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WATERSHED BASED SIMULATION OF FECAL COLIFORMS WITHIN THE BACK BAY OF BILOXI AND ITS SURROUNDING STREAMS

By

Matthew Edward Renick

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WATERSHED BASED SIMULATION OF FECAL COLIFORM WITHIN THE BACK BAY OF BILOXI AND ITS SURROUNDING STREAMS

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In the development of the watershed, hydrodynamic, and water quality models for Back Bay of Biloxi in Mississippi, the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS 2.0) - Nonpoint Source Model (NPSM) was selected as the watershed model. The hydrodynamic and water quality models DNYHYD5 and EUTRO5 were selected as the tidally influenced bay models. The watershed model simulated nonpoint source flow and pollutant loadings for all sub-watersheds, routed flow and water quality, and accounted for all major point source discharges in the Back Bay of Biloxi watershed. Time varying output from the watershed model was applied directly to the Back Bay of Biloxi model. The Bay models, in turn simulated hydrodynamics and water quality, including water depth, velocities, and fecal coliform concentrations. Both watershed and Bay models were calibrated and verified against observed data. The calibrated/verified model was used as a planning tool to assess the water quality in the

Watershed and the Bay as well as for calculating Total Maximum Daily Load (TMDL) and Waste Load Allocation (WLA).

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CHAPTER I

INTRODUCTION

The Total Maximum Daily Load (TMDL) is the maximum amount of a pollutant a body of water can receive and still remain within water quality standards. Through TMDL development, the sum of both point and nonpoint sources for a specific pollutant can be allocated among the various contributors. The Clean Water Act (CWA), is the federal law that protects rivers, streams, lakes, and estuarine environments by requiring states to develop and maintain certain water quality standards. According to Section 303(d) of the CWA and its implementing regulations at 40CFR (Code of Federal Regulations) Part 130, states must develop and implement a TMDL for waters that are not or not expected to meet standards for their required usage. This bi-annual process called the “303(d) list” includes the names of impaired waterbodies and the reasons for impairment. Each state determines the proper water use classification of its surface water resources to be followed by development of TMDLs that are necessary to protect the water quality for the designated use.

The state of Mississippi 1998 303(d) List of Impaired and Threatened Waterbodies has identified ten segments within the Back Bay of Biloxi and surrounding drainage area as impaired in regards to fecal coliform water quality standards. Current data indicate that fecal coliform concentration levels in the bay and in several streams segments of the surrounding drainage areas exceed the criteria established for secondary contact recreation. Therefore, a TMDL for fecal coliform bacteria in this area must be established. Figure 1.1 depicts the water bodies within the Back Bay of Biloxi designated area.

In order to develop a watershed based TMDL, mathematical models that can simulate both hydrodynamics and water quality are normally utilized. These models simulate the impact of waste loads from point and nonpoint sources on the water quality within the watershed and as such can be used as planning tools in reaching desirable water quality standards. In 1996 the Water Quality Analysis Simulation Program-5 (WASP5) model was developed for the Back Bay of Biloxi utilizing the Dynamic Estuary Model-5 (DYNHYD5) for hydrodynamic simulation and the Eutrophication Model-5 (EUTRO5) for water quality simulation (Shindala et al., 1996). Since the previously developed model was not formulated to simulate fecal coliform within the Back Bay of Biloxi, it is extended in the study reported here to allow for fecal coliform simulation along with TMDL development within the Bay proper. The updated model was coupled with a watershed model in order to allow watershed based development of TMDL for fecal coliform for the Back Bay of Biloxi watershed.

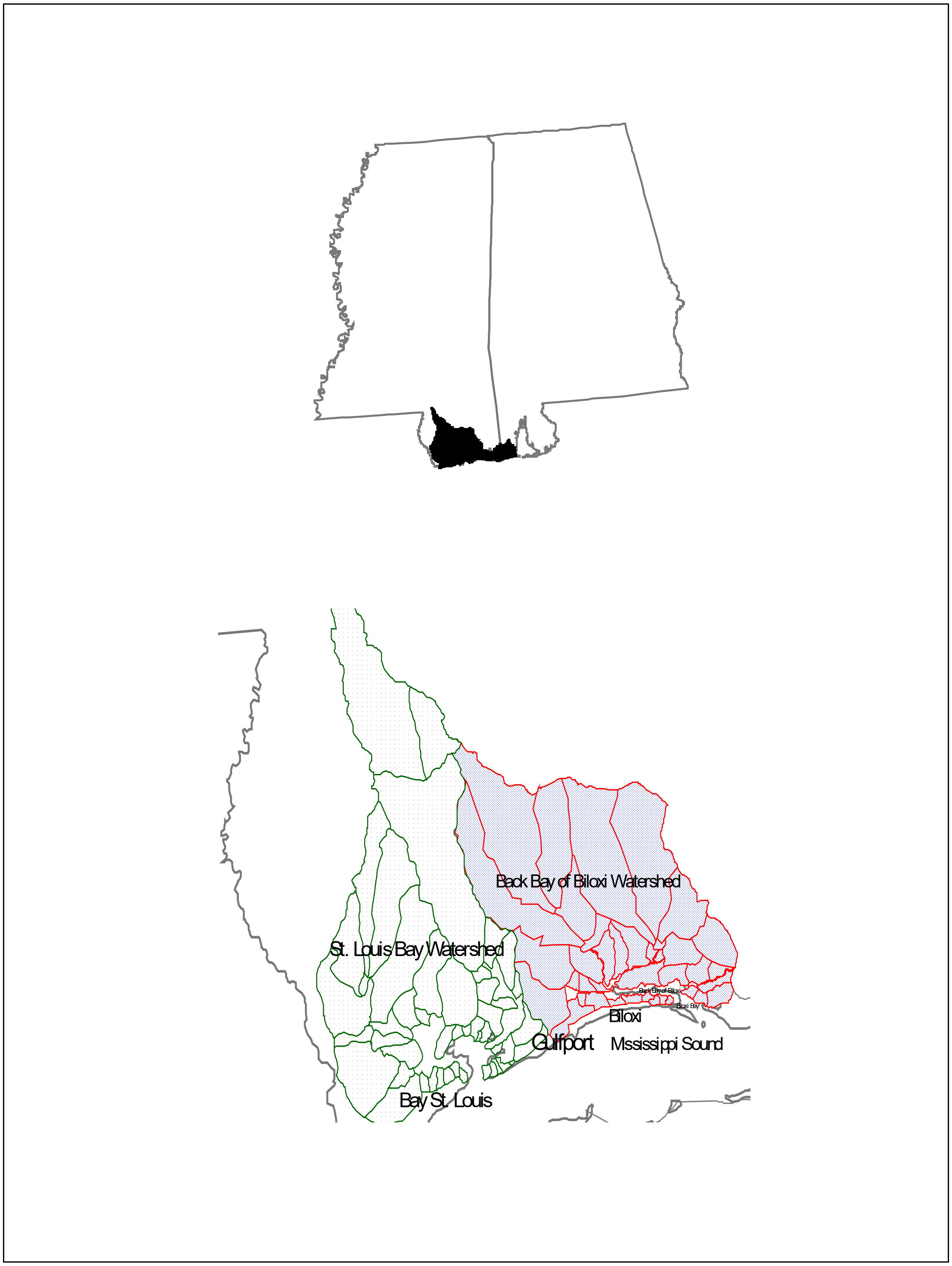


Figure 1.1: Mississippi Coastal Watershed

The watershed model chosen for application to the Back Bay of Biloxi watershed is the nonpoint source model (NPSM), which is interfaced through the BASINS 2.0 environment (USEPA, 1991b). As was previously indicated, the selected tidal models were the Dynamic Estuary Model (DYNHYD5) for hydrodynamic simulation and the Eutrophication Model (EUTRO5) for water quality simulation (Ambrose et al., 1993). Information pertaining to the watershed model selection and additional details on the models can be found in following chapters.

The main objective of this study is therefore to utilize the mathematical models listed above to define and quantify fecal coliform levels within the Back Bay of Biloxi and its surrounding drainage areas. The models were subsequently used as planning tools to quantify TMDLs for waterbodies within the Back Bay watershed

In order to facilitate review, this thesis is presented such that the overall problem is discussed in this chapter. Chapter 2 provides a description of the Back Bay of Biloxi study area. Chapter 3 provides a brief summary of literature reviewing various applicable models. Chapter 4 describes the development of the watershed model and model application to selected scenarios. Chapter 5 describes the development and application of the estuary model. Finally, in Chapter 6 conclusions and recommendations from the study are summarized.

CHAPTER II

DESCRIPTION OF STUDY AREA

Geographical Description

Approximately 740 square miles (1916 sq km) are encompassed in the Back Bay of Biloxi study area. The study area lies almost entirely within Harrison County with small sections of Jackson and Stone Counties included. The metropolitan areas include Biloxi, D'Iberville, Gulfport, and Ocean Springs. Figure 1.1 and Figure 2.1 show the location of drainage areas comprising the Back Bay of Biloxi watershed.

Back Bay of Biloxi is an integral part of the Mississippi Sound estuarine system. Its geological origin is that of an incompletely sediment-filled drowned river valley (Eleuterius, 1973). The Biloxi Bay estuarine water body is defined as that area contained on the mainland side of Deer Island, on the west bounded by a line projected due north from the western tip of Deer Island, on the east bounded by a line projected with a heading of thirty degrees from the eastern tip of Little Deer Island, including all bayous, slews and rivers as far upstream as salinity intrusion occurs.

These combined areas make up a long, narrow and rather shallow estuarine embayment, separated from the more saline Mississippi Sound by the Biloxi Peninsula (Figure 2.2). This estuary receives fresh water from the inflow of the Biloxi River, Tchoutacabouffa River, Bernard Bayou, Turkey Creek, Brickyard Bayou, Old Fort

Bayou, Davis Bayou, Tidewater Bayou, and Heron Bayou. The seawater inflow comes from the Mississippi Sound around both ends of Deer Island through Biloxi Bay.

Bernard Bayou, a nominally eight-foot (2.4 m) deep natural body, empties into the west end of Big Lake and extends from Big Lake westward to the Industrial Seaway. Bernard Bayou has two tributaries that drain areas within or near Gulfport. Turkey Creek drains 25 square miles (64.7 sq km) north and west of Gulfport and confluences with Bernard Bayou near the west end of Gulfport Lake. Brickyard Bayou drains seven square miles (18.1 sq km) along the northern edge of the metropolitan area and confluences with Bernard Bayou near Handsboro.

The Gulfport Industrial Seaway, usually referred to as the Industrial Seaway, is a 12 x 150-foot (3.66 x 45.73-m) industrial canal that allows access to industrial areas along the “seaway” and to Bernard Bayou north of Gulfport. The seaway extends westward from Big Lake (near shallow point) in a land cut for 2.5 miles (4.02 km) to Bernard Bayou, thence through Bernard Bayou and Gulfport Lake for 2.1 miles (3.38 km) to a point near Three Rivers Road.

The Biloxi River drains 271 square miles (701.8 sq km) in Harrison, Jackson, and Stone Counties. The Tchoutacabouffa River drains 242 square miles (626.7 sq km). These rivers drain initially into Big Lake which is located on the west of the Back Bay of Biloxi and separated form the Back Bay by a narrow peninsula. A dredged channel runs through Big Lake from Back Bay of Biloxi into the Industrial Seaway.

Back Bay of Biloxi extends 7.5 miles (12.01 km) eastward from Big Lake to Biloxi Bay. Its width varies from a quarter of a mile (0.40 km) to one mile (1.6 km).

Depths outside of channel areas range from one to 10 feet (0.3 to 3.05 m) with most areas less than three feet (0.91 m). There is a dredged channel from Biloxi Bay to the Back Bay of Biloxi near Big Island and Little Island with a natural channel extending through the remainder of the Back Bay of Biloxi to Big Lake.

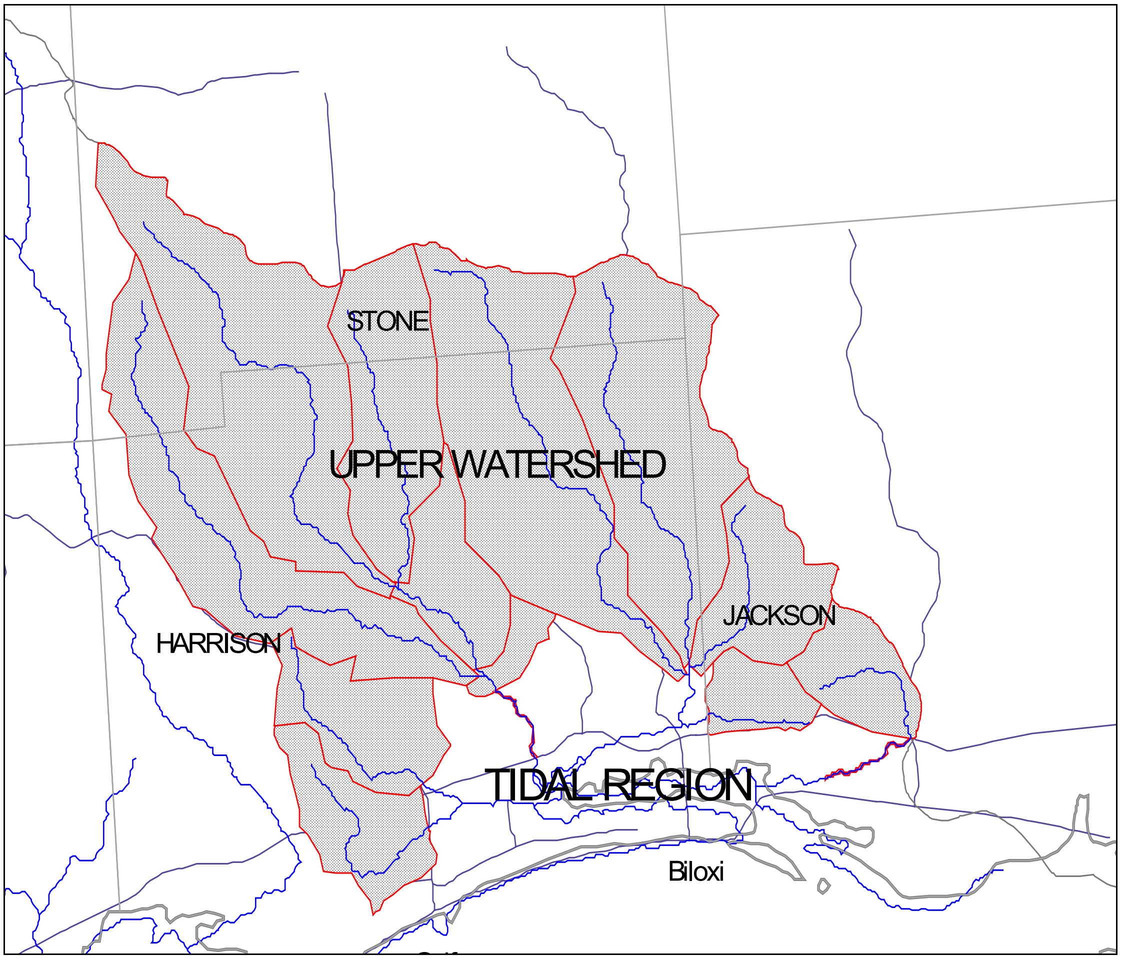


Figure 2.1: Back Bay of Biloxi Watershed

Biloxi Bay, not including all tributaries, is approximately 13.5 miles (21.7 km) in length. At mean low water (MLW) it has a wet surface area of 16.52 square miles (42.79 sq km) with an average depth of 4.3 feet (1.3 m), including channels, and a water volume of 73,7517,612 cubic yards (56,208,247 cubic meter) (Eleuterius, 1973). The estuarine subsystem receives fresh water via direct runoff and the discharges of the Biloxi and Tchoutacabouffa Rivers with drainage basins of 271 and 242 square miles (701.9 sq km and 626.8 sq km) respectively. Figure 2.2 illustrates the major tributaries that contribute freshwater flow into the Back Bay. Tchoutacabouffa River discharges at the average rate of 463.6 cfs (13.1 cms) with record extremes of 4.2 cfs (0.12 cms) and 46,357 cfs (1312.7 cms) (Eleuterius, 1973). Biloxi River has an average discharge of 201 cfs (5.7 cms) with record extremes of 1.5 cfs (0.04 cms) and 13,500 cfs (382.3 cms) (USGS, 1999a). Also draining directly into the Bay are the following bayous: Poito, Old Fort, Week's, Grand, Auguste, Keegan, La Porte, Bernard, Brasher, Biglin, Ravine Canne, Ditch, Davis, St. Martin, Heron, Tidewater, and Brodie.

In addition to the tributaries already mentioned, there are many smaller unnamed bayous and tidal slews that meander through the marshes and empty directly into Back Bay of Biloxi. The small slews are very shallow and are frequently devoid of all but a trace of water at low tide.

Approximately 475 acres (192 ha) of marsh had been filled prior to 1969 in the Biloxi Bay estuary (Eleuterius, 1973). Williams Bayou, also known as Ott's Bayou, and the extensive surrounding marsh area, which it drains, were covered with hydraulic fill to a height of 12 feet (3.66 m) above mean sea level to convert it into the East Harrison County Industrial Park.

The Biloxi west approach channel skirts the west end of Deer Island turning east to intersect with the second approach channel in the lower Bay. The second approach channel begins midway between Dog Keys Pass and the mainland and enters Biloxi Bay east of Deer Island. The two approach channels converge in the lower portion of the bay and continue up the bay bifurcating in the Big Lake with branches extending to the mouths of Bayou Bernard and Biloxi River. These channels are designated at a depth of 12 feet (3.66 m), but over dredging, rapid shoaling and siltation preclude the possibility of maintaining a uniform depth.

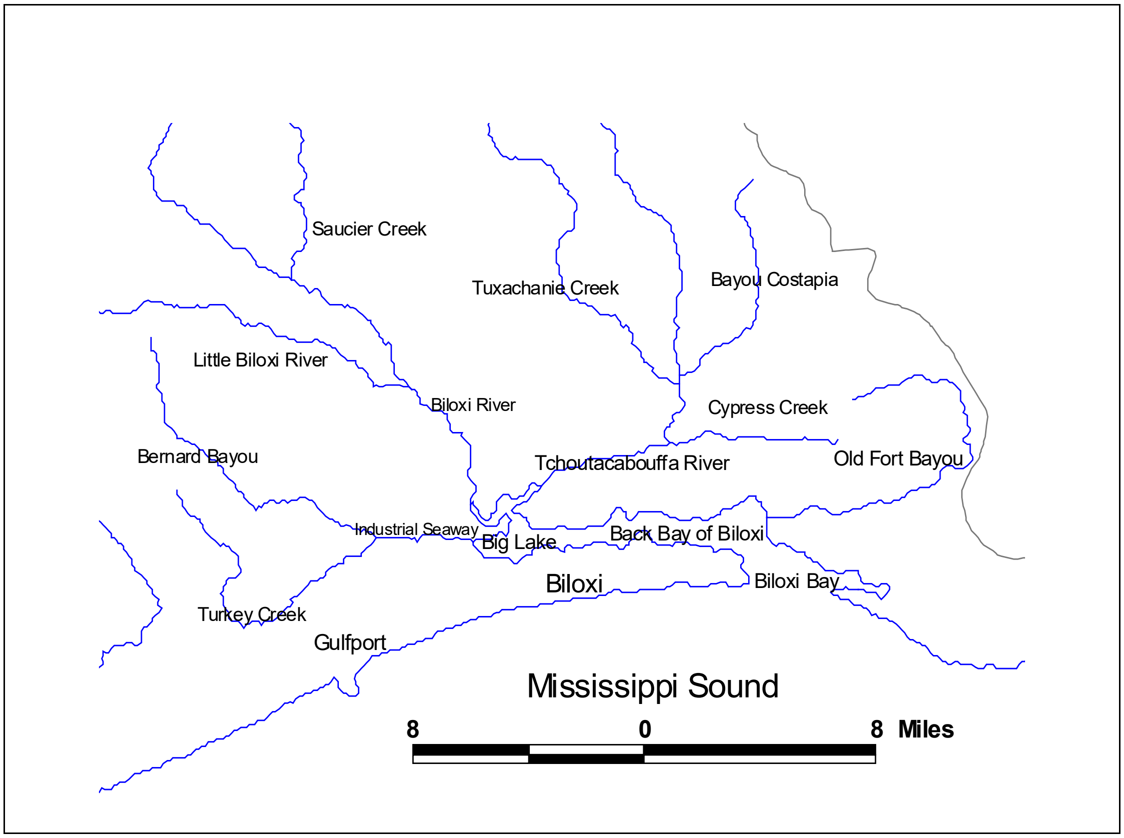


Figure 2.2: Back Bay of Biloxi Tributaries

Climate

The Back Bay of Biloxi and its vicinity have a temperate, humid climate with short, mild winters and long, warm summers. The average summer temperature along the coast is in the low 80's ^{0}F (26.7 ^{0}C), while 40 miles (64.4 km) inland, the temperature is 15 ^{0}F (8.3 ^{0}C) higher (USEPA, 1973). The normal annual temperature for the study area is about 68 ^{0}F (20 ^{0}C), varying from monthly averages of low 50's ^{0}F (10 ^{0}C) in January to low 80's ^{0}F (26.7 ^{0}C) in July and August. During summer months, the prevailing southerly winds provide a moist semitropical climate; conditions are often favorable for afternoon thundershowers occur 70-80 days per year.

The average precipitation in the study area is 55-60 inches (140-152 cm) per year (USEPA, 1973). Heaviest rainfall usually occurs in winter and spring, with the lightest in the fall. This area is often subjected to hurricanes and high tides. However the typical tide range is about 1.6 feet (0.5 m) (USEPA, 1973).

Demographics

The study area is located in one of the most rapidly growing regions of the State. Back Bay of Biloxi provides extensive recreational opportunities and stimulates industrial development within the region. This industrialization, in turn, tends to promote population growth and economic development within the adjoining communities and counties of Jackson, Harrison, and Hancock. Since 1950, cheap water transportation, unlimited supplies of water and natural gas, an availability of refining products as raw materials, and extensive timber resources have provided the base for rapid industrial growth. Growth has also been stimulated by resort facilities legalizing riverboat gambling, presence of abundant fresh and saltwater fish life and by the establishment or expansion of military installations.

The metropolitan areas in the study area are comprised of Biloxi, D'Iberville, Gulfport, and Ocean Springs. Biloxi is the oldest city in the Gulf Coastal Region. Major industries include seafood processing, canning, boat building and repair, tourism, and casinos. Principal shipments through the ports are seafood, pulpwood, and petroleum products.

D'Iberville is located on the north side of Back Bay of Biloxi. Its major industry is seafood processing. Kessler Air Force Base is also located on the south side of the Back Bay of Biloxi.

Gulfport is located in Harrison County. Its major industries include fishing, seafood processing, glass making, chemicals, pharmaceuticals, steel products, iron and machine works and aluminum extrusions. Waterborne commerce includes fertilizers, chemicals, seafood, and wood pulp products.

Ocean Springs, located in Jackson County on the east side of Biloxi Bay, is primarily a satellite community serving Biloxi and Pascagoula. Local industries include seafood packaging, tourism, soft drink bottling, and manufacture of ladies handbags, pottery and boats.

Water Quality

According to the Mississippi 1998 303(d) List of Impaired and Threatened Waterbodies, the Mississippi Department of Environmental Quality (MDEQ) has identified ten waterbody segments within the Back Bay of Biloxi and surrounding drainage areas as impaired with regards to fecal coliform water quality standards (Figure 2.3). The water segments are considered impaired based on the standard set for secondary contact recreation, which applies to waters intended for fishing, propagation of aquatic life, and occasional swimming. Under this classification, the maximum allowable level of fecal coliform shall not exceed a geometric mean of 200 MPN per 100ml nor shall more than 10% of the monthly samples exceed 400 MPN/100ml from May to October and 2000 MPN/100ml for the months of November through April when incidental recreational contact is not likely, fecal coliform shall not exceed 2000 MPN/100ml as a geometric mean based on at least five samples taken over a 30 day period nor exceed a maximum concentration of 4000 MPN/100ml for any one sample. These ten segments have been deemed impaired according to the Mississippi 1998 305(b) Water Quality Assessment Report compiled by the MDEQ, Office of Pollution Control (OPC). The 305(b) report contains a review of the available historical, evaluated and monitored water quality data taken from over 20 different monitoring stations throughout the study area from 1992 to 1997. The results of the historical data indicated the presence of violations or possible violations occurring in each of the listed water segments, thus necessitating TMDL development.

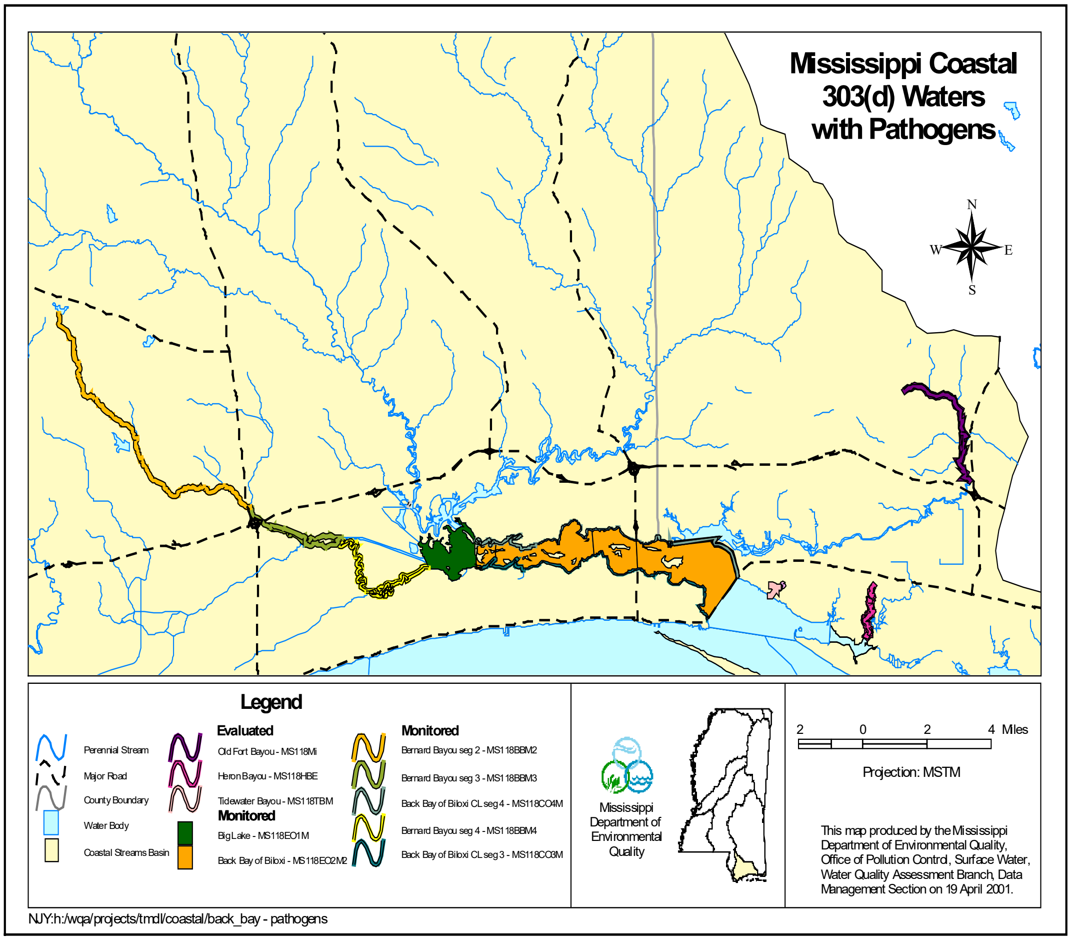


Figure 2.3: Mississippi Coastal 303(d) Waters with Pathogens (MDEQ, 2001)

CHAPTER III

LITERATURE REVIEW

Selection Criteria

Over the years, many different models for predicting water quality within a specified watershed have been developed and implemented all across the United States. Consequently, the large number of available models and techniques can make the task of selecting an appropriate model for a specific application a complex and difficult exercise. To help ease this selection process several guidelines were considered. The software must (1) be able to run effectively and efficiently on a personal computer, (2) be supported by MDEQ and USEPA, (3) be available to the public, and (4) be backed by adequate technical support.

Watershed Models

Typically, watershed models are classified as simple, mid-range, or detailed. Simple models provide a very rough estimate of pollutant loadings and are very limited in their predictive capability. Simple models are used as a tool for identifying critical pollution areas within a watershed with minimal effort and time. Mid-range models evaluate water quality over a broad geographic scale, however; they are still relatively simple and are meant to be used to identify a problem and suggest preliminary best management practice alternatives. Detailed models are able to identify the cause of a problem instead of simply indicating the presence of a problem. When calibrated and applied correctly, detailed models can provide accurate prediction of variable flows and water quality at any point in a watershed (Shoemaker et al., 1997). A summary of watershed models was presented by Kilpatrick, (2001) in conjunction with a modeling effort of the Escatawpa watershed in Southeastern Mississippi. Since the objectives of that study are comparable to those established for the Back Bay of Biloxi, the watershed portion of this literature review will reflect that of Kilpatrick (2001). Due to the complexity of the Back Bay of Biloxi watershed and the critical nature of the TMDL development, only detailed models were considered for this project (Table 3.1). This section provides a brief description of some of the watershed models with potential for application to the Back Bay of Biloxi watershed.

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

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

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 its major focus on urban storm water management and the intensive data required for model calibration and verification. SWMM has been applied to urban hydrologic quantity and quality problems in many locations across the country (Huber, 1992).

Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS) was developed by the Agricultural Engineering Department at Purdue University to evaluate water quality in smaller agricultural and non agricultural watersheds such as farmland and construction sites (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 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 simulate stormwater runoff from urban areas coupled with the moderate to high calibration effort limited its use for this study.

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 U.S. EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system, which was selected for application to the Back Bay of Biloxi, 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). In addition to non point source, NPSM can also model point sources such as municipal and industrial waste discharges, failing septic tanks, cattle in the stream, etc. The model is limited to well mixed rivers and reservoirs because it assumes the instream water body is well mixed (Shoemaker et al., 1997).

Within NPSM, nonpoint source loading can be calculated using three different approaches. First, the 'potency factor' approach calculates nonpoint loads as a function of sediment loading rate. The sediment loading rate can be calculated from the Universal Soil Loss Equation (Wischmeier and Smith, 1978). Second, the 'detailed modeling' approach simulates both chemical and biochemical processes in the soil. These processes used in conjunction with hydrologic and erosion modeling can be used to calculate both subsurface and surface nonpoint source loads. Detailed modeling is most often used to predict nonpoint nutrient loadings. Finally, the 'first-order washoff' approach calculates a daily accumulation/deposition on the land surface, and the corresponding washoff of pollutants during storm events. Washoff is a first order function of the storm runoff (Hashim, 2001).

When using the "first-order washoff" approach to simulate fecal coliform concentrations, the decay rate is extremely sensitive to temperature and is related by the equation.

$$(K_B)_T = (K_B)_{20}.(1.048)^{T-20} \tag{3.1}$$

where:

$(K_B)_T$ = KGEN= first-order decay rate for a fecal coliform at temperature

$K_B)_{20}$ = KGEND= base first-order decay rate for fecal coliform @ 20 ^oC

(1.048) = THGEN= temperature correction parameter for first-order decay

The NPSM model has been applied to several watersheds across the country including the Chesapeake Bay, North Reelfoot Creek, and St. Louis Bay 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). Recently, the model was applied to the St. Louis Bay, 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., 2001).

The NPSM/HSPF was chosen as the most appropriate model for application to the Back Bay of Biloxi watershed. The NPSM/HSPF model provides the best balance of land uses, hydrology, and pollutant loading capabilities. As was previously stated, NPSM/HSPF has already been applied to similar study areas in the state of Mississippi and provided acceptable results. In addition, the model is distributed by the USEPA and provides technical support, data, and software accessible via the Internet.

