NUMERICAL MODELING FOR BARATARIA BAY INTERIOR DRAINAGE STUDY

BY

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PREFACE

The application of the HEC-RAS portion of the study to assess interior drainage in the Barataria Basin was conducted by Mr. Michael Trawle of Computational Hydraulics and Transport LLC (CHT). The application of RMA-2 and RMA-4 to assess velocities in navigation openings and salinity intrusion into Barataria Bay was conducted by Dr. Allen Teeter of CHT. General project management was provided by Dr. Billy Johnson of CHT.

The study was conducted during the period of November 2006 – February 2007. Mr. Rodney Mach of the New Orleans District was the Contracting Officer's Representative. Ms Stacy Frost of the District provided technical assistance.

This report should be sited as:

Computational Hydraulics and Transport. (2007). "Numerical Modeling for the Barataria Interior Drainage Study", Contract Report 2007-01, Edwards, MS 39066.

Part I: Introduction

Background

In September 2006, CHT was awarded an Indefinite Delivery Indefinite Quantity (IDIQ) contract with the Hydraulics and Hydrology Branch of the New Orleans District. In October 2006, the New Orleans District awarded CHT its first task order under the IDIQ contract. That task order called for using numerical models of the Barataria Basin and Bay to assess the impact of constructing a proposed hurricane surge levee on interior drainage, velocities in navigation openings, and salinity conditions in the bay. Two proposed levee alignments were provided (see Figures 1.1 and 1.2).

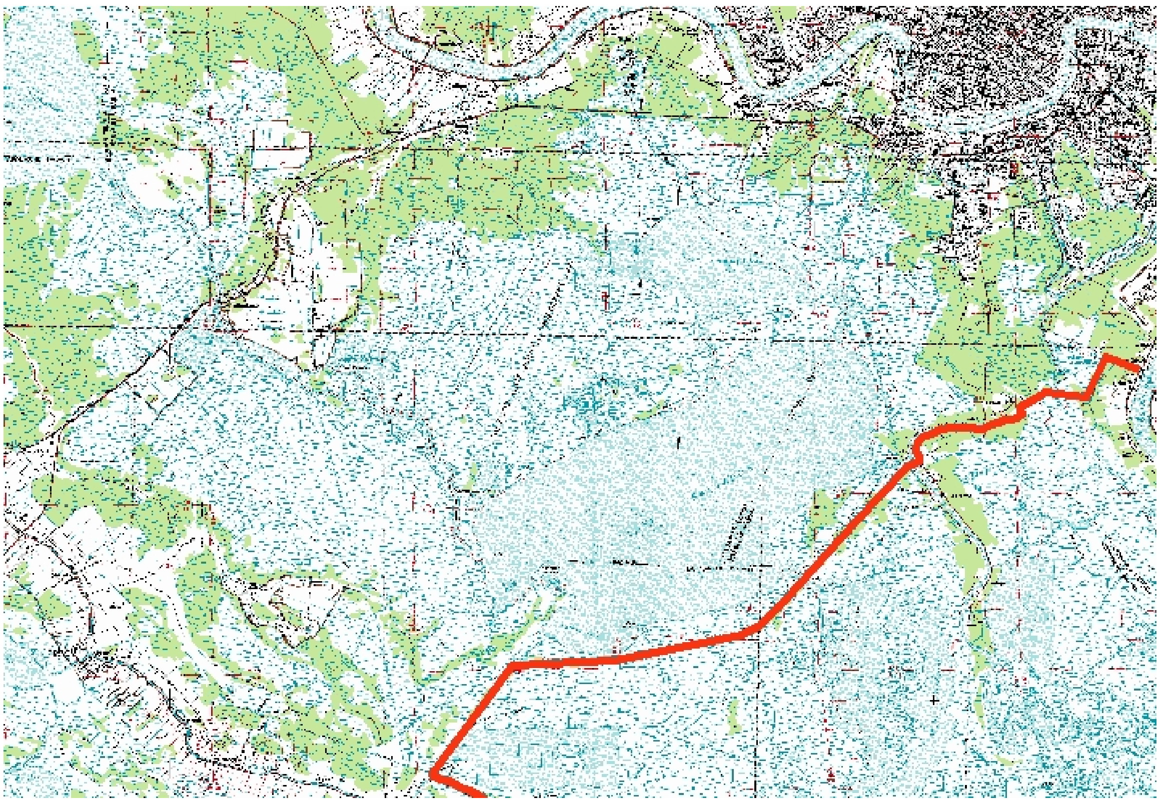

Figure 1.1. Levee Alignment 1

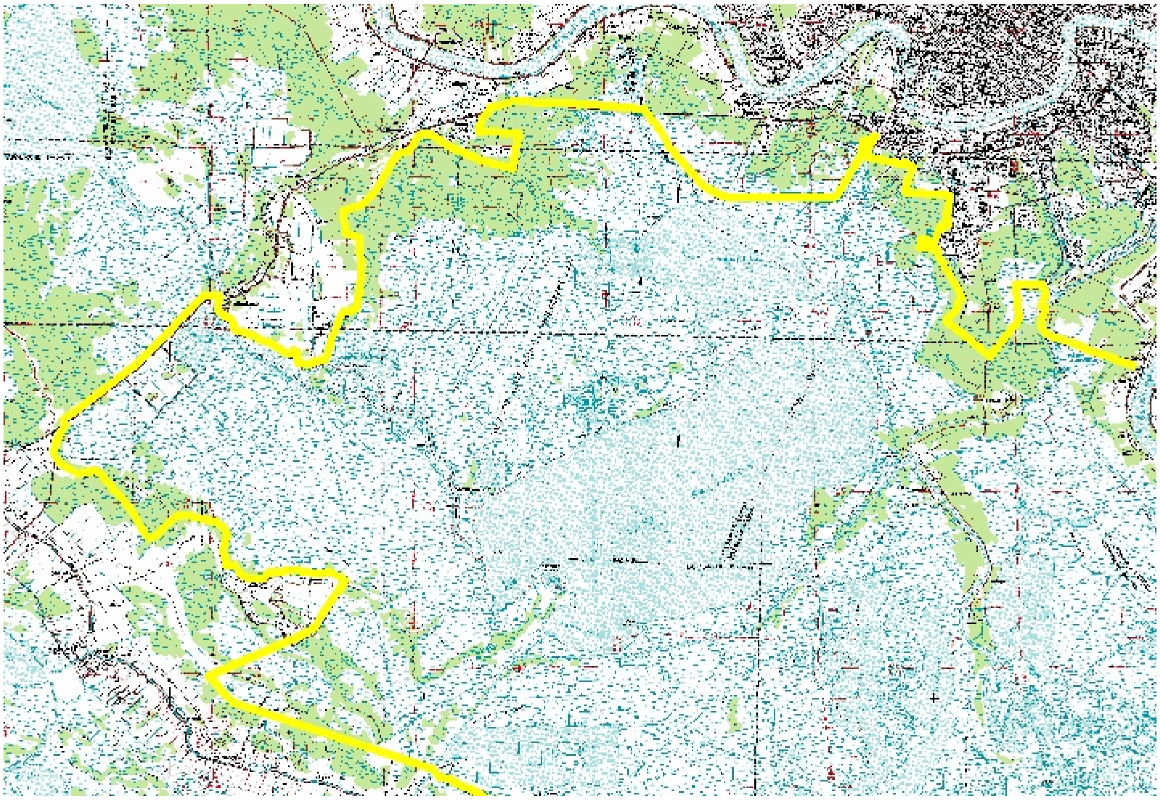

Figure 1.2. Levee Alignment 2

The models to be employed had previously been constructed by District personnel. The HEC-RAS model was to be used to size openings in the surge protection levee that would be required to keep interior water levels for various rainfall frequencies close to those that would occur without the levee. In addition, the model was also to be used to evaluate the effectiveness of pump stations that would be required if all openings were closed.

The RMA-2 hydrodynamic model was to be used to help size navigation openings such that velocities in the navigation passes would be low enough to accommodate vessels moving through the openings. In addition, flow fields generated by RMA-2 would be used in the RMA-4 model to compute salinity conditions in Barataria Bay.

Modeling Strategy

As noted, numerical grids for both the HEC-RAS and RMA-2 models were provided by the District. However, some modifications of the initial grids were required to make the models more stable and / or more efficient. One modification of the HEC-RAS model consisted of installing narrow slots in the channel geometry to ensure more stable computations during low rainfall periods. Another modification consisted of unblocking two small culverts located in the Tisamond Foret channel reach, resulting in a much more robust model.

With the HEC-RAS model modified, it was then applied with and without the surge protection levees in place for rainfall frequencies of 2, 10, 25, 50, 100, and 500 years.

Various openings at different locations along the levees were sized with the goal of reducing interior water levels to those without the levee in place.

The initial two-dimensional (2D) numerical mesh for RMA-2 contained over 50,000 computational nodes (Figure 3.1). In some areas the resolution was much finer than required for this study while in other areas resolution had to be added. Thus, the first task was to edit the mesh to make it accurate for the study area and manageable to run fairly efficiently on a personal computer. The resulting mesh now contains about 42,000 computational nodes (Figure 3.2).

After validating the RMA-2 model to June 2002 water levels and salinity conditions, it was then used to assess navigation conditions in the two proposed navigation passes. Flow fields were then passed to the RMA-4 model to determine the impact of the surge protection levee on salinity conditions in Barataria Bay. Only the Levee 1 alignment shown in Figure 1.1 was modeled in RMA-2 and RMA-4 since the second levee alignment (Figure 1.2) was outside the RMA-2 numerical mesh.

PART II: HEC-RAS Modeling

Model Setup

The HEC-RAS model shown in Figure2.1 extends from Lac Des Allemands into the Gulf of Mexico.

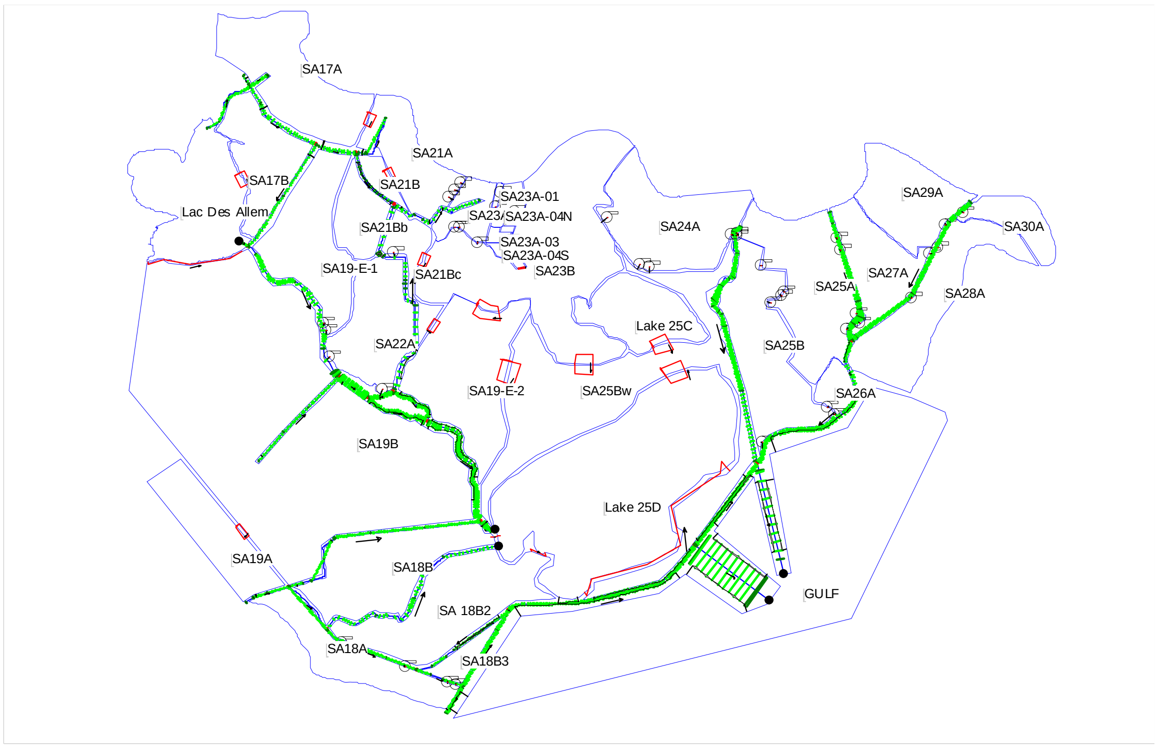

Figure 2.1. HEC-RAS Model

The model consists of numerous storage areas as well as channel segments. In addition, numerous pump stations are located within the model boundaries. As previously noted two minor modifications to the model provided by the District were made before conducting the required simulations.

The HEC-RAS model requires discharges generated by rainfall events as boundary conditions. The District had previously developed a HEC-HMS model of the entire Barataria Basin to compute runoff from the different rainfall events, i.e. 2, 10, 25, 50, 100, and 500-year frequencies. The flow hydrographs from the HEC-HMS runs were provided to CHT and used as input to the HEC-RAS model. There are a total of 33 locations where runoff hydrographs from HEC-HMS are input into HEC-RAS using the HMS output DSS file, and an additional 13 boundary locations where the data were manually input. As examples of the runoff hydrographs used in the HEC-RAS model, the 100-Year, 7-day hydrograph for Lake Salvador (Storage Area 25D) and Lake Catouatchie (Storage Area 25C) are presented in Figures 2.2 and 2.3.

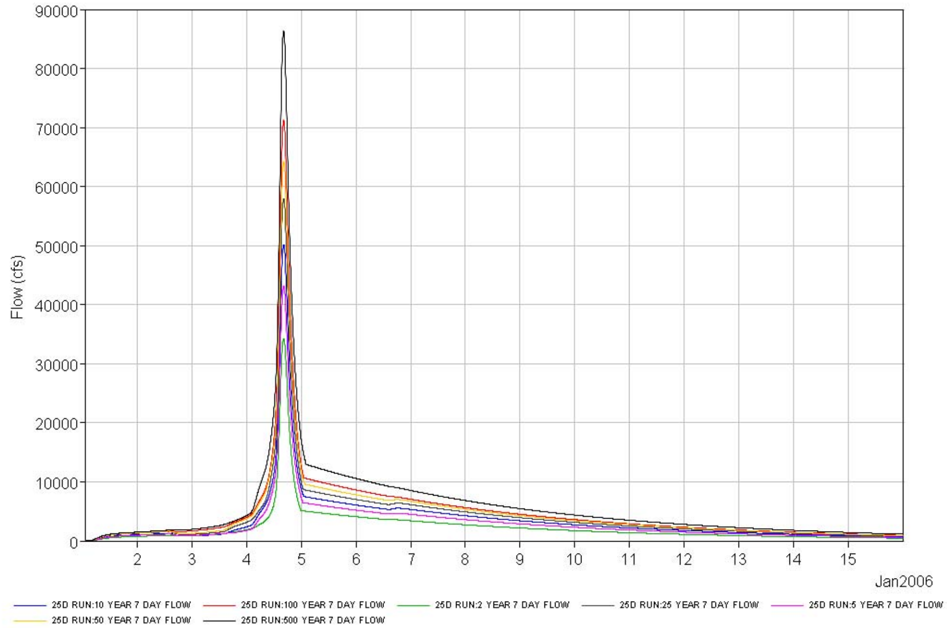

Figure 2.2. Lake Salvador 500-, 100-, 50-, 25-, 10-, 5-, and 2-Year, 7-Day hydrographs

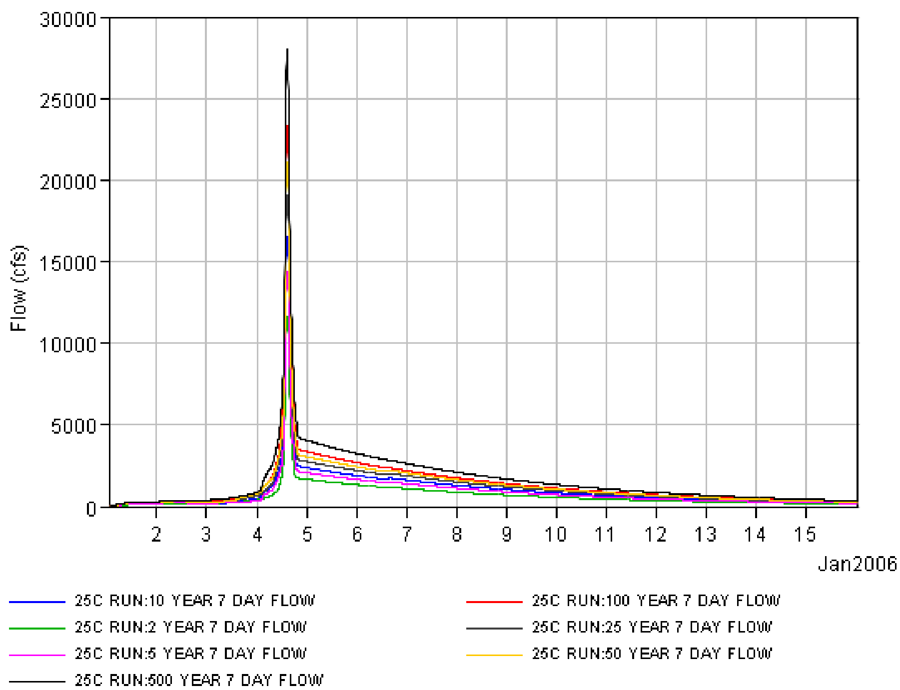

Figure 2.3. Lake Catouatchie 500-, 100-, 50-, 25-, 10-, and 2-Year, 7-Day runoff hydrographs

The downstream boundary condition in the HEC-RAS model was set in the following manner. A volume versus water level table was prescribed for the large storage area representing a portion of the Gulf of Mexico. Thus, in essence a rating type curve (Elevation-Storage Volume) was employed as the downstream boundary condition. Runs were also made using a tidal boundary by adding a time-varying lateral inflow to the Gulf storage area. The primary purpose of this endeavor was to determine the sensitivity of the interior model results to the downstream boundary condition. An example (Existing – 10 Yr vs Existing – 10 Yr Tidal at Lake Salvador) is shown in Figure 2.4. Such comparisons indicated that the tidal influence did not significantly alter the interior drainage results. All other model results presented were generated using the Gulf storage area without tide.

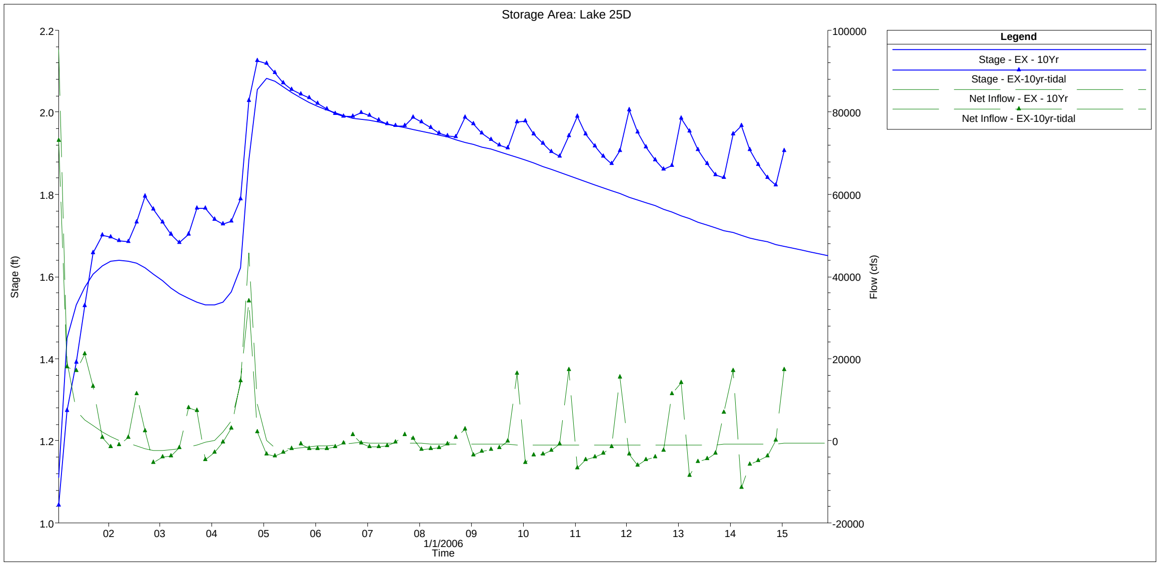

Figure 2.4. Comparison of Lake Salvador stage and flow for tidal and non-tidal

Model Validation

The HEC-RAS model provided to CHT by the District had been validated by District personnel to the Tropical Storm Allison that occurred during the period from 4 June – 12 June 2001. Since some minor modifications were made to the HEC-RAS geometry, e.g., adding slots in the channels and unplugging two small culverts in Tisamond Foret, the Allison event was re-run to compare computed and recorded water levels at several locations. Figures 2.5 through 2.9 show the model comparisons at the limited locations where measured data were available for Tropical Storm Allison. These results are virtually identical to those obtained by District personnel during their validation of the model. Therefore, the model was considered sufficiently validated to proceed with the production runs.

