

**Final Report Trajectory Analysis Planner for the
Sabine Lake**

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Abstract

Spill accidents are likely to occur within estuaries that experience heavy oil traffic. Therefore, it is important that spill contingency plans evaluate the threats that toxic contaminants pose to fish, marine mammals, aquatic species, and supporting habitats. The development of a Trajectory Analysis Planner (TAP) computer model for the Sabine Estuarine System will help oil spill contingency planners and managers investigate how spilled oil might move and spread within this estuary. The model can provide critical information regarding sensitive sites within the estuarine system, as well as the time available to take remedial actions before a spill might impact these sensitive areas. The model can also be used to assess how a spill might affect sensitive sites, such as seabird colonies, rookeries, or marine mammal hauling grounds. The modeling system Trajectory Analysis Planner (TAP) was developed at the NOAA-HAZMAT Office. The U.S. Navy has provided much of the funding for the TAP's development. The TAP model is currently being implemented for other estuarine systems across the nation (e.g. the Delaware Bay and San Francisco Bay). The Principal Investigator (PI) has worked collaboratively with NOAA personnel to develop the TAP for the Sabine Lake. Implementing the TAP model for any given estuarine system includes three steps: (1) calibrating the hydrodynamic component of the TAP, (2) populating the TAP trajectory database with numerous simulations, and (3) mapping potential spill sites.

1.0 Background

The TAP model is a comprehensive database tool that can be used for oil spill contingency planning. It takes into account the impact of hydrodynamic and meteorological conditions on the fate and spread of a spill. The TAP presents the potential damage from oil spills in the form of a spill-risk index. This index shows the probability of a spill as well as a projected quantity of oil that would be expected to reach a compiled list of receptor sites. More detailed information about the TAP can be found in Galt and Payton (1999), and at the following website: <http://response.restoration.noaa.gov/tap/tap.html>. The website provides information about the latest development of the computer model.

As indicated above, the TAP requires information on the currents (velocities) and tidal elevations throughout the estuary basin in order to accurately determine the fate and spread of an oil spill. This information should be provided to the TAP through a hydrodynamic model. The PI and Co-PI have implemented a three-dimensional model (H3D) for the Calcasieu-Sabine Basin. The results of the hydrodynamic model were used to calculate oil spill trajectories. H3D provides three components: velocity, tidal elevations, and salinities (Stronach et al. 1993).

Since the investigators intended to develop a TAP model and wanted to avoid duplication of effort, they conducted a thorough literature review on oil spill modeling in the Sabine Lake. The Texas General Land Office (TGLO) compiles real time oceanographic data system that supports oil spill prevention and response. Called the Texas Automated Buoy System (TABS), the system provides real time wind, tide, and surface currents information. More information about the system can be found on the website: <http://resolute.gerg.tamu.edu/tglo>. Another useful site providing information on hydrodynamic and oil spill modeling is maintained by the Texas Water Development Board: <http://hyper20.twdb.state.tx.us/bhydpge.html>. These real time monitoring and modeling systems are primarily used for “response” purposes as opposed to “contingency planning” purposes.

The Sabine Lake is located in southwestern Louisiana. The centerline of the lake defines the Louisiana-Texas border. Oil traffic incoming from the Gulf of Mexico passes through the Sabine-Neches Ship Channel, which is 400 feet wide, 40 feet deep, and located at the western side of the Sabine Lake. This high volume of traffic increases the probability of oil spills that could affect the Sabine National Wildlife Refuge on the eastern border of the Sabine Lake.



2.0 Objectives

The Sabine National Wildlife Refuge includes approximately 559,227 acres of fresh, intermediate, brackish, and salt marsh. When the TAP is fully implemented for the Sabine Lake, 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 a spill can harm sensitive areas;
- determinations of the temporal and spatial extent of damage caused by a particular spill; and
- how the potential hazard to a particular sensitive site—such as a bird rookery—could change in the first five days after a spill.

