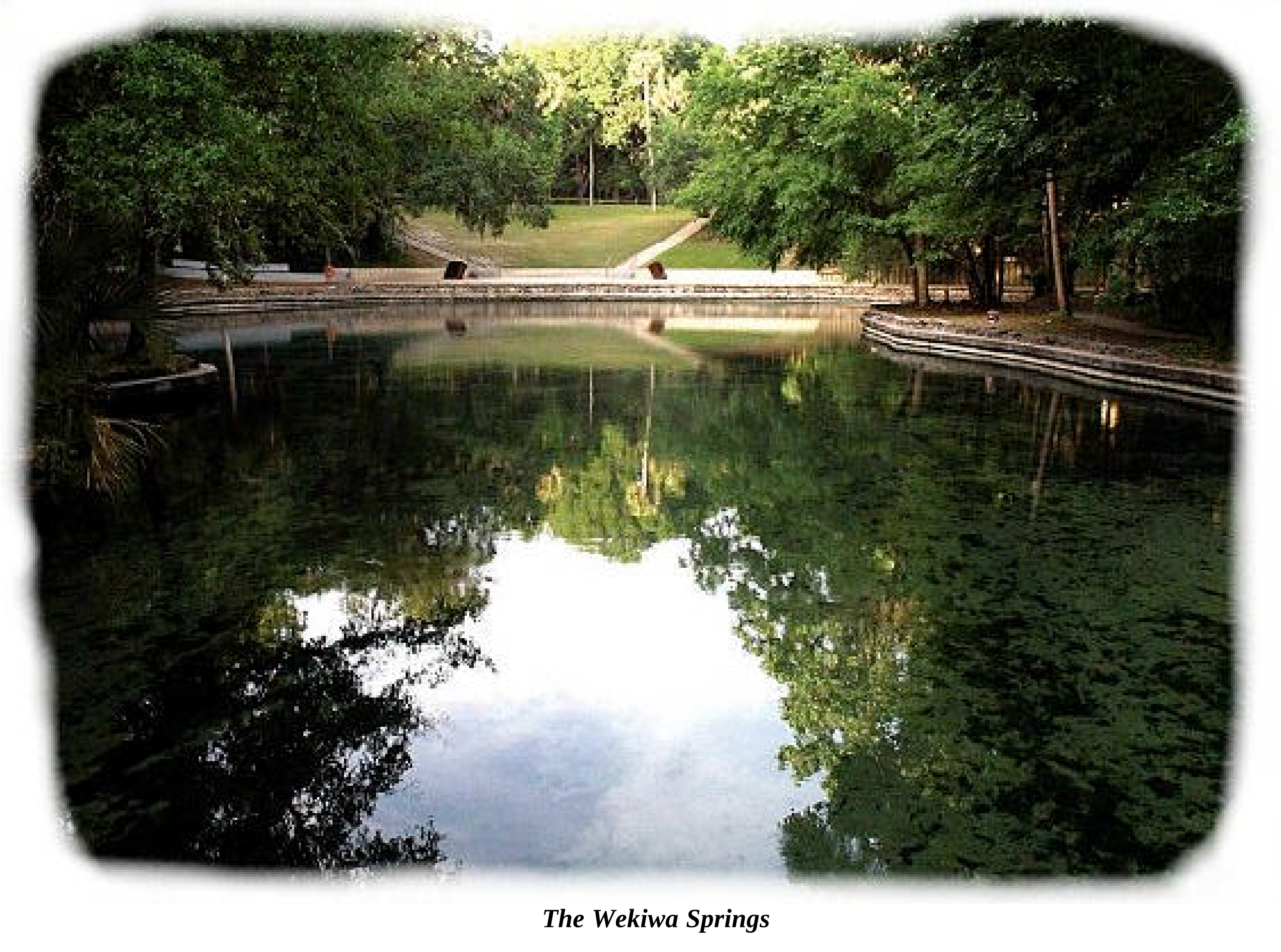
A STRATEGY FOR WATER QUALITY PROTECTION: WASTEWATER TREATMENT IN THE WEKIVA STUDY AREA

Florida Department of Environmental Protection

December 2004



The Wekiwa Springs

A STRATEGY FOR WATER QUALITY PROTECTION: WASTEWATER TREATMENT IN THE WEKIVA STUDY AREA

A report to the Governor and the Department of Community Affairs on the efficacy and applicability of water quality and wastewater treatment standards needed to achieve nitrogen reductions protective of surface and ground water quality within the Wekiva Study Area.

This report is submitted pursuant to Section 369.318(1), F.S., of the Wekiva Parkway and Protection Act, Chapter 2004-384, Laws of Florida.

DECEMBER 1, 2004

DEPARTMENT OF ENVIRONMENTAL PROTECTION
FLORIDA

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Cover Photo: Wekiwa Sprints, courtesy of Florida Geological Survey

EXECUTIVE SUMMARY

This study was prepared for the Governor and the Department of Community Affairs in response to the Wekiva Parkway and Protection Act, specifically section 369.318(1), Florida Statutes. The law requires the Department of Environmental Protection (DEP) to study the efficacy and applicability of water quality standards needed to achieve nitrogen reductions protective of surface and ground water quality in the Wekiva Study Area (WSA). It also requires the DEP, if appropriate, to initiate rule making by March 1, 2005 to achieve nitrogen reductions protective of surface and ground water quality or recommend additional statutory authority needed to implement report recommendations.

The WSA covers about 300,000 acres and includes the surface and most of the recharge area to its 27 named springs. These springs discharge an average of 71 million gallons per day. The study area is underlain by karst geology, characterized by sinkholes, caves, and springs. Generally, higher topographic regions in the west and south serve to recharge the Floridan Aquifer system that in turn feeds the springs and wetlands in the lower elevations in the central, northern, and eastern regions of the Study Area.

The springsheds and their associated land uses directly influence water quality in the springs. Water quality data from ambient monitoring programs, compliance monitoring, reports presented to the Wekiva River Basin Coordinating Committee, and other recent investigations in the WSA create a complex picture of specific cause and effect relationships. These relationships are made complex not only by the difficult-to-define system of underground conduits feeding each spring, but also by the time it takes a molecule of water to travel from the ground surface to the aquifer to the spring. This time ranges from a few days to greater than 40 years, so the impacts of land use changes made 30 years ago could be observed in a spring today. Likewise, the impact of land use changes made today may not be observed for years.

Water quality impacts in the spring boil and run are not easily measured using traditional methods of analysis, like chlorophyll a levels. Instead the changes resulting from increased nutrient levels may be measured through the changes in the macrophytes (larger plants like eelgrass) and their associated animal community. This type of analysis is the focus of work in progress by the Florida Springs Task Force, and by the St. Johns River Water Management District (SJRWMD) and the DEP in assessments to be completed in the next two years.

For purposes of this report and based on the studies to date, the DEP has concluded that: 1) Water and most of the nitrogen entering the ground in the springshed will ultimately find its way to a spring; 2) Water quality in a 'natural' spring can be assessed by examining the quality of the springs in the WSA and surrounding areas; and, 3) Depending on specific geologic characteristics of the WSA, definable areas recharge the aquifer, therefore the springs, more quickly than other areas.

To identify the 'natural' spring and its associated nitrogen levels we used an assessment completed by the SJRWMD (an examination of nitrogen concentrations from springs in the WSA and the Ocala National Forest areas). Springs from relatively unaffected areas show nitrate [as nitrogen] to be less than 0.2 milligrams per liter (mg/l). Those affected by urbanization and agriculture exhibit nitrate [as nitrogen] concentrations greater than 0.5 mg/l. Using the 0.2 mg/l figure as a target concentration indicating "natural" water quality conditions, it is clear that there are several impacted springs in the Study Area. It should be noted that the Florida Springs Task Force Report [2000] also observed that the typical nitrate concentrations in unaffected springs in Florida were less than 0.2 mg/l. Refinement of these numbers will occur with the development of detailed Pollutant Load Reduction Goals (PLRG) and Total Maximum Daily Loads (TMDL) required by law for the Study Area.

To establish the vulnerable areas, DEP has prepared a site-specific Wekiva Aquifer Vulnerability Assessment (WAVA), using an established statewide model (the Florida Aquifer Vulnerability Assessment). The draft WAVA is included as Appendix A. Three protection zones have been identified (see Figure 9, page 23, and for more detail see the **Response Theme** section, starting on page 54 of Appendix A).

As required in s. 369.318(1), F.S., this report focuses on wastewater treatment facilities regulated by DEP, which is only one of several contributing sources of nitrogen to the Study Area. These other sources are being addressed by other agencies or in different timeframes, according to the provisions of the Wekiva Parkway and Protection Act.

There are 48 wastewater treatment facilities in the WSA and all utilize land application of reclaimed water. Two of these systems use surface water discharge for back-up disposal and two have continuous surface water discharges as a component of their disposal systems.

The DEP reviewed existing treatment at these facilities as well as more advanced nitrogen removal technologies and associated costs. This analysis was done for large (greater than 100,000 gallons per day) and small systems. Based on this analysis, DEP recommends that upgraded treatment be required for wastewater facilities discharging in those areas most directly affecting the springs.

Three protection zones generated by the WAVA analysis were used to develop the appropriate treatment technology strategies for large and small facilities. Costs associated with the treatment upgrades and reliability of compliance were considered in making these recommendations. DEP recommends the following actions:

1. Adopt the WAVA Protection Zones.
2. Adopt the enhanced wastewater treatment requirements for ground water discharges, as follows:

   Within the Primary Protection Zone, the following enhanced wastewater treatment requirements are recommended:

   - No new rapid rate or restricted access slow-rate land application systems.
   - Existing large wastewater treatment facilities with rapid rate systems as the primary reuse method will be required to reduce nitrogen in applied reclaimed water to 3.0 mg/l Total Nitrogen as N within five years. Where rapid rate systems are utilized **only** as back-up to the regional reuse irrigation system, they will be considered to be part of the regional reuse system.

- Existing large wastewater treatment facilities with regional reuse irrigation systems or restricted access irrigation systems will be required to reduce nitrogen in the applied reclaimed water to 10.0 mg/l Total Nitrogen as N within five years.
- Existing small wastewater treatment facilities will be required to connect to a regional wastewater treatment facility within five years, or reduce nitrogen in reclaimed water to 10.0 mg/l Total Nitrogen as N.
- No land application of wastewater residuals.

Within the Secondary Protection Zone, the following enhanced wastewater treatment requirements are recommended:

- Existing large wastewater treatment facilities with rapid rate systems as the primary reuse method will be required to reduce nitrogen in applied reclaimed water to 6.0 mg/l Total Nitrogen as N within five years. New systems shall be required to meet this requirement. Where rapid rate systems are utilized **only** as back-up to the regional reuse irrigation system, they will be considered to be part of the regional reuse system.
- Existing large wastewater treatment facilities with regional reuse irrigation systems or restricted access irrigation systems will be required to reduce nitrogen in the applied reclaimed water to 10.0 mg/l Total Nitrogen as N within five years. New systems shall be required to meet this requirement.
- Existing small wastewater treatment facilities will be required to connect to a regional wastewater treatment facility within ten years or reduce nitrogen in reclaimed water to 10.0 mg/l Total Nitrogen as N.
- No land application of wastewater residuals.

In applying these treatment requirements, large wastewater treatment facilities are identified as those with a permitted capacity of 100,000 gallons per day (gpd) or more and small wastewater treatment facilities are those with a permitted capacity of less than 100,000 gpd.

Within the Tertiary Protection Zone, facilities will be required to meet the existing regulations, with the possibility of requiring increased monitoring.

3. Adopt enhanced wastewater treatment requirements for surface water discharges, as follows:

New surface water discharges shall only be permitted as back-up to a regional reuse system and must comply with s. 403.086(5), Florida Statutes.

- Existing surface water discharges shall be limited to a back-up to a regional reuse system, and shall constitute no more than 30% of the wastewater treatment plant flow on an annual average basis. Facilities in this category would be required to be in compliance within five years.

The authority to establish the recommended treatment and disposal practices would require legislation, such as that passed for the Tampa Bay Estuary, the Indian River Lagoon and, most recently, the Florida Keys. The DEP would not be able to implement the requirements through rulemaking under its existing authorities.

A. INTRODUCTION

1. Background

The Wekiva River system and its associated springshed areas are of irreplaceable value to the quality of life and well being of the people of the State of Florida. Its tributaries have been designated an Outstanding Florida Water, a National Wild and Scenic River, a Florida Wild and Scenic River, and a Florida Aquatic Preserve. The River is a spring-fed system that derives a majority of its base flow from numerous springs whose source of water is the Floridan Aquifer.

In 1988, the Florida Legislature enacted the Wekiva River Protection Act, codified in Part II of Chapter 369, Florida Statutes, to protect the resources of the Wekiva River system. The Act delineated an area comprising portions of Lake, Orange, and Seminole Counties as the Wekiva River Protection Area.

Protection of the surface and ground water resources, including recharge within the springshed that provides for the Wekiva River system, is crucial to the long-term viability of the Wekiva River and springs and the central Florida region's water supply. The primary ground water recharge area of the Wekiva River system lies to the west and south and outside the Wekiva River Protection Area.

Construction of the Wekiva Parkway and other roadway improvements to the west of the Wekiva River system will add to the pressures for growth and development already affecting the surface and groundwater resources in the study area. Governor Bush created the Wekiva Basin Area Task Force in 2002 by Executive Order 2002-259. The Task Force was charged with considering, evaluating and making recommendations for the most appropriate location for an expressway that connects State Road 429 to Interstate 4 in Seminole County, that also causes the least disruption and provides the greatest protection to the Wekiva Basin ecosystem. The Task Force submitted its recommendations to Governor Bush in a final report dated January 15, 2003.

The Governor appointed the members of the Wekiva River Basin Coordinating Committee (Committee) on July 1, 2003, by Executive Order 2003-112. The Committee was asked to build upon the recommendations of the Wekiva Basin Area Task Force through a cooperative, coordinated effort with local governments, state, and regional agencies, and affected interests. The Executive Order directed the Committee to present its report to the Governor and the Department of Community Affairs by February 15, 2004. Executive Order 2003-112 was amended by Executive Order 2004-10, which extended the Committee's work to March 16, 2004 *(from the Committee Final Report)*.

The Committee presented its recommendations in the "Wekiva River Basin Coordinating Committee Final Report – Recommendations for Enhanced Land Use Planning Strategies and Development Standards to Protect Water Resources of the Wekiva River Basin" (Committee Final Report). The 2004 Florida Legislature passed the Wekiva Parkway and Protection Act, Part III of Chapter 369, Florida Statutes, to implement the recommendations of the Committee as presented in the Committee Final Report.

The WSA and the Wekiva Springshed are depicted in **Figure 1** (adapted from WRBCC, 2004).

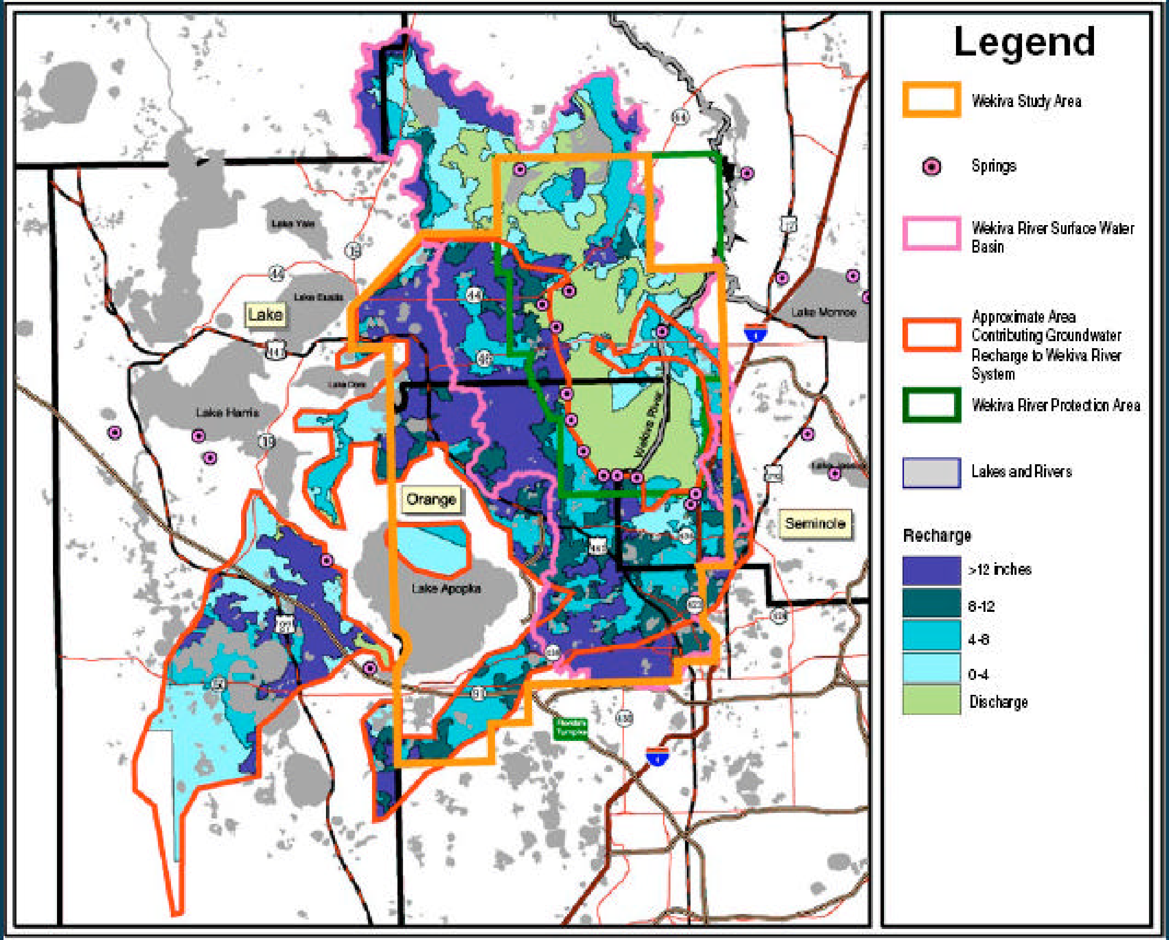


Figure 1. Wekiva Study Area: Surface Water Basin, Groundwater Basin and Recharge

2. Purpose

The Wekiva Parkway and Protection Act, as codified in Part III of Chapter 369, Florida Statutes, requires that certain studies be conducted to review and evaluate the effectiveness of water quality and wastewater treatment standards to protect waters in the WSA. This report to the Governor and Department of Community Affairs has been prepared in response to the following directive:

> "369.318 Studies. —
>
> (1) The Department of Environmental Protection shall study the efficacy and applicability of water quality and wastewater treatment standards needed to achieve nitrogen reductions protective of surface and groundwater quality within the Wekiva Study Area and report to the Governor and Department of Community Affairs no later than December 1, 2004.

> Based on the December 2004 report, the Department of Environmental Protection shall, if appropriate, by March 1, 2005, initiate rulemaking to achieve nitrogen reductions protective of surface and groundwater quality or recommend additional statutory authority needed to implement the report recommendations."

To accomplish this task, the Department of Environmental Protection has:

- Identified existing wastewater treatment systems and their treatment technologies
- Evaluated existing treatment technologies to remove nutrients and their respective costs
- Surveyed existing ground water and surface water quality information in the study area, particularly related to the springs
- Established target nitrogen concentrations for the spring boils
- Developed a specific aquifer vulnerability assessment (WAVA) for the study area to identify those areas most directly affecting the aquifer that feeds the springs
- Applied WAVA to delineate protection zones in the study area
- Identified treatment upgrade strategies for each WAVA protection zone
- Recommended an implementation strategy.

It is envisioned that delineation of these protection zones will assist in the other protection efforts called for by the Wekiva Parkway and Protection Act.

3. Other Protection Efforts

The revisions made to Chapter 369, Florida Statutes, as a result of the passage of the Wekiva Parkway and Protection Act, also require that nitrogen derived from other domestic wastewater sources be reduced to improve and assure protection of surface water and groundwater resources within the WSA. Section 369.318(2), Florida Statutes, requires that the Department of Health, in coordination with the Department of Environmental Protection, study the efficacy and applicability of onsite disposal system standards needed to achieve nitrogen reductions, protective of groundwater quality within the WSA. The WAVA protection zones should be useful in setting treatment standards that most effectively control nutrient loading to the ground water and springs.

To assure protection of surface waters, the St. Johns River Water Management District must establish Pollutant Load Reduction Goals (PLRGs) for the WSA by December 1, 2005. This information will assist the Department of Environmental Protection in adopting Total Maximum Daily Loads (TMDLs) for impaired waters within the WSA by December 1, 2006. It is important to note that these efforts will evaluate in detail the surface water quality in the study area and establish nutrient concentrations that must be maintained in order to achieve the desired water quality of a Class III water.

The Department of Agriculture and Consumer Services is the lead agency in coordinating the reduction of agricultural non-point sources of pollution. This will be accomplished by studying and, if necessary, initiating rulemaking to implement new or revised best management practices for improving and protecting water bodies, including those basins with impaired water bodies addressed by the TMDLs program. Again, the establishment of

WAVA protection zones should be useful in setting best management strategies for the study area.

The St. Johns River Water Management District is charged with a number of tasks dealing with recharge and water quantity issues for the WSA as follows:

- Initiate rulemaking to amend the recharge criteria in Rule 40C-41.063(3), Florida Administrative Code,
- Adopt a consolidated environmental resources permit/consumptive use permit for projects that require both permits,
- Complete an assessment of the significance of water use below the current consumptive permit thresholds in the WSA,
- Conduct an analysis of the impact of redevelopment projects upon aquifer recharge, and
- Update the minimum flows and level standards for Rock Springs and Wekiwa Springs by December 1, 2007.

Local governments within the WSA are required to develop master storm water management plans and master wastewater management plans. The master wastewater plans will include improvements necessary to meet enhanced wastewater treatment standards, provisions for central wastewater systems in areas currently served by existing onsite septic tank systems, and a reclaimed water reuse program. A part of the master storm water management plan should focus on the treatment of waters using the existing drainage wells that affect the aquifer in the study area.

B. WATER QUALITY WITHIN THE WEKIVA STUDY AREA

1. Nitrogen Concerns and Sources

The Committee Final Report has an excellent description of groundwater quality issues associated with the Wekiva Spring system and the information in this section regarding spring water quality has been partially adapted from the discussion found in the Committee Final Report. In addition, to the water quality-related studies presented to the commission, this discussion extracts other pertinent information that agencies such as the SJRWMD, United States Geological Survey (USGS), Florida Geological Survey (FGS) have performed concerning nitrogen levels observed in the Wekiva River spring system.

In general, the beauty of Florida springs, whether found in urban or rural settings, public parks or private lands, are threatened by actual or potential flow reductions and declining water quality. Since the 1960s, scientists have documented a decline in water quality and water quantity in a number of springs. While some of the decline in quantity is tied to changes in rainfall, Florida's population quadrupled from 1950 to 1990 and there has been an unavoidable increase in water use, as well as extensive land use changes. As a result of climate patterns and population changes, over the past fifty years, many of Florida's springs have begun to exhibit signals of distress, including increased nutrient concentrations and lowered water flow. The nature and magnitude of threats to any one spring vary according to land use practices and the geology within its springshed. An example of this is shown in **Figures 2a and 2b**, the long term monitoring of nitrogen at Wekiwa Springs and Rock Springs. The nitrogen reflects the high nutrient loading to both springsheds.

