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FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Division of Water Resource Management, Bureau of Watershed Management

CENTRAL DISTRICT • MIDDLE ST. JOHNS BASIN

TMDL Report

Dissolved Oxygen TMDL for Long Branch, WBID 3030

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TMDL Program

http://www.dep.state.fl.us/water/tmdl/index.htm

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STORET Program

http://www.dep.state.fl.us/water/storet/index.htm

2004 305(b) Report

http://www.dep.state.fl.us/water/docs/2004_Integrated_Report.pdf

Criteria for Surface Water Quality Classifications

http://www.dep.state.fl.us/legal/rules/shared/62-302t.pdf

Basin Status Reports

http://www.dep.state.fl.us/water/tmdl/stat_rep.htm

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Allocation Technical Advisory Committee (ATAC) Report

http://www.dep.state.fl.us/water/tmdl/docs/Allocation.pdf

U.S. Environmental Protection Agency

Region 4: Total Maximum Daily Loads in Florida

http://www.epa.gov/region4/water/tmdl/florida/

National STORET Program

http://www.epa.gov/storet/

Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the Total Maximum Daily Load (TMDL) for the pollutants (nitrogen, phosphorus, and biochemical oxygen demand [BOD]) causing the low dissolved oxygen (DO) concentration for Long Branch in the Middle St. Johns Basin. The stream was verified as impaired for low DO based on the observation that DO values for 26 out of 28 samples collected during the verified period (January 1, 1996, through June 30, 2003) were lower than 5 milligrams per liter (mg/L), which is the state water quality criterion for Class III freshwater systems. BOD was considered the causative pollutant because the median value of 21 BOD measurements in the verified period exceeded the 2.0 mg/L screening level for streams. The stream was therefore included on the Verified List of impaired waters for the Middle St. Johns Basin that was adopted by Secretarial Order in May 2004. The TMDL establishes the allowable loadings of total nitrogen (TN), total phosphorus (TP), and BOD to Long Branch that would restore the waterbody so that it meets its applicable water quality criterion for DO.

1.2 Identification of Waterbody

Long Branch, which is located in the northeast part of Orange County, flows primarily in a westerly direction into the Econlockhatchee (Econ) River and drains about 5.7 square miles **(Figure 1.1).** State Road 50 (S. R. 50) runs through the eastern part of the watershed in a northwest-to-southeast direction, and County Road 13 (C. R. 13) runs through the central watershed in a north-to-south direction. The majority of the development in the watershed is in an area east of C. R. 13 and west of S. R. 50 in the northern part of the watershed. Pastureland, rangeland, pine flatwoods, and mixed wetland hardwoods dominate the rest of the watershed.

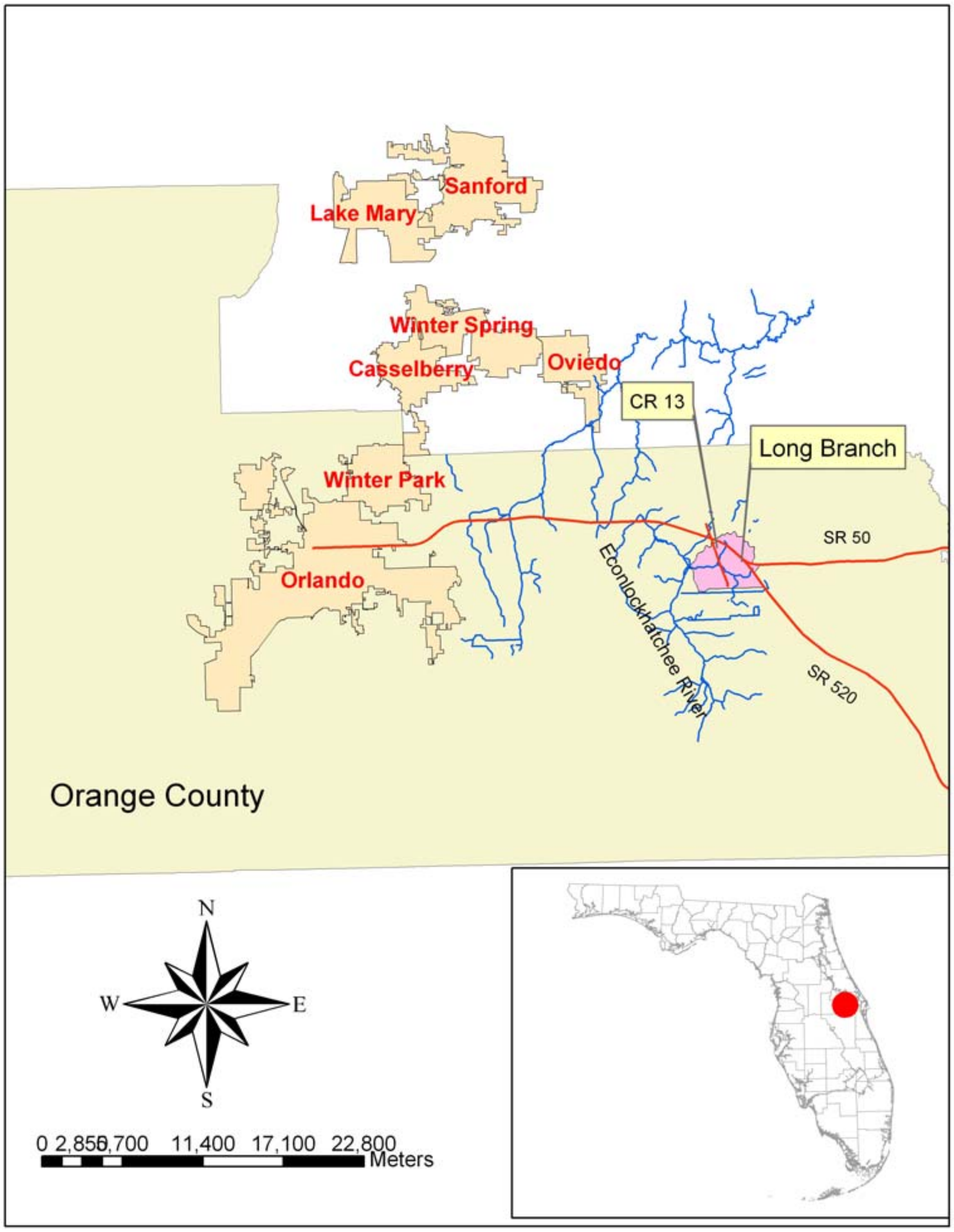
According to the U. S. Geological Survey (USGS) 1:100,000 quadrangle map, the elevation decreases from about 20 feet (NGVD) in the eastern part of the watershed, to about 15 feet (NGVD) at the Long Branch outlet in the western part. The average slope for the watershed is about 0.03 percent. More detailed information about the Long Branch watershed can be found in the *Big Econlockhatchee River Basin stormwater management master plan* (CDM, 2003).

For assessment purposes, the Department has divided the Middle St. Johns Basin into water assessment polygons with a unique **w**ater**b**ody **id**entification (WBID) number for each watershed or stream reach. This TMDL addresses **WBID 3030, Long Branch,** for low DO.

1.3. Development of TMDL

This TMDL was developed in cooperation with the Orange County Environmental Protection Division (OECPD) and the Orange County Stormwater Management Division. These agencies also actively coordinated with a variety of local stakeholders throughout the TMDL development process (including meetings to discuss the available modeling approaches and possible sources of pollutants) and provided the Department with the local information required for TMDL development.

Figure 1.1 Location of Long Branch in Orange County, and Locations of S. R. 50, S. R. 520, C. R. 13, and Major Municipalities to the West of the Long Branch Watershed, WBID 3030



Chapter 2: DESCRIPTION OF WATER QUALITY PROBLEM

2.1 Statutory Requirements and Rulemaking History

Section 303(d) of the federal Clean Water Act requires states to submit to the U. S. Environmental Protection Agency (EPA) lists of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for each pollutant causing the impairment of listed waters on a schedule. The Department has developed such lists, commonly referred to as 303(d) lists, since 1992. The list of impaired waters in each basin, referred to as the Verified List, is also required by the Florida Watershed Restoration Act (FWRA) (Subsection 403.067[4], Florida Statutes [F.S.]); the state's 303(d) list is amended annually to include basin updates.

Florida's 1998 303(d) list included 22 waterbodies in the Middle St. Johns Basin. However, the FWRA (Section 403.067, F.S.) stated that all previous Florida 303(d) lists were for planning purposes only and directed the Department to develop, and adopt by rule, a new science-based methodology to identify impaired waters. After a long rulemaking process, the Environmental Regulation Commission adopted the new methodology as Chapter 62-303, Florida Administrative Code (F.A.C.) (Identification of Impaired Surface Waters Rule, or IWR), in April 2001.

2.2 Information on Verified Impairment

The Department has used the IWR to assess water quality impairments in the Long Branch watershed and has verified the impairments listed in **Table 2.1**. The stream was verified as impaired for low DO based on the observation that in 26 out of 28 samples collected during the verified period (January 1, 1996, through June 30, 2003), DO concentrations were lower than the state's water quality criterion for Class III freshwater streams. BOD was considered the causative pollutant because the median value of 21 BOD measurements in the verified period exceeded the 2 mg/L screening level for streams. The stream was also verified as impaired for fecal and total coliform bacteria, as well as iron. This TMDL establishes the allowable loads of possible pollutants, including BOD, TN, and TP, that may be causing the low DO in the stream. **Table 2.2** summarizes the DO observations for the verified period for Long Branch.

As shown in **Table 2.1**, the projected year for TMDL development was 2004, but the Settlement Agreement between the EPA and Earthjustice, which drives the TMDL development schedule for waters on the 1998 303(d) list, allows an additional nine months to complete the TMDL. As such, the TMDL must be adopted and submitted to the EPA by September 30, 2005.

Table 2.1. Verified Parameters for Long Branch, WBID 3030

Waterbody Segment	Parameters of Concern	Priority for TMDL Development	Projected Year for TMDL Development
Long Branch	DO (BOD)	High	2004
Long Branch	Fecal coliform	High	2004
Long Branch	Total coliform	High	2004
Long Branch	Iron	High	2004

Note: The parameters listed in **Table 2.1** provide a complete picture of the impairment in the stream, but this TMDL only addresses the DO impairment.

Table 2.2. Summary of DO Monitoring Data in the Verified Period for Long Branch, WBID 3030

Parameter	Summary of Observations
Total number of samples	28
IWR required number of violations for the Verified List	6
Number of observed violations	26
Number of observed nonviolations	2
Number of seasons during which samples were collected	4
Highest observation (mg/L)	6.1
Lowest observation (mg/L)	0.5
Median observation (mg/L)	3.6
Mean observation (mg/L)	3.4
Screening value for BOD (mg/L)	2.0
Screening value for TN (mg/L)	1.60
Screening value for TP (mg/L)	0.22
Median value for 21 BOD observations (mg/L)	2.6
Median value for 27 TN observations (mg/L)	0.82
Median value for 30 TP observations (mg/L)	0.20
Possible causative pollutant by IWR	BOD
FINAL ASSESSMENT	**Impaired**

2.3 Spatial and Temporal Distribution of DO Concentrations in Long Branch

Long Branch is divided into three segments: a northern tributary, a southern tributary, and the main channel. This study used data from three water quality monitoring stations: 21FLCEN 20010374 on the northern tributary, 21FLCEN 20010384 on the southern tributary, and

21FLCEN 20010395 on the main channel. **Figure 2.1** shows the locations of the monitoring stations used to provide data for this analysis.

All the DO measurements in the verified period were taken in 2002. **Figures 2.2** and **2.3** show the spatial distribution and temporal variation, respectively, of DO along Long Branch in 2002. Although the DO concentration was lower than 5.0 mg/L most of the time at all three monitoring stations, the mean DO concentrations were similar at the two tributary stations and were consistently higher than 4.0 mg/L. In contrast, the mean DO concentration at the main channel site was substantially lower than those at the tributary sites and was in most cases lower than 2.0 mg/L **(Figure 2.2).**

It is not entirely appropriate to establish a seasonal trend with only one year's worth of data. Comparing DO concentrations from different sites at different times of the year, however, sheds some light on a possible seasonal pattern. Based on **Figure 2.3**, the northern and southern tributaries show a similar seasonal pattern—i.e., the lowest DO concentration was observed in the second quarter, and relatively high DO concentrations were observed in the first, third, and fourth quarters (**Note:** The northern tributary did not have first-quarter data).

The major environmental factors that control this pattern are not entirely clear. However, high DO concentrations appear more often in low-temperature conditions, such as those in the first and fourth quarters. Higher DO may also occur under high-temperature conditions combined with high rainfall, such as those in the third quarter. In cold seasons, low temperature increases the solubility of DO in the water, and therefore high DO concentrations are usually observed. In the third quarter, although temperatures increased, under the high-flow condition the reaeration rate increased. High oxygen consumption rates (due to the high temperature) may be compensated for by a high reaeration rate, which may in turn result in a not-so-low DO concentration. Temperatures are usually higher in May and June (i.e., the second quarter) than in the first and fourth quarters. Stream flow in these months is also low due to low rainfall. These factors could result in the low DO solubility and reaeration rate that caused the low DO concentrations in Long Branch.

Since TMDLs primarily address impairments caused by pollutants, this report focuses on the effects of BOD and nutrients on DO concentrations in Long Branch. It should be noted that, while physical factors could have an important influence on DO concentration, BOD and nutrients could also play a significant role because they usually determine the oxygen consumption rate in the water. In cold months, low organismal metabolic rates—especially the low oxygen consumption rate of bacteria in a heterotrophic ecosystem such as Long Branch—could be a major factor in causing the relatively high DO concentrations. In contrast, when the temperature increases, high BOD and nutrient concentrations would support a higher oxygen consumption rate by bacteria and result in low DO if the consumption rate were not compensated for by the reaeration rate.

The temporal pattern of DO concentrations at the main channel site appears to differ from those of the tributary sites. In the main channel, DO concentrations in the first and fourth quarters were lower than in the second and third quarters. Since the main channel runs through mixed hardwood wetlands and cypress swamps, the low DO in the first and fourth quarters could be caused by falling leaves, which add nutrient and organic carbon into the system during cold weather. As a result, even though the specific bacterial respiration rate during cold weather decreases, the total oxygen consumption rate for the system could increase because more bacteria are present at this time of the year. In addition, the flow velocity of the main channel is significantly lower than that of the two tributaries. This could strengthen the low DO concentrations caused by high bacterial respiration together with the low reaeration rate.