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

3.0 Methods

To present the desired information, the TAP makes use of a results database obtained by running a computerized oil spill trajectory model for numerous individual oil spill scenarios. All of the scenarios for a particular waterbody account for that waterbody's bathymetry, tides, current, wind patterns, and other factors. Because complex computer simulations are run prior to the TAP user interaction, the computer system can be highly responsive to user queries. The user may specify a spill launch site and receptor site. The TAP then provides a flythrough visualization of the spill trajectory, and the probability of impact at the receptor site. Each implementation of the TAP is specific for a particular waterbody.

Considerable effort is required to develop a TAP model for a waterbody. However, once developed, the model requires minimal training to operate. Detailed information about the TAP model can be found in Galt and Payton (1999). The main steps needed to develop the TAP model for the Sabine Estuary were: hydrodynamic modeling of the system, designing receptor and release sites, carrying out spill trajectory simulations, and creating a resource database.

3.1 Hydrodynamic Modeling

The first step in setting up a TAP model is to provide hydrodynamic information about the Sabine Estuarine System. Hydrodynamic models provide projections of water level and velocity over time and space for a wide range of hydrological and meteorological conditions. It was necessary to further develop a hydrodynamic model that could best simulate the complex hydrodynamic characteristics of the lake.

A robust, flexible, and efficient numerical model was required to incorporate all of the complex estuarine processes. The three-dimensional unsteady hydrodynamic model (H3D) was therefore used to simulate the hydrodynamic characteristics of the Sabine Lake. H3D computes the three components of velocity as well as 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. The model uses a shear-dependent turbulence formulation in the horizontal, and a shear and stratification dependent formulation in the vertical. The numerical model includes provisions for wetting and drying, which are important considerations for the shallow marshland surrounding the Sabine Lake. Flooding and drying are 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 allowance is essential for the operational uses planned for the TAP model.

The implementation of the H3D to best simulate the Sabine Lake requires extensive effort. The main tasks needed to implement the H3D are: geometric data collection; collection and compilation of boundary conditions, as well as hourly water levels and salinity records for different gage stations within the estuary; and calibration and validation of the H3D model.

3.2 Design of Receptor Sites

The shoreline was divided into segments called “receptor sites.” Careful consideration was taken to make sure that each segment was 1.0 miles long and 0.6 miles wide. Using equal segments helps to ensure that the results are consistent along the shorelines.



Figure 2. Receptor sites



Figure 3. Receptor Sites

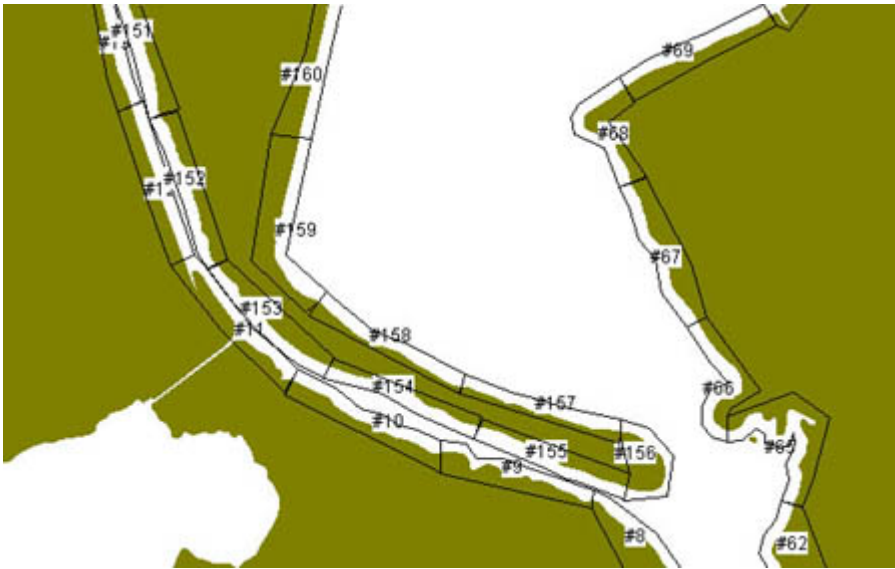


Figure 4. Receptor Sites.

