FINAL

Nutrient TMDLs for Marshall Lake (WBID 2854A)

and Documentation in Support of the Development of Site-Specific Numeric Interpretations of the Narrative Nutrient Criterion

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Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the total maximum daily loads (TMDLs) for nutrients for Marshall Lake in the Ocklawaha River Basin. The TMDLs will constitute the site-specific numeric interpretations of the narrative nutrient criterion set forth in Paragraph 62-302.530(47)(b), Florida Administrative Code (F.A.C.), that will replace the otherwise applicable numeric nutrient criterion (NNC) in Subsection 62-302.531(2), F.A.C., for this particular water. The lake was verified as impaired for nutrients due to elevated annual average Trophic State Index (TSI) values, and was included on the Verified List of impaired waters for the Ocklawaha River Basin that was adopted by Secretarial Order on February 12, 2013.

According to the 1999 Florida Watershed Restoration Act (FWRA) (Chapter 99-223, Laws of Florida), once a waterbody is included on the Verified List, a TMDL must be developed. The purpose of these TMDLs is to establish the allowable loadings of pollutants to Marshall Lake that would restore the waterbody so that it meets its applicable water quality criteria for nutrients.

1.2 Identification of Waterbody

Marshall Lake is a 58-acre lake located in northwestern Orange County (**Figure 1.1**). Its drainage basin spans 720 acres and primarily drains a portion of the western area of the City of Apopka along State Road (SR) 500 and a portion of Orange County west of SR 500 and along SR 451 (**Figure 1.2**). The lake and its watershed are part of the Lake Apopka watershed and are located east of Lake Apopka. This area is part of the Apopka Upland Lake Region (Region 75-15), which consists primarily of residual sand hills modified by karst processes, with many small lakes and scattered sinkholes (Griffith *et al.* 1997). In fact, Marshall Lake, together with Heiniger Lake, Sheppard Lake, Upper Doe Lake, Lower Doe Lake, Lake Witherington, and Lake Fuller, comprise the chain of lakes in the eastern part of the Lake Apopka watershed.

The elevation of the Marshall Lake watershed ranges from 70 feet immediately adjacent to the lake to more than 155 feet on the eastern boundary of the watershed. The average slope of the watershed is 2.8%. The runoff from the eastern, southeastern, and northwestern part of the watershed flows into the lake, which then discharges to the west into Lower Doe Lake. Based on lake stage data collected for the period from 1971 to 2004, the long-term average stage of the lake was 63.5 feet (ft) National Geodetic

Vertical Datum (NGVD). The lake bottom elevation is 53 ft NGVD, which is about the same elevation as the potentiometric head of the Floridan aquifer. Long-term average annual rainfall, based on the Doppler radar–converted rainfall data for the period from 2000 through 2012 provided by the St. Johns River Water Management District (SJRWMD), was 48 inches/year (in/yr). The annual average air temperature, based on data collected from 2000 to 2012 from a weather station located at Orlando International Airport, was 23°C. The summer maximum temperature ranged from 35° to 37° C. The winter minimum temperature ranged from -4° to 1° C.

For assessment purposes, DEP has divided the Ocklawaha River Basin into water assessment polygons with a unique waterbody identification (WBID) number for each watershed or stream reach. Marshall Lake is WBID 2854A.

1.3 Background

This report was developed as part of DEP's watershed management approach for restoring and protecting state waters and addressing TMDL Program requirements. The watershed approach, which is implemented using a cyclical management process that rotates through the state's 52 river basins over a five-year cycle, provides a framework for implementing the TMDL Program–related requirements of the 1972 federal Clean Water Act and the FWRA.

A TMDL represents the maximum amount of a given pollutant that a waterbody can assimilate and still meet water quality standards, including its applicable water quality criteria and its designated uses. TMDLs are developed for waterbodies that are verified as not meeting their water quality standards and provide important water quality restoration goals that will guide restoration activities.

This TMDL report will be followed by the development and implementation of a restoration plan to reduce the amount of nutrients that caused the verified impairment of Marshall Lake. These activities will depend heavily on the active participation of Orange County, Apopka, businesses, and other stakeholders. DEP will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDLs for the impaired waterbody.

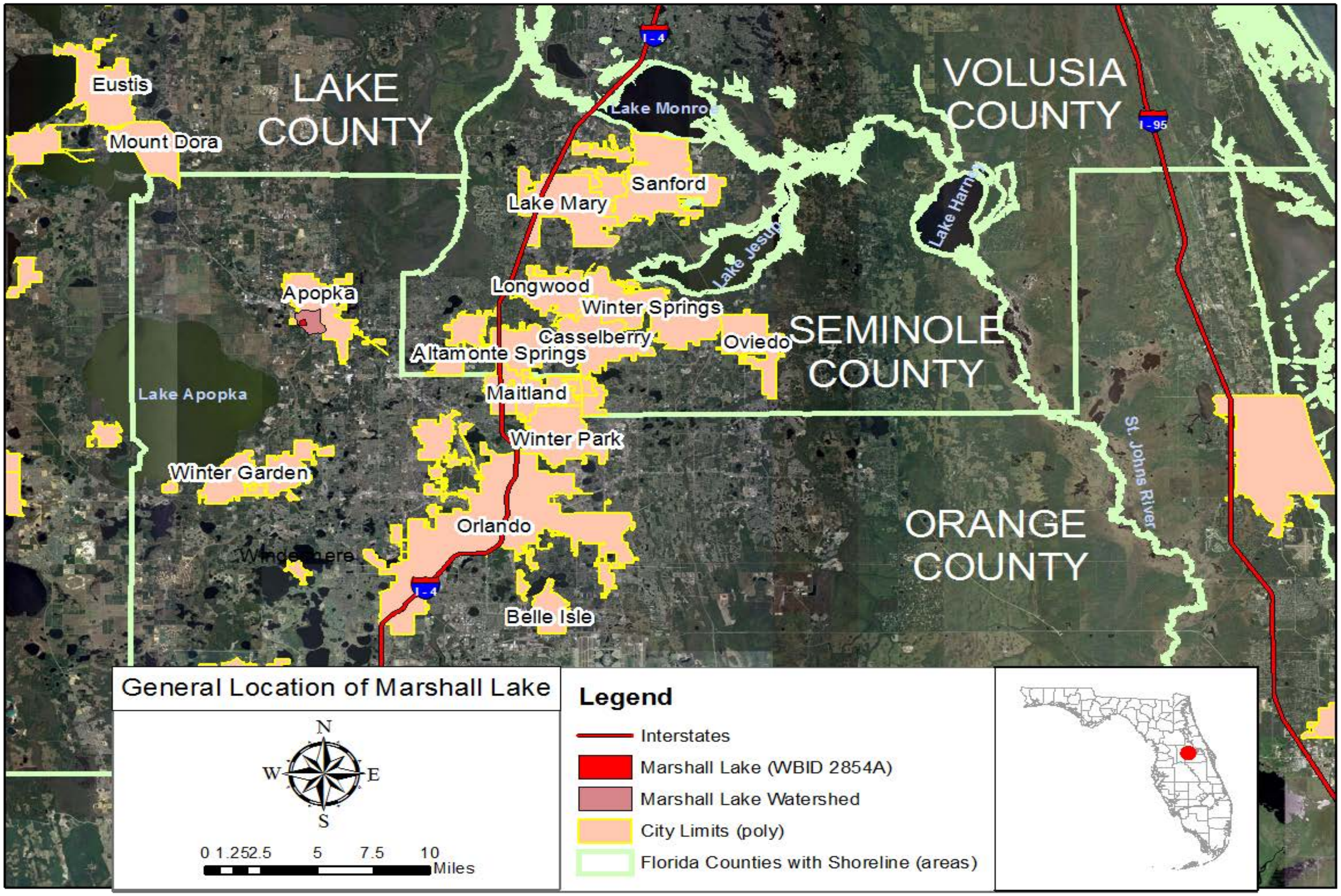

Figure 1.1. General Location of Marshall Lake, with Major Geopolitical and Hydrologic Features in the Area

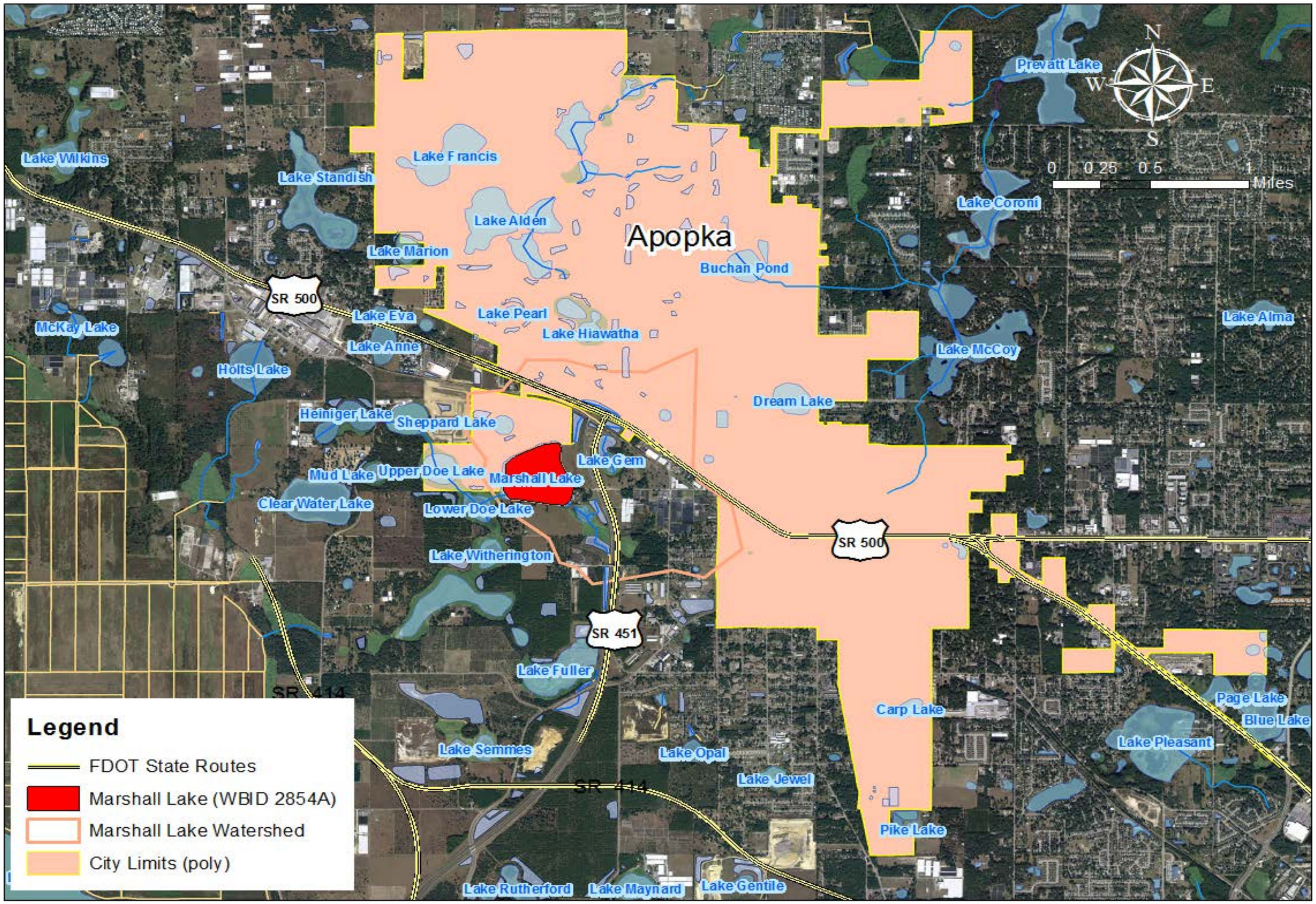

Figure 1.2. Detailed Location of Marshall Lake

Chapter 2: DESCRIPTION OF WATER QUALITY PROBLEM

2.1 Statutory Requirements and Rulemaking History

Section 303(d) of the Clean Water Act requires states to submit to the U.S. Environmental Protection Agency (EPA) a list of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for each pollutant source in each of these impaired waters on a schedule. DEP has developed these lists, commonly referred to as 303(d) lists, since 1992. The list of impaired waters in each basin is also required by the FWRA (Subsection 403.067[4], F.S.), and the list is amended annually to include updates for each basin statewide.

Florida's 1998 303(d) list included 41 waterbodies in the Ocklawaha River Basin. However, the FWRA (Section 403.067, F.S.) stated that all previous Florida 303(d) lists were for planning purposes only and directed DEP 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, F.A.C. (Identification of Impaired Surface Waters Rule, or IWR), in April 2001. The list of waters for which impairments have been verified using the methodology in the IWR is referred to as the Verified List.

2.2 Information on Verified Impairment

DEP used the IWR to assess water quality impairments in the Ocklawaha River Basin and verified that Marshall Lake was impaired for nutrients based on the fact that, in the verified period (January 1, 2005–June 30, 2012), annual average Trophic State Index (TSI) values exceeded the applicable threshold of 60 in 2006 and 40 in 2011 (**Table 2.1**).

Table 2.1. Summary of Annual TSI Values for Marshall Lake in the Verified Period, 2005–12

PCU = Platinum cobalt units

Year	Mean Color (PCU*)	TSI Threshold	Calculated TSI Based on Measured TN, TP, and Corrected Chlorophyll *a* (Chla)
2006	No color data	60	69
2011	24	40	63

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criteria Applicable to the TMDLs

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

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Fish consumption; recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class III-Limited	**Fish consumption; recreation or limited recreation; and/or propagation and maintenance of a limited 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)**

Marshall Lake is a Class III waterbody, with a designated use of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criteria applicable to the impairments addressed by these TMDLs are for nutrients.

3.2 Numeric Interpretation of the Narrative Nutrient Criterion

Marshall Lake was verified for as impaired for nutrients in the Group 1, Cycle 3 assessment, exceeding the annual average TSI threshold of 60. Florida adopted NNC for lakes, spring vents, and streams in 2011 that were approved by the EPA in 2012 and became effective on October 27, 2014. **Table 3.1** lists the NNC for Florida lakes specified in Subparagraph 62-302.531(2)(b)1., F.A.C.

Table 3.1. Chla, TN, and TP Criteria for Florida Lakes (Subparagraph 62-302.531[2][b]1., F.A.C.)

AGM = Annual geometric mean; $CaCO_3$ = Calcium carbonate
[1] For lakes with color > 40 PCU in the West Central Nutrient Watershed Region, the maximum TP limit shall be the 0.49 milligrams per liter (mg/L) TP streams threshold for the region.

Lake Group Long-Term Geometric Mean Color and Alkalinity	Lake Group AGM Chlorophyll *a* (Chl*a*)	Minimum NNC AGM TP	Minimum NNC AGM TN	Maximum NNC AGM TP	Maximum NNC AGM TN
>40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L[1]	2.23 mg/L
≤ 40 PCU and > 20 mg/L $CaCO_3$	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L $CaCO_3$	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

Based on Subparagraph 62-302.531(2)(b)1., F.A.C., if a given lake has a long-term geometric mean color greater than 40 PCU, or if the long-term geometric mean color of the lake is less than 40 PCU but the long-term geometric mean of alkalinity (represented as $CaCO_3$) of the lake is greater than 20 mg/L, the Chla criterion is 20 µg/L. For a lake with a long-term geometric mean color less than 40 PCU and a long-term geometric mean alkalinity less than 20 mg/L $CaCO_3$, the Chla criterion is 6 µg/L. For a lake to comply with the Chla criterion, the AGM of Chla should not exceed the criterion more than once in any consecutive three-year period. These Chla criteria were established by taking into consideration results from paleolimnological studies, expert opinion, biological responses, user perceptions, and Chla concentrations in a set of carefully selected reference lakes.

If there are sufficient data to calculate the AGM Chla and the mean does not exceed the Chla criterion for the lake type listed in **Table 3.1**, then the TN and TP criteria for that calendar year are the AGMs of lake TN and TP samples, subject to the minimum and maximum limits in the table. If there are insufficient data to calculate the AGM Chla for a given year, or the AGM Chla concentration exceeds the Chla criterion specified in **Table 3.1** for the lake type, then the TN and TP criteria are the minimum values in the table. However, for lakes with color > 40 PCU in the West Central Nutrient Watershed Region, the maximum TP criterion is the 0.49 mg/L TP streams threshold for the region.

For the purpose of Subparagraph 62-302.531(2)(b)1., F.A.C., color is assessed as true color and should be free from turbidity. Lake color and alkalinity are the long-term geometric mean, based on a minimum of 10 data points over at least 3 years with at least 1 data point in each year. If insufficient alkalinity data are available, long-term geometric mean specific conductance values can be used, with a value of <100 micromhos/centimeter (µmhos/cm) used to estimate the 20 mg/L $CaCO_3$ alkalinity concentration until alkalinity data are available.

DEP has also assessed the data for Marshall Lake using the NNC. Based on the data retrieved from the IWR Database, the long-term geometric mean color value for Marshall Lake is 19 PCU, which is less than the 40 PCU value that distinguishes high-color lakes from clear-water lakes. The long-term geometric mean of alkalinity is 38 mg/L, which is greater than the 20 mg/L threshold that distinguishes high-alkalinity lakes from low-alkalinity lakes. Marshall Lake is therefore considered a low-color lake. The Chla target applicable to Marshall Lake is 20 µg/L.

Marshall Lake did not meet the NNC based on a preliminary analysis of the available data and remained listed as verified impaired for nutrients. The nutrient TMDLs presented in this report, upon adoption into Chapter 62-304, F.A.C., will constitute site-specific numeric interpretations of the narrative nutrient criterion set forth in Paragraph 62-302.530(47)(b), F.A.C., that will replace the otherwise applicable NNC in Subsection 62-302.531(2), F.A.C., for this particular water, pursuant to Paragraph 62-302.531(2)(a), F.A.C.

The Water Quality Standards template document in **Appendix A** provides the relevant TMDL information, including how the TMDLs provide for the attainment and maintenance of water quality standards in downstream waters (pursuant to Subsection 62-302.531[4], F.A.C.), to support using the TMDL nutrient targets as the site-specific numeric interpretations of the narrative nutrient criterion. Targets used in TMDL development are designed to restore surface water quality to meet a waterbody's designated use. Criteria are based on scientific information used to establish specific levels of water quality constituents that protect aquatic life and human health for particular designated use classifications.

DEP developed the lake NNC based on an evaluation of a response variable, Chla, and stressor variables, TN and TP, to develop water quality criteria that are protective of designated uses (DEP 2012). To establish the nutrient targets for Marshall Lake, DEP used the 20 µg/L Chla criterion as a starting point because this level is considered protective of the designated use of low-color and high-alkalinity lakes. Based on the available information, there is nothing unique about the lake's characteristics that would make the use of the Chla threshold of 20 µg/L inappropriate for Marshall Lake.

To determine the TN and TP TMDLs for Marshall Lake, DEP used calibrated watershed and receiving waterbody models to establish the in-lake TN and TP concentrations and associated watershed loads that meet an in-lake Chla of 20 µg/L. **Chapter 5** provides details on the simulation of the in-lake TN and TP concentration targets required to achieved an in-lake Chla of 20 µg/L. The simulated TN and TP target concentrations were checked against TN and TP concentrations to avoid abating the natural background condition. Based on the calibrated model simulation, as explained in **Chapter 5**, the final in-lake TN and TP targets are 0.037 mg/L for TP and 0.90 mg/L for TN, which are expressed as AGMs not to be exceeded in any year.

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 the pollutant of concern in the target watershed 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, such as those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see **Appendix B** 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 (see **Section 6.1, Expression and Allocation of the TMDL**). However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES 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 Nutrients in the Marshall Lake Watershed

4.2.1 Point Sources

4.2.1.1 Wastewater Point Sources

When these TMDLs were being developed, no NPDES-permitted wastewater facilities that discharge to Marshall Lake were identified in the watershed.

4.2.1.2 Municipal Separate Storm Sewer System (MS4) Permittees

In the Marshall Lake watershed, the stormwater collection systems owned and operated by Orange County, Apopka, and Florida Department of Transportation (FDOT) District 5 are covered by an NPDES MS4 Phase I permit (FLS000011).

4.2.2 Nonpoint Sources

Nutrient loadings to Marshall Lake are primarily generated from nonpoint sources. Nonpoint sources addressed in this analysis primarily include loadings from surface runoff, ground water seepage entering the lake, and precipitation directly onto the lake surface.

In this TMDL analysis, nutrient loadings from the watershed were estimated by multiplying the runoff volume by the TN and TP event mean concentrations (EMCs). The runoff volume from the watershed was primarily estimated using the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) curve number approach, which takes into consideration the land use type, soil type, imperviousness of the watershed, and antecedent moisture condition of the soil. Curve numbers between 20 and 100 were assigned to different land use–soil combinations to represent different runoff potentials. Rainfall is the driving force of the curve number approach.

The land use information used in this analysis came from the SJRWMD land use shapefiles. Because the watershed nutrient loading simulation covers a relatively long period (2000–12), land use geographic information system (GIS) shapefiles from the following two years were used in the loading estimation: the 2004 land use shapefile for estimating annual nutrient loads from 2000 through 2005, and the 2009 land use shapefile for simulating nutrient loads from 2006 through 2012. Soil hydrologic characteristics for the watershed were obtained from the NRCS 2010 Soil Survey Geographic (SSURGO) Database GIS shapefile.

4.2.2.1 Land Uses

Land use is one of the most important factors in determining nutrient loadings from the Marshall Lake watershed. Nutrients can be flushed into a receiving water through surface runoff and stormwater conveyance systems during stormwater events. Both human land areas and natural land areas generate nutrients. However, human land areas typically generate more nutrient loads per unit of land surface area than natural lands can produce.

The land use information used in developing these TMDLs was from the SJRWMD's 2004 and 2009 land use shapefiles. These define land use types based on the land use classification system adopted in the Florida Land Cover and Land Use Classification System (FLUCCS). To estimate nutrient loads from the Marshall Lake watershed, the detailed land use types defined by the Level III FLUCCS code in these shapefiles were aggregated based on a 16-land use classification system used by the SJRWMD in developing pollutant load reduction goals (PLRGs) for seven major lakes in the Upper Ocklawaha Basin (Fulton *et al.* 2004). In addition, high-density commercial was subdivided into two different land use types: high-density commercial and roads and highways.

Table 4.1 lists the land use types and their corresponding acreages in the Marshall Lake watershed for 2004 and 2009, and the change in these acreages between 2004 and 2009. **Figures 4.1a** and **4.1b** show the spatial distribution of different land use types in the watershed in 2004 and 2009, respectively. Based on **Table 4.1**, the total watershed area is 720 acres. The predominant land use type in 2004 was forest/rangeland, which covered 192 acres and accounted for 26.7% of the total watershed area. The second largest land use type in 2004 was medium-density residential, which encompassed 124 acres and accounted for 17.2% of the watershed.

The third largest land use type, roads and highways, occupied 85.8 acres and accounted for 12% of the total watershed area. Overall, human land uses, including all the residential, commercial, industrial, and agricultural areas, occupied 482 acres of the watershed and accounted for 67% of the total watershed area. Among these human land use areas, 73% are urban lands—including all the residential, commercial, industrial, mining, and recreational areas—and 27% are agricultural. Thus urban land is the predominant human land use in the Marshall Lake watershed.

