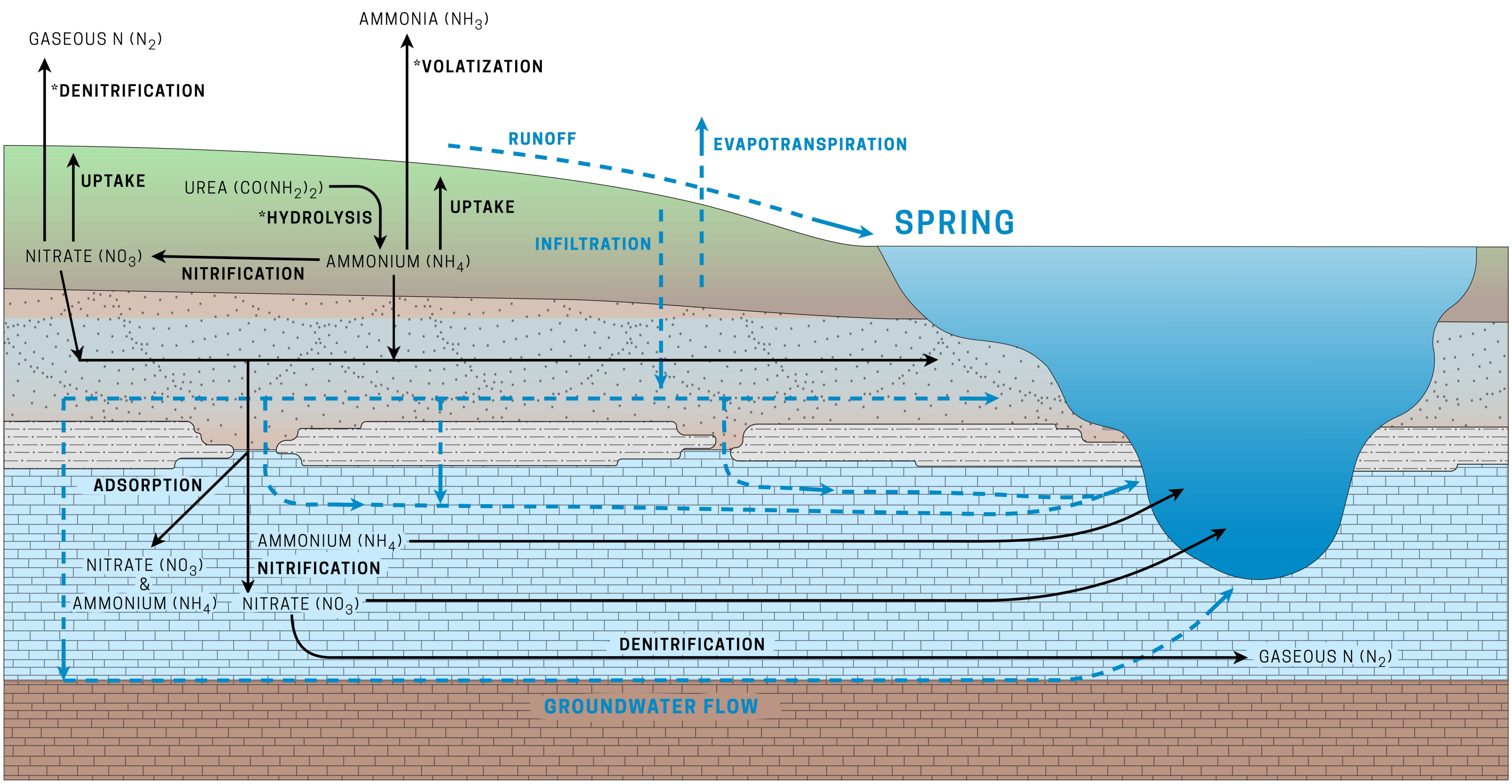
Orange County TMDL BMAP Support Nitrogen Modeling Assessment Technical Memorandum

Prepared for: **7 October 2021**

Water Sciences Section
Orange County Environmental Protection Division
3165 McCrory Pl #200
Orlando, FL 32803



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ORANGE COUNTY GOVERNMENT
F L O R I D A

Orange County TMDL BMAP Support:

Nitrogen Modeling Assessment

Technical Memorandum

Prepared for:

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Orange County EPD PO # C20906A022

Prepared by:

Drummond Carpenter, PLLC
47 East Robinson St., Suite 210
Orlando, FL 32801

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Drummond Carpenter, PLLC
47 East Robinson St., Suite 210
Orlando, FL 32801

Olivia Warren, GIT
Staff Geologist

Ryan Hupfer, PG
Senior Staff Geologist

Nathan Holt, PE
Project Engineer

Chad Drummond, PE, D.WRE, BCEE
Project Manager

In accordance with Chapter 471 of Florida Statues, this Report has been prepared under the direct supervision of a registered Professional Engineer in the State of Florida.

REGISTERED ENGINEERS
STATE OF FLORIDA
Drummond Carpenter, PLLC
47 E. Robinson Street, Suite 210
Orlando, Florida 32801

Nathan Holt, PE
October 7, 2021
Drummond Carpenter, PLLC
Florida Registered Professional Engineer Number 87082

1. CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

bgs	Below Ground Surface
cm	Centimeter
BMAP	Basin Management Action Plan
DTW	Depth to Water Table
ECFTX	East-Central Florida Transient Expanded
FAWN	Florida Automated Weather Network
FDEP	Florida Department of Environmental Protection
ft	Feet
ICU	Intermediate Confining Unit
IFAS	University of Florida Institute of Food and Agricultural Sciences
K_d	Distribution Coefficient
L	Liter
lbs	Pounds
M	Mass
m	Meter
mg	Milligrams
mg/L	Milligrams per liter
mi	Miles
mm	Millimeter
N	Nitrogen
NH_4-N	Ammonium nitrogen
NO_3-N	Nitrate nitrogen
NO_x-N	Nitrate + Nitrite nitrogen
OCEPD	Orange County Environmental Protection Division
RT3D	Reactive Transport in 3-Dimensions
SAS	Surficial Aquifer System
SRN	Slow-Release Nitrogen

T	Time
TMDL	Total Maximum Daily Load
TMR	Telescopic Mesh Refinement
UF	University of Florida
UFA	Upper Floridan Aquifer
USDA	United States Department of Agriculture
USGS	United States Geological Survey

2. Introduction

This document serves as the Technical Memorandum deliverable for Task 2 (Nitrogen Modeling) and Task 3 (Ongoing Technical Support) as outlined in the Drummond Carpenter, PLLC (Drummond Carpenter) Scope of Work for the Wekiva River BMAP/TMDL Support project, under Orange County contract Y20-906A, purchase order C20906A022.

The Wekiwa Spring and Wekiva River system have been listed as impaired due to excessive nitrogen and phosphorous nutrients. The Florida Department of Environmental Protection (FDEP) established Total Maximum Daily Loads (TMDLs) for nitrate and phosphorous as water quality restoration targets for Wekiwa and Rock Springs (FDEP, 2018). In 2017, Orange County implemented a fertilizer ordinance to help reduce nutrient pollutant loading to surface water, groundwater, and springs within the County, including Wekiwa Spring. Section 15-803 of the ordinance restricts residential application of nitrogen in fertilizer during the wet season (June 1st -September 30th), with an exception for commercial applicators who meet training and compliance requirements as defined in Section 15-809. To limit the impact of significant nutrient leaching from urban turfgrass due to high precipitation events, Section 15-803 of the ordinance also prohibits application or nitrogen or phosphorus fertilizers when any part of the County is under a flood, severe thunderstorm, tropical storm, or hurricane warning or watch.

Section 15-804 of Orange County's fertilizer ordinance provides guidance on the use and application of fertilizer within the County. Section 15-804(b) prohibits application of phosphorous in fertilizer year-round unless a soils test identifies a phosphorous deficiency. As of July 1, 2020, Section 15-804(c) of the ordinance requires fertilizer be applied at a rate no greater than 1 pound (lb) nitrogen (N) per 1000 ft^{-2} and contain at least 65% slow-release nitrogen (SRN) provided the product is available on the local commercial market. An exception to Section 15-804(c) is provided for commercial applicators. Section 15-804(d) allows commercial applicators to apply up to 0.5 lbs N 1000 ft^{-2} of readily available nitrogen per application. Currently, Orange County's fertilizer ordinance does not regulate 1) the total annual amount of fertilizer nitrogen that can be applied or 2) when commercial applicators can apply fertilizer nitrogen.

Orange County Environmental Protection Division (OCEPD) is actively evaluating the current fertilizer ordinance for protectiveness of water quality throughout Orange County. As part of this effort, Drummond Carpenter developed unsaturated zone and saturated zone flow and pollutant fate and transport models to evaluate fertilizer nitrogen impacts under varying environmental conditions and application rates on the nitrate-impaired Wekiwa Spring. A conceptualization of how fertilizer nitrogen applied to lawns reaches downstream waterbodies (i.e., Wekiwa Spring) is shown in Figure 1. The modeling pathways considered in this effort are also summarized in Figure 1.

Applied Ecology, Inc. (AEI) has prepared an accompanying fertilizer data compilation and review memorandum (Attachment A). The memorandum focuses on compiling, reviewing, and synthesizing relevant fertilizer application data associated with urban areas, as well as ordinance information and associated relevant research. AEI's memorandum details the following tasks:

- Review and comparison of the state model ordinance for urban landscapes with the OC fertilizer ordinance.
- Compilation of UF/IFAS fertilizer recommendations for turfgrass and BMP recommendations.
- Estimate average pervious area based on simplified land use/land cover GIS coverage for urban areas and assign UF/IFAS recommended low-, mid-, and high-range fertilizer application to the pervious cover.
- Summarization of available statewide or countywide representative survey data of fertilizer practices (application frequency, type, season, etc.).
- Synthesis of recent relevant UF/IFAS and other sources of peer reviewed research on the use of fertilizer in urban setting and its impact.

The remainder of this technical memorandum presents unsaturated zone and saturated zone modeling conducted to evaluate the fate and transport of fertilizer nitrogen applied to turfgrass (Figure 1), including potential transport to downstream water bodies via the groundwater pathway (i.e., Wekiwa Spring). Unsaturated zone modeling (Section 3) focuses on evaluating what happens to fertilizer nitrogen when it is applied to turfgrass, including turfgrass uptake, storage in the soil column, and leaching to the underlying saturated zone. A suite of scenarios were developed to evaluate fertilizer nitrogen dynamics under different application rates, climatic conditions, and hydrologic drivers for a lawn that could be considered representative of those found in Orange County, including within the Wekiwa Spring and Rock Springs Basin Management Action Plan (Wekiwa BMAP) area.

Using nitrogen leaching rates simulated in the unsaturated zone modeling (Section 3), two saturated zone (groundwater) models were developed to evaluate the fate and transport of fertilizer nitrogen once it enters the saturated zone (Section 4). The Wekiwa Springshed groundwater model was developed by refining a portion of the regional East Central Florida Transient Expanded (ECFTX) groundwater flow model (Central Florida Water Initiative, 2020). This model was used to evaluate the transport of nitrogenous compounds related to fertilizer leaching to Wekiwa Spring and to perform a comparative check on the expected nitrogen leaching rates predicted by the unsaturated zone model. The Hypothetical Site groundwater model was developed to represent typical hydrologic conditions within the Wekiwa BMAP area.

The Hypothetical Site model was used to evaluate the impacts of nitrogen loading on downgradient water bodies (i.e., a spring) and to perform a relative comparison of nitrogen transport under different hydrologic conditions.

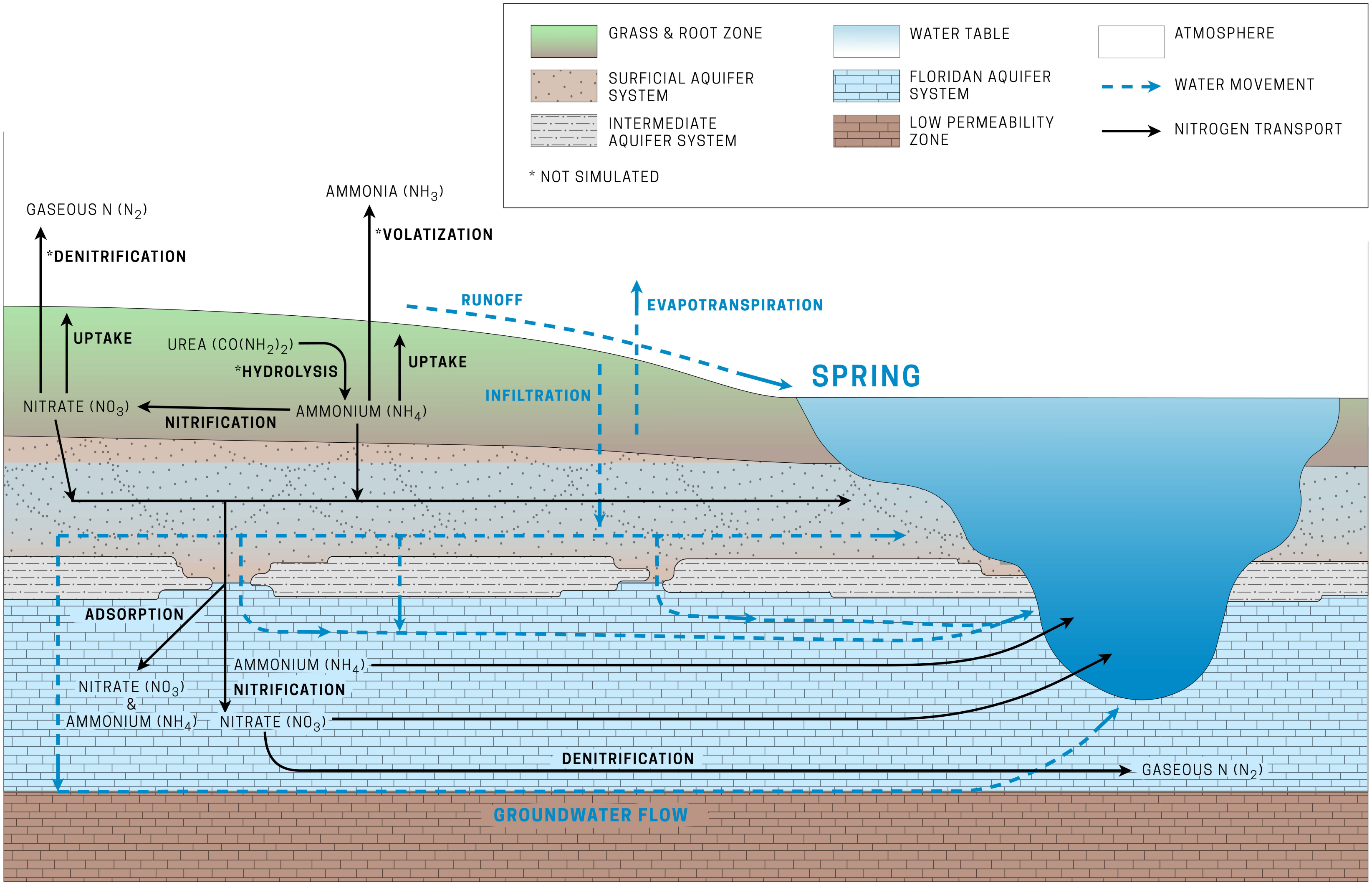

Figure 1. Conceptual Model of the Fate and Transport of Fertilizer Nitrogen Applied to a Lawn in Orange County

3. Unsaturated Zone Modeling

HYDRUS is a suite of modeling software that can be used for the analysis of water flow and heat and solute transport in variably-saturated porous media (Šimůnek et al., 2013). The software suite was developed by the USDA's United States Salinity Laboratory in cooperation with the International Groundwater Modeling Center, the University of California Riverside, and PC-Progress, Inc. (Šimůnek et al., 2008, 2016). The most up-to-date versions of HYDRUS can be downloaded from the HYDRUS website (https://www.pc-progress.com/en/Default.aspx).

The HYDRUS modeling software is capable of simulating irrigation, sequential solute decay and transport, and root water and solute uptake in the unsaturated zone, which can all be important processes when simulating solute transport and decay in soils. As such, HYDRUS has been used extensively to evaluate water and solute (e.g., nitrogen) transport under various climatic, physiographic, irrigation, and fertilizer management conditions, including for agricultural and turfgrass systems (Geza et al., 2021; Hansen et al., 2006; Holt et al., 2017, 2019; Kadyampakeni et al., 2018; Ramos et al., 2012; Šimůnek et al., 2016; Sun et al., 2021; Zhang et al., 2020).

The one-dimensional version of HYDRUS (HYDRUS-1D) is public domain and simulates vertical transport of water and solute through the vadose zone while accounting for root water and solute uptake as well as solute transport and decay processes in the solid, liquid, and gaseous phases. Considering the capabilities of the model, HYDRUS-1D was selected for use in this study to simulate the transport of fertilizer nitrogen applied on residential lawns in Orange County through the vadose zone to the water table.

The model was conceptualized to be generally representative of an irrigated and fertilized residential lawn within the Wekiwa BMAP area (FDEP, 2018). HYDRUS-1D modeling was conducted to evaluate different fertilizer application rates and management strategies, impacts of recharge (precipitation + irrigation), water table depths, and large storm events. To capture climatic variability, two-year model simulations with a daily time step were conducted to evaluate nitrogen leaching. Existing water quality data from a groundwater monitoring well located within a residential lawn in the Wekiwa BMAP area was selected to serve as a comparative check for model simulations.

Modeling scenarios are described in greater detail in Section 3.2.

3.1. HYDRUS Model Construction

Key components of the unsaturated zone modeling performed in this study are described in subsequent sections. Summary tables of HYDRUS-1D parameters developed for the Base Case scenario, described in Section 3.2, are provided in Appendix A.

3.1.1. Water Flow Parameters and Temporal Discretization

The unsaturated zone was conceptualized in HYDRUS-1D as a two-layer model: (1) sandy loam representing topsoil within the root zone and (2) sand below the root zone (Figure 2). The lawn's root zone was defined as 8 inches deep based on the depth where the majority of roots are contained for warm season turfgrasses in Florida lawns (Fuentealba et al., 2015; Romero and Dukes, 2020; Trenholm et al., 2018). Layer 2 represented Candler Fine Sand and was defined from soil identified in the Web Soil Survey at Orange County monitoring well MW07 and as reported in the well installation log (Appendix B). MW07 was selected to serve as the comparative check in this analysis based on its location in a residential lawn within the Wekiwa BMAP area, near average depth to water (10.8 ft), representative sandy soil, available water quality data, and observed isotopic signature for fertilizer nitrogen.

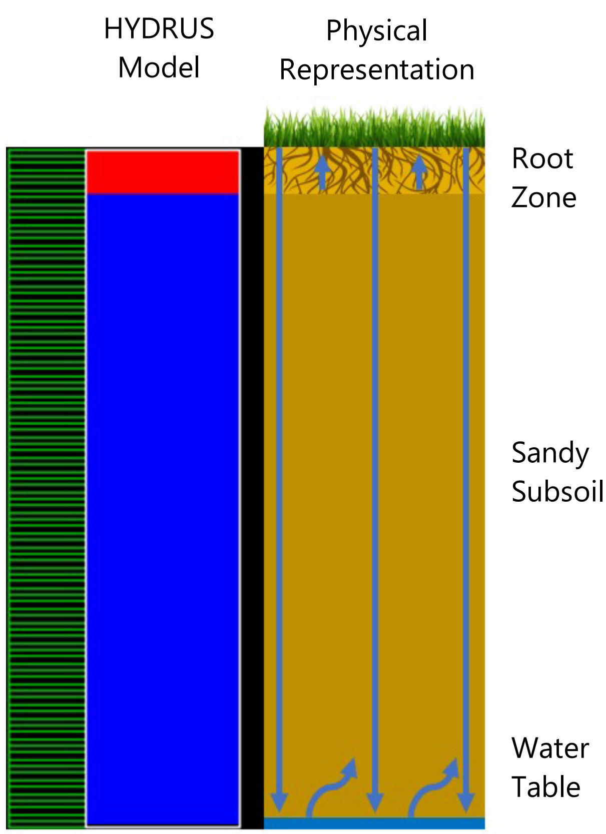

Figure 2. HYDRUS Representation of the Transport of Fertilizer Nitrogen Applied to Lawn

Note: HYDRUS model on left showing finite elements (green) and soil layers (topsoil with root zone – red, sandy subsoil – blue)

Based on soils data taken from the Web Soil Survey operated by the USDA NRCS, the majority (>85%) of soils in the Wekiwa BMAP area within the Orange County fall within Soil Hydrologic Group A or A/D, when excluding soils associated with land uses classified as water bodies or pits. Type A soils typically have over 90% sand, readily transmit water, and are conductive. Type A/D soils have the same soil properties as Type A soils, but their drainage ability is restricted due principally to the presence of a shallow water table. Review of available lithology logs of the well network within the Wekiwa BMAP area indicate the assumption of sandy soil extending to the water table is generally representative of subsurface soil characteristics underneath lawns in the area. Based on soil hydrologic groups and a review of lithology logs, the Candler Fine Sand selected as the Layer 2 in the HYDRUS models was considered a representative sandy subsoil for the study area. Exploring the impact of different soil types on model results is a potential future consideration.

HYDRUS-1D simulates vertical water flow in variably-saturated porous media by numerically solving a mixed form of the Richards equation for equilibrium water flow assuming an incompressible fluid, rigid media, isothermal uniform flow, and that the air phase plays an insignificant role in the liquid flow process (Equation 1). In Equation 1, *h* represents soil-water pressure head (L), $\theta(h)$ represents water content (L^3L^{-3}) at a given soil water pressure head, $K(\theta)$ represents hydraulic conductivity ($L^{-1}T^{-1}$) at a given water content, *t* is time (T), and *S* represents a source sink/term that includes an accounting for root water uptake ($L^3L^{-3}\ T^{-1}$).

Topsoil and subsurface soil hydraulic characteristics used in the Richards equation were defined using the van Genuchten soil water retention function (Equation 2) and the Mualem-van Gentuchten hydraulic conductivity function (Equation 3) (Mualem, 1976; van Genuchten, 1980). The soil water retention and hydraulic functions are defined via saturated (θ_S) and residual (θ_R) water contents (L^3L^{-3}) and parameters related to air entry (α, L^{-1}), curve shape (*m*, *n*, unitless), and pore connectivity (*l*, unitless). The empirical curve shape parameters *m* and *n* are related as $m = 1 - n^{-1}$. Hydraulic parameters (K_s, θ_S, θ_R, *n*, *m*, and *l*) for the model layers were derived from the neural network prediction function built into HYDRUS-1D (Šimůnek et al., 2013). The neural network prediction function in HYDRUS-1D utilizes the Rosetta Dynamically Linked Library developed by Schaap et al. (2001) to predict soil hydraulic parameters based on USDA soil textural classes or surrogate soil data (Schaap et al., 2001; Šimůnek et al., 2013). Soil hydraulic properties for the Layer 1 topsoil in the model were defined using the sandy loam textural class. Web Soil Survey data (1.9% clay, 1.2% silt, 96.9% sand, 1.6 g cm^{-3}, and 0.025 cm^3cm^{-3} water content at 1/3 bar) for the Candler Fine Sand were used to derive soil hydraulic parameters for model Layer 2. Water retention and hydraulic conductivity properties used in the model for Layers 1 and 2 are provided in Table 1.

$$\frac{\partial\theta(h)}{\partial t} = \frac{\partial}{\partial x}\left[K(\theta)\left(\frac{\partial h}{\partial x}+1\right)\right] - S \quad \text{(Eq. 1)}$$

$$\theta(h) = \theta_R + \frac{\theta_S - \theta_R}{[1+|\alpha * h|^n]^m} \quad \text{(Eq. 2)}$$

$$\mathrm{K}(\theta) = K_s\left(\frac{\theta-\theta_R}{\theta_S-\theta_R}\right)^l\left[1-(1-\left(\left(\frac{\theta-\theta_R}{\theta_S-\theta_R}\right)^{1/m}\right)^m\right] \quad \text{(Eq. 3)}$$

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Table 1. Soil Hydraulic Properties of Hydrus-1D Material Layers

Model Layer	θ_R (cm^3cm^{-3})	θ_s (cm^3cm^{-3})	α (1/cm)	n (-)	K_s (cm/day)	l (-)
1: Sandy Loam	0.065	0.41	0.075	1.89	106.1	0.5
2: Sand	0.0542	0.3511	0.0449	4.1247	1376.99	0.5

*θ_R = Residual water content; θ_s = Saturated water content; α, n = van Genuchten curve shape parameters, l = pore connectivity parameter, K_s = Saturated hydraulic conductivity

Two-year model simulations were used to evaluate nitrogen transport from a representative lawn under the different scenarios described in Section 3.2. The model utilized time units of days, an initial time step of 0.001 days, a minimum time step of 0.0001 days, and a maximum time step of 5 days. Each model was assumed to start on January 1st of the first year simulated. Time variable boundary conditions, described in Section 3.1.2, were assigned on a daily basis in accordance with model time units.

3.1.1. Nitrogen Transport Parameters

Nitrogen fate and transport in previous HYDRUS studies have been described as a sequential first-order decay process (Hanson et. al, 2006; Ramos et al., 2012; Sun et al., 2021). A similar approach has been adopted in this study with the advection-dispersion equations describing transport of solutes involved in a sequential first-order decay chain during transient variably-saturated water flow in a rigid porous media utilized in HYDRUS-1D presented in Section 3 of the HYDRUS – 1D User Manual (Šimůnek et al. 2013). Liquid and solid phase nitrogen dynamics of ammonium and nitrate associated with fertilizer application to turfgrass were considered in this study and are be described below and represented in Figure 1.

$$
\begin{array}{l}
Gaseous\ N \\
\quad\uparrow \\
NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^- \rightarrow Gaseous\ N
\end{array}
$$

Volatilization represents the transformation of ammonium to gas. Fertilizer nitrogen losses to volatilization have been reported to vary widely from <1% to 60% depending on conditions (Shaddox and Unruh, 2018). In this effort, ammonium volatilization and subsequent gaseous diffusion were not considered, which is consistent with previous modeling studies of nitrogen transport involving ammonium (Hanson et al., 2006; Ramos et al., 2012; Sun et al., 2021). Additionally, this modeling effort assumes a quarter-inch irrigation event follows each fertilizer application which acts to facilitate incorporation of fertilizer into the soil and reduce volatilization (Shaddox, 2017).

Nitrification is a microbial process causing the sequential transformation of ammonium (NH_4^+) to nitrite (NO_2^-) and nitrite to nitrate (NO_3^-). Hanson et al. (2006) indicates many studies lump the nitrification process because the rate of nitrification from nitrite to nitrate is significantly faster than the rate of nitrification from ammonium to nitrite. Thereby, the nitrification process was lumped in our study into a single decay coefficient (i.e., NH_4^+ → Nitrification → NO_3^-). The first-order decay coefficient representing nitrification from ammonium to nitrate was specified as 0.2 day^{-1} in the HYDRUS models. The selected decay coefficient has been used in previous HYDRUS modeling studies to represent nitrification from ammonium to nitrate (Akbariyeh et al., 2018; Hansen et al., 2006; Ramos et al., 2012) and the value falls within values reported in literature (0.02-0.72 day^{-1}) provided in Hansen et al. (2006).

Denitrification is a microbial process causing the reduction of nitrate to gaseous nitrogen. Shaddox and Unruh (2018) indicate denitrification of fertilizer nitrogen applied to Florida turfgrass is typically low from <1% to 5%. Transformation of nitrate to gaseous nitrogen generally requires low levels of dissolved oxygen (i.e., anaerobic conditions) and an electron donor source, typically organic carbon. Much of the area within the Wekiwa BMAP area, including the comparative check well, MW07, is underlain by type A soils. These are highly conductive, well-drained sands with low organic matter, which present conditions not conducive to denitrification of nitrate before reaching the water table. Therefore, denitrification processes were not considered in the unsaturated zone modeling portion of this study.

Solute partitioning between the solid and liquid phases in the HYDRUS models was described using a linear absorption isotherm in the form of

$$S = K_d C$$

where K_d (L^3M^{-1}) is the distribution coefficient between the solid (S, MM^{-1}) and liquid (C, ML^{-3}) phases of a solute. Ammonium, which was assumed to be present in both the solid and liquid phases, was assigned a K_d of 0.0035 cm^3mg^{-1}. The K_d assigned to ammonium falls within the range of values reported in literature of 0.00112-0.0040 cm^3mg^{-1} (Hanson et al., 2006; Kadyampakeni et al., 2018). The selected K_d value for ammonium used in this study (0.0035 cm^3mg^{-1}) has also been used in other HYDRUS modeling studies simulating nitrogen transport in the unsaturated zone (Hansen et al., 2006; Ramos et al., 2012). Nitrate was assumed to be present solely in the dissolved phase (K_d = 0 cm^3mg^{-1}), which is a common assumption of other HYDRUS studies modeling nitrogen fate and transport in the unsaturated zone (Hanson et al., 2006; Kadyampakeni et al., 2018; Ramos et al., 2012; Sun et al., 2021).

3.1.2. Boundary Conditions

Water Flow Boundary Conditions

An atmospheric boundary condition was utilized in the HYDRUS models as the upper boundary condition. Daily precipitation, irrigation, and evapotranspiration were applied to the atmospheric boundary condition in the HYDRUS models as time variable boundary conditions. Infiltration into the model was taken as a combination of rainfall and irrigation. Irrigation included quarter inch events following fertilizer application and along with weekly three-quarter inch irrigation events. A small irrigation event is recommended following fertilizer application to avoid fertilizer burn and reduce volatilization (Shaddox, 2017). Irrigation was applied at a consistent rate of three-quarter inch once per week throughout the year as most homeowners do not adjust their irrigation schedule throughout the year (Trenholm et al. 2017).

Precipitation and evapotranspiration data in the HYDRUS model were taken from the Apopka weather station (Station ID: 320) that is part of the UF/IFAS Florida Automated Weather Network (FAWN). The station was selected for use in the HYDRUS modeling because the site 1) is located within Orange County, 2) has co-located precipitation and reference evapotranspiration data with a period of record of greater than 20 years, and 3) is part of FAWN which was partially created to obtain weather data to assist Florida growers in irrigation scheduling.

Runoff from lawns on the coarse sands found across much of Orange County is small. Romero and Dukes (2020) neglected runoff when determining net irrigation requirements for lawn turfgrass in the Orlando area based on the dominant soils covering the area (i.e., conductive sands). Similar observations have been reported for nitrogen runoff. Shaddox and Unruh (2018) report nitrate runoff from turfgrass on soils with lower permeability than those typically found in Florida commonly have 0% nitrogen runoff but could approach up to 7% under topographic and environmental conditions not typical to Florida. While runoff was assumed to be small, runoff of precipitation was accounted for in the HYDRUS model utilizing mean annual runoff coefficients presented in Harvey and Baker (2007). These coefficients represent the portion of annual rainfall which becomes runoff in different regions across Florida. Based on curve numbers for open space (i.e., a lawn) in good condition under type A (low runoff potential, CN = 39) and D (high runoff potential, CN = 80) soils (USDA, 1986), the mean annual runoff coefficient for lawn turfgrass in Zone 2 (Orange County) was estimated to range from 0.0064 to 0.111. In other words, runoff from turfgrass was estimated to range between <1% to 11% of precipitation in Orange County. In the HYDRUS models, 5% of precipitation was assumed to be lost to runoff and initial abstraction.

HYDRUS requires partitioning of evapotranspiration into its individual evaporation and transpiration components. Daily evaporation and transpiration were derived from daily reference evapotranspiration from the Apopka FAWN weather station using the F.A.O. 56 dual-crop coefficient method (Allen et al., 1998). In the HYDRUS models, the daily transpiration and evaporation components of evapotranspiration were determined for a warm season turfgrass. The crop coefficients for warm season turfgrass are applicable for varieties that include Bermuda grass and St. Augustine grass (Allen et al., 1998).

The lower boundary of the HYDRUS models was assigned a variable head boundary condition. The lower boundary condition represented the water table and was kept constant throughout each simulation. The boundary condition was specified as variable head in the model to provide flexibility and allow water table functions if future simulations require temporal changes in the water table throughout a simulation.

Solute Boundary Conditions

The nitrogen component of fertilizer was the sole nutrient simulated as part of this study. Fertilizer nitrogen was introduced into the model through a concentration flux boundary condition at the upper boundary of the model domain. The reference fertilizer modeled in this study was assumed to be representative of a commercial fertilizer available at hardware stores in Orange County. The fertilizer was composed of 65% SRN in accordance with Section 15-804(c) of the Orange County fertilizer ordinance. The reference fertilizer contained urea nitrogen, other water-soluble nitrogen, and water insoluble nitrogen.

Introduction of fertilizer nitrogen into the HYDRUS models in this study was conceptualized based on the methodology provided in Sun et al. (2021) for simulating SRN in HYDRUS. Two nitrogen species are explicitly included in the modeling: (1) ammonium nitrogen (NH_4-N) and (2) nitrate nitrogen (NO_3-N). Soluble urea and other water-soluble nitrogen species contained in the reference fertilizer were introduced into the model as NH_4-N. The readily available nitrogen component of the fertilizer was introduced into the model on the day of application as flux concentrations by taking the application rate divided by the irrigation amount (0.25-inches). The SRN component of the fertilizer was introduced into the model as NO_3-N on an infiltration-flux basis for the 60 days following application. The 60-day period was selected based on the feed duration of the fertilizer.

Utilizing the concentration flux boundary condition and inputting fertilizer nitrogen into the HYDRUS models in the manner described above provided control over the conservation of nitrogen mass entering the model domain. The bottom solute boundary condition was considered free drainage into the water table.

3.1.3. Root Water and Solute Uptake

Water uptake from turfgrass was defined using a water stress response function built into HYDRUS that is described by Feddes (1978). In the Feddes model, root water uptake is a function of water stress and can be calculated using Equation 4:

$$S(h) = \alpha * S_P \quad \text{(Eq. 4)}$$

where *S(h)* is actual root water uptake ($L^3L^{-3}T$), S_p is potential root water uptake ($L^3L^{-3}T$), and α is a dimensionless water stress function that limits root water uptake under stressed conditions (i.e., near saturation or wilting point). Potential root water uptake, S_p, is defined as the volume of water removed from the root zone based on transpiration demand (Šimůnek et al., 2013). In this study, transpiration demand was entered into the model as a time-variable boundary condition and was determined from reference evapotranspiration using the F.A.O. 56 dual-crop coefficient method. The depth of the root zone used in the HYDRUS modeling in this study is 8 inches. The water stress response function, α, was defined using parameters recommended for turfgrass available in a database built into HYDRUS that provides recommended parameter values for the water stress response function for different plants based on studies by Taylor and Ashcroft (1972) and Wesseling (1991).

Fertilizer nitrogen uptake by turfgrass was simulated in the HYDRUS models. Hydrus-1D allows for both passive and active root uptake of solutes (Šimůnek et al., 2013). Passive root uptake represents dissolved nutrients in soil water being taken up by roots during transpiration, while active root uptake represents nutrient uptake due to a range of biological energy-driven processes (Šimůnek and Hopmans, 2009). Active root uptake is considered the difference between plant nutrient demand and passive nutrient uptake. Nitrogen uptake by roots likely involves both passive and active mechanisms (Ramos et al., 2012). Active root uptake can only be specified for one solute in HYDRUS-1D. Similar to the HYDRUS modeling of nitrogen described in Sun et al. (2021), ammonium was set to passive uptake and nitrate was set to passive and active uptake in this study. Active root uptake is simulated in HYDRUS using Michaelis-Menten kinetics (Šimůnek et al., 2013). The Michaelis-Menten constant was specified as 0.17 mg cm^{-3} in this study based on published values for nitrate in sandy soils (Bowman and Focht, 1974).

3.1.4. Initial Conditions

Three HYDRUS simulations were conducted to obtain initial soil moisture conditions for the HYDRUS nitrogen modeling conducted in this study. As described in Section 3.2, three different water table depths were evaluated in this study (shallow – 5 feet, average – 10 feet, and deep – 20 feet). One initial conditions model simulation was constructed for each water table depth.

The initial conditions model simulations utilized the same model domains as the HYDRUS nitrogen models. The initial condition models were simulated for 14 days without any precipitation, irrigation, fertilizer application, or evapotranspiration. The initial conditions models provided a moisture distribution in the soil profile under "drained-to-equilibrium" conditions by accounting for applicable draining of soil-water from soil pores and the redistribution of soil moisture above the water table due to capillary action. Soil moisture profiles from the initial condition simulations were used to specify initial water contents in the soil profile for the HYDRUS nitrogen modeling. No legacy nitrogen was assumed to be in the root zone or soil profile at the start of the HYDRUS nitrogen models, which is biased towards lower leaching over the simulation period as the amount of simulated nitrogen loads leached do not account for any nitrogen that may be in the soil profile before the first fertilizer application is applied in the model. Therefore, the HYDRUS models used to evaluate nitrogen transport from fertilizer applied to lawns in this study were assumed to start under "drained-to-equilibrium" soil moisture conditions without any legacy nitrogen in the soil profile.

3.1.5. HYDRUS Model Assumptions

Key assumptions made in the unsaturated zone HYDRUS modeling in this study are provided below. Discussions of these assumptions and parameters can be found in Sections 3.1.1 – 3.1.4.

- Volatilization and denitrification of nitrogen is negligible in the unsaturated zone.
- Nitrate is mobile and does not sorb to the soil.
- Fertilizer is the sole source of nitrogen in the model (i.e., no atmospheric nitrogen contributed from precipitation, irrigation water does not contain nitrogen, and lawn clippings are not returned to the lawn after mowing).
- The homeowner's irrigation schedule is maintained regardless of rainfall and season, consistent with observed behaviors described in Trenholm et al. (2017).
- The homeowner is not receiving reclaimed water service.

3.2. Model Scenarios

Sixteen scenarios were developed to evaluate the transport dynamics of fertilizer nitrogen applied on residential lawns. Two-year simulations were conducted in HYDRUS to account for rainfall variability. A summary of the sixteen scenarios is provided in Table 2 with more detailed descriptions of each scenario presented in Sections 3.2.1 – 3.2.7.

As mentioned in Section 3.1, nitrogen was the sole nutrient contained with residential lawn fertilizer that was simulated in this study. The FDEP and Orange County fertilizer ordinances are written in terms of pounds of total nitrogen applied per one thousand square feet (lbs N 1000 ft^{-2}). Section 15-804(c) of the Orange County fertilizer ordinance requires a 65% SRN standard for residential fertilizer applications at a rate up to 1 lb N 1000 ft^{-2}. For Scenarios #1-7 in Table 2, modeled fertilizer applications were constructed to follow guidance outlined in Section 15-804(c). Scenario #1 is defined as the Base Case and is parameterized with average values for a representative residential lawn within the Wekiwa BMAP area. Scenarios #2-7 explore the impact of recharge, depth to groundwater, and yearly total fertilizer loading on nitrogen dynamics. Scenarios #8-16 are exploratory model simulations performed to investigate the impact of varying proportions of SRN in fertilizer, application rates, and storm events on nitrogen dynamics.

Table 2. Summary of HYDRUS-1D Scenarios

Scenario	Fertilizer Loading Rate (Application Rate, Frequency)	% SRN*	DTW*	Meteorological*
1. Base Case (BC)	3 lbs N 1000 ft^{-2} yr^{-1} (1 lbs N 1000 ft^{-2}, 3x/yr)	65%	10 ft	FAWN 2013-2014
2. High Recharge	BC	BC	BC	FAWN 2017-2018
3. Low Recharge	BC	BC	BC	FAWN 2007-2008
4. Shallow DTW	BC	BC	5 ft	BC
5. Deep DTW	BC	BC	20 ft	BC
6. IFAS-Low	0.4 lbs N 1000 ft^{-2} yr^{-1} (1x/yr)	BC	BC	BC
7. IFAS-High	6 lbs N 1000 ft^{-2} yr^{-1} (1 lbs N 1000 ft^{-2}, 6x/yr)	BC	BC	BC
8. 0% SRN	3 lbs N 1000 ft^{-2} yr^{-1} (1 lbs N 1000 ft^{-2}, 3x/yr)	0%	BC	BC
9. 50% SRN	3 lbs N 1000 ft^{-2} yr^{-1} (1 lbs N 1000 ft^{-2}, 3x/yr)	50%	BC	BC
10. Commercial Applicator	3 lbs N 1000 ft^{-2} yr^{-1} (0.5 lbs N 1000 ft^{-2}, 6x/yr)	0%	BC	BC
11. 10-inch, 24-hour Storm (65% SRN)	1 lbs N 1000 ft^{-2} (Single application)	65%	BC	24-hr storm event + BC
12. 10-inch, 24-hour Storm (0% SRN)	1 lbs N 1000 ft^{-2} (Single application)	0%	BC	24-hr storm event + BC
13. 5-inch, 24-hour Storm (65% SRN)	1 lbs N 1000 ft^{-2} (Single application)	65%	BC	24-hr storm event + BC
14. 5-inch, 24-hour Storm (0% SRN)	1 lbs N 1000 ft^{-2} (Single application)	0%	BC	24-hr storm event + BC
15. 2-inch, 24-hour Storm (65% SRN)	1 lbs N 1000 ft^{-2} (Single application)	65%	BC	24-hr storm event + BC
16. 2-inch, 24-hour Storm (0% SRN)	1 lbs N 1000 ft^{-2} (Single application)	0%	BC	24-hr storm event + BC

*SRN = Slow-Release Nitrogen, DTW = Depth to Water Table (ft), FAWN = Florida Automated Weather Network (Apopka Station)

3.2.1. Base Case

The Base Case scenario was constructed to simulate a representative residential lawn within the Wekiwa BMAP area. Average values for depth to water (10 ft), recharge (2013-2014), and annual fertilizer nitrogen loading rate (3 lbs N 1000 ft^{-2} yr^{-1} with 65% SRN) were selected for the Base Case. These values are discussed in more detail in Sections 3.2.2-3.2.4.

The Base Case fertilizer rate of 3 lbs N 1000 ft^{-2} yr^{-1} was selected as an average value based on UF/IFAS recommended fertilizer rates for turfgrasses in Central Florida (Trenholm, 2018). The fertilizer was assumed to be applied through three applications each year at a rate of 1 lbs N 1000 ft^{-2}. A total of 6 lbs N 1000 ft^{-2} was applied over the two-year HYDRUS model simulation for the Base Case. Application days were selected considering growing seasons for turfgrasses in Central Florida and Orange County's fertilizer ordinance blackout period for nitrogen fertilizers (June-September). The three fertilizer applications throughout the year were modeled to occur in Mid-February, Late-May, and Late-October.

3.2.2. Recharge

The impact of varying recharge was explored in HYDRUS using precipitation and evapotranspiration datasets from the FAWN Apopka station (ID: 320). The Orlando International Airport NOAA weather station (ID: USW00012815) indicates the average annual precipitation for Orlando, Florida is 51.45 inches a year based on 30-year average data 1991-2020 (NOAA, 2021). The average annual precipitation from the FAWN Apopka Station from 1998-2020 was slightly lower at 47.80 inches. Total yearly precipitation is presented in Figure 3 with selected years for simulations indicated by striped bars. The record of water quality data for wells in the study area generally starts in 2008.

Based on near-average precipitation for the period with water quality data (2008-2020), precipitation and evapotranspiration for the years 2013-2014 were selected to represent an average recharge condition for use in the Base Case model. Two scenarios with different precipitation and evapotranspiration records were developed from the Base Case scenario to evaluate the impact of recharge on fertilizer nitrogen dynamics. The scenarios were termed Low Recharge and High Recharge. Based on below-average precipitation, the years 2007-2008 were selected to develop the Low Recharge scenario. Based on above-average precipitation, the years 2017-2018 were selected to develop the High Recharge scenario. Precipitation totals over the two-year simulation periods for the Low Recharge, Base Case, and High Recharge scenarios were 69, 95, and 116 inches, respectively.