Figure 2.1. Locations of Water Quality Monitoring Stations in the Long Branch Watershed, WBID 3030

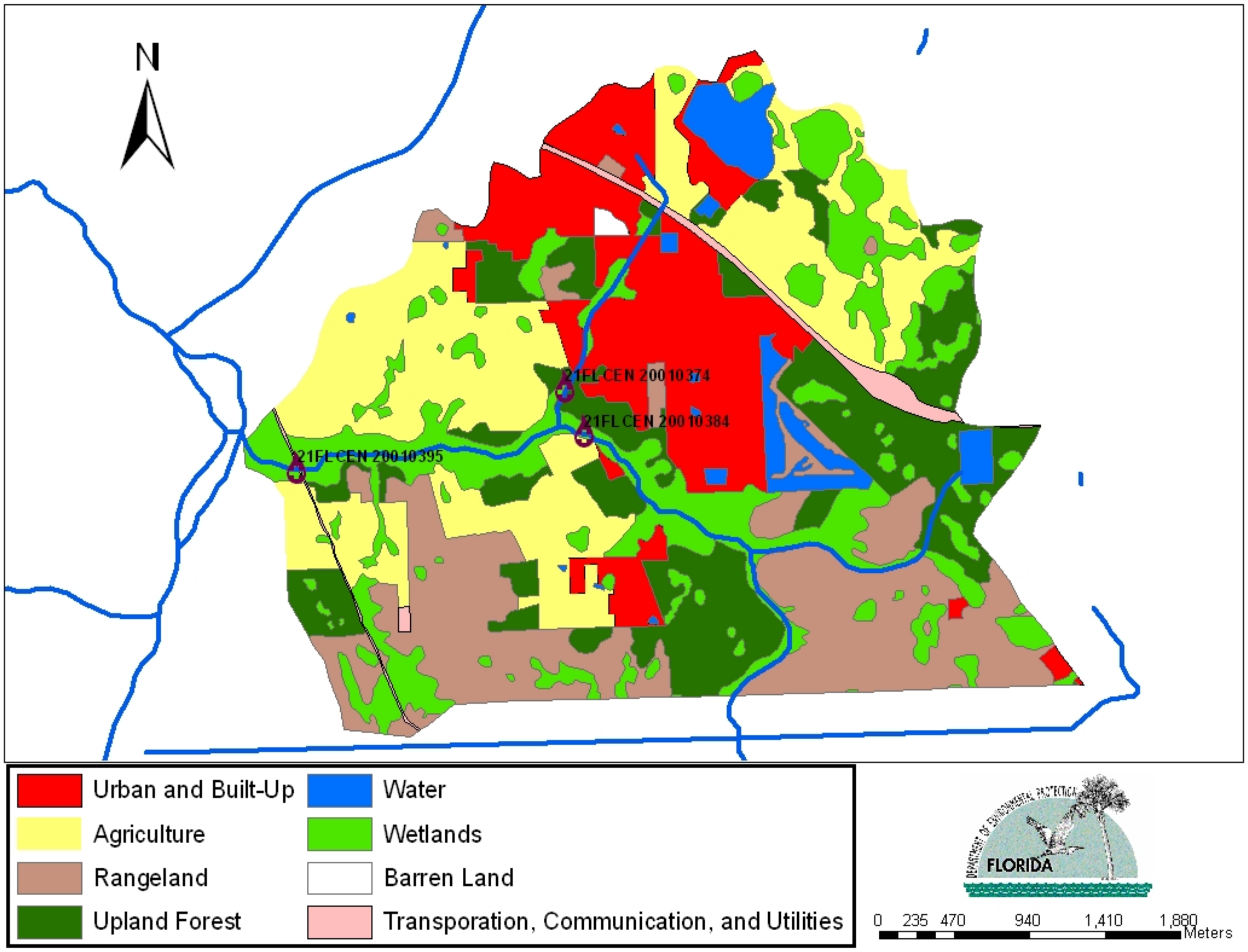


Figure 2.2. Spatial Variation of DO in Long Branch, WBID 3030

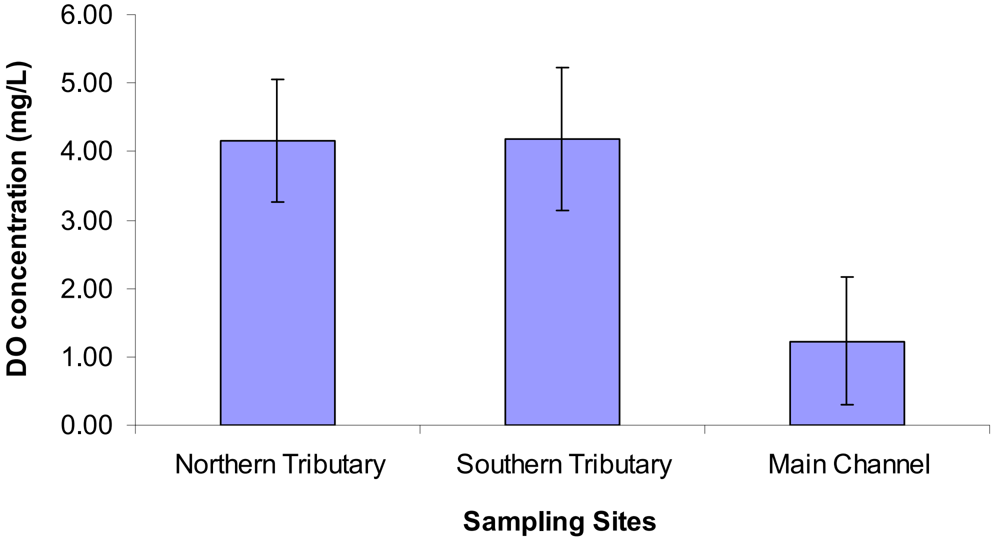
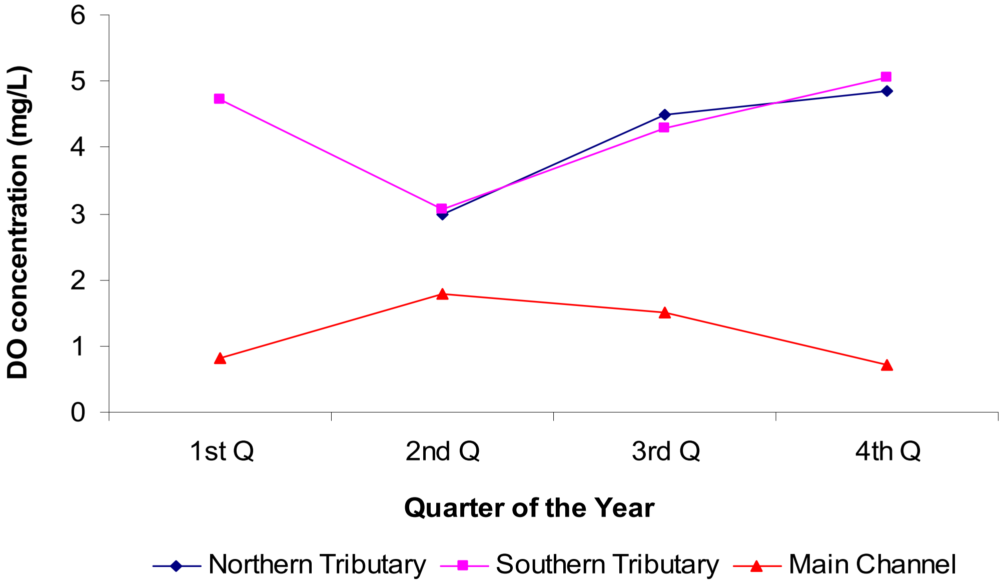


Figure 2.3. Temporal Variation of DO in Long Branch, WBID 3030



Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criteria Applicable to the TMDL

Florida's surface waters are protected for five designated use classifications, as follows:

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class IV	**Agricultural water supplies**
Class V	**Navigation, utility, and industrial use (there are no state waters currently in this class)**

Long Branch is a second-order stream, and in this report, was assessed according to the surface water quality criteria developed for Class III waterbodies, with a designated use of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. The criterion applicable to this TMDL is the Class III DO criterion for freshwater streams.

3.1.1 Applicable Water Quality Standards and Numeric Water Quality Target

Development of Water Quality Targets for Pollutants that May Cause Low DO in the Long Branch Watershed

Based on Florida's Water Quality Criteria for Surface Water (Rule 62-302, F.A.C), the DO concentration for Class III freshwater bodies "shall not be less than 5.0 mg/L, and the normal daily and seasonal fluctuations above this level shall be maintained."

DO concentrations in ambient waters can be controlled by many factors, including the following:

DO solubility, which is controlled by temperature and salinity;

DO enrichment processes, which are influenced by reaeration and photosynthesis, which in turn are controlled by flow velocity and the presence of phytoplankton, periphyton, and other aquatic plants;

DO consumption, which is caused by the decomposition of organic materials in the water column and sediment, and by the oxidation of reductants such as ammonia and metals; and

Respiration from aquatic organisms.

Due to the limited time available, the Department did not conduct a comprehensive analysis to address each of these factors individually. Instead, it examined the overall effects of nitrogen, phosphorus, and BOD on DO concentrations in Long Branch. The analysis assumed that the existing regimes of temperature, flow velocity, and salinity would remain the same under the TMDL condition, and that oxygen consumption from aquatic organisms is the consequence of the influence of nitrogen, phosphorus, and BOD. The attainment of the DO target (5.0 mg/L) is based on the achievement of nitrogen, phosphorus, and BOD targets.

To evaluate the influence of nitrogen, phosphorus, and BOD on DO concentrations in Long Branch, correlation analyses were conducted using the TN, TP, and BOD data retrieved from the IWR database. The vast majority of TN, TP, BOD, and DO measurements for Long Branch were taken in 2002. As described in Chapter 2, DO measurements were primarily taken from the three monitoring stations (21FLCEN 20010374, 21FLCEN20010384, and 21FLCEN 20010395) located in the northern and southern tributaries and the main channel, respectively **(Figure 2.1).**

Longitudinal trends were found between DO and total Kjeldahl nitrogen (TKN) concentrations **(Figure 3.1)** in four sampling events, during which pairwise DO and TKN were measured at all three stations. This analysis used TKN instead of TN, because to calculate TN, some TKN measurements do not have nitrate/nitrite concentrations measured at the same time. For those TKN measurements that did have nitrate/nitrite measurements taken at the same time, nitrate/nitrite typically composed less than 10 percent of the TN (the long-term average portion of nitrate/nitrite in TN is about 8 percent). Therefore, TKN could be used as a reasonably good surrogate for TN for the correlation analysis. Significant negative correlations were observed between DO and TKN for all four sampling events examined. The TKN concentrations for the two tributary stations were consistently lower than the TKN concentration at the monitoring site on the main stem of Long Branch, while DO concentrations at the two tributary sites were consistently higher.

It is not known why the main channel station has higher TN concentrations than the two tributary sites. Examining land use and possible pollutant sources for the area directly discharging to the main channel did not identify any human sources that could cause the enhanced TN concentration. One possible source is sediment nutrient release from the wetland area that the main channel runs through.

No similar correlation was observed between DO and TP, and between DO and BOD along the longitudinal direction of the stream, suggesting that the low DO at the main stem site might be influenced by the elevated nitrogen concentration. Target TKN concentrations to achieve a 5 mg/L DO concentration were calculated for each sampling event based on the correlation equation shown in **Figure 3.1 (Table 3.1).** The final target TN concentration was calculated using Equation 1:

$$TN_{target} = TKN_{average} * (1+0.08) \qquad \textbf{(1)}$$

Where:
TN_{target} is the target TN concentration to achieve the 5.0 mg/L DO concentration, and
$TKN_{average}$ is the average for all the target TKN values from the four sampling events.

The value of 0.08 used in the above equation is the percent of nitrate/nitrite in the TN. It was obtained based on the percentage of nitrate/nitrate in the TN of all the sampling events during which both TKN and nitrate/nitrite were measured. The final TN target calculated using this method is 0.66*(1+0.08) = 0.71 mg/L.

Figure 3.1. Correlation between DO and TKN during Four Monitoring Events in 2002

Note: The red, blue, and green dots represent results from the northern and southern tributaries and main channel, respectively.

