5-12-2001

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Recommended Citation

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WATERSHED BASED ANALYSIS FOR WATER QUALITY MANAGEMENT WITHIN THE ESCATAWPA RIVER SYSTEM

By

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A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Civil Engineering
in the Department of Civil Engineering

Mississippi State, Mississippi

May 2001

WATERSHED BASED ANALYSIS FOR WATER QUALITY MANAGEMENT WITHIN THE ESCATAWPA RIVER SYSTEM

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Pages in Study: 107

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Assessment of water quality within the Escatawpa River system was accomplished utilizing the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS 2.0) to develop the watershed model, and the CE-QUAL-W2 software to develop the estuary model. The watershed model was utilized to quantify both hydrodynamic and water quality (fecal coliforms) characteristics of the watershed for a simulation period spanning from 1990 through 1999. Herein, calibration and application results are presented for watershed and estuary simulations made in an uncoupled manner. The models were developed such that loose coupling of watershed and estuary models can be accomplished as a subsequent phase of this ongoing project. CE-QUAL-W2 model calibration was performed utilizing a set of site specific data acquired on the Escatawpa Estuary System during an intensive survey period of

September 10-15, 1997. Dissolved oxygen levels in the system were closely examined, with regards to the impacts from point source discharges.

ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to several individuals. First, I would like to express my deepest thanks to my major advisor, Dr. David Huddleston, for his effort, support, and career advice. Appreciation is also extended to committee members, Dr. Vic Zitta and Dr. Adnan Shindala, without their technical expertise and advice this research could have never been accomplished. I would like to thank my parents for giving me the guidance needed to accomplish such a task. I would also like to thank my girlfriend, Lori, for listening numerous nights to the frustrations and complaints associated with the long hours spent on this research. Last but certainly not least, I would like to thank The Lord for giving me the knowledge, patience, and faith needed to complete an accomplishment such as this.

TABLE OF CONTENTS

Page

CHAPTER

CHAPTER Page

APPENDIX

LIST OF TABLES

TABLE Page

LIST OF FIGURES

FIGURE Page

FIGURE Page

FIGURE Page

CHAPTER I

INTRODUCTION

The Clean Water Act (CWA), the primary federal law that protects our nation's waters, including rivers, streams, lakes, and estuarine environments, requires each state to develop water quality standards that establish and maintain the water quality within the water body. Section 303(d) of the CWA and its implementing regulations at 40CFR (Code of Federal Regulations) Part 130 require that all States develop total maximum daily loads (TMDLs) for waterbodies that are not or not expected to meet designated uses under technology based controls or waterbodies that are considered threatened. This process, often termed the "303(d) list", is required of States every two years and not only lists the water body segments within the State that are impaired, but identifies the reason for impairment.

A TMDL is the maximum load of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load to the pollutant's sources. More specifically, a TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The TMDL estimate must include a margin of safety, and must account for seasonal variation in order to ensure that the waterbody can be used for the purposes the State has designated.

Each state must designate the primary uses for each waterbody, for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing), and the scientific criteria to support that use.

The Mississippi Department of Environmental Quality (MDEQ) is the designated regulatory agency responsible for monitoring and assessing the water quality within the state of Mississippi. The Mississippi 1998 303(d) List of Impaired and Threatened Waterbodies, the MDEQ identified several segments in the Escatawpa/Pascagoula Estuary System (Figure 1.1) as being impaired to support aquatic life due to organic enrichment and low dissolved oxygen concentrations (MDEQ, 1998). Historic and current data suggest that the dissolved oxygen impairment is a result of both non point source pollutants and wastewater discharges from various industries located along the water body (Shindala et al., 1973, Winfield and Nusser, 1984, USEPA, 1997,1999e).

To achieve future attainment of the water quality in the estuary and surrounding areas, management efforts to minimize both point and nonpoint sources of pollution must be developed. Water quality and hydrodynamic models that integrate point and nonpoint sources can be used as a planning tool in achievement of water quality standards. These models can further be utilized in the development of appropriate total maximum daily loads (TMDLs) for implementation in the Escatawpa Estuary.

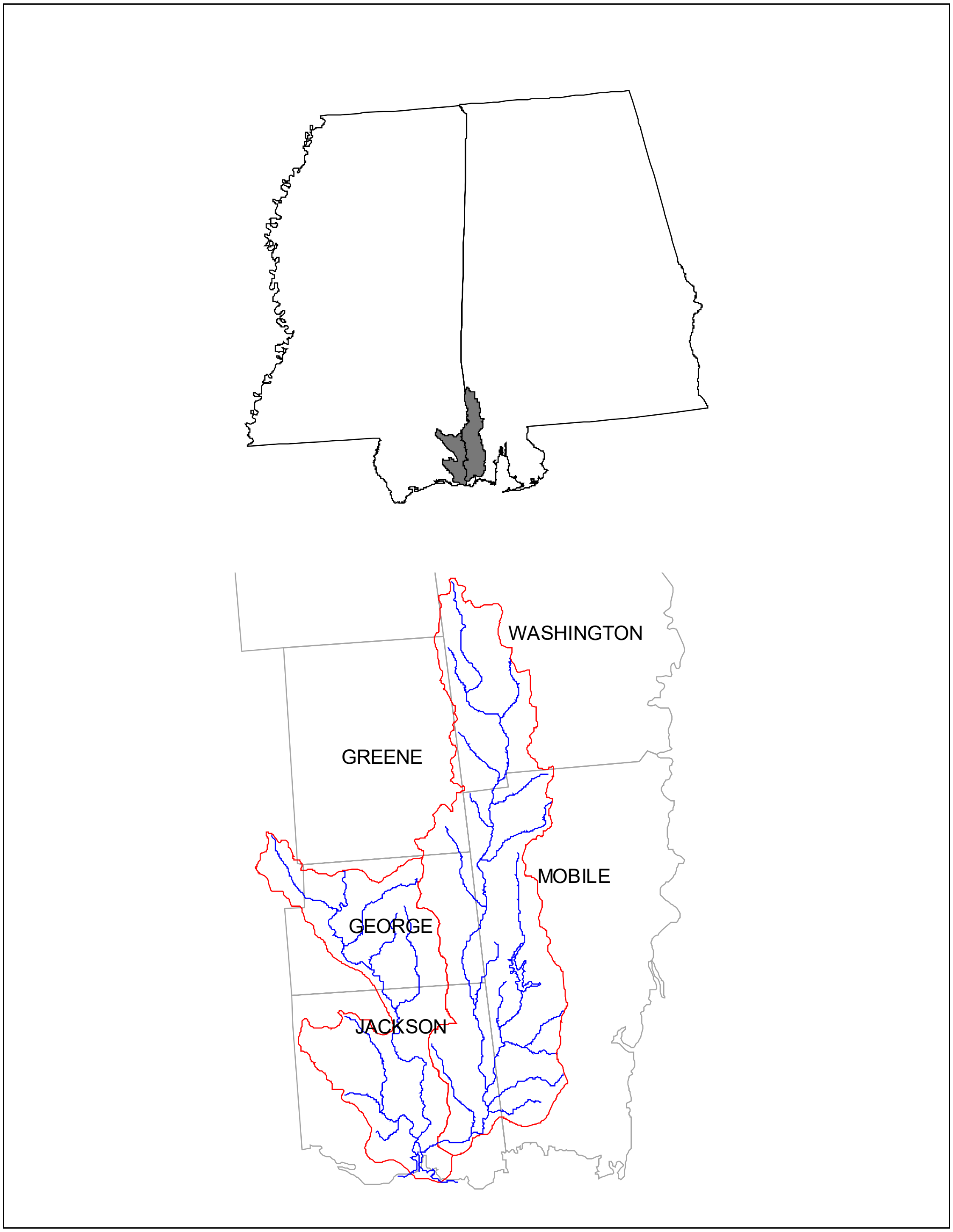

Figure 1.1: Escatawpa River Estuary Study Area

In order to achieve watershed based analysis, mathematical models that simulate water quality and hydrodynamics in the estuary as well as the upper watershed must be utilized. Coupling of the watershed and estuary models for the purpose of long term estuary simulation are beyond the scope of this thesis, but will be accomplished in a subsequent phase of an ongoing study of this study area.

The watershed model chosen to quantify the contributions from nonpoint sources in the upper watershed of the Escatawpa system is the nonpoint source model (NPSM), which is interfaced through the BASINS 2.0 environment (USEPA, 1991b). The U.S. Army Corp of Engineers' two-dimensional, laterally averaged, hydrodynamic and water quality model, CE-QUAL-W2 (Cole and Buchak, 1995), was selected to model the contributions from point source pollutants in the estuary. Information pertaining to the model selection and additional details on the models can be found in subsequent chapters.

The objective of this study is therefore to utilize the mathematical models listed above to define and assess the water quality in the Escatawpa Estuary System. The models can then be used as a planning tool to develop TMDL values. Some of the more specific objectives of the study include: (1) to customize the watershed model to determine impacts from non point sources, (2) to adapt the estuarine water quality model for application to the Escatawpa Estuary for the purposes of assessing the impact of permitted industrial point source discharge facilities along the estuary, and (3) to demonstrate the applicability of the models.

The organization of this thesis is presented such that the overall problem is discussed in this chapter. Chapter 2 presents a brief description of the Escatawpa River Estuary Study area. A brief literature survey of previously developed models is presented in Chapter 3. Chapter 4 describes development of the watershed model and presents results of application scenarios. Development and application of the estuary model is described in Chapter 5. Lastly, in Chapter 6 conclusions from the study along with recommendations for future work are presented.

CHAPTER II

DESCRIPTION OF STUDY AREA

General Description

The Escatawpa River Estuary System encompasses a drainage area of approximately 1030 square miles. The Mississippi Coastal Basin bounds the drainage basin on the west, while the Chickasawhay Basin borders on the north. The Mobile Bay forms the eastern boundary, and the Mississippi Sound forms the southern boundary of the basin. The estuary system traverses portions of Wayne, Greene, George, and Jackson counties in extreme southeastern Mississippi and portions of Washington and Mobile counties in southwestern Alabama (Figure 2.1). Runoff from the eastern portion of the watershed flows by way of the Escatawpa River into the east branch of the Pascagoula River and ultimately into the Mississippi Sound. Runoff from the remainder of the watershed flows into the Pascagoula River, which splits into an East and West Branch approximately 18 miles prior to flowing into the Mississippi Sound. The watershed area has several land use classifications with the primary land uses in the watershed being forest, agricultural, and urban. The three largest urban areas are Moss Point, Pascagoula, and Gautier.

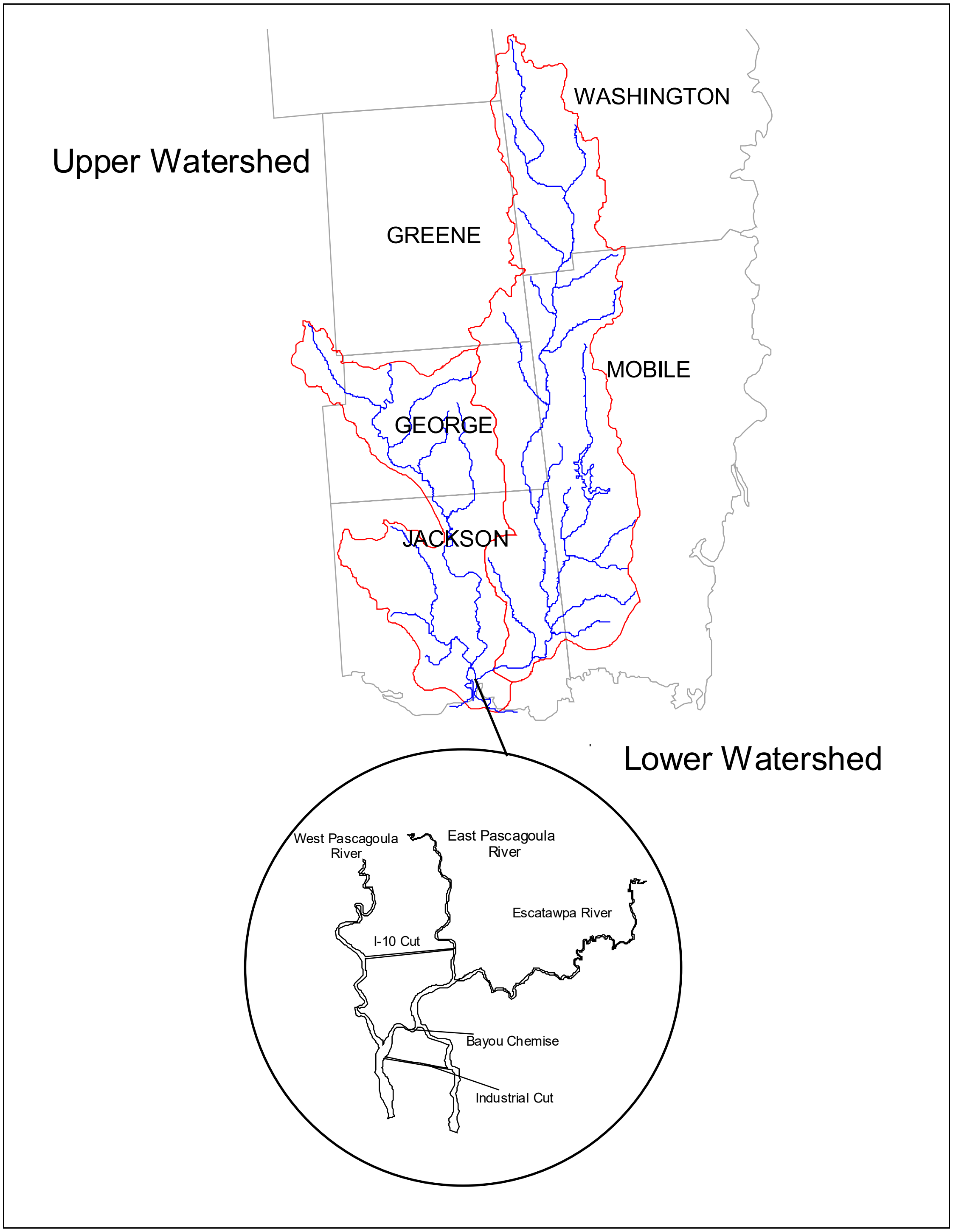

Figure 2.1: Escatawpa River Estuary Study Area

Several major streams comprise the lower portion of the estuary system, including both the East and West Pascagoula Rivers, and the Escatawpa River. As previously stated, the Pascagoula River splits into the East and West Pascagoula Rivers near river mile 17.6. Bayou Chemise interconnects the East Pascagoula river at river mile 4.5, and the West Pascagoula river at river mile 2.0. The Industrial Cut also interconnects the East and West Pascagoula River just south of Bayou Chemise, at river miles 2.0 on the East River and 2.0 on the West River, respectively. The Escatawpa River has several small tributaries that contribute to the total flow in the Escatawpa River. The river network described above is depicted in Figure 2.2. The Pascagoula River and East Pascagoula River are synonymous with each other, and will be interchanged throughout this document.

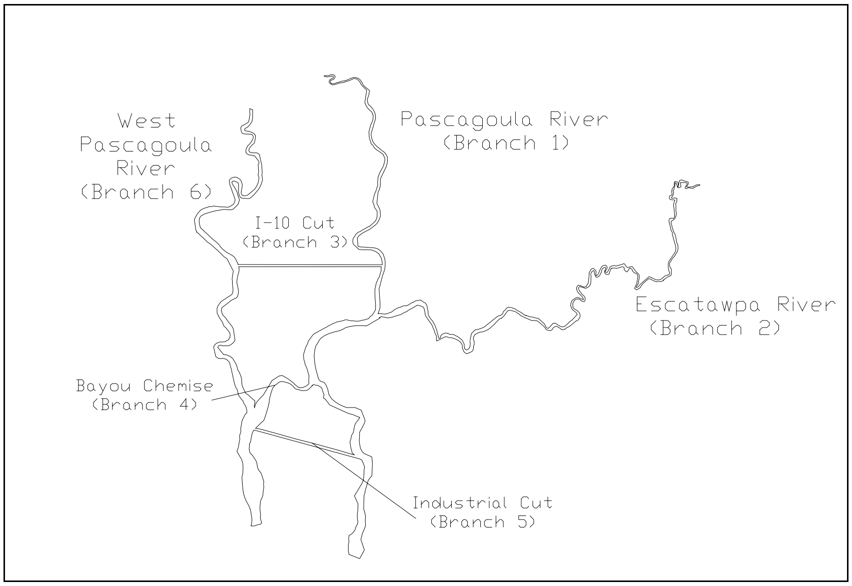

Figure 2.2: Digitized Image of Instream River Network

Hydrology

The hydraulic regime associated with this complex estuary is one that must be fully understood to develop a representative model. Flow data is available from several continuously operating gage stations as well as several other stations with intermittent discharge measurements. The stations located at Merrill and Grahams Ferry on the Pascagoula, and at Agricola on the Escatawpa provided the most useful data for this study. Table 2.1 summarizes the nominal flow characteristics at these gage stations, while their locations are depicted on Figure 2.3.

Several studies have been conducted to determine the distribution of flow between the east and west branches of the Pascagoula River. Flow measurements taken by the USGS in August of 1972 indicated 60 percent of the flow was discharging through the West Pascagoula River while the remaining 40 percent was flowing through the East Pascagoula River (Shindala et al., 1973). The results reported in the "Pascagoula Low Flow Management Study" suggests a 65% and 35% flow distribution in the West Pascagoula and East Pascagoula, respectively (MDEQ 1994). Flow measurements taken by the USEPA-SESD during the 1997 intensive survey period suggested 57% of the flow was discharged into the West Pascagoula, while 43% flowed through the East Pascagoula (USEPA, 1997). It is quite evident from the above data that the flow patterns have remained consistent over time.

Table 2.1: Flow Characteristics of Gaging Stations (USGS, 2000)

Gaging Station	**Minimum Flow (cfs)**	**Maximum Flow (cfs)**	**Mean Flow (cfs)**	**Period of Record**
Pascagoula River at Graham Ferry	10,600	44,200	26,600	6 years
Pascagoula River at Merrill	3,820	76,200	20,900	69 years
Escatawpa River at Agricola	575	15,000	2,510	26 years

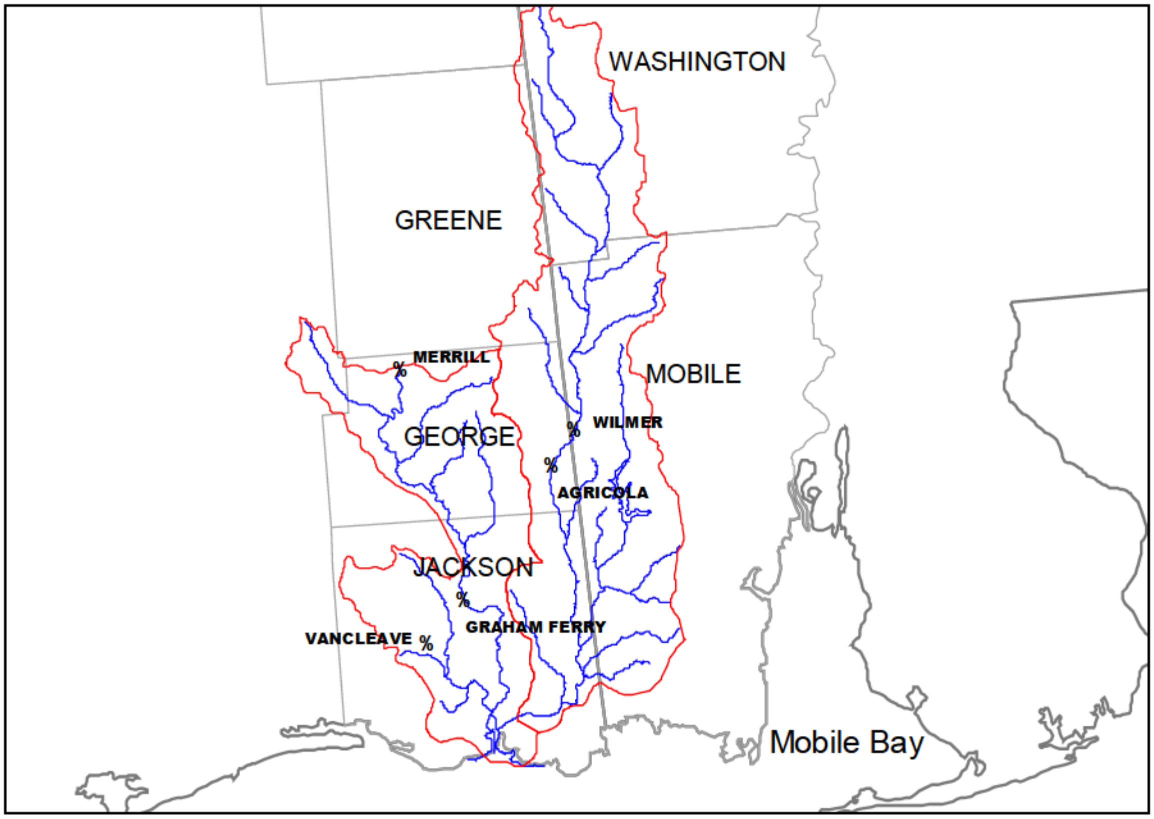

Figure 2.3: Physical Location of Gage Stations

The tidal influx within the system is of major importance, and must be fully understood. The tide, which is produced by interactions between the gravitational fields of the earth, moon, sun, and to a lesser degree, other planets, is the primary force that drives the hydrodynamics in estuarine environments (Martin and McCutcheon, 1999). The tidal amplitude that normally occurs in this region fluctuates on the magnitude of approximately two feet. The 1997 intensive survey, conducted by USEPA, provided tidal data at four locations within the estuary, with the tidal range being approximately 1.5 feet at each station (USEPA, 1997). There was no tidal action evident at the upstream boundaries of the study area during the survey period. Previous studies have concluded that during low flow periods, the tidal action may be evident up to a maximum of 53 miles upstream in the Pascagoula River, and 25 miles upstream in the Escatawpa River (Shindala et al., 1973).

Water Quality

The waters within the estuary system are currently used as a source of municipal and industrial water supplies, recreation, shellfish harvesting, and for the propagation of fish and wildlife. Water quality must therefore meet the requirements necessary to protect the multiple uses of these waters. Dissolved oxygen (D.O.) levels below the required minimum of 5 mg/l have been historically measured in the Escatawpa River and in the estuary system (Winfield and Nusser, 1984, USEPA 1997, 1999). The low D.O. levels may be attributed to several possible sources including point and nonpoint source discharges, large sediment oxygen demands, and other naturally occurring conditions (Winfield and Nusser, 1984). Point sources include several significant municipal and industrial waste discharges, while nonpoint sources include urban runoff as well as runoff from farming practices.

The State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters specifies that the minimum D.O. applicable to all waters should be maintained at a daily average of not less than 5.0 mg/l with an instantaneous minimum of not less than 4.0 mg/l (MDEQ, 1995). The Escatawpa River, from river mile 10 to its confluence with the Pascagoula River, has been granted an exception to the above criteria. Minimum dissolved oxygen concentrations of not less than 3.0 mg/l must be maintained in this portion of the river for propagation of fish and wildlife (MDEQ, 1995).

CHAPTER III

LITERATURE REVIEW

Selection Criteria

Many different water quality techniques and models have been successfully applied and implemented to various watersheds across the country. A limited number of models were considered for this study because of the extensive number of available models. The selection process for purposes of this study was limited to models that meet the following criteria: (1) available in the public domain, (2) supported by governing agencies such as the MDEQ and the USEPA, (3) have adequate technical support, (4) and meet data requirements for personal computers.

