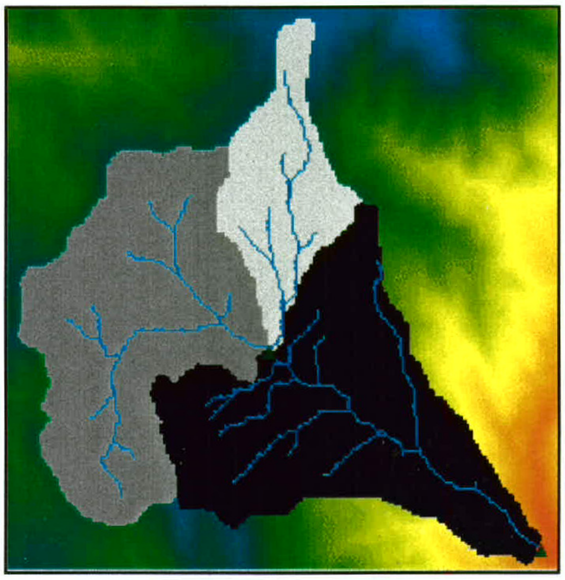
WATER RESOURCES ENGINEERING

Hydrology • Hydraulics • Water Quality
Integrated Watershed Management

May River Water Quality Model

Beaufort County, South Carolina



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Palmetto Bluff, LLC

Thomas & Hutton Engineering Co.
Ralph A. Lopez, PE, DEE
Camp Dresser & McKee
Richard A. Wagner, PE

April 2002

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Section 1
Introduction

The need to understand the current state of water quality has never been greater. Understanding is not merely reporting a water quality observation but rather involves developing insight to explain its value. Specifically, the insight must help explain the relationships between human activities and desired water quality.

A continued growth in population coupled with increased expectations of acceptable water quality places an ever-growing demand on this need to understand. The financial ramifications associated with limited understanding are increasing dramatically. The drive to establish Total Maximum Daily Loads (TMDLs) for over 20,000 river segments, lakes, and estuaries across the United States highlights the need to better understand water quality.

It is therefore crucially important to monitor appropriate system attributes at correct spatial and temporal scales, and to model (i.e., to interpret) the collected data so as to capture true system functionality while clearly relating management alternatives to desired water quality goals.

- Monitoring involves the use of spatiotemporally organized systems of long-term data collection.

- Modeling involves the application of formal methods of data interpretation such as statistical analysis and numerical simulation.

A study was conducted to evaluate levels of bacteria in the May River. For the evaluation, a computer model was developed to assess river bacteria concentrations for various land use and water quality control alternatives. In order to provide an accurate representation of current conditions, the model was calibrated to a set of existing water quality monitoring data (i.e., river salinity and bacteria concentrations), and was then applied to evaluate how future development will affect river bacteria concentrations.

This report presents the findings of the study. Characteristics of the study area, which affect the bacteria loads to the river and resulting river concentrations, are discussed in Section 2. The development of the model and calibration of the model for existing land use and average flow conditions is presented in Section 3. Section 4 documents the model evaluations for future land use and average flow conditions. In Section 5, more detailed model results for a range of wet weather conditions and associated runoff bacteria concentrations are presented. A summary of the model development and model results is included in Section 6. References are listed in Section 7.

Section 2
Study Area Characteristics

This section summarizes the acquisition, evaluation and processing of the data necessary to develop the May River computer model and to evaluate the impacts of alternative land use conditions and management strategies. In general, the data acquisition was limited to available data; no data were collected during the study strictly for the purposes of the study.

2.1 Watershed Delineation

For the purpose of this study, the May River watershed was delineated from a Digital Elevation Model (DEM) using Geographic Information Systems (GIS) technology. The source DEM is a hybrid model assembled from LIDAR-derived topography (where available) merged with 10-meter USGS DEMs, purchased from Land Info, a commercial provider of spatial data products. The hybrid DEM was hydro-enforced to reveal breaches not present in the source DEM. The breaches included open water, ditches, culverts, and pipes. The hydro-enforced DEM was used to calculate flow models in GIS. The flow models, consisting of direction and accumulation, served as the basis of watershed and subwatershed delineation. The downstream boundary was chosen based on the location of existing and future land uses, as well as the location of existing water quality monitoring stations. The delineation upstream of the chosen boundary was extracted using the flow models. Upon comparison, it was determined that the delineated watershed was more realistic than the published "14-digit Hydrologic Unit Code" watershed due to the accuracy of the topographic source. The delineated watershed and the DEM used for delineation are shown in Figure 2-1.

2.2 Land Use

An existing land use map is presented in Figure 2-2. The map was produced using the following sources:

- Land use classification published by the South Carolina Division of Natural Resources 1994
- National Wetlands Inventory 1994
- Color Infrared NAPP 1999
- Color Photography (where available) 2001
- Beaufort County Tax Parcels

The South Carolina DNR classification was generated from NAPP photography flown in 1994. It was deemed the most current and detailed land use layer available. This dataset served as a foundation layer, which was updated using the more recent aerial photography and tax parcel information. The land use classification scheme was devised to meet the requirements of this study.

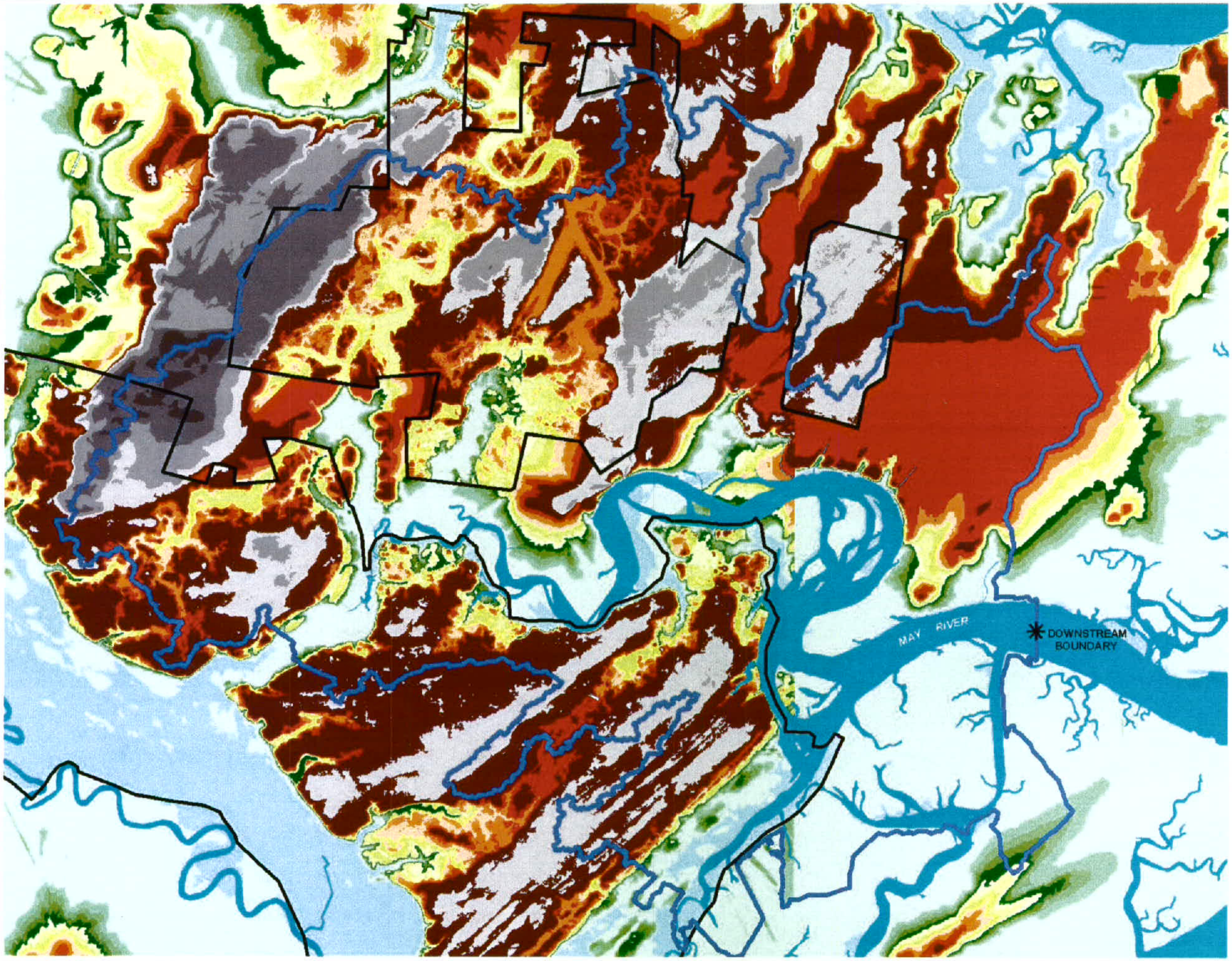

FIGURE 2-1

MAY RIVER WATERSHED AND DIGITAL ELEVATION MODEL

May River Water Quality Model
Beaufort County, South Carolina

N

LEGEND

- May River Watershed
- LIDAR-Flown Areas

Elevation
Units in Feet NGVD 1929

- Below 0
- 0 - 6
- 6 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 16
- 16 - 17
- 17 - 18
- 18 - 19
- 19 - 20
- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 50

SOURCE:
Hybrid DEM generated from LIDAR-derived DEM merged with 10-m Land Info DEM's

Scale:
1 inch = 4,500 feet
4500 0 4500 Feet

DISCLAIMER

Thomas & Hutton Engineering Co. compiled the map information from the following sources

DATA	SOURCE	DATE (if applicable)
USGS 10-m DEM	USGS & Land Info	
Hydrography	SCDNR	1994

Thomas & Hutton used the data "as is" and has made no independent investigation of the data nor make any representation as to the accuracy or completeness of the data. [illegible]

Other data sets delineated are from the following sources:

DATA	SOURCE	DATE (if applicable)
May River Watershed	Thomas & Hutton Engineering Co.	
LIDAR & Hybrid DEM's	Thomas & Hutton Engineering Co.	
LIDAR-Flown Areas	Thomas & Hutton Engineering Co.	

Job Number: J-14483	Prepared For: Palmetto Bluff, LLC		Scale: 1" = 4,500'
Produced By: AMB	Produced: 4/2/2002	Last Modified:	Modified by: AMB
Projection: SC Stateplane	Horizontal Datum: NAD83	Vertical Datum: NGVD 1929	
File: I:\J-14483_WaterQuality\MayR_Watershed\J-14483_mayriverwatershed.apr			

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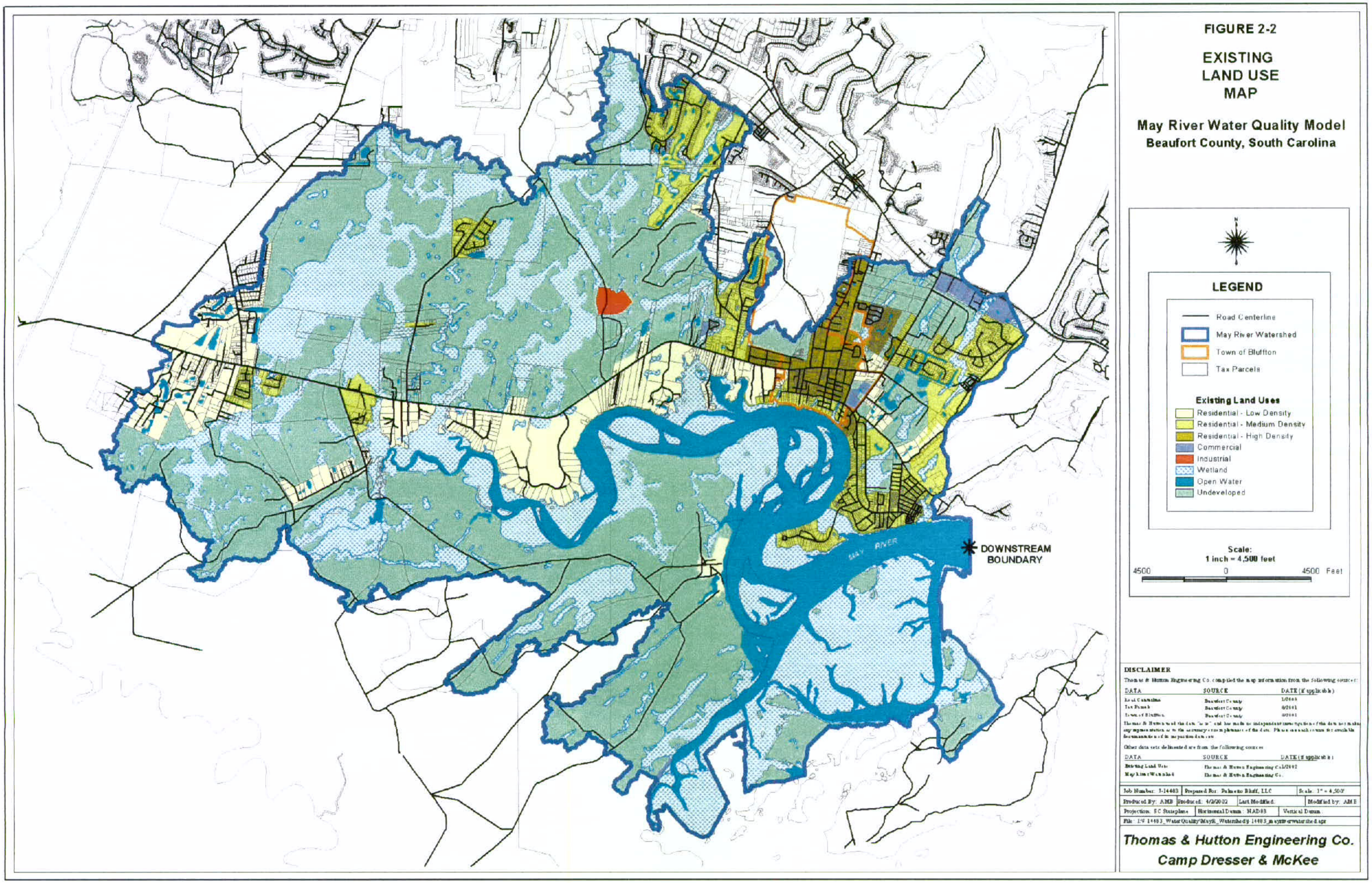


FIGURE 2-2
EXISTING LAND USE MAP
May River Water Quality Model
Beaufort County, South Carolina
LEGEND
Road Centerline
May River Watershed
Town of Bluffton
Tax Parcels
Existing Land Uses
Residential - Low Density
Residential - Medium Density
Residential - High Density
Commercial
Industrial
Wetland
Open Water
Undeveloped
Scale:
1 inch = 4,500 feet
4500
0
4500 Feet
DOWNSTREAM BOUNDARY
DISCLAIMER
DATA
SOURCE
Other data sets delineated are from the following sources
DATA
SOURCE
Existing Land Use
Thomas & Hutton Engineering Co.
Job Number: J-14483
Prepared For: Palmetto Bluff, LLC
Scale: 1" = 4,500'
Produced By: AMB
Produced: 4/3/2002
Last Modified:
Modified by: AMB
Projection: SC Stateplane
Horizontal Datum: NAD83
Vertical Datum:
Thomas & Hutton Engineering Co.
Camp Dresser & McKee

A future land use map with a ten-year horizon is presented in Figure 2-3. The map was produced by re-classifying "undeveloped" in the existing land use map using information from the following sources:

- Beaufort County Future Land Uses
- Beaufort County Planned Unit Development
- Beaufort County Zoning Information
- Beaufort County Tax Parcels
- Local engineering knowledge

The land uses for existing and future conditions are presented in Table 2-1. As shown in the table, a total of 10 land uses were identified. Developed land use categories include commercial, industrial, and three residential land use categories. Water and wetlands land uses were further subdivided to distinguish open water and marshland associated with the tidal river from wetlands and water surfaces in the upland areas.

TABLE 2-1

MAY RIVER WATERSHED
LAND USE

Land Use Category	Existing Land Use		Future Land Use	
	Area (acres)	% of Total	Area (acres)	% of Total
Commercial	131	1%	131	1%
Industrial	49	0%	191	1%
Open Water	393	2%	393	2%
Open Water - River	1,730	7%	1,730	7%
Residential - High Density	542	2%	1,093	5%
Residential - Low Density	2,260	10%	5,703	25%
Residential - Medium Density	1,732	7%	5,782	25%
Undeveloped - Other	9,811	42%	1,623	7%
Wetland - Tidal Marsh	2,408	10%	2,408	10%
Wetland	4,131	18%	4,131	18%
TOTAL	23,186	100%	23,186	100%

The table shows a substantial increase in developed area in the future. Under existing land use conditions, 20 percent of the watershed is developed, and another 42 percent is open land use that can potentially be developed. The remaining land is wetland or water land use that will not be developed in the future. The future land use includes 57 percent developed area, and only 7 percent open land that could potentially be developed.

