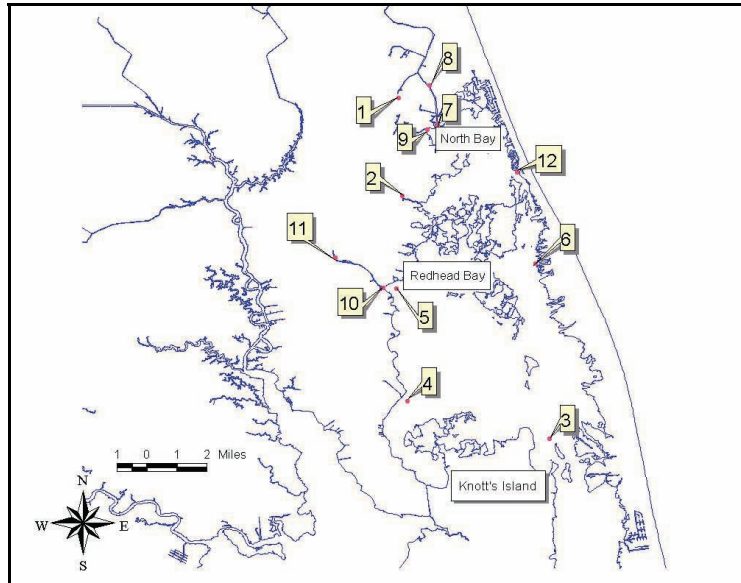


**PRELIMINARY ASSESSMENT OF NONPOINT SOURCE FECAL
COLIFORM LOADING AND FLUSHING CAPABILITY IN THE
BACK BAY, VIRGINIA**



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Final Report to:

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TABLE OF CONTENTS

TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	iii
LIST OF APPENDICES	v
I. INTRODUCTION	1
A. BACKGROUND	1
B. THE FECAL COLIFORM NONPOINT SOURCE LOADING AND THE FLUSHING CAPABILITY OF BACK BAY	2
II. HISTORICAL DATA ANALYSIS FOR FECAL COLIFORM	4
III. APPROACH	10
A. HYDRODYNAMIC FIELD SURVEY	10
1. High-frequency measurements of velocity at Knotts Island Channel	11
2. High-frequency measurement of surface elevations.....	13
B. ASSESSMENT OF NONPOINT SOURCES OF FECAL COLIFORM LOADING IN THE BACK BAY WATERSHED	15
1. Wildlife contributions	18
2. Human contributions.....	19
3. Pet contributions	19
4. Livestock contributions.....	20
C. RESIDENCE TIME CALCULATION USING UnTRIM MODEL	28
1. Grid generation	28
2. Preliminary Model Results	29
3. Residence Time Determination.....	30
IV. CONCLUSIONS	34
V. REFERENCES.....	35
Appendix A. VIMS Back Bay Inter-Agency Database (Microsoft ACCESS format)	A-1
Appendix B. Time series of Dissolved Oxygen (DO) and Total Suspended Solids (TSS) at VA-DEQ Back Bay Stations.....	B-1

LIST OF TABLES

Table II.1. Comparison of Back Bay Observed Bacteria Levels to Virginia Criteria	5
Table III.1. Data Summary for VIMS 2007 Back Bay Hydrodynamic Survey.....	11
Table III.2. Land Use Percentage Distribution for the Back Bay Watershed.....	17
Table III.3. Summary of Nonpoint Sources.....	18
Table III.4. Wildlife Habitats and Densities	18
Table III.5. Wildlife Fecal Coliform Production Rates	19
Table III.6. Estimated Loading Rates for Livestock.....	20
Table III.7. Loading Distribution for the Back Bay Basin	21
Table III.8. Total and Percentage Distributions of Fecal Coliform Source Loads for Each Back Bay Subwatershed	22

LIST OF FIGURES

Figure I.1. Back Bay estuary of Virginia Beach, VA	1
Figure I.2. Back Bay, Virginia Beach showing Location of Nawney Creek along its Western Shore	3
Figure II.1. VA-DEQ monitoring stations in Back Bay having long-term measurements	4
Figure II.2. Bacterial Levels at VA-DEQ Back Bay Station 1 (5BASH002.20).....	6
Figure II.3 Bacterial Levels at VA-DEQ Back Bay Station 2 (5BBBC000.76).....	6
Figure II.4. Bacterial Levels at VA-DEQ Back Bay Station 3 (5BBKY000.99)	6
Figure II.5. Bacterial Levels at VA-DEQ Back Bay Station 4 (5BBKY003.47)	7
Figure II.6. Bacterial Levels at VA-DEQ Back Bay Station 5 (5BBKY006.37)	7
Figure II.7 Bacterial Levels at VA-DEQ Back Bay Station 6 (5BBKY006.48)	7
Figure II.8. Bacterial Levels at VA-DEQ Back Bay Station 7 (5BHPC000.00).....	8
Figure II.9. Bacterial Levels at VA-DEQ Back Bay Station 8 (5BHPC001.46).....	8
Figure II.10. Bacterial Levels at VA-DEQ Back Bay Station 9 (5BMDY000.00)	8
Figure II.11. Bacterial Levels at VA-DEQ Back Bay Station 10 (5BNWN000.00)	9
Figure II.12 Bacterial Levels at VA-DEQ Back Bay Station 11 (5BNWN001.84)	9
Figure II.13. Bacterial Levels at VA-DEQ Back Bay Station 12 (5BSHB000.57).....	9
Figure III.1. Measurement Locations for VIMS 2007 Back Bay Hydrodynamic Survey	10
Figure III.2. Knott’s Island Channel Velocity Magnitude – Deployment # 1	11
Figure III.3. Knott’s Island Channel North Velocity Component – Deployment # 1	12
Figure III.4. Knott’s Island Channel Velocity Magnitude – Deployment # 2	12
Figure III.5. Knott’s Island Channel North Velocity Component – Deployment # 2	12
Figure III.6. Surface Elevations at Nawney Creek Mouth – Deployment # 1	13

Figure III.7. Surface Elevations at Nawney Creek Mouth – Deployment # 2.....	13
Figure III.8. Surface Elevations at Nawney Creek Mouth – Deployment # 3.....	13
Figure III.9. Surface Elevations at Back Bay National Wildlife Refuge – Deployment # 1	14
Figure III.10. Surface Elevations at Back Bay National Wildlife Refuge – Deployment #2.....	14
Figure III.11. Surface Elevations at Back Bay National Wildlife Refuge – Deployment #3.....	14
Figure III.12. Location of the Back Bay Area and its Subwatersheds.....	15
Figure III.13. Land Use in the Back Bay Watershed.....	17
Figure III.14. Fecal Coliform Loadings from Wildlife.....	23
Figure III.15. Fecal Coliform Loadings from Human Sources (failing septic systems).....	24
Figure III.16. Fecal Coliform Loadings from Pets	25
Figure III.17. Fecal Coliform Loadings from Livestock	26
Figure III.18. Fecal Coliform Loadings from All Contributing Sources.....	27
Figure III.19. The UnTRIM Unstructured Grid for Back Bay	28
Figure III.20. Observed vs. predicted surface elevation at Nawney Creek Entrance	29
Figure III.21. Observed vs. predicted surface elevation at Back Bay National Wildlife Refuge	29
Figure III.22. Observed vs. predicted velocity at Knott’s Island Channel	30
Figure III.23. Portions of Back Bay Used for Residence Time Determination.....	31
Figure III.24. Concentration Time Series Showing that Residence Time in Back Bay (South Portion) Is Approximately 500 Days.....	32
Figure III.25. Spatial plots of largest predicted velocities for a) entire Back Bay and b) near Knott’s Island Channel showing relative magnitudes.....	33

LIST OF APPENDICES

Appendix A. VIMS Back Bay Inter-Agency Database (Microsoft ACCESS format)

Table A-1. Fixed Station Locations used for Back Bay.

Table A-2. DEQ Measurements in Back Bay, 1993-2006.

Appendix B. Time series of Dissolved Oxygen (DO) and Total Suspended Solids (TSS) at VA-DEQ Back Bay Stations

Figure B-1. Dissolved Oxygen at VA-DEQ Back Bay Station 1 (5BASH002.20)

Figure B-2. Dissolved Oxygen at VA-DEQ Back Bay Station 2 (5BBBC000.76)

Figure B-3. Dissolved Oxygen at VA-DEQ Back Bay Station 3 (5BBKY000.99)

Figure B-4. Dissolved Oxygen at VA-DEQ Back Bay Station 4 (5BBKY003.47)

Figure B-5. Dissolved Oxygen at VA-DEQ Back Bay Station 5 (5BBKY006.37)

Figure B-6. Dissolved Oxygen at VA-DEQ Back Bay Station 6 (5BBKY006.48)

Figure B-7. Dissolved Oxygen at VA-DEQ Back Bay Station 7 (5BHPC000.00)

Figure B-8. Dissolved Oxygen at VA-DEQ Back Bay Station 8 (5BHPC001.46)

Figure B-9. Dissolved Oxygen at VA-DEQ Back Bay Station 9 (5BMDY000.00)

Figure B-10. Dissolved Oxygen at VA-DEQ Back Bay Station 10 (5BNWN000.00)

Figure B-11. Dissolved Oxygen at VA-DEQ Back Bay Station 11 (5BNWN001.84)

Figure B-12. Dissolved Oxygen at VA-DEQ Back Bay Station 12 (5BSHB000.57)

Figure B-13. Total Suspended Solids at VA-DEQ Back Bay Station 1 (5BASH002.20)

Figure B-14. Total Suspended Solids at VA-DEQ Back Bay Station 2 (5BBBC000.76)

Figure B-15. Total Suspended Solids at VA-DEQ Back Bay Station 3 (5BBKY000.99)

Figure B-16. Total Suspended Solids at VA-DEQ Back Bay Station 4 (5BBKY003.47)

Figure B-17. Total Suspended Solids at VA-DEQ Back Bay Station 5 (5BBKY006.37)

Figure B-18. Total Suspended Solids at VA-DEQ Back Bay Station 6 (5BBKY006.48)

Figure B-19. Total Suspended Solids at VA-DEQ Back Bay Station 7 (5BHPC000.00)

Figure B-20. Total Suspended Solids at VA-DEQ Back Bay Station 8 (5BHPC001.46)

Figure B-21. Total Suspended Solids at VA-DEQ Back Bay Station 9 (5BMDY000.00)

Figure B-22. Total Suspended Solids at VA-DEQ Back Bay Station 10 (5BNWN000.00)

Figure B-23. Total Suspended Solids at VA-DEQ Back Bay Station 11 (5BNWN001.84)

Figure B-24. Total Suspended Solids at VA-DEQ Back Bay Station 12 (5BSHB000.57)

I. INTRODUCTION

A. Background

Back Bay is located in the extreme southeastern portion of Virginia Beach and is separated from the Atlantic Ocean by the narrow Sandbridge to False Cape land barrier (see Figure 1). The watershed of Back Bay covers 104 square miles [largest in Virginia Beach] and contains 40 square miles of surface water, with an average depth of only 4 feet (Back Bay Restoration Foundation, 2007). The Back Bay watershed is also in the Atlantic flyway, a major corridor for migratory birds. Approximately ten thousand snow geese and a large variety of ducks frequent the refuge during fall migration. The Back Bay National Wildlife Refuge serves as a breeding area for migratory birds and other wildlife, some of which are included as federally listed endangered and threatened species, such as the Bald Eagle and the Loggerhead turtle.

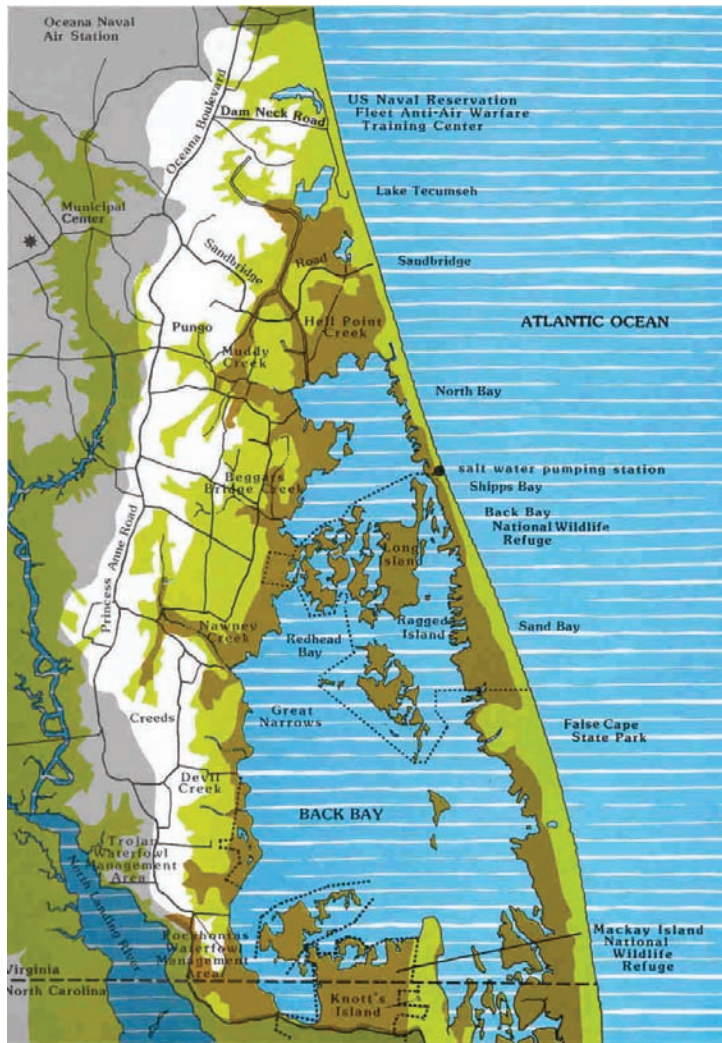


Figure I.1. Back Bay estuary of Virginia Beach.

The Back Bay estuary, however, is impaired by pollution generated by changing land uses in one of the fastest growing cities in the country. For example, the Nawney Creek, which drains into Back Bay along its western side, was recently listed as impaired for fecal coliform levels under the Virginia Department of Environmental Quality (VA-DEQ) total maximum daily load assessment program.

A TMDL performed by VA-DEQ provides quantitative assessments of overall reduction needs, which are informative and useful to local municipalities. The U.S. Army Corps of Engineers and the City of Virginia Beach have a need for a management assessment tool capable of evaluating water quality standards and effects of reductions in localized fecal coliform loading on the resulting fecal coliform concentrations in the Back Bay receiving waters. Such a tool can provide invaluable information in the decision making process involved in selection of implementation of Best Management Practices (BMPs).

The Virginia Institute of Marine Sciences (VIMS) of the College of William and Mary proposes to work with the Army Corps of Engineers and the City of Virginia Beach to perform a preliminary assessment of Back Bay residence time related to the Nawney Creek fecal coliform best management practice (BMP) involving fecal coliform load reductions, using the 3D hydrodynamic model UnTRIM.

B. The Fecal Coliform Nonpoint Source Loading and the Flushing Capability of Back Bay

Back Bay is a shallow coastal bay at the headland portion of Currituck Sound, which connects to Albemarle Sound, NC. It is characterized by depths averaging 4 feet only throughout the system. Back Bay flows south into the Currituck Sound, but the currents and turbulence throughout the system are generally very low. With diminished tidal forces, the flushing capability of this system is of great concern. Elevated fecal coliform levels along the Western Shore of Back Bay may result from compounded issues of source loadings, including wastes from farm animals, humans, and pets. Specifically, Nawney Creek was initially placed on the *Virginia 1996 Section 303(d) TMDL Priority List and Report* based on monitoring performed (MAPTECH, 2005). In the executive summary of the fecal coliform TMDL report for Nawney Creek in the MAPTECH report to VA-DEQ, it is stated:

“Prior to 2003, Virginia Water Quality Standards specified the following criteria for a non-shellfish waterbody to be in compliance with Virginia’s fecal standard for contact recreation use:”

General requirements: In all surface water, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.

Based on the above criteria, the Nawney Creek portion of Back Bay was not in compliance and required the evaluation for Total Maximum Daily Load (TMDL) performed and reported by MAPTECH in 2005. Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop TMDLs for water bodies which do not meet water quality standards.

The southern portion of Back Bay including Nawney Creek is shown in Figure 2. In June 2005, representatives of the City of Virginia Beach specifically requested the inclusion of fecal coliform modeling capability within the VIMS UnTRIM model. Such a capability is intended to allow for scenario testing of the effects of fecal coliform load reduction. Fecal coliform spatial and temporal distributions in the Back Bay system depend on source loadings from the watershed as well as hydrodynamic transport and decay of fecal coliform once inside the receiving waters.



Figure I.2. Back Bay, Virginia Beach showing location of Nawney Creek along its Western Shore.

II. Historical Data Analysis for Back Bay Fecal Coliform

The Virginia Department of Environmental Quality (VA-DEQ) has monitored water quality conditions at 12 primary stations over the 15-year period from 1993 to 2007. Bacteria data from these 12 stations, the locations for which are shown in Figure II.1, have been examined for fecal coliform, *E. coli*, and enterococci. Virginia criteria for primary contact waters specify violation when instantaneous limits of 1000 MPN/100 ml for fecal coliform, 235 MTEC-MF NO/100 ML for *E. coli*, and 104 ME-MF NO/100 ML for enterococci are exceeded. A summary of violation percentage for each of these bacteria for VA-DEQ Back Bay stations is provided in Table II.1. Individual time series of the measured data and derived statistics are shown in Figures II.2 through II.13.

Table II.1 shows a range of percentage violation values over the 12 VA-DEQ Back Bay stations. However, Stations 10 and 11 (Nawney Creek) exhibit the highest values of all Back Bay stations that have had a statistically significant amount of sampling.

