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INTRODUCTION

This report presents the Total Maximum Daily Loads (TMDLs) for three coastal water bodies in the United States Virgin Islands to address the impairment of these waters due to dissolved oxygen deficiency. The three water bodies are Mangrove Lagoon and Benner Bay/Lagoon Marina, which are located on the southeast coast of St. Thomas. Together, these water bodies form a single interconnected estuarine system, wherein the water quality and pollution sources in one water body undeniably affects the water quality of the other. As a result of this linkage, the TMDLs for these systems have been developed jointly based on a single water quality model.

This report discusses both systems together throughout the report, but presents two distinct TMDL values, including Waste Load Allocations, Load Allocations, and Margins of Safety. However, as exhibited in the model described in this report, the effective implementation of a TMDL for Mangrove Lagoon will, by default, improve the water quality in Benner Bay/Lagoon Marina to meet the required water quality standards. The dissolved oxygen TMDLs are developed based on the interaction between biochemical oxygen demand (BOD) loads and dissolved oxygen consumption in the water bodies. Therefore, the TMDL values are presented as BOD loads.

Nutrient inputs to the system are not explicitly included in this TMDL analysis because of a lack of necessary data to properly incorporate nutrient loading and nutrient interaction into the water quality model. However, it is clearly recognized that nutrient loading and the subsequent eutrophication and dissolved oxygen consumption, are important factors in driving the dissolved oxygen deficiencies in these water bodies. Because pollutant sources that contribute BOD also tend to contribute nutrient loads to some degree, the proposed management and implementation measures presented in this TMDL to address BOD load reductions are also expected to address nutrient loading. Consequently, the monitoring plan presented in this TMDL addresses the need to gather detailed nutrient information to effectively assess the role of eutrophication in the system.

This report is organized into four sections:

1) Problem Identification;
2) Linkage Analysis;
3) Calculation of the TMDL; and
4) Implementation Plan.

I. PROBLEM IDENTIFICATION

A. Background

Mangrove Lagoon and Benner Bay/Lagoon Marina are located adjacent to one another on the southeastern shore of St. Thomas in the United States Virgin Islands (USVI) (see Figure 1.1). These two coastal embayments are linked together by a narrow passageway, called Bovoni Channel, which allows water to flow between Mangrove Lagoon and Benner Bay/Lagoon Marina. Together, these coastal waterbodies form a single hydrologic and biotic system.

The watersheds draining to these coastal embayments have experienced significant and rapid growth over the past 40 years, which has affected the quality of the water such that it no longer meets the applicable Class B water quality standards published in Subchapter 186, the Water Quality Standards for Coastal Waters of the US Virgin Islands. As a result, these waterbodies have been listed on the USVI 2002 Clean Water Act Section 303(d) lists of impaired waterbodies for dissolved oxygen deficiency. The pollutants of concern and pollutant sources for the two waterbodies listed in the 303(d) lists are presented in Table 1.1.

Table 1.1. USVI 303(d) List of Impairments and Impairment Sources in Mangrove Lagoon and Benner Bay/Lagoon Marina.

Assessment Unit ID	Assessment Unit Name	Class	Impairment	Source
AU-STT-33	Benner Bay	B	Dissolved Oxygen	Other Marina/Boating On-vessel Discharges Changes in Tidal Circulation/Flushing
SU-STT-34	Benner Bay Lagoon Marina	B	Dissolved Oxygen Total Fecal Coliform	Other Marina/Boating On-vessel Discharges Discharges from Municipal Separate Storm Sewer Systems (MS4) Changes in Tidal Circulation/Flushing Highway/Road/Bridge Runoff (Non-construction Related) Sanitary Sewer Overflows (Collection System Failures)
AU-STT-35	Mangrove Lagoon	B	Dissolved Oxygen Total Fecal Coliform	Changes in Tidal Circulation/Flushing Discharges from Municipal Separate Storm Sewer Systems (MS4) Highway/Road/Bridge Runoff (Non-construction Related) Other Marina/Boating On-vessel Discharges Sanitary Sewer Overflows (Collection System Failures)

Legend

AU-STT-33 Benner Bay

AU-STT-35 Mangrove Lagoon

AU-STT-34 Benner Bay Lagoon Marina

North

0 1000

Scale in Feet

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General Location Map
Mangrove Lagoon and
Benner Bay

1237-Monitoring-2.cdr

Figure 1.1

The watershed surrounding this system is comprised of steep topography with only one significant stream, Turpentine Run, which feeds into the eastern edge of Mangrove Lagoon. A small intermittent stream leads to the northeastern corner of Benner Bay/Lagoon Marina. Due to the steep surroundings and slowly moving protected waters, Benner Bay/Lagoon Marina has been popularly used for moorings and marinas by live-aboard boaters and holiday sailors. The mangrove-lined shores and shallow waters of Mangrove Lagoon have provided a nursery area for fish, protection against shoreline erosion and flooding, and productive habitat for benthic biota (Towle, 1985). The area has seen very significant population growth in the past 40 years, with estimates from approximately 4,000 people in 1960 to 15,000 in 1980 (Towle, 1985). The population and development has continued to date. The estimated 2000 population within the drainage area, based on watershed-specific population projections, was 18,650 people (US EPA, 1984).

B. Physical Description of Mangrove Lagoon and Benner Bay/Lagoon Marina

Mangrove Lagoon is a shallow restricted bay forming the western side of the Mangrove Lagoon/Benner Bay system (Figure 1.2). Two narrow reaches to the south of the lagoon connect the water body to the open ocean. However, shoals built up at the mouths of these inlets restrict the rate of flow that passes through these entrances. The majority of the flow that enters Mangrove Lagoon appears to flow along the north side of Cas Cay and enters between Patricia Cay and Bovoni Cay. A narrow deep channel called Bovoni Channel at the northeastern corner of Mangrove Lagoon connects the lagoon to Benner Bay/Lagoon Marina to the east. Mangroves border the western shores of the lagoon and the inner islands of Bovoni and Patricia Cays, which form the barrier between Mangrove Lagoon and Benner Bay/Lagoon Marina. The average depth of the lagoon is approximately 1.3 meters (4.3 feet) within the lagoon, with more shallow depths in the northwest region, in the vicinity of the lagoon head (Nichols and Towle, 1997). The average tidal range in Mangrove Lagoon is approximately 0.275 meters (0.9 feet) (Nichols and Kuo, 1979).

According to previous studies of the Mangrove Lagoon and Benner Bay/Lagoon Marina system conducted by the Island Resources Foundation (Nichols and Towle, 1977; Nichols and Kuo, 1979; Towle, 1985), the circulation in the estuarine system is dominated by four separate driving forces: "(1) a broad clockwise pattern driven by mass wave transport which is directed inward through Cas Cay entrance and outward through Benner Bay; (2) a reversing tidal current; (3) a local wind drift; and (4) a stream runoff flow seaward through both entrances." The general dominating circulation pattern is the clockwise pattern, in which water flows in through the entrance at the southern end of Mangrove Lagoon, slows down in the main body of the lagoon, moves eastward through Bovoni Channel to Benner Bay/Lagoon Marina and then out to the ocean (Nichols and Towle, 1977). However, due to the entrance restrictions into Mangrove Lagoon, the water that does not enter the base of Mangrove Lagoon flows up into Benner Bay/Lagoon Marina along the eastern side of Bovoni Cay, circulates within Benner Bay/Lagoon Marina, and discharges from the system without ever reaching Mangrove Lagoon. As the tides flow in and out of the system, the direction of water flow

Legend

North

0 3000

Scale in Feet

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Delineation of Watersheds to Mangrove Lagoon and Benner Bay

1237-Watershed.cdr

Figure 1.2

within the system alternates.

In some instances, the Bovoni Channel experiences simultaneous flows in opposite directions, with surface flows out of Mangrove Lagoon occurring at the same time that bottom flow enters the lagoon (Nichols and Towle, 1977).

The 'critical condition' within the system appears to occur when wind and wave action is very limited, resulting in very slow flushing and circulation through the system (Towle, 1985). Under these conditions, the tidal forces are dominant and the broad clockwise pattern of flow described above is slowed. This condition of relatively slow movement through the system is used as the baseline 'critical condition' in the development of this TMDL.

C. Pollutant Sources

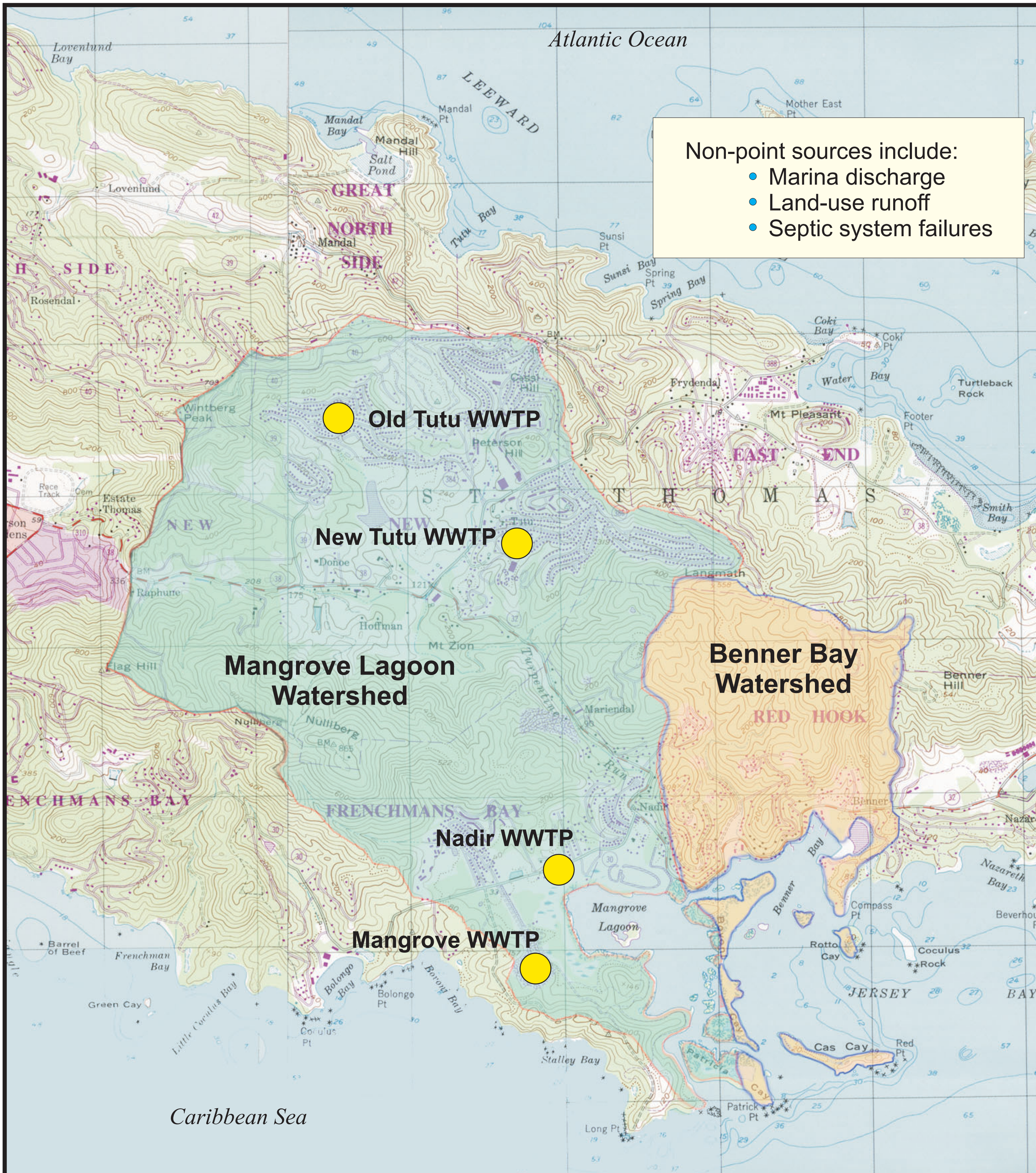
The pollutant sources contributing to the decline in water quality within Mangrove Lagoon and Benner Bay/Lagoon Marina include sewage effluent from wastewater treatment plants (WWTPs), surface runoff from the watershed area, septic effluent from failing septic systems, and marine vessel wastewater in the Bay. These sources are identified within the watersheds to Mangrove Lagoon and Benner Bay/Lagoon Marina in Figure 1.3.

These pollutant sources contribute significant loads of biochemical oxygen demand (BOD) to the water bodies. BOD is the amount of oxygen consumed during decomposition of oxidizable organic matter, in concentration units of milligrams (mg) of oxygen per liter (mg/L)of water. It is generally measured by a standard 5-day procedure of decomposition within a bottle at 20°C, with the resulting measure denoted as BOD_5. However, this measure typically does not capture the full oxygen demand of the material because decomposition often requires more than 5 days. The full oxygen demand is referred to as ultimate BOD (BOD_U), and can be estimated according to a standard relationship. The conversion between BOD_5 at 20°C and BOD_U used for these calculations is:

$$BOD_U = (BOD_5)/\ (1-e^{-(5)(K_d)})$$

where K_d is the estimated BOD decomposition rate ($K_d = 0.23$, assuming that the wastewater has undergone the equivalent of primary treatment). The concentrations of BOD_U and BOD_5 are calculated in units of mg/L. The BOD_U is then corrected for ambient water temperature. BOD loads in this analysis are presented as BOD_U due to the input requirements of the water quality model used in the TMDL analysis. This model is described in detail in subsequent sections of this report.

Average daily loads from these sources have been estimated based on best available information and best professional judgment (Table 1.2). Further discussion of how these loads were developed is provided in Section 3 of this report.



Legend

North

0 3000

Scale in Feet

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Location of BOD
Point Sources

1237-Watershed.cdr

Figure 1.3

Table 1.2. Watershed Based* Pollutant Sources and Estimated BOD Loads to Mangrove Lagoon and Benner Bay/Lagoon Marina.**

Source		TPDES Permit #	Estimated Average daily BOD_U load (kg/day)
MANGROVE LAGOON			
WWTPs			
	Nadir WWTP	VI0020125	215.14
	Old Tutu WWTP	VI0039918	86.09
	New Tutu WWTP	VI0039918	115.97
Land Use Runoff		N/A	118.09
Septic System Failures		N/A	2.24
TOTAL			*537.53*
BENNER BAY/LAGOON MARINA			
Boat Discharge			
	Moorings in Compass Point, Benner/Jersey Bays	N/A	0.22
	Compass Point Marina	N/A	0.25
	Independent Boat Yard	N/A	0.26
	La Vida Marina	N/A	0.07
	Tropical Marine Inc. (Marina)	N/A	0.06
	Fish Hawk Marina	N/A	0.01
Septic Failures		N/A	1.10
Land Use Runoff		N/A	19.18
TOTAL			*21.05*

*There are additional BODU loads associated with water flowing into the system from adjoining water bodies. These loads are discussed in Section 3 when the WASP6 model is introduced.

**BOD loads are presented as BOD_U at ambient water temperature because of the input requirements of the USEPA WASP6 model. A description of the WASP6 model and its use in this TMDL is provided in detail in Section 3.

D. Current Conditions

The TMDLs for both Mangrove Lagoon and Benner Bay/Lagoon Marina were developed based on conditions that existed during 1998 to 2000. This time frame is concurrent with the majority of the available ambient water quality data. Succeeding Sections III-D and III-E discuss calculations of point sources and non-point sources such as septic systems, land use runoff and marina contributions.

During the past two years, a new regional secondary treatment WWTP, Mangrove Lagoon WWTP, has been brought on line to address the sewage treatment demand in the Mangrove Lagoon watershed. Mangrove Lagoon WWTP, with a maximum design flow of 2.25 MGD and an average design flow of 0.75 MGD, discharges to the open ocean southwest of Long Point, which forms the south western barrier of Mangrove Lagoon. In effect, a portion of the wastewater treated at the new Mangrove Lagoon WWTP is wastewater being removed from the Mangrove Lagoon and Benner Bay/Lagoon Marina system.