2.3 Rainfall

Daily rainfall data were available for a rainfall gage designated as "Beaufort Seven SW" in Beaufort County. Data from this gage, presented in the *Beaufort County Stormwater Management Drainage Plan* (BES, 1994), were previously used to determine

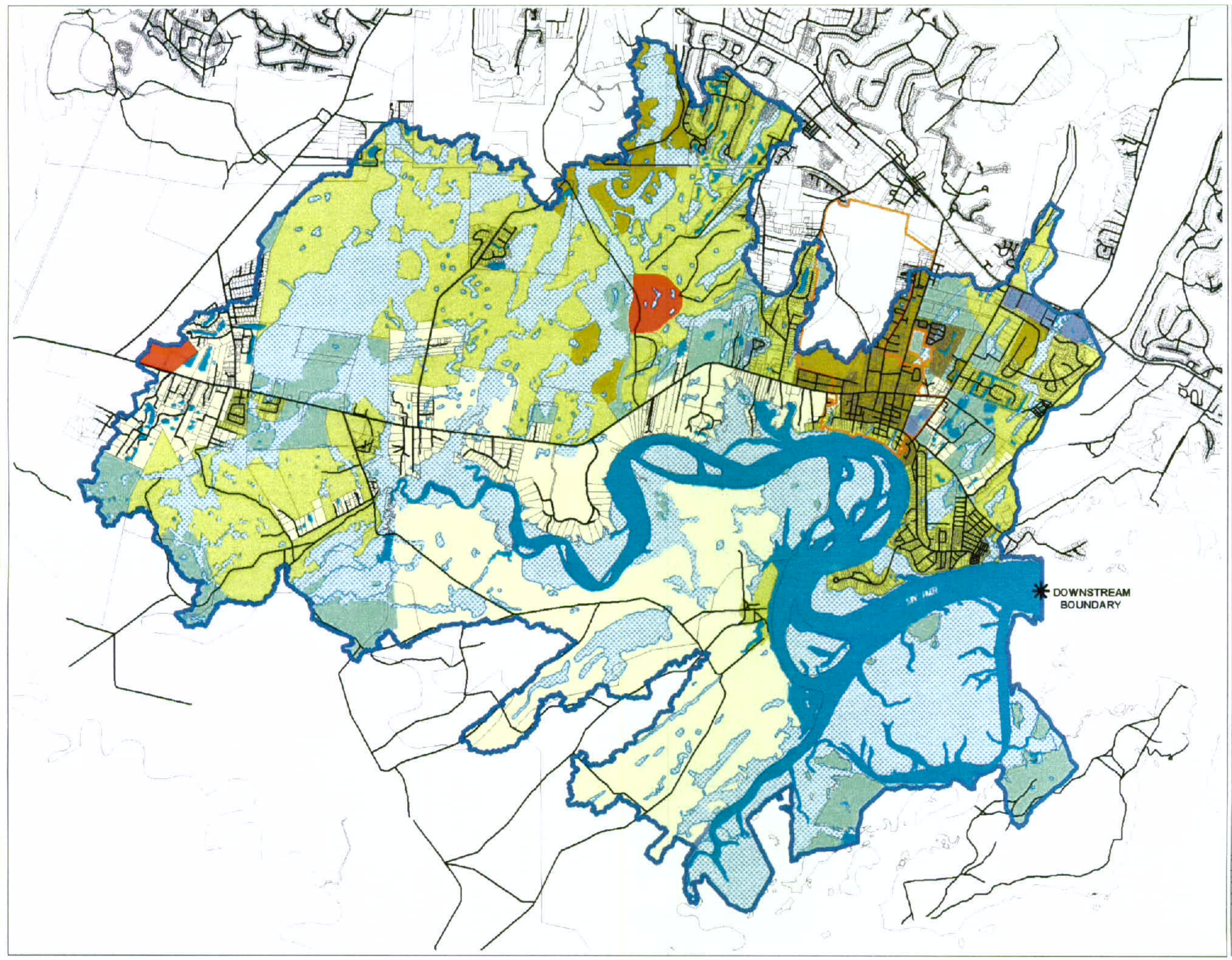


FIGURE 2-3

FUTURE LAND USE MAP

May River Water Quality Model
Beaufort County, South Carolina

N

LEGEND

- Road Centerline
- May River Watershed
- Town of Bluffton
- Tax Parcels

Future Land Uses

- Residential - Low Density
- Residential - Medium Density
- Residential - High Density
- Commercial
- Industrial
- Wetland
- Open Water
- Undeveloped

Scale:
1 inch = 4,500 feet

4500 0 4500 Feet

DISCLAIMER

Thomas & Hutton Engineering Co. compiled the map information from the following sources:

DATA	SOURCE	DATE (if applicable)
[illegible]	Beaufort County	[illegible]
Tax Parcels	Beaufort County	[illegible]
Town of Bluffton	Beaufort County	[illegible]

[illegible]

Other data sets delineated are from the following sources:

DATA	SOURCE	DATE (if applicable)
Future Land Use	Thomas & Hutton Engineering Co.	[illegible]
May River Watershed	Thomas & Hutton Engineering Co.	

Job Number: 1-14483	Prepared For: Palmetto Bluff, LLC		Scale: 1" = 4,500'
Produced By: AMB	Produced: 4/2/2003	Last Modified:	Modified by: AMB
Projection: SC Stateplane	Horizontal Datum: NAD83	Vertical Datum:	
File: [illegible]			

Thomas & Hutton Engineering Co.

Camp Dresser & McKee

the average annual rainfall for the *Beaufort County Manual for Stormwater Best Management Practices* (CDM, 1998). The recent data collection updates the original database by including data through the year 2000.

The daily rainfall data were analyzed to re-evaluate the average annual rainfall for purposes of estimating average annual runoff totals for existing and future land use conditions, and to determine the frequency associated with various daily rainfall totals.

Table 2-2 summarizes the monthly and annual rainfall data for the period 1930 through 2000. As shown in the table, the average annual rainfall at the gage is 48.4 inches per year, which is the same value that was used in the Beaufort County BMP Manual.

TABLE 2-2

MONTHLY AVERAGE RAINFALL TOTALS
BEAUFORT COUNTY

Month	Average Rainfall (inches)
January	3.4
February	3.1
March	3.9
April	2.8
May	3.5
June	5.4
July	6.3
August	6.9
September	5.3
October	2.7
November	2.1
December	2.9
TOTAL	48.4

The frequency of various daily rainfall totals is presented in Table 2-3. As shown in the table, measurable rainfall only occurs on 26% of the days in the long-term record (roughly once every four days on the average). A daily rainfall of 0.5 inches or greater is expected to occur on between 8% and 9% of the days (2 to 3 times a month on the average) and a daily rainfall of 1 inch or greater is expected to occur on about 4% of the days (about once per month on the average).

TABLE 2-3

DAILY RAINFALL FREQUENCY
BEAUFORT COUNTY

Percent of Time Daily Rainfall Value is Exceeded	Daily Rainfall (inches)
0.0%	10.80
0.1%	4.35
0.2%	3.50
0.3%	3.05
0.4%	2.75
0.5%	2.50
0.6%	2.33
0.7%	2.25
0.8%	2.15
0.9%	2.02
1.0%	2.00
2.0%	1.45
3.0%	1.15
4.0%	0.99
5.0%	0.83
6.0%	0.72
7.0%	0.62
8.0%	0.55
9.0%	0.48
10.0%	0.42
11.0%	0.36
12.0%	0.31
13.0%	0.27
14.0%	0.23
15.0%	0.20
16.0%	0.17
17.0%	0.15
18.0%	0.12
19.0%	0.10
20.0%	0.08
21.0%	0.06
22.0%	0.05
23.0%	0.03
24.0%	0.02
25.0%	0.01
26.0%	0.00
100.0%	0.00

This information will be used to assess the probability of exceeding a river bacteria MPN of 43/100 ml. The State standard dictates that a bacteria MPN of 43/100 ml should not be exceeded by more than 10% of the water quality samples. The computer model will be run for various quantities of rainfall and associated runoff, and the model results will be used to assess whether the bacteria standard of 43/100 ml is exceeded, and the duration of the exceedance. The results generated for various storm sizes will be combined to estimate the overall percentage of time that the 43/100 ml standard is exceeded.

The rainfall data were also evaluated to identify the "wettest" 3-year period (i.e., the 3-year period with the highest total rainfall). Because the evaluation of compliance with the receiving water bacteria standard is based on the analysis of bacteria sampling data over a 3-year period, the river model will be applied to the 3-year period with the highest historical rainfall data. Model results for these conditions should reflect a "worst case" scenario for May River bacteria concentrations.

A review of the data indicated that the period of 1964 through 1966 had the greatest 3-year total rainfall. The annual rainfall for the years 1964, 1965 and 1966 was 81.6, 53.3 and 55.1 inches, respectively. The average annual rainfall for the 3-year period (63.3 inches) is 30 percent greater than the average annual rainfall of 48.4 inches per year. The rainfall in each of the three years is at least 10 percent greater than the average annual rainfall.

2.4 Runoff/Baseflow Quantity

There are no streamflow gages in the May River watershed. Consequently, typical annual streamflow volumes in the area were estimated using data from United States Geological Survey (USGS) streamflow gages located closest to the May River study area.

Table 2-4 presents the analysis results for several USGS gages. For each gage, the table lists the USGS gage ID, the gage description, tributary area, period of data, and average annual streamflow. The average streamflow is expressed in units of cubic feet per second (cfs), and in inches of flow over the tributary area.

As shown in the table, the average annual flows for the selected gages range from 12.3 to 15.5 inches per year. Differences in the values may be attributed to a number of factors including the tributary area land uses and soil types.

The values that are believed to be most appropriate for the May River study are the values for the Coosawatchee River and Salkehatchee River, and the value for the area between the North Fork/South Fork Edisto gages and the Edisto River gage near Givhans. These areas are closest to the study and are expected to be most representative of the area. The average annual flow values for these areas range from 11.0 to 13.9 inches.

Based on the evaluated streamflow data, it was estimated that pervious land areas (e.g., forest) would be characterized by an average annual flow of 12 inches per year. It was further estimated that the average annual surface runoff would be about 5 inches, based on an average annual rainfall of 48.4 inches per year and a runoff coefficient of 0.1 (i.e., 10% of rainfall on pervious areas is converted to runoff as a long-term average). The remaining 7 inches of annual flow is attributed to baseflow.

For impervious areas (e.g., streets, parking lots, buildings), a runoff coefficient of 0.90 was assigned (i.e., 90% of rainfall on impervious areas is converted to runoff as a long-term average). Consequently, impervious land areas are characterized by an average annual runoff flow of 43.6 inches per year. The 4.8 inches of rainfall not converted to surface runoff is lost through evaporation of water ponded on the impervious surface. Impervious areas do not contribute to baseflow.

TABLE 2-4

LONG-TERM STREAMFLOW DATA FOR GAGES NEAREST THE STUDY AREA

Gage ID	Description	Tributary Area (square miles)	Data Period	Average Annual Streamflow cfs	inches
02176500	Coosawatchee River near Hampton, SC	203	1952 - 1999	184	12.3
02175500	Salkehatchee River near Miley, SC	341	1952 - 1999	349	13.9
02173000	South Fork Edisto River near Denmark SC	720	1932 - 1999	769	14.5
02173500	North Fork Edisto River near Bamberg, SC	683	1939 - 1999	781	15.5
02175000	Edisto River near Givhans, SC	2730	1939 - 1999	2623	13.0
---	Edisto River between Denmark/Bamberg gages and Givhans gage	1327	1939 - 1999	1073	11.0

Water and wetlands land use require special consideration. In this study, open water and tidal marshland associated with the tidal river are treated differently than water and wetlands located in the upland areas. In the upland areas, the water and wetlands land uses were assigned a runoff coefficient of 0.30 (i.e., 30% of rainfall is converted to surface runoff). This value is consistent with studies from the southeastern U.S. (CDM, 2000). All flow from these areas was attributed to the surface runoff, with no baseflow. For the open water and tidal marshland, a runoff coefficient of 1.0 was assigned (i.e., 100% conversion of rain to runoff).

The average annual flow for a particular land use type (e.g., commercial) will depend on the relative fractions of impervious and pervious land surface associated with that land use. In this study, imperviousness values that were previously used in the Beaufort County Stormwater BMP Manual (CDM, 1998) were used. For developed land use types, the percent imperviousness ranged from 10% (low density residential) to 85% (commercial).

Table 2-5 summarizes imperviousness characteristics and average annual flows for the land uses considered in the May River watershed model. For each land use, the table lists the percent imperviousness, average annual surface runoff and baseflow, and average annual total flow (runoff plus baseflow).

TABLE 2-5

MAY RIVER WATERSHED
LAND USE AVERAGE FLOW CHARACTERISTICS

Land Use Category	% Impervious	Average Flows (inches/year)		
		Runoff	Baseflow	Total
Commercial	85%	37.8	1.1	38.8
Industrial	70%	31.9	2.1	34.0
Open Water	30%	14.5	0.0	14.5
Open Water - River	100%	48.4	0.0	48.4
Residential - High Density	50%	24.2	3.5	27.7
Residential - Low Density	10%	8.7	6.3	15.0
Residential - Medium Density	25%	14.5	5.3	19.8
Undeveloped - Other	0%	4.8	7.0	11.8
Wetland - Tidal Marsh	100%	48.4	0.0	48.4
Wetland	30%	14.5	0.0	14.5

2.5 Runoff/Baseflow Quality

Estimates of bacteria levels in surface runoff were developed using a database of surface runoff monitoring data collected in locations throughout the southeastern United States. Many of the samples were collected as part of the United States Environmental Protection Agency's National Pollution Discharge Elimination System (NPDES) stormwater permit requirements for large communities. Generally, most of the samples were collected for urban land uses (residential, commercial, industrial), with limited sampling for undeveloped lands.

Summary statistics from the runoff bacteria database are presented in Table 2-6. For various land use types, the table lists the number of storms sampled, the geometric mean of the sample values, and the bacteria level associated with various "percentiles". The "percentile" value indicates what percentage of samples in the database had a lower bacteria value. For example, the 10th percentile bacteria value for commercial land use is 190/100 ml, which means that 10 percent of the bacteria values in the database are less than or equal to 190/100 ml.

The table includes "open" and "adjusted open" land use statistics. The open land use bacteria data included a small number of samples, some of which seemed to be excessively high when compared to comparable data for developed land uses.

Consequently, the open land use data were adjusted to reflect what were considered to be more reasonable values relative to the other land uses. The bacteria percentile values for the open land use category are of limited value based on the limited amount of samples taken. The bacteria percentile values for the adjusted open land use are based on the assumption that the variability of the values will be consistent with the variability observed for the other land use types.

TABLE 2-6

MAY RIVER WATERSHED
LAND USE BACTERIA CONCENTRATION CHARACTERISTICS

Land Use Category	Number of Samples	Runoff Bacteria (MPN/100 ml)					
		Geometric Mean	10th Percentile	30th Percentile	50th Percentile	70th Percentile	90th Percentile
Commercial	89	2,700	190	940	2,400	6,000	41,200
Industrial	94	2,300	130	700	2,470	9,070	26,100
Residential	190	6,600	470	2,500	9,000	24,600	67,700
Open	13	4,800	550	2,340	3,950	12,240	44,400
Adjusted Open	---	1,400	160	680	1,150	3,570	12,950

Baseflow bacteria levels were estimated based on previous studies and literature values. In a recent watershed study (CDM, 2000) baseflow bacteria MPN values of 100 to 500/100 ml were used. The lower value was assumed for undeveloped areas, and the higher value was used for developed areas. The higher value of 500/100 ml is based on values cited by Schueler (1999) for urban areas. The lower level reflects the higher quality of baseflow in undeveloped areas, and is half of the typical free-flowing stream standard (200/100 ml).

The geometric mean bacteria values assumed for purposes of calculating bacteria loads in this study are presented in Table 2-7. For each land use, the table lists the average annual flow and bacteria concentration, plus the combined flow and concentration.

The values in Table 2-7 for runoff and baseflow quality are derived from the values in Table 2-6. For developed land uses, the values in Table 2-7 come directly from Table 2-6. The values for "adjusted open" land use in Table 2-6 were used for the undeveloped, tidal marsh and river open water land uses. For wetlands and open water in upland areas, the runoff bacteria concentration is assumed to be an order of magnitude lower than for the wetlands and open water directly connected to the tidal river. This reflects the fact that direct bacteria loads to the upland water and wetlands will receive some treatment before being discharged to the primary stream network in the watershed.

TABLE 2-7

MAY RIVER WATERSHED
LAND USE AVERAGE FLOW AND BACTERIA CONCENTRATION CHARACTERISTICS

Land Use Category	% Impervious	Average Flows (inches/year)			Geometric Mean Bacteria Concentration (#/100 ml)		
		Runoff	Baseflow	Total	Runoff	Baseflow	Total
Commercial	85%	37.8	1.1	38.8	2700	500	2580
Industrial	70%	31.9	2.1	34.0	2300	500	2090
Open Water	30%	14.5	0.0	14.5	140	100	140
Open Water - River	100%	48.4	0.0	48.4	1400	100	1400
Residential - High Density	50%	24.2	3.5	27.7	6600	500	4760
Residential - Low Density	10%	8.7	6.3	15.0	6600	500	2240
Residential - Medium Density	25%	14.5	5.3	19.8	6600	500	3330
Undeveloped - Other	0%	4.8	7.0	11.8	1400	100	290
Wetland - Tidal Marsh	100%	48.4	0.0	48.4	1400	100	1400
Wetland	30%	14.5	0.0	14.5	140	100	140

2.6 Tide Data

Tide data for the May River study were obtained from the National Oceanic and Atmospheric Administration (NOAA) web site. Data at the web site indicated that the mean tidal range for station 8669262 (North Bull Island, May River) is 7.52 feet. Furthermore, the data indicated that the mean low water (MLW) elevation at this location is 0.23 feet above the mean lower low water (MLLW) elevation.

This information was used to calculate average low tide and high tide river volumes at various locations in the May River. A number of transects (cross-sections) were drawn across the river, from the downstream boundary to the headwaters. At each transect, the mean water depth at MLLW was determined based on USGS quadrangle maps and NOAA's National Ocean Service nautical charts. The value of 0.23 feet was added to the MLLW depth to get the mean water depth at MLW. The average low tide volume between transects was calculated as the average of the mean depths at the upstream and downstream transects, multiplied by the surface area of open water between the two transects. The average intratidal volume (i.e., the difference in volume between low tide and high tide) between transects was calculated by averaging the open water surface area and the combined open water/tidal marsh surface area between the two transects, and then multiplying this average area value by the average tidal range (7.52 feet).

The low tide and intratidal volume calculations were used in conjunction with freshwater inflow data to divide the May River into tidal prism model segments. This will be discussed further in Section 3 of this report.

2.7 River Water Quality

Monitoring data were obtained from the South Carolina Department of Health and Environmental Control (SCDHEC). The database provided by SCDHEC included measurements of salinity, water temperature and bacteria levels at 8 monitoring stations in the tidal May River. The period of data collection ranged from three to seven years at the stations, with samples generally collected on a monthly basis.