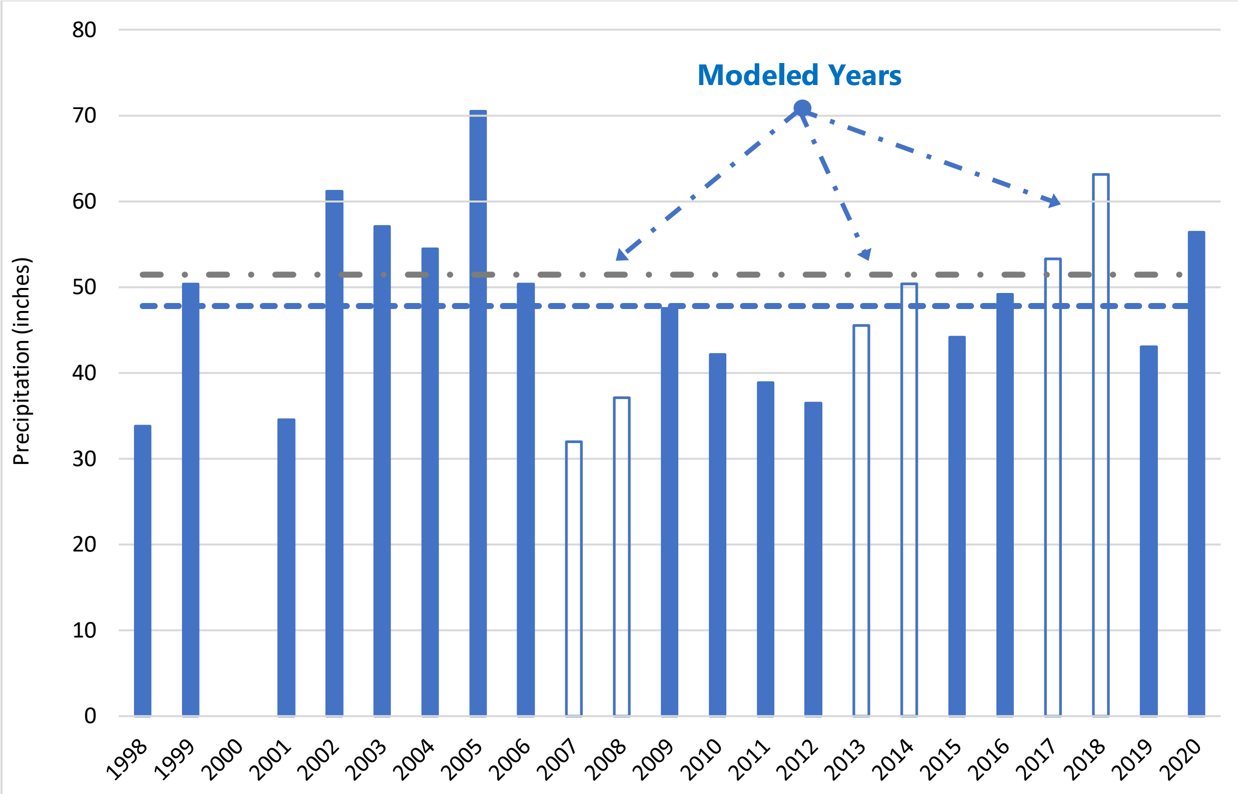

Figure 3. Average Annual Precipitation from the Apopka Station (ID: 320) of the Florida Automated Weather Network (FAWN)

Notes: Blue dashed line represents 23-year (1998-2020) average annual precipitation (47.80 inches) from the Fawn Apopka station (FAWN ID: 320). Grey dashed line represents 30-year (1991-2020) average annual precipitation (51.45 inches) from the NOAA Orlando International Airport station (NOAA ID: USW00012815). FAWN Data not available for year 2000.

3.2.3. Depth to Groundwater

The depth to groundwater was simulated at 10 feet below ground surface (bgs) in the Base Case scenario. A depth to groundwater of 10 feet was selected for the Base Case model based on the water table depth for the surficial aquifer system (SAS) within the Wekiwa BMAP area (FDEP, 2008). Water table depth can vary within Orange County and within the Wekiwa BMAP area. To explore the impact of depth to groundwater on the fate of nitrogen applied as fertilizer, two additional scenarios were developed for relatively 1) shallow (5 feet bgs) and 2) deep (20 feet bgs) water table depths.

3.2.4. Fertilizer Loading

The impact of fertilizer loading was explored by developing scenarios with fertilizer applied at the low- and high-end values of the current UF/IFAS recommendations for annual nitrogen fertilization rates for Central Florida (Trenholm, 2018). The Base Case scenario, which had an applied fertilizer rate of 3 lbs N 1000 ft^{-2} yr^{-1}, was modified to develop the IFAS-Low and IFAS-High fertilizer loading scenarios. The low-end of IFAS-recommended rates for Central Florida is 0.4 lbs N 1000 ft^{-2} yr^{-1} for Centipede grass. This value was applied through a single annual application occurring in late-May in the IFAS-Low scenario. A total of 0.8 lbs N 1000 ft^{-2} was applied over the two-year simulation period in the IFAS-Low scenario.

The high-end recommended IFAS rate for Central Florida of 6 lbs N 1000 ft^{-2} yr^{-1} for Bermudagrass was used for the IFAS-High scenario. Fertilizer application occurred six times a year on a bimonthly schedule at a rate of 1 lbs N 1000 ft^{-2} per application in the IFAS-High scenario. A total of 12 lbs N 1000 ft^{-2} was applied over the two-year simulation period in the IFAS-High scenario. A survey conducted as part of a University of Central Florida study indicates some within the Wekiwa Spring BMAP area apply fertilizer over 10 times a year (Souto et al., 2009). Assuming an application rate of 1 lbs N 1000 ft^{-2}, results from the UCF survey indicate the annual application of 6 lbs N 1000 ft^{-2} yr^{-1} used in the IFAS-High scenario may be conservative relative to the rates utilized by some of the high-end fertilizer applicators.

3.2.5. Slow-Release Nitrogen (SRN)

Section 15-804(c) of the OCEPD fertilizer ordinance requires fertilizer to contain at least 65% SRN for residential applications at a rate up to 1 lb N 1000 ft^{-2}. The impact of the proportion of SRN was explored through scenarios developed from the Base Case scenario where the same fertilizer loading of 3 applications a year at 1 lb N 1000 ft^{-2} per application was used but with different proportions of SRN. The first scenario, 50% SRN, was developed for a fertilizer containing 50% SRN, which under the current ordinance could still be used as fertilizer in applicable situations per language in Sections 15-804(c) and 15-804(d). A second scenario was developed to represent a conceptual fertilizer containing 100% readily available nitrogen (i.e., 0% SRN).

3.2.6. Commercial Applicator

Orange County's fertilizer ordinance contains a clause specific to a commercial applicator of fertilizer. Section 15-804(d) indicates commercial applicators may apply readily available nitrogen at a rate of no greater than 0.5 lbs N 1000 ft^{-2}. To evaluate the impact of this section of the fertilizer ordinance, a Commercial Applicator scenario was developed from the Base Case scenario. The total amount of applied fertilizer was kept the same as the Base Case scenario (3 lbs N 1000 ft^{-2} yr^{-1}), but fertilizer containing 0% SRN was applied six times a year at a rate of 0.5 lbs N 1000 ft^{-2} in the Commercial Applicator scenario.

3.2.7. Storm Events

The impact of storm events (i.e., high precipitation incidences) on fertilizer nitrogen dynamics was explored through modifications to the Base Case scenario. The Storm Event scenarios were developed to evaluate nitrogen uptake and leaching from a single fertilizer application followed by a storm event the next day. The Storm Event scenarios were developed through modifications to the Base Case scenario. Both the Storm Event and Base Case scenarios had the same simulation period (two years, 730 days) and time step (daily). In the Storm Event scenarios, fertilizer was applied on Day 1 of the simulation and was followed by a prescribed storm event on Day 2. No irrigation was applied for the rest of week following the storm. Starting in the second week of the two-year simulation period (Day 8), the same precipitation record along with weekly irrigation used in the Base Case scenario was applied to the Storm Event scenarios. However, no other fertilizer applications occurred throughout the Storm Event scenarios in order to evaluate the fate and transport of fertilizer nitrogen associated with the pre-storm application. Evapotranspiration from the Base Case scenario was not modified for the Storm Event scenarios.

Two fertilizers were evaluated in the Storm Event scenarios. The first fertilizer was the same as the Base Case, which is a representative fertilizer with 65% SRN. As in the Base Case scenario, the SRN portion of the fertilizer was released on an infiltration-flux basis through 60 days following application. The second Storm Event scenario used a conceptualized fertilizer containing 100% readily available nitrogen (0% SRN). For direct comparison, fertilizer in all Storm Event scenarios was applied at the same rate of 1 lbs N 1000 ft^{-2} on Day 1 of the respective simulation.

Storm event modeling was conducted for three different precipitation events: 2-inch 24-hour, 5-inch 24-hour, and 10-inch 24-hour storms. Precipitation totals associated with the 24-hour "mean-annual" (2.3 year) and the 50-year storm events in Orange County are around 4.5 and 10.0 inches, respectively (SJRWMD, 2018; FDOT, 2020). Therefore, the storms simulated in HYDRUS evaluated fertilizer nitrogen fate and transport from 24-hour storm events ranging from those more common than the "mean-annual" storm to the 50-year storm. In each Storm Event scenario, daily precipitation totals associated the prescribed storm were applied on Day 2 under the same runoff assumptions utilized in the Base Case scenario (see Section 3.2.1).

Both fertilizers, 0% and 65% SRN, were evaluated for each storm event. Therefore, a total of six Storm Event scenarios were evaluated: 2-inch 24-hr (65% SRN), 2-inch 24-hr (0% SRN), 5-inch 24-hr (65% SRN), 5-inch 24-hr (0% SRN), 10-inch 24-hr (65% SRN), and 10-inch 24-hr (0% SRN).

3.3. Hydrus-1D Results

The dynamics of nitrogen fertilizer applied to lawn turfgrass were explored through a series of two-year HYDRUS model simulations. An overview of HYDRUS-1D modeling results is presented in this section. Unless specified, root uptake, retained, and leached nitrogen presented herein respectively represent both ammonium and nitrate taken up by turfgrass, retained in the root zone and soil column, and leached to the groundwater. Modeling results indicate that ammonium leaching was insignificant compared to nitrate leaching.

3.3.1. Evaluation Scenarios

A comparison of fertilizer nitrogen fate at the end of two years for the seven scenarios developed to evaluate Section 15-804(c) are shown in Figure 4. The Base Case scenario symbolizes a representative lawn in the Wekiwa BMAP area under average fertilizer, rainfall, and water table conditions. The other six scenarios represent variations developed to evaluate the impacts of high and low recharge, water table depth, and fertilizer nitrogen application rate. All scenarios shown in Figure 4 were simulated for a representative fertilizer containing 65% SRN.

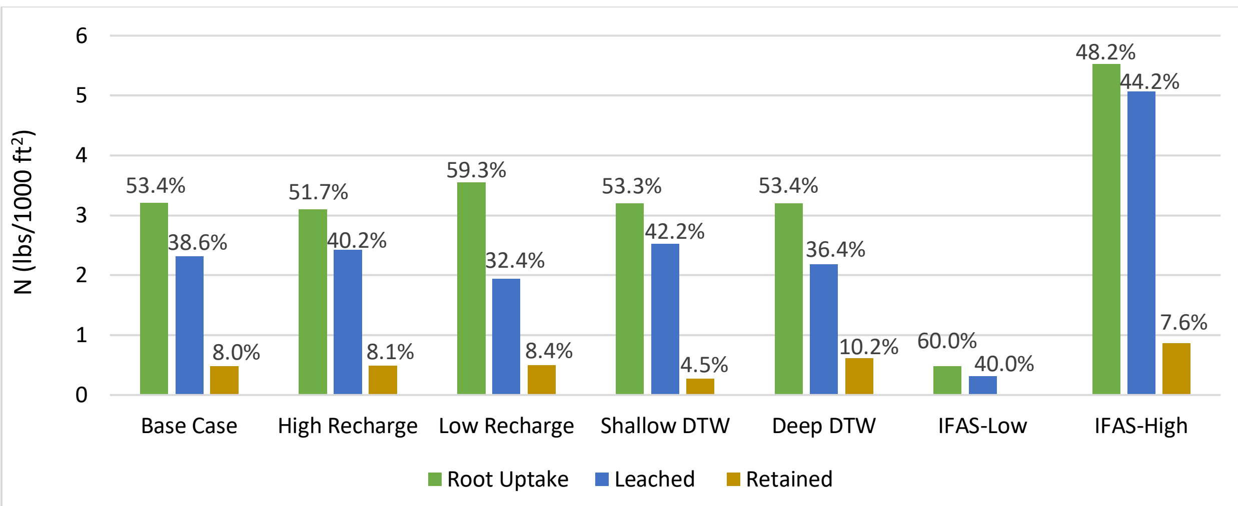

Figure 4. Simulated Fate of Fertilizer Nitrogen Applied to Lawn Turfgrass under Various Conditions

3.3.2. Base Case

The Base Case HYDRUS-1D simulation predicted approximately 53.4% of applied fertilizer nitrogen would be taken up by the turfgrass, 38.6% would leach to the water table, and 8.0% would remain within the soil column at the end of the 2-year simulation period (Figure 5). These percentages fall within UF/IFAS published ranges for nitrogen fate applied to Florida turfgrasses (40-64% plant uptake, 1-55% leaching, 7-15% soil storage; Shaddox and Unruh, 2018).

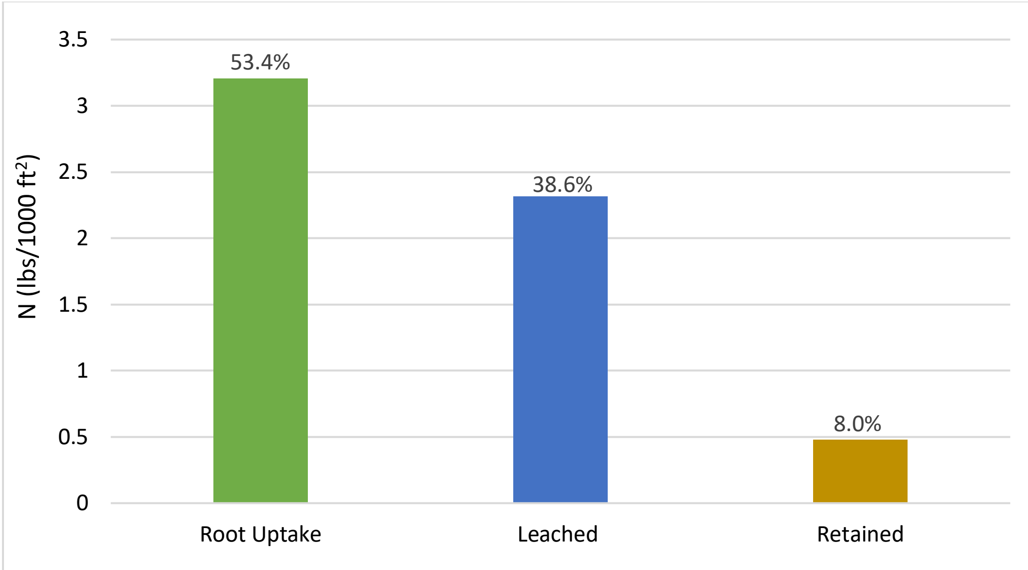

Figure 5. Fate of Fertilizer Nitrogen in the Base Case Scenario

3.3.3. Recharge

Results from HYDRUS-1D modeling suggest higher recharge (e.g., precipitation or excess irrigation) rates can lead to decreased uptake of applied fertilizer nitrogen and increased leaching. As shown in Figure 4, nitrogen uptake by the turfgrass decreased (53.4% to 51.7% of applied) and leaching increased (38.6% to 40.2% of applied) over the two-year simulation periods under average (Base Case) and high recharge. Nitrogen uptake increased and leaching decreased in the Low Recharge scenario. Results of the HYDRUS-1D modeling indicate fertilizer nitrogen may be susceptible to leaching in years where there is increased precipitation or in situations where lawns receive excessive irrigation.

3.3.4. Depth to Groundwater

As shown in Figure 4, results from HYDRUS-1D modeling suggests depth to groundwater did not have a significant impact on turfgrass uptake, which was just over 53% of total fertilizer nitrogen applied under shallow (5 ft), average (10 ft), and deep (20 ft) water table conditions. Lack of observed differences in nutrient uptake may be an indication that even at a shallow depth of 5 feet, the water table was still deep enough to have minimal impact on soil water dynamics within the root zone due to capillary action.

Modeling does indicate depth to the water table impacts the time it takes for nitrogen to reach the water table. Storage of nitrogen in the soil increased from 4.5% to 10.2% as depth to the water table increased from 5 to 20 ft (Figure 4). The differences in total nitrogen leached to groundwater can be attributed to more nitrogen retained within the soil column above the water table at the end of the modeled period as depth to water (travel time) increased. The impact of depth to water on travel time can be seen in the example provided in Figure 6 where simulated dissolved nitrogen concentrations entering the water table following the first fertilizer application, on Day 50, are shown. As the depth to water table decreases, it takes less time for fertilizer nitrogen to reach the water table and for peak concentrations to occur. Peak nitrogen concentrations entering the water table occurred within 75 days of the first fertilizer application for water tables at 5 and 10 feet bgs, but nitrogen concentrations had not peaked after 100 days for the deepest simulated water table at 20 feet bgs (Figure 6).

Longer travel times can provide more opportunity for denitrification if the appropriate conditions exist (low dissolved oxygen, electron donor source, etc.). The lithology considered in the modeled scenarios would not likely produce environmental conditions that would promote denitrification. Additionally, denitrification of fertilizer nitrogen applied to Florida turfgrass is typically low from <1% to 5% (Shaddox and Urea, 2018). Consequently, denitrification was not considered in the unsaturated zone modeling performed in this study.

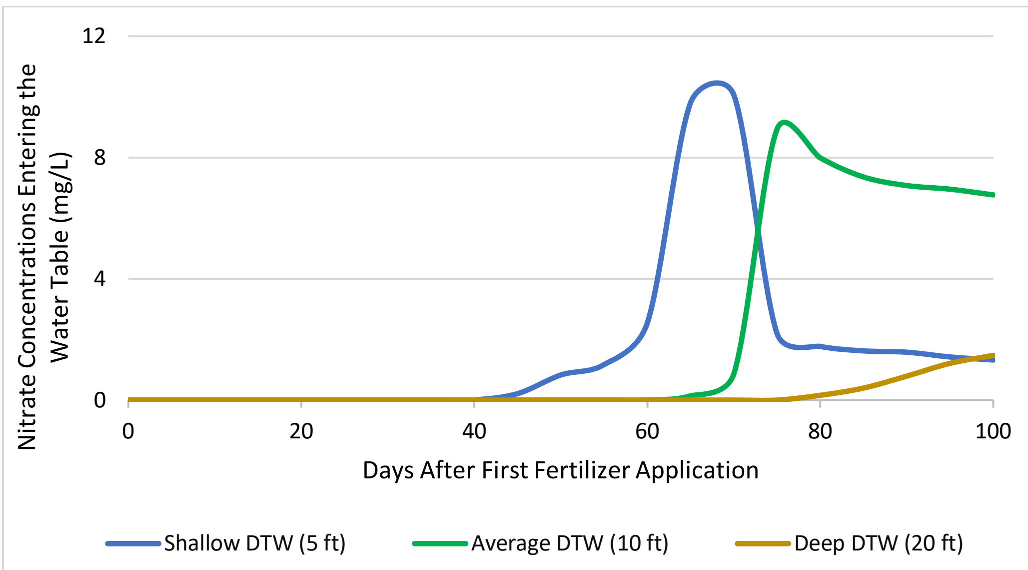

Figure 6. Impact of Depth to the Water Table (DTW) on Nitrogen Travel Times

3.3.5. Fertilizer Loading

Fertilizer loading can play a key role in controlling the total mass of fertilizer nitrogen reaching the groundwater table. In the IFAS-Low scenario, which represents a scenario with low-end fertilizer loading (0.4 lbs N 1000 ft^{-2} yr^{-1}), 60.0% of applied fertilizer nitrogen was taken up by turfgrass, which was the highest uptake percentage of the scenarios evaluated (Figure 7). The total mass of fertilizer nitrogen leached in the IFAS-Low scenario was 0.32 lbs N 1000 ft^{-2} over two years, which was significantly less than the Base Case where 2.3 lbs N 1000 ft^{-2} leached.

The IFAS-High scenario, which represents a scenario with a high-end fertilizer loading rate (6 lbs N 1000 ft^{-2} yr^{-1}), had the greatest mass of fertilizer nitrogen uptake by the turfgrass over the two-year period of any scenario. However, the percentage of nitrogen uptake by turfgrass in the IFAS-High scenario, 48.2% of total applied nitrogen, was less than in the Base Case scenario, 53.4% of total applied nitrogen (Figure 7). The amount of fertilizer nitrogen leached to the water table was also highest in the IFAS-High scenario (5.1 lbs N 1000 ft^{-2}), compared to the IFAS-Low and Base Case scenarios (range: 0.32-2.3 lbs N 1000 ft^{-2}). Modeling suggests that turfgrass can continue to utilize fertilizer at higher application rates; however, nitrogen use efficiency decreases leading to increased nitrogen mass loads leaching beneath the root zone and transporting to the water table.

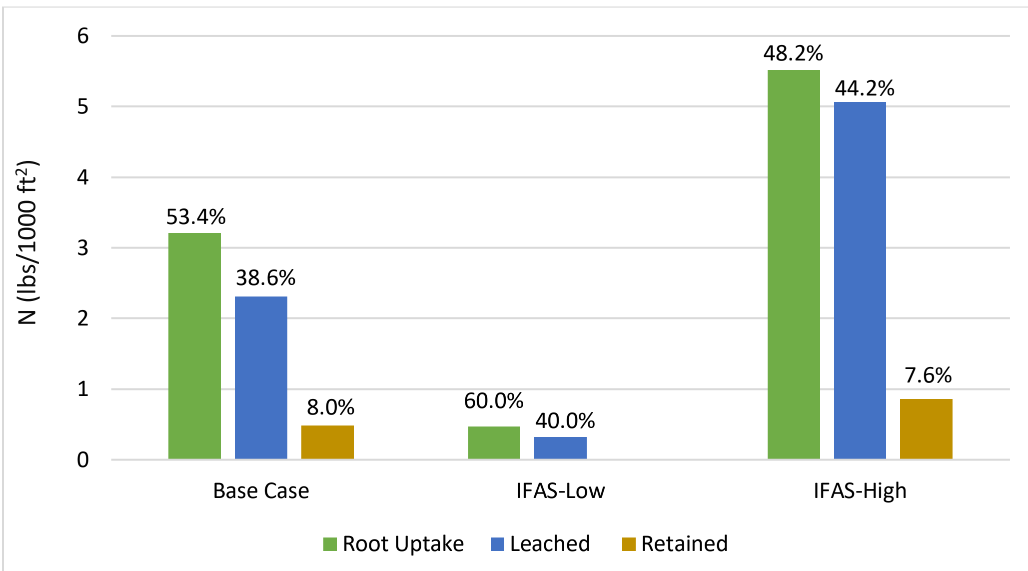

Figure 7. Fate of Fertilizer Nitrogen under Different Application Rates

3.3.6. Exploratory Scenarios

The exploratory scenarios performed as part of this study to investigate the impact of varying proportions of SRN in fertilizer, application rates, and storm events on nitrogen dynamics are described in Sections 3.3.7 – 3.3.9.

3.3.7. Slow-Release Nitrogen (SRN)

The impact of SRN on uptake and leaching dynamics was explored by comparing the Base Case scenario, which simulates a fertilizer containing 65% SRN, to scenarios where the proportion of

SRN varied. Scenarios were developed for a conceptualized fertilizer comprised of 100% readily available nitrogen (0% SRN) and a representative fertilizer containing 50% SRN. Modeling results indicate that fertilizers containing higher amounts of SRN reduce nitrogen leaching compared to fertilizers containing higher amounts of readily available nitrogen. Over the two-year simulation period, nitrogen uptake by the turfgrass decreased from 53.4% to 44.7% and leaching increased from 38.6% to 50.3% as the slow-release proportion of nitrogen fertilizer decreased from 65% to 0% (Figure 8).

Decreasing the proportion of nitrogen in fertilizer that is slow release increases the amount that is readily available. While readily available nitrogen can be utilized by the turfgrass, it is also susceptible to leaching. As shown in Figure 9, nitrate leaching was shown to correspond with water leaching events (i.e., infiltration events) over the two-year simulation period with nitrate leaching greater for the fertilizers with lower amounts of SRN.

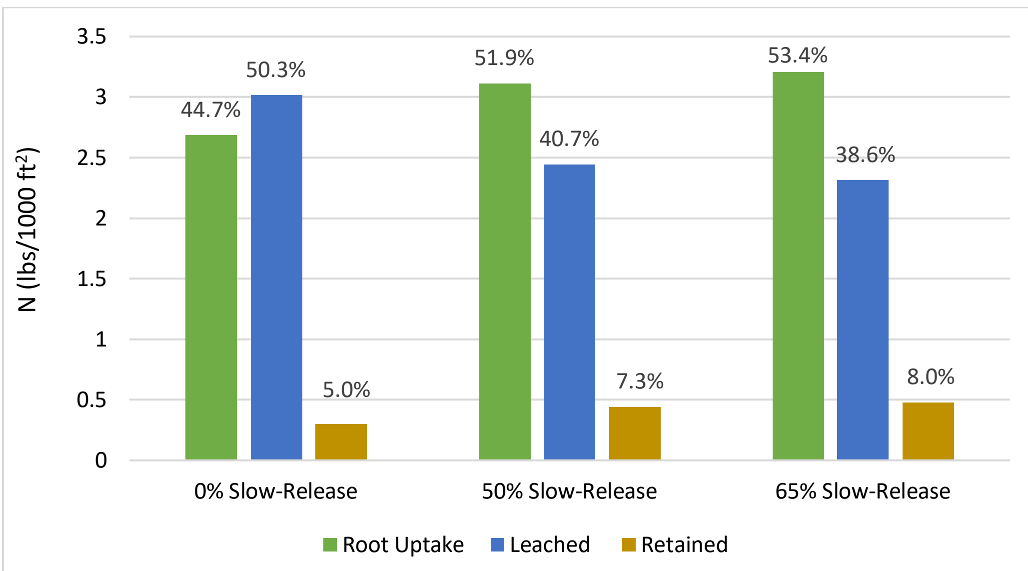

Figure 8. Fate of Fertilizer Nitrogen Containing Different Amounts of Slow-Release Nitrogen

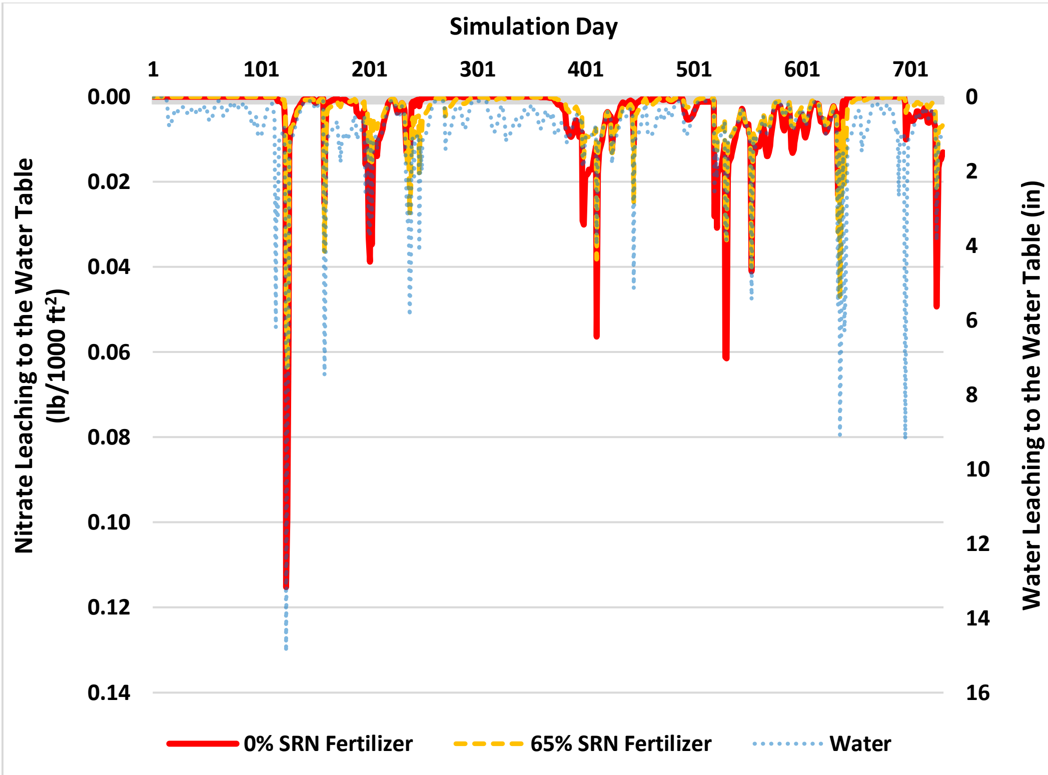

Figure 9. Comparison of Nitrate Leaching to the Water Table for Fertilizer Containing 0% and 65% Slow-Release Nitrogen (SRN)

Figure 10 shows nitrate concentrations in the root zone for the first 50 days after the fertilizer application occurring on Day 415 of the model simulations. Dissolved nitrogen concentrations in the root zone shortly after application were greater for the fertilizers with lower amounts of SRN. However, the amount of time after application that dissolved nitrate remained in the root zone increased as the amount of SRN increased. Providing nitrogen to the root zone at lower concentrations over a longer period with SRN can increase turfgrass nitrogen uptake and minimize leaching, especially from high precipitation events. However, fertilizers containing some portion of readily available nitrogen that is immediately available for uptake by the grass can be beneficial provided applications correspond with times when the grass has a nutrient demand and storm events do not flush the nitrogen out of the root zone.

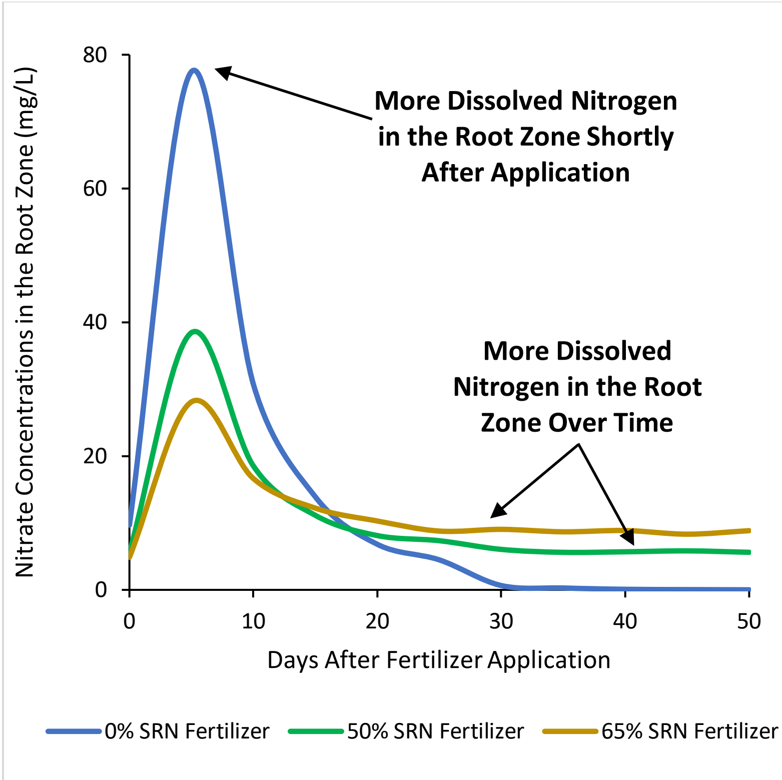

Figure 10. Nitrate Concentration in the Root Zone for Fertilizers Containing Various Proportions of Slow-Release Nitrogen (SRN)

3.3.8. Commercial Applicator

Section 15-804(d) of the OCEPD Fertilizer Ordinance states commercial applicators may apply readily available nitrogen (0% SRN) at a rate no greater than 0.5 lbs N 1000 ft^{-2}. This section of the ordinance was evaluated through a Commercial Applicator modeling scenario, where six fertilizer applications were applied per year at a rate of 0.5 lbs N 1000 ft^{-2} to achieve an annual application total of 3 lbs N 1000 ft^{-2} yr^{-1}, the same annual loading applied in the Base Case over three applications per year. Over the 2-year simulation period, the Commercial Applicator scenario resulted in reduced turfgrass uptake (44.7%) and increased leaching (50.3%) compared to 53.4% uptake and 44.7% leaching observed in the Base Case scenario (Figure 11).

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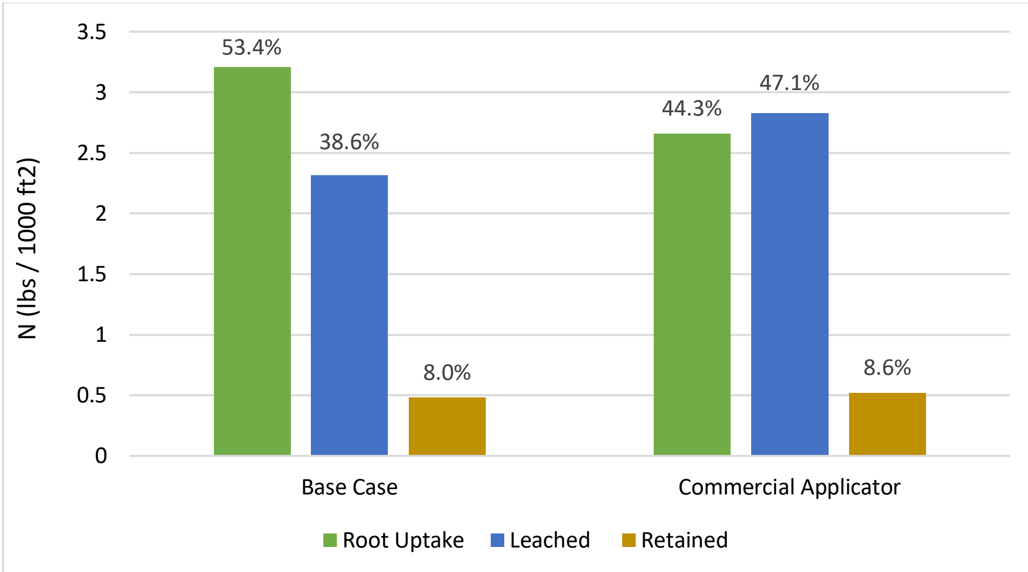

Figure 11. Fertilizer Nitrogen Fate in the Base Case and Commercial Applicator Scenarios

3.3.9. Storm Events

Results from a series of modeling scenarios developed to evaluate the impact of storm events and fertilizer composition on nitrogen dynamics are presented in Figure 12. HYDRUS 1-D modeling indicates high precipitation events can impact fertilizer nitrogen leaching and turfgrass uptake. High precipitation events occurring the day after fertilizer application were found to increase fertilizer nitrogen leaching and reduce nitrogen uptake by turfgrass. For the representative fertilizer containing 65% SRN, over 50% of applied fertilizer nitrogen leached out of the root zone to the water table with the 2-inch 24-hr storm and over 75% leached to the water table with the 10-inch 24-hr storm.

The Base Case scenario utilized the same fertilizer representation and application rate (1 lbs N 1000 ft^{-2}) as the Storm Event scenarios, but six fertilizer applications were simulated with an average of 39% of applied fertilizer nitrogen leaching over the two-year simulation. The storm events caused 50% to 77% of the fertilizer applied the previous day to leach. Turfgrass nitrogen uptake also decreased from 53% of applied fertilizer nitrogen in the Base Case scenario to 23-48% in the Storm Event scenarios.

While larger storm events increased nitrogen leaching associated with the fertilizer containing 65% SRN, leaching was more pronounced for the fertilizer comprised entirely of readily available nitrogen (0% SRN). The high precipitation events flushed the nitrogen below the root zone before it could be utilized by the turfgrass with 80% to 99% of applied fertilizer nitrogen leaching to the water table in the Storm Event scenarios.

Results from the Storm Events scenarios indicate that fertilizer nitrogen can be susceptible to leaching caused by large precipitation events. While fertilizer containing 100% readily available nitrogen provides more nitrogen in a form that is accessible to the turfgrass (Figure 10), this fertilizer form poses a greater leaching threat during high precipitation events than fertilizer containing higher percentages of SRN (Figure 12). Results from the Storm Event modeling support modeling results evaluating the impact of SRN on uptake and leaching dynamics discussed in Sections 3.3.7 and 3.3.8.

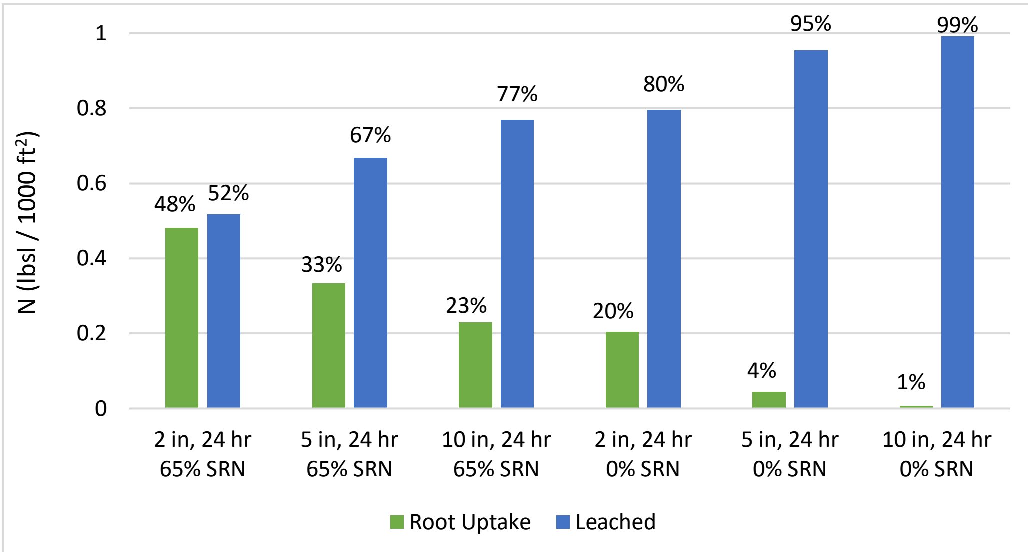

Figure 12. Impact of High Precipitation Events on Fertilizer Nitrogen Fate

3.3.10. Comparative Check

The Hydrus modeling effort was undertaken to better understand leaching of fertilizer nitrogen applied to residential lawns within the Wekiwa BMAP area under varying conditions (e.g., high/low recharge, application rates, depths to groundwater). Thus, modeling was designed to be generally representative of residential lawns within the study area. The scenario generally representing average conditions was termed the Base Case scenario. The HYDRUS modeling effort considered fertilizer as the sole source of nitrogen for simulations. A comparative check was designed to verify model results fall in a range that is considered realistic compared to available data.

Orange County monitoring well MW07, which was used to inform soil properties in the Base Case, was selected to complete the comparative check of existing water quality data and model-predicted concentrations entering the water table. MW07 was selected based on several attributes: a close to average depth to water (10.8 ft) for the Wekiwa BMAP area, the sandy soil subsurface representative of the area, a relatively high frequency of available water quality data, and a strong isotopic signature of fertilizer nitrogen (~80%, Drummond Carpenter March 2021). Groundwater quality data are available at varying frequency from 2008 to 2021 (OCEPD 2021).

Average measured nitrate + nitrite (NO_x-N) concentration at MW07 is approximately 2.2 milligrams per liter (mg/L) with a range of 0.12 to 7.3 mg/L from data collected 2008 to 2021 (OCEPD, 2021). As mentioned in Section 3.1.1, nitrite and nitrate were lumped in HYDRUS modeling. Consequently, the HYDRUS nitrate concentrations were compared to measured NO_x-N concentrations at MW07 to evaluate if simulated HYDRUS concentrations were reasonable in relation to measured groundwater concentrations.

The HYDRUS-1D Base Case scenario predicted an average nitrate concentration of 4.1 mg/L at the water table with a maximum value of 11.9 mg/L. It should be noted that nitrate concentrations entering the water table simulated by HYDRUS were not directly comparable to groundwater concentrations measured at MW07. Nitrate concentrations simulated by HYDRUS represent nitrate entering the top of the water table due to leaching of surface applied fertilizer. Concentrations in MW07 represent nitrate concentrations in the groundwater across the screen interval of the monitoring well, which can be a function of a variety of factors including nitrate entering the water table from above, upgradient loading, downgradient discharge, and biological processes that can impact nitrate concentrations (e.g., denitrification). However, the predicted HYDRUS-1D concentrations fall within the expected range relative to water quality data measured at MW07 (Figure 13).

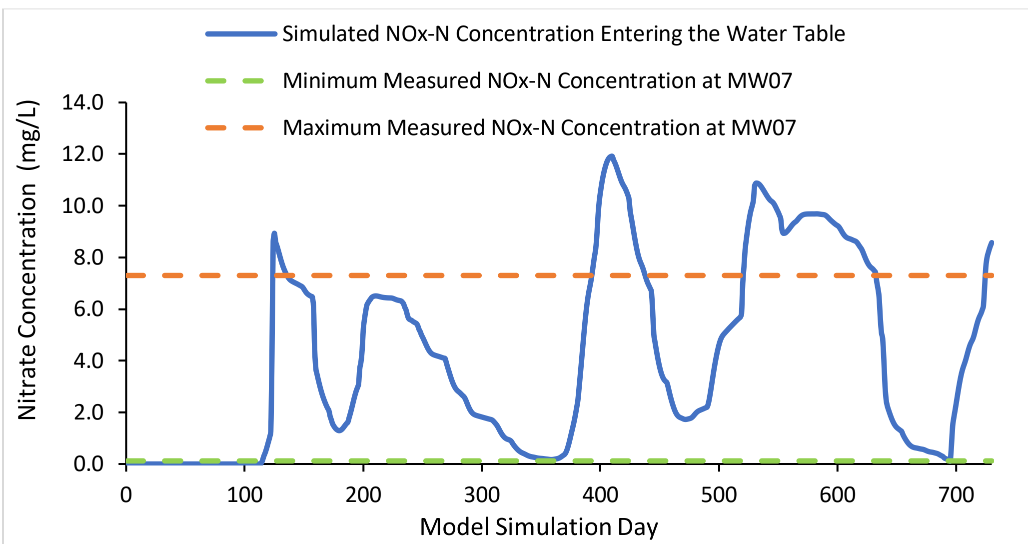

Figure 13. Comparison of Simulated Base Case Nitrate Concentrations Entering the Water Table to Measured NOx-N Values at Monitoring Well MW07

4. Groundwater Modeling

Fertilizer nitrogen applied at the ground surface that leaches to underlying groundwater can contribute nitrogen loads to downgradient waterbodies, including springs. To assess the transport of nitrogenous compounds related to fertilizer leaching to Wekiwa Spring and to perform a comparative check on the nitrogen leaching rates predicted in the Base Case HYDRUS simulation, groundwater flow and contaminant transport models were developed for a portion of the Wekiwa Springshed. The domain this model, termed the Wekiwa Springshed model, included an area of unincorporated Orange County east of Apopka and south of Wekiwa Spring. To assess the transport of nitrogenous compounds under different hydrologic conditions possible within the Wekiwa Springshed, a groundwater flow and contaminant transport model was also developed for a hypothetical site. The model for the Hypothetical Site was developed to mimic the hydrologic features (e.g., hydraulic gradient) of the Wekiwa Springshed. In addition to the Base Case scenario, which used the results of the Base Case HYDRUS simulation, eight additional flow and transport scenarios were developed with the Hypothetical Site model to assess the effects of variations in recharge, groundwater flow, and nitrogen loading rates from surface-applied fertilizer on nitrogen loads at the spring.

Groundwater flow and nitrogen transport models were developed using Groundwater Vistas version 8 (Rumbaugh and Rumbaugh, 2020), a pre- and post-processor for MODFLOW models. Groundwater flow was simulated using MODFLOW-2000 (Harbaugh et al., 2000). Transport of nitrogenous compounds was simulated using the Reactive Transport in 3-Dimensions (RT3D) version 2.5 code, which simulates multi-species reactive transport in three-dimensional saturated groundwater systems (Clement, 1998).

4.1. Model Development

4.1.1. Wekiwa Springshed Groundwater Flow Model

The Wekiwa Springshed groundwater model was developed by refining the regional East Central Florida Transient Expanded (ECFTX) groundwater flow model (Central Florida Water Initiative, 2020). The ECFTX model includes the area of peninsular Florida from the Gulf of Mexico to the Atlantic Ocean between northern Volusia County and the Charlotte-DeSoto County line. For the purposes of this assessment, the ECFTX model was refined and modified to better represent local groundwater flow conditions in the area around Wekiwa Spring (Figure 14).

The model domain and grid resolution were modified using the Telescopic Mesh Refinement (TMR) tool available in Groundwater Vistas version 8. This tool refines the model grid to a desired resolution throughout a specified area and partitions the existing boundary condition cells (river, drain, general head, well) that represent water bodies and other hydrogeologic features to the corresponding cells at the new grid resolution. The rectangular area specified for the TMR included the southern portion of Wekiwa Springs State Park adjacent the spring and the area to the south of Wekiwa Springs State Park bounded by North Hunt Club Boulevard to the east, East Semoran Boulevard to the south, and North Thompson Road to the west. The model extent is shown in Figure 14. The model grid was refined from the original ECFTX model's 1,250 ft by 1,250 ft cell spacing to a cell spacing of 20 ft by 20 ft. Such refinement facilitates the ability to simulate groundwater flow at a finer resolution than the original ECFTX model, better represent local boundary conditions, and allows for increased accuracy in simulating solute (i.e., nitrogen) transport. Monitoring points within the refined model domain that are currently sampled for nitrogenous compounds by Orange County and other consultants were added to the model for comparison of simulated heads and nitrate concentrations to reported values. These monitoring points include MW03, MW06, MW07, MW10, MW11, XDEPPBS, XDEPPBD, MWAS, MWAI, MWBS, MWBU, MWCI, MWCU, and SW01 (Figure 14).

