GIS-Aided Water Quality Monitoring and Assessment System for Lake Pontchartrain

Problem and Research Objectives

The pumping of New Orleans floodwaters from Hurricanes Katrina and Rita into Lake Pontchartrain has raised serious environmental concerns regarding adverse impacts of the contaminated floodwaters and sediments on the water quality of the receiving lake. Although water quality sampling programs have been initiated by Federal and State agencies for Lake Pontchartrain, no existing efforts can effectively predict temporal and spatial variations of the pumped contaminants in the lake. This information is crucial to guiding water and sediment quality sampling and to assessing short-term and long-term environmental impacts of the pumped floodwaters and sediments on Lake Pontchartrain.

The goal of this project is to develop a GIS-aided water quality monitoring and assessment system for Lake Pontchartrain. The system can be employed (1) to simulate temporal and spatial variations of water temperature and dissolved oxygen in the lake, (2) to provide guidance to water quality and sediment sampling in the lake, (3) to visualize modeling results, and (4) to provide necessary scientific information for assessment of short-term and long-term environmental impacts of the pumped New Orleans floodwaters on Lake Pontchartrain. To achieve the primary goal of this project, the research is split into six specific objectives: (1) Modeling of New Orleans floodwater plume trajectory and sediment deposition in Lake Pontchartrain, (2) Water and sediment quality sampling, (3) Development of multi-layered water quality database, (4) Development of lake temperature model, (5) Development of dissolved oxygen model, (6) Integration of numerical models and GIS interface.

Methodology

The three-dimensional Hydrodynamic-Eutrophication Model (HEM-3D), also referred to as the Environmental Fluid Dynamics Computer Code (EFDC), is used to simulate flow circulation. The hydrodynamic model of HEM-3D is based on continuity, momentum, salt balance and heat balance equations, with hydrostatic and Boussinesq approximations (Hamrick, 1992). For turbulent closure, the second moment turbulence model developed by Mellor and Yamada (1982) and modified by Galperin et al. (1988) is used. The model includes a wetting and drying scheme, and uses orthogonal curvilinear of Cartesian horizontal coordinates with stretched sigma vertical coordinate. Detailed description of the model, including the governing equations and numerical solution method, can be founded in Hamrick (1992, 1996) ,Park et al. (1995), Ji et al., 2001, and Park et al., 2005. The modeling domain includes the entire Lake Pontchartrain system. The Surface-Water Modeling System (SMS) software is employed for generation of the model grid with a varying-grid size of 200 – 900 m, as shown in Figure 1. The driving forces for lake circulation include winds and tidal wave propagation through Rigolets Pass and Inner Harbor Navigation Canal (IHNC). Harmonic constants for M2, S2, K1, O1 and P1 tidal constituents are measured at USGS New Canal by NOAA. Surface elevations for Rigolets Pass and IHNC are very similar in terms of tidal phase and amplitude (Chilmakuri, 2005). The depth averaged 2-D sediment transport module of EFDC is used to determine distributions of contaminated sediments from the floodwaters pumped from New Orleans. Five outfalls located along south shorelines of Lake Pontchartrain, as shown in Figure 1, are taken into account. The flow rate for each outfall was determined using total floodwaters volume (8.86 billion cfs) pumped from New Orleans to the lake from 9/7/2005 to 9/16/2005 after Hurricane Katrina. A sediment concentration of 100 mg/l is utilized in a boundary condition at the outfalls. Sediments pumped into the lake were mainly silt and clay. Settling velocity used in this model is determined as 1.e-5 m/sec.