Estuary Models

As was previously stated, the current modeling of the Back Bay of Biloxi is a continuation of a previous modeling effort (Shindala et al., 1996), where WASP5 was used to model Dissolved Oxygen, Nutrients, and Phytoplankton for waste load allocations. Consequently, a brief discussion of only WASP5 is presented in this section.

The WASP5 model contains two stand-alone water quality models, EUTRO5 and TOXI5. EUTRO5 was developed to simulate eutrophication kinetics for eight different state variables (Table 3.2). TOXI5 was specifically created to predict dissolved and sorbed chemical concentrations in the bed and overlying waters (Ambrose et al., 1993). EUTRO5 can be applied in one, two, or three dimensions and is designed for linkage with a hydrodynamic model. Although DYNHYD5 is the default hydrodynamic model linked with EUTRO5, several other programs such as RIVMOD, SED3D, and EFDC can be used depending on the application (Shoemaker et al., 1997). DYNHYD5 was used in conjunction with EUTRO5 for hydrodynamic and water quality simulations within the Back Bay of Biloxi. Detailed information on both models is well presented in the literature (Ambrose et al., 1993) and thus will not be repeated here. Only the modifications made to EUTRO5 that enable the simulation of fecal coliform will be discussed.

Traditionally, coliform modeling has only taken into account disappearance and a simple first-order kinetics approach, as shown in Equation 3.2. This approach is adopted for modeling fecal coliform in the Back Bay of Biloxi. Fecal coliform concentration is expressed as:

$$\frac{C}{t} \qquad KC \bullet \bullet^{T \quad 20} \tag{3.2}$$

Where:

C = coliform concentration, MPN/100ml
K = disappearance rate constant, d^{-1}
t = exposure time
θ = temperature correction factor for K

The disappearance rate constant takes into consideration such factors as die-away, predation, sunlight, and salinity.

Table 3.2: Eight State Variable Kinetic Processes Incorporated in Model EUTRO5

1. Ammonia (NH_3) Mineralization of Organic Nitrogen Phytoplankton Death Algal Uptake (Growth) Nitrification Benthic Flux	5. CBOD Phytoplankton Death Oxidation CBOD Denitrification Settling
2. Nitrate Nitrogen (NO_3) Nitrification Algal Uptake Denitrification	6. Dissolved Oxygen (DO) Reaeration Phytoplankton Growth Nitrification CBOD Oxidation Sediment Oxygen Demand
3. Orthophosphorus (PO_4) Mineralization of Organic Phosphorus Phytoplankton Death Algal Uptake Benthic Flux	7. Organic Nitrogen (ON) Phytoplankton Respiration Phytoplankton Death Mineralization
4. Phytoplankton (CHL) Growth Respiration Settling	8. Organic Phosphorus (OP) Phytoplankton Respiration Phytoplankton Death Mineralization

Although, as previously stated, EUTRO5 is capable of modeling eight different kinetic processes (Table 3.2), the current problem for Back Bay of Biloxi lies in pathogen concentration only. Since EUTRO5 has no explicit state variable for bacteria modeling, the CBOD model is simplified to conform to the simplified coliform model presented in Equation 3.2. The equation used by EUTRO5 to solve for CBOD considers Phytoplankton death, oxidation, denitrification, and settling (Equation 3.3). To convert Equation 3.3 to the simplified form (Equation 3.2), required the elimination of all terms in Equation 3.3 except for the CBOD oxidation. Furthermore the impact of dissolved oxygen level on CBOD decay is eliminated by setting K_{BOD} equal to zero.

$$\frac{C_5}{t} = a_{oc} K_{1D} C_4 - k_D \;\; {}^{(T-20)}_{D} \;\; \frac{C_6}{K_{BOD} + C_6} \; C_5 - \frac{v_s 3 (1 - f_D 5)}{D} C_5$$

death oxidation settling

(3.3)

$$- \frac{5}{4} \frac{32}{14} k_{2D} \;\; {}^{(T-20)}_{2D} \;\; K_{NO} \frac{3}{K_{NO} 3 + C_6} \;\; C_2$$

denitrification

Thus Equation 3.3 is reduced to Equation 3.4, which is comparable to Equation 3.2 generally used to model fecal coliform

$$\frac{C_5}{t} = - k_D \;\; {}^{(T-20)}_{D} C_5 \tag{3.4}$$

where:

C_5 = concentration of water quality constituent, MPN/100ml
t = time, days
k_D = first order decay rate constant
$\bullet_D$ =temperature correction factor
T =temperature degrees C

CHAPTER IV

WATERSHED MODEL CALIBRATION AND APPLICATION

As was previously stated, the BASINS2.0/NPSM watershed model was selected for application to the upstream portion of the Back Bay of Biloxi watershed. Watershed models simulate flow as a series of hydrologic and hydraulic processes. The processes included in the BASINS/NPSM model are water quality and surface runoff.

BASINS is an environmental analysis program used in modeling watershed and water quality studies. Data is provided through a geographic information system (GIS) that allows the user to analyze and display a wide variety of landscape information such as landuses, water quality monitoring stations, and point source dischargers. BASINS allows the user to specify the watershed of interest and incorporate site-specific GIS data to that watershed through the USEPA website www.epa.gov/ost/basins (USEPA, 1998a). The NPSM model is integrated with BASINS (Lahlou, M. et al., 1998) within an ARCVIEW GIS environment. This interface allows NPSM to simulate non-point source runoff from specified watersheds, as well as the flow and transport of pollutants through the waterbodies.

Development of a BASINS/NPSM model requires several different types of input data. Weather data including precipitation, air temperature, global radiation, potential evapotranspiration, and wind velocity, land-use data, topographic data, and soil data are all examples of information required to run the model. This data is readily available for most watersheds in the United States and can be obtained from the same website as the BASINS/NPSM software.

Calibration and development of a watershed model (BASINS2/NPSM) requires performing several 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. This chapter contains a description of the factors used for the calibration and results of the model application for the Back Bay of Biloxi watershed.

Watershed Description and Data Summary

The study area for the watershed model includes the Back Bay of Biloxi and all major tributaries. Input data related to stream characteristics, topography, land use, and climatic characteristics were obtained from the World Wide Web (USEPA, 1999a) and imported directly into the BASINS2.0 interface, thus facilitating development of the model for the study area. Figure 4.1 illustrates the Back Bay of Biloxi watershed, identifies the subwatersheds, and the locations of data collection sites within the study area. 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 illustrated in Figure 4.2.

Figure 4.1: Back Bay of Biloxi Study Area

Table 4.1: Biloxi Bay Subwatershed Description

Sub-Watershed	ID	Stream Name	Area (acres)
03170009015	015	Biloxi River	62,391
03170009016	016	Little Biloxi River	48,412
03170009014	014	Saucer Creek	30,563
03170009010	010	Tuxachanie Creek	59,108
03170009013	013	Biloxi River	14,811
03170009009	009	Tchoutachabouffa	51,248
03170009008	008	Bayou Costapia	18,558
03170009036	036	Bernard Bayou	19,017
03170009012	012	Biloxi River	4,238
03170009037	037	Turkey Creek	16,648
03170009002	002	Old Forest Bayou	12,762
03170009005	005	Cypress Creek	8,024
03170009006	006	Tchoutachabouffa	812
03170009004	W0	Brickyard Bayou	5724
03170009004	W1		882
03170009004	W2		2748
03170009004	W4	Bayou La Porte	1325
03170009004	W6	Keegan Bayou	708
03170009004	W7	Auguste Bayou	594
03170009004	W9		1462
03170009004	W10	Fritz Creek	7357
03170009004	W11		1758
03170009004	W12		1261
03170009004	W13		5727
03170009004	W14	Parker Creek	5066
03170009004	W15	Howard Creek	7636
03170009004	W18		1743
03170009004	W22	St. Martin Bayou	4414
03170009004	W23	Bayou Porto	4246
03170009004	W24		2173
03170009004	W26		1121
03170009004	W27		1341
03170009004	W28	Heron/Davis Bayou	3986

Meteorological data are available from several climatological stations in the area and are distributed via the World Wide Web (USEPA, 1999a). In order to run NPSM, precipitaion data must be prescribed on an hourly basis. Therefore, in order for a climatalogical station to be useful for model development, its data must be presented in hourly intervals. Because the Saucier Experiment Station, the Wiggins Ranger Station, and the Biloxi Station all contain hourly recordings of rainfall data, they can all be input directly into the model. One the other hand, Gulfport Naval Center, Merrill, Ocean Springs, and Vancleave (Figure 4.1) are all limited to daily recordings of rainfall data and must be disaggregated into hourly data before being used in NPSM. The disaggregation of the monthly data was done by applying the METCMP (USGS, 1994), and WDMutil (USEPA, 1999b) programs obtained from the USGS and USEPA, respectively. (Hashim 2001). Table 4.2 summarizes the name, location, frequency, and available dates for each station within the Back Bay of Biloxi study area.

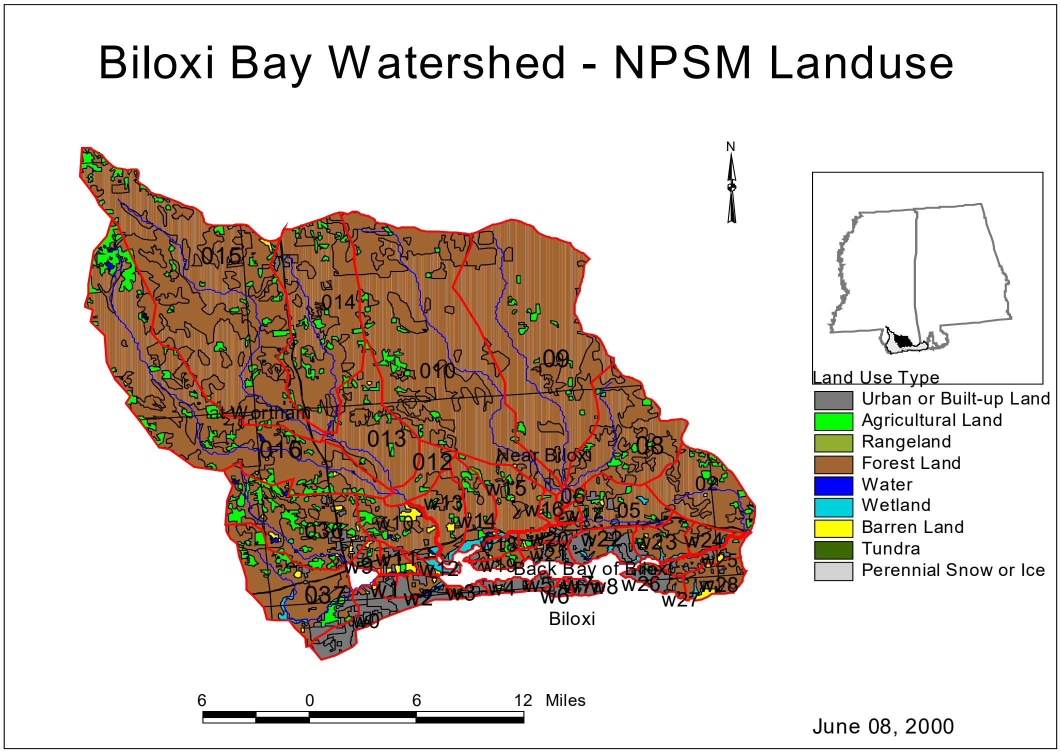


Figure 4.2: Biloxi Bay Watershed Landuse Distribution Map

Table 4.2: Biloxi Bay Meteorological Data

Station Name	COOPID	Location (Lat., Long)	Frequency	Available Dates
Biloxi		30 26 N, 89 02 W	Daily/Hourly	01/1948-present
Gulfport Naval Center	MS223671	30 23 N, 89 08 W	Daily	06/1956-present
Merril	MS225789	30 59 N, 88 43 W	Daily	01/1970-present
Ocean Springs		30 25 N, 88 47 W	Daily	1994-1999
Saucier Exp Forest	MS227840	30 38 N, 89 03 W	Daily/Hourly	05/1954-present
Vancleave	MS229157	30 29 N, 88 40 W	Daily	06/1948-present
Wiggins Ranger Station	MS229648	30 51 N, 89 09 W	Hourly	10/1973-present

Hydrologic Model Calibration

The hydrologic model was developed by application of the USEPA supported BASINS2 interface and the coupled Non-Point Source Model (NPSM) (USEPA, 1998a). Historical calibration was accomplished utilizing the USGS flow data (USGS, 1999a, USGS, 1999b) from Tuxachanie Creek and Biloxi River. The location of gauging stations, available data, time period of availability and sampling frequency are summarized in Table 4.3.

Table 4.3: Hydraulic Data for the Biloxi Bay Watershed

Location	Station ID	Available Dates	Frequency
Biloxi River at Wortham	USGS02480500	1952-1999	Daily
Tuxachanie creek near Biloxi	USGS02481000	1952-1973	Daily

Flow at station USGS02481000 was used to calibrate the Tuxachanie Creek sub-watershed. This calibration was verified using the flow station USGS02480500 on the Biloxi River sub-watershed. The modeling parameters obtained from this calibration/verification process were extrapolated throughout the remainder of the subwatersheds.

Sub-Watershed Delineation at Tuxachanie Creek

In order to calibrate a watershed, delineation must be performed such that a flow station is located at the outlet of the watershed as illustrated in Figure 4.3. The sub-watershed delineation for the USGS station near Biloxi drains the Tuxachanie Creek from headwaters to approximately 3 miles (4.8 km) upstream of the junction of the Tuxachanie, Tchoutacabouffa, and Costapia Bayous. The sub-watershed was superimposed upon the land use map illustrated in Figure 4.3.

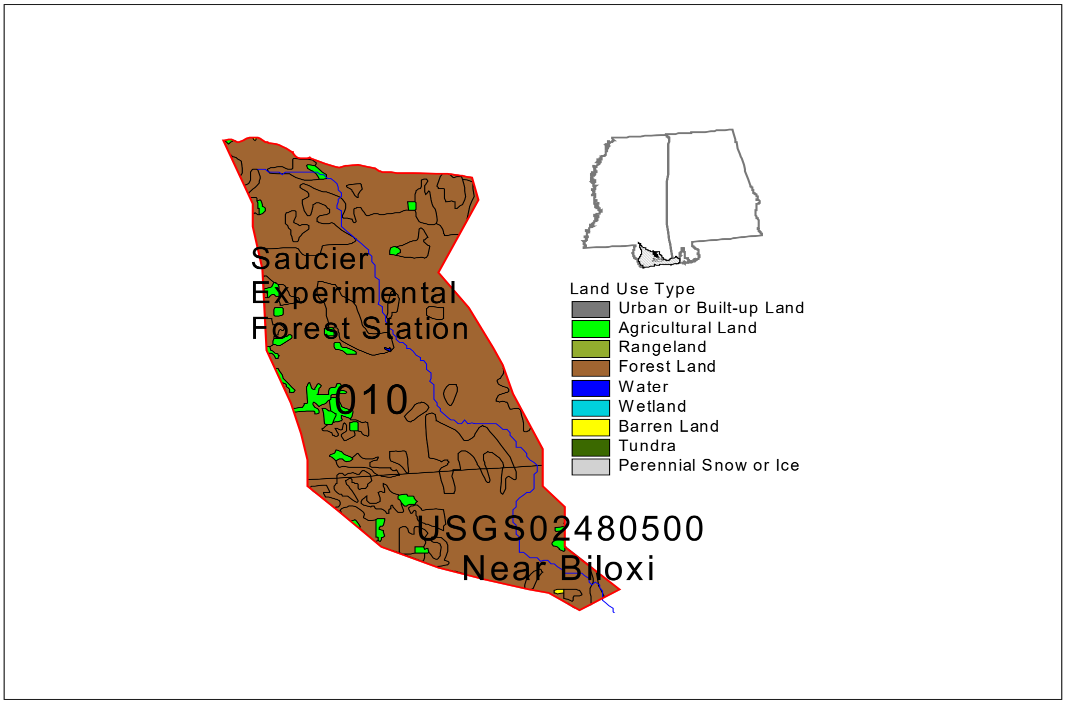


Figure 4.3: Delineation and NPSM Land-Use Tuxachanie Creek Watershed

The Tuxachanie gauging station includes a drainage area of approximately 58,269 acres (23,580 ha). The vast majority of the area is forestland with elevations ranging from 150 feet (45.7 m) at the headwaters to 40 feet (12.2 m) at the gauging station. Delineation of the watershed was based on the reach file 1 (RF1) and reach file 3 (RF3) networks along with the watershed topography (USEPA 1998a). The reach networks are defined by their detail, with RF1 networks containing extensive information for major streams and RF3 networks include less extensive information for small tributaries and streams. Both RF1 and RF3 data can be downloaded from the BASINS website (USEPA, 1998a) and imported into the BASINS/NPSM model. Table 4.4 and Table 4.5 describe the watershed land use and the river reach characteristics for Tuxachanie Creek.

Table 4.4: Land-Use for Tuxachanie Creek near Biloxi

Sub-Watershed ID	Stream Name	Urban (acres)	Agriculture (acres)	Forest (acres)	Wetland (acres)	Barren (Acres)	Total Acres
03170009010	Tuxachanie	0	1,740	56,490	9	30	58,269

Table 4.5: River Reach Characteristics for Biloxi River

Sub-Watershed ID	Stream Name	River Length (miles)	Delta H (Ft)	River Elevation (ft)
03170009015	Biloxi River	21.35	119	76.0

Stream Flow Data

The stream flow data utilized for calibration of the Tuxachanie near Biloxi is available from October 1, 1952 to September 30, 1973, as referenced in Table 4.3. A sample hydrograph for 1970, illustrated in Figure 4.4, indicates the wet as well as the dry seasons. Major rainfall events are clearly evident on the graph. The calibration was mainly focused on accurately predicting the base flow of the stream along with the rising and recession limbs of the major rain events.

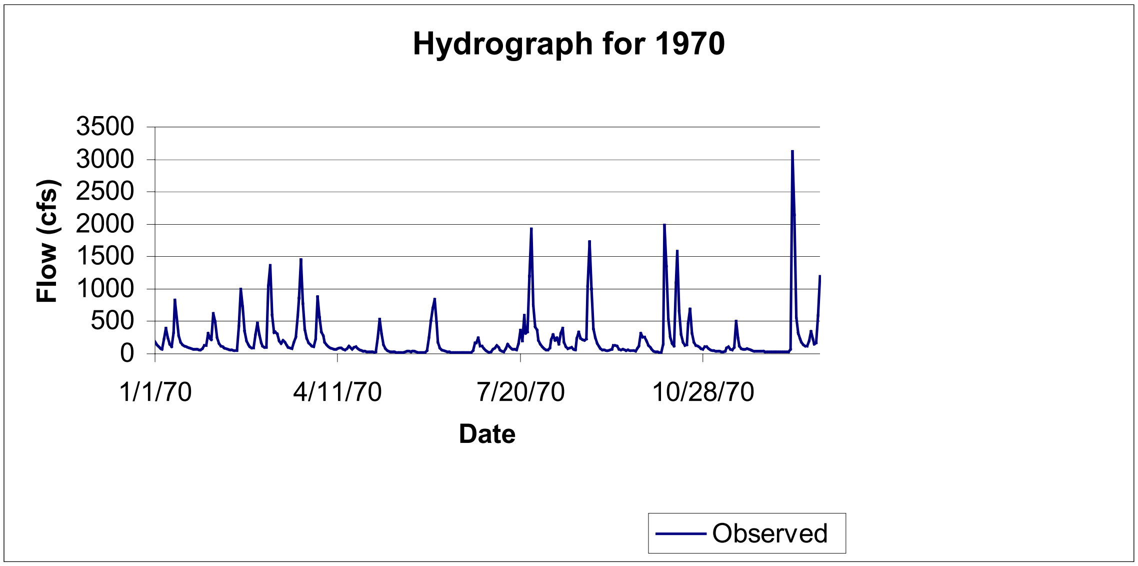


Figure 4.4: Rainfall Hydrograph for Tuxachanie near Biloxi

Meteorological Data

As with other hydrologic models, NPSM applies spatially uniform precipitation at the sub watershed level. The spatial application of a rainfall event over an entire watershed can be a source of error in the model due to localized showers. Fortunately, the Tuxachanie watershed is inclusive of the Saucier Experimental Forest weather station, which will ensure the accuracy of rainfall events within the watershed, whether localized or regional.

The model also requires other meteorological data, which includes evaporation, temperature, wind speed, solar radiation, potential evapotranspiration, dew point temperature, and cloud cover. This data is input into the NPSM model through a Watershed Data Management (WDM) file in order for the NPSM model to run properly. The WDM file contains times series data for all of the parameters listed above and can be downloaded and imported into BASINS (USEPA, 1998a). The data for all meteorological stations in the U.S. is located at web site www.ncdc.noaa.gov/ for the National Climate Data Center and is available from 1965 to present (NOAA, 1999).

Land Use Data

As noted earlier, landuse characteristics can be prescribed within the BASINS/NPSM model. Applied land use files were obtained from the USGS Geographic Information Retrieval and Analysis System (GIRAS) and were based upon Anderson Level I and II classification systems. The GIRAS land use data was derived from data collected by the USGS in the 1970's and was applicable for the Tuxachainie Creek calibration period.

Hydrologic Modeling Parameters

Several studies have been performed on the sensitivity of modeling parameters used in NPSM and its predecessor HSPF. The USEPA has overseen several studies on watersheds across the U.S. for the last two decades, and have compiled a database with typical ranges (Donigan et al., 1999). Initial calibration parameters for Biloxi Bay were obtained from the USEPA based on a previous Biloxi Bay modeling effort (USEPA, 2001).

NPSM uses numerous parameters to simulate hydrological processes in a watershed. However, the definitions of the most pertinent parameters are presented in Table 4.6 (Laroche et al., 1996).

Table 4.6: Parameters for Hydrologic Components of NPSM

Identification	**Description**	**Units**
INFILT	Index zone nominal storage	In/hr
IRC	Interflow recession parameter	None
INTFW	Interflow inflow parameter	None
UZSN	Upper zone nominal storage	Inches
LZSN	Lower zone nominal storage	Inches
LZETP	Lower zone ET parameter	None
AGWRC	Basic ground-water recession water	None
KVARY	Ground-water recession flow	1/Inches
INFEXP	Exponent in the infiltration equation	-
INFILD	Ratio between the maximum and me infiltration capacities	-

Hydrologic Calibration Results for Tuxachanie Near Biloxi

Using the described boundary data and watershed delineation, NPSM was applied to model the Tuxachanie watershed for the period January 1965 through September 1971. Precipitation data was based on measured values from the Saucier Experimental Station. Simulated stream flows were correlated to site specific field data, graphically and by calculation of integral stream volumetric flux on both seasonal and individual storm variations (USEPA, 1999f).

NPSM parameters were adjusted to further refine model correlation with field data. Refinement efforts were performed on various storage, infiltration, interception, friction, and hydrograph parameters.

Table 4.7 represents the final calibration values for each parameter along with the range of typical values determined by the USEPA (USEPA, 1999c). Representative comparison of observed and modeled daily stream flow rate is presented in Figures 4.5 and 4.6 for selected model years. Comparison of integrated stream volumetric flux calculated from field data was made to the flux calculated from simulated flows in a spreadsheet analysis tool provided by the USEPA (USEPA, 1999f). The tool integrates the modeled stream volumetric flux using quadratic integration and compares with data for selected time periods by comparing the percent error between modeled and measured stream volume on the basis of annual, seasonal, and major storm events. Table 4.8 quantifies the percent difference between modeled and measured flows and gives the USEPA's recommended criteria.

As illustrated, a good overall correlation with measured values is attained. Stream base flow and the rising and recession limbs of storm hydrographs are well replicated and most major storm events are reproduced accurately. Since the Saucier Experimental Forest station is located within the Tuxachanie watershed, no correlation of adjoining rainfall data was used for the calibration of this sub-watershed. Results of flow simulation for the period 1965-1970 are summarized in Table 4.8. As shown, the fall of 1966 produced the least favorable results. This may be attributed to the fact that the nominal flow rate during this period was much lower than other seasons reaching levels as low as the 7Q10 flow of 7 cfs (0.2 cms), therefore; leading to a large percentage deviation for relatively small actual deviations.

Table 4.7: NPSM/HSPF Hydrology Parameters and Ranges (USEPA, 1999c)

Name	**Definition**	**Units**	**Range of Values**				**Biloxi Bay 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	0.120
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	0.00
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	0.30
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	0.00
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	0.20
UZSN	Upper zone nominal soil moisture storage	Inches	0.1	1.0	0.05	2.0	1.750
INTFW	Interflow inflow parameter	None	1.0	3.0	1.0	10.0	1.50
IRC	Interflow recession parameter	None	0.5	0.7	0.3	0.85	0.30
LZETP	Lower zone ET parameter	None	0.2	0.7	0.1	0.90	0.10

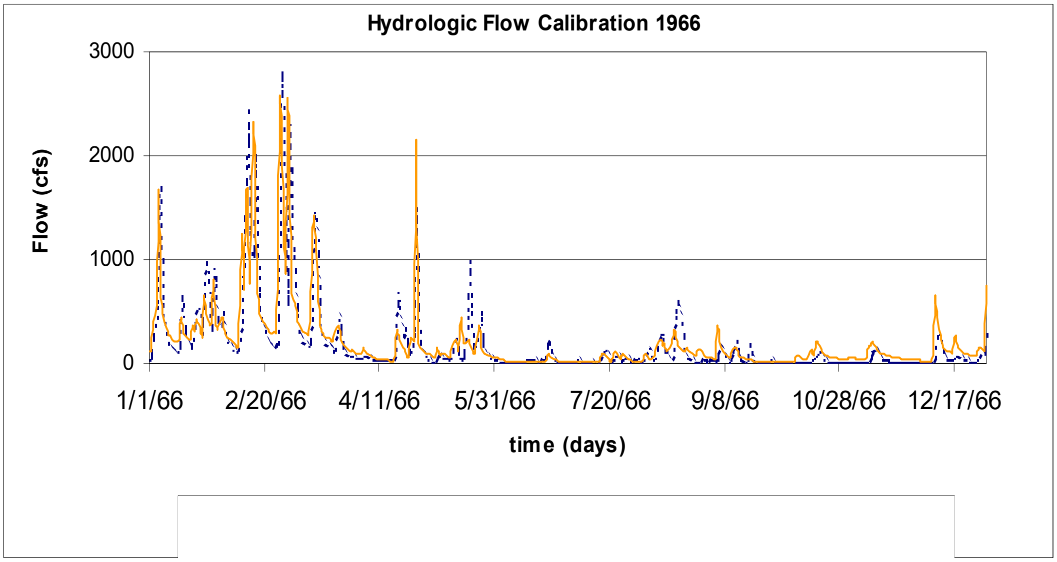


Figure 4.5: Hydrologic Flow Calibration at USGS 02481000 – 1966

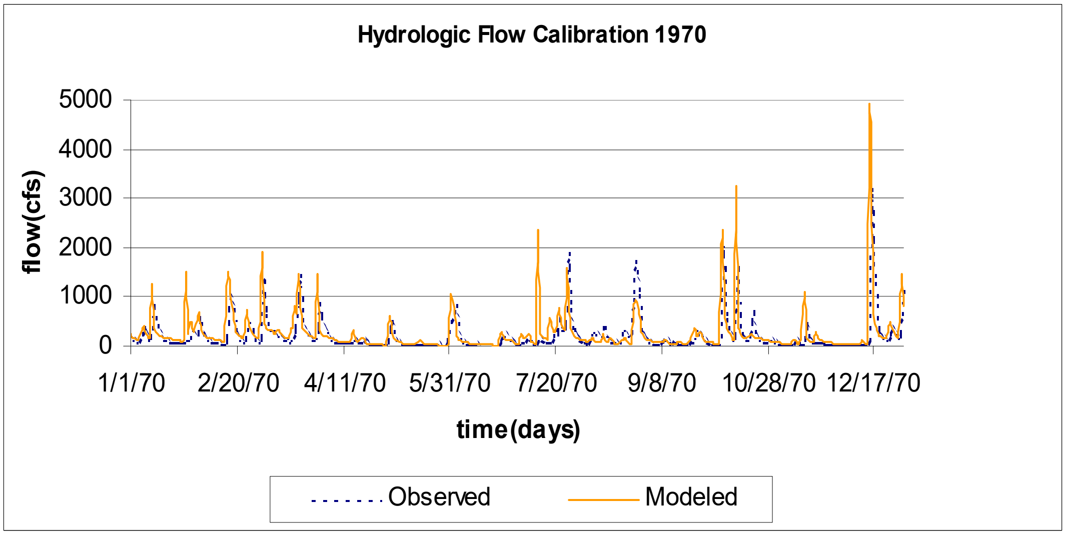


Figure 4.6: Hydrologic Flow Calibration at USGS 024801000 – 1970

Table 4.8: Percent Error and Comparison of Observed and Computed Values

	Simulated		**Observed**	
Year	**1966**	**1970**	**1966**	**1970**
Total in-stream Flow	31.34	39.72	28.92	31.94
Total of highest 10% flow	15.84	19.82	16.56	15.42
Total of lowest 50% flow	3.15	5.14	1.75	3.81
Summer flow volume (months 7-9)	2.86	8.53	2.61	8.25
Fall flow volume (months 10-12)	3.52	13.03	1.42	9.76
Winter flow volume (months 1-3)	20.71	14.07	20.01	9.96
Spring flow volume (months 4-6)	4.25	4.09	4.88	3.97
Total storm volume	28.03	37.0	25.74	28.82
Summer storm volume (7-9)	2.45	8.00	2.29	7.57
Errors (Simulated - Observed)	**1966**	**1970**	**Recommended Criteria**	
Error in total volume	7.73	19.59	10	
Error in 50% lowest volume	44.55	25.90	10	
Error in 10% highest flows	-4.54	22.18	15	
Seasonal volume error -Summer	8.71	3.33	30	
Seasonal volume error - Fall	59.81	25.12	30	
Seasonal volume error - Winter	3.38	29.18	30	
Seasonal volume error - Spring	-14.89	2.94	30	
Error in storm volumes	8.15	22.12	20	
Error in summer storm volumes	6.84	5.30	50	

Sub-Watershed Delineation at Wortham

NPSM delineation of the Biloxi River watershed for calibration at Wortham is depicted in Figure 4.7. The Wortham gauging station reflects a drainage area of about 61,800 acres (25,009 ha). The vast majority of the area is forestland with elevations ranging from 200 ft (61 m) at the headwaters to 40 ft (12.2 m) at the gauging station.

