Final Report
Wekiva River Basin
Nitrate Sourcing Study

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List of Acronyms and Abbreviations

ac	acre
bls	below land surface
BMP	Best Management Practice
CAFO	concentrated animal feeding operations
CASTNET	Clean Air Status and Trends Network
cfs	cubic feet per second
CGW	groundwater concentrations
DIY	Do-It-Yourself
DPT	direct push technology
EMC	event mean concentration
F.A.C.	Florida Administrative Code
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
FDOH	Florida Department of Health
FS	Florida Statutes
ft^2	square foot
GIS	geographic information system
ha	hectare
HNO3-N	nitric acid nitrogen
ICU	Intermediate Confining Unit
in	inches
IRL	Indian River Lagoon
IFAS Extension	Institute of Food and Agricultural Sciences Florida Cooperative Extension Service
lb	pound
kg	kilograms
L	Liters
MACTEC	MACTEC Engineering and Consulting, Inc.
mg	milligrams
MGD	million gallons per day
mi^2	square mile
MT	metric tons
N	Nitrogen
N_2	nitrogen gas
NADP	National Atmospheric Deposition Program
NH_3	ammonia
NH3-N	nitrogen present as ammonia
NH_4	ammonium
NH4-N	nitrogen present as ammonium ion
NO2-N	nitrogen present as nitrite
NO_3	nitrate
NO3-N	nitrogen present as nitrate (often stated as nitrate nitrogen)
NO_x	nitrogen oxides
NTN	National Trends Network
OAWP	Office of Agricultural Water Policy

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List of Acronyms and Abbreviations (continued)

OSTDS	Onsite Sewage Treatment and Disposal Systems
RIB	rapid infiltration basin
SAS	Surficial Aquifer System
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
TKN	Total Kjeldahl Nitrogen is the mass of nitrogen present as ammonia, ammonium, and/or organic nitrogen
TN	total nitrogen
TMDL	Total Maximum Daily Load
µm	microns
UCF	University of Central Florida
UF	University of Florida
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
WAVA	Wekiva Aquifer Vulnerability Assessment
WMM	Watershed Management Model
WSA	Wekiva Study Area
WWTF	Wastewater Treatment Facilities
yr	year

Executive Summary

Description of Project Area

For purposes of this project, "Wekiva Basin" or "basin" refers to the area contributing groundwater recharge[1] to the Wekiva River and its tributaries, and the watershed of the Wekiva River (Figure ES-1). The Wekiva Basin is generally consistent with the Wekiva Study Area (WSA) as defined by F.S. Chapter 369.316, but not identical. The Wekiva Basin has an area of 415,000 acres (ac) [648 square mile (mi^2)], which is 37% larger than the WSA. The portion of the Wekiva Basin that is not part of the WSA is generally to the west and southwest of the WSA, in Lake County, and in areas that are less densely populated.

Project Goals

The Wekiva Parkway and Protection Act of 2004 (Chapter 369, Part III, FS) established the legislative framework for construction of a limited-access expressway across the Wekiva Basin in parts of Seminole, Orange and Lake counties, while providing enhanced protection to the Wekiva River ecosystem. Additional legislation passed in 2006 authorized funds to the Florida Department of Environmental Protection (FDEP) "to determine nitrate impacts to the system". The Wekiva River and Rock Springs Run have been identified as impaired by FDEP, with nitrate as a causative pollutant.

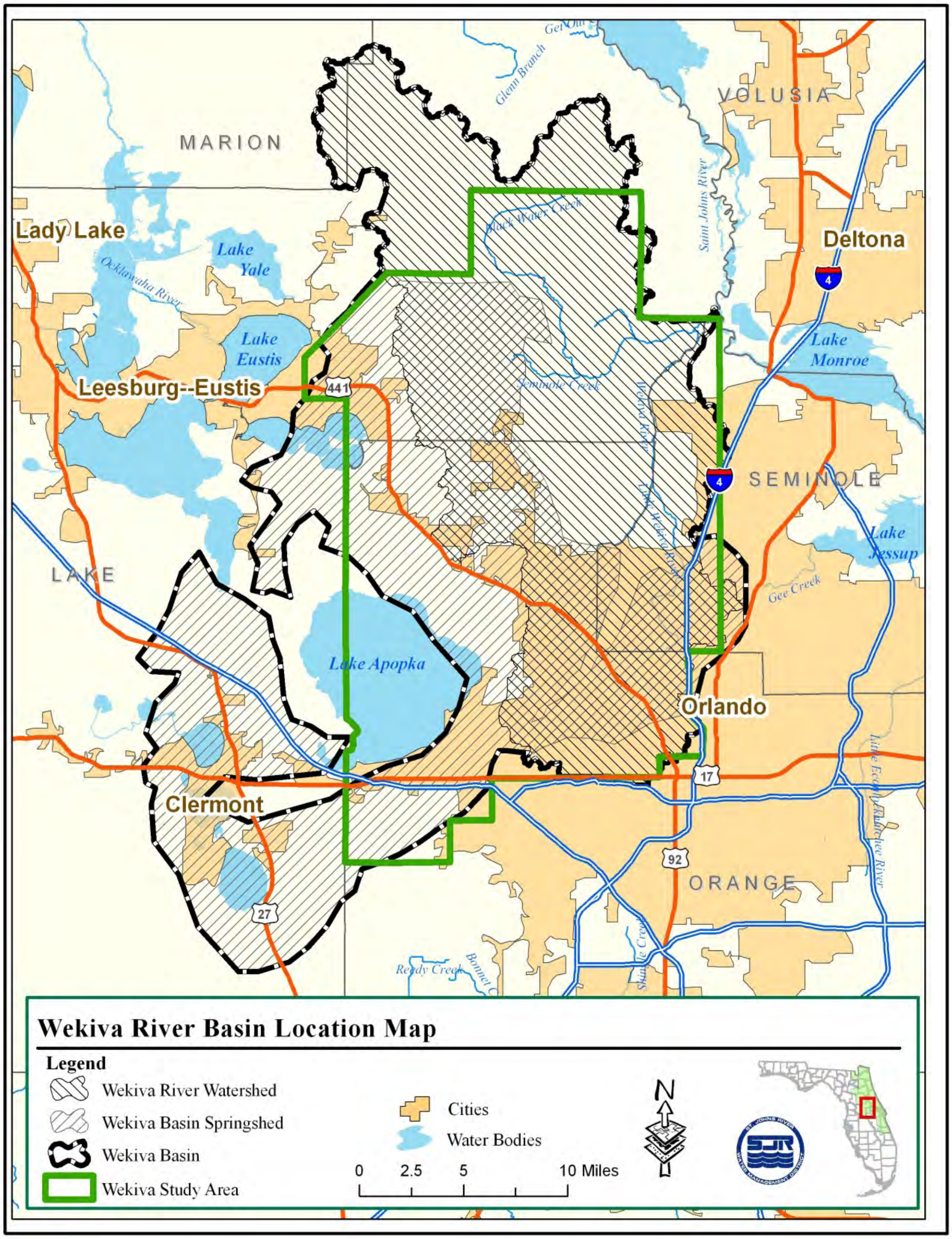
The Nitrate Sourcing Study was performed in two Phases. In Phase I existing information was collected and synthesized to produce a preliminary understanding of nitrate (NO_3) inputs to the basin and loadings to the Wekiva River. In Phase II, FDEP focused on an important area of uncertainty identified by the Phase I study – the effects of residential fertilizer use. To reduce uncertainty associated with this source type, FDEP funded the University of Central Florida (UCF) to survey residential fertilizer practices in the Wekiva Study Area (WSA), and the St. Johns River Water Management District (SJRWMD) to monitor water quality in the surficial aquifer in residential areas within the Wekiwa Springs springshed.

The Florida Department of Health (FDOH) performed companion studies in 2007, including groundwater monitoring in the WSA, focusing on effects of Onsite Treatment and Disposal Systems (OSTDS).

This Final Report presents a best estimate of inputs of nitrogen to the Wekiva Basin and nitrate loadings to the River, incorporating findings from recent state-funded studies within the study area and related technical information. The report also addresses stakeholder comments on the Phase I study.

[1] Recharge is the downward flow of water to a subsurface groundwater aquifer.

Figure ES-1. Project Location



Source: MACTEC and SJRWMD
Created by: JAT Checked by: WAT

Inputs of Nitrogen (Sources of Nitrate)Nitrogen is an important plant nutrient, and a major ingredient in commercial fertilizers. Nitrogen is also associated with human and other animal waste, and is found in raw sewage. Nitrate is a form of nitrogen that is highly soluble in water, so it migrates readily into groundwater. In surface waters, nitrate is a nutrient that can be used as food by algae and other plants, and excessive growth of such plants may cause nuisance conditions in springs, lakes, and rivers, often referred to as eutrophication.

Total nitrogen (TN) input to the Wekiva Basin was estimated for the following source types:

- Wastewater Treatment Facilities (WWTF) (sewer);
- Onsite Treatment and Disposal Systems (OSTDS) (septic systems);
- Fertilizer – Agricultural, Residential, Golf Course, and Other;
- Livestock; and
- Atmospheric Deposition

Nitrate from these sources is delivered to ground or surface waters of the Wekiva Basin by the following transport mechanisms:

- Direct discharge to surface waters (e.g., a wastewater outfall pipe that discharges to a river);
- Generation of stormwater runoff that flows to surface waters (stormwater-direct);
- Generation of stormwater in closed basins, or other stormwater that percolates to groundwater (stormwater-diffuse); and
- Infiltration to groundwater (e.g., the leaching process in which fertilizer applied in excess of crop or turfgrass requirements is carried by infiltrating rainwater to a groundwater aquifer).

Loadings

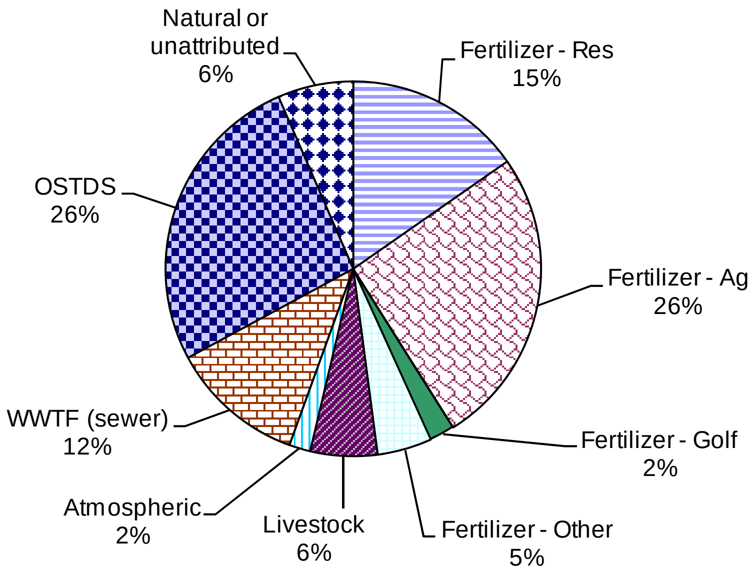
The delivery of nitrate to waters of the Basin by these transport mechanisms is referred to as "loading" in this report. Loadings represent a portion of the TN inputs that actually reach surface waters or groundwater in the Basin as nitrate. To understand the difference between inputs and loadings, as the terms are used here, consider fertilizer use. Inputs represent the total amount of fertilizer nitrogen applied on the land. Some of this fertilizer nitrogen is taken up by plants and incorporated into plant biomass. Not all the fertilizer nitrogen is taken up, however; some is lost during application, and some escapes the root zone, etc. The portion of the applied nitrogen that escapes the soil root zone as nitrate and dissolves in surface runoff or infiltrates to groundwater is a loading.

Results

It was estimated that in 2004, the rate of nitrate nitrogen[2] loading to groundwater and surface water in the Wekiva Basin was 1,800 metric tons per year (MT/yr). Most of this nitrate (about 93%) initially affects groundwater, with only a small amount discharged directly to surface waters. Figure ES-2 illustrates the apportionment of the total estimated loadings by source type.

[2] To compare various chemical forms of nitrogen it is customary to express amounts in terms of the mass of nitrogen in the chemical. For example the mass of nitrogen in nitrate is referred to as nitrate nitrogen or NO3-N

Figure ES-2. Nitrate Loadings to the Wekiva Basin, Partitioned by Source



Source: MACTEC
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Major contributors to total Basin loading include agricultural and residential fertilizer use, OSTDS and WWTF. Fertilizer use comprises about half (48%) of total loadings. Treated domestic wastewater (OSTDS and WWTF) comprises 38% of total nitrate loading. Livestock contribute 6% of the total loading. Approximately 8% of the total loading is natural or cannot be attributed to specific sources.

Residential land uses, which are affected by both fertilizer use, OSTDS, and reused WWTF effluent account for 41% of total loading, while agricultural land uses contribute 33%. Wastewater effluents are the predominant contributor to the utilities land use, which contribute 12% of total loadings of nitrate.

Residential land uses are major contributors to nitrate loadings, in part, because they comprise a large portion (21%) of the Wekiva Basin. Similarly transportation, utilities, commercial, industrial, institutional, and golf course land uses contribute a greater proportion of the nitrate loadings than their proportion of the acreage, while undeveloped land uses that make up more than 50% of the area of the Basin contribute only 6% of the nitrate loading.

Uncertainties

Several of the factors used to estimate inputs and loadings are uncertain, and the procedures themselves do not represent all factors that affect nitrate loadings. Sources of uncertainties are characterized in the report. Phase II investigations were targeted to reduce the most important sources of uncertainty. Results are based on the best available information at this time.

1.0 Introduction and Background

The Wekiva Parkway and Protection Act of 2004 (Chapter 369, Part III, FS) established the legislative framework for construction of a limited-access expressway across the Wekiva Basin in parts of Seminole, Orange and Lake counties, while providing enhanced protection to the Wekiva River ecosystem. Additional legislation passed in 2006 authorized funds to the Florida Department of Environmental Protection (FDEP) "to determine nitrate impacts to the system". Nitrate has been identified as a problem pollutant in springs and spring-run streams in Florida, including the Wekiva River and its main tributary, Rock Springs Run (Mattson, *et al*., 2006; Gao, 2008).

The FDEP contracted with the St. Johns River Water Management District (SJRWMD) to perform this nitrate sourcing work. MACTEC Engineering and Consulting, Inc (MACTEC) assisted the SJRWMD under three different contracts. The study was performed in two Phases. In Phase I existing information was collected and synthesized to produce a preliminary understanding of nitrate sources and loadings in the basin (MACTEC, 2007). In Phase II, FDEP focused on an important area of uncertainty identified by the Phase I study – the effects of residential fertilizer use. To reduce uncertainty associated with this source type, FDEP funded the University of Central Florida (UCF) to survey residential fertilizer practices in the Wekiva Study Area (WSA), and SJRWMD to monitor groundwater quality in the surficial aquifer in residential areas within the Wekiwa Springs springshed. MACTEC conducted the latter study under contract with SJRWMD.

The Florida Department of Health (FDOH) performed companion studies in 2007, including groundwater monitoring in the WSA, focusing on effects of Onsite Treatment and Disposal Systems (OSTDS).

This Final Report presents a best estimate of sources of nitrate to the Wekiva Basin, incorporating findings from these state-funded studies within the study area and related technical information. This report also addresses stakeholder comments on the Phase I study.

1.1 Description of Project Area

For purposes of this project, "Wekiva Basin" refers to (a) the area contributing groundwater recharge[3] to the Wekiva River and its tributaries as delineated by the SJRWMD Division of Groundwater Programs, and (b) the watershed of the Wekiva River (Figure 1-1).

The Wekiva Basin as shown in Figure 1-1 is generally consistent with the WSA as defined by F.S. Chapter 369.316, but not identical. The Wekiva Basin, which includes portions of Lake,

[3] Recharge is the downward flow of water to a subsurface groundwater aquifer.

Orange, Seminole, and Marion Counties, has an area of 415,000 acres (ac) [648 square miles (mi^2)], which is 37% larger in area than the WSA (303,000 ac or 473 mi^2). The population of the Wekiva Basin was approximately 423,000 in 2000, or 9% greater than the population of the WSA (388,000 in 2000)[4]. The portion of the Wekiva Basin that is not part of the WSA is generally to the west and southwest of the WSA, in Lake County, and in areas that are less densely populated. The additional area included within the Wekiva Basin for the purpose of this study is somewhat more rural and agricultural than the portion of the Basin included within the WSA (see Figures 1-2 and 1-3).

Groundwater in the Wekiva Basin generally occurs in three aquifer systems, the Surficial Aquifer System (SAS), overlying an Intermediate Confining Unit (ICU), and deeper, the Floridan Aquifer (McGurk and Presley, 2002). Springs within the basin are primarily fed by the Floridan Aquifer. Surface pollution, for example nitrate from fertilizers, initially enters the SAS, from which it can migrate downward through the ICU to the Floridan. The ICU generally has reduced permeability, which reduces the rate of flow from the SAS to the Floridan; however, the thickness and therefore the degree of confinement varies throughout the basin. The ICU is occasionally absent due to sinkholes and other solution cavities, such that the ICU is “leaky”.