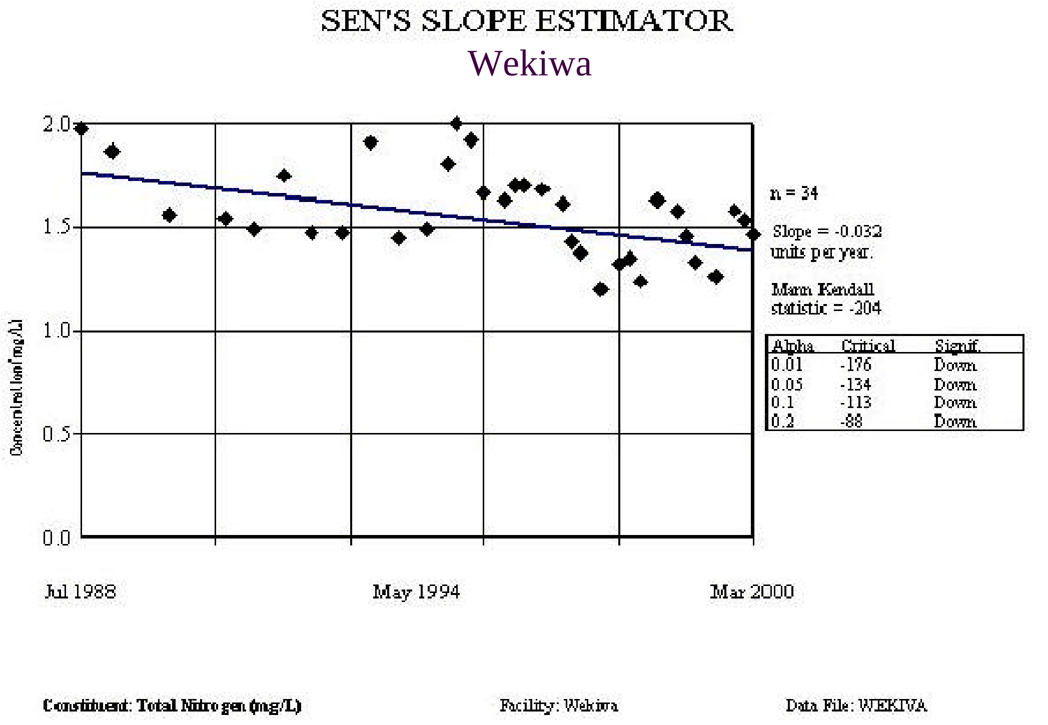


Figure 2a. Sen's Slope estimation for total nitrogen (nitrate + nitrite) at Wekiwa Springs for the period 1988-2000. The decreasing trend is significant at the 99% confidence limit.

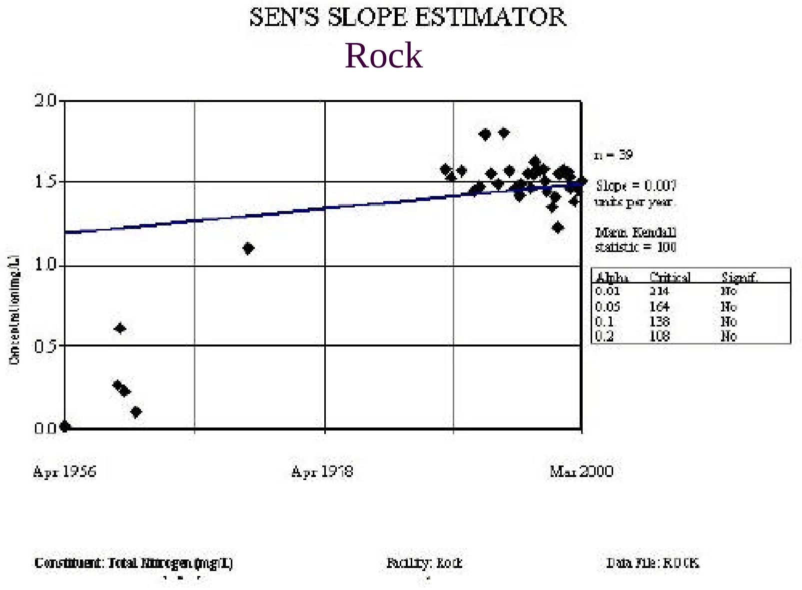
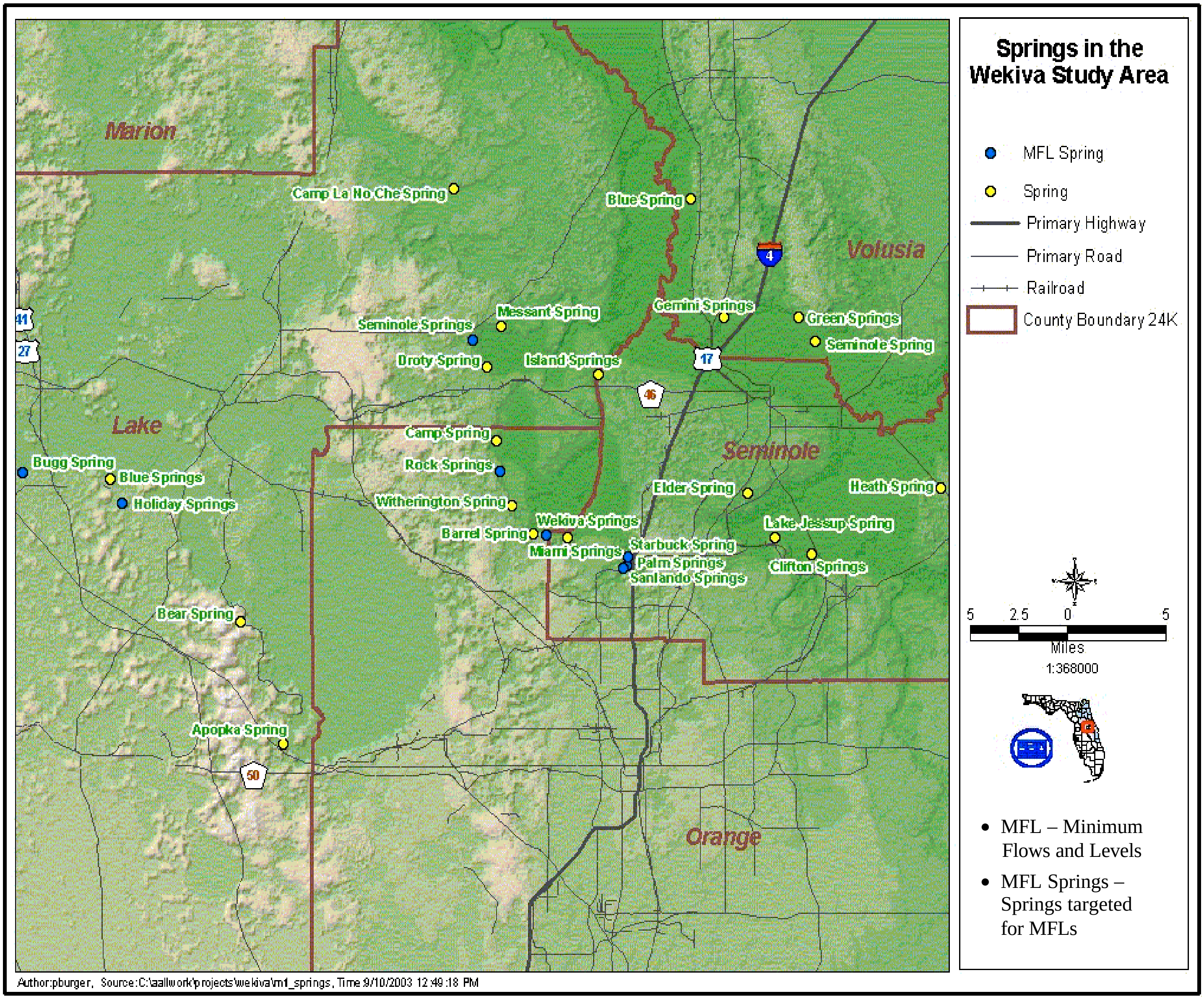


Figure 2b. Sen's Slope estimation for total nitrogen (nitrate + nitrite) at Rock Springs for the period of record. There is no statistically significant trend.

Figures 2a and 2b, an analysis provided by the SJRWMD showing the Long Term Monitoring of NO3-NO2 at Wekiwa and Rock Springs (adapted from Osburn, et al., 2002)

There are 27 known springs in the Wekiva River basin **[Figure 3].** The collective springshed for these springs or the land area that contributes recharge to the aquifer from which springs discharge, is approximately 300,000 acres **[see Figure 1]**. Each spring (and its springshed) is vastly different in its environmental, historical, and cultural setting making the entire system one of the State's most valuable environmental and water resources. Of the 27 springs, 19 are within public ownership and eight are on private property. The largest spring is Wekiwa Spring, a second magnitude spring, with a long-term average discharge of 43 million gallons per day (mgd) followed by Rock Spring, a second magnitude spring, with an average discharge of 38 mgd. The remaining 25 springs are small with discharges totaling less than 26 mgd. Periodic discharge measurements for Wekiwa Springs and Rock Springs go back as far as the 1930s.



- MFL – Minimum Flows and Levels
- MFL Springs – Springs targeted for MFLs

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Figure 3 – Springs of the Wekiva Study Area (adapted from WRBCC reports, 2003).

The springshed itself is highly varied in topography, land use and hydrologic character. Generally, the springs are located in the lower elevations where water pressures in the Floridan aquifer supply the driving force for spring discharge.

Higher topographic elevations in the western and southern portions of the springshed are considered high recharge areas to the Floridan aquifer. These ridges and lowlands are illustrated in **Figure 4.**

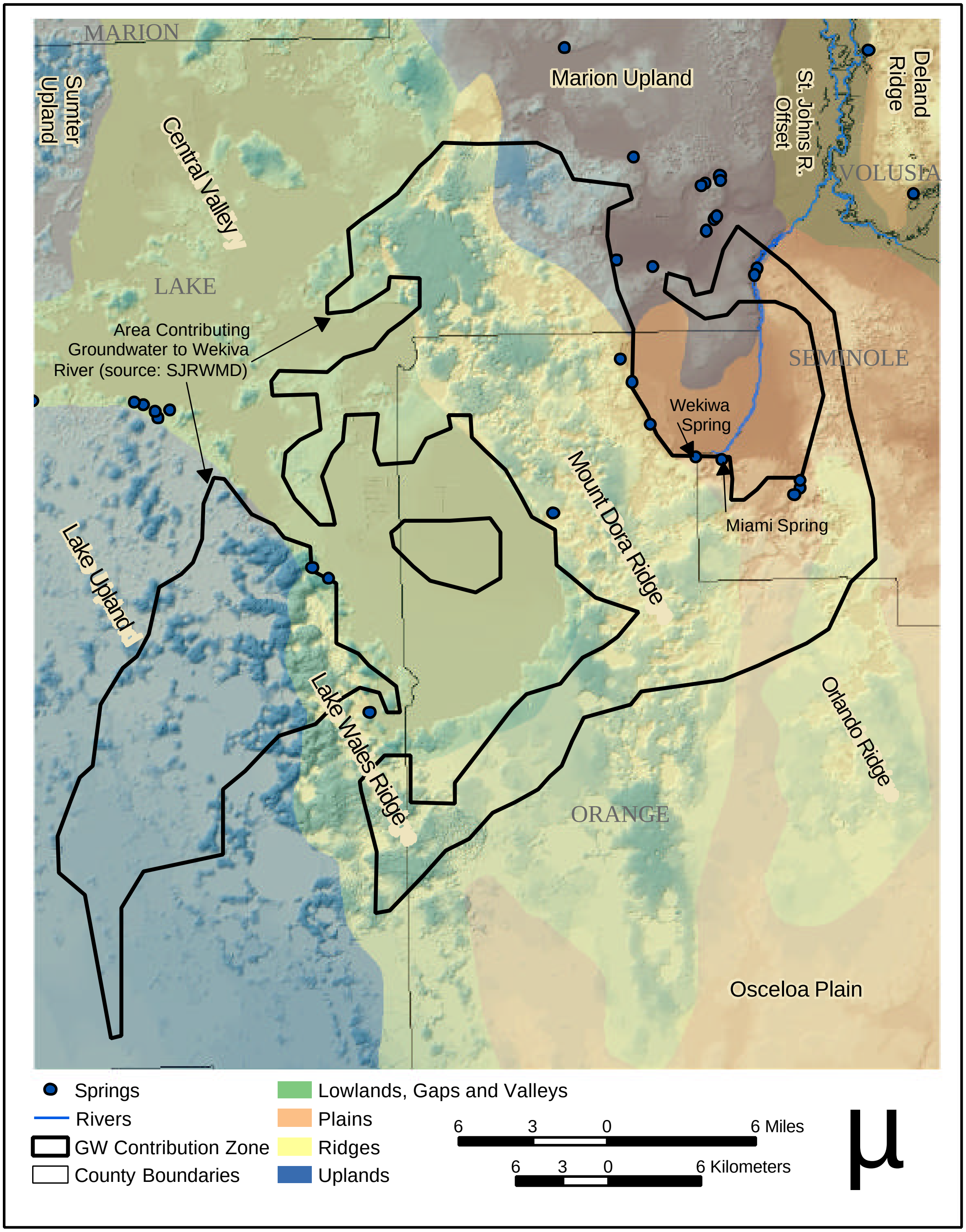

Figure 4, Major Landforms of the Wekiva Study Area (adapted from Cichon, et al., 2004).

Historically, the springshed has been dominated by agricultural land use in the form of citrus, row crops, and pasture. After the severe freeze of 1983-84 much of the citrus area remained unplanted. In Orange County, acreage planted in citrus dropped from 65,960 acres in 1970 to 7000 acres in 2003. Row crops in Orange County dropped from 108,000 acres in 1969 to 30,000 acres in 1997. Further reduction of row crops occurred in 1999, when the SJRWMD completed a 20,000-acre buy out of the muck farms along the northern and northwestern shores of Lake Apopka. In addition to substantially reducing the remaining row crop acreage in the basin and its associated fertilization practices, it has provided sites for wetland treatment of Lake Apopka waters. These actions are intended to improve the water quality of the Upper Ocklawaha chain of lakes, but will also improve to quality of water recharging the springsheds of the WSA. The wetlands to the north of the lake and a northeastern part of Lake Apopka have been identified as active recharge areas to the WSA.

As the metropolitan Orlando area grew, much of the agricultural and undeveloped lands were converted to residential and urban development, and to a lesser extent, specialty crops (woody ornamentals and foliage plant nurseries – about 4500 acres). By 2000, over 80,000 acres of agriculture were converted to other land uses, of which 32,000 acres had been converted to urban residential use.

In the WSA, the springs are fed by rainfall and irrigation that percolates through the ground to the aquifer or directly through conduits such as sinkholes [**Figure 5**]. Because of this, the

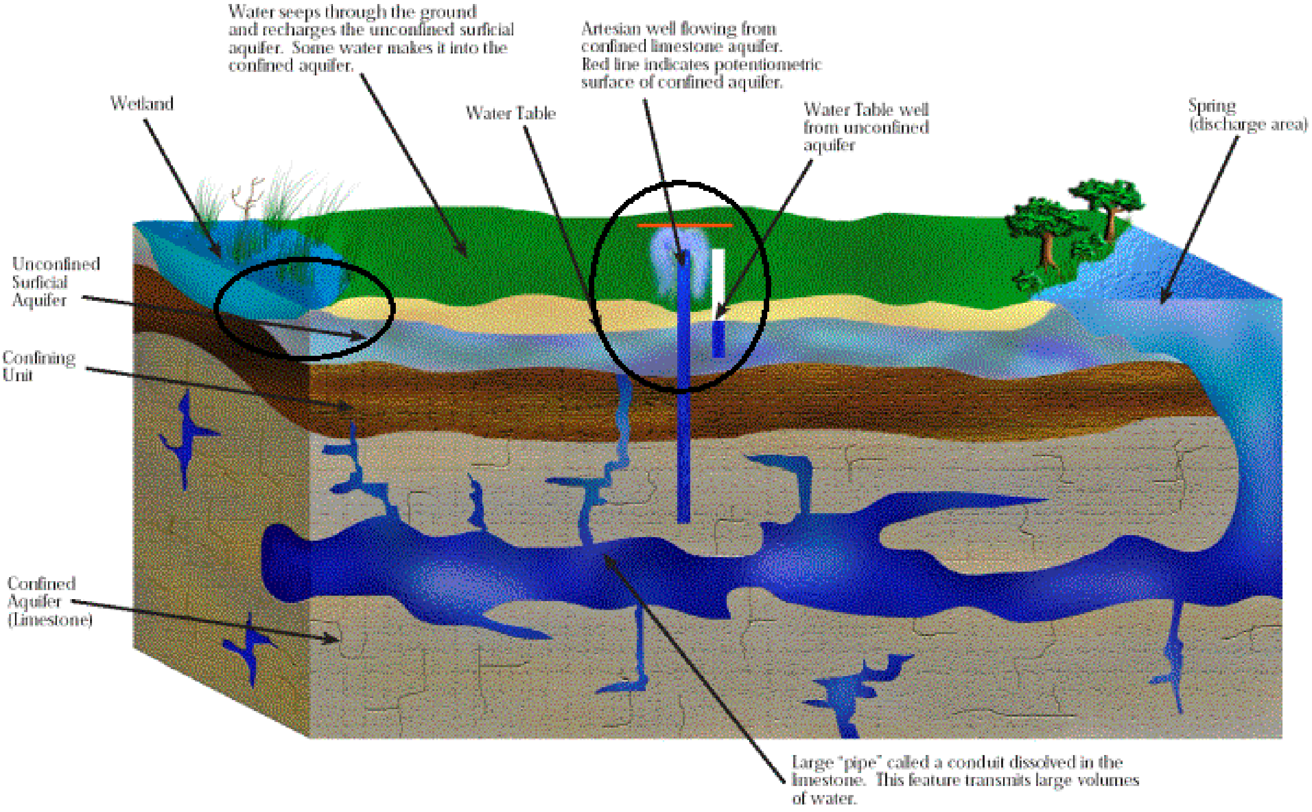

Figure 5, Hydrology in a Karst Area

health of spring systems can be slowly or much more rapidly influenced by activities and land uses within the spring recharge basin. Numerous studies by Florida's water management districts, the FGS, and the USGS have demonstrated the connection between the land activities and water quality in the aquifer. In the WSA some of those studies include: (Toth and Fortich, 2002; Toth, 1999; Katz, et al., 1995; Adamski and Knowles, 2001; Adams and German, 2004; O'Reilly, et al., 2002; O'Reilly, 1998; Schiffer, 1998; Spechler and Halford, 2001; Sumner and Bradner, 1996; Cichon, et al., 2004; Rabbani, et al., 2000). In other spring locations in Florida, these same relationships have been documented (Katz, et al., 1999; Champion and Upchurch, in press; Champion and DeWitt, 2000; Jones, et al., 1996; Chelette, et al., 2002).

Based on this information, information presented to the Wekiva Coordinating Committee, ambient groundwater monitoring programs, and wastewater treatment facility compliance monitoring reports, one discovers a complex relationship existing between the sources and the springs. The relationship is made complex by the difficult-to-define system of underground conduits feeding each spring and the time it takes a water molecule to travel from the ground surface to the aquifer, and then to the spring. As mentioned earlier, any one spring in the WSA is fed by water moving slowly through the sediment or rapidly through karst features. Slower where there are confining layers [geologic formation of very low permeability/transmissivity], and more rapidly in their absence and the presence of sandy well drained soils. Dating studies by Toth and others in the WSA show that the time of travel can range from a few hours to decades. The median age of water from groundwater wells and springs in the WSA ranges from 17 years at the Wekiwa Springs to greater than 30 years at other locations in the study area. Therefore historic changes in land use, such as the decline of the citrus industry in the mid-1980s, could be affecting the nitrogen concentrations of a spring measured in the last few years. Likewise, the impact of land use changes made today may not be observed for years or may have an immediate impact. The bottom line is, what occurs on the land directly and indirectly affects the quality and quantity of water moving through the subsurface conduits.

The WSA, as shown in **Figure 6**, is permeated with conduit or karst features and indicates the potential for land use activities to influence the quality of the area's springs.

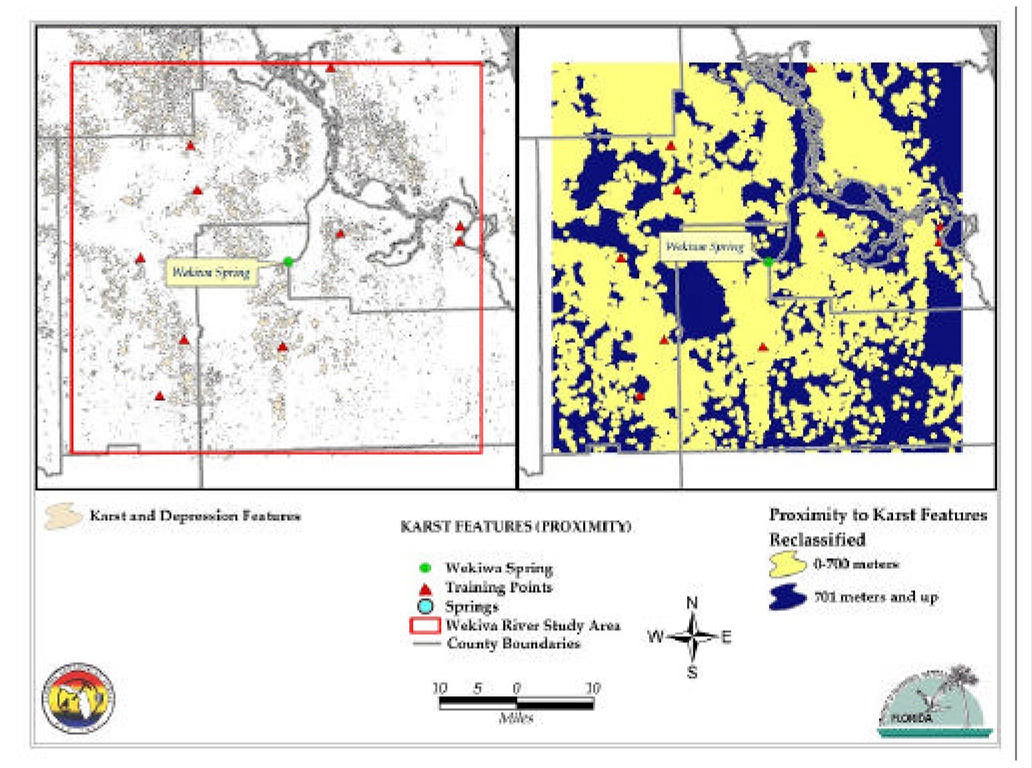

Figure 6, Karstic Features of the Wekiva Study Area

So water, whether it moves slowly or quickly, ultimately reaches the springs, but what does it carry? Water can carry contaminants from a variety of land surface activities. Stormwater runoff can carry oil, fertilizer, pesticides, and bacteria (Martin and Smoot, 1986; Schiffer, 1989). Septic tanks leachate, reclaimed water land applied for irrigation or for aquifer recharge at rapid rate infiltration basins, and leaking underground storage tanks can contribute nutrients, bacteria and chemicals via seepage to the aquifers. This contamination can seep to the ground water and travel to a spring in the WSA. Increased nutrients, including soluble forms of nitrogen, essentially fertilize the water in springsheds. Non-point source-derived nitrogen arrives from numerous sources: animal wastes; automobile and industrial exhausts; and inorganic fertilizer applications to residential lawns, cemeteries, urban greenways, golf courses, and agriculture fields. Nutrients, at levels exceeding plant uptake, will make their way into ground water and surface waters. Once the excessive nutrients reach the surface waters through direct (runoff) or indirect (ground water to springs) pathways, problems often arise in the spring boil and run and farther downstream in rivers and lakes. Problems related to increased nutrient concentrations can include the overgrowth of aquatic plants or the loss of aquatic species richness and diversity. These changes will affect the habitat of the native fauna and flora, and eventually the decline of their numbers. Water quality impacts in the springs and their runs are not easily measured using traditional stream assessment methods, i.e., chlorophyll *a* concentrations from algae. Instead changes related to nutrient increases may be measured through changes in the macrophytes or aquatic plant community and its associated fauna. This type of analysis is the focus of work in progress by the Florida Springs Task Force, and by the SJRWMD and the DEP in assessments to be completed in the next two years.