The current conditions used in these TMDLs are conditions prior to the operation of Mangrove Lagoon WWTP which coincides with the ambient water quality data used in the analysis. The impact of the new Mangrove Lagoon WWTP will be used in the TMDL allocations to build on the benefit this plant is expected to bring to the study area and predict water quality compliance with the dissolved oxygen standard for Mangrove Lagoon and Benner Bay/Lagoon Marina. As of the development of this TMDL report, the wastewater from the Nadir WWTP has been diverted to the new Mangrove Lagoon WWTP. As a result, the current BOD load to Mangrove Lagoon is assumed to be lower than the load assumed under the modeled conditions. According to the Department of Planning and Natural Resources (DPNR), the sewage currently treated at the New Tutu and Old Tutu WWTPs will soon be diverted to the Mangrove Lagoon WWTP for treatment, thus further reducing the BOD load to Mangrove Lagoon (Personal Communication, Antony Tseng, January 30, 2003). These two improvements in BOD load are addressed in the Management Section. In effect, some management recommendations specified in this TMDL document (Section IV) are already underway to address the excessive BOD load to Mangrove Lagoon.

II. LINKAGE ANALYSIS

Mangrove Lagoon and Benner Bay/Lagoon Marina are estuarine systems that suffer from low dissolved oxygen. Figures 2.1 and 2.2 present the data sets for dissolved oxygen concentrations within Mangrove Lagoon and Benner Bay/Lagoon Marina, respectively. Table 2.1 presents a summary of the water quality data, including average, minimum, maximum, 25th percentile and 75th percentile. The data sets for each waterbody are presented in Appendix A. The approximate EPA/DPNR monitoring locations for the data are presented in Figure 2.3. These locations are based on the EPA STORET database. Ambient water quality data from a USGS (2000) report were collected at a series of USGS sampling stations that are located within close proximity to the EPA/DPNR locations.

A deficiency of dissolved oxygen in shallow low-flushing estuarine systems is generally caused by a combination of high biochemical oxygen demand, sediment oxygen demand, nutrient inputs, and the process of eutrophication. Low dissolved oxygen can be expected even under background conditions in systems such as Mangrove Lagoon and Benner Bay/Lagoon Marina, where the water temperature is warm, fresh water inflow is limited, flow, circulation, and reaeration are generally low for significant periods of the year, and tidal flushing is very slow. The prediction of dissolved oxygen concentrations is difficult in these complex estuarine systems.

Table 2.1. Ambient Concentration of Dissolved Oxygen In Mangrove Lagoon and Benner Bay & Benner Bay Lagoon Marina – Segment 3.

	Minimum	**25th Percentile**	**Average**	**75th Percentile**	**Maximum**	**Sample Size**
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
Mangrove Lagoon	1.70	4.52	5.17	5.80	7.30	53
Benner Bay/Lagoon Marina	4.50	5.14	5.94	6.50	7.60	26

Sources: Desadata (1998), USGS (2000), STORET Database, U.S. EPA (2002), and USVI DPNR (2001).

Figure 2.1 Mangrove Lagoon - Dissolved Oxygen Data (mg/L)

Number of data points used: 59

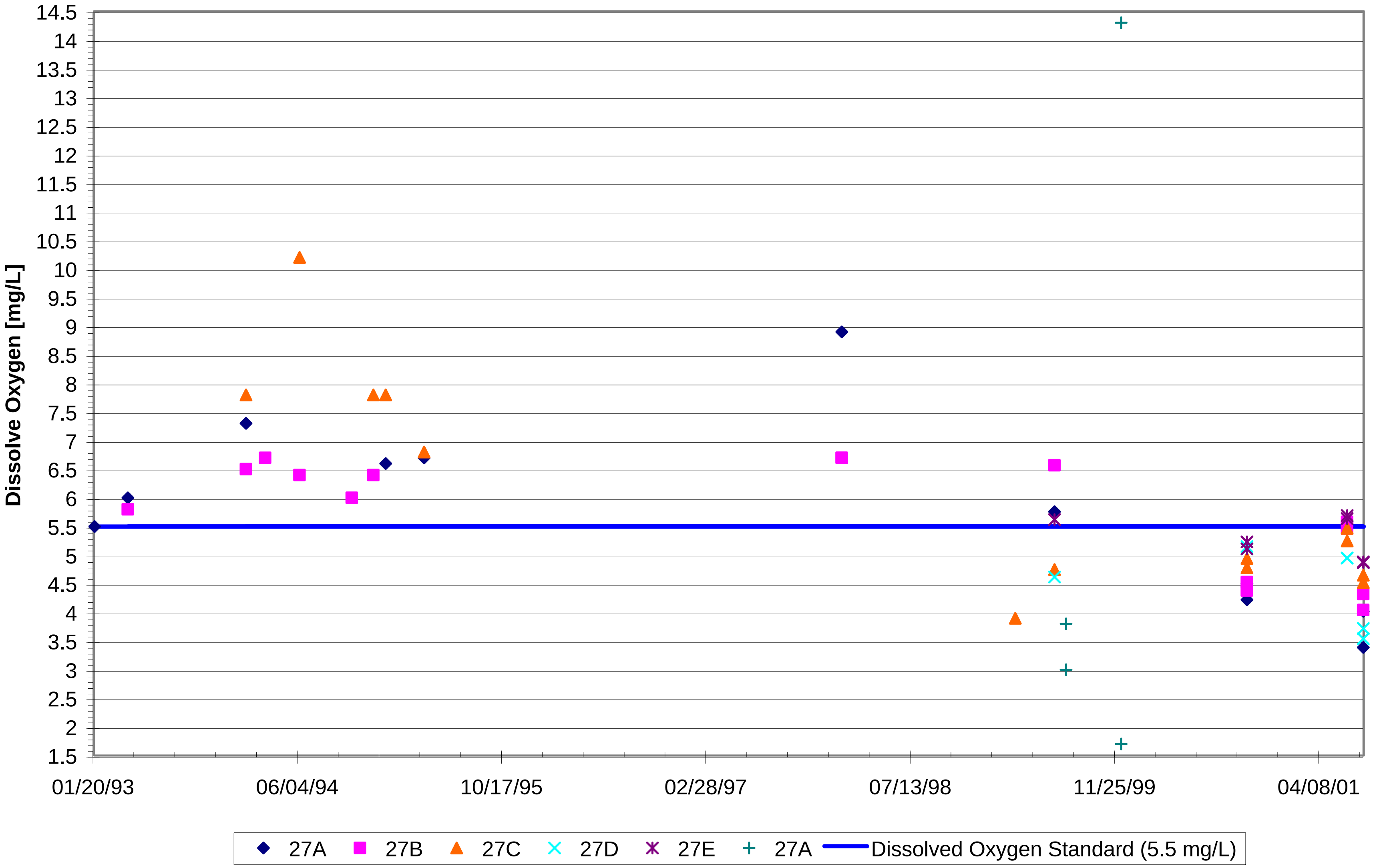
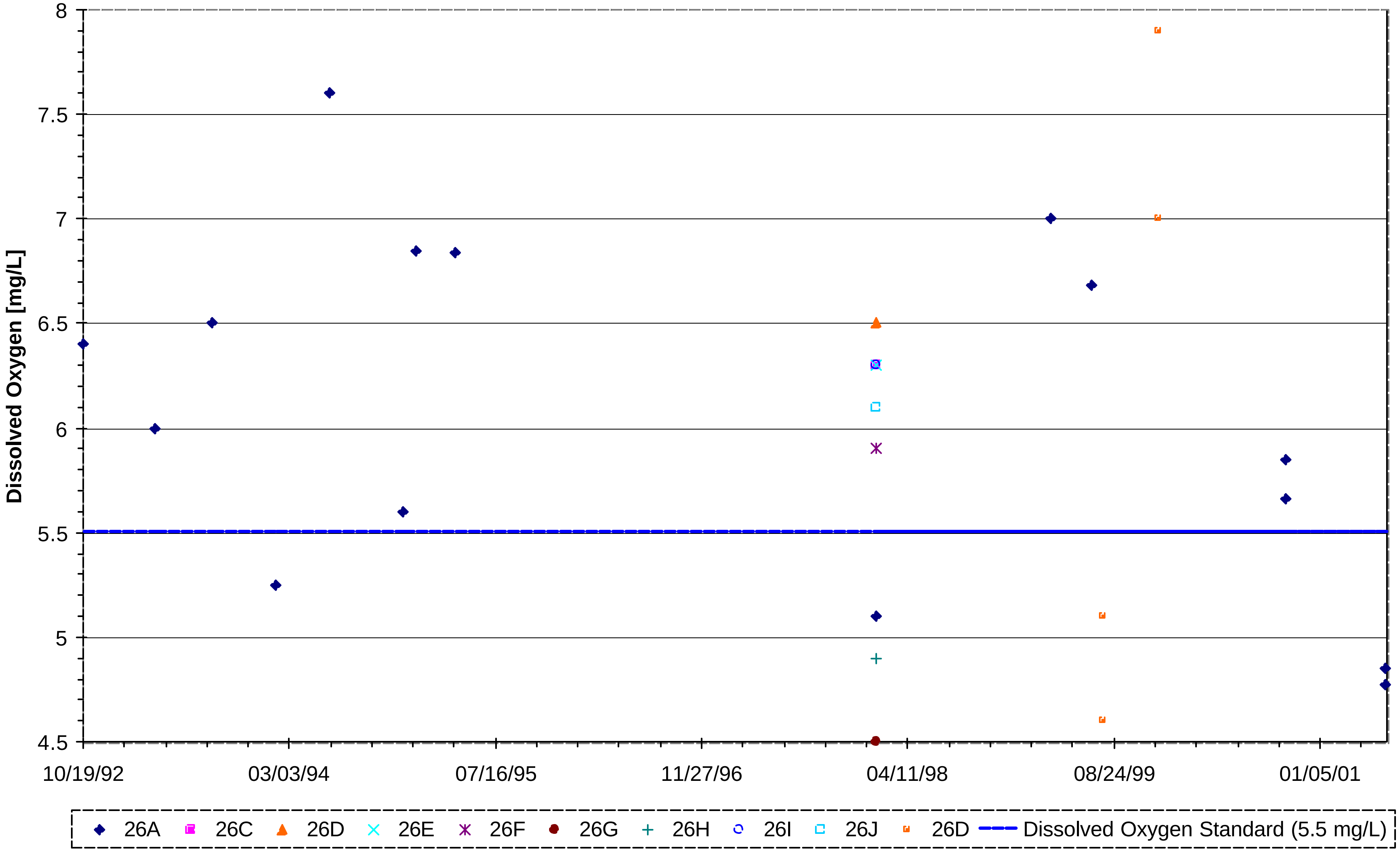
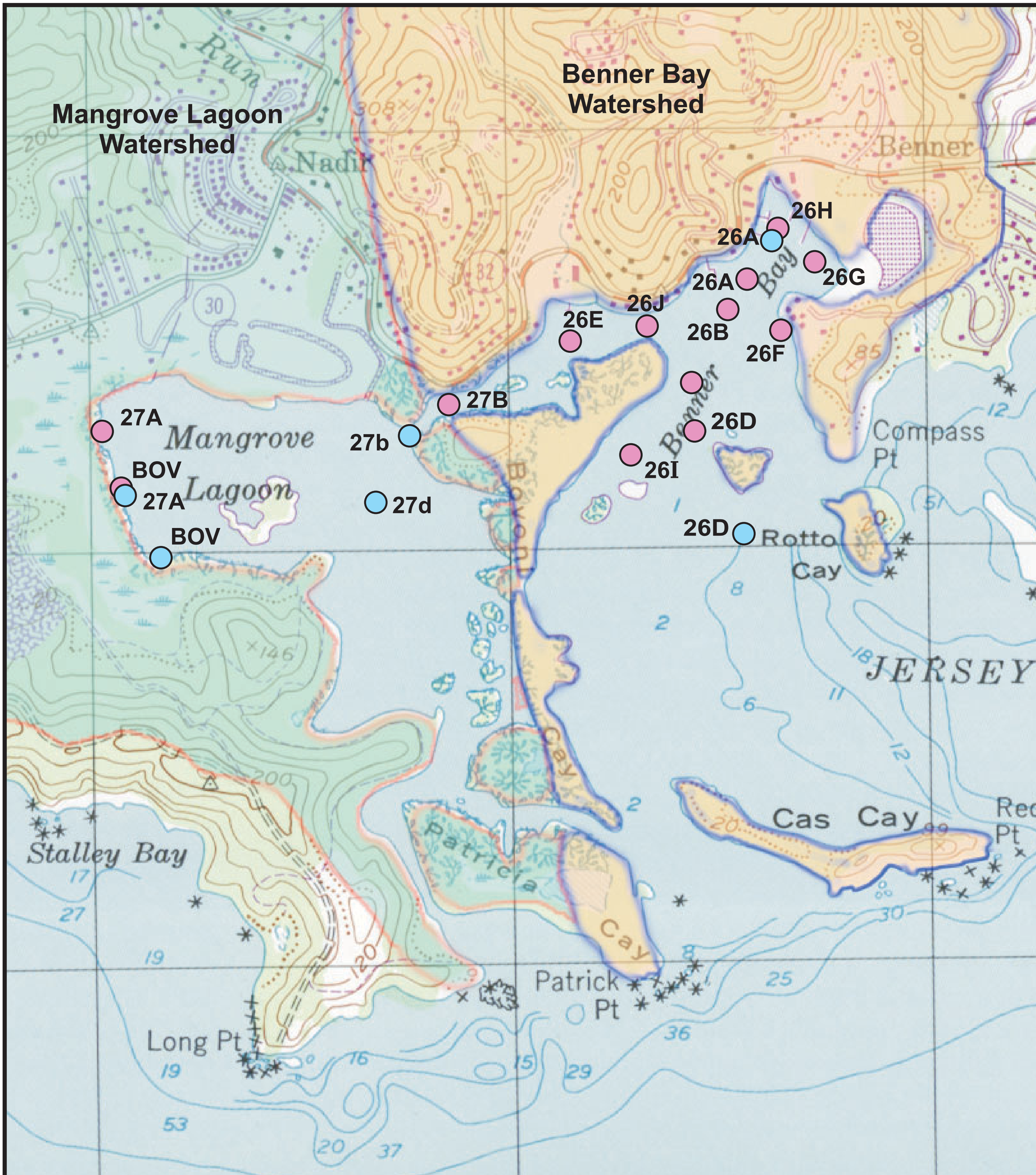


Figure 2.2 Benner Bay/Lagoon Marina - Dissolved Oxygen Data (mg/L)

Number of data points used: 27





Legend

2000 DPNR/EPA Sampling Locations

1998 DPNR & USGS Sampling

North

0 1000

Scale in Feet

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Location of Monitoring Stations
1998 and 2000

1237-Monitoring-2.cdr

Figure 2.3

A review of the potential sources of pollutants in conjunction with the available ambient water quality data led to the selection of BOD as the primary pollutant of concern contributing to the oxygen deficiency. Biochemical oxygen demand can be directly related to dissolved oxygen concentration using the Streeter-Phelps relationship (Chapra, 1997). This relationship takes into account the rate of oxygen consumption by BOD in conjunction with flow. As water flows downstream of a BOD discharge location, dissolved oxygen is consumed within the water body at the same time that reaeration is occurring. When a new load of BOD enters the water column, this process repeats itself. This is appropriate for the Mangrove Lagoon and Benner Bay/Lagoon Marina system since the oxygen concentration and BOD export from Mangrove Lagoon to Benner Bay/Lagoon Marina affects the oxygen concentration downstream in Benner Bay/Lagoon Marina. Sediment oxygen demand is also similarly incorporated into the calculations, although this is treated as a constant consumer of dissolved oxygen that does not travel with flow.

