FINAL

Nutrient TMDL for Lake Denham (WBID 2832A)

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

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March 2017

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Acknowledgments

This analysis could not have been accomplished without significant contributions from staff in the Florida Department of Environmental Protection's Watershed Assessment Section, Standards Development Section, Chemistry & Biology Laboratories, Groundwater Management Section, and Watershed Evaluation and TMDL Section. The Department acknowledges the significant input of the St. Johns River Water Management District, especially the contributions of Rolland Fulton, Dale Smith, and Walt Godwin. They provided the watershed model, valuable suggestions on the modeling approach, and constantly exchanged information with the Department on their research on Lake Denham.

Editorial assistance provided by Xueqing Gao, Wayne Magley, Woo-Jun Kang, Kevin Petrus, Erin Rasnake, and Linda Lord.

Map production assistance was provided by Janis Morrow.

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Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the Total Maximum Daily Loads for nutrients for Lake Denham in the Ocklawaha River Basin. The TMDLs will constitute the site-specific numeric interpretation 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 criteria (NNC) in Subsection 62-302.531(2), F.A.C., for this particular water. Lake Denham 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 adopted by Secretarial Order on August 28, 2002. The nutrient impairment was confirmed in the Cycle 2 and 3 assessment periods.

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

1.2 Identification of Waterbody

Lake Denham is a shallow 250-acre lake located in central Florida approximately two miles southwest of Leesburg, Lake County, within the Ocklawaha River Basin and the Lake Harris Planning Unit (**Figure 1.1**). Surface runoff from the surrounding wetlands, agricultural areas, and upland forests is the major water source to the lake. The largest source of nutrient loading to the lake is the discharge from a former muck farm in the watershed. The lake water flows about two miles easterly to Lake Harris through Helena Run, although there is occasional reverse flow from Helena Run to Lake Denham (**Figure 1.2**) which does not give significant effects in nutrient flux to the lake.

Lake Denham has a watershed area of 6,641 acres, occupied by wetlands (50% of the watershed), agricultural areas (20%), and urban areas (14%). The lake and its watershed are also a part of the Lake Harris watershed west of Lake Harris. This area is within the Central Valley Lake Region (Region 75-08), which is characterized by high nutrients, high chlorophyll *a* (chl *a*) concentrations, and low transparency. The lakes in the region receive mineralized ground water and surface inflow through calcareous, nutrient-rich soils and are naturally eutrophic to hypereutrophic hardwater lakes (Griffith *et al.* 1997).

The elevation of the Lake Denham watershed ranges from about 65 feet immediately adjacent to the lake to 150 feet on the southeastern boundary of the watershed. Based on lake stage data collected for the period from 2000 to 2012, the long-term average stage of the lake was about 62 feet National Geodetic Vertical Datum (NGVD). The lake bottom elevation is about 56 feet NGVD, which is lower than the potentiometric head (about 72 feet NGVD) of the Floridan aquifer, suggesting that the seepage into the lake from the Floridan aquifer may be important in this area.

Long-term average annual rainfall, based on the Doppler radar–converted rainfall data from 2000 to 2012 provided by the St. Johns River Water Management District (SJRWMD), was about 45 inches per year. The annual average air temperature, based on data collected from 2000 to 2012 from a weather station located at the Leesburg Municipal Airport, was about 22°C. The summer maximum temperature ranged from 35° to 37°C. The winter minimum temperature ranged from -4° to 1°C.

For assessment purposes, the Florida Department of Environmental Protection has divided the Ocklawaha River Basin into water assessment polygons with a unique **w**ater**b**ody **id**entification (WBID) number for each watershed or stream reach. Lake Denham is WBID 2832A. This TMDL report addresses the nutrient impairment of the lake.

1.3 Background

This report was developed as part of the department'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. They provide important water quality restoration goals that will guide restoration activities.

This TMDL report will be followed by the development and implementation of a Basin Management Action Plan, or BMAP, to reduce the amount of nutrients that caused the verified impairment of Lake Denham. There is an existing Upper Ocklawaha BMAP that may be used to address restoration of Lake Denham. These activities will depend heavily on the active participation of the SJRWMD, Florida

Department of Agriculture & Consumer Services, Florida Department of Transportation (FDOT), Lake County Water Authority, local governments, businesses, and other stakeholders. The department will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDLs for impaired waterbodies.

Figure 1.1. Location of the Lake Denham Watershed (WBID 2832A) in the Ocklawaha Basin and Major Geopolitical and Hydrologic Features in the Area

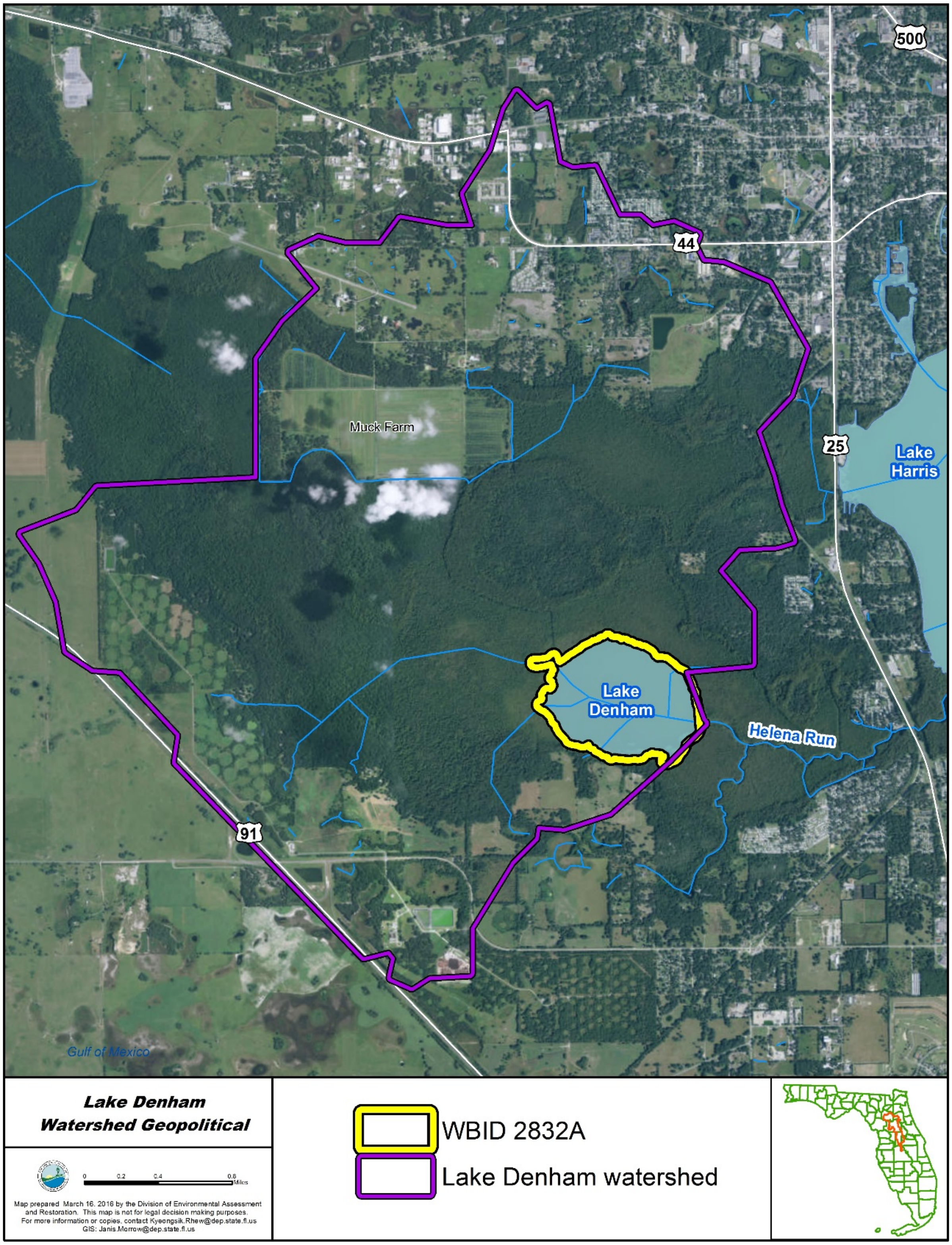


Figure 1.2. Detailed View of Lake Denham (WBID 2832A) in Lake County and Hydrologic Features in the Area

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 United States 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. The department 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], Florida Statutes [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 the department to develop, and adopt by rule, a new science-based methodology to identify impaired waters. After a long rulemaking process, the Environmental Regulation Commission adopted the new methodology as Chapter 62-303, F.A.C. (Identification of Impaired Surface Waters Rule, or IWR), in April 2001; the rule was modified in 2006, 2007, 2012, 2013, and 2015. 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

The department used the IWR to assess water quality impairments in the Ocklawaha River Basin (Group 1) for Lake Denham. The lake was placed on the Verified List for nutrient impairment based on the fact that in the Cycle 1 assessment (verified period for the Group 1 basins; January 1, 1995–June 30, 2002) annual average TSI values (Gao and Gilbert 2003) exceeded the applicable threshold for impairment. The nutrient impairment was confirmed in the Cycle 2 assessment (January 1, 2000–June 30, 2007) and in the Cycle 3 assessment (January 1 2005–June 30, 2012) (**Table 2.1**). In addition, the department assessed the water quality of Lake Denham using the NNC, which became effective on October 27, 2014. The results indicate that Lake Denham does not attain the applicable lake NNC and will remain impaired for nutrients (see **Chapter 3**).

In Florida waterbodies, nitrogen and phosphorus are most often the limiting nutrients. A limiting nutrient limits plant growth (both macrophytes and algae) when it is not available in sufficient quantities. A limiting nutrient is a chemical that is necessary for plant growth, but available in quantities smaller than those needed for optimal growth of algae, represented by chl *a*, and macrophytes.

In the past, management activities to control lake eutrophication focused on phosphorus reduction, as phosphorus was generally recognized as the limiting nutrient in freshwater systems. Recent studies, however, have supported the reduction of both nitrogen and phosphorus as necessary to control algal growth in aquatic systems (Conley *et al.* 2009; Lewis *et al.* 2011; Paerl 2009; Paerl and Otten 2013). Furthermore, the analysis used to develop the Florida lake NNC supports this idea, as statistically significant relationships were found between chl *a* values and both nitrogen and phosphorus concentrations (Department 2012).

Table 2.1. Summary of TSI for Lake Denham (WBID 2832A), 2000–12

PCU = Platinum cobalt units; TN = Total nitrogen; TP = Total phosphorus

YEAR	MEAN COLOR (PCU)	TSI THRESHOLD	CALCULATED TSI BASED ON MEASURED TN, TP AND CHL *A*	EXCEEDANCE
2000	38	40	78	Yes
2001	125	60	75	Yes
2002	238	60	76	Yes
2003	88	60	74	Yes
2004	100	60	70	Yes
2005	118	60	77	Yes
2006	61	60	82	Yes
2007	33	40	83	Yes
2008	113	60	82	Yes
2009	65	60	75	Yes
2010	39	40	73	Yes
2011	67	60	75	Yes
2012	50	60	79	Yes

Chapter 3: DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criterion Applicable to the TMDL

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)**

Lake Denham is a Class III (fresh) waterbody, with a designated use of fish consumption, recreation, propagation and maintenance of a healthy, well balanced population of fish and wildlife. The Class III water quality criterion applicable to the verified impairment (nutrients) for this water is Florida's nutrient criterion in Paragraph 62-302.530(47)(b), F.A.C.

3.2 Applicable Water Quality Standards and Numeric Water Quality Target

3.2.1 Numeric Interpretation of the Narrative Nutrient Criterion

The NNC for lakes were adopted on December 8, 2011, and have been effective since October 27, 2014. The department has assessed the data for Lake Denham using the new criteria. Lake Denham does not attain the new NNC and remains listed as verified impaired for nutrients under the new criteria. The nutrient TMDLs presented in this report 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. **Appendix A** summarizes the relevant TMDL information, including justification for the protection of 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.

TMDL targets and water quality criteria are generally very similar, as both measures are used to protect the designated uses of surface waters. In fact, for many non-nutrient TMDLs, the TMDL target is the applicable water quality criterion, and the TMDL identifies the load that will attain the concentration-based criteria. This is the case for some nutrient TMDLs in which the target is to attain the generally applicable NNC (for a lake, for example), and the TMDL establishes the allowable nutrient load. Under Florida's nutrient standard in Rule 62-302.531, F.A.C., the allowable load becomes the applicable NNC for the lake when the TMDL is adopted.

3.2.1.1 NNC Values Adopted by the State

The adopted lake NNC include criteria for chl *a*, TN, and TP, with the specific values depending on the color and alkalinity condition of a given lake. **Table 3.1** lists the NNC for Florida lakes specified in Subparagraph 62-302.531(2)(b)1, F.A.C.

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

mg/L = Milligrams per liter; $CaCO_3$ = 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 mg/L TP streams threshold for the region.

LAKE GROUP LONG-TERM GEOMETRIC MEAN LAKE COLOR AND ALKALINITY	LAKE GROUP AGM 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 chl *a* criterion is 20 micrograms per liter (µg/L). For a lake with long-term geometric mean color less than 40 PCU and long-term geometric mean alkalinity less than 20 mg/L $CaCO_3$, the chl *a* criterion is 6 µg/L. For a lake to attain the chl *a* criterion, the AGM for chl *a* should not exceed the criterion more than once in any consecutive three-year period. These chl *a* criteria were established by taking into consideration results from paleolimnological studies, expert opinion, biological responses, user perceptions, and chl *a* concentrations in a set of carefully selected reference lakes.

If there are sufficient data to calculate the AGM for chl *a* and the mean does not exceed the chl *a* target concentration for the lake type listed in **Table 3.1**, then the TN and TP target concentrations for that calendar year are the AGMs of lake TN and TP samples, subject to the minimum and maximum limits in

Table 3.1. However, for lakes with color > 40 PCU in the West Central Nutrient Watershed Region, the maximum TP limit is the 0.49 mg/L TP streams threshold for the region. If there are insufficient data to calculate the AGM for chl *a* for a given year, or if the AGM chl *a* concentration exceeds the chl *a* target concentration specified in **Table 3.1** for the lake type, then the TN and TP criteria are the minimum values in **Table 3.1**.

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 set at the long-term geometric mean, based on a minimum of 10 data points over at least three years with at least one data point in each year. If insufficient alkalinity data are available, the long-term geometric mean specific conductance value is used, with a value of <100 microohms/cm (µohms/cm) used to estimate the 20 mg/L $CaCO_3$ alkalinity concentration until alkalinity data are available.

Based on the data retrieved from IWR Database Run_49, the long-term geometric mean color for Lake Denham is about 57 PCU (**Table 2.1**), which is higher than the 40 PCU value that distinguishes high-color lakes from clear lakes. The generally applicable chl *a* criterion for Lake Denham, therefore, is 20 µg/L.

Based on Subsection 62-302.531(6), F.A.C., to calculate an AGM for TN, TP, or chl *a*, there must be at least four temporally independent samples per year with at least one sample taken between May 1 and September 30 and at least one sample taken during the other months of the calendar year. To be treated as temporally independent, samples must be taken at least one week apart.

Table 3.2 lists the number of chl *a* samples available for Lake Denham from 2000 to 2012 and the AGM chl *a* concentrations for the years that meet the data sufficiency requirements of Subsection 62-302.531(6), F.A.C. These chl *a* data were retrieved from IWR Run_49. The table shows that all 13 years have sufficient data to calculate the chl *a* AGM and that all 13 years exceeded the 20 µg/L target criterion. Therefore, the applicable TN and TP criteria are the minimum TN and TP concentrations listed in **Table 3.1** for high-color lakes, or 1.27 and 0.05 mg/L, respectively. **Table 3.2** shows that TN and TP AGM for all 13 years exceeded the applicable TN and TP criteria.

Table 3.2. Number of Chl *a* Samples Collected in Lake Denham and Calculated AGM Chl *a*, TN, and TP Concentrations, 2000–12

YEAR	NUMBER OF SAMPLES COLLECTED IN EACH YEAR	AT LEAST ONE SAMPLE COLLECTED BETWEEN MAY AND SEPTEMBER?	AGM CHL *A* (µG/L)	AGM TN (MG/L)	AGM TP (MG/L)
2000	24	Yes	62.1	3.09	0.08
2001	24	Yes	48.7	3.04	0.10
2002	8	Yes	50.3	2.83	0.11
2003	10	Yes	77.4	2.24	0.11
2004	13	Yes	55.0	2.22	0.10
2005	12	Yes	87.3	2.47	0.11
2006	26	Yes	118.2	3.21	0.09
2007	12	Yes	96.8	3.86	0.11
2008	12	Yes	96.8	3.61	0.11
2009	10	Yes	70.2	2.52	0.08
2010	7	Yes	61.1	2.08	0.06
2011	6	Yes	51.5	2.67	0.07
2012	6	Yes	77.8	3.31	0.09

3.2.2 TN and TP Target Concentrations Established Based on the Modeling Approach

When establishing TMDL targets, a critical consideration is to avoid abating the natural background condition. If the modeled chl *a* concentration under the natural background condition is lower than or equal to the generally applicable chl *a* criterion (20 µg/L), the calibrated watershed–receiving water model set will be used to simulate the in-lake TN and TP concentrations and TN and TP loads from the watershed that will achieve an in-lake chl *a* concentration of 20 µg/L. These TN and TP concentrations and loads will be considered target concentrations and loads for the TMDLs. However, if the modeled chl *a* concentration for the natural background condition is higher than the 20 µg/L criteria, the 80th percentile of the TN and TP concentrations under the natural background condition will be used to set the TMDL targets. The 80th percentile of unimpacted condition is consistent with the methods used in developing the Florida NNC as well as the EPA recommendation to set nutrient concentration targets based on the reference condition. Therefore, it is considered protective of designated uses.

TN and TP target concentrations for Lake Denham were established using the modeling approach, which is discussed in detail in **Chapters 4** and **5** of this TMDL report. This approach links the watershed TN and TP loading simulation to the in-lake TN and TP concentration simulation. The watershed simulation was conducted using the Natural Resources Conservation Service ’s (NRCS) curve number model for watershed runoff calculation and multiplying the runoff volume by TN and TP event mean concentrations (EMCs) to calculate the total watershed nutrient loads. Nutrient loading directly deposited onto the lake surface from the atmosphere and nutrient loadings through ground water seepage were also estimated. The ground water nutrient contribution through the in-lake seepage process was estimated using the average potentiometric surface of the Floridan aquifer (feet NGVD) and the Lake Denham annual average stage (feet NGVD) (Keesecker 1992).

The simulated nutrient loads were then entered into a lake eutrophication model, BATHTUB, which was developed by the United States Army Corps of Engineers (USACOE) to simulate in-lake TN, TP, and chl *a* concentrations. The watershed nutrient loadings were linked to the in-lake TN, TP, and chl *a* concentrations through model calibration. The natural background TN, TP, and chl *a* concentrations of the lake were simulated by converting all human land uses in the watershed model to natural land areas (forest/rangeland area). Long-term average AGM TN, TP, and chl *a* concentrations were simulated using these background conditions in the modeling period from 2000 through 2012.