Water quality in Wekiwa Springs and Rock Springs has changed over time. From 1961 to 1977, Wekiwa Springs's nitrate-nitrogen concentrations were below .8 mg/L. In the 80's and 90's, nitrate-nitrogen concentrations increased to a high of 2.0 mg/L at Wekiwa Springs in 1989 and 1995 and averaged over 1.5 mg/L. Over the past five years the concentrations have declined to near 1.0 mg/L at the Wekiwa Springs, but still remain high compared to the 70's and substantially above background levels (0.2 mg/L) for the Floridan aquifer system, and other unaffected springs in the WSA **[Figure 7].**

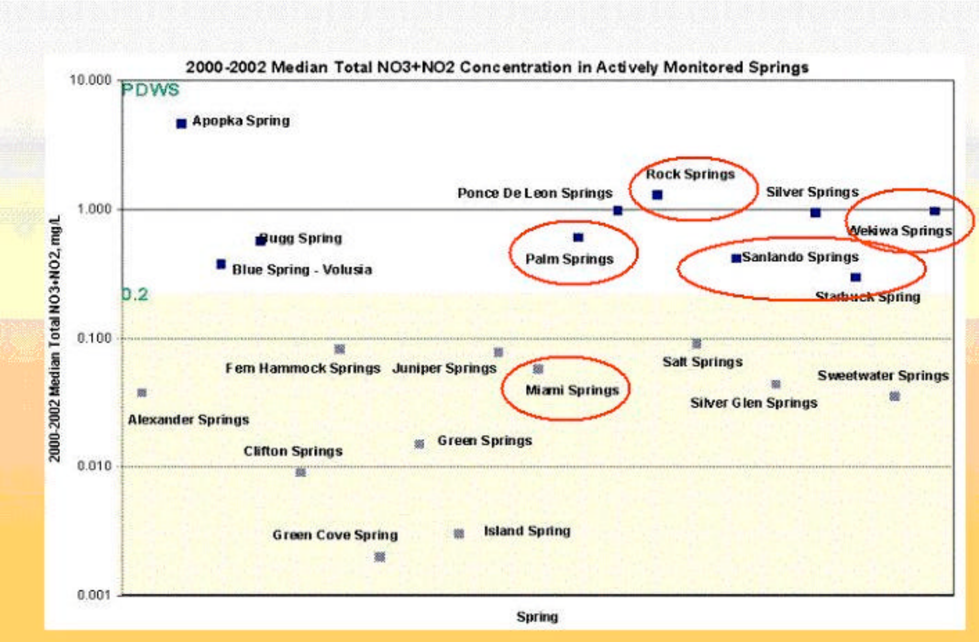

Figure 7. 2000-2002 Median Total NO3+NO2 Concentration in Actively Monitored Springs (adapted from Osburn, 2203).

Nitrogen isotope data suggest that the source of nutrients in Wekiwa Springs is a mixture of fertilizers alone or a combination of fertilizers and wastewater. As mentioned previously, the age of this spring water, measured with isotope samples taken from the spring waters in the study area, suggests that changing land use patterns in the springshed have influenced the water quality (Toth and Fortich, 2002; Toth, 2003). In this case, the rapid decline of the citrus industry in the WSA was credited for at least part of the decrease in nitrogen measured over the last five years.

The nitrate-nitrogen levels of these springs are approximately 10 to 100 times higher than the levels in the near pristine springs found in the Ocala National Forest and those located in other areas of the WSA, such as Miami Springs or Island Springs. The nitrate trend for Rock Springs has remained at the about the 1.5 mg/L level for the last 10 years. Miami Springs provides the most striking evidence of land use influence on spring water quality, as it is located just a few miles to the east of the Wekiwa Springs and exhibits nitrate concentrations of less than 0.2 mg/L.

As mentioned previously, the nitrates that feed undesirable plant growth in the Wekiva River Basin, come from a variety of sources including residential fertilizers, thousands of onsite sewage treatment and disposal systems [OSTDS or septic tanks systems], and wastewater treatment facilities that discharge to groundwater. **Figure 8**, shows the size and location of wastewater treatment facilities located in the study area. A detailed discussion of the wastewater treatment facilities is provided in the next section of this report. Information on the OSTDS is provided in a separate report produced by the Department of Health in accordance with the Wekiva Parkway and Protection Act.

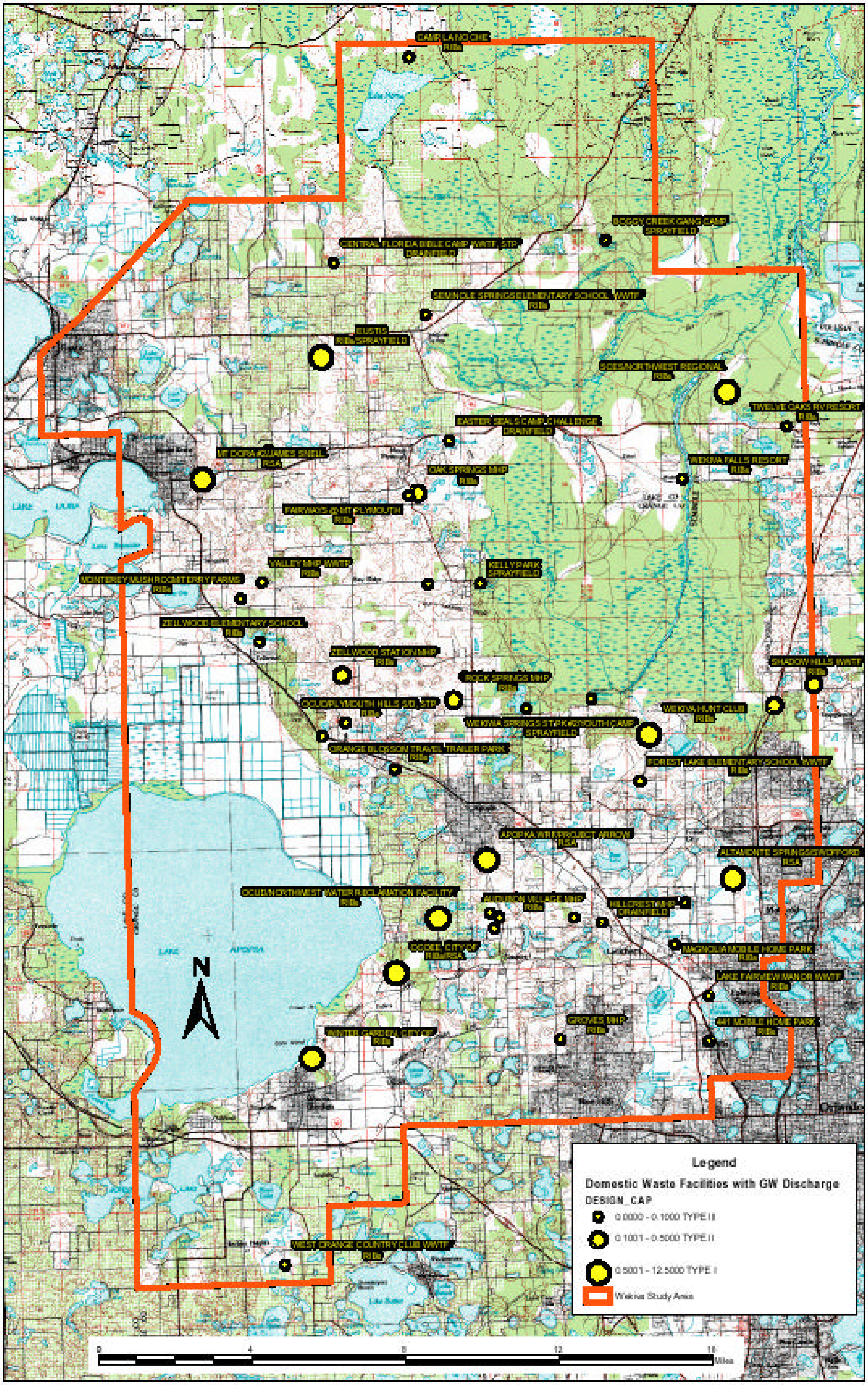

Figure 8. Wastewater Treatment Facilities in the Wekiva Study Area

DEP regulated wastewater treatment systems that land apply reclaimed water, must meet primary and secondary drinking water quality standards at the edge of the property boundary or zone of discharge, whichever is smaller. For nitrate-nitrogen this means the facility must meet the State groundwater quality standard of 10.0 mg/L. This standard is based upon public health considerations, specifically the sensitivity of infants [less than 3 months old] to high levels of nitrate tying up the hemoglobin in red blood cells and interfering with its ability to carry oxygen through the body. This condition is called methemoglobinemia and commonly referred to as "blue baby" syndrome. Although the nitrate-nitrogen concentrations recorded at springs have not violated state groundwater quality standards, the values are far greater than the recommended target of 0.2 mg/L of the Florida Springs Task Force and found in the unaffected springs of the WSA and Ocala National Forest.

As part of the Wekiva Parkway and Protection Act, the SJRWMD and DEP will be developing PLRGs and TMDLs, respectively, for the surface waters in the WSA. These studies will examine the effects of nutrient enrichment on an increase of exotic invasive aquatic plants and algae species such as Lyngbya, water hyacinth, water lettuce, elephant ear, torpedo grass, and paragrass. These exotics can better tolerate the higher nutrient levels and crowd out the native species of plants, and in turn the animals that utilize these native food sources. One such example is the change in the limpkin bird population. Nitrate-caused shifts in the plant population in spring runs have caused declines in apple snail populations that result in declines in limpkin populations that feed on the apple snail. Limpkin populations have declined in the Wekiva River Basin from 43 pair reported in a 1992 survey, to 28 pair in 2002.

For purposes of this report and based on the studies to date, we conclude that: 1) Water and most of the nitrogen entering the ground water in the springshed will ultimately find its way to one the WSA springs; 2) Water quality in a 'natural' spring can be assessed by examining the quality of the springs in the WSA and the surrounding region; and, 3) Depending on specific geologic characteristics of the WSA, definable areas more quickly recharge [and are less likely to remove nutrients] the aquifer and the springs.

C. A STRATEGY FOR WATER QUALITY PROTECTION

1. Strategy

The information presented to this point has described the existing conditions for the WSA. While there is the need for continued research into the specific interactions in the area, it is clear that elevated nitrogen concentrations have been observed in study area springs, such as Wekiwa Springs, Starbuck Springs, and Rock Springs. Given the characteristics of the area contributing to spring flow, there are regions that have a more direct influence or more rapid impact on the spring systems and therefore require a higher level of protection. To better define these 'protection' zones, the Florida Geological Survey has refined an analytical process to the WSA that has previously been developed for Florida, known as the Floridan Aquifer Vulnerability Assessment or FAVA.

Once the Protection Zones are delineated, what level of treatment is needed to reduce the nitrogen loadings from the various sources to achieve springs nutrient concentrations necessary to maintain a healthy ecological environment? What nutrient concentrations provide a healthy environment? As previously discussed in Section B., one way to establish these nutrient goals this is to examine the existing springs in the WSA and their corresponding nitrogen levels. Those unaffected by point and non-point sources should reflect the 'natural' spring conditions, including nitrogen concentrations. Figure 7 presents the nitrate concentrations for some of the springs of the WSA and adjacent areas. Using these and other nutrient information for the area springs, it appears that the target concentration to achieve should be about 0.2 mg/L of nitrate-nitrogen. This is in agreement with the concentration recommended by the State Springs Task Force.

The need or ability to be more specific than this, at this time is well beyond the scope of this report. Currently a statewide technical workgroup is examining feasibility of establishing a spring nutrient standard. This work is scheduled to reach a conclusion in the next year. The SJRWMD and the DEP are tasked with establishing PLRGs and TMDLs, respectively for the WSA. The due dates for these tasks are 12/05 for the PLRGs and 12/06 for the TMDLs. These studies will be crucial in evaluating site-specific impacts of nutrient on the surface waters and establishing specific limits to be achieved.

However, having a target of 0.2 mg/L of nitrate nitrogen enables us to make recommendations of a minimum treatment level strategy for wastewater treatment systems based on the zone [primary, secondary, or tertiary] and volume of the discharge [greater than 0.1 mgd or less].

2. Delineation of Protection Zones

The Florida Geological Survey (FGS) has refined modeling techniques utilized in the statewide Florida Aquifer Vulnerability Assessment (FAVA) project to the WSA, the purpose being to delineate protection zones for the Floridan Aquifer System (FAS) based on existing and available data. The site specific application of the FAVA model to the WSA is called the Wekiva Aquifer Vulnerability Assessment (WAVA) for the FAS. WAVA uses the following hydrogeologic data layers:

- Soil permeability
- Buffered effective karst features (based on closed topographic depressions)
- Thickness of Intermediate Confining Unit
- Head difference between Surficial Aquifer System and FAS

The FGS team worked with State, Water Management District and local government staff to acquire data that would facilitate refinement of the model input data layers for specific application to the WSA. A detailed description of the process used and the data inputs are provided in Appendix A. The result of this effort was the development of study area, specific protection zones.

The three Protection Zones as determined by the WAVA report are depicted in **Figure 9**. The Primary Protection Zone is comprised of those areas expected to most directly [time of travel and reduced natural attenuation] affect the water quality surfacing at the springs within the WSA. The Secondary Protection Zone still contributes water to the springs, but over a longer period of time and allowing for somewhat greater natural treatment and reduction of

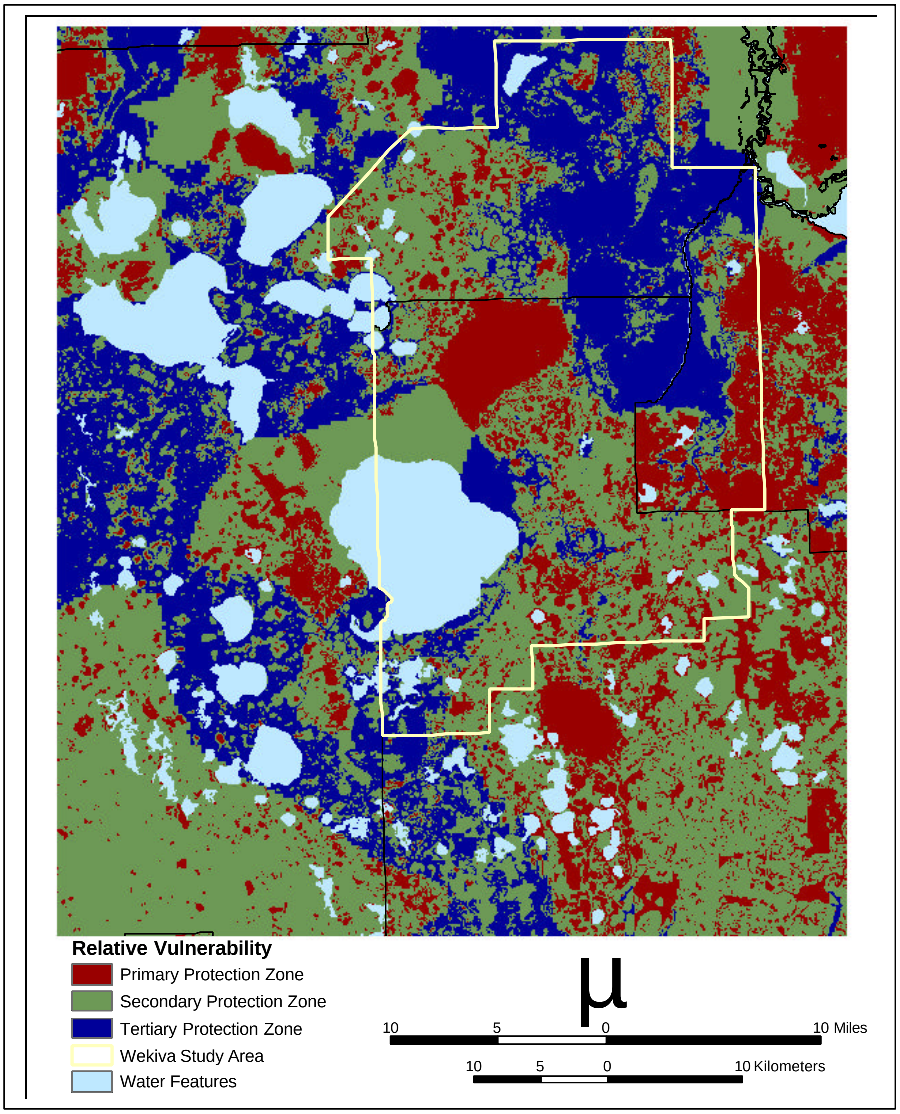

Figure 9. Relative vulnerability of the FAS WAVA model showing primary, secondary and tertiary protection zones.

the nitrogen. The Tertiary Protection Zone covers all other areas in the WSA, where the flow to the springs is minimal or non-existent.

3. Existing Wastewater Regulations

The Florida Department of Environmental Protection has a very detailed and comprehensive set of regulations applicable to wastewater treatment facilities, including those that utilize contains requirements for various types of reuse or land application of reclaimed water. An overview of pertinent elements of Chapter 62-610, F.A.C. is provided below:

Part I	General
Part II	Slow-Rate Land Application Systems; Restricted Public Access
Part III	Slow-Rate Land Application Systems; Public Access Areas, Residential Irrigation, and Edible Crops
Part IV	Rapid-Rate Land Application Systems (Rapid Infiltration Basins and Absorption Fields)
Part V	Ground Water Recharge and Indirect Potable Reuse

The types of land application projects that are utilized by the wastewater treatment facilities within the WSA include slow-rate land application systems with restricted public access (Part II), slow-rate land application systems with public access (Part III), and rapid-rate land application systems (Part IV).

Slow-rate land application projects with restricted access typically involve irrigation of a vegetated land surface or cover crop and are often referred to as sprayfields. The applied reclaimed water receives further treatment as it flows through the plant-soil matrix. The plants take up part of the reclaimed water, and part will percolate to the ground water. The design application rate is generally no greater than 2 inches per week annual average and is determined with consideration of the ability of the plant-soil system to remove pollutants from the reclaimed water. Nitrogen loading rates are established taking into consideration both nitrogen uptake capability of the vegetation on site as well as nitrification-denitrification reactions in the soil. One of the advantages of Part II projects is that the application rates utilized are within the control of the wastewater treatment facility since they own or have control of the site.

Slow-rate land application projects with public access include the regional reuse systems where reclaimed water is utilized within a reuse service area. The uses of reclaimed water within the service area can include irrigation of golf courses, parks, open areas, and residential properties, as well as irrigation of agricultural areas growing edible crops. Miscellaneous uses of reclaimed water also can occur such as use in car washes, for street sweeping, construction dust control and fire fighting. Control over the acceptable uses of reclaimed water is usually accomplished through agreements with users or by local ordinance. Public health considerations are greater with this type of project due to the public access to these sites and therefore, higher levels of treatment are provided, as well as substantial public education and cross-connection control considerations. With these systems there is less control over the quantity of reclaimed water utilized by any one user. This lack of control presents problems during drier times of the year when the demand often exceeds the supply of reclaimed water. Utilities are beginning to consider establishment of volumetric rate schedules for reclaimed water use in attempts to achieve more effective and efficient use of reclaimed water.

Rapid-rate land application projects such as rapid infiltration basins and absorption fields have relatively higher application rates of 3 inches per day annual average, up to a maximum of 9 inches per day annual average. With these systems, there is more limited potential for further treatment of the reclaimed water as it passes through the soil or soil-plant system and so there is a nitrate-nitrogen limit of 12 mg/L (as Nitrogen) for reclaimed water discharged to rapid rate systems.

For both slow-rate irrigation systems and rapid-rate land application systems, the nitrate-nitrogen concentration in down-gradient groundwater monitoring wells cannot exceed 10.0 mg/L (as Nitrogen), the state ground water standard. Groundwater monitoring is provided for wastewater treatment facilities with a permitted capacity of 100,000 gallons per day and greater, and for newer wastewater treatment facilities that are less than this threshold. Background and compliance wells are incorporated into ground water monitoring programs.

4. Recommendations for Wastewater Nitrogen Reduction

Ground Water Discharges

The Department of Environmental Protection presented recommendations for nitrogen reduction from wastewater treatment facilities within the WSA to the Wekiva Coordinating Committee. The Committee determined that additional study and refinement of the recommendations were appropriate and that recommendation was included in the Committee Final Report. The areas within the WSA and the Wekiva Springshed are not identical in their coverage. Requiring enhanced levels of nitrogen removal in areas that do not contribute ground water to the springshed would not benefit spring water quality. At this time, specific wastewater treatment facilities have not been directly implicated in contributing to the increase in nitrogen observed in Wekiva Spring System discharges. This is likely due to factors such as the travel time to the spring and the fact that wastewater treatment facility flow is considerably less than the permitted design flow for build-out. In consideration of how both wastewater flows and corresponding population will increase in the future, it is important to adopt measures now that will result in springs protection for the future. However, reduction of all sources of nitrogen within the Primary and Secondary Protection Zones should be the goal of spring protection efforts, and not just reduction of wastewater nitrogen loading. Within the Primary Protection Zone, the following enhanced wastewater treatment requirements are recommended:

- No new rapid rate or restricted access slow-rate land application systems.

- Existing large wastewater treatment facilities with rapid rate systems as the primary reuse method will be required to reduce nitrogen in applied reclaimed water to 3.0 mg/L Total Nitrogen as N within five years. Where rapid rate systems are utilized **only** as back up to the regional reuse irrigation system, they will be considered to be part of the regional reuse system.

- Existing large wastewater treatment facilities with regional reuse irrigation systems or restricted access irrigation systems will be required to reduce nitrogen in the applied reclaimed water to 10.0 mg/L Total Nitrogen as N within five years.

- Existing small wastewater treatment facilities will be required to connect to a regional wastewater treatment facility within five years, or reduce nitrogen in reclaimed water to 10.0 mg/L Total Nitrogen as N.

- No land application of wastewater residuals.

Within the Secondary Protection Zone, the following enhanced wastewater treatment requirements are recommended:

- Existing large wastewater treatment facilities with rapid rate systems as the primary reuse method will be required to reduce nitrogen in applied reclaimed water to 6.0 mg/L Total Nitrogen as N within five years. New systems shall be required to meet this requirement. Where rapid rate systems are utilized **only** as back up to the regional reuse irrigation system, they will be considered to be part of the regional reuse system.

- Existing large wastewater treatment facilities with regional reuse irrigation systems or restricted access irrigation systems will be required to reduce nitrogen in the applied reclaimed water to 10.0 mg/L Total Nitrogen as N within five years. New systems shall be required to meet this requirement.

- Existing small wastewater treatment facilities will be required to connect to a regional wastewater treatment facility within ten years or reduce nitrogen in reclaimed water to 10.0 mg/L Total Nitrogen as N.

- No land application of wastewater residuals.

Large wastewater treatment facilities are those with a permitted capacity of 100,000 gpd and greater, small wastewater treatment facilities are those with a permitted capacity of less than 100,000 gpd.
Within the Tertiary Protection Zone, facilities will be required to meet the existing regulations, with the possibility of requiring an increased monitoring program.

Surface Water Discharges

When considering measures to protect spring water quality it is important not to overlook measures that should be undertaken to protect spring runs and the downstream surface waters from nutrient enrichment through wastewater discharges to surface waters. The following measures are recommended to protect the spring run and surface waters of the Wekiva River Basin.