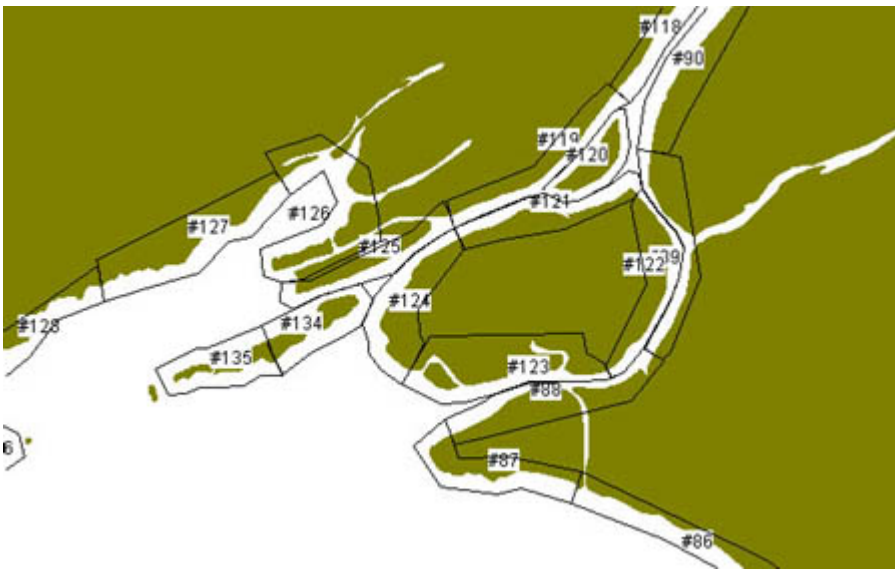


Figure 5. Receptor Sites.

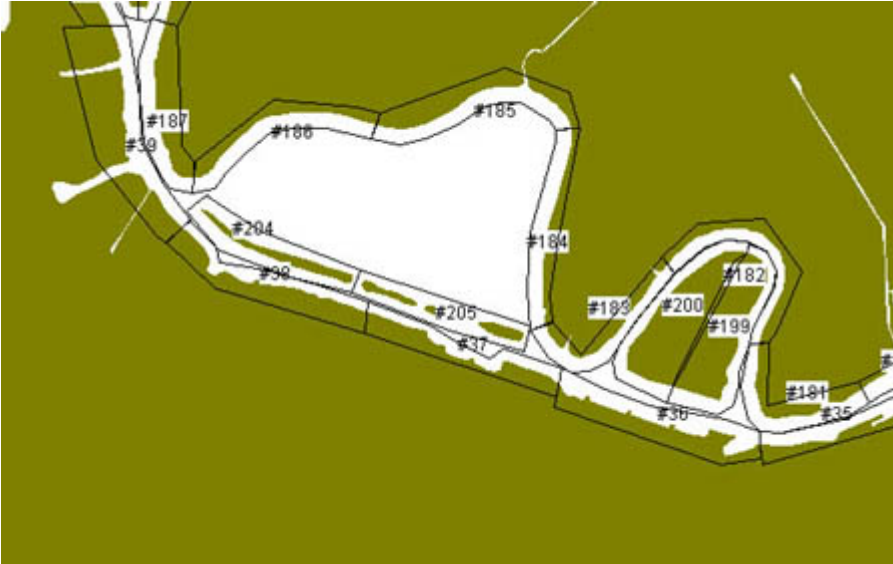


Figure 6. Receptor Sites



Figure 7. Receptor Sites

3.3 Design of Release Sites

Release sites at approximately 45 locations along the Sabine River were chosen, and oil spill simulations were run 500 times per season at each site. For this study, three seasons were selected: winter, summer, and the entire year. Sites were picked based on the likeliness of an oil spill occurring at that particular location. In other words, they were selected along the main navigation route of oil barges.

3.4 Spill Trajectory Simulations

Once the hydrodynamic simulations were complete, they could be used to model a variety of spill scenarios. Over 65,000 hypothetical oil spills of different magnitudes and locations were modeled for the Sabine Lake.

3.5 Database

The impact of each spill on every individual receptor site was determined and stored. The last step of the TAP's development was to compile all of these data in a database to produce a reliable oil spill management tool.

