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 permeablity soils that formed in clayey alluvium. Other soil characteristics include its stickiness and the

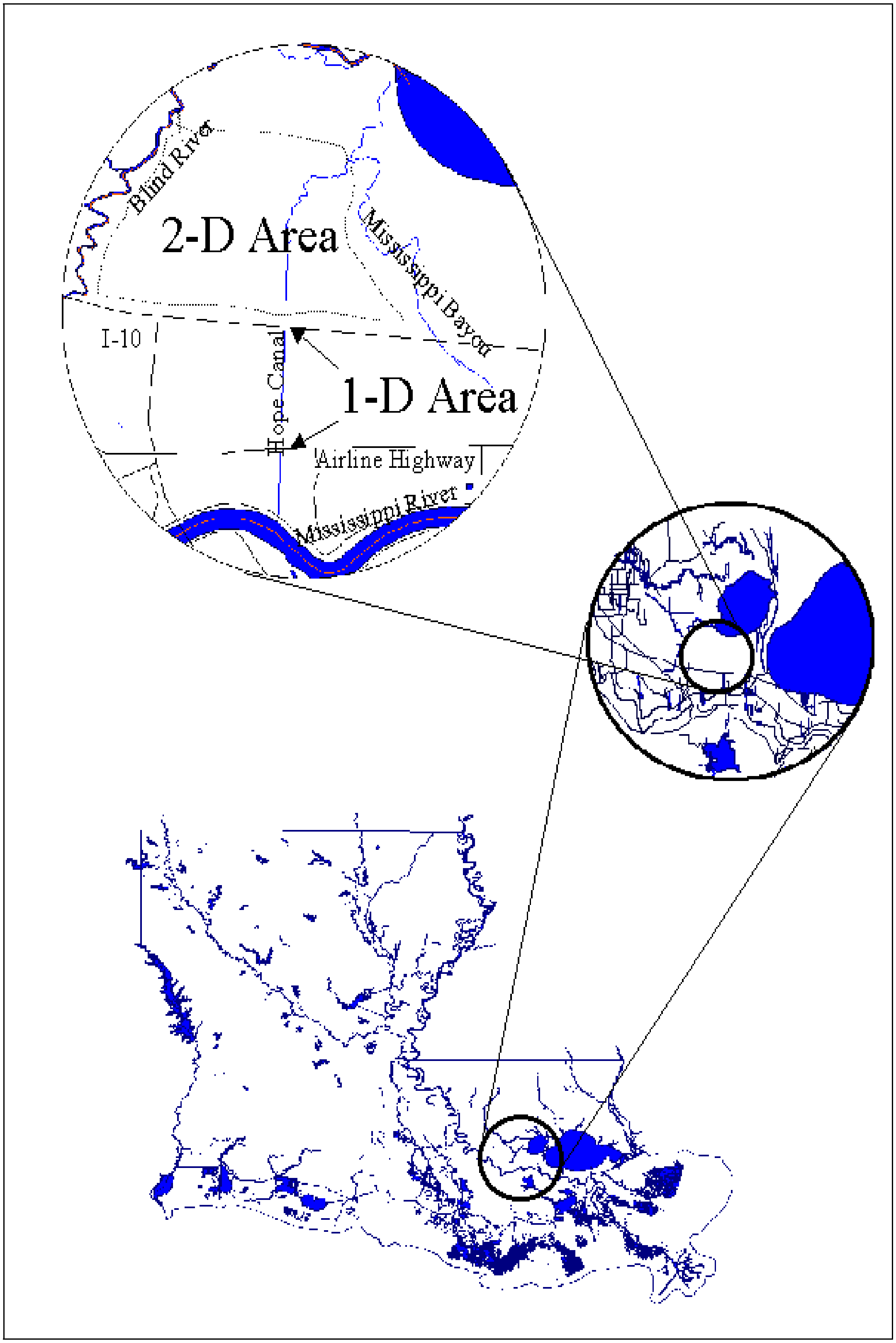


Figure 2: Study area (created from the Louisiana GIS CD, 2000)

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.