For Lake Denham, the modeled TN, TP, and chl *a* concentrations under the natural background condition were 1.07 mg/L, 0.03 mg/L, and 24.5 µg/L, respectively. The natural background chl *a* concentration was higher than the 20 µg/L NNC chl *a* target. Therefore, the 20 µg/L target was not pursued in this TMDL. Instead, the 80th percentiles of the modeled natural background TN and TP concentrations were established as targets for the Lake Denham nutrient TMDLs. The 80th percentile AGM TN and TP concentrations were calculated using the mean and the coefficient of variance (CV) provided by the BATHTUB Water Quality Model:

$$C = e^{(\sum_{1}^{n} \frac{LnAG}{n} + (t^{*}\sqrt{SD^{2} - \frac{SD^{2}}{n}}))}$$

Where,

C is the TN and TP concentrations that are exceeded at a frequency of one in three years.

$LnAG$ is the natural log of the AGM of TN and TP concentrations.

n is the number of years that the AGM of TN and TP concentrations can be calculated.

t is the inverse of the student's t distribution.

SD is the standard deviation of the natural log of the AGM.

The 80th percentile of the natural background TN and TP concentrations were 1.10 and 0.04 mg/L, respectively. The in-lake chl *a* concentration resulting from the model simulation corresponding to the TN and TP targets was 26.8 µg/L.

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, including 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** on **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 Lake Denham Watershed

4.2.1 Point Sources

4.2.1.1 Wastewater Point Sources

When this analysis was conducted, no wastewater point sources were identified in the Lake Denham watershed that discharge directly to surface waters.

4.2.1.2 Municipal Separate Storm Sewer System (MS4) Permittees

Within the Lake Denham watershed, the stormwater collection systems owned and operated by Lake County and the city of Leesburg are covered by NPDES MS4 Phase II permits (FLR04E106 and FLR04E110, respectively). No Phase I permittees were identified in the watershed.

4.2.2 Nonpoint Sources

Pollutant sources that are not NPDES wastewater or stormwater dischargers are generally considered 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's surface.

In this TMDL analysis, the runoff volume and nutrient loadings from the watershed was primarily estimated using the NRCS's curve number approach. This approach estimates runoff volume by taking into consideration land use type, soil type, the imperviousness of the watershed, and the antecedent moisture condition of the soil (**Appendix D**). Rainfall is the driving force of the curve number simulation.

The land use information included in this TMDL analysis was obtained from the SJRWMD's land use shape files. Because the watershed nutrient loading simulation covers a relatively long period from 2000 through 2012, land use geographic information system (GIS) shape files from two years were used in the loading estimation; the 2004 land use shape file used for estimating the annual nutrient loads for the period from 2000 through 2005, and the 2009 land use shape file used for simulating nutrient loads for the period from 2006 through 2012. Soil hydrologic characteristics for the watershed were obtained from the NRCS's 2010 Soil Survey Geographic Database (SSURGO) GIS shape file from the department's GIS dataminer.

4.2.2.1 Land Uses

Land use is an important factor in determining the nutrient loadings created in the Lake Denham 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.

As discussed earlier, the land use information used in developing this TMDL was obtained from the SJRWMD's 2004 and 2009 land use shape files. These define land use types based on the land use classification system adopted in the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999). To estimate nutrient loads from the Lake Denham watershed, the detailed land use types defined by the Level III FLUCCS code in these shape files were aggregated based on a 16-land use classification system used by the SJRWMD in developing the Pollutant Load Reduction Goals (PLRGs) for seven major lakes in the Upper Ocklawaha River Basin (Fulton *et al.* 2004). **Table 4.1** lists these land use types and their corresponding acreages in the Lake Denham watershed for 2004 and 2009, and the change of acreage in land uses between 2004 and 2009. The table in **Appendix C** relates the 16 land use types to the FLUCCS code. **Figures 4.1a** and **4.1b** show the spatial distribution of the different land use types in the Lake Denham watershed in 2004 and 2009, respectively.

Based on **Table 4.1**, the total area of the Lake Denham watershed is about 6,641 acres. The dominant land use type in the watershed in 2004 was wetlands, which covered about 3,453 acres and accounted for about 52% of the total watershed area. The second largest land use type in 2004, forest/rangeland, covered about 989 acres and accounted for about 14.9% of the area. The third largest land use type was cropland, which occupied about 668 acres of land and accounted for about 10.1% of the total watershed area. Overall, human land uses, including all the residential, commercial, industrial, and agricultural areas, occupied about 2,136 acres of the watershed and accounted for about 32.2% of the total watershed area. Of these human land use areas, 11.7% are urban lands that include all the residential, commercial, industrial, mining, and recreational areas, and 20.5% are agricultural lands.

Table 4.1. Comparison of the SJRWMD's 16 Land Uses and Their Corresponding Acreage in the Lake Denham Watershed in 2004 and 2009

SJRWMD's Land Use	2004 Acreage	2004 Acreage (%)	2009 Acreage	2009 Acreage (%)	2004/2009 Difference Acreage	2004/2009 Difference (%)
Low-density residential	181.9	2.7%	178.6	2.7%	-3.3	-1.8%
Medium-density residential	47.1	0.7%	47.1	0.7%	0.0	0.0%
High-density residential	83.5	1.3%	94.1	1.4%	10.7	12.8%
Low-density commercial	185.3	2.8%	336.8	5.1%	151.4	81.7%
High-density commercial	213.3	3.2%	187.5	2.8%	-25.8	-12.1%
Industrial	45.9	0.7%	45.9	0.7%	0.0	0.0%
Mining	20.0	0.3%	25.3	0.4%	5.3	26.8%
Open land/recreational			19.4	0.3%	19.4	
Pasture	307.2	4.6%	572.7	8.6%	265.5	86.4%
Cropland	667.7	10.1%	463.9	7.0%	-203.8	-30.5%
Tree crops	22.9	0.3%	22.9	0.3%	0.0	0.0%
Other agriculture	20.5	0.3%	20.5	0.3%	0.0	0.0%
Forest/rangeland	988.7	14.9%	789.1	11.9%	-199.6	-20.2%
Water	63.4	1.0%	58.2	0.9%	-5.3	-8.3%
Wetlands	3,452.7	52.0%	3,438.0	51.8%	-14.6	-0.4%
Muck farms	340.7	5.1%	340.7	5.1%	0.0	0.0%
Total	**6,640.8**	**100.0%**	**6,640.8**	**100.0%**		

Compared with 2004, the land use pattern in the Lake Denham watershed exhibited some changes. The largest change was a 266-acre increase in pasture, from 307 acres in 2004 to about 573 acres in 2009, representing an 86% increase. At the same time, low density commercial increased by about 152 acres, going from 185 to about 337 acres, representing an 82% increase. The other significant changes in 2009 were a 204-acre decrease in cropland and a 200-acre decrease in forest/rangeland. Overall, in 2009, human land use areas occupied about 2,355 acres of the watershed, accounting for about 35.5% of the total area. Among these human land use areas, 14.1% were urban lands and 21.4% were agricultural lands. Apparently, areas occupied by human land uses were larger in 2009 than in 2004, mainly because of an increase in the amount of urban land.

4.2.2.2 Hydrologic Soil Groups

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

— **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 Lake Denham watershed used in this TMDL analysis were based on the soil hydrologic groups included in the NRCS's 2010 SSURGO GIS shapefile. **Figure 4.2** shows the spatial distribution of these groups in the Lake Denham watershed. The watershed is dominated by Type A/D soil, which has Type A soil characteristics when unsaturated but behaves like Type D soil when saturated. This type of soil was found in wetland areas. Types A and C/D soils are present in the north and southwest area, and are scattered in the wetland area of the watershed. Types B, C, B/D, and D soils are found in the northwest area of the watershed. In this TMDL analysis, A/D, B/D, and C/D soils are treated as D soils when assigning the curve number.

Soil types in some portions of the watershed were not defined in the SSURGO shapefile (soil type X). Most are located in water or wetland areas. In this TMDL analysis, these undefined soils were all considered Type D when assigning the curve number because soils in water and wetland areas typically show a low potential for water infiltration. **Table 4.2** shows the soil hydrologic groups in the Lake Denham watershed and their corresponding acreage.

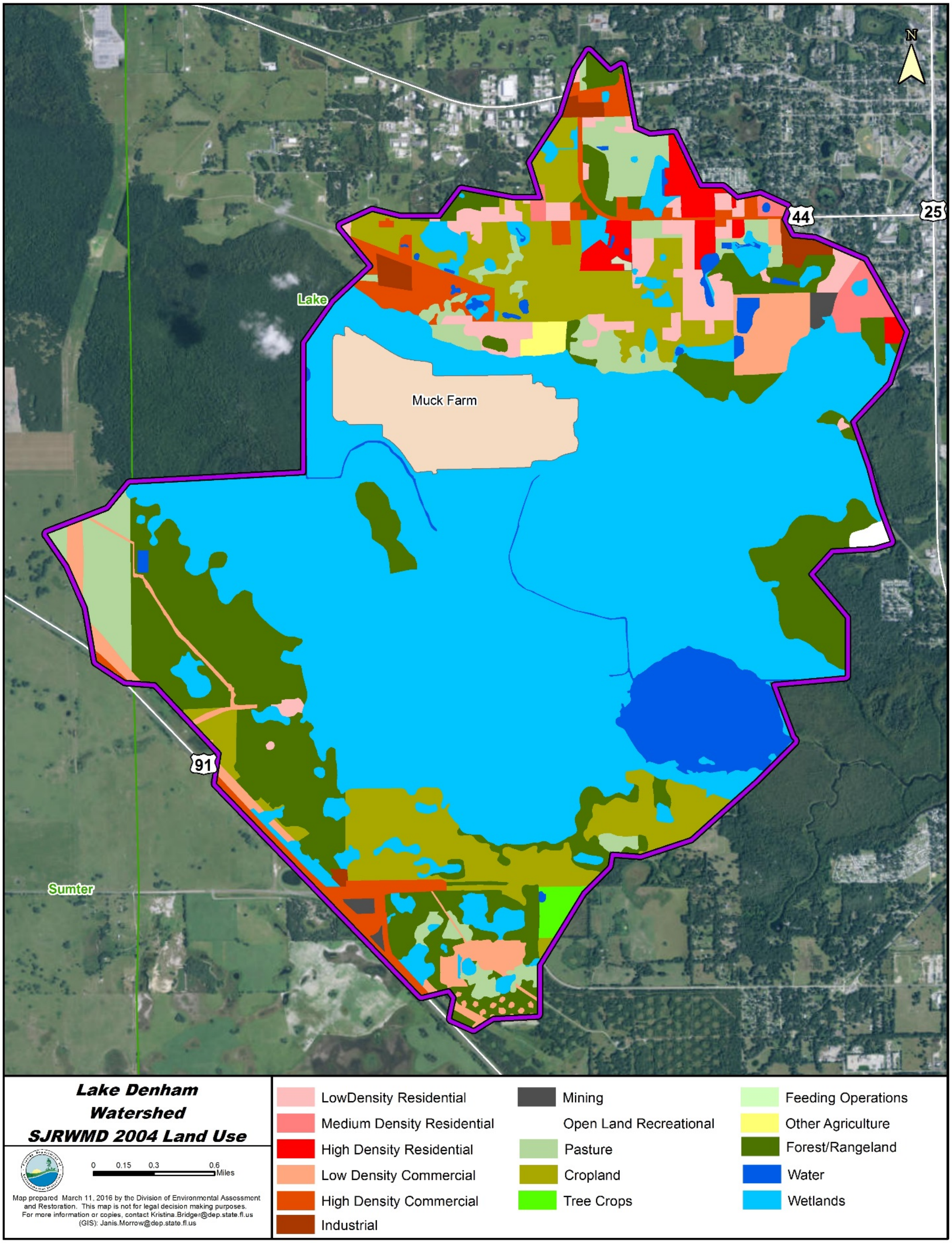


Figure 4.1a. Lake Denham Watershed Land Use Spatial Distribution (2004)

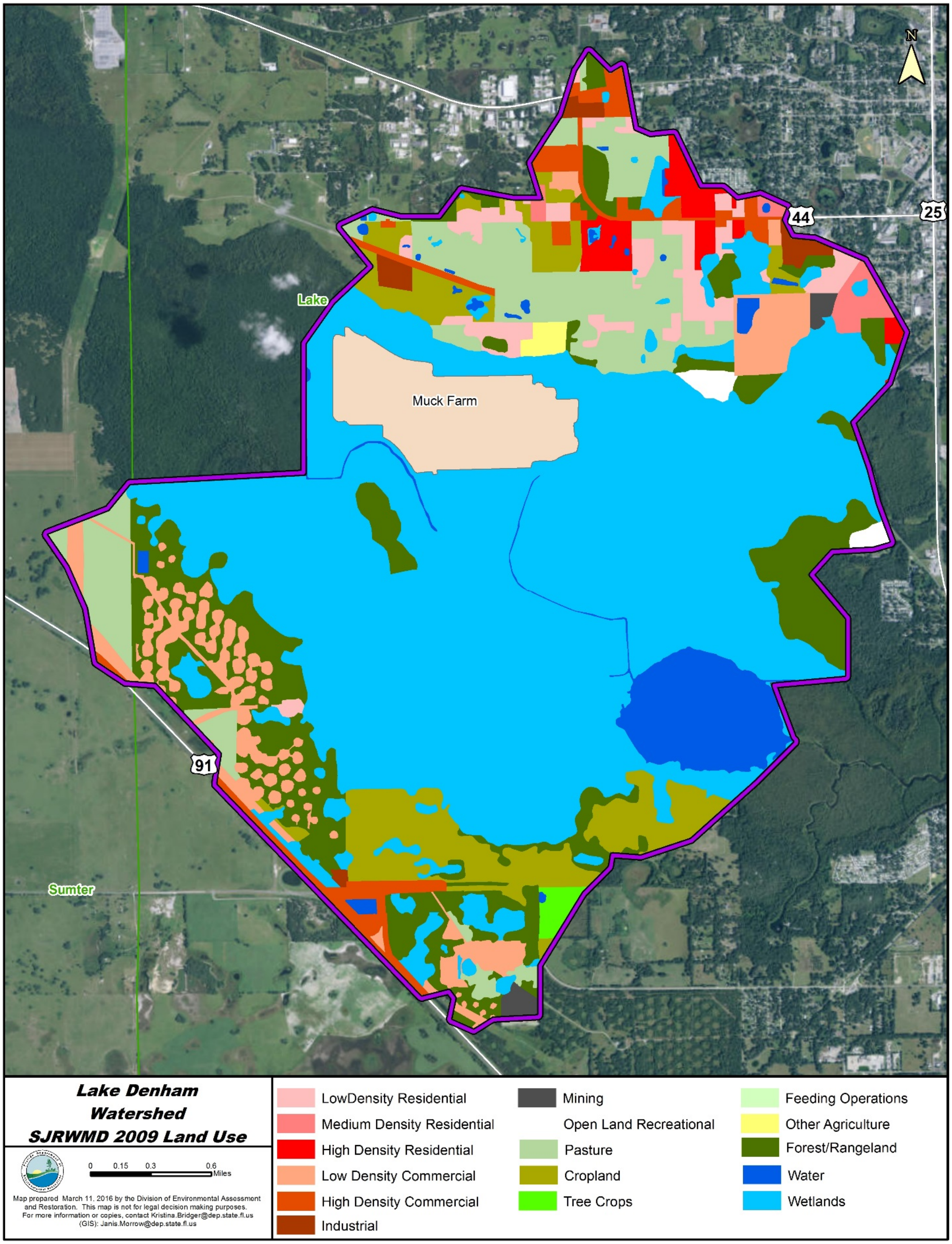
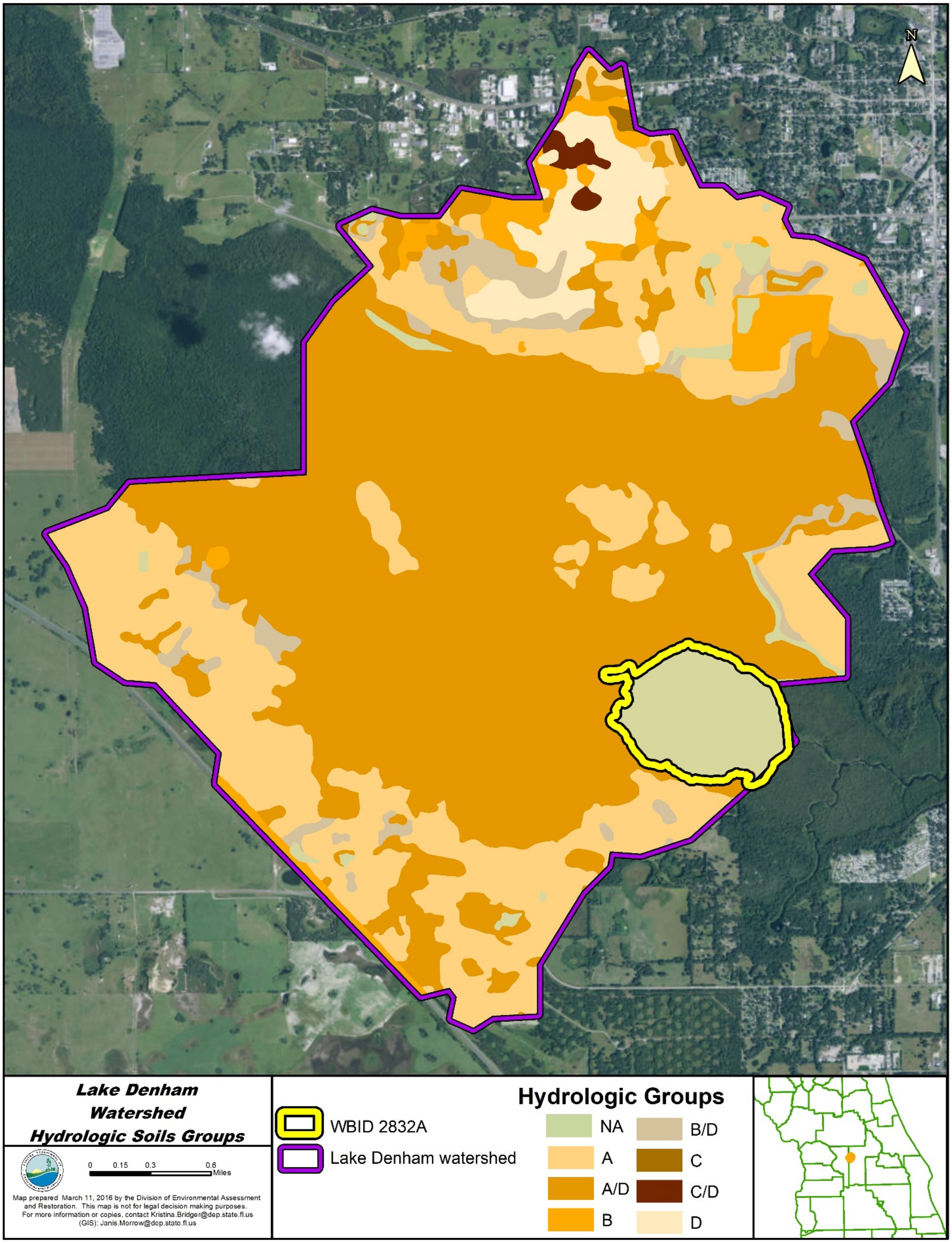


Figure 4.1b. Lake Denham Watershed Land Use Spatial Distribution (2009)



Map prepared March 11, 2016 by the Division of Environmental Assessment and Restoration. This map is not for legal decision making purposes. For more information or copies, contact Kristina.Bridger@dep.state.fl.us (GIS): Janis.Morrow@dep.state.fl.us

Figure 4.2. Lake Denham Watershed Soil Hydrologic Groups (NRCS 2010)

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

SOIL HYDROLOGIC GROUP	ACREAGE	ACREAGE (%)
A	1,940.0	29.2%
B	241.3	3.6%
C	15.3	0.2%
D	241.6	3.6%
D (A/D)	3,794.1	57.1%
D (B/D)	276.9	4.2%
D (C/D)	29.3	0.4%
D(X)	102.5	1.5%
TOTAL	**6,641.0**	**100.0%**

4.2.2.3 Estimating Nonpoint Loadings from the Lake Denham Watershed

ESTIMATING RUNOFF VOLUME USING THE NRCS'S CURVE NUMBER APPROACH

Stormwater runoff from the Lake Denham watershed was estimated using the NRCS's curve number approach and followed the procedure in Fulton *et al.* (2004) (**Appendix D**). The SJRWMD implemented this approach when developing the nutrient PLRG for the Upper Ocklawaha Chain of Lakes. The SJRWMD also provided muck farm discharge data, which were estimated by using a multiple regression equation developed by Fulton (1995). The regression relates discharge volumes including pump discharges from permit records to area in production, rainfall, and evaporation. There were big differences in runoff flow between using the runoff coefficient (140 ac-ft/yr) and estimated discharge data (1,739 ac-ft/yr) due to pump discharges. In this report, estimated discharge data were used to calculate nutrient loads.