Tables 2-8 and 2-9 summarize the water quality data for the sampling stations. For the data analysis, the available data were pooled to combine the data from stations that are in the same water quality model segment. (Figure 2-4 shows the segmentation of the river for modeling purposes, as well as the location of SCDHEC monitoring stations. The segmentation of the water quality model will be discussed later in the report.) Table 2-8 summarizes data for only the stations that had a full seven years of monitoring data (years 1994-2000). Table 2-9 presents data summaries for all stations for the period of October 1997 through December 2000. All eight of the stations had data for that period.

The summary statistics presented in the tables include average salinity, average water temperature and geometric mean fecal coliform bacteria concentration. The geometric mean was calculated for bacteria because the May River water quality standard for bacteria (MPN of 14/100 ml) is based on the geometric mean concentration calculated from 36 consecutive monthly sampling values.

For all three parameters, the tables also show the 90 percent confidence interval of the average or geometric mean value. The "confidence interval" concept reinforces the fact that the measured values reflect samples taken once a month over a period of several years, and the mean calculated from these samples may not equal the mean that would be calculated if samples were taken continuously over a long period of time. Based on the number of samples taken, and the mean and variability of the sampling data, we are 90% sure that the "actual" mean value is between the low and the high ends of the 90% confidence interval.

The values presented in Table 2-8 indicate similar values for salinity, temperature and bacteria in river segments 2 through 4. (Segment 1, a short river segment that typically is primarily or totally composed of upstream freshwater inflow during low tide conditions, is not monitored by SCDHEC. This segment would not have the required salinity level to support shellfish population even under totally undeveloped watershed conditions.)

FIGURE 2-4

MAY RIVER SEGMENTATION AND WATER QUALITY MONITORING STATIONS

May River Water Quality Model
Beaufort County, South Carolina

N

LEGEND

- Monitoring Stations
- May River Segmentation
- May River Subwatersheds
- May River Watershed

Scale:
1 inch = 4,500 feet

4500 0 4500 Feet

DISCLAIMER

Thomas & Hutton Engineering Co. compiled the map information from the following sources:

DATA	SOURCE	DATE (if applicable)
Monitoring Stations	DHEC	
CIR Orthophotography	NAPP & Palmetto GIS	1999

[illegible]

Other data sets delineated are from the following sources:

DATA	SOURCE	DATE (if applicable)
May River Watershed	Thomas & Hutton Engineering Co.	
May River Segmentation	Thomas & Hutton Engineering Co.	
May River Subwatersheds	Thomas & Hutton Engineering Co.	

Job Number: J-14483	Prepared For: Palmetto Bluff, LLC		Scale: 1" = 4,500'
Produced By: AMB	Produced: 4/2/2002	Last Modified:	Modified by: AMB
Projection: SC Stateplane	Horizontal Datum: NAD83	Vertical Datum	
File: I:\J-14483_WaterQuality\MayR_Watershed\J-14483_mayriverwatershed.apr			

Thomas & Hutton Engineering Co.

Camp Dresser & McKee

TABLE 2-8

MAY RIVER
MEASURED WATER QUALITY DATA JANUARY 1994 THROUGH DECEMBER 2000

River Segment	Monitoring Station(s)	Number of Observations	Constituent	Units	Average Value	90% Confidence Interval For Average Value	
						Low	High
1	None	---	Temperature	average (degrees C)	---	---	---
			Salinity	average (ppt)	---	---	---
			Bacteria	geometric mean (#/100 ml)	---	---	---
2	19-19	77	Temperature	average (degrees C)	21.9	20.7	23.1
			Salinity	average (ppt)	26.9	26.2	27.6
			Bacteria	geometric mean (#/100 ml)	5.3	4.6	6.2
3	19-16	77	Temperature	average (degrees C)	21.9	20.7	23.1
			Salinity	average (ppt)	27.4	26.9	27.8
			Bacteria	geometric mean (#/100 ml)	5.6	4.7	6.7
4	19-18	154	Temperature	average (degrees C)	21.9	21.0	22.7
	19-01		Salinity	average (ppt)	27.5	27.0	27.9
			Bacteria	geometric mean (#/100 ml)	3.5	3.2	3.9
Downstream	19-11	154	Temperature	average (degrees C)	21.9	21.0	22.7
Boundary	19-12		Salinity	average (ppt)	27.7	27.2	28.1
			Bacteria	geometric mean (#/100 ml)	4.2	3.7	4.7

NOTE: Results include only the records from stations having data for the full 7-year period.

TABLE 2-9

MAY RIVER
MEASURED WATER QUALITY DATA OCTOBER 1997 THROUGH DECEMBER 2000

River Segment	Monitoring Station(s)	Number of Observations	Constituent	Units	Average Value	90% Confidence Interval For Average Value	
						Low	High
1	None	---	Temperature	average (degrees C)	---	---	---
			Salinity	average (ppt)			
			Bacteria	geometric mean (#/100 ml)			
2	19-19	39	Temperature	average (degrees C)	21.5	19.8	23.2
			Salinity	average (ppt)	27.6	26.5	28.7
			Bacteria	geometric mean (#/100 ml)	4.5	3.6	5.6
3	19-24	78	Temperature	average (degrees C)	21.5	20.3	22.7
	19-16		Salinity	average (ppt)	28.1	27.4	28.9
			Bacteria	geometric mean (#/100 ml)	5.0	4.2	5.8
4	19-18	117	Temperature	average (degrees C)	21.5	20.5	22.5
	19-25		Salinity	average (ppt)	28.3	27.6	28.9
	19-01		Bacteria	geometric mean (#/100 ml)	3.3	2.9	3.7
Downstream	19-11	78	Temperature	average (degrees C)	21.5	20.3	22.7
Boundary	19-12		Salinity	average (ppt)	28.5	27.8	29.1
			Bacteria	geometric mean (#/100 ml)	3.8	3.2	4.5

Regarding segments 2 through 4, we would expect segment 2 to be influenced most by freshwater inflows, and therefore to have the lowest salinity and highest bacteria levels. We would also expect segment 4 to be most heavily influenced by the incoming tide, and therefore to have the highest salinity and lowest bacteria concentration.

The values in the table generally are consistent with our expectations. The average salinity is lowest in segment 2 and highest in segment 4, though the difference in the average values is small. This reflects the substantial tidal effect on the entire river. The bacteria values in segments 2 and 3 are higher than in segment 4, which again is consistent with expectations. The geometric mean bacteria level in segment 3 is higher than the geometric mean for segment 2, which was not expected. However, this may simply be a function of the relatively small database and the variability of bacteria in nature.

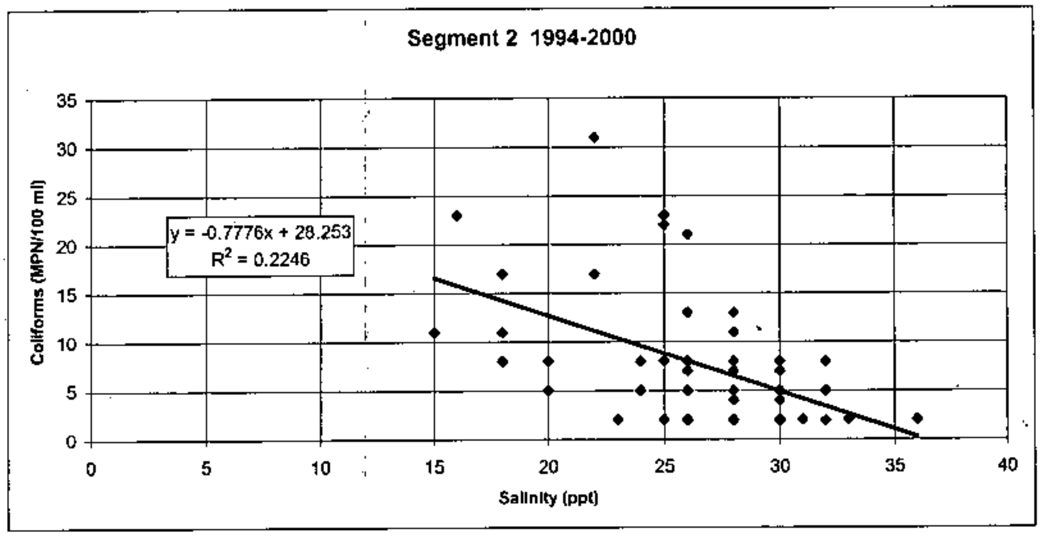
The values in Table 2-9 follow the same trends as the values in Table 2-8. In general, the average salinity values suggest that the period of October 1997 through December 2000 was relatively drier than the period of 1994 through 2000, having less freshwater inflow and resulting in higher salinity values throughout the tidal river system. The geometric mean bacteria levels for the period October 1997 through December 2000 are lower in all segments, compared to the means for the period 1994 through 2000.

Figures 2-5 through 2-8 illustrate the relationship between bacteria level and salinity, and bacteria level and water temperature, for the sampling data in segments 2 through 4 and the downstream river boundary. The plots of bacteria versus salinity illustrate the effect of wet weather discharges on bacteria concentrations in the tidal river, with lower salinity values representing wet weather periods with above-average freshwater inflow, and higher salinity values representing dry weather periods with below-average freshwater inflow. The plots of bacteria versus water temperature reflect the seasonal nature of bacteria concentrations, with average water temperature being highest during summer months and lowest during winter months.

The plots suggest that there is a relationship between bacteria level and salinity. The slope of the best-fit line in all cases indicates that higher bacteria levels are associated with low salinity, wet weather conditions. This is not surprising, given that wet weather runoff concentrations of bacteria are generally an order of magnitude higher than dry weather baseflow concentrations. Typical bacteria concentrations for surface runoff and baseflow are discussed later in this report.

In contrast, the plots show no apparent relationship between bacteria level and water temperature. Surface runoff bacteria data indicate that the geometric mean bacteria concentration during warm weather months is typically higher than the geometric mean during cold weather months, by an order of magnitude or more (CDM, 2001; USEPA, 1983). In the river, the substantial difference in warm weather and cold weather surface runoff concentrations is offset in part by mixing with incoming tidal water having low bacteria levels. Furthermore, the bacteria die-off rate in the river is expected to be much higher in warm weather than in cold weather. A model developed by Thomas & Hutton (2001) indicates that the die-off of bacteria is primarily a function of water temperature and surface light intensity. During warm weather, the water temperature is higher, the days are longer and the sun's intensity is greater. All of these factors contribute to higher die-off rates. Conversely, the die-off rates are lower in winter because the water temperature is relatively low, the days are shorter, and the sun is less intense.

Based on these results, the focus of the modeling will be in evaluating impacts of alternative flows and loads caused by differences in land use and management strategies, and will not do detailed seasonal analyses.



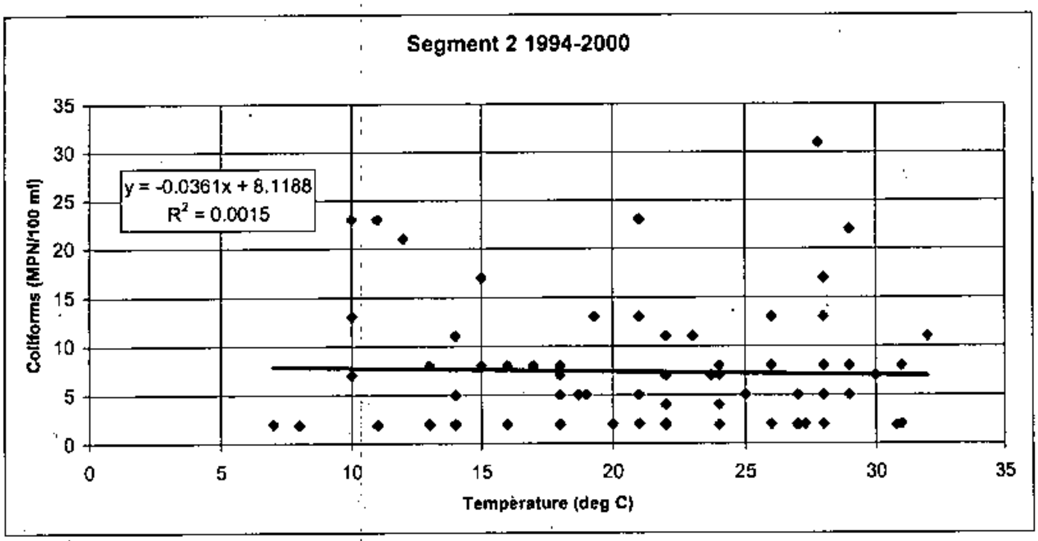
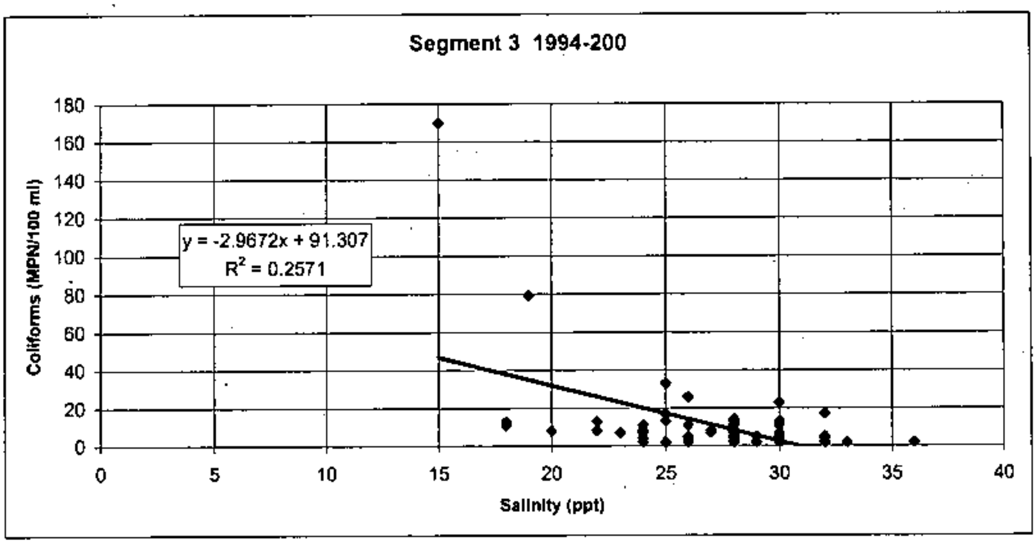


Figure 2-5. Salinity/Bacteria and Water Temperature/Bacteria Plots for May River Segment 2.



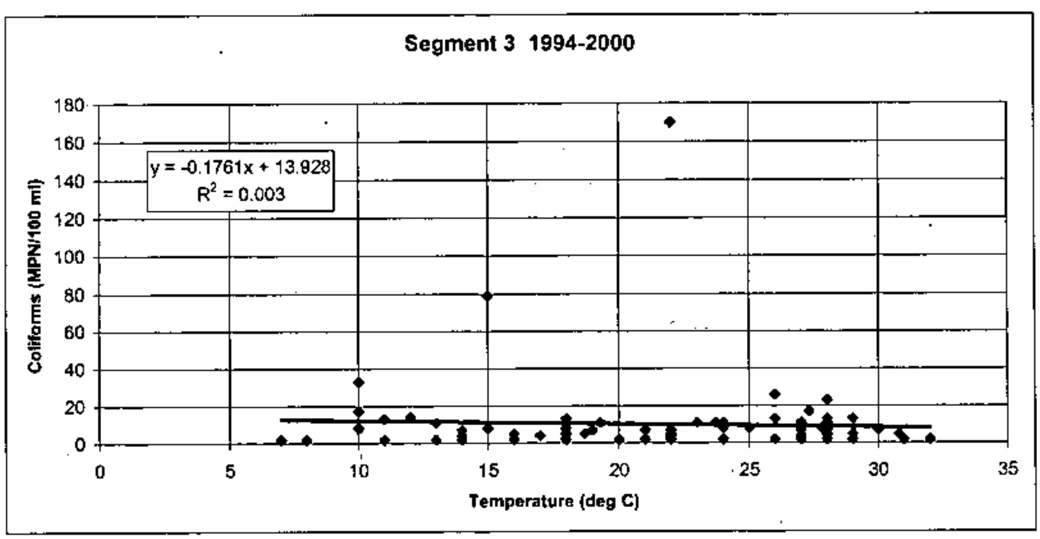
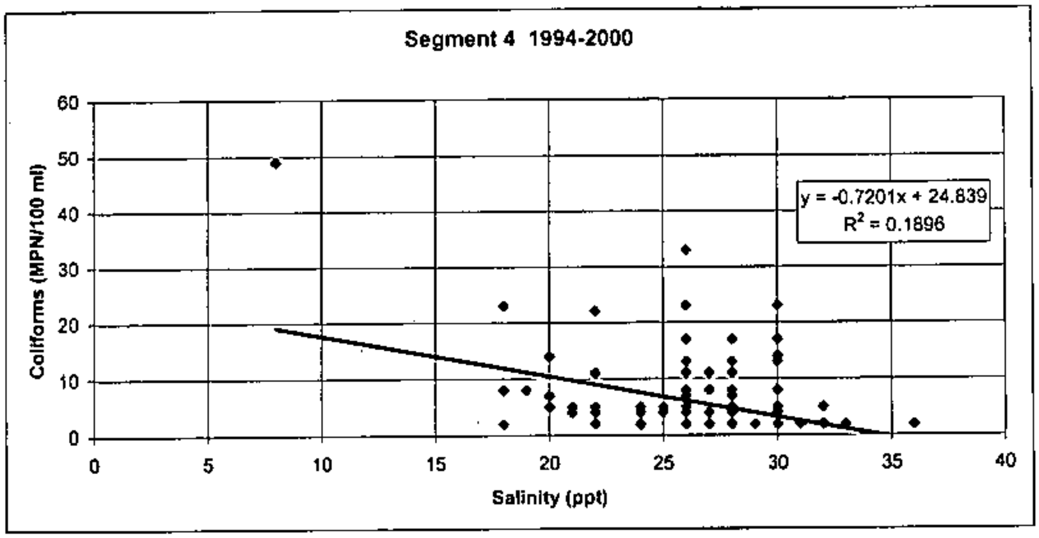


Figure 2-6. Salinity/Bacteria and Water Temperature/Bacteria Plots for May River Segment 3.