1.2 Objectives of Project

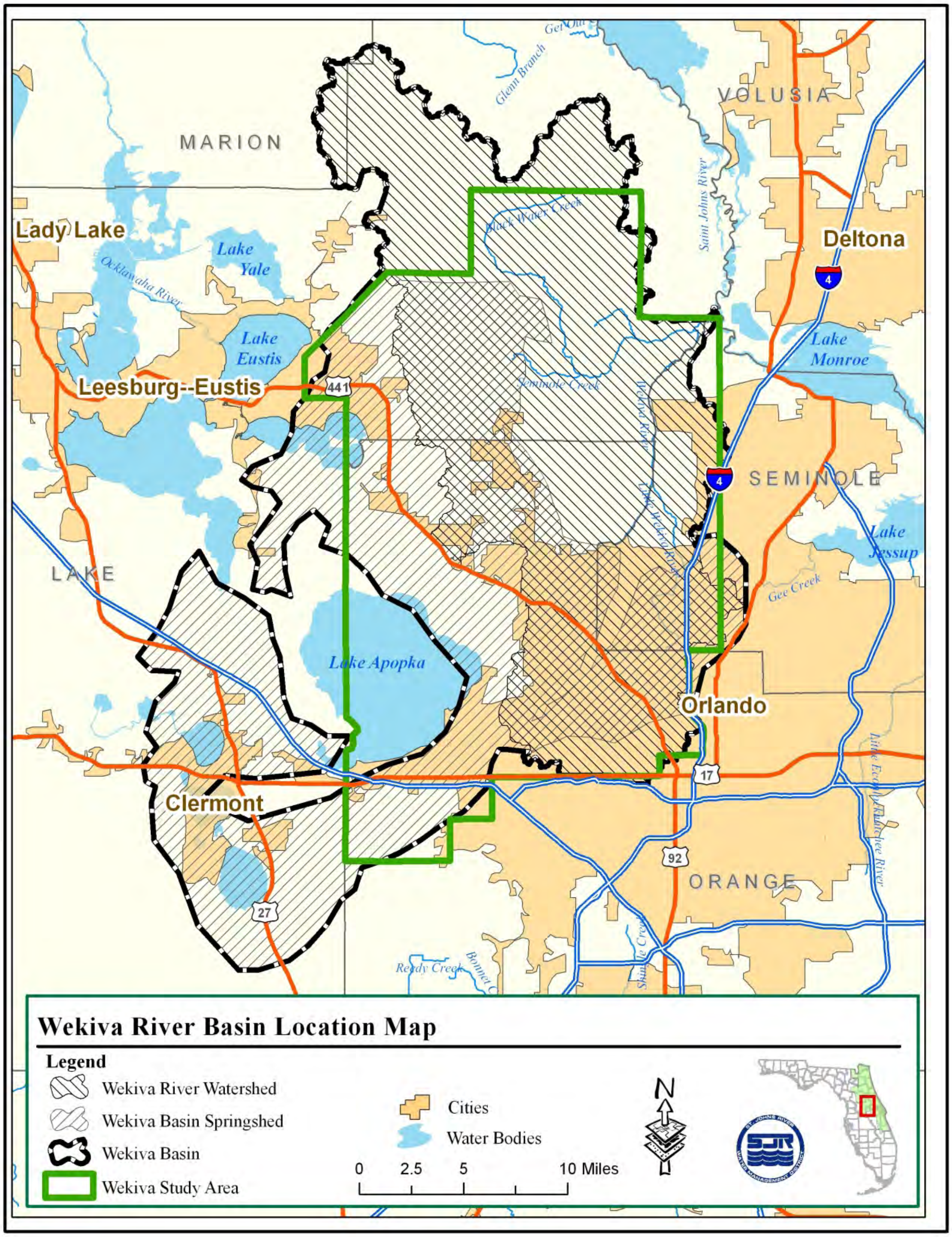
The objectives of this project include:

- Evaluate relevant information developed after publication of the Phase I report in 2007 including Phase II monitoring conducted by FDEP/SJRWMD/MACTEC and FDOH/Ellis & Associates; residential fertilizer practices survey performed by UCF, stakeholder comments on the Phase I report, and other pertinent technical information;
- Revise the Phase I nitrate budget for the Wekiva Basin, as appropriate;
- Apportion the loadings by source type and land use; and
- Prepare a report that summarizes the above.

The base year for estimates provided in this report is 2004 because the estimates are closely related to land use, and the most current land use map available from the SJRWMD at the time of publication characterizes land use in 2004. The estimates do not account for Best Management Practices (BMPs) implemented after 2004.

[4] Note: Various statistics presented in this report are based on land use in 2004, while these population statistics are based on the 2000 U.S. census. Population is increasing rapidly in the Basin – acreage in residential land use increased by 10% from 1999 to 2004.

Figure 1-1. Project Location



Source: MACTEC and SJRWMD
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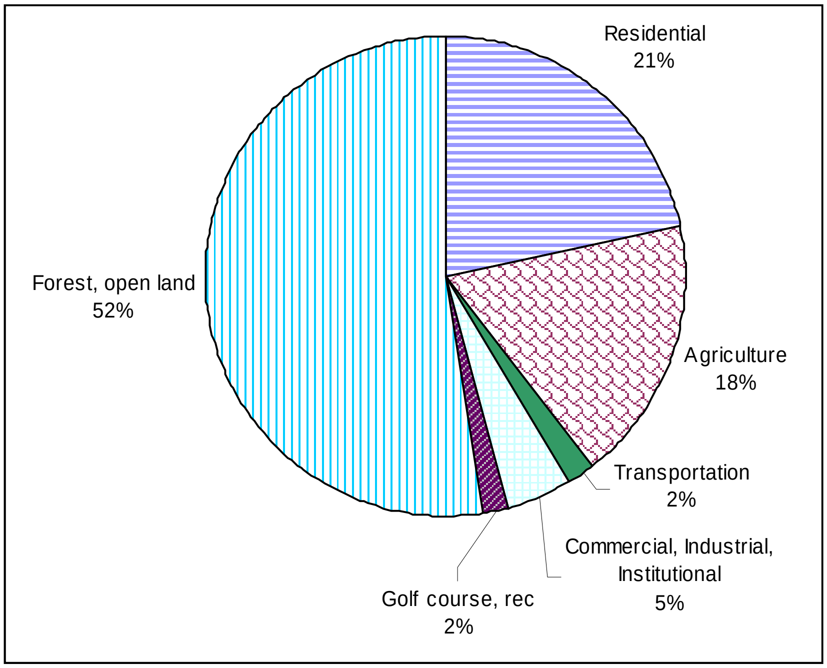
Figure 1-2. Land Use in 2004, Wekiva Basin



Source: MACTEC and SJRWMD
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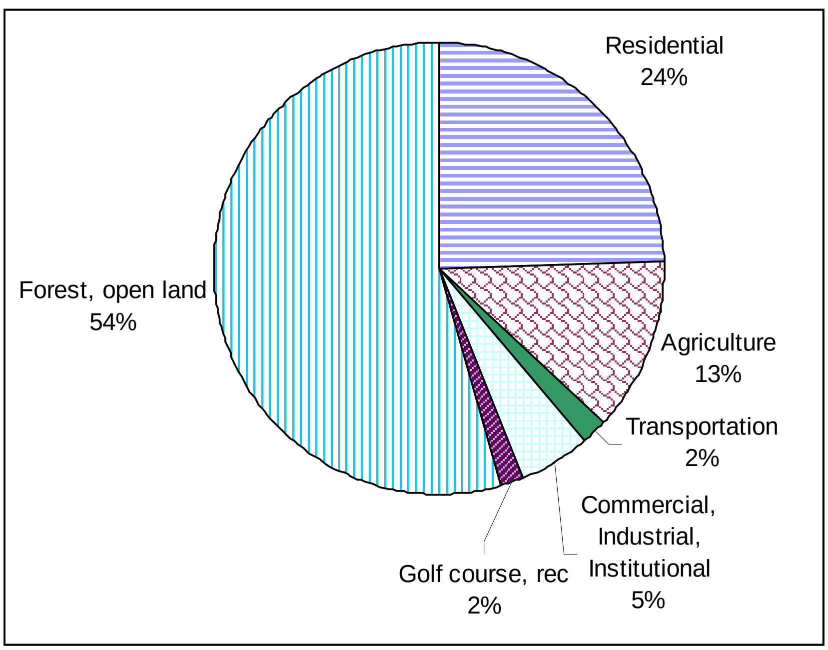
Figure 1-3. Land Use in 2004, Wekiva Study Area



Source: MACTEC and SJRWMD
Created by: SAR Checked by: WAT

2.0 Approach to Nitrate Loading and Partitioning

Existing information and models were collected and synthesized to produce a preliminary understanding of nitrate sources and loadings in the Wekiva Basin.

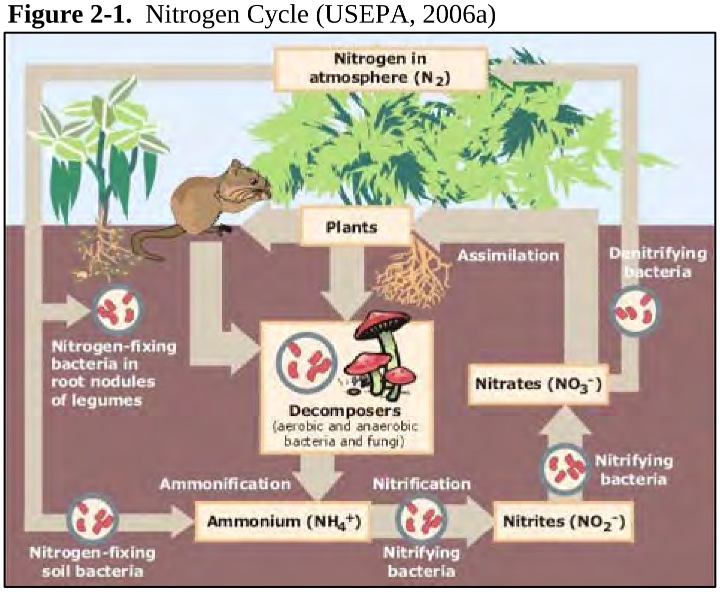
2.1 Review of Available Information

Information sources specified by FDEP and SJRWMD were reviewed. The SJRWMD provided MACTEC with two bibliographic searches conducted by others, and MACTEC identified additional references by review of reference lists of publications reviewed and by keyword search of multiple web-based databases. References identified were then further reviewed for relevance to the project, and copies of technical publications were acquired. The acquired publications were reviewed by the project team to determine their value to the study. In all, approximately 250 technical publications were acquired and reviewed for relevance. The entire list of references consulted appears in Appendix A. Publications actually cited in the report are in Section 4.0 References.

2.2 Conceptual Model of Nitrate Loading to Waters of the Wekiva Basin

2.2.1 The Nitrogen Cycle

Figure 2-1. Nitrogen Cycle (USEPA, 2006a)



Nitrate (NO_3) is an anion that participates in the complex nitrogen cycle (Figure 2-1) in the earth's biosphere (see, for example, Loreti, 1988; the nitrogen cycle is also described on a variety of websites). Nitrate may be either created or destroyed in the biochemically active root zone, in surface water and groundwater.

Nitrogen gas (N_2) comprises about 78% of the atmosphere. Nitrogen is essential for many biological processes, but is not readily available to plants or animals in the N_2 form. In nature, N_2 is converted to biologically usable forms [ammonium (NH_4), nitrate or nitrite (NO_2) ions] by some algae and bacteria, a process called fixation. These anionic forms can be taken up by plants, which convert them to amino acids and proteins, a process known as assimilation; while the reverse decomposition reaction is known as mineralization. Decomposition in anaerobic environments generally yields ammonia (NH_3) or ammonium ions, a process called ammonification. Nitrification is the process whereby microorganisms convert organic nitrogen[5] to nitrate and nitrite. Nitrification is favored in aerobic environments, while ammonification is more likely to occur in reducing environments[6]. Finally, denitrification is a biochemical process that converts nitrate or nitrite ions back to N_2, completing the nitrogen cycle (Cohen, *et* al., 2007). Denitrification depends on the availability of electron donors used by autotrophic bacteria. The electron donors, typically pyrite or ferrous silicates, are rare in the Florida environment. Additionally, when calcium, pH, alkalinity and/or specific conductance are high, denitrification is less likely to occur. All of these parameters are characteristically high in Florida's groundwater. Consequently, denitrification is generally negligible in groundwater in Florida (Cohen, *et* al., 2007). Denitrification has been shown to occur in shallow groundwater in Florida where the water table is near the surface (McNeal, *et al*., 1995; Crandall, 2000).

In soils, organic nitrogen and ammonia are more likely to be associated with solids than nitrate, which is highly soluble and not sorbed to any significant extent (Loreti, 1988). Although ammonium ion is soluble, it is more readily sorbed to soils, and thus not as leachable as nitrate (Cohen, *et* al., 2007). This is one reason that nitrate represents a more significant water quality concern than other forms of nitrogen.

Based on the importance of these processes in the environment, nitrate cannot be considered a conservative (never changing) constituent. Nitrate applied as fertilizer may be assimilated by plants, or denitrified and returned to the atmosphere. Ammonium in fertilizers or in animal waste may be converted to nitrate in soil or water, and so on.

This project did not attempt to quantify these processes in the Wekiva Basin. Certain simplifying assumptions and/or conventions were adopted that partially account for some features of the nitrogen cycle. The target constituent for this study is nitrate. Although it was not feasible to account for all the complex biochemistry of the nitrogen cycle, a limited attempt was made to account for assimilation by plants and other processes that occur in the root zone. Specifically it was not assumed that all fertilizer nitrogen (N) applied to the land surface would reach ground and/or surface water of the Wekiva Basin as nitrate. Specific procedures were adopted that were intended to more realistically account for the inputs, cycling and loadings to water, as described in the following sections.

2.2.2 Conceptual Model

Figure 2-2 presents a conceptual model of nitrate movement from sources (inputs) to loadings to waters of the Wekiva Basin. The model, developed as an organizing concept for this study, defines terms in the nitrate budget of the Wekiva Basin to be quantified in this project.

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[5] Organic nitrogen, such as proteins, amino acids, and urea, includes nitrogen in organic compounds found within living organisms and decaying plant and animal tissues.
[6] A reducing environment is one characterized by little or no free oxygen. In soils, reducing environments are more common in wetlands and where soils are rich in organic matter.

In Figure 2-2, source types of nitrogen are on the left, while the arrows represent transport mechanisms that deliver nitrate to either groundwater or surface waters of the Wekiva Basin. The text summarizes key principals or assumptions that guided the quantification of each term in the nitrate budget.

Inputs of nitrogen from the following source types were quantified:

- Wastewater Treatment Facilities (WWTF)
- OSTDS
- Fertilizer – Agriculture
- Fertilizer – Residential
- Fertilizer – Golf Course
- Fertilizer – Other
- Livestock
- Atmospheric Deposition

For each of these sources, the annual rate of total nitrogen (TN) released to the environment within the Wekiva Basin (inputs) was estimated.

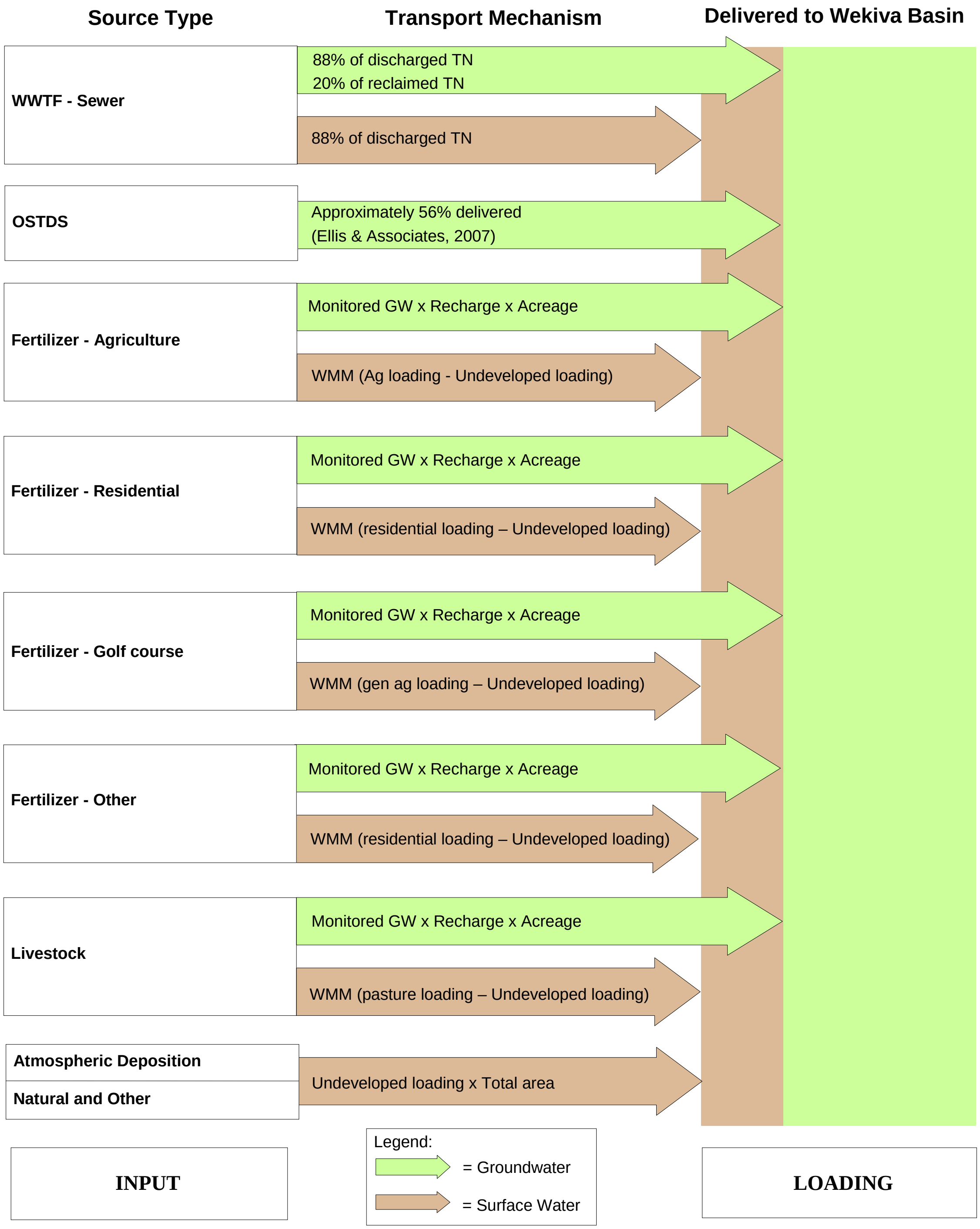
Nitrate from these sources is delivered (loaded) to ground or surface waters of the Wekiva Basin by the following transport mechanisms:

- Direct discharge to surface waters (e.g., a wastewater outfall pipe that discharges to a river);
- Generation of stormwater runoff that flows to surface waters (stormwater-direct);
- Generation of stormwater in closed basins, or other stormwater that percolates to groundwater (stormwater-diffuse); and
- Infiltration to groundwater (e.g., the leaching process in which fertilizer applied in excess of crop requirements is carried by infiltrating rainwater to a groundwater aquifer).

Each of these transport mechanisms was quantified. The delivery of nitrate to waters of the Basin is referred to as "loading" in the remainder of this report. Loadings consistently represent NO3-N[7] loading, not TN. Procedures for each mechanism are described below. Procedures were developed to partition loadings in two ways – by source type and by land use.

[7] NO3-N is the amount of nitrogen present as nitrate, often referred to as "NO_3 expressed as N" or "nitrate nitrogen". Chemical analyses of nitrate are customarily presented in this form. Although the NO_3 ion has an ionic weight of 62, only 23% of the ionic weight is comprised of nitrogen. Expressing NO_3 mass or concentration in this way permits ready comparison with the mass of other nitrogen containing chemicals, which are customarily also expressed as "N". The analytical method routinely used to measure nitrate actually measures nitrate plus nitrite, however under environmental conditions nitrite is usually a very small fraction of nitrate, so the analyses reported here are based on the assumption that nitrate plus nitrite is equivalent to nitrate.