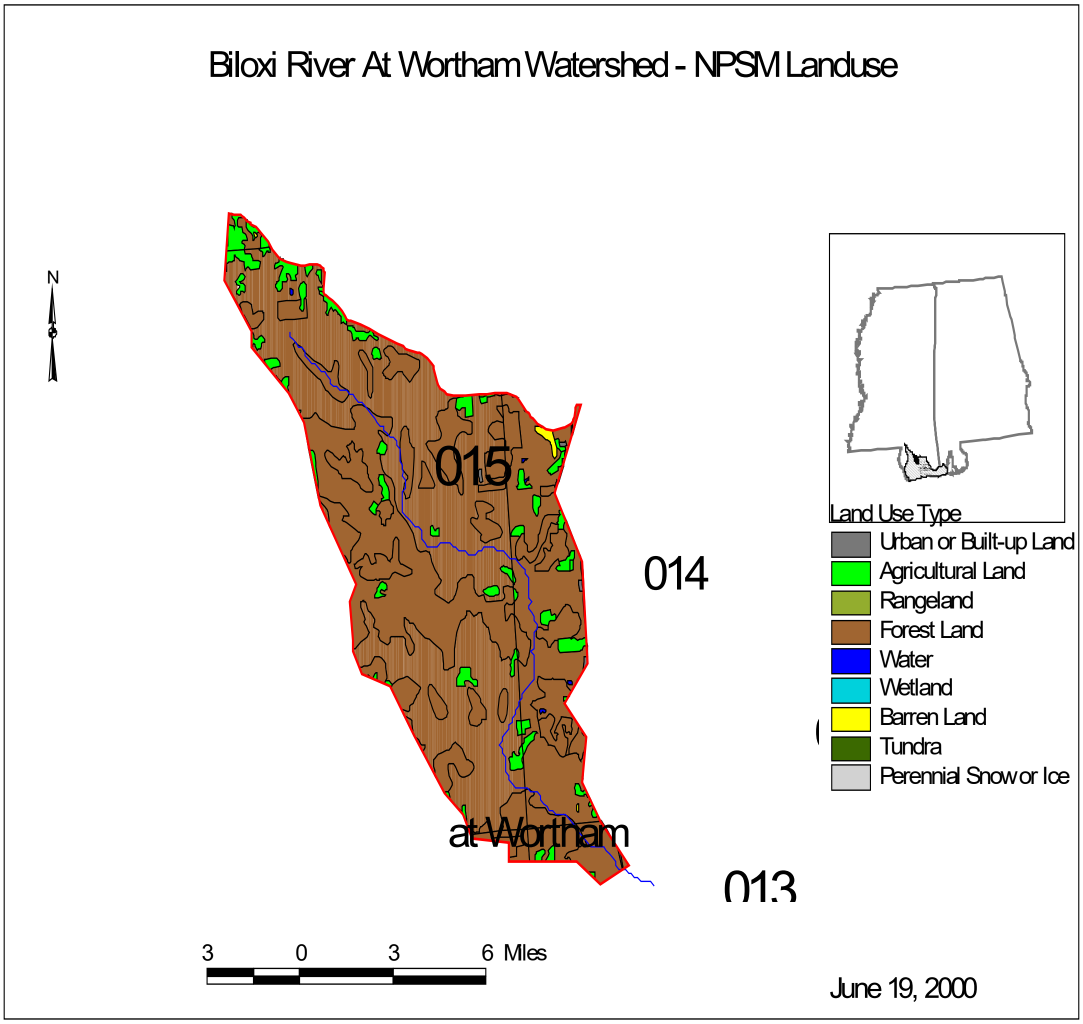


Figure 4.7: Delineation and NPSM Land-Use Wortham Watershed

The delineation was performed using both RF1 and RF3 reach data, which are both imported into BASINS (USEPA 1998a). Table 4.9 and Table 4.10 describe the watershed land use for both GIRAS and MARIS, respectively. It is clearly shown that urban landuse increased from the 1970's to the 1990's, while agricultural and forest landuses decreased. These changes in landuse are important to incorporate into watershed calibration due to the great variability in runoff between different landuse types. The landuse, Table 4.11, describes the river reach characteristics for Biloxi River at Wortham.

Table 4.9: GIRAS Watershed Land use for Biloxi River at Wortham

Sub-Watershed ID	Stream Name	Urban (acres)	Agriculture (acres)	Forest (Acres)	Barren (Acres)	Total Acres
03170009015	Biloxi River	144	3632	57810	155	61,799

Table 4.10: MARIS Watershed Land use for Biloxi River at Wortham

Sub-Watershed ID	Stream Name	Urban/ Barren (acres)	Agriculture (acres)	Forest (Acres)	Pasture (Acres)	Total Acres
03170009015	Biloxi River	2557	1754	52829	5188	62,328

Table 4.11: River Reach Characteristics for Biloxi River

Sub-Watershed ID	Stream Name	River Length (miles)	Delta H (Ft)	River Elevation (ft)
03170009015	Biloxi River	21.80	160	120.0

Meteorological Data

NPSM applies spatially uniform precipitation at the sub watershed level. The spatial application of a rainfall event over an entire watershed can be a source of error in the model due to localized showers. Unfortunately, the Biloxi River watershed is not inclusive of a weather station that contains the required hourly data. Therefore, data from the Saucier Experimental Station and the Wiggins Ranger Station were selected for use due to their location with respect to the Biloxi River watershed (Figure 4.1). Consequently, some variability in the results is anticipated considering that the locations of the weather stations are outside the watershed.

Land Use Data

As noted earlier, GIRAS land use data was used for the runs made during the 1970's. However, updated land use data from 1992-1993 were obtained from the Mississippi Automated Resource Information System (MARIS) data set and merged with the BASINS2 data by using the USEPA Watershed Characterization System (WCS) utility program (USEPA, 1999e). This land use information is based on data collected by the State of Mississippi's Automated Information System (MARIS, 1997). This dataset is based on Landsat Thematic Mapper digital images taken between 1992 and 1993. The MARIS data are classified on a modified Anderson level I and II system. The MARIS land use dataset was used for the 1992 hydrologic calibration period.

Stream Flow Data

The stream flow data available from the USGS for calibration of the Biloxi River at Wortham is from October 1, 1952 to present (Table 4.3). Unlike the Tuxachainie flow station, the Biloxi River at Wortham flow station contained flow data for many years. With this extensive data, the model was run for periods in the 1970's as well as the 1990's

Hydrologic Modeling Parameters

Initial hydrologic calibration on Biloxi River at Wortham was accomplished utilizing historical data for period 1970 to 1980 using the GIRAS land-use data. Final hydrologic calibration on Biloxi River at Wortham was accomplished utilizing historical data for period 1990 to 1995 using MIRAS land-use data. Hydrologic parameters found in the initial hydrologic calibration of Tuxachanie Creek near Biloxi were used in the hydrologic calibration near Wortham.

Hydrologic Calibration Results for Wortham

With the previously stated watershed delineation and boundary conditions, the NPSM model was applied to the Wortham watershed from 1970 to 1980 and 1990 to 1995 As expected, simulation results were very sensitive to the precipitation data. Simulations were made using two different weather station strategies summarized in Table 4.12. The two strategies each represent a reasonable application of available measured precipitation to the defined Wortham sub-watershed. In strategy 1, the flow for the Wortham watershed simulated using the rainfall data from the Saucier Experimental

Station, which is located to the east of the watershed. In strategy 2, the flow was simulated using the rainfall data from the Wiggins Ranger Station located North of the watershed. Comparisons with field measured data were made graphically and by calculation of integral stream volumetric flux on both seasonal and individual storm variations. The integral stream quantities were calculated following the procedure outlined by USEPA for TMDL studies. Based on these comparisons, strategy 2 produced the results that best fit the field observations.

Table 4.12: Applied Precipitaion Scenarios

Strategy	Biloxi River (03170009015)
1	Saucier Exp Station
2	Wiggins Ranger Station

Although NPSM was run for a total of 15 years, selected calibration years were 1977 and 1979 for GIRAS landuse and 1992 for MARIS landuse. Observed and modeled stream hydrographs are compared in Figures 4.8, 4.9, and 4.10. Measured versus calculated stream volume, using the calibrated NPSM parameters and the precipitation strategy 2 is depicted in Table 4.13 for various times between 1977 and 1992. The overall trend of the comparisons is good with many of the major storm events being well replicated.

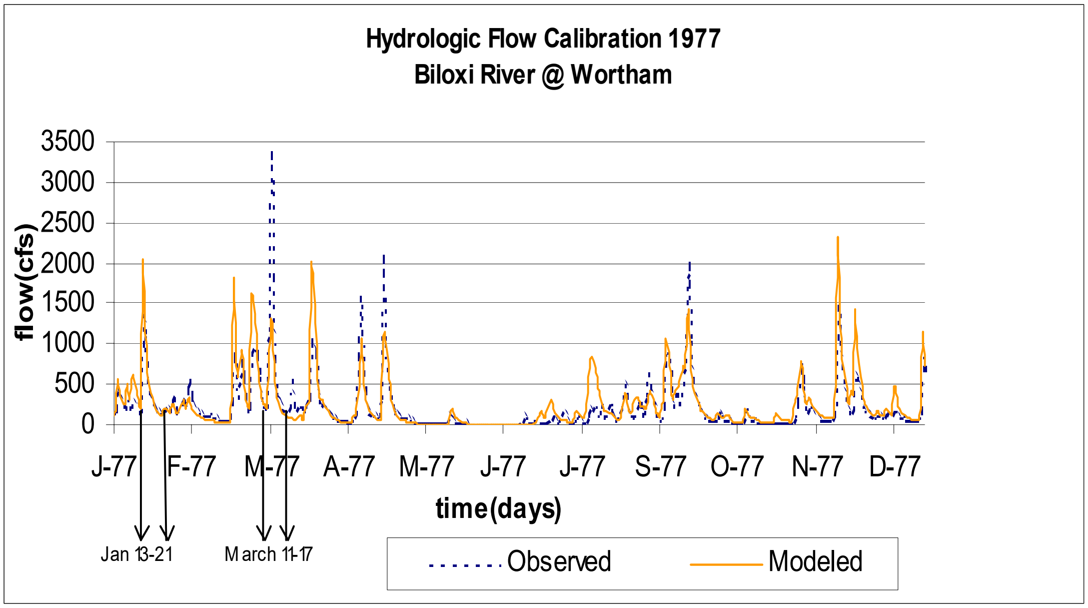


Figure 4.8: Hydrologic Flow Calibration at USGS 02480500 – 1977

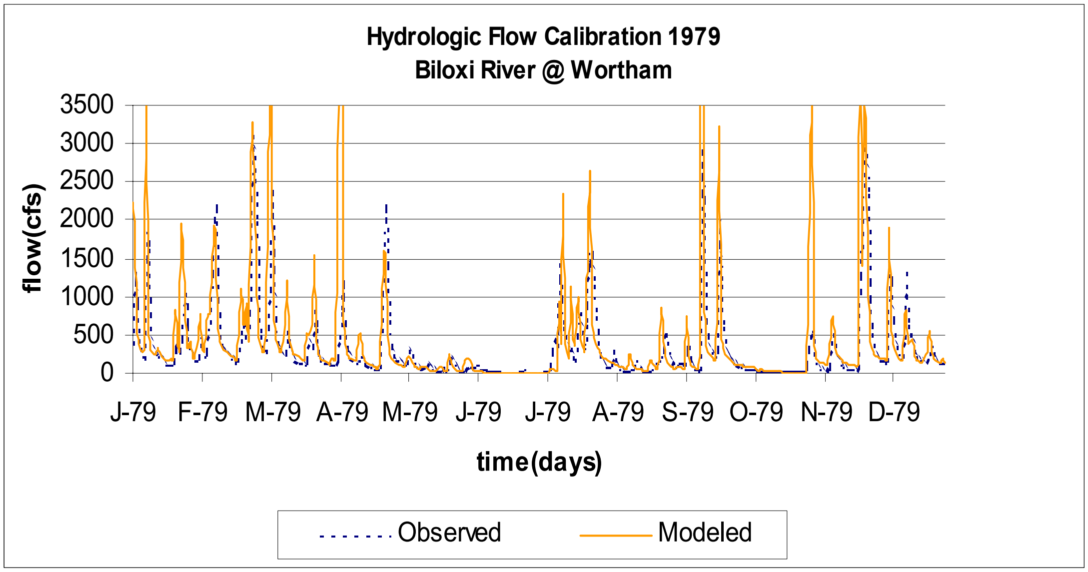


Figure 4.9: Hydrologic Flow Calibration at USGS 02480500 – 1979

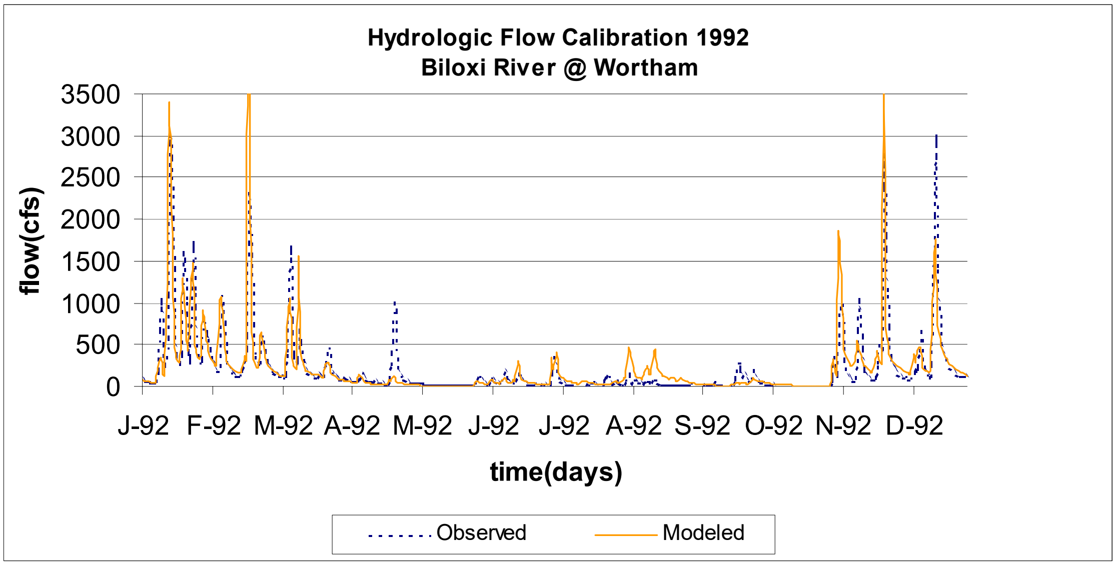


Figure 4.10: Hydrologic Flow Calibration at USGS 02480500 – 1992

Table 4.13: Percent Error and Comparison of Observed and Computed Values

	Simulated			**Observed**		
Year	**1977**	**1979**	**1992**	**1977**	**1979**	**1992**
	35.77	61.35	30.68	31.1	47.0	29.1
Total of highest 10% flow	15.76	33.63	16.23	14.8	23.2	16.6
Total of lowest 50% flow	3.60	5.19	2.04	3.34	4.60	1.78
Summer flow volume (months 7-9)	8.94	16.82	3.06	7.37	12.2	1.75
Fall flow volume (months 10-12)	9.08	13.20	10.82	5.68	10.1	9.73
Winter flow volume (months 1-3)	12.97	23.37	15.51	12.4	18.7	15.3
Spring flow volume (months 4-6)	4.79	7.96	1.30	5.61	6.05	2.34
Total storm volume	34.91	57.50	30.29	29.6	43.9	28.6
Summer storm volume (7-9)	8.94	16.79	2.99	7.14	12.0	1.66

Errors (Simulated - Observed)	**1977**	**1979**	**1992**	**Recommended**
Error in total volume	12.9	23.36	5.09	10
Error in 50% lowest volume	7.17	11.31	12.6	10
Error in 10% highest flows	5.78	31.04	-2.36	15
Seasonal volume error-Summer	17.6	27.26	42.7	30
Seasonal volume error - Fall	37.4	23.75	10.0	30
Seasonal volume error - Winter	3.83	20.13	1.38	30
Seasonal volume error - Spring	-17.2	23.94	-81	30
Error in storm volumes	15.3	23.62	5.49	20
Error in summer storm volumes	20.1	28.81	44.6	50

As shown, here again, a good overall comparison between simulated and observed values is attained. Stream base flow and the rising and recession limbs of storm hydrographs are replicated well in addition to most major storm events being reproduced.

As expected, model simulation of major storm events is heavily influenced by the spatial distribution of rainfall across the region. The storm of January 13-21, 1977, for example, indicates a storm that was well simulated as illustrated in Figure 4.8. The spatial rainfall for this event is illustrated in Figure 4.11. The results indicate a very uniform rain throughout the whole coastal region, therefore resulting in an accurate representation of watershed response to this storm event. The storm of March 11-17, 1977, on the other hand, indicates a storm that was simulated poorly as illustrated in Figure 4.8. The spatial rainfall for this event is illustrated in Figure 4.12. As illustrated, there is substantial spatial variability, which lead to significant error between the simulated and observed storms. Similar evaluation of isolated storm events exhibiting poor correlation improves the level of confidence in the computational model calibration since a cause for inaccurate model response other than fundamental watershed modeling parameters can be isolated. Therefore, it can be concluded that the computational model represents the watershed and can be applied with confidence.

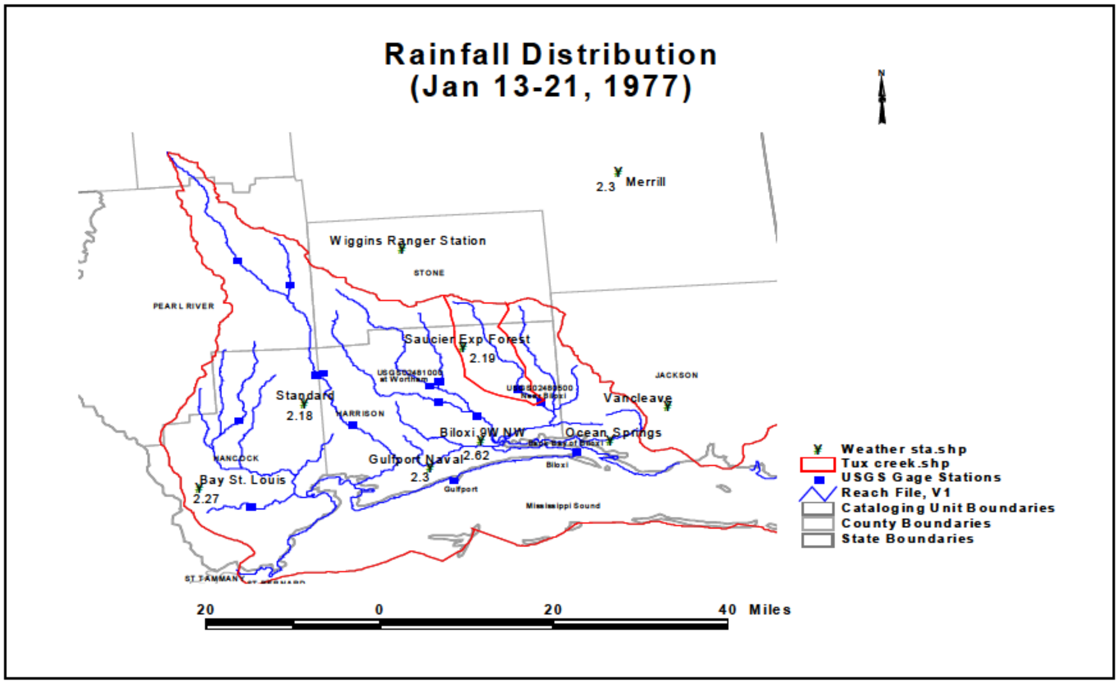


Figure 4.11: Rainfall Distribution Jan 13-21, 1977

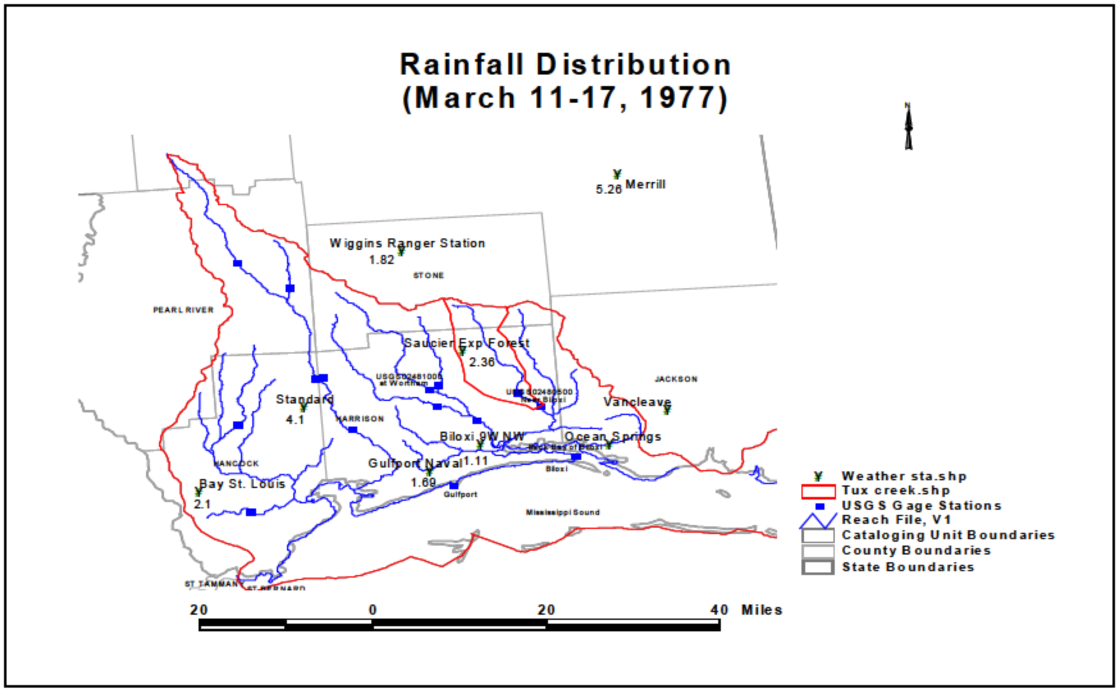


Figure 4.12: Rainfall Distribution March 11-17, 1977

Similar analyses were made for other storm events resulting in poor correlation. The conclusion was reached that the majority of the storms that vary spatially result in a poorly simulated storm event in NPSM. In order to improve data correlation for these events, the watershed model would have to be developed in much more detail with respect to spatial and temporal variation for both land use and atmospheric data. A watershed model at this level of detail would not be possible or practical utilizing the NPSM software. In addition, it is important to note that this model is being used as a predictive tool used to determine the TMDL for Back Bay of Biloxi. In order to do this, an artificial wet and dry year will be defined and precipitation data from those years will be applied. However it is significant that reasons for discrepancies in the model runs were identified in order to prove that the watershed parameters accurately describe the watershed. Given the available data, the Tuxachanie and Biloxi River watersheds were both accurately modeled with respect to hydrology and stream hydraulics.

Watershed Water Quality Analysis

The establishment of the relationship between the instream water quality target and the waste source loadings is a critical component of TMDL development. It allows for the evaluation of management practices that will achieve the desired water quality goals. The link can be established through several techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, in this study, the linkage will be supported by the instream monitoring data to associate the response of Back Bay of Biloxi to flow and loading conditions.

Several parameters are specified in NPSM in order to compute the quality of runoff from each subwatershed in Back Bay of Biloxi. In the present study, emphasis was placed on modeling the level of fecal coliforms within the watershed. For each subwatershed, the NPSM requires pollutant accumulation and deposition rates for fecal coliform bacteria. A review of the literature (USEPA, 1983, Najarian, et al., 1986) shows a large variation in pollutant loading rates from case studies performed across the country. In this section, the relationship between the instream water quality target and the waste source loadings is established by using the instream monitoring data, flow, and loading conditions.

The water quality phase was initiated following completion of the hydrology calibration as previously described. In this study, water quality data was limited, therefore, model input parameters for application were extrapolated from a similar study of the St. Louis Bay (Huddleston et al., 2001).

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. 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 13 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 (Horsely and Whitten, 1996). 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 precinct voting blocks. Fecal coliform loads from failing septic systems (Table 4.14) 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. The initial approximation was based upon values utilized in the calibration of the St. Louis Bay Model (Huddleston et al., 2001). 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 4.15.

Table 4.14: Fecal Coliform Loading Rate Due to Failed Septic Systems

Subwatershed	**Total # of Septics in Subwatershed**	**Existing Flow (cfs)**	**Existing Load (counts/hr)**
03170009002	351	5.71e-02	5.81e08
03170009005	174	2.83e-01	2.88e08
03170009006	89	1.45e-02	1.47e08
03170009008	486	7.91e-02	8.05e08
03170009009	531	8.64e-02	8.79e08
03170009010	538	8.76e-02	8.91e08
03170009012	209	3.40e-02	3.46e08
03170009013	312	5.08e-02	5.17e08
03170009014	381	6.20e-02	6.31e08
03170009015	944	1.54e-01	1.56e09
03170009016	1337	2.18e-01	2.21e09
03170009036	418	6.80e-02	6.92e08
03170009037	356	5.79e-02	5.81e08

Table 4.15: Fecal Coliform Loading Rate Due 2% Cattle Access to Stream

Subwatershed	**Total # of Cattle in Subwatershed**	**Existing Flow (cfs)**	**Existing Load (counts/hr)**
03170009037	96	1.63E-05	4.30E+08
03170009036	110	1.88E-05	4.96E+08
03170009016	411	7.01E-05	1.85E+09
03170009015	743	1.27E-04	3.34E+09
03170009014	302	5.16E-05	1.36E+09
03170009013	86	1.46E-05	3.86E+08
03170009012	24	4.04E-06	1.07E+08
03170009010	505	8.63E-05	2.27E+09
03170009009	438	7.49E-05	1.97E+09
03170009008	155	2.64E-05	6.96E+08
03170009006	5	8.54E-07	2.25E+07
03170009005	68	1.16E-05	3.05E+08
03170009002	107	1.82E-05	4.81E+08

Contribution From Animals

Contributions of fecal coliforms from both wildlife and farm animals, must also be considered. Table 4.16 contains the animal populations in each subwatershed. Table 4.17 contains land uses in each subwatershed. Table 4.18 depicts the fecal coliform loading rates for each subwatershed characterized by land use type. More detailed information on the source and specific loadings of fecal coliforms from animal population within the watershed is presented below. As illustrated in Table 4.16, some of the animal populations are very small and will have no real effect on the simulation results; however, given the data, all animals listed in the table were included in the model.

Table 4.16: Subwatershed ID's with Applied Animal Populations.

SUBWATERSHED	BEEF COWS	SWINE (HOGS)	DAIRY COWS	POULTRY	CATTLE
03170009037	88	2	9	1	169
03170009036	101	3	11	1	193
03170009016	383	10	33	2	703
03170009015	699	17	52	1	1249
03170009014	283	7	23	1	512
03170009013	79	2	8	1	150
03170009012	22	1	2	0	43
03170009010	471	12	41	2	863
03170009009	414	10	29	1	763
03170009008	153	3	2	0	289
03170009006	5	0	0	0	9
03170009005	67	1	1	0	126
03170009002	106	2	1	1	201
TOTAL	2871	70	212	11	5270

Table 4.17: Subwatershed Areas with Selected Land Uses

Subshed	Cropland (acres)	Forest (acres)	Urban (acres)	Pastureland (acres)	Total (acres)
03170009037	620	11610	1075	2149	15454
03170009036	1360	11555	834	4356	18105
03170009016	1623	35086	31	7172	43912
03170009015	1754	52829	28	5188	59799
03170009014	1075	26354	101	2364	29894
03170009013	322	13269	7	839	14437
03170009012	65	3843	27	250	4185
03170009010	837	54138	13	2101	57089
03170009009	489	48176	65	1549	50279
03170009008	379	16308	6	1329	18022
03170009006	93	613	1	89	796
03170009005	242	6072	237	968	7519
03170009002	302	10648	65	1265	12280
TOTAL	9161	290501	2490	29619	331771

Table 4.18: Fecal Coliform Loading Rates (#cfu/acre/day) by Land Use

Subwatershed	**Urban & Barren**	**Forrest & Wetland**	**Cropland**	**Pastureland**
03170009037	7.18E+06	2.34E+07	2.34E+07	2.67E+08
03170009036	7.18E+06	2.34E+07	2.34E+07	1.63E+08
03170009016	7.18E+06	2.34E+07	2.34E+07	3.38E+08
03170009015	7.18E+06	2.34E+07	2.34E+07	8.08E+08
03170009014	7.18E+06	2.34E+07	2.34E+07	7.25E+08
03170009013	7.18E+06	2.34E+07	2.34E+07	5.85E+08
03170009012	7.18E+06	2.34E+07	2.34E+07	5.55E+08
03170009010	7.18E+06	2.34E+07	2.34E+07	1.34E+09
03170009009	7.18E+06	2.34E+07	2.34E+07	1.57E+09
03170009008	7.18E+06	2.34E+07	2.34E+07	6.55E+08
03170009006	7.18E+06	2.34E+07	2.34E+07	3.21E+08
03170009005	7.18E+06	2.34E+07	2.34E+07	4.02E+08
03170009002	7.18E+06	2.34E+07	2.34E+07	4.81E+08

Wildlife

Fecal coliform loading parameters for forestland uses were based on the wildlife population within the study area. The Department of Wildlife and Fisheries at Mississippi State University (GAP, 1999) incorporated the information of wildlife population into the ARC/INFO GIS system. Deer are distributed throughout the watershed based on a density of 30 deer per square mile. Since reported unit contributions of fecal coliform from small animals (ducks, geese, raccoons, squirrel etc.) are significantly lower than that from deer, fecal coliform load from wildlife population was limited to only deer. Deer population density of 30 deer per square mile was utilized. A fecal coliform production rate of 5.00E+08 counts/day/deer (Metcalf and Eddy, 1991) was used in the model. Fecal coliform accumulation loading rate for deer population habitat (forest land use) is 2.34E+07 counts/acre/day (USEPA, 1998a, 1998b, 1998c).

Land Application of Hog and Cattle Manure

The aforementioned 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, obtained through the Watershed Characterization System (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.

Instream Fecal Calibration

As stated earlier, field measurements of fecal coliforms within the watershed were very limited. Consequently, 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 for fecal coliform to equal 0.6 d^{-1} at 20 •C with a temperature correction factor of 1.07. It is significant to note that the applied first order decay rate is considered conservative and serves to increase the margin of safety (MOS) in the TMDL development. The various monthly accumulation rates and limiting storage values were taken directly from the EPA's fecal coliform spreadsheet (USEPA, 1999d), as previously discussed.

Once all of the site specific sources of fecal coliform were incorporated into the model, an initial baseline run for the Biloxi River was made to indicate how the model would respond to the addition of the various loads. Overall correlation between field grab samples and simulated values are presented in Figure 4.13. As shown, the simulation results for fecal coliform are generally good and within the range of observed values.

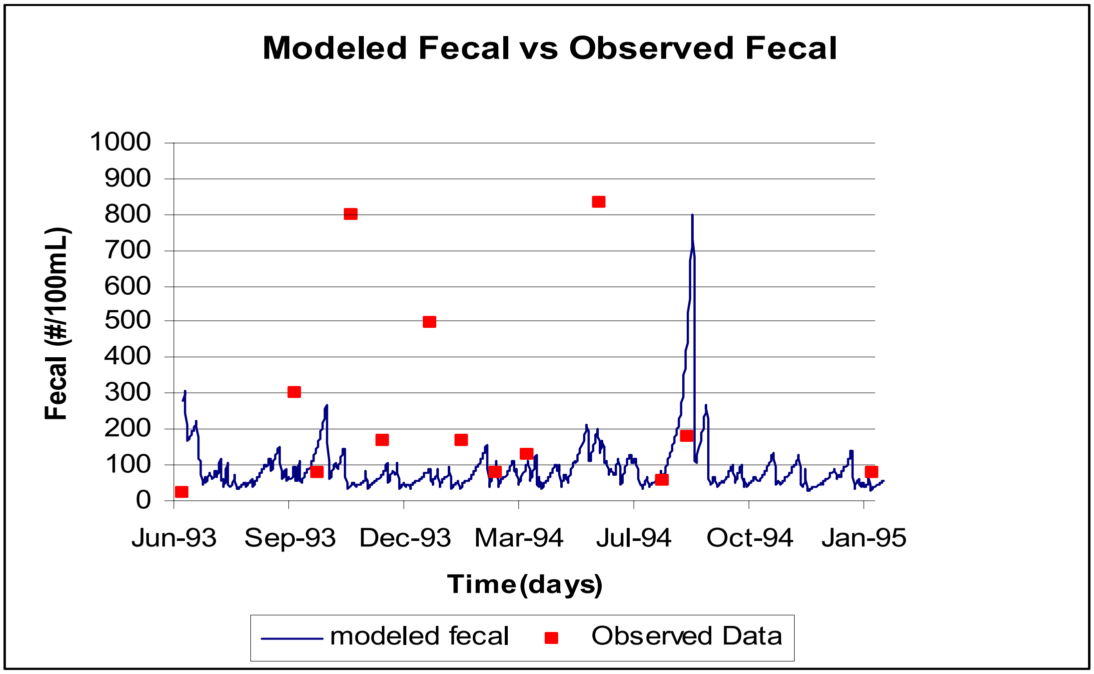


Figure 4.13: Watershed Fecal Coliform Profile in Biloxi River

Model Application

Fecal coliform levels in the watershed were simulated for theoretical wet (1995) and dry (1986) years. The wet and dry years were determined through a statistical analysis of average annual rainfall on the Mississippi Gulf Coast (Hashim, 2001) and will be explained in detail in chapter 5. Figures 4.14-4.17 depict the calculated 30-day geometric mean of fecal coliform concentration during each of these years for both the Old Fort Bayou and Bernard Bayou (Figure 4.1). Results are presented for a baseline simulation of 2 % cattle in stream access and 50% failing septic systems. As illustrated in Figures 4.14 and 4.15, no violations of the water quality standard of 200 MPN/100 ml occur for Old Fort Bayou during the baseline simulation. However, Figures 4.16 and 4.17 illustrate several violations for Bernard Bayou. In order to isolate the source of these violations, several runs were performed altering the values for cattle access to the stream and septic tank failure rates. By totally eliminating the load from cattle in the stream it became obvious that the high fecal coliform concentrations were attributed to septic tank failure. Because Bernard Bayou has approximately 100 cows and 418 septic tanks, this conclusion was easily validated. Finally, it was concluded that septic tank failure rate would have to be decreased to 20% in order to bring Bernard Bayou within water quality standards. Figures 4.18 and 4.19 illustrate the reduction scenario with Bernard Bayou meeting the 200 MPN/100ml standard.

