Modeling Impacts of Louisiana Barrier Islands on Wetland Hydrology

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ABSTRACT


Management and restoration of natural systems requires the quantitative assessment of the impact and cost effectiveness of management alternatives. This paper provides a description of the methodology being used in Louisiana to evaluate the role of barrier islands in influencing wetland hydrology and some preliminary results. The steps that were taken to develop the methodology are reviewed. The objective of the evaluation was to determine the effect of barrier island geometry on the duration and depth of inundation of coastal wetlands under average and extreme conditions. The model selected for use was the overland flooding model developed by the Federal Emergency Management Agency to predict hurricane flood elevations for the National Flood Insurance Program. The model uses an explicit, two dimensional, spaced staggered, finite difference scheme to simulate the flow of water caused by tides and wind systems. The current size of the inlets between the islands is several times the equilibrium area based upon the tidal prisms. Slight reductions in the cross sectional areas of the inlets between the islands had only a very minor effect on reducing the depth and duration of wetland flooding. If the barrier islands were removed from the model, the depth and duration of tidal flooding slightly increased. Under extreme conditions, the island height and inlet size did have a significant effect on the depth and duration of wetland flooding. Hurricane Andrew produced a maximum surge elevation at Cocodrie of about 2.7 m. The predicted surge elevation at Cocodrie would have been about 3 m higher if the present barrier islands were destroyed and would have been as much as 1.2 to 1.5 m lower if the barrier islands were raised and the inlets narrowed.

ADDITIONAL INDEX WORDS: Restoration, assessment, tides, hurricane.

INTRODUCTION

Management and restoration of natural systems requires the quantitative assessment of the impact and cost effectiveness of management alternatives (ORTH, 1994). One means for conducting this type of assessment is with computer models. This paper provides a description of the methodology being used to evaluate the role of barrier islands in Louisiana in influencing wetland hydrology and some preliminary results.

The barrier islands in Louisiana, as shown in Figure 1, are being considered for restoration as one means for reducing the severe loss of coastal wetlands. Several of the processes thought to be involved with wetland loss, such as wetland inundation, salt water intrusion and storm surges, involve the hydrology of the estuary (BOESCH et al., 1994). An overview of the historic changes in barrier island size and planform is presented in McBride et al., (1992). A method for determining the effect of the barrier islands on wave action is being developed at Louisiana State University by Dr. Gregory Stone (personal communication).

The barrier islands are located at the southern boundary of the estuary and are therefore in a position to control the effects of marine processes on wetland hydrology. It had been suggested that the islands would control the duration and depth of inundation of wetlands under average and extreme conditions. However, there was no method available for quantitatively assessing this influence. This paper describes an assessment methodology that has been developed for use in Louisiana. The results of the assessments are being provided to planning and management groups consisting of local, state and federal agencies that are considering various restoration options. These groups have provided input concerning the environmental conditions under which the evaluations were to be conducted and have periodically reviewed the results of the evaluations. Only preliminary results of the work are reported herein. The methodology will be used in the future to evaluate new configurations to be developed in a barrier island feasibility study being conducted by the Louisiana Department of Natural Resources.

ESTUARINE HYDROLOGY

The hydrology of the Barataria and Terrebonne estuaries is subject to a variety of influences that need to be included in the evaluation. Eustatic sea level rise is increasing the annual mean water level at a rate of about 0.23 cm per year (BARNETT, 1984). Subsidence is lowering land elevations by up to 1 cm/yr (SUHAYDA, 1987; PENLAND and RAMSEY, 1990). Seasonal variations in sea level are about 40 cm with a minimum in December and a maximum in September (CHEW, 1964). Freshwater input to the system includes a mean an-
annual rainfall of about 150 cm (Muller and Fielding, 1988), annual run-off of about 300 cubic meters per second (Wang, 1988; Wiseman and Swenson, 1989), riverine input from the Atchafalaya river and pumped or siphoned water from the Mississippi river. Astronomical tides in the study area are diurnal with an average range of about 40 cm (Marmet, 1954; Zetler and Hansen, 1970) and a fortnightly range that varies from a low of about 10 cm to a high of about 60 cm (National Ocean Survey, 1995). Tides propagate well into the estuaries and have a range of about 3 to 6 cm in Lake Salvador (Byrne et al., 1976). The tidal prism for the estuaries has been estimated to be about 26 billion cubic feet (Wiseman and Swenson, 1989). Winter storms can cause major movements of water and sediments within the system (Murray et al., 1993). Storm surges can inundate large areas of the estuary causing vegetation loss and the introduction of saline waters into freshwater swamps (Adams et al., 1978). The movement of water within the estuaries is controlled by the distribution of land and water areas of differing hydraulic properties, by numerous natural channels and man made canals, and by the presence of levees and roadways (McKee et al., 1995).