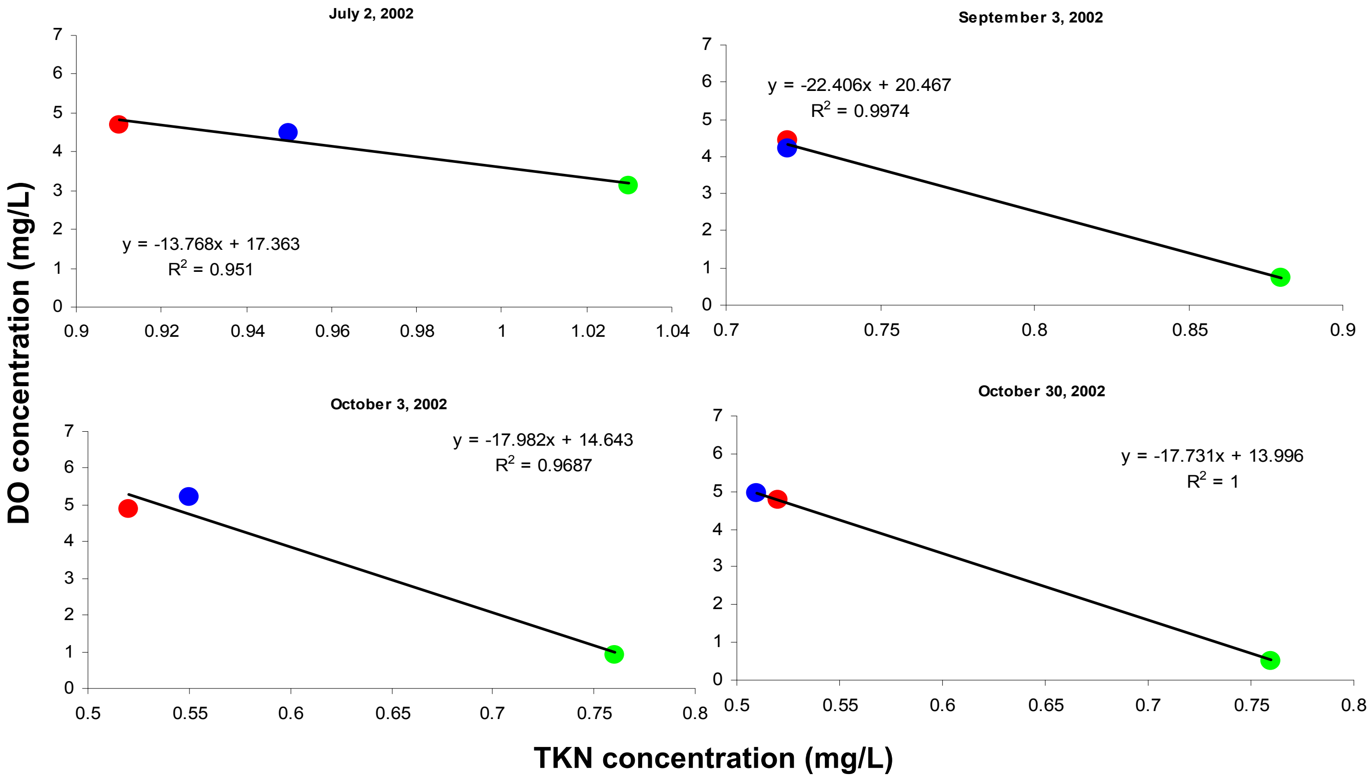


Table 3.1. Target TKN Concentrations To Achieve the DO Concentration of 5.0 mg/L During Four Sampling Events in 2002

Sampling Event	Target TKN (mg/L)
July 2, 2002	0.90
September 3, 2002	0.69
October 3, 2002	0.54
October 30, 2002	0.50
Average	**0.66**

Although no similar correlation was observed between DO and TP, and between DO and BOD, along the longitudinal direction of the stream, significant negative correlations were observed between DO and TP, and DO and BOD **(Figures 3.2a** and **3.2b),** when DO, TN, and TP data from the two tributaries were analyzed. This suggests that, at least for the tributary sites, TP and BOD could be the controlling factors for DO concentrations. As the DO, TP, and BOD measurements from the two tributaries were collected at different times of the year, water temperature could have influenced DO solubility. To avoid interference from the effects of temperature, DO concentrations were converted to DO saturation using Equation 2:

$$S = \frac{C_m}{C_s} * 100\% \qquad \textbf{(2)}$$

Where:

C_m is the measured DO concentration (mg/L), and
C_s is the saturated DO concentration at a given temperature (mg/L), calculated using the procedure specified by the American Public Health Association (1995).

Table 3.2 lists, for the sampling stations in the northern and southern tributaries to Long Branch, the sampling dates, temperatures under which DO were measured, measured DO concentrations, saturated DO concentrations, observed percent DO saturation (S), target percent DO saturation concentrations at 5.0 mg/L at different temperatures, and BOD and TP concentrations measured at the same time.

Figures 3.2a and 3.2b. (a) Correlations between DO and TP and (b) Correlations between DO and BOD

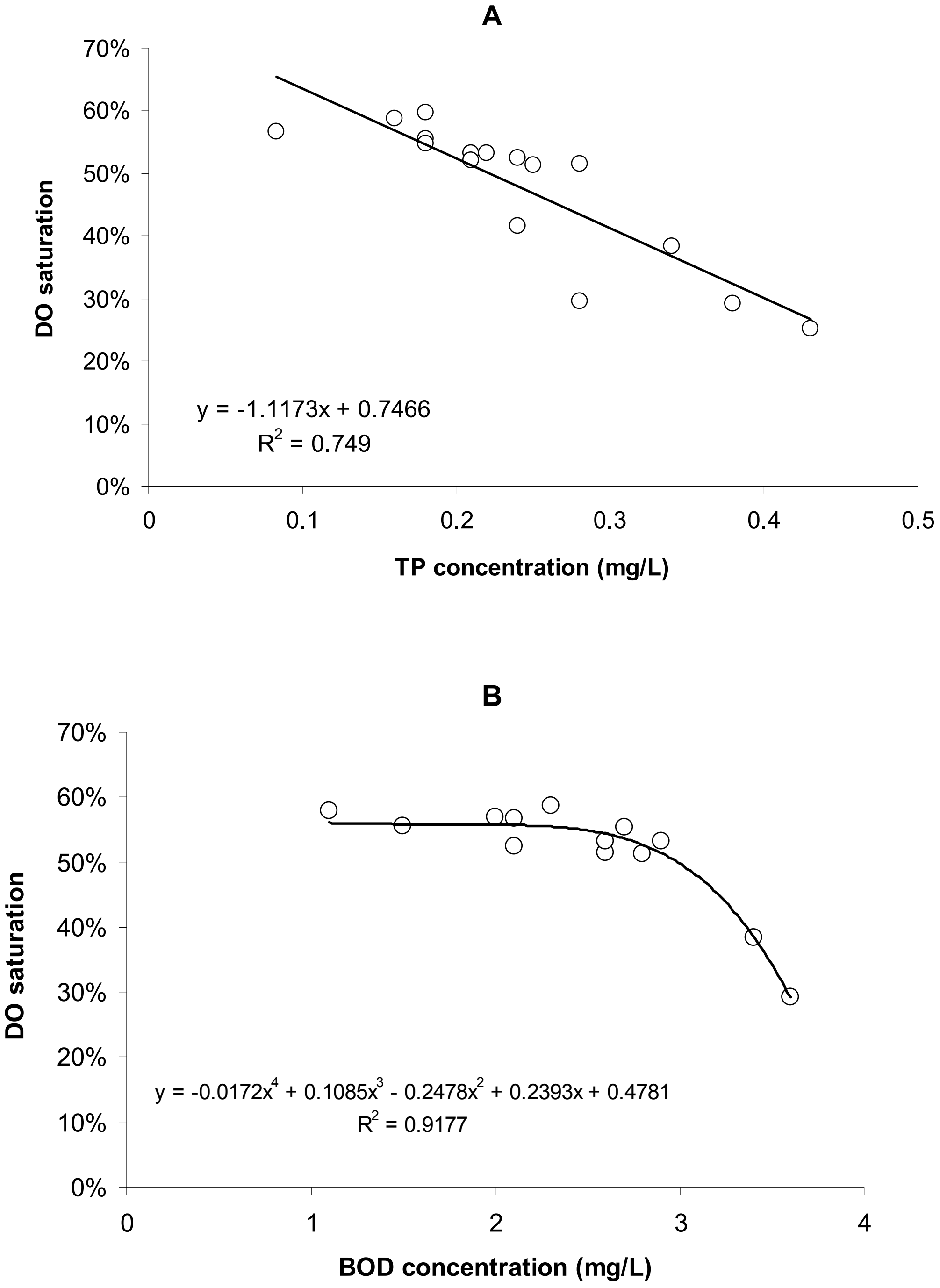


Table 3.2. DO, TP, and BOD Concentrations for the Northern and Southern Tributaries to Long Branch, WBID 3030

Station	Sampling Date	T (^{0}C.)	Observed DO (mg/L)	Saturated DO (mg/L)	Observed Saturation (%)	Target Saturation (%)	TP (mg/L)	BOD (mg/L)
Northern Tributary	07/02/2002	23.67	4.69	8.46	55%	59%	0.18	2.7
	09/03/2002	25.96	4.44	8.11	55%	62%	0.18	***
	09/16/2002	25.98	4.32	8.11	53%	62%	0.22	2.9
	10/22/2002	22.6	4.9	8.64	57%	58%	0.083	2.1
	10/30/2002	23.95	4.79	8.42	57%	59%	0.83*	2
Southern Tributary	01/25/1999	15.8	5.5	9.90	56%	50%	**	1.5
	07/12/2002	25.9	4.7	8.12	58%	62%	**	1.1
	03/18/2002	20.32	4.73	9.03	52%	55%	0.24	2.1
	04/30/2002	23.32	3.27	8.52	38%	59%	0.34	3.4
	05/15/2002	21.33	2.59	8.85	29%	56%	0.38	3.6
	06/05/2002	25.64	2.06	8.16	25%	61%	0.43	2
	06/19/2002	23.75	4.35	8.45	51%	59%	0.28	2.6
	07/02/2002	23.76	4.5	8.45	53%	59%	0.21	2.6
	09/03/2002	25.88	4.23	8.12	52%	62%	0.21	**
	09/16/2002	25.99	4.16	8.11	51%	62%	0.25	2.8
	10/22/2002	22.53	5.16	8.65	60%	58%	0.18	**
	10/30/2002	23.95	4.94	8.42	59%	59%	0.16	2.3
Mean			**4.31**	**8.50**	**51%**	**59%**	**0.24**	**2.41**

* The 0.83 mg/L TP was not used in the analyses because it was considered too high for this site.
** No measurement was available.

Based on **Table 3.2,** the 5 mg/L DO target concentration can be translated into an average 59 percent of DO saturation (shown in red in the table). The target TP concentration, based on the correlation equation shown in **Figure 3.2a,** is about 0.14 mg/L (the average TP concentration for the existing condition is 0.27 mg/L for the two tributary sites).

The influence of BOD on DO concentration is complex. When BOD is higher than 2.3 mg/L, a decrease in BOD appears to enhance DO saturation. Further decreases of BOD below the 2.3 mg/L level, however, do not stimulate any further increase in DO saturation—perhaps because Long Branch is a blackwater system that receives large amount of recalcitrant organic carbon from mixed hardwood wetlands and cypress swamps. The BOD analysis technique may not detect recalcitrant organic carbon, but some bacterial species can still use the carbon and consume oxygen. When the BOD concentration is lower than 2.3 mg/L, the organic carbon readily available to bacteria likely becomes insignificant in the total organic carbon pool, which contains a fairly large amount of recalcitrant organic carbon, and therefore a further decrease in BOD would not change the DO saturation significantly. Therefore, in this analysis, the target BOD concentration was set at 2.3 mg/L. The average BOD concentration for the existing condition is about 2.6 mg/L.

In summary, to achieve the target DO concentration of 5 mg/L, the required target TN, TP, and BOD concentrations for Long Branch are 0.71, 0.14, and 2.3 mg/L, respectively.

Chapter 4: ASSESSMENT OF SOURCES

4.1 Types of Sources

An important part of the TMDL analysis is the identification of pollutant source categories, source subcategories, or individual sources of pollutants in the basin and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either “point sources” or “nonpoint sources.” Historically, the term “point sources” has meant discharges to surface waters that typically have a continuous flow via a discernable, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term “nonpoint sources” was used to describe intermittent, rainfall-driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, agriculture, silviculture, and mining; discharges from failing septic systems; and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under the EPA’s National Pollutant Discharge Elimination System (NPDES) Program. These nonpoint sources included certain urban stormwater discharges, including those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see **Appendix A** for background information on the federal and state stormwater programs).

To be consistent with Clean Water Act definitions, the term “point source” is used to describe traditional point sources (such as domestic and industrial wastewater discharges) **AND** stormwater systems requiring an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL. However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this source assessment section does not make any distinction between the two types of stormwater.

4.2 Potential sources of TN, TP, and BOD in the Long Branch Watershed

4.2.1 Point Sources

No state- or NPDES-permitted facilities or wastewater sites were identified in the Long Branch watershed. There are four automobile junkyards at the northwest end of S. R. 50 and the north end of C. R. 13 in the watershed. These facilities, however, are not expected to discharge a significant amount of nitrogen, phosphorus, and BOD into ambient waters.

Municipal Separate Storm Sewer System Permittees

An Orange County Phase 1 MS4 permit covers the Long Branch watershed. Orange County and the Florida Department of Transportation (FDOT) are co-permittees. No Phase 2 MS4 permit was identified in the watershed.

4.2.2 Land Uses and Nonpoint Sources

No point sources were identified in the Long Branch watershed; TN, TP, and BOD loadings to Long Branch are generated primarily from nonpoint sources in the watershed. Nonpoint sources addressed in this report include loadings from surface runoff, baseflow contribution from the surficial aquifer, and the contribution from leaking septic tanks. TN, TP, and BOD loadings through these sources were estimated using the EPA Storm Water Management Model (SWMM) Version 5.0,[1] based on the imperviousness of the watershed and event mean concentrations (EMCs) of TN, TP, and BOD for different land use types in the watershed. The spatial distribution and acreage of different land use categories were identified using the St. Johns River Water Management District's (SJRWMD) 2000 land use coverage (scale 1:40,000) contained in the Department's geographic information system (GIS) library. Methods used to estimate the loadings of TN, TP, and BOD from various sources are discussed in detail later in this report.

Land Uses

Land use categories in the Long Branch watershed were aggregated using the simplified FLUCCS Level 1 codes and tabulated in **Table 4.1. Figure 2.1** shows the spatial distribution of different land use areas in the watershed.

As shown in **Table 4.1,** Long Branch drains about 3,625 acres of land. The dominant land use categories are agriculture and rangeland, which combined account for about 42 percent of the total watershed area. Urban and built-up land; residential; and transportation, communication, and utilities (basically roads) claim about 18 percent of the watershed area. About 36 percent remains natural lands, including water/wetland and forest.

Possible human sources of nitrogen, phosphorus, and BOD in the Long Branch watershed include surface runoff from residential and agricultural areas. The majority of the residential areas are located in the northern and north-central part of the watershed, between S. R. 50 and C. R. 13. These areas contain about 150 housing units, most of which are mobile homes. According to the OCEPD, all the residential areas in the watershed are on septic tanks. Failed septic tanks are therefore considered important potential sources of nutrients and BOD to Long Branch. The majority of the residential areas discharge into the northern tributary of Long Branch, with a smaller portion discharging to the southern tributary.

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[1] The EPA's SWMM model, originally developed by Metcalf & Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc., is a dynamic rainfall-runoff simulation model used for the single-event or long-term (continuous) simulation of runoff quantity and quality. The model simulates both runoff and instream routing processes. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of channels, pipes, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated in each subcatchment; the flow rate, flow depth, and quality of water in each channel and pipe during a simulation period comprise multiple time steps. SWMM 5.0 was produced by the Water Supply and Water Resources Division of the EPA's National Risk Management Research Laboratory, with assistance from the consulting firm CDM, Inc (Rossman, 2004).

