Predicting Elevations of Water Surface in A Tidal Water System

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ABSTRACT

In predicting the tidal elevations in the Back Bay of Biloxi in Mississippi, the Water Quality Analysis Simulation-5 (WASP5) hydrodynamics model DYNHYD5 was utilized. Model calibration of the tidal elevations was initially accomplished utilizing historical data collected by the U.S. Geological Survey (USGS) during the period June 14-16, 1977 along with a second set of data collected by the U.S. Environmental Protection Agency (USEPA) during the period July 28-August 2, 1972. Final model calibration was performed utilizing a set of field data acquired on the Back Bay of Biloxi, during September 12-21, 1994 and during April 25 - May 2, 1995. Comparisons of the predicted and observed tidal data are made qualitatively by using temporal comparisons. The response of model prediction calculations is consistent with trends of the observed data ranges, but not with absolute values in all cases. The results indicate that the model can accurately predict the tidal elevations in the Bay under varying conditions of estuarine flow.

INTRODUCTION

In predicting the tidal elevations in the Back Bay of Biloxi, the Water Quality Analysis Simulation-5 (WASP5) hydrodynamics model DYNHYD5 was utilized. This model is an update of DYNHYD4 (Ambrose et al., 1988), which was an enhancement of the Potomac Estuary hydrodynamic model DYNHYD2 (Roesch et al., 1979) derived from the original Dynamic Estuary Model (Feigner and Harris, 1970). DYNHYD5 is capable of solving the one-dimensional equations of continuity and momentum for a branching or channel-junction (link-node), computational network. This model can predict water velocities, flows, tidal heights, volumes in computational network. This paper will show the prediction of tidal elevations in the estuarine system under varying conditions of estuarine flow.