The SJRWMD's 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 consists of approximately 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 Lake Denham watershed boundary. The SJRWMD provided the rainfall data used in calculating the runoff coefficient and runoff volume for this TMDL (Dr. R.S. Fulton, personal communication).

Table 4.3 summarizes annual rainfall in the Lake Denham watershed for each year from 2000 through 2012. In this period, total rainfall ranged from 67.8 to 142.6 centimeters (cm) a year. The long-term average annual rainfall for the period was about 113.8 cm.

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

YEAR	ANNUAL RAINFALL (CM)
2000	67.8
2001	105.1
2002	140.8
2003	120.9
2004	131.1
2005	142.6
2006	83.2
2007	101.3
2008	111.2
2009	130.9
2010	113.6
2011	106.8
2012	123.7

Appendix D lists the runoff coefficients for each land use–soil type combination for each year from 2000 through 2012. **Table 4.4** lists the annual runoff volume from different land use areas in the Lake Denham watershed. This ranges from 6,133 to 15,856 acre-feet (ac-ft) from 2000 through 2012. Long-term average annual runoff was about 12,088 ac-ft.

Different land use areas contributed different amounts of runoff in the Lake Denham watershed. Of the total runoff, about 9,319 ac-ft came from natural land areas, including forest/rangeland, waters, and wetlands. This accounted for about 77% of total runoff volume from the entire watershed. The land use area contributing the most runoff volume was wetlands, which alone contributed about 8,969 ac-ft of runoff, accounting for 74% of total runoff from the watershed. Urban land areas—including low-, medium-, and high-density residential areas and low- and high-density commercial and industrial areas—contributed about 950 ac-ft, accounting for about 8% of total watershed runoff. The runoff contribution from rural land areas, including pasture, cropland, and other agricultural land, plus some runoff from open and recreational land areas, was relatively low at about 232 ac-ft, accounting for about 2% of total watershed runoff. Discharge from the muck farms was 1,581 ac-ft and accounted for 13% of total watershed runoff.

Table 4.4. Runoff Volume (ac-ft/yr) for Different Land Use Categories in the Lake Denham Watershed, 2000–12

LAND USE	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Low-density residential	20.7	48.7	90.7	42.0	89.8	52.4	35.1	39.4	67.4	87.5	39.0	69.1	68.9
Medium-density residential	14.4	25.1	37.6	26.7	35.8	31.9	19.4	23.1	29.1	35.5	25.1	28.6	31.4
High-density residential	42.2	71.9	105.1	77.8	99.7	92.8	63.5	75.9	93.7	113.8	82.9	91.9	101.6
Low-density commercial	148.1	241.1	336.5	269.9	316.0	319.8	343.4	415.1	477.9	570.4	460.4	463.3	526.0
High-density commercial	192.2	315.7	444.8	351.0	418.6	416.5	217.8	262.6	307.0	367.9	290.3	298.5	336.8
Industrial	45.7	73.7	101.8	83.1	95.4	98.3	58.0	70.2	79.9	95.1	78.1	77.3	88.2
Mining	0.7	2.7	6.1	1.7	6.2	2.3	2.1	2.2	5.2	7.0	1.9	5.5	5.1
Open land/recreational	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.5	3.4	4.5	1.3	3.5	3.3
Pasture	11.2	47.4	110.6	28.7	112.9	39.1	71.3	72.1	184.1	252.3	58.4	196.0	178.7
Cropland	26.1	117.0	276.7	68.9	282.9	94.7	48.6	49.6	122.8	167.7	41.1	130.4	119.6
Tree crops	0.7	2.2	4.9	1.5	5.0	2.0	1.5	1.6	3.6	4.8	1.4	3.8	3.6
Other agriculture	0.7	2.8	6.5	1.8	6.7	2.4	1.9	2.0	4.8	6.5	1.7	5.1	4.7
Forest/rangeland	35.6	149.9	349.4	91.1	356.6	124.0	83.2	84.9	210.3	287.3	70.2	223.4	204.9
Water	107.0	169.8	230.4	193.7	215.0	228.7	122.8	149.2	166.1	196.5	166.8	160.1	184.2
Wetlands	5,151	8,258	11,329	9,349	10,601	11,057	6,477	7,853	8,869	10,530	8,748	8,569	9,802
Muck farms (estimated discharges)	337	1,547	2,426	1,974	2,383	2,747	570	1,216	1,698	2,307	1,908	1,491	2,003
TOTAL	**6,133**	**11,073**	**15,856**	**12,560**	**15,024**	**15,308**	**8,117**	**10,318**	**12,322**	**12,979**	**11,974**	**11,817**	**13,662**

ESTIMATING RUNOFF NUTRIENT LOADS

Runoff nutrient loads from the Lake Denham 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 the land use type.

Tables 4.5a and **4.5b** list the stormwater runoff TN and TP loads from the Lake Denham watershed estimated using the procedures described in **Appendix D**. The annual runoff TP loads in the period from 2000 to 2012 reaching Lake Denham ranged from 412 kilograms per year (kg/yr) in 2000 to 1,603 kg/yr in 2002 (**Table 4.5a**). The long-term average annual TP runoff loads for the period were about 1,136 kg/yr. Different land use areas contributed different amounts of runoff TP loads in the watershed. About 380 kg/year came from natural land areas, including forest/rangeland, waters, and wetlands, accounting for about 33% of total runoff TP loads from the entire watershed. Urban land areas, including low-, medium-, and high-density residential and low- and high-density commercial and industrial, contributed about 149 kg/yr, accounting for about 13% of total watershed runoff TP loads. Runoff TP loads from rural land areas, including pasture, cropland, and other agricultural land, plus some runoff from open/recreational land areas, were about 106 kg/yr, accounting for about 9% of total watershed runoff TP loads. The land use area contributing the highest runoff load was muck farms, which alone contributed about 500 kg/yr of runoff loads, accounting for about 44% of total watershed runoff.

The runoff TN annual loads in the period from 2000 to 2012 ranged from 8,529 kg/yr in 2000 to 25,868 kg/yr in 2002 (**Table 4.5b**). The interannual pattern is similar to that of runoff TP loads. The long-term average annual runoff TN loads from the entire watershed were about 19,455 kg/yr. The majority were created in natural areas, which contributed about 11,579 kg/yr and accounted for about 60% of the total runoff TN loads from the watershed. The single most important contributor of runoff TN loads was wetland areas, which alone contributed about 11,283 kg/yr and accounted for about 58% of total watershed TN runoff loads. Urban areas contributed about 1,327 kg/yr of runoff TN, accounting for about 7% of total runoff TN loads. Other rural areas contributed about 934 kg/yr, accounting for about 5% of total watershed runoff TN loads. The runoff TN load from the muck farms area was 5,611 kg/yr, and accounted for about 29% of total watershed runoff TN loads.

Table 4.5a. Runoff TP Annual Loads (kg/yr) for Different Land Use Categories in the Lake Denham Watershed, 2000–12

LAND USE	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	MEAN	MEAN (%)
Low-density residential	1.6	3.9	7.4	3.2	7.3	4.1	2.8	3.1	5.5	7.1	3.0	5.6	5.6	4.6	0.4%
Medium-density residential	3.2	5.5	8.2	5.8	7.8	7.0	4.2	5.1	6.4	7.8	5.5	6.3	6.9	6.1	0.5%
High-density residential	11.5	19.2	27.7	21.0	26.2	25.0	16.0	19.2	23.2	28.0	21.1	22.7	25.3	22.0	1.9%
Low-density commercial	7.2	11.8	16.4	13.2	15.4	15.6	16.3	19.8	22.7	27.1	21.9	22.0	25.0	18.0	1.6%
High-density commercial	49.7	81.6	114.8	90.8	108.0	107.7	59.3	71.5	83.4	99.9	79.1	81.0	91.5	86.0	7.6%
Industrial	6.8	11.0	15.3	12.4	14.3	14.7	8.7	10.5	12.0	14.3	11.7	11.6	13.2	12.1	1.1%
Mining	0.1	0.3	0.6	0.2	0.6	0.2	0.2	0.2	0.5	0.6	0.2	0.5	0.5	0.4	0.0%
Open land/recreational	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.0%
Pasture	4.1	17.5	40.8	10.6	41.6	14.4	26.3	26.6	67.9	93.0	21.5	72.3	65.9	38.6	3.4%
Cropland	14.4	64.7	153.0	38.1	156.4	52.3	26.9	27.4	67.9	92.7	22.7	72.1	66.1	65.8	5.8%
Tree crops	0.1	0.3	0.6	0.2	0.6	0.2	0.2	0.2	0.4	0.6	0.2	0.5	0.4	0.3	0.0%
Other agriculture	0.3	1.3	3.0	0.8	3.0	1.1	0.9	0.9	2.2	2.9	0.7	2.3	2.1	1.6	0.1%
Forest/rangeland	1.5	6.2	14.4	3.8	14.7	5.1	3.4	3.5	8.7	11.8	2.9	9.2	8.4	7.2	0.6%
Water	0.9	1.5	2.0	1.7	1.8	2.0	1.1	1.3	1.4	1.7	1.4	1.4	1.6	1.5	0.1%
Wetlands	214.1	343.2	470.9	388.5	440.6	459.5	269.2	319.3	360.6	437.6	363.6	356.1	407.4	371.6	32.7%
Muck farms	96.9	512.2	727.7	555.5	670.6	770.8	160.3	342.3	477.9	649.3	536.9	419.8	575.6	499.7	44.0%
TOTAL	**412**	**1,080**	**1,603**	**1,146**	**1,509**	**1,480**	**596**	**851**	**1,141**	**1,475**	**1,092**	**1,084**	**1,296**	**1,136**	**100%**

Table 4.5b. Runoff TN Annual Loads (kg/yr) for Different Land Use Categories in the Lake Denham Watershed, 2000–12

Land Use	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean	Mean (%)
Low-density residential	26.2	63.0	119.0	53.6	118.1	67.1	45.3	50.6	88.2	114.9	49.7	90.7	90.0	75.1	0.4%
Medium-density residential	32.4	56.6	84.6	60.2	80.6	72.0	43.7	52.1	65.6	80.0	56.6	64.5	70.8	63.1	0.3%
High-density residential	84.4	142.5	206.6	155.2	195.6	184.8	121.5	145.4	177.3	214.8	159.2	173.6	192.8	165.7	0.9%
Low-density commercial	95.2	154.9	216.1	173.4	202.9	205.5	218.2	263.7	303.6	362.3	292.5	294.3	334.1	239.7	1.2%
High-density commercial	399.5	655.8	923.2	729.5	868.8	865.5	465.5	561.3	655.4	785.2	620.7	637.0	719.2	683.6	3.5%
Industrial	56.7	91.5	126.5	103.1	118.6	122.0	72.0	87.1	99.3	118.2	96.8	96.1	109.6	99.8	0.5%
Mining	0.7	2.7	6.3	1.7	6.4	2.3	2.0	2.1	4.9	6.6	1.8	5.2	4.8	3.7	0.0%
Open land/recreational	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.8	4.1	5.6	1.6	4.3	4.1	1.8	0.0%
Pasture	31.5	133.9	312.8	81.1	319.3	110.5	201.6	203.8	520.6	713.5	165.2	554.3	505.3	296.4	1.5%
Cropland	135.7	607.5	1,436.9	357.7	1,469.4	491.7	252.6	257.7	637.7	871.0	213.3	677.3	621.2	617.7	3.2%
Tree crops	1.5	5.2	11.4	3.6	11.6	4.7	3.6	3.8	8.4	11.3	3.4	8.8	8.3	6.6	0.0%
Other agriculture	2.3	9.2	21.1	5.7	21.5	7.7	6.2	6.4	15.4	21.0	5.4	16.3	15.1	11.8	0.1%
Forest/rangeland	43.7	184.3	429.6	112.0	438.5	152.5	102.4	104.4	258.6	353.3	86.3	274.7	251.9	214.8	1.1%
Water	49.1	77.9	105.7	88.9	98.7	105.0	56.4	68.5	76.3	90.2	76.5	73.5	84.5	80.9	0.4%
Wetlands	6,480	10,389	14,253	11,761	13,337	13,910	8,149	9,879	11,158	13,247	11,005	10,780	12,331	11,283	58.0%
Muck farms	1,090	5,197	7,615	6,372	7,692	8,837	1,839	3,926	5,482	7,447	6,159	4,815	6,475	5,611	28.4%
Total	**8,529**	**17,771**	**25,868**	**20,059**	**24,979**	**25,138**	**11,580**	**15,614**	**19,555**	**24,442**	**18,993**	**18,566**	**21,818**	**19,455**	**100%**

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

5.1 Historical Trends for TN, TP, and Chl *a* in Lake Denham

Monthly TN, TP, and corrected chl *a* concentrations for Lake Denham from 2000 through 2012 were retrieved from IWR Database Run_49. **Figure 5.1** shows the locations of the individual stations where water quality data were collected. AGM values for TN, TP, and chl *a* concentrations were calculated based on all sampling data for the year, and quarterly geometric mean values for TN, TP, and chl *a* concentrations were calculated using data sorted by quarter in the 2000–12 period. The seasonal trends for TN, TP, and chl *a* were examined using the quarterly geometric mean values (**Table 5.2**).

As shown in **Table 5.1**, the AGM of TN concentrations in Lake Denham ranged from 2.08 to 3.86 mg/L, and averaged 2.86 mg/L from 2000 through 2012. TN concentrations fluctuated throughout this period. The AGM of TP concentrations ranged from 0.06 to 0.11 mg/L and averaged 0.10 mg/L. TP concentrations also fluctuated but not as distinctively as TN concentrations (**Figure 5.3a**). Regression analyses showed no statistically significant relationships between the AGMs for chl *a* and either TN or TP.

There were no significant seasonal differences in TN and TP concentrations (**Table 5.2**). The AGM of chl *a* concentrations ranged from 48.7 to 118.2 µg/L and averaged 73.3 µg/L from 2000 to 2012 (**Figure 5.4a**). There were significant seasonal differences in chl *a* concentrations. Based on the TN:TP ratio (**Table 5.1**), phytoplankton growth was colimited by both nitrogen and phosphorus in earlier years (2001–05), except for 2000, and limited by phosphorus in later years (2006–12). This indicates a gradual shift from nitrogen-phosphorus colimitation to phosphorus limitation. The trend was caused by a decrease in in-lake TP concentrations and an increase in TN concentrations during the 2006–12 period. TN:TP ratio above 30 indicates P limitation, a ratio below 10, N limitation and values between 10 and 30, N and P colimitation. It has been commonly accepted that limiting nutrient is the nutrients that controls the growth of phytoplankton.

Figures 5.2b, 5.3b, and **5.4b** show the variations between TP, TN, and chl *a* concentrations, respectively, and annual rainfall. Annual rainfall and the AGMs of both TN and chl *a* concentrations tend to fluctuate in opposite directions over time.

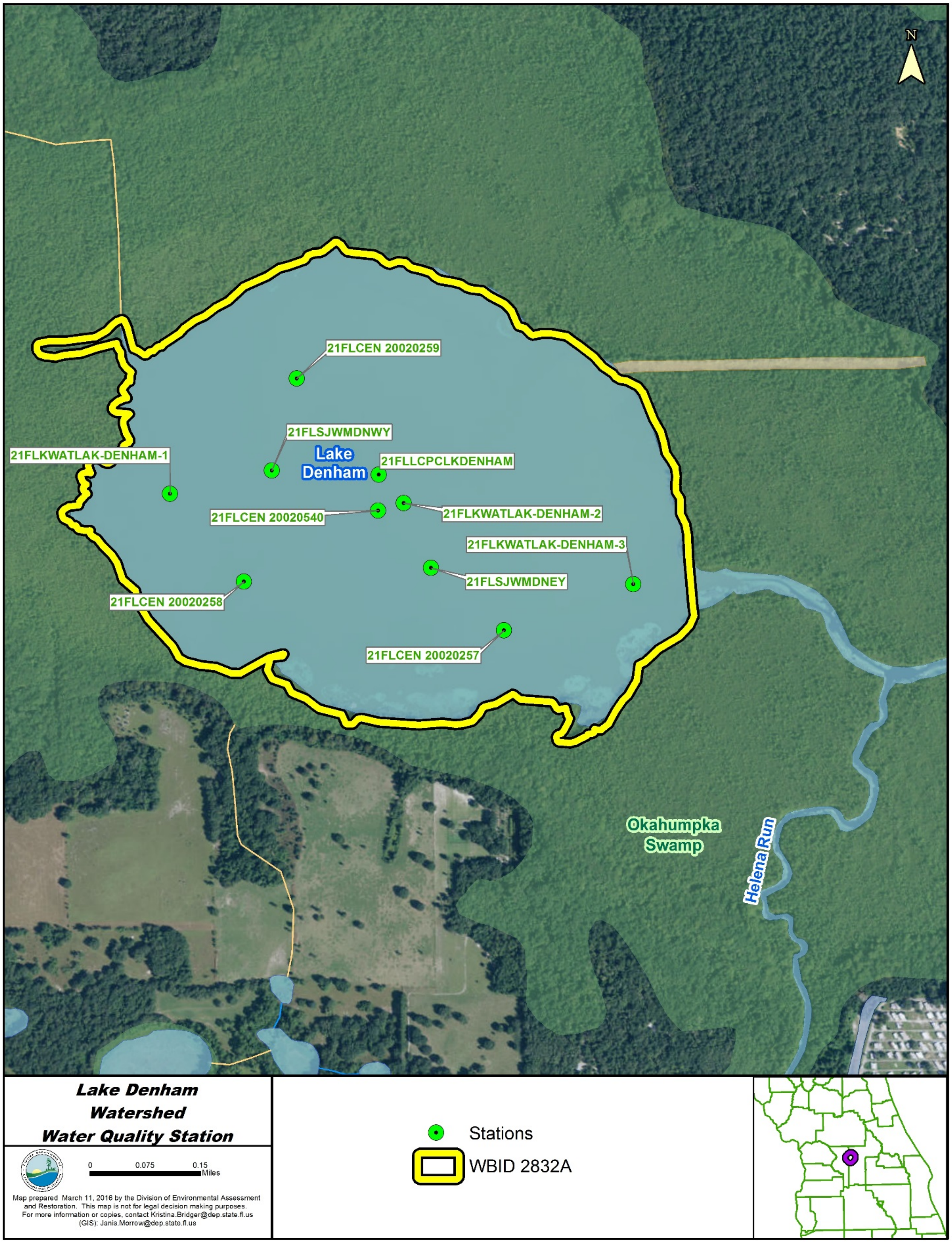


Figure 5.1. **Locations of Water Quality Stations in Lake Denham**

Table 5.1. AGMs of TN, TP, and Chl *a* of Lake Denham, 2000–12

YEAR	TN (MG/L)	TP (MG/L)	CHL A (µG/L)	TN:TP RATIO
2000	3.09	0.08	62.1	38
2001	3.04	0.10	48.7	29
2002	2.83	0.11	50.3	27
2003	2.24	0.11	77.4	20
2004	2.22	0.10	55.0	22
2005	2.47	0.11	87.3	22
2006	3.21	0.09	118.2	34
2007	3.86	0.11	96.8	34
2008	3.61	0.11	96.9	34
2009	2.52	0.08	70.2	33
2010	2.08	0.06	61.1	34
2011	2.67	0.07	51.5	38
2012	3.31	0.09	77.8	36
MEAN	**2.86**	**0.10**	**73.3**	**31**

Table 5.2. Seasonal Variation of TN, TP, and Chl *a* in Lake Denham; Long-Term Mean of Quarterly Geometric Mean

QUARTER (MONTH)	TN (MG/L)	TP (MG/L)	CHL *A* (µG/L)
1st quarter (1,2,3)	2.51	0.09	54.8
2nd quarter (4,5,6)	2.92	0.09	70.4
3rd quarter (7,8,9)	2.93	0.08	94.2
4th quarter (10,11,12)	2.93	0.09	73.4

The high TN and chl *a* concentrations observed in 2006, 2007, and 2008 appear to be associated with relatively low annual rainfall in these three years. Annual rainfall and the AGMs of TP concentrations exhibited similar patterns in earlier years (**Figure 5.3b**). It appears that when annual rainfall is high, TP concentrations are high, and when annual rainfall is low, TP concentrations are low, suggesting that the in-lake TP concentration is controlled primarily by stormwater input from the watershed.