Table 4.1. Classification of Land Use Categories in the Long Branch Watershed, WBID 3030

Level 1 Code	Land Use	Acreage	% Acreage
1000	Urban and built-up	286	8%
	Low-density residential	27	1%
	Medium-density residential	245	7%
	Rural residential	54	1%
2000	Agriculture	825	23%
3000	Rangeland	688	19%
7000	Barren land	7	0%
8000	Transportation, communication, and utilities	54	1%
4000	Forest/rural open	614	17%
5000/6000	Water/wetland	825	19%
	TOTAL	**3,625**	**100%**

Livestock production used to be an important agricultural practice in the watershed. Pastureland and rangeland are the dominant agricultural land uses. There were many horse farms in the southern and southeastern part of the watershed before 2000. In 2000, Orange County purchased the rangeland in the southeastern portion of the watershed, and horse farm activities there have since stopped. However, the remaining horse farms, in the southern part of the watershed, that mainly discharge to the southern tributary of Long Branch could contribute both nutrients and BOD from animal droppings that are washed off the land surface by rain, or from animals with direct access to the receiving waters.

Wetlands flank the lower reach of the main channel. Orange County and the SJRWMD also purchased agricultural areas along the main channel and returned them to wetlands. According to the OCEPD, these wetland areas form a buffer zone of about 500 feet on each side of the main channel, preventing the direct access of livestock. They also may reduce the amount of nutrients and BOD transported from the surrounding watershed into the main channel.

Estimating Nonpoint Loadings

GENERAL APPROACH

Estimating Nonpoint TN and TP Loadings Using EPA SWMM 5.0

In this analysis, the Long Branch watershed was divided into four subcatchments to accommodate the different land use characteristics in each subcatchment and to take advantage of the BOD, TN, and TP concentrations measured at the three water quality stations for model calibration. The subcatchments are as follows:

1. The northern subcatchment (S1), primarily discharging to the northern tributary upstream of Station 21FLCEN 20010374 **(Figure 2.1),**
2. The southern subcatchment (S2), primarily discharging into the southern tributary upstream of Station 21FLCEN 20010384,
3. The subcatchment discharging to the tributary segments between the two stations and the confluence of the stream (S3); and

4. The subcatchment areas discharging directly to the outlet of the main channel (S4).

Stream channels that receive discharges from these subcatchments are designated as conduits in SWMM, and were named C1, C2, and C3. They receive discharges from S1, S2, and S3, respectively, and also stream inflows from the corresponding upstream channels. S4 discharges to the outlet of the watershed (Out1).

To define the starting point of instream simulation, SWMM requires that the subcatchment discharge into conduits goes through discharge points called "junctions" (J). Thus, S1 discharges into C1 through J1, S2 discharges into C2 through J2, and so on for the discharges from other subcatchments. **Figure 4.1** shows the model scheme for the Long Branch watershed. **Appendix B** briefly introduces the mechanisms through which SWMM simulates hydrology and hydraulic processes.

Pollutant loading from the subcatchments can be simulated using a build-up and wash-off method in which pollutants are allowed to build up on the land surface during the no-rain period and wash off at a given rate during rainfall events. The pollutant loading can also be simulated as the product of surface runoff and the EMC of the pollutant under consideration. In this case, the model specifies the pollutant EMSs for different land use categories, and the total loadings are calculated based on the subcatchment runoff and EMCs.

Once the pollutants are transported into channels, they can be considered conservative, or a first-order decay rate can be assigned to them for their attenuation in the channel. For a watershed as small as Long Branch, decay is not usually suggested.

DATA REQUIREMENT FOR MODEL SIMULATION

Data are required to simulate four aspects of the pollutant loadings, as follows:

1. Subcatchment hydrology,
2. Ground water flow,
3. Pollutant loading from surface runoff, and
4. Instream hydraulic and pollutant concentration.

Data required for subcatchment hydrology simulation include the following:

Rainfall,

Evaporation,

Subcatchment area,

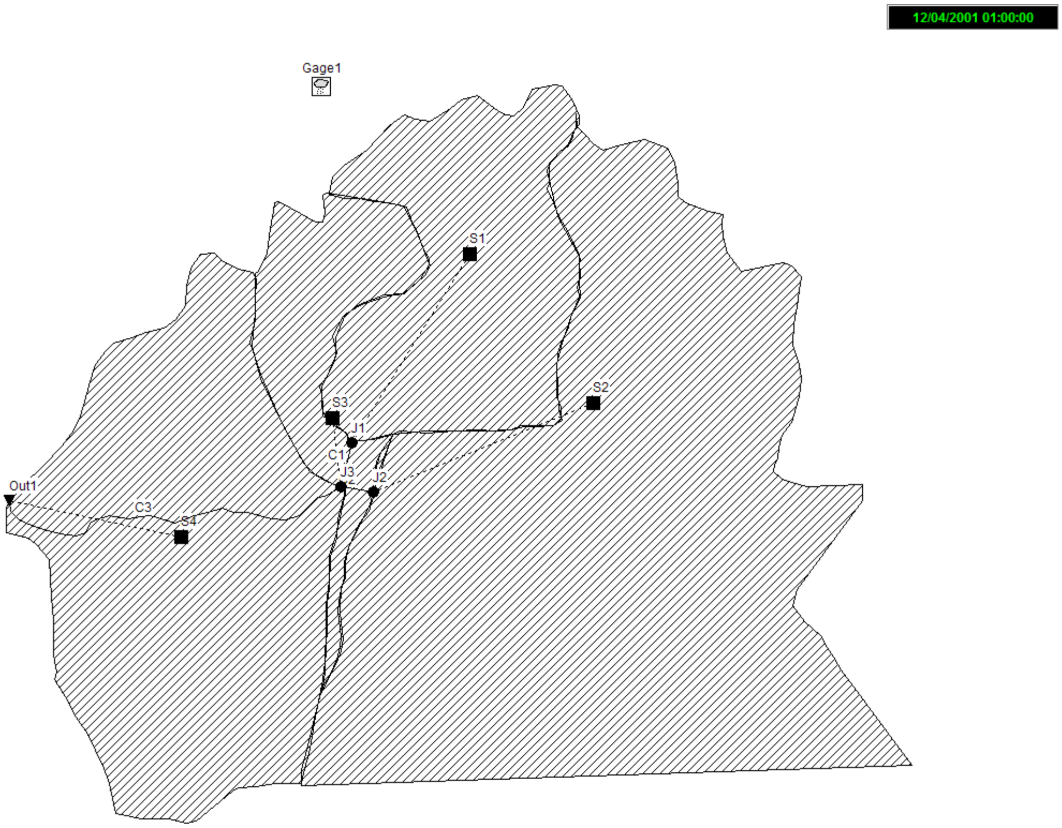
Subcatchment slope,

Directly connected impervious area (DCIA),

Manning's roughness coefficients for pervious and impervious areas,

Figure 4.1. Model Scheme for Long Branch Runoff and Channel Routing Simulation

Note: In the scheme, S represents the subcatchment. J represents the junction through which surface runoff discharges into the channel. C represents the channel (conduit) that receives water from the subcatchment and upstream channel. Gage1 represents the rainfall and evaporation time series that drives the runoff and stream flow.



Depression storage for pervious and impervious areas,

Percent impervious area without depression storage,

Soil suction head,

Soil saturation conductivity, and

Initial moisture deficit.

The SJRWMD provided daily rainfall data from January 1989 through May 2003 from a weather station located at Storey Ranch, in Orange County (Latitude 283325.85, Longitude 810758.95). As no evaporation information was available at the Storey Ranch station, daily evaporation data were obtained from a weather station located in Lisbon, Florida (UCAN: 4025, COOP: 085076). To avoid the possible daily difference between areas, long-term average daily evaporations were calculated for each month of the year based on the Lisbon data and applied in the modeling. **Table 4.2** shows the daily average evaporation for the different months used in this analysis. **Table 4.3** tabulates all the other model parameters used in simulating the subcatchment hydrology.

Sensitivity analyses indicated that surface runoff was most sensitive to the change of percent impervious area of the watershed. This analysis used DCIA to represent the percent impervious area. The percent DCIA was calculated using Equation 3.

$$\%DCIA = \frac{DCIA}{A} \qquad \textbf{(3)}$$

Where:

DCIA is the area of the directly connected impervious area (in acres) in a given subcatchment, and
A is the total area of the subcatchment (in acres).

The total DCIA for each subcatchment was calculated as the sum of the DCIAs of all the land use categories in the watershed. The DCIA for each land use category was calculated as the product of the total area and the percent DCIA of the land use category obtained from published literature **(Table 4.4).**

The SWMM User Manual (Rossman, 2004) proposes Manning's roughness coefficients for several land use types, including light underbrush (0.42), dense underbrush (0.80), smooth asphalt (0.011), and smooth concrete (0.012). In this analysis, the roughness coefficients for agriculture, rangeland, and barren land were considered similar to those of light underbrush, forest was similar to dense underbrush, transportation was similar to smooth asphalt, and urban and built-up was similar to smooth concrete. Area-weighted subcatchment average Manning's roughness coefficients for both pervious (total watershed area minus DCIA) and pervious (DCIA) areas were calculated for each subcatchment **(Table 4.4).**

Table 4.2. Long-term Average Daily Evaporations of Different Months Using SWMM Model Simulation

Month	Long-term Daily Average for Different Months (inches/day)
January	0.06
February	0.09
March	0.16
April	0.20
May	0.25
June	0.22
July	0.22
August	0.20
September	0.17
October	0.13
November	0.07
December	0.05

Table 4.3. Model Parameters Used in the SWMM Subcatchment Hydrology Simulation

Parameters	S1	S2	S3	S4
Subcatchment area (acre)	561	1,826	246	994
Subcatchment slope (%)	0.44	0.33	0.80	0.73
Percent impervious area (DCIA %)	14	11	10	8
Manning's roughness coefficient for pervious area	0.2	0.48	0.32	0.46
Manning's roughness coefficient for impervious area	0.03	0.06	0.03	0.06
Depression storage for pervious area (inches)	0.2	0.2	0.2	0.2
Depression storage for impervious area (inches)	0.05	0.05	0.05	0.05
Percent impervious area without depression storage (%)	25	25	25	25
Soil suction head (inches)	1.93	1.93	1.93	1.93
Soil saturation conductivity (inches/hour)	4.74	4.74	4.74	4.74
Initial moisture deficit (%)	4	4	4	4

Table 4.4. Area-weighted Mean Percent DCIA and Manning's Coefficients for Pervious and Impervious Area Used in This Analysis

Subcatchment	Land Use	Area (acre)	% Area	DCIA (%)*	Area-weighted % DCIA	n**	Area-weighted n for Pervious Area	Area-weighted n for Impervious Area
S1	Agriculture	102	18%	1.0	0.18	0.4	0.072	0.001
	Barren Land	0	0%	0.5	0.00	0.4	0.000	0.000
	Rangeland	9	2%	1.0	0.02	0.4	0.007	0.000
	Transportation, Communication, and Utilities	12	2%	36.2	0.80	0.011	0.000	0.000
	Upland Forest	42	8%	1.0	0.08	0.8	0.060	0.001
	Urban and Built-up	302	54%	15.0	8.10	0.012	0.006	0.001
	Water	64	11%	30.0	3.41	0.4	0.032	0.014
	Wetland	28	5%	30.0	1.50	0.8	0.028	0.012
	Total/average	559	100%		**14.08**		**0.20**	**0.03**
S2	Agriculture	248	14%	1.0	0.14	0.4	0.054	0.001
	Rangeland	425	23%	1.0	0.23	0.4	0.092	0.001
	Transportation, Communication, and Utilities	29	2%	36.2	0.58	0.011	0.000	0.000
	Upland Forest	438	24%	1.0	0.24	0.8	0.190	0.002
	Urban and Built-up	197	11%	15.0	1.62	0.012	0.001	0.000
	Water	75	4%	30.0	1.24	0.4	0.012	0.005
	Wetland	412	23%	30.0	6.77	0.8	0.126	0.054
	Total/average	1824	100%		**10.82**		**0.48**	**0.06**
S3	Agriculture	62	26%	1.0	0.26	0.4	0.101	0.001
	Barren Land	7	3%	1.0	0.03	0.4	0.011	0.000
	Rangeland	4	2%	1.0	0.02	0.4	0.007	0.000
	Transportation, Communication, and Utilities	3	1%	36.2	0.50	0.011	0.000	0.000
	Upland Forest	44	18%	1.0	0.18	0.8	0.141	0.001
	Urban and Built-up	100	41%	15.0	6.13	0.011	0.004	0.001
	Wetland	24	10%	30.0	2.94	0.8	0.055	0.024
	Total/average	244	100%		**10.05**		**0.32**	**0.03**
S4	Agriculture	413	42%	1.0	0.42	0.4	0.165	0.002
	Rangeland	249	25%	1.0	0.25	0.4	0.099	0.001
	Transportation, Communication,	9	1%	36.2	0.32	0.011	0.000	0.000

Subcatchment	Land Use	Area (acre)	% Area	DCIA (%)*	Area-weighted % DCIA	n**	Area-weighted n for Pervious Area	Area-weighted n for Impervious Area
	and Utilities							
	Upland Forest	90	9%	1.0	0.09	0.8	0.072	0.001
	Urban and Built-up	10	1%	15.0	0.15	0.012	0.000	0.000
	Water	1	0%	30.0	0.03	0.4	0.000	0.000
	Wetland	221	22%	30.0	6.67	0.8	0.124	0.053
	Total/average	992	100%		**7.93**		**0.46**	**0.06**

* Based on the User's Manual, Watershed Management Model, Version 4.1, 1998; Brown, 1995; and Harper and Livingston, 1999.
n** Manning's roughness coefficient
Note: Bold numbers are the area-weighted percent DCIA and Manning's coefficients for pervious and impervious areas.

The USGS 1:100,000 quadrangle map was used to estimate the percent slope for each subcatchment. This was estimated as the ratio between the change in land surface elevation along a given slope and the length of the slope. Twenty randomly selected slope profiles (the change in surface elevation and length of the slope) were measured and percent slope calculated for each subcatchment, and the average percent slope was calculated. The average percent slope was used for the subcatchment simulation. Values for soil suction head, soil saturation conductivity, and initial moisture deficit used in this analysis were based on recommended values for sandy soil by the SWMM 5.0 User Manual **(Table 4.3).** No site-specific values for depression storage for pervious and impervious areas, or for percent impervious area with no depression storage, were available at the time this analysis was conducted. Therefore, these values were adjusted for surface runoff calibration.