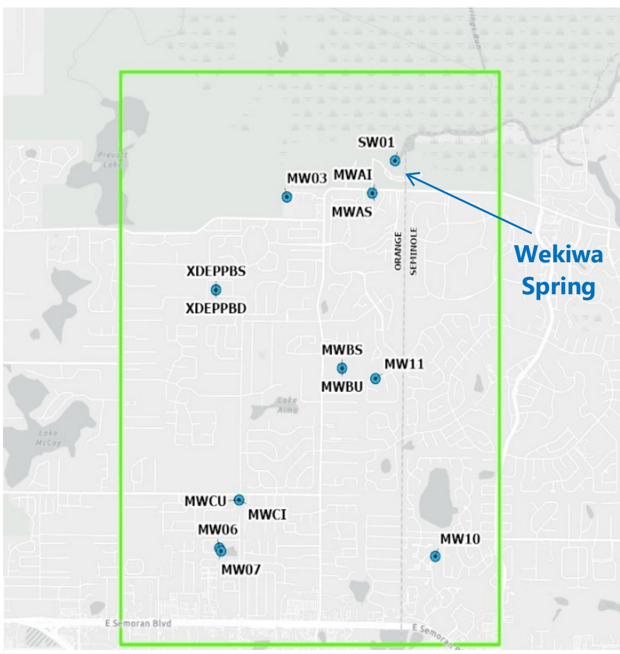

Figure 14. Wekiwa Springshed Groundwater Model Domain with Monitoring Points

When the TMR tool is used to refine a model, groundwater flow is not simulated outside of the area specified for refinement. For this assessment, flow of groundwater in and out of the refined domain is represented using general head boundary condition cells at the edges of the model domain with conductance terms assigned by the TMR tool. Head and saturated thickness values for the general head cells were calculated by the TMR tool using results from a steady-state simulation of the original ECFTX model under 2003 hydrologic conditions.

The original ECFTX model includes 11 layers, which represent the Surficial Aquifer System (SAS; Layer 1), Intermediate Confining Unit (ICU; Layer 2), Upper Floridan Aquifer (UFA; Layers 3-5), Middle Confining Units (Layers 6-8), and Lower Floridan Aquifer (Layers 9-11). To increase computational efficiency, only layers 1-3 (SAS, ICU, and upper portion of the UFA) were included in the refined model.

Hydraulic properties (e.g., hydraulic conductivity), with the exception of porosity, were partitioned to corresponding model grid cells during the TMR process and were not modified from the original ECFTX model values. A general porosity value of 0.25 was assigned to all model cells, as this value falls within the ranges of representative values for the materials which compose the SAS (sand), ICU (clay, silt, and carbonate rocks), and UFA (carbonate rocks) (USGS, 2004; Yu et al., 2015),

In the ECFTX model, river boundary condition cells are used to represent rivers and open basin lakes as well as wetland areas adjacent these surface water bodies. Drain boundary condition cells are used to represent closed basin lakes and adjacent wetland areas. The drain boundary condition is also used in Layer 3 of the model to represent Wekiwa Spring. River and drain boundary condition cells were modified to represent surface water features at the refined grid resolution. River and drain boundary condition cells that appeared to represent a surface water body but did not either overlap with the corresponding water body defined in the hydrology shapefiles obtained from Orange (Orange County Planning and Development Division) and Seminole (Seminole County Information Services Department) counties or appear to represent a wetland based on aerial imagery were removed from the model. Additionally, select drain boundary condition cells in Layer 3 representing Wekiwa Spring were removed, as the spatial extent of the spring vent is smaller than the original 1,250 ft x 1,250 ft cell that represented the spring at the original ECFTX grid resolution.

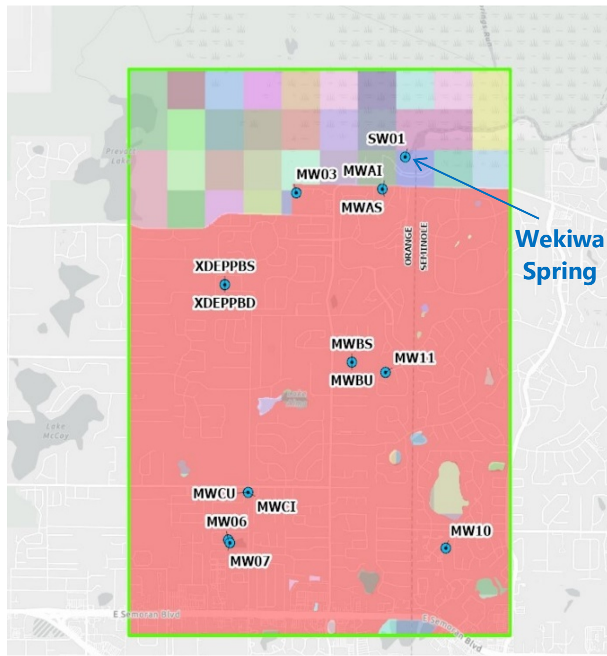

Figure 15. Recharge Zones Specified for the Wekiwa Springshed Model

Note: HYDRUS-derived recharge rates and concentrations applied to red zone

The Wekiwa Springshed groundwater flow model simulated daily transient flow over a four-year simulation period. The model included 1,461 stress periods consisting of one steady-state stress period and 1,460 transient stress periods. Steady-state evapotranspiration rates specified in the ECFTX model were not modified and were assumed to be constant throughout the simulation period. Recharge rates in the urbanized areas south of Wekiwa Springs State Park were varied in each stress period. ECFTX recharge rates were retained for the area of Wekiwa Springs State Park within the model domain and the water bodies identified in the hydrology shapefiles obtained from Orange (Orange County Planning and Development Division) and Seminole (Seminole County Information Services Department) counties and were not varied. Zones with ECFTX recharge rates and HYDRUS-derived recharge rates are shown in Figure 15.

A recharge rate of 0.00383 ft/day was specified for the steady-state stress period, since the simulated water level at monitoring well MW07 using this recharge rate was similar to the observed water level in 2014. MW07 was the monitoring well used for the comparative check in the HYDRUS modeling (see Section 3.3.10). The unsaturated zone modeling effort conducted in this study (HYDRUS) simulated daily water leaching, which represented water from the soil profile entering the water table. From a groundwater perspective, water leaching from the HYDRUS models represents "recharge" to the groundwater. Predicted water leaching rates from the HYDRUS Base Case scenario were used to derive recharge rates for the transient stress periods in the groundwater model. Daily water leaching rates simulated using the two-year HYDRUS Base Case model were used to derived recharge for stress periods 2-731 of the groundwater model. Since leaching of water and nitrogenous compounds was not simulated for 2015 and 2016, daily simulated leaching rates for 2014 from the HYDRUS Base Case model were used to derive recharge for the two additional years of the four-year groundwater model simulation (stress periods: 732-1461).

Water leaching simulated by the HYDRUS modeling effort conducted in this study represents groundwater recharge beneath a representative resident lawn receiving irrigation. The area over which the HYDRUS-derived recharge rates were applied to the groundwater model is shown in red on Figure 15 and largely consists of residential subdivisions, but also includes other land uses (e.g., commercial). While the HYDRUS-derived recharge area includes residential lawns, the area also includes impervious areas (e.g., homes and roads), irrigated areas that are not residential lawns, and areas that are not irrigated. Therefore, the HYDRUS-derived water leaching rates were reduced by approximately 55% to account for these factors. This adjustment was derived based on the average fraction of pervious area in the groundwater model domain south of Wekiwa Springs State Park (Figure 15), 0.74, plus an additional factor of 0.6 applied based on a comparison of simulated and observed water levels throughout the simulation period.

4.1.2. Wekiwa Springshed Nitrogen Transport Model

The transformation of ammonium (NH_4^+) to nitrate (NO_3^-) to gaseous nitrogen (N_2) and associated transport of all three species through the transient groundwater flow field was simulated in the nitrogen transport model. Transformation of nitrogenous compounds was simulated using a sequential reaction chain with first-order decay. Since the transformation of nitrite (NO_2^-) to nitrate is a much faster reaction than the transformation from ammonium to nitrite (Hansen et al., 2006), the formation and transformation of nitrite was not simulated explicitly in the groundwater transport model, but instead lumped together with nitrate.

In addition to the hydraulic properties specified for the groundwater flow model, the transport modeling software, RT3D, requires specification of source terms and chemical reaction parameters for each component to simulate reactive transport. Averages of recorded nitrate concentrations from 2008-2021 in active monitoring wells screened in the SAS, ICU, and UFA were used as initial concentrations for Layers 1, 2, and 3. Recorded ammonium concentrations were not available for site monitoring wells, so initial concentrations were not specified. Specified initial concentrations for nitrate are provided in Table 3.

Leaching of nitrogenous compounds from fertilizer was simulated by specifying recharge concentrations for ammonium and nitrate. Similar to groundwater recharge rates, predicted nitrate and ammonium leaching concentrations for 2013 and 2014 from the HYDRUS Base Case scenario were used for stress periods 2-731. Predicted leaching concentrations from 2014 were used for stress periods 732-1461. Recharge concentrations were applied to the same area south of Wekiwa Springs State Park where HYDRUS-derived recharge rates were applied as shown in Figure 15. Neither initial concentrations nor recharge concentrations were specified for N_2.

Specified chemical reaction parameters include bulk density, distribution coefficient (K_d), half-life, and longitudinal, transverse, and vertical dispersivities. Different bulk densities were specified for each model layer since they are composed of different materials. Likewise, different K_d values for ammonium were specified for each model layer since ammonium will adsorb to the materials differently. A K_d of 0 L/mg was specified for nitrate in all model layers since it does not strongly adsorb to soil (Krupka et al., 2004 as reported in Serne, 2007). Bulk density and K_d values in the three model layers are provided in Table 3. Half-life values of 6 years (2191.5 days) (Puckett et al., 2011; Uffink, 2003; Yan and Zhou, 2018 as reported in Zhang et al., 2020) and 3 years (1095.75 days) (Roy and Krapac, 2009) were used for nitrate and ammonium, respectively. N_2 was neither assumed to adsorb to aquifer materials nor degrade to another species, and therefore, was assigned a K_d of 0 L/mg and a half-life of 0 days.

Dispersivity values were chosen based on the match between simulated and observed concentrations using different values. Longitudinal, transverse, and vertical dispersivities of 200 ft, 20 ft, and 2 ft were assigned for Layers 1 and 2. Longitudinal, transverse, and vertical dispersivities of 1,000 ft, 100 ft, and 10 ft were assigned to Layer 3. Specified transverse and vertical dispersivities are $1/10^{th}$ and $1/100^{th}$ of the longitudinal dispersivity, respectively. Layer-specific source terms and chemical reaction properties for the Wekiwa Springshed transport model are presented in Table 3.

Table 3. Source Terms and Chemical Reaction Properties Specified for the Wekiwa Springshed Model

Layer	Initial Nitrate Concentration (mg/L)	Bulk Density (mg/L)	Distribution Coefficient (L/mg)		Dispersivity (ft)		
			Nitrate[4]	Ammonium	Longitudinal	Transverse	Vertical
1	1.99	1.51E+06[1]	0	4.00E-07[5]	200	20	2
2	2.27	1.64E+06[2]	0	6.50E-07[6]	200	20	2
3	0.33	2.73E+06[3]	0	3.60E-07[7]	1000	100	10

[1] Yu et al. 2015 Table 2.1.1, dry bulk density of sand
[2] Yu et al. 2015 Table 2.1.1, dry bulk density of sandy clay
[3] Bennett 2003, mean grain density measurements from limestone samples; Appendix D Table 2
[4] Krupka 2004 as reported in Serne 2007
[5] Buss et al. 2004, peak value of triangular distribution for clean sand and gravel from Table 2
[6] Buss et al. 2004, median range of clayey sand and gravel from Table 2
[7] Buss et al. 2004, average value for Lincolnshire Limestone from Table 2

4.1.3. Hypothetical Site Groundwater Flow Model

The Hypothetical Site model domain is approximately 12 mi^2 and includes three layers, which represent the SAS (Layer 1), ICU (Layer 2), and UFA (Layer 3). Like the Wekiwa Springshed model, the grid spacing is 20 ft x 20 ft. Layer top and bottom elevations were specified to represent the transition from the urbanized, higher elevation area upgradient of the spring, in which the SAS and ICU are relatively thick, to the undeveloped, lower elevation area around and downgradient of Wekiwa Spring, in which the SAS and ICU are thin.

General head boundary condition cells at the southern and northern boundaries of the model were used to simulate groundwater flow in and out of model layers. A spring is represented in Layer 3 through drain boundary condition cells located 15,300 ft from the southern boundary of the model in the center of the domain. Head values and conductance terms for the general head and drain boundary condition cells were specified to produce hydraulic gradients and computed head values similar to those observed in the Wekiwa Springshed. Average values of aquifer properties (e.g., hydraulic conductivity, storage, porosity) specified in the Wekiwa Springshed model layers were assigned to the three model layers. Key hydraulic properties specified for the hypothetical site model are summarized in Table 4.

Table 4. Key Hydraulic Properties Specified in the Hypothetical Site Model

Layer	Hydraulic Conductivity (ft/day)		Storage[1]	Hydraulic Gradient[2] (ft/ft)	Porosity
	Horizontal	Vertical			
1	15	15	1.48E-01	0.00388	0.25
2	0.1	0.01	1.02E-06	0.00193	0.25
3	5400	5400	1.16E-06	0.00035	0.25

[1]Specific yield specified for Layer 1, specific storage specified for Layers 2 and 3
[2]Average hydraulic gradient between southern boundary and spring monitoring points for the four-year simulation period

The Hypothetical Site groundwater flow model simulated daily transient flow over a four-year period. The model included 1,461 stress periods consisting of one steady-state stress period and 1,460 transient stress periods. Like the Wekiwa Springshed model, a recharge rate of 0.00383 ft/day was specified for the steady-state stress period. Two different recharge zones were specified to represent 1) the urbanized area upgradient of the spring where irrigation and fertilizer were applied, and 2) the area downgradient of the spring where neither irrigation nor fertilizer were applied. The adjusted recharge rates developed for the Wekiwa Springshed model were applied to the upgradient zone. Daily water leaching rates simulated using the two-year HYDRUS Base Case model were used to derive recharge for stress periods 2-731 of the Hypothetical Site groundwater model. Since leaching of water and nitrogenous compounds was not simulated for 2015 and 2016, daily simulated leaching rates for 2014 from the HYDRUS Base Case model were used to derive recharge for the two additional years of the four-year groundwater model simulation (stress periods: 732-1461). The recharge rates for the downgradient zone were equal to 50% of the recharge rates applied to the upgradient zone. The average of the steady-state evapotranspiration values from the Wekiwa Springshed model was assigned to all cells in Layer 1 of the model and not varied temporally.

4.1.4. Hypothetical Site Nitrogen Transport Model

Similar to the Wekiwa Springshed model, the transformation of ammonium (NH_4^+) to nitrate (NO_3^-) to gaseous nitrogen (N_2) and associated transport of all three species through the transient groundwater flow field was simulated in the nitrogen transport model for the Hypothetical Site. Chemical reaction parameters for the Hypothetical Site nitrogen transport model were the same as those specified for the Wekiwa Springshed nitrogen transport model.

Transformation of nitrogenous compounds due to denitrification was simulated using a sequential reaction chain with first-order decay (Zhang et al., 2020).

Ammonium and nitrate leaching concentrations simulated in the HYDRUS Base Case model were applied through recharge concentration to the upgradient areas of the groundwater model for stress periods 2-731. HYDRUS-simulated ammonium and nitrate leakage concentrations for 2014 were applied through recharge concentrations to stress period 732-1461 of the groundwater model. Ammonium and nitrate leaching concentrations were not applied to the downgradient area of the groundwater model. Initial concentrations were not specified for ammonium or nitrate.

4.1.5. Hypothetical Site Sensitivity Scenarios

In addition to the Base Case scenario, eight two-year scenarios were developed using the Hypothetical Site model to assess the effects of variations in recharge, groundwater gradient, nitrogen loading, and depth to water (unsaturated zone thickness) on predicted concentrations of nitrogenous compounds (Table 5). Model sensitivity to recharge, nitrogen loading, and unsaturated zone thickness was assessed by applying daily simulated recharge rates and concentrations from HYDRUS Scenarios 2-7 (described in Sections 3.2 and 3.3) to the upgradient area in the Hypothetical Site model. Similar to the Wekiwa Springshed model, recharge rates applied to the upgradient area were reduced by approximately 55% to account for areas that are either impervious or not irrigated. Recharge rates for the downgradient zone were equal to 50% of the recharge rates applied to the upgradient zone in the sensitivity scenarios.

To assess variation in hydraulic gradient, general head boundary condition heads were modified to increase or decrease the Layer 3 hydraulic gradient between the upgradient boundary of the model and the spring by a factor of 3. General head boundary condition heads in Layers 1 and 2 were modified accordingly to produce consistent gradients between the southern boundary of the model and the spring. Recharge rates and concentrations used in the first two years of the Hypothetical Site Base Case models were used in these scenarios. Parameter modifications made to the Hypothetical Site model for the eight sensitivity scenarios are summarized in Table 5.

Table 5. Hypothetical Site Groundwater Model Parameter Changes for Sensitivity Scenarios

Scenario #	Description	Parameter Change
1	Base Case	NA
2	High Recharge	Recharge rates and concentrations from HYDRUS Scenario 2*
3	Low Recharge	Recharge rates and concentrations from HYDRUS Scenario 3*
4	High GW Gradient	Boundary conditions modified to increase Layer 3 gradient by a factor of 3
5	Low GW Gradient	Boundary conditions modified to decrease Layer 3 gradient by a factor of 3
6	High IFAS Fertilizer Loading	Recharge rates and concentrations from HYDRUS Scenario 7*
7	Low IFAS Fertilizer Loading	Recharge rates and concentrations from HYDRUS Scenario 6*
8	Shallow Depth to Water	Recharge rates and concentrations from HYDRUS Scenario 4*
9	Deep Depth to Water	Recharge rates and concentrations from HYDRUS Scenario 5*

*HYDRUS scenarios provided in Table 2.

4.2. Nitrogen Transport Model Results

4.2.1. Wekiwa Springshed Transport Model

Predicted nitrate concentrations were tabulated for comparison with existing monitoring wells within the model domain in the SAS (MW06, MW07, MWAS, MWBS, SW01), ICU (MW03, MW10, MW11, PBS, MWAI, MWCI), and UFA (PBD, MWBU, MWCU) (Figure 14). An additional virtual monitoring point named Wekiwa_L3 was added in Layer 3 directly below SW01, which is located at the spring.

Simulated nitrate concentrations at Layer 1 monitoring locations MW06, MW07, MWAS, and MWBS oscillate between approximately 1.9 and 2.5 mg/L and gradually increase throughout the simulation period (Figure 16). These monitoring points are in the residential area upgradient of the spring, where nitrate is being continuously supplied via recharge, so it is reasonable for concentrations at these locations to increase. Additionally, since nitrate is being applied to Layer 1, simulated nitrate concentrations in Layer 1 exhibit an expected oscillatory behavior in response to the transient nature through which nitrate enters the model via recharge. The simulated nitrate concentration at monitoring point SW01, which is located in Layer 1 at Wekiwa Spring, asymptotically approaches 0.65 mg/L towards the end of the simulation. The stabilization of nitrate concentrations at this monitoring point in the latter half of the simulation indicates that nitrate loading from the upgradient sources reach the spring.

Simulated nitrate concentrations in Layer 2 wells MW03, MW10 MW11, XDEPPBS, MWAI, and MWCI decrease throughout the simulation period from the initial concentration of 2.27 mg/L in this layer and asymptotically approach equilibrium values between 0.6 and 1.3 mg/L after approximately 2.5 years (Figure 17). These trends in Layer 2 nitrate concentrations are reasonable considering the low horizontal and vertical hydraulic conductivities in Layer 2.

Simulated nitrate concentrations in Layer 3 wells XDEPPBD, MWBU, MWCU, and Wekiwa_L3 increase from their initial concentrations of 0.33 mg/L, peak between 0.7 and 1.2 mg/L, and then begin to stabilize between 0.5 and 1 mg/L towards the end of the four-year simulation period (Figure 18). These trends in Layer 3 nitrate concentrations are reasonable given that Layer 2 has an initial concentration higher than Layer 3 and that the source of nitrate in Layer 3 is leakage from Layer 2.

Predicted ammonium concentrations for the four-year simulation period were negligible (<1.0E-03 mg/L) at all monitoring points. Minimal ammonium concentrations were expected because of the magnitude of ammonium leaching predicted by the HYDRUS models and the reactive transport processes (nitrification, retardation, and adsorption) that affect ammonium concentrations in the transport model.

As was done in the HYDRUS modeling effort, a comparative check of simulated nitrate concentrations at monitoring well MW07 (Figure 14) was conducted with the Wekiwa Springshed groundwater model. The average measured nitrate + nitrite (NO_x-N) concentration at MW07 is approximately 2.2 mg/L with a range of 0.12 to 7.3 mg/L based on data collected from 2008 to 2021 (OCEPD, 2021). The simulated nitrate concentration at MW07 initially decreases to 1.86 mg/L, but gradually increases and oscillates between 1.8 and 2.5 mg/L, with an average concentration of 2.15 mg/L (Figure 16). Comparing average simulated (2.15 mg/L) and measured (2.2 mg/L) nitrate concentrations and considering the range of simulated nitrate concentrations oscillates within the range of observed values, the model produced a relatively good match at MW07.

The average measured nitrate + nitrite (NO_x-N) concentration in surface water discharging from Wekiwa Spring from 2008-2021 ranges from 0.007 to 1.53 mg/L, with an average concentration of 1.06 mg/L (OCEPD, 2021). Nitrate values at Wekiwa Spring were simulated in Layer 1 (SW01 in Figure 16) and Layer 3 (Wekiwa_L3 in Figure 18) of the Wekiwa Springshed groundwater model. While nitrate concentrations at SW01 and Wekiva_L3 exhibit different behavior early in the simulation due different initial conditions and hydrologic properties, nitrate concentrations at both monitoring points asymptotically approach approximately 0.65 mg/L in the latter half of the simulation period. Stabilization of simulated nitrate concentrations at monitoring points SW01 and Wekvia_L3 toward the end of the simulation indicate that fertilizer nitrogen from the upgradient area shown in Figure 14 would contribute between 0.6 and 0.7 mg/L to the Wekiwa Spring nitrate concentration under Base Case conditions. Modeling results appear to agree with results from an isotopic study that indicates around 60% of the nitrate that migrates to Wekiwa Spring is derived from fertilizer nitrogen application (Drummond Carpenter, 2021).

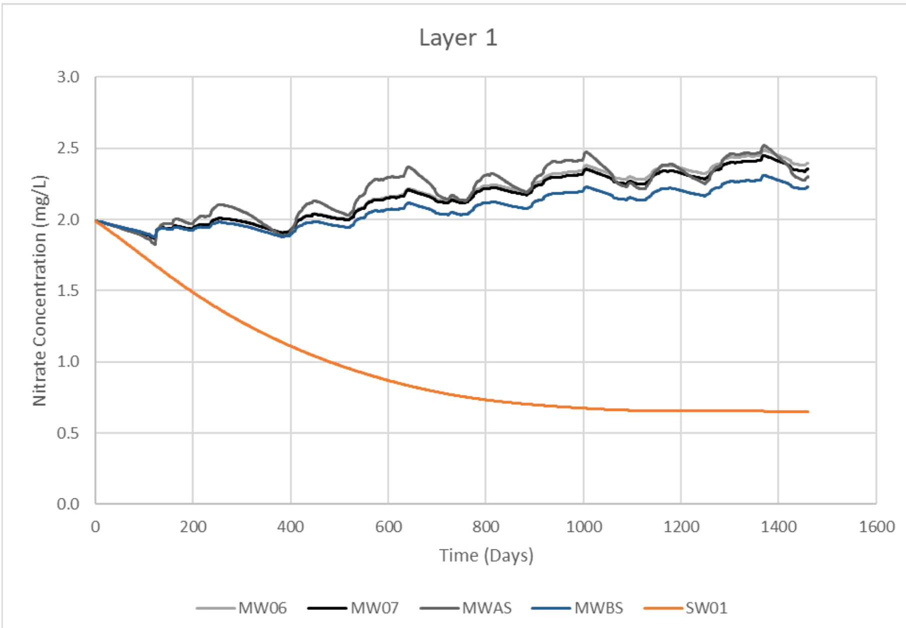

Figure 16. Predicted Nitrate Concentrations for Layer 1 Monitoring Points in the Wekiwa Springshed Model

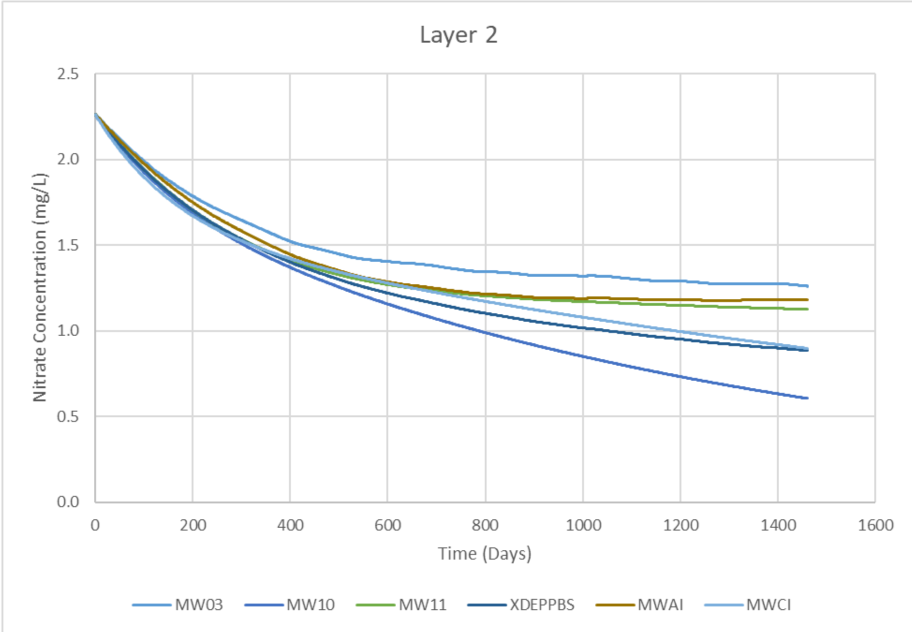

Figure 17. Predicted Nitrate Concentrations for Layer 2 Monitoring Points in the Wekiwa Springshed Model

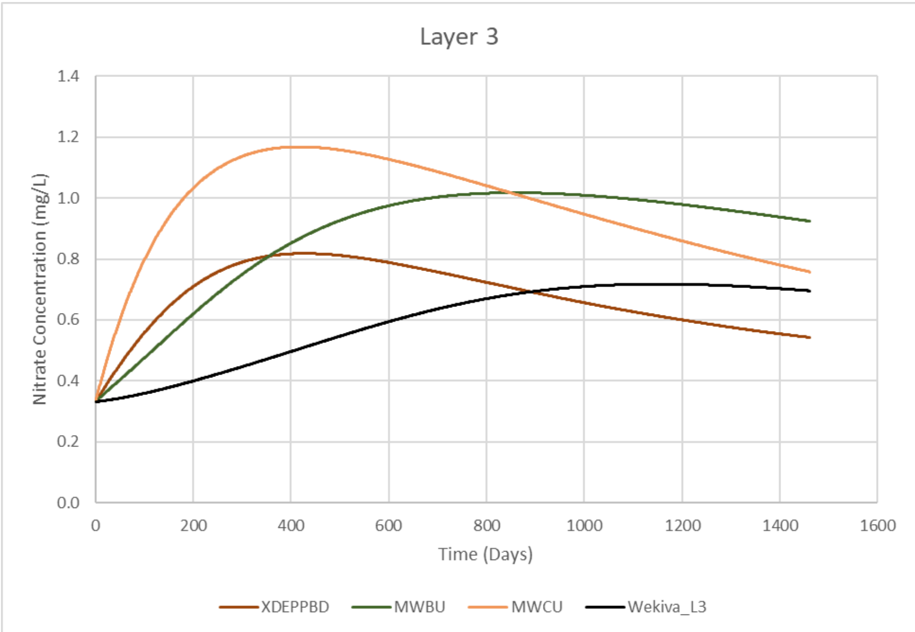

Figure 18. Predicted Nitrate Concentrations for Layer 3 Monitoring Points in the Wekiwa Springshed Model

4.2.2. Hypothetical Site Transport Model

Simulated nitrate concentrations were tabulated for virtual monitoring points in the center of the model domain in Layers 1, 2, and 3, which represent the SAS, ICU, and UFA, respectively (Figure 19). Virtual monitoring points were named to contain their distance downgradient of the southern boundary of the model and the layer (e.g., MP_2500_L1 is 2,500 feet downgradient of the southern boundary of the model in Layer 1 of the model). Virtual monitoring points were placed 15,800 ft downgradient in Layers 1, 2, and 3 to monitor concentrations in and above the cells representing the spring.

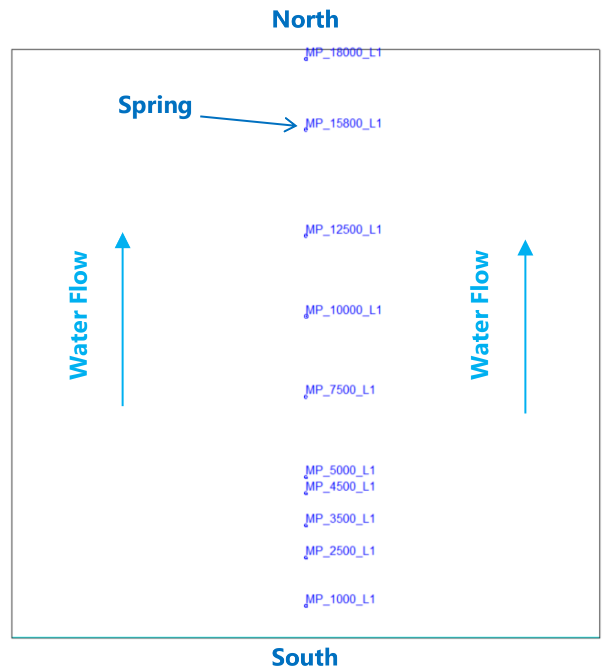

Figure 19. Monitoring Points in the Hypothetical Site Model

4.2.3. Hypothetical Site - Base Case

Temporal plots of predicted nitrate concentrations at select monitoring points in the Base Case are provided in Figures 20-22. Simulated nitrate concentrations in the Base Case scenario in Layer 1 increase throughout the four-year simulation period to values between 1.5 and 2.5 mg/L, with apparent stabilization of concentrations in Layer 1 occurring around year 4. This trend is reasonable since nitrate is continuously supplied to Layer 1 via recharge. The highest predicted nitrate concentration is in virtual monitoring point MP_15800_L1, which is located above the drain cells in Layer 3 that represent the spring. Layer 2 concentrations gradually increase throughout the four-year simulation period as nitrate migrates down to Layer 2. The greatest predicted nitrate concentration in Layer 2 is 1.39 mg/L at MP_2500_L2. Nitrate concentrations in Layer 3 also increase gradually throughout the four-year simulation period as nitrate migrates down through Layer 2. The greatest predicted nitrate concentration in Layer 3 is 0.21 mg/L at MP_15800_L3, which is located in the drain cells that represent the spring. The greatest nitrate concentrations in each layer are predicted at MP_15800. The elevated nitrate concentrations in MP_15800 in Layers 1, 2, and 3 are due to the hydrologic low point caused by the drain cells (i.e., the spring) in Layer 3, which pulls water and dissolved nitrate towards it.

Like the Wekiwa Springshed model, predicted ammonium concentrations for the four-year simulation period were negligible (<1.0E-03 mg/L) at all monitoring points. Minimal ammonium concentrations were expected because of the magnitude of ammonium leaching predicted by the HYDRUS models and the reactive transport processes (nitrification, retardation, and adsorption) that affect ammonium concentrations in the transport model.

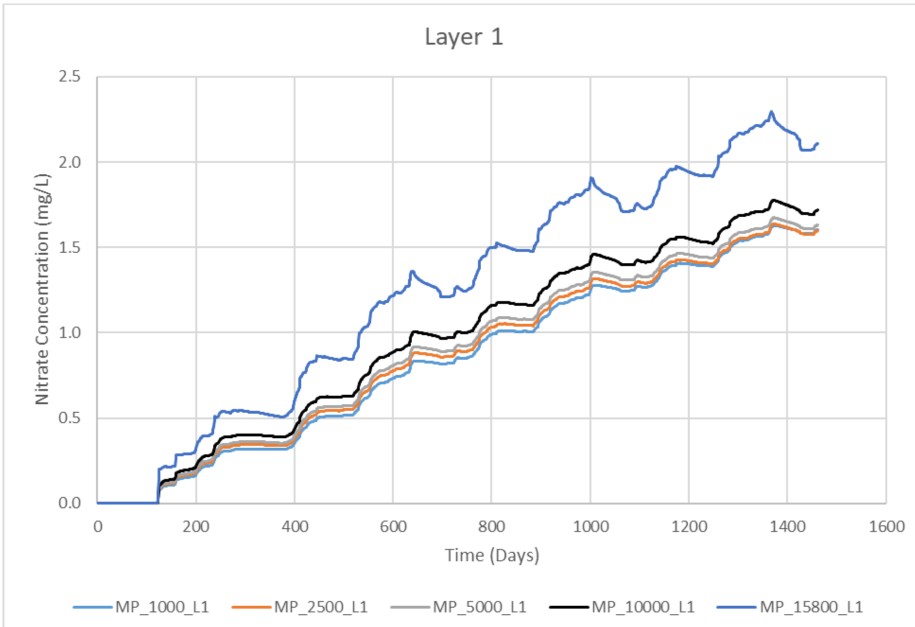

Figure 20. Predicted Nitrate Concentrations for Select Monitoring Points in Layer 1 of the Hypothetical Site Model

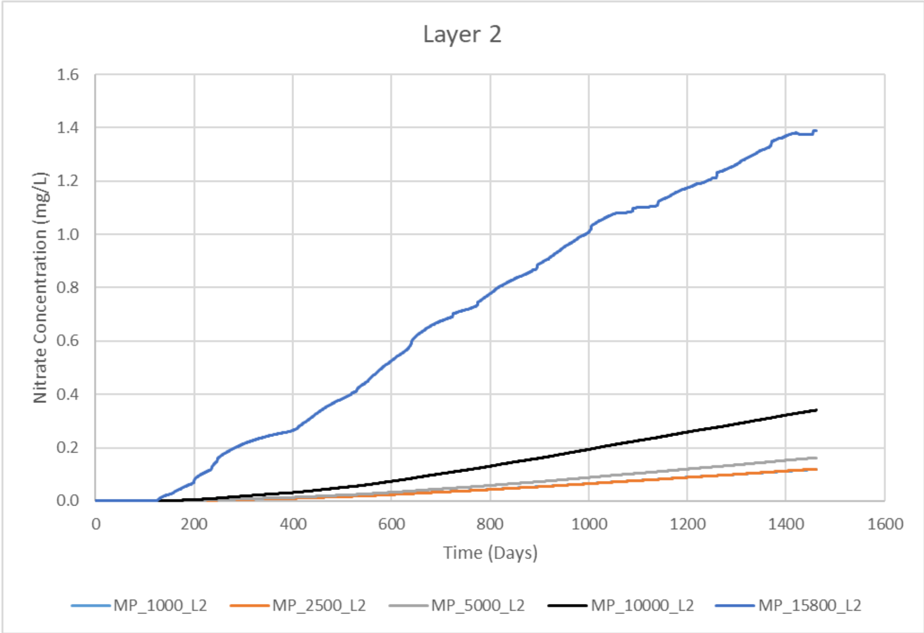

Figure 21. Predicted Nitrate Concentrations for Select Monitoring Points in Layer 2 of the Hypothetical Site Model

Figure 22. Predicted Nitrate Concentrations for Select Monitoring Points in Layer 3 of the Hypothetical Site Model

4.2.4. Hypothetical Site – Sensitivity Scenarios

Simulated nitrate concentrations in the sensitivity scenarios generally follow the same pattern as the Base Case scenario in the Hypothetical Site model. The additional transport simulations performed with different hydrologic and nitrate loading assumptions indicate that, in general, predicted nitrate concentrations are moderately sensitive to variation in recharge, hydraulic gradient, and depth to water and most sensitive to changes in nitrate loading. These results are reasonable considering the predicted nitrogen leaching rates from the HYDRUS scenarios (Figure 4). Nitrogen leaching to the water table over the two-year simulation period from HYDRUS scenarios evaluating different recharge rates and depths to the water table (Scenarios 1-5, Table 2) ranged from 1.9 to 2.5 lbs N 1000 ft^{-2}, whereas nitrogen leaching over the two-year simulation period from the HYDRUS scenarios evaluating different fertilizer nitrogen rates (Base Case, IFAS-Low, and IFAS-High in Table 2) ranged from 0.3 to 5 lbs N 1000 ft^{-2}.

Temporal plots of predicted nitrate concentrations for the Base Case and sensitivity scenarios are provided in Figures 23-26. Qualitative comparison of timeseries plots indicates that changes in nitrogen loading rates in the IFAS-High and IFAS-Low Scenarios affect nitrate concentrations in all layers similarly, whereas the changes in recharge, depth to water, and hydraulic gradient affect nitrate concentrations in model layers differently. Nitrate concentrations in Layer 3 are more sensitive to changes in hydrologic parameters (recharge, gradient, depth to water) than those in Layer 1. This is reasonable, since recharge applied directly in Layer 1 acts to “attenuate” the impact of changing hydrologic parameters on nitrate concentrations. As expected, additional recharge does not affect head values in Layers 2 and 3 as much as in Layer 1, since recharge is not directly applied to underlying layers, therefore, variations in nitrate concentrations in these layers are not dampened by additional recharge.

As shown in Figures 23-26, modeling indicates that the fertilizer nitrogen application rate had a significant impact on predicted nitrate concentrations in groundwater and at the spring in the Hypothetical Site model. Simulated nitrate concentrations in the groundwater and at the spring (MP_15800_L1 and MP_15800_L3) under the IFAS-High fertilizer rate (6.0 lbs N 1000 ft^{-2} yr^{-1}) were approximately 16-fold and 2-fold greater than nitrate concentrations under the IFAS-Low (0.4 lbs N 1000 ft^{-2} yr^{-1}) and Base Case (3.0 lbs N 1000 ft^{-2} yr^{-1}) fertilizer rates.

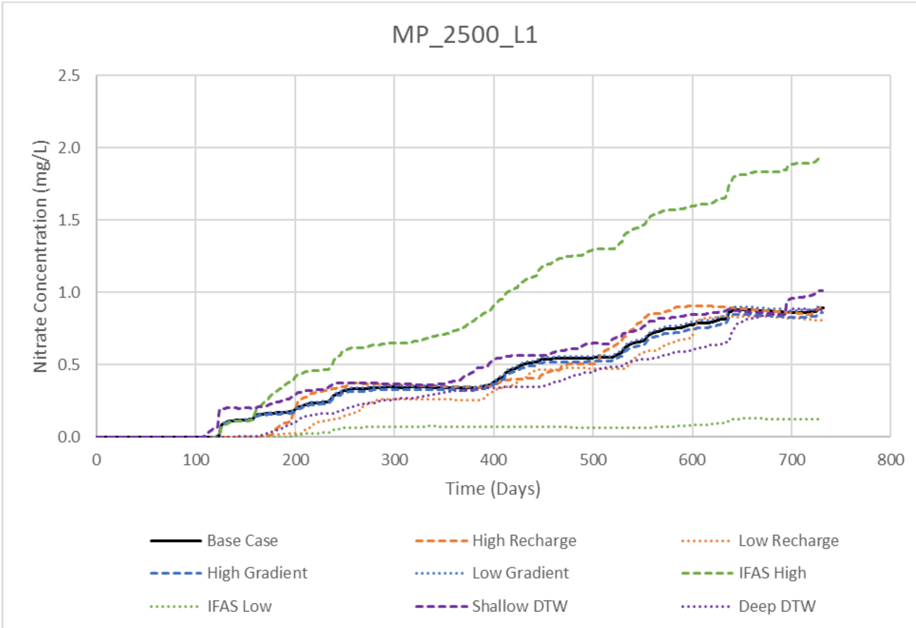

Figure 23. Predicted Nitrate Concentrations for MP_2500_L1 for Hypothetical Site Scenarios

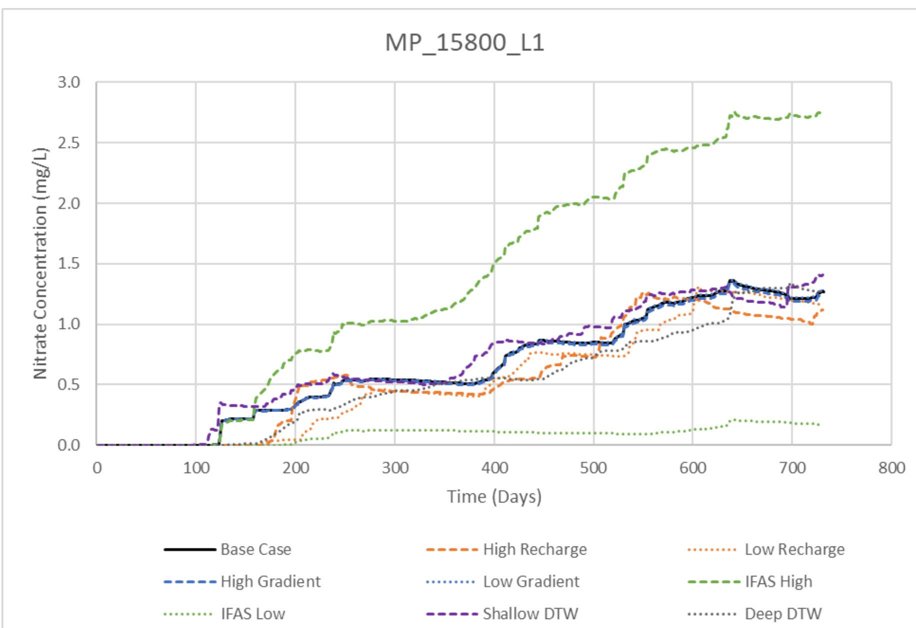

Figure 24. Predicted Nitrate Concentrations for MP_15800_L1 for Hypothetical Site Scenarios

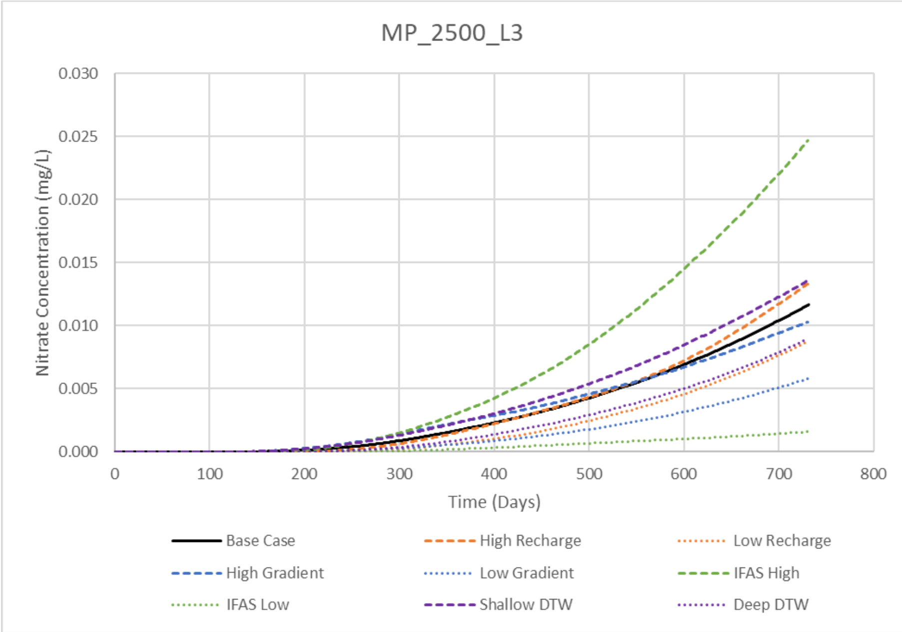

Figure 25. Predicted Nitrate Concentrations for MP_2500_L3 for Hypothetical Site Scenarios

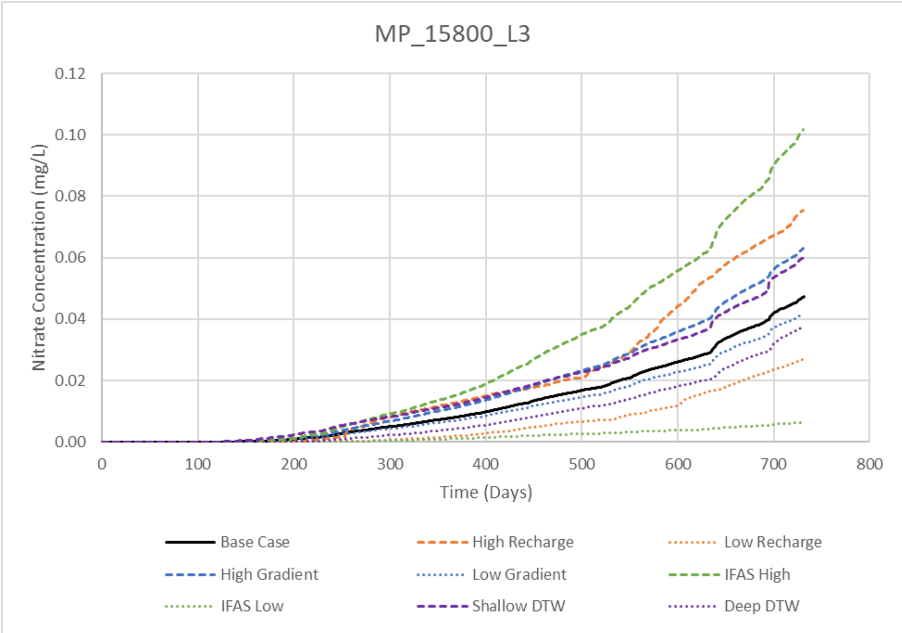

Figure 26. Predicted Nitrate Concentrations for MP_15800_L3 for Hypothetical Site Scenarios

5. Findings, Recommendations, and Future Considerations

<u>Findings</u>

A series of findings based on results of the unsaturated and saturated nitrogen fate and transport modeling conducted as part of this effort are summarized below.