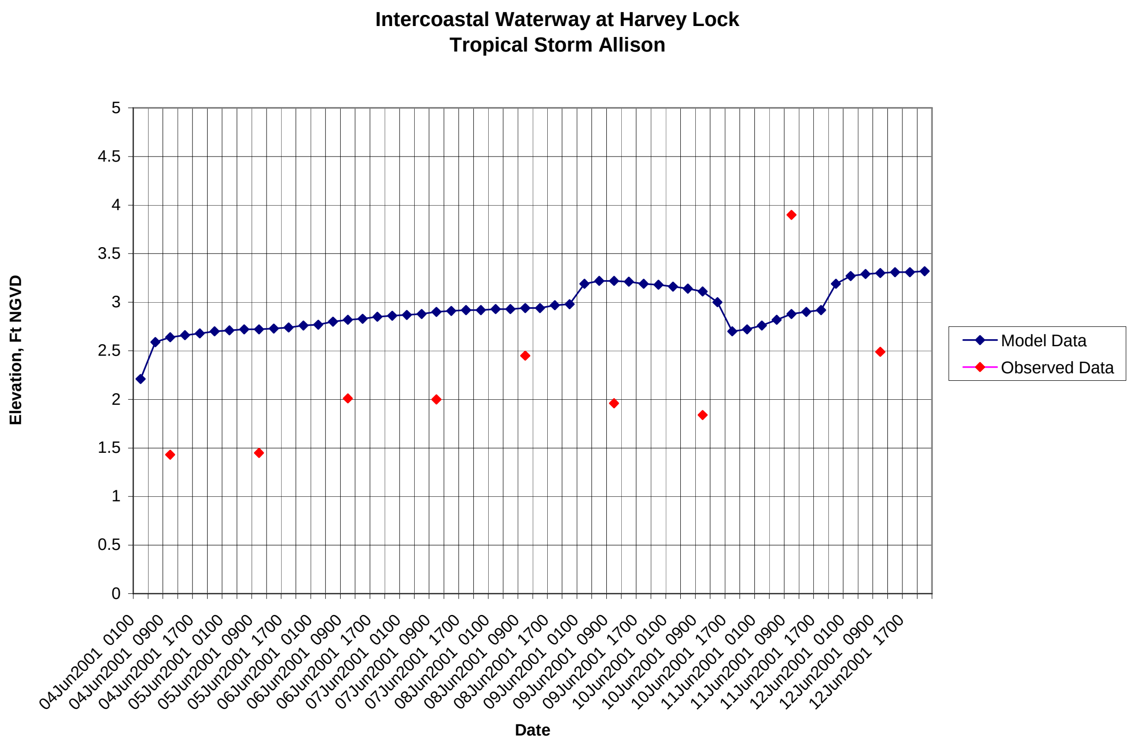

Figure 2.5. IWW at Harvey Lock

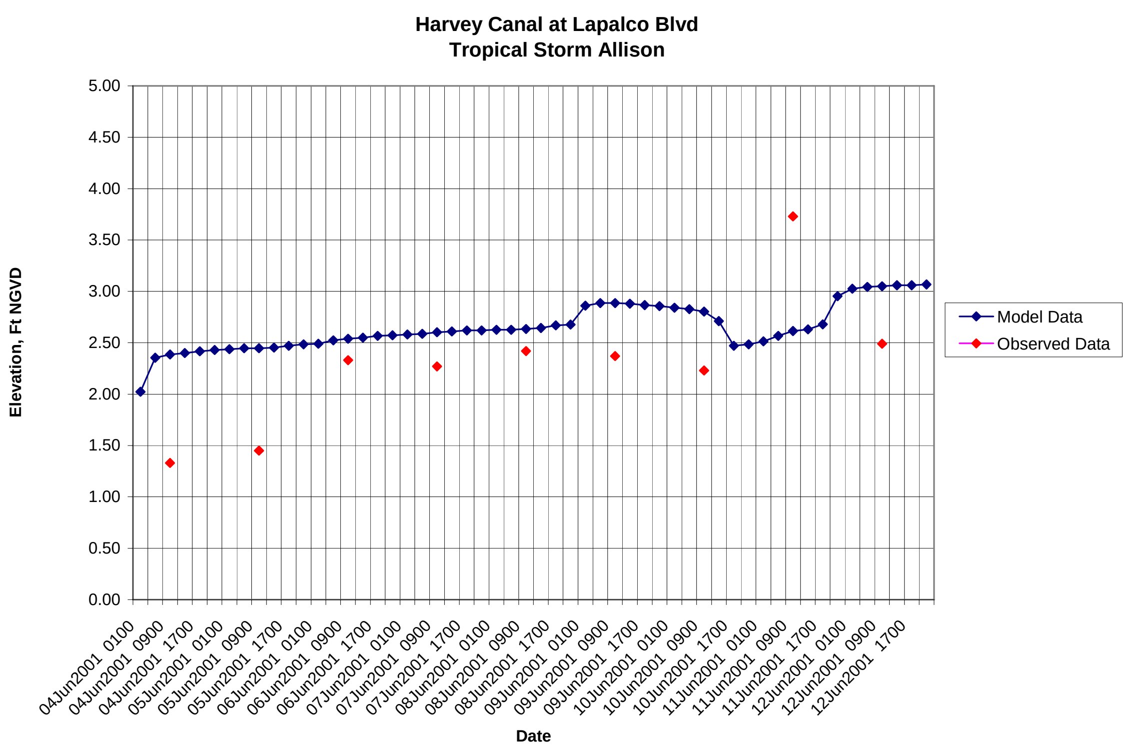

Figure 2.6. Harvey Canal at Lapalco Blvd

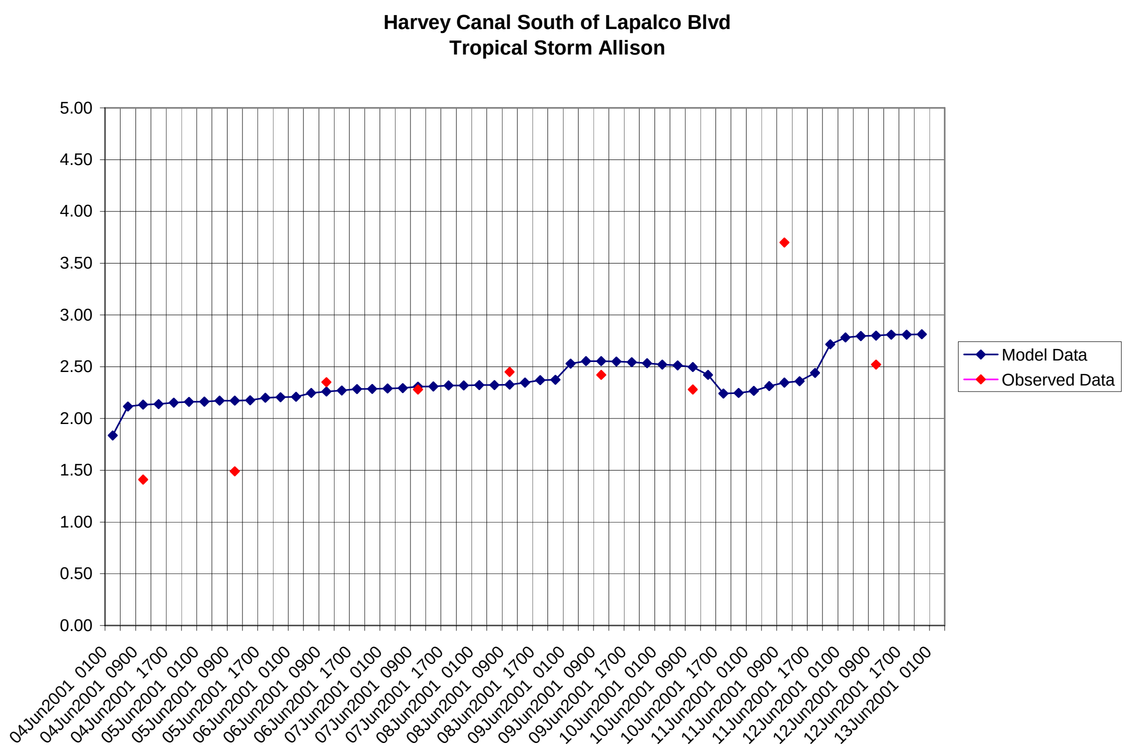

Figure 2.7. Harvey Canal South of Lapalco Blvd

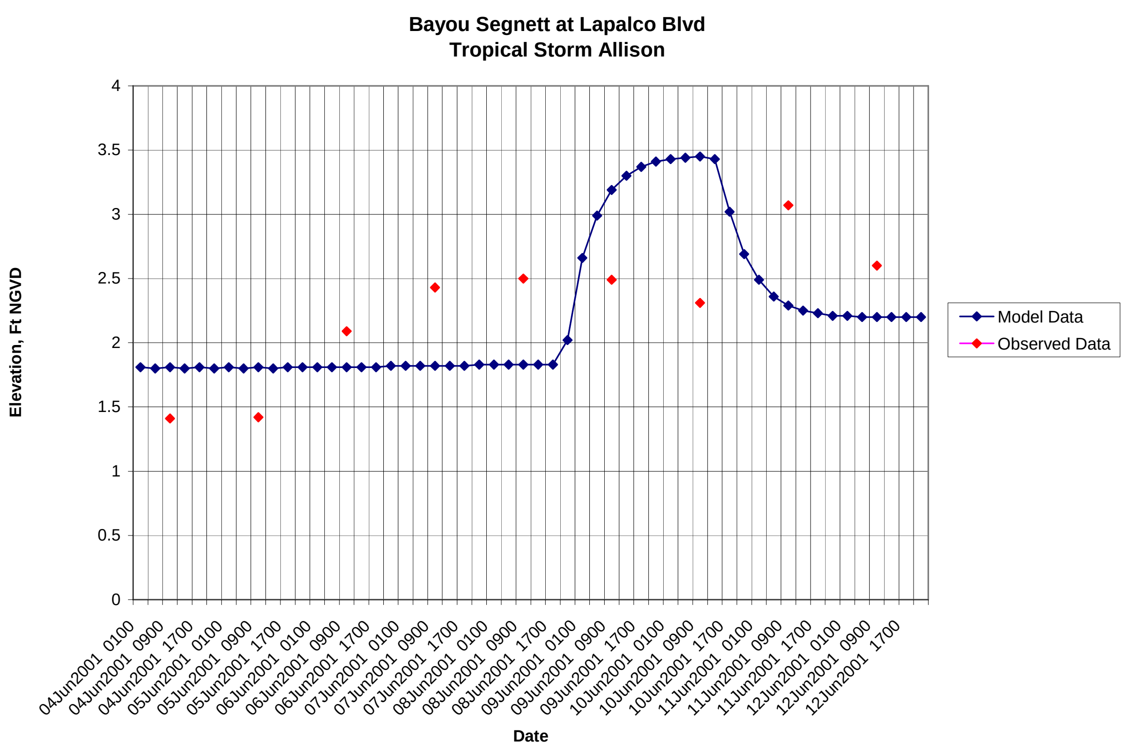

Figure 2.8. Bayou Segnett at Lapalco Blvd

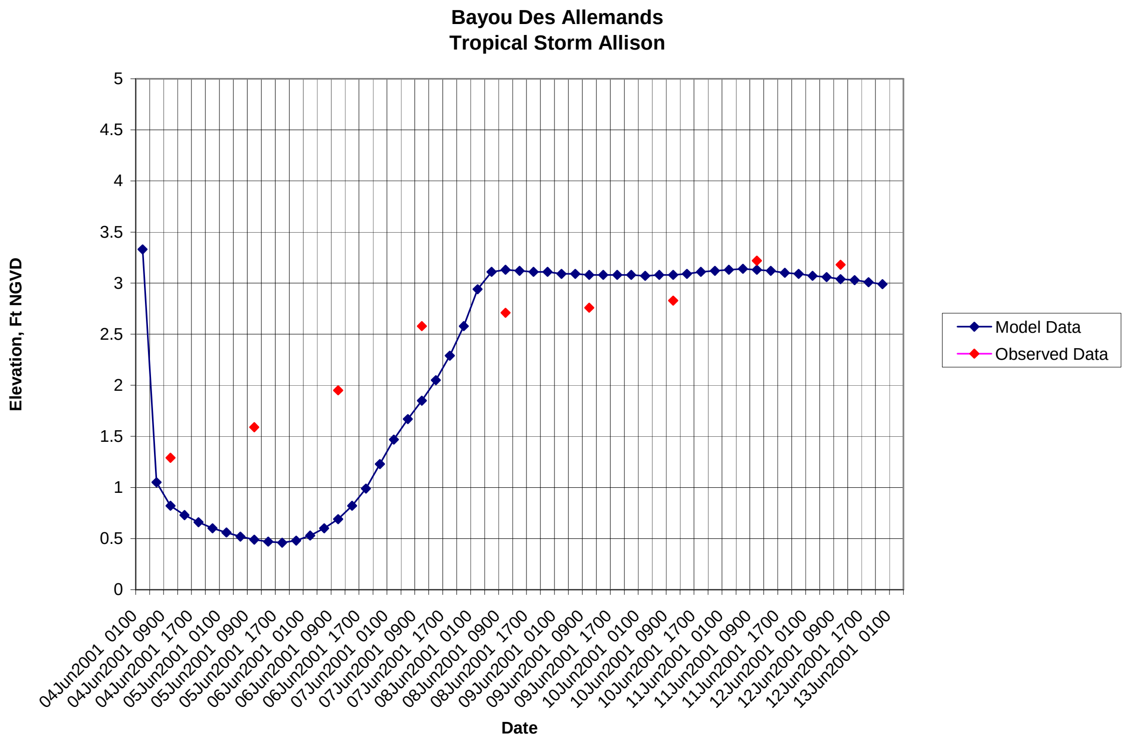

Figure 2.9. Bayou Des Alemands

Production Runs

As previously noted, the HEC-RAS model was used to simulate 2, 5, 10, 25, 50, 100, and 500-year rainfall events. Simulations were made without a surge protection levee and then the exact same runs were made with first levee 1 (Figure 2.10) and then levee 2 (Figure 2.11) in place.

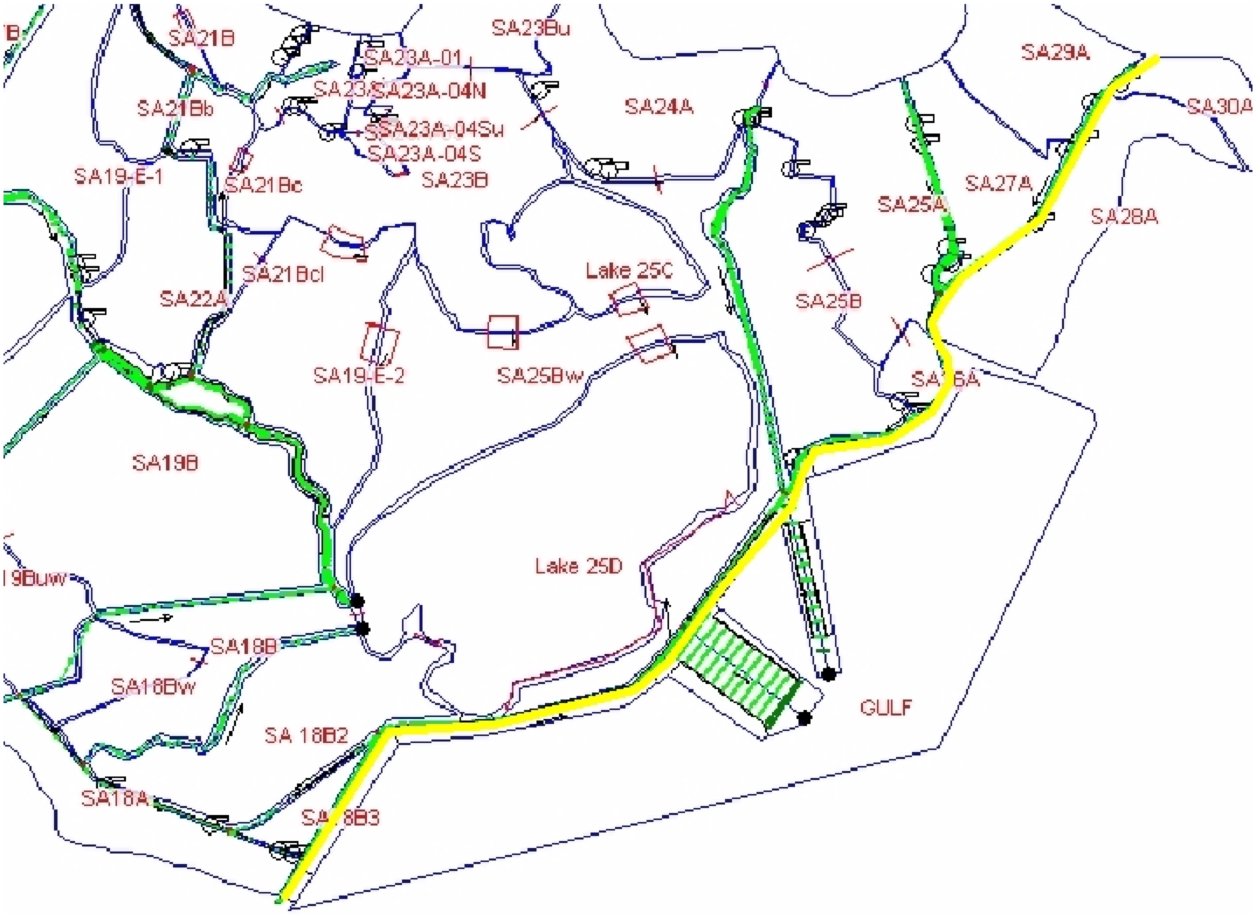

Figure 2.10. Levee 1 alignment in HEC-RAS (Yellow Line)

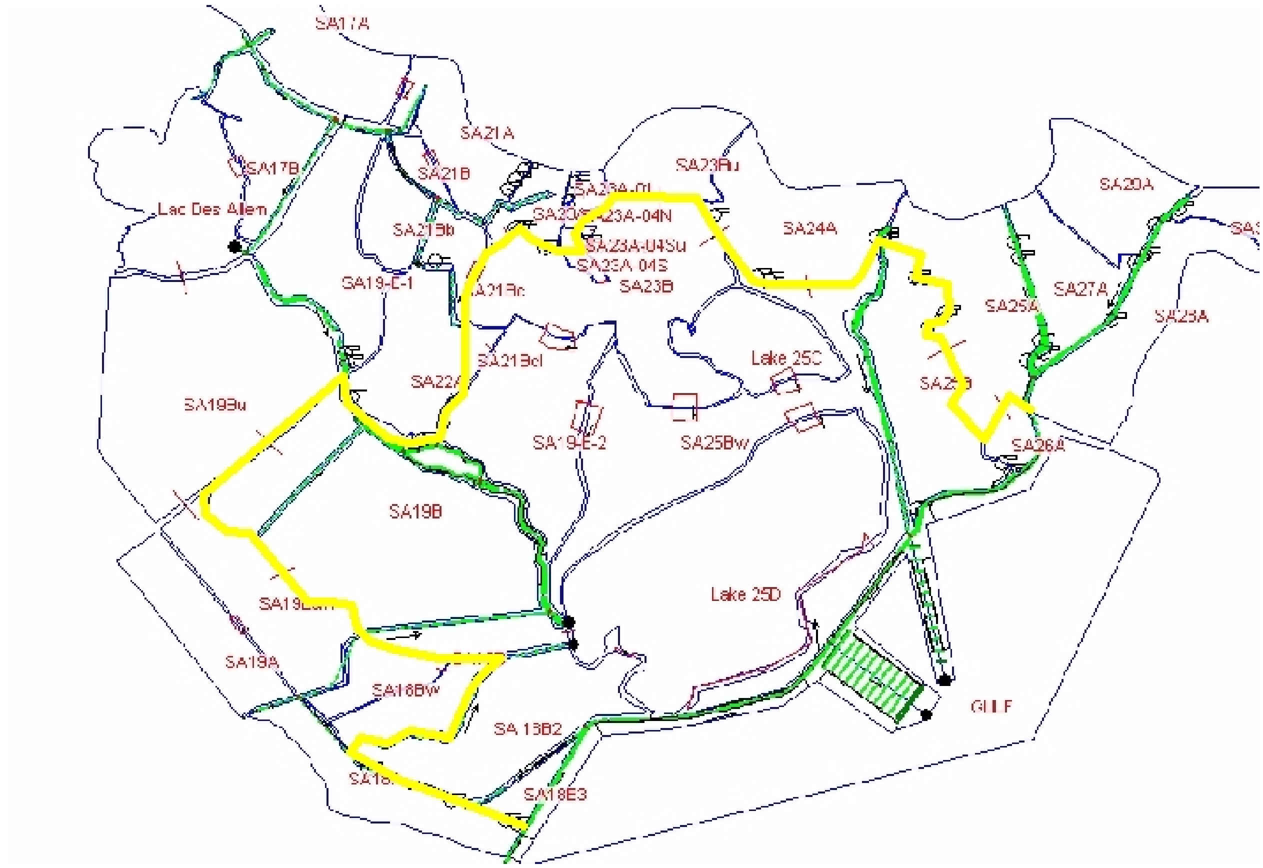

Figure 2.11. Levee 2 alignment in HEC-RAS (Yellow Line)

Many simulations were made with levee 1 in place in an attempt to size levee openings such that interior water levels were restored as close as possible to their pre-levee stages. The levee crest elevation was set at +12 ft NGVD. Four types of structural features were addressed in the model along Levee alignment 1.

The first type of feature was navigation gates in Barataria and Bayou Perot. At Barataria, the structure was 110 ft wide with a bottom elevation of -14 ft NGVD. At Bayou Perot, the navigation structure was 110 ft wide with a bottom elevation of -21 ft NGVD.

The second type of feature was flood gates in Barataria and Bayou Perot adjacent to the navigation structures. At Barataria, there were two floodgates, each 80 ft wide with bottom elevations of -10 ft NGVD. At Bayou Perot, there were two floodgate, each 850 ft wide with bottom elevations of -10 ft NGVD.

The third type of feature was 10-ft x 10-ft box culverts located along the levee adjacent to Reaches 2 and 3 of the GIWW. Two culvert sets were tested – 50 culverts and 100 culverts. All culverts were 50 feet in length and had inverts of -10 feet.

The fourth type of feature was pump stations pumping from the GIWW in the vicinity of the lower end of Lake Salvador to the Gulf storage area. Two sets of pumps stations were tested – 13,000 cfs and 26,000 cfs capacities.

Levee 1 – Scenario 1A: Scenario 1A consisted of Levee 1 with only the navigation structures open.

Levee 1 – Scenario 1B: Scenario 1B consisted of Levee 1 with only the navigation and adjacent flood gate structures open.

Levee 1 – Scenario 1C: Scenario 1C consisted of Levee 1 with the navigation and adjacent flood gate structures open and 50 10x10 box culverts installed in the levee adjacent to reaches 2 and 3 of the GIWW. The culvert inverts were set at -10 ft NGVD, which will require some channeling on the downstream side of the levee. The higher the inverts, the less effective the culverts will be in draining the interior.

Levee 1 – Scenario 1D: Scenario 1D was the same as C except that the culvert inverts were raised from –10 ft to –5 ft.

Levee 1 – Scenario 1E: Scenario 1E consisted of Levee 1 with all openings closed (culverts and passes) and only pump stations with a total capacity of 13,000 cfs operating.

Levee 1 – Secenario 1F: Scenario 1F was the same as E except that the pump stations had a total capacity of 26,000 cfs.

As with the Levee 1 alignment, many simulations were made to size Levee 1 openings such that interior water levels were restored as close as possible to pre-levee stages. As with Levee 1, the Levee 2 crest elevation was set at +12 ft NGVD. Four types of structural features were addressed in the model along Levee alignment 2.

The first type of feature was flood gates in Bayou Vacherie (Reach 1), Bayou Des Allemands (Reach 9), Paradis (Reach 1), and Company Canal (Reach 2). The Bayou Vacherie gate is 20 ft wide by 6 ft high with the invert set at -4 ft NGVD. The Bayou Des Allemands gate is 100 ft wide by 26 ft high with the invert set at -14 ft NGVD. The Company Canal gate is 40 ft wide by 14 ft high with the invert set at -2 ft NGVD. The Paradis gate is 20 ft wide by 16 ft high with the invert set at -4 NGVD.

The second type of feature was 10x10 box culverts located along the Levee 2 alignment. The total number of culverts was 27. Two culverts were located between storage areas 23Bu and 25Bw with the inverts set at -10 ft NGVD. Five culverts were located along Paradis (Reach 1) with the inverts set at -4 ft NGVD. Five culverts were located along Des Allemands (Reach 10B) with the inverts set at -6 ft NGVD. Five culverts were located between storage areas 19Bu and 19B with the inverts set at -7 ft NGVD. Five culverts were located between 19Buw and 19B with the inverts set at -6 ft NGVD. Five culverts were located between 18Bw and 18B with the inverts set at -3 ft NGVD.

The third type of feature was a pump station Pumping from Paradis (Reach 1) to storage area 19-E-2 with a total capacity of 6500 cfs.

Levee 2 - Scenario 2A: Scenario 2A was the Levee 2 alignment with all culverts closed, but with the four floodgates open.

Levee 2 - Scenario 2B: Scenario 2B was the Levee 2 alignment with all 27 culverts and the four floodgates open.

Levee 2 - Scenario 2C: Scenario 2C was the Levee 2 alignment with all culverts and floodgates closed, but with the 6500 cfs capacity pump station operating.

Results

Levee 1 and levee 2 results in Lac Des Allemands, Lake Cataouatche, and Lake Salvador for the modeled storm frequencies are shown in the following tables.

TABLE 2.1. 2-year, 7-day

		2-YEAR, 7-DAY	
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*2.97*	*1.54*	*1.94*
Levee 1 Scenario 1A	*2.98*	*2.51*	*2.49*
Levee 1 Scenario 1B	*2.98*	*2.42*	*2.40*
Levee 1 Scenario 1C	*2.97*	*1.63*	*1.85*
Levee 1 Scenario 1D	*2.97*	*1.67*	*1.89*
Levee 1 Scenario 1E	*2.97*	*2.14*	*2.11*
Levee 1 Scenario 1F	*2.97*	*2.05*	*1.41*
Levee 2 Scenario 2A	*3.46*	*1.51*	*1.78*
Levee 2 Scenario 2B	*2.97*	*1.51*	*1.88*
Levee 2 Scenario 2C	2.99	1.53	1.90

TABLE 2.2. 5-year, 7-day

	5-YEAR, 7-DAY		
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*3.03*	*1.60*	*2.03*
Levee 1 Scenario 1A	*3.03*	*2.94*	*2.92*
Levee 1 Scenario 1B	*3.03*	*2.69*	*2.67*
Levee 1 Scenario 1C	*3.03*	*1.79*	*1.97*
Levee 1 Scenario 1D	*3.03*	*1.88*	*1.99*
Levee 1 Scenario 1E	*3.03*	*2.42*	*2.39*
Levee 1 Scenario 1F	*3.03*	*2.12*	*1.70*
Levee 2 Scenario 2A	*3.93*	*1.53*	*1.91*
Levee 2 Scenario 2B	*3.03*	*1.54*	*1.98*
Levee 2 Scenario 2C	*3.04*	*1.55*	*2.00*

TABLE 2.3. 10-year, 7-day

	10-YEAR, 7-DAY		
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*3.09*	*1.65*	*2.08*
Levee 1 Scenario 1A	*3.20*	*3.15*	*3.13*
Levee 1 Scenario 1B	*3.10*	*2.90*	*2.87*
Levee 1 Scenario 1C	*3.09*	*1.97*	*2.04*
Levee 1 Scenario 1D	3.09	2.05	2.06
Levee 1 Scenario 1E	*3.10*	*2.66*	*2.63*
Levee 1 Scenario 1F	*3.10*	*2.17*	*2.11*
Levee 2 Scenario 2A	*4.29*	*1.57*	*1.99*
Levee 2 Scenario 2B	*3.18*	*1.60*	*2.04*
Levee 2 Scenario 2C	3.10	1.58	2.05

TABLE 2.4. 25-year, 7-day

	25-YEAR, 7-DAY		
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*3.14*	*1.72*	*2.15*
Levee 1 Scenario 1A	*3.44*	*3.38*	*3.37*
Levee 1 Scenario 1B	*3.20*	*3.12*	*3.10*
Levee 1 Scenario 1C	*3.14*	*2.12*	*2.12*
Levee 1 Scenario 1D	*3.14*	*2.20*	*2.14*
Levee 1 Scenario 1E	*3.14*	*2.92*	*2.89*
Levee 1 Scenario 1F	*3.14*	*2.41*	*2.36*
Levee 2 Scenario 2A	*4.70*	*1.61*	*2.06*
Levee 2 Scenario 2B	*3.51*	*1.62*	*2.10*
Levee 2 Scenario 2C	3.14	1.63	2.11

TABLE 2.5. 50-year, 7-day

	50-YEAR, 7-DAY		
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*3.16*	*1.77*	*2.19*
Levee 1 Scenario 1A	*3.62*	*3.56*	*3.54*
Levee 1 Scenario 1B	*3.38*	*3.29*	*3.27*
Levee 1 Scenario 1C	*3.15*	*2.23*	*2.18*
Levee 1 Scenario 1D	*3.15*	*2.33*	*2.26*
Levee 1 Scenario 1E	*3.21*	*3.12*	*3.10*
Levee 1 Scenario 1F	*3.15*	*2.61*	*2.56*
Levee 2 Scenario 2A	*5.00*	*1.65*	*2.11*
Levee 2 Scenario 2B	*3.76*	*1.66*	*2.14*
Levee 2 Scenario 2C	*3.16*	*1.67*	*2.15*

TABLE 2.6. 100-year, 7-day

	100-YEAR, 7-DAY		
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*3.18*	*1.82*	*2.24*
Levee 1 Scenario 1A	*3.76*	*3.70*	*3.68*
Levee 1 Scenario 1B	*3.75*	*3.68*	*3.66*
Levee 1 Scenario 1C	*3.16*	*2.34*	*2.26*
Levee 1 Scenario 1D	*3.16*	*2.44*	*2.36*
Levee 1 Scenario 1E	*3.27*	*3.18*	*3.15*
Levee 1 Scenario 1F	*3.18*	*2.77*	*2.72*
Levee 2 Scenario 2A	*5.23*	*1.69*	*2.15*
Levee 2 Scenario 2B	*3.95*	*1.72*	*2.20*
Levee 2 Scenario 2C	*3.18*	*1.73*	*2.22*

TABLE 2.7. 500-year, 7-day

	500-YEAR, 7-DAY		
	Lac Des Allemands	Lake Cataouatche	Lake Salvador
Existing	*3.23*	*1.95*	*2.35*
Levee 1 Scenario 1A	*4.17*	*4.10*	*4.09*
Levee 1 Scenario 1B	*4.15*	*4.08*	*4.06*
Levee 1 Scenario 1C	*3.22*	*2.62*	*2.52*
Levee 1 Scenario 1D	*3.22*	*2.72*	*2.62*
Levee 1 Scenario 1E	*3.78*	*3.68*	*3.65*
Levee 1 Scenario 1F	*3.36*	*3.21*	*3.17*
Levee 2 Scenario 2A	*5.86*	*1.78*	*2.24*
Levee 2 Scenario 2B	*4.50*	*1.80*	*2.27*
Levee 2 Scenario 2C	*3.88*	*1.81*	*2.27*

Levee 1 Discussion. It was determined from the simulations that a series of culverts could restore the interior water levels to their pre-levee values with the levee 1 alignment, if the culvert inverts were set low enough and the water was able to flow away downstream. With the inverts set at –10 ft NGVD, the culverts were effective through the 100-Year event. With the inverts set at –5 ft, the culverts were effective through the 50-year event. In both cases, the model assumes that water below the levee can be removed effectively. Neither the 13,000 cfs nor the 26,000 pump stations were effective

in restoring the existing conditions beyond the 10-year event. Pumping stations larger than the 26,000 cfs capacity would be required to restore pre-levee stages at the 100-year event.

Levee 2 Discussion. The Levee 2 alignment can more easily be designed to restore the pre-levee stages. However, the 27 culverts did not completely restore the Lac DesAllemands to the pre-levee condition. The 27-culvert condition was only effective to the 10-year event. Additional culverts will be required to achieve full restoration to the 100-year event. Since both Lake Cataouatche and Lake Salvador are below the levee 2 alignment, they are at or below the pre-levee conditions in all cases. The 10000 cfs pump station completely restores Lake Des Allemands to pre-levee stages at the 100-year event.

Note that the scenarios with all openings closed and pump stations incorporated (Scenarios 1F, 1E, and 2C) did not assume any overtopping of the surge protection levee since the District was not able to provide estimates of overtopping in time to incorporate them in these simulations. It is anticipated that additional model simulations will be made in the future which will incorporate levee overtopping.

PART III: RMA-2/RMA-4 MODELING

The numerical models RMA-2 and RMA-4 are part of a family of iso-parametric, finite element models originally developed by Resource Management Associates, Inc. (King 1993), supported by the Corps of Engineers, and included in the SMS modeling system. These particular models are two-dimensional, depth-averaged and assume uniform conditions in the vertical dimension. Several special model features were used in this study. For example, wetlands were represented using the "marsh porosity" feature in which areas lose water surface gradually over a vertical interval and always retain a small sub-mesh-scale wetted area (i.e. card 'DA 1 8 0.6 0.03 -0.9'). One-dimensional elements were used to represent the GIWW west of Barataria and much of the Houma Canal. Bed friction, based on Manning's formulation, was varied by depth using the "Miss River Delta" defaults except for the maximum non-vegetated value which was set to *n*-value 0.022 (i.e. card 'RD 1 1 0.022 2 0.026 0.08'). The model executed on a Mac Pro computer (with quad-Xeon 2.66 GHz processors and 4 GB RAM) at the simulation:clock time ratio of 12:1 for low-inflow conditions.

Model Setup

As previously noted, the initial numerical mesh provided by the District contained more resolution in certain areas than required for this study while more resolution was needed in other areas - mainly in the western bays. Water depths specified on the numerical mesh were provided by the District in the original mesh. However, based on National Ocean Survey charts displayed in MAPTECH, some modification of the bathymetry was made in the western part of the model as described below.

Boundary conditions are required to make simulations with the RMA-2 and RMA-4 models. Boundary conditions for RMA-2 consist of time varying water surface elevations on the Gulf portion of the mesh and freshwater inflows at the locations noted on Figure 3.1. Water depths on the southern edge of the mesh reach 500 ft. Figure 3.2 shows the water surface elevation boundary condition imposed on the southern boundary of the mesh for June 2002. The same elevations were imposed at all Gulf boundary nodes. For all ocean tidal boundary conditions, a mean tide level of +1.5 ft NGVD29 was used.

Boundary conditions for RMA-4 consist of values for salinity at the Gulf boundary and at the freshwater inflow locations. The Gulf salinity was set to be a constant 28 ppt, whereas the salinity of the freshwater inflow was assumed to be 0.0 ppt. Of course, as previously noted, time varying flow fields from RMA-2 were input to RMA-4 to provide the transport of the salinity.

Initial conditions for the RMA-2 model assumed no motion with a flat-water surface. First a steady-state solution is obtained for specified inflow rates and flat ocean boundary. This result is then used to spinup the hydrodynamic model dynamically with a repeating tide. This spinup run is then used to initialize the model for dynamic simulations. Initial conditions on salinity were also required for the RMA-4 model. The initial salinity conditions were constructed by initializing salinity by material type and operating the model in steady-state mode with appropriate inflow conditions. By trial and error, dispersion coefficients were adjusted so that this steady-state solution approximated the observed salinity distribution. Dynamic RMA-4 runs were then made, first with a repeating tide to observe model spinup and ensure that the model has reached dynamic equilibrium. This process was repeated until the salinity distribution was acceptable.

As will be discussed below, several freshwater inflows were prescribed. For the validation of RMA-2 to June 2002 conditions, a constant base inflow of 100 cfs was prescribed at the upstream boundary in the upper Baratiaria basin at Lac Des Allemands shown in Figure 3.1. Production runs were made using (a) the base flow of 100 cfs to gauge plan salinity impacts, (b) constant upland inflows of 16,000 and 32,000 cfs, and (c) a time-varying inflow corresponding to a rainfall event with a frequency of 2 years. This inflow hydrograph was provided by the HEC-RAS model.

Mesh Development

The numerical mesh for this study was based on MVN Mesh 24 (Barataria Bay) and a portion of mesh further to the west as combined by MVN into Mesh 25. Mesh 25 was refined in the western parts to include more wetland areas and additional open water areas along the Houma Canal. Elements in the eastern part of the mesh were lightly decimated to make spatial resolution more uniform over flat areas and make the mesh more efficient to operate. Care was taken not to edit tidal channels in the mesh or alter mesh geometry. The new Mesh Bp05 is shown in Figure 3.3 along with Mesh 25 for comparison of mesh geometries near the study area. The western bays were modified slightly to be more consistent with NOS charts. Then, during tidal adjustment, very shallow areas were added to the fringe of the bay and along waterways as necessary to appropriately damp the upstream tidal signal. A plot showing the final geometry is shown in Figure 3.4 Finally, elements were altered along the plan alignment such that plans (as far as could be anticipated) could be installed by dropping out elements, and thus base and plan mesh were made comparable with regards to the SMS system and differed only by the plan. Only the Levee 1 alignment was tested in the model.

Model Validation

The numerical mesh was validated to tidal water levels and to salinities. For salinity validation, boundary conditions used with Mesh 25 provided by MVN for June 2002 were used to drive the model and model results were then compared to daily field data. For an initial water level validation, hourly and 15-minute data from 6 November to 7 December 2006 were used to improve temporal resolution. Daily mean, minimum, and maximum salinity and water level data for May - July 2002 and time-series data for November 2006 were downloaded from the USGS National Water Inventory System (http://nwis.waterdata.usgs.gov/la/nwis/inventory). Stations where water level or salinity data were available are listed in Table 3.1 and station locations are shown in Figure 3.5. Note that stations 8 and 13 are actually outside the mesh to the west.

TABLE 3.1. Station Descriptions.

Station	USGS ID / Short ID	Station Description	Latitude, DDMMSS	Longitude, DDDMMSS
1	073802375 / s02375	Lake Salvador near Lafitte	294607	0901115
2	07380251 / s80251	Barataria Bay N of Grand Isle	292511	0895650
3	073802512 / s02512	Hackberry Bay NW of Grand Isle	292354	0900228
4	073802515 / s02515	Barataria Bay Pass E of Grand Isle	291632	0895629
5	07380335 / s80335	Little Lake near Cutoff	293103	0901053
6	07381328 / s81328	Houma Navigation Canal at Dulac	292306	0904347
7	07381331 / s81331	GIWW at Houma	293553	0904236
8	07381349 / s81349	Caillou Bay SW of Dulac	291508	0905518
9	292859090004000/ s04000	Barataria Waterway S of Lafitte	292859	0900040
10	292800090060000/ s60000	Little Lake near Bay Dosgris E of Galliano	292800	0900600
11	291929089562600/ s62600	Barataria Bay near Grand Terre Island	291929	0895626
12	295501090190400/ s90400	Davis Pond Diversion near Boutte	295501	0901904
13	073813498 / s13498	Caillou Bay SW of Cocodrie	290441	905217
14	07380340 / s80340	Tennessee Canal near Cutoff	292722	901145

Tidal Validation. Average tide range and relative tidal phases were estimated from time-series water level records. Water level time-series data were compared for a 5.5-day period of record when meteorological disturbances appeared to be minimal and after bandpass filtering time series to obtain records containing only 3- to 36-hour period fluctuations. An example of the former is shown in Figure 3.6 and for the latter is shown in Figure 3.7 - both for Stations 4, 8, and 11. In the case of these stations, no clear systematic phase difference could be detected by digitizing high and low peaks on the plots. For these stations along the coast, data were hourly. Similar plots for stations 6, 7, and 8 (Terrebonne Bay near the coast and along the Houma Canal), shown in Figures 3.8 and 3.9, show a more clear phase difference. Field phases at Lake Salvador and the coast are shown in Figure 3.10 Average tide range was taken as three times the standard deviation of the filtered records.

The model was operated by first doing a steady-flow only simulation without time derivative terms (so-called steady-state run) using the boundary flows from the beginning of the June 2002 boundary condition file. The model was then hot started with the results of the steady-state run and operated 280 hours with an average repeating 25-hour period tide. The boundary tide range was 1.6 ft and mean tide level was +1.5 ft. The ocean boundary was forced with a uniform tidal signal. That spinup run allowed for establishment of inland tidal setup. An example time-series plot of water levels during spinup is shown in Figure 3.11 The last tidal cycle of this run was used to determine tidal amplitudes and phases. Since the model time step was one hour (25 points per cycle), limiting phase resolution, a cubic spline with 200 points was fit to the model data to determine phases. Results of this tidal validation are presented in Table 3.2 as absolute and normalized values.

With the RMA-2 model considered adequately validated, it was operated for the June 2002 period using the 280-hr repeating-tide spinup to initialize the model. Water level results are shown in Figure 3.12a-d for the validation stations along with available daily field data (mean, minimum, and maximum).

Salinity Validation. RMA-4 was executed on the same numerical mesh using flow fields generated by RMA-2 for June 2002. The manner in which the initial salinity field was generated was discussed above, and an example time-series plot of model spinup is shown in Figure 3.13. The salinity field was initialized with the end of the 301-hr repeating tide simulation. Results are shown in Figure 3.14a-d along with available field data. (A modeling glitch prevented stations 6 and 7 model data from being displayed.) Some apparent inconsistencies or problems with the field salinity data should be noted. From the location of stations it appears that Station 10 field salinities are too high (higher than Stations 2 and 3 which are seaward and Station 14 which is nearby) and Station 11 are too low (lower than both 2 and 3 which are landward and much lower than nearby Station 4).

TABLE 3.2. Tidal Validation Results

FIELD				
	Tide Range		Peak Lag to Coastline, hr	
Station	ft	/ Station 4	HW	LW
1	0.23	0.14	10.1	9.9
2	1.59	0.98	0	0
3	1.41	0.87	0	0
4	1.63	1.0	0	0
5	0.74	0.45	3.9	4.2
6	0.93	0.57	4.5	4.3
7	0.39	0.24	7.3	6.1
8	1.80	1.10	0	0
9	1.16	0.71	NA	NA
10	0.78	0.48	3.9	4.2
11	1.57	0.96	0	0

MODEL (Bp05e)				
	Tide Range		Peak Lag to Station 4, hr	
Station	ft	/ Station 4	HW	LW
1	0.17	0.13	9.4	10.9
2	1.17	0.85	1.3	2.2
3	0.98	0.71	1.9	3.3
4	1.38	1.0	0	0
5	0.66	0.48	4.0	5.7
6	0.88	0.64	4.0	5.7
7	0.52	0.38	6.4	8.4
8	0.91	0.66	2.1	3.4
9	0.84	0.61	2.5	3.7
10	0.69	0.50	3.5	4.7
11	1.31	0.95	0.4	0.7

Figure 3.14 shows that at the beginning of June 2002 salinities varied from a high of almost 20 ppt in southern Barataria Bay to a low of about 7 ppt in the northern portion of the bay. While the RMA-4 model accurately computes the distribution of salinity at the beginning of the validation period, it does not produce the observed variation within during the month-long simulation. This could be because the boundary conditions were not accurately described. Indeed, there is nothing in the boundary conditions that would account for or drive the salinities down during the month and the hydrology of the basin is not known for this period. However, the boundary conditions do appear to be representative of salinity conditions at the beginning of the month, and the model is most useful for gauging changes in salinity rather than absolute salinity values.

Unfortunately, there were no salinity data available from Lake Salvador for the validation period. The model predicted salinity values of about 1 ppt in the Lake, which is similar to salinity values available from the USGS for November 2006.

Plan Tests

Four plan variations were tested. All plans followed Levee 1 alignment but had different openings or gaps. Plans are described in Table 3.3 and opening locations are shown in Figure 3.15. All plans also had navigation locks on Bayou Lafourche (56-ft wide) and the Houma Canal (110-ft wide) where Levee 1 alignment crosses these waterways far to the west of the study area (see Figure 3.5) and where these locks were sufficiently removed as to not directly impact drainage of the upper Barataria basin.

TABLE 3.3. Plan Description

Plan	No. Opening	Description
PR01	2	Two 110-ft-wide navigation locks
PR02	3	As PR01 with a 540-ft-wide auxiliary structure
PR03	5	As PR02 with 315- and 901-ft-wide openings on west side
PR04	6	As PR03 with 215 ft-wide opening on east side

The model navigation locks have -24 and -15 ft NGVD29 bottom elevation for Bayou Perot Pass and Barataria Waterway, respectively. The 315-ft-wide opening on the west side leads to a man-made lake in the area (bottom elevation about -4 ft). The opening has a bottom elevation of -3 to -4 ft. The other opening on the west side (901 ft wide) has a bottom elevation of +0.66 ft and opens onto wetland with an elevation of +1.75 ft. The 215-ft-wide opening on the east has a bottom elevation of -4 ft and leads to a system of tidal canal with bottom elevations of about -3 ft.

The Bayou Perot Pass is the most important connection between the Bay with Lake Salvador. The cross section is about 20,000 ft^2 and a plot is shown in Figure 3.16. The constriction of this pass to only the navigation lock reduces the cross section roughly 90 percent and increases velocities accordingly. From Figure 3.17, it can be seen that velocities of as much as 8 ft/s will exist in this lock under low-inflow and normal tidal conditions. However, with the additional opening of 540 ft adjacent to the navigation lock, velocities were reduced to 3.5 ft/s (under these conditions) as shown in Figure 3.18.

Salinity Tests. All plans were tested with conditions similar to the beginning of June 2002 to gauge plan effects on normal low-inflow salinity conditions. Boundary inflows came from the previous Mesh 25. A 100-cfs inflow was specified for a new boundary at Lac Des Allemands, as in the salinity validation run. A 1-cfs inflow at Davis Pond is the only other direct inflow to the upper Barataria basin above the Project although the GIWW carries roughly 120 cfs in from the west under the imposed boundary conditions. Also, the repeating 25-hr period tide was imposed instead of an observed tide. This allowed hydrodynamic model spinup to be observed as shown in Figure 3.12. The hydrodynamic model was first operated for steady flow and a hotstart file saved, and then the model was run dynamically for 280 hr. The salinity transport model was operated in a steady mode (without time terms) using the steady hyrdo output file and a hotstart file saved. Then RMA-4 was operated dynamically using the last 25 hr of the 280 hr hydro simulation repeatedly. The salinity transport model was operated for 301 hr.

Results for the time of maximum salinity intrusion (high water - hour 297) near the study area are shown in Figures 3.19 to 3.23 for the base and four plans. The salinity differences between the base and four plans are shown in Figures 3.24 to 3.27.

Salinity results indicate that plans PR01 and PR02 isolate the southwest corner of wetland area adjacent and seaward of the levee, causing an appreciable increase in salinity of about 5 ppt there. Plans PR03 and PR04 ameliorate this potential problem by allowing tidal exchange through the levee in the western two openings (see Figures 3.26 and 3.27).

Flow Tests. While it was not the intention to use the hydrodynamic model to predict extreme flow events, the model was used with certain higher flows to determine stage-discharge relationships for common flow conditions. Steady inflows were specified at Lac Des Allemands and near Davis Pond (close to Lake Cataouatche) in a ratio of 10:6. The repeating 25-hr-period tide was imposed on the ocean boundary as described above. Water levels were extracted at five location for the final tidal cycle for steady-inflows of 16,000 and 32,000 cfs. Summary statistics are presented in Tables 3.4 and 3.5. The location of the five points are shown in Figure 3.28. Tidal discharges were extracted at continuity lines and results presented in Table 3.6. The locations of the continuity lines are shown in Figure 3.29. Note that CL05 does not gauge the entire Bayou Perot Pass discharge since an appreciable flow occurs over the wetland between the Pass and the continuity line. Lake Salvador stage-discharge relationships for base and plan PR03 are shown in Figure 3.30.

Hydrograph Simulation. A 2-yr return period rainfall event was simulated based on hydrology developed for the HEC-RAS modeling. Hydrology data were lumped together (except the inflow to Lac Des Allemands) and applied as rainfall in the model. The area of rainfall is shown in Figure 3.31 and includes areas both landward and seaward of the project alignment. The area landward of the project (10.43e9 ft^2) is sufficient to produce 241,530 cfs inflow per 1 in./hr rainfall. A plot of the resulting rainfall hydrograph is shown in Figure 3.32. The hydrograph was run for base and plan PR01 - the most similar conditions common to both the RMA-2 and HEC-RAS models. Model water level results for the five points shown in Figure 3.28 are shown in Figures 3.33 and 3.34 for base and plan PR01 conditions. Water level differences are shown in Figure 3.35. Discharges for the continuity lines (shown in Figure 3.29) are shown in Figure 3.36 and 3.37.

Water level results of the 2-yr hydrograph simulation were very similar to the HEC-RAS model for Lake Salvador.

TABLE 3.4. Base and Plan Water Levels (ft, NVGD29) for 16,000 cfs Inflow Above Project

Point/Location		Base	PR01	PR02	PR03
1 Lake Salvador	Mean	1.944	2.186	1.993	1.984
	Min	1.869	2.153	1.924	1.916
	Max	2.013	2.214	2.054	2.043
3 Hackberry Bay	Mean	1.651	1.647	1.650	1.651
	Min	1.180	1.177	1.178	1.180
	Max	2.140	2.13	2.137	2.138
5 Little Lake Bay	Mean	1.736	1.724	1.733	1.736
	Min	1.419	1.386	1.412	1.415
	Max	2.056	2.065	2.060	2.061
16 Lake Cataouatche	Mean	1.986	2.220	2.034	2.024
	Min	1.921	2.192	1.974	1.966
	Max	2.044	2.245	2.085	2.075
17 Lac Des Allemands	Mean	3.212	3.282	3.227	3.223
	Min	3.210	3.279	3.225	3.221
	Max	3.214	3.284	3.229	3.225

TABLE 3.5. Base and Plan Water Levels (ft, NVGD29) for 32,000 cfs Inflow Above Project				
Point/Location		Base	PR03	PR04
1 Lake Salvador	Mean	2.192	2.319	2.279
	Min	2.138	2.277	2.233
	Max	2.238	2.356	2.319
3 Hackberry Bay	Mean	1.694	1.696	1.696
	Min	1.228	1.230	1.230
	Max	2.175	2.175	2.175
5 Little Lake Bay	Mean	1.827	1.832	1.830
	Min	1.512	1.514	1.511
	Max	2.150	2.160	2.156
16 Lake Cataouatche	Mean	2.298	2.417	2.379
	Min	2.257	2.386	2.345
	Max	2.332	2.444	2.409
17 Lac Des Allemands	Mean	4.480	4.526	4.521
	Min	4.474	4.525	4.520
	Max	4.485	4.527	4.521

TABLE 3.6. Tidal Discharges for 32,000 cfs Inflow Above Project			
Continuity Line		Base	PR04
CL03 Barataria Waterway	Mean	132	137
	Min	74	93
	Max	167	164
CL05 Bayou Perot Pass	Mean	8243	9813
	Min	3607	6057
	Max	11122	12237
CL06 GIWW to east	Mean	421	420
	Min	340	359
	Max	473	462
CL07 GIWW to west	Mean	16	44
	Min	-100	-159
	Max	121	205
CL19 Western 315-ft opening	Mean	56	551
	Min	37	340
	Max	78	680
CL20 Western 901-ft opening	Mean	12	456
	Min	-2	426
	Max	24	506

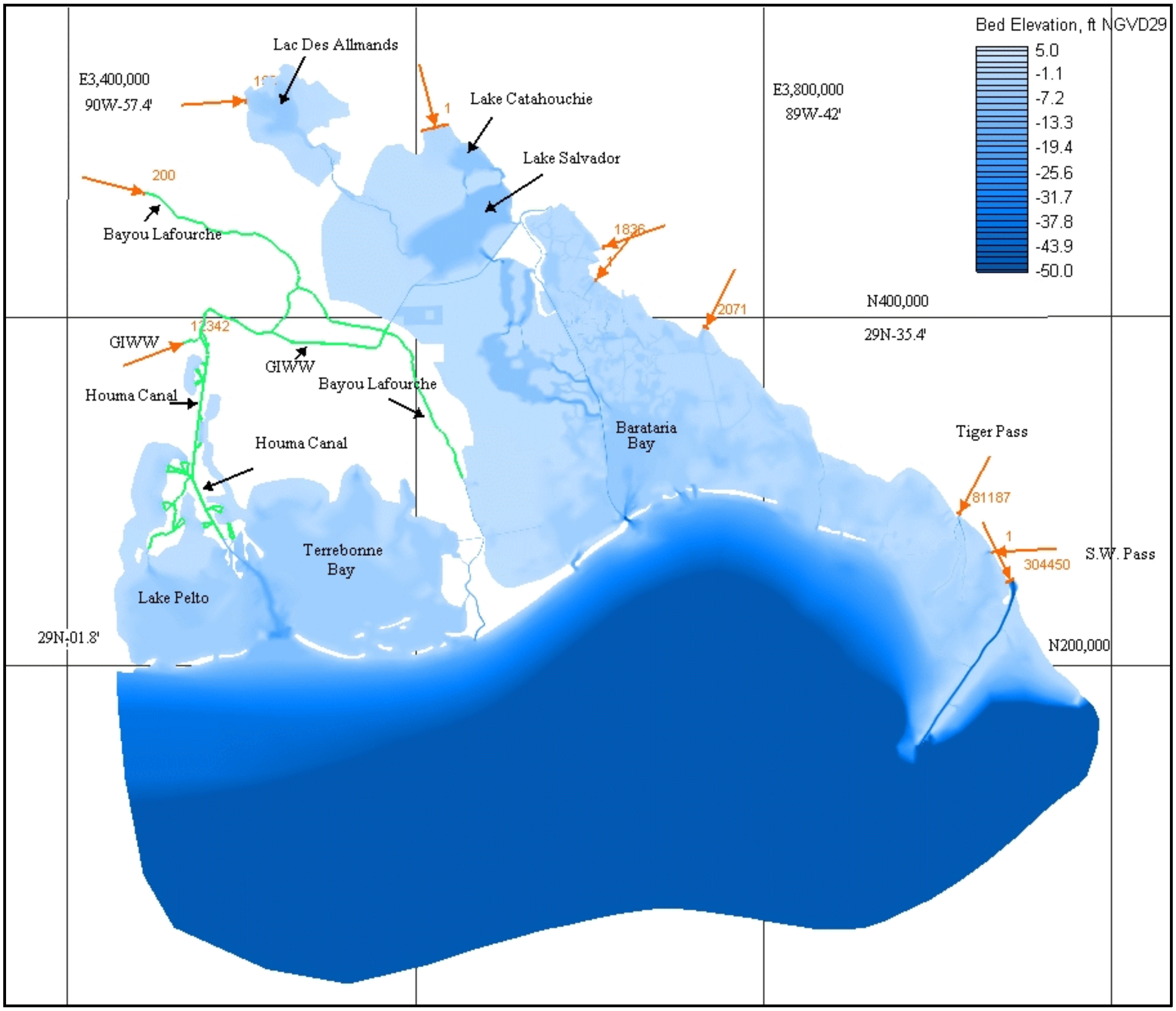

Figure 3.1. Mesh Bp05 showing inflow points (red arrows) and ocean boundary.

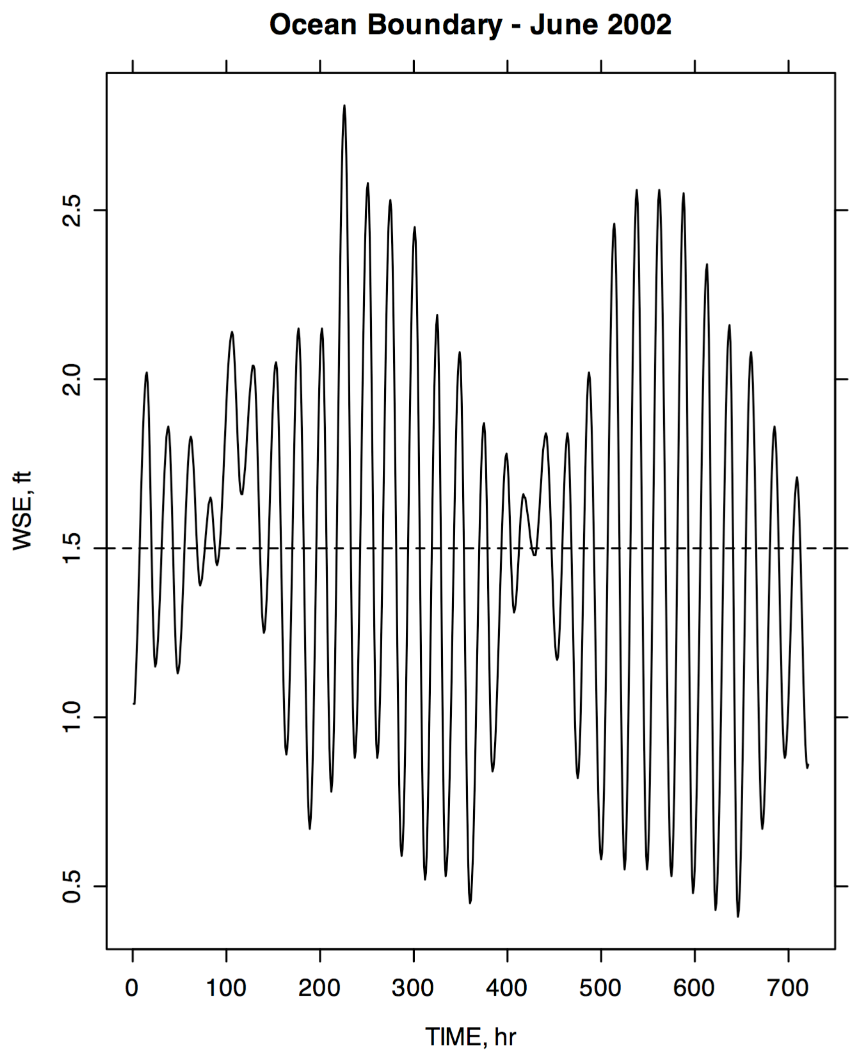

Figure 3.2. Ocean boundary for June 2002.

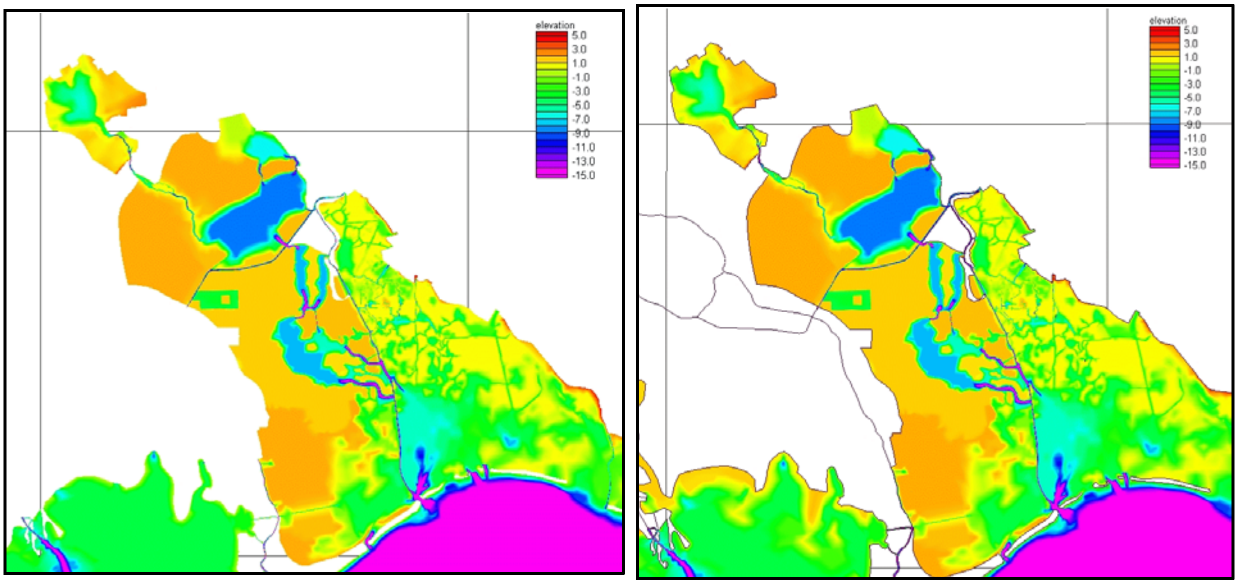

Figure 3.3. Geometry of Mesh 25 (left) and Bp05 (right)

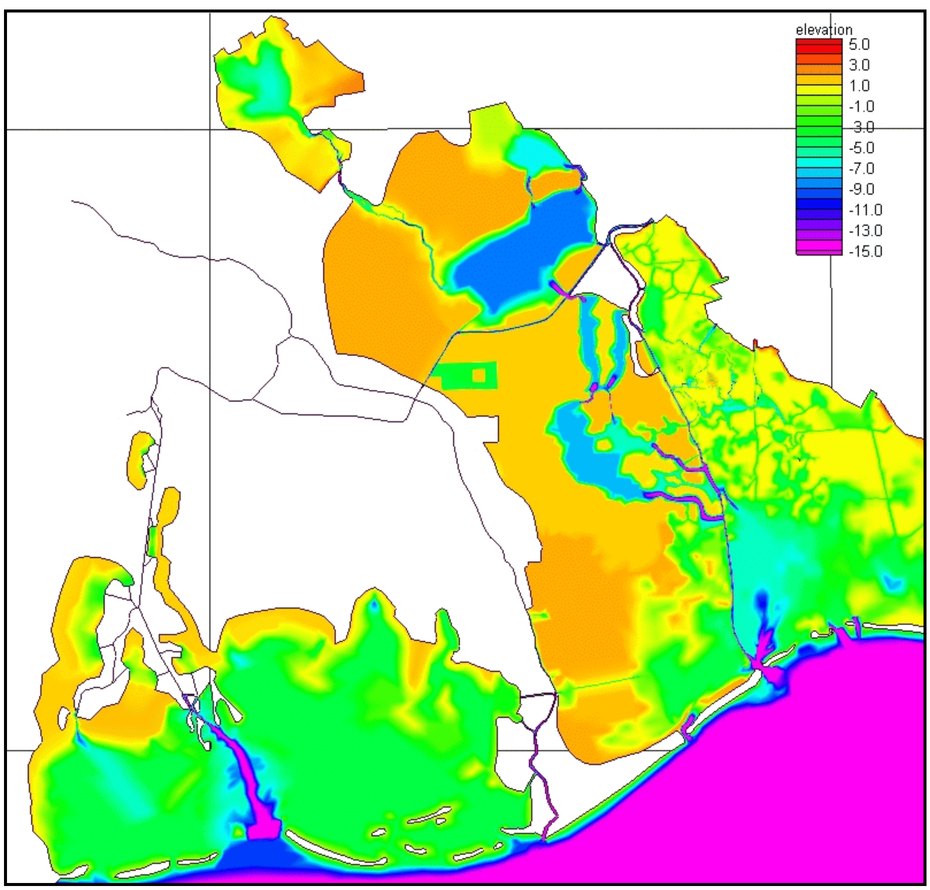

Figure 3.4. Mesh Bp05 with western bays edited.

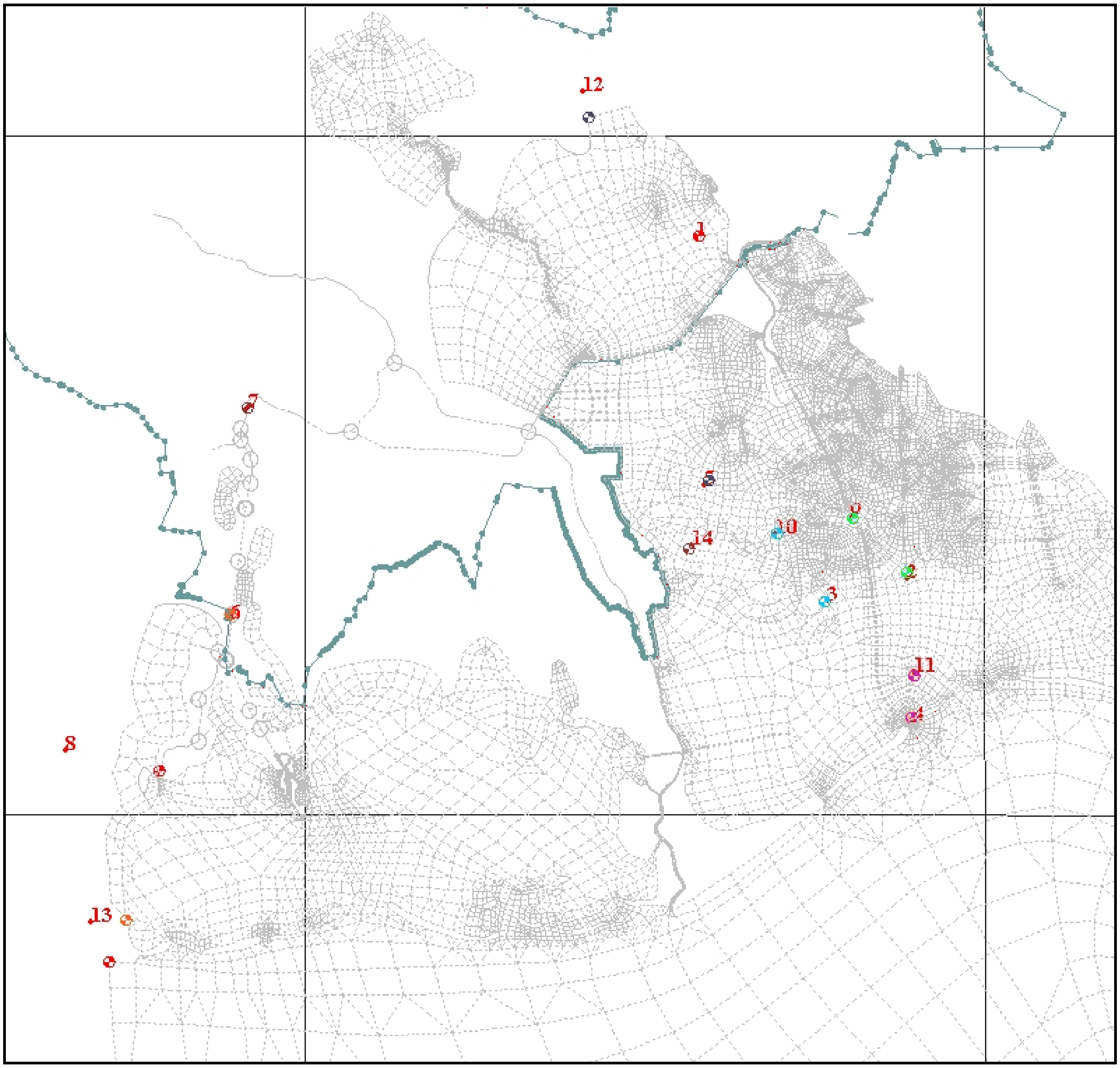

Figure 3.5. Validation station locations and Levee 1 alignment (blue).

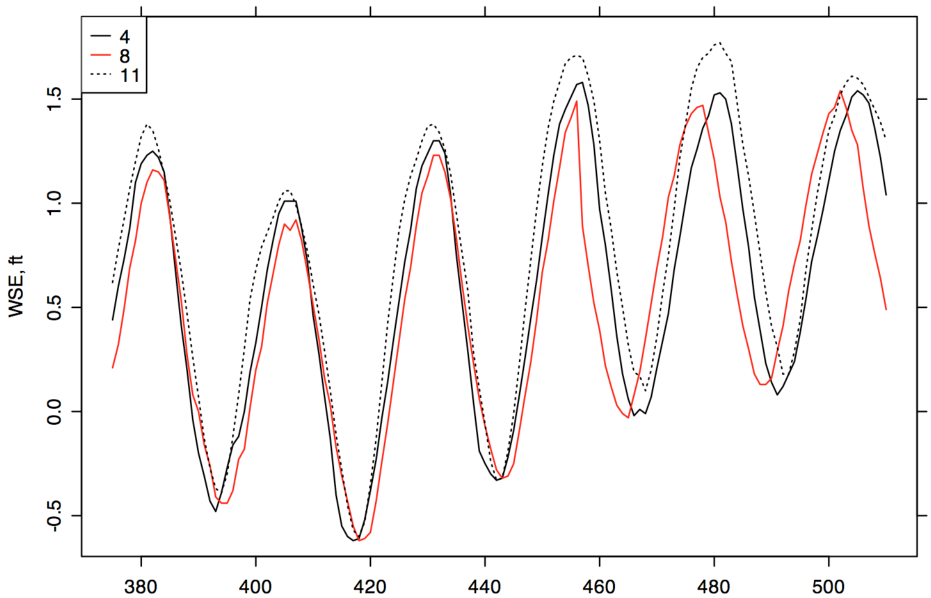

Figure 3.6. Raw water levels from stations 4, 8, and 11 used for phase inspection.

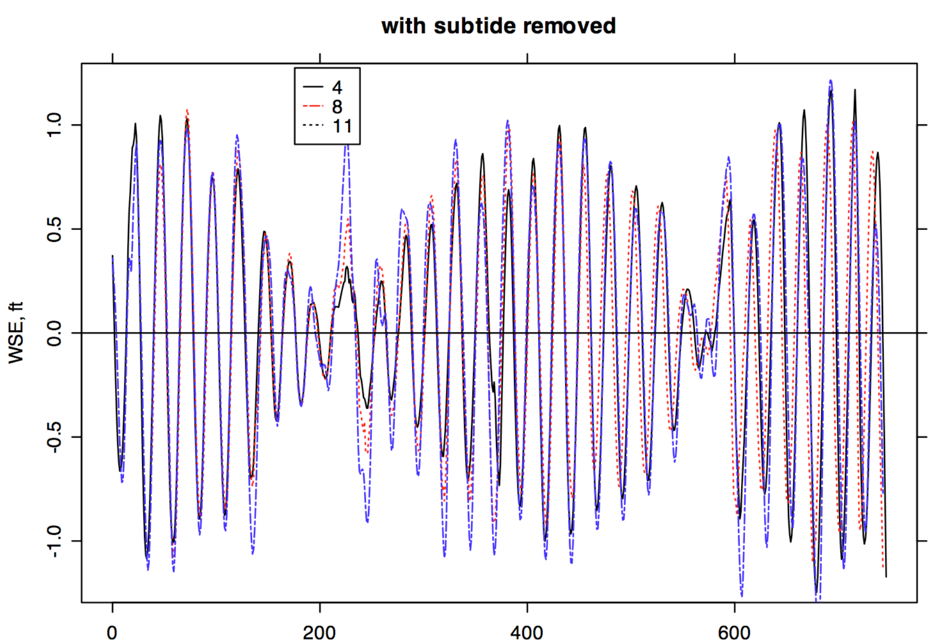

Figure 3.7. Filtered water levels from stations 4, 8, and 11 used for phase determination.

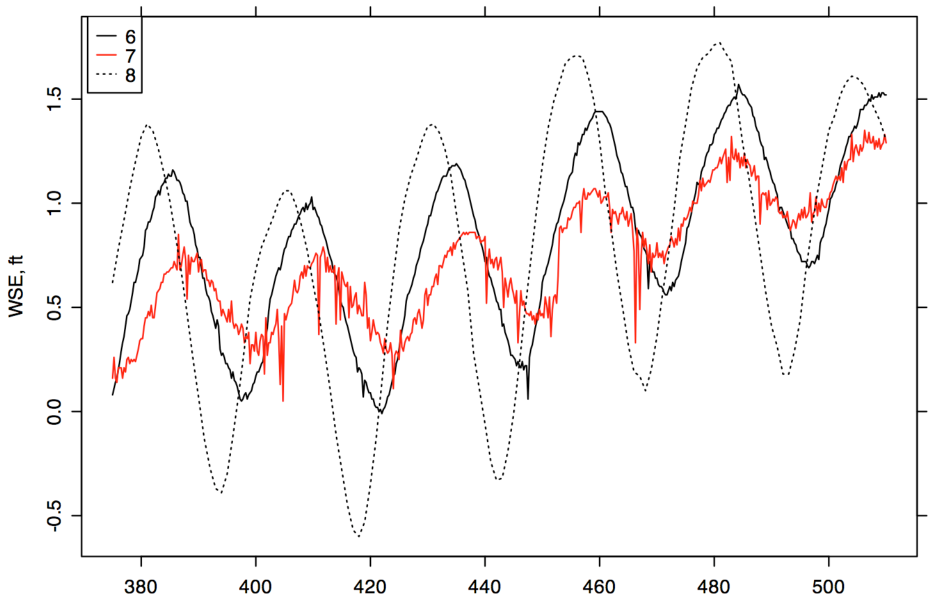

Figure 3.8. Raw water level record for stations 6,7, and 8 used for phase inspection.

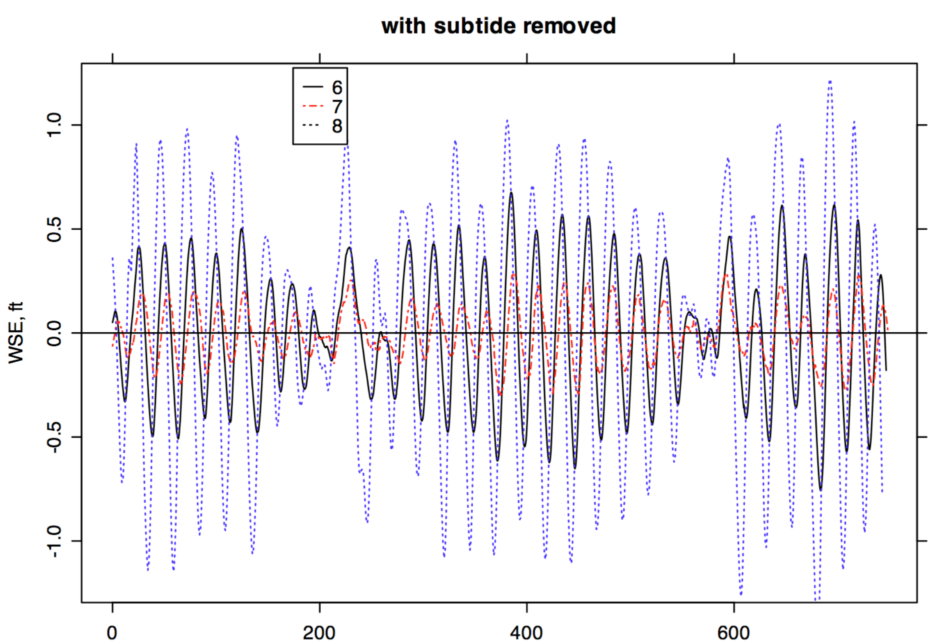

Figure 3.9. Filtered water levels for stations 6, 7, and 8 used for phase determination.

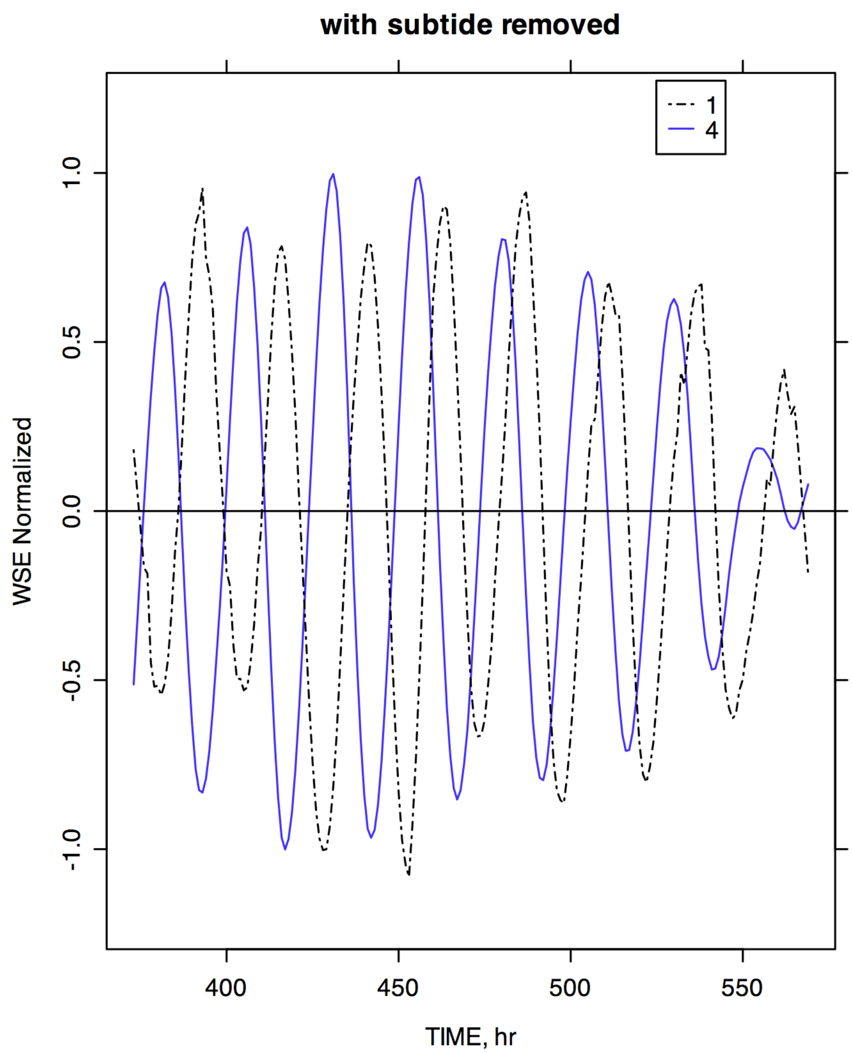

Figure 3.10. Filtered and normalized water level records from stations 1 and 4 used for phase determination.

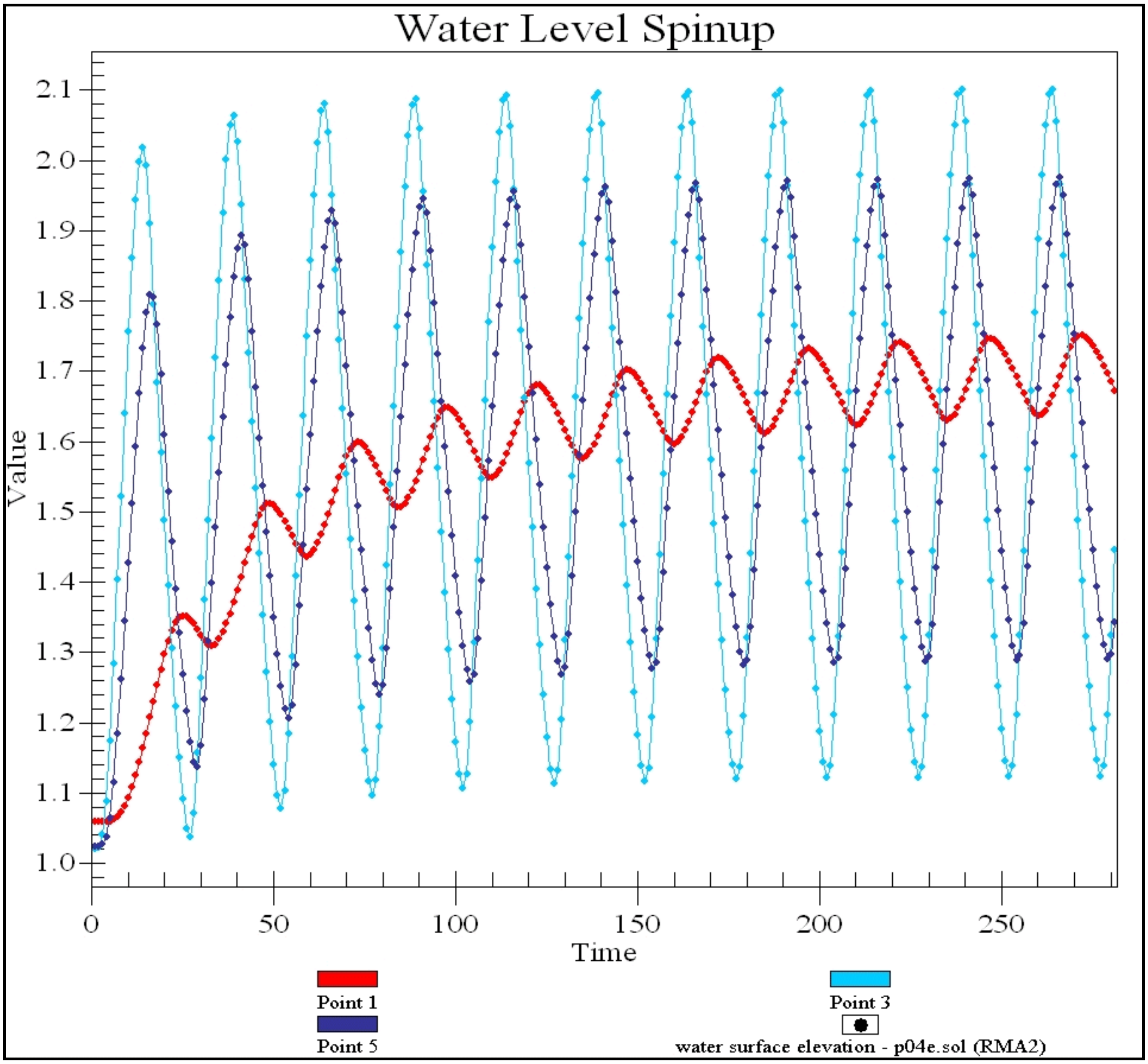

Figure 3.11. Example RMA-2 water level spinup for PR01 for normal low-flow conditions.

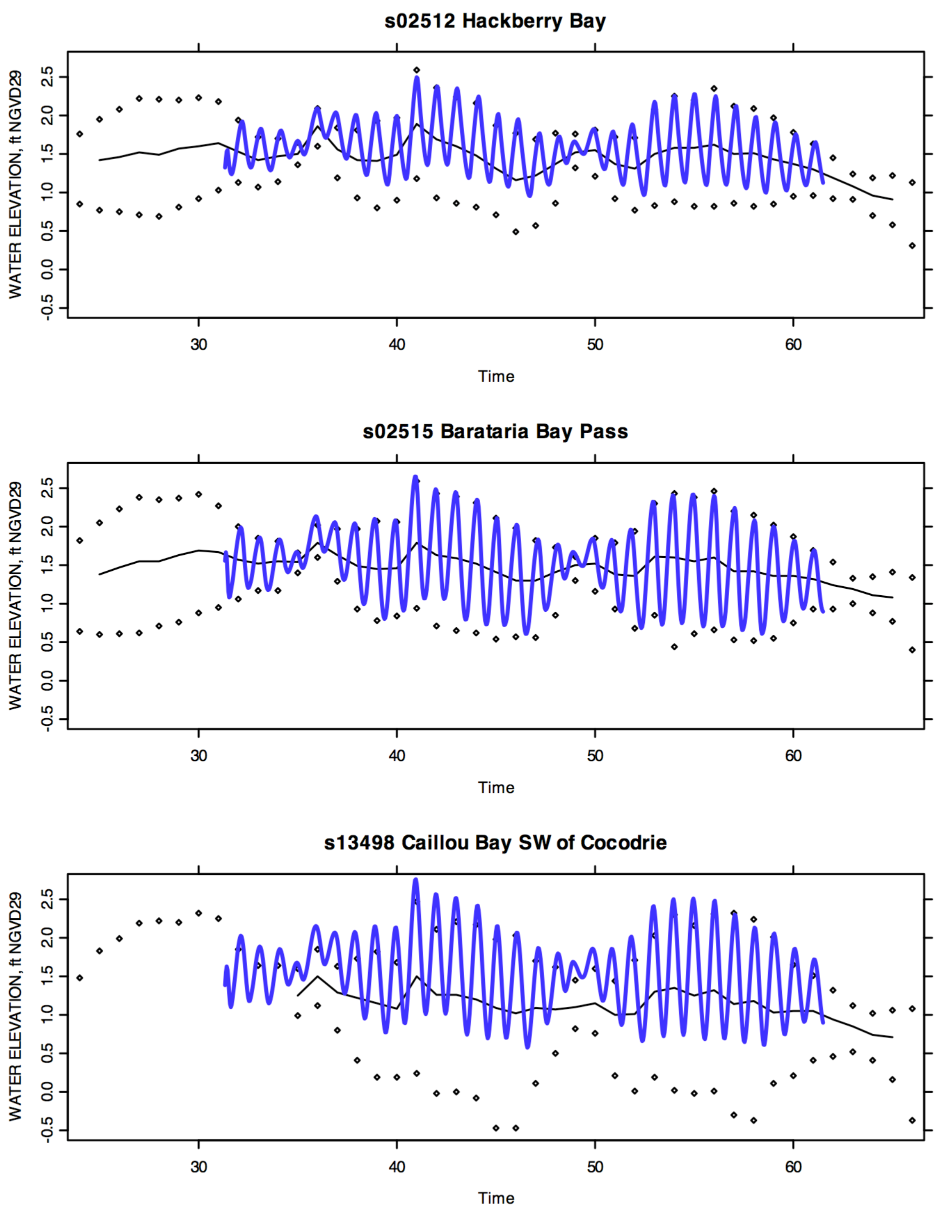

Figure 3.12a. Field versus model water level comparisons for June 2002 stations 3, 4, and 13.

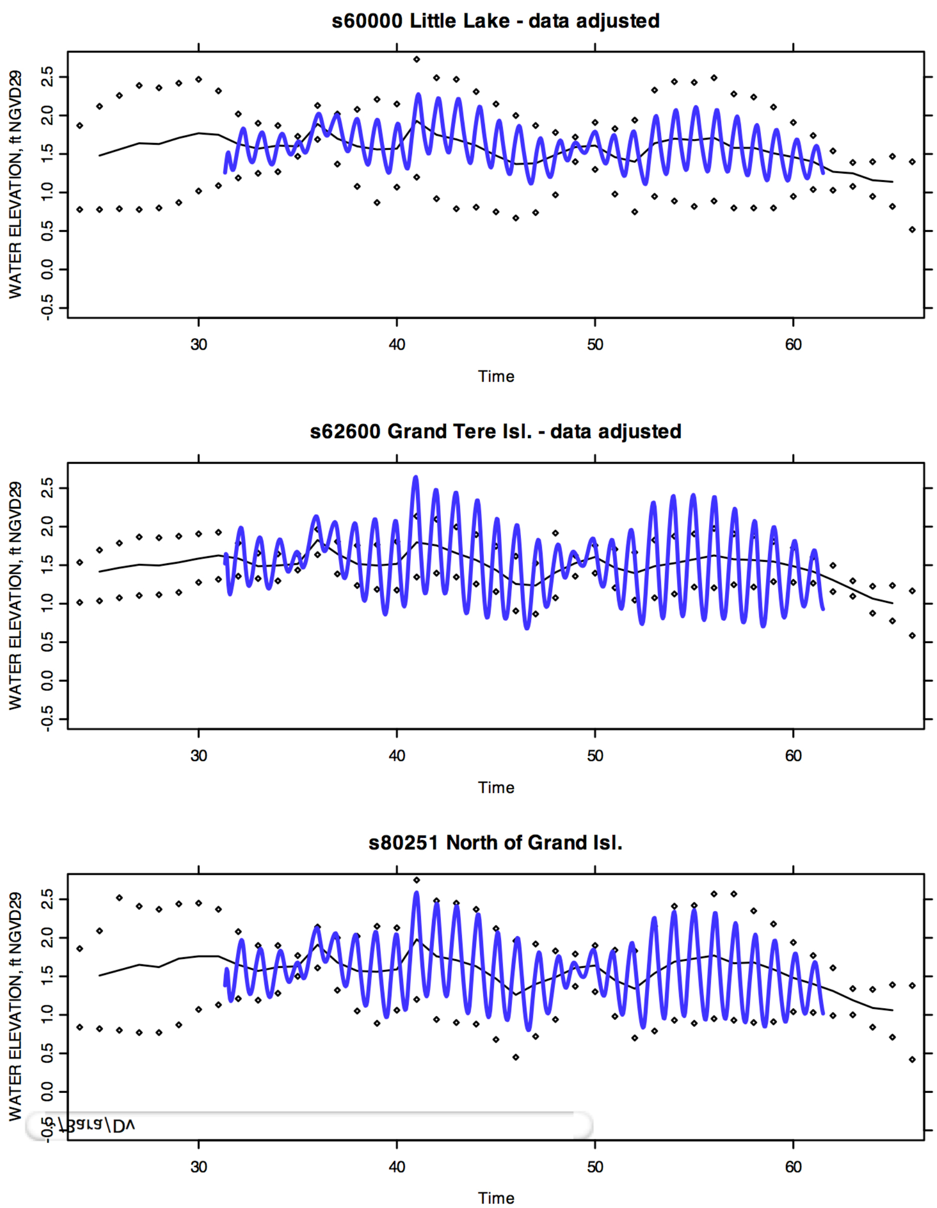

Figure 3.12b. Field versus model water level comparisons for June 2002 stations 10, 11, and 2.

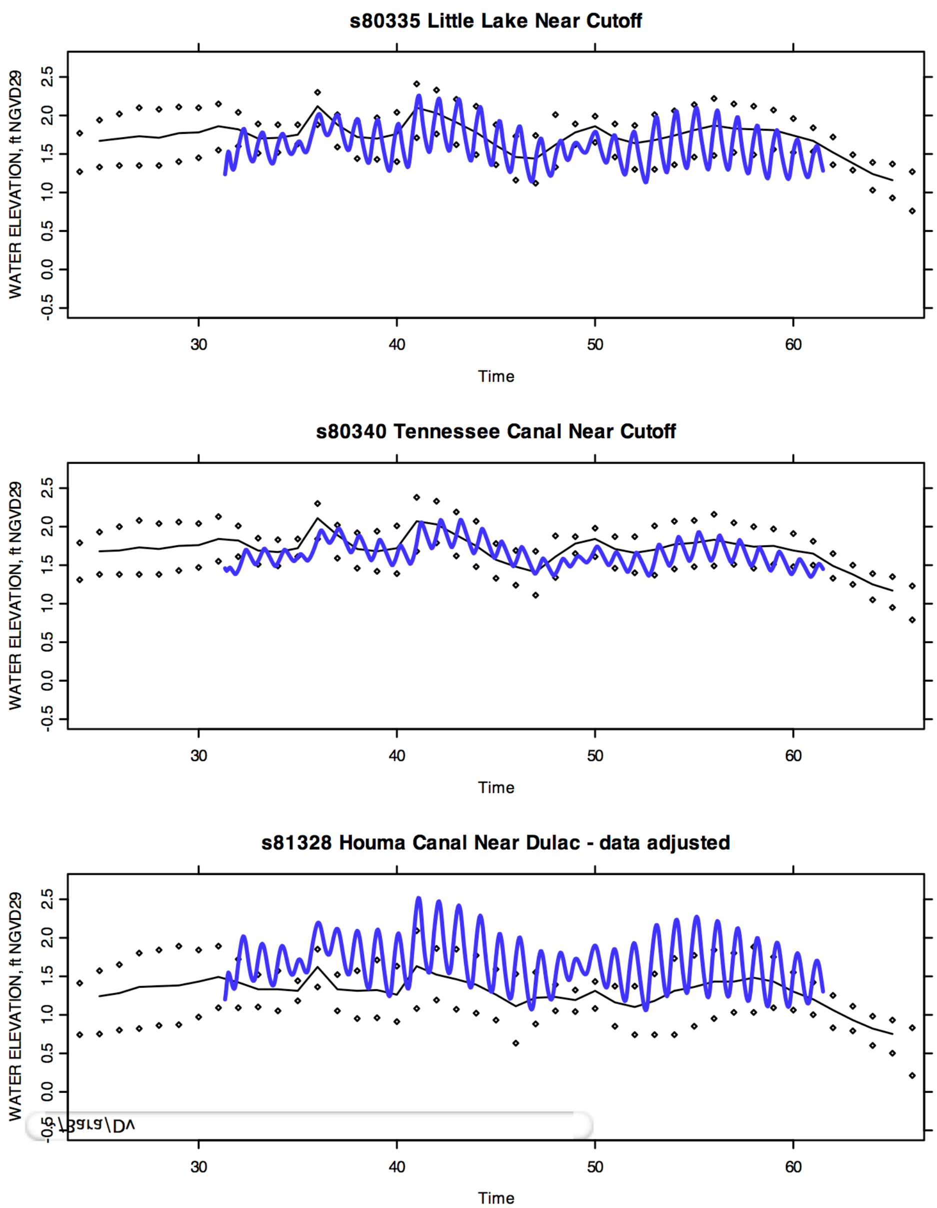

Figure 3.12c. Field versus model water level comparisons for June 2002 stations 5, 14, and 6.

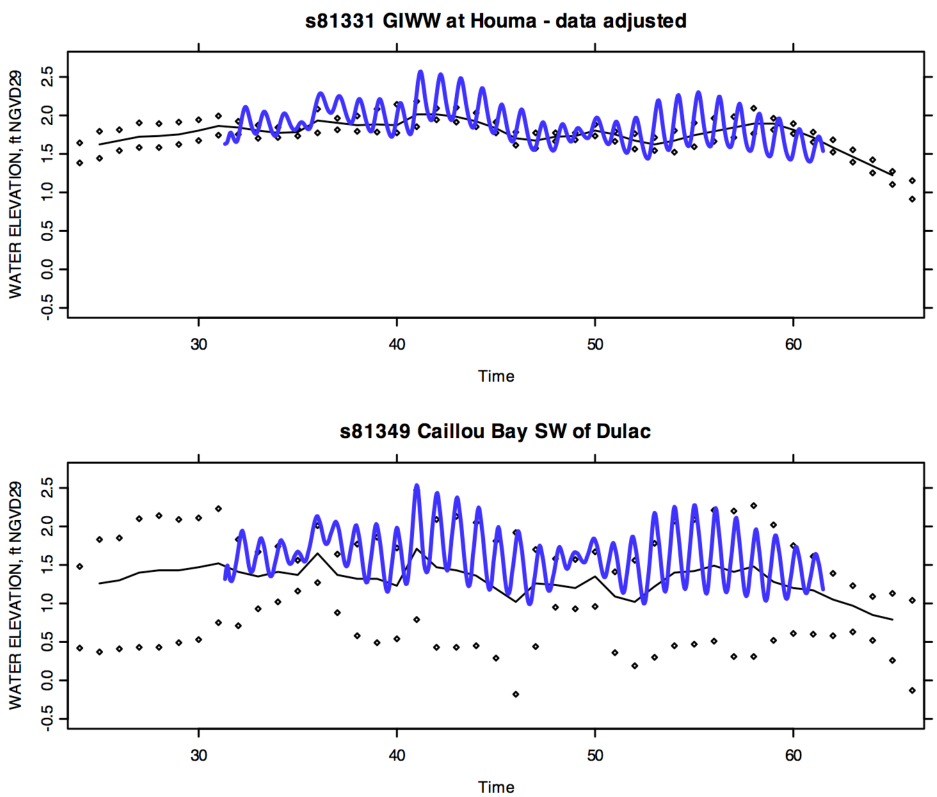

Figure 3.12d. Field versus model water level comparisons for June 2002 stations 7 and 8.

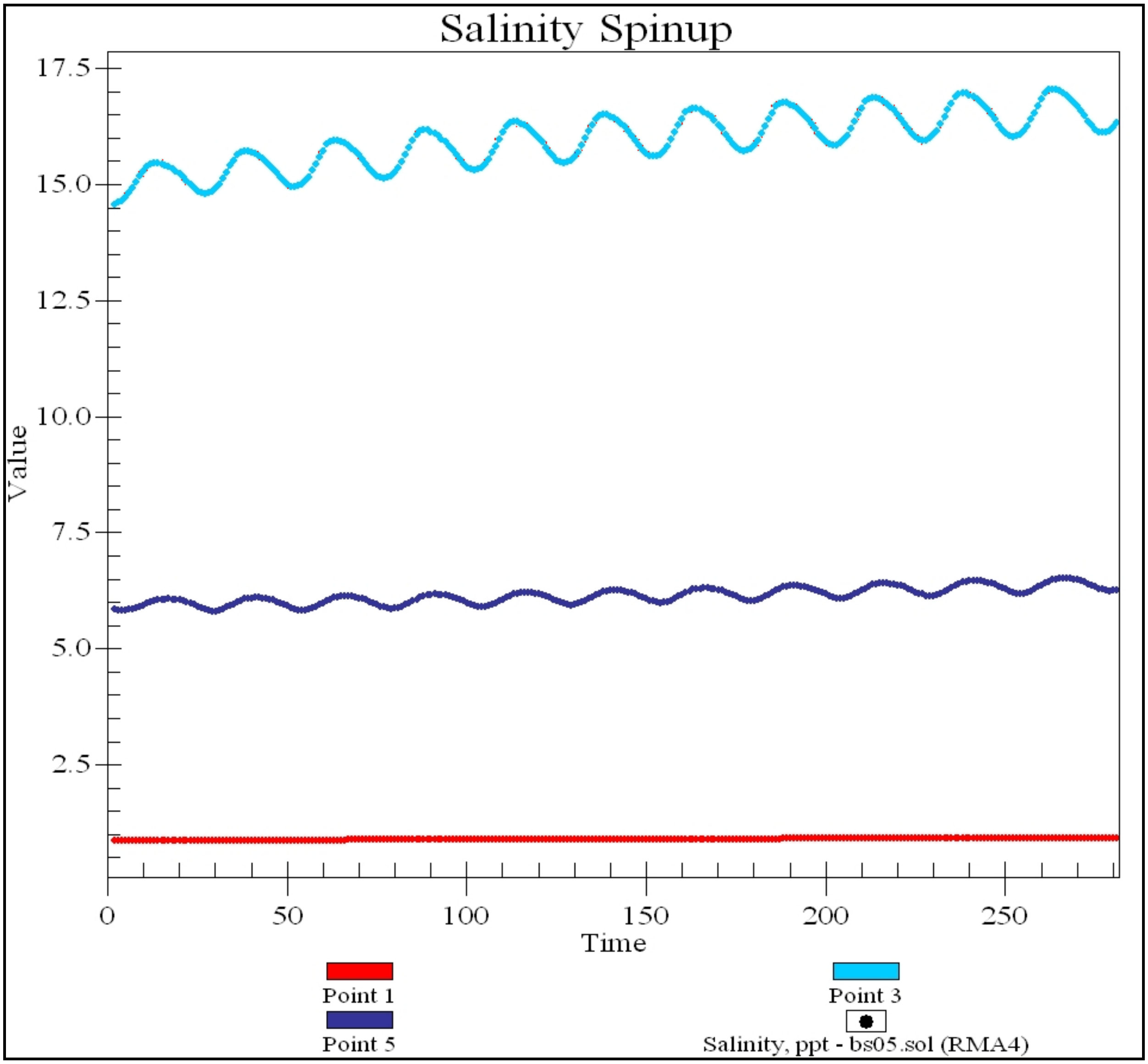

Figure 3.13. Example RMA-4 spinup for Base condition and normal low-flow conditions.

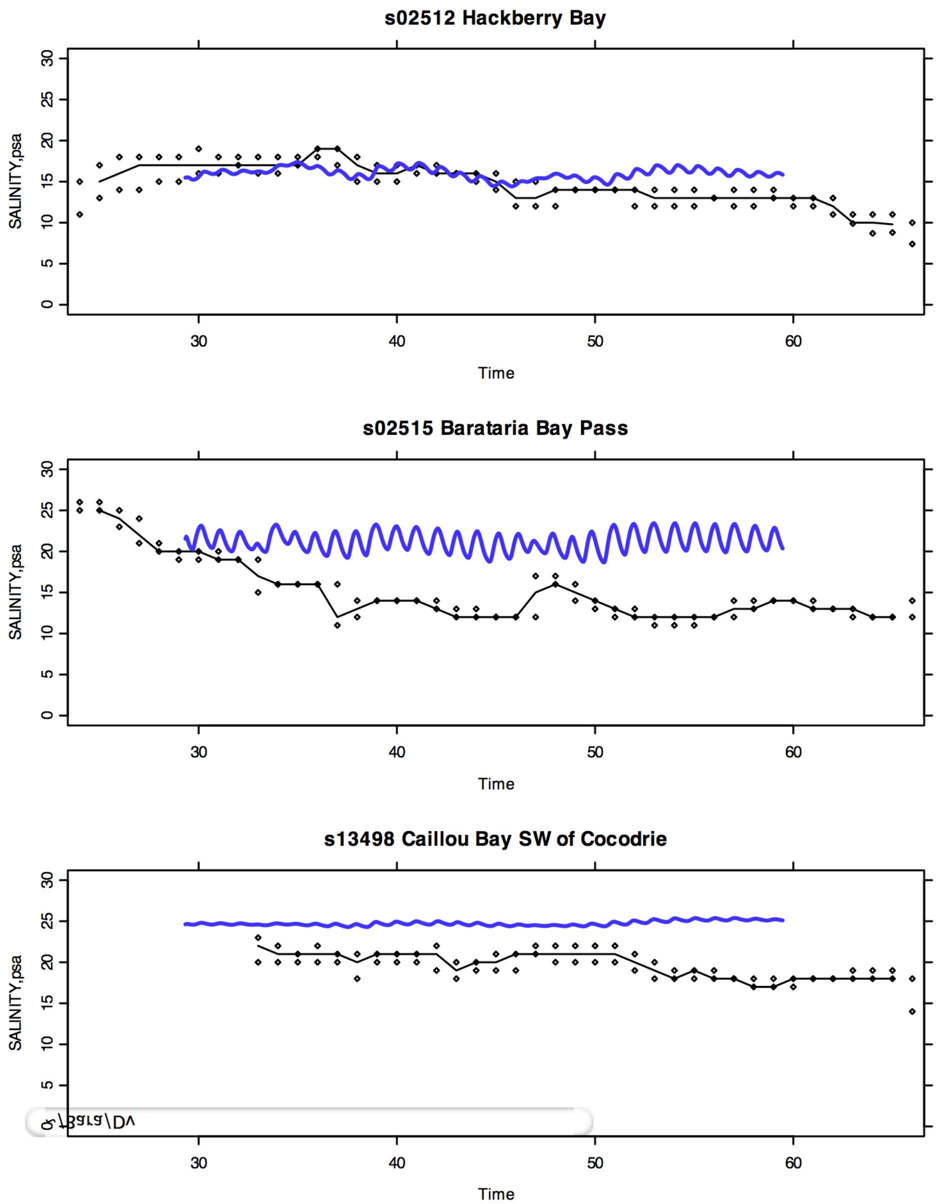

Figure 3.14a. Field versus model salinity comparisons for June 2002 stations 3, 4, and 13.

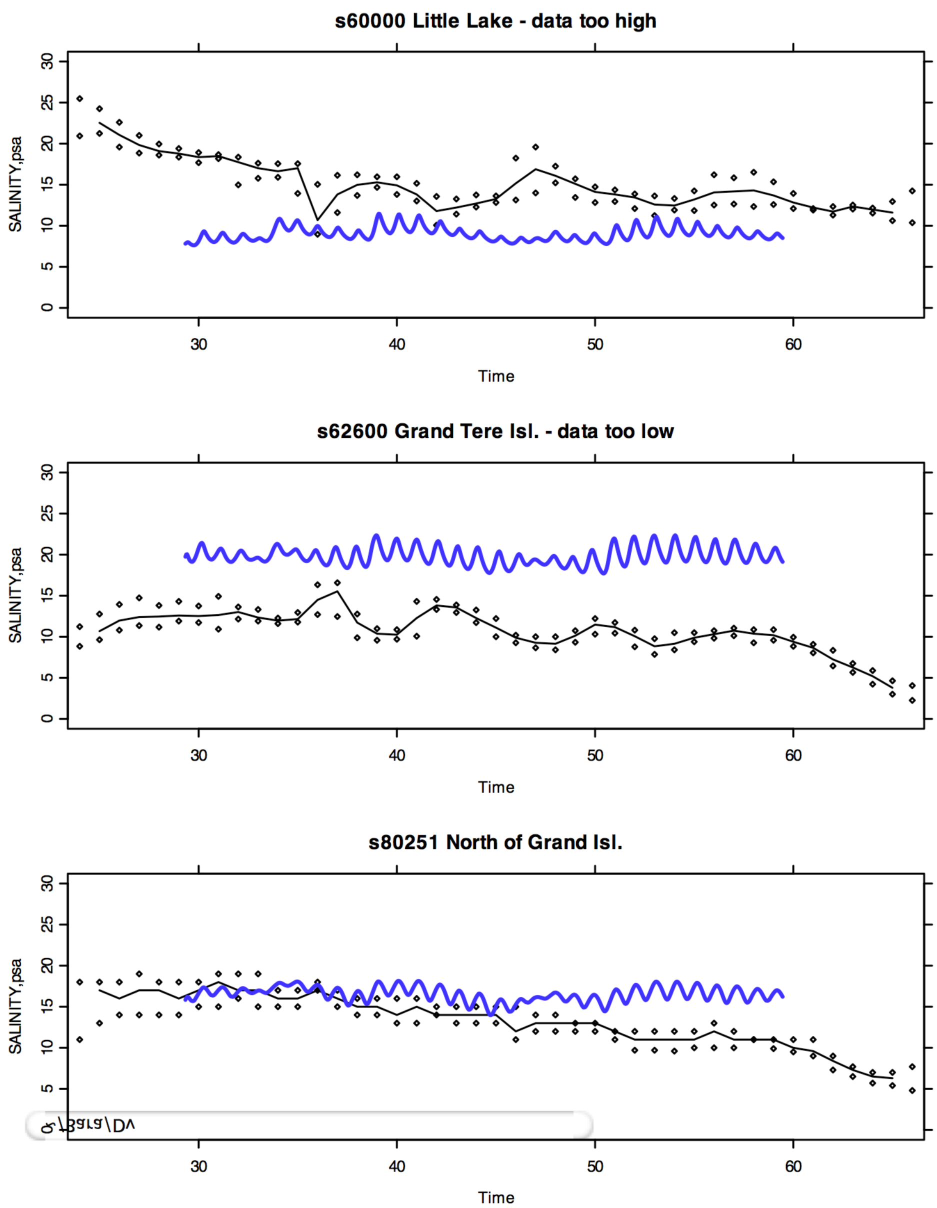

Figure 3.14b. Field versus model salinity comparisons for June 2002 stations 10, 11, and 2.

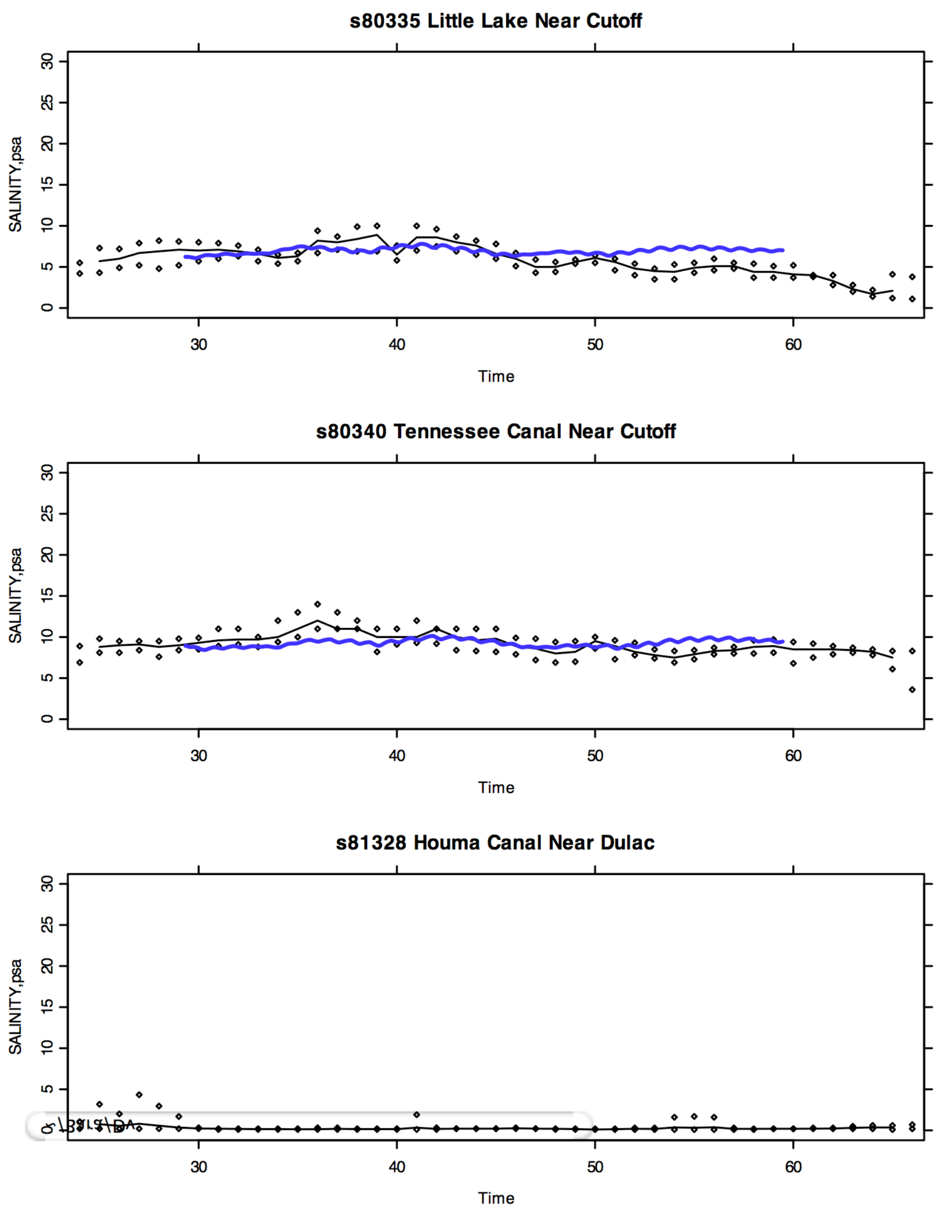

Figure 3.14c. Field versus model salinity comparisons for June 2002 stations 5, 14, and 6.

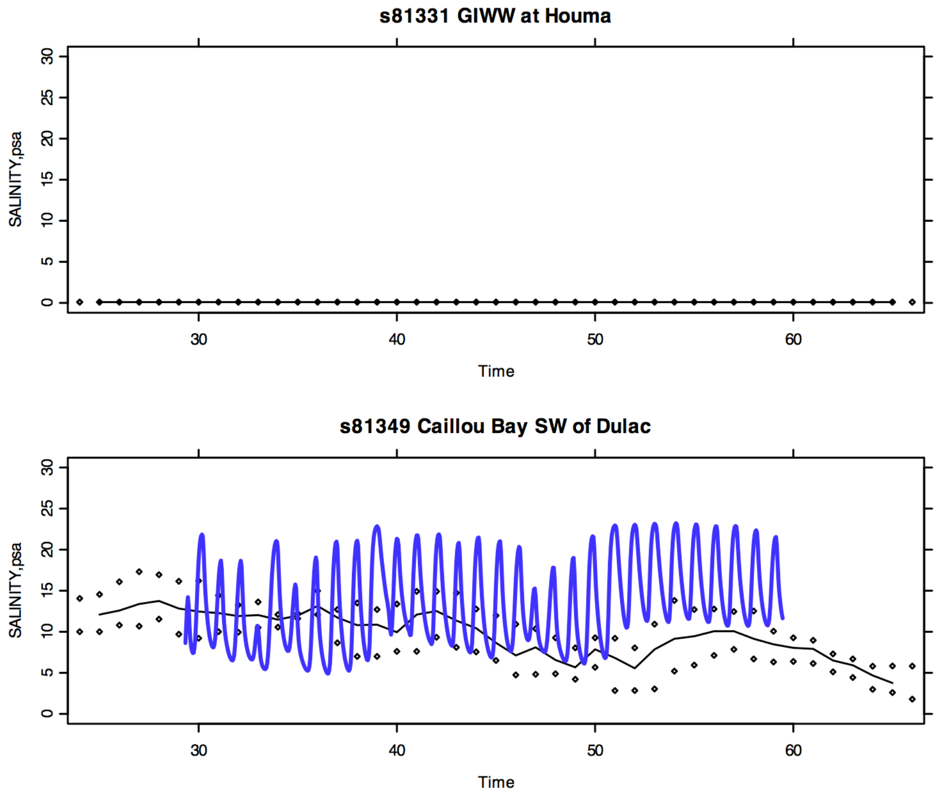

Figure 3.14d. Field versus model salinity comparisons for June 2002 stations 7 and 8.

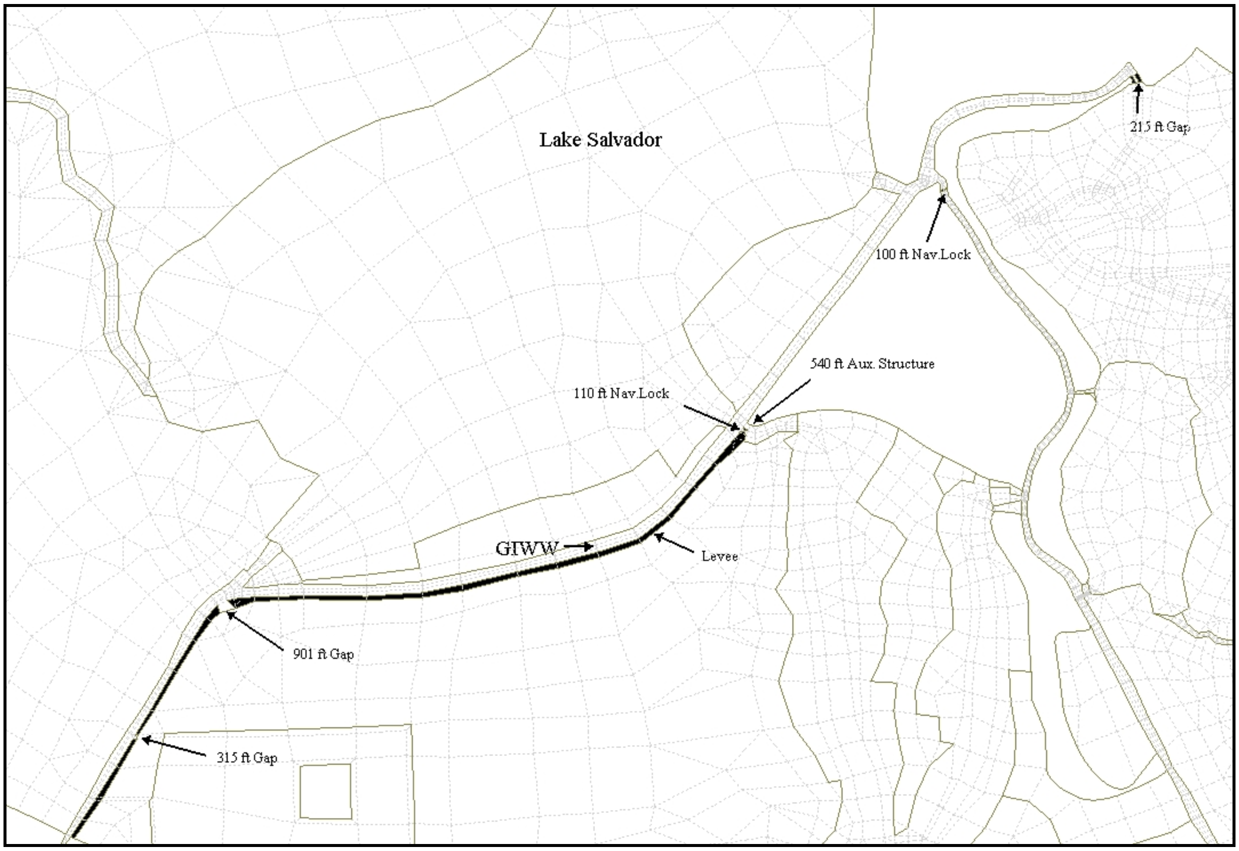

Figure 3.15. Locations of plan openings along Levee 1 alignment.

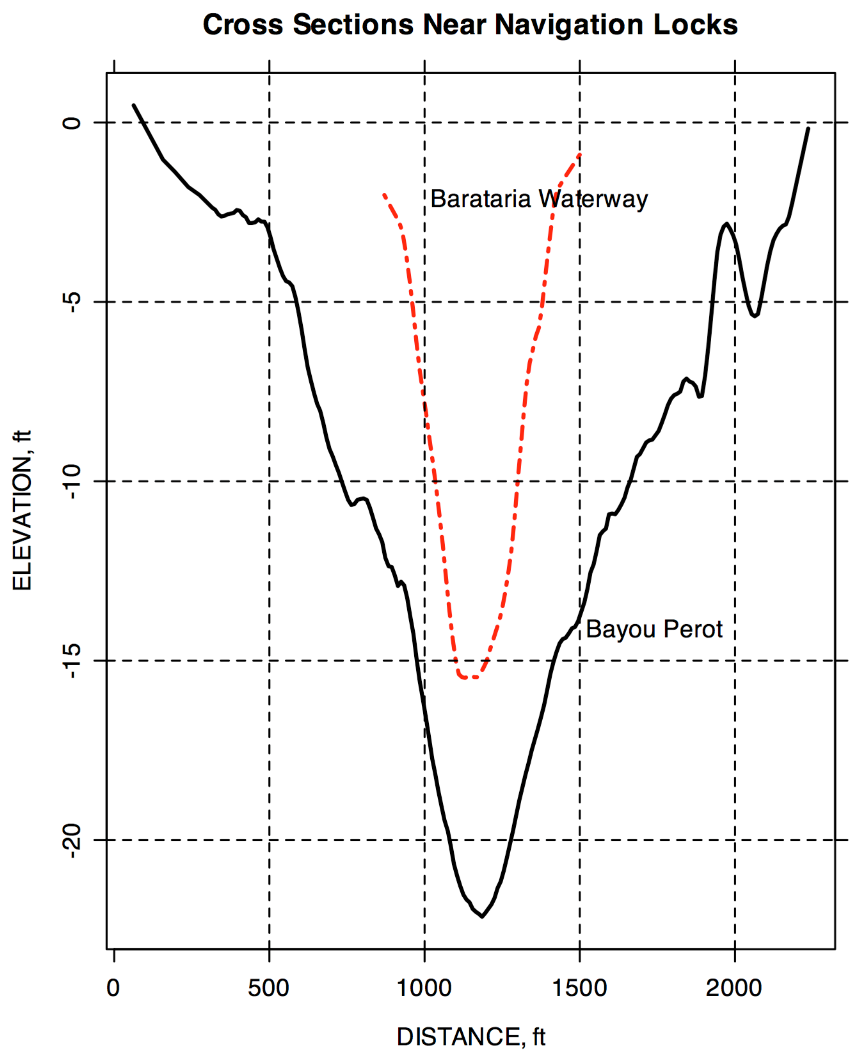

Figure 3.16. Cross sections at Bayou Perot Pass and Barataria Waterway near lock locations.

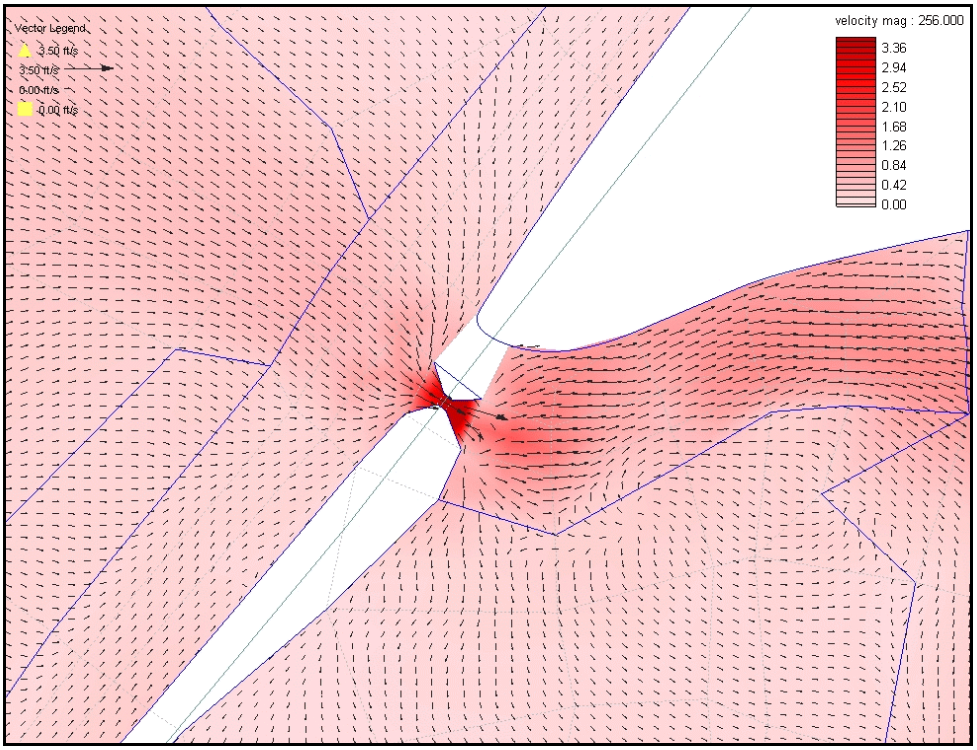

Figure 3.17. Flow through Bayou Perot navigation lock.

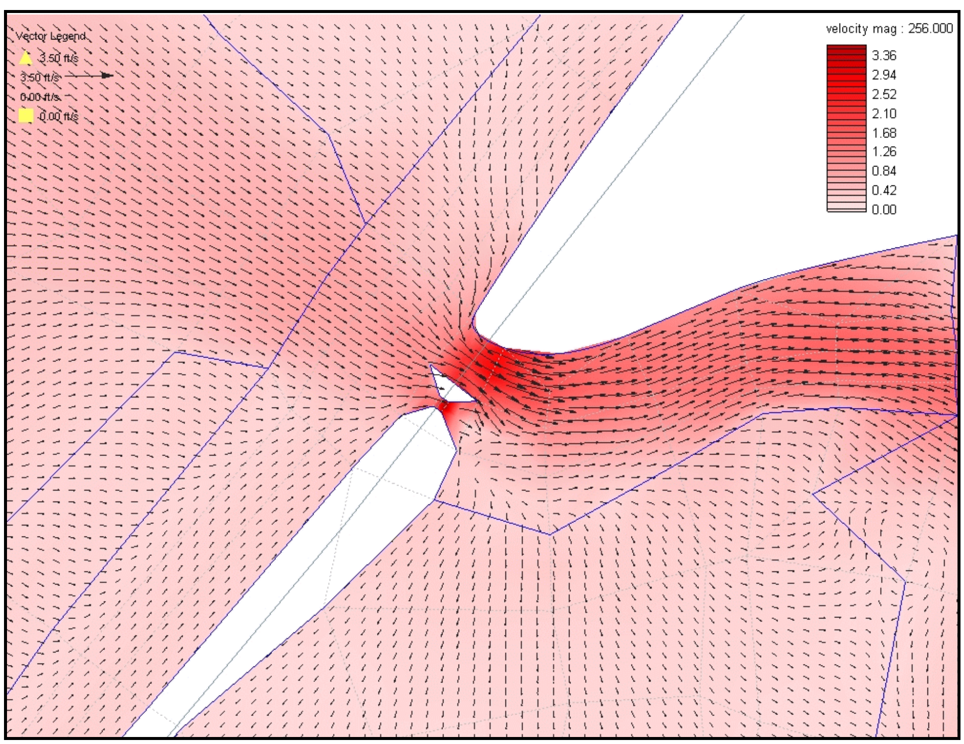

Figure 3.18. Flow through Bayou Perot navigation lock and auxiliary structure.

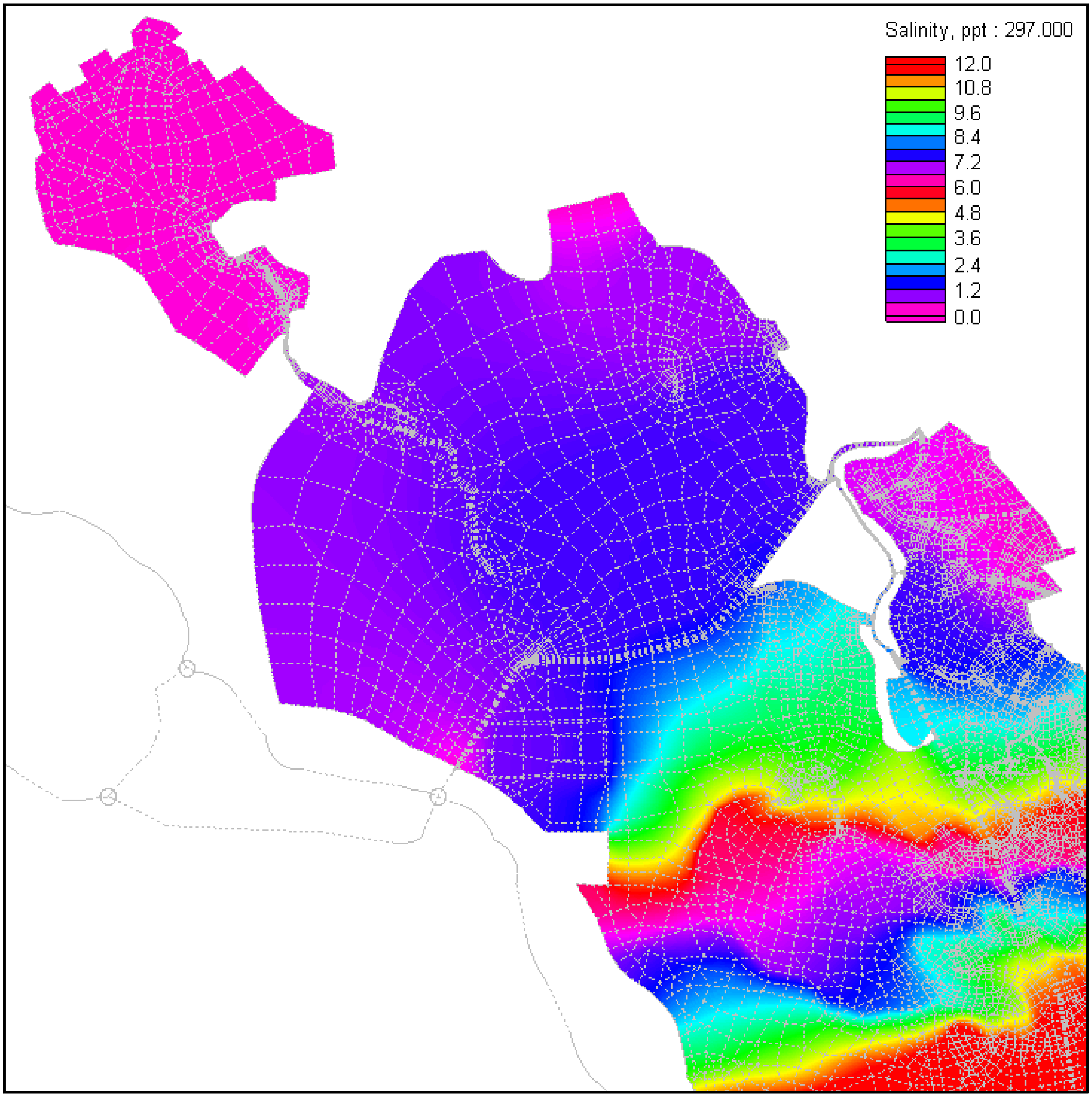

Figure 3.19. Base salinity field at hour 297 near high water.

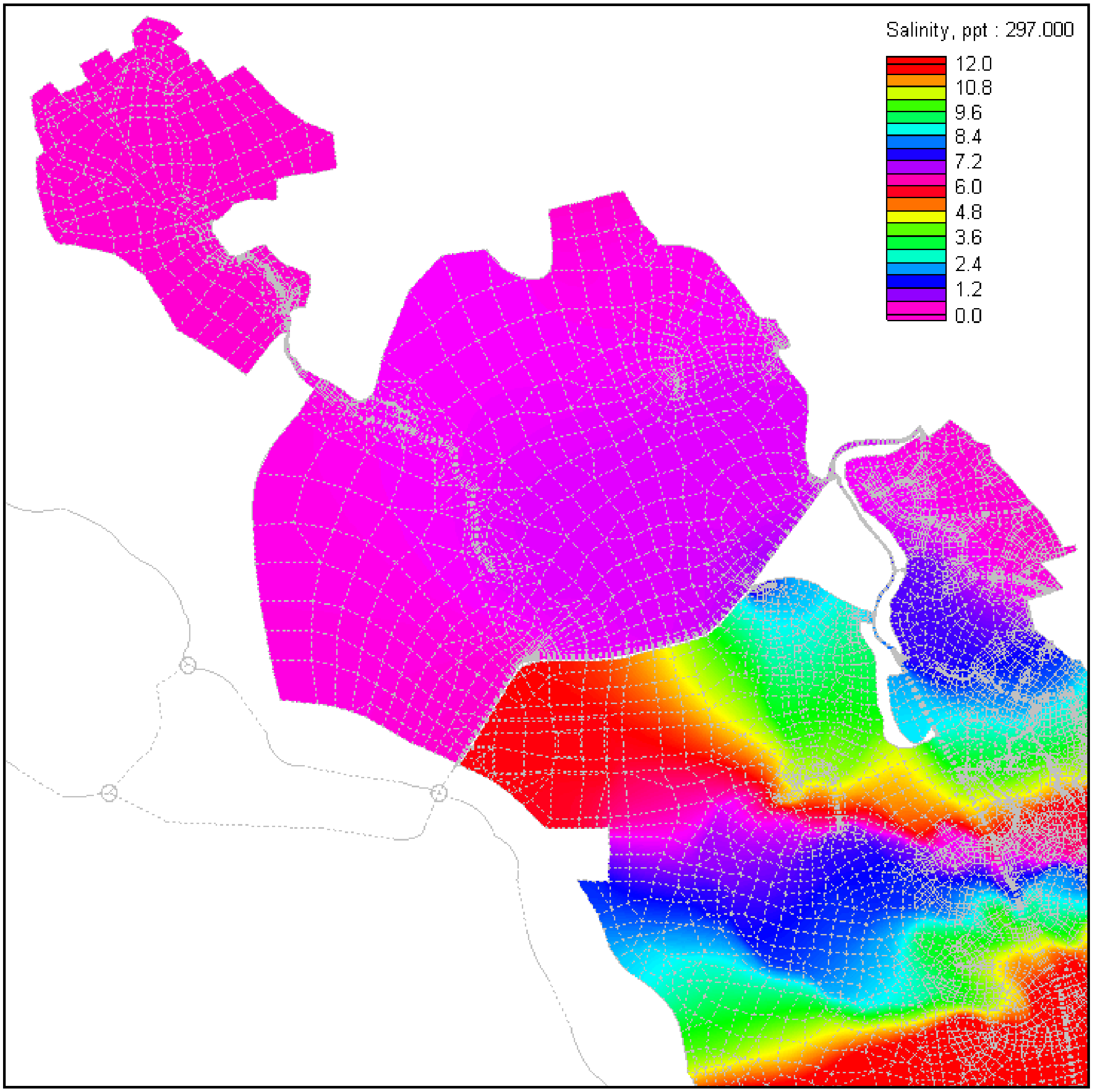

Figure 3.20. Plan PR01 salinity field at hour 297 near high water.

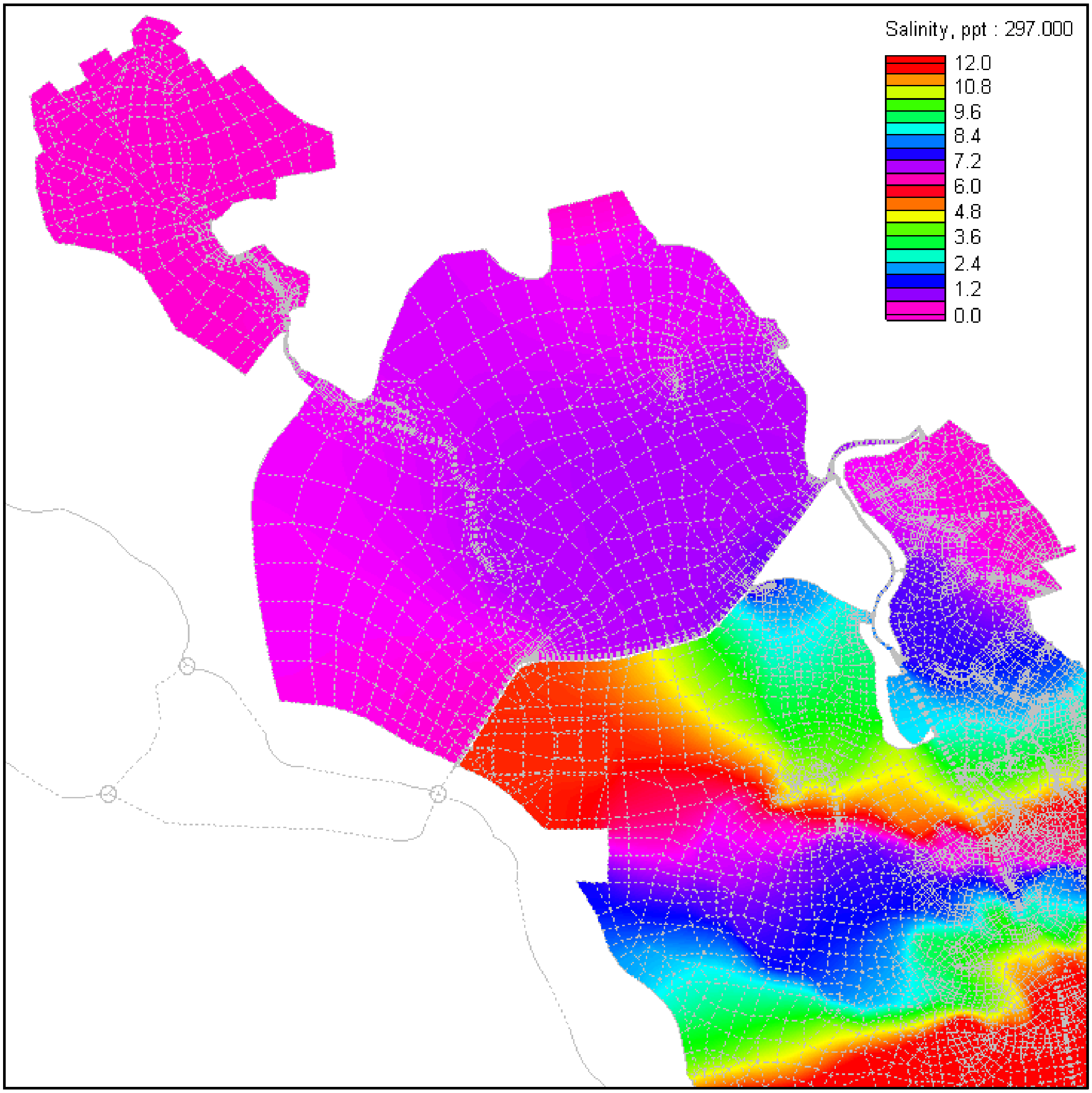

Figure 3.21. Plan PR02 salinity field at hour 297 near high water.

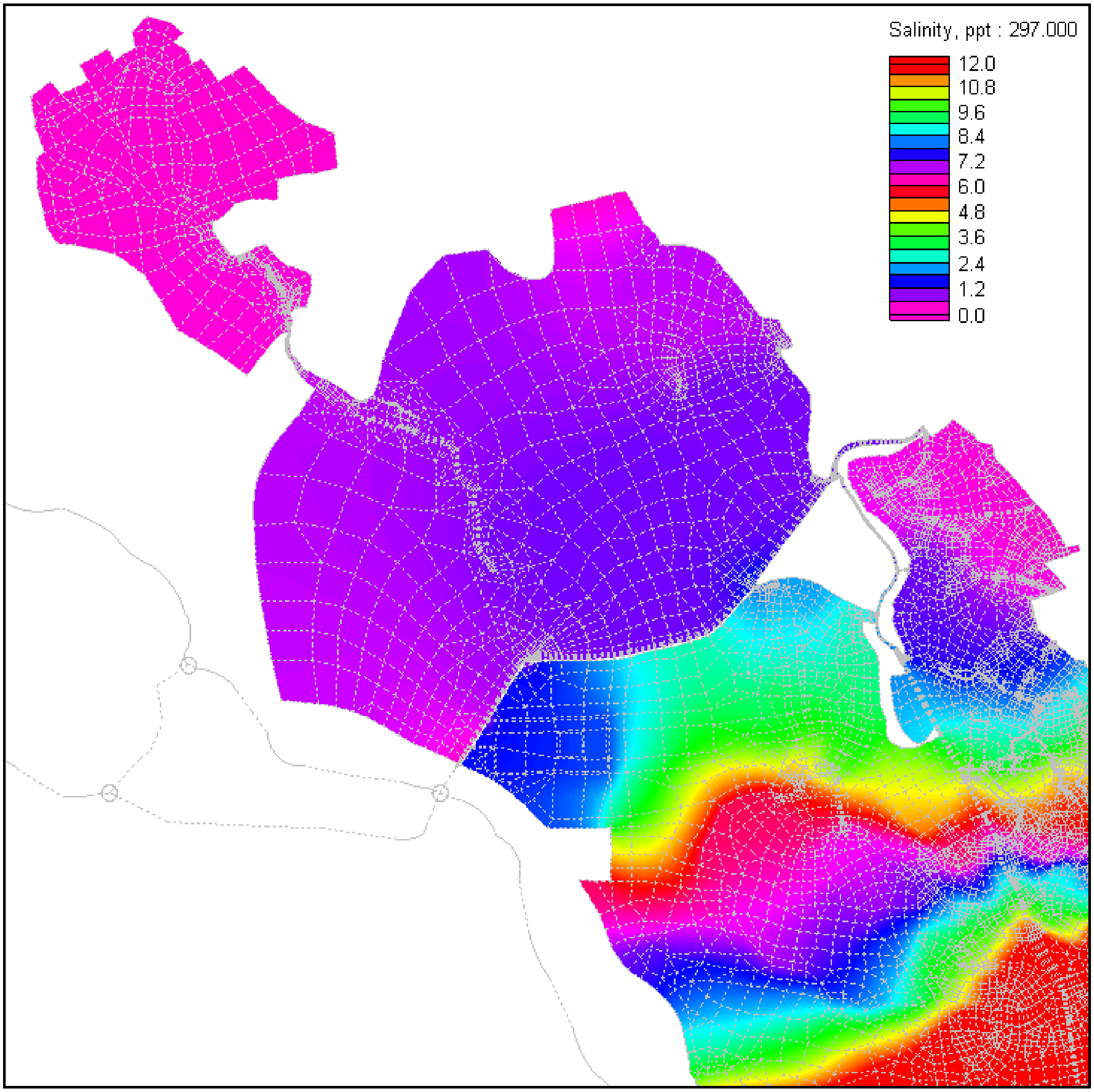

Figure 3.22. Plan PR03 salinity field at hour 297 near high water.

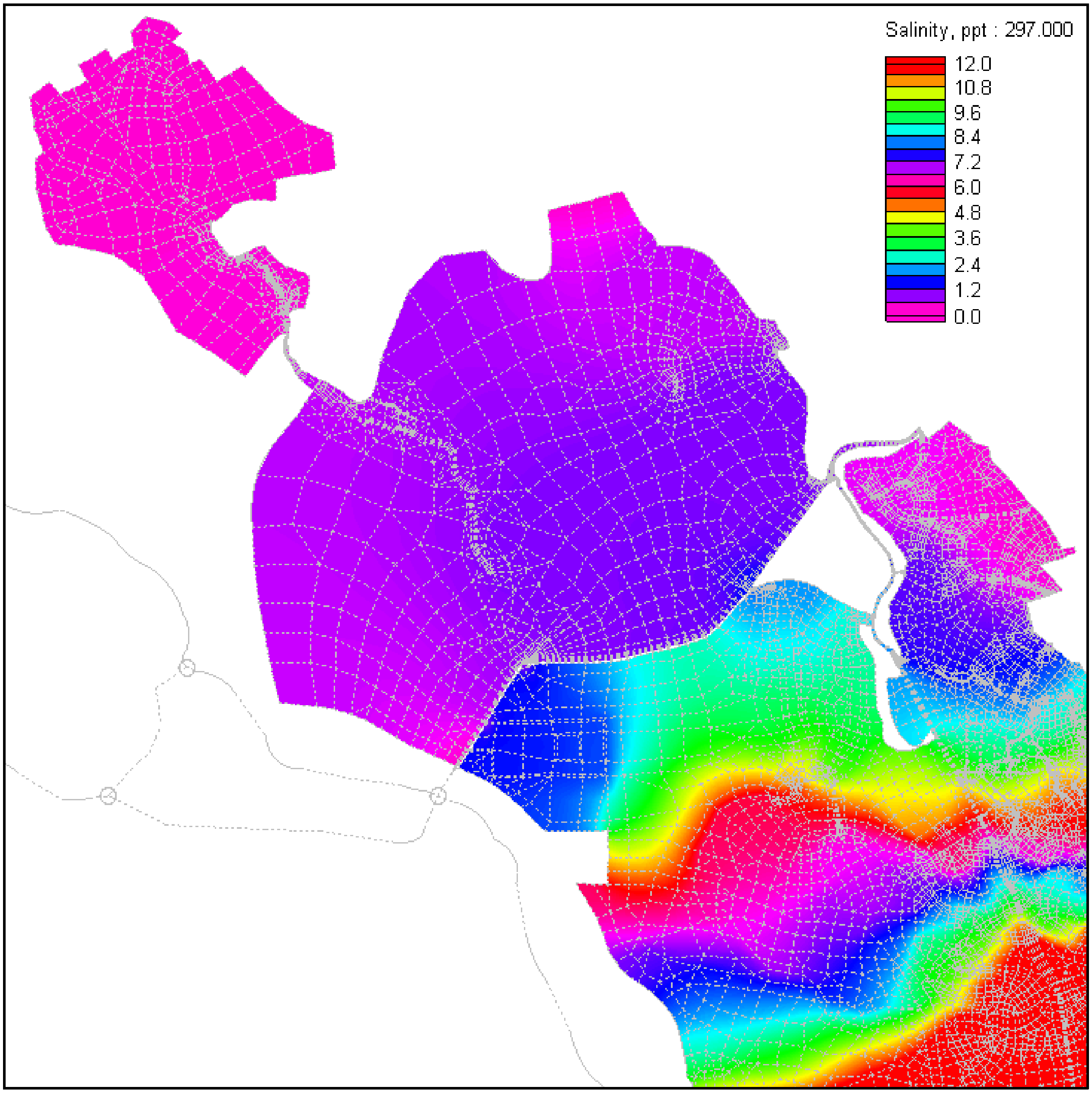

Figure 3.23. Plan PR04 salinity field at hour 297 near high water.

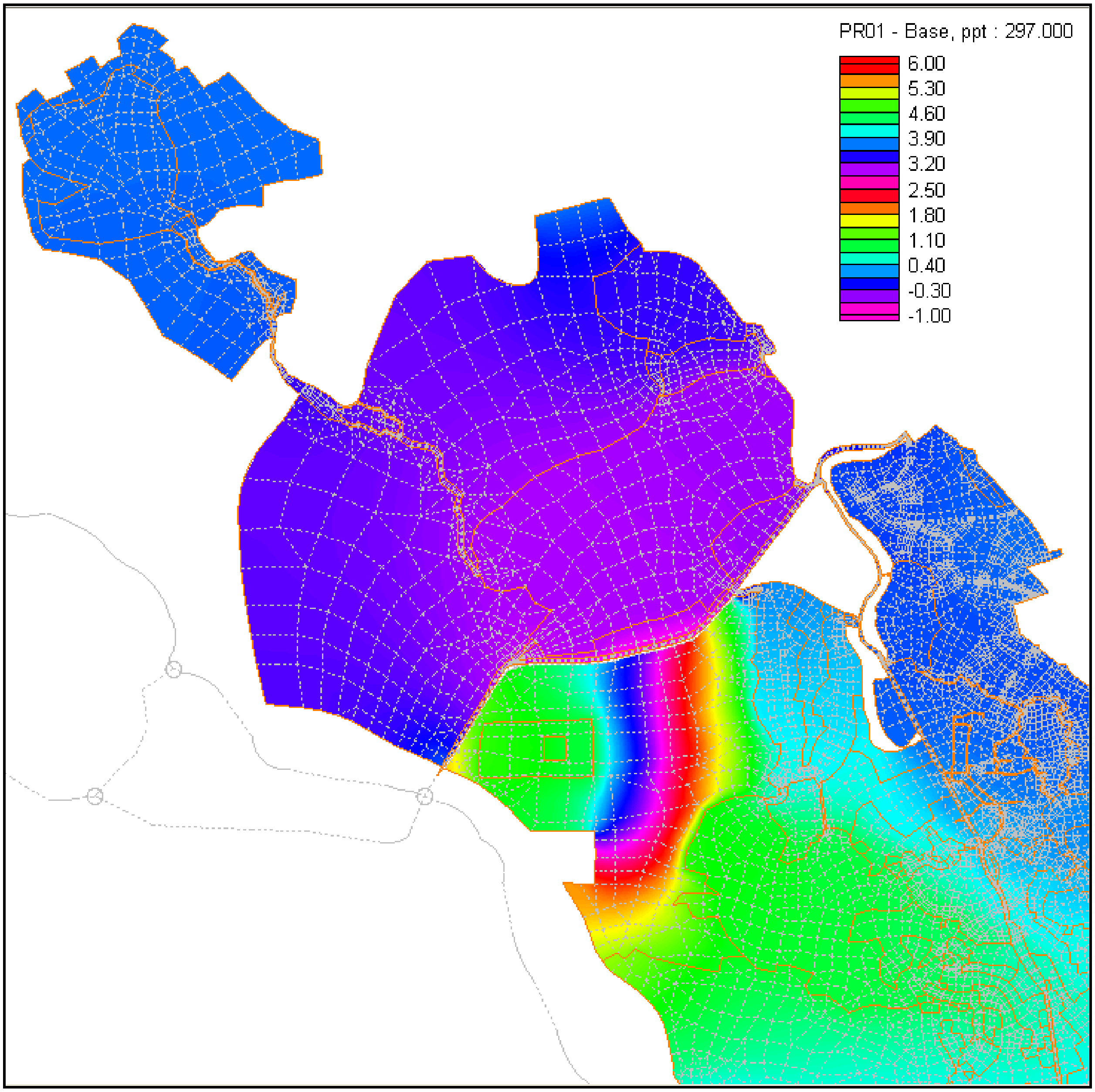

Figure 3.24. Plan PR01 salinity difference from Base at hour 297 near high water.

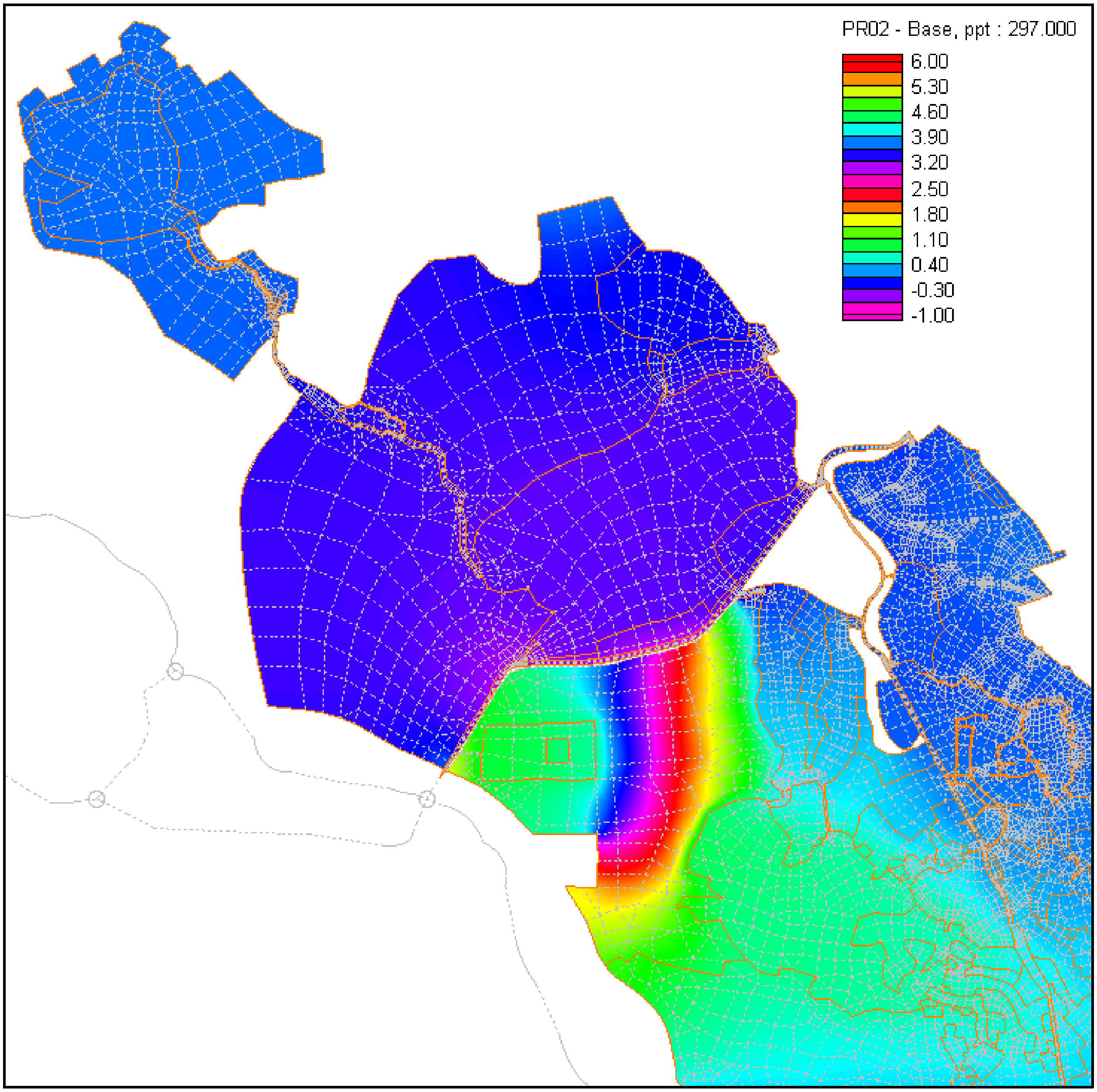

Figure 3.25. Plan PR02 salinity difference from Base at hour 297 near high water.

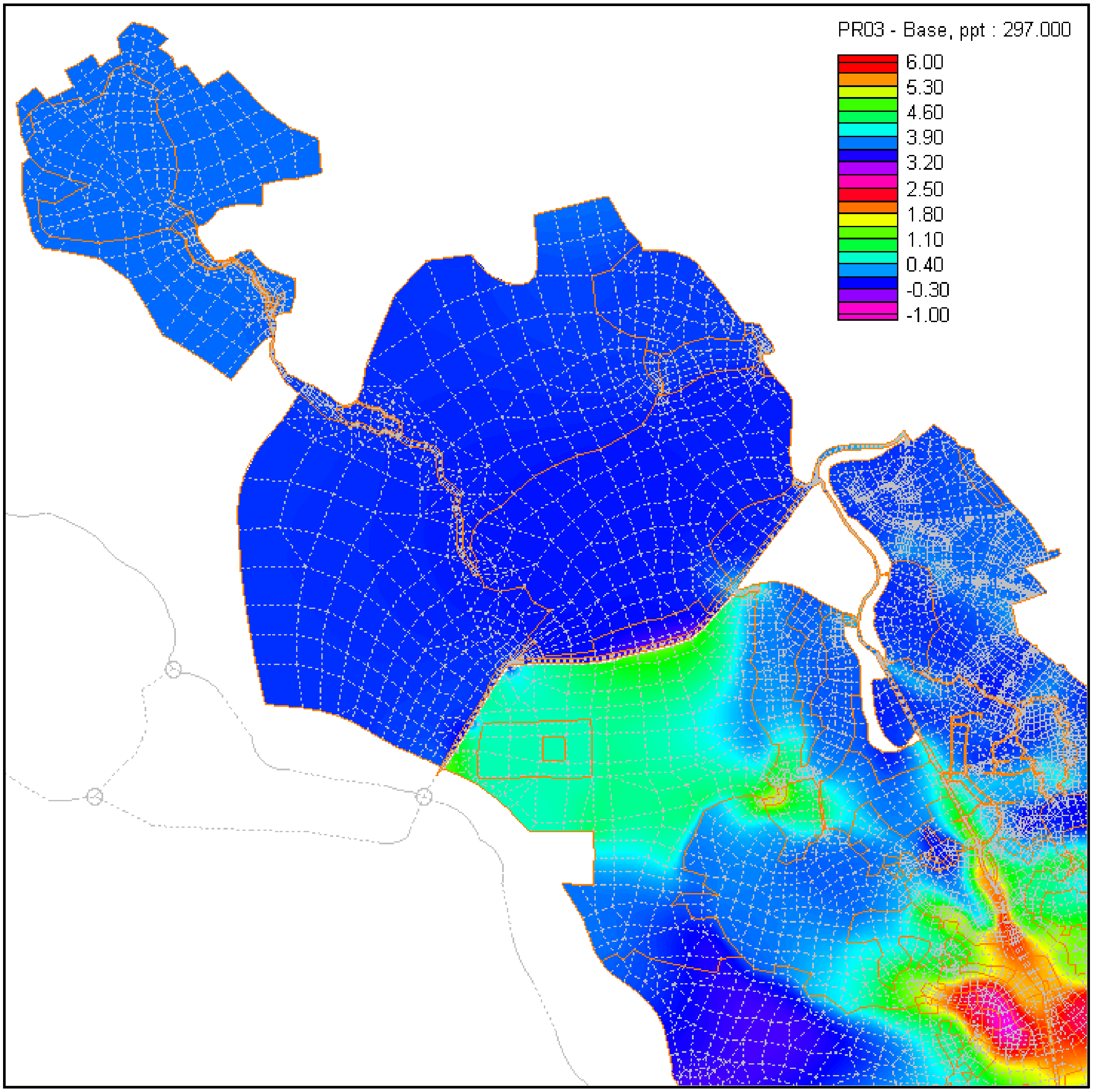

Figure 3.26. Plan PR03 salinity difference from Base at hour 297 near high water.

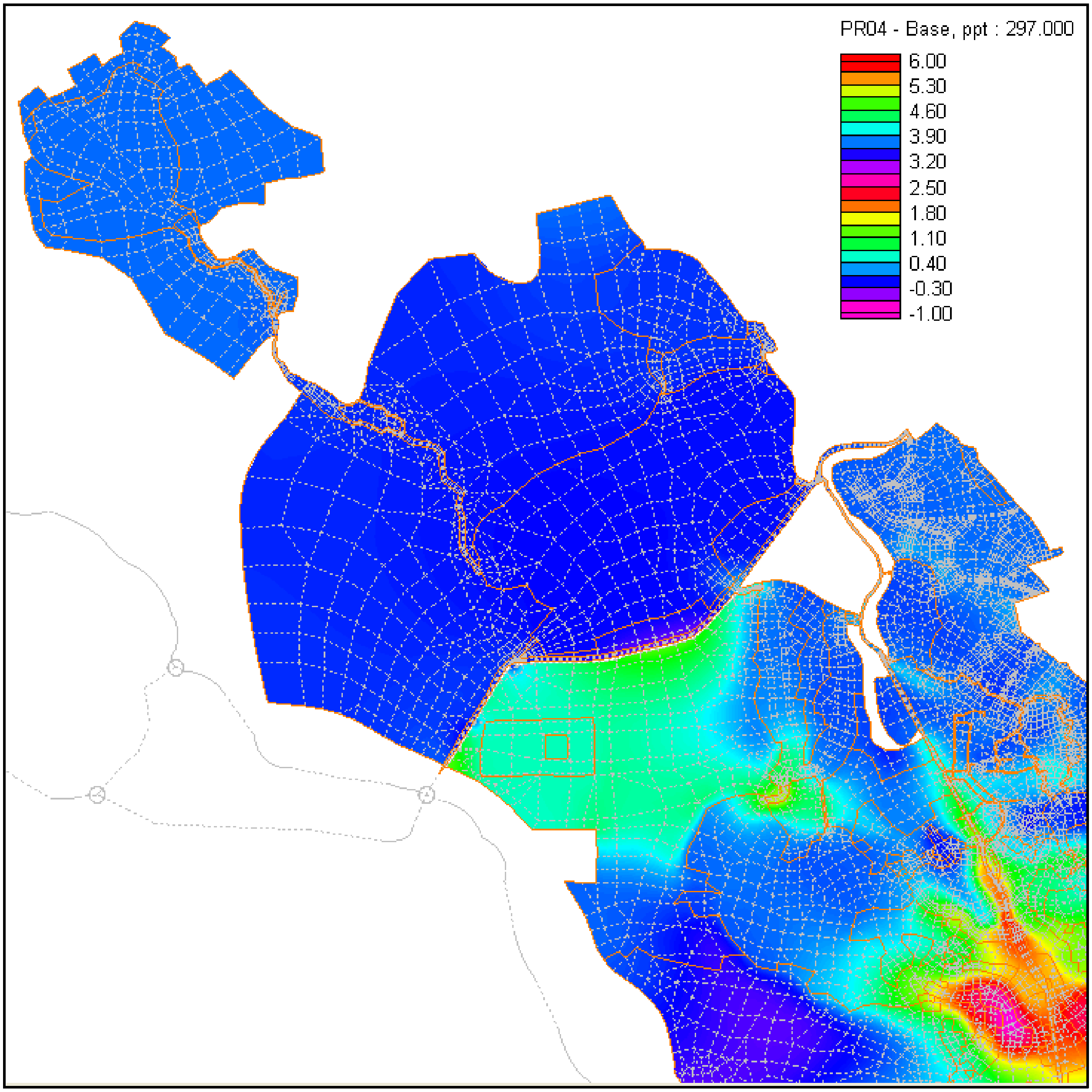

Figure 3.27. Plan PR04 salinity difference from Base at hour 297 near high water.

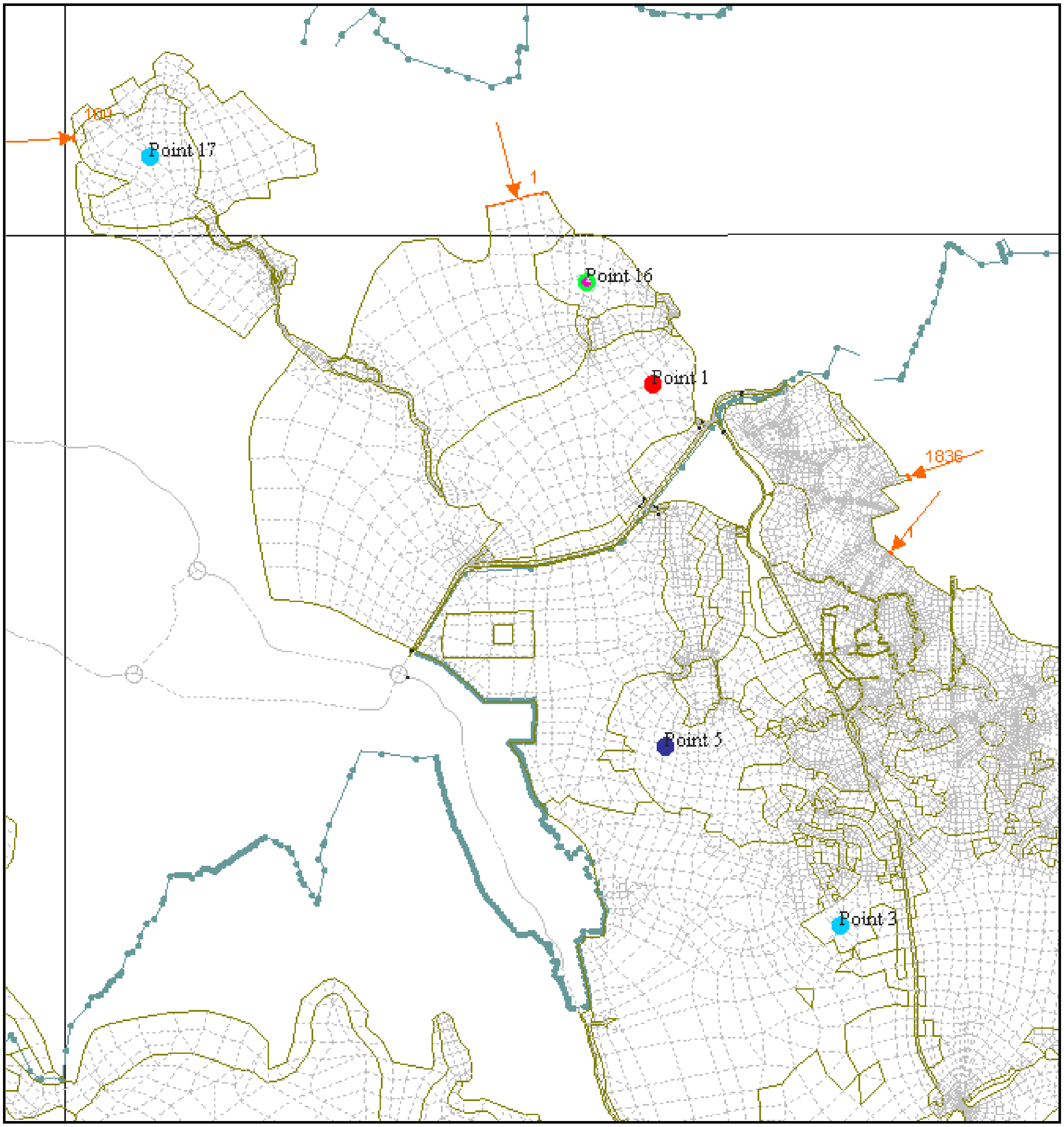

Figure 3.28. Location for the water level points presented in Tables 3.4 and 3.5.

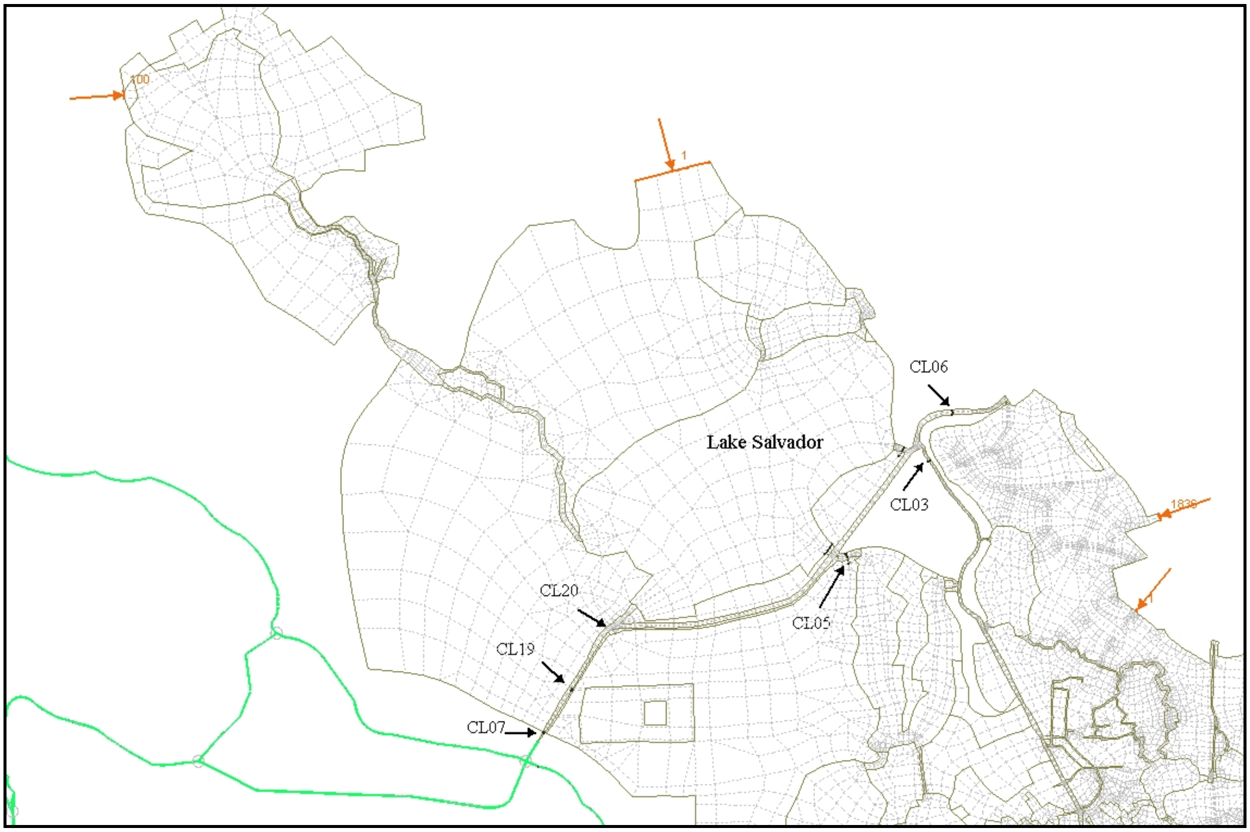

Figure 3.29. Discharge continuity line locations.

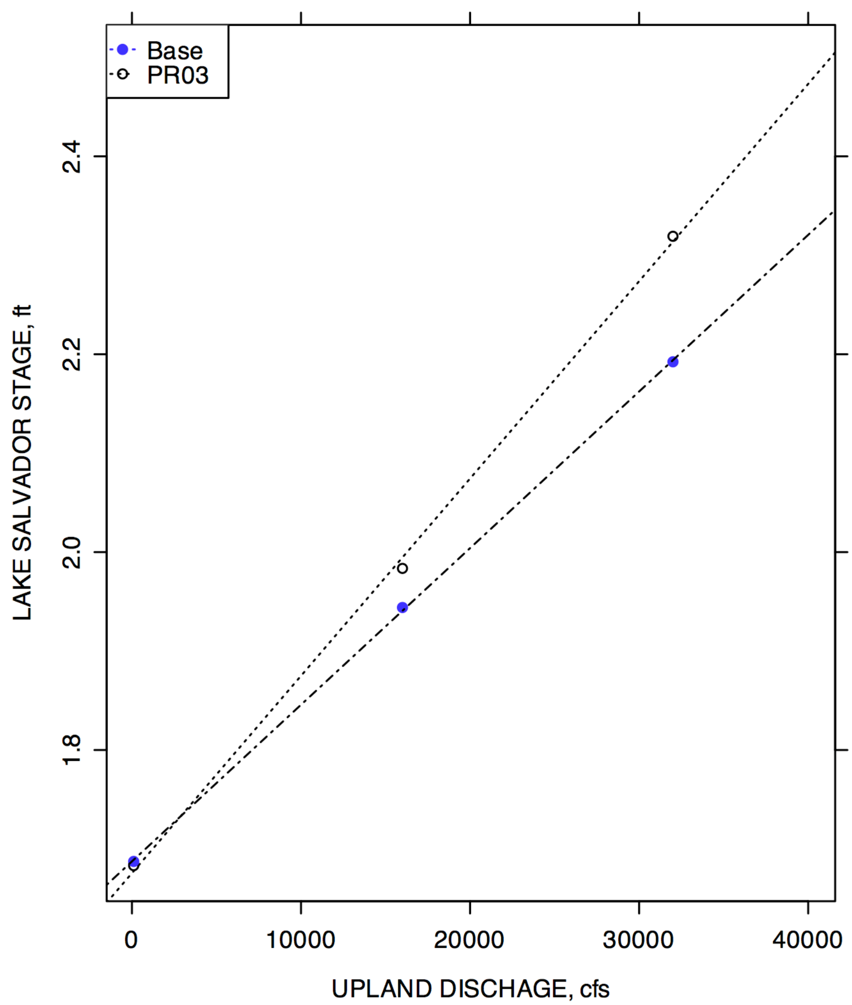

Figure 3.30. Lake Salvador stage-discharge relationships for the base and plan PR03.

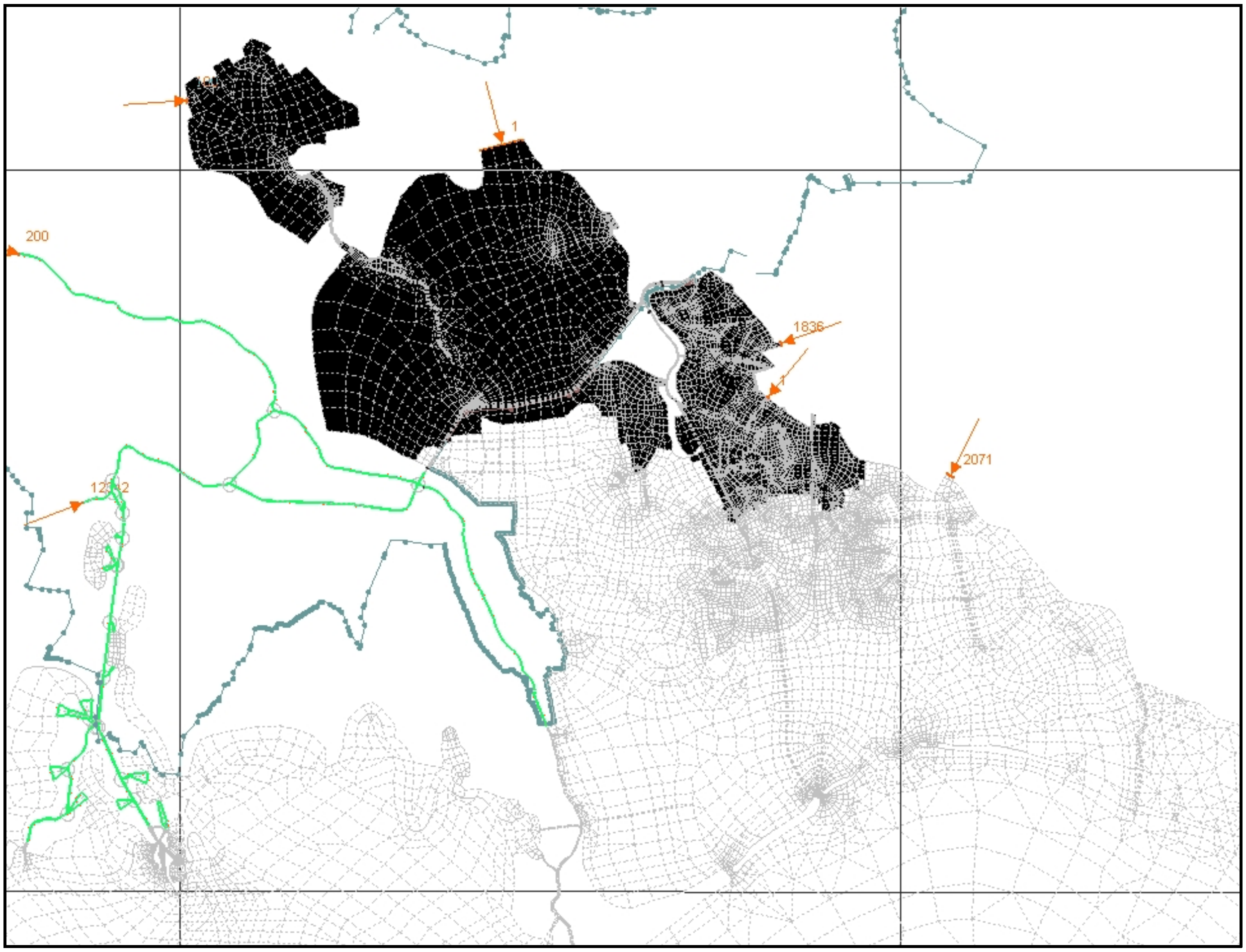

Figure 3.31. Rainfall area (black) used for the 2-yr hydrograph simulation.

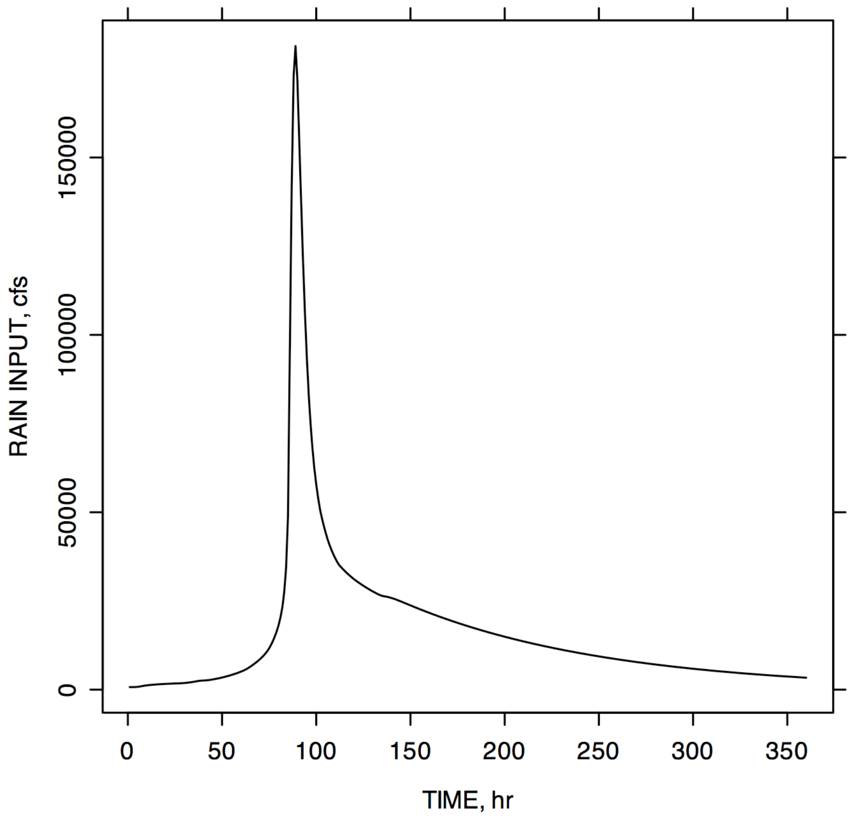

Figure 3.32. Rainfall hydrograph for the 2-yr event simulation.

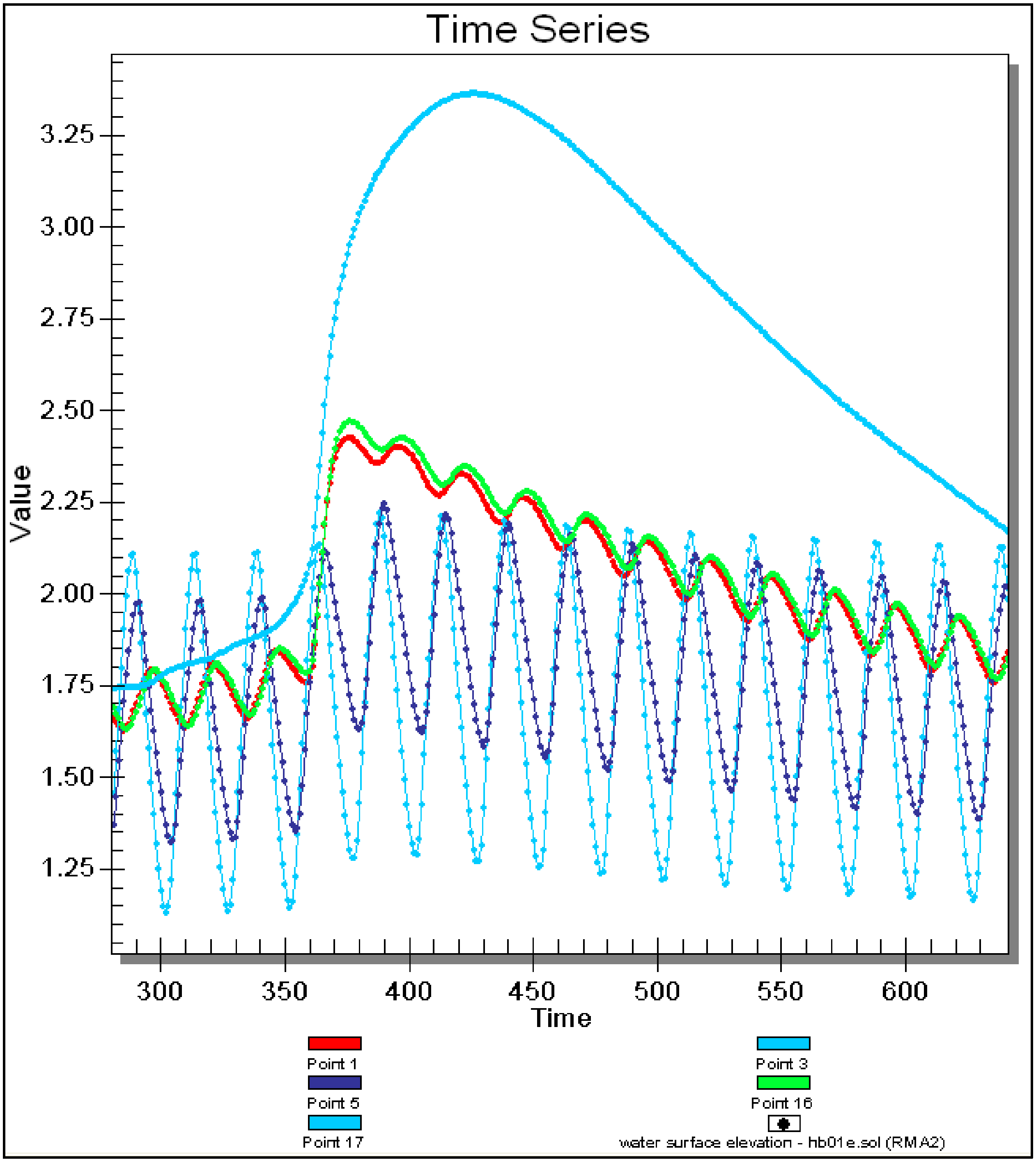

Figure 3.33. Base water levels for the 2-yr hydrograph at select points.

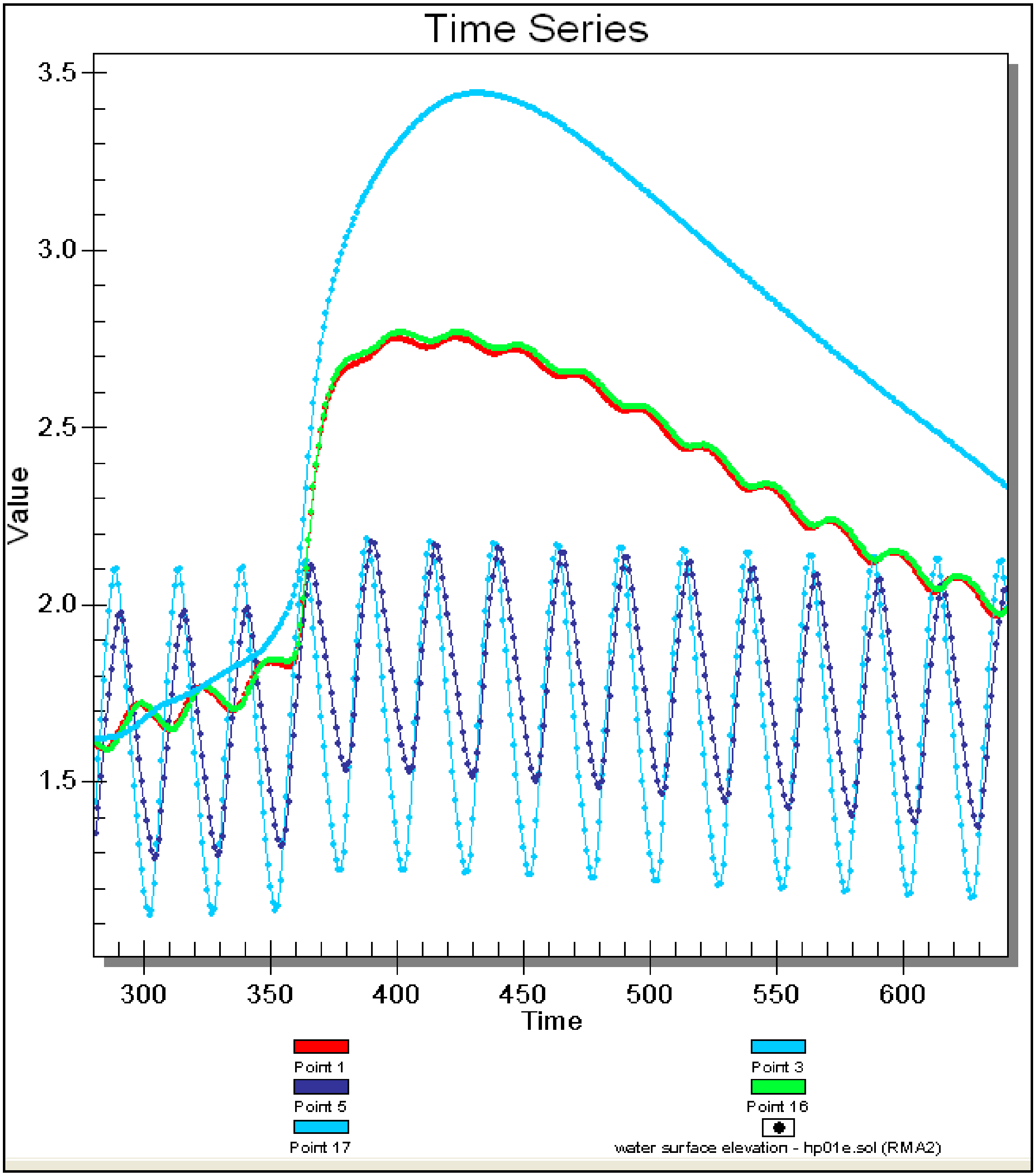

Figure 3.34. Plan PR01 water levels for the 2-yr hydrograph at select points.

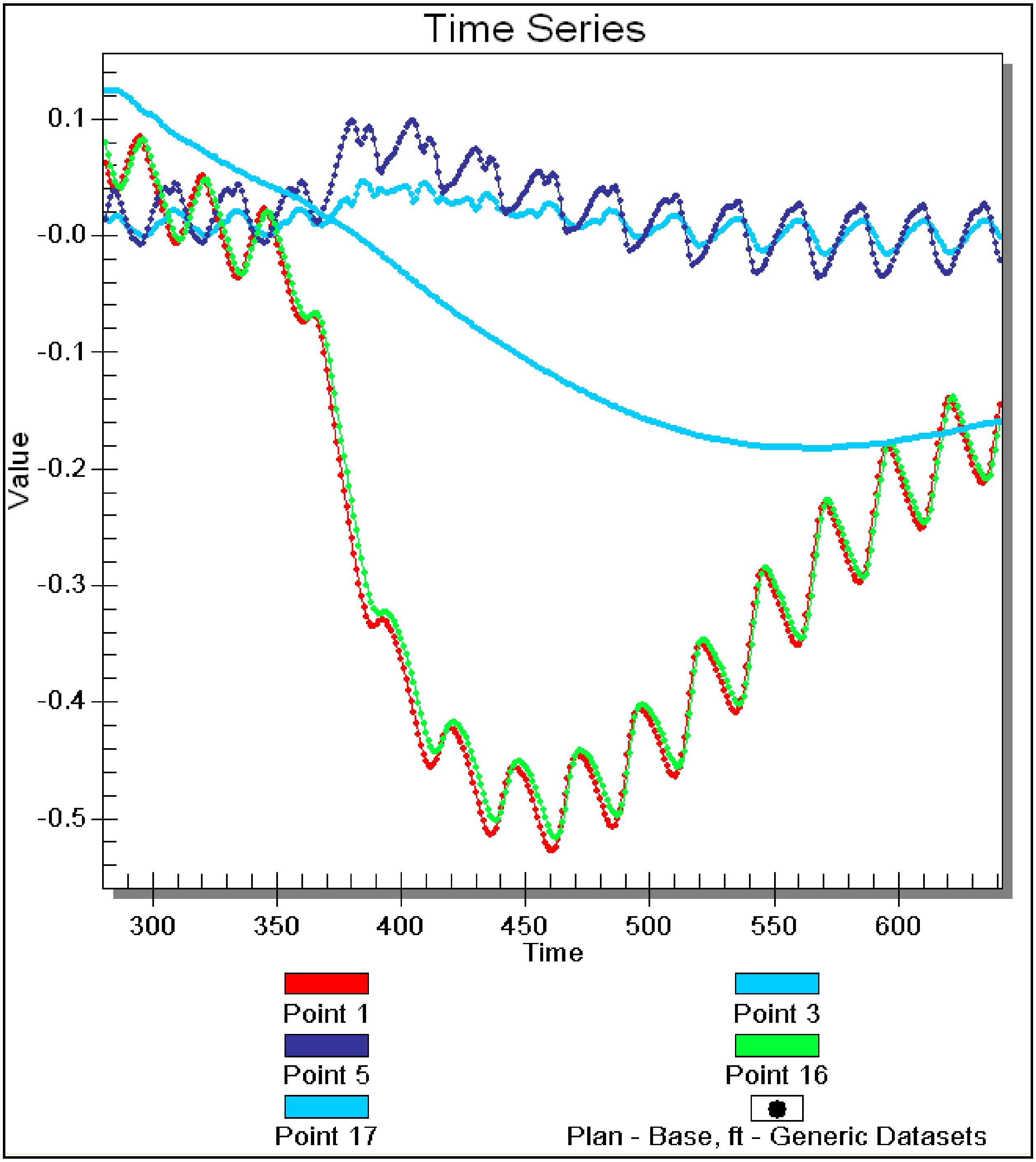

Figure 3.35. Base minus plan PR01 water levels for the 2-yr hydrograph at select points.

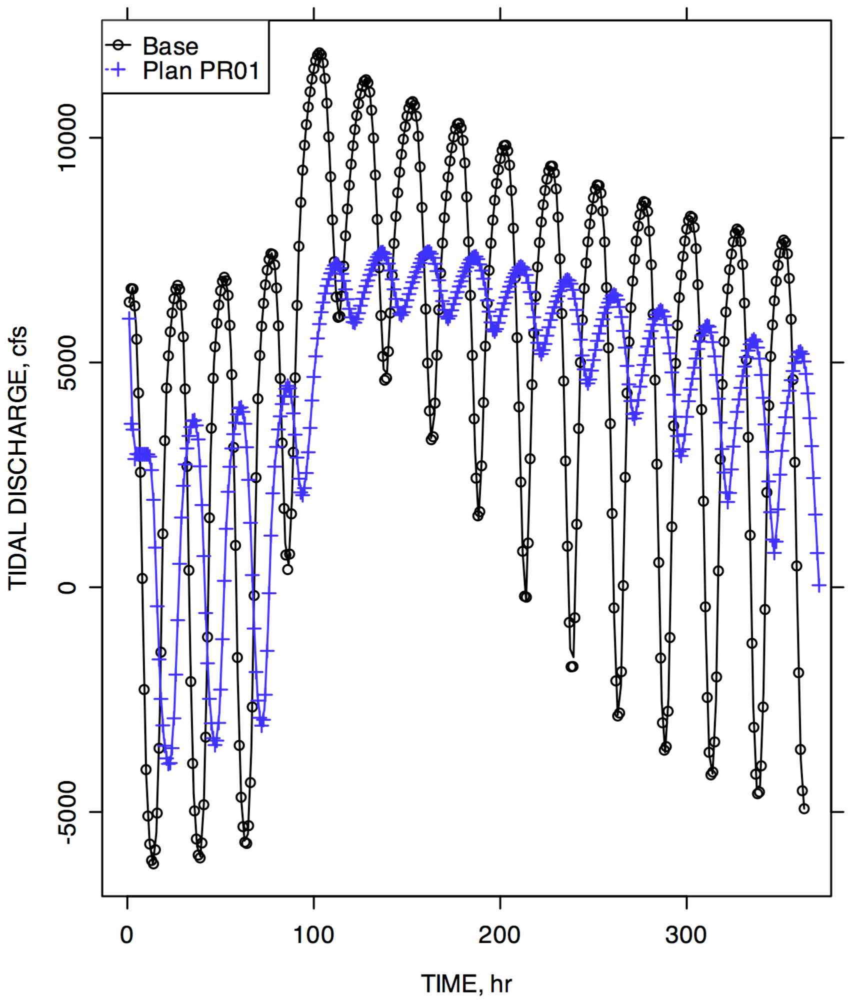

Figure 3.36. Base and plan PR01 tidal discharge seaward of Bayou Perot Pass (CL05) for the 2-yr hydrograph.

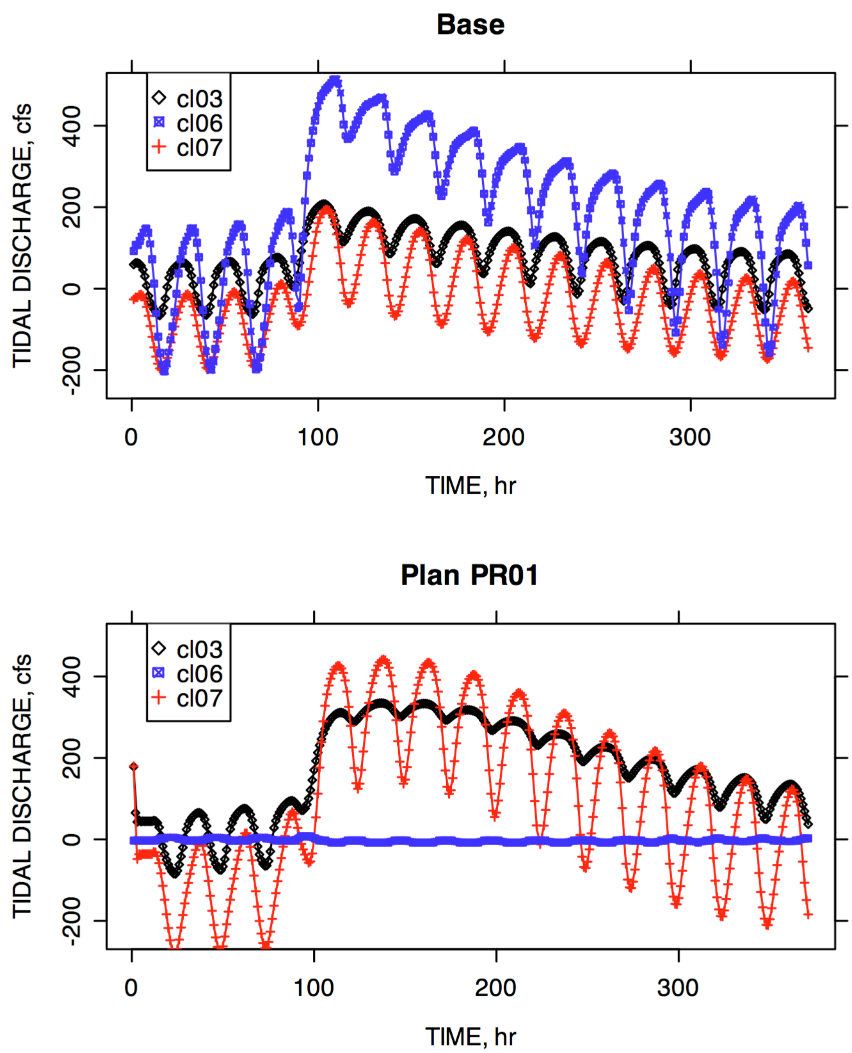

Figure 3.37. Base and plan PR01 tidal discharges at Barataria Waterway (CL03), GIWW-east (CL06) and GIWW-west (CL07).

PART IV: Summary and Conclusions

Summary

The New Orleans District is proposing the construction of a hurricane surge protection levee in the Barataria Basin. Two levee alignments have been proposed. One is aligned near the southern boundary of Barataria Bay, whereas the second one is aligned along the northern boundary of the bay. Two numerical modeling efforts have been conducted to assess the impact of these proposed surge levees.

The first modeling effort involved the application of a HEC-RAS model that had previously been constructed by the District. The model was validated to the Allison storm event that occurred in June 2001. The validated model was then applied with both levee alignments in place. The purpose of the modeling was to provide guidance on openings in the surge levees required to restore interior water levels to their pre-levee levels. In addition, the modeling was conducted to provide guidance on pump stations required to restore water levels during the approach of a hurricane, resulting in the complete closure of all openings. This included closure of the navigation passes. Simulations with and without the levees in place were made for several rainfall events of varying frequency, e.g., 2, 5, 10, 25, 50, 100, and 500-years.

The second modeling effort involved the application of the RMA-2 hydrodynamic model and the RMA-4 transport model for salinity. The purpose of this modeling effort was to size the navigation passes (and adjacent structures) to maintain adequate navigation conditions, maintain salinity levels at pre-levee levels, and to restore water levels at their pre-levee levels. Only Levee 1 was considered in this modeling effort since Levee 2 did not fall within the numerical grid provided by the District.

Conclusions

Conclusions for the two modeling efforts are given first for the Levee 1 alignment and then for the Levee 2 alignment. Recall that the RMA-2 / RMA-4 modeling was only done with the Levee 1 alignment.

Levee 1. With the Levee 1 alignment, the HEC-RAS modeling showed that 50 - 10’ x 10’ gated box culverts at an invert elevation of -5 ft will restore interior water levels to pre-levee levels up through a 50 year storm event. To restore the interior water levels to pre-levee levels for a 100 year event requires that the 50 box culverts be installed at an invert elevation of -10 ft or that the number of culverts set at -5 ft be increased beyond 50. For the case of an approaching hurricane, with all openings closed, Lake Salvador water levels would be about 0.5 ft higher than pre-levee levels for a 100 year event even with a 26,000 cfs pump station.

The RMA-2 / RMA-4 modeling was performed for relatively low freshwater inflows, e.g., 100 cfs, 16,000 cfs, 32,000 cfs, and a rainfall event with a 2 year frequency. For the most severe case, e.g., the 2 year event, with 110 ft gates in the two navigation passes and no other openings (PR01), it was determined that interior water levels would be about 0.5 ft above the pre-levee level in Lake Salvador, consistent with the HEC-RAS model results. However, for the other inflows tested, when additional openings such as those in PR02-PR04 are incorporated interior water levels can be approximately maintained at the pre-levee levels.

With only the 110 ft navigation passes, velocities in the passes can become as high as 8 fps for 100 cfs inflow and normal tide. For higher inflows and/or extreme tides, the velocities in the passes would probably become as high as 16 fps. With the additional openings proposed in PR02-PR04., more acceptable velocities on the order of 3.5 fps are computed.

For plans PR01 and PR02, salinities in the southwest corner of the wetlands that are seaward of Levee 1 are computed to be about 5 ppt higher than pre-levee salinities. However, for plans PR03-PR04 that contain openings along the western side of the levee, salinities in those locations are only about 1 ppt higher than pre-levee levels.

Levee 2. With the Levee 2 alignment, 27 box culverts with invert elevations varying from -3 ft to -10 ft were tested in the HEC-RAS model. Interior water levels can be maintained at pre-levee levels through the 10 year storm event. Additional culverts appropriately placed could increase the frequency of event through which the pre-levee levels could be maintained. If all openings are closed, a pump station of 10,000 cfs will be able to maintain interior water levels in Lake Des Almonds at their pre-levee levels through a 100 year event.

PART V: References

Hydrologic Engineering Center (2006). “HEC-RAS, River Analysis System 4.0 Users Manual”, U.S. Army Hydrologic Engineering Center, Davis, California.

King, I. P. (1993). “RMA-10, A Finite-Element Model for Three Dimensional Density Stratified Flow”, Dept. Civil Environ. Engrg., University of California, Davis, California.