Table 4.1. Land Uses and Their Corresponding Acreage in the Marshall Lake Watershed

N/A = Not applicable

Land Use	2004 Land Use (acreage)	2004 Land Use (% area)	2009 Land Use (acreage)	2009 Land Use (% area)	Difference between 2004 and 2009 (acreage)	% Difference
Low-density residential	6.1	0.8%	5.6	0.8%	-0.5	-9%
Medium-density residential	123.9	17.2%	92.9	12.9%	-30.9	-25%
High-density residential	30.6	4.2%	102.8	14.3%	72.2	236%
Low-density commercial	33.0	4.6%	35.8	5.0%	2.8	8%
High-density commercial	48.5	6.7%	65.9	9.1%	17.3	36%
Industrial	22.3	3.1%	22.3	3.1%	0.0	0%
Roads and highways	85.8	11.9%	85.8	11.9%	0.0	0%
Open land/recreational	0.0	0.0%	24.1	3.3%	24.1	N/A
Pasture	56.1	7.8%	28.1	3.9%	-28.0	-50
Cropland	0.0	0.0%	31.7	4.4%	31.7	N/A
Tree crops	0.0	0.0%	0.0	0.0%	0.0	N/A
Feeding operations	0.0	0.0%	0.0	0.0%	0.0	N/A
Other agriculture	75.6	10.5%	74.7	10.4%	-0.9	-1%
Forest/rangeland	192.0	26.7%	103.9	14.4%	-88.1	-46%
Water	13.6	1.9%	12.0	1.7%	-1.6	-12%
Wetlands	32.4	4.5%	34.4	4.8%	2.0	6%
Total	**719.9**	**100.0%**	**719.9**	**100.0%**		

Compared with 2004, land use patterns in the Marshall Lake watershed changed significantly by 2009. The largest change was an 88-acre decrease in forest/rangeland, from 192 acres in 2004 to 104 acres in 2009, representing a 46% decrease. At the same time, high-density residential increased by 72 acres, from 31 acres in 2004 to 103 acres in 2009, a 236% increase. The other significant changes in land use types in 2009 were a 32-acre increase in cropland, a 31-acre decrease in medium-density residential, a 28-acre decrease in pastureland, and a 17-acre increase in high-density commercial. Overall, in 2009, human land uses occupied 570 acres of the watershed, or 79% of the total area. Among these human land use areas, 76% were urban and 24% were agricultural. Thus human land use types were more dominant in 2009 than in 2004, mostly because of an increase in the amount of urban land.

4.2.2.2 Hydrologic Soil Groups

The hydrologic characteristics of soil can significantly influence the capability of a watershed to hold rainfall or produce surface runoff. Soils are generally classified into four major types, as follows, based on their hydrologic characteristics (Viessman *et al.* 1989):

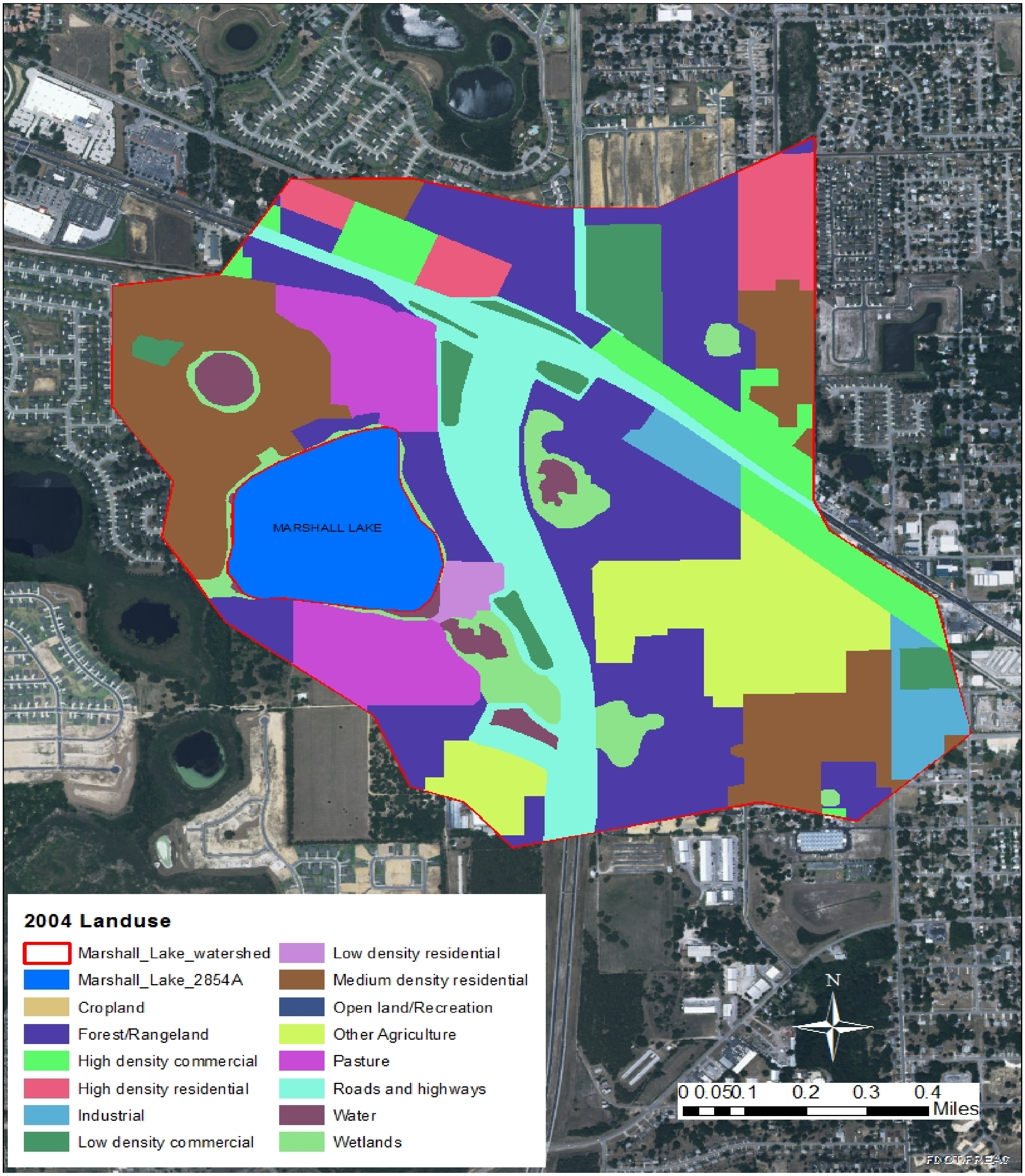

Figure 4.1a. Marshall Lake Land Use Spatial Distribution, 2004

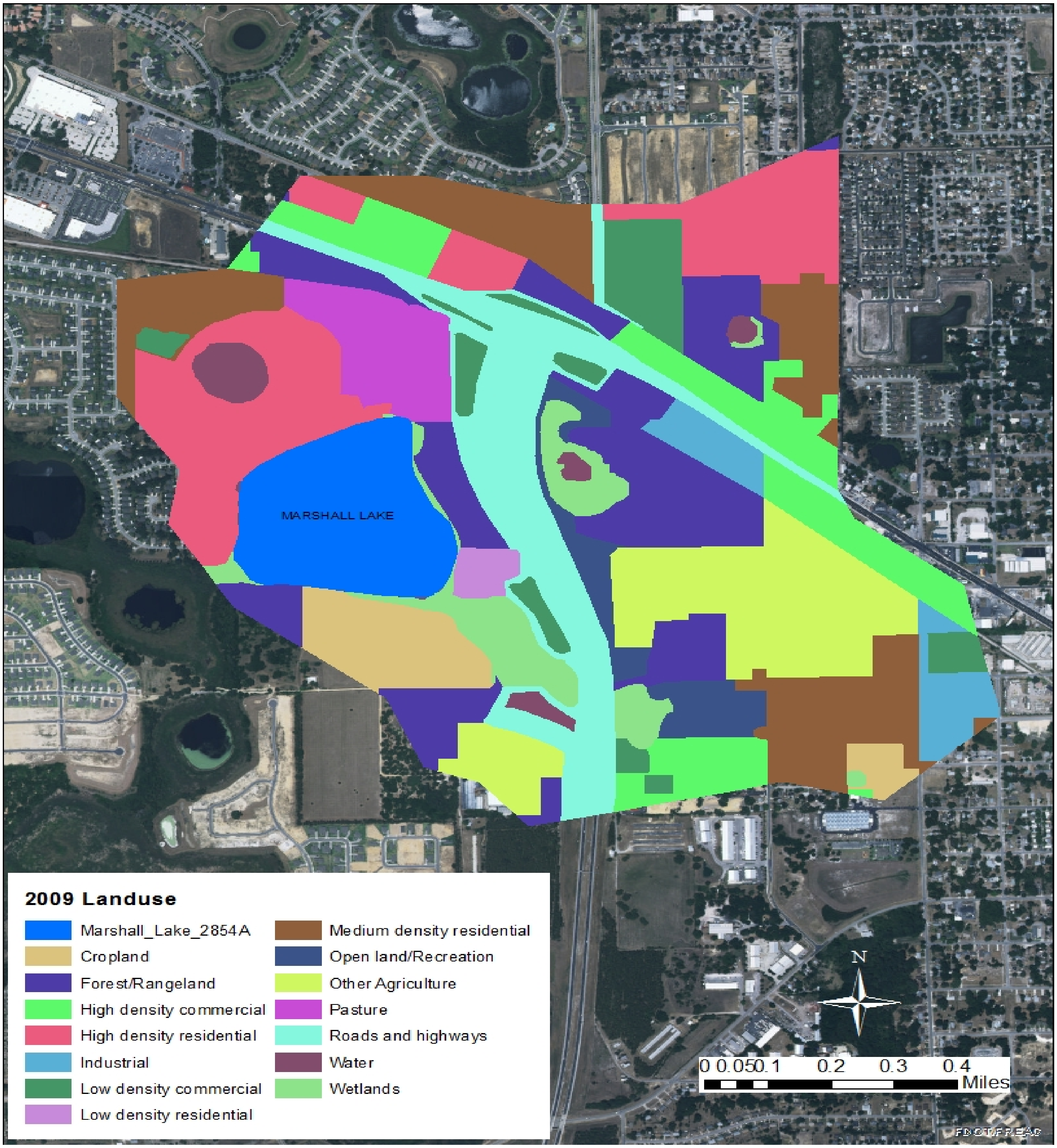

Figure 4.1b. Marshall Lake Land Use Spatial Distribution, 2009

— **Type A soil (low runoff potential):** Soils having high infiltration rates even if thoroughly wetted and consisting chiefly of deep, well-drained to excessively drained sands or gravels. These soils have a high rate of water transmission.

— **Type B soil:** Soils having moderate infiltration rates if thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well-drained to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

— **Type C soil:** Soils having slow infiltration rates if thoroughly wetted and consisting chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

— **Type D soil (high runoff potential):** Soils having very slow infiltration rates if thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission.

The soil hydrologic characteristics of the Marshall Lake watershed in this TMDL analysis were based on the soil hydrologic classifications included in the NRCS 2010 SSURGO GIS shapefile. **Figure 4.2** shows the spatial distribution of the soil hydrologic groups in the Marshall Lake watershed. Type A soil predominates. Small amounts of Type A/D soil are present around the northwest to southwest of the lake, in some wetland areas, and also in the southeast corner of the watershed. A/D soil has Type A soil characteristics when unsaturated but behaves like Type D soil when saturated. In this TMDL analysis, A/D soil was treated as D soil when assigning the curve number.

Soil types in some parts of the watershed were not defined in the SSURGO shapefile (soil type X). Most were located in the areas covered by waterbodies or wetlands. These undefined soils were all considered Type D when assigning the curve number. This is reasonable because soils in waterbody and wetland areas typically show a low potential for water infiltration. **Table 4.2** lists the soil hydrologic groups in the Marshall Lake watershed and their corresponding acreages.

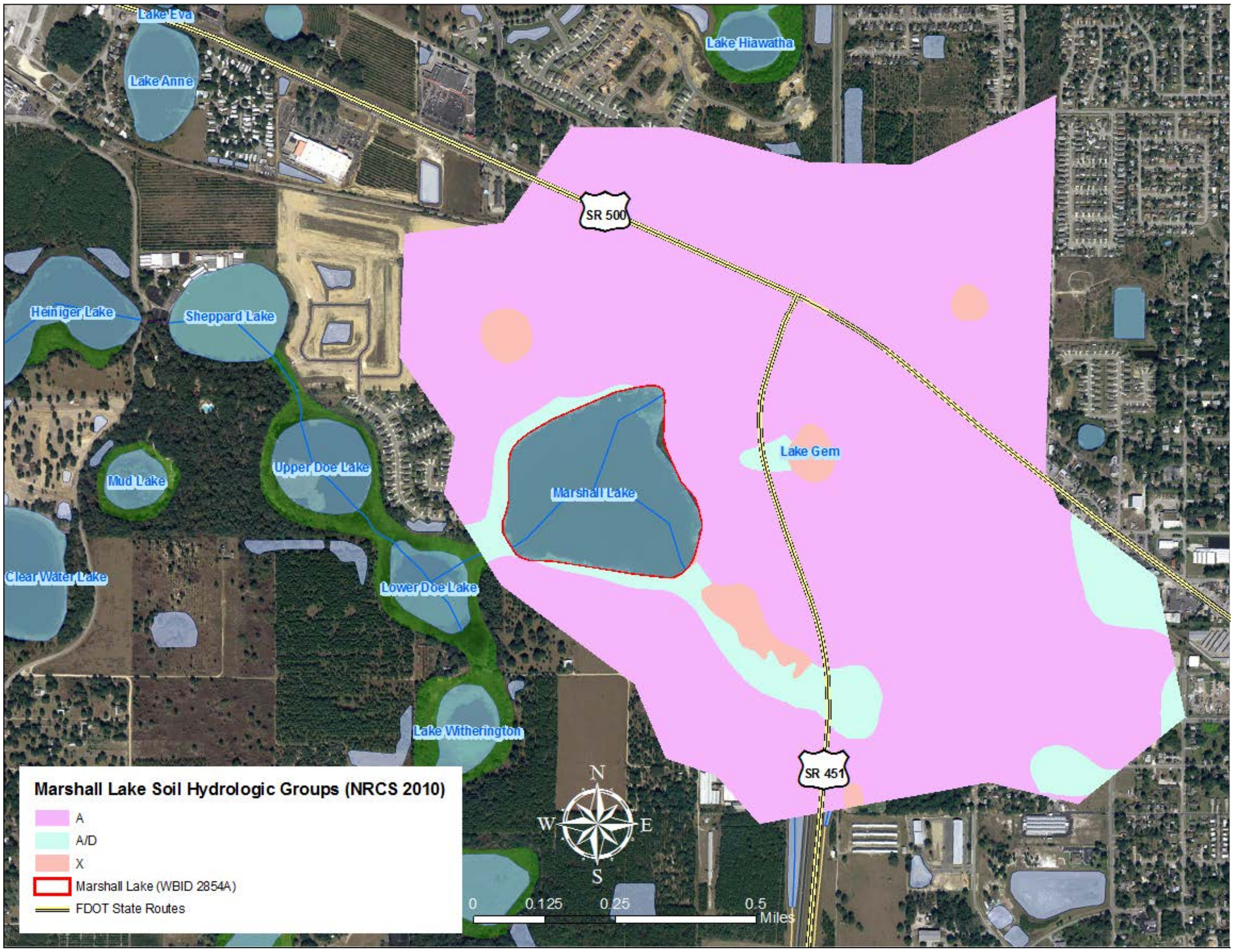

Figure 4.2. Marshall Lake Soil Hydrologic Groups (NRCS 2010)

Table 4.2. Acreage of Hydrologic Soil Groups in the Marshall Lake Watershed

Soil Hydrologic Group	Acreage	% Acreage
A	648.2	90.0%
D (A/D)	52.6	7.3%
D(X)	19.2	2.7%
Total	**719.9**	**100.0%**

4.2.2.3 Estimating Runoff Nutrient Loadings from the Marshall Lake Watershed

A. Estimating Runoff Volume Using the NRCS Curve Number Approach

Stormwater runoff from the watershed was estimated using the NRCS curve number approach. When developing the nutrient PLRG for the Upper Ocklawaha Chain of Lakes, the SJRWMD implemented this approach by setting up a spreadsheet model (Fulton *et al.* 2004). The same spreadsheet model was used to estimate stormwater runoff volume for this analysis, and the governing equations and curve numbers were previously described in the PLRG report (Fulton *et al.* 2004). The key function of this spreadsheet model is to estimate the annual average runoff coefficient for each land use–soil type combination for each year. Once these are estimated, runoff volume can be calculated as the product of rainfall, runoff coefficient, and acreage of the land use–soil type combination.

The SJRWMD runoff volume spreadsheet model is based on a classification system comprising 16 land uses. Each land use is associated with one of four soil hydrologic groups (Types A, B, C, and D), resulting in a total of 64 land use–soil type combinations. To calculate the runoff volume for the entire Marshall Lake watershed and, at the same time, quantify the runoff contribution from each land use area, the runoff coefficient for each land use–soil type combination must be estimated. The runoff model achieved this goal by estimating an average stormwater runoff coefficient ($ASRC_{wb}$) first, and then derived the runoff coefficient for the land use–soil type combination.

The SJRWMD provided the rainfall data used in calculating the runoff coefficient and runoff volume for this TMDL analysis. The SJRWMD Doppler rainfall data were created based on the measured rainfall from 75 rain gauges located in the SJRWMD area and the Next Generation Radar (NEXRAD) data that the SJRWMD received from the National Weather Service (NWS). Based on the SJRWMD's Doppler radar rainfall webpage, the individual radar station data are combined into a radar mosaic that completely covers the SJRWMD territory with an array of pixels. Each pixel represents an area of two square kilometers.

The SJRWMD combines the gauge and radar data to calculate a gauge–radar ratio and applies the ratio in a radar calibration algorithm to derive a gauge-adjusted rainfall dataset that maintains the spatial signature of the radar data, while incorporating the volume estimates from the rain gauge. For this TMDL analysis, the set of pixels for which the radar rainfall data were retrieved were defined by the Marshall Lake watershed boundary. **Table 4.3** summarizes annual rainfall to the Marshall Lake watershed from 2000 through 2012.

Table 4.3. Annual Rainfall in the Marshall Lake Watershed, 2000–12

Year	Annual Rainfall (inches)
2000	25.4
2001	33.9
2002	57.2
2003	51.9
2004	54.2
2005	57.5
2006	40.7
2007	44.1
2008	55.1
2009	53.1
2010	46.6
2011	45.7
2012	38.6
Mean	**46.5**

From 2000 to 2012, annual total rainfall ranged from 25.4 inches per year (in/yr) in 2000 to 57.5 in/yr in 2005 (**Table 4.3**). Long-term average annual rainfall for the period was 46.5 in/yr. Years with rainfall lower than the long-term average included 25.4 in/yr in 2000, 33.9 in/yr in 2001, 40.7 in/yr in 2006, 44.1 in/yr in 2007, and 45.7 in/yr in 2011. The highest annual rainfall occurred in 2005.

Total watershed runoff volume from the Marshall Lake watershed ranged from 429 to 1,437 acre-feet per year (ac-ft/yr) from 2000 through 2012 (**Table 4.4**). Long-term average annual runoff was 945 ac-ft/yr. The lowest runoff volume occurred in 2000 (429 ac-ft/yr), and this is consistent with the annual rainfall pattern. The highest runoff occurred in 2008 (1,437 ac-ft/yr) instead of 2005, which had the highest rainfall in the modeling period.

The increase in high-density residential and commercial land areas in 2008 compared with 2005 may have increased the imperviousness of the watershed, which, under the same rainfall condition, produced more runoff. The highest runoff volume in 2008 may have also resulted when Tropical Storm Fay passed through the central Florida area in August. This storm produced a large amount of rainfall in relatively short period, causing the antecedent moisture condition of the soil to elevate and, therefore, resulting in a higher runoff volume in 2008.

Table 4.4. Runoff Volume (ac-ft/yr) in the Marshall Lake Watershed

LDR = Low-density residential; MDR = Medium-density residential; HDR = High-density residential; LDC = Low-density commercial; HDC = High-density commercial; IND = Industrial; RAH = Roads and highways; OPE = Open land/recreational; PAS = Pasture; CRO = Cropland; AGR = Other agriculture; FOR = Forest, WAT = Water; WET = Wetlands

Year	LDR	MDR	HDR	LDC	HDC	IND	RAH	OPE	PAS	CRO	AGR	FOR	WAT	WET	Flow (ac-ft/yr)
2000	2.1	60.6	19.4	29.5	49.1	24.7	86.9	0.0	14.9	0.0	18.6	47.8	23.6	52	429
2001	3.4	92.3	28.5	42.4	70.7	35.4	124.9	0.0	25.1	0.0	31.3	80.5	33.3	73	641
2002	5.1	137.5	42.1	62.3	104.0	52.0	183.8	0.0	38.3	0.0	47.5	122.5	48.8	108	951
2003	5.8	151.7	45.6	66.8	111.5	55.6	197.1	0.0	44.1	0.0	54.8	141.2	51.8	115	1,041
2004	6.8	170.8	50.2	72.3	120.8	60.2	213.6	0.0	52.5	0.0	65.1	167.8	55.3	123	1,158
2005	6.1	159.0	48.0	70.4	117.5	58.7	207.8	0.0	45.9	0.0	57.0	146.8	54.7	121	1,093
2006	3.3	78.1	118.1	53.7	111.6	41.2	145.8	11.7	12.5	22.3	36.5	47.8	34.0	91	808
2007	3.0	74.8	115.5	53.8	111.8	41.4	146.0	10.3	11.0	19.5	32.2	42.1	34.6	92	788
2008	7.5	149.8	208.0	83.8	174.8	63.9	228.8	30.1	32.0	57.6	93.5	122.2	48.3	137	1,437
2009	5.7	120.6	173.2	73.4	152.8	56.2	199.9	21.9	23.3	41.7	68.0	88.9	44.1	122	1,191
2010	4.3	97.8	144.5	63.7	132.5	48.9	173.3	16.1	17.1	30.6	50.1	65.5	39.4	107	991
2011	4.8	103.8	149.8	63.9	133.1	48.9	174.1	18.6	19.7	35.4	57.7	75.4	38.6	106	1,030
2012	2.9	70.5	107.1	48.9	101.7	37.6	132.9	10.4	11.1	19.8	32.4	42.5	31.1	83	732
Average	**4.7**	**112.9**	**96.2**	**60.4**	**114.8**	**48.1**	**170.4**	**9.2**	**26.7**	**17.5**	**49.6**	**91.6**	**41.4**	**102.3**	**945**

Different land use areas contributed different amounts of runoff in the Marshall Lake watershed. Of the long-term annual total runoff of 945 ac-ft/yr, 607 ac-ft/yr were from urban areas, including low-, medium-, and high-density residential and low- and high-density commercial and industrial. The runoff from these urban areas accounted for 64% of the total runoff volume from the entire watershed. The land use contributing the greatest runoff volume was roads and highways, which alone contributed 170 ac-ft/yr of runoff, accounting for 18% of total runoff from the watershed. Natural land areas, including upland forest/rangeland, water, and wetlands, contributed 235 ac-ft/yr, accounting for 25% of total watershed runoff. The runoff from rural areas, including pasture, cropland, and other agricultural land, plus some runoff from open land and recreational areas, was relatively low at 103 ac-ft/yr, accounting for 11% of total watershed runoff. Thus urban areas are the most important runoff contributor in the Marshall Lake watershed.

B. Estimating Runoff Nutrient Loads from the Marshall Lake Watershed

Runoff nutrient loads from the watershed were calculated as the sum of nutrient loads from areas occupied by different land use types. The loads from each land use type were calculated by multiplying the runoff volume from the land use area by runoff TN and TP concentrations specific to that land use type. These runoff nutrient concentrations are commonly referred to as EMCs. EMCs can be determined through stormwater studies, in which both runoff volume and runoff nutrient concentrations are measured at a series of phases from a given stormwater event. The EMC for the stormwater event is then calculated as the mean concentration weighted for the runoff volume.

The TN and TP EMCs (**Table 4.5**) in this analysis were originally used by the SJRWMD in the nutrient PLRG for the Upper Ocklawaha Chain of Lakes (Fulton *et al.* 2004). Based on the SJRWMD PLRG report, these EMCs were primarily cited from Dr. Harvey Harper's stormwater review reports (Harper 1994). The results of several other published studies (including Goldstein and Ulevich 1981; Izuno *et al.* 1991; Fonyo *et al.* 1991; and Hendrickson and Konwinski 1998) were also analyzed to supplement the numbers in the Harper (1994) report. It was the SJRWMD's opinion that the wetland EMCs in the Harper (1994) report were measured from wetlands impacted by human activities (Fulton *et al.* 2004). Therefore, the wetlands EMCs cited in the PLRG report were for the upland forest land use type in the Harper (1994) report. The EMCs for water were the natural background concentrations for the Lake Weir and Harris Chain of Lakes Basins (Fulton *et al.* 2004).

