Final TMDL Report

Nutrient TMDLs for Crescent Lake (WBID 2606B)

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

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May 2017

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Acknowledgments

Significant contributions were made by staff in the Florida Department of Environmental Protection (DEP) TMDL and Watershed Assessment Sections. DEP also recognizes the substantial support and assistance provided by the St. Johns River Water Management District, especially from John Hendrickson. Editorial assistance was provided by Douglas Gilbert, Wayne Magley, Erin Rasnake, Xueqing Gao, Kevin O'Donnell, Katrina Sanders, and Linda Lord.

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Contents

List of Tables

List of Figures

Websites

Florida Department of Environmental Protection

- TMDL Program
- BMAP Program
- Watershed Assessment Program
- Identification of Impaired Surface Waters Rule
- Florida STORET Program
- 2016 Integrated Report
- Criteria for Surface Water Quality Classifications
- Surface Water Quality Standards

U.S. Environmental Protection Agency

- Region 4: TMDLs in Florida
- National STORET Program

Chapter 1: Introduction

1.1 Purpose of Report

This report presents the total maximum daily loads (TMDLs) for nutrients for Crescent Lake in the Lower St. Johns River Basin. The TMDLs will constitute the site-specific numeric interpretations of the narrative nutrient criterion set forth in Paragraph 62-302.530(47)(b), Florida Administrative Code (F.A.C.), that will replace the otherwise applicable numeric nutrient criteria (NNC) in Subsection 62-302.531(2) for this particular water.

The lake was verified as impaired for nutrients due to elevated annual average Trophic State Index (TSI) values, and was included on the Verified List of impaired waters for the Lower St. Johns River Basin that was adopted by Secretarial Order on May 27, 2004. According to the 1999 Florida Watershed Restoration Act (FWRA) (Chapter 99-223, Laws of Florida), once a waterbody is included on the Verified List, a TMDL must be developed for the pollutant(s) causing the impairment. The purpose of these TMDLs is to establish the allowable loadings of pollutants to Crescent Lake that would restore the waterbody so that it meets the applicable water quality criteria for nutrients.

1.2 Identification of Waterbody

For assessment purposes, the Florida Department of Environmental Protection (DEP) has divided the St. Johns River Basin into water assessment areas with a unique waterbody identification (WBID) number. Crescent Lake is located in WBID 2606B. Situated in the Lower St. Johns River Basin, Crescent Lake is a natural, river-fed, and river-drained lake located in Putnam and Flagler Counties, with portions of the watershed in Volusia and St. Johns Counties.

Crescent Lake is one of the larger freshwater lakes in the Lower St. Johns River Basin, with a surface area of 69 square kilometers (km^2) (**Figure 1.1**). The watershed draining to Crescent Lake covers 1,485.9 km^2. It comprises a mix of woody wetlands, agricultural land, short-rotation forestry, and residential development in the outer fringes of the watershed. Compared with many of Florida's lakes, Crescent Lake is relatively deep, with an average depth of 2.43 meters (m) and a maximum depth of 4.27 m.

Crescent Lake is fed primarily by Haw Creek (WBID 2622A), which flows north and receives discharges from several smaller streams arranged in a dendritic pattern. Other smaller first-order streams and artificial channels draining roads and agricultural areas discharge directly into Crescent Lake. The lake drains through Dunns Creek to the north, tying Crescent Lake to the Lower St. Johns Estuary.

Dunns Creek (WBID 2606A) is subject to reversing flow from the influence of the St. Johns River. This influence extends upstream to Crescent Lake. All water leaving Crescent Lake flows from the outlet on the north side of Crescent Lake into Dunns Creek and eventually into the St. John's River.

1.3 Background

This report was developed as part of DEP's watershed management approach for restoring and protecting state waters and addressing TMDL Program requirements. The watershed approach, which is implemented using a cyclical management process that rotates through the state's 52 river basins over a 5-year cycle, provides a framework for implementing the TMDL Program–related requirements of the 1972 federal Clean Water Act (CWA) and the FWRA.

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

This TMDL report will be followed by the development and implementation of a restoration plan designed to reduce the amount of nutrients that caused the verified impairment of Crescent Lake (WBID 2606B). These activities will depend heavily on the active participation of the St. Johns River Water Management District (SJRWMD), local municipalities, the Tri-County Agricultural Area (TCAA), and other stakeholders. DEP will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDLs for impaired waterbodies.

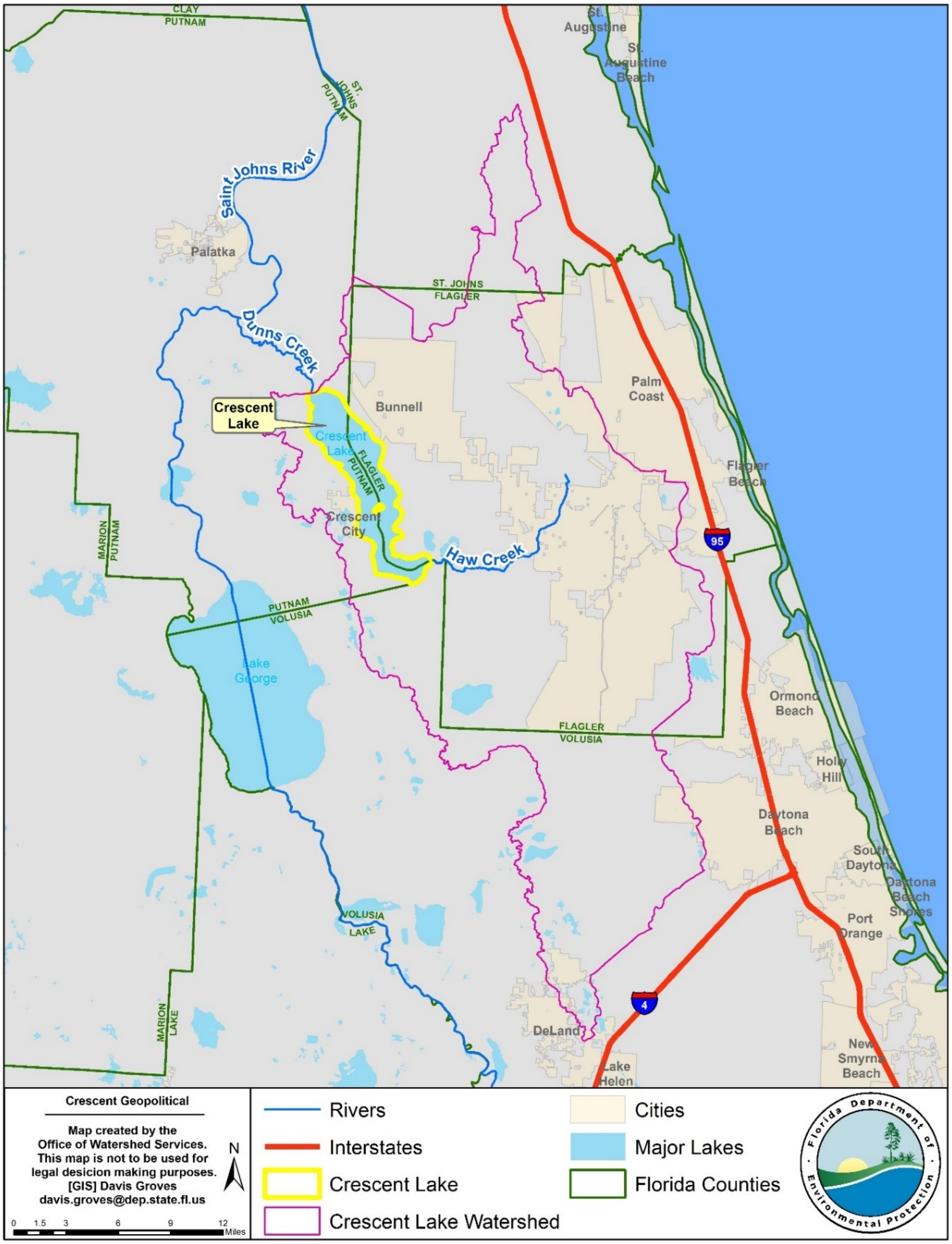

Figure 1.1. General location of Crescent Lake and watershed in Flagler, Putnam, and Volusia Counties

Chapter 2: Description of Water Quality Problem

2.1 Statutory Requirements and Rulemaking History

Section 303(d) of the federal CWA requires states to submit to the U.S. Environmental Protection Agency (EPA) a list of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for certain point and nonpoint pollutant sources in each of these impaired waters on a schedule. Since 1992, DEP has developed these lists, commonly referred to as the 303(d) list. 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 adopted numeric nutrient standards for lakes, spring vents, and streams in 2011 that were approved by the EPA in 2012. Pursuant to Chapter 2013-71, Laws of Florida, the criteria went into effect on October 27, 2014. It is envisioned that these standards, in combination with the related bioassessment tools, will facilitate the assessment of designated use attainment for the state's waters and provide a better means to protect them from the adverse effects of nutrient overenrichment. The lake NNC, which are set forth in Subparagraph 62-302.531(2)(b)1., F.A.C., are expressed as annual geometric mean (AGM) values for chlorophyll *a* (Chla), total nitrogen (TN), and total phosphorus (TP), which are further described in **Chapter 3**.

2.2 Information on Verified Impairment

DEP used the Impaired Surface Waters Rule (IWR) methodology to assess for water quality impairments in Crescent Lake. The lake was verified as impaired for nutrients based on elevated annual average TSI values during the Cycle 1 verified period for the Group 2 basins (January 1, 1996–June 30, 2003). The TSI annual averages exceeded the TSI threshold of 60 for high-color lakes in 1997, 1999, and 2000. When the Cycle 2 assessment was performed (verified period January 1, 2001–June 30, 2008), the annual mean TSI values continued to exceed the TSI threshold of 60 in 2006, supporting the continued listing of the waterbody. When this TMDL was developed, the Cycle 3 assessment (verified period January 1, 2007–June 30, 2014) had not been finalized. Some preliminary assessments using the NNC indicated that the nutrient impairment was reaffirmed.

Preliminary results indicate that the lake would not attain the lake NNC for Chl*a*, TN, and TP for high-color lakes and thus remains impaired for nutrients (long-term color > 40 platinum cobalt units [PCU]). **Table 2.1** lists the preliminary AGM values for Chl*a*, TN, and TP during the 2006–13 verified period.

Table 2.1. AGMs of water quality parameters in Crescent Lake. Red shaded cells and boldface type indicate concentrations that exceed the NNC.

mg/L = Milligrams per liter
µg/L = Micrograms per liter

Year	TN (mg/L)	TP (mg/L)	Chl*a* (µg/L)	Color (PCU)
2007	**1.37**	**0.083**	**37.1**	62
2008	1.50	0.076	16.6	158
2009	1.84	0.112	4.1	498
2010	1.48	0.088	11.9	209
2011	1.18	**0.061**	**25.7**	49
2012	1.24	**0.062**	**24.9**	70
2013	1.32	0.054	19.6	99
2014	1.34	0.05	14.1	202

Chapter 3. Description of Applicable Water Quality Standards and Targets

3.1 Classification of the Waterbody and Criteria Applicable to the Waterbody

Florida's surface waters are protected for six designated use classifications, as follows (**Table 3.1)**:

Table 3.1. Classification and designated uses of Florida surface waters

Waterbody Class	Designated Use
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)

Crescent Lake is a Class III freshwater body and therefore must meet water quality criteria relevant for fish consumption, recreation, propagation, and maintenance of a healthy and well-balanced population of fish and wildlife. The Class III water quality criteria applicable to the impairment addressed by this TMDL are for nutrients.

3.2 Applicable Water Quality Standards and Numeric Water Quality Target

When Crescent Lake was originally included on Florida's Verified List and the CWA 303(d) list, the applicable criteria for nutrients were narrative. The numeric threshold used for nutrient assessment in high-color lakes (color > 40 PCU) was a TSI less than 60. The TSI combines the concentrations of Chl*a*, TP, and TN into a single composite index. Crescent Lake exceeded the TSI threshold of 60 in 1997, 1999, 2000, and 2006, while the TSI was below the threshold for the intervening period from 2001 to 2005.

The adopted lake NNC include criteria for Chl*a*, TN, and TP, with the specific values depending on the color and alkalinity long-term geometric means for a lake. **Table 3.2** lists the NNC for Florida lakes specified in Subparagraph 62-302.531(2)(b)1., F.A.C.

Table 3.2. Applicable NNC for lakes in Florida

$CaCO_3$ = Calcium carbonate

Color and Alkalinity	Chlorophyll *a* (Chl*a*)	TP if Chl*a* Exceeded	Total TN if Chl*a* Exceeded	TP	TN
>40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	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 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 $CaCO_3$) is greater than 20 mg/L, the Chl*a* criterion is 20 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 of Chl*a* should not exceed the criterion more than once in any consecutive 3-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 (DEP 2012).

If there are sufficient data to calculate the AGM Chl*a*, and the mean does not exceed the Chl*a* target concentration for the lake type listed in **Table 3.2**, then the TN and TP target concentrations for that calendar year are the AGMs of lake TN and TP samples, subject to the limits in the table. However, for lakes with color > 40 PCU in the West Central Nutrient Watershed Region, the maximum TP target concentration is 0.49 mg/L. If there are insufficient data to calculate the AGM Chl*a* for a given year, or the AGM Chl*a* concentration exceeds the Chl*a* target concentration specified in **Table 3.2** for the lake type, then the TN and TP criteria are the minimum limits in the table.

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 3 years with at least 1 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 micromhos/centimeter (µmhos/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 Crescent Lake is 214 PCU. Crescent Lake is, therefore, considered a high-color lake, and the generally applicable NNC are Chl*a* of 20 µg/L, TN of 1.27 to 2.23 mg/L, and TP of 0.05 to 0.16 mg/L.

3.2.1 Site-Specific Numeric Interpretation of the Narrative Nutrient Criterion

The nutrient TMDLs in this report, upon adoption into Chapter 62-304, F.A.C., will constitute site-specific numeric interpretations of the narrative nutrient criterion set forth in Paragraph 62-302.530(47)(b), F.A.C., that will replace the otherwise applicable NNC in Subsection 62-302.531(2), F.A.C., for this particular water, pursuant to Paragraph 62-302.531(2)(a), F.A.C.

Appendix A provides the relevant information on the derivation and maintenance of water quality standards in downstream waters (pursuant to Subsection 62-302.531[4], F.A.C.), to support the establishment of nutrient targets as site-specific numeric interpretations of the narrative nutrient criterion. Targets used in TMDL development are designed to meet water quality criteria and thereby restore surface water quality to meet a waterbody's designated uses. Criteria are based on scientific information used to establish specific target concentrations of water quality constituents that will protect aquatic life and human health for particular designated use classifications.

For the Crescent Lake nutrient TMDLs, DEP's general approach (explained more in detail in subsequent sections) established the target Chl*a* concentration using a site-specific biological community–based target. The TN and TP loads identified as the site-specific standard were determined using models to identify watershed loading limits that will achieve the target Chl*a* concentrations in Crescent Lake.

3.2.2 Site-Specific Target for Phytoplankton Community Composition

While the applicable lake-specific NNC have been demonstrated to be protective for most Florida lakes, there is strong evidence that they may not be fully protective for Crescent Lake. Waterbody criteria are designed to protect designated uses, which for Crescent Lake are fish consumption, recreation, propagation and maintenance of a healthy, well-balanced population of flora and fauna. The applicable NNC are designated to protect all of these designated uses. However, there is evidence that a lower Chl*a* concentration may be needed to maintain a balanced phytoplankton community. Therefore, the site-specific target presented below seeks to maintain a diverse and balanced phytoplankton community.

Within Crescent Lake, lake-specific biological responses were used to set the site-specific Chl*a* criterion. The best available data to create such a criterion were a set of high-quality monthly algal community composition samples collected by the SJRWMD from 2000 to 2014. The algal community composition samples were analyzed to determine organism identity (to the lowest practical taxonomic levels), associated cell counts, and total biovolumes. Because different algal groups were identified to different taxonomic levels, the taxonomic identities were taken to the highest common taxonomic level between samples (division level) to carry out an unbiased evaluation of the algal community structure.

A statistical indicator, the Shannon-Weaver Diversity Index, was used to represent the complexity of the algal community based on the available species composition data. Higher diversity is a positive trait in biological systems, and in lakes, reduced diversity is associated with a problematic bloom condition that is dominated by relatively few species. The Shannon-Weaver Index was calculated as follows based on the annual average algal community composition data (biovolume):

$$H = -\sum_{i=1}^{S} P_i * ln(P_i)$$

Where,

H = Shannon-Weaver Diversity Index.

P_i = The proportion of species i relative to the total number of species.

The Shannon-Weaver Diversity Index is a widely used ecological statistic that evaluates the overall evenness of the algal community to the number of species. In this context, higher values indicate a more diverse community that is not dominated by any one species. Low values indicate a more monoculturelike community structure. In a lake system, high values for species diversity are linked to more oligotrophic conditions with a range of species, while low concentrations are associated with algal blooms in eutrophic states. Therefore, the diversity of the algal community is one important component of the natural biota supported in the lake ecosystem.

Bloom conditions are associated with a host of harmful effects on humans, other organisms, and nutrient balances. The harmful effects are typically caused under acute bloom conditions, for which the default NNC is protective. However, deleterious effects to the phytoplankton community structure occur in sub-bloom conditions as well. Therefore, DEP will need to set a lower Chla criteria to meet the biologic integrity designated use associated with the phytoplankton community.

A second metric of community structure defined as part of the TMDL for the Lower St. Johns River was used. The site-specific criteria outlined in the LSJR TMDL document identify that designated uses are impaired during conditions where cyanobacteria biovolume comprised 50 % or more of the total phytoplankton community. DEP interprets this metric in a similar condition to the NNC, where annual average cyanobacterial abundance is evaluated and the waterbody is held to a standard in which cyanobacteria do not dominate for more than 1 year in a 3-year period. Compared with the first metric, this approach also identifies bloom conditions as problematic. However, the second metric is focused on bloom organisms specifically, rather than the other organisms in the measured algal community composition.

Figure 3.1 shows a plot of the Shannon-Weaver Index results and the proportion of blue-green algae compared with the total algal biovolume. A change-point analysis was conducted in the R statistical programming language using the change-point package, generating several change points that are overlain on the trend lines from the above analysis. The lines displayed are the trends from the yearly data points extracted using a local nonparametric regression line (LOESS). The Shannon-Weaver Index shows a distinct transition at a Chl*a* concentration of 15 µg/L from a regime of high community diversity under lower Chl*a* concentrations to a zone of decreasing community diversity above 15 µg/L. A change-point analysis revealed that this point on the graph was statistically significant (p=0.04).

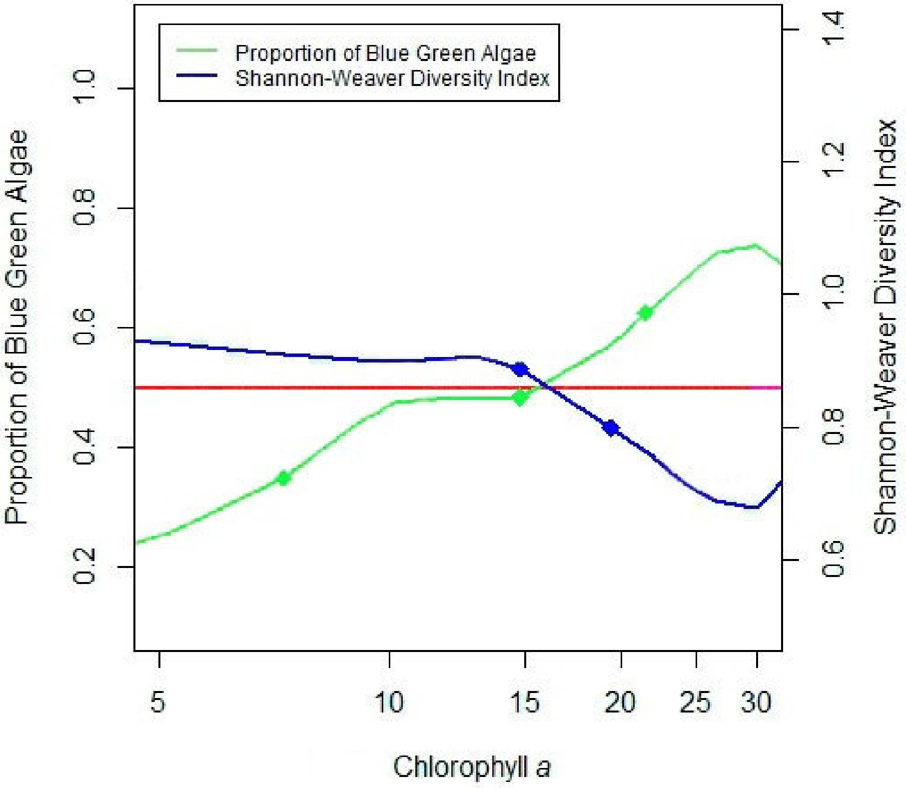

Figure 3.1. **Biological community responses to increasing annual AGM Chl*a* (points on the 2 trend lines show LOESS regression trends of the Shannon-Weaver Diversity Index and the proportion of blue-green algae with significant change points on both lines). The red horizontal line shows the point where cyanobacteria comprise 50 % of the phytoplankton community.**

Additionally, a Bayesian change-point algorithm was used to confirm the results from the first change-point analysis. The Bayesian technique used here allows DEP to determine which point along the graph has the highest probability of being a change point. Unlike the conventional change-point analysis discussed in the previous paragraph, this analysis does not require the user to choose the number of estimated change points before beginning the analysis.
As with all Bayesian algorithms, the assumption being tested is the degree of support for a given hypothesis. This contrasts with the interpretation of probability under a frequentist approach, which is generally held to be the probability of the null hypothesis being true. In a frequentist analysis, one seeks to reject the null hypothesis, while in Bayesian analysis, one seeks to assess degree of beliefs in competing ideas. The produced plot (**Figure 3.2**) simply shows the probability that a change in the underlying distribution has occurred at a given point.

In plain English, this plot shows the likelihood that a given change point occurs at each observed value. The results of this technique reveal that along the range of observed points, a Chl*a* concentration of 15 µg/L (corresponding to Location 9 in **Figure 3.2**, which is simply the order of the points, sorted from the lowest to the highest Chl*a*) had the highest likelihood of being a change point in the range of yearly values. The single highest observed probability in this figure strongly suggests that the phytoplankton community experiences a fundamental change at an AGM Chla value of 15 µg/L.

The fact that only 1 point was found with a probability exceeding 0.8 suggests that 2 compositional regimes are present in the phytoplankton regime. The constant diversity regime occurs at Chl*a* concentrations between 0 and 15 µg/L, and, under this scenario, average phytoplankton community diversity is unaffected by the overall Chl*a* biomass or the proportion of cyanobacteria. In the decreased diversity regime, which occurs at Chl*a* concentrations above 15 µg/L, phytoplankton diversity linearly declines with increasing phytoplankton biomass.

The analysis shown in **Figures 3.1** and **3.2** strongly suggest that plankton community structure is progressively degraded at Chl*a* concentrations above 15 µg/L expressed as an AGM. The corresponding increase in the proportion of blue-green algae suggests that these organisms harm the overall algal community when they comprise more than 50 % of the total phytoplankton biovolume. Therefore, the criterion will be set at an AGM chlorophyll *a* of 15 µg/L with a 1-in-3-year exceedance to allow for natural exceedances in dry years.

Algal growth is a natural feature of Florida lakes, although historically far less extreme than current conditions. Thus some flexibility is needed to allow for natural drought-related changes to algal communities. The site-specific standard for Crescent Lake is a chlorophyll concentration of 15 µg/L, a 7-year TP load not to exceed 57,959 pounds (lbs), and a 7-year TN load not to exceed 1,018,666 lbs. For reference purposes, the TN and TP concentrations corresponding to the 15 µg/L chlorophyll *a* and the loading criteria are 1.16 and 0.05 mg/L, respectively.

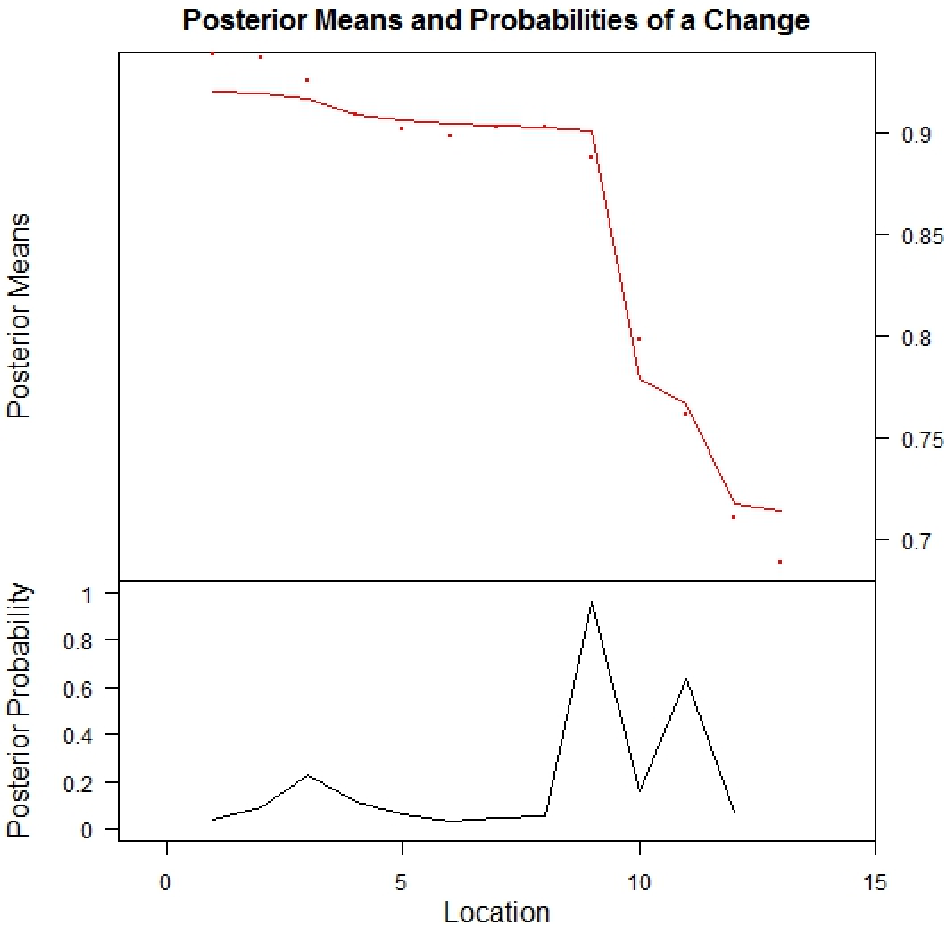

Figure 3.2. Posterior distributions of means and probabilities from a Bayesian change-point analysis conducted on the Shannon-Weaver Index of algal community composition data

The analysis shown in **Figure 3.1** and **3.2** strongly suggest that plankton community structure is progressively degraded at Chl*a* concentrations above 15 µg/L expressed as an AGM. The corresponding increase in the proportion of blue-green algae suggests that these organisms harm the overall algal community when they comprise more than 50% of the total phytoplankton biovolume. Therefore, the criterion will be set at an AGM Chl*a* of 15 µg/L with a one-in-three-year exceedance to allow for natural exceedances in dry years. Algal growth is a natural feature of Florida lakes, albeit in a far less severe manner than is observed at present. Therefore, we need to allow some flexibility for natural drought related changes to algal communities. The site specific standard for Crescent Lake is a chlorophyll concentration of 15 µg/L, a seven year TP load not to exceed 57,959 lbs and a seven year TN load not to exceed 1,018,666 lbs. For reference purposes, the TN and TP concentrations corresponding to the 15 µg/L Chl*a* and the loading criteria are 1.16 and 0.05 mg/L, respectively. These reference concentrations are AGMs not to be exceeded more than once in a 3-year period when the site-specific criteria for TN and TP loads are met. The nutrient loads and concentrations were determined using the U.S. Army Corps of Engineers (USACOE) BATHTUB water quality model, as described in **Chapter 5**. The new water quality standard will incorporate the *Chla criteria* of 15 µg/L and the associated loads comprising the TMDLs described in **Chapter 6**.