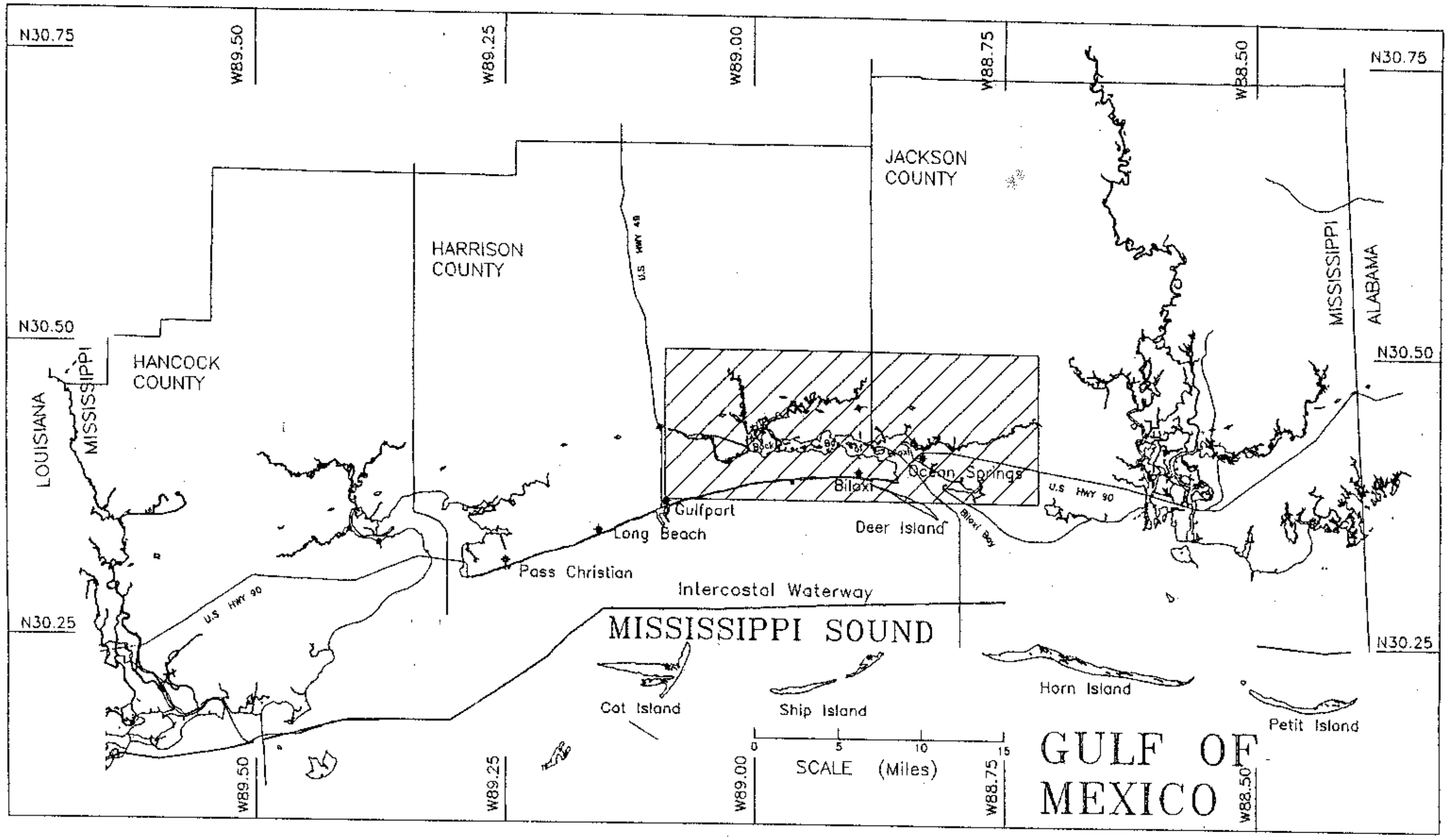


Figure 1: Location of the Study Area

The study area is located along the Mississippi Gulf Coast and adjacent to Jackson and Hancock Counties (Figure 1). Also included in the study area are the metropolitan areas of Biloxi, Gulfport, Ocean Springs, and D'Iberville. This estuary receives its fresh water from the inflow of the Biloxi River, Tchoutacabouffa River, Bernard Bayou, Turkey Creek, Brickyard Bayou, Old Fort Bayou, and Davis Bayou. The seawater inflow during flood tide comes from Mississippi Sound around both ends of Deer Island through Biloxi Bay into the inner embayments and tributaries. The initial model calibration of tidal elevations was accomplished utilizing historical data collected during the periods of July 28-August 2, 1972 and June 14-16, 1977 (Shindala et al, 1996). Final model calibration of tidal elevations was performed utilizing two sets of field data acquired on the Back Bay of Biloxi, during September 12-21, 1994 and April 25-May 2, 1995.