4.0 Work Plans

The main objective of this study was to provide oil spill contingency planners and decision makers with a useful spill management tool. To this end, we implemented the NOAA Trajectory Analysis Planner (TAP) computer model to provide oil spill analyses.

The first step in setting up the TAP model was to accurately provide hydrodynamic information about the Sabine Lake. The credibility of the TAP projections is critical to its value for planning, management, and response. Because of this need for credibility, it was crucial to develop a hydrodynamic model that accurately simulated the hydrodynamic characteristics of the lake. A robust, flexible, and efficient three-dimensional numerical model (H3D) was implemented to meet these needs. The recorded water level and salinity measurements at different stations along the lake were used to calibrate and validate the hydrodynamic model.

After achieving the successful hydrodynamic simulation of the lake, the validated H3D was used to produce various spill trajectory simulations. Fifteen hundred hypothetical oil spills of different magnitudes and locations were modeled. The impacts of each spill on the receptor sites were determined and then incorporated into the comprehensive TAP database

5.0 Deliverables

5.1 Hydrodynamic Model of the Sabine Lake

One of the first main deliverables is a fully calibrated and validated three-dimensional hydrodynamic and salinity model. The model can accurately provide water level and salinity information.

5.2 The Geographic Records of Water Levels and Salinity

The PI also compiled bathymetry information and extensive water level and salinity records at several monitoring stations. This information will be quite useful for future studies of the area.

5.3 Trajectory Analysis Planner

The final main deliverable is a comprehensive TAP database that can be used as a contingency planning tool. Considerable effort was required to develop a TAP model for the Sabine Lake. However, once developed, the model is easy to use and learn. The results can be viewed in several different modes:

1. Shoreline Impact Analysis

For this type of analysis, the planner can select a potential spill site within the lake. The shoreline segments impacted by a particular spill can then be determined.

2. Site Oiling Analysis

This type of analysis allows the planner to determine the amount of oil that reaches a particular shoreline segment from a particular spill.

3. Resource Analysis

This category of analysis is particularly important for contingency planners. The planner will be able to specify a location for a potential spill within the Sabine Estuary, and then investigate the impact of this spill on different resources. These resources can include biological data, shoreline data, and other fields. Resource analysis was not performed during this project. However, it can be easily added to the database in the future.

4. Threat Zone Analysis

This type of analysis will allow planners to assess the threat zone around a particularly important shoreline segment within the Sabine Lake. After identifying a shoreline segment, the planner can find areas where spills have a very high chance of damaging natural resources.

5. Response Time Analysis

This type of analysis allows planners to see how portions of a spill are distributed over time. For example, one can see the percentage of the total amount of oil received at a receptor site at a specified duration.

6. Shoreline Impact by Spill

This analysis is basically the same as the shoreline impact analysis. As in #1., the planner selects a potential spill site within the Sabine Lake. The results of how the shoreline segments are impacted, however, are calculated based on one particular spill.

7. Response Time by Spill

This is similar to response time analysis, except that it is used to find the distribution of a spill over time for one particular spill.

8. Threat Zone by Spill

This is similar to the threat zone analysis in that it allows planners to assess the threat zone around a particularly important shoreline segment within the lake. However, only one spill is considered in the analysis.

5.4 Publications and Presentations

A journal publication describing this work on the Sabine Lake will be prepared by Dr. Meselhe and the staff at the NOAA office.

6.0 Results

The H3D hydrodynamic model was set up to simulate the hydrodynamic characteristics of the Sabine Lake. Detailed information about the calibration and validation of the Calcasieu-Sabine Basin Hydrodynamic Model can be found in Gammill et al. (2001) and Meselhe and Noshi (2001).

A compact disk (CD) containing the TAP for the Sabine Lake can be obtained either from OSRADP or directly from Dr. Meselhe at the University of Louisiana at Lafayette. The CD contains all of the trajectory simulations and can be accessed through the TAP Graphical User Interface. The interface is quite easy to use, and the information can be processed in several modes. Workshops that train interested personnel on the use of TAP can be arranged through OSRADP.