Determining whether the selected criteria are sufficient to protect downstream waters is a critical step in ensuring watershed-level protection of aquatic resources. Crescent Lake drains north through Dunns Creek, and then into the Lower St. Johns River (which has an existing TMDL and site specific target and is therefore protected). Dunns Creek transports water from the northern end of Crescent Lake to the Lower St. Johns River. Setting a target that allows Crescent Lake to meet its designated uses will likely protect Dunns Creek.

Specifically, both waterbodies are Class III waterbodies are used for swimming, boating, and fishing. Dunns Creek has an impairment for Chl*a* which is the result of the high Chl*a* water in Crescent Lake entering Dunns Creek. Therefore, choosing the above target, which is protective of phytoplankton communities in Crescent Lake, will protect these same resources in Dunns Creek. The criterion selected for Crescent Lake defines lower Chla, TN, and TP concentrations than the generally applicable stream NNC criteria (Chla = 20 µg/L, TN = 1.54 mg/L, TP = 0.12 mg/L). Given that Dunns Creek is dominated by water flowing out of Crescent Lake, the outflow water from Crescent Lake will support the achievement of the NNC within the stream reach, and thus support the attainment of designated uses.

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

To be consistent with CWA 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 Nutrient Sources in the Crescent Lake Watershed

4.2.1 Point Sources

4.2.1.1 Wastewater Facilities

There are 2 permitted domestic wastewater facilities and 2 industrial wastewater facilities in the Crescent Lake watershed (**Figure 4.1**). Both domestic wastewater facilities (**Table 4.1**) treat wastewater from small towns and therefore have low outlet flows of 0.1 to 0.2 million gallons per day (mgd). The industrial wastewater sources are excluded from load reductions because their permits and activities result in minimal nutrient loadings (**Table 4.2**). The Crescent City wastewater facility directs all its discharge to a spray field, and therefore the modeling demonstrated that they do not directly contribute to loading in Crescent Lake. The Crescent City WWTF has an NPDES permit but has not discharged in over a decade and retains the permit for extreme wet weather discharges.

In the unlikely event that an extreme precipitation event caused the Crescent City WWTF to make an emergency discharge, the lake would be at its least vulnerable state given the low residence time and high-color conditions that are strongly associated with wet conditions. Therefore, such a rare event would not contribute to the elevated Chl*a* concentrations that occur during dry periods.

The Bunnell facility discharges water with moderate to high nitrogen and phosphorus concentrations. However, the effluent flow rate is low and the overall load contribution is low. In addition, the discharge is 10 miles upstream from Crescent Lake, and there is likely considerable attenuation between the facility and Crescent Lake.

Both industrial wastewater discharges are from concrete batch mixers and therefore are not expected to contribute significant amounts of nutrients into Crescent Lake given the requirements for best management practices (BMPs) contained in the generic permit language (Paragraph 62-621.300[2][a], F.A.C.).

Table 4.1. Domestic wastewater facilities in the Crescent Lake watershed

Facility ID	Name	NPDES	Facility Type	Treatment Process Summary	Permitted Capacity (mgd)	Domestic Waste Class
FL0020907	City of Bunnell WWTF	Yes	Domestic WWTP	Activated Sludge Treatment Plant with Effluent to Polishing Pond	0.3	IIC
FL0021610	Crescent City WWTF	Yes	Domestic WWTP	Extended Aeration Sewage Treatment Plant	0.25	IIIC

Table 4.2. Industrial wastewater facilities in the Crescent Lake watershed

Facility ID	Name	NPDES	Major/Minor Discharge	Facility Type	City	State	Ownership Type
FLG110625	Argos Ready Mix Bunnell Terminal	Yes	Minor	Concrete Batch GP	Bunnell	FL	Private
FLG110637	CEMEX LLC - North Bunnell CBP	Yes	Minor	Concrete Batch GP	Bunnell	FL	Private

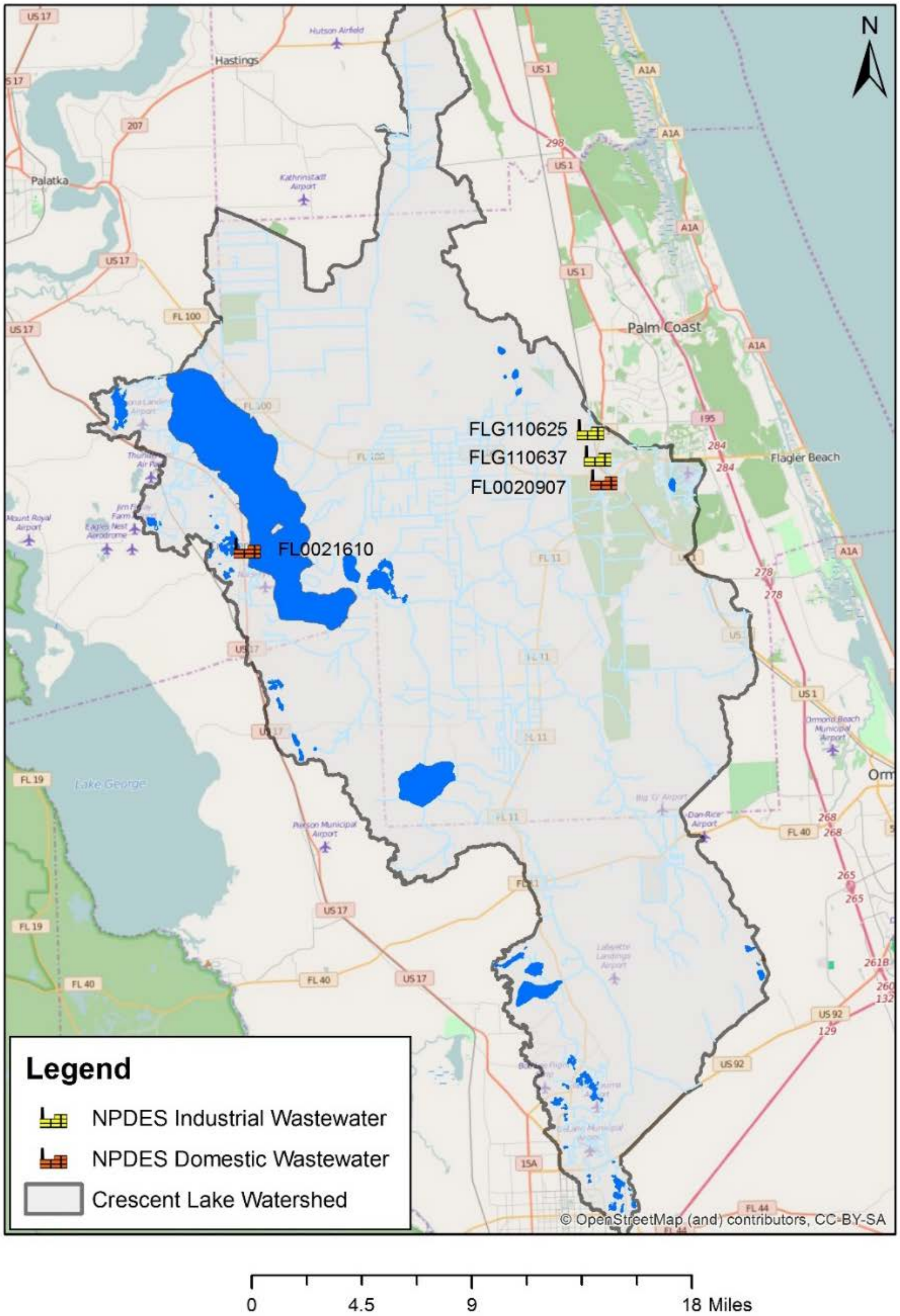

Figure 4.1. **Permitted point sources in the Crescent Lake watershed (facility IDs are shown as labels next to the facility icons)**

4.2.1.2 Municipal Separate Storm Sewer System (MS4) Permittees

There are 4 MS4 point source discharge permits in the Crescent Lake watershed (**Figure 4.2**): the City of DeLand Phase II (# FLR04E078), City of Daytona Beach Phase II (# FLR04E011), Volusia County Phase II-C (# FLR04E033), and St. Johns County Phase II-C (# FLR04E025). Only 2 of the 4 MS4 permittees intersect with urban areas in the Crescent Lake watershed (**Table 4.3**). Therefore, possible nutrient reductions will only apply to the city of DeLand and Volusia County. Loadings from these sources are currently unknown because the quality of water discharged from these sources has not been tested, and the true extent of the stormwater system is unknown.

4.2.2 Nonpoint Sources

The watershed supplying Crescent Lake is primarily rural, with few point source and stormwater areas contributing to nutrient loading. Therefore, the major source of nutrient loading to Crescent Lake is distributed nonpoint source land uses. Based on the SJRWMD 2009 land use coverage, agriculture and silviculture are the most common non-natural land uses in the watershed (**Figure 4.3**; **Table 4.4**).

Silviculture likely has a relatively low loading rate and may already be meeting BMPs if these operations are certified by the Sustainable Forestry Institute or Forest Stewardship Council. Agricultural operations contribute significantly to the nutrient loads reaching Crescent Lake. The loadings depend on hydrology and on the type and extent of BMPs currently being used. Because point sources are not likely to be the main contributor to nutrient loading in the lake, the major nutrient contributors are likely nonpoint sources and MS4s.

4.2.2.1 Land Uses

As explained above, nonpoint sources cause the majority of nutrient loading to Crescent Lake. Compared with much of the rest of the state, land use in the Crescent Lake watershed has remained largely unchanged over the past 20 years (**Figure 4.4**).

Table 4.3. MS4 permits in the Crescent Lake watershed

Permittee	Phase	Permit ID	County	Urban Area (acres)	% of Watershed Area
St. Johns County	II-C	FLR04E025	St. Johns	0	0.00
City of Daytona Beach	II	FLR04E011	Volusia	0	0.00
Volusia County	II-C	FLR04E033	Volusia	3,620	0.99
City of Deland	II	FLR04E078	Volusia	414	0.11

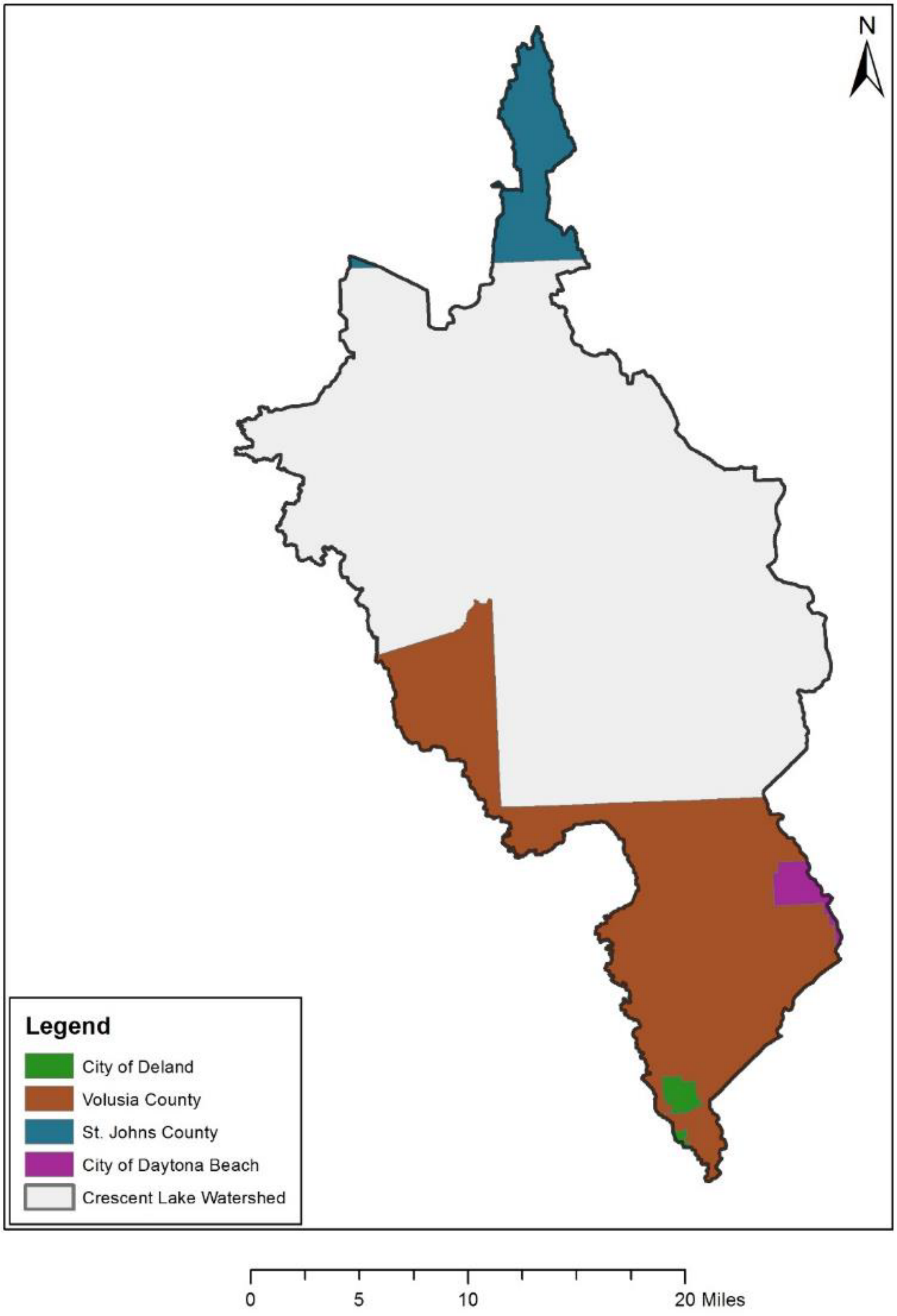

Figure 4.2. NPDES MS4 permit coverage in the Crescent Lake watershed

Three small towns are partially situated in the Crescent Lake watershed: Crescent City, Bunnell, and DeLand. Based on the 2009 land use shape file (Florida Land Use and Cover Classification System [FLUCCS] Level 1) created by the SJRWMD, developed land covers 7.1 % of the watershed. The overall impact of towns and other developed areas is relatively minor given the size of the contributing area and the placement of these cities on the edge of the watershed. Natural cover, comprising both forested and wetland areas, covers 77.8 % of the watershed (see **Table 4.4** for a more detailed breakdown).

Processing techniques for aerial and satellite imagery cannot easily differentiate between natural forest lands and those managed for silviculture. Therefore, roughly half or more of the natural forested land in the Crescent Lake watershed is likely managed for short-rotation southern pine. The runoff characteristics of silviculture are generally close to that of natural lands, and therefore the precise distinction between these two categories is not needed for an accurate prediction of nutrient loading from watershed sources. Open water, including Crescent Lake and Lake Disston, comprises 6.5 % of the watershed. Land managed for agricultural production accounts for 8.7 % of the total land in the watershed. Agricultural land is primarily managed for row crops, pasture, and leatherleaf fern farming (**Figure 4.3**).

Table 4.4. 2009 land use in the Crescent Lake watershed

Area (hectares [ha])	%	Category
9,714.3	6.5	Open water
10,541.3	7.1	Developed
310.7	0.2	Barren land
36,690.7	24.7	Forest
19,894.8	13.4	Shrub/scrub
6,464.7	4.4	Herbaceous
12,855.3	8.7	Agricultural
52,118.4	35.1	Wetlands

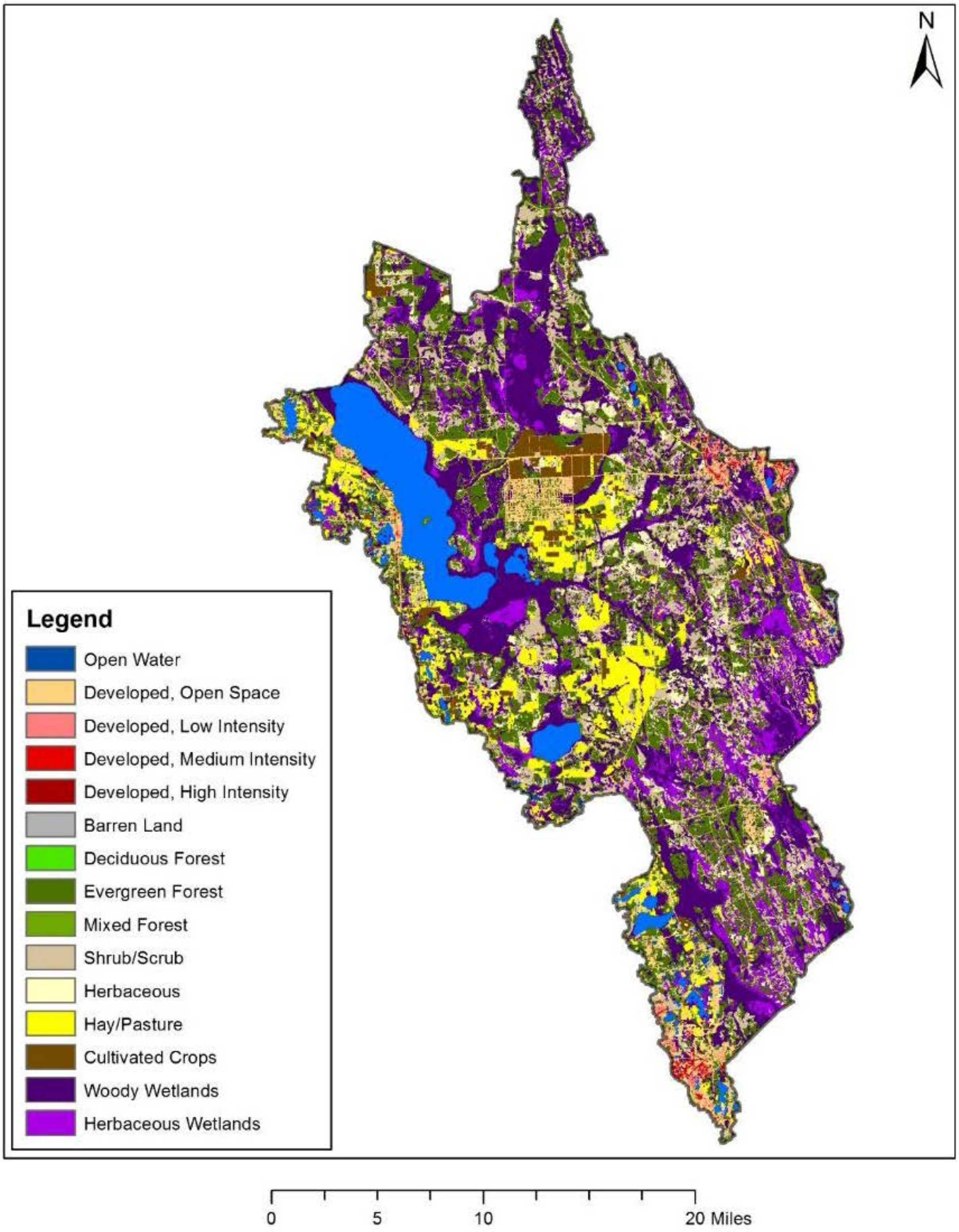

Figure 4.3. 2009 land use in the Crescent Lake watershed

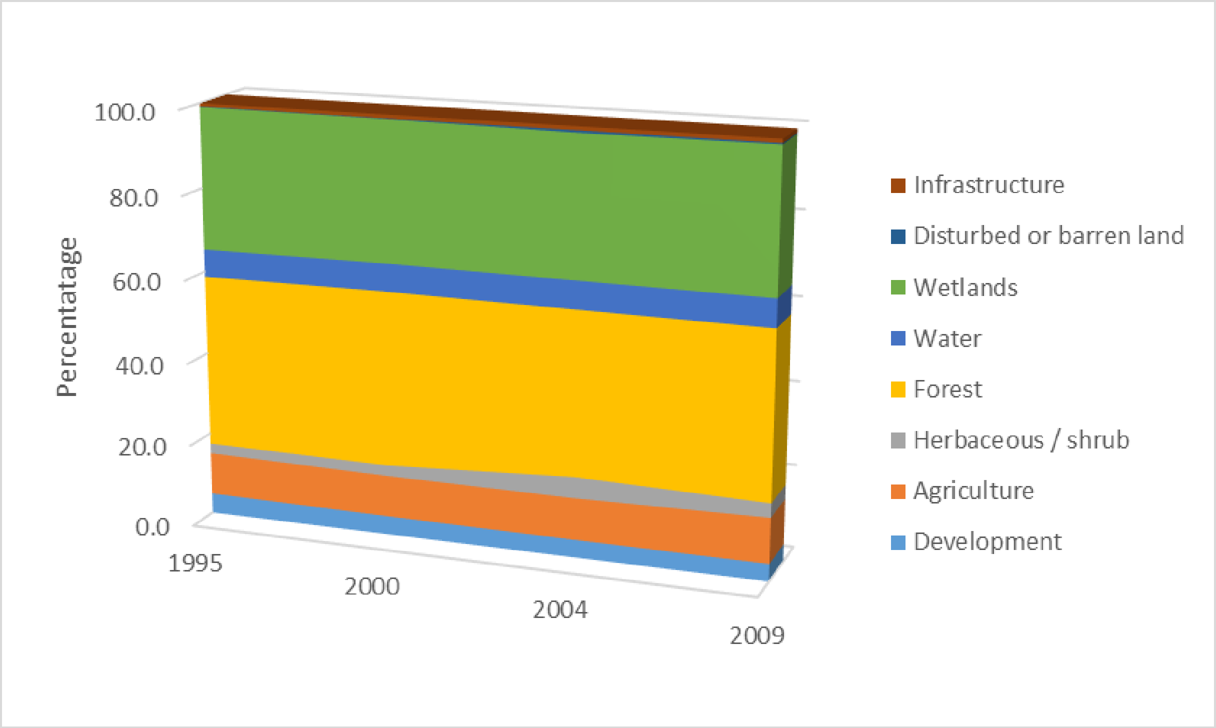

Figure 4.4. Change in land use in the Crescent Lake watershed, 1995–2009

4.2.2.2 Hydrologic Soil Groups

Soil infiltration rate is an important characteristic of soils that determines how much surface runoff is produced from a given area. Traditionally, soils are classified into four categories, from the fastest infiltrating A soils to the slowest infiltrating D soils (**Table 4.5**). Typically, these soil categories correlate to soil properties such as grain size and porosity. Soils with larger grain sizes and higher porosity tend to have higher infiltration rates, while denser soils with smaller particles tend to have lower infiltration rates. Type A soils with their high infiltration rates produce less Horton overland flow, while D soils produce comparatively more overland flow.

In the Crescent Lake watershed, the Crescent and Deland Ridges, with their sandy substrates, have distinctly higher infiltration rates than the silt-dominated lowlands surrounding Crescent Lake.

Table 4.5. Acreage of hydrologic soil groups in the Crescent Lake watershed

Note: The wet columns refer to the acreage under wet conditions per soil group, while the dry columns refer to the acreage under dry conditions. The acreage of each group is different in wet and dry conditions because a given soil can have a different hydrologic group for dry versus wet conditions.

Soil Group	Wet Area (ha)	Wet %	Dry Area (ha)	Dry %
A	87,139	63.0	12,630	9.1
B	7,870	5.7	4	0.0
C	35,539	25.7	9	0.0
D	7,866	5.7	125,771	90.9

4.2.2.3 Estimating Runoff Nutrient Loadings from the Crescent Lake Watershed

The hydrology of the area draining into Crescent Lake was represented by the curve number model developed by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The model was processed to return yearly flows from specific land uses, which feed into the receiving waterbody model. The freshwater inputs were calculated for four watershed segments (see **Section 5.3.2**).

4.2.3 Watershed Loading Model

To simulate nutrient loading from the Crescent Lake watershed, the runoff volumes from the curve number model were multiplied by the nutrient concentrations derived from the SJRWMD's previous modeling work. The Pollutant Load Simulation Model (PLSM) used by the SJRWMD for the Lower St. Johns River TMDL uses event mean concentrations (EMCs) along with an estimate of flow to calculate nutrient loading. Such loading is calculated per unit of land area and is multiplied by the land use area of the basin to derive watershed-scale loading estimates. The PLSM application gives distinct EMCs for three seasonal zones.

For TMDL development purposes, annual average EMCs (**Table 4.6**) were needed, and so a calculated weighted average of the EMCs of the three periods was derived by multiplying the EMC in each season by the average rain in that season and dividing the products by the total annual rainfall. These concentrations were multiplied by the yearly curve number flow derived in the previous section and entered into the receiving waterbody model to estimate the watershed nutrient contributions (**Tables 5.5** and **5.6** list the final calculated loadings).

Table 4.6. Volume-weighted EMCs from the SJRWMD PLSM

BOD = Biochemical oxygen demand
SS = Suspended solids
TIN = Total inorganic nitrogen
$P0_4$ = Orthophosphate

Land Use	TN (mg/L)	TP (mg/L)	BOD (mg/L)	SS (mg/L)	TIN (mg/L)	PO4 (mg/L)
Low-density residential	0.80	0.08	1.00	5.63	0.05	0.06
Medium-density residential	1.51	0.31	2.00	24.15	0.32	0.12
High-density residential	1.84	0.46	4.00	32.82	0.42	0.16
Low-density commercial	1.21	0.24	2.00	20.44	0.31	0.11
High-density commercial	1.68	0.46	4.00	37.78	0.46	0.16
Industrial	1.24	0.26	2.00	30.44	0.36	0.11
Mining	1.24	0.26	2.00	30.44	0.36	0.11
Open land/recreational	0.74	0.07	1.00	22.29	0.03	0.04
Pasture	3.24	1.34	4.00	13.19	1.07	1.25
Cropland	6.05	1.57	1.00	33.23	2.10	0.86
Tree crops	1.55	0.30	2.00	17.14	0.19	0.22
Feeding operations	5.23	1.78	6.00	26.01	1.47	1.52
Other agriculture	6.05	1.57	1.00	33.23	2.10	0.86
Forest/rangeland	0.74	0.07	1.00	22.29	0.03	0.04
Water	0.43	0.02	0.00	0.00	0.43	0.02
Wetlands	0.70	0.06	1.00	3.00	0.03	0.04

4.2.2.4 Groundwater Flow and Loading

Groundwater flow was calculated based on transport from the relatively high topography of the DeLand Ridge to the perimeter of Crescent Lake. The Darcy flow equation was used to estimate the magnitude of this flow in the water table in the surficial aquifer (**Table 4.7**). The land to the east of Crescent Lake is low relief, gaining only 5 feet (ft) of elevation over 10 miles. Combined with the substrate of quaternary estuarine silt (**Figure 4.5**), this combination of potential energy and low flow rate means that flow through the surface layers is negligible.

For Darcy's law, saturated conductivity is the most sensitive parameter in the calculation. Saturated conductivity has been estimated for various substrates and is commonly listed as a range of several orders of magnitude (indicative of the fundamental uncertainty in groundwater modeling). The DeLand Ridge is composed of coarse sand above a nonconformity, below which lies porous Miocene limestone that houses the Floridan aquifer. Given that both of these geologic materials are present, the correct infiltration rate should fall in the range of both medium sand and fractured limestone. For the DeLand Ridge, a saturated conductivity was chosen that would be reasonable both as a high estimate for medium sand and a low estimate for fractured limestone bedrock. If one assumes that the area through which flow occurs through the lake perimeter (the lake averages 8 ft in depth), the average predicted flow is 27 cubic feet per second (cfs), or one-sixteenth of the overall water budget.