The concentration effect due to the decrease in lake volume could have caused the increase in nutrient concentrations; however, the simple concentration effect could not fully explain nutrient dynamics under the low-rainfall condition, because no significant increase in TP concentrations was observed during these same dry years. Some in-lake chemical and biochemical processes must also be affecting the nutrient and algal biomass dynamics observed.

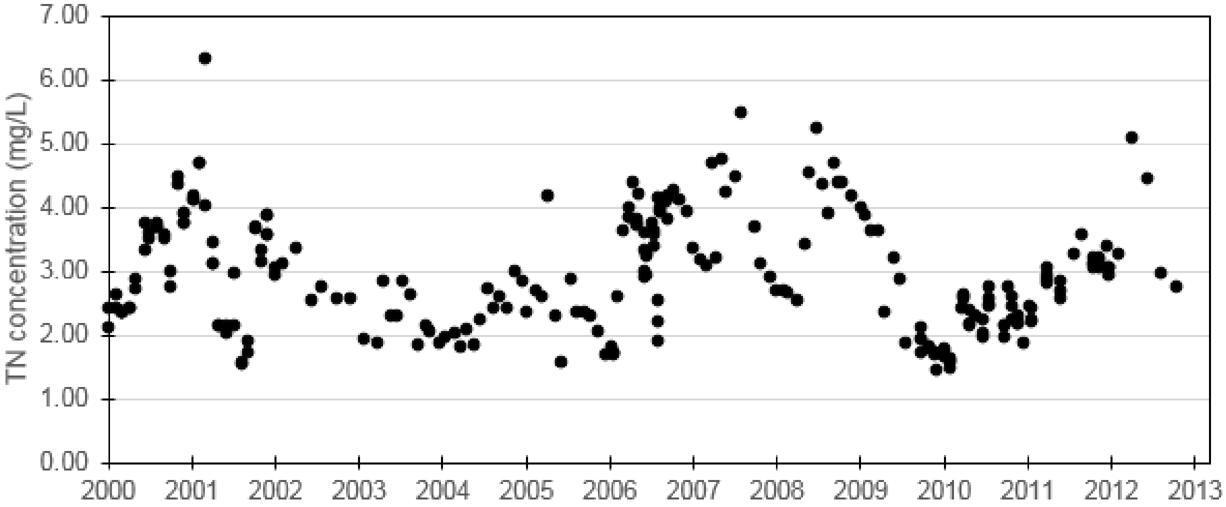


Figure 5.2a. **TN Concentrations Measured for Lake Denham, 2000–12**

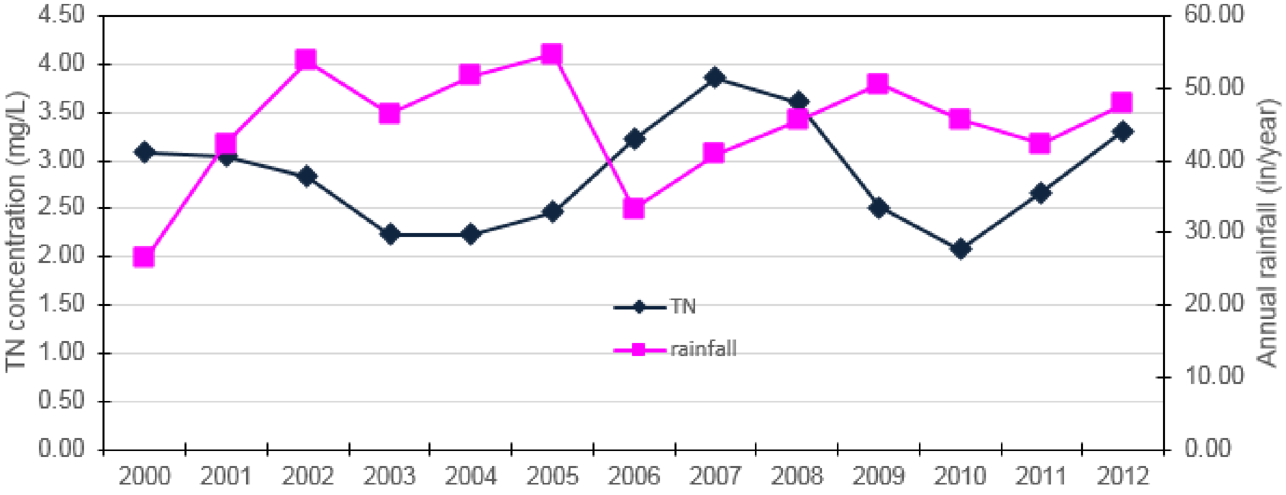


Figure 5.2b. **Relationship between Annual Rainfall and TN AGM for Lake Denham, 2000–12**

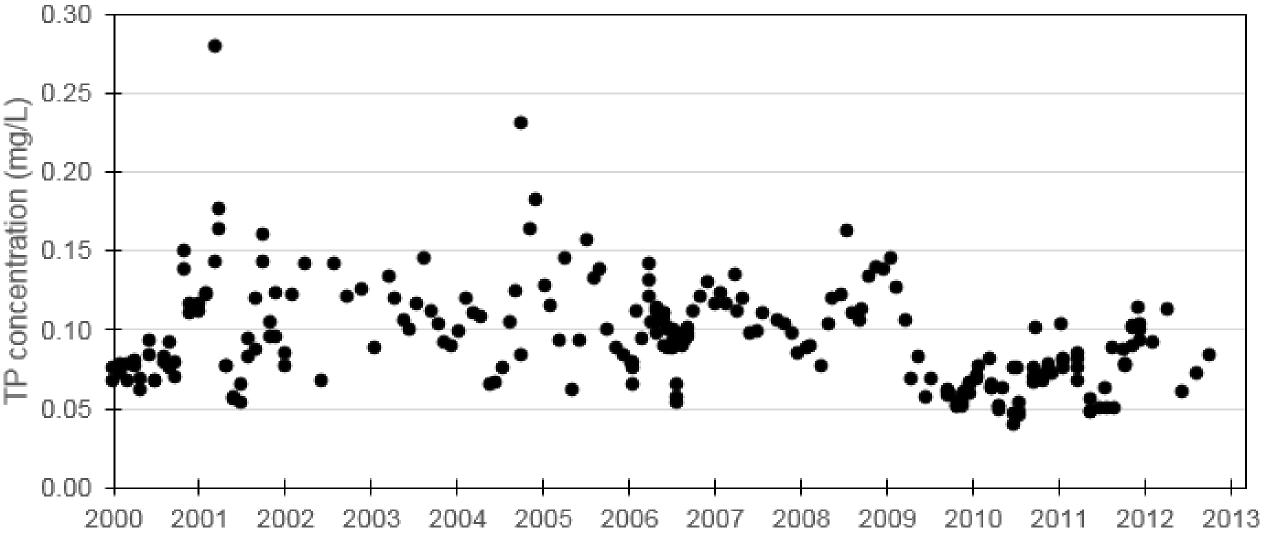


Figure 5.3a. TP Concentrations Measured for Lake Denham, 2000–12

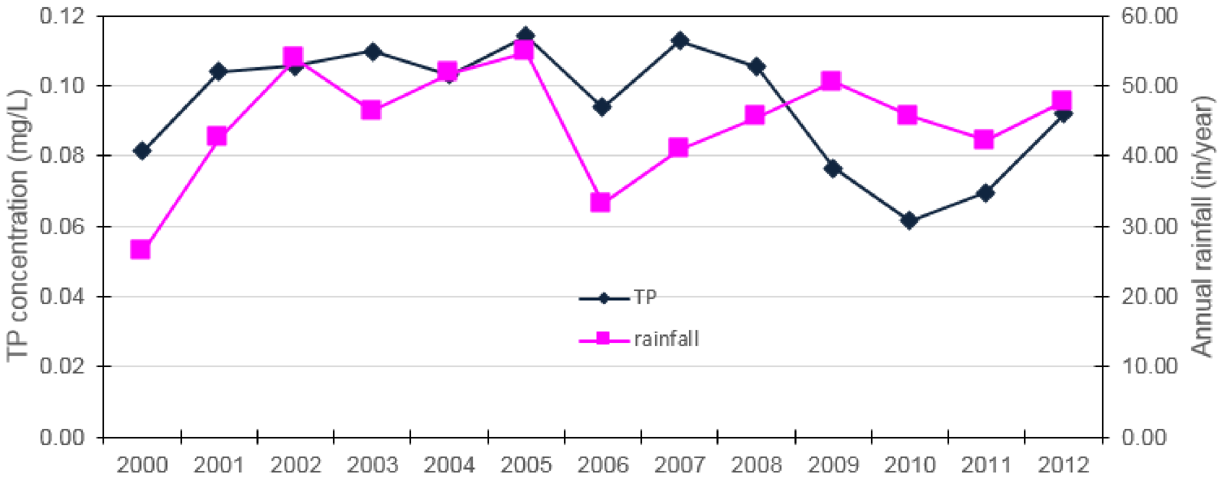


Figure 5.3b. Relationship between Annual Rainfall and TP AGM for Lake Denham, 2000–12

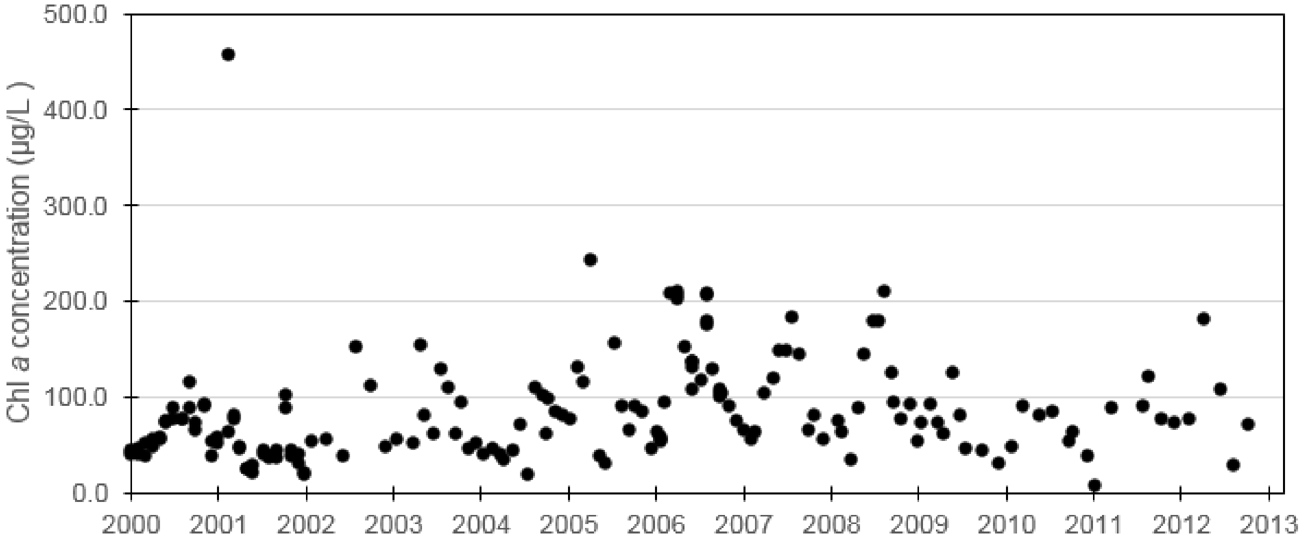


Figure 5.4a. **Chl *a* Concentrations Measured for Lake Denham, 2000–12**

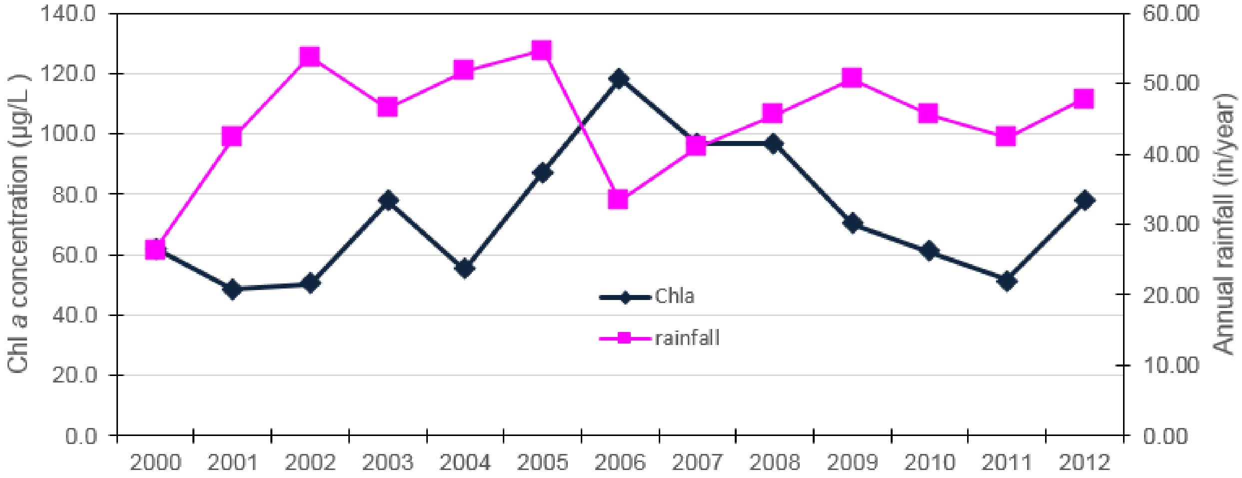


Figure 5.4b. **Relationship between Annual Rainfall and Chl *a* AGM for Lake Denham, 2000–12**

5.2 Relationship between Nutrient Loadings and In-Lake Nutrients and Chl *a* Concentrations

The goal of nutrient TMDL development for Lake Denham is to identify the maximum allowable TP and TN loadings to the lake so that the lake will meet the water quality standard and maintain its function and designated use. Specifically, the water quality targets in this analysis are TN of 1.10 mg/L and TP of 0.04 mg/L (see **Chapter 3**). In general, the processes used for identifying the water quality targets and establishing the nutrient TMDLs are divided into four main steps:

1. TP and TN loadings from the Lake Denham watershed were estimated using the curve number approach (see **Chapter 4**). Loading from atmospheric deposition directly onto the lake's surface was also considered in the loading estimation.

2. Loading estimates from all sources were entered into the BATHTUB Eutrophication Model to establish the relationship between TN and TP loadings and in-lake TN, TP, and chl *a* concentrations by calibrating the BATHTUB model against the measured in-lake TN, TP, and chl *a* concentrations. The calibrated BATHTUB model was then used to predict in-lake existing TN, TP, and chl *a* concentrations.

3. TN and TP concentrations for all human land uses in the watershed were then converted to those of natural land uses in the BATHTUB model—in this case, forest/rangeland—but without changing the flow volume to simulate natural background TN, TP, and chl *a* concentrations. The natural background condition was used to determine the target nutrient concentrations.

4. Nutrient loads to the lake were simulated by adjusting the TN and TP concentrations of the watershed until lake concentrations reached the target concentrations, and the TN and TP loads that resulted in the target concentration in the lake were considered the TN and TP (nutrient) TMDLs for Lake Denham.

5.2.1 Lake Modeling Using the BATHTUB Model

5.2.1.1 BATHTUB Eutrophication Model

BATHTUB is a suite of empirically derived steady-state models developed by the USACOE Waterways Experimental Station. The primary function of these models is to estimate nutrient concentrations and algal biomass resulting from different patterns of nutrient loadings. The *User's Manual* describes the procedures for selecting the appropriate model for a particular lake. The empirical prediction of lake eutrophication using this approach is typically a two-stage procedure using the following two categories of models (Walker 2004):

— ***Nutrient balance model.*** This type of model relates in-lake nutrient concentration to the external nutrient loadings, morphometry, and hydraulics of the lake.

— ***Eutrophication response model.*** This type of model describes relationships among eutrophication indicators in the lake, including nutrient levels, chl *a*, transparency, and hypolimnetic oxygen depletion.

Figure 5.5 shows the scheme used by BATHTUB to relate the external loading of nutrients to the in-lake nutrient concentrations and the physical, chemical, and biological response of the lake to the level of nutrients.