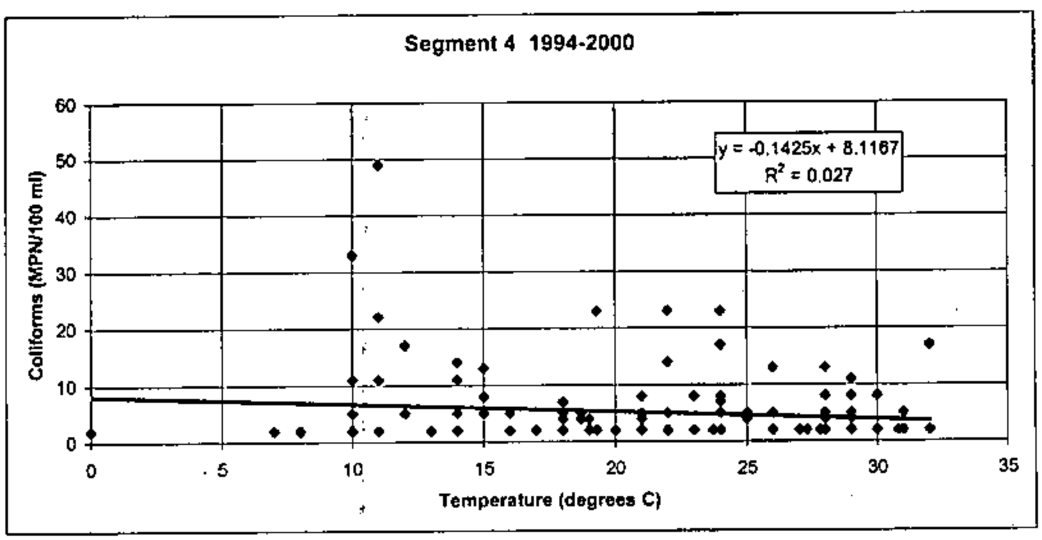
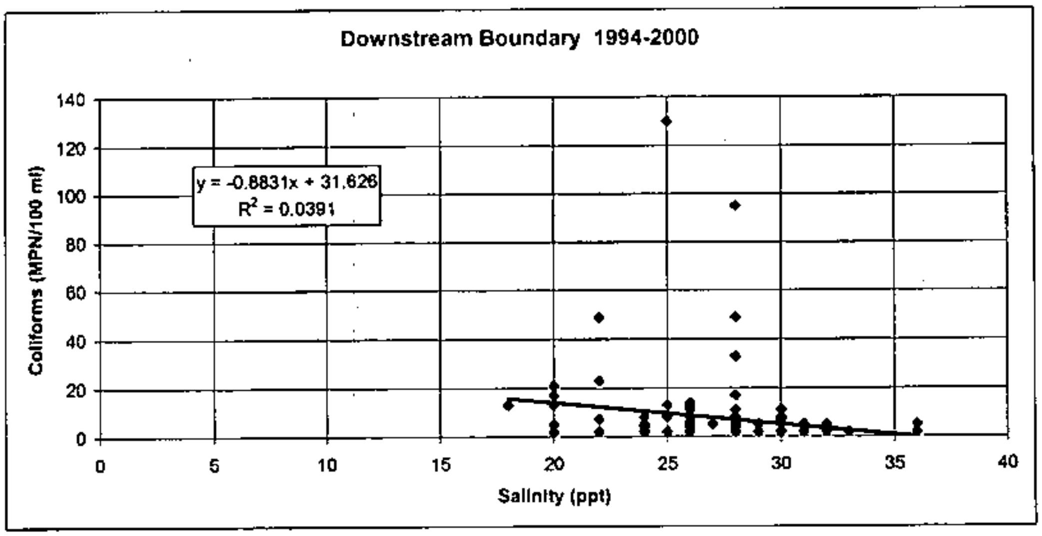


Figure 2-7. Salinity/Bacteria and Water Temperature/Bacteria Plots for May River Segment 4.



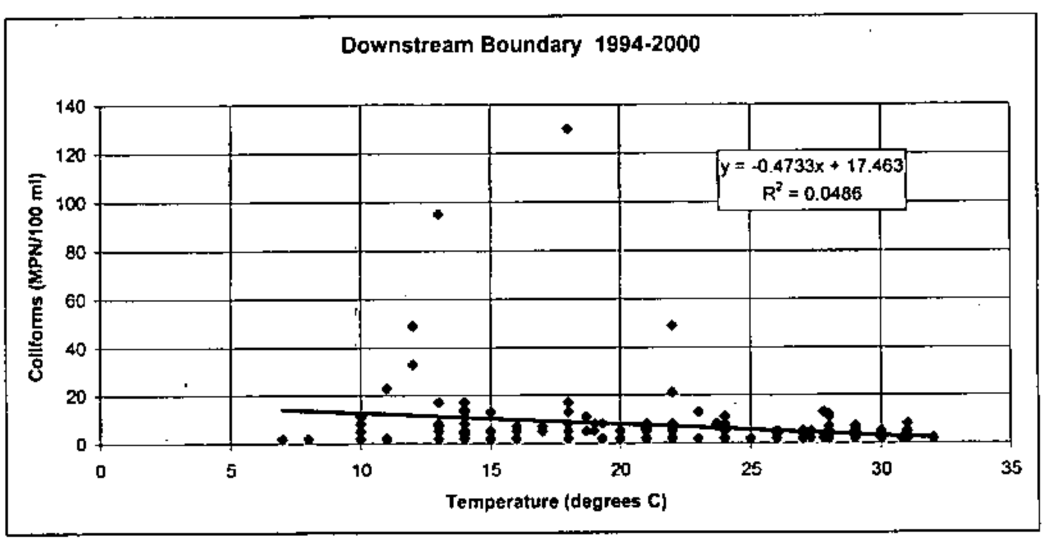


Figure 2-8. Salinity/Bacteria and Water Temperature/Bacteria Plots for May River Downstream Boundary.

Section 3
May River Model Development and Calibration to Existing Land Use Conditions

A spreadsheet-based computer model of the May River was developed to evaluate bacteria levels in the river for various land use conditions, management practices, and meteorological conditions. The model uses the "tidal prism" approach to evaluate the interaction of tidal inflow/outflow and freshwater inflows from upland areas. The model also includes a bacteria loss factor to assess the rate at which bacteria loads decline in the river.

The overall "tidal prism" structure of the model was tested by comparing salinity results calculated by the model with the measured salinity data provided by SCDHEC.. The bacteria die-off rate was established initially based on the method developed by Thomas & Hutton (2001). The initial estimates were then refined so that the river bacteria levels calculated by the model were consistent with the bacteria data provided by SCDHEC.

3.1 Overview of River Model

Using the "tidal prism" method, the tidal river is divided into segments whose lengths are defined by the maximum travel distance during a tidal cycle. The following paragraphs provide an example to demonstrate how the tidal cycle is represented in the model.

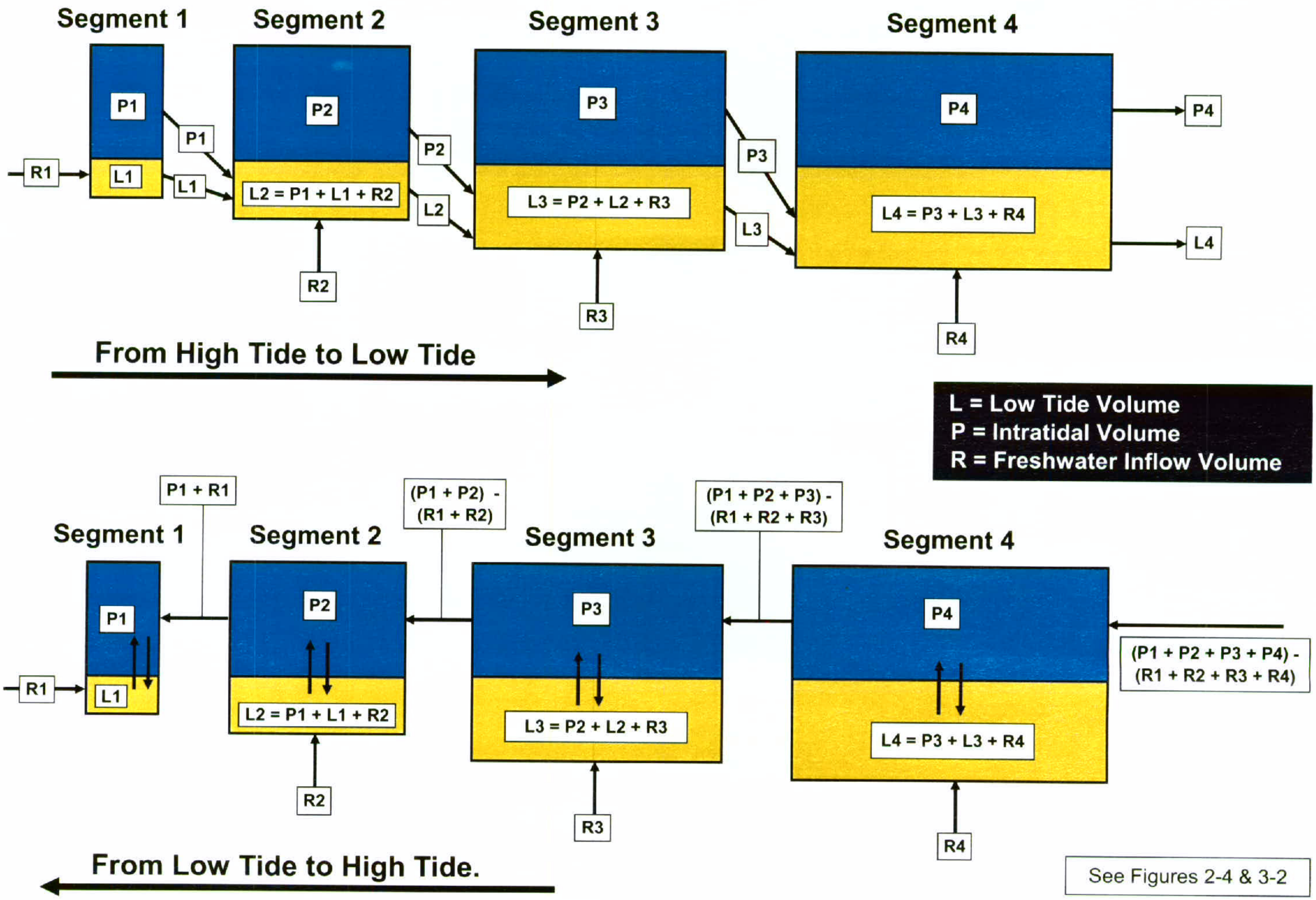
Figure 3-1 is a schematic representation of an example tidal prism model setup. In this case, the model includes four segments for modeling purposes. For each model segment, the following physical parameters are defined:

- L is the volume of water in the segment at low tide
- P is the "intratidal" volume of water in the segment (i.e., the difference between low tide and high tide water volumes in the segment). The sum of L and P represents the high tide volume in the segment.
- R is the average freshwater inflow volume to the segment during half a tidal cycle (i.e., 0.26 days or 6.24 hours).

In the transition from high tide to low tide, the high tide volume in an upstream segment moves to the downstream segment and combines with the freshwater inflow to the downstream segment. Consequently, the model segments are developed so that the low tide volume in each segment is equal to the sum of the high tide volume in the upstream segment plus the freshwater inflow to the segment over half a tidal cycle. In the example, the low tide volume in segment 2 (L_2) is equal to the high tide

Figure 3-1

Tidal Prism Schematic



See Figures 2-4 & 3-2

volume in segment 1 (P_1+L_1) plus the freshwater inflow to segment 2 (R_2). Similarly, the low tide volume in segment 3 (L_3) is equal to the high tide volume in segment 2 (P_2+L_2) plus the freshwater inflow to segment 3 (R_3), and so on.

In the transition from low tide to high tide, the tidal inflow to the system starts at the downstream end of the system and works its way upstream. In this example, the total tidal inflow volume to segment 4 is equal to the difference between the total intratidal volume of the system ($P_1 + P_2 + P_3 + P_4$) and the total freshwater inflow ($R_1 + R_2 + R_3 + R_4$). The tidal inflow mixes with the low tide volume already in segment 4 (L_4) and the freshwater inflow R_4. From this mixture, flow is discharged to the next upstream segment, with the amount of flow equal to the difference between the intratidal volume in segments 1 through 3 ($P_1 + P_2 + P_3$) and the freshwater inflow to segments 1 through 3 ($R_1 + R_2 + R_3$). This mixing and subsequent upstream discharge continues to the upstream end of the system.

Table 3-1 lists the physical data and Figure 3-2 depicts the volumetric characteristics for the river segments in the May River model. The river is divided into 4 segments for modeling purposes. (These segments are shown in Figure 2-4).

TABLE 3-1

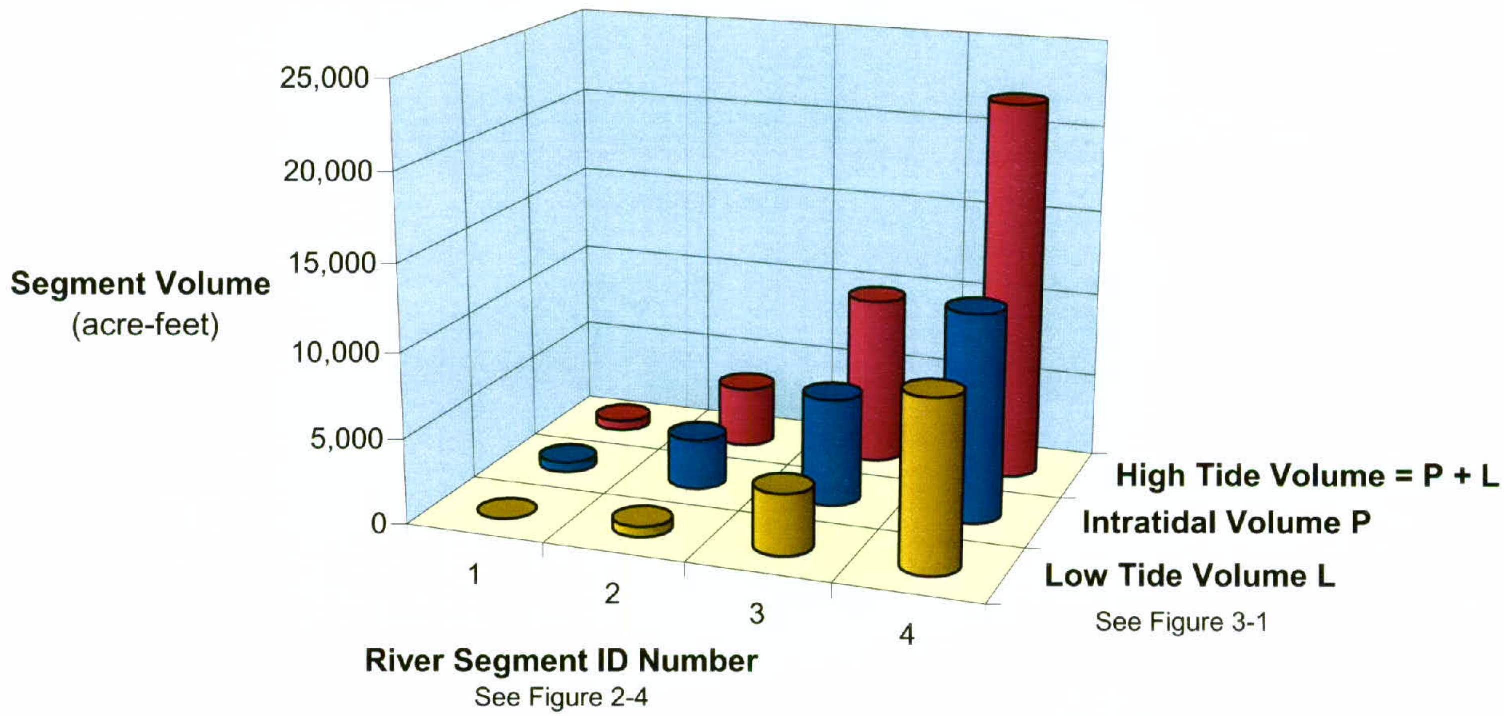
MAY RIVER
RIVER SEGMENT CHARACTERISTICS

Characteristic	Segment 1	Segment 2	Segment 3	Segment 4	TOTAL
Mean Low Water Volume (acre-ft)	6	602	3564	9893	14065
Mean Low Water Surface Area (acres)	3	169	554	1001	1727
Mean Low Water Depth (feet)	1.6	3.6	6.4	9.9	8.1
Mean High Water Volume (acre-ft)	596	3557	9885	22068	36106
Mean High Water Surface Area (acres)	153	617	1128	2237	4135
Mean High Water Depth (feet)	3.9	5.8	8.8	9.9	8.7

For the May River model, the segmentation process began by evaluating the average freshwater volume to the upstream end of the tidal river system. Based on the existing land use, this was calculated to be about 6 acre-feet per half tidal cycle. The downstream boundary of segment 1 was then set such that the low tide volume of the segment was equal to 6 acre-feet. Based on the location of the downstream segment 1 boundary, the surface area of tidal marsh associated with segment 1 was determined from the land use coverage. The water surface area at low tide (3 acres) and at high tide (153 acres) was averaged, and multiplied by the average tidal excursion (7.52 feet)

Figure 3-2

River Segment Volumetric Characteristics



NOTE: River Segment 1 does not have the required salinity level to support shellfish population.

to calculate an intratidal volume of 590 acre-feet. The total high tide volume in segment 1 is 6 acre-feet plus 590 acre-feet, or 596 acre-feet.