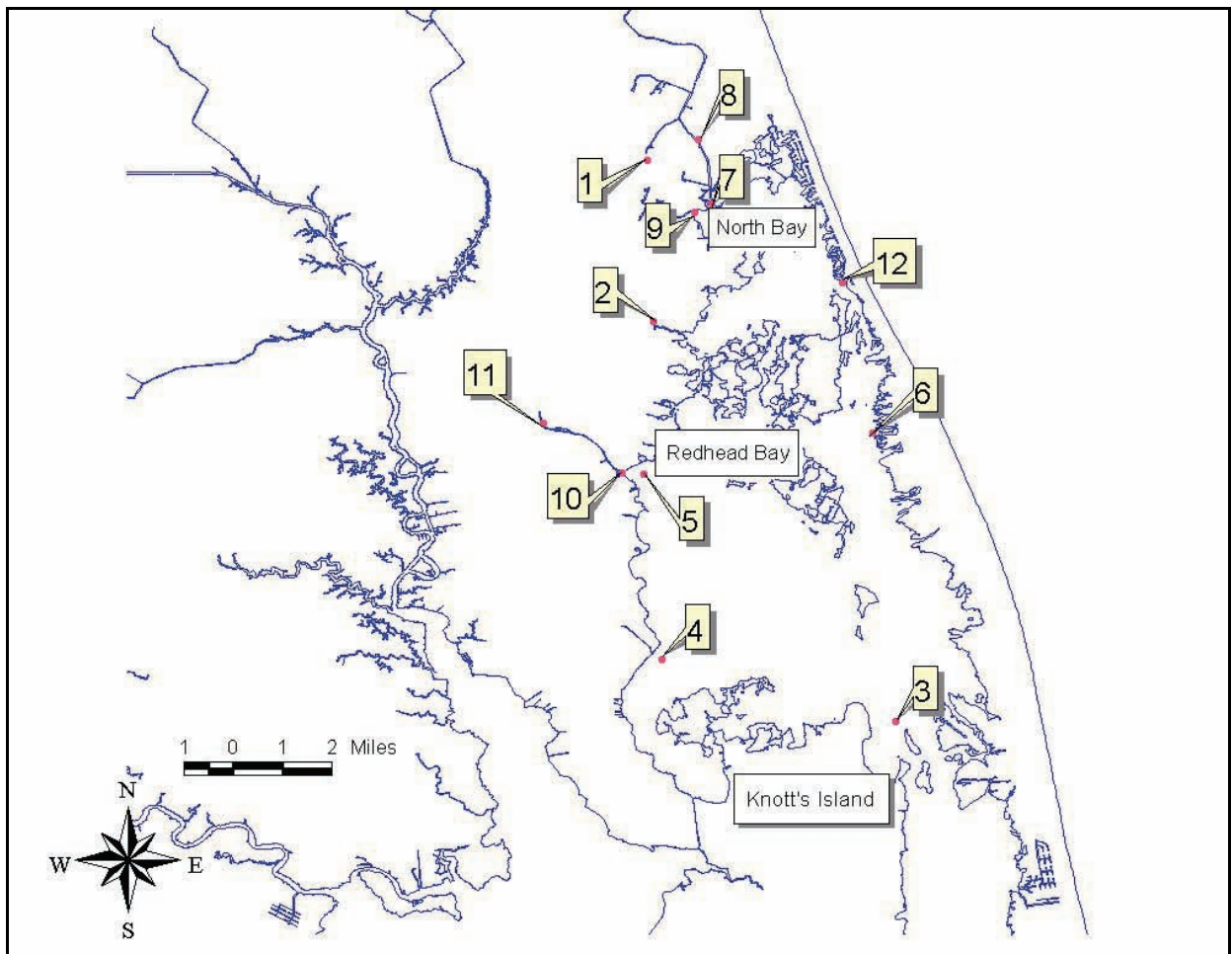


Figure II.1. VA-DEQ monitoring stations in Back Bay having long-term measurements.

Table II.1. Comparison of Back Bay Observed Bacteria Levels to Virginia Criteria

No.	Station Name	Fecal coliform Criterion	Number of Samples	Samples in Violation	Percentage Violation
1	5BASH002.20	1000	20	1	5.0 %
2	5BBBC000.76	1000	121	6	4.9 %
3	5BBKY000.99	1000	61	0	0.0 %
4	5BBKY003.47	1000	61	0	0.0 %
5	5BBKY006.37	1000	61	2	3.3 %
6	5BBKY006.48	1000	61	1	1.6 %
7	5BHPC000.00	1000	61	3	4.9 %
8	5BHPC001.46	1000	315	14	4.4 %
9	5BMDY000.00	1000	121	7	5.8 %
10	5BNWN000.00	1000	120	20	16.7 %
11	5BNWN001.84	1000	122	21	17.2 %
12	5BSHB000.57	1000	61	0	0.0 %
No.	Station Name	E. Coli Criterion	Number of Samples	Samples in Violation	Percentage Violation
1	5BASH002.20	235	6	1	16.7 %
2	5BBBC000.76	235	11	1	9.1 %
3	5BBKY000.99	235	4	0	0.0 %
4	5BBKY003.47	235	4	0	0.0 %
5	5BBKY006.37	235	4	0	0.0 %
6	5BBKY006.48	235	4	0	0.0 %
7	5BHPC000.00	235	4	2	50.0 %
8	5BHPC001.46	235	10	1	10.0 %
9	5BMDY000.00	235	11	1	9.1 %
10	5BNWN000.00	235	11	2	18.2 %
11	5BNWN001.84	235	10	2	20.0 %
12	5BSHB000.57	235	4	0	0.0 %
No.	Station Name	Enterococci Criterion	Number of Samples	Samples in Violation	Percentage Violation
1	5BASH002.20	104	20	5	25.0 %
2	5BBBC000.76	104	31	8	25.8 %
3	5BBKY000.99	104	26	1	3.8 %
4	5BBKY003.47	104	26	0	0.0 %
5	5BBKY006.37	104	26	3	11.5 %
6	5BBKY006.48	104	26	0	0.0 %
7	5BHPC000.00	104	26	9	34.6 %
8	5BHPC001.46	104	31	8	25.8 %
9	5BMDY000.00	104	32	13	40.6 %
10	5BNWN000.00	104	30	16	53.3 %
11	5BNWN001.84	104	31	14	45.2 %
12	5BSHB000.57	104	26	2	7.7 %

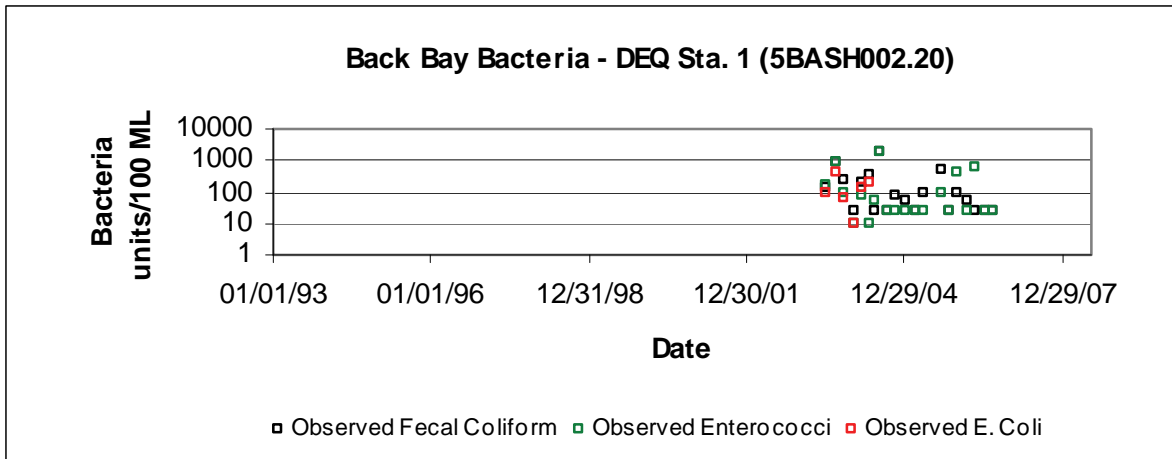


Figure II.2. Bacterial Levels at VA-DEQ Back Bay Station 1 (5BASH002.20).

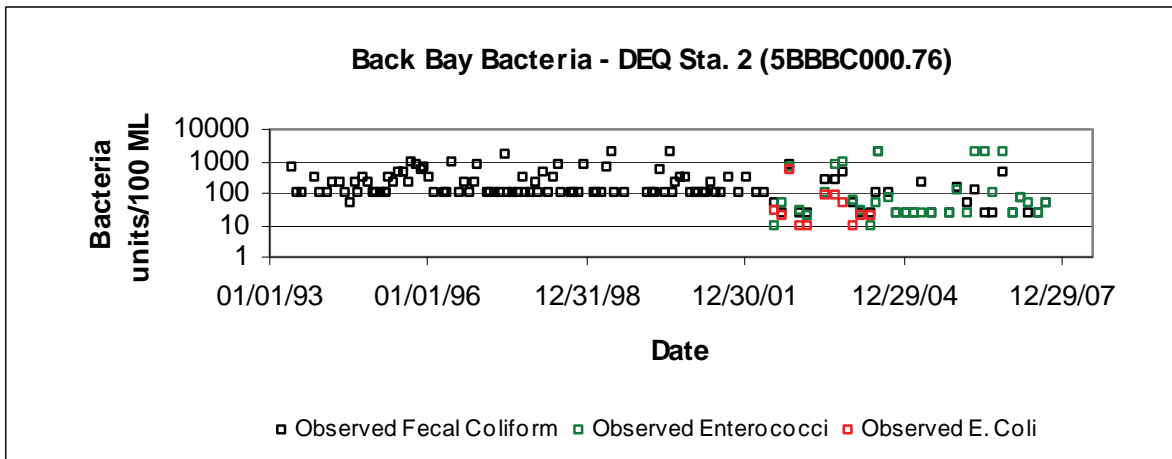


Figure II.3. Bacterial Levels at VA-DEQ Back Bay Station 2 (5BBBC000.76).

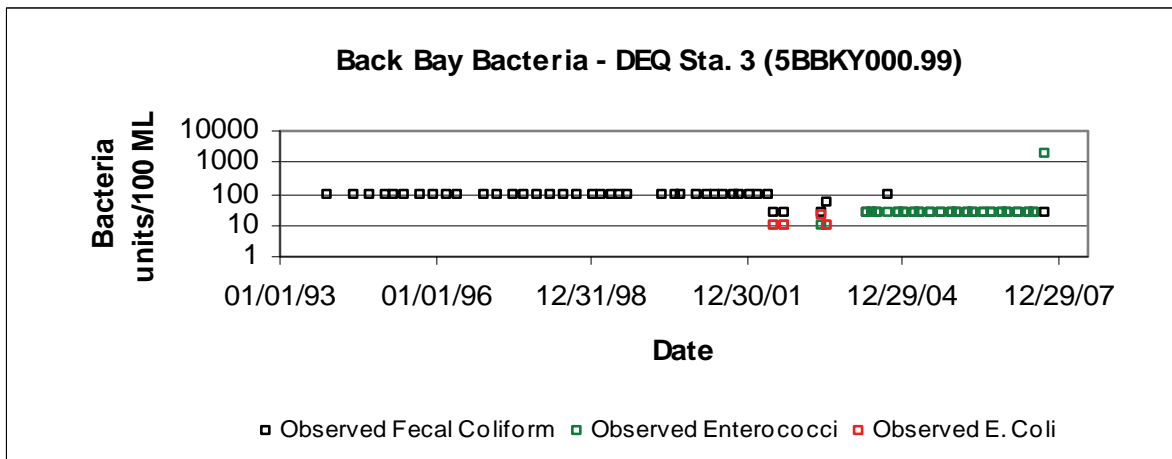


Figure II.4. Bacterial Levels at VA-DEQ Back Bay Station 3 (5BBKY000.99).

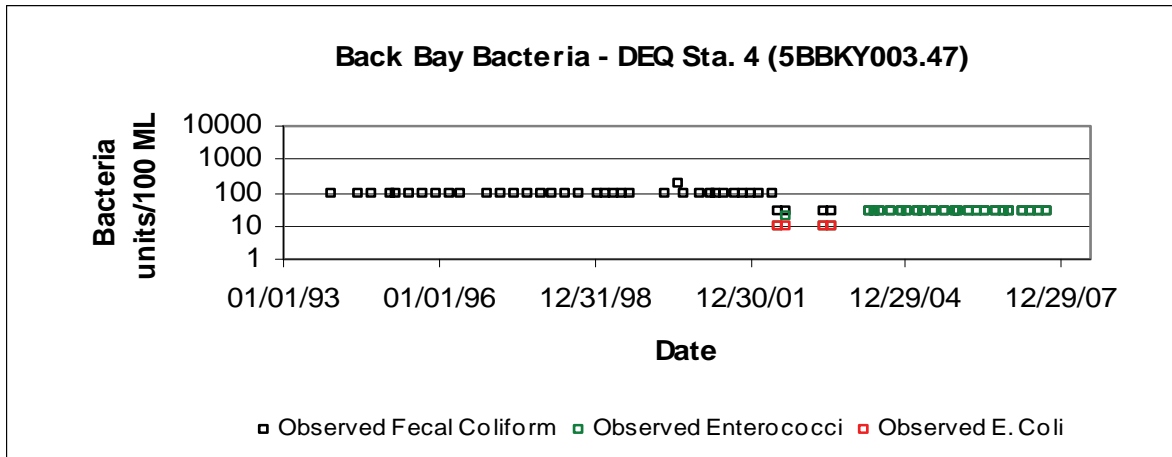


Figure II.5 Bacterial Levels at VA-DEQ Back Bay Station 4 (5BBKY003.47).

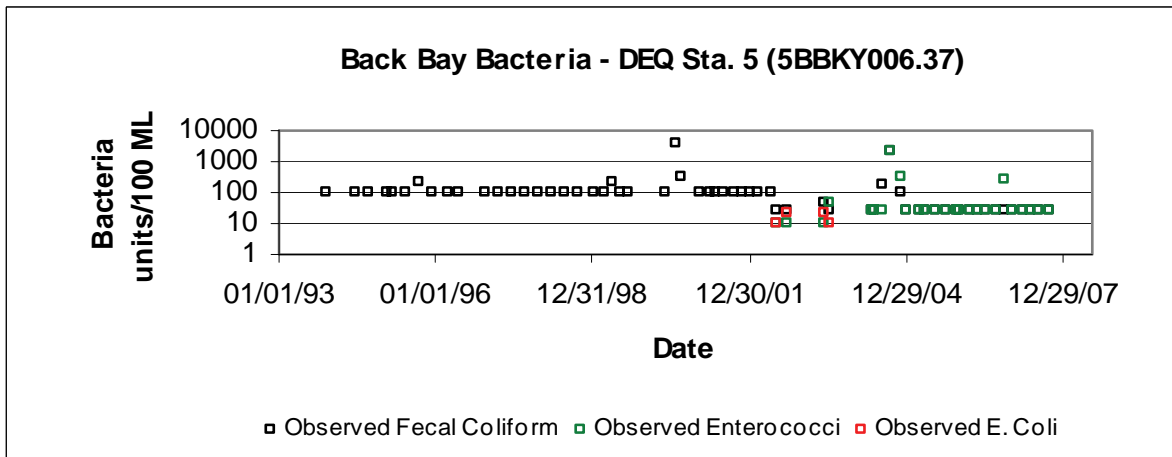


Figure II.6. Bacterial Levels at VA-DEQ Back Bay Station 5 (5BBKY006.37).

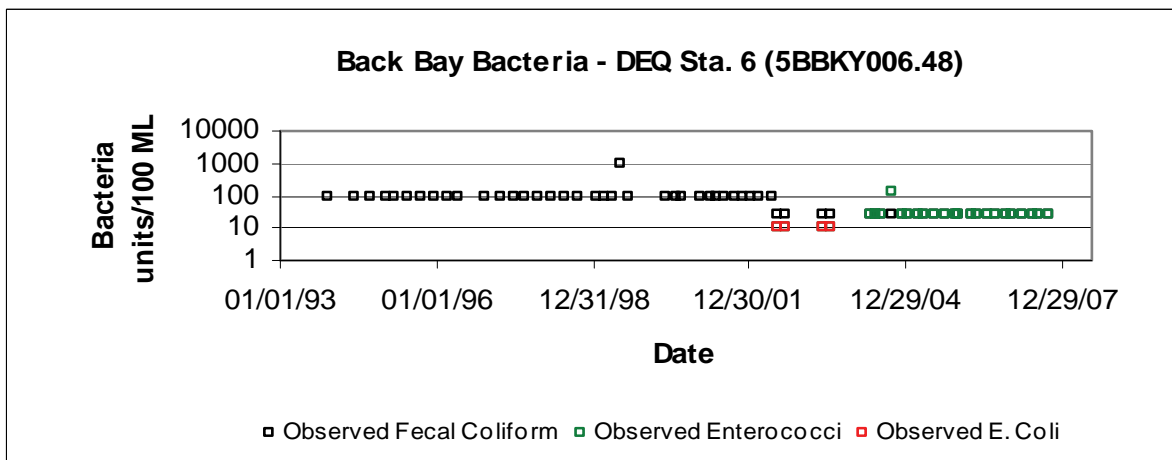


Figure II.7. Bacterial Levels at VA-DEQ Back Bay Station 6 (5BBKY006.48).

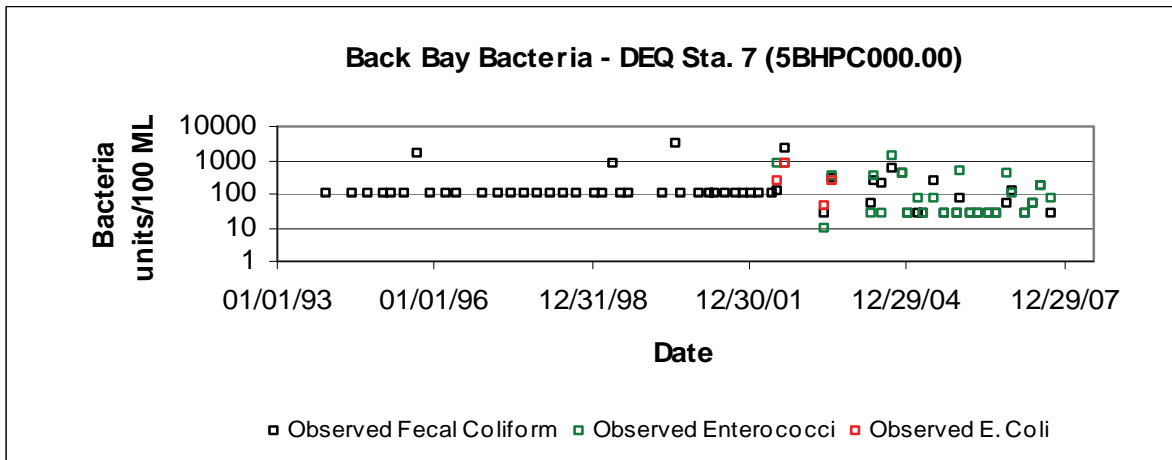


Figure II.8. Bacterial Levels at VA-DEQ Back Bay Station 7 (5BHPC000.00).

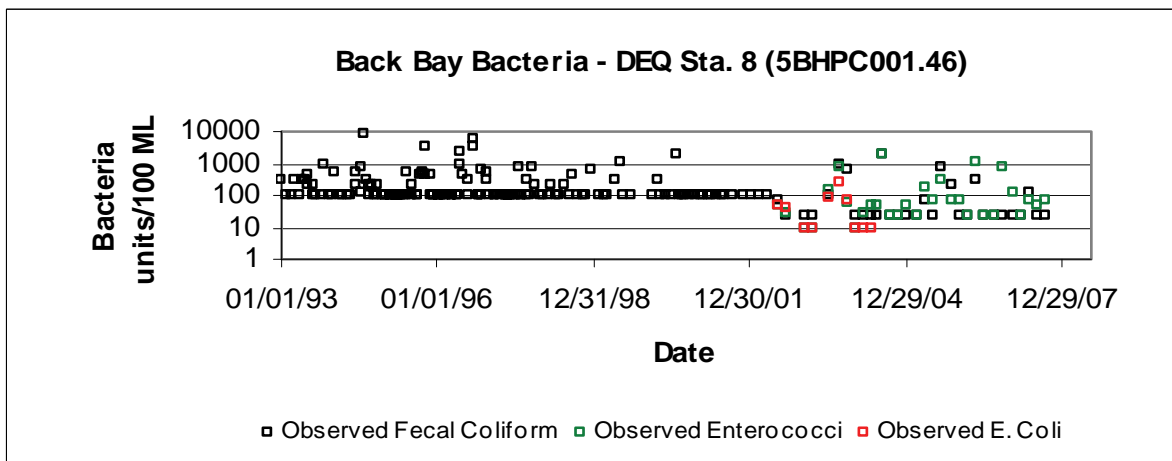


Figure II.9. Bacterial Levels at VA-DEQ Back Bay Station 8 (5BHPC001.46).