Ground Water

Ground water is a significant part of the total stream flow for the Long Branch watershed. Based on a study by Wanielista et al. (1993), up to 80 percent of the stream flow in the Econ River watershed could come from baseflow. As site-specific information on ground water flow was not available for this analysis, ground water flow was not simulated. The contribution from ground water flow was estimated through baseflow separation analysis using a set of continuous daily flow values derived for the Long Branch outlet. The baseflow from each subcatchment was then estimated, based on the baseflow at the outlet of the whole watershed and the acreage of each subcatchment. The model calibration section describes in detail the procedures used in this analysis to derive the total stream flow at the watershed outlet.

Simulation of Pollutant Loadings from Each Subcatchment

Pollutant loadings, including TN, TP, and BOD, from each subcatchment were estimated as the product of subcatchment surface runoff and the EMCs of these pollutants. In this study, the EMCs for TN, TP, and BOD for different land use types were adjusted to match the model simulation with measured data. The model calibration section describes the detailed water quality calibration.

Instream Hydraulics and Pollutant Concentration Simulation

Major outputs for the instream simulation used in this analysis include total stream flow and pollutant concentrations. Total stream flow includes subcatchment surface runoff and baseflow. As discussed previously, the analysis did not simulate baseflow. Instead, baseflow derived using a baseflow separation analysis was added to total stream flow in the “conduit” as direct inflow to the beginning point of the channel, or “junction,” of each conduit (consult the SWMM 5.0 User Manual for details).

Data required for instream hydraulic simulation include the following:

Geometry of the channel cross-section (assumed to be parabolic),

Invert elevation of the channel (conduit, in feet),

Maximum depth of the channel (in feet),

Top width (in feet),

Length of the channel segment (in feet),

Channel roughness coefficient, and

Direct inflow to the junction (the beginning point of the channel, in cubic feet per second [cfs]).

Table 4.5 tabulates the values of these data and model parameters for each channel (conduit).

Table 4.5. Data Required for Instream Hydraulic Simulation

Parameter	Channel 1 (C1)	Channel 2 (C2)	Channel 3 (C3)
Invert elevation (feet)	48.8	50.7	39.5
Maximum depth (feet)	2.9	1.5	3.6
Top width (feet)	36	27	42
Channel segment length (feet)	853	509	5,600
Channel roughness	0.03	0.03	0.03
Direct inflow (cfs)	Time series	Time series	Time series

The Department calculated channel cross-section values, including invert elevation, maximum depth, and top width, based on data provided by CDM. Segment lengths were measured using GIS waterline coverage. The channel roughness coefficient was used as a calibration factor. It influences flow velocity but not total stream flow. Direct inflow represents baseflow contribution to total stream flow. As discussed in the previous section, baseflow to each stream channel segment was estimated based on the baseflow time series at the Long Branch outlet and the acreage of the subcatchment discharging to the stream channel segment under evaluation.

TN and TP concentrations in baseflow were considered the same as those of the surficial aquifer, which was estimated as the median values of the data obtained from a monitoring well located in the Long Branch watershed (Well ID: OR0264). **Figure 4.2** shows the location of the well supplying the ground water data used in this analysis. Median values of TN and TP concentrations used in this analysis of the baseflow contribution were 0.43 and 0.06 mg/L, respectively.

BOD is not a routinely monitored parameter for ground water wells, and no BOD ground water concentrations were available at the time this analysis was conducted. Therefore, the stream BOD concentration measured during the lowest flow condition was considered the baseflow concentration, assuming that, under the low-flow condition, most of the stream flow is baseflow. This analysis used 2.2 mg/L as the baseflow concentration.

The final concentrations for BOD, TN, and TP were simulated by SWMM 5.0 based on the subcatchment runoff, EMC, ground water contribution, and ground water BOD, TN, and TP concentrations.

Model calibration

Model calibration includes the calibration of total stream flow and BOD, TN, and TP concentrations for stream flow. Flow calibration was conducted using a stream flow time series derived for the Long Branch outlet. Because no measured flow data were available for the Long Branch watershed, flow measurements from two USGS gaging stations (Station 02233484, on the Econ River near Oviedo, Latitude $28^{0}39'19''$, Longitude $81^{0}10'12''$; and Station 02233500, on the Econ River near Chuluota, Latitude $28^{0}40'40''$, Longitude $81^{0}06'51''$) were used for deriving the flow for Long Branch. Flow measurements from both USGS gaging stations were downloaded from the USGS water resource Web site (http://waterdata.usgs.gov/usa/nwis/sw). **Figure 4.3** shows the locations of these stations.

As both stations measure the flow in the main stem of the Econ River, the areas of the watersheds draining to these stations are much larger than the Long Branch watershed area, and the characteristics of these watersheds differ from those of the Long Branch watershed. According to the USGS water resource Web site, the watershed area draining to Station 02233484 is about 228.6 square miles, and the watershed area draining to Station 02233500 is about 241 square miles. The watershed area for the Long Branch watershed is about 5.7 square miles. Therefore, deriving the flow for the Long Branch watershed directly based on either station would not be reasonable.

However, as the two USGS gaging stations are located very close to each other, the difference in the flow between these two stations is the surface runoff contributed by a relatively small watershed **(Figure 4.3).** This small watershed, called the Oviedo–Chuluota (OC) watershed, was designated as the reference watershed in this analysis. The area of the OC watershed is 241 square miles minus 228.6 square miles, or 12.4 square miles. The area ratio between the OC and Long Branch watersheds is about 12.4/5.7 = 2.2, which is allowable for applying the basin ratio method to develop the flow for an ungaged watershed.

Land use patterns in the OC watershed were analyzed and compared with those of the Long Branch watershed. **Table 4.6** lists the percent land use for both the OC and Long Branch watersheds. The distribution of percent land use is generally similar, except that the OC watershed has relatively more wetland area and the Long Branch watershed has more rangeland area. Wetlands usually have a higher runoff coefficient than rangeland. Therefore, using the stream flow from the OC watershed to derive the stream flow for the Long Branch watershed may, to some extent, overestimate the actual flow for Long Branch.

Figure 4.2. Location of the Surficial Aquifer Well and Subcatchment Delineation in the Long Branch Watershed, WBID 3030

Note: The red circle indicates the well location.

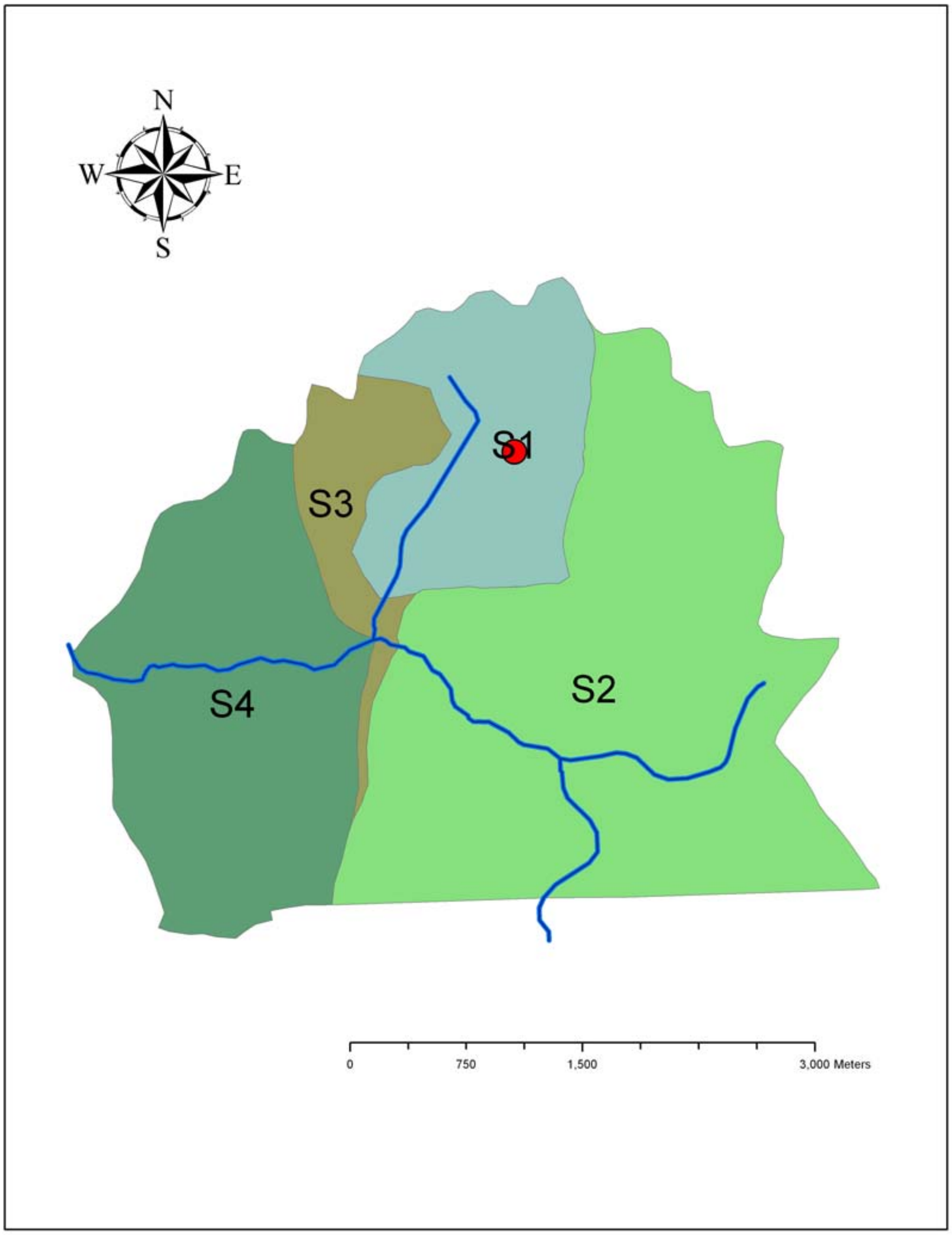


Figure 4.3. Locations of USGS Gaging Stations Used to Derive the Stream Flow Measurements for the Long Branch Watershed, WBID 3030

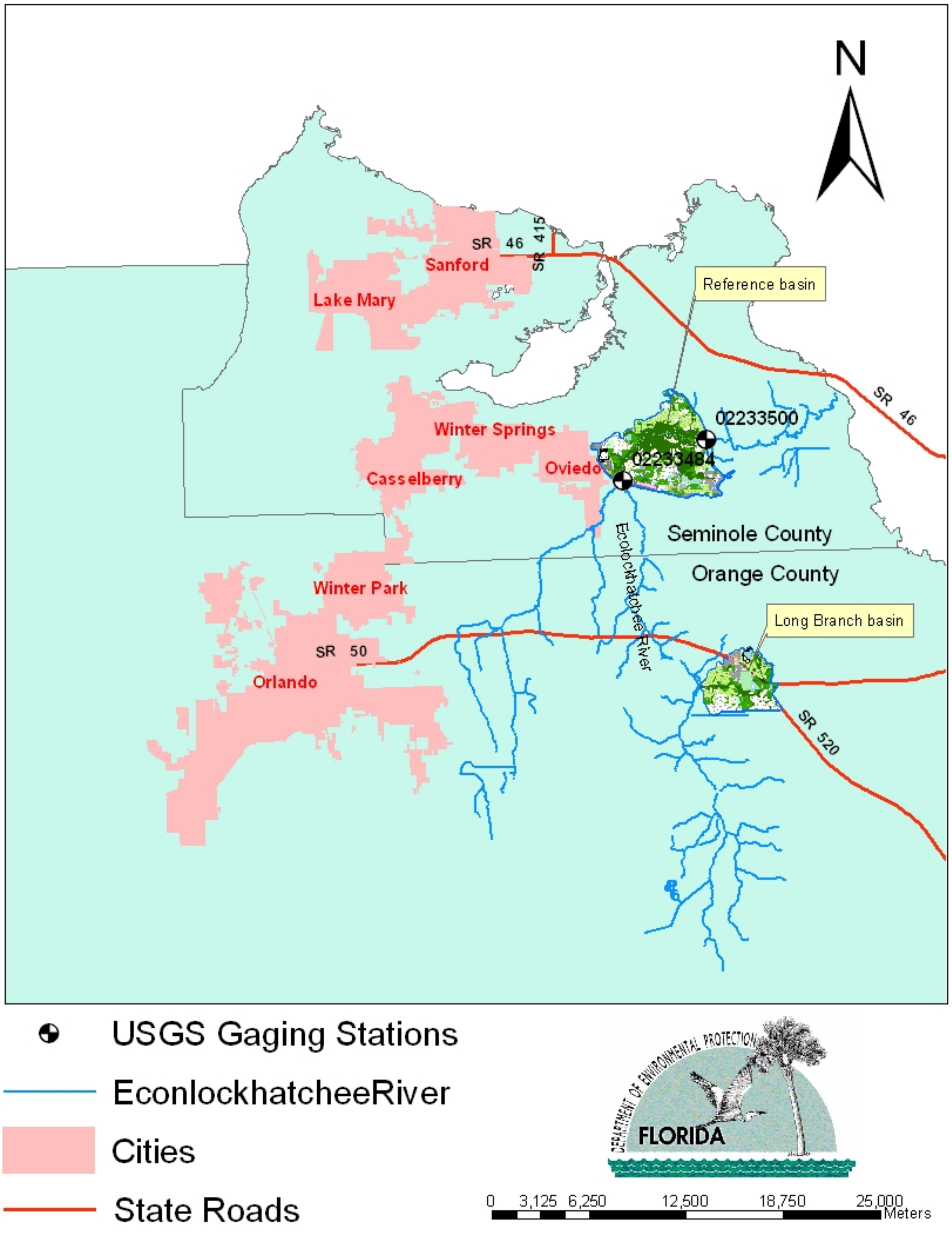


Table 4.6. Land Use Patterns in the Long Branch and OC Watersheds

FLUCCS Level 1	Description	OC Watershed	Long Branch Watershed
1000	Urban and Built-up	10%	16%
2000	Agriculture	20%	24%
3000	Rangeland	6%	19%
4000	Upland Forest	19%	17%
5000	Water	3%	4%
6000	Wetland	41%	19%
7000	Barren Land	0%	0%
8000	Transportation	1%	1%

The hydrologic characteristics of the soil in both the Long Branch and OC watersheds were also analyzed. For Long Branch, B/D, C, and D soils, which have relatively low permeability but a high potential to produce surface runoff, account for about 98 percent of all the soil acreages in the watershed. Water and some unidentified soils account for the remaining 2 percent. For the OC watershed, B/D, C, and D soils account for about 84 percent of the watershed area, while A soil, which has a relatively high permeability and low potential to produce surface runoff, accounts for 14 percent. Water and other unidentified soils account for the remaining 2 percent.