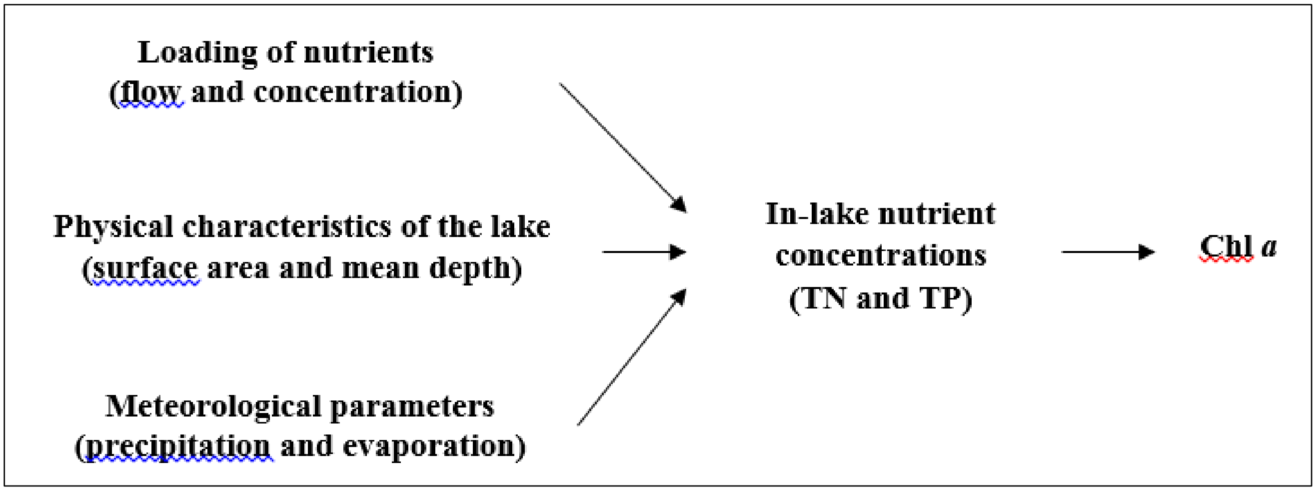


Figure 5.5. BATHTUB Concept Scheme

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 losses of nutrient through whatever decay processes occur inside the lake:

$$\text{Net accumulation} = \text{Inflow} - \text{Outflow} - \text{decay}$$

The equation is solved by assuming that the pollutant dynamics in the lake are at a steady state, *i.e.*, the net accumulation of the pollutants in the lake equals zero.

In this analysis, "inflow" included TN and TP loadings through stormwater surface runoff from various land use categories, atmospheric deposition directly onto the surface of the lake, potential nutrient flux from lake sediments, and possible nitrogen fixation. Nutrient outflow was considered primarily through the outflow stream. To address nutrient losses through processes other than outflow from the lake, BATHTUB provided several alternatives depending on the inorganic/organic nutrient partitioning coefficient and reaction kinetics. The major pathway for TN and TP to be removed from the water column, in these simplified empirical equations, is through sedimentation to the bottom of the lake. The actual sedimentation rate is the net difference between the gross sedimentation rate and the sediment nutrient release rate.

Prediction of the *eutrophication response* by BATHTUB also involves choosing one of several alternative models, depending on whether the algal communities are limited by phosphorus or nitrogen, or colimited by both nutrients. The suite of models also includes scenarios such as algal communities limited by light intensity or controlled by the lake flushing rate. In addition, the response of chl *a* concentration to the in-lake nutrient level is characterized by two different kinetic processes: linear or exponential. The variety of models available in BATHTUB allows the user to choose specific models based on a lake's particular condition.

One feature offered by BATHTUB is the "calibration factor." The empirical models implemented in the model are mathematical generalizations about lake behavior. When applied to data from a particular reservoir, measured data may differ from predictions by a factor of two or more. Such differences reflect data limitations (measurement or estimation errors in the average inflow and outflow concentrations), the unique features of a particular lake (Walker 2004), and unexpected processes inherent to the lake. The calibration factor offered by BATHTUB provides model users with a method to calibrate the magnitude of lake response predicted by the empirical models. The model calibrated to current conditions against measured data from the lake can then be applied to predict changes in lake conditions likely to result from specific management scenarios under the condition that the calibration factor remains constant for all prediction scenarios.

5.2.1.2 TMDL Scenario Development for Lake Denham

The TMDLs for the lake were developed by evaluating the target concentrations of TN and TP for the following scenarios:

A. TN, TP, and chl a for current condition. The current concentrations of Lake Denham were based on the AGMs of TN, TP, and corrected chl *a* concentrations obtained from the department's IWR Database Run_49. The calculated AGMs of TN, TP, and corrected chl *a* concentrations were used for model calibration.

B. Natural background concentration. This is based on the TN, TP, and chl *a* concentrations resulting from a watershed condition in which all human land uses—including low-, medium-, and high-density residential; low- and high-density commercial; industrial; mining; open land/recreational: pasture; cropland; tree crops, other agriculture, and muck farms—discharge pollutants with the same characteristics as those associated with natural land uses. In the actual modeling process, all the areas covered by human land uses were converted to forest/rangeland and the loadings from internal loads and nitrogen fixation were completely removed. The natural background concentrations of TN, TP, and chl *a* were estimated using the model settings calibrated against the measured data.

C. Model simulation for the target concentrations. The loadings to the lake were then adjusted until the BATHTUB model simulated the in-lake target concentrations derived in **Chapter 3**. The nutrient loadings that resulted in the target concentrations were considered the TMDLs for the lake.

5.2.2 BATHTUB Model Calibration

5.2.2.1 Available Data and Data Use

The relationship between TN and TP loadings and in-lake TN and TP concentrations was established by fitting the BATHTUB predictions with the measured TN and TP concentrations of the lake. To calibrate the model, the following data were required:

- The lake's physical characteristics (surface area, mean depth, length, and mixed layer depth).
- Meteorological data (precipitation and evaporation).
- Areal atmospheric deposition of nutrients directly onto the surface of the lake.
- Measured water quality data (TN, TP, and chl *a* concentrations of the lake water).
- Loading data (flow and TN and TP concentrations in the flow from various sources).
- CV of all the measured data.

LAKE PHYSICAL CHARACTERISTICS

Lake surface area and lake water volume were calculated using lake bathymetric chart and stage data provided by the SJRWMD. Regression equations were obtained from the relationships between contour elevation and area, and between elevation and volume (**Figures 5.6** and **5.7**). Stage data were applied to the equation to obtain lake surface area and lake water volume. Mean depth was calculated by lake volume divided by lake area. **Table 5.3** shows the lake stage, surface area, volume, mean depth, mixed layer depth, and change in storage for Lake Denham from 2000 through 2012.

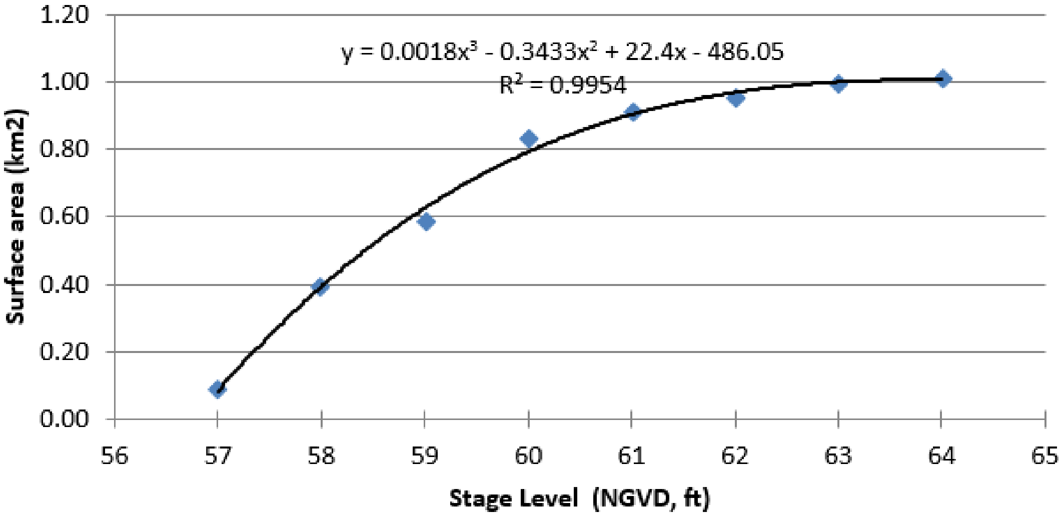


Figure 5.6. Characteristic Curve between Lake Stage and Lake Surface Area for Lake Denham

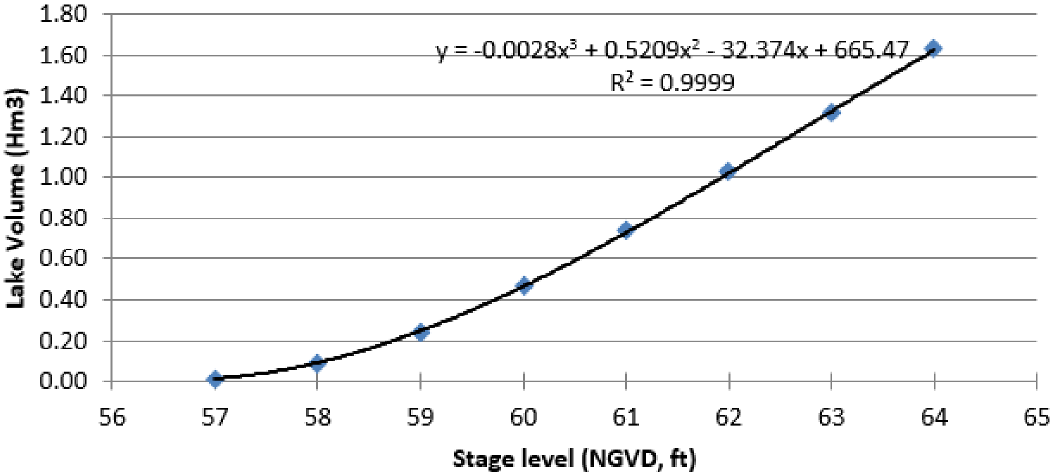


Figure 5.7. Characteristic Curve between Lake Stage and Lake Cumulative Volume for Lake Denham

Table 5.3. Annual Lake Characteristics, Mean Depth, and CV of Lake Characteristics of Lake Denham for the Modeling Period, 2000–12

ft = Feet; km^2 = Square kilometer; Hm^3 = Hectometer; m = Meter

YEAR	ANNUAL AVERAGE LAKE STAGE NGVD (FT)	ANNUAL AVERAGE LAKE SURFACE (KM^2)	ANNUAL AVERAGE LAKE VOLUME (HM^3)	ANNUAL AVERAGE MEAN DEPTH (M)	ANNUAL AVERAGE MIXING DEPTH (M)	ANNUAL CHANGE OF LAKE STORAGE (FT)
2000	61.86	0.95	0.983	1.04	1.04	-2.06
2001	60.82	0.89	0.688	0.77	0.77	0.28
2002	61.73	0.94	0.945	1.01	1.01	1.97
2003	62.98	0.99	1.312	1.33	1.33	-0.21
2004	62.77	0.98	1.251	1.27	1.27	0.23
2005	63.01	0.99	1.321	1.33	1.33	0.05
2006	62.24	0.96	1.096	1.14	1.14	-1.95
2007	60.75	0.89	0.669	0.75	0.75	-0.65
2008	60.98	0.90	0.731	0.81	0.81	0.54
2009	62.01	0.95	1.028	1.08	1.08	1.70
2010	62.81	0.98	1.262	1.28	1.28	-1.01
2011	62.25	0.96	1.095	1.14	1.14	-0.29
2012	61.55	0.93	0.894	0.96	0.96	-0.34
Mean	**61.98**	**0.95**	**1.021**	**1.07**	**1.07**	**-0.13**
CV	**0.004**	**0.01**	**0.063**	**0.053**	**0.053**	**-2.45**

The annual change in lake storage shown in **Table 5.3** was calculated as the difference between lake stage at the beginning (January 1) and the end (December 31) of each year (Walker 2004). Because the mean depth of the lake is relatively low (a long-term average of 1.07 meters), it was assumed that most of the time the lake was completely mixed vertically, and therefore the annual average mixing depth was assumed to be equal to the mean depth of the lake.

BATHTUB is a steady-state model; it is not usually appropriate in systems with significant year-to-year variations in lake volume such as those in Lake Denham (**Table 5.3**). Therefore, the department carried out a long-term simulation for the in-lake TN, TP, and chl *a* concentrations for Lake Denham instead of yearly simulations. To calculate the 80th percentile of the natural background condition, the department used the mean values of geometric means of 13 years as input data with the CV for the BATHTUB model.

METEOROLOGICAL DATA

The SJRWMD provided meteorological data. The daily rainfall estimates were developed from the NEXRAD Doppler rainfall coverage, which has a grid resolution of two square kilometers. The evaporation data were obtained from the Lisbon weather station. These data are not the pan evaporation estimates reported by the weather station. Rather, they are potential evapotranspiration (PET) estimates developed in the SJRWMD's Water Supply Impact Study. These estimates are based on the Hargreaves equation for water or normally saturated wetlands. **Table 5.4** lists annual rainfall and evaporation values for 2000 through 2012.

Table 5.4. Mean and CV of Annual Meteorological Data Used for BATHTUB Modeling, 2000–12

VALUE	ANNUAL RAINFALL (M/YR)	ANNUAL EVAPORATION (M/YR)
Mean	1.1353	1.3051
CV	0.0498	0.0084

AREAL ATMOSPHERIC NUTRIENT LOADINGS

One source of loading to Lake Denham is the TN and TP falling directly onto Lake Denham through atmospheric deposition. TN and TP concentrations of wet and dry depositions collected in Apopka, Florida, were obtained from the SJRWMD. Atmospheric wet depositions of TN and TP were calculated by multiplying the amount of precipitation directly falling on to the lake surface (calculated by multiplying annual precipitation by the surface area of the lake) by the TN and TP concentrations of the rainfall. Atmospheric dry depositions were calculated by the equation:

(concentration * sample volume) / (bucket collection area * exposure time)

To obtain total atmospheric loading, wet deposition values were added to dry deposition. **Table 5.5** lists the mean of the areal atmospheric deposition rate of TN and TP loadings for the modeling period from 2000 through 2012.

Table 5.5. Mean and CV of Annual Areal Atmosphere Nutrient Loadings to Lake Denham, 2000–12

in/yr = Inches per year; mg/m^2/y = Milligrams per square meter per year

VALUE	ANNUAL RAINFALL (IN/YR)	ANNUAL AVERAGE LAKE SURFACE (KM^2)	ATMOSPHERIC TP CONC. WET (MG/L)	ATMOSPHERIC TN CONC. WET (MG/L)	ATMOSPHERIC TP FLUX DRY (MG/M^2/Y)	ATMOSPHERIC TN FLUX DRY (MG/M^2/Y)	TOTAL AREAL ATMOSPHERIC LOAD FOR TP (MG/M^2/Y)	TOTAL AREAL ATMOSPHERIC LOAD FOR TN (MG/M^2/Y)
Mean	44.70	0.95	0.014	0.580	22	178	37	830
CV	0.05	0.01	0.088	0.046	0.13	0.08	0.11	0.05

MEASURED WATER QUALITY DATA (TN, TP, AND CHL *A* CONCENTRATIONS OF LAKE WATER)

TN, TP, and chl *a* concentrations for Lake Denham from 2000 to 2012 were retrieved for IWR Database Run_49. AGM values for TN, TP, and chl *a* were calculated each year and then long-term average AGM and CV were calculated. Corrected chl *a* values were used for the analysis. **Table 5.6** lists the long-term average AGM and CV of each parameter for Lake Denham from 2000 through 2012.

Table 5.6. Mean of Geometric Means and CV of Measured TN, TP, and Corrected Chl *a* Concentrations for Lake Denham, 2000–12 (Unit: Parts per billion [ppb])

VALUE	TN	TP	CHL *A*
Mean	2,856	95	73.3
CV	0.05	0.05	0.08

LOADING DATA (FLOW AND TN AND TP CONCENTRATIONS OF VARIOUS SOURCES IN THE WATERSHED)

BATHTUB does not allow the direct input of loading. Therefore, data presented here are flow (hm^3/yr), and TN and TP concentrations (ppb) in the watershed. TN and TP concentrations presented for each source were calculated by dividing TN and TP loadings by the flow from the watershed. Seepage into Lake Denham from the Floridan aquifer is possible because the potentiometric head of the Floridan aquifer is higher than the lake surface elevation in this area. The average of the Lake Denham annual mean stage was 62 feet NGVD (SJRWMD) during the modeling period, and the average potentiometric surface of the Floridan aquifer was 72 feet NGVD from 2009 to 2012 (SJRWMD GIS data). The seepage into Lake Denham from the Floridan aquifer was determined using an equation suggested by Keesecker (1992):

$$\text{Seepage flow rate} = \text{SeepageC} * (\text{PSURF} - \text{LDSTG}) * \text{days/year} * A * 0.001233$$

Where:

Seepage flow rate is the annual seepage from the Floridan aquifer (hm^3/yr).

SeepageC is the seepage coefficient (feet per day per foot [ft/day/ft] head difference between PSURF and STG).

PSURF is the average potentiometric surface of the Floridan aquifer (feet NGVD).

STG is the Lake Denham annual average stage (feet NGVD).

A is the annual average surface area for Lake Denham (acres).

0.001233 is the conversion factor from ac-ft/yr to hm^3/yr.

SeepageC (0.000025 ft/day/ft) was set at the median of the range of values given by Tibbals (1990, cited from Keesecker 1992). The seepage flow rate was calculated as 0.028 hm^3/yr. The department's Ground Water Management Section provided mean nutrient concentration (TP: 0.234 mg/L and TN: 0.913 mg/L) data for ground water, obtained from 17 waterbodies (21 wells) for TP and 19 waterbodies (24 wells) for TN in the Ocklawaha Basin. **Table 5.7** lists the mean and CV of the annual flow and nutrient concentrations from each major nonpoint source into Lake Denham from 2000 through 2012.

Table 5.7. Long-Term Mean and CV of Flow and TN and TP Concentrations into Lake Denham from Different Land Use Categories, 2000–12

* Indicates the discharge estimated for neighboring muck farm by Dr. R. Fulton of the SJRWMD. TN and TP concentrations were calculated by using TN and TP loading and the discharges.

LAND USE CATEGORY	FLOW MEAN (HM^3/YR)	FLOW CV	TN MEAN (PPB)	TN CV	TP MEAN (PPB)	TP CV
Low-density residential	0.071	0.110	1050	0.004	64	0.007
Medium-density residential	0.035	0.066	1827	0.000	178	0.000
High-density residential	0.106	0.063	1573	0.007	209	0.011
Low-density commercial	0.464	0.090	518	0.002	39	0.004
High-density commercial	0.400	0.065	1710	0.004	215	0.007
Industrial	0.099	0.056	1007	0.000	122	0.001
Mining	0.005	0.159	797	0.012	77	0.019
Open land/recreational	0.002	0.319	997	0.000	33	0.000
Pasture	0.129	0.200	2293	0.000	299	0.000
Cropland	0.147	0.193	4212	0.000	448	0.000
Tree crops	0.003	0.148	1896	0.000	97	0.000
Other agriculture	0.004	0.161	2620	0.000	366	0.000
Forest/rangeland	0.215	0.170	997	0.000	33	0.000
Water	0.217	0.059	372	0.000	7	0.000
Wetlands	11.059	0.055	1020	0.000	34	0.002
Ground water	0.028		913	0.36	234	0.44
Muck farms*	2.144	0.114	2621	0.004	233	0.016

5.2.2.2 Calibrating the BATHTUB Eutrophication Model

To calibrate the BATHTUB model, each land use identified in **Table 5.7** was entered into the BATHTUB model as an independent tributary. BATHTUB provides alternative models for estimating the influence of sedimentation on in-lake TN and TP concentrations (Walker 2004). In this analysis, the Settling Velocity Model was chosen for both TN and TP. This model assumes that the sedimentation of TN and TP follows first-order kinetics and should linearly correlate with in-lake TN and TP concentrations. The model also assumes that the depth of the lake influences sedimentation, *i.e.*, the deeper the lake, the slower the sedimentation.