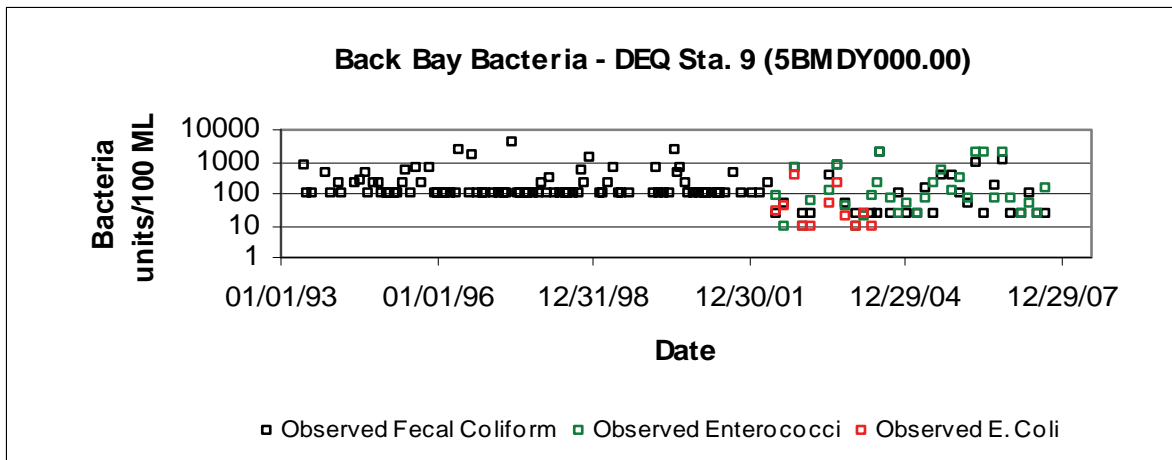


Figure II.10. Bacterial Levels at VA-DEQ Back Bay Station 9 (5BMDY000.00).

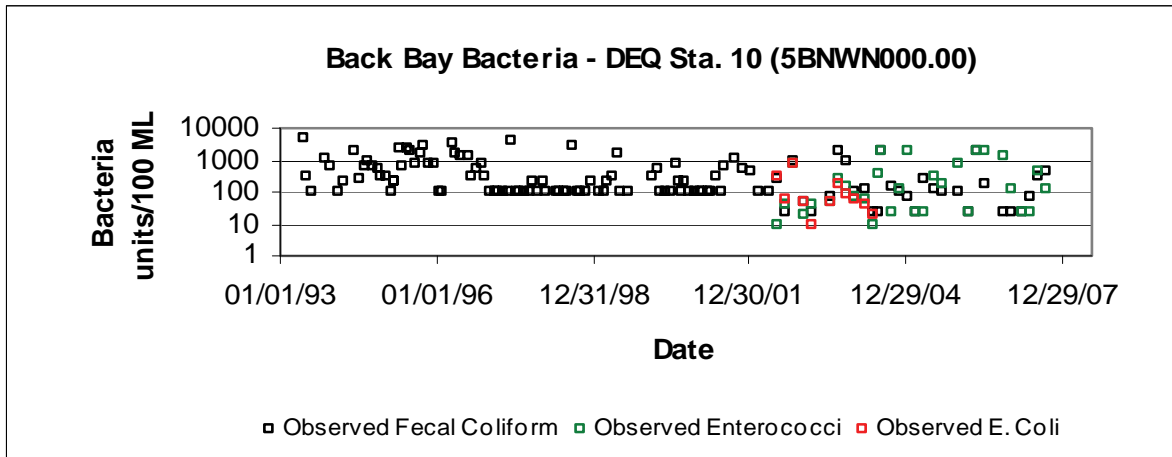


Figure II.11 Bacterial Levels at VA-DEQ Back Bay Station 10 (5BNWN000.00).

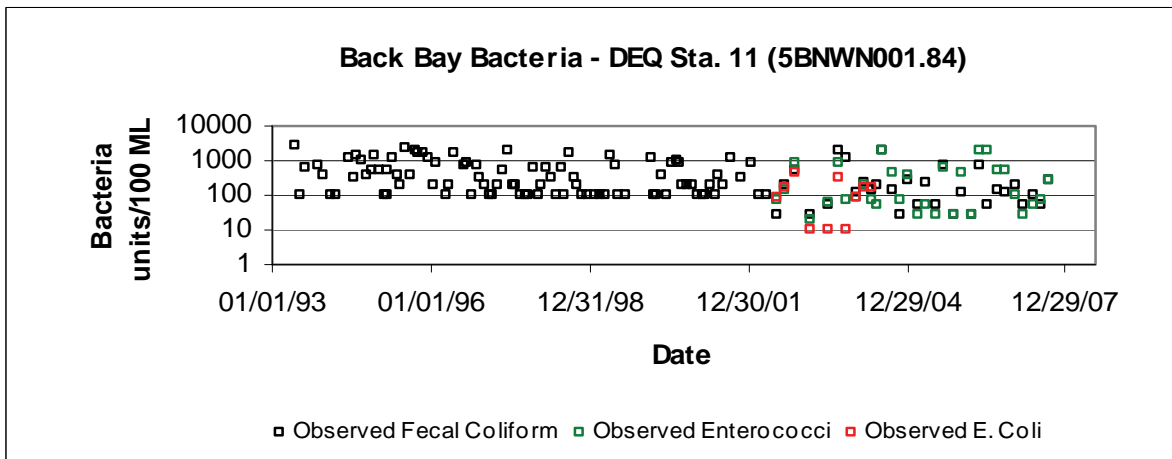


Figure II.12 Bacterial Levels at VA-DEQ Back Bay Station 11 (5BNWN001.84).

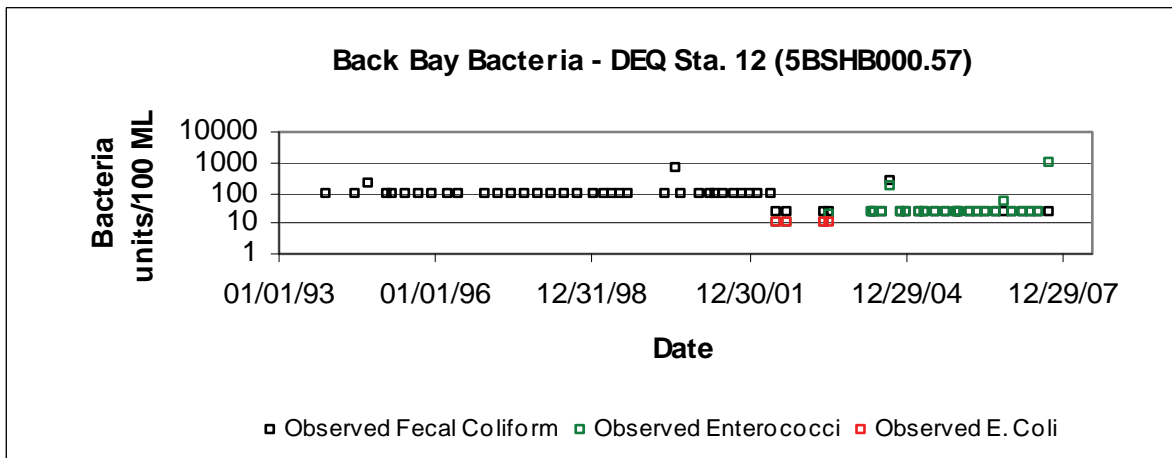


Figure II.13. Bacterial Levels at VA-DEQ Back Bay Station 12 (5BSHB000.57).

III. APPROACH

The approach of this preliminary study of the fecal coliform problem in Back Bay consists of the following three elements: a) conducting a hydrodynamic field survey in Back Bay, b) assessing the non-point fecal coliform loadings throughout the Back Bay watershed, and c) calculating the residence time using the UnTRIM model.

A. Hydrodynamic Field Survey

On August 23, 2007, VIMS began a 3-month survey, deploying an S4 current meter to measure velocity at Knotts Island Channel and YSI sondes to measure surface elevations at both the mouth of Nawney Creek and the Back Bay National Wildlife Refuge (see Figure III.1 and Table III.1).

High-frequency, synoptic field measurements of velocity and elevations in Back Bay serve to:

- 1) provide a better understanding of the primarily wind-driven dynamics that control the circulation in Back Bay.
- 2) apply the boundary condition for driving the hydrodynamic model
- 3) perform a preliminary calibration of the model, including water elevations and velocities at key locations

VIMS Back Bay Hydrodynamic Survey (Aug-Nov. 2007) - Measurement Locations

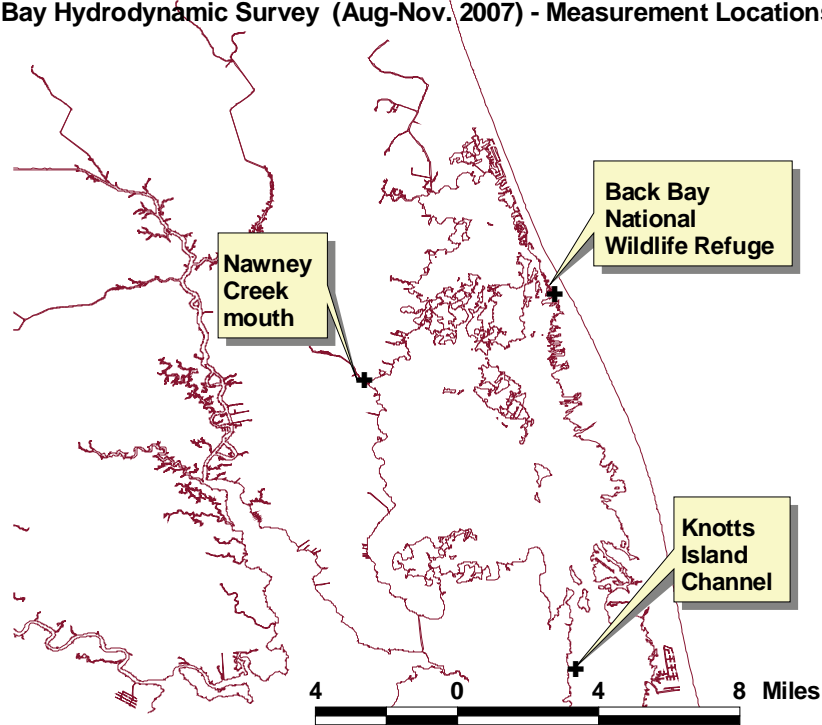


Figure III.1. Measurement Locations for VIMS 2007 Back Bay Survey

Table III.1. Data Summary for VIMS 2007 Back Bay Hydrodynamic Survey

Location	Measurement	Frequency	Duration	# Obs.	Comments
Knotts Island Channel	Velocity	Every 30 min	Aug 23, 2007- October 8, 2007	2,947	S4 Current Meter lost during Deployment #3
Nawney Creek mouth	Surface Elevation	Every 15 min	Aug 23, 2007- November 30, 2007	9,510	
Back Bay National Wildlife Refuge	Surface Elevation	Every 15 min	Aug 23, 2007- November 30, 2007	9,511	

1. High-frequency measurements of velocity at Knotts Island Channel

Velocity was measured at mid-depth in a 2.1-m portion of the Knotts Island Channel through which Back Bay exchanges water with Currituck Sound to the south. Several weeks of measurements showed a maximum velocity of about 30 cm/sec (see Figures III.2 and III.4) and the north-south component reached a maximum of about 20 cm/sec, comprising most of the overall magnitude (see Figures III.3 and III.5).

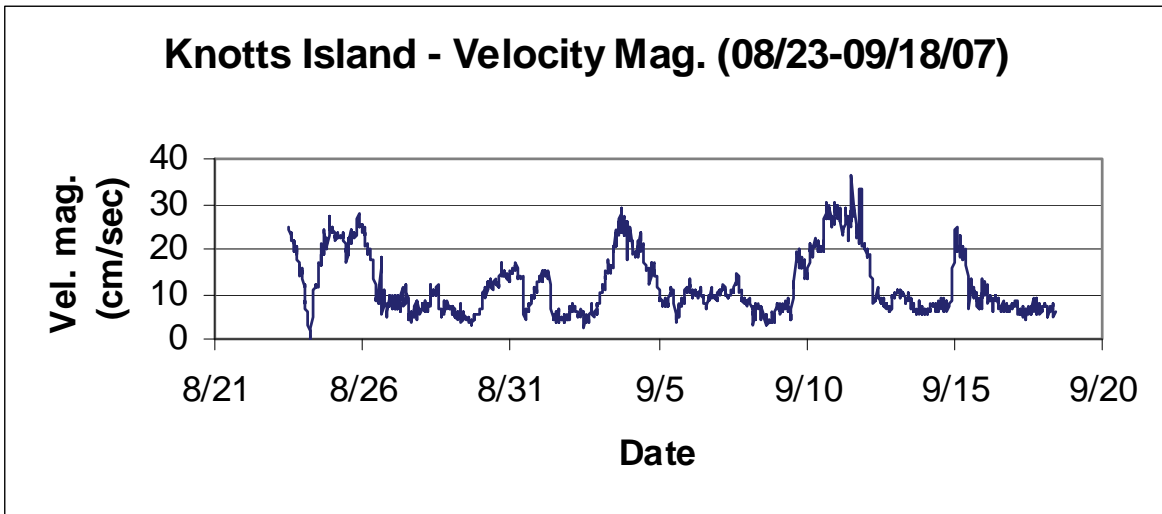


Figure III.2. Knott’s Island Channel Velocity Magnitude – Deployment # 1

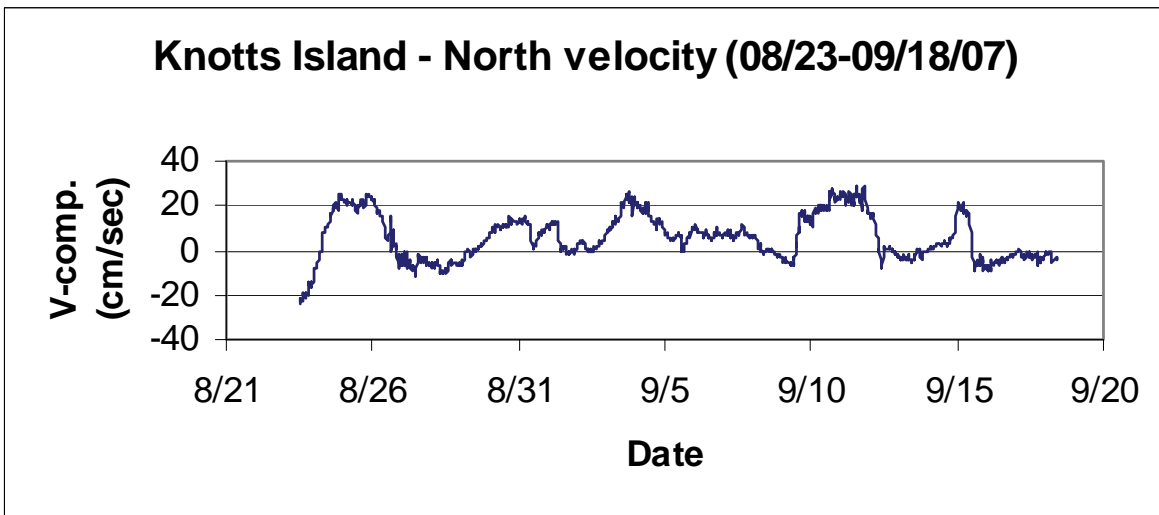


Figure III.3. Knott's Island Channel North Velocity Component – Deployment # 1

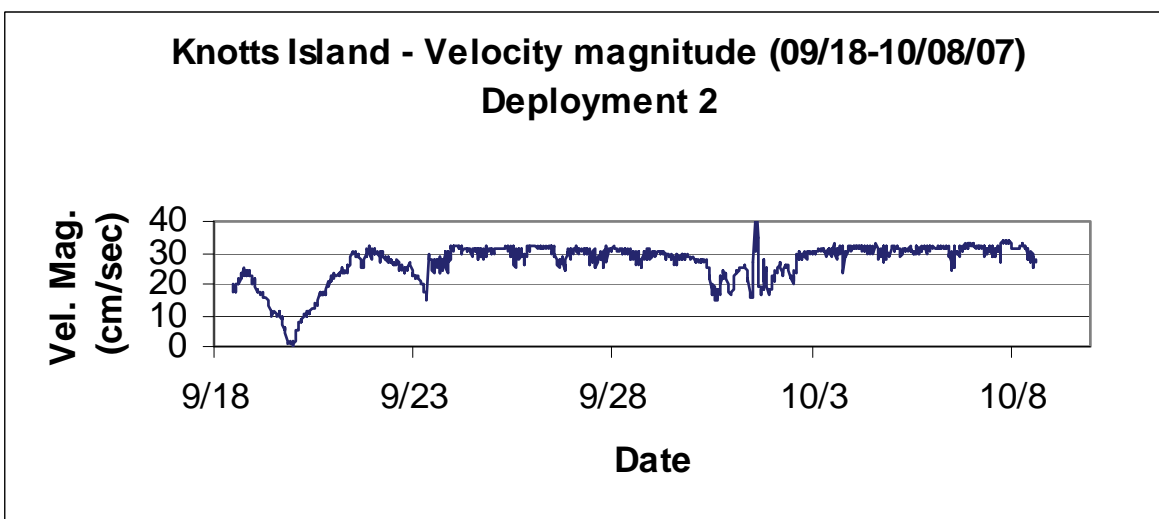


Figure III.4. Knott's Island Channel Velocity Magnitude – Deployment # 2

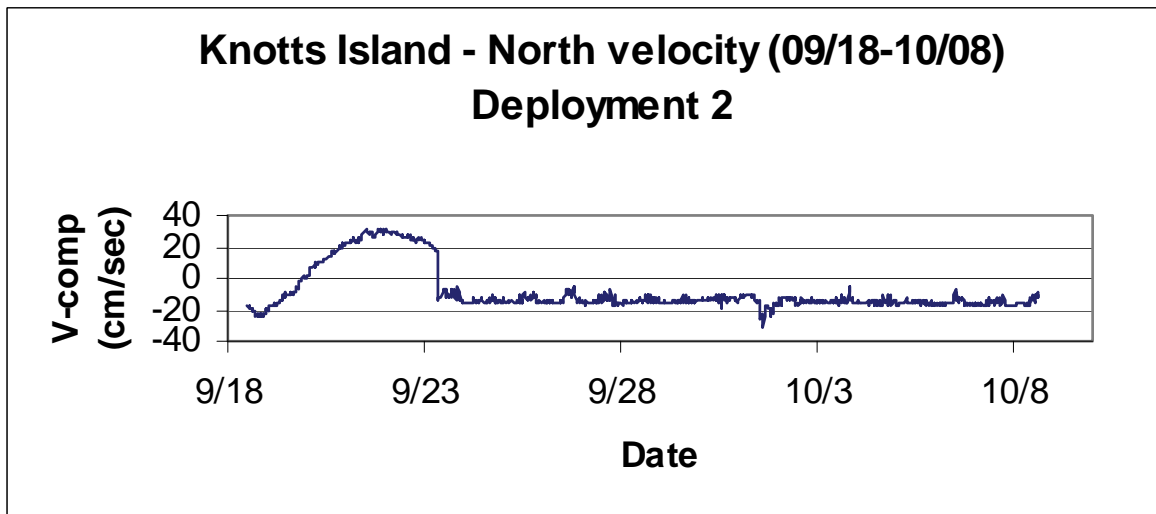


Figure III.5. Knott's Island Channel North Velocity Component – Deployment # 2

2. High-frequency measurements of surface elevations

Surface elevations were measured every 15 minutes at 2 locations: from the pier of a residence near the mouth of Nawney Creek and from the pier of the Back Bay National Wildlife Refuge. Time series of Nawney Creek elevations are shown in Figures III.6 through III.8 and those of the Back Bay Refuge are shown in Figures III.9 through III.11.