The higher percentage of B/D, C, and D soils in the Long Branch watershed than in the OC watershed may result in more surface runoff in the former. This trend tends to compensate for the trend in the land use pattern, which suggests that the OC watershed, with more wetland areas, may produce more runoff than the Long Branch watershed.

The total flow contributed by the OC watershed (including surface runoff and baseflow) was calculated as the difference in flow measured at the two USGS gaging stations. Because the flow measurements at these two stations are substantially larger than the difference in flow between the two stations, the estimates of the flow contribution from the OC watershed will be affected by any error in the flow measurements. To minimize this interference, the following steps were taken:

1. Annual average daily flows were calculated for both gaging stations,
2. An average ratio between the long-term annual average daily flows for the two gaging stations was estimated,
3. The long-term average ratio was multiplied by the daily flow measurement of the upstream station (USGS 02233484) to produce the flow measurement for the downstream station (USGS 02233500), and
4. The difference between the calculated flow at the downstream station (USGS 02233500) and the measured flow at the upstream station (USGS 02233484) was considered to be the flow contribution from the OC watershed.

Flow measurements for the period between December 4, 2001, and September 30, 2003, for both USGS gaging stations were used to conduct the calculation discussed previously, because this is the only period of record for both stations. **Table 4.7** lists the annual average daily flow and the ratio between the daily flows of the two stations. The long-term average ratio between annual average daily flows from the two stations was calculated as the flow at USGS 02233500 divided by the flow at USGS 02233484, which is about 106 percent. The flow for USGS gaging Station 02233500 was calculated by multiplying the flow measurement at Station 02233484 by the flow ratio. The flow contribution from the OC watershed was calculated as the difference between the calculated flow at USGS 02233500 and the measured flow at USGS 02233484.

Table 4.7. Annual Average Daily Flows and the Ratio between Annual Average Daily Flows Measured at USGS Gaging Stations 02233484 and 02233500, 2000–02

Year	Annual Average Daily Flow for USGS 02233484 (cfs)	Annual Average Daily Flow for USGS 02233500 (cfs)	Difference of Average Daily Flow between the Two Stations (cfs)	Ratio of Average Daily Flow, Station 02233500/02233484 (%)
2000	91	97	6	106%
2001	408	431	23	106%
2002	465	488	24	105%

Because the watershed area ratio between the OC and Long Branch watersheds is about 2.2, the daily flows at the Long Branch outlet were derived by dividing the flow of the OC watershed by 2.2.

The SWMM-simulated stream flow at the Long Branch outlet to the Econ River was calibrated against the flow time series established using the method described above. **Figure 4.4** shows the calibration results at the outlet. Based on **Figure 4.4**, the model-simulated results generally fit the flow time series established for the outlet, except for the period between December 4, 2002, and February 4, 2003, when the model-simulated results were significantly lower than the established time series.

An examination of the rainfall time series indicated that there was no rain during this period at the Storey Ranch weather station **(Figure 4.5).** The difference between the model-simulated stream flow and the flow established for the Long Branch outlet could have occurred because rainfall in the Long Branch and OC watersheds, where stream flow was used to derive the stream flow for Long Branch, differed for this period. Based on **Figure 4.5**, rainfall records at the Storey Ranch weather station appear to be consistent with the established flow at the Long Branch outlet in all the other periods used for model calibration.

Figure 4.4. Results of Stream Flow Calibration

Note: The "measurement" time series is the flow time series established for the Long Branch outlet, using the method described in the text.

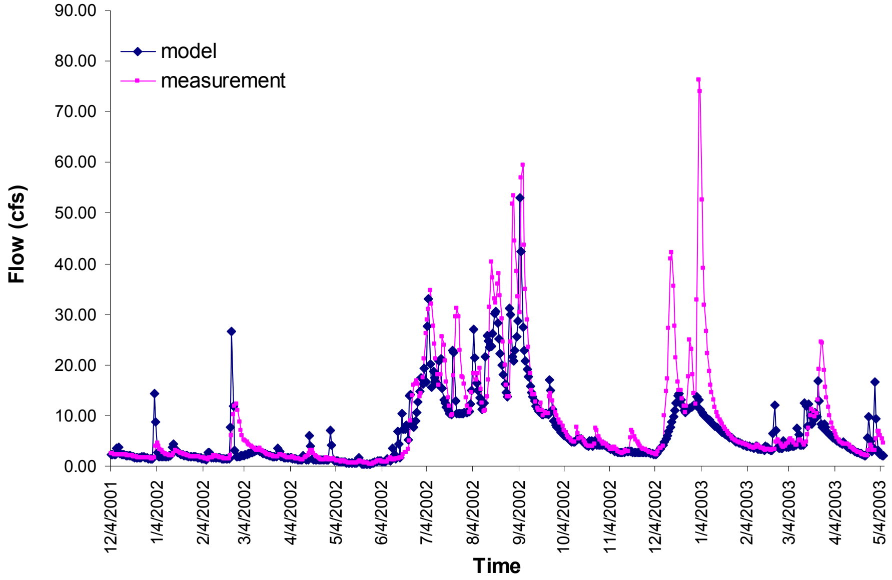
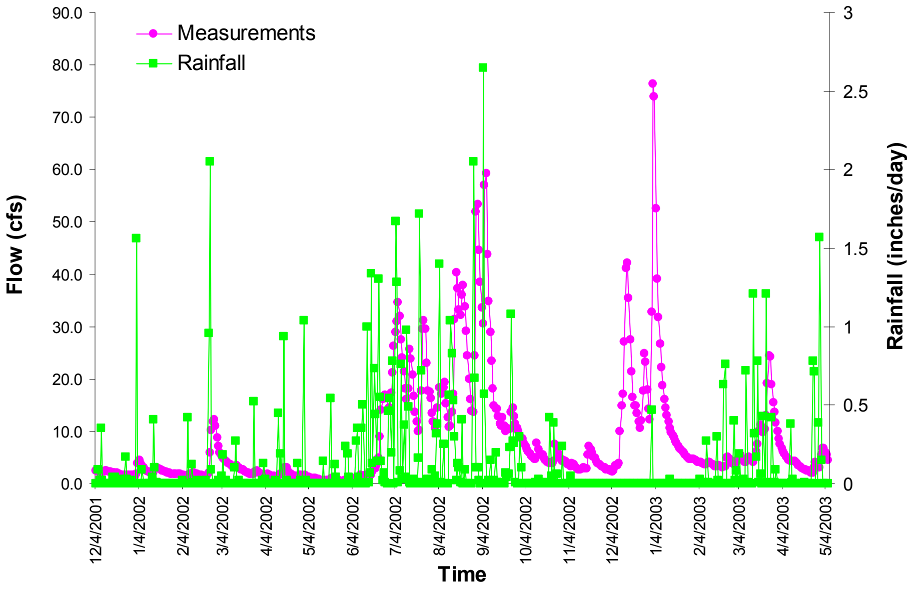


Figure 4.5. Flow Established for the Outlet of the Long Branch Watershed and Rainfall at the Storey Ranch Weather Station



The calibration of BOD, TN, and TP concentrations in Long Branch was conducted using the BOD, TN, and TP concentrations measured at the three monitoring stations described in previous sections. **Figures 4.6a** through **4.6c, 4.7a** through **4.7c,** and **4.8a** through **4.8c** show the calibration results for BOD, TN, and TP concentrations at these stations.

The majority of the EMCs for BOD, TN, and TP used in this analysis were from PBS&J for the Middle St. Johns area, except for the EMCs for agriculture and urban land uses. Because most agricultural land use in the Long Branch watershed is pastureland, the EMCs for pastureland were used to simulate pollutant loading from the watershed's agricultural area (Harper and Baker, 2003). The EMCs for urban land use were adjusted to account for the possible input from failed septic tanks. According to the OCEPD, the entire residential area in the Long Branch watershed is on septic tanks. Therefore, this analysis used relatively high BOD, TN, and TP values to calibrate the model. These values are allowed by the SWMM 5.0 User Manual for runoff from urban areas. **Table 4.8** tabulates the EMCs used in this analysis.

This analysis used a new land use type, feeding operation, to account for the possible high concentration of runoff from horse farms. This land use category was only used in simulating pollutant loading from the agricultural area of Subcatchment 2, which primarily drains to the southern tributary of Long Branch. TN and TP EMCs as high as 78 and 7 mg/L, respectively, were reported for animal-feeding operations (Fulton et al., 2003). Because information on the exact number of horses in the watershed and the length of time animals were kept on ranches was not available at the time this analysis was conducted, the EMCs for this land use type were used to calibrate the BOD, TN, and TP concentrations measured in the southern tributary.

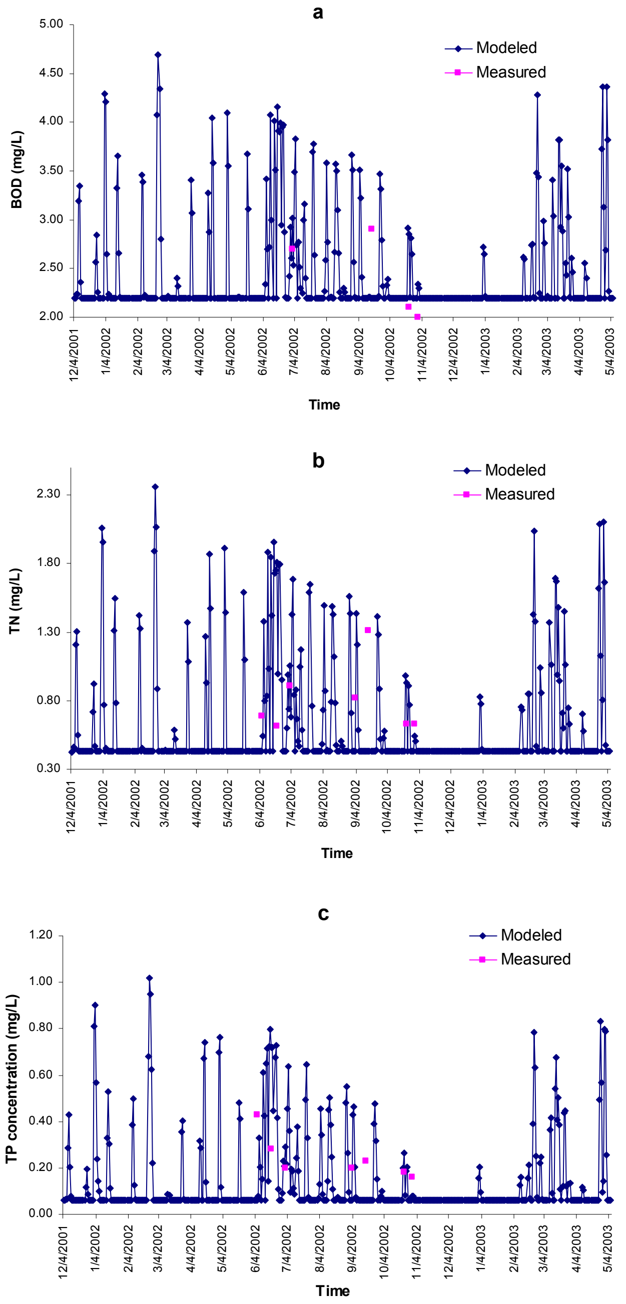
In this analysis, extra loadings of BOD and TN were added to the main channel of Long Branch to account for elevated BOD and TN concentrations. Why BOD and TN concentrations in the main channel are higher than those in the tributaries is not known. They may be caused by sediment nutrient release from the wetland area and the accumulation of BOD due to the input from the cypress swamp and low-flow velocity.

According to **Figures 4.6a** through **4.6c, 4.7a** through **4.7c,** and **4.8a** through **4.8c**, model-simulated BOD, TN, and TP concentrations are generally consistent with the measured BOD, TN, and TP concentrations.

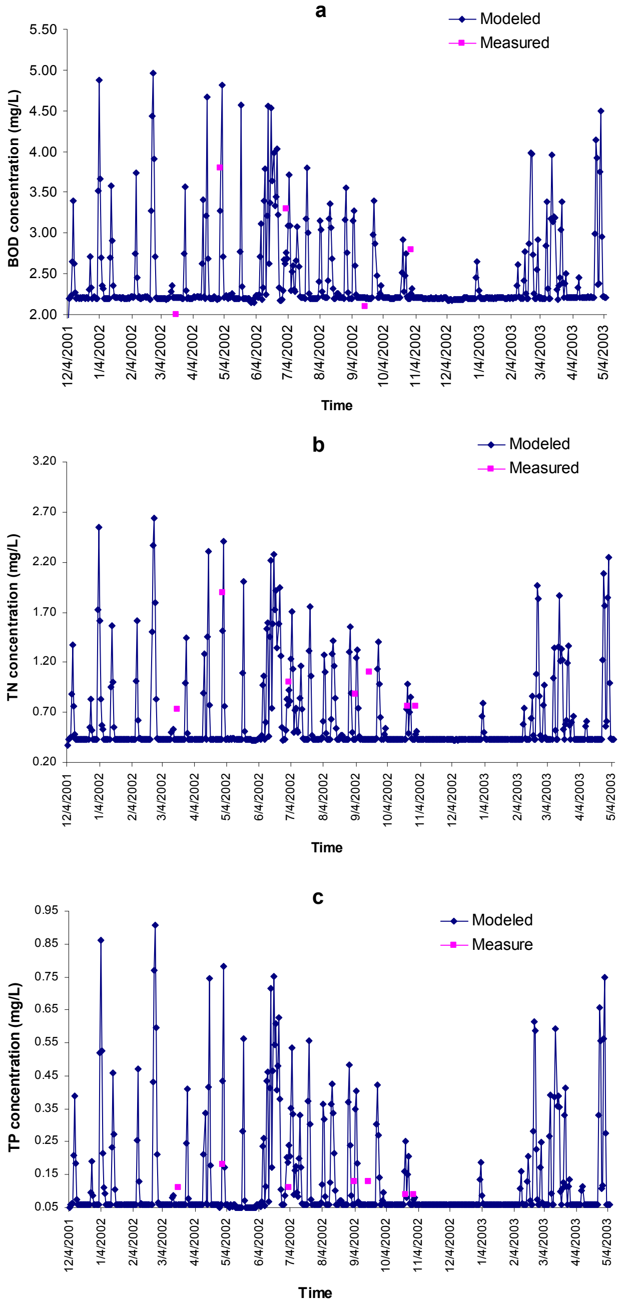
Table 4.8. EMCs for BOD, TN, and TP for Different Land Use Types