Table 4.7. Darcy flow using the lake perimeter as the flow surface

FT = Feet

Groundwater Zones	Width (ft)	Vertical Distance (ft)	Horizontal Distance (ft)	Flow Layer Thickness (ft)	Ksat	Darcy Flow (cfs)
1	28,358	40	3,235	8	0.001	9.3
2	15,581	40	3,500	8	0.001	4.7
3	22,264	38	3,750	8	0.001	6.0
4	33,450	35	4,623	8	0.001	6.7
Total						**26.6**

To estimate actual loadings to Crescent Lake, groundwater data were extracted from the DEP Generalized Well Information System (GWIS) Database. In particular, data on nutrient concentrations were extracted for the sites in the Crescent Lake watershed within the surficial aquifer. The existing data suggest that surficial groundwater entering Crescent Lake is low in TN (0.029 mg/L) and yet somewhat enriched in TP (0.09 mg/L) (**Table 4.8**). This suggests an interaction between the surficial aquifer and phosphorus-rich sediments of the Miocene Hawthorne Formation.

Table 4.8. Average nutrient concentrations in the surficial aquifer (mg/L)

System	TP (mg/L)	TN (mg/L)	Count
Crescent Ridge Average	0.11	0.036	9
TC Agricultural Average	0.10	0.028	9
Middle Haw Average	0.05	0.028	4
Overall Average	0.09	0.029	22

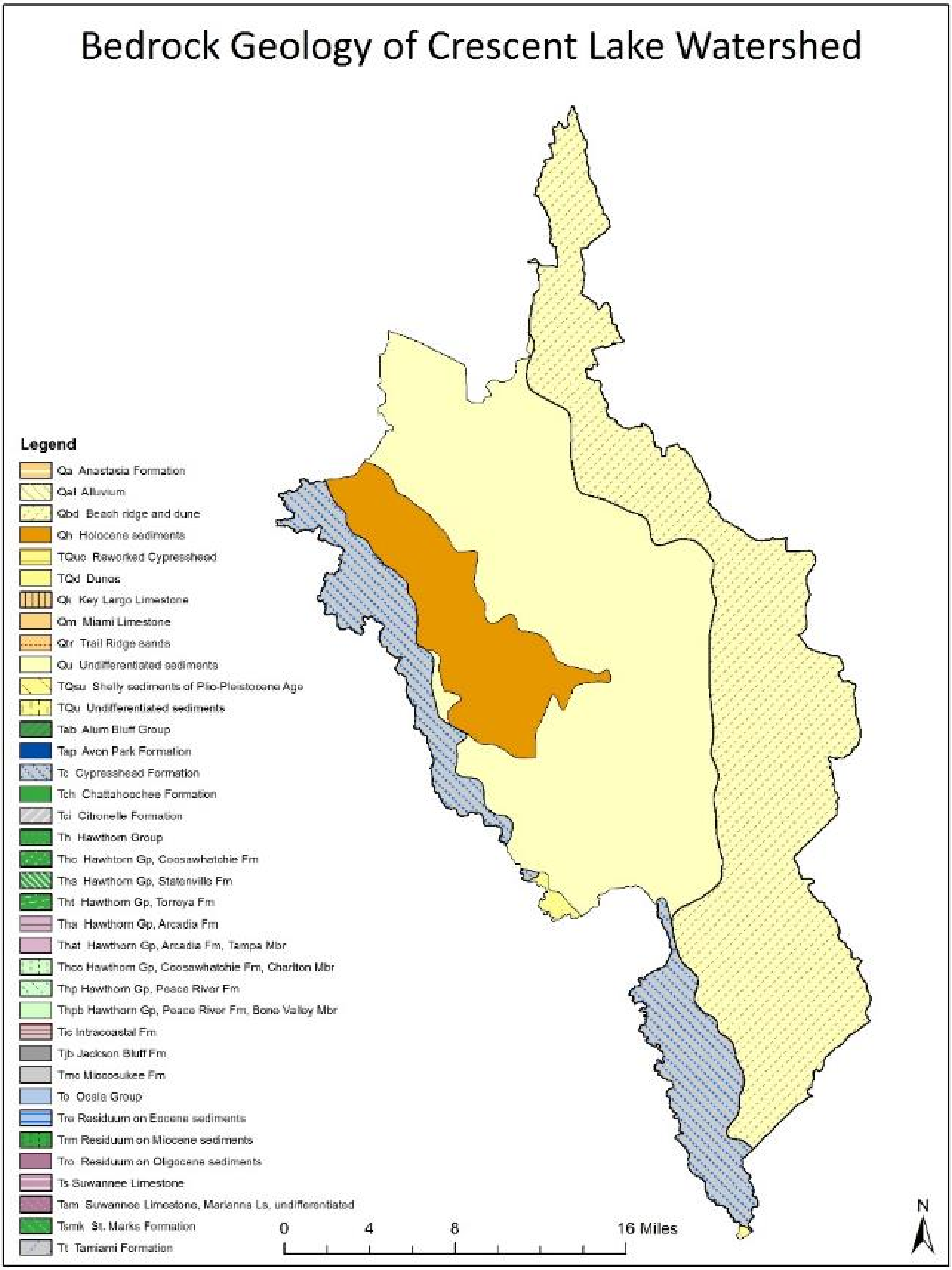

Figure 4.5. Map of the surficial geology of the Crescent Lake watershed

4.2.2.5 Estimating Septic Tank Nutrient Loadings

Residential areas not served by a centralized sewer and water treatment system may contribute nutrients to waterbodies through seepage from septic tanks. The majority of the phosphorus load in the groundwater contributed by septic tanks is either adsorbed onto particles or will rapidly do so. Nitrate nitrogen is the contaminant most often associated with septic tank loadings.

To estimate the loads derived from septic tanks, the ArcNLET model was used (the model was developed by J. Fernando Rios, Ming Ye, and Liying Wang from Florida State University, and Paul Z. Lee from DEP). This approach simulates groundwater flow based on input geographic information system (GIS) layers of watershed delineation, Soil Survey Geographic (SSURGO) Database soil data, digital elevation model (DEM), and septic tank spatial locations. The basis of ArcNLET is a cell-by-cell determination of Darcy's flow down the gradient of land surface contour defined by DEM. The septic tanks are then added and the contaminant plume is modeled, including a calculation of soil denitrification. Septic tank locations were obtained from a Florida Department of Health (FDOH) shape file residing in the DEP GIS dataminer, which is also publicly available (**Figure 4.6)**.

The loading rate generated from ArcNLET was incorporated into the BATHTUB model as a component of the groundwater flow calculated using Darcy's equation. The calculated watershed TN loading from ArcNLET of 2,160 kilograms per year (kg/yr) was included as an additional concentration to the tributaries, resulting in groundwater flow based on total load divided by groundwater flow. This additional concentration was added to groundwater as determined from regional groundwater monitoring data (which were collected in rural portions of the watersheds far from septic tanks and hence did not receive septic tank loading). **Table 4.9** summarizes the septic tank loads for each lake zone.

Table 4.9. Summary of septic tank loads per lake zone (see Section 5.3.2 for an explanation of lake zones)

Zone	N Load (kg/yr)
1	1,991
2	46
3	58
4	65

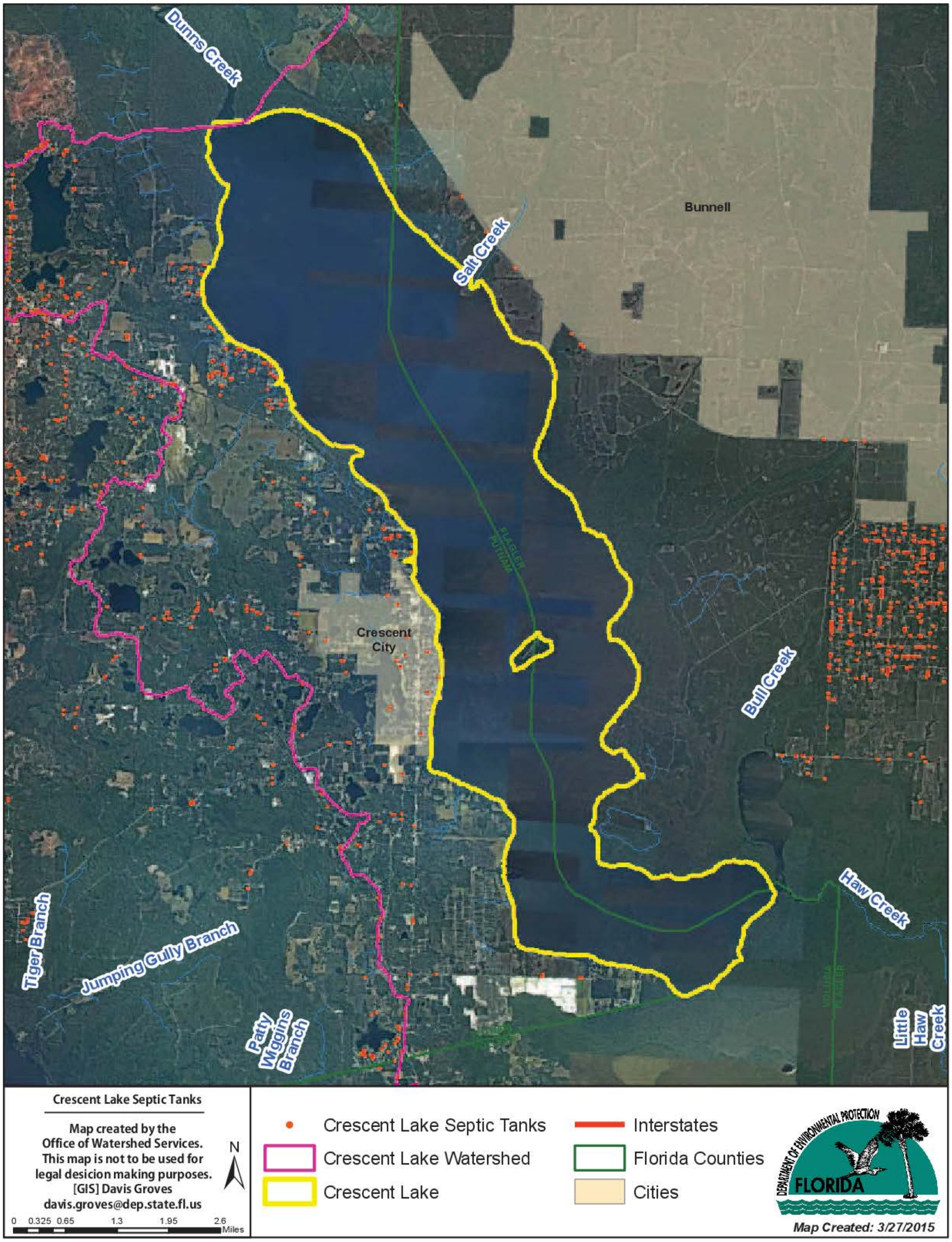

Figure 4.6. Location of FDOH-permitted septic tanks near Crescent Lake

Chapter 5: Determination of Assimilative Capacity

5.1 Determination of Loading Capacity

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

5.2 Crescent Lake Water Quality Trends

A thorough understanding of the major limnological and hydrological processes occurring in a waterbody is critical to developing a realistic TMDL. In accordance with the Florida NNC, water quality parameters were expressed as AGMs. Relationships between nutrients were evaluated to identify the driving factors behind the high Chl*a* and phosphorus levels that form the basis of the current verified impairment.

The commonly held understanding of lake biochemistry posits that increased anthropogenic nutrient loading will lead to additional algal growth above what would be expected under a natural condition. Clear relationships between stressor and response variables are expected and necessary to determine the waterbody's response to varying nutrient loadings.

However, water quality data from Crescent Lake show that the years with high nutrient levels have lower Chl*a* concentrations (**Figures 5.1** and **5.2**). This trend holds for both nitrogen and phosphorus, suggesting some other causal factor. Lake color (**Figures 5.3** and **5.4**) has a strong negative relationship with Chl*a* ($r^2 = 0.95$), suggesting that light limitation is the primary factor controlling algal growth. Chl*a* concentrations were highest during dry years when the discharge from nearby wetlands was low, causing the lake to be clear (**Figures 5.4** through **5.6**).

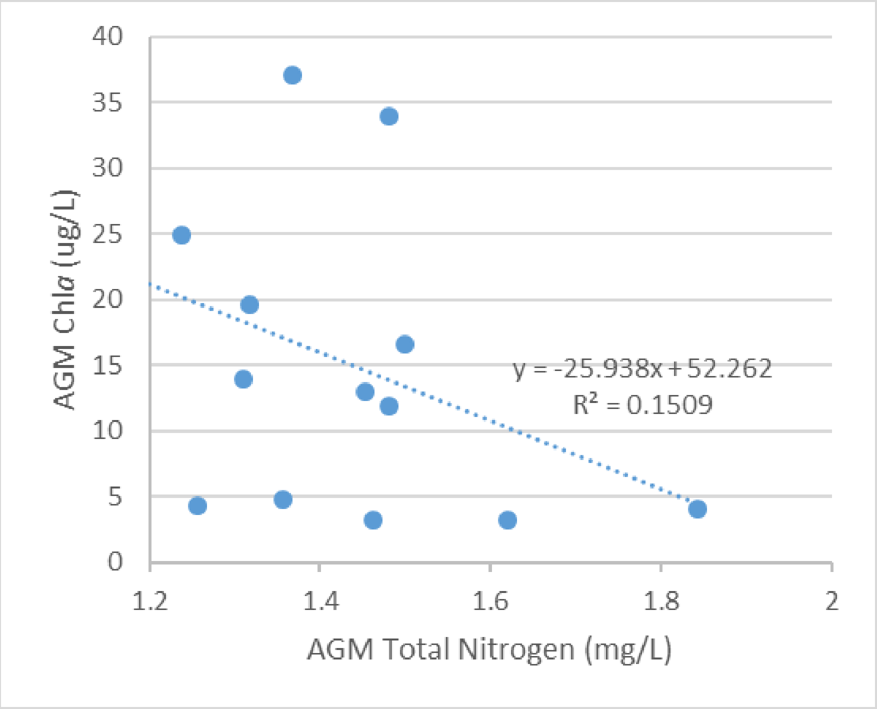

Figure 5.1. **AGM Chl*a* as a function of AGM TN in Crescent Lake**

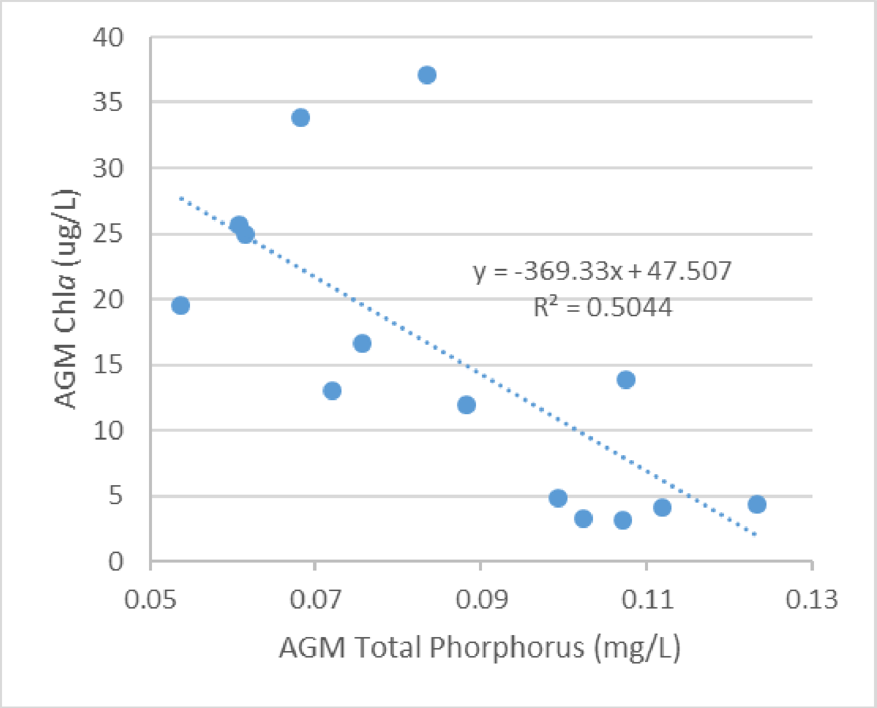

Figure 5.2. **AGM Chl*a* as a function of AGM TP in Crescent Lake**

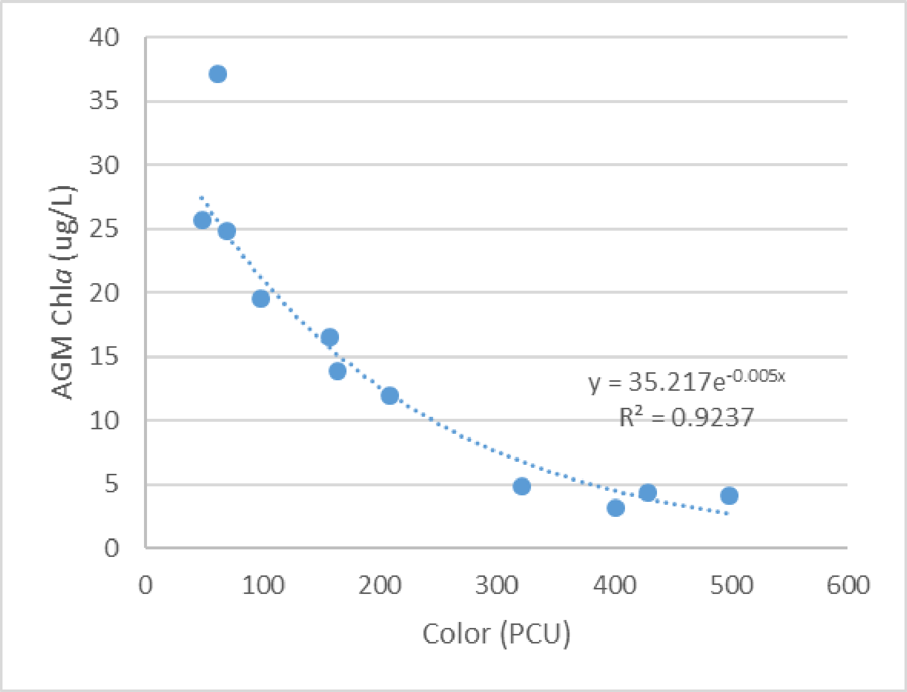

Figure 5.3. AGM Chl*a* as a function of AGM color in Crescent Lake

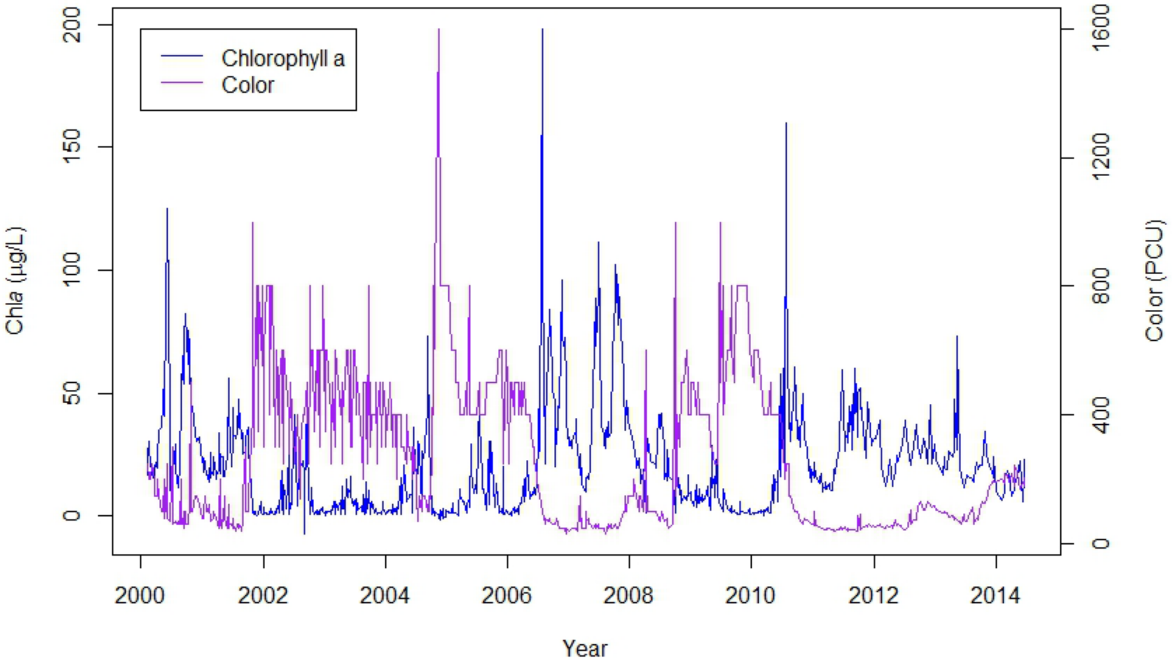

Figure 5.4. Time series of Chl*a* and color in Crescent Lake, 2000–14

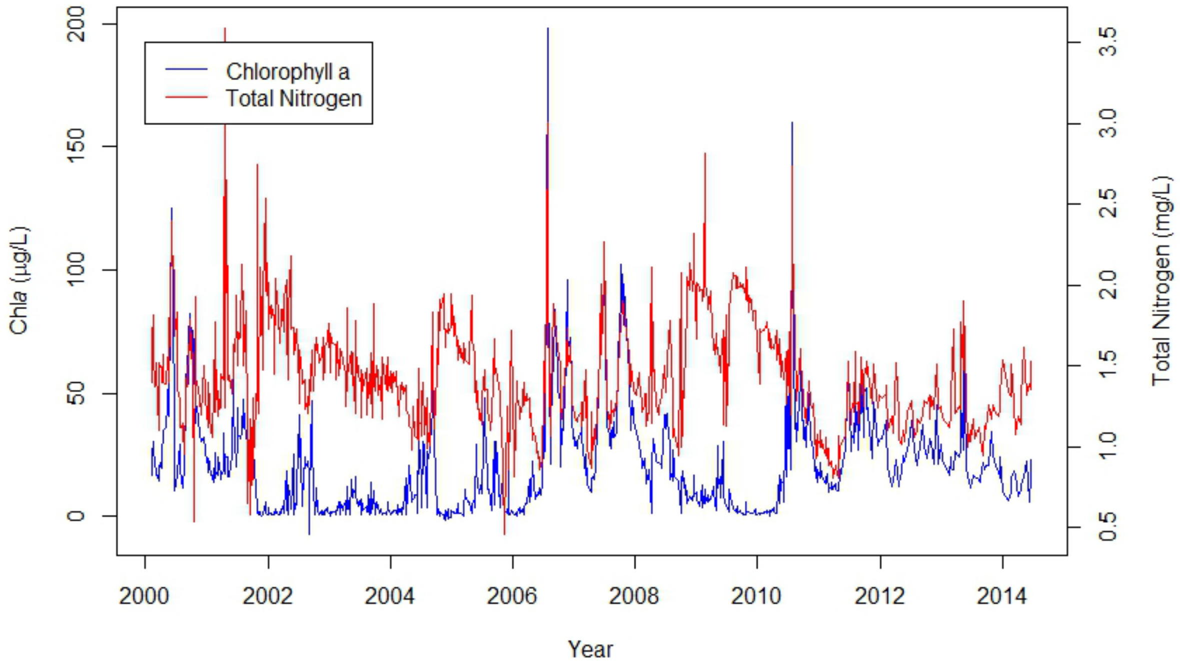

Figure 5.5. Time series of Chl*a* and TN in Crescent Lake, 2000–14

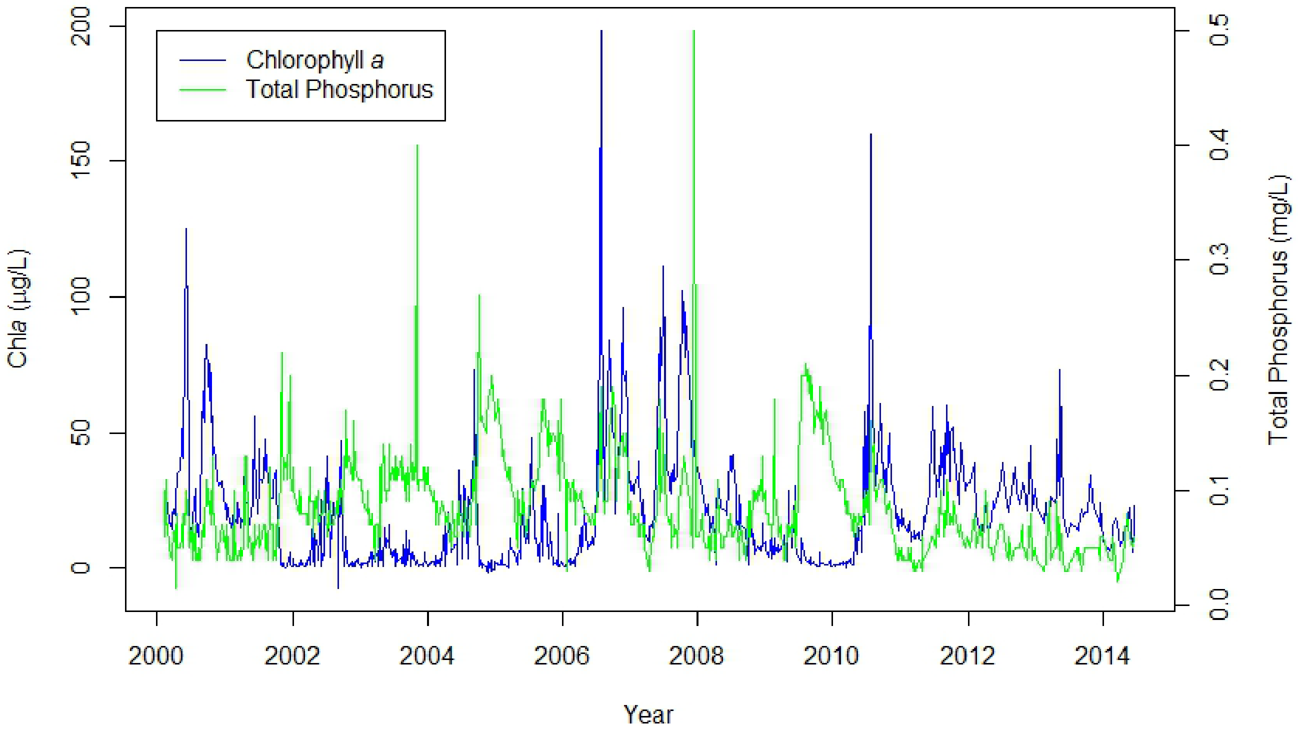

Figure 5.6. Time series of Chl*a* and TP in Crescent Lake, 2000–14

Phytoplankton community composition also responded to the light conditions of Crescent Lake, with blue-green algae dominating in clear conditions and diatoms dominating in high-color conditions (**Figure 5.7**). During dry years, when light limitation was not a controlling factor, there were strong relationships between nutrients and Chl*a* concentrations. Phosphorus, in particular, had a stronger relationship that was closer to being statistically significant (**Figure 5.8**) with Chl*a* concentrations ($r^2 = 0.83$, p=0.095) than nitrogen (**Figure 5.9**) did with Chla ($r^2 = 0.67$, p=0.497). This suggests that the limiting factor for algal growth shifted between color and nutrients, mainly phosphorus, under different hydrologic conditions.

To assess the relative impact of color and nutrients on Chl*a*, a plot of Chl*a* and color as a function of TN and a similar graph for TP were produced. Nutrient values and associated Chl*a* and color values were binned into ranges of 0.01 mg/L for TP and 0.1 mg/L for TN and expressed as geometric means per bin. In **Figure 5.10**, the nutrient control of Chl*a* concentrations is suggested by areas of the line with positive slope, and color control is shown by areas of negative slope. Zero slope indicates no relationship or a transition between light and nutrient control.