Figure 2-2. Conceptual Model of Nitrate Inputs to the Wekiva Basin



Note:

Ag	=	Agriculture
GW	=	groundwater; recharge is the downward flow of water to a subsurface groundwater aquifer
OSTDS	=	Onsite Sewage Treatment and Disposal Systems
TN	=	total nitrogen
WMM	=	Watershed Management Model (used to estimate stormwater loadings)
WWTF	=	Wastewater Treatment Facilities

Source: MACTEC
Created by: WAT Checked by: SAR

2.3 Procedures – Nitrogen Inputs to the Basin

Inputs to the Basin include direct application (use) of fertilizer; animal waste production, which is assumed to be released to the environment; atmospheric deposition (wet and dry); WWTF effluents; and OSTDS discharges. Inputs and loadings per area are presented in this report in metric units of kilogram per hectare per year (kg/ha/yr). Results for the entire Wekiva Basin are presented in metric tons per year (MT/yr).[8]

Appendix D contains a summary of inputs by land use and source type.

2.3.1 Fertilizer Use

The general procedure for estimating fertilizer use was to assume fertilizer is applied at rates recommended by the University of Florida Institute of Food and Agricultural Sciences Florida Cooperative Extension Service (UF/IFAS Extension), with limited modifications if there is evidence that actual usage differs from UF/IFAS Extension recommendations.

2.3.1.1 Residential, Commercial, Institutional and Transportation

Fertilizer use for residential, commercial, institutional, and transportation land uses was estimated using the following equation:

$$Fertilizer\,Use_{LU} = \frac{Pervious\,Fraction_{LU} \;x\; Application\,Rate_{LU} \;x\; Area_{LU}}{CF}$$

Where *Fertilizer Use*$_{LU}$ = TN contained in fertilizer applied for a specific land use (LU), totaled for that land use over the entire Wekiva Basin; (MT/yr)

Pervious Fraction$_{LU}$ = Fraction of the land use area that is not paved or under roof;

Application Rate$_{LU}$ = Application rate of TN in fertilizer (kg/ha/yr);

Area$_{LU}$ = Area within a given land use classification totaled over the entire Wekiva Basin (ha); and

CF = conversion factor to achieve desired units of measurement, 1000 (kg/MT).

Harper (1994) was used to estimate pervious fraction for each land use. The basis for application rate for each land use follows.

Residential

UF/IFAS Extension recommends application of fertilizer containing 98 to 269 kg TN/ha/yr in Central Florida, depending on the variety of turfgrass (Sartain, 2007). Hipp, *et al.* (1993) and Morton, *et al.* (1988) provide survey and/or anecdotal information that suggest a range from 122 to 450 kg/ha/yr. Of course some homeowners do not fertilize at all, therefore, the lower end of

[8] One kilogram equals 2.205 pounds (lb); one hectare equals 2.472 acres (ac); and one metric ton equals 2,205 lb or 1.102 tons. To convert from metric to English units, multiply the loading rate in (kg/ha/yr) by 0.8920 to yield a loading rate in (lb/ac/yr).

the range is zero. Hodges, *et al*. (1994) surveyed Florida residents and found that 39% do not fertilize. Knox, *et al*. (1995) found that 82% fertilize, averaging three applications per year. Assuming each application is 50 kg/ha, Knox *et al*.'s (1995) findings indicate that most homeowners apply about 150 kg/ha/yr.

As a component of Phase II of this Nitrate Sourcing Study, UCF, under contract with FDEP conducted a survey of homeowners within the WSA to determine their turfgrass management practices and attitudes, including fertilizer use and irrigation practices (UCF, 2009). The UCF survey area was smaller than the WSA, but the surveyed area is expected to be representative of the WSA. Seven hundred forty (740) residents were interviewed by telephone, and 42 of the telephone survey participants were subsequently interviewed in person to determine if they were willing to participate in a Phase II groundwater monitoring program. UCF also conducted a windshield survey of residential subdivisions examining the health of turfgrass landscapes. UCF stratified their data set into two main categories: internal and external fertilizers. Internal fertilizers are those who apply fertilizer themselves (do-it-yourself or DIY), while external fertilizers rely on a commercial lawn service to apply fertilizer. Internal fertilizers generally had more complete knowledge of the rate of fertilizer use than people who relied on a commercial lawn service, but the limited information provided by external fertilizers indicates that commercial lawn services apply more fertilizer, on average, than the DIY residents. About half of all respondents were internal fertilizers (51% including those helped by friends or neighbors). One-third (33%) were serviced by a commercial lawn service, while 16% did not fertilize at all.

The internal fertilizers apply fertilizer 2.88 times per year on average; and UCF estimated, from survey responses, that the average application rate was 0.5 lb TN/1000 square foot (ft^2) per application (UCF, 2009; p. 6). This average practice results in a TN application rate of 70 kg/ha/yr. Thus, the DIY subset applies less fertilizer than recommended by Sartain (2007). External fertilizers reported that fertilizer was applied 4.76 times per year on average, but were generally not aware of the amount applied. The frequency is consistent with the frequency of a "high maintenance program" for St. Augustine grass recommended by Sartain (2007) to "produce an optimum quality turfgrass". Therefore, it is assumed that the commercial lawn service providers are applying at the Sartain (2007) "high maintenance" recommended rate for St. Augustine grass, i.e., 220 kg/ha/yr.

With 51% applying at 70 kg/ha/yr; 33% applying 220 kg/ha/yr; and 16% not fertilizing, the average residential application rate would be 108 kg/ha/yr on pervious surfaces. Although not all residential pervious surfaces are maintained in turfgrass, other residential landscapes include ornamentals which are also likely to be fertilized. Therefore, this rate was assumed to apply to pervious surfaces, rather than the area in turfgrass. The findings of the Phase II UCF survey are generally consistent with results reported by Knox, *et al*. (1995) in a broader survey of Florida residents.

Commercial, Institutional, Recreational, Transportation

Commercial land uses are assumed to apply fertilizer at the average rate recommended for Central Florida turfgrass by Sartain (2007), i.e., 168 kg/ha/yr. Institutional, recreational, and transportation land uses are assumed to receive fertilizer at the residential average rate of 108 kg/ha/yr. A higher rate for commercial properties is expected considering the commercial value of attractive landscaping.

2.3.1.2 Agricultural

Pervious fraction was assumed to be 1.00 for all agricultural land uses. Therefore, fertilizer use for all agricultural land uses was estimated using the following equation:

$$Fertilizer\,Use_{LU} = \frac{Application\ Rate_{LU}\ x\ Area_{LU}}{CF}$$

The basis for application rates for various agricultural land uses are summarized below.

Row Crops

Principal vegetables produced in the Wekiva Basin are cabbage, cucumbers, greens, spinach, sweet corn, eggplant, and peppers [U.S. Department of Agriculture (USDA, 2005)]. The U.S. Environmental Protection Agency (USEPA) (1999) provides average fertilizer use and ranges for each of these crops except greens. The average of these is 180 kg/ha/crop, ranging from 70 to 360 kg/ha/crop. UF/IFAS Extension (Hochmuth and Hanlon, 2000) recommendations for the same vegetables in Florida average 192 kg/ha/crop and range from 100 to 225 kg/ha/crop. Assuming the higher of the USEPA actuals and IFAS recommendations for each vegetable yields 210 kg/ha/crop (average of the seven crops). Kraft and Stites (2003) report that typical application to sweet corn exceeds Extension recommendations in Wisconsin. McNeal, *et al*. (1995) report that typical application rates to peppers, potatoes, and tomatoes substantially exceed UF/IFAS Extension recommendations (300-400 kg/ha/yr typical; 227 kg/ha/yr recommended). These anecdotal reports support using the higher of USEPA actuals or UF/IFAS Extension recommendations.

It is customary to produce two or three vegetable crops per year in central Florida. Therefore, fertilizer application rate per year may be two to three times higher than the application rate per crop. Although it is unlikely that fields consistently produce three crops per year, the anecdotal evidence that actual application rates exceeds UF/IFAS Extension recommendations supports the assumption that three times the fertilizer that would be applied to each crop is applied per year, with the resultant row crop application rate of 630 kg/ha/yr (3 crops/yr x 210 kg/ha/crop).

Field Crops

UF/IFAS Extension recommended fertilization rates for hay are 150 to 180 kg/ha/yr (Mylavarapu, *et al*., 2002). No anecdotal information was found indicating actual use differs. An application rate of 150 kg/ha/yr was assumed for field crops. This rate was also applied to land uses designated "cropland and pastureland."

Tree Crops, Nurseries, and Ornamentals

In Florida, most land designated as "tree crops" are used for citrus. UF/IFAS Extension (Zekri, *et al*., 2005) recommends 138 to 227 kg/ha/yr for established orange groves. Florida Department of Agriculture and Consumer Services (FDACS) has established 240 kg/ha/yr as a best management practice (BMP) for mature oranges, and 238 kg/ha/yr for grapefruit. MACTEC assumed the upper bound of IFAS recommendations and BMP for oranges will be actual.

This application rate (240 kg/ha/yr) was also assumed for nurseries and ornamentals.

Pasture

UF/IFAS Extension (Mylavarapu, *et al*., 2002) recommends between 56 and 179 kg/ha/yr depending on cattle product pricing, fertilizer pricing, and intensity of use. Sumner, *et al*. (1992) conducted a survey of nine ranches in Florida and found that actual application rates averaged 69 kg/ha/yr. Two of the nine ranches did not fertilize at all. The average of the minimum IFAS recommendation and the nine ranch average, or 63 kg/ha/yr, was assumed to be applied on improved pasture.

2.3.1.3 Golf Courses

UF/IFAS Extension (Sartain and Miller, 2002) recommends application rates for various golf course landscapes:

- Greens – 588 kg/ha/yr;
- Tees – 441 kg/ha/yr;
- Fairways – 294 kg/ha/yr; and
- Rough – 98 kg/ha/yr.

USEPA (2006b) has estimated the portion of golf courses in each of these conditions as:

- Greens – 2.4%;
- Tees – 2.6%;
- Fairways – 28.6%; and
- Rough and other – 66.4%.

Applying these percentages to the recommended application rates indicates that the average application rate on golf courses is 175 kg/ha/yr. No reliable information was identified that actual use differed from UF/IFAS Extension recommendations, so this average recommended application rate was applied to lands used as golf course.

2.3.2 Livestock

Anderson and Cabana (2006) estimate that cattle (including calves) produce on average 56 kg TN/yr. Sumner, *et al.* (1992) and Arthington, *et al.* (2003) indicate that pasture stocking rates in Florida range from 0.27 to 0.40 cattle/ac. USDA (2006) provides a cattle census by county. Given the acreage of pasture and feedlots in Lake, Marion, Orange, and Seminole counties, it appears that the average pasture stocking rate in the Wekiva Basin is approximately 0.3 cattle/ac (approximately 30 cattle/ac in feedlot land uses). The inferred stocking rates are consistent with industry practice, and produce total head of cattle in the counties comprising the Wekiva Basin within 2% of the USDA 1999 cattle census statistics. The inferred number of cattle in the Wekiva Basin is approximately 18,600.

At 0.3 cattle/ac (0.7 cattle/ha) times 56 kg/cattle/yr, livestock waste on pasture land is 41 kg/ha/yr. With 30 head per ac on feedlot land uses, waste production would be 4100 kg/ha/yr. Therefore, animal waste production of TN is:

$$Livestock\ Waste,\ Pasture\ (MT/yr) = \frac{41\ (kg/ha/yr)\ x\ Area\ (ha)}{1000\ (kg/MT)}$$

$$Livestock\ Waste,\ Feedlots\ (MT/yr) = \frac{4100\ (kg/ha/yr)\ x\ Area\ (ha)}{1000\ (kg/MT)}$$

In 2004, approximately 46,000 ac in the Wekiva Basin were used for pasture, while only 160 ac were used for feeding operations. As a result, feeding operations represent a relatively small contribution to inputs of TN in the Basin.

The number of horses stabled in the Wekiva Basin was not readily estimated from sources reviewed, nor was the production of TN per horse. Horses were accounted for in a crude manner, essentially as if they were cattle. Some pastureland is used to support horses, but all was assumed to support cattle. Horse farms were also included in the total area of land treated as pasture, so the total number of animals, modeled as if they were cattle, may include both horses and cattle. Horse farm acreage was also treated as pasture acreage. Although this approach is not ideal it accounts in a crude way for TN inputs from horses as well as cattle.

2.3.3 Wastewater Treatment Facilities (WWTF – sewer)

Most permitted effluent streams have not been required to monitor for TN unless they were discharging directly to surface waters, while most discharges are required to be monitored for NO3-N. As a result, there is a substantial database of NO3-N concentrations in WWTF effluents, but a very limited set of TN concentration results. Following a December 2008 change in FDEP permitting policy, WWTF with permitted discharge exceeding 100,000 gallons per day will be required to monitor for TN if they are in watersheds of water bodies impaired for nutrients or dissolved oxygen, and this requirement will be incorporated in permit renewals. Therefore, more data will be available to estimate TN inputs in the future than were available in preparation of this report.

To estimate TN inputs from this source type, a limited number of effluent samples from the Wekiva Basin that have been monitored for both TN and NO3-N were evaluated to determine a typical ratio of TN:NO3-N in effluents. Wastewater discharges of NO3-N to surface water and groundwater were estimated using monitored discharge rates and NO3-N effluent concentrations obtained from FDEP. Then the ratio of TN:NO3-N was applied to the NO3-N discharge rates to estimate TN inputs to the Basin.

Permitted domestic and industrial wastewater discharge facilities within the Wekiva Basin were obtained from the FDEP Wastewater website (FDEP, 2006). Facilities were segregated into industrial and domestic effluents. Within the Basin there were three (3) industrial dischargers with the potential to emit NO_3 and 53 permitted domestic discharges. Permits were obtained from FDEP for the industrial dischargers. Due to the large number of domestic dischargers, the permitted facilities were sorted by permitted capacity, and the largest 26 facilities were selected for NO_3 loading quantification. These 26 facilities encompassed 99% of the total permitted capacity within the Wekiva Basin. Permits were obtained from FDEP for these 26 facilities.

Permits for the 3 industrial and 26 domestic wastewater facilities were reviewed. Eleven of the 29 facilities are either not required to monitor for NO3-N in effluent, have no available nitrate monitoring data, or have no discharges. The remaining 18 are required to monitor NO3-N concentrations in effluent. For these 18 facilities effluent NO3-N concentrations and actual discharge rates during the period 2004-2006 were obtained from FDEP (Sudano, 2006).

Effluents were segregated by disposal type (e.g., sprayfield, percolation basins, rapid infiltration basins (RIBs), surface water discharge), and subsequently separated into two categories, discharge to surface water or groundwater. In addition, several facilities have a reclamation/reuse disposal system. Inputs of wastewater effluents to groundwater, surface water, and reclaimed/reused were estimated by:

$$Input = \frac{Actual\,Discharge x\ Concentraton\,(NO_3 - N) x\ TN / NO3 - N}{CF}$$

Where *Input* = Wastewater facility effluent (MT/yr);
Actual Discharge = Total annual discharge (L/yr);
Concentration (NO3-N) = Average effluent concentration of NO3-N during 2004 through 2006 (mg/L); and
TN/NO3-N = Ratio of TN:NO3-N in effluents (limited monitoring);
CF = Conversion Factor to achieve desired units of measurement (1×10^9 mg/MT).

Total NO3-N discharged to groundwater from permitted facilities was estimated at 180 MT/yr. Direct discharges to surface water were 9 MT/yr. The amount of NO3-N that is reclaimed/reused was estimated at 109 MT/yr (see Appendix D).

Effluents from two WWTF in the Wekiva Basin have been monitored for TN. These are the two largest NO3-N discharges in the Basin: Orange County's Northwest Water Reclamation Facility, which discharges part of its effluent to a treatment wetland, and the Water Conserv II facility, jointly owned by the City of Orlando and Orange County Utilities. From the Northwest Reclamation Facility, 15 samples were collected during 2005 and 2006 and analyzed for both TN and NO3-N. For Conserv II, one sample was collected in 2009 and analyzed for both parameters. The average TN:NO3-N ratio of these 16 samples was 1.14. This ratio was applied to the NO3-N discharge rates to estimate the total TN input from WWTF of 339 MT/yr.

Industrial wastewater contributes a negligible amount of NO3-N to the Wekiva Basin, at 0.04 MT/yr.

Appendix E contains a summary of the WWTF that were evaluated during this study, and their estimated TN loadings.

2.3.4 Onsite Treatment and Disposal Systems (OSTDS - septic tanks)

FDOH (Roeder, 2006) provided MACTEC with a geographic information system (GIS) map layer identifying the location of all known OSTDS in the WSA. The FDOH OSTDS inventory was developed from 1990 US Census data, FDOH permit files, and consideration of areas served by sewer systems (Roeder, 2006). The primary basis of the FDOH WSA OSTDS inventory was the identification of improved parcels that are not paying for sewer service.

Although there is substantial overlap in the footprint of the Wekiva Basin as defined for this study and the WSA, they are not identical. Therefore, it was necessary to estimate the number of OSTDS in portions of the Wekiva Basin that are not included in the WSA. An estimate was developed under the assumption that the density of OSTDS (OSTDS/ac) was a function of land use. The density of tanks by land use was determined for the WSA, using the FDOH data, and then this same density was assumed in portions of the Wekiva Basin outside the WSA. By this procedure, the number of OSTDS in the Wekiva Basin was estimated to be approximately 65,000. Within the WSA, the FDOH data were used directly. Approximately 85% of the tanks are within residential land use categories, with the largest number in the medium density (2 to 6 dwelling units per ac) residential land use category.

The accuracy of the extrapolation procedure used to estimate the number of tanks in the Basin, but not in the WSA, was evaluated using the same OSTDS densities by land use to estimate the total number of OSTDS in Lake and Orange Counties, and these results were compared with

FDOH estimates of the total number of tanks in each county (using 1999 data for both land use and number of tanks) (FDOH, 2007). This test indicated extrapolation errors of 13% and 4% for Lake and Orange Counties, respectively. Considering these two extrapolation error tests, it appears that the OSTDS density by land use procedure is accurate to about 10%. Since only about 20% of the tanks in the Basin were estimated by the extrapolation method (the rest within the WSA are directly from the FDOH data), the estimate of 65,000 tanks in the Wekiva Basin is expected to be accurate to within about 2%.

Based on monitoring of OSTDS impacts at three locations within the Wekiva Basin, each tank was assumed to release 29 lb TN/yr to the environment (Ellis & Associates, 2007; Roeder, 2008).