- New surface water discharges shall only be permitted as back up to a regional reuse system and must comply with the provisions of the APRICOT Act, as codified in Section 403.086(5) Florida Statutes.

- Existing surface water discharges shall be limited to a back-up to a regional reuse system, and shall constitute no more than 30% of the wastewater treatment plant flow on an annual average basis. Facilities in this category would be required to be in compliance within five years.

Within the State of Florida there have been initiatives in other geographic areas to protect critical resources. These efforts have primarily been targeted at improving the quality of wastewater discharges to surface waters. The Grizzle-Figg Act, the Indian River Lagoon Protection Act, the APRICOT Act all require that domestic wastewater treatment facilities provide advanced wastewater treatment (AWT). In Section 403.086, F.S., AWT is defined as treatment of a reclaimed water product that contains not more, on a permitted annual average basis, than the following concentrations: Biochemical Oxygen Demand (CBOD5) of 5 mg/l; Total Suspended Solids of 5 mg/l; Total Nitrogen, expressed as N, of 3.0 mg/L; Total Phosphorus, expressed as P of 1 mg/l; and high level disinfection. There are many facilities within the State of Florida that are required to meet these treatment levels.

While the requirement to meet full AWT levels may not be necessary for ground water discharges to protect spring water quality, it would be appropriate to utilize the AWT limit for Total Nitrogen of 3.0 mg/L for rapid rate systems within the Primary Protection Zone to assure protection of spring water quality. The level of 3.0 mg/L was selected due to the fact that it is the highest level of nitrogen reduction that a wastewater treatment facility can reliably meet, and therefore could be considered to be best available wastewater treatment for nitrogen.

In the Secondary Protection Zone, 6.0 mg/L Total Nitrogen was selected as the proposed limit due to the additional groundwater travel time and dilution available within the Floridan Aquifer System. The limit of 6.0 mg/L has been used in Central Florida for projects where reclaimed water is discharged into created wetland systems due to the additional treatment provided by the created wetland prior to discharge to surface waters. It has also been utilized as a reclaimed water limit on rapid-rate, land application systems where adjacent surface water quality concerns are present.

For regional public access reuse irrigation systems, a limit of 10.0 mg/L Total Nitrogen was selected as the proposed limit due to the additional nitrogen uptake afforded by vegetation prior to percolation of remaining reclaimed water into the groundwater table. A limit was determined to be necessary to assure protection of spring water quality due to the inability to directly control the quantity of reclaimed water that a customer uses as well as the seasonal nature of nitrogen uptake rates by vegetation. This limit can often be achieved with much less capital expense than 3.0 mg/L or 6.0 mg/L.

Appendix B and C contain information on the types of treatment processes available for reduction of nitrogen in wastewater for reclaimed water limits of 3, 6, and 10.0 mg/L Total Nitrogen for both large and small facilities, and preliminary cost curves for estimating the expense of meeting these enhanced treatment requirements.

Some facilities, not regional in nature, may consider connecting to a larger regional wastewater collection system in lieu of meeting more stringent nitrogen limits, especially if located in a part of the service area where on-site systems also exist at a density appropriate for extending collection system service.

Wastewater residuals are another source of nitrogen from wastewater and these residuals are generally land applied on pasturelands. Although nitrogen-loading rates for residuals land application sites are determined based on the nitrogen needs of the vegetation, other alternatives exist for management of wastewater residuals. Ideally, regional facilities would be constructed to produce a beneficial fertilizer product for use by the agricultural community and the general public, and thus negating the need for residuals application sites.

It is hoped that these recommendations will be implemented within the Wekiva Spring System Protection Zones and that they could be used as a model for wastewater management in other spring protection efforts.

5. Wastewater Facilities in the Wekiva Study Area

There are 48 wastewater treatment facilities that utilize land application of reclaimed water within the Wekiva Study Area. Two of the treatment facilities are actually located outside of the Wekiva Study Area, but have reclaimed water land application sites within the area.

Locations of wastewater treatment facilities with respect to the Protection Zones as determined in the WAVA are shown in **Figure 10**.

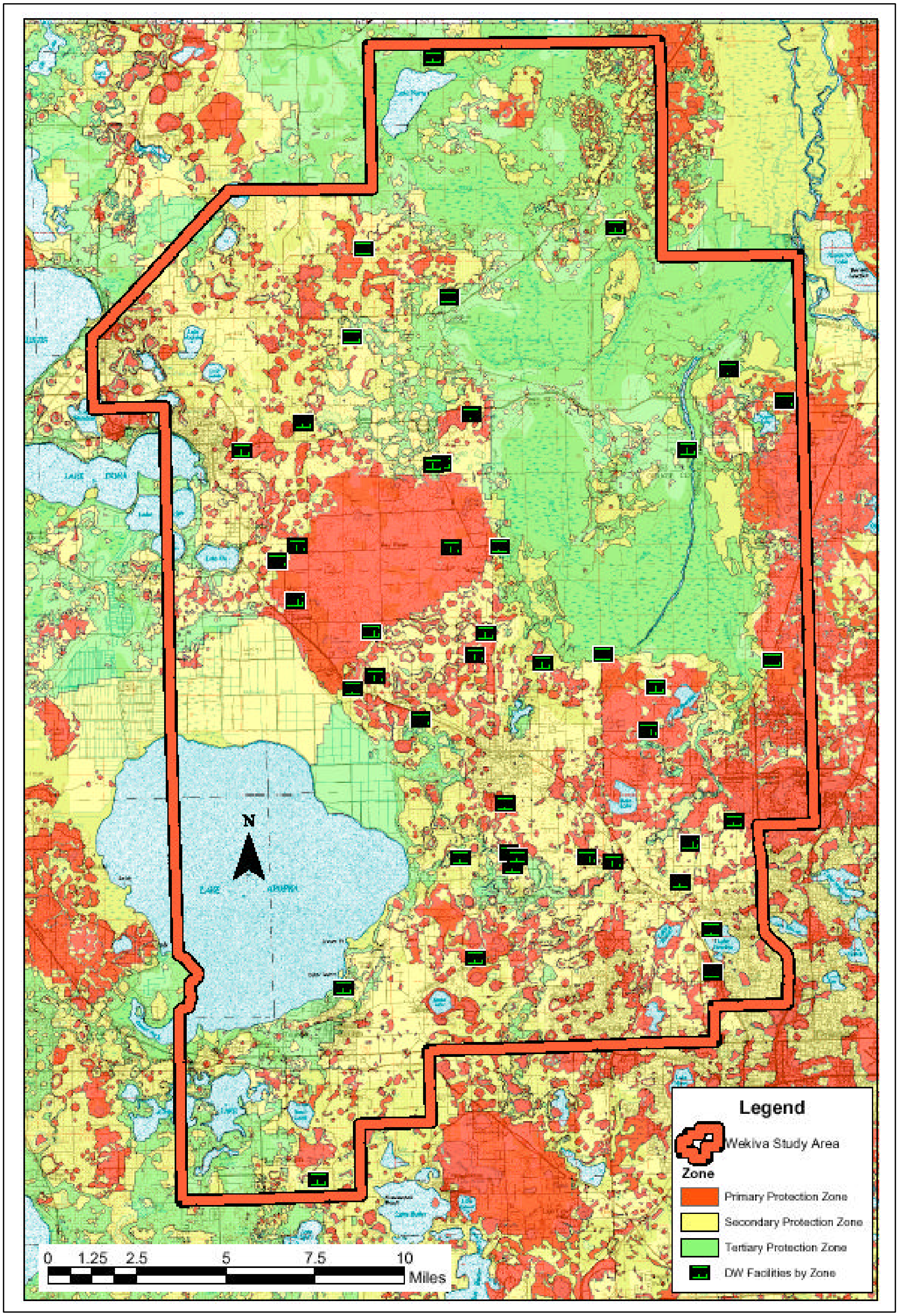

Figure 10. WastewaterTreatment Facilities within the Protection Zones

It is important to note that all facilities with ground water discharges within the Primary and Secondary Protection Zones will be affected by the proposed enhanced treatment requirements. If these recommendations are adopted, the DEP will evaluate where each facility's land application site(s) is located and the applicable enhanced treatment requirements.

Wastewater treatment facilities with a permitted capacity greater than 100,000 gallons per day (gpd) are listed in **Table 1**. There are 16 domestic wastewater treatment facilities within this category. One can see that most of the larger wastewater treatment facilities in the Wekiva Study Area have regional public access reuse irrigation systems. All municipal wastewater treatment facilities should have development of regional reuse systems as a goal to reduce water use within the Wekiva Study Area. Other provisions of the Wekiva Parkway and Protection Act call for reuse of reclaimed water in developing local government wastewater master plans and Sections 403.064 and 373.250 Florida Statutes both state that reuse of reclaimed water is a formal state objective. The other wastewater treatment facilities located within the Wekiva Study Area utilize slow rate restricted access irrigation systems or rapid infiltration basins.

Table 1. Wastewater Treatment Facility Inventory – 100,000 GPD and Greater.

Facility	Permitted Capacity MGD	Type of Reuse/Disposal System
Altamonte Springs Swofford – Project APRICOT	12.5	Public Access Reuse Irrigation System and Surface Water Discharge as Back-up
Orange County Northwest	7.5	Rapid Infiltration Basins
City of Apopka – Project ARROW	4.0	Public Access Reuse Irrigation System
City of Ocoee	3.0	Public Access Reuse Irrigation System with Rapid Infiltration Basins
Utilities Inc – Wekiva Hunt Club	2.9	Public Access Reuse Irrigation System, Rapid Infiltration Basins and Surface Water Discharge
Seminole County Northwest Regional	2.5	Public Access Reuse Irrigation System with Rapid Infiltration Basins and Wetland System as Back-up
City of Eustis # 1 *	2.4	Public Access Reuse Irrigation System, Rapid Infiltration Basins and Slow Rate Restricted Access Irrigation System
City of Winter Garden	2.0	Public Access Reuse Irrigation System with Rapid Infiltration Basins and Surface Water Discharge
City of Mount Dora #1 *	1.5	Public Access Reuse Irrigation System and Rapid Infiltration Basins
City of Mount Dora # 2 James Snell	1.0	Public Access Reuse Irrigation System
Utilities Inc. – Woodlands	0.5	Rapid Infiltration Basins
Shadow Hills	0.5	Rapid Infiltration Basins
Zellwood Station	0.3	Rapid Infiltration Basins
City of Eustis # 2	0.3	Rapid Infiltration Basins
Rock Springs	0.15	Rapid Infiltration Basins
Oak Springs Mobile Home Park	0.15	Rapid Infiltration Basins

* *Facility location outside, land application area within Wekiva Study Area*

There are 32 wastewater treatment facilities with permitted capacities of less than 100,000 gpd and these utilize rapid rate systems such as percolation ponds and absorption fields, or slow rate restricted access irrigation systems. From an examination of **Table 2**, one can see that the 32 wastewater-treatment facilities listed represent a total permitted capacity of 0.861 MGD. These facilities generally serve a single development like a mobile home park, subdivision, school, or camp and generally do not have funds available for major improvements. These facilities, if located in an area where on-site septic systems are also prevalent, may want to consider connection to a regional wastewater collection system in lieu of upgrading to meet more stringent nitrogen limits.

Table 2. Wastewater Treatment Facility Inventory – less than 100,000 GPD.

Facility	Permitted Capacity MGD	Type of Reuse/Disposal System
Wekiva Falls Resort	0.099	Rapid Infiltration Basins
Clarcona Resort Condo	0.080	Rapid Infiltration Basins
Brightwood Manor MHP	0.080	Rapid Infiltration Basins
Fairways at Mt. Plymouth	0.075	Rapid Infiltration Basins
Groves MHP	0.070	Rapid Infiltration Basins
Audobon Village MHP	0.490	Rapid Infiltration Basins
Camp La No Che	0.045	Rapid Infiltration Basins
Plymouth Hills S/D	0.030	Rapid Infiltration Basins
Kelly Park	0.030	Slow Rate Restricted Access Irrigation System
Boggy Creek Gang Camp	0.030	Slow Rate Restricted Access Irrigation System
Valley MHP	0.025	Rapid Infiltration Basins
Valencia Estates MHP	0.025	Rapid Infiltration Basins
Twelve Oaks RV Resort	0.025	Rapid Infiltration Basins
Wekiwa Springs State Park 1	0.020	Slow Rate Restricted Access Irrigation System
Central Florida Bible Camp	0.020	Absorption Field
Easter Seals Camp Challenge	0.017	Absorption Field
Orange Blossom Trailer Park	0.015	Rapid Infiltration Basins
Magnolia MHP	0.015	Rapid Infiltration Basins
Clarcona Elem School	0.0125	Rapid Infiltration Basins
Sorrento Elem School A	0.012	Absorption Field
Seminole Springs Elem	0.010	Rapid Infiltration Basins
Forest Lake Elem School	0.010	Rapid Infiltration Basins
Zellwood Elem School	0.009	Rapid Infiltration Basins
Lost Lake RV Resort	0.009	Rapid Infiltration Basins
Riverside Elem School	0.008	Rapid Infiltration Basins
Wekiwa Spring State Park 2	0.0075	Slow Rate Restricted Access Irrigation System
441 Mobile Home Park	0.0075	Rapid Infiltration Basins
Monterey Mushroom	0.007	Rapid Infiltration Basins
Lake Fairview Manor	0.006	Rapid Infiltration Basins
Rock Springs Elem School	0.005	Rapid Infiltration Basins
Hillcrest MHP	0.005	Absorption Field
West Orange Country Club	0.0025	Rapid Infiltration Basins

D. SUMMARY AND CONCLUSIONS

Based on nitrogen concentrations observed in unaffected springs in the Study Area and the Ocala National Forest, a wastewater treatment strategy has been developed to reduce nutrient loading to the springshed. In order to focus on facilities that would most directly impact spring water quality, now or in the future, the statewide Florida Aquifer Vulnerability Assessment was tailored for the WSA. From this analysis three protection zones were delineated, with the primary protection zone requiring the highest level of wastewater treatment.

DEP recommends the following actions:

1. Adopt the WAVA Protection Zones

2. Adopt the enhanced wastewater treatment requirements for ground water discharges, as follows:

   Within the Primary Protection Zone, the following enhanced wastewater treatment requirements are recommended:

   - No new rapid rate or restricted access slow-rate land application systems.

   - Existing large wastewater treatment facilities with rapid rate systems as the primary reuse method will be required to reduce nitrogen in applied reclaimed water to 3.0 mg/L Total Nitrogen as N within five years. Where rapid rate systems are utilized **only** as back up to the regional reuse irrigation system, they will be considered to be part of the regional reuse system.

   - Existing large wastewater treatment facilities with regional reuse irrigation systems or restricted access irrigation systems will be required to reduce nitrogen in the applied reclaimed water to 10.0 mg/L Total Nitrogen as N within five years.

   - Existing small wastewater treatment facilities will be required to connect to a regional wastewater treatment facility within five years, or reduce nitrogen in reclaimed water to 10.0 mg/L Total Nitrogen as N.

   - No land application of wastewater residuals.

   Within the Secondary Protection Zone, the following enhanced wastewater treatment requirements are recommended:

   - Existing large wastewater treatment facilities with rapid rate systems as the primary reuse method will be required to reduce nitrogen in applied reclaimed water to 6.0 mg/L Total Nitrogen as N within five years. New systems shall be required to meet this requirement. Where rapid rate systems are utilized **only** as back up to the regional reuse irrigation system, they will be considered to be part of the regional reuse system.

- Existing large wastewater treatment facilities with regional reuse irrigation systems or restricted access irrigation systems will be required to reduce nitrogen in the applied reclaimed water to 10.0 mg/L Total Nitrogen as N within five years. New systems shall be required to meet this requirement.

- Existing small wastewater treatment facilities will be required to connect to a regional wastewater treatment facility within ten years or reduce nitrogen in reclaimed water to 10.0 mg/L Total Nitrogen as N.

- No land application of wastewater residuals.

Large wastewater treatment facilities are those with a permitted capacity of 100,000 gpd and greater, small wastewater treatment facilities are those with a permitted capacity of less than 100,000 gpd.

Within the Tertiary Protection Zone, facilities will be required to meet the existing regulations, with the possibility of requiring an increased monitoring program.

3. Adopt enhanced wastewater treatment requirements for surface water discharges, as follows:

   - New surface water discharges shall only be permitted as back up to a regional reuse system and must comply with the provisions of the APRICOT Act, as codified in Section 403.086(5) Florida Statutes.

   - Existing surface water discharges shall be limited to a back-up to a regional reuse system, and shall constitute no more than 30% of the wastewater treatment plant flow on an annual average basis. Facilities in this category would be required to be in compliance within five years.

To accomplish this, a legislative bill should be crafted in the same manner as used for the Tampa Bay Estuary, the Indian River Lagoon, and most recently, the Florida Keys. The DEP would not be able to implement the requirements through rulemaking under its existing authorities.

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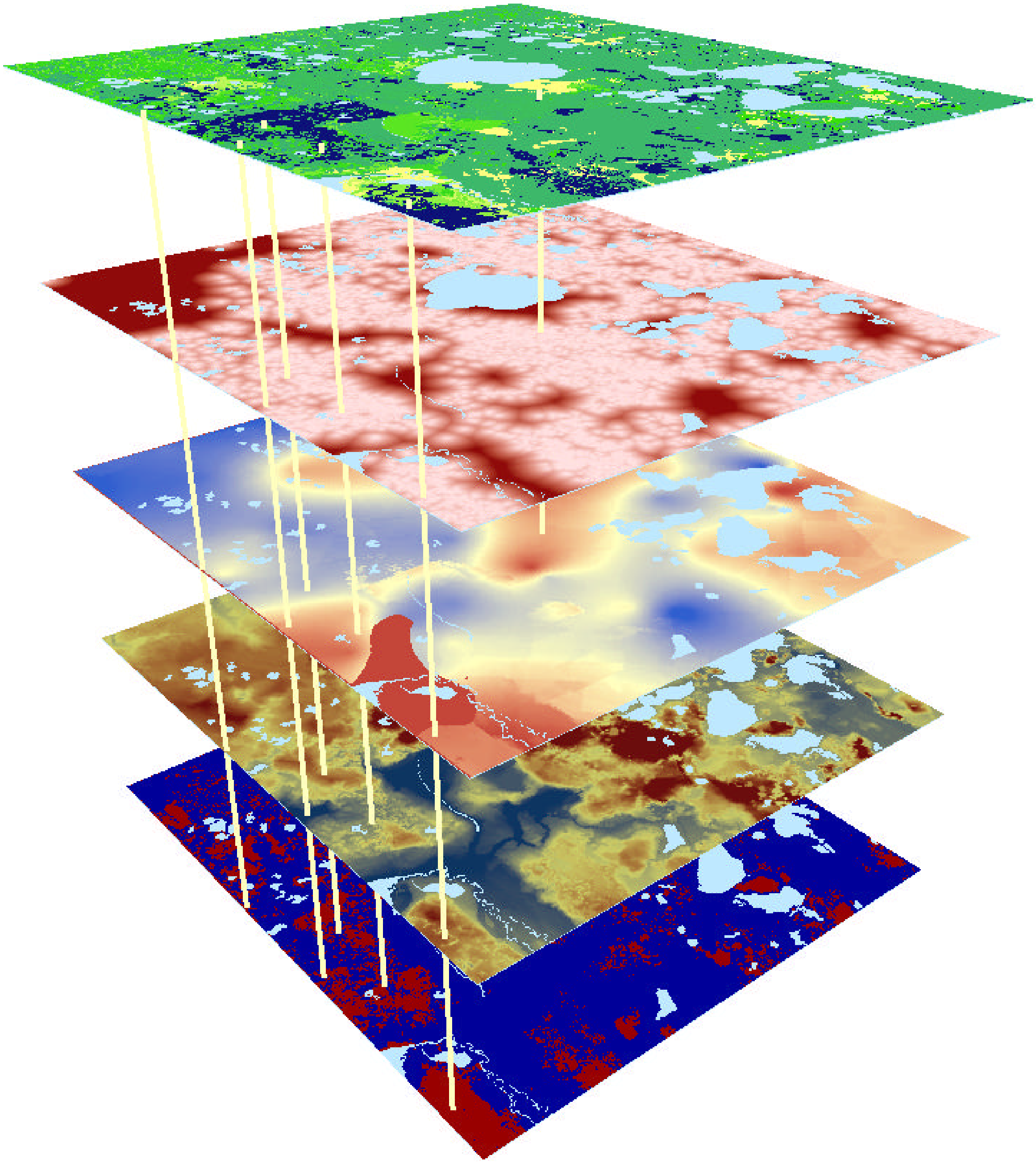
APPENDICES

APPENDIX A

WEKIVA AQUIFER VULNERABILITY ASSESSMENT (WAVA)



Preliminary Report submitted to the Florida Springs Initiative and
the Wekiva River Basin Coordinating Committee
Revised November 24, 2004
James R. Cichon, Alan E. Baker, P.G. 2324, Alex R. Wood, and
Jonathan D. Arthur, P.G. 1149

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APPENDIX A - Introduction

Florida's aquifer systems are of the most important and unique hydrogeologic resources in the nation. A remarkable 90% of Florida's drinking water originates from these ground-water resources. More than 700 springs are known to exist in Florida, allowing a unique window into the aquifer systems. These springs have long been a resource for recreation and fresh water. Protection of Florida's springs becomes an increasingly important issue as the population of Florida continues to grow at a rate of almost 900 people per day. As a result, pressures on these unique natural resources become intensified.

It is important to note that water quality of Florida's springs is a reflection of the condition of the surrounding ground water system and not just an indication of individual spring health. Springsheds, or the spring's area of groundwater contribution, must also be taken into consideration for any vulnerability assessment if proper protection of the spring itself is to take place. An assessment of the vulnerability of the groundwater which includes the springshed can therefore be a potential resource for decision making, development of rules, or policies regarding environmental conservation, protection, growth management and planning.

Due to Florida's unique hydrogeologic setting, all of Florida's ground water is vulnerable to contamination. In fact, this statement, in a more broad sense, is considered the "First Law of Ground Water Vulnerability" by the National Research Council (NRC, 1993) which states: "All ground water is vulnerable." Furthermore, the NRC defines the phrase "ground-water vulnerability to contamination" as the tendency or likelihood for contaminants to reach a specified position in the ground-water system after introduction at some location above the uppermost aquifer. In this report, a similar definition of aquifer vulnerability is adopted: The tendency or likelihood for contaminants to reach the top of the Floridan Aquifer System (FAS) after introduction at land surface.

The hydrogeology of the Wekiva River Study Area is characterized by moderate to no confinement and a multitude of karst features (Figure 1). Groundwater recharges the FAS by infiltration through these sediments or directly through sinkholes. The Wekiva River Coordinating Committee Final Report identifies numerous studies by Florida's water management districts and the United States Geological Survey (USGS) that clearly demonstrate contamination attributable to changes in land use. In other words, what occurs on the land directly and indirectly affects the quality of water moving through the subsurface conduits. Many of these conduits flow to surface water bodies via springs.

The Florida Geological Survey (FGS) proposes to apply a modeling technique used in the statewide Florida Aquifer Vulnerability Assessment (FAVA) project to the Wekiva Study Area, the purpose of which is to delineate primary, secondary and tertiary protection zones for the FAS based on available data. This modeling technique, Weights of Evidence (WofE), is briefly described below. For a more thorough explanation of this method refer to FGS Bulletin 67, Florida Aquifer Vulnerability Assessment:

Contamination potential of Florida's principal aquifer systems (Arthur et al., in preparation).

The WofE software and the GIS Albers projection require certain layers (i.e., study area) to be listed in meters. However, some data layers are listed in units standard to that particular data set. For reader convenience we list the primary unit followed by the alternative unit in parenthesis.