Likewise, nutrient loading is recognized as a significant contributing factor to oxygen deficiency in these embayments. Nutrients contribute to the process of eutrophication, which is a significant factor in oxygen consumption, particularly in low flushing warm water systems. Unfortunately, the lack of information concerning nitrogen and phosphorus loading and ambient nutrient concentrations in the water bodies precluded the explicit incorporation of eutrophication into this TMDL analysis. The application of the Streeter-Phelps relationship omits the effects of nutrient loading and the subsequent eutrophication process in the analysis. This was a necessary omission given the lack of nutrient loading data for the estuary system, and the lack of ambient water quality data for the nutrients and other parameters associated with eutrophication: ammonia, organic nitrogen, organic phosphorus, nitrate/nitrite-nitrogen, and chlorophyll a. In addition, each of the sources contributing BOD loads to the system also likely contributes nutrients to the system. For example, poorly functioning sewage treatment plants, marina discharges, septic system failures and land use runoff can all be assumed to contribute nutrients along with BOD to the receiving waters. Therefore, by managing sources of BOD loads, it is expected that nutrient loading will also be reduced.

Future water quality and flow monitoring information collected during implementation of this TMDL will provide more detailed information to allow for the possible incorporation of nutrients into the model, and into future revisions of the TMDL. The collection and analysis of monitoring information is key to the implementation of the proposed management plan, and critical to the verification of models to be use for future decision making.

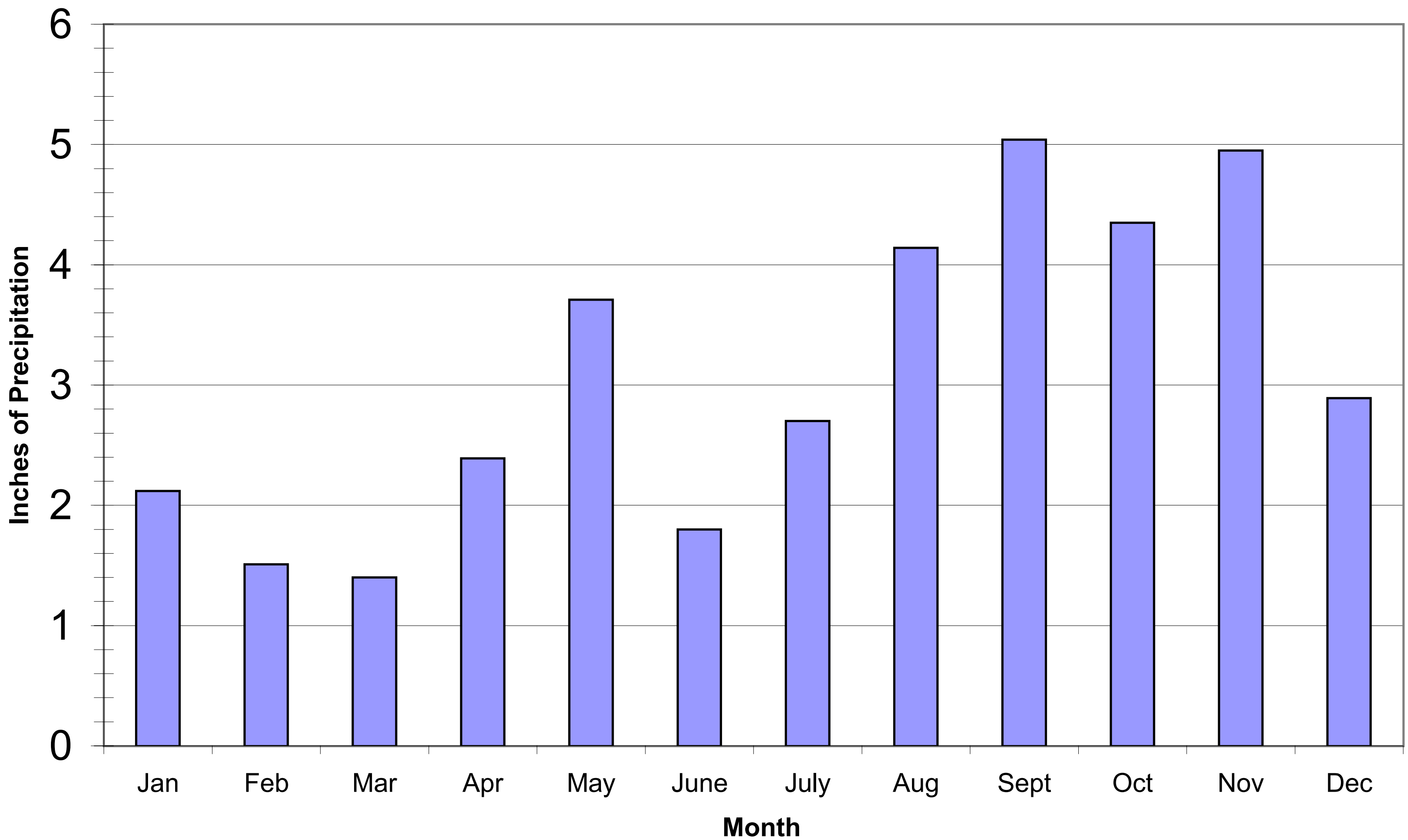
A. Establishing a Critical Condition

The dissolved oxygen data for locations within each water body were evaluated with respect to precipitation. No sufficient statistical correlation was found between low dissolved oxygen (DO) concentrations and monthly rainfall normals (NOAA, 2002). The U.S. Virgin Islands experiences two seasons, the dry season and the rainy season. The rainy season actually occurs twice a year, with the major rainy season occurring from approximately August to November and a short less significant rainy season occurring around May (Figure 2.4).

As shown in the figures, the occurrence of low dissolved oxygen levels, defined as concentrations less than the standard of 5.5 mg/L, in both Mangrove Lagoon and Benner Bay/Lagoon Marina, could not be isolated to either the dry season or the rainy season. Therefore, a critical condition directly linked to precipitation levels could not be established as a baseline for this TMDL.

However, it does appear that low DO occurrences are more common during or near the end of the dry seasons. The dry season also coincides with periods of weaker weather, meaning lower winds and less circulation. When the weather is weak and there is little wave and wind-driven movement within the system, the reaeration rate is limited and the rate of movement of the water is slow. These limiting conditions are considered the "critical conditions" for this TMDL. The circulation and flow pattern utilized as a basis for the WASP model in developing this TMDL takes into account the "worst case" flushing and exchange conditions that occur within the system during the year (Towle, 1985). Clearly, when wave action and wind are low, and the weak tidal exchange is the primary driver in the circulation of the system, the flushing rate and reaeration rate will be at the lowest levels and the tendency for the system to develop dissolved oxygen deficiencies is at its greatest. However, it should be noted that once additional data for water quality, flow and circulation are collected as part of the implementation of this TMDL, the critical conditions may be refined.

Figure 2.4 Monthly Precipitation Normals
Redhook Bay. St. Thomas, Station No. 020 - (1971-2000)



NOAA: December, 2002

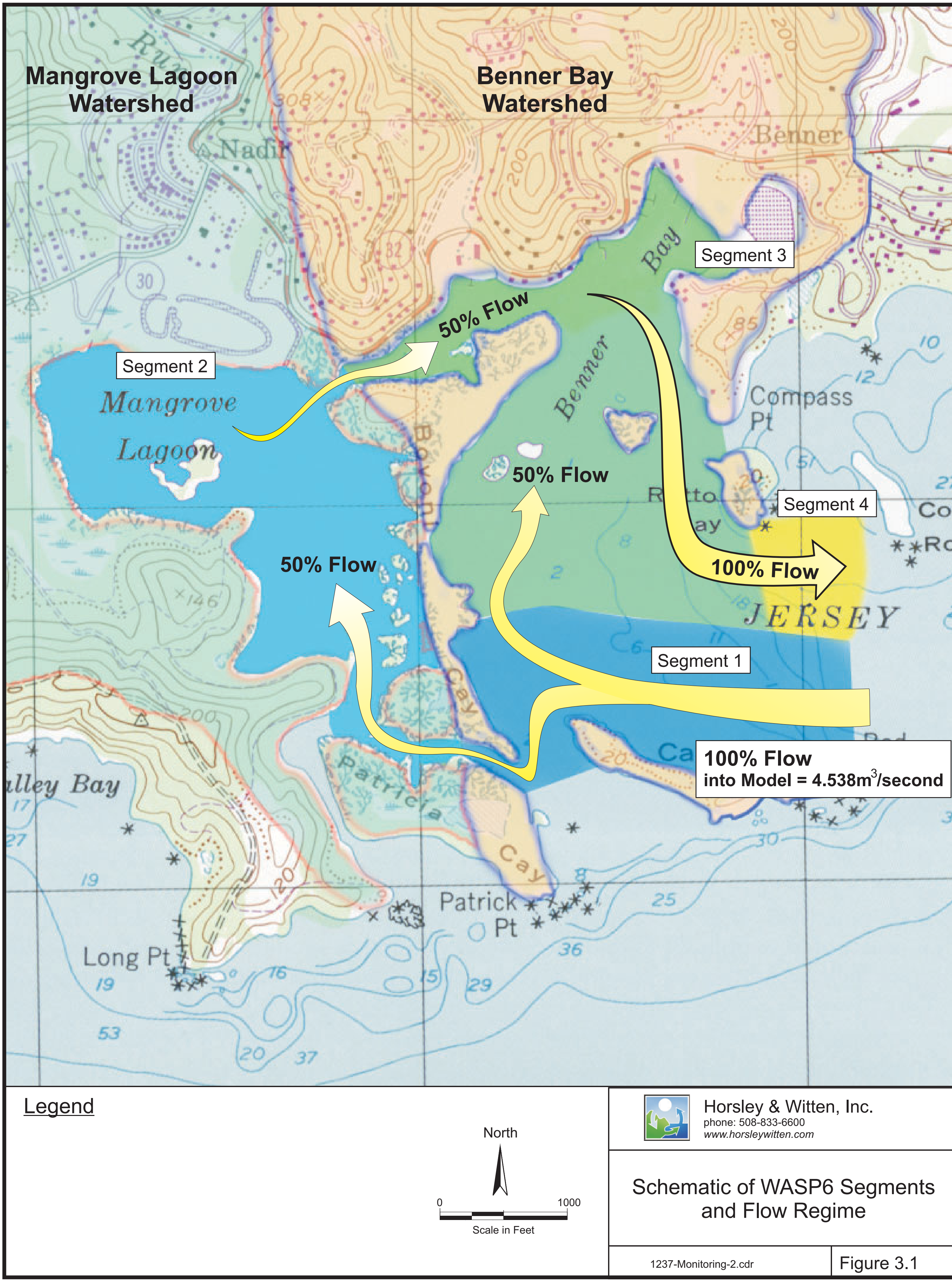
III. The TMDL Analysis

A. Model Selection

The EPA Water Quality Analysis Simulation Program Version 6 (WASP6) model was selected to develop the dissolved oxygen TMDL for Mangrove Lagoon and Benner Bay/Lagoon Marina. This model is a very versatile and flexible model that combines water flow modeling with ambient water quality modeling. WASP6 can be used to develop a one-, two- or three-dimensional model, which can be run as time-variable or steady-state. It allows for varying degrees of eutrophic interaction, ranging from a simple Streeter-Phelps-based model to a detailed eutrophication model utilizing information about concentrations and exchanges of ammonia, nitrate, orthophosphate, chlorophyll a, BOD, dissolved oxygen, organic nitrogen, and organic phosphorus within the system. The flow model serves as the template within which the chemical and biological interactions occur. WASP6 allows the flow regime to be defined in one of two general ways: 1) a simple flow regime can be entered directly by the user, or 2) a hydrodynamic model can be linked to WASP6 such that the time-variable output of the hydrodynamic model is drawn upon by WASP6 as the water quality interactions are calculated. A detailed hydrodynamic model is a very significant undertaking that requires significant long-term daily data concerning flow throughout the system, detailed bathymetry of the system, and other climatic information such as wind speed and direction, temperature, evaporation, rainfall, tidal fluctuations, and wave refraction.

A simple two-dimensional Streeter-Phelps model of the Mangrove Lagoon and Benner Bay/Lagoon Marina system was developed using WASP6 for the purpose of developing the dissolved oxygen TMDLs. The flow regime that forms the network within which the water quality interactions occur is a basic regime entered directly into the model by the user. A large-scale hydrodynamic model was not an option for this system due to lack of detailed data. The basic user-defined flow regime was developed based on flow velocity information provided in Nichols and Towle (1977) and Towle (1985).

A flow model was developed that utilized model segments defined at a scale smaller than that of the entire Mangrove Lagoon and Benner Bay/Lagoon Marina water bodies because the conditions in the water bodies could not be defined at a smaller scale. Mangrove Lagoon (AU-STT-35) is assessed as one segment in the model (Segment 2) and Benner Bay Lagoon Marina (AU-STT-34) and approximately one half of the area of Benner Bay (AU-STT-33) are assessed as another segment (Segment 3) in the model. Figure 3.1 presents the segmentation of the model into four segments. The limited number and frequency of ambient water quality data at each monitoring station within the water bodies made it inappropriate to break down the major water bodies into smaller units, and the generalized flow data made it impossible to differentiate flow among units smaller than Mangrove Lagoon and Benner Bay/Lagoon Marina.



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Schematic of WASP6 Segments and Flow Regime

1237-Monitoring-2.cdr

Figure 3.1

B. Assumptions and Limitations

The following is a list of the assumptions incorporated into the development of the WASP6 model and TMDL for the Mangrove Lagoon and Benner Bay/Lagoon Marina system:

1) The watershed boundaries and water body boundaries used in the analyses for Mangrove Lagoon and Benner Bay/Lagoon Marina are presented in Figure 1.2. The watershed delineations were completed by hand on a United States Geographic Society (USGS) topographic map (Eastern St. Thomas, Virgin Islands Quad, 1954, Photorevised 1982 and Central St. Thomas, Virgin Islands, Quad, 1955, Photorevised 1982; scale 1:24,000) and transcribed to ArcView GIS, over a digital base map of the USGS Hydrologic Unit Code 14 (HUC14) delineations and digital land use information for 1999 prepared by the Virgin Islands Conservation Data Center (October 12, 2001).

2) The time frame for the analyses of the water bodies is approximately 1998-2000. This is the time period for which concurrent point source discharge data and ambient water quality data are available. Limited additional ambient water quality data for 1992-1998 were utilized to develop average water quality values used for comparison with the model results.

3) The transport mechanisms (cross-sectional area, flow velocity, reaeration) within and between the segments of the WASP model were estimated based on available information from Towle (1985) and Nichols and Towle (1977). It is assumed that the general flow patterns described by Towle have not changed significantly since the publication of those documents.

4) Mangrove Lagoon and Benner Bay/Lagoon Marina have been analyzed together in one model due to the transport and circulation connection between the two water bodies. Towle (1977) evaluated transport and circulation in Mangrove Lagoon and Benner Bay/Lagoon Marina as a single system and stated that the “broad clockwise mode [of circulation] is the most distinct” in the Mangrove-Benner system.

5) The model simulates two-dimensional flow in which the segments are defined by a volume of water, rather than an exact shape in space. The model is a single layer of four segments within the water column, and the exchange of flow between segments is specified directly by the user.

6) The model does not explicitly consider sediment/water column interactions through the use of a bottom segment. Instead, a constant sediment oxygen demand (SOD) is applied to each segment. The SOD values applied to segments 2 and 3 is derived from available SOD sample data (USGS, 2000), and the SOD

values used in segments 1 and 4 are based on an assumption that the bottom sediment is sandy (Chapra, 1997). It should be noted that SOD is a key coefficient in the development of the TMDL and should receive an emphasis in future research and monitoring efforts, to improve modeling accuracy and evaluate improvements in the conditions of the system.

7) Average annual ambient water quality data within each water body were used to evaluate the model results. The conditions within each WASP6 segment are instantaneously mixed throughout the segment.

8) The model is a steady-state model that will reflect the average annual loading conditions present during the period 1998-2000. This is the most recent period for which concurrent ambient water quality and BOD loading data are available. All BOD loads, flows, segment-specific conditions and boundary conditions are constant over time at an average estimated daily rate. The model has been developed to represent the water quality of the critical conditions (see Section II-A). The dissolved oxygen concentration under these conditions is assumed to be the lowest 25th percentile of all dissolved oxygen data (see Section III-F).

9) All BOD load data that is presented as 5-day BOD (BOD_5) was converted to ultimate BOD for input into the WASP model. Ultimate BOD (BOD_U) is the oxygen required to fully decompose the BOD matter, while 5-day BOD is a standard measure of the oxygen required for decomposition over a 5-day period. This conversion is based on a conversion equation that takes into account the typical BOD bottle decomposition rate observed for the equivalent of primary treatment (Chapra, 1997, page 357).