Table 4.5. EMCs of TN and TP for Different Land Use Types

Land Use	TP EMC (mg/L)	TN EMC (mg/L)
Low-density residential	0.17	1.77
Medium-density residential	0.30	2.29
High-density residential	0.49	2.42
Low-density commercial	0.19	1.22
High-density commercial	0.43	2.83
Industrial	0.33	1.98
Roads and highways	0.16	1.37
Pasture	0.38	2.48
Tree crops	0.14	2.05
Cropland	0.66	4.56
Other agriculture	0.49	2.83
Feeding operations	6.53	78.23
Open land/recreational	0.05	1.25
Forest/rangeland	0.05	1.25
Wetlands	0.05	1.25
Water	0.01	0.49

Nutrient removal by stormwater treatment facilities in urban areas was also considered in simulating watershed nutrient loads. It was assumed that all urban construction that took place after 1984, when Florida implemented the Stormwater Rule, included stormwater treatment facilities that removed TN and TP loads at certain efficiencies. To identify the construction taking place after 1984, watershed land use distribution data from 2004 and 2009 were compared with the 1988 land use distribution GIS shapefile, which was the earliest available in the DEP GIS dataminer.

It was assumed that urban land use areas in the 1988 land use shapefile did not have any stormwater treatment facilities required by the state Stormwater Rule. This assumption should be close to reality, because the 1988 land use shapefile was created based on 1987 land use aerial photography. Compared with the periods from 1984 to 2004 and 1984 to 2009, the chances of missing some urban construction between 1984 and 1987 were relatively small and should not cause significant errors in the nutrient load simulation.

Any urban land areas that did not appear in the 1988 land use shapefile but were in the 2004 or 2009 land use shapefiles were considered new construction with stormwater treatment facilities. When calculating watershed nutrient loads, nutrient loads generated from these urban land use areas were subject to stormwater treatment and a certain percentage of TN and TP removal. Based on studies of 13 stormwater treatment systems, it was assumed that 63% of the phosphorus load and 42% of the nitrogen load was removed by these facilities (Fulton *et al.* 2004).

Another aspect of the nutrient load simulation was calculating the stormwater nutrient load delivered to the receiving water after going through the overland transport process. In this TMDL analysis, all dissolved components of TN and TP were considered to be reaching the receiving water with no loss, while particulate fractions of TN and TP were considered subject to loss through overland transport. Therefore, the nutrients that eventually reach the receiving water consist of two parts: the unattenuated dissolved fraction (T) and the particulate fraction attenuated through overland transport.

The portion of nutrients that eventually reaches the receiving water is represented using **Equation 1**, which is a function established in the Reckhow *et al.* (1980) analyses.

$$D = (1 - T) * e^{(1.01 - 0.34 * \ln(L))} + T$$

Equation 1

Where,

D is the amount of nutrients that eventually reaches the receiving water.

T is the dissolved fraction of the total nutrient (TN and TP) concentrations.

(1-T) is the particulate fraction of the total nutrient (TN and TP) concentrations.

The exponential item of the equation represents the delivery ratio of the particulate nutrients.

L is the length of the overland flow path.

The percent dissolved TN and TP concentrations for different land uses in this analysis were cited from the SJRWMD's Upper Ocklawaha Chain of Lakes PLRG report (Fulton *et al.* 2004). These numbers were created by comparing concentrations of TN, TP, orthophosphate (PO_4), total dissolved phosphorus (TDP), and total dissolved nitrogen (TDN) from several studies of stormwater runoff conducted in Florida (Hendrickson 1987; Fall and Hendrickson 1988; German 1989; Fall 1990; Dierberg 1991; Izuno *et al.* 1991; Harper and Miracle 1993). **Table 4.6** shows the percent concentration of dissolved phosphorus and nitrogen for different land uses.

Table 4.6. Dissolved Fraction of TN and TP Concentrations for Different Land Uses

Land Use	% Dissolved Phosphorus	% Dissolved Nitrogen
Low-density residential	50.1%	75.3%
Medium-density residential	50.1%	75.3%
High-density residential	50.1%	75.3%
Low-density commercial	41.4%	65.7%
High-density commercial	76.7%	76.7%
Industrial	76.1%	76.1%
Roads and highways	76.7%	76.7%
Pasture	72.2%	90.8%
Tree crops	62.9%	90.8%
Cropland	60.0%	90.8%
Other agriculture	68.7%	90.8%
Feeding operations	58.3%	90.8%
Open land/recreational	50.1%	75.3%
Forest/rangeland	50.1%	75.3%
Wetlands	50.7%	77.5%
Water	11.8%	41.3%

The length of the overland flow path can be estimated by defining the location of the centroid of the watershed using ArcGIS's spatial analyst applications. The distance between the centroid and the boundary of the lake is then considered the length of the overland flow path. This approach works well for watersheds divided into multiple subwatersheds. However, it underestimates the length of the flow path if the entire watershed is treated as the only entity that discharges into a lake—especially if the lake is located close to the center of the watershed, in which case the centroid of the watershed is located in the lake and the length of the overland flow path is considered zero.

Therefore, for this analysis, since no subwatershed is delineated, the length of the overland flow path was estimated by randomly picking 20 transects of the watershed and measuring the distance between the watershed boundary and the lake boundary. The final length of the overland flow path was calculated as the mean value of the lengths of these 20 transect measurements. For the Marshall Lake watershed, the average length of the overland flow path was estimated at 722 meters.

Tables 4.7 and **4.8** list the stormwater runoff TN and TP loads from the Marshall Lake watershed estimated using the procedures described above. The annual runoff TP loads reaching the lake ranged from 91 to 373 kg/yr in the period from 2000 to 2012. The long-term average annual TP runoff load for the period was 224 kg/yr. The lowest and highest runoff TP loads occurred in 2000 and 2008, respectively, which is consistent with the pattern of annual runoff volume shown in **Table 4.9**. Again, the highest TP loads may have resulted from Tropical Storm Fay passing through the area in August 2008.

Different land use areas contribute different amounts of runoff TP loads in Marshall Lake watershed. Of the long-term annual total runoff TP loads of 224 kg/yr, 171 kg/yr were from urban land areas, including low-, medium-, and high-density residential; roads and highways; and low- and high-density commercial and industrial. Runoff TP loads from these areas accounted for 76.1% of total runoff TP loads from the entire watershed (**Figure 4.3**). The highest runoff TP loads came from high-density commercial, which alone contributed 51 kg/yr, accounting for 22.7% of total runoff TP loads from the watershed and 34.5% of total runoff TP loads from urban areas. Natural land areas, including upland forest/rangeland, water, and wetlands, contributed 9.0 kg/yr, accounting for 4% of total runoff TP loads. Runoff TP loads from rural areas—including pasture, cropland, and other agricultural land, plus some runoff from open land and recreational areas—were 44 kg/yr, accounting for 19.8% of total watershed runoff TP loads. Therefore urban areas are the most important runoff TP contributor in the Marshall Lake watershed.

Runoff TN annual loads in the period from 2000 to 2012 ranged from 782 kg/yr in 2000 to 3,021 kg/yr in 2008. The interannual pattern is similar to that of runoff TP loads. The long-term average annual runoff TN loads from the entire watershed were 1,873 kg/yr. The majority of these were created in urban areas, which contributed 1,262 kg/yr and accounted for 67.4% of total runoff TN loads from the watershed (**Figure 4.4**). Again, the single most important contributor of runoff TN loads was high-density commercial areas, which alone contributed 338 kg/yr and accounted for 18% of total watershed TN runoff loads. Natural land areas contributed runoff TN of 266 kg/yr, accounting for 14.2% of total runoff TN loads. Other rural areas, including agriculture, open land, and recreational, contributed 345 kg/yr, accounting for 18.4% of total watershed runoff TN loads.

Table 4.7. Runoff TP Annual Loads (kg/yr) in the Marshall Lake Watershed

LDR = Low-density residential; MDR = Medium-density residential; HDR = High-density residential; LDC = Low-density commercial; HDC = High-density commercial; IND = Industrial; RAH = Roads and highways; OPE = Open land/recreational; PAS = Pasture; CRO = Cropland; AGR = Other agriculture; FOR = Forest, WAT = Water; WET = Wetlands

Year	LDR	MDR	HDR	LDC	HDC	IND	RAH	OPE	PAS	CRO	AGR	FOR	WAT	WET	Total TP Loads (kg/yr)
2000	0.30	14.5	7.6	4.2	21.8	8.6	15.0	0.0	5.7	0.0	8.8	2.15	0.14	2.36	91
2001	0.48	22.1	11.1	6.0	31.3	12.3	21.5	0.0	9.6	0.0	14.8	3.63	0.20	3.35	136
2002	0.72	32.9	16.5	8.8	46.1	18.1	31.6	0.0	14.7	0.0	22.5	5.52	0.29	4.92	203
2003	0.82	36.3	17.8	9.4	49.4	19.3	33.9	0.0	16.9	0.0	25.9	6.37	0.31	5.24	222
2004	0.96	40.9	19.6	10.2	53.5	20.9	36.8	0.0	20.1	0.0	30.8	7.57	0.33	5.63	247
2005	0.85	38.1	18.8	9.9	52.1	20.4	35.8	0.0	17.6	0.0	26.9	6.62	0.33	5.54	233
2006	0.46	18.7	46.2	7.6	49.4	14.3	25.1	0.5	4.8	13.1	17.3	2.16	0.20	4.18	204
2007	0.42	17.9	45.2	7.6	49.5	14.4	25.1	0.5	4.2	11.5	15.2	1.90	0.21	4.22	198
2008	1.06	35.9	81.3	11.8	77.5	22.2	39.4	1.4	12.3	33.9	44.2	5.51	0.29	6.26	373
2009	0.80	28.9	67.7	10.3	67.7	19.5	34.4	1.0	8.9	24.6	32.2	4.01	0.26	5.58	306
2010	0.61	23.4	56.5	9.0	58.7	17.0	29.8	0.7	6.6	18.1	23.7	2.95	0.24	4.91	252
2011	0.68	24.9	58.6	9.0	59.0	17.0	30.0	0.8	7.6	20.9	27.3	3.40	0.23	4.87	264
2012	0.41	16.9	41.9	6.9	45.1	13.1	22.9	0.5	4.3	11.6	15.3	1.91	0.19	3.81	185
Average	**0.66**	**27.0**	**37.6**	**8.5**	**50.9**	**16.7**	**29.3**	**0.4**	**10.3**	**10.3**	**23.5**	**4.13**	**0.25**	**4.68**	**224**

Table 4.8. Runoff TN Annual Loads (kg/yr) in the Marshall Lake Watershed

LDR = Low-density residential; MDR = Medium-density residential; HDR = High-density residential; LDC = Low-density commercial; HDC = High-density commercial; IND = Industrial; RAH = Roads and highways; OPE = Open land/recreational; PAS = Pasture; CRO = Cropland; AGR = Other agriculture; FOR = Forest, WAT = Water; WET = Wetlands

Year	LDR	MDR	HDR	LDC	HDC	IND	RAH	OPE	PAS	CRO	AGR	FOR	WAT	WET	Total TN Loads (kg/yr)
2000	4	141	48	34	143	50	123	0	43	0	61	61	8	67	782
2001	6	215	70	48	206	72	177	0	72	0	102	102	12	95	1,177
2002	10	362	117	80	342	119	293	0	124	0	175	176	20	157	1,977
2003	10	354	112	76	325	113	278	0	126	0	179	180	18	149	1,921
2004	12	398	124	82	352	122	302	0	150	0	213	213	20	160	2,148
2005	11	371	118	80	343	119	294	0	131	0	186	187	13	157	2,009
2006	6	182	291	61	325	84	206	15	36	117	119	61	12	118	1,634
2007	5	174	285	61	326	84	206	13	32	103	105	54	12	120	1,580
2008	14	349	512	95	510	130	323	38	91	302	306	155	17	177	3,021
2009	10	281	426	84	446	114	283	28	67	219	222	113	16	158	2,466
2010	8	228	356	73	387	99	245	20	49	161	164	83	14	139	2,025
2011	9	242	369	73	388	99	246	24	56	186	189	96	14	138	2,128
2012	5	164	264	56	297	76	188	13	32	104	106	54	7	108	1,474
Average	**9**	**266**	**238**	**69**	**338**	**99**	**243**	**12**	**78**	**92**	**164**	**118**	**14**	**134**	**1,873**

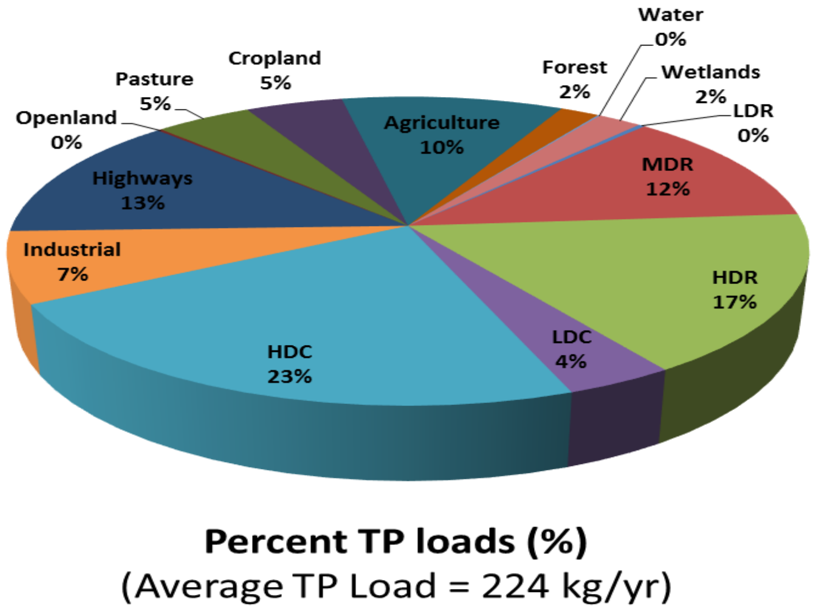

Figure 4.3. Percent TP Runoff Loads from Different Land Uses in the Marshall Lake Watershed

Note: LDR and MDR represent low- and high-density residential, and LDC and HDC indicate low- and high-density commercial, respectively.

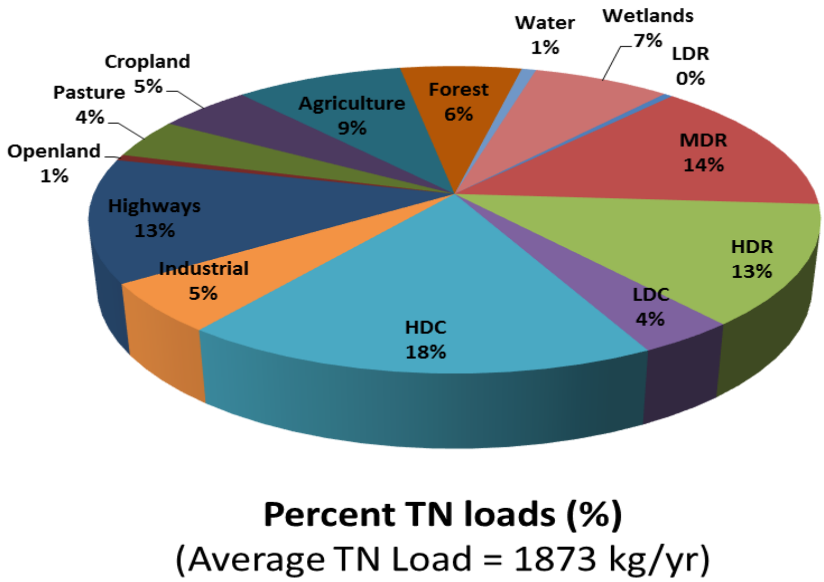

Figure 4.4. Percent TN Runoff Loads from Different Land Uses in the Marshall Lake Watershed

Note: LDR and MDR represent low- and high-density residential, and LDC and HDC indicate low- and high-density commercial, respectively.

4.2.2.4 Estimating Septic Tank Nutrient Loadings in the Marshall Lake Watershed

Septic tanks are an important source of nutrients for many eutrophic lakes. Failed septic tanks contribute nutrient loads primarily through surface runoff, which was implicitly considered when simulating runoff nutrient loads using the EMCs for different land use types. However, even normally functioning septic tanks can contribute nutrients through ground water.

While nutrient removal can happen due to uptake by vegetation and adsorption by soil particles in the drain field, neither process can remove 100% of the nutrients. There is always a portion of the nutrients that enters ground water, and, through this pathway, flows to an impaired surface water. For this TMDL analysis, septic tank phosphorus loads and nitrogen loads were estimated using different methods, and these loading estimates were used to better understand the role of anthropogenic nutrient loads in total nutrient loadings from ground water seepage.

ESTIMATING PHOSPHORUS LOADS FROM SEPTIC TANKS

Phosphorus compounds from septic tanks are either organic or inorganic. Soil removes phosphorus compounds relatively easily compared with nitrogen compounds, because organic phosphorus compounds have large molecules, and inorganic phosphorus compounds contain a large electrical charge. These characteristics are responsible for the high removal rate of phosphorus in soil. It is generally accepted that within 200 meters, 90% of the phosphorus loads from septic tanks can be removed through plant uptake and soil removal (Fulton 1995). For this analysis, septic tank phosphorus loads (L_{ST}) were estimated using **Equation 2**.

$$L_{ST} = (L_{Cap} * CY) * (1 - SR) \qquad \textbf{Equation 2}$$

Where,

LCap is the phosphorus load to septic systems per capita-year.

CY is the number of capita-years in the watershed serviced by septic systems impacting the lake.

SR is the soil retention coefficient. Here, SR = 0.9.

The per capita-year phosphorus load was cited from the SJRWMD's first version of the nutrient PLRG for the Upper Ocklawaha Chain of Lakes (Fulton 1995), which was 1.48 kg/capita/yr. This number came from a septic tank review analysis conducted by Reckhow *et al.* (1980) based on eight septic tank studies.

To obtain the CY value, the number of families in the Marshall Lake watershed on septic tanks and located within 200 meters of Marshall Lake was determined. It was assumed that each family was serviced with one septic tank. Therefore, the number of families serviced with septic tanks was considered equal to the number of septic tanks.

The number of septic tanks in the Marshall Lake watershed was obtained from a septic tank GIS shapefile in the DEP GIS dataminer. This shapefile, created by the Florida Department of Health (FDOH) in July 2011, includes the septic tanks inspected by FDOH. A subset of septic tanks located in the Marshall Lake watershed was selected using the Selection by Location tool of ArcGIS 10.1.

The selected septic tanks were exported as a separate shapefile that included only the septic tanks located in the Marshall Lake watershed. A shapefile of a 200-meter septic tank impact zone around Marshall Lake was then created using the ArcGIS Buffer tool. The impact zone shapefile was used to identify septic tanks located within 200 meters of Marshall Lake. Based on this analysis, two septic tanks were identified. **Figure 4.5** shows the locations of the septic tanks in the Marshall Lake watershed and the septic tanks within 200 meters of the lake.

When these TMDLs were developed, no information was obtained on the number of people living in the 2 households located within 200 meters of Marshall Lake. Therefore, the average household size of Orange County was used as the surrogate for these 2 households. Based on 2010 data from the U.S. Census Bureau, the total population living in the Apopka CCD area of the Orange County was 87,104 individuals. There were 30,736 occupied households in the Apopka CCD area. The average number of people in each household, based on these numbers, was 2.8. This TMDL analysis assumes that both households are long-term residents of Orange County. Using **Equation 18**, the septic tank phosphorus load contribution in the Marshall Lake watershed is 0.83 kg/yr:

$$L_{ST} = 1.48 \text{ kg/capita/yr} \times 2.8 \text{ people/household} \times 2 \text{ households} \times (1-0.9) = 0.83 \text{ kg/yr}$$

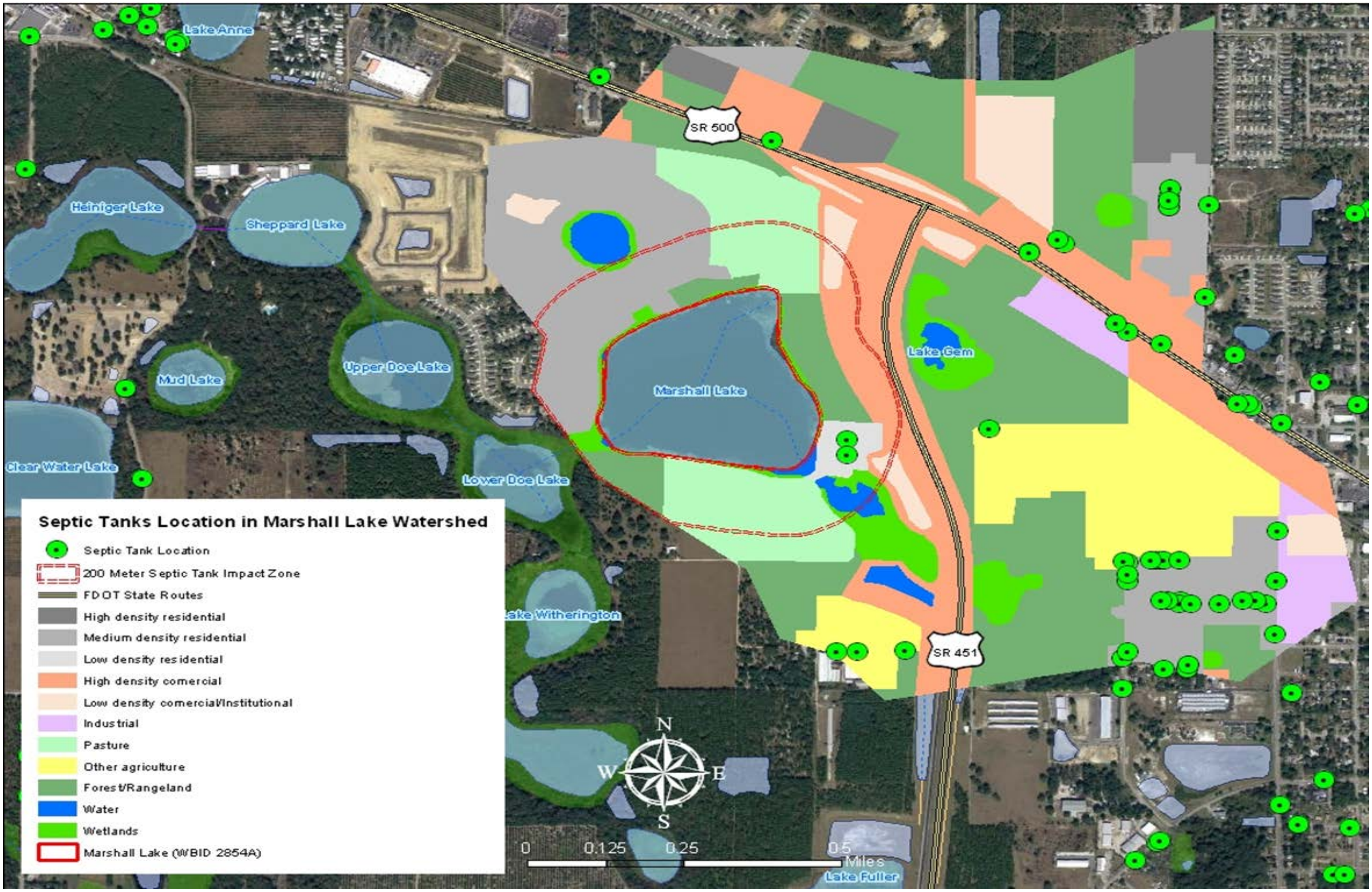

Figure 4.5. Location of Septic Tanks in the Marshall Lake Watershed

Estimating Nitrogen Loads from Septic Tanks

Nitrogen discharged from septic tanks cannot be removed from the soil as easily as phosphorus because septic tank effluent mainly comprises ammonia, which, under the aerobic conditions of a drain field, is oxidized to nitrate/nitrite through nitrification. Nitrate/nitrite is very soluble and can percolate into ground water with septic tank effluent or rainfall infiltration. In addition, nitrate/nitrite molecules have a monovalent bond and thus a very weak soil binding capacity. The only way they can be removed, other than by vegetation uptake, is through denitrification, which is an anaerobic process in which denitrification bacteria convert nitrate to nitrogen gas. Nitrate-nitrogen is removed when nitrogen gas leaves the soil solution. Depending on soil conductivity, porosity, surface topography, ground water flow speed, and soil organic content, different amounts of nitrate/nitrite-nitrogen coming from septic tanks can be removed before they reach the impaired receiving water.

