FINAL REPORT

VOLUME I OF VII
EXECUTIVE SUMMARY

MISSISSIPPI RIVER REINTRODUCTION INTO MAUREPAS SWAMP PROJECT PO-29

Louisiana Department of Natural Resources
U.S. Environmental Protection Agency

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URS Corporation (URS) has undertaken a Hydraulic Feasibility Study to evaluate physical hydrologic impacts for a proposed diversion of freshwater from the Mississippi River to the Maurepas Swamp, near Garyville, Louisiana. This study is part of the Mississippi River Reintroduction into Maurepas Swamp Project (PO-29) sponsored by the U.S. Environmental Protection Agency (USEPA) and the Louisiana Department of Natural Resources (LDNR) under the federal Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA).

The study has determined that a diversion with 2,000 cubic feet per second (cfs) nominal capacity is hydraulically feasible, incorporating recommendations for outfall management, diversion operation, drainage impact mitigation, scour protection, sand/silt removal, and minimizing adverse sedimentation and aquatic vegetation growth.

The feasibility study has been a collaborative effort. Project sponsors have contributed extensively to planning the project data collection and analysis. In addition, several subcontractors have contributed to the project execution. Furthermore, key insights regarding the proposed diversion have been developed and shared by independent researchers at Louisiana State University (LSU):

- Ken Teague and Patty Taylor, (USEPA);
- Chris Williams, Luke Lebas, Russ Joffrion, and Brad Miller, (LDNR);
- Mike Patorno, Bob Jacobsen, Harry Harlan, Chris Reed, Lindsay Nakashima, Justin Roper, and Nathan Dill (URS);
- Gerry Menard, (Evans-Graves Engineers, Inc.) and Randy Dixon, (3001, Inc.) surveying subcontractors.
- Elizabeth Valenti and Ben Jelley (WorldWinds, Inc.) high performance computing subcontractor.
- Joannes Westerink, (University of Notre Dame) and Rick Luettich, (University of North Carolina) co-authors of the ADCIRC model; and
- John Day, Paul Kemp, Hassan Mashriqui, and Dane Dartez, (LSU), who were engaged in a parallel research effort of the Maurepas diversion sponsored by USEPA.

Due to the unprecedented nature of the hydrodynamic issues addressed in this study—and the ensuing innovations in data collection, analysis, and modeling that were required—work extended to a period of 28 months. The study timeline is worth noting as an indication of the project complexity:

August 2003	URS commences work.
Nov 2004	Secondary Benchmarks are established.
	LSU begins hydrographic data collection.
Dec 2004 to Feb 2004	Delays in field surveys due to local hunting season.
Feb 2004	2-D model (RMA2) development initiated.
April 2004	Field topographic and bathymetric surveying completed.
Spring 2004	1-D (SWMM) model development initiated.
Summer 2004	Extensive model trials demonstrated limitations of RMA2.
Sept – Oct 2004	Project team re-evaluated alternative 2-D programs to accommodate high resolution requirements.
	Project area impacted by three tropical events.
Nov 2004	LSU completed hydrographic data collection.
Dec 2004	Project Team agrees to switch to high performance version of ADCIRC for 2-D model.
April 2005	1-D model development completed.
June 2005	Initial phase of ADCIRC model development and stability testing completed.
July – Aug 2005	High performance computing subcontractor upgrades equipment.
	1D model calibration completed.
Sept – Oct 2005	Project delays associated with Hurricane Katrina.
Feb 2005	Final ADCIRC model development and stability testing completed.

May 2005	ADCIRC model parameter evaluation completed.
June 2005	ADCIRC model calibration and validation completed.
Sept 2005	Outfall Management alternative simulations completed.
October 2005	Combined ADCIRC/SWMM drainage impact alternative simulations completed.
December 2005	Study conclusions and recommendations finalized with Project Team.

Subtracting several months in project delays associated with local landowner restrictions to site access and Hurricane Katrina, the effective duration of the Hydraulic Feasibility Study was approximately two years.

The Maurepas Swamp is a generally freshwater cypress-tupelo forested landscape located at the upper tidal margin of the Lake Pontchartrain/Lake Maurepas estuary system (Figure1). The swamp is threatened by episodic brackish water intrusion from Lake Maurepas, long-term subsidence, and the elimination of nutrient inputs, a consequence largely of the century-plus isolation of the swamp from the annual nourishment of Mississippi River overbank floods. The CWPPRA Phase 0 reconnaissance level study (Lee Wilson, 2001) of a reintroduction of Mississippi River water estimated the potential wetland landscape benefits to be among the most cost-effective identified to-date in Louisiana coastal restoration.

The diversion concept is illustrated in Figure 2 and features a gated structure at the river, a sand/silt settling basin, a new banked diversion channel taking the Hope Canal alignment north of US Highway 61 (Airline Highway), and outfall management structures in the swamp north of Interstate 10 to distribute diversion water within the 50,000 acre north of Airline Highway between Reserve Relief Canal on the east and Blind River on the west.

The Phase 0 diversion concept defined a nominal diversion flow on the order of 1,500 cfs, based on preliminary assessments of scouring limitations at the Hope Canal Interstate 10 overpass. Based on the nutrient deficient condition of the Maurepas Swamp, consideration of higher diversion flow alternatives was recommended. The Phase 0 study also recommended evaluation of outfall management requirements to provide for effective circulation of diversion water throughout the swamp.

In addressing the sizing and circulation of the Maurepas diversion, the Hydraulic Feasibility Study focuses on the physical hydrodynamics and the key question of “Will the water go where we want it to go?” This question reflects four important *physical*[1] hydrologic objectives for the project:

1. Broad and uniform flow distribution should be achieved to deliver nutrients, fine sediments, and freshening throughout the declining forest, and to avoid exacerbating stagnant areas.

2. The diversion water should be retained in the swamp for a reasonable time and short-circuiting to Lake Maurepas should be avoided.

[1] The water quality aspects of diversion alternatives, including sedimentation and nitrate removal with the project area, were not a subject for this study phase, in accordance with the feasibility study scope of work.

3. The planned diversion and associated outfall management features should have no adverse impact on the stormwater drainage systems for the nearby Garyville/Reserve communities. These communities are served by existing gravity network, which drains through the swamp to Lake Maurepas. Performance of this gravity drainage system is controlled by very mild slopes and is sensitive to tailwater conditions in the swamp.

4. Diversion velocities should be modest to prevent scouring, particularly at sensitive bank locations, such as near Interstate 10.

To address the physical hydrodynamics of the Maurepas diversion URS has completed an extensive data collection and analysis effort, documented in this Hydraulic Feasibility Study Final Report and consisting of six additional volumes:

- *Volume II, Secondary Benchmark GPS Static Survey*
- *Volume III, Topographic and Bathymetric Survey*
- *Volume IV, Hydrologic Data*
- *Volume V, One Dimensional (SWMM) Model*
- *Volume VI, Two Dimensional Hydrodynamic Swamp Area Model, Development and Calibration*
- *Volume VII, Diversion Modeling*

The attached six volumes describe the methodologies, detailed findings, conclusions, and recommendations for the Hydraulic Feasibility Study tasks. Digital copies of large information sets—such as acquired survey and hydrologic data, model input files, and model output files—as well digital copies of the report text, table, and figures, are included in the individual volume appendices. A brief summary of each volume is presented below.

In accordance with LDNR's *Guide to Minimum Standards* the Project Team established a network of seven secondary control monuments in the project area using static global positioning system (GPS) survey techniques. Five of these monuments were new and two were existing. The monuments were tied to the LDNR Primary Network[2] and are therefore referenced as NAVD88-LDNR. All project elevations are given in this vertical reference unless otherwise noted. The relative vertical accuracy of the secondary network is considered to be within plus/minus 0.05 feet.

[2] This work was completed prior to the recent advancements for regional vertical control by the National Geodetic Survey following Hurricane Katrina. The vertical referencing used for the Hydraulic Feasibility Study provides sufficient local vertical accuracy for the work undertaken.

The topographic and bathymetric survey work was divided into nine activities:

- Review of Existing Data and Planning
- Channel Cross Sections South of Airline Highway
- Channel Cross Sections North of Airline Highway/South of I-10
- Channel Cross Sections North of I-10
- Crossing and Culvert Surveys
- Additional Channel Bathymetry
- Additional Embankment Topography
- Swamp Topography
- Data QC and Development of High Resolution Digital Terrain Model

All project topographic and bathymetric data—along with project 1-foot infrared imagery and a broad range of publicly available spatial data—were incorporated into a Geographic Information System (GIS). Previous channel survey work for the Phase 0 study by Pyburn and Odom were transferred to digital format and included in the GIS. Other historic topographic and bathymetric information was collected and reviewed.

In order to establish accurate conveyance properties for the extensive network of small project area channels, detailed surveying encompassed:

- 28 populated area drainage cross sections south of Airline Highway;
- 62 swamp channel cross sections north of Airline Highway, covering 6 primary channels (45 miles), 17 secondary channels (29 miles), and 25 minor channels (35 miles);
- 47 spot inverts in swamp channels and bank gaps north of Airline Highway; and
- Surveys of crossings and culverts along Interstate 10, Airline Highway, Louisiana Highway 641, and railroads.

Based on initial field reconnaissance, URS added additional field inspections and spot surveying of channel banks to obtain high resolution data on both natural and artificial (spoil) banks and bank gaps. In addition, complete walking surveys and spot inspections were performed on the low levees north of Airline Highway, the old cypress lumbering railroad embankment that divides the swamp, and the berm that rims the south shore of Lake Maurepas.

Swamp vegetation is very dense and the swamp floor is heavily littered with detritus. Except for the dragline scars created from cypress lumbering in the early 20th century, point elevations tend to fall randomly within a narrow range. The swamp channel cross sections and spot surveys routinely indicated that swamp elevations typically range from 0.0 to 1.0 ft., with an average of about +0.5 ft. Elevations below 0.0 ft are seen in sloughs while elevations above +1.0 are common on the natural banks. This narrow swamp elevation range is consistent with observations by LSU researchers, accounting for vertical reference differences.

Slightly higher swamp elevations are present around the lower end of Blind River and Alligator Bayou due to active deposition of Amite River Diversion Channel/Blind River fines in this area. Higher elevations are also seen toward the southern margins of the central area swamp, as typified by the presence of oak and palmetto vegetation.

Project area light detecting and ranging (LIDAR) data was obtained from the LSU Atlas website and confirmed the location of known higher artificial banks within the swamp areas and did not indicate the presence of additional swamp topographic features. Based on the LIDAR data, discussions with local landowners and hunting guides, and reconnaissance surveys, swamp profiles surveys were not considered worthwhile..

Topographic and bathymetric data for the area north of Airline Highway were used to prepare a high resolution digital terrain model (DTM). Development of the DTM facilitated quality control (QC) reviews of project topographic and bathymetric data and supported a detailed evaluation of the swamp geometry, hydrodynamics, and planning for the two-dimensional modeling effort. The high resolution DTM was subsequently used to generate a triangular irregular network (TIN)—with 175,000 vertices—for the development of the two-dimensional (2D) model finite element mesh.

Hydrologic data collection and analysis consisted of seven activities:

- Review of Existing Data
- Summary of Background Information
- Planning for Hydrologic Data Collection
- Installation and Operation of Continuous Hydrologic Data Instruments
- Additional Field Hydrologic Data Collection
- Data Compilation and QC
- Analysis of Hydrologic Data

Terrain data from the *Volume III, Topographic and Bathymetric Survey* were used to develop a detailed description of project area hydrographic features, including those raised features that can significantly control surface flow patterns. Existing regional and project area hydrologic data have been used to construct a water budget.

Continuous hydrologic data were collected primarily by researchers from LSU with support from URS. Stage data was continuously recorded at 13 selected channel locations for approximately one year (November 2003 through October 2004). Velocity data was obtained using an Acoustic Doppler Current Profiler at a major interior channel intersection. The continuous data was supplement by an extensive amount of discrete stage and velocity measurements obtained by URS during field topographic and bathymetric investigations.

Gage data were adjusted to the project datum (NAVD88-LDNR) and corrected using additional field leveling observations and hydrograph inspections. URS estimates that the final stage data are accurate to better than plus/minus 0.1 feet. Given that the observed range in stage over the period exceeded 4 feet, an estimate of the relative error is less than 2.5 percent of the range.

URS analyzed the project area hydrologic characteristics and trends for:

- Precipitation
- Stage Ranges
- Velocity, Flow, and Water Budget
- Water Surface Slopes
- Tidal Propagation and Channel Over-banking
- Low Frequency Signal Propagation and Channel-Swamp Exchange Resistance

Stage hydrographs by waterbody were prepared for three critical data periods using the final adjusted data. The periods selected included:

- December 26, 2003 to January 25, 2004, which covers the period used by the LSU researchers to calibrate their RMA-2 model;

- April through June 2004, during which the lowest water surface elevation (WSE) occurred in Lake Maurepas, followed by a modest flood on the ARDC and Blind River; the period also included the 3-day 5-inch Garyville rain event.

- September-October 2004, which saw the passage of three tropical storms: Hurricane Ivan (as it passed to the east of Louisiana toward a northwest Florida landfall); Tropical Storm Ivan (when the storm regenerated in the Gulf of Mexico and passed to the south of Louisiana); and Tropical Storm Matthew, which passed directly over the project area.

Surface water gradients throughout the project area are extremely mild, consistent with the very flat topography and bathymetry. Evaluation of gradient data indicated that the typical slope of the surface water within the swamp interior is likely to be very low—less than 1 x 10-6. At these very low gradients the flow is stagnant and critical thresholds for full turbulence may not be reached. It is important to note that as turbulence declines, the physical mechanisms controlling water velocities and solute mixing (e.g., nutrients and salinity) require special consideration.

Very small amplitude tidal signals readily propagate up project area channels and low stages. However, as stages rise and channel flow exchanges with adjacent swamps, tidal signals are lost. Over-banking occurs in two phases: 1) as stages reach the inverts of bank gaps, limited flow is exchanged via the small openings; and 2) with further stage increase channels overflow their entire banks. After stages fall below bank level, the tidal signal is once again seen. Thus, the characteristics of high frequency signal propagation in the channel hydrographs reflect the elevation of banks and bank gaps, which control the stage-dependent exchange between the channels and swamp.

Tides propagate into the north swamp but are much more dampened than in the channels. Tides do not appear to propagate into the isolated central swamp. Comparison of the velocity and stage hydrographs at S-9 shows that the "high frequency" tidal velocity and stage signals are generally in phase. Tidal prism—the volume change in water covering an area between a low tide and the subsequent high tide—is not a useful calculation for the Maurepas project area due to: 1) Lake-driven tidal signals affecting only the footprint of the interior channels, less than 10 percent of the overall interior project area, and 2) the long lag in the tidal propagation up the interior channels which means that a simultaneous change in volume within the entire channel network does not occur.

The characteristic propagation of low frequency (multi-day) shifts in WSEs through the project area are also an important aspect of the project *Conceptual Hydrologic Model*. The low frequency signatures of the system—including both the incoming (or filling or wetting) and outgoing (or draining or drying) phases of the events—are important indicators of several "resistance" factors which control the extent/rate of channel-swamp exchange:

- Bottom friction, or shear stress in the swamp and on the banks,
- Vegetation form drag in the swamp and on the banks,
- The width, bottom friction, and drag (i.e., conveyance) of gaps, and
- The "effective" exchangeable storage volume of interior swamp areas,

As with tidal propagation, low frequency propagation characteristics are stage dependent, indicating that resistance factors vary with water depth, which is consistent with the physical nature of shear stress, drag, and swamp storage.

The various signatures of channel-swamp exchange are indicative of the system's response to hydrologic forcing. Understanding and modeling these observed events, including the nature of swamp resistance, facilitate prediction of the system's response to a diversion. Taken together, these characteristics comprise a Maurepas Swamp *Conceptual Hydrologic Model*, which has been used in the development of the high resolution 2D hydrodynamic model of the swamp, and to evaluate the swamp circulation, retention, and depth associated with a freshwater diversion.

URS developed and calibrated a one-dimensional (1D) model for the gravity drainage channel network in the populated area east of Hope Canal and generally south of Airline Highway in St. John the Baptist Parish (Garyville/Reserve). This model was developed to enable estimates of drainage flow rates and WSEs within the drainage network under various rainfall input and tailwater conditions.

The model was constructed using the program Storm Water Management Model (SWMM). The EXTRAN, or flow, regime of the model area was divided into nearly 2,000 individual links (channel segments) and 23 storage areas. The geometry of the model was based on the topographic and bathymetric survey data. The RUNOFF regime of the model area was divided into sub-catchments. Runoff for rural sub-catchments were modeled using the Soil Conservation Service method, while more urban sub-catchments were addressed using the SWMM model subroutine based on size, width, slope, and imperviousness. The percent impervious values used were 30, 40, and 45 percent for older residential, newer residential and industrial areas respectively.

The SWMM model was calibrated using a rainfall event during February 10-14, 2004. The model was calibrated using a comparison of computed versus observed hydrographs for two locations, Hope Canal at Airline Highway and Reserve Relief Canal at Airline Highway. Adjustments were made to the Manning's n value for selected channel segments. The observed and computed hydrographs were judged to be in fair agreement without revising any RUNOFF parameters. A second rainfall event from February 23-26, 2004 was used to validate the model. The observed and computed hydrographs for Hope Canal were evaluated and the validation results were deemed acceptable. Observations at Reserve Relief Canal were not available for this validation period.

Following calibration and validation a series of simulations were conducted to examine the sensitivity of network discharge to tailwater conditions for 5-, 10-, 50-, and 100-year frequency return, 24-hour rainfall events. Alternative tailwater WSEs of 0.5, 1.0, 1.5, 2.0, and 2.25 feet were used. The analysis showed a significant decline in discharge with increased tailwater. For example, one location showed a 50 percent decline in the peak discharge for a 10-year rainfall event when the tailwater was increased from 1.0 to 2.5 feet. These results demonstrated that the diversion should not be allowed to cause a significant increase in WSE in the swamp area south of Interstate 10.

The 1D SWMM model was subsequently coupled with the 2D ADCIRC model to assess a Without- versus With-Diversion comparison of the performance of the drainage network for a 10-year rainfall event (see Volume VII below).

In order to perform a comprehensive study of the physical hydrodynamic issues, URS developed and calibrated a two-dimensional (2D) numerical model capable of assessing swamp water elevations, circulation patterns, retention times, and channel velocities under various diversion scenarios. The 2D model development and calibration consisted of seven activities:

- Review of Previous Swamp Modeling Efforts
- Planning and Numerical Code Selection
- Mesh Development and Stability Testing
- Defining Key Swamp Hydrodynamic Characteristics and Model Physical Parameters
- Physical Parameter Testing
- Calibration and Validation
- Development of Conclusions and Recommendations

URS reviewed other Maurepas Swamp diversion modeling efforts by researchers at LSU—including 1D unsteady simulations using the UNET model done as part of the Phase 0 work and 2D unsteady simulations using RMA2 done as part of a USEPA sponsored ecological study. In addition, a separate RMA2 modeling effort done as part of a master's thesis was reviewed.

As a result of these previous efforts URS initially attempted to utilize RMA2 for the present study. However, the *Conceptual Hydrologic Model*—particularly the role of narrow topographic and bathymetric features in two-dimensional circulation issues—dictated the use of a model program capable of handling a very high resolution geometric representation of the project area. The high resolution unstructured mesh represents the project area geometry with node spacing as close as 15 feet (Figure 3). This high density geometry results in the total number of nodes exceeding 160,000.

The Advanced Circulation (ADCIRC) finite element program was selected for use based on: a) compatibility with basic requirements to simulate shallow 2D free surface transient flow, with wetting and drying, using an unstructured mesh; b) capability to run large mesh size simulations on a high performance computer; c) access to the source code; d) available support from the two principal code authors; and e) previous and ongoing demonstrated coastal hydrodynamic application of ADCIRC by U.S. Army Corps of Engineers in Louisiana.

URS conducted the majority of simulations on a parallel cluster leased from WorldWinds, Inc., which included 32 Xeon 64-bit processors (Intel 7520 dual-core 3.0GHz with 2GB DIMM). The dual core processors allowed for the assignment of 64 sub-domains. The resulting run speed on this cluster approached 10:1 using a 0.5 second time step.

Development of the final stable model mesh and associated numeric parameters took 40 simulations and over 38 weeks. Following model development a series of 40 additional simulations were conducted over 13 weeks to define appropriate values for several physical resistance parameters.

The final model was shown to represent 2D physical hydrodynamics in the project area—including channel flow, propagation of tidal signals, overbank flow, flow through bank gaps, and swamp circulation—during a variety of conditions. However, the model as parameterized has recognized limitations in simulating swamp resistance, particularly with respect to apparent over-draining of the swamp during falling Lake water level conditions. Representation of swamp resistance has been addressed in part by artificially raising the elevation of the swamp floor in the model.

URS evaluated the performance of the "High Swamp" model through a series of calibration and validation simulations. The calibration and validation data consisted of gage and ADCP data. The calibration data were selected from a 15 day period in January 2004, which coincided with part of the period used by LSU researchers to calibrate their RMA2 model. Root Mean Square (RMS) errors were evaluated for 9 gages and the ADCP, and ranged from 1 to 36 percent of the observed range.

Two validation periods were used—16 days in May 2004 which reflected a Blind River flood, and 20 days in October 2004 which corresponded to Tropical Storm Matthew. RMS errors for the 9 gages plus ADCP in the High Blind River validation ranged from 3 to 33 percent of the observed range. For the TS Matthew validation, with 11 gages and the ADCP, RMS errors ranged from 4 to 18 percent.

Key conclusions from calibration and validation are:

- The calibration/validation stage and velocity hydrographs generally demonstrated reasonable model behavior at the appropriate water elevations. The results of the TS Matthew validation in particular show the ability of the model to simulate a low frequency event at above normal stage, similar to the nature of a diversion pulse.

- With the high resolution geometry of channels, banks, and gaps, the tidal signals are well represented in the model.
- The animations of the three simulations depict high resolution two-dimensional circulation patterns that are consistent with the domain bathymetry and model forcings.
- The amplitude and phase of certain low frequency signals in the calibration and validation simulations indicate that swamp conveyance and exchange with the channels in the "High Swamp" model is still too high.
- Raising the swamp floor elevation in the "High Swamp" model—as a means to improve the representation of swamp resistance—has not resulted in an overall overly resistive model. The results of calibration and validation indicate that the 2-D model should be regarded as under-representing swamp resistance.
- This finding must be tempered by 1) the uncertainty in the boundary flow inputs, which may also be contributing to some distortion in signal amplitude, and 2) evidence from the velocity hydrographs that the resistance in the major channels may be over-represented.
- Under-representation of swamp resistance in the 2-D model (i.e., excess swamp conveyance) implies that diversion backwater values, particularly in the Central Swamp, and short-circuiting may be under-represented.
- The ADCIRC "High Swamp" model is unlikely to be significantly impacted by wetting/drying numerical limitations except at very low, near-dry stages, when errors can overwhelm the solution. The parameter testing indicates that diversion conditions will not be near-dry and that the drying algorithm will not be an issue. (The exception would be for very low, extended Lake stages which could produce some swamp drying.)
- The calibration and validation results are consistent in their depiction of the swamp resistance issue, which, combined with a similar general level of accuracy among the simulations, indicate that the model is robust and reliable.

- The relative percentage error for the calibration and validation results is consistent with a feasibility study level hydrodynamic model.

Calibration and validation demonstrated the model to be appropriate for a feasibility-level analysis of diversion alternatives in meeting the four diversion objectives, with two major considerations:

1. Diversion results should be interpreted consistent with the findings of model development and testing. Most importantly, allowances should be made for the model's under-representation of swamp resistance.

2. Analyzing diversion alternatives at "fully developed" flow conditions (i.e., near steady flow) and comparing results between simulations should provide the most validity. Non-steady results are likely to be subject to the most complex effects of swamp resistance under-representation. The effects of swamp resistance under-representation may be minimized by examining relative differences between scenarios. Swamp resistance under-representation may be non-linear and relative results should not be considered totally free of resistance inaccuracies.

Additional recommendations were identified for improving physical hydrodynamic modeling to support future engineering, operation, and adaptive management of the diversion.

URS conducted simulations of diversion alternatives using the calibrated/validated 2-D ADCIRC model, including the following seven activities:

- Planning for Diversion Modeling
- Evaluation of Outfall Management Requirements
- Evaluation of Alternative Diversion Flows
- Evaluation of Alternative Lake Conditions
- Assessment of Impacts to Garyville/Reserve Drainage System
- Examination of Velocity Scouring Impacts
- Development of Conclusions and Recommendations

URS undertook a total of 48 ADCIRC simulations over an 18 week period in order evaluate the diversion objectives. All diversion simulations were conducted with the basic "High Swamp" calibrated/validated model, including typical values for flow inputs for intersecting channels at model boundaries.

9.1 OUTFALL MANAGEMENT

URS initially conducted a series of diversion simulations with the nominal 1,500 cfs diversion and steady WSE in Lake Maurepas at mean level to investigate the circulation and retention of diversion water in the swamp. To support the evaluation of diversion circulation URS developed a particle-tracking code for use in conjunction with the 2-D steady-state flow field output. The code was used to define representative steady-state streamlines and estimate Median Swamp Retention Time (MSRT).

The initial diversion simulations were conducted to also evaluate the effect of various outfall management alternatives. Simulation results for outfall management alternatives were regularly reviewed by the Project Team (typically weekly) and subsequent simulations incorporated modification strategies that reflected general agreement among the Project Team. A comprehensive, systematic modeling of detailed outfall management design alternatives was beyond the scope of this phase of work.

Major findings were:

- Early simulations demonstrated the need to control flow in the Interstate 10 culverts and widen gaps in the north-south portion of the Old Railroad Embankment. The former was needed to restrict over-inundation of the swamp between Airline Highway and Interstate 10, which would create severe drainage impacts. The latter was needed to allow for even, westward spreading of diversion water.

- The resulting "Refined Outfall Management" scenario incorporated these features—along with placing flow restrictions at the mouths of Bourgeois Canal and Bayou Secret and closing gaps on the east bank of Blind River between I-10 and the Transmission Line Right-of-Way. This scenario demonstrated the most improved flow distribution without significantly impacting WSEs south of Interstate 10 (Figures 4 and 5). However, circulation to the northern swamp remained limited. The MSRT is the longest, at 5.8 days, for scenarios that included closure of the Interstate 10 culverts.

- The "Refined Outfall Management" results showed that diversion water fans out evenly throughout the swamp north of Interstate 10 during flow development, with fully developed flow (near steady-state) approximated by Day 10 of the simulation. Comparing the animation with the steady-state streamlines provides strong evidence for short-term pulsing of the diversion as a way to effectively distribute flow (and related benefits such as freshening, nutrients, and fine sediments) throughout the swamp. Gradients toward the northern swamp reaches are steeper during flow development, drawing higher relative amounts of flow and possibly extending MSRTs.

- The various outfall management scenarios taken together indicated that circulation and MSRT could be further improved by reducing the eastward/westward surface water gradient, creating a better impounding of the diversion water. This might be accomplished with further upgrading of the integrity of the western bank of Reserve Relief Canal and the eastern bank of Blind River.

The Project Team gave extensive consideration to circulation issues related to the currently stagnant swamp area north of Airline Highway and south of Interstate 10 and agreed that release of diversion water into this area could be handled through controlling flow in the interstate culverts and using additional gated conduits along the east and west bank of the diversion channel between Airline Highway and Interstate 10. Because the amount and duration of controlled releases into this area are likely to be small and short, to minimize drainage impacts, these releases were not simulated during this phase of study.

9.2 ALTERNATIVE DIVERSION FLOW AND LAKE CONDITIONS

Following the identification of basic outfall management requirements, the Project Team agreed to simulate alternative diversion flows of 1,000 and 2,000 cfs[3]. A shut-down simulation of the 1,500 cfs diversion was performed to provide an indication of the time frame for re-establishing initial conditions. Steady-state simulations of 1,500 cfs diversion were also undertaken for alternative Lake WSEs (0.5, 2.0 and 3.0 ft). A 1,500 cfs diversion simulation was also conducted using one unsteady Lake condition—the LSU Calibration Period. Important findings from these simulations included:

- The alternative diversion rate simulations, with plus/minus 33 percent change compared to 1,500 cfs, showed less than a 20 percent decrease/increase in MSRT. This indicated that the general diversion circulation is not highly sensitive to small increases in diversion rate.
- The results of the shutdown simulation showed that project area stages generally fall back to pre-diversion WSEs within 20 days. The combination of the "Refined Outfall Management" and "Shutdown" simulations suggest that 10 days of flow followed by a 20 day shutdown could be considered for a pulsing operation.
- The diversion exhibited stronger short-circuiting to east/west at low Lake (0.5 ft) due to the greater confinement of flow and steeper gradients. At higher Lake WSEs circulation improved and retention times increased because under these conditions the diversion flow is less confined—overtopping channel banks—and gradients flatten. This suggests diversion circulation will be better during prolonged periods of above average Lake WSE.
- Comparing the results of the unsteady diversion simulation with earlier calibration results (without the diversion) showed a greater impact at low versus high Lake, consistent with the steady simulation results.

[3] These represented a reasonable range of flows targeted by the Phase 0 Report. Higher flow rates have been discussed by other researchers based on the needs to restore the larger complex of swamps south of Lake Maurepas, especially areas east of Reserve Relief Canal, and to deliver more nutrients to the project area.

9.3 DRAINAGE IMPACT

The "Refined Outfall Management" simulation indicated that steady-state increases in WSE south of Interstate 10 would likely be on the order of 0.2 ft. or less. In order to further assess the potential impact of diversion on the Garyville/Reserve drainage system URS undertook a simulation with flow inputs for a typical design storm—the 24-hour/10-year return frequency rainfall event—with a steady Lake boundary WSE of 1.1 ft.

In order to simulate the rainfall event and take into account the combined transient response of both the drainage system and the swamp, URS developed an interactive link between the 1D SWMM model and the 2D ADCIRC model. Simulations were run to compare existing drainage conditions for a 24-hour, 10-year return frequency rainfall event Without Diversion, versus conditions With Diversion (a 1,500 cfs) using "Refined Outfall Management" and the Lake at 1.1 ft. A key modification to the With-Diversion scenario is that the Hope Canal watershed, which can no longer drain to Hope Canal due to the diversion channel, is converted to a forced drainage system and served by a pump station.

Major findings regarding the drainage impact of the diversion included:

- At drainage channel locations just north of Airline Highway, between Hope Canal and Godchaux Canal, the peak stage impacts were 0.2 ft or less.
- The Godchaux Canal stage increased 0.36 ft (10 percent) and the discharge was reduced by 26 cfs (8 percent) with the diversion, reflecting the downstream diversion impact to Mississippi Bayou.
- The peak stage result at Mississippi Bayou at Interstate 10 was increased by 0.38 ft (30 percent) from diversion.
- The Reserve Relief Canal showed only a 0.1 ft (3 percent) increase in stage.
- The results south of Airline Highway reflected lower impact than the north of Airline Highway. Upstream on Godchaux Canal the peak stage impact is reduced to 0.2 ft.
- Overall, the diversion impact to stages in the swamp area east of Hope Canal and north of Airline Highway appeared to be minor for a 24-hour/10-year return frequency rainfall. Peak stage increased about 0.2 ft between the Reserve Airport and Godchaux Canal, north of the protection levee, and about

0.3 ft in an isolated area just east of Godchaux Canal and north of Airline Highway.

Based on the results of this comparison, and the negligible stage impacts of the diversion at higher Lake WSEs, the Project Team agreed that no further drainage impact simulations were warranted for this phase of study.

9.4 VELOCITY IMPACT

The simulation of a 1,500 cfs at low Lake WSE (0.5 ft) and the simulation of a higher diversion rate (2,000 cfs) would be expected to exhibit the highest velocities and were used to identify potential scouring issues. Key findings were:

- Modeled velocities throughout the diversion area were typically mild, with only two locations exhibiting velocities greater than 1 fps.
- The Hope Canal channel experienced a peak velocity of 3.8 fps during the 2,000 cfs diversion at the Interstate 10 overpass. The peak velocity at the same location was 3.0 fps during the "Low Lake" simulation. The ADCIRC model does not incorporate the reduced channel cross-section and drag forces associated with the interstate overpass support piers. Also, the model velocity is depth averaged. Therefore, these results provide only a general indication of the level of scour potential at the interstate overpass. Velocities consistent with these values are readily addressed through conventional channel armoring techniques.
- The low Lake simulation indicated a peak velocity of 1.2 fps at the mouth of Bourgeois Canal at Blind River. Some isolated bank sections and bank gap locations may also experience temporary velocities above 1 fps during diversion, although none were seen in the simulations. The velocities at these locations can be re-evaluated based on final diversion flow and outfall management design, and addressed as needed with conventional stabilization techniques.

Minimum diversion velocities are also a critical factor in order to effectively transport suspended sediments and nutrients from the diversion channel into the swamp. The ADCIRC model showed that diversion velocities in Hope Canal typically drop below 0.5 fps within 5,000 feet of the outlet north of Interstate 10, and continue to decline through Bayou

Tent. The model also showed a dramatic fall in velocity in the swamp just outside the diversion channel. These areas may experience significant deposition of suspended sediment and aquatic vegetation growth, which could in turn alter diversion circulation.

9.5 CONCLUSIONS

The findings from the physical hydrodynamic modeling support the reintroduction of the Mississippi River into the Maurepas Swamp via Hope Canal as technically feasible. All model findings must be considered in light of the 2D ADCIRC model calibration/validation results, which showed that the model under-represents swamp resistance relative to the channels. This indicates that while swamp velocities are likely to be lower, diversion flow through channels (i.e., short-circuiting) is likely to be greater than found in the model results. Thus, MSRTs may be shorter. Also, drainage impacts could be slightly higher than estimated, particularly during Lake surge events.

With regard to the four objectives of this study:

1. Flow distribution throughout the North Swamp (between Blind River and Reserve Relief Canal) can be improved by including the identified outfall management features in combination with pulsing the diversion flow. Targeting sustained flow for prolonged periods of above mean Lake Maurepas WSE, and controlling minimum diversion velocities, will also aid in diversion distribution.

2. Pulsing and control of diversion flow in response to Lake WSE should aid in extending MSRT and reducing short-circuiting to Lake Maurepas. Control of sediment deposition and aquatic vegetation is crucial to long-term circulation maintenance.

3. The planned diversion and associated outfall management features will not adversely impact the stormwater drainage systems for the Hope Canal watershed provided that a forced drainage system of adequate capacity replaces the gravity Hope Canal drainage system. The impact on the Garyville/Reserve gravity drainage system east of Hope Canal is minimal for a 24-hour/10-year return frequency rainfall event and can be mitigated.

4. Diversion velocities at Interstate 10 are in a moderate range and can be readily addressed to prevent scouring. Isolated locations of minimal bank and gap scouring potential can also be addressed.

9.6 RECOMMENDATIONS

The simulation findings provide the basis for eight specific project design and operating requirements:

1. The major features included in the "Refined Outfall Management" simulation, and additional features indicated by the results, to provide improved circulation and MSRT.

2. A maximum diversion design flow of at least 2,000 cfs, with controls to manage flow, circulation, and retention time in response to forecasted Lake WSE conditions.

3. Flow control features to regulate flow through the culverts under Interstate 10 between Louisiana Highway 641 and Mississippi Bayou.

4. Additional flow control features to provide limited introduction of water into the swamp south of Interstate 10 from the diversion channel. Occasional introduction of low rates of diversion water is needed to prevent stagnation and improve nourishment of the swamp south of Interstate 10.

5. Replacement of the Hope Canal watershed gravity drainage system by forced drainage, including a pump station of adequate capacity.

6. Increased drainage or pumping capacity for the eastern Garyville and Reserve drainage systems to address mitigation of minor impacts. This could include several options: a) increasing drainage capacity from Godchaux Canal to Reserve Relief Canal via the Cross-Over Canal; b) increased capacity of the above Hope Canal pump station (and drainage system), or c) increased capacity for the Reserve Airport and/or Reserve Relief Canal pump stations. The Reserve Airport and Reserve Relief pump stations currently provide limited augmentation to the gravity drainage system.

7. Upgraded armoring of the Diversion Channel at the current Interstate 10 overpass over Hope Canal and additional erosion controls at locations where diversion velocities may exceed scouring thresholds (e.g., 1 to 2 fps).

8. Design and operating measures to prevent sediment deposition and aquatic vegetation growth that would adversely affect circulation, including optimization of the sand/silt settling basin.

These requirements are refinements of, and in some cases additions to, the Phase 0 Report conceptual diversion plan. Preliminary engineering plans, cost estimates, and construction schedules, along with revised assessments of project benefits, are expected to be developed for the diversion plan by the Project Team during the subsequent phase of work.

URS has also provided recommendations for further hydrodynamic physical and water quality modeling to support finalizing project designs, detailed assessments of project environmental benefits and impacts, and development of project operation and adaptive management plans.

FIGURES

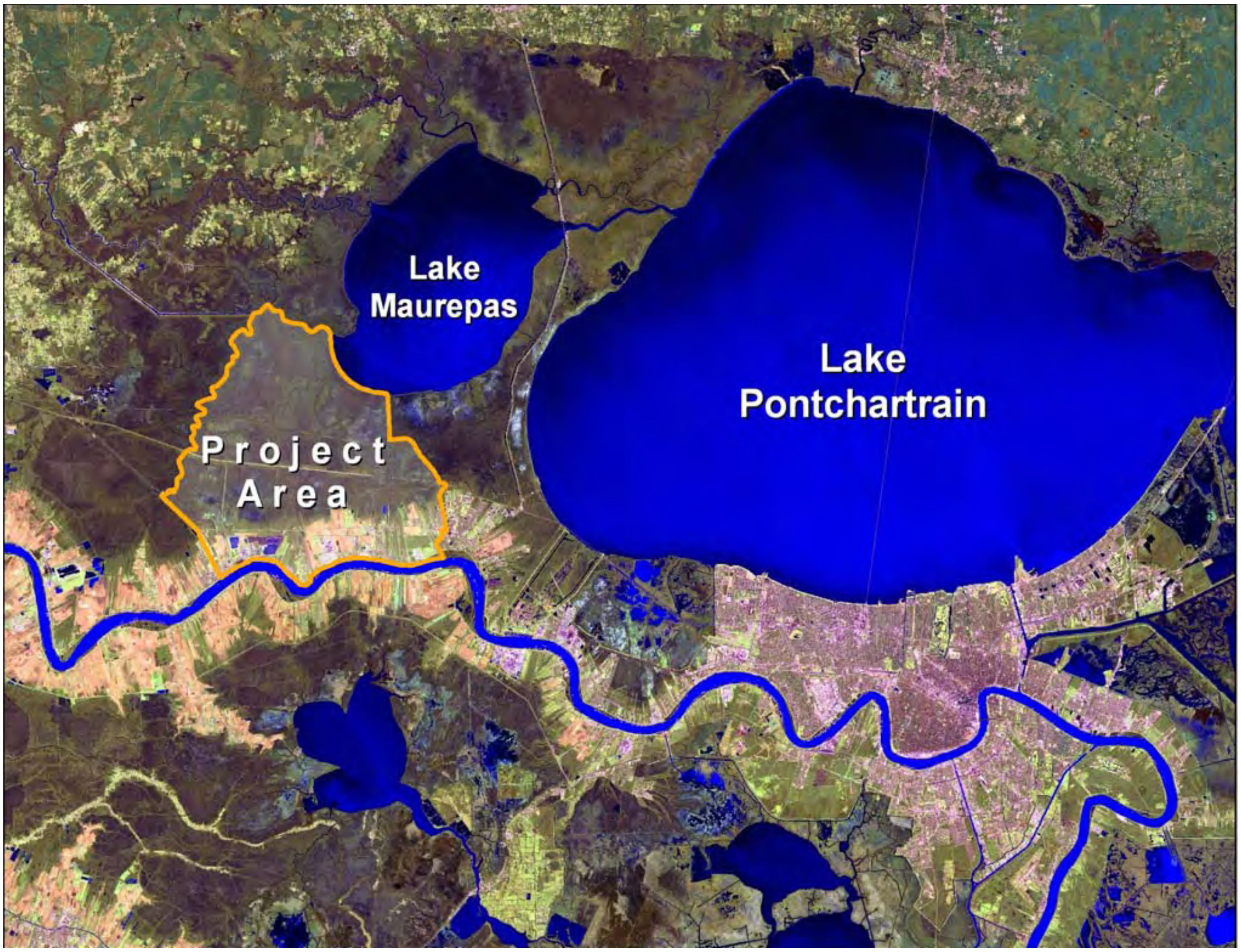

Figure 1

Project Location

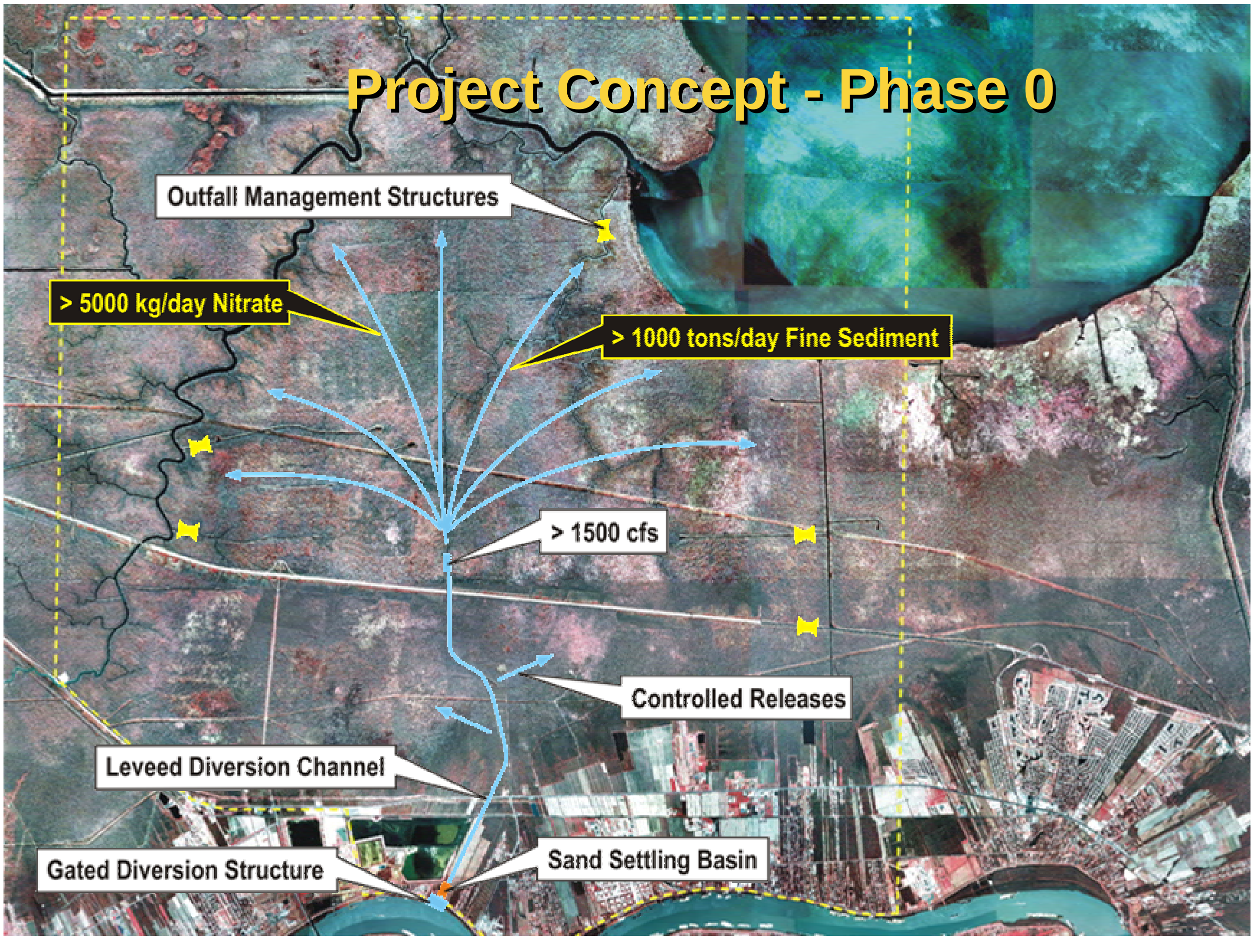

Figure 2

Proposed Maurepas Diversion

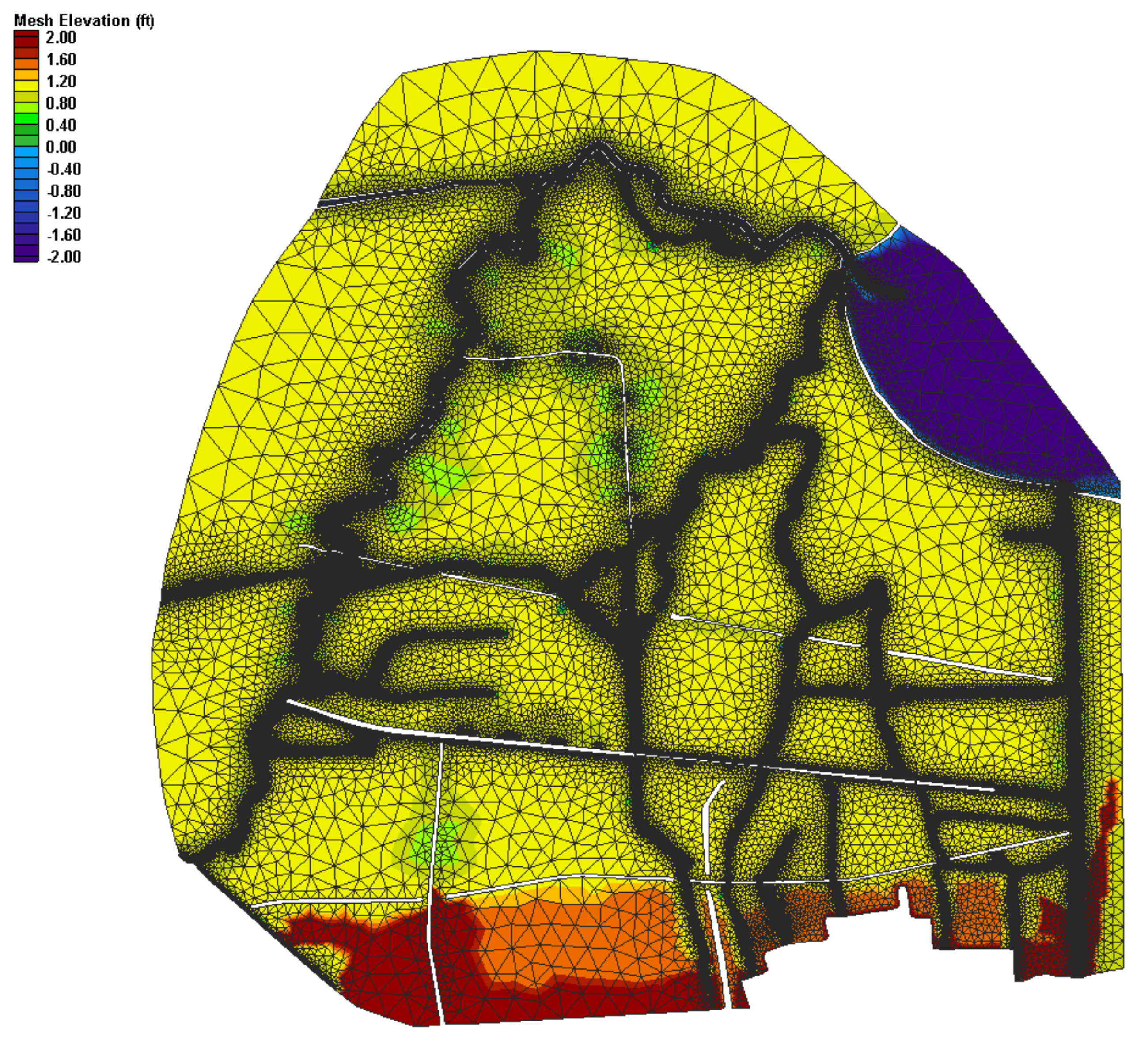

Figure 3

2D ADCIRC Model Mesh

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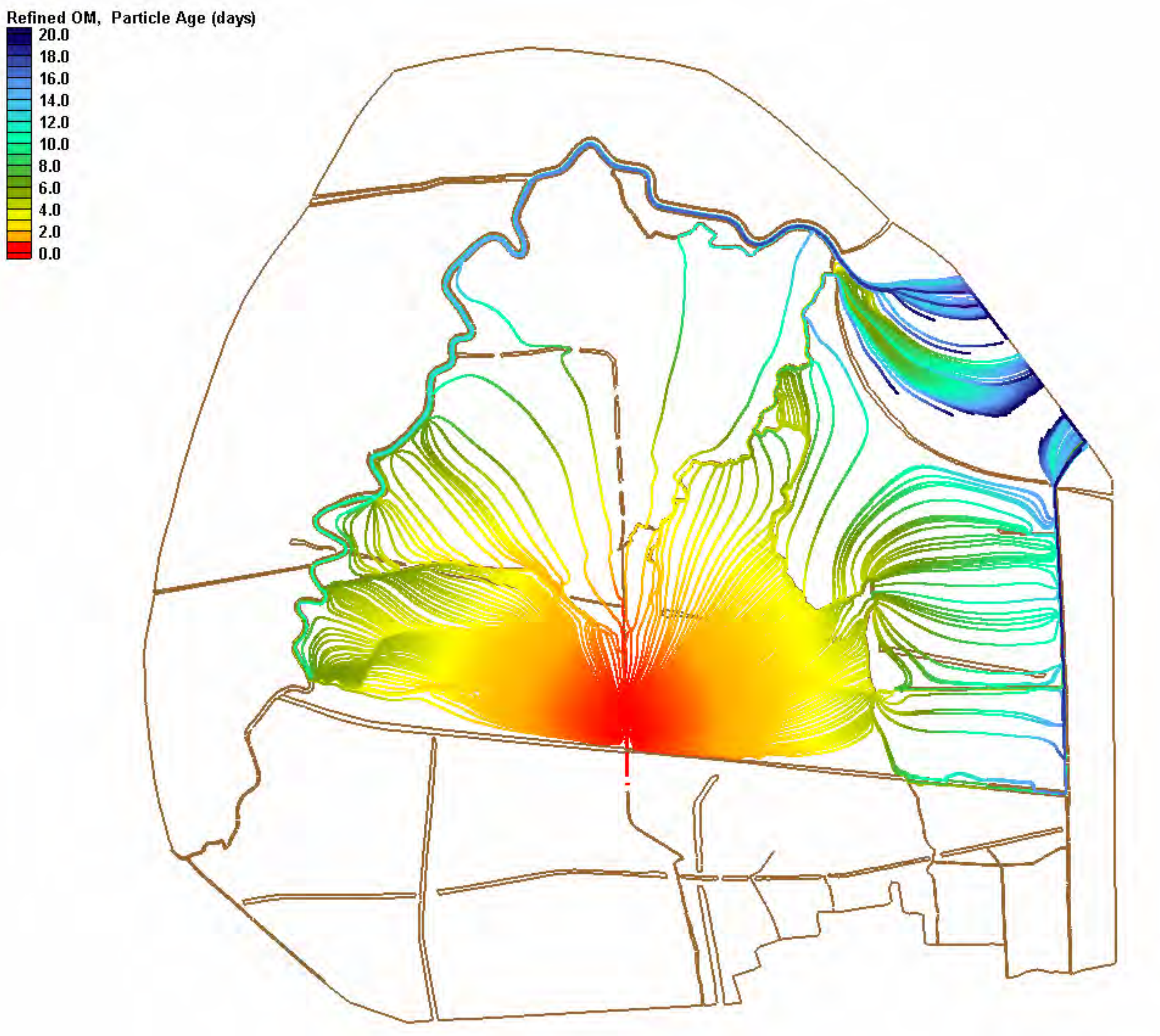

Figure 4

Streamlines for a 1,500 CFS Diversion at Fully Developed Flow Refined Outfall Management

with Lake and Regional Swamp at Elevation 1.1 ft

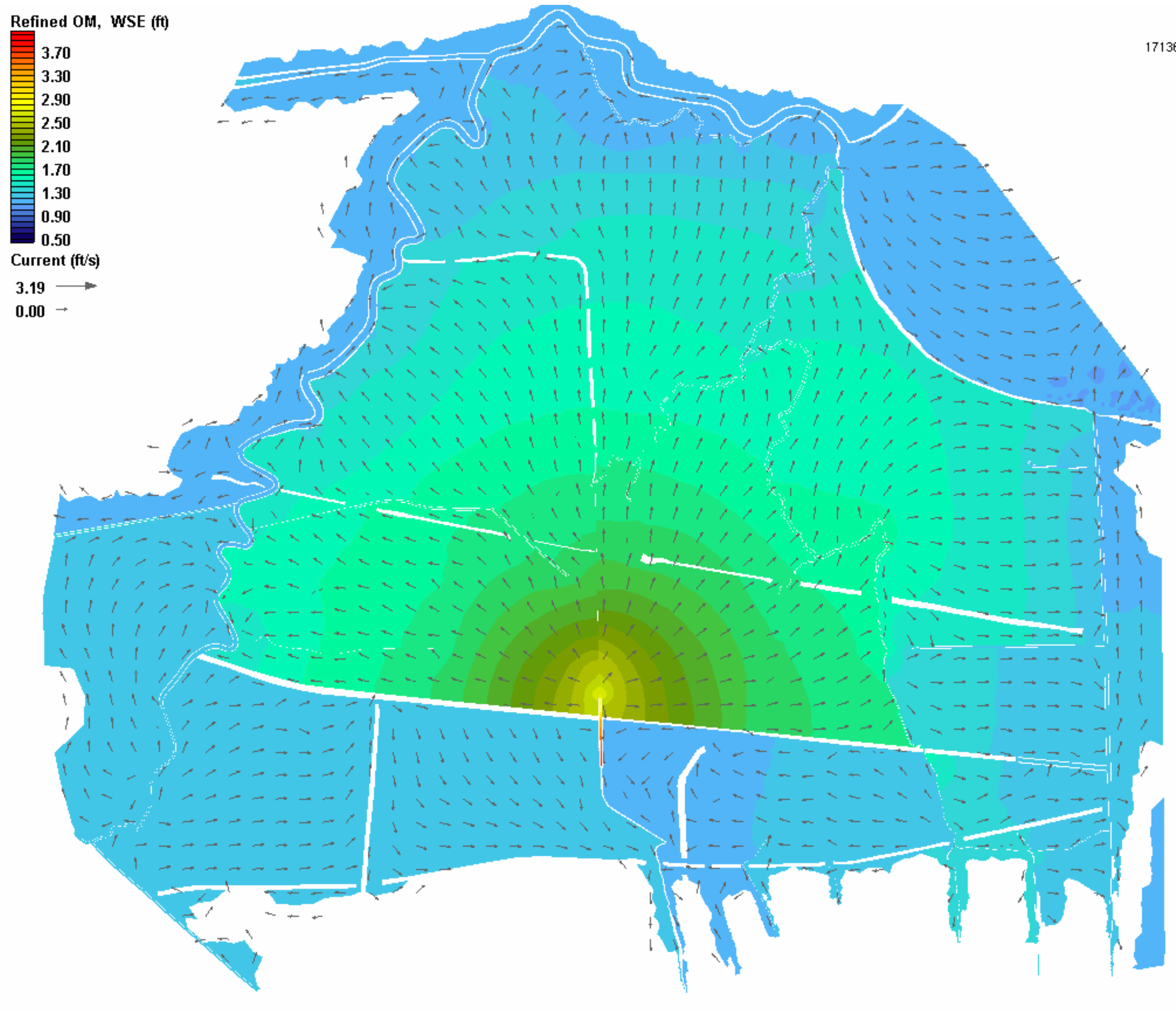

Figure 5

Water Surface Elevations for a 1,500 CFS Diversion at Fully Developed Flow Refined Outfall Management

with Lake and Regional Swamp at Elevation 1.1 ft

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