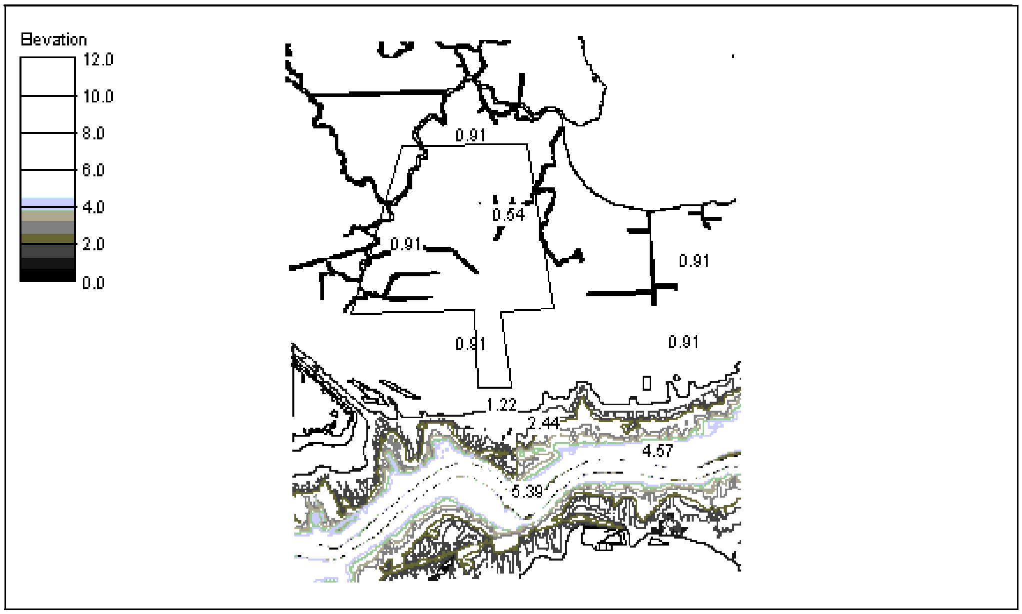
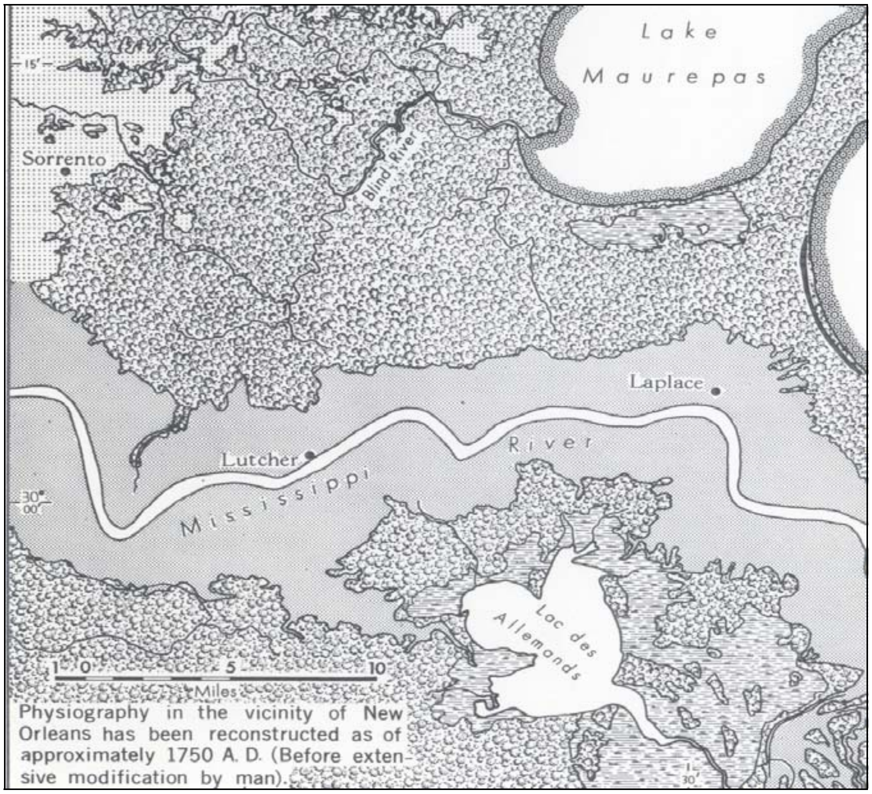


Figure 3: USGS DEM. Elevation is in feet. Boxed area denotes approximate extent of the modeled area.

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.



Physiography in the vicinity of New Orleans has been reconstructed as of approximately 1750 A. D. (Before extensive modification by man).

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).