In this analysis, the septic tank nitrogen loading eventually reaching Marshall Lake was simulated using a grid-based GIS-based model called ArcNLET, developed by the Florida State University Department of Scientific Computing. The model simulates nitrogen transport in ground water and the nitrogen loads that eventually reach a receiving water by taking into consideration nitrogen advection, hydrodynamic dispersion, and denitrification in the soil. The model also considers the spatial heterogeneity of the land surface topography, soil conductivity and porosity, and the location of septic tanks corresponding to the receiving waterbody. A major advantage of the model is that it can be used to estimate the loading impact of each individual septic tank in the watershed on the final nitrogen loads reaching the receiving water. Major state variables simulated by ArcNLET include ground water seepage velocity, nitrogen concentration at any location in the concentration plume, and nitrogen loading that eventually reaches the receiving waterbody.

Ye *et al.* (2014) conducted the study for DEP to estimate the nitrogen loads from septic systems to Marshall Lake and three other lakes in the Ocklawaha River Basin. **Appendix C** provides details of the ArcNLET modeling. The specific hydraulic conductivity and porosity were then linked to the SSURGO shapefile to create the spatial distribution of soil hydraulic conductivity and porosity for the Marshall Lake watershed. The Feature to Raster converting tool of ArcGIS 10.1 was used to create raster files for hydraulic conductivity and porosity for the watershed. The GIS shapefile that identifies the location of septic tanks in the watershed used for simulating septic tank nitrogen loads was the same as the septic tank point shapefile used to quantify the septic tank phosphorus loads. This shapefile was retrieved from the DEP GIS dataminer and created based on FDOH septic tank survey results.

A subset of septic tanks located in the watershed was chosen using the Selection by Location tool of ArcGIS 10.1 and the boundary shapefile for the Marshall Lake watershed. The shapefile showing waterbody locations in the watershed was created using the waterbody and swamp and marsh shapefiles included in the U.S. Geological Survey (USGS) 1:24,000 National Hydrography Dataset (NHD) coverage residing in the DEP GIS dataminer. Depending on the location of septic tanks, topography, and distance between septic tanks and receiving waters, plumes may enter lakes, ponds, and wetland areas other than Marshall Lake. The Ye *et al.* study (2014) estimated that septic tank nitrogen loads to Marshall Lake were 117 kg/yr, much less than the watershed loading of TN (1,873 kg/yr) and the ground water seepage loading of TN (850 kg/yr).

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

5.1 Determination of Loading Capacity

Nutrient enrichment and the resulting problems related to eutrophication tend to be widespread and are frequently manifested far (in both time and space) from their sources. Addressing eutrophication involves relating water quality and biological effects such as photosynthesis, decomposition, and nutrient recycling as acted on by environmental factors (*i.e.*, rainfall, point source discharge, *etc*.) to the timing and magnitude of constituent loads supplied from various categories of pollution sources. The assimilative capacity should be related to some specific hydrometeorological condition during a selected time span or to cover some range of expected variation in these conditions.

The goal of this TMDL development is to identify the maximum allowable TN and TP loadings from the watershed, so that Marshall Lake will meet the TMDL targets and thus maintain its function and designated use as a Class III water. To achieve the goal, DEP selected BATHTUB as the waterbody model. The model simulated in-lake Chla responses to watershed nutrient loadings and ultimately estimated the lake's assimilative capacity.

5.2 Water Quality Trends for Marshall Lake

Water quality data for Marshall Lake from 1994 to 2011 were retrieved from IWR Database Run 49. A total of 10 water quality stations in the lake were identified, and most of the water quality data were collected between 2000 and 2011 (**Table 5.1** and **Figure 5.1**). **Figure 5.2** shows temporal trends of Chla, TN and TP concentrations, and TN/TP ratios in Marshall Lake. Concentrations of Chla observed between 2004 and 2011 ranged from 13 to 80 μg/L, with an average of 37 ± 16.7 μg/L (n = 25) and a coefficient of variance (CV) of 46% (**Table 5.2**). However, no Chla data were available when the peak concentration (293 μg/L) of uncorrected Chla appeared in June 2001. Elevated concentrations of uncorrected Chla in 2001 may be associated with peak concentrations of TN and TP (**Table 5.3**).

A long-term average of TN was 1.85 ± 0.86 mg/L (n = 35) during the planning and verified periods, with a CV of 47% (**Table 5.2**). Similarly, TP concentrations averaged 0.087 ± 0.043 mg/L (n = 34) with a CV of 50%. Concentrations of uncorrected Chla, TN, and TP tended to be higher during 2000 and 2001 when rainfall was the lowest during the period of observation. TN/TP ratios (n = 33) ranged from 8 to 42 over the period, with an average of 25 ± 8.9 and a CV of 36%. The TN/TP ratio indicates that the lake may have been co-limited during the period of the observation.

Table 5.3 summarizes annual mean concentrations of Chla, TN, and TP and the TN/TP ratio observed between 2000 and 2011. No Chla data were available for 2000 through 2003, while elevated uncorrected Chla concentrations were consistently shown for 2000 and 2001. Therefore, these annual average concentrations of uncorrected Chla in 2000 through 2003 were included in calculating a long-term annual average of Chla for the BATHTUB simulation to better represent the driest condition of the system and reflect increases in TN and TP during the period from 2000 to 2003.

Table 5.1. Water Quality Stations in Marshall Lake, 1994–2011

WBID	Station	Latitude	Longitude	Number of Observations	Period of Observation
2872A	21FLCEN 20020571	28.67842	-81.53416	472	2011
2872A	21FLCEN 20020572	28.67685	-81.53140	316	2011
2872A	21FLCEN 20020643	28.67786	-81.53267	118	2011
2872A	21FLCEN 20020643	28.67786	-81.53267	118	2011
2872A	21FLCEN 20020647	28.67921	-81.53205	84	2011
2872A	21FLCEN 20020648	28.67638	-81.53347	84	2011
2872A	21FLKWATORA-MARSHALL-1	28.67663	-81.53091	44	2000–01
2872A	21FLKWATORA-MARSHALL-2	28.67772	-81.53333	44	2000–01
2872A	21FLKWATORA-MARSHALL-3	28.67751	-81.53460	44	2000–01
2872A	21FLORANA25	28.67778	-81.53306	525	1994–2010

Annual mean Chla concentrations including uncorrected Chla ranged from 21 μg/L in 2008 to 115 μg/L in 2001, with a long-term annual average of 46.1 μg/L. Some elevated concentrations also were recorded in 2005 and 2009, suggesting a linkage of watershed runoff during the wet years. Annual concentrations of TN and TP ranged from 1.25 mg/L in 2010 to 3.06 mg/L in 2001, and from 0.041 mg/L in 2011 to 0.180 mg/L in 2005, respectively. In general, elevated concentrations of TN and TP appeared in 2005 and 2009 during the wet years of observation, suggesting that watershed runoff to the lake may also play an important role in delivering TN and TP to the lake. It should be noted that the TN and TP data on December 14, 2005, were eliminated for water quality analysis due to unrealistic values.

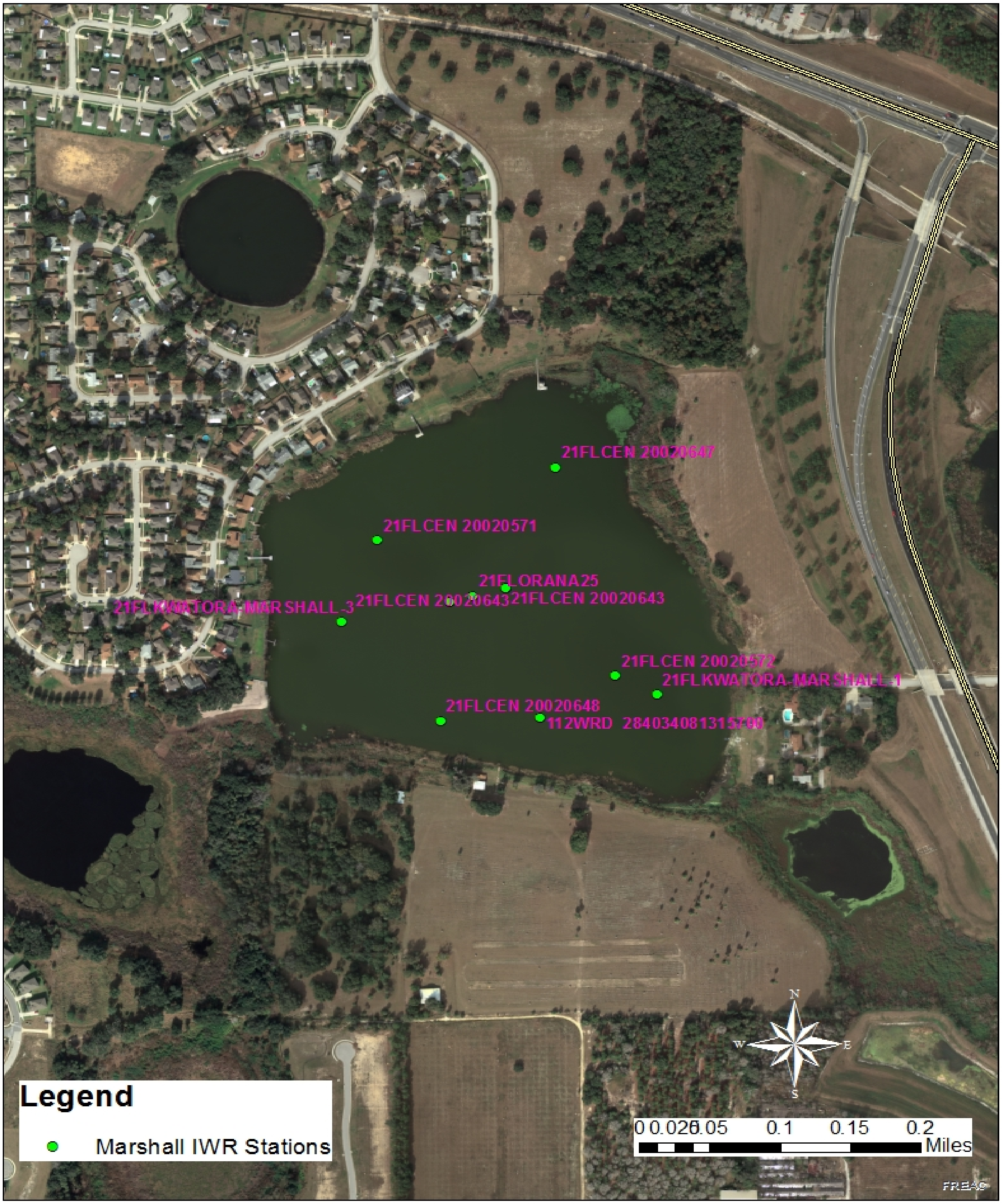

Figure 5.1. Location of Water Quality Stations in Marshall Lake

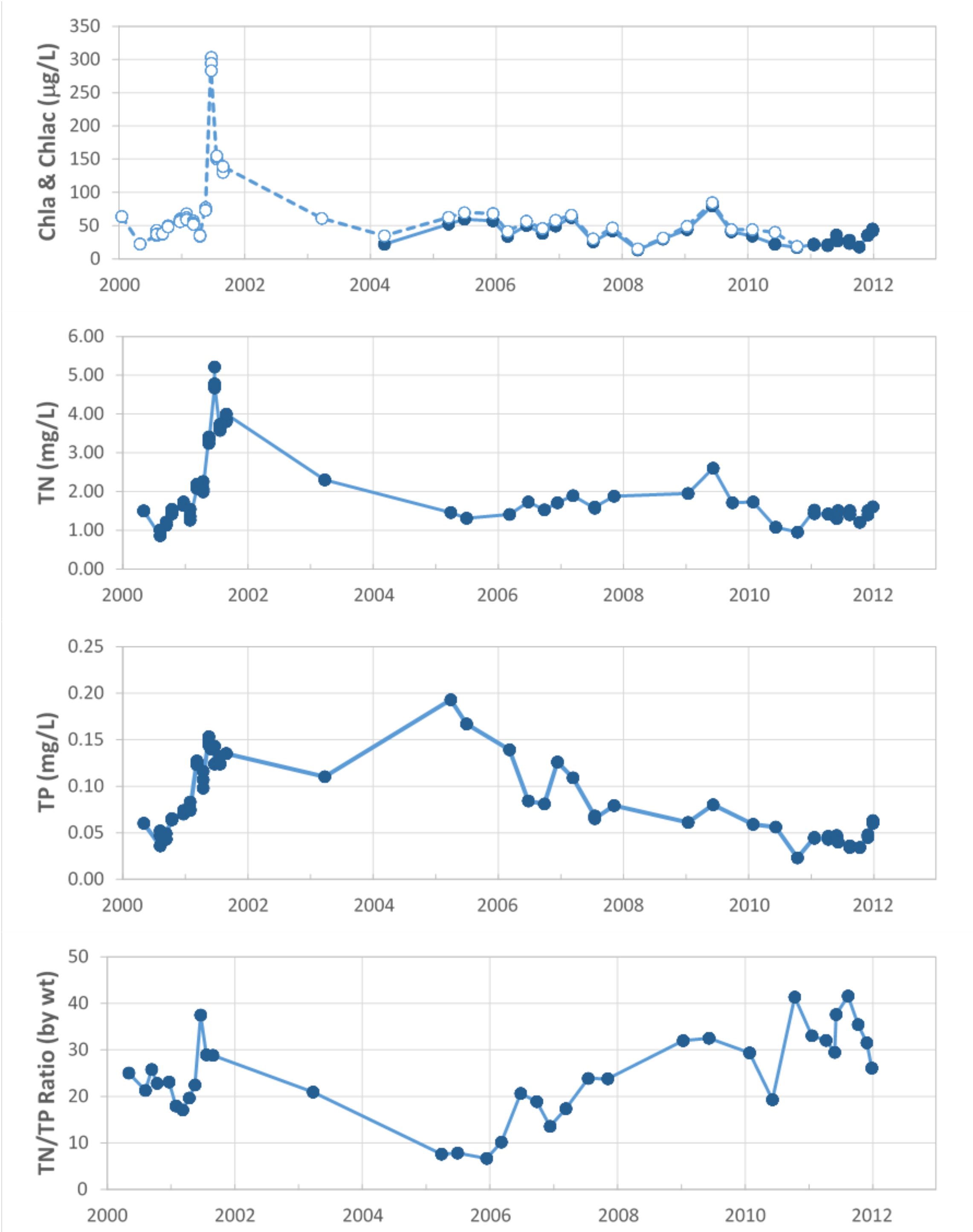

Figure 5.2. Long-Term Trends of Daily Concentrations of Chla, TN, and TP and TN/TP Ratios in Marshall Lake, 2000–11

Table 5.2. Summary of Statistics of Water Quality Parameters in Marshall Lake Observed during the Assessment (Planning and Verified) Period, 2000–11

STD = Standard deviation

Water Quality Variables	Unit	No. of Obs.	Median	Mean	STD	Min	Max	CV (%)
Chla	μg/L	25	34	37	16.7	13	80	46%
TN	mg/L	35	1.53	1.85	0.86	0.95	4.89	47%
TP	mg/L	34	0.078	0.087	0.043	0.023	0.193	50%
DO	mg/L	11	8.93	8.57	1.29	7.1	11.1	14%
Color	PCU	9	20	21	8.6	1	30	41%
Secchi depth	Meters	41	0.64	0.76	0.47	0.2	2.1	62%
Alkalinity	$CaCO_3$	13	44.5	43.0	13.9	2.0	59.5	32%
TN/TP ratio	No unit	33	24	25	8.9	7.5	41.5	36%

Table 5.3. Annual Means and Standard Deviation (± 1-sigma standard deviation) of Chla, TN, and TP and TN/TP Ratios in Marshall Lake, 2000–11

STD = 1-sigma standard deviation
NA = Not available
Note: The Chla data in 2000, 2001, and 2003 represent annual averages of uncorrected Chla.

Year	Chla (μg/L)	Chla STD	TN (mg/L)	TN STD	TP (mg/L)	TP STD	TN/TP Ratio (No unit)	TN/TP Ratio STD
2000	41.6	16.1	1.38	0.264	0.057	0.012	23.6	1.8
2001	115.0	89.5	3.06	1.227	0.124	0.022	24.6	7.5
2003	61.0	NA	2.30	NA	0.110	NA	20.9	NA
2004	22.1	NA	NA	NA	NA	NA	NA	NA
2005	56.4	NA	1.39	0.106	0.180	0.018	7.7	0.2
2006	43.0	3.6	1.60	0.153	0.108	0.029	15.8	4.8
2007	43.3	8.2	1.79	0.173	0.085	0.022	21.7	3.7
2008	21.5	18.1	NA	NA	NA	NA	NA	NA
2009	54.8	11.7	2.09	0.460	0.071	0.013	32.2	0.4
2010	24.5	21.7	1.25	0.418	0.046	0.020	30.0	11.0
2011	24.3	8.9	1.40	0.108	0.041	0.005	34.8	4.3

Figure 5.3 shows monthly mean TN, TP, and Chla concentrations observed for Marshall Lake from 2000 through 2011. As expected, no seasonal trends were observed for TN and TP concentrations or TN/TP ratios during the period of observation. An average concentration of Chla during the growing season (May through September) was 35 μg/L, while concentrations during the nongrowing season (December through April) averaged 36 μg/L, indicating no concentration difference between the growing and nongrowing seasons.

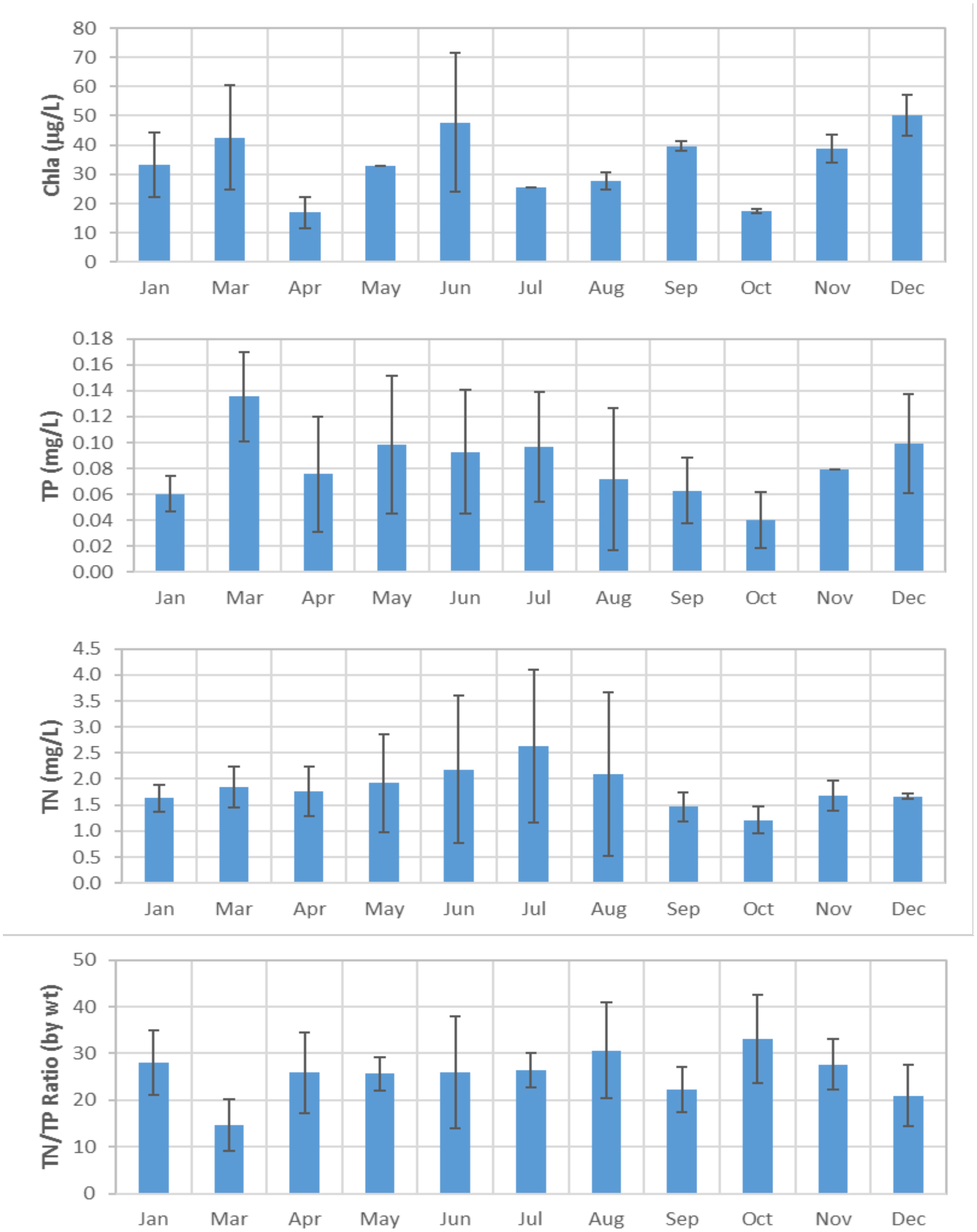

Figure 5.3. Monthly Variations of Chla, TN, and TP and TN/TP Ratios in Marshall Lake, 2000–11

Note: Error bars represent a 1-sigma standard deviation.

5.3 Marshall Lake Water Quality Modeling

5.3.1 BATHTUB Overview

The U.S. Army Corps of Engineers (USACOE) BATHTUB model was used to assess in-lake water quality responses to the watershed TN and TP loads. BATHTUB is a series of empirical nutrient and eutrophication models for lakes and reservoirs. The model performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network, which accounts for advective and diffusive transport and nutrient sedimentation (Walker 1999). BATHTUB is often used to simulate the fate and transport of nutrients and water quality conditions and responses to the nutrient load into a lake or similar waterbody.

BATHTUB is composed of three major components: water balance, nutrient sedimentation, and eutrophication response models (expressed in terms of TN, TP, Chla, transparency, organic N, and organic P). To simulate water quality conditions, BATHTUB requires input information on various lake characteristics such as length, width, mean depth, and nutrient loads from various sources in the surrounding watershed. These data are then used to evaluate key in-lake water quality parameters such as nutrient concentrations, turbidity, and algal growth. One major advantage of BATHTUB over other lake models is its use of simple steady-state calculations to address eutrophication processes, which reduces data demands. Particularly where data are limited, BATHTUB is an effective tool for lake and reservoir water quality assessment and management.

The net accumulation of nutrients in a lake is a result of nutrient mass balance between incoming flow to the lake and outgoing flow from the lake and the decay of nutrients in the lake. BATHTUB provides several submodels depending on the inorganic/organic nutrient partitioning coefficient and reaction kinetics. The major pathway for removing TN and TP from the water columns, in these simplified empirical equations, is through sedimentation to the lake bottom.

The prediction of Chla concentrations by BATHTUB also involves choosing one of several alternative models depending on whether the algal communities are limited by phosphorus or nitrogen, or co-limited by both nutrients. Scenarios that include algal communities limited by light intensity or controlled by the lake flushing rate are also included in the suite of models. The variety of models available in BATHTUB allows the user to choose specific models based on the particular condition of a lake.

The nutrient balance model adopted by BATHTUB assumes that the net accumulation of nutrients in a lake is the difference between nutrient loadings into the lake from various sources and the nutrients carried out through outflow and the losses of nutrients through whatever decay processes occur inside the lake. In this analysis, nutrient inputs included TN and TP loadings though stormwater surface runoff from various land uses, baseflow contribution (including contributions from septic tanks), artesian input, and atmospheric deposition. Nutrient output was considered primarily through lake outflow and settling.

To address nutrient decay in the lake, BATHTUB provides several alternatives, depending on the inorganic/organic nutrient partitioning coefficient and reaction kinetics. The major pathway of decay for TN and TP in the model is through sedimentation to the bottom of the lake. The actual sedimentation rate is the net difference between the gross sedimentation rate and sediment resuspension rate.