Watershed Models

Watershed models typically simulate flow as a series of hydrologic and hydraulic processes. These processes include surface runoff and associated water quality characteristics. Several watershed models described by Donigian et al., (1991) were considered applicable for this study (Table 3.1). This section provides a brief description of some of the considered watershed models along with their applicability to the Escatawpa watershed.

Table 3.1: Overview of Watershed Models (Donigian et al., 1991)

ACRONYM	**MODEL NAME**	**SPONSOR**
SWMM	Storm Water Management Model	USEPA
HSPF or NPSM	Hydrological Simulation Program-FORTRAN	USEPA
STORM	Storage, Treatment, Overflow, Runoff Model	US Army Corps of Engineers
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation	Purdue University
DR3M-QUAL	Distributed Routing Rainfall Runoff Model	USGS

The USGS version of the Distributed Routing Rainfall Runoff Model-Quality (DR3M-QUAL) incorporates water quality routines into an urban hydrologic model. The runoff is generated from the rainfall utilizing the kinematic wave method (Chow et al., 1988). The model can be run over any period of time, and is often used to simulate a group of storms while bypassing simulation of the dry periods. It has been used to simulate the quality of surface runoff from impervious areas, pervious areas, and contributions from precipitation in urban watersheds. The model has been applied by the USGS to several urban modeling studies in South Florida, Anchorage, Alaska, Denver, Colorado, and Fresno, California (Donigian et al., 1991). This model has predominantly been used for modeling urban areas; consequently, it was determined to be inappropriate for this study.

The Storm Water Management Model (SWMM) was developed by USEPA (Huber and Dickinson, 1988) to simulate processes that occur in the urban hydrologic cycle such as storm sewers, combined sewers, and natural drainage scenarios. It simulates time-varying processes of precipitation onto land of varying characteristics, converts rainfall to runoff, and collects and transports stormwater runoff (Metcalf and Eddy, 1991). The model has performed well for both continuous and single event simulations; however, the true physical, chemical, and biological processes that occur in nature are often times not accurately represented during the SWMM simulation. The SWMM model was deemed inappropriate for this study because of the intensive data required for model calibration and verification. Secondly, the model was also eliminated from consideration for use in this study because of the excessive team effort that is required to apply SWMM to complex watersheds. This model has been applied to urban hydrologic quantity and quality problems in many locations across the country (Huber, 1992).

The Storage, Treatment, Overflow, Runoff Model (STORM) developed by the U.S. Army Corps of Engineers (COE) contains simplified routines for both water quality and hydraulics. Runoff coefficients are used to compute runoff for both pervious and impervious portions of the watershed, while the alternative Soil Conservation Service (SCS) method (Schwab et al., 1993) can be used to compute runoff hydrographs. In applying these methods to determine runoff, the flow routing is neglected as such. The water quality parameters are modeled using linear build-up and first-order exponential wash-off functions. The STORM model is primarily used for comparative evaluations; therefore, extensive calibration is not necessary. The model has been applied to the San Francisco master drainage plan to evaluate the effects of combined sewer overflows into the San Francisco Bay (Roesner et al., 1974). The primary application of this model being to model stormwater runoff from urban areas coupled with the moderate to high calibration effort limited its use for purposes of this study.

Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS) was developed by the Agricultural Engineering Department at Purdue University to evaluate water quality in both agricultural and non agricultural watersheds (Beasley and Huggins, 1981). It was developed on a storm event basis to analyze the effects of land use and management practices. The model is capable of predicting hydrologic and erosion response of agricultural watersheds. This model has been used in Indiana to evaluate best management practices in both agricultural watersheds and construction sites, and also to evaluate the contributions of point and nonpoint sources in Michigan's Saginaw Bay (Donigian et al., 1991). The ANSWERS model was eliminated from further consideration in this study, because of its complex data file preparation that requires the use of a mainframe computer.

The U.S. EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system integrates three models; river models QUAL2E (USEPA, 1995) and TOXIROUTE (Lahlou et al., 1998), and the Non Point Source Model (NPSM), into an ARCVIEW GIS environment. QUAL2E and TOXIROUTE river models were not used in this study and will not be discussed in this review. NPSM uses most simulation capabilities of the Hydrologic Simulation Program-Fortran (HSPF) version 11 (Bicknell et al., 1997) as the model engine. The NPSM model is based on the concepts of the Stanford Watershed Model (Crawford et al., 1966) and has undergone continuous development since its inception, which dates to the early 1960’s.

NPSM has the capability to run a single watershed or a system of multiple watersheds that have been delineated through the BASINS environment. Several inputs are required including land use data, reach data, meteorological data, and information on the pollutants of concern in the watershed. NPSM is designed to interact with the utilities in BASINS to facilitate the necessary data extraction for selected geographic regions.

NPSM simulates non point source runoff from mixed land use watersheds including agricultural, forested, and urban areas, as well as the transport of pollutants through stream reaches. It is the only model that allows the integrated simulation of land and soil contaminant runoff processes with instream hydraulic and sediment-chemical reactions (Donigian et al., 1991). The model is limited to well mixed rivers and reservoirs because it assumes the instream water body is well mixed (Shoemaker et al., 1997).

The NPSM model has been applied to several watersheds across the country including the Chesapeake Bay, North Reelfoot Creek, and Bay St. Louis watersheds. The model was applied to the Chesapeake Bay to model total watershed contributions of flow, sediment, nutrients, and associated constituents to the tidal region of the bay (Donigian et al., 1994). The model has also been applied to determine effects of best management practices (BMP's) on North Reelfoot Creek in Tennessee (Moore et al., 1992). Most recently, the model was applied to the Bay of St. Louis, a water body on the southwestern coast of Mississippi, to determine the impact of fecal coliform contributions on shellfish harvesting in areas of the bay (Huddleston et al., 2000).

Although the models noted above have been applied to many different watersheds across the country, these models are either limited in scope or do not meet the selection criteria for this study. The literature search revealed that the NPSM/HSPF model most closely met the selection criteria established for this study. The fact that the model was developed by the USEPA, along with the data, software, and technical support being easily accessible via the World Wide Web, led to the selection of this model. Several successful applications to similar study areas also deemed the model as being appropriate.

Estuary Models

Estuaries are semi-enclosed coastal bodies of water where freshwater mixes with seawater (Dyer, 1973). Estuaries are biologically productive bodies of water that serve as spawning and nursery grounds for many coastal fish and invertebrates. They also serve as a means of recreation, contain important harbors, ports, and, navigational channels, and contain many of the world's leading seaports (Martin and McCutcheon, 1999). The multiple uses of estuaries place conflicting demands and burdens on the water quality. Mathematical models serve as an aid in assessing water quality response to the effects of these demands and burdens (Martin and McCutcheon, 1999).

H.A. Lorentz (1926), the Nobel-prize winning physicist, began estuarine model applications when he simulated the closure of the Zuider Zee in the Netherlands in the early part of the 20th century. In the 1960's with the advent of the practical, large-frame computers and the necessity to improve upon physical models, worldwide application of estuary models began (Martin and McCutcheon, 1999).

Estuary models, although often times more complex, solve the same set of equations as any other hydrodynamic model for lakes, rivers, or oceans. The primary difference in estuarine models is the processes by which the governing equations are solved, the scope of the parameters, and the functional structure of the model (i.e. 1-D, 2-D, or 3-D). Various estuary models, listed in Table 3.2, were considered for this study. However, this review will focus on models such as TRIM, WASP5, CH3D-WES, EFDC, and CEQUAL-W2. All of these models have been applied to various estuary systems world wide, and meet the selection criteria for this study.

One of the more recent innovations in vertically averaged estuarine modeling is the Tidal, Residual, Intertidal Mudflat (TRIM) model (Cheng et al., 1993). It is especially useful in coastal plain estuaries and embayments dominated by tidal currents. The model was applied to the San Francisco Bay (Cheng et al., 1993) to investigate residual circulation and other hydrodynamic processes. The model was also applied, by the U.S. Geological Survey, to Charleston Harbor with satisfactory results except in the stratified regions.

Table 3.2: Available Estuary Models

MODEL NAME	PRIMARY APPLICATION	DIMENSIONS	REFERENCE
Branch Network Flow Model	Rivers, Estuaries	1-D	Schaffranek, 1987
CE-QUAL-RIV1	Streams, Rivers, Estuaries	1-D	Environmental Lab, 1995
Dynamic Estuary Model (DEM)	Estuaries	1-D	Genet et al., 1974
MIT Transient Water Quality Network Model	Estuaries	1-D	Harleman et al., 1977
DYNHYD	Rivers, Estuaries	1-D	Ambrose et al., 1988
EXPLORE-I	Rivers, Estuaries	1-D	Baca et al., 1973
DYNTOX	Rivers, Streams	1-D	Martin and McCutcheon, 1999
TABS-MD	Rivers, Estuaries, Bays, Marshes	2-D (Horizontal)	Thomas and McAnally, 1985
RMA2-WES	Rivers, Estuaries, Bays, Marshes	2-D (Horizontal)	Martin and McCutcheon, 1999
WIFM-SAL	Estuaries	2-D (Horizontal)	Schmalz, 1995
CAFEX	Estuaries	2-D (Horizontal)	Wang and Conner, 1975
HSCTM-2D	Rivers, Estuaries	2-D (Horizontal)	Hayter et al., 1997
FESWMS-2DH	Streams, Rivers, Estuaries	2-D (Horizontal)	Froehlich, 1989
SIMSYS2D	Estuaries, Bays, Marshes	2-D (Horizontal)	Leendertse, 1970
FETRA	Rivers, Estuaries	2-D (Horizontal)	Onishi et al., 1979
H.S. Chen's Model	Rivers, Estuaries, Seas	2-D (Horizontal)	Chen, 1978
TRIM	Estuaries, Bays	2-D (Horizontal)	Cheng et al., 1993
CE-QUAL-W2	Lakes, Reservoirs, Estuaries	2-D (Vertical)	Cole and Buchak, 1995
Blumberg's Model	Lakes, Estuaries, Bays	2-D (Vertical)	Blumberg, 1977
CH3D/CH3D-WES	Lakes, Rivers, Estuaries, Bays	3-D	Sheng and Butler, 1982
EHSM3D	Lakes, Estuaries	3-D	Sheng et al., 1986
EFDC	Rivers, Lakes, Estuaries, Bays	3-D	Hamrick, 1996
RMA Models	Rivers, Estuaries, Bays	3-D	Martin and McCutcheon, 1999
HOTDIM	Estuaries, Seas	3-D	Waldrop and Tatom, 1976
WASP5	Rivers, Estuaries, Bays	3-D	Ambrose et al., 1988
CE-QUAL-ICM	Rivers, Estuaries, Bays	3-D	Martin and McCutcheon, 1999
HYDRO-3D / SED3D	Rivers, Estuaries	3-D	Martin and McCutcheon, 1999

*Note: Many of the 2-D and 3-D codes may function as 1-D or 2-D, respectively.

DYNHYD5 is a one-dimensional linked node hydrodynamic model that is often times linked with WASP5 (Ambrose et al., 1988) to model water quality. The model is designed for well-mixed, unstratified rivers and estuaries. The model has been applied to a number of rivers and estuaries as part of wasteload allocation and eutrophication studies. The coupled models were applied to the Upper Delaware Estuary to determine impacts of waste loads on water quality (Ambrose et al., 1988). Shindala et al., (1996, 1998), applied the model to the Back Bay of Biloxi and the Big Sunflower River in Mississippi as a planning tool to assess existing water quality standards, as well as to determine waste load allocations.

Curvilinear Hydrodynamics in Three Dimensions (CH3D) is a three-dimensional code originally developed by Sheng (1983), and is the basis for the CH3D-WES model that is maintained by the U.S. Corp of Engineers (Chapman et al. 1996). The model is capable of modeling physical processes that impact circulation and vertical mixing including tides, wind, density effects, freshwater inflows, turbulence, and the effect of the Earth's rotation. The CH3D-WES model was applied to, among other sites, the Chesapeake Bay (Johnson et al., 1989). Cerco et al., (1993), coupled CH3D-WES with the integrated compartment model, CE-QUAL-ICM, to predict water column and sediment processes that affect water quality in the Chesapeake Bay.

The Environmental Fluid Dynamic Code (EFDC), originally developed by Hamrick (1994), is a comprehensive three-dimensional numerical model capable of simulating hydrodynamics, salinity, temperature, suspended sediment, water quality, and the fate of toxic materials. The EFDC model has been applied to several water bodies across the country including the James and York River estuaries in Virginia (Hamrick, 1995) and the Chesapeake Bay estuarine system (Hamrick, 1994). The model is currently being used to determine fecal coliform concentrations and their impact on shellfish harvesting in the Bay of St. Louis estuary system located in south Mississippi (Huddleston et al., 2000). Other applications of the model include the Indian River Lagoon and Lake Okeechobee in Florida, the Peconic Bay System in New York, Stephens Passage in Alaska, and Nan Wan Bay, Taiwan (Shoemaker et al., 1997).

The EFDC model is similar to the CH3D code, with both solving the shallow water equations in three dimensions utilizing the "mode splitting" concept in the numerics. With the main differences in the two models being the implementation process.

The U.S. Corp of Engineers' two dimensional, laterally averaged, hydrodynamic and water quality model, CE-QUAL-W2 is based on laterally averaged equations of momentum, continuity, and transport. It includes water quality routines for 22 different parameters. Heat transport, salt transport, and momentum equations are dynamically coupled through the density gradient terms.

A finite difference numerical scheme is used to solve the system of partial differential equations that describe flow and transport in the estuary. The time step is automatically computed to ensure numerical stability; however, the time step can be somewhat controlled by setting a maximum allowable value for the simulation.

CE-QUAL-W2 requires the development of a computational grid, which is divided into a series of longitudinal segments, each having a unique length. All layers within a segment must have the same length, but each layer can have a unique width and thickness. Figure 3.1 illustrates a typical segment of the computational grid having multiple layers. Each computational cell is assumed to have uniform conditions throughout so that the governing equation can be solved to represent conditions for each cell. The cell-averaged longitudinal velocity, vertical velocity, density, temperature, and constituent concentrations are calculated by laterally averaging the solution of the governing equations across each cell.

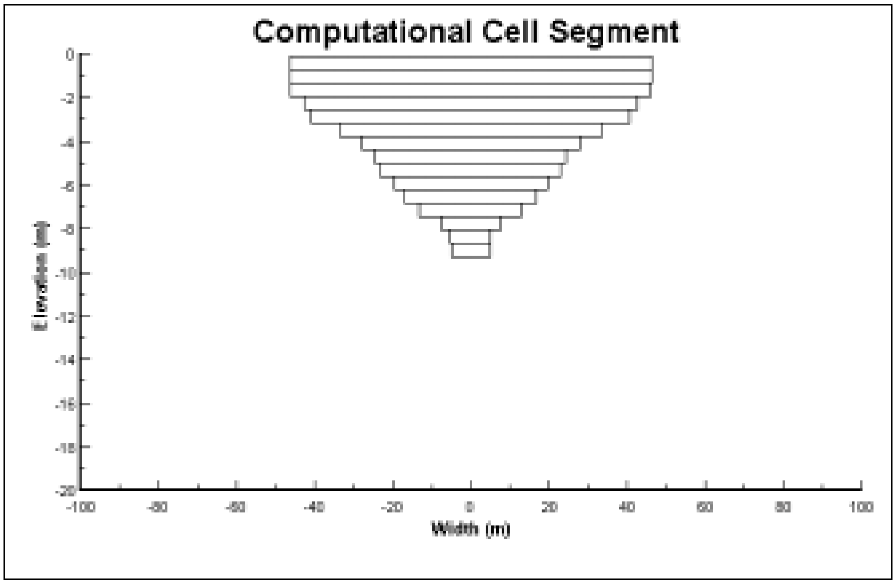

Figure 3.1: Typical Computational Cell Segment

Several limitations must be addressed when applying the model and interpreting and analyzing the model results. It assumes the estuary is well mixed at all points. Inflows from tributaries enter the estuary along the shoreline and are assumed to be instantaneously mixed across the estuary at that point. The inflows are also assumed to be instantaneously mixed in the computational cell that they enter into. The model is limited to one algal component, so algal succession cannot be simulated. Finally, the model uses a simplistic approach of zero or first order kinetics to model chemical processes.

Since its development in the early 1970’s, CE-QUAL-W2 has been widely and successfully used throughout the country. Although most applications of CE-QUAL-W2 have been limited to lakes and reservoir problems, the model has also been applied to address estuarine circulation and water quality issues in selected estuaries. Hall (1987) applied the model to the Savannah River Estuary in Georgia to estimate the impact of changes in flow and waste loads on dissolved oxygen concentrations in the estuary. Bales and Robbins (1999) applied the model to the Neuse River Estuary in North Carolina to determine best management practices (BMP’s) to improve water quality in the estuary. Wells (2000) has applied the model to several estuarine applications in Oregon including the South Slough Estuary, Columbia Slough Estuary, Columbia and Willamette River, and the Siletz Bay.

All of the models discussed above have been given consideration for applicability to this study. The CH3D and EFDC codes were eliminated from consideration because the complexity of data requirements and computing resource requirements of a 3-D model was not warranted for this phase of the study. The characteristic of the Escatawpa System being predominantly laterally averaged limited the use of the 1-D code, DYNHYD5. For purposes of this study, the laterally averaged 2-D model CE-QUAL-W2 has been deemed the most appropriate.

The U.S. Corp of Engineers’ two dimensional, laterally averaged, hydrodynamic and water quality model, CE-QUAL-W2 (Cole and Buchak, 1995) was selected as being the most applicable model for this study. Some favorable considerations for the CE-QUAL-W2 model include: (1) it was developed at the Waterways Experiment Station in Vicksburg, MS, which provided for easily accessible technical support, (2) it is in the public domain, (3) it is PC based with minimum run time requirements, and (4) it has been successfully applied to several stratified waterbodies such as reservoirs and narrow estuaries. Most importantly, the USEPA Region IV initiated the modeling effort on the Escatawpa utilizing the CE-QUAL-W2 model.

CHAPTER IV

Watershed Model Calibration and Application

As was previously stated, the BASINS2.0/NPSM watershed model has been selected for application in the upstream portion of the Escatawpa watershed. Calibration and application of the model to assess the impact of nonpoint source loading on the fecal coliform levels in the impaired portion of the Escatawpa River watershed are presented in this chapter.

Watershed Description and Data Summary

The study area for the watershed model includes the Escatawpa River and all tributaries. Data describing topography, stream characteristics, land use, and climatic characteristics were obtained from the World Wide Web (USEPA, 1999a) and imported directly into the BASINS2.0 interface facilitating development of the model for the study area. Figure 4.1 depicts the Escatawpa Watershed, identifies the subwatersheds, and the locations of important data collection sites within the study area. Contours are shaded by elevation providing an overview of topography within the region. The USGS hydrologic unit boundary names, identification numbers, and drainage areas indicated on Figure 4.1 are summarized in Table 4.1. The land use distribution for the study area is depicted in Figure 4.2.

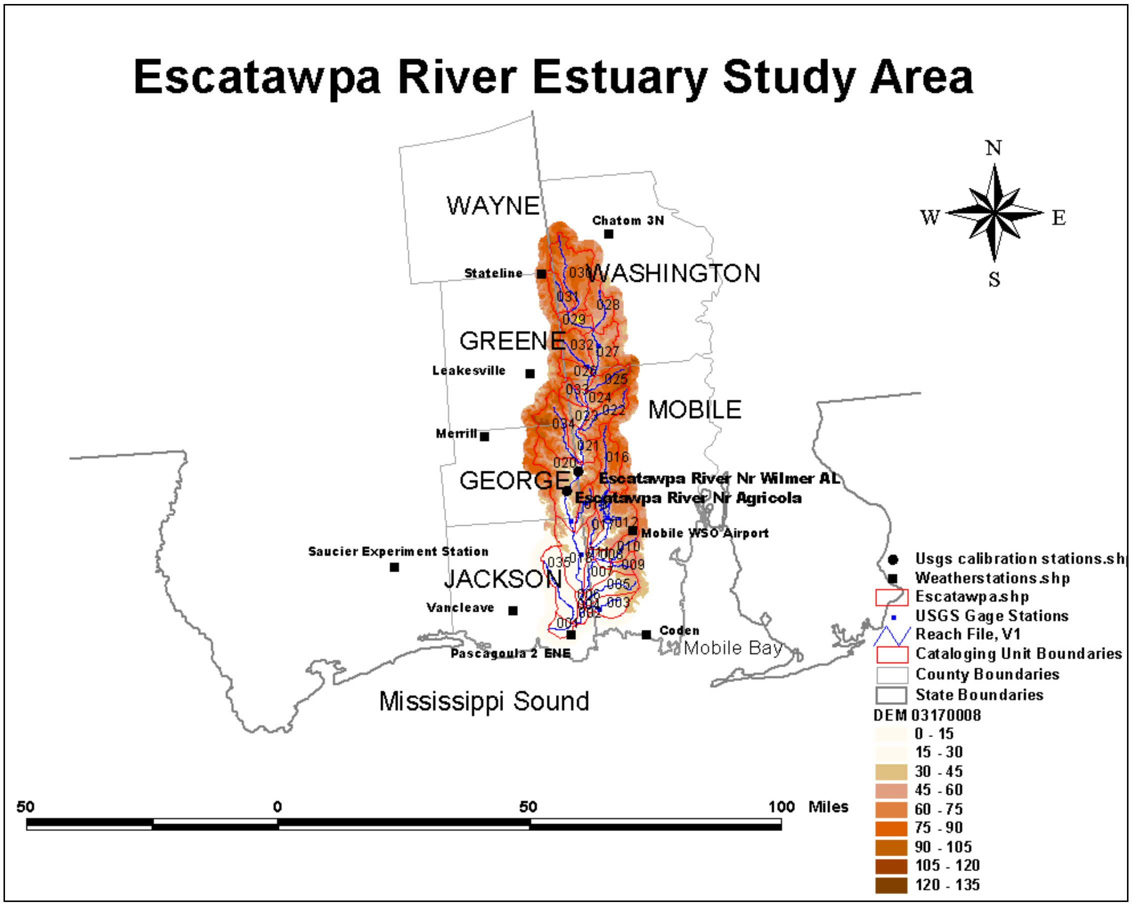

Figure 4.1: Escatawpa River Estuary Study Area.

Table 4.1: Escatawpa River Subwatershed Description.

Subwatershed	ID Number	Stream Name	Area (acres)
0317008001	001	Escatawpa River	9,491
0317008002	002	Escatawpa River	4,403
0317008003	003	Franklin Creek	18,964
0317008004	004	Escatawpa River	480
0317008005	005	Jackson Creek	23,937
0317008006	006	Escatawpa River	2,676
0317008007	007	Big Creek	13,643
0317008008	008	Miller Creek	5,841
0317008009	009	*A	8,167
0317008010	010	Miller Creek	13,883
0317008011	011	Big Creek	2,469
0317008012	012	Big Creek	51,429
0317008016	016	Big Creek	30,639
0317008017	017	Pasture Creek	8,857
0317008018	018	Escatawpa River	40,419
0317008019	019	Flat Creek	14,009
0317008020	020	Escatawpa River	65,296
0317008021	021	Escatawpa River	17,341
0317008022	022	Puppy Creek	26,855
0317008023	023	Escatawpa River	14,348
0317008024	024	Escatawpa River	9,567
0317008025	025	Bennett Creek	19,318
0317008026	026	Escatawpa River	16,882
0317008027	027	Escatawpa River	29,295
0317008028	028	Pine Branch Creek	25,533
0317008029	029	Escatawpa River	15,555
0317008030	030	Escatawpa River	49,780
0317008031	031	Brushy Creek	16,407
0317008032	032	Pond Creek	22,788
0317008033	033	Nobodies Creek	9,698
0317008034	034	Brushy Creek	37,123
0317008035	035	Black Creek	34,876
Total			659969

Meteorological data is available from several climatological stations in the area and are distributed via the World Wide Web (USEPA, 1999a). The data is quite comprehensive for most applications; however, it is very limited for development of a computational watershed model. This is primarily due to the limited amount of hourly precipitation data that is recorded and accessible from the various stations. The most relevant data for the watershed was obtained from the Leakesville Station, the Saucier Experiment Station, the station located near Vancleave, the station located at Chatom, the station located at Merrill, and the Mobile WSO Airport. The location of these stations is indicated in Figure 4.1.