Land Use	BOD	TN	TP
Agriculture	5.10	2.48	0.476
Feeding Operation	16.00	9.80	6.530
Rangeland	1.50	1.25	0.050
Barren Land	1.50	1.25	0.050
Urban and Built-up	6.00	3.00	0.880
Transportation, Communication, and Utilities	5.60	1.87	0.280
Upland Forest	1.50	1.25	0.050
Water	1.60	1.25	0.110
Wetlands	4.63	1.60	0.19

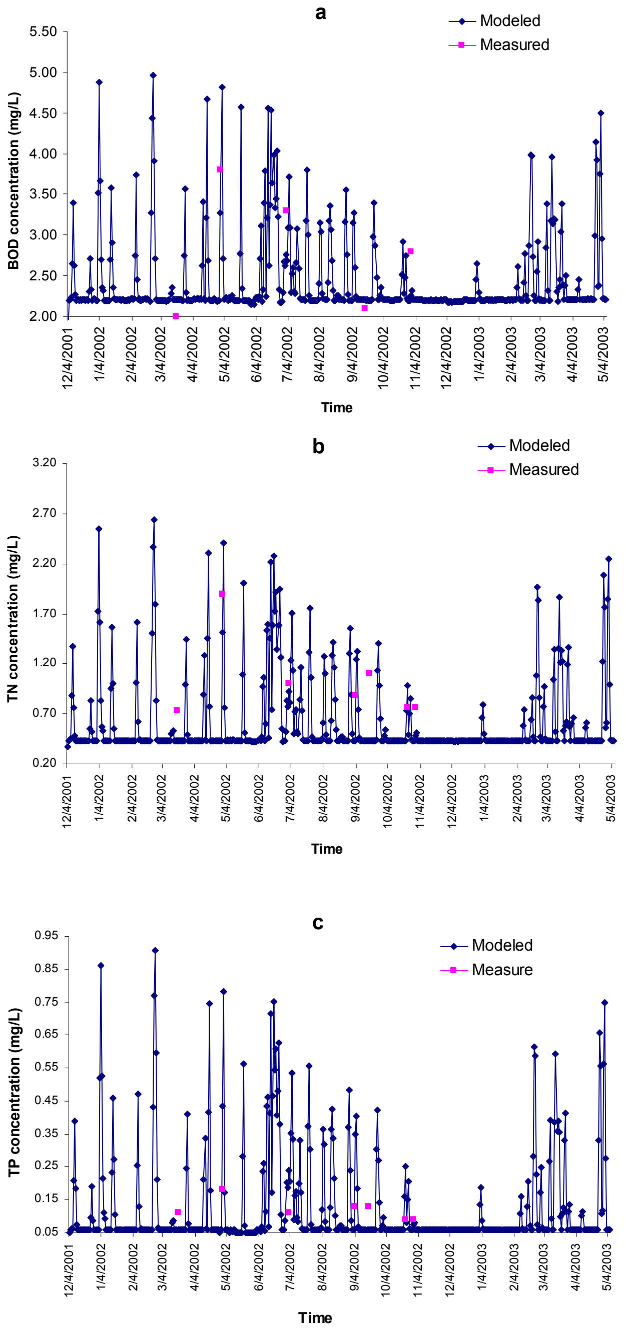
Figures 4.6a, 46.b, and 4.6c. Model Calibration Results for the Water Quality Monitoring Station Located on the Northern Tributary of Long Branch: (a) BOD, (b) TN, and (c) TP concentrations



Figures 4.7a, 4.7b, and 4.7c. Model Calibration Results for the Water Quality Monitoring Station Located on the Main Channel of Long Branch: (a) BOD, (b) TN, and (c) TP concentrations



Figures 4.8a, 4.8b, and 4.8c. Model Calibration Results for the Water Quality Station Located on the Main Channel of Long Branch: (a) BOD, (b) TN, and (c) TP Concentrations



ESTIMATES OF EXISTING POLLUTANT LOADS

Pollutant loadings from each subcatchment were calculated by multiplying the amount of surface runoff from each subcatchment by the pollutant concentrations of the runoff. Loadings contributed by baseflow were calculated by multiplying baseflow by the baseflow BOD, TN, and TP concentrations. As discussed previously, ground water flow was not simulated due to a lack of information, and separated baseflow was entered into model junctions as direct inflows. Because separated baseflow was only available for the period between December 4, 2001, and September 30, 2003, annual pollutant loadings were only calculated for 2002.

Table 4.9 lists the flow and pollutant loadings from four subcatchments and baseflow, as well as from unknown sources of high TN and BOD in the main channel. **Table 4.10** lists the percent contribution from each subcatchment and baseflow, and **Table 4.11** lists the per-acre flow and pollutant contribution from each subcatchment.

Table 4.9. Flow and Pollutant Loadings from Subcatchments and Baseflow

Source	Flow (acre-feet/year)	BOD loading (tons/year)	TN loading (tons/year)	TP loading (tons/year)
Subcatchment 1	170	0.98	0.50	0.12
Subcatchment 2	394	2.31	1.32	0.52
Subcatchment 3	57	0.31	0.16	0.03
Subcatchment 4	175	0.78	0.39	0.06
Unknown sources for the main channel	0	0.25	1.53	0
Baseflow	4426	12.01	2.35	0.33
Total	5222	16.65	6.24	1.06

Table 4.10. Percent Flow and Loadings Contribution from Subcatchments and Baseflow

Source	Flow	BOD loading	TN loading	TP loading
Subcatchment 1	3.3%	5.9%	8.0%	11.3%
Subcatchment 2	7.5%	13.9%	21.1%	49.3%
Subcatchment 3	1.1%	1.9%	2.5%	3.3%
Subcatchment 4	3.4%	4.7%	6.2%	5.3%
Unknown sources for the main channel	0.0%	1.5%	24.5%	0.0%
Baseflow	84.8%	72.1%	37.6%	30.9%

Table 4.11. Per-acre Flow and Pollutant Loadings from Each Subcatchment

Source	BOD loading (kg/acre/year)	TN loading (kg/acre/year)	TP loading (kg/acre/year)
Subcatchment 1	1.75	0.89	0.21
Subcatchment 2	1.27	0.72	0.29
Subcatchment 3	1.26	0.64	0.14
Subcatchment 4	0.79	0.39	0.06

Based on **Tables 4.9** and **4.10**, the total discharge at the Long Branch outlet is about 5,222 acre-feet/year, of which 4,426 acre-feet/year come from baseflow, and 796 acre-feet/year come from surface runoff. Baseflow accounts for about 84.8 percent of total stream flow. This is consistent with the study by Wanielista et al. (1993), which showed that the baseflow contribution for the Econ watershed is about 80 percent. In addition, baseflow contributes about 37.8 and 30.9 percent of TN and TP loadings, respectively. As no ground water BOD concentration was available to the Department at the time of this analysis, the surface water BOD concentration at the lowest stream flow condition was assumed to be the ground water concentration, which is 2.2 mg/L. Based on this concentration, baseflow contributes about 72.1 percent of total BOD loading from the Long Branch watershed.

About 1.5 percent of BOD and 24.5 percent of TN loads were added to the main channel to account for the observed BOD and TN concentrations in the lower reach of the stream. The exact reason for these concentrations is not clear in this analysis. As discussed previously, it could come from sediment nutrient release and the accumulation of organic carbon in this part of the stream.

Of the pollutant loadings from surface runoff, the majority appear to come from Subcatchments 1 and 2, which discharge to the northern and southern tributaries, respectively, of Long Branch. Per-acre pollutant loadings, especially TN and TP, are higher in Subcatchments 1 and 2 than in the other subcatchments **(Table 4.11).** These results are reasonable because the majority of the residential areas and horse farms in the watershed drain to these two tributaries. Pollutant loadings and per-acre loadings from Subcatchment 4, which primarily drains to the main channel of Long Branch, are relatively low because Subcatchment 4 is mostly pervious land with a relatively low potential to produce surface runoff. Since enhanced BOD and TN concentrations were observed in the lower reach of the main channel, however, wetlands in Subcatchment 4 may contribute more BOD and TN than model-simulated results.

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

5.1 Overall Approach

To determine the allowable pollutant loadings to achieve the water quality targets defined in Chapter 3, pollutant loadings from human land uses were reduced in a stepwise manner until target BOD, TN, and TP concentrations, which are 2.3, 0.71, and 0.14 mg/L, respectively, were achieved at all sampling sites. In the modeling, reductions in pollutant loadings were achieved by reducing the EMCs of different pollutants and different land use types. Pollutant loading reduction was applied only to human land use categories, including agriculture (feeding operation), residential areas, and transportation, communication, and utilities. The EMCs of upland forest, rangeland, barren land, waters, and wetlands were not changed during the model simulation, since they are not heavily influenced by human activities. In addition, ground water BOD, TN, and TP concentrations were not changed because the TN and TP concentrations used in this analysis are low (0.43 and 0.06 mg/L for TN and TP, respectively) and are considered to be close to natural background condition.

The unknown sources causing elevated BOD and TN concentrations in the main channel were not reduced in the load reduction simulation. Because no known nonpoint sources in the watershed that directly discharge to the main channel were identified as causing BOD and TN concentrations higher than those observed in the tributaries, it was assumed the extra BOD and TN could come from wetland sediment nutrient release and the accumulation of BOD input from cypress swamps. It was also assumed that even if the input from these unknown sources continues, as long as nutrient and BOD loadings from all human sources are addressed, the BOD and nutrient concentrations in the main channel, which receives pollutants from upstream segments, should be addressed.

To determine whether water quality targets are met with a given set of pollutant loads, model-simulated BOD, TN, and TP concentrations were averaged and these concentrations were compared with the target BOD, TN, and TP concentrations, respectively. It should be noted that the average model-simulated BOD, TN, and TP concentrations were not calculated based on the model-simulated BOD, TN, and TP concentrations for all the days in the model simulation period. This is because the relationships between DO and nutrients and BOD concentrations used in this analysis to derive the target pollutant concentrations were established based only on sampling data. These sampling data were not collected in a random manner temporally throughout the period of record, because samples were usually not collected during storm events. It is therefore not reasonable to compare the model-simulated average BOD, TN, and TP concentrations that include the model-simulated storm event pollutant concentrations with the average measured pollutant concentrations that do not include storm event concentrations. In this study, the model-simulated average BOD, TN, and TP concentrations were calculated only based on the model-simulated pollutant concentrations on dates when BOD, TN, and TP concentrations were actually measured.

5.2 Allowable BOD, TN, and TP loadings

Tables 5.1, 5.2, and **5.3** list pollutant loadings from different sources that achieve BOD, TN, and TP concentration targets; load reductions required for each source; and percent load reduction required, respectively.

Table 5.1. Allowable Pollutant Loadings from Different Subcatchments and Baseflow

Source	BOD Loading (tons/year)	TN Loading (tons/year)	TP Loading (tons/year)
Subcatchment 1	0.53	0.26	0.07
Subcatchment 2	1.44	0.65	0.28
Subcatchment 3	0.18	0.09	0.02
Subcatchment 4	0.55	0.33	0.04
Unknown sources for the main channel	0.25	1.53	0
Baseflow	12.01	2.35	0.33
Total	**14.96**	**5.21**	**0.74**

Table 5.2. Pollutant Load Reduction Requirements for Different Subcatchments

Source	BOD Load Reduction (tons/year)	TN Load Reduction (tons/year)	TP Load Reduction (tons/year)
Subcatchment 1	0.45	0.24	0.05
Subcatchment 2	0.87	0.67	0.24
Subcatchment 3	0.13	0.07	0.02
Subcatchment 4	0.24	0.11	0.02
Unknown sources for the main channel	0	0	0
Baseflow	0	0	0
Total	**1.69**	**1.10**	**0.33**

Table 5.3. Percent Pollutant Load Reduction Requirements for Different Subcatchments

Source	% BOD Load Reduction	% TN Load Reduction	% TP Load Reduction
Subcatchment 1	46%	48%	44%
Subcatchment 2	38%	51%	46%
Subcatchment 3	43%	44%	33%
Subcatchment 4	30%	14%	33%
Unknown sources for the main channel	0%	0%	0%
Baseflow	0%	0%	0%
Overall*	**10%**	**17%**	**30%**

* The "Overall" percent load reduction required is the ratio between the total allowable load (including loadings from unknown sources and baseflow) and the total existing load (including existing loadings from unknown sources and baseflow).

According to **Table 5.1**, the total allowable loads of BOD and TP that achieve the target BOD and TP concentrations of 2.3 and 0.14 mg/L are 14.96 and 0.74 tons/year, respectively. Compared with existing BOD and TP loadings of 16.65 and 1.06 tons/year **(Table 4.9),** the allowable loads represent a 10 and 30 percent reduction in overall BOD and TP loading, respectively. This "overall" percent load reduction was calculated by including loading from baseflow and unknown sources, which contribute a significant portion of the BOD and TP total loads. These loads are considered natural background in this analysis, and as such, no pollutant load reduction was applied to these sources. Reductions were only applied to the major human land use categories, including agriculture (feeding operation), residential areas, and transportation, communication, and utilities.

Percent load reduction requirements for all the subcatchments are significant: 30 to 46 percent for BOD, 14 to 51 percent for TN, and 33 to 46 percent for TP **(Table 5.3).** It should be noted that while these percent load reductions may help to achieve water quality targets at the two tributary sites, the TN target concentration of 0.71 mg/L cannot be achieved at the main channel site.

The allowable TN load is 4.16 tons/year. However, the average TN concentration achieved with this TN load for the main channel site is about 0.87 mg/L, which is higher than the 0.71 mg/L target and which will not attain the Class III DO criterion. Based on the correlation between DO and TN discussed in Chapter 3, 0.87 mg/L TN corresponds to an average annual DO concentration of about 2.6 mg/L. The allowable load was set at 4.16 tons/year because reductions in TN concentration below 0.87 are not achievable. The value of 0.87 mg/L TN was achieved by reducing the TN loading from all human sources to the level of the natural environment (reducing the TN EMC for all human land use to the TN EMC of upland forests, or 1.25 mg/L).