2.3.5 Atmospheric Deposition

Deposition of atmospheric nitrogen species has been monitored in Florida by several researchers using differing procedures. TN deposition includes wet and dry deposition. Analytes comprising TN include NO3-N, nitric acid (HNO3-N), ammonia (NH3-N), ammonium (NH4-N), and organic nitrogen. The National Atmospheric Deposition Program / National Trends Network (NADP/ NTN) measures wet deposition of nitrate and ammonium at 8 sites in Florida, of which the closest to the Basin is approximately 20 miles southeast at the campus of the UCF in Orlando. USEPA's Clean Air Status and Trends Network (CASTNET) monitors dry deposition of HNO3-N, particulate NO3-N, and particulate NH4-N at three monitoring sites in Florida: one in the panhandle region (Sumatra), one near the Indian River Lagoon (IRL), and one in Everglades National Park. Of these, the IRL site would be expected to be most representative of the Wekiva Basin. The IRL site is at Coconut Point near Sebastian Inlet in northern Indian River County and is 87 miles southeast of Wekiva Springs.

The SJRWMD operated a wet deposition monitoring station at the IRL site using NADP procedures from 2001 through 2006. In addition to nitrate and ammonium, which are monitored by NADP, the SJRWMD also measured organic nitrogen. Results were analyzed by Rogers (2007).

Figure 2-3 presents annual deposition totals for these three stations in Florida from 2001 to 2006. These results combine wet deposition of NO3-N and NH4-N and dry deposition of NO3-N, HNO3-N, and NH4-N at all sites but also includes organic nitrogen at the IRL site. Since 2000, the Florida sites have reported similar TN deposition rates with annual values ranging from 2.6 to 5.1 (kg/ha/yr). The average deposition rate at the IRL site is 3.9 ± 0.4 (kg/ha/yr).

TN deposition rates are expected to be higher in urban areas. Nationwide, approximately half of nitrogen oxide (NO_x) emissions are from mobile sources, e.g., automobiles. Poor, *et al.* (2001) measured TN deposition rates in the Tampa metropolitan area from 1996 to 1999. They observed a deposition rate of 7.3 ± 1.3 kg/ha/yr. In addition to the parameters accounted for at

CASTNET/NADP sites, Poor, *et* al. (2001) determined dry deposition of ammonia. Ammonia deposition over Tampa Bay can be impacted either positively (down) or negatively (up) by the bi-directional flux of the analyte due to air-sea interactions. The dry deposition of ammonia, which Poor, *et al.* (2001) estimate may account for approximately 30% of TN deposition in the Tampa area, can be either increased or decreased by this process depending on the relative concentrations of ammonia in the Bay and the atmosphere. Periods of negative deposition reduced the ammonia dry deposition rate, and therefore the TN deposition rate, by 0.7 kg/ha/yr. Over land, this negative component of deposition would not occur. Their dry deposition procedure also did not account for particles larger than 2.5 microns (μm), while CASTNET devices collect particles as large as 10 μm. Poor, *et al.* (2001) conclude this may result in an underestimate of TN deposition by 0.5 to 1.5 kg/ha/yr. Finally, they did not account for organic nitrogen, which was included in wet deposition measurements conducted by the SJRWMD.

Table 2-1 summarizes TN deposition information from IRL and the Tampa metropolitan area, showing the components of TN that were quantified and the measured deposition rates. None of the monitoring programs captures dry deposition of organic nitrogen, so its contribution remains unknown. Each program has certain distinct deficiencies, which are accounted for as follows:

- Poor, *et al*. (2001) found that dry deposition of NH3-N accounts for approximately 32% of TN deposition in the Tampa Bay area. When considering the common analytes analyzed by Poor, *et al.* (2001) and CASTNET/NADP, the dry deposition of NH3-N equaled 46% of the components quantified at CASTNET/NADP stations. At IRL, these same components (all except organic nitrogen) account for 3.6 kg/ha/yr. Therefore the IRL (rural) value should be adjusted to 3.9 + 0.46 x 3.6 = 5.6 kg/ha/yr. Apply this to rural areas within the Wekiva Basin.
- The Wekiva Basin is primarily land, so the negative impact to NH3 dry deposition observed over Tampa Bay will not occur – add 0.7 kg/ha/yr to Poor, *et al.*'s (2001) results to estimate overland deposition in urban areas of the Wekiva Basin.
- Add 1 kg/ha/yr to the Tampa results to account for particles larger than 2.5 μm.
- Therefore deposition of TN in urban areas within the Wekiva Basin is estimated as 7.3 + 0.7 + 1.0 = 9.0 kg/ha/yr.

The higher urban rate (9.0 kg/ha/yr) is assumed to occur in the following urban land uses: medium and high density residential; transportation, communication, and utilities; and commercial and services. The rural rate (5.6 kg/ha/yr) is assumed to occur in low density residential, agricultural, and undeveloped land uses.

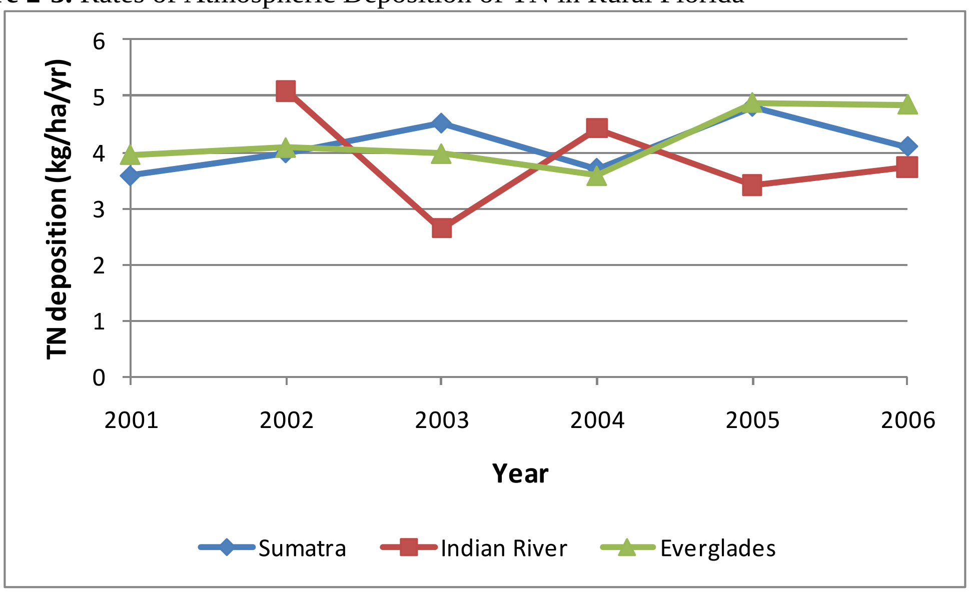
Nitrogen deposition rates could also be higher in agricultural areas where fertilizers are routinely applied, but fertilizer use has been accounted as TN applied, without accounting explicitly for volatile or other application losses. Therefore, if atmospheric deposition rates are higher in and downwind of agricultural areas due to application/volatile losses of applied fertilizer, these amounts are already included in the fertilizer application totals.

Table 2-1. Summary of TN Deposition Rates at Two Florida Sites

Site			IRL	Tampa Bay
Type			rural	urban
Source			CASTNET / SJRWMD	Poor, *et al*. (2001)
Components Quantified	**Dry**	NO3-N	✓	✓
		HNO3-N	✓	✓
		NH4-N	✓	✓
		NH3-N		✓
		Organic N		
		Particles > 2.5 μm	✓	
	Wet	NO3-N	✓	✓
		NH4-N	✓	✓
		Organic N	✓	
Deposition Rate (kg/ha/yr)			3.9	7.3

Created by: WAT Checked by: CMR

Figure 2-3. Rates of Atmospheric Deposition of TN in Rural Florida



Source: MACTEC.
Created by: WAT Checked by: CMR

2.4 Loadings to Waters of the Basin

A portion of the nitrogen released to the environment actually reaches groundwater or surface waters of the Basin. In particular, a significant portion of nitrogen applied to the land as fertilizer is used by plants in the root zone. Denitrification processes also convert NO_3 to N_2, which is released to the atmosphere. A portion of TN in fertilizers and in wastewater effluents is volatilized as ammonia. Consequently, only a portion of the nitrogen input to the Basin will reach ground and surface waters. The nitrate delivered to waters of the Basin will be referred to here as loading.

Available information was sufficient to support estimation and partitioning of loads to groundwater at the water table (generally to the surficial aquifer) and to surface water. The portion of the groundwater load (at the water table) that eventually reaches the Floridan aquifer is expected to be significant (Cohen, *et al*., 2007), but that portion has not been quantified.

The following subsections summarize the procedures and information sources used to estimate loadings, which are primarily based on land use, as well as procedures used to partition those loadings to specific source types.

The primary basis for estimating loadings to waters of the Basin was distinct for the following loading or delivery categories:

- Groundwater recharge as a function of land use,
- Stormwater loadings as a function of land use,
- WWTF (sewer), and
- OSTDS (septic tanks).

Appendix F contains a summary of estimated nitrate loadings by land use and source type.

2.4.1 Groundwater Recharge

Loadings to groundwater associated with various land uses were estimated by multiplying shallow groundwater concentrations (CGW) representative for each land use by the recharge rate (by location) using the following equation:

$$Groundwater\ Loading_{LU} = \frac{Recharge\ x\ CGW_{LU}\ x\ Area_{LU}}{CF}$$

Where $Groundwater\ Loading_{LU}$ = Amount of NO3-N reaching the water table from specific land uses (MT/yr);

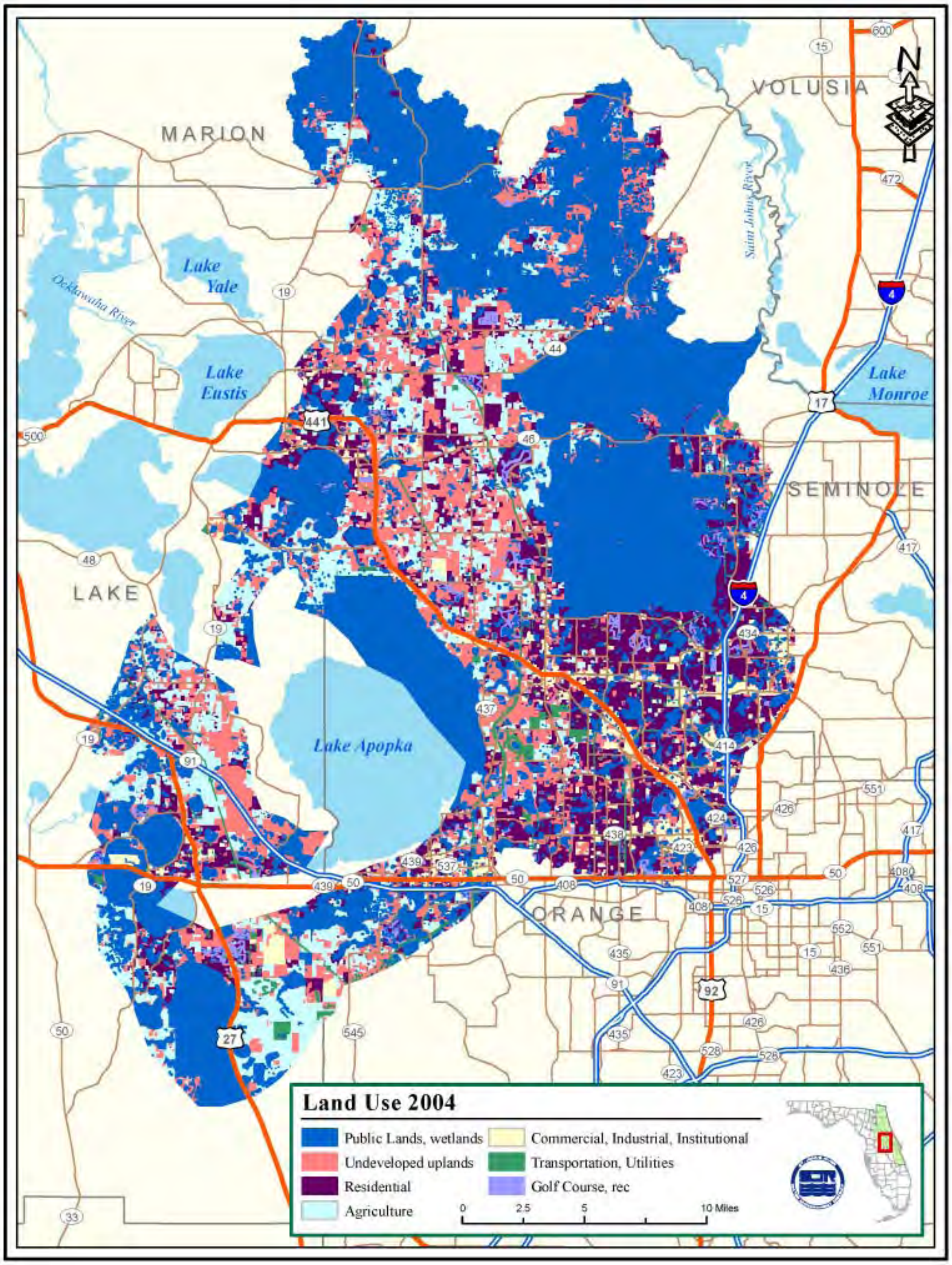
Recharge = downward flow of water to the Floridan aquifer (inch/yr);

CGW_{LU} = Concentration of NO3-N in recharging groundwater, estimated here from concentrations near the water table (mg/L); and

CF = Conversion Factor to achieve desired units of measurement, 3937 (mg inch ha/MT L).

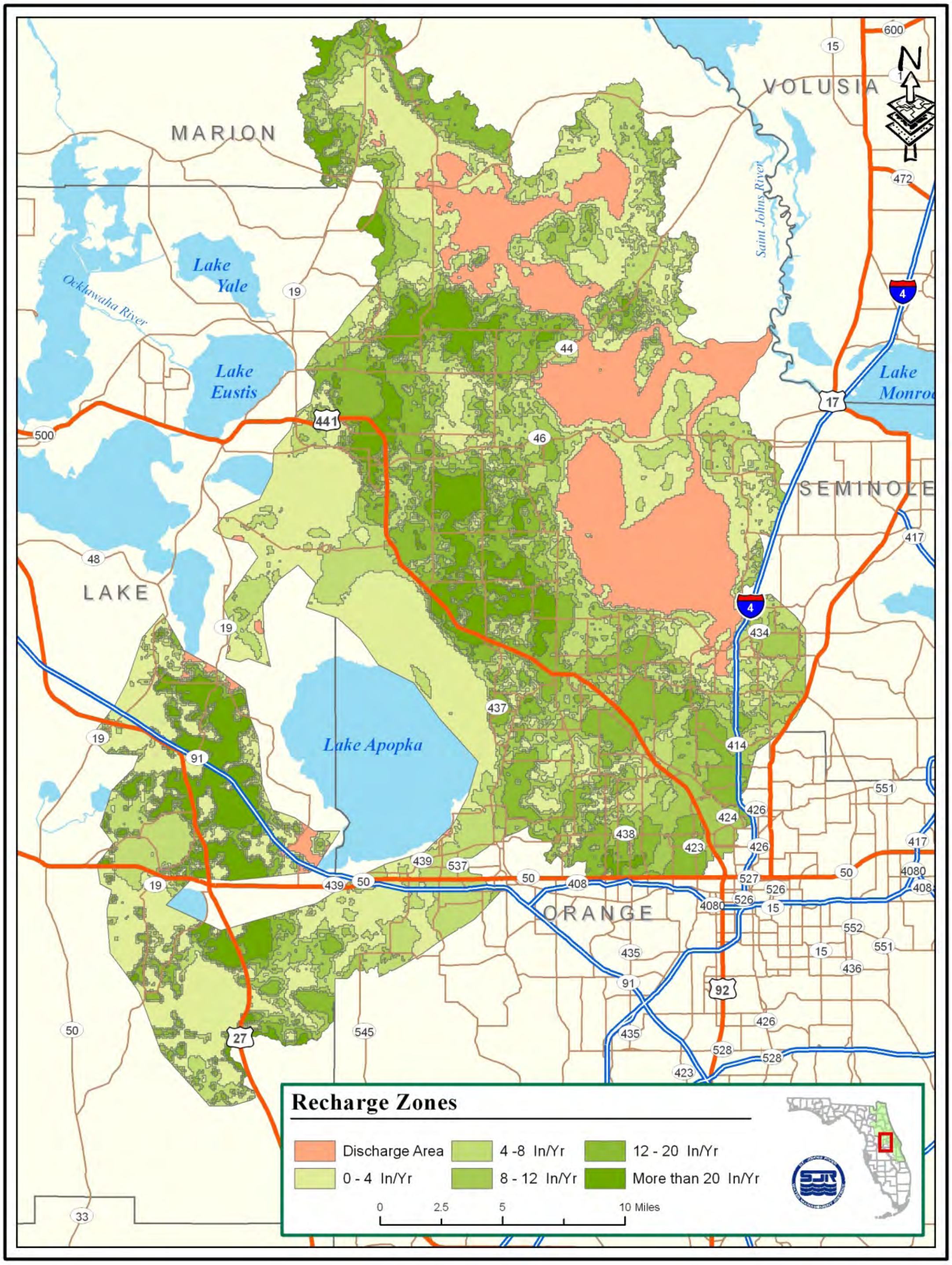
The calculation is performed for each land use category and recharge rate (after overlaying land use and recharge rate using GIS software), then summed across the entire Basin, by land use. Figures 2-4 through 2-6 illustrate the application of this procedure. Figure 2-4 shows land use in the Basin, and Figure 2-5 shows recharge rates. When the two maps are overlaid, using ArcGIS™, a matrix of area by land use and recharge rate was developed, as illustrated in Figure 2-6.