This model fits the condition of Lake Denham, because the lake is relatively shallow. Continued wind mixing prevents the lake from forming thermal stratification, which would otherwise prevent the particles from being resuspended once they settled to the bottom. Continued wind mixing through the entire water column also reduces the particle-settling rate by bringing the settled particles back into the water column. These processes produce a relatively low net settling rate in the lake.

Other sedimentation models provided by BATHTUB assume second-order kinetics, which fit reasonably well with lakes that develop thermal stratification during the summer. However, these models would overestimate the net sedimentation in Lake Denham and in turn cause the in-lake TN and TP concentrations to be underestimated.

BATHTUB provides two chl *a* responding models based on the assumption of nitrogen and phosphorus colimitation: Model 1 and 3. Model 1 assumes that algal communities are not only limited by nutrients but also by light intensity. This model seemed to fit the situation for Lake Denham because the lake has high color, total suspended solids, and turbidity, all of which would be expected to lead to light limitation. BATHTUB allows the user to control the light limitation caused by suspended particles using the nonalgal turbidity function, which is calculated by chlorophyll and Secchi depth. The value for nonalgal turbidity used in this analysis was 0.8/m.

Calibration factors may be applied to fit TN and TP predictions to the measured data. In this analysis, the department adopted the calibration method, which calibrates decay rates, because wind mixing could significantly lower the sedimentation rate.

Table 5.8 show the simulations for in-lake TN, TP, and chl *a* concentrations with the mean of the AGM (2000–12) without any calibration and internal loads such as sediment nutrient flux and nitrogen fixation.

Table 5.8. Simulation Results for TN, TP, and Chl *a* Concentration Using the BATHTUB Model without Calibration (Unit: ppb)

VALUE	TN	TP	CHL *A*
Measured	2,856	95	73.3
Simulated	1,355	74	35.6

The model underestimated TN, TP, and chl *a* concentrations. There were large gaps between the model-simulated and the measured results in all the parameters.

Typical calibration factors for TN and TP recommended by the BATHTUB *User's Manual* are 0.5 to 2.0 for TP and 0.33 to 3.00 for TN. In this TMDL analysis, a default calibration factor of 1.0 was applied to the TN and TP calibrations because TN concentration was not sensitive to the change in calibration factor.

TN calibration was primarily conducted by applying internal load, assuming nitrogen fixation and nutrient flux from the sediment such that the BATHTUB-simulated TN concentrations matched up with the measured concentrations. Internal load was also applied for TP calibration, assuming the resuspension of orthophosphate from the bottom sediments. The following possibilities were examined to address the difference between the measured and model-simulated TN concentrations:

NUTRIENT FLUX FROM SEDIMENT

Iron cation exists in either the ferric form (Fe3+) or ferrous form (Fe2+). When combined with phosphate, the ferric form is highly insoluble and tends to settle to the bottom. In contrast, the ferrous-phosphate compound is very soluble and tends to re-enter the water column. Ferric exists in large amounts under aerobic conditions, while ferrous dominates the ferric-ferrous system under anaerobic conditions. Therefore, when redox potential increases in the aerobic condition, ferric will dominate and combine with phosphate into insoluble compounds and settle down to the sediment. On the other hand, when redox potential is decreased in the sediments (anaerobic condition), ferrous will increase, resulting in the release of ferrous ion and phosphate back to the water column (Olila and Reddy 1997; Reddy and DeLaune 2008). Lake Denham is shallow and would be subject to resuspension from bottom sediments by wind that would add nutrients to the water column.

POSSIBLE NITROGEN LOADINGS (NITROGEN FIXATION) CREATED INSIDE THE LAKE

Algal Composition

As shown in **Table 5.8**, the model-simulated TN concentrations were significantly lower than the measured in-lake concentrations. It is possible that nitrogen fixation in the lake caused the observed difference between simulated and measured data. Many studies have documented the importance of nitrogen fixation in eutrophic lakes (Ashton 1981; Horne and Goldman 1972; Keirn and Brezonik 1971). Up to 82% of the TN loading into eutrophic lakes could come from nitrogen fixation (Howarth *et al.* 1988). In freshwater lakes, blue-green algae, especially filamentous blue-green algae with a heterocystic structure, appear to be the most important organisms in nitrogen fixation (Stewart 1969), although nitrogen fixation by other photosynthetic or heterotrophic bacteria has also been documented (Hill 1992; Keirn and Brezonik 1971). The rates of nitrogen fixation are reasonably correlated with the biomass of nitrogen-fixing blue-green algae (Goldman and Horne 1983; Wetzel 1983). The major blue-green algal taxa capable of fixing nitrogen include *Anabaena, Anabaenopsis*, *Aphanizomenon, Nodularia, Cylindrospermopsis*, and benthic *Lyngbya*.

According to data from the SJRWMD, the total cell biovolume for these nitrogen-fixing taxa accounted for about 3 to 82% of the total algal community in Lake Denham, averaging 48.5% on an annual basis (**Table 5.10**). The annual average cell biovolume for nitrogen-fixing blue-green algae ranged from 0.43 $\times 10^6$ cubic micrometers per milliliter ($\mu m^3/mL$) to 4.93×10^7 $\mu m^3/mL$ and averaged 1.9×10^7 $\mu m^3/mL$ from 2000 to 2012. *Cylindrospermopsis raciborskii* dominated the algal community in Lake Denham, occupying about 47% of total algal cell biovolume.

The department also conducted an algal community survey on August 6, 2013, during an intensive field survey, and identified two major nitrogen-fixing blue-green algae, *Aphanizomenon* and *Cylindrospermopsis*. In this survey, *Aphanizomenon* dominated the algal community in Lake Denham, representing about 31% of the total algal cell biovolume, while *Cylindrospermopsis* accounted for 25%. These data support the high possibility of nitrogen fixation in Lake Denham.

DIN:DIP Ratio

The critical condition that triggers nitrogen fixation by blue-green algae is when the molar ratio between dissolved inorganic nitrogen (DIN) (including ammonia [NH_4] and nitrate-nitrite [NO_3/NO_2]) and dissolved inorganic phosphorus (DIP) (primarily phosphate) is lower than the Redfield ratio of 16:1 (Flett *et al.* 1980).

No directly measured data on nitrogen fixation specific to Lake Denham were available when this TMDL analysis was carried out. However, measured DIN (including nitrate/nitrite and ammonia) and DIP (mainly phosphate) from the IWR database indicated that the annual DIN:DIP molar ratio in Lake Denham was about 10 when used long-term geometric mean from 2000 through 2012 (**Table 5.9**). This low DIN:DIP ratio (below the Redfield ratio of 16 : 1) suggested the necessary condition that can trigger nitrogen fixation existed in Lake Denham.

Table 5.9. Long-Term DIN:DIP Ratio of Lake Denham, 2000–12

PARAMETER	LONG-TERM GEOMETRIC MEAN
DIN (µM)	4.06
DIP (µM)	0.40
Ratio	10

Table 5.10. Long-Term Mean Percentage of Nitrogen-Fixing Blue-Green Algae in Lake Denham, 2000–12

VALUE	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Annual Mean (%)	67%	3%	28%	58%	42%	76%	82%	33%	27%	65%	69%	68%	57%

TN Concentration Difference between Inflow and In-Lake

Another piece of evidence that is consistent with the nitrogen fixation hypothesis for the observed difference between the model-simulated TN concentration and the measured TN concentration is the difference between inflow TN concentrations and Lake Denham TN concentrations (**Table 5.11**). During the intensive survey (August 5, 2013), the TN concentration of the muck farm inlet stream to Lake Denham (inflow) was 2.00 mg/L, while the in-lake TN concentration was about 2.80 mg/L. On this day, the inflow TN concentration was lower than the in-lake TN concentration, suggesting that a portion of the TN load to the lake is likely created in the lake due to nitrogen fixation.

Table 5.11. Comparison of TN and TP Concentrations between Inflow and Lake Denham

SAMPLING LOCATION	SAMPLING PERIOD	TN (MG/L)	TP (MG/L)
Lake Denham	2000–13	2.94 (n=242)	0.10 (n=237)
Muck Farm Inlet Stream Intensive Survey	8/6/2013	2.00 (n=1)	0.36 (n=1)
Lake Denham (center) Intensive Survey	8/6/2013	2.80 (n=1)	0.07 (n=1)

5.2.2.3 BATHTUB Simulation

Table 5.12 shows the measured and BATHTUB-simulated TN, TP, and chl *a* concentrations. The BATHTUB model was calibrated using the measured concentrations, which are the long-term annual AGMs of TN, TP, and chl *a* concentrations measured from 2000 to 2012. The model-simulated TN and TP concentrations were consistent with the measured TN and TP concentrations because those concentrations were calibrated by applying internal loading rates. The internal loading rates assuming sediment nutrient flux and nitrogen fixation, as mentioned above, were entered into the BATHTUB model to match the model-simulated TN concentration and the measured TN concentration. The internal load rates required to balance the model results were 64.8 milligrams per square meter per day (mg/m^2/day) and 0.94 mg/m^2/day for TN and TP, respectively.

Although TN and TP conditions were calibrated by using internal load rates, the model still underestimated chl *a* concentrations. Therefore, a calibration factor of 1.42 was applied for the chl *a* simulation.

Table 5.12. Long-Term BATHTUB Calibration and Simulation Results

PARAMETER	MEASURED	CV	SIMULATED	CV
TN (mg/L)	2.86	0.05	2.86	0.03
TP (mg/L)	0.10	0.05	0.10	0.04
Chl *a* (µg/L)	73.3	0.08	73.3	0.27

TN AND TP LOADINGS FROM VARIOUS SOURCES

According to **Table 5.13**, the total TP loading from various sources to Lake Denham was 1,504 kg/yr. TP loading from surface runoff was 1,136 kg/yr, accounting for 76% of total TP loading. The TP internal load was 326 kg/yr, accounting for 22% of the total load. Atmospheric deposition to the Lake Denham water surface was 35 kg/yr and represented about 2% of total TP loading. TP loading from the Floridan aquifer was 7 kg/yr, representing less than about 0.1% of total TP loads.

Based on **Table 5.14**, annual TN loading from various sources to Lake Denham was 42,755 kg/yr. The internal load was separated into two components: internal load released from bottom sediment and nitrogen fixation. The bottom sediment internal load was estimated using the release rate of ammonia: phosphate from the sediments, or 4.6:1 (Fillos and Swanson 1975). Nitrogen fixation was the largest nitrogen loading source in Lake Denham and reached 20,993 kg/yr, accounting for 49% of the total TN load. Surface runoff, the second largest source, accounted for 46% of total TN loading. The TN internal load released from bottom sediment was 1,492 kg/yr, accounting for 3%. Atmospheric deposition to the Lake Denham water surface was 789 kg/yr and represented 2% of total TN loading on average. TN loading from the Floridan aquifer was 26 kg/yr, representing less than 0.1% of the total TN load.

Table 5.13. Long-Term Mean Annual TP Loads (kg/yr) from Different Sources into Lake Denham, 2000–12

VALUE	ATMOSPHERIC DEPOSITION	SURFACE RUNOFF	FLORIDAN AQUIFER	INTERNAL LOAD (SEDIMENT)	TOTAL
Long-Term Mean Annual	35	1,136	7	326	1,504
TOTAL LOADS (%)	**2%**	**76%**	**0%**	**22%**	**100%**

Table 5.14. Long-Term Mean Annual TN Loads (kg/yr) from Different Sources into Lake Denham, 2000–12

VALUE	ATMOSPHERIC DEPOSITION	SURFACE RUNOFF	FLORIDAN AQUIFER	INTERNAL LOAD (SEDIMENT)	NITROGEN FIXATION	TOTAL
Long-Term Mean Annual	789	19,455	26	1,492	20,993	42,755
TOTAL LOAD (%)	**2%**	**46%**	**0%**	**3%**	**49%**	**100%**

EVALUATION OF INFLUENCE FROM INTERNAL LOADING OF LAKE DENHAM

Sensitivity analyses were conducted to evaluate the influence of internal loads on water column nutrient concentrations. Changes in in-lake nutrient concentrations were examined by comparing the existing condition simulation with the simulation when the internal loads were completely eliminated. All the calibrated model parameters were kept the same as the existing scenario, except that the internal loads for TN and TP were reset to 0. **Table 5.15** lists the model-estimated TN, TP, and chl *a* concentrations with and without internal loads. As the table shows, by completely removing the TN and TP internal loads, the TN concentration in the lake was reduced by 53%, TP by 22%, and chl *a* by 31%.

Table 5.15. TN, TP, and Chl *a* Values after Internal Loading Was Eliminated

EXISTING CONDITION TP (MG/L)	EXISTING CONDITION TN (MG/L)	EXISTING CONDITION CHL *A* (µG/L)	INTERNAL LOAD ELIMINATED TP (MG/L)	INTERNAL LOAD ELIMINATED TN (MG/L)	INTERNAL LOAD ELIMINATED CHL *A* (µG/L)
0.10	2.86	73.3	0.07	1.36	50.6

EVALUATING THE NATURAL BACKGROUND CONDITION OF LAKE DENHAM

The natural background TN and TP loadings were estimated using the following procedures:

a. The loadings from internal loads and nitrogen fixation were completely removed.

b. All the human land use categories (urban open, agricultural, low-density residential, and transportation and communication) in the watershed were converted to natural lands such as forest/rangeland or wetland. In order to allocate existing human land uses into either forest or wetland areas, **Table 5.16** was used to determine the hydrologic soil group compositions in human land use areas. Because these areas in the Lake Denham watershed are dominated by Soil Types A and B, which are mostly considered forest soil, those were converted to forest/rangeland when simulating the natural background condition.

c. TN and TP loadings from atmospheric direct deposition and from seepage into Lake Denham from the Floridan aquifer were maintained the same.

d. The flow and TN and TP concentrations of surface runoff from forest/rangeland, water, and wetlands were entered into BATHTUB to estimate the in-lake TN, TP, and chl *a* background concentrations.

Table 5.16 lists the acreage and percentage of different soil types for human land use areas in the watershed.

Table 5.16. Soils Type Distribution for Human Land Use Areas in the Lake Denham Watershed

SOIL HYDROLOGIC GROUP	ACREAGE	ACREAGE (%)
A	1,219.3	51.8%
B	214.5	9.1%
C	15.0	0.6%
D	197.6	8.4%
D (A/D)	548.6	23.3%
D (B/D)	139.3	5.9%
D (C/D)	19.0	0.8%
D(X)	2.2	0.1%
TOTAL	**2,355.5**	**100%**

Table 5.17 lists the resulting TN, TP, and chl *a* concentrations. As shown **in the table, the** long-term annual AGMs of TN, TP, and chl *a* concentrations decreased from the existing condition of 2.86 mg/L, 0.10 mg/L, and 73.3 µg/L to the natural background condition of 1.07 mg/L, 0.03 mg/L, and 24.5 µg/L, respectively. This represents a 63% decrease in TN, a 64% decrease in TP, and a 67% decrease in chl *a* concentrations from the existing condition.

Table 5.17. Long-Term Average Annual Background Condition and the 80th Percentile of the Background Condition: TN, TP, and Chl *a* Concentrations

VALUE	TN (MG/L)	TP (MG/L)	CHL *A* (µG/L)
Background Condition	1.07	0.03	24.5
CV	0.01	0.03	0.27
80th Percentile	1.10	0.04	

The 80th percentile of the natural background condition, which was calculated using the mean and CV (see the equation in **Chapter 3**), was used to establish the target TN and TP concentrations (1.10 and 0.04 mg/L, respectively) (**Table 5.17**). The target TN and TP loadings for Lake Denham were estimated by adding the nutrient loads to the human land use areas of the natural background condition in an iterative manner until the TN and TP concentrations in Lake Denham were achieved. The TN and TP loads that result in the target in-lake TN and TP concentrations are the TMDLs for Lake Denham. The chl *a* concentration resulting from the target TN and TP loads is 26.8 µg/L (**Table 5.18**).

Table 5.18. Annual Target Condition for TN, TP, and Chl *a* Concentrations

TP (MG/L)	TN (MG/L)	CHL *A* (µG/L)
0.04	1.10	26.8

The target TN concentration was evaluated to see if there would be residual nitrogen fixation using the following regression equation developed between the nitrogen fixation rate and chl *a* concentration in the Lake Jesup TMDL report (Gao 2006): Nitrogen fixation rate = 0.307* Chl *a* conc. - 8.721. According to the equation, when chl *a* concentration is 28.4 µg/L or less, the nitrogen fixation rate should be zero. Therefore, there was no remaining nitrogen fixation rate when the chl *a* target concentration of 26.8 µg/L is applied.

Table 5.19 lists the TN and TP target loadings from major sources to Lake Denham during the period of this analysis. **Table 5.20** lists the annual TN and TP load reductions required to achieve the water quality target, the TMDLs for TN and TP, and the long-term average annual load reductions required to achieve the TMDLs.

The long-term average annual loadings to Lake Denham were 42,755 kg/yr for TN and 1,504 kg/yr for TP under the existing condition. These loadings result in a long-term average AGM for chl *a* of 73.3 µg/L. To achieve the target TN and TP concentrations, the long-term average annual loadings need to be 16,468 kg/yr for TN and 593 kg/yr for TP, which represent a 61% reduction of both TN and TP loadings from the existing condition (**Table 5.20)**.

It should be noted that the TN loading from nitrogen fixation will decrease along with the TP loading from the watershed because (1) the overall decrease of nutrient loading will decrease the biomass of nitrogen-fixers, and thus the nitrogen loads through nitrogen fixation will decrease, and (2) the decrease of TP loading into the system may make the system less nitrogen limited. Likewise, the TN and TP internal loadings from bottom sediments will decrease over time in response to the reduction of the TN and TP loadings. A decrease in watershed nutrient loading will decrease the overall biomass of phytoplankton in the lake, which will in turn decrease nutrients and organic matter accumulating in the sediment. This will reduce the potential for sediment nutrient flux.

Table 5.19. Target Annual TN and TP Loads from Different Sources into Lake Denham (kg/yr)

PARAMETER	ATMOSPHERIC DEPOSITION	SURFACE RUNOFF	FLORIDAN AQUIFER	TOTAL
TN	789	15,653	26	16,468
TP	35	551	7	593

Table 5.20. Annual TN and TP Load Reductions Required To Achieve the Water Quality Target for Lake Denham (kg/yr)

PARAMETER	EXISTING LOADING	TARGET LOADING	REQUIRED LOAD REDUCTION	REQUIRED LOAD REDUCTION (%)
TN	42,755	16,468	26,287	61%
TP	1,504	593	911	61%

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

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

$$\text{TMDL} = \sum \square\text{WLAs} + \sum \square\text{LAs} + \text{MOS}$$

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

This approach is consistent with federal regulations (40 Code of Federal Regulations § 130.2[I]), which state that TMDLs can be expressed in terms of mass per time (*e.g.*, pounds per day), toxicity, or other appropriate measure. The TMDLs for Lake Denham are expressed in terms of kilograms per year (kg/yr) and percent reduction of TN and TP, and represent the maximum long-term annual average TN and TP loadings that the lake can assimilate and maintain a balanced aquatic flora and fauna (**Table 6.1**).

Based on an EPA memorandum (2006), daily loads of TN and TP from point and nonpoint sources were also calculated. These daily loads were calculated by dividing the annual loads by 365 days/yr and are only provided in this report for informational purposes. The implementation of the TMDLs in this report should be carried out using an annual time scale.

