HYDRODYNAMIC MODELING

of the

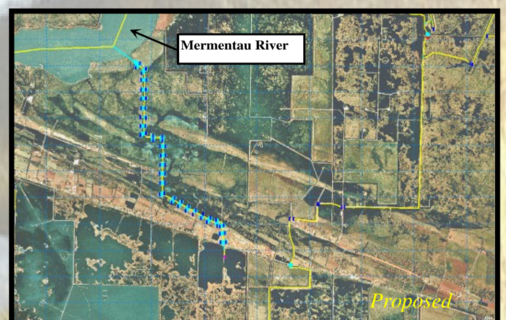
SOUTH GRAND CHENIER HYDROLOGIC RESTORATION PROJECT (ME-20)

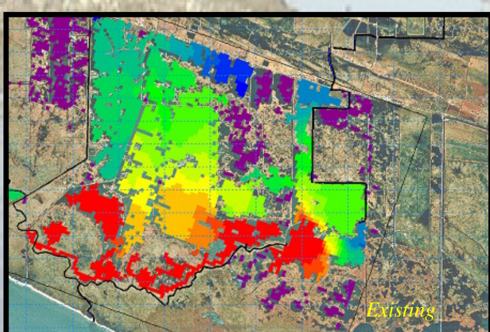
With Additional Runs Showing the Effects of the Combined

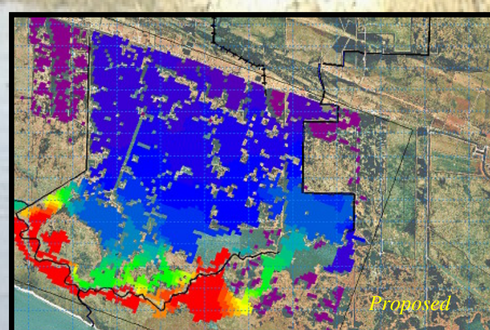
SOUTH GRAND CHENIER HYDROLOGIC RESTORATION PROJECT (ME-20)

and the

LITTLE PECAN BAYOU HYDROLOGIC RESTORATION PROJECT (ME-17)







December 2005

Submitted By:

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EXECUTIVE SUMMARY

The South Grand Chenier Hydrologic Restoration Project (ME-20) is a Priority Project List (PPL) 11 Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) project located west of the Rockefeller State Wildlife Refuge on the eastern end of the Grand Chenier ridge, south of the community of Grand Chenier, and within the Mermentau Basin in Cameron Parish, Louisiana. The project is bounded on the west by the Mermentau River, on the south by the Gulf of Mexico shoreline, on the east by Second Lake, and on the north by LA Hwy 82.

The project area includes existing barriers that affect the hydrology of the study area. These features include the elevated roadbed of LA Hwy. 82, canals, levees, and plugs. These features prevent or slow fresh water from north to the target marshes south of LA Hwy. 82.

The effort presented in this study is aimed to evaluate the performance of the proposed project features, namely the Dr. Miller Canal and BP Canal. The project features, as proposed in the scope of services, included channel enlargements and freshwater introduction structures to improve flow of water from north to south across Hwy. 82. The project features also include the creation of approximately 400 acres of marsh by the use of dedicated dredging.

In order to assess the impact of the proposed project features, both LDNR and USFWS have proposed using a hydrodynamic and salinity numerical model to study the impact of the project features on the hydrology of the area. The model will be used to address two main goals set forth by the government agencies. These goals include the ability to:

- Introduce fresher water to marsh areas south of LA Hwy. 82 especially in the brackish marshes to the south, thereby reducing salinity levels and lessening salinity spikes;

- Improve marsh productivity, reduce marsh loss, and increase submerged aquatic vegetation within the project limits.

A coupled one and two-dimensional (MIKE FLOOD: MIKE 11 & MIKE 21) numerical computer was set up and then initially calibrated and validated for the existing hydrologic conditions of the project area. Afterwards, a direct comparison of the "Base Run (Existing Conditions)" and the "Conceptual Design Run (with proposed project features)" was performed. The model provided information regarding salinity and water level fluctuations, velocities, and discharges throughout the project area. The salinity transport was computed through an Advection Dispersion (AD) module, which was dynamically coupled with the hydrodynamic model. The final results of the model for water level and salinity were displayed through time series graphical plots, animations, and contour map illustrations.

Four model runs were performed with the proposed project features in place. These runs included the original conceptual model run and the following additional runs:

- Additional Run No. 1: Area 'A' S-Shaped Canal Weir Model Run - Place a weir with a sill height set at one foot below marsh level across the S-Shaped Pipeline Canal at its intersection with Hog Bayou south of the BP Plant. This would formally verify if constricting this opening increases the benefits to Area 'A'.

- Additional Run No. 2: Model Run with Pumps - A model run with the weir structure described above and 48" diameter pumps [approximately 22,000 Gallons per minute (GPM) each] at the BP/Tennessee Gas and the Dr. Miller Canals north of LA Hwy. 82. These pumps will be operated to introduce water from the Mermentau River when salinities are lower than five parts per thousand. Results of this simulation will be used to quantify the salinity benefits and water level changes in areas A, B, and C.

- Additional Run No. 3: Model Run with larger culverts at the LA Hwy. 82 crossing- run the conceptual project gravity flow model and increase the LA Hwy. 82 crossing structure sizes from 2 - 48" diameter culverts to 4 - 48" diameter culverts.

Each of these concepts were modeled to determine what would be the most effective way to attain the goals of the project, specifically in the following geographical areas: Area C, A-1, A-2, and Second Lake Cut. The locations of these features are further illustrated in the report.

Upon completion of all modeling simulations and analyzing the post-processed data, the following conclusions were determined. A detailed analysis of how these conclusions were derived can be found in Chapter Three of this report.

1. The Dr. Miller Canal component of the project was beneficial in terms of reducing salinities in the target areas with an average salinity reduction of 3 parts per thousand (p.p.t.) (from 5 p.p.t. to 2 p.p.t., base salinity). The anticipated results of providing fresh water from the Mermentau River to the open water bodies south of Hwy.82 were accomplished and the proposed control structures prevented the salinity from exceeding five parts per thousand south of LA Hwy. 82. Water levels along the length of Dr. Miller Canal was in the order of 1.0 to 2.0 ft N.A.V.D.88, which is slightly higher than the average marsh elevation in this area (average marsh = 1.5 ft N.A.V.D.88). The impact of this increase in water level on the surrounding marshes should be taken into account when constructing the project features.

2. The model results showed that the BP canal component of the project was not beneficial in terms of lowering salinities in the target areas. In fact, in some instances, it increased salinities in certain areas.

3. Additional Run No. 1- adding the weir across the S-Shape Canal did not improve the effectiveness of the fresh water introduction through BP canal

4. The proposed pumps in Additional Run No. 2 allowed for more control over the process of introducing fresh water to the target areas rather than relying on the availability of water head for the gravity driven alternatives. The use of pumps also delivered the fresh water faster to the target areas. The pumps however, increased the water level in the target areas more than the gravity driven alternatives. The salinity reduction was of the same magnitude of the other two runs with an average decrease of 3 p.p.t. (from 5 p.p.t. to 2 p.p.t., base salinity).

5. Increasing the size of the structures at LA Hwy. 82 had a negligible effect on the salinity level in the target areas (less than one part per thousand of salinity reduction over the conceptual run).

Another CWPPRA project, namely the Little Pecan Bayou Hydrologic Restoration Project (ME-17)[1], is being studied in conjunction with this project. The main goal of both of these projects is to improve freshwater flows from north to south across Hwy. 82 within the South Grand Chenier project area. After presenting the final model results for this project and the Little Pecan Bayou Hydrologic Restoration Project (ME-17), all of the contracting agencies (DNR, USFWS, and NRCS) agreed to the idea of setting up a dynamically linked combined model for the two projects. This was a necessary step to investigate the effects of constructing the two project features together. As will be mentioned in Chapter One, both the South Grand Chenier Hydrologic Restoration Project (ME-20) and the Little Pecan Bayou Hydrologic Restoration Project (ME-17) are two hydrological connected projects with similar project goals and objectives. [1]

Upon completion of all combined modeling simulations and analyzing the post-processed data, the following conclusions were determined. A detailed analysis of how these conclusions were derived can be found in Chapter Four of this report.

1. Setting up and running a combined model for the Little Pecan Bayou and South Grand Hydrologic Restoration projects helped to address the uncertainties that were raised of what will be the effects if the two projects were constructed, and how will the marsh environment react to two sources of freshwater flowing at the same time. The results showed that

[1] For detail information and description of the Little Pecan Bayou Hydrologic Restoration Project (ME-17), refer to the report prepared by C.H. Fenstermaker and Associates, Inc., dated December 2005, entitled "Hydrodynamic Modeling of the Little Pecan Hydrologic Restoration Project (ME-17)"

having the combined features for the two projects produced the optimum favorable conditions in terms of reducing the salinities throughout the whole area. It should be emphasized that the benefits of both projects combined, reach beyond the overlap of the two individual project boundaries.

2. In terms of flow and water level, having the two projects together reduced the head differential and caused lesser water to flow from the north to south especially during the flushing period where the highest head existed. Once the water level difference started to dissipate, both projects behaved in a similar fashion producing similar water level increases.

I. CHAPTER ONE

1.1 PROJECT BACKGROUND

The South Grand Chenier Hydrologic Restoration Project (ME-20) is a Priority Project List (PPL) 11 Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) project located west of the Rockefeller State Wildlife Refuge on the eastern end of the Grand Chenier ridge, south of the community of Grand Chenier, and within the Mermentau Basin in Cameron Parish, Louisiana. The project is bounded on the west by the Mermentau River, on the south by the Gulf of Mexico shoreline, on the east by Second Lake, and on the north by LA Hwy 82. This project includes 7,496 acres of intermediate to saline marsh. Figure 1 below shows a vicinity map of the location of the project area.

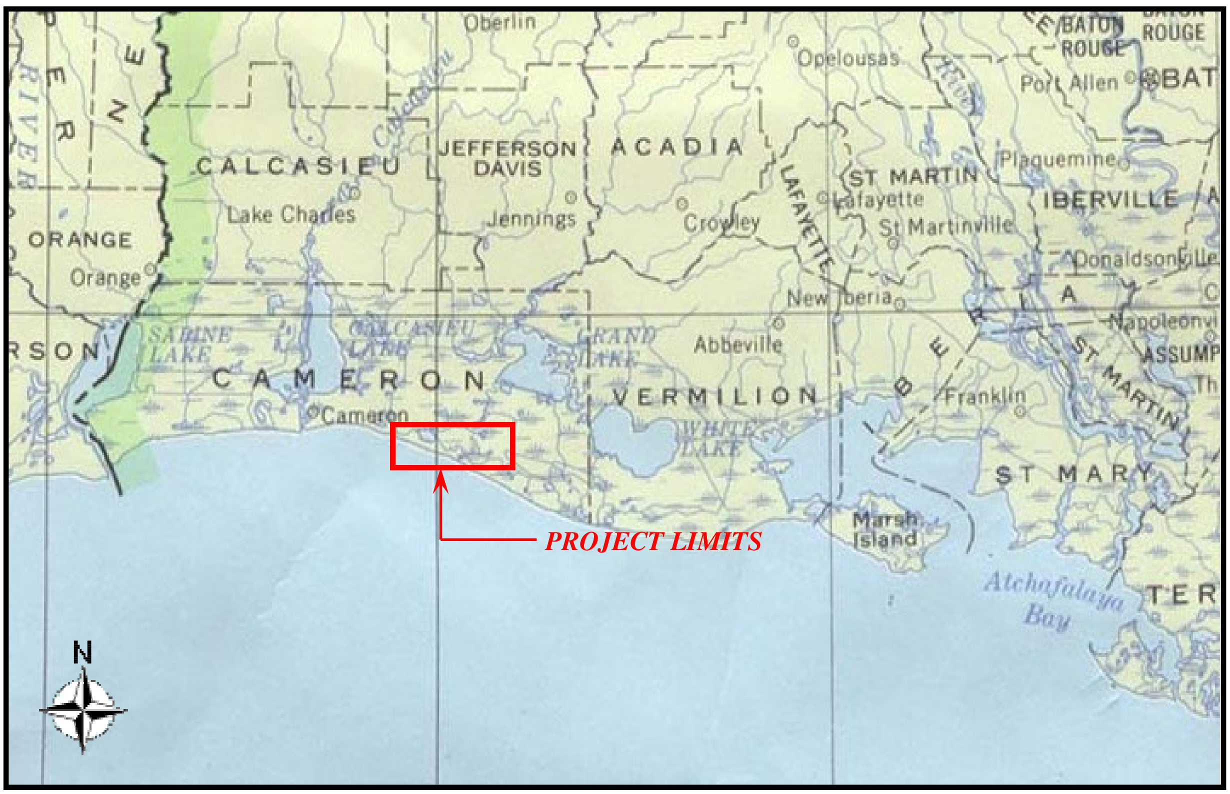

Figure 1: Project Location Map

The federal sponsor for the project is the United States Fish and Wildlife Service (USFWS), and the local sponsor is the Louisiana Department of Natural Resources (LDNR). The Natural Resource Conservation Service (NRCS) is providing engineering design services for the project upon completion of the modeling phase of the project.

The project area includes existing barriers that affect the hydrology of the study area. These features include the elevated roadbed of LA Hwy. 82, canals, levees, and plugs. These features prevent or slow fresh water from north to south to the target marshes south of LA

Hwy. 82 as shown in Figure 2. This project is hydrologically connected to another CWPPRA project, namely the Little Pecan Bayou Hydrologic Restoration Project (ME-17).

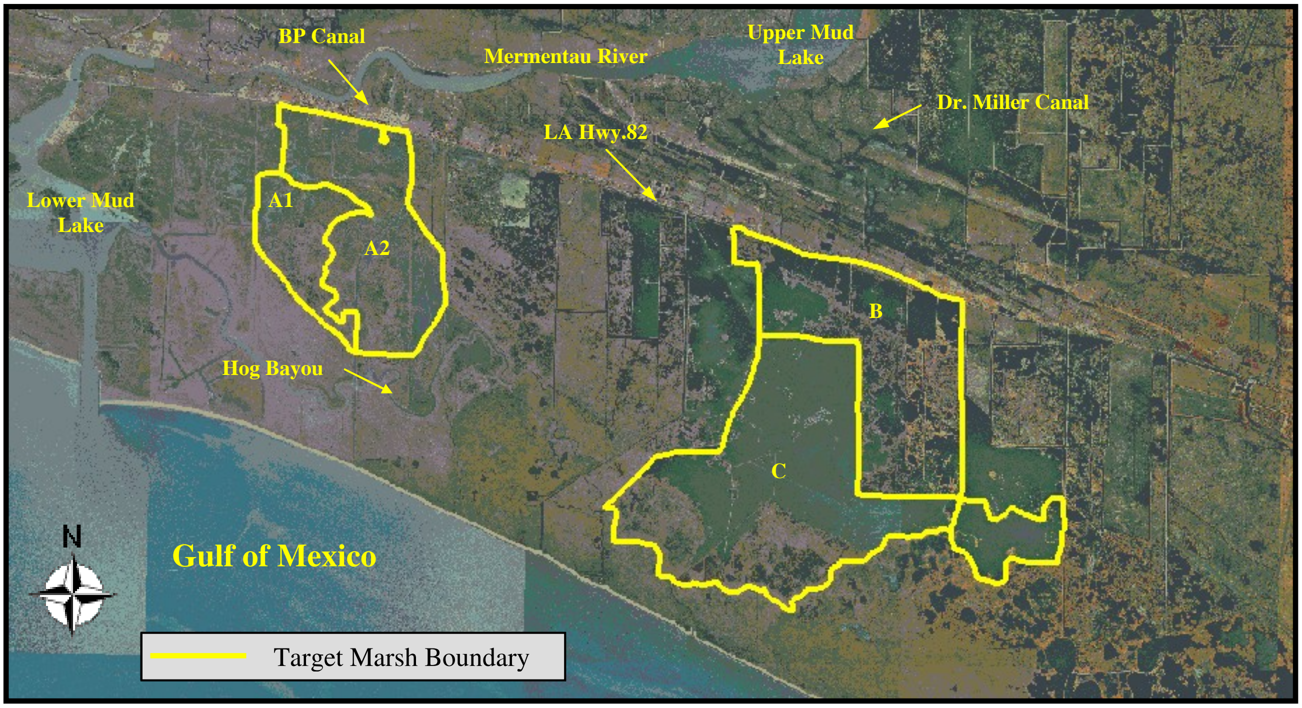

Figure 2: Target Marshes Within the Project Area

1.2 PROJECT OBJECTIVE

In order to assess the impact of the proposed project features, which will be further described in Section 1.3, both LDNR and USFWS have proposed using a hydrodynamic and salinity numerical model to study the impact of the project features on the hydrology of the area. The model will be used to address two main goals set forth by the government agencies. These goals include the ability to:

1) Introduce fresher water to marsh areas south of LA Hwy. 82 especially in the brackish marshes to the south, thereby reducing salinity levels and lessening salinity spikes;

2) Improve marsh productivity, reduce marsh loss, and increase submerged aquatic vegetation within the project limits.

Based on the numerical model results, both LDNR and USFWS will be able to assess whether or not the proposed project features will remain as planned, be modified, or be deleted from the project scope. It should noted that the performance of the this proposed project will be evaluated only for the time period where field data was collected and used to calibrate and validate the model. Conclusions cannot be drawn regarding the performance of the project under all possible hydrologic and meteorological conditions. In order to determine if the project would meet the objectives under all possible conditions, a long-term record of water levels in Grand Lake and in the Gulf of Mexico should be considered. The availability of differential water head between these two water bodies is the main controlling factor of delivering fresh water to the target areas. The periods during which differential water head is available can be checked against the periods of high salinity in the target area, and as such, conclusions can be drawn of whether the project meets the objectives during these times. Such analysis, though, is beyond the scope of this project and was not requested.

Numerical modeling has been used extensively throughout the world to offer practical engineering solutions to various engineering, environmental, and ecological studies. The use of a numerical model for this project has allowed decisions to be made for the most effective design and location of the proposed project features. The model has provided a tool for the assessment of the effectiveness of each of the proposed project features.

The model was initially calibrated and then validated against field measurements. Afterwards, a direct comparison of the "Base Run (Existing Conditions)" and the "Conceptual Design Run (with proposed features)" was performed. The model provided information regarding salinity and water level fluctuations, velocities, and discharges throughout the main channels and open water bodies within the project area and near existing and proposed structures. The salinity transport was computed through an Advection Dispersion (AD) numerical module, which was coupled with the hydrodynamic numerical model. The final results for water level, velocity, discharge, and salinity were displayed though time series graphical plots, animated time series illustrations, and contour map illustrations.

1.3 PROJECT DESCRIPTION

Upon field observations and visual inspection of the Digital Ortho Quarter Quad (DOQQ) maps for the project area, it was determined that the water movement throughout the project limits occurs within shallow sheet flow movement and a network of channels. The project study limits also include various small shallow lakes mixed with inundated marsh areas.

The conceptual project features as proposed in the original scope of services submitted on June 14, 2002 include channel enlargements and freshwater introduction structures that are predicted to improve flows from north to south across LA Hwy. 82. It is also planned to create approximately 400 acres of marsh by the use of dedicated dredging. The conceptual design of the proposed project features are shown in Figures 3 through 6, and are described thereafter.