Figure 2-4. Land Use



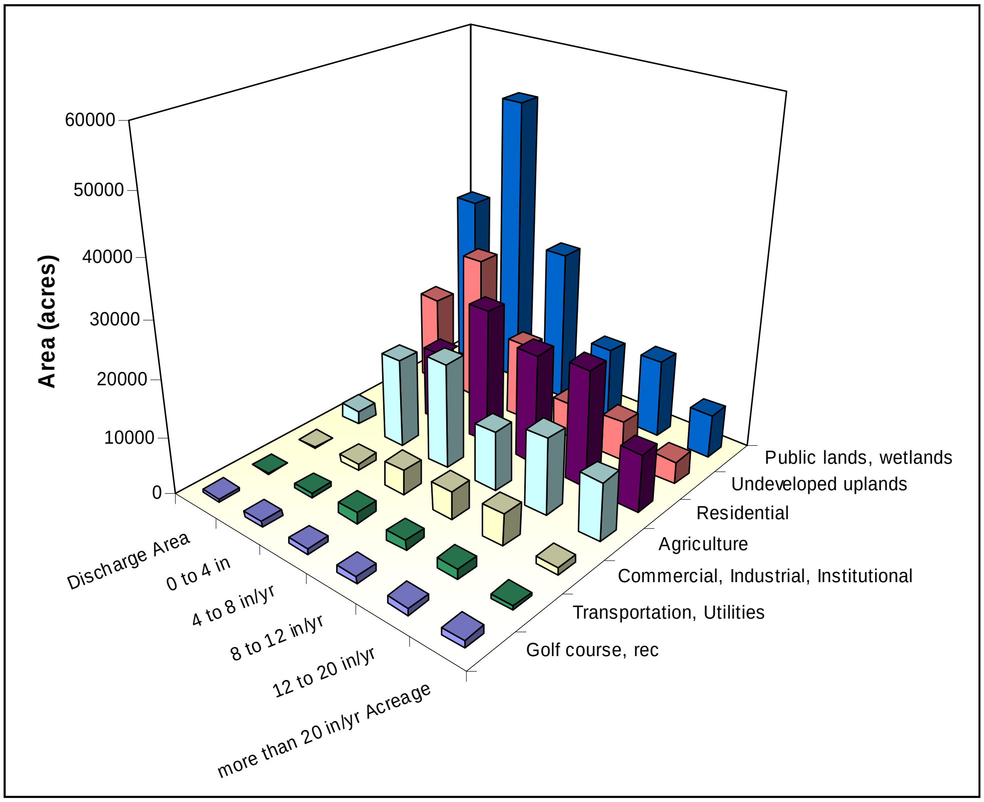
Source: MACTEC and SJRWMD
Created by: NMG Checked by: WAT

Figure 2-5. Recharge Rates



Source: MACTEC and SJRWMD
Created by: NMG Checked by: WAT

Figure 2-6. Acreage by Land Use and Recharge Rate



Note: Golf course, rec = golf courses and other recreational land uses

Source: MACTEC and SJRWMD
Created by: SAR Checked by: WAT

Groundwater recharge rates used as input to the East Central Florida MODFLOW model (McGurk and Presley, 2002) within the Wekiva Basin were acquired from SJRWMD (http://sjr.state.fl.us/programs/index.html). The recharge rate map indicates total recharge within the Basin of approximately 400 cubic feet per second (cfs). This recharge rate compares reasonably with the estimated discharge rate from springs in the Wekiva Basin of approximately 230 cfs, since not all groundwater flowing through the Basin is expected to discharge via springs.

Representative groundwater concentrations for all land uses were estimated from relevant technical literature as discussed in the following subsections. Estimated groundwater concentrations are intended to represent area sources of contamination associated with the land use, not point source contamination due to such sources as OSTDS or WWTF.

Whereas the primary load estimation calculation for groundwater was based on land use, attribution (partitioning) to specific source types was specified according to the primary source presumed to be contributing nitrate to groundwater for each land use. For undeveloped land, the source type was identified as "Natural or Unattributed". For most land uses, the source type was assumed to be fertilizer use. For pasture, groundwater loadings were proportionately assigned to livestock waste and fertilizer use.

2.4.1.1 Residential

The objective of this section is to present procedures used to estimate groundwater concentrations associated with the use of fertilizer in residential areas. Loadings derived using these estimates are attributed to fertilizer use. The residential land use may also be associated with loadings from OSTDS and irrigation with reclaimed effluent, but these loadings are estimated separately (see Section 2.4.4).

The Phase I report (MACTEC, 2007) concluded that field data characterizing groundwater quality in residential areas unaffected by OSTDS were insufficient to reliably estimate the groundwater concentration for residential land uses. To reduce this uncertainty, FDEP conducted a Phase II investigation of groundwater quality in residential areas of the Wekiva Basin that were isolated from known OSTDS (MACTEC, 2009).

Twenty-four (24) shallow wells were installed in residential areas unaffected by known OSTDS. Two (2) shallow wells were installed in undeveloped natural areas on state lands (Wekiwa Springs State Park and Rock Springs Run State Reserve). Wells were completed in the surficial aquifer with depths ranging from 10 to 48 ft below land surface (bls), averaging 21 ft. Most of these wells were sampled four (4) times between October 2008 and July 2009, and samples were analyzed for nutrient constituents of residential fertilizer and other water quality parameters.

NO3-N concentrations in the residential area wells averaged 2.4 mg/L during the study, significantly greater than observed in the natural reference areas (0.3 mg/L). Supplementary analyses of stable isotopes of nitrogen and oxygen in the wells with the highest NO3-N concentrations support the conclusion that these wells were not affected by organic wastewater discharges (MACTEC, 2009). The U.S. Geological Survey (USGS) conducted a companion study, sampling four of the MACTEC Phase II wells in March 2009; approximately one week after one of MACTEC’s sampling events. USGS analyzed the same chemical parameters and stable isotopes as MACTEC, but also analyzed for bacteria that may indicate source attribution (Katz and Griffin, undated). Their results for nutrient constituents of fertilizer and stable isotopes of nitrogen and oxygen closely match MACTEC’s results. Their microbial data indicates that the MACTEC Phase II wells were not affected by organic wastewater.

One of the MACTEC Phase II wells may be affected by fertilizer use and irrigation practices on an adjacent golf course. This well had the highest NO3-N concentrations observed in this study, averaging 10 mg/L, and was about 125 feet (ft) from a golf course. Excluding this well from the others, for which the primary source of nitrate is residential fertilizer use, the average groundwater concentration (85 samples) in residential areas unaffected by organic wastewater discharges is 2.0 ± 0.2 mg/L.

The Wekiva Phase II results may be compared with a groundwater quality investigation in the springshed of Silver Springs, Marion County, FL (Phelps, 2004). Phelps sampled 17 existing wells in residential areas ranging in depth from 65 to 220 ft bls, averaging 109 ft bls. The author believed that all wells were completed in the upper Floridan aquifer. Concentrations in 18 samples from residential areas averaged 1.2 ± 0.2 mg/L. Phelps' results are generally consistent with the Phase II results from the Wekiva Basin, recognizing that Phelps' wells sampled the upper Floridan aquifer, while MACTEC's Phase II wells sampled the surficial aquifer, which is more directly affected by fertilizer, or other surface sources of nitrate.

Due to a lack of information on groundwater concentrations for commercial and services, institutional, recreational, transportation, communication, and utilities land uses, these land uses were assumed to have similar groundwater concentration to those occurring in residential land uses because significant portions of these land uses are maintained in turfgrass. These combined land uses comprise only 4% of the total area of the Wekiva Basin, while residential land use makes up about 19%. Therefore, errors in estimation of groundwater concentrations under these land uses would not contribute significantly to total uncertainty in nitrate loadings.

2.4.1.2 Agricultural

Representative groundwater concentrations associated with row and vegetable crops, tree crops (citrus), nurseries, pasture, and concentrated animal feeding operations (CAFOs) were estimated from field scale monitoring studies of groundwater concentrations associated with these land uses. Available monitoring studies were reviewed, and well designed studies specific to a given land use from Florida or the Southeastern U.S. were selected to represent the groundwater impacts of these land uses.

Loadings for all agricultural land uses were attributed to fertilizer use, with the exception of pasture and CAFOs. For pasture, approximately 1/3 of the loading was attributed to animal waste and 2/3 to fertilizer use, based on the TN inputs of these two source types to pastureland as detailed in Sections 2.3.1.2 and 2.3.2. All groundwater loadings determined for the feeding operations land use were attributed to livestock waste.

Row and Vegetable Crops

Within the Wekiva Basin, most row and field crop production is in Lake and Orange Counties. About half of the field and row crop production is in hay and other forage, mostly in Lake County; and about half in vegetables (more concentrated in Orange County). Principal vegetables produced are cabbage, cucumbers, greens, spinach, sweet corn, eggplant, and peppers (USDA, 2005).

McNeal, *et al*. (1995) measured shallow groundwater concentrations under vegetable fields and at the downgradient edge of fields in Manatee County. Average monitored groundwater concentrations under fields and at their downgradient edge were 1.3 mg/L for tomato, 1.9 mg/L for pepper, and 1.4 mg/L for all vegetables monitored by McNeal, *et al*. (1995). These concentrations are much lower than those reported for impacts from potatoes and sweet corn in Suwannee County [UF/IFAS and Suwannee River Water Management District (SRWMD), 2006] where concentrations averaged 26 mg/L; cropland in a review of literature on nitrate contamination in the southeastern coastal plain by Hubbard and Sheridan (1989); and under sweet corn in Wisconsin, averaging 20 mg/L (Kraft and Stites, 2003). The Manatee County farms investigated by McNeal *et al*. (1995) were maintained under a high water table condition (about 1 ft bls) with irrigation by shallow ditches throughout the fields. These conditions would favor denitrification of applied NO_3.

To evaluate whether denitrification processes are likely to be important in association with row crop agriculture impacts in the Wekiva Basin, soil types in areas with row crop agriculture land use were assessed. The primary soil characteristic considered was whether the soils were hydric. Such soils occur in wetlands and areas of high water table, and reducing conditions that would favor denitrification are a signal characteristic of hydric soils. It was found that only 12% of row crop agriculture land use occurs in hydric soils within the Wekiva Basin. Consequently, it is assumed that denitrification would not be an important process in fields used for row crop agriculture in the Wekiva Basin, and the results of McNeal, *et al*. (1995) in Manatee County are probably not representative of conditions in row crop land use in the Wekiva Basin. Concentrations observed by UF/IFAS and SRWMD (2006) in Suwannee County and by Hubbard and Sheridan (1989) in the southeastern coastal plain are considered representative, and an average concentration of 23 mg/L NO3-N is assumed under row crops.

Although limited information was identified regarding concentrations under field crops, leaching rates that have been reported from wheat (15 kg/ha/yr; Riley, *et al*., 2001) and alfalfa (7 kg/ha/yr; Randall and Mulla, 2001) are substantially less than those associated with row crops and are consistent with GW concentrations of approximately 4 mg/L.

Tree Crops (Citrus)

In the Wekiva Basin, virtually all land used for tree crops is in citrus. Crandall (2000), Lamb, *et al*. (1999) and McNeal, *et al.* (1995) provide the most thorough and representative data on groundwater concentrations under citrus. Crandall (2000) monitored six groves in Indian River, Martin, and St. Lucie Counties. Lamb, *et* al. (1999) monitored five groves in Highlands County. McNeal, *et al*. (1995) monitored two groves in Manatee County. Each study observed significant NO_3 levels in groundwater collected near the water table and as deep as 10 ft below the water table. In this shallow interval, Crandall (2000) observed an average concentration of 5 mg/L NO3-N in the Indian River groves; Lamb, *et al*. (1999) an average of 11 mg/L; while McNeal, *et al*. (1995) observed an average concentration of 16 mg/L in the Manatee County groves.

Although concentrations observed by Crandall (2000) and McNeal, *et al*. (1995) were similar in groundwater near the water table, the two studies observed distinctly different concentrations at greater depths in the groundwater. McNeal, *et al*. (1995) observed a gradual decline in NO3-N with depth, from 16 mg/L at 10 ft to about 8 mg/L at 19 ft depth. In the Indian River groves, on the other hand, Crandall (2000) observed a marked reduction with depth, declining from an average of 5 mg/L at a depth of 5 ft to 0.8 mg/L at 10 ft and undetectable (<0.02 mg/L) at 20 ft. Crandall (2000) also demonstrated that the process primarily responsible for the reduction was denitrification as evidenced by elevated levels of N_2 gas in shallow groundwater. Apparently conditions favoring denitrification were not in place at the Manatee County groves studied by McNeal, *et al*. (1995). Lamb, *et al*. (1999) monitored one grove on a flatwoods site with concentrations similar to the low lying Indian River groves, three groves on ridge sands (uplands) with concentrations similar to those observed in Manatee County, and one grove that was probably not representative because it had been recently established.

Within the Wekiva Basin, 99% of tree crop land use is on uplands (non-hydric soils). Therefore, the denitrification processes observed by Crandall (2000) are not likely to be important in the Wekiva Basin, so the average concentrations observed by McNeal, *et al*. (1995) and at the three established upland sites monitored by Lamb, *et* al. (1999) were assumed to be representative of tree crop land use in the Wekiva Basin. The grove-weighted average concentration in shallow groundwater at these five groves was 15 mg/L, NO3-N.

It is noted that these studies were conducted prior to the current FDACS BMP for citrus fertilization, and therefore may represent the effect of fertilization at rates greater than the current BMP (see further discussion in Section 3.4.2).

Nurseries

Although very high concentrations (20 to 100 mg/L) of nitrates have been observed in nursery leachates under controlled experimental conditions (McAvoy, *et al.*, 1992; Yeager and Cashion, 1993), a comprehensive monitoring survey of 29 container nurseries in six states, including Florida (Yeager, *et al*., 1993), found groundwater concentrations on and downgradient of nurseries average 6 mg/L, up to a maximum observed concentration of 55 mg/L. It was assumed that a representative groundwater concentration associated with nurseries is 6 mg/L.

FDEP recently investigated a container nursery site in Eustis, FL, due to observations of groundwater contamination by nitrate (Hicks, 2009; Newton, 2010). The Eustis site is within the Wekiva Basin. NO3-N concentrations in eight (8) wells on site and at the site's downgradient boundary averaged 23 mg/L in September 2009. The facility participates in the Container Nursery BMP program and available information indicates it is operating as a typical container nursery in this region. Newton's (2010) observations indicate that the nurseries sampled by Yeager, *et al*. (1993) may not be representative of the groundwater impacts of container nurseries in well drained, sandy soils typical of the Wekiva Basin. Newton's results suggest that the effect of container nurseries in the Basin may be underestimated in the current model. Further investigations are warranted to determine if the levels of groundwater contamination observed at the Eustis container nursery site are representative of this land use within the Wekiva Basin. This concern is addressed further in Section 3.3.2.

Pasture

Limited data are available to estimate groundwater nitrate concentrations under pasture in Florida. Ator and Ferrari (1996) compiled and analyzed groundwater concentrations of NO3-N from more than 850 sites in the Mid-Atlantic Region (including parts of Delaware, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Virginia, and West Virginia) and categorized the sites by land use. The median concentration in pasture lands was 5.5 mg/L, and not significantly different from areas in row or field crops. They concluded that field rotation or the close proximity of crops and pastures within agricultural areas leads to a mixed-agricultural effect on groundwater quality.

The groundwater concentration associated with pasture for the Wekiva Basin was assumed to be 5.5 mg/L.

Concentrated Animal Feeding Operations (CAFOs)

This represents a very limited land use within the Wekiva Basin (< 0.05%), but may have disproportionate nitrate loadings.

Hatzell (1995) monitored groundwater near poultry (broiler) farms in North Central Florida and found that concentrations averaged 13 mg/L.

Woodard, *et al*. (2002) monitored a dairy in the panhandle region of Florida (near Bell) for four years. Dairy effluent was applied to forage crops onsite. Forage crop rotations and application rates were varied in separate plots. Concentration of NO3-N was measured in soil moisture (by lysimeters) and loading rates (kg/ha/yr) were estimated. Soil moisture concentrations are expected to be higher than concentrations in groundwater, which were not monitored. Soil moisture concentrations ranged from about 1 mg/L to 68 mg/L, and averaged 18 mg/L. A bermudagrass-rye rotation was more efficient in N uptake, with an average soil moisture concentration of approximately 6 mg/L, while a corn-sorghum-rye rotation yielded an average leachate concentration of 30 mg/L.

Collins (1995) monitored groundwater at four swine farms in Jackson County, FL. Concentrations ranged from 0.04 to 11 mg/L, averaging 2.8 mg/L.

Although groundwater impacts of these three distinct CAFOs are similar, cattle are the predominant livestock in the Wekiva Basin, so the results of Woodard, *et al*. (2002) for a dairy were assumed to be most representative of CAFOs in the Wekiva Basin, with an average groundwater concentration of 18 mg/L.

2.4.1.3 Golf Courses

All groundwater loadings from golf courses were attributed to fertilizer use.

Groundwater concentrations have been monitored at a number of golf courses nationwide, and leachate quality has been monitored from experimental turfgrass plots designed to simulate golf course landscape management practices. Of the variety of monitoring studies available, the study by Swancar (1996) a USGS study of groundwater impacts of nine central Florida golf courses was used. Swancar's results are generally consistent with results reported outside of Florida (e.g. Flipse and Bonner, 1985; Petrovic, 1995; Branham, *et al.*, 1995; Rufty and Bowman, 2004). Concentrations ranged from not detected (< 0.02 mg/L) to 26 mg/L in 228 groundwater samples, averaging 2.6 mg/L. The distribution of concentrations appeared to be lognormal, so the more conservative Land procedure (Gilbert, 1987) was used to estimate the mean concentration. Only data from permanent monitor wells, rather than direct push technology (DPT) samples that were only collected near tees and greens, were used. The conservative estimate of the mean concentration is 8 mg/L.

2.4.2 Stormwater Loadings

The stormwater pollutant loading model developed by CDM (2005) using the Watershed Management Model (WMM) and used to support the WSA Stormwater Master Plan was the primary basis for estimation of stormwater loadings to the Wekiva Basin. The appendix to the WSA Stormwater Master Plan that describes the application of WMM by CDM (2005) is reproduced as Appendix B.

WMM estimates stormwater runoff volumes and pollutant loadings within basins. Inputs include Event Mean Concentrations (EMCs)[9] by land use, annual precipitation, and descriptions of structural stormwater treatment systems or BMPs. CDM modified basin boundaries and mapped BMPs following field investigations. EMCs were identified after a comprehensive literature review and consideration of inputs from Basin stakeholders (e.g., state and local governments). WMM is capable of estimating loads from groundwater (referred to as baseflow), but CDM's (2005) application to the WSA did not account for loadings by baseflow. Their report does not discuss any attempt to calibrate the runoff volumes or loadings.

[9] Event Mean Concentration (EMC) is the average of individual measurements of storm pollutant mass loading divided by the storm runoff volume taken over a storm event (CDM, 2005).

A number of ancillary calculations were performed using the CDM (2005) WMM application to achieve the objectives of this study to:

- Update the loading estimates to the 2004 land use baseline used for this study (the WMM model used to develop the WSA Stormwater Master Plan was based on 1999 land use);
- Extend the WSA results to portions of the Wekiva Basin outside the WSA;
- Partition loadings by land use and source type; and
- Distinguish between direct stormwater loadings to surface waters and diffuse stormwater loadings to groundwater.

The basic approach used in these ancillary calculations was to assume that loadings by land use as determined by the CDM (2005) WMM application were valid. The approach retains the detailed evaluation of WSA hydrology represented by the CDM (2005) WMM application. Sub-basin boundaries, rainfall/runoff relationships, and EMCs by land use were not modified. Acreage in each land use was (a) extended to the Wekiva Basin, and (b) updated to 2004 land use.

WMM does not automatically output totals by land use. Rather it reports total loadings by sub-basin. To determine the loadings by land use, the WSA WMM model was rerun, sequentially "turning on" each land use while turning off all others. These simulations produced results for each land use within the WSA. Next, by a simple ratio, the loading for the Wekiva Basin (2004 land use) could be estimated. These calculations were performed outside the WMM software, in EXCEL™ spreadsheets.