10) The WASP6 model developed for this analysis is comprised of four (4) segments of specified volume:

   - Segment 1: Open ocean at southern opening of Benner Bay and Mangrove Lagoon;
   - Segment 2: Mangrove Lagoon;
   - Segment 3: Benner Bay Lagoon Marina and Benner Bay; and
   - Segment 4: Open ocean at southeastern mouth of Benner Bay.

   Segment two was used to define the TMDL for Mangrove Lagoon and Segment 3 was used to define the TMDL for Benner Bay Lagoon Marina and Benner Bay jointly. The WASP 6 model uses volumes to define each segment. The volumes used to define Segments 2 and 3 were calculated based on available bathymetry from Nichols and Olsen (1979) and the NOAA navigational chart (November 23, 2001). The volumes of Segments 1 and 4 are an average of the volumes of Segments 2 and 3. The exact volumes of segments 1 and 4 are not relevant given that they represent open water at the entrance and exit to the system. It is recommended that segments used in WASP6 be relatively similar in size (Wool et al., no date).

11) The WASP model requires the user to specify several coefficients and constants. Table 3.1 presents those coefficients and constants used in the model for the Mangrove Lagoon and Benner Bay/Lagoon Marina system under baseline modeled conditions.

Table 3.1. Coefficients and Constants Used in the Model of the Mangrove Lagoon and Benner Bay/Lagoon Marina Baseline Model.

Coefficient/Constant Name	Value	Source and Comments
Sediment Oxygen Demand (SOD) in Segments 1 and 4	0.5 $g/m^2/day$	Estimate used for parameterization. This is the observed SOD in sandy bottom sediments (Chapra, 1997).
Sediment Oxygen Demand (SOD) in Segments 2 and 3	1.7 $g/m^2/day$ and 1.3 $g/m^2/day$	SOD for Segments 2 and 3 are based on available data (USGS, 2000).
BOD fraction dissolved	1 (100%)	It is assumed that all loads reported in wastewater treatment plant data (TPDES DMR reports) is dissolved BOD, reported as BOD_5.
BOD Decay Rate at 20C	0.63/day	This is also referred to as BOD Deoxygenation Rate. This rate is within the range for observed in-stream decomposition at a depth of 1.5-10 m in slow-moving rivers (Bowie et al., 1985, in Chapra, 1997).
BOD Decay Rate Temperature Correction Factor	1.047	Chapra (1997).
Dissolved Oxygen reaeration rate	.69/day	Covar Method (1976) for determining reaeration rate based on depth and velocity of water, in Chapra. (1997).

12) The WASP model requires the user to specify certain segment-specific parameters and boundary conditions. These are presented in Table 3.2 for the baseline conditions model of Mangrove Lagoon and Benner Bay/Lagoon Marina. Note that Segments 1 and 4 are assumed to have small BOD concentrations at their boundaries, and healthy concentrations of dissolved oxygen (7.2 mg/L). These boundary conditions translate into a baseline condition that must be considered in the TMDLs for Segments 2 and 3 (Mangrove Lagoon and Benner Bay/Benner Bay Lagoon Marina). These boundary conditions lead to an influx of dissolved oxygen and BOD across the boundaries into Segment 2, and that influx is quantified as a background BOD load in the load allocation presented in Table 3.10 in Section 3 of this report.

Table 3.2. Segment-Specific Parameters and Boundary Conditions for the WASP6 Model.

	Segment 1	Segment 2 (Mangrove Lagoon)	Segment 3 (Benner Bay/Lagoon Marina)	Segment 4
Volume (m^3)	898,773 *	770,945	1,026,00	898,773 *
Depth (m)	3.0	1.3	1.3	11.0
Water Temp. (C)	23.0	29.4	28.4	23.0
Salinity (ppt)	36.0	35.2	35.7	36.0
Boundary BOD Concentration (mg/L)	0.5	0	0	0.5
Boundary DO Concentration (mg/L)	7.20	0 0	0	7.2

*These volumes were calculated as an average of Segments 2 and 3.

C. Flow Model

The flow regime within the Mangrove Lagoon and Benner Bay/Lagoon Marina system was described earlier in Section 1. The flow regime forms the framework for the water quality model (Figure 3.1). The flow rate was estimated from the estimated flow velocities provided in Nichols and Towle (1977) under tidal currents, assuming a clockwise flow pattern. These velocities were multiplied by the estimated cross sectional areas at the entrance to Mangrove Lagoon, calculated from the bathymetric information in Nichols and Towle (1977) and NOAA (2001). After discussion with the USVI DPNR staff, the circulation pattern was revised to reflect the limited entry of water into Mangrove Lagoon. This resulted in an estimation that the flow entering Jersey Bay split into two flow paths, with approximately 50 percent entering Mangrove Lagoon at the southern entrance and 50 percent flowing north along the eastern coast of Bovoni Cay into Benner Bay/Lagoon Marina (Figure 3.1). The total flow rate of water entering the system from the model boundary and leaving the system through the model boundary is estimated to be 4.538 m^3/second (158 ft^3/second). The rate of flow entering Mangrove Lagoon and then exiting from the Lagoon into Benner Bay/Lagoon Marina via Bovoni Channel is estimated to be 50 percent of 4.538 m^3/second, or 2.269 m^3/second. The rate of flow entering Benner Bay from the open ocean from the south is also 50 percent of 4.538 m^3/second, or 2.269 m^3/second.

D. Point Source Loading Calculations

The known point sources contributing BOD loads to Mangrove Lagoon and Benner Bay/Lagoon Marina are limited to WWTPs. Three WWTPs are located within the watershed to Mangrove Lagoon. Two of the plants, Old Tutu and New Tutu WWTPs, discharge to Turpentine Run, which discharges to the northeastern corner of Mangrove Lagoon, and the remaining WWTP, Nadir WWTP, discharges directly to Mangrove Lagoon at the lagoon head.

The estimated BOD loads contributed from each treatment plant were calculated from the Discharge Monitoring Reports (DMRs) submitted by each plant on a monthly basis as required according to the individual Territorial Pollution Discharge Elimination System (TPDES) permits. The TPDES permits require each of these dischargers to report the average BOD concentration in the effluent during the reporting month, as well as the maximum effluent flow rate that occurred during the reporting month. The estimated load can be calculated by multiplying effluent flow rate by effluent BOD concentration. Daily flow rates through the three WWTPs between October 1998 and December 2000 were used to calculate an average daily flow rate at each plant (USVI DPW, 2003). Flow rates were provided by the USVI DPW to the extent possible; data for January through October 1998 and select additional months for each plant were not available. All BOD loads were calculated as a daily average over all months for which DMR data was available, which spanned from January, 1998, through December, 2001, or in some cases through March, 2002 (Note: Data from 2001 and 2002 were used in this calculation because it was assumed that a larger data set would provide a more accurate representation of the average effluent concentrations from the WWTPs, despite the fact that the 2001 and 2002 DMR data are outside of the model time frame).

E. Non-Point Source Loading Calculations

Three non-point sources of BOD were identified within the watersheds to Mangrove Lagoon and Benner Bay/Lagoon Marina. These are listed in Tables 3.3 and 3.4 , and the loading assumptions used for each are described below. In addition, there is a BOD load delivered to Mangrove Lagoon in the water flow from the open ocean, and a BOD delivered to Benner Bay/Lagoon Marina from both Mangrove Lagoon and the open ocean. These load are accounted for as non-point sources in the load allocation for each waterbody. These loads are implicit in the WASP6 model, but the explicit calculation of these loads is discussed in Section 3.G of this report. The tables below present explicit non-point BOD sources and loads.

Table 3.3. Non-Point Sources and Estimated BOD* Loads to Mangrove Lagoon.

Source	TPDES Permit #	Estimated Average daily BOD_U load (kg/day) (modeled conditions)
Land Use Runoff	N/A	118.09
Septic System Failures	N/A	2.24
TOTAL		**120.33**

Table 3.4. Non-Point Sources and Estimated BOD* Loads to Benner Bay/Lagoon Marina.

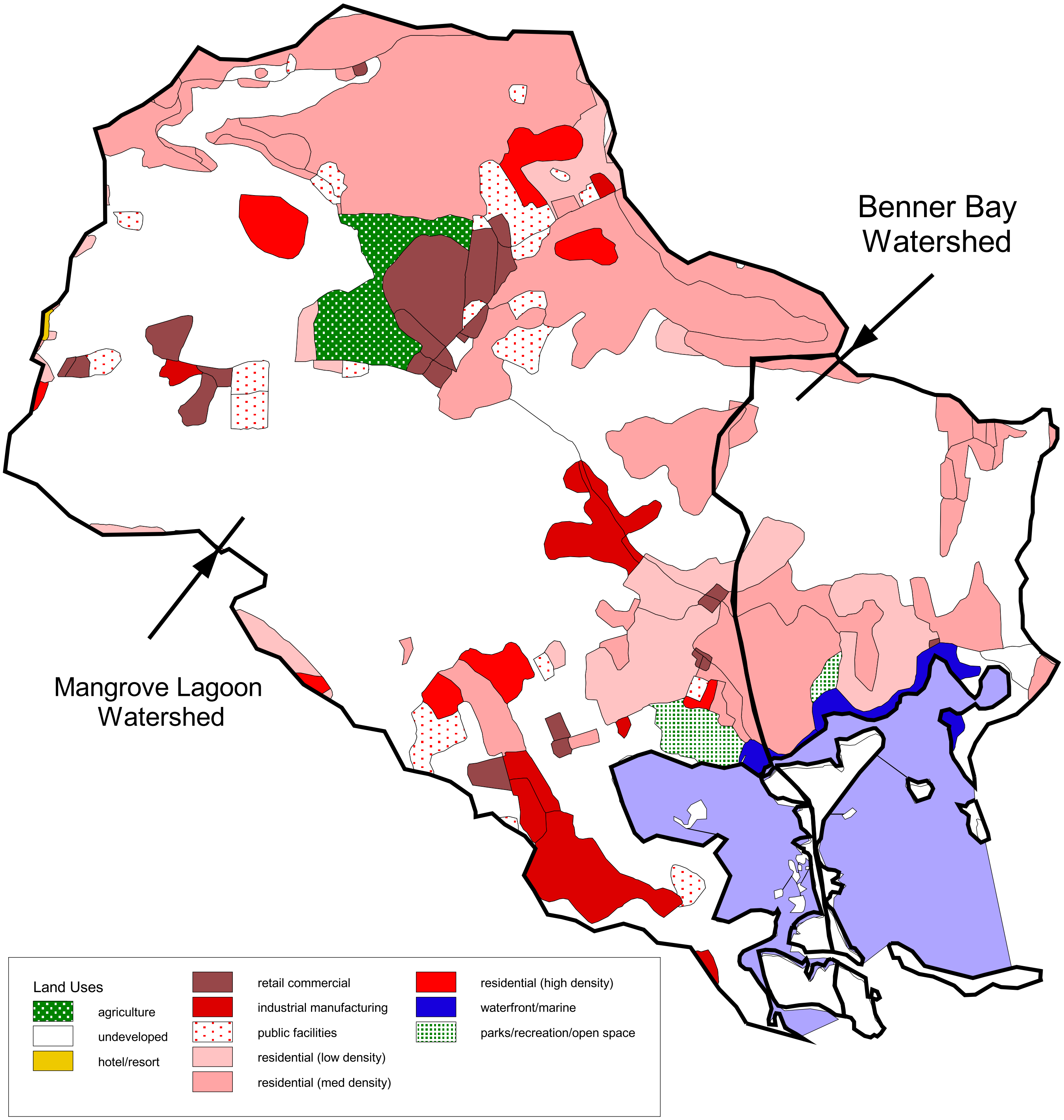
Source		TPDES Permit #	Estimated Average daily BOD_U load (kg/day) (modeled conditions)
Boat Discharge			
	Moorings in Compass Point, Benner/Jersey Bays	N/A	0.22
	Compass Point Marina	N/A	0.25
	Independent Boat Yard	N/A	0.26
	La Vida Marina	N/A	0.07
	Tropical Marine Inc. (Marina)	N/A	0.06
	Fish Hawk Marina	N/A	0.01
Septic Failures		N/A	1.10
Land Use Runoff		N/A	19.18
TOTAL			**21.15**

*BOD loads are presented as BOD_U at ambient water temperature because of the input requirements of the USEPA WASP6 model. A description of the WASP6 model and its use in this TMDL is provided in detail in Section 4.

1.0 Land Use Runoff

The estimated BOD load from land use runoff was calculated based on an analysis of land use within each watershed (Figure 3.2). Spatial land use data (ArcView shape files) from the First Edition Draft Land Use Inventory, U.S. Virgin Islands, (Virgin Islands Conservation Data Center, October 12, 2001) for the year 1999 was used in this analysis. The delineated watersheds for Mangrove Lagoon and Benner Bay/Lagoon Marina were overlaid on the land use data to calculate the total area of each land use type within the watersheds. Tables 3.5 and 3.6 and Figure 3.2 present the land use distribution and associated estimated BOD run-off loads within the watersheds to Mangrove Lagoon and Benner Bay/Lagoon Marina.

The estimated BOD loads associated with land use runoff were calculated based on BOD_5 loading rate constants from the Guidebook for Screening Urban Nonpoint Pollution Management Strategies, prepared by the Northern Virginia Planning District Commission (November, 1979). These loading rates are based on comprehensive sampling over a 12-month period in the northern Virginia and Washington, D.C. area. More than 1,300 samples during 300 runoff events were sampled for BOD in watersheds ranging from 6 to 71 acres in area. The loading rate constants were developed based on annual precipitation in the northern Virginia region and vary by land use and underlying soil conditions.



N

0 0.2 0.4 0.6 0.8 1 Miles

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Land-Use Map of Watersheds to Mangrove Lagoon and Benner Bay, St. Thomas, U.S.V.I.

ES 2/12/03
File: X:/1237/GIS_VI/ working_project_usvi/USVI.apr

Figure 3.2

Table 3.5 Land-Use Runoff BOD Load - Mangrove Lagoon Watershed

Land Use	Total Acres per Land Use	BOD5 Loading Coefficient (sandy loam soils)	Rain Correction Factor	Annual BOD5 Load	BOD5 Load	BODu load
Units	*Acres*	*lbs/acre/yr*	*in/in*	*lbs/yr*	*kg/day*	kg/day
Agriculture	64.47	29.00	0.92	1,712.21	2.13	3.11
Hotel/Resort	1.34	137.00	0.92	168.26	0.21	0.31
Retail Commercial	112.96	163.00	0.92	16,862.47	20.96	30.67
Industrial Manufacturing	109.96	111.00	0.92	11,178.05	13.89	20.33
Public Facilities	100.18	111.00	0.92	10,184.45	12.66	18.52
Residential (Low Density)	147.91	14.00	0.92	1,896.46	2.36	3.45
Residential (Medium Density)	647.30	20.00	0.92	11,856.56	14.73	21.56
Residential (High Density)	78.16	26.00	0.92	1,861.16	2.31	3.38
Urban	-	206.00	0.92	-	-	-
Waterfront/Marine	4.37	206.00	0.92	825.21	1.03	1.50
Parks/Recreation/Open Space	24.66	6.00	0.92	135.52	0.17	0.25
Undeveloped	1,502.12	6.00	0.92	8,254.23	10.26	15.01
Total	**2,793.44**			**64,934.56**	**80.70**	**118.09**

This methodology is from the Northern VA Planning District Commission, Guidebook for Screening Urban Nonpoint Pollution Management Strategies, Nov. 1979.