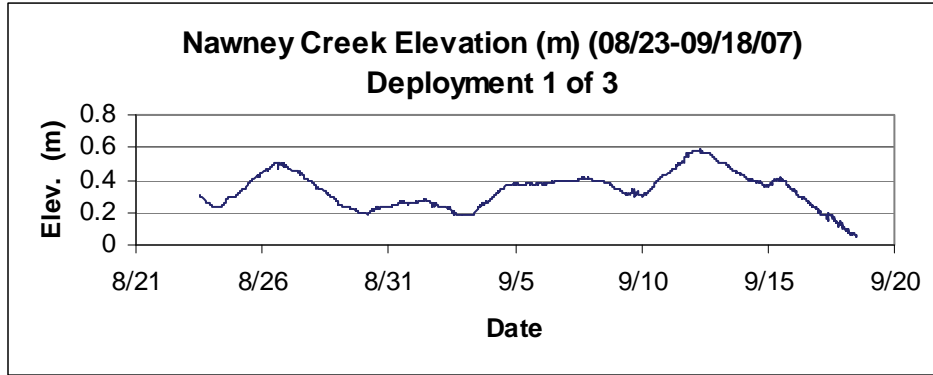


Figure III.6. Surface Elevations at Nawney Creek Mouth – Deployment 1

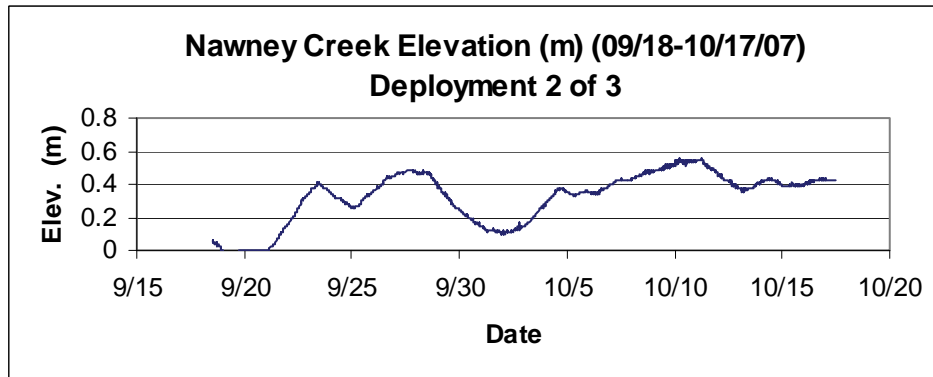


Figure III.7. Surface Elevations at Nawney Creek Mouth – Deployment 2

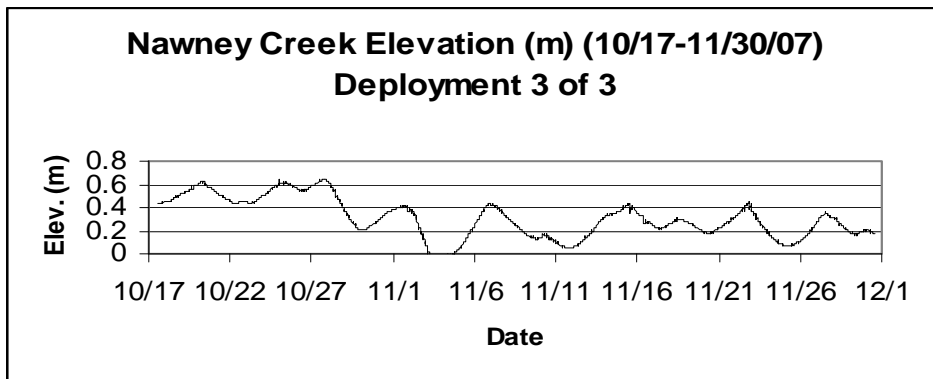


Figure III.8. Surface Elevations at Nawney Creek Mouth – Deployment 3

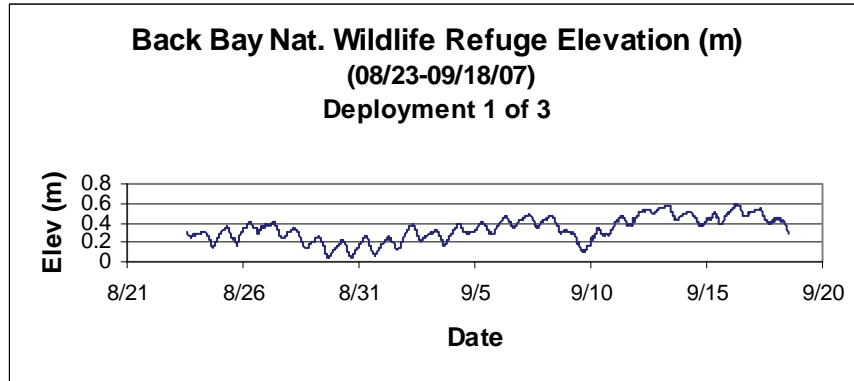


Figure III.9. Surface Elevations at Back Bay National Refuge – Deployment 1

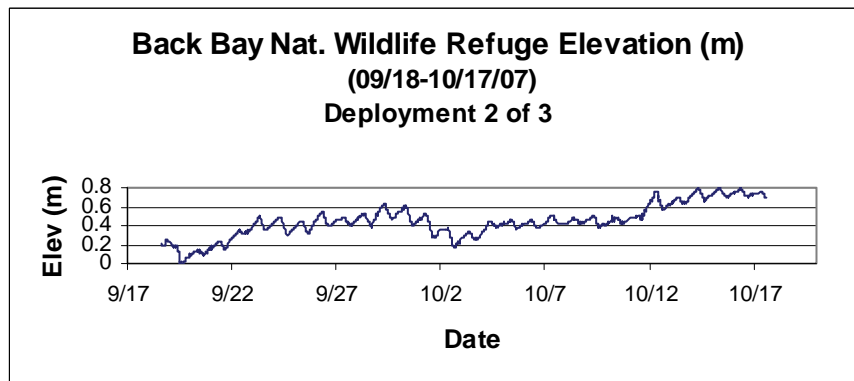


Figure III.10. Surface Elevations at Back Bay National Refuge – Deployment 2

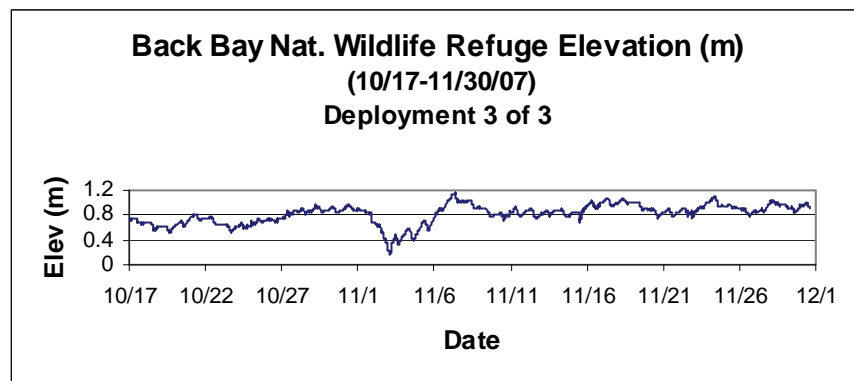


Figure III.11. Surface Elevations at Back Bay National Refuge – Deployment 3

B. Assessment of Nonpoint Sources of Fecal Coliform Loading in the Back Bay Watershed

The Back Bay watershed is comprised of 31 subwatersheds that have been evaluated for nonpoint sources in the present study. The locations of these subwatersheds are shown below in Figure III.12.

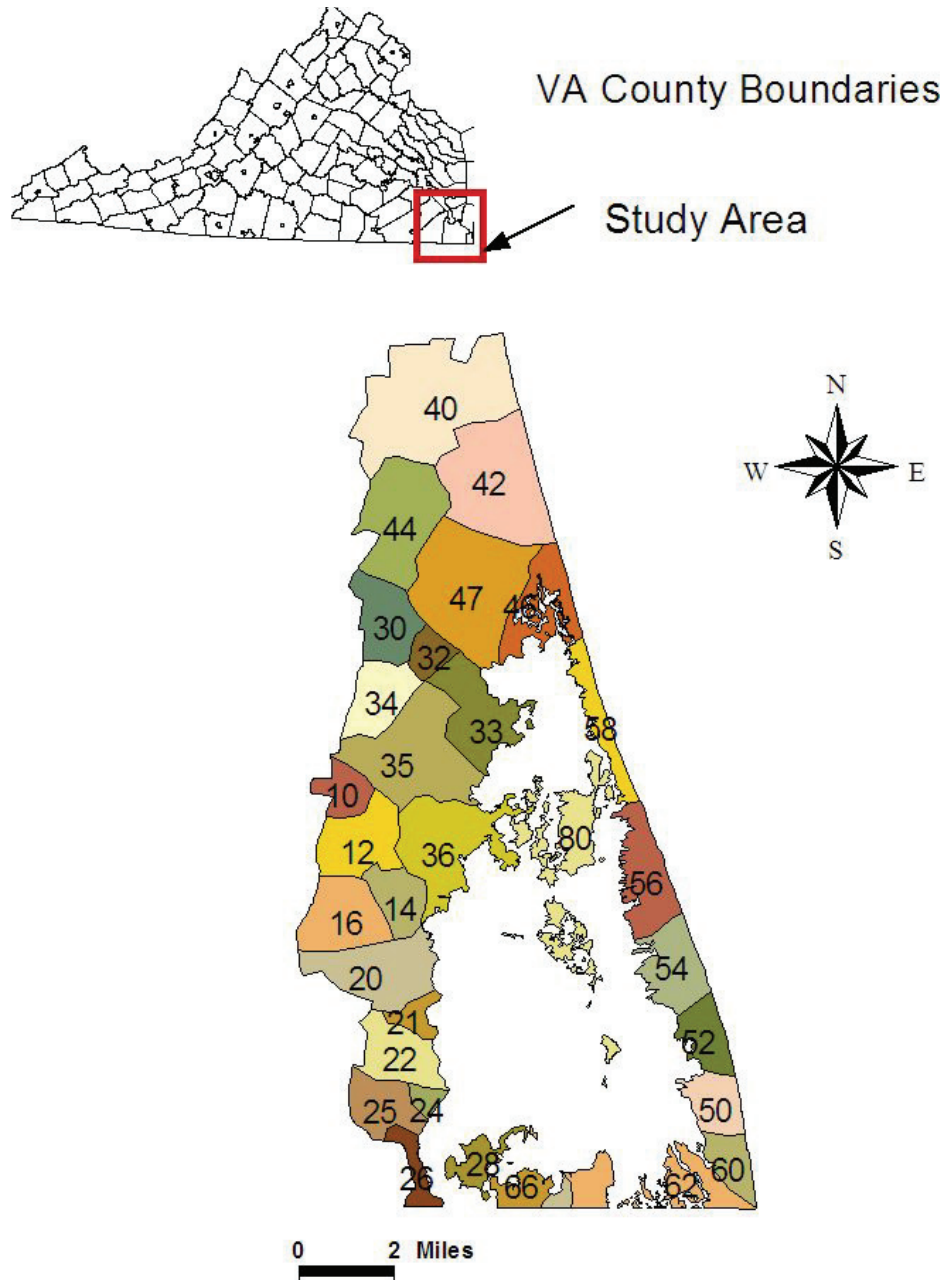


Figure III.12. Location of the Back Bay Area and its Subwatersheds

The Back Bay watershed can be characterized as primarily rural with nearly 30% being agricultural and another 30% being wetlands. The land use percentage distribution is shown in Table III.2 and the land use types are shown in Figure III.13.

Nonpoint sources of fecal coliform do not have a single discharge point but occur over the entire length of a stream or waterbody. There are many types of nonpoint sources in watersheds discharging to the Back Bay area. The possible introductions of fecal coliform bacteria to the land surface are through direct deposition from livestock during the grazing season, and through excretions from pets and wildlife. As runoff occurs during rain events, surface runoff transports water and fecal coliform over the land surface and discharges to the Back Bay area. The deposition of non-human fecal coliform directly to the area occurs when livestock or wildlife have direct access to the waterbody. Nonpoint source contributions to the bacterial levels from human activities generally arise from failing septic systems and their associated drain fields, as well as through pollution from recreation vessel discharges. The transport of fecal coliform from land surfaces to the area is dictated by the hydrology, soil type, land use, and topography of the watershed.

In order to determine the sources of fecal coliform contribution and reduction needed to achieve water quality criteria, and to allocate fecal coliform loads among these sources, it is necessary to identify all existing sources. The nonpoint source assessment was conducted using available data collected in the watershed. Multiple data sources were used to determine the potential sources of the fecal coliform load from the watershed. The data used for source assessment are:

1. Land use data from the City of Virginia Beach and MRLC 2000 land use/land cover data
2. GIS 2000 Census Block and STF1 Summary Files (US Census Bureau)
3. VA County Boundaries, Stream Lines, Reaches, and Land Segments GIS coverages (Chesapeake Bay Program, Phase V)
4. USGS National Hydrographic Dataset
5. Wildlife population density (Technical Memorandum - Lynnhaven River Watershed)
6. Livestock inventories from 2002 Census of Agriculture (Zip code based)
7. Zip code polygon boundaries were downloaded from US Census Bureau

In the Back Bay basin, wildlife contributions, both mammalian and avian, are natural conditions and may represent a background level of bacterial loading. Livestock contributions, such as those from mammalian and avian livestock, mainly result from surface runoff. Pet contributions usually occur through runoff from streets and land. Since there are no direct point source discharges to the embayment and there is a lack of information available for the discharge from boats, it is assumed that human loading results from failures in septic waste treatment systems. The major nonpoint source contributions assessed in the study are summarized in Table III.3.

Table III.2. Land Use Percentage Distribution for the Back Bay Watershed

Land Type	Acreage	%	Land Type	Acreage	%
Mixed Forest	1,399.3	3.4	Developed	1,129.8	2.7
Cultivated Crops	2,003.9	4.8	Open Space and Barren	1,761.7	4.2
Grass Land	99.6	0.2	Campground	404.2	1.0
Pasture/Hay	409.3	1.0	Wetland	12,462.2	29.9
Residence High	209.4	0.5	Water	1,199.7	2.9
Residence Med	3,061.6	7.3	Unconsolidated Shore	0.9	0.0
Residence Low	4,895.3	11.7	Agriculture	11,962.1	28.7
Commercial	686.8	1.6	TOTAL	41,685.8	100

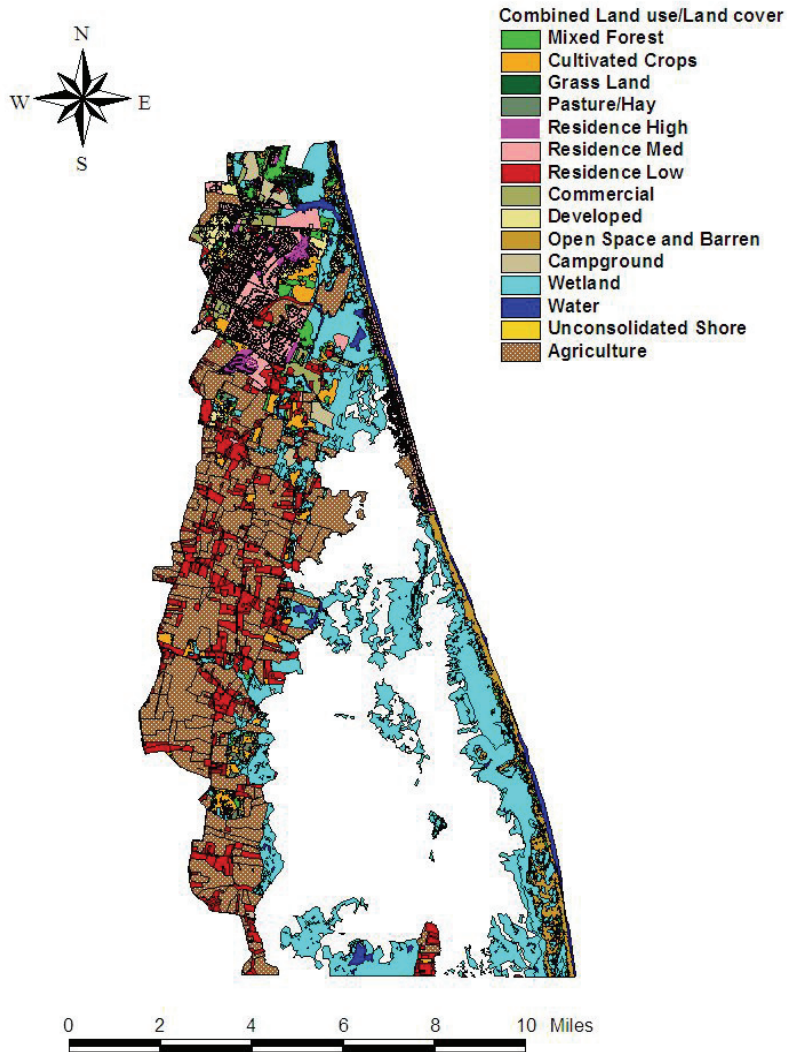


Figure III.13. Land Use in the Back Bay Watershed

The potential nonpoint sources were grouped into four categories: wildlife; human; pets; and livestock. These categories will be presented in detail in the following sections. (Due to insufficient data sources, the source assessment method does not account for boat discharge, resuspension from bottom sediment, and the potential for regrowth of fecal coliform in the embayment.)

Table III.3. Summary of Nonpoint Sources

Category	Source
Wildlife	Deer, Waterfowl (Goose & Duck), Muskrat, Raccoon
Human	Septic
Pets	Dog
Livestock	Cattle, Beef, Milk cow Hogs, Sheep, Layers, Horse

1. Wildlife Contributions

In general it is assumed that the wildlife species existent in the watershed include deer, goose, duck, muskrat, and raccoon. Fecal coliform from wildlife can be from excretion on land that is subject to runoff or direct deposition into the stream. The primary habitat densities for relevant wildlife types were obtained from a URS Technical Memorandum (URS, 2007) and are listed in Table III.4.

Table III.4. Wildlife Habitat and Densities

Wildlife Type	Population Density	Habitat Requirements
Deer ¹	15 animals/sq. mi	Open land next Forest – Barren Lands
Goose ¹	44.2 animals/sq. mi	Within 150 feet of shoreline
Duck ¹	57.2 animals/sq. mi	Within 150 feet of shoreline
Muskrat ¹	9600 animals/sq. mi	Wetlands and inland waters
Raccoon ¹	50 animals/sq. mi	Within 600 feet of streams and ponds

¹: All the density data were cited from URS (2007)

The habitat areas for each species were determined using ArcView GIS 3.2 and ArcGIS Desktop 9.2 with the combined Land use and shorelines from the modified Chesapeake Bay Program land segment boundaries (i.e. smaller delineations). The GIS tool was applied to the shoreline or land use to create a buffer area for wildlife habitats according to Table III.4. Wildlife populations were obtained by applying assumed wildlife densities to these buffer areas. The populations of the wildlife were obtained by applying density factors to estimated habitat areas. The fecal coliform contributions were estimated based on the estimated number of wildlife and fecal coliform production rates, which are listed in Table III.5. To obtain the total wildlife contribution, population density is multiplied by the applicable acreage (from buffer area) and that product is multiplied by fecal coliform production rates for each animal.