The segmentation process then moved to the next downstream segment (segment 2). In this case, the downstream boundary of segment 2 was set so that the low tide volume of segment 2 was equal to the high tide volume in segment 1 (596 acre-feet) plus the freshwater inflow to segment 2 over a half tidal cycle (6 acre-feet), or 602 acre-feet. Based on the location of the upstream and downstream segment 2 boundaries, the surface area of tidal marsh associated with segment 2 was determined from the land use coverage. The water surface area at low tide (169 acres) and at high tide (617 acres) was averaged, and multiplied by the average tidal excursion (7.52 feet) to calculate an intratidal volume of 2,955 acre-feet. The total high tide volume in segment 1 is 602 acre-feet plus 2,955 acre-feet, or 3,557 acre-feet.

The same procedure was used to determine the boundary locations, low tide characteristics, and high tide characteristics for segments 3 and 4.

3.2 Comparison of Model Results with Measured Salinity

The tidal prism model was used to evaluate average salinity conditions in the May River, and the results calculated by the model were compared to the monitoring data provided by SCDHEC to assess the model's ability to accurately represent the mixing of freshwater and tidal inflows to the river.

3.2.1 Freshwater Inflows

The average freshwater inflows to the river were calculated based on the existing land use coverage and the average annual surface runoff and baseflow rates calculated for each land use type.

Table 3-2 lists the land use distribution for the area tributary to each of the river model segments. The tributary area to each of the four segments is relatively consistent, ranging from 5,144 to 6,514 acres (8 to 10 square miles).

The average freshwater flow to each of the segments is determined in Table 3-3. For each segment, the table shows the percent of the tributary area associated with each land use, and the associated average annual inflow. The sum of the flow values for all land uses represents the total inflow to the segment. For existing land use, the average annual segment inflows range from 14 to 29 inches per year. The lowest value corresponds to the May River headwaters (segment 1). The highest value corresponds to the most downstream segment, which is because the land use includes substantial percentages of river water surface and tidal marshland, plus some urban development.

TABLE 3-2

MAY RIVER WATERSHED
EXISTING LAND USE

Land Use Category	Tributary Area (acres) to Tidal River Segments					% of Total
	Segment 1	Segment 2	Segment 3	Segment 4	TOTAL	
Commercial	0	0	61	70	131	0.6%
Industrial	0	49	0	0	49	0.2%
Open Water	83	47	120	143	393	1.7%
Open Water - River	6	169	554	1,001	1,730	7.5%
Residential - High Density	0	0	542	0	542	2.3%
Residential - Low Density	889	444	829	99	2,260	9.7%
Residential - Medium Density	221	478	411	621	1,732	7.5%
Undeveloped - Other	3,300	3,028	1,853	1,630	9,811	42.3%
Wetland - Tidal Marsh	150	448	574	1,236	2,408	10.4%
Wetland	1,866	1,421	500	344	4,131	17.8%
TOTAL	6,514	6,084	5,444	5,144	23,186	100.0%

TABLE 3-3

MAY RIVER WATERSHED
AVERAGE FRESHWATER INFLOWS FOR EXISTING LAND USE

Land Use Category	Segment 1		Segment 2		Segment 3		Segment 4	
	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)
Commercial	0%	0.0	0%	0.0	1%	0.4	1%	0.5
Industrial	0%	0.0	1%	0.3	0%	0.0	0%	0.0
Open Water	1%	0.2	1%	0.1	2%	0.3	3%	0.4
Open Water - River	0%	0.0	3%	1.3	10%	4.9	19%	9.4
Residential - High Density	0%	0.0	0%	0.0	10%	2.8	0%	0.0
Residential - Low Density	14%	2.0	7%	1.1	15%	2.3	2%	0.3
Residential - Medium Density	3%	0.7	8%	1.6	8%	1.5	12%	2.4
Undeveloped - Other	51%	6.0	50%	5.9	34%	4.0	32%	3.8
Wetland - Tidal Marsh	2%	1.1	7%	3.6	11%	5.1	24%	11.6
Wetland	29%	4.2	23%	3.4	9%	1.3	7%	1.0
TOTAL	100%	14.2	100%	17.2	100%	22.7	100%	29.4

The model was used to calculate average segment salinity values assuming average freshwater inflows and average tidal conditions. The average freshwater inflows to the river were assigned a salinity value of zero. The salinity of the tidal inflow at the downstream end of the system was set based on the measured salinity values at the SCDHEC monitoring stations downstream of the segment 4 boundary.

3.2.2 Model Salinity Results

The salinity values calculated by the model are presented in Table 3-4. The model calculates segment salinity values at low tide and high tide conditions. The value listed in the table reflects the average of the low tide and high tide salinity values. Measured average salinity values, and the 90 percent confidence interval for the average of the measured salinity values, are presented for comparison purposes.

The values in the table show very good agreement between the measured and calculated average salinity values in the river. The difference between the measured and calculated values are in all cases less than or equal to 0.1 parts per thousand (ppt). These results suggest that the geometry of the river, and the mixing of freshwater and tidal inflows, is represented well by the model.

TABLE 3-4

MAY RIVER
MODELED SALINITY CONCENTRATIONS FOR AVERAGE FRESHWATER INFLOWS

River Segment	Land Use/ Management Scenario	Modeled Salinity Concentration (ppt)	Measured Values 1994-2000		
			Average Value	90% Confidence Interval For Average Value	
				Low	High
1	Existing Land Use	13.4	---	---	---
2	Existing Land Use	26.9	26.9	26.2	27.6
3	Existing Land Use	27.4	27.4	26.9	27.8
4	Existing Land Use	27.6	27.5	27.0	27.9
Downstream Boundary	Existing Land Use	27.7	27.7	27.2	28.1

3.3 Comparison of Model Results with Measured Bacteria Concentrations

After the salinity evaluation, the model was used to evaluate geometric mean bacteria concentrations in the tidal river. In this case, the basis for evaluating the model is the geometric mean of the sampling data provided by SCDHEC. Consequently, the inflow bacteria concentrations reflect a geometric mean concentration that is calculated based on the geometric mean concentration from each land use type and the relative fraction of freshwater inflow contributed by each land use type.

3.3.1 Freshwater Inflows and Bacteria Loads

The weighted geometric mean bacteria concentration for freshwater inflows to each segment is shown in Table 3-5. The geometric mean values for the freshwater discharge to the river segments ranges from 398/100 ml to 1166/100 ml. The flow to segment 1 has the lowest bacteria value because 80 percent of the tributary area consists of undeveloped and wetland land uses that have relatively low bacteria levels. In contrast, the bacteria levels for segments 3 and 4 are highest because the tributary areas for those segments have more urban land use and more river open water and tidal marshland (see Table 2-7).

TABLE 3-5

MAY RIVER WATERSHED
GEOMETRIC MEAN BACTERIA CONCENTRATIONS FOR EXISTING LAND USE

Land Use Category	Geometric Mean Bacteria Concentration (#/100 ml)	Segment 1 % of Tributary Area	Segment 1 Average Freshwater Inflow (inches)	Segment 2 % of Tributary Area	Segment 2 Average Freshwater Inflow (inches)	Segment 3 % of Tributary Area	Segment 3 Average Freshwater Inflow (inches)	Segment 4 % of Tributary Area	Segment 4 Average Freshwater Inflow (inches)
Commercial	2580	0%	0.0	0%	0.0	1%	0.4	1%	0.5
Industrial	2090	0%	0.0	1%	0.3	0%	0.0	0%	0.0
Open Water	140	1%	0.2	1%	0.1	2%	0.3	3%	0.4
Open Water - River	1400	0%	0.0	3%	1.3	10%	4.9	19%	9.4
Residential - High Density	4760	0%	0.0	0%	0.0	10%	2.8	0%	0.0
Residential - Low Density	2240	14%	2.0	7%	1.1	15%	2.3	2%	0.3
Residential - Medium Density	3330	3%	0.7	8%	1.6	8%	1.5	12%	2.4
Undeveloped - Other	290	51%	6.0	50%	5.9	34%	4.0	32%	3.8
Wetland - Tidal Marsh	1400	2%	1.1	7%	3.6	11%	5.1	24%	11.6
Wetland	140	29%	4.2	23%	3.4	9%	1.3	7%	1.0
TOTAL		100%	14.2	100%	17.2	100%	22.7	100%	29.4
		Weighted bacteria concentration (MPN/100 ml)	398	Weighted bacteria concentration (MPN/100 ml)	574	Weighted bacteria concentration (MPN/100 ml)	1166	Weighted bacteria concentration (MPN/100 ml)	1120

Weighted bacteria concentration is the antilog of the flow-weighted average of the log bacteria concentration values for each land use.

3.3.2 Bacteria Loss in the River

Unlike salinity, bacteria is not considered a conservative substance. Instead, the model includes a first-order loss rate description to account for processes that tend to reduce the bacteria quantities in the river. In a first-order loss calculation, the rate of bacteria loss is considered to be proportional to the first-order loss rate and the bacteria concentration, with more rapid die-off when the concentration is higher.

Preliminary estimates of the first-order bacteria loss rates for each model segment were developed based on the methodology used by Thomas & Hutton (2001) for evaluating bacteria removal in wet detention ponds. The methodology assumed that overall bacteria loss was due to three factors, which include a base die-off rate, loss due to light, and loss due to settling. Of the three factors, the base die-off rate and loss due to light tend to dominate the overall loss rate, and loss due to settling is minimal.

The base die-off rate is a function of several factors, including salinity and temperature. Higher salinity values result in higher die-off rates. Similarly, higher water temperature also results in a higher die-off rate. In water with no salinity and a water temperature of 20 degrees Celsius, the base die-off rate is assumed to be 0.8/day. Under the average salinity conditions observed in the May River segments (27-28 ppt), the base die-off rate increases to 0.96 to 0.97/day. In addition, the average water temperature in the river segment s is 22 degrees C, and the base die-off rate increases by 7% per degree above the base temperature of 20 degrees C. This increases the base die-off rate to 1.00 to 1.11/day.

The loss rate due to light is a function of several factors, including surface light intensity and the extinction coefficient, a measure of how well the light penetrates into the water. The surface light energy varies over the year as a function of daylight hours and the distance from the sun. In the study area, the average daily light intensity is 397 langleys/day, based on solar radiation data collected in the Savannah, Georgia region (U.S. Department of Energy, 2001). The estimate of the light extinction coefficient was based on an assumed relationship with the concentration of suspended solids in the river segments. In the absence of any measured suspended solids data, a concentration of 10 mg/l was assumed for the model segments, with a higher concentration of 20 mg/l assumed for segment 1 at low tide conditions (when the segment is totally influenced by freshwater inflows).

The loss rate due to light was calculated during low tide and high tide conditions. Under low tide conditions, water is confined to the river channel and the loss rate is calculated only for the channel. During high tide conditions, water is present in the channel and in the tidal marsh areas. A separate loss rate is calculated for the channel and the marsh area, and the separate loss rates are weighted by the volume of water in the channel and in the marsh areas to calculate an overall light loss rate for the channel/marsh area system.

The total loss rate during low tide and high tide conditions was calculated as the sum of the loss rate due to die-off and the loss rate due to light. The overall loss rate for each river segment was then calculated as the average of the low tide and high tide loss rates. These average values were used as the preliminary loss rate estimates in the river water quality model.

The values used to calculate the loss rates, and the initial loss rate estimates, are presented in Tables 3-6 and 3-7. As shown in Table 3-7, the preliminary first-order loss rates for the river segments range from 2.11 to 3.82/day. The higher values correspond to the shallower upstream segments where light penetration will be more complete. The values calculated here are within the range of bacteria loss rates presented in the USEPA document *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water - Part II* (1985). The typical values presented in the report ranged from 0.5 to 2.0/tidal cycle, which is equivalent to 1.0 to 3.9/day.

3.3.3 Model Bacteria Results

When the model was run with the preliminary first-order loss rates and the average bacteria loads, the resulting instream bacteria concentrations were too low. This is likely due to the fact that the loss rate tends to be lower at low river bacteria concentrations, because the bacteria present under low-concentration conditions tend to be more resistant to die-off. In contrast, bacteria present during high-concentration conditions (i.e., following a storm event) will have a range of resistance to die-off, with the least resistant dying off most rapidly.

TABLE 3-6

MAY RIVER
RIVER SEGMENT DATA USED TO ESTIMATE BACTERIA DECAY RATES

River Segment	Tide Status	Open Water Volume (acre-feet)	Marsh Water Volume (acre-feet)	Total Water Volume (acre-feet)	% of Volume Attributed to Open Water	Open Water Mean Depth (feet)	Marsh Water Mean Depth (feet)	Salinity (ppt)	Temperature (deg C)
1	Low Tide	5.5	0	5.5	100%	1.6	---	0	22
1	High Tide	31	564	595	5%	9.1	3.8	26	22
2	Low Tide	601	0	601	100%	3.6	---	26	22
2	High Tide	1874	1682	3556	53%	11.1	3.8	28	22
3	Low Tide	3560	0	3560	100%	6.4	---	28	22
3	High Tide	7726	2157	9883	78%	14.0	3.8	28	22
4	Low Tide	9887	0	9887	100%	9.9	---	28	22
4	High Tide	17415	4647	22062	79%	17.4	3.8	28	22

TABLE 3-7

MAY RIVER
CALCULATION OF ESTIMATED BACTERIA DECAY RATES

River Segment	Tide Status	Base Decay Rate (1/day)	Average Surface Light Energy (langley/hr)	Light Extinction Coefficient (1/meter)	Open Water Light Decay Rate (1/day)	Open Water Overall Decay Rate (1/day)	Marsh Water Light Decay Rate (1/day)	Marsh Overall Decay Rate (1/day)	Total Decay Rate (1/day)	Average Decay Rate
1	Low Tide	0.92	16.5	11.0	3.13	4.04	---	---	4.04	
1	High Tide	1.09	16.5	5.5	1.09	2.18	2.62	3.71	3.63	3.82
2	Low Tide	1.09	16.5	5.5	2.77	3.87	---	---	3.87	
2	High Tide	1.11	16.5	5.5	0.89	2.00	2.62	3.73	2.82	3.21
3	Low Tide	1.11	16.5	5.5	1.53	2.64	---	---	2.64	
3	High Tide	1.11	16.5	5.5	0.71	1.82	2.62	3.73	2.23	2.42
4	Low Tide	1.11	16.5	5.5	1.00	2.11	---	---	2.11	
4	High Tide	1.11	16.5	5.5	0.57	1.68	2.62	3.73	2.11	2.11

Consequently, the model was modified to adjust the first-order loss rate as a function of the river segment bacteria concentration. The equation that calculates the actual loss rate is as follows:

$$K_a = (K_b * C) / (K_c + C)$$

where

K_a = Bacteria loss rate (1/day) adjusted for instream bacteria concentration

K_b = Base bacteria loss rate (1/day) before adjustment for instream bacteria concentration

C = Segment bacteria concentration (MPN/100 ml)

K_c = Concentration of bacteria (MPN/100 ml) for which the loss rate will be one-half of the base bacteria loss rate

A similar formulation has been used in water quality modeling studies such as the Rouge River National Wet Weather Demonstration Project (Rouge Program Office, 1995). In that study, a similar equation was used to adjust the first-order decay rate of instream biochemical oxygen demand (BOD) as a function of the instream BOD concentration. The equation was implemented in that project to account for higher decay rates during wet weather conditions which included combined sewer overflow (CSO) discharges with high BOD levels, and lower BOD decay rates during dry weather conditions with low baseflow BOD levels.

The instream concentrations of bacteria were calibrated by adjusting the segment bacteria loss rates and the factor for reducing the loss rates as a function of segment bacteria concentration. The best results were produced with a single value of K_c (8.6/100 ml) assigned to each model segment, and the base segment bacteria loss rates adjusted by segment to provide a good match with the measured geometric mean bacteria concentrations. The adjusted base loss rates in all cases were within 30% of the preliminary rates calculated as a function of base die-off and mortality due to light.

The bacteria values calculated by the model are presented in Table 3-8. The model calculates segment bacteria values at low tide and high tide conditions. The value listed in the table reflects the average of the low tide and high tide bacteria values. Measured geometric mean bacteria values, and the 90 percent confidence interval for the mean of the measured bacteria values, are presented for comparison purposes.