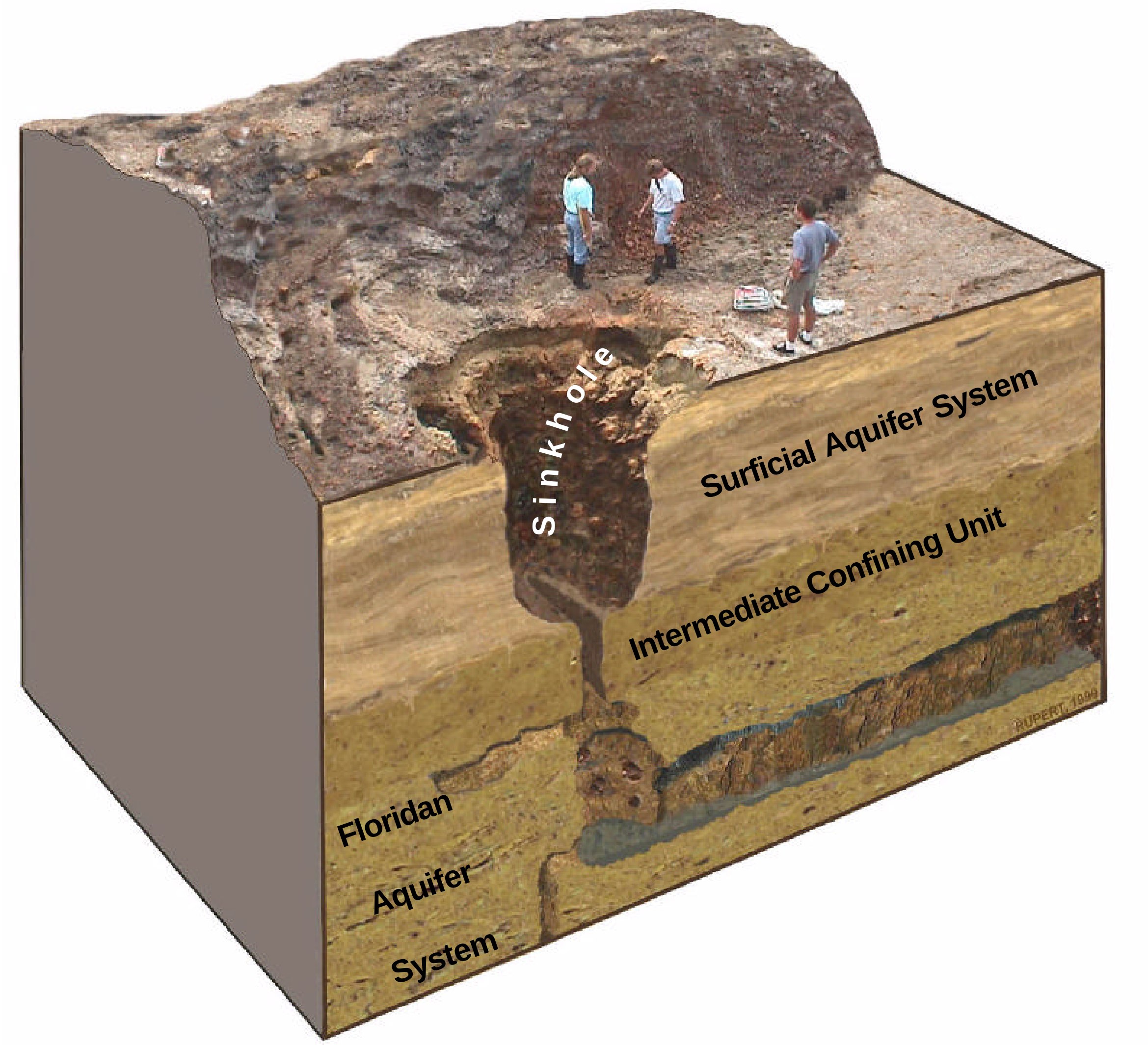


Figure 1. Hydrogeologic conceptual model of the Wekiva River study area depicting the major aquifer systems, confining unit and karst features.

Wekiva aquifer vulnerability assessment model

Weights of Evidence

Use of WofE requires the combination of diverse spatial data which are used to describe and analyze interactions and generate predictive models (Raines et al., 2000). When applied in the WAVA project, WofE was used to generate maps of aquifer vulnerability (response themes). These response themes were generated in the Environmental Systems Research Institute ArcView 3.2 environment. WofE was executed using the Arc Spatial Data Modeler which is available free of charge as an internet download (Kemp, et al., 2001).

A primary benefit of applying WofE to the WAVA project is that it is data-driven, rather than expert-driven. The data that "train" the model consist of known occurrences of parameters (water quality values) that reflect relative aquifer vulnerability, such as high levels of dissolved oxygen in ground-water wells. These wells are the training points used to calculate weights for laterally continuous input data layers (evidential themes), which are then combined to yield a response theme (Raines, 1999).

When reviewing the model results, it is important to note that all aquifers, to some degree, are vulnerable to contamination from land surface. The model results simply identify those areas within the study area that are more vulnerable or less vulnerable based on the evidential themes and training points used in the model.

Study Area

The initial step in the development of the Wekiva – WofE model was the delineation of a study area extent. The study area was used in the calculation of weights and probabilities throughout the modeling process. The extent of the study area used for input into the WAVA model was based on a combination of the Wekiva study area (as identified in the Wekiva River Basin Coordinating Committee Final Report, 2004) and the area contributing groundwater to the Wekiva River. The extent is composed of 30 m^2 grid cells and is displayed in **Figure 2**.

Large water bodies were omitted from the WAVA model because a well would never be drilled in these areas – therefore, they would never contain a training point. Additionally, if lakes are left in the model, the surface area is increased with no chance of increasing the number of training points. This would unnecessarily bias the model. Further, large water bodies typically have no soils or other input data associated with them, thus the model output omits these areas due to lack of data or potential bias in the calculated probabilities.

Although standing surface water bodies are highly vulnerable to contamination, these waters do not reflect waters residing "in" an aquifer system. Instead, these waters reside "on" an aquifer system. Due to the geostatistical framework and evidential layers (spatial hydrogeological data) of WAVA, aquifer systems in discharge areas were sometimes predicted by the output model to be low in vulnerability, even though the discharging surface waters are highly vulnerable to contamination. These discharging surface waters are not part of the aquifer, although they can originate from it. The WAVA project was designed to focus on the ability for a contaminant to travel through soils, overburden, karst features, etc. to enter into the aquifer system. As a result, it is very important that the WAVA model never be applied to assess contamination of surface waters or discharge areas.

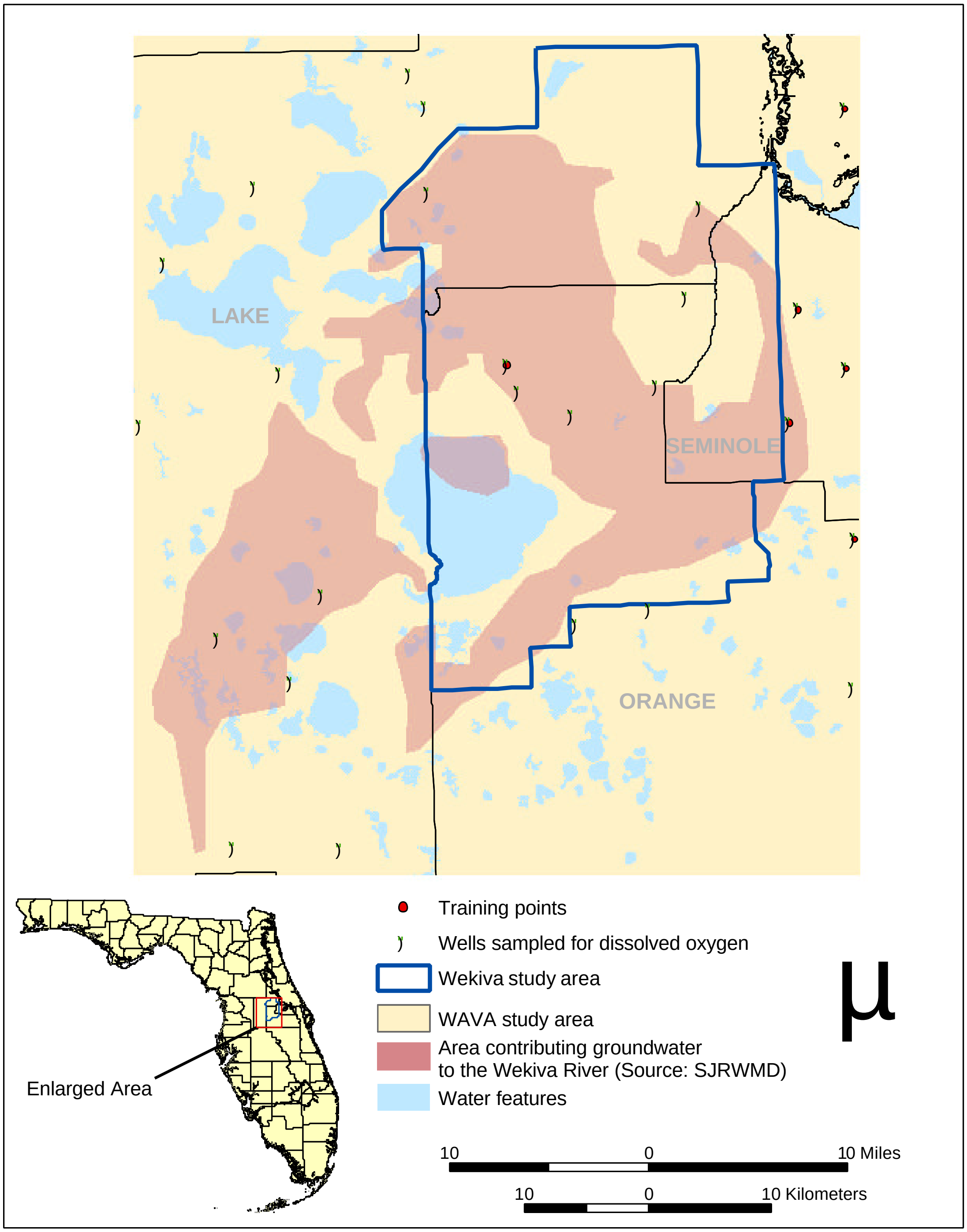


Figure 2. Extent of the WAVA study area with dissolved oxygen training point set. Large water bodies have been omitted from the analysis to avoid biasing the model.

Training Points

Training points are locations of known measured occurrences. In mining applications for example, ore deposits are known occurrences. In an aquifer vulnerability assessment, wells with water quality indicative of high recharge are potential known occurrences (i.e., areas where a good connection exists between top of aquifer and land surface). Training points are used in WofE to calculate the following parameters: prior probability, weights for each evidential theme, and posterior probability of the response theme. Training points are converted to represent a unit area of the study area, such as a grid cell within a GIS application.

The water-quality parameters selected for the WAVA training data set included nitrogen and oxygen. Background levels of nitrogen and oxygen in the FAS are typically low where the aquifer system is not affected by activities at land surface. Therefore, where $NO_3^- + NO_2^-$ dissolved as N (hereafter, referred to as dissolved nitrogen) and dissolved oxygen occur at concentrations above background levels in an aquifer system, it can generally be assumed a relatively greater hydrologic connection exists between land-surface activities and ground water.

There were a total of 202 wells that were completed in the FAS for the WAVA study area. These wells were compiled from the Florida Department of Environmental Protection (FDEP) Background Water Quality Monitoring Network, the FDEP STATUS network, and the St. John's River Water Management District monitoring network. Of these wells, 28 were measured for dissolved oxygen. Using statistical methods, described in Arthur et al. (in preparation), two wells were identified as outliers and removed from the dataset leaving 26 wells for further analysis. The 75th percentile value is the statistical break used to identify dissolved oxygen values most indicative of a surface water influence in groundwater, which is considered herein as a proxy for areas of higher recharge and vulnerability. The 75th percentile median value for dissolved oxygen concentration equals 0.4 mg/L. Six wells exist in the dataset that have a measured median dissolved oxygen value greater than the 0.4 mg/L threshold. These six wells comprise the training point theme for input into the WAVA – WofE model. These training points represent a unit area of 1 km^2.

The chance that a training point will occupy any given unit area within the study area, independent of any evidential theme data, is known as prior probability. The prior probability is calculated by dividing the training point unit area by the total study area. In less complex terms, the prior probability is based on prior knowledge of the problem without the benefit of supporting evidence. The prior probability for the WAVA – WofE model was calculated at 0.0017. The distribution of all wells considered as potential training points, and the wells meeting training point criteria are displayed in **Figure 2.**

Wells measured for dissolved nitrogen were also applied as a training point set for the WAVA – WofE model. However, confidence values calculated did not meet the 90% level required for each evidential theme to be included in the WAVA – WofE model. As a result dissolved nitrogen was used only as an independent validation of the model. This validation technique will be presented in the final version of this report.

Evidential Themes

Several evidential themes were considered for use in the WofE – WAVA model due to their potential influence on ground-water quality. They are:

- Soil permeability
- Buffered effective karst features (based on closed topographic depressions)
- Thickness of Intermediate Confining Unit (ICU)
- Head difference between Surficial Aquifer System (SAS) and FAS
- Vertical leakage rate to and from the FAS

Vertical leakage rate to and from the FAS ultimately was not used because it was based on model simulations with a grid cell size of 1000 meters and there was large variability in the leakage rate between adjacent grid cells. Weights were calculated for each of the other four evidential themes and generalized as discussed below.

Generalization of Evidential Themes

During calculation of weights for each evidential theme used in the WAVA project, a contrast value was calculated for each class of the theme. These values were used to determine where to sub-divide evidential themes into generalized categories. The most common method of categorizing an ordered evidential theme is to select the maximum contrast as a threshold value. A binary break in the evidential theme data was based on this contrast threshold.

Soil Permeability

Soil permeability values were obtained from the soils statewide grid layer developed for FAVA (Arthur et al., in preparation). The WAVA study area contains the SSURGO database of permeability values. This database is mapped at a scale of 1:24 000 and contains the most detailed soil permeability data. However, different permeability values can exist along some county boundaries due to the different mapping techniques used by different soil scientists. The development of this layer included the calculation of average soil permeability values for each soil horizon layer. Then, based on soil horizon thicknesses, weighted-average permeability values were calculated for the entire soil column. This allowed the generation of a data coverage of soils containing a single permeability value per soil polygon **(Figure 4).**

Soil permeability is a measure of the rate at which water travels through the vadose (unsaturated) zone. Areas with high soil permeability values are normally associated with higher aquifer vulnerability. Weights were calculated for soil permeability using the cumulative descending method (refer to glossary) of the WofE model technique. The highest contrast of any class was calculated at 13.1 in/hr **(Figure 3).**

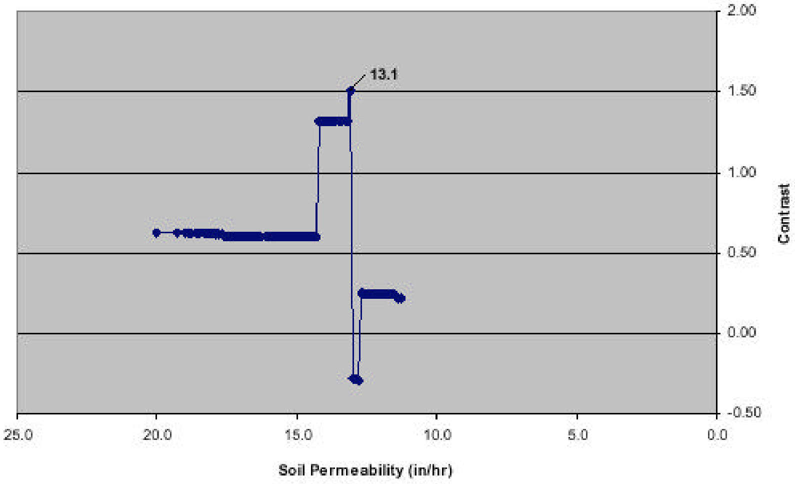
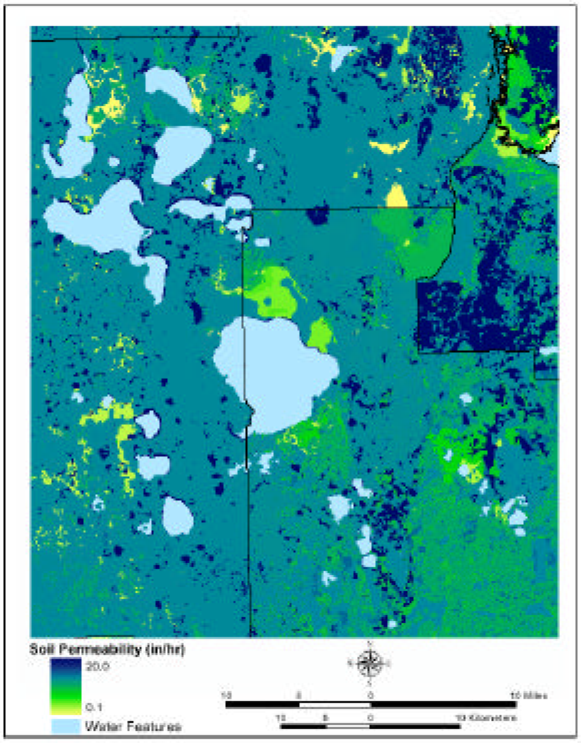


Figure 3. Soil permeability values (in/hr) plotted against contrast values calculated using WofE. The highest contrast value was calculated at 13.1 in/hr (0.333 m/hr).

Based on the calculated weights, the most appropriate break in the soil permeability evidential theme was at 13.1 in/hr (0.333 m/hr), creating a binary generalized theme for input into the WAVA model. This contrast break indicates that values exceeding 13.1 in/hr (0.333 m/hr) are strongly correlated with aquifer vulnerability as defined by the training point data, whereas values less than 13.1 in/hr (0.333 m/hr) are less significant. The generalized theme is displayed in **Figure 5.**

Figure 4. Soil permeability map of the WAVA study area (FGDL, 2003).



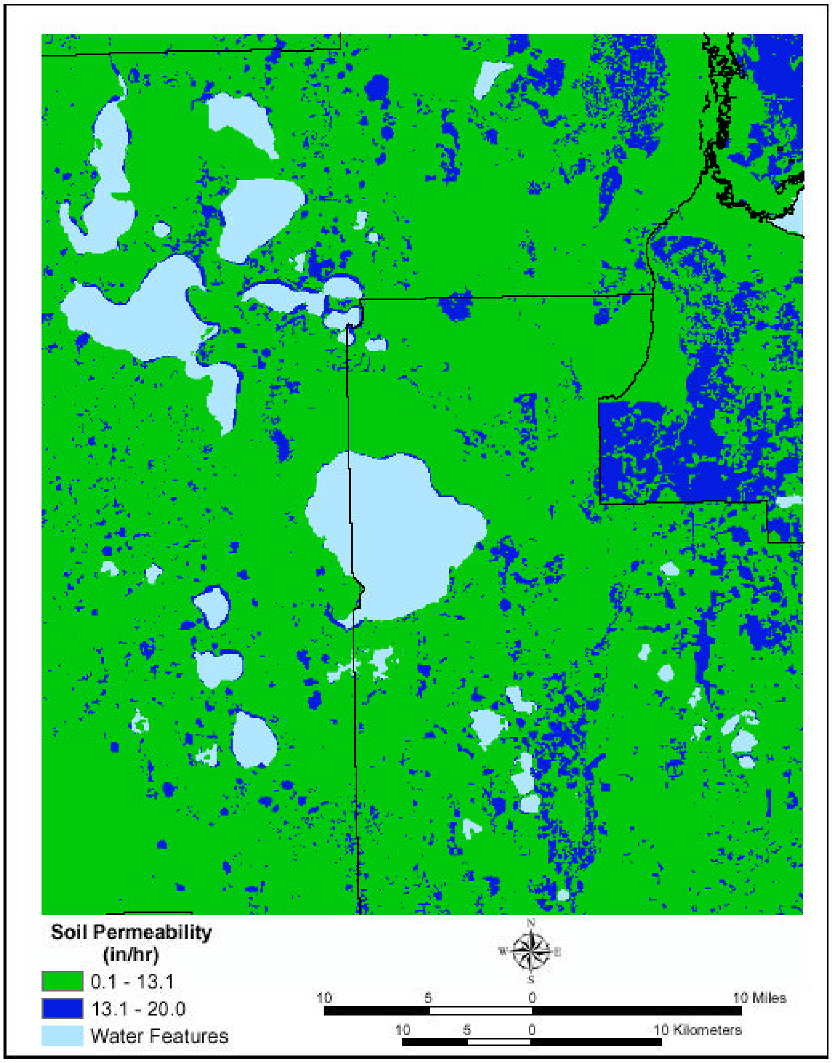


Figure 5. Map showing binary generalization of the soil permeability evidential theme, based on a contrast value of 13.1 in/hr (0.333 m/hr).

Buffered Effective Karst Features

To represent karst features (i.e., sinkholes) affecting vulnerability in the WAVA model study area, an effective karst GIS grid was generated based on a combination of closed topographic depressions identified in USGS 7.5-minute quadrangle maps and FAS overburden (**Figure 6**). Closed topographic depressions (considered an estimation of karst feature distribution) are represented on USGS 7.5-minute maps as enclosed hachured contour lines. The effective karst feature evidential theme was developed by evaluating which of these closed topographic depressions were more likely to be hydrologically connected to the underlying FAS. This was accomplished by first calculating which depressions were underlain by more than 100 feet (30.5 m) of FAS overburden thickness and filtering them out. Cichon et al. (2004) and Wright (1974) have used the 100-ft (30.5 m) threshold of overburden thickness to identify karst-prone areas. Additionally, all training points occur in areas underlain by less than 100 feet (30.5 m) of overburden thickness.

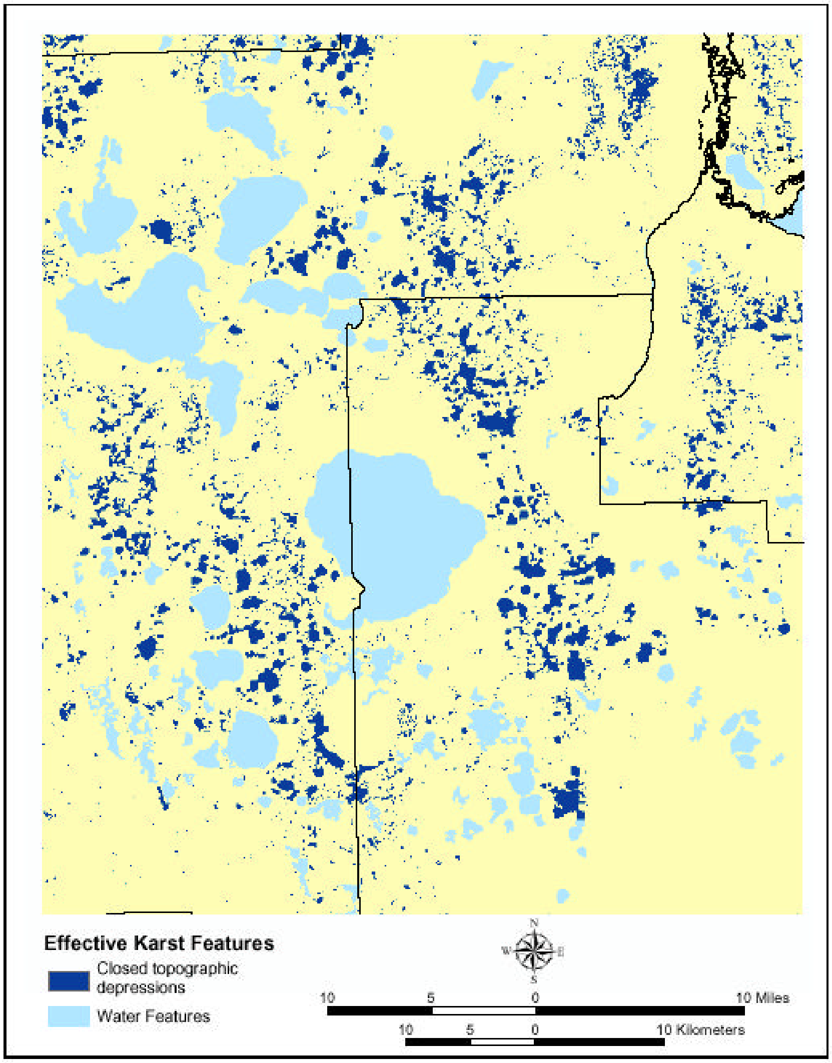


Figure 6. Closed topographic depressions underlain by less than 100 feet (30.5 m) of FAS overburden.

