

Literature Review on the Lower Mississippi River

**The Louisiana Applied And Educational
Oil Spill Research And Development Program (OSRADP)**

Final Report

Literature Review on the Lower Mississippi River

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Final Report

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Abstract

The Mississippi River is one of largest rivers in the world and has major economic, environmental, ecological, and industrial value, not only to Louisiana but to the entire United States. The lower portion of the river houses the largest port complex in the world. This area's intensive industrial use highlights the need for a three-dimensional numerical model that can determine the transport of spilled toxic chemicals along the lower stretch of the river. An extensive literature review was conducted on the background, previous studies, and modeling efforts of the lower Mississippi River. The review was designed to ensure that similar research had not previously been conducted. The review revealed no previous or ongoing research to model or develop contingency plans for this portion of the lower Mississippi River. There is thus a need to develop an efficient river management and analysis tool. Such a tool will help planners and responders understand how the hydrodynamics of the river affect the transport of oil and chemical spills.

1. Background

The Mississippi River is a major natural, economic, and industrial resource for the United States. The longest and largest river in North America flows 2,300 miles from its source at Lake Itasca in the Minnesota north woods, through the mid-continental United States, the Gulf of Mexico

coastal plain, and the subtropical Louisiana delta (Wiener et al.). The approximate drainage area of the Mississippi River Basin is 1,245,000 square miles, which covers about 40% of the continental United States and about one-eighth of North America. A general layout of the Mississippi River Basin is shown in Figure 1 (Gagliano and Beek 1976).

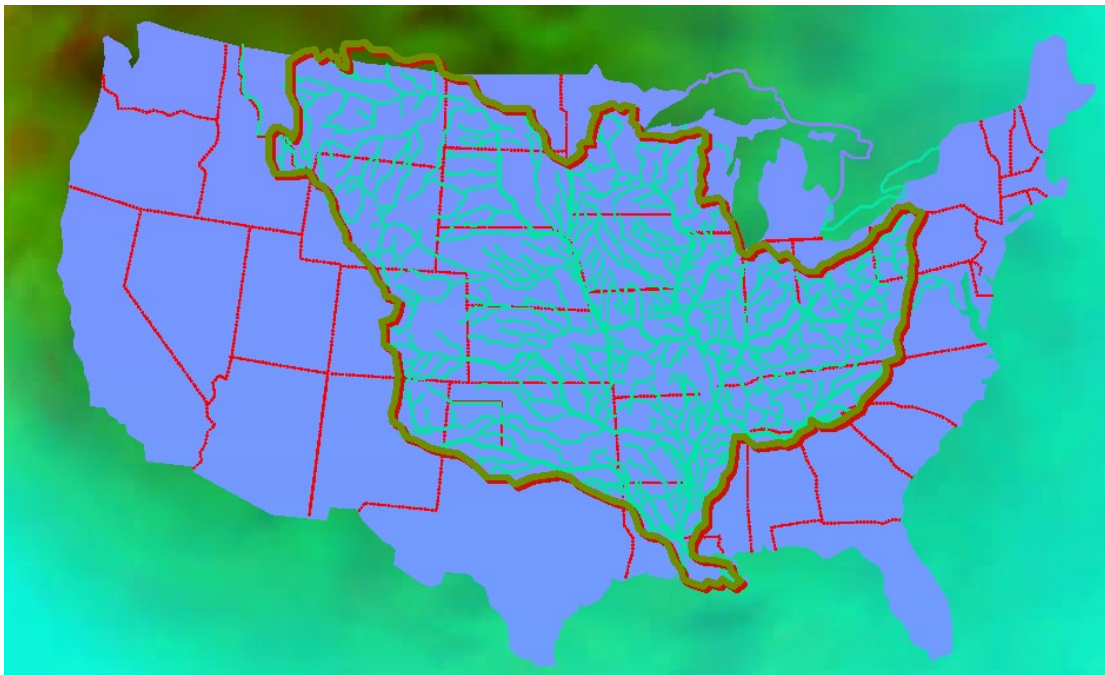


Figure 1: Mississippi River Basin modified after Banks as presented in River Resources Workshop in New Orleans, 2003.

The lower Mississippi River houses one of the world's busiest port complexes, including the ports of New Orleans, Baton Rouge, and South Louisiana. Each year, more than 6,000 ocean vessels move through the Port of New Orleans alone. These vessels move an average of 11.4 million tons of cargo, including steel, grain, containers, and manufactured goods. A 23,330-kilometer inland waterway system provides the ports with

access to the American Midwest. Along with the cargo, however, comes some of the heaviest chemical and oil traffic in the world.