TABLE 3-8

MAY RIVER
MODELED BACTERIA CONCENTRATIONS FOR AVERAGE FRESHWATER INFLOWS

River Segment	Land Use/ Management Scenario	Adjusted First-Order Loss Rate (1/day)	Modeled Bacteria Concentration (MPN/100 ml)	Measured Values 1994-2000		
				Average Value	90% Confidence Interval For Average Value	
					Low	High
1	Existing Land Use	3.3	28.9	---	---	---
2	Existing Land Use	2.0	5.7	5.3	4.6	6.2
3	Existing Land Use	1.0	5.1	5.6	4.7	6.7
4	Existing Land Use	1.4	3.8	3.5	3.2	3.9
Downstream Boundary	Existing Land Use	NA	4.1	4.0	3.7	4.7

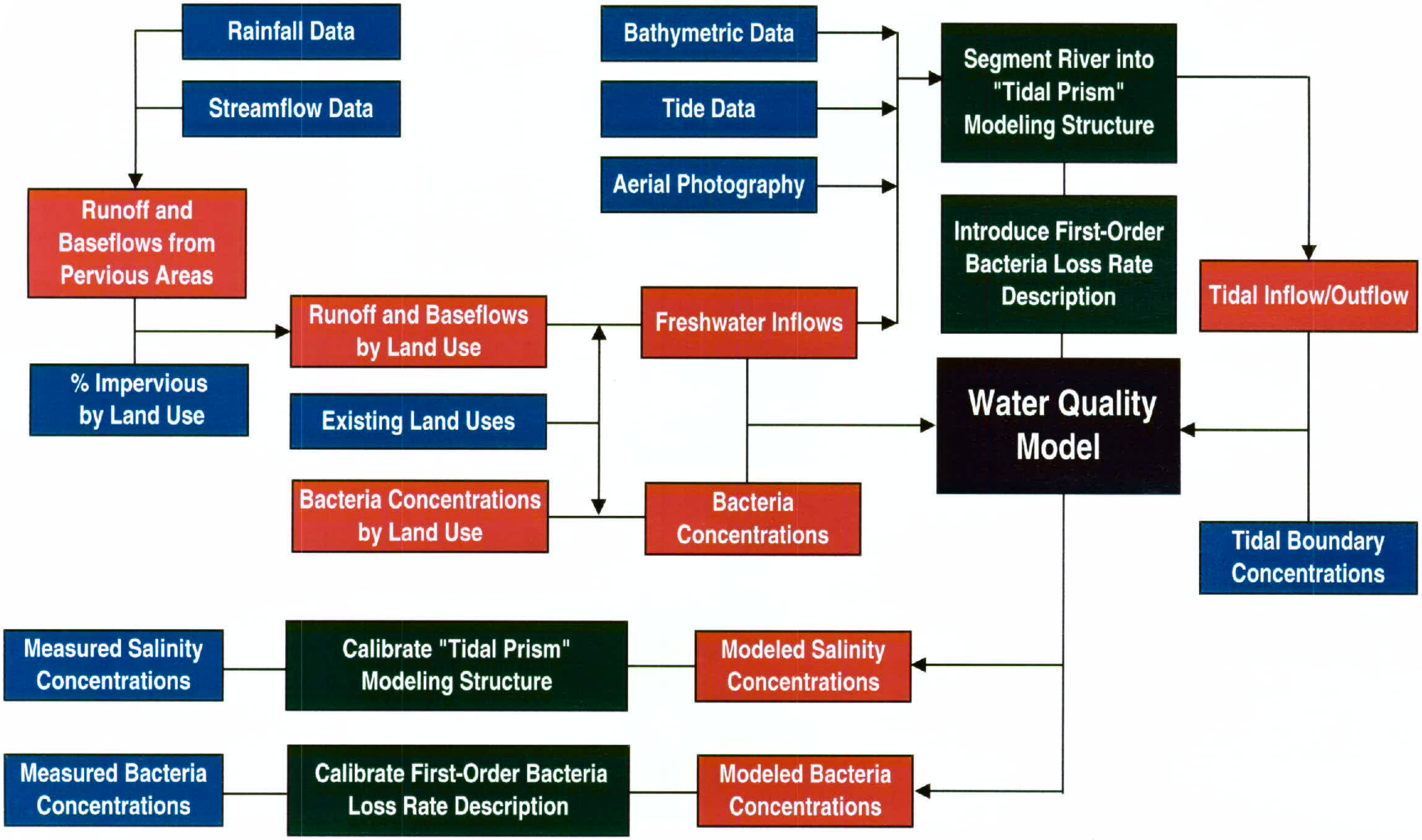
The values in the table show very good agreement between the measured and calculated bacteria values in the river. The difference between the measured and calculated geometric mean values are in all cases less than 10%, and the calculated mean is well within the 90% confidence interval for the mean of the measured data. In addition, the final loss rate values are still consistent with the literature values cited earlier. The calibrated rates range from 1.0 to 3.3/day, at an average temperature of 22 degrees C. These values correspond to a range of 0.5 to 1.5/tidal cycle at a base temperature of 20 degrees C. The literature listed typical values of 0.5 to 2.0/tidal cycle at the base temperature of 20 degrees C.

3.4 Summary

A tidal prism model of the May River was developed and calibrated for existing land use conditions (see Figure 3-3). Comparison of the measured and modeled salinity data suggests that the model representation of the interaction between freshwater and tidal inflows is accurate. Comparison of the measured and modeled bacteria data suggests that the calculated bacteria loads to the river and the calibrated bacteria loss rates in the river result in a good representation of bacteria concentrations measured in the river. Both the load calculations and the calibrated loss rates are based on the best available literature values. Overall, the results suggest that the model successfully represents processes occurring in the river, and is suitable for evaluation of alternative land use and management conditions.

Figure 3-3

Model Development and Calibration Schematic



Section 4
Model Evaluations for Future Land Use Conditions

The methodology used to evaluate May River water quality under existing land use conditions was also used to evaluate water quality under future land use conditions. Based on the predicted land use changes in the watershed, future freshwater bacteria loads to the river were calculated. The tidal prism river model was then used to calculate the expected geometric mean bacteria concentrations in the river segments. The results are compared to the State water quality standards for Outstanding Resource Waters (geometric mean of 14/100 ml).

4.1 Future Land Use with No Controls

The presumed future land use conditions are presented in Table 4-1. Overall, the future land use conditions presume that only 7% of the watershed is developable land that is undeveloped. The remaining 93% includes water and wetland areas that will not be developed (37%) and developed land (56%). Most of the development is either low density or medium density residential land use.

TABLE 4-1

MAY RIVER WATERSHED
FUTURE LAND USE

Land Use Category	Tributary Area (acres) to Tidal River Segments					% of Total
	Segment 1	Segment 2	Segment 3	Segment 4	TOTAL	
Commercial	0	0	61	70	131	0.6%
Industrial	64	127	0	0	191	0.8%
Open Water	83	47	120	143	393	1.7%
Open Water - River	6	169	554	1,001	1,730	7.5%
Residential - High Density	0	406	630	57	1,093	4.7%
Residential - Low Density	1,104	1,267	1,959	1,374	5,703	24.6%
Residential - Medium Density	2,465	1,996	618	703	5,782	24.9%
Undeveloped - Other	777	203	428	215	1,623	7.0%
Wetland - Tidal Marsh	150	448	574	1,236	2,408	10.4%
Wetland	1,866	1,421	500	344	4,131	17.8%
TOTAL	6,514	6,084	5,444	5,144	23,186	100.0%

For this analysis, no controls were assumed for new development. Therefore, the results would represent a "worst-case" future scenario. In fact, Beaufort County requires best management practices (BMPs) such as detention ponds and vegetated swales to reduce the pollution loads from new development sites, before and after construction. An analysis of future land use with BMPs is presented in Section 4.2 of this report.

4.1.1 Freshwater Inflows and Bacteria Loads

The average freshwater flow to each of the river model segments is listed in Table 4-2. For each segment, the table shows the percent of the tributary area associated with each land use, and the associated average annual inflow. The sum of the flow values for all land uses represents the total inflow to the segment.

TABLE 4-2

MAY RIVER WATERSHED
AVERAGE FRESHWATER INFLOWS FOR FUTURE LAND USE

	Segment 1		Segment 2		Segment 3		Segment 4	
Land Use Category	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)
Commercial	0%	0.0	0%	0.0	1%	0.4	1%	0.5
Industrial	1%	0.3	2%	0.7	0%	0.0	0%	0.0
Open Water	1%	0.2	1%	0.1	2%	0.3	3%	0.4
Open Water - River	0%	0.0	3%	1.3	10%	4.9	19%	9.4
Residential - High Density	0%	0.0	7%	1.8	12%	3.2	1%	0.3
Residential - Low Density	17%	2.5	21%	3.1	36%	5.4	27%	4.0
Residential - Medium Density	38%	7.5	33%	6.5	11%	2.2	14%	2.7
Undeveloped - Other	12%	1.4	3%	0.4	8%	0.9	4%	0.5
Wetland - Tidal Marsh	2%	1.1	7%	3.6	11%	5.1	24%	11.6
Wetland	29%	4.2	23%	3.4	9%	1.3	7%	1.0
TOTAL	100%	17.3	100%	21.0	100%	23.9	100%	30.5

For future land use, the average annual segment inflows range from 17.3 to 30.5 inches per year. This reflects a freshwater flow increase of about 22 percent to river segments 1 and 2, and a 4 to 5 percent increase in freshwater inflow to segments 3 and 4, compared to freshwater inflows for existing land use.

Table 4-3 shows the weighted geometric mean bacteria concentrations for the freshwater inflow to each model segment. The geometric mean values range from 1084 - 1614/100 ml. For river segments 1 and 2, the concentrations are more than double the values for existing land use conditions. The increases in concentration in segments 3 and 4 are in the range of 30 to 50 percent.

4.1.2 Model Bacteria Results

The river model was applied using the same loss rate coefficients and boundary bacteria concentration as for existing land use. The only change from existing land use was the freshwater inflow and bacteria concentration to each model segment.

The results of the analysis for future land use with no controls are presented in Table 4-4. As shown in the table, the model predicts that the long-term geometric mean bacteria concentration in segments 2 through 4 will be less than the standard of 14/100 ml, even if no BMPs are required for new development.

TABLE 4-3

MAY RIVER WATERSHED
AVERAGE FRESHWATER INFLOWS AND BACTERIA CONCENTRATIONS FOR FUTURE LAND USE

Land Use Category	Geometric Mean Bacteria Concentration (#/100 ml)	Segment 1		Segment 2		Segment 3		Segment 4	
		% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)
Commercial	2580	0%	0.0	0%	0.0	1%	0.4	1%	0.5
Industrial	2090	1%	0.3	2%	0.7	0%	0.0	0%	0.0
Open Water	140	1%	0.2	1%	0.1	2%	0.3	3%	0.4
Open Water - River	1400	0%	0.0	3%	1.3	10%	4.9	19%	9.4
Residential - High Density	4760	0%	0.0	7%	1.8	12%	3.2	1%	0.3
Residential - Low Density	2240	17%	2.5	21%	3.1	36%	5.4	27%	4.0
Residential - Medium Density	3330	38%	7.5	33%	6.5	11%	2.2	14%	2.7
Undeveloped - Other	290	12%	1.4	3%	0.4	8%	0.9	4%	0.5
Wetland - Tidal Marsh	1400	2%	1.1	7%	3.6	11%	5.1	24%	11.6
Wetland	140	29%	4.2	23%	3.4	9%	1.3	7%	1.0
TOTAL		100%	17.3	100%	21.0	100%	23.9	100%	30.5
		Weighted bacteria conc. (MPN/100 ml)	1084	Weighted bacteria conc. (MPN/100 ml)	1465	Weighted bacteria conc. (MPN/100 ml)	1614	Weighted bacteria conc. (MPN/100 ml)	1446

Weighted bacteria concentration is the antilog of the flow-weighted average of the log bacteria concentration values for each land use.

TABLE 4-4

MAY RIVER
MODELED BACTERIA CONCENTRATIONS FOR AVERAGE FRESHWATER INFLOWS
FUTURE LAND USE CONDITIONS WITH NO CONTROLS

River Segment	Land Use/ Management Scenario	Adjusted First-Order Loss Rate (1/day)	Modeled Bacteria Concentration (MPN/100 ml)
1	Future Land Use/No Controls	3.7	64.8
2	Future Land Use/No Controls	2.5	10.1
3	Future Land Use/No Controls	1.1	6.5
4	Future Land Use/No Controls	1.5	4.3
Downstream Boundary	Future Land Use/No Controls	NA	4.1

4.2 Future Land Use with BMPs for New Development

For this analysis, BMP controls were assumed for new development in the watershed. Beaufort County requires best management practices (BMPs) such as detention ponds and vegetated swales to reduce the pollution loads from new development sites, before and after construction. BMPs must be deployed on new development to demonstrate that post-development loads will not exceed loads that would be generated by uncontrolled low-density residential development.

In the analysis, it was assumed that runoff from all new development would be treated by BMPs, with the exception of low-density residential development. By its nature, low density development limits surface runoff pollution load impacts, and therefore can be considered a BMP. For other new development, it was assumed that runoff would be treated by wet detention ponds designed in accordance with sizing criteria set forth in the Beaufort County Stormwater BMP Manual (CDM, 1998). Based on previous analyses (Thomas & Hutton, 2001; CDM, 2001), a bacteria removal efficiency of 90% was used in the analysis.

4.2.1 Freshwater Inflows and Bacteria Loads

The average freshwater flow to each of the river model segments is the same as for future land use without BMP controls. The only difference is that the bacteria concentration in stormwater runoff treated by BMPs will be reduced by 90%.

Table 4-5 shows the weighted geometric mean bacteria concentrations for the freshwater inflow to each model segment. The geometric mean values range from 533 - 1473/100 ml. For all river segments, the concentrations range from 20 to 40 percent higher than the values for existing land use conditions.

TABLE 4-5

MAY RIVER WATERSHED
AVERAGE FRESHWATER INFLOWS AND BACTERIA CONCENTRATIONS FOR FUTURE LAND USE
WITH WET DETENTION POND BMPS FOR NEW DEVELOPMENT

		Segment 1		Segment 2		Segment 3		Segment 4	
Land Use Category	Bacteria Concentration (#/100 ml)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)	% of Tributary Area	Average Freshwater Inflow (inches)
Commercial	2580	0%	0.0	0%	0.0	1%	0.4	1%	0.5
Commercial with BMP	270	0%	0.0	0%	0.0	0%	0.0	0%	0.0
Industrial	2090	0%	0.0	1%	0.3	0%	0.0	0%	0.0
Industrial with BMP	240	1%	0.3	1%	0.4	0%	0.0	0%	0.0
Open Water	140	1%	0.2	1%	0.1	2%	0.3	3%	0.4
Open Water - River	1400	0%	0.0	3%	1.3	10%	4.9	19%	9.4
Residential - High Density	4760	0%	0.0	0%	0.0	10%	2.8	0%	0.0
Res. High Density with BMP	640	0%	0.0	7%	1.8	2%	0.4	1%	0.3
Residential - Low Density	2240	14%	2.0	7%	1.1	15%	2.3	2%	0.3
Res. Low Density with BMP	2240	3%	0.5	14%	2.0	21%	3.1	25%	3.7
Residential - Medium Density	3330	3%	0.7	8%	1.6	8%	1.5	12%	2.4
Res. Medium Density with BMP	610	34%	6.8	25%	4.9	4%	0.8	2%	0.3
Undeveloped - Other	290	12%	1.4	3%	0.4	8%	0.9	4%	0.5
Wetland - Tidal Marsh	1400	2%	1.1	7%	3.6	11%	5.1	24%	11.6
Wetland	140	29%	4.2	23%	3.4	9%	1.3	7%	1.0
TOTAL		100%	17.3	100%	21.0	100%	23.9	100%	30.5
		Weighted bacteria conc. (MPN/100 ml)	533	Weighted bacteria conc. (MPN/100 ml)	787	Weighted bacteria conc. (MPN/100 ml)	1473	Weighted bacteria conc. (MPN/100 ml)	1392

Weighted bacteria concentration is the antilog of the flow-weighted average of the log bacteria concentration values for each land use.

BMP assumes 90% reduction in runoff concentration

BMPs assumed for new development except for low density residential.

4.2.2 Model Bacteria Results

The river model was applied using the same loss rate coefficients and boundary bacteria concentration as for existing land use. The only change from existing land use was the freshwater inflow and bacteria concentration to each model segment.

The results of the analysis for future land use with no controls are presented in Table 4-6. As shown in the table, the model predicts that the long-term geometric mean bacteria concentration in segments 2 through 4 will be less than the standard of 14/100 ml.

TABLE 4-6

MAY RIVER
MODELED BACTERIA CONCENTRATIONS FOR AVERAGE FRESHWATER INFLOWS
FUTURE LAND USE CONDITIONS WITH BMPs FOR NEW DEVELOPMENT

River Segment	Land Use/ Management Scenario	Adjusted First-Order Loss Rate (1/day)	Modeled Bacteria Concentration (MPN/100 ml)
1	Future Land Use with BMPs	3.4	37.5
2	Future Land Use with BMPs	2.2	7.3
3	Future Land Use with BMPs	1.1	5.9
4	Future Land Use with BMPs	1.4	4.1
Downstream Boundary	Future Land Use with BMPs	NA	4.1

4.3 Future Land Use with BMPs - Wet Conditions

The SCDHEC evaluates compliance with the 14/100 ml geometric mean standard for bacteria by calculating the geometric mean of samples taken monthly over a 3-year sampling period. If the geometric mean value calculated from the sampling data exceeds 14/100 ml, that segment of the water body is considered to in non-compliance with designated waterbody uses, and may be shut down for uses such as shellfish harvesting.

Consequently, the model was used to evaluate the "wettest" 3-year period of record. A review of local rainfall data indicated that the years 1964 through 1966 had the greatest 3-year rainfall (190 inches total; 63.3 inches annual average for the 3-year period). All three years had more than the average annual rainfall of 48.4 inches.

For each of the years in the 3-year period, annual freshwater inflows and geometric mean bacteria concentrations were calculated. These data were used to calculate the geometric mean bacteria concentration in each river segment for each of the three years. The values for each of the three years were then used to calculate the overall 3-year geometric mean for each segment.

The results of the analysis are summarized in Tables 4-7 and 4-8. Table 4-7 shows the results assuming no controls for future development, whereas Table 4-8 shows results assuming BMPs for future development (excluding low density residential land use). Both tables show that segments 2 through 4 have a geometric mean bacteria concentration less than 14/100 ml, even in the wettest 3-year period on record.