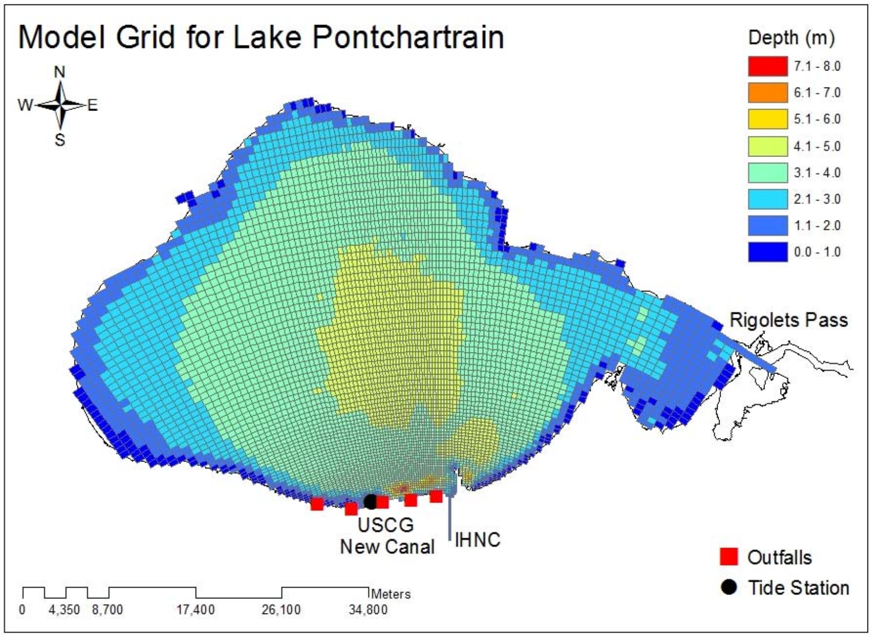

Figure 1: Model grid and water depth of Lake Pontchartrain

To determine temporal and spatial variations in monthly mean dissolved oxygen (DO) the water depth is divided into three sigma-layers and HEM-3D is used. Temperature modeling was performed by considering daily averaged heat exchange between water surface and atmosphere (Edinger et al. 1974). All data, including wind, water and air temperature, dew point temperature, etc., required to estimate the heat exchange are collected from NOAA. Initial and boundary values for DO modeling were collected and analyzed from previous studies and measurements conducted by USGS. In addition, spatially varying sediment oxygen demand (SOD) was applied to consider the effect of contaminated bottom sediments from New Orleans stormwaters. The simulation is conducted for the period of April 1st - October 31st, 2006

Principal Findings and Significance

1. **Lake Circulation:** Figures 2a and 2b show current distribution produced by spring tide and southeasterly wind (dominant wind), respectively. Generally, currents generated by tides are much weaker than those by winds and the effect of tidal currents is limited to tidal entrances. Flow patterns in shallow area along shorelines are controlled by wind direction while flow in the center of Lake Pontchartrain is determined by wind set up, resulting in two large eddies, as shown in Figure 2b. The flow velocity is very small in the center parts of the eddies. Low velocity may facilitate the formation of stratification and thereby hypoxic condition in the bottom layer of water column. In addition to the dominant wind, flow circulation computations are also conducted for other wind directions (N, NE, E, S, SW, W, NW). The

simulation results are similar. The results are saved in the GIS database developed in this study.