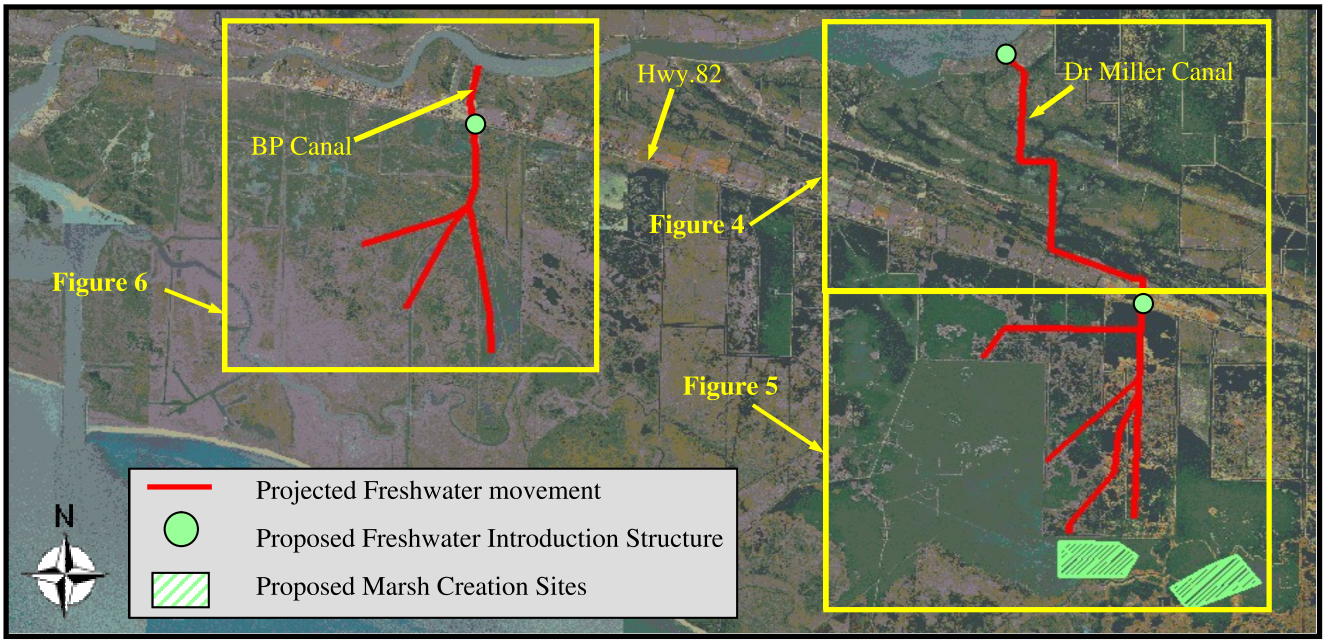

Figure 3: Base Map Showing Project Proposed Features

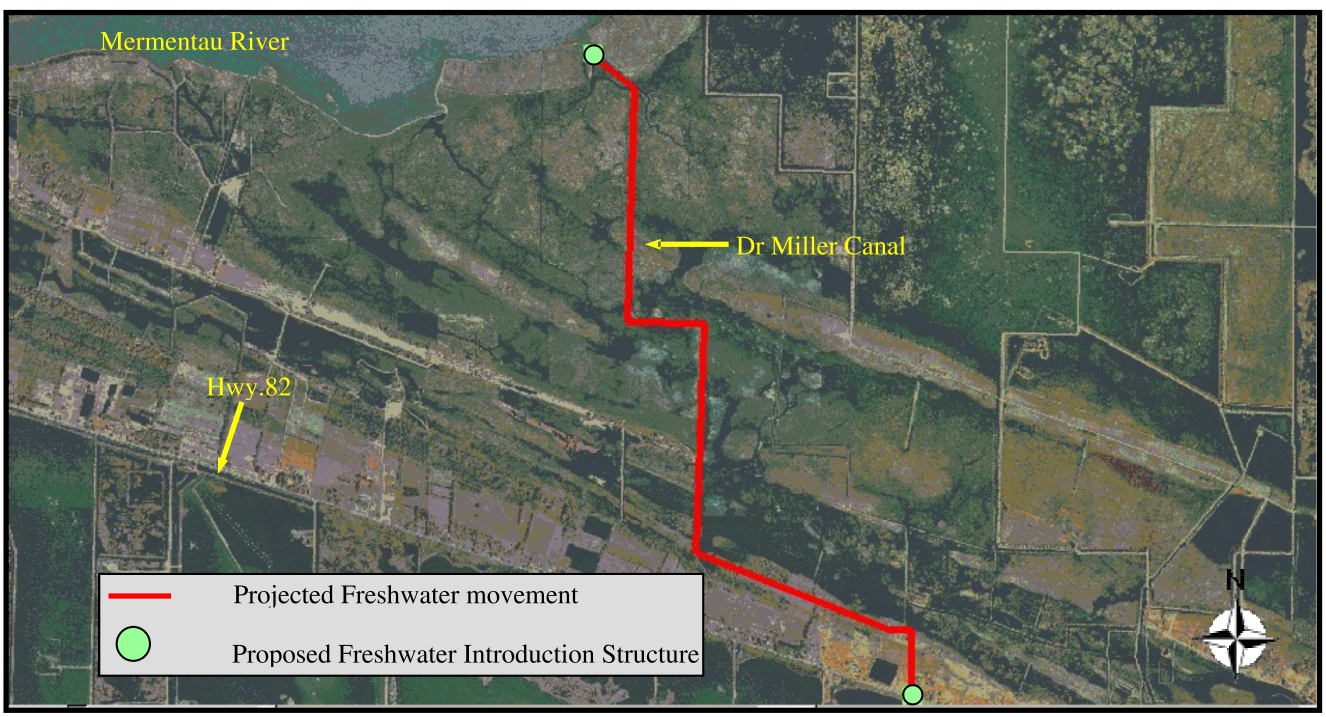

Figure 4: Dr. Miller Canal Channel Improvements North of Highway 82

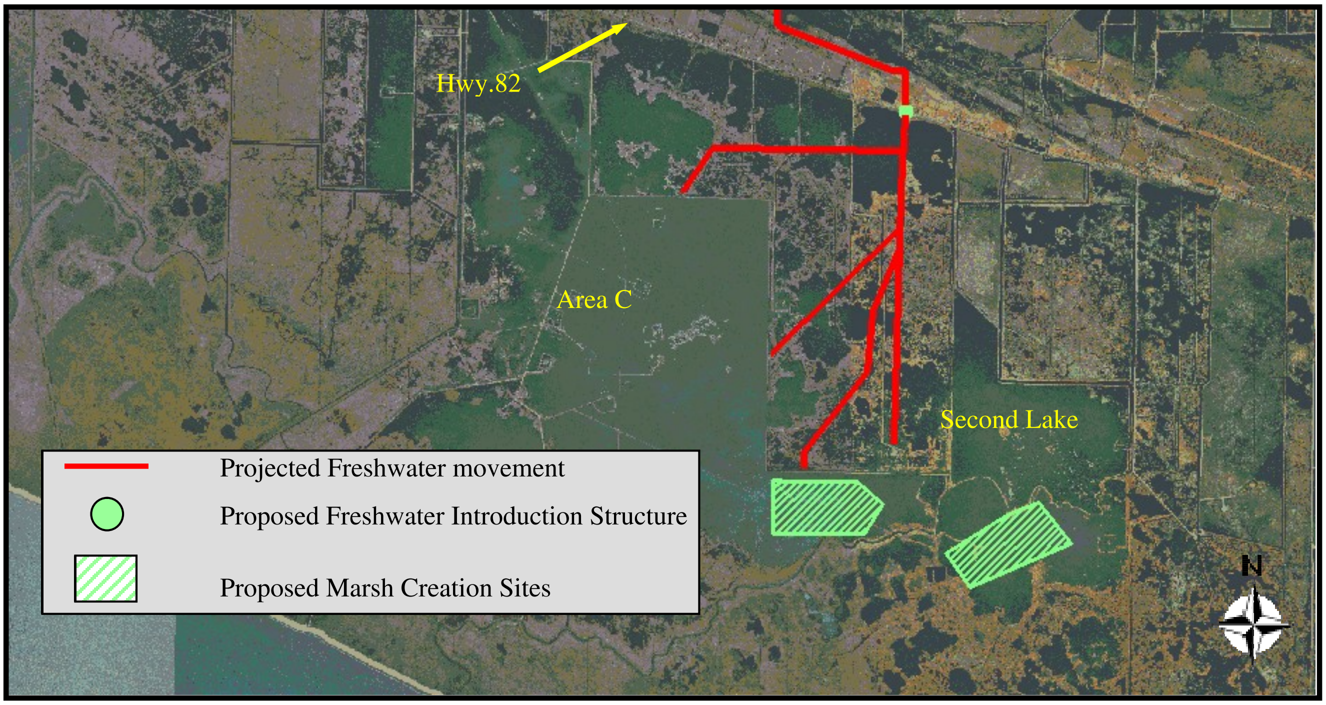

Figure 5: Dr. Miller Canal Channel Improvements South of Highway 82

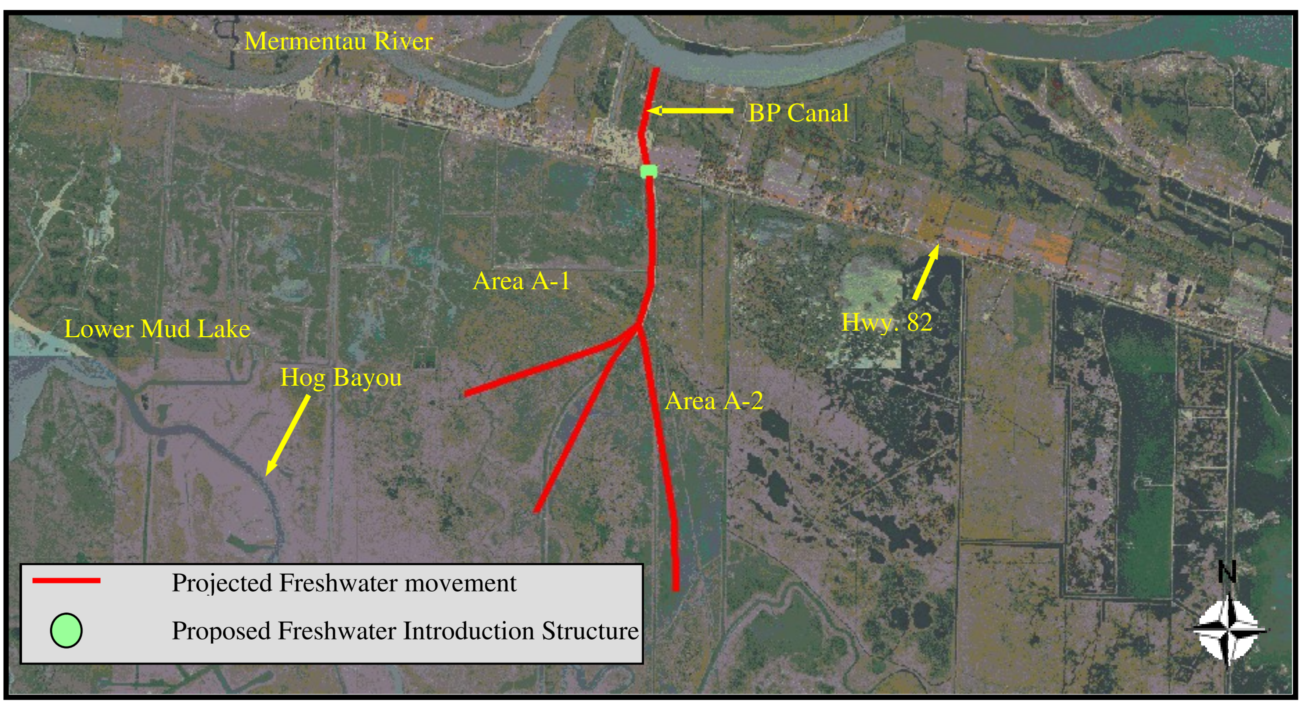

Figure 6: Freshwater Introduction Components at BP-Tennessee Gas Pipeline Canal

On March 13, 2002, C.H. Fenstermaker along with all other government entities attended a field trip to the project site. During this meeting, a PPL11 Candidate Project Fact Sheet for the project was handed out to all attendees. The following information contained in the handout describes in detail the original freshwater introduction components of the project.

1. **Freshwater Introduction Components at BP-Tennessee Gas Pipeline Canal (Figure 6)**

    - Install a pump (or gravity flow structure) at the southern end of the Tennessee Gas Canal (or BP Canal) north of LA Hwy 82;

    - Install a 1,200-foot long x 48-inch diameter (or larger) pipeline (or canal) (above or below ground) from the southern portion of the north/south Tennessee Gas Canal southward to LA Hwy. 82;

    - Dredge the mouth of the Tennessee Gas Canal to 5 feet deep x 80 feet wide x 100 feet long at its intersection with the Mermentau River. (Existing depths are about 1.5 to 2 feet deep at this intersection.);

    - Jack or bore a pipeline 60 feet southward under LA Hwy 82, or place a bridge at LA Hwy 82;

    - Connect the pipeline to the north-south pipeline canal south of the BP/Tennessee Gas Plant. [A borrow ditch is south of and parallel to Hwy 82 (25 feet wide x 1 to 2 feet deep) that connects to the North/South Tennessee Gas pipeline canal (Pipeline canal is 100 feet wide x 1 foot deep at northern end and 4 feet deep, 200 feet north of Hog Bayou)];

    - Channel fresh water down smaller bayous (bayous are approximately 10 feet to 20 feet wide x 1 foot to 2 feet deep) intersecting the north/south pipeline canal. Connect pipeline canal to marshes east and west of canal for fresh water flow to marshes.

2. **Dr. Miller Canal Freshwater Introduction Component (Figures 4 and 5)**

    - Dredge access channel in Upper Mud Lake to Dr. Miller Canal (4 ft deep x 50 feet wide x 300 feet);

    - Improve the existing 48-inch diameter culverts with flapgates at the intersection of the Dr. Miller Canal and Upper Mud Lake to allow fresh water flow southward;

    - Maintenance dredge the Dr. Miller Canal to dimensions 40 feet wide x 4 feet deep x 8,290 feet long from Upper Mud Lake to the terminus near LA Hwy 82 (existing dimensions are 44 feet wide and depths range from 2.2 to 3.4 feet deep);

- Construct a double-levee with 24" flapgate culverts possibly every 500 feet along the Dr. Miller Canal route. [About 40% of the route is leveed; therefore levees are needed for 10,000 feet (both bank lines). The height of the levees should be 4 or 5 feet NAVD 88 (3 to 4 feet above marsh level). Existing pasture land and marsh is about 1-foot NAVD 88[1];

- Drainage ditch maintenance dredging and double levee construction to convey water from the southern terminus of the Dr. Miller Canal east to north of Cannick Pond, then southward across LA Hwy 82. Improve 4,040 feet of an existing 15 to 20 feet wide x 1 to 2 feet deep drainage ditch along first east/west leg to 25 feet wide x 4 feet deep;

- Construct a 1,275 feet long 25 feet X 4 feet deep ditch, or install subsurface 48" diameter culvert(s) (or larger), southward to LA Hwy. 82;

- Install a double levee with 24" culverts (additional 22 culverts needed) with flapgates along the length of the canal from the terminus of Dr. Miller canal and LA Hwy 82 (5,315 ft x 2 = 10,630 ft). Levee dimensions are described above;

- Jack or bore a 48" culvert 60 feet under LA Hwy 82, or construct a bridge to the McCall/Sturlese Tract (Area B). Consider the possibility of installing a pump near LA Hwy. 82 at the Cannick Pond Crossing.

<u>Summary of Dr. Miller Canal Channel improvements North of Hwy. 82</u>

- Enlarge Dr. Miller Canal to dimensions 40 feet wide X 4 feet deep for a length of 8,290 feet;

- Maintenance dredge existing canal East from Dr. Miller Canal to North of Cannick Pond for a length of 4,040 feet;

- Construct a new ditch or culvert south from A to Hwy 82 for a length of 1,275 feet;

- Dr Miller Canal Channel Improvement South of Highway 82, jack or bore or install bridge under Hwy 82 to McCall / Sturlese tract for a length of 60 feet.

[1] NAVD 88- North American Vertical Datum of 1988. This datum is used throughout this study for all vertical elevations

Total canal maintenance or new canal/culverts is 13,665 ft.

Summary of Double Levee and Culverts

Reach	Levee Length	Number of 24" Culverts
Dr. Miller Canal	10,000 ft.	33
Dr. Miller Canal to Hwy 82	10,630 ft.	22
Total	**20,630 ft.**	**55**

3. **Dr. Miller Canal Freshwater Introduction South of Hwy 82**

   - Make at least 6 breaches or place 6 - 48 inch open culverts in the existing McCall Tract levees/board roads to convey freshwater southward and westward;

   - Install at least 3, 3-barreled 48-inch diameter flapgate culverts in the McCall Tract western levee (one in each of the northwestern, western, and southern levee reaches) to convey water westward and southward to the Sweeney Tract or Area C.

4. **Marsh Creation Sites**

   - Dredged Material for Marsh Creation - Restore approximately 200 acres of brackish marsh in the southeast corner of the Sweeney Tract (Area C shown in Figure 5). Dredge and transport dredged material from the Gulf of Mexico northward approximately 14,875 feet to create 200 acres of marsh in shallow (1.5 feet deep) open water;

   - Construct Retention Levees - This area is bounded on 3 sides by levees (Hog Bayou, southern McCall levee and the eastern Sweeney Tract levee). A north/south levee about 3,400 feet long is proposed on the western and southern side to tie into other levees;

5. **Second Lake Marsh Creation Site**

   - Dredged material for Marsh Creation- Dredge material from the Gulf of Mexico and transport northward 14,875 feet to create 200 acres of marsh in shallow (1.5 feet deep) open water in the Second Lake area southeast of the Sweeney Tract;

- Construct Retention Levees - Total dimensions of confined area are 4,000 feet x 2,200 feet (13,400 feet total); marsh borders the area on two sides and can possibly be used as means of confinement. If this is acceptable, about 6,200 feet of retention levees are needed at 6.5 cu. yds. per foot = 40,300 cu. yds. If marsh confinement is not acceptable, 12,400 feet of total levee is needed (2 feet x 4,000 feet + 2 x 2,200 feet). At 6.5 cu. yds./feet, the total cu. yds. needed for that retention levee = 80,600 cu. yds.;

A detailed discussion of the model setup, calibration, and validation results is presented in Chapter Two and the implementation of the proposed project features is described further in detail in Chapter Three.

II. CHAPTER TWO

2.1 MODEL SELECTION

The first process in performing a numerical model study is to select an appropriate model capable of capturing the hydrologic characteristics of the project area. It is well beyond the scope and budget of this project to perform an elaborate model selection task. Therefore, an adequate modeling tool was selected for this study based on the background information available about the project site.

The focus of this project is to introduce fresher water into the marshes south of LA Hwy 82 through various canals within the project area, and to reduce the amount of saltwater intrusion from the Gulf of Mexico. It is important here to mention that the area of this project is hydrologically connected to the Little Pecan Bayou Hydrologic Restoration Project (ME-17). With this in mind, setting up a separate model for each project will not accurately mimic the hydrology of the area. After consulting with federal and local government agencies for the two projects, it was decided to setup one coupled model for the two projects. The methodology used to setup the model is described in Section 2.3.

Field observations and inspections of the project area indicate that the water movement within the South Grand Chenier Hydrologic Restoration Project (ME-20) occurs as a combination of shallow sheet flow movement and open channel flow. Meanwhile, the water movement within the Little Pecan Bayou Hydrologic Restoration Project (ME-17) area boundaries predominantly occur within the banks of a network of channels, trenasses, and canals, rather than through dominant shallow sheet flow movement. Therefore, an appropriate modeling tool for this study should dynamically integrate these two flow regimes. A one and two-dimensional coupled modeling approach will be used for modeling the flow through the channel network, the flow through marsh areas, and the exchange between the channels and the marsh. It should be noted that a three-dimensional model would not be needed since the project area is predominately shallow (water depth in the project area range between 2 and 15 feet) making salinity stratification negligible.

There are several reliable coupled modeling systems commercially available on the market. Differences between these packages are primarily in their ability to adequately model hydraulic structures, and in their pre-and post-processing capabilities. One of the popular and widely used coupled modeling packages is MIKE FLOOD. This software is produced by the Danish Hydraulic Institute (DHI).

MIKE FLOOD integrates the widely used one-dimensional model MIKE 11 and the two-dimensional model MIKE 21 into a single package. The special features of MIKE FLOOD include:

- Preservation of mass and Momentum through links between MIKE11 and MIKE21;
- Simulation of over bank flow from channels to floodplains through lateral links;
- Inclusion of a comprehensive hydraulic structure package;
- Full compatibility with GIS packages;
- A user-friendly graphical interface for data preparation, processing, and analysis;
- A thorough on-line help system, user manual and technical reference documentation;
- Support and continuing commitment from model developers (DHI Water and Environment)

MIKE FLOOD can also be used to model applications like:

- Floodplain applications;
- Storm surge studies;
- Urban drainage projects;
- Dam break studies;
- Hydraulic design of structures;
- Broad scale estuarine applications.

Using MIKE FLOOD allows the modeler to take advantage of the available capabilities of both MIKE11 and MIKE21. A list summarizing these capabilities is included below:

MIKE11:

- Comprehensive hydraulic structures routines;
- Modeling of complex channel networks;
- Linkage to rainfall and runoff programs;

- Modeling of sediment and water quality constituents;
- Computationally efficient.

MIKE21:

- Modeling overland flow, shallow lakes and ponds;
- Wetting and drying capability to model marsh inundation;
- Modeling of sediment and water quality constituents;
- More computational effort.

2.1.1 MODEL RESOLUTION

The alignments of the channels were digitized directly from geo-referenced aerial imagery (1988 DOQQ) in order to best capture the alignment of each channel. Typical spacing between digitized computational points for this project was in the range of 200 to 600 feet.

For the marsh areas where a two-dimensional model will be used, the model grid resolution is an important factor. It affects the model's ability to resolve the spatial variability of the flow characteristics. Typically, a grid refinement exercise needs to be performed in order to determine the optimum grid size for each application. Sometimes in practical applications, the grid has to be finer than the optimum grid size in order to capture particular features of importance. In the project discussed here, a grid resolution of 75 meters (approximately 250 ft) in both directions of the horizontal plane has been selected. This grid size was selected to capture the exchange between over-bank and channel flows. This grid size is finer than the size needed to resolve the circulation pattern in and near the project area. In the horizontal plane, the grid has 83 x 303 computational nodes (25,149 computational points).

2.2 DATA COLLECTION & REVIEW

2.2.1 BATHYMETRIC DATA

The accuracy of the results of any numerical model is directly proportional to the accuracy of the bathymetric data. For one-dimensional numerical models, the bathymetric information is required in the form of cross sections along the length of channels within the model domain. Spot elevations to define the storage capacity of all open water bodies are also required. The following guidelines are used as a general standard practice to identify the locations where surveyed cross sections are needed:

- Upstream and downstream of abrupt changes in channel geometry;
- At all canal intersections (cross section at each approaching leg);
- At all channel bed slope changes along the channel's longitudinal direction;
- Upstream and downstream of all existing structure locations.

For two and three-dimensional numerical models, bathymetric information is required in the form of bare earth spot elevations within all open water areas, canals, and marshes within the project model domain. The information used to generate the 2D- bathymetry file include:

- Spot elevations of the bottom of open water bodies, canals, and open marshes;
- Spot elevations of all significant hydrologic barriers or features (i.e. levees, ridges, etc.).

Upon visual inspection of this project's area and through the use of aerial photography, it was estimated that 103 cross sections and 165 spot elevation points would need to be surveyed in order to create the bathymetry for the numerical model. The channel inverts in the project area ranged from +0.0 to approximately –10.0 ft-NAVD88 (National Adjusted Vertical Datum of 1988).

On July 24, 2002, survey crews from C.H. Fenstermaker & Associates were mobilized to the project site to survey the required cross sections and spot elevations needed to set up the numerical model. The surveying effort included establishing horizontal and vertical positions on three new secondary monuments within the LDNR Primary Network. These monuments were to be used in conjunction with existing secondary monuments to perform the necessary survey effort. The approximate location of the proposed monuments, cross sections, and also data sondes were determined jointly by C.H. Fenstermaker and Associates, Inc. and LDNR personnel. The secondary monument locations were strategically selected in order to populate the existing LDNR secondary network in the areas that were lacking sufficient monumentation to collect the necessary survey data and to comply with specifications produced by LDNR entitled, "A Contractor's Guide to Minimum Standards". Once installed, the new monumentation along with the existing monuments allowed the entire project to be surveyed utilizing GPS (Global Positioning System) Real-Time Kinematic (RTK) techniques. The survey crews were able to successfully complete the proposed survey in the allocated time initially proposed in the work plan for the project. Figures 7 through 12 below show the final location of the project's cross-sections and surveyed points. It is very important to note that survey data shown in the following figures are for both this project and the Little Pecan Bayou Hydrologic Restoration Project (ME-17) since both projects were modeled together.