A comparison of phosphorus, color, and Chl*a* concentrations suggests that there is a zone of nutrient control at color levels of less than 100 PCU, a zone of co-limitation by color and nutrients from 100 to 150 PCU, and color control above 150 PCU (**Figure 5.10**). Comparing nitrogen with color and Chl*a* reveals a much weaker pattern than with phosphorus, which may derive from the fact that nitrogen was less correlated with Chl*a*, and that nitrogen fixation may alter the simple stressor-response relationship during blue-green algal blooms (**Figure 5.11**).

To better understand the changes in the algal community, a nonmetric multidimensional scaling (NMDS) ordination was performed on algal abundances with Bray Curtis distances used on Wisconsin double standardized abundances. Ordination is a statistical approach to extract relevant patterns from multidimensional data and express the results in fewer dimensions (**Figure 5.12**). NMDS ordination is similar to a principal components analysis (PCA). However, it is nonparametric and the procedure is typically repeated to ensure that solutions which represent local minima are avoided, in contrast to a PCA.

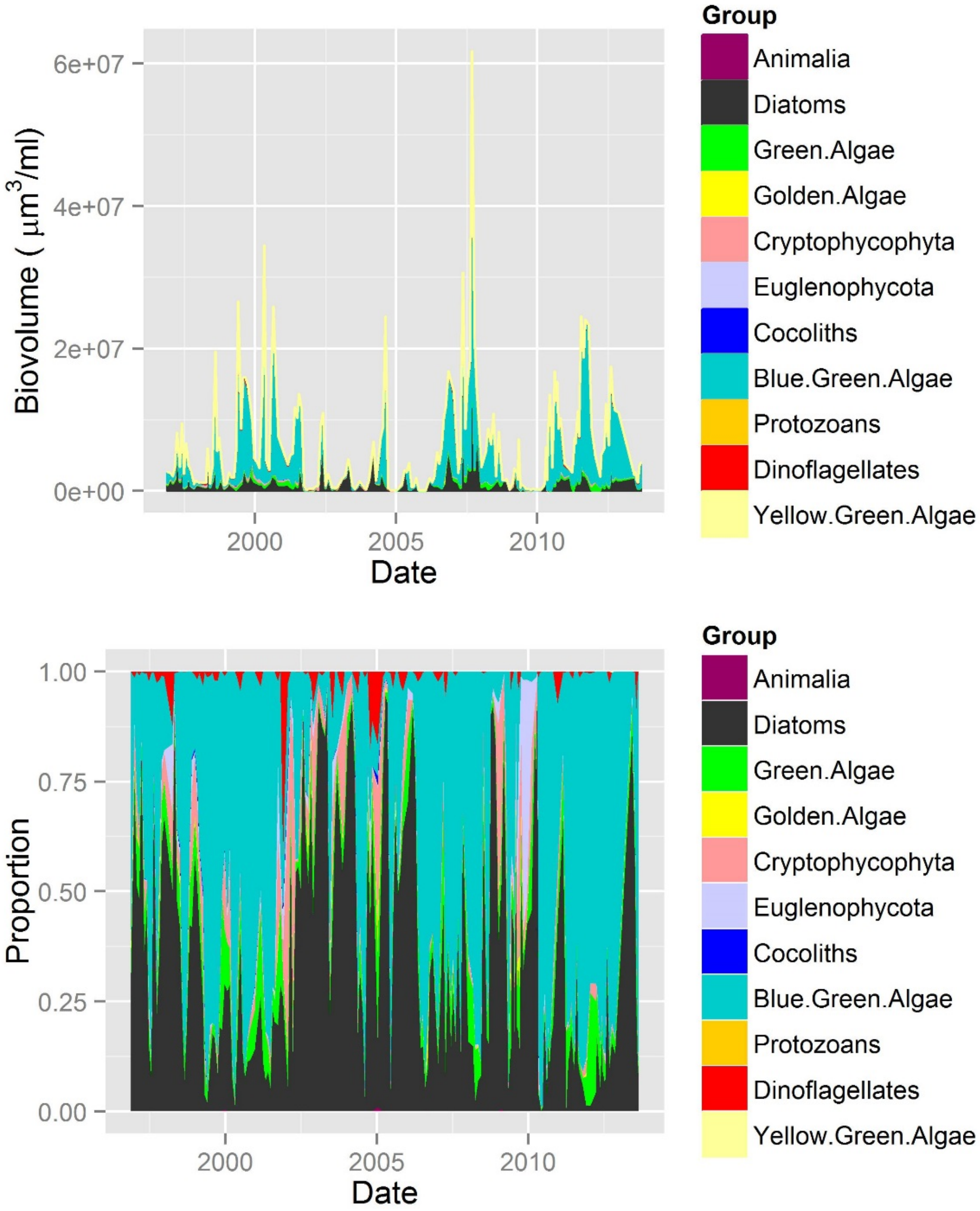

Figure 5.7. Algal community composition (biovolume and proportion) of Crescent Lake, 2000–14

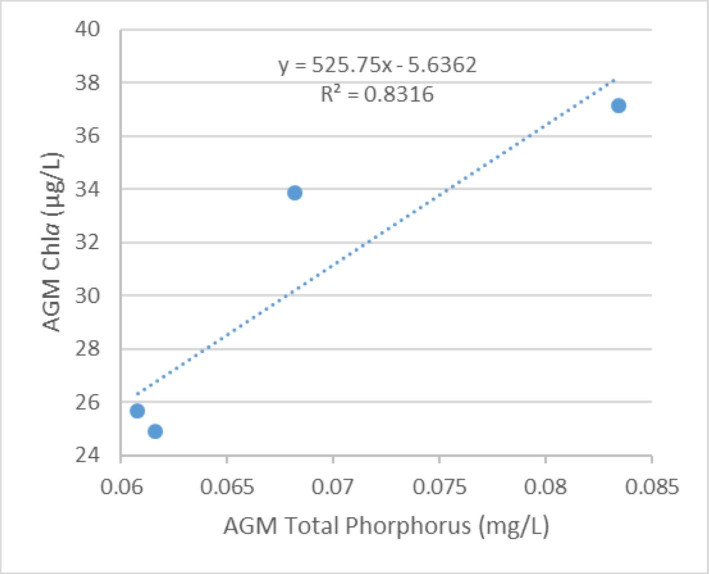

Figure 5.8. **Dry year AGM Chl*a* as a function of AGM TP in Crescent Lake**

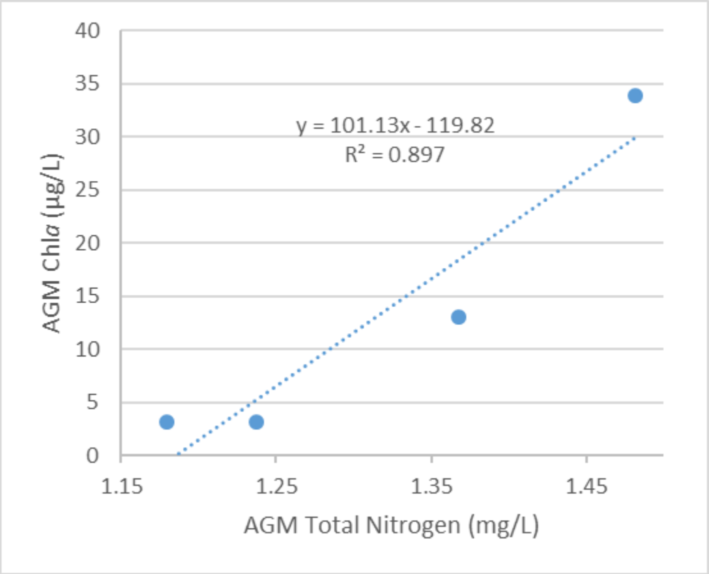

Figure 5.9. **Dry year AGM Chl*a* as a function of AGM TN in Crescent Lake**

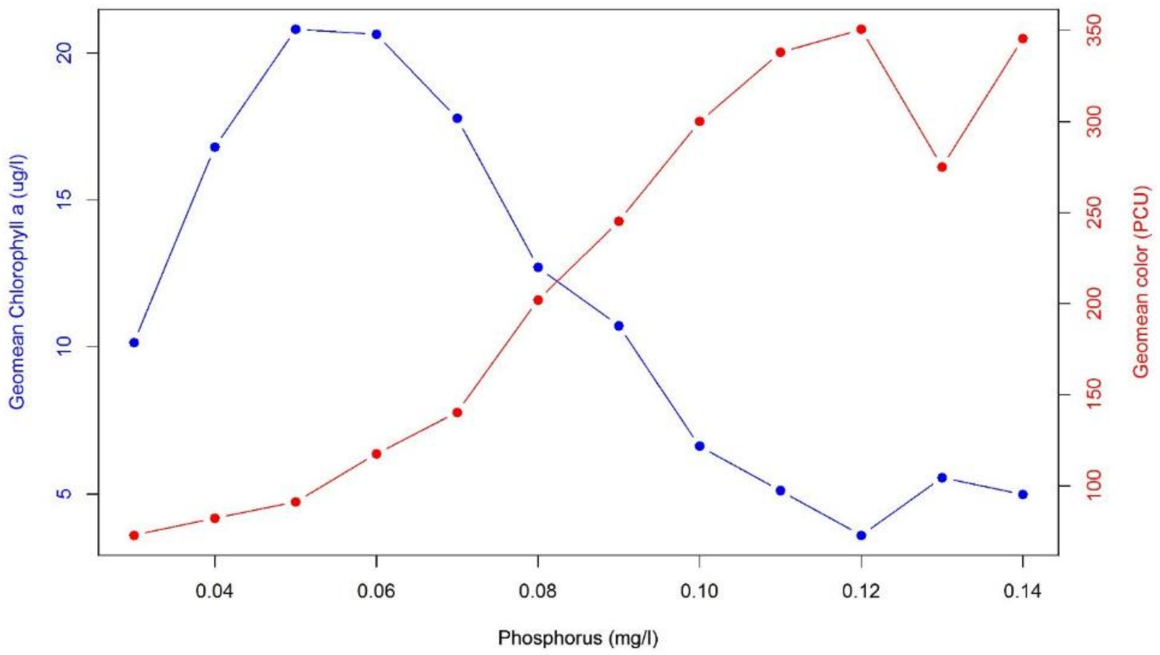

Figure 5.10. Geometric mean Chl*a* and color (Y-axis) plotted against phosphorus concentrations (X-axis) in Crescent Lake

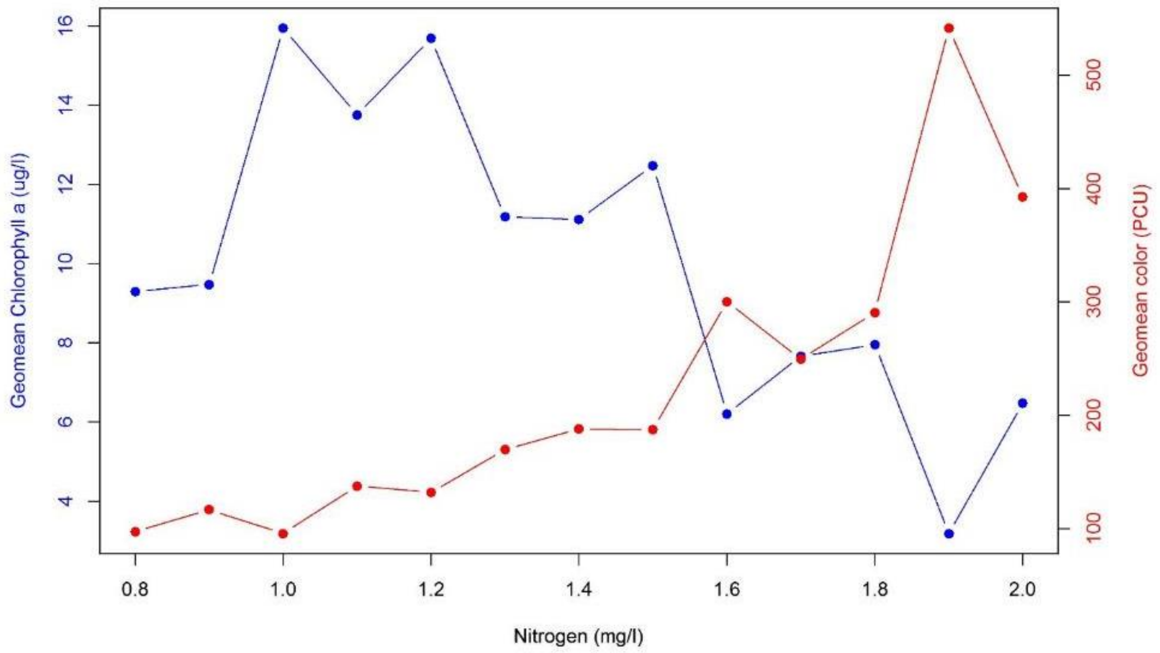

Figure 5.11. Geometric mean Chl*a* and color (Y-axis) based on phosphorus concentrations (X-axis) in Crescent Lake

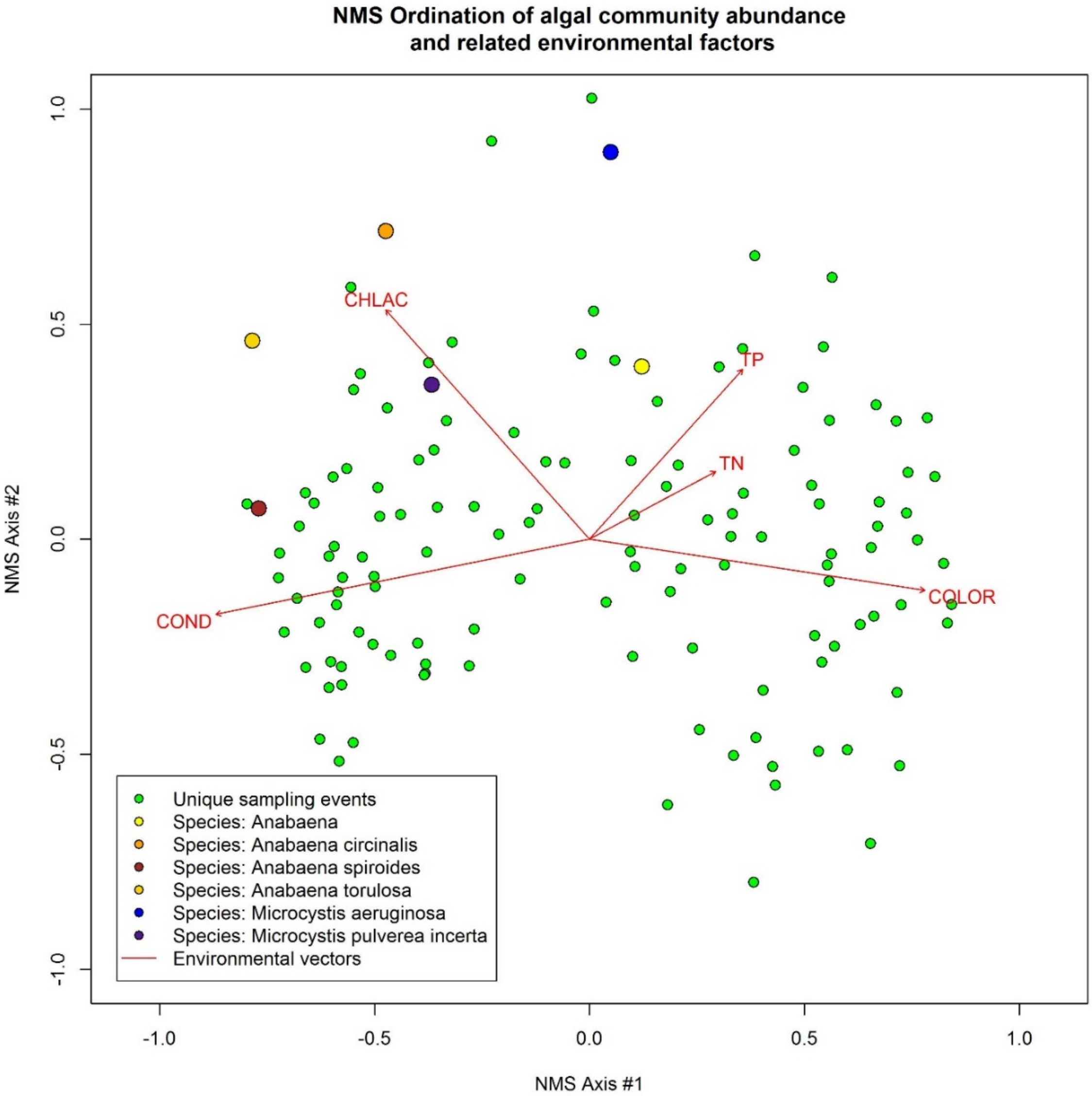

Figure 5.12. NMS ordination of algal species abundance, with Wisconsin double standardization. Red vectors indicate the correlation of environmental variables with the ordination axes.

One important decision that needed to be made was the dimensionality of the ordination solution. Dimensionality was assessed with a scree plot that shows the stress of the solution representing divergence between the ordination distances and the original distances in the distance matrix, or more simply the badness of fit of a given solution. For the Crescent Lake data, a two-dimensional solution was chosen as a tradeoff between the complexity of the solution (lower with fewer dimensions) and stress (lower with a higher number of dimensions) (**Figure 5.13**).

Relevant environmental variables (TN, TP, conductivity, color, and Chl*a*) were chosen from the nearest water quality station in Crescent Lake and displayed on the ordination diagram (**Figure 5.12**). The length of the vector represents the strength of the relationship, while the X and Y portions of its direction correspond to the degree of correlation to each axis. The environmental variables with the strongest correlation are conductivity and color, both of which load onto the X-axis in opposite directions. Collectively, both variables describe the amount of rainfall in a given year and therefore the color and flushing rate of the system, with wet years on the right side of the ordination and dry years on the left side. This ordination analysis found meaningful relationships. Overall, a strong relationship was observed between observed environmental conditions and the major aspects of community change through time.

Individual species can be plotted to show their average location in the ordination space. Both blue-green species, *Anabaena* and *Microcystis*, were displayed on the ordination plot because of their role as the primary bloom-forming organisms. Within the ordination, both blue-green algal species are clustered high on the Y-axis, suggesting that positive Y-axis values represent community composition during a harmful algal bloom. The most correlated variables with this axis are Chl*a* and TP. TN is correlated with the Y-axis. However, the strength of the correlation is much less than with TP (**Figure 5.12**).

The Y-axis was plotted as a function of month (**Figure 5.14**) with LOESS central tendencies and confidence intervals added. The peak values of the second ordination axis occurred during August and September, indicating that algal blooms are most likely to occur during late summer. The ordination analysis shows that cyanobacteria growth occurs predominantly in dry conditions in Crescent Lake, when light penetration in the water is high. Under this drought condition, the lake is quite sensitive to nutrient concentrations, and small increases in nutrient concentrations leads to large increases in algal growth. This state is in direct contrast to the more common state of very high color and therefore very low light penetration, with associated high levels of nutrients. This result is also indicated by the bivariate plots shown at the beginning of this section, but reality has more than two dimensions and is in actuality more like an n-dimensional hyperspace where N is the number of species observed. In nearly all cases N is greater than 4 and therefore beyond the realm of simple visualization.

This problem of understanding a high dimensional system reveals one of the primary advantages of ordination, particularly a nonconstrained approach such as NMDS. In particular, the ability of the ordination technique to help with dimension reduction and pattern extraction allows the human mind to better understand the highly complex functional relationships that are often embedded in environmental data.

Another aspect of algal community composition is the progression of algal community composition through time (**Figure 5.15**). Note that most years showed algal community composition making a roughly circular pattern, with the exception of 2010, which showed the transition between wet conditions and dry conditions (**Figure 5.27** shows yearly rainfall patterns from 2000 to 2013). The higher rainfall in 2009 (58 inches) compared with the very low rainfall in 2010 (33 inches) and the moderately low rainfall in 2011 and 2012 (49 and 41 inches, respectively) resulted in shifts in the average location of the yearly points along the first or X ordination axis.

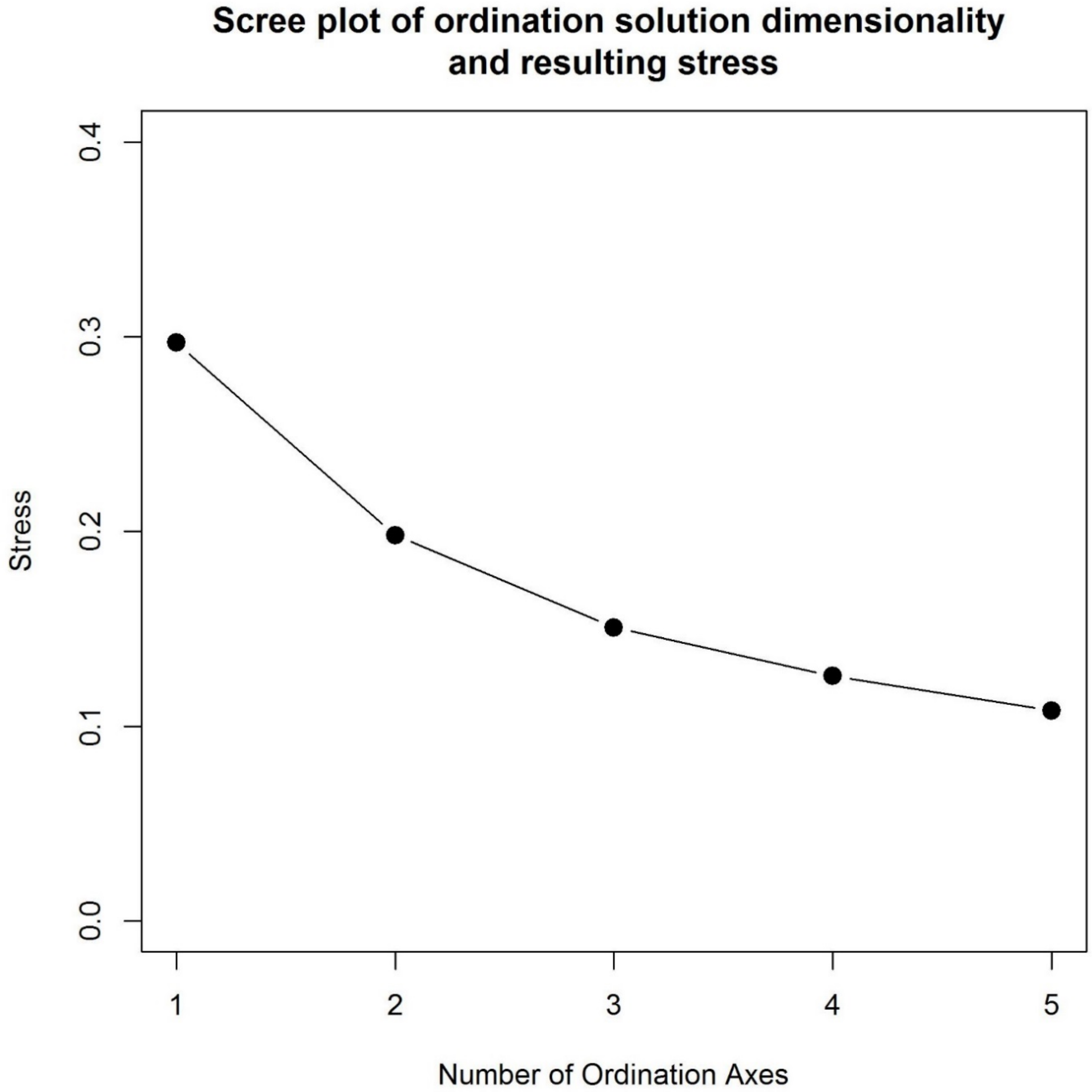

Figure 5.13. Scree diagram for the NMDS ordination depicting the stress of each ordination solution as a function of the number of calculated axes. The two-dimensional solution was chosen for ease of analysis despite the relatively high stress of the solution.

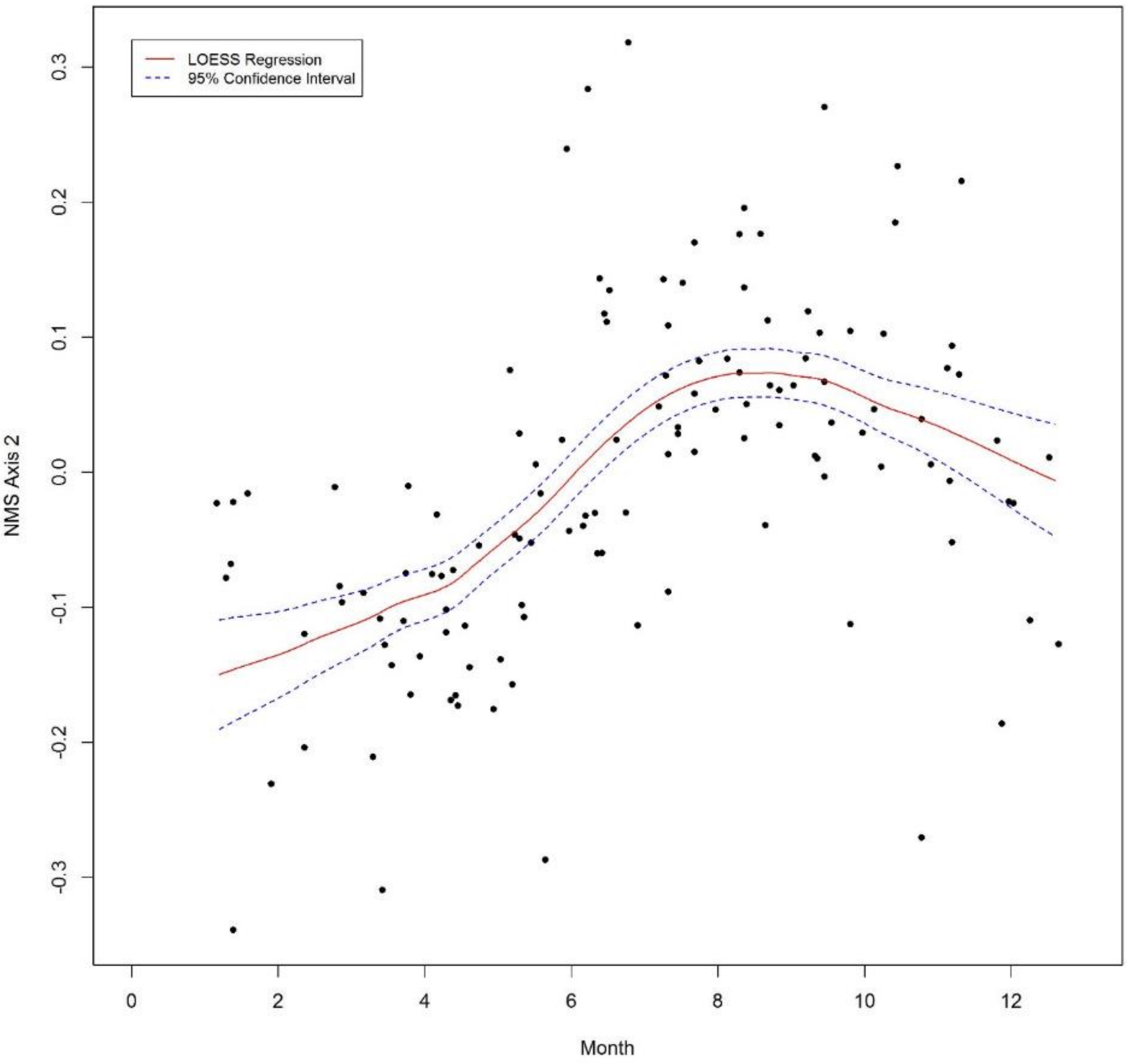

Figure 5.14. Monthly variation in Ordination Axis #2, which represents the degree of impairment in the algal community

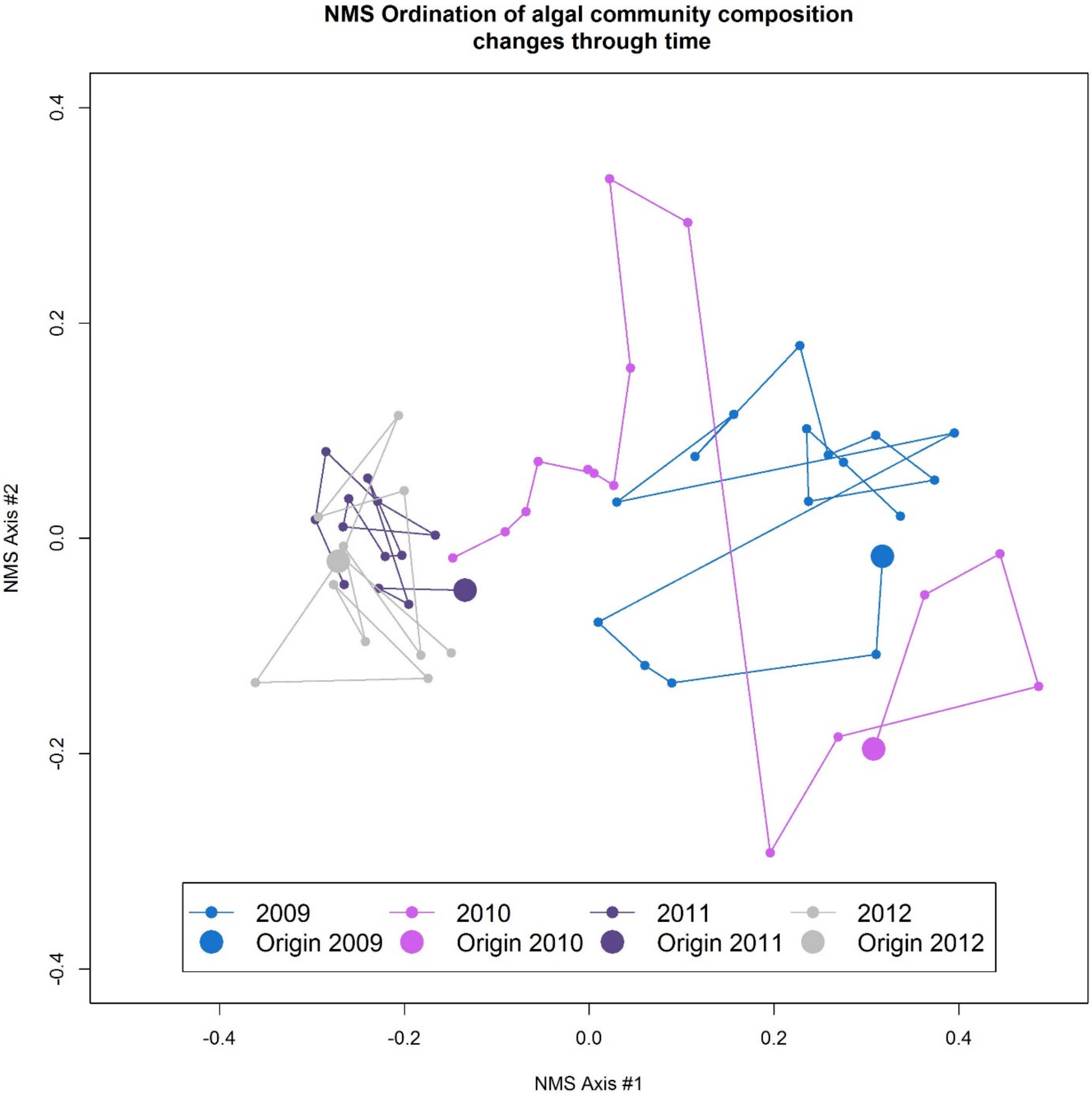

Figure 5.15. Time series plot in ordination space showing the yearly composition trajectories, 2009–12

Crescent Lake experiences dynamic water quality conditions from year and season to season. The variation in color levels and therefore light availability is the primary factor controlling annual Chl*a* concentrations. In clear conditions, both nitrogen and phosphorus appear to be correlated with Chl*a* concentrations.