The selected BASINS/NPSM software utilizes a temporal scale of one hour. Consequently, hourly boundary data (primarily precipitation) must be supplied to the model. However, the Leakesville Station, Saucier Station, and Mobile WSO Airport were the only sites that recorded hourly data; therefore, daily data obtained from the remaining sites was disaggregated into hourly data. This was done by applying the METCMP (USGS, 1994), and WDMutil (USEPA, 1999b) programs obtained from the USGS and USEPA, respectively. All disaggregation was based upon the hourly precipitation patterns measured at the Saucier Experiment Station. Table 4.2 summarizes the location, frequency, and available dates for the available meteorological data.

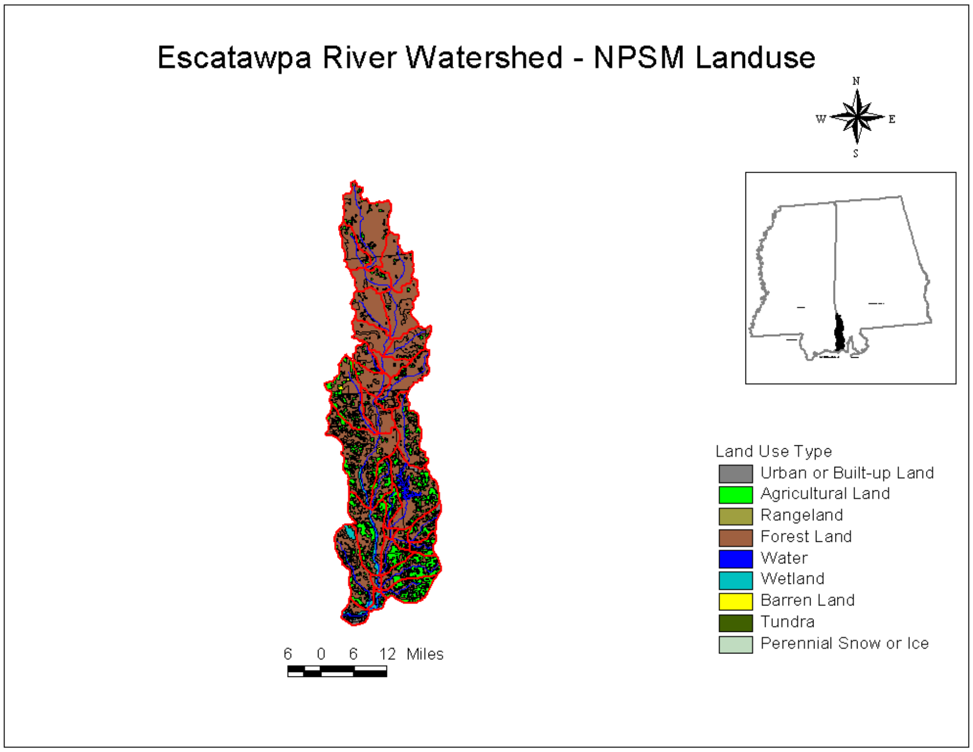

Figure 4.2: Escatawpa River Watershed Land Use Distributions.

Table 4.2: Escatawpa River Estuary System Meteorological Data.

Station Name	COOPID	Location (Lat., Long)	Frequency	Available Dates
Saucier Experiment Station	MS227840	30 38 N, 89 03 W	Hourly	5/1/1954-present
Leakesville	MS224966	31 09 N, 88 33 W	Hourly	01/1930-present
Mobile WSO Airport	AL015478	30 41 N, 88 15 W	Hourly	01/1960-present
Chatom	AL011566	31 32 N, 88 15 W	Daily	01/1970-present
Merrill	MS225789	30 59 N, 88 43 W	Daily	01/1960-03/1998
Pascagoula 2 ENE	MS226718	30 24 N, 88 29 W	Daily	01/1948-present
Vancleave	MS229157	30 29 N, 88 40 W	Daily	06/1948-present

Hydrologic Model Calibration

Hydrologic calibration of the watershed model was accomplished utilizing historical flow data at the USGS gage station near Agricola, Mississippi (RM 50) was used for historical calibration of the model (USGS, 1999a, USGS 1999b). This gage station replaced the gage station located near Wilmer, AL (RM 55) in late 1973. The station near Agricola is located on the Escatawpa River, approximately in the center of the watershed area and provides the most current data. Historically there have been other operable gage stations within the study area; however, either the available dates or frequency of data collection deemed them inappropriate for purposes of this calibration effort. A summary of data collection frequency and reporting dates is provided in Table 4.3 for identified stations in the study area.

Table 4.3: Hydrologic Flow Data for the Escatawpa River System.

Locations	**Station ID**	**Available Dates**	**Frequency**
Escatawpa River Near Wilmer, AL	USGS 02479500	10/1/1945-9/30/1973	Daily
Escatawpa River Near Agricola, MS	USGS 02479560	10/1/1973-Present	Daily
Franklin Creek Nr. Grand Bay, AL	USGS 02480150	1959-1979	Daily
Big Creek Nr. Mobile, AL	USGS 02480000	12/1/1944-9/30/1950	Daily

As illustrated in Figure 4.1, the USGS gage station at Agricola is located in the middle portion of the watershed. Hydrologic calibration of the NPSM model at Agricola incorporated the drainage area contributing flow to the Agricola station. Following a satisfactory calibration, modeling parameters used at Agricola were extrapolated throughout the remaining portion of the watershed.

Successful application of the watershed model (BASINS2/NPSM) requires the execution of numerous tasks including: (1) subwatershed delineations, (2) analysis of meteorological data, (3) land use distribution, (4) assessment of stream data, and (5) specification of proper modeling parameters. A brief description of these factors for the calibration at the Agricola station is presented in the following section.

Subwatershed Delineation

The subwatershed delineation for the station near Agricola, MS is superimposed on the land use distribution map shown in Figure 4.3. The most southern reach of the subwatershed delineation has been configured with a land area that approaches zero. This coupled with the manual modification of the stream reach characteristics allows for an accurate representation of the drainage area associated with the Agricola gaging station.

The total drainage area at Agricola is approximately 350,000 acres. This acreage is primarily forestland ranging in elevation from 300 feet at the headwaters to near 100 feet at the gage station. Delineation of the watershed was based on the RF1 and RF3 reach networks along with the watershed topography. The reach networks are characterized by their complexity, with RF1 networks containing only major streams whereas RF3 networks include minor streams and tributaries. As previously discussed on page 26, the river networks and topography were taken from the World Wide Web and supplied to the BASINS interface. Table 4.4 and Table 4.5 summarize the watershed land use and the river reach characteristics for Agricola as taken from the BASINS2.0 interface. As can be seen from Figure 4.3, less than 1% of the land use is designated as urban with the remainder designated as forest, agricultural, barren, or wetlands.

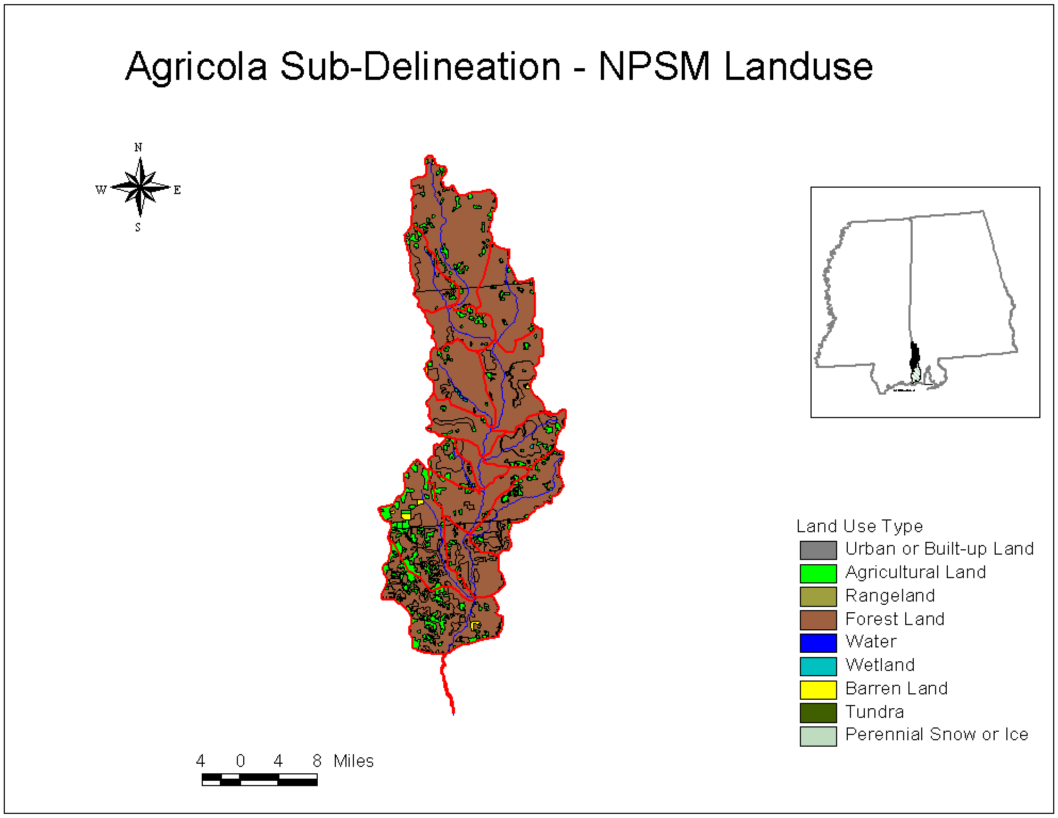

Figure 4.3: Delineation and NPSM Land Use for the Agricola Watershed.

Table 4.4: Watershed Land Use for Escatawpa River Near Agricola, MS.

Subwatershed ID	Stream Name	Urban (acres)	Agriculture (acres)	Forest (acres)	Wetland (acres)	Barren (acres)	Total Acres
03170008020	Escatawpa River	50	9089	32947	290	355	42731
03170008021	Escatawpa River	0	830	16756	0	0	17586
03170008022	Puppy Creek	274	2741	23584	0	0	26599
03170008023	Escatawpa River	0	1746	17118	0	0	18864
03170008024	Escatawpa River	0	40	6974	0	0	7014
03170008025	Bennett Creek	85	1660	16986	72	0	18803
03170008026	Escatawpa River	0	536	14433	0	0	14969
03170008027	Escatawpa River	47	550	28107	0	81	28785
03170008028	Pine Branch Creek	0	1030	24750	0	0	25780
03170008029	Escatawpa River	18	1164	14320	0	0	15502
03170008030	Escatawpa River	0	4029	45373	0	83	49485
03170008031	Brushy Creek	184	1555	14926	0	0	16665
03170008032	Pond Creek	0	642	22274	190	185	23291
03170008033	Nobodies Creek	0	1346	8357	147	0	9850
03170008034	Brushy Creek	0	9394	27488	0	660	37546
Total							353467

Table 4.5: River Reach Characteristics for Agricola Calibration.

Subwatershed ID	Stream Name	River Length (miles)	Delta H (ft)	River Elevation (ft)	Mean Flow (cfs)
03170008020	Escatawpa River	7.33	36.0	48.0	1307.0
03170008021	Escatawpa River	8.20	19.0	75.50	1070.0
03170008022	Puppy Creek	16.0	207.0	188.50	144.0
03170008023	Escatawpa River	5.40	10.0	90.0	852.0
03170008024	Escatawpa River	4.00	7.0	98.50	745.0
03170008025	Bennett Creek	10.0	146.8	175.40	90.0
03170008026	Escatawpa River	3.50	10.0	107.0	619.0
03170008027	Escatawpa River	10.60	29.0	126.50	498.0
03170008028	Pine Branch Creek	10.50	48.8	165.40	94.0
03170008029	Escatawpa River	7.30	20.0	151.0	308.0
03170008030	Escatawpa River	19.50	130.8	226.40	175.0
03170008031	Brushy Creek	7.50	38.8	180.40	67.0
03170008032	Pond Creek	9.90	87.8	155.91	89.0
03170008033	Nobodies Creek	6.60	154.0	172.01	59.0
03170008034	Brushy Creek	14.70	104.8	118.39	132.0

Meteorological Data

As with other hydrologic models, NPSM applies the precipitation over each subwatershed with spatial uniformity. The model requires precipitation data to be input on an hourly basis. As stated earlier, the only weather stations with adequate temporal (hourly) data are the Leakesville Station, Mobile WSO Airport, and the Saucier Experiment Station. There are no meteorological stations located within the upstream portion of the watershed; therefore, the data was extrapolated from the Leakesville station because of its proximity to the drainage area. Consequently, flow and water quality simulation results may be impacted due to the spatial difference in the weather station and the drainage area.

The non-point source model also requires other meteorological data; including evaporation, temperature, wind speed, solar radiation, potential evapotranspiration, dew point temperature, and cloud cover. These variables must be supplied in the Watershed Data Management (WDM) input file in order to run the NPSM model. Meteorological data for the period of January 1970 through May 1999 has been gathered and prepared for input into the model. Data beyond 1995 has not yet been released; therefore, 1995 meteorological data was applied for simulations beyond 1995. As a result, the WDM input file applied to the model includes meteorological data from 1970 through May 1999.

Land Use Data

As noted earlier, BASINS 2.0 interface land use data was downloaded from the BASINS web site (USEPA, 1998a). The default land use data supplied in BASINS was obtained from the USGS Geographic Information Retrieval and Analysis System (GIRAS) and uses the Anderson Level I and II classification systems. The GIRAS land use data is based upon data collected by the USGS in the 1970's. This land use data was applied for the calibration period.

Multi Resolution Land Characterization (MRLC) land use data was imported into the BASINS system for simulation periods beyond 1990. This data was taken from the Watershed Characterization System (WCS) (USEPA, 1999d), which is interfaced with the Arc View 3.0 package. The MRLC land use information data is based on Landsat Thematic Mapper digital images and utilizes a modified Anderson Level I and II system for classification.

Stream Flow Data

As indicated in Table 4.3, stream flow data is available from the USGS for calibration at Agricola from October 1, 1973 to the present date. The reported stream hydrograph for one representative year during the calibration period (1983) is illustrated in Figure 4.4. This is representative of a typical precipitation year in this study area. The wet season can be seen as being from late fall to early spring with the dry season being the summer and early autumn months.

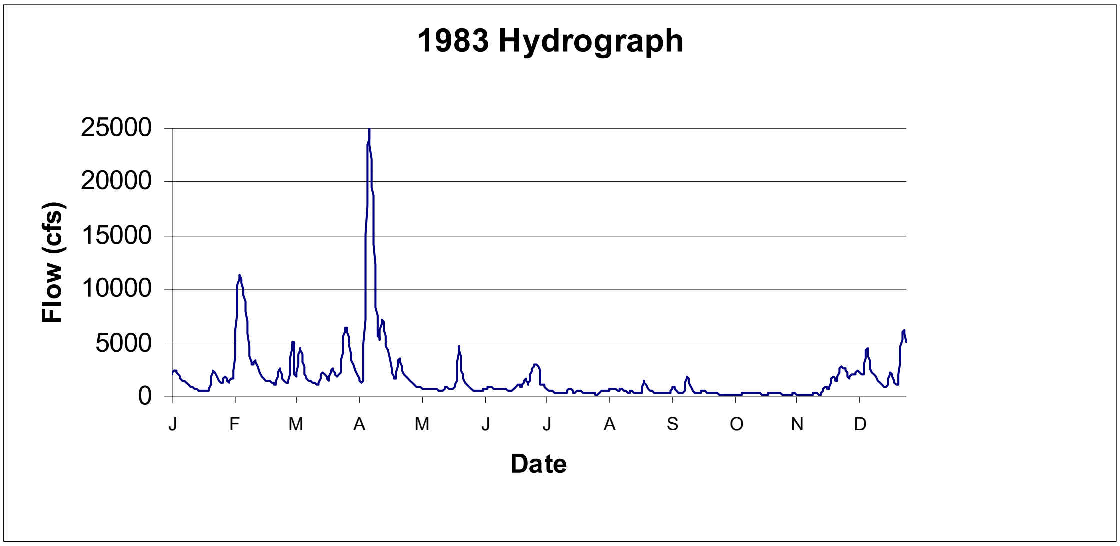

Figure 4.4: Escatawpa Stream Hydrograph at Agricola for 1983

Hydrologic Modeling Parameters

There have been several studies on the sensitivity of the NPSM model and predecessor HSPF to variations in the various modeling parameters (USEPA, 1998b, 1998c, 1998d, Jaconimo and Fields, 1997). The USEPA, as a result of several studies on watersheds across the U.S. in the past two decades, has compiled a database, HSPFParm, with typical value ranges for various model parameters (Donigian et al, 1999). Reference was also made to the values applied to the modeling of the Pascagoula Basin by Davis (1999).

For most applications, the most influential parameters in the hydrologic simulation are storage, infiltration and interception parameters for the lower and upper soil zones (LZSN, UZSN, INFILT, CEPSC, LZETP), and the friction and hydrograph parameters for stream reaches (NSUR, INTFW).

Hydrologic Calibration Results for Agricola

With the previously stated watershed delineation and boundary conditions, the NPSM model was applied to the Agricola watershed to simulate watershed hydrology and hydrodynamics for the time period of January 1974 through December 1986. Various strategies utilizing different combinations of atmospheric data and hydrologic parameters were initially investigated. It was determined that the atmospheric data from the Leakesville Station yielded the best simulation of the measured flow at Agricola. Table 4.6 depicts the key parameter values that yielded the best calibration along with the range of typical values as reported by the USEPA (USEPA, 1999c).

Calibration was assessed qualitatively through graphical comparison of field measurements with simulated flows from the NPSM model. Quantitative assessment was made by comparing integrated stream volumetric flux calculated from field measurements to the flux calculated from simulated flows (USEPA, 1999f). The procedure for calculating the volumetric flux integrates the modeled stream volumetric flux using quadratic integration and compares the data with selected observed data. Graphical comparisons of the simulated and actual stream hydrographs are illustrated in Figures 4.5-4.7; whereas, Table 4.7 quantifies the volumetric flux comparisons by comparing the percent error between modeled and measured stream volume on the basis of annual, seasonal, and major storm events, along with target comparison values recommended by the USEPA.

Table 4.6: NPSM/HSPF Hydrology Parameters and Value Ranges (USEPA, 1999c)

Name	**Definition**	**Units**	**Range of Values**				**Escatawpa Watershed**
			Typical		**Possible**		
			MIN	**MAX**	**MIN**	**MAX**	
PWAT-PARM2							
FOREST	Fraction forest cover	None	0.0	0.5	0.0	0.95	0.0
LZSN	Lower zone nominal soil moisture storage	Inches	3.0	8.0	2.0	15.0	14.00
INFILT	Index to infiltration capacity	In/ hr	0.01	0.25	0.001	0.50	0.350
LSUR	Length of overland flow	Feet	200	500	100	700	400
SLSUR	Slope of overland flow plane	None	0.01	0.15	0.001	0.30	0.035
KVARY	Variable groundwater recession	1/ inches	0.0	3.0	0.0	5.0	0.50
AGWRC	Base groundwater recession	None	0.92	0.99	0.85	0.999	0.90-urban/barren 0.97-agriculture 0.99-forest
PWAT-PARM3							
PETMAX	Temp below which ET is reduced	°F	35.0	45.0	32.0	48.0	40.0
PETMIN	Temp below which ET is set to zero	°F	30.0	35.0	30.0	40.0	35.0
INFEXP	Exponent in infiltration equation	None	2.0	2.0	1.0	3.0	2.0
INFILD	Ratio of max/mean infiltration capacities	None	2.0	2.0	1.0	3.0	2.0
DEEPFR	Fraction of GW inflow to deep recharge	None	0.0	0.20	0.0	0.50	0.50
BASETP	Fraction of remaining ET from baseflow	None	0.0	0.05	0.0	0.20	0.05
AGWETP	Fraction of remaining ET from active GW	None	0.0	0.05	0.0	0.20	0.20
PWAT-PARM4							
CEPSC	Interception storage capacity	Inches	0.03	0.20	0.01	0.40	0.10
NSUR	Manning’s n (roughness) for overland flow	None	0.15	0.35	0.10	0.50	0.150
UZSN	Upper zone nominal soil moisture storage	Inches	0.1	1.0	0.05	2.0	1.960
INTFW	Interflow inflow parameter	None	1.0	3.0	1.0	10.0	19.50
IRC	Interflow recession parameter	None	0.5	0.7	0.3	0.85	0.60
LZETP	Lower zone ET parameter	None	0.2	0.7	0.1	0.90	0.30

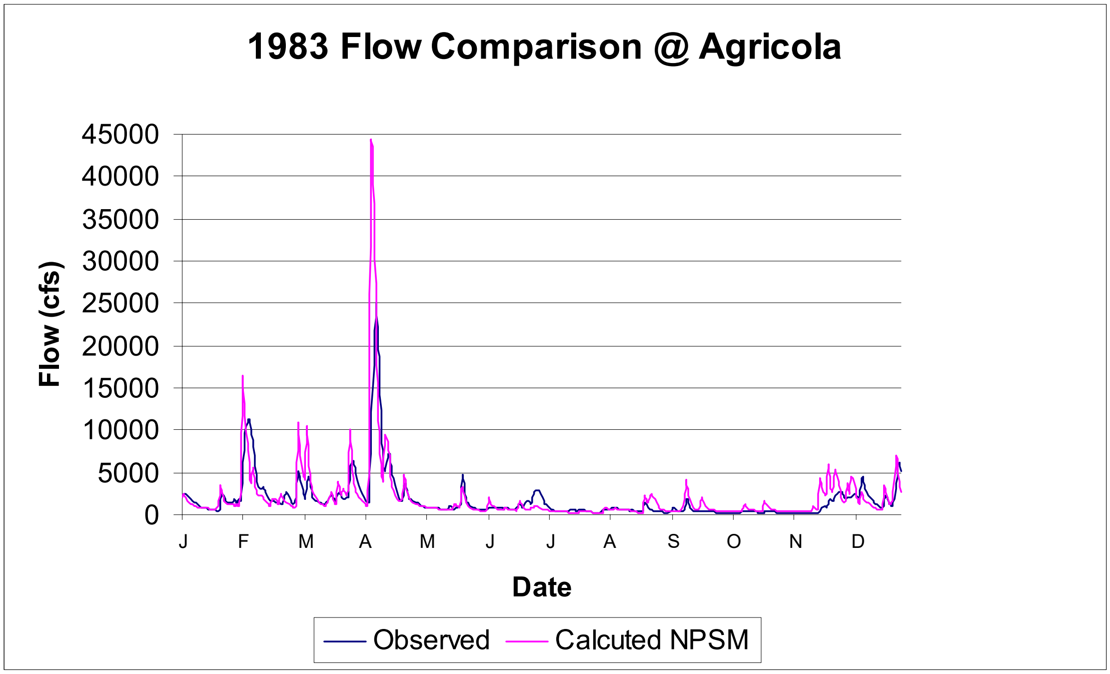

Figure 4.5: Hydrologic Flow Calibrations at USGS 02479560 – 1983.