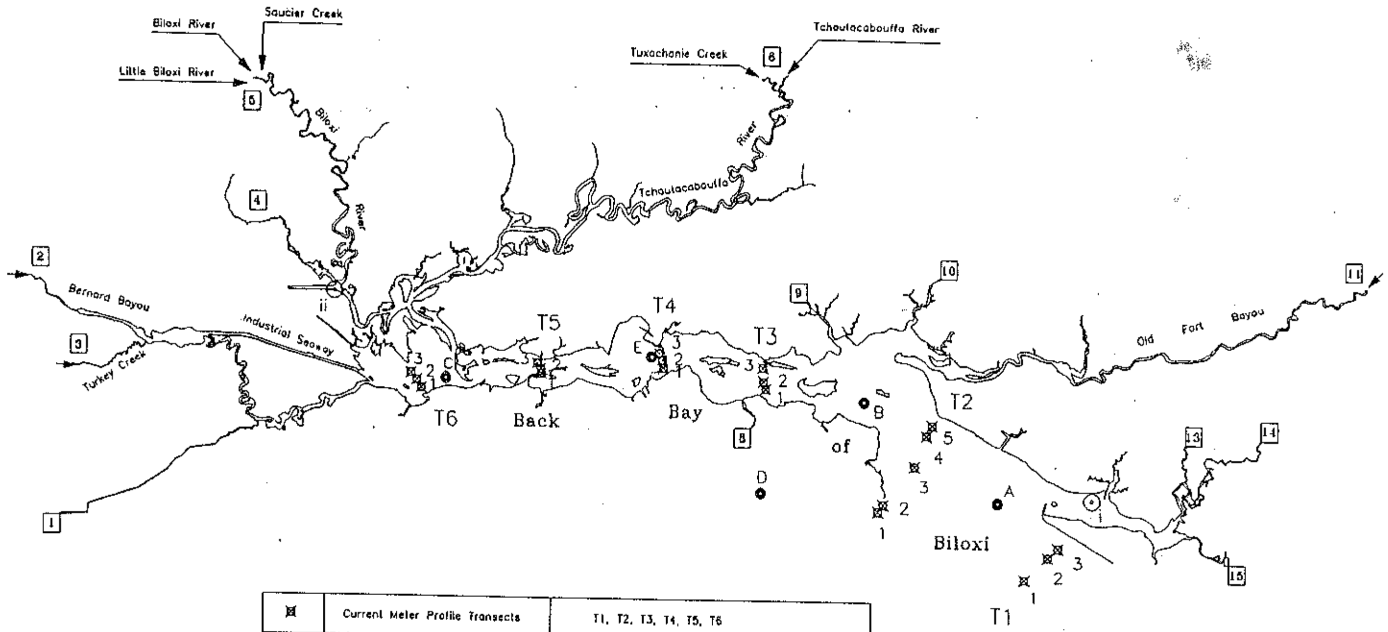
PHYSIOGRAPHY-HYDROLOGY

The study area is within two drainage basins. The Pascagoula and the Coastal Stream Basins. The Pascagoula is the largest basin with a 9,400 square mile drainage area. The Coastal Streams drain approximately 1,350 square miles and includes two sub-basins drainage into Bay St. Louis and drainage into Biloxi Bay. These basins are primarily in the physiographic province known as the coastal plain. The coastal plain extends from 25 feet above sea level upward; coastal meadows, a division of the coastal plain, ranges from sea level to the 25-foot elevation. All of these basins drain into Mississippi Sound. The ten-year, seven-day low flow (7Q10) for Estacawpa River (at mouth), and Wolf River (at mouth) is 120 cfs, 1230 cfs, 6 cfs, 5 cfs, and 23 cfs respectively. Streams within Coastal Stream Basin-Biloxi Bay System include the Biloxi River, the Tchooutacabouffa River a tributary of the Biloxi River, Bernard Bayou, and two of its tributaries Turkey Creek and Brickyard Bayou, and the Gulfport Industrial Seaway.

Mississippi Sound, into which all of the basins drain, is a elongated, shallow body of water situated between a chain of narrow, low, sand islands and the mainland which extends from Mobile Bay westerly for 70 miles. Natural depths of 12 to 18 feet are found throughout the sound. A 12-foot channel is maintained in the Intracoastal Waterway which traverses the area from Mobile Bay to New Orleans Diurnal tidal ranges vary from 1.6 to 1.8 feet; the mean tide level ranges from 0.8 to 0.9 feet. The salibity gradient ranges from near oceanic levels near the barrier islands to freshwater in some marsh areas.

DATABASE

The location and type of hydrodynamic sampling stations during the period September 12-21, 1994 are shown in Figure 2. As shown in the figure, tide gauge measurements were conducted at Marsh Point, Channel Island, and Big Lake. The maximum tide level is about 0.757 meter (2.48 ft); and the minimum is about 0.025



⌧	Current Meter Profile Transects	T1, T2, T3, T4, T5, T6
•	Tide Gage Stations	A: Marsh Point–Marker 23 Tide Gage B: Channel Island–Marker 4 Tide gage C: Big Lake–Marker Red/Green Tide Gage D: Deer Island – Marker 16 Tide gage E: O'Neal Point– Marker 16 Tide Gage
⊙	Meteorological Stations	i: GCRL – Spoil Island Meteorological Station ii: Mississippi Power Company Meteorological Station
→	Major River Inflow	Boundary Cells 2, 3, 5, 6, 11

Figure 2 Location of Hydrodynamic Sampling Stations (September 12 ■ 21 MSDEQ)