The development of a comprehensive spill contingency plan is an essential part of protecting Louisiana's valuable ecological resources. Louisiana's coastal zone contains 41% of the United States' coastal wetlands and 25% of all U.S. wetlands, making it one of the earth's largest and richest estuarine areas. Protecting these resources along the riverbanks, especially near the river mouth at the Head of Passes, is a challenging task. The flow pattern near the Head of Passes is complex, but it should be determined accurately in order to predict how an oil spill might move and spread.

John M. Barry (1997) describes the flow of the river:

“The Mississippi never lies at rest. It roils....Its waters and currents are not uniform. Rather, it moves south in layers and whorls, like an uncoiling rope made up of a multitude of discrete fibers, each one following an independent and unpredictable path, each one separately and together capable of snapping like a whip. It never has one current, one velocity....the water swirls about, as if trying to devour itself. Eddies of gigantic dimension can develop, sometimes accompanied by great spiraling holes in the water.”

A contingency model will help decision makers predict how spilled oil will travel. This information, in turn, will ensure that cleanup and protection measures are deployed quickly and effectively.

2. Objectives

- To establish the importance of developing an efficient management and analysis tool that can help decision makers fully understand the hydrodynamics of the river and the fate of oil spills.
- To ensure that there is no previous research effort to model the Mississippi River from Tarbert Landing to the Head of Passes.

3. Findings

3.1 Early Studies

Early studies on contaminant transport in the lower Mississippi River were mainly performed by injecting a fluorescent tracer, such as Rhodamine WT, into the river and monitoring the tracer's dispersion and dilution downstream. With limited resources available for cleanup, the main concern was preventing water-supply contamination in the event of a toxic spill. In 1971, Everett stated, "By using the time of arrival, duration, and concentrations of the contaminant at downstream locations, withdrawal of water can be discontinued until after the contaminant has passed."

Time-of-travel studies were performed in 1965 (Stewart 1967) and 1969 (Everett 1971) to determine the travel time and dispersion characteristics of water flowing between Baton Rouge and New Orleans, Louisiana. Both studies were conducted at low discharge levels of 240,000 cfs and 364,000 cfs, respectively, and both found variations in travel time with discharge for the leading edge, peak, and trailing edge of the dye cloud. Noting that the duration of a contaminant

at a particular site is inversely proportional to discharge, graphs were formed relating discharge to travel time from Baton Rouge to four monitoring sites downstream. Another graph was constructed relating elapsed travel time to unit concentration, and a final graph calculated the peak concentration at a point downstream from Baton Rouge. This was done by multiplying the unit concentration times the weight of contaminant spilled and then dividing this figure by the river discharge. Those studies also included lateral dispersion, whereby dye was injected at different locations along the cross section and monitored in downstream meanders. Those results were site- and spill-specific and did not provide information for a general application to lateral dispersion at other points in the river. Also, the results applied only to those solutes whose density and behavior were similar to those of water. Additional considerations had to be taken with materials that were not soluble in water.

A similar study in 1974 (Martens and others 1974) was conducted for a discharge value approaching flood level, at approximately 800,000 cfs. Martens notes that during low and medium flow, the discharge of the river between Baton Rouge and the Gulf of Mexico is constantly changing as a result of tidal effects. In 1969, the flow at Baton Rouge, where the dye was injected, was 364,000 cfs, and the flow at New Orleans when the tracer arrived was only 290,000 cfs. Discharge measurements made during this study at high flow changed very slightly. Therefore, Martens claims that the relation between travel time and distance at high flows is essentially linear. However, because of tidal influences at lower discharges, this relation becomes curvilinear. Martens also tested the vertical dispersion of the dye by simultaneously taking samples at the surface and at 50-foot depths at three downstream locations. Results showed that six miles downstream, surface concentrations were almost double those at the 50-

foot depth. At the 11- and 18-mile downstream sites, however, concentrations at both depths were practically the same.

In 1976 and 1977, Calandro conducted research on the travel time of solutes in the Mississippi River from the Arkansas-Louisiana state line to Plaquemine, LA and from Belle Chasse, LA to the vicinity of Head of Passes, LA, respectively. Similarly, he injected a tracer to determine the travel time, the maximum concentration, the dispersion characteristics, and the duration of the tracer cloud. His research and previous measurements were used to calibrate a mathematical model developed at the U.S. Geological Survey's Gulf Coast Hydroscience Center by McQuivey and Keefer (1976 a,b). The model was then used to generate time-of-travel curves of the leading edge, the peak, and the trailing edge of the tracer cloud for discharges ranging from 200,000 to 1,500,000 cfs. As in the previous studies, the results only applied to those solutes whose density and behavior were similar to those of water. Additional considerations had to be taken with materials that were not soluble in water.