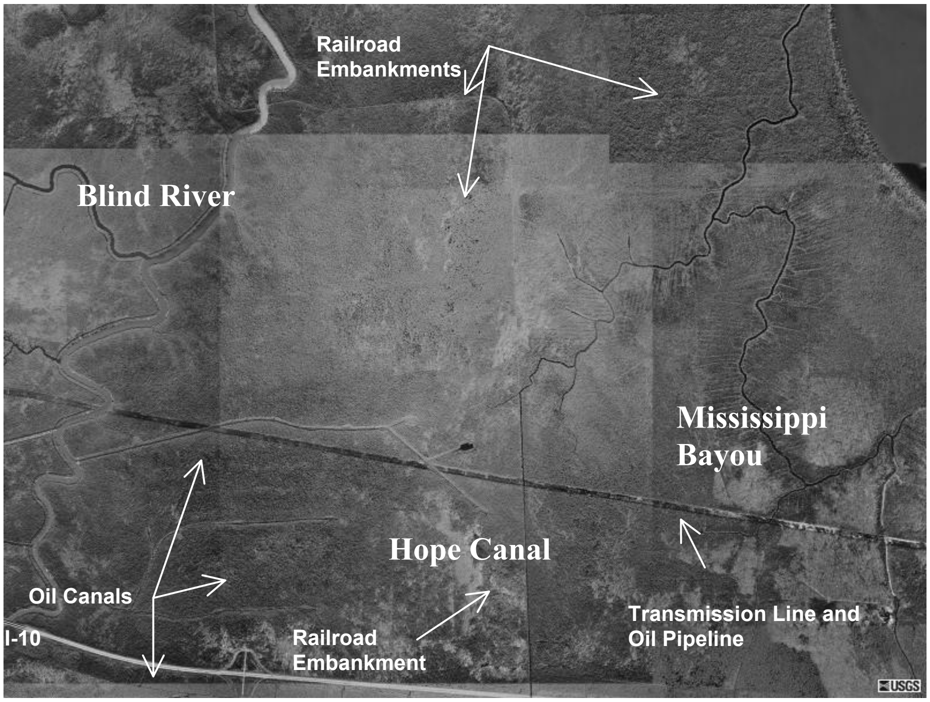


Figure 5: Anthropogenic modifications to the study area.

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

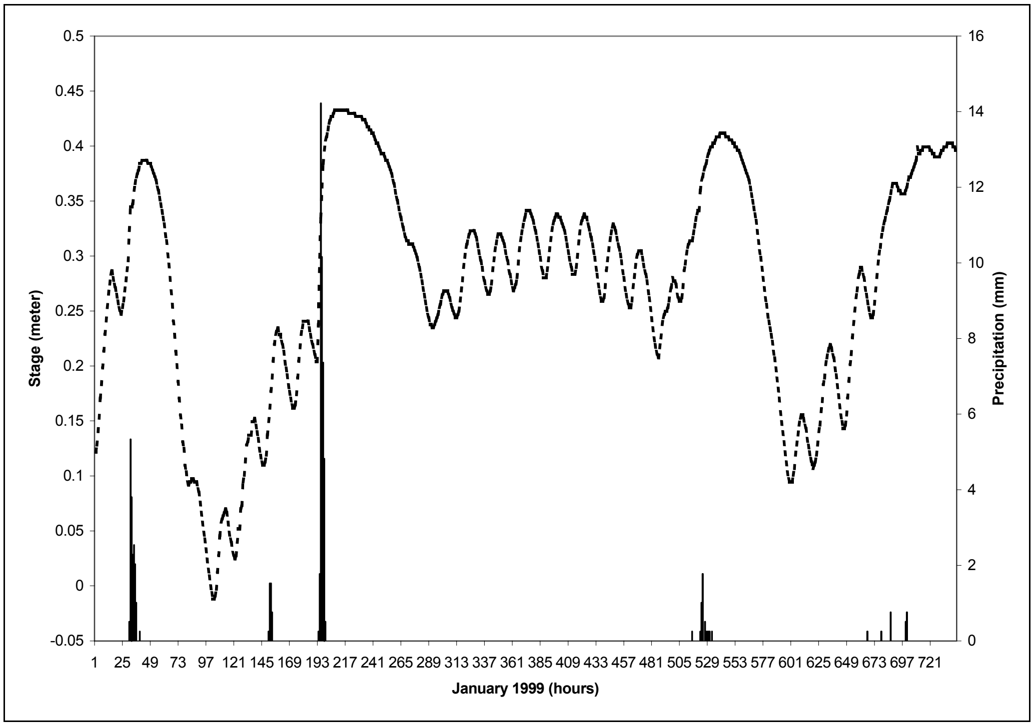


Figure 6: Hope Canal hydrograph and precipitation

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:

$$nValue = \frac{RDR0}{\left(AVEDEP^{RDCOEF}\right)} + \left(RDRM \times EXP\left(\frac{-AVEDEP}{RDD0}\right)\right)$$

where

nValue = 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)