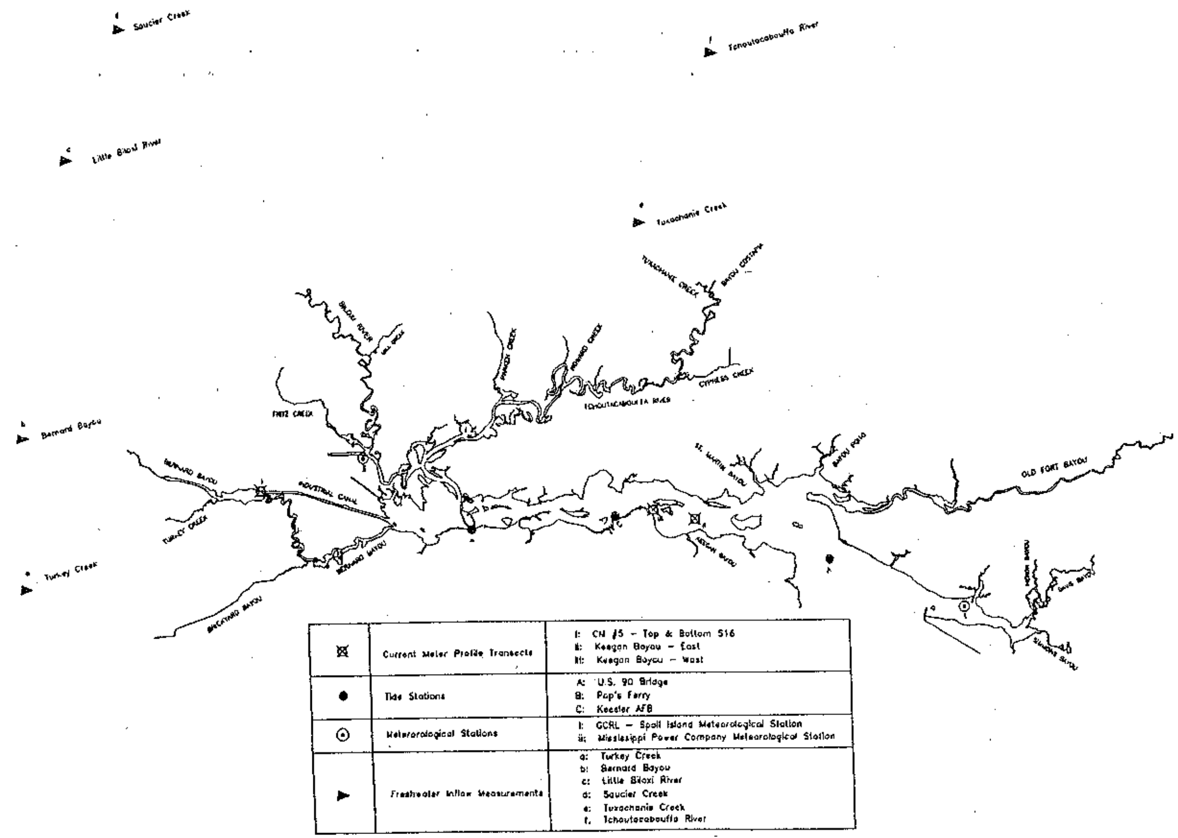


Figure 3 Location of Hydrodynamic Sampling Stations (April 1995, MSDEQ)

meter (0.08 ft). As shown in the figure, current velocity and direction were measured at six transects. The location and type of hydrodynamic sampling stations during the period April 25-May 2, 1995 are shown in Figure 3. As shown in the figure, tide measurements were conducted at U.S. 90 Bridge, Pop's Ferry, and Keesler Air Force Base. The maximum tide level is about 0.64 meter (2.1 ft); and the minimum is about 0.03 meter (0.10 ft). As shown in the figure, current velocity and direction were measured at three sites.

The bathymetry data used in the study was provided by Center for Ocean and Atmospheric Modeling, University of Southern Mississippi (COAM) and United States Geological Survey (USGS). Measurements of stream flows at the upstream model boundaries of Biloxi River, Tchoutacabouffa River, Old Fort Bayou, Bernard Bayou, and Turkey Creek were conducted during the two studies. Rainfall and wind data used in the calibration were collected during the two period of studies by Mississippi Department of Environmental Quality and National Oceanic and Atmospheric Administration (NOAA, 1994).

HYDRODYNAMIC MODEL COMPUTATIONAL METHODOLOGY

The computational procedure developed in DYNHYD5 program is based on the solution of one-dimensional equations describing the propagation of a long wave through a shallow water system while conserving both momentum (energy) and volume (mass). Prediction of water velocities and flow can be made based on the conservation of momentum by using the equation of motion.

Based on the conservation of volume, prediction of water heights (heads) and

$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} - a_{g,\lambda} + a_f - a_{w,\lambda} \qquad (1)$$

volume of every segment in the model network can be made using the equation of continuity. The equations of motion and continuity used in DYNHYD5 are presented below (Ambrose et al., 1993):

$$\frac{\partial A}{\partial t} = -\frac{\partial Q}{\partial x} \quad OR \quad \frac{\partial H}{\partial t} = -\frac{1}{B}\frac{\partial Q}{\partial x} \qquad (2)$$

where the first term on left side of equation (1) is the local inertia term, or the velocity rate of change with respect to time (m/sec^2); the first term of right side of equation (1) is the Bernoulli acceleration, or the rate of momentum change by mass transfer; also defined as the connective inertia term from Newton's second law, (m/sec^2); $a_{g,\lambda}$ is gravitational acceleration along the axis of the channel (m/sec^2);

