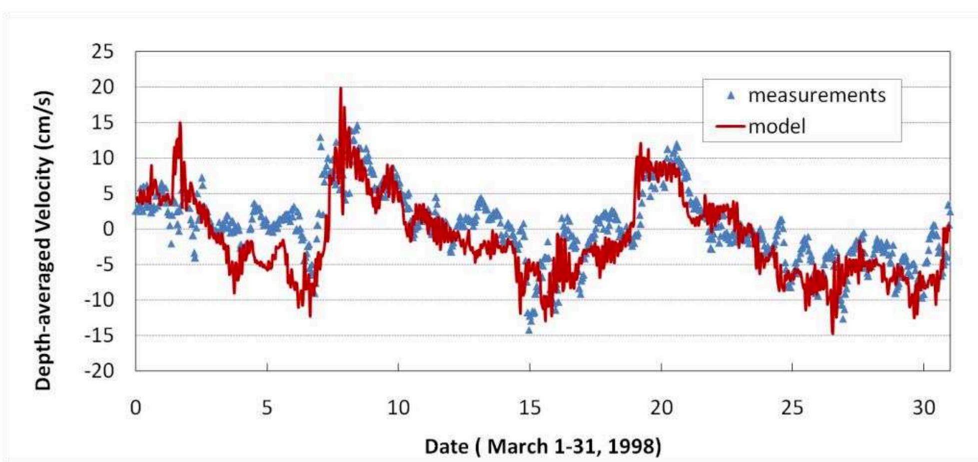


Figure 6 Simulated and measured velocities in west-east direction at the South Lake Site

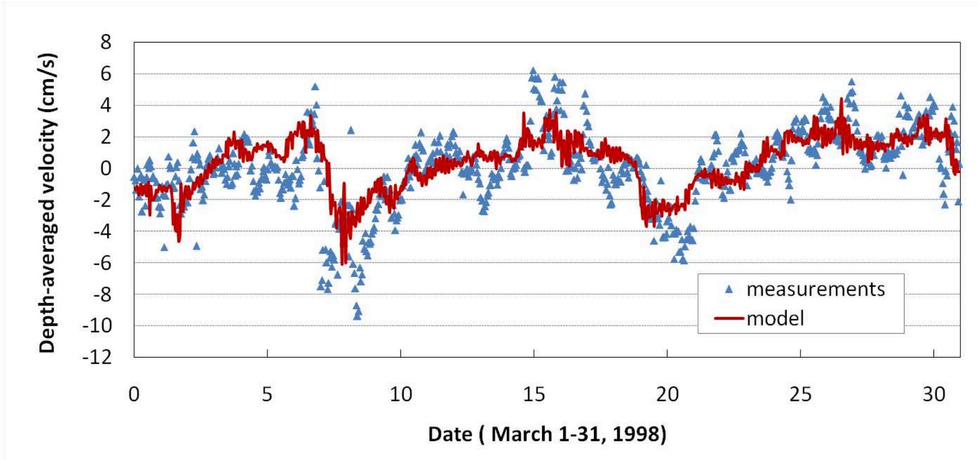


Figure 7 Simulated and measured velocities in south-north direction at the South Lake Site

5. MODEL APPLICATION TO LAKE PONTCHARTRAIN DUE TO BCS OPENING FOR FLOOD RELEASE

After the Bonnet Carré Spillway (BCS) was built to divert Mississippi River flood waters to the Gulf of Mexico via Lake Pontchartrain, there were 10 times opening events occurred from 1937 to 2011. In this study, the calibrated model was applied to simulate the flow field, sediment transport and salinity distribution in Lake Pontchartrain during the BCS opening for flood release.

5.1 Comparison of Flow Fields due to Recent BCS Opening for Flood Release

In recent 20 years, BCS was opened for the Mississippi River flood release for three times, which occurred in 1997, 2008 and 2011. In 1997, the BCS was partially opened on March 17, and then the opened bays were gradually increased. The partial opening was completed on March 27, about 10 days after its opening. Total 298 bays were opened for flood release, and the maximum discharge at BCS was 6881 m^3/s. USACE began to close the spillway structure on April 2, and the spillway was completely closed on April 18.

In 2008, the BCS was partially opened from April 11 to 19. Total 160 bays were opened for flood release, and the maximum discharge at BCS was 4531m^3/s. This was the second smallest flood discharge among the BCS opening events. USACE began to close the spillway structure on April 30, and the spillway was completely closed on May 8.

In 2011, the BCS was partially opened to release the great Mississippi River flood from May 9 to May 15. At peak operation, 330 of the 350 total bays were opened and the maximum discharge at BCS was 8892m^3/s, which was the second biggest flood discharge among the all opening events. USACE began closing bays on June 11, and completed the operation on June 20.