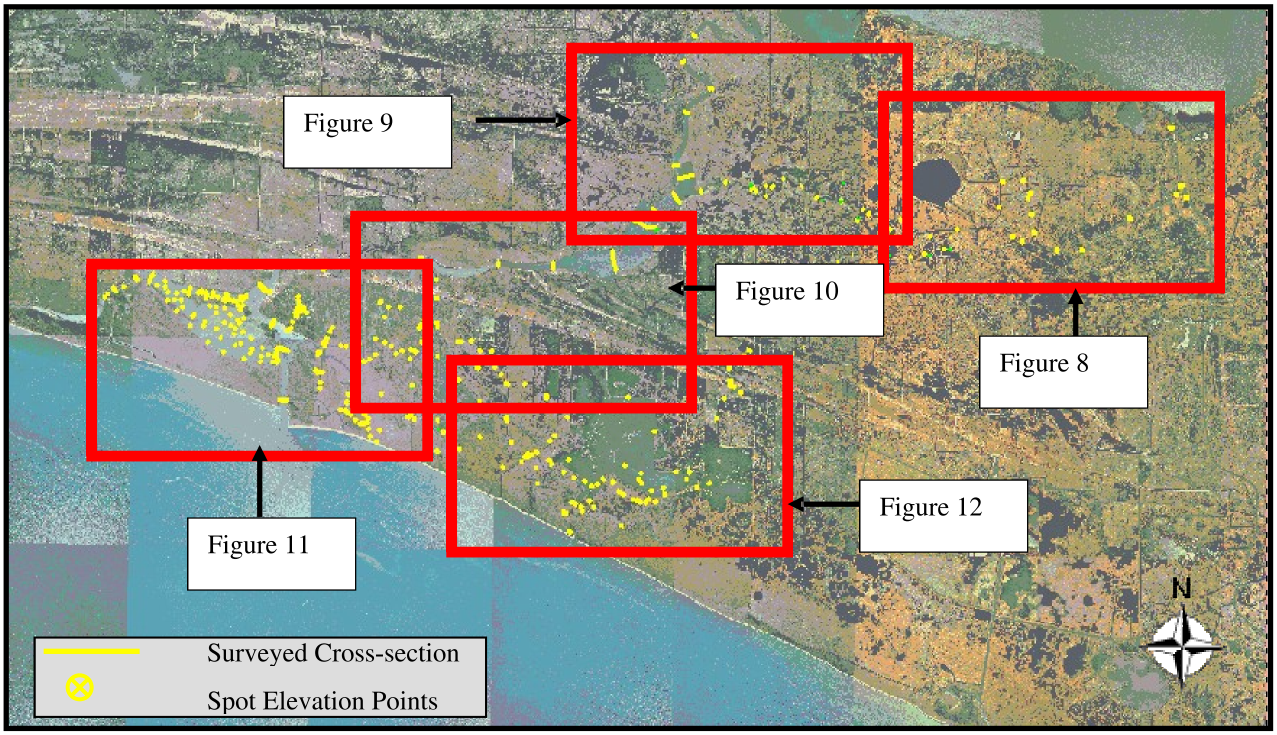

Figure 7: Basemap Showing Location Of Final Surveyed Cross-Sections for both the South Grand Chenier Hydrologic Restoration Project (ME-20) and the Little Pecan Bayou Hydrologic Restoration Project (ME-17) (103 Total)

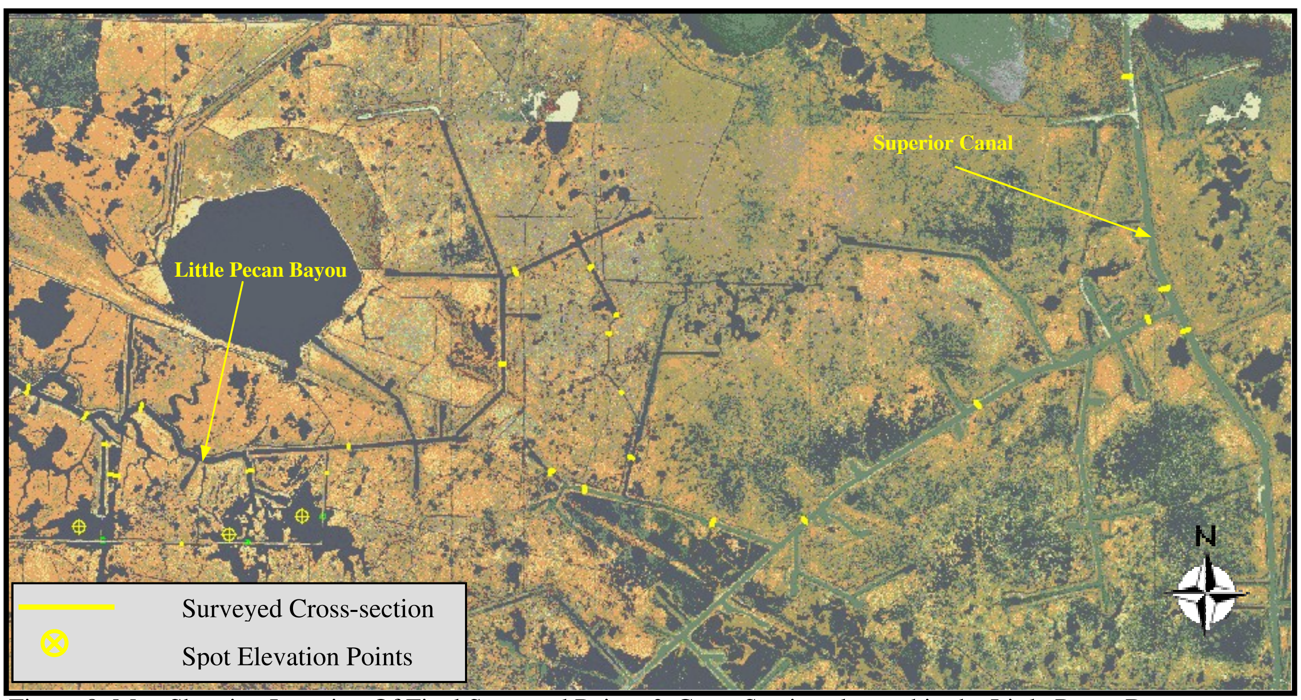

Figure 8: Map Showing Location Of Final Surveyed Points & Cross Sections located in the Little Pecan Bayou Hydrologic Restoration Project (ME-17)

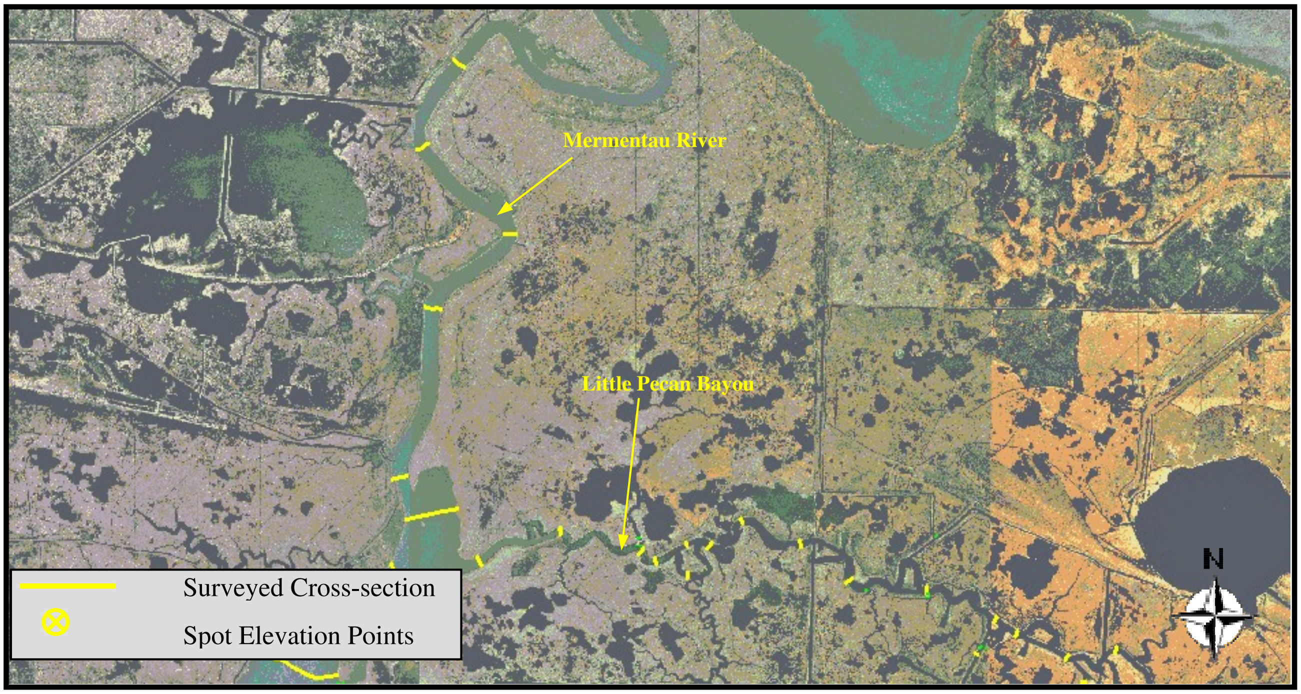

Figure 9: Map Showing Location Of Final Surveyed Points & Cross Sections located in the Little Pecan Bayou Hydrologic Restoration Project (ME-17)

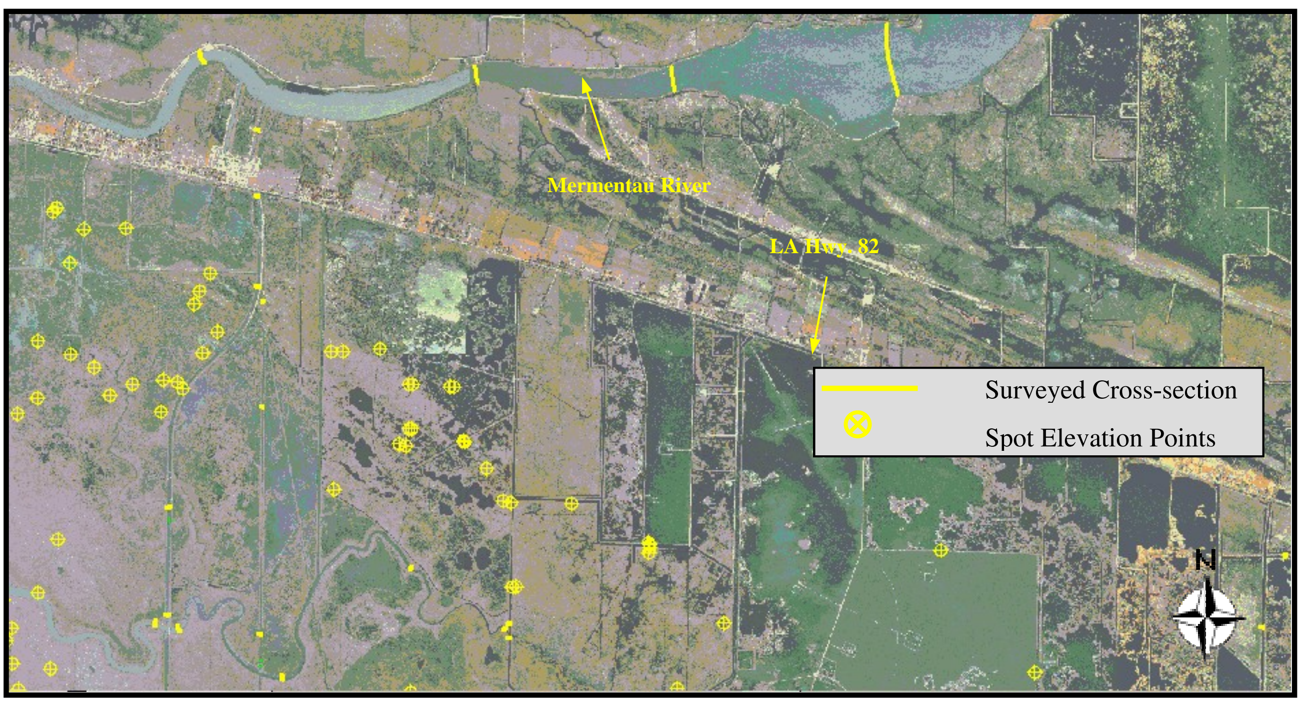

Figure 10: Map Showing Location Of Final Surveyed Points & Cross Sections for both the South Grand Chenier Hydrologic Restoration Project (ME-20) and the Little Pecan Bayou Hydrologic Restoration Project (ME-17)

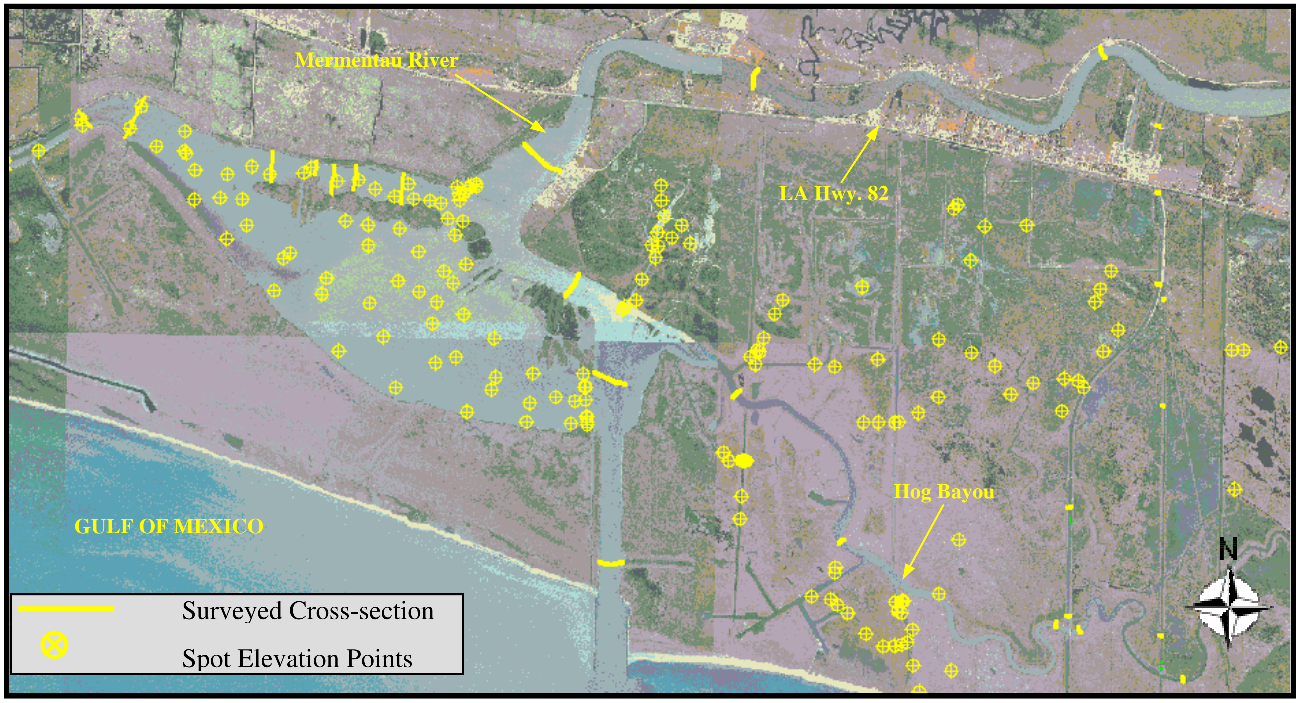

Figure 11: Map Showing Location Of Final Surveyed Points & Cross Sections for the South Grand Chenier Hydrologic Restoration Project (ME-20)

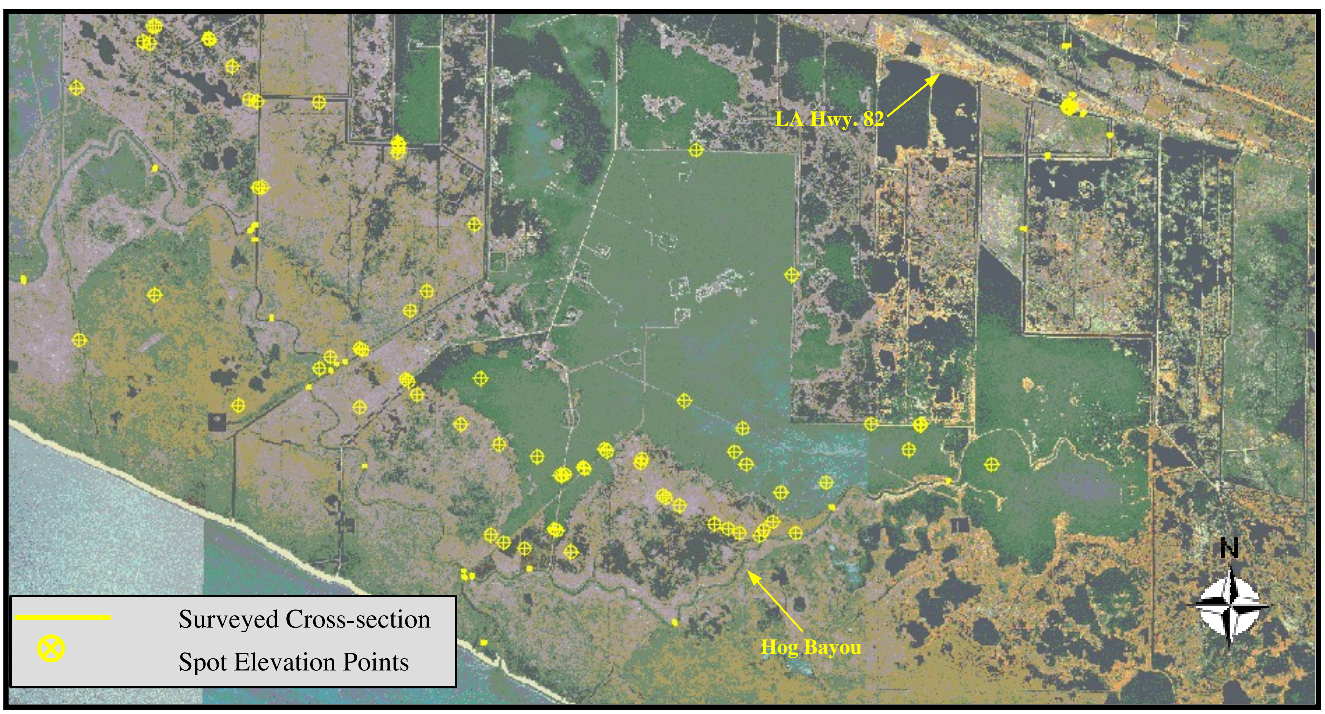

Figure 12: Map Showing Location Of Final Surveyed Points & Cross Sections for the South Grand Chenier Hydrologic Restoration Project (ME-20)

Detailed information and dimensions of existing hydraulic structures were also surveyed. Survey crews were instructed to collect all possible information needed to accurately setup the model's structure components.

To facilitate the survey effort for hydraulic structures, the field crews utilized coding techniques that are common in the surveying industry. Figures 13 through 17 describe the basic coding requirements for structures like or similar to the ones shown in these illustrations. Figure 18 illustrates a sample page of field notes that were taken at the LA Hwy. 82 structure along with a color photograph for the records.

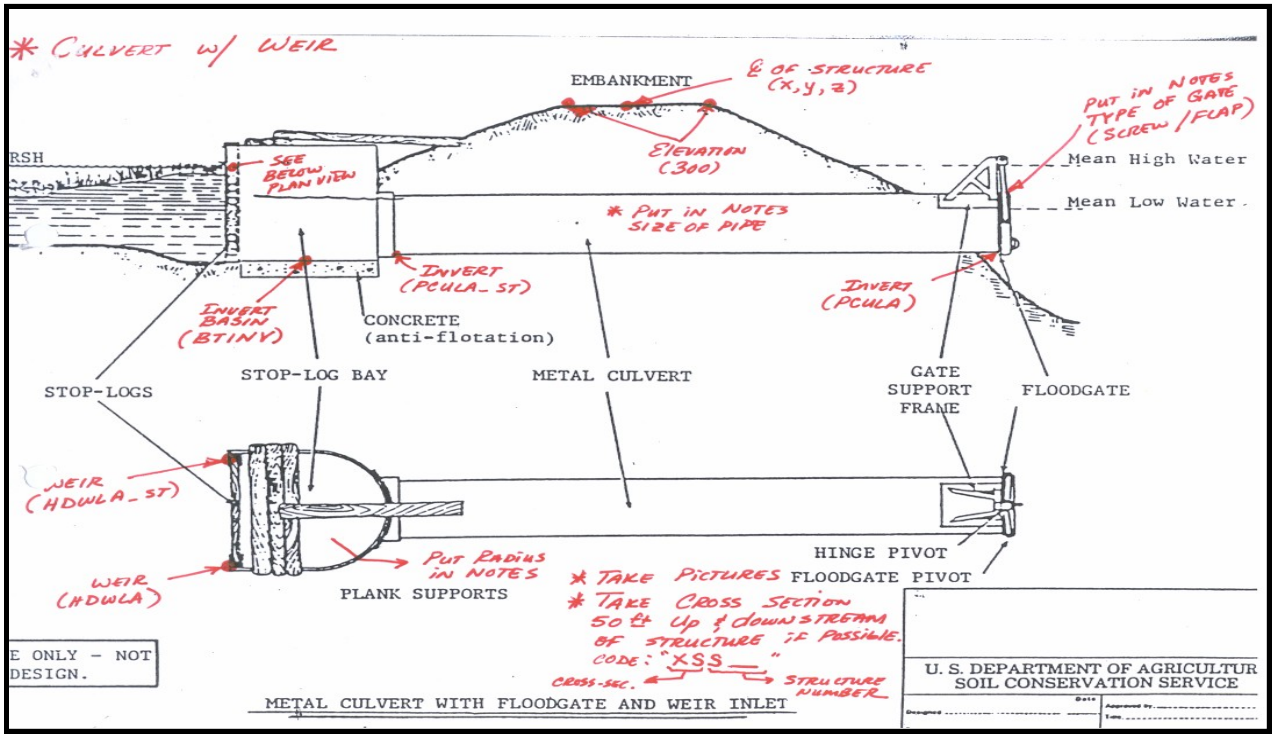

Figure 13: Basic Survey Coding For Culvert System With Flapgates And Stop Logs.

