

# **TRAJECTORY ANALYSIS PLANNER FOR THE CALCASIEU ESTUARY (YEAR 2)**

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## TABLE OF CONTENTS

### 1.0 Background

### 2.0 Methods

#### 2.1 Hydrodynamic Modeling

#### 2.2 Spill Trajectory Simulations

#### 2.3 Database

### 3.0 Work Plan

#### 3.1 First Year

#### 3.2 Second Year

### 4.0 Deliverables

#### 4.1 First Year Deliverables

##### 4.1.1 Hydrodynamic Modeling of the Calcasieu Estuarine System

##### 4.1.2 Geographic Data and Records of Water Level and Salinity

#### 4.2 Second Year Deliverables

##### 4.2.1 Trajectory Analysis Planner

##### 4.2.2 Trajectory Analysis Planner

### 5.0 Results

### 6.0 Conclusion

### 7.0 References

## LIST OF FIGURES

**Figure 1** Layout of the Calcasieu Estuarine System

**Figure 2** General layout showing the location of the four gage stations used for calibration

**Figure 3A** Comparison between measured and modeled salinity values at North Calcasieu Lake near Hackberry (USGS Gage Station 08017095)

**Figure 3B** Comparison between measured and modeled water level values at North Calcasieu Lake near Hackberry (USGS Gage Station 08017095)

**Figure 4A** Comparison between measured and modeled salinity values at Brown Lake (Station CS09-2r)

**Figure 4B** Comparison between measured and modeled water level values at Brown Lake (CS09-2r)

**Figure 5A** Comparison between measured and modeled salinity values at Calcasieu River at Cameron (USGS Gage Station 08017118)

**Figure 5B** Comparison between measured and modeled water level values at Calcasieu River at Cameron (USGS Gage Station 08017118)

**Figure 6A** Comparison between measured and modeled salinity values at South Calcasieu Lake (Station CS17-1R)

**Figure 6B** Comparison between measured and modeled water level values at South Calcasieu Lake (Station CS17-1R)

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# **Trajectory Analysis Planner for the Calcasieu Estuary (Year 2)**

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## **Abstract**

In addition to their commercial and recreational values, wetlands filter water and protect coastal areas from hurricane storm surges. Potential adverse effects resulting from oil spills include extensive damage to or death of large areas of marsh grass, which in turn reduces an important food source for many fishery species. To help prevent these effects, this study seeks to develop a Trajectory Analysis Planner (TAP) computer model for Louisiana's Calcasieu Estuarine System. The model can help oil spill contingency planners and managers track the travel and spread of oil spills within the estuary. The model can provide needed information pertaining to sites within the estuarine system that will be most vulnerable to specified oil spills. Furthermore, the model can estimate the time available for mitigation and remedial actions before a specified spill might impact such sensitive areas. The modeling system Trajectory Analysis Planner (TAP) was developed at the Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration (NOAA). The first step in setting up a TAP model is to represent the hydrodynamic characteristics of the estuarine system of interest. The velocity field along with tide, wind, and fresh water inflow information can then be used to calculate the trajectory of oil spills. Finally, the impact of these oil spills on the shoreline can be estimated and presented in an interactive and easy to use database. A three-dimensional model was fully calibrated and validated for the Calcasieu Lake during the first year of the project. The model provided detailed velocity and water level information. The oil spill trajectory simulations and the development of the TAP database were completed in the second year.

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## **1.0 Background**

The Louisiana wetlands have great value as habitats for fish and wildlife. It is estimated that over 50,000 people are engaged in wetland dependent fisheries in Louisiana. Louisiana contributes about 28% of the total volume of the U.S. fisheries, with a value of about \$1 billion annually. The Louisiana annual shrimp and oyster harvest supplies 35 to 40 % of the nation's needs. In addition to their commercial and recreational values, wetlands reduce storm and erosion damage, detain floodwaters, recharge groundwater aquifers, and maintain water quality.

Calcasieu Lake is located in the southwest corner of the state of Louisiana. The Calcasieu River discharges fresh water at the north end of the lake. The lake is connected to the Gulf of Mexico through a narrow channel called Calcasieu Pass as shown in Figure (1). Heavy oil traffic passes through the Calcasieu Ship Channel, which is adjacent to the west edge of the lake. Such heavy traffic creates a high likelihood of accidents. The resulting spills would have severe negative impacts on the region's entire ecological system. It is therefore necessary to establish a rigorous oil spill contingency plan for the Calcasieu Estuarine System.