As no further decrease in TN load reduction is possible, the Department deems the water quality criterion of 5 mg/L as unachievable for the main channel of Long Branch, and considers 2.6 mg/L to be the highest achievable annual average concentration. As part of the adoption of this TMDL, the Department will adopt an alternative dissolved oxygen criterion (ADOC) of 2.6 mg/L for the main channel. Even with this lower ADOC, reductions in BOD, TN, and TP loading will still be needed to meet the existing Class III criterion in the tributaries and to meet the ADOC in the main channel (the existing annual average DO concentration of the main channel is about 1.2 mg/L).

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

The objective of a TMDL is to provide a basis for allocating acceptable loads among all of the known pollutant sources in a watershed so that appropriate control measures can be implemented and water quality standards achieved. A TMDL is expressed as the sum of all point source loads (wasteload allocations, or WLAs), nonpoint source loads (load allocations, or LAs), and an appropriate margin of safety (MOS), which takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\mathbf{TMDL = \sum WLAs + \sum LAs + MOS}$$

As discussed earlier, the WLA is broken out into separate subcategories for wastewater discharges and stormwater discharges regulated under the NPDES Program:

$$\mathbf{TMDL \cong \sum WLAs_{wastewater} + \sum WLAs_{NPDES\ Stormwater} + \sum LAs + MOS}$$

It should be noted that the various components of the revised TMDL equation may not sum up to the value of the TMDL because (a) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is also accounted for within the LA, and (b) TMDL components can be expressed in different terms (for example, the WLA for stormwater is typically expressed as a percent reduction, and the WLA for wastewater is typically expressed as mass per day).

WLAs for stormwater discharges are typically expressed as “percent reduction” because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges also differs from the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored, and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the “maximum extent practical” through the implementation of best management practices (BMPs).

This approach is consistent with federal regulations (40 CFR § 130.2[I]), which state that TMDLs can be expressed in terms of mass per time (e.g., pounds per day), toxicity, or **other appropriate measure**. The TMDLs for Long Branch are expressed in terms of tons of allowable pollutants per year and represent the maximum annual loads of BOD, TN, and TP that the stream can assimilate and maintain the DO criterion of 5.0 mg/L. It should be noted that, as discussed in the section on establishing water quality targets, BOD and TP primarily control DO in the two tributaries to Long Branch, while TN appears to control the DO concentration of the main channel. Therefore, BOD and TP TMDLs are established only for the two tributaries. Once the BOD and TP TMDLs established in this report are achieved, the tributary DO concentration should meet the 5.0 mg/L criterion.

It should be noted that the TN TMDL does not apply to the tributaries, as there was no statistically significant relationship between TN and DO in the tributaries. The reductions in TP and BOD in the tributaries should improve DO in the main channel, but achieving the tributary BOD and TP targets does not guarantee that the main channel DO will reach 5.0 mg/L because TP controls the DO concentration in the main channel. The TN TMDL applies to the main channel, but it too does not result in the attainment of the Class III DO criterion in the main channel. Instead, it ensures that natural background DO levels of 2.6 mg/L are achieved.

Table 6.1 lists the TMDLs and percent load reduction requirements for BOD, TN, and TP. Because no major point sources were identified in the Long Branch watershed, the WLA in the table represents the load reduction requirement from the MS4 areas, which were assigned the same percent load reduction requirement as the other nonpoint sources.

Table 6.1. TMDL Components for the Long Branch Watershed, WBID 3030

Parameter	TMDL (tons/year)	WLA NPDES Stormwater	LA	MOS
BOD (for tributaries)	14.96	10%	10%	Implicit
TP (for tributaries)	0.74	30%	30%	Implicit
TN (for main channel)	5.20	17%	17%	Implicit

Note: The required percent pollutant reductions specified in this table are the overall percent reduction requirements. They are relatively low because contributions from baseflow and unknown sources are considered natural sources, and no pollutant reductions are applied to these sources. The percent reductions required for all the subcatchments are 30 to 46 percent for BOD, 14 to 51 percent for TN, and 33 to 46 percent for TP **(Table 5.3).**

6.2 Load Allocation

Because there are no wastewater point sources discharging directly into any surface water in the watershed, the TMDLs for BOD, TN, and TP were assigned to the LA (and, as discussed below, to the MS4 as well). The long-term annual average LAs for BOD, TN, and TP into Long Branch are 14.96, 5.20, and 0.74 tons/year, respectively. Nonpoint sources (including MS4 loadings) are responsible for all these loads. The existing annual loads are 16.65 tons/year for BOD, 6.24 tons/year for TN, and 1.06 tons/year for TP. These figures include loadings from surface runoff, baseflow from the surficial aquifer, possible septic tank failures in the residential areas, and unknown sources of BOD and TN in the lower reach of the main channel. A significant portion of the TN load comes from these unknown sources.

To achieve the LA, existing BOD, TN, and TP loadings require overall 10, 17, and 30 percent reductions, respectively. The load reductions applied to major human land use areas, including agriculture (horse farms); residential; and transportation, communication, and utilities are 30 to 46 percent for BOD, 14 to 51 percent for TN, and 33 to 46 percent for TP **(Table 5.3).**

6.3 Wasteload Allocation

6.3.1 NPDES Wastewater Discharges

Because no wastewater facilities discharge to surface waters in the watershed, the only WLA considered in this report is the stormwater load from MS4 areas.

6.3.2 NPDES Stormwater Discharges

As no information was available to the Department at the time this report was prepared regarding the boundaries and locations of all the NPDES stormwater dischargers in the watershed, the exact stormwater TN and TP loadings from MS4 areas were not explicitly estimated. Within the Long Branch watershed, an MS4 Phase 1 permit covers the stormwater collection systems owned and operated by Orange County and the FDOT. No Phase 2 permittees were identified in the watershed.

The $\text{WLA}_{\text{NPDESStormwater}}$ was set as the same percent reduction required to achieve the TMDLs as for the other conventional nonpoint sources, which are 10, 17, and 30 percent for BOD, TN, and TP, respectively. As with the LA, these percent load reductions are the overall percent load reductions, including no reduction requirement for natural sources. Percent load reduction requirements for all the subcatchments are significant: 30 to 46 percent for BOD, 14 to 51 percent for TN, and 33 to 46 percent for TP **(Table 5.3).**

6.4 Margin of Safety

Consistent with the recommendations of the Allocation Technical Advisory Committee (Department, February 2001), an implicit MOS was used in the development of this TMDL. An implicit MOS was provided by the conservative decisions associated with a number of modeling assumptions. For example, this analysis assumed that BOD decay rates and TN and TP attenuation rates during the overland and instream transport were 0. These assumptions attribute the downstream pollutant concentration more to human sources in the upstream area or subcatchment areas than to natural processes such as sediment release. In doing so, the estimated pollutant load reduction from human sources required to achieve the water quality targets becomes more conservative. In addition, to establish the achievable TN concentration in the main channel, TN EMCs from human land use categories were all reduced to the level of upland forest, which is the most conservative concentration that can be reasonably achieved from human land use categories.

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

7.1 Basin Management Action Plan

Following the adoption of these TMDLs by rule, the next step in the TMDL process is to develop an implementation plan for the TMDLs, referred to as the BMAP. This document will be developed over the next two years after the Secretary signs the TMDL in cooperation with local stakeholders, who will attempt to reach consensus on detailed allocations and on how load reductions will be accomplished. The BMAP will include, among other things:

- Appropriate load reduction allocations among the affected parties,
- A description of the load reduction activities to be undertaken, including structural projects, nonstructural BMPs, and public education and outreach,
- A description of further research, data collection, or source identification needed in order to achieve the TMDLs,
- Timetables for implementation,
- Confirmed and potential funding mechanisms,
- Any applicable signed agreement(s),
- Local ordinances defining actions to be taken or prohibited,
- Any applicable local water quality standards, permits, or load limitation agreements,
- Milestones for implementation and water quality improvement, and
- Implementation tracking, water quality monitoring, and follow-up measures.

An assessment of progress toward the BMAP milestones will be conducted every five years, and revisions to the plan will be made as appropriate, in cooperation with basin stakeholders.

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Appendices

Appendix A: Background Information on Federal and State Stormwater Programs

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as authorized in Chapter 403, F.S., was established as a technology-based program that relies on the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Rule 62-40, F.A.C.

The rule requires the state's water management districts (WMDs) to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a Surface Water Improvement and Management (SWIM) plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, the Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka. No PLRG had been developed for Newnans Lake at the time this report was prepared.

In 1987, the U. S. Congress established Section 402(p) as part of the federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES stormwater permitting program to designate certain stormwater discharges as "point sources" of pollution. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific standard industrial classification (SIC) codes, construction sites disturbing 5 or more acres of land, and master drainage systems of local governments with a population above 100,000, which are better known as MS4s. However, because the master drainage systems of most local governments in Florida are interconnected, the EPA has implemented Phase 1 of the MS4 permitting program on a countywide basis, which brings in all cities (incorporated areas), Chapter 298 urban water control districts, and the FDOT throughout the 15 counties meeting the population criteria.

An important difference between the federal and state stormwater permitting programs is that the federal program covers both new and existing discharges, while the state program focuses on new discharges. Additionally, Phase 2 of the NPDES Program will expand the need for these permits to construction sites between 1 and 5 acres, and to local governments with as few as 10,000 people. The revised rules require that these additional activities obtain permits by 2003. While these urban stormwater discharges are now technically referred to as "point sources" for the purpose of regulation, they are still diffuse sources of pollution that cannot be easily collected and treated by a central treatment facility, as are other point sources of pollution such as domestic and industrial wastewater discharges. The Department recently accepted delegation from the EPA for the stormwater part of the NPDES Program. It should be noted that most MS4 permits issued in Florida include a re-opener clause that allows permit revisions to implement TMDLs once they are formally adopted by rule.

Appendix B: General Hydrology and Hydraulic Processes that SWMM Simulates

In SWMM, surface runoff is generated from subcatchments by approximating them as nonlinear reservoirs **(Figure B.1).** Equation B-1 is used for runoff simulation:

$$Q = W\frac{1.49}{n}(d - d_p)^{5/3} * S^{1/2} \qquad \textbf{(B-1)}$$

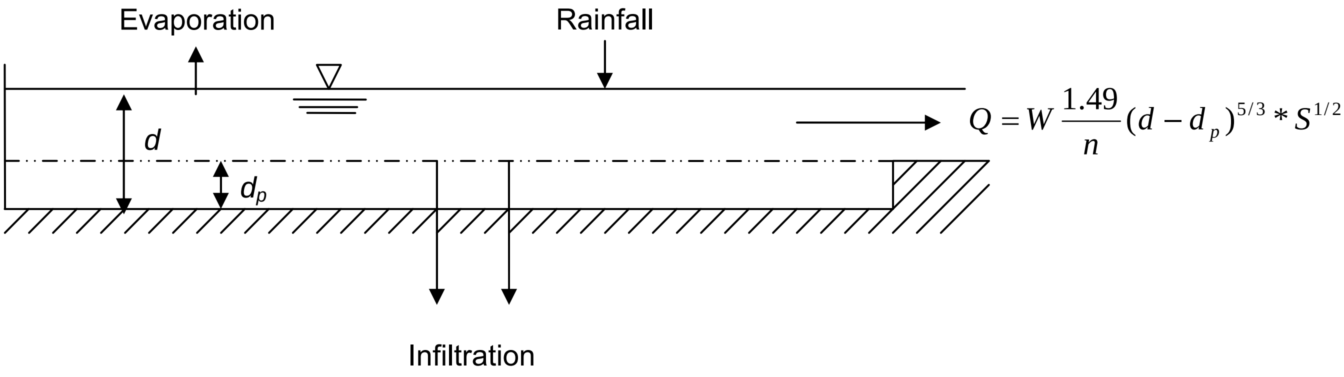

Figure B.1. Nonlinear Reservoir Model for SWMM Subcatchment Simulation

Where:
Q is surface runoff (cfs),
W is subcatchment width (feet),
n is Manning's roughness coefficient,
d is water depth on the ground surface (feet),
d_p is depth of depression storage (feet), and
S is subcatchment slope (feet/feet).

The water depth on the ground surface (d) is constantly updated during the simulation using Equation B-2:

$$\frac{dd}{dt} = i - \frac{1.49 * W}{A * n}(d - d_p)^{5/3} * S^{1/2} \qquad \textbf{(B-2)}$$

Where:
i is rainfall excess (feet/second),

A is subcatchment surface area (feet^2),
dd is change of water depth on the ground surface (feet), and
dt is change of time (s).

In the model, *i* is calculated as total rainfall minus evaporation and infiltration. SWMM provides three different methods to simulate the infiltration: Horton's equation, the Green-Ampt method, and the Curve Number method.

This analysis used the Green-Ampt method in simulating infiltration. The method uses a two-stage model simulation (Mein and Larson, 1973). The first step predicts the volume of water that will infiltrate before the surface becomes saturated. From this point onward, the Green-Ampt equation predicts infiltration capacity. Thus, using Equations B-3 and B-4:

For $F < F_s$: $$F_s = \frac{S * IMD}{i / K_s - 1} \quad \text{for } i > K_s \qquad \textbf{(B-3)}$$

$f = i$ and

No calculation of f_s for $i \le K_s$

For $F \ge Fs$:

$f = f_p$ and $$f_p = K_s \left(1 + \frac{S * IMD}{F}\right) \qquad \textbf{(B-4)}$$

Where:
f is infiltration rate (feet/second),
f_p is infiltration capacity (feet/second),
i is rainfall intensity (feet/second),
F is cumulative infiltration volume, this event (feet),
F_s is cumulative infiltration volume required to cause surface saturation (feet),
S is average capillary suction head at the wetting front (feet water),
IMD is initial moisture deficit for this event (feet/feet), and
K_s is saturated hydraulic conductivity of soil (feet/second).

In SWMM 5.0, rainfall on the pervious area is lost through both evaporation and infiltration processes. No infiltration is estimated for the impervious area. For areas that are impervious but do not directly connect to the receiving water, runoff will eventually flow to the pervious area and therefore will be lost through both evaporation and infiltration. In this analysis, impervious area means DCIA.

Once surface runoff and other flow contributions—e.g., baseflow—discharge into a channel, the flow in the channel is estimated using Equation B-5:

$$Q = \frac{1.49}{n} A * R^{2/3} * \sqrt{S} \qquad \textbf{(B-5)}$$

Where:
Q is stream flow (cfs),
n is Manning's roughness coefficient,
A is cross-sectional area (feet^2),
R is hydraulic radius (feet), and
S is conduit slope (feet/feet).

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