5.3.2 BATHTUB Inputs

5.3.2.1 Morphologic Characteristics of Marshall Lake

DEP conducted a bathymetric survey for Marshall Lake in August 2013. The survey was performed using a Hummingbird Wide-100 fathometer attached to a boat that took depth readings from designated points along lake transects. Depth readings and satellite-based positioning information determined using a global positioning system (Trimble GeoXT GPS unit) were used to develop bathymetric contour maps and morphologic characteristics for the lake. To ensure that correct depth readings were obtained, depth measurements from the fathometer were confirmed periodically using the total depth readings from an YSI 600 series unit.

Figure 5.4 shows the location of the 67 bathymetry transect points across Marshall Lake and the bathymetry contours. These bathymetric maps were created based on the depth readings and location information using ArcGIS to obtain the relationship of lake surface area versus depth for use in model development. A depth–surface area relationship was then computed using the bathymetric maps, and surface area as a function of stage was obtained using a best-fit polynomial equation based on the relationship. Lake volumes were calculated using surface area and depth within each contour with a contour interval of 0.2 meters (m). The water volume contained between the shoreline and the 0.2 m depth interval was calculated using the truncated cone method (Wetzel 1983). The calculation was completed for all contour intervals, and a best-fit polynomial equation was established to provide estimates of lake volume as a function of water depth. This method was used by Environmental Consulting and Technology (ECT) for a bathymetric analysis of Lake Apopka (ECT 1989).

Figure 5.5 shows the relationships between water depth and surface area and between water depth and cumulative volume for Marshall Lake. The best-fit equations were obtained from these relationships to calculate the annual surface area and lake volume for BATHTUB inputs. Lake stage data had been collected by Orange County for Marshall Lake since 1971, but the effort stopped after 2004. **Table 5.4** shows the annual average lake stage between 1971 and 2004. Stage data for the lake were downloaded from the Orange County Water Atlas website.

Based on **Table 5.4**, the annual average stage for Marshall Lake ranges from 55.1 to 66.5 ft. NGVD with a long-term mean annual average stage of 63.7 ft. When DEP conducted the bathymetry survey, the lake stage was at 62.0 ft., which was lower than the historical mean long-term annual average.

Because lake stage measurements were not recorded after 2004, the lake surface areas after 2004 were derived using water depth measurements taken at two sites designed for water quality sample collection: 21FLCEN 20020571 collected by DEP, and 21FLORANA25 collected by Orange County. Both stations are located close to the center of the lake where the bottom elevation is 53.1 ft.

To estimate the annual average lake stage since 2005, the depth measurements collected during several sampling events in each year since 2005 were first averaged to obtain the annual average water depth measurement for each year. The annual average lake stage for each year was then calculated as the sum of the annual average water depth and 53.1 ft. Based on observed and estimated annual average lake levels from 2000 to 2012, annual average lake surface area and lake volume were calculated using the best-fit equations (**Tables 5.5a** and **5.5b**).

Lake elevation in Marshall Lake ranged from 55.1 ft. in 2001 to 69.5 ft. in 2005, with an average of 63.5 ft., showing that the lake level varied over the course of dry and wet year conditions. During the dry years in 2000 and 2001, the lake level was the lowest, while the lake level was higher during the wet years in 2005 and 2010. Lake surface area varied as a function of changing lake levels during the period from 2000 to 2012, ranging from 0.40 square kilometers (km^2) in 2001 to 0.46 km^2 in 2009, with an average of 0.43 km^2.

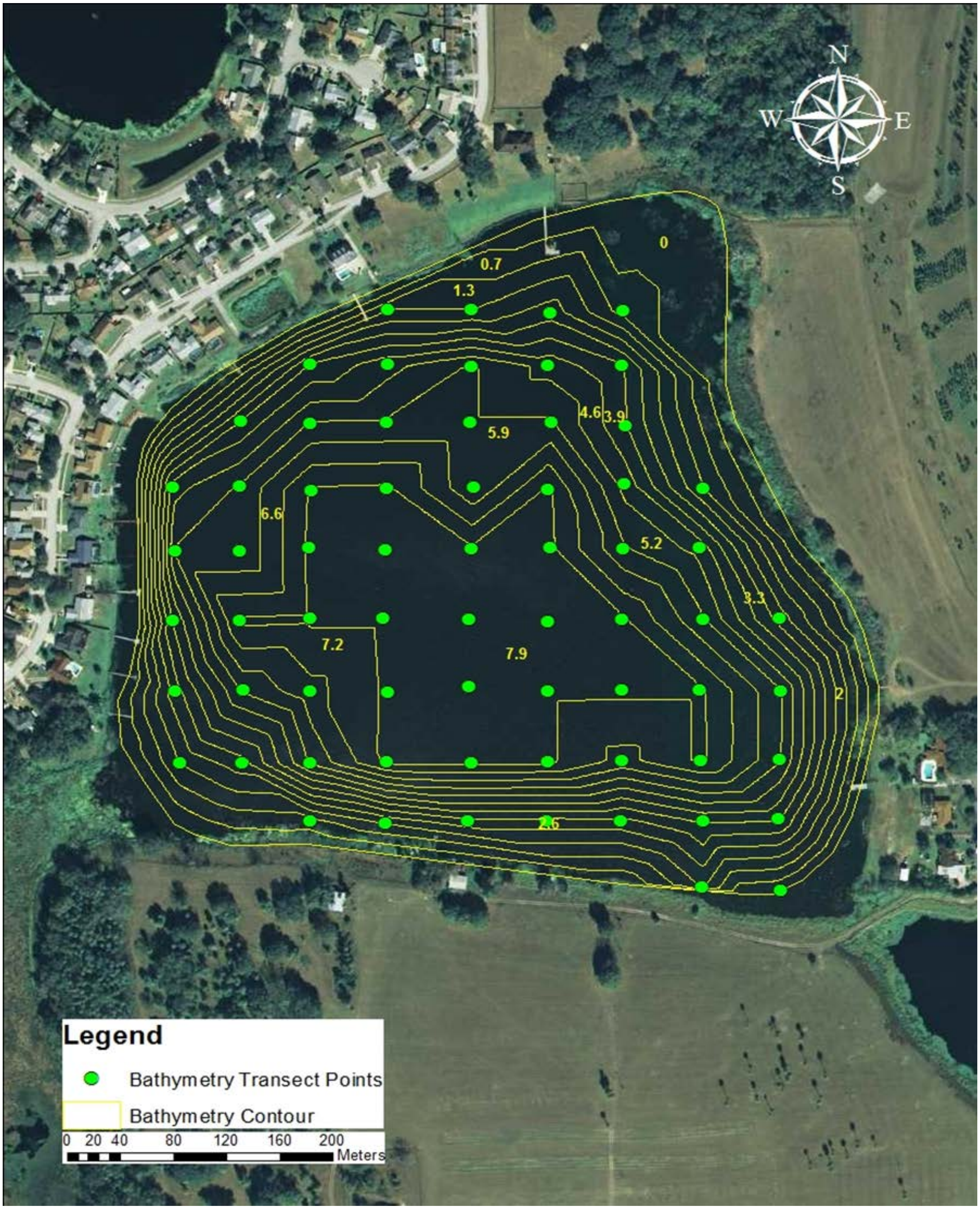

Figure 5.4. Bathymetry Contours and Location of Transect Points for the Marshall Lake Bathymetry Survey (ft. NGVD)

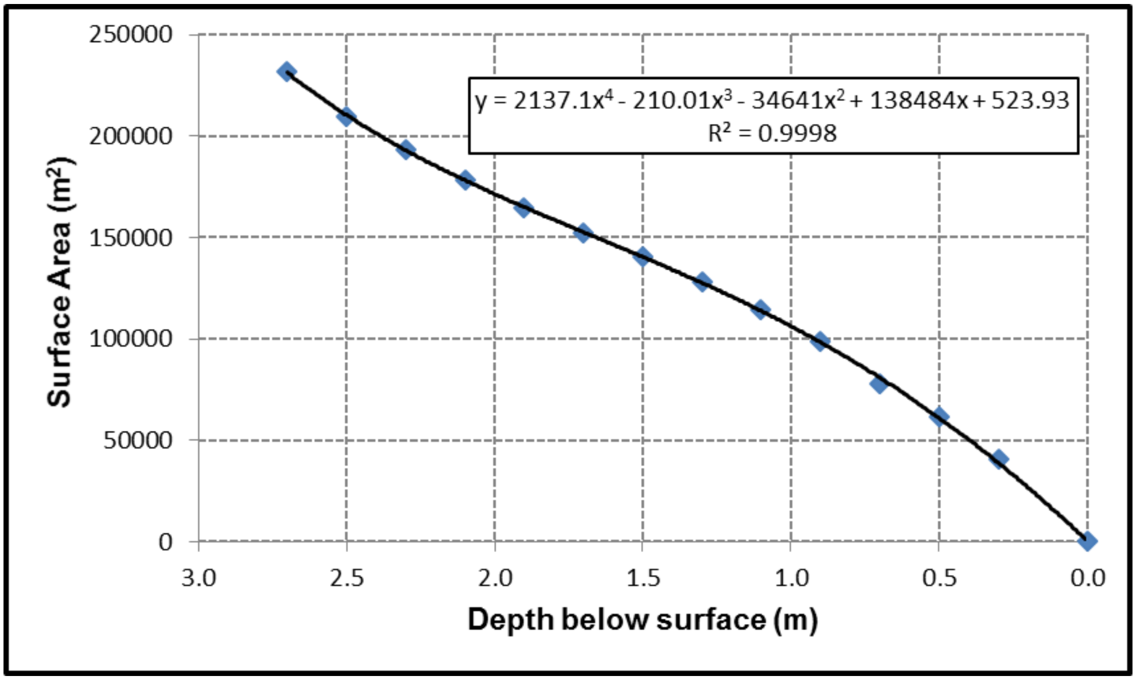

Figure 5.5a. Relationship of Depth versus Surface Area for Marshall Lake. Solid Line is a Best-Fit Line

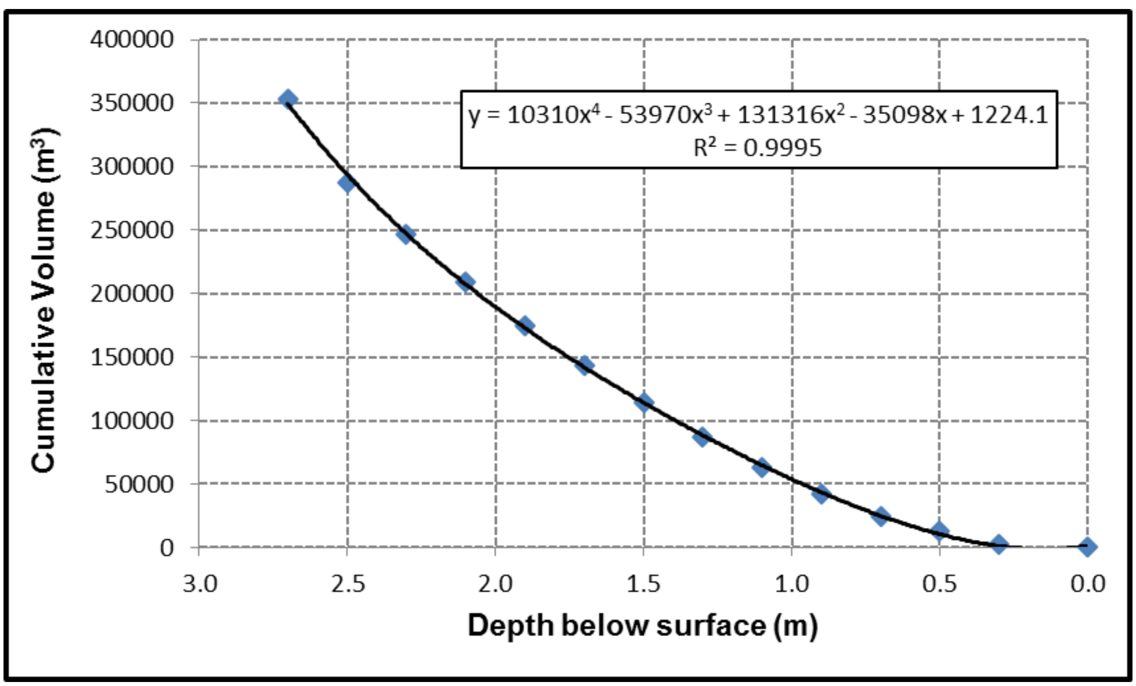

Figure 5.5b. Relationship of Depth versus Cumulative Volume for Marshall Lake. Solid Line is a Best-Fit Line

Table 5.4. Lake Stage Measurements for Marshall Lake, 1971–2004

Year	Annual Average Lake Stage (ft)
1971	66.5
1972	66.2
1973	65.3
1975	64.7
1987	66.0
1988	66.1
1989	65.0
1990	62.6
1991	62.0
1992	62.4
1993	63.4
1994	64.2
1995	65.9
1996	65.9
1997	63.8
1998	64.7
1999	63.4
2000	61.3
2001	55.1
2002	55.6
2003	64.2
2004	66.3

The change in lake volume was significant between the dry and wet years (**Table 5.5**). The lowest lake volume was estimated at 17,205 cubic meters (m^3) in 2001 while the peak volume of 4,719,417 m^3 was predicted in 2010, showing a coefficient variation of 255%. Such an extreme change in lake volume could have impacts on a steady-state assumption for BATHTUB model simulation. Mean depth was calculated by lake surface area and lake volume. Because Marshall Lake is a shallow lake, and assumed to be a well-mixed lake for modeling purposes, the mixed layer depth was assumed to be equal to the mean depth of the lake.

Table 5.5. Annual Means of Morphologic Characteristics of Marshall Lake, 2000–12

Year	Annual Average Lake Stage (ft NGVD)	Annual Average Depth (ft)	Annual Average Depth (m)	Surface Area (m^2)	Surface Area (km^2)	Lake Volume (m^3)	Mean Depth (m)
2000	61.3	8.2	2.51	211,667	0.212	296,973	1.40
2001	55.1	2.0	0.60	71,493	0.071	17,205	0.24
2002	55.6	2.5	0.76	86,515	0.087	30,277	0.35
2003	64.2	11.1	3.40	347,483	0.347	654,409	1.88
2004	66.3	13.2	4.03	544,465	0.544	1,175,514	2.16
2005	69.5	16.4	5.00	1,135,274	1.135	2,803,082	2.47
2006	64.4	11.3	3.43	355,912	0.356	676,505	1.90
2007	63.1	10.0	3.05	280,152	0.280	478,031	1.71
2008	60.8	7.7	2.36	197,775	0.198	259,745	1.31
2009	67.4	14.3	4.35	697,460	0.697	1,588,268	2.28
2010	71.6	18.5	5.64	1,800,789	1.801	4,719,417	2.62
2011	63.1	10.0	3.05	280,441	0.280	478,788	1.71
2012	62.5	9.4	2.87	252,004	0.252	404,029	1.60
Average	**63.5**	**10.4**	**3.16**	**298,300**	**0.482**	**525,597**	**1.66**

Meteorological Data

The SJRWMD provided daily NEXRAD rainfall data from January 1, 2000, to December 31, 2012, for TMDL development. The original rainfall data were output for each 2-km by 2-km grid at 15-minute intervals. When providing the rainfall data to DEP, the SJRWMD aggregated the 15-minute rainfall into daily rainfall, and a single watershed-wide average daily rainfall depth time series was generated by averaging the rainfall depth time series of all the grid cells falling within the boundary of the Marshall Lake watershed. These daily precipitation data were expressed as an annual total in meters per year for the BATHTUB input (**Table 5.6**).

Pan evaporation is also an important parameter for simulating direct evaporation from a lake surface. Free water-surface evaporation from a lake is different from pan evaporation, which can be computed by using methods to correct for the difference in heat storage capabilities of water in a pan versus in a lake (Lee and Swancar 1997). Lee and Swancar (1997) derived pan coefficients for lakes in central Florida, ranging from 0.70 to 0.77 for Lake Lucerne and 0.71 to 0.75 for Lake Alfred. On an annual basis, the long-term annual average coefficient of 0.74 was derived by Farnsworth *et al.* (1982). Trommer *et al.* (1999) also used a coefficient of 0.75 applied to pan evaporation data from the Bradenton 5 ESE weather station to estimate evaporation for Ward Lake in Manatee County, Florida. Given the range in Florida values, a pan coefficient of 0.76 was used for this TMDL modeling. **Table 5.6** lists the actual inputs of rainfall and direct evaporation used in the model.

The SJRWMD provided the direct atmospheric TN and TP deposition data for Marshall Lake. These data were collected from a wet/dry deposition collector operated by the SJRWMD at the Lake Apopka Marshall Flow-Way. The data collected from this site include nitrate/nitrite, total Kjeldahl nitrogen (TKN), and TP concentrations. The TN concentration was calculated as the sum of nitrate/nitrite and TKN concentrations.

According to the SJRWMD, these concentration data are skewed, and as a result, an annual median value was calculated for each year based on the measured nutrient concentration for each individual sample. **Table 5.7** shows the annual median TN and TP concentrations for the wet deposition and annual median TN and TP flux for the total (wet + dry) deposition.

Table 5.6. Annual Total Evaporation and Precipitation for Marshall Lake, 2000–12

Year	Lake Evaporation (m/yr)	Precipitation (m/yr)	Difference (m/yr)
2000	1.14	0.648	-0.49
2001	1.10	0.901	-0.20
2002	1.16	1.485	0.33
2003	1.13	1.384	0.25
2004	1.00	1.461	0.46
2005	0.99	1.465	0.47
2006	1.06	1.048	-0.01
2007	1.02	1.080	0.06
2008	1.01	1.398	0.38
2009	1.03	1.315	0.28
2010	1.01	1.200	0.19
2011	1.08	1.155	0.08
2012	1.05	0.961	-0.08
Average	**1.06**	**1.19**	**0.13**

Table 5.7. Direct Atmospheric Deposition of TN and TP to Marshall Lake, 2000–12

Year	Wet TN Concentration (mg/L)	Wet TP Concentration (mg/L)	Total (Wet+Dry) TN Flux ($mg/m^2/yr$)	Total (Wet+Dry) TP Flux ($mg/m^2/yr$)
2000	0.65	0.016	678	37
2001	0.75	0.012	827	21
2002	0.50	0.009	895	25
2003	0.61	0.011	958	28
2004	0.57	0.011	1,018	34
2005	0.50	0.011	880	31
2006	0.56	0.008	782	24
2007	0.67	0.016	953	44
2008	0.56	0.017	962	47
2009	0.50	0.018	835	47
2010	0.47	0.015	740	48
2011	0.43	0.015	632	37
2012	0.70	0.024	972	71
Average	**0.58**	**0.014**	**856**	**38**

Estimates of Annual Ground Water Seepage TN and TP Loadings for BATHTUB

Ground water inflow is an important means to deliver TN and TP to drainage and seepage lakes (Brock *et al.* 1982; Belanger and Mikutel 1985; Kang *et al.* 2005). Even drainage lakes have a significant inflow from ground water seepage (Lee 1977). For example, Brock *et al.* (1982) reported that ground water inputs to Lake Mendota, Wisconsin, were significant, accounting for 30% of the water budget.

However, estimating ground water inflow and its nutrient delivery is not easy, and the data for calculating nutrient loads are not readily available. Previous investigations have used different methods to estimate ground water nutrient inputs: chemical tracers (Lee *et al.* 1980; Corbett *et al.* 1999), seepage meters (Lee 1977; Belanger and Mikutel 1985), a simple advection-diffusion model (Kang *et al.* 2005), and a water balance model (Sutula *et al.* 2001). For Marshall Lake, no ground water flow measurements or associated nutrient data were available for the period from 2000 to 2012 for estimating annual ground water inputs of TN and TP for BATHTUB model simulation.

A water balance model was constructed to better estimate ground water inflows over the dry and wet period, as follows:

$$\Delta V = P - E + R + S_{in} - L_{out} \qquad \textbf{Equation 3}$$

Where,

ΔV = Change in lake storage volume.

P = Direct rainfall on the lake.

E = Lake evaporation.

R = Runoff volume from the watershed.

Sin = Seepage in to the lake (ground water input).

Lout = Seepage out and lake outflow.

Table 5.8 presents calculated annual water budgets. The sum of annual seepage inflow and lake outflow ($S_{in} - L_{out}$) volume was negative each year over the 13-year period, with a long-term average of -743 ac-ft/yr, indicating that the lake discharge was greater than the volume of seepage inflow each year. This estimated volume and annual pattern are similar to those estimated for Lake Roberts, located in the same basin. Therefore, DEP decided to use the ratio of ground water seepage inflow to lake outflow for Lake Roberts to quantify a long-term average volume of ground water seepage inflow to Marshall Lake.

Assuming that Marshall Lake maintained its lake level with S_{in} = the sum of ($S_{in} - L_{out}$) + (the sum of ($S_{in} - L_{out}$)/0.82) over the 13-year period, annual seepage inflow each year during the period of BATHTUB simulation was calculated as shown in **Table 5.8**. Inflow ranged from 30 to 262 ac-ft/yr, with a 13-year average of 163 ac-ft/yr. The long-term average ground water inflow is slightly higher than that (132 ac-ft/yr) obtained from Lake Roberts. This ground water seepage contribution to the lake accounted for 17% of the total incoming surface flows from the watershed. Existing nutrient loads from seepage inflows were calculated using the estimated long-term average seepage flow and the averaged TN and TP concentrations observed from seepage meters from Lake Roberts.

Table 5.8. Water Balance for Marshall Lake, 2000–12

Year	Average of Volume (ac-ft)	Rainfall (ac-ft)	Lake Evaporation (ac-ft)	Runoff Volume (ac-ft)	Difference in Volume (ac-ft)	S in- L out (ac-ft)	S in (ac-ft)
2000	243.7	108.5	202.9	328.5	-304.8	-538.9	118
2001	19.2	43.2	56.0	475.7	-92.5	-555.4	122
2002	44.3	94.5	54.7	817.2	200.5	-656.5	144
2003	391.0	334.4	276.9	779.0	315.4	-521.1	114
2004	504.1	426.1	297.8	854.2	-14.7	-997.1	219
2005	677.6	570.0	386.2	849.2	174.1	-858.9	189
2006	400.4	242.4	261.8	545.9	-355.0	-881.5	193
2007	330.8	222.6	218.6	554.4	-23.2	-581.6	128
2008	211.7	211.6	160.5	1,036.6	-104.6	-1,192.2	262
2009	560.6	390.9	320.4	882.5	814.7	-138.4	30
2010	791.0	527.0	440.8	681.2	-331.9	-1099.3	241
2011	331.2	249.5	232.1	737.6	-380.9	-1,135.9	249
2012	296.7	193.3	210.2	516.8	0.0	-500.0	110
Average	**369.4**	**278.0**	**239.9**	**696.8**	**-7.9**	**-742.8**	**163**

5.3.3 BATHTUB Calibration

For TN and TP prediction, the subroutines of nutrient sedimentation models in BATHTUB were used to estimate the net removal of TN and TP in the waterbody. Although a second-order decay model in BATHTUB is the most generally applicable formulation representing TP and TN sedimentation in reservoirs (Walker 1987), DEP attempted to use a second-order nutrient fixed model (Model 3) and Bachmann Flushing (Model 5) for Marshall Lake for model calibration on an annual basis over observed TN and TP data.

However, due to input data limitation and nonsteady-state conditions such as extreme variation in lake volume (*i.e.*, a coefficient variation of 255%), the BATHTUB model performed better on a long-term basis for predicting in-lake concentrations of Chla, TN, and TP. Therefore, DEP selected Model 1 for TP and Model 5 for TN to calibrate TP and TN in the water column. These models were used to perform mass balance calculations on TP and TN from stormwater runoff, ground water inputs, in-lake sedimentation, and outflow from the lake. It should be noted that calibration factors were not applied to fit the model predictions to the observed TN and TP data.

The prediction of Chla concentrations can be based on one of five BATHTUB sub-models. Observed TN/TP ratios in Marshall Lake indicated that the lake was co-limited by both TN and TP for algae growth. Chla Model 1 in BATHTUB accounted for the effects of both TP and TP limitations on Chla levels. Considering co-limitation on algal responses, the N fixation of atmospheric nitrogen by blue-green algae for Marshall Lake was not considered because of positive retention coefficients for TN (*i.e.*, watershed inflow TN is similar to or greater than in-lake or outflow TN concentrations) and co-limitation by both TN and TP in both inflows and the lake. It should be also noted that calibration factors were not applied to fit the Chla model prediction to the observed Chla data.