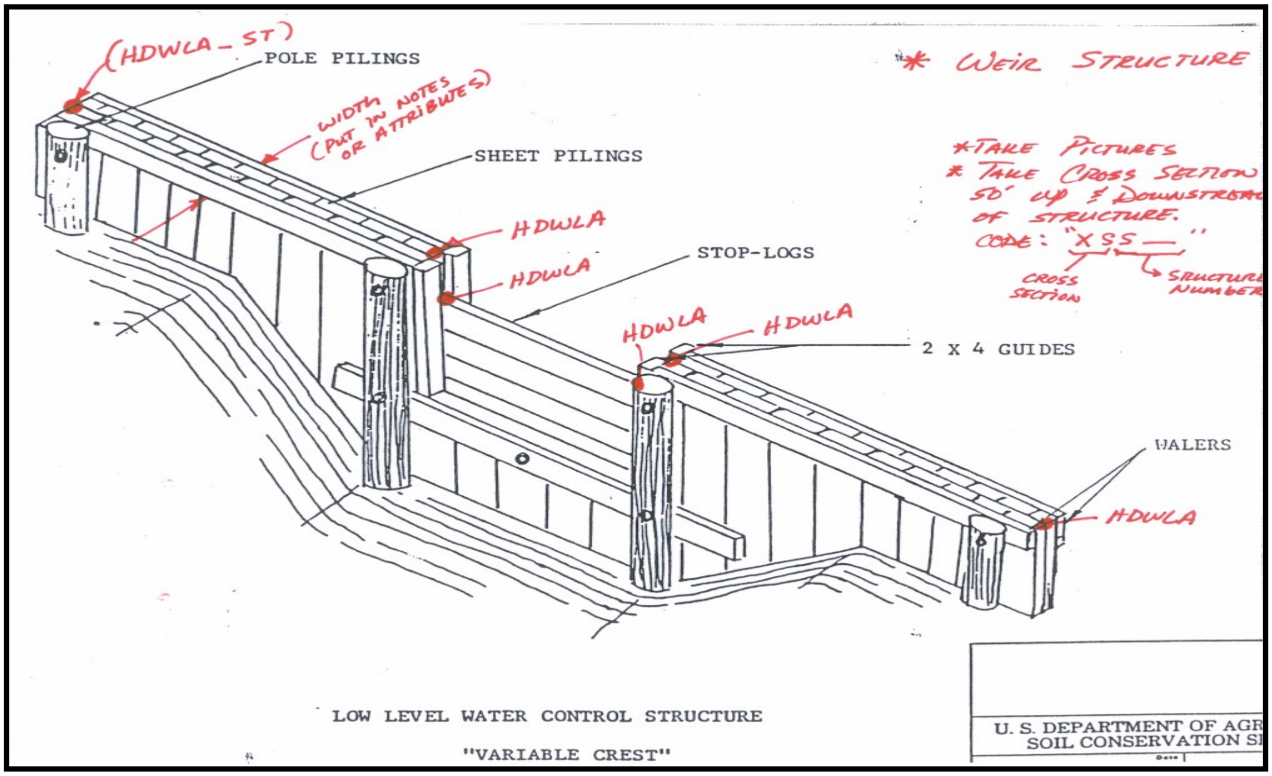

Figure 14: Basic Survey Coding For Weir Structure

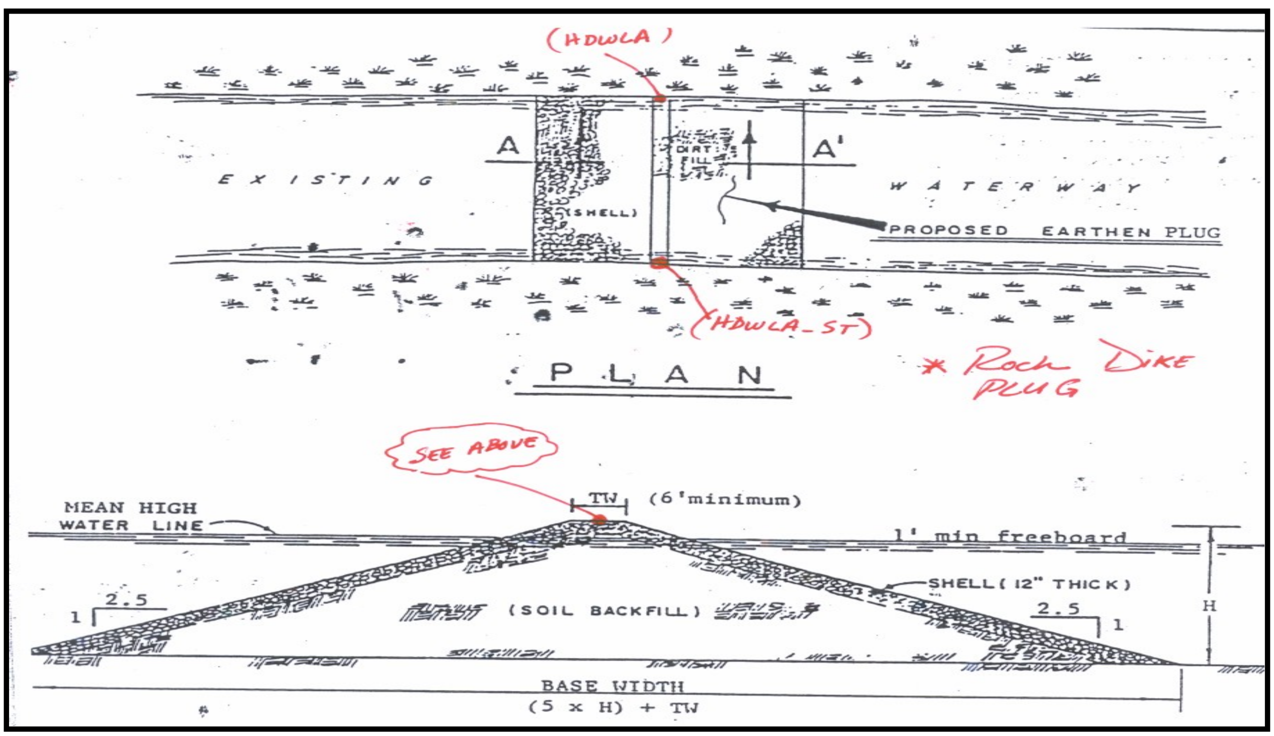

Figure 15: Basic Survey Coding For Earthen Or Rock Plug

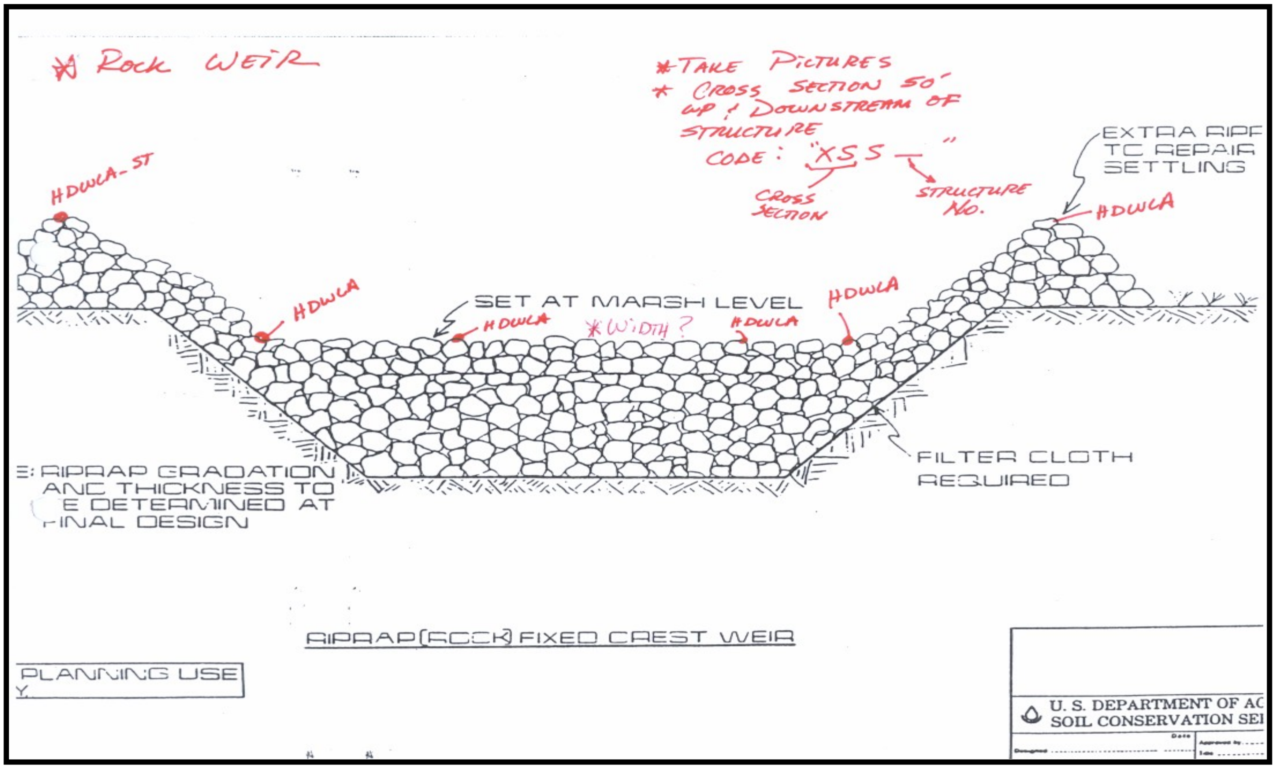

Figure 16: Basic Survey Coding For Rock Weir Structure

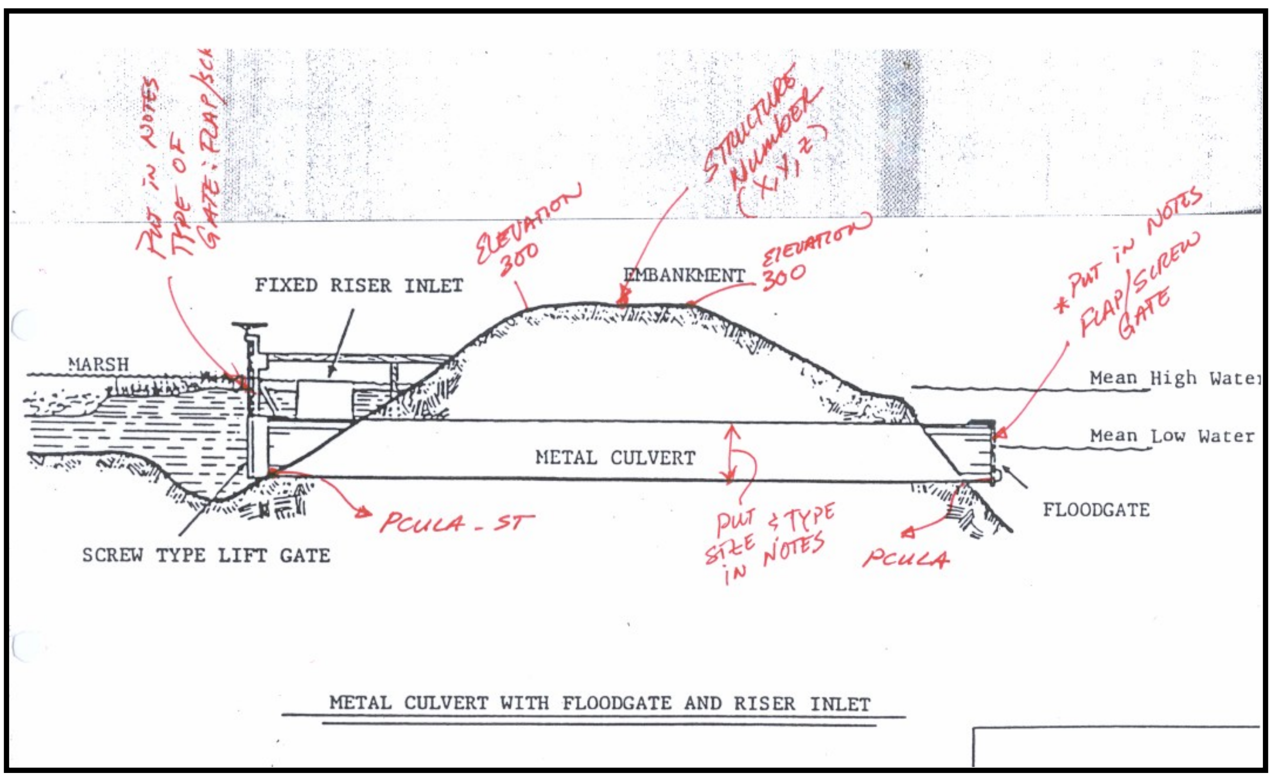

Figure 17: Basic Survey Coding For Culvert With Screw Gate And Flap Gate Inlets.

Figure 18: Example Clip From Survey Field Book Describing Existing LA Hwy.82 Multiple Box Culvert.

2.2.2 HYDROLOGIC DATA COLLECTION

Hydrologic data is needed to set up the boundary conditions and to calibrate and validate the numerical model. The hydrologic parameters needed for this modeling effort are water level, velocities, discharge, and salinity. Per LDNR's recommendations through previous experiences, YSI 600-OMS data sondes (manufactured by YSI, Inc) were used in this study. It is a product similar to the YSI 6920 data sonde currently used by LDNR. This device measures water level, water temperature, and specific conductivity.

Information from continuous recorders G1, G6, G7, G8 and G9 were used as boundary conditions for the numerical model, while G2, G3, G4, and G5 were used for the model's calibration and validation. Locations of all the gages are shown in Figure 19.

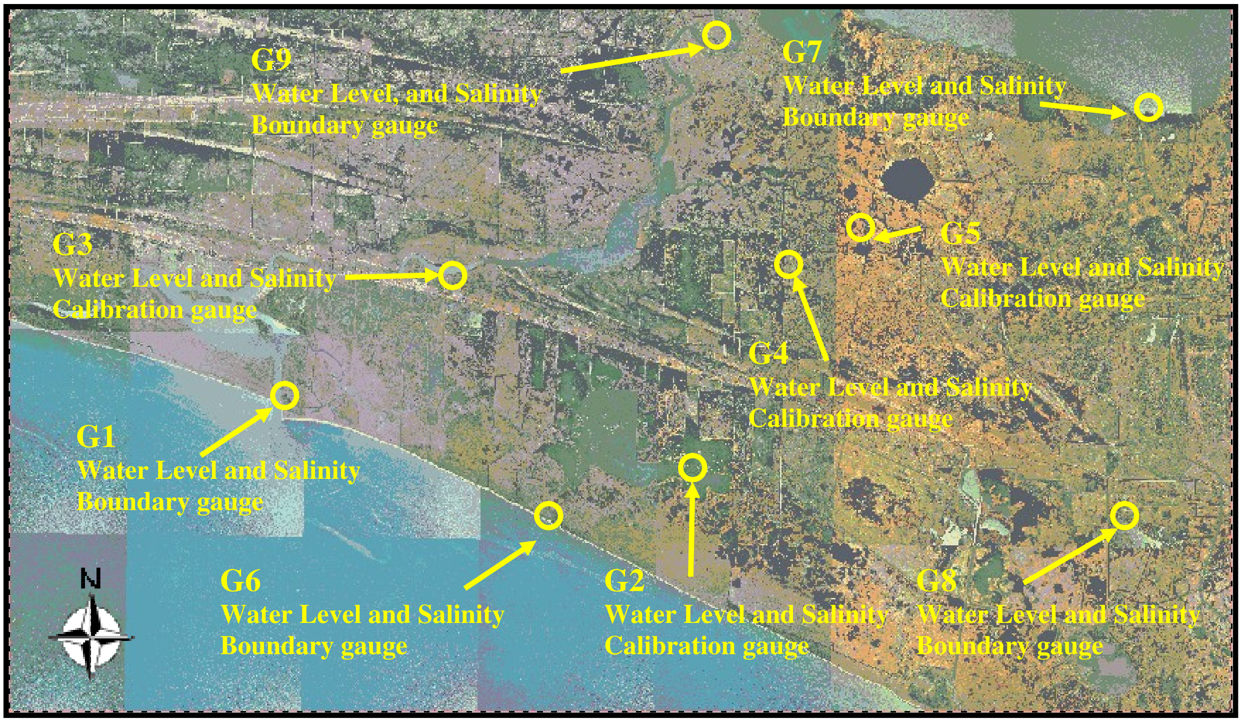

Figure 19: Basemap Showing The Location Of Continuous Recorders Used For The Model. (Recorders are located in both the South Grand Chenier Hydrologic Restoration Project (ME-20) and the Little Pecan Bayou Hydrologic Restoration Project (ME-17).

Not shown in Figure 19 is the continuous recorder used to collect wind direction and speed. This recorder is located in Lake Charles, Louisiana and is owned and operated by Louisiana State University-Southern Regional Climate Center. Figures 20 and 21 show some pictures of the monitoring stations mentioned above, while Table 1 shows the available data record at each station.

Figure 20:Water Level And Salinity Data Sonde
Installed In The Mouth Of The Mermentau River

Figure 21: Discharge And Water Level Gauge Installed
In The Mermentau River Near Grand Lake.

Recorder Name and Location	Data Type	Date From:	Date To:
G1, Mouth of the Mermentau River at the Gulf of Mexico	Water Level and Salinity	7/29/02	4/7/03
G2, Second Lake	Water Level and Salinity	8/1/02	4/30/03
G3, Mermentau River near BP canal	Water Level and Salinity	7/29/02	4/30/03
G4, Miller Property	Water Level and Salinity	8/20/02	4/30/03
G5 Little Pecan Bayou	Water Level and Salinity	7/29/02	4/30/03
G6, Beach Prong	Water Level and Salinity	8/1/02	4/30/03
G7, North Superior Canal at Grand Lake	Water Level and Salinity	8/22/02	4/30/03
G8, Superior Bridge	Water Level and Salinity	8/1/02	4/30/03
G9, Mermentau River at Grand Lake	Water Level and Discharge	8/22/02	6/3/03

Table 1: Record of Data available at each of the monitoring stations

2.3 MODEL SETUP

The steps needed to setup the numerical model for this project include:

1. Determining the extent of the numerical model domain. Care should be taken to ensure that:
    - The boundaries of the model extend beyond the area of interest.
    - The hydrologic or topographic adjustments and changes within the project area do not impact the conditions at the numerical model boundaries.

2. Setting up the channel network and the computational grid within the numerical model domain. (NOTE: In coastal Louisiana where a network of channels runs through the marsh, it is not practical to include all the channels as some are quite small in dimensions and do not carry or convey significant flow).

3. Assigning surveyed and estimated cross sections to all channels included in the model domain.

4. Include storage areas into the one-dimensional model if they exist.

5. Include all hydraulic structures within the numerical model domain.

6. Assign proper boundary conditions to each open end of every channel in the numerical model domain.

The surveyed spot elevations shown in Figure 7 through 12 were combined with the surveyed cross-sections to generate the bathymetry input file for the numerical model. As discussed in Section 2.1, the grid resolution for the two-dimensional model area is 75 meters (approximately 250 feet) in both directions (north-south and east-west) of the horizontal plane. This grid is adequate to capture the circulation patterns of water level and salinity within the model domain. It should be noted that the vertical datum for all the bathymetric data as well as the water level data was set to NAVD 88, while the state plane Louisiana South Zone, NAD83 (National Adjusted Datum of 1983) was used as the horizontal datum.

2.3.1 SETUP OF CHANNEL NETWORK

The general layout of the channel network, boundaries, and hydraulic structures for the existing conditions are shown in Figures 22 and 23. An aerial is shown in the background of these figures to facilitate identifying the channels and their locations in the field.

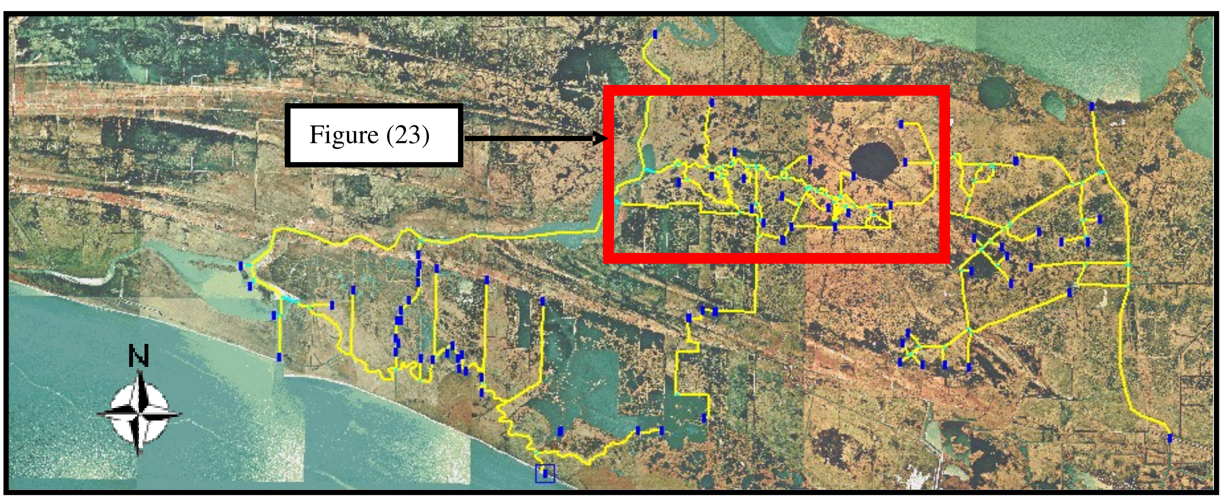

Figure 22: Basemap Showing The MIKE11 Channel Network, Cross Sections, Structures And Boundaries. (The network encompasses both the South Grand Chenier Hydrologic Restoration Project (ME-20) and the Little Pecan Bayou Hydrologic Restoration Project (ME-17)

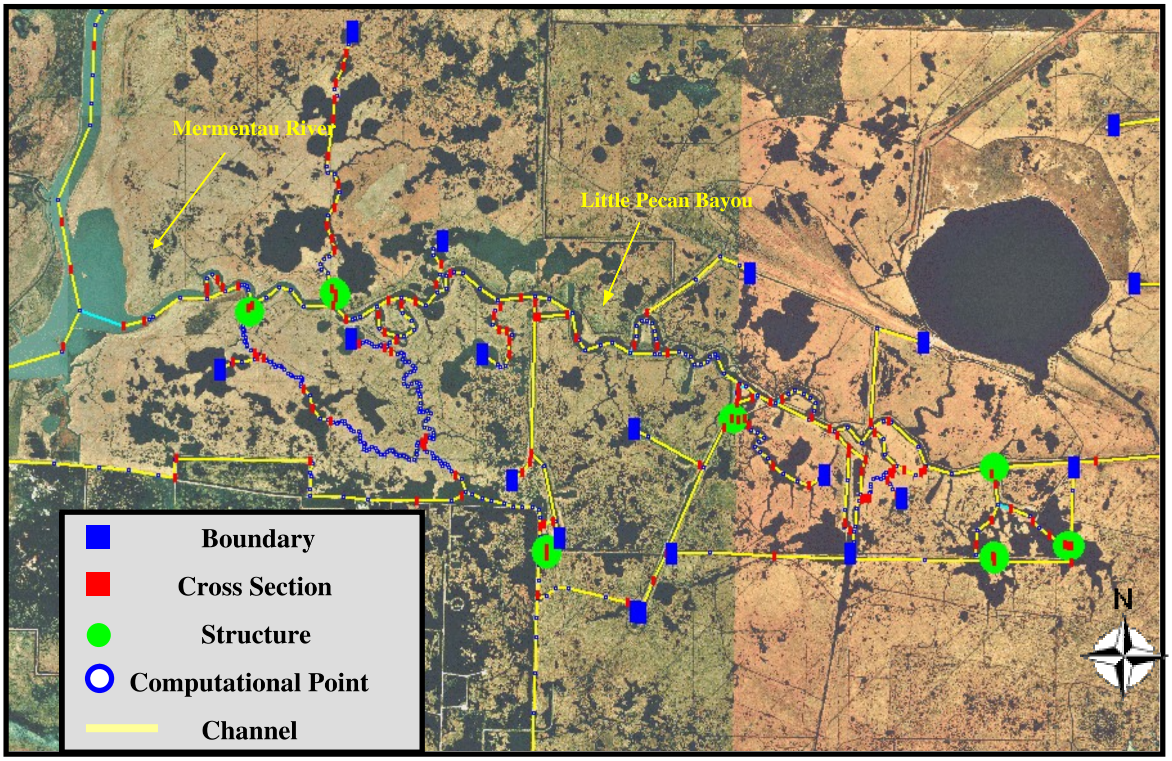

Figure 23: MIKE11 Channel Network, Cross-Sections, Structures And Boundaries. (Network shown within the Little Pecan Bayou Hydrologic Restoration Project (ME-17)

An extensive effort was made to ensure that the channel connectivity mimics the field conditions. Although most of the flow is conveyed through the channel network and not through over-bank sheet flow, care was taken to include the storage areas of the open water bodies. Storage areas can, at times, have significant impact on attenuating the tidal signal and the transport of salinity.

2.3.2 SETUP OF TWO-DIMENSIONAL GRID

The bathymetric data for the project area, including any hydrologic barriers within the domain, is shown in Figure 24 and 25. Figure 26 shows a three-dimensional visualization of Lower Mud Lake, near the Mermentau River mouth. These figures show the level of topographic details included in the model.