Table 3.6 Land-Use Runoff BOD Load - Benner Bay Watershed

Land Use	Total Acres per Land Use	BOD5 Loading Coefficient (sandy loam soils)	Rain Correction Factor	Annual BOD5 Load	BOD5 Load	BODu load
Units	*Acres*	*lbs/acre/yr*	*in/in*	*lbs/yr*	*kg/day*	kg/day
Agriculture	0.000	29.00	0.92	-	-	-
Hotel/Resort	0.000	137.00	0.92	-	-	-
Retail Commercial	0.373	163.00	0.92	55.68	0.07	0.10
Industrial Manufacturing	0.000	111.00	0.92	-	-	-
Public Facilities	0.000	111.00	0.92	-	-	-
Residential (Low Density)	66.505	14.00	0.92	852.71	1.06	1.55
Residential (Medium Density)	174	20.00	0.92	3,190.77	3.97	5.80
Residential (High Density)	0	26.00	0.92	-	-	-
Urban	0.000	206.00	0.92	-	-	-
Waterfront/Marine	22.482	206.00	0.92	4,241.53	5.27	7.71
Parks/Recreation/Open Space	4.652	6.00	0.92	25.56	0.03	0.05
Undeveloped	396.421	6.00	0.92	2,178.35	2.71	3.96
Total	**664.632**			**10,544.61**	**13.10**	**19.18**

This methodology is from the Northern VA Planning District Commission, Guidebook for Screening Urban Nonpoint Pollution Management Strategies, Nov. 1979.

The rate constants applied to the Mangrove Lagoon and Benner Bay/Lagoon Marina watersheds were adjusted to account for general soils conditions and precipitation differences between northern Virginia and the U.S. Virgin Islands. Based on the soils descriptions in the Soil Survey of the United States Virgin Islands (2000), Virgin Islands soils were deemed to be most closely associated with the sandy loam soils category (as opposed to clay loam soils, silt loam soils or loam soils) for the purposes of selecting an appropriate loading coefficient. While it is recognized that the Virgin Islands soils and geology contain significant components of limestone-derived soils, the "sandy loam" description closely mimics the runoff/BOD load producing characteristics of the Virgin Islands. A rainfall correction factor of 0.92 was used to adjust the loading coefficients. This correction factor is the ratio of annual rainfall at the NOAA Station at Redhook Bay, St. Thomas (NOAA, 2002) to annual rainfall at Reagan National Airport in Northern Virginia (Global Historical Climatology Network, 1992).

2.0 Septic System Failures

The estimated BOD loads associated with septic system failures within each watershed were calculated based on an estimated septic system failure rate of 10 percent within the watersheds. According to the Draft Environmental Impact Statement for the Proposed Mangrove Lagoon/Turpentine Run Wastewater Treatment Facilities (US EPA, 1984), the population within the Mangrove Lagoon and Benner Bay/Lagoon Marina watersheds in 1983 was 15,064 people, and the projected population for 2000 was 18,650 people. Based on a review of the zoning map for areas within the watersheds, provided in US EPA (1984), the total population estimate of 18,650 in 2000 was divided among the Mangrove Lagoon watershed and the Benner Bay/Lagoon Marina watershed on a 2:1 ratio. It has been estimated that approximately 15 percent of the population in these two watersheds is serviced by on-site septic systems (Bortman, 1997; US EPA, 1984). The average per-person BOD_5 loading rate for sewage is 0.18 lbs. per day (Metcalf and Eddy, 1991). With an estimated failure rate of 10 percent, and an assumed loading rate of 10 percent (meaning that 10 percent of the BOD in a failed septic system will actually reach the receiving waters), the total estimated BOD_U loads from failed septic systems were calculated. These are presented in Table 3.7.

Table 3.7. Estimated BOD loads from Septic System Failures in Mangrove Lagoon and Benner Bay/Lagoon Marina.

Watershed	Estimated 2000 Pop.	Estimted Pop. on Septic Systems	Ave. BOD_5 Loading Coefficient	Septic System Failure Rate	BOD_5 Load Rate	BOD_5 Load	BOD_U Load
	(persons)	*(persons)*	*(lbs/pers.-day)*	*(%)*	*(%)*	*(lbs/yr)*	*(kg/day)*
Mangrove Lagoon and Benner Bay/Lagoon Marina (together)	18,650	2797.5	0.18	10	10	1838	3.34
Mangrove Lagoon	12,433	1,865	0.18	10	10	1231	2.24
Benner Bay/Lagoon Marina	6,217	932.5	0.18	10	10	607	1.10

Note: BOD_U is calculated from BOD_5, assuming a temperature of 20C.

3.0 Marina Discharge

The BOD load from inappropriate and illicit wastewater discharge in marinas and mooring locations was estimated based on a 2002 DPNR survey of the number of slips and mooring permits for boats within Benner Bay/Lagoon Marina (Table 3.8). Mangrove Lagoon is restricted and does not have any marinas or moorings. Several assumptions were used in developing these BOD loading estimates:

- The average BOD_5 concentration in vessel wastewater is 2,600 mg/L, which is the mean of the range of 1700 – 3500 mg/L estimated in Hinkey (1996);

- The average vessel holding tank capacity is 40 gallons (Hinkey, 1996), the average service frequency is 1.4 services per week (Caraco, 2001), the average waste production per person on board is 8 gallons/cap/day (Caraco, 2001), and the average number of people per boat is 2 people (Caraco, 2001);

- Fifty (50) percent of all boats within Benner Bay/Lagoon Marina illegally dump their wastewater within the Bay. This is an estimate based on discussion with DPNR;

- The BOD_U load is calculated assuming an average ambient water temperature of 28.4 ^oC and a K_d of 0.23.

Table 3.8. Estimated BOD Loading to Benner Bay/Lagoon Marina from Marina Wastewater Discharge.

Marina/Mooring Location	**# slips or moorings permits**	**BOD_U Load**
		(kg/day)
Compass Point marina	85	0.25
Independent Boat yard	89	0.26
La Vida Marina	24	0.07
Tropical Marine Inc.	19	0.06
Fish Hawk Marina	4	0.01
Moorings	75	0.22
TOTAL		**0.87**

F. Model Accuracy Assessment

An assessment of the accuracy of the WASP6 model for the Mangrove Lagoon and Benner Bay/Lagoon Marina system was performed by comparing the resulting dissolved oxygen concentrations against the ambient water quality data for the two water bodies. It was not possible to perform a statistical calibration of the model due to a lack of consistent water quality data at a location representative of the center of each WASP segment over a long period of time. Instead, the ambient water quality data within each water body were pooled together and analyzed as a whole. This is consistent with the steady state approach. The ambient dissolved oxygen concentration data within Mangrove Lagoon and Benner Bay/Lagoon Marina were summarized previously in Table 2.1.

The model was assessed for accuracy against the lower 25th percentile of the ambient dissolved oxygen concentration values within each water body. This method contributes to a conservative approach to meeting the dissolved oxygen standard. The dissolved oxygen standard according to the USVI Water Quality Standards for Class B waters states that dissolved oxygen shall be "not less than 5.5 mg/L from other than natural conditions." Clearly, the average dissolved oxygen values do not represent the core of the dissolved oxygen problem in Mangrove Lagoon and Benner Bay/Lagoon Marina. This is particularly true for Benner Bay/Lagoon Marina where the average dissolved oxygen concentration is actually greater than the water quality standard.

It is hypothesized that the "worst case scenario" flow condition coincides with the occurrence of a majority of the low dissolved oxygen readings. The flow regime used in the model is representative of the worst case scenario (i.e., low wind and wave action). The data required to link low dissolved oxygen readings and coincident flow conditions are not available. Therefore, it is reasonable to compare the model results to the worst case dissolved oxygen concentrations. The lower 25th percentile of the ambient dissolved oxygen concentrations is assumed to represent the critical conditions. Verification of the model against the lower 25th percentile dissolved oxygen concentration aligns with the assumptions incorporated into the flow regime and the corresponding water quality data.

The baseline model results show a dissolved oxygen concentration of 4.49 mg/L in Mangrove Lagoon and 5.12 mg/L in Benner Bay/Lagoon Marina. The percentage deviation from the observed 25th percentile dissolved oxygen concentration values are:

Segment	**25th Percentile DO concentration (mg/l)**	**Modeled DO concentration (mg/l)**	**% Deviation**
2. Mangrove Lagoon	4.52	4.49	0.66
3. Benner Bay/Lagoon Marina	5.14	5.12	0.39

These critical conditions will likely include effects, if any, of low dissolved oxygen due to seasonal variability and the do not warrant a discreet analyses for seasonal variation. A critical condition directly linked to precipitation levels could not be established.

G. Calculation of the TMDL

Once the WASP6 model of the Mangrove Lagoon and Benner Bay/Lagoon Marina system was developed and assessed as representative of the system, it was used to determine the total maximum daily load (TMDL) that could be contributed to each watershed while still meeting the dissolved oxygen standard of 5.5 mg/L. The TMDL is calculated according to the following equation:

TMDL =
Margin of Safety (MOS) + Waste Load Allocation (WLA) + Load Allocation (LA)

The TMDL calculation was a unique process for this system for several distinct reasons:

1. The water quality of Benner Bay/Lagoon Marina is directly affected by the water quality in Mangrove Lagoon, such that as the water quality in Mangrove Lagoon improves or declines, so too does the water quality in Benner Bay/Lagoon Marina. However, due to better flushing conditions, lower current loads, and greater flow rates in Benner Bay/Lagoon Marina, the water quality in Benner Bay/Lagoon Marina will always be better than that of Mangrove Lagoon as long as loads do not increase over the current rates.

2. The improvements in dissolved oxygen concentrations in Mangrove Lagoon that are expected as a result of a Mangrove Lagoon TMDL will ensure that the water quality in Benner Bay/Lagoon Marina will meet the dissolved oxygen standards. In effect, the implementation of a stand-alone TMDL for Benner Bay/Lagoon Marina will not be necessary if the TMDL for Mangrove Lagoon is properly implemented and dissolved oxygen conditions are successfully improved there. However, the TMDL for Benner Bay/Lagoon Marina was calculated based on the assumption that the TMDL for Mangrove Lagoon is met.

3. Major reductions in the BOD load to Mangrove Lagoon have already been made, or are planned for the near future. The Nadir WWTP has already been taken offline and rerouted to the new Mangrove Lagoon WWTP, which discharges outside of Mangrove Lagoon. The New Tutu and Old Tutu WWTPs are planned to be taken offline and diverted to the new Mangrove Lagoon WWTP by Summer, 2003 (Personal Communication, Antony Tseng, January 30, 2003). In effect, significant management measures have already been taken.

4. A driving force in the WASP6 model is the SOD exerted by sediments in both Mangrove Lagoon and Benner Bay/Lagoon Marina. It was determined that if SOD values in both water bodies do not improve over time as a result of WWTP load reductions, then the dissolved oxygen standard of 5.5 mg/L will not be met in either water body. If the SOD values improve significantly to values representative of sandy bottom sediments, the allowable BOD load is unreasonably large. Therefore, the assumption regarding the amount of improvement in the SOD over time is critical to the final TMDL value.

The final TMDLs for both Mangrove Lagoon and Benner Bay/Lagoon Marina were determined through an iterative process of examining SOD improvement possibilities in conjunction with varying BOD loads to Mangrove Lagoon. The total BOD load to

Benner Bay/Lagoon Marina was maintained constant while reductions in the Mangrove Lagoon BOD load were assessed. Several SOD scenarios were examined:

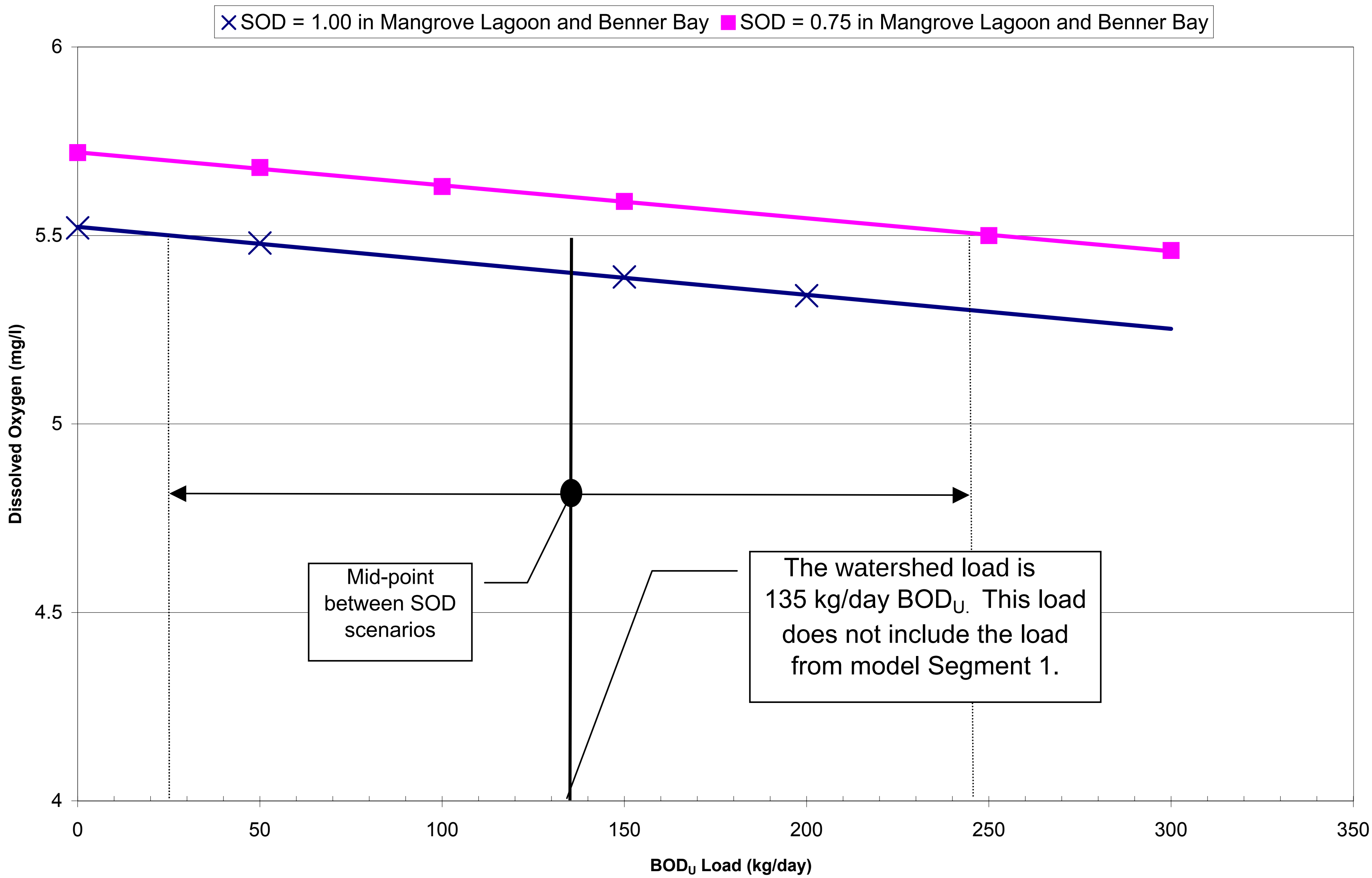
> **Scenario 1**. The observed SOD values in Mangrove Lagoon and Benner Bay/Lagoon Marina, of 1.7 g/m^2/day and 1.30 g/m^2/day respectively, do not improve over time as BOD loads to Mangrove Lagoon are reduced.
>
> **Scenario 2**. The SOD value in Mangrove Lagoon improves to 1.5 g/m^2/day, which is representative of typical estuarine mud (Chapra, 1997), and the value in Benner Bay/Lagoon Marina improves to 1.0 g/m^2/day. A map of bottom sediments in the system presented in Nichols and Towle (1977) shows that bottom sediments in Mangrove Lagoon are mainly muddy sediments, and the bottom sediments in Benner Bay/Lagoon Marina are primarily composed of sandy composites.
>
> **Scenario 3**. The SOD values in both Mangrove Lagoon and Benner Bay/Lagoon Marina improve to 1.00 g/m^2/day.
>
> **Scenario 4**. The SOD values in both Mangrove Lagoon and Benner Bay/Lagoon Marina improve to 0.75 g/m^2/day.
>
> **Scenario 5**. The SOD values in both Mangrove Lagoon and Benner Bay/Lagoon Marina improve to 0.50 g/m^2/day.

A relationship between the BOD_U load and resulting dissolved oxygen concentration in Mangrove Lagoon was developed for each SOD scenario using the WASP6 model.