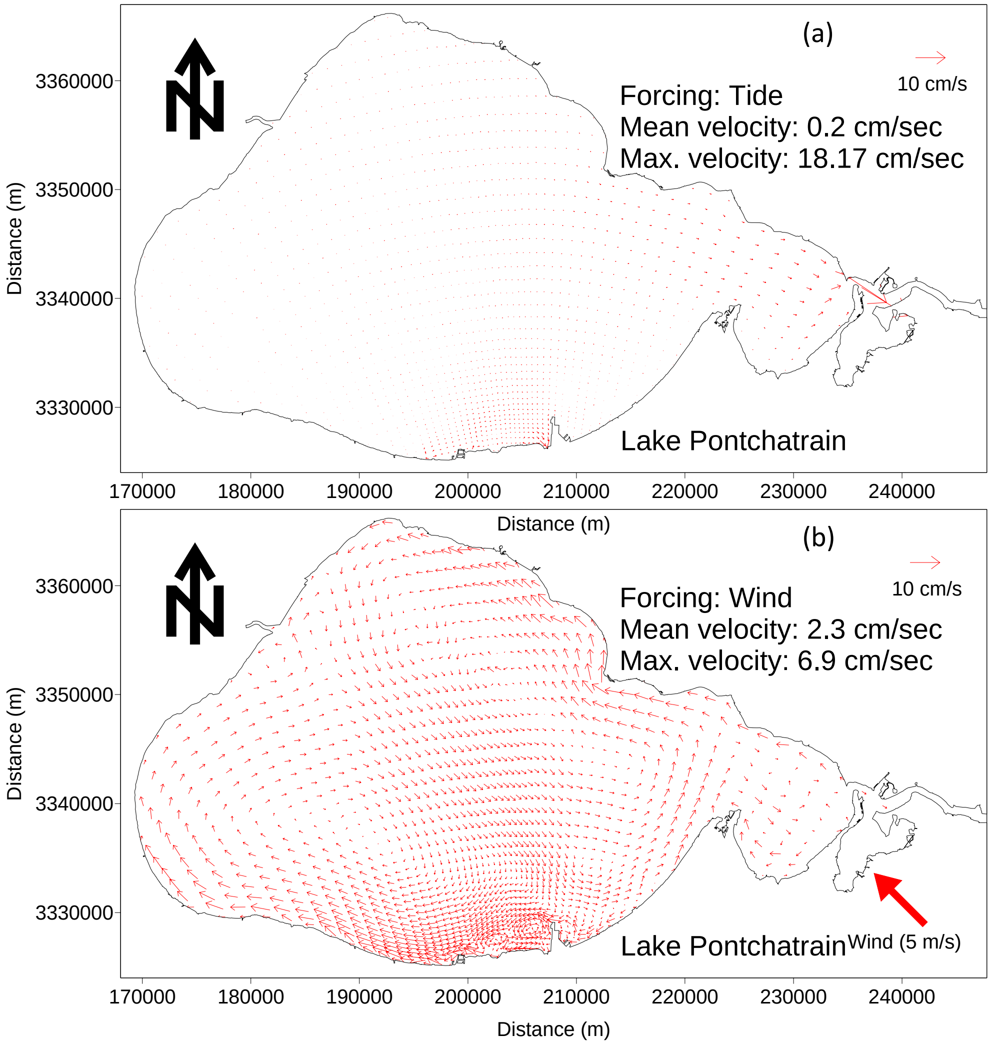

Figure 2: Comparison of velocity distributions produced by tidal forcing (through Rigolets Pass and IHNC) and wind (southeasterly wind) forcing

2. **Contaminated Sediment Distribution:** Figure 3 (a) and (b) show distributions of the contaminated sediments pumped from New Orleans floodwaters under southeasterly and northerly winds. The distributions of the sediments are mainly determined by flow patterns. For southeasterly wind, the sediments are distributed along the south shoreline of the lake and the dispersion of sediments to the center of the lake is limited, as shown in Figure 3 (a). For northerly wind, the sediment plume spread toward the center of the lake but sediment concentration decrease rapidly before the plume reaches the center, as shown in Figure 3 (b). Under the forcing of other wind directions the sediment plumes are limited in the area close to the south shoreline. It means that the contaminated sediments from New Orleans floodwaters are mainly distributed in a belt area along the south shoreline of the lake. Computation results for sediment distributions are saved in the GIS database.