Figures 5.6 through **5.8** show the predicted versus observed concentrations of TN, TP, and Chla for Marshall Lake. Concentrations of TN and TP were predicted to be 1,429 ± 271 µg/L and 86.7 ± 15 µg/L, respectively. The predicted concentrations are similar to those of observed TN (1,804 ± 595 µg/L) and TP (91 ± 45 µg/L). The predicted Chla concentrations of 45.2 ± 13.0 µg/L are also consistent with the observed Chla concentrations of 46.1 ± 14.8 µg/L.

Overall, the annual mean concentrations of TN, TP, and Chla predicted by BATHTUB are comparable to the annual concentrations observed for Marshall Lake, within the CV and the long-term means with 95% confidence intervals. Therefore, the BATHTUB model was considered calibrated for Marshall Lake.

Based on the calibrated BATHTUB model, current long-term average watershed loads of TN and TP were estimated, as shown in **Table 5.9.** A long-term average of TP loads to the lake was estimated to be 224 kg/yr from the watershed, 68 kg/yr from ground water seepage, and 18 kg/yr from direct atmospheric deposition. The watershed load of TP is much higher than other transport pathways of TP, accounting for 72% of total incoming loads (311 kg/yr) over the prediction period (**Figure 5.9**).

The contribution of watershed TN loads was also predominant, with a long-term average load of 1,873 kg/yr. This watershed load of TN accounted for 60% of the total incoming TN load (3,135 kg/yr) to the lake during the model simulation period. Ground water seepage was the second largest contributor, delivering 27% of the total TN loads to Marshall Lake (**Figure 5.10**). A portion of the incoming TN was retained in Marshall Lake, accounting for 35%, while a majority of the incoming TN, accounting for 65%, was removed from the lake via surface and seepage outflows.

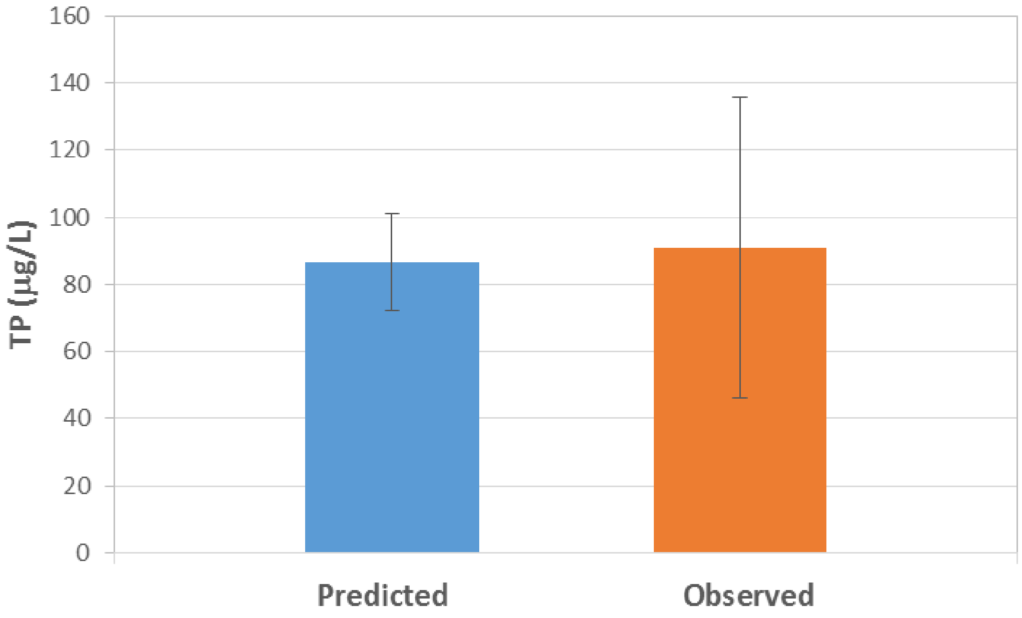

Figure 5.6. Calibration of Simulated TP with Observed Long-Term Average TP in Marshall Lake

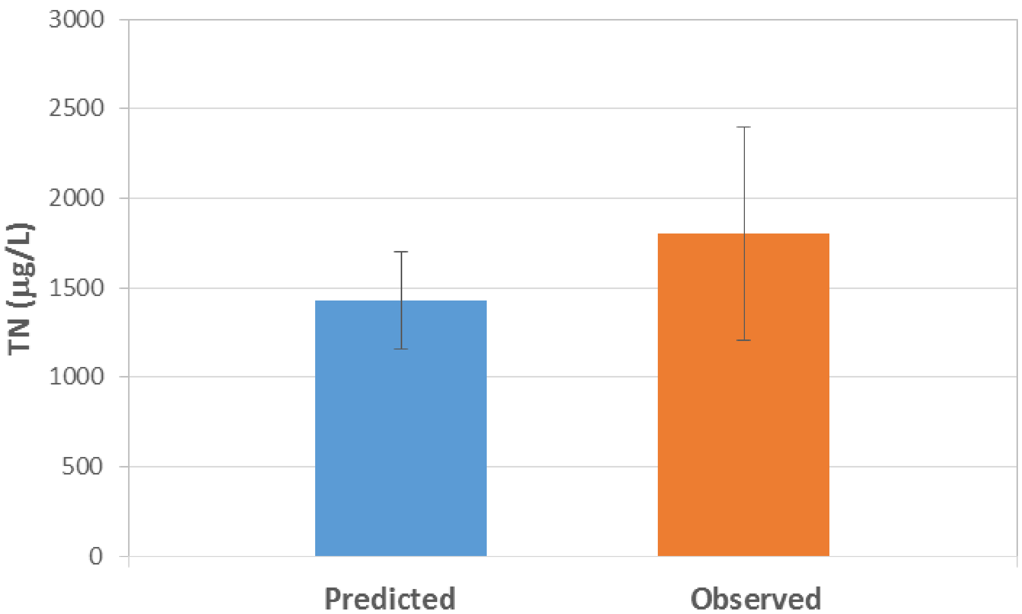

Figure 5.7. Calibration of Simulated TN with Observed Long-Term Average TN in Marshall Lake

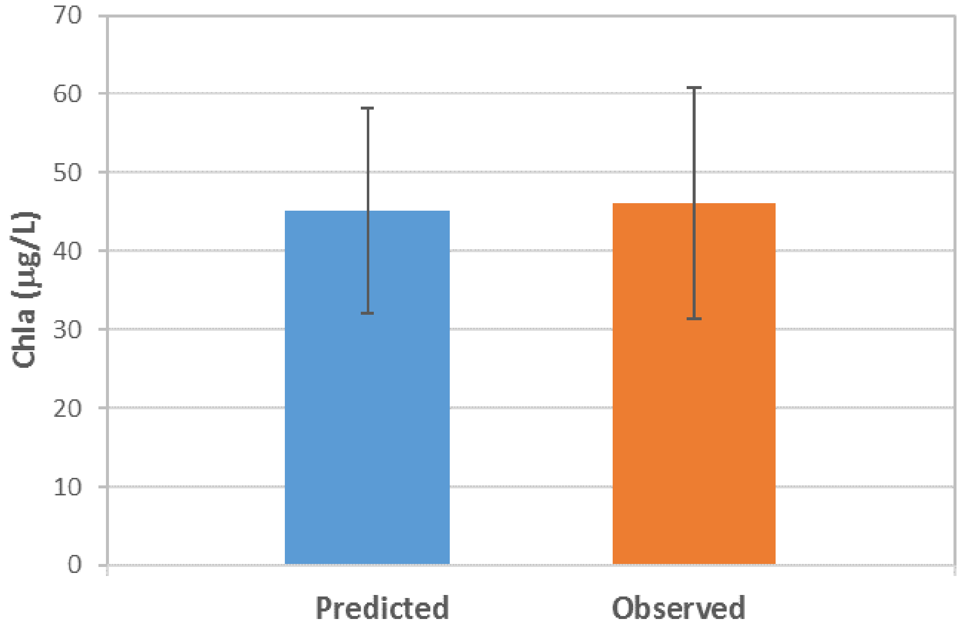

Figure 5.8. Calibration of Simulated Chla with Observed Long-Term Average Chla in Marshall Lake

Table 5.9. Calibrated TP and TN Mass Balance for Marshall Lake

Parameter	Load from Watershed (kg/yr)	Load from Direct Atmospheric Deposition (kg/yr)	Ground Water Seepage Loads (kg/yr)	Retention (kg/yr)	Outflow (kg/yr)
TP	224	18	68	187	124
TN	1,873	413	850	1,091	2,045

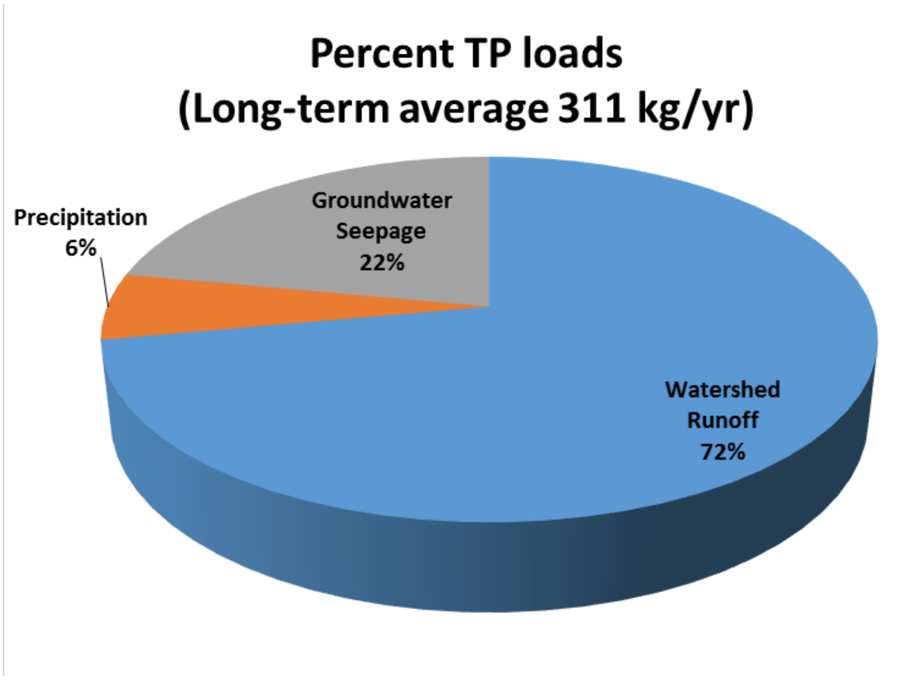

Figure 5.9. Percent Contribution of Long-Term Average TP Loads from Various Pathways to Marshall Lake, 2000–12

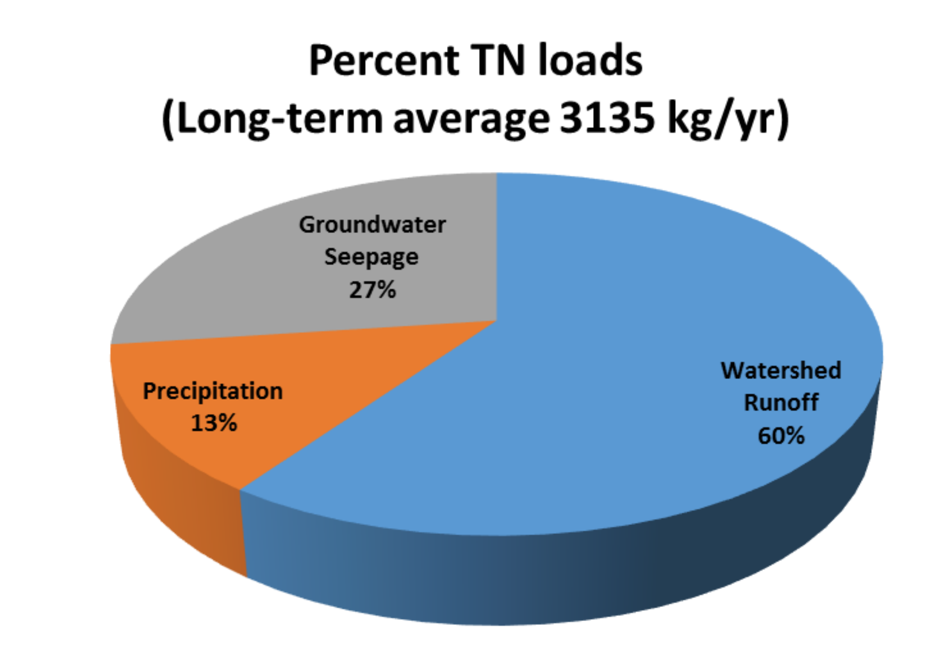

Figure 5.10. Percent Contribution of Long-Term Average TN Loads from Various Pathways to Marshall Lake, 2000–12

5.3.4 Establishing Natural Background Conditions To Determine Natural Levels of Chla, TN, and TP

The natural background land use conditions for the Marshall Lake watershed were established to ensure that the proposed TN and TP targets would not abate the natural background condition. For this simulation, all anthropogenic land uses were converted to a natural land use type such as "forest" in the model, and anthropogenic ground water seepage inputs of TN and TP from septic tanks were removed from current ground water seepage TN and TP loadings to the lake. The existing seepage TN and TP concentrations were reduced by the same percentage as those applied to anthropogenic land use in the watershed. The other characteristics of the background model remain the same as the current condition model.

Figure 5.11 shows that simulated annual concentrations of TN and TP in the predevelopment lake were 561 ± 106 µg/L and 22.7 ± 2.2 µg/L, respectively. The corresponding annual Chla concentration under the natural condition was 9.1 ± 2.6 µg/L.

Simulated annual concentrations of Chla, TN, and TP for the natural background condition were converted to annual geometric means using the linear relationships between annual average concentrations and AGMs that were identified during the lake NNC analyses (K. Weaver, DEP, personal communication, January 15, 2015). **Figures 5.12a** and **5.12b** confirm that observed TN and TP data for Marshall Lake fall along the best-fit lines of TN and TP identified using the lake NNC dataset. Based on the background model run, the predevelopment lake should have had AGMs of 0.021 mg/L for TP and 0.54 mg/L for TN. The predevelopment Chla was simulated to be a geometric mean of 8.0 µg/L, lower than the Chla NNC of 20 µg/L, indicating that setting the Chla target of 20 µg/L for Marshall Lake will not abate the natural background condition of the lake.

5.3.5 Load Reduction Scenarios To Determine the TMDLs

The final targets of in-lake TN and TP concentrations for the restoration of Marshall Lake were determined by reducing the watershed TN and TP loads iteratively until a simulated geometric mean of Chla in Marshall Lake met the Chla target of 20 µg/L.

For the TP load reduction scenarios, the existing total watershed TP loads were reduced to 60% and 73% of the total watershed loads (**Table 5.10** and **Figure 5.13**). **Figure 5.13** depicts the in-lake TP responses to different load reduction scenarios. To meet the geometric mean Chla target of 20 µg/L, the existing watershed TP loads need to be reduced by 73%, so that TP does not exceed the annual geometric mean of 0.037 mg/L, maintaining the AGM above the natural background level.

For the TN load reduction scenarios, the existing watershed TN loads were reduced to 20% and 40% of the total watershed loads (**Table 5.11** and **Figure 5.14**). **Figure 5.14** shows the in-lake responses of TN to different load reduction scenarios. For a scenario with the total watershed load reduced by 40%, the lake was predicted to have a AGM (0.90 mg/L) of TN above the natural background TN level (AGM TN = 0.54 mg/L), meeting the AGM Chla target of 20 µg/L. **Figure 5.15** shows that the lake is expected to achieve the AGM Chla target of 20 µg/L under the watershed TMDL reductions (73% reduction for TP and 40% for TN).

The final allowable TMDLs for Marshall Lake should be calculated including all incoming TN and TP loads such as watershed loads, ground water seepage loads, and atmospheric loads, as shown in **Table 5.9**. However, direct atmospheric deposition of TN and TP is not regulated by the Clean Water Act, and this was kept the same for the TMDL load calculation as the existing condition. The final TMDL percent reductions were calculated as follows:

$$\text{Percent TN and TP reduction (\%)} = \left\{1 - \frac{(W_{tmdl} + G_{tmdl} + P_{atm})}{(W_{existing} + G_{existing} + P_{atm})}\right\} \times 100 \quad \textbf{Equation 4}$$

Where,

W_{tmdl} and G_{tmdl} are the TMDL TN and TP loads (kg/yr) from watershed runoff and ground water seepage under the TMDL reduction condition (73% reduction in TP and 40% in TN from the watershed), respectively.

$W_{existing}$ and $G_{existing}$ are the existing TN and TP loads (kg/yr) from watershed runoff and ground water seepage under the current condition, respectively.

P_{atm} is the existing direct atmospheric deposition of TN and TP (kg/yr).

Table 5.12 summarizes TN and TP loads from all sources to achieve the target concentrations in Marshall Lake. Therefore, the final allowable TMDLs (*i.e.*, the sum of P_{atm}, W_{tmdl} and G_{tmdl}) for Marshall Lake are 2,046 kg/yr of TN and 97 kg/yr of TP, which represent a 35% reduction in TN and a 69% reduction in TP from all existing incoming TN and TP loads. These TMDLs will achieve the Chla target of 20 µg/L, which will protect the designated use of Marshall Lake.

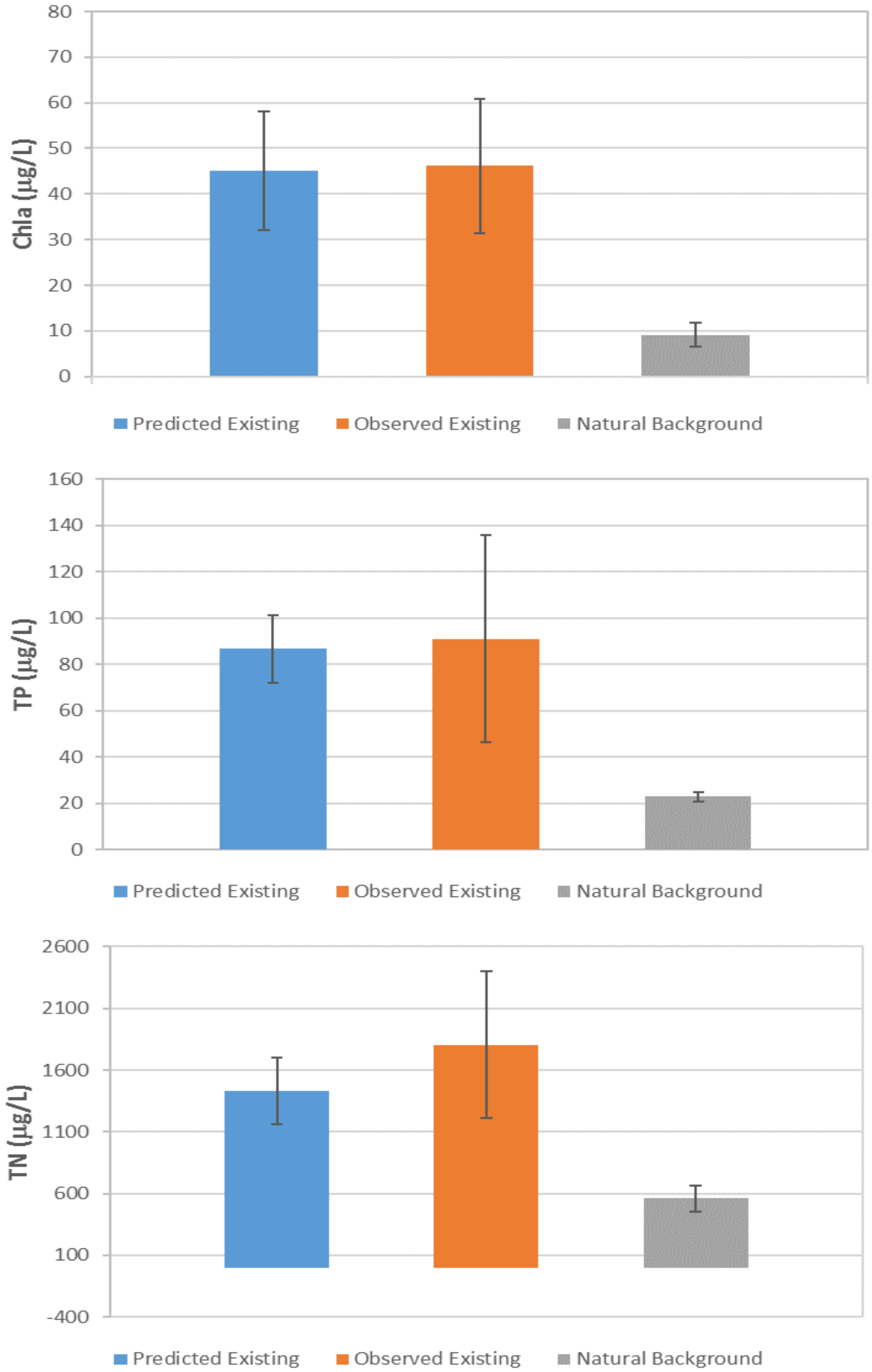

Figure 5.11. Concentrations of Chla, TN, and TP for Existing, Observed versus Natural Background Conditions

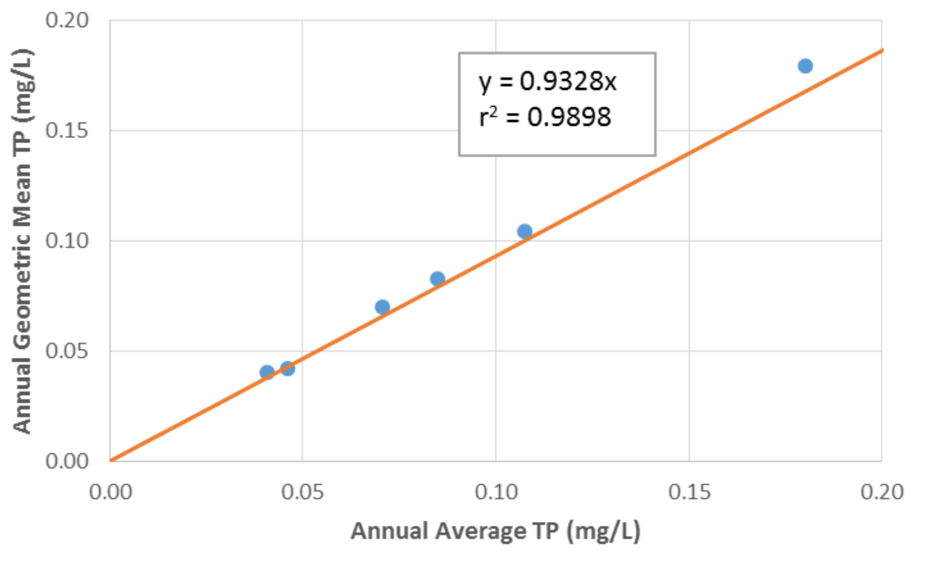

Figure 5.12a. Linear Relationship between AGMs and Annual Average Concentrations of TP used for Lake NNC Development

Note: The dataset (circles) obtained from the observed data for Marshall Lake were plotted along the regression lines derived from the lake NNC dataset.