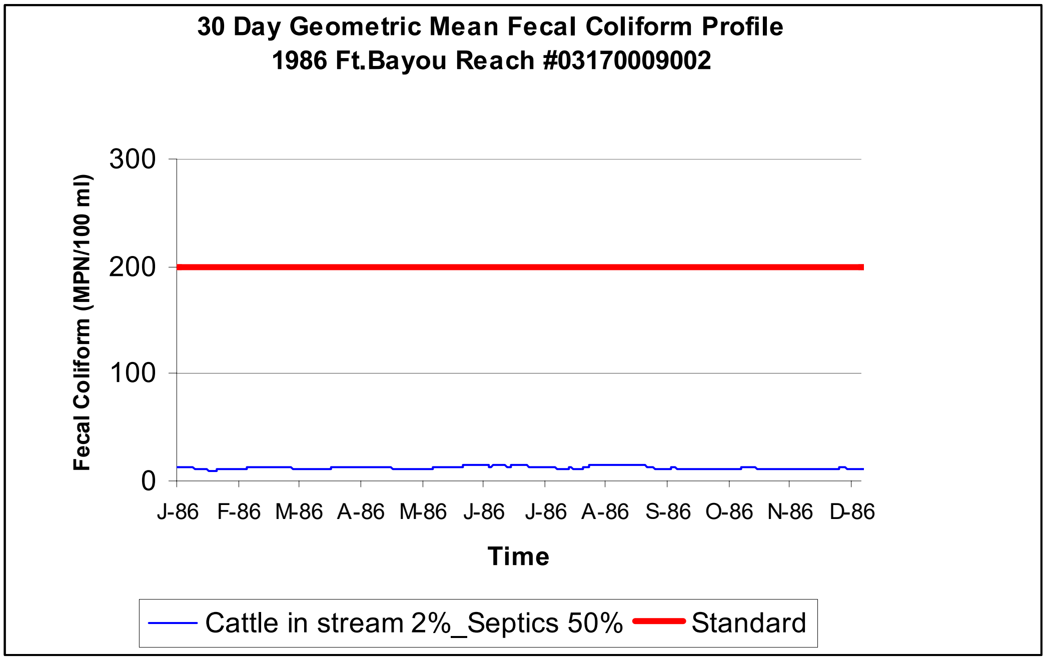


Figure 4.14: Dry Year Baseline Results from Fecal Analysis

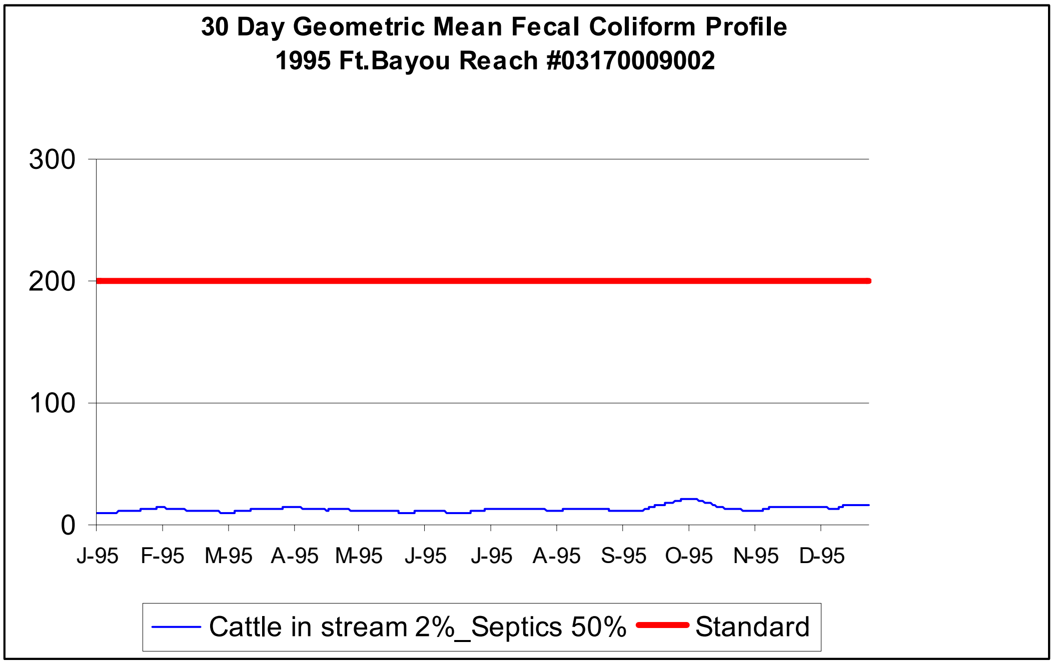


Figure 4.15: Wet Year Baseline Results from Fecal Analysis

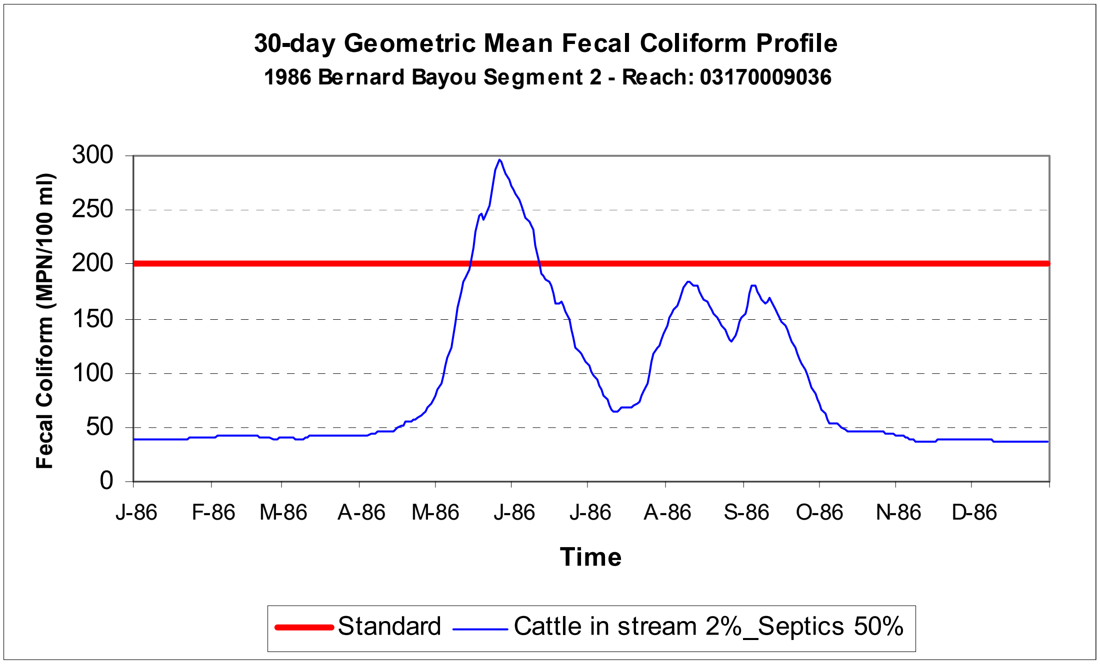


Figure 4.16: Dry Year Baseline Results from Fecal Analysis

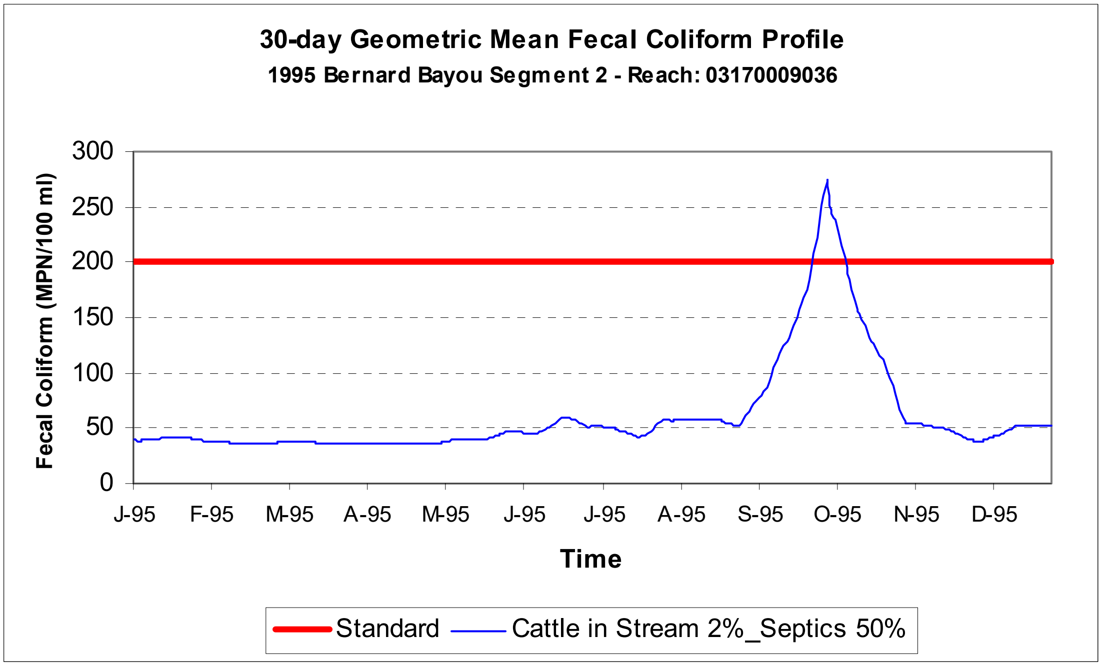


Figure 4.17: Wet Year Baseline Results from Fecal Analysis

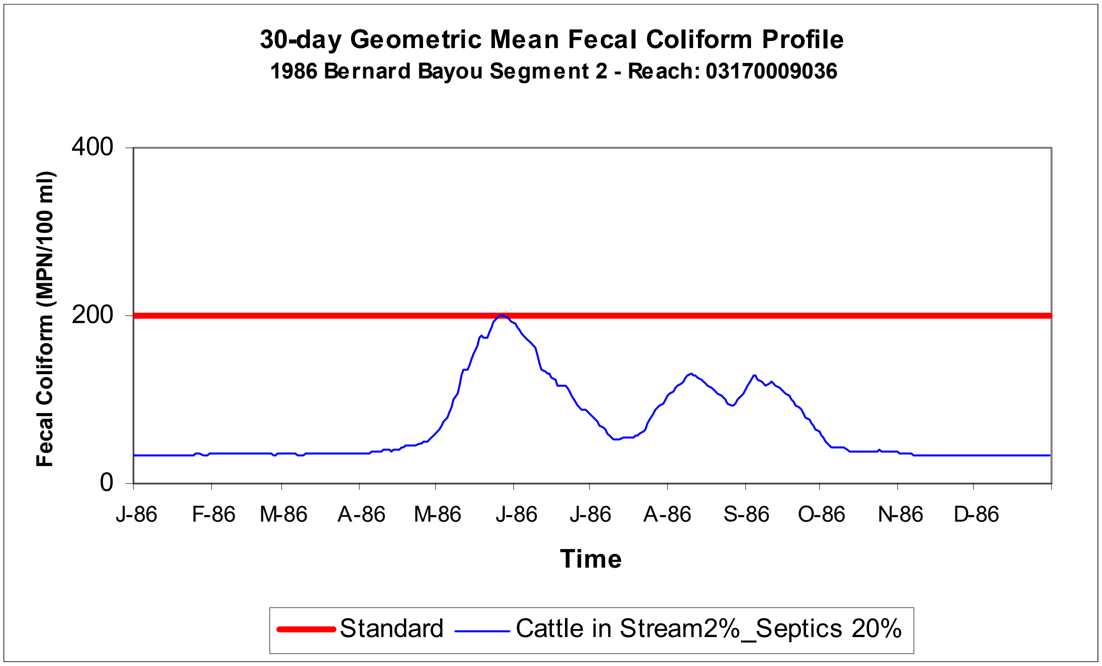


Figure 4.18: Dry Year Reduction Scenario for Bernard Bayou

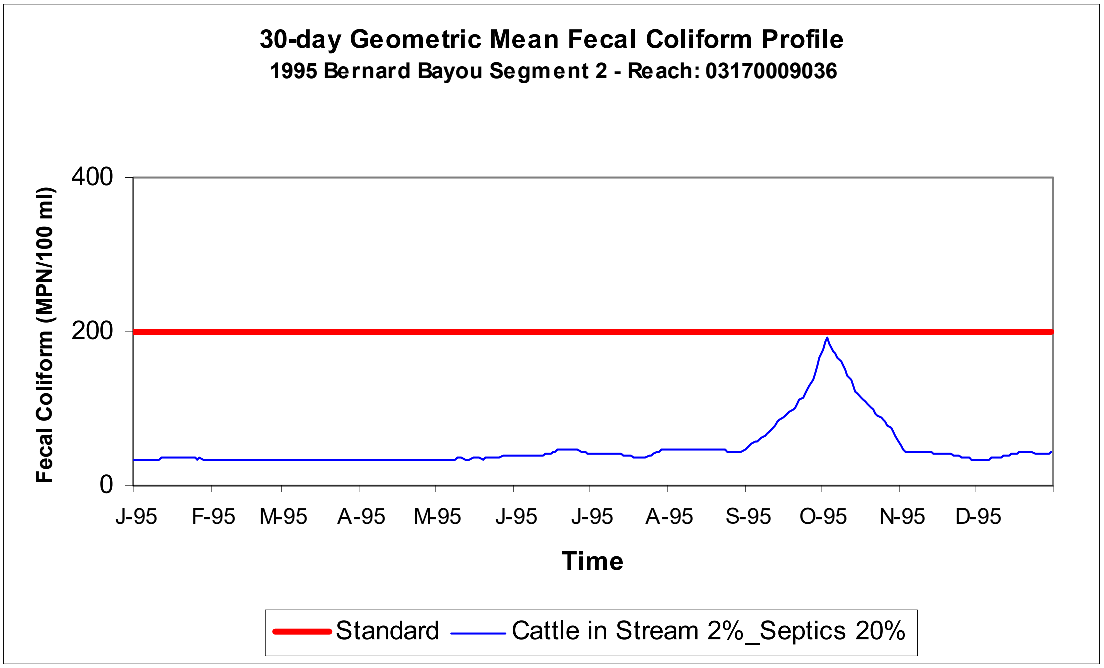


Figure 4.19: Wet Year Reduction Scenario for Bernard Bayou

CHAPTER V

BAY MODEL CALIBRATION, VERIFICATION, AND APPLICATION

The estuary or bay model was developed for the lower, tidally influenced region of the Back Bay of Biloxi watershed. The model includes fourteen combined small bayous and rivers as well as the entire Back Bay of Biloxi (Figure 5.1).

As stated in Chapter 3, the hydrodynamic and water quality models chosen to simulate the tidally influenced region of the watershed were DYNHYD5 and EUTRO5, respectively. These models represent two modules that are incorporated into WASP5. The model selection was attributed to the fact that the present study is simply an extension of the previous modeling work on the Back Bay of Biloxi (Shindala et al., 1996). Extensive hydrodynamic calibration/verification of DYNHYD5 was performed in 1996 and will not be repeated here. Thus, calibration/verification of only EUTRO5 for fecal coliforms will be presented.

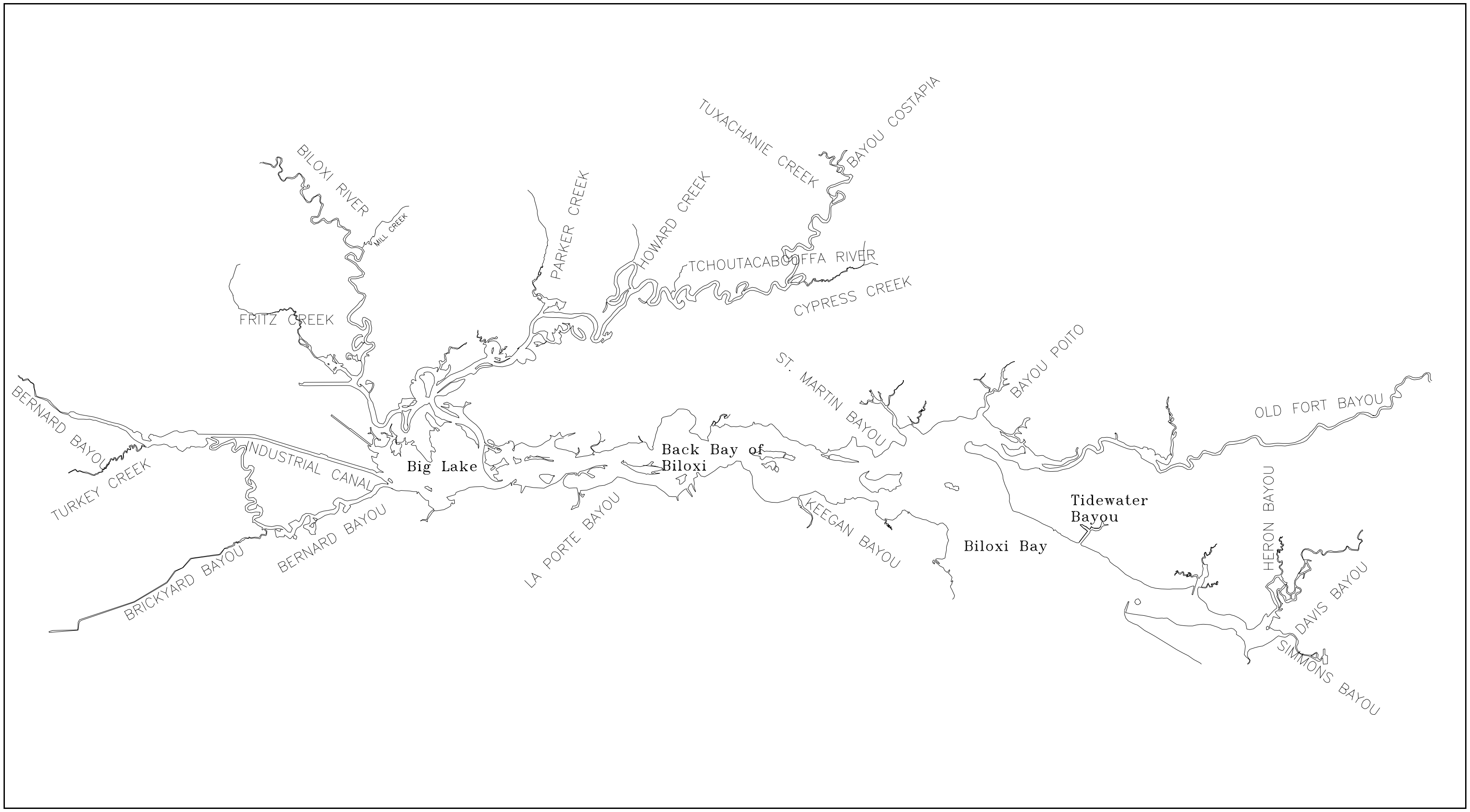


Figure 5.1: Waterbodies included in Bay Model

Grid Discretization

Model segmentations for both DYNHYD5 and EUTRO5 that were developed in the 1996 study of the Back Bay of Biloxi were retained for use in the present study. As shown in Figures 5.2 and 5.3, the grid geometry used to represent the Bay is two-dimensional in the lateral and longitudinal directions. By applying approximately equal surface areas to each cell, this type of grid is capable of representing the physical geometry of the waterbody. For the more narrow tributaries, a one-dimensional grid is used. The models assume the waterbodies are vertically mixed, therefore no vertical resolution is included in the segmentation (Shindala et al., 1996). The total number of computational cells included 669 cells and 641 cell for DYNHYD5 and EUTRO5, respectively (Figure 5.2, Figure 5.3). Additional segments in DYNHYD5 corresponding to EUTRO5 boundaries are denoted by a nominal segment number "0" (Figure 5.3). The additional segments in DYNHYD5 are necessary because, while flows are calculated only within the hydrodynamic network, EUTRO5 required boundary flows from outside of its network (Ambrose, et al., 1993).

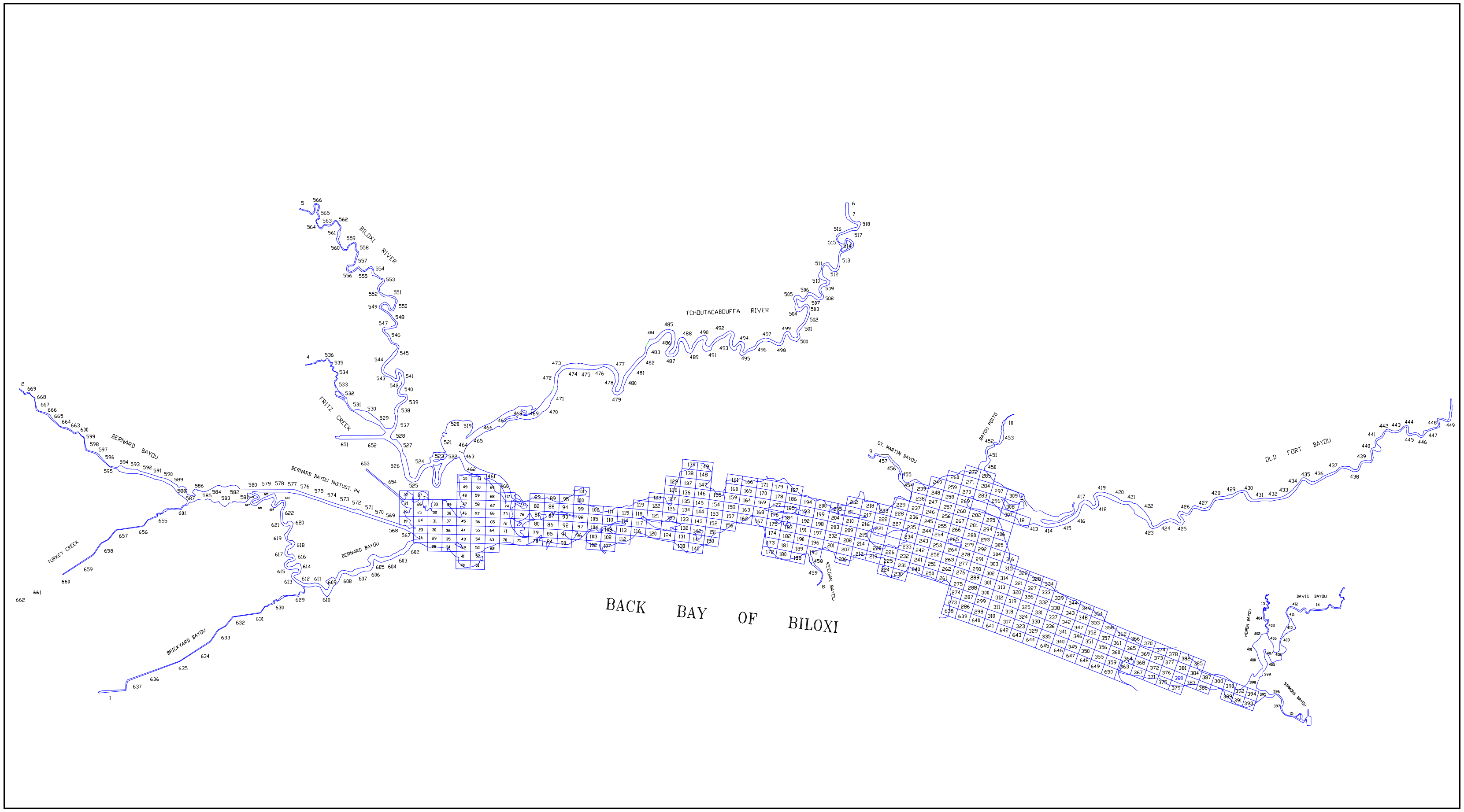


Figure 5.2: Back Bay of Biloxi DYNHYD5 Segmentation Map (Shindala et al., 1996)

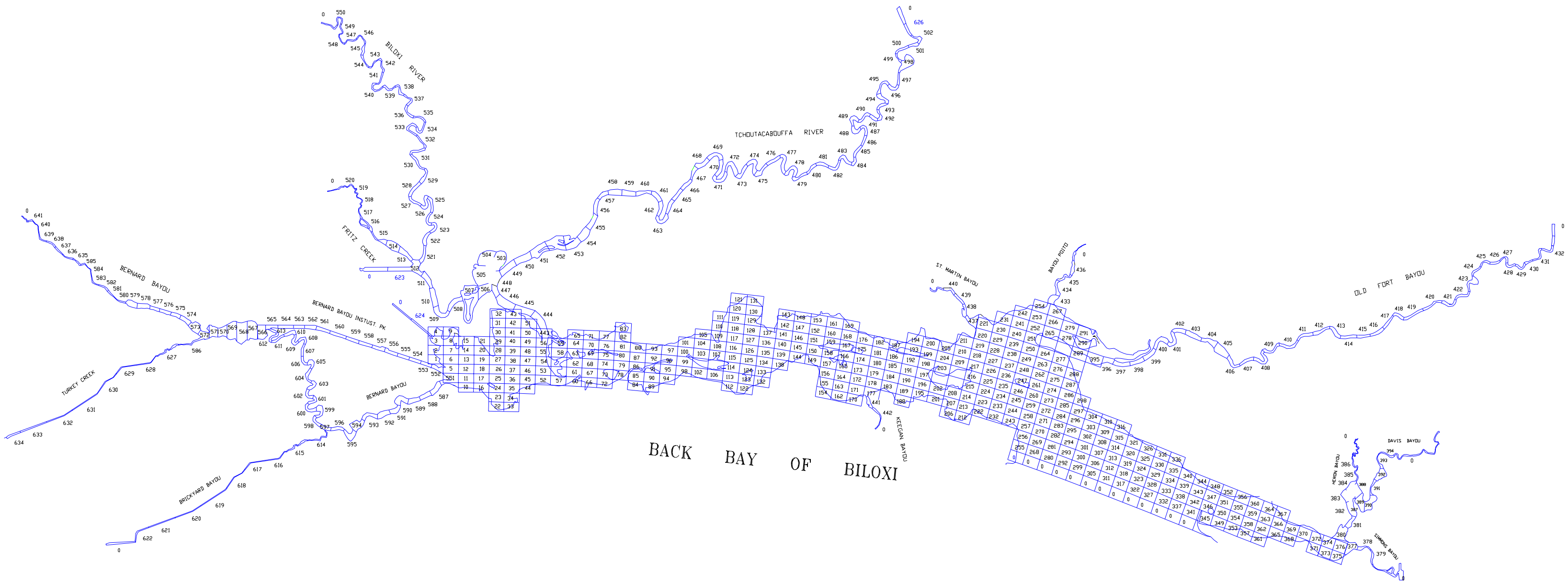


Figure 5.3: Back Bay of Biloxi EUTRO5 Segmentation Map (Shindala et al., 1996)

DYNHYD5 Model Calibration/Verification

The hydrodynamic parameters that were generated by Shindala et al., 1996 during the calibration/verification of DYNHYD5 were retained for this study. The only exception is that for the present study, the fresh water inflows at the upper boundaries will represent those generated by the watershed model rather than inputted, measured or simulated unit hydrographs, as was done in the 1996 study. Furthermore, the inflow/outflow from the Mississippi Power's Plant Watson were measured and applied as a constant over the calibration/verification period of the water quality model. Sample hydrodynamic calibration/verification profiles for tidal heights, velocity, and salinity are reproduced here as Figures 5.4-5.9 (Shindala et al., 1996).