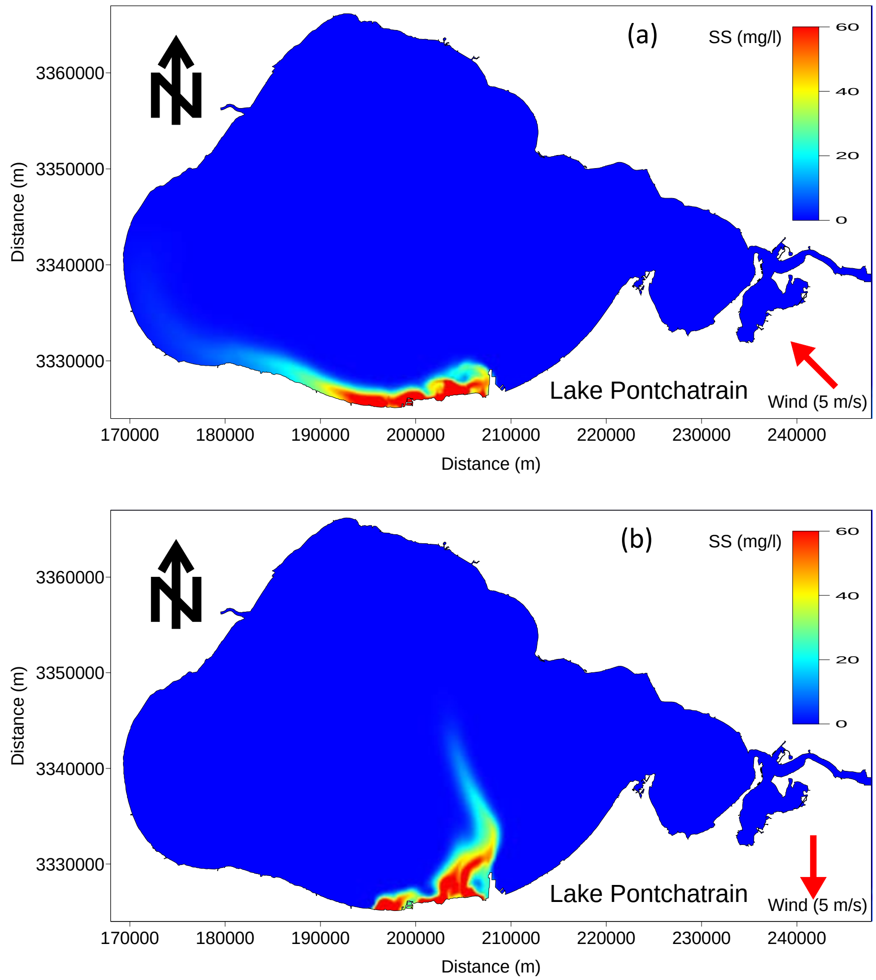

Figure 3: Sediment distributions due to southeasterly (a) and northerly (b) wind.

3. **Spatial and Temporal Variations in DO:** The simulated temporal and spatial variations in monthly mean dissolved oxygen (DO) for the period from April 1st - October 31st are shown in Figure 5. Figure 4 indicates the simulated distribution of sediment oxygen demand (SOD) in the lake. The figure clears shows that the contaminated sediments from New Orleans floodwaters cause high SOD in the area close to the outfalls along the south shoreline. Figures (5a) – (5d) demonstrate the temporal variation of DO in the lake due to the combined effect of the contaminated sediments and stratification. DO concentrations in surface layer from April - August were higher than 7 mg/l. However, bottom DO concentration decreased from April to August. The decrease in DO concentration at bottom of the lake is highly related to the formation of stratification and the contaminated sediments. Strong stratification prevents high DO surface water from mixing with low DO bottom water. The low DO zone was formed in the deep water area in the south east part of the lake.