Figure 8 shows the comparison of flow discharges at the BCS during the flood release events in 1997, 2008 and 2011. The flow discharge in 2011 was much stronger than that in 1997 and 2008. The time-averaged flow discharges in 2011, 2008 and 1997 were about 6056m^3/s, 3294 m^3/s and 4172 m^3/s, respectively. In 2011, the maximum discharge was reached just 6 days after the BCS opening for flood release. However, in 1997 and 2008, it took 10 days to reach the maximum discharge at BCS. Figure 9 shows the flow circulations in Lake Pontchartrain for these three flood release events when the flow discharges reached to the maximum values. Due to the effect of flood flow at BCS, the flow circulation in the lake shows a general eastern pattern. Among the three flood events, the flow patterns in the east area of the lake are similar. For 2011 event, due to the huge flood discharge, the eastern flow in the lake was much stronger than that in 2008 and 1997. It can be observed that the north area of the lake can also be affected by the flood discharge, especially for 2011 and 1997 events. The transport of sediment and pollutants in the lake are greatly affected by the flood water. Figure 10 shows the sediment distribution in Lake Pontchartrain on May 17, 2011, eight days after the BCS was opened for flood release.

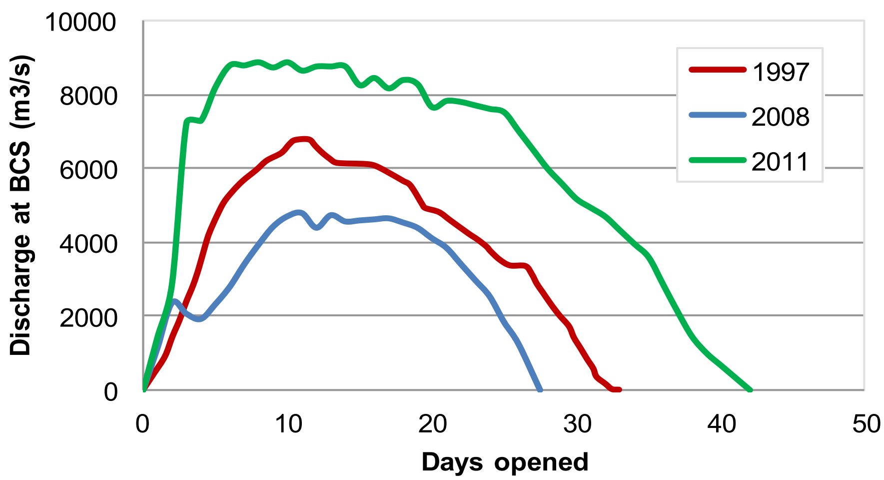


Figure 8 The flow discharges at the BCS during the flood release events in 1997, 2008 and 2011

Figure 10 Sediment distribution in Lake Pontchartrain on May 17, 2011(NASA astronaut photo)