Finally, the sub-basins in the Wekiva Basin were identified as either closed or open. A closed basin is one with no outlet. Closed basins are assumed to deliver their stormwater loadings to groundwater. Open basins are assumed to deliver their loadings to surface waters. Total annual runoff from open basins within the Wekiva River watershed was estimated to be 340 cfs. This flow may be compared with the average discharge of the Wekiva River, which is about 300 cfs. Spring flow to the river is about 230 cfs.

This procedure produced untreated loading (prior to effect of BMPs) and BMP-treated loading by land use for both open and closed sub-basins in the Wekiva Basin. Loading to surface water (stormwater direct) by land use was defined as BMP-treated load from open basins. Loading to groundwater (stormwater diffuse) by land use is untreated load in the entire Wekiva Basin minus loading to surface water. Inherent in this calculation is an assumption that treatment by BMPs reduces the direct loading to surface water, but that all nitrate removed by the BMP goes to groundwater. This assumption is conservative. In fact, some portion of the nitrate load treated by BMPs does not reach groundwater. For example, in wetlands used as BMPs, a portion of the nitrate treatment efficiency represents a true recycling of nitrate into plant biomass and soils. Harper (1988) found that nitrate concentrations in groundwater below detention ponds were similar to concentrations in the ponds (indicating limited treatment effectiveness). Bahk and Kehoe (1997) studied effectiveness of agricultural retention ponds, but their study was not designed to address the question of whether nitrate mass is removed by the ponds. Generally it is found that structural BMPs have limited effectiveness in removal of nitrate mass (e.g., Koob and Barber, 1999; Rea, 2004).

To partition stormwater loadings by source type, it was assumed that nitrate loading from undeveloped lands (e.g., forest, wetlands, and open land) was natural, attributable to atmospheric deposition, or otherwise unattributable. The load from each land use that could be attributed to specific source types is given by [Loading (land use) – Loading (Forest / Open Land)]. WMM was used to estimate the loading from each land use if its land use were changed to Forest / Open Land. The difference between the actual loading and the undeveloped loading was attributed to the most relevant source, e.g., fertilizer use associated with the land use.

2.4.3 Wastewater Treatment Facilities (WWTF – sewer)

All discharges of NO3-N, as estimated according to Section 2.3.3, were assumed to reach waters of the Basin. This represents 88% of the TN inputs. Some nitrate associated with wastewater may be assimilated or denitrified in systems such as artificial wetlands, sprayfields or RIBs; however, the concentrated nature of wastewater disposal facilities minimizes the potential for losses during transport to the water table, and losses were not quantified. Sumner and Bradner (1996) found that denitrification losses were minimal from a RIB in Orange County, FL. Merritt (2006) intensively studied recharge of domestic effluent meeting reclaimed water standards at the City of Orlando Water Conserv II RIB systems in Orange County, FL, which are within the Wekiva Basin. Their study did not specifically quantify denitrification losses, but they performed a variety of dilution and mixing calculations that were based on the assumption that denitrification losses were minimal, and that nitrate could be used as a conservative tracer of effluent impacts. Their results are generally supportive of the assumption used in this study that essentially all effluent nitrate discharged to groundwater via RIBs reaches groundwater. At the Conserv II site, essentially all nitrate also reached the Floridan aquifer. Therefore, based on Sumner and Bradner (1996) and Merritt (2006) studies of RIBs in the Wekiva Basin, all nitrate nitrogen in treated effluent discharged to RIBs is assumed to reach groundwater. This amounts to 88% of the TN discharged by WWTFs from monitoring results reported to FDEP (2006).

York (2007), however, commented on a draft of the Phase I report indicating his opinion that approximately 50% of TN discharged to RIBs is lost, primarily by nitrification/denitrification processes and does not reach groundwater. Dr. York’s comments are included as Appendix C.

Reclaimed effluent from several large capacity WWTF in the Basin is reused as irrigation water (slow-rate public access reuse systems). Approximately 37% of permitted wastewater discharges in the Basin were reused as of 2004. Land use within the permitted reuse service areas was quantified. Most of the land in the permitted service areas is classified as residential (36%); commercial, services, transportation, communications, utilities, institutional (16%); agricultural (9%), and recreational, including golf courses (7%). Each of these land uses is assumed, in this study, to receive fertilizer (see Section 2.3.1). In fact, each of these land uses (except residential; see Section 2.3.1.1) is assumed to have fertilizer applications at recommended agronomic rates. If so, the additional nutrients in the reclaimed water would be excess to plant requirements. It is possible that some users understand that reclaimed water has nutrient value, and therefore reduce their rate of fertilizer application. UF/IFAS Extension developed guidelines for using reclaimed water for landscape irrigation (Martinez and Clark, 2009), including recommendations to adjust fertilizer use. For the most part, however, reclaimed water is managed for irrigation value, without consideration of its nutrient value. UCF (2009) found that residents receiving reclaimed water actually applied fertilizer more frequently than those who didn't have access to reclaimed water. Although there remains considerable uncertainty regarding the groundwater impacts of reclaimed water use under actual field conditions, it is assumed here that the ratio of (NO3-N loadings) / (TN inputs) for reclaimed water nutrients is 20% as recommended by York (2007) and approximately the same as the ratio observed for fertilizer use.

Domestic wastewater loadings, excluding effluent reused as irrigation water, were assigned to the land use category of Transportation, Communication, and Utilities (Sewage Treatment).

2.4.4 OSTDS

See Section 2.3.3 for the procedure for estimating the number of OSTDS and their distribution by land use in the Wekiva Basin. Groundwater impacts observed at three OSTDS in the Wekiva Basin, performed by Ellis & Associates (2007) and interpreted by Roeder (2008), are the basis for estimating OSTDS loading per tank.

Ellis & Associates, under contract with FDOH, measured the components of TN [NO3-N, NO2-N, and Total Kjeldahl Nitrogen (TKN)] in septic tank effluent and groundwater below and surrounding their drainfields at three sites in the WSA, one each in Lake, Orange, and Seminole Counties. They estimated the percentage of TN that reached the water table by dividing the maximum observed groundwater TN concentration by the average TN concentration in the septic tank effluent. Since the objective of this study is to determine nitrate loadings to groundwater and related releases of TN, we follow Ellis & Associates (2007) procedure, but divide the maximum observed groundwater NO3-N concentration by the average TN concentration in the effluent to estimate the percentage of TN discharged that reaches groundwater as nitrate.

Results are summarized in Table 2-2. At all sites most of the effluent TN is present as TKN. The water table was higher at the Seminole County site than at the other two sites, resulting in less nitrification occurring prior to the effluent reaching groundwater. At the Seminole County site most of the TN in groundwater was present as TKN. At the other two sites, essentially all TN had nitrified prior to reaching the water table, with all of the TN present in groundwater as NO3-N. The average portion of effluent TN reaching groundwater as NO3-N for the three sites was

56%. With an average TN discharge of 29 lb TN/tank (Section 2.3.4), the estimated loading of NO3-N to groundwater is 29 lb TN/tank x 56% = 16.3 lb NO3-N/tank.

Table 2-2. Fraction of TN in OSTDS Effluent Reaching Groundwater as NO3-N

Site	Maximum NO3-N (mg/L) in Groundwater	Average TN (mg/L) in Effluent	Percent of Effluent TN Reaching Groundwater as NO3-N
Seminole County	24	74	32%
Lake County	22	43	51%
Orange County	59	69	86%
		Average	**56%**

Source: Concentrations from Ellis & Associates (2007); percentages calculated by MACTEC.
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3.0 Estimated Nitrate Loadings

Procedures described in Section 2.0 were applied to estimate TN inputs to the Wekiva Basin and NO3-N loadings to groundwater and surface waters of the Basin.

TN inputs include:

- Application of fertilizer;
- Discharges from WWTF (sewer);
- Discharges from OSTDS (septic tanks);
- Livestock waste; and
- Atmospheric deposition.

NO3-N loadings represent the portion of these inputs that are delivered to groundwater and surface water in the Basin. Loadings are consistently expressed as NO3-N. Loadings were attributed (partitioned) by land use and by source type as described in Section 2.4.

The portion of nitrogen inputs applied as fertilizer that reaches groundwater or surface waters of the Basin as NO3-N is the result of two essentially independent calculations. Nitrogen inputs are based on estimated fertilizer use, while loadings are based on estimated groundwater concentrations and recharge rates (loadings to groundwater) and the results of application of a stormwater loading model (modification of the WMM model application developed by CDM, 2005).

Results of input and loading estimates are presented in the following sections.

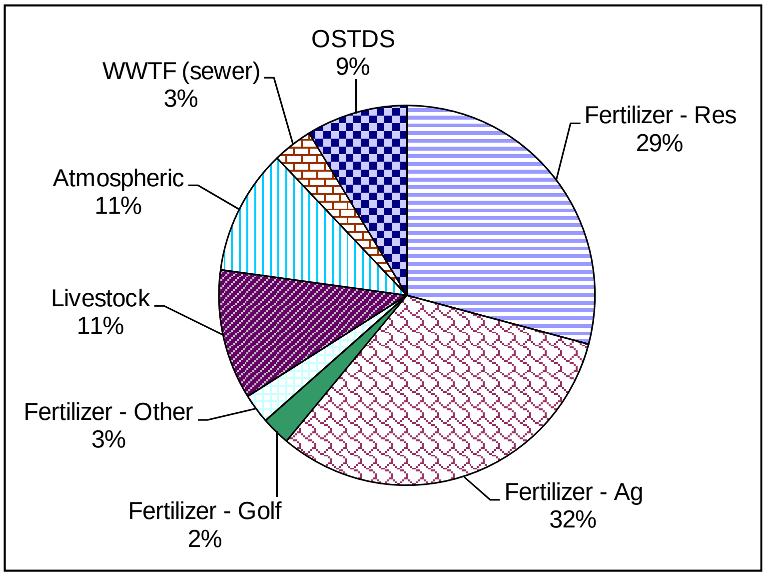
3.1 Inputs of Nitrogen to the Wekiva Basin

The total amount of nitrogen input to the Wekiva Basin is estimated at approximately 9,900 MT/yr. Partitioning of these inputs by source is illustrated in Figure 3-1, which shows approximately 29% of TN input to the Basin results from the application of fertilizer in residential areas; 31% is fertilizer applied in agriculture; 3% fertilizer used on golf courses and 3% other fertilizer use. In all 6,500 MT of TN is applied as fertilizer within the Wekiva Basin annually, accounting for about 2/3 of the TN input to the Basin.

Livestock waste contributes approximately 1,100 MT TN to the Basin annually, or 11% of the total input. Remaining sources are OSTDS, contributing approximately 9% of TN input to the Basin; domestic wastewater, 3%, and atmospheric deposition, 11%.

Some nitrogen inputs have a greater impact on water quality than others. For example, a direct discharge of nitrate to surface water is likely to have a greater impact than an equivalent amount of nitrogen applied as fertilizer on uplands far from streams or springs. Nitrogen applied as fertilizer is used by plants. Nitrogen as ammonia in septic effluents may volatilize to the atmosphere. The next section provides additional information regarding the contribution of each of these nitrogen inputs as nitrate loads to groundwater and surface water of the Basin.

Figure 3-1. Nitrogen Inputs to the Wekiva Basin, Partitioned by Source Type



Notes: Fertilizer – Res = Fertilizer used on residential land uses
Fertilizer – Ag = Fertilizer used on agricultural land uses
Source: MACTEC.
Created by: WAT Checked by: JAT

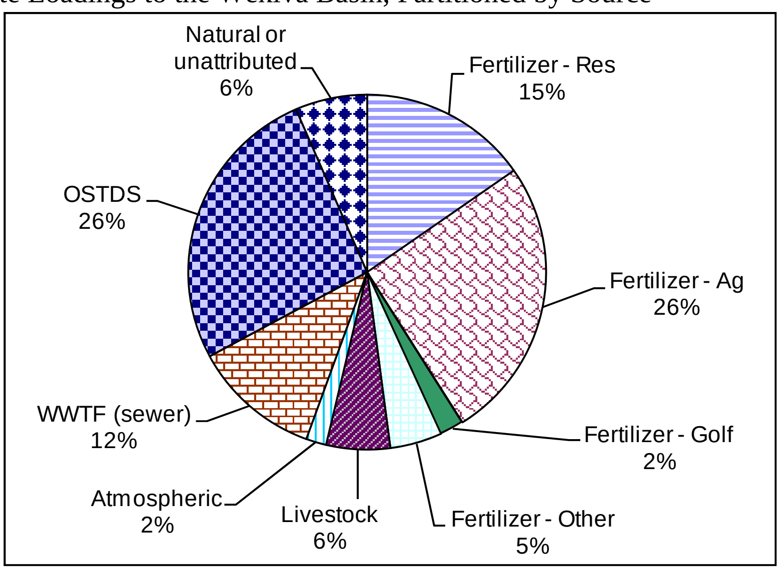
3.2 Loadings to Waters of the Wekiva Basin

Procedures described in Section 2.0 were applied to estimate NO3-N loadings to groundwater and surface waters of the Basin. Total loading of NO3-N to waters of the Basin is estimated to be 1,800 MT/yr. Contrasting this estimate with the nitrogen input to the Basin of 9,900 MT/yr indicates that only 19% of the TN input to the Basin reaches groundwater and surface water as NO3-N. Although the importance of removal processes has not been evaluated quantitatively, it appears that a significant portion of nitrogen input is lost by assimilation (plant uptake), storage as soil organic nitrogen, denitrification, and volatilization to the atmosphere as N_2 or ammonia. Only about 140 MT/yr is discharged directly to surface water in the Wekiva River watershed. The remainder of the loading, i.e., approximately 1,700 MT/yr is a load to groundwater resources. This amount may be compared with the estimated discharge of NO3-N from springs in the Wekiva Basin, which has been estimated to be 232 MT/yr (Gao, 2008).

There are several possible explanations for this discrepancy between estimated groundwater loading and spring discharge. A portion of the nitrate initially discharged to groundwater may be lost by denitrification or other chemical processes, while a portion of the loading may underflow the springs, perhaps eventually discharging to the St. Johns River. Toth (1999, 2003) and Toth and Fortich (2002) demonstrated that water discharging to springs in the Basin reflects impacts from past activities in the Basin. The average age of water discharging from springs is about 20 years, which reflects a mixture of some water that was at the surface recently as well as some older water. Therefore it would not be expected that discharges today are directly related to land use today.

Figure 3-2 illustrates the sources of nitrate loadings. Fertilizer use by agriculture (26% of total loading) and for residential turfgrass (15%) are major contributors, as are OSTDS (26%). Fertilizer use on all land uses comprises 48% of total loadings. WWTF and livestock waste add 12 and 6%, respectively. Approximately 6% of the total loading is apparently natural or cannot be attributed to identified sources. This amount consists of the groundwater recharge and stormwater loadings that would be expected to occur if all land in the Basin were undeveloped. This "natural or unattributed" amount was calculated by setting all groundwater concentrations to 0.1 mg/L, representative of values generally observed in undeveloped areas (Phelps, 2004; MACTEC, 2009)[10], and generating stormwater loadings using WMM in a separate application by changing all upland land uses to an undeveloped classification. Combining this amount with atmospheric deposition (2%, a portion of which is natural) suggests that anthropogenic loadings are about 92% of the total, or that pre-cultural loadings would have been about 1/12th of current loading rates.

Figure 3-2. Nitrate Loadings to the Wekiva Basin, Partitioned by Source

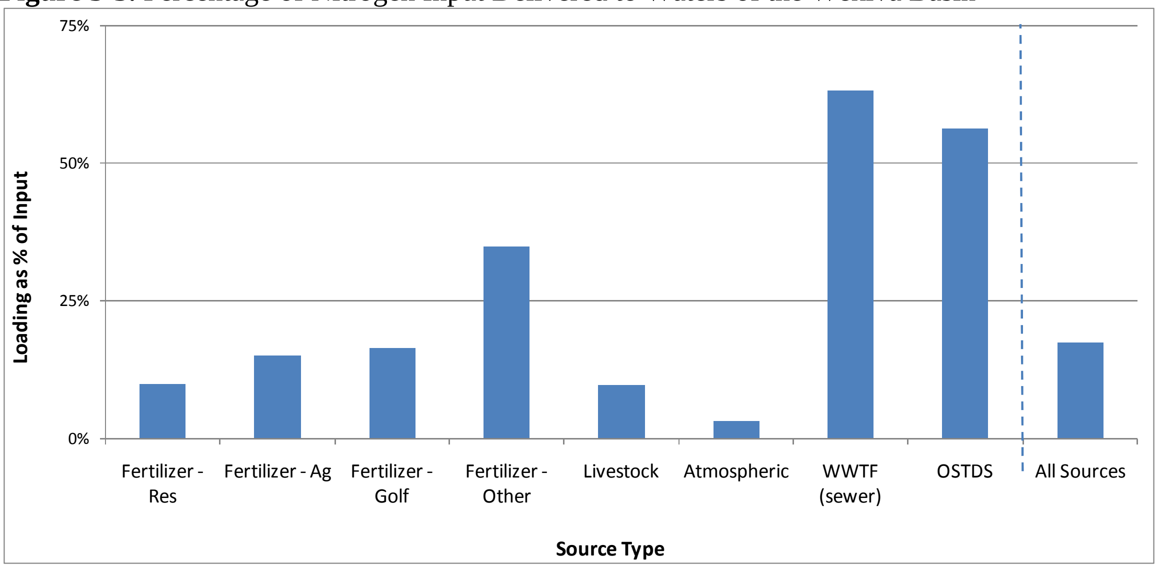


Source: MACTEC
Created by: WAT Checked by: JAT

[10] Note: the natural concentration of NO3-N in the surficial aquifer may be less than 0.1 mg/L. Hicks (2010) summarized data from FDEP's groundwater monitoring database, concluding that median concentrations are 0.02 to 0.05 mg/L. If the lower value had been used in the calculations, they would indicate a greater effect of anthropogenic loadings.

Figure 3-3 shows the percentage of nitrogen inputs that are delivered as nitrate loads to waters of the Basin by source type. It was assumed that all effluent nitrate from permitted wastewater facilities, excluding effluent that is reclaimed or reused, is discharged to waters of the Basin. This amounts to 88% of TN discharged. Effluent TN that is reclaimed or reused was assumed to be processed in the root zone similarly to fertilizer TN, resulting in approximately 20% released to groundwater as NO3-N. Approximately 37% of wastewater effluent TN is reclaimed or reused in the Wekiva Basin. As a result approximately 63% of WWTF effluent TN is estimated to reach waters of the Basin as NO3-N. Approximately 56% of septic tank effluent nitrogen was assumed to reach groundwater as NO3-N (section 2.4.4, based on Ellis & Associates, 2007). The remainder is presumed to be volatilized as ammonia or denitrified and volatilized as N_2 during transport from the drainfield to the water table.