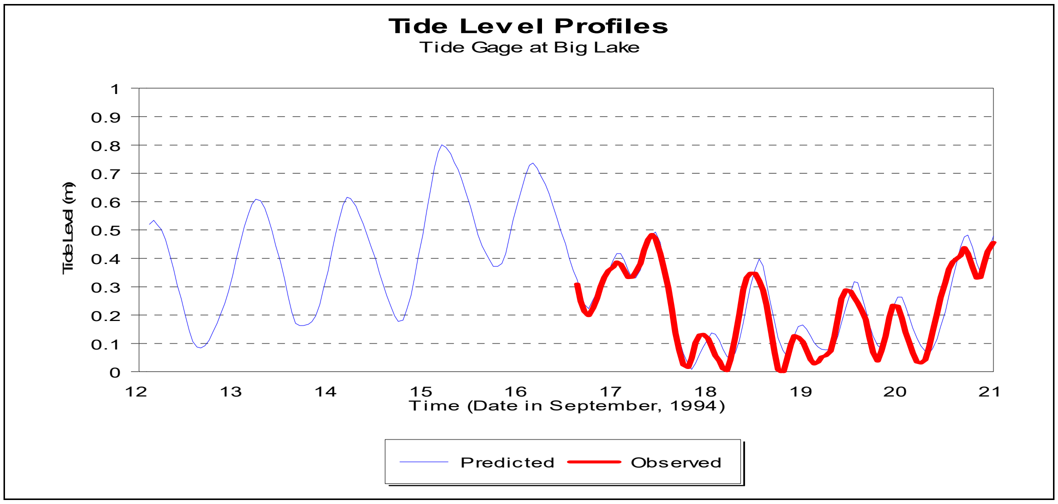


Figure5.4: Sample Tidal Profiles 1994 (Shindala et al., 1996)

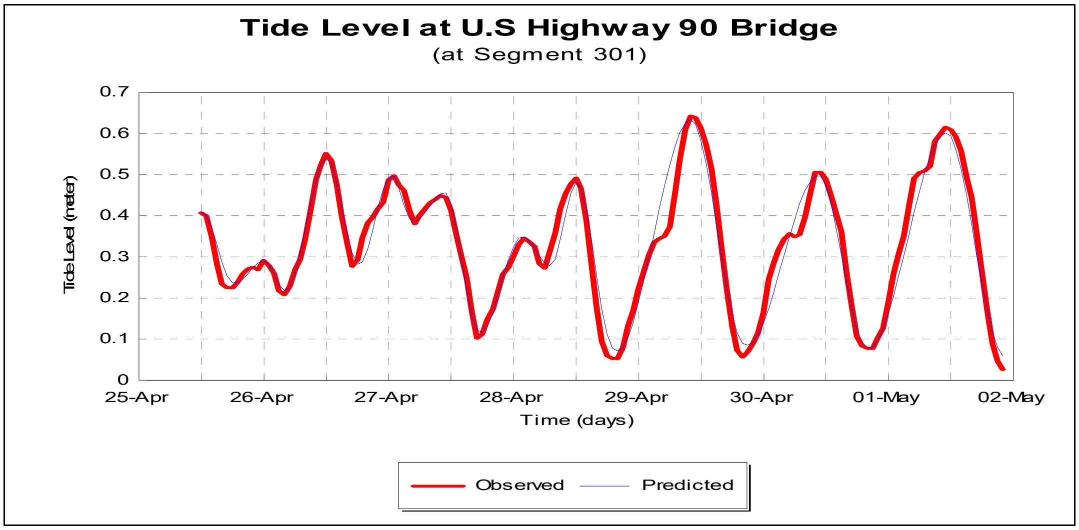


Figure 5.5: Sample Tidal Profiles 1995 (Shindala et al., 1996)

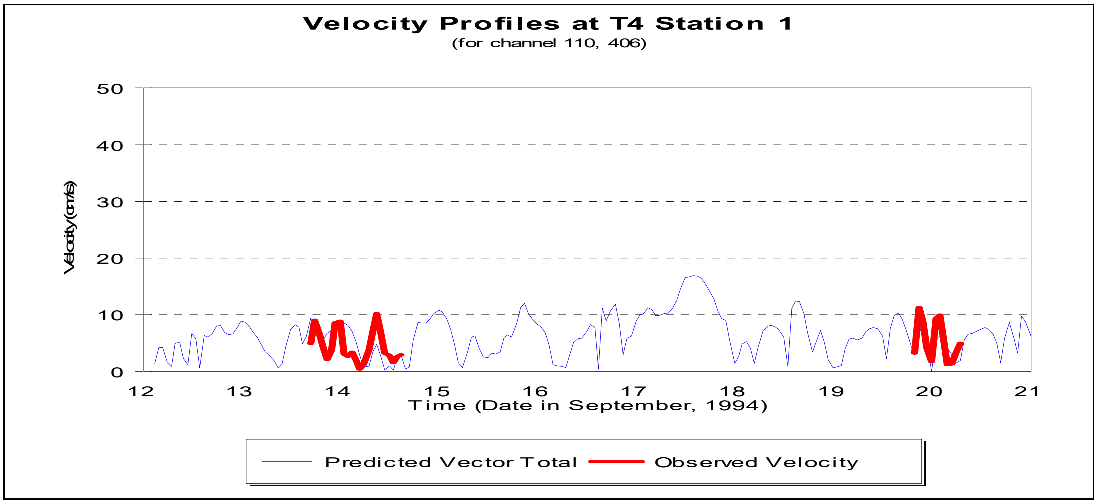


Figure 5.6: Sample Velocity Profiles 1994 (Shindala et al., 1996)

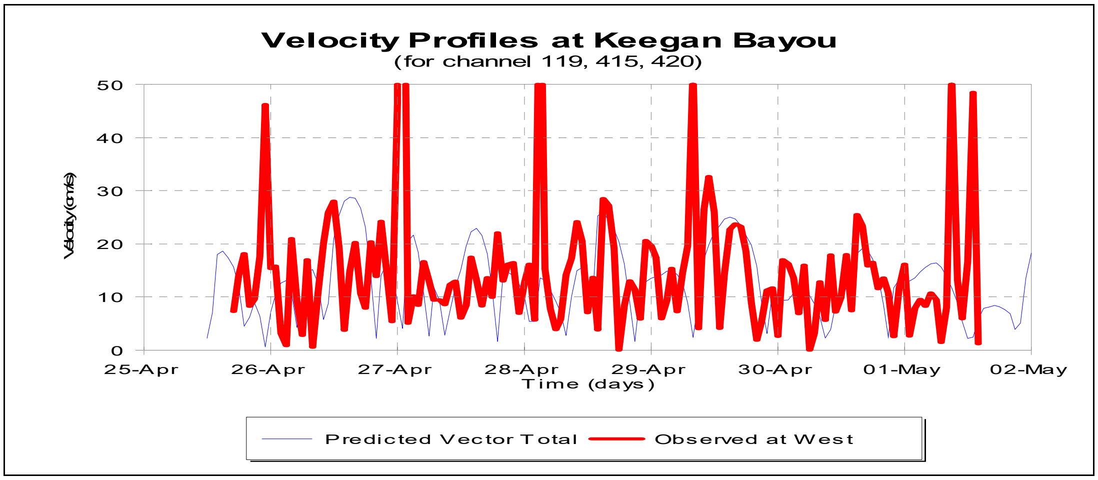


Figure 5.7: Sample Velocity Profiles 1995 (Shindala et al., 1996)

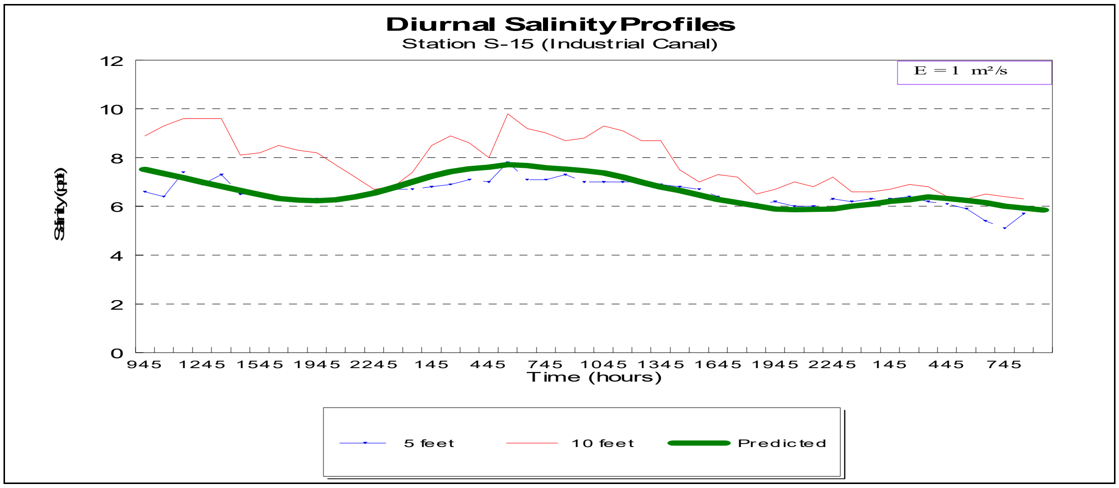


Figure 5.8: Sample Salinity Profiles 1994 (Shindala et al., 1996)

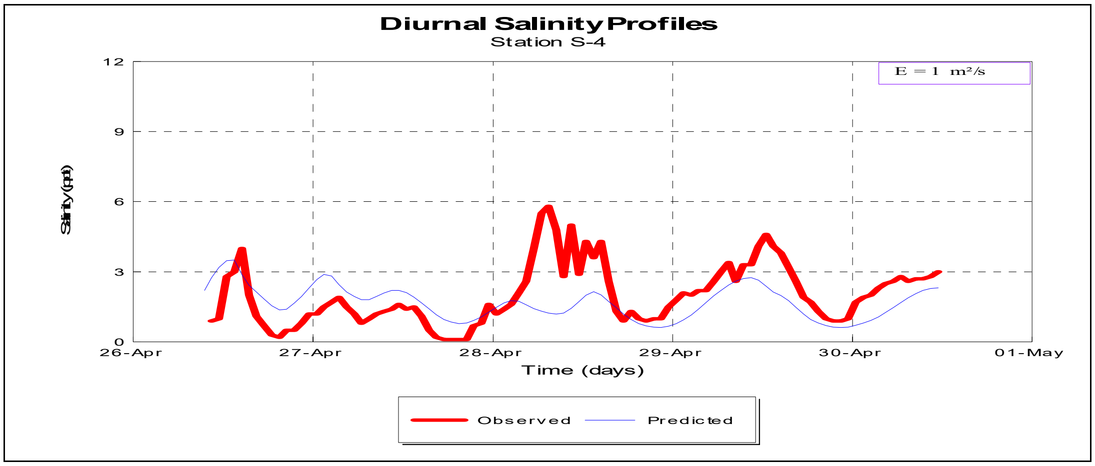


Figure 5.9: Sample Salinity Profiles 1995 (Shindala et al., 1996)

EUTRO5 Model Calibration/Verification

Like DYNHYD5, EUTRO5 was also previously developed and calibrated/verified for the Back Bay of Biloxi (Shindala et al., 1996). The work done in 1996 was performed to model dissolved oxygen, nutrients, and phytoplankton as part of a waste load allocation project. Although the 1996 work does not consider fecal coliform, it was used as a starting point for the development of a fecal coliform model for the Back Bay of Biloxi. The current model was calibrated/verified for fecal coliform using data collected by the MDEQ during the intensive surveys conducted September 12-20, 1994 and April 25- May 2, 1995.

The final calibration/verification basically consists of a arriving at a reasonable coliform rate of disappearance that will result in model simulation reasonably reproducing the observed data for fecal coliform. The method used in determining the values for this coefficient is trial and error. Value of coliform disappearance rate from a similar study performed on the Bay of St. Louis in Southwestern Mississippi was used as a starting point (Huddleston et al., 2001).

Data Requirements

In order to calibrate EUTRO5 for the Back Bay of Biloxi, there are several critical data requirements. The MDEQ provided most of the required data through intensive surveys performed September 12-20, 1994 and April 25- May 2, 1995. The study was performed specifically for the Back Bay of Biloxi study area and contains vital data for the development and calibration of the EUTRO5 model. Flow and fecal coliform concentration from municipal, industrial, and domestic sources discharging into the study area were obtained from the intensive surveys. Figures 5.10 and 5.11 illustrate the location of the waste sources within the study area, which were used to determine the cell number that receives each waste source discharge. For fecal coliform concentrations in seafood processors, a master composite sample of five facilities was used to calculate an average concentration that characterized all waste discharges from seafood processing facilities (Table 5.1). For all other point source discharges, a permitted value of 200 MPN/100ml was used to represent the effluent concentration of fecal coliform (Table 5.2, 5.3, and 5.4). In-situ fecal coliform concentrations were also measured at several sampling locations throughout the Bay and major tributaries. Figure 5.12 illustrates the locations of these sampling stations within the study area.

Table 5.1: Sampled Seafood Waste Loads (Shindala et al., 1996)

NAME OF FACILITY	FLOW (MGD)	Fecal Coliform (MPN/100ml)	Receiving Segment #
M&M Shrimp Co.	1.11	60	206
Gulf Pride Enterprises Inc.	0.7	130	206
Del's Seaway	0.54	20	201
C. F. Gollott & Sons Seafood	0.67	40	187
R. A. Lesso Seafood	0.67	40	201
Average of the above values	**0.738**	**58**	

Table 5.2: Industrial Waste Source

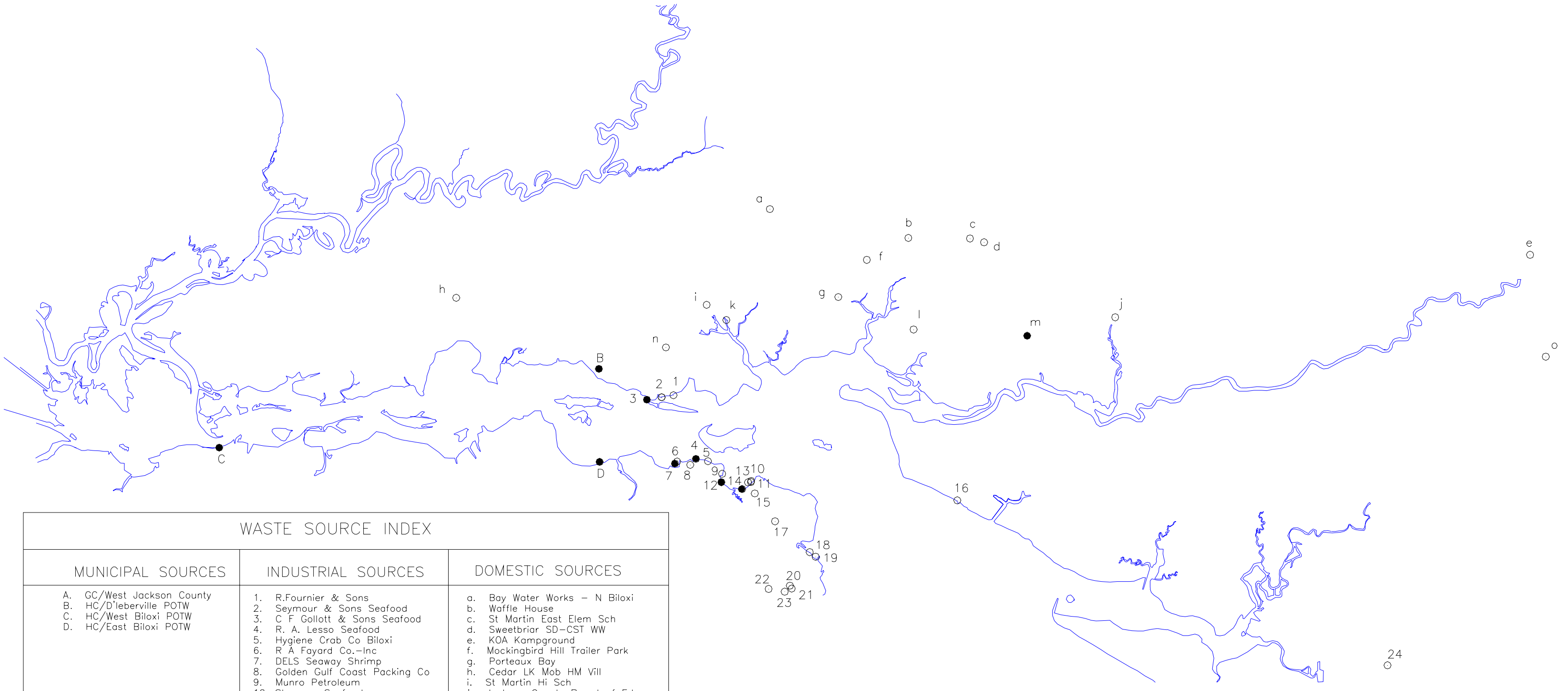
NAME OF FACILITY	FLOW (mgd)	Fecal Coliform (MPN/100ml)	Receiving Segment #	TRT
Arizona Chemical Corp. *	0.11	2200	3	AL
Bernard Bayou * IndustrialPark	0.25	50	570	AS
C F Gollott & Sons Seafood	0.67	40	187	EOP
Captain Dan's Seafood	0.074	58	212	EOP
Chemfax Inc-Gulfport	0.01	200	580	AW
Custom Pack	0.105	58	256	EOP
David Gollot Seafood	0.114	58	212	EOP
Dels Seaway Shrimp	0.54	20	201	EOP
Golden Gulf Coast	0.082	58	201	EOP
Gollott Brothers Seafood	0.105	58	212	EOP
Gulf Central Seafood	0.089	58	256	EOP
Gulf Pride EnterprisesInc	0.7	130	206	EOP
Hygiene Crab Co Biloxi	0.005	58	201	EOP
J & W Seafood	0.105	58	212	EOP
Ocean Springs Seafood .	0.072	58	316	EOP
R A Fayard Co. - Inc.	0.041	58	201	EOP
R. A. Lesso Seafood	0.67	40	201	EOP
R.Fournier & Sons	0.10	58	187	EOP
Sea Products-Inc	0.12	58	256	EOP
Sea Ranch (AC Foods)	0.374	200	256	OF
Sea Ranch-Inc.	0.374	58	256	PS
Seymour & Sons	0.034	725	187	EOP
Shemper Seafood	0.012	58	212	EOP
M&M Seafood	1.11	60	206	EOP
Weem's Brothers	0.108	58	256	EOP

Table 5.3: Waste Source Classification (Shindala et al., 1996)

TYPE	SYMBOL	CLASSIFICATION	SYMBOL	CLASSIFICATION
Facility	D	Domestic	N	Nonreporting Commercial
	F	Federal	P	Pretreatment
	I	Industrial	X	Nonreporting Industrial
	M	Municipal		
Treatment (TRT)	AC	Activated Carbon	NC	Non-Contact Cooling
	AS	Activated Sludge	OD	Off Site Disposal
	AL	Aerated Lagoon	OF	Overland Flow
	AN	Anaerobic Lagoon	OO	Oxidation Ditch
	API	API Separator	PH	pH Adjustment
	AW	Artificial Wetlands	PC	Physical Chemical
	CG	Contact Cooling	PS	Primary Sedimentation
	CL	Conventional Lagoon	RR	Recycle and Reuse
	CT	Cooling Tower	RO	Reverse Osmosis
	DW	Deepwell	RSC	Rotating Biological Contractor
	DF	Diffuser	SF	Sand Filter
	EOP	End of Pipe	SS	Secondary Sedimentation
	EV	Evaporation	SL	Spray Irrigation
	HC	Hydrograph Controlled	TF	Trickling filter
	ML	Multiple Lagoon		

Table 5.4: Municipal and Domestic Waste Sources

NAME OF FACILITY	FLOW (mgd)	Fecal Coliform (MPN/100ml)	Receiving Segment #	Type	TRT
Apple Valley MHP	0.0035	200	534	D	CL
Country Living Mobile Home PK	0.023	200	468	D	AL
Destination RV Park	0.003	200	500	D	AS
Direct Mail Specialist	0.009	200	430	D	AS
Eagle Point S/D	0.15	200	522	D	AL
EXXON Service Station	0.0015	200	516	D	AS
Flat Branch Settlement	0.03	200	584	N	CL
GC/West Jackson	1.6	200	500	M	AW
HC/ East Biloxi POTW *	6.0	20	170	M	TF
HC/West Biloxi POTW *	9.0	20	57	M	AS
HC/D'Iberville POTW *	1.16	170	169	M	OD
HC/ Gulfport POTW *	10.5	30	570	M	TF
Jackson County Board of Educ.		200	405	D	CL
KOA Kampground	0.008	200	430	D	AL
Mazalea Travel Park	0.0075	200	457	D	AS
Mockingbird Hill Trailer	0.054	200	435	D	AW
Parkwood SD-Mag. Utl	0.06	200	439	D	AS
Pine Haven Mobile Home Village	0.02	200	457	D	AL
Porteaux Bay	0.05	200	435	D	AS
St Martin East Elem Sch	0.015	200	435	D	AS
St Martin Hi Sch	0.015	200	435	D	AS
Sweetbriar SD-CST WW	0.3	200	435	D	AS
The Royal Gulf Hills	0.03	200	10	D	AS
Windsor Park *	0.5	230	402	D	AL
Woolmarket Elem	0.015	200	535	D	AL



WASTE SOURCE INDEX

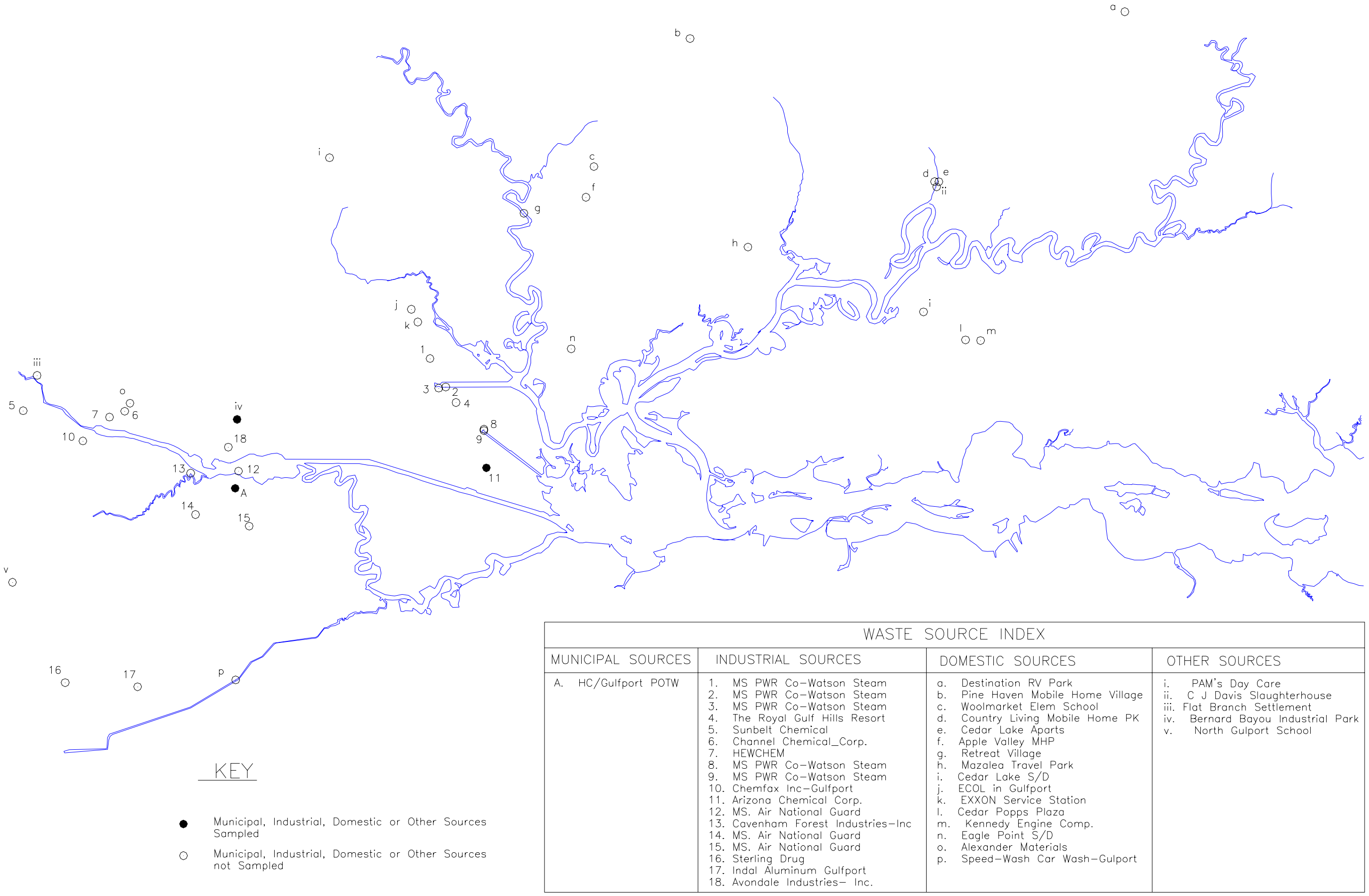
MUNICIPAL SOURCES	INDUSTRIAL SOURCES	DOMESTIC SOURCES
A. GC/West Jackson County	1. R.Fournier & Sons	a. Bay Water Works – N Biloxi
B. HC/D'Iberville POTW	2. Seymour & Sons Seafood	b. Waffle House
C. HC/West Biloxi POTW	3. C F Gollott & Sons Seafood	c. St Martin East Elem Sch
D. HC/East Biloxi POTW	4. R. A. Lesso Seafood	d. Sweetbriar SD–CST WW
	5. Hygiene Crab Co Biloxi	e. KOA Kampground
	6. R A Fayard Co.–Inc	f. Mockingbird Hill Trailer Park
	7. DELS Seaway Shrimp	g. Porteaux Bay
	8. Golden Gulf Coast Packing Co	h. Cedar LK Mob HM Vill
	9. Munro Petroleum	i. St Martin Hi Sch
	10. Shemper Seafood	j. Jackson County Board of Educ.
	11. Captain Dan's Seafood	k. Parkwood SD – Mag. Utl
	12. Suarez Seafood	l. The Royal Gulf Hills Resort
	13. David Gollot Seafood	m. Windsor Park
	14. Gulf Pride Enterprises Inc.	n. Thrifty Car Wash
	15. J & W Seafood	o. Direct Mall Specialist
	16. Ocean Springs Seafood Co.	
	17. Sea Ranch – Inc.	
	18. Sea Products – Inc.	
	19. Gulf Central Seafood	
	20. Custom Pack	
	21. Quality King	
	22. Henry & Biloxi Seafood	
	23. Dejean Packing Co	
	24. Sea Ranch	

KEY

● Municipal, Industrial, Domestic or Other Sources Sampled

○ Municipal, Industrial, Domestic or Other Sources not Sampled

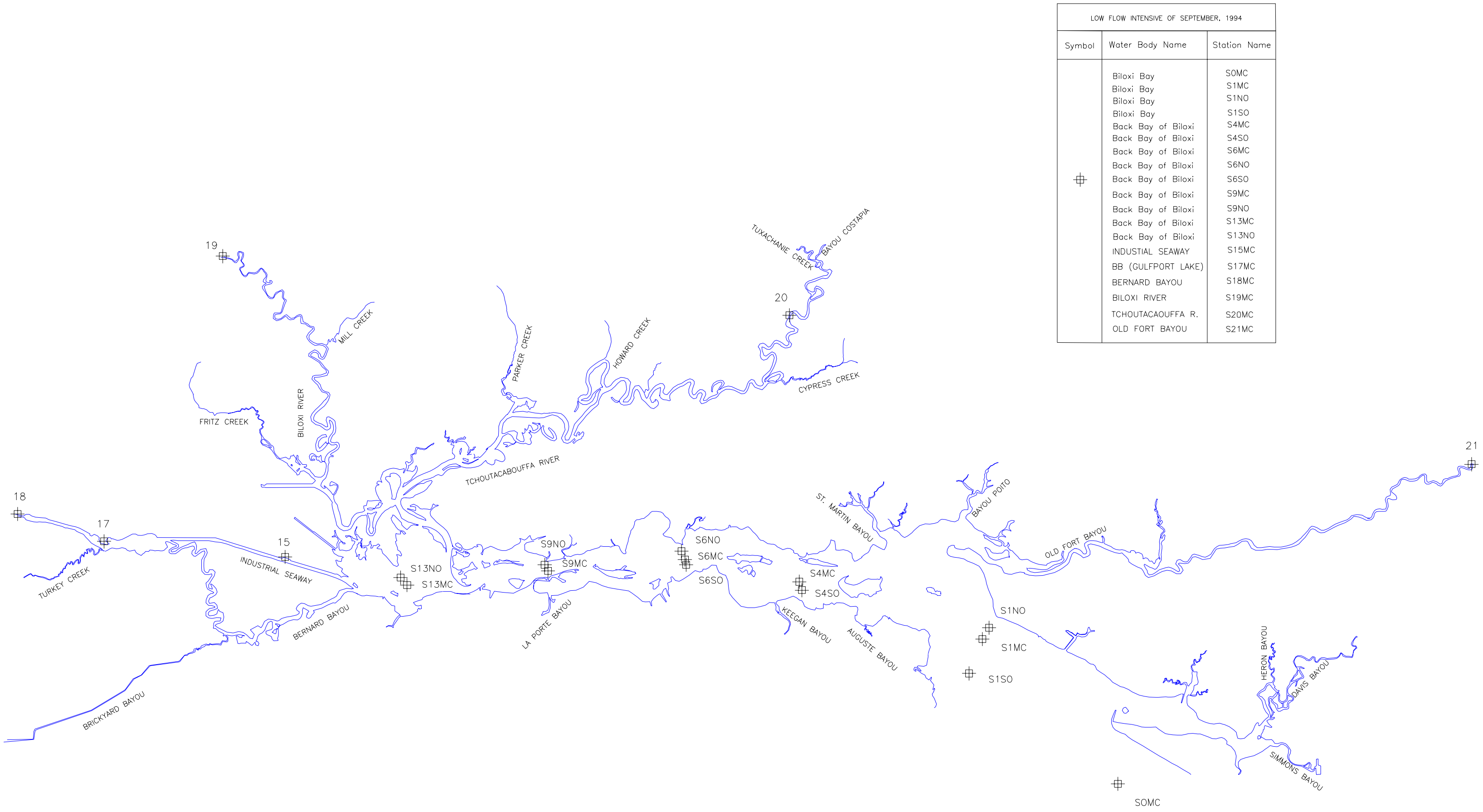
Figure 5.10: Locations of Waste Loads for Back Bay of Biloxi (Map_1)



WASTE SOURCE INDEX			
MUNICIPAL SOURCES	INDUSTRIAL SOURCES	DOMESTIC SOURCES	OTHER SOURCES
A. HC/Gulfport POTW	1. MS PWR Co–Watson Steam 2. MS PWR Co–Watson Steam 3. MS PWR Co–Watson Steam 4. The Royal Gulf Hills Resort 5. Sunbelt Chemical 6. Channel Chemical_Corp. 7. HEWCHEM 8. MS PWR Co–Watson Steam 9. MS PWR Co–Watson Steam 10. Chemfax Inc–Gulfport 11. Arizona Chemical Corp. 12. MS. Air National Guard 13. Cavenham Forest Industries–Inc 14. MS. Air National Guard 15. MS. Air National Guard 16. Sterling Drug 17. Indal Aluminum Gulfport 18. Avondale Industries– Inc.	a. Destination RV Park b. Pine Haven Mobile Home Village c. Woolmarket Elem School d. Country Living Mobile Home PK e. Cedar Lake Aparts f. Apple Valley MHP g. Retreat Village h. Mazalea Travel Park i. Cedar Lake S/D j. ECOL in Gulfport k. EXXON Service Station l. Cedar Popps Plaza m. Kennedy Engine Comp. n. Eagle Point S/D o. Alexander Materials p. Speed–Wash Car Wash–Gulport	i. PAM's Day Care ii. C J Davis Slaughterhouse iii. Flat Branch Settlement iv. Bernard Bayou Industrial Park v. North Gulport School

KEY	
●	Municipal, Industrial, Domestic or Other Sources Sampled
○	Municipal, Industrial, Domestic or Other Sources not Sampled

Figure 5.11: Location of Waste Loads for Back Bay of Biloxi (Map_2)



LOW FLOW INTENSIVE OF SEPTEMBER, 1994		
Symbol	Water Body Name	Station Name
⌖	Biloxi Bay	S0MC
	Biloxi Bay	S1MC
	Biloxi Bay	S1NO
	Biloxi Bay	S1SO
	Back Bay of Biloxi	S4MC
	Back Bay of Biloxi	S4SO
	Back Bay of Biloxi	S6MC
	Back Bay of Biloxi	S6NO
	Back Bay of Biloxi	S6SO
	Back Bay of Biloxi	S9MC
	Back Bay of Biloxi	S9NO
	Back Bay of Biloxi	S13MC
	Back Bay of Biloxi	S13NO
	INDUSTIAL SEAWAY	S15MC
	BB (GULFPORT LAKE)	S17MC
	BERNARD BAYOU	S18MC
	BILOXI RIVER	S19MC
	TCHOUTACAOUFFA R.	S20MC
	OLD FORT BAYOU	S21MC

Figure 5.12: Location of MDEQ Water Quality Sampling Stations (Shindala et al., 1996)

Freshwater flows at the upstream boundaries were generated by the watershed model. Fecal coliform levels were either generated from the watershed model, where applicable, or set at a constant arbitrary value of 20 MPN/100ml, which was based on the author's experience. Fecal coliform levels in urban stormwater runoff were based on data collected during urban stormwater monitoring studies throughout the United States (Pitt, 1998; Center of Watershed, 1999). Water temperatures within the study area were provided by the USGS (Table 5.5).

Table 5.5: Back Bay of Biloxi Water Temperature (USGS, 2001)

Water Temperature in Degrees Celsius	
Month	**Temperature**
January	14
February	16
March	21
April	22
May	26
June	30
July	30
August	30
September	28
October	24
November	18
December	11

Boundary Conditions

To reiterate, boundary concentrations for fecal coliform are specified for the twenty eight boundary segments in the Back Bay of Biloxi EUTRO5 model. The calibrated watershed model provided fecal coliform concentrations for Biloxi River, Tchoutacabouffa River, Old Fort Bayou, Turkey Creek, and Bernard Bayou. The remaining ten upstream boundaries were set at a constant background fecal coliform concentration value of 20 MPN/100ml. The thirteen seaward values were also set at a constant background fecal coliform concentration of 20 MPN/100ml based on 1994 and 1995 intensive survey data.

Initial Conditions

Initial conditions for the Back Bay of Biloxi study area include initial concentrations, flows and segment volumes. An original fecal coliform concentration of 14 MPN/100ml, representing the standard for shellfish harvesting, was applied to each of the 641 segments in the EUTRO5 model. Flow and volumes were obtained from the output file (*.hyd) created by the calibrated DYNHYD5 model.

In order to ensure that the model was given ample time to stabilize before the actual calibration/verification period was reached, a forty-day warmup period was provided previous to the intensive survey dates.