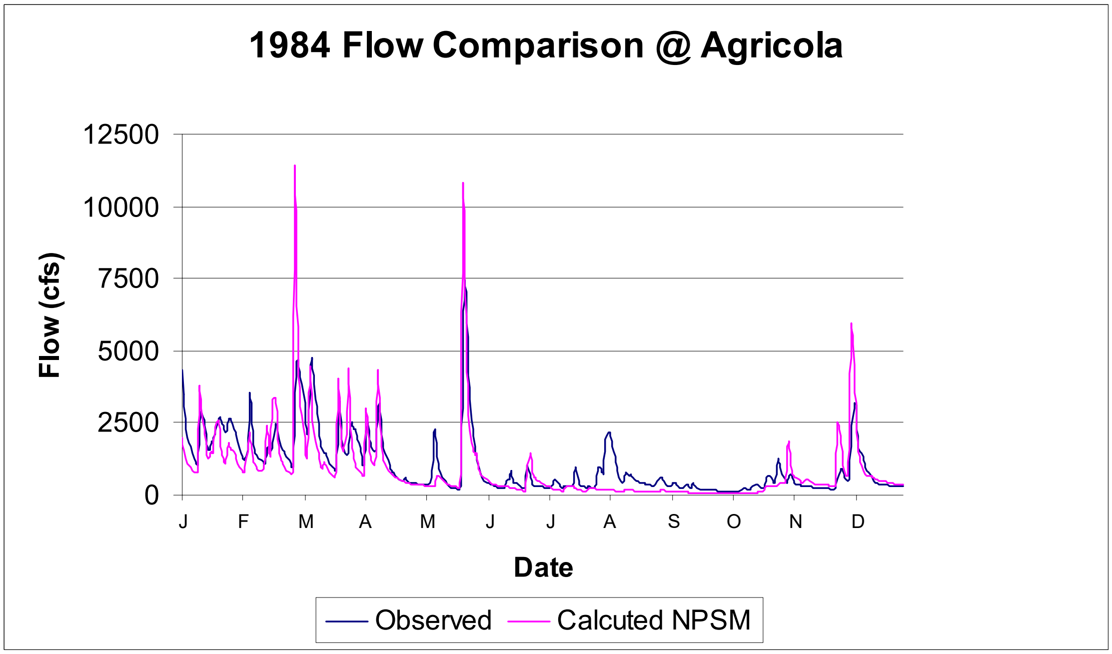

Figure 4.6: Hydrologic Flow Calibrations at USGS 02479560 – 1984.

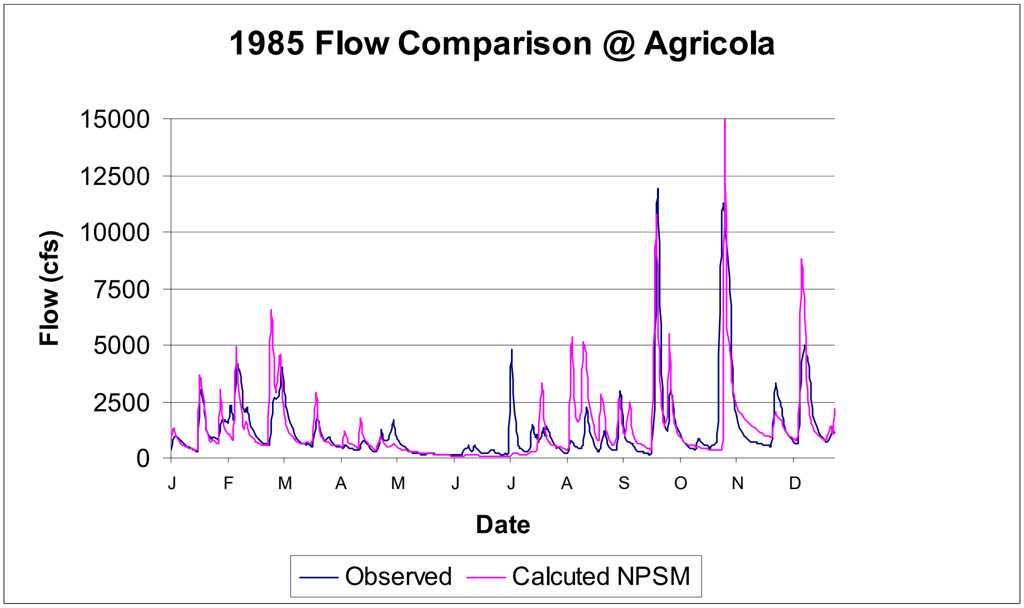

Figure 4.7: Hydrologic Flow Calibrations at USGS 02479560 – 1985.

Table 4.7: Comparisons of Observed and Computed Volumetric Flow Rates

	Simulated			**Observed**		
Year	**1983**	**1984**	**1985**	**1983**	**1984**	**1985**
Total In-stream Flow	47.63	22.07	30.68	43.44	25.23	30.26
Total of highest 10% flow	22.05	9.57	12.34	19.20	8.44	12.49
Total of lowest 50% flow	6.79	2.52	4.67	6.06	3.81	4.90
Summer flow volume (months 7-9)	4.49	0.95	9.19	3.72	2.98	7.56
Fall flow volume (months 10-12)	9.25	3.75	10.66	7.18	3.17	11.98
Winter flow volume (months 1-3)	16.53	11.16	8.61	15.98	12.63	8.22
Spring flow volume (months 4-6)	17.37	6.21	2.23	16.56	6.46	2.49
Total storm volume	42.40	20.63	28.98	37.34	20.69	27.34
Summer storm volume (7-9)	3.34	0.73	8.85	2.40	2.10	6.91

Errors (Simulated - Observed)	**1983**	**1984**	**1985**	**Recommended**
Error in total volume	8.8	-14.33	1.39	10
Error in 50% lowest volume	10.65	-51.39	-4.91	10
Error in 10% highest flows	12.92	11.77	-1.20	15
Seasonal volume error-Summer	17.02	-214.24	17.66	30
Seasonal volume error - Fall	22.31	15.70	-12.38	30
Seasonal volume error - Winter	3.33	-13.18	4.51	30
Seasonal volume error - Spring	4.69	-4.05	-11.85	30
Error in storm volumes	11.94	-0.26	5.66	20
Error in summer storm volumes	28.19	-189.62	22.00	50

The results presented in Figures 4.5-4.7 and Table 4.7 are for the three-year period beginning from January 1983 through December 1985. As can be seen, simulated stream flows compared favorably with stream base flow and the recession limbs of the major storm events. Overall comparisons of error in flow and volume between measured and simulated values are very good. The stream base flow and the rising and recession limbs of storm hydrographs were replicated well, and many of the major storm events were reproduced.

Comparison for the summer of 1984 is the least favorable. It is evident that several significant precipitation events were not included in the applied precipitation boundary condition during this period. Note that the nominal flow rate during this period was quite low leading to large percentage deviation for relatively small actual deviations.

As would be expected, the model does not replicate all storm events equally well. This is due in part to the precipitation data not being representative of the rainfall throughout the entire watershed. The rainfall patterns were examined extensively for the meteorological stations located in close proximity of the watershed, since they have direct impact on the simulation of flows for the specified storm events. The stations located at Merrill, Leakesville, Vancleave and Mobile were the stations of utmost importance in the sensitivity analysis of the rainfall distribution patterns on the selected watershed. The selection of these weather stations is thought to be representative of the watershed; therefore, appropriate sensitivity analyses were conducted with the data from these stations.

The storm event of March 20-21, 1985 is representative of a storm event that was simulated well. The rainfall distribution is depicted in Figure 4.8, with little spatial variability in the rainfall patterns throughout the watershed. Conversely, the magnitude of the storm event of April 8-10, 1983 was simulated less accurately. As illustrated in Figure 4.9, this storm demonstrated significant spatial variability of rainfall throughout the watershed. Similar comparisons for other major storm events indicate that the calibrated model provides good correlation with field data for precipitation events that are accurately prescribed. Storm events that are simulated with less accuracy generally correlate to a high level of spatial storm variability that is not prescribed within the model boundary conditions.

Similar evaluations of storm events exhibiting poor correlation improved the level of confidence in the computational model calibration since the degradation in results can be isolated and attributed to applied boundary data rather than fundamental watershed modeling parameters. Thus, it may be concluded that the computational watershed model is representative of the watershed and can be applied with confidence as a predictive or assessment model.

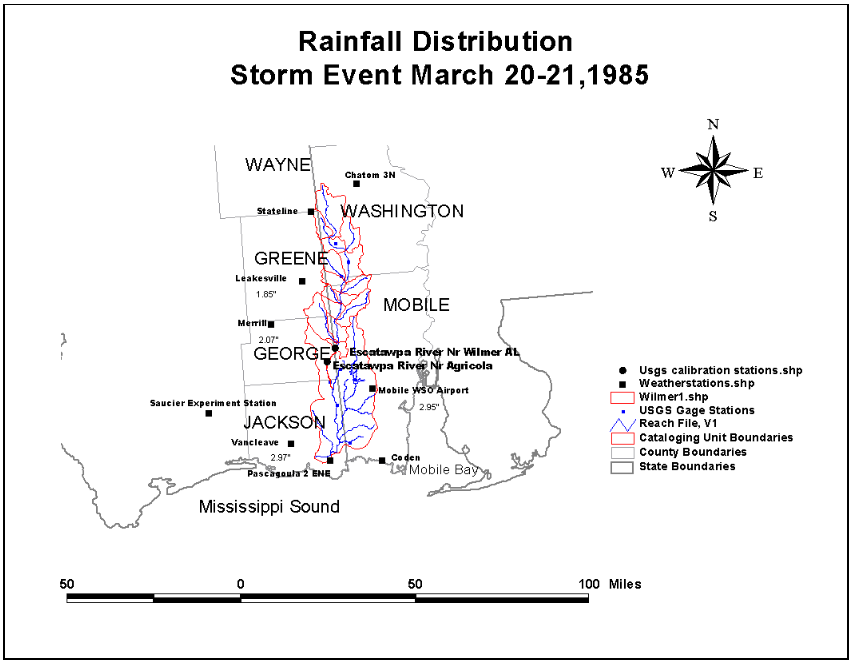

Figure 4.8: Rainfall Distribution March 20-21, 1985.

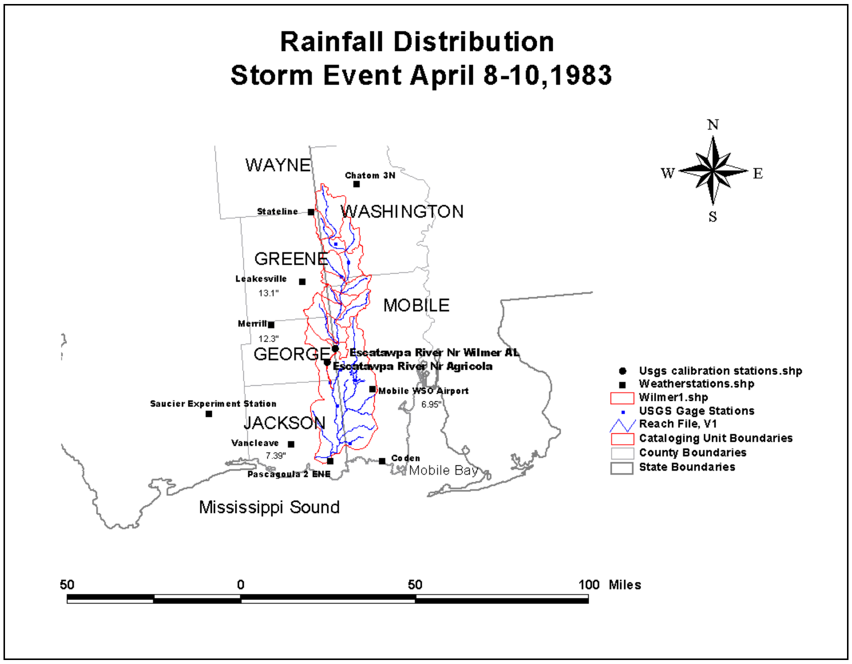

Figure 4.9: Rainfall Distribution April 8-10, 1983.

Fecal Coliform Analysis on the Escatawpa River

The BASINS/NPSM model calibrated for hydrologic and hydrodynamic simulation was applied to the study area to simulate fecal coliform levels in the Escatawpa River. The model delineation was slightly modified from that used in the hydrologic calibration in order to extend the model from the Agricola gage station downstream to the confluence of the Escatawpa River with Black Creek. This segment of the Escatawpa River is listed as a monitored water body by the MDEQ. There is no historical data for fecal coliform levels in this segment but the stream was listed assuming that agricultural activities in the watershed may have adversely affected water quality in this specific segment (RM 10 to the Mouth of the Pascagoula River). The land uses in this section that contribute to the fecal coliform loadings are predominantly forest and agricultural. Hence, relatively low fecal coliform levels would be anticipated. Due to the lack of field data, model input parameters for application were extrapolated from a similar study of the St. Louis Bay (Huddleston et al., 2000).

Point sources and nonpoint sources were both considered for the analysis of fecal coliform. There are no permitted point source discharges in the upper portion of the watershed. Point sources discharging in the tidally influenced portion of the study area were considered in the estuary model and were not included as part of the watershed model input data. On the other hand, major nonpoint source contributors such as failing septic systems, direct access of cattle and other animals to the stream, impact of wildlife, and the various land uses are all accounted for in the model.

To accurately predict runoff and fecal coliform loading from the nonpoint source contributors, a variety of parameters must be quantified. A spreadsheet developed by USEPA (USEPA, 1999f) was used to quantify the fecal coliform loadings from the various nonpoint sources incorporated into the model. The spreadsheet calculates fecal coliform loading rates in units consistent with required BASINS/NPSM input format from user specified values for animal density and unit fecal production per land use type. The following sections will briefly describe the values and assumptions made to quantify the fecal coliform loadings applied to the model.

Failing Septic Systems

Septic system discharges were quantified based on the following information: the number of septic tanks within each of the 31 subwatersheds, assumed average daily discharge of 70 gallons per person per day, and assumed septic effluent fecal coliform concentration of 10^4 MPN/100 ml. A 50 % failure rate was assumed for all septic systems in the study area. This assumption was based upon personal communication with personnel from the Mississippi Department of Health pertaining to prior studies in south Mississippi (MSDH, 1999). The number of septic tanks in each subwatershed was based on 1990 Census data from each county, and an area ratio between the subwatershed and the county. Urban areas in both Jackson County, MS and Mobile

County, AL were not considered because these areas lie outside the study area boundary. Fecal coliform loads from failing septic systems (Table 4.8) were input into the NPSM model as an equivalent point source discharge. Consequently, these discharges were assumed to be constant throughout the simulation period.

Direct Contribution of Fecal Coliform Bacteria to Stream

The direct contribution of fecal coliform from cattle and other animals having direct access to a stream is represented as a point source in the model. It is assumed that 2 % of the cattle waste is a direct input to the streams. Note that this is a calibration factor that also represents other contributions into the system such as contributions from large wildlife animals that inhabit the area. The initial approximation was based upon values utilized in the calibration of the St. Louis Bay Model (Huddleston et al., 2000). The applied level correlates reasonably well with Mississippi Department of Agriculture and Commerce estimates (USDA, 2000). The fecal coliform loading due to cattle having direct access to streams is shown in Table 4.9.

Table 4.8: Fecal Coliform Loading Rate Due to Failed Septic Systems

Subwatershed	Total # of People in Subwatershed	Existing Flow (cfs)	Existing Load (counts/hr)
03170008002	259	2.82e-02	2.86e08
03170008003	987	1.07e-01	1.09e09
03170008004	19	2.07e-03	2.11e07
03170008005	1484	1.61e-01	1.64e09
03170008006	238	2.58e-02	2.63e08
03170008007	577	6.26e-02	6.37e08
03170008008	253	2.75e-02	2.80e08
03170008009	379	4.11e-02	4.18e08
03170008010	778	8.45e-02	8.59e08
03170008011	135	1.46e-02	1.49e08
03170008012	1135	1.23e-01	1.25e09
03170008014	1511	1.64e-01	1.67e09
03170008016	1727	1.87e-01	1.91e09
03170008017	521	5.66e-02	5.76e08
03170008018	1707	1.85e-01	1.88e09
03170008019	728	7.90e-02	8.04e08
03170008020	3498	3.80e-01	3.86e09
03170008021	829	9.00e-02	9.16e08
03170008022	1385	1.50e-01	1.53e09
03170008023	892	9.68e-02	9.85e08
03170008024	328	3.55e-02	3.62e08
03170008025	961	1.04e-01	1.06e09
03170008026	733	7.95e-02	8.09e08
03170008027	1553	1.68e-01	1.71e09
03170008028	1353	1.47e-01	1.49e09
03170008029	789	8.56e-02	8.71e08
03170008030	2694	2.92e-01	2.97e09
03170008031	773	8.38e-02	8.53e08
03170008032	1249	1.35e-01	1.38e09
03170008033	417	4.53e-02	4.61e08
03170008034	2035	2.21e-01	2.25e09

Table 4.9: Fecal Coliform Loading Rate Due to 2% Cattle Access to Stream

Subwatershed	Total # of Cattle in Subwatershed	Existing Flow (cfs)	Existing Load (counts/hr)
03170008002	45	7.86e-06	2.03e08
03170008003	10	1.71e-06	4.50e07
03170008004	3	5.12e-07	1.35e07
03170008005	18	3.07e-06	8.10e07
03170008006	40	6.83e-06	1.80e08
03170008007	34	5.81e-06	1.53e08
03170008008	0	0.00e00	0.00e00
03170008009	0	0.00e00	0.00e00
03170008010	0	0.00e00	0.00e00
03170008011	0	0.00e00	0.00e00
03170008012	0	0.00e00	0.00e00
03170008014	0	0.00e00	0.00e00
03170008016	0	0.00e00	0.00e00
03170008017	11	1.88e-06	4.95e07
03170008018	270	4.60e-05	1.21e09
03170008019	37	6.29e-06	1.66e08
03170008020	857	1.46e-04	3.86e09
03170008021	36	6.09e-06	1.61e08
03170008022	0	0.00e00	0.00e00
03170008023	43	7.34e-06	1.94e08
03170008024	0	0.00e00	0.00e00
03170008025	0	0.00e00	0.00e00
03170008026	30	5.12e-06	1.35e08
03170008027	0	0.00e00	0.00e00
03170008028	0	0.00e00	0.00e00
03170008029	2	3.42e-07	9.0e06
03170008030	9	1.54e-06	4.05e07
03170008031	66	1.13e-05	2.97e08
03170008032	16	2.73e-06	7.20e07
03170008033	34	5.81e-06	1.53e08
03170008034	542	9.26e-05	2.44e09

Contributions from Animals

Contributions of fecal coliforms from animal population, both farm and wildlife, must be considered. Table 4.10 illustrates animal populations in each respective subwatershed. Table 4.11 illustrates land uses in each subwatershed, while Table 4.12 depicts the fecal coliform loading rates for each subwatershed characterized by land use type. More detailed information as to the source and associated loadings of fecal coliforms from animal population within the watershed is presented below.

Wildlife

Fecal coliform loadings for forestland uses were based on the estimated wildlife population within the study area. Since reported unit contributions of fecal coliform from small animals (ducks, geese, raccoons, squirrel etc.) are significantly lower than that from deer, the fecal coliform load from wildlife population was limited to only deer. Deer population density of 18 deer per square mile was utilized in this study. This estimate was based on the Pascagoula River Basin Study conducted by the USEPA (Davis, 1999). A fecal coliform production rate of 5.00E+08 counts/day/deer was assumed in the model (USEPA, 1998d). Fecal coliform accumulation rate for deer population habitat (forest land use) is 1.41E+07 counts/acre/day (USEPA, 1999f).

Land Application of Hog and Cattle Manure

The fecal coliform spreadsheet was used to estimate the fecal coliform loadings contributed by hog and cattle from each subwatershed. Fecal coliform production rates of 1.08E+08 MPN/day/hog and 5.40E+09 MPN/day/cow were used to quantify the fecal coliform loadings (ASAE, 1998 and Metcalf and Eddy, 1991). Manure application rates to pastureland normally vary on a monthly basis, but for purposes of this study the application rate was averaged over all twelve months to obtain a representative value to be used with NPSM. Data from Pascagoula River Basin study were used to estimate the manure application rates (MDEQ, 1999).

Grazing Animals

Manure produced by grazing beef and dairy cattle is assumed to be spread on pastureland throughout the year, with no manure applied to cropland areas. The number of grazing cattle is computed by subtracting the number of confined cattle from the total number of cattle on each subwatershed. The cattle population was determined from the 1997 Census of Agriculture Data, which was provided by WCS (USEPA, 1999d). The fecal coliform content of manure produced by grazing cattle is estimated by multiplying the number of grazing cattle by a fecal coliform production rate of 5.40E+09 MPN/day/cow (Metcalf and Eddy, 1991).

Land Application of Poultry Litter

The fecal coliform spreadsheet was used to estimate the loading of fecal coliform bacteria that accumulates in the dry litter where poultry waste is collected. A fecal coliform production rate of 6.75E+07 MPN/day/chicken (ASAE, 1998) was used to calculate the loading of fecal coliform. The chicken population was determined from the 1997 Census of Agriculture Data for the number of chickens sold for each county per year and was obtained from the WCS software (USEPA, 1999d). A watershed area normalized chicken population was assumed. Variable monthly loading rates of litter were applied to pastureland. No litter was applied to cropland areas.

It was anticipated that the impacts from the above mentioned sources would be minimal when assessing the water quality at the location of interest, the confluence of Black Creek with the Escatawpa River. The small loading rates coupled with large drainage area would suggest minimal effects at the impaired segment. The flow rate in the system is also rather high compared to the loading rates. This would tend to dilute the concentrations, and as a result have minimal impacts on the water quality criteria.

Table 4.10: Subwatershed ID's with Applied Animal Populations.

SUBWATERSHED	**BEEF COWS**	**SWINE (HOGS)**	**DAIRY COWS**	**POULTRY**	**CATTLE**
3170008002	45	1	0	0	84
3170008003	10	0	0	0	20
3170008004	3	0	0	0	6
3170008005	18	0	0	0	35
3170008006	40	1	0	0	76
3170008007	34	1	0	0	65
3170008008	0	0	0	0	0
3170008009	0	0	0	0	0
3170008010	0	0	0	0	0
3170008011	0	0	0	0	0
3170008012	0	0	0	0	0
3170008014	0	0	0	0	0
3170008016	0	0	0	0	0
3170008017	11	0	0	0	20
3170008018	267	5	3	2	505
3170008019	36	1	1	0	69
3170008020	811	53	55	3	1545
3170008021	34	2	2	648	65
3170008022	0	0	0	0	0
3170008023	43	1	0	5487	80
3170008024	0	0	0	0	0
3170008025	0	0	0	0	0
3170008026	30	0	0	3840	56
3170008027	0	0	0	0	0
3170008028	0	0	0	0	0
3170008029	2	0	0	289	4
3170008030	9	0	0	4302	17
3170008031	66	1	0	10572	122
3170008032	16	0	0	2070	30
3170008033	34	0	0	4256	62
3170008034	523	25	23	25615	987
TOTAL	2032	91	84	57084	3848

Table 4.11: Subwatershed Areas with Selected Land Uses

Subshed	**Cropland (acres)**	**Forest (acres)**	**Urban (acres)**	**Pastureland (acres)**	**Total (acres)**
3170008002	62	4276	98	363	4799
3170008003	3095	6748	338	8066	18247
3170008004	2	298	0	53	353
3170008005	4190	11445	113	11705	27453
3170008006	91	3819	1	495	4406
3170008007	1627	6442	2	2603	10674
3170008008	467	3263	1	953	4684
3170008009	1217	2885	3	2899	7004
3170008010	2194	8303	472	3428	14397
3170008011	84	2064	0	347	2495
3170008012	2074	14805	373	3734	20986
3170008014	3923	18153	474	5394	27944
3170008016	3824	23515	40	4558	31937
3170008017	2240	3441	5	3960	9646
3170008018	2684	22345	28	6511	31568
3170008019	2680	7418	12	3355	13465
3170008020	7588	45715	203	11200	64706
3170008021	398	14495	5	443	15341
3170008022	1894	21435	180	2108	25617
3170008023	911	14570	4	1022	16507
3170008024	70	5926	0	62	6058
3170008025	931	15916	60	864	17771
3170008026	485	12618	6	446	13555
3170008027	397	28009	9	304	28719
3170008028	409	24124	1	489	25023
3170008029	605	13453	4	524	14586
3170008030	1696	45624	14	2490	49824
3170008031	582	13017	56	639	14294
3170008032	400	22336	10	351	23097
3170008033	824	6126	2	769	7721
3170008034	5651	27385	12	4600	37648
TOTAL	53295	449969	2526	84735	590525

Table 4.12: Fecal Coliform Loading Rates (#cfu/acre/day) by Land Use Category.