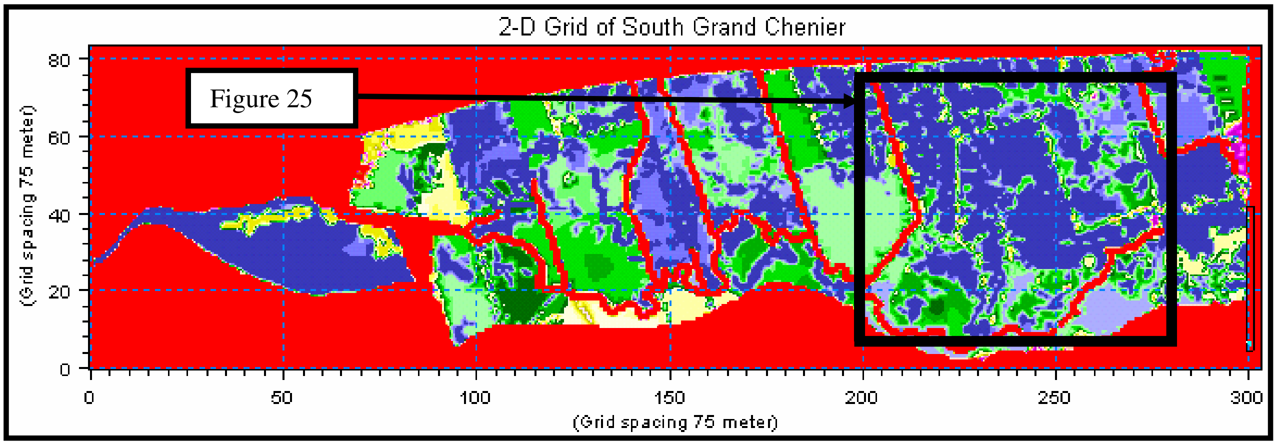

Figure 24: Basemap Showing The MIKE 21 Model Grid. (Model Grid was used only for the South Grand Chenier Hydrologic Restoration Project (ME-20)

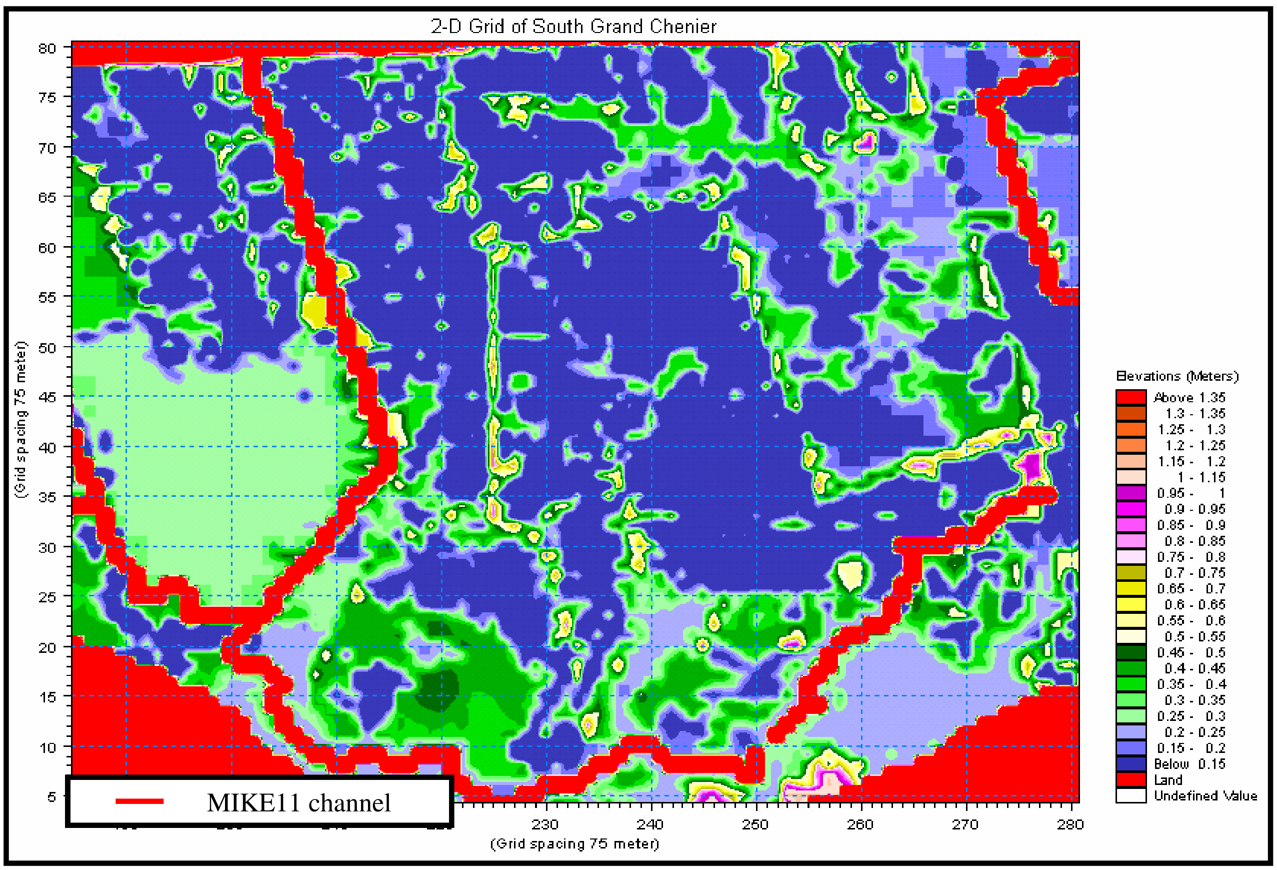

Figure 25: MIKE 21 Model Grid

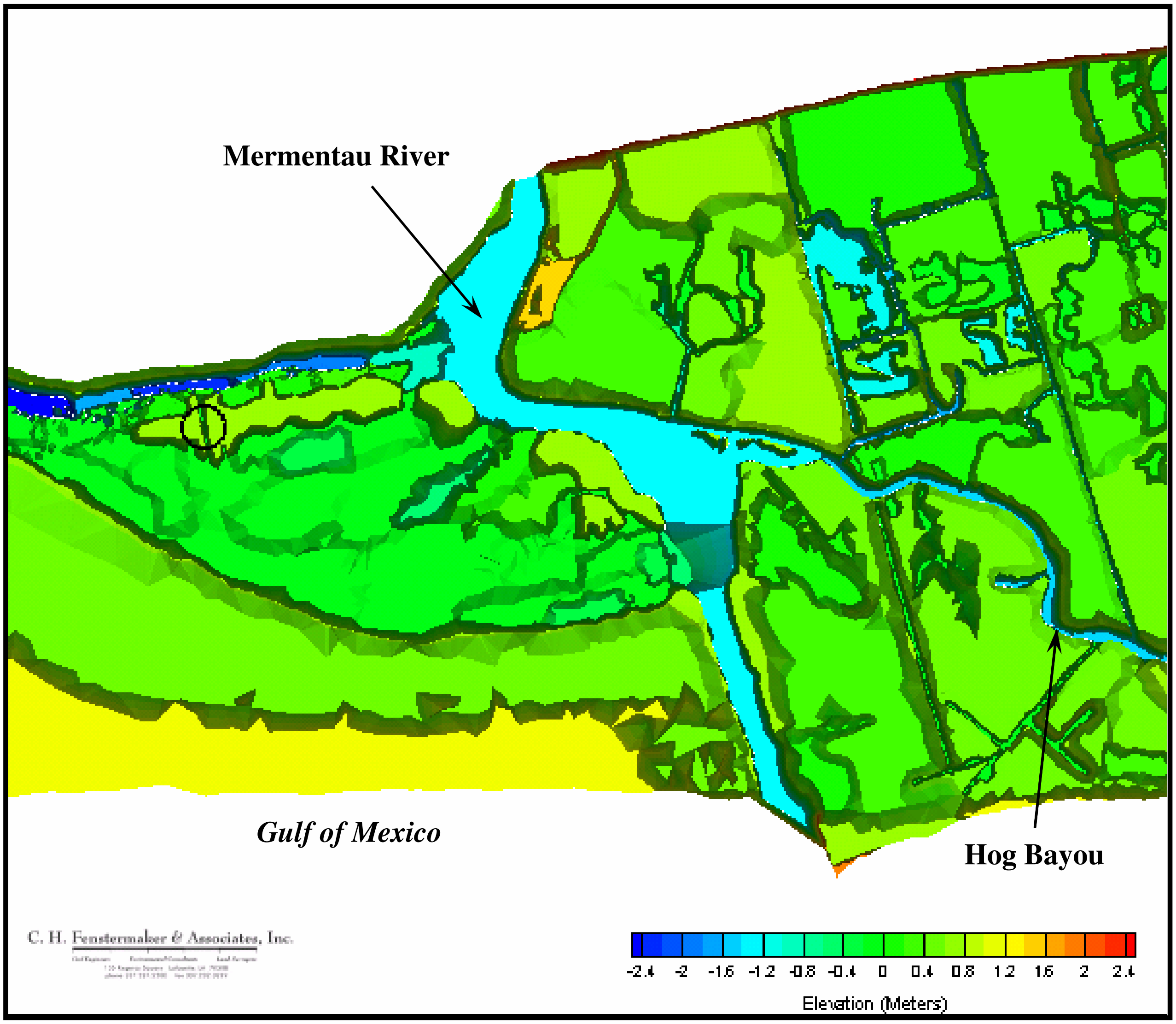

Figure 26: 3-Dimensional Visualization Of The Lower Mud Lake

An overall summary of the model setup includes:

- Over 100 miles of waterways (158 channels)
- 1,533 computational points and 69 structures (weirs, culverts with flap gates including proposed structures).
- 25,149 (250 x 250 ft) grid cells.

2.3.3 PROCESSING OF SURVEYING DATA

The modeling team at C.H. Fenstermaker & Associates, Inc. developed a FORTRAN program to process the raw survey cross-section data used to create the model. The computer program uses the following information as input:

- The raw survey data.
- The channel names from the network file of MIKE11.
- The NAD83 (North American Datum of 1983) coordinates of each computational point, the name of the branch to which it belongs, and its location (chainage) along that branch.

The program then performs the following operations:

- Through the knowledge of the coordinates of the computational points and the coordinates of the start and end points of the cross section, the program assigns each cross section to the appropriate channel.
- Corrects any misalignments in the raw survey data for each cross section.

In essence, the program converts the raw survey data directly to a format readable by MIKE 11. In addition to saving effort and time spent on processing the survey data, this program eliminates the potential human error introduced during manipulating the raw survey data. Figure 27 below illustrates an output file from the FORTRAN program that can be imported directly to the MIKE 11 software.

```
SURV2002
HUMBLE CANAL
      6022.370
COORDINATES
2   861583.58   132364.81   861681.84   132358.43
FLOW DIRECTION
 0
DATUM
 0.00
RADIUS TYPE
 0
DIVIDE X-Section
 0
SECTION ID
62
INTERPOLATED
 0
ANGLE
 0.00
PROFILE  40
     0.00    0.451.00  <#1>  0  0.00
    14.30    0.231.00  <#0>  0  0.00
    17.43    0.161.00  <#0>  0  0.00
    19.76    0.041.00  <#0>  0  0.00
    22.21   -0.031.00  <#0>  0  0.00
    24.35   -0.131.00  <#0>  0  0.00
    27.57   -0.331.00  <#0>  0  0.00
    29.70   -0.511.00  <#0>  0  0.00
    31.51   -0.701.00  <#0>  0  0.00
    32.93   -0.871.00  <#0>  0  0.00
    34.75   -1.061.00  <#0>  0  0.00
    36.35   -1.301.00  <#0>  0  0.00
    37.63   -1.381.00  <#0>  0  0.00
    39.36   -1.591.00  <#0>  0  0.00
    40.52   -1.921.00  <#0>  0  0.00
```

Figure 27: Program Output Of Cross Sectional Data In MIKE11 Format

2.3.4 MODEL BOUNDARY CONDITIONS

The locations of the model boundaries are shown in Figure 28. A time series of hourly field measurements for water level and salinity is used as the boundary condition at each of these locations. Information relative to how the data was collected, reference datum, etc., is found in Section 2.2.2.

2.3.5 MODELING OF HYDRAULIC STRUCTURES & MANAGEMENT PLAN

There are numerous existing and proposed hydraulic structures within the project area that needed to be carefully modeled. The existing hydraulic structures found within the project site include:

- Earthen plugs. These types of structures are fairly easy to model as long as the invert elevation of the plug is known;

- Rock weirs. These types of structures are also fairly easy to model if the invert elevation and the dimensions are known. The flow over a broad crested weir is determined by the head differential between upstream and downstream water levels, the geometry of the weir, and head losses. There are two regimes for flow over weirs (in addition to the trivial case of zero flow when the water levels are lower than the weir crest). These regimes are submerged or drowned flow, and free flow. Drowned flow, as the name indicates, occurs when the weir is submerged, i.e., when the flow is influenced by both the upstream and downstream water levels. The flow over a submerged or drowned weir can be expressed as follows:

$$Q = \mu b(h_1 - Z_c)(h_1 - h_2)^{1/2}$$

Where μ is the weir discharge coefficient
h_1 is the upstream water level
h_2 is the downstream water level
Z_c is the weir crest elevation

Free overflow, on the other hand, is controlled only by the upstream water level. The following equation (in System International, SI, units) can be used to describe a free flowing weir:

$$Q_c = \alpha_c 1.705 b H_s^{3/2}$$

Where α_c is the free overflow factor (a default value of 1.0 was used herein)
H_s is the available energy head above the weir crest

For all the weirs modeled here, an entrance head loss factor of 0.5 and an exit head loss factor of 1.0 were used;

- Variable crested weir. These types of structures are modeled as "control" structures. Knowledge of controlling factors for adjusting the crest elevation is required. MIKE11 requires a relationship between the controlling factor and the weir crest elevation;

- Culvert with flap gates. These types of structures are conceptually simple to model once the dimensions of the culvert barrels and the orientation of the flap gates are known. The energy losses from the entrance, exit, friction, and obstacles such as bends, trapped debris, should be incorporated into the model. Entrance and expansion losses are dependent on the inlet and outlet geometries. The more streamlined and rounded the inlet and outlet geometrics are, the less the energy losses. Numerically, these losses are coefficients that are usually fine-tuned during the calibration procedure. Losses due to the presence of flap gates were not explicitly accounted for. However, these losses were lumped together with other losses (such as entrance and exit losses), i.e. the flap gates losses were implicitly accounted for.

There are several regimes of flow through culverts depending on the upstream and downstream water levels and geometric characteristics of the inlet and exit of the structure. A brief description of the flow through culverts is described below:

Critical flow at the culvert outlet:

$$Q_c = \alpha_c A_c \sqrt{g \frac{A_c}{T}}$$

Orifice flow at the culvert inlet:

$$Q_o = \alpha_c C_o A_{full} \sqrt{2g(H_1 - z_{inv_1})}$$

Full culvert flow with free outflow:

$$Q_p = A_{full} \sqrt{\frac{2g(H_1 - z_{obv_2})}{\varsigma_1 + \varsigma_f + \varsigma_b + 1}}$$

Where

α_c is the critical flow correction factor
C_o is the coefficient of discharge
Ac is the critical flow area
T is the flow width at the water surface
A_{full} is the full cross-section area of the culvert

H_1 is the approach flow energy level
z_{inv_1} is the inflow invert level
z_{obv_2} is the outflow obvert (soffit) level (i.e. invert plus culvert depth)
ζ_1 is the contraction loss coefficient
ζ_2 is the expansion loss coefficient
ζ_f is the friction loss coefficient

Friction losses along the culvert barrel length are accounted for using the conventional Manning's roughness coefficient. All other losses, including culverts with curved barrels, debris, and any obstacles, are accounted for in the bend loss coefficient. An entrance head loss factor of 0.5, an exit head loss factor of 1.0, Manning's roughness coefficient of 0.026 (value determined from Manning's roughness coefficient for corrugated steel pipe), and a coefficient of discharge of 0.65 were used in the model. All existing culverts are made of corrugated steel pipe. All proposed culverts are assumed to be made of corrugated steel pipe.

2.3.6 MODELING OF STORAGE AREAS WITHIN THE MODEL DOMAIN

Flood plains or storage areas in a coastal hydrologic system have a dampening affect on tidal surges and salinity spikes. Therefore, it is important to account for these storage areas in any modeling effort of coastal wetland systems. One-dimensional models cannot describe in detail the flow pattern in flood plains. There are modeling techniques, however, that can be used to incorporate the impact of storage areas in one-dimensional models. Off-stream storage areas are modeled using volumetric balance. The storage-elevation relationship derived from a contour map for each storage area is entered in the cross-section editor in MIKE11. From this relationship the storage volume can be determined as a function of the elevation of the channel to which the storage area is connected. In this project however, MIKE11 was used strictly for the channels, and was dynamically linked to MIKE21 to model the marsh areas and the open water lakes and ponds. Using the two dimensional model MIKE21 ensures accurate representation of the circulation patterns, inundation and the salinity distribution of the marsh area.

2.4 MODEL CALIBRATION

Model calibration is defined as "fine tuning of parameters until the numerical model produces results that mimics the field measurements within an acceptable tolerance." These parameters may include bed-roughness coefficients, losses through hydraulic structures, diffusion coefficients, etc. The fine-tuning of these parameters should be physically based. In other words, numerical values assigned to these parameters should remain within the established range as documented in existing literature. A brief background about each calibration parameter is provided herein:

- **Friction Coefficient**

  A) **1-Dimensional model**:
  The channel's beds and banks and the marsh's surface cause friction losses to the energy of water flow. In the context of one-dimensional modeling, these losses are taken into account by the friction slope term in the momentum equation. In MIKE11, the bed-resistance term in the momentum equation is described as follows:

  $$\frac{g\,\mathrm{n}^2\,\mathrm{Q}|\mathrm{Q}|}{A\,\mathrm{R}^{4/3}}$$

  Where g is the gravitational acceleration, Q is the discharge, A is the cross sectional flow area, R is the hydraulic radius, and n is Manning's friction coefficient. The Manning n coefficient is used as one of the calibration parameters.

  B) **2-Dimensional model:**
  The Bed Resistance in the context of the 2D model is described as:

  $$\frac{g\,\mathrm{u}|\mathrm{u}|}{\mathrm{C}^2}$$

  Where g is the gravity, u is the velocity and C is the Chezy number.

- **Dispersion Coefficient**:

  A) **1-Dimensional model**:
  The one-dimensional equation for conservation of mass of a constituent in solution (such as temperature, salinity, etc) can be expressed as follows:

  $$\frac{\partial AC}{\partial t}+\frac{\partial QC}{\partial x}-\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)=-AKC+C_2.q$$

  Where C is concentration (arbitrary unit), D is the dispersion coefficient, K is a linear decay coefficient, q is the lateral inflow, and C_2 is source/sink concentration.

  The dispersion coefficient is related to the cross sectional average velocity via the following relationship:

  $$D=aV^b$$

Where a and b are constants to be specified and they can be considered as additional calibration parameters.

B) 2-Dimensional model:

The mass conservation equation in two-dimensions for dissolved or suspended solids is given by:

$$\frac{\partial(hc)}{\partial t}+\frac{\partial(uhc)}{\partial x}+\frac{\partial(vhc)}{\partial x}=\frac{\partial}{\partial x}h*D_x*\frac{\partial c}{\partial x}+\frac{\partial}{\partial y}\left(h*D_y*\frac{\partial c}{\partial x}\right)-F*h*c+S$$

Where c is the compound concentration (arbitrary units), u, v are the depth-averaged horizontal velocity components in the x, y directions (m/s), h is the water depth (m), D_x, D_y are the dispersion coefficients in x, y directions (m^2/s), F is the linear decay coefficient (sec^{-1}), S = Q_s (c_s-c), Qs is the source/sink discharge $m^3/s/m^2$ and c_s is the concentration of compound in the source/sink discharge $Q_{s.}$ Information on u, v are provided from the hydrodynamic module.

- **Mixing Coefficient**:

  At an outflow (flow is leaving the numerical model domain) boundary, the concentration at the boundaries is calculated based on the concentration at the points neighboring that boundary, even if there is a time series of salinity concentration specified at that boundary. At an inflow (flow is entering the numerical model domain) boundary, the concentration at the boundary is calculated as follows:

$$C = C_{bf} + \left(C_{out} - C_{bf}\right)e^{-t_{mix}K_{mix}}$$

  Where C_{bf} is the boundary concentration specified in the time series file, C_{out} is the concentration at the boundary immediately before the flow direction changed (from outflow to inflow), K_{mix} is the time-scale mixing coefficient, and t_{mix} is the time since the flow direction changed.

The model was calibrated for the field data in the time period between November 01, 2002 and January 01, 2003. The following list shows values assigned to each of the aforementioned parameters used to calibrate the model. These values produced a good match between the model results and the field data.

- Manning's Friction Coefficient: 0.033-0.05 *
- Mixing Coefficient K_{mix}: 0.5
- Dispersion Coefficient (1D):

* Equivalent composite value (channel and marsh roughness)

- Dispersion factor a: 1.0
- Dispersion exponent b: 0.0

- Dispersion Coefficient (2D):
  - X-Direction: 0.25
  - Y-Direction: 0.25
- It should be noted that the dispersion coefficient range in the 1-dimensional model was limited to a maximum of 100 m^2/s and a minimum of 1 m^2/s.

The model calibration results for salinity and water level are shown in Figures A-1 through A-6 (located in the Appendix). It should be noted that there is uncertainty associated with the field measurements even though they are used herein, and in most modeling studies used as a reference to evaluate the model performance. It is important to understand, and whenever possible, to quantify these uncertainties. Aside from the accuracy limits of the sensors used in the continuous recorders, residue always builds up on the recorders and affects their accuracy. To quantify the impact of this build up, a reading of the sensor prior and after the periodic cleaning is recorded. The field personnel use the difference between the two readings to apply a linear correction to the record since the previous download of data. However, applying a linear correction to account for the build up of residue is only an assumption and may introduce an error. Another issue that should be stated herein is that the salinity measurements were collected at singular points. In other words, neither transverse profiles, nor vertical profiles of salinities were available to estimate cross sectional average salinities to compare with the cross sectional average salinities produced by the numerical model within the channels. Keeping such uncertainties in mind is important, even though they could not be quantified precisely in this study.

2.5.1.