Table III.5. Wildlife Fecal Coliform Production Rates

Source	Fecal Coliform Production (cfu/animal-day)
Deer ¹	2.93E+08
Goose ¹	5.25E+05
Duck ¹	5.25E+05
Muskrat ¹	1.90E+08
Raccoon ¹	9.45E+08

¹URS (2007)

2. Human Contributions

Septic unit for each land use type (units/acres) has been estimated in the report of URS (2007). This septic unit was multiplied by each land use area (acreage) and by 3% septic leakage to obtain total fecal coliform load (cfu/acre-day) from failing septic systems for each subwatershed. It is assumed that the human contribution is attributed to septic systems (although recreational vessels might be a source, we have not attempted to quantify that source). The estimated fecal coliform loading from humans is calculated as follows:

$$\text{Load} = \sum_{i=1}^n (\text{UC}_i * \text{AC}_i * \text{ADF} * \text{SL} * \text{FCconc} * f) / \text{ACt}$$

Where,

Load = fecal Loads (cfu/acre-day)

n = number of land use type

UC = septic units per acreage (units /acreage)

AC_i = the area of each land use type (acreage)

ADF = the average daily flow (gpd / septic)

SL = septic leakage (3%, constant)

FCconc = fecal coliform concentration, 1.04 x 10⁴ cfu/ml (URS, 2007)

f = unit conversion factor (37.85)

ACt = the total area of each subwatershed (AC)

3. Pet Contributions

The number of households was estimated from the GIS 2000 Census Block. Since each subwatershed is a sub-area of the Census Block, the GIS tool was used to extract this area from the 2000 Census Block. The percentage of the subwatershed area relative to the total area of the 2000 Census Block was calculated. This percentage was applied to

partition total census block number of households to each land use type within each subwatershed. The constants for estimates, such as the percentage of households owning dogs, the number of dogs in each household, waste load, and the scoop ratio, were obtained from URS (2007). Therefore, the estimated fecal coliform loading from pets is calculated as follows:

$$\text{Load} = \sum_{i=1}^n (\% \text{HOG} * \text{HH}_i * \text{Hho} * \text{WL} * \text{SR}) / \text{AC}$$

Where:

Load = fecal Loads (cfu/acre-day)

n = the number of land use types

%HOG = % household owning dogs (0.361, constant)

HH_i = the number of households for each land use type

Hho = the number of dogs in households owning dogs (0.6, constant)

WL = the constant of waste load (= 2.16 x 10⁸ cfu/animal-day)

SR = scoop ratio (= 40%; 1 – 0.6, scoop the poop)

AC = the total acreage area for the subwatershed

4. Livestock Contributions

Zip Code based Census of agriculture was used to estimate livestock for each subwatershed. The numbers of livestock animals from original zipcode-based polygons in Census of Agriculture were proportional to the total area of Agriculture and Pasture/Hay lands for each subwatershed. To estimate FC loads from livestock, the waste load (cfu/animal-day) for each animal type was calculated from the existing VA-DEQ TMDL reports i.e., VA-DEQ 2004 (a) and (b). The estimated loading rates for livestock in the Back Bay watershed are shown below in Table III.6.

Table III.6. Estimated Loading Rates for Livestock

	cfu/animal-day
Cattle ²	2.12E+09
Beef ¹	6.00E+11
MilkCow ¹	8.80E+11
Hogs ¹	8.60E+12
Sheep ¹	2.47E+11
Layers ²	6.61E+07
Horse ¹	8.40E+08

¹: Average values of High/Low; Bacterial TMDL for Matadequin Creek Hanover County, VA

²: Bacterial TMDL for Cub Run in Rockingham County, VA

The loading (cfu/acre-day) for each category and its percentage of the total loading are shown below in Table III.7. Combining all 31 of the Back Bay subwatersheds, the wildlife accounts for nearly 90% of the total loading.

Table III.7. Loading Distribution for the Back Bay Basin

Fecal Coliform Source	Loading cfu/acre-day	Loading Percent
Livestock	1.39E+06	0.01
Pets	1.13E+09	9.40
Human	8.53E+07	0.71
Wildlife	1.08E+10	89.88
Total	1.20E+10	100.00

The total and percentage distributions of source loads for each subwatershed in the Back Bay watershed are tabulated in Table III.8.

The spatial distributions of the source loading for each category (wildlife, human, pets, and livestock) are shown in Figures III.14 through III.17. For the category of wildlife loading input, the relative importance of the southeastern portion of the watershed (subwatersheds 54, 52, and 50) can readily be seen from Figure III.14. For the category of human input from failing septic systems, the subwatersheds 40, 42, 44, and 47 (to the north) and 58 (to the east) have the higher contribution. For the category of pets, the subwatersheds 40, 42, 44, and 46 (to the north) and 58 (to the east) have the higher contribution. For the category of livestock input, the subwatersheds 12, 16, 20, and 35 (to the west) contribute the most.

Lastly, the total loadings for all four of these categories, the watersheds 50, 52, and 54 to the southeast, subwatershed 14 to the west, and subwatersheds 40, 42, and 46 to the north are the dominant sources, as shown in Figure III.18.

Table III.8. Total and Percentage Distributions of Fecal Coliform Source Loads for Each Back Bay Subwatershed

Sub watershed	Pets	%	Human	%	Wildlife	%	Livestock	%	Total
10	2.21E+06	26.49	2.70E+06	32.30	2.09E+06	25.05	0.00E+00	0.00	7.01E+06
12	2.49E+06	4.73	2.66E+06	5.05	4.54E+07	86.21	2.99E+05	0.59	5.08E+07
14	9.42E+08	84.15	2.17E+06	0.19	1.75E+08	15.65	0.00E+00	0.00	1.12E+09
16	2.64E+06	18.83	2.61E+06	18.64	6.12E+06	43.59	4.99E+05	4.21	1.19E+07
20	1.97E+06	1.24	2.24E+06	1.41	1.53E+08	96.32	2.99E+05	0.19	1.57E+08
21	1.42E+06	2.57	1.98E+06	3.59	5.18E+07	93.85	0.00E+00	0.00	5.52E+07
22	9.94E+05	1.65	2.24E+06	3.73	5.65E+07	94.02	0.00E+00	0.00	5.98E+07
24	8.10E+05	0.35	1.32E+06	0.57	2.28E+08	99.08	0.00E+00	0.00	2.31E+08
25	9.86E+05	2.71	2.68E+06	7.35	3.19E+07	87.56	0.00E+00	0.00	3.55E+07
26	1.98E+06	5.75	2.71E+06	7.86	2.98E+07	86.39	0.00E+00	0.00	3.44E+07
28	0.00E+00	0.00	0.00E+00	0.00	1.44E+08	100.00	0.00E+00	0.00	1.44E+08
30	3.25E+06	3.78	3.62E+06	4.21	7.91E+07	92.00	0.00E+00	0.00	8.60E+07
32	1.82E+06	0.96	2.00E+06	1.06	1.85E+08	97.98	0.00E+00	0.00	1.89E+08
33	9.78E+05	0.47	2.02E+06	0.97	1.96E+08	94.67	0.00E+00	0.00	1.99E+08
34	3.21E+06	24.53	2.63E+06	20.09	7.25E+06	55.38	0.00E+00	0.00	1.31E+07
35	3.19E+06	4.80	2.62E+06	3.94	5.94E+07	89.48	2.88E+05	0.44	6.55E+07
36	2.21E+06	1.21	1.73E+06	0.95	1.77E+08	97.63	0.00E+00	0.00	1.81E+08
40	4.91E+07	7.95	8.03E+06	1.30	5.60E+08	90.75	0.00E+00	0.00	6.17E+08
42	2.76E+07	2.75	6.05E+06	0.60	9.70E+08	96.64	0.00E+00	0.00	1.00E+09
44	5.52E+07	48.19	1.14E+07	9.96	4.80E+07	41.85	0.00E+00	0.00	1.15E+08
46	1.08E+07	2.11	3.83E+06	0.75	4.95E+08	97.14	0.00E+00	0.00	5.10E+08
47	3.35E+06	2.91	7.65E+06	6.65	1.04E+08	90.44	0.00E+00	0.00	1.15E+08
50	0.00E+00	0.00	1.18E+05	0.01	1.25E+09	99.99	0.00E+00	0.00	1.25E+09
52	0.00E+00	0.00	0.00E+00	0.00	1.73E+09	100.00	0.00E+00	0.00	1.73E+09
54	0.00E+00	0.00	1.04E+05	0.01	1.30E+09	99.99	0.00E+00	0.00	1.30E+09
56	0.00E+00	0.00	0.00E+00	0.00	2.98E+08	100.00	0.00E+00	0.00	2.98E+08
58	1.04E+07	3.21	9.36E+06	2.88	3.05E+08	93.90	0.00E+00	0.00	3.25E+08
60	0.00E+00	0.00	1.36E+05	0.02	7.79E+08	99.98	0.00E+00	0.00	7.79E+08
62	4.26E+05	0.00	7.16E+05	0.00	3.19E+08	1.18	0.00E+00	0.00	3.20E+08
64	1.18E+06	1.72	4.77E+03	0.01	6.75E+07	98.27	0.00E+00	0.00	6.87E+07
66	1.99E+05	0.03	0.00E+00	0.00	6.94E+08	99.97	0.00E+00	0.00	6.94E+08
80	0.00E+00	0.00	0.00E+00	0.00	2.64E+08	100.00	0.00E+00	0.00	2.64E+08
SUM	1.13E+09	9.40	8.53E+07	0.71	1.08E+10	89.88	1.39E+06	0.01	1.20E+10

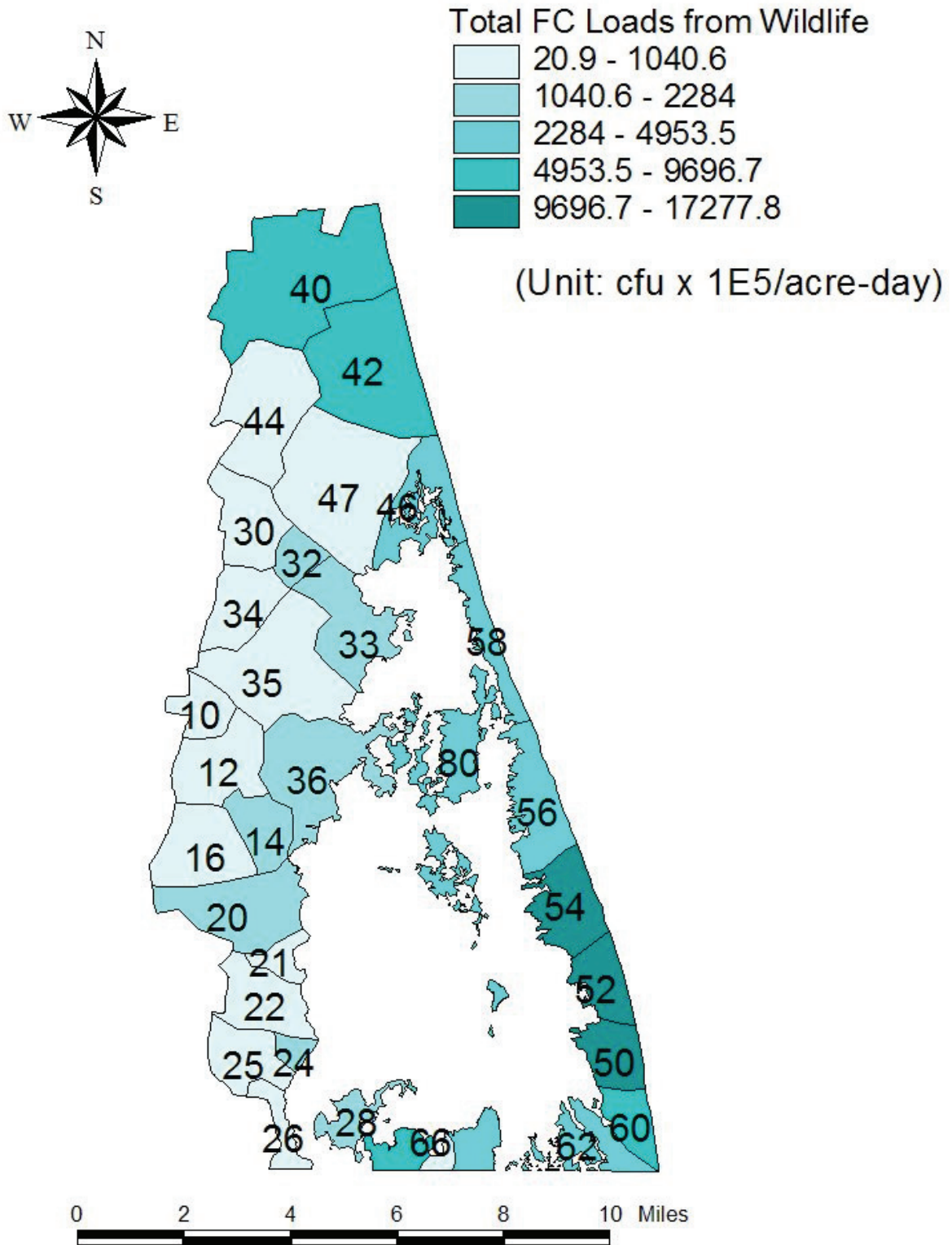


Figure III.14. Fecal Coliform Loadings from Wildlife

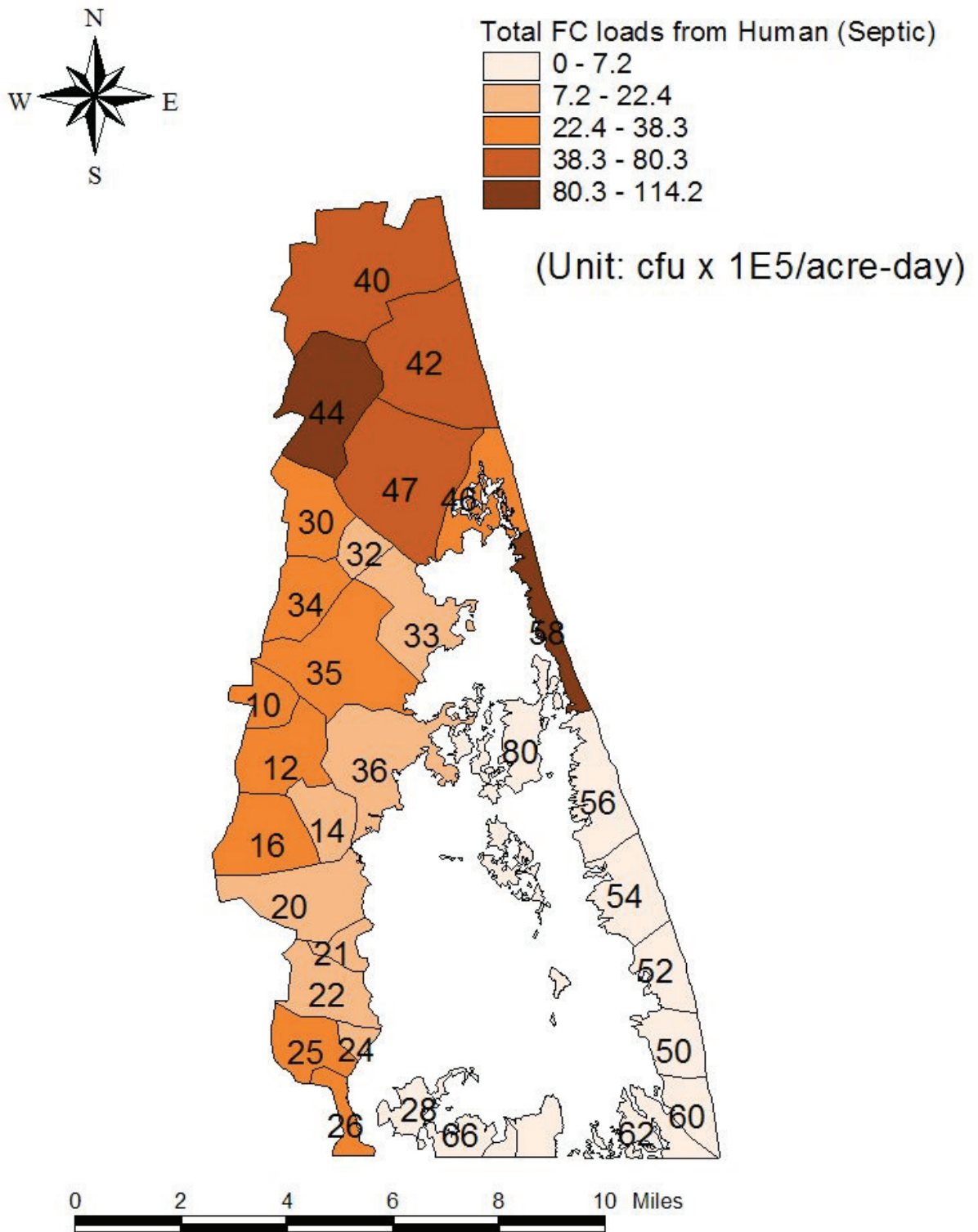


Figure III.15. Fecal Coliform Loads from Human Sources (failing septic systems).