EUTRO5 Calibration/Verification Results

The EUTRO5 model was calibrated using September 12-21, 1994 intensive survey data. Verification was performed used April 25-May 2, 1995 intensive survey data. Due to limited in-situ data, the fecal coliform decay rate could not be specifically determined within the Back Bay of Biloxi. Therefore, reference to a similar study performed on the St. Louis Bay in Southwestern Mississippi was made in order to obtain a fecal coliform die-off rate and temperature correction factor. The values taken from that study were a first order fecal coliform die-off rate of 1.0/day at 20^0 C and temperature correction factor of 1.07 (Hashim 2001). These two values were assumed to remain constant for both calibration and verifications runs.

Fecal coliform calibration in the Back Bay of Biloxi was performed by varying concentrations in stormwater runoff from small watersheds surrounding the Bay. The initial set of Event Mean Fecal Coliform Concentration (EMC) calibration parameters were based upon the Bay St Louis study, which varied with landuse as shown in Table 5.6. It should be noted that fecal coliform loading from urban storm water constitutes a composite value that results from numerous sources including combined sewer overflows, sanitary sewer overflows, illegal sanitary connections to storm drains, transient wastewater dumping into storm drains, failing septic systems, domestic animals, and other small animals in urban areas (Hashim 2001). Several iterations were made, with the EMC ranging from 500 MPN/100ml to 20,000 MPN/100ml. EMC values were the major contributor to fecal coliform loading, therefore adjustments made to the values greatly influenced the final concentrations in the Bay. In the future, site-specific EMC data would be very helpful in further understanding the fecal coliform loadings in the Bay and their sources. Graphical comparisons between simulated and observed fecal coliform levels resulted in the final calibration values for urban runoff (EMC) concentration as summarized in Table 5.7. The EMC values were applied to the model by taking a weighted average fecal coliform concentration based on landuse for each small watershed as illustrated in Table 5.8. The location of each small watershed can be seen in Figure 4.1.

Table 5.6: EMC Values from Bay St. Louis Study (Hashim, 2001)

Land Use Type	**EMC Values for January, February, December (MPN/100ml)**	**EMC Values for March-October (MPN/100ml)**
Urban/barren	2,000	20,000
Pastureland	250	2,500
Cropland	250	2,500
Forest	10	100

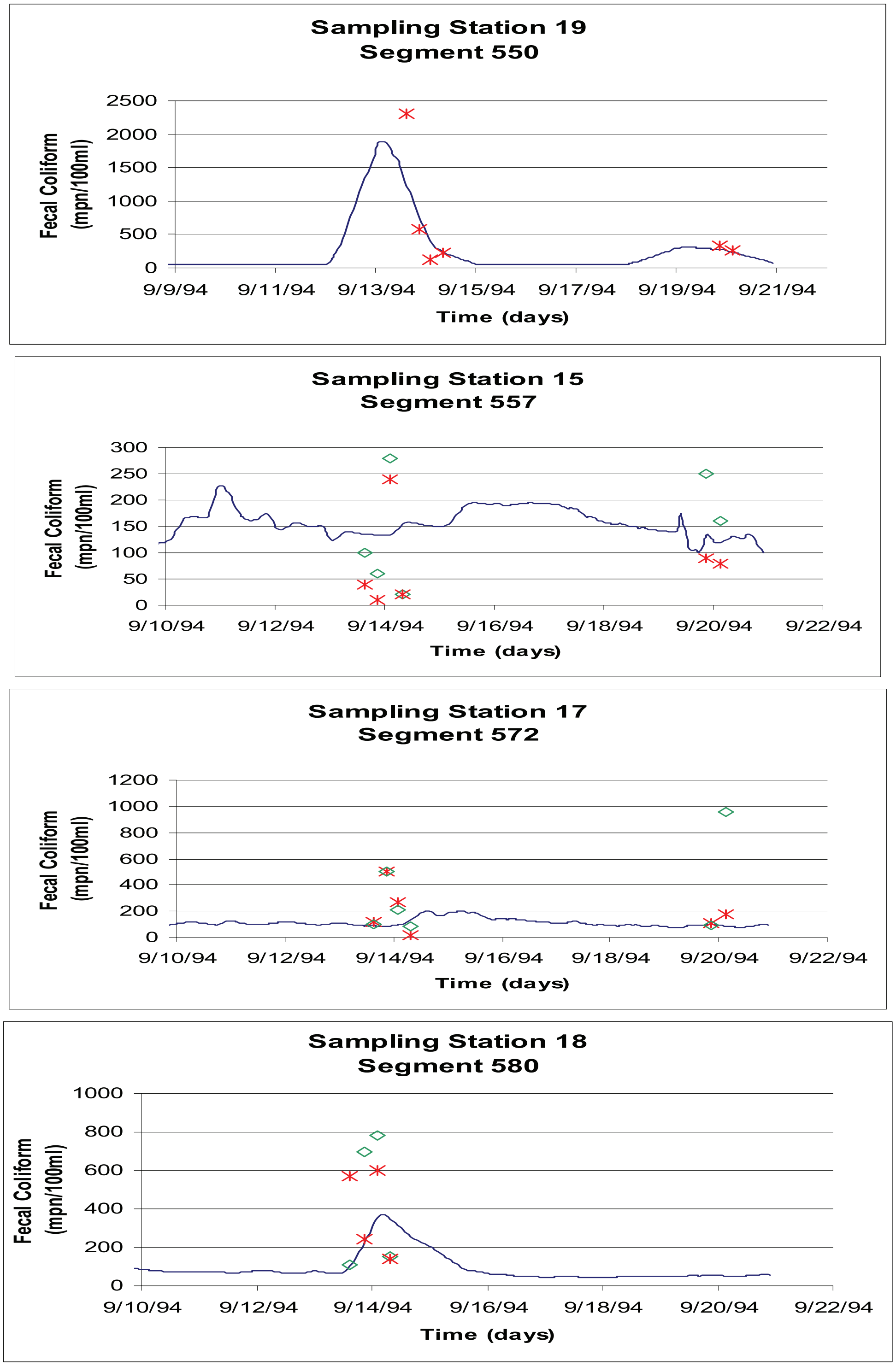
Table 5.7: Back Bay of Biloxi Calibrated EMC Values

Land Use Type	EMC Values (MPN/100ml)
Urban/barren	1,000
Pastureland	2500
Cropland	2500
Forest	100

Table 5.8: Modeled EMC Values for Small Watersheds

Watershed ID #	Waterbody Name	Receiving Segment	Modeled EMC Value MPN/100ml
W0	Brickyard Bayou	614	970
W1		571	877
W2		597	664
W4	La Porte Bayou	89	1000
W6	Keegan Bayou	177	1000
W7	Auguste Bayou	206	1000
W9		577	594
W10	Fritz Creek	513	558
W11		567	691
W12		30	357
W13		535	254
W14	Parker Creek	457	404
W15	Howard Creek	468	299
W18		194	572
W22	St. Martin Bayou	221	625
W23	Porto Bayou	433	284
W24		402	112
W26	Tidewater Bayou	326	978
W27		360	619
W28	Heron/Davis Bayous	380	223

Results of the EUTRO5 water quality calibration/verification are presented in Figures 5.13 and 5.14. Modeled fecal coliform concentrations are compared to field data collected by the MDEQ in September 12-20, 1994 and April 25 – May 2, 1995. The locations of the sampling sites are shown in Figure 5.12. Figure 5.13 illustrates the results for the calibration period from September 12-21, 1994. Figure 5.14 shows the results for the verification period from April 25 – May 2, 1995. These figures represent a reasonable comparison in water quality trends between model simulation and field data for fecal coliform. It should be noted that the observed in-situ fecal coliform levels are based on single grab samples collected at specific depths at each location. However, EUTRO5 is a single-layer vertically mixed model and thus is not capable of predicting fecal coliform concentration with depth.



Note: ● - Top Sample ●- Bottom Sample

Figure 5.13: Fecal Coliform CalibrationProfiles, September 12-21, 1994

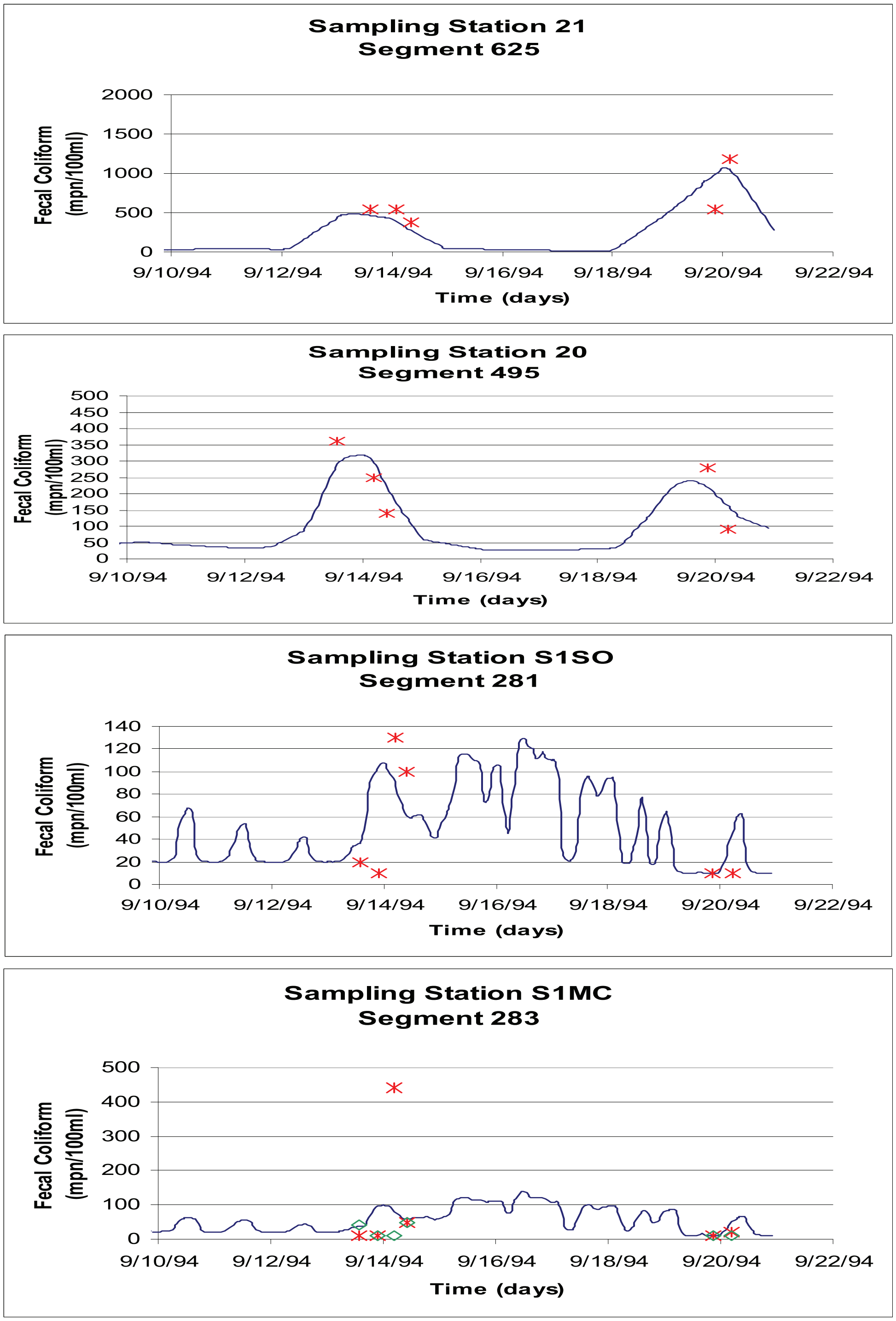


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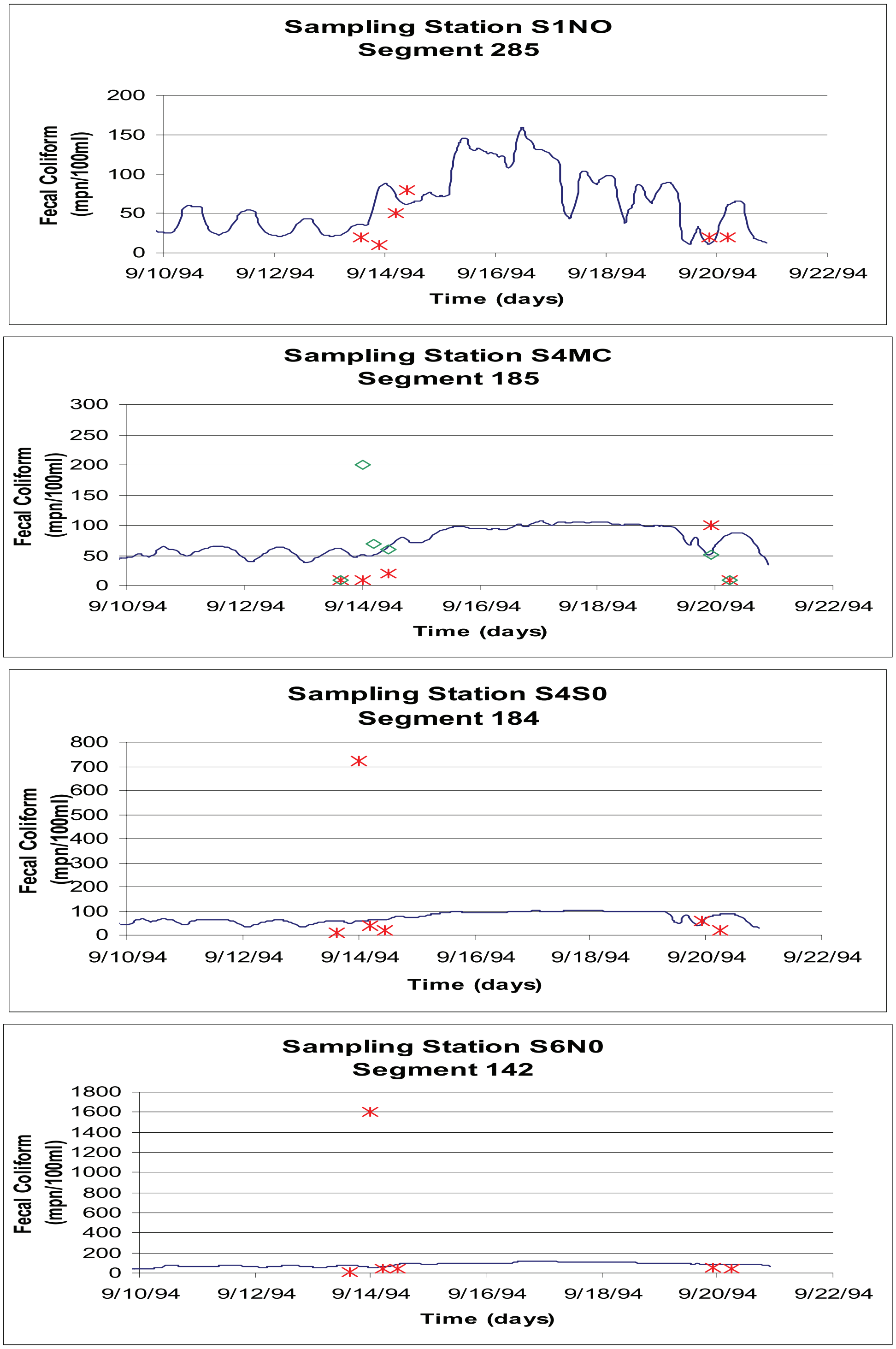
Figure 5.13 (Continued)



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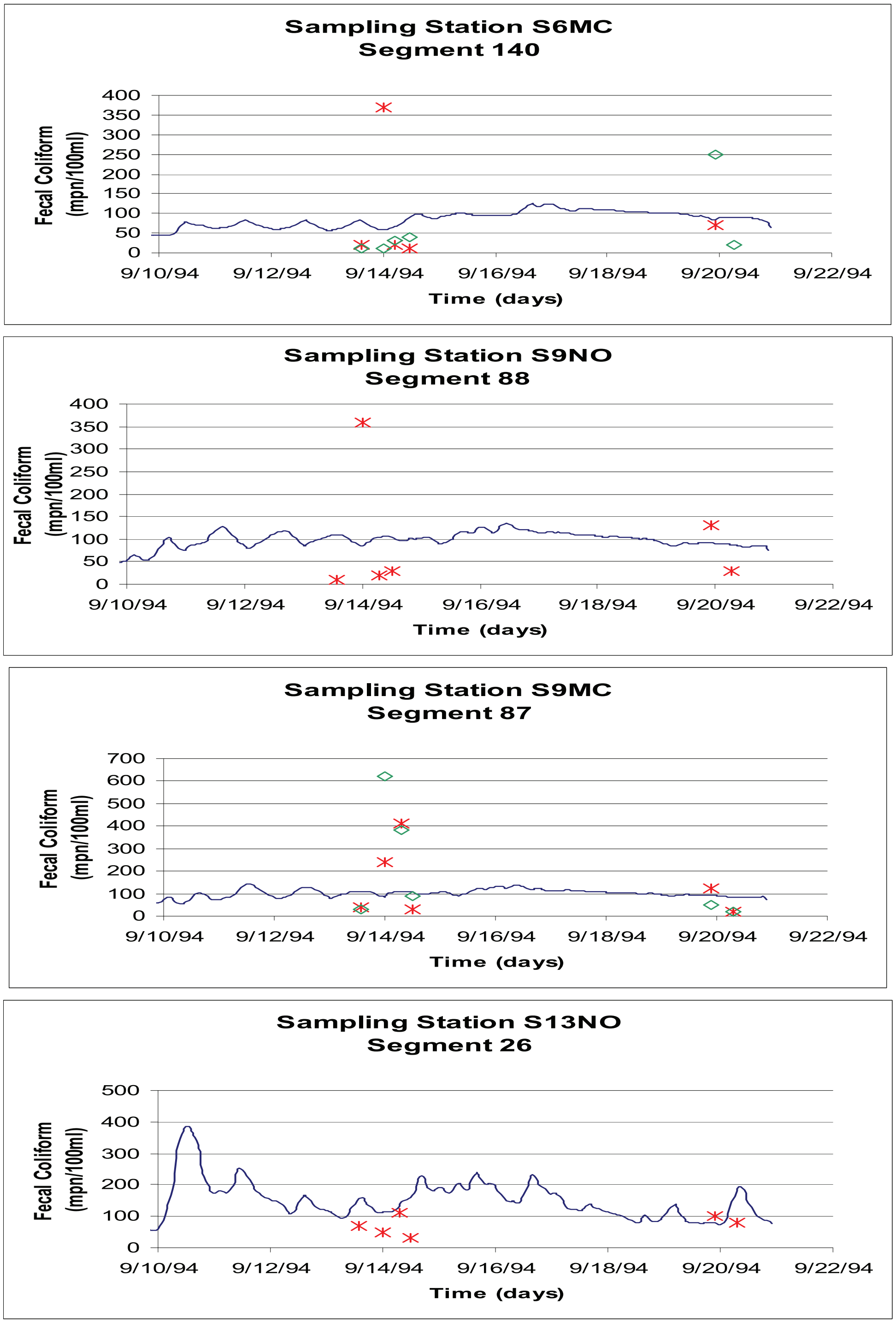

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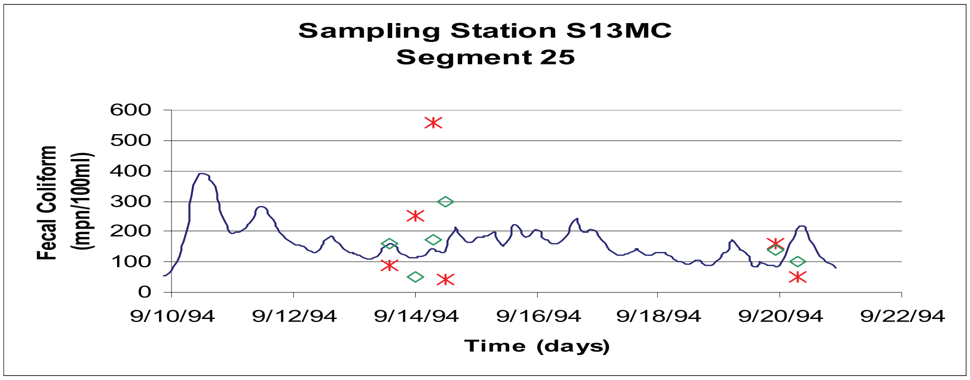

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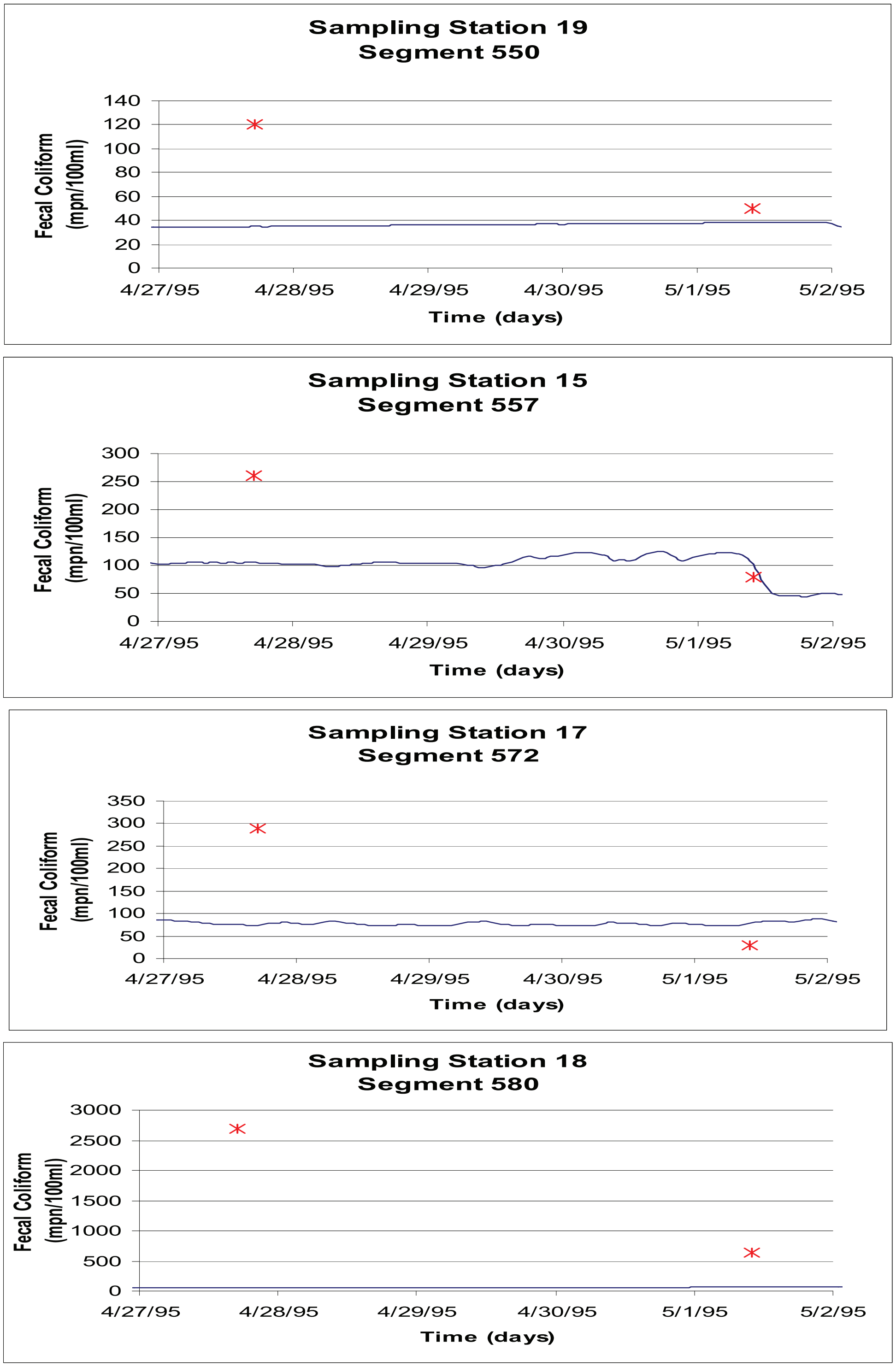
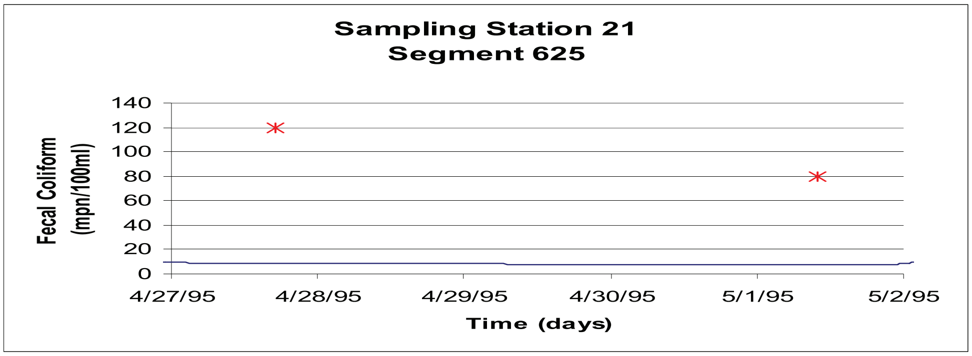
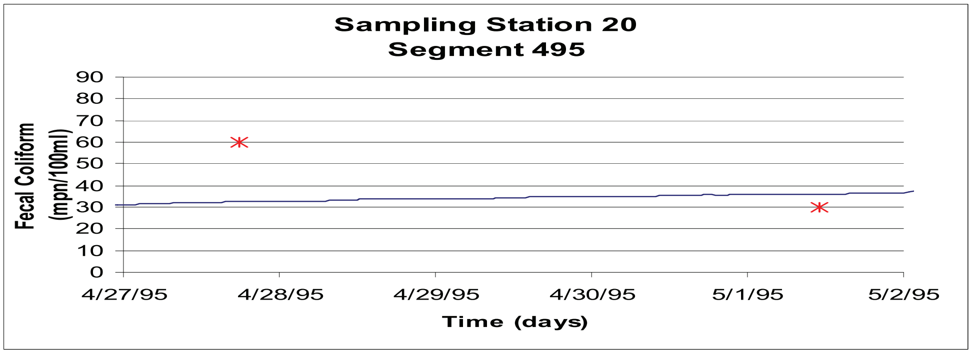
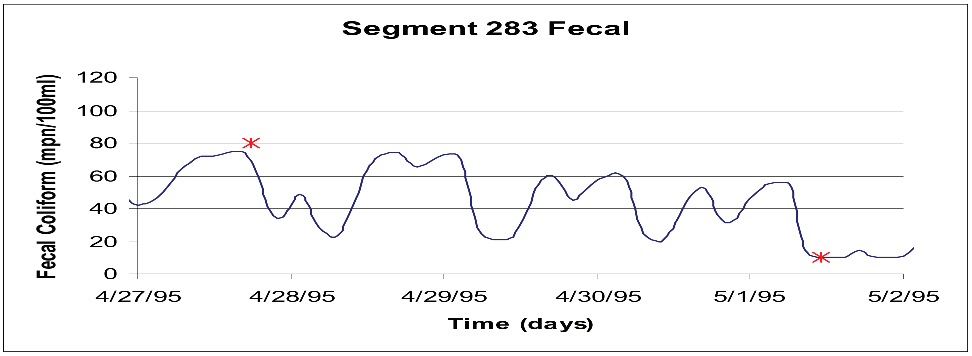


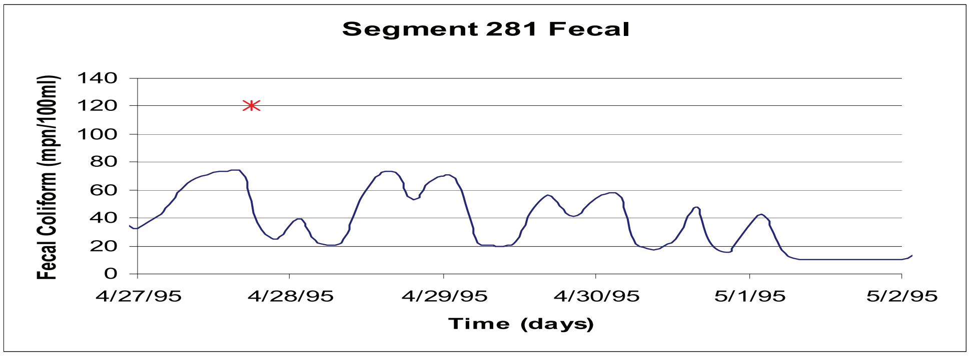
Note: ● - Top Sample ●- Bottom Sample

Figure 5.14: Fecal Coliform Verification Profiles, April 27-May 2, 1995



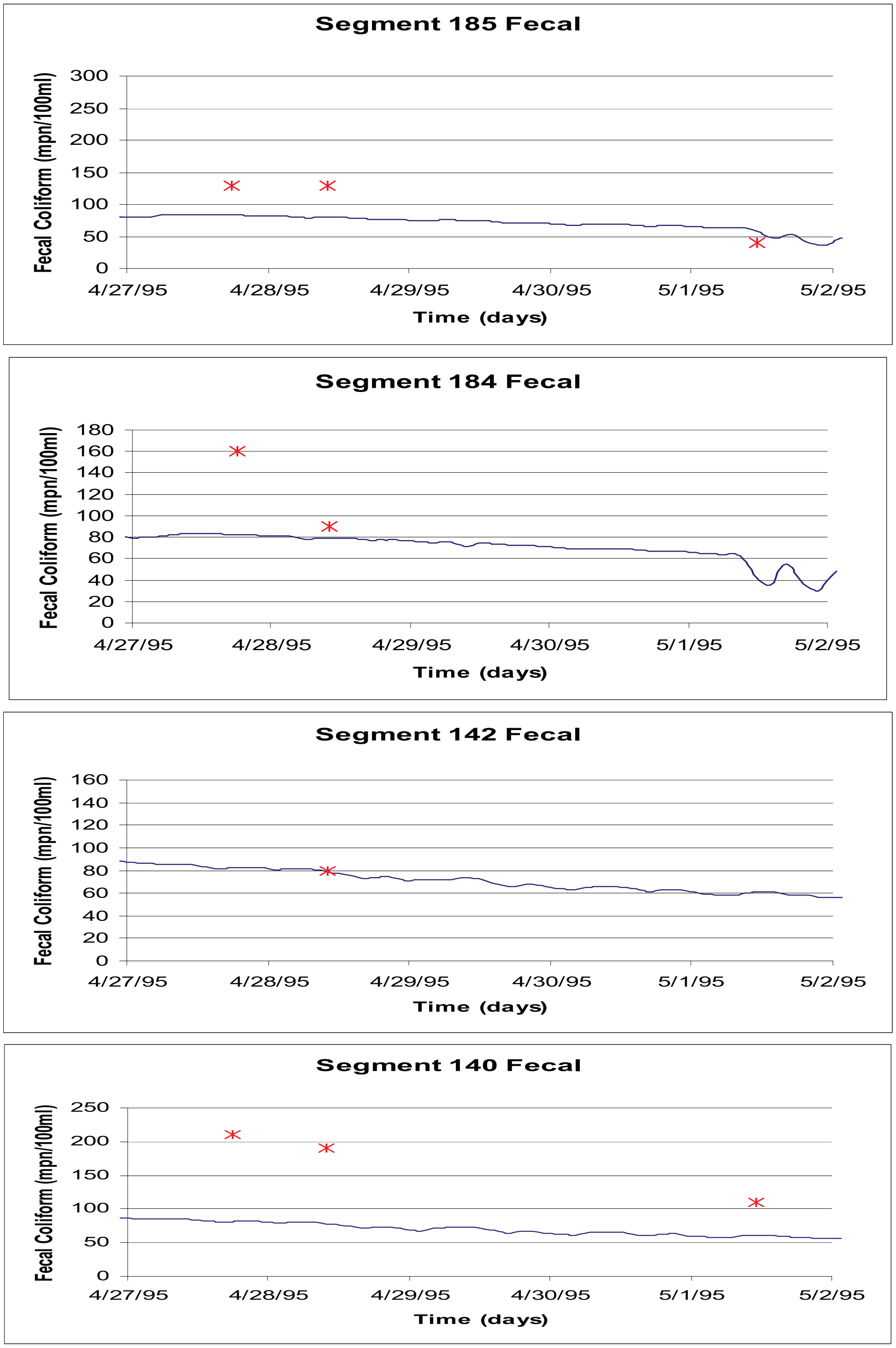






Note: ● - Top Sample ●- Bottom Sample

Figure 5.14 (Continued)



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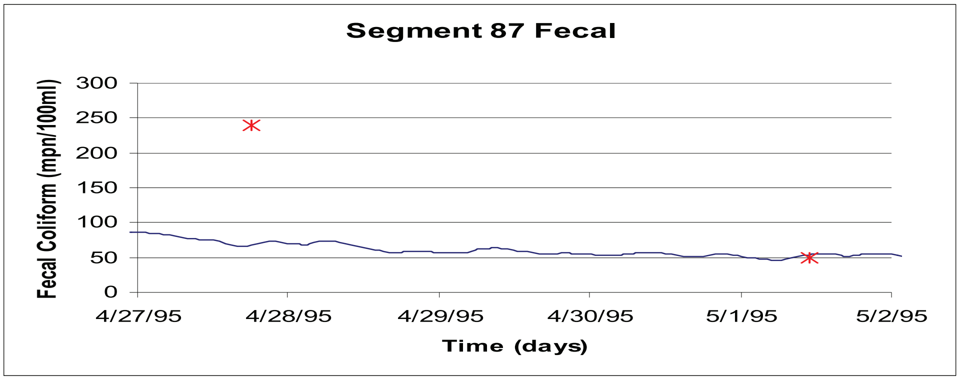
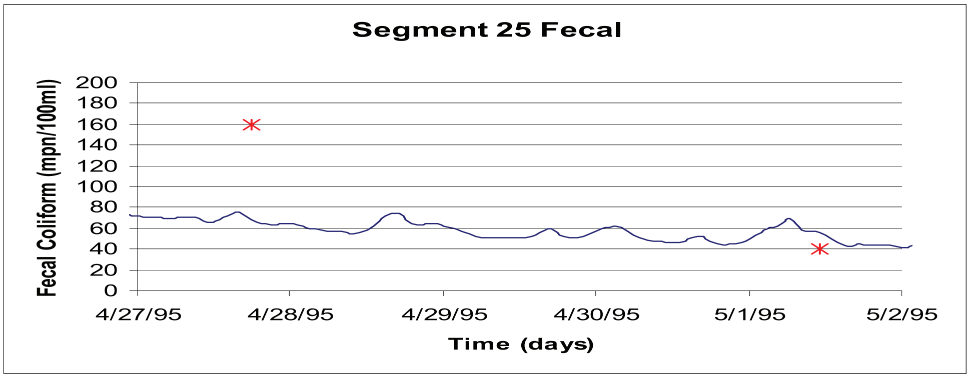




Note: ● - Top Sample ●- Bottom Sample

Figure 5.14 (Continued)

DYNHYD5 and EUTRO5 Application

The ultimate goal of this project was to develop and demonstrate the application of both DYNHYD5 and EUTRO5 models to predict fecal coliform levels in the Back Bay of Biloxi. The models can then be used to develop a TMDL for fecal coliform. The calculation of a TMDL provides a basis for the Mississippi Department of Environmental Quality (MDEQ) to formulate a plan for the Back Bay of Biloxi to maintain water quality standards for fecal coliform.