Subwatershed	**Urban & Barren**	**Forrest & Wetland**	**Cropland**	**Pastureland**	**Total**
03170008002	7.18e06	1.41e07	1.41e07	6.74e08	7.09e08
03170008003	7.18e06	1.41e07	1.41e07	2.05e07	5.59e07
03170008004	0.00e00	1.41e07	1.41e07	3.07e08	3.35e08
03170008005	7.18e06	1.41e07	1.41e07	2.20e07	5.74e07
03170008006	7.18e06	1.41e07	1.41e07	4.46e08	4.81e08
03170008007	7.18e06	1.41e07	1.41e07	8.43e07	1.20e08
03170008008	7.18e06	1.41e07	1.41e07	1.41eo7	3.54e07
03170008009	7.18e06	1.41e07	1.41e07	1.41eo7	3.54e07
03170008010	7.18e06	1.41e07	1.41e07	1.41eo7	3.54e07
03170008011	0.00e00	1.41e07	1.41e07	1.41eo7	2.82e07
03170008012	7.18e06	1.41e07	1.41e07	1.41eo7	3.54e07
03170008014	7.18e06	1.41e07	1.41e07	1.41eo7	3.54e07
03170008016	7.18e06	1.41e07	1.41e07	1.41eo7	3.54e07
03170008017	7.18e06	1.41e07	1.41e07	2.85e07	6.39e07
03170008018	7.18e06	1.41e07	1.41e07	2.34e08	2.69e08
03170008019	7.18e06	1.41e07	1.41e07	7.31e07	1.08e08
03170008020	7.18e06	1.41e07	1.41e07	4.44e08	4.79e08
03170008021	7.18e06	1.41e07	1.41e07	4.98e08	5.33e08
03170008022	7.18e06	1.41e07	1.41e07	1.41e07	4.95e07
03170008023	7.18e06	1.41e07	1.41e07	3.68e08	4.03e08
03170008024	0.00e00	1.41e07	1.41e07	1.41e07	4.23e07
03170008025	7.18e06	1.41e07	1.41e07	1.41e07	4.95e07
03170008026	7.18e06	1.41e07	1.41e07	5.71e08	6.06e08
03170008027	7.18e06	1.41e07	1.41e07	1.41e07	4.95e07
03170008028	7.18e06	1.41e07	1.41e07	1.41e07	4.95e07
03170008029	7.18e06	1.41e07	1.41e07	4.72e07	8.26e07
03170008030	7.18e06	1.41e07	1.41e07	7.46e07	1.10e08
03170008031	7.18e06	1.41e07	1.41e07	9.59e08	9.94e08
03170008032	7.18e06	1.41e07	1.41e07	3.93e08	4.28e08
03170008033	7.18e06	1.41e07	1.41e07	3.77e08	4.12e08
03170008034	7.18e06	1.41e07	1.41e07	7.98e08	8.33e08

Model Application

As previously stated, no field measurement levels of fecal coliforms within the watershed exist for model calibration/verification. In addition to the various nonpoint sources of fecal coliforms previously discussed, model application will require an estimate of fecal coliform die off rates along with a temperature correction coefficient. Due to the limited site-specific data, calibration/verification results of the adjoining St. Louis Bay watershed were used to define the first order decay rate equal to 0.6 at 20 °C with a temperature correction of 1.07. It is significant to note that the applied first order decay rate is considered conservative and serves to increase the resultant margin of safety (MOS). The various monthly accumulation rates and limiting storage values were taken directly from the EPA's fecal coliform spreadsheet (USEPA, 1999d), as previously discussed.

Results

Fecal coliform levels in the watershed were simulated for the period of January 1, 1990 through May 28, 1999. Figures 4.10-4.13 depict the calculated 30-day geometric mean of fecal coliform concentration during the ten-year modeling scenario at the selected location, the confluence of Black Creek with the Escatawpa River. Results are presented for a baseline simulation of 2 % cattle stream access and 50% failing septic systems and selected parametric variations. As shown in Figure 4.10, no violations of the water quality standard of 200 MPN/100 ml are noted during the ten-year modeling period for the baseline simulation.

As an illustration of the relative significance of cattle and septic loadings (the two principal factors), simulations were made by completely eliminating cattle access to the stream and loading from septic systems, individually and collectively. Figure 4.11 presents the calculated fecal coliform concentration for a loading scenario of fifty percent septic failure rate and zero percent cattle stream access. Figure 4.12 presents the calculated fecal coliform concentration for a loading scenario of zero percent septic failure rate and two percent cattle stream access. Figure 4.13 presents the calculated fecal coliform concentration for a loading scenario of zero percent septic failure rate and zero percent cattle stream access. From Figure 4.11 and 4.12, it appears that the magnitude of the loadings from cattle access and failing septic systems are roughly equal.

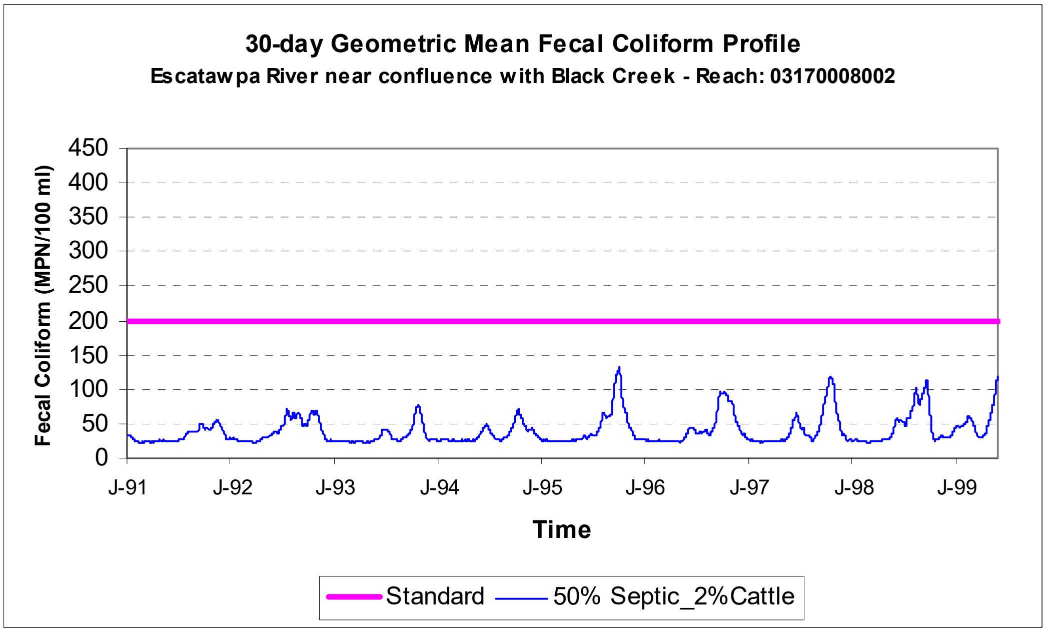

Figure 4.10: Baseline Results from Fecal Analysis.

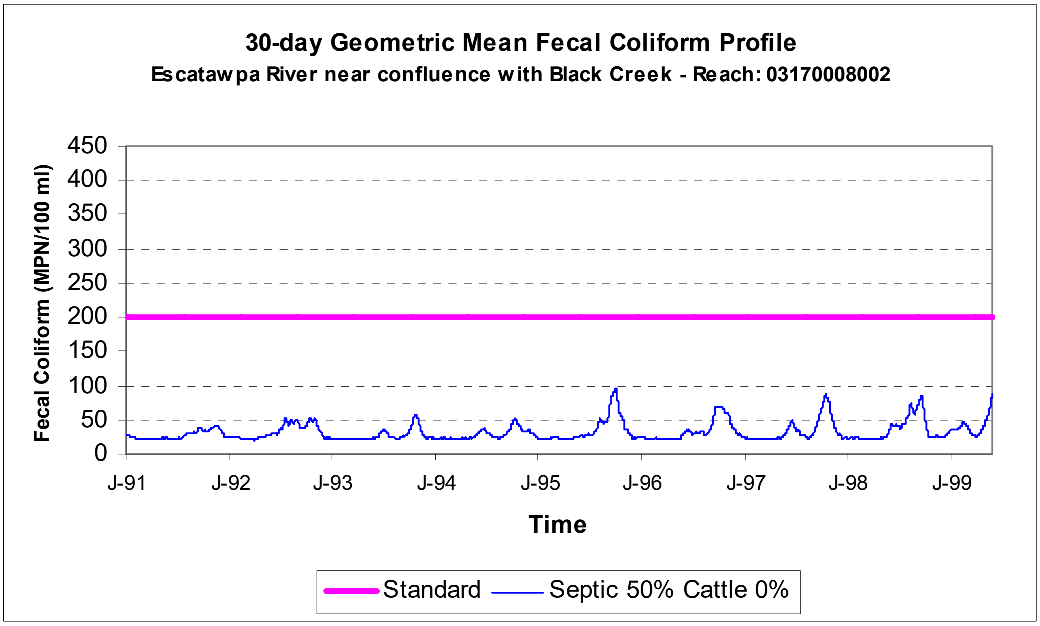

Figure 4.11: Load Scenarios for Fecal Analysis.

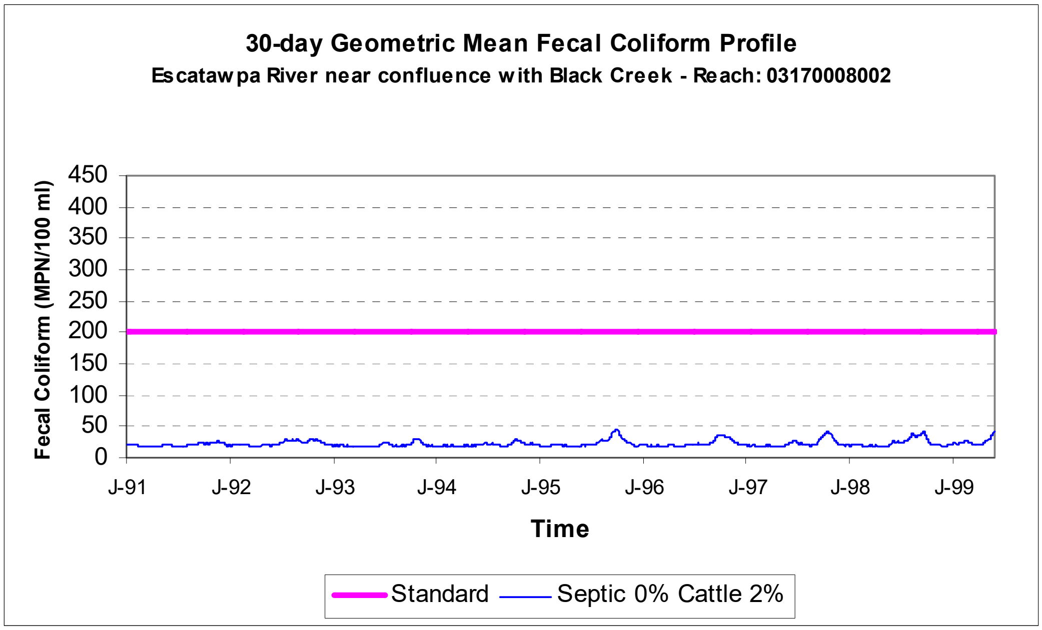

Figure 4.12: Load Scenarios for Fecal Analysis.

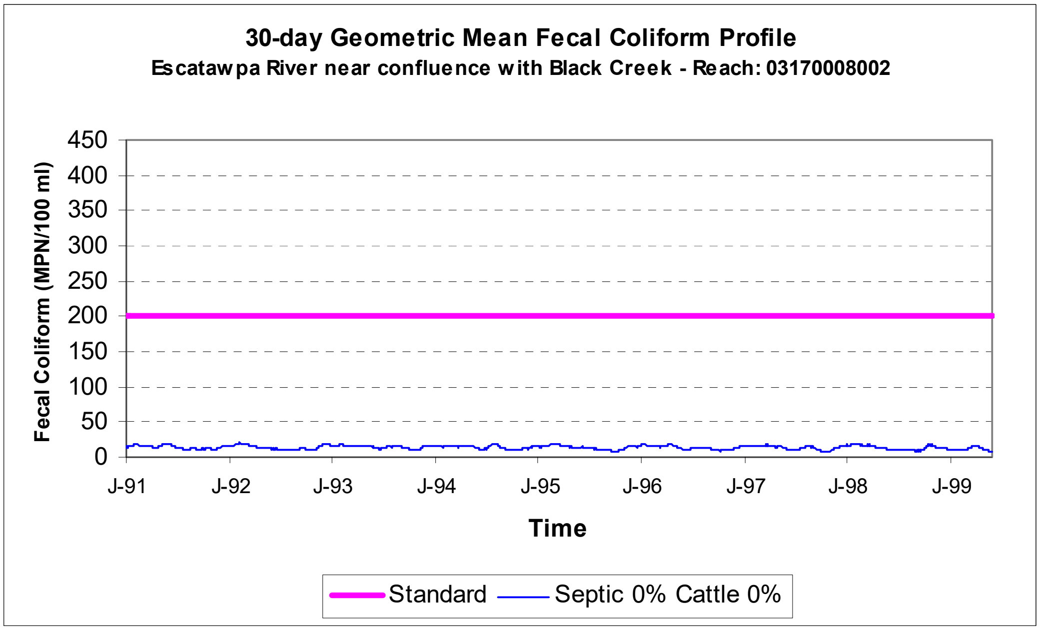

Figure 4.13: Load Scenarios for Fecal Analysis.

CHAPTER V

Estuary Model Calibration and Application

The estuary model was developed for the lower portion of the watershed, including: the Escatawpa River from river mile 14 to the confluence with the East Pascagoula, the East Pascagoula from river mile 14 to its mouth at the Mississippi Sound, and the West Pascagoula from river mile 13 to its mouth at the Mississippi Sound.

As discussed in Chapter 3, CE-QUAL-W2 was selected as the modeling software for this application. The 2-D, laterally averaged assumption is consistent with the stream geometry throughout most of the study area; however, there are notable exception in the vicinity of the large lakes and marshes where the main river channel is not well defined. This may degrade solution accuracy but CE-QUAL-W2 should produce simulations that are adequate for preliminary evaluation. The CE-QUAL-W2 model is capable, and has been applied to estuarine environments to simulate the hydrodynamics and water quality that would be expected in a system such as the Escatawpa (Hall 1999, Bales and Robbins 1999, Wells 2000). The calibration and application of the CE-QUAL-W2 model (Cole and Buchak, 1995), as applied to the Escatawpa River Estuary, is described in this chapter. Specific focus is placed on

(1) grid discretization, (2) applied boundary conditions, (3) evaluation of calibration parameters, and (4) an application of the model to assess the impact of point sources on the water quality in the estuary.

Grid Discretization

The first step in developing the CE-QUAL-W2 model is to develop the geometry that will be used to define the finite difference representation of the waterbody. The grid geometry of the system is determined by longitudinal and vertical spacing, and also by the average cross section width. The computational grid (Figure 5.1) for the system was determined from bathymetric data collected during the Pascagoula Low Flow Management Study (MDEQ, 1994), whereas, the segment lengths and orientations were taken from USGS topographic maps. The grid consists of 194 longitudinal segments ranging in length from over 100 meters to over 1000 meters, and 31 layers with a uniform 0.61-meter vertical depth for each layer. The number of active layers in each respective segment varies with the bottom bathymetric data to most closely represent the actual field conditions. A representative computational cell illustrating the respective layers was previously discussed in Chapter 3, and illustrated in Figure 3.2. Each longitudinal cell segment has an orientation associated with it to allow for curvature in the grid. The grid was generated not only to provide for the greatest resolution, but also to meet computing resource requirements.

Boundary Conditions

Development of the CE-QUAL-W2 model of the Escatawpa Estuary System was initiated by the USEPA (USEPA, 1999g), and subsequently continued by the Department of Civil Engineering at Mississippi State University. The initial grid discretization and boundary condition data were developed by the USEPA (USEPA, 1999g). Herein, several model modifications were made including: (1) refinement of the segment orientations, (2) smoothing of the bottom bathymetry, and (3) incorporating Black Creek and other lateral inflows, and (4) refinement of atmospheric boundary data. Alterations of the model segment orientations and bottom bathymetry were mad to more accurately represent the physical system and to enhance model stability. Introduction of additional sources of fresh water and boundary data refinement resulted from model calibration efforts. The model, as applied to the Escatawpa Estuary, ultimately incorporated six branches, and seven tributaries (point source discharges) as defined in Table 5.1, and illustrated in Figure 5.1.

As with any simulation, boundary conditions applied to the Escatawpa Estuary model represented temporal and spatial variations. Boundary conditions denoted in Figure 5.1 with a B.C., are imposed on the model grid at three upstream branches (Branch 1, 2, and 6) and two downstream branches (Branch 1 and 6). The conditions were imposed upon the model for a period of August 1, 1997 (Julian Day 213) through September 17, 1997 (Julian Day 261). This encompassed the intensive field study period of September 10, 1997 through September 15, 1997 and provided a forty-day model stabilization period.

The data for the forty-day model stabilization period was extrapolated from the model study period data, as appropriate. The flow rates imposed for the first day of the simulation (Julian Day 213) were arbitrarily set equal to the initial flow rate used for the model calibration period (Julian Day 246). A similar approach was used in regards to the initialization period for the constituent concentrations and temperature boundary conditions. The downstream tidal elevations were superimposed forward in time to represent a repetition of the tidal cycle observed during the survey period.

Table 5.1: List of Branches and Tributaries.

Branch 1	Pascagoula River	Tributary 1	Black Creek
Branch 2	Escatawpa River	Tributary 2	I.P./Jackson County
Branch 3	I-10 Cut	Tributary 3	Zapata Haynie
Branch 4	Bayou Chemise	Tributary 4	Morton
Branch 5	Industrial Cut	Tributary 5	Escatawpa POTW
Branch 6	W. Pascagoula River	Tributary 6	Gautier WWTP
		Tributary 7	Pasc./Moss Point WWTP

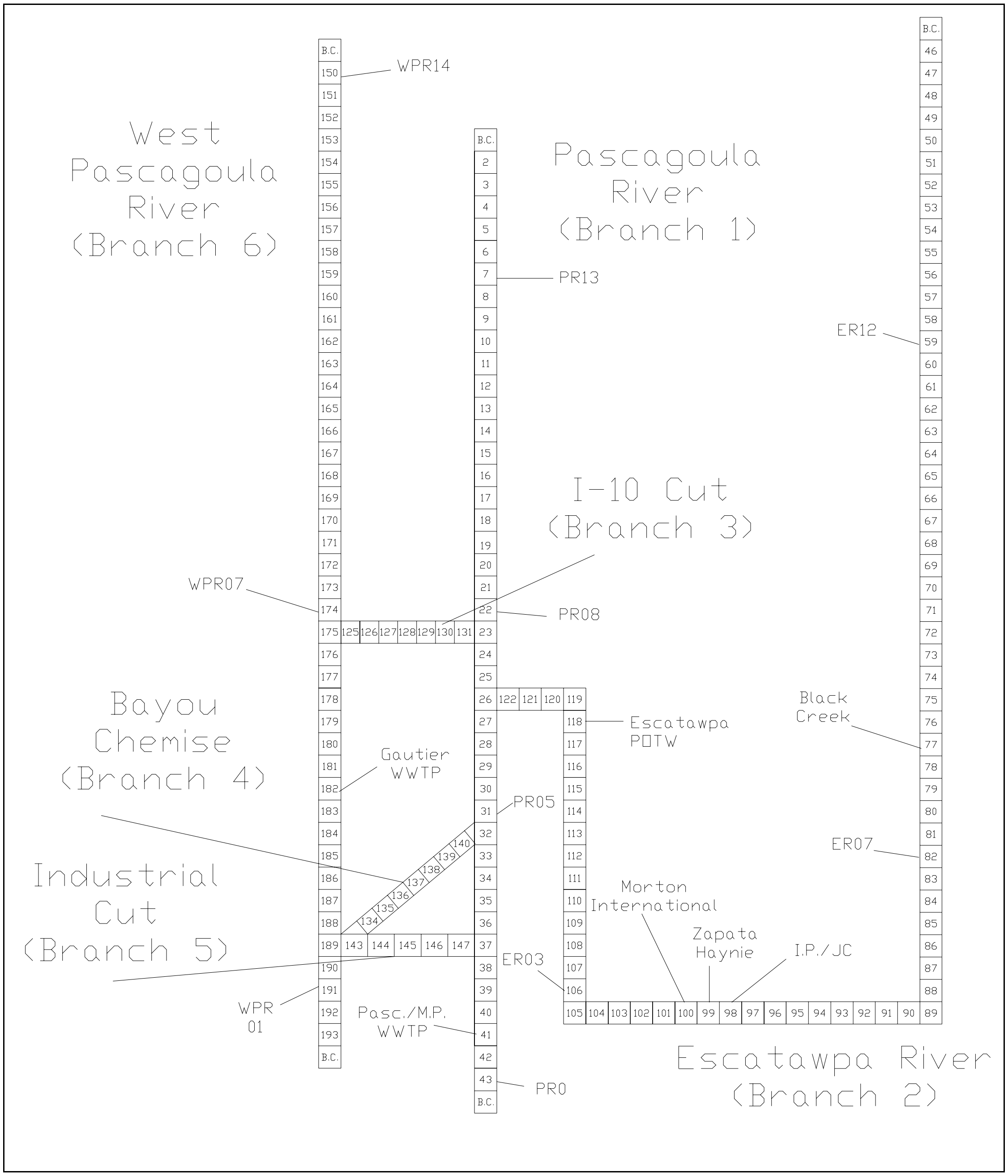

Figure 5.1: Computational Grid of Escatawpa Estuary Model

The hydrodynamic boundary conditions for the model were imposed as flow rates at the most upstream segments of the Escatawpa, East Pascagoula, and West Pascagoula Rivers, and as tidal elevations imposed at the most downstream segments of the East Pascagoula and West Pascagoula Rivers. Prescribed boundary data was taken from field survey measurements. The temporal resolution of the input data varied with the actual field data, that is the flow rates were introduced to the model on a daily basis, whereas, the tidal elevations were input on an hourly basis. Based on prior modeling experience (Shindala et al., 1973) and the calibration study, fresh water flow was spatially introduced as a distributed source into the Escatawpa to account for small tributaries and lateral inflows.