Phytoplankton community structure is similarly affected by the clarity of the lake as the primary determinant of variation in species abundance. Nutrients appear to be secondary factors affecting phytoplankton community structure. On a seasonal basis, phytoplankton community structure shifts in a roughly circular pattern that usually progresses clockwise starting in the 6:00 position. Years with more stationary water quality parameters appear to have more stationary algal communities. Therefore, it can be concluded that water quality conditions, primarily clarity and secondarily nutrient levels, are the main determinants of algal biomass and species composition.

5.3 Crescent Lake Water Quality Modeling

5.3.1 BATHTUB Overview

The USACOE BATHTUB model was selected to represent the water quality processes occurring in Crescent Lake (Walker 1999; Walker 1987). BATHTUB was designed to represent reservoirs and other large bodies of water with relatively stable water levels, and to simulate steady-state lake conditions Therefore the model is more appropriate for long-term receiving water simulation than simulation over short periods.

The model runs in a hydrologic framework consisting of lakes or lake segments that may be directly or indirectly connected. Tributaries deliver incoming water and nutrients to specific lakes or lake segments. Meteorological inputs are also considered, including the atmospheric deposition of nutrients, rainfall, and evaporation directly onto the lake surface. The BATHTUB model is actually a modeling framework that calculates a series of empirical relationships between nutrient loading, physical parameters, and Chl*a* growth.

5.3.2 BATHTUB Inputs

5.3.2.1 Model Segmentation

In the BATHTUB model, lakes can either be represented as one unified waterbody, or as segmented portions of a larger lake. The original model runs were conducted with the lake as one unified segment. However, there was later refinement in response to a number of lines of evidence. Crescent Lake is a large and long lake, and therefore water quality conditions in different parts of the lake are expected to be spatially heterogeneous because of the lake geometry. The majority of the watershed drains through Haw Creek into the southern end of the lake. This configuration should lead to differences in water quality in different parts of the lake as the high-nutrient stream flow is mixed and transported north along the length of Crescent Lake.

In addition, water quality information collected by DEP's TMDL staff and the EPA (1977) was used to characterize the degree of homogeneity between water samples collected across the lake surface. Longitudinal samples collected by TMDL staff in October 2014 (**Figure 5.16**) show differences in water quality in different parts of the lake. TP concentrations decreased by 30 % to

50 % from the south end of the lake to the northern end (**Figure 5.17**). TN concentrations decreased along this transect as well, though only by 10 % to 30 % (**Figure 5.18**). Similarly, both Chl*a* concentrations (**Figure 5.19**) and color (**Figure 5.20**) decreased along the south-north transect. These water quality results suggest that Crescent Lake is not homogeneous and therefore should be represented by more than one model grid segment.

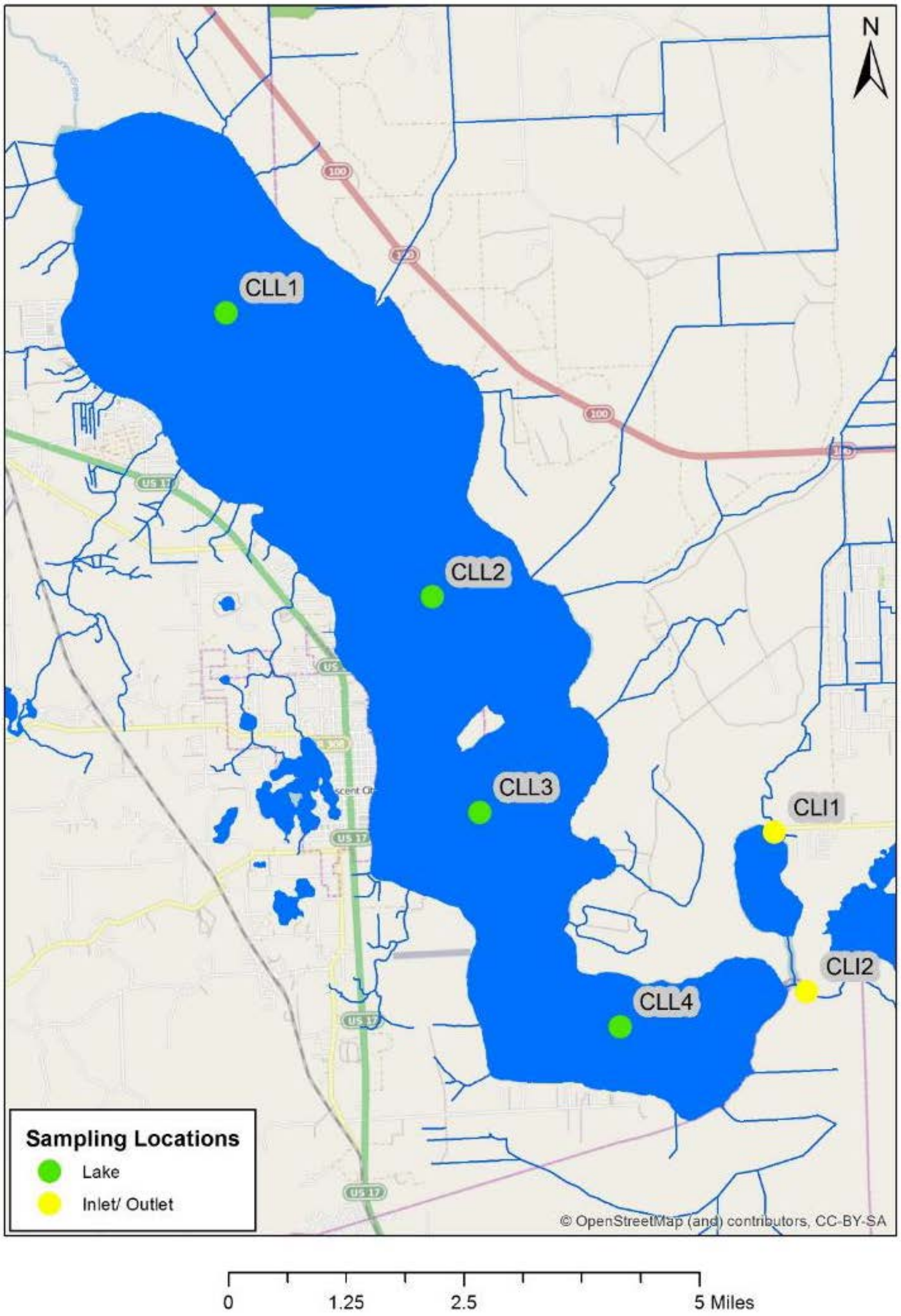

Figure 5.16. Sampling locations in Crescent Lake

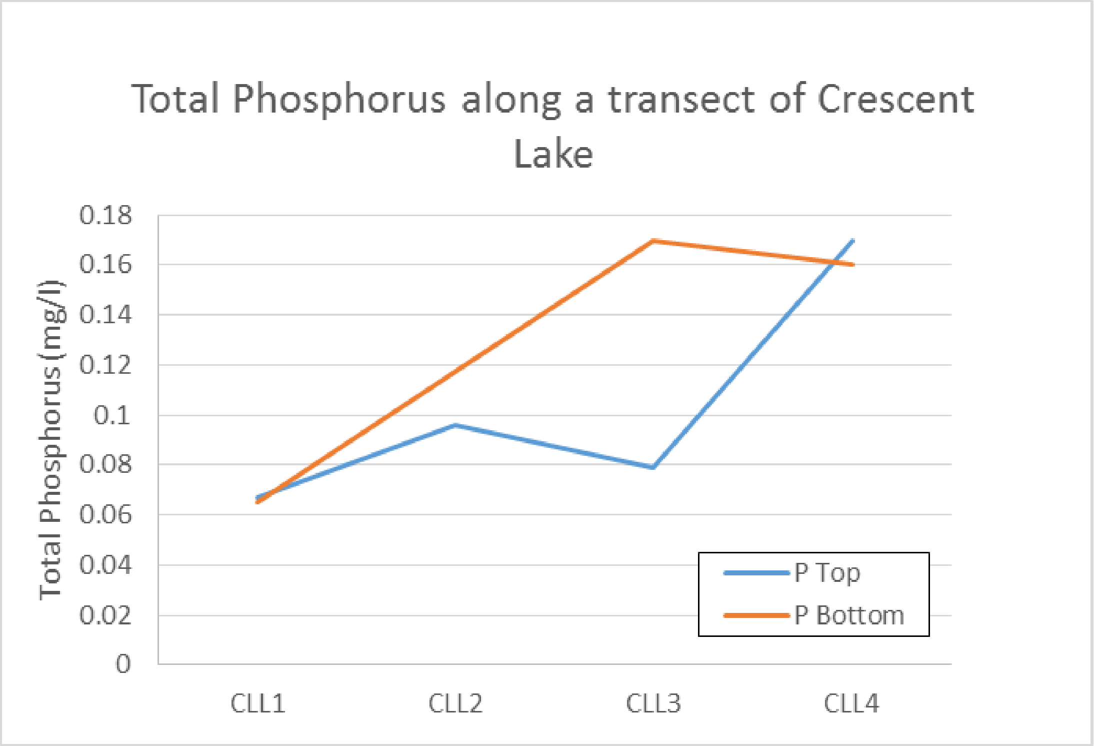

Figure 5.17. TP along a north (CLL1) to south (CLL4) transect of Crescent Lake

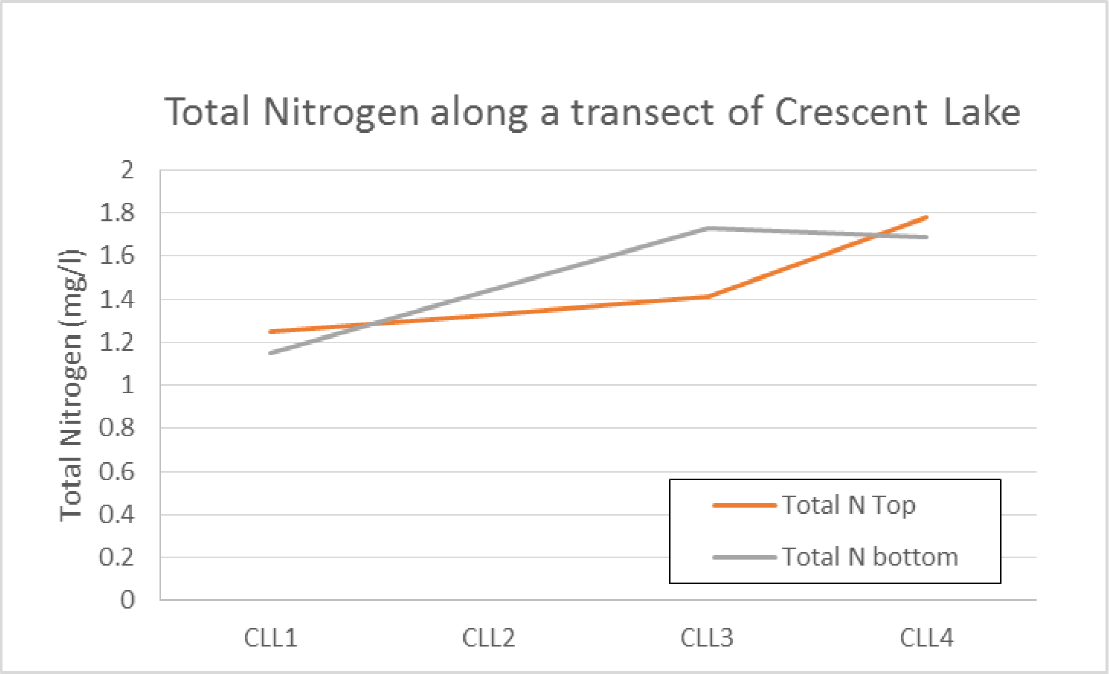

Figure 5.18. TN along a north (CLL1) to south (CLL4) transect of Crescent Lake

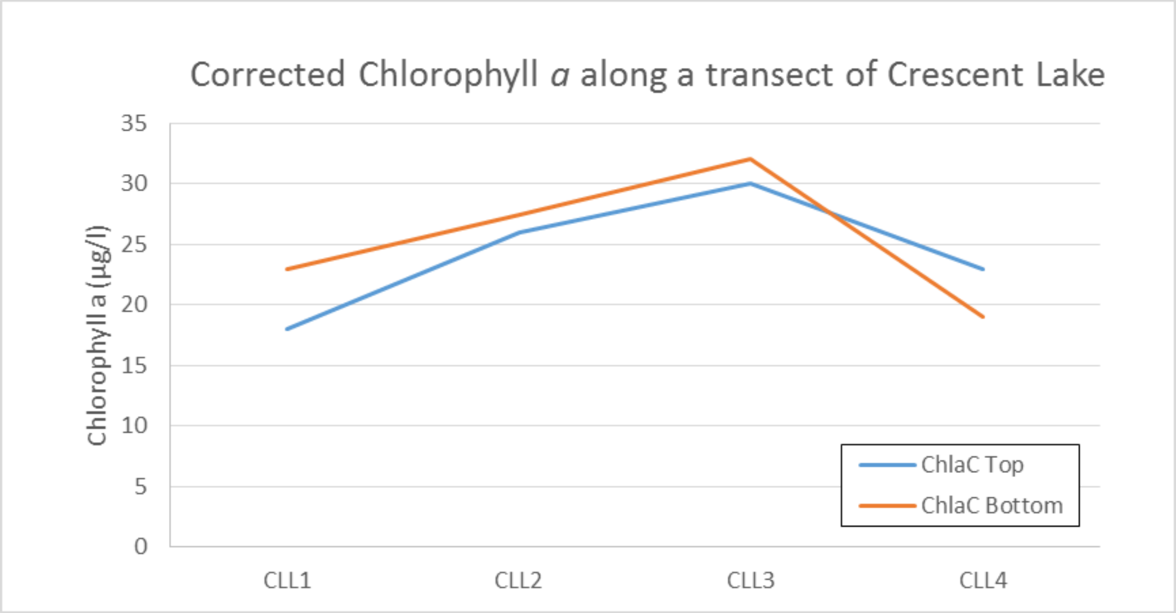

Figure 5.19. Chl*a* along a north (CLL1) to south (CLL4) transect of Crescent Lake

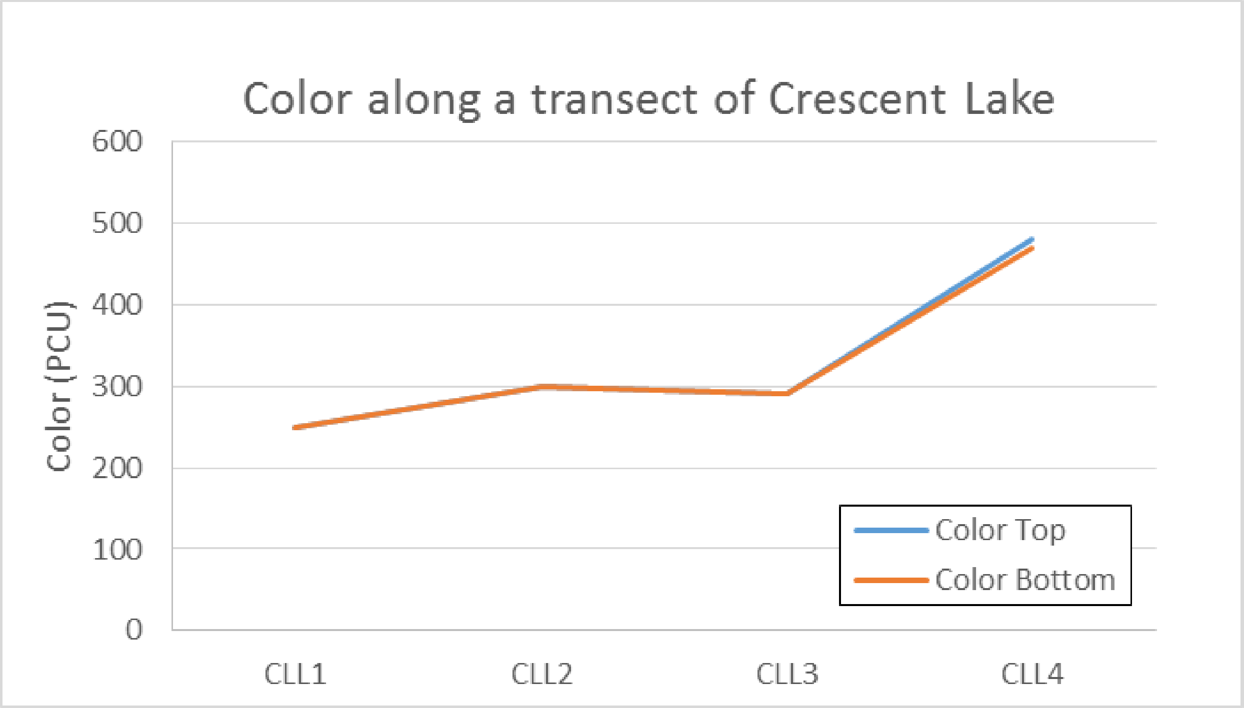

Figure 5.20. True color along a north (CLL1) to south (CLL4) transect of Crescent Lake

In BATHTUB, the surface area of the lake was split into 4 segments to allow the model to more specifically represent the flow of water and solutes through the 10-mile-long expanse of the lake (**Figures 5.21** and **5.22**). The zones were defined based on the morphology of the lake and water quality results, with a goal of keeping similarly homogeneous areas of the lake in the same cell. The watershed model was similarly divided to allow for nutrient delivery from the curve number model to each lake segment (**Figure 5.22**). In addition, groundwater flux was added to each lake cell as calculated using Darcy's law (see **Section 4.2.3**).

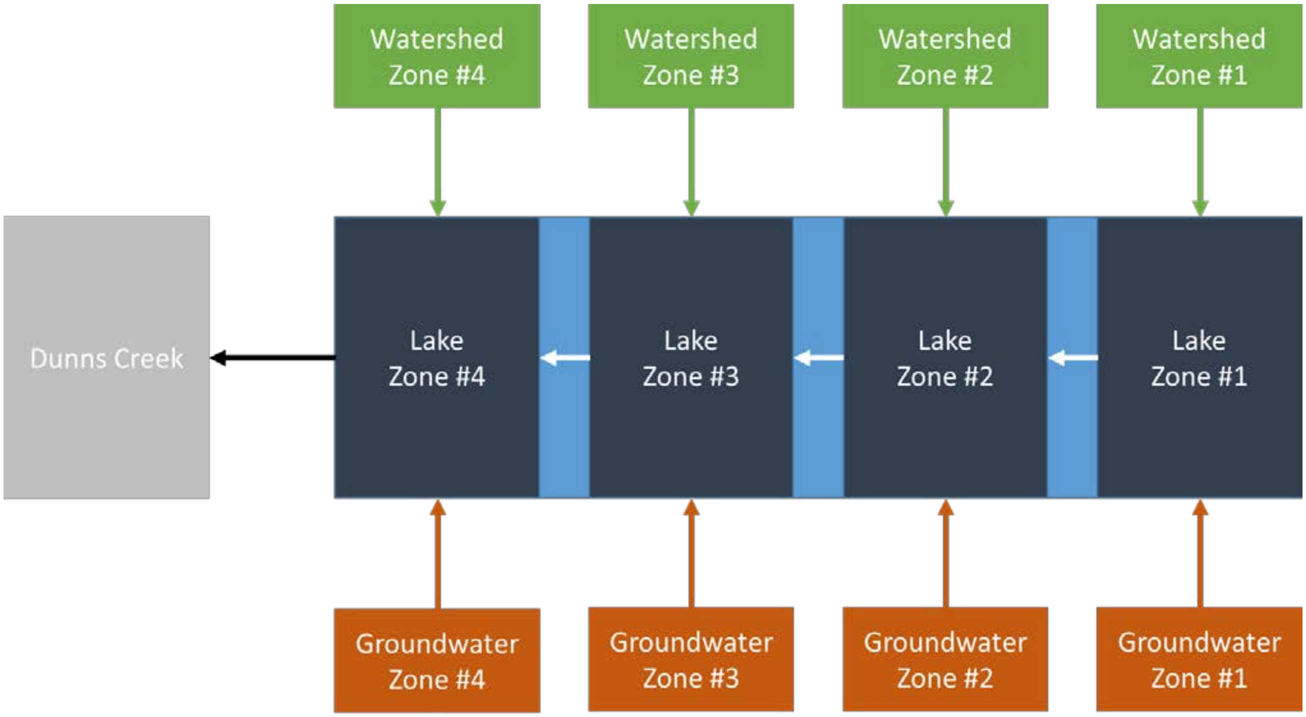

Figure 5.21. Watershed configuration used in the BATHTUB model showing inputs from the watershed and groundwater, and output through Dunns Creek

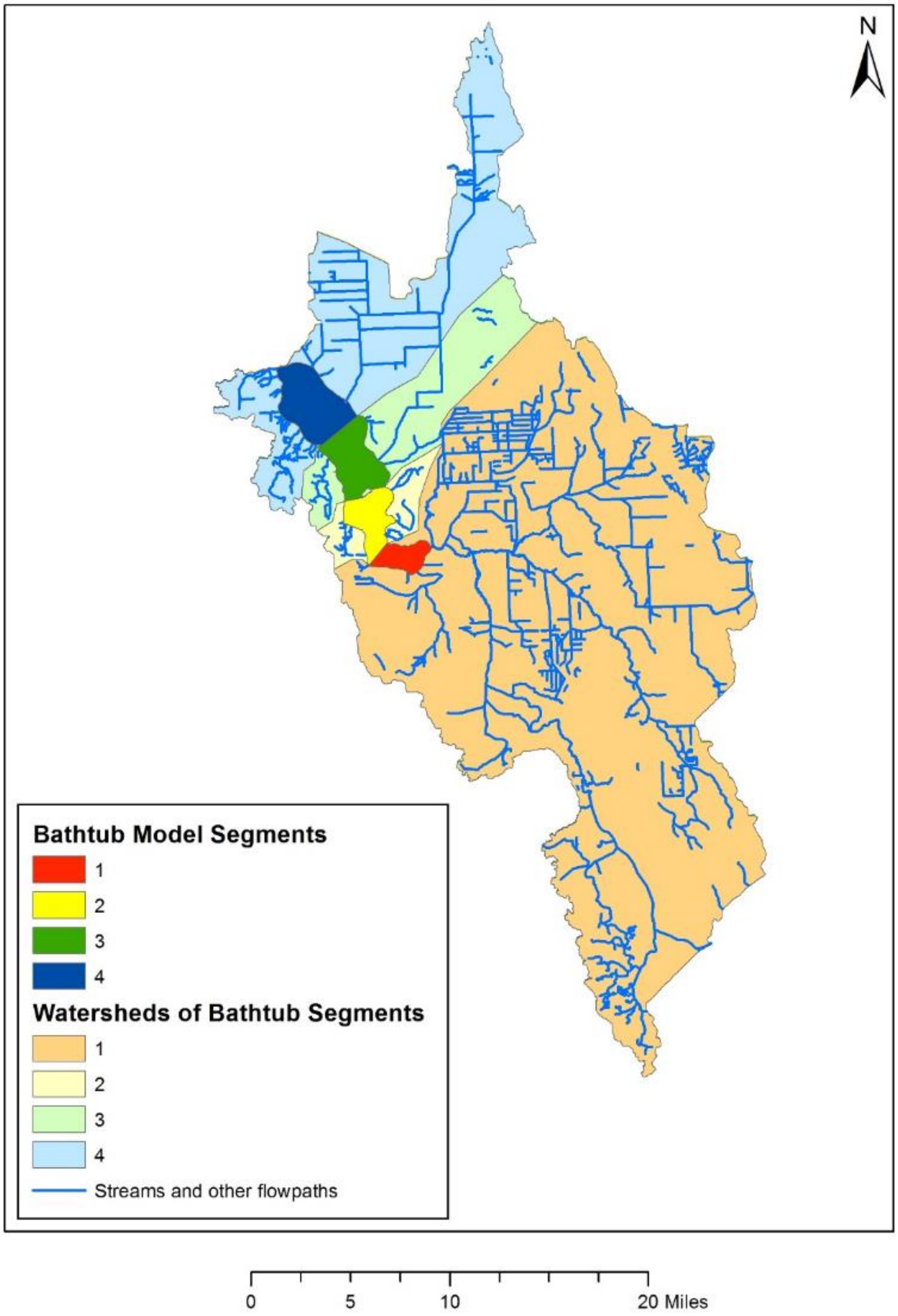

Figure 5.22. Model segmentation of the watershed and receiving waterbody model segments for Crescent Lake

5.3.2.2 Morphologic Inputs

The physical characteristics of a given waterbody are important parameters in the BATHTUB model. Factors such as residence time and nutrient fate and transport depend on the size and configuration of a given waterbody. Crescent Lake averages 2.4 m deep, though the northern portion of the lake is significantly deeper than the southern portion, reaching a maximum depth of 4.2 m (**Figure 5.23**). Crescent Lake is 10 miles long and has a surface area of 67 km^2, with a watershed area of 574 km^2.