It is assumed that dramatic improvement in the SOD within the two water bodies is unlikely, but a substantial improvement can be reasonably expected. As wastewater discharges are removed from Mangrove Lagoon, a major source of organic material and nutrients is eliminated. Over time, it is expected that the amount of organic material available to settle into the bottom sediments will be significantly reduced. The exact time frame during which this improvement may occur cannot be explicitly projected.

Due to the uncertainty in this parameter, a range of SOD between 0.75 g/m^2/day and 1.00 g/m^2/day was used to bracket the allowable BOD_U load (Figure 3.3). If SOD improves to 0.75 g/m^2/day in both water bodies, the maximum allowable load of BOD_U that results in a dissolved oxygen concentration of 5.5 mg/L is 245 kg/day of BOD_U. If the SOD improves to 1.00 g/m^2/day in both water bodies, the maximum allowable load of BOD_U that results in 5.5 mg/L of dissolved oxygen is 25 kg /day. The maximum allowable watershed BOD_U load that will reasonably result in 5.5 mg/L of dissolved oxygen in Mangrove Lagoon was taken as the average of these two loads (see Figure 3.3). Therefore, preliminary total maximum daily load for Mangrove Lagoon is 135 kg/day BOD_U. This assumes that the boundary condition of 0.5 mg/L of BOD and 7.2 mg/L of dissolved oxygen for water entering the WASP model. Under the prescribed flow conditions, the load from Segment 1 into Mangrove Lagoon (Segment 2) is 37.3 kg/day.

Figure 3.3 Dissolved Oxygen Concentration vs. BODU Load Under Varying SOD Improvement Scenarios in Mangrove Lagoon



Therefore, the TMDL for Mangrove Lagoon is 135 kg/day plus the 37.3 kg/day load from Segment 1, which totals 172.3 kg/day.

As stated above, the water quality of Benner Bay/Lagoon Marina is dependent to a large degree on the water quality in Mangrove Lagoon. Water that leaves Mangrove Lagoon enters Benner Bay/Lagoon Marina and mixes to a degree with the water in Benner Bay/Lagoon Marina. As indicated by the water quality monitoring data used in this analysis, the ambient water quality in Mangrove Lagoon is worse than that of Benner Bay/Lagoon Marina. This is most assuredly a result of the combination of higher loads and lower flushing in Mangrove Lagoon. The implication of this connection is that the water quality in Benner Bay/Lagoon Marina will improve simply as a result of improvements in the water quality in Mangrove Lagoon. As long as BOD_U loads in Benner Bay/Lagoon Marina remain constant or decrease, the dissolved oxygen standard of 5.5 mg/L will automatically be met in Benner Bay/Lagoon Marina, if it is met in Mangrove Lagoon.

With this in mind, the TMDL for Benner Bay/Lagoon Marina has been developed by quantifying the maximum load that Benner Bay/Lagoon Marina can assimilate given the baseline condition that the Mangrove Lagoon TMDL is met. If the TMDL for Mangrove Lagoon is implemented and the dissolved oxygen concentration in Mangrove Lagoon improves as projected, the dissolved oxygen concentration in Benner Bay/Lagoon Marina will correspondingly exceed the 5.5 mg/L standard. According to the flow conditions specified in this model, Benner Bay/Lagoon Marina receives flow and associated BOD_U load from both Mangrove Lagoon (Segment 2) and the open ocean at the mouth of Benner Bay/Lagoon Marina (Segment 1).

The allowable watershed BOD_U load to Benner Bay/Lagoon Marina (the TMDL) was calculated by assuming that the TMDL conditions in Mangrove Lagoon are met, and that SOD improvements in both water bodies are equal to 0.875, which is the mid-point between 1.00 g/m^2/day (Scenario 3 above) and 0.75 g/m^2/day (Scenario 4 above). Figure 3.4 presents the relationship between dissolved oxygen concentration and BOD_U load from in Benner Bay/Lagoon Marina under these conditions. (Loads from Segments 1(open ocean) and 2 (mangrove Lagoon) are implicit in the model and are not presented explicitly within the load values presented on the x-axis.) Therefore the allowable watershed BOD_U load for Benner Bay/Lagoon Marina is 245 kg/day BOD_U. The BOD_U export from Mangrove Lagoon (Segment 2) to Benner Bay/Lagoon Marina (Segment 3) when the Mangrove Lagoon TMDL is met is 172.25 kg/day. The BOD_U load to Benner Bay/Lagoon Marina (Segment 3) from the open ocean (Segment 1) is 37.3 kg/day. Therefore, the total allocated load to Benner Bay/Lagoon Marina from other water bodies is 209.6 kg/day, under the Benner Bay/Lagoon Marina TMDL conditions. The model is predicting higher allowable loads in Benner Bay/Lagoon Marina due primarily to the model's representation of richer oxygen exchange from Mangrove Lagoon to Benner Bay/Lagoon Marina when the Mangrove Lagoon TMDL is met.

The calculated current loads from land use runoff, septic system failure rates, and marina discharges in Benner Bay/Lagoon Marina was 19.18 kg/day, 1.10 kg/day and 0.87 kg/day respectively. Therefore, the total calculated Benner Bay/Lagoon Marina current watershed load is 21.15 kg/day. Even though the model predicts a higher allowable watershed load, the TMDL for Benner Bay/Lagoon Marina will not allow any increase in watershed load with an allocation of 21.16 kg/day. USVI DPNR is limiting this load to prevent any increase in watershed loads into Benner Bay/Lagoon Marina while dissolve oxygen standard is not met in this segment and the Mangrove Lagoon TMDL is implemented. Further more, USVI DPNR will further evaluate the WASP6's model Segment 3, as necessary, when more data becomes available to identify any possible localized dissolved oxygen problems. Currently, Segment 3 addresses both STT-33 Benner Bay and STT-34 Benner Bay Lagoon Marina in one model segment. If necessary, USVI DPNR will revise the Benner Bay/Lagoon Marina TMDL, public notice, respond to comments and submit to EPA for review and approval.

Tables 3.10 and 3.11 summarize the existing loads, general TMDL allocations, and required load reductions for Mangrove Lagoon and Benner Bay/Lagoon Marina. The margin of safety, required load reductions, and load and waste load allocations are discussed in detail in the following sections.

Figure 3.4 Dissolved Oxygen Concentration vs. BOD_U Load in Benner Bay When TMDL in Mangrove Lagoon is Met

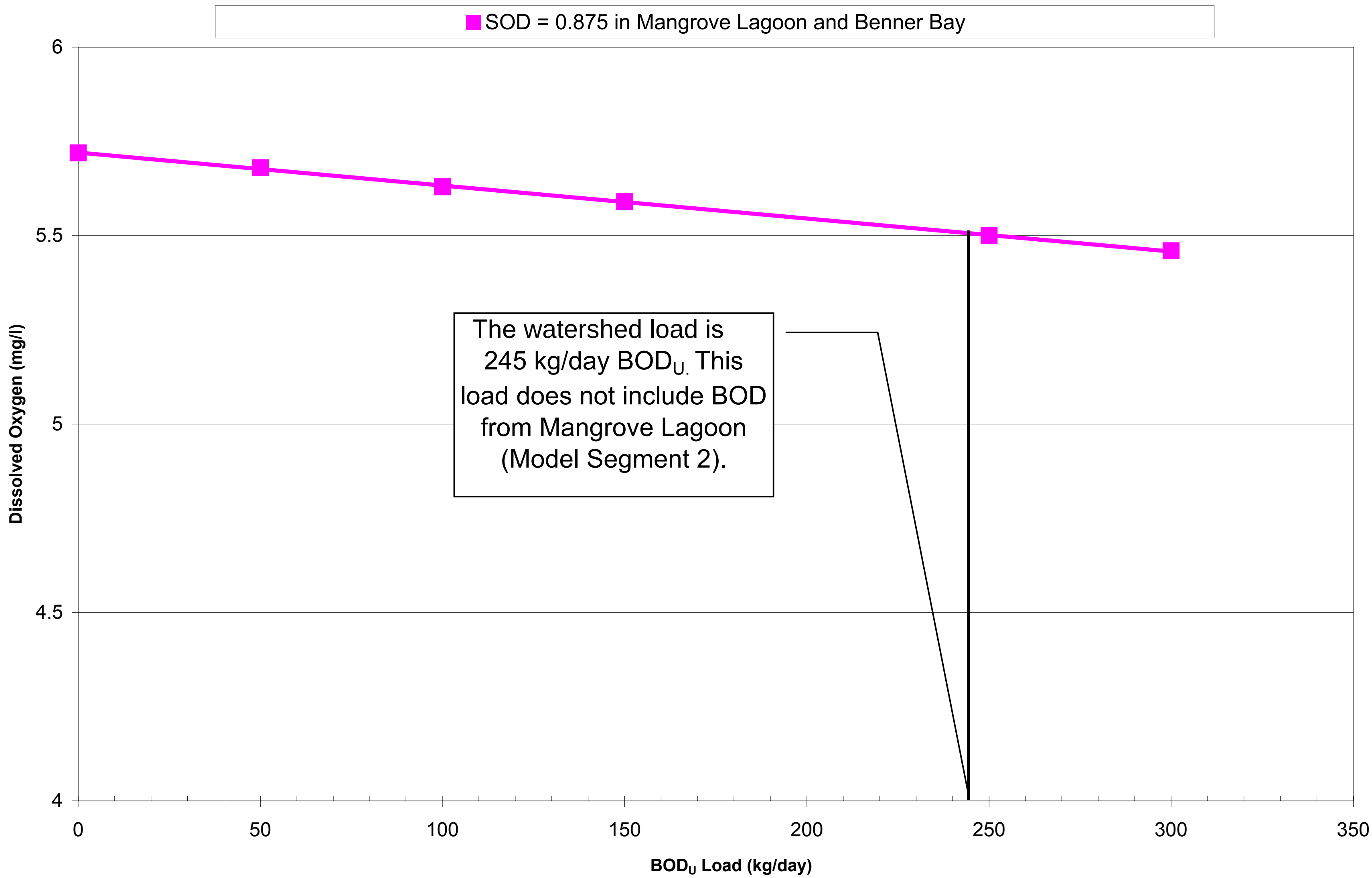


Table 3.9. Summary of Mangrove Lagoon TMDL and Load Reduction Requirements.

Condition	Load (Land Use Runoff and Septic Failures) (kg/day)	Load from Ocean (implicit in WASP model) (kg/day)	Waste Load (WWTPs*) (kg/day)	Margin of Safety (kg/day)	Total (kg/day)
Existing Load (1998-2000)	120.33	37.25	417.20	0	574.78
TMDL Allocations	109.16	37.25	0	25.84**	172.25
Total Load Reduction Required* **	11.17 (2.24 from septic failures) (8.93 from land use runoff)	0	417.20 (diversion of 3 WWTPs)	-	402.53

*The only permitted BOD loads discharging to Mangrove Lagoon are Nadir, New Tutu an Old Tutu WWTPs. Nadir WWTP is already off-line and New Tutu and Old Tutu WWTPs are planned to be taken off-line by summer 2003 (Personal Communication Tseng, 2003).

**The Margin of Safety is calculated as 15% of the TMDL. The reduction to account for the margin of safety is taken from the loads from land use runoff and septic failures, as opposed to the load from ocean water, because these are the loads that can reasonably and measurably be reduced through best management practices within the Mangrove Lagoon watershed.

***Total Load Reduction = (-1) x (TMDL Allocation – Existing Load)

Table 3.10. Summary of Benner Bay/Lagoon Marina TMDL and Load Reduction Requirements*.

Condition	Load (Land Use Runoff, Marina Discharge and Septic Failures) (kg/day)	Load from Mangrove Lagoon and Ocean (implicit in WASP model) (kg/day)	Waste Load (WWTPs*) (kg/day)	Margin of Safety (kg/day)	Total (kg/day)
Existing Load (1998-2000)	21.15	152.10 (114.85 from Mangrove Lagoon) (37.25 from open ocean)	0	0	173.25
TMDL Allocations	21.15	209.50 (172.25 from Mangrove Lagoon) (37.25 from open ocean)	0	223.95**	454.60
Total Load Reduction Required* **	0	-	0	-	-

*The TMDL Load/ Waste Load Allocations and Margin of Safety is calculated assuming that the TMDL for Mangrove Lagoon is met.

** The margin of safety was calculated to prevent any increase in the current non-point source loads from the Benner Bay/Lagoon Marina's watershed (see Margin of Safety section).

***Total Load Reduction = (-1) x (TMDL allocation – Existing Load)

The TMDL value will produce a dissolved oxygen concentration greater than or equal to 5.5 mg/L under all conditions, including the critical conditions represented by the model. This provides a reasonable assurance that the water quality standard will be met at all times when BOD loading is at or below the TMDL.

1.0 Margin of Safety

A margin of safety (MOS) must be incorporated into the final TMDL value in order to account for uncertainties and to assure that the dissolved oxygen standard will be met by the requisite maximum load. In this TMDL, an explicit rather than implicit MOS is applied to the calculated maximum allowable load for Mangrove Lagoon. It is not feasible to quantify the total uncertainty associated with the modeling of this system.

An explicit MOS of 15 percent is being applied to the estimated total allowable load to each water body. The MOS for Mangrove Lagoon is 25.84 kg/day BOD_U (15 % of

172.25 kg/day). The 15 percent MOS was selected based on best professional judgment as a conservative number in excess of the typically applied value of 10 percent due to the simplicity of the model and the limited data set.

The MOS for Benner Bay/Lagoon Marina is 223.85 kg/day BODU (> 15 % of 454.60 kg/day). The margin of safety was calculated as the difference between Benner Bay/Lagoon Marina's loading capacity, the loads from Mangrove Lagoon and Ocean, and the current loads calculated for land use runoff, marina discharge and septic failures. This was done to prevent any increase in the current non-point source loads from the Benner Bay/Lagoon Marina's watershed

In addition to the explicit margin of safety, the WASP6 baseline model results were matched to 25th percentile oxygen values. WASP6 is a steady-state model typically representative of average or 50th percentile conditions. The model was calibrated to meet the lower 25th percentile oxygen concentrations as a representation of critical conditions. Reductions to meet the "not less than" 5.5 mg/L oxygen standard were based on the reduction of loads to the model at this critical condition.

2.0 Required Total Load Reductions

The required reductions in the BOD_U load to Mangrove Lagoon are calculated as the current estimated loads to the water body, including loads from neighboring water bodies, minus the difference between the TMDL and the MOS. The total required reduction in BOD_U load to Mangrove Lagoon is 402.53 kg/day, which is equal to 574.8 kg/day (537.5 kg/day from WWTPs, land use runoff, septic failures, and marinas, plus 37.3 kg/day from the open ocean), minus 172.25 kg/day (the TMDL). An additional reduction of 25.84 kg/day associated with the MOS is also allocated as well.

Assuming that this load reduction to Mangrove Lagoon is met, the total required load reduction to Benner Bay/Lagoon Marina will be zero. USVI DPNR is limiting this load to prevent any increase in watershed loads into Benner Bay/Lagoon Marina while dissolve oxygen standard is not met in this segment and the Mangrove Lagoon TMDL is implemented. Further more, USVI DPNR will further evaluate the WASP6's model Segment 3, as necessary, when more data becomes available to identify any possible localized dissolved oxygen problems. Currently, Segment 3 addresses both STT-33 Benner Bay and STT-34 Benner Bay Lagoon Marina in one model segment. If necessary, USVI DPNR will revise the Benner Bay/Lagoon Marina TMDL, public notice, respond to comments and submit to EPA for review and approval.

3.0 Load Reductions Accomplished to Date

The current point source loadings to Mangrove Lagoon and Benner Bay/Lagoon Marina are determined based on the existing TPDES permits within the watersheds for sources that contribute BOD to the water bodies. There are three TPDES permitted dischargers regulated for BOD concentration in the Mangrove Lagoon watershed and none in the Benner Bay/Lagoon Marina watershed. The three TPDES permit holders are New Tutu

WWTP, Old Tutu WWTP, and Nadir WWTP. The Nadir WWTP has already been taken offline and the wastewater previously treated at Nadir WWTP is being diverted to the new Mangrove Lagoon WWTP. The Mangrove plant discharges outside of Mangrove Lagoon. By removing the Nadir WWTP, an effective BOD_U load reduction of 215.14 kg/day has already been accomplished.