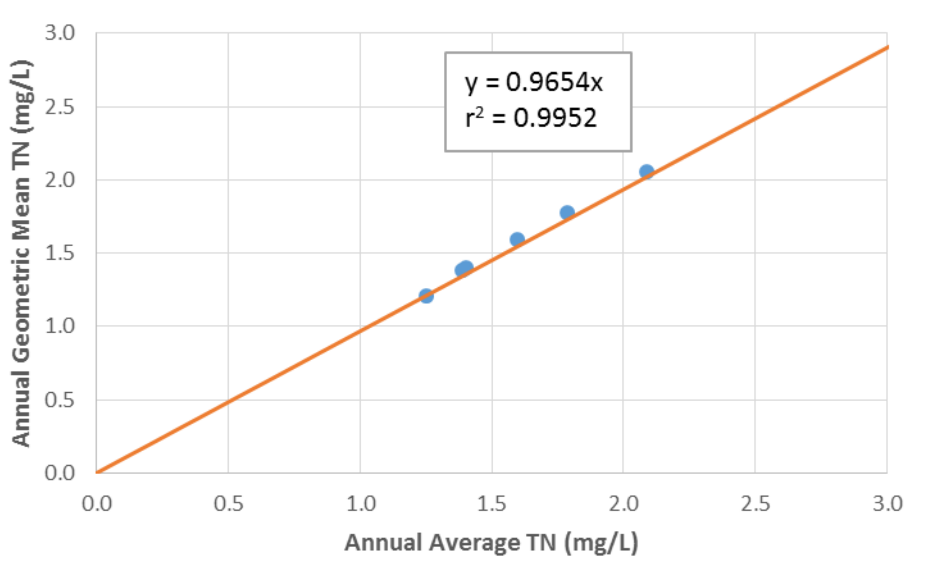

Figure 5.12b. Linear Relationships between AGMs and Annual Average Concentrations of TN used for Lake NNC Development

Note: The dataset (circles) obtained from the observed data for Marshall Lake were plotted along the regression lines derived from the lake NNC dataset.

Table 5.10. Load Reduction Scenarios for TP under Existing, Load Reduction, and TMDL Conditions (73% reduction)

Year	Existing Anthropogenic Watershed Loads (kg/yr)	Natural Watershed Loads (kg/yr)	Existing Total Watershed TP Loads (kg/yr)	Allowable TP Loads under 60% Reduction (kg/yr)	Allowable TP Loads under 73% Reduction (kg/yr)	Allowable Anthropogenic TP loads (kg/yr)
Long-Term Average	215	9.1	224	90	61	52

Table 5.11. Load Reduction Scenarios for TN under Existing, Load Reduction, and TMDL Conditions (40% reduction)

Year	Existing Anthropogenic Watershed Loads (kg/yr)	Natural Watershed Loads (kg/yr)	Existing Total Watershed TN Loads (kg/yr)	Allowable TN Loads under 20% Reduction (kg/yr)	Allowable TN Loads under 40% Reduction (kg/yr)	Allowable Anthropogenic TN loads (kg/yr)
Long-Term Average	1,606	266	1,873	1,498	1,124	857

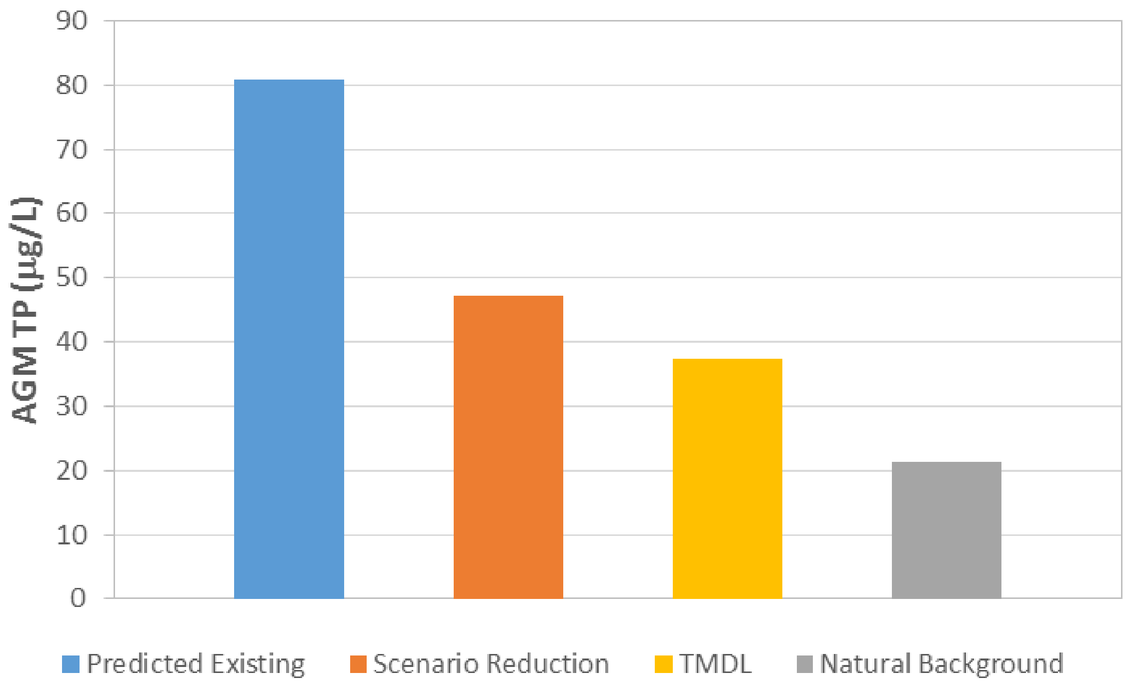

Figure 5.13. Simulated Geometric Means of TP for Existing, Natural Background, Scenario Reduction (60%), and TMDL Conditions (73% reduction)

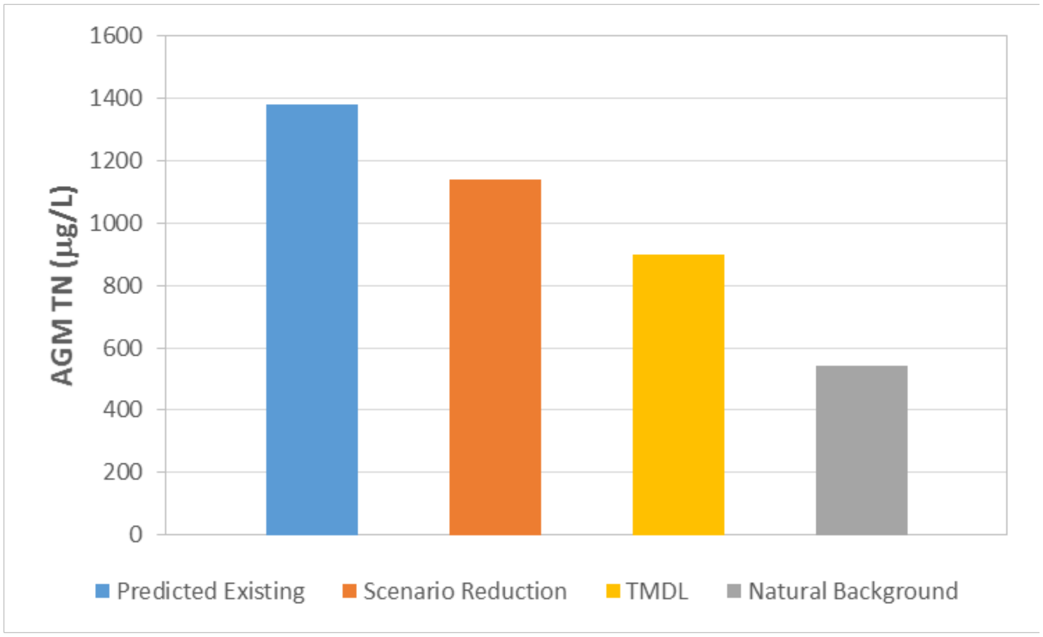

Figure 5.14. Simulated Geometric Means of TP (Top) and TN (Bottom) for Existing, Natural Background, Scenario Reduction (20%), and TMDL Conditions (40% reduction)

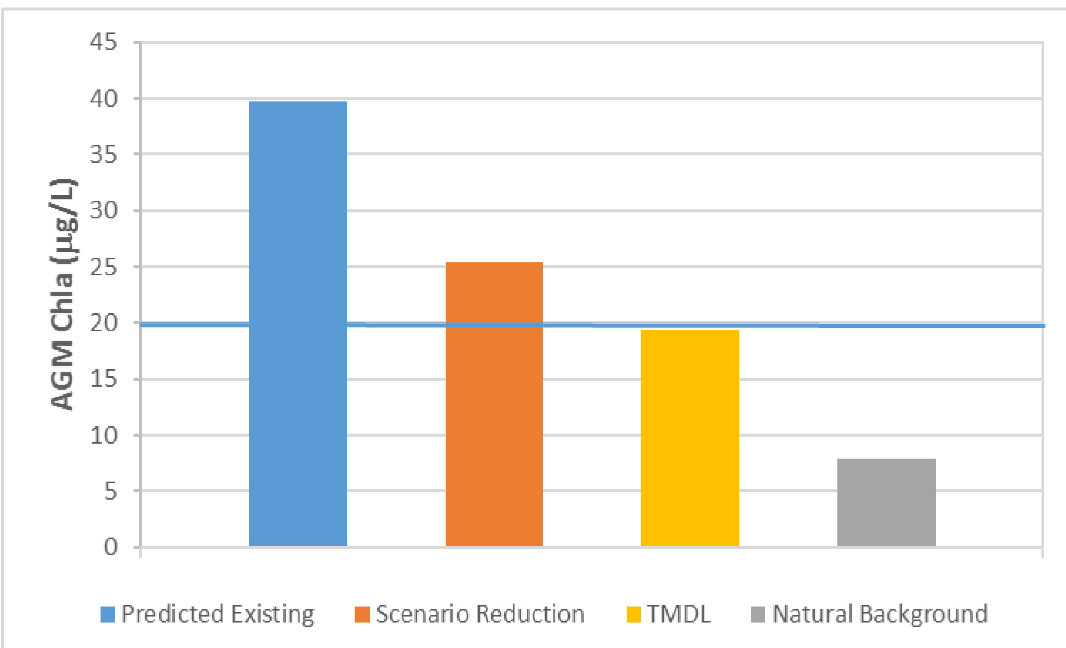

Figure 5.15. Simulated Geometric Means of Chla for Existing, Scenario Reductions (60% for TP and 20% for TN), Natural Background, and TMDL Conditions (73% for TP and 40% for TN). The TMDL Condition Was Achieved at the Chla Target of 20 µg/L

Table 5.12. Total TP and TN Loads Including Direct Atmospheric Deposition To Achieve the Water Quality Target (Chla of 20 µg/L) for Marshall Lake

Parameter	Existing Watershed Load (kg/yr)	Existing Ground Water Seepage Load (kg/yr)	Direct Atmospheric Load (kg/yr)	TMDL Watershed Load (kg/yr)	TMDL Ground Water Seepage Load (kg/yr)	% Reduction
TP	224	68	18	61	18	69%
TN	1,873	850	413	1,124	510	35%

Chapter 6: DETERMINATION OF THE TMDLs

6.1 Expression and Allocation of the TMDLs

A TMDL can be 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) that takes into account any uncertainty about the relationship between effluent limitations and water quality:

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

$$\text{TMDL} \cong \sum \square \text{WLAs}_{\text{wastewater}} + \sum \square \text{WLAs}_{\text{NPDES Stormwater}} + \sum \square \text{LAs} + \text{MOS}$$

It should be noted that the various components of the TMDL equation may not sum up to the value of the TMDL because (1) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is accounted for within the LA, and (2) 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 a "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 nonpoint sources (given the nature of stormwater transport). The permitting of MS4 stormwater discharges is also different than the permitting of most wastewater point sources. Because MS4 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 NPDES stormwater WLA is expressed as a percent reduction in the stormwater from MS4 areas. The load allocation and TMDLs for Marshall Lake are expressed as load and percent reductions, and represent the long-term annual average load of TN and TP from all watershed sources that will maintain the Class III NNC (**Table 6.1**). The expression and allocation of the TMDLs in this report are based on the loadings necessary to achieve the water quality criteria and designated use of the surface water.

Table 6.1. Marshall Lake Load Allocations

The LA and TMDL daily load for TN is 5.6 kg/day; for TP 0.266 kg/day, and corresponding in-lake target AGM concentrations are 0.90 mg/L for TN and 0.037 mg/L for TP, not to be exceeded in any year.
NA = Not applicable
* The required percent reductions listed in this table represent the reduction from all sources. The needed percent reduction to each individual source type can be calculated based on the relative load contribution from each source type provided in **Chapter 5**.

WBID	Parameter	TMDL (kg/yr)	WLA Wastewater (kg/yr)	WLA Stormwater (% reduction)*	LA (% reduction)*	MOS
2854A	TN	2,046	NA	35%	35%	Implicit
2854A	TP	97	NA	69%	69%	Implicit

These TMDLs are based on modeling the long-term (13-year) averages of simulated annual watershed data from 2000 to 2012. The restoration goal is to restore the AGM Chla concentration to no greater than 20 µg/L, meeting water quality criteria and thus protecting Marshall Lake's surface water designated use.

6.2 Load Allocation (LA)

Because the exact boundaries between those areas of the watershed covered by the WLA allocation for stormwater and the LA allocation are unknown, both the LA and the WLA for stormwater received the same percent reduction. The LA is a 69% reduction in TP and a 35% reduction in TN of the total nonpoint source loadings during the period from 2000 to 2012.

As the TMDLs are based on the percent reduction in total watershed loading and any natural land uses are held harmless, the percent reductions for anthropogenic sources may be greater. It should be noted that the LA may include loading from stormwater discharges regulated by DEP and the SJRWMD that are not part of the NPDES Stormwater Program (see **Appendix B**).

6.3 Wasteload Allocation (WLA)

6.3.1 NPDES Wastewater Discharges

As noted in **Chapter 4, Section 4.2.1**, no active NPDES-permitted facilities in the Marshall Lake watershed discharge either into the lake or its watershed. Therefore, the $WLA_{wastewater}$ for the Marshall Lake TMDLs is not applicable.

6.3.2 NPDES Stormwater Discharges

The stormwater collection systems in the Marshall Lake watershed, which are owned and operated by Orange County, Apopka, and FDOT District 5, are covered by an NPDES Phase I MS4 permit

(FLS000011). The wasteload allocation for stormwater discharges is a 69% reduction in TP and a 35% reduction in TN of the total loading during the period from 2000 to 2012; these are the same required percent reductions for the total TN and TP loads from all sources.

It should be noted that any MS4 permittee is only responsible for reducing the anthropogenic loads associated with stormwater outfalls that it owns or otherwise has responsible control over, and it is not responsible for reducing other nonpoint source loads in its jurisdiction. As the TMDLs are based on the percent reduction in total watershed loading and any natural land uses are held harmless, the percent reduction for only anthropogenic sources may be greater.

6.4 Margin of Safety (MOS)

TMDLs must address uncertainty issues by incorporating a MOS into the analysis. The MOS is a required component of a TMDL and accounts for the uncertainty about the relationship between pollutant loads and the quality of the receiving waterbody (Clean Water Act, Section 303[d][1][c]). Considerable uncertainty is usually inherent in estimating nutrient loading from nonpoint sources, as well as in predicting water quality response. The effectiveness of management activities (*e.g.*, stormwater management plans) in reducing loading is also subject to uncertainty.

The MOS can either be implicitly accounted for by choosing conservative assumptions about loading or water quality response, or explicitly accounted for during the allocation of loadings.

Consistent with the recommendations of the Allocation Technical Advisory Committee (DEP 2001), an implicit MOS was used in the development of the Marshall Lake TMDLs because they were based on the conservative decisions associated with modeling assumptions in determining the TMDLs (*i.e.*, loading and water quality response) for the lake.

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

7.1 Implementation Mechanisms

Following the adoption of a TMDL, implementation takes place through various measures. It may occur through specific requirements in NPDES wastewater and MS4 permits, and, as appropriate, through local or regional water quality initiatives or basin management action plans (BMAPs).

Facilities with NPDES permits that discharge to the TMDL waterbody must respond to the permit conditions that reflect target concentrations, reductions, or wasteload allocations identified in the TMDLs. NPDES permits are required for Phase I and Phase II MS4s as well as domestic and industrial wastewater facilities. MS4 Phase I permits require permit holders to prioritize and take action to address a TMDL unless their management actions are already defined in a BMAP or alternative restoration plan. MS4 Phase II permit holders must also implement responsibilities defined in a BMAP or other form of restoration plan (for example, a reasonable assurance plan).

7.2 BMAPs

BMAPs are discretionary and are not initiated for all TMDLs. A BMAP is a TMDL implementation tool that integrates the appropriate management strategies through existing water quality protection programs. DEP or a local entity may develop a BMAP that addresses some or all of the contributing areas to the TMDL waterbody.

The FWRA (Section 403.067, F.S.) provides for the development and implementation of BMAPs. BMAPs are adopted by the DEP Secretary and are legally enforceable.

BMAPs describe the management strategies that will be implemented as well as funding strategies, project tracking mechanisms, water quality monitoring, and the fair and equitable allocation of pollution reduction responsibilities to the sources in the watershed. BMAPs also identify mechanisms to address potential pollutant loading from future growth and development.

The most important component of a BMAP is the list of management strategies to reduce pollution sources, as these are the activities needed to implement the TMDL. The local entities that will conduct these management strategies are identified and their responsibilities are enforceable. Management strategies may include wastewater treatment upgrades, stormwater improvements, and agricultural BMPs. Additional information about BMAPs is available on the DEP website,

7.3 Implementation Considerations for Marshall Lake

In addition to addressing reductions in watershed pollutant contributions to impaired waters during the implementation phase, it may also be necessary to consider the impacts of internal sources (*e.g.*, sediment nutrient fluxes or the presence of nitrogen-fixing cyanobacteria) and the results of any associated remediation projects on surface water quality. In the case of Marshall Lake, other factors—such as the ratios of seepage inflow to lake outflow, the calibration of watershed nutrient loading, sediment nutrient fluxes, and/or nitrogen fixation—also influence lake nutrient budgets and the growth of phytoplankton. Approaches for addressing these other factors should be included in a comprehensive management plan for the lake.

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Appendices

Appendix A: Summary of H1 Site Specific Interpretation of the Narrative Nutrient Criterion for Marshall Lake

Table A-1. Spatial Extent of the Waterbody where the Site-Specific Numeric Interpretation of the Narrative Nutrient Criterion Will Apply

Location	Description
Waterbody name	Marshall Lake
Waterbody type(s)	Lake
Waterbody ID (WBID)	WBID 2854A
Description	Marshall Lake is located in Orange County, Florida. The estimated average surface area of the lake is 58 acres, with a normal pool volume of 525,597 m^3 and an average depth of 3.16 m. Marshall Lake receives runoff from the eastern, southeastern, and northwestern part of the watershed, occupied by forest/rangeland, urban and residential, agricultural areas, and wetlands. The major pathways of water include surface runoff from the watershed, seepage flow from ground water, and direct rainfall into the lake. Marshall Lake, together with Heiniger Lake, Sheppard Lake, Upper Doe Lake, Lower Doe Lake, Lake Witherington, and Lake Fuller, forms the chain of lakes in the eastern part of the Lake Apopka watershed. The watershed elevation ranges from 70 feet immediately adjacent to the lake to more than 155 feet on the eastern boundary of the watershed.
Specific location (latitude/longitude or river miles)	The center of Marshall Lake is located at Latitude N: 28°40'40", Longitude W: - 81°31'57".
Map	The general location of Marshall Lake and land uses in the watershed are shown in Figures 1.1 and 1.2, and Figures 4.1 and 4.2, respectively, of the Marshall Lake nutrient TMDL report. Land uses in the watershed include urban and residential (57.1%), forest/rangeland (14.4%), agriculture and open land (22.0%), and water and wetlands (6.5%).
Classification(s)	Class III Freshwater
Basin name (Hydrologic Unit Code [HUC] 8)	Ocklawaha River Basin (03080102)

Table A-2. Default NNC, Site-Specific Interpretation of the Narrative Criterion Developed as TMDL Targets, and Data Used To Develop the Site-Specific Interpretation of the Narrative Criterion

Narrative Nutrient Criterion	Description
NNC Summary: Default nutrient watershed region or lake classification (if applicable) and corresponding NNC	Marshall Lake is a low-color and high-alkalinity lake, and the default NNC, expressed as AGM concentrations not to be exceeded more than once in any 3-year period, are Chla of 20 µg/L, TN of 1.05 to 1.91 mg/L, and TP of 0.03 to 0.09 mg/L.
Proposed TN, TP, chlorophyll a, and/or nitrate+nitrite (magnitude, duration, and frequency)	Numeric Interpretations of the Narrative Nutrient Criterion: This TMDL is only modifying the default NNC for TN and TP. (The default NNC for CHLA is not being changed, as the department has no evidence that the default criterion is not protective of the designated uses of the lake.) The revised TN and TP NNC are expressed as long-term loads. Specifically, the TN load of 2,046 kg/yr and TP load of 97 kg/yr are both expressed as long-term (7 year) averages of annual loads not to be exceeded. These loading limits will result in in-lake TN and TP AGM concentrations of 0.90 and 0.037 mg/L, respectively, not to be exceeded in any single year. Watershed model and BATHTUB model simulation with these loadings will result in the default in-lake AGM Chla concentration of 20 µg/L being attained. This approach establishes lake-specific NNC that are more representative of conditions in Marshall Lake than the generally applicable TN and TP NNC. The TMDL loads will be considered the site-specific interpretation of the narrative criterion. Nutrient concentrations are provided for comparative purposes only.
Period of record used to develop the numeric interpretations of the narrative nutrient criterion for TN and TP criteria	The criteria were developed based on application of the NRCS watershed curve number model and the receiving water BATHTUB model that simulated hydrology and water quality conditions over the 2000–12 period. The primary datasets for this period include the water quality data from IWR Database Run 49, rainfall and evapotranspiration data, and lake stage data for the 2000–12 period. Land use data from two years were used to establish watershed nutrient loads. For the 2000–05 simulation period, SJRWMD 2004 land use was used. For the 2006–12 period, SJRWMD 2009 land use was used in the model simulation.
Indicate how criteria developed are spatially and temporally representative of the waterbody or critical condition. **Are the stations used representative of the entire extent of the WBID and where the criteria are applied? In addition, for older TMDLs, an explanation of the representativeness of the data period is needed (*e.g.*, have data or information become available since the TMDL analysis?). These details are critical to demonstrate why the resulting criteria will be protective as opposed to the otherwise applicable criteria (in cases where a numeric criterion is otherwise in effect, unlike this case).**	The model simulated the 2000–12 period, which included both wet and dry years. During the period of model simulation from 2000 to 2012, total annual average rainfall varied from 25.5 to 58.5 inches and averaged 46.9 inches. A comparison with long-term average rainfall data indicated that 2000 and 2001 were dry years, while 2002, 2004, and 2005 were considered wet years. NEXRAD rainfall data that the SJRWMD received from the NWS were used as the model input for estimating nutrient loads from the watershed. These rainfall datasets have a spatial resolution of two kilometers by two kilometers, which properly represented the spatial heterogeneity of the rainfall in the targeted watershed area. The model simulated the entire watershed to evaluate how changes in watershed loads impact lake nutrient and Chla concentrations. **Figure 5.1** in the main body of this report shows the locations of the sampling stations used in the Marshall Lake model calibration process. These water quality stations are located throughout the entire lake and properly represent a well-mixed lake.

Table A-3. History of Nutrient Impairment, Quantitative Indicator(s) of Use Support, and Methodologies Used To Develop the Site-Specific Interpretation of the Narrative Criterion

Designated Use	Description
History of assessment of designated use support	Marshall Lake was initially verified as impaired for nutrients during the Cycle 3 assessment (verified period January 1, 2005–June 30, 2012) using the methodology in the IWR (Chapter 62-303, F.A.C.), and was included on the Cycle 3 Verified List of impaired waters for the Ocklawaha River Basin adopted by Secretarial Order on February 12, 2013. In addition, DEP assessed water quality in Marshall Lake using the adopted lake NNC. These results also confirmed that Marshall Lake is impaired for nutrients. Chla data from 2004 to 2011 were used to assess the nutrient impairment based on the NNC. There were sufficient Chla data in 2006 and 2011 to meet the data sufficiency requirements of Paragraph 62-302.531(6), F.A.C., to calculate the AGM of Chla concentrations. This exceeded the 20 µg/L criterion in 2006 and 2011, indicating that the lake is impaired for Chla.
Quantitative indicator(s) of use support	The quantitative indicator of use support is Chla concentration. The NNC Chla concentration of 20 µg/L was used in this TMDL analysis as the Chla target. This target is considered protective of designated use for low-color and high-alkalinity lakes. The in-lake nutrient concentrations needed to achieve this Chla concentration target are 0.90 mg/L of TN and 0.037 mg/L of TP. Based on the available information, there is nothing unique about the characteristics of Marshall Lake that would make the use of a Chla threshold of 20 µg/L inappropriate.
Summarize approach used to develop criteria and how it protects uses	For the Marshall Lake nutrient TMDLs, DEP established the site-specific TN and TP concentration and loading targets using a set of calibrated models to achieve an in-lake Chla AGM concentration of 20 µg/L. Because the 20 µg/L Chla target is the generally applicable NNC demonstrated to be protective of the designated use for low color, high alkalinity lakes, the TN and TP concentrations and loading targets established to achieve the 20 µg/L Chla concentration target will also be protective of the designated use.
Discuss how the TMDL will ensure that nutrient-related parameters are attained to demonstrate that the TMDL will not negatively impact other water quality criteria. These parameters must be analyzed with the appropriate frequency and duration. If compliance with 47(a) is not indicated in the TMDL, it should be clear that further reductions may be required in the future.	Model simulations indicated that the target Chla concentration (20 µg/L) in the lake will be attained at the TMDL loads for TN and TP. DEP notes that no other impairments were verified for Marshall Lake that may be related to nutrients (such as DO or un-ionized ammonia). Reducing the nutrient loads entering the lake will not negatively impact other water quality parameters of the lake.