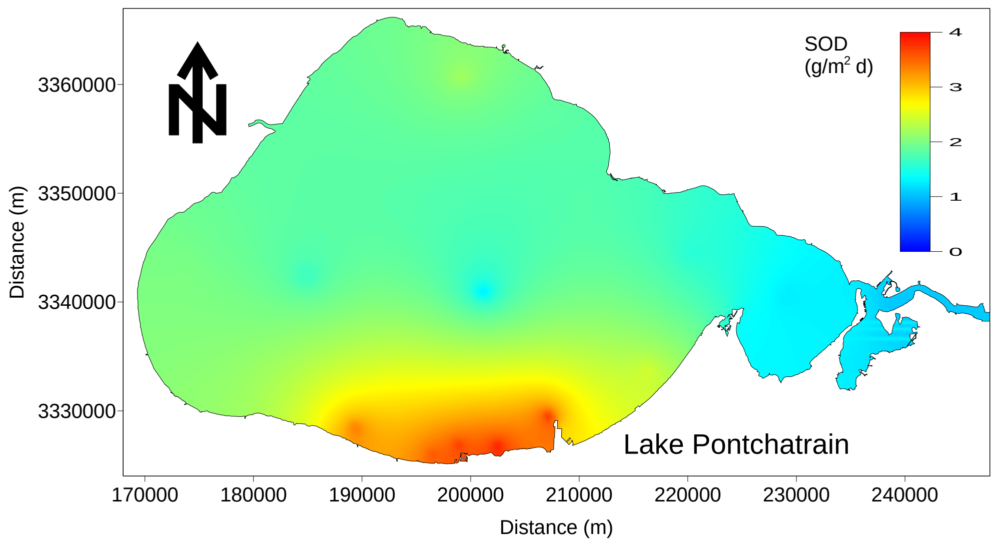

Figure 4: Spatial distribution of Sediment Oxygen Demand (SOD) used for the DO-Model

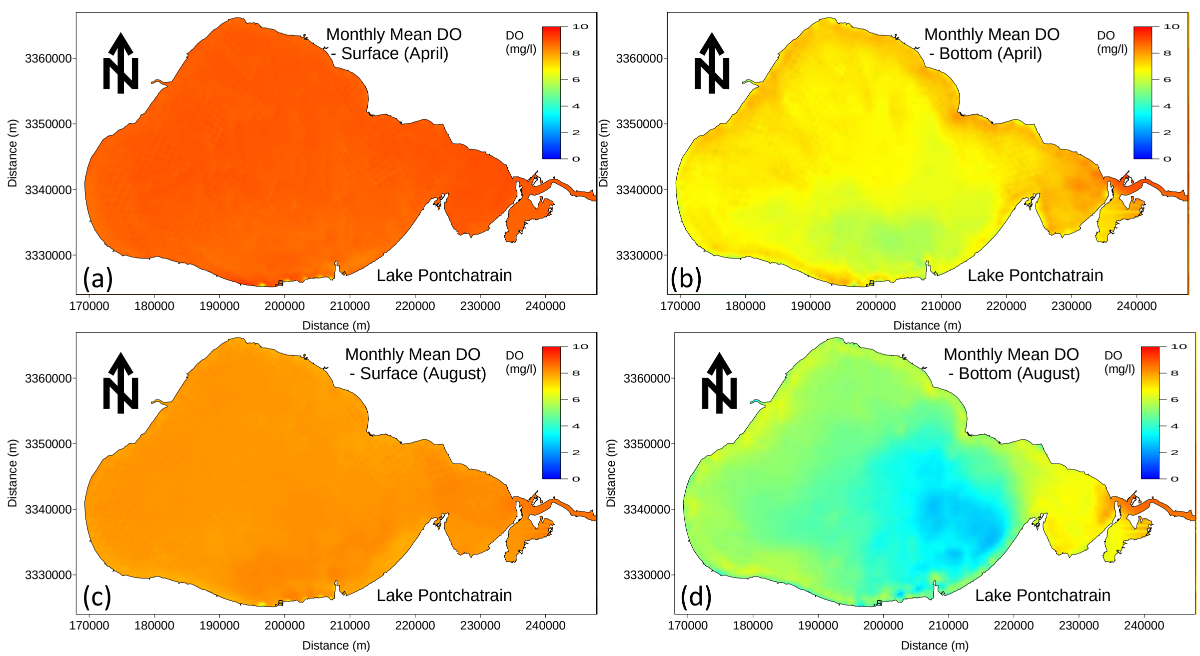

Figure 5: Monthly mean surface and bottom DO distributions in April and August.