TABLE 4-7

MAY RIVER
MODELED BACTERIA CONCENTRATIONS FOR INFLOWS BASED ON 1964-1966 RAINFALL
FUTURE LAND USE CONDITIONS WITH NO CONTROLS

River Segment	Land Use/ Management Scenario	Rainfall Year	Modeled Bacteria Concentration (MPN/100 ml)
1	Future Land Use with No Controls	1964	76.2
		1965	66.6
		1966	67.3
		AVERAGE	69.9
2	Future Land Use with No Controls	1964	15.0
		1965	10.9
		1966	11.1
		AVERAGE	12.2
3	Future Land Use with No Controls	1964	8.7
		1965	6.9
		1966	7.1
		AVERAGE	7.5
4	Future Land Use with No Controls	1964	5.1
		1965	4.5
		1966	4.6
		AVERAGE	4.7

TABLE 4-8

MAY RIVER
MODELED BACTERIA CONCENTRATIONS FOR INFLOWS BASED ON 1964-1966 RAINFALL
FUTURE LAND USE CONDITIONS WITH BMPs FOR NEW DEVELOPMENT

River Segment	Land Use/ Management Scenario	Rainfall Year	Modeled Bacteria Concentration (MPN/100 ml)
1	Future Land Use with BMPs	1964	43.3
		1965	38.5
		1966	38.9
		AVERAGE	40.2
2	Future Land Use with BMPs	1964	10.3
		1965	7.8
		1966	8.0
		AVERAGE	8.6
3	Future Land Use with BMPs	1964	7.7
		1965	6.3
		1966	6.4
		AVERAGE	6.8
4	Future Land Use with BMPs	1964	4.9
		1965	4.4
		1966	4.4
		AVERAGE	4.6

4.4 Summary

The calibrated tidal model was used to evaluate the impacts of future development on May River bacteria concentrations. Despite increases in freshwater inflows and bacteria concentrations, the model suggests that the long-term geometric mean bacteria concentrations in segments 2 through 4 of the river model will not exceed the bacteria geometric mean standard of 14/100 ml, even if no BMPs are used to treat runoff from new development. Further model results suggest that the geometric mean bacteria concentration would not exceed the instream water quality standard for the wettest 3-year period on record, again with or without BMPs for new development.

Section 5
Model Evaluations for Wet Weather Events

The methodology and results presented in Sections 3 and 4 focused on calculating the geometric mean bacteria concentrations in each river segment. The calculated values were compared to the geometric mean water quality standard of 14/100 ml to assess the compliance with the instream standard and the need for runoff BMP controls. The model results suggest that the geometric mean bacteria concentrations in the river will not exceed the receiving water standard, even if no BMPs are implemented for new development.

In addition to the geometric mean bacteria standard, there is another receiving water bacteria standard for the May River. This standard dictates that no more than 10% of the bacteria samples from the river shall be greater than 43/100 ml.

Additional analyses were conducted to evaluate compliance with this second standard. Historical data were evaluated to examine the relationship between the geometric mean bacteria concentration and the frequency of bacteria measurements above 43/100 ml. In addition, the model was applied over a range of daily rainfall totals and bacteria runoff concentrations. By examining the model results for various combinations of rainfall and runoff quality, and the probability of the rainfall and concentrations occurring, the frequency of exceeding the 43/100 ml threshold was evaluated.

5.1 Historical Data

Figure 5-1 presents a plot of geometric mean bacteria concentration versus percent of samples exceeding 43/100 ml, for sampling stations in the May River and Okatie River. The linear regression line shows a coefficient of determination R^2 of 0.95 (i.e., 95% of the variability in the percent of samples with bacteria exceeding 43/100 ml can be explained by the geometric mean bacteria concentration).

The plotted values suggest that a geometric mean of 14/100 ml is no guarantee that the threshold value of 43/100 ml will be exceeded less than 10% of the time. Based on the regression line, a geometric mean concentration of 14/100 ml corresponds to about 20% exceedance of the 43/100 ml threshold. A 10% exceedance would be expected at a geometric mean concentration of 8.8/100 ml, based on the regression line equation.

5.2 Model Evaluation of Rainfall and Runoff Bacteria Concentration Variability

As another method of estimating the frequency of bacteria concentrations exceeding the 43/100 ml threshold, the model was applied for various combinations of daily rainfall and runoff bacteria concentrations. The methodology for the analysis is described in the following paragraphs.

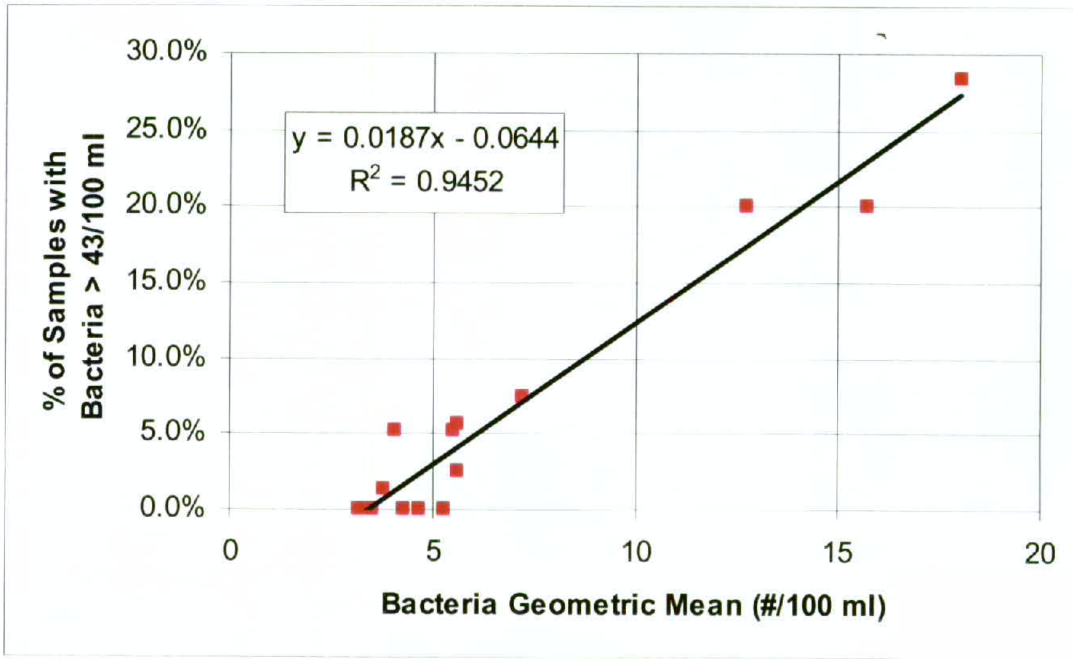


Figure 5-1. Relationship between Geometric Mean Bacteria and Percent of Samples Exceeding 43/100 ml Threshold

Table 5-1 lists the rainfall events for which the bacteria model was run. Based on the daily rainfall analysis discussed previously in Section 2.3, only about 20% of the days during the year have enough rainfall to cause any stormwater runoff to occur. As shown in the table, the model was run for daily rainfalls ranging from 0.08 inches to 10.8 inches, the greatest daily rainfall in the 70-year period of record. The runoff from impervious areas was determined assuming an initial abstraction of 0.07 inches for depression storage, and complete conversion of rainfall to runoff after the depression storage was filled. For pervious areas, the runoff was based on the excess rainfall resulting from a curve number of 70 (e.g., "woods in good hydrologic condition" on hydrologic soil group C). This curve number for pervious area was selected so that the overall annual runoff was consistent with the assumed pervious runoff coefficient of 0.10 (i.e., 10% of rainfall is converted to runoff from pervious areas).

The freshwater inflows from these storms were applied to the model segments over a one-day (two tidal cycle) period. Following the day of stormwater runoff, the freshwater inflows were assumed to return to the average annual freshwater inflow values.

For each of the daily storms, several different surface runoff bacteria concentrations were assumed. These include the 10th, 30th, 50th, 70th, and 90th percentile runoff bacteria concentrations, as presented in Table 2-6. Baseflow bacteria concentrations were assumed to remain constant. Following the day of rain, the freshwater bacteria concentrations were assumed to return to the average geometric mean freshwater concentrations.

TABLE 5-1

DAILY RAINFALL/RUNOFF FREQUENCY
BEAUFORT COUNTY 1930-2000

Percent of Time Daily Rainfall Value is Exceeded	Daily Rainfall (inches)	Daily Runoff (inches)	
		Impervious Area	Pervious Area
0.0%	10.80	10.73	6.95
1.0%	2.00	1.93	0.24
2.0%	1.45	1.38	0.07
3.0%	1.15	1.08	0.02
4.0%	0.99	0.92	0.00
5.0%	0.83	0.76	0.00
6.0%	0.72	0.65	0.00
7.0%	0.62	0.55	0.00
8.0%	0.55	0.48	0.00
9.0%	0.48	0.41	0.00
10.0%	0.42	0.35	0.00
15.0%	0.20	0.13	0.00
20.0%	0.08	0.01	0.00

For each evaluated combination of daily rainfall and bacteria runoff concentration, the model was run assuming that the initial (pre-storm) concentrations in the river were equal to the geometric mean river bacteria concentrations calculated previously for the appropriate land use and management conditions. Then, the freshwater inflows and bacteria concentrations were modified for the day of rainfall, and calculations were made for the two "wet" tidal cycles. Subsequent tidal cycles assumed average freshwater inflows and geometric mean bacteria concentrations.

The methodology used to estimate the percent exceedance of the 43/100 ml threshold will be explained further in Section 5.2.1, which provides details of the evaluation for existing land use conditions.

5.2.1 Existing Land Use Conditions

The evaluation for existing land use conditions considered the daily rainfall distribution for the years 1994-2000, as shown in Table 5-2. This period was selected so that the model results could be compared directly with the monitoring data collected in the May River during that period. In general, the distribution of daily rainfall is not substantially different than the 1930-2000 distribution in Table 5-1.

The results of the evaluation for existing land use conditions are presented in Table 5-3. For each combination of rainfall exceedance probability and runoff bacteria concentration percentile, the table lists the number of tidal cycles that have an exceedance of the 43/100 ml threshold in each model segment. In some cases, there is an exceedance in the one half of the tidal cycle but no exceedance in the second half of the tidal cycle, and the number of tidal cycles with an exceedance is therefore not a whole number of tidal cycles.

TABLE 5-2

DAILY RAINFALL/RUNOFF FREQUENCY
BEAUFORT COUNTY 1994-2000

Percent of Time Daily Rainfall Value is Exceeded	Daily Rainfall (inches)	Daily Runoff (inches)	
		Impervious Area	Pervious Area
0.0%	6.83	6.76	3.65
1.0%	2.01	1.94	0.29
2.0%	1.48	1.41	0.10
3.0%	1.12	1.05	0.03
4.0%	0.98	0.91	0.01
5.0%	0.83	0.76	0.00
6.0%	0.72	0.65	0.00
7.0%	0.61	0.54	0.00
8.0%	0.52	0.45	0.00
9.0%	0.45	0.38	0.00
10.0%	0.38	0.31	0.00
15.0%	0.21	0.14	0.00
20.0%	0.11	0.04	0.00

Based on these data, an overall percent exceedance of the 43/100 ml threshold is calculated for each of the evaluated runoff bacteria percentiles. The following discussion uses the calculations for segment 2 and the 90th percentile bacteria concentration as an example of how the percent exceedance was calculated. For this example, the threshold concentration of 43/100 ml was exceeded for 1.5 tidal cycles for the daily rainfall that is exceeded 10% of the time, and was exceeded for 2.5 tidal cycles for the daily rainfall that is exceeded 5% of the time. The methodology then assumes that the average exceedance duration between the 10% and 5% rainfall exceedance is 2.0 tidal cycles (the average of the 1.5 value at 10% rainfall exceedance and the 2.5 value at 5% rainfall exceedance). Given that 5% of the daily rainfall values fall between the 10% and 5% exceedance, and the average duration of the exceedance is 2 tidal cycles (1.04 days), a value of 5.2% exceedance (1.04 days times 5% interval of rainfall exceedance) is calculated. This represents the percent exceedance associated with that increment of daily rainfall exceedance. Similar calculations are made for the other rainfall exceedance increments, and the results are summed to calculate the total percent exceedance for the segment.

TABLE 5-3

PERCENT OF TIME 43/100 ML THRESHOLD IS EXCEEDED
FOR EXISTING LAND USE CONDITIONS
BASED ON MODEL ANALYSIS

Daily Rainfall Percent Exceedance	Number of Tidal Cycles with Bacteria Conc > 43/100 ml			Percent of Year with Bacteria Concentration > 43/100 ml		
	Segment 2	Segment 3	Segment 4	Segment 2	Segment 3	Segment 4
90th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	1	1	0	1.3%	1.3%	0.0%
10%	1.5	1.5	0.5	3.2%	3.2%	0.6%
5%	2.5	2.5	1	5.2%	5.2%	1.9%
4%	2.5	3	1	1.3%	1.4%	0.5%
3%	2.5	3	1.5	1.3%	1.6%	0.6%
2%	3	3	1.5	1.4%	1.6%	0.8%
1%	3	3.5	2	1.6%	1.7%	0.9%
0%	4	4	3.5	1.8%	1.9%	1.4%
TOTAL				17.1%	17.9%	6.9%
70th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0.5	0	0	0.6%	0.0%	0.0%
5%	1	1	0	1.9%	1.3%	0.0%
4%	1.5	1	0	0.6%	0.5%	0.0%
3%	1.5	1.5	0.5	0.8%	0.6%	0.1%
2%	2.5	2	1	1.0%	0.9%	0.4%
1%	2.5	3	1	1.3%	1.3%	0.5%
0%	3.5	3.5	2.5	1.6%	1.7%	0.9%
TOTAL				7.9%	6.3%	1.9%
50th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	1	0	0	1.3%	0.0%	0.0%
4%	1	0	0	0.5%	0.0%	0.0%
3%	1	0.5	0	0.5%	0.1%	0.0%
2%	1	1	0	0.5%	0.4%	0.0%
1%	1.5	1	0	0.6%	0.5%	0.0%
0%	3	3	1.5	1.2%	1.0%	0.4%
TOTAL				4.7%	2.1%	0.4%
30th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	0	0	0	0.0%	0.0%	0.0%
4%	0	0	0	0.0%	0.0%	0.0%
3%	0	0	0	0.0%	0.0%	0.0%
2%	1	0	0	0.3%	0.0%	0.0%
1%	1	0	0	0.5%	0.0%	0.0%
0%	2.5	2.5	1	0.9%	0.6%	0.3%
TOTAL				1.7%	0.6%	0.3%
10th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	0	0	0	0.0%	0.0%	0.0%
4%	0	0	0	0.0%	0.0%	0.0%
3%	0	0	0	0.0%	0.0%	0.0%
2%	0	0	0	0.0%	0.0%	0.0%
1%	0	0	0	0.0%	0.0%	0.0%
0%	1	1	0	0.3%	0.3%	0.0%
TOTAL				0.3%	0.3%	0.0%
OVERALL TOTAL				6.3%	5.4%	1.9%

Using the approach discussed above, a total percent exceedance is calculated for each segment, for each of the bacteria runoff percentiles that were evaluated. The exceedance values calculated for the five bacteria runoff percentiles are then averaged to calculate the overall estimate of exceedance. For example, the calculated exceedance frequency for segment 2 is 6.3%, which is the average of 5 values ranging from 0.3% (10^{th} percentile bacteria runoff concentration) to 17.1% (90^{th} percentile bacteria runoff concentration).

Comparisons of the model results with actual monitoring data suggest that the model provides a conservative estimate of the frequency of exceeding the 43/100 ml threshold. In segment 2, the calculated value of exceedance is 6.3%, whereas the sampling data (77 observations at one monitoring station) measured no exceedances. The model results are closer to the measured data in segment 3, where the model calculated an exceedance frequency of 5.4% and the measured data (77 observations at one monitoring station) shows an exceedance frequency of 2.6%. In segment 4, the model calculates an exceedance frequency of 1.9%, compared to an exceedance frequency of 0.6% based on 154 observations at two sampling stations.

5.2.2 Future Land Use Conditions with No Controls

The evaluation of future land use with no controls considered the daily rainfall distribution for the years 1930-2000, as shown in Table 5-1. Runoff bacteria concentrations were assigned assuming no runoff water quality treatment by BMPs.

The results of the evaluation for existing land use conditions are presented in Table 5-4. The model predicts that the 43/100 ml threshold will be exceeded 11% of the time in river segment 2, which is not allowed by the current water quality standard. The frequency of exceedance in segments 3 and 4 is 8% and 3%, respectively.

The results suggest that some water quality controls will be required to meet the river bacteria water quality standard in river segment 2.

5.2.3 Future Land Use Conditions with BMPs for New Development

The evaluation of future land use with BMPs for new development considered the daily rainfall distribution for the years 1930-2000, as shown in Table 5-1. Runoff bacteria concentrations were assigned assuming no runoff water quality treatment by BMPs for existing development and for future low-density residential development. Treatment by wet detention pond BMPs was assumed for future development of commercial, industrial, medium density residential, and high-density residential land use.

TABLE 5-4

PERCENT OF TIME 43/100 ML THRESHOLD IS EXCEEDED
FOR FUTURE LAND USE CONDITIONS WITH NO CONTROLS
BASED ON MODEL ANALYSIS

Daily Rainfall Percent Exceedance	Number of Tidal Cycles with Bacteria Conc > 43/100 ml			Percent of Year with Bacteria Concentration > 43/100 ml		
	Segment 2	Segment 3	Segment 4	Segment 2	Segment 3	Segment 4
90th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	1.5	1	0	1.9%	1.3%	0.0%
10%	3	2.5	1	5.8%	4.5%	1.3%
5%	3	3	1.5	7.8%	7.1%	3.2%
4%	3	3	1.5	1.6%	1.6%	0.8%
3%	3	3	1.5	1.6%	1.6%	0.8%
2%	3	3.5	2	1.6%	1.7%	0.9%
1%	3.5	3.5	3	1.7%	1.8%	1.3%
0%	4.5	4.5	4.5	2.1%	2.1%	1.9%
TOTAL				23.9%	21.6%	10.2%
70th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	1	0	0	1.3%	0.0%	0.0%
10%	1.5	1	0	3.2%	1.3%	0.0%
5%	2.5	1.5	0.5	5.2%	3.2%	0.6%
4%	2.5	2.5	0.5	1.3%	1.0%	0.3%
3%	3	2.5	1	1.4%	1.3%	0.4%
2%	3	3	1	1.6%	1.4%	0.5%
1%	3	3	1.5	1.6%	1.6%	0.6%
0%	4	4	3.5	1.8%	1.8%	1.3%
TOTAL				17.3%	11.6%	3.8%
50th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	1	0	0	1.3%	0.0%	0.0%
5%	1	1	0	2.6%	1.3%	0.0%
4%	1.5	1	0	0.6%	0.5%	0.0%
3%	1.5	1	0	0.8%	0.5%	0.0%
2%	2.5	1	0	1.0%	0.5%	0.0%
1%	2.5	2.5	0.5	1.3%	0.9%	0.1%
0%	3.5	3.5	2.5	1.6%	1.6%	0.8%
TOTAL				9.2%	5.3%	0.9%
30th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	1	0	0	1.3%	0.0%	0.0%
4%	1	0	0	0.5%	0.0%	0.0%
3%	1	0	0	0.5%	0.0%	0.0%
2%	1	0	0	0.5%	0.0%	0.0%
1%	1	1	0	0.5%	0.3%	0.0%
0%	3	3	1.5	1.0%	1.0%	0.4%
TOTAL				4.4%	1.3%	0.4%
10th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	0	0	0	0.0%	0.0%	0.0%
4%	0	0	0	0.0%	0.0%	0.0%
3%	0	0	0	0.0%	0.0%	0.0%
2%	0	0	0	0.0%	0.0%	0.0%
1%	0	0	0	0.0%	0.0%	0.0%
0%	2	1.5	0.5	0.5%	0.4%	0.1%
TOTAL				0.5%	0.4%	0.1%
OVERALL TOTAL				11.1%	8.0%	3.1%

For the land uses with BMPs, the runoff bacteria concentrations were adjusted to reflect the flow and bacteria load equalization of the wet detention pond, and the bacteria loss in the pond. The flow/load equalization reduces the variability of pollutants such as bacteria in the pond, because it is unlikely that two or more consecutive storms will each have extremely high or extremely low concentrations. Then, the first-order loss of bacteria in the pond reduces the discharge concentration substantially.