### **Figure 1.** Layout of the Calcasieu Estuarine System

Literature on modeling oil spill trajectories is extensive. Most of this work has been done on open water systems that are unaffected by shoreline interactions with current direction (Borthwick and Joynes 1992; Overstreet and Galt 1995). The state of the art of transport and fate of oil spills has been reviewed by the American Society of Civil Engineers Task Committee on Modeling of Oil Spills (ASCE 1996), and more recently by Reed *et al.* (1999-a) and Reed *et al.* (1999-b). Over the past few decades, a few researchers used numerical models to study the Calcasieu Basins. Forbes (1988) described the surface-water features and processes in this area. His study provided valuable information on stream discharge under different flow conditions, tidal and wind characteristics, descriptions of dredged channels, controls, tributaries and distributaries, representative cross-sections, and details of openings between the Calcasieu Ship Channel and Calcasieu Lake.

In 1989, Wyman presented a quantitative risk model that estimates the probabilities and consequences of hazardous material transportation spills in the urbanized portion of Calcasieu Parish, Louisiana. The computer program incorporates spill event probabilities, impact zone calculations, and day/night population densities to estimate relative risks. Consequences considered include injuries and fatalities to persons as an immediate result of a spill. Hazardous substances studied include chemical products, fuels, petroleum products, explosives, acids, fertilizers, radioactive materials, biological products, and many forms of hazardous waste.

## **2.0 Methods**

The Trajectory Analysis Planner (TAP) computer model was developed as a tool for improving oil spill management in the Calcasieu Estuarine System. The TAP was developed at the Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration (NOAA). The U.S. Navy provided much of the funding for the TAP's development. Oil spill contingency planners and decision makers

can use the TAP to investigate how potential oil spills travel and spread. For the area under study, the TAP presents various kinds of information including:

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

To present this information, the TAP makes use of a database of results obtained by running a computerized oil spill trajectory model for numerous individual oil spill scenarios. All 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. In application, the user may specify a spill launch site and receptor site. The TAP then provides a flythrough visualization of the spill trajectory and probability of impact at the receptor site. Each implementation of the TAP is specific for a particular waterbody.

The effort required to develop a TAP model is considerable. However, once developed, the model is quite simple to operate. In fact, one of the attractive features of the TAP is that it requires minimal training to operate. Detailed information about the TAP model can be found in Galt & Payton (1999). The main steps needed to develop the TAP model for the Calcasieu Estuary System were performing hydrodynamic modeling of the system, carrying out spill trajectory simulations, and creating a resources database.

## **2.1 Hydrodynamic Modeling**

The first step in setting up a TAP model is to provide hydrodynamic information describing the estuarine system in question. Hydrodynamic models provide projections of water level and velocity over time and space for wide range of hydrological and meteorological conditions. It was therefore necessary to develop a hydrodynamic model that could best simulate the complex hydrodynamic characteristics of Louisiana's Calcasieu Estuarine System.

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 further developed to simulate the hydrodynamic characteristics of the Calcasieu Estuarine System. 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 also 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 Calcasieu Lake. 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 option is essential for the operational uses planned for the model.

The implementation of the H3D to best simulate the Calcasieu Estuary required extensive efforts in the completion of different tasks. The main tasks needed to implement the H3D were: 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.

## **2.2 Spill Trajectory Simulations**

Once the hydrodynamic simulations are done, they can be used to model a variety of spill scenarios. Approximately 1500 hypothetical oil spills of different magnitudes and locations were modeled for the Calcasieu Estuarine System.

## **2.3 Database**

To determine the impact of a particular spill, the shoreline was divided into equal sized segments called receptor sites. The impact of each spill on every individual receptor site was determined and stored. The last step of the TAP development was to compile all these data in a database to produce a reliable oil spill management tool.

## **3.0 Workplan**

The overall objective of this study was to provide oil spill contingency planners and decision makers with a useful spill management tool. Specifically, our aim was to implement the NOAA Trajectory Analysis Planner (TAP) computer model to provide the necessary oil spill analyses for the Calcasieu Estuary System.

### **3.1 First Year**

The first step in setting up the TAP model was to accurately provide the hydrodynamic information of the Calcasieu Estuarine System. Credibility of the TAP projections is critical to the model's value for planning, management, and response. Because of this need for credibility, it was the objective of the first year of this study to further develop a hydrodynamic model that accurately simulated the hydrodynamic characteristics of the Calcasieu Estuarine System. A robust, flexible, and efficient three-dimensional numerical

model (H3D) was implemented to simulate the hydrodynamics of the Calcasieu Estuary. The recorded water level and salinity measurements at different stations along the estuary were used to calibrate and validate the hydrodynamic model.

### **3.2 Second Year**

During the project's second year, the NOAA Trajectory Analysis Planner (TAP) computer model was implemented. As part of this effort, the validated H3D was used to produce various spill trajectory simulations. Fifteen hundred hypothetical oil spills of different magnitudes and locations were modeled for the Calcasieu Estuarine System. The impact of every spill on the receptor sites was determined and incorporated into the comprehensive TAP database.

## **4.0 Deliverables**

### **4.1 First Year Deliverables**

#### **4.1.1 Hydrodynamic Model of the Calcasieu Estuarine System**

The main deliverable of the first year was a fully calibrated and validated three-dimensional hydrodynamic and salinity model. The model can accurately provide water level and salinity information.