4. **Recommended Water Quality Monitoring Stations**: The computation results of lake circulation, sediment plume development, DO distribution in the lake and current sampling locations are used to identify the most efficient water quality monitoring stations for the Lake Pontchartrain. The current sampling stations by US EPA are concentrated in few areas of the lake and thus they do not sufficiently give the spatial variation in water quality parameters in the lake. In addition to the existing 39 water quality stations, twelve new sampling stations

are recommended based on the above analyses. These sampling stations were selected in such a way that the new stations along with existing stations cover the low bottom dissolved oxygen zone and the sediment plume trajectories obtained by sediment plume modeling. The recommended sampling stations will cover the areas where water quality varies significantly. This will be very helpful for decision makers to implement the water quality monitoring program for lake Pontchartrain. The recommended sampling stations can be seen by clicking "Recommended Stations" button in "Lake Pontchartrain Water Quality Modeling Toolbar" in the following GIS-Aided Water Quality Monitoring and Assessment System developed in this study for Lake Pontchartrain.

5. Operational Manual of the GIS-Aided Water Quality Monitoring and Assessment System for Lake Pontchartrain

1) Open the ArcGIS application by clicking the ArcGIS icon in the "Start>All Programs>ArcGIS>ArcMap".
2) Locate the project file "C:\Pontchartrain GIS \pont.mxd" to open it.
3) The open GIS project will display ten basic lake Pontchartrain GIS layers including the Sediment Concentration, bottom Dissolved Oxygen Concentration, Sediment Plume trajectory under dominant wind condition (SSC under Wind SE), Landsat TM Satellite Imagery, Water Quality Stations (with link), Streams, Pontchartrain basin boundary, Hydrodyamic link, recent land use (1992) and lake Pontchartrain basin boundary. (Figure 6).
4) There are fifteen more GIS layers saved in "C:\Pontchartrain GIS \GIS layers". These layers are the mean dissolved oxygen in month of April, May, June, and September and the sediment plume trajectory under different wind conditions which can be viewed as per the requirement.
5) This geo-database has been customized to perform user specific functions for the lake Pontchartrain. The figure 7 shows the customized toolbar "*Lake Pontchartrain Water Quality Modeling Tool*" to conduct the project specific task. There are seven functions included in this tool.
    a. To add a new layer for the geo-database in "C:\Pontchartrain GIS \GIS layers".
    b. To add the urban outfall from New Orleans metropolitan area.
    c. To add the contoured bathymetry of the Lake Pontchartrain.
    d. This button adds the current water quality monitoring stations identified by the USEPA.
    e. This button will display the recommended sampling stations based on the above analysis.
    f. This button will import any new layer to the ArcMap.
    g. This will give the output in the JPEG format saved in location C:\Pontchartrain GIS \Output\pont_output.jpg".

6) To view the hydrodynamic modeling results, select the “Hydrodynamic Link” Layer. Click the Hyperlink button shown in the red box of figure 6. An adobe file will open which shows the hydrodynamic profile under various wind direction was investigated all are categorically saved. This is a set of twelve figures in each simulation showing the instantaneous wind direction.