The volume of Crescent Lake is 0.17 cubic kilometers (km^3), making it one of the largest lakes in Florida. The floor of Crescent Lake is bathtublike in that a broad flat plain across most of the lake is 8 to 11 feet deep. The lake has steep slopes along the littoral zone. The bottom is dominated by large flat areas of the pelagic zone (**Figure 5.23**).

It is assumed that the water level in Crescent Lake remains relatively constant from season to season and from year to year. The land surrounding Dunns Creek is within several inches of the lake surface elevation, and therefore the flow path out of the lake will expand to a 2-mile-wide swath if the lake elevation increases by 1 foot. Given the shape of the lake bottom as previously described, the lake surface area will not decrease dramatically if the lake stage decreases (**Figure 5.24**). The lake volume, on the other hand, decreases linearly with decreasing lake stage below the average stage (**Figure 5.25**). Lake stages above the current lake stand increase the surface area in a nonlinear fashion due to 2 terraces, the first a foot above the current lake elevation, and the second at 6 feet above the present lake level.

5.3.2.3 Meteorological Data

5.3.2.3.1. RAINFALL

Rainfall inputs to the modeling processes were based on 1 rainfall gage located in the center of the Crescent Lake watershed (**Figure 5.26**). Maintained and measured by the SJRWMD, it is referred to as the Cody Corner station. The gauge site is located east of Lake Disston, in the southern half of the watershed. Rainfall varies from year to year, with distinct dry periods occurring in 2000, 2006, 2010, and 2014 based on total annual rainfall of 40 inches or less (**Figure 5.27**).

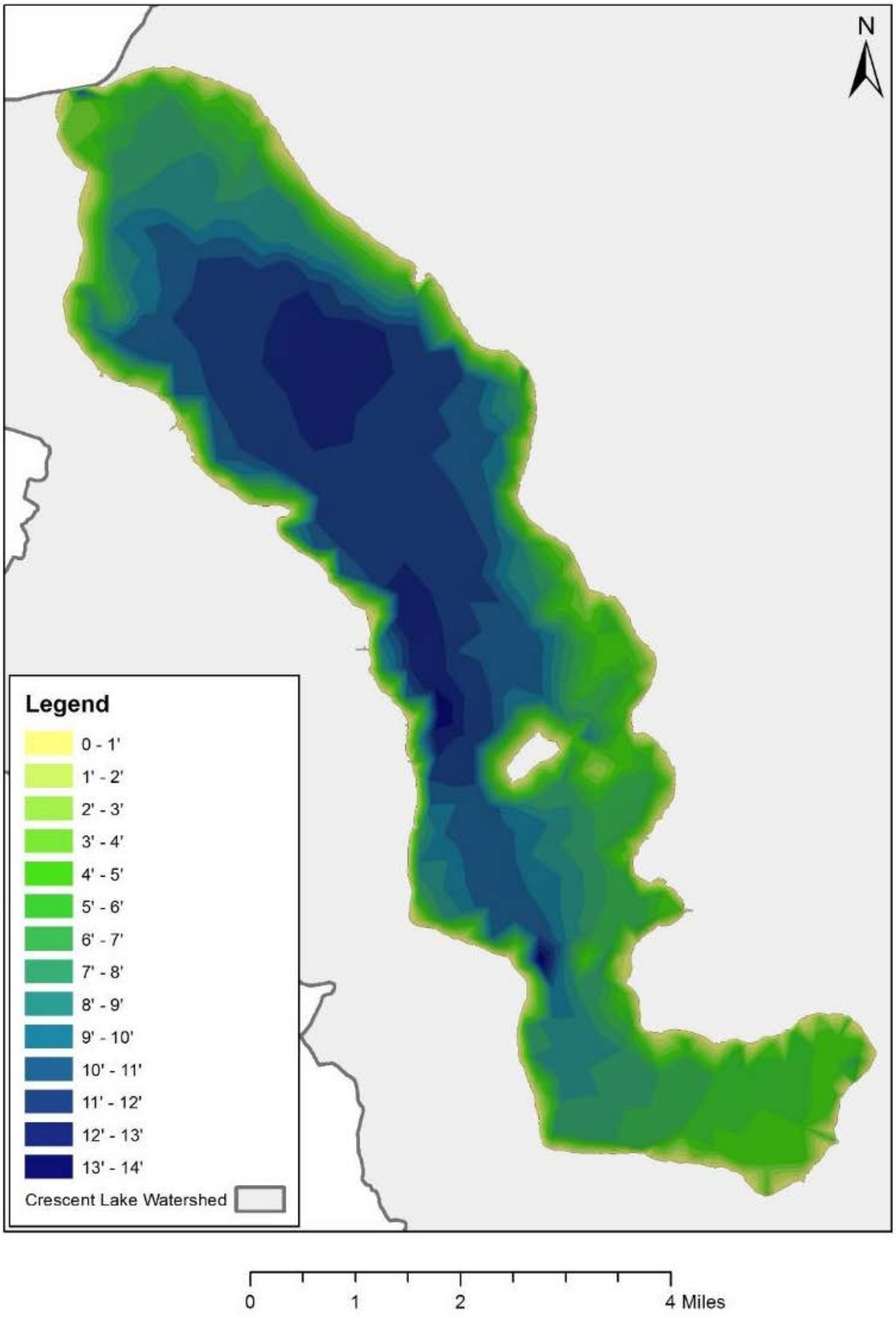

Figure 5.23. **Crescent Lake bathymetry (data from a National Oceanic and Atmospheric Administration [NOAA] coastal navigation chart)**

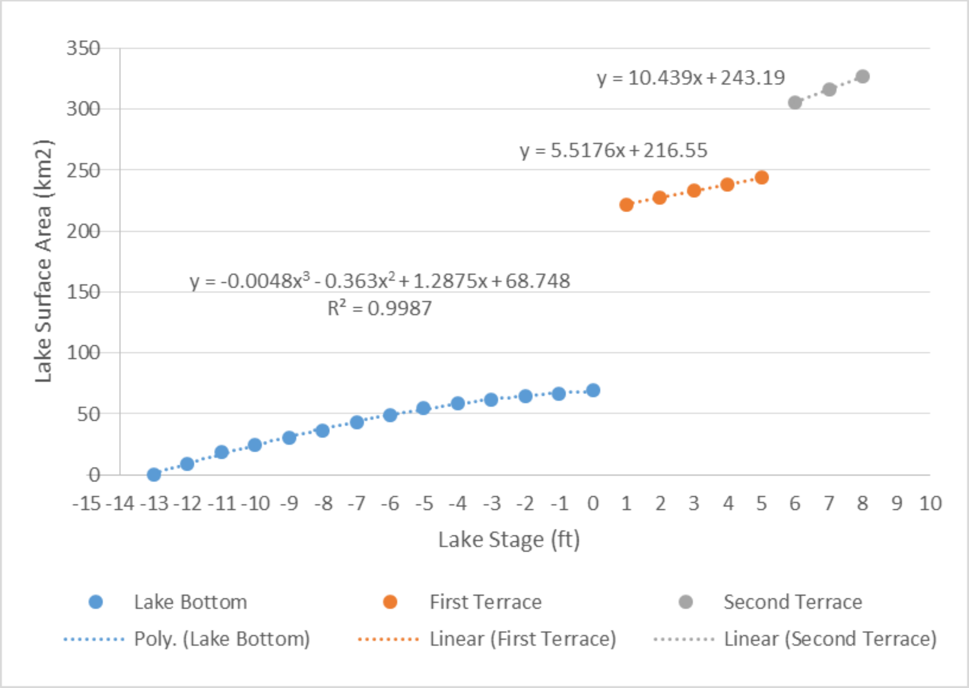

Figure 5.24. Lake surface area as a function of lake stage relative to current average elevation (zero on the X-axis)

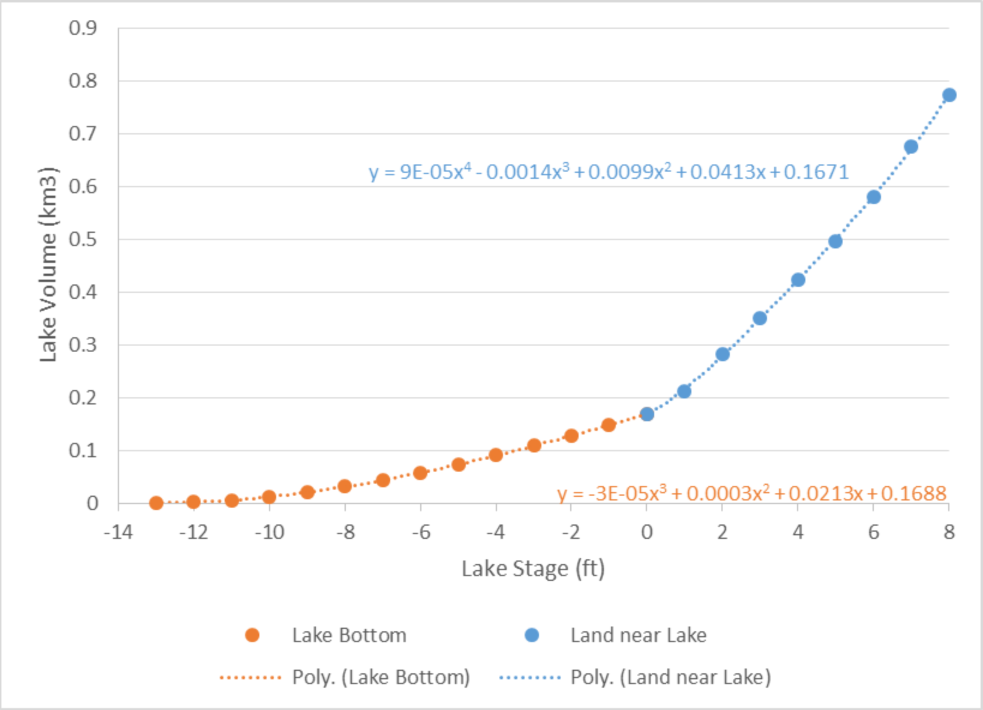

Figure 5.25. Lake volume as a function of lake stage relative to current average elevation (zero on the X-axis)

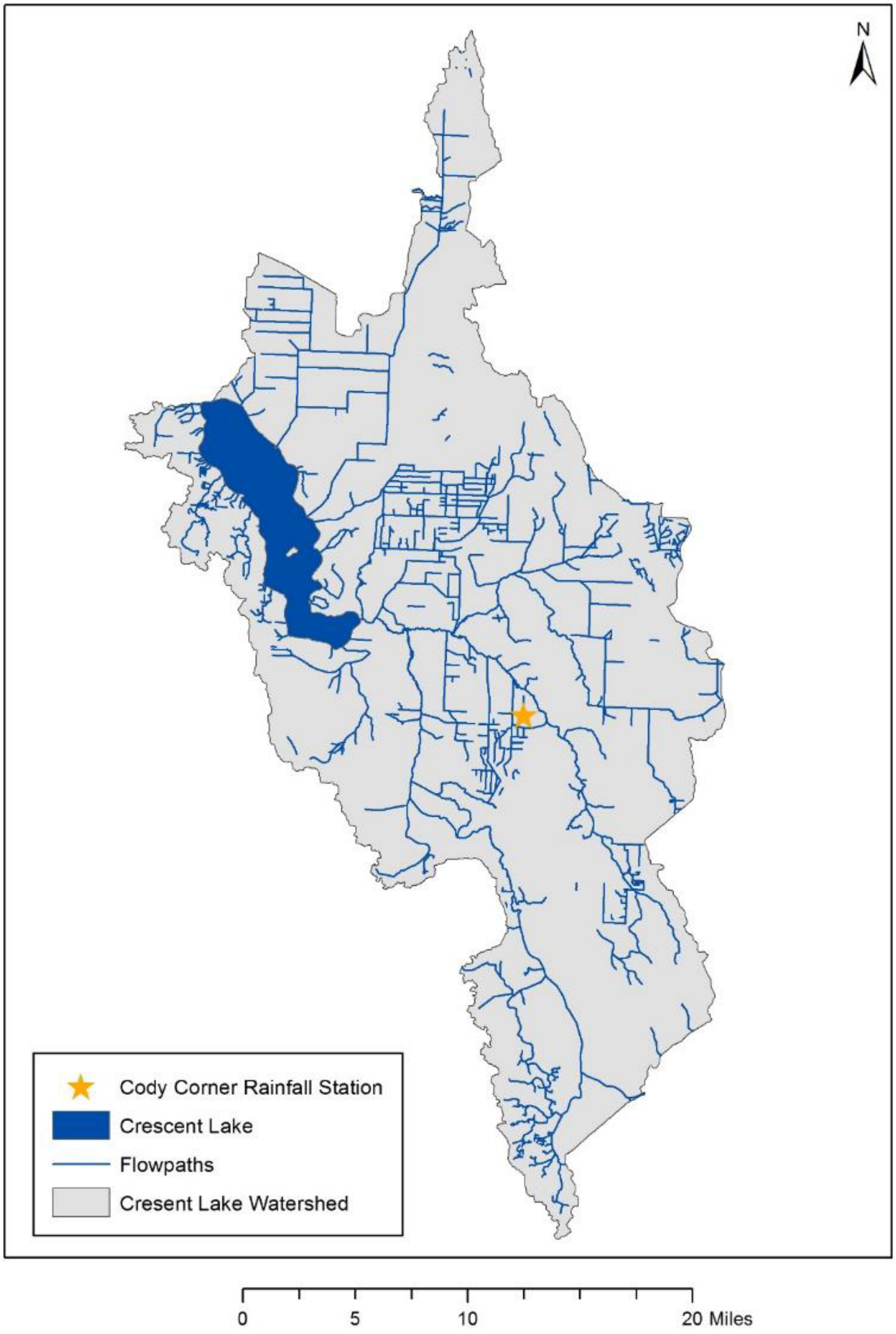

Figure 5.26. Location of the Cody Corner rainfall monitoring site in the Crescent Lake watershed

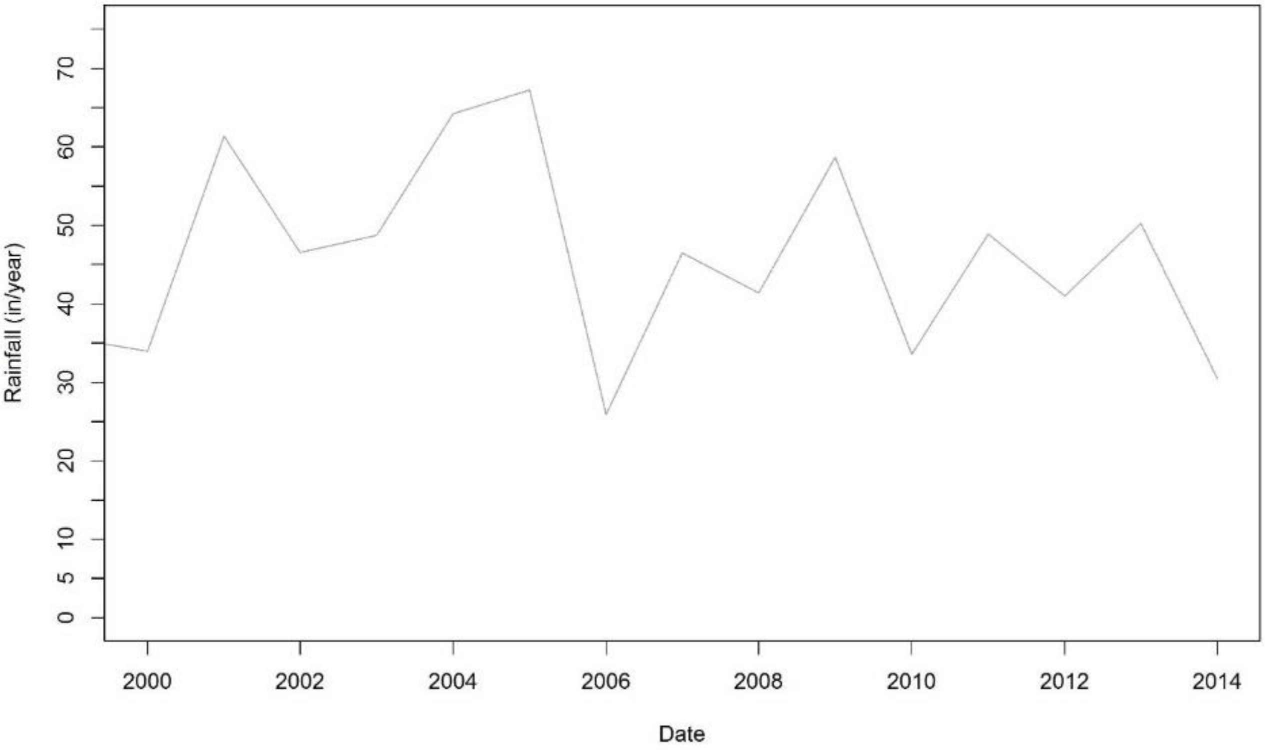

Figure 5.27. Annual rainfall at Cody Corner near Middle Haw Creek, 2000–13

5.3.2.3.2. EVAPORATION FROM WATERBODIES

Evaporation from the surface of Crescent Lake was predicted using measurements of lake surface evaporation, based on historical pan evaporation data. Historical data from the NOAA Evaporation Atlas (1982) suggest a lake surface evaporation rate of 1.22 meters/year (48 inches/year) for the eastern portion of Florida (U.S. Department of Commerce 1982). This evaporation rate was used as an input to the BATHTUB receiving waterbody model.

5.3.2.3.3. EVAPOTRANSPIRATION AND PERCOLATION ON LAND SURFACES

Watershed evapotranspiration is potentially higher than pure evaporation from waterbodies, yet is often more difficult to calculate and input into hydrologic models. Given that transpiration by terrestrial vegetation can strongly affect water budgets, its effect on the overall water budget needs to be accounted for separately from direct evaporation from waterbodies. The curve number model accounts for the amount of water stored in the soil and antecedent moisture conditions. Yet this model only considers the generation of surface runoff at source cells, not its fate and transport through a watershed. To improve this estimate, it must be determined whether all of the surface runoff is attenuated by transpiration or other processes en route to Crescent Lake.

A comparison of annual flow in Haw Creek and annual rainfall at the nearest weather station (Cody Corner) reveals that stream flow approaches zero when total precipitation is at or below 20 to 30 inches of rain per year (**Figure 5.28.**). This is likely because of evapotranspiration and percolation, which can remove a portion of the surface runoff before it reaches Crescent Lake. To accurately add this effect to the curve number model, yearly rainfall was reduced by 30 inches.

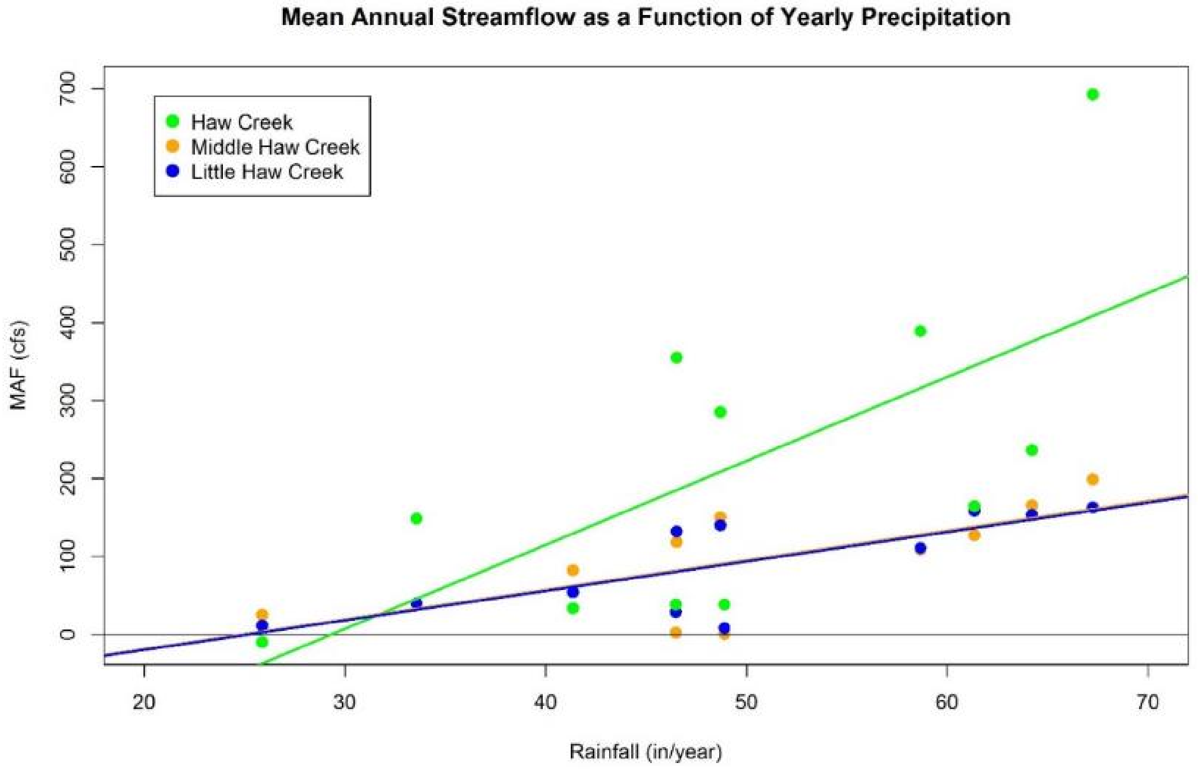

Figure 5.28. Mean annual streamflow versus yearly precipitation

5.3.2.3.4. ATMOSPHERIC DEPOSITION

Nutrient loadings from the atmosphere are an important component of the nutrient budget in many Florida lakes and marine waters. Nutrient delivery comes through two pathways: wet atmospheric deposition with precipitation and dry particulate-driven deposition. The SJRWMD collected dry and wet atmospheric deposition data in Lake Apopka, and these formed the basis for the atmospheric deposition assumed to occur in Crescent Lake.

The dry deposition is expressed as a per area loading rate (areal loading rate) on an annual scale. The area of the lake was multiplied by the annual areal loading rate to calculate the total annual dry deposition. Wet deposition is delivered in rainwater, and therefore the annual amount is expressed as a concentration of solutes in precipitation multiplied by the volume of precipitation. The wet deposition for the entire lake was then divided by the lake surface area to express the result in a similar annual areal loading used for the dry deposition. The wet and dry components of atmospheric nutrient deposition (**Table 5.1**) were added and used to build the receiving waterbody model.

Table 5.1. Calculated atmospheric deposition in Crescent Lake based on field measurements in Lake Apopka, 2000–13

mg/m^2/yr = Milligrams per square meter per year

Year	Dry Deposition TN (mg/m^2/yr)	Dry Deposition TP (mg/m^2/yr)	Wet Deposition TN (mg/m^2/yr)	Wet Deposition TP (mg/m^2/yr)	Total Deposition TN (mg/m^2/yr)	Total Deposition TP (mg/m^2/yr)
2000	253	27	566	14	819	40
2001	145	11	1,180	18	1,325	29
2002	146	12	596	11	742	22
2003	110	13	758	14	868	26
2004	181	18	935	18	1,116	36
2005	136	15	866	18	1,003	33
2006	186	16	374	5	560	21
2007	221	27	800	19	1,021	46
2008	168	23	596	18	764	41
2009	166	23	758	26	924	50
2010	167	30	407	13	574	43
2011	136	19	534	19	670	38
2012	296	48	732	25	1,028	73
2013	178	22	741	18	918	39
Mean	**177.7**	**21.6**	**700.1**	**16.7**	**877.9**	**38.3**

5.3.2.4 Watershed Nutrient Inputs

The curve number model was used to simulate surface runoff as discussed in the previous chapter. The aggregated EMCs from the SJRWMD's PLSM were input separately and used to calculate loading rates. In BATHTUB, these inputs were entered as a separate tributary for each unique combination of watershed zone and land use for a total of 51 unique combinations (not all land uses were present in every watershed zone).

Watershed loads were not attenuated based on travel time and distance, and therefore it was assumed that overland flow generated anywhere in the watershed reaches Crescent Lake. The weather patterns that generate overland flow in one portion of the watershed are likely to cause similar overland flow in the rest of the watershed. In this condition, where the entire watershed has saturated soils, it is likely that all overland flow will be transported into the nearest waterbody.

5.3.2.5 BATHTUB Model Input Selection

The BATHTUB model package can use a range of input equations to predict a waterbody's responses to long-term physical and chemical factors. For Crescent Lake, second-order available phosphorus and nitrogen models were used to represent the nutrient dynamics in the lake. The Chl*a* model used in this TMDL analysis assumes that phytoplankton growth is co-limited by phosphorus, nitrogen, light, and flushing.

5.3.3 BATHTUB Model Calibration

The results of the model suite described above were compared with and calibrated to water quality and flow data. On average, the models are able to represent average conditions reasonably well. The parameters used to fit the model included the attenuation of TN and TP and the light attenuation assumed for each year. Light attenuation associated with high-color water explains 95 % of the variation in the measured Chl*a* data (**Figure 5.3**). Therefore, it is reasonable that this parameter should explain much of the model calibration for Chl*a*. The calibration factors (applied to nutrient concentrations) for both TN and TP in each of the 4 segments were adjusted to 0.33 and 0.50, respectively. The model suggests that nutrient exchange with the sediment is low. However, there appears to be net sedimentation of both TN and TP.

The majority of the data collected in Crescent Lake was from the north end of the lake (**Table 5.2; Figure 5.29**). Water quality data collected from two sites (IWR Site ID# 21FLSJWMSAVCRL2I and 21FLSJWMSAVCRL2O) visited by the SJRWMD once every two weeks account for the vast majority of these data. Therefore, the northernmost segment of the BATHTUB model was chosen to represent the calibration point for nutrient concentrations.