The Old Tutu and New Tutu WWTPs are scheduled to be taken offline and diverted to the new Mangrove Lagoon WWTP in 2003. The additional load that will be reduced once these two plants are diverted is equivalent to a daily BOD_U load of 202.07 kg/day. Once all three WWTPs are offline, the total completed BOD_U load reduction will be 417.20 kg/day.

4.0 Required Remaining Load Reductions

The BOD_U load reduction required to meet the Mangrove Lagoon TMDL of 172.25 kg/day is 402.53 kg/day, plus the MOS of 25.84 kg/day. Once the New Tutu and Old Tutu WWTPs are taken offline, the remaining required load reduction to Mangrove Lagoon will be 11.17 kg/day. There is no required load reduction to Benner Bay/Lagoon Marina.

Waste Load Allocation

Waste load allocations (WLA) are the allocations of loads for TPDES permitted point sources discharging within the watersheds to Mangrove Lagoon and Benner Bay/Lagoon Marina. The three permitted BOD point sources in the watersheds were the three WWTPs discussed throughout this report: Nadir WWTP, New Tutu WWTP and Old Tutu WWTP. The Nadir WWTP is offline already, so it does not receive a WLA. The Old Tutu and New Tutu WWTPs are planned to be taken offline and diverted to the new Mangrove Lagoon WWTP in 2003. Therefore, these WWTPs also do not receive WLAs. There are no point sources located within the Benner Bay/Lagoon Marina watershed. The WLAs are summarized in Table 3.12.

Load Allocation

Load allocations are applied to all non-point sources within the watersheds to Mangrove Lagoon and Benner Bay/Lagoon Marina. The required load reduction to Mangrove Lagoon will be 11.17 kg/day. USVI DPNR is limiting this load to prevent any increase in watershed loads into Benner Bay/Lagoon Marina while dissolve oxygen standard is not met in this segment and the Mangrove Lagoon TMDL is implemented. The calculated current loads from land use runoff, septic system failure rates, and marina discharges in Benner Bay/Lagoon Marina was 19.18 kg/day, 1.10 kg/day and 0.87 kg/day respectively (total of 21.15 kg/day). These load allocations are summarized in Table 3.12 below.

Table 3.11. Specific Waste Load and Load Allocations in Mangrove Lagoon and Benner Bay/Lagoon Marina.

Source			BOD_U Allocation (kg/day)
Mangrove Lagoon (Model Segment 2)			
WASTE LOADS			
	Nadir WWTP		0
	New Tutu WWTP		0
	Old Tutu WWTP		0
	TOTAL		*0*
LOADS			
	Land Use Runoff		109.4
	Septic System Failures		0
	Load from Open Ocean (Model Segment 1)		37.3
	TOTAL LOAD ALLOCATION		*146.7*
MARGIN OF SAFETY			*25.84*
TMDL			172.25
Benner Bay/Lagoon Marina (Model Segment 3)			
WASTE LOADS			
	no NPDES permitted point sources of BOD		*0*
LOADS			
	Boat Discharge		
		Moorings in Compass Point, Benner/Jersey Bays	0.22
		Compass Point Marina	0.25
		Independent Boat Yard	0.26
		La Vida Marina	0.07
		Tropical Marine Inc. (Marina)	0.06
		Fish Hawk Marina	0.01
	Septic Failures		1.10
	Land Use Runoff		19.18
	Load from Mangrove Lagoon (Model Segment 2)		172.25
	Load from Open Ocean (Model Segment 1)		37.25
	TOTAL LOAD ALLOCATION		*230.65*
MARGIN OF SAFETY			*223.95*
TMDL			454.60

IV. IMPLEMENTATION AND MANAGEMENT PLAN

The implementation required to meet the calculated TMDL is already well underway. The primary BOD_U load affecting the dissolved oxygen concentration in Mangrove Lagoon and subsequently in Benner Bay/Lagoon Marina is the load associated with the poorly functioning and often overloaded WWTP discharges from Nadir WWTP, New Tutu WWTP and Old Tutu WWTP. As has been stated, the Nadir WWTP discharge has been eliminated and the sewage diverted to the new Mangrove Lagoon WWTP for treatment. The primary task in the implementation of this TMDL, therefore, is to ensure that the New Tutu and Old Tutu WWTPs are taken offline and the sewage diverted to the Mangrove Lagoon WWTP as scheduled in 2003. Once these WWTP discharges are eliminated, the requisite implementation of this TMDL will be nearly met.

An additional load reduction of 11.17 kg/day of BOD_U required within the Mangrove Lagoon watershed can be met by addressing the two watershed-based non-point sources identified in this document: septic system failures and land use runoff. Elimination of BOD loading from septic system failures will account for approximately 2.24 kg/day of load. Best management practices, both structural and non-structural, can be applied to retrofit existing residential development, industrial facilities, retail commercial development and public facilities to limit sources of BOD_U in stormwater runoff and possibly to remove or treat BOD in stormwater prior to discharge.

Management of these sources provides additional benefits to the water bodies as well. Discharge from these pollution sources typically contributes other contaminants such as bacteria, pathogens and nutrients in addition to BOD. Therefore, successful source control, treatment, and best management practices will also almost certainly reduce the contribution of these other pollutants to Mangrove Lagoon and Benner Bay/Lagoon Marina as well. A brief discussion of management options for each of these source types in the Mangrove Lagoon and Benner Bay/Lagoon Marina watersheds is presented below.

A. Management

1.0 Land Use Runoff

The current BOD_U load for the Mangrove Lagoon watershed from land use runoff is 120.33 kg/day, which is 11.17 kg/day greater than the allocated load of 109.16 kg/day. Some modest reductions in BOD loading will be required from existing development and projected loads from future development will need to be considered and appropriate management measures applied, including those outlined in the UVI Environmental Protection Handbook (UVI, 2002).

In conjunction with exceeding the Class B dissolved oxygen standards and the BOD_U loading allocated through this TMDL document, the Benner Bay/Mangrove Lagoon system has been identified as a Category I Watershed in the 2002 Draft USVI Watershed Restoration Action Strategies (DPNR, 2000). Category I watersheds are those that do not now meet or are in imminent danger of not meeting clean water and other natural resource objectives. A number of issues were identified as contributing to water quality impacts, including two "land use runoff" issues involving: 1)"a number of vehicle repair facilities" located in the watershed and 2) approximately one-third of the population of St. Thomas residing in the watershed. Restoration goals and management practices were identified that include compliance with the Coastal Zone Management Act requirements for compliance with all zoning and subdivision law rules and regulations.

In addition to this requirement, watershed retrofit activities should be implemented to identify, design and construct stormwater management best management practices (BMPs) to help capture and treat urban runoff from existing development. The implementation of any retrofit ponds would help reduce loading from land use runoff.

The issue of how future development is handled is also a key to compliance with the established TMDL. In association with computing a TMDL for Mangrove Lagoon, a loading analysis was also performed for potential "future buildout" conditions. According to the land use loading coefficients applied from Table 3.5, future land use runoff loading to Mangrove Lagoon could equal 164.7 kg/day under full buildout conditions (see Appendix B for the "full buildout condition" land use runoff loading assessment). This represents a 46.6 kg/day increase in BOD_U loading and would further contribute to the current exceedance of the Load Allocation specified in this TMDL. If appropriate BMPs are applied to all new development, the future projected BOD_U load could be reduced by approximately 30%, but would still be in excess of the TMDL (Winer, 2000). In order to meet a net 30% BOD removal efficiency, future development would need to be developed in accordance with the provisions of the VI Environmental Protection Handbook (UVI, 2002). In order for future develop to not have a negative impact on the Benner Bay/Mangrove Lagoon system, at least some portion of the currently undeveloped land would need to remain undeveloped or currently existing development would need to be retrofitted to reduce load generation from those sources.

Implementation of the proposed monitoring plan, discussed in Section 4.B, and analysis of the resulting data will likely refine the allowable loading estimates. Depending on the outcome of this assessment, the significance of the impact from current and future land use runoff can be further quantified.

2.0 <u>Marina Wastewater Discharge</u>

The discharge of wastewater from boats located at marinas or moorings in Benner Bay/Lagoon Marina has been shown in this report and previous reports (Hinkey, 1996; Wernicke and Towle, 1983; Towle, 1985) to contribute minor loads of BOD to the estuary. However, this should not preclude the effort to properly manage that waste and discourage illicit dumping of wastewater within near shore waters. Two key studies, one in 1983 and one in 1996, have been produced to address vessel waste management within the Virgin Islands, within the context of the existing legislation and best management practices. These studies are:

- Wernicke, Werner and Edward L. Towle. March 1983. *Vessel Waste Control Plan for the U.S. Virgin Islands.* Island Resources Foundation. St. Thomas, Virgin Islands.

- Hinkey, Lynne M. April 1996. *The U.S. Virgin Islands Clean Vessel Act Program: Implementation Plan.* Prepared for: The Virgin Islands Division of Fish and Wildlife, Department of Planning and Natural Resources and The U.S. Fish and Wildlife Service. University of the Virgin Islands.

These studies should be referenced and implemented within Benner Bay/Lagoon Marina to address vessel waste. In general, there are several keys to vessel waste management. The first is to make sure that wastewater discharge stations are readily accessible to vessels, and are maintained in proper order. Another key is to increase boater education and awareness about the importance of proper wastewater treatment and the effects of illicit discharges into the marine environment. Finally, enforcement of the regulations by the local government is required, and could be enhanced by self-regulation by marina owners and boaters alike.

3.0 Failure of On-Site Septic Systems

The failure of on-site septic systems in the Mangrove Lagoon watershed is estimated to contribute 2.24 kg/day BODU to the water body. In Benner Bay/Lagoon Marina, that number is estimated to be 1.10 kg/day. The load to Mangrove Lagoon must be eliminated in order to meet the associated load allocation. The management efforts focused on Mangrove Lagoon to address septic failures can and should be extended to nearby Benner Bay/Lagoon Marina, to the extent feasible, despite the fact that there is no TMDL requirement to do so, in order to take advantage of the economy of scale in addressing this issue. Inspections should be performed for on-site septic systems with previously reported problems or failures, and for systems located in soils or on slopes that are known to be inadequate for effective wastewater treatment. To the extent possible, efforts should be made to replace on-site septic systems with hook-ups to the sewage system that leads to the newly constructed Mangrove WWTP.

The placement of additional on-site septic systems within the watersheds of Mangrove Lagoon and Benner Bay/Lagoon Marina should be prohibited, given the limestone and karst soils and steep terrain that characterize the area. Numerous studies and reports reflect upon the failures of septic systems to properly remove pollutants, including BOD, nutrients, and bacteria, from the effluent in this area (Kimball Chase, 1994; Kimball Chase, 1996; Wernicke and Towle, 1983; DPNR, 2000). The most effective way to address septic systems that are failing due to environmental conditions rather than poor maintenance, which appears to be the case in these watersheds, is to tie these residences into the sewer system. Given that a new Mangrove Lagoon WWTP has been constructed and has recently come online, it would be effective to begin to tie in neighborhoods with numerous failing septic systems, particularly those within close proximity to Mangrove Lagoon and Benner Bay/Lagoon Marina.

B. Monitoring Plan

A water quality monitoring plan is an essential component of effective implementation of this TMDL. A primary limiting factor in this TMDL analysis was the lack of consistent comprehensive monitoring data within Mangrove Lagoon and Benner Bay/Lagoon Marina. Monitoring will be essential for three main purposes:

1) measuring the success of the TMDL implementation;
2) improving the water quality and flow regime (transport) modeling of the system; and
3) identifying potential water quality problems and pollution sources in the future.

The monitoring plan, in terms of location, frequency, and parameters monitored, must capture ambient water quality and flow conditions within Mangrove Lagoon and Benner Bay/Lagoon Marina, as well as point source discharge conditions, and flow and water quality in streams discharging to Mangrove Lagoon and Benner Bay/Lagoon Marina. The monitoring plan should also incorporate a sampling frequency that captures the seasonal variations in water quality, climate, precipitation and flow conditions. The plan presented below has been developed to meet all of these requirements.

1.0 Monitoring Locations

Seasonal variations including temperature, precipitation, wind direction and speed, water and air temperature, currents, and seasonal population fluctuations most likely affect the water quality within this system. Sample locations should be predetermined based on several factors, including location relative to critical land uses, stormwater outfall discharge point, stream discharge locations, and wastewater treatment plant discharge location. Additional sample locations should be selected to capture the general ambient water quality and flow conditions within the water bodies. Most importantly, sample locations should be consistently adhered to for all sampling events. If sample locations are too loosely defined, it becomes increasingly difficult to accurately interpret the resulting data and the sampling effectiveness decreases significantly.

Figure 4.1 presents a set of recommended sample locations. It should be noted that the open water locations are similar to the DPNR/EPA network of sample locations. That network appears on paper to be comprehensive; however, during discussions with DPNR during the development of this TMDL and a comparison of location coordinates from past sampling events, it is apparent that the actual locations where samples were collected varied drastically between sampling events, despite having the same location name.

Legend

● Monitoring Location

North

0 3000

Scale in Feet

Inland monitoring stations are located at the WWTP discharge points

Horsley & Witten, Inc.
phone: 508-833-6600
www.horsleywitten.com

Proposed Monitoring Locations for Mangrove Lagoon and Benner Bay

1237-Watershed.cdr

Figure 4.1

In addition to open water sampling, point source discharges should be monitored. These include the locations of discharge from the Nadir, New Tutu and Old Tutu WWTP (to verify the effectiveness of diverting the flow to the new Mangrove WWTP), the mouth of Turpentine Run, or other observed concentrated flow discharges into Turpentine Run, Mangrove Lagoon or Benner Bay/Lagoon Marina. This likely includes runoff from the municipal separate sewer system, runoff from the barn associated with the horse track near the Mangrove Lagoon Head, and runoff from existing or defunct landfills.

In order to effectively evaluate the impacts of these point source discharge, it will be useful to sample the receiving waters above and below the discharge location, as well as the discharge itself. The suite of parameters sampled at each discharge location can be selected according to professional knowledge of the likely pollutants in each discharge stream.

2.0 Sampling Frequency

Ideally, all sampling will be implemented on a monthly basis. This will provide a consistent and comprehensive data set that can be effectively analyzed and utilized in a transient model. At the very least, monitoring shall be carried out on a quarterly basis.

3.0 Parameters to Sample

In order to meet the goals of the monitoring plan, as discussed at the beginning of this section, the suite of parameters to be sampled is extensive. However, this is to be expected given the complex nature of these estuarine systems. The TMDL analysis presented in this document addresses the BOD-dissolved oxygen interaction within the system, which is clearly a significant mechanism leading to diminished dissolved oxygen concentrations. However, enhanced eutrophication caused by nutrient loading undeniably contributes to the dissolved oxygen deficiencies in this system. More detailed water quality data specific to nutrient species is required to assess the nutrient load and nutrient cycling in the water column during the eutrophication process.