a_f is frictional acceleration (m/sec^2); $a_{w,\lambda}$ is wind stress acceleration along axis of channel (m/sec ^{2}); x is distance along axis of channel (m); t is time (sec); U is velocity along that axis of channel (m/sec); λ is longitudinal axis; g is acceleration due to gravity (m/sec^2); A is cross-sectional area of a segment (m^2); Q is flow (m^3/sec); B is width (m); H is water surface elevation (m); $\partial H/\partial t$ is rate of water surface elevational change with respect to time (m/sec); $\partial Q/B\partial t$ is rate of water volume change with respect to distance per unit width (m/sec).

Equations (1) and (2) form a basis for the hydrodynamic model, and their solutions give the velocities and heads throughout the water body over the duration of model simulation. The "link-node" network is used in this model to solve the equations of motion and continuity at alternating points. At each time step, the equation of motion is solved at the links, giving velocities for mass transport calculations, and the equation of continuity is solved at the nodes, giving heads for pollutant concentration calculations. The link-node networks in this program cannot be used for stratified water bodies, small streams, or rivers with a large bottom slope.

The equations of motion and continuity have to be written in a finite difference form, as shown below, in order to apply them to a link-node computational network (Ambrose et al., 1993).

$$\frac{U_i^t - U_i}{\Delta t} = -U_i\frac{\Delta U_i}{\Delta x_i} - g\frac{\Delta H_i}{\Delta x_i} - \frac{g\eta^2}{R_i^{4/3}}|U_i|U_i + \frac{C_d\,\rho_a}{R_i\,\rho_w}W_i^2\cos\Psi_i \qquad (3)$$

$$\frac{H_j^t - H_j}{\Delta t} = -\frac{\Delta Q_j}{B_j \Delta x_j} \qquad (4)$$

where U_i^t is the velocity in channel i at time t (m/sec); Δx_i is the channel length (m); Δt is the time (sec); i is channel or link number; $\Delta U_i/\Delta x_i$ is velocity gradient in channel i with respect to distance (sec^{-1}); $\Delta H_i/\Delta x_i$ is water surface gradient in channel i with respect to distance (m/m); j is junction or node number; C_d is the drag coefficient (assumed to retain constant value of 0.0026) (dimensionless); n is Manning's roughness coefficient; R_i is hydraulic radius; ρ_a and ρ_w are the density of air and water respectively (kg/m^3); W_i is the wind speed (relative to the moving water surface) measured at a height of 10 meters (m/sec); Ψ_i is the angle between the channel direction and the wind direction (relative to the moving water surface).

After preparing all input parameters in the network such as initial values for channel velocities and junction heads, boundary conditions for downstream heads, and forcing functions for freshwater inflow and wind stress, equations (3) and (4) in explicit finite difference form are solved using a modified Runge-Kutta procedure.

The downstream boundaries for the Bay was defined by specifying surface elevations (tidal function). Surface elevations at each downstream boundary can be specified by an average tidal function or by a variable tidal function. However, since enough data were available, a variable tidal function was utilized.

For some simulations, the average tidal variability will produce accurate predictions of tidal transport. Tidal heights (referenced to the model datum) are specified at equally spaced intervals throughout the average tidal cycle. Normally, 30-minute intervals will suffice. These data can be obtained from tidal stage recorders located at or near the model boundary. If no recorders are available, the predictions presented in the U.S. Coast and Geodetic Survey Tide Tables can be used.

DYNHYD5 reduces the height versus time data to the following function using the subroutine REGAN.

$$y = A_1 + A_2 \sin(\omega t) + A_3 \sin(2\omega t) + A_4 \sin(3\omega t) \qquad (5)$$

$$+ A_5 \cos(\omega t) + A_6 \cos(2\omega t) + A_7 \cos(3\omega t)$$

where:

y = tidal elevation above or below the model datum, m

A_i = regression coefficients, m

ω = 2π / tidal period, hr^{-1}

t = time, hr

If the regression coefficients A_i are known, they can be specified instead of the height versus time data. All seven of the coefficients must be specified in the above order. The average tidal function is repeated throughout the simulation.

If data are available, variable tidal patterns may be simulated by specifying the high and low tidal heights versus time for multiple tidal cycles. In this case, the subroutine RUNKUT in DYNHYD5 will interpolate with a sinusoidal curve between the data points.