Design Conditions

In order to insure the maintenance of water quality standards under various combinations of point and non-point sources, freshwater flows, precipitation, and temperature extremes, a specific critical timeframe must be identified for TMDL development. These conditions were determined to be approximately ten-year return period dry year and wet year. According to a statistical analysis of the mean annual rainfall distribution performed over several rainfall stations along the Mississippi Gulf Coast, it was determined that 1986 and 1995 satisfies the 10 year return period requirements for dry and wet years, respectively (Hashim, 2001). Tables 5.9 and 5.10 show the results of the statistical analysis indicating how the “wet” and “dry” conditions were obtained. Once the historical wet and dry years were identified, the model was applied to the Bay watershed and TMDL values were developed.

Table 5.9: Summary of Annual Rainfall Distribution (Hashim, 2001)

YEAR	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
65	6.87	5.46	7.08	0.94	3.62	5.66	4.92	6.25	7.20	1.55	3.34	5.31	58.20
66	10.63	12.25	4.19	5.86	4.82	3.95	5.46	6.23	2.99	2.45	2.23	5.21	66.28
67	5.51	4.41	1.57	3.52	3.21	4.39	4.57	7.48	7.58	7.09	0.59	8.43	58.34
68	2.16	2.63	2.28	2.63	3.77	3.24	4.24	3.99	4.09	1.58	5.04	7.14	42.77
69	5.02	3.33	8.16	6.18	4.33	0.54	9.63	9.31	1.13	2.01	2.04	5.65	57.32
70	3.99	4.41	7.10	1.73	5.53	5.21	6.73	8.24	3.12	6.84	1.62	6.36	60.88
71	2.36	7.32	4.10	0.84	2.40	3.60	5.51	6.65	8.95	0.62	3.02	7.32	52.69
72	10.08	4.24	6.03	1.90	10.64	2.43	5.44	3.26	2.62	2.38	5.42	8.25	62.69
73	2.71	4.33	10.76	10.19	4.63	4.17	4.26	6.24	12.13	3.24	4.24	6.33	73.23
74	6.35	5.46	5.96	9.38	5.79	3.18	4.20	6.45	6.79	0.47	5.49	4.91	64.43
75	4.66	3.01	5.31	7.56	7.09	6.64	9.46	9.43	7.48	3.75	4.11	4.38	72.89
76	1.76	3.85	4.57	1.24	6.86	5.12	4.46	2.87	3.14	5.35	5.93	5.40	50.53
77	6.43	3.68	6.84	3.89	3.97	1.75	5.33	9.95	9.00	3.06	6.74	4.11	64.75
78	10.27	2.96	3.38	3.70	10.82	6.58	7.33	5.78	3.03	0.00	3.83	4.75	62.43
79	6.15	10.95	4.28	8.81	5.57	1.83	14.40	4.25	7.46	1.71	6.58	4.78	76.76
80	4.95	1.75	14.27	13.55	14.01	2.37	5.77	1.62	4.17	4.50	3.47	1.26	71.70
81	0.73	11.12	2.81	1.07	3.17	5.37	4.50	6.03	3.00	1.33	0.79	5.85	45.76
82	3.72	7.92	5.31	6.17	2.30	4.82	7.73	5.81	2.00	2.41	6.62	7.39	62.19
83	5.23	11.53	7.13	11.46	3.92	9.26	3.55	6.50	6.32	2.16	4.55	8.92	80.52
84	4.24	5.79	4.21	3.00	4.37	4.93	6.05	9.38	1.92	3.56	2.98	3.07	53.50
85	5.62	6.13	6.02	2.14	1.81	4.25	9.41	8.42	10.19	11.20	1.78	4.71	71.67
86	2.81	3.83	4.65	2.14	3.55	3.89	2.66	4.22	4.72	4.97	8.40	4.93	50.77
87	7.83	8.43	7.88	1.95	6.79	4.29	4.55	10.82	1.13	0.21	4.25	4.04	62.17
88	3.86	10.52	10.13	5.40	1.79	1.92	8.80	12.22	10.68	1.87	2.57	3.76	73.52
89	2.98	1.23	5.12	4.04	6.45	10.73	11.88	3.10	3.84	2.31	9.21	6.70	67.60
90	6.64	10.19	6.22	3.61	7.08	3.41	3.51	2.78	2.29	2.89	2.78	4.83	56.24
91	17.28	4.11	6.15	11.29	14.04	6.42	5.20	4.95	4.86	6.11	2.76	6.10	89.26
92	11.24	8.60	6.23	3.03	1.57	8.05	6.71	8.48	4.12	0.36	11.65	6.27	76.31
93	12.88	3.17	6.94	4.33	5.52	6.41	10.41	5.33	5.41	7.05	3.61	3.61	74.66
94	4.12	1.73	5.24	4.70	3.79	6.68	10.23	3.96	5.53	6.01	4.51	4.98	61.48
95	7.16	5.97	11.80	9.07	12.88	3.71	7.34	5.01	1.91	3.64	6.30	5.55	80.34
96	6.02	3.49	8.41	9.27	4.41	5.52	7.01	6.87	3.62	2.70	2.03	6.84	66.19
97	6.81	7.73	4.69	6.13	8.43	8.00	11.15	3.62	0.76	5.01	9.55	3.02	74.90
98	16.18	5.47	9.78	3.80	0.73	1.98	8.69	3.38	14.78	1.88	4.45	2.17	73.28
Mean	6.33	5.79	6.31	5.13	5.58	4.71	6.80	6.14	5.23	3.30	4.49	5.36	65.18
	Standard Deviation												10.64

Table 5.10: Statistical Analysis of Annual Precipitation (Hashim, 2001)

	Probabilities and Return Periods (Normal Distribution)					Mean	Std Dev
						65.18	10.64
				Probability of Less Than		**Probability of Exceedance**	
				Prob(P(x)=<))		Prob(P(x)=>))	
Year	Ppt, (x)	PDF, f(x)		F(x)	Tr, yrs	1-F(x)	Tr, yrs
	in				1/F(x)		1/(1-F(x))
	5	4.20929E-09		0			
	10	5.38259E-08	1.45088E-07	1.45088E-07	6892374.943	0.99999985	1.000000145
	15	5.51874E-07	1.51425E-06	1.65934E-06	602650.4294	0.99999834	1.000001659
	20	4.53685E-06	1.27218E-05	1.43812E-05	69535.46551	0.99998562	1.000014381
	25	2.99044E-05	8.61032E-05	0.000100484	9951.794738	0.99989952	1.000100494
	30	0.000158046	0.000469876	0.00057036	1753.2784	0.99942964	1.000570686
	35	0.000669725	0.002069427	0.002639787	378.8183778	0.99736021	1.002646774
	40	0.002275497	0.007363056	0.010002844	99.97157133	0.98999716	1.010103912
	42.8	0.004098577	0.008923704	0.018926548	52.83583655	0.98107345	1.019291673
	45	0.006199009	0.021186267	0.031189111	32.06247232	0.96881089	1.032193188
86	**50**	0.013540493	0.049348756	0.080537866	12.41651965	0.91946213	1.087592369
	55	0.023714439	0.093137329	0.173675195	5.757874624	0.8263248	1.21017788
	60	0.033301013	0.142538629	0.316213825	3.162417081	0.68378618	1.462445478
	65	0.037494559	0.176988929	0.493202753	2.027563702	0.50679725	1.973175676
	70	0.033848954	0.178358782	0.671561536	1.48906682	0.32843846	3.044710374
	75	0.024501263	0.145875544	0.81743708	1.223335746	0.18256292	5.477563571
	80	0.014219945	0.096803021	0.914240101	1.09380457	0.0857599	11.66046146
95	**80.3**	0.013666893	0.004183026	0.918423126	1.088822756	0.08157687	12.25837612
	85	0.006617189	0.047667593	0.966090719	1.035099479	0.03390928	29.49045119
	85.3	0.006276093	0.049857465	0.968280592	1.032758488	0.03171941	31.52643918
	90.3	0.002310868	0.021467405	0.989747996	1.010358196	0.010252	97.54190782
	95.3	0.000682224	0.007482732	0.997230729	1.002776962	0.00276927	361.1058005
	100.3	0.00016149	0.002109286	0.999340014	1.000660421	0.00065999	1515.184666
	105.3	3.065E-05	0.00048035	0.999820364	1.000179668	0.00017964	5566.820072
	110.3	4.66424E-06	8.82855E-05	0.99990865	1.000091359	9.135E-05	10946.87564
	115.3	5.69112E-07	1.30834E-05	0.999921733	1.000078273	7.8267E-05	12776.79431
	120.3	5.56776E-08	1.56197E-06	0.999923295	1.000076711	7.6705E-05	13036.97333
Note:	PDF=> Probability Density Function						
	F(x) => Cumulative Probability Density Function						
	Tr => Return Period in Years						

Model Loadings

The calibrated BASINS/NPSM model discussed in Chapter 4 was run for both dry and wet year conditions. For the larger watersheds with RF1 streams, the model was run using existing conditions subjected to the design year precipitation. Existing conditions include the 50% septic tank failure (Table 4.13), 2% cattle access to stream (Table 4.14) and overall fecal coliform loadings by land-use category (Table 4.17). The output includes both flow rates and fecal coliform concentrations on a daily basis for the entire wet and dry years. For small streams and bayous, the watershed model was only used to simulate flow for the two application years. The flows were combined with the calibrated Event Mean Concentration (EMC) values indicated in Table 5.8 and used to compute loadings for each small watershed based on land-use. Permitted flow and concentration for municipal, industrial, and private waste sources were used for the application runs as illustrated in Table 5.11.

Table 5.11: Permitted Waste Loads Flow and Concentration (MDEQ, 2001b)

NAME	Receiving Segment	FLOW MGD	Fecal Coliform MPN/100ml
REICHHOLD INC	3	0.0250	200
HC/WEST BILOXI POTW	57	9.0000	200
D'IBERVILLE POTW	169	1.156	200
HC/EAST BILOXI POTW	170	10.0000	200
FAST LANE #735 CAR WASH	176	0.0015	200
GOLLOTT BROTHERS SEAFOOD	177	0.039	58
COAST TO COAST SEAFOOD	183	0.0048	58
HARRISON COUNTY	187	0.0100	200
C F GOLLOTT & SON SEAFOOD CO	187	0.0830	58
SEYMOUR & SONS SEAFOOD INC	187	0.0340	58
HARRISON COUNTY	201	0.0990	200
HARRISON COUNTY	201	0.0420	200
GOLDEN GULF COAST PACKING CO	201	0.198	58
GULF PRIDE ENTERPRISES INC	206	0.0060	58
M & M SHRIMP COMPANY INC	206	0.2	200
J & W SEAFOOD	212	0.04	58
DAVID GOLLOT SEAFOOD	212	0.019	58
G & R SEAFOOD L.L.C.	212	0.06	58
DAVID GOLLOT SEAFOOD, INC.	212	0.019	58
WEEMS BROTHERS SEAFOOD	255	0.0130	58
A C FOOD'S INC	256	0.015	200
CUSTOM PACK	256	0.06	58
SEVEN OAKS GULF HILLS RESORT	291	0.0300	200
OCEAN SPRINGS SEAFOOD COMPAN	316	0.3600	58
KOA KAMPGROUND	430	0.008	200
1ST AM PRINTING & DIRECT MAIL	430	0.009	200
ST MARTIN HIGH SCHOOL	439	0.0150	200
SCHMIDT APARTMENTS	440	0.0015	200
GULFCOAST 7TH DAY ADVENTIST C	450	0.0006	200
PARKER'S LANDING RV PARK ALT	450	0.012	200
PINE HAVEN MOBILE HOME PARK	457	0.0200	200
MAZALEA RV PARK	457	0.0165	200
HARRISON COUNTY	468	0.023	200
NORTH WOOLMARKET VILLAGE EST	469	0.0635	200
HARRISON COUNTY	469	0.0227	200
DESTINATION RV PARK	500	0.0030	200
WEST JACKSON CO ARTIFICIAL WET	500	5	200
HARRISON COUNTY	500	0.0005	200
CLARK OIL COMPANY #11 - EXXON	516	0.0015	200
JIG'S FISH CAMP	521	0.0005	200
HC/EAGLE POINT POTW	522	0.1820	200
APPLE VALLEY TRAILER PARK	534	0.0126	200
HARRISON COUNTY	535	0.0150	200
HARRISON COUNTY WWM DISTRICT	570	10.5000	200
BERNARD BAYOU INDUSTRIAL PARK	570	0.6000	200
HC/GULFPORT POTW - NORTH #2	570	5.5	200
HOMESTEAD TRAILER VILLAGE	639	0.029	200
WALTERS TRAILER PARK	641	0.0015	200

Wet Year Simulation

The simulation period for the wet weather year was November 12, 1994 to December 31, 1995. The fifty days prior to 1995 were used as a warmup period to stabilize the model. Boundary conditions such as water temperatures, tidal elevations, and background fecal coliform concentrations applied to the application runs were based upon the data collected in 2000, 1997, and 1999 respectively. Water temperature data was taken from a sampling buoy at the junction of the Back Bay of Biloxi and Biloxi Bay (USGS, 2001). The tidal elevation series was measured in the Bay St. Louis study area near Waveland (NOAA/NOS, 1999). Background fecal coliform concentrations for upstream boundaries were set at 20 MPN/100ml and seaward boundaries were set at 2 MPN/100ml based on values taken from the Mississippi Department of Marine Resources (MSDMR) database spanning from 1988 to present (MSDMR, 1999). Since the wet and dry years are synthetic events, the same water temperature and tidal data were used for both 1995 and 1986.

Applicable water quality standards are based upon monthly water quality samples collected within the listed water segments (Figure 2.3). The hydrodynamic and fecal coliform concentration models described herein were based upon spatial and temporal discretization appropriate to describe the important physical, chemical and biological processes within the Back Bay of Biloxi. Consequently, the value of fecal coliform concentration computed from the simulation data for a specific water segment is not a unique process. Fecal concentration computed from the simulation data for each study area will vary depending upon (1) the specific model cells used to define the study area,

(2) selected temporal decretization, and (3) selected temporal averaging period. DYNHYD5 was run using a thirty second time step. EUTRO5 was run using a two and a half minute time step and fecal concentrations were output for post processing every two hours.

Eight zones (Table 5.12) were defined from the model grid corresponding to the Back Bay of Biloxi impaired water segments included on the most recent 303(d) listing (MDEQ, 2001b). Figure 5.15 illustrates the location and identification of each of the eight zones. Once divided into zones, a spatial average was calculated and used to represent the fecal coliform concentration for that zone. The fecal concentrations were output in two hour intervals from EUTRO5. These data were processed to obtain a spatial average of fecal concentration in two hour increments for each of the eight zones. Finally, the 30 day geometric mean was taken for each zone based on the two hour spatially averaged values. Figure 5.16 illustrates the 30 day geometric mean of the spatial average data for each of the eight zones. Violation of water quality standards in the Back Bay of Biloxi study area was defined as any day during which the 30 day geometric mean exceeded the secondary contact recreation fecal coliform standards of 200 MPN/100ml for May through October and 2000 MPN/100ml for November through April. Figures 5.17 and 5.18 are color contour plots of instantaneous fecal coliform concentration throughout the Back Bay of Biloxi for the high flow period of April 7, 1995 and the low flow period October 1, 1995. After reviewing Figure 5.16, it is seen that no violations of fecal coliform concentration for secondary contact recreation occur for any of the eight zones. Zone one exceeds 200MPN/100ml from February to April but remains less than 2000MPN/100ml, therefore no violation occurs. In addition, the most recent fecal coliform samples taken in the Back Bay of Biloxi support these results by indicating that the Bay is within water quality standards (MDEQ, 2001b).

Table 5.12: Back Bay of Biloxi Study Area Spatial Average Zones

Zone Number	**Zone Name**	**Number of Segments**
1	Bernard Bayou Segment 4	27
2	Bernard Bayou Segment 3	19
3	Heron Bayou	9
4	Big Lake	61
5	Back Bay of Biloxi	239
6	Back Bay of Biloxi Coastline Segment 3	63
7	Back Bay of Biloxi Coastline Segment 4	87
8	Tidewater Bayou	1

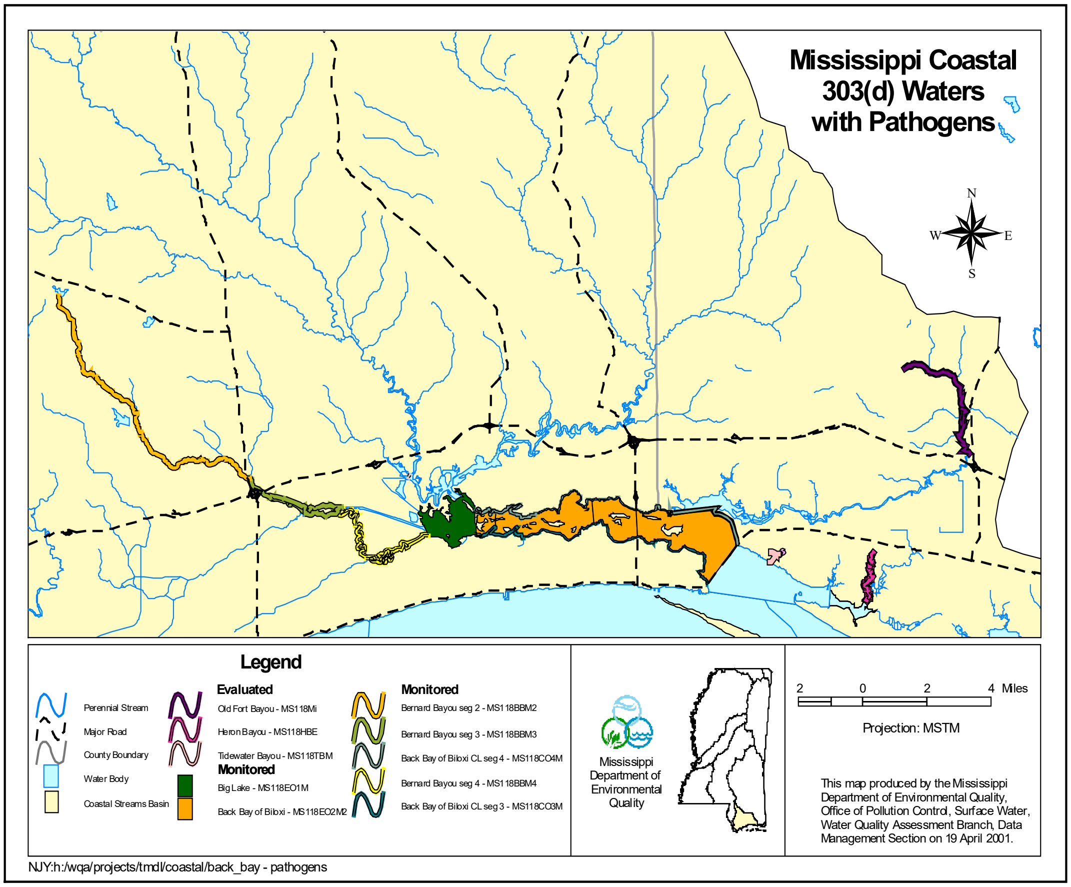


Figure 5.15: Location of Enlisted Waterbody Zones

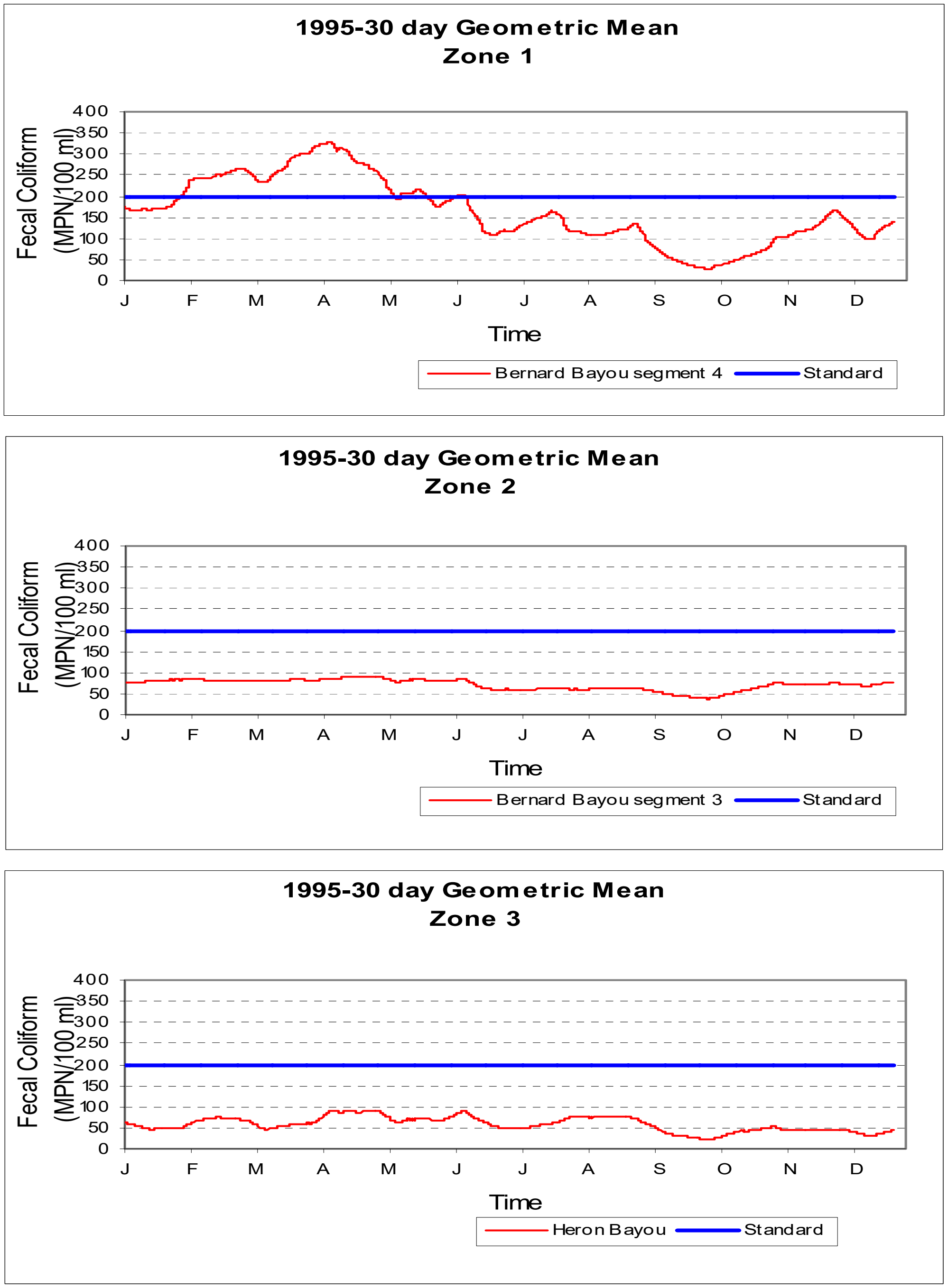
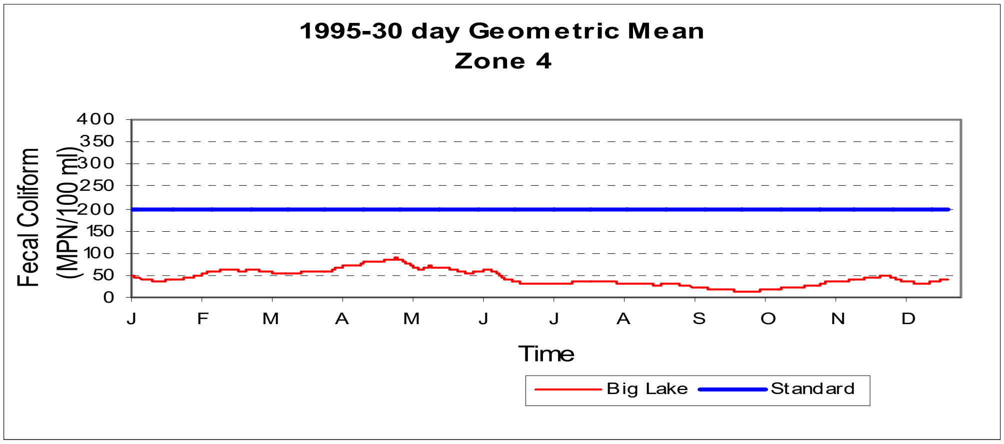
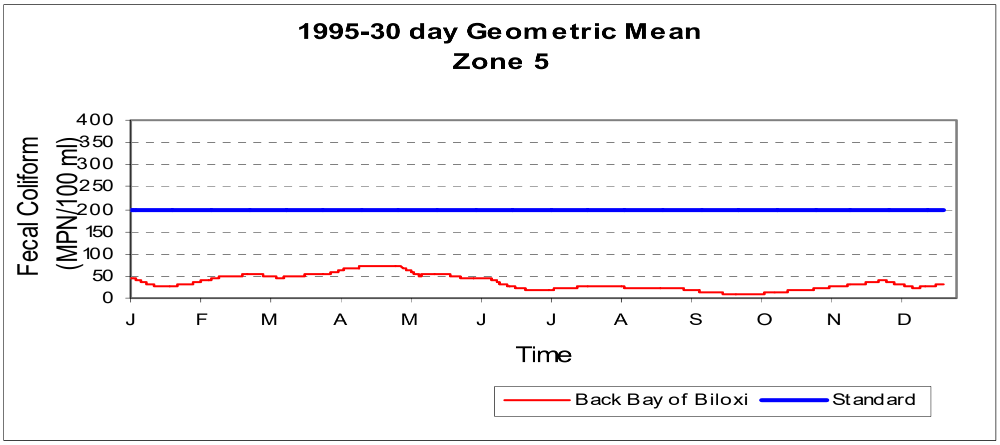


Figure 5.16: Fecal Coliform Profiles Zones 1-8, 1995





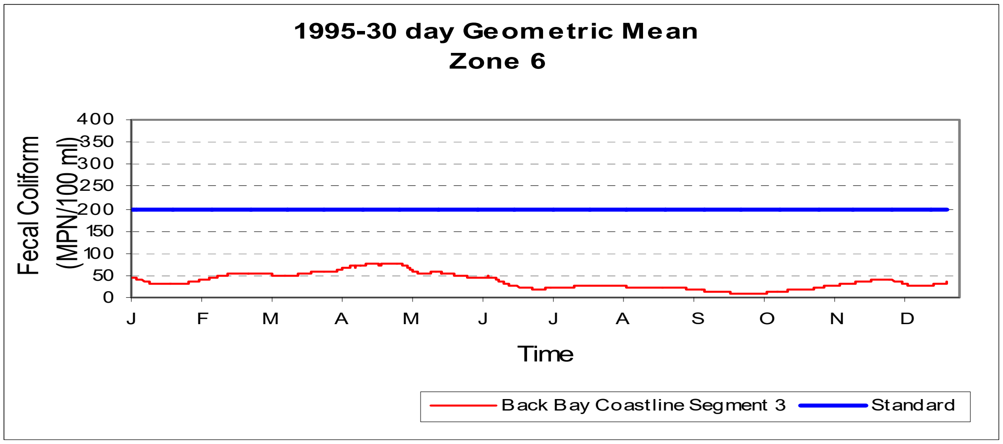
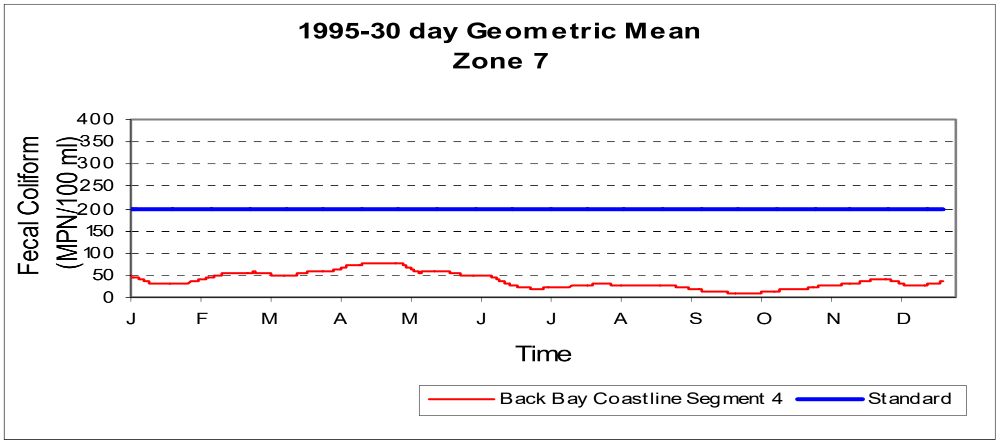
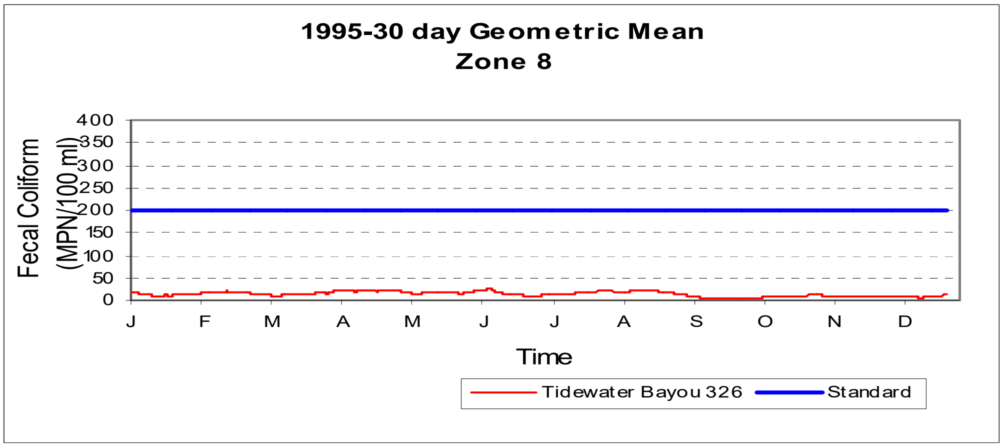