Table 6.1. TMDL Components for Nutrients in Lake Denham (WBID 2832A)

N/A = Not applicable
Note: The daily loading targets for TN and TP are 45.1 and 1.6 kg/day, respectively.
* The required percent reductions shown 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	WLA WASTEWATER (KG/YR)	WLA* STORMWATER (% REDUCTION)	LA* (% REDUCTION)	TMDL (KG/YR)	MOS
2832A	TN	N/A	61%	61%	16,468	Implicit
2832A	TP	N/A	61%	61%	593	Implicit

6.2 Load Allocation

To achieve the LA requires a 61% reduction in current TN and TP loadings. The load reduction needs to apply to surface runoff and nitrogen fixation for TN. It should be noted that the load reduction for nitrogen fixation and internal loads is associated with the watershed load reduction. As long as nutrient loadings from human nonpoint sources are reduced, the nutrient loading from nitrogen fixation and internal recycling should decrease as well. The department estimates that when TP is reduced by 61%, phytoplankton biomass will decrease, and in turn nitrogen fixation and internal recycling rates will be reduced to background natural conditions.

6.3 Wasteload Allocation

6.3.1 NPDES Discharges

No NPDES-permitted wastewater discharges were identified in the Lake Denham watershed.

6.3.2 NPDES Stormwater Discharges

Within the Lake Denham watershed, the stormwater collection systems owned and operated by Lake County and the city of Leesburg are covered by an NPDES MS4 Phase II permit (FLR04E106 and FLR04E110, respectively). The areas within their jurisdiction in the Lake Denham watershed may be responsible for a 61% reduction of both TN and TP from current anthropogenic loading. 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.

6.4 Margin of Safety

TMDLs must address uncertainty issues by incorporating an 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 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 (Department 2001), an implicit MOS was used in the development of the Lake Denham TMDLs. The implicit MOS was used because the TMDLs were based on the conservative decisions associated with a number of the modeling assumptions in determining the assimilative capacity (*i.e.*, loading and water quality response) for Lake Denham.

Chapter 7: TMDL IMPLEMENTATION

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 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 TMDL. NPDES permits are required for Phase I and Phase II MS4s as well as domestic and industrial wastewater facilities. MS4 Phase I permits require that a permit holder prioritize and take action to address a TMDL unless management actions are already defined in a BMAP. MS4 Phase II permit holders must also implement responsibilities defined in a BMAP.

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 applicable through existing water quality protection programs. The department or a local entity may develop a BMAP that addresses some or all of the contributing areas to the TMDL waterbody.

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

BMAPs describe the management strategies that will be implemented, funding strategies, project tracking mechanisms, and water quality monitoring, as well as fair and equitable allocations of pollution reduction responsibilities to the sources in the watershed. They 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 the pollutant 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 department's website.

7.3 Implementation Considerations for Lake Denham

A BMAP is already adopted for the Upper Ocklawaha River Basin that includes Lake Harris (the downstream receiving water). Because of the relation between Lake Denham and Lake Harris, it may be appropriate to include Lake Denham's restoration efforts in the Upper Ocklawaha BMAP.

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Appendices

Appendix A: Summary of Information in Support of Site-Specific Interpretations of the Narrative Nutrient Criterion for Lake Denham

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

LOCATION	DESCRIPTIVE INFORMATION
Waterbody name	Lake Denham
Waterbody type(s)	Lake
Waterbody ID (WBID)	WBID 2832A (see **Figure 1.1**)
Description	Lake Denham is located in Lake County, Florida. The estimated average surface area of the lake is 250 acres, with a normal pool volume of 828 acre/feet (ac/ft) and an average depth of 3.5 feet. Lake Denham receives runoff from a watershed area of 6,641 acres occupied by wetlands, urban lands, agriculture, and forest/rangeland. The lake water flows about two miles easterly to Lake Harris through Helena Run. Lake Denham is characterized by high nutrients, high chl *a* concentration, and low transparency.
Specific location (latitude/longitude or river miles)	The center of Lake Denham is located at latitude N: 28^{o}46'02" longitude W: -81^{o}54'25".
Map	**Figures 4.1a** and **4.1b** show the general location of Lake Denham and its watershed and land uses in the watershed, respectively, in 2004 and 2009. These land uses in 2009 include wetlands (51.8%), agriculture (21.4%), urban and residential (14.1%), and forest/rangeland (11.9%).
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	Lake Denham is a high-color lake, and the default NNC, expressed as AGM concentrations not to be exceeded more than once in any three-year period, are chl *a* of 20 µg/L, TN of 1.27 – 2.23 mg/L, and TP of 0.05 – 0.16 mg/L.
Proposed TN, TP, chl *a*, and/or nitrate+nitrite (magnitude, duration, and frequency)	Numeric Interpretations of the Narrative Nutrient Criterion: This TMDL is modifying the default NNC for TN, TP and chl *a*. The revised TN and TP NNC are expressed as long-term loads, and the revised chl *a* is expressed as a long-term concentration. Specifically, the TN load of 16,468 kg/yr and TP load of593 kg/yr, are both expressed as long-term (7 year) averages of annual loads, not to be exceeded. These loadings were derived from watershed and receiving water modeling (which revealed that the chl *a* concentration of the model simulated natural background condition was higher than the default criterion) and resulted in the revised H1 AGM chl *a* concentration of 26.8 µg/L, not to be exceeded. For assessment purposes, the long-term annual loads will be calculated using the annual loads of the most recent 7 years in the Verified Period. Chl *a* will be assessed in accordance with Rule 62-303.350, F.A.C. This approach establishes lake-specific NNC that is more representative of natural conditions in the lake than the generally applicable TN, TP and chl *a* NNC. The TMDL loads and the chl *a* concentration will be considered as site-specific interpretation of the narrative criterion.
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 the IWR database (IWR Run_49), rainfall and evapotranspiration data, and lake stage data for 2000–12 obtained from the SJRWMD. Land use data from two years were used to establish watershed nutrient loads. For the 2000–05 simulation period, the SJRWMD's 2004 land use was used. For the 2006–12 period, the SJRWMD's 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 this period, total annual average rainfall varied from 26.4 to 54.8 inches and averaged 44.7 inches. A comparison with long-term average rainfall data indicated that 2000 and 2006 were dry years, while 2002, 2004, 2005, and 2009 were 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 square 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 nutrients and chl *a* concentrations. In addition, model calibration for the Lake Denham TMDLs was based on water quality data collected across the lake. **Figure 5.1** shows the water quality sampling stations used in the Lake Denham model calibration process. These stations are located across the entire lake and properly represent the spatial distribution of nutrient dynamics in the lake.

Table A-3. History of Nutrient Impairment, Quantitative Indicator of Designated 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	The department used the IWR to assess water quality for Lake Denham. The lake was initially verified as impaired for nutrients during the Cycle 1 assessment (verified period January 1, 1995, through June 30, 2002) using the methodology in the IWR (Chapter 62-303, F.A.C.), and was included on the Cycle 1 Verified List of impaired waters for the Ocklawaha River Basin adopted by Secretarial Order on August 28, 2002. Subsequently, the nutrient impairment was confirmed in the Cycle 2 assessment (January 1, 2000, through June 30, 2007) and the Cycle 3 assessment (January 1, 2005, through June 30, 2012) based on the fact that the annual average TSI values of the lake exceeded 40 or 60 every year depending on the lake color. The department also assessed water quality in Lake Denham using the adopted NNC. The results confirmed that Lake Denham is impaired for nutrients. The number of chl *a* samples available for Lake Denham for 2000 to 2012 met the data sufficiency requirements of Subsection 62-302.531(6), F.A.C. These chl *a* data show that all 13 years had sufficient data for calculating the chl *a* AGMs. In all 13 years, the chl *a* AGM concentrations exceeded the 20 µg/L NNC.
Basis for use support	Water quality targets for the TMDL were based on estimates of natural background conditions, which are inherently protective of designated uses.
Summarize approach used to develop criteria and how it protects uses	For the Lake Denham nutrient TMDLs, the department established the TN and TP target concentrations using the 80th percentile of the model-simulated natural background condition. To estimate natural background conditions, the department used the BATHTUB model in which all human land uses were converted to natural land use (forest/rangeland) and all the internal loads and nitrogen fixation loads were eliminated. The 80th percentile of the natural background concentrations of TN and TP (1.10 mg/L for TN and 0.04 mg/L for TP) were established as the TMDL target. At the 80th percentile of the natural background TN and TP concentrations, the model-simulated in-lake chl *a* concentration was 26.8 µg/L. The TN and TP TMDLs were set at the loads that attained the target TN and TP concentrations, and these loads, along with the target chl *a* concentration, constitute the site-specific interpretations of the narrative nutrient criterion for Lake Denham. Because the nutrient targets for these TMDLs are based on natural background condition, the TMDLs and resultant NNC are considered protective of designated uses. In addition, choosing the 80th percentile of TN and TP concentrations of unimpacted condition is consistent with the methods used in developing the Florida NNC as well as the EPA recommendation to set nutrient concentration targets based on the reference condition.
Discuss how the TMDLs will ensure that nutrient-related parameters are attained to demonstrate that the TMDLs 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 TMDLs, it should be clear that further reductions may be required in the future.**	The department notes that no other impairments were verified for Lake Denham that may be related to nutrients (such as dissolved oxygen [DO] or unionized 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 the 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	Lake Denham drains to Lake Harris. A TP TMDL already developed for Lake Harris requires a 32% reduction from the watershed area that includes the Lake Denham watershed. The Lake Denham TP TMDL will protect the water quality of Lake Harris, because the TP reduction for Lake Denham (61%) is higher than that required for Lake Harris. No TN reduction is needed for the Lake Harris nutrient TMDL. The proposed TN TMDL for Lake Denham that requires a 61% reduction of TN will provide further protection to downstream Lake Harris. The higher percent TP reduction requirement and the TN loading reduction for Lake Denham are more stringent than the nutrient reduction requirement to achieve the Lake Harris nutrient TMDL, and therefore will further improve water quality in Lake Harris.
Provide summary of existing monitoring and assessment related to implementation of Subsection 62-302.531(4), F.A.C., and trends tests in Chapter 62-303, F.A.C.	Water quality data were collected in Lake Denham and the downstream water (Lake Harris) by the department, Lake County, LakeWatch, and SJRWMD. 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. The department, Lake County, LakeWatch, and the SJRWMD will continue to carry out monitoring activities in Lake Denham to evaluate future water quality trends in the lake.

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

ADMINISTRATIVE REQUIREMENTS	DESCRIPTION
Notice and comment notifications	The department held two public workshops on February 17, 2015, and July 19, 2016 in Lady Lake, Florida, to present the TMDL development approach and draft Lake Denham TMDLs to local stakeholders. The department announced these workshops through notices published in the *Florida Administrative Register* (FAR), TMDL workshop announcements on the department's TMDL homepage and Sharepoint website, advertisements in a local newspaper, and email notices to all interested parties. Before the workshops, draft TMDL reports were provided to stakeholders for review and comments. A 30-day public comment period for the first workshop and a 14-day public comment period for the second were provided to stakeholders for the workshop events. After these public comment periods ended, the public comments received by DEP were carefully reviewed to determine whether significant revisions to the TMDL were needed. So far, all public comments on the Lake Weir TMDLs have been addressed. Once the department reaches an agreement with the EPA on the target-setting language in the TMDL report, the department will publish a Notice of Proposed Rule (NPR) to initiate the TMDL rule adoption process.
Hearing requirements and adoption format used; responsiveness summary	Following the publication of the NPR, the department will provide a 21-day challenge period.
Official submittal to the EPA for review and GC certification	If the department does not receive a challenge, the certification package for the rule will be prepared by the department's program attorney. At the same time, the department 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, the department's stormwater treatment requirements were integrated with the stormwater flood control requirements of the water management districts, along with wetland protection requirements, into the Environmental Resource Permit (ERP) regulations, as authorized under Part IV of Chapter 373, F.S.

Chapter 62-40, F.A.C., also requires the state's water management districts to establish stormwater PLRGs and adopt them as part of a Surface Water Improvement and Management (SWIM) plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, they have been established for Tampa Bay, Lake Thonotosassa, the Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka.

In 1987, the United States 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 to address, stormwater discharges associated with industrial activity, which includes eleven categories of industrial activity, construction activities disturbing five or more acres of land, and "large" and "medium" MS4s located in incorporated places and counties with populations of 100,000 or more. However, because the master drainage systems of most local governments in Florida are physically interconnected, the EPA implemented Phase I of the MS4 permitting program on a countywide basis, which brought in all cities (incorporated areas), Chapter 298 special districts; community development districts, water control districts, and FDOT throughout the 15 counties meeting the population criteria. The department received authorization to implement the NPDES Stormwater Program in 2000. The department authority to administer the program is set forth in section 403.0885 F.S.

Phase II NPDES stormwater program, promulgated in1999, addresses additional sources, including small MS4s and small construction activities disturbing between one and five acres, and urbanized area serving a minimum resident population of at least 1,000 individuals. While these urban stormwater discharges are 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 Phase I 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: Lookup Table for Converting the Land Use Types in This Report from FLUCCS Code

NUMBER	LAND USE TYPE	FLUCCS CODE
1	Low-density residential	1100-1199
2	Medium-density residential	1200-1299
3	High-density residential	1300-1399
4	Low-density commercial/institutional	1700-1799, 1830, 1840, 8200-8999
5	High-density commercial	1400-1499, except 1480, 8100-8199
6	Industrial	1500-1599
7	Mining	1600-1699
8	Open land/recreational	1480, 1800,1810, 1850, 1890,1900-1999, 7000-7999
9	Pasture	2110-2139, 2500 (horse farm), 2510
10	Cropland	2140-2169, 2600-2619
11	Tree crops	2200-2290, except 2240
12	Feeding operations	2300-2399, 2500, 2522
13	Other agriculture	1820, 2400-2499, 2540
14	Forest/rangeland	3000-3999, 4000-4999, 2240
15	Water	5000-5999
16	Wetlands	6000-6999
17	Spray fields	
18	Muck farms and restoration areas	
19	Lakes	

Appendix D. Estimating the Runoff Volume and Nutrient Loads from the Lake Denham Watershed

A. NRCS's Curve Number Approach

The stormwater runoff volume for this TMDL was estimated using the same spreadsheet model created by SJRWMD (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 the runoff coefficient is decided, the runoff volume can be calculated as the product of rainfall, runoff coefficient, and acreage of the land use–soil type combination.

The SJRWMD's runoff volume spreadsheet model was built based on a 16-land use classification system. Each land use was associated with four soil hydrologic groups (Types A, B, C, and D). This gives a total of 68 land use–soil type combinations. To calculate the runoff volume for the entire Lake Denham watershed and, at the same time, be able to quantify the runoff contribution from each land use area, the runoff coefficient for each land use–soil type combination needs to be estimated. The SJRWMD's runoff model achieved this goal by estimating a watershed-basin average stormwater runoff coefficient ($ASRC_{wb}$) first, and then derived the runoff coefficient for land use–soil type combination.

The NRCS's curve number approach estimates the runoff volume from a given land surface using **Equation 1**:

$$Q = \frac{\left(P - 0.2 * S\right)^2}{P + 0.8 * S} \qquad \textbf{Equation 1}$$

Where,

Q is the runoff volume (cm).

P is the rainfall amount (cm).

S is the potential soil storage (cm), which can be calculated using **Equation 2**:

$$S = \frac{2540}{CN} - 25.4 \qquad \textbf{Equation 2}$$

Where,

CN is the curve number.

The curve number is a dimensionless value ranging from 0 to 100. It is used in the runoff equation to characterize the runoff potential for different land use–soil combinations. Specific curve numbers are assigned to different combinations. In addition, curve numbers are influenced by the antecedent moisture condition (AMC) of the soil. **Table D-1** lists the curve numbers used in developing these TMDLs. These numbers were cited in Suphunvorranop (1985) and were also used by the SJRWMD in developing the nutrient PLRG for the Upper Ocklawaha Chain of Lakes.

The curve numbers listed in **Table D-1** are established for the average soil AMC, which is commonly referred to as AMC II. The low and high soil AMCs are usually referred to as AMC I and AMC III, respectively. In the curve number approach, the soil AMC status is judged by comparing the total amount of rainfall a given watershed area received for the total of five days with a set of five-day threshold rainfall values in either the dormant season or the growth season. **Table D-2** lists the five-day threshold rainfall values used to determine the soil AMC for these TMDLs. **Table D-3** lists the curve numbers under the AMC I and AMC III corresponding to each curve number value under the AMC II condition.

Table D-1. Curve Numbers by Hydrologic Soil Groups and Land Use Types

LAND USE	SOIL GROUP A	SOIL GROUP B	SOIL GROUP C	SOIL GROUP D
Low-density residential	51	68	79	84
Medium-density residential	57	72	81	86
High-density residential	77	85	90	92
Low-density commercial	77	85	90	92
High-density commercial	89	92	94	95
Industrial	81	88	91	95
Mining	32	58	72	79
Open land/recreational	49	69	79	84
Pasture	47	67	81	88
Cropland	64	75	82	84
Tree crops	32	58	72	79
Other agriculture	59	74	82	86
Forest/rangeland	36	60	73	79
Water	98	98	98	98
Wetlands	89	89	89	89
Muck farms	70	81	86	90

Table D-2. Threshold Five-Day Antecedent Rainfall Volume (cm) for AMC Classification

SOIL AMC CLASSIFICATION	DORMANT SEASON (NOVEMBER–MARCH)	GROWTH SEASON (APRIL–OCTOBER)
I	< 1.3	< 3.6
II	– 2.8	3.6 – 5.3
III	> 2.8	> 5.4

Table D-3. Relationship between Curve Numbers under AMCs I, II, and III

AMC I	AMC II	AMC III
0	0	0
2	5	17
4	10	26
7	15	33
9	20	39
12	25	45
15	30	50
19	35	55
23	40	60
27	45	65
31	50	70
35	55	75
40	60	79
45	65	83
51	70	87
57	75	91
63	80	94
70	85	97
78	90	98
87	95	99
100	100	100

One common practice to calculate runoff volume from a given watershed using the curve number approach is to calculate the runoff from the pervious area and impervious area, and then add the runoff volumes from these two areas together to determine total watershed runoff. To apply this method, the impervious areas are usually divided into two types: directly connected impervious area (DCIA) and non-directly connected impervious area (NDCIA). The DCIA represents the areas that are directly connected to the stormwater drainage system. It is typically assumed that about 90% of the rainfall that falls on the DCIA will become runoff.

In contrast, the runoff created from the NDCIA will reach the pervious area and contributes to the pervious area runoff. Therefore, the NDCIA typically is not considered a part of the impervious area. Instead, it is usually considered a part of the pervious area. **Table D-4** lists the percent areas occupied by DCIA, NDCIA, and pervious areas for each land use type used in developing these TMDLs. The SJRWMD used these percent area values in developing the nutrient PLRG for the Upper Ocklawaha Chain of Lakes. The values included in **Table D-4** were assembled by Camp Dresser and McKee (CDM) (1994).

The total runoff from a watershed can be represented using **Equation 3**:

$$Q = Q_{Pervious} + Q_{DCIA} \qquad \textbf{Equation 3}$$

Where,

Q is the total runoff from the watershed area (cm).

$Q_{Pervious}$ is the runoff from the pervious area (cm).

Q_{DCIA} is the runoff from the DCIA (cm).

Table D-4. Land Use–Specific Percent DCIA, NDCIA, and Pervious Areas

Note: This table was cited from the SJRWMD's nutrient PLRG for the Upper Ocklawaha River Basin. Data were assembled by CDM (1994).

