Modeling a Mississippi River diversion into a Louisiana wetland

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MODELING A MISSISSIPPI RIVER DIVERSION INTO A LOUISIANA WETLAND

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
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in

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by
Stephan Alexander Capps
B.S., United States Military Academy, 1989
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ABSTRACT

Wetland loss has significant impacts. Numerous loss mechanisms have been hypothesized, and a greater number of solutions have been proposed. One proposed solution is to divert river water into a degraded area with the intent of increasing sedimentation, introducing nutrients, and/or decreasing salinity within the wetland. However, wetland hydraulics and hydrology are complex processes and any hydrologic modification may result in unintended consequences. Predicting these consequences can be problematic due to the complexity and difficulty associated with proper modeling of the hydraulics and topography. The primary objective of this study is to evaluate the suitability of established one- and two-dimensional (1-D and 2-D) models for investigating flow diversions in a wetland environment. This study focused on a Mississippi River diversion through Hope Canal into Maurepas Swamp, Louisiana. The 1-D models used to investigate canal flow were HEC RAS 3.0 for hydraulics and QUAL2E for nutrients. These provided data and boundary conditions for the 2-D RMA2 (hydraulics) and RMA4 (constituent transport) models that were used to evaluate the 2-D modeled area. The secondary objective of this study is to use these models to evaluate the effects of a river diversion through the existing canal into the freshwater swamp. Results showed that the existing canal can convey 300 ft³/sec (8.5 m³/sec) and the total nitrogen content within this channel decreased by less than 3 percent. At this flow rate, the existing hydrological features in the swamp limit the impact of the diversion to the southeastern quadrant of the model area. The remaining area of the swamp is still dominated by the pre-existing hydrological inputs. According to the nutrient transport model (RMA4), nitrogen will not get assimilated in the modeled area. In terms of
applicability, the HEC RAS 3.0 and QUAL2E are sufficient tools to investigate
diversions with no overbank flow. The RMA2 model is a good investigative tool for
wetland flows due to its ability to account for some of the unique hydrodynamic aspects
of wetland flow. The RMA4 program models nutrients only superficially, thus, it is
sufficient as a screening tool but not robust enough to investigate wetland nitrogen
processes.
CHAPTER 1
INTRODUCTION

Wetland loss in Louisiana is a well-documented issue with numerous processes cited as responsible. These processes range from natural causes such as sea level rise and geological subsidence, to anthropogenic factors such as dredged canals and associated spoil banks, decline of river-borne suspended sediments, and Mississippi River levee construction (Templet, 1988). In some cases, salt-water intrusion has also been suggested as a possibility (Turner, 1997). Various strategies have been proposed to counteract these processes. Among them is the diversion of Mississippi River flow into degraded wetland areas, impounding areas to prevent salt-water intrusion, and reducing or eliminating anthropogenic hydraulic modifications to the wetland system. Hypothesized benefits of diversions include increased mineral sediment deposition, increased nutrient influx, and decreased salinity and decreased phytotoxins (Templet, 1988).

The wetlands along the southern shore of Lake Maurepas are one example of this stressed regional wetland ecosystem. While the loss is significantly less than coastal wetlands (USGS, 1996), concern exists about the long term health of this ecosystem since these wetlands are susceptible to the previously mentioned processes (Templet, 1988). One proposed remedy for this strained ecosystem is to divert Mississippi River water through an existing canal system to provide a fresh influx of sediments and nutrients to the swamp. This technique has been implemented in other sections of the lower Mississippi, but the benefits are still being studied.
Currently, one lower Mississippi River diversion structure is operational with the express purpose of diverting river water to improve habitat. This diversion is located south of New Orleans at Caernarvon on the eastern side of the Mississippi River. The structure has a maximum flow rate of 8000 ft$^3$/sec (227 m$^3$/sec) and an outflow channel approximately 1.5 miles (2.4 km) long. Another structure was recently opened at Davis Pond 22 miles (35 km) upstream from New Orleans and is designed to divert up to 10,650 ft$^3$/sec (300 m$^3$/sec) into Barataria Basin. A third diversion is planned within the Bonne Carre spillway 33 (53 km) miles upstream from New Orleans. The preliminary design calls for a diversion of up to 25,000 ft$^3$/sec (708 m$^3$/sec) into Lake Ponchartrain, though the final details have yet to be negotiated between the state of Mississippi, the state of Louisiana, and the Corps of Engineers (USACE, 1998).

Impacts from the operational Caernarvon diversion have been favorable. Since it opened in 1991, areas downstream from the Caernarvon structure show an increase in freshwater vegetation, a decrease in saltwater vegetation, and a net increase of 406 acres of marshland (USACE, 1998). The important thing to note is that the purpose of the Caernarvon and Davis Pond structures is to divert water into estuarine wetland ecosystems, whereas the focus of this study is the diversion of river water into Maurepas Swamp, a palustrine wetland ecosystem. Successful diversion into one type of ecosystem (e.g., estuary) does not necessarily imply that such a scheme will be successful for a different type of ecosystem (e.g., swamp).

This investigation of the impacts associated with Mississippi River diverted water into the Maurepas Swamp utilized four models: HEC RAS 3.0, QUAL2E, RMA2, and RMA4. All are established and tested models previously applied to hydrologic and
nutrient investigations. HEC RAS 3.0 and QUAL2E are one-dimensional models that can simulate hydraulics and water quality respectively. RMA2 and RMA4 are two-dimensional models used to simulate hydraulics and material transport.

A sequential process was used to model this system (Fig. 1). First, HEC RAS 3.0 was used to determine the maximum flow rate that may be carried through the existing canal to the swamp without overbank flow or excessive scour. QUAL2E was then applied to determine nutrient consumption, specifically organic nitrogen, based on flow rates determined by HEC RAS 3.0. The flow rate calculated by HEC RAS 3.0 was also used as a flow boundary for the RMA2 simulations of two dimensional flow through a portion of the swamp. The flow field calculated by RMA2 was then used to drive the RMA4 model to simulate nutrient transport through the swamp.

The objectives in this study were the following: (1) to evaluate the utility of the four models described above for investigating the impacts of a river diversion in a wetland system, and (2) to use the four models to evaluate the effects of a Mississippi River diversion in terms of both hydraulics and nitrogen loading, with the former being the key focus area.

To accomplish these objectives, the following tasks were undertaken:

A. Construct the 1-D geometry for HEC RAS 3.0 utilizing surveyed Hope Canal cross-sections.

B. Run HEC RAS 3.0 to determine a maximum flow through the canal based on scour and overbank flow.

C. Construct the 1-D geometry for QUAL2E interpolated from the Hope Canal cross sections.
Figure 1: Modeling sequence
D. Run QUAL2E with typical nitrogen loading of Mississippi River water as a boundary condition to estimate the total organic nitrogen concentration that will enter the modeled Maurepas Swamp area.

E. Construct the 2-D geometry for RMA2 and RMA4 with the Surface Water Modeling System (SMS) utilizing USGS digital elevation models, scanned topographic maps, and digitized orthophotos.

F. Run the RMA2 program to evaluate the 2-D flow field through Maurepas Swamp with USGS stage data and a flow rate determined with the HEC RAS 3.0 model as boundary conditions.

G. Run the RMA4 program to evaluate nutrient transport within Maurepas Swamp utilizing the flow field determined by RMA2.

H. Conduct a sensitivity analysis on parameters for all four models.

I. Evaluate the utility of and appropriateness of each model in this type of modeling environment.
CHAPTER 2
LITERATURE REVIEW AND BACKGROUND

Study Area Description

The study area is bounded by US Highway 61 (Airline Highway) on the south, the Blind River on the west, the area in the vicinity of Mississippi and Dutch Bayous on the east, and an existing old railroad grade on the north. This railroad grade is assumed to be a no flow boundary. This area is further subdivided into two areas by the presence of Interstate-10 (I-10). South of I-10, the HEC RAS 3.0 and QUAL2E models model flow and transport of the diversion through a 4 mile (6.4 km) section of Hope Canal. North of I-10, the flow and transport through a 35 square mile (90.7 km$^2$) segment of the swamp is modeled with the two dimensional RMA2 and RMA4 programs (see Figure 2).

Geologic and Geomorphic Setting

The dominant geologic characteristic of the Maurepas Swamp / Hope Canal area is the quaternary alluvial plain formed by active Mississippi River sedimentation over the last 4000 years (Saucier, 1963). The clays, silty clays, silts, and small quantities of sand were deposited primarily when the Cocodrie Delta was active, with smaller deposition occurring during high river stage while the St. Bernard Delta complex was active. This area is subsiding at a rate of one to two feet per century (Coast 2050, 1998).

The predominant soil series in the study area are the Fausse, Barbary and Schriever series. All consist of very deep, very poorly drained, and very low permeability soils that formed in clayey alluvium. Other soil characteristics include its stickiness and the
Figure 2: Study area (created from the Louisiana GIS CD, 2000)
tendency to remain saturated for long durations. The O horizons (organic) range from a depth of 0 to 6 inches (0 – 15 cm) while the A horizon (upper mineral) extends as far as 12 inches (30.5 cm) below the O horizon. The A horizon is slightly acidic and is characterized as very sticky. A representative grain size distribution in the A horizon is 75% clay, 24% silt, and 1% sand (USDA, 2001).

The topography of the area is flat with an extremely mild slope that drops gradually from the Mississippi River to Lake Maurepas (see Figure 3). The majority of the area is at an elevation of 0.9 feet (0.3 m) (based on the NAVD27 datum). Natural levees are present along the Blind River and the Mississippi/Dutch Bayou complex that do not rise more than one foot (0.3 m) above the swamp elevation.

Figure 3: USGS DEM. Elevation is in feet. Boxed area denotes approximate extent of the modeled area.

Anthropogenic topographic features present in the study area include canals, their associated spoil banks, and abandoned railroad beds. The latter typically rise one to two feet (0.3 – 0.6 m) above the study area elevation and form no flow boundaries for stages
less than about two to three feet (0.6 – 0.9 m) in the wetland (compare Figures 4 and 5). These constructed features significantly impact the hydraulic regime in the swamp with their intentional (canals) and unintentional (railroad beds) flow modifications.

Figure 4: Region prior to major hydraulic changes (Saucier, 1963)

**Hydrologic Setting**

The study area (i.e., Hope Canal and Maurepas Swamp) is located within the Lake Ponchartrain Basin hydrologic unit. Major surface water features that contribute to the study area hydrologic budget include Hope Canal (storm water flow from upstream), Bayou Tent, Bayou Secret, Bourgeois Canal (tidal input when Lake Maurepas levels are high), and lateral inflows from Blind River and Mississippi Bayou when stages are high due to tidal influences or precipitation. The study area averages 60 inches (152 cm) of rain per year with the monthly average of 5 inches (12.7 cm) (NWS, 1999).
Figure 5: Anthropogenic modifications to the study area.

Water level within Hope Canal is dominated by two factors – precipitation and Lake Maurepas levels (see Figure 6; stage data is from USGS gauge number 073802292 located at Hope Canal on the I-10 bridge; precipitation data is from NOAA station number WBAN 12916 at the New Orleans International Airport). As can be seen in Figure 6, a variation in swamp water levels occurs due to Lake Maurepas whether or not rainfall has occurred. It is also evident that precipitation dominates the hydrograph for approximately 100 hours as Hope Canal conveys runoff from upstream areas to Lake Maurepas. Otherwise, Lake Maurepas water levels drive the swamp water level.

Four anthropogenic features are present within the study area that impact natural water flow (see Figure 5). The first is a series of canals built to serve two functions: (1) drain upland areas and move excess water out of populated areas; and (2) provide access to oil wells within the study area. A second hydraulic feature in the wetland is a series of
abandoned railroad embankments. These embankments typically have an elevation 1-2 feet (0.3 – 0.6 m) higher than the swamp elevation and act as no flow boundaries. Since these are abandoned structures, the potential exists to remove or breach them in order to restore a more natural flow regime. A second embankment structure is I-10, which splits the study area into northern and southern halves. Unlike the abandoned railroad embankments, this structure cannot be modified easily to improve circulation. The final feature is a cleared right of way occupied by a high voltage transmission line and subsurface pipeline.

These features impact the flow and distribution of water in the study area in several ways. The embankments confine sheet flow and inhibit distribution within the study area. The canals also inhibit marsh inundation through the area by channelizing flow and diverting it directly to the Blind River and Bayou Tent. The canals also serve as
conduits to move water and contaminants into or out of the study area when lake levels or precipitation are dominating the flow.

**Biological Setting**

The majority of the area is classified as a palustrine forested wetland with some channels classified as riverine (US Department of the Interior Fish and Wildlife Service, 1992). Palustrine wetlands are defined as tidal or nontidal freshwater wetlands in which vegetation is predominately trees, shrubs, or rooted herbaceous plants while riverine wetlands are classified as nontidal or tidal freshwater within a channel or along its banks (USGS, 1996). Both wetlands are tidal freshwater wetlands with the palustrine areas being intermittently flooded. The dominant tree types are needle deciduous (cypress) with broadleaf deciduous trees present in lesser numbers.

Impacts of a diversion on the native vegetative species are a function of the diversion’s duration and degree of inundation. For example, constant inundation has a negative effect on Bald cypress germination since these seeds do not germinate under flooded conditions. Seedlings are also adversely affected by prolonged inundation. The degree of inundation determines wetland long-term health, where the range in growth is from successful germination, dispersal, and seedling establishment in slow moving water to excessive flooding which results in the net transport of seeds out of the wetland area (Souther, 2000). Thus, diversion flow would need to be managed with spring-time “new-growth” in mind. This implies that any planned diversion scheme needs to take into account and balance the competing physical (reduced salinity), geomorphic (sedimentation), and biological (flood inundation period and depth) requirements.
Optimizing only one or two of these competing factors may result in conversion of the wetland to open water and negate the usefulness of the diversion.

**Field Observations**

A site survey of the study area revealed that the most significant channel (Hope Canal) within the study area had no significant flow when precipitation was absent. Other than the elevated levee, most areas consisted of highly organic saturated soils with low bearing capacity. Vegetation present was primarily bald cypress and gum tupelo.

Swamp surface features which contribute to surface flow energy losses include surface litter ranging from small debris to large logs, live vegetation, and exposed cypress roots (cypress knees). See Figures 7 and 8 for typical views. Live vegetative structures to include standing trees and exposed cypress roots are highlighted in Figure 7, while surface litter and decaying vegetation are highlighted in Figure 8.

**Wetland Hydrology and Hydraulics**

The wetland hydrologic budget has the typical inputs and withdrawals that apply to other ecosystems. These inputs include direct precipitation, overland flow, channel and overbank flow, groundwater discharge, and tidal flow. Withdrawals include evaporation and transpiration, groundwater recharge, and overland, channel, and tidal flows. Temporary storage within the wetland includes channel and overbank storage as well as groundwater storage. At the wetland boundaries, this budget and corresponding flow rates are easy to calculate with conventional methods. The difficulties arise when modeling hydrodynamic flow that occurs within a wetland.

Though the underlying concepts of continuity and conservation of momentum apply to modeling wetlands, adjustments to numerical models need to be made to account
for the hydrodynamic processes that occur within these areas. Key differences from open channel flow environments include shallow flow over an extended surface, flow through emergent vegetation, and microtopography that forms networks of small channels within the wetland system, particularly at low flow. Also, intermittent flooding and draining of the marsh surface can create a challenging modeling environment (Roig, 1995).

Preliminary research also indicates that wetland channels have different geomorphic characteristics from other alluvial non-wetland streams. These include tighter bends, lengthier straight reaches, and unusual thalweg patterns (Jurmu, 1997). Another anomaly is that typical definitions of bank full flow may not apply in these situations. The presence of water beyond the channel and ill characterized banks impact the definition of what bank full flow is in a wetland (Jurmu, 1997). Because these unique processes are very difficult to model using the standard hydrodynamic equations, additional procedures and parameters are added to the hydrodynamic model. Adjustable roughness parameters and marsh porosity factors are two techniques that have been implemented in numerical modeling to represent some of the physical hydrodynamic processes occurring in wetlands. The vegetative drag force within a wetland is typically more pronounced than open channel flow. Manning’s roughness coefficients (n) values have been found to be 2-5 times higher than published data (Hall, 1995). This drag force is primarily caused by vegetation and is a function of the spatial variability, stem sizes, leaf areas, and stem surface roughness of the resident plant community. Other factors affecting energy losses are the vegetative biomechanical strength, the water velocity and the flow depth. Several alternatives have been advanced to determine roughness coefficients. One is to expand techniques developed for open channels (Chow, 1959) to
Figure 7: Typical swamp surface features.

Figure 8: Typical swamp surface features.
flood plains and include vegetative density (Arecement, 1989). Other alternatives incorporate varying depths of flow and vegetative structure and density (e.g. Wu, 1999, Petryk, 1975). Flow velocity and the vegetative biomechanical strength have also been incorporated into roughness coefficient calculations (e.g. Fathi, 1997, Kouwen, 1980). In contrast to typical open channel flow, calculating model parameters to determine these coefficients may involve flume studies to determine biomechanical properties and site surveys to obtain vegetative drag coefficients (Fischenich, 1999). To account for these energy losses, RMA2 has the capability to generate a roughness coefficient based on the element’s flow depth. The program allows the user to specify the coefficients to define an exponential curve that will be used after each iteration to calculate the roughness coefficient (Donnell, 1997).

The formula used for generating this curve is:

\[
    n_{\text{Value}} = \frac{RDR0}{AVEDEP^{RDCOEF}} + \left( RDRM \times \exp \left( -\frac{AVEDEP}{RDD0} \right) \right)
\]

where

- \( n_{\text{Value}} \) = Roughness coefficient
- \( RDR0 \) = Maximum Manning’s n for non-vegetated water
- \( AVEDEP \) = Calculated depth
- \( RDRM \) = Manning’s n for vegetated water
- \( RDCOEF \) = Roughness by depth coefficient
- \( RDD0 \) = Depth at which vegetation effects roughness

Example values for previous projects from the Waterways Experiment Station are presented in Table 1 and an example plot is shown in Figure 9. While this method accounts for the vegetative structural properties and flow depth, it does not account for the vegetative biomechanical properties or the flow velocity.
Table 1: RMA2 default values for automatic roughness assignment (Donnell, 1997)

<table>
<thead>
<tr>
<th>Flow Environment</th>
<th>RDR0</th>
<th>RDD0</th>
<th>RDRM</th>
<th>RDCOEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miss. R. Delta</td>
<td>.02</td>
<td>2.0</td>
<td>.026</td>
<td>.08</td>
</tr>
<tr>
<td>S-shaped river (test case)</td>
<td>.04</td>
<td>4.0</td>
<td>.040</td>
<td>.167</td>
</tr>
<tr>
<td>San Francisco Bay Estuary</td>
<td>.04</td>
<td>2.0</td>
<td>.040</td>
<td>.167</td>
</tr>
</tbody>
</table>

Figure 9: Roughness by depth (San Francisco Bay Estuary)

Microtopography is another area that can be problematic when modeling wetlands. When looking at this wetland system on a macro scale, the USGS digital elevation model (DEM) has a uniform elevation and an extremely mild slope (Figure 3). The limitation of using such a DEM in a wetland setting is that it lacks spatial resolution to capture accurately the microtopography of a site. Typically, wetlands have a non-uniform bed shape with small channels, hummocks, and depressions (Kadlec, 1990). Figure 10 is a schematic of a representative wetland cross section. Acquiring survey data to construct a DEM on a large scale is restricted by vegetation. Also, the wetland’s soil
surface is not obvious necessarily due to the muck and litter layer (Kadlec, 1990). Some systems, such as LIDAR (Light Detection and Ranging), have the capability to record the topography at a finer resolution. Higher resolutions create additional modeling challenges since this quantity of data ultimately justifies a very dense mesh, which in turn leads to excessive computational demands.

One method to account for the effects of microtopography in a hydrodynamic model is by defining a marsh porosity factor (Roig, 1994; Donnell, 1997). This factor represents the microtopography of the site by allowing a computational element to transmit water when the water level falls below the base elevation of that element. The computational element represents an analog for litterfall where water storage and movement may still occur even when marshes are not inundated. The three marsh porosity factor parameters and their meaning are illustrated in Figure 11. The first parameter, AC1, represents the difference between the element’s nodal elevation and the model domain’s lowest elevation. The AC2 parameter represents the elevation range around the nodal elevation where the

![Figure 10: Representative cross section of a wetland (Donnell, 1997).](image)
element is able to convey water. At the upper end of the range, the element has available
100% of its surface area to convey water. At the lower end of the AC2 range, the
element is only able to convey a certain percentage (AC3) of the total possible. Thus,
when the water surface elevation is the nodal elevation plus one half of AC2, the element
can convey water over 100% of the element’s surface area. When the elevation reaches
an elevation that is the nodal elevation minus one half of AC2, the element can only
convey a percentage defined by AC3. Default values for RMA2 are AC1 = 3 feet, AC2 =
2 feet, and AC3 = .02 (Donnell, 1997).

![Figure 11: Marsh porosity parameters (Donnell, 1997)](image)

Suggested values for these parameters are to equate AC1 at least as large as the range of
expected water surface elevations. The second parameter, AC2, has worked with a range
of two to five feet in tidal marshes or one to two feet in tidal flats. The third parameter is
dependent on quantity of flow transmitted in below-grade finger channels in the modeled
area. No specific value for this parameter has been published (King, 1996).
Wetland Nitrogen Cycle

The evolution of nitrogen in water bodies occurs through a complex set of interactions that vary vertically throughout the water column as well as the aerobic and anaerobic soil layers. These processes include enzymatic hydrolysis of organic N, mineralization, nitrification, NH$_4$-N volatilization, denitrification, and vegetative assimilation and decay (Figure 12; Martin, 1997). Vertical transport mechanisms include diffusion and settling, while the primary horizontal mechanism is water flow. In wetlands, these mechanisms are more complex due to the processes that occur within the saturated soil layers. Research indicates that this aspect of nitrogen evolution plays a more significant role when compared to the processes occurring in the water column (Davidsson, 2000; White, 1999). While QUAL2E can model the processes that occur in the water column (see Appendix 2), it does not take into account processes occurring in the soil layers.

Figure 12: Wetland nitrogen cycles (Martin, 1997).
RMA4 takes an even more simplistic approach by only superficially simulating these processes with a first order decay rate. Wetland nitrogen assimilation rates are highly dependant on variables such as the type of wetland (i.e. ombrotrophic bogs, fens, or freshwater marsh), their hydraulic regime, and their nutrient loading rates. Published values vary from 0.1 to 2.0 mg/L/day (Kadlec, 1996).

**Wetlands Modeling**

Several available mathematical models have the potential or have been applied to wetlands including BRANCH (Schaffranek, 1981), RMA2 (Richards, 1993), and the MIKE suite of programs (DHI, 1999; Somes, 1999).

BRANCH utilizes a four-point finite difference scheme to calculate one dimensional flow dynamics in a single reach or a dendritic network. This scheme would be sufficient if all flow was confined to channels in the system. However, once overbank flow occurs, BRANCH is not applicable due to the now two-dimensional flow regime. One advantage BRANCH has over other mentioned models is its ability to be coupled with MODFLOW in order to simulate surface water and ground water interactions (Schaffranek, 1981).

RMA2 has been used previously to model flows in wetland and other aquatic ecosystems (Roig, 1994 and Crowder, 2000). It has several capabilities, which will be discussed later, that allow the user to take into account the unique features of wetland flow.

Of the above mentioned models, the MIKE suite has the greatest versatility and potential to be applied to wetlands. The MIKE modeling system of program includes 1-D and 2-D models that are constructed in a modular manner. The modules include
hydrodynamic, non-cohesive and cohesive sediment transport, and water quality
modules. An added benefit is that the 1-D and 2-D models can be linked together (DHI,
1999). The main disadvantage of the MIKE suite of programs is cost. Commercial
versions of the software that will compute 2-D flow fields and perform water quality
calculations (including pre and post processors) cost over $40,000.

Models Used

**HEC-RAS 3.0 Model**

HEC-RAS 3.0 performs one-dimensional steady and unsteady water surface
profile calculations. The unsteady flow equation solver is based on the UNET model and
solves linearized finite difference equations. HEC-RAS 3.0 is primarily used for
subcritical flow regime calculations. Governing equations for this model are summarized
in Appendix 1.

Input parameters include roughness coefficients (overbank and channel), and
contraction and expansion coefficients. HEC RAS 3.0 can be obtained free of charge
from the US Army Corps of Engineers Hydraulic Engineering Center at

**QUAL2E Model**

QUAL2E is a stream water quality model designed to evaluate various water
quality constituents including biochemical oxygen demand (BOD), various forms of
nitrogen (organic nitrogen, ammonia, nitrates, and nitrites), and conservative constituents.
Hydraulically, QUAL2E is limited to steady flow regimes. For nutrient evolution,
QUAL2E is capable of conducting dynamic simulations that vary due to temperature,
sunlight, and nutrient loading. The governing equations for the QUAL2E model are outlined in Appendix 2.

Input parameters include growth rates, Michaelis-Menton constants, and other factors that govern nitrification/denitrification, nutrient consumption, and algal growth in water bodies. QUAL2E can be obtained free of charge from the U.S. Environmental Protection Agency at www.epa.gov/OST/QUAL2E_WINDOWS/.

**RMA2 Model**

RMA2 is a two-dimensional depth-averaged finite element hydrodynamic numerical model that can compute water surface elevation and horizontal velocity components in subcritical free-surface flow fields. It has been applied to calculate circulation and flow fields in wetlands (Barrett, 1998) and Mississippi River diversions. RMA2 computes the finite element solution of the Reynolds form of the Navier-Stokes equations (Donnell, 1997). See Appendix 3 for the RMA2 governing equations. RMA2 can be obtained from the Coastal Hydraulics Lab (CHL) of the Waterways Experiment Station at http://chl.wes.army.mil/software/. RMA2 is also included as part of the Surface Water Modeling System (SMS) package available from WES. SMS is a pre- and post-processor used for building the finite element mesh and viewing the solution files for RMA2 and RMA4, as well as a number of other surface water models.

Besides study area topography and hydraulic boundary conditions, input parameters include friction and turbulence coefficients. There are also options to modify these inputs with marsh porosity and wetting and drying factors (topography), parallel flow and stagnation point factors (boundary conditions), automatic roughness by depth
factors (roughness coefficients) and defining turbulent exchange coefficients by either material type or automatically by Peclet number.

**RMA4 Model**

RMA4 is a finite element water quality transport model designed to compute concentrations of up to six conservative or non-conservative constituents. (Donnell, 2001). It assumes the depth concentration is uniform which is probably accurate for shallow water environments. This program uses the hydrodynamic solution file produced during the RMA2 simulation and an advection-diffusion equation to obtain a solution. See Appendix 4 for the RMA4 governing equations. RMA4 can be obtained from the same location as RMA2 and is also included as a component of SMS.

Input for RMA4 includes boundary conditions and model control parameters such as diffusion coefficients, fluid qualities, and growth or decay coefficients.
CHAPTER 3
MATERIALS AND METHODS

HEC RAS 3.0

Two goals of the HEC-RAS simulations were: (1) to determine how much water the existing channel can convey to the target study area without spilling over its banks; and (2) to examine the maximum channel velocities and shear to ensure no scour would occur. Also, the minimum velocity was examined for a given flow rate to determine if the potential for deposition within the channel existed. Three surveys from an EPA gauge study form the base model geometry (Figures 13 to 15). From these cross sections, nineteen additional cross sections were interpolated using HEC-RAS 3.0’s automatic interpolation scheme (Figure 16). Cross sections were interpolated approximately every 500 feet (152 m).

Roughness coefficients used were 0.1 for overbank flow and 0.03 for channel flow. These values fall into the range of typical published values for similar site conditions (Chow, 1959). Expansion and contraction coefficients were 0.3 and 0.1 respectively. Losses due to channel expansion and contraction were assumed to be negligible.

The downstream boundary condition for all runs was the Hope Canal stage data for January 1998. These data were obtained from the USGS gauge number 073802292 positioned at the I-10-Hope Canal Bridge (Figure 15). Note that these stage levels vary with time. Upstream boundary conditions used were steady flow rates ranging from 100 ft³/sec (2.9 m³/sec) to 400 ft³/sec (11.3 m³/sec) in 25 ft³/sec (0.7 m³/sec) increments. Initial conditions were 10 ft³/sec (0.3 m³/sec) for all runs.
Figure 13: Hope Canal surveyed cross sections – upper section

Figure 14: Hope Canal surveyed cross sections - middle section

Figure 15: Hope Canal surveyed cross sections - lower section
Once the “design” flow rate was determined (i.e., one that didn’t cause overbank flow and/or excessive scour), a sensitivity analysis was conducted on the in-channel roughness parameters. Values ranging from 0.02 to 0.04 were used; these are within the typical range of published roughness coefficients for this type of channel.

**QUAL2E**

The application of the QUAL2E model was to determine the nutrient, specifically nitrogen, transformation within the Hope Canal channel between Airline Highway and I-10. The results of this modeling run (i.e., the concentrations at the I-10 bridge) provide the nutrient input boundary condition for the RMA4 model. For hydraulic calculations, QUAL2E is only capable of working with uniform cross sections in a given reach (Figure 17). As a result, the surveyed and interpolated cross sections from the HEC RAS 3.0 model were converted to a trapezoidal cross section in order to be usable in QUAL2E (Figure 18).
Figure 17: QUAL2E cross section.

Figure 18: QUAL2E reach
Table 2: QUAL2E Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Range</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_1$</td>
<td>Fraction of algal biomass that is Nitrogen</td>
<td>mg N/mg A</td>
<td>.07-.09</td>
</tr>
<tr>
<td>$\alpha_5$</td>
<td>$O_2$ uptake per unit of NH$_3$ oxidation</td>
<td>mg O/mg N</td>
<td>3.0-4.0</td>
</tr>
<tr>
<td>$\alpha_6$</td>
<td>$O_2$ uptake per unit of NO$_2$ oxidation</td>
<td>mg O/mg N</td>
<td>1.0-1.14</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>Rate constant for the biological oxidation of NH$_3$ to NO$_2$</td>
<td>day$^{-1}$</td>
<td>0.10-1.0</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>Rate constant for the biological oxidation of NO$_2$ to NO$_3$</td>
<td>day$^{-1}$</td>
<td>0.20-2.0</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>Rate constant for the hydrolysis of organic N to ammonia</td>
<td>day$^{-1}$</td>
<td>0.02-0.4</td>
</tr>
<tr>
<td>$\sigma_3$</td>
<td>Benthos source rate for ammonia nitrogen</td>
<td>mg O/ft$^2$ day</td>
<td>Variable</td>
</tr>
<tr>
<td>$\sigma_4$</td>
<td>Organic nitrogen settling rate</td>
<td>day$^{-1}$</td>
<td>0.001-0.1</td>
</tr>
</tbody>
</table>

There are two major classes of parameters utilized in the QUAL2E model. The first are the hydraulic parameters that include flow rates (obtained from the HEC RAS 3.0 simulations) and reach geometry (Figures 17 and 18). The second are the concentrations and parameters driving the evolution of the materials of interest, which is nitrogen in this case (Table 2). For the hydraulic parameters, an input flow rate of 300 ft$^3$/sec (8.5 m$^3$/sec) was used while the stream geometry was interpolated from the surveyed cross sections shown in Figures 11 to 13. Concentrations of various forms of nitrogen as well as water temperature were obtained from the USGS 1999 water year data obtained at Luling, Louisiana (Table 3). This station, which is 20 miles (32.2 km) downstream from the study area, is the closest USGS station available with this type of data on record.

A sensitivity analysis was conducted on several of the parameters that influence the nitrogen evolution in the QUAL2E model. These parameters include
organic nitrogen, nitrate, nitrite, and ammonia decay rates in addition to organic nitrogen settling and ammonia benthic source rates.

Table 3: Mississippi River Water Quality at Luling LA in mg/L. (USGS, 1999)

<table>
<thead>
<tr>
<th>Date</th>
<th>Nitrite Total</th>
<th>Nitrite Dissolved</th>
<th>Nitrogen NO₂ + NO₃ Total</th>
<th>Nitrogen NO₂ + NO₃ Dissolved</th>
<th>Nitrogen Ammonia Total</th>
<th>Nitrogen Ammonia Dissolved</th>
<th>Nitrogen Ammonia + Organic Total</th>
<th>Nitrogen Ammonia + Organic Dissolved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 31</td>
<td>&lt;0.01</td>
<td>0.02</td>
<td>1.4</td>
<td>1.4</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>.65</td>
<td>E.26</td>
</tr>
<tr>
<td>Apr 29</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>1.8</td>
<td>1.8</td>
<td>0.03</td>
<td>0.01</td>
<td>.68</td>
<td>E.28</td>
</tr>
<tr>
<td>May 27</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>2.2</td>
<td>2.2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>.49</td>
<td>E.20</td>
</tr>
<tr>
<td>Aug 11</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.9</td>
<td>1.9</td>
<td>0.01</td>
<td>0.01</td>
<td>.50</td>
<td>0.34</td>
</tr>
<tr>
<td>Sep 15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.1</td>
<td>1.1</td>
<td>0.03</td>
<td>&lt;0.01</td>
<td>.51</td>
<td>0.42</td>
</tr>
</tbody>
</table>

E Estimated

RMA2

The purpose of running RMA2 was to determine the flow patterns and water depths in the Maurepas Swamp resulting from the “design” flow entering the swamp at the I-10-Hope Canal Bridge. As mentioned previously, the binary solution files (i.e., flow field) produced by these runs were also used to track nitrogen movement in the study area. The primary tools used to construct the finite element mesh were the USGS 1:24000 Quad map sheets and a digital DEM. A scanned and georegistered map sheet was imported into SMS and used as a template to draw the arc segments for the modeling area boundaries. Additional arcs were constructed to represent major streams, old railroad embankments, high voltage transmission lines, and manmade canals. The railroad embankments were assumed to be no flow areas due to their significant elevation difference relative to the rest of the wetland study area.

Once the arcs were complete, a triangular mesh was automatically generated with the SMS preprocessor. This mesh was edited to eliminate sharp triangles with an interior angle of less than 30 degrees as well as size differences of greater than fifty percent between adjacent elements. This edit was performed to eliminate any possibilities of
model instability due to the mesh geometry. Originally, the intent was to have the range of the study area be the Blind River on the west, Mississippi Bayou on the east, Lake Maurepas on the North, and I-10 on the south. However, the mesh generated for the proposed study area exceeded the RMA2 capabilities in terms of nodes, elements, and array front width. Thus, these factors had to be reduced to meet the limitations of the program. After editing for quality, elements were removed from the northern and eastern sectors of the grid until the mesh met the input requirements for the RMA suite. The final mesh characteristics are 2593 elements, 5801 nodes, and a frontal array width (Figure 19). The GFGEN program, within SMS, was then used to create a binary file for the RMA2 program.
The elements in the mesh were classified into four categories: swamp, natural channel, oil filed canals and Hope Canal (Figure 20). These categories were assigned roughness parameters as shown in Table 4. In addition, the swamp area and transmission line were assigned marsh porosity values.

![Figure 20: Element types.](image)

<table>
<thead>
<tr>
<th>Area</th>
<th>Roughness</th>
<th>Marsh Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/veg.</td>
<td>w/o veg.</td>
</tr>
<tr>
<td>Swamp</td>
<td>.12</td>
<td>.08</td>
</tr>
<tr>
<td>Hope Canal</td>
<td>.033</td>
<td>.025</td>
</tr>
<tr>
<td>Transmission Line</td>
<td>.08</td>
<td>.04</td>
</tr>
<tr>
<td>Oil Canals</td>
<td>.033</td>
<td>.025</td>
</tr>
<tr>
<td>Bayou Tent</td>
<td>.05</td>
<td>.035</td>
</tr>
</tbody>
</table>

Table 4: RMA2 Parameters
Boundary conditions were based on the January hydrograph presented (Figure 6) and the “design” flow rate calculated during the HEC RAS 3.0 modeling phase. Initial conditions within the modeling domain were the start elevation at 1.5 feet (0.5 m). A hotstart file was generated to draw down the stage from 1.5 feet (0.5 m) to 0.4 feet (0.1m), which was used as the starting conditions for the dynamic simulation.

The RMA2 sensitivity analysis was conducted on the roughness, marsh porosity, and turbulent exchange coefficients to determine the robustness of the model with respect to these parameters. The impact of these parameters on water levels was investigated at both high and low lake levels.

**RMA4**

The objective of the RMA4 modeling was to evaluate the organic nitrogen transport through the modeled area. RMA4 uses the hydrodynamic solution files from RMA2 and simulates constituent transport and evolution with a first order decay rate. In addition to the flow data from RMA2, the primary input parameters for the RMA4 model are growth or decay parameters and diffusion coefficients. Initial conditions were a 0 mg/L nitrogen concentration within the swamp, and boundary conditions were 0 mg/L at the downstream end of the model and the results from the QUAL2E simulation introduced at the upstream (Hope Canal) end of the model. A sensitivity analysis was conducted on the diffusion coefficients and decay rates in order to determine their impact on simulation. This sensitivity analysis was conducted at both high and low steady state downstream boundary stages.
CHAPTER FOUR
RESULTS AND DISCUSSION

HEC RAS 3.0 Results

HEC RAS 3.0 model runs indicate that the Hope Canal Channel can convey 300 ft$^3$/sec (8.5 m$^3$/sec) at bank full capacity. At higher rates, flow overtopped the banks and was diverted into the adjacent swamps south of I-10. Figures 21 and 22 show the impact of both channel geometry and downstream stage conditions. For the 300 ft$^3$/sec (8.5 m$^3$/sec) flow rate, the maximum velocity was 1.76 ft/sec (0.5 m/sec) which occurred at the second (mid reach) surveyed cross section. The minimum velocity was 0.6 ft/sec (0.2 m/sec), which occurred at the first surveyed (upstream) cross section. The maximum bed shear was 0.05 lbs/ft$^2$ (2.4 N/m$^2$) at the mid reach cross section, while the minimum was 0.0045 lbs/ft$^2$ (0.22 N/m$^2$) occurring at the upstream cross section (see Figures 21 and 22). From Figures 21 and 22, one can see that the maximums occurred when the downstream boundary conditions were high (i.e., 05JAN1999) while the minimums corresponded with low downstream boundary conditions (i.e., 09JAN1999). The locations of these maximums and minimums are not unexpected since the mid-reach cross section is the smallest in the reach and acts as a constriction. Thus, in order to maintain continuity, the velocity had to be higher relative to the upper and lower surveyed cross sections.

Channels composed of colloidal stiff clay or silts can withstand velocities of up to 5 ft/sec (1.5 m/sec) when the water is transporting colloidal silts and while the corresponding maximum shear is 0.46 lb/ft$^2$ (22 N/m$^2$) (Morris, 1972). This implies that, under these conditions, stream erosion will not be a significant factor.
Figure 21: Maximum and Minimum Channel Velocities.

Figure 22: Maximum and Minimum Bed Shear
The sensitivity analysis was conducted at the design flow rate (300 ft$^3$/sec (8.5 m$^3$/sec)) for a range of roughness parameters expected for the channel’s geomorphic condition (see Table 5). In all cases, the maximum shear never exceeded 0.46 lb/ft$^2$ (22 N/m$^2$). Results of the sensitivity analysis indicate that for this model scenario, HEC RAS 3.0 is insensitive to changes in energy loss coefficients. This implies that the most critical aspect of this model is constructing the proper geometrical representation.

<table>
<thead>
<tr>
<th>n Value</th>
<th>Velocity (m/s)</th>
<th>Bed Shear (N/m$^2$)</th>
<th>n Value</th>
<th>Velocity (m/s)</th>
<th>Bed Shear (N/ft$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td>0.57</td>
<td>1.436</td>
<td>0.031</td>
<td>0.52</td>
<td>2.394</td>
</tr>
<tr>
<td>0.021</td>
<td>0.57</td>
<td>1.436</td>
<td>0.032</td>
<td>0.52</td>
<td>2.394</td>
</tr>
<tr>
<td>0.022</td>
<td>0.56</td>
<td>1.436</td>
<td>0.033</td>
<td>0.51</td>
<td>2.873</td>
</tr>
<tr>
<td>0.023</td>
<td>0.56</td>
<td>1.436</td>
<td>0.034</td>
<td>0.51</td>
<td>2.873</td>
</tr>
<tr>
<td>0.024</td>
<td>0.55</td>
<td>1.915</td>
<td>0.035</td>
<td>0.50</td>
<td>2.873</td>
</tr>
<tr>
<td>0.025</td>
<td>0.55</td>
<td>1.915</td>
<td>0.036</td>
<td>0.49</td>
<td>2.873</td>
</tr>
<tr>
<td>0.026</td>
<td>0.54</td>
<td>1.915</td>
<td>0.037</td>
<td>0.49</td>
<td>3.352</td>
</tr>
<tr>
<td>0.027</td>
<td>0.52</td>
<td>1.915</td>
<td>0.038</td>
<td>0.49</td>
<td>3.352</td>
</tr>
<tr>
<td>0.028</td>
<td>0.54</td>
<td>2.394</td>
<td>0.039</td>
<td>0.48</td>
<td>3.352</td>
</tr>
<tr>
<td>0.029</td>
<td>0.53</td>
<td>2.394</td>
<td>0.04</td>
<td>0.48</td>
<td>3.352</td>
</tr>
<tr>
<td>0.03</td>
<td>0.52</td>
<td>2.394</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**QUAL2E Results**

The “base case” QUAL2E simulation for the Hope Canal diversion showed that the total nitrogen concentration was reduced from 1.78 mg/L to 1.77 mg/L (Figure 23). Of the four modeled species, organic nitrogen was lowered from 0.63 mg/L to 0.56 mg/L, ammonia nitrogen increased from 0.02 mg/L to 0.07 mg/L, nitrite remained steady at 0.03 mg/L, while nitrate decreased from 1.78 mg/L to 1.77 mg/L. Overall, the slight reduction is due to the relatively short reach length and residence time. The slight increase in ammonia was due to the benthos source term.
Results from the sensitivity analysis (Table 6) indicate that, as with the HEC RAS 3.0, the QUAL2E model is insensitive in this relatively simple modeling environment. Parameters were varied one at a time, and those that had the greatest impact were the organic nitrogen hydrolysis and settling rates, though they were not great enough to impact the overall nitrogen content. Thus, the proper geometric representation and accurate flow rates are the most critical aspect in setting up an accurate representation of a diversion scenario.

![Figure 23: Nitrogen concentration (organic, nitrate, nitrite, ammonia, and total N)](image)

### Table 6: QUAL2E Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter Varied</th>
<th>Range</th>
<th>Organic N</th>
<th>NH3N</th>
<th>NO2N</th>
<th>NO3N</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-N Hydrolysis</td>
<td>.02-.3</td>
<td>0.61-0.56</td>
<td>0.02-0.07</td>
<td>0.01</td>
<td>1.39</td>
<td>2.03</td>
</tr>
<tr>
<td>O-N Settling</td>
<td>.001-.1</td>
<td>0.57-0.55</td>
<td>0.07</td>
<td>0.01</td>
<td>1.39</td>
<td>2.04-2.02</td>
</tr>
<tr>
<td>NH3 Oxidation</td>
<td>.1-1</td>
<td>0.56</td>
<td>0.07</td>
<td>0.01-0.02</td>
<td>1.39</td>
<td>2.03-2.04</td>
</tr>
<tr>
<td>NH3 Benthos</td>
<td>0-1</td>
<td>0.56</td>
<td>0.07</td>
<td>0.01</td>
<td>1.39</td>
<td>2.03</td>
</tr>
<tr>
<td>NO2 Oxidation</td>
<td>.2-.2</td>
<td>0.56</td>
<td>0.07</td>
<td>0.02-0.01</td>
<td>1.39-1.4</td>
<td>2.03-2.04</td>
</tr>
<tr>
<td>O2 uptake/NH3 oxidation</td>
<td>3.0-4.0</td>
<td>.056</td>
<td>0.07</td>
<td>0.01</td>
<td>1.39</td>
<td>2.03</td>
</tr>
<tr>
<td>O2 uptake/NO2 oxidation</td>
<td>1-1.14</td>
<td>0.56</td>
<td>0.07</td>
<td>0.01</td>
<td>1.39</td>
<td>2.03</td>
</tr>
</tbody>
</table>
**RMA2 Results**

To facilitate data evaluation, the 2-D modeled area was separated into the four lettered regions (i.e., A-D) shown in Figure 24. Furthermore, numerical results were recorded at the nodes identified in Figure 25. Hydrographs of the four regions (see Figures 26 thru 29) indicate that for the design flow, the diversion’s greatest impacts are in the A and C regions. Regions B and D remain dominated by the model’s downstream boundary condition – the lake level.
Figure 25: Evaluation nodes

Figure 26: Region A stages (dynamic simulation)
Figure 27: Region B stages (dynamic simulation)

Figure 28: Region C stages (dynamic simulation)
Region A experiences the greatest inundation primarily because it is the point of introduction of the upstream boundary condition flow. The old railroad bed that separates Region A from Region B restricts most of the flow in Region A. Region C is impacted by a flow diversion due to the momentum that the flow has when it reaches the railroad bed breaks in the center of the modeled area. Here, water still contains a significant south to north momentum component that enables the flow to move north past the breaks (see Figure 30).

At this flow rate, existing drainage and topographic features capture a significant amount of the flow and prevent inundation from diverted Mississippi River water from reaching Regions B and D (see Figure 30). In these areas, inundation only occurs when the lake levels are high enough to force water into the swamp.
Figure 30: Flow fields during low dynamic boundary condition.

This confirms information contained in the RMA2 user's manual on the influence of boundary conditions. With respect to stages, the model was more sensitive to parameter changes at the low steady state stage (0.8 foot stage) when compared to the high steady state (1.5 foot stage) scenario. The maximum difference at any node during the high steady stage was less than 2.6%, while at the low steady stage, the maximum difference was nearly 5.5% with many nodes experiencing between 2 and 3% difference. This is because the roughness and marsh porosity factors are a function of depth. At low stages, vegetation, which in turn results in greater friction losses. At higher stages, vegetation is entirely underwater and the swamp is completely inundated. In this regime, energy losses due to vegetation are less and marsh porosity factors have little effect since the entire element is available to flow.

Examination of Tables 7 and 8 show that the model is more sensitive to variations in roughness parameters.
Table 7: RMA2 Sensitivity Analysis (on Stages) – Varying Marsh Porosity

<table>
<thead>
<tr>
<th>Node</th>
<th>Ref.</th>
<th>+ 20%</th>
<th>% Δ</th>
<th>-20%</th>
<th>% Δ</th>
<th>Ref.</th>
<th>+ 20%</th>
<th>% Δ</th>
<th>-20%</th>
<th>% Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>258</td>
<td>1.646</td>
<td>1.631</td>
<td>-0.91</td>
<td>1.658</td>
<td>-0.73</td>
<td>1.56</td>
<td>1.52</td>
<td>-2.25</td>
<td>1.59</td>
<td>-1.80</td>
</tr>
<tr>
<td>791</td>
<td>1.500</td>
<td>1.500</td>
<td>0.00</td>
<td>1.500</td>
<td>0.00</td>
<td>0.80</td>
<td>0.80</td>
<td>0.00</td>
<td>0.80</td>
<td>0.00</td>
</tr>
<tr>
<td>841</td>
<td>1.632</td>
<td>1.625</td>
<td>-0.43</td>
<td>1.635</td>
<td>-0.18</td>
<td>1.56</td>
<td>1.53</td>
<td>-1.61</td>
<td>1.57</td>
<td>-0.96</td>
</tr>
<tr>
<td>1017</td>
<td>1.534</td>
<td>1.532</td>
<td>-0.13</td>
<td>1.535</td>
<td>-0.07</td>
<td>1.24</td>
<td>1.20</td>
<td>-3.39</td>
<td>1.28</td>
<td>-2.91</td>
</tr>
<tr>
<td>1078</td>
<td>1.513</td>
<td>1.512</td>
<td>-0.07</td>
<td>1.513</td>
<td>0.00</td>
<td>0.98</td>
<td>0.94</td>
<td>-3.89</td>
<td>1.02</td>
<td>-4.60</td>
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Table 8: RMA2 Sensitivity Analysis (on Stages) – Varying Roughness Parameters

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Results of the sensitivity analysis indicate that the best locations for calibration gages are off the main channels in Regions A and C. The optimal times to gather stages for calibration purposes are during low downstream boundary
conditions, where model parameter changes have the greatest impact on model outcomes.

Velocity magnitudes were examined during the steady state runs while conducting the sensitivity analysis (see Figures 31 and 32). The velocity plots indicate that Lake Maurepas hydraulically affects areas where the stage is dominated by the upstream boundary condition. In regions A and C, velocities are reduced during high downstream boundary conditions when compared to low boundary conditions. This implies that, during high downstream boundary condition periods, the hydraulic residence time will be greater in both the swamp areas and channels. Impacts of higher lake stages would include increased net sedimentation due to the lower velocities as well as increased net nutrient absorption due to the higher hydraulic residence time.

Figure 31: Velocities at high steady state boundary stage.
RMA4 Results

Results from the RMA4 model indicate that after approximately 400 hours the modeled area reaches a quasi steady state nitrogen concentration, meaning that the nitrogen concentration contours don’t appreciably change with the unsteady downstream hydrodynamic boundary condition (Figure 33). As with the RMA2 simulations, the areas that had the greatest impact from the flow diversion were areas A and C. Area B received minimal impact in terms of nitrogen concentration. After approximately 50 hours, nitrogen levels exiting the modeled area via Dutch Bayou were equal to the 2 mg/L input at the Hope Canal upstream boundary condition. This suggests that nutrients diverted into the modeled area may potentially move out of the area via preferential flow paths before becoming assimilated.
Figure 33: Nitrogen concentration at after 400 hours in the dynamic simulation

An examination of nitrogen levels and stages from the dynamic simulation indicates that after the swamp reaches the quasi steady state nitrogen concentration level, downstream hydraulic boundary conditions have at most a small impact on concentrations (see Figures 34 thru 37). In Region A, where flow is dominated by the upstream boundary condition, there is no impact from a changing downstream hydraulic boundary. In Region B, nitrogen levels are low due to this region receiving minimal diversion water. The one exception to the low concentration levels are the nodes located in vicinity of the preferential flow paths (an oil field canal in this case) leading to the downstream boundary. In Region C, nitrogen concentrations are also in the high range due to the amount of flow that reaches this area. After the nitrogen reach a steady concentration, high downstream boundary conditions depress concentration levels due to the higher hydraulic residence time and corresponding increase in net assimilation. The concentration levels in Region D exhibit the most effect from a changing downstream hydraulic boundary
condition. In contrast to Region C, Region D’s nitrogen concentration rises when the downstream stage rises. This is due to the recorded node’s proximity to the boundary and the boundary-mixing chamber (Donnell, 2001).

When examining nitrogen concentration outputs from RMA4, one must keep three critical factors in mind. First, the RMA4 model can only simulate a first order decay rate, which oversimplifies the biochemical processes taking place as the various forms of nitrogen evolve in the wetland. Second, at low hydrodynamic downstream boundary stages, the majority of the swamp is experiencing the marsh porosity flow. In other words, the flow is extremely shallow. Implications in nutrient modeling are that different biochemical processes take place in the shallow aerobic ponds when compared to deeper water bodies.

Finally, in order to maintain numerical stability, RMA4 utilizes an optional boundary mixing chamber. This numerical technique is designed to maintain model stability by preventing numerical shocks due to oscillating boundary conditions (O’Donnell, 2001). This impacts the simulations during high downstream stages when flow enters the model at the downstream boundary, because nitrogen is introduced into the modeled area at a concentration that has been averaged over the previous 10 time steps. The potential net effect will be to increase the net mass of nitrogen into the modeled area.

A sensitivity analysis on the RMA4 parameters (Figures 38 thru 45) shows that, in this modeling environment, that the program is insensitive to parameter changes. Of the two parameters tested (decay and diffusion), varying the decay parameters forced the greatest model change (Figure 38). In contrast to RMA2 where the model was most sensitive at low downstream changes, the RMA4 model
was most sensitive at high downstream changes. Results of the sensitivity analysis indicate that in this modeling environment, calibration will be a complex task. This, combined with the lack of sophistication of the model, indicate that RMA4 would best be utilized as a screening model to assist in focusing more advanced modeling efforts.

![Nitrogen Concentration: Dynamic Simulation Region A](image)

**Figure 34**: Nitrogen concentration: dynamic simulation – Region A
Figure 35: Nitrogen concentration: dynamic simulation – Region B

Figure 36: Nitrogen concentration: dynamic simulation – Region C
Figure 37: Nitrogen concentration: dynamic simulation – Region D

Figure 38: High stage RMA4 sensitivity analysis (high decay) – Region A concentration
High Stage RMA4 Sensitivity Analysis (Low Decay) - Region A Concentration

Figure 39: High stage RMA4 sensitivity analysis (low decay) – Region A concentration

High Stage RMA4 Sensitivity Analysis (High Diffusion) - Region A Concentration

Figure 40: High stage RMA4 sensitivity analysis (high diffusion) – Region A concentration
Figure 41: High stage RMA4 sensitivity analysis (low diffusion) – Region A concentration

Figure 42: Low stage RMA4 sensitivity analysis (high decay) – Region A concentration
Figure 43: Low stage RMA4 sensitivity analysis (low decay) – Region A concentration

Figure 44: Low stage RMA4 sensitivity analysis (high diffusion) – Region A concentration
Figure 45: Low stage RMA4 sensitivity analysis (low diffusion) – Region A concentration
CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Modeling Results

Without modifications, Hope Canal can convey 300 ft$^3$/sec (8.5 m$^3$/sec) from Airline Highway (US 61) to the I-10 bridge at bank full capacity and with minimal scour. Higher flow rates would result in overbank flow. At 300 ft$^3$/sec (8.5 m$^3$/sec), velocities would create a depositional environment. Within Hope Canal, total nitrogen concentrations would be reduced from 1.40 mg/L to 1.36 mg/L, basically an insignificant change. Results from RMA2 show that the influx of 300 ft$^3$/sec (8.5 m$^3$/sec) at the Hope Canal I-10 bridge would most significantly impact the southeastern quadrant of the modeled area. Due to breaks in the north-south railroad bed, some impact would also be felt in a portion of the northwestern section of the modeled area. Otherwise, the dominating factors are precipitation and tidal exchange, with precipitation having the most significant effect. Under these conditions, any nitrogen introduced into the swamp via this flow would move through the southeastern quadrant of the study area and out of the modeled area. It must be noted, though, RMA4 models nitrogen as a first order decay and does not take into account the nitrogen cycle or the processes that occur in marsh sediments during the march porosity flow.

Model Utility

For the 1-D modeling environments, HEC-RAS 3.0 and QUAL2E have sufficient capabilities to investigate various diversion scenarios while the flow is contained within the channel banks. Once overbank flow occurs, the environment becomes a 2-D flow environment and the utility (or application) of these models become questionable.
In the 2-D environment, RMA2 has the capability to take into account the microtopography and roughness characteristics that can be problematic in wetland hydrodynamics. RMA4, though, is not suitable for detailed nutrient modeling. Nitrogen evolution in a biological system is a complex interdependent process of the various elemental species (i.e., nitrogen, ammonia, nitrate, and nitrite) present. RMA4 only has the capability to model a first order decay rate independent from other modeled constituents. Thus, RMA4 would be best used as a screening model.

**Recommendations for Future Work**

To examine diversion impacts on the entire Maurepas ecosystem, model boundaries need to be extended to encompass the whole swamp. Note, however, that this will result in increased computational requirements due to a significantly larger mesh. A higher resolution digital elevation model is also necessary to confirm the nuances of the microtopography in the area. This increased resolution is especially critical since the fine distinctions in topography can have significant impacts on water flow.

Model parameters such as marsh porosity and roughness coefficients can be refined through fieldwork and laboratory studies. A denser gauge system should also be placed out in the swamp to provide calibration data. Results from this study indicate that the optimal locations for stage gauges are away from boundary conditions and in the vicinity (but not in) the existing drainage channels.

For detailed nutrient modeling, a more sophisticated model is needed. RMA4, in this environment, does not adequately replicate nutrient evolution with in the swamp.

As for Maurepas Swamp, any diversion scheme would have to be closely scrutinized not only in terms of hydraulic effects but also in terms of the biological
impacts. Critical questions to ask would be how any proposed flow diversions would affect seed dispersal dynamics and the life cycles of native plant species. Excessive flooding may result in the conversion of swamp to open water due to ecosystem disruptions.

Other techniques are available to help maintain this ecosystem. One is to remove or degrade structures that no longer serve their design purpose. In the model runs, the abandoned railroad embankments had a significant impact on flow patterns within the modeled area. Breaching these structures will assist in restoring water circulation to the pre-existing patterns.
REFERENCES


Louisiana Oil Spill Coordinator's Office (LOSCO), 19990128, Color Infrared Orthophoto, NW quadrant of Lutcher Quadrangle, LA, 50:1 MrSID compressed, LOSCO (1999) [c3009059_nws_50]


APPENDIX A

HEC RAS 3.0 GOVERNING EQUATIONS

The HEC RAS 3.0 unsteady solver is adapted from Barkau’s UNET model (Brunner, 2001). UNET utilizes a four point implicit scheme to solve the unsteady flow equations (Barkau, 1997). The continuity and momentum equations are:

\[ \frac{\partial A}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0 \]  \hspace{1cm} \text{Continuity}

\[ \frac{\partial Q}{\partial t} + \frac{\partial (VQ)}{\partial x} + gA \left( \frac{\partial z}{\partial x} + S_f \right) = 0 \]  \hspace{1cm} \text{Momentum}

where:

- \( x \) = distance along the channel
- \( t \) = time
- \( Q \) = flow
- \( A \) = cross-sectional area
- \( S \) = storage
- \( q_l \) = lateral inflow per unit distance

The finite difference approximations of the terms in the continuity equation are:

\[ \Delta Q = \left( Q_{j+1} - Q_j \right) + \theta \left( \Delta Q_{j+1} - \Delta Q_j \right) \]

\[ \frac{\partial A_c}{\partial t} \Delta x_c = 0.5 \Delta x_{c_j} \frac{\left( \frac{dA_c}{dz} \right)_j \Delta z_j + \left( \frac{dA_c}{dz} \right)_{j+1} \Delta z_{j+1}}{\Delta t} \]

\[ \frac{\partial A_f}{\partial t} \Delta x_f = 0.5 \Delta x_{f_j} \frac{\left( \frac{dA_f}{dz} \right)_j \Delta z_j + \left( \frac{dA_f}{dz} \right)_{j+1} \Delta z_{j+1}}{\Delta t} \]

\[ \frac{\partial S}{\partial t} \Delta x_f = 0.5 \Delta x_{f_j} \frac{\left( \frac{dS}{dz} \right)_j \Delta z_j + \left( \frac{dS}{dz} \right)_{j+1} \Delta z_{j+1}}{\Delta t} \]
The finite difference approximations of the terms in the momentum equation are:

\[
\frac{d}{dt} \left( \frac{\partial (Q_c \Delta x_c + Q_f \Delta x_f)}{\partial t} \right) = 0.5 \frac{\partial Q_c \Delta x_c}{\partial t} + \frac{\partial Q_f \Delta x_f}{\partial t} + \frac{\partial Q_{c+1} \Delta x_{c+1}}{\partial t} + \frac{\partial Q_{f+1} \Delta x_{f+1}}{\partial t} \]

\[
\frac{\partial \beta V Q}{\partial x_{c+1}} \left[ (\beta V Q)_{c+1} - (\beta V Q)_{c} \right] + \frac{\partial \theta V Q_{c+1}}{\partial x_{c+1}} \left[ (\beta V Q)_{c+1} - (\beta V Q)_{c} \right] \]

\[
g \frac{\Delta z}{\Delta x_c} \left[ \frac{z_{c+1} - z_{c}}{\Delta x_{c+1}} + \frac{\theta}{\Delta x_{c+1}} (z_{c+1} - z_{c}) \right] + \frac{\partial g A \left( \frac{\Delta z}{\Delta x_c} \right)}{\partial x_{c+1}} (z_{c+1} - z_{c}) \]

\[
g \left( S_f + S_h \right) + 0.5 g A \left[ (\Delta S_{f+1} + \Delta S_f) + (\Delta S_{h+1} + \Delta S_h) \right] + 0.5 \theta \left( S_f + S_h \right) (\Delta A_f + \Delta A_{f+1}) \]

\[
\tilde{A} = 0.5 (A_f + A_{f+1}) \]

\[
\tilde{S}_f = 0.5 (S_{f+1} + S_f) \]

\[
\frac{\partial A_f}{\partial z} \left( \frac{dA}{dz} \right)_j \Delta z_j \]

\[
\frac{\partial S_{f+1}}{\partial z} \left( \frac{-2S_f dK}{K} \right) \Delta z_j + \left( \frac{2S_f}{Q} \right) \Delta Q_j \]

\[
\frac{\partial \tilde{A}}{\partial A} = 0.5 (\Delta A_f + \Delta A_{f+1}) \]

Subscript \( c \) indicates channel, \( f \) indicates overland flow, and \( j \) indicates the space domain.
APPENDIX B

QUAL2E GOVERNING EQUATIONS

QUAL2E is a water quality model that can simulate up to 15 water quality constituents. For this investigation, only nitrogen is modeled. The model is applicable to dendritic streams that are well mixed. Each stream reach is divided into a number of computational elements wherein a hydrologic balance for stream flow and material balance in terms of concentration are written. Both advective and dispersive mechanisms are considered in the material balance. Mass is gained or lost from the computational element by transport, injections or withdrawals, as well as internal process such as release from benthic sources or biological transformations (Brown, 1987).

Hydraulically, the program computes a series of steady state water surface profiles. The calculated stream flow rate serves as a basis for determining the mass fluxes into and out of each element due to flow. For constituent evolution and transport, QUAL2E solves for the concentration using the implicit backward finite difference method.

For nitrogen specifically, the nitrogen cycle is divided into organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen compartments. The model takes into account the stepwise transformation of organic nitrogen to ammonia, to nitrite, and finally to nitrate.

Assumptions of the model include that each computational element is completely mixed and that the hydraulic regime is steady state, and that the major transport mechanisms and advection and dispersion are significant only along the main direction of flow.
For mass transport, the governing equations are:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \left( A_x D_x \frac{\partial C}{\partial x} \right) - \frac{\partial}{\partial x} \left( A_x \bar{u} C \right) \frac{dC}{dt} + \frac{s}{V}$$

where:

- $x$ = distance
- $C$ = concentration
- $t$ = time
- $D_x$ = dispersion coefficient
- $A_x$ = cross-sectional area
- $s$ = external sources or sinks
- $\bar{u}$ = mean velocity

The right hand terms respectively represent dispersion, advection, constituent changes due to growth and decay and external sources and sinks.

The equations governing the transformation of nitrogen from one form to another are:

$$\frac{dN_1}{dt} = \alpha_1 \rho A - \beta_1 N_1 - \sigma_1 N_4$$  Organic nitrogen

$$\frac{dN_2}{dt} = \beta_2 N_1 - \beta_2 N_2$$  Nitrite nitrogen

$$\frac{dN_3}{dt} = \beta_3 N_2 - (1 - F) \alpha_3 \mu A$$  Nitrate nitrogen

where:

$N_i$ = concentration of ammonia nitrogen
\( N_2 \) = concentration of nitrate nitrogen
\( N_3 \) = concentration of nitrite nitrogen
\( N_4 \) = concentration of organic nitrogen
\( \alpha_i \) = fraction of algal biomass that is nitrogen
\( \beta_1 \) = rate constant for the biological oxidation of ammonia nitrogen, temperature dependent
\( \beta_2 \) = rate constant for the biological oxidation of nitrate nitrogen, temperature dependent
\( \beta_3 \) = rate constant for hydrolysis of organic nitrogen to ammonia nitrogen, temperature dependent
\( \rho \) = algal respiration rate
\( A \) = algal biomass concentration
\( \sigma_3 \) = benthos source rate for ammonia nitrogen
\( \sigma_4 \) = rate coefficient for nitrogen settling, temperature dependent
\( d \) = mean depth of flow
\( F_1 \) = fraction of algal nitrogen uptake from ammonia pool
\( \mu \) = local specific growth rate of algae
\( P_N \) = preference factor for ammonia nitrogen
APPENDIX C

RMA2 GOVERNING EQUATIONS

RMA2 solves the depth integrated equations of mass and momentum in the two horizontal directions (Donnel, 1997). The solved equations are:

\[
\begin{align*}
\frac{h}{\partial t} + h u \frac{\partial h}{\partial x} + h v \frac{\partial h}{\partial y} - \frac{\partial}{\partial x} \left( E_{xx} \frac{\partial^2 h}{\partial x^2} + E_{xy} \frac{\partial^2 h}{\partial x \partial y} \right) + \frac{\partial a}{\partial x} \left( \frac{\partial h}{\partial x} + \frac{\partial h}{\partial y} \right) \\
+ \frac{g u n^2}{(1.486 h^{1/6})^2} + \left( u^2 + v^2 \right)^{1/2} - \zeta V_a^2 \cos \psi - 2 h \omega_v \sin \phi = 0
\end{align*}
\]  

(1)

\[
\begin{align*}
\frac{h}{\partial t} + h u \frac{\partial h}{\partial x} + h v \frac{\partial h}{\partial y} - \frac{\partial}{\partial y} \left( E_{yx} \frac{\partial^2 h}{\partial y^2} + E_{xy} \frac{\partial^2 h}{\partial x \partial y} \right) + \frac{\partial a}{\partial y} \left( \frac{\partial h}{\partial x} + \frac{\partial h}{\partial y} \right) \\
+ \frac{g v n^2}{(1.486 h^{1/6})^2} + \left( u^2 + v^2 \right)^{1/2} - \zeta V_a^2 \sin \psi - 2 h \omega_v \sin \phi = 0
\end{align*}
\]  

(2)

\[
\frac{\partial h}{\partial t} + h \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) + u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y} = 0
\]  

(3)

where:

- \( h \) = depth
- \( u, v \) = velocities in the Cartesian directions
- \( x, y, t \) = Cartesian coordinates and time
- \( \rho \) = fluid density
- \( E \) = Eddy viscosity coefficient,
  for \( xx \) = normal direction on \( x \) axis surface
  for \( yy \) = normal direction on \( y \) axis surface
  for \( xy \) and \( yx \) = shear direction on each surface
- \( g \) = acceleration due to gravity
- \( a \) = bottom elevation
- \( n \) = Manning’s roughness coefficient
- \( \zeta \) = empirical wind shear coefficient
- \( V_a \) = wind speed
- \( \psi \) = wind direction
\( \omega = \) rate of earth’s angular rotation
\( \varphi = \) local latitude

Equations 1, 2, and 3 are solved by the finite element method using the Galerkin Method of weighted residuals. The shape functions are quadratic for velocity and linear for depth. Integration in space is performed by Gaussian integration. Derivatives in time are replaced by a nonlinear finite difference approximation. Variables are assumed to vary over each time interval in the form

\[
f(t) = f(0) + at + bt^2 \quad t_0 \leq t < t_o + \Delta t
\]

which is differentiated with respect to time, and cast in finite difference form. The solution is fully implicitly and the set of simultaneous equations is solved by Newton-Raphson non-linear iteration. The computer code executes the solution by means of a front type solver, which assembles a portion of the matrix and solves it before assembling the next portion of the matrix.
RMA4 solves the depth integrated equations of the transport and mixing process (Donnel, 2001). The form of the depth averaged equations is:

\[
0 = h \left( \frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} - \frac{\partial}{\partial x} D_x \frac{\partial c}{\partial x} - \frac{\partial}{\partial y} D_y \frac{\partial c}{\partial y} - \sigma + kc + \frac{R(c)}{h} \right)
\]

where

- \( h \) = depth
- \( u,v \) = velocities in the Cartesian directions
- \( x,y,t \) = Cartesian coordinates and time
- \( c \) = concentration of pollutant for a given constituent
- \( D_x, D_y \) = turbulent mixing (dispersion) coefficient
- \( k \) = first order decay of pollutant
- \( \sigma \) = source/sink of constituent
- \( R(c) \) = rainfall/evaporation rate

This equation is solved by the finite element using Galerkin weighted residuals. Spatial integration of the equations is performed by Gaussian techniques and the temporal variations are handled by nonlinear finite differences similar to the method described for RMA2.
VITA

Stephan Alexander Capps was born on April 21, 1977, in Stuttgart, Federal Republic of Germany. After graduating high school in Fayetteville, North Carolina, he enlisted in the United States Army as an Infantryman and served at Fort Campbell, Kentucky. In 1985, he attended the United States Military Academy at West Point, New York, and graduated with a bachelor of science in 1989.

Upon receiving his commission as Second Lieutenant in the U. S. Army Corps of Engineers, he was stationed in Germany with the 7th Engineer Brigade in Karlsruhe. During his tour there, he served in three engineer battalions, including the 249th Engineer Battalion with which he deployed to Operations Desert Shield and Desert Storm in Southwest Asia.

After his tour of duty in Germany, he was assigned to Fort Lewis, Washington, and served as a battalion operations officer, United Nations Military Observer in the Western Sahara, brigade training officer, and Company Commander of Headquarters Support Company, 864th Engineer Battalion, and A Company, 249th Engineer Battalion.

In 1999, he was assigned as adviser to the 1088th Engineer Battalion, Louisiana National Guard. He started pursuing a master’s degree at Louisiana State University at this time and graduated in May 2003.

Stephan Capps is currently a Major in the United States Army and is serving as a Project Engineer with the Far East District, U. S. Army Corps of Engineers, at Camp Casey, Republic of Korea.