Barrier islands have a direct effect on wetland hydrology as a boundary condition. Tidal exchange in the estuaries is influenced by the size of the inlets and passes through the islands (Jarret, 1976). The height, width and vegetative cover of barrier islands also have an effect on extreme water levels. Wetland and bay water salinity and circulation are affected by the locations, number and sizes of tidal inlets (Kjerfve, 1975; Wiseman and Inoue, 1994).

Analysis of the linkage between barrier islands and estuarine hydrology thus indicates that a hydrodynamic model of the appropriate spatial and temporal scale could evaluate the effect of barrier island geometry on average and extreme water levels. The model would have to incorporate the size and location of the barrier islands and barrier inlets. The model would also have to incorporate the estuarine hydraulic features affecting water movement. Finally the model would

Table 1. Barrier island inlet areas.

<table>
<thead>
<tr>
<th>Estuary</th>
<th>Year</th>
<th>Tidal Prism, P (cum)</th>
<th>Equilibrium Inlet Area, Ac</th>
<th>Inlet Area (sqm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrebonne</td>
<td>1990</td>
<td>500,000,000</td>
<td>19,500</td>
<td>57,400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.9 Ac</td>
</tr>
<tr>
<td></td>
<td>1935</td>
<td></td>
<td>42,500</td>
<td>31,400</td>
</tr>
<tr>
<td></td>
<td>1890</td>
<td></td>
<td>31,400</td>
<td>21,600</td>
</tr>
<tr>
<td></td>
<td>1853</td>
<td></td>
<td>21,600</td>
<td></td>
</tr>
<tr>
<td>Barataria</td>
<td>1990</td>
<td>226,000,000</td>
<td>9,700</td>
<td>16,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.6 Ac</td>
</tr>
<tr>
<td></td>
<td>1935</td>
<td></td>
<td>11,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1890</td>
<td></td>
<td>4,400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1853</td>
<td></td>
<td>5,300</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. The 1 km computational grid used in the hydrodynamic model showing the representation of the barrier islands.

have to forecast the depth and duration of wetland flooding under average and extreme conditions.

**COMPUTER MODEL**

The model selected for use was the overland flooding model developed by the Federal Emergency Management Agency to predict hurricane flood elevations for the National Flood Insurance Program (FEMA, 1988). This model is well documented and has been used extensively throughout coastal areas of the United States to make quantitative predictions of engineering accuracy. It had been previously applied to Louisiana (Suhayda and Young, 1987). The model uses an explicit, two-dimensional, spaced staggered, finite difference scheme to simulate the flow of water caused by tides and wind systems. The inputs to the model include the bathymetry, coastline configuration, boundary conditions, and bottom friction and other flow resistance coefficients. Hurricane storm parameters can also be input to the model including position, central pressure, radius to maximum winds and forward velocity. The model uses a rectangular grid to discretize the simulated region of the ocean and coast. The model grid expands and contracts during a simulation to predict the flooding and drying of low lying areas. Barriers and rivers which occur in the computational grid are typically much smaller in width than a typical grid cell and are included in the model as sub-grid elements. The model predicts water level elevation and water transport everywhere in the modeled region, and can display the results as time series at a point and as two-dimensional maps in a GIS compatible format.

**DATA BASE**

A data base of wetland physical features, barrier island geometry, hydrologic data and climatic data was established to support the model.

The topographic data for the study was taken from 7.5' and 15' United States Geological Survey quad sheets and from a recent survey funded by the Barataria/Terrebonne National Estuaries Program (Alawady and Khaled, 1995). Additional topographic data were collected for levees and roadways. Bathymetric data were taken from National Ocean Survey charts and channel cross section information was obtained from hydrographic charts and from local, state and federal agencies. LANDSAT and AVHRR satellite data were collect-
ed to determine land/water boundaries and density of land. The data indicate that much of the land areas of the estuaries might in fact be considered shallow bays with emergent vegetation.

The data for the barrier islands included island planform, elevation and vegetative cover, and the location, width and depth of inlets. Table 1 gives the cross sectional areas of the passes for each estuary for present and historic times. The

![Figure 3. Comparison of the observed and predicted maximum storm surge elevations for Hurricane Andrew.](image)

![Figure 4. Tidal water level predictions at Catfish Lake for present and future barrier island conditions.](image)
Table also indicates the equilibrium cross sectional area computed from the current estimates of the tidal prisms for each estuary (Jarret, 1976).

Hydrologic information included in the data base are observed water levels at several locations under average and extreme conditions and salinity measurements collected by governmental agencies such as the U.S. Army Corps of Engineers, the United States Geological Survey, the Louisiana Department of Wildlife and Fisheries, and the Louisiana Department of Natural Resources.