The spatially introduced flow was determined by using the flow coefficient method utilizing the flow recorded at the Agricola gaging station. Flows in the Pascagoula and West Pascagoula Rivers were determined by assuming that the flow recorded at the Graham Ferry gaging station is divided 35% and 65% between the two branches, respectively. The flow introduced to the model through Black Creek was assumed to be approximately half the base flow of the Escatawpa River (Winfield and Nusser, 1984). Point source flows introduced to the model were based upon field monitoring data obtained during the 1997 field survey period (USEPA, 1997). Downstream tidal elevations were obtained from field measurements taken at the Mary Walker Marina during the 1997 survey period and are depicted in Figures 5.2 and 5.3. All flows introduced into the model are summarized in Table 5.2 and Table 5.3.

Table 5.2: Upstream Flows and Distributed Tributary Flow.

Time	**Branch 1 Flow (cms)**	**Branch 2 Flow (cms)**	**Branch 3 Flow (cms)**	**Distributed Tributary Br2 Flow (cms)**
213	26.9	13.1	49.9	10.5
246	26.9	13.1	49.9	10.5
247	27.4	11.5	50.8	10.5
248	26.6	10.8	49.3	10.5
249	24.9	10.5	46.2	10.5
250	24.9	10.1	46.2	10.5
251	24.3	9.8	45.1	10.5
252	24	9.5	44.5	10.5
253	24.1	9.7	44.7	10.5
254	23.3	9.5	43.3	10.5
255	23	9.1	42.7	10.5
256	23	8.9	42.7	10.5
257	23.4	8.7	43.4	10.5
258	22.7	8.6	42.1	10.5
259	22.7	8.4	42.1	10.5
260	21.5	8.3	39.9	10.5
261	21.1	8.1	39.2	10.5

Table 5.3: Tributary (Point Source) Flows

	Flow (cms)
Tributary 1 (Black Creek)	5.04
Tributary 2 (International Paper)	0.72
Tributary 3 (Zapata Haynie)	0.42
Tributary 4 (Morton Int.)	0.049
Tributary 5 (Escatawpa POTW)	0.030
Tributary 6 (Gautier WWTP)	0.057
Tributary 7 (Pasc./M.P. WWTP)	0.19

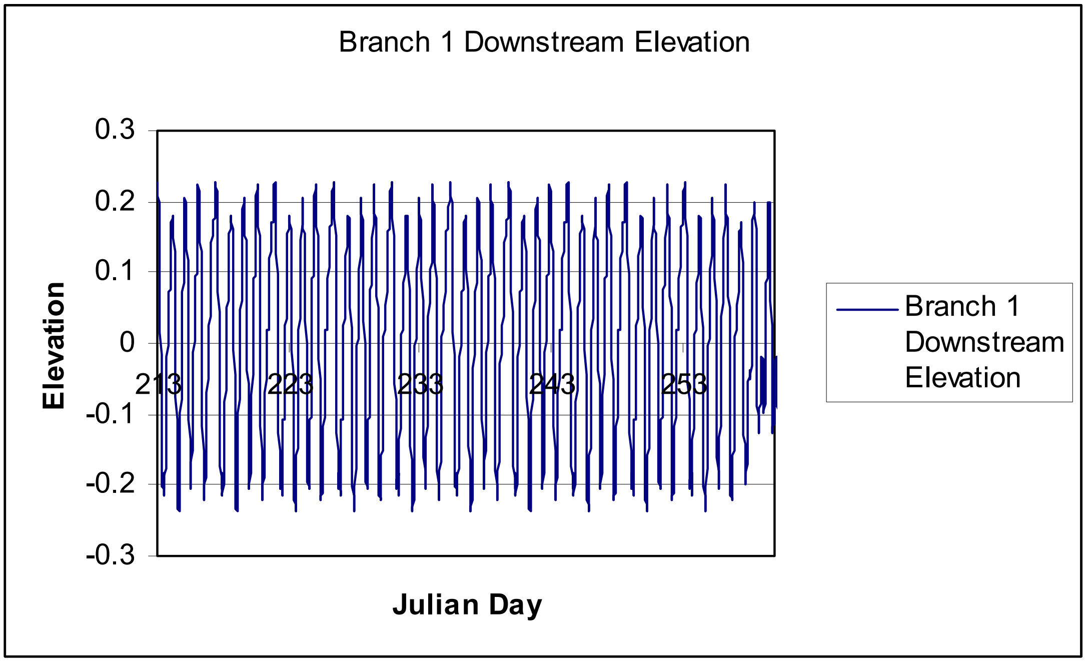

Figure 5.2: Branch 1 Downstream Elevation.

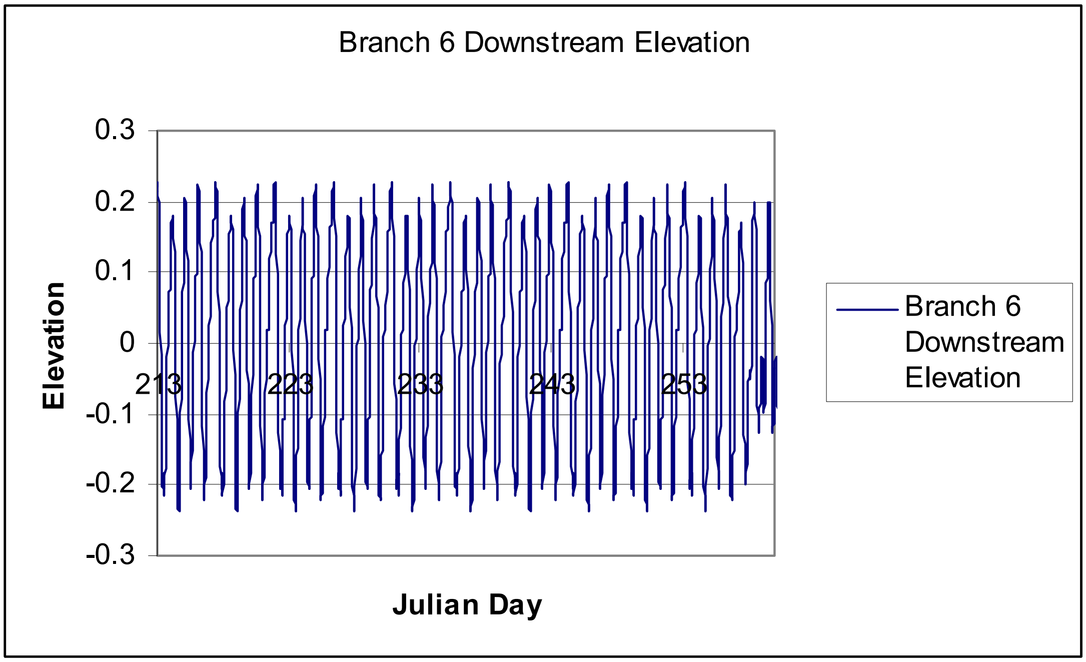

Figure 5.3: Branch 6 Downstream Elevation.

The water quality simulation in the model is driven by boundary conditions, initial conditions, and external loads input from point and nonpoint sources. Initial conditions and upstream boundary concentrations were taken directly from the 1997 survey data, with the exception of CBODU values, which were applied as a background value of 4 mg/l. Point source discharge concentrations were based upon the limits established in the NPDES permits for each respective discharger with the exception of CBODU. CBODU values for the point source discharges were determined in collaboration with the USEPA personnel (USEPA, 1999f), from the long term BOD test conducted during the intensive survey period. The constituent concentrations applied to Black Creek were extrapolated from the Escatawpa River. Initial and upstream concentrations applied to the model are summarized in Table 5.4. Concentrations associated with point sources are summarized in Table 5.5.

The meteorological data requirements of the model include: air temperature, dew point temperature, wind speed and direction, and cloud cover data to the model. The air temperature data was obtained from NOAA information Buoy 42007 located 20 miles S/SE of Biloxi, Mississippi (NOAA, 1999). The dew point temperature and cloud cover data were obtained from the Leakesville weather station MS224966 (USEPA, 1999d). The wind speed and direction were taken from direct measurements taken during the 1997 intensive survey period and are extrapolated in time for the model stabilization period (USEPA, 1997).

Table 5.4: Initial and Upstream Concentrations

INITIAL CONCENTRATIONS		UPSTREAM CONCENTRATIONS		
		Branch 1	Branch 2	Branch 6
Constituent	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**
Tracer	0.001	0	0	0
Salinity	Varies Longitudinally (interpolated from field data)	1	1	1
Labile DOM	0.01	0.01	0.01	0.01
Refractory DOM	0.01	0.01	0.01	0.01
Algae	Varies Longitudinally (interpolated from field data)	0.8	0.09	0.7
Detritus	0.01	0.01	0.01	0.01
Phosphate	0.25	0.05	0.05	0.06
Ammonium	0.2	0.17	0.15	0.24
Nitrate-Nitrite	0.02	0.02	0.3	0.02
D.O.	Varies Longitudinally (interpolated from field data)	6	5	6.5
CBOD	4	4	4	4

Table 5.5: Tributary and Distributed Tributary Concentrations

	Trib 1	Trib 2	Trib 3	Trib 4	Trib 5	Trib 6	Trib 7	Branch 2
Constituent	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**	**Conc. (mg/l)**
Tracer	0	100	0	0	0	0	0	0
Salinity	0	0	0	0	0	0	0	0
Labile DOM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Refractory DOM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Algae	0	0	0	0	0	0	0	0
Detritus	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Phosphate	0.05	0.95	0.35	0.5	3.06	3.66	2.81	0.05
Ammonium	0.15	1.96	3.3	0.57	0.67	0.56	5.12	0.15
Nitrate-Nitrite	.3	.01	.1	.03	14	11	1.81	0.3
D.O.	5	6	6	6	6	6	6	5
CBOD	2	90	50	9	6	5.6	15.6	4

Calibration Parameters

The CEQUAL-W2 model was applied to simulate the hydrodynamics and water quality in the Escatawpa/Pascagoula study area for the intensive survey period of September 10, 1997 through September 15, 1997. Model calibration was accomplished by adjusting pertinent model parameters until reasonable correlation between model output and field data was attained.

The initial calibration effort was focused on the hydrodynamics of the system. Several simulation scenarios were conducted to reach an acceptable calibration. First, the bottom geometries were smoothed to correlate the model more closely to actual field conditions. Secondly, as previously discussed, lateral inflows were introduced into the Escatawpa River to account for small streams, creeks, and tributaries that were initially neglected. The introduction of Black Creek into the model was also deemed appropriate to aid in an accurate correlation of hydrodynamics. Lastly, several parametric analyses of the chezy coefficient were simulated. The Chezy coefficient is analogous to the Manning's n, and is associated with the bottom roughness coefficient. It was determined that the hydrodynamic simulations were the most sensitive to changes in the Chezy coefficient. After several sensitivity analyses, it was concluded that a Chezy value of 30 $m^{0.5}$/sec best represented the hydrodynamics of the system. This relatively low value such has been reported in similar estuarine applications such as this (Cole, 2000, Martin and McCutcheon, 1999).

After acceptable hydrodynamic calibration was accomplished, water quality calibration was initiated. Since the dissolved oxygen (D.O.) in the system was the water quality criteria of concern, the model was specifically targeted to simulate the D.O. in the system. The maximum algae growth rate (AG), the CBOD decay rate (KBOD), and the ammonium decay rate (NH4DK) were determined to have the greatest influence on D.O. distribution by parametric assessment. After several iterations it was determined that the best correlation was obtained when AG=1.0, KBOD=0.06, and NH4DK=0.06. Appendix A defines all of the CEQUAL-W2 model calibration parameters along with typical values used in similar studies.

Simulation Results

Calibrations results of the CE-QUAL-W2 model will be presented in this section. As was previously stated, model calibration is based upon graphical comparison of model output to field measured data during the intensive survey period. Graphs of key spatial locations at snapshots in time along with time series graphs are presented to demonstrate model applicability. In addition, several color contour plots are also presented to illustrate the effects of point source discharges on the water quality in the estuary.

The CE-QUAL-W2 model as described was applied to simulate the September 10, 1997 through September 17, 1997 period during which an USEPA field study was conducted. Figures 5.4-5.7 compare simulation results of the tidal action in the system at specified stations where field data was collected. Data collections sites are noted on

Figure 5.1. Figures 5.8-5.18 compare salinity simulation results with field data at specific locations. As can be seen, the salinity profiles and water surface elevations in the primary area of interest (Escatawpa River Mile 10 to Mouth of the Pascagoula River) correlates reasonably well with field data. Data correlation further upstream in the Escatawpa and in the West Pascagoula River is less satisfactory. The surface elevation and salinity data correlation in the primary area of interest indicates that the dominant hydrodynamic features are represented with reasonable accuracy, as is convection of the salinity wedge into the estuary. The degraded correlation in the West Pascagoula and in the upstream portion of the Escatawpa River may in part, be attributable to the laterally averaged assumption inherent in CE-QUAL-W2, and/or possible in the placement of the system boundary conditions.

Comparisons of dissolved oxygen profiles for the comparative scenarios with field data are presented in Figures 5.19-5.29. There again, the correlation between model results and field data in the area of interest along the Escatawpa River are reasonable, in view of noted hydrodynamic deficiencies. The dissolved oxygen impairment is quite evident from both the field data and the results of the model computations in this portion of the study area. This correlation provides an adequate confidence level for drawing comparative conclusions from the model results.

The time series comparisons provided at selected locations, Figures 5.30-5.37, provide further confidence in the model results. It should be noted that the field data at these locations were taken at a depth of five feet, whereas, the model results represent values averaged over the entire layer that most closely corresponds to the depth of five feet.

When analyzing the results, it must be noted that the model results are not captured at the exact time and location as the gathered filed data. This leads to distorted variations in results both spatially and temporally. The locations of the predicted results, as noted on the figures, can be determined from the river mile locations noted on the computational grid (Figure 5.1). Rather than artificially smoothing computed results via interpolation, these figures compare the field data with computations that most closely represent the field data.

To provide a more detailed analysis of the results on the Escatawpa River, various color contour plots are presented in Figures 5.38-5.47. The color contour plots not only graphically depict the conditions in the Escatawpa Branch of the system, but also demonstrate the physical locations of the point source discharges within the system. These plots are presented only to demonstrate the water quality conditions under current waste loads compared to the hypothetical scenario of deleting all point source discharges from the system.

Velocity vectors are superimposed upon flood tide and ebb tide salinity contours in Figures 5.38 and 5.39. These representative plots demonstrate the magnitude and direction of the flow fields associated with the tidal action. It is evident that the ebb tide velocities have a higher magnitude than the flood tide velocities, and illustrates the expected flow reversal.

The salinity profiles associated with ebb and flood tides are presented in Figures 5.40 and 5.41. The salinity profiles depict the stratified conditions, along with the magnitude of salinity in the system. The presence of the freshwater inflow is evident between the two scenarios, with the nominal salinity concentrations being somewhat lower during ebb tide conditions.

Figures 5.42–5.43 illustrate the impact of point sources on the CBOD level in the system. This impact is due in part to the significant CBOD loads supplied by the point source discharge facilities as compared to the background levels in the system. As illustrated in Figure 5.43, CBOD levels are significantly elevated in the vicinity of the International Paper, Morton International, and Zapata Haynie discharge facilities. This elevated concentration is also convected downstream to the mouth of the Escatawpa. CBOD levels will, of course, have direct impact on the DO concentration in the water body. It is quite evident from the field data and the model predictions on the Escatawpa River that the water quality is quite degraded below the discharge facility sites, which was anticipated before the modeling effort.

Figures 5.44 – 5.47 illustrate the negative impacts that the point source facilities have on dissolved oxygen. The improvement in the level of dissolved oxygen in the entire system as a result of removing the discharge facility effluent is evident in Figures 5.44 and 5.45. These graphs also indicate that the low naturally occurring anoxic zone is increased to some extent by the oxygen demanding waste. It is evident (Figures 5.44 and 5.45) that the anoxic zone encompasses much more of the system when the oxygen demanding wastes are present. Figures 5.46 and 5.47 present a more localized area of the system, including the major waste source contributors, that illustrates the levels of dissolved oxygen in more detail. It is clear from these plots that the anaerobic zone encompasses much more of the system when the discharge facilities are present.

To ensure better understanding of the processes occurring within the system, three distinct movie files are presented. Movie 5.1 illustrates the salinity intrusion in the Escatawpa River. Effects the tidal cycle has on the intrusion of salinity into the system is clearly demonstrated by this movie. Movies 5.2 and 5.3 present the effects of the point sources on the dissolved oxygen level within the system. This demonstrates the impact the discharge facilities have on the dissolved oxygen concentrations in the affected water body.