General data that should be collected from NOAA climate stations or other local accurate climate stations include:

- Tidal Cycle and Water Elevation
- Daily Precipitation
- Average Daily Temperature

Following is a recommended list of the parameters to be monitored within Mangrove Lagoon and Benner Bay/Lagoon Marina:

- Water Temperature
- Salinity
- Air Temperature
- Wind Direction/Velocity

- pH
- Total Nitrogen
- Nitrate
- Nitrite
- Total Kjeldahl Nitrogen
- Total Phosphorus
- Orthophosphate
- Dissolved Oxygen (DO) (at consistent depths)
- Biochemical Oxygen Demand (BOD_5)
- Sediment Oxygen Demand
- Flow Velocity/rate (open estuarine water)
- Depth of Sample

4.0 Sampling Protocol

A sampling protocol should be established within a DPNR-approved Quality Assurance Project Plan (QAPP). Adherence to this QAPP should be enforced throughout the project by a project manager familiar with its requirements. Because of the potential for variation with procedures in field sampling, and the time-critical nature of the required analyses, the following general sampling protocols are suggested:

- All sampling events shall be conducted by personnel familiar with each location, trained in using the sampling equipment, with working knowledge of the QAPP.
- Each sampling location shall have a distinct identification number. That number should not be used for any other location at any time. Each sample location should be accurately mapped.
- Equipment should be properly calibrated prior to each sampling event. The date, time and personnel who completed the calibration of the equipment should be recorded and stored in a central location.
- The laboratory should be contacted in advance of sampling events to ensure compliance with hold times.
- Field sampling forms should be designed, and completed during each sampling event. The sampling form shall be completed so that sample identifications are clearly recorded and match each respective bottle. The person(s) conducting the sampling shall sign the sampling form.
- A laboratory chain of custody shall be completed during the sampling event. The chain of custody shall be kept with the sample until analysis is completed. The form should be signed with date and time each time custody is transferred.
- Samples should be kept at the appropriate temperature during sampling events and shipping for laboratory analysis.
- Inspect each sample container to ensure proper lid closure, proper labeling, and correct number of samples and QA/QC bottles for each location.

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Table A1. Dissolved Oxygen Concentration Data - Benner Bay

Sampling Location	Date	Dissolved Oxygen (mg/L)	Water T (deg C)	Data Source
26A	10/20/92	6.4	28.8	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	01/19/93	-	28	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	04/13/93	6	29	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	06/24/93	-	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	08/26/93	6.5	28.5	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	01/27/94	5.25	30	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	06/07/94	7.6	30.1	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	12/05/94	5.6	29	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	01/04/95	6.85	28.7	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	04/08/95	6.84	29.9	VI 2000 Water Quality Assessment, DPNR, April 2001
26A	01/24/98	5.1	28.1	DESAdata, 1998
26A	03/25/99	7	26.7	STORET Database, EPA, 2002
26A	06/29/99	6.68	29	STORET Database, EPA, 2002
26A	12/13/99	-		STORET Database, EPA, 2002
26A	10/12/00	5.66	30.3	STORET Database, EPA, 2002
26A	10/12/00	5.85	30.2	STORET Database, EPA, 2002
26A	06/14/01	4.77	30	STORET Database, EPA, 2002
26A	06/14/01	4.85	30.4	STORET Database, EPA, 2002
26C	01/24/98	6.3	27.2	DESAdata, 1998
26D	01/24/98	6.5	27.6	DESAdata, 1998
26D	07/28/99	5.1	30.2	Ramos-Gines, Orlando, USGS, 2000
26D	07/28/99	4.6	30.2	Ramos-Gines, Orlando, USGS, 2000
26D	12/09/99	7.9*	26.2	Ramos-Gines, Orlando, USGS, 2000
26D	12/09/99	7	26.2	Ramos-Gines, Orlando, USGS, 2000
26E	01/24/98	6.3	27.1	DESAdata, 1998
26F	01/24/98	5.9	27.6	DESAdata, 1998
26G	01/24/98	4.5	28	DESAdata, 1998
26H	01/24/98	4.9	28.3	DESAdata, 1998
26I	01/24/98	6.3	27.1	DESAdata, 1998
26J	01/24/98	6.1	27.1	DESAdata, 1998

Note: * = denotes dissolved oxygen readings that were eliminated from the data set because they exceed the maximum allowable saturation value (7.75 mg/L) at the average ambient temperature (28.54 degrees C)

Table A2. Dissolved Oxygen Concentration Data - Mangrove Lagoon

Sampling Location	Date	Dissolved Oxygen (mg/L)	Water T (deg C)	Data Source
27A	10/20/92	-	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	01/21/93	5.5	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	04/13/93	6	29	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	06/24/93	-	28.7	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	01/27/94	7.3	28.7	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	03/15/94	-	28.9	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	06/07/94	-	30	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	10/13/94	-	29.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	12/05/94	-	30	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	01/04/95	6.6	28.6	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	04/08/95	6.7	28.6	VI 2000 Water Quality Assessment, DPNR, April 2001
27A	01/24/98	8.9*	28.5	DESAdata, 1998
27A	06/29/99	5.76	29.2	STORET
27A	07/27/99	3.8	30.2	Ramos-Gines, Orlando, USGS, 2000
27A	07/27/99	3	30.4	Ramos-Gines, Orlando, USGS, 2000
27A	12/09/99	14.3*	25	Ramos-Gines, Orlando, USGS, 2000
27A	12/09/99	1.7	26.2	Ramos-Gines, Orlando, USGS, 2000
27A	10/12/00	4.22	30.7	STORET Database, EPA, 2002
27A	10/12/00	4.5	30.9	STORET Database, EPA, 2002
27A	06/14/01	5.48	29.8	STORET Database, EPA, 2002
27A	06/14/01	5.58	29.8	STORET Database, EPA, 2002
27A	07/24/01	3.39	29.9	STORET Database, EPA, 2002
27A	07/24/01	4.02	29.8	STORET Database, EPA, 2002
27B	04/13/93	5.8	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	01/27/94	6.5	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	03/15/94	6.7	39.1	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	06/07/94	6.4	28.5	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	10/13/94	6	29.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	12/05/94	6.4	28.7	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	01/24/98	6.7	27.2	DESAdata, 1998
27B	01/24/98	6.7	27.2	DESAdata, 1998
27B	06/29/99	6.57	29.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27B	12/13/99	-	-	STORET Database, EPA, 2002
27B	10/12/00	4.38	30.7	STORET Database, EPA, 2002
27B	10/12/00	4.53	30.8	STORET Database, EPA, 2002
27B	06/14/01	5.46	29.8	STORET Database, EPA, 2002
27B	06/14/01	5.58	29.7	STORET Database, EPA, 2002
27B	07/24/01	4.04	29.9	STORET Database, EPA, 2002
27B	07/24/01	4.32	29.9	STORET Database, EPA, 2002
27C	01/27/94	7.8*	28.4	VI 2000 Water Quality Assessment, DPNR, April 2001
27C	06/07/94	10.2*	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27C	12/05/94	7.8*	28.1	VI 2000 Water Quality Assessment, DPNR, April 2001
27C	01/04/95	7.8*	28.1	VI 2000 Water Quality Assessment, DPNR, April 2001
27C	04/08/95	6.8	28.2	VI 2000 Water Quality Assessment, DPNR, April 2001
27C	03/25/99	3.9	27.2	STORET Database, EPA, 2002
27C	06/29/99	4.75	29.1	STORET Database, EPA, 2002
27C	12/13/99	-	-	STORET Database, EPA, 2002
27C	10/12/00	4.78	30.7	STORET Database, EPA, 2002
27C	10/12/00	4.94	30.7	STORET Database, EPA, 2002
27C	06/14/01	5.25	30	STORET Database, EPA, 2002
27C	06/14/01	5.47	30	STORET Database, EPA, 2002
27C	07/24/01	4.52	29.9	STORET Database, EPA, 2002
27C	07/24/01	4.65	30	STORET Database, EPA, 2002
27D	06/29/99	4.62	29	STORET Database, EPA, 2002
27D	12/13/99	-	-	STORET Database, EPA, 2002
27D	10/12/00	5.11	30.7	STORET Database, EPA, 2002
27D	10/12/00	5.15	30.8	STORET Database, EPA, 2002
27D	06/14/01	4.95	30.4	STORET Database, EPA, 2002
27D	06/14/01	4.95	30.4	STORET Database, EPA, 2002
27D	07/24/01	3.54	30.7	STORET Database, EPA, 2002
27D	07/24/01	3.72	31	STORET Database, EPA, 2002
27E	04/22/99	-	-	STORET Database, EPA, 2002
27E	06/29/99	5.62	28.7	STORET Database, EPA, 2002
27E	12/13/99	-	-	STORET Database, EPA, 2002
27E	10/12/00	5.11	30.7	STORET Database, EPA, 2002
27E	10/12/00	5.23	30.5	STORET Database, EPA, 2002
27E	06/14/01	5.64	29.9	STORET Database, EPA, 2002
27E	06/14/01	5.69	30	STORET Database, EPA, 2002
27E	07/24/01	4.87	30.6	STORET Database, EPA, 2002
27E	07/24/01	4.88	30.6	STORET Database, EPA, 2002

Note: * denotes dissolved oxygen readings that were eliminated from the data set because they exceed the maximum allowable saturation value (7.62 mg/L) at the average ambient temperature (29.50 degrees C)

Table B-1 Approximate Land-Use Runoff BOD Load at Buildout - Mangrove Lagoon Watershed

(Assumption: Future land use based on current zoning)

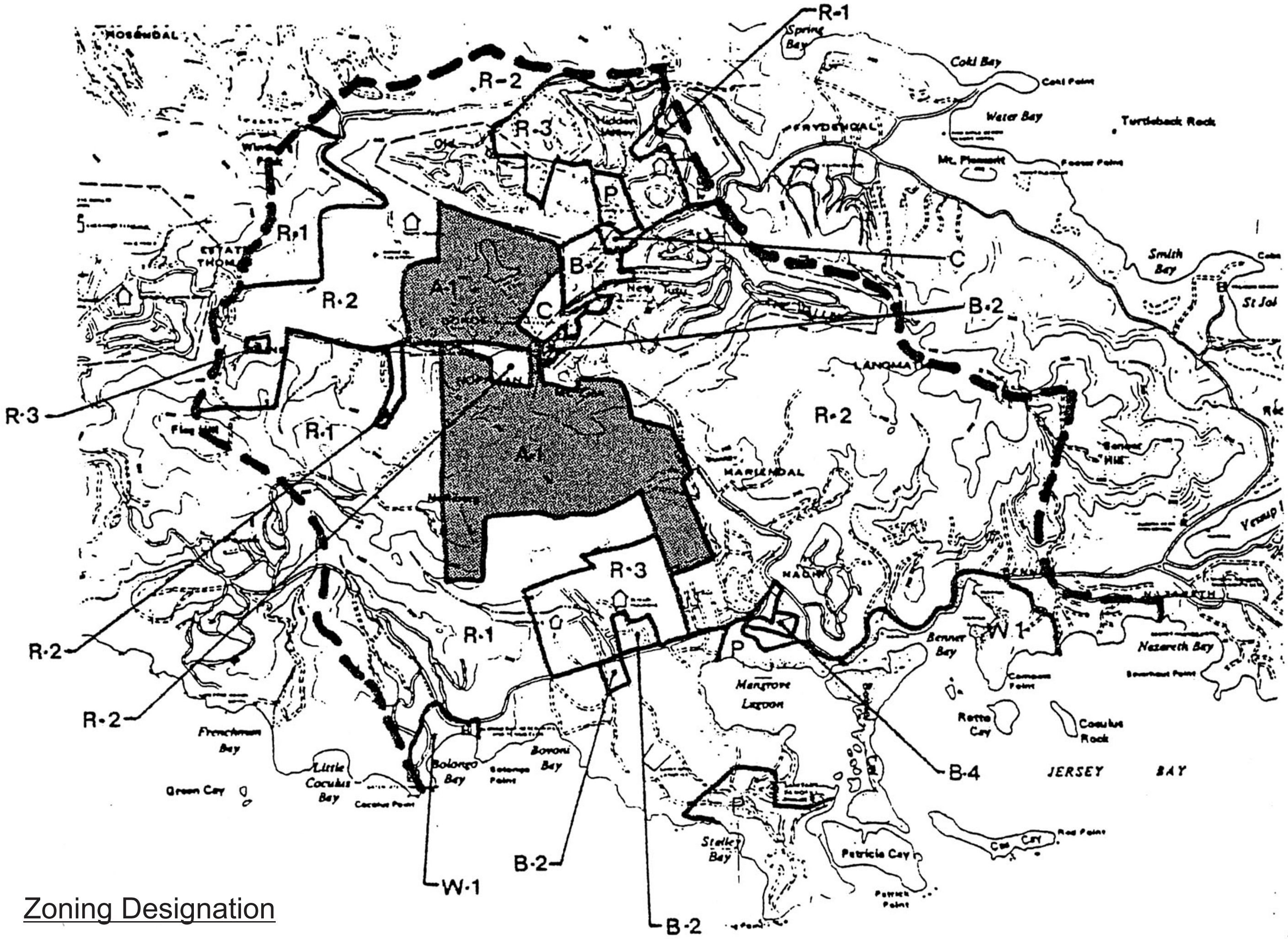
Land Use	Total Acres per Land Use	BOD5 Loading Coefficient (sandy loam soils)	Rain Correction Factor	Annual BOD5 Load	BOD5 Load	BODu load
Units	*Acres*	*lbs/acre/yr*	*in/in*	*lbs/yr*	*kg/day*	kg/day
Agriculture	315.00	29.00	0.92	8,366.21	10.40	15.21
Hotel/Resort	1.34	137.00	0.92	168.26	0.21	0.31
Retail Commercial	164.72	163.00	0.92	24,589.76	30.56	44.72
Industrial Manufacturing	109.96	111.00	0.92	11,178.05	13.89	20.33
Public Facilities	100.18	111.00	0.92	10,184.45	12.66	18.52
Residential (Low Density)	698.00	14.00	0.92	8,949.60	11.12	16.28
Residential (Medium Density)	1,197.00	20.00	0.92	21,925.25	27.25	39.87
Residential (High Density)	178.20	26.00	0.92	4,243.28	5.27	7.72
Urban	-	206.00	0.92	-	-	-
Waterfront/Marine	4.37	206.00	0.92	825.21	1.03	1.50
Parks/Recreation/Open Space	24.66	6.00	0.92	135.52	0.17	0.25
Undeveloped	-	6.00	0.92	-	-	-
Total	**2,793.44**			**90,565.59**	**112.55**	**164.70**

This methodology is from the Northern VA Planning District Commission, Guidebook for Screening Urban Nonpoint Pollution Management Strategies, Nov. 1979.

Table B-2 Approximate Land-Use Runoff BOD Load at Buildout - Benner Bay Watershed
(Assumption: Future land use based on current zoning)

Land Use	Total Acres per Land Use	BOD5 Loading Coefficient (sandy loam soils)	Rain Correction Factor	Annual BOD5 Load	BOD5 Load	BODu load
Units	*Acres*	*lbs/acre/yr*	*in/in*	*lbs/yr*	*kg/day*	kg/day
Agriculture	0.000	29.00	0.92	-	-	-
Hotel/Resort	0.000	137.00	0.92	-	-	-
Retail Commercial	0.373	163.00	0.92	55.68	0.07	0.10
Industrial Manufacturing	0.000	111.00	0.92	-	-	-
Public Facilities	0.000	111.00	0.92	-	-	-
Residential (Low Density)	66.505	14.00	0.92	852.71	1.06	1.55
Residential (Medium Density)	570	20.00	0.92	10,448.29	12.98	19.00
Residential (High Density)	0	26.00	0.92	-	-	-
Urban	0.000	206.00	0.92	-	-	-
Waterfront/Marine	22.482	206.00	0.92	4,241.53	5.27	7.71
Parks/Recreation/Open Space	4.652	6.00	0.92	25.56	0.03	0.05
Undeveloped	0.000	6.00	0.92	-	-	-
Total	**664.432**			**15,623.77**	**19.42**	**28.41**

This methodology is from the Northern VA Planning District Commission, Guidebook for Screening Urban Nonpoint Pollution Management Strategies, Nov. 1979.



Zoning Designation

A-1 Agricultural Zone

A-2 Agricultural Zone

R-1 Residential - low density

R-2 Residential - low density 1 and 2 family

R-3 Residential - medium density

R-4 Residential - medium density

R-5 Residential - high density

B-1 (C-1) Central Business District

B-2 (C-2) Business - secondary/neighborhood

B-3 (C-3) Business - scattered

B-4 Business - residential areas

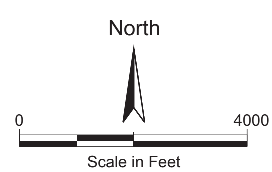
I-1 Heavy Industry

I-2 Light Industry

W-1 Waterfront - pleasure

W-2 Waterfront - industrial

P Public



Source: USEPA, 1984

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U.S.V.I. Zoning Designation

1237-zoning.cdr

Figure B.1