Unsaturated zone modeling indicates the following:

- A portion of fertilizer nitrogen applied to urban turfgrass in the Wekiwa BMAP area is likely to leach into the underlying water table, regardless of fertilizer rate or management strategy. UF/IFAS indicates fertilizer nitrogen applied to turfgrass in Florida can leach at a rate ranging from <1% to 55% of total applied nitrogen (Shaddox and Unruh, 2018). Across the two-year HYDRUS scenarios developed to evaluate Section 15-804(c) of Orange County's fertilizer ordinance (Scenarios #1-7, see Section 3.2), 30% to 45% of the applied fertilizer nitrogen was predicted to leach to the groundwater, which falls within the UF/IFAS range.
- For the same fertilizer composition and conditions representative of urban turfgrass within the Wekiva BMAP area, fertilizer rates had greater impacts on nitrogen leaching loads compared to annual recharge patterns or the depth to the water. Under varying degrees, fertilizer leaching increased with increasing annual application rate, higher annual recharge, and a shallower water table as compared to average conditions.
- Fertilizers containing slow-release nitrogen (SRN) can improve nutrient uptake and reduce nitrogen leaching compared to fertilizers with higher portions of readily available nitrogen. Simulated results found fertilizer containing 65% SRN reduced nitrate leaching to the water table by over 10% over the course of two years when compared to a fertilizer containing 0% SRN applied at the same rates and times (Figure 8).
- Fertilizer nitrogen applied before high precipitation events is susceptible to leaching, particularly fertilizer containing lower amounts of SRN. For example, simulations predicted 52% of fertilizer nitrogen from a fertilizer containing 65% SRN would leach when applied the day before a 2-inch 24-hour storm, while 80% of fertilizer nitrogen from a fertilizer containing 0% SRN would leach due to the storm (Figure 12).

Groundwater modeling indicates the following:

- Fertilizer nitrogen from upgradient sources can be a significant contributor to nitrate loading at Wekiwa Spring.
- Under modeled conditions, annual fertilizer application rate had greater impacts on nitrate concentration at Wekiwa Spring than local annual precipitation patterns, groundwater gradient, and depth to water table.

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Recommendations

- Orange County's fertilizer ordinance specifies allowable amounts of fertilizer nitrogen that can be applied per application. However, the existing ordinance does not limit the total amount of fertilizer nitrogen that can be applied on an annual basis. Considering the impact of annual fertilizer rates on simulated nitrogen leaching and nitrate concentrations Wekiwa Spring, Orange County should consider incorporating a maximum annual load of fertilizer nitrogen that can be applied to turfgrass.
- Based on the impact of high precipitation events on simulated fertilizer nitrogen leaching (Section 3.3.9) and the likelihood of larger precipitation events occuring during the summer months within Orange County, it is recommended that Orange County maintain its existing blackout period for residential applicators during the wet season (June-September). Orange County should also consider expanding its wet season ban to include commercial applicators or require commercial applicators to limit the amount of readily available nitrogen applied during the wet season. Simulated results found fertilizers containing more readily available nitrogen have a higher propensity to leach compared to fertilizers containing more SRN (Sections 3.3.7-3.3.9). Currently, under Orange County's fertilizer ordinance, commercial applicators may apply up to 0.5 lbs N 1000 ft^{-2} of readily available nitrogen throughout the year.
- Encourage all applicators to use fertilizer containing at least 65% SRN and apply when the weather forecast does not call for precipitation in the coming days.

Future Considerations

To improve the understanding of the fate and transport of fertilizer nitrogen applied to turfgrass within the Wekiwa BMAP area, Orange County could consider the following:

- Explore the impact of soil composition on nitrate leaching.
- Explore the impact of adding denitrification, volatilization, and nitrogen loads from grass clippings and reclaimed water to evaluate other potential processes and inputs that can impact nitrogen fate and transport in the unsaturated zone.
- Collect data on the spatial coverage and varieties of fertilized turfgrasses within the Wekiwa BMAP area.
- Conduct field experiments on various turfgrass varieties under different application rates to improve simulated uptake and leaching rates.
- Lengthen simulation durations to provide predictions on long-term impacts of fertilizer application.

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7. Appendix A: HYDRUS Base Case Model Parameter Summary Table

Hydrus-1D Parameter Summary Table

Parameter	Range	Units	Base Case	Notes
Main Processes				
Heading		-	Base Case 1 – 2013-2014 -2 Solute	2-year simulation with FAWN data from 2013-2014.
Water Flow	Water Flow; Vapor Flow; Snow Hydrology		Water Flow	Water flow simulated.
Solute Transport	Standard Solute Transport; Major Ion Chemistry; HP1 (PHREEQC)	-	Standard Solute Transport	Standard solute transport simulated.
Heat Transport	Y/N		N	Heat transport not simulated.
Root Water Uptake	Y/N		Y	Root water uptake simulation.
Root Growth	Y/N		N	Assume established turfgrass.
Inverse Solution	Y/N		N	Inverse solution not used.
Geometry Information				
Length Units	mm; cm; m		cm	Centimeters selected as length units.
Number of Soil Materials	1 to 100		2	Assume 8-inch root zone, followed by sand.
Number of Layers for Mass Balance	1 to 10		1	Default.
Decline from Vertical (=1:vertical; =0: horizontal)		-	1	Vertical soil profile.
Depth of the Soil Profile	-	cm	305	Depth to water table (10 ft).
Time Information				
Time Units	Seconds; Minutes; Hours; Days; Years	days	days	Daily time step selected for 2-year simulation.
Initial Time		day	0	Simulation begins on first day of 2-year model period.
Final Time		day	730	Equal to number of days in 2-year simulation.
Initial Time Step		day	0.001	Default.
Minimum Time Step		day	1.00E-05	Default.
Maximum Time Step		day	5	Default.
Time-Variable Boundary Conditions	Y/N		Y	Values included in following table.
Number of Time-Variable Boundary Records (e.g., Precipitation)		-	730	Equal to number of days in 2-year simulation.
Repeat the same set of BC records n times	Y/N; n		N	No records are repeated for Base Case simulation duration.
Daily Variations of Transpiration During Day Generated by Hydrus	Y/N	-	Y	Simulation setup on a daily time step.
Sinusoidal Variations of Precipitation Generated by Hydrus	Y/N	-	Y	Simulation setup on a daily time step.
Meteorological Data	Y/N		N	Function not used.
Number of Meteorological Records (e.g., Radiation)		-	-	Function not used.
Penman-Monteith Equation	Y/N		-	Function not used.
Hargreaves Formula	Y/N		-	Function not used.
Energy Balance Boundary Condition	Y/N		-	Function not used.
Daily Variations of Meteo Data During Day Generated by Hydrus	Y/N		-	Function not used.
Print Information				
T-Level Information	Y/N		N	Print preference.
Every n time steps		-	1	Print preference.
Print at Regular Time Interval	Y/N		Y	Print preference.
Time Interval		days	1	Print preference.
Screen Output	Y/N		Y	Print preference.
Print Fluxes (instead of Temp)for Observation Nodes	Y/N		Y	Print preference.

Hydrus-1D Parameter Summary Table

Parameter	Range	Units	Base Case	Notes
Hit Enter at End?	Y/N		Y	Print preference.
Number of Print Times		-	146	Print preference.
Select Print Times…	Default; Default (log); manual input	hour	Default	Print preference.
Water Flow-Iteration Criteria				
Maximum Number of Iterations		-	10	Default.
Water Content Tolerance		-	0.001	Default.
Pressure Head Tolerance		cm	1	Default.
Low Optimal Iteration Range		-	3	Default.
Upper Optimal Iteration Range		-	7	Default.
Lower Time Step Multiplication Factor		-	1.3	Default.
Upper Time Step Multiplication Factor		-	0.7	Default.
Lower Limit of the Tension Interval		cm	1.00E-06	Default.
Upper Limit of the Tension Interval		cm	10000	Default.
Water Flow-Soil Hydraulic Property Model				
Single Porosity Model	van Genuchten-Mualem; Modified van Genuchten; Brooks-Corey; Kosugi		van Genuchten-Mualem	Soil water retention curve and unsaturated hydraulic conductivity functions (Mualem, 1976; van Genuchten, 1980).
Hysteresis	No hysteresis; Hysteresis in retention curve; Hysteresis in retention curve and conductivity; Hysteresis in retention curve (no pumping, Bob Lenhard)		No hysteresis	Default.
Water Flow-Soil Hydraulic Parameters				
Material Layer 1	-			
Qr		-	0.065	Sandy Loam.
Qs		-	0.41	
Alpha		1/cm	0.075	
n		-	1.89	
Ks		cm/day	106.1	
l		-	0.5	
Material Layer 2				
Qr		-	0.0542	MW07 Sand (Web Soil Survey: weighted average of layers at site-- 1.9% clay, 1.2% silt, 96.9% sand; 1.6 g/cm3 bulk density; 2.5% water content).
Qs		-	0.3511	
Alpha		1/cm	0.0449	
n		-	4.1247	
Ks	-	cm/day	1376.99	
l		-	0.5	
Water Flow-Boundary Conditions				
Upper Boundary Condition	Constant Water Content; Constant Flux; Atmospheric BC with Surface Layer; Atmospheric BC with Surface Run Off; Variable Pressure Head; Variable Pressure Head/Flux	-	Atmospheric BC with Surface Run Off	An atmospheric boundary condition was utilized in the HYDRUS models to represent the turfgrass soil surface.
Lower Boundary Condition	Constant Water Content; Constant Flux; Variable Pressure Head; Variable Flux; Free Drainage; Deep Drainage; Seepage Face; Horizontal Drains	-	Variable Pressure Head	The boundary condition was specified as variable head in the model to provide flexibility and allow water table functions if future simulations require temporal changes in the water table throughout a simulation.

Hydrus-1D Parameter Summary Table

Parameter	Range	Units	Base Case	Notes
Initial Condition	In Pressure Heads; In Water Contents	-	In Water Contents	Initial Conditions in water contents. No initial concentration input for Base Case simulation.
Atmospheric BC: Input PET and LAI	Y/N		N	Function not used.
Solute Transport-General Information				
Time Weighting Scheme	Explicit Scheme; Crank-Nicholson Scheme; Implicit Scheme	-	Crank-Nicholson Scheme	Default.
Space Weighting Scheme	Galerkin Finite Elements; Upstream Weighting FE; GFE with Artificial Dispersion	-	Galerkin Finite Elements	HYDRUS spacing weighting option.
Mass Units		-	mg	
Stability Criterion		-	2	Hydrus recommended value.
Temperature Dependence of Transport and Reaction Parameters	Y/N	-	N	Default.
Water Content Dependence of Transport and Reaction Parameters	Y/N	-	N	Default.
Nonequilibrium Solute Transport Models	Equilibrium Model; One-site sorption model; Two-site sorption model; Two Kinetic Sites Model; Two Kinetic Sites Model; Dual-Porosity Model; Dual Porosity Model with Two-Site Sorption in the Mobile Zone	-	Equilibrium Model	Default.
Iteration Criteria: Absolute Concentration Tolerance		mg/cm^3	0	Default. Applicable for nonlinear problems.
Iteration Criteria: Relative Concentration Tolerance		-	0	Default. Applicable for nonlinear problems.
Iteration Criteria: Maximum Number of Iterations		-	10	Default. Applicable for nonlinear problems.
Use Tortuosity Factor	Y/N		Y	Default.
Millington & Quirk	Y/N		Y	Default.
Number of Solutes			2	Number of solutes to be simulated simultaneously or involved in a decay chain reaction: 1. Ammonium and 2. Nitrate. Urea and slow-release nitrogen distributed to Solute 1 and Solute 2 accordingly.
Pulse Duration			100	Default. When time-variable boundary conditions are used (e.g., atmospheric BCs or time-variable head or fluxes), then the Pulse Duration value is ignored, and boundary concentrations must be specified using the time-variable boundary conditions window.
Solute Transport-Transport Parameters				
Material Layer 1				
Bulk Density		mg/cm^3	1.6	Default.
Longitudinal Dispersivity		cm	5	Default.
Frac=1		-	1	Default.
Thlm=0		-	0	Default.
Material Layer 2				
Bulk Density	-	mg/cm^3	1.6	Default.
Longitudinal Dispersivity	-	cm	5	Default.
Frac=1		-	1	Default.
Thlm=0		-	0	Default.
Solute Transport-Reaction Parameters				
Solute 1				
Material Layer 1: Kd		cm^3/mg	0.0035	Hansen et al. 2006

Hydrus-1D Parameter Summary Table

Parameter	Range	Units	Base Case	Notes
Material Layer 2: Kd		cm^3/mg	0.0035	Hansen et al. 2006
Material Layer 1: Nu		cm^3/mg	0	Default.
Material Layer 2: Nu		cm^3/mg	0	Default.
Material Layer 1: Beta		-	1	Default.
Material Layer 2: Beta		-	1	Default.
Material Layer 1: Henry		-	0	Default.
Material Layer 2: Henry		-	0	Default.
Material Layer 1: SinkWater1'		day^{-1}	0.2	Hansen et al. 2006
Material Layer 2: SinkWater1'		day^{-1}	0.2	Hansen et al. 2006
Solute 2				
Material Layer 1: Kd		cm^3/mg	0	A common assumption of other HYDRUS studies modeling nitrogen fate and transport in the unsaturated zone (Hanson et al., 2006; Kadyampakeni et al., 2018; Ramos et al., 2012; Sun et al., 2021).
Material Layer 2: Kd		cm^3/mg	0	A common assumption of other HYDRUS studies modeling nitrogen fate and transport in the unsaturated zone (Hanson et al., 2006; Kadyampakeni et al., 2018; Ramos et al., 2012; Sun et al., 2021).
Material Layer 1: Nu		cm^3/mg	0	Default.
Material Layer 2: Nu		cm^3/mg	0	Default.
Material Layer 1: Beta		-	1	Default.
Material Layer 2: Beta		-	1	Default.
Material Layer 1: Henry		-	0	Default.
Material Layer 2: Henry		-	0	Default.
Material Layer 1: SinkWater1'		day^{-1}	0	Assume no denitrification in unsaturated zone.
Material Layer 2: SinkWater1'		day^{-1}	0	Assume no denitrification in unsaturated zone.
Solute Transport-Boundary Conditions				
Upper Boundary Condition	Concentration BC; Concentration Flux BC; Stagnant BC for Volatile Solutes	-	Concentration Flux BC	The recommended third-type (Cauchy) boundary condition where solute flux is specified at the boundary and enters the profile with infiltrating water. Boundary condition provides user control over the amount of solute mass entering the model.
Lower Boundary Condition	Concentration BC; Concentration Flux BC; Zero Concentration Gradient	-	Zero Concentration Gradient	Free drainage concentration boundary condition representing leachate entering the water table.
Initial Conditions	In Liquid Phase Concentrations; In Total Concentrations; Nonequilibrium phase is initially at equilibrium with equilibrium phase	-	In Total Concentrations [Mass_solute/Volume_soil]	No initial concentration input for Base Case simulation.
Root Water Uptake-Models				
Water Uptake Reduction Model	Feddes; S-Shape		Feddes	Default.
Solute Stress Model	No Solute Stress; Additive Model; Multiplicative Model	-	No Solute Stress	Default.
Critical Stress Index for Water Uptake		-	1	Default.
Maximum Allowed Concentration for Passive Root Solute Uptake: Solute 1, cRoot		mg/cm2/day	0.025	The maximum concentration for passive uptake was set at 0.025 mg/cm3. The potential active uptake rate across the root zone was specified as 0.025 mg/cm2/day.
Maximum Allowed Concentration for Passive Root Solute Uptake: Solute 2, cRoot		mg/cm2/day	0.025	The maximum concentration for passive uptake was set at 0.025 mg/cm3. The potential active uptake rate across the root zone was specified as 0.025 mg/cm2/day.

Hydrus-1D Parameter Summary Table

Parameter	Range	Units	Base Case	Notes
Active Solute Uptake	Y/N		Y	Nitrate selected for active uptake.
Solute with Active Uptake		mg/cm2/day	0	Inactive; specified in time variable boundary conditions.
Michaelis-Menten Constant		mg/cm3	0.17	Based on published values for nitrate in sandy soils (Bowman and Focht 1974).
Minimum Concentration for Uptake		mg/cm2	0	Default.
Critical Stress Index for Active Solute Uptake		-	1	Default.
Reduced Potential Solute Uptake due to Reduced Water Uptake	Y/N	-	N	Default.
Root Water Uptake-Water Stress Reduction				
P0		cm	10	Database value for turfgrass.
P0pt		cm	25	Database value for turfgrass.
P2H		cm	240	Database value for turfgrass.
P2L		cm	360	Database value for turfgrass.
P3		cm-	8000	Database value for turfgrass.
r2H		cm/day	0.4999999	Database value for turfgrass.
r2L		cm/day	0.1	Database value for turfgrass.
Database	common crops; grasses	-	Turfgrass	Model scenarios conceptualized for turfgrass.

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
1	1.905	0.00762	10000	0.1143	0	0	0	0.0000	0.025
2	0.04826	0.00762	10000	0.1143	0	0	0	0.0000	0.025
3	0.12065	0.00635	10000	0.09525	0	0	0	0.0000	0.025
4	0.7239	0.00508	10000	0.0762	0	0	0	0.0000	0.025
5	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
6	0.04826	0.00889	10000	0.13335	0	0	0	0.0000	0.025
7	0.31369	0.00635	10000	0.09525	0	0	0	0.0000	0.025
8	1.905	0.00889	10000	0.13335	0	0	0	0.0000	0.025
9	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
10	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
11	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
12	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
13	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
14	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
15	1.905	0.00889	10000	0.13335	0	0	0	0.0000	0.025
16	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
17	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
18	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
19	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
20	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
21	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
22	1.905	0.00635	10000	0.09525	0	0	0	0.0000	0.025
23	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
24	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
25	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
26	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
27	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
28	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
29	1.905	0.01143	10000	0.17145	0	0	0	0.0000	0.025
30	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
31	0.14478	0.01016	10000	0.1524	0	0	0	0.0000	0.025
32	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
33	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
34	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
35	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
36	1.905	0.01016	10000	0.1524	0	0	0	0.0000	0.025
37	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
38	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
39	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
40	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
41	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
42	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
43	1.95326	0.0127	10000	0.1905	0	0	0	0.0000	0.025
44	0.65151	0.0127	10000	0.1905	0	0	0	0.0000	0.025
45	0.55499	0.00762	10000	0.1143	0	0	0	0.0000	0.025
46	0.02413	0.01016	10000	0.1524	0	0	0	0.0000	0.025
47	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
48	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
49	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
50	0.635	0.0127	10000	0.1905	0	0.269110	0	0.0130	0.025
51	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
52	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
53	0	0.01651	10000	0.24765	0	0	0	0.0000	0.025
54	0.04826	0.01651	10000	0.24765	0	0	0	0.0130	0.025
55	0.74803	0.00889	10000	0.13335	0	0	0	0.0130	0.025
56	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
57	2.31521	0.00762	10000	0.1143	0	0	0	0.0130	0.025
58	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
59	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
60	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
61	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
62	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
63	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
64	1.905	0.0127	10000	0.1905	0	0	0	0.0130	0.025
65	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
66	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
67	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
68	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
69	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
70	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
71	2.12217	0.00889	10000	0.13335	0	0	0	0.0130	0.025
72	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
73	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
74	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
75	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
76	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
77	0.02413	0.01143	10000	0.17145	0	0	0	0.0130	0.025
78	1.905	0.01905	10000	0.28575	0	0	0	0.0130	0.025
79	0.62738	0.01016	10000	0.1524	0	0	0	0.0130	0.025
80	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
81	0.04826	0.01397	10000	0.20955	0	0	0	0.0130	0.025
82	0.2413	0.01524	10000	0.2286	0	0	0	0.0130	0.025
83	0.94107	0.01143	10000	0.17145	0	0	0	0.0130	0.025
84	0	0.01651	10000	0.24765	0	0	0	0.0000	0.025
85	1.905	0.01397	10000	0.20955	0	0	0	0.0130	0.025
86	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
87	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
88	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
89	0	0.01651	10000	0.24765	0	0	0	0.0000	0.025
90	0	0.01778	10000	0.2667	0	0	0	0.0000	0.025
91	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
92	1.905	0.02032	10000	0.32512	0	0	0	0.0130	0.025
93	2.84734	0.01524	10000	0.24384	0	0	0	0.0130	0.025
94	0.26543	0.00762	10000	0.12192	0	0	0	0.0130	0.025
95	0.12065	0.0127	10000	0.2032	0	0	0	0.0130	0.025
96	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
97	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
98	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
99	1.905	0.02032	10000	0.32512	0	0	0	0.0130	0.025
100	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
101	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
102	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
103	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
104	1.9304	0.01651	10000	0.26416	0	0	0	0.0130	0.025
105	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
106	1.905	0.02159	10000	0.34544	0	0	0	0.0130	0.025
107	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
108	0.07239	0.02159	10000	0.34544	0	0	0	0.0130	0.025
109	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
110	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
111	6.44271	0.01143	10000	0.18288	0	0	0	0.0000	0.025
112	0.79629	0.01143	10000	0.18288	0	0	0	0.0000	0.025
113	1.905	0.02286	10000	0.36576	0	0	0	0.0000	0.025
114	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
115	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
116	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
117	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
118	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
119	1.9304	0.01905	10000	0.3048	0	0	0	0.0000	0.025
120	4.00431	0.02286	10000	0.36576	0	0	0	0.0000	0.025
121	0.45847	0.00889	10000	0.14224	0	0	0	0.0000	0.025
122	6.97357	0.00889	10000	0.14224	0	0	0	0.0000	0.025
123	5.86359	0.01778	10000	0.28448	0	0	0	0.0000	0.025
124	0.02413	0.02032	10000	0.32512	0	0	0	0.0000	0.025
125	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
126	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
127	1.905	0.01905	10000	0.3048	0	0	0	0.0000	0.025
128	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
129	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
130	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
131	0.09652	0.02159	10000	0.34544	0	0	0	0.0000	0.025
132	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
133	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
134	1.905	0.02286	10000	0.36576	0	0	0	0.0000	0.025
135	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
136	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
137	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
138	0.635	0.0254	10000	0.4064	0	0.269110	0	0.0063	0.025
139	0.82042	0.02286	10000	0.36576	0	0	0	0.0063	0.025
140	0.16891	0.02159	10000	0.34544	0	0	0	0.0063	0.025
141	2.33934	0.01524	10000	0.24384	0	0	0	0.0063	0.025
142	0.07239	0.02032	10000	0.32512	0	0	0	0.0063	0.025
143	0.14478	0.02413	10000	0.38608	0	0	0	0.0063	0.025
144	0	0.02921	10000	0.46736	0	0	0	0.0000	0.025
145	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
146	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
147	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
148	1.905	0.02413	10000	0.38608	0	0	0	0.0063	0.025
149	0.4826	0.02159	10000	0.34544	0	0	0	0.0063	0.025
150	0.31369	0.02032	10000	0.32512	0	0	0	0.0063	0.025
151	0.12065	0.02286	10000	0.36576	0	0	0	0.0063	0.025
152	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
153	0.82042	0.0254	10000	0.4064	0	0	0	0.0063	0.025
154	0.07239	0.01905	10000	0.3048	0	0	0	0.0063	0.025
155	3.78714	0.01397	10000	0.22352	0	0	0	0.0063	0.025
156	1.64084	0.0127	10000	0.2032	0	0	0	0.0063	0.025
157	4.27101	0.01016	10000	0.16256	0	0	0	0.0063	0.025
158	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
159	1.15824	0.01905	10000	0.3048	0	0	0	0.0063	0.025
160	0.02413	0.02159	10000	0.34544	0	0	0	0.0063	0.025
161	0	0.02667	10000	0.42672	0	0	0	0.0000	0.025
162	2.07391	0.01778	10000	0.28448	0	0	0	0.0063	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
163	0.07239	0.02921	10000	0.46736	0	0	0	0.0063	0.025
164	0	0.02921	10000	0.46736	0	0	0	0.0000	0.025
165	0	0.02921	10000	0.46736	0	0	0	0.0000	0.025
166	1.42367	0.01905	10000	0.3048	0	0	0	0.0063	0.025
167	0.43434	0.01905	10000	0.3048	0	0	0	0.0063	0.025
168	2.09931	0.02413	10000	0.38608	0	0	0	0.0063	0.025
169	1.92913	0.02921	10000	0.46736	0	0	0	0.0063	0.025
170	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
171	1.90627	0.02413	10000	0.38608	0	0	0	0.0063	0.025
172	0.31369	0.02159	10000	0.34544	0	0	0	0.0063	0.025
173	0.02413	0.02032	10000	0.32512	0	0	0	0.0063	0.025
174	0.45847	0.02032	10000	0.32512	0	0	0	0.0063	0.025
175	1.25476	0.0254	10000	0.4064	0	0	0	0.0063	0.025
176	1.905	0.0254	10000	0.4064	0	0	0	0.0063	0.025
177	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
178	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
179	0.7239	0.02159	10000	0.34544	0	0	0	0.0063	0.025
180	0.09652	0.02032	10000	0.32512	0	0	0	0.0063	0.025
181	0.38608	0.01524	10000	0.24384	0	0	0	0.0063	0.025
182	0.57912	0.0127	10000	0.2032	0	0	0	0.0063	0.025
183	2.02565	0.01397	10000	0.22352	0	0	0	0.0063	0.025
184	0.69977	0.01651	10000	0.26416	0	0	0	0.0063	0.025
185	1.42367	0.02032	10000	0.32512	0	0	0	0.0063	0.025
186	0.14478	0.02286	10000	0.36576	0	0	0	0.0063	0.025
187	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
188	0	0.02667	10000	0.42672	0	0	0	0.0000	0.025
189	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
190	1.905	0.02794	10000	0.44704	0	0	0	0.0063	0.025
191	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
192	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
193	2.09931	0.01651	10000	0.26416	0	0	0	0.0063	0.025
194	3.1369	0.02032	10000	0.32512	0	0	0	0.0063	0.025
195	0.07239	0.01778	10000	0.28448	0	0	0	0.0063	0.025
196	0.14478	0.01778	10000	0.28448	0	0	0	0.0063	0.025
197	2.74955	0.01778	10000	0.28448	0	0	0	0.0063	0.025
198	1.83388	0.01778	10000	0.28448	0	0	0	0.0063	0.025
199	0.02413	0.01778	10000	0.28448	0	0	0	0.0000	0.025
200	2.31648	0.01905	10000	0.3048	0	0	0	0.0000	0.025
201	0.16891	0.01905	10000	0.3048	0	0	0	0.0000	0.025
202	0.33782	0.01905	10000	0.3048	0	0	0	0.0000	0.025
203	0.16891	0.02159	10000	0.34544	0	0	0	0.0000	0.025
204	2.29108	0.01016	10000	0.16256	0	0	0	0.0000	0.025
205	0.50673	0.01778	10000	0.28448	0	0	0	0.0000	0.025
206	0.28956	0.01651	10000	0.26416	0	0	0	0.0000	0.025
207	0.09652	0.02159	10000	0.34544	0	0	0	0.0000	0.025
208	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
209	0.02413	0.02032	10000	0.32512	0	0	0	0.0000	0.025
210	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
211	1.92913	0.0254	10000	0.4064	0	0	0	0.0000	0.025
212	0.55499	0.02413	10000	0.38608	0	0	0	0.0000	0.025
213	0.02413	0.02032	10000	0.32512	0	0	0	0.0000	0.025
214	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
215	0.86868	0.02032	10000	0.32512	0	0	0	0.0000	0.025
216	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
217	0.2413	0.0254	10000	0.4064	0	0	0	0.0000	0.025
218	2.48412	0.02159	10000	0.34544	0	0	0	0.0000	0.025
219	0.2413	0.01905	10000	0.3048	0	0	0	0.0000	0.025
220	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
221	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
222	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
223	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025
224	0.07239	0.02286	10000	0.36576	0	0	0	0.0000	0.025
225	3.64236	0.02794	10000	0.44704	0	0	0	0.0000	0.025
226	0.14478	0.02032	10000	0.32512	0	0	0	0.0000	0.025
227	0.02413	0.02159	10000	0.34544	0	0	0	0.0000	0.025
228	0.2413	0.02032	10000	0.32512	0	0	0	0.0000	0.025
229	1.9304	0.01651	10000	0.26416	0	0	0	0.0000	0.025
230	1.71323	0.02159	10000	0.34544	0	0	0	0.0000	0.025
231	0.16891	0.01778	10000	0.28448	0	0	0	0.0000	0.025
232	1.905	0.0254	10000	0.4064	0	0	0	0.0000	0.025
233	1.66497	0.01651	10000	0.26416	0	0	0	0.0000	0.025
234	0.4826	0.0127	10000	0.2032	0	0	0	0.0000	0.025
235	3.25755	0.01397	10000	0.22352	0	0	0	0.0000	0.025
236	2.21996	0.01778	10000	0.28448	0	0	0	0.0000	0.025
237	0.33782	0.02032	10000	0.32512	0	0	0	0.0000	0.025
238	0.4826	0.02159	10000	0.34544	0	0	0	0.0000	0.025
239	1.905	0.02286	10000	0.36576	0	0	0	0.0000	0.025
240	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
241	0.02413	0.02413	10000	0.38608	0	0	0	0.0000	0.025
242	0.02413	0.0254	10000	0.4064	0	0	0	0.0000	0.025
243	2.21996	0.02286	10000	0.36576	0	0	0	0.0000	0.025
244	2.87147	0.023495	10000	0.37592	0	0	0	0.0000	0.025
245	0	0.0238125	10000	0.381	0	0	0	0.0000	0.025
246	1.905	0.02413	10000	0.38608	0	0	0	0.0000	0.025
247	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
248	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
249	0.67564	0.02159	10000	0.34544	0	0	0	0.0000	0.025
250	0	0.022225	10000	0.3556	0	0	0	0.0000	0.025
251	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
252	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
253	1.95326	0.02286	10000	0.36576	0	0	0	0.0000	0.025
254	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
255	0.09652	0.01905	10000	0.3048	0	0	0	0.0000	0.025
256	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
257	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
258	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
259	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
260	1.905	0.02032	10000	0.32512	0	0	0	0.0000	0.025
261	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
262	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
263	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
264	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
265	0.45847	0.01524	10000	0.24384	0	0	0	0.0000	0.025
266	2.60604	0.00889	10000	0.14224	0	0	0	0.0000	0.025
267	2.8702	0.01016	10000	0.16256	0	0	0	0.0000	0.025
268	0.07239	0.01016	10000	0.16256	0	0	0	0.0000	0.025
269	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
270	0.60325	0.01016	10000	0.16256	0	0	0	0.0000	0.025
271	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
272	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
273	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
274	1.905	0.01524	10000	0.24384	0	0	0	0.0000	0.025
275	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
276	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
277	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
278	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
279	0.2413	0.01651	10000	0.26416	0	0	0	0.0000	0.025
280	1.6891	0.01016	10000	0.16256	0	0	0	0.0000	0.025
281	1.905	0.01524	10000	0.24384	0	0	0	0.0000	0.025
282	0	0.015875	10000	0.254	0	0	0	0.0000	0.025
283	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
284	0	0.015875	10000	0.254	0	0	0	0.0000	0.025
285	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
286	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
287	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
288	1.905	0.00889	10000	0.14224	0	0	0	0.0000	0.025
289	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
290	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
291	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
292	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
293	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
294	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
295	1.905	0.01524	10000	0.24384	0	0	0	0.0000	0.025
296	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
297	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
298	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
299	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
300	0.635	0.01143	10000	0.18288	0	0.269110	0	0.0130	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
301	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
302	1.905	0.0127	10000	0.2032	0	0	0	0.0130	0.025
303	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
304	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
305	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
306	1.61671	0.00762	10000	0.12192	0	0	0	0.0130	0.025
307	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
308	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
309	2.02565	0.01143	10000	0.18288	0	0	0	0.0130	0.025
310	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
311	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
312	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
313	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
314	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
315	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
316	1.905	0.00889	10000	0.14224	0	0	0	0.0130	0.025
317	0.12065	0.00889	10000	0.14224	0	0	0	0.0130	0.025
318	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
319	0.19304	0.00762	10000	0.12192	0	0	0	0.0130	0.025
320	2.00279	0.00635	10000	0.1016	0	0	0	0.0130	0.025
321	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
322	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
323	1.905	0.00889	10000	0.14224	0	0	0	0.0130	0.025
324	0.02413	0.00889	10000	0.14224	0	0	0	0.0130	0.025
325	0.60325	0.00762	10000	0.12192	0	0	0	0.0130	0.025
326	0.04826	0.00889	10000	0.14224	0	0	0	0.0130	0.025
327	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
328	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
329	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
330	2.17043	0.00889	10000	0.14224	0	0	0	0.0130	0.025
331	0.33782	0.00889	10000	0.14224	0	0	0	0.0130	0.025
332	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
333	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
334	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
335	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
336	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
337	1.905	0.00762	10000	0.12192	0	0	0	0.0130	0.025
338	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
339	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
340	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
341	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
342	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
343	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
344	1.905	0.00889	10000	0.14224	0	0	0	0.0130	0.025
345	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
346	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
347	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
348	0.04826	0.00762	10000	0.12192	0	0	0	0.0130	0.025
349	0.84455	0.00635	10000	0.1016	0	0	0	0.0130	0.025
350	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
351	1.905	0.00508	10000	0.08128	0	0	0	0.0130	0.025
352	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
353	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
354	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
355	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
356	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
357	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
358	2.26695	0.00635	10000	0.1016	0	0	0	0.0130	0.025
359	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
360	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
361	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
362	0.04826	0.00762	10000	0.12192	0	0	0	0.0000	0.025
363	0.4826	0.00635	10000	0.1016	0	0	0	0.0000	0.025
364	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
365	1.905	0.00635	10000	0.1016	0	0	0	0.0000	0.025
366	0.2413	0.00508	10000	0.0762	0	0	0	0.0000	0.025
367	1.10998	0.00762	10000	0.1143	0	0	0	0.0000	0.025
368	0	0.00508	10000	0.0762	0	0	0	0.0000	0.025
369	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
370	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
371	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
372	1.905	0.00381	10000	0.05715	0	0	0	0.0000	0.025
373	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
374	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
375	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
376	1.71323	0.00889	10000	0.13335	0	0	0	0.0000	0.025
377	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
378	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
379	2.00152	0.00635	10000	0.09525	0	0	0	0.0000	0.025
380	0.02413	0.00635	10000	0.09525	0	0	0	0.0000	0.025
381	0.07239	0.00508	10000	0.0762	0	0	0	0.0000	0.025
382	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
383	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
384	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
385	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
386	2.1463	0.00762	10000	0.1143	0	0	0	0.0000	0.025
387	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
388	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
389	0	0.00635	10000	0.09525	0	0	0	0.0000	0.025
390	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
391	0.04826	0.00635	10000	0.09525	0	0	0	0.0000	0.025
392	0.91694	0.00889	10000	0.13335	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
393	1.92913	0.01016	10000	0.1524	0	0	0	0.0000	0.025
394	0.91694	0.00762	10000	0.1143	0	0	0	0.0000	0.025
395	0.77216	0.00508	10000	0.0762	0	0	0	0.0000	0.025
396	0.84455	0.00635	10000	0.09525	0	0	0	0.0000	0.025
397	0.33782	0.00762	10000	0.1143	0	0	0	0.0000	0.025
398	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
399	0.14478	0.01143	10000	0.17145	0	0	0	0.0000	0.025
400	1.905	0.01143	10000	0.17145	0	0	0	0.0000	0.025
401	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
402	0.16891	0.00889	10000	0.13335	0	0	0	0.0000	0.025
403	0.28956	0.00635	10000	0.09525	0	0	0	0.0000	0.025
404	0.65151	0.00508	10000	0.0762	0	0	0	0.0000	0.025
405	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
406	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
407	1.905	0.01143	10000	0.17145	0	0	0	0.0000	0.025
408	2.31648	0.01016	10000	0.1524	0	0	0	0.0000	0.025
409	0.02413	0.01016	10000	0.1524	0	0	0	0.0000	0.025
410	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
411	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
412	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
413	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
414	1.905	0.0127	10000	0.1905	0	0	0	0.0000	0.025
415	0.635	0.01397	10000	0.20955	0	0.269110	0	0.0103	0.025
416	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
417	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
418	1.01346	0.01143	10000	0.17145	0	0	0	0.0103	0.025
419	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
420	0	0.01016	10000	0.1524	0	0	0	0.0000	0.025
421	1.905	0.01397	10000	0.20955	0	0	0	0.0103	0.025
422	1.73736	0.00762	10000	0.1143	0	0	0	0.0103	0.025
423	0.12065	0.00889	10000	0.13335	0	0	0	0.0103	0.025
424	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
425	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
426	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
427	0.04826	0.01524	10000	0.2286	0	0	0	0.0103	0.025
428	1.905	0.01397	10000	0.20955	0	0	0	0.0103	0.025
429	0	0.01143	10000	0.17145	0	0	0	0.0000	0.025
430	0.60325	0.00762	10000	0.1143	0	0	0	0.0103	0.025
431	0	0.00762	10000	0.1143	0	0	0	0.0000	0.025
432	0	0.0127	10000	0.1905	0	0	0	0.0000	0.025
433	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
434	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
435	1.905	0.01524	10000	0.2286	0	0	0	0.0103	0.025
436	0.28956	0.01397	10000	0.20955	0	0	0	0.0103	0.025
437	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
438	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
439	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
440	0	0.01651	10000	0.24765	0	0	0	0.0000	0.025
441	2.02692	0.00635	10000	0.09525	0	0	0	0.0103	0.025
442	3.93192	0.01651	10000	0.24765	0	0	0	0.0103	0.025
443	0	0.01651	10000	0.24765	0	0	0	0.0000	0.025
444	0	0.01651	10000	0.24765	0	0	0	0.0000	0.025
445	0	0.01778	10000	0.2667	0	0	0	0.0000	0.025
446	0	0.01905	10000	0.28575	0	0	0	0.0000	0.025
447	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
448	0.02413	0.01016	10000	0.1524	0	0	0	0.0103	0.025
449	1.95326	0.01397	10000	0.20955	0	0	0	0.0103	0.025
450	0	0.01397	10000	0.20955	0	0	0	0.0000	0.025
451	0	0.00889	10000	0.13335	0	0	0	0.0000	0.025
452	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
453	3.32994	0.00762	10000	0.1143	0	0	0	0.0103	0.025
454	0	0.01778	10000	0.2667	0	0	0	0.0000	0.025
455	0	0.01524	10000	0.2286	0	0	0	0.0000	0.025
456	1.905	0.01778	10000	0.28448	0	0	0	0.0103	0.025
457	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
458	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
459	0	0.019685	10000	0.31496	0	0	0	0.0000	0.025
460	0	0.0193675	10000	0.30988	0	0	0	0.0000	0.025
461	0	0.01920875	10000	0.30734	0	0	0	0.0000	0.025
462	0.04826	0.01905	10000	0.3048	0	0	0	0.0103	0.025
463	3.47345	0.00889	10000	0.14224	0	0	0	0.0103	0.025
464	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
465	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
466	0	0.01778	10000	0.28448	0	0	0	0.0000	0.025
467	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
468	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
469	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
470	3.37693	0.019685	10000	0.31496	0	0	0	0.0103	0.025
471	0	0.0193675	10000	0.30988	0	0	0	0.0000	0.025
472	0	0.01920875	10000	0.30734	0	0	0	0.0000	0.025
473	0.41021	0.019129375	10000	0.30607	0	0	0	0.0103	0.025
474	0.02413	0.019089688	10000	0.305435	0	0	0	0.0103	0.025
475	0	0.019069844	10000	0.3051175	0	0	0	0.0000	0.025
476	0	0.019059922	10000	0.30495875	0	0	0	0.0000	0.025
477	1.95326	0.01905	10000	0.3048	0	0	0	0.0000	0.025
478	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
479	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
480	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
481	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
482	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
483	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
484	3.69062	0.0254	10000	0.4064	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
485	1.03759	0.0254	10000	0.4064	0	0	0	0.0000	0.025
486	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
487	2.50952	0.0254	10000	0.4064	0	0	0	0.0000	0.025
488	0.60325	0.0254	10000	0.4064	0	0	0	0.0000	0.025
489	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
490	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
491	1.905	0.0254	10000	0.4064	0	0	0	0.0000	0.025
492	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
493	0.04826	0.0254	10000	0.4064	0	0	0	0.0000	0.025
494	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
495	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
496	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
497	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
498	1.905	0.0254	10000	0.4064	0	0	0	0.0000	0.025
499	0.09652	0.0254	10000	0.4064	0	0	0	0.0000	0.025
500	1.27889	0.0254	10000	0.4064	0	0	0	0.0000	0.025
501	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
502	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
503	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
504	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
505	0.635	0.0254	10000	0.4064	0	0.269110	0	0.0069	0.025
506	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
507	0.04826	0.02667	10000	0.42672	0	0	0	0.0069	0.025
508	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025
509	0	0.02667	10000	0.42672	0	0	0	0.0000	0.025
510	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
511	0.07239	0.02286	10000	0.36576	0	0	0	0.0069	0.025
512	1.95326	0.02286	10000	0.36576	0	0	0	0.0069	0.025
513	0.43434	0.02286	10000	0.36576	0	0	0	0.0069	0.025
514	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
515	1.52019	0.02286	10000	0.36576	0	0	0	0.0069	0.025
516	1.71323	0.02286	10000	0.36576	0	0	0	0.0069	0.025
517	3.52298	0.02286	10000	0.36576	0	0	0	0.0069	0.025
518	0.02413	0.02286	10000	0.36576	0	0	0	0.0069	0.025
519	1.905	0.02286	10000	0.36576	0	0	0	0.0069	0.025
520	0.09652	0.02413	10000	0.38608	0	0	0	0.0069	0.025
521	0	0.02667	10000	0.42672	0	0	0	0.0000	0.025
522	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
523	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
524	0.09652	0.02286	10000	0.36576	0	0	0	0.0069	0.025
525	0.02413	0.0254	10000	0.4064	0	0	0	0.0069	0.025
526	3.93192	0.02159	10000	0.34544	0	0	0	0.0069	0.025
527	2.48539	0.01524	10000	0.24384	0	0	0	0.0069	0.025
528	1.85801	0.01651	10000	0.26416	0	0	0	0.0069	0.025
529	0.14478	0.02032	10000	0.32512	0	0	0	0.0069	0.025
530	1.13411	0.01524	10000	0.24384	0	0	0	0.0069	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
531	0.04826	0.0254	10000	0.4064	0	0	0	0.0069	0.025
532	0.02413	0.01778	10000	0.28448	0	0	0	0.0069	0.025
533	1.905	0.0254	10000	0.4064	0	0	0	0.0069	0.025
534	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
535	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
536	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
537	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025
538	1.49606	0.01651	10000	0.26416	0	0	0	0.0069	0.025
539	0.7239	0.02032	10000	0.32512	0	0	0	0.0069	0.025
540	1.92913	0.02794	10000	0.44704	0	0	0	0.0069	0.025
541	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025
542	1.25476	0.02794	10000	0.44704	0	0	0	0.0069	0.025
543	0.84455	0.02413	10000	0.38608	0	0	0	0.0069	0.025
544	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025
545	0.16891	0.02159	10000	0.34544	0	0	0	0.0069	0.025
546	1.08585	0.01524	10000	0.24384	0	0	0	0.0069	0.025
547	1.905	0.02667	10000	0.42672	0	0	0	0.0069	0.025
548	0.77216	0.01524	10000	0.24384	0	0	0	0.0069	0.025
549	0.02413	0.0254	10000	0.4064	0	0	0	0.0069	0.025
550	0.50673	0.01778	10000	0.28448	0	0	0	0.0069	0.025
551	4.15036	0.01905	10000	0.3048	0	0	0	0.0069	0.025
552	0.38608	0.01143	10000	0.18288	0	0	0	0.0069	0.025
553	0.02413	0.01778	10000	0.28448	0	0	0	0.0069	0.025
554	2.00152	0.02413	10000	0.38608	0	0	0	0.0069	0.025
555	0.02413	0.02032	10000	0.32512	0	0	0	0.0069	0.025
556	0.26543	0.02413	10000	0.38608	0	0	0	0.0069	0.025
557	0.04826	0.0254	10000	0.4064	0	0	0	0.0069	0.025
558	0.02413	0.02413	10000	0.38608	0	0	0	0.0069	0.025
559	0.53086	0.02032	10000	0.32512	0	0	0	0.0069	0.025
560	1.30302	0.02159	10000	0.34544	0	0	0	0.0069	0.025
561	2.1463	0.01905	10000	0.3048	0	0	0	0.0069	0.025
562	0.79629	0.01143	10000	0.18288	0	0	0	0.0069	0.025
563	0.21717	0.02413	10000	0.38608	0	0	0	0.0069	0.025
564	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025
565	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
566	0.21717	0.02286	10000	0.36576	0	0	0	0.0000	0.025
567	0.38608	0.02286	10000	0.36576	0	0	0	0.0000	0.025
568	2.02565	0.02667	10000	0.42672	0	0	0	0.0000	0.025
569	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
570	0.02413	0.02413	10000	0.38608	0	0	0	0.0000	0.025
571	0.07239	0.01905	10000	0.3048	0	0	0	0.0000	0.025
572	0	0.02159	10000	0.34544	0	0	0	0.0000	0.025
573	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
574	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
575	3.76301	0.01651	10000	0.26416	0	0	0	0.0000	0.025
576	0	0.02794	10000	0.44704	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
577	0	0.02413	10000	0.38608	0	0	0	0.0000	0.025
578	0	0.022225	10000	0.3556	0	0	0	0.0000	0.025
579	0	0.0212725	10000	0.34036	0	0	0	0.0000	0.025
580	0.21717	0.02079625	10000	0.33274	0	0	0	0.0000	0.025
581	0.31369	0.020558125	10000	0.32893	0	0	0	0.0000	0.025
582	1.905	0.020439063	10000	0.327025	0	0	0	0.0000	0.025
583	0	0.020379531	10000	0.3260725	0	0	0	0.0000	0.025
584	2.31648	0.020349766	10000	0.32559625	0	0	0	0.0000	0.025
585	0.91694	0.020334883	10000	0.325358125	0	0	0	0.0000	0.025
586	0	0.020327441	10000	0.325239063	0	0	0	0.0000	0.025
587	0	0.020323721	10000	0.325179531	0	0	0	0.0000	0.025
588	0.09652	0.02032186	10000	0.325149766	0	0	0	0.0000	0.025
589	1.92913	0.02032093	10000	0.325134883	0	0	0	0.0000	0.025
590	0	0.020320465	10000	0.325127441	0	0	0	0.0000	0.025
591	0.09652	0.02032	10000	0.32512	0	0	0	0.0000	0.025
592	0.09652	0.0127	10000	0.2032	0	0	0	0.0000	0.025
593	0.31369	0.01524	10000	0.24384	0	0	0	0.0000	0.025
594	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
595	1.71323	0.02413	10000	0.38608	0	0	0	0.0000	0.025
596	1.97739	0.02667	10000	0.42672	0	0	0	0.0000	0.025
597	0	0.02667	10000	0.42672	0	0	0	0.0000	0.025
598	0.09652	0.02667	10000	0.42672	0	0	0	0.0000	0.025
599	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
600	1.03759	0.02159	10000	0.34544	0	0	0	0.0000	0.025
601	0	0.0254	10000	0.4064	0	0	0	0.0000	0.025
602	0.04826	0.02159	10000	0.34544	0	0	0	0.0000	0.025
603	1.905	0.02286	10000	0.36576	0	0	0	0.0000	0.025
604	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
605	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
606	0.36195	0.01524	10000	0.24384	0	0	0	0.0000	0.025
607	0.31369	0.02032	10000	0.32512	0	0	0	0.0000	0.025
608	0.02413	0.02032	10000	0.32512	0	0	0	0.0000	0.025
609	1.03759	0.02032	10000	0.32512	0	0	0	0.0000	0.025
610	1.905	0.01905	10000	0.3048	0	0	0	0.0000	0.025
611	0	0.02032	10000	0.32512	0	0	0	0.0000	0.025
612	0.09652	0.01397	10000	0.22352	0	0	0	0.0000	0.025
613	0.31369	0.01524	10000	0.24384	0	0	0	0.0000	0.025
614	0.4826	0.01651	10000	0.26416	0	0	0	0.0000	0.025
615	1.18237	0.0127	10000	0.2032	0	0	0	0.0000	0.025
616	0.14478	0.01905	10000	0.3048	0	0	0	0.0000	0.025
617	2.1463	0.01905	10000	0.3048	0	0	0	0.0000	0.025
618	0.07239	0.01905	10000	0.3048	0	0	0	0.0000	0.025
619	0.12065	0.01905	10000	0.3048	0	0	0	0.0000	0.025
620	0.43434	0.01778	10000	0.28448	0	0	0	0.0000	0.025
621	0	0.02286	10000	0.36576	0	0	0	0.0000	0.025
622	0.21717	0.02032	10000	0.32512	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
623	0.02413	0.01778	10000	0.28448	0	0	0	0.0000	0.025
624	2.72542	0.01524	10000	0.24384	0	0	0	0.0000	0.025
625	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
626	0.26543	0.02032	10000	0.32512	0	0	0	0.0000	0.025
627	0.79629	0.00889	10000	0.14224	0	0	0	0.0000	0.025
628	0.79629	0.0127	10000	0.2032	0	0	0	0.0000	0.025
629	0	0.01905	10000	0.3048	0	0	0	0.0000	0.025
630	0.62738	0.0127	10000	0.2032	0	0	0	0.0000	0.025
631	4.26974	0.0127	10000	0.2032	0	0	0	0.0000	0.025
632	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
633	1.83388	0.01397	10000	0.22352	0	0	0	0.0000	0.025
634	5.28447	0.01143	10000	0.18288	0	0	0	0.0000	0.025
635	0.60325	0.01143	10000	0.18288	0	0	0	0.0000	0.025
636	0.07239	0.01524	10000	0.24384	0	0	0	0.0000	0.025
637	3.69189	0.01016	10000	0.16256	0	0	0	0.0000	0.025
638	2.50825	0.0127	10000	0.2032	0	0	0	0.0000	0.025
639	0.94107	0.01143	10000	0.18288	0	0	0	0.0000	0.025
640	0.33782	0.01778	10000	0.28448	0	0	0	0.0000	0.025
641	0.14478	0.01778	10000	0.28448	0	0	0	0.0000	0.025
642	0.09652	0.01524	10000	0.24384	0	0	0	0.0000	0.025
643	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
644	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
645	1.905	0.01397	10000	0.22352	0	0	0	0.0000	0.025
646	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
647	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
648	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
649	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
650	0	0.01524	10000	0.24384	0	0	0	0.0000	0.025
651	0	0.01651	10000	0.26416	0	0	0	0.0000	0.025
652	4.92125	0.0127	10000	0.2032	0	0	0	0.0000	0.025
653	0.09652	0.0127	10000	0.2032	0	0	0	0.0000	0.025
654	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
655	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
656	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
657	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
658	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
659	1.905	0.0127	10000	0.2032	0	0	0	0.0000	0.025
660	0	0.01397	10000	0.22352	0	0	0	0.0000	0.025
661	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
662	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
663	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
664	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
665	0.635	0.0127	10000	0.2032	0	0.269110	0	0.0084	0.025
666	1.905	0.01143	10000	0.18288	0	0	0	0.0084	0.025
667	0	0.0127	10000	0.2032	0	0	0	0.0000	0.025
668	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
669	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
670	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
671	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
672	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
673	1.905	0.01016	10000	0.16256	0	0	0	0.0084	0.025
674	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
675	0	0.01143	10000	0.18288	0	0	0	0.0000	0.025
676	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
677	0.19304	0.00889	10000	0.14224	0	0	0	0.0084	0.025
678	0.98933	0.00762	10000	0.12192	0	0	0	0.0084	0.025
679	0.09652	0.00635	10000	0.1016	0	0	0	0.0084	0.025
680	1.92913	0.01016	10000	0.16256	0	0	0	0.0084	0.025
681	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
682	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
683	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
684	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
685	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
686	2.38887	0.00762	10000	0.12192	0	0	0	0.0084	0.025
687	1.92913	0.00762	10000	0.12192	0	0	0	0.0084	0.025
688	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
689	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
690	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
691	0.14478	0.00635	10000	0.1016	0	0	0	0.0084	0.025
692	0.33782	0.00889	10000	0.14224	0	0	0	0.0084	0.025
693	0	0.01016	10000	0.16256	0	0	0	0.0000	0.025
694	12.57046	0.00508	10000	0.08128	0	0	0	0.0084	0.025
695	0.45847	0.00762	10000	0.12192	0	0	0	0.0084	0.025
696	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
697	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
698	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
699	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
700	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
701	1.905	0.00889	10000	0.14224	0	0	0	0.0084	0.025
702	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
703	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
704	0.02413	0.00762	10000	0.12192	0	0	0	0.0084	0.025
705	0	0.00889	10000	0.14224	0	0	0	0.0000	0.025
706	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
707	0.16891	0.00635	10000	0.1016	0	0	0	0.0084	0.025
708	1.905	0.00635	10000	0.1016	0	0	0	0.0084	0.025
709	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
710	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
711	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
712	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
713	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
714	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025