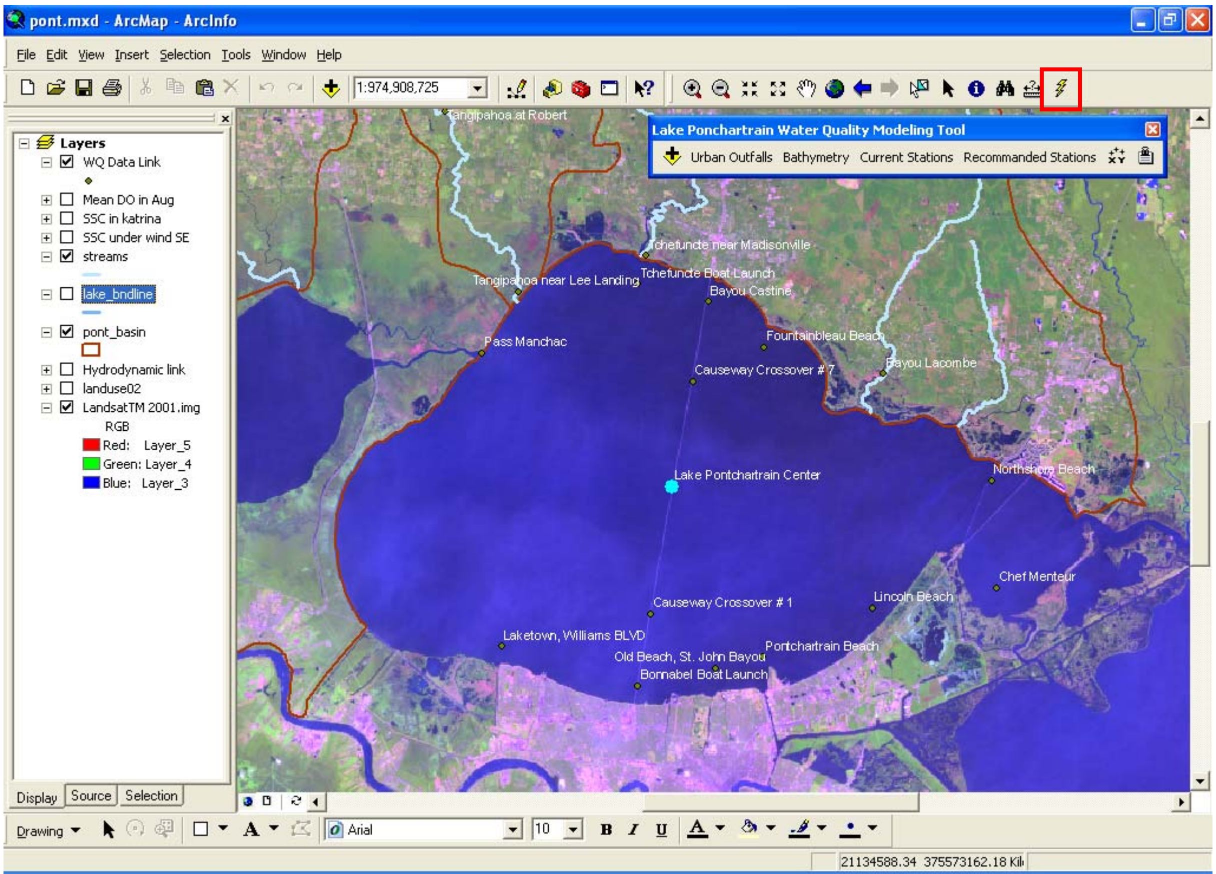

Figure 6: Lake Pontchartrain Base Layers

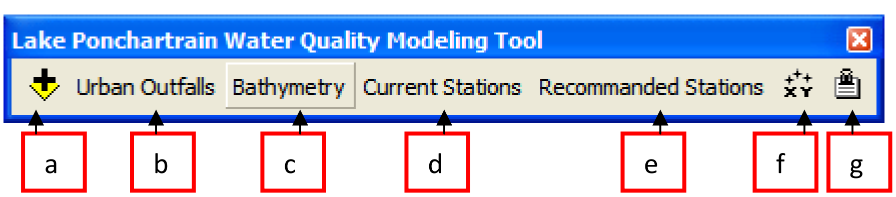

Figure 7: Lake Pontchartrain Water Quality Modeling tool

The GIS-Aided Water Quality Monitoring and Assessment System developed in this project for Lake Pontchartrain will improve water quality monitoring and provide an efficient tool for water quality assessment and restoration of Lake Pontchartrain. This project also leads to the publication of two journal papers and two conference papers. Furthermore, the project and its results will be introduced in some civil and environmental engineering courses at LSU, immediately benefiting both graduate and undergraduate students in learning how science applications solve real world problems related to coastal restoration in Louisiana.

Reference

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