Areas nearer to an effective karst feature are normally associated with higher aquifer vulnerability due to the increased chance of overland flow and the infiltration into the depression. Therefore, buffer zones of 3,600-m (11,811 ft) divided into 30-m (98.4 ft) intervals were generated around each karst feature, and weights were calculated for the effective karst feature evidential theme using the cumulative ascending method. The highest contrast of any class was calculated at a distance of 60 m (196.9 ft) from a depression creating a binary generalized theme for input into the WAVA model. The generalized theme is displayed in **Figure 7**.

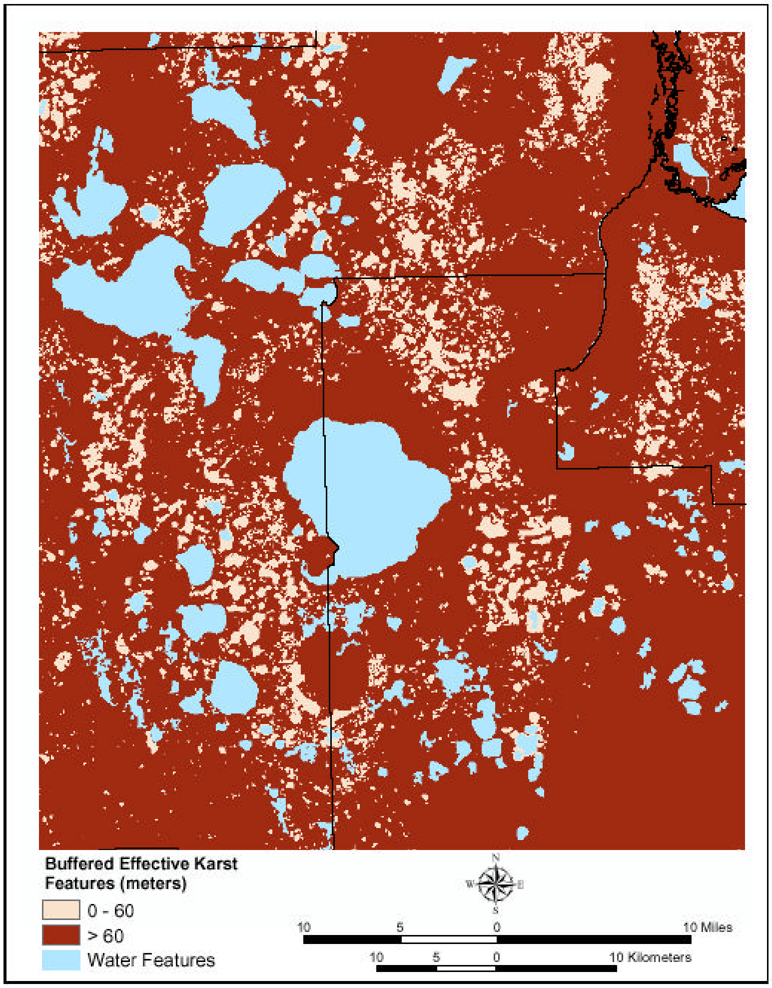


Figure 7. Map showing binary generalization of the buffered effective karst features evidential theme based on a contrast buffer distant of 60 m (196.9 ft).

Intermediate Confining Unit Thickness

For the purposes of the WAVA – WofE project, "Intermediate Confining Unit," or ICU, refers to the statewide hydrostratigraphic unit (formations that can be grouped into aquifer systems or confining units) that provides variable confinement to the FAS. The initial step in the development of the ICU was to create a database of well core and cuttings data. The well database was then used to create a hydrostratigraphic surface for the top of the ICU and the top of the FAS (which coincides with the base of the ICU). Following creation of these surface models, it was necessary to resolve the ICU with land-surface elevation in localized areas where the ICU surface interpolation extended above land surface. After the hydrostratigraphic surfaces were developed and refined, calculation of a thickness map was completed by subtraction of the ICU surface from the FAS surface. The final output yields a continuous thickness map of the ICU **(Figure 8).**

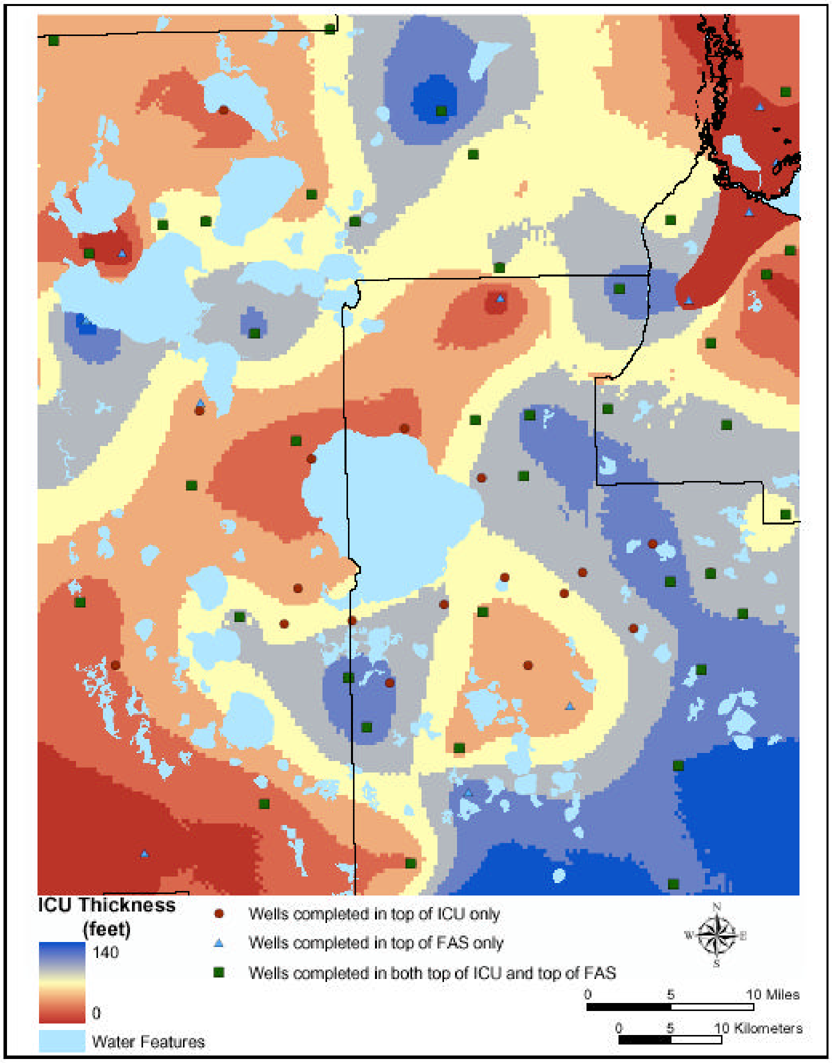


Figure 8. Thickness of ICU in feet and the distribution of wells used to determine ICU thickness. Geophysical well logs (Davis et al., 2001) were also used to fill in gaps

Areas underlain by thinner ICU sediments are normally associated with higher aquifer vulnerability. Weights were therefore calculated for the ICU evidential theme using the cumulative ascending method. The highest contrast of any class was calculated at a thickness of 48 feet (14.6 m) creating a binary generalized theme for input into the WAVA model **(Figure 9).**

The area in the vicinity of Wekiwa Spring is not included in the 0 to 48 feet thickness interval based on the best available data. The well database created from well core and cuttings data and geophysical (gamma) well logs from Florida Geological Survey Special Publication No. 50 indicate that the ICU is greater than 50 feet thick. In fact, the exposed rocks within the spring pool are from the Coosawhatchie formation of the Hawthorn Group that is part of the Intermediate Confining Unit.

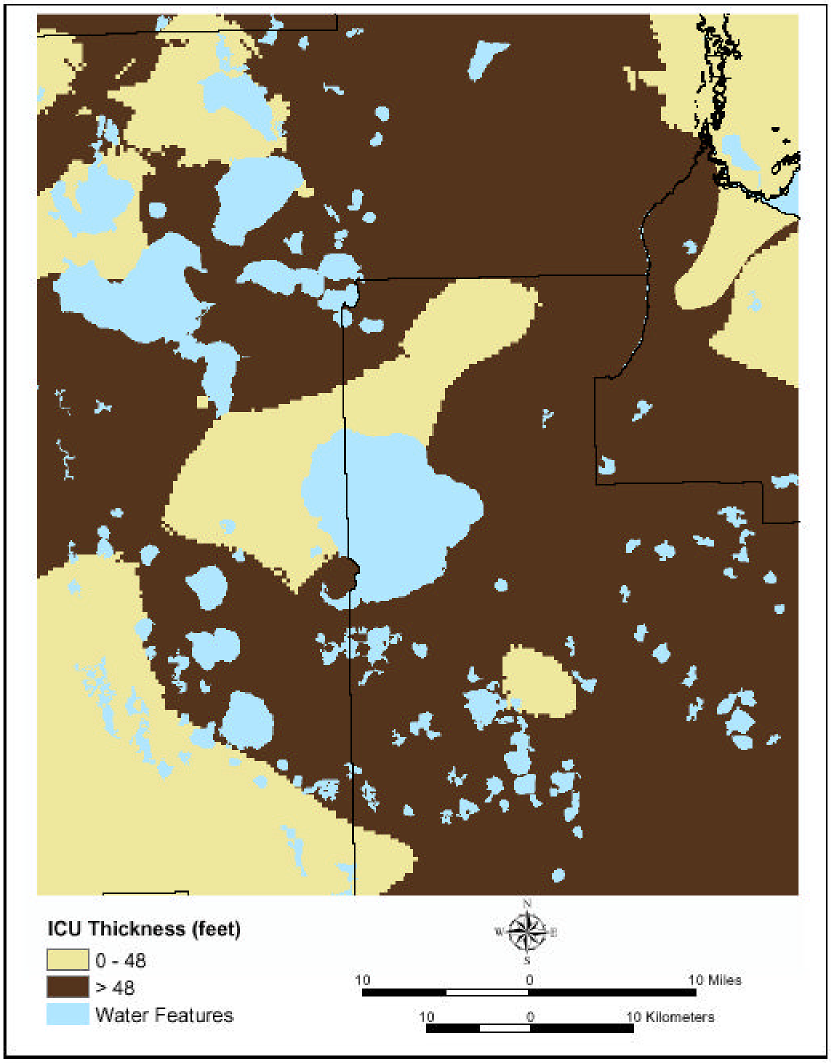


Figure 9. Map showing binary generalization of the ICU thickness evidential theme based on a contrast value of 48 ft (14.6 m).

Head Difference between SAS and FAS

Head difference was calculated by subtracting the FAS 1993–1994 potentiometric surface (Sepulveda, 2002) from the SAS water-table surface (Arthur et al., in preparation). Although more recent potentiometric surfaces for the FAS have been published, the data control in Sepulveda's (2002) map is more dense and therefore the potentiometric surface is more highly resolved. Areas where the head difference is a positive value indicates

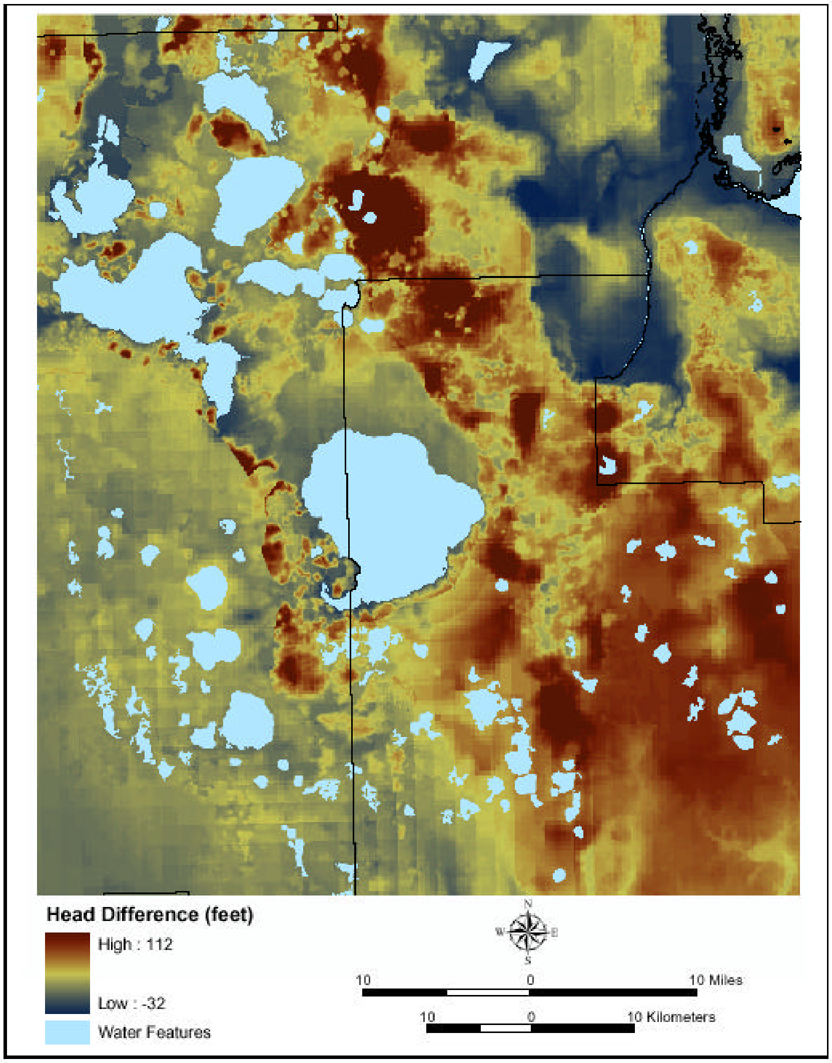


Figure 10. Head difference between the SAS water table surface (Arthur et al., in preparation) and the FAS potentiometric surface (Sepulveda, 2002).

that the SAS has the potential to recharge the FAS, whereas areas with a negative value indicate the FAS has the potential to discharge to the SAS **(Figure 10).**

Areas of greater head difference between the SAS and FAS indicate greater potential for downward recharge to the FAS, which is normally associated with higher aquifer vulnerability. Weights were therefore calculated for the head difference evidential theme using the cumulative descending method. The highest contrast of any class was calculated at a head difference value of 17 ft (5.2 m) creating a binary generalized theme for input into the WAVA model. **Figure 11** displays the binary generalization used for the head difference evidential theme.

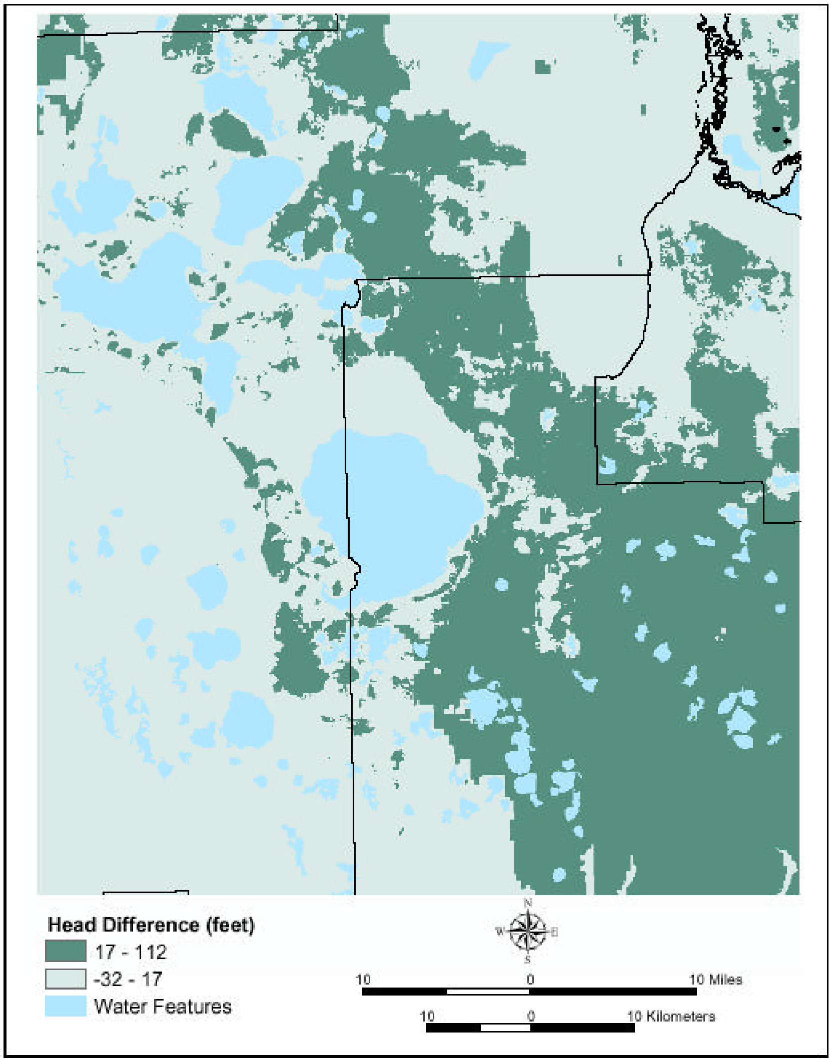


Figure 11. Map showing binary generalization of the head difference evidential theme based on a contrast value of 17 ft (5.2 m).

Response Theme

The WAVA response theme is an output map, calculated using WofE, showing the probability (posterior probability) that a unit area is vulnerable to contamination from land surface based on the evidence provided. A response theme is portrayed as relative vulnerability and is classified based on the inflections in a chart in which cumulative study area is plotted against the posterior probability. The chart may allow for the selection of several classes of posterior probability. The more vulnerable areas correspond with higher posterior probabilities, while the less vulnerable areas are associated with lower posterior probabilities. In essence, a higher posterior probability indicates that an area is more likely to contain a training point, or more likely to be contaminated, and therefore more vulnerable to contamination from land surface.

As identified in the introduction, the WAVA model is based on the modeling technique used in the FAVA project. FAVA compares the vulnerability of an aquifer system over its entire extent and consolidates vulnerability into three classes (more vulnerable, vulnerable and less vulnerable). The FAVA response theme clipped to the WAVA study area **(Figure 12)** shows that the majority of the study area is located in the "more vulnerable" zone. A smaller part of the study area is located in the "vulnerable" zone and *none* of the study area is located in the less vulnerable zone. By applying the FAVA modeling technique to the WAVA study area it is possible to identify zones of vulnerability within the study area since the predicted vulnerability of the smaller area will not be masked by the predicted vulnerability of the FAS statewide extent. Note, however, that by applying the FAVA model as a baseline for the WAVA study area, all protection zones should be considered "vulnerable" to "more vulnerable" in context of the statewide relative aquifer vulnerability.

Using the four evidential themes discussed above, a response theme was generated showing the posterior probability that a unit area contained a training point based on the evidential themes provided. A conceptual model showing the association between the training points and the evidential themes is shown in Figure 13. The posterior probabilities of the response theme ranged from 0.0007609 to 0.08354 across the model domain. Plotting posterior probability against cumulative area as a percentage (Figure 14) allows the delineation of class breaks for display of protection zones in the final response theme (Figure 15). The breaks for these protection zones are selected where a notable stepwise increase in posterior probability relating to cumulative area occurs. The first break, which delineates the *tertiary protection zone* from the *secondary protection zone*, occurs at a posterior probability value of 0.00023. The *tertiary protection zone* represents approximately 28% of the study area. The second break delineating the *secondary protection zone* from the *primary protection zone* occurs at the next significant stepwise increase in posterior probability at a value of 0.0017, which corresponds with the prior probability. The *secondary protection zone* represents approximately 50% of the study area. The remainder of the study area falls into the *primary protection zone* and represents approximately 22% of the study area. This *primary protection zone* contains the greatest probability of containing a training point.

For the purposes of this project, three classes are delineated as protection zones; however, based on the methodology used to select these classes, a third probability break could be delineated, representing approximately 3% of the study area. This area would represent the most vulnerable part of the primary zone and is located principally in the "more vulnerable" area defined in the FAVA study.

The response theme indicates that the areas of highest vulnerability (high probabilities) tend to be associated with ICU sediments that are thin to absent, dense karst-feature distribution, high positive head difference, and high soil permeability. Conversely, areas of lowest vulnerability (low probabilities) tend to be determined by thick ICU sediments, sparse karst-feature distribution, head difference less than 17 feet (5.2 m) and low soil permeability values.

In addition to the large surface water bodies that contain limited data, the study area is comprised of a multitude of other surface water features (Figure 16). These features can represent areas of discharge and may be predicted with low posterior probability values. These discharging surface waters are not part of the aquifer, although they can originate from it. The WAVA project was designed to focus on the ability for a contaminant to travel through soils, overburden, karst features, etc. to enter into the aquifer system. As a result, it is very important that the WAVA model never be applied to assess contamination of surface waters or discharge areas.

As noted earlier, an assumption is made when using WofE that there is conditional independence between the layers used as predictors. Conditional independence is violated when the presence of one evidential theme influences the probability of another evidential theme. The validity of posterior probability values depends upon the degree of conditional independence calculated for the model. Evidential themes are considered independent of each other if the conditional independence value is around 1.00. For the WAVA project, appropriate conditional independence values fall within the range of 1.00 ± 0.15 (Gary Raines, personal communication, 2003). Conditional independence was calculated at 1.15 indicating minimal dependence between evidential themes.

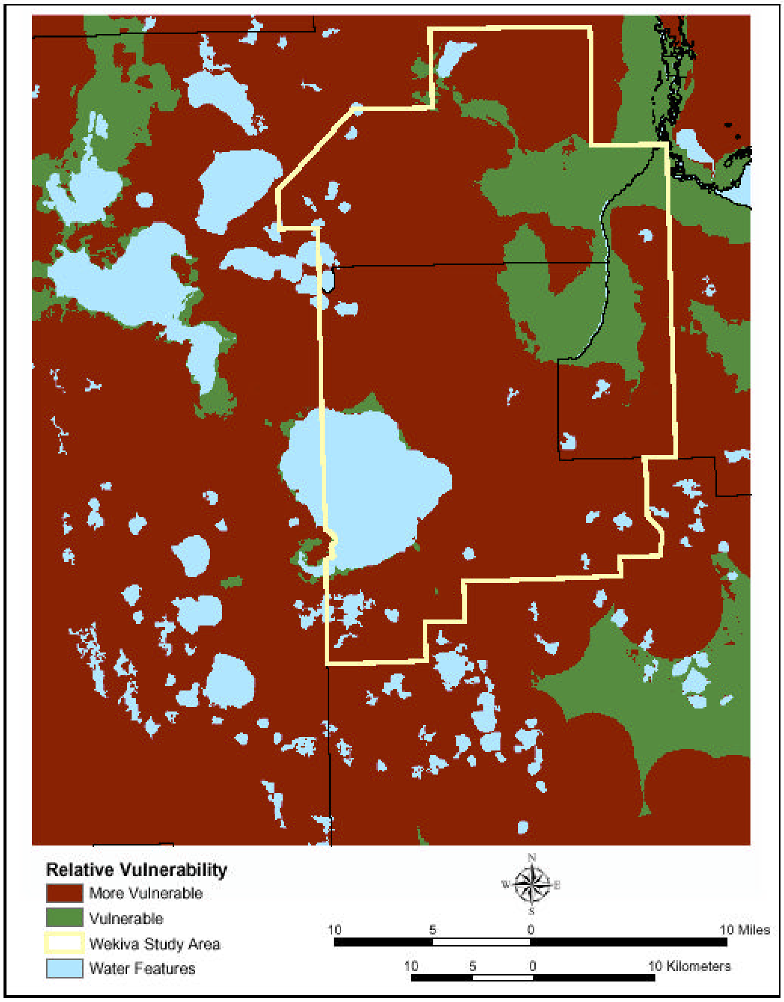


Figure 12. Relative vulnerability of the FAS FAVA model (Arthur et al., in preparation) showing zones of vulnerability based on the extent of the Floridan Aquifer System.