Base Case: Time Variable Boundary Conditions

Time (days)	Precip. (cm/day)	Evap. (cm/day)	hCritA (cm)	Transp. (cm/day)	GWL (cm)	cTop-1	cBot-1	cTop-2	CRoot
715	1.905	0.00635	10000	0.1016	0	0	0	0.0084	0.025
716	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
717	0	0.00508	10000	0.08128	0	0	0	0.0000	0.025
718	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
719	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
720	2.24409	0.00762	10000	0.12192	0	0	0	0.0084	0.025
721	0.91694	0.00762	10000	0.12192	0	0	0	0.0084	0.025
722	1.905	0.00762	10000	0.12192	0	0	0	0.0084	0.025
723	1.18237	0.00889	10000	0.14224	0	0	0	0.0084	0.025
724	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
725	0	0.00635	10000	0.1016	0	0	0	0.0000	0.025
726	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
727	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
728	0	0.00762	10000	0.12192	0	0	0	0.0000	0.025
729	2.41173	0.00508	10000	0.08128	0	0	0	0.0000	0.025
730	0.2413	0.00508	10000	0.08128	0	0	0	0.0000	0.025

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
0	0.1272	1	1	1	1	1	1	20	0	0
0.305	0.1274	1	1	1	1	1	1	20	0	0
0.61	0.1276	1	1	1	1	1	1	20	0	0
0.915	0.1278	1	1	1	1	1	1	20	0	0
1.22	0.128	1	1	1	1	1	1	20	0	0
1.525	0.1282	1	1	1	1	1	1	20	0	0
1.83	0.1284	1	1	1	1	1	1	20	0	0
2.135	0.1286	1	1	1	1	1	1	20	0	0
2.44	0.1288	1	1	1	1	1	1	20	0	0
2.745	0.129	1	1	1	1	1	1	20	0	0
3.05	0.1291	1	1	1	1	1	1	20	0	0
3.355	0.1293	1	1	1	1	1	1	20	0	0
3.66	0.1295	1	1	1	1	1	1	20	0	0
3.965	0.1297	1	1	1	1	1	1	20	0	0
4.27	0.1298	1	1	1	1	1	1	20	0	0
4.575	0.13	1	1	1	1	1	1	20	0	0
4.88	0.1302	1	1	1	1	1	1	20	0	0
5.185	0.1304	1	1	1	1	1	1	20	0	0
5.49	0.1305	1	1	1	1	1	1	20	0	0
5.795	0.1307	1	1	1	1	1	1	20	0	0
6.1	0.1309	1	1	1	1	1	1	20	0	0
6.405	0.131	1	1	1	1	1	1	20	0	0
6.71	0.1312	1	1	1	1	1	1	20	0	0
7.015	0.1313	1	1	1	1	1	1	20	0	0
7.32	0.1315	1	1	1	1	1	1	20	0	0
7.625	0.1317	1	1	1	1	1	1	20	0	0
7.93	0.1318	1	1	1	1	1	1	20	0	0
8.235	0.132	1	1	1	1	1	1	20	0	0
8.54	0.1321	1	1	1	1	1	1	20	0	0
8.845	0.1323	1	1	1	1	1	1	20	0	0
9.15	0.1324	1	1	1	1	1	1	20	0	0
9.455	0.1326	1	1	1	1	1	1	20	0	0
9.76	0.1327	1	1	1	1	1	1	20	0	0
10.065	0.1329	1	1	1	1	1	1	20	0	0
10.37	0.133	1	1	1	1	1	1	20	0	0
10.675	0.1332	1	1	1	1	1	1	20	0	0
10.98	0.1333	1	1	1	1	1	1	20	0	0
11.285	0.1335	1	1	1	1	1	1	20	0	0
11.59	0.1336	1	1	1	1	1	1	20	0	0
11.895	0.1337	1	1	1	1	1	1	20	0	0
12.2	0.1339	1	1	1	1	1	1	20	0	0
12.505	0.134	1	1	1	1	1	1	20	0	0
12.81	0.1342	1	1	1	1	1	1	20	0	0
13.115	0.1343	1	1	1	1	1	1	20	0	0
13.42	0.1344	1	1	1	1	1	1	20	0	0
13.725	0.1346	1	1	1	1	1	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
14.03	0.1347	1	1	1	1	1	1	20	0	0
14.335	0.1349	1	1	1	1	1	1	20	0	0
14.64	0.135	1	1	1	1	1	1	20	0	0
14.945	0.1351	1	1	1	1	1	1	20	0	0
15.25	0.1353	1	1	1	1	1	1	20	0	0
15.555	0.1354	1	1	1	1	1	1	20	0	0
15.86	0.1355	1	1	1	1	1	1	20	0	0
16.165	0.1357	1	1	1	1	1	1	20	0	0
16.47	0.1358	1	1	1	1	1	1	20	0	0
16.775	0.1359	1	1	1	1	1	1	20	0	0
17.08	0.1361	1	1	1	1	1	1	20	0	0
17.385	0.1362	1	1	1	1	1	1	20	0	0
17.69	0.1363	1	1	1	1	1	1	20	0	0
17.995	0.1365	1	1	1	1	1	1	20	0	0
18.3	0.1366	1	1	1	1	1	1	20	0	0
18.605	0.1367	1	1	1	1	1	1	20	0	0
18.91	0.1368	1	1	1	1	1	1	20	0	0
19.215	0.137	1	1	1	1	1	1	20	0	0
19.52	0.1371	1	1	1	1	1	1	20	0	0
19.825	0.1372	1	1	1	1	1	1	20	0	0
20.13	0.1374	1	1	1	1	1	1	20	0	0
20.435	0.0608	0	1	1	1	2	1	20	0	0
20.74	0.0608	0	1	1	1	2	1	20	0	0
21.045	0.0608	0	1	1	1	2	1	20	0	0
21.35	0.0608	0	1	1	1	2	1	20	0	0
21.655	0.0608	0	1	1	1	2	1	20	0	0
21.96	0.0608	0	1	1	1	2	1	20	0	0
22.265	0.0608	0	1	1	1	2	1	20	0	0
22.57	0.0608	0	1	1	1	2	1	20	0	0
22.875	0.0609	0	1	1	1	2	1	20	0	0
23.18	0.0609	0	1	1	1	2	1	20	0	0
23.485	0.0609	0	1	1	1	2	1	20	0	0
23.79	0.0609	0	1	1	1	2	1	20	0	0
24.095	0.0609	0	1	1	1	2	1	20	0	0
24.4	0.0609	0	1	1	1	2	1	20	0	0
24.705	0.0609	0	1	1	1	2	1	20	0	0
25.01	0.0609	0	1	1	1	2	1	20	0	0
25.315	0.0609	0	1	1	1	2	1	20	0	0
25.62	0.0609	0	1	1	1	2	1	20	0	0
25.925	0.0609	0	1	1	1	2	1	20	0	0
26.23	0.0609	0	1	1	1	2	1	20	0	0
26.535	0.061	0	1	1	1	2	1	20	0	0
26.84	0.061	0	1	1	1	2	1	20	0	0
27.145	0.061	0	1	1	1	2	1	20	0	0
27.45	0.061	0	1	1	1	2	1	20	0	0
27.755	0.061	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
28.06	0.061	0	1	1	1	2	1	20	0	0
28.365	0.061	0	1	1	1	2	1	20	0	0
28.67	0.061	0	1	1	1	2	1	20	0	0
28.975	0.061	0	1	1	1	2	1	20	0	0
29.28	0.061	0	1	1	1	2	1	20	0	0
29.585	0.061	0	1	1	1	2	1	20	0	0
29.89	0.061	0	1	1	1	2	1	20	0	0
30.195	0.061	0	1	1	1	2	1	20	0	0
30.5	0.061	0	1	1	1	2	1	20	0	0
30.805	0.061	0	1	1	1	2	1	20	0	0
31.11	0.061	0	1	1	1	2	1	20	0	0
31.415	0.061	0	1	1	1	2	1	20	0	0
31.72	0.061	0	1	1	1	2	1	20	0	0
32.025	0.061	0	1	1	1	2	1	20	0	0
32.33	0.061	0	1	1	1	2	1	20	0	0
32.635	0.0609	0	1	1	1	2	1	20	0	0
32.94	0.0609	0	1	1	1	2	1	20	0	0
33.245	0.0609	0	1	1	1	2	1	20	0	0
33.55	0.0609	0	1	1	1	2	1	20	0	0
33.855	0.0609	0	1	1	1	2	1	20	0	0
34.16	0.0609	0	1	1	1	2	1	20	0	0
34.465	0.0609	0	1	1	1	2	1	20	0	0
34.77	0.0609	0	1	1	1	2	1	20	0	0
35.075	0.0609	0	1	1	1	2	1	20	0	0
35.38	0.0609	0	1	1	1	2	1	20	0	0
35.685	0.0609	0	1	1	1	2	1	20	0	0
35.99	0.0609	0	1	1	1	2	1	20	0	0
36.295	0.0609	0	1	1	1	2	1	20	0	0
36.6	0.0609	0	1	1	1	2	1	20	0	0
36.905	0.0609	0	1	1	1	2	1	20	0	0
37.21	0.0609	0	1	1	1	2	1	20	0	0
37.515	0.0609	0	1	1	1	2	1	20	0	0
37.82	0.0609	0	1	1	1	2	1	20	0	0
38.125	0.0609	0	1	1	1	2	1	20	0	0
38.43	0.0609	0	1	1	1	2	1	20	0	0
38.735	0.0609	0	1	1	1	2	1	20	0	0
39.04	0.0609	0	1	1	1	2	1	20	0	0
39.345	0.0609	0	1	1	1	2	1	20	0	0
39.65	0.0609	0	1	1	1	2	1	20	0	0
39.955	0.0609	0	1	1	1	2	1	20	0	0
40.26	0.0609	0	1	1	1	2	1	20	0	0
40.565	0.0609	0	1	1	1	2	1	20	0	0
40.87	0.0609	0	1	1	1	2	1	20	0	0
41.175	0.0609	0	1	1	1	2	1	20	0	0
41.48	0.0609	0	1	1	1	2	1	20	0	0
41.785	0.0609	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
42.09	0.0609	0	1	1	1	2	1	20	0	0
42.395	0.0609	0	1	1	1	2	1	20	0	0
42.7	0.0609	0	1	1	1	2	1	20	0	0
43.005	0.0609	0	1	1	1	2	1	20	0	0
43.31	0.0609	0	1	1	1	2	1	20	0	0
43.615	0.0609	0	1	1	1	2	1	20	0	0
43.92	0.0609	0	1	1	1	2	1	20	0	0
44.225	0.0608	0	1	1	1	2	1	20	0	0
44.53	0.0608	0	1	1	1	2	1	20	0	0
44.835	0.0608	0	1	1	1	2	1	20	0	0
45.14	0.0608	0	1	1	1	2	1	20	0	0
45.445	0.0608	0	1	1	1	2	1	20	0	0
45.75	0.0607	0	1	1	1	2	1	20	0	0
46.055	0.0607	0	1	1	1	2	1	20	0	0
46.36	0.0606	0	1	1	1	2	1	20	0	0
46.665	0.0606	0	1	1	1	2	1	20	0	0
46.97	0.0606	0	1	1	1	2	1	20	0	0
47.275	0.0606	0	1	1	1	2	1	20	0	0
47.58	0.0606	0	1	1	1	2	1	20	0	0
47.885	0.0605	0	1	1	1	2	1	20	0	0
48.19	0.0605	0	1	1	1	2	1	20	0	0
48.495	0.0605	0	1	1	1	2	1	20	0	0
48.8	0.0605	0	1	1	1	2	1	20	0	0
49.105	0.0605	0	1	1	1	2	1	20	0	0
49.41	0.0604	0	1	1	1	2	1	20	0	0
49.715	0.0604	0	1	1	1	2	1	20	0	0
50.02	0.0604	0	1	1	1	2	1	20	0	0
50.325	0.0604	0	1	1	1	2	1	20	0	0
50.63	0.0604	0	1	1	1	2	1	20	0	0
50.935	0.0603	0	1	1	1	2	1	20	0	0
51.24	0.0603	0	1	1	1	2	1	20	0	0
51.545	0.0603	0	1	1	1	2	1	20	0	0
51.85	0.0603	0	1	1	1	2	1	20	0	0
52.155	0.0603	0	1	1	1	2	1	20	0	0
52.46	0.0602	0	1	1	1	2	1	20	0	0
52.765	0.0602	0	1	1	1	2	1	20	0	0
53.07	0.0602	0	1	1	1	2	1	20	0	0
53.375	0.0602	0	1	1	1	2	1	20	0	0
53.68	0.0602	0	1	1	1	2	1	20	0	0
53.985	0.0601	0	1	1	1	2	1	20	0	0
54.29	0.0601	0	1	1	1	2	1	20	0	0
54.595	0.0601	0	1	1	1	2	1	20	0	0
54.9	0.0601	0	1	1	1	2	1	20	0	0
55.205	0.06	0	1	1	1	2	1	20	0	0
55.51	0.06	0	1	1	1	2	1	20	0	0
55.815	0.06	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
56.12	0.06	0	1	1	1	2	1	20	0	0
56.425	0.06	0	1	1	1	2	1	20	0	0
56.73	0.0599	0	1	1	1	2	1	20	0	0
57.035	0.0599	0	1	1	1	2	1	20	0	0
57.34	0.0599	0	1	1	1	2	1	20	0	0
57.645	0.0599	0	1	1	1	2	1	20	0	0
57.95	0.0598	0	1	1	1	2	1	20	0	0
58.255	0.0598	0	1	1	1	2	1	20	0	0
58.56	0.0598	0	1	1	1	2	1	20	0	0
58.865	0.0598	0	1	1	1	2	1	20	0	0
59.17	0.0597	0	1	1	1	2	1	20	0	0
59.475	0.0597	0	1	1	1	2	1	20	0	0
59.78	0.0597	0	1	1	1	2	1	20	0	0
60.085	0.0597	0	1	1	1	2	1	20	0	0
60.39	0.0597	0	1	1	1	2	1	20	0	0
60.695	0.0596	0	1	1	1	2	1	20	0	0
61	0.0596	0	1	1	1	2	1	20	0	0
61.305	0.0596	0	1	1	1	2	1	20	0	0
61.61	0.0596	0	1	1	1	2	1	20	0	0
61.915	0.0596	0	1	1	1	2	1	20	0	0
62.22	0.0595	0	1	1	1	2	1	20	0	0
62.525	0.0595	0	1	1	1	2	1	20	0	0
62.83	0.0595	0	1	1	1	2	1	20	0	0
63.135	0.0595	0	1	1	1	2	1	20	0	0
63.44	0.0594	0	1	1	1	2	1	20	0	0
63.745	0.0594	0	1	1	1	2	1	20	0	0
64.05	0.0594	0	1	1	1	2	1	20	0	0
64.355	0.0594	0	1	1	1	2	1	20	0	0
64.66	0.0594	0	1	1	1	2	1	20	0	0
64.965	0.0593	0	1	1	1	2	1	20	0	0
65.27	0.0593	0	1	1	1	2	1	20	0	0
65.575	0.0593	0	1	1	1	2	1	20	0	0
65.88	0.0593	0	1	1	1	2	1	20	0	0
66.185	0.0593	0	1	1	1	2	1	20	0	0
66.49	0.0592	0	1	1	1	2	1	20	0	0
66.795	0.0592	0	1	1	1	2	1	20	0	0
67.1	0.0592	0	1	1	1	2	1	20	0	0
67.405	0.0592	0	1	1	1	2	1	20	0	0
67.71	0.0592	0	1	1	1	2	1	20	0	0
68.015	0.0591	0	1	1	1	2	1	20	0	0
68.32	0.0591	0	1	1	1	2	1	20	0	0
68.625	0.0591	0	1	1	1	2	1	20	0	0
68.93	0.0591	0	1	1	1	2	1	20	0	0
69.235	0.0591	0	1	1	1	2	1	20	0	0
69.54	0.059	0	1	1	1	2	1	20	0	0
69.845	0.059	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
70.15	0.059	0	1	1	1	2	1	20	0	0
70.455	0.059	0	1	1	1	2	1	20	0	0
70.76	0.059	0	1	1	1	2	1	20	0	0
71.065	0.0589	0	1	1	1	2	1	20	0	0
71.37	0.0589	0	1	1	1	2	1	20	0	0
71.675	0.0589	0	1	1	1	2	1	20	0	0
71.98	0.0589	0	1	1	1	2	1	20	0	0
72.285	0.0589	0	1	1	1	2	1	20	0	0
72.59	0.0589	0	1	1	1	2	1	20	0	0
72.895	0.0588	0	1	1	1	2	1	20	0	0
73.2	0.0588	0	1	1	1	2	1	20	0	0
73.505	0.0588	0	1	1	1	2	1	20	0	0
73.81	0.0588	0	1	1	1	2	1	20	0	0
74.115	0.0588	0	1	1	1	2	1	20	0	0
74.42	0.0588	0	1	1	1	2	1	20	0	0
74.725	0.0588	0	1	1	1	2	1	20	0	0
75.03	0.0587	0	1	1	1	2	1	20	0	0
75.335	0.0587	0	1	1	1	2	1	20	0	0
75.64	0.0587	0	1	1	1	2	1	20	0	0
75.945	0.0587	0	1	1	1	2	1	20	0	0
76.25	0.0587	0	1	1	1	2	1	20	0	0
76.555	0.0587	0	1	1	1	2	1	20	0	0
76.86	0.0587	0	1	1	1	2	1	20	0	0
77.165	0.0586	0	1	1	1	2	1	20	0	0
77.47	0.0586	0	1	1	1	2	1	20	0	0
77.775	0.0586	0	1	1	1	2	1	20	0	0
78.08	0.0586	0	1	1	1	2	1	20	0	0
78.385	0.0586	0	1	1	1	2	1	20	0	0
78.69	0.0586	0	1	1	1	2	1	20	0	0
78.995	0.0586	0	1	1	1	2	1	20	0	0
79.3	0.0586	0	1	1	1	2	1	20	0	0
79.605	0.0586	0	1	1	1	2	1	20	0	0
79.91	0.0585	0	1	1	1	2	1	20	0	0
80.215	0.0585	0	1	1	1	2	1	20	0	0
80.52	0.0585	0	1	1	1	2	1	20	0	0
80.825	0.0585	0	1	1	1	2	1	20	0	0
81.13	0.0585	0	1	1	1	2	1	20	0	0
81.435	0.0585	0	1	1	1	2	1	20	0	0
81.74	0.0585	0	1	1	1	2	1	20	0	0
82.045	0.0585	0	1	1	1	2	1	20	0	0
82.35	0.0585	0	1	1	1	2	1	20	0	0
82.655	0.0585	0	1	1	1	2	1	20	0	0
82.96	0.0585	0	1	1	1	2	1	20	0	0
83.265	0.0584	0	1	1	1	2	1	20	0	0
83.57	0.0584	0	1	1	1	2	1	20	0	0
83.875	0.0584	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
84.18	0.0584	0	1	1	1	2	1	20	0	0
84.485	0.0584	0	1	1	1	2	1	20	0	0
84.79	0.0584	0	1	1	1	2	1	20	0	0
85.095	0.0584	0	1	1	1	2	1	20	0	0
85.4	0.0584	0	1	1	1	2	1	20	0	0
85.705	0.0584	0	1	1	1	2	1	20	0	0
86.01	0.0584	0	1	1	1	2	1	20	0	0
86.315	0.0584	0	1	1	1	2	1	20	0	0
86.62	0.0584	0	1	1	1	2	1	20	0	0
86.925	0.0584	0	1	1	1	2	1	20	0	0
87.23	0.0584	0	1	1	1	2	1	20	0	0
87.535	0.0584	0	1	1	1	2	1	20	0	0
87.84	0.0584	0	1	1	1	2	1	20	0	0
88.145	0.0584	0	1	1	1	2	1	20	0	0
88.45	0.0583	0	1	1	1	2	1	20	0	0
88.755	0.0583	0	1	1	1	2	1	20	0	0
89.06	0.0583	0	1	1	1	2	1	20	0	0
89.365	0.0583	0	1	1	1	2	1	20	0	0
89.67	0.0583	0	1	1	1	2	1	20	0	0
89.975	0.0583	0	1	1	1	2	1	20	0	0
90.28	0.0583	0	1	1	1	2	1	20	0	0
90.585	0.0583	0	1	1	1	2	1	20	0	0
90.89	0.0583	0	1	1	1	2	1	20	0	0
91.195	0.0583	0	1	1	1	2	1	20	0	0
91.5	0.0583	0	1	1	1	2	1	20	0	0
91.805	0.0583	0	1	1	1	2	1	20	0	0
92.11	0.0583	0	1	1	1	2	1	20	0	0
92.415	0.0583	0	1	1	1	2	1	20	0	0
92.72	0.0583	0	1	1	1	2	1	20	0	0
93.025	0.0583	0	1	1	1	2	1	20	0	0
93.33	0.0583	0	1	1	1	2	1	20	0	0
93.635	0.0583	0	1	1	1	2	1	20	0	0
93.94	0.0583	0	1	1	1	2	1	20	0	0
94.245	0.0583	0	1	1	1	2	1	20	0	0
94.55	0.0583	0	1	1	1	2	1	20	0	0
94.855	0.0583	0	1	1	1	2	1	20	0	0
95.16	0.0583	0	1	1	1	2	1	20	0	0
95.465	0.0583	0	1	1	1	2	1	20	0	0
95.77	0.0583	0	1	1	1	2	1	20	0	0
96.075	0.0583	0	1	1	1	2	1	20	0	0
96.38	0.0583	0	1	1	1	2	1	20	0	0
96.685	0.0583	0	1	1	1	2	1	20	0	0
96.99	0.0583	0	1	1	1	2	1	20	0	0
97.295	0.0583	0	1	1	1	2	1	20	0	0
97.6	0.0583	0	1	1	1	2	1	20	0	0
97.905	0.0583	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
98.21	0.0583	0	1	1	1	2	1	20	0	0
98.515	0.0583	0	1	1	1	2	1	20	0	0
98.82	0.0583	0	1	1	1	2	1	20	0	0
99.125	0.0583	0	1	1	1	2	1	20	0	0
99.43	0.0583	0	1	1	1	2	1	20	0	0
99.735	0.0583	0	1	1	1	2	1	20	0	0
100.04	0.0583	0	1	1	1	2	1	20	0	0
100.345	0.0583	0	1	1	1	2	1	20	0	0
100.65	0.0583	0	1	1	1	2	1	20	0	0
100.955	0.0583	0	1	1	1	2	1	20	0	0
101.26	0.0583	0	1	1	1	2	1	20	0	0
101.565	0.0583	0	1	1	1	2	1	20	0	0
101.87	0.0583	0	1	1	1	2	1	20	0	0
102.175	0.0583	0	1	1	1	2	1	20	0	0
102.48	0.0583	0	1	1	1	2	1	20	0	0
102.785	0.0583	0	1	1	1	2	1	20	0	0
103.09	0.0583	0	1	1	1	2	1	20	0	0
103.395	0.0583	0	1	1	1	2	1	20	0	0
103.7	0.0583	0	1	1	1	2	1	20	0	0
104.005	0.0583	0	1	1	1	2	1	20	0	0
104.31	0.0583	0	1	1	1	2	1	20	0	0
104.615	0.0583	0	1	1	1	2	1	20	0	0
104.92	0.0583	0	1	1	1	2	1	20	0	0
105.225	0.0583	0	1	1	1	2	1	20	0	0
105.53	0.0583	0	1	1	1	2	1	20	0	0
105.835	0.0583	0	1	1	1	2	1	20	0	0
106.14	0.0583	0	1	1	1	2	1	20	0	0
106.445	0.0583	0	1	1	1	2	1	20	0	0
106.75	0.0582	0	1	1	1	2	1	20	0	0
107.055	0.0582	0	1	1	1	2	1	20	0	0
107.36	0.0582	0	1	1	1	2	1	20	0	0
107.665	0.0582	0	1	1	1	2	1	20	0	0
107.97	0.0582	0	1	1	1	2	1	20	0	0
108.275	0.0582	0	1	1	1	2	1	20	0	0
108.58	0.0582	0	1	1	1	2	1	20	0	0
108.885	0.0582	0	1	1	1	2	1	20	0	0
109.19	0.0582	0	1	1	1	2	1	20	0	0
109.495	0.0582	0	1	1	1	2	1	20	0	0
109.8	0.0582	0	1	1	1	2	1	20	0	0
110.105	0.0582	0	1	1	1	2	1	20	0	0
110.41	0.0582	0	1	1	1	2	1	20	0	0
110.715	0.0582	0	1	1	1	2	1	20	0	0
111.02	0.0582	0	1	1	1	2	1	20	0	0
111.325	0.0582	0	1	1	1	2	1	20	0	0
111.63	0.0582	0	1	1	1	2	1	20	0	0
111.935	0.0582	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
112.24	0.0582	0	1	1	1	2	1	20	0	0
112.545	0.0582	0	1	1	1	2	1	20	0	0
112.85	0.0582	0	1	1	1	2	1	20	0	0
113.155	0.0582	0	1	1	1	2	1	20	0	0
113.46	0.0582	0	1	1	1	2	1	20	0	0
113.765	0.0582	0	1	1	1	2	1	20	0	0
114.07	0.0582	0	1	1	1	2	1	20	0	0
114.375	0.0582	0	1	1	1	2	1	20	0	0
114.68	0.0582	0	1	1	1	2	1	20	0	0
114.985	0.0582	0	1	1	1	2	1	20	0	0
115.29	0.0582	0	1	1	1	2	1	20	0	0
115.595	0.0582	0	1	1	1	2	1	20	0	0
115.9	0.0582	0	1	1	1	2	1	20	0	0
116.205	0.0582	0	1	1	1	2	1	20	0	0
116.51	0.0582	0	1	1	1	2	1	20	0	0
116.815	0.0582	0	1	1	1	2	1	20	0	0
117.12	0.0582	0	1	1	1	2	1	20	0	0
117.425	0.0582	0	1	1	1	2	1	20	0	0
117.73	0.0582	0	1	1	1	2	1	20	0	0
118.035	0.0582	0	1	1	1	2	1	20	0	0
118.34	0.0582	0	1	1	1	2	1	20	0	0
118.645	0.0582	0	1	1	1	2	1	20	0	0
118.95	0.0582	0	1	1	1	2	1	20	0	0
119.255	0.0582	0	1	1	1	2	1	20	0	0
119.56	0.0582	0	1	1	1	2	1	20	0	0
119.865	0.0582	0	1	1	1	2	1	20	0	0
120.17	0.0582	0	1	1	1	2	1	20	0	0
120.475	0.0582	0	1	1	1	2	1	20	0	0
120.78	0.0582	0	1	1	1	2	1	20	0	0
121.085	0.0582	0	1	1	1	2	1	20	0	0
121.39	0.0582	0	1	1	1	2	1	20	0	0
121.695	0.0582	0	1	1	1	2	1	20	0	0
122	0.0582	0	1	1	1	2	1	20	0	0
122.305	0.0582	0	1	1	1	2	1	20	0	0
122.61	0.0582	0	1	1	1	2	1	20	0	0
122.915	0.0582	0	1	1	1	2	1	20	0	0
123.22	0.0582	0	1	1	1	2	1	20	0	0
123.525	0.0582	0	1	1	1	2	1	20	0	0
123.83	0.0582	0	1	1	1	2	1	20	0	0
124.135	0.0582	0	1	1	1	2	1	20	0	0
124.44	0.0582	0	1	1	1	2	1	20	0	0
124.745	0.0582	0	1	1	1	2	1	20	0	0
125.05	0.0582	0	1	1	1	2	1	20	0	0
125.355	0.0582	0	1	1	1	2	1	20	0	0
125.66	0.0582	0	1	1	1	2	1	20	0	0
125.965	0.0582	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
126.27	0.0582	0	1	1	1	2	1	20	0	0
126.575	0.0582	0	1	1	1	2	1	20	0	0
126.88	0.0582	0	1	1	1	2	1	20	0	0
127.185	0.0582	0	1	1	1	2	1	20	0	0
127.49	0.0582	0	1	1	1	2	1	20	0	0
127.795	0.0582	0	1	1	1	2	1	20	0	0
128.1	0.0582	0	1	1	1	2	1	20	0	0
128.405	0.0582	0	1	1	1	2	1	20	0	0
128.71	0.0582	0	1	1	1	2	1	20	0	0
129.015	0.0582	0	1	1	1	2	1	20	0	0
129.32	0.0582	0	1	1	1	2	1	20	0	0
129.625	0.0582	0	1	1	1	2	1	20	0	0
129.93	0.0582	0	1	1	1	2	1	20	0	0
130.235	0.0582	0	1	1	1	2	1	20	0	0
130.54	0.0582	0	1	1	1	2	1	20	0	0
130.845	0.0582	0	1	1	1	2	1	20	0	0
131.15	0.0582	0	1	1	1	2	1	20	0	0
131.455	0.0582	0	1	1	1	2	1	20	0	0
131.76	0.0582	0	1	1	1	2	1	20	0	0
132.065	0.0582	0	1	1	1	2	1	20	0	0
132.37	0.0582	0	1	1	1	2	1	20	0	0
132.675	0.0582	0	1	1	1	2	1	20	0	0
132.98	0.0582	0	1	1	1	2	1	20	0	0
133.285	0.0582	0	1	1	1	2	1	20	0	0
133.59	0.0582	0	1	1	1	2	1	20	0	0
133.895	0.0582	0	1	1	1	2	1	20	0	0
134.2	0.0582	0	1	1	1	2	1	20	0	0
134.505	0.0582	0	1	1	1	2	1	20	0	0
134.81	0.0582	0	1	1	1	2	1	20	0	0
135.115	0.0582	0	1	1	1	2	1	20	0	0
135.42	0.0582	0	1	1	1	2	1	20	0	0
135.725	0.0582	0	1	1	1	2	1	20	0	0
136.03	0.0582	0	1	1	1	2	1	20	0	0
136.335	0.0582	0	1	1	1	2	1	20	0	0
136.64	0.0582	0	1	1	1	2	1	20	0	0
136.945	0.0582	0	1	1	1	2	1	20	0	0
137.25	0.0582	0	1	1	1	2	1	20	0	0
137.555	0.0582	0	1	1	1	2	1	20	0	0
137.86	0.0582	0	1	1	1	2	1	20	0	0
138.165	0.0582	0	1	1	1	2	1	20	0	0
138.47	0.0582	0	1	1	1	2	1	20	0	0
138.775	0.0582	0	1	1	1	2	1	20	0	0
139.08	0.0582	0	1	1	1	2	1	20	0	0
139.385	0.0582	0	1	1	1	2	1	20	0	0
139.69	0.0582	0	1	1	1	2	1	20	0	0
139.995	0.0582	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
140.3	0.0582	0	1	1	1	2	1	20	0	0
140.605	0.0582	0	1	1	1	2	1	20	0	0
140.91	0.0582	0	1	1	1	2	1	20	0	0
141.215	0.0582	0	1	1	1	2	1	20	0	0
141.52	0.0582	0	1	1	1	2	1	20	0	0
141.825	0.0582	0	1	1	1	2	1	20	0	0
142.13	0.0582	0	1	1	1	2	1	20	0	0
142.435	0.0582	0	1	1	1	2	1	20	0	0
142.74	0.0582	0	1	1	1	2	1	20	0	0
143.045	0.0582	0	1	1	1	2	1	20	0	0
143.35	0.0582	0	1	1	1	2	1	20	0	0
143.655	0.0582	0	1	1	1	2	1	20	0	0
143.96	0.0582	0	1	1	1	2	1	20	0	0
144.265	0.0582	0	1	1	1	2	1	20	0	0
144.57	0.0582	0	1	1	1	2	1	20	0	0
144.875	0.0582	0	1	1	1	2	1	20	0	0
145.18	0.0582	0	1	1	1	2	1	20	0	0
145.485	0.0582	0	1	1	1	2	1	20	0	0
145.79	0.0582	0	1	1	1	2	1	20	0	0
146.095	0.0582	0	1	1	1	2	1	20	0	0
146.4	0.0582	0	1	1	1	2	1	20	0	0
146.705	0.0582	0	1	1	1	2	1	20	0	0
147.01	0.0582	0	1	1	1	2	1	20	0	0
147.315	0.0582	0	1	1	1	2	1	20	0	0
147.62	0.0582	0	1	1	1	2	1	20	0	0
147.925	0.0582	0	1	1	1	2	1	20	0	0
148.23	0.0582	0	1	1	1	2	1	20	0	0
148.535	0.0582	0	1	1	1	2	1	20	0	0
148.84	0.0582	0	1	1	1	2	1	20	0	0
149.145	0.0582	0	1	1	1	2	1	20	0	0
149.45	0.0582	0	1	1	1	2	1	20	0	0
149.755	0.0582	0	1	1	1	2	1	20	0	0
150.06	0.0582	0	1	1	1	2	1	20	0	0
150.365	0.0582	0	1	1	1	2	1	20	0	0
150.67	0.0582	0	1	1	1	2	1	20	0	0
150.975	0.0582	0	1	1	1	2	1	20	0	0
151.28	0.0582	0	1	1	1	2	1	20	0	0
151.585	0.0582	0	1	1	1	2	1	20	0	0
151.89	0.0582	0	1	1	1	2	1	20	0	0
152.195	0.0582	0	1	1	1	2	1	20	0	0
152.5	0.0582	0	1	1	1	2	1	20	0	0
152.805	0.0582	0	1	1	1	2	1	20	0	0
153.11	0.0582	0	1	1	1	2	1	20	0	0
153.415	0.0582	0	1	1	1	2	1	20	0	0
153.72	0.0582	0	1	1	1	2	1	20	0	0
154.025	0.0582	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
154.33	0.0582	0	1	1	1	2	1	20	0	0
154.635	0.0582	0	1	1	1	2	1	20	0	0
154.94	0.0582	0	1	1	1	2	1	20	0	0
155.245	0.0582	0	1	1	1	2	1	20	0	0
155.55	0.0582	0	1	1	1	2	1	20	0	0
155.855	0.0582	0	1	1	1	2	1	20	0	0
156.16	0.0582	0	1	1	1	2	1	20	0	0
156.465	0.0582	0	1	1	1	2	1	20	0	0
156.77	0.0582	0	1	1	1	2	1	20	0	0
157.075	0.0582	0	1	1	1	2	1	20	0	0
157.38	0.0582	0	1	1	1	2	1	20	0	0
157.685	0.0582	0	1	1	1	2	1	20	0	0
157.99	0.0582	0	1	1	1	2	1	20	0	0
158.295	0.0582	0	1	1	1	2	1	20	0	0
158.6	0.0582	0	1	1	1	2	1	20	0	0
158.905	0.0582	0	1	1	1	2	1	20	0	0
159.21	0.0582	0	1	1	1	2	1	20	0	0
159.515	0.0582	0	1	1	1	2	1	20	0	0
159.82	0.0582	0	1	1	1	2	1	20	0	0
160.125	0.0582	0	1	1	1	2	1	20	0	0
160.43	0.0582	0	1	1	1	2	1	20	0	0
160.735	0.0582	0	1	1	1	2	1	20	0	0
161.04	0.0582	0	1	1	1	2	1	20	0	0
161.345	0.0582	0	1	1	1	2	1	20	0	0
161.65	0.0582	0	1	1	1	2	1	20	0	0
161.955	0.0582	0	1	1	1	2	1	20	0	0
162.26	0.0582	0	1	1	1	2	1	20	0	0
162.565	0.0582	0	1	1	1	2	1	20	0	0
162.87	0.0582	0	1	1	1	2	1	20	0	0
163.175	0.0582	0	1	1	1	2	1	20	0	0
163.48	0.0582	0	1	1	1	2	1	20	0	0
163.785	0.0582	0	1	1	1	2	1	20	0	0
164.09	0.0582	0	1	1	1	2	1	20	0	0
164.395	0.0582	0	1	1	1	2	1	20	0	0
164.7	0.0582	0	1	1	1	2	1	20	0	0
165.005	0.0582	0	1	1	1	2	1	20	0	0
165.31	0.0582	0	1	1	1	2	1	20	0	0
165.615	0.0582	0	1	1	1	2	1	20	0	0
165.92	0.0582	0	1	1	1	2	1	20	0	0
166.225	0.0582	0	1	1	1	2	1	20	0	0
166.53	0.0582	0	1	1	1	2	1	20	0	0
166.835	0.0582	0	1	1	1	2	1	20	0	0
167.14	0.0582	0	1	1	1	2	1	20	0	0
167.445	0.0582	0	1	1	1	2	1	20	0	0
167.75	0.0582	0	1	1	1	2	1	20	0	0
168.055	0.0582	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
168.36	0.0582	0	1	1	1	2	1	20	0	0
168.665	0.0582	0	1	1	1	2	1	20	0	0
168.97	0.0582	0	1	1	1	2	1	20	0	0
169.275	0.0582	0	1	1	1	2	1	20	0	0
169.58	0.0582	0	1	1	1	2	1	20	0	0
169.885	0.0582	0	1	1	1	2	1	20	0	0
170.19	0.0582	0	1	1	1	2	1	20	0	0
170.495	0.0582	0	1	1	1	2	1	20	0	0
170.8	0.0582	0	1	1	1	2	1	20	0	0
171.105	0.0582	0	1	1	1	2	1	20	0	0
171.41	0.0582	0	1	1	1	2	1	20	0	0
171.715	0.0582	0	1	1	1	2	1	20	0	0
172.02	0.0582	0	1	1	1	2	1	20	0	0
172.325	0.0582	0	1	1	1	2	1	20	0	0
172.63	0.0582	0	1	1	1	2	1	20	0	0
172.935	0.0582	0	1	1	1	2	1	20	0	0
173.24	0.0582	0	1	1	1	2	1	20	0	0
173.545	0.0582	0	1	1	1	2	1	20	0	0
173.85	0.0582	0	1	1	1	2	1	20	0	0
174.155	0.0582	0	1	1	1	2	1	20	0	0
174.46	0.0582	0	1	1	1	2	1	20	0	0
174.765	0.0582	0	1	1	1	2	1	20	0	0
175.07	0.0582	0	1	1	1	2	1	20	0	0
175.375	0.0582	0	1	1	1	2	1	20	0	0
175.68	0.0582	0	1	1	1	2	1	20	0	0
175.985	0.0582	0	1	1	1	2	1	20	0	0
176.29	0.0582	0	1	1	1	2	1	20	0	0
176.595	0.0582	0	1	1	1	2	1	20	0	0
176.9	0.0582	0	1	1	1	2	1	20	0	0
177.205	0.0582	0	1	1	1	2	1	20	0	0
177.51	0.0582	0	1	1	1	2	1	20	0	0
177.815	0.0582	0	1	1	1	2	1	20	0	0
178.12	0.0582	0	1	1	1	2	1	20	0	0
178.425	0.0582	0	1	1	1	2	1	20	0	0
178.73	0.0582	0	1	1	1	2	1	20	0	0
179.035	0.0582	0	1	1	1	2	1	20	0	0
179.34	0.0582	0	1	1	1	2	1	20	0	0
179.645	0.0582	0	1	1	1	2	1	20	0	0
179.95	0.0582	0	1	1	1	2	1	20	0	0
180.255	0.0582	0	1	1	1	2	1	20	0	0
180.56	0.0582	0	1	1	1	2	1	20	0	0
180.865	0.0582	0	1	1	1	2	1	20	0	0
181.17	0.0582	0	1	1	1	2	1	20	0	0
181.475	0.0582	0	1	1	1	2	1	20	0	0
181.78	0.0582	0	1	1	1	2	1	20	0	0
182.085	0.0582	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
182.39	0.0582	0	1	1	1	2	1	20	0	0
182.695	0.0582	0	1	1	1	2	1	20	0	0
183	0.0582	0	1	1	1	2	1	20	0	0
183.305	0.0582	0	1	1	1	2	1	20	0	0
183.61	0.0582	0	1	1	1	2	1	20	0	0
183.915	0.0582	0	1	1	1	2	1	20	0	0
184.22	0.0582	0	1	1	1	2	1	20	0	0
184.525	0.0582	0	1	1	1	2	1	20	0	0
184.83	0.0582	0	1	1	1	2	1	20	0	0
185.135	0.0582	0	1	1	1	2	1	20	0	0
185.44	0.0582	0	1	1	1	2	1	20	0	0
185.745	0.0582	0	1	1	1	2	1	20	0	0
186.05	0.0582	0	1	1	1	2	1	20	0	0
186.355	0.0582	0	1	1	1	2	1	20	0	0
186.66	0.0582	0	1	1	1	2	1	20	0	0
186.965	0.0582	0	1	1	1	2	1	20	0	0
187.27	0.0582	0	1	1	1	2	1	20	0	0
187.575	0.0582	0	1	1	1	2	1	20	0	0
187.88	0.0582	0	1	1	1	2	1	20	0	0
188.185	0.0582	0	1	1	1	2	1	20	0	0
188.49	0.0582	0	1	1	1	2	1	20	0	0
188.795	0.0582	0	1	1	1	2	1	20	0	0
189.1	0.0582	0	1	1	1	2	1	20	0	0
189.405	0.0582	0	1	1	1	2	1	20	0	0
189.71	0.0582	0	1	1	1	2	1	20	0	0
190.015	0.0582	0	1	1	1	2	1	20	0	0
190.32	0.0582	0	1	1	1	2	1	20	0	0
190.625	0.0582	0	1	1	1	2	1	20	0	0
190.93	0.0582	0	1	1	1	2	1	20	0	0
191.235	0.0582	0	1	1	1	2	1	20	0	0
191.54	0.0582	0	1	1	1	2	1	20	0	0
191.845	0.0582	0	1	1	1	2	1	20	0	0
192.15	0.0582	0	1	1	1	2	1	20	0	0
192.455	0.0582	0	1	1	1	2	1	20	0	0
192.76	0.0582	0	1	1	1	2	1	20	0	0
193.065	0.0582	0	1	1	1	2	1	20	0	0
193.37	0.0582	0	1	1	1	2	1	20	0	0
193.675	0.0582	0	1	1	1	2	1	20	0	0
193.98	0.0583	0	1	1	1	2	1	20	0	0
194.285	0.0583	0	1	1	1	2	1	20	0	0
194.59	0.0583	0	1	1	1	2	1	20	0	0
194.895	0.0583	0	1	1	1	2	1	20	0	0
195.2	0.0583	0	1	1	1	2	1	20	0	0
195.505	0.0583	0	1	1	1	2	1	20	0	0
195.81	0.0583	0	1	1	1	2	1	20	0	0
196.115	0.0583	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
196.42	0.0583	0	1	1	1	2	1	20	0	0
196.725	0.0583	0	1	1	1	2	1	20	0	0
197.03	0.0583	0	1	1	1	2	1	20	0	0
197.335	0.0583	0	1	1	1	2	1	20	0	0
197.64	0.0583	0	1	1	1	2	1	20	0	0
197.945	0.0583	0	1	1	1	2	1	20	0	0
198.25	0.0583	0	1	1	1	2	1	20	0	0
198.555	0.0583	0	1	1	1	2	1	20	0	0
198.86	0.0583	0	1	1	1	2	1	20	0	0
199.165	0.0583	0	1	1	1	2	1	20	0	0
199.47	0.0583	0	1	1	1	2	1	20	0	0
199.775	0.0583	0	1	1	1	2	1	20	0	0
200.08	0.0583	0	1	1	1	2	1	20	0	0
200.385	0.0583	0	1	1	1	2	1	20	0	0
200.69	0.0583	0	1	1	1	2	1	20	0	0
200.995	0.0583	0	1	1	1	2	1	20	0	0
201.3	0.0583	0	1	1	1	2	1	20	0	0
201.605	0.0583	0	1	1	1	2	1	20	0	0
201.91	0.0583	0	1	1	1	2	1	20	0	0
202.215	0.0583	0	1	1	1	2	1	20	0	0
202.52	0.0583	0	1	1	1	2	1	20	0	0
202.825	0.0583	0	1	1	1	2	1	20	0	0
203.13	0.0583	0	1	1	1	2	1	20	0	0
203.435	0.0583	0	1	1	1	2	1	20	0	0
203.74	0.0583	0	1	1	1	2	1	20	0	0
204.045	0.0583	0	1	1	1	2	1	20	0	0
204.35	0.0583	0	1	1	1	2	1	20	0	0
204.655	0.0583	0	1	1	1	2	1	20	0	0
204.96	0.0583	0	1	1	1	2	1	20	0	0
205.265	0.0584	0	1	1	1	2	1	20	0	0
205.57	0.0584	0	1	1	1	2	1	20	0	0
205.875	0.0584	0	1	1	1	2	1	20	0	0
206.18	0.0584	0	1	1	1	2	1	20	0	0
206.485	0.0584	0	1	1	1	2	1	20	0	0
206.79	0.0584	0	1	1	1	2	1	20	0	0
207.095	0.0584	0	1	1	1	2	1	20	0	0
207.4	0.0584	0	1	1	1	2	1	20	0	0
207.705	0.0584	0	1	1	1	2	1	20	0	0
208.01	0.0584	0	1	1	1	2	1	20	0	0
208.315	0.0584	0	1	1	1	2	1	20	0	0
208.62	0.0585	0	1	1	1	2	1	20	0	0
208.925	0.0585	0	1	1	1	2	1	20	0	0
209.23	0.0585	0	1	1	1	2	1	20	0	0
209.535	0.0585	0	1	1	1	2	1	20	0	0
209.84	0.0585	0	1	1	1	2	1	20	0	0
210.145	0.0585	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
210.45	0.0585	0	1	1	1	2	1	20	0	0
210.755	0.0586	0	1	1	1	2	1	20	0	0
211.06	0.0586	0	1	1	1	2	1	20	0	0
211.365	0.0586	0	1	1	1	2	1	20	0	0
211.67	0.0586	0	1	1	1	2	1	20	0	0
211.975	0.0586	0	1	1	1	2	1	20	0	0
212.28	0.0587	0	1	1	1	2	1	20	0	0
212.585	0.0587	0	1	1	1	2	1	20	0	0
212.89	0.0587	0	1	1	1	2	1	20	0	0
213.195	0.0587	0	1	1	1	2	1	20	0	0
213.5	0.0587	0	1	1	1	2	1	20	0	0
213.805	0.0588	0	1	1	1	2	1	20	0	0
214.11	0.0588	0	1	1	1	2	1	20	0	0
214.415	0.0588	0	1	1	1	2	1	20	0	0
214.72	0.0588	0	1	1	1	2	1	20	0	0
215.025	0.0589	0	1	1	1	2	1	20	0	0
215.33	0.0589	0	1	1	1	2	1	20	0	0
215.635	0.0589	0	1	1	1	2	1	20	0	0
215.94	0.0589	0	1	1	1	2	1	20	0	0
216.245	0.059	0	1	1	1	2	1	20	0	0
216.55	0.059	0	1	1	1	2	1	20	0	0
216.855	0.059	0	1	1	1	2	1	20	0	0
217.16	0.0591	0	1	1	1	2	1	20	0	0
217.465	0.0591	0	1	1	1	2	1	20	0	0
217.77	0.0591	0	1	1	1	2	1	20	0	0
218.075	0.0592	0	1	1	1	2	1	20	0	0
218.38	0.0592	0	1	1	1	2	1	20	0	0
218.685	0.0592	0	1	1	1	2	1	20	0	0
218.99	0.0593	0	1	1	1	2	1	20	0	0
219.295	0.0593	0	1	1	1	2	1	20	0	0
219.6	0.0593	0	1	1	1	2	1	20	0	0
219.905	0.0594	0	1	1	1	2	1	20	0	0
220.21	0.0594	0	1	1	1	2	1	20	0	0
220.515	0.0595	0	1	1	1	2	1	20	0	0
220.82	0.0595	0	1	1	1	2	1	20	0	0
221.125	0.0595	0	1	1	1	2	1	20	0	0
221.43	0.0596	0	1	1	1	2	1	20	0	0
221.735	0.0596	0	1	1	1	2	1	20	0	0
222.04	0.0596	0	1	1	1	2	1	20	0	0
222.345	0.0597	0	1	1	1	2	1	20	0	0
222.65	0.0597	0	1	1	1	2	1	20	0	0
222.955	0.0598	0	1	1	1	2	1	20	0	0
223.26	0.0598	0	1	1	1	2	1	20	0	0
223.565	0.0599	0	1	1	1	2	1	20	0	0
223.87	0.0599	0	1	1	1	2	1	20	0	0
224.175	0.0599	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
224.48	0.06	0	1	1	1	2	1	20	0	0
224.785	0.06	0	1	1	1	2	1	20	0	0
225.09	0.0601	0	1	1	1	2	1	20	0	0
225.395	0.0601	0	1	1	1	2	1	20	0	0
225.7	0.0602	0	1	1	1	2	1	20	0	0
226.005	0.0602	0	1	1	1	2	1	20	0	0
226.31	0.0602	0	1	1	1	2	1	20	0	0
226.615	0.0603	0	1	1	1	2	1	20	0	0
226.92	0.0603	0	1	1	1	2	1	20	0	0
227.225	0.0604	0	1	1	1	2	1	20	0	0
227.53	0.0604	0	1	1	1	2	1	20	0	0
227.835	0.0605	0	1	1	1	2	1	20	0	0
228.14	0.0605	0	1	1	1	2	1	20	0	0
228.445	0.0606	0	1	1	1	2	1	20	0	0
228.75	0.0606	0	1	1	1	2	1	20	0	0
229.055	0.0607	0	1	1	1	2	1	20	0	0
229.36	0.0607	0	1	1	1	2	1	20	0	0
229.665	0.0609	0	1	1	1	2	1	20	0	0
229.97	0.061	0	1	1	1	2	1	20	0	0
230.275	0.0611	0	1	1	1	2	1	20	0	0
230.58	0.0612	0	1	1	1	2	1	20	0	0
230.885	0.0614	0	1	1	1	2	1	20	0	0
231.19	0.0615	0	1	1	1	2	1	20	0	0
231.495	0.0616	0	1	1	1	2	1	20	0	0
231.8	0.0618	0	1	1	1	2	1	20	0	0
232.105	0.0619	0	1	1	1	2	1	20	0	0
232.41	0.062	0	1	1	1	2	1	20	0	0
232.715	0.0621	0	1	1	1	2	1	20	0	0
233.02	0.0623	0	1	1	1	2	1	20	0	0
233.325	0.0624	0	1	1	1	2	1	20	0	0
233.63	0.0625	0	1	1	1	2	1	20	0	0
233.935	0.0627	0	1	1	1	2	1	20	0	0
234.24	0.0628	0	1	1	1	2	1	20	0	0
234.545	0.0629	0	1	1	1	2	1	20	0	0
234.85	0.0631	0	1	1	1	2	1	20	0	0
235.155	0.0632	0	1	1	1	2	1	20	0	0
235.46	0.0633	0	1	1	1	2	1	20	0	0
235.765	0.0635	0	1	1	1	2	1	20	0	0
236.07	0.0636	0	1	1	1	2	1	20	0	0
236.375	0.0637	0	1	1	1	2	1	20	0	0
236.68	0.0638	0	1	1	1	2	1	20	0	0
236.985	0.064	0	1	1	1	2	1	20	0	0
237.29	0.0641	0	1	1	1	2	1	20	0	0
237.595	0.0642	0	1	1	1	2	1	20	0	0
237.9	0.0644	0	1	1	1	2	1	20	0	0
238.205	0.0645	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
238.51	0.0646	0	1	1	1	2	1	20	0	0
238.815	0.0648	0	1	1	1	2	1	20	0	0
239.12	0.0649	0	1	1	1	2	1	20	0	0
239.425	0.065	0	1	1	1	2	1	20	0	0
239.73	0.0652	0	1	1	1	2	1	20	0	0
240.035	0.0653	0	1	1	1	2	1	20	0	0
240.34	0.0654	0	1	1	1	2	1	20	0	0
240.645	0.0656	0	1	1	1	2	1	20	0	0
240.95	0.0657	0	1	1	1	2	1	20	0	0
241.255	0.0658	0	1	1	1	2	1	20	0	0
241.56	0.066	0	1	1	1	2	1	20	0	0
241.865	0.0661	0	1	1	1	2	1	20	0	0
242.17	0.0662	0	1	1	1	2	1	20	0	0
242.475	0.0664	0	1	1	1	2	1	20	0	0
242.78	0.0665	0	1	1	1	2	1	20	0	0
243.085	0.0666	0	1	1	1	2	1	20	0	0
243.39	0.0668	0	1	1	1	2	1	20	0	0
243.695	0.0669	0	1	1	1	2	1	20	0	0
244	0.067	0	1	1	1	2	1	20	0	0
244.305	0.0672	0	1	1	1	2	1	20	0	0
244.61	0.0673	0	1	1	1	2	1	20	0	0
244.915	0.0674	0	1	1	1	2	1	20	0	0
245.22	0.0677	0	1	1	1	2	1	20	0	0
245.525	0.068	0	1	1	1	2	1	20	0	0
245.83	0.0683	0	1	1	1	2	1	20	0	0
246.135	0.0687	0	1	1	1	2	1	20	0	0
246.44	0.069	0	1	1	1	2	1	20	0	0
246.745	0.0693	0	1	1	1	2	1	20	0	0
247.05	0.0697	0	1	1	1	2	1	20	0	0
247.355	0.07	0	1	1	1	2	1	20	0	0
247.66	0.0703	0	1	1	1	2	1	20	0	0
247.965	0.0707	0	1	1	1	2	1	20	0	0
248.27	0.071	0	1	1	1	2	1	20	0	0
248.575	0.0713	0	1	1	1	2	1	20	0	0
248.88	0.0717	0	1	1	1	2	1	20	0	0
249.185	0.072	0	1	1	1	2	1	20	0	0
249.49	0.0724	0	1	1	1	2	1	20	0	0
249.795	0.0727	0	1	1	1	2	1	20	0	0
250.1	0.073	0	1	1	1	2	1	20	0	0
250.405	0.0734	0	1	1	1	2	1	20	0	0
250.71	0.0737	0	1	1	1	2	1	20	0	0
251.015	0.074	0	1	1	1	2	1	20	0	0
251.32	0.0744	0	1	1	1	2	1	20	0	0
251.625	0.0747	0	1	1	1	2	1	20	0	0
251.93	0.075	0	1	1	1	2	1	20	0	0
252.235	0.0754	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
252.54	0.0757	0	1	1	1	2	1	20	0	0
252.845	0.076	0	1	1	1	2	1	20	0	0
253.15	0.0764	0	1	1	1	2	1	20	0	0
253.455	0.0767	0	1	1	1	2	1	20	0	0
253.76	0.077	0	1	1	1	2	1	20	0	0
254.065	0.0774	0	1	1	1	2	1	20	0	0
254.37	0.0777	0	1	1	1	2	1	20	0	0
254.675	0.078	0	1	1	1	2	1	20	0	0
254.98	0.0784	0	1	1	1	2	1	20	0	0
255.285	0.0787	0	1	1	1	2	1	20	0	0
255.59	0.079	0	1	1	1	2	1	20	0	0
255.895	0.0794	0	1	1	1	2	1	20	0	0
256.2	0.0797	0	1	1	1	2	1	20	0	0
256.505	0.0801	0	1	1	1	2	1	20	0	0
256.81	0.0804	0	1	1	1	2	1	20	0	0
257.115	0.0807	0	1	1	1	2	1	20	0	0
257.42	0.0811	0	1	1	1	2	1	20	0	0
257.725	0.0818	0	1	1	1	2	1	20	0	0
258.03	0.0826	0	1	1	1	2	1	20	0	0
258.335	0.0834	0	1	1	1	2	1	20	0	0
258.64	0.0842	0	1	1	1	2	1	20	0	0
258.945	0.085	0	1	1	1	2	1	20	0	0
259.25	0.0858	0	1	1	1	2	1	20	0	0
259.555	0.0866	0	1	1	1	2	1	20	0	0
259.86	0.0874	0	1	1	1	2	1	20	0	0
260.165	0.0882	0	1	1	1	2	1	20	0	0
260.47	0.089	0	1	1	1	2	1	20	0	0
260.775	0.0898	0	1	1	1	2	1	20	0	0
261.08	0.0906	0	1	1	1	2	1	20	0	0
261.385	0.0914	0	1	1	1	2	1	20	0	0
261.69	0.0922	0	1	1	1	2	1	20	0	0
261.995	0.0931	0	1	1	1	2	1	20	0	0
262.3	0.0939	0	1	1	1	2	1	20	0	0
262.605	0.0947	0	1	1	1	2	1	20	0	0
262.91	0.0955	0	1	1	1	2	1	20	0	0
263.215	0.0963	0	1	1	1	2	1	20	0	0
263.52	0.0971	0	1	1	1	2	1	20	0	0
263.825	0.0979	0	1	1	1	2	1	20	0	0
264.13	0.0987	0	1	1	1	2	1	20	0	0
264.435	0.0995	0	1	1	1	2	1	20	0	0
264.74	0.1003	0	1	1	1	2	1	20	0	0
265.045	0.1011	0	1	1	1	2	1	20	0	0
265.35	0.1019	0	1	1	1	2	1	20	0	0
265.655	0.1027	0	1	1	1	2	1	20	0	0
265.96	0.1035	0	1	1	1	2	1	20	0	0
266.265	0.1043	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
266.57	0.1052	0	1	1	1	2	1	20	0	0
266.875	0.106	0	1	1	1	2	1	20	0	0
267.18	0.1068	0	1	1	1	2	1	20	0	0
267.485	0.108	0	1	1	1	2	1	20	0	0
267.79	0.1097	0	1	1	1	2	1	20	0	0
268.095	0.1115	0	1	1	1	2	1	20	0	0
268.4	0.1132	0	1	1	1	2	1	20	0	0
268.705	0.115	0	1	1	1	2	1	20	0	0
269.01	0.1167	0	1	1	1	2	1	20	0	0
269.315	0.1184	0	1	1	1	2	1	20	0	0
269.62	0.1202	0	1	1	1	2	1	20	0	0
269.925	0.1219	0	1	1	1	2	1	20	0	0
270.23	0.1237	0	1	1	1	2	1	20	0	0
270.535	0.1254	0	1	1	1	2	1	20	0	0
270.84	0.1271	0	1	1	1	2	1	20	0	0
271.145	0.1289	0	1	1	1	2	1	20	0	0
271.45	0.1306	0	1	1	1	2	1	20	0	0
271.755	0.1324	0	1	1	1	2	1	20	0	0
272.06	0.1341	0	1	1	1	2	1	20	0	0
272.365	0.1359	0	1	1	1	2	1	20	0	0
272.67	0.1376	0	1	1	1	2	1	20	0	0
272.975	0.1393	0	1	1	1	2	1	20	0	0
273.28	0.1411	0	1	1	1	2	1	20	0	0
273.585	0.1428	0	1	1	1	2	1	20	0	0
273.89	0.1446	0	1	1	1	2	1	20	0	0
274.195	0.1463	0	1	1	1	2	1	20	0	0
274.5	0.1481	0	1	1	1	2	1	20	0	0
274.805	0.1498	0	1	1	1	2	1	20	0	0
275.11	0.1515	0	1	1	1	2	1	20	0	0
275.415	0.1543	0	1	1	1	2	1	20	0	0
275.72	0.1574	0	1	1	1	2	1	20	0	0
276.025	0.1604	0	1	1	1	2	1	20	0	0
276.33	0.1634	0	1	1	1	2	1	20	0	0
276.635	0.1664	0	1	1	1	2	1	20	0	0
276.94	0.1695	0	1	1	1	2	1	20	0	0
277.245	0.1725	0	1	1	1	2	1	20	0	0
277.55	0.1755	0	1	1	1	2	1	20	0	0
277.855	0.1785	0	1	1	1	2	1	20	0	0
278.16	0.1815	0	1	1	1	2	1	20	0	0
278.465	0.1846	0	1	1	1	2	1	20	0	0
278.77	0.1876	0	1	1	1	2	1	20	0	0
279.075	0.1906	0	1	1	1	2	1	20	0	0
279.38	0.1936	0	1	1	1	2	1	20	0	0
279.685	0.1967	0	1	1	1	2	1	20	0	0
279.99	0.1997	0	1	1	1	2	1	20	0	0
280.295	0.2027	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
280.6	0.2057	0	1	1	1	2	1	20	0	0
280.905	0.2088	0	1	1	1	2	1	20	0	0
281.21	0.2118	0	1	1	1	2	1	20	0	0
281.515	0.2152	0	1	1	1	2	1	20	0	0
281.82	0.219	0	1	1	1	2	1	20	0	0
282.125	0.2227	0	1	1	1	2	1	20	0	0
282.43	0.2265	0	1	1	1	2	1	20	0	0
282.735	0.2302	0	1	1	1	2	1	20	0	0
283.04	0.234	0	1	1	1	2	1	20	0	0
283.345	0.2377	0	1	1	1	2	1	20	0	0
283.65	0.2415	0	1	1	1	2	1	20	0	0
283.955	0.2452	0	1	1	1	2	1	20	0	0
284.26	0.249	0	1	1	1	2	1	20	0	0
284.565	0.2528	0	1	1	1	2	1	20	0	0
284.87	0.2565	0	1	1	1	2	1	20	0	0
285.175	0.2603	0	1	1	1	2	1	20	0	0
285.48	0.264	0	1	1	1	2	1	20	0	0
285.785	0.2678	0	1	1	1	2	1	20	0	0
286.09	0.2715	0	1	1	1	2	1	20	0	0
286.395	0.2751	0	1	1	1	2	1	20	0	0
286.7	0.2783	0	1	1	1	2	1	20	0	0
287.005	0.2815	0	1	1	1	2	1	20	0	0
287.31	0.2847	0	1	1	1	2	1	20	0	0
287.615	0.288	0	1	1	1	2	1	20	0	0
287.92	0.2912	0	1	1	1	2	1	20	0	0
288.225	0.2944	0	1	1	1	2	1	20	0	0
288.53	0.2976	0	1	1	1	2	1	20	0	0
288.835	0.3009	0	1	1	1	2	1	20	0	0
289.14	0.3041	0	1	1	1	2	1	20	0	0
289.445	0.3073	0	1	1	1	2	1	20	0	0
289.75	0.3106	0	1	1	1	2	1	20	0	0
290.055	0.3138	0	1	1	1	2	1	20	0	0
290.36	0.3162	0	1	1	1	2	1	20	0	0
290.665	0.3183	0	1	1	1	2	1	20	0	0
290.97	0.3204	0	1	1	1	2	1	20	0	0
291.275	0.3225	0	1	1	1	2	1	20	0	0
291.58	0.3246	0	1	1	1	2	1	20	0	0
291.885	0.3267	0	1	1	1	2	1	20	0	0
292.19	0.3287	0	1	1	1	2	1	20	0	0
292.495	0.3308	0	1	1	1	2	1	20	0	0
292.8	0.3329	0	1	1	1	2	1	20	0	0
293.105	0.335	0	1	1	1	2	1	20	0	0
293.41	0.3365	0	1	1	1	2	1	20	0	0
293.715	0.3377	0	1	1	1	2	1	20	0	0
294.02	0.3388	0	1	1	1	2	1	20	0	0
294.325	0.34	0	1	1	1	2	1	20	0	0