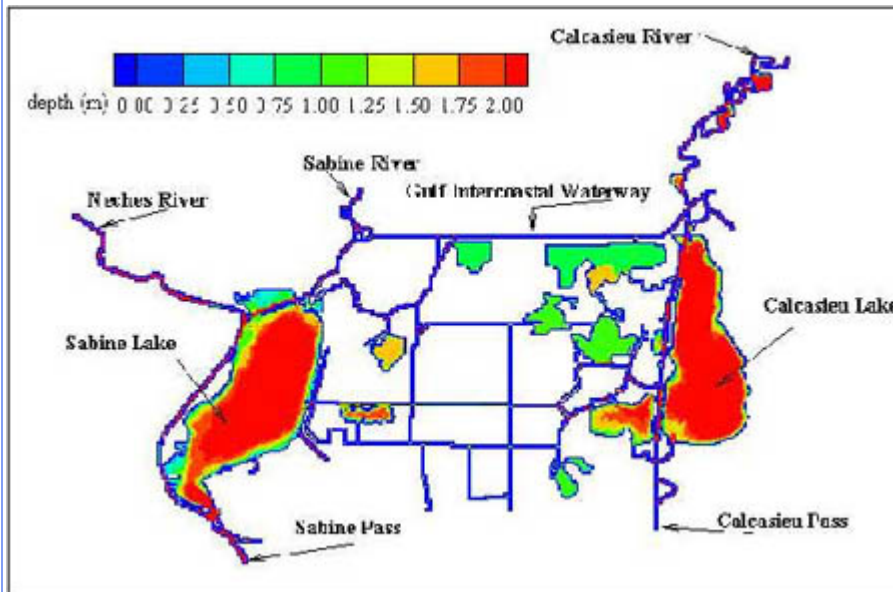


Figure 3. Hydrodynamic model for the Calcasieu-Sabine Basin.

Station	Salinity Data			Water Level Data		
	Corr. Coeff. %	RMS Error ppt	RMS Error %	Corr. Coeff. %	RMS Error ft	RMS Error %
Station 09-2r	80.95%	3.41	14.09	89.23%	0.29	6.57
Station 095	88.64%	3.27	12.39	89.71%	0.32	5.65
Station 118	81.42%	4.86	14.37	90.40%	0.32	5.59
Station 17-1R	80.85%	4.61	17.47	88.07%	0.51	10.88
Johnson Bayou	85.15%	1.94	14.19	88.94%	0.37	8.92
Lower Sabine	82.06%	4.93	16.88	79.55%	0.60	9.51
Upper Sabine	81.22%	2.20	13.93	89.46%	0.49	8.33

Figure 4. Summary of Error Analysis.

$$\begin{aligned} \text{RMS Error} &= \\ \text{Root Mean Square Error} &= \sqrt{\frac{\sum (\text{measured} - \text{simulated})^2}{\text{No. of observations}}} \\ \text{RMS Error \%} &= \frac{\text{RMS Error}}{\text{Maximum} - \text{Minimum Measured Values}} \times 100 \end{aligned}$$

7.0 Conclusion

The objective of this study was to develop a Trajectory Analysis Planner (TAP) computer model for Louisiana's Sabine Lake. The model can help oil spill contingency planners and managers investigate how oil spills travel and spread within the estuary. The model identifies sites within the estuary that will be most vulnerable to specified oil spills. Furthermore, the model can estimate the time available for mitigation and remedial actions before the specified spill might impact sensitive areas.

The objective of this study was to develop and implement a hydrodynamic model to simulate the hydrodynamic characteristics of the Sabine Lake. A three-dimensional unsteady hydrodynamic model (H3D) was used to simulate the complex hydrodynamic characteristics of the system. The H3D provides the three components of velocity as well as scalar quantities, such as water levels, temperature and salinity distribution, on a Cartesian three-dimensional grid. The H3D provides the detailed information that is required for the spill trajectory analysis.

The information produced by the H3D was used to simulate the trajectories of over 65,000 hypothetical oil spills. The impact of these spills on the shoreline was estimated and then stored in a comprehensive database. The database can be easily accessed through a user-friendly graphical interface. The compact disk attached to this report contains the TAP for the Sabine Lake.

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