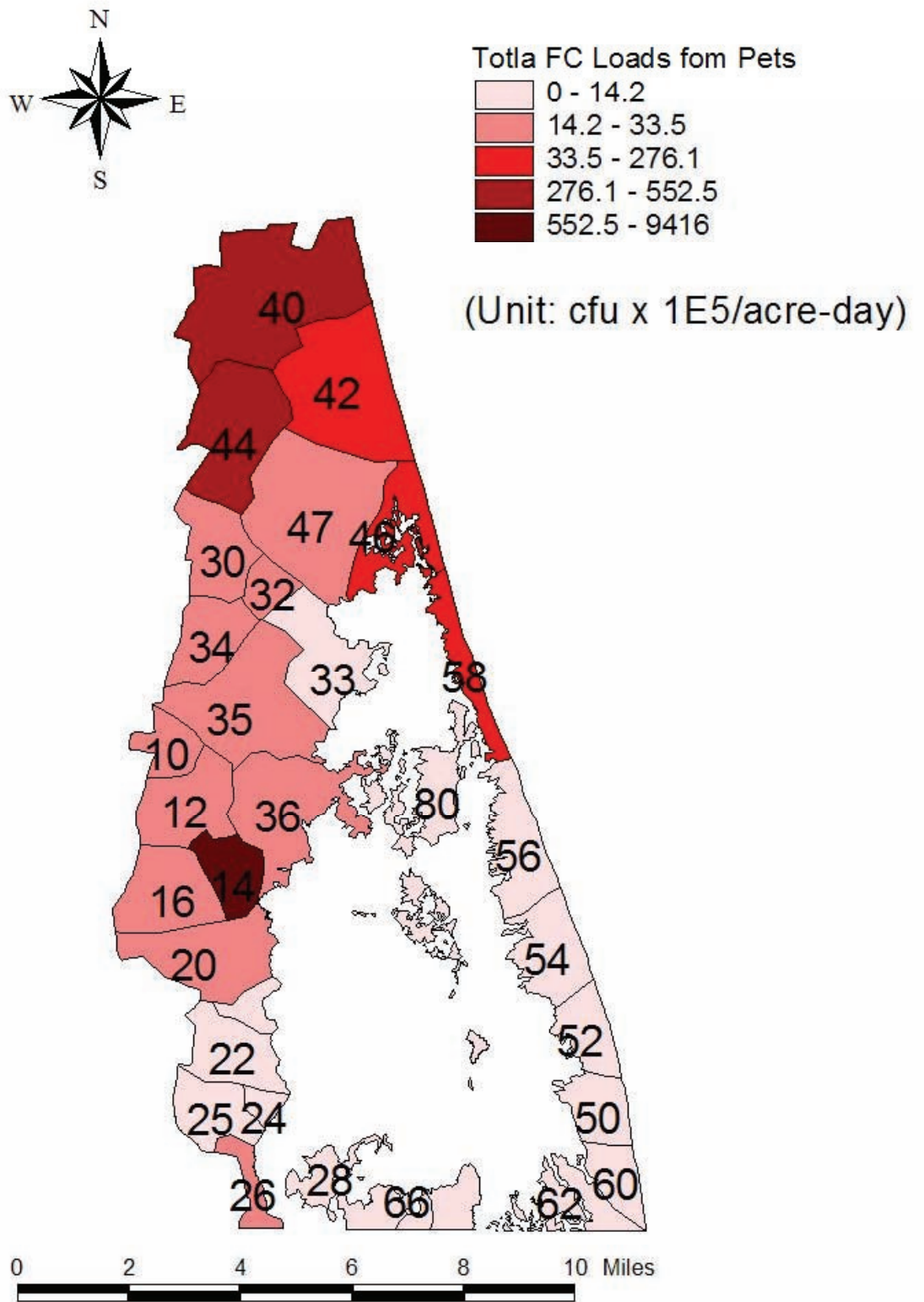


Figure III.16. Fecal Coliform Loadings from Pets

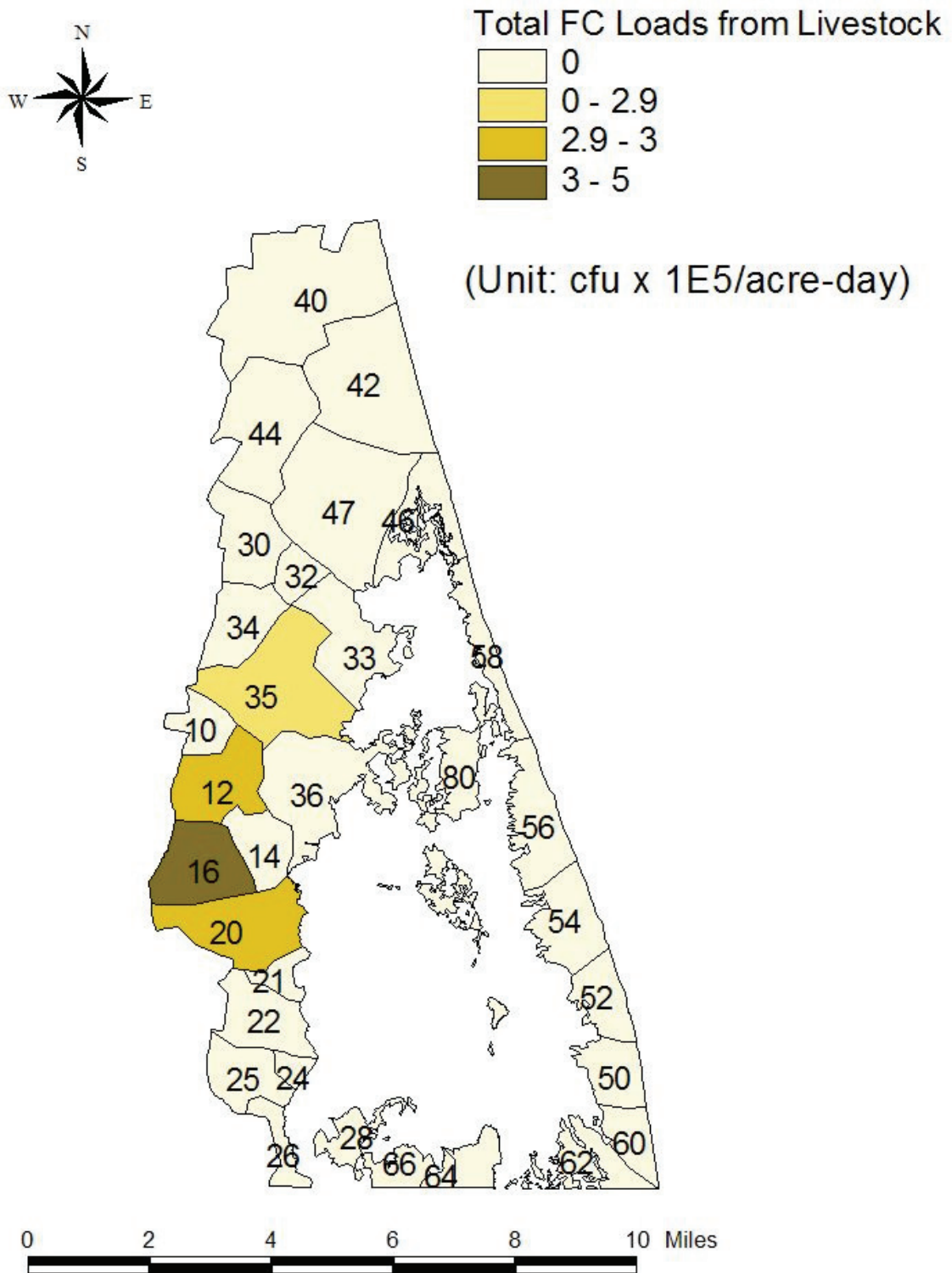


Figure III.17. Fecal Coliform Loadings from Livestock

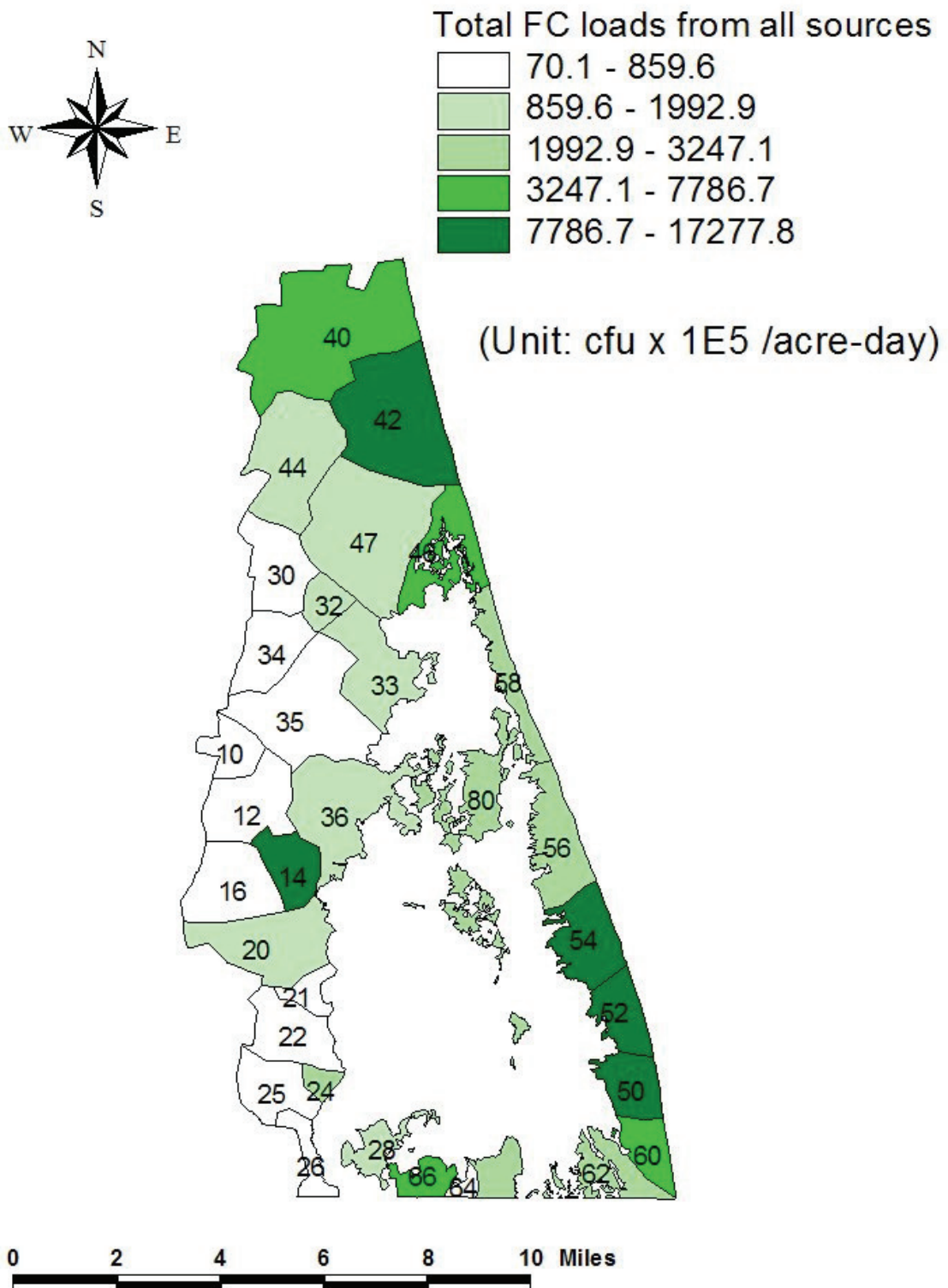


Figure III.18. Fecal Coliform Loadings from All Contributing Sources

C. Residence time calculation using the UnTRIM model

The UnTRIM hydrodynamic model has been setup for application to Back Bay. This involved the construction of a high-resolution unstructured grid, construction of required input data sets, driving the model at its southside open boundary with surface elevations specified south of the Knotts Island Channel, and performing a preliminary calibration of the model by comparing the model's predicted surface elevations at Nawney Creek and Back Bay National Wildlife Refuge with those observed in the VIMS 2007 Back Bay hydrodynamic survey. Additionally, velocities measured during the survey in Knott's Island Channel were compared to velocities predicted by the model.

1. Grid generation

The UnTRIM grid consisting of 18,824 cells with a horizontal resolution of 50 to 200 m was constructed over the domain of the 104-square-mile Back Bay. A plan view of this grid is shown in Figure III.19.

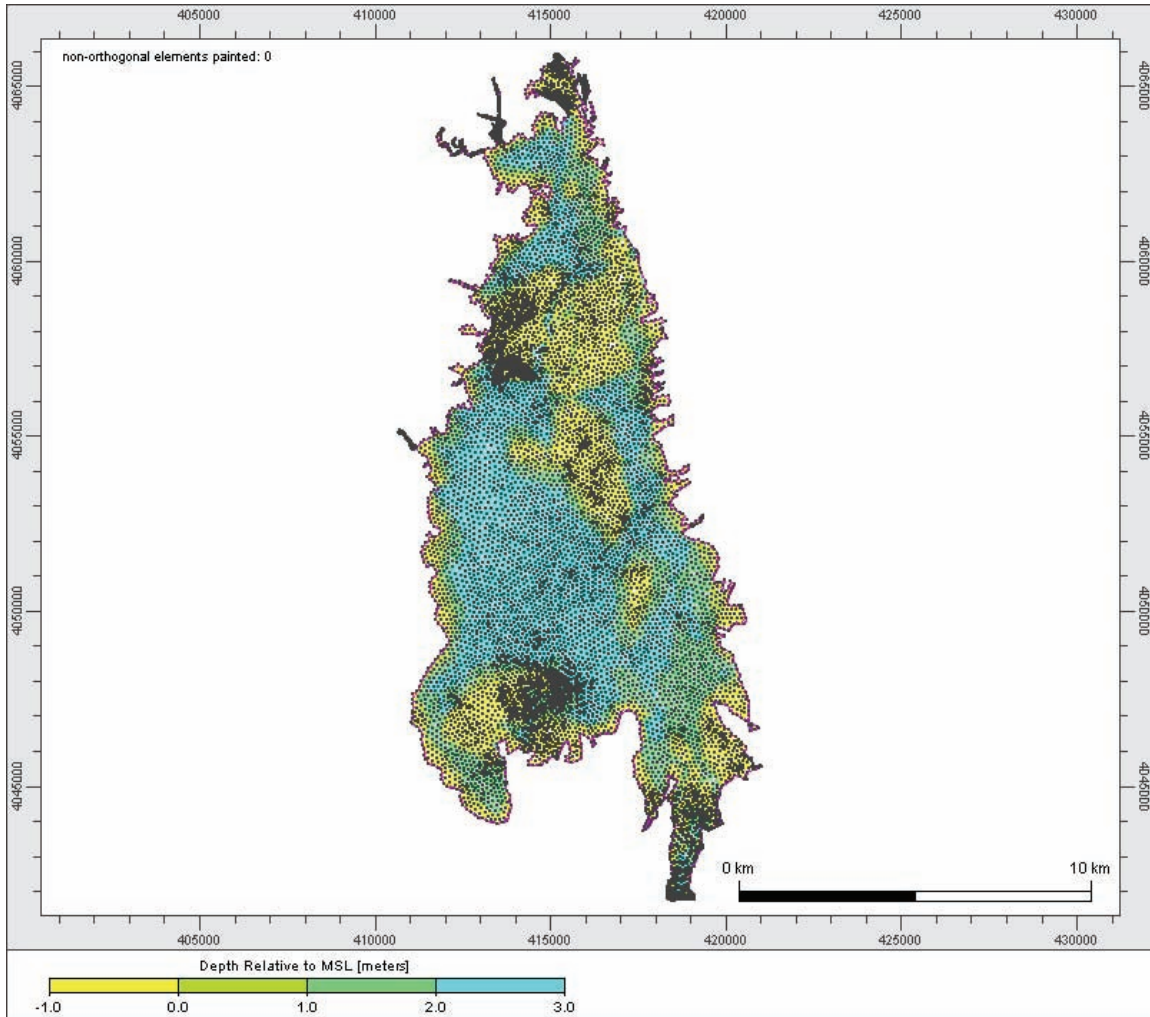


Figure III.19. The UnTRIM Unstructured Grid for Back Bay

2. Preliminary Model Results

The model was executed by specifying a surface elevation time series along the open boundary in the southern portion of the domain near Knott's Island Channel. Comparisons of model predictions of surface elevations with observations are shown in Figures III.20 and III.21, respectively, for Nawney Creek and the Back Bay National Wildlife Refuge. A comparison of model-predicted velocities with observations in Knott's Island Channel is shown in Figure III.22. Since the Knott's Island Channel is oriented in the north-south direction, the comparison is made on the north-south component of velocity.

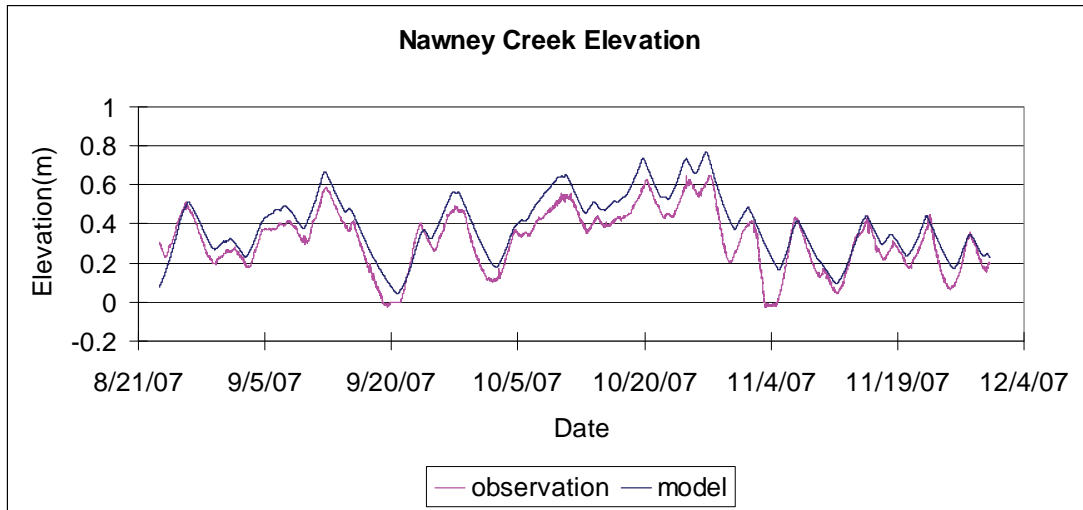


Figure III.20. Observed vs. predicted surface elevation at Nawney Creek Entrance

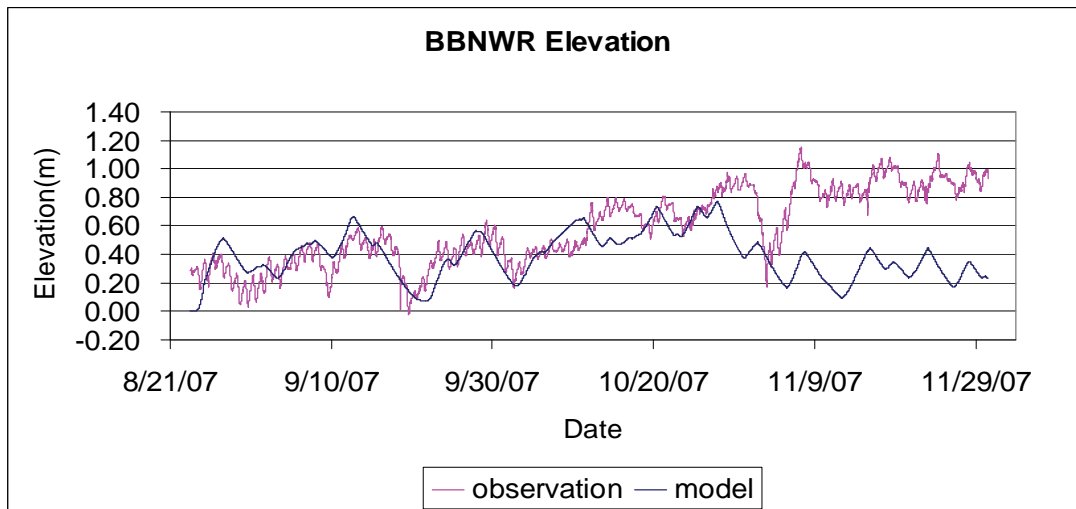


Figure III.21. Observed vs. predicted surface elevation at Back Bay National Wildlife Refuge

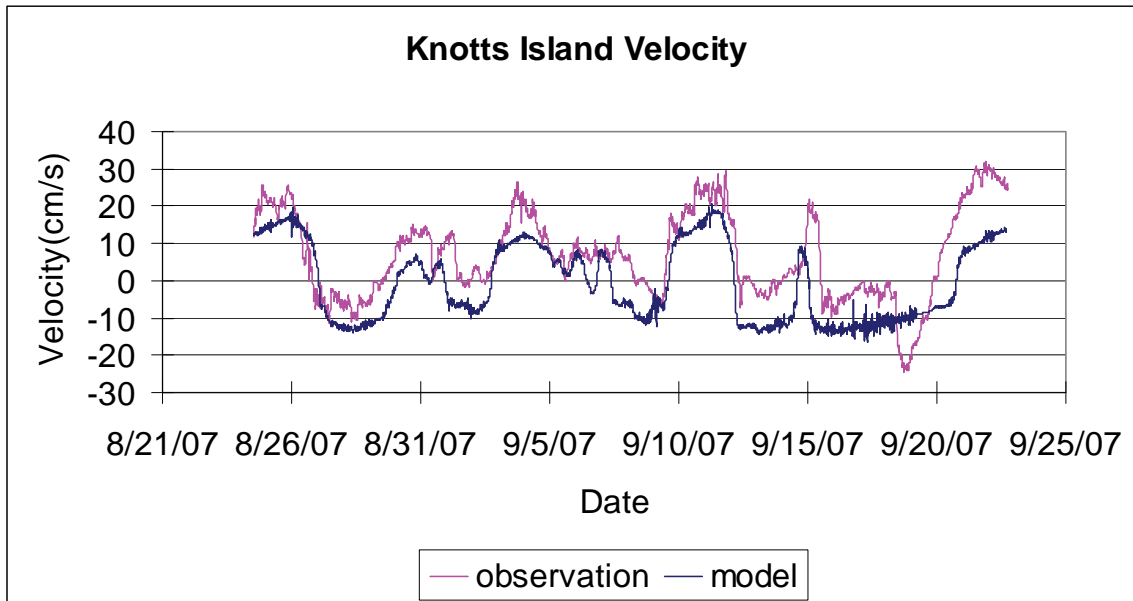


Figure III.22. Observed vs. predicted velocity in Knott’s Island Channel (positive magnitude denotes north and negative magnitude denotes south)

These preliminary results show good qualitative agreement with observations during these initial simulations. The wind forcing used was from the Chesapeake Bay Bridge Tunnel; a high-frequency wind field collected from a nearby weather station would prove to be advantageous in future efforts to fine-tune the model’s performance.