Table A-4. Site-Specific Interpretation of the Narrative Criterion and Protection of Designated Use of Downstream Segments

Downstream Protection and Monitoring	Description
Identification of Downstream Waters: List receiving waters and identify technical justification for concluding downstream waters are protected.	In general, Marshall Lake drains to the west into Lower Doe Lake which eventually drains to Lake Apopka. The group of lakes in the Lake Apopka watershed are known as the chain of lakes in the eastern part of Lake Apopka watershed. Lake Apopka is a major downstream water that receives runoff from this chain of lakes. The upper Ocklawaha Basin Management Action Plan (BMAP) adopted by the Secretarial Order in August 2007 included Lake Apopka and its watershed. The restoration goal of the BMAP for Lake Apopka is to achieve the TP target of 0.055 mg/L. The applicable nutrient criteria for stream systems are 0.12 mg/L of TP and 1.54 mg/L of TN expressed as AGMs not to be exceeded more than once in any three calendar year period. Since the lake nutrient targets for Marshall Lake (i.e., 0.037 mg/L for TP and 0.90 mg/L for TN) are lower than the nutrient targets for the Lake Apopka BMAP and the NNC targets for these downstream waters, the nutrient targets developed for Marshall Lake will be protective of the nutrient conditions in the downstream waters.
Provide summary of existing monitoring and assessment related to implementation of Paragraph 62-302.531(4), F.A.C., and trends tests in Chapter 62-303, F.A.C.	DEP and Orange County collected water quality data in Marshall Lake. These monitoring activities will be continued in order to evaluate future water quality trends in Marshall Lake. The data collected through these monitoring activities will be used to evaluate the effect of BMPs implemented in the watershed on the lake's TN and TP concentrations in subsequent water quality assessment cycles.

Table A-5. Public Participation and Legal Requirements for Rule Adoption

Administrative Requirements	Descriptive Information
Notice and comment notifications	DEP published a Notice of Development of Rulemaking on December 15, 2014, to initiate TMDL development for impaired waters in the Ocklawaha River Basin. A technical workshop for the Marshall Lake TMDL was held on February 14, 2015, to present the general TMDL approach to local stakeholders. On March 20, 2015, a second public workshop focused on rule development for the Marshall Lake TMDLs was conducted. Public comments were received for the TMDLs after that. DEP is in the process of preparing responses to these public comments. DEP published an updated Notice of Development of Rulemaking on April 6, 2015, that covers the Ocklawaha River Basin, to address the requirement that TMDLs be adopted within one year after the Notice of Development of Rulemaking is published.
Hearing requirements and adoption format used; responsiveness summary	Following the publication of a Notice of Proposed Rule (NPR), DEP will provide a 21 day-challenge period.
Official submittal to EPA for review and GC Certification	If DEP does not receive a challenge, the certification package for the rule will be prepared by DEP's program attorney. At the same time, DEP will prepare the TMDL and site-specific interpretation package for the TMDL and submit these documents to the EPA.

Appendix B: 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 Chapter 62-40, F.A.C. In 1994, DEP's stormwater treatment requirements were integrated with the stormwater flood control requirements of the state's water management districts, along with wetland protection requirements, into the Environmental Resource Permit (ERP) regulations.

Chapter 62-40, F.A.C., also requires the water management districts 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.

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 permitting program to designate certain stormwater discharges as "point sources" of pollution. The EPA promulgated regulations and began implementing the Phase I NPDES stormwater program in 1990. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific standard industrial classification (SIC) codes, construction sites disturbing five or more acres of land, and the 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 implemented Phase I of the MS4 permitting program on a countywide basis, which brought in all cities (incorporated areas), Chapter 298 urban water control districts, and FDOT throughout the 15 counties meeting the population criteria. DEP received authorization to implement the NPDES stormwater program in 2000.

An important difference between the federal NPDES and the state's stormwater/ERP programs is that the NPDES Program covers both new and existing discharges, while the state's program focuses on new discharges only. Additionally, Phase II of the NPDES Program, implemented in 2003, expands the need for these permits to construction sites between 1 and 5 acres, and to local governments with as few as 1,000 people. 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. It should be noted that all MS4 permits issued in Florida include a reopener clause that allows permit revisions to implement TMDLs when the implementation plan is formally adopted.

Appendix C: Monthly Water Budget for Marshall Lake, 2000–12

Year	Month	Average of Stage (ft)	Average of Area (ac)	Average of Volume (ac-ft)	Sum of Rain Lake (in)	Sum of Evaporation (in)	Rainfall (ac-ft)	Lake Evap (ac-ft)	Runoff Vol (ac-ft)	GW-S out (ac-ft)	Del vol (ac-ft)
2000	1	64.4	76.9	400.7	1.22	2.37	7.80	12.8	15.67	-9.6	1.1
2000	2	64.3	76.0	394.7	1.39	2.82	8.79	13.6	17.86	-19.1	-6.0
2000	3	63.9	73.0	374.5	1.22	4.34	7.41	21.1	15.68	-22.1	-20.1
2000	4	63.4	68.5	344.6	1.69	4.98	9.63	25.9	21.73	-35.4	-29.9
2000	5	62.6	62.3	303.3	0.32	6.16	1.66	28.5	4.13	-18.7	-41.4
2000	6	61.4	52.0	234.7	3.73	5.94	16.14	23.7	47.98	-109.0	-68.6
2000	7	60.8	48.2	204.3	3.25	5.71	13.05	22.3	41.83	-63.1	-30.4
2000	8	60.1	44.6	175.6	4.74	5.51	17.64	19.9	61.07	-87.5	-28.7
2000	9	59.5	41.2	147.3	5.58	4.22	19.14	13.3	71.86	-106.0	-28.3
2000	10	59.3	40.5	141.5	0.21	3.54	0.72	9.9	2.74	0.7	-5.8
2000	11	58.5	36.5	108.6	1.66	2.69	5.05	6.4	21.35	-52.9	-32.9
2000	12	58.1	34.9	94.8	0.51	2.18	1.48	5.6	6.57	-16.2	-13.7
2001	1	57.5	32.0	74.5	0.76	2.28	2.02	5.1	9.73	-27.0	-20.4
2001	2	57.0	29.5	58.9	0.40	2.79	0.99	5.2	5.17	-16.5	-15.6
2001	3	56.5	26.6	44.6	5.55	3.91	12.29	6.9	71.49	-91.1	-14.3
2001	4	55.6	20.3	23.7	1.19	5.00	2.00	7.7	15.28	-30.6	-21.0
2001	5	54.7	14.4	8.1	1.23	5.98	1.47	6.4	15.82	-26.4	-15.5
2001	6	54.5	12.8	5.6	5.17	5.98	5.50	5.9	66.60	-68.8	-2.6
2001	7	54.3	11.2	3.0	6.59	5.35	6.12	4.8	103.92	-107.8	-2.6
2001	8	54.4	12.0	4.3	4.45	5.43	4.43	5.3	57.26	-55.2	1.3
2001	9	54.1	9.6	1.1	7.60	3.91	6.10	2.9	97.87	-104.2	-3.2
2001	10	54.2	10.7	2.3	1.14	3.29	1.02	2.4	14.68	-12.1	1.2
2001	11	54.2	10.7	2.3	1.00	2.49	0.89	1.7	12.82	-12.0	0.0
2001	12	54.2	10.7	2.3	0.39	2.19	0.35	1.7	5.07	-3.7	0.0
2002	1	54.2	10.7	2.3	0.92	2.49	0.82	1.9	11.83	-10.8	0.0
2002	2	54.3	11.7	3.9	2.95	2.94	2.88	2.2	37.97	-37.1	1.6
2002	3	54.3	11.1	2.9	1.03	4.62	0.95	3.4	13.33	-11.9	-1.0
2002	4	53.8	6.4	0.8	1.99	5.17	1.06	2.5	25.68	-26.4	-2.1
2002	5	53.4	2.8	0.3	2.01	6.22	0.47	1.3	25.88	-25.5	-0.4
2002	6	53.4	2.9	0.3	10.00	5.62	2.44	1.3	132.27	-133.4	0.0
2002	7	53.4	3.0	0.4	9.51	5.96	2.40	1.5	128.61	-129.5	0.0
2002	8	54.7	14.9	9.0	9.51	5.35	11.84	6.5	132.50	-129.2	8.7
2002	9	57.0	29.8	60.7	3.69	4.48	9.15	10.2	47.52	5.2	51.7
2002	10	58.3	35.6	100.6	3.78	3.67	11.19	9.0	48.63	-10.9	39.9
2002	11	59.5	41.2	147.9	1.88	2.66	6.46	7.1	24.21	23.7	47.3
2002	12	60.7	48.0	202.8	11.19	2.21	44.79	7.9	188.78	-170.8	54.9
2003	1	61.7	54.4	251.0	0.53	2.30	2.39	8.8	6.79	47.8	48.3
2003	2	62.1	58.2	276.3	2.82	2.92	13.68	10.8	36.29	-13.9	25.3

Year	Month	Average of Stage (ft)	Average of Area (ac)	Average of Volume (ac-ft)	Sum of Rain Lake (in)	Sum of Evaporation (in)	Rainfall (ac-ft)	Lake Evap (ac-ft)	Runoff Vol (ac-ft)	GW-S out (ac-ft)	Del vol (ac-ft)
2003	3	62.6	62.0	301.6	7.32	4.12	37.87	17.0	95.24	-90.8	25.3
2003	4	63.5	69.6	351.7	3.18	5.03	18.44	26.5	40.96	17.2	50.1
2003	5	63.5	69.5	351.2	2.22	6.12	12.87	31.5	28.62	-10.5	-0.5
2003	6	63.1	66.1	328.3	11.06	5.74	60.90	29.1	148.50	-203.2	-22.9
2003	7	64.3	75.8	393.0	6.97	5.98	44.03	36.6	108.90	-51.6	64.7
2003	8	64.5	77.5	404.5	10.35	5.17	66.84	32.4	184.55	-207.6	11.4
2003	9	66.1	90.6	491.5	3.77	4.36	28.44	30.3	48.52	40.4	87.1
2003	10	66.4	92.9	506.8	2.68	3.58	20.78	23.0	34.57	-17.1	15.2
2003	11	66.6	94.6	518.2	1.84	2.72	14.54	16.7	23.75	-10.1	11.4
2003	12	66.6	94.6	518.2	1.73	2.31	13.66	14.2	22.31	-21.7	0.0
2004	1	66.4	93.3	509.5	3.31	2.49	25.71	15.1	45.28	-64.6	-8.7
2004	2	66.4	93.4	510.0	4.38	2.63	34.04	16.0	56.94	-74.5	0.5
2004	3	66.7	95.3	522.5	0.97	4.31	7.68	26.7	12.46	19.1	12.5
2004	4	66.2	91.7	498.6	2.74	4.99	20.93	29.7	35.28	-50.4	-23.9
2004	5	65.9	89.2	482.3	1.26	6.06	9.34	35.1	16.18	-6.7	-16.3
2004	6	65.1	82.5	437.7	8.82	6.27	60.65	33.6	113.60	-185.2	-44.6
2004	7	65.3	84.1	448.5	5.48	6.13	38.45	33.5	81.44	-75.5	10.9
2004	8	64.9	81.3	429.5	12.55	5.36	85.00	28.3	238.01	-313.7	-19.0
2004	9	66.2	91.3	496.4	11.56	4.18	88.01	24.8	171.79	-168.1	66.9
2004	10	68.1	106.9	600.4	2.32	3.47	20.71	24.1	29.92	77.4	103.9
2004	11	68.3	108.5	610.7	2.74	2.59	24.76	18.3	35.27	-31.4	10.3
2004	12	66.3	92.4	503.5	1.40	2.08	10.78	12.5	18.03	-123.5	-107.2
2005	1	69.5	118.6	677.6	1.86	2.36	18.34	18.2	23.90	150.1	174.1
2005	2	69.5	118.6	677.6	1.92	2.66	18.96	20.5	24.70	-23.2	0.0
2005	3	69.5	118.6	677.6	4.35	3.72	42.95	28.7	55.97	-70.2	0.0
2005	4	69.5	118.6	677.6	1.35	5.08	13.34	39.2	17.38	8.4	0.0
2005	5	69.5	118.6	677.6	5.34	6.07	52.79	46.8	68.80	-74.8	0.0
2005	6	69.5	118.6	677.6	13.61	5.42	134.42	41.8	249.56	-342.2	0.0
2005	7	69.5	118.6	677.6	7.73	6.22	76.37	47.9	100.16	-128.6	0.0
2005	8	69.5	118.6	677.6	8.46	5.94	83.58	45.8	140.22	-178.0	0.0
2005	9	69.5	118.6	677.6	4.42	4.51	43.72	34.8	56.97	-65.9	0.0
2005	10	69.5	118.6	677.6	5.27	3.39	52.05	26.1	67.83	-93.8	0.0
2005	11	69.5	118.6	677.6	1.60	2.67	15.85	20.6	20.66	-15.9	0.0
2005	12	69.5	118.6	677.6	1.79	2.08	17.66	16.1	23.02	-24.6	0.0
2006	1	69.2	115.7	658.6	0.60	2.55	5.83	19.2	7.78	-13.4	-19.0
2006	2	69.2	115.7	658.6	3.66	2.75	35.30	20.7	49.25	-63.8	0.0
2006	3	68.8	112.8	639.5	0.03	4.46	0.32	32.7	0.43	12.9	-19.0
2006	4	64.1	74.0	381.1	1.93	5.53	11.91	26.6	24.88	-268.7	-258.5
2006	5	64.1	74.0	381.1	1.44	6.52	8.86	31.3	18.50	4.0	0.0
2006	6	64.1	74.0	381.1	7.75	6.05	47.77	29.1	99.77	-118.5	0.0

Year	Month	Average of Stage (ft)	Average of Area (ac)	Average of Volume (ac-ft)	Sum of Rain Lake (in)	Sum of Evaporation (in)	Rainfall (ac-ft)	Lake Evap (ac-ft)	Runoff Vol (ac-ft)	GW-S out (ac-ft)	Del vol (ac-ft)
2006	7	64.1	74.0	381.1	7.03	6.15	43.34	29.6	90.52	-104.3	0.0
2006	8	64.1	74.0	381.1	5.76	5.92	35.49	28.5	82.71	-89.7	0.0
2006	9	59.3	40.3	140.3	5.94	4.66	19.97	12.2	80.44	-329.0	-240.8
2006	10	61.5	52.7	239.6	1.49	4.03	6.55	13.8	19.20	87.3	99.3
2006	11	61.5	52.7	239.6	3.31	2.51	14.53	8.6	42.60	-48.5	0.0
2006	12	63.0	65.2	322.6	2.31	2.25	12.57	9.5	29.79	50.2	83.0
2007	1	64.0	73.6	378.4	0.87	2.39	5.35	11.4	11.24	50.6	55.7
2007	2	64.0	73.6	378.4	1.29	2.74	7.94	13.1	16.67	-11.5	0.0
2007	3	64.4	76.9	400.1	1.05	4.26	6.71	21.3	13.49	22.8	21.8
2007	4	62.9	64.2	315.8	1.95	5.12	10.44	21.4	25.13	-98.5	-84.3
2007	5	62.9	64.2	315.8	3.25	6.02	17.38	25.1	41.85	-34.1	0.0
2007	6	62.9	64.2	315.8	6.52	6.04	34.88	25.2	83.98	-93.7	0.0
2007	7	61.3	51.6	231.6	6.71	6.17	28.86	20.7	90.74	-183.0	-84.1
2007	8	62.8	63.8	313.1	5.24	5.88	27.84	24.4	67.47	10.5	81.4
2007	9	62.8	63.8	313.1	7.96	4.62	42.30	19.1	105.39	-128.5	0.0
2007	10	62.8	63.8	313.1	5.76	3.38	30.60	14.0	74.16	-90.8	0.0
2007	11	64.3	76.0	394.7	0.46	2.67	2.89	13.2	5.87	86.1	81.6
2007	12	62.6	61.7	299.5	1.43	2.42	7.37	9.7	18.45	-111.3	-95.2
2008	1	62.6	61.7	299.5	3.30	2.41	16.97	9.7	42.49	-49.8	0.0
2008	2	62.6	61.7	299.5	1.45	3.11	7.45	12.5	18.66	-13.6	0.0
2008	3	62.6	61.7	299.5	3.03	4.19	15.59	16.8	39.03	-37.8	0.0
2008	4	60.8	48.5	206.8	3.15	5.06	12.73	16.0	40.53	-130.0	-92.7
2008	5	60.1	44.2	171.9	1.58	6.15	5.80	17.6	20.30	-43.3	-34.9
2008	6	60.1	44.2	171.9	6.99	6.36	25.72	18.3	89.97	-97.4	0.0
2008	7	60.1	44.2	171.9	6.57	5.97	24.18	17.1	84.60	-91.6	0.0
2008	8	59.3	40.3	140.3	18.79	5.13	63.13	13.4	569.64	-650.9	-31.6
2008	9	60.6	47.0	194.8	4.00	4.42	15.68	13.5	51.52	0.9	54.5
2008	10	60.6	47.0	194.8	3.47	3.45	13.59	10.5	44.63	-47.7	0.0
2008	11	60.6	47.0	194.8	1.67	2.52	6.54	7.7	21.49	-20.3	0.0
2008	12	60.6	47.0	194.8	1.06	2.39	4.17	7.3	13.71	-10.6	0.0
2009	1	61.8	55.6	258.7	1.53	2.44	7.09	8.8	19.71	45.8	63.8
2009	2	61.7	54.8	253.2	0.87	2.79	3.98	9.9	11.24	-10.7	-5.4
2009	3	61.7	54.8	253.2	1.18	4.31	5.38	15.4	15.17	-5.2	0.0
2009	4	61.7	54.8	253.2	1.24	5.44	5.67	19.4	15.99	-2.3	0.0
2009	5	61.7	54.8	253.2	15.07	5.98	68.76	21.3	390.32	-437.8	0.0
2009	6	61.6	53.9	247.8	7.31	6.53	32.88	22.9	94.17	-109.6	-5.4
2009	7	68.2	107.9	606.9	6.04	5.85	54.36	41.1	77.82	268.0	359.1
2009	8	68.2	107.9	606.9	9.01	5.80	81.02	40.7	135.53	-175.9	0.0
2009	9	74.8	161.9	966.0	3.39	4.51	45.68	47.5	43.59	317.3	359.1
2009	10	75.6	168.5	1009.5	0.76	3.76	10.68	41.2	9.80	64.2	43.5

Year	Month	Average of Stage (ft)	Average of Area (ac)	Average of Volume (ac-ft)	Sum of Rain Lake (in)	Sum of Evaporation (in)	Rainfall (ac-ft)	Lake Evap (ac-ft)	Runoff Vol (ac-ft)	GW-S out (ac-ft)	Del vol (ac-ft)
2009	11	75.6	168.5	1009.5	0.86	2.62	12.07	28.7	11.07	5.5	0.0
2009	12	75.6	168.5	1009.5	4.51	2.16	63.35	23.7	58.11	-97.8	0.0
2010	1	76.4	175.0	1053.1	3.43	2.19	50.06	24.9	44.20	-25.8	43.5
2010	2	72.2	140.2	821.8	3.51	2.25	41.06	20.5	45.25	-297.1	-231.2
2010	3	72.2	140.2	821.8	7.65	3.76	89.40	34.3	117.19	-172.3	0.0
2010	4	72.2	140.2	821.8	3.79	5.17	44.30	47.1	48.81	-46.0	0.0
2010	5	72.2	140.2	821.8	2.47	6.03	28.84	54.9	31.77	-5.7	0.0
2010	6	67.9	105.5	590.6	5.58	6.50	49.04	44.6	71.84	-307.6	-231.2
2010	7	71.0	130.8	759.2	4.07	6.02	44.36	51.2	106.79	68.7	168.7
2010	8	71.0	130.8	759.2	7.60	5.42	82.87	46.1	97.87	-134.7	0.0
2010	9	71.0	130.8	759.2	6.82	4.62	74.39	39.3	87.86	-122.9	0.0
2010	10	74.1	156.2	927.9	0.00	4.03	0.02	40.9	0.02	209.5	168.7
2010	11	69.5	118.6	677.6	1.96	2.75	19.36	21.2	25.23	-273.7	-250.3
2010	12	69.5	118.6	677.6	0.34	2.06	3.34	15.8	4.35	8.2	0.0
2011	1	64.9	80.9	427.3	4.42	2.35	29.85	12.4	78.05	-345.8	-250.3
2011	2	64.5	77.3	402.8	0.31	2.93	2.03	14.7	4.05	-15.8	-24.5
2011	3	64.5	77.3	402.8	7.82	4.58	50.34	23.0	223.12	-250.5	0.0
2011	4	64.0	73.6	378.4	1.32	5.63	8.11	26.9	17.03	-22.7	-24.5
2011	5	61.6	53.9	247.8	2.56	6.76	11.50	23.7	32.94	-151.3	-130.6
2011	6	63.9	72.8	372.9	3.30	6.63	19.99	31.3	42.45	94.1	125.1
2011	7	62.8	63.4	310.3	5.37	6.38	28.33	26.3	69.09	-133.7	-62.6
2011	8	61.6	53.9	247.8	9.12	5.84	40.99	20.5	120.09	-203.2	-62.6
2011	9	62.3	59.3	283.1	4.51	4.62	22.26	17.8	58.04	-27.2	35.4
2011	10	62.9	64.6	318.5	6.17	3.59	33.22	15.1	85.28	-68.0	35.4
2011	11	62.3	59.7	285.9	0.17	2.81	0.85	10.9	2.19	-24.8	-32.6
2011	12	62.5	61.3	296.7	0.41	2.39	2.09	9.5	5.26	13.1	10.9
2012	1	62.5	61.3	296.7	0.31	2.66	1.58	10.6	3.98	5.1	0.0
2012	2	62.5	61.3	296.7	1.37	3.07	6.99	12.2	17.62	-12.4	0.0
2012	3	62.5	61.3	296.7	1.07	4.43	5.49	17.7	13.83	-1.7	0.0
2012	4	62.5	61.3	296.7	1.42	5.57	7.28	22.2	18.35	-3.4	0.0
2012	5	62.5	61.3	296.7	2.18	6.25	11.16	24.9	28.12	-14.4	0.0
2012	6	62.5	61.3	296.7	10.49	5.57	53.62	22.2	164.10	-195.5	0.0
2012	7	62.5	61.3	296.7	4.62	6.26	23.58	24.9	59.43	-58.1	0.0
2012	8	62.5	61.3	296.7	7.82	5.70	39.97	22.7	101.34	-118.6	0.0
2012	9	62.5	61.3	296.7	1.55	4.63	7.94	18.4	20.00	-9.5	0.0
2012	10	62.5	61.3	296.7	4.98	3.59	25.43	14.3	64.08	-75.2	0.0
2012	11	62.5	61.3	296.7	0.07	2.58	0.36	10.3	0.90	9.0	0.0
2012	12	62.5	61.3	296.7	1.95	2.44	9.96	9.7	25.10	-25.3	0.0

Appendix D: Estimation of Ground Water Seepage and Nitrogen Load from Septic Systems to Lakes Marshall, Roberts, Weir, and Denham

The report by Ye *et al.* (2014) is available upon request. Please contact the individual listed below to obtain this information.

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