#### **4.1.2 Geographic Data and Records of Water Level 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 when future studies of the area are performed.

#### **4.1.3 Publications and Presentations**

A conference paper was prepared describing the development and implementation of the H3D for the Calcasieu Estuarine System. The PI presented the publication at the Hydroinformatics '2000 Conference, July 24-27, 2000, in Cedar City, Iowa. A technical note was also submitted to the Spill Science & Technology Bulletin.

### **4.2 Second Year Deliverables**

#### **4.2.1 Trajectory Analysis Planner**

The main deliverable of the second year was a comprehensive TAP database that can be used as an oil spill contingency planning tool. Although it required extensive effort, the resulting model is easy to use and can be viewed in four different modes:

##### **Mode 1. Shoreline Impact Analysis**

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

**Mode 2. Site Oiling Analysis**

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

**Mode 3. Resource Analysis**

This category of analysis is particularly important for contingency planners. The planner can specify a location for a potential spill within the Calcasieu Estuary, and then investigate the impact of this particular spill on different resources (biological data, shoreline data, etc.) This type of analysis was not performed as part of the project. However, it can be easily added to the database in the future.

**Mode 4. Threat Zone Analysis**

This type of analysis allows planners to assess the threat zone around specific shoreline segments within Calcasieu Lake. After identifying a particular shoreline segment, the planner can pinpoint the regions within that segment that would most likely be damaged by a spill.

#### 4.2.2 Publications and Presentations

A conference paper was presented at the Arctic and Marine Oil Spill (AMOP) Conference, June 12-14, 2001, at Edmonton, Alberta, Canada. A refereed journal publication is currently being prepared and will be submitted to the Spill Science & Technology Bulletin or to an appropriate journal of the American Society of Civil Engineers.

**5.0 Results**

The H3D hydrodynamic model was set up to simulate the hydrodynamic characteristics of the Calcasieu Estuary. The model boundaries were expanded to include the exchange of flows that occurs in a system of interconnected canals and marshland between the Calcasieu and Sabine Lakes. The hourly water levels and salinity records for four different gage stations within the estuary were used to calibrate and validate the model. Figure (2) shows a general layout of the four stations' locations. The modeled values were compared with the corresponding recorded water levels and salinity values at these gage stations. Figures (3) through (6) compare the modeled and measured values for the four gage stations. The figures show that H3D accurately reproduced the water level and salinity patterns of Calcasieu Lake.

A compact disk (CD) containing the TAP for Calcasieu Lake is attached to this report. The CD contains all the trajectory simulations and can be accessed through the TAP Graphical User Interface. The interface is easy to use, and the information can be processed in several modes as discussed above. Workshops to train interested personnel in the use of the TAP can be arranged through OSRADP.

**Figure 2.** *General layout showing the location of the four gage stations used for calibration.*

**Figure 3a.** *Comparison between measured and modeled salinity values at North Calcasieu Lake near Hackberry (USGS Gage Station 08017095).*

**Figure 3b.** *Comparison between measured and modeled water level values at North Calcasieu Lake near Hackberry (USGS Gage Station 08017095).*

**Figure 4a.** *Comparison between measured and modeled salinity values at Brown Lake (Station CS09-2r).*

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**Figure 5a.** *Comparison between measured and modeled salinity values at Calcasieu River at Cameron (USGS Gage Station 08017118).*

**Figure 5b** *Comparison between measured and modeled water level values at Calcasieu River at Cameron (USGS Gage Station 08017118).*

**Figure 6a.** *Comparison between measured and modeled salinity values at South Calcasieu Lake (Station CS17-1R).*

**Figure 6b.** *Comparison between measured and modeled water level values at South Calcasieu Lake (Station CS17-1R).*

## 6.0 Conclusion

The objective of this study was to develop a Trajectory Analysis Planner (TAP) computer model for Louisiana's Calcasieu Estuarine System. The model can help oil spill contingency planners investigate how oil spills travel and spread within the estuary. The model provides information pertaining to sites within the estuarine system 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 impacts such sensitive areas.

The first step in setting up a TAP model is to represent the hydrodynamic characteristics of the estuarine system of interest. The objective of the first year of this study was to develop and implement a hydrodynamic model to simulate the hydrodynamic characteristics of the Calcasieu Estuarine System. A three-dimensional unsteady hydrodynamic model (H3D) was used to simulate the complex hydrodynamic characteristics of that system. 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. H3D provides the detailed information that is required for the spill trajectory analysis.

The information produced by H3D was used to simulate the trajectories of 1500 hypothetical oil spills. The impact of these spills on the shoreline was estimated and stored in a comprehensive database. The database can be easily accessed through a user-friendly graphical user interface. A compact disk is attached to this report that contains the TAP for Calcasieu Lake.

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