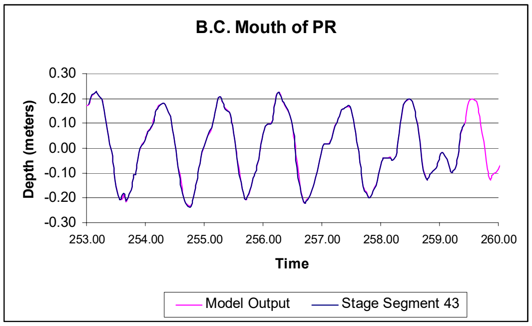

Figure 5.4: Tidal Elevation @ Mouth of East Pascagoula River

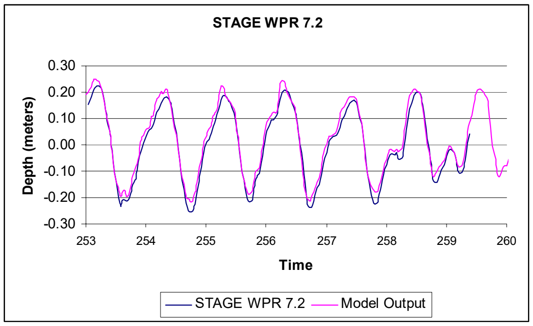

Figure 5.5: Tidal Elevation @ West Pascagoula River Mile 7.2

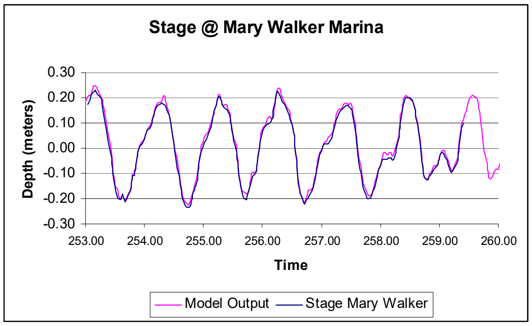

Figure 5.6:Tidal Elevation @ Mary Walker Marina

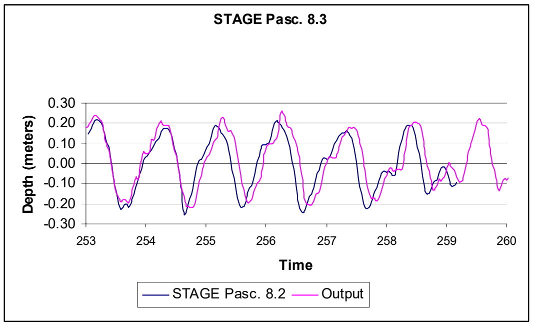

Figure 5.7: Tidal Elevation @ East Pascagoula River Mile 8.2

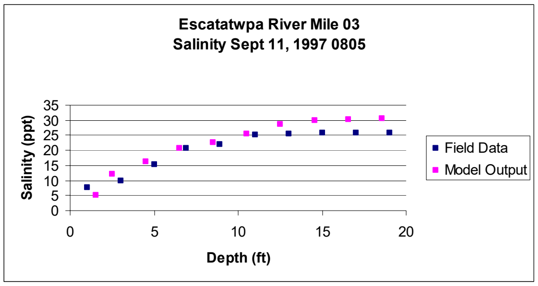

Figure 5.8: Salinity Profile Escatawpa River Mile 03

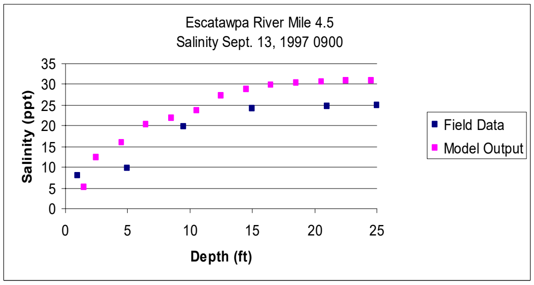

Figure 5.9: Salinity Profile Escatawpa River Mile 4.5

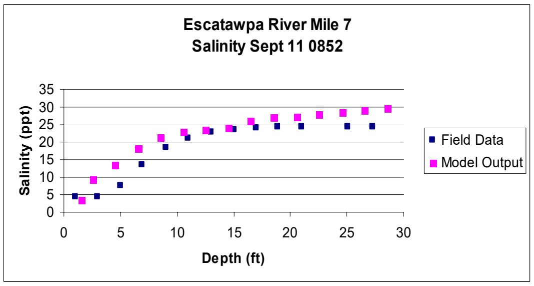

Figure 5.10: Salinity Profile Escatawpa River Mile 7

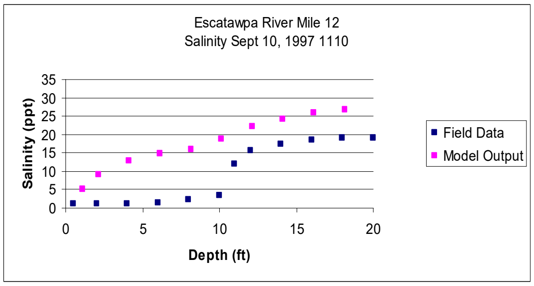

Figure 5.11: Salinity Profile Escatawpa River Mile 12

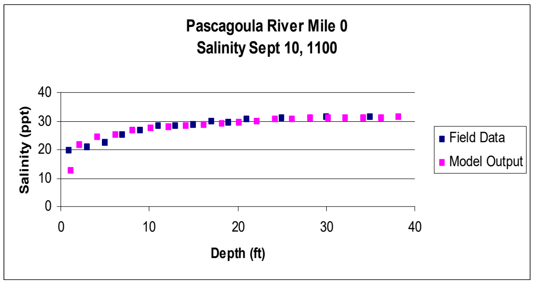

Figure 5.12: Salinity Profile East Pascagoula River Mile 0

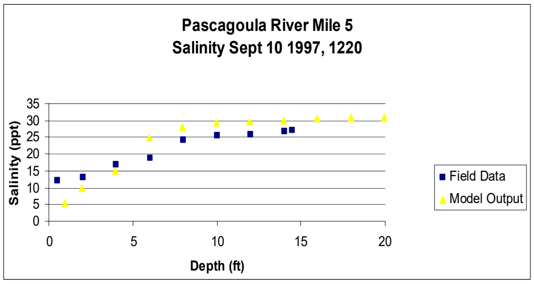

Figure 5.13: Salinity Profile East Pascagoula River Mile 5

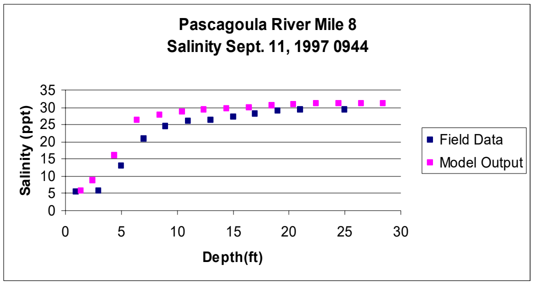

Figure 5.14: Salinity Profile East Pascagoula River Mile 8

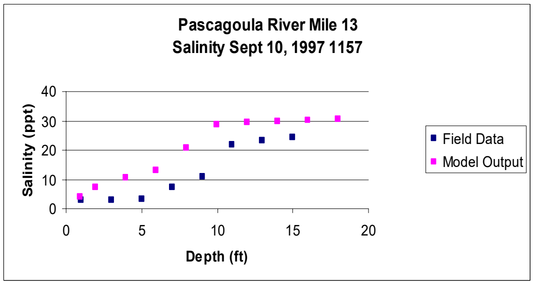

Figure 5.15: Salinity Profile East Pascagoula River Mile 13

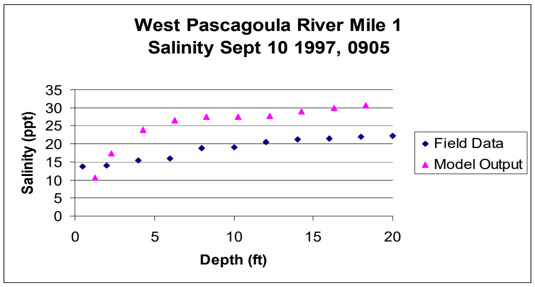

Figure 5.16: Salinity Profile West Pascagoula River Mile 1

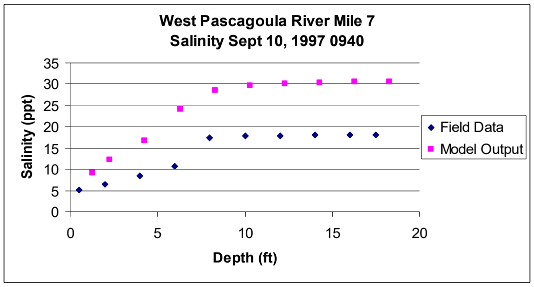

Figure 5.17: Salinity Profile West Pascagoula River Mile 7

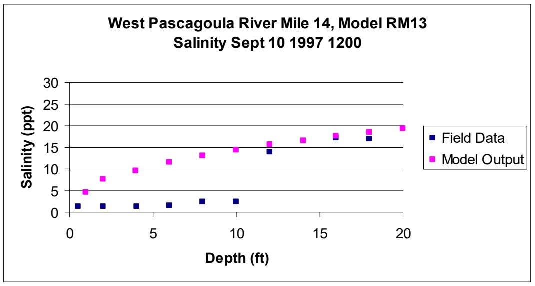

Figure 5.18: Salinity Profile West Pascagoula River Mile 14

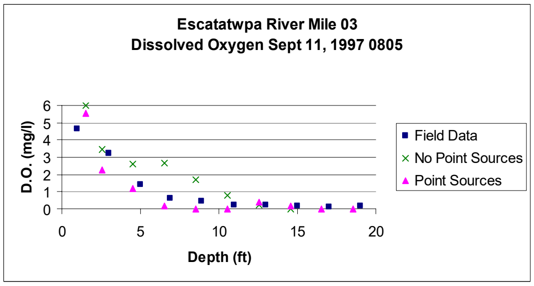

Figure 5.19: Dissolved Oxygen Profile Escatawpa River Mile 03

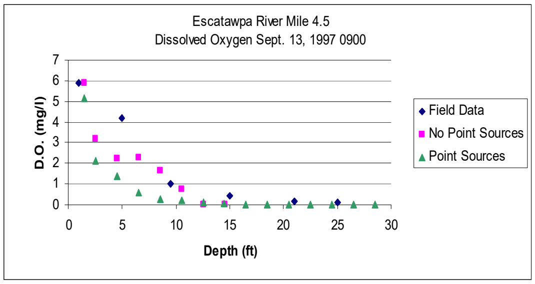

Figure 5.20: Dissolved Oxygen Profile Escatawpa River Mile 4.5

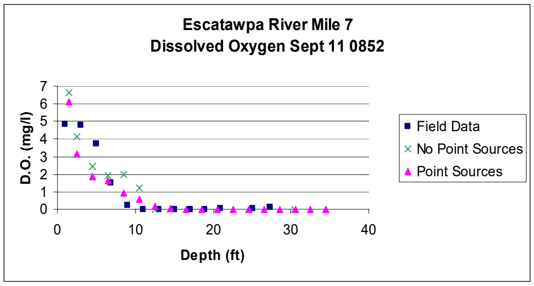

Figure 5.21: Dissolved Oxygen Profile Escatawpa River Mile 7

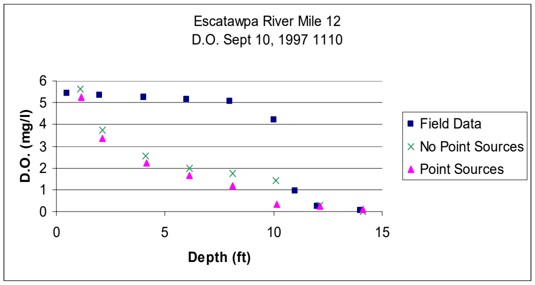

Figure 5.22: Dissolved Oxygen Profile Escatawpa River Mile 12

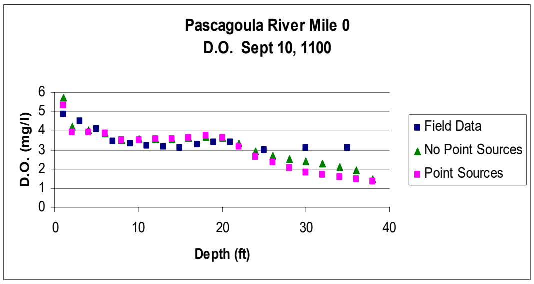

Figure 5.23: Dissolved Oxygen Profile East Pascagoula River Mile 0

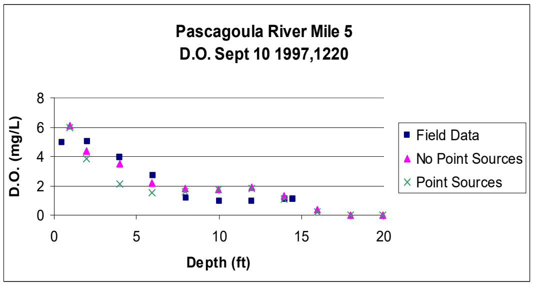

Figure 5.24: Dissolved Oxygen Profile East Pascagoula River Mile 5

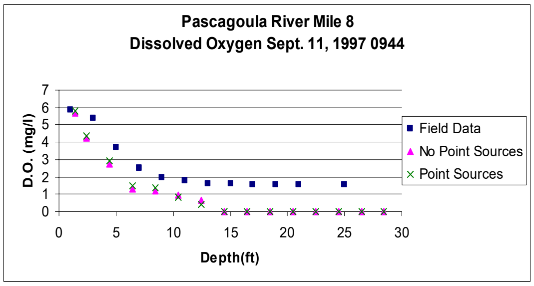

Figure 5.25: Dissolved Oxygen Profile East Pascagoula River Mile 8

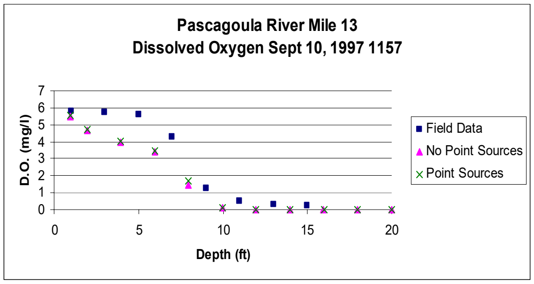

Figure 5.26: Dissolved Oxygen Profile East Pascagoula River Mile 13

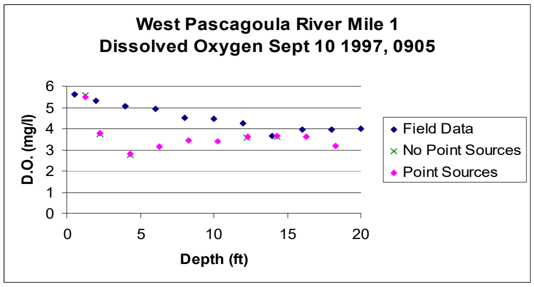

Figure 5.27: Dissolved Oxygen Profile West Pascagoula River Mile 1

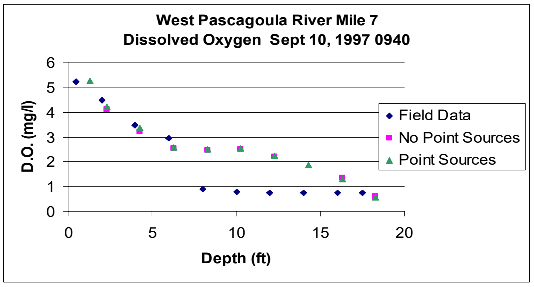

Figure 5.28: Dissolved Oxygen Profile West Pascagoula River Mile 7

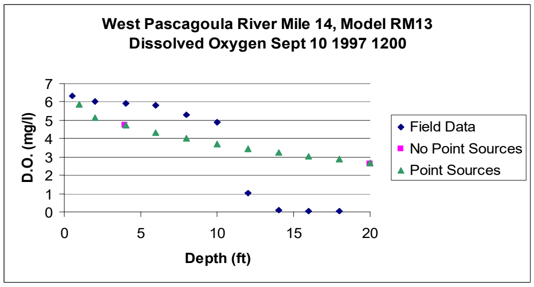

Figure 5.29: Dissolved Oxygen Profile West Pascagoula River Mile 14

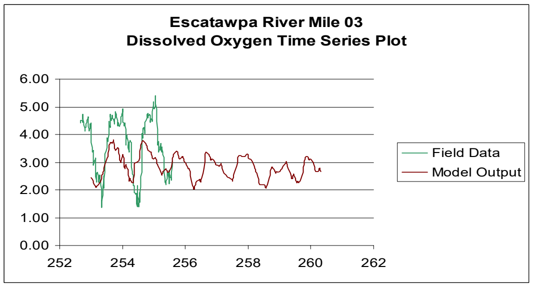

Figure 5.30: Dissolved Oxygen Time Series Profile Escatawpa River Mile 03

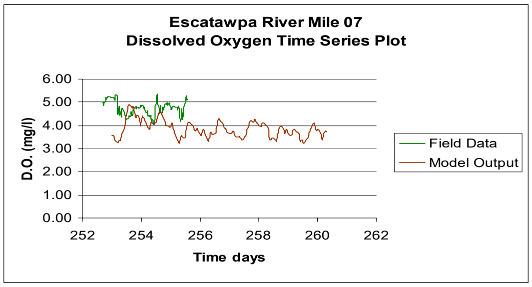

Figure 5.31: Dissolved Oxygen Time Series Profile Escatawpa River Mile 7

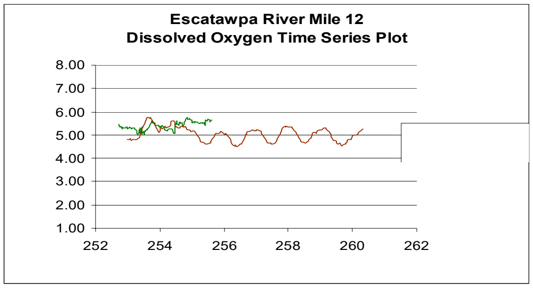

Figure 5.32: Dissolved Oxygen Time Series Profile Escatawpa River Mile 12

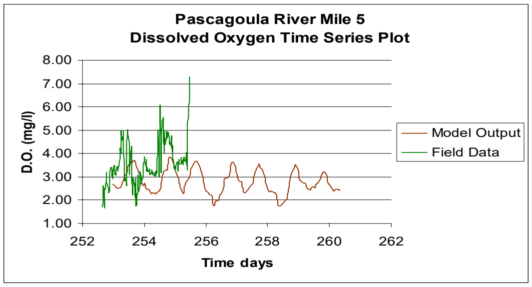

Figure 5.33: Dissolved Oxygen Time Series Profile East Pascagoula River Mile 5

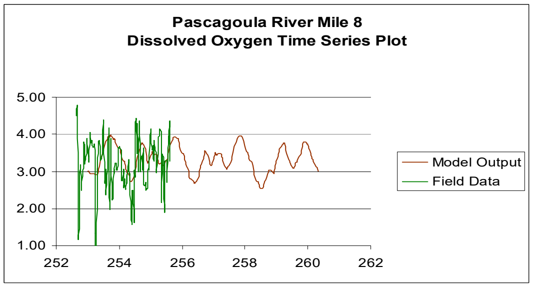

Figure 5.34: Dissolved Oxygen Time Series Profile East Pascagoula River Mile 8

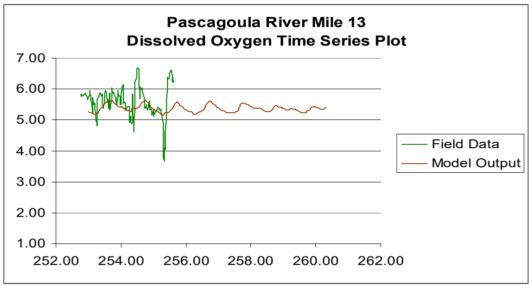

Figure 5.35: Dissolved Oxygen Time Series Profile East Pascagoula River Mile 13

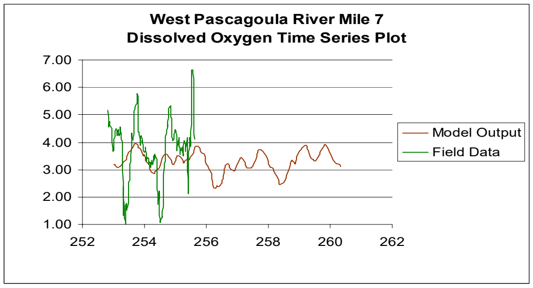

Figure 5.36: Dissolved Oxygen Time Series Profile West Pascagoula River Mile 7

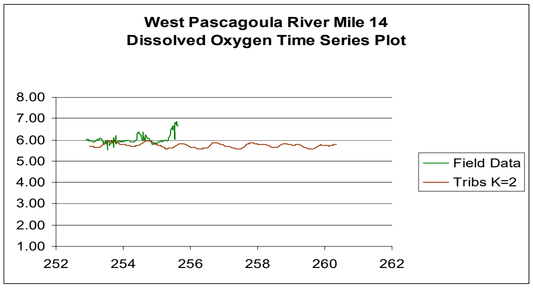

Figure 5.37: Dissolved Oxygen Time Series Profile West Pascagoula River Mile 14

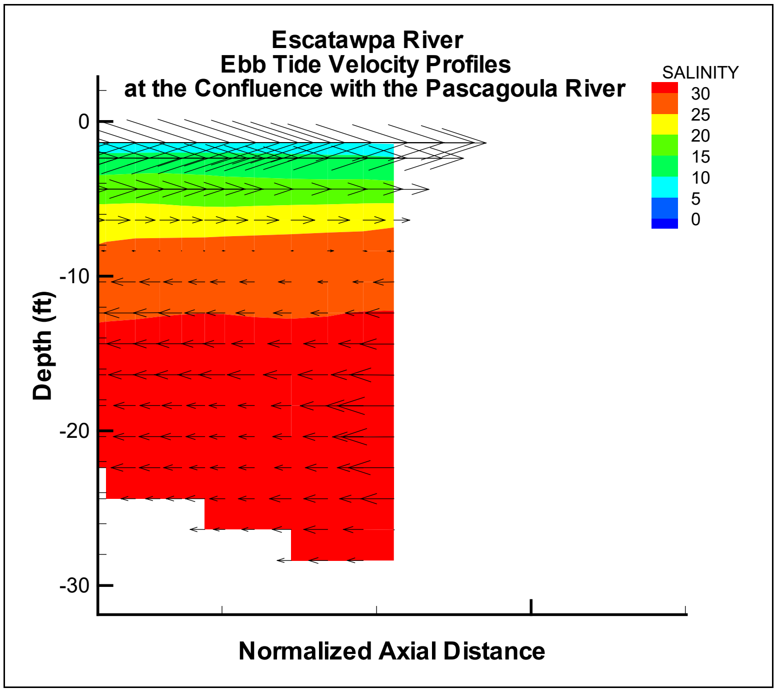

Figure 5.38: Velocity Profile at Ebb Tide Conditions

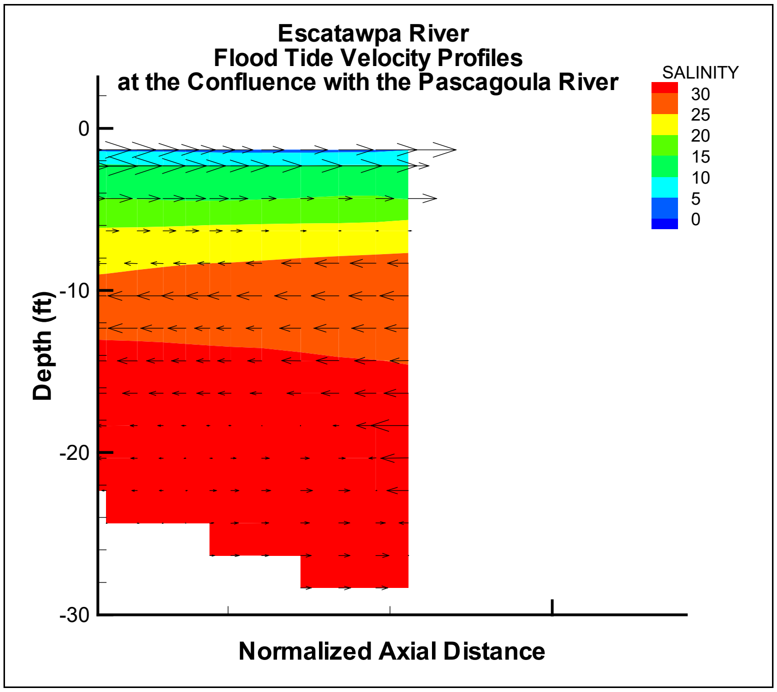

Figure 5.39:Velocity Profile at Flood Tide Conditions

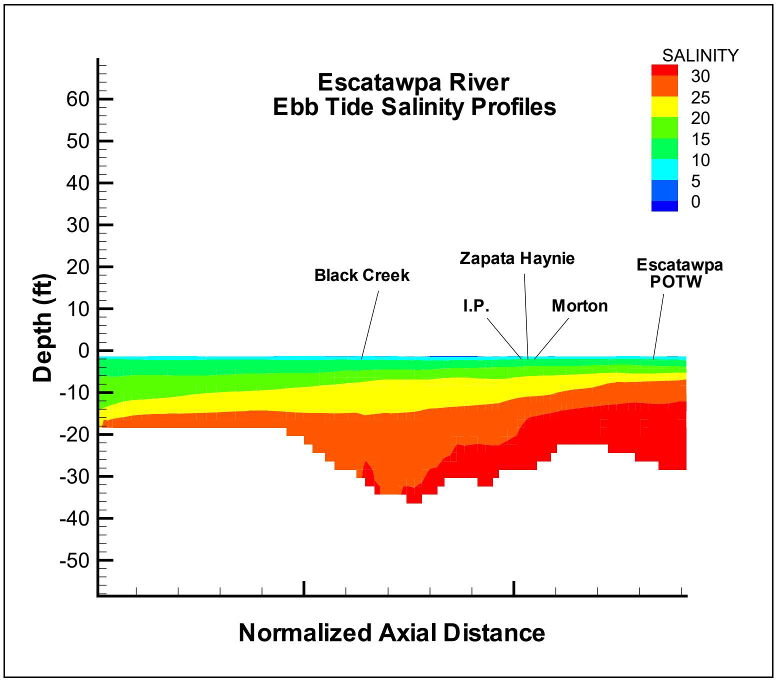

Figure 5.40: Ebb Tide Salinity Profile

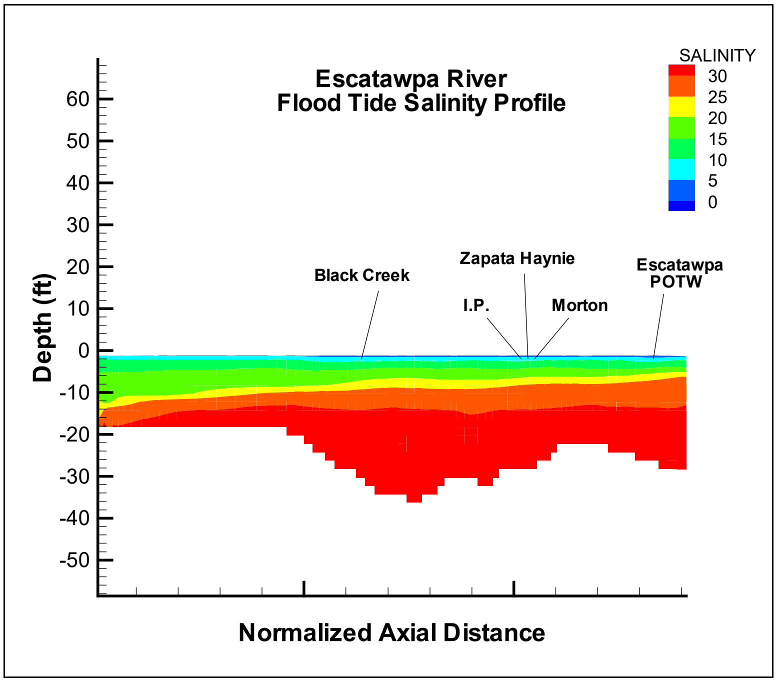

Figure 5.41: Flood Tide Salinity Profile

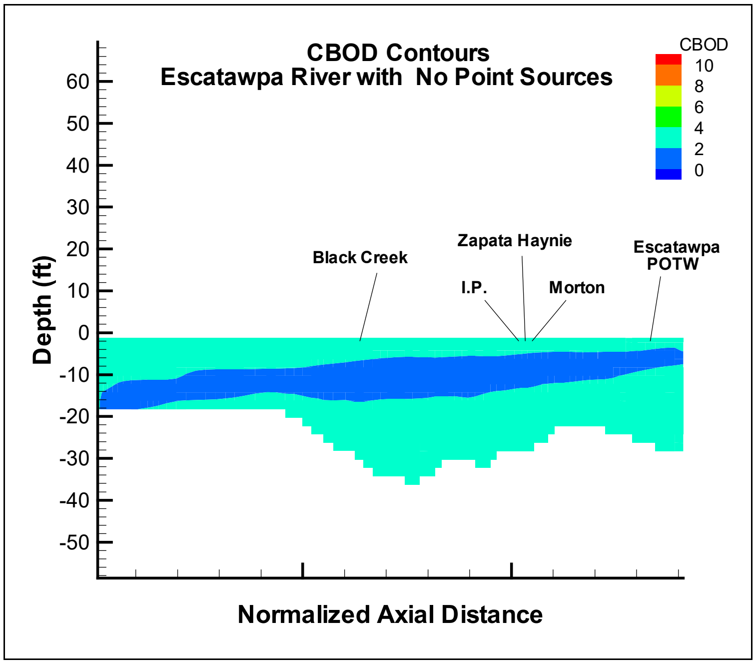

Figure 5.42: Color Contours of CBOD (mg/l) With No Point Sources

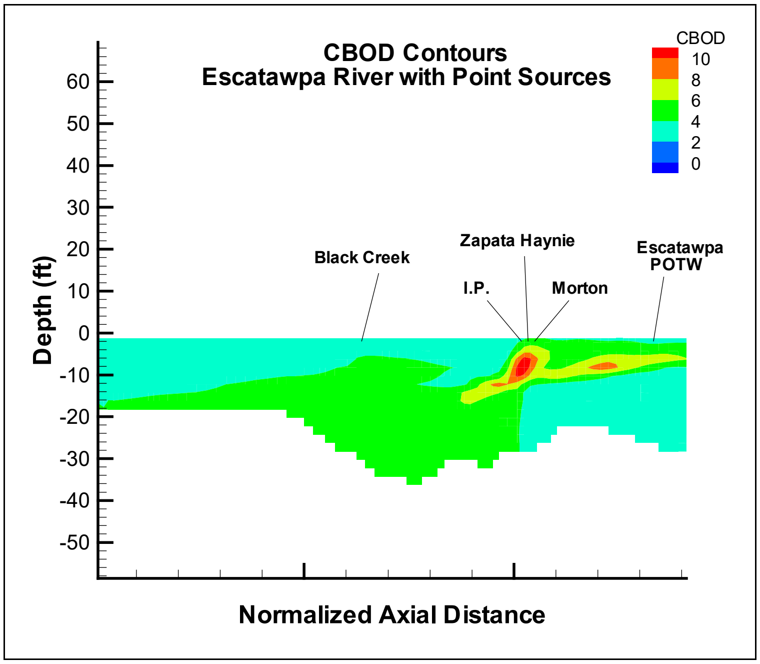

Figure 5.43: Color Contours of CBOD (mg/l) With Point Sources

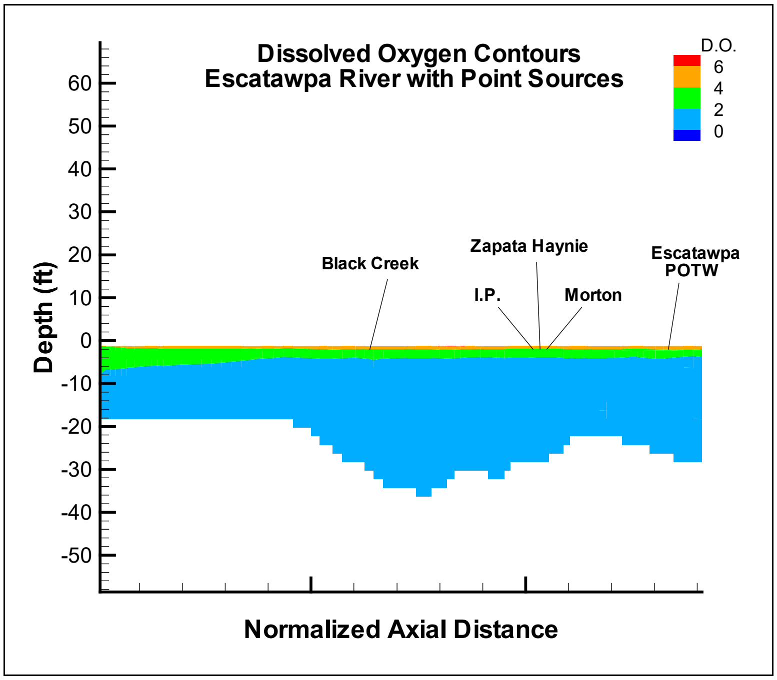

Figure 5.44: Color Contours of D.O. (mg/l) With Point Sources

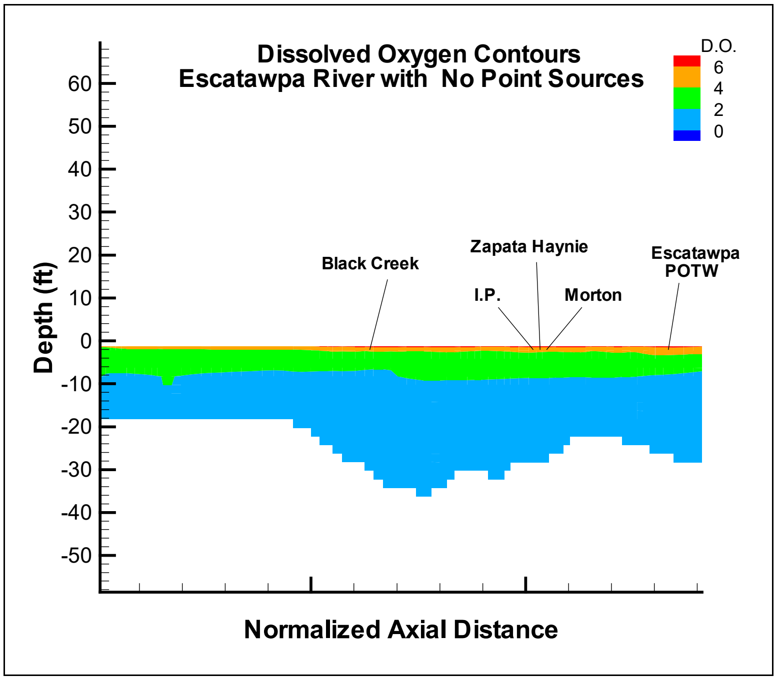

Figure 5.45: Color Contours of D.O. (mg/l) With No Point Sources

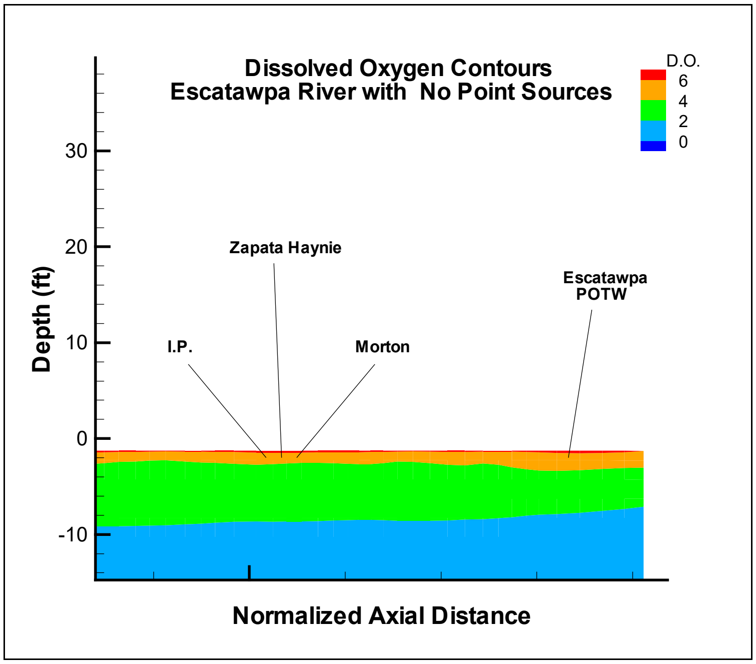

Figure 5.46: DO Contours with No Point Sources zoomed to Discharge Sites

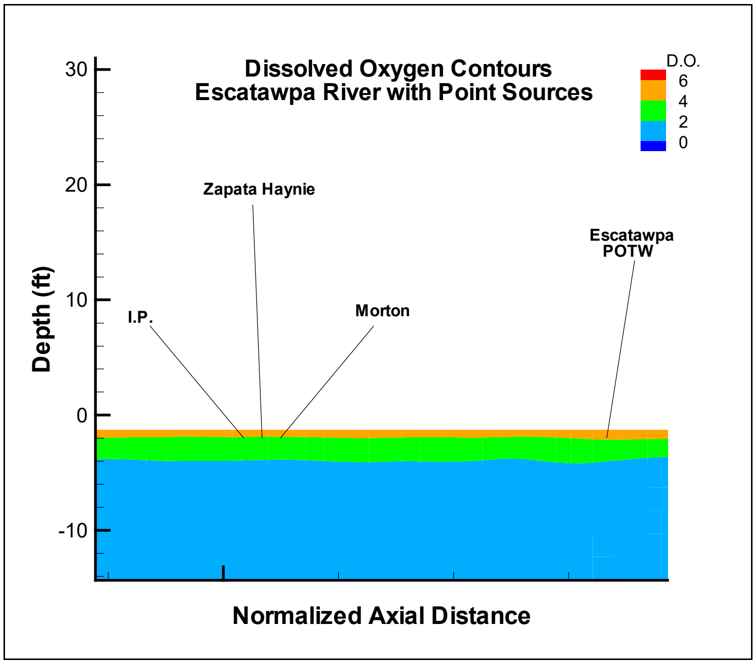

Figure 5.47: DO Contours with Point Sources zoomed to Discharge Sites

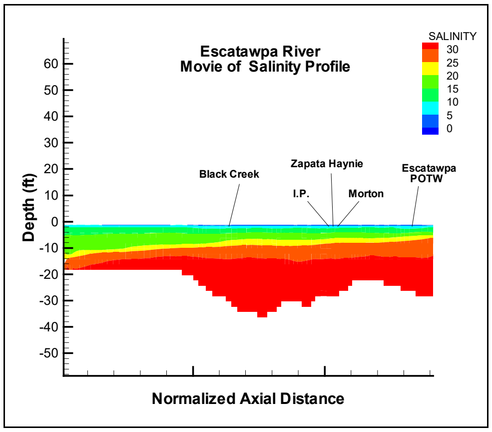

Figure 5.48: Movie of Salinity Intrusion

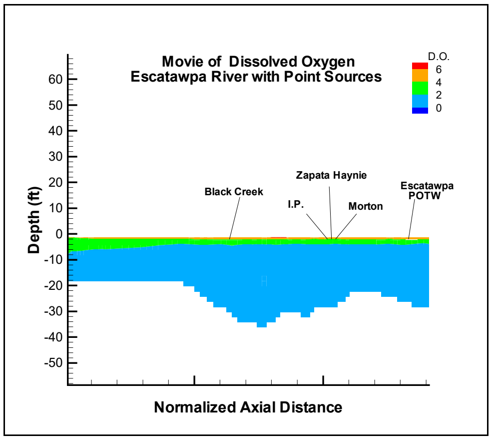

Figure 5.49: Movie of D.O. with No Point Sources

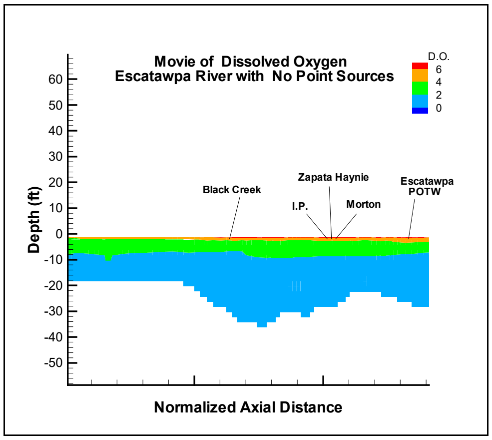

Figure 5.50: Movie of D.O. with Point Sources

CHAPTER VI

CONCLUSIONS & RECOMMENDATIONS

This thesis presents the development of a hydrologic and water-quality model of fecal coliform within the Pascagoula/Escatawpa watershed and a hydrodynamic and water-quality eutrophication model of sections of the Escatawpa and Pascagoula Rivers. The modeled watershed and river system comprise a complex coastal estuary bordering the Mississippi Sound. The BASINS and NPSM software was applied to model hydrology and in-stream processes for the modeled watershed. The CE-QUAL-W2 software was applied to model hydrodynamics and water-quality within the river system. Successful application of these mathematical models was demonstrated by comparing collected field data to tabulated model values.

Results presented demonstrate that the BASINS/NPSM watershed model provides adequate representation of the watershed hydrology. Fecal coliform calibration data was not available within the selected study area. Consequently, modeling coefficients were based upon calibration data from the neighboring St. Louis Bay Estuary. The studied section of the Escatawpa River is listed on the state 303(d) impairment list as an evaluated water body. Land use in the upper portion of the watershed is predominantly agricultural and forest. Model results indicate that dominant fecal coliform sources in the upper watershed are (1) the number of cattle and the corresponding level of stream access and (2) the number and maintenance condition of individual septic systems. Model results reinforce initial assessment, indicating that the fecal coliform levels do not exceed water-quality standards under the applied conditions. Consequently, model results are considered adequate for an initial phase TMDL assessment of an evaluated water body.

The CE-QUAL-W2 modeling software was applied to simulate both hydrodynamic and water-quality processes within the estuarine rivers. Results indicate that CE-QUAL-W2 adequately simulates both hydrodynamic and water quality under specified conditions in the tidal estuary. Calibration against fall 1997 survey data was reasonable; however, discrepancies with some hydrodynamic features were noted. This does not preclude use of the model for the comparative studies presented herein but does reduce the confidence level for application to extended period simulations. Discrepancies most likely are a result of (1) the laterally averaged assumption versus three-dimensional effects, (2) inadequate imposition of field boundary conditions, and (3) CE-QUAL-W2 limitations such as the vertical mixing model.

The developed models of this tidal estuary simulate complex physical, biological and chemical processes. A large number of modeling parameters have been defined based upon previous similar studies, the best available data, standard modeling assumptions, and comparison with relevant literature. It is anticipated and recommended that the development of this model be extended to more accurately predict and assess the hydrodynamics and water quality of this system. It is recommended that a three-dimensional code, such as the EFDC shallow water solver, be applied to simulate system hydrodynamics in the subsequent phase of this study, thereby improving the ability to simulate water quality processes.

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APPENDIX

CALIBRATION PARAMETERS

Computational Parameters and Values

Parameter Abbreviation	Parameter	Computational Purpose	Value used in Escatawpa Study	Value from Cole and Buchak, 1995	Value from Giorgino and Bales, 1997
EXH2O	Light-extinction coefficient for pure water (1/m)	Amount of solar radiation absorbed in the surface layer	.45	0.18-4.0	0.5
EXSS	Light-extinction coefficient for suspended solids ($m^3(m/g)$)	Amount of solar radiation absorbed by total suspended material	.10	.10	--
EXOM	Light-extinction coefficient for organic matter ($m^3(m/g)$)	Amount of solar radiation absorbed by organic matter	.17	.17	.20
BETA	Fraction of incident solar radiation absorbed at water surface	Amount of solar radiation absorbed in surface layer	.45	.45	.30