LAND USE	DCIA	NDCIA	PERVIOUS	SUM OF NDCIA AND PERVIOUS
Low-density residential	5	10	85	95
Medium-density residential	15	20	65	85
High-density residential	25	40	35	75
Low-density commercial	40	40	20	60
High-density commercial	45	35	20	55
Industrial	50	30	20	50
Mining	1	1	98	99
Open land/recreational	1	1	98	99
Pasture	1	1	98	99
Cropland	1	1	98	99
Tree crops	1	1	98	99
Other agriculture	1	1	98	99
Forest/rangeland	1	1	98	99
Water	85	15	0	15
Wetland	75	0	25	25
Muck farms	2	2	96	98

The Q_{DCIA} can be calculated using **Equation 4**:

$$Q_{DCIA} = P * 0.9 * \left(\frac{DCIA}{TotalArea}\right) \qquad \textbf{Equation 4}$$

Where,

P is the rainfall (cm).

$DCIA$ is the area of DCIA.

$TotalArea$ is the total watershed area.

The $Q_{Pervious}$ can be calculated using **Equation 5**:

$$Q_{Pervious} = \frac{\left(P' - 0.2 * S\right)^2}{P' + 0.8 * S} * \left(\frac{PerviousArea}{TotalArea}\right) \qquad \textbf{Equation 5}$$

Where,

P' is the adjusted rainfall (cm).

S is the potential soil storage of the rainfall (cm).

$PerviousArea$ is the acreage of the pervious area in the watershed.

Measured rainfall was adjusted in **Equation 5** to account for the rain falling in the NDCIA. It was assumed that rainfall on these areas would reach and uniformly spread out onto the pervious area. To account for the rain to the NDCIA, the measured rainfall was adjusted using **Equation 6**.

$$P' = \frac{P * PerviousArea + P * NDCIA}{PerviousArea} \qquad \textbf{Equation 6}$$

Where,

$NDCIA$ is the area of the NDCIA.

Equation 6 can be simplified to **Equation 7**:

$$P' = P * (1 + \frac{NDCIA}{PerviousArea}) \qquad \textbf{Equation 7}$$

The potential soil storage can be calculated using **Equation 8**:

$$S = \frac{2540}{CN_{Pervious}} - 25.4 \qquad \textbf{Equation 8}$$

Where,

$CN_{Pervious}$ is the curve number for the pervious area.

The $CN_{Pervious}$ can be derived from the watershed average curve number, which can be calculated using **Equation 9**:

$$CN_{Watershed} = \frac{\sum (Area * CN)}{TotalArea} \qquad \textbf{Equation 9}$$

Where,

$CN_{Watershed}$ is the watershed average curve number.

CN is the land use–soil combination specific curve number listed in **Table 4.3**.

$Area$ is the area occupied by a specific land use–soil combination.

$TotalArea$ is the total area of the entire watershed.

The $CN_{Watershed}$ can also be represented using **Equation 10**:

$$CN_{Watershed} = \frac{(CN_{DCIA} * Area_{DCIA}) + (CN_{Pervious} * Area_{Pervious})}{TotalArea} \qquad \textbf{Equation 10}$$

Where,

CN_{DCIA} is the curve number of the DCIA area.

$Area_{DCIA}$ is the acreage occupied by the DCIA area.

$Area_{Pervious}$ is the acreage of the watershed occupied by both NDCIA and pervious areas.

Equation 10 can be rewritten to solve for $CN_{Pervious}$ as **Equation 11**:

$$CN_{Pervious} = \frac{(CN_{Watershed} * TotalArea) - (CN_{DCIA} * Area_{DCIA})}{Area_{Pervious}} \qquad \textbf{Equation 11}$$

With all the above equations, the watershed runoff volume Q defined in **Equation 4** can be calculated. The watershed-basin average stormwater runoff coefficient ($ASRC_{wb}$) can be calculated as the quotient between the watershed runoff volume and rainfall to the watershed.

The $ASRC_{wb}$ can also be represented using **Equation 12**:

$$ASRC_{wb} = \frac{(DCIA * 0.9) + (PerviousArea * WRC_{Pervious})}{TotalArea} \qquad \textbf{Equation 12}$$

Equation 12 can be rewritten to solve for the weighted runoff coefficient for the pervious area (**Equation 13**):

$$WRC_{Pervious} = \frac{(ASRC_{wb} * TotalArea) - (DCIA * 0.9)}{PerviousArea} \qquad \textbf{Equation 13}$$

When developing the nutrient PLRG for the Upper Ocklawaha Chain of Lakes, the SJRWMD assumed that Type D soil would have four times the runoff compared with Type A (Fulton *et al.* 2004). This assumption was made based on the typical depth to ground water and the resultant soil storage (**Table D-5**).

Table D-5. Ground Water Depth and Soil Runoff Potential

SOIL TYPE	DEPTH TO GROUND WATER (METERS)	RUNOFF RATIO	SOIL TYPE COEFFICIENT
A	>1.2	1	PRC
B	0.9	2	2*PRC
C	0.6	3	3*PRC
D	0.3	4	4*PRC

Based on this assumption, $WRC_{Pervious}$ can also be represented using **Equation 14**:

$$WRC_{Pervious} = \frac{PRC * Area_{Asoil} + 2PRC * Area_{Bsoil} + 3PRC * Area_{Csoil} + 4PRC * Area_{Dsoil}}{PerviousArea}$$ **Equation 14**

Where,

PRC is the proportional runoff coefficient.

AreaAsoil is the area occupied by A soil.

AreaBsoil is the area occupied by B soil.

AreaCsoil is the area occupied by C soil.

AreaDsoil is the area occupied by D soil.

Equation 14 can be rewritten to solve for PRC (**Equation 15**):

$$PRC = \frac{PerviousArea * WRC_{Pervious}}{Area_{Asoil} + 2 * Area_{Bsoil} + 3 * Area_{Csoil} + 4 * Area_{Dsoil}}$$ **Equation 15**

The final area weighted runoff coefficient for each land use–soil combination ($ASRC_{LS}$) is calculated using **Equation 16**:

$$ASRC_{LS} = \frac{(DCIA_{LS} * 0.9) + (PerviousArea_{LS} * n * PRC)}{TotalArea_{LS}}$$ **Equation 16**

Where,

$DCIA_{LS}$ is the DCIA area occupied by a specific land use–soil type combination.

$PerviousArea_{LS}$ is the pervious area (including the NDCIA) occupied by a specific land use–soil type combination.

n is the runoff ratio listed in **Table D-5**. The n values for Type A, B, C, and D soils are 1, 2, 3, and 4, respectively.

$TotalArea_{LS}$ is the total area occupied by a specific land use–soil type combination.

The SJRWMD provided the rainfall data used in calculating the runoff coefficient and runoff volume for these TMDLs. **Table 4.3** summarizes the annual rainfall to the Lake Denham watershed for each year from 2000 to 2012. **Table D-6** lists the runoff coefficients for each land use–soil type combination for each year from 2000 to 2012. **Table 4.4** lists the annual runoff volume from different land use areas in the Lake Denham watershed.

Table D-6. Runoff Coefficient for Different Land Use–Soil Type Combinations for Each Year from 2000 to 2012

NA = Not applicable because there is no such land use or soil type.

LAND USE	SOIL	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Low-density residential	A	0.049	0.063	0.080	0.052	0.083	0.054	0.060	0.057	0.077	0.082	0.052	0.080	0.072
Low-density residential	B	0.053	0.081	0.114	0.060	0.122	0.063	0.074	0.068	0.108	0.120	0.060	0.116	0.099
Low-density residential	C	0.056	0.099	0.149	0.067	0.160	0.072	0.089	0.080	0.140	0.157	0.067	0.151	0.126
Low-density residential	D	0.060	0.117	0.184	0.074	0.199	0.082	0.104	0.091	0.172	0.195	0.074	0.187	0.154
Low-density residential	X	0.060	0.117	0.184	0.074	0.199	0.082	0.104	0.091	0.172	0.195	0.074	0.187	0.154
Medium-density residential	A	0.138	0.151	0.166	0.142	0.169	0.143	0.148	0.145	0.163	0.168	0.142	0.167	0.159
Medium-density residential	B	0.142	0.167	0.197	0.148	0.204	0.151	0.161	0.156	0.192	0.202	0.148	0.198	0.184
Medium-density residential	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Medium-density residential	D	0.149	0.199	0.259	0.161	0.273	0.168	0.187	0.176	0.248	0.269	0.161	0.262	0.232
Medium-density residential	X	0.149	0.199	0.259	0.161	0.273	0.168	0.187	0.176	0.248	0.269	0.161	0.262	0.232
High-density residential	A	0.228	0.239	0.252	0.231	0.255	0.232	0.237	0.234	0.250	0.255	0.231	0.253	0.246
High-density residential	B	0.231	0.253	0.280	0.237	0.286	0.239	0.248	0.243	0.275	0.284	0.237	0.281	0.268
High-density residential	C	0.234	0.268	0.307	0.242	0.316	0.247	0.260	0.252	0.300	0.314	0.242	0.309	0.289
High-density residential	D	0.237	0.282	0.334	0.248	0.346	0.254	0.271	0.261	0.325	0.343	0.248	0.337	0.311
High-density residential	X	0.237	0.282	0.334	0.248	0.346	0.254	0.271	0.261	0.325	0.343	0.248	0.337	0.311
Low-density commercial	A	0.362	0.371	0.382	0.365	0.384	0.366	0.369	0.367	0.380	0.384	0.365	0.382	0.377
Low-density commercial	B	0.365	0.383	0.404	0.369	0.409	0.372	0.378	0.375	0.400	0.407	0.369	0.405	0.394
Low-density commercial	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Low-density commercial	D	0.370	0.405	0.448	0.378	0.457	0.383	0.397	0.389	0.440	0.455	0.379	0.450	0.429
Low-density commercial	X	0.370	0.405	0.448	0.378	0.457	0.383	0.397	0.389	0.440	0.455	0.379	0.450	0.429
High-density commercial	A	0.407	0.415	0.425	0.409	0.427	0.410	0.413	0.412	0.423	0.427	0.409	0.426	0.421
High-density commercial	B	0.409	0.426	0.445	0.413	0.450	0.416	0.422	0.418	0.442	0.448	0.414	0.446	0.436
High-density commercial	C	0.412	0.436	0.465	0.418	0.472	0.421	0.430	0.425	0.460	0.470	0.418	0.467	0.452
High-density commercial	D	0.414	0.447	0.485	0.422	0.494	0.426	0.439	0.432	0.478	0.492	0.422	0.487	0.468
High-density commercial	X	0.414	0.447	0.485	0.422	0.494	0.426	0.439	0.432	0.478	0.492	0.422	0.487	0.468
Industrial	A	0.452	0.459	0.468	0.454	0.470	0.455	0.458	0.456	0.467	0.470	0.454	0.469	0.464
Industrial	B	0.454	0.469	0.486	0.458	0.490	0.460	0.465	0.462	0.483	0.489	0.458	0.487	0.479
Industrial	C	0.456	0.478	0.505	0.462	0.511	0.464	0.473	0.468	0.500	0.509	0.462	0.506	0.493
Industrial	D	0.458	0.488	0.523	0.465	0.531	0.469	0.481	0.474	0.517	0.529	0.465	0.525	0.507

Land Use	Soil	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Industrial	X	0.458	0.488	0.523	0.465	0.531	0.469	0.481	0.474	0.517	0.529	0.465	0.525	0.507
Mining	A	0.013	0.028	0.045	0.017	0.049	0.019	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Mining	B	0.017	0.046	0.081	0.024	0.089	0.028	0.040	0.033	0.075	0.087	0.024	0.083	0.066
Mining	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mining	D	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Mining	X	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Open land/recreational	A	NA	NA	NA	NA	NA	NA	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Open land/recreational	B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Open land/recreational	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Open land/recreational	D	NA	NA	NA	NA	NA	NA	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Open land/recreational	X	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pasture	A	0.013	0.028	0.045	0.017	0.049	0.019	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Pasture	B	0.017	0.046	0.081	0.024	0.089	0.028	0.040	0.033	0.075	0.087	0.024	0.083	0.066
Pasture	C	0.021	0.065	0.117	0.032	0.129	0.038	0.055	0.045	0.108	0.126	0.032	0.120	0.094
Pasture	D	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Pasture	X	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Cropland	A	0.013	0.028	0.045	0.017	0.049	0.019	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Cropland	B	0.017	0.046	0.081	0.024	0.089	0.028	0.040	0.033	0.075	0.087	0.024	0.083	0.066
Cropland	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cropland	D	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Cropland	X	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Tree Crop	A	0.013	0.028	0.045	0.017	0.049	0.019	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Tree Crop	B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tree Crop	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tree Crop	D	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Tree Crop	X	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Other agriculture	A	0.013	0.028	0.045	0.017	0.049	0.019	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Other agriculture	B	0.017	0.046	0.081	0.024	0.089	0.028	0.040	0.033	0.075	0.087	0.024	0.083	0.066
Other agriculture	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other agriculture	D	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Other agriculture	X	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

LAND USE	**SOIL**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Forest/rangeland	A	0.013	0.028	0.045	0.017	0.049	0.019	0.024	0.021	0.042	0.048	0.017	0.046	0.037
Forest/rangeland	B	0.017	0.046	0.081	0.024	0.089	0.028	0.040	0.033	0.075	0.087	0.024	0.083	0.066
Forest/rangeland	C	0.021	0.065	0.117	0.032	0.129	0.038	0.055	0.045	0.108	0.126	0.032	0.120	0.094
Forest/rangeland	D	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Forest/rangeland	X	0.025	0.084	0.154	0.039	0.169	0.047	0.070	0.057	0.141	0.165	0.040	0.157	0.122
Water	A	0.766	0.768	0.770	0.766	0.771	0.766	0.767	0.767	0.770	0.771	0.766	0.771	0.769
Water	B	0.766	0.771	0.776	0.767	0.777	0.768	0.770	0.769	0.775	0.777	0.767	0.776	0.774
Water	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Water	D	0.767	0.776	0.787	0.770	0.789	0.771	0.774	0.772	0.785	0.789	0.770	0.787	0.782
Water	X	0.767	0.776	0.787	0.770	0.789	0.771	0.774	0.772	0.785	0.789	0.770	0.787	0.782
Wetland	A	0.676	0.680	0.684	0.677	0.685	0.677	0.679	0.678	0.683	0.685	0.677	0.684	0.682
Wetland	B	0.677	0.684	0.693	0.679	0.695	0.680	0.683	0.681	0.692	0.695	0.679	0.694	0.689
Wetland	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wetland	D	0.679	0.694	0.711	0.683	0.715	0.685	0.690	0.687	0.708	0.714	0.683	0.712	0.704
Wetland	X	0.679	0.694	0.711	0.683	0.715	0.685	0.690	0.687	0.708	0.714	0.683	0.712	0.704

B. Estimating Runoff Nutrient Loads

The runoff nutrient loads from a watershed are calculated by multiplying the runoff volume from the land use area by runoff TN and TP concentrations specific to the 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 during phases of 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 D-7**) used in this TMDL analysis were those used by the SJRWMD in the nutrient PLRG for the Upper Ocklawaha Chain of Lakes (Fulton *et al.* 2004). Based on the SJRWMD's PLRG report, these EMCs were primarily cited from Dr. Harvey Harper's stormwater review report (1994). Several other published studies—including Fonyo *et al.* 1991, Goldstein and Ulevich (1981), Hendrickson and Konwinski (1998), Izuno *et al.* (1991), and Rushton and Dye (1993)—were also analyzed to supplement the numbers in the Harper (1994) report. The SJRWMD thought that the wetland EMCs included in the Harper (1994) report were measured from wetlands impacted by human activities (Fulton *et al.* 2004). Therefore, the wetland EMCs cited in the PLRG report were for the forest/rangeland land use type included in the Harper (1994) report. The muck farm EMCs were calculated using the water discharge and nutrient load estimates from Ja-Mar Muck Farm provided by the SJRWMD.

Nutrient removal by the stormwater treatment facilities in urban areas was also considered in simulating watershed nutrient loads. It was assumed that all urban construction after 1984, when Florida implemented the Stormwater Rule, had some type of stormwater treatment facilities to remove TN and TP loads at certain removal efficiencies. To identify the construction taking place after 1984, the watershed land use distribution data from 2004 and 2009 were compared with the land use distribution GIS shape file of 1988, which was the earliest land use GIS shape file available in the department's GIS dataminer.

It was assumed that the urban land use areas included in the 1988 land use shape file 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 shape file 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 taking place between 1984 and 1987 were relatively small and therefore should not cause significant errors for nutrient load simulation. Any urban land areas that did not appear in the 1988 land use shape file but appeared in the 2004 or 2009 land use shape files were considered new construction with stormwater treatment facilities.

Table D-7. EMCs of TN and TP for Different Land Use Types

LAND USE	TP EMC (MG/L)	TN EMC (MG/L)
Low-density residential	0.177	1.77
Medium-density residential	0.3	2.29
High-density residential	0.49	2.42
Low-density commercial	0.195	1.22
High-density commercial	0.43	2.83
Industrial	0.339	1.98
Mining	0.15	1.18
Pasture	0.387	2.48
Tree crops	0.14	2.05
Cropland	0.666	4.56
Other agriculture	0.492	2.83
Open land/recreational	0.057	1.25
Forest/rangeland	0.057	1.25
Wetlands	0.057	1.25
Water	0.025	0.72
Muck farm	0.233	2.62

When calculating watershed nutrient loads, the loads from these urban land use areas are subject to the stormwater treatment and TN and TP removal at certain percentages. Based on studies of 13 stormwater treatment systems, it was assumed that about 63% of the phosphorus load and 42% of the nitrogen load can be removed by these urban stormwater facilities (Fulton *et al.* 2004).

Another aspect of the nutrient load simulation was the effective delivery of nutrient 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 reach the receiving water without any loss, while particulate fractions of TN and TP were considered subject to loss through the overland transport process. Therefore, the amount of nutrients eventually reaching the receiving water includes two components: the unattenuated dissolved fraction (T) and the particulate fraction that is attenuated through the overland transport process. The portion of the nutrients that eventually reaches the receiving water can be represented using **Equation 7**, which is a function established in the Reckhow *et al.* (1989) analyses.

$$D = (1-T) * e^{(1.01-0.34*\ln(L))} + T \qquad \textbf{Equation 17}$$

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 used in this TMDL 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 on stormwater runoff conducted in Florida (Dierberg 1991; Fall 1990; Fall and Hendrickson 1988; German 1989; Harper and Miracle 1993; Hendrickson 1987; Izuno *et al.* 1991). **Table D-8** lists the percent concentration of dissolved phosphorus and nitrogen for different land uses.

The length of the overland flow path was estimated by randomly picking 20 transects of the watershed and measuring the distance between the boundary of the watershed and the boundary of the lake. The final length of the overland flow path was calculated as the mean values of the lengths of these 20 transect measurements. For the Lake Denham watershed, the average length of the overland flow path was estimated this way as 2,903 m.

Tables 4.5a and **4.5b** list the stormwater runoff TN and TP loads from the Lake Denham watershed estimated using the procedures described above.

Table D-8. 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%
Mining	46.7%	65.7%
Pasture	72.2%	90.8%
Tree crops	62.9%	90.8%
Cropland	60.0%	90.8%
Other agriculture	68.7%	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%

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