Figure 3-3. Percentage of Nitrogen Input Delivered to Waters of the Wekiva Basin



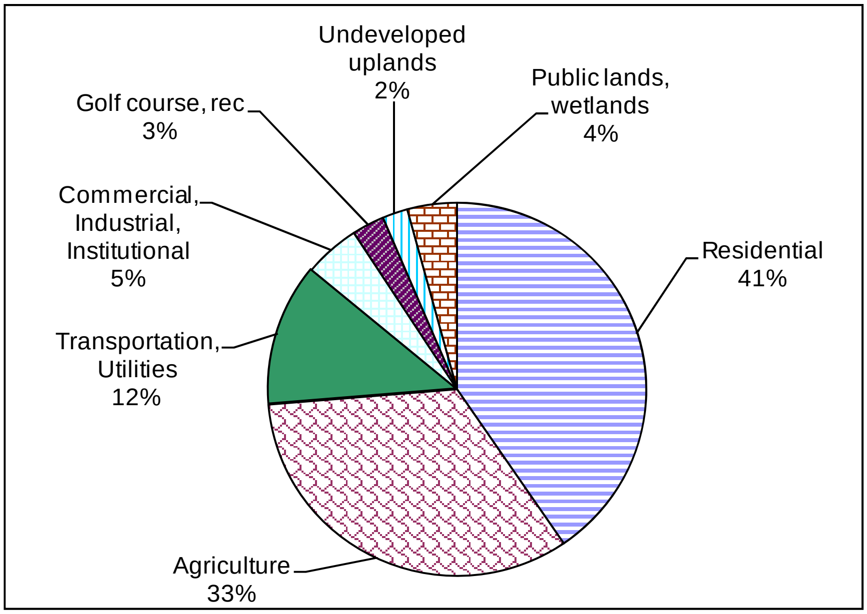
Source: MACTEC.
Created by: JAT Checked by: WAT

The percentage of nitrogen inputs applied as fertilizer that reaches groundwater or surface waters of the Basin as NO3-N (Figure 3-3) is the result of two essentially independent calculations. Nitrogen inputs are based on estimated fertilizer use, while loadings are based on estimated groundwater concentrations and recharge rates (loadings to groundwater) and the results of application of a stormwater loading model (modification of the WMM model application developed by CDM, 2005). Although there is significant potential for errors in both the loadings and the inputs estimated in accordance with Section 2.0, the portion of fertilizer applied that actually reaches ground and surface water is consistent with the literature. For example, leachate and/or runoff losses of NO3-N have been reported to range from 1 to 44% (most results less than 15%) of TN applied as fertilizer to residential turfgrass by Hipp, *et al.* (1993), Morton, *et* al. (1988), Raulerson, *et al*. (2002), and Snyder, *et al*. (1984). This range compares favorably with the portions estimated for residential turfgrass and golf courses in the Wekiva Basin of 10 and

14% respectively. Bottcher and Rhue (2000) estimate NO3-N losses by runoff and leaching of 5 to 30% in agricultural applications, which compares with 20% estimated in the Wekiva Basin.

Figure 3-4 illustrates the partitioning of nitrate loadings by land use. Residential land uses, which are affected by fertilizer use, OSTDS, and reused WWTF effluent, account for 41% of total loading; while agricultural land uses contribute 33%. Wastewater effluents are the predominant contributor to the transportation, communications, and utilities land use which contributes 12% of total loadings of nitrate. In Figure 3-4 the undeveloped sector (as depicted in Figure 1-2) has been disaggregated into two parts, undeveloped uplands (which may be presumed to be developable in the future, and currently contribute 2% to total loading) and those undeveloped lands that are protected from future development, including publicly owned conservation lands, wetlands, and water bodies, which contribute 4% of total Basin loading.

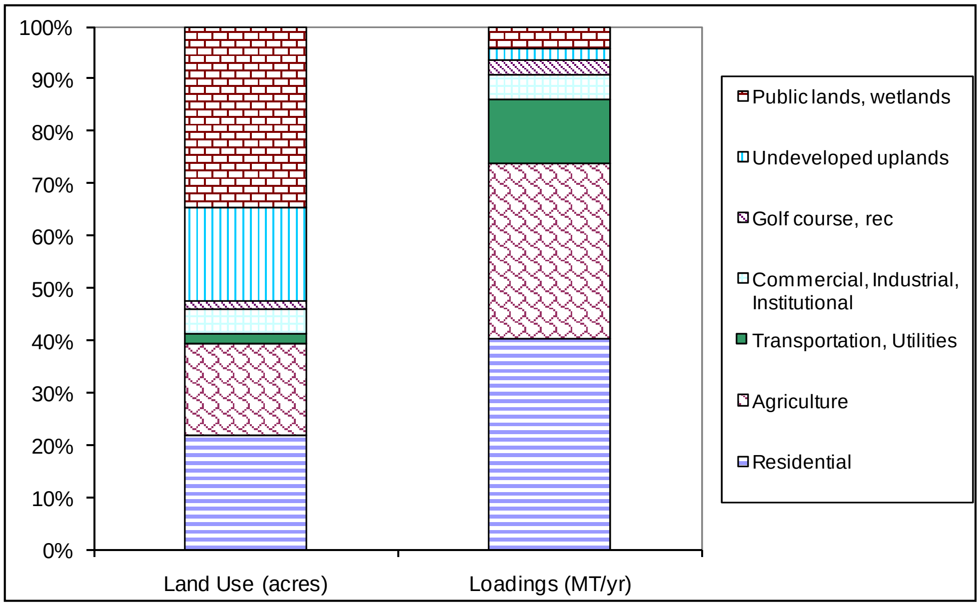
Figure 3-4. Nitrate Loading to the Wekiva Basin, Partitioned by Land Use



Source: MACTEC.
Created by: JAT Checked by: WAT

Residential land uses are major contributors to loadings, in part, because they comprise a large portion of the Wekiva Basin (21%, see Figure 1-2). Figure 3-5 presents information on land use acreage from Figure 1-2, and partitioning of nitrate loadings by land use from Figure 3-4 in a stacked bar chart format. This illustration shows, for example, that although residential land uses comprise 21% of the total area of the Basin, they contribute 41% of the nitrate loadings. Similarly agriculture, transportation, utilities, commercial, industrial, institutional, and golf course land uses contribute a greater proportion of the nitrate loadings than their proportion of the acreage, while undeveloped land uses that make up more than 50% of the area of the Basin contribute only 6% of the nitrate loading.

Figure 3-5. Loadings by Land Use Compared with Proportionate Acreage in Each Land Use



Source: MACTEC.
Created by: JAT Checked by: WAT

Information presented on Figure 3-4 can also be presented in terms of loading rates per area. Residential land uses, in aggregate, yield about 20 kg/ha/yr, while agricultural land uses yield about 21 kg/ha/yr. The loading from specific residential parcels, however, depends primarily on whether they are served by a central sewer system or septic tanks (OSTDS). About half of the aggregate residential loading is from OSTDS, but less than half of residences are on septic systems in the Wekiva Basin, so residential parcels with septic systems have much higher loading rates. Loading rates from undeveloped lands, on the other hand, were estimated to average about 1 kg/ha/yr.

Considering the number of septic systems (65,000), the average number of people served by each OSTDS (approximately 2.5), and the actual discharge rate from WWTF in the Basin (about 48 million gallons per day, MGD), it is estimated that about 160,000 people are served by septic, and 265,000 by central sewer systems. Loadings from OSTDS are estimated at 484 MT/yr, or about 3.0 kg NO3-N/person/yr. Loadings from central sewer average 0.8 kg/person/yr. Therefore, central WWTF reduce 73% more nitrate loading than septic systems.

These loading rates represent conditions in the Basin in 2004. Projections of future loadings were not one of the objectives of this study. Nonetheless, some trends are apparent. From 1999 to 2004, residential land use (and correspondingly the number of dwelling units) increased by about 10% (an increase of about 10,000 ac). During the same five year period, acreage in citrus decreased by 28% (a loss of 5,000 ac). Citrus was converted primarily to residential (1,200 ac); silviculture (1,100 ac); other agricultural uses (800 ac), including pasture (440 ac), and nurseries (140 ac); or abandoned (800 ac). Assuming these trends continue, the percent contribution of residential land uses to nitrate loadings would be expected to increase in the future, with a decrease in the importance of agricultural land uses.

Alternate Analysis – Wekiva Study Area

It is appropriate that this study address all areas contributing water to the Wekiva River. However, it is possible that some administrative actions would only address the Wekiva Study Area considering its special designation by F.S. Chapter 369.316. Therefore the FDEP requested that analogous results be calculated for the WSA. These calculations would also permit more transparent comparison with comparable estimates made by Roeder (2008) for the WSA. Appendix H presents loadings apportioned by major source categories for the WSA only. These estimates were generally made following the same methodology as described in the main body of the report, but limiting the area of interest to the WSA.

Apportionment to major source types is similar in the basin and the WSA. The estimated apportionment to major source types in the WSA, using procedures adopted in this report, are also similar to the apportionment determined by Roeder (2008). OSTDS are a somewhat larger contributor to total loading in the WSA than in the basin, because the density of OSTDS is greater in the WSA (0.17 OSTDS/ac) than in the portion of the basin that is outside the WSA (0.10 OSTDS/ac). Agricultural is slightly more important in the basin than in the WSA, because the areas in the basin that are outside the WSA are generally more agricultural. The total loading of NO3-N estimated in Appendix H for the WSA is similar to, and slightly less, than the loading of TN estimated by Roeder (2008). Overall the procedures used here, when applied to the WSA, produced similar results to those reported by Roeder (2008).

3.3 Uncertainties in Loading Estimates and Limitations of the Selected Procedures

Several of the factors used to estimate inputs and loadings are uncertain, and the procedures themselves do not represent all factors that affect nitrate loadings. Procedures were selected, in part, because available information supported estimation of all quantities specified in the Statement of Work (partitioning by specific source types and partitioning by specific land uses) using those procedures consistently across all source types and land uses.

In the following two subsections limitations of the selected procedures are identified, and uncertainties in input parameters are discussed qualitatively or semi-quantitatively.

3.3.1 Procedural Issues

Procedural issues identified include:

- Definition of the springshed – There are at least three published maps depicting the Wekiva Groundwater Basin and/or the springshed (Toth and Fortich, 2002, Wekiva River Basin Coordinating Committee, 2004). The District has determined that the map used to define the scope of this project is the most reliable. Boundaries of the springshed may change with

season, or from year to year. The relative importance of predominantly agricultural areas in the western portion of the springshed would be affected if different assumptions had been made regarding the boundary of the springshed.
- Relative importance of loadings near springs versus loadings far from springs – Although this factor would not affect the estimate of loadings within the Wekiva Basin as defined by this study, not all loadings to the Floridan Aquifer will have an equivalent impact on springs and Wekiva River water quality. Loadings to the Floridan Aquifer that occur near a spring probably have a disproportionately greater impact, and certainly the effects of loading changes in areas near a spring will have a more immediate effect on spring water quality.
- Use of shallow groundwater concentrations and/or leachate concentrations as representative of the quality of recharge to the Floridan Aquifer – By the selected procedure for estimating groundwater loadings (multiplying shallow groundwater concentrations by recharge rates) the ideal groundwater concentration input would be deeper groundwater, the water actually recharging the Floridan. Unfortunately these data are not as readily available as shallow groundwater concentrations, nor could deeper concentrations be attributed to specific sources and land uses. In order to attribute loadings to specific sources and land uses, it was important that the concentrations used as characteristic of a source should clearly reflect the source type. By the time groundwater has recharged to the top of Floridan, in many locations, its concentration represents the combined impacts of multiple land uses, multiple sources, with some dilution and/or other chemical transformations. In this study shallow groundwater concentrations, generally within 20 ft of the water table, were used to estimate concentrations in water recharging the Floridan.
- Primary reliance on UF/IFAS Extension recommended fertilization rates rather than actual fertilizer use – Most researchers and Extension agents generally believe that most farmers apply more fertilizer than the amounts recommended by UF/IFAS Extension. In some cases "over fertilization" has been documented in published reports. For the most part, however, such assertions are not well documented. An alternative approach that was considered was to use fertilizer sales (e.g., by County) as the primary method for estimating fertilizer use. This approach was rejected, however, for several reasons, including (a) difficulty of assigning County-wide fertilizer sales to source types and land uses of interest; (b) recognition that the Wekiva Basin includes small portions of several Counties such that it would be difficult to assign a portion of County-wide sales to the Basin; (c) concern that fertilizer is not necessarily used in the County where it is purchased (one example – large agricultural concerns may use significant quantities of fertilizer purchased elsewhere by corporate purchasing systems).
- Disposal of wastewater treatment residuals was not tracked or accounted for.
- Assumption that structural BMPs (e.g., stormwater detention ponds) simply reroute nitrate from surface water to groundwater, without reducing total Basin loading – Clearly structural BMPs effect some treatment of nitrate, although structural BMPs are less effective for soluble nitrate than for constituents strongly associated with suspended solids, including Total Suspended Solids, Biochemical Oxygen Demand, and Total Phosphate. This assumption is conservative, partially supported by published research, and was made primarily for simplification.

3.3.2 Uncertainties in Input Parameters

All inputs used in estimation of inputs and loadings are uncertain to some extent. Land use designations may not be accurate on a parcel by parcel basis, but the aggregate (total acres by land use through the entire Basin) is probably relatively accurate and not a significant source of uncertainty.

Stormwater loadings (per ac of land use) are the product of stormwater flow for a climatically average year and an EMC (representative concentration of NO3-N in stormwater). Stormwater flow can vary widely from year to year, depending on rainfall rates, but the climatological average is assumed to be reasonably reliable, and not a significant source of uncertainty in this analysis.

EMCs used in this study were developed by CDM (2005) and represent a consensus estimate based on the literature and the input of stakeholders. Information on the uncertainty in EMCs presented by CDM (2005)[11] indicate that the uncertainty in EMCs for the land uses contributing significantly to nitrate loadings in the Wekiva Basin is roughly a factor of 2. The consensus value selected by CDM (2005) was usually near the high end of the range of reported values, suggesting that stormwater loadings are unlikely to be underestimated, but may be overestimated by as much as a factor of 2. Considering that stormwater represents 14% of total nitrate loading in the Basin, the effect of this potential error is that total loadings may be overestimated by 5 to 10%.

The concentrations of NO3-N in recharging groundwater assigned as representative of specific land uses are uncertain. For most land uses these estimates are based on published studies from locations outside the Wekiva Basin, and, in some cases, from outside the state of Florida. Representative data from Florida locations were used if available. Different monitoring studies generally yield fairly consistent results for given land uses, but limitations and variability observed in the data suggest that each land use estimate may not be reliable to much better than ± 50%.

Recent investigation of a container nursery site within the Wekiva Basin (Newton, 2010) indicates that groundwater NO3-N concentrations associated with the nurseries and ornamentals land uses may be higher than the value assumed in this study. Groundwater NO3-N concentrations observed by Newton (2010) at a single site in the Wekiva Basin averaged 23 mg/L in September 2009, while loadings estimates for this land use are based on a representative concentration of 6 mg/L (see Section 2.4.1.2). Each nursery operation is unique, depending on the plants cultivated. The Eustis, FL, operation investigated by Newton (2010) may not be representative of the entire land use. Nonetheless Newton's results indicate significant uncertainty in loadings for this land use, and the potential that its impact has been underestimated in this report. Nurseries apply fertilizer at rates similar to those applied to citrus groves, where representative groundwater concentrations of NO3-N have been observed to be approximately

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[11] The information referred to here has been reproduced in an appendix to this report, and can be found in CDM's table E-6. In that table it is shown that CDM (2005) considered a variety of sources of information on EMCs and selected a value based on technical evaluation and a process of consensus building among stakeholders. The values used by CDM (2005) may differ by roughly a factor of 2 from values that have been reported in the technical literature considered by CDM in developing their consensus EMCs.

15 mg/L. If 15 mg/L is representative of the nursery land use, then loadings from this land use would be 150% higher than estimated in this study, and could amount to 7% of total nitrate loading in the Basin. Further investigations of groundwater impacts of container nurseries in the Basin, or similar areas in Florida, may be warranted to reduce this uncertainty.

3.4 Effect of Recently Promulgated Regulations

3.4.1 Wastewater Management Requirements for the WSA (62-600.550, F.A.C.)

In April 2006 FDEP promulgated Chapter 62-600.550, F.A.C., establishing specific wastewater management requirements for the WSA. The purpose of the rule is to reduce nitrate discharges to protect surface and groundwater quality in the WSA. Existing domestic wastewater facilities discharging within the WSA are to comply with requirements of the rule by April 2011. New facilities are to comply immediately.

The approach adopted in 62-600.550 is to target more stringent requirements in portions of the WSA where the Floridan Aquifer is particularly vulnerable to contamination, as defined by the Wekiva Aquifer Vulnerability Assessment (WAVA; Cichon, *et al*., 2005). Cichon, *et al*. (2005) found that the Floridan Aquifer is vulnerable to surface contamination throughout the entire WSA, but further identified areas with relatively greater vulnerability. Areas where the Floridan Aquifer is most vulnerable to contamination are designated the Primary Protection Zone. The Floridan Aquifer is also relatively vulnerable in the Secondary Protection Zone, and least vulnerable in the Tertiary Protection Zone. F.A.C. 62-600.550 requires the most stringent discharge requirements in the Primary Protection Zone, relatively stringent requirements in the Secondary Protection Zone, and less stringent requirements in the Tertiary Protection Zone.

Specifically, in the Primary Protection Zone:

- Expanded rapid-rate or restricted access slow-rate land application systems are prohibited;
- Facilities with a permitted capacity exceeding 0.1 MGD must achieve effluent concentration of 3 mg/L TN in water discharged to rapid rate land applications systems (e.g., RIBs) unless the RIB is used only as backup (<30% of total discharge) to a public access reuse system for which the effluent concentration shall not exceed 10 mg/L TN; and
- Smaller facilities must achieve effluent concentration of 10 mg/L, regardless of disposal method.

In the Secondary Protection Zone:

- Larger facilities (permitted capacity > 0.1 MGD) must achieve effluent concentration of 6 mg/L TN in water discharged to RIBs unless the RIB is used only as backup to a public access reuse system; and
- Other requirements similar to those for facilities in the Primary Protection Zone, except that small facilities have until 2016 to comply.

Facilities do not have to meet these requirements if their effluent contains less than 0.2 mg/L NO3-N. Discharge to surface waters is prohibited except as backup to a public access reuse system. In both the Primary and Secondary Protection Zones, the concentration in effluent supplied to slow rate public access reuse systems must not exceed 10 mg/L TN.