3. Residence Time Determination

Residence time is defined as “the time it takes for any water parcel of the sample to leave the lagoon through its outlet to the sea” (Zimmerman, 1976). Takeoka (1984) introduced the remnant function to define residence time. Consider a parcel of material in a reservoir at time $t = 0$. Let the amount of the material at $t = 0$ be R_0 , and the amount of the material which still remains in the reservoir at the time t be $R(t)$. Hence, $R(t)$ is the amount of the material whose residence time is larger than t . The residence time distribution function can be defined as:

$$\phi' = -\frac{1}{R_0} \frac{dR(\tau)}{d\tau} \quad (1)$$

It can be further assumed that:

$$\lim_{\tau \rightarrow \infty} R(\tau) = 0 \quad (2)$$

The averaged residence time (τ_r) of the material is defined as:

$$\tau_r = \int_0^{\infty} \tau \phi'(\tau) d\tau \quad (3)$$

Integrating above Eq. (3) by parts gives:

$$\tau_r = \int_0^{\infty} \frac{R(t)}{R_0} d\tau = \int_0^{\infty} r(t) d\tau \quad (4)$$

where $r(t) = R(t)/R_0$ is called the remnant function. It can be easily calculated from a numerical model and the result of τ_r gives the average residence time for a given waterbody.

After a preliminary calibration effort, the model was configured to determine the residence time within both its north and south portions (Figure III.23).

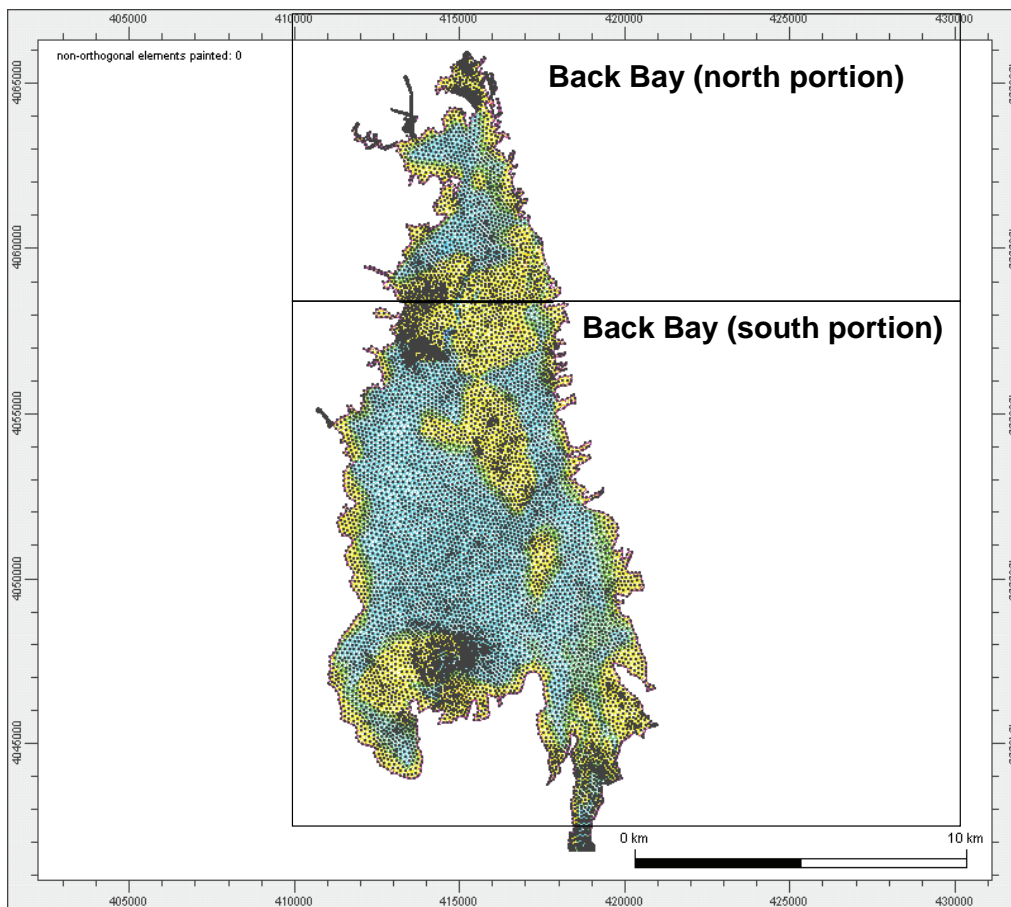


Figure III.23. Portions of Back Bay Used for Residence Time Determination

By running the model cyclically, a 3-year period was simulated, and it was quickly realized that the residence time in the Bay is relatively long. Figure III.24 shows the slow decrease of the concentration of a conservative substance over time for the south portion of Back Bay. The fact that it took 1.5 years for the concentration in the south portion of the Bay to decrease by 50% indicates the poor flushing in this region. The residence time for the northern portion of Back Bay (not shown) required even longer for the concentration of a conservative substance to decrease with time. It can be concluded that the residence time for the Back Bay is a relatively long period compared to residence times of estuaries of similar size. For example, the residence time of the Lynnhaven River System, under extreme low flow conditions, is on the order of 80 days, much shorter than that of the Back Bay.

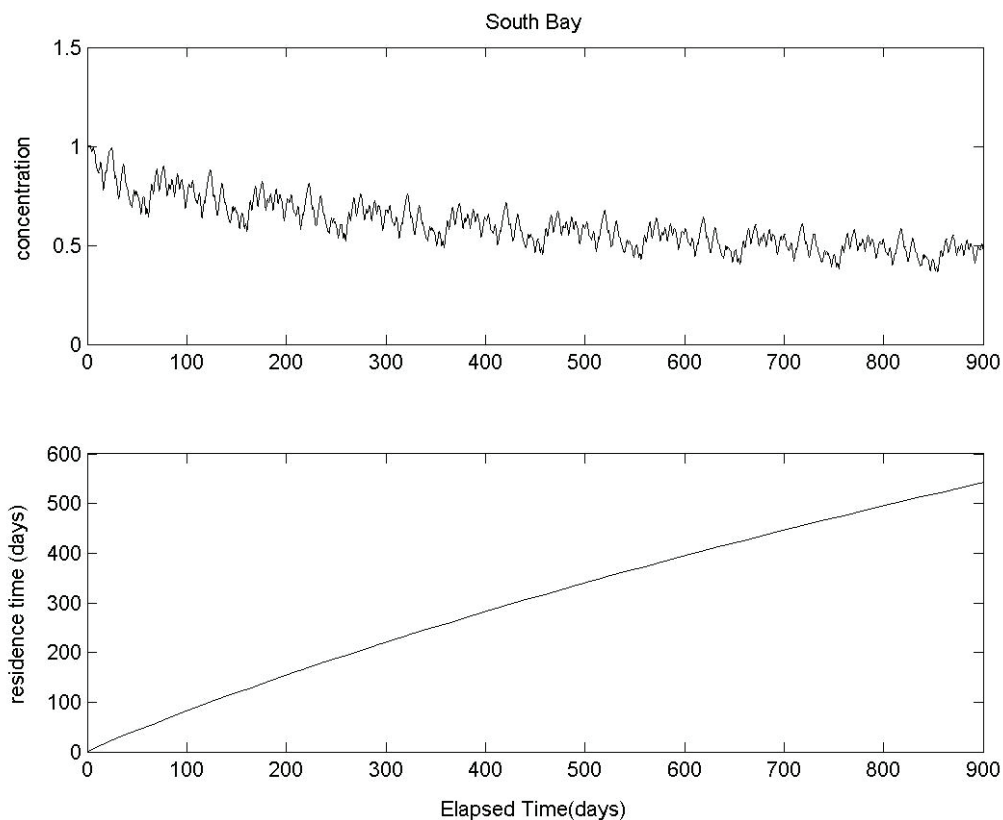
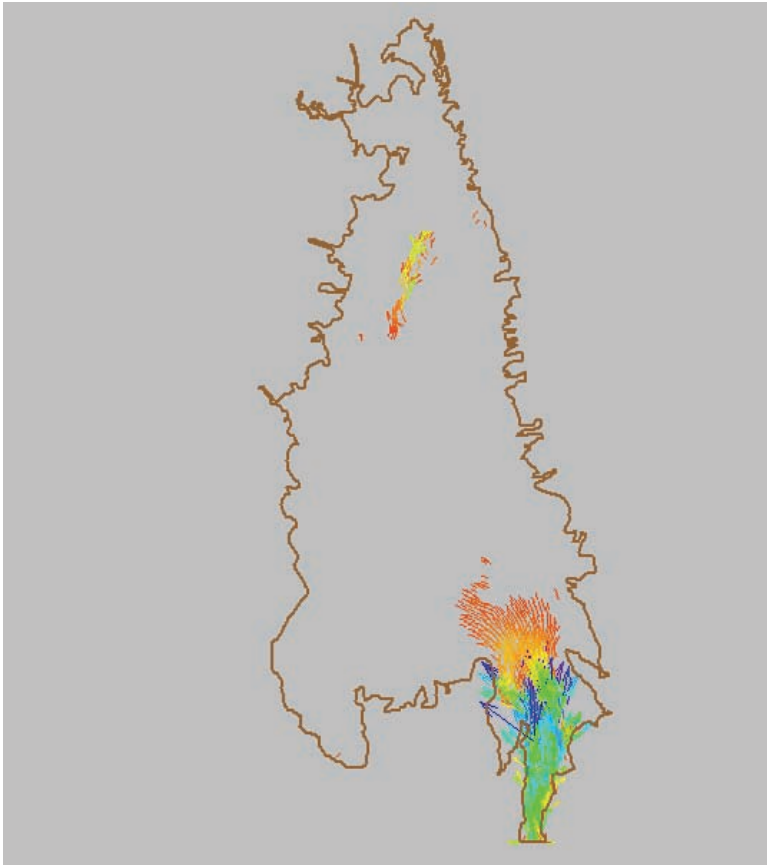


Figure III.24. Concentration Time Series Showing that Residence Time in Back Bay (south portion) Is Approximately 500 days

The reason for this long residence time is because the Bay lacks the tidal and density-driven circulation to efficiently flush the concentration of the substances that discharge into it. Figure III.25 is an example of the spatial distribution of the current velocity. As can be seen, most of the velocities are small in magnitude except at Knott's Island Channel, through which only a limited amount of water can pass because of the narrowness of the channel.

a)



b)

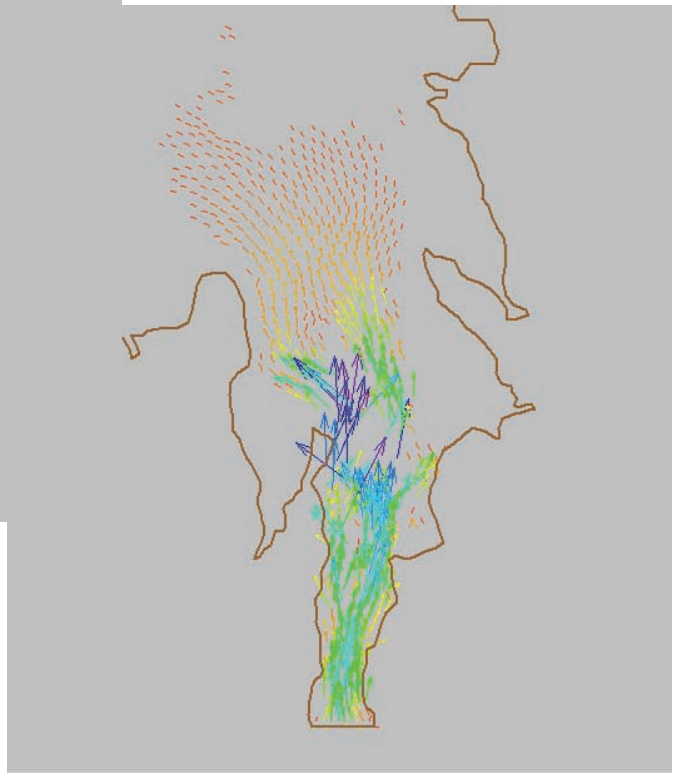


Figure III.25. Spatial plots of largest predicted velocities for a) entire Back Bay and b) near Knott's Island Channel showing relative magnitudes (Note: maximum velocities shown are approximately 20 cm/sec).

IV. CONCLUSIONS

Back Bay is a shallow estuary at the headland portion of the Currituck Sound, connected to Albemarle Sound, NC, approximately 60 miles from the Oregon Inlet. It is in the famous Atlantic Flyway, and is the home of two key national wildlife refuges. As part of this reconnaissance study, a historical data analysis for fecal coliform and a hydrodynamic field study were conducted. Also carried out were an estimation of the nonpoint source fecal coliform loading and the calculation of residence time for the entire Back Bay.

An examination of long-term historical bacterial levels from 1993-2007 at most of the stations throughout Back Bay shows occasional violations (below 20% of the time) for *E. coli* and enterococci. The two stations around Nawney Creek exhibit the highest values of all Back Bay stations whose measurements are statistically significant – exceeding 40% for enterococci.

The hydrodynamic survey was conducted by VIMS from August 23, 2007 to November 30, 2007 for two water level sites as well as one velocity site with high-frequency measurements. The water level was recorded every 15 minutes along the Western Shoreline near the mouth of Nawney Creek and along the Eastern Shoreline at the Back Bay National Wildlife Refuge. The velocity was recorded at Knott's Island Channel near the southern boundary of the Bay with measurements every 15 minutes. The water level and velocity measurements indicate a very small tidal signal, if there is any. Most of the water elevation and velocity measurements are related to wind-driven circulation.

The Back Bay watershed was divided into 31 sub-watersheds using data from the MRLC 2000 database. The land use analysis of the Back Bay region shows that the high levels of agricultural activity (wetlands 29.9%, agriculture 28.7%, and low intensity residential 11.7%) over much of the Western Shore of the Bay. The source assessment of fecal coliform loading in the Back Bay watershed shows that wildlife, including deer, waterfowl (e.g., goose and duck), muskrats, and raccoons, accounts for nearly 90% of the total loading into the Back Bay receiving waters.

The VIMS UnTRIM hydrodynamic model has been applied to the 104-square mile Back Bay. The model operates over an unstructured grid and uses 18,824 high-resolution grid cells to resolve the complicated geometry of the Bay. Model results compare reasonably well to observed high-frequency elevations at Nawney Creek and the Back Bay National Wildlife Refuge and to velocities in Knott's Island Channel.

The model was further applied to calculate residence time, referring to the required time for a conservative substance to leave the Bay through its outlet. The results show that the residence time for the entire Bay is nearly 1.5 years, which is relatively long compared to residence times of estuaries of similar size. The lack of tidal and density-driven currents, and the limited access to the Currituck Sound, are the main reasons for this long residence time in the Back Bay.

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**Appendix A.VIMS Back Bay Database
(MSWord ACCESS FORMAT)**

The inter-agency database for physical and water quality data collected in the Lynnhaven River system by various Virginia State agencies has been reorganized with a focus on the inclusion of data collected in support of the numerical modeling development currently underway at VIMS. This document describes its contents and key format issues.

Agencies contributing to this database include:

- 1) Virginia Institute of Marine Science (VIMS)
- 2) Virginia Department of Environmental Quality (VA-DEQ)
- 3) National Oceanic and Atmospheric Administration (NOAA)

The database consists of several tables that are described below by size, content, and format. In each case the table name is underlined.