Flow Environment	**RDR0**	**RDD0**	**RDRM**	**RDCOEF**
Miss. R. Delta	.02	2.0	.026	.08
S-shaped river (test case)	.04	4.0	.040	.167
San Francisco Bay Estuary	.04	2.0	.040	.167

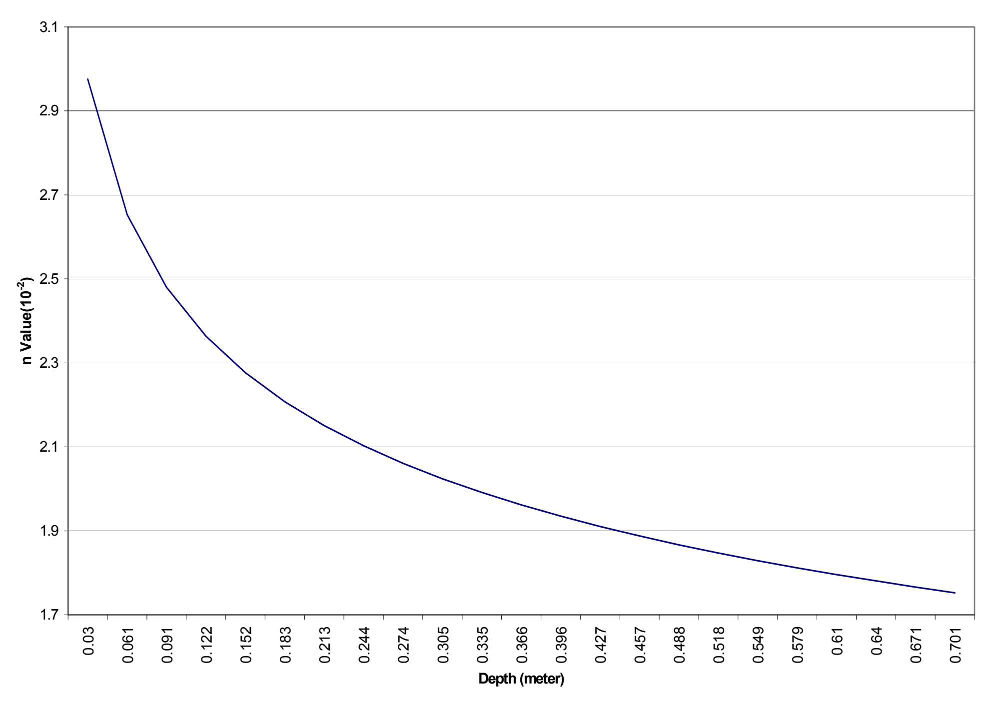


Figure 9: Roughness by depth (San Francisco Bay Estuary)

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

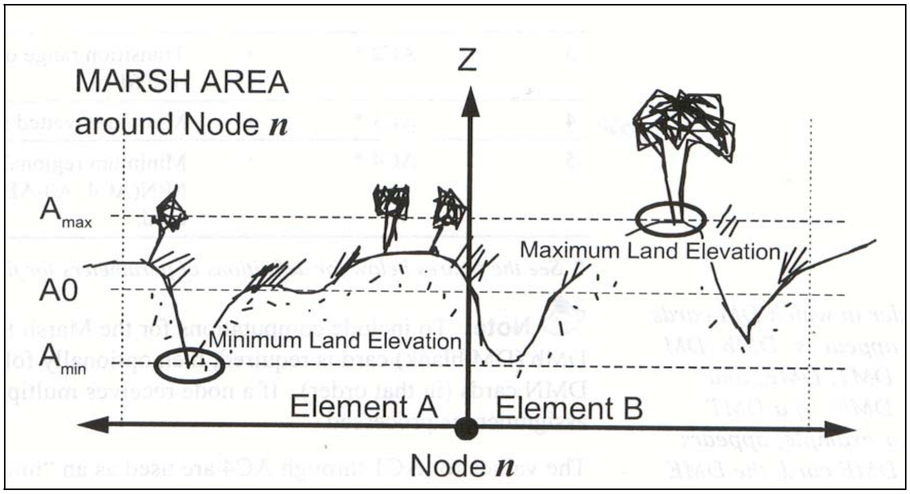


Figure 10: Representative cross section of a wetland (Donnell, 1997).