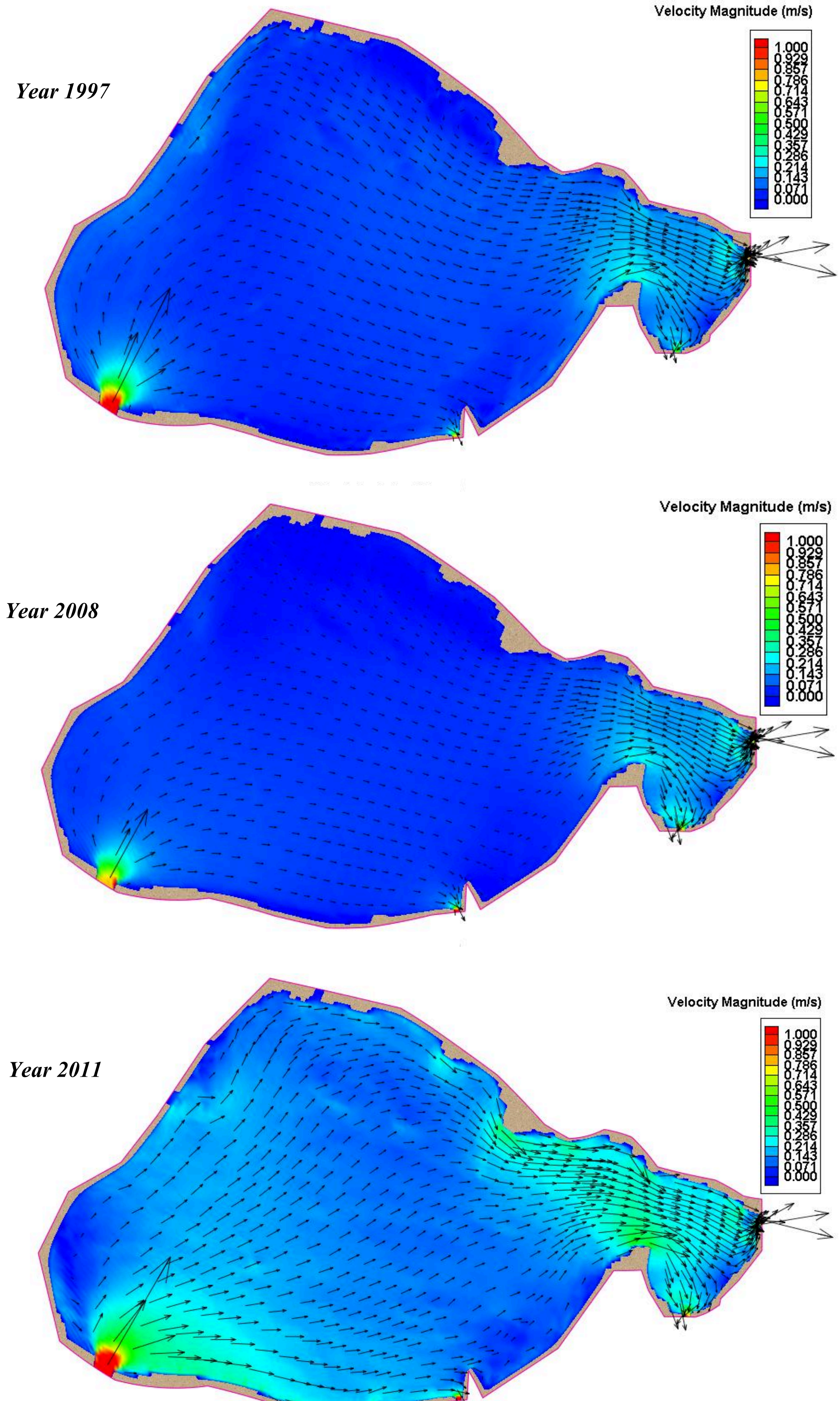


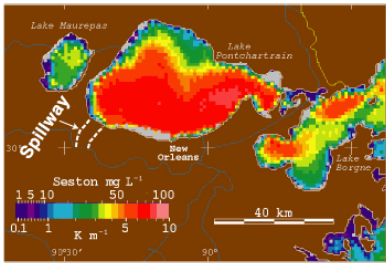
Figure 9 The flow patterns in the lake due to BCS opening for flood release

5.2 Modeling the Flow and Sediment during the BCS Opening for 1997 Flood Release

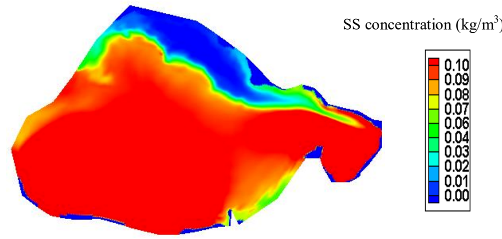
In 1997, the BCS was opened from 3/17 to 4/18, over 31 days of flood release. Figure 8 shows the flow hydrograph at the spillway. The total volume of sediment-laden water entering Lake Pontchartrain was approximately 1.18×10^{10} m^3, or twice the volume of the lake (Turner et al., 1999). The total amount of sediment entering the lake was about 9.1 million tons, more than 10 times as much as the normal yearly sediment loads of the lake. The suspended sediment (SS) concentration at the spillway gate was about 240 mg/l (Manheim and Hayes, 2002).

The calibrated CCHE2D model was applied to simulate the lake flow fields, sediment and salinity during the BCS opening in 1997. In this period, the flow discharge was very strong, and the "suspended load approach" was adopted for simulating sediment transport in the lake. The observed flow discharge was set as inlet boundary condition at BCS. The water surface elevations at Rigolets and Chef Menteur were set as tidal boundaries. The wind speeds and directions at the New Orleans International Airport were used for model simulation. The observed SS concentration was set as inlet sediment boundary condition at BCS. In general, the sediment in Lake Pontchartrain is cohesive sediment. However, during the BCS opening, sediment concentration in Lake Pontchartrain is dominated by the sediment coming from the Mississippi River. It was assumed that the effect of sediment cohesion on suspended sediment transport is not significant. Due to the lack of measured sediment data, the classes of non-uniform sediment size at BCS were estimated based on the observed sediment data in the lower Mississippi River (Thorne et al. 2008). Four size classes, including 0.005mm, 0.01mm, 0.02mm and 0.04mm were assumed to represent the non-uniform sizes of suspended sediment discharged into the lake from BCS. The fall velocity of each size class of sediment was calculated using the Eq. (7) proposed by Zhang and Xie (1993). During this period, the flow discharge over the spillway dominated the lake hydrodynamics and suspended sediment transport. The bottom shear stress due to water flow as well as wind driven flow were obtained using the hydrodynamic model. The critical shear stress and equilibrium sediment concentration c_{t*k} were calculated using formulas proposed by Wu (2008).