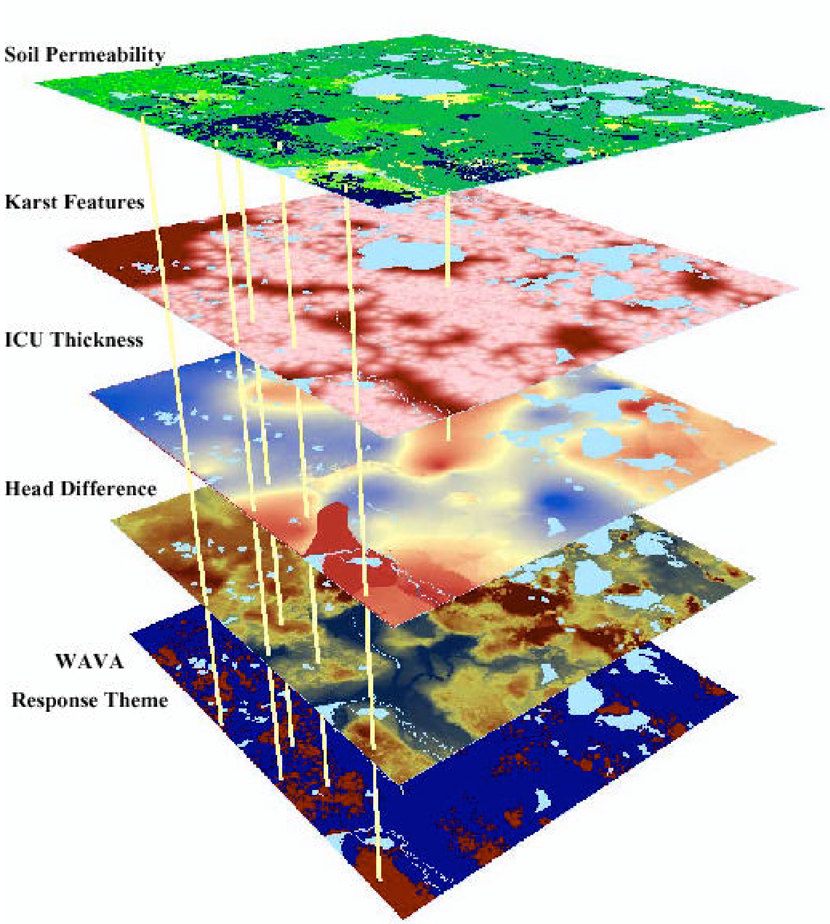


Figure 13. WofE conceptual model of the FAS. The top four layers are evidential themes and the bottom layer is the response theme. Yellow lines represent training points (wells) projected throughout the layers. Areas designated as red on the response theme are primary protection zones of the FAS whereas the dark blue areas are secondary protection zones.

Weights calculated for the evidential themes used in the WAVA model are included in Table 1. This table displays the evidential themes used, weights calculated for those evidential themes, as well as the theme contrast and confidence of the evidential theme. A positive weight indicates areas where training points are likely to occur, while a negative weight indicates areas where training points are not likely to occur. The contrast column is a combination of the highest and lowest weights (positive weight – negative weight) and is a measure of how well the generalized evidential themes predict training points. A positive contrast that is significant, based on its confidence, suggests that a generalized evidential theme is a useful predictor. The confidence of the evidential theme is the contrast divided by its standard deviation and provides a useful measure of significance of the contrast because of the uncertainties of the weights and areas of missing data (Raines, 1999).

The head difference evidential theme had a stronger association with the training points (i.e., highest contrast) than the other evidential themes and was therefore the primary determinant in predicting areas of vulnerability in this model. Three (buffered effective karst, confining unit thickness and soil permeability) of the evidential themes indicated where training points are more likely to occur because the positive weights (W1) were stronger (had a greater absolute value) than the negative weights (W2). Confidence values, for each evidential theme, exceed the target value of 1.282, which corresponds to a level of significance of approximately 90% (Table 2). In fact, all confidence values for the evidential themes exceeded the 95% level of significance (1.645). For the dissolved oxygen response theme all of the training points occur within areas of higher vulnerability, thus supporting the results of the model output.

Table 1. WofE final output table listing weights calculated for each evidential theme and their associated contrast and confidence values of the evidential themes.

Evidential Theme	W1	W2	Contrast	Confidence
Head Difference	0.7412	-1.2857	2.0269	1.8494
Buffered Effective Karst	1.3546	-0.5550	1.9096	2.3343
Confining Unit Thickness	0.8739	-0.7726	1.6465	1.8994
Soil Permeability	1.0126	-0.4927	1.5052	1.8409

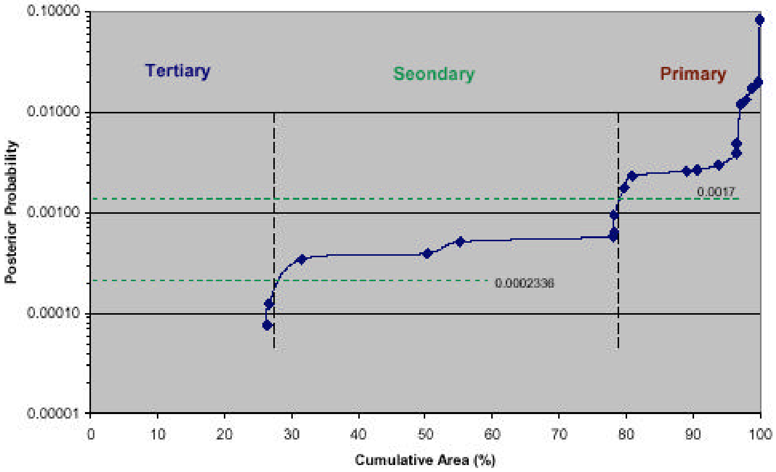


Figure 14. Class breaks, represented by green dashed lines, were placed where both a significant increase in probability and area were observed. These breaks represent the boundaries between protection zones.

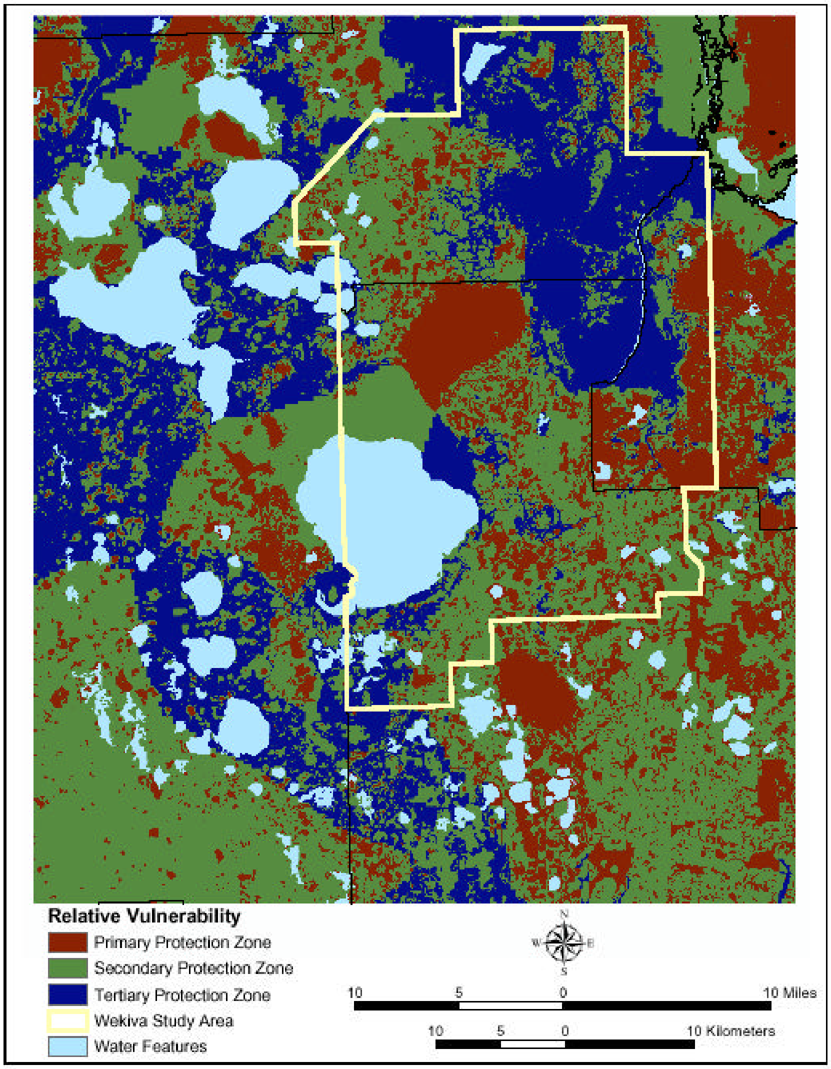


Figure 15. Relative vulnerability of the FAS WAVA model showing primary, secondary and tertiary protection zones.

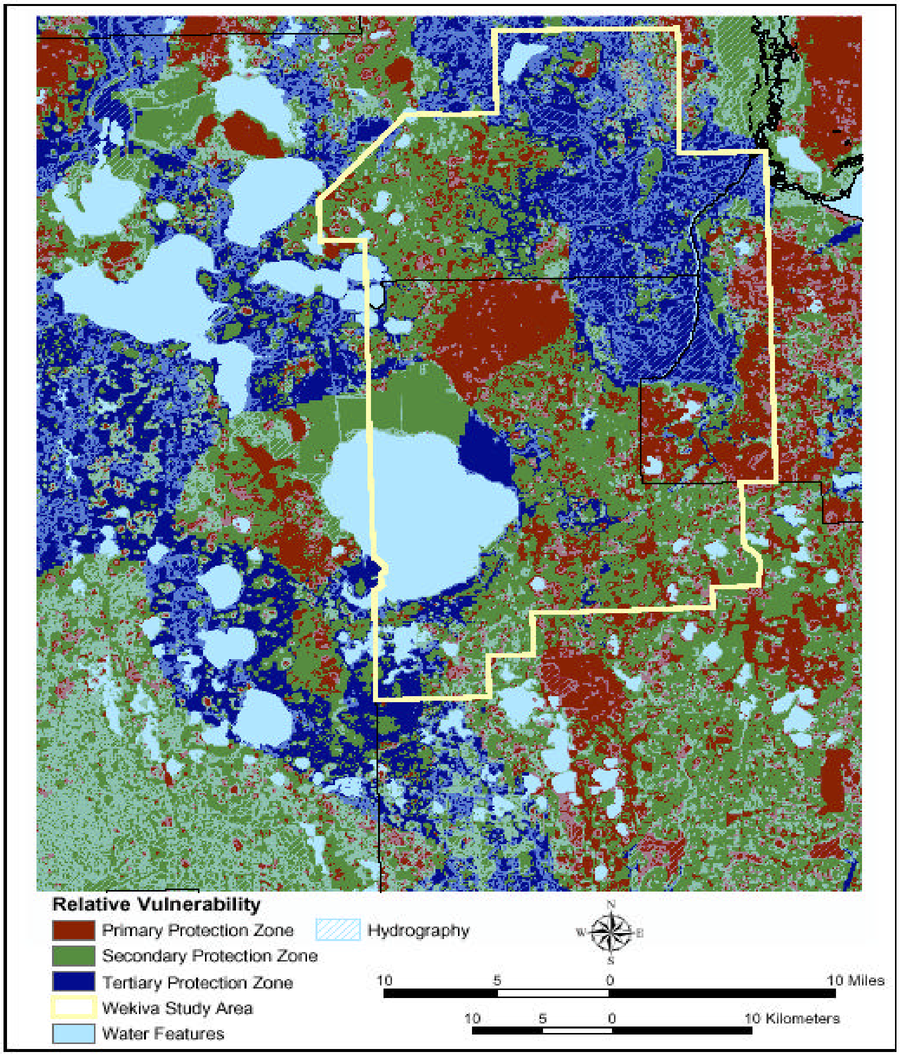


Figure 16. Relative vulnerability of the FAS WAVA model showing primary, secondary and tertiary protection zones. Hydrography represents seasonal and permanent wetlands, ponds and small lakes.

Confidence Map

There are two types of confidence used on the WofE model. Confidence of the evidential theme, as reported in Table 1, equals the contrast divided by the standard deviation (a student T test) for a given evidential theme and provides a useful measure of significance of the contrast due to the uncertainties of the weights and areas of possible missing data (Raines, 1999). The second type of confidence can be calculated for each response theme by dividing the theme's posterior probability by its total uncertainty (standard deviation). A confidence map can be generated based on these calculations. Confidence values approximately correspond to the statistical levels of significance listed in **Table 2.**

Table 2. Test values (based on infinite degrees of freedom) calculated in WofE and their respective confidence expressed as percentages.

Studentized T Value (Confidence expressed as level of significance)	Test Value (Posterior Probability ÷ Total Uncertainty)
99.5%	2.576
99%	2.326
97.5%	1.960
95%	1.645
90%	1.282
80%	0.842
75%	0.674
70%	0.542
60%	0.253

Areas with a high posterior probability tend to have higher confidence values and therefore have a higher level of certainty with respect to predicting aquifer vulnerability. A small population of training points along with missing data raises the total uncertainty for the response theme that in turn lowers the confidence. A confidence (of posterior probability) map containing all evidential themes **(Figure 17)** can therefore contain a lower level of significance than those calculated for each separate evidential theme.

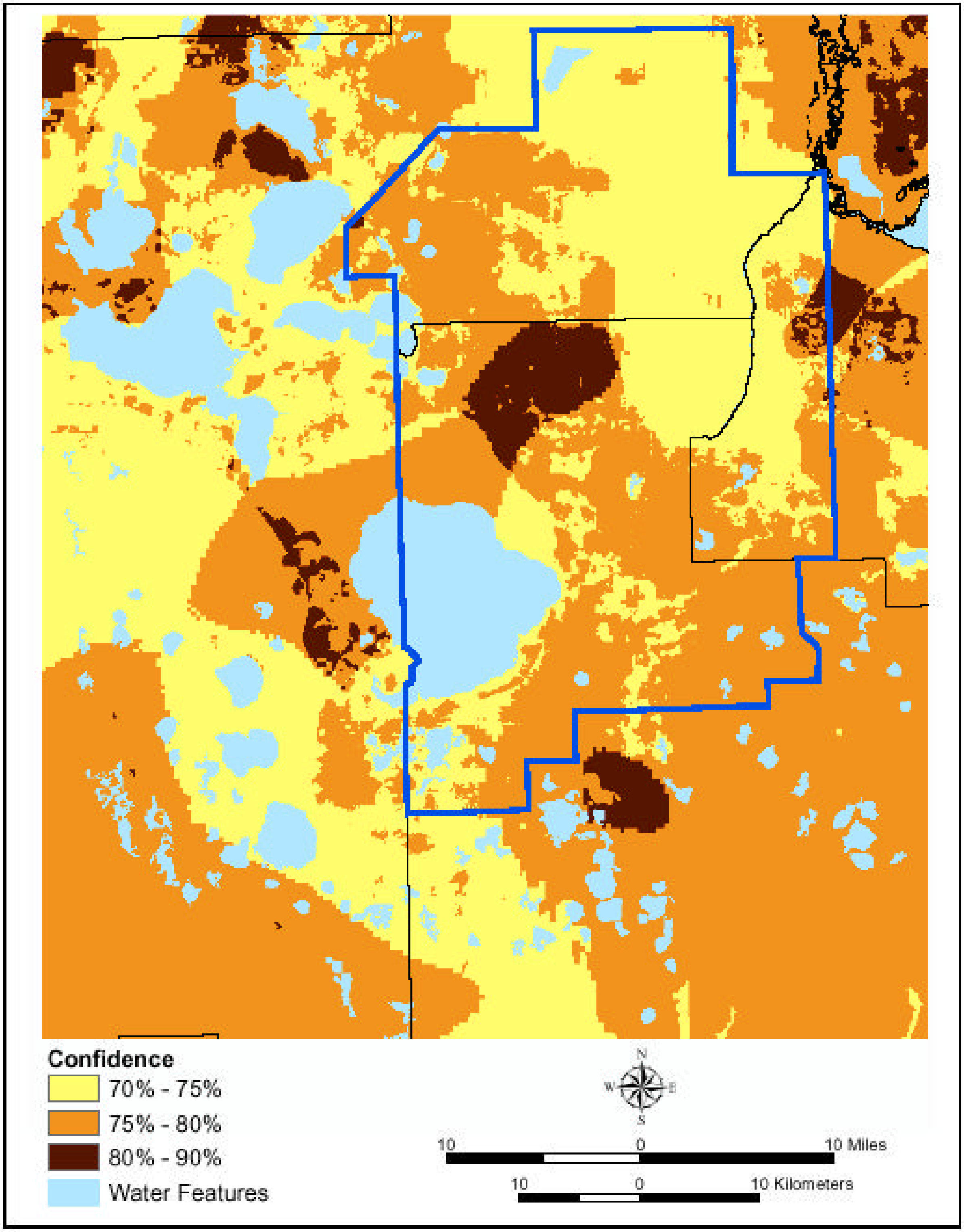


Figure 17. Distribution of confidence values calculated for WAVA response theme.

Weights of Evidence Glossary

Binary – Refers to the generalization or simplification of evidential themes or data layers. Binary layers are reclassified from the original dataset into presence/absence type themes or into two classes.

Conditional Independence (CI) – Occurs when an evidential theme does not affect the probability of another evidential theme. Evidential themes are considered independent of each other if the conditional independence value calculated is within the range 1.00 ± 0.15 (Raines, personal communication, 2003). Values that significantly deviate from this range can over inflate the posterior probabilities resulting in unreliable response themes.

Confidence of evidential theme – Contrast divided by its estimated standard deviation; provides a useful measure of significance of the contrast.

Confidence of Posterior Probability – A measure based on the ratio of posterior probability to its estimated standard deviation.

Contrast – W+ minus W- (see weights), which is an overall measure of the spatial association (correlation) of an evidential theme with the training points.

Cumulative Ascending – Calculates the cumulative weights from the first class to the last class while increasing the area. Areas nearest a training point have a stronger association, and those farthest away have a weaker association. This method is applicable for themes where the training points are mainly associated with the lower values of the evidential theme (e.g., higher vulnerability correlates with lower confinement thickness).

Cumulative Descending – Calculates the cumulative weights from the last class to the first class while increasing the area (opposite of cumulative ascending). This method is applicable for themes where the training points are mainly associated with the higher values of the evidential theme (e.g., higher vulnerability correlates with higher soil permeability).

Evidential Theme – A set of continuous spatial data that is associated with the location and distribution of known occurrences (i.e., training points); these map data layers are used as predictors of vulnerability.

Model – The characteristics of a set of training points, and the relationships of the training points to a collection of evidential themes.

Posterior Probability – The probability that a unit cell contains a training point after consideration of the evidential themes. This measurement changes from location to location depending on the values of the evidence.

Prior Probability – The probability that a unit cell contains a training point before considering the evidential themes. It is a constant value over the study area equal to the training point density (total number of training points divided by total study area in unit cells).

Response Theme – An output map that displays the probability that a unit area would contain a training point, estimated by the combined weights of the evidential themes. The output is displayed in classes of relative aquifer vulnerability or favorability to contamination (i.e., this area is more vulnerable than that area) or favorability. The response theme is the relative vulnerability map.

Spatial Data – Information about the location and shape of, and relationships among, geographic features, usually stored as coordinates and topology.

Study Area – A grid theme that acts as a mask to define the area where the model is developed and applied. It may be irregular in outline and may contain interior holes (e.g., lakes and no data areas).

Training Points – A set of locations (points) reflecting a parameter used to calculate weights for each evidential theme, one weight per class, using the overlap relationships between points and the various classes. In an aquifer vulnerability assessment, training points are wells with one or more water quality parameters indicative of relatively higher recharge that is an estimate of relative vulnerability.

Weights – A measure of an evidential-theme class. A weight is calculated for each theme class. For binary themes, these are often labeled as W+ and W-. For multiclass themes, each class can also be described by a W+ and W- pair, assuming presence/absence of this class versus all other classes. Positive weights indicate that more points occur on the class than due to chance, and the inverse for negative weights. The weight for missing data is zero. Weights are approximately equal to the proportion of training points on a theme class divided by the proportion of the study area occupied by theme class, approaching this value for an infinitely small unit cell.

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APPENDIX B

NITROGEN REMOVAL TECHNOLOGIES AND COSTS FOR LARGE DOMESTIC WASTEWATER TREATMENT FACILITIES

This appendix discusses nitrogen removal technologies for “large” domestic wastewater treatment plants (WWTPs) within the Wekiva Study Area. For purposes of this report, large facilities include all WWTPs having design capacities of 0.1 million gallons per day (MGD) or larger. A separate chapter addresses nitrogen removal for “small” domestic WWTPs – facilities having design capacities less than 0.1 MGD.

NITROGEN REMOVAL TECHNOLOGIES

A number of proven technologies are available for removal of nitrogen from domestic wastewater. These include a number of integrated, biological nutrient removal (BNR) processes and several processes that either remove nitrogen in a single step or involve two separate processes for nitrification (conversion of ammonia in the wastewater to nitrate) and for denitrification (conversion of nitrate in the wastewater to nitrogen gas).

Particularly for new facilities, integrated BNR processes (like Bardenpho), which feature aerobic, anoxic, and anaerobic zones in the biological treatment reactor may offer significant advantages. These BNR systems also can be used to retrofit some exiting treatment facilities. These systems are relatively cost effective and can achieve relatively low effluent limits for total nitrogen (TN). Some BNR technologies may be able to achieve TN limits of 3.0 mg/L. In addition, depending on the process, some removal of phosphorus also may be achieved without chemical addition. Depending on the nitrogen limitation imposed and on the processes employed at existing facilities, these facilities may want to evaluate the feasibility of implementing some type of integrated biological treatment process.

There are a number of single-step processes for removal of nitrogen. For facilities that do not nitrify (nitrogen is primarily in the form of ammonia), air stripping can be used to remove ammonia. The major disadvantages are the fact that process performance will vary with atmospheric conditions and nitrogen stripped to the atmosphere may be re-deposited within the basin with precipitation. Particularly during the winter months, it may be difficult to achieve a 3-mg/L TN limit using air stripping.

Ion exchange also can be used to remove nitrogen. Selective resins are available for removal of either ammonia or nitrate forms of nitrogen. Ion exchange can be used to remove ammonia as part of a system designed to recover ammonia for sale. This ammonia recovery system is expensive, complex, and has been used at very few facilities in the U.S. In general the ion exchange process is relatively complex and is more costly than other nitrogen removal processes.

Breakpoint chlorination also could be used to remove ammonia. This process involves relatively high O&M costs and is not widely used for ammonia removal. The process also features potential for increased concentration of disinfection byproducts.