Table 5.2. Count of IWR water quality measurements in each lake zone

Lake Zone	Measurement Count	% of Total
1	4,226	6
2	6,553	9
3	5,552	8
4	56,741	78
Total	**73,072**	**100**

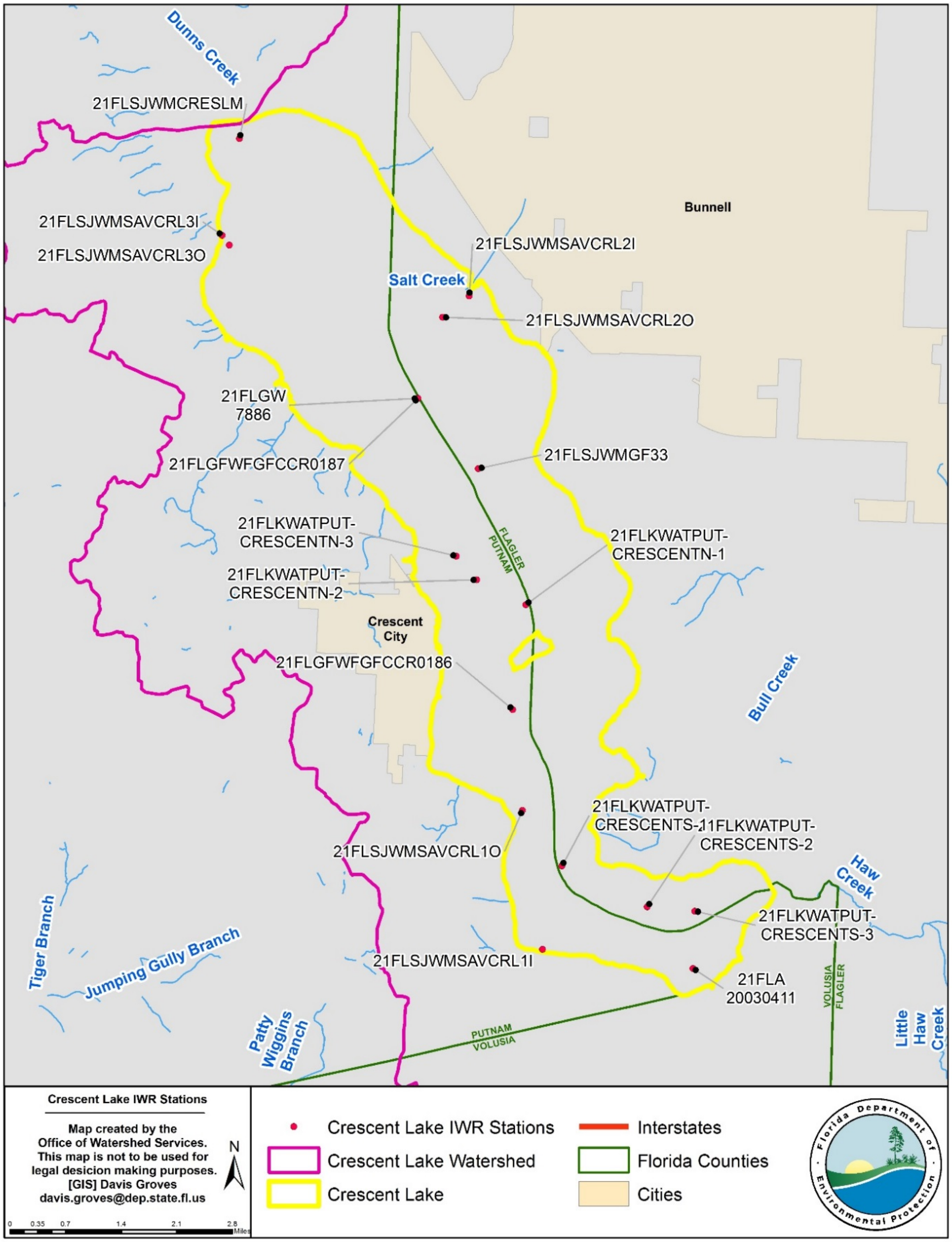

Figure 5.29. Map of major IWR stations (20 or more measurements per site)

Comparing the model predictions with the measured data reveals a close match in the overall long-term average concentrations. The long-term average and 80th percentile of the AGM values all have errors of less than 15 %, and 5 out of 6 have errors below 3 % when comparing predicted with measured values (**Tables 5.3** and **5.4**).

Table 5.3. Model calibration–Comparison of average AGM concentrations

Parameter	Measured	Model	Difference (%)
Chl*a* (µg/L)	15	15	0.0
TN (µg/L)	1,419	1,402	-1.2
TP (µg/L)	87	81	-6.5

Table 5.4. Model calibration–Comparison of 80th percentile of AGM concentrations

Parameter	Measured	Model	Difference (%)
Chl*a* (µg/L)	25	23	-9.5
TN (µg/L)	1,489	1,462	-1.8
TP (µg/L)	107	86	-19.8

5.3.3.1 Flow Calibration

Model-predicted flow was calibrated to the USGS gauge located on Dunns Creek, which connects Crescent Lake to the St. Johns River. Annual average flows were compared and, based on an initial comparison, the outflow from the curve number approach was modified to produce lower flows (**Figure 5.30**). Tributary flow approaches zero in years receiving less than 30 inches of rain (**Figure 5.28**). The initial curve number approach flows overpredicted the flow in dry years. Therefore, the curve number–derived flows were reduced by reducing input rainfall by 30 inches per year.

The reasoning behind such an alteration is that water is removed from the system through evapotranspiration, especially as it flows through the extensive wetlands in the Crescent Lake watershed. In addition, evaporation from the lake surface may further reduce flows in low-rainfall years when total water losses from evaporation are greater than direct precipitation onto the lake surface. Even though tributary flows approach zero in dry years, the lake outflow remains positive, suggesting water flow from other sources. Irrigation is one possible source of dry-year flow, yet the tributary draining the major area of row crops remains ungauged, and thus this flow cannot be estimated. Groundwater likely provides the remaining portion of flow to Crescent Lake; this is especially important in dry years.

Compared with the measured data, the model predicts the same large trends but sometimes does not precisely match the pattern of the measured flow. Yet given the nature of the watershed model and BATHTUB, it likely represents a good flow calibration.

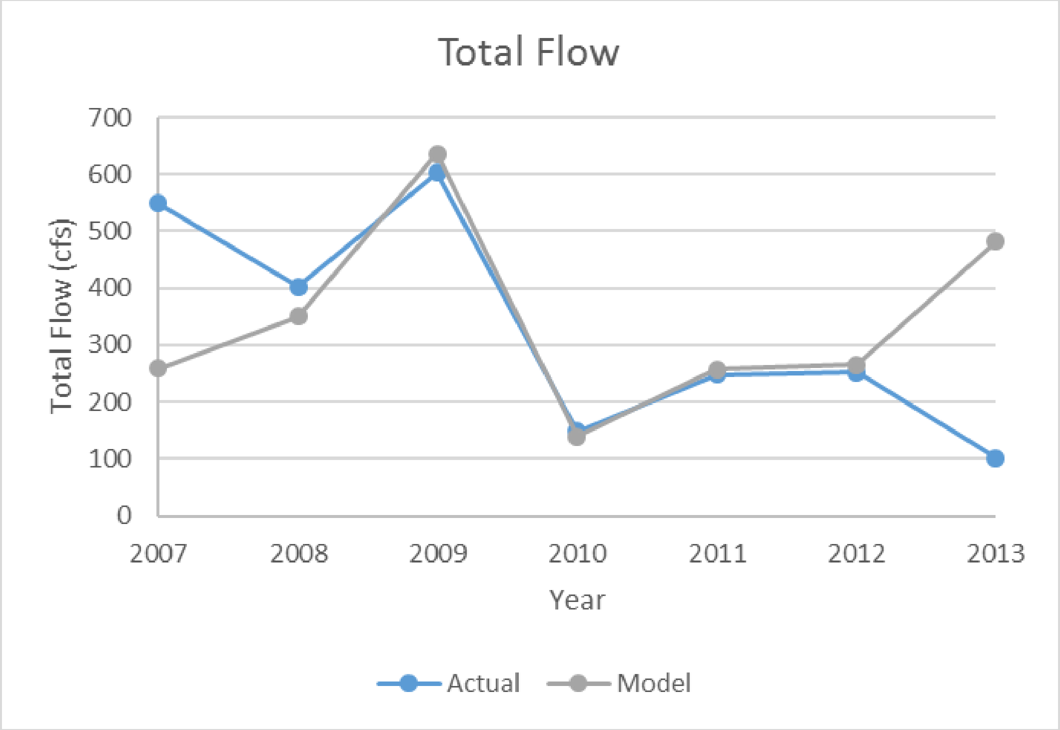

Figure 5.30. Comparison of measured and model-predicted flows in Dunns Creek, 2007–13

5.3.3.2 Nutrient Calibration

The concentrations of both TN and TP were calibrated by adjusting the decay rate of each parameter in the lake to match the measured concentrations at the north end of the lake. As a long-term average, both model-simulated TN and TP concentrations are very similar to the measured data. A comparison of year-to-year data (**Figures 5.31** and **5.32**) shows that the concentrations are in a similar range. Annual outflow TP and TN loads match the measured data (calculated with the annual average flow in Dunns Creek multiplied by the annual average nutrient concentrations in the northernmost section of the lake) more closely than the concentrations in Crescent Lake (**Figures 5.33** and **5.35**).

Model results suggest that the largest differences between annual loadings are caused by changing loads from watershed sources (**Figures 5.34** and **5.36**). Some years do show discrepancies, and this may be caused by differences between predicted and measured flows. Rainfall may have been higher or lower in another part of the watershed than the rain gauge, and this difference would cause a deviance between the model-predicted and measured nutrient data. In addition, this model assumes fixed EMCs, and therefore it may not perfectly capture trends caused by changes in runoff nutrient loading due to variable nutrient concentration.

Watershed sources contribute 48 % of TN and 91 % of TP (**Tables 5.5** and **5.6**). Natural sources contribute 63 % of watershed nitrogen but only 33 % of watershed-derived phosphorus, suggesting more anthropogenic alteration to the phosphorus budget than the nitrogen budget. There are no measured data on nitrogen fixation from Crescent Lake. Observed differences in the BATHTUB TN concentrations between the current condition and measured data were assumed to result from nitrogen fixation. Under the current condition, an internal load of 10 mg N/m^2/day was added to the BATHTUB input file to represent biological fixation.

Under other loading scenarios, the rate was adjusted as a scalar value of the Chl*a* concentration in proportion to the ratio of the current condition Chl*a* to fixation rate. At the assumed rates, fixation accounted for 41 % of the TN budget for Crescent Lake. Phosphorus is derived primarily from the watershed and is highly enriched by anthropogenic sources. The large contributions of nitrogen from fixation suggest that excess phosphorus may drive the overabundance of phytoplankton, including blue-green algae, which in turn causes fixation.

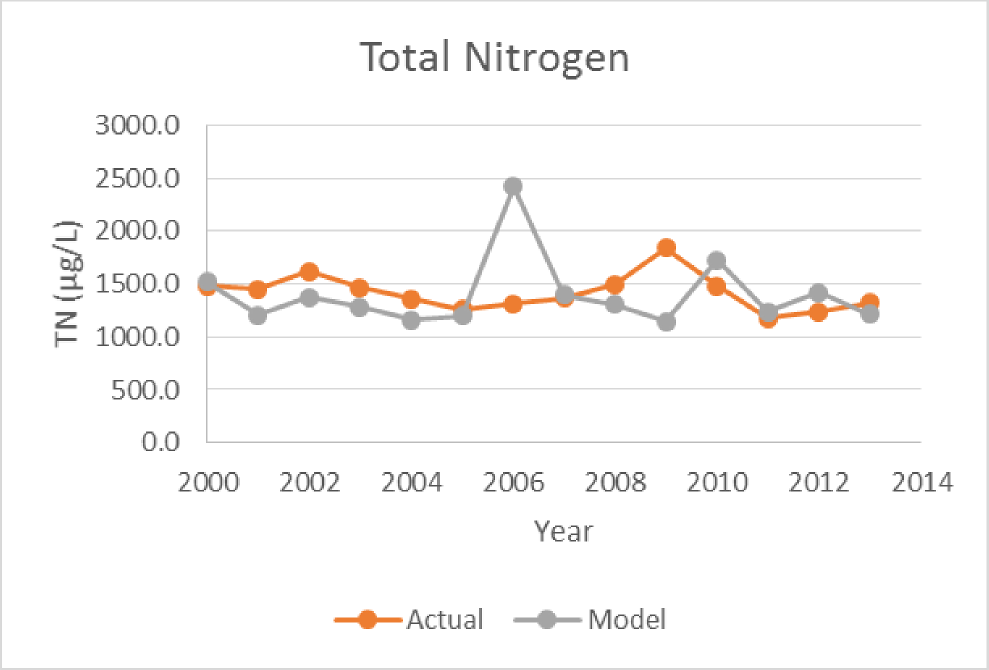

Figure 5.31. Comparison of measured and model-predicted AGM TN, 2000–13

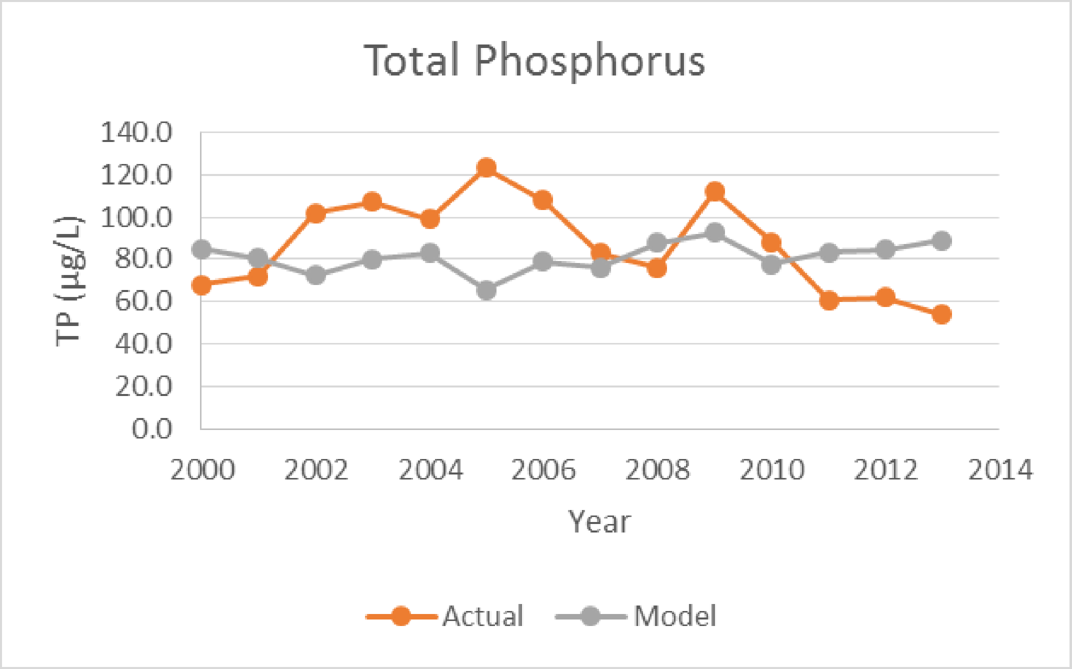

Figure 5.32. Comparison of measured and model-predicted AGM TP, 2000–13

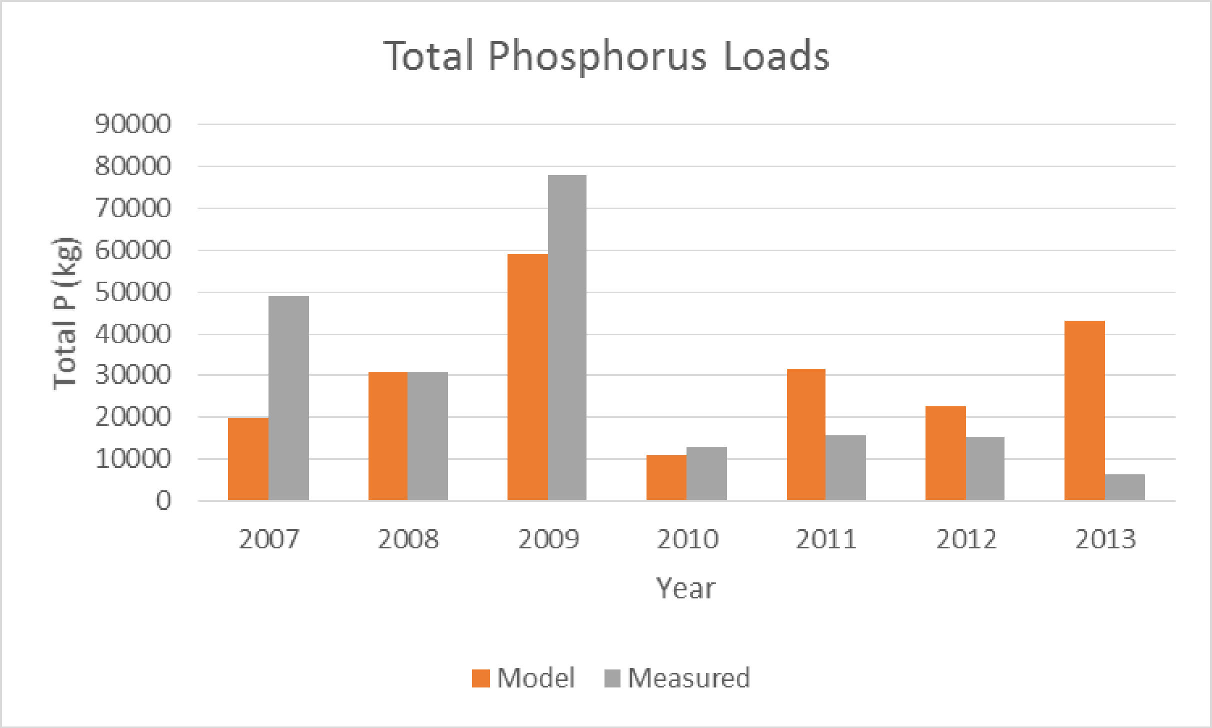

Figure 5.33. Measured and modeled TP loads in the northernmost segment of Crescent Lake, 2007–13

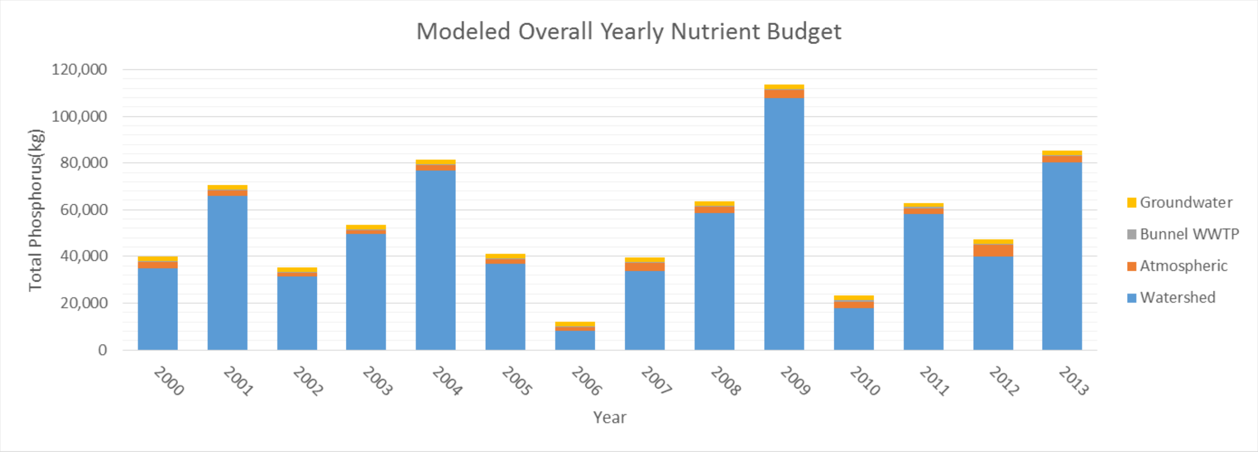

Figure 5.34. Modeled annual phosphorus budget for Crescent Lake, 2000–13

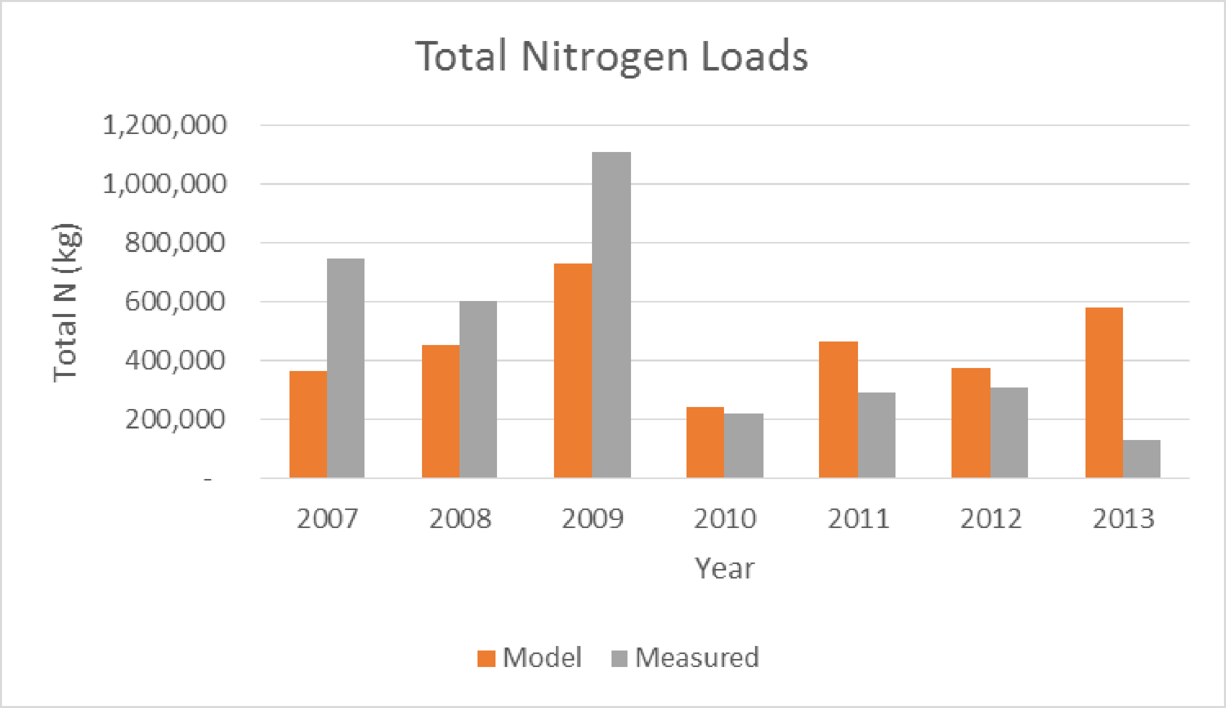

Figure 5.35. Measured and modeled TN loads in the northernmost segment of Crescent Lake, 2007–13

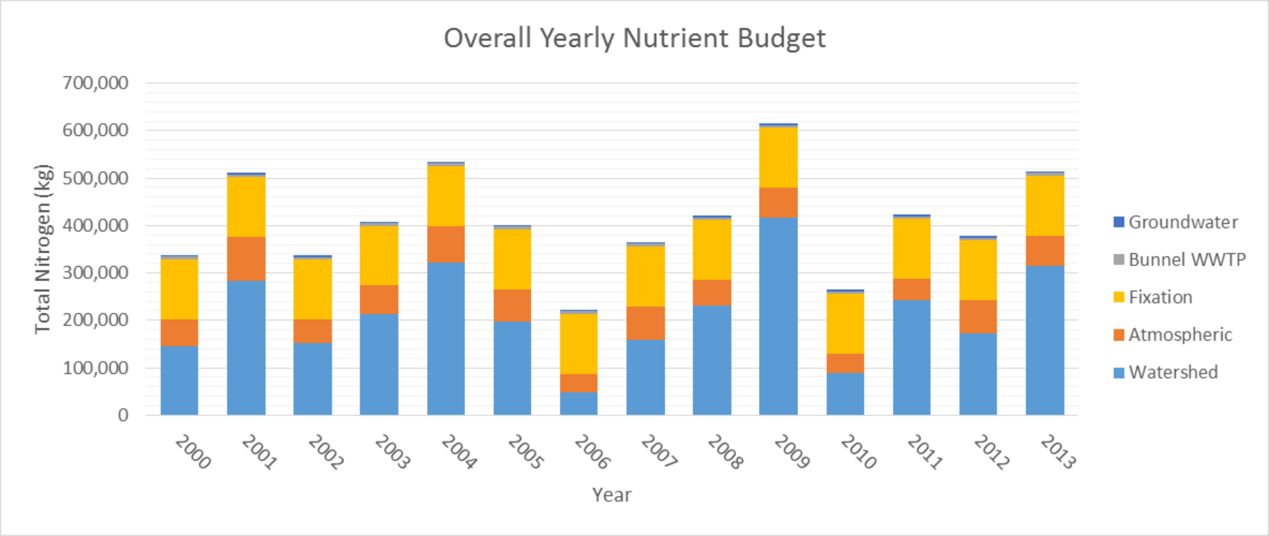

Figure 5.36. Modeled annual nitrogen budget for Crescent Lake, 2000–13

Table 5.5. Detailed summary of watershed nutrient loads

Land Use	N Loading (kg/yr)	% of Total N	P Loading (kg/yr)	% of Total P
Low-density residential	5,520.4	1.9	552.0	1.1
Medium-density residential	3,702.3	1.3	747.8	1.5
High-density residential	854.2	0.3	213.1	0.4
Low-density commercial	3,795.6	1.3	765.4	1.6
High-density commercial	2,923.6	1.0	798.9	1.7
Industrial	1,208.1	0.4	251.0	0.5
Mining	108.7	0.0	22.6	0.0
Open land/recreational	468.3	0.2	42.6	0.1
Pasture	38,513.0	13.3	15,940.1	33.0
Cropland	26,978.7	9.3	7,003.4	14.5
Tree crops	548.9	0.2	107.0	0.2
Feeding operations	5.2	0.0	1.8	0.0
Other agriculture	22,350.4	7.7	5,802.0	12.0
Forest/rangeland	64,310.1	22.1	5,846.4	12.1
Wetlands	119,280.2	41.1	10,224.0	21.2
Total	**290,567.7**	**100**	**48,318.0**	**100**

Table 5.6. Average Annual nutrient loads into Crescent Lake

Land Use	N Loading (kg/yr)	% of Total N	P Loading (kg/yr)	% of Total P
Watershed	290,568	47.6	48,318	90.6
Point source	3,489	0.6	424	0.8
Groundwater	3,641	0.6	1,920	3.6
Atmospheric deposition	60,776	10.0	2,647	5.0
Fixation	252,012	41.3	0	0.0
Total	**610,485**	**100**	**53,309**	**100**

5.3.3.3 Chlorophyll *a* Calibration

Chl*a* concentrations in Crescent Lake were calibrated using the estimated color and therefore light levels. Watershed runoff emanating from wetland areas delivers high-color water to Crescent Lake. Higher rainfall years generally have higher color (**Figure 5.37**), and therefore relative rainfall was used as the basis for the equation to calculate nonalgal turbidity as an input to BATHTUB. The model was empirically fitted to allow relative rainfall to influence algal turbidity and therefore mimic the effects of high-color conditions restraining phytoplankton growth, and therefore Chl*a* concentrations. As seen in the calibration comparison (**Figure 5.38**), this equation allows the BATHTUB model to reasonably reproduce the variations in Chl*a* concentration observed in Crescent Lake:

$$Turbidity\ = 2 * \left(1.8 * \frac{Yearly\ Rain}{Average\ Rain} - 0.1\right)^{3.2}$$

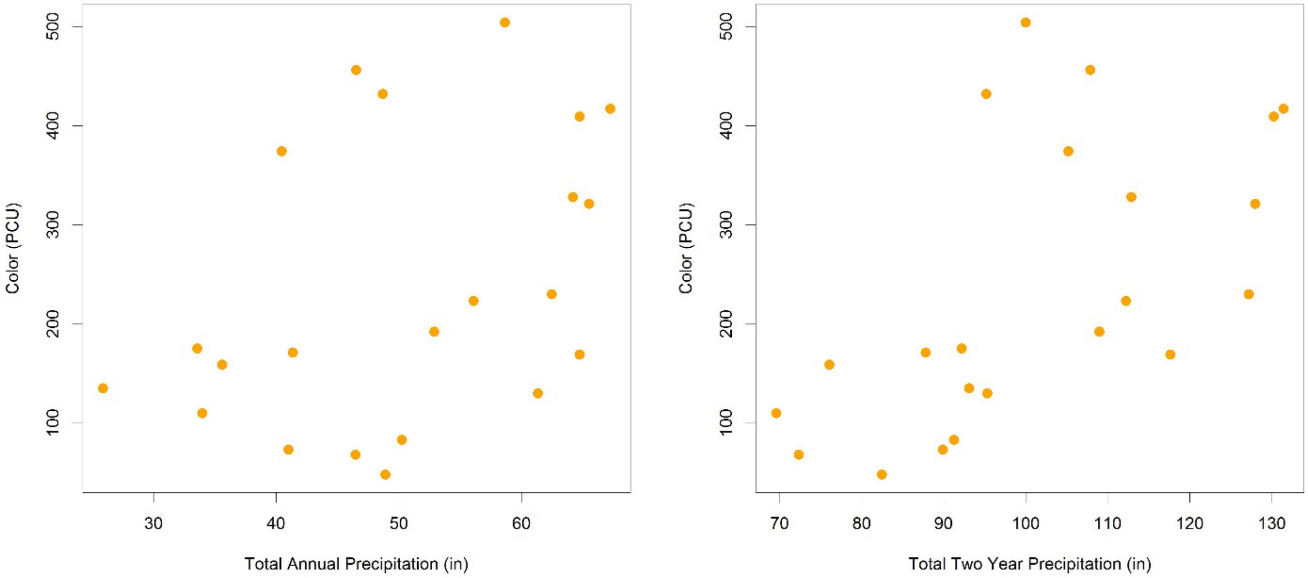

Figure 5.37. Annual precipitation and color data comparison in Crescent Lake. Color is shown as a function of precipitation summed over two years (correlation = 0.68) in the left panel and with annual total precipitation (correlation = 0.40) in the right panel.