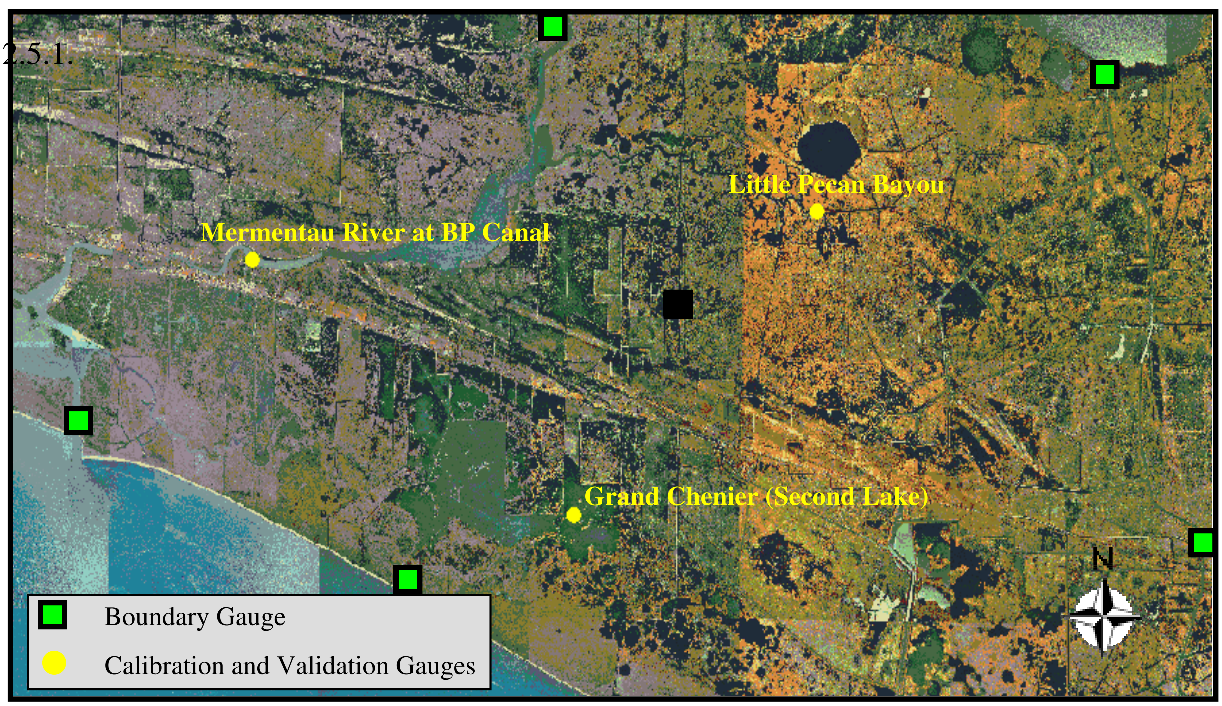

Figure 28: Location Of Calibration And Validation Gauges for both the South Grand Chenier Hydrologic Restoration Project (ME-20) and the Little Pecan Bayou Hydrologic Restoration Project (ME-17)

2.5 MODEL VALIDATION

2.5.1 EVALUATION OF MODEL PERFORMANCE

When the calibration process is complete, an independent data set is used to validate the model. As mentioned earlier, the model was calibrated for the field data in the time period between November 01, 2002 and January 01, 2003. The data set that was used to validate the model extends to April 03, 2003. A quantitative assessment of the model results is presented in Table 2:

	Salinity		
	RMS Deviation	*RMS Percent*	*Range*
Gage	(ppt)	%	(ppt)
Mermentau River G3	4.49	17.33	25.93
Little Pecan G5	1.71	40.17	4.26
2D Model G2	0.91	13.33	6.81
	Water Level		
	RMS Deviation	*RMS Percent*	*Range*
Gage	(ft)	%	(ft)
Mermentau River G3	0.40	11.73	3.42
Little Pecan G5	0.30	12.03	2.46
2D Model G2	0.31	27.36	1.13

Table 2: Quantitative Assessment of Model Results

The root mean square and range used in Table 2 are defined as follows:

$$RMS\ \text{Deviation} = \frac{1}{N}\sum_{1}^{N}\frac{\sqrt{(\text{computed - observed})^2}}{Observed\ \text{Range}}$$

Range = Max Measured value- Min Measured value

Gauge I.D.	Water Level	Salinity
	Bias (ft)	*Bias (ppt)*
Mermentau River G3	0.27	7.22
Little Pecan G5	-0.37	0.43
2D Model G2	0.09	-0.34

Table 3: Quantitative Assessment of Model Bias

$$\text{Bias} = \frac{1}{N}\sum_{i}(computed - observed)$$

Where N is the number of hourly field observations.

There are numerous peer-reviewed publications that report comparable uncertainty levels to that presented herein, e.g. (Blumberg[1] et al, 1999, and Jin[2], 2000). The acceptable uncertainty level varies depending on the project objective. The uncertainty level for water level and salinity shown in Tables 2 and 3 are acceptable for the project studied herein with the exception for the Mermentau River results as will be discussed in the model limitation section. The model bias water level results at G3 is showing that the model has a tendency to over-predict the water level within the magnitude of 0.27 ft, while at G5, the model has a tendency to under-predict the results within the magnitude of 0.37 ft. For gauge G2, the model has a tendency to over-predict the results within the magnitude of 0.09 feet. For the salinity results on the other hand, model results at G3 is over-predicting the results within the magnitude of 7.22 ppt (model was successful in creating the envelope of the salinity fluctuations). For G5, the model is over-predicting the results within the magnitude of 0.43 ppt, while for G2, the model is under-predicting the results within the magnitude of 0.34 ppt. Again, the magnitude of the bias is in the acceptable range for numerical model results with the exception of the salinity results for the Mermentau River (G3). The reasons behind these deviations are discussed in details below.

In general, deviations can be attributed to the uncertainty of bathymetry and channel dimensions, approximation to the impact of the storage areas on the flow and salinity patterns, uncertainties in field measurements, and numerical approximations.

Model Validation results are presented as a series of time series plots for the water level and the salinities as shown in Figures A-7 through A-12 (located in the Appendix). Contour maps of salinity and water level are shown in Figures A-13 through A-20 (located in the Appendix). These maps show the spatial distribution of water level and salinity.

In general, and as can be seen from Figures A-7 through A-12 and Table 2 above, the model matches the field data reasonably well. The model can be used to evaluate the effectiveness of the proposed project features.

2.5.2. DISCUSSION OF LIMITATION AND CAPABILITIES OF THE MODEL

One-dimensional models, in general, do not provide information of salinity distribution across the width of channels or over the water column. Rather, it provides a cross-section salinity average. A one-dimensional model assumes that the salinity is mixed over any given channel cross section. However, one-dimensional models do provide for the changes in salinity from one station to another along the length of channels. In the project considered in this study, the channels are fairly small and shallow (except for the Mermentau River), therefore flow stratification is minimal and the variation of salinity from one bank of a channel to the other is small.

[1] Blumberg A. F., Khan L.A., John J.P. (1999). Three-Dimensional Hydrodynamic Model for New Youk Harbor Region, Journal of Hydraulic Engineering, Vol. 125, No. 8.
[2] Jin K.R. (2000). Application of Three-Dimensional Hydrodynamic Model for Lake Ockeechobee. Journal of Hydraulic Engineering, Vol 126, No.10.

The deviation between the model salinity results and the field data in the Mermentau River can be mainly attributed to the assumption of the one-dimensional numerical model of salinity being fully mixed over the cross section of the channel. Having said that, and baring in mind that the objective of this project is not to model the Mermentau River itself, but rather the surrounding areas and to assess the proposed project features, the uncertainties shown in Figure A-10 (located in the Appendix) where the model was able to create an envelop for the measured data but it missed the high-frequency fluctuations can be considered acceptable for this project.

The two-dimensional model is capable of providing detailed water level and salinity spatial information over the marsh. Parameters such as hydro-period and marsh salinities can be computed from the two-dimensional model results. Overall, the information provided by the numerical model is adequate to provide a reliable assessment of the project features. A detailed evaluation of the proposed project along with the suggestions and improvements to the design of the project features are provided in Chapter Three.

2.6 REVIEW OF THE MODEL SETUP

On February 06, 2004, a modeling presentation was held at the offices of C.H. Fenstermaker & Associates Inc. in Lafayette, Louisiana to present the validation and conceptual model simulations. It was commented by one of the landowners (Mr. David Richard) that there are currently no breaks in the levee of the S-Shaped canal shown in Figures 29 through 32. After consulting with LDNR, USFWS, and NRCS, the decision was made to remove the breaks in the levee from the existing model setup and to treat these breaks as project features in the conceptual model setup, which will be discussed further in Chapter Three. Also, an additional break in the levee of the North-South canal just east of the S-Shaped canal was made. This break was not in the original model setup.

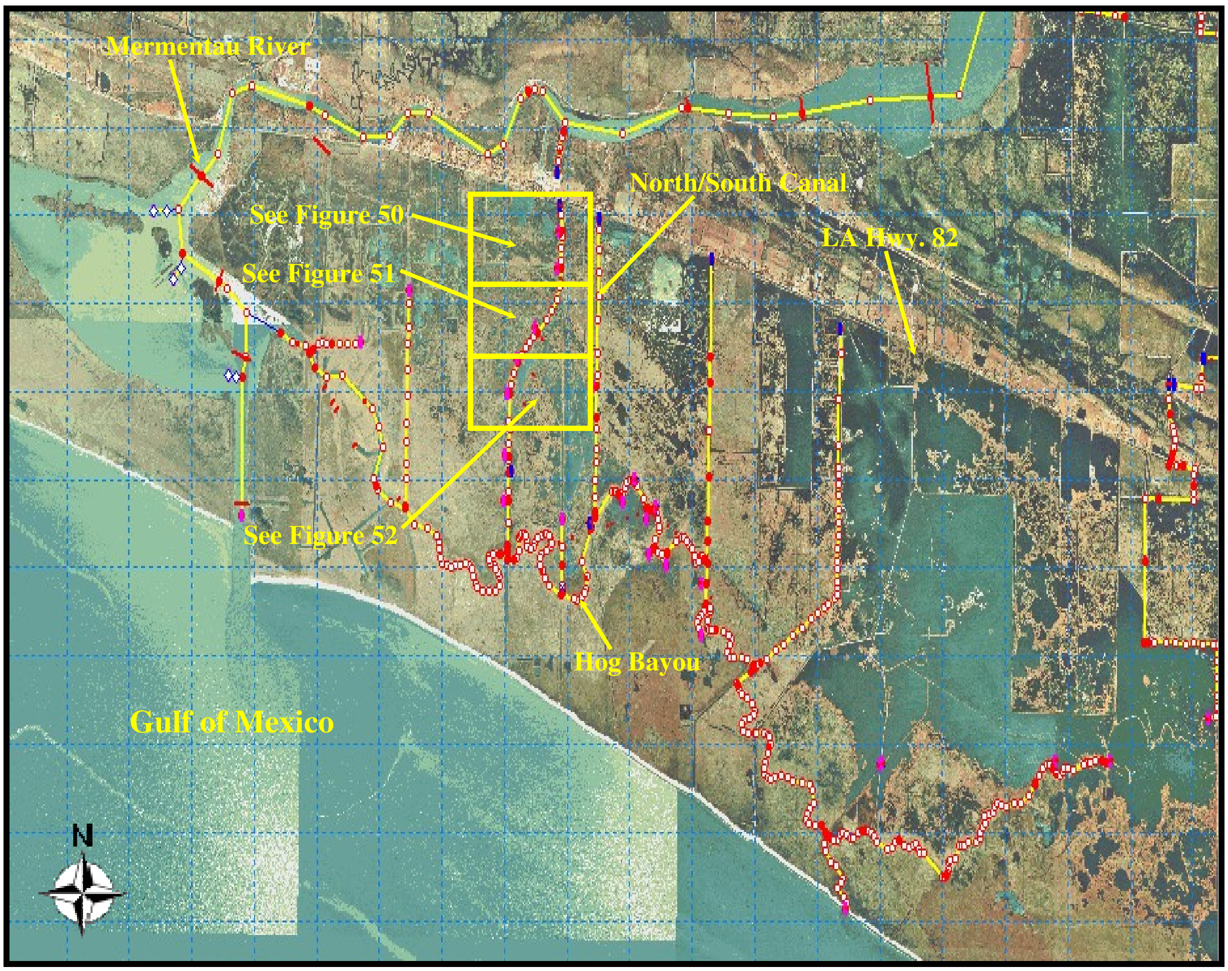

Figure 29: Location of the S-Shaped Canal in the Model Domain.

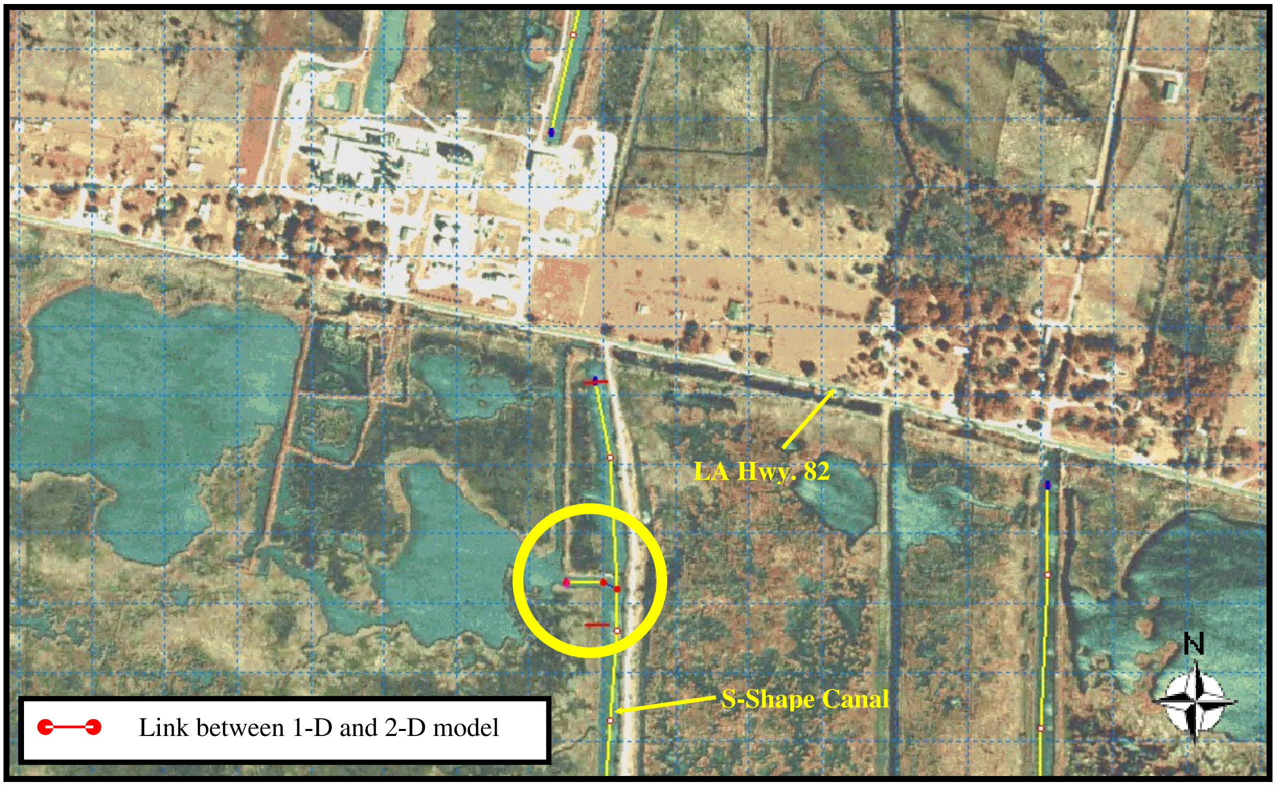

Figure 30: Existing Breaks in the Levee of the S-Shaped Canal

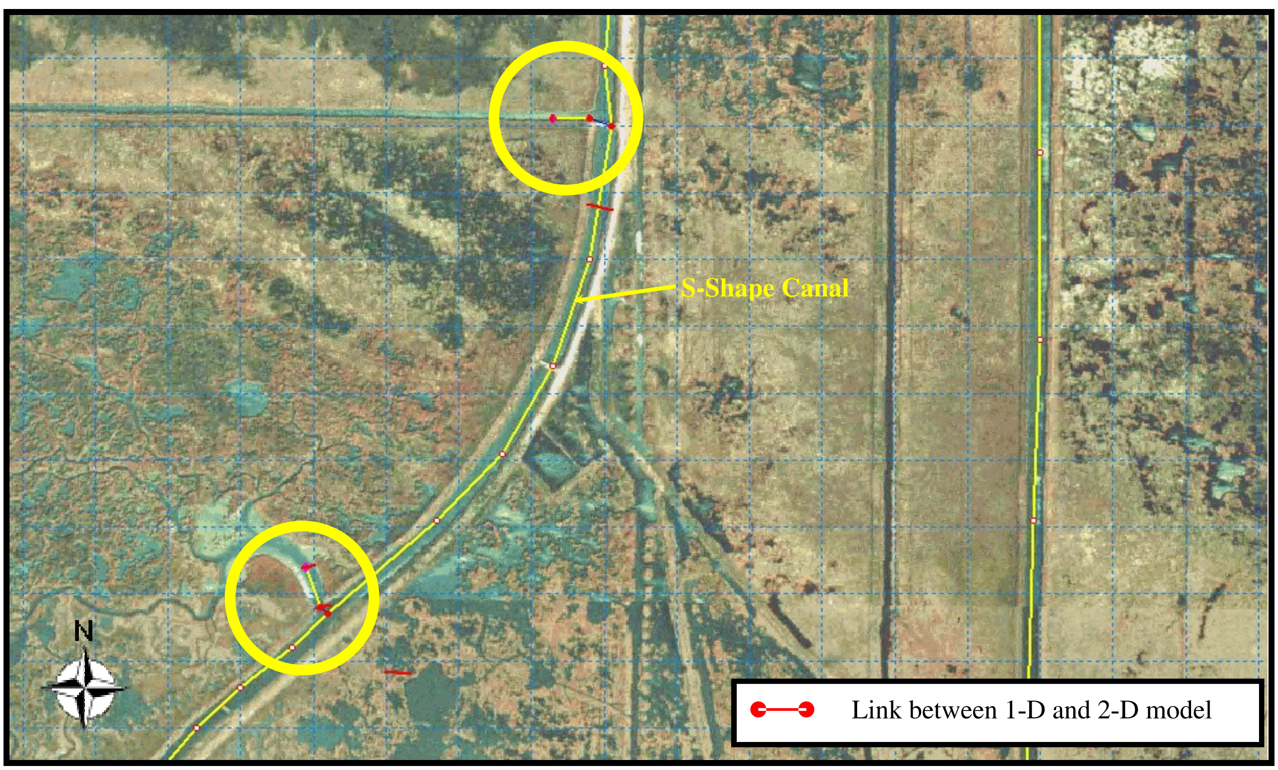

Figure 31: Existing Breaks in the Levee of the S-Shaped Canal

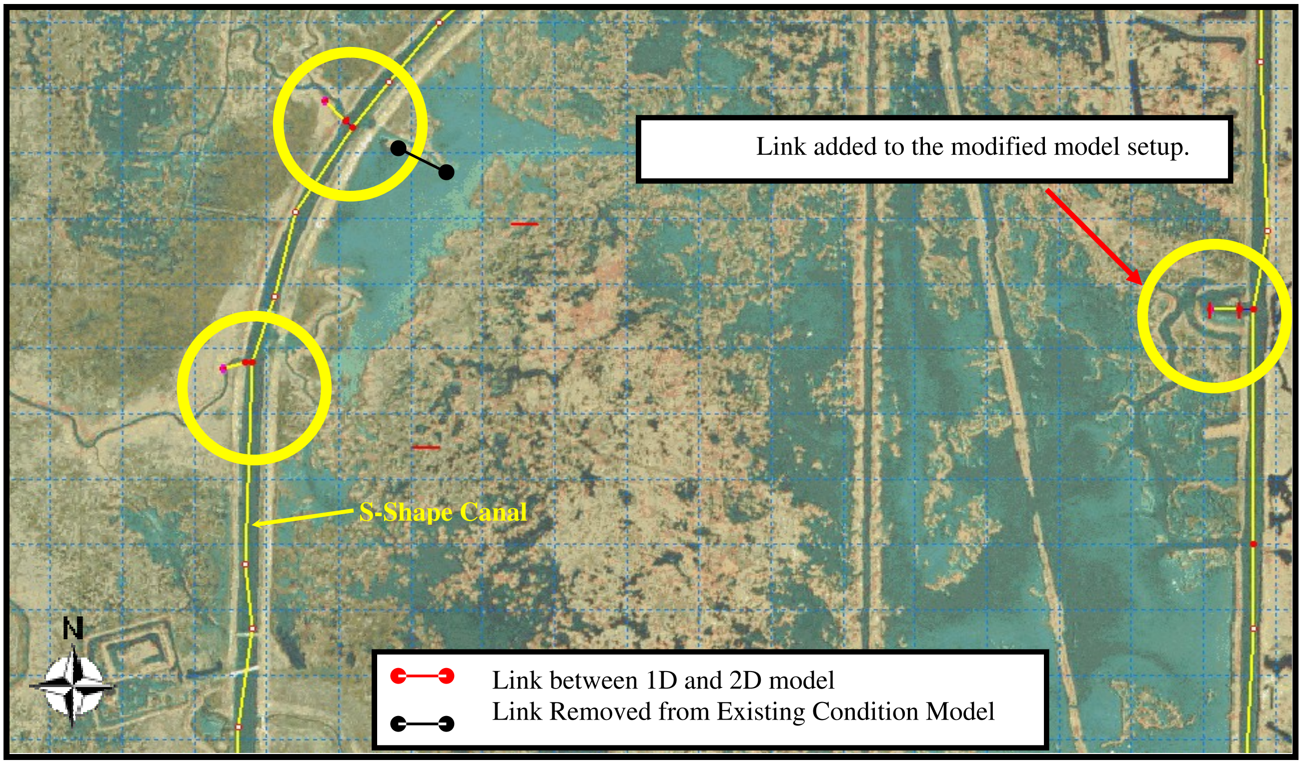

Figure 32: Existing Breaks In The Levee Of The S-Shaped Canal Showing the Break that was Removed From the Existing Condition Model.

The removal of this opening (link between one and two-dimensional models) did not have any affect on the salinity or water level in the Mermentau River, Little Pecan Bayou, or Hog Bayou, and therefore no modification on the model validation results were needed as shown in Figures A-21 to A-26 (located in the Appendix).

III. CHAPTER THREE

3.1 INITIAL ASSESSMENT OF PROJECT FEATURES

The proposed project features described in Chapter One were incorporated into the numerical model. Figures 33 through 35 show the modified model setup after incorporating the project features. Salinity and water level data at the locations shown in Figures 36 and 37 were examined to evaluate the impact of the project features. To maintain consistency in the notation, the simulation of the existing conditions (without any of the proposed project features) is referred to as the "Base Run." The simulation that incorporates the conceptual project features is referred to as "Conceptual Design Run."

A comparison between the "Base Run" and the "Conceptual Design Run" was performed. Model results after incorporating the project features are presented as a series of time series plots for water level and salinities as shown in Figures A-27 through A-38 (located in the Appendix). Water level and salinity contour maps for both the "Base Run" and the "Conceptual Design" are shown in Figures A-39 through A-54. Note that Figures A-39 through A-46 depict the eastern half of the South Grand Chenier project area, and Figures A-47 through A-54 depicts the western half.