No.	Table Name	Records by Agency	Total Records
1	Stations	VIMS (3) VA-DEQ (12) NOAA (1)	16
2	Elevations	VIMS	19,021
3	Velocity	VIMS	2,947
4	Wind	NOAA	30,240
5	WQ_data	VA-DEQ	6,014

Table 1: Stations. This table provides the station name and the latitude and longitude coordinates (to 6 decimal places) for those stations referenced by all other tables (except Dataflow) in this database. There are 16 stations, which include 3 VIMS stations, 12 DEQ stations, and a NOAA station (CBBT) for the measurement of wind. Table A-1 lists these stations individually by Agency and Station Name. The format of this table is:

AGENCY, STATION, STATION_DESCRIPTION, LATITUDE, LONGITUDE

Table 2. Elevations. This table includes measurements made from August 2007 to November 2007 at two locations in Back Bay, near the mouth of Nawney Creek and at the pier of the Back Bay National Wildlife Refuge (BBNWR):

- 1) Nawney Creek - start 08/23/2007 (12:00) end 11/30/2007 (13:15) (9,510 obs)
- 2) BBNWR - start 08/23/2007 (13:00) end 11/30/2007 (14:30) (9,511 obs)

Datums for records in this table are undetermined. Elevations are in meters using local standard time as the time reference. The two stations in this table require a total of 19,021 records. The format for this table is as follows:

AGENCY, STATION, LATITUDE, LONGITUDE, DATE/TIME,
PARAMETER, PARAM_VALUE, UNITS

Table 3. Velocity. This table includes the VIMS S4 measurements (Knotts Island Channel) from August 2007 to October 2007 (2,947 records). In addition to magnitude and direction, the components u (east-west, positive east) and v (north-south, positive north) are provided. The format for this table is:

AGENCY, STATION, LATITUDE, LONGITUDE, DATE/TIME,
TOTAL_DEPTH_m, SENSOR_DEPTH_m, MAG_cm/s, DIR_deg, U_cm/s,
V_cm/s, PARAMETER, UNITS

Table 4. Wind. This table includes wind magnitudes (knots) and wind directions (degrees from) recorded over 6-minute intervals at the Chesapeake Bay Bridge Tunnel (CBBT) from August 9, 2007 to December 12, 2007. Because the circulation in Back Bay is primarily wind-driven, a high-frequency record of wind spanning the period of velocity measurements has been included in the database. In the database table for wind, parameter1 refers to wind magnitude (knots) and parameter2 refers to wind direction. The format for this table is:

AGENCY, STATION, LATITUDE, LONGITUDE, DATE/TIME,
PARAMETER1, PARAM_VALUE1, UNITS, PARAMETER2,
PARAM_VALUE2, UNITS

Table 5: WQ_data. This table provides some of the monthly and bi-monthly data obtained during monitoring surveys conducted by VA-DEQ. An entire suite of 20 water quality state variables is measured by DEQ. However, most are relevant to water quality issues beyond the present study. Those relevant to the present study are tabulated, along with federal STORET codes, in Table A-2. The total number of records from VA-DEQ is 6,014 (includes survey data through October 2006). The format of the fields in each record of this table is as follows:

AGENCY, STATION, LATITUDE, LONGITUDE, DATE/TIME,
SAMPLE_DEPTH, PARAMETER, PARAM_CODE, PARAM_VALUE, UNITS

Table A-1. Fixed Station Locations used for Back Bay

Station No.	Agency	Station Name	Latitude	Longitude	Comments
1	VIMS	Knotts_Island	36.518400	-75.908267	S4 Velocity
2	VIMS	Nawney_Creek	36.636600	-75.995000	YSI Elev#1
3	VIMS	BBNWR	36.672200	-75.917000	YSI Elev#2
4	DEQ	5BASH002.20	36.726861	-75.986083	
5	DEQ	5BBBC000.76	36.679692	-75.984017	Back Bay VA-DEQ Stations Monitored Bi-monthly from 1991 to 2007.
6	DEQ	5BBKY000.99	36.562611	-75.913167	
7	DEQ	5BBKY003.47	36.580667	-75.981639	
8	DEQ	5BBKY006.37	36.634833	-75.987000	
9	DEQ	5BBKY006.48	36.647000	-75.920056	
10	DEQ	5BHPC000.00	36.714056	-75.966972	
11	DEQ	5BHPC001.46	36.732842	-75.971064	
12	DEQ	5BMDY000.00	36.711667	-75.972222	
13	DEQ	5BNWN000.00	36.635369	-75.993289	
14	DEQ	5BNWN001.84	36.649722	-76.016667	
15	DEQ	5BSHB000.57	36.691000	-75.928694	
16	NOAA	NOAA-CBBT	36.966667	-76.113333	6-min wind data

Table A-2. DEQ Measurements in Back Bay, 1993-2006

Parameter	STORET Code	Total Records
Temperature	00010	1652
Salinity	00096	1652
DO Probe	00299	572
Total Suspended Solids	00530	485
Total coliform	31506	53
Fecal coliform	31616	1185
E. Coli	31648	83
Enterococci	31649	331

Appendix B. Time series of Dissolved Oxygen (DO) and Total Suspended Solids (TSS) at VA-DEQ Back Bay Stations

It can be useful to examine the spatial distributions of key water quality parameters over the domain of a waterbody such as Back Bay. Whereas not necessarily directly related to bacterial concentrations, reduced levels of dissolved oxygen and increased levels of suspended solids may result from the poor circulation and flushing prevalent throughout much of Back Bay.

Time series of dissolved oxygen measured at the 12 primary VA-DEQ stations in Back Bay over the past several years are shown in Figures B-1 through B-12. Time series for total suspended solids are shown in Figures B-13 through B-24.

Upon inspection of the dissolved oxygen time series, it can be seen that the typical pattern of low DO (i.e., less than 5 mg/l) occurs at several Back Bay stations during the summer months. The most severe hypoxia conditions occur at the upstream Nawney Creek Station (Station 11, 5BNWN001.84, shown in Figure B-11). Less frequent violations are noted at the downstream Nawney Creek station (Station 10, 5BNWN000.00, Figure B-10) and at landward locations to the north along the Western Shore (Stations 1 and 2, 5BASH002.20 and 5BBBC000.76, Figures B-1 and B-2).

The total suspended solids show the Back Bay's highest values (i.e., in excess of 100 mg/l) along the Western Shore in both the North Bay (Station 9, 5BMDY000.00, Figure B-21) and at two Western Shore stations towards the south (Station 5, 5BBKY006.37, Figure B-17 and Station 4, 5BBKY003.47, Figure B-16).

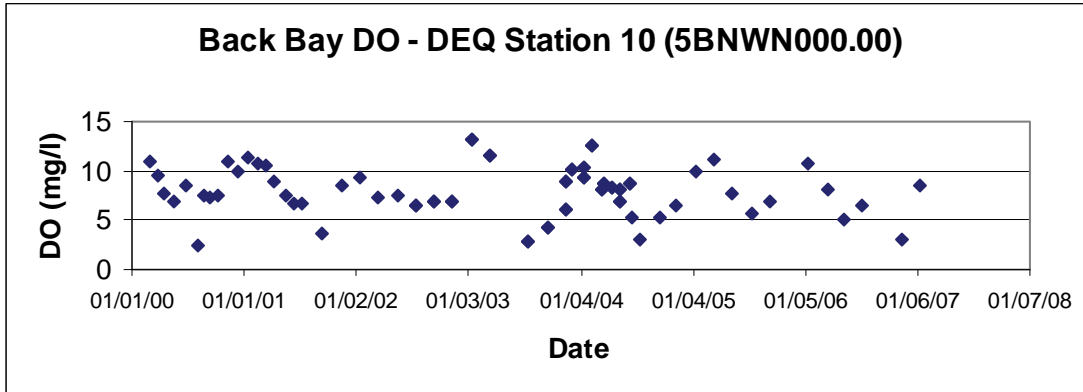


Figure B-10. Dissolved Oxygen at VA-DEQ Back Bay Station 10 (5BNWN000.00)

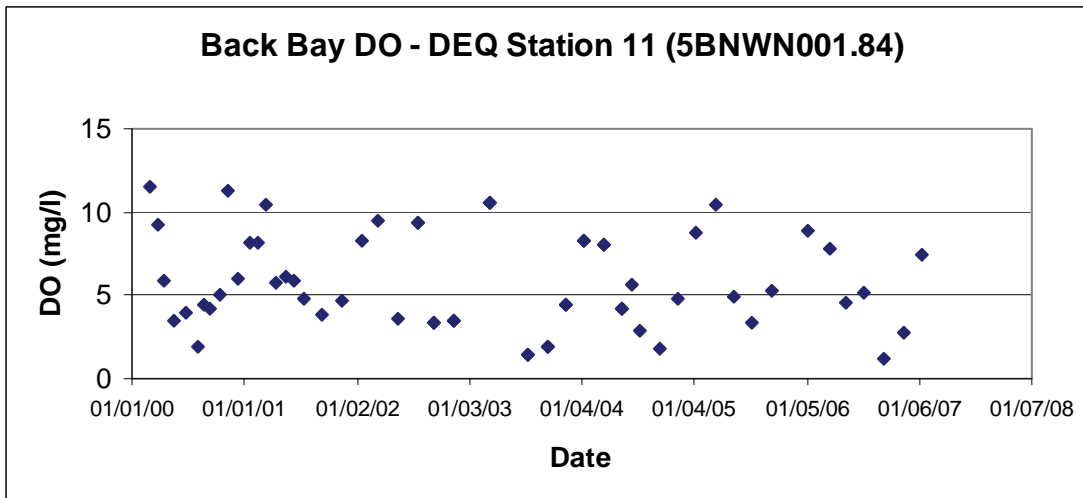


Figure B-11. Dissolved Oxygen at VA-DEQ Back Bay Station 11 (5BNWN001.84)

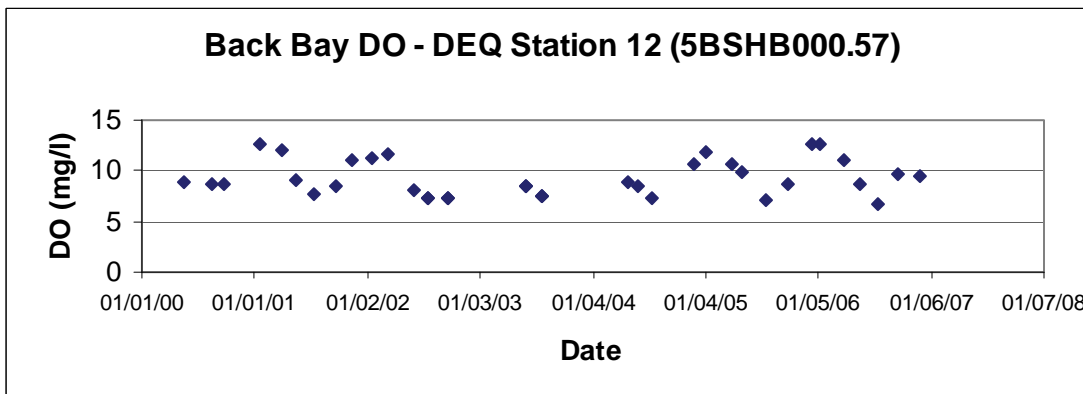


Figure B-12. Dissolved Oxygen at VA-DEQ Back Bay Station 12 (5BSHB000.57)

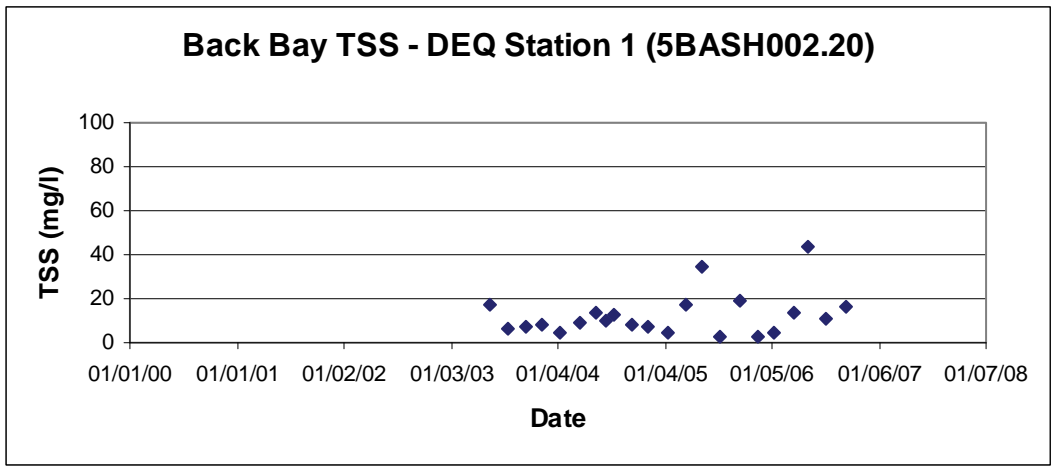


Figure B-13. Total Suspended Solids at VA-DEQ Back Bay Station 1 (5BASH002.20)

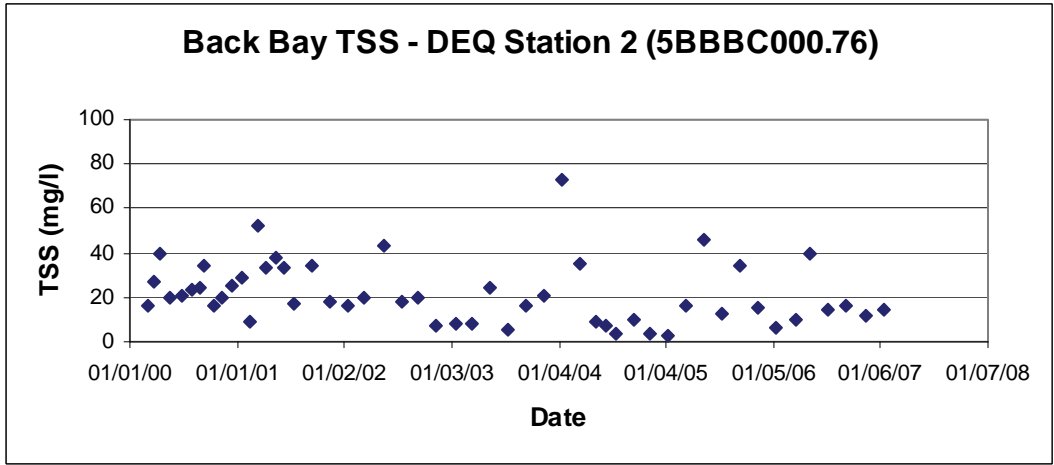


Figure B-14. Total Suspended Solids at VA-DEQ Back Bay Station 2 (5BBBC000.76)

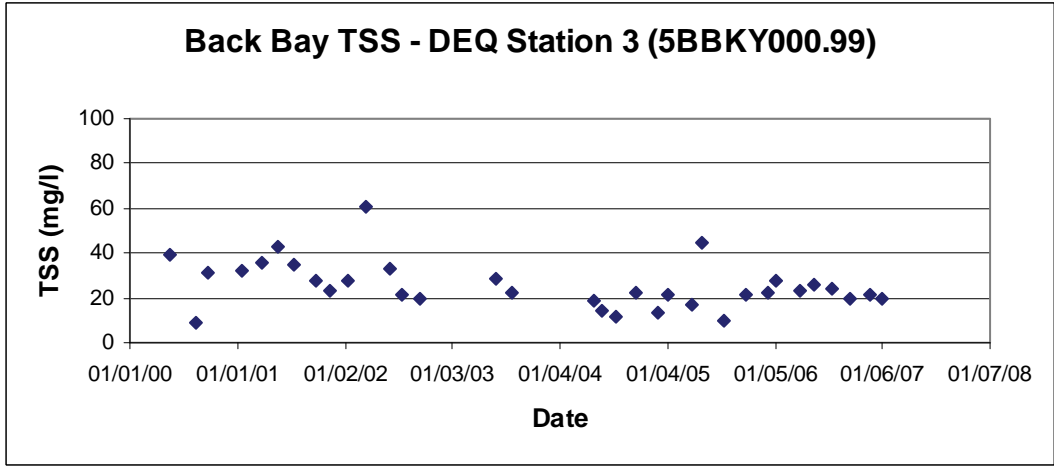


Figure B-15. Total Suspended Solids at VA-DEQ Back Bay Station 3 (5BBKY000.99)

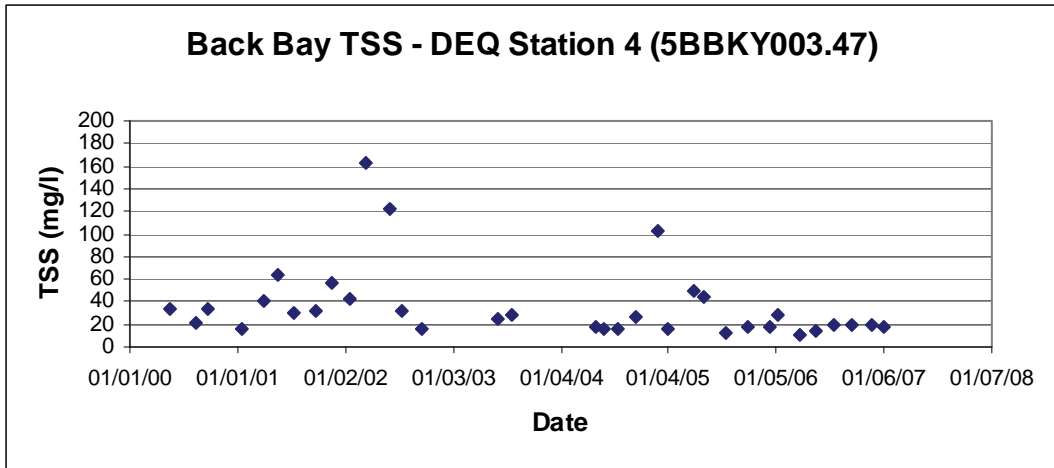


Figure B-16. Total Suspended Solids at VA-DEQ Back Bay Station 4 (5BBKY003.47)

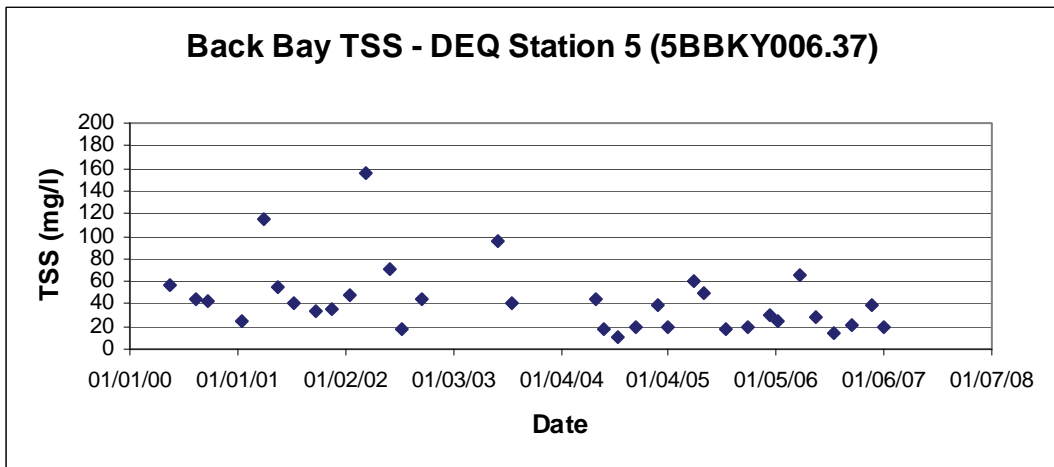


Figure B-17. Total Suspended Solids at VA-DEQ Back Bay Station 5 (5BBKY006.37)

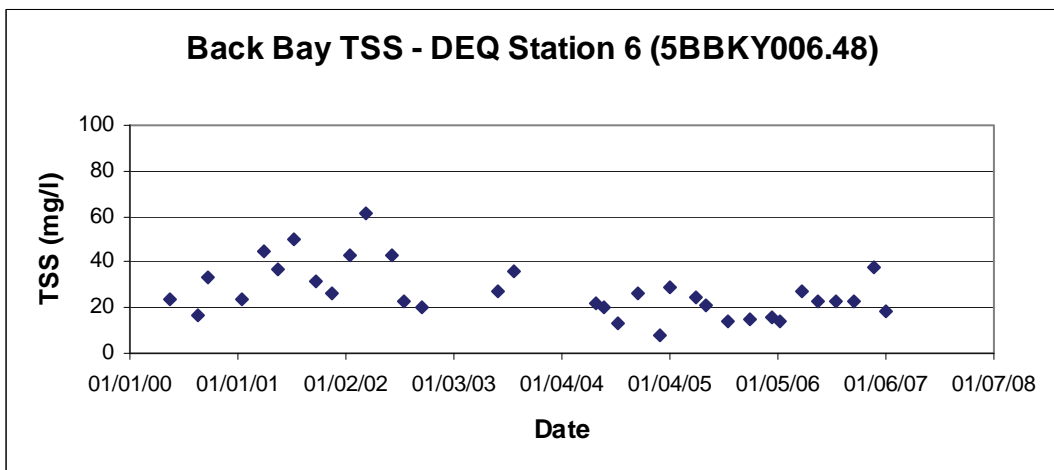


Figure B-18. Total Suspended Solids at VA-DEQ Back Bay Station 6 (5BHPC006.48)