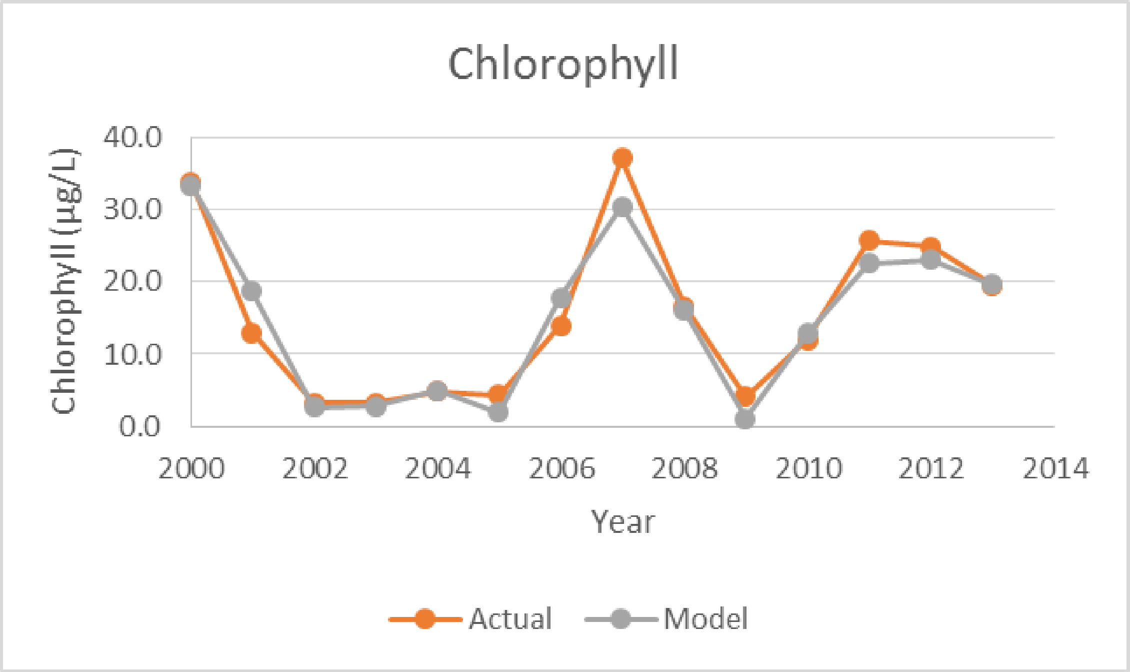

Figure 5.38. Comparison of model AGM-predicted and measured , 2000–13

5.3.4 Load Reduction Scenarios To Determine the TMDLs

The first reduction scenario that DEP considered is the Lower St. Johns River TMDL, which calls for a 30 % reduction in nitrogen and phosphorus loads at the boundary conditions (including Dunns Creek) of the Lower St. Johns Estuary. These reductions apply to the entire load, with all required reductions occurring from anthropogenic land uses. Therefore, DEP sought to determine whether Crescent Lake would meet the target Chl*a* concentration if these reduction targets were met.

Nutrient reductions from the Lower St. Johns River TMDL were incorporated into a BATHTUB model simulation to determine whether these targets would be protective. As called for in the report, nitrogen and phosphorus reductions of 30 % and 30 %, respectively, were applied to anthropogenic watershed loads and incorporated into a set of model input files.

The resulting Chl*a* concentrations were well below the existing condition but above the 15 µg/L Chl*a* target. Chl*a* concentrations exceeded 20 µg/L 4 times over the course of the 14-year simulation period, twice consecutively in 2011 and 2012 (**Figure 5.39**). These reduction targets for the Lower St. Johns River would not enable Crescent Lake to meet either the NNC or the site-specific criteria for the lake.

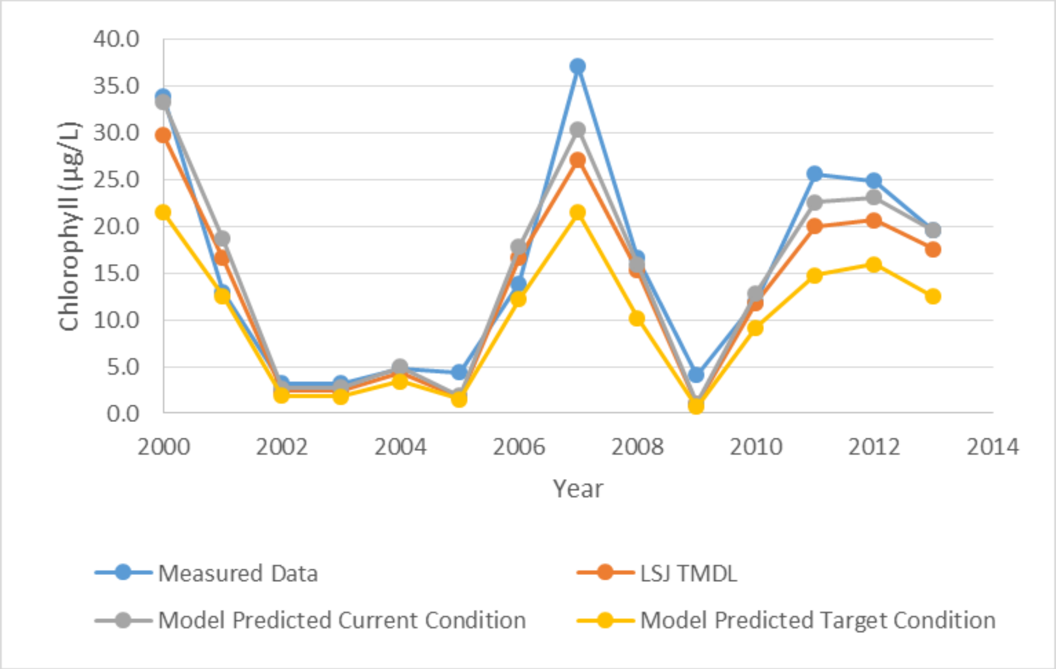

Figure 5.39. Modeled AGM Chl*a* concentrations under the load reductions from the Lower St. Johns River TMDL and the Crescent Lake TMDL target condition, 2000–13

The site-specific criteria developed in **Chapter 3** call for more stringent nutrient reductions than would be required to meet the generally applicable NNC. Watershed nutrient loadings to the BATHTUB model were reduced until the lake met the 15 µg/L target at the 80th percentile of annual AGM Chl*a* concentrations. The EMC associated with each individual anthropogenic land use was reduced until the EMC target condition was achieved (individual EMCs were not reduced below a wetland or upland forest concentration, depending on which category was most appropriate).

5.3.4.1 Point Source Load Limits

Nutrient loads from point sources are minor contributors, yet specific limits for these facilities must be developed. The BATHTUB background scenario was modified to include several permit limits to test the effect of the Bunnell wastewater plant on the water quality of Crescent Lake. In the BATHTUB model, nutrient loads were added directly to Crescent Lake with no attenuation from Haw Creek, thus simulating a worst-case scenario. Scenarios were tested that included setting the limit at zero and the current discharge rate. It was assumed that the concentration of nutrients in the effluent would not change, only the volume.

Based on the yearly results for the 2 scenarios, the Bunnell plant has no significant effect on water quality (**Table 5.7**). A 2-sample heteroscedastic t-test was run for each parameter between the no discharge and the actual permitted discharge. There is no statistically significant difference between Chl*a* (p = 0.99), nitrogen (p = 0.91), or phosphorus (p = 0.37). Given that the Bunnell plant does not have a statistically significant impact, the load limit will be set at the maximum permitted rate.

Table 5.7. Point source discharge effects

Parameter	Zero Discharge	Historical Discharge
Chl*a* (µg/L)	9.9	10.0
TN (mg/L)	1.11	1.11
TP (mg/L)	0.05	0.05

Under the target condition in Crescent Lake, annual total nutrient loads would have to be substantially lower than the present day. Comparing long-term average loads yields a nutrient reduction target of 34 % of the nitrogen load and 58 % of the phosphorus load. These loading reduction estimates are for the entire watershed load. Reductions will be taken from anthropogenic loading sources and will likely require higher reductions from sources that contribute the highest loads per unit area.

The majority of the anthropogenic enrichment of nutrient loading occurs from agricultural activities the south of Crescent Lake. The model predictions for the target condition (**Table 5.8**) suggest a nitrogen budget that is fed primarily by watershed loading (48 %), and secondarily by fixation (38 %) and atmospheric deposition (14 %). The phosphorus budget is dominated by watershed sources (80 %), while atmospheric deposition (11 %) and groundwater are distant secondary and tertiary sources.

Table 5.8. Average annual Nutrient budget under the target condition

Land Use	N Loading (kg/yr)	% of Total N	P Loading (kg/yr)	% of Total P
Watershed	211,179	48.1	18,578	80.3
Point source – wastewater	3489	0.0	424	0.0
Groundwater	576	0.1	1,920	8.3
Atmospheric deposition	60,776	13.8	2,647	11.4
Fixation	166,328	37.9	0	0.0
Total	**442,348**	**100**	**23,569**	**100**

Based on the BATHTUB model predictions, nutrient concentrations for the target condition were derived from the distribution of yearly results. Nutrient concentration targets are expressed based on the 80th percentile of this distribution. Based on the properties of the 80th percentile and the binomial distribution, this limit will be exceeded no more than once in a 3-year period under the original distribution (with a 10 % Type 1 error rate). For the target condition, this corresponds to an AGM Chl*a* concentration of 15 µg/L, a 7-year rolling average TN concentration of 1.16 mg/L, and an AGM TP concentration of 0.05 mg/L.

Chapter 6: Determination of the TMDL

6.1 Expression and Allocation of the TMDL

A TMDL can be expressed as the sum of all point source loads (wasteload allocations or WLAs), nonpoint source loads (load allocations or LAs), and an appropriate margin of safety (MOS) that takes into account any uncertainty about the relationship between effluent limitations and water quality:

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

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

It should be noted that the various components of the TMDL equation may not sum up to the value of the TMDL because (1) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is accounted for within the LA, and (2) TMDL components can be expressed in different terms (for example, the WLA for stormwater is typically expressed as a percent reduction and the WLA for wastewater is typically expressed as mass per day).

WLAs for stormwater discharges are typically expressed as a "percent reduction" because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from nonpoint sources (given the nature of stormwater transport). The permitting of MS4 stormwater discharges is also different than the permitting of most wastewater point sources. Because MS4 stormwater discharges cannot be centrally collected, monitored, and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the "maximum extent practical" through the implementation of 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 measures**. The NPDES stormwater WLA is expressed as a percent reduction in the stormwater from MS4 areas. The LA and TMDL for Crescent Lake are expressed as loads and percent reductions, and represent the maximum 7-year rolling average loads of TN and TP from all watershed sources that the waterbody can assimilate and maintain the Class III NNC (**Table 6.1**). The expression and allocation of the TMDLs in this report are based on the loadings necessary to achieve the water quality criteria and designated uses of these surface waters.

Table 6.1. TMDL components for Crescent Lake

[*] 151 lbs TP per day

[†] 2672 lbs TN per day

WBID	Parameter	TMDL (lbs/yr)	WLA–NPDES wastewater (lbs/yr)	WLA–NPDES MS4 Stormwater (%)	LA (%)	MOS
2606B	TP	57,959[*]	701	58	58	Implicit
2606B	TN	1,018,666[†]	12,702	34	34	Implicit

The TMDL allocation is based on 14 years of data, including model results from 2000 through 2013. The loading limits for TN and TP are expressed as a 7-year rolling average not to be exceeded. The maximum allowable loads were derived from the highest calculated 7-year rolling average over the 14-year model time frame. Chl*a* criteria are expressed as not to be exceeded more than once in any 3-year period.

The analysis of Crescent Lake presented in this report identifies a 7-year average loading of 57,959 lbs of TP and 1,018,666 lbs of TN per year, never to be exceeded. These target loads represent a 34 % reduction of TN and a 58 % reduction of TP from the existing condition. It should be noted that these percent reductions are for the total loads from all sources. Specific load reductions will need to come from anthropogenic sources, and specific reductions can be calculated based on a comparison of the TMDL loads and loads in the current condition.

6.2 Load Allocation (LA)

Crescent Lake receives the majority of its anthropogenic nutrient loading from watershed sources located in nonurbanized areas, and therefore the load allocation is the most important part of the TMDLs. The modeling efforts described in previous sections identify a 58 % reduction in aggregate TP loads and a 34 % reduction in aggregate TN loads as necessary to achieve the TMDL targets. When these loads are allocated to individual sources, the actual reductions necessary for each source may be above or below the target reduction.

6.3 Wasteload Allocation (WLA)

6.3.1 NPDES Wastewater Discharges

As previously mentioned, there are 2 NPDES domestic wastewater outfalls in the Crescent Lake watershed. The Crescent City WWTP does not discharge into the waters of Crescent Lake and therefore currently does not contribute to nutrient loading the lake. This facility retains a NPDES point source permit and an outfall in case of an extreme wet weather discharge. The load limit for Bunnell is set at the maximum discharge as defined in its permit. Per year, point sources can contribute a maximum of 701 pounds of phosphorus and 12,702 pounds of nitrogen.

6.3.2 NPDES Stormwater Discharges

Two covered MS4 permittees in the Crescent Lake watershed are subject to load reductions. The city of DeLand Phase II MS4 (#FLR04E078) and Volusia County Phase II MS4 (#FLR04E033) both have urbanized areas in the watershed. Because the actual extent of their stormwater conveyance systems is not known, the general landscape load reduction requirement applies to both MS4 permit holders for the urbanized land in the Crescent Lake watershed. The permit conditions require a 58 % reduction in TP and a 34 % reduction in TN from the existing condition.

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 (MOS)

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 (CWA, 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.

A conservative assumption was used in setting up and calibrating the TMDL model suite for Crescent Lake. The attenuation of nutrients in transport from point source outfalls and nonpoint source areas to Crescent Lake was not considered, and therefore the required load reductions may lead to lower than anticipated nutrient concentrations by the time the loads reach the lake.

Chapter 7: Next Steps: Implementation Plan Development and Beyond

7.1 Implementation Mechanisms

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

Facilities with NPDES permits that discharge to the TMDL waterbody must respond to the permit conditions that reflect target concentrations, reductions, or waste load 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 permit holders prioritize and take action to address a TMDL unless their management actions are already defined in a BMAP. MS4 Phase II permit holders must also implement responsibilities defined in a BMAP.

7.2 Basin Management Action Plans

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. DEP 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 DEP Secretary and are legally enforceable. They describe the management strategies that will be implemented, funding strategies, project tracking mechanisms, and water quality monitoring, in addition to the fair and equitable allocations of pollution reduction responsibilities to sources in the watershed. BMAPs also identify mechanisms to address potential pollutant loading from future growth and development.

The most important component of a BMAP is the list of management strategies to reduce 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 DEP BMAP website.

7.3 Implementation Considerations for Crescent Lake

Given the nature of the loading in Crescent Lake, nonpoint source reductions are required to reach the TMDL target. The regulatory nature of TMDLs is least effective at decreasing loadings from nonpoint sources and will therefore require significant coordination between DEP, the SJRWMD, and local entities.

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Appendices

Appendix A: Summary of Information Supporting the TMDLs as Site-Specific Interpretations of the Narrative Nutrient Criterion for Crescent Lake

Table A-1. Spatial extent of the waterbody where the site-specific numeric interpretation of the narrative nutrient criteria will apply

Location	Description
Waterbody name	Crescent Lake
Waterbody type(s)	Lake
Waterbody ID (WBID)	WBID 2606B
Description	Crescent Lake is located in Flagler, Volusia, and Putnam Counties, Florida. The estimated average surface area of the lake is 69 km^2, with a normal pool volume of 0.17 km^3 and an average depth of 2.4 m. Crescent Lake receives runoff from a watershed area of 1,485.9 km^2 occupied by forest/rangeland, urban and residential, agricultural area, and wetlands. Haw Creek, which is the main freshwater input to Crescent Lake and enters at the southern end of Crescent Lake, receives the majority of the nutrient loading from agricultural land.
Specific location (latitude/longitude or river miles)	The center of Crescent Lake is located at Latitude N: 29°28'34.86," Longitude W: - 81°30'19.44."
Map	The general location of Crescent Lake and land uses in the watershed are shown in **Figure 1.1**, and **Figures 4.1** and **4.2**, respectively, of this TMDL report.
Classification(s)	Class III freshwater
Basin name (HUC 8)	Lower St. Johns (03080103)

Table A-2. The default NNC, site-specific interpretation of the narrative criterion developed as TMDL targets, and the 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	Crescent Lake is a high-color lake, and the generally applicable NNC, expressed as AGM concentrations not to be exceeded more than once in any consecutive 3-year period, are Chla of 20 µg/L, TN of 1.27 to 2.23 mg/L, and TP of 0.05 to 0.16 mg/L.
Proposed TN, TP, chlorophyll *a*, and/or nitrate+nitrite (magnitude, duration, and frequency)	Numeric interpretations of the narrative nutrient criterion: TP = 57,959 lbs/yr and TN = 1,018,666 lbs/yr, which are 7-year average annual loads not to be exceeded. The Chl*a* criterion of 15 µg/L as an AGM is not to be exceeded more than once in any consecutive 3-year period. This approach establishes a lake-specific target that is more representative of natural conditions in the lake than the generally applicable NNC. The TMDL loads and chlorophyll *a* will be considered as the site-specific interpretation of the narrative criterion. Nutrient concentrations are provided for comparative purposes only (1.16 mg/L TN and 0.05 mg/L TP).
Period of record used to develop the numeric interpretations of the narrative nutrient criterion for TN and TP criteria	The model-simulated time domain was from 2000 to 2013. Land use information was gathered from GIS layers developed by the SJRWMD (2009 layer). ArcNLET was used to predict nitrogen loads from onsite sewage treatment and disposal systems (OSTDS), while water quality and processes in Crescent Lake were modeled with the USACOE BATHTUB model for the period from 2000 through 2013.
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 calibration for Crescent Lake used all available data for the lake from 2000 to 2013. This time span includes two wet periods and three dry periods, capturing the hydrologic variability of the Crescent Lake system. Lake monitoring stations were found across the spatial extent of Crescent Lake. More data were available from the center and northern end of the lake. However, transects of the lake revealed that the main portion appeared to be well mixed. Water quality data revealed that the northern portion of Crescent Lake generally had lower nutrient and Chl*a* concentrations than the southern portion. Therefore, setting criteria that are slightly biased towards the northern portion will hold the southern portion of the watershed to a high standard and therefore, add to the MOS in the TMDL.

Table A-3. History of Nutrient Impairment, Quantitative Indicator of The Use Support, And the Methodologies Used to Develop The Site Specific Interpretation of The Narrative Criteria.

Designated Use	Description
History of assessment of designated use support	Crescent Lake was initially verified as impaired for nutrients during the Cycle 2 assessment (verified period January 1, 2005–June 30, 2012) using the methodology in the IWR (Chapter 62-303, F.A.C.), and was included on the Cycle 2 Verified List of impaired waters for the Lower St. Johns River. In addition, DEP assessed the water quality of Crescent Lake using the adopted lake NNC. The AGM Chl*a* concentration exceeded the threshold of 20 µg/L for high-color lakes in 2011 and 2012, indicating that the lake is impaired for Chl*a*. During the years when the Chl*a* criterion was exceeded, the phosphorus criterion of 0.05 mg/L AGM was also exceeded.
Quantitative indicator(s) of use support.	DEP evaluated a site-specific interpretation of the narrative criterion for Crescent Lake by developing a site-specific chlorophyll *a* based on the phytoplankton community composition. This approach identified a target Chl*a* concentration of 15 µg/L as an AGM that can be exceeded no more than once in any consecutive 3-year period. The corresponding target nutrient concentrations (for informational purposes only) are 1.16 mg/L of TN and 0.05 mg/L of TP.
Summarize approach used to develop criteria and how it protects uses	The chlorophyll *a* criterion for Crescent Lake was determined by analyzing algal community diversity as a function of AGM Chl*a* concentrations. A Shannon-Weaver Diversity Index measurement of the phytoplankton community showed a significant decreasing trend when AGM Chl*a* concentrations were higher than 15 µg/L. The significance of 15 µg/L as the change point was verified using a Bayesian change-point analysis. The relationship between phytoplankton community structure and Chl*a* concentration was also confirmed with nonmetric multidimensional scaling ordination analyses and the observation that, when the Chl*a* level was above 15 µg/L, the percent blue-green algal biomass accounted for more than 50 % of the total community biomass. Therefore, criteria were set at this breakpoint to allow no more than 1 exceedance in any 3-year period. Setting the criterion in this way allows for natural variation and alterations during droughts, but maintains healthy plankton communities during most years. Because DEP is using a sensitive population and basing the target on this community's health, it is by definition protecting the lake biota. Fish populations are likely less sensitive to Chl*a* concentrations and will be protected by this standard
Discuss how the TMDL will ensure that nutrient-related parameters are attained to demonstrate that the TMDL will not negatively impact other water quality criteria. These parameters must be analyzed with the appropriate frequency and duration. If compliance with 47(a) is not indicated within the TMDLs, it should be clear that further reductions may be required in the future.	Model simulations indicated that the target Chl*a* concentration (15 µg/L) in the lake will be attained at the TMDL loads for TN and TP. Reducing nutrient loads entering the lake will not negatively impact other water quality parameters in 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.	Crescent Lake drains into the Lower St. Johns River through Dunns Creek. The Lower St Johns River was verified for nutrient impairment, and TMDLs have been adopted requiring a 30 % reduction in TN and TP. The Crescent Lake TMDL calls for a 58 % reduction in TP and a 34 % reduction in TN to protect the lake. The required reductions in phosphorus and nitrogen loading to Crescent Lake are greater than that of the Lower St. Johns River TMDL and will therefore protect the downstream waterbody. The nitrogen reductions needed to protect Crescent Lake are lower than the reductions needed to protect the St. Johns River, and therefore other areas of the St. Johns River watershed will need to reduce nutrient loading further to protect the Lower St. Johns River. The 34 % TN reduction represents a natural background condition, and it is not DEP's intent to require a higher percent reduction in the Crescent Lake watershed because that would require abating natural conditions, which is prohibited by Subsection 62-302.300(15). F.A.C.
Provide summary of existing monitoring and assessment related to implementation of Rule 62-302.531(4), F.A.C., and trends tests in Chapter 62-303, F.A.C.	The SJRWMD regularly samples Crescent Lake and will increase monitoring starting in 2015 to better characterize agricultural loadings from the watershed area south of the lake.

Table A-5. Public participation and legal requirements of rule adoption

Administrative Requirements	Descriptive Information
Notice and comment notifications	DEP held a public workshop on August 42, 2016, in Palatka, Florida, to present the draft Crescent Lake nutrient TMDLs to local stakeholders. DEP publicized the workshop through a notice published in the *Florida Administrative Register* (FAR), a TMDL workshop announcement on the DEP TMDL homepage and SharePoint website, an advertisement on a local newspaper, and an email notice to interested parties. Before the public workshop, the draft TMDL report was posted on the DEP TMDL website and shared with the general public. A 30-day public comment period ended on August 16, 2016. Public comments received during the workshop and public comment period were evaluated and considered for incorporating into the revised TMDL report. DEP will soon publish a Notice of Proposed Rule (NPR) to initiate the TMDL rule adoption process once DEP reaches an agreement with the EPA on the approach to convert these TMDLs to the site-specific numeric interpretations of the narrative criterion.
Hearing requirements and adoption format used; Responsiveness summary	Following the publication of the NPR, DEP will provide a 21 day-challenge period.
Official submittal to the EPA for review and General Counsel (GC) certification	If DEP does not receive a challenge or a public hearing request, a certification package for the rule will be prepared by the DEP program attorney. At the same time, DEP will prepare the TMDL and site-specific interpretation package for the TMDL and submit these documents to the EPA.

Appendix B: Background Information on Federal and State Stormwater Programs

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

Chapter 62-40, F.A.C., also requires the water management districts to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a Surface Water Improvement and Management (SWIM) plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL.

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

An important difference between the federal NPDES and the state's stormwater/environmental resource permitting programs is that the NPDES Program covers both new and existing discharges, while the state's program focuses on new discharges only. Additionally, Phase II of the NPDES Program, implemented in 2003, expands the need for these permits to construction sites between 1 and 5 acres, and to local governments with as few as 1,000 people. While these urban stormwater discharges are now technically referred to as "point sources" for the purpose of regulation, they are still diffuse sources of pollution that cannot be easily collected and treated by a central treatment facility, as are other point sources of pollution such as domestic and industrial wastewater discharges.

It should be noted that all MS4 permits issued in Florida include a reopener clause that allows permit revisions to implement TMDLs when the implementation plan is formally adopted.

Appendix C: Important Links

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Florida Department of Environmental Protection websites:

TMDL Program: http://www.dep.state.fl.us/water/tmdl/index.htm
BMAP Program: http://www.dep.state.fl.us/water/watersheds/bmap.htm
Watershed Assessment Program: http://www.dep.state.fl.us/water/watersheds/assessment/
Identification of Impaired Surface Waters Rule:
http://www.dep.state.fl.us/legal/Rules/shared/62-303/62-303.pdf
Florida STORET Program: http://www.dep.state.fl.us/water/storet/index.htm
2016 Integrated Report: http://www.dep.state.fl.us/water/docs/2016-Integrated-Report.pdf
Criteria for Surface Water Quality Classifications:
http://www.dep.state.fl.us/legal/Rules/shared/62-302/62-302.pdf
Surface Water Quality Standards:
https://www.flrules.org/gateway/ChapterHome.asp?Chapter=62-302

U.S. Environmental Protection Agency websites:

Region 4: TMDLs in Florida:
https://archive.epa.gov/pesticides/region4/water/tmdl/web/html/index-2.html
National STORET Program:
https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange

Chapter 4 website:

ArcNLET model website: https://people.sc.fsu.edu/~mye/ArcNLET/

Chapter 7 website:

DEP BMAP website: http://www.dep.state.fl.us/water/watersheds/bmap.htm

References websites:

Florida Department of Health OSTDS statistics website:
http://www.floridahealth.gov/environmental-health/onsite-sewage/ostds-statistics.html

U.S. Census Bureau website: http://www.census.gov/