Figure 9 shows the computed flow circulations in Lake Pontchartrain during the BCS opening. Due to the flood release, the entire lake water were moved eastward through Rigolets and Chef Menteur into the Gulf of Mexico, which was completely different from the flow patterns induced by tide and wind. Figure 11 shows the comparisons of SS concentration obtained from the numerical simulation and remote sensing imageries (AVHRR data) provided by NOAA. The simulated SS concentrations are generally in good agreement with satellite imageries. The transport processes of SS in the lake were reproduced by the numerical model. The simulated results and satellite imageries revealed that a large amount of sediment discharged into the lake, moved eastward along the south shore and gradually expanded northward, eventually affecting the entire Lake after one month of diversion.



Remote sensing imagery



Simulation results

Figure 11 Comparisons of simulated SS concentration and remote sensing imageries (4/7/97)

5.3 Salinity Recovery Process in Lake Pontchartrain after BCS Opening for Flood Release

During the BCS opening for flood release in 1997, a large amount of fresh water and sediment were discharged from the Mississippi River into Lake Pontchartrain for one month of diversion. Numerical results show that the flow pattern during this period is dominated by current instead of circulation (Figure 9). Due to large amount of fresh water discharged into the lake, the salinity in the lake decreased significantly. At Rigolets and Chef Menteur tidal inlets, the salinity reduced from 4.5 ppt to less than 1 ppt (Department of Natural Resources, 1997). Lake water temperature was also decreased due to the colder water from the Mississippi River. Those changes caused negative impacts on oyster beds and fishery nursery grounds in the lake. It was observed that in response to the dramatic changes of the habitat (salinity, temperature and water surface elevation in the lake), some species of shrimp, particularly brown shrimp, adjusted their places to stay or migrated away entirely (Penland et al. 2002). It may take a long time for the fishery resources to recover from the flood release event. The decrease of salinity in the lake also caused negative impact on the growth of submersed aquatic vegetation (Poirrier et al., 1999)

The recovery of salinity in Lake Pontchartrain from BCS opening event is governed by the limited exchanges from three tidal passes (Rigolets, Chef Menteur and IHNC). Because tidal passes are narrow, the salinity recovery could be very slow. To improve our understanding of the salinity recovery process for management purpose, the numerical model was applied to simulate the salinity distribution in Lake Pontchartrain during and after BCS opening for flood release.

A period from March 17, 1997, when the BCS started to release flood water, to the end of year 1997, was selected for simulating the salinity distribution in Lake Pontchartrain. The hourly salinity boundary conditions were obtained from USGS. After obtaining flow fields, the salinity distribution can be solved using the numerical model.

Figure 12 shows the simulated and observed time series of salinity distributions at the Salt Station (Figure 3) provided by Gulf Engineers & Consultants (GEC 1998). The trend of salinity obtained from the numerical model is generally in good agreement with field measurements. Some peaks were consistent with the higher salinity at the inlet boundary due to meteorological factors.

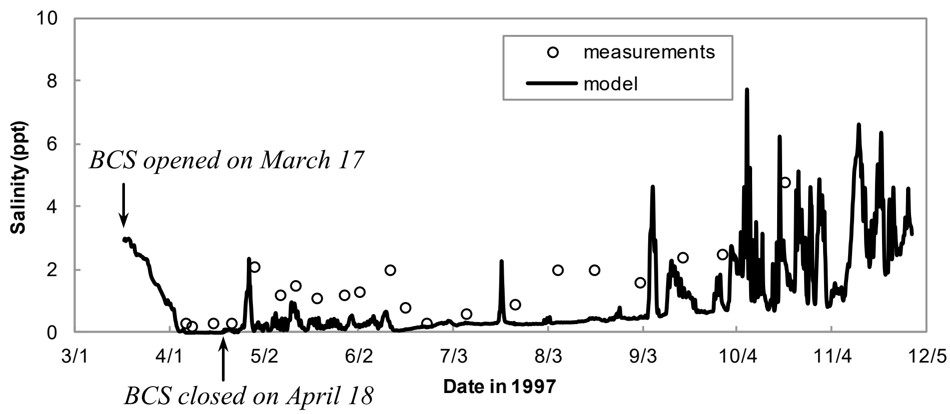


Figure 12 Simulated and observed salinity at Salt Station during and after BCS opening

6. DISUSSION

In general, wind and tide are the major driving mechanisms of circulation in Lake Pontchartrain. When the tidal level changes, most of the water that enters or leaves the lake must come through the three narrow tidal passes at the east and south end of the lake. Since the tidal passes are very narrow, the tidal force may affect the flow fields near the tidal passes. When the wind blows over the lake, it may affect flow circulations of the whole lake. Figure 13 shows the general flow pattern of the lake induced by tide and wind. It was completely different from the one when the BCS was opened for flood release and caused the entire lake water to be moved eastward into the Gulf of Mexico (Figure 9). Due to the effects of tide and wind, the stronger currents occur along the shoreline where the water depth is shallow and near the narrow tidal passes, and weaker currents are in the center of the lake. These results are similar to results obtained by other researchers (Signell and List 1997, McCorquodale et al., 2005).

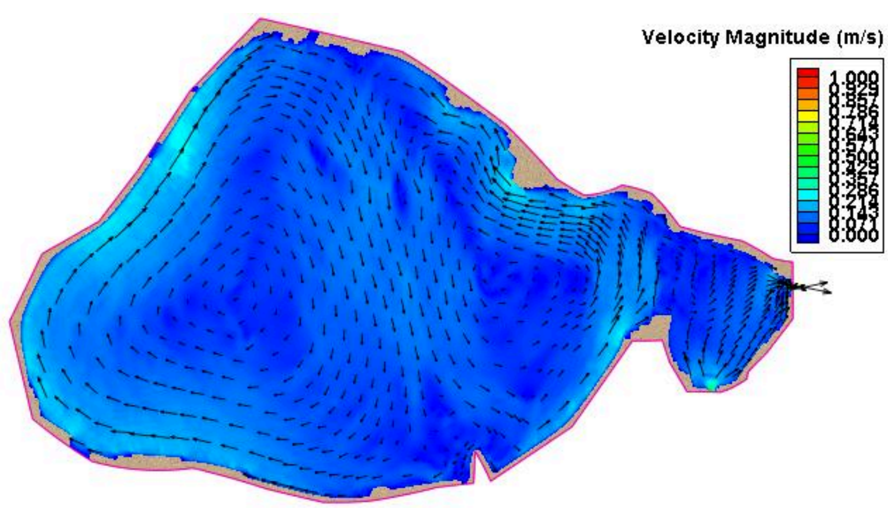


Figure 13 General flow circulations in Lake Pontchartrain due to tide and wind

7. CONCLUSIONS

A numerical model was applied to simulate the flow circulations, suspended sediment transport and salinity in Lake Pontchartrain in Louisiana, under tide, wind and flood release. It is one of the most significant real life problems we can find with reasonable field measurements obtained from USGS and USACE. Additional satellite imageries were obtained from NOAA for model validation. The results of these comparisons are in good agreement within the accuracy limitations of both the approximate numerical model solutions and the field measurements under the difficult conditions.

In the BCS flood release event, a vast amount of fresh water, sediment and nutrients were discharged into Lake Pontchartrain. The dispersion and transport processes of the suspended sediment in the lake were simulated successfully using the numerical model. The simulated SS concentrations are generally in good agreement with satellite imageries provided by NOAA. The differences of flow circulation and sediment transport in the lake under normal condition and BCS opening event were discussed. The simulated results and satellite imageries show that after the BCS opening, a large amount of sediment discharged into the lake, moved eastward and gradually expanded northward, eventually affecting the entire lake. The lake salinity recovery processes were predicted and the general trend agreed well with field observations. The flow fields in Lake Pontchartrain due to the recent three BCS opening events were simulated, and compared with general flow pattern induced by tide and wind. It was observed that the sediment and mass transport were greatly affected by the flood water during the BCS opening.

ACKNOWLEDGEMENTS

This research was funded by the US Department of Homeland Security and was sponsored by the Southeast Region Research Initiative (SERRI) at the Department of Energy's Oak Ridge National Laboratory. The authors would like to thank Rich Signell and David Walters of the USGS, and George Brown of the USACE for providing field measured data in Lake Pontchartrain. The technical assistance from Yaoxin Zhang, Weiming Wu and suggestions and comments provided by Yan Ding, Tingting Zhu and Kathy McCombs of the University of Mississippi are highly appreciated.

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