Climatic data in the data base describes the frequency and intensity of hurricanes, and longterm changes in the project area, such as subsidence and sea level rise.

MODEL SETUP, CALIBRATION AND SENSITIVITY ANALYSIS

The hydrodynamic model was set-up to run simulations using several different spatial resolutions. A coarse scale grid was used to generate the boundary conditions for input to a fine scale grid for the hurricane simulations. The coarse and fine scale grids are based on the Universal Transverse Mercator (UTM) coordinates. The coarse grid had a cell size of 3,049 m (10,000 ft), and the fine grid had a size of 1,000 m (3,280 feet). The coverage and resolution of the 1,000 m grid is shown in Figure 2.

The sensitivity of model predictions to small variations in input conditions was evaluated. The model was run with several values of the Manning coefficient for the offshore areas and land areas. The model was calibrated for average and extreme conditions for the time period of August 1992, which included Hurricane Andrew. Observed water level data from several tide and river stage water level gauges (Lovelace, 1994) were compared to the predicted values and showed good agreement, as indicated in Figure 3.

RESULTS

The model has been run to date for several different types of barrier island geometries that represent the range in management configurations that may be proposed. The base case representing conditions in 1989 is shown in Figure 3, where the islands are represented as individual cells in the 1 km grid. To represent known historic conditions (McBride et al., 1992) additional “barrier” cells were added to the present configuration. A future condition of complete loss of all barriers was also considered. Finally, a one inlet configuration was considered involving elongation of the islands and closure of all present inlets excepting Barataria Pass and Cat Island Pass.

The effect of losing the barrier islands on the amplitude of the tides is shown in Figures 4 and 5. Figure 4 shows the predicted elevation for present and for future conditions at Catfish Lake. The elevation of the marsh at this location is 3 cm (MSL) and as the marsh surface is exposed the water level elevation is shown in the figure as zero, thus the duration of the flooding can be determined. Figure 4 shows that the increase in tidal amplitude and duration of flooding is very slight. Figure 5 shows the water level elevation at Lake Salvador for the same conditions. The change in the tidal amplitude again is very small. The rise in mean water level is associated with the transient effect of starting the simulation with a lake water level at mean sea level.

Figures 6 and 7 show the results of simulating the effect of restoring the barriers to the historic condition of 1890. The changes in the amplitude and duration of flooding at Catfish Lake.
Lake, shown in Figure 6, are also very small. Figure 7 shows the tidal amplitude change at Lake Salvador is also very small.

The effect of barrier geometry on extreme flooding is shown in Figure 8. The Figure shows the predicted storm surge at Cocodrie resulting from Hurricane Andrew for present, 1853, future, and one inlet configurations. The predicted storm surge peak is increased by about 30 cm without the islands and decreased by about 30 cm for the 1853 geometry. The one inlet geometry decreased the peak surge by about 1.2 m.

CONCLUSIONS

The work reported herein describes the methodology that has been developed to evaluate one of the effects of the bar-
rrier islands on wetlands, particularly the effect of barrier geometry on wetland hydrology. Specifically, a computer model was selected, set-up and used to determine how much of an effect different barrier island and inlet configurations would have on the depth and duration of wetland flooding under average and extreme weather conditions.

The preliminary results of the work can be summarized as follows. Under average tide conditions, reducing the cross-sectional areas of the inlets between the islands has a slight effect on reducing the depth and duration of wetland flooding. If the barrier islands were removed from the model, the depth and duration of tidal flooding would slightly increase.

Under extreme conditions, the island height and inlet size did have a significant effect on the depth and duration of flooding. Hurricane Andrew was used as an example of extreme conditions. The hurricane produced a maximum surge elevation at Cocodrie of about 2.3 m. The predicted surge elevation at Cocodrie would have been about 30 cm higher if the present barrier islands were removed and would have been as much as 1.2 m to 1.5 m lower if the barrier islands were raised and the inlets narrowed.

The importance of the effects of barrier islands on wetland hydrology predicted by the modeling should be considered in the context of implementing an overall strategy for restoring coastal Louisiana. Small changes in wetland inundation depth and duration could shorten or prolong the viability of stressed wetlands while other restoration approaches, such as diversions, are implemented. Storm surge reduction could reduce the adverse impact of hurricanes on marsh management and hydrologic restoration projects that are not designed to survive extreme conditions. To achieve either of these benefits would require major modifications of barrier inlets and islands.

ACKNOWLEDGEMENTS

This work was funded by the Barataria/Terrebonne Natural Estuaries Program whose support is gratefully acknowledged.

LITERATURE CITED