To meet these requirements, several facilities will have to upgrade their treatment systems and/or change their effluent disposal system(s). The need to reduce discharge or modify effluent disposal systems was evaluated by review of effluent concentrations from 2004 through mid-2006. It was assumed that if more than 20% of the historical sample results exceed the revised effluent concentration limits, the facility would upgrade. Further it was assumed the design criterion for upgrades would be that fewer than 20% of discharge measurements would exceed the revised limits, with 95% confidence. Results of this analysis are summarized in Appendix E. The effect of the rule is estimated to be a 56% reduction in TN input and a 68% reduction in loadings within the WSA. Since there are a number of wastewater facilities in the Wekiva Basin that are not within the WSA, and therefore not subject to the requirements of 62-600.550 F.A.C., the overall effect of the required upgrades on effluent loads in the Basin would be a 22% reduction (from 214 to 168 MT/yr). The estimated load reduction is relatively uncertain, based on the analyses performed. The largest discharger in the Basin (Conserv II) is not in the WSA and therefore not subject to the new rule, but has agreed to meet the 62-600.550 requirements for reused water, since the reuse service area is within the WSA. The effect on total loading (entire Basin, all source types) would be a reduction of 3%.

3.4.2 Agricultural BMPs

The Office of Agricultural Water Policy (OAWP) was established in 1995 by the Florida Legislature to facilitate communications among federal, state, local agencies, and the agricultural industry on water quantity and water quality issues involving agriculture. In this effort, the OAWP is actively involved in the development of BMPs, addressing both water quality and water conservation on a site specific, regional, and watershed basis. As a significant part of this effort, the office is directly involved with statewide programs to implement the Federal Clean Water Act's Total Maximum Daily Load (TMDL) requirements for agriculture. The OAWP works cooperatively with agricultural producers and industry groups, the FDEP, the university system, the water management districts, and other interested parties to develop and implement BMP programs that are economically and technically feasible.

BMPs are developed by the Office of Agricultural Water Policy to benefit water quality while maintaining or enhancing agricultural production. The BMP program is completely voluntary, but by implementing the BMPs, landowners are exempted from water quality monitoring requirements and protected from enforcement actions if the water quality standards are not met. Also, those enrolled in the BMP program are eligible for cost-sharing funds used to implement new BMP practices. Finally, the Florida Water Restoration Act includes provisions to require implementation of BMPS if the voluntary programs are not effective in achieving water quality objectives. To take place in the BMP program, one must:

- Do a full assessment of the property using a Decision Tree Flowchart;
- Submit a Notice of Intent to Implement (Outlined in 5M-8.004);
- Implement all applicable BMPs that were needed from the assessment and listed on the Notice of Intent to Implement; and
- Maintain documentation to verify implementation and maintenance of BMPs.

BMPs have been developed for the following agricultural activities:

- Citrus production (BMPs vary by producing region),
- Silviculture,
- Aquaculture,
- Vegetable and agronomic crops,
- Leather leaf ferns,
- Nurseries,
- Forage grass,
- Cow/calf operations, and
- Sod farms.

Considering their importance in the Wekiva Basin, the vegetable and agronomic crop, ridge citrus, and container nurseries BMPs are discussed further below.

Potential Effect of Vegetable and Agronomic Crop BMP

This BMP was promulgated in February 2006, and therefore its effectiveness cannot be determined at this time. The BMP encourages implementation of UF/IFAS Extension recommended fertilization rates. In this study (see Section 2.3.1.2) the assumed application rate is 210 kg N/ha/crop, while UF/IFAS Extension recommended rates are slightly lower at 192 kg/ha/crop. Therefore implementation of the BMP is expected to represent a 9% reduction in fertilizer use from the baseline condition assumed during this study. Extensive guidance is provided regarding water and fertilizer management to reduce nutrient leaching and runoff. Implementation of the BMP would be expected to reduce loadings to surface water and groundwater, but there is no basis to estimate the magnitude of the effect at this time.

Potential Effect of Ridge Citrus BMP

The ridge citrus BMP was promulgated in 2002. The BMP does not require a significant reduction in fertilization rate from the rates assumed as the baseline situation. FDEP, UF/IFAS, and FDACS have conducted research to determine the effectiveness of the BMP.

The primary beneficial effect of the BMP is expected to be the requirement to apply less TN per application, at a greater frequency, than the standard practice of the industry prior to implementation of the BMPs. More frequent fertilization, in smaller amounts, reduces the potential for excessive runoff or leaching if heavy rains follow closely after fertilization, while maintaining, and perhaps enhancing, agricultural productivity. For example, Lamb, *et al*. (1999)

reported an average rate of 257 kg/ha/yr distributed in three applications per year (86 kg/ha/application) on three ridge citrus groves in Highlands County during the period 1988 to 1993. The ridge citrus BMP permits an application rate up to 240 kg/ha/yr[12], similar to rates actually used pre-BMP. Roeder (2008) analyzed data acquired to evaluate the effectiveness of the Ridge Citrus BMP, and found that groundwater concentrations of NO3-N averaged 10 mg/L for facilities implementing BMPs as of 2007, compared with the estimated concentration used in loading estimation in this report of 15 mg/L. FDEP (Brooks, 2008) has verified the effectiveness of the Ridge Citrus BMP, finding that average NO3-N concentrations at 8 groves participating in the BMP program decreased from 11.6 mg/L to 7.8 mg/L from 2004 to 2007, a reduction of 33%. The UF/Citrus Research and Education Center (2007) reports that approximately ½ of citrus acreage is participating in the BMP program as of 2007. Therefore, the effect of the BMP is expected to be less than a 30% reduction in loading rates from the citrus land use under current regulations. If BMP implementation were required under F.S. 403.067(7)(c), available data (Brooks, 2008) indicates that a 33% reduction in loading would be achievable for ridge citrus operations.

Although neither of these BMPs represent a substantial reduction of fertilizer use from the assumed baseline condition, the most critical factor in preventing leaching and runoff to springs and streams is the effective utilization of fertilizer applied by the crop by timing and frequency of fertilizer applications and minimization of irrigation. A small percentage reduction in fertilizer use could result in a much larger percentage reduction in loadings so long as the fertilizer that was applied is used more efficiently by the crop. Increasing the efficient utilization of applied fertilizer is, in fact, a primary objective of the promulgated BMPs so their implementation is expected to result in a more effective reduction in loading than might be indicated by any reduction in fertilizer applied.

Container Nurseries BMP

FDACS promulgated this BMP in August 2007. Its effects have not been evaluated to date. Considering the diversity of container nursery operations, this BMP does not specify a rate of fertilizer application. It addresses a wide range of container nursery operations including nursery layout, container substrate, fertilization management, irrigation, and runoff management. Nutrients are monitored in the container substrate nutrient solution. With respect to fertilization, controlled release fertilizers are to be used on the majority of the nursery, fertilizer is applied at manufacturer's recommended rates or as indicated by substrate nutrient monitoring. Fertilizer use is to be minimized to the amount required for crop production. Acceptable levels of NO3-N in container substrate nutrient solutions range from 15 to 100 mg/L. Since these concentrations exceed Florida groundwater quality standards, minimization of impacts to groundwater requires effective irrigation, leachate, and runoff management.

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[12] The allowable application rate varies with age of trees and productivity of the grove. Rates are likely to be limited to 240 kg/ha/yr for mature trees in the Wekiva Basin.

3.5 Summary of Revisions to Phase I Loadings

FDEP's Phase I report (MACTEC, 2007) analyzed available information to develop nitrate loadings to the Wekiva Basin, and made recommendations for Phase II investigations to reduce uncertainties identified by the Phase I study. FDEP's Phase II investigations emphasized the impacts of residential fertilizer use because the Phase I evaluation found that the effects of residential fertilizer use were not well established by field studies. FDEP's Phase II investigations are detailed in MACTEC (2009), UCF (2009), and Katz and Griffin (undated).

In companion studies, the FDOH studied groundwater impacts of OSTDS systems within the WSA. The results of FDOH research were published after publication of FDEP's Phase I report (Ellis & Associates, 2007, Young, 2007, and Roeder, 2008).

The SJRWMD received comments from stakeholders on the Phase I report. Comments were received from Anderson (2007) representing the Florida Home Builders Association, the Florida Onsite Wastewater Association, the Florida Association of Realtors, and the Orlando Regional Realtor Association; and Martinez (2007) and Wible (2007) representing The Scott's Miracle-Gro Company. Stakeholder comments on the Phase I report are reproduced in Appendix G.

This Final report responds to stakeholder comments, and incorporates information developed by the Wekiva Basin studies funded by FDEP and FDOH since publication of the Phase I report, as well as other technical publications not considered by MACTEC (2007). This section summarizes the changes to input and loading estimates made after consideration of stakeholder comments and other new information.

3.5.1 Revisions to Inputs

FDEP's charge from the legislature was to determine nitrate impacts to the Wekiva River and Floridan Aquifer system. Based on this direction, the Phase I estimates were designed to represent nitrate inputs and loadings to waters of the basin. If reliable nitrate data were available for any component of the budget, nitrate data were used. If reliable nitrate data were not available, then total nitrogen data were used. All loadings were quantified as NO3-N, but more than 90% of the inputs were quantified as TN because NO3-N data were not available for most of the inputs (for example, fertilizer use, livestock waste, and OSTDS effluents). As a result the inputs pie charts represented a mixture of NO3-N and TN values. Anderson (2007) commented that "all forms of nitrogen should be considered in quantifying inputs" while Young (2007) commented that MACTEC's (2007) approach "distorts the relative inputs". This report addresses those comments by defining all inputs as TN, resulting in revisions to the WWTF and atmospheric deposition input quantification. Those revisions are reflected in Section 2.3.3 and 2.3.5 of this report.

Anderson (2007), Young (2007), and Roeder (2007) comment that MACTEC (2007) underestimated atmospheric deposition. They present two reasons for their opinions:

- MACTEC (2007) quantified nitrate deposition, not accounting for other forms of nitrogen; this valid point has been addressed as described in the previous paragraph (see Section 2.3.5 of this report); and
- They disagree with use of rural deposition values from the CASTNET IRL site, and recommend use of values obtained in the Tampa metropolitan area.

Atmospheric deposition values have been recalculated in response to these comments, and increased by 120% - an increase of 577 MT/yr. The change primarily results from inclusion of all forms of TN. Deposition rates from both urban (Tampa) and rural (IRL) sites were used in this report. The Wekiva Basin is substantially less urban than either Tampa or the WSA. Urban deposition rates are more appropriate for the WSA (as addressed by Roeder, 2008), while a mixture of urban and rural deposition rates are appropriate for the Wekiva Basin as evaluated in this report.

Martinez (2007) and Wible (2007) commented that residential fertilizer usage rates estimated by MACTEC (2007) were too high, based on county-wide fertilizer sales data and nationwide surveys of residential fertilizer users. Roeder (2008) relied primarily on county-wide fertilizer sales data to develop fertilizer inputs to the WSA. Roeder's analysis assumes that residential fertilizer is applied only to areas managed as turfgrass. This assumption is implausible, since flower beds, ornamentals, and vegetable gardens are routinely fertilized. UCF (2009) found that most residents apply fertilizer at lower rates than were assumed for the Phase I report, a finding that is consistent with the comments of Martinez and Wible. The UCF study also addressed other issues raised by Martinez and Wible. UCF's Wekiva Basin survey should be used, rather than nationwide surveys cited by Martinez and Wible. For example, Martinez, using nationwide survey data, assumed that 50% of residents do not use fertilizer at all, while UCF found that 84% of WSA residents use fertilizer. Disadvantages of using county-wide fertilizer sales as the basis for inputs in this study are presented in Section 3.3.1, and difficulties in use of this type of data are also discussed by Wible (2007). This report has revised the estimates for residential fertilizer use based on the UCF (2009) findings (see Section 2.3.1.1), reducing residential fertilizer inputs (usage rates) by 27%, specifically a reduction of 1,066 MT/yr.

Ellis & Associates (2007) conducted intensive monitoring of OSTDS effluents at three sites in the WSA. This site-specific data, collected to support this study and published after the Phase I report, has been used to revise estimates of OSTDS inputs as detailed in Section 2.3.4. OSTDS inputs were increased by 45% as a result of using site-specific data, an increase of 267 MT/yr.

MACTEC (2007) assumed that nutrients in reclaimed water would "displace" fertilizer use, i.e., that landscape managers (e.g., residents, golf course managers) would apply less TN in fertilizer if they were receiving reclaimed water. Anderson (2007) and Roeder (2008) found this assumption unrealistic. Furthermore, the survey of residential fertilizer users conducted by UCF (2009) found that residents on reclaimed water actually used more fertilizer than those using other sources for irrigation water. In effect, the MACTEC (2007) assumption reduced the apparent contribution of reclaimed water use in the nitrogen budget. In this final report reclaimed water is retained as an input related to the WWTF source category. In addition, as previously discussed, inputs from WWTF are now expressed as TN. The combined effect of these two revisions is to increase WWTF inputs by 79%, an increase of 150 MT/yr.

The estimated fertilizer application rate to tree crops (citrus) was increased from 227 kg/ha/yr to 240 kg/ha/yr, consistent with the Ridge Citrus BMP, correcting an error in the Phase I report. Since nurseries and ornamentals land uses were assumed to received similar fertilization as citrus, this change was also applied to nurseries and ornamentals. The effect is an increase in TN inputs of 6% for these land uses, an increase of 99 MT/yr.

Finally, a computational error reflected in the Phase I report was corrected. The Phase I summary of the agricultural fertilizer inputs did not sum fertilizer use for all agricultural land uses. The nurseries category was incorrectly omitted from the agriculture inputs subtotal. This error has been corrected.

Differences between the inputs estimated in the Phase I report and in this final report are illustrated in Figure 3-6.

3.5.2 Revisions to Loadings

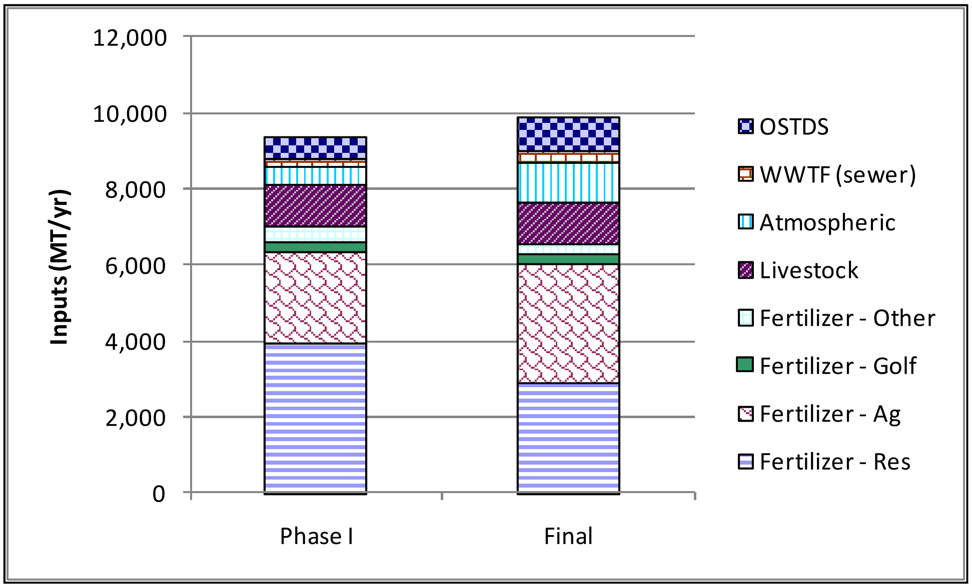
Ellis & Associates (2007) conducted intensive monitoring of OSTDS groundwater impacts at three sites in the WSA. This site-specific data, collected to support this study and published after the Phase I report, has been used to revise estimates of OSTDS loadings, as detailed in Section 2.4.4. OSTDS loadings were increased by 16% (68 MT/yr), compared with Phase I estimates based on national data.

MACTEC (2009) monitored groundwater quality in residential portions of the Wekiva Basin that were isolated from known OSTDS. These site-specific data were used to estimate groundwater quality in residential areas of the Wekiva Basin, resulting in a 33% reduction in NO3-N loading to groundwater associated with residential fertilizer use, a reduction of 98 MT/yr. These revisions, using site-specific data, are also responsive to comments by Wible (2007).

Nitrogen in reclaimed water has now been allocated to land uses receiving the reclaimed water. It is assumed that 20% of the TN in the reclaimed water leaches to groundwater as NO3-N based on York (2007). This represents a similar percentage as other types of fertilizer use. Effectively, this approach treats the nitrogen in reclaimed water as fertilizer, but it is no longer assumed that fertilizer use is reduced on lands receiving reclaimed water. This increased loadings from WWTF by 13% or 25 MT/yr.

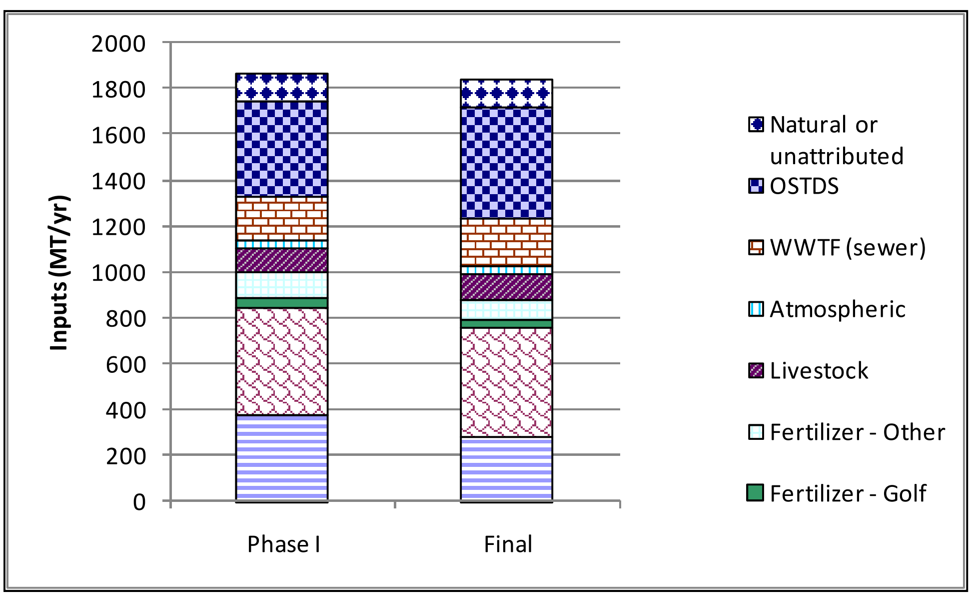
Differences between the loadings estimated in the Phase I report and in this final report are illustrated in Figure 3-7.

Figure 3-6. Comparison of Final Inputs with Estimates from the Phase I Report



Source: MACTEC.
Created by: JAT Checked by: WAT

Figure 3-7. Comparison of Final Loadings with Estimates from the Phase I Report



Source: MACTEC.
Created by: JAT Checked by: WAT

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