Figure 5.16 (Continued)





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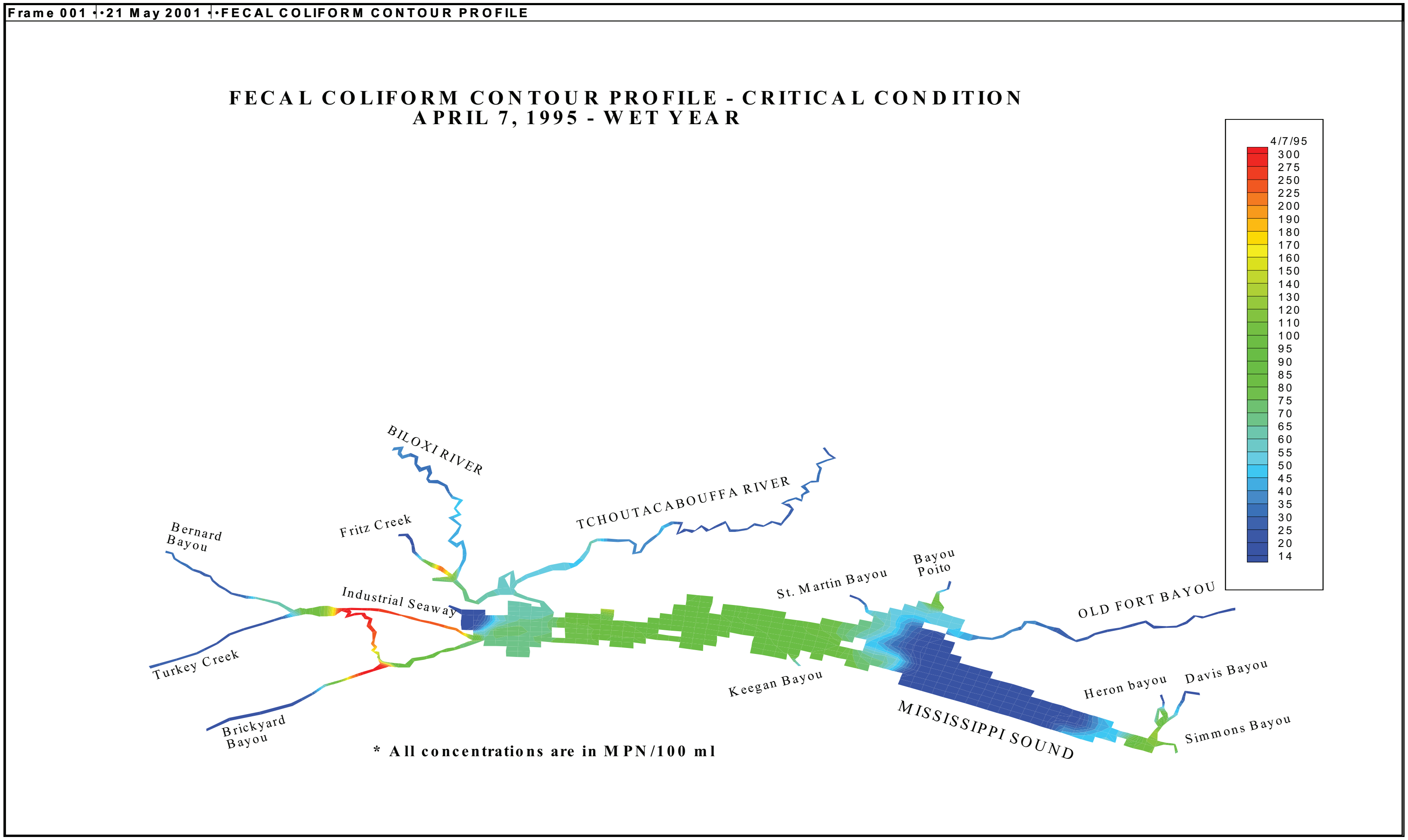


Figure 5.17: Back Bay of Biloxi Fecal Coliform Concentration Profile April 7, 1995

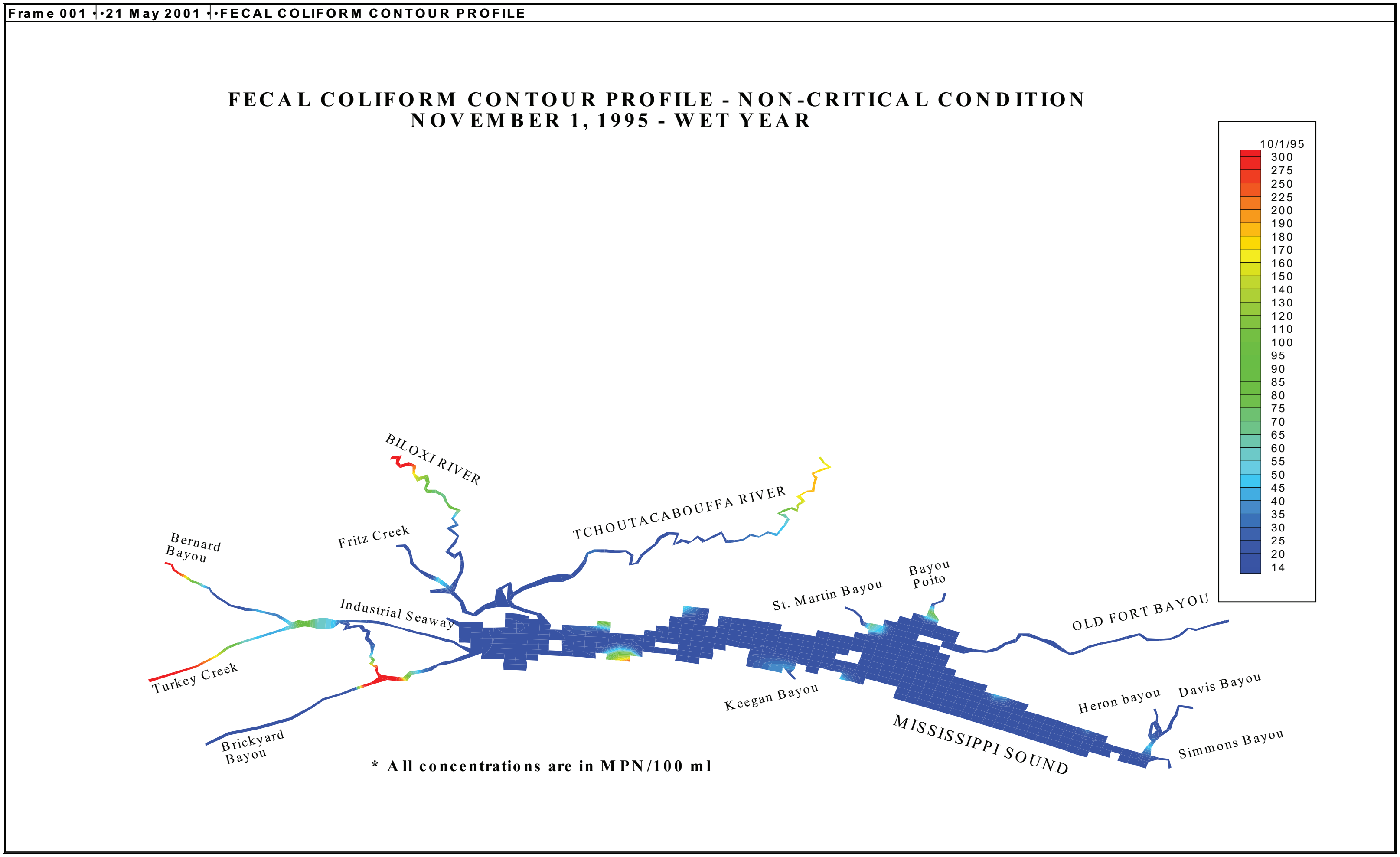


Figure 5.18: Back Bay of Biloxi Fecal Coliform Concentration Profile October 1, 1995

Dry Year Simulation

The simulation period for the dry weather year was November 12, 1985 to December 31, 1986. Like the wet years, the model stabilization period was set at fifty days. As was previously discussed, the tidal and temperature data used were the same as those used in the wet year simulation. Figure 5.19 illustrates the 30 day geometric mean of the spatially averaged data for each of the eight zones for the entire year. Figures 5.20 and 5.21 are color contour plots of fecal coliform concentration throughout the Back Bay of Biloxi for the high flow period February 25, 1986 and the low flow period August 9, 1986.

Like the wet year, the results indicated no violations of the secondary contact recreation water quality standards for any of the eight zones. Therefore, no further loading scenarios were performed. However, it is important to note that, since the urban runoff or EMC loads most heavily influenced fecal coliform concentrations in the Bay, the wet year was expected to be the critical loading period. This is supported by comparing the results found in Figures 5.16 and 5.19.

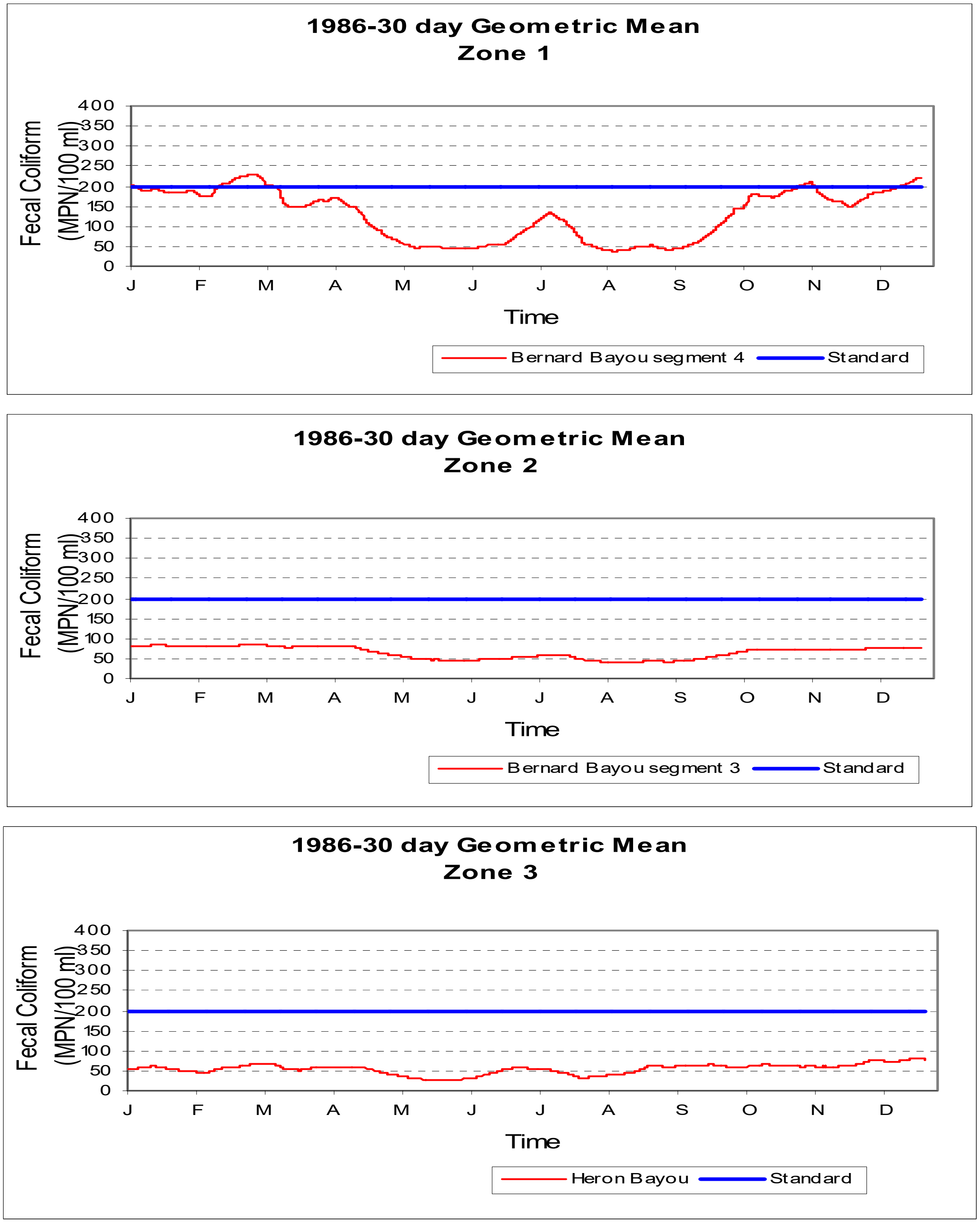
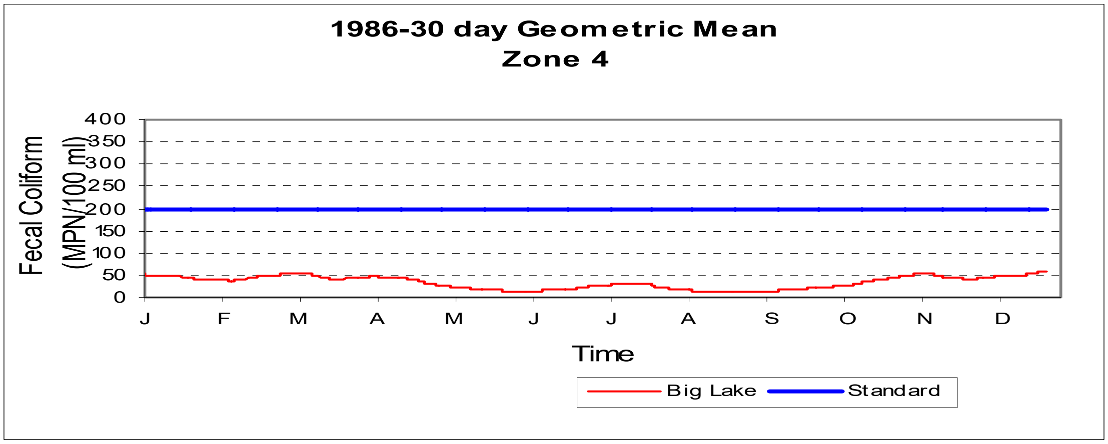
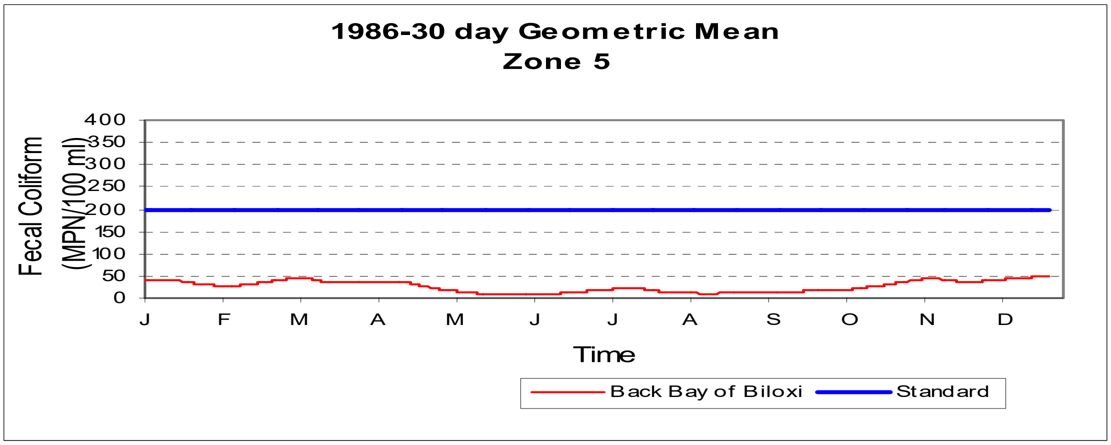


Figure 5.19: Fecal Coliform Profiles Zones 1-8, 1986





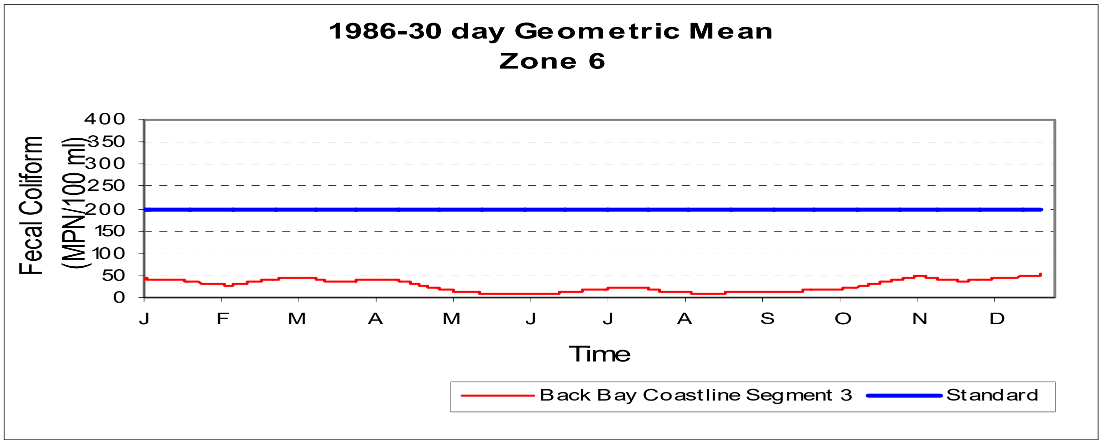
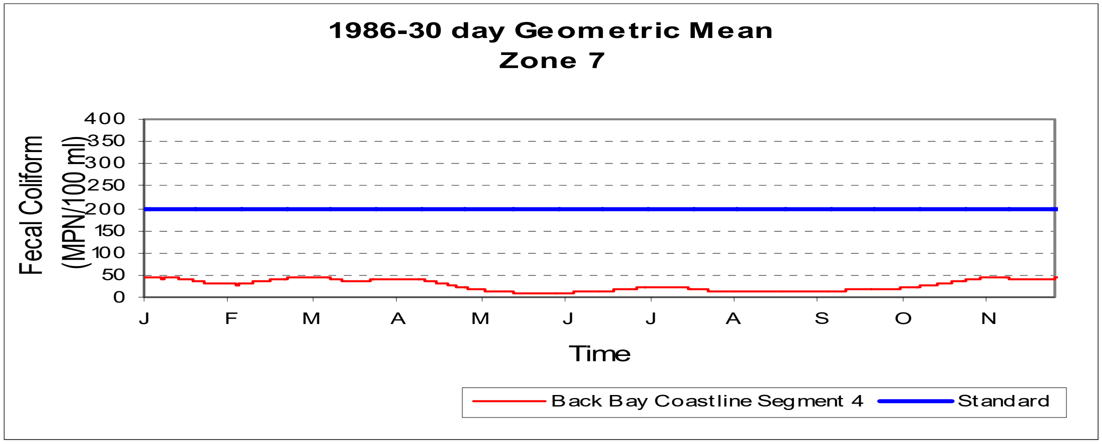


Figure 5.19 (Continued)



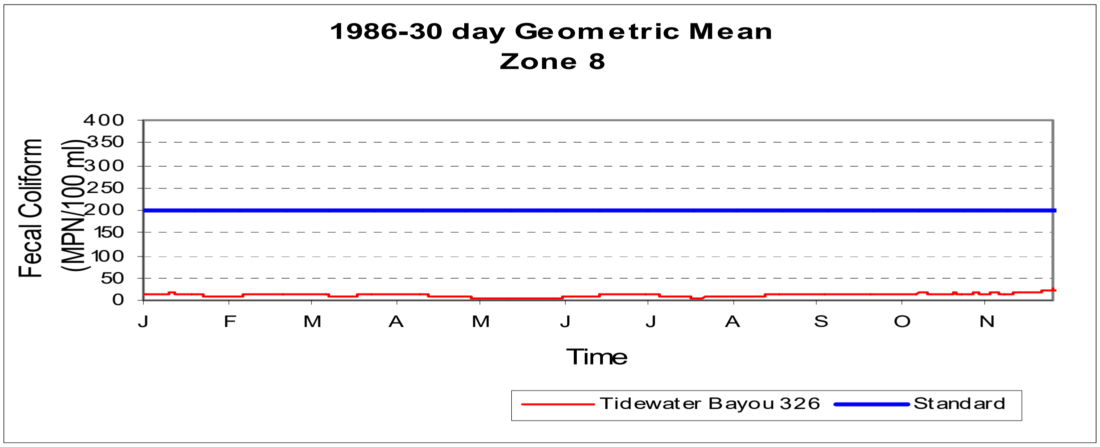


Figure 5.19 (Continued)

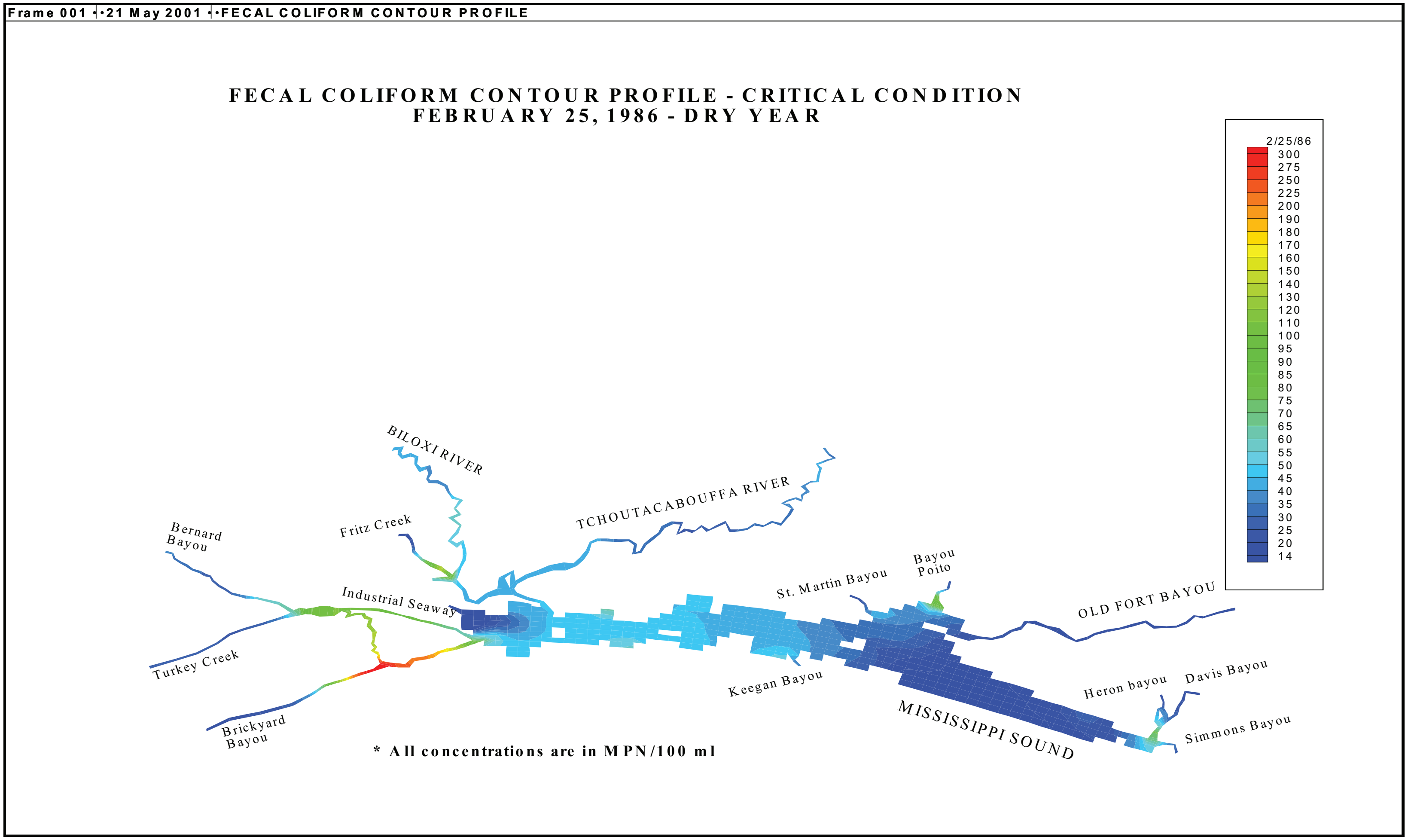


Figure 5.20: Back Bay of Biloxi Fecal Coliform Concentration Profile February 25, 1986

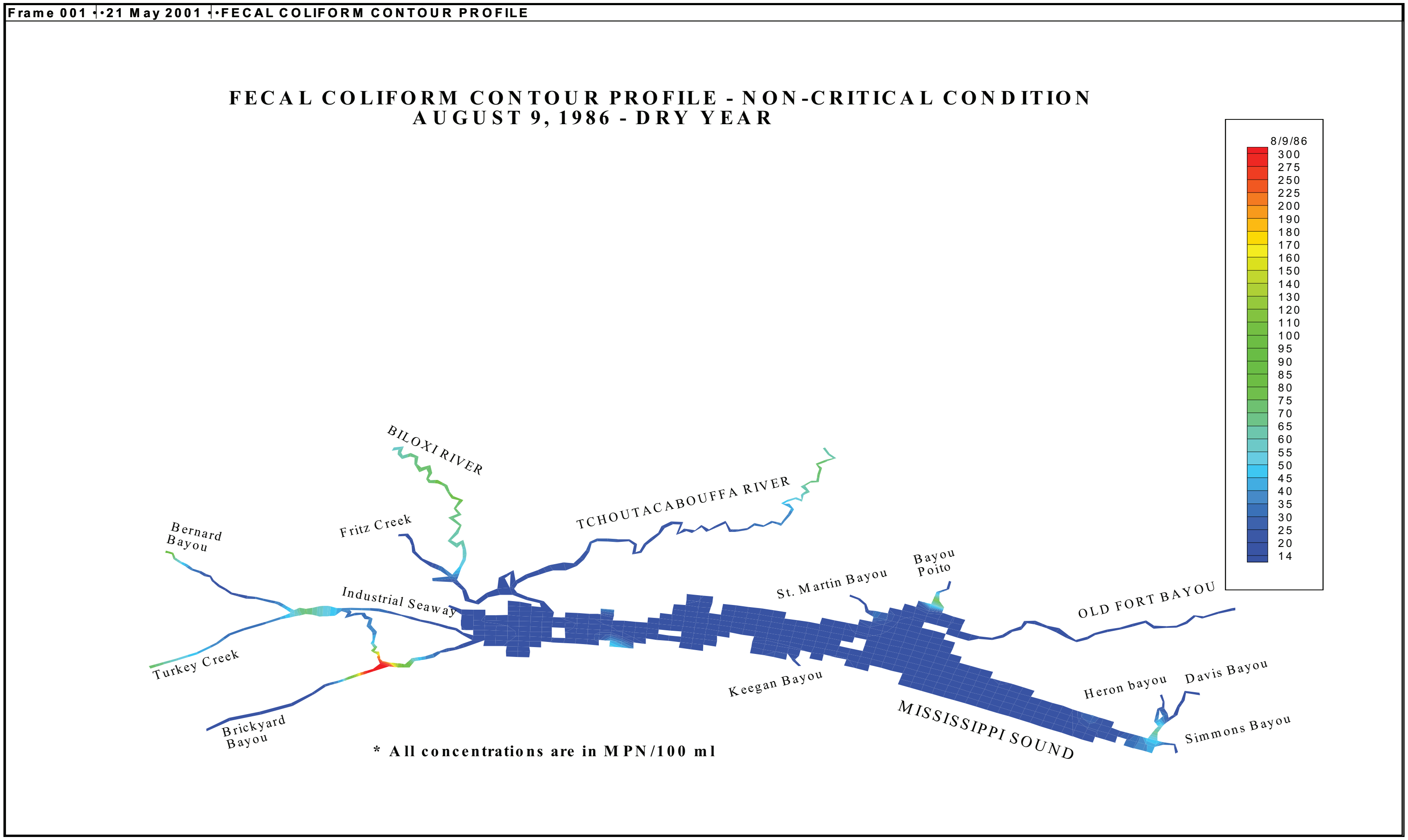


Figure 5.21: Back Bay of Biloxi Fecal Coliform Concentration Profile August 9, 1986

CHAPTER VI

CONCLUSIONS

This thesis presents the development and application of BASINS/NPSM, DYNHYD5, and EUTRO5 to access fecal coliform levels within the Back Bay of Biloxi study area. The hydrologic, hydrodynamic and water quality models were loosely coupled and used to aid in the development of the Total Maximum Daily Load (TMDL) for the Back Bay of Biloxi study area. The BASINS and NPSM software was applied to model watershed hydrology and in-steam processes for the upper region of the watershed. The calibrated watershed model was then loosely coupled with the lower tidal region of the watershed utilizing the hydrodynamic model DYNHYD5 and the water quality model EUTRO5. Application of these mathematical models was demonstrated by comparing observed data to results of long term simulation of both the upper and lower tidal watershed regions.

Results presented demonstrate that the BASINS/NPSM watershed model accurately depicts the watershed hydrology. In-situ fecal coliform data is limited within the study, however, the results indicated adequate water quality simulation for initial TMDL assessment. Land-use in the upper region of the watershed is mostly forest and agricultural. Model results indicate that the major fecal coliform sources in the upper watershed are attributed to the percentage of cattle with access to the stream and the number of failing septic tanks. Simulation results support field data indicating fecal coliform levels exceeded water quality standards in monitored waterbodies but did not exceed standards in evaluated waterbodies.

The calibrated BASINS/NPSM model was used with DYNHYD5 and EUTRO5 to model hydrodynamics and water quality within the Back Bay of Biloxi study area. DYNHYD5 and EUTRO5 were loosely coupled with the watershed model to simulate both hydrodynamic and water-quality processes. Here again in-situ fecal coliform data was limited, however, model simulation results were within the ranges of observed values. Simulation results indicated that urban runoff has the most significant impact upon the fecal coliform concentrations in the Bay. Results indicated that the fecal coliform levels in the Back Bay of Biloxi study area did not exceed secondary contact recreation water quality standards under wet or dry conditions. The calibrated models can be used as a planning tool to protect the water quality standards within the Back Bay of Biloxi watershed.

The model of this tidally influenced study area simulates physical, biological, and chemical processes. Many modeling parameters have been defined based on previous studies, standard modeling assumptions, best available data, and comparison to relevant literature. It is recommended that the development of these models be continued to incorporate additional, more thorough site-specific data. In addition, it is recommended that a three-dimensional code such as the EFDC shallow water solver be applied to more accurately simulate the complex circulation patterns in this geometrically complex estuary increasing the level of confidence in the water quality application.

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