Base Case: Soil Profile with Initial Water Contents and Concentrations

z (cm)	Theta (cm3/cm3)	Root (1/cm)	Axz	Bxz	Dxz	Mat	Lay	Temp (c)	Conc - 1	Conc - 2
294.63	0.3411	0	1	1	1	2	1	20	0	0
294.935	0.3423	0	1	1	1	2	1	20	0	0
295.24	0.3434	0	1	1	1	2	1	20	0	0
295.545	0.3446	0	1	1	1	2	1	20	0	0
295.85	0.3454	0	1	1	1	2	1	20	0	0
296.155	0.346	0	1	1	1	2	1	20	0	0
296.46	0.3465	0	1	1	1	2	1	20	0	0
296.765	0.3471	0	1	1	1	2	1	20	0	0
297.07	0.3477	0	1	1	1	2	1	20	0	0
297.375	0.3483	0	1	1	1	2	1	20	0	0
297.68	0.3488	0	1	1	1	2	1	20	0	0
297.985	0.3491	0	1	1	1	2	1	20	0	0
298.29	0.3494	0	1	1	1	2	1	20	0	0
298.595	0.3497	0	1	1	1	2	1	20	0	0
298.9	0.35	0	1	1	1	2	1	20	0	0
299.205	0.3502	0	1	1	1	2	1	20	0	0
299.51	0.3504	0	1	1	1	2	1	20	0	0
299.815	0.3505	0	1	1	1	2	1	20	0	0
300.12	0.3506	0	1	1	1	2	1	20	0	0
300.425	0.3508	0	1	1	1	2	1	20	0	0
300.73	0.3508	0	1	1	1	2	1	20	0	0
301.035	0.3509	0	1	1	1	2	1	20	0	0
301.34	0.351	0	1	1	1	2	1	20	0	0
301.645	0.351	0	1	1	1	2	1	20	0	0
301.95	0.351	0	1	1	1	2	1	20	0	0
302.255	0.3511	0	1	1	1	2	1	20	0	0
302.56	0.3511	0	1	1	1	2	1	20	0	0
302.865	0.3511	0	1	1	1	2	1	20	0	0
303.17	0.3511	0	1	1	1	2	1	20	0	0
303.475	0.3511	0	1	1	1	2	1	20	0	0
303.78	0.3511	0	1	1	1	2	1	20	0	0
304.085	0.3511	0	1	1	1	2	1	20	0	0
304.39	0.3511	0	1	1	1	2	1	20	0	0
304.695	0.3511	0	1	1	1	2	1	20	0	0
305	0.3511	0	1	1	1	2	1	20	0	0

8. Appendix B: Groundwater Monitoring Well MW07 Installation Log

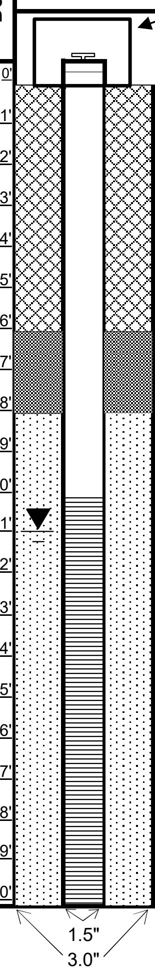
WELL COMPLETION LOG OF MONITORING WELL MW-7

Project: **Wekiva Nitate Study**
Project No: **6063-08-0128**
Drilling Contractor: **JAEE Environmental**
Driller: **Jason**
Installation Method: **Direct Push**
MACTEC Geologist: **Bill Waite**

Well ID: **MW-7**
Installation Date: **10/03/2008**
Location Address: **1525 Sunset View Cir.**
County: **Orange**
Latitude: **28.679028° N**
Longitude: **81.478232° W**

Depth	Lithologic Description	USCS Code	Moisture Content	Munsel Color Code
0'–2'	Sand; very fine to fine grained; organics; loose.	SW	Damp	10YR-4/2
2'–4'	Sand; very fine to fine grained; loose.	SW	Damp	10YR-6/3
4'–7'	Sand; very fine to fine grained; loose.	SW	Damp	2.5Y-8/3
7'–10'	Sand; very fine to fine grained; loose.	SW	Damp (to 9'); Wet (9'–11')	10YR-7/2
10'–14'	Sand; very fine to fine grained; loose.	SW	Wet (to 11'); Saturated	10YR-8/1
14'–16'	Sand; very fine to fine grained; loose.	SC	Saturated	10YR-6/3
16'–18'	Sand; very fine grained, some clay, soft.	SC	Saturated	10YR-5/2
18'–19'	Sand; very fine grained, some clay, soft.	SC	Saturated	10YR-6/3
19'–20'	Sand; very fine grained, some clay, soft.	SC	Saturated	10YR-6/3

Well Diagram



Well Construction Details

7-inch plastic manhole

Total Depth: 20 feet
Well Type: Pre-packed
Borehole Diameter: 3 inches
Well Diameter: 1.5 inches
Well Material: Schedule 40 PVC
Riser Length: 10 feet
Screen Length: 10 feet
Screen Slot Size: 0.01 inch
Filter Pack Material: 20/30 sand
Filter Pack length: 12 feet
Seal Material: Fine Sand
Seal Length: 2 feet
Grout Length: 6 feet

Well Development Data

Depth to Water: 10.8 feet
Method: Trash Pump
Duration: 20 minutes
Rate: 0.5 gpm
Volume: 10 gallons
Appearance Before: Light brown
Appearance After: Clear

= Cement Grout
= Fine Sand Seal
= 20/30 Sand Filter Pack

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9. Attachment A: Applied Ecology Memomrandum - Data Review and Compliation of Florida Fertilzier Application and Recommendation Data

Wekiva River BMAP/TMDL Support Final Memorandum

DATA REVIEW AND COMPILATION OF FLORIDA FERTILIZER APPLICATION AND RECOMMENDATION DATA (PO #C20906A022)

CLAUDIA LISTOPAD, PH.D., GISP

PREPARED FOR: DRUMMOND CARPENTER engineering + research

PREPARED BY: APPLIED ECOLOGY INC

October 3, 2021

CONTENTS

List of Figures

List of Tables

INTRODUCTION

Applied Ecology, Inc (AEI) was contracted by Drummond Carpenter, PLLC to compile, review, and synthesize relevant fertilizer application data associated with Florida urban areas in support of nitrogen modeling efforts to examine the impact of fertilizer usage on local water quality. The goal of this document is to also provide information for the further development or refinement of the Orange County fertilizer ordinance. This memo report provides the findings from the comparison of the Orange County Fertilizer Ordinance with the Florida Department of Environmental Protection (FDEP) Model Ordinance. A spatial estimate of nitrogen fertilizer applications across Orange County was generated through the interpretation of the National Land Cover Dataset (NLCD) Imperviousness product for 2016 and 2019. A brief review was performed of recent research and literature published on the topic of urban turfgrass nitrogen (N) fertilizers and their Best Management Practices (BMPs).

The review includes:

- Recommendations provided by UF-IFAS summarized for Central Florida;
- Recent literature summarized from academic journals on topics of turfgrass and fertilization research;
- Additional literature reviewed as it relates to the use of fertilizer at the household level.

ORANGE COUNTY FERTILIZER ORDINANCE REVIEW

In 2009 Orange County enacted the Article 17 - Fertilizer Management Ordinance which restricted the application of nitrogen fertilizers during the summer wet seasons (June 1st to September 30th) and year-round for phosphorus fertilizer. This ordinance was based on the 2008 FDEP Model Ordinance and focused on the application of fertilizer by private, non-commercial homeowners. Commercial applicators were required to acquire a county-approved BMP training, such as the FDACS urban landscape commercial fertilizer certification.

The most recent amendment to Article 17 was in 2017, which updated the language and clauses to reflect changes to the fertilizer management regulations at the state level. This included the requirement for commercial applicators to obtain specifically the Florida Department of Agriculture and Consumer Services (FDACS) certification or the Florida Department of Environmental Protection's (FDEP) Florida Friendly Best Management Practices for Protection of Water Resources by the Green Industries training by University of Florida Institute of Food and Agricultural Sciences.

There are several notable variations between the FDEP Model Ordinance and Article 17, a table of variations is provided in Appendix A. Within the definition of a Fertilizer, Article 17 specifically exempts the application of organic compost or biosolids from the ordinance. Orange County municipal code Sec 37-703 "Water and Wastewater" defines a biosolid as "… primarily organic solids that are produced by wastewater treatment processes; …". A key variation is in the exemption provided in Section 15-803 "Weather and seasonal restrictions", which allows for any applicator who completes county approved training to apply fertilizer during the restricted period. Section 15-809 "Training requirements; proof of compliance" has in addition to the commercial applicators training requirements a county managed training program for non-commercial applicators which would allow them to apply fertilizer during the restricted period.

ORANGE COUNTY PERVIOUSNESS ESTIMATED NITROGEN FERTILIZER APPLICATIONS

There are very limited data pertaining to the application of fertilizers at the finer spatial scales. The FDACS Fertilizer Licensing and Tonnage Reporting system has county level data, however it is not conducive to spatial analysis within the county due to intermittent reporting and uncertainties about the reporting of fertilizer purchased for turf care. The Fiscal Year 2012-2013 and 2019-2020 Fertilizer Licensing and Tonnage reports for Orange County are provided in Appendix C. The amount of nitrogen fertilizer applied to the urban areas of Orange County and its spatial variability was estimated based on the pervious surfaces and land use within the county. Estimated annual fertilizer application was based on the assumptions that fertilizers were only applied to urban land use types and that they were only applied to pervious surfaces within those land use types.

The Multi-Resolution Land Characteristics Consortium (www.mrlc.gov/) has generated the National Land Cover Dataset (NLCD) from Landsat imagery and other ancillary sources. Included with the NLCD is an estimated percent imperviousness raster layer. The years 2016 and 2019 were acquired and inverted into percent perviousness. As the NLCD provides only generalized urban land cover classifications, the University of Florida GeoPlan Center (www.fgdl.org/) annual Florida Department of Revenue parcel derived land use data to identify the residential, commercial, industrial, institutional, and golf course land covers. Using ESRI ArcMap, the percent pervious layers were then extracted by land use type and multiplied by the estimated pounds of N fertilizer applied per 1,000 square feet. The resulting value reflected the estimated pounds of N fertilizer applied to the percent of the pixel that was considered pervious. This method was unable to account for the portion of the land uses that had pervious covers other than turfgrass.

Two map series were created, the first assumes a uniform application of fertilizer across all land use types in the county with the rates 0.4, 3, and 6 pounds per 1,000 sqare feet per year. The second map series assumes that golf courses apply the most fertilizer (6 pounds N), followed by residential (3 pounds N), and then commercial/industrial/institutional (0.4 pounds N). The tons of estimated N fertilizer applied in Orange County between 2016 and 2019 decreased in the Uniform map series but had an increase with the Mixed Land Use series. Example maps from these series are shown in Figure 1 and Figure 2 with the remaining maps in Appendix B.

Table 1 – National Land Cover Dataset (NLCD) perviousness estimate of tons of Nitrogen fertilizer applied in Orange County for 2016 and 2019 by uniform applications to urban land use (0.4, 3.0, and 6.0 pounds N per 1,000 square feet per year) and the Mixed Land Use.

NLCD Year	0.4 lbs N	3.0 lbs N	6.0 lbs N	Mixed Land Use
2016	130.3	977.6	1,955.2	826.1
2019	126.0	945.2	1,890.4	884.1

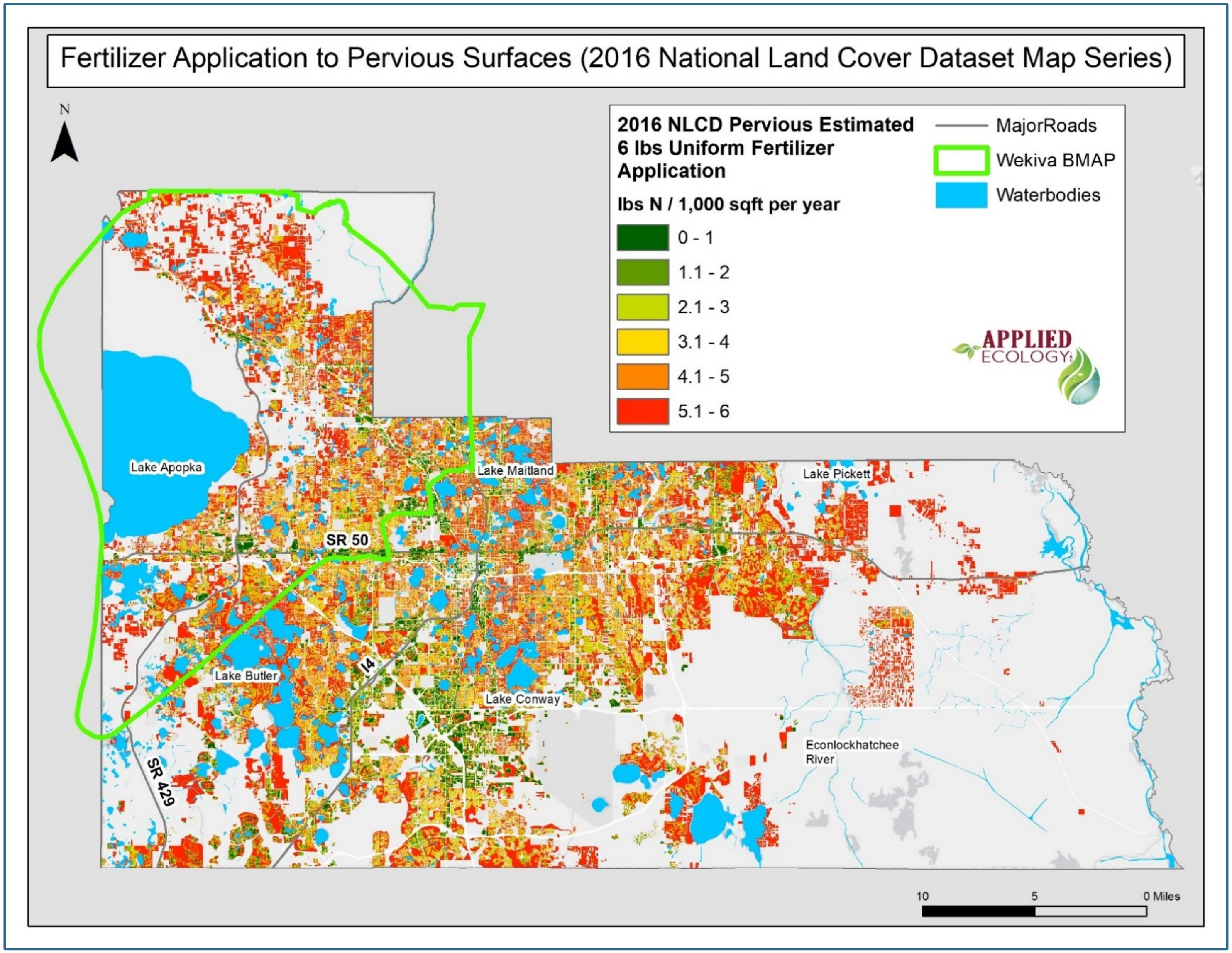

Figure 1 - 2016 National Land Cover Dataset (NLCD) pervious estimated uniform 6 pounds N per 1,000 square feet per year.

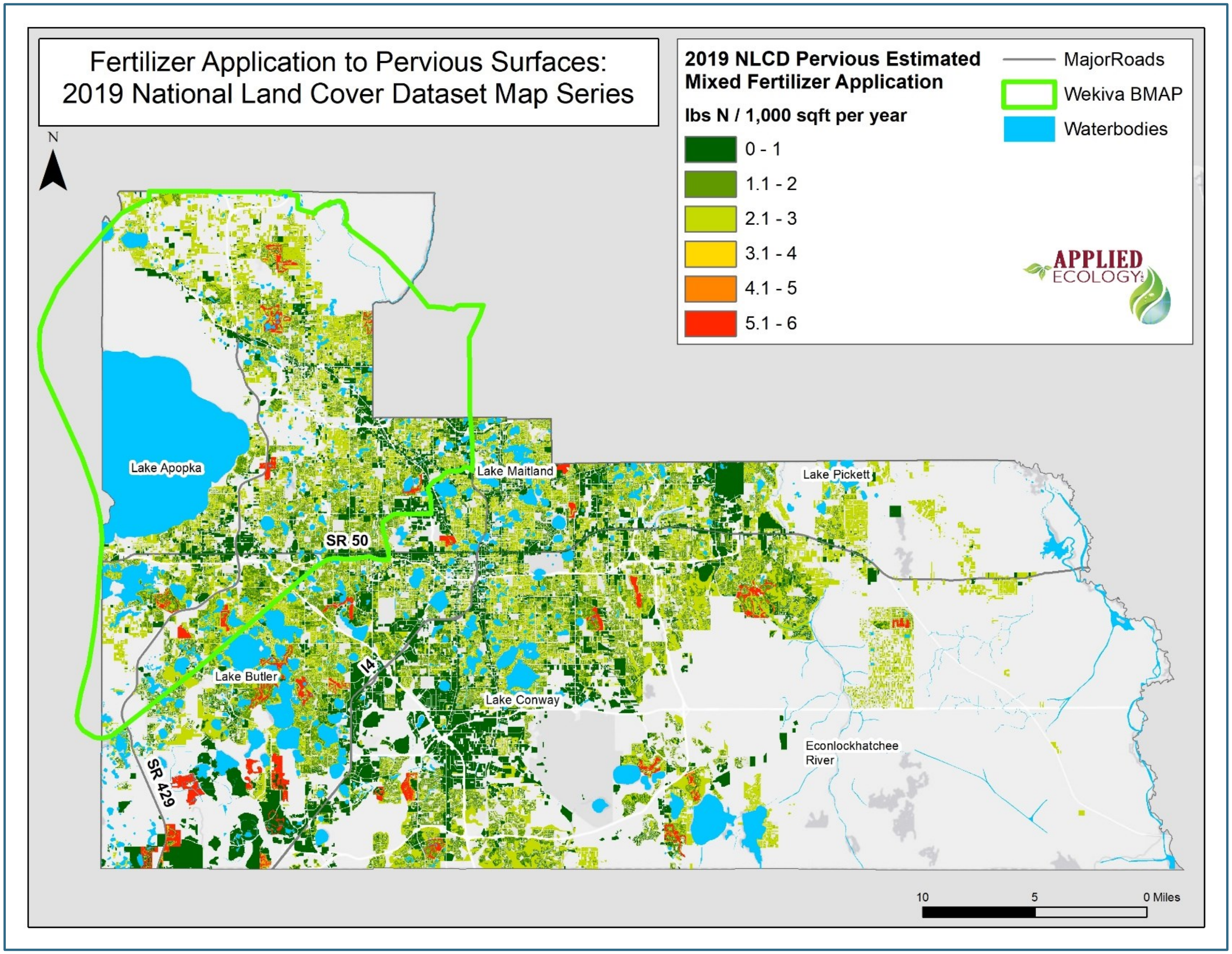

Figure 2 - 2019 National Land Cover Dataset (NLCD) pervious estimated land use type mixed N per 1,000 square feet per year.