More recently in 1996, Jobson gives a more detailed analysis of the prediction of travel time and longitudinal dispersion in rivers and streams without the use of mathematical models. He uses previously presented concepts along with extensive data collected on time of travel and dispersion to help water-resources managers and planners respond to spills. His refined methods are ideal for waterbodies in which mathematical models are too expensive to implement.

In 1988, Curwick solved the fully dynamic, one-dimensional equations of unsteady open-channel flow and convective diffusion to create an uncoupled numerical model of the lower Mississippi

River from Tarbert Landing, MS to Venice, LA. The flow model uses a weighted, four-point, implicit, finite-difference approximation for solution of the unsteady flow equations. The transport model uses an explicit finite-difference approximation of the continuity of mass equation for solution in a Lagrangian coordinate system. The flow model was calibrated and verified with three months of stage and discharge data from the floods of 1979 and 1983, respectively. The average root-mean-square errors for the calibration and validation of the model were 0.47 foot and 0.40 foot for stage and 113,400 cfs and 86,280 cfs for discharge, respectively. The transport model was calibrated and validated with dye-tracer data from the dye injections of 1965 and 1974, respectively. The average root-mean-square errors of dye concentration for the calibration and validation of the model were 0.18 ppb (parts per billion) and 0.087 ppb, respectively.

Curwick states that the flow pattern in the lower Mississippi River is usually unidirectional, turbulent, and pulsating. Exceptions occur during long periods of extreme low flow and during hurricane surges, when a significant length of the lower study reach is affected by bi-directional flow. However, previous studies indicate that vertical dispersion exists along most reaches of the river. Curwick also shows that turbulent flow is always characterized by local eddying, which results in pulsations in the velocity at a fixed point. Velocities are shown to vary plus or minus 20 % about the mean at a fixed location in as little as 15 minutes. Therefore, a model representing the three-dimensional flow of the Mississippi River is necessary to properly represent the movement of spilled toxic chemicals in the longitudinal, lateral, and vertical directions.

To the best of the PI's knowledge, there is no 3D numerical hydrodynamic and contaminant transport model that includes the reach of the lower Mississippi from Tarbert Landing, MS to Venice, LA. Such a detailed numerical model would provide information about the longitudinal, lateral, and vertical dispersion of many different chemicals with different properties. To use such a model, the shoreline would be divided into segments. This would enable the model to specify when and how much of each contaminant would travel to each of the segments in various seasons and under hydrologic conditions. This additional information will also be useful for environmental impact assessment and critical for predicting the behavior of rapidly dispersed oils or accidents that occur under water (ASCE Task Committee 1996). With the port complex of the lower Mississippi River hosting 35 ocean going vessels per day, there is a clear need for a highly accurate management tool (Thibodeaux 2003).

3.2 Previous Modeling Efforts

The United States Corps of Engineers' Engineering Research and Development Center (ERDC) (formerly known as the Experimental Waterway Station [WES]) developed a computer model for the a portion of the lower Mississippi River that includes the Head of Passes, and approximately 10 miles of the main channel. The model used for this study was the TABS-MD modeling system. It is a multidimensional model that can include one-dimensional, two-dimensional, and three-dimensional formulations in the same application. The model can also include freshwater inflows, tidal fluctuations, wind forcing, waves, rainfall, and groundwater flows.

Spasojevic and Holly (1994) incorporated a 2-D mobile bed technique into the USACE CH3D model [Chapman et al. 1996] to simulate the flow and sediment transport at the Old River reach of the Mississippi River. This model is based on the finite volume concept and has a non-orthogonal grid in plan and sigma vertical discretization, which satisfies the requirement that the model be fitted to a complex boundary. CH3D has also been applied to other large rivers, including the Detroit River (S. Ritzma 2002 personal communication). In its current form, however, CH3D may have execution times that are too long for operational applications.