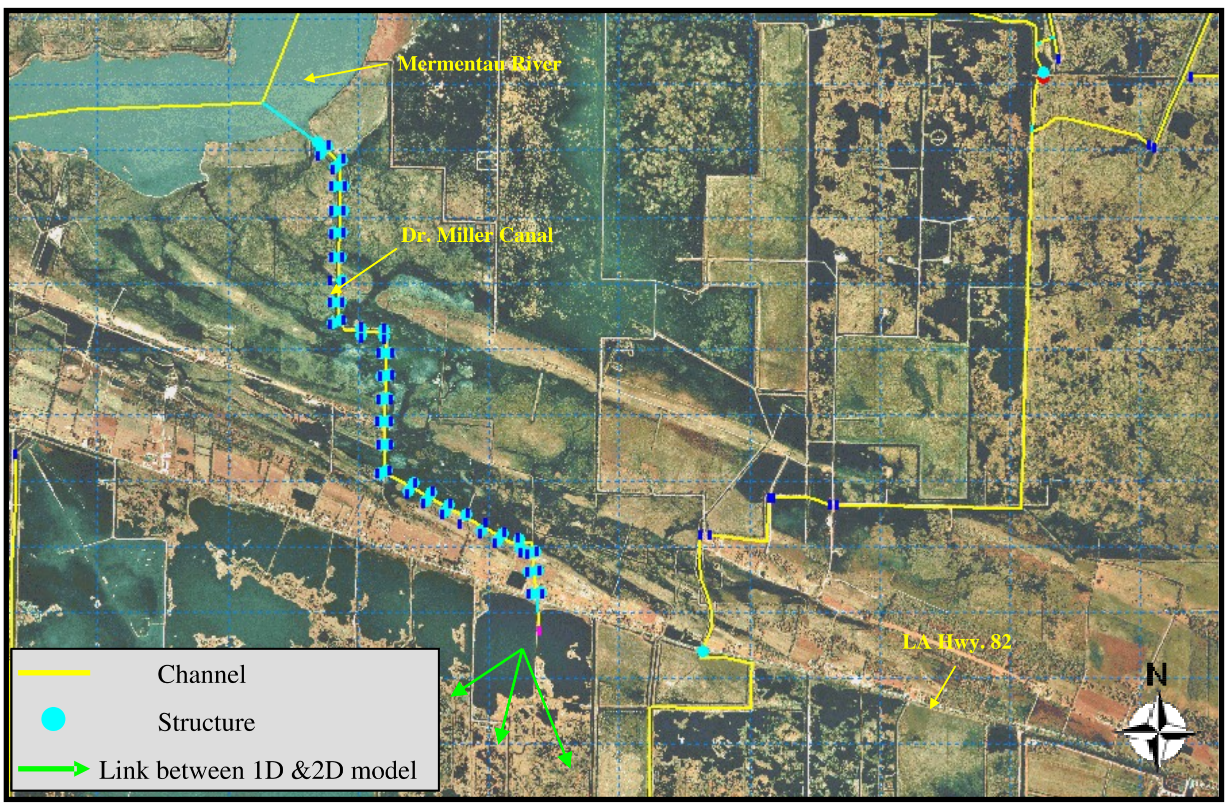

Figure 33: Base Map Showing the Modified Channel Network After Incorporating Project Features for Dr. Miller Freshwater Component

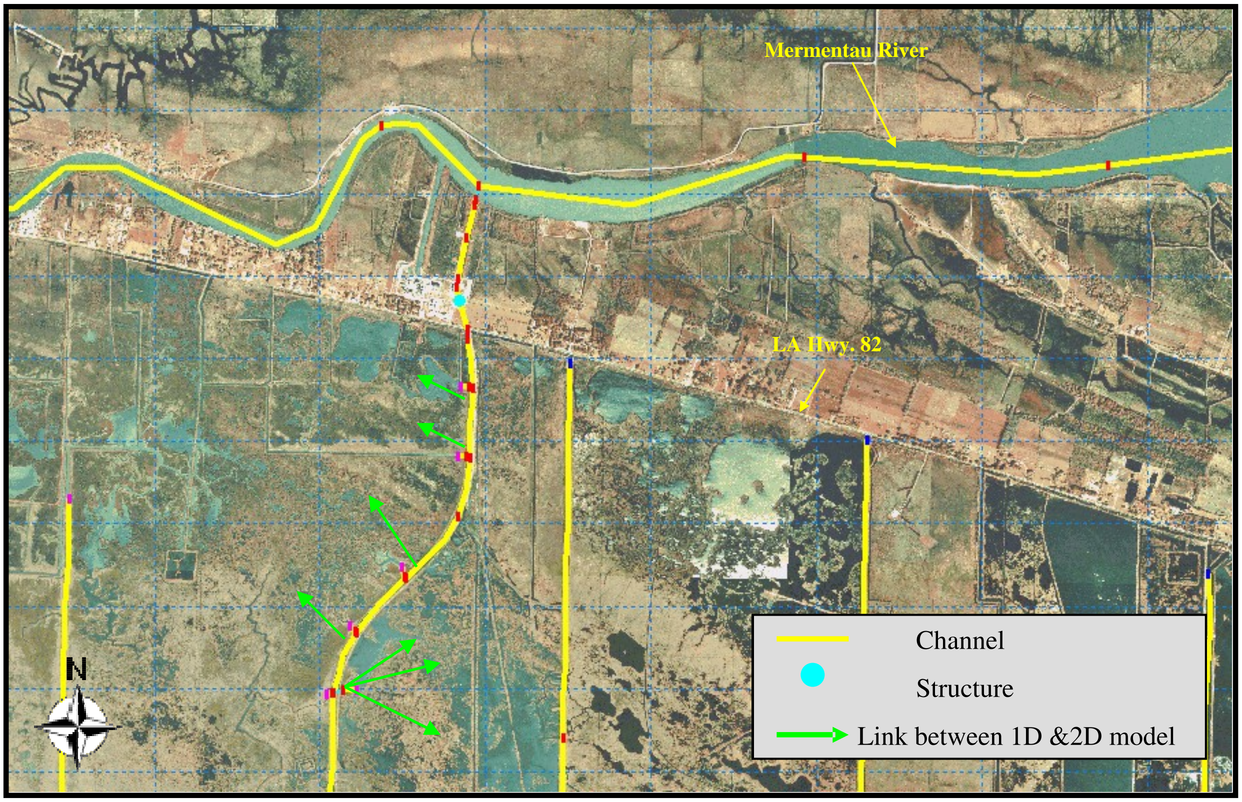

Figure 34: Basemap Showing the Modified Channel Network after Incorporating Project Features for the BP Canal Component

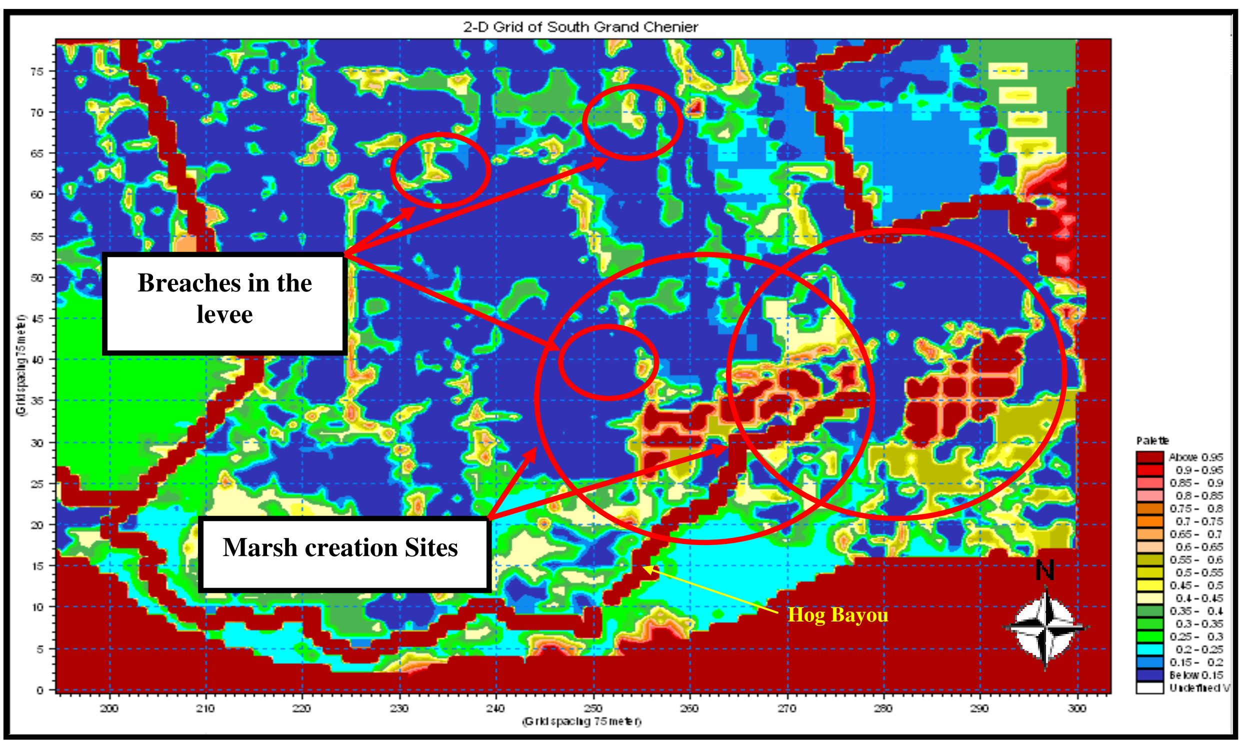

Figure 35: Model Grid after Incorporating Project Features

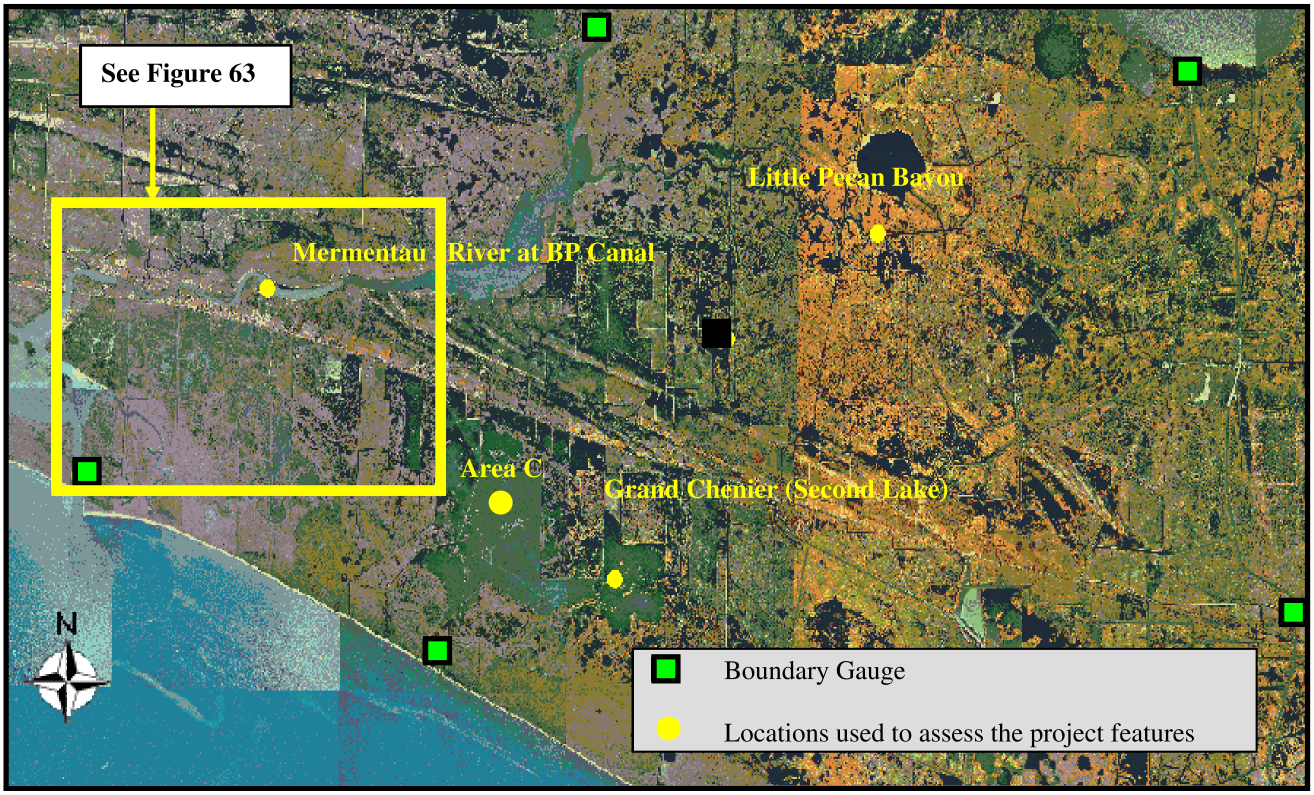

Figure 36: Basemap Showing Boundary Gauges and Locations Used to Assess the Project Features

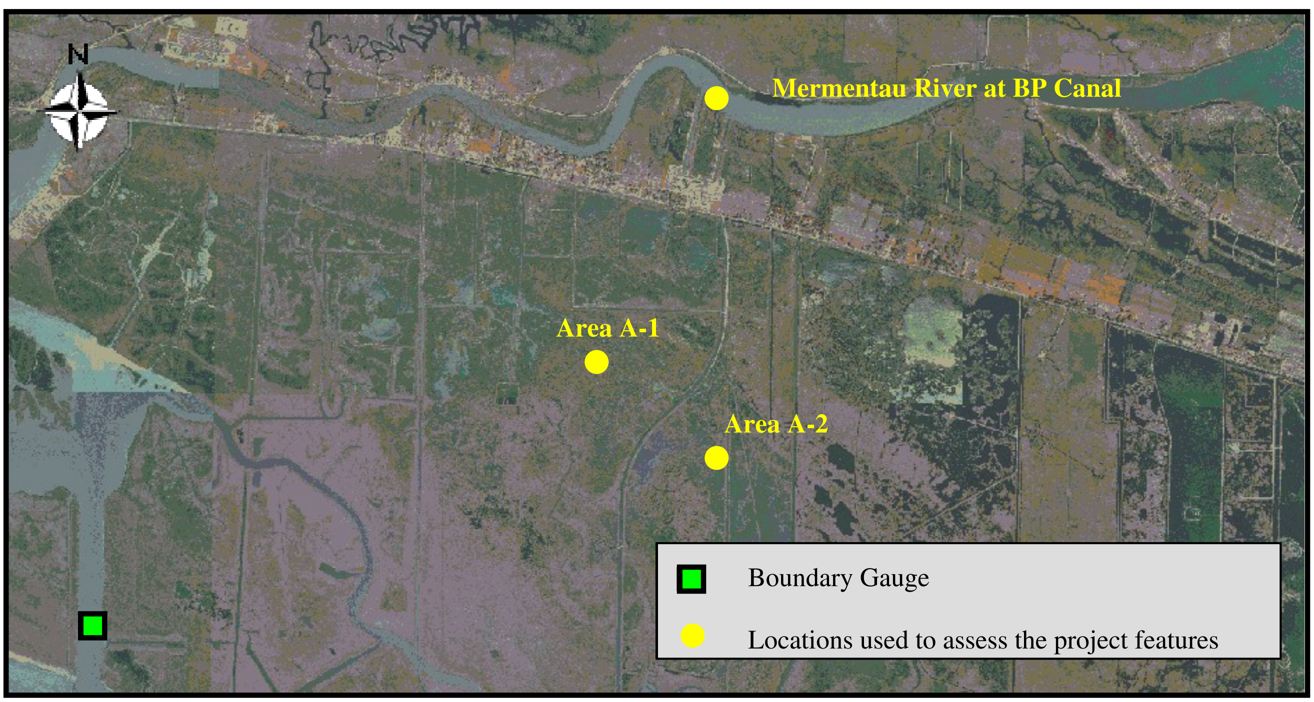

Figure 37: Boundary Gauges and Locations Used to Assess the Project Features

From the results presented in the appendix, it can be seen that the project reduced salinity in Areas C and Second Lake. The magnitude of salinity reduction at these two locations ranged from one to four parts per thousand (ppt). The salinity reduction in Area C was more than Second Lake. This is attributed to the fact that fresh water is introduced directly into Area C compared to the salinity reduction near Second Lake, which has to pass through the McCall Strulese Tract and through breaks in the Levee. These factors relatively reduce the ability of fresher water to reach the area of Second Lake.

In general, since the source of freshwater is the Mermentau River, the salinity level in the river channel directly affects the salinity in Area C. This correlation is clear in Figure A-36 and A-43 where the high salinity experienced in the Mermentau River was also observed in Area C (This phenomenon was eliminated with the modified conceptual run, refer to Section 3.2 for more details)

The project features did not have a strong impact on the water level within the project area. It was observed from the model results that the increase in the water level was in the order of one to two tenths of a foot on average. Analysis of the impact of the project on the hydro-period of the region will be presented in a later section in the report.

3.2 REVIEW OF THE CONCEPTUAL DESIGN RUN AND NEW ADDITIONAL MODEL RUNS

On March 03, 2004, LDNR requested the following modifications to be made on the conceptual design run:

1) Revisions to the Conceptual Project Model Run

- The conceptual and future model runs need to reflect that water from the Mermentau entering the South Grand Chenier project area should not have salinity higher than 5 parts per thousand;

- Present the water elevations in the marshes on either side of the Dr. Miller Canal north of Hwy 82 along the length of the canal either animated or by line graphs. The purpose is to show how the project will affect drainage of excess waters above marsh elevation or increasing flooding frequencies in those marshes adjacent to the Dr. Miller Canal. The modification also included three new additional model runs.

2) Additional Project Model Runs

- Area 'A' S-Shaped Canal Weir Model Run - Place a weir with a sill height set at one foot below marsh level across the S-Shaped Pipeline Canal at its intersection with Hog Bayou south of the BP Plant. This would formally verify if constricting this opening increases the benefits to Area 'A'.

- Model Run with Pumps - A model run with the weir structure described above and 48" diameter pumps [approximately 22,000 Gallons per minute (GPM) each] at the BP/Tennessee Gas and the Dr. Miller Canals north of LA Hwy. 82. These pumps will be operated to introduce water from the Mermentau River when salinities are lower than five parts per thousand.

- Model Run with larger culverts at the LA Hwy. 82 crossing- Run the conceptual project gravity flow model and increase the LA Hwy. 82 crossing structure sizes from 2 - 48" diameter culverts to 4 - 48" diameter culverts.

3.3 FINAL ASSESSMENT OF PROJECT FEATURES

Four new simulations were performed with the new proposed project features in place. The model results are presented as time series plots for water level, salinity, and discharge. The results are also presented as salinity contour maps. Figures 38 and 40 show the locations of the points on which the operation plan of the control structures at the entrance of Dr. Miller and BP canals, respectively, is based. Figures 39 and 41 illustrate the points used to evaluate the salinity and water level changes as a result of the proposed project features in the Dr. Miller Canal and the S-Shape Canal. Figures A-55 and A-56 illustrate the salinity model results upstream and downstream of the control structures in the Dr. Miller and BP canals. These plots are presented to provide a visual assessment of the performance of the salinity control structures.

Figures A-57 through A-76 show a comparison of water level and salinity between the Base Run (Existing Conditions) and all the design runs (Conceptual Run, Additional Run No.1, Additional Run No.2 and Additional Run No.3). To visually facilitate observing the difference between the conditions with and without the project, plots are prepared to show the change in salinity and water levels. The controlling salinity time series (in the Mermentau River at the intersection with the Dr. Miller and BP canals) are shown in these figures to identify the time periods when the proposed control structures were opened or closed according to the operational rules being that the structures are to be closed whenever the controlling salinity value is higher than five parts per thousand.

To illustrate the effect of the Dr. Miller Canal component on the surrounding marshes and the open water bodies, Figures A-77 through A-81 show contour maps for the monthly average water elevation for all proposed alternatives as well as the "Base Run". Figures A-82 through A-86 show contour maps of the monthly average water elevation change (Alternative Run minus the Base Run). Figures A-87 through A-91 show contour maps of the monthly average salinity for all proposed alternatives as well as the "Base Run". Figures A-92 through A-96 show contour maps of the monthly average salinity change (Alternative Run minus the Base Run). To show the effect of the BP Canal project component on the surrounding marshes and the open water bodies, figures A-97 through A-101 show contour maps for the monthly average water elevation for all proposed alternatives as well as the "Base Run". Figures A-102 through A-106 show contour maps of the monthly average water elevation change (Alternative Run minus the Base Run). Figures A-107 through A-111 (located in the Appendix) show contour maps of the monthly average salinity for all proposed alternatives as well as the "Base Run". Figures A-112 through A-116 (located in the Appendix) show contour maps of the monthly average salinity change (Alternative Run minus the Base Run).

3.3.1 FINAL ANALYSIS OF DR. MILLER CANAL PROPOSED PROJECT FEATURE

I. Salinity

Analyzing the model results near Area C and Second Lake Cut (shown in Figure 36) for the conceptual run as well as additional run numbers one, two, and three reveal an overall decrease in salinity. The magnitude of salinity decrease varied from one run to another, with an average decrease of three parts per thousand (from 5 p.p.t. base salinity to 2 p.p.t.). It can also be determined that the decrease in salinity is affected by the duration of the "opening and closing" of the control structures. As expected, the longer the control structures remain open, the more reduction in salinity will be gained.

II. Water Level

Analyzing the model results for Area C and Second Lake Cut revealed a slight increase in overall water level. The ponding that occurred was clearly evident during the time periods where the structure was opened. Among all the alternatives examined in this study, additional run number two (with pumps) produced the highest increase in water level (in the order of 0.4 feet). This increase occurred as the pumps added water to the target area faster than the target area could "drain" (refer to marsh overtopping analysis in Table 3).

III. Dr. Miller Canal

The same behavior of water level and salinity mentioned above was experienced along the length of Dr. Miller canal. Water levels varied from one to two feet NAVD 88, with alternate run number two producing the greatest increase in water level. The average marsh elevation on either side of the Dr. Miller canal is approximately 1.5 ft NAVD88. The impact of the water level increase on the surrounding marshes should be taken into account when constructing the project features (refer to marsh drainage analysis in Table 4). The salinity in Dr. Miller canal never exceeded five parts per thousand since it was controlled by the intake structure at the intersection with the Mermentau River.

3.3.2 FINAL ANALYSIS OF BP CANAL PROPOSED PROJECT FEATURE

I. <u>Salinity</u>

The model results for areas A-1 (shown in Figure 37) showed that installing a control structure in the BP canal is not effective in preventing the salinity from exceeding five parts per thousand in the target area. Figure A-63 shows that although the control structure was closed when the salinity in the Mermentau River exceeded five parts per thousand, the salinity still increased up to 20-22 parts per thousand. This highly saline water entered the project area from the south through Hog Bayou.

For area A-2, implementing the project features actually increased the salinity in the area. The proposed breaks in the levee of the S-shape canal allowed the high-salinity water to intrude into previously protected areas such as Area A-2. In other words, Area A-2 in the base run model simulation received water only from the North-South canal coming out of Hog Bayou, but after implementing the project, the area is now being fed with water from the S-Shape canal also.

II. <u>Water Level</u>

The model results for areas A-1 and A-2 revealed that the proposed project features in the BP canal had a negligible affect on the water level in the target areas. It can be observed from the model results that the tidal signal is more pronounced in Area A-2 “with” the project than “without”. This behavior is natural because after implementing the project, this area is connected to the Mermentau River, which has stronger tidal signal than Hog Bayou.

III. <u>S-Shape Canal</u>

This alternative had minimal impact on the water level in the S-shape Canal. During the time periods where the structure was closed, the salinity in the Base Runs and the Conceptual Runs was virtually identical. However, when the structure was opened, the salinity of the Conceptual Design simulation as well as Additional runs number one and three were higher. Only additional run number two resulted in the reduction of salinity in the S-Shape Canal compared to the base run.

3.4 FINAL CONCLUSIONS AND CLOSING REMARKS

The effort presented in this study is aimed to evaluate the performance of the proposed project features for the Dr. Miller canal and BP Canal project components. The project features as proposed in the scope of services included channel enlargements and freshwater introduction structures to improve flows from north to south across Hwy. 82. The project scope includes creation of approximately 400 acres of marsh by the use of dedicated dredging.

A coupled one and two-dimensional (MIKE FLOOD) numerical computer model was used to perform the evaluation of the proposed project features. The model was able to capture water level and salinity variations in channels (1-D) along with variations in open water bodies (2-D).

The model was calibrated and then validated against field data for the time period extending from November 2002 until April 2003.