FLORIDA NITROGEN FERTILIZER LITERATURE REVIEW

In the state of Florida, the sale of turfgrass fertilizer is regulated under Florida Administrative Code (FAC) 5E-1.003 (https://www.flrules.org/gateway/RuleNo.asp?id=5E-1.003). Initially approved in 1998, 5E-1.003 did not include fertilizer application rate recommendations. The regulation of the application of turfgrass fertilizer in the state of Florida fell under county or city jurisdiction. Following an effort in 2000 by St. Johns County to implement a wet season (May-October) fertilizer restriction, the Florida Department of Environmental Protection (FDEP) convened stakeholder meetings and published the first "Model Ordinance for Florida-Friendly Use of Fertilizer on Urban Landscapes" in 2003. This document was then updated in 2008, 2010, and 2015. As of 2019 over 100 wet season fertilizer restrictions (or "Blackout Periods") have been enacted at the county or city level in Florida (Ryan et al 2019).

In 2007, recommended turfgrass fertilizer application rates determined by the Florida Department of Agriculture and Consumer Services (FDACS) and the University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) were included in the 5E-1.003 rule. This code outlines the labeling requirements for bags of fertilizer sold at retail for use on "Urban Turf" and "Sports Turf". These retail labels are required to include a series of recommended fertilizer application rates for the region of Florida and species of turfgrass being fertilized. Starting in 2014, FDACS required commercial fertilizer applicators to be licensed and complete a Florida-Friendly Best Management for Protection of Water Resources by the Green Industries (GI-BMP) training.

UF-IFAS FERTILIZER RECOMMENDATIONS FOR TURFGRASS

UF-IFAS supports ongoing research on turfgrass BMPs and publishes recommendations for Florida through its Environmental Horticulture program. The primary means that UF-IFAS disseminates this information is through county-level Extension Service and Master Gardener Program. The Florida Friendly Landscaping (FFL) program (https://ffl.ifas.ufl.edu/) operates through the UF-IFAS Extension Service to provide outreach and additional resources on sustainable landscaping. FFL consists of the Florida Yards and Neighbors (FYN), Florida Friendly Community (FFC), and GI-BMP programs. Additionally, the "Ask IFAS" website (https://edis.ifas.ufl.edu/) provides a clearinghouse of information and includes the peer-reviewed Extension Data Information Source (EDIS) journal. With a recent Florida wide study (Khachatrayan et al. 2021) that identified that over 54% of 610 participants had majority turfgrass properties, the maintenance of turfgrass and dissemination of the knowledge is a pressing issue.

General Turfgrass Recommendations

In 2003, UF-IFAS published the ENH962/EP2210 "Figuring Out Fertilizer for the Home Lawn" (Trenholm & Unruh 2003) which included a set of recommendations for the use and application of nitrogen fertilizers for several species of Florida turfgrass. These recommendations included recommendations for fertilizer application such as use of high percentage slow-release fertilizers, application of ¼ inch of water to irrigate the applied fertilizer, avoid applying fertilizer before heavy rains, sweeping up of spilled fertilizer, and a 10-foot application setback from water bodies. It also provided specific ranges of pounds of N fertilizer to be applied per species of grass.

The fertilizer application ranges in ENH962 were updated in the 2008 ENH1089/EP353 "Urban Turf Fertilizer Rule for Home Lawn Fertilization" and again revised in 2018 (Table 2) to reflect the update to 5E-1.003 (Trenholm 2018a). Between the two sets of recommendations, the current recommended N fertilization rates for Bahiagrass, Centipededgrass, and Zoysiagrass were lowered. It was also recommended that no more than 2 pounds of 65% slow-release N per 1,000 square feet should be applied at any one time during the spring or summer and no more than 1 pound N per 1,000 square feet should be applied at any one time during the fall or winter. Additionally, no more than 0.7 pounds of quick release N per 1,000 square feet should be applied at any one time.

Table 2 - Current UF/IFAS recommendations for annual nitrogen fertilization rates based on species and location in state. Modified from ENH962/EP221.

Species/Location[a]	Nitrogen Recommendations (lbs 1000 ft yr)[b,c]
Bahiagrass - Central	1.0 – 3.0
Bermudagrass - Central	4.0 – 6.0
Centipedegrass - Central	0.4 – 3.0
St. Augustinegrass - Central	2.0 – 5.0
Zoysiagrass - Central	2.0 – 4.0

[a] **Central Florida from Ocala to State Road 60**

[b] **Homeowner preferences for lawn quality and maintenance level vary; therefore, we recommend a range of fertility rates for each grass and location. Additionally, effects within a localized region (i.e., microenvironmental influences such as shade, drought, soil conditions, and irrigation) necessitate that a range of fertility rates be used.**

[c] **These recommendations assume that grass clippings are recycled.**

Additional guidance on fertilizer application is provided in SL21/LH014 "General Recommendations for Fertilization of Turfgrass on Florida Soils" first published in 1991 and then updated in 2007, 2013, 2015, and 2017 (Shaddox 2017). This document provides reference information for determining a turfgrass fertilization program such as additional considerations in terms of what types of N fertilizers could be used and an example fertilization schedule (Table 3).

In the example fertilization schedule, three fertilization maintenance levels are listed: basic which will provide minimum quality turfgrass, moderate which will provide an intermediate quality turfgrass, and high which should produce an optimal quality turfgrass and not result in nitrogen leaching. Quality is described as color and growth characteristics. All these example plans call for the application of complete (contains nitrogen, phosphorus, and potassium) fertilizers before the summer wet season and then again in the fall. Quick-Release N is recommended to be applied to Bahiagrass and Bermudagrass in May. It also recommended that Bermudagrass and St. Augustinegrass have Slow-Release Nitrogen (SRN) applied during the summer. It is also recommended that iron fertilizer be applied during the summer if N fertilizers are not being applied to maintain the green color of the grass.

Table 3 - Fertilization guide for turfgrasses maintained without the benefit of a soil test. - Modified from SL21/LH014.*

Turfgrass	Maintenance Level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Central Florida													
Bahiagrass	Basic	--	--	C	--	N	--	--	--	C	--	--	--
	Moderate	--	--	C	--	N	--	Fe	--	--	C	--	--
	High	--	--	C	N	--	SRN	--	Fe	--	C	--	--
Bermudagrass	Basic	--	--	C	--	N	--	SRN	--	C	--	--	--
	Moderate	--	--	C	--	N	--	SRN	--	SRN	--	C	--
	High	--	--	C	N	SRN	--	C	Fe	SRN	--	C	--
Centipedegrass	Basic	--	--	C	--	SRN	--	--	--	--	--	--	--
	Moderate	--	--	C	--	SRN	--	--	Fe	--	--	--	--
	High	--	--	C	--	SRN	--	--	--	C	--	--	--
St. Augustinegrass	Basic	--	--	C	--	--	--	Fe	--	C	--	--	--
	Moderate	--	--	C	--	SRN	--	Fe	SRN	--	C	--	--
	High	--	C	--	N	SRN	--	Fe	SRN	--	C	--	--
Zoysiagrass	Basic	--	--	C	--	SRN	--	--	--	--	--	--	--
	Moderate	--	--	C	--	SRN	--	--	--	--	N	--	--
	High	--	--	C	--	SRN	--	--	--	--	C	--	--

C, N, SRN, and Fe identified in the following page.

Fertilization Guide Index

* This guide is for turfgrass fertilization under circumstances where a soil test does not exist. To properly apply the rate of P and K required, a soil test is required. It is recommended to always test soil.

C = Complete fertilizer (Contains N, P, K) applied at 1.0 lb N/1000 sq ft containing no more than 0.7 lb soluble N.

N = Soluble N applied at no more than 0.7 lb N/1000 sq ft.

SRN = Slow-release N applied at no more than 2.0 lb N/1000 sq ft. in the spring and summer only; no more than 1.0 lb N/1000 sq ft in the fall and winter.

Fe = Apply Fe to provide dark green color without stimulating excessive growth. For foliar application use ferrous sulfate (2 oz /3-5 gal water/1000 sq ft). If the Fe is applied to an acidic soil, use 1 lb of iron sulfate per 1000 sq ft. If the soil is calcareous, use the container label recommended rate of an iron chelate.

A comparison of "Organic and Inorganic" fertilizers is also provided in SL21/LH014, with a recommendation to use a combination of the two sources. Advantages and disadvantages are listed for the two types as well. The Organic fertilizer advantage is primarily being composed of slow-release N with the disadvantage being potentially more expensive to effectively use. Inorganic fertilizer advantages are being cost effective and easy to apply with the disadvantage being the risk of generating nutrient pollution from leaching. Specific types of organic and inorganic N fertilizer are provided along with their estimated percent N and recommended pounds needed to apply 0.7 pounds of N per 1,000 square feet (Table 4)

Table 4 - A guide to rate of fertilizer material to use on Florida turfgrass. Modified from SL21/LH014 (Shaddox 2017).

Nitrogen Fertilizers	% N	Pounds needed to supply 0.7 lb of actual N per 1000 sq ft
Soluble N Sources (Inorganic)		
Ammonium Nitrate	33.5	2
Ammonium Sulfate	21	3.3
Calcium Nitrate	15.5	4.5
Potassium Nitrate	13	5.3
Sodium Nitrate	16	4.4
Nitrate of Soda-Potash	15	4.6
Monoammonium Phosphate	11	6.4
Diammonium Phosphate	18	3.8
Soluble N Sources (Organic)		
Urea	46	1.5
Calcium Cyanamide	21	3.3
Slow Release N Sources (Synthetic) (Can apply up to 2.0 lb N/1000 sq ft)		
Urea Formaldehyde	38	5.3
Methylene Urea	40	5
Isobutylidene Diurea (IBDU)	31	6.4
Sulfur-coated Urea	38	5.3
Polymer-coated Urea	42	4.8
Slow Release N Sources (Natural Organics) (Can apply up to 2.0 lb N/1000 sq ft)		
Sewage Sludge	6	33
Cow Manure	2	100
Poultry Manure	4	50
Cottonseed Meal	7	29
Alfalfa Meal	6	33
Blood Meal	3	66
Processed Tankages	5-10 (varies)	40 to 20
Garbage Tankages	2-3 (varies)	100 to 66

The ENH979/EP236 "Homeowner Best Management Practices for the Home Lawn" was published in 2004 and then updated in 2018 (Trenholm 2018b). This document provides additional recommendations to a homeowner on how best to fertilize and maintain their lawns. For fertilizer timing, it is recommended that the first application be performed in early April and last application in early October for Central Florida. Fertilizer should not be applied from January to March due to the dormant state of the turfgrass. Additionally, newly planted turfgrass should not be fertilized for 30-60 days due the high rates of runoff and leaching.

Application rates are recommended to abide by those set out in 5E-1.003 with the same recommended annual N applications as listed in Table 2. It is also recommended that for homeowners in areas with summer fertilizer bans, that they apply a slow-release N fertilizer before the ban starts and then a more quick-release fertilizer when the ban ends. It is also specifically mentioned that a homeowner should not fertilize if there is a forecast of over 2 inches of rain in the next 24 hours.

TURFGRASS SPECIFIC RECOMMENDATIONS

5E-1.003 and UF-IFAS specifically list N fertilization recommendations for St. Augustinegrass, Bahiagrass, Bermudagrass, Zoysiagrass, and Centipedegrass turfgrasses. A statewide survey of sod production in 2007 identified St. Augustinegrass comprising 50.9% of all sod produced, followed by Bahiagrass at 32.8%, Bermudagrass at 7.4%, Zoysiagrass at 5.1%, Centipedegrass at 3.1%, and Seashore Paspalum at 0.7% (Satterthwaite et al 2009).

In Florida, St. Augustine was the most common lawn turfgrass (Trenholm et al 2021a) with the Floratam cultivar the most dominant (81% of all St. Augustinegrass sod in 2007). The Floratam cultivar was established in 1973 and was known for its resistance to chinch bug infestations but was less cold and shade tolerant compared to other cultivars. There were several new cultivars established in the 2000s that have stronger cold and shade tolerances, with the Classic variety the second most produced in 2007 at 6%. Fertilizer recommendations per cultivar were not discussed. Overall, it was recommended to apply between 2-5 pounds of N per 1,000 square feet per year over 2-6 applications starting in early April.

Bahiagrass was recommended as a roadside cover or on large lots where irrigation and fertilization are not practical (Unruh et al 2018), with the Argentine cultivar the most dominant (84.0% of all Bahiagrass sod in 2007). The Argentine cultivar is insect, disease, and cold resistant while being more aesthetically pleasing for turfgrass use. The Pensacola cultivar (15.9% of all Bahiagrass sod in 2007) was primarily recommended as roadside cover due to aesthetic concerns. It was recommended to apply between 2-5 pounds of N per 1,000 square feet per year over 2-4 applications starting in early April.

Bermudagrass was recommended for sports, athletic fields, and other locations where aesthetics are of primary concern (Trenholm et al 2021b), with the Tifway cultivar being the most dominant (56.2% of all Bahiagrass sod in 2007). The Tifway cultivar was recommended for use on golf and athletic fields due to its good wear resistance but higher maintenance requirements. The Celebration and Common (21.3% and 18.4% of all Bermudagrass sod in 2007, respectively) cultivars are recommended for home lawns as they require less maintenance and fertilization but are less resistant to wear. It was recommended to apply between 4-6 pounds of N per 1,000 square feet per year over starting in early April.

Zoysiagrass was also recommended for sports, athletic fields, and other locations where aesthetics are concern (Unruh et al 2019a), with the Empire cultivar being the most dominant (81.0% of all Zoysiagrass sod in 2007). The Empire cultivar had been observed to perform well in all regions of Florida but has a low shade tolerance. UF-IFAS research has identified that some cultivars have less nitrogen requirements but have not released guidelines yet. It was recommended to apply between 2-4 pounds of N per 1,000 square feet per year over starting in early April.

Centipedegrass was recommended for use in north and central Florida and for sports and home lawns (Unruh et al 2019b) with the Common cultivar being the most dominant (98.7% of all Bahiagrass sod in 2007). The Common cultivar has low fertility and maintenance requirements but has poor insect, disease, and cold resistance. It is recommended to apply between 0.4-3 pounds of N per 1,000 square feet per year over starting in early April and no later than October over 1-3 applications.

Seashore Paspalum had the lowest sod production in 2007 (0.7% of all turfgrass) and was typically used exclusively for golf courses, with the Seadwarf cultivar the most common and "Other" making up another large portion (42.0% and 37.2% of all Seashore Paspalum sod in 2007, respectively). UF-IFAS last published Seashore Paspalum recommendations in 2002 (Trenholm & Unruh 2002). It was recommended to apply between 2-3 pounds of N per 1,000 square feet per year over 2-3 applications starting in late March to August. There are no recommendations in 5E-1.003 for ranges of N fertilizer application.

Recent Turfgrass and Fertilizer Literature

The recommended application rates of N fertilizer to turfgrass attempt to achieve a balance between the urban lawn aesthetic and environmental management, with the goal of providing enough N fertilizer to maintain a healthy lawn and prevent nutrient pollution. The turfgrass fertilization recommendations in 5E-1.003 and the GI-BMP training requirement for commercial fertilizer applicators are based on the available turfgrass research and professional experiences of managing turfgrasses in Florida. These recommendations are provided in ranges of pounds of N fertilizer per species for three regions of Florida. This is to account for the local variations in microclimate, soil type, cultivar, and other factors which impact turfgrass growth and health.

However, these recommendations only include qualitative descriptions of how to adjust fertilization rates to local conditions and do not provide numerical nutrient requirements between cultivars.

Optimal Nitrogen Fertilization of Florida Turfgrasses

Research on the optimal N fertilization rates in Florida is somewhat limited. Starting in the early 2000's Trenholm & Unruh (2005, 2007, 2009) conducted a series of multi-year statewide evaluations of St. Augustinegrass, Bermudagrass, Zoysiagrass, and Bahiagrass fertilization practices. The intent of this research was to evaluate the UF-IFAS recommended fertilization ranges for the dominant lawn species of turfgrass used throughout Florida (Table 5). The studies concluded that all species of turfgrass responded favorably to higher application rates of N fertilizer but acceptable turfgrass conditions could be maintained at the mid recommended rates.

Trenholm & Unruh (2006) did find that both St. Augustinegrass and Bermudagrass treated with a low rate of 27% N fertilizer had similarly good performance as the higher application rates. Trenholm & Unruh (2007) evaluated St. Augustinegrass performance at a sod farm in Bradenton, FL under low maintenance conditions and found that under normal conditions high rates of N fertilizer application were not necessary to maintain the turfgrass but may need to be increased if under stress from pests. Then the Trenholm & Unruh (2009) study found that both Zoysiagrass and the Pensacola Bahiagrass required less N fertilizer than St. Augustinegrass to maintain acceptable turf conditions but would still need higher rates if there were pest or other stresses.

Table 5 – Trenholm & Unruh Florida turfgrass fertilizer trials N fertilizer recommendations for acceptable turfgrass quality.

Reference	Study Years	Turfgrass Species	lbs N / 1,000 sqft
Trenholm & Unruh 2006	2000-2001	St. Augustinegrass	4*
Trenholm & Unruh 2006	2000-2001	Bermudagrass	5*
Trenholm & Unruh 2007	2002-2003	St. Augustinegrass	4
Trenholm & Unruh 2009	2001-2003	Zoysiagrass	3
Trenholm & Unruh 2009	2001-2003	Pensacola Bahiagrass	2-3

Reported in abstract as low and high rate consistent with UF-IFAS recommendations

The National Turfgrass Evaluation Program (NTEP) (www.ntep.org) is a partnership program with the United States Department of Agriculture (USDA) to coordinate the evaluation of turfgrass species and cultivars. Within Florida, the program includes data from five locations for several species of turfgrass (Table 6). These are research facilities managed by UF-IFAS for the purpose of turfgrass research in Florida.

Table 6 – National Turfgrass Evaluation Program (NTEP) Florida study sites and the species of turfgrass data available at each site

Turfgrass	Citra	Ft. Lauderdale	Gainesville	Jay	Tequesta
St. Augustinegrass	x	x	x	x	
Bahiagrass					
Bermudagrass			x	x	x
Zoysiagrass	x		x	x	
Centipedegrass					
Seashore Paspalum			x	x	

Schiavon et al (2021) at the Ft. Lauderdale facility evaluated the performance of the CitraBlue, Floratam, Palmetto, and Raleigh cultivars from 2017 to 2020, comparing two treatment regimens of 2.5 and 5 pounds of N per 1,000 square feet per year with a mixture of quick and slow-release N fertilizer. The study identified that the lower fertilization rate of 2.5 pounds of N per 1,000 square feet per year yielded acceptable St. Augustinegrass turf conditions in soil with 3.4% organic matter over the 4-year study period with CitraBlue performing best. A key conclusion from the study was that as N accumulated in the soil from regular fertilization and became available from mineralized organic matter, N fertilization rates could be decreased with the age of the turf. They also highlighted that the current recommended N rates from UF-IFAS do not take in consideration lawn age, cultivar, or soil organic matter.

NITROGEN FERTILIZER LEACHING FROM TURFGRASS

Studies comparing the rate of fertilizer application to both lawn turfgrass conditions and N leaching in Florida are limited as well, with many studies focusing on recently established turfgrass or in ideal greenhouse conditions (Reisinger et al 2020). Within the UF-IFAS program, three research stations were utilized across Florida to perform outdoor mesocosm turf tests to examine the relationship between fertilizer applications and leaching into the surficial groundwater. These facilities are in Jay, Citra, and Ft. Lauderdale. These studies assumed the bulk of N export from turfgrass occurred as leaching into groundwater and evaluated this using lysimeters.

Erickson et al (2008) performed one of the first of these studies at Ft. Lauderdale from 2000 to 2003. They compared a St. Augustinegrass monoculture with mixed ornamental design of non-turfgrass ground cover, shrubs, and trees with average observed seasonal rainfall. The St. Augustinegrass was fertilized at 6 pounds of N per 1,000 square feet per year with a mix of urea, sulfur coated urea, and ammonium phosphate fertilizer. Over the study they observed that of the estimated 900 kg N per hectare applied to the St. Augustinegrass, a cumulative mean of 4.1 kg (0.4% of total N) of inorganic-N was measured in leached water. 1.3 kg inorganic-N per hectare had leached in the first year, 1.03 the second, and then 1.76 during the third year. The ornamental design had 480 kg N per hectare applied during the first two years of the study. The ornamental design had 3.58 kg inorganic-N leached in the first season but was not significantly different from the St. Augustinegrass for the rest of the study until it was lower in the last season.

Trenholm et al (2012) then varied N fertilizer application rate to Floratam St. Augustinegrass and Empire Zoysia grass to determine the impact on N leachate and turf performance from 2006 to 2007 in Citra, FL. Using only urea fertilizer, the Floratam was above acceptable quality at 4 pounds of N per 1,000 square feet per year with less than 1.5% leaching into the lysimeters. The Empire however was at acceptable quality at 1 pound of N per 1,000 square feet per year but was leaching an average of 25.9% of the applied N in the first year which dropped to 11.6% the second year, with higher fertilization rates resulting in higher leaching rates. The authors concluded that the fertilization rates of Empire Zoysia grass in central Florida should be decreased from the 2-4 pounds of N per 1,000 square feet per year as recommended in 5E-1.003.

In parallel, Shaddox et al (2016a, 2016b) performed a pair of studies that sought to provide additional information regarding the UF-IFAS recommendations for turfgrass management. The first study (Shaddox et al 2016a) evaluated St. Augustinegrass across Florida with the specific goal of identifying what the minimum N application rate was to maintain acceptable quality while also characterizing the associated potential N leaching. From 2006 to 2008, again only using urea fertilizer, they identified that at Jay and Ft. Lauderdale the UF-IFAS minimum recommended N application rates for St. Augustine resulted in acceptable turf quality with less than 2% of the applied nitrogen leaching. At Citra, the acceptable turf quality was obtained with 4 pounds of N per 1,000 square feet though they suggest this may be due to high temperatures during the study period. Also noted was that during periods of stress, such as damage from herbicide applications, N leaching did increase and should be a consideration in future turfgrass BMPs.

The second study (Shaddox et al 2016b) focused on the leaching of N fertilizer during the winter dormant period for St. Augustinegrass and Centipede grass, based on the assumption that more fertilization will occur in the winter in response to the summer fertilizer restrictions. This study was performed in Jay, FL (North Florida fertilizer rate) from 2006 to 2009 using only urea. They found that only winter applications below 0.5 pounds of N per 1,000 square feet do not result in significant N leaching for both turfgrass species, which is less than the 1-pound N recommended in 5E-1.003. This study also did not examine the resulting turfgrass quality from the winter applications and recommend further investigation of the value of it.

Centipede grass N fertilization rates were evaluated by Shaddox et al (2017) in Jay, FL from 2006 to 2007. The study identified that applying the minimum recommended fertilization rate of 0.5 pounds of N per 1,000 square feet per year did not result in significant leaching and maintained acceptable turf quality. They also note that at the maximum recommended rate of 2 pounds of N per 1,000 square feet per year did not result in a higher rate of leaching.

Ideal Bahia grass fertilization rates and their leaching rates were evaluated by McGroary et al (2017) at the Ft. Lauderdale facility from 2006 to 2008. This study found that the lower rate of 1 pound of N per 1,000 square feet per year of urea resulted in acceptable turf quality with only 2% nitrate leaching. The study concludes that the recommended N fertilization range for Bahia grass could be reduced and still maintain acceptable turf quality.

The studies performed at the UF-IFAS research facilities examined the common turfgrass species used in Florida lawns and their corresponding recommended fertilization BMPs. Overall, these studies found that the lower range of N fertilization rates would yield acceptable quality turf conditions and generally resulted in low nitrate leaching. The studies also identified that when under stress due to pests, herbicide treatments, or other forces that the application of fertilizer should be reduced to avoid leaching. Shaddox & Unruh (2018) reported ranges of potential fates of N fertilizers applied to turfgrass with leaching having a potential range of 1-55% (Table 7).

Table 7 – Percent ranges of the potential fates of N fertilizer applied to Florida turfgrass (Shaddox & Unruh 2018)

N Fate	Percent Range
Volatilization	<1%–60%
Denitrification	<1%–5%
Plant uptake	40%–68%
Soil Storage	7%–15%
Leaching	<1%–55%
Runoff	<1%–7%

A significant limitation of several of these studies is that they only evaluated the application of quick-release urea fertilizer and only nitrate was analyzed in the leachate. This does not provide a complete picture as the inclusion of organic nitrogen could identify higher leaching rates than inorganic alone. Lusk et al (2018) sought to address this issue by examining the source of dissolved organic nitrogen (DON) in newly planted St. Augustine on converted pastureland and concluded that DON was the dominant form of N in the leachate and a portion of the DON likely came from the applied fertilizer. Additionally, the Erickson et al (2008) study compared St. Augustine to the mixed ornamentals in a timeframe that did not account for the slower root growth rate of the woody plants, in which a study in Apopka, FL (Qin et al 2013) had found that established woody plants had significant reductions in both organic and inorganic N leaching. Future studies on turfgrass leaching should examine both organic and inorganic forms of N as well as more localized studies to Orange County.

FIELD OBSERVATIONS OF NITROGEN NUTRIENTS FROM TURFGRASS FERTILIZATION

The environmental impacts on surface and groundwater from the use of fertilizers on lawn turfgrass have been long evaluated across the United States (Smith et al 1999, Badruzzaman et al 2012, Reisinger et al 2020). However, the characterization and quantification of the relative contribution of nitrogen fertilizers in the urban nitrogen cycle is complicated by the multitude of other sources such as atmospheric deposition, reclaimed water, septic systems, and decaying organic matter. There are few investigations of nitrogen fertilizer contributions in Florida with experimental design that controls for the confounding nitrogen sources and tend to have been performed more recently as analytical methods that allow for the differentiation between the sources have matured.

In support of the Wekiva Spring protection efforts, one of the first fertilizer sourcing studies in Florida was conducted from 2008 to 2009 (Tucker et al 2014). Nitrate concentrations and isotopes were evaluated at surficial groundwater wells representing non-septic residential communities that apply fertilizer to their turfgrass against reference wells in undeveloped natural areas. The study identified that the average concentration of 0.3 mg/L nitrate observed in the undeveloped areas was significantly lower than the 2.0 mg/L nitrate found in the residential areas. The isotopic analysis of the wells with the highest nitrate concentrations (4.2 mg/L nitrate) also supported the conclusion that nitrogen fertilizer was the likely source of the nitrate in the groundwater.

Fertilizer applied to turfgrass can also have impacts on water quality through runoff of the fertilizer itself or remobilization of the N stored in the soil. Vegan & Ryan (2016) evaluated the potential impact that the implementation of the summer fertilizer restriction would have on nutrients in 9 stormwater ponds across Lee County, FL. Total Phosphorus (TP), Total Nitrogen (TN), and Chlorophyll a (ChlA) were evaluated from before the ordinance (2004 to 2008) and after (2009-2013). They found that TP and ChlA were significantly reduced, however a non-significant decrease in TN was observed.

To perform a more focused analysis of nitrogen sources, stable isotopic analysis has been utilized to statistically determine the potential percent contribution when there are additional confounding sources. Yang & Toor (2016) performed an isotopic study of nitrate sources in a stormwater pond in Hillsborough County in 2014. The study found that on average 42% of the nitrate was from a fertilizer source. The pond's catchment was primarily pervious surfaces with St. Augustinegrass turf, which the authors suggest the nitrate may be the fertilizer runoff from the turf treatments. Jani et al (2020) performed an isotopic study of stable water, nitrate, and Particulate Organic Nitrogen (PON) in a stormwater basin in Manatee County, FL in 2016. This study found that 47% of N was in the form of DON of which 32% was likely from grass clippings and 41.9% of nitrate was likely from turfgrass fertilizers. Krimsky et al (2021) performed stable isotope study of nitrate from lawn runoff in Brevard County, FL in 2018 between the wet and dry seasons. This study found that during the dry season the likely average percent contribution of inorganic fertilizers was 44.2% but dropped to 30.8% during the wet season, when a fertilizer ban was in place. These isotope studies highlight the significant contribution of fertilizer applications and the potential impact of remobilized legacy N nutrients, which may not be clear from nutrient studies alone.

The Southwest Florida Regional Planning Council (SWFRPC) adopted an urban fertilizer use model ordinance in 2007. This model ordinance was stricter than the current FDEP state model as it called for the restriction of fertilizer application during the summer and had lower recommended fertilizer application rates. This model ordinance was then adopted by municipalities and counties in the Tampa Bay and Charlotte Harbor areas from 2007 to 2012 (Beever 2016). This was one of the first widespread adoptions of summer fertilizer application restrictions in Florida.

In addition to the evaluation of potential N fertilizer impacts at the neighborhood scale, landscape studies were initiated in response to the enactment of county wide summer fertilizer bans. The Charlotte Harbor National Estuary Program (CHNEP) performed an analysis of the ongoing surface water monitoring data from 2000 to 2015 to examine the efficacy of the ordinance (Beever 2016). The study had found that prior to the adoption of the ordinances in 2007 TP, TN, and Total Kjeldahl Nitrogen (TKN) were all significantly increasing. Following the full adoption of the ordinance in 2012 TP, TN, and TKN were all significantly lower and decreasing. With a corresponding increase in fecal coliform counts, the study concludes that the decrease is not likely due to decreases in septic system pollution or animal waste. However, a focused study comparing canal TN, TP, and ChlA in Cape Coral against Ft. Lauderdale as a control found that both locations experienced decreases in nutrients after 2010 but only Cape Coral had a decrease in ChlA (Motsch 2018). These two studies highlight the impact that scale and spatial variability have on evaluating the impacts of the ordinance, suggesting future evaluations need to bridge these constraints.

Documenting the effectiveness of fertilizer application restrictions require specific experimental designs that filter out as many potential confounding factors as possible. However, given the challenges and costs associated with field data collection on a sufficient scale to capture all potential sources of variability, a mixture of methods should be utilized. Assessing existing long term water quality data will likely require careful design and consideration. The use of stable isotope analysis has in multiple studies proven valuable in providing additional information regarding the source of nitrogen nutrients that may otherwise be swamped by other confounding factors. By pairing stable isotope analysis with more traditional water quality parameters, a larger selection of sites can be used for a study or statistical models developed to better interpret existing long-term data.

RECENT TURF DESIGN AND MAINTENANCE LITERATURE

Recommendations and BMPs for turfgrass maintenance and fertilization can be based on the best available science and knowledge but are still reliant on the property owner or commercial applicator to implement them. The factors that can influence the decision-making process on turf design and its maintenance range from the economic such as income and wealth, to social influence from neighboring properties, and compliance with applicable fertilizer regulations. Further complicating the management of the urban landscape is obtaining the relevant data about the decision-making process and how to interpret and act upon it.

Household Lawn Fertilization Activity

A key factor to identify is how many households are fertilizing their laws, how they go about it, and what factors may influence the rate. In conjunction with the 2008 Wekiva groundwater study, 740 households in the area were also interviewed to ascertain their turf fertilization practices informing the groundwater study (Souto & Listopad 2013). This study identified a linkage between increased income and wealth with increased fertilizer applications, decreasing rates of fertilizer application with older homes, and that on average the fertilizer application rate was estimated to be near 0.74 pounds N per 1,000 square feet for 84% of the households that applied fertilizer.

Carrico et al (2018) found in a 2011 Nashville, Tennessee survey that 54% of 379 household's fertilized their lawns. They also found that wealthier areas tended to have higher fertilization rates but there was a low overall average fertilizer rate at 0.98 pounds N per 1,000 square feet. As part of a 2013 survey, 728 households were surveyed about their fertilizer use and found 61% Hillsborough, 64% Manatee, and 55% Pinellas households fertilized their lawns with a similar pattern of higher fertilization rates in wealthier counties (Souto et al 2019). Then Ryan et al (2019) performed a 2015 Florida-wide survey of 523 resident and 161 decision maker (county clerk, commissioners, managers, etc.) households, which identified that 49% of residents fertilized their lawns while only 33% of decision-makers did. These studies highlight the variability that can exist in how many households apply fertilizer to their lawns but a common observation and in the literature cited between several of these studies is that as a household's wealth increases, they are more likely to apply more fertilizer.

Knowledge of and Compliance with Ordinances

Another concern with the implementation of fertilizer restrictions or recommendations is if the end user is aware that they are in place and if they understand them correctly. As part of the UF-IFAS FFL program, much of their material includes notices to be aware of local ordinances in how and when fertilizer applies, and their county level Master Gardner program encourages compliance with these regulations. However, the efficacy of UF-IFAS and municipal outreach regarding the applicable ordinances may need to be reconsidered as the studies mentioned above also identified significant lack of ordinance knowledge.

Souto et al (2019) identified that 26% Hillsborough, 44% of Pinellas, and 24% of Manatee residents were aware of fertilizer application regulations with between 66-75% of those respondents aware that it restricts rainy season fertilization. Ryan et al (2019) found that only 31% of residents correctly knew if they were under a fertilizer ordinance while 80% of decision-makers were correctly aware. Persaud et al (2016) surveyed 626 Manatee County Homeowner Association (HOA) residents in 2014 and identified only 16% knew of a year-long phosphorus restriction and 32% knew of the nitrogen rainy season restriction. These studies highlight that the general awareness of fertilizer restrictions needs improvement and that in particular with the knowledge gap between residents and decision makers that there is also low civic engagement on the topic.

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APPENDIX A

Comparison table between the FDEP Model Ordinance and OC Fertilizer Ordinance.

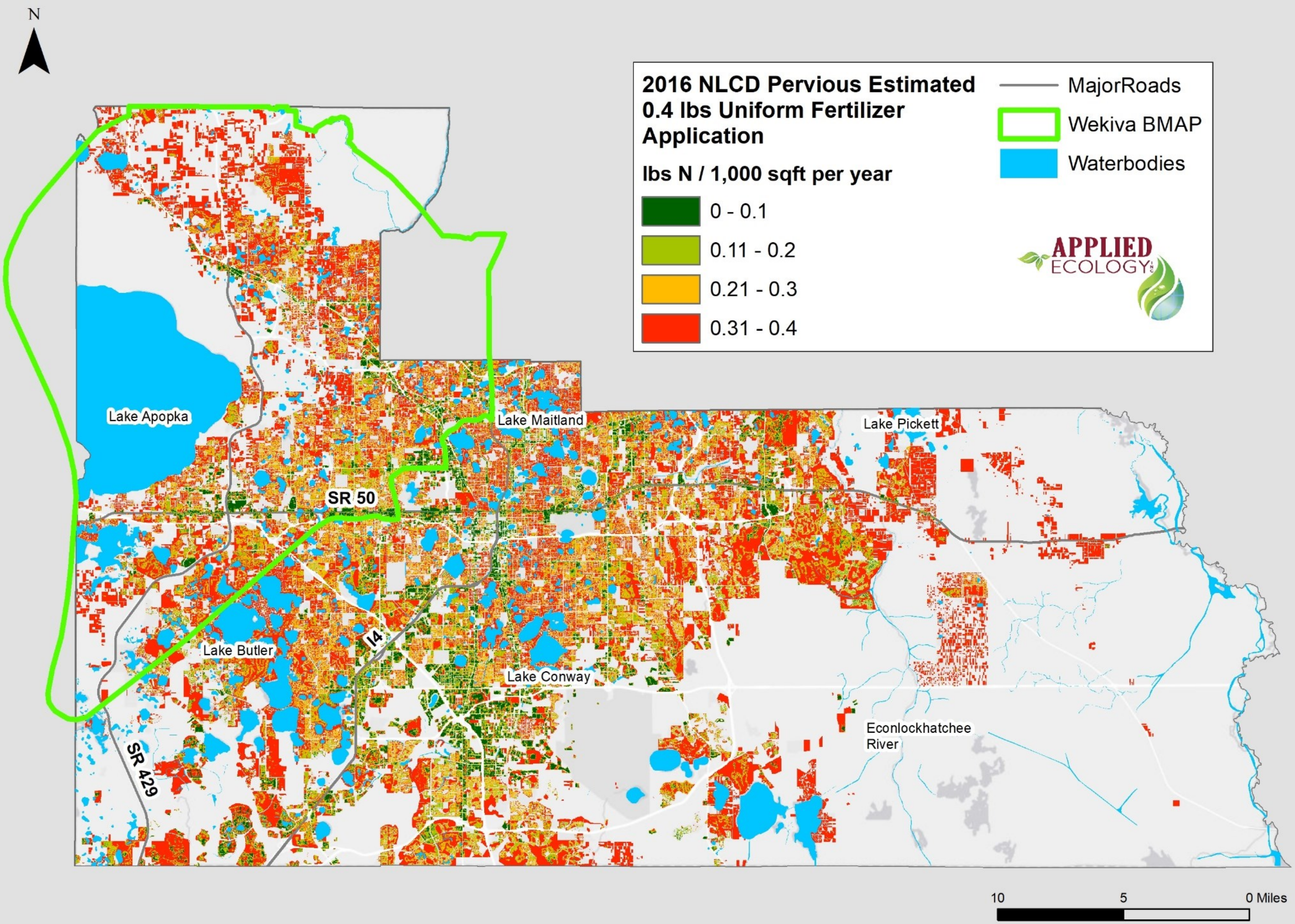
Section	FDEP Model Ordinance	Orange County Fertilizer Management Ordinance	Variation
Findings			No Significant Variation
Purpose and Intent			No Significant Variation
Definitions	Fertilizer - means any substance or mixture of substances that contains one or more recognized plant nutrients and promotes plant growth, or controls soil acidity or alkalinity, or provides other soil enrichment, or provides other corrective measures to the soil.	*Fertilizer* - means any substance or mixture of substances, excluding pesticides, organic composts, and fertilizer derived from biosolids , that contains one (1) or more recognized plant nutrients and promotes plant growth, or controls soil acidity or alkalinity, or provides other soil enrichment, or provides other corrective measures to the soil.	OC definition of fertilizer excludes organic compost and fertilizer derived from biosolids. Neither are defined as such in the OC municpal code. Biosolids are defined in OC municipal code Sec 37-703 as "Biosolids shall mean the primarily organic solids that are produced by wastewater treatment processes; and can be beneficially recycled. Refer to residuals on sludge."
	No specific definition provided	*Golf course* means any public or private area of land designed and used exclusively for playing or practicing golf, including tees, fairways, greens, rough areas, hazards and driving ranges (stand-alone ranges or those associated with a golf course). A golf course shall also include the following uses if they are accessory to the above uses: clubhouses, and all facilities adjacent to and associated with the daily operations of the above-referenced areas. Golf-related structures or features on residentially zoned private land shall not constitute a golf course.	OC defines golf course beyond both the Model Ordinance and 5E-1.003(3) ((a) "Sports Turf" means non-agricultural land planted exclusively for golf courses, parks and athletic fields.)
	No specific definition provided	*Groundcover* means plants used in mass as alternative to turf or lawn and/or to create variety in landscape; usually not having a mature height over two (2) feet tall.	Not defined in Model Ordinance
	"Landscape Plant" means any native or exotic tree, shrub, or groundcover (excluding turf).	*Landscape plants* means any shrub, tree, or groundcover, excluding turf and vegetable gardens.	OC does not include exotics and adds vegetable gardens
	"Institutional Applicator" means any person, other than a private, non-commercial or a Commercial Applicator (unless such definitions also apply under the circumstances), thatapplies fertilizer for the purpose of maintaining turf and/or landscape plants. Institutional Applicators shall include, but shall not be limited to, owners, managers or employees of public lands, schools, parks, religious institutions, utilities, industrial or business sites and any residential properties maintained in condominium and/or common ownership.	No specific definition provided	OC does not define "Institutional Applicator"
	"Saturated soil" means a soil in which the voids are filled with water. Saturation does not require flow. For the purposes of this ordinance, soils shall be considered saturated if standing water is present or the pressure of a person standing on the soil causes the release of free water.	No specific definition provided	OC does not define "Saturated soil"
	"Turf," "Sod," or "Lawn" means a piece of grass-covered soil held together by the roots of the grass	*Turf, sod* , or *lawn* means a mat layer of monocotyledonous plants, including but not limited to, Bahia, Bermuda, Centipede, Paspalum, St. Augustine, or Zoysia.	OC has more specific definition.
Applicability			No Significant Variation
Timing of Fertilizer Application - Storm Events	"Prohibited Application Period" means the time period during which a Flood Watch or Warning, or a Tropical Storm Watch or Warning, or a Hurricane Watch or Warning is in effect for any portion of (CITY/COUNTY), issued by the National Weather Service, or if heavy rain is likely. (Heavy rainfall is greater than 50mm (2 inches) per 24 hours)	No fertilizer containing nitrogen or phosphorus shall be applied to turf or landscape plants during a period for which the National Weather Service has issued any of the following advisories for any portion [of] the county: a severe thunderstorm warning or watch , flood warning or watch, tropical storm warning or watch, or hurricane warning or watch.	OC has the addition of NWS "Severe Thunderstorm warning or watch". NWS typically defines it as "winds of at least 58 mph (50 knots or ~93 km/h), and/or hail at least 1" in diameter." but is up to the local weather office's discretion to an extent. (i.e. Binghamton, NY station severe thunderstorm warning https://www.weather.gov/bgm/severedefinitions).
Timing of Fertilizer Application - Seasonal	**Guidance**: Some ordinances have prohibited the application of fertilizer, even slow release formulations, during the summer rainy season, typically June 1 to September 30.	No person, except applicators certified pursuant to section 15-809 herein, shall apply fertilizer containing nitrogen or phosphorus to turf or landscape plants during the restricted season from June 1 through September 30	Model Ordinance provides guidance that fertilizer applications be prohibited in the wet season. OC worded that as long as state and/or county level training was completed, fertilizer can be applied.
Fertilizer Free Zones	Fertilizer shall not be applied within ten (10) feet of any pond, stream, watercourse, lake, canal, or wetland	No fertilizer shall be applied within fifteen (15) feet of any wetland or surface waters, including but not limited to a lake, pond, stream, water body, water course, or canal.	OC extends zone to 15 feet
Low Maintenance Zones	A voluntary ten (10) foot low maintenance zone is strongly recommended, but not mandated, from any pond, stream, water course, lake, wetland or from the top of a seawall	A low-maintenance zone is strongly recommended, though not required, for all areas within ten (10) feet of the normal high water elevation of any lake, pond, stream, water body, water course or canal, or any wetland, excluding permitted stormwater ponds.	OC excludes stormwater ponds. OC asks for high water mark for only LMZ.