One disadvantage of the single-step methods (ion exchange, air stripping, breakpoint chlorination) is that these processes generally are effective in removing only a single form of nitrogen. For example, ammonia stripping is relatively effective in removal of ammonia, but is ineffective in removing organic nitrogen, nitrite, and nitrate.

Perhaps the most common means for removing nitrogen from domestic wastewater involves the two-step nitrification/denitrification process. In the first stage, an aerobic reactor is used to convert ammonia to nitrate. In the second stage, anaerobic conditions are established to promote conversion of nitrate to nitrogen gas, which is allowed to escape to the atmosphere. While a number of processes are available for the denitrification step, perhaps the two most popular involve use of anaerobic basins followed by a clarifier, or use of anaerobic, denitrification filters. Denitrification filters offer possible advantages in terms of better removal of suspended solids, but this generally is done at a somewhat higher cost. Regardless of the denitrification method used, a carbon source (typically methanol) will be added to the wastewater being treated to fuel the biological activity needed to convert nitrate to nitrogen gas. The two-stage nitrification/denitrification process is cost effective, is commonly used for nitrogen removal, is relatively easy to operate and control, and can be easily applied to retrofit situations. Hence, this process offers significant potential for use within the Wekiva Study Area.

COST DATA

Separate cost curves were developed for both capital costs and for operation and maintenance (O&M) costs for two processes:

1. Nitrification (includes an aerobic reactor and clarifier).

2. Denitrification (includes an anaerobic reactor, methanol feed, and a clarifier).

Existing domestic WWTPs in the Wekiva Study Area employ a wide range of treatment technologies. Provision of the two sets of cost curves enables planning level cost estimates to be developed for virtually all domestic WWTPs in the Wekiva Study Area. For WWTPs that currently do not nitrify (those using contact stabilization or conventional activated sludge), both sets of curves will be needed to estimate costs associated with providing both nitrification and denitrification facilities. For WWTPs that already nitrify (those using extended aeration), the cost curves for denitrification will be applicable. Some facilities may already provide advanced wastewater treatment and will not require any upgrades to meet TN limits.

For denitrification facilities, the cost curves include costs needed to meet TN limits of 10.0 mg/L, 6.0 mg/L, and 3.0 mg/L. Treatment of the entire wastewater stream will be needed to meet a TN limit of 3.0 mg/L. Assuming that the influent to the denitrification process contains 20 mg/L of TN, only a portion of the entire flow would need to be treated to meet alternate limits of 6.0 mg/L or 10.0 mg/L.

Basis of Cost Estimates

Cost curves for nitrification and denitrification facilities were developed from information contained in EPA's ***Innovative and Alternative Technology Assessment Manual*** (1). Costs in the EPA manual are expressed in terms of September 1976 dollars. Construction costs were updated to June 2004 dollars using the ENR Construction Cost Index. O&M costs were updated to June 2004 dollars using the Consumer Price Index (CPI). For June 2004, the ENR index was 7109 and the CPI was 189.7.

Using the procedure in the EPA manual (1), construction costs were adjusted to account for non-component costs (piping 10%, electrical 8%, instrumentation 5%, site preparation 5%). The resulting adjusted construction costs were converted to capital costs by adding 15 percent for engineering and 15 percent for contingencies.

Cost Curves

Capital costs for nitrification facilities are presented in Figure 1. Associated O&M costs for these nitrification facilities are shown in Figure 2.

Capital costs for denitrification facilities are presented in Figure 3. For denitrification facilities, O&M costs are shown in Figure 4.

All cost curves cover facilities having capacities in the range of 0.1 MGD to 10 MGD. All cost curves are in terms of June 2004 dollars.

Figure 1. Capital Costs for Nitrification Facilities

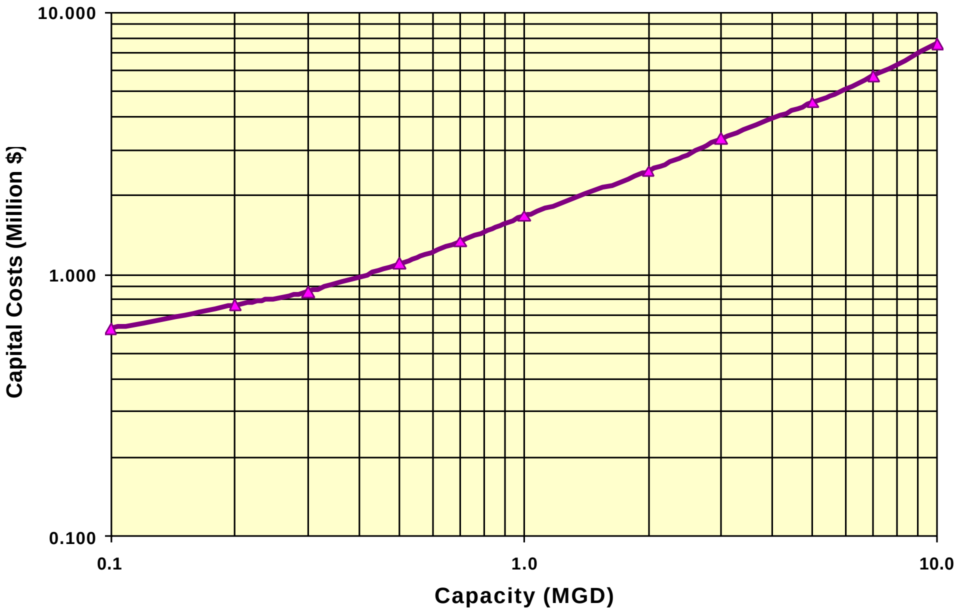


Figure 2. O&M Costs for Nitrification Facilities

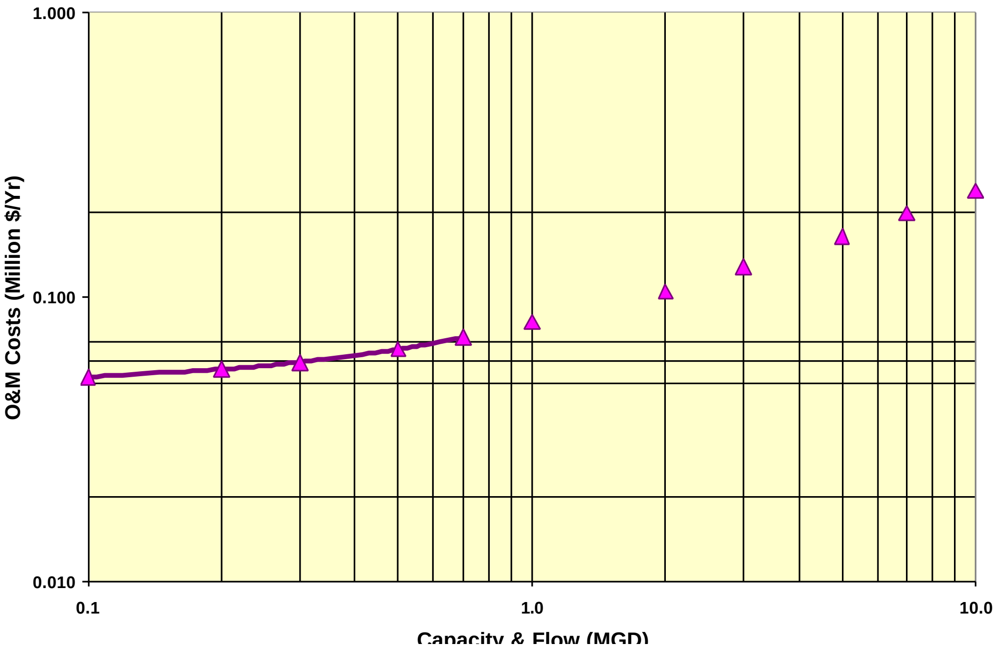


Figure 3. Capital Costs for Denitrification Facilities

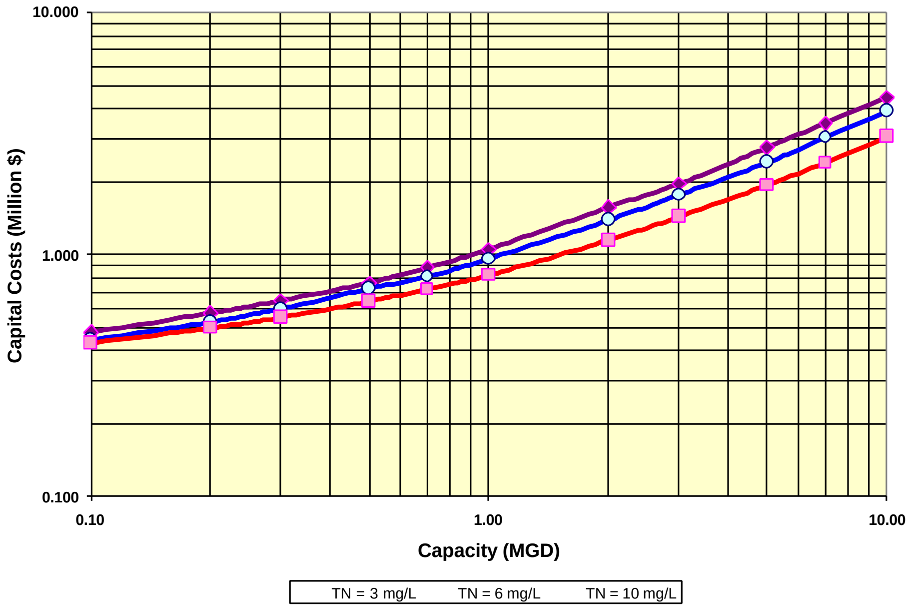
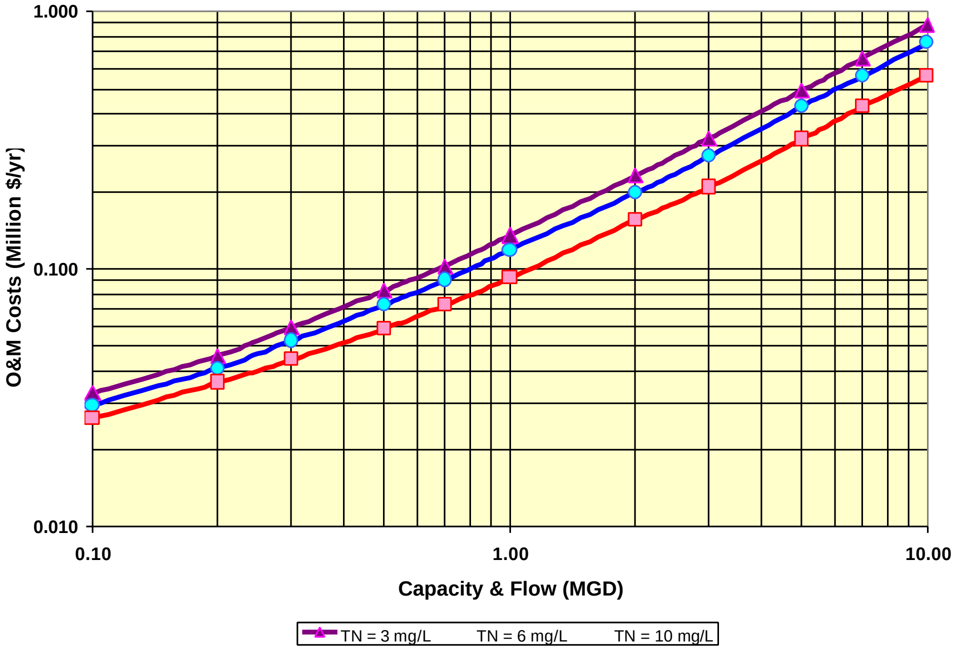


Figure 4. O&M Costs for Denitrification Facilities



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APPENDIX C

NITROGEN REMOVAL TECHNOLOGIES AND COSTS FOR SMALL DOMESTIC WASTEWATER TREATMENT FACILITIES

This appendix discusses nitrogen removal technologies for "small" domestic wastewater treatment plants (WWTPs) within the Wekiva Study Area. For the purpose of this report, small facilities include all WWTPs having design capacities of 2,000 to 100,000 gallons per day (gpd).

Three studies (1,2,3) were conducted which analyzed the treatment capabilities and technologies of small wastewater treatment plants in the Florida Keys for achieving "best available technology" (BAT) treatment. The effluent limits (as annual averages) for BAT in the Florida Keys were 10 milligrams per liter (mg/L) biochemical oxygen demand (BOD_5), 10.0 mg/L total suspended solids (TSS), 10.0 mg/L total nitrogen, and 1 mg/L total phosphorus. Much of the information provided in this chapter was drawn from these three studies.

NITROGEN REMOVAL TECHNOLOGIES

Three studies (1,2,3) of treatment technologies for achieving BAT in the Florida Keys provide insight into technologies that may be appropriate for use by small facilities within the Wekiva Study Area. This section presents a summary of the key information extracted from these three studies.

CH2M HILL (3) evaluated a range of technologies for nutrient removal for small facilities. Processes evaluated included the Modified Ludzak-Ettinger (MLE) process, the four-stage process, the three-stage process, the suspended-growth sequencing batch reactor (SBR) process, the Intermittent-Cycle Process (a modified SBR process involving four stages), MLE with deep-bed filtration, submerged biofilters, and rotating biological contactors (RBC). The technologies evaluated involve suspended- or attached-growth biological treatment processes having various combinations of aerobic, anoxic, and anaerobic zones. The five top-ranked technologies are shown in **Table 1.** This table also shows the scores assigned by CH2M HILL for costs of treatment and for the processes' ability to remove nitrogen. Table 2 presents the effluent limits achievable by the five top-ranked treatment technologies.

Table 1. Ranking of Treatment Technologies

Technology	Rank	Unit Cost Score	Nitrogen Removal Score
Three-Stage Process	1	3	5
Modified Ludzak-Ettinger (MLE)	2	4	4
MLE+Deep Bed Filtration	3	2	5
Sequencing Batch Reactor (SBR)	4 (tie)	3	4
Intermittent Cycle	4 (tie)	3	4

Notes: Source (3). Scores range from 1 (Less Favorable) to 5 (More Favorable).

Table 2. Achievable Effluent Quality of Treatment Technologies

Technology	BOD (mg/L)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
Three-Stage Process	10	10	6	2
Modified Ludzak-Ettinger (MLE)	10	10	10	2
MLE+Deep Bed Filtration	10	5	6	1
Sequencing Batch Reactor (SBR)	10	10	8	2
Intermittent Cycle	10	10	8	2

Note: Source (3).

For small facilities, the ability of treatment processes to reliably meet relatively stringent TN limits is a potential concern. This issue was evaluated in the ***Florida Keys Report*** (1) and subsequently in the ***BAT Survey Report*** (2). Table 3 shows four domestic wastewater treatment plants located in the Florida Keys that were evaluated in the ***BAT Survey Report*** (2) for their ability to remove nitrogen from domestic wastewater.

Table 3. Domestic Wastewater Treatment Nitrogen Data

Treatment Plant Name	Design Capacity (MGD)	Treatment Type	Influent Total Nitrogen (mg/L)	Effluent Total Nitrogen (mg/L)
Waffle House	0.003	Mack-Modified Ludzak-Ettinger (MLE)	89.1	31.4
Islander Resort	0.06	Upflow Sludge Blanket (USBF)	35.1	18.2
Island Tiki Bar	0.012	Upflow Sludge Blanket (USBF)	65.7	3.87
Ziggie's	0.006	Upflow Sludge Blanket (USBF)	59.1	9.1

Notes: Source (2). Samples taken in February 2003.

In addition, discharge monitoring reports (DMR) were reviewed for nine facilities in the Florida Keys in an effort to evaluate their ability to achieve TN limits of 10.0 mg/L. Results of this review are shown in Table 4 for the January to June 2004 period (unless otherwise noted). Currently, small facilities in the Florida Keys use either the Modified Ludzak-Ettinger or USBF processes for nitrogen removal.

Table 4. DMR data for Small Treatment Plants in the Florida Keys

Treatment Plant Name	Treatment Type	Design Capacity (MGD)	Total Nitrogen (mg/L)
Waffle House	MLE	0.003	12.40 - 13.10
Islander Resort	USBF	0.06	5.95 - 8.63
Island Tiki Bar	USBF	0.012	6.93 - 7.45
Ziggie's	USBF	0.006	7.50 - 11.50
Tradewind Hammocks	MLE	0.012	7.50 - 8.40(a)
Boy Scouts BEC	MLE	0.015	6.00 - 11.30(b)
Oceanside Marina	USBF	0.020	12.60 - 20.13
Marathon Marina	USBF	0.025	14.95 - 18.12
John Pennecamp	MLE	0.014	12.50 - 13.90

Notes: (a) Only data from April-June 2004 available. (b) Represents July 2002 - September 2003 data.

Inspection of Tables 3 and 4 reveals that, while small facilities can achieve a 10-mg/L TN limitation, meeting a 10-mg/L limitation will be challenging. Prudent design and careful operation of these facilities will be needed.

COST DATA

Table 5 presents a summary of unit costs for the five top-ranked technologies as reported in the CH2M HILL report (3). These costs are in 1998 dollars and are included solely as a basis for comparison. Inspection of **Table 5** reveals that there are significant economies of scale in moving from capacities of 4,000 gpd to 100,000 gpd. It also is interesting to note that unit costs are similar for all technologies for any given facility size. For example, for a 100,000-gpd facility, costs for the most expensive processes (three-stage and MLE with deep bed filters) are only about 11 percent greater than costs for the least costly process (MLE). For the smallest facilities (4,000 gpd), costs for the most expensive process (MLE with deep bed filters) are about 33 percent greater than costs for the least costly process (Intermittent Cycle).

Table 5. Unit Costs ($/1,000 gallons)

Technology	Treatment Plant Design Capacity (gpd)				
	4,000	**10,000**	**25,000**	**50,000**	**100,000**
Three-Stage Process	71.2	32.9	17.6	12.2	9.1
Modified Ludzak-Ettinger (MLE)	61.8	29.1	16.0	11.1	8.2
MLE+Deep Bed Filtration	74.1	34.7	18.7	12.4	9.1
Sequencing Batch Reactor (SBR)	66.5	31.3	16.9	11.9	8.6
Intermittent Cycle	55.7	31.0	18.6	13.3	8.8

Note: Source (3). Costs from manufacturers/vendors. All costs in 1998 dollars.

As noted in previous tables, the USBF process offers promise for small facilities needing to meet relatively stringent TN limits. Unfortunately, reliable cost data for the USBF process currently are not available.

Cost Curves

Capital costs for retrofitting an existing facility to the MLE process are presented in Figure 1. The MLE retrofit includes an anoxic basin before the existing biological secondary treatment process. Associated operation and maintenance (O&M) costs for the MLE retrofit are shown in Figure 2. Given the relative consistency of costs for the various processes (as shown in Table 5), these costs are considered indicative of the costs of the various available technologies.

If a facility owner wanted to provide a greater level of certainty of being able to meet a 10-mg/L TN limitation, he/she might consider adding a deep-bed denitrification filter to the facility. Capital costs for the deep-bed denitrification filter retrofit are presented in Figure 3. The O&M costs for denitrification filters are shown in Figure 4.

All cost curves cover facilities having capacities of 4,000 gpd to 100,000 gpd. All cost curves are in terms of June 2004 dollars.

Basis of Cost Estimates and Cost Curves

The cost curves were derived from the CH2M HILL report (3). Technology vendors and manufacturers provided the costs included in the CH2M HILL report. Costs in the CH2M Hill report were expressed in terms of 1998 dollars. Construction costs were updated to June 2004 dollars using the ENR Construction Cost Index. O&M costs were updated to June 2004 dollars using the Consumer Price Index. For June 2004, the ENR index was 7109 and the CPI index was 189.7.

Construction costs in the CH2M Hill report (3) included allowances for piping, instrumentation, electrical, and site preparation along with a contingency. A 15-percent allowance for engineering services was added in converting construction costs to capital costs in Figures 1 and 3.

CONCLUSIONS AND RECOMMENDATIONS

There are several technologies available that could be used to meet a 10-mg/L TN limitation. Cost curves are presented for retrofitting existing facilities to the MLE process. With prudent design and careful operation, the MLE process is capable of meeting a 10-mg/L TN limitation. However, some utilities may want to consider the addition of a deep-bed denitrification filter to provide greater assurances of being able to meet this TN limitation. While reliable cost data are not currently available, the USBF process also offers potential for nitrogen removal.

Figure 1. Capital Costs for MLE Upgrade

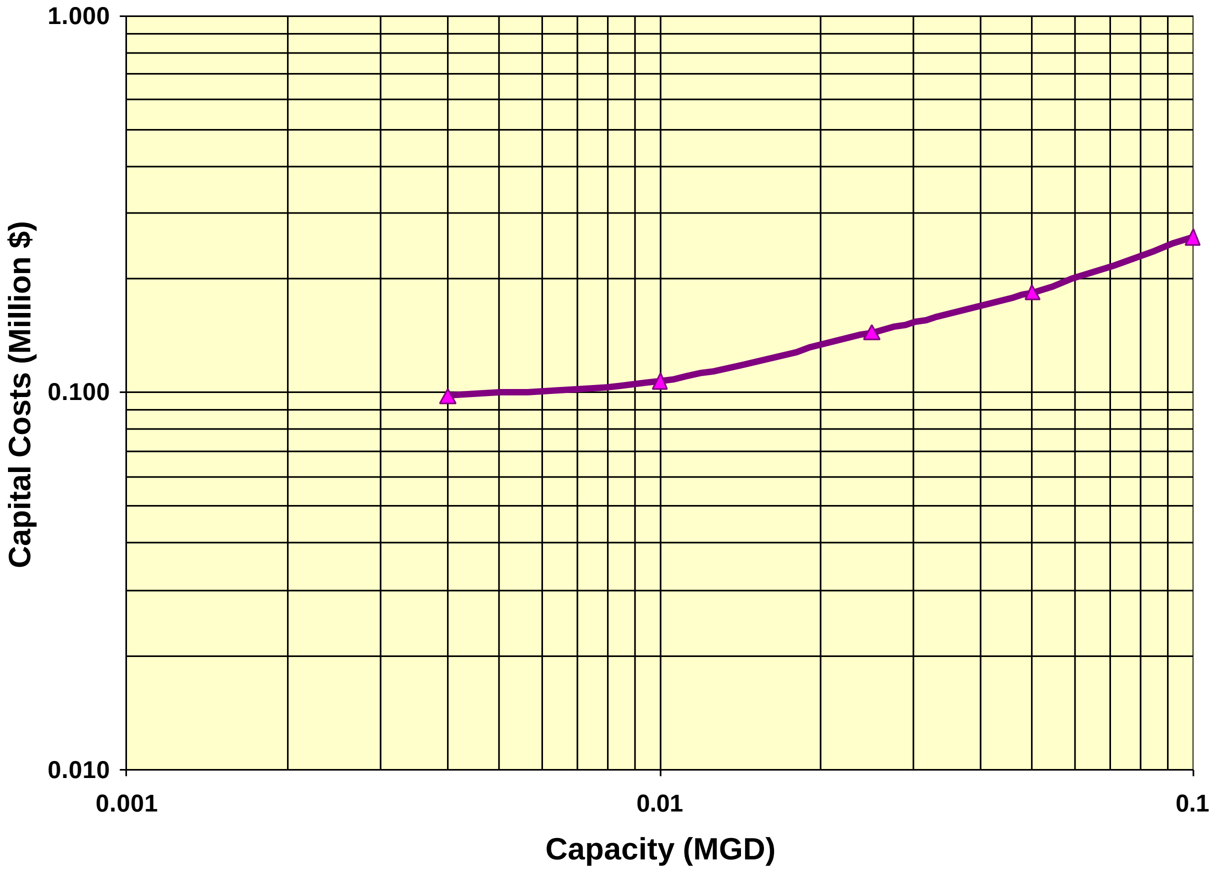

Figure 2. O&M Costs for MLE Upgrade