SSS	Suspended solids settling rate (m/d)	Settling rates and sediment accumulation on reservoir bottom	2.0	.86	2.0
AG	Algal growth rate (1/d)	Maximum gross algal-production rate, uncorrected for respiration, mortality, excretion, or settling; temperature dependent	1.0	1.1	1.9
AM	Algal mortality rate (1/d)	Maximum algal-mortality rate; temperature dependent	.01	.01-.03	.09
AE	Algal excretion rate (1/d)	Maximum algal-photorespiration rate, which becomes labile dissolved organic matter	.01	.014-.44	.005
AR	Algal dark respiration rate (1/d)	Maximum algal dark-respiration rate	.02	.01-.92	.005
AS	Algal settling rate (1/d)	Representative settling velocity for algal assemblages	.14	.0-30	.10

Computational Parameters and Values (Continued)

Parameter Abbreviation	Parameter	Computational Purpose	Value used in Escatawpa Study	Value from Cole and Buchak, 1995	Value from Giorgino and Bales, 1997
ASAT	Saturation light intensity (watts/m^2)	Saturation light intensity at maximum algal-photosynthesis rate	150	150	150
APOM	Fraction of algal biomass lost by mortality to detritus	Detritus and dissolved organic-matter concentrations; remaining biomass becomes labile dissolved organic matter	0.8	0.8	0.8
ATI	Lower temperature for algal growth (°C)	Algal-growth rate as a function of water temperature	10	10	10
AKI	Fraction of algal growth at lower temperature	Algal-growth rate as a function of water temperature	0.1	0.1	0.1
AT2	Lower temperature for maximum algal growth (°C)	Algal-growth rate as a function of water temperature	30	30	22
AK2	Fraction of maximum growth at lower temperature	Algal-growth rate as a function of water temperature	.99	.99	.99
AT3	Upper temperature for algal growth (°C)	Algal-growth rate as a function of water temperature	35	35	22.5
AK3	Fraction of maximum growth at upper temperature	Algal-growth rate as a function of water temperature	.99	.99	.95
AT4	Upper temperature for algal growth (°C)	Algal-growth rate as a function of water temperature	40	40	35
AK4	Fraction of algal growth at upper temperature	Algal-growth rate as a function of water temperature	0.1	0.1	0.1

Computational Parameters and Values (Continued)

Parameter Abbreviation	**Parameter**	**Computational Purpose**	**Value used in Escatawpa Study**	**Value from Cole and Buchak, 1995**	**Value from Giorgino and Bales, 1997**
LDOMDK	Labile dissolved organic-matter-decay rate (d^{-1})	Dissolved-oxygen loss and production of inorganic carbon, ammonium, and phosphate from algal decay; temperature dependant	.001	.01-.63	.04
LRDK	Labile to refractory decay rate (d^{-1})	Transfer of labile to refractory dissolved organic matter	.001	.001	.005
RDOMDK	Maximum refractory dissolved organic-matter-decay-rate (d^{-1})	Dissolved-oxygen loss and production of inorganic carbon, ammonium, and phosphate from decay of refractory dissolved organic matter; temperature dependant	.001	.001	.001
LPOMDK	Detritus decay rate (d^{-1})	Dissolved-oxygen loss and production of inorganic carbon, ammonium, and phosphate from decay of particulate organic matter; temperature dependant	.001	.001-.111	.002
POMS	Detritus settling velocity (m/d)	Loss of particulate organic matter to bottom sediment	.35	.001-20.0	2.5
OMT1	Lower temperature for organic matter decay(°C)	Organic-matter decay as a function of temperature	4.0	4.0	5.0
OMK1	Fraction of organic matter decay at lower temperature	Organic-matter decay as a function of temperature	0.1	0.1	0.5
OMT2	Lower temperature for maximum organic matter decay(°C)	Organic matter decay as a function of temperature	20	20	25

Computational Parameters and Values (Continued)

Parameter Abbreviation	Parameter	Computational Purpose	Value used in Escatawpa Study	Value from Cole and Buchak, 1995	Value from Giorgino and Bales, 1997
OMK2	Fraction of maximum organic matter decay at lower temperature	Organic matter decay as a function of temperature	.99	.99	.95
SDK	Sediment decay rate (d^{-1})	Decay rate of organic matter in bed sediments	.06	.06	.015
FSOD	Fraction of SOD	Sediment oxygen demand function	1.0	.9	--
SOD	Sediment oxygen demand by 20 segments (g O_2m^2/d)	Factor for assessing sediment oxygen demand at various strata and computational segments	1.4	.10-5.8	.0
KBOD	5-day chemical oxygen demand decay rate (d^{-1})	Effects of BOD loading on dissolved oxygen	.06	.25	.15
TBOD	BOD temperature rate coefficient	Adjusts 5-day BOD decay rate at 20 C to ambient temperature	1.047	1.047	1.0147
RBOD	Ratio of 5-day BOD to ultimate BOD	Effects of BOD loading on dissolved oxygen	1.0	1.85	1.20
PO4R	Release rate of phosphorus from bottom sediments	Phosphorus balance; computed as a fraction of the sediment oxygen demand	.015	0-0.30	.005
PARTP	Phosphorus partitioning coefficient	Describes sorption of phosphorus onto suspended solids	1.2	1.2	3.0
AHSP	Algal half-saturation constant for phosphorus (g/m)	The phosphorus concentration at which the uptake rate is one half the maximum uptake rate; upper concentration at which algal growth is proportional to phosphorus concentration	.09	.001-1.520	.005
NH4R	Release rate of ammonia from bottom sediments	Nitrogen balance; computed as a fraction of the sediment oxygen demand	.08	0-0.4	.003

Computational Parameters and Values (Continued)

Parameter Abbreviation	Parameter	Computational Purpose	Value used in Escatawpa Study	Value from Cole and Buchak, 1995	Value from Giorgino and Bales, 1997
NH4DK	Ammonia decay rate (d^{-1})	Rate at which ammonia is oxidized to nitrate	.06	.09-1.30	.20
AHSN	Algal half saturation constant for ammonia	Nitrogen concentration at which the algal uptake rate is one half the maximum uptake rate	.014	.006-4.34	.014
NH4T1	Lower temperature for ammonia decay (°C)	Ammonia nitrification as a function of temperature	5.0	5.0	5.0
NH4K1	Fraction of nitrification at lower temperature	Ammonia nitrification as a function of temperature	0.1	0.1	0.1
NH4T2	Lower temperature for maximum ammonia decay (°C)	Ammonia nitrification as a function of temperature	20	20	25
NH4K2	Fraction of maximum nitrification at lower temperature	Ammonia nitrification as a function of temperature	.99	.99	.99
NO3DK	Nitrate decay rate (d^{-1})	Rate at which nitrate is denitrified; temperature dependant	0.2	.05-.15	.15
NO3T1	Lower temperature for nitrate decay (°C)	Denitrification as a function of temperature	5.0	5.0	5.0
NO3K1	Fraction of denitrification at lower temperature	Denitrification as a function of temperature	0.1	0.1	0.1
NO3T2	Lower temperature for maximum nitrate decay (°C)	Denitrification as a function of temperature	20	20	25

Computational Parameters and Values (Continued)

Parameter Abbreviation	**Parameter**	**Computational Purpose**	**Value used in Escatawpa Study**	**Value from Cole and Buchak, 1995**	**Value from Giorgino and Bales, 1997**
NO3K2	Fraction of maximum denitrification at lower temperature	Denitrification as a function of temperature	.99	.99	.99
CO2R	Sediment carbon dioxide release rate; fraction of sediment oxygen demand	Rate at which CO_2 is released from sediments	0.1	0.1	--
FER	Iron release rate from bottom sediments	Iron balance; computed as a fraction of sediment oxygen demand	0.5	.3-.5	1.0
FES	Iron settling velocity (m/d)	Particulate iron settling velocity under anoxic conditions	2.0	.5-2.0	2.0
02NH4	Oxygen stoichiometric equivalent for ammonia decay	Relates oxygen consumption to ammonia decay	4.57	4.57	4.0
O2OM	Oxygen stoichiometric equivalent for organic matter decay	Relates oxygen consumption to decay of organic matter	1.4	1.4	1.5
O2AR	Oxygen stoichiometric equivalent for dark respiration	Relates oxygen consumption to algal dark respiration	1.4	1.4	0.9
O2AG	Oxygen stoichiometric equivalent for algal growth	Relates oxygen production to algal growth	1.4	1.4	3.0

Computational Parameters and Values (Continued)

Parameter Abbreviation	Parameter	Computational Purpose	Value used in Escatawpa Study	Value from Cole and Buchak, 1995	Value from Giorgino and Bales, 1997
BIOP	Stoichiometric equivalent between organic matter and phosphorus	Relates phosphorus release to decay of organic matter	.011	.011	.009
BION	Stoichiometric equivalent between organic matter and nitrogen	Relates nitrogen release to decay of organic matter	.08	.08	.08
BIOC	Stoichiometric equivalent between organic matter and carbon	Relates carbon release to decay of organic matter	.45	.45	--
O2LIM	Dissolved Oxygen Limit (mg/L)	Dissolved oxygen concentration below which anaerobic processes, such as nitrification and sediment nutrient releases occur	.20	>.0	.10
CHEZY	Chezy resistance coefficient ($m^{0.5}/s$)	Represents turbulent exchange of energy at reservoir bottom	30	70	70
CBHE	Coefficient of sediment water heat exchange ($watts/m^2/°C$)	Computes heat exchange between reservoir bottom and overlying water	$7.0x10^{-8}$	$7.0x10^{-8}$	$8.0x10^{-7}$
WSC	Wind sheltering coefficient	Reduces measured wind speed to effective wind speed at water surface	1.0	0-1.0	--
AX	Longitudinal eddy viscosity (m^2/s)	Represents laterally averaged longitudinal turbulent transport of momentum	1.0	1.0	1.0
DX	Longitudinal eddy diffusivity (m^2/s)	Represents laterally averaged longitudinal turbulent transport of mass and heat	1.0	1.0	1.0