Another candidate that is being considered is the Princeton Ocean Model (POM), which has been adapted to the Pontchartrain Estuary [Signell and List 1997] and Georgiou et al. [2001, 2002]. POM was developed by Blumberg and Mellor (1987) for modeling free surface flows with coupled hydrodynamics and density state equations. This is a finite volume based model that uses an orthogonal grid in plan and a sigma coordinate transformation in the vertical direction. It has a split external-internal mode. The external mode is second order explicit while the internal mode is implicit. Upwinding and anti-numerical options are available. The University of New Orleans has applied a modified POM model to the entire Pontchartrain Estuary [Georgiou and McCorquodale (2002a, 2002b)] and has succeeded in modeling the saltwater wedge from the Inner Harbor Navigation Canal at Lake Pontchartrain.

TELEMAC software developed by Electricité de France–Laboratoire National d’Hydraulique is also a candidate modeling system. TELEMAC is based on finite element techniques that are applied to unstructured triangular grids. It solves the Saint-Venant equations vertically arranged in two dimensions or the Navier-Stokes equations layered in three dimensions. The software

incorporates hydrodynamic, water quality, sediment transport, pollutant dispersion, and wave dynamics modules.

H3D is another modeling system that will be considered for the lower Mississippi. A robust, flexible and efficient numerical model, H3D computes the three components of velocity. The model also computes scalar quantities, such as temperature, water levels, and contaminant concentrations, on a Cartesian three-dimensional grid. The current version of the model is described in detail in Stronach et al. (1993). The model solves the Reynolds equations of motion, with the turbulent fluxes expressed in an eddy viscosity/diffusivity formulation. It uses a shear-dependent turbulence formulation in the horizontal, and a shear and stratification dependent formulation in the vertical. The numerical model includes provision for wetting and drying. Flooding and drying is implemented in a straightforward manner, and care is taken to ensure that scalar quantities, such as salinity or contaminants, are conserved in the wetting and drying processes. The model is semi-implicit, so that relatively large time steps can be used. This feature is essential for the operational uses planned for this model. More details about H3D can be found in Stronach et al. (1993), Gammill et al. (2001), Meselhe (2001-a), Meselhe and Noshi (2001-b), Meselhe and Stronach (2001-c), and Meselhe and Noshi (2001-d).

4. Workplan

After surveying the literature, the PI concluded that there was a need for further study and research on the lower Mississippi River. A proposal for a project that will continue this study has been written and will focus on developing a three-dimensional numerical flow and transport model.

The objective of the proposed project is to develop a three-dimensional (3D) model for a portion of the lower Mississippi River (from Tarbet Landing to Venice). The model should provide detailed information on the spatial and temporal patterns of the river's hydrodynamics, salinity, sediment, water quality parameters, and oil and chemical transport. The model will serve as an excellent overall management and analysis tool for the lower Mississippi River.

Extensive investigations will be performed to select an appropriate model that will be used in this study. Issues such as model accuracy, robustness, and efficiency will be considered. A significant effort will be devoted to collecting the field data that is necessary for model design and analysis (e.g. stage, discharge, salinity, sediment, nutrients, and water quality parameters). This will enable the researcher to design, calibrate, and validate the model and its main modules.

When a contingency model is fully implemented for the lower Mississippi River, it will provide planners and spill management agencies with critical information such as:

- sensitive sites that would likely be affected by a spill at a particular location and time of year
- the amount of boom or other response resources needed to protect the areas most likely to be affected by a particular spill
- the amount of time available for application of dispersants or other remedial actions before an impact can take place on sensitive areas

- the potential threats (as a probability of oil spills at different locations and during different seasons of the year)
- how the potential hazard to a sensitive site—such as a bird rookery—could change during the first five days after a spill

The aforementioned information will be presented in graphical format that can be easily understood and analyzed.

5. Deliverables

5.1 Final Report with the Contents of the Literature Review

Literature on the background and previous studies of the lower Mississippi River has been surveyed, and the findings are presented in this report. The findings are being used to justify further study on the fate of spilled toxic chemicals in the lower Mississippi River.

5.2 Proposal to Continue the Project

Proposals to continue this project and utilize the information found have been written and are beginning. The PI has generated strong interest in the proposed project and has attracted financial support from the New Orleans District of the Corps of Engineers (COE), the Baton Rouge District office of the United States Geological Survey (USGS), and the National Marine Fisheries Services (NMFS).

Fully understanding the dynamics of the river constitutes the foundation of any future management plan. Only a detailed and accurate numerical model combined with a carefully designed field measurement campaign will produce this essential information.

6. Conclusion

To the best of the research team's knowledge, there is no previous or ongoing research to model the portion of lower Mississippi River from Tarbert Landing to Venice, LA.

There is a need for an efficient and accurate management and analysis tool that provides information about the hydrodynamics of the river and how they affect the transport of spills.

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