MODEL INPUT PARAMETERS

The input parameters of the hydrodynamic model DYNHYD5 included estimation of junctions (nodes), channel (links), freshwater inflow, downstream boundary, and wind. All of the parameters incorporated in the model are either temporally or spatially variable.

They are approximated by a series of piecewise linear functions. Detailed description and input data used in the study can be found in the Completion Report (Shindala et al., 1996).

Junction Parameters

The input parameters associated with junctions in DYNHYD5 are initial elevation (head), surface area, and bottom elevations. Segment volumes and mean depths are calculated internally by using the above parameters.

Channels Parameters

The input parameters associated with the channels in DYNHYD5 are characteristic length, width, hydraulic radius or depth, channel orientation, initial velocity, and Manning's roughness coefficient. The channel length is the distance between the midpoints of the two junctions it connects. Channels must be rectangular and should be oriented so as to minimize the depth variation as well as reflect the

$$L_i \geq \Delta t \sqrt{g y_i} \pm U_i$$

location and position of the actual prototype channels. The channel length is generally dependent on a computational stability criteria given by:

Where

L_i = length of channel i, m.
Y_i = mean depth of channel i, m
U_i = velocity in channel i, m/sec
Δt = computational time step, sec
g = acceleration of gravity, m/sec^2

There is no apparent limit on the width of a channel. If a channel is too wide in relation to its length, however, the mean velocity predicted may mask important velocity patterns occurring on a more local scale. For well defined channels, the network channel widths are equated to the average bank to bank width. The cross-sectional area of a channel is equal to the product of the channel width and depth. Channels are assigned "typical" Manning Roughness coefficients. The value of this coefficient should usually lie between 0.01 and 0.08. Manning's n of 0.03 was selected for use in this study. An initial estimate of the mean channel velocity is required. Although any value may be assigned, the computational time required for convergence to an accurate solution will depend on how close the initial estimate is to the true value. Convergence is usually rather quick. Hydraulic radius is usually assumed to be equal to the mean channel depth. Channel orientation is the direction of the channel axis measured from true north.

Downstream Boundary Parameters

The downstream boundaries are specified by surface elevations (tidal function). The surface elevations at thirteen downstream boundaries are specified by a variable tidal function.

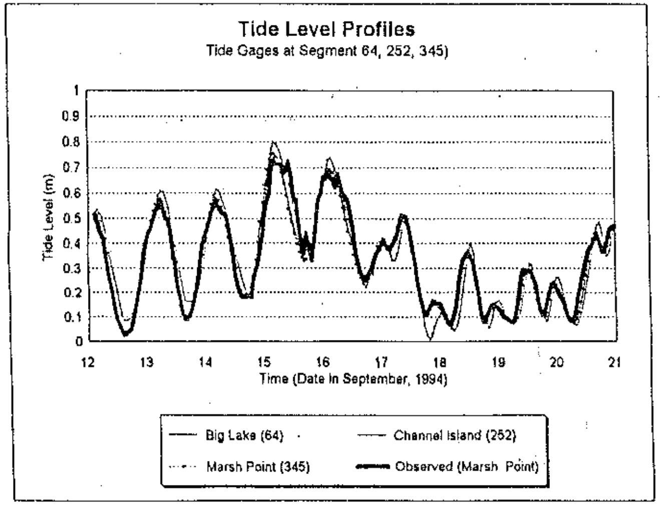
RESULTS AND DISCUSSION

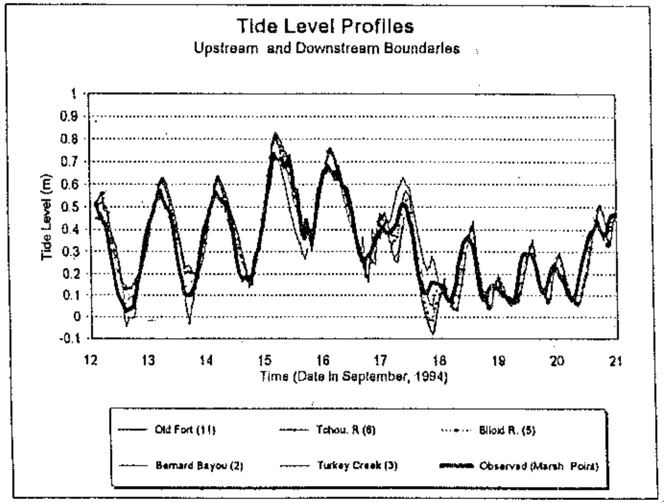
The hydrodynamic model DYNHYD5 consists of 669 segments. The characteristic length of the channels ranges from 200 m to 400 m. Based on the stability criteria, the time step used in the study was 10 sec. The maximum time step allowed is 25 sec.