The overall conclusions of this study are summarized below:

- The Dr. Miller canal component of the project was beneficial in terms of reducing salinities in the target areas. The magnitude of salinity reduction was in the range of 3 ppt (from 5 ppt base salinity to 2 ppt), while the increase in water level was in the range of 0.2 ft for the conceptual, additional run number one and three and an average increase of 0.4 ft for additional run number two. This increase was more evident when the structures at the Mermentau were opened. The anticipated results of providing fresh water from the Mermentau River to the open water bodies south of Hwy.82 were accomplished and the proposed control structures prevented the salinity from exceeding five parts per thousand south of LA Hwy. 82. However, water levels along the length of Dr. Miller canal was in the range of 1 -2 ft NAVD 88, which is slightly higher than the average marsh elevation of 1.5 ft NAVD 88.
- The model results showed that the BP canal component of the project was not beneficial in terms of lowering salinities in the target areas. In fact, in some instances, it increased salinities in certain areas. This phenomenon was attributed to the fact that although the gate at the BP canal was closed during the simulation period, the salt water was able to enter the target areas from the south through Hog Bayou.

- For Additional Run Number One, adding the weir across the S-Shape Canal did not improve the effectiveness of the fresh water introduction through BP canal. The freshwater delivery was mainly governed by the existing head differential between the areas north and south of Highway 82, which overcame the effect of installing the weir.

- The proposed pumps in Additional Run Number Two allowed for more control over the process of introducing fresh water to the target areas rather than relying on the availability of water head for the gravity driven alternatives. The use of pumps also delivered the fresh water faster to the target areas, however the magnitude of salinity reduction was in the same range as the other two runs (approximately 3 ppt. from 5 ppt base salinity to 2 ppt) The pumps however, increased the water level in the target areas more than the gravity driven alternatives. The added cost to setup and maintain the pump stations should be taken into account for the final decision if these pumps are to be implemented.

- Water level in Dr. Miller Canal ranged from 1.0 to 2.0 ft NAVD88 during the model run period (January to April 2003). Gates installed at the Dr. Miller canal were closed from mid-January to the end of February due to higher salinities in the Mermentau River.

- Increasing the size of the structures at LA Hwy. 82 had a negligible effect on the salinity level in the target areas (less than one part per thousand of salinity reduction over the conceptual run).

A brief analysis has been performed to gain a better understanding of how the marshes south of Highway 82 could be affected by the predicted water level increases as stated previously. Two main issues are of concern with the water level increase. The first issue is the frequency of marsh inundation within a given period, and the second is related to the length of time the marsh remains inundated. The assumption was made that water levels experienced at Area C (refer to Figure 36) can be projected onto the nearby marsh. The marshes around Area C are at an average elevation of 1.5 feet NAVD 88.

Table 3 shows the results of the marsh inundation analysis for all the proposed runs to bring fresher water into the project target areas. The analysis utilizes the data that was used to produce Figure A-69. The time period for this analysis is from January 1, 2003 to April 3, 2003. During this period, the number of inundation events, the average duration of these events, and the longest inundation event are reported in Table 3. An inundation event is counted when the water level exceeds marsh elevation, while the duration is computed as the time elapsed from the time the water rises above marsh elevation until it falls below it. The average inundation is calculated as the simple mean of all inundation events experienced in each month. Table 3 also documents the longest inundation duration for each month. It should be emphasized that a complete and valid hydro-period analysis requires long-term records. Such records were not available at the time of writing this report. The analysis shown in Table 3 is a simplified hydro-period analysis for only the months used in this current modeling effort, therefore care should be taken while drawing conclusions from this partial analysis. The ecological impact of this hydro analysis is outside the scope of this study and will be determined by LDNR personnel.

MONTH	Area C (Avg. Marsh = 1.5' NAVD 88)			
	No. of Events (Water Level > Marsh Elevation)			
	Conceptual	Additional Run No. 1	Additional Run No. 2	Additional Run No. 3
January-03	0	0	7	0
February-03	0	0	1	0
March-03	18	17	7	15
April-03*	0	0	1	0
	Average Inundation Period			
	Conceptual	Additional Run No. 1	Additional Run No. 2	Additional Run No. 3
January-03	0 hours	0 hours	88.5 hours (3.7 days)	0 hours
February-03	0 hours	0 hours	1.5 hours	0 hours
March-03	14.5 hours	15.5 hours	101 hours (4.2 days)	36 hours (1.5 days)
April-03*	0 hours	0 hours	88 hours (3.6 days)	0 hours
	Longest Inundation Duration			
	Conceptual	Additional Run No. 1	Additional Run No. 2	Additional Run No. 3
January-03	0 hours	0 hours	659 hours (27.5 days)	0 hours
February-03	0 hours	0 hours	1.5 hours	0 hours
March-03	120.5 hours (5 days)	121 hours (5 days)	685.5 hours (28.5 days)	259.5 hours (10.8 days)
April-03*	0 hours	0 hours	88 hours (3.6 days)	0 hours
* Time Period Ends on April 3, 2003				

Table 3 Marsh Inundation Analysis for Area C

The same concept was performed for the land on either side of the Dr. Miller Canal. This study was done to address some concerns raised by federal and state agencies of the potential impact to the surrounding land that currently drains into the Dr. Miller. It is to be noted that the proposed project features include a continuous levee (top elevation of +5.0' NAVD 88) on both sides of the Dr. Miller Canal with proposed culverts with flapgates spaced at 500' intervals along the canal (within the proposed levees). The flapgates are proposed to only allow drainage into the Dr. Miller Canal. If the water levels in the Dr. Miller Canal exceed the natural elevation of the adjacent land, then drainage into the Dr. Miller Canal from the proposed culverts will not occur until the water level recedes (due to no available differential water head). Table 4 below quantifies the number of times that the predicted water level in the Dr. Miller Canal for each model simulation rises above an average marsh elevation of +1.5' NAVD 88. Table 4 also quantifies the average length of time that the water level remains above the average marsh elevation. As was the case for Area C, the marshes on the sides of the canal were assumed to be at an elevation 1.5 ft NAVD88. It is imperative to note that Table 4 must be viewed in conjunction with the appropriate time series graphs shown in the appendix to determine the magnitude of the predicted water level elevations.

Dr. Miller (Avg. Marsh = 1.5' NAVD 88)				
MONTH	No. of Events (Water Level > Average Marsh Elevation)			
	Conceptual	Additional Run No. 1	Additional Run No. 2	Additional Run No. 3
January-03	3	3	14	3
February-03	6	6	12	6
March-03	33	33	1	28
April-03*	1	1	1	2
	Average Length of Time Water Levels Are Greater than Average Marsh Elevation			
	Concep	ADD1	ADD2	ADD3
January-03	4 hours	4 hours	42 hours (1.75 days)	4 hours
February-03	12 hours	12 hours	6 hours	14 hours
March-03	14 hours	14 hours	299 hours (12.45 days)	17 hours
April-03*	1.5 hours	1.5 hours	88 hours (3.6 days)	2 hours
	Longest Duration			
	Conceptual	Additional Run No. 1	Additional Run No. 2	Additional Run No. 3
January-03	5 hours	5 hours	375 hours (15.6 days)	5 hours
February-03	19 hours	19 hours	25 hours	21 hours
March-03	83 hours (3.45 days)	83 hours (3.45 days)	299 hours (12.45 days)	96 hours (4 days)
April-03*	1.5 hours	1.5 hours	88 hours (3.6 days)	2.5 hours
* Time Period Ends on April 3, 2003				

Table 4 Drainage Analysis for Dr. Miller

The overall volume of freshwater conveyed to the target area is not large. Since this volume is spread over almost the entire target area (approximately 4,913 acres), the resulting increase in water level is expected to be small. Moreover, the target area is connected to the Gulf through Hog Bayou, which is an efficient drainage channel especially during low tides. Therefore, an excessive inundation of the marsh is not expected or at least it could not be sustained for prolonged periods.

NOTE: As illustrated in Figure 38, the area highlighted in green is an impoundment area. All data within this area shown in Figures A-1 through A-152 is not to be used

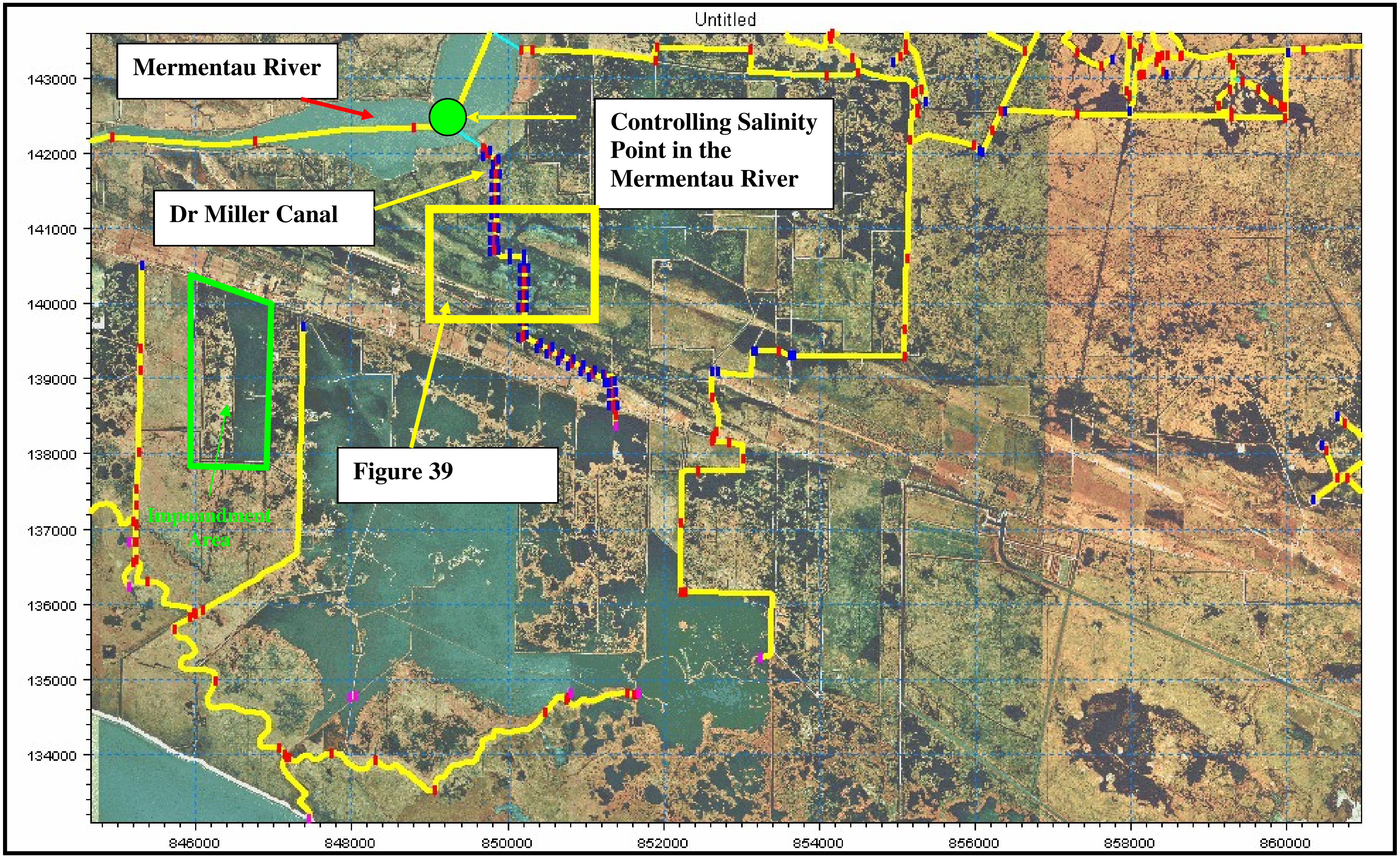

Figure 38: Base map showing Dr Miller canal component of the project

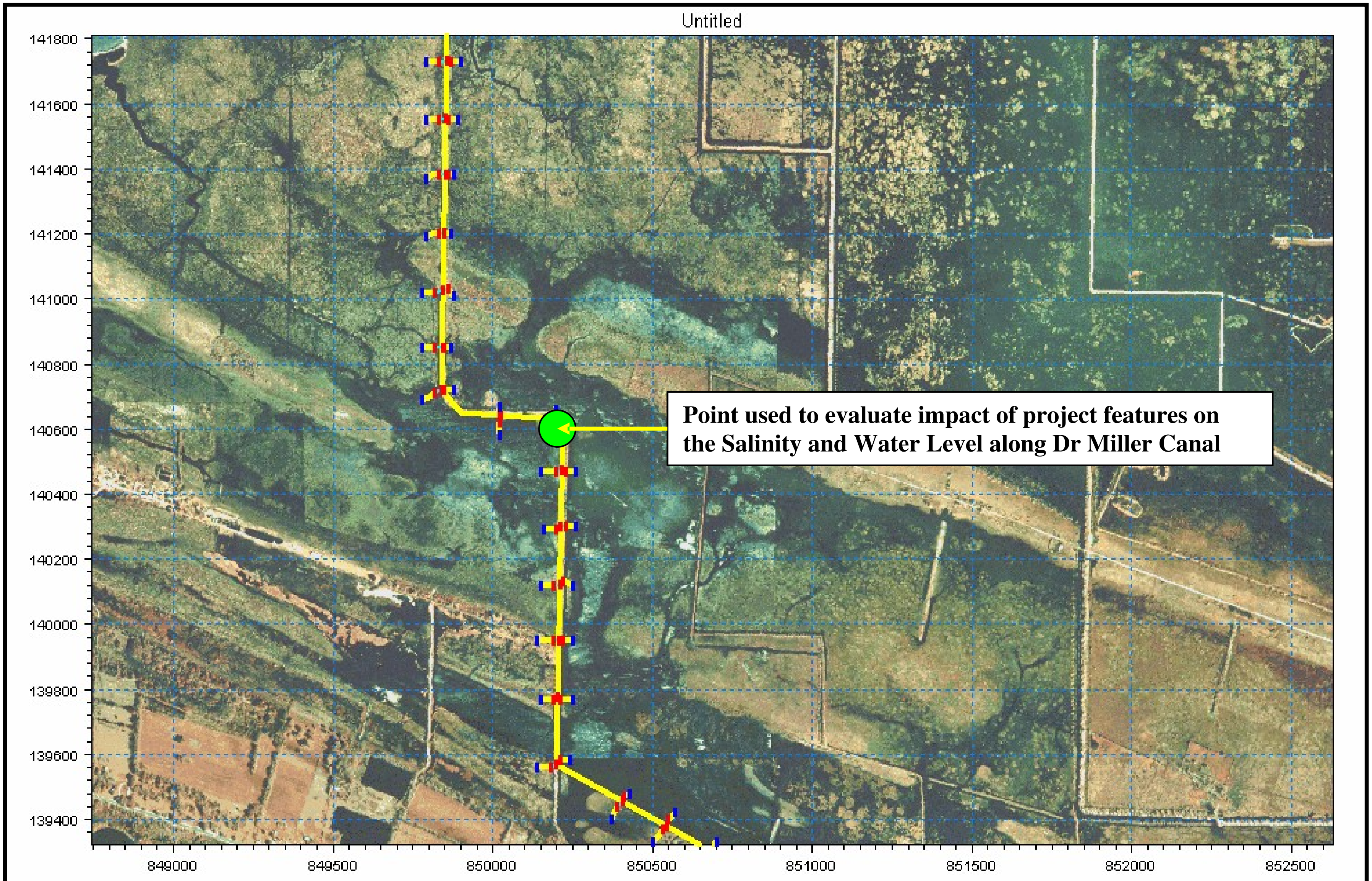

Figure 39: Zoomed Inset in Dr Miller canal

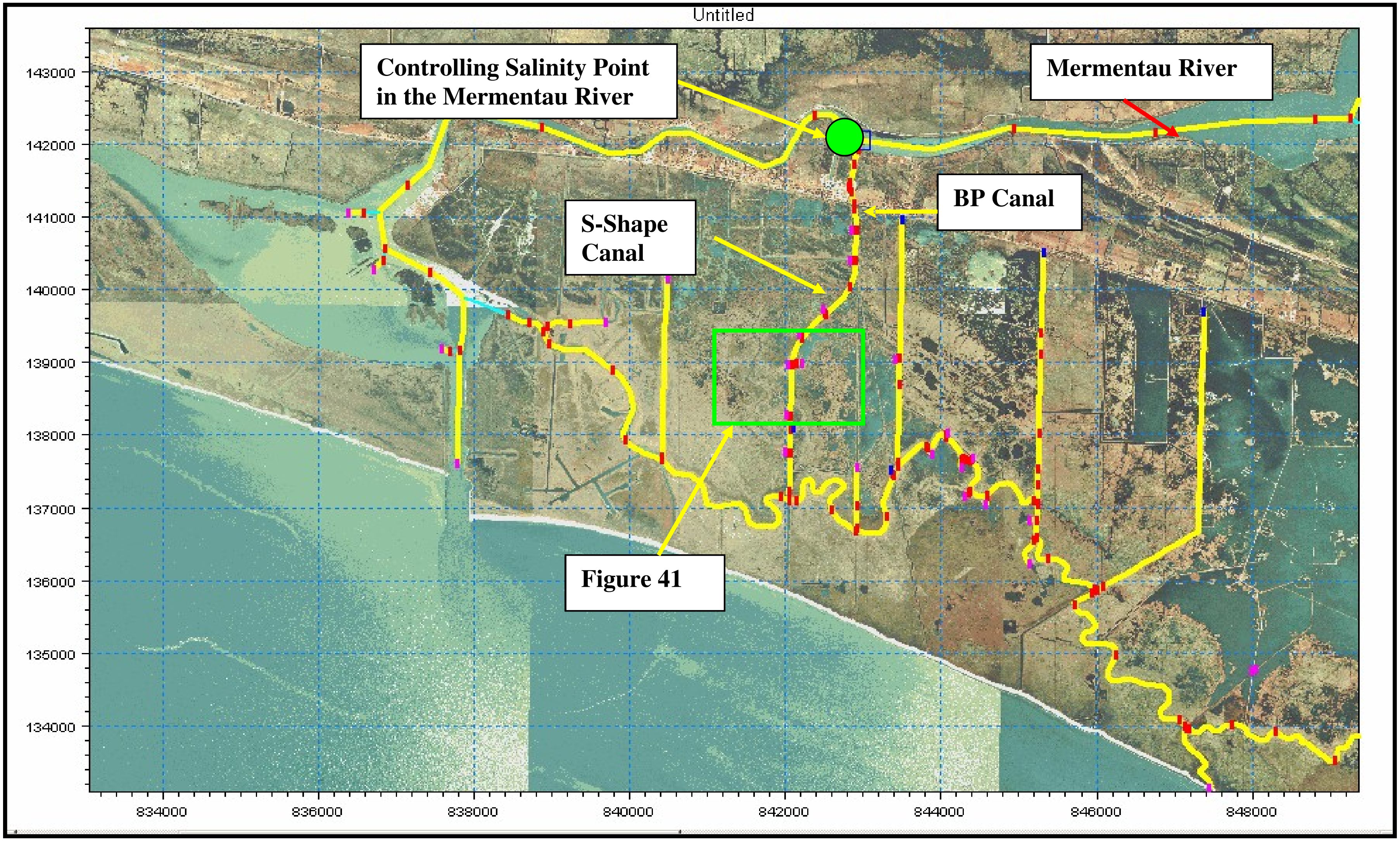

Figure 40: Base map showing BP canal component of the project

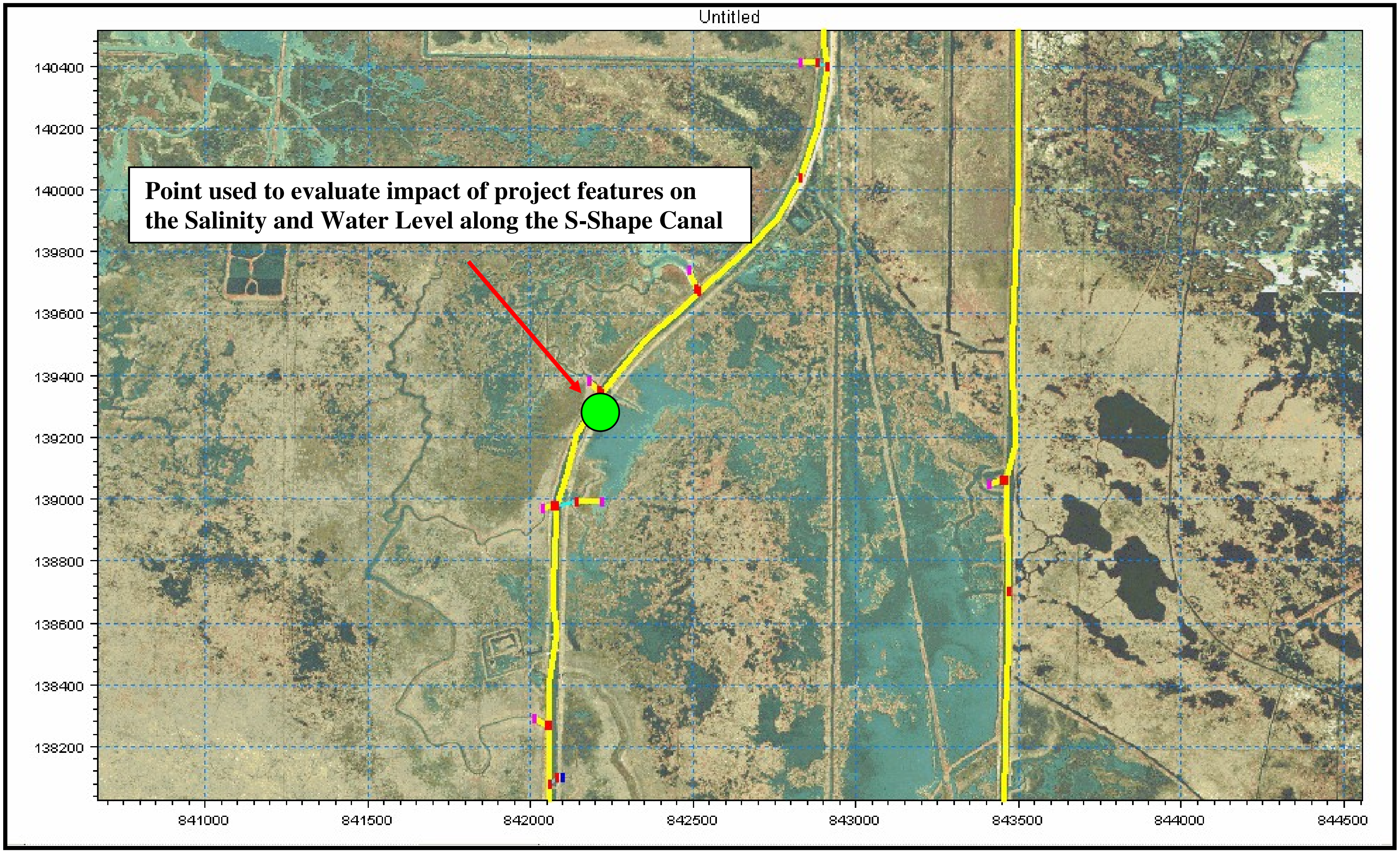

Figure 41: Zoomed Inset in the S-Shape canal south of the BP canal