Section	FDEP Model Ordinance	Orange County Fertilizer Management Ordinance	Variation
Fertilizer Content and Application Rates - General	**Guidance**: RULE 5E-1.003(2)(d), F.A.C contains the following provisions for golf courses, parks and athletic fields. As such, no additional specific requirements are included for these types of urban turf	No specifics on this included	Model Ordinance out of date. As of 2015, 5E-1.003(2) has provisions for "Urban Turf" or "Lawns" N & P applications
Fertilizer Content and Application Rates - Phosphorus	Nitrogen or phosphorus fertilizer shall not be applied to turf or landscape plants except as provided in (a) above for turf, or in UF/IFAS recommendations for landscape plants, vegetable gardens, and fruit trees and shrubs, unless a soil or tissue deficiency has been verified by an approved test.	No fertilizer containing phosphorus shall be applied to turf or landscape plants. Provided, however, where phosphorus deficiency has been demonstrated in the soil by a soil analysis test	No Significant Variation
	When the soil test indicates a need for P fertilization do not apply more than 0.25 lb of P_2O_5/1000 sq ft per application to established turfgrass. ("Recommendations for N, P, K, and Mg for Golf Course and Athletic Field Fertilization Based on Mehlich III Extractant" https://edis.ifas.ufl.edu/publication/ss404)	... phosphorus may then be applied at a rate no greater than one-quarter (0.25) of one (1) pound of phosphorus per one thousand (1,000) square feet per application, not to exceed one-half (0.5) pound of phosphorus per one thousand (1,000) square feet per year.	No Significant Variation
Fertilizer Content and Application Rates - Nitrogen	Nitrogen or phosphorus fertilizer shall not be applied to turf or landscape plants except as provided in (a) above for turf, or in UF/IFAS recommendations for landscape plants, vegetable gardens, and fruit trees and shrubs, unless a soil or tissue deficiency has been verified by an approved test.	No fertilizer containing nitrogen shall be applied unless at least fifty (50) percent of its nitrogen content is slow release. ... This requirement shall change to at least sixty-five (65) percent slow release if the product is readily available on the local commercial market by July 1, 2020.	OC allows for the application of Nitrogen without a soil or plant tissue test. Does require slow release formulation.
		… no more than one (1) pound total nitrogen per one thousand (1,000) square feet of area per application.	OC uses most stringent application rate of SS404 and 5E-1.003
		... commercial applicators may apply fertilizer at a rate that does not exceed one-half (0.5) of one (1) pound of readily available nitrogen per one thousand (1,000) square feet of area, provided, however, that any application that exceeds one-half (0.5) of one (1) pound of nitrogen	OC uses most stringent application rate of SS404 and 5E-1.003
Application Practices			No Significant Variation
Exemptions	Golf courses/athletic field exemptions not directly included; rates included in ordinance do link to golf course and sports field rates	Sections 15-805 through 15-810 of this article shall not apply to golf courses; provided, however, fertilizer shall not be applied to golf courses in excess of the provisions set forth in Rule 5E-1.003(3), F.A.C., as it may be amended.	Fertilizer-free zones, Mode of application, Grass clippings and vegetative material/debris, Training requirements, Commercial applicators; business tax certificate. Rule 5E-1.003(3) applies to "Sports Turf": "Have directions for use not to exceed rates recommended in the document entitled University of Florida, Institute of Food and Agricultural Sciences SL191"
		This article shall not apply to sports turf areas at parks and athletic fields.	Defaults to Rule 5E-1.003(3)
	Any lands used for bona fide scientific research, including, but not limited to, research on the effects of fertilizer use on urban stormwater, water quality, agronomics, or horticulture	Not included	No OC exemption for research
Training - Commercial	shall abide by and successfully complete the six-hour training program in the “Florida-friendly Best Management Practices for Protection of Water Resources by the Green Industries”	Florida Department of Environmental Protection's Florida Friendly Best Management Practices for Protection of Water Resources by the Green Industries training by UF/IFAS shall suffice	No Significant Variation
Training - Non-Commercial	Private, non-commercial applicators are encouraged to follow the recommendations of the University of Florida IFAS Florida Yards and Neighborhoods program when applying fertilizers.	Non-commercial applicators shall provide proof on an annual basis of successful completion of the online training "Orange County Fertilizer Application Education Course for Citizens " on the Orange County fertilizer web page. (http://www.ocfl.net/environment/fertilizerquizform.aspx)	OC requires a county provided private, non-commercial training materials
Enforcement	**Guidance**: Local governments should consider making penalties consistent with their other fines and penalties.	(1)First violation: Written notice. (2)Second violation: Fine of fifty dollars ($50.00), except for commercial applicators it shall be five hundred dollars ($500.00). (3)Third and subsequent violations: Fine of one hundred dollars ($100.00), except for commercial applicators it shall be seven hundred fifty dollars ($750.00).	

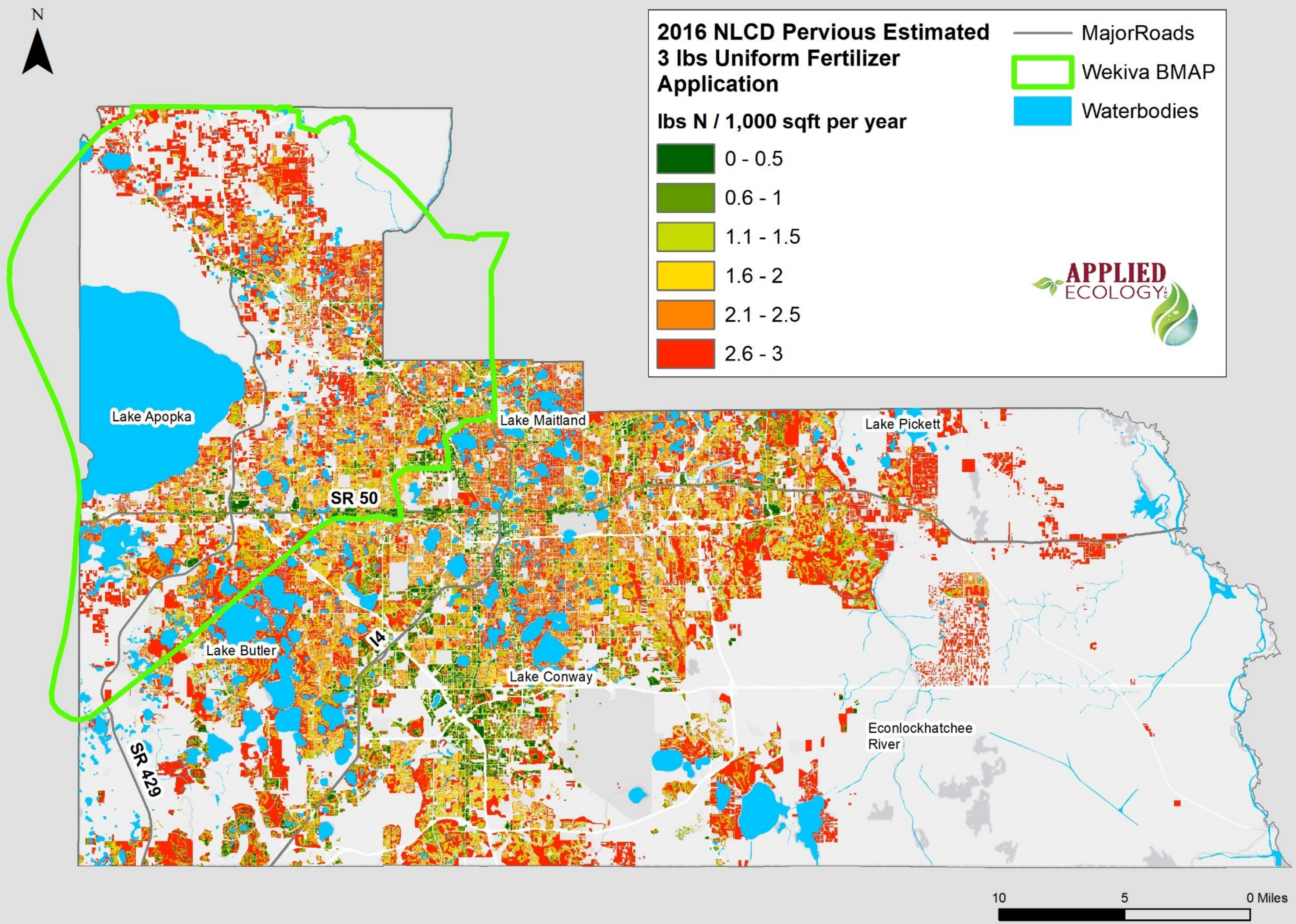
APPENDIX B

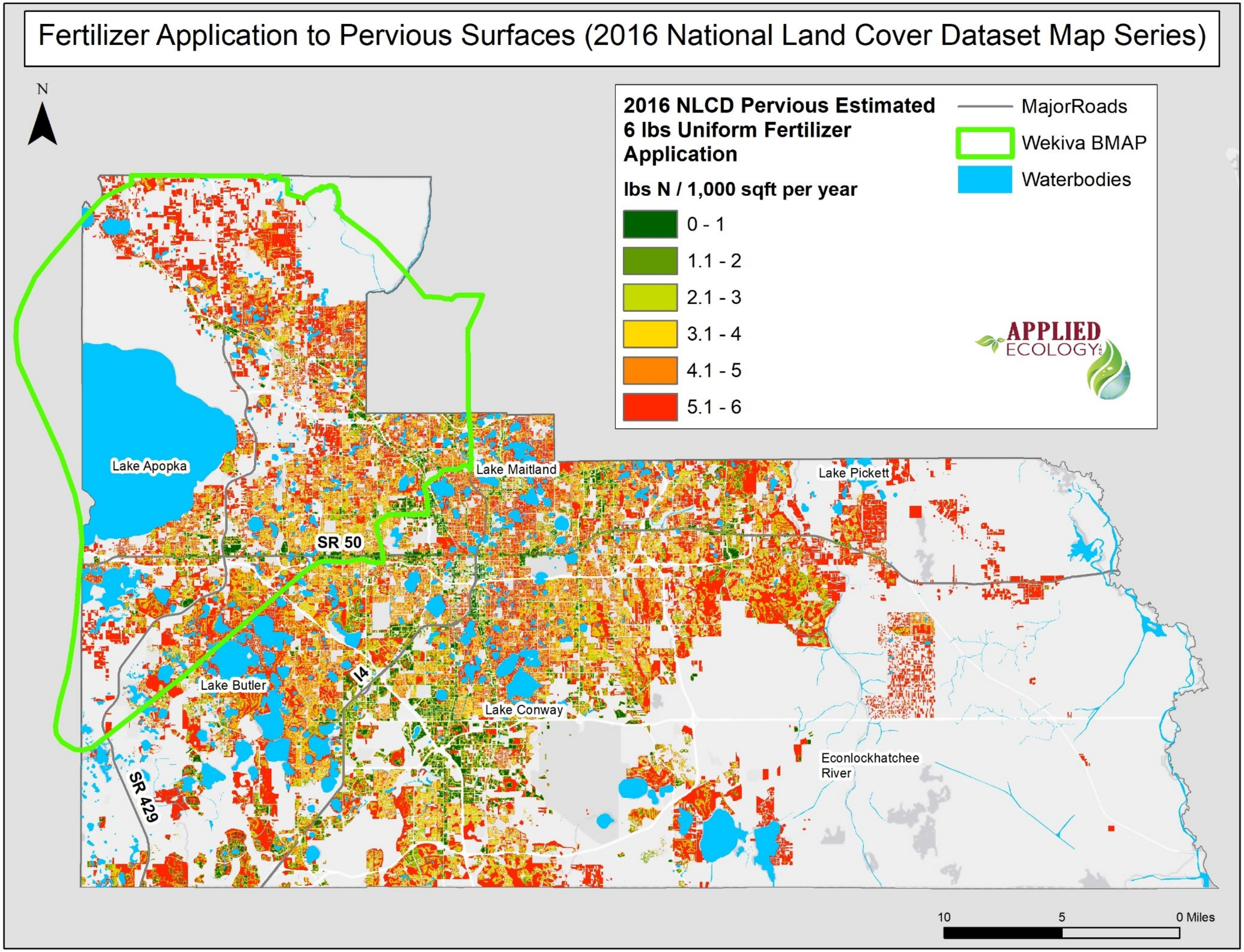
Map series of the 2016 and 2019 pervious cover estimated fertilizer applications.

Fertilizer Application to Pervious Surfaces (2016 National Land Cover Dataset Map Series)

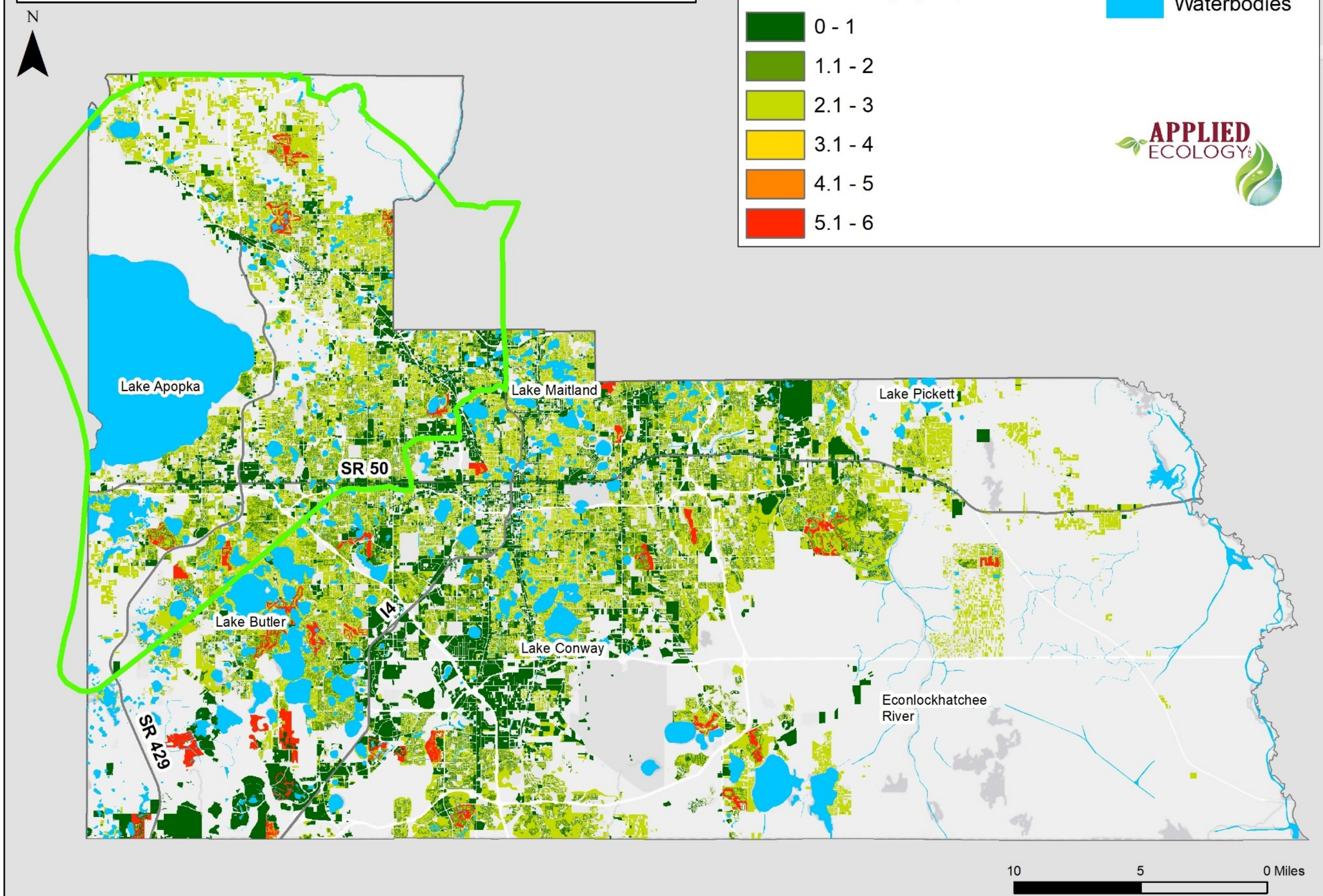


Fertilizer Application to Pervious Surfaces (2016 National Land Cover Dataset Map Series)

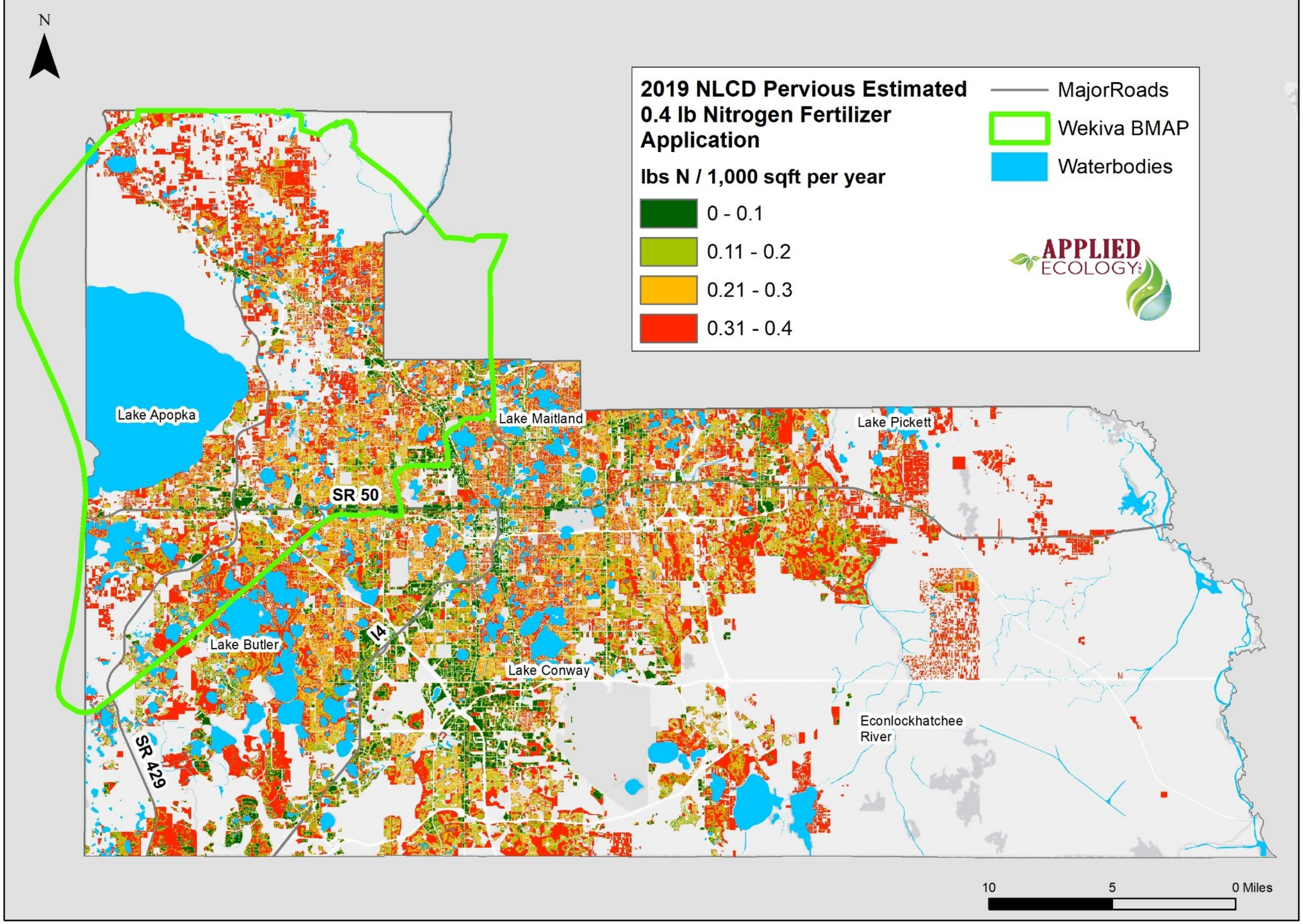


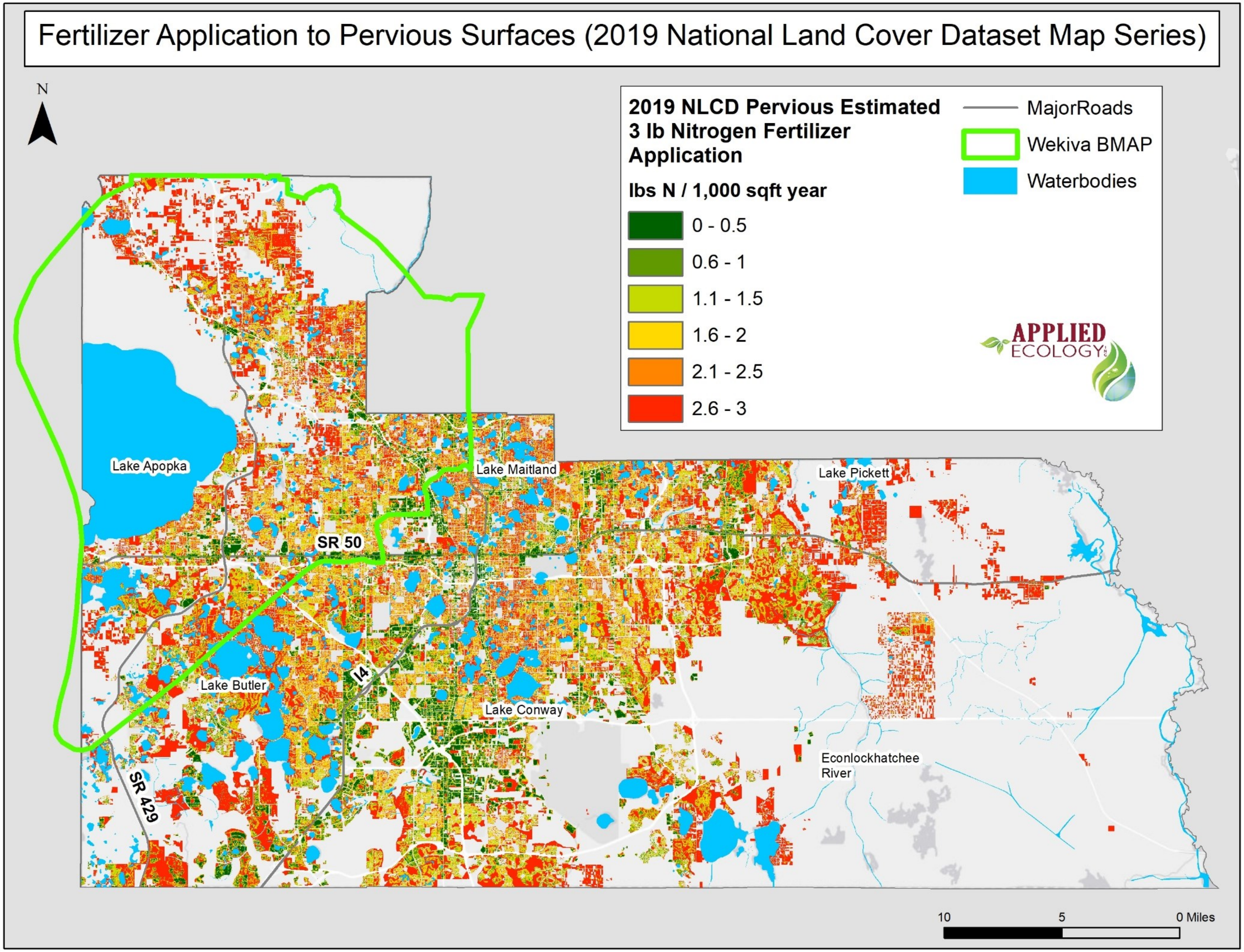

Fertilizer Application to Pervious Surfaces (2016 National Land Cover Dataset Map Series)
N
2016 NLCD Pervious Estimated 6 lbs Uniform Fertilizer Application
lbs N / 1,000 sqft per year
0 - 1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
MajorRoads
Wekiva BMAP
Waterbodies
APPLIED ECOLOGY
Lake Apopka
Lake Maitland
Lake Pickett
SR 50
I4
Lake Butler
Lake Conway
SR 429
Econlockhatchee River
10
5
0 Miles

Fertilizer Application to Pervious Surfaces: 2016 National Land Cover Dataset Map Series



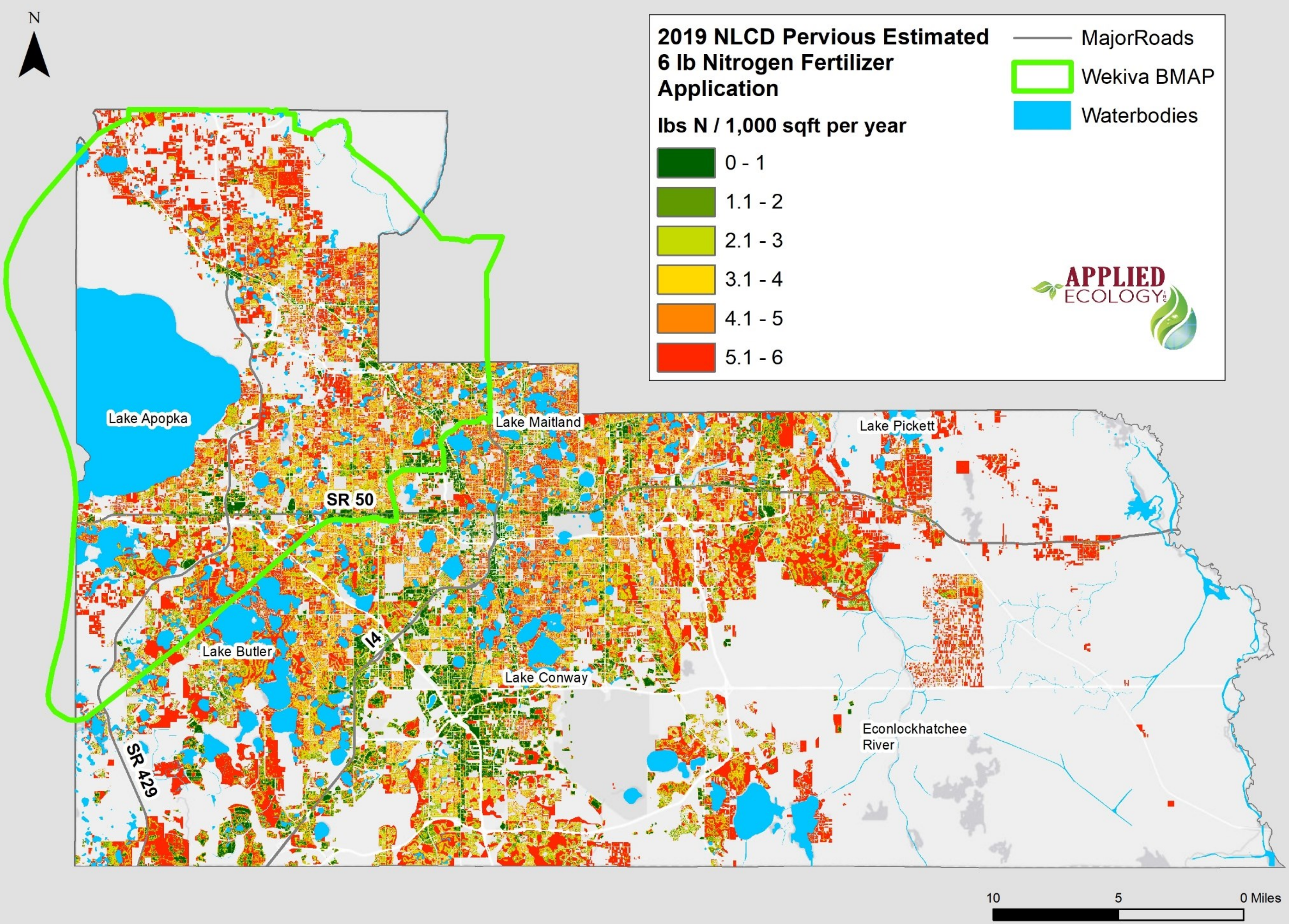
Fertilizer Application to Pervious Surfaces (2019 National Land Cover Dataset Map Series)

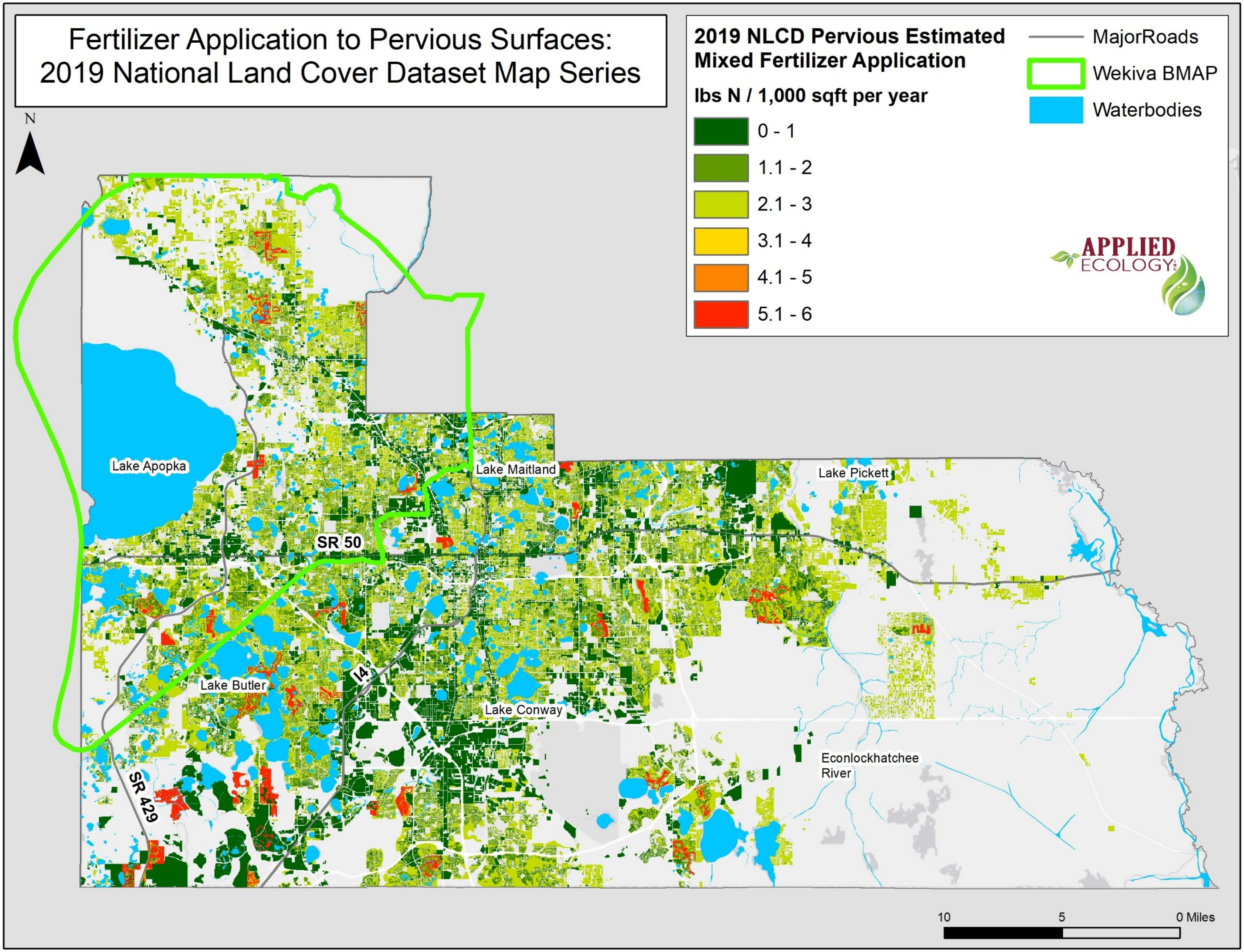




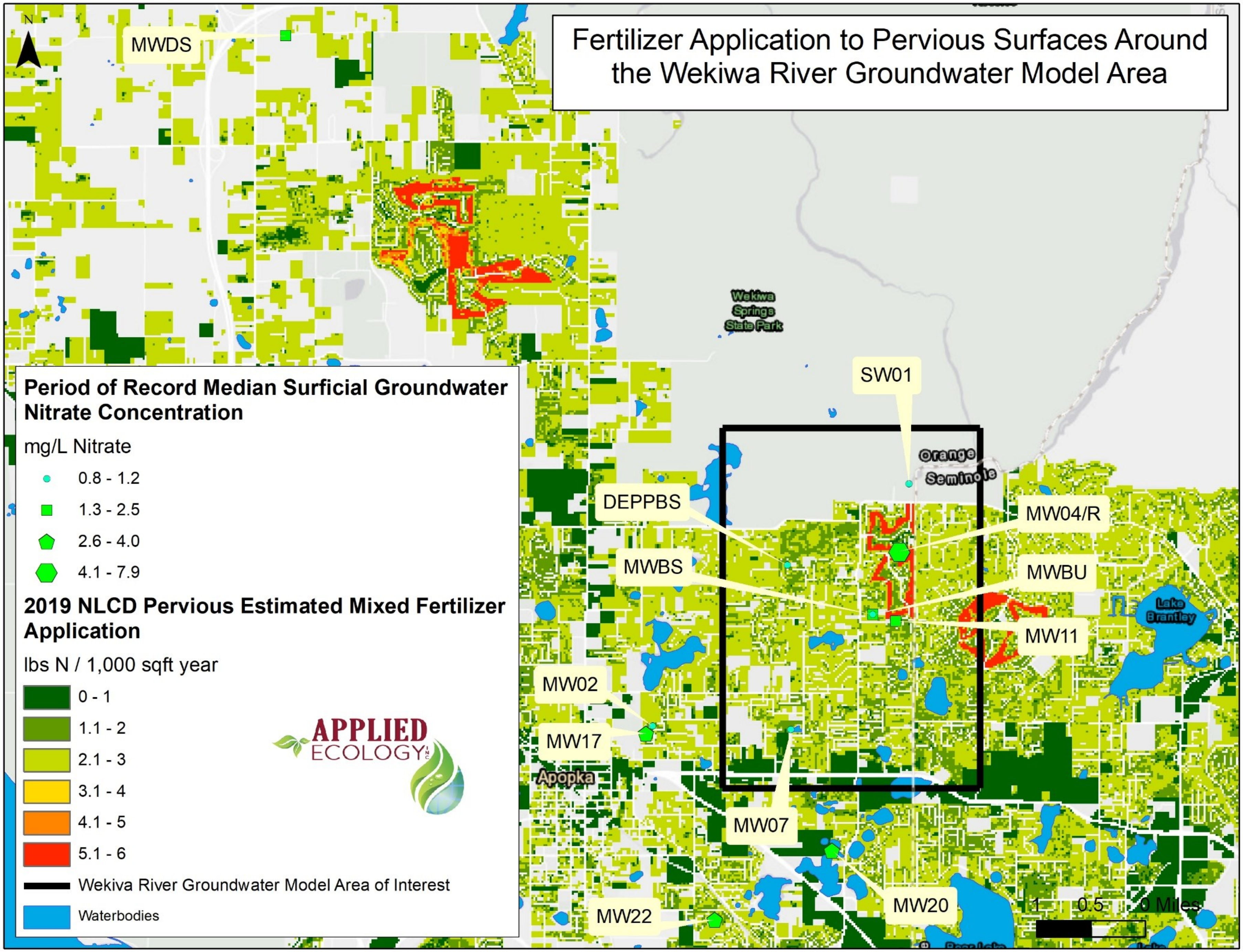
Fertilizer Application to Pervious Surfaces (2019 National Land Cover Dataset Map Series)
N
2019 NLCD Pervious Estimated 3 lb Nitrogen Fertilizer Application
lbs N / 1,000 sqft year
0 - 0.5
0.6 - 1
1.1 - 1.5
1.6 - 2
2.1 - 2.5
2.6 - 3
MajorRoads
Wekiva BMAP
Waterbodies
APPLIED ECOLOGY
Lake Apopka
Lake Maitland
Lake Pickett
SR 50
I4
Lake Butler
Lake Conway
Econlockhatchee River
SR 429
10
5
0 Miles

Fertilizer Application to Pervious Surfaces (2019 National Land Cover Dataset Map Series)





Fertilizer Application to Pervious Surfaces:
2019 National Land Cover Dataset Map Series
2019 NLCD Pervious Estimated
Mixed Fertilizer Application
lbs N / 1,000 sqft per year
0 - 1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
MajorRoads
Wekiva BMAP
Waterbodies
APPLIED
ECOLOGY
N
Lake Apopka
Lake Maitland
Lake Pickett
SR 50
I4
Lake Butler
Lake Conway
SR 429
Econlockhatchee
River
10
5
0 Miles



Fertilizer Application to Pervious Surfaces Around the Wekiwa River Groundwater Model Area
N
MWDS
Wekiwa Springs State Park
SW01
Orange
Seminole
DEPPBS
MW04/R
MWBS
MWBU
MW11
Lake Brantley
MW02
MW17
Apopka
MW07
MW20
MW22
1 0.5 0 Miles
Period of Record Median Surficial Groundwater Nitrate Concentration
mg/L Nitrate
0.8 - 1.2
1.3 - 2.5
2.6 - 4.0
4.1 - 7.9
2019 NLCD Pervious Estimated Mixed Fertilizer Application
lbs N / 1,000 sqft year
0 - 1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
Wekiwa River Groundwater Model Area of Interest
Waterbodies
APPLIED ECOLOGY INC

APPENDIX C

Summary of Fiscal Year 2012-2013 and 2019-2020 Fertilizer Licensing and Tonnage Report for Orange County, FL.

Florida Department of Agriculture and Consumer Services Fertilizer Licensing and Tonnage Reporting Fiscal Year 2019-2020 for Orange County, FL
General Public Records Request: P021929-061021

Product Code	Product Name	% N	% P	FY2019 2020 Tons by Farm Use Code (1)	Estimated Farm N Tons	Estimated Farm P Tons	FY2019 2020 Tons by Non Farm Use Codes (2 6)	Estimated Non Farm N Tons	Estimated Non Farm P Tons
10	AMMONIUM NITRATE	34.0	-	114.1	38.8	-	-	-	-
12	AMMONIUM NITRATE SOLUTION	20.0	-	59.6	11.9	-	-	-	-
24	AMMONIUM SULFATE	21.0	-	34.1	7.2	-	27.0	5.7	-
43	CALCIUM NITRATE	15.5	-	18.7	2.9	-	6.2	1.0	-
56	NITROGEN SOLUTION <28% *	-	-	82.3	-	-	21.5	-	-
58	NITROGEN SOLUTION 28%	28.0	-	-	-	-	1.0	0.3	-
59	NITROGEN SOLUTION 30%	30.0	-	-	-	-	2.0	0.6	-
60	NITROGEN SOLUTION 32%	32.0	-	138.7	44.4	-	-	-	-
61	NITROGEN SOLUTION >32% *	-	-	10.3	-	-	-	-	-
66	UREA	46.0	-	4.9	2.3	-	10.7	4.9	-
97	NITROGEN PRODUCT - CODE UNKNOWN *	-	-	0.0	-	-	1.0	-	-
98	NITROGEN PRODUCT - CODE/GRADE UNKNOWN *	-	-	4.0	-	-	4.0	-	-
209	MONOAMMONIUM PHOSPHATE	11.0	52.0	31.3	3.4	16.3	-	-	-
267	SUPERPHOSPHATE, TRIPLE	-	46.0	8.2	-	3.7	-	-	-
297	PHOSPHATE PRODUCT - CODE UNKNOWN *	-	-	2.1	-	-	1.0	-	-
298	PHOSPHATE PRODUCT - CODE/GRADE UNKNOWN *	-	-	1.0	-	-	-	-	-
423	POTASSIUM CARBONATE	-	-	-	-	-	4.0	-	-
430	MURIATE OF POTASH 62%	-	-	-	-	-	7.4	-	-
443	POTASSIUM-MAGNESIUM SULFATE	-	-	231.9	-	-	19.0	-	-
453	POTASSIUM NITRATE	14.0	-	2.2	0.3	-	7.9	1.1	-
463	POTASSIUM SULFATE	-	-	2,148.0	16.8	18.5	1.0	-	-
497	POTASH PRODUCT - CODE UNKNOWN *	-	-	0.2	-	-	-	-	-
498	POTASH PRODUCT - CODE/GRADE UNKNOWN *	-	-	-	-	-	3.3	-	-
613	COMPOST	2.0	2.0	-	-	-	400.3	8.0	8.0
617	FISH SCRAP	6.0	6.0	235.0	14.1	14.1	-	-	-
649	MANURE	0.5	0.5	-	-	-	1,770.4	8.9	8.9
661	SEWAGE SLUDGE, ACTIVATED	6.0	2.0	-	-	-	339.0	20.3	6.8
665	SEWAGE SLUDGE, HEAT DRIED	6.0	2.0	48.0	2.9	1.0	275.3	16.5	5.5
697	NATURAL ORGANIC PRODUCT - CODE UNKNOWN *	-	-	-	-	-	1.0	-	-
702	ALUMINUM SULFATE	-	-	1.4	-	-	-	-	-
720	COPPER SULFATE	-	-	2.0	-	-	-	-	-
728	FERROUS SULFATE	-	-	1.0	-	-	56.0	-	-
730	IRON CHELATE	-	-	2.0	-	-	39.0	-	-
731	IRON COMPOUND	-	-	0.3	-	-	-	-	-
732	GYPSUM (CALCIUM SULFATE)	-	-	25.8	-	-	46.0	-	-
742	MAGNESIA (MAGNESIUM OXIDE)	-	-	22.0	-	-	-	-	-
744	EPSOM SALT (MAGNESIUM SULFATE)	-	-	5.3	-	-	1.4	-	-
745	MAGNESIUM CHELATE	-	-	7.6	-	-	-	-	-
754	MANGANESE SULFATE	-	-	2.6	-	-	3.0	-	-
764	SOIL AMENDMENT	-	-	1.2	-	-	8.1	-	-
765	SOIL ADDITIVE	-	-	1.1	-	-	-	-	-
767	POTTING SOIL **	-	-	2,885.1	16.8	18.5	1.0	-	-
770	SULFUR	-	-	1.1	-	-	-	-	-
773	CALCIUM CHLORIDE	-	-	0.1	-	-	-	-	-
774	SULFURIC ACID	-	-	-	-	-	2.1	-	-
797	SEC./MICRONUT. - CODE UNKNOWN *	-	-	46.3	-	-	2.0	-	-
798	SEC./MICRONUT. - CODE/GRADE UNKNOWN *	-	-	35.3	-	-	-	-	-
902	CALCIUM HYDROXIDE (HYDRATE)	-	-	20.3	-	-	-	-	-
903	STANDARD DOLOMITE	-	-	687.9	-	-	424.8	-	-
904	DOLOMITIC LIME (75% NEUTRAL)	-	-	569.4	-	-	-	-	-
906	CALCITIC LIME (75% NEUTRAL)	-	-	94.2	-	-	1.0	-	-
907	LIME PRODUCT - CODE UNKNOWN *	-	-	1,005.0	-	-	-	-	-
978	FERTILIZER PRODUCT - CODE/GRADE UNKNOWN **	-	-	126.9	2.9	17.9	48.2	-	-
988	SINGLE NUTRIENT - CODE/GRADE UNKNOWN *	-	-	2.2	-	-	-	-	-
990	SPECIALITY - CODE/GRADE UNKNOWN *	-	-	-	-	-	2.8	-	-
998	MULTIPLE NUTRIENT - CODE/GRADE UNKNOWN *	-	-	1.3	-	-	31.8	-	-
	Total Estimated Tons			8,722.0	164.6	89.9	3,570.0	67.3	29.1

* No estimate of N or P provided by Uniform Fertilizer Tonnage Reporting System (UFTRS) Codes
** Unique N & P values were provided by individual report entry

Florida Department of Agriculture and Consumer Services Fertilizer Licensing and Tonnage Reporting Fiscal Year 2012-2013 for Orange County, FL
General Public Records Request: P022321-070121

Product Code	Product Name	% N	% P	FY2012 2013 Tons by Farm Use Code (1)	Estimated Farm N Tons	Estimated Farm P Tons	FY2012 2013 Tons by Non-Farm Use Codes (2 6)	Estimated Non-Farm N Tons	Estimated Non-Farm P Tons
10	AMMONIUM NITRATE	34.0	-	125.0	42.5	-	-	-	-
24	AMMONIUM SULFATE	21.0	-	50.0	10.5	-	5.0	1.1	-
43	CALCIUM NITRATE	15.5	-	1.0	0.2	-	-	-	-
56	NITROGEN SOLUTION <28% *	-	-	30.0	-	-	-	-	-
203	DIAMMONIUM PHOSPHATE	18.0	46.0	1.0	0.2	0.5	-	-	-
218	BONE, PRECIPITATED	-	35.0	-	-	-	6.0	-	2.1
443	POTASSIUM-MAGNESIUM SULFATE	-	-	73.0	-	-	-	-	-
453	POTASSIUM NITRATE	14.0	-	40.0	5.6	-	-	-	-
463	POTASSIUM SULFATE	-	-	7.0	-	-	10,954.0	-	-
498	POTASH PRODUCT - CODE/GRADE UNKNOWN *	-	-	2.0	-	-	-	-	-
649	MANURE	0.5	0.5	-	-	-	32.9	0.2	0.2
665	SEWAGE SLUDGE, HEAT DRIED	6.0	2.0	7.0	0.4	0.1	-	-	-
706	BORAX	-	-	11.0	-	-	-	-	-
728	FERROUS SULFATE	-	-	1.0	-	-	50.0	-	-
730	IRON CHELATE	-	-	1.0	-	-	4.1	-	-
731	IRON COMPOUND	-	-	2.7	-	-	-	-	-
732	GYPSUM (CALCIUM SULFATE)	-	-	1,312.6	-	-	114.0	-	-
742	MAGNESIA (MAGNESIUM OXIDE)	-	-	3.0	-	-	-	-	-
744	EPSOM SALT (MAGNESIUM SULFATE)	-	-	13.0	-	-	-	-	-
754	MANGANESE SULFATE	-	-	8.0	-	-	-	-	-
764	SOIL AMENDMENT	-	-	27.0	-	-	-	-	-
770	SULFUR	-	-	3.0	-	-	12.0	-	-
782	ZINC SULFATE	-	-	2.0	-	-	-	-	-
797	SEC./MICRONUT. - CODE UNKNOWN *	-	-	18.0	-	-	10.0	-	-
798	SEC./MICRONUT. - CODE/GRADE UNKNOWN *	-	-	16.0	-	-	-	-	-
902	CALCIUM HYDROXIDE (HYDRATE)	-	-	-	-	-	4.0	-	-
903	STANDARD DOLOMITE	-	-	1,462.6	-	-	724.5	-	-
905	STANDARD CALCITE	-	-	128.5	-	-	11.0	-	-
978	FERTILIZER PRODUCT - CODE/GRADE UNKNOWN *	-	-	1.0	-	-	-	-	-
988	SINGLE NUTRIENT - CODE/GRADE UNKNOWN *	-	-	3.0	-	-	-	-	-
990	SPECIALITY - CODE/GRADE UNKNOWN *	-	-	-	-	-	1.0	-	-
998	MULTIPLE NUTRIENT - CODE/GRADE UNKNOWN *	-	-	1.0	-	-	-	-	-
	Total Estimated Tons			3,350.4	59.4	0.6	11,928.5	1.2	2.3

* No estimate of N or P provided by Uniform Fertilizer Tonnage Reporting System (UFTRS) Codes