Ponds designed in accordance with the Beaufort County Storm Water BMP Manual (CDM, 1998) will have an average hydraulic residence time in excess of 14 days, which means that the water in the permanent pool is typically a mixture of runoff from several storm events. For this analysis, it was assumed that the water in the permanent pool is representative of runoff from four previous storm events. Based on standard statistical methods, mean concentrations calculated for groups of four samples from a given population (e.g., all storm event bacteria concentrations) will exhibit half of the variability of the total population. Consequently, the base values for the 10th, 30th, 70th, and 90th percentile bacteria values in the wet pond were adjusted to reflect half the variability of bacteria concentrations for individual storm events.

The ponds will also remove bacteria based on a first-order loss rate. As discussed earlier, the major factors included in the overall loss rate include a base die-off rate and mortality due to light. Based on values previously developed by Thomas & Hutton (2001) and CDM (2001), a removal efficiency of 90% is assumed for the wet pond BMPs.

The results of the model evaluation for future land use with BMPs are presented in Table 5-5, as well as depicted in Figure 5-2. The model predicts that the 43/100 ml threshold will not be exceeded in any of the river segments. In general, the percent exceedance of the 43/100 ml threshold for this scenario is about 1% greater than the corresponding exceedance frequency calculated for existing land use conditions.

5.3 Discussion of Historical Data and Model Evaluation

Both a review of historical data and the results generated by the May River model suggest that the receiving water bacteria standard allowing no more than 10% of samples to exceed a bacteria concentration of 43/100 ml is more restrictive than the geometric mean standard of 14/100 ml. The historical data suggest that a geometric mean of 8 to 9/100 ml can be expected to correspond to a 10% exceedance frequency for the 43/100 ml threshold.

Figure 5-3 shows a plot of the historical data (the same data as Figure 5-1) combined with the data calculated by the model for existing land use, future land use with no controls, and future land use with BMPs for new development. The model results appear to be consistent with the historical data, and the regression line for the combined historical data and model results is very similar to the regression with the historical data only.

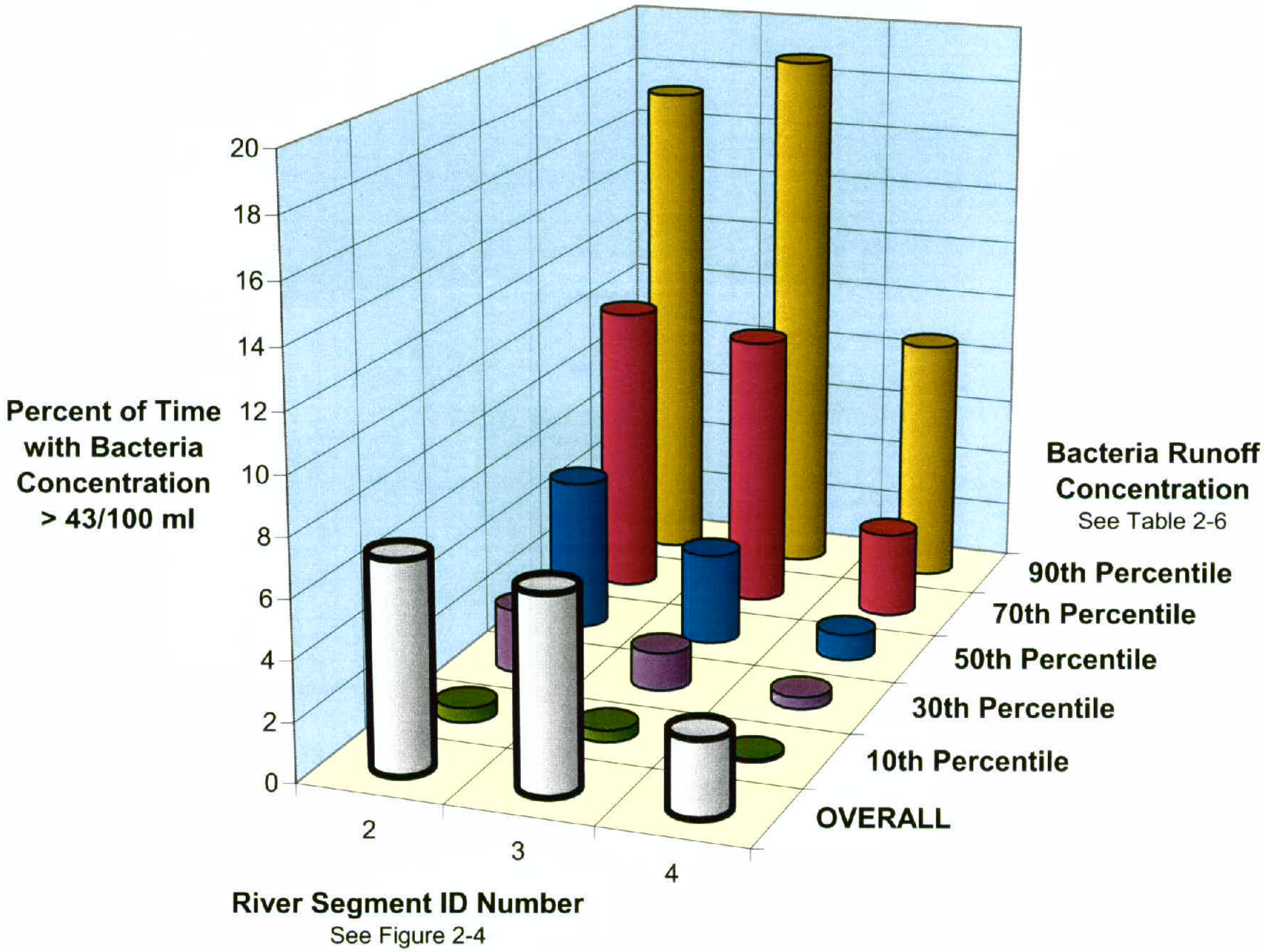
TABLE 5-5

PERCENT OF TIME 43/100 ML THRESHOLD IS EXCEEDED
FOR FUTURE LAND USE CONDITIONS WITH BMPs FOR NEW DEVELOPMENT
BASED ON MODEL ANALYSIS

Daily Rainfall Percent Exceedance	Number of Tidal Cycles with Bacteria Conc > 43/100 ml			Percent of Year with Bacteria Concentration > 43/100 ml		
	Segment 2	Segment 3	Segment 4	Segment 2	Segment 3	Segment 4
90th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	1	1	0	1.3%	1.3%	0.0%
10%	1.5	1.5	1	3.2%	3.2%	1.3%
5%	2.5	3	1	5.2%	5.8%	2.6%
4%	2.5	3	1.5	1.3%	1.6%	0.6%
3%	3	3	1.5	1.4%	1.6%	0.8%
2%	3	3	1.5	1.6%	1.6%	0.8%
1%	3	3.5	2.5	1.6%	1.7%	1.0%
0%	4	4.5	3.5	1.8%	2.1%	1.6%
TOTAL				17.3%	18.8%	8.7%
70th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	1	1	0	1.3%	1.3%	0.0%
5%	1.5	1	0	3.2%	2.6%	0.0%
4%	1.5	1.5	0.5	0.8%	0.6%	0.1%
3%	2	1.5	1	0.9%	0.8%	0.4%
2%	2.5	2.5	1	1.2%	1.0%	0.5%
1%	2.5	3	1.5	1.3%	1.4%	0.6%
0%	3.5	4	3.5	1.6%	1.8%	1.3%
TOTAL				10.2%	9.6%	3.0%
50th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	1	0	0	1.3%	0.0%	0.0%
4%	1	1	0	0.5%	0.3%	0.0%
3%	1	1	0	0.5%	0.5%	0.0%
2%	1.5	1	0	0.6%	0.5%	0.0%
1%	2	1.5	0.5	0.9%	0.6%	0.1%
0%	3.5	3.5	2.5	1.4%	1.3%	0.8%
TOTAL				5.3%	3.2%	0.9%
30th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	0	0	0	0.0%	0.0%	0.0%
4%	0	0	0	0.0%	0.0%	0.0%
3%	1	0	0	0.3%	0.0%	0.0%
2%	1	0	0	0.5%	0.0%	0.0%
1%	1	1	0	0.5%	0.3%	0.0%
0%	2.5	3	1.5	0.9%	1.0%	0.4%
TOTAL				2.2%	1.3%	0.4%
10th Percentile Bacteria Runoff Concentration						
20%	0	0	0			
15%	0	0	0	0.0%	0.0%	0.0%
10%	0	0	0	0.0%	0.0%	0.0%
5%	0	0	0	0.0%	0.0%	0.0%
4%	0	0	0	0.0%	0.0%	0.0%
3%	0	0	0	0.0%	0.0%	0.0%
2%	0	0	0	0.0%	0.0%	0.0%
1%	0	0	0	0.0%	0.0%	0.0%
0%	2	1.5	0.5	0.5%	0.4%	0.1%
TOTAL				0.5%	0.4%	0.1%
OVERALL TOTAL				7.1%	6.6%	2.6%

Figure 5-2

Percent Exceedance for Future Land Use with BMPs



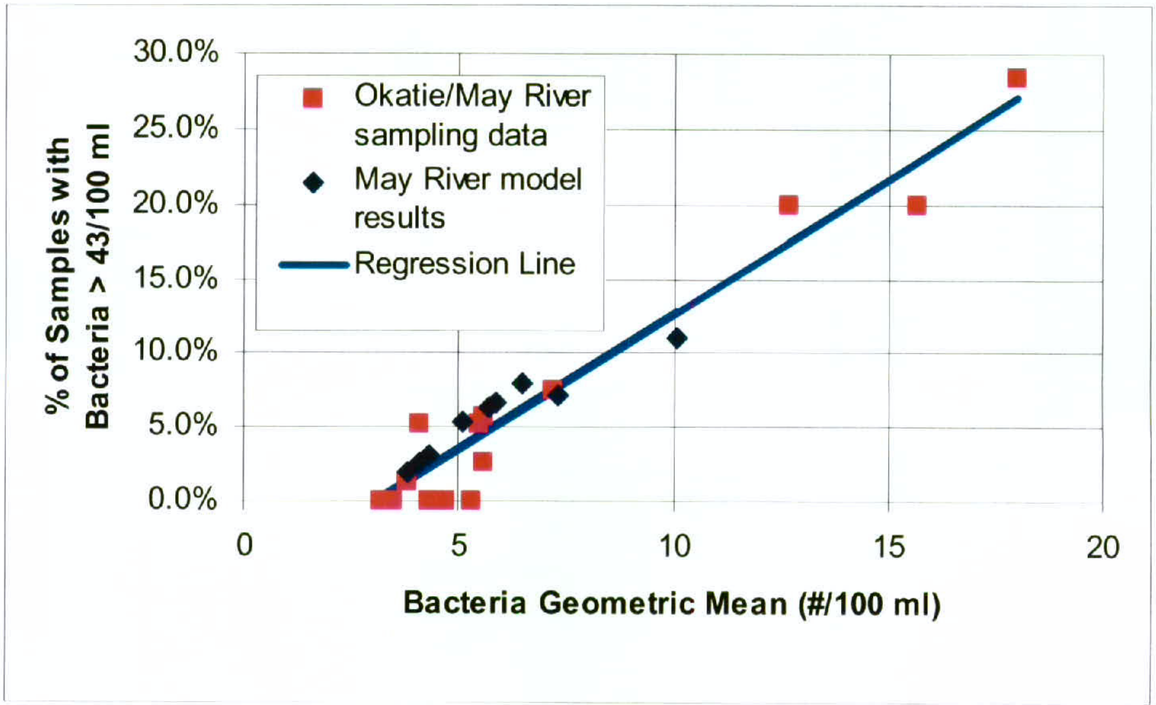


Figure 5-3. Historical data and model output comparing geometric mean and percent of samples exceeding 43/100 ml threshold

Based on the inherent variability of bacteria concentrations, it is difficult to state definitively that the threshold concentration of 43/100 ml will not be exceeded in segment 2 under future land use conditions with BMPs. As presented earlier in Section 4.3, the calculated geometric mean bacteria concentration in segment 2 was 8.6/100 ml for the "wettest" 3-year period on record (1964-1966). Looking at Figure 5-2, the regression line predicts an exceedance frequency of about 10% for the 1964-1966 period.

The threshold concentration of 43/100 ml will not be exceeded more than 10% of the time in segments 3 and 4, for any future condition and meteorological conditions. Assuming future development with no controls, the geometric mean bacteria concentration for the period 1964-1966 are 7.5 and 4.7/100 ml for segments 3 and 4, respectively. The regression line suggests that the 43/100 ml threshold would be exceeded less than 10% of the time, even for the greatest bacteria load resulting from the wettest meteorological conditions and no treatment of surface runoff.

Section 6
Summary

A computer model of the May River was developed and applied to evaluate the bacteria levels in the river for existing and future conditions. The model was calibrated to available water quality data to demonstrate that the model accurately represented existing watershed conditions. The model was then applied to future conditions, with and without water quality controls for new development in the watershed. Model results were compared with receiving water quality standards to assess the potential for standard exceedances (see Table 6-1).

There are two bacteria standards that apply to the May River. These are:

- The geometric mean bacteria concentration shall not exceed an MPN of 14/100 ml.
- No more than 10% of the bacteria samples shall exceed a bacteria concentration of 43/100 ml.

The SCDHEC evaluates compliance with these standards based on an evaluation of 36 consecutive monthly samples (i.e., 3 years of monthly data).

The model results for existing conditions indicate that the bacteria standards are being met in the May River. These results are consistent with SCDHEC monitoring data, which show compliance with the standards at all of the May River monitoring stations. The bacteria loads to the river are subject to dilution with low-bacteria tidal inflows, and mortality due to light and other environmental factors. The resulting river bacteria concentrations are lower than the water quality standards.

For future conditions with no water quality controls for new development, the model results suggest that the water quality standards may be exceeded in the upper third of the river (i.e., River Segment 2). Despite the increase in watershed bacteria loads due to future development, the model still predicts that the geometric mean bacteria concentration will be less than 14/100 ml throughout the river. However, the model also predicts that the concentration of 43/100 ml will be exceeded more than 10% of the time in the upper third of the river. SCDHEC bacteria data for the May River and other rivers including the Okatie River verify the fact that the 43/100 ml 10% exceedance standard is more restrictive than the 14/100 ml geometric mean standard.

When water quality controls for new development are considered, the model predicts that the bacteria standards will be met in the May River. Bacteria loads were calculated assuming that wet detention pond BMPs would be used to treat stormwater runoff from new commercial, industrial, high density residential, and medium density residential development. A bacteria removal efficiency of 90% was assumed, based on typical Beaufort County pond design criteria. With the load reduction attributed to the water quality controls for new development, the river bacteria concentrations are low enough to satisfy both river bacteria standards.

Table 6-1

Modeling Summary

Bacteria Concentration (MPN/100 ml) See Sections 3 & 4				
Land Use / Management Scenario	**May River Segment ID Number**			
	1	**2**	**3**	**4**
	Based on Average Freshwater Inflows			
Existing Conditions	28.9	5.7	5.1	3.8
Future Conditions with No Controls	64.8	10.1	6.5	4.3
Future Conditions with BMPs for New Development	37.5	7.3	5.9	4.1
Land Use / Management Scenario	Based on Annual Freshwater Inflows for the "Wettest" 3-Year Period of Record			
Future Conditions with No Controls	69.9	12.2	7.5	4.7
Future Conditions with BMPs for New Development	40.2	8.6	6.8	4.6
Water Quality Standard: The geometric mean bacteria concentration shall not exceed a MPN of 14/100 ml.				

Percent of Year with Bacteria Concentration > 43/100 ml See Section 5				
Land Use / Management Scenario	**May River Segment ID Number**			
	1	**2**	**3**	**4**
	Based on Various Combinations of Daily Rainfall and Runoff Bacteria Concentrations			
Existing Conditions	**See NOTE**	6.3%	5.4%	1.9%
Future Conditions with No Controls		11.1%	8.0%	3.1%
Future Conditions with BMPs for New Development		7.1%	6.6%	2.6%
Water Quality Standard: No more than 10% of the bacteria samples shall exceed a bacteria concentration of 43/100 ml.				

NOTE

River Segment 1, a short river segment that typically is primarily or totally composed of upstream freshwater inflow during low tide conditions, is not monitored by SCDHEC. This segment would not have the required salinity level to support shellfish population even under totally undeveloped watershed conditions (see Figures 2-4 & 3-2).

Section 7
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