The temporal profiles of observed and predicted tide level during the period September 12-21, 1994 are presented in Figure 4. As shown, the predicted tide levels reasonably matched the observed data at three sampling stations; Marsh Point, Channel Island, and Big Lake. As shown in the figure, the predicted tide level at Marsh Point matched well the observed data while the upstream tide level at five (5) major tributaries reasonably followed the trend of the downstream observed data taken at Marsh Point.

The temporal profiles of observed and predicted tide level during the period April 25-May 2, 1995 are presented in Figure 5. As shown, predicted tide levels reasonably matched the observed data at three sampling stations; U.S 90 Bridge, Pop's Ferry, and Keesler Air Force Base. As shown, the predicted tide level at U.S 90 Bridge perfectly matched the observed data and the other two also reasonably followed the trend of the observed data. The response of model prediction calculations is consistent with trends of the observed data ranges, but not with absolute values in all cases.

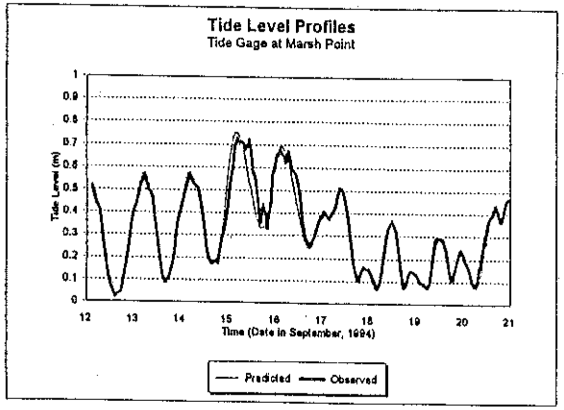
The results cannot compute accurate absolute values due to insufficient continuous inflow measurements at upper boundaries and limited surface elevations measurements at seaward boundaries. Furthermore, the initial conditions throughout the computational domain (segments) were made based on limited tide gages. Insufficient bathymetry data of the estuarine system also contributed to the inaccuracies. Busy traffic (barge) in the area was also a factor. Considering the above limitations, numerical errors and instrumental errors were not considered to be major factors contributing to the inaccuracies.

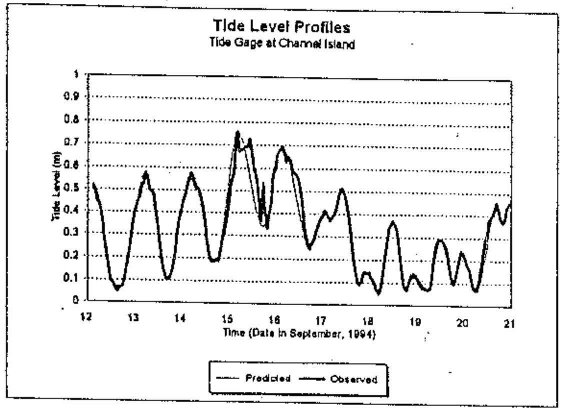


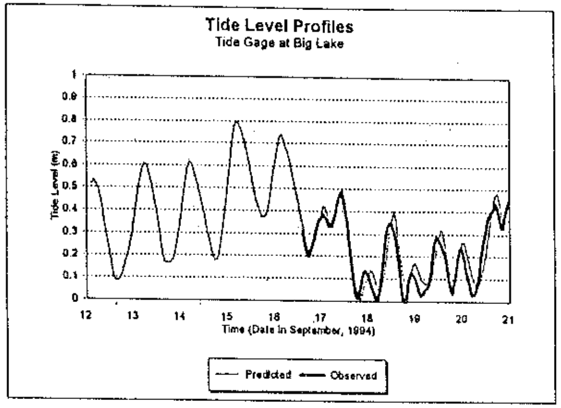


Water Body / Station No.	Big Lake / 9	Channel Island / 8	Marsh Point / 7	Old Fort Bayou	Tchoutacabouffa River	Biloxi River	Bernard Bayou	Turkey Creek
Upstream Channel No.	40, 337	186, 496	284, 581, 639	701	774	827	883	926
Downstream Channel No.	39, 330	185, 488	576					
Segment No.	64	252	345	11 - 12	6 - 7	5 - 566	2 - 669	3 - 682

Figure 4: Temporal Stage Profiles at Back Bay of Biloxi (September 12 - 21, 1994, MSDEQ)







Water Body	Big Lake	Channel Island	Marsh Point
Station No.	9	8	7
Upstream Channel No.	40, 337	186, 498	264, 581, 639
Downstream Channel No.	39, 330	185, 488	576
Segment No.	64	252	345

Figure 4 (continued)

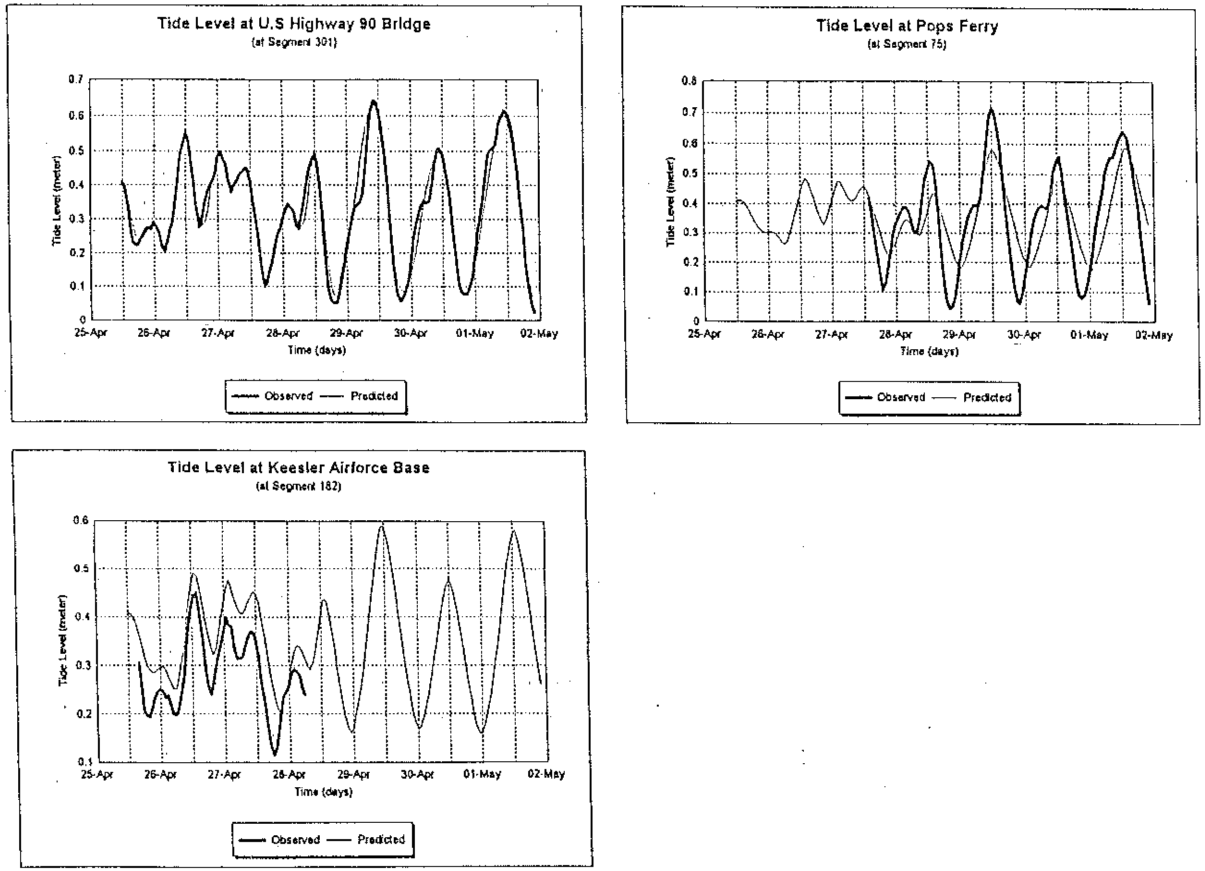


Figure 5: Temporal Stage Profiles at Back Bay of Biloxi (April 25 - May 2, 1995, MSDEQ)

CONCLUSIONS

The predicted tide levels reasonably matched the observed data at different locations of tide gage stations. The response of model prediction calculations is consistent with trends of the observed data ranges, but not with absolute values in all cases. The results indicate that the model can accurately predict the tidal elevations in the Bay under varying conditions of estuarine flow.

ACKNOWLEDGMENTS

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