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).

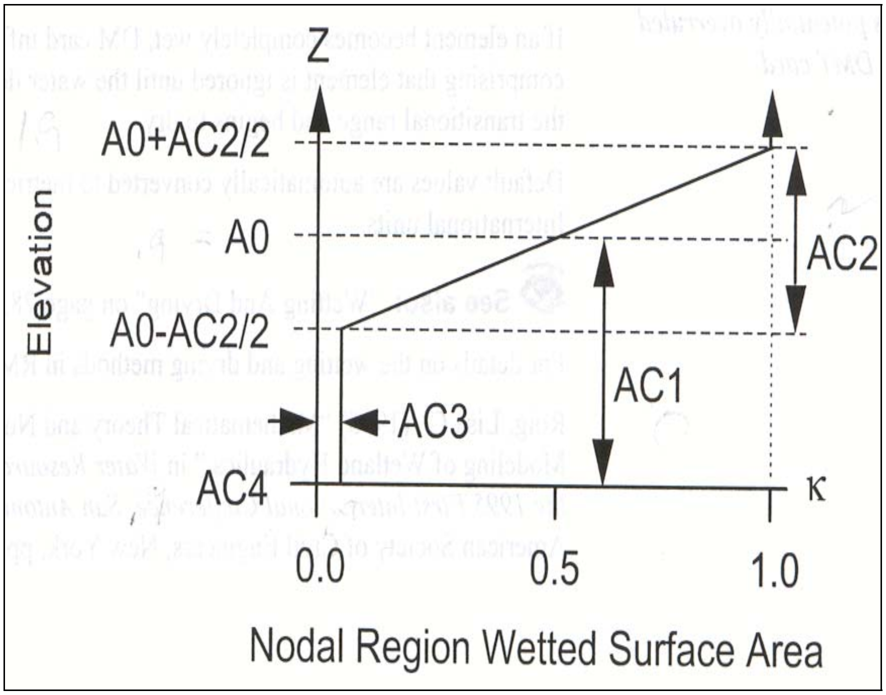


Figure 11: Marsh porosity parameters (Donnell, 1997)

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.

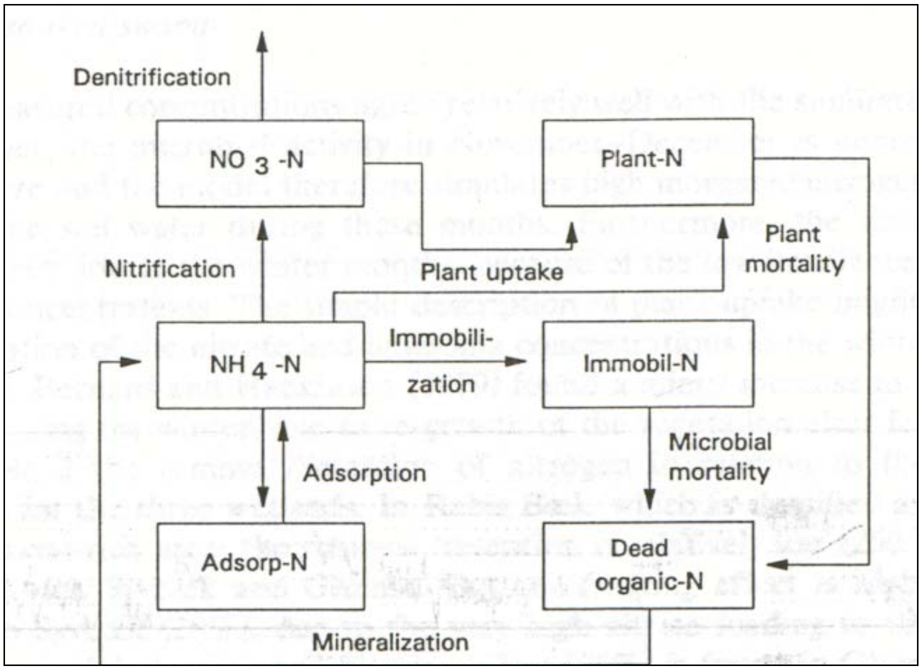


Figure 12: Wetland nitrogen cycles (Martin, 1997).

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 www.hec.usace.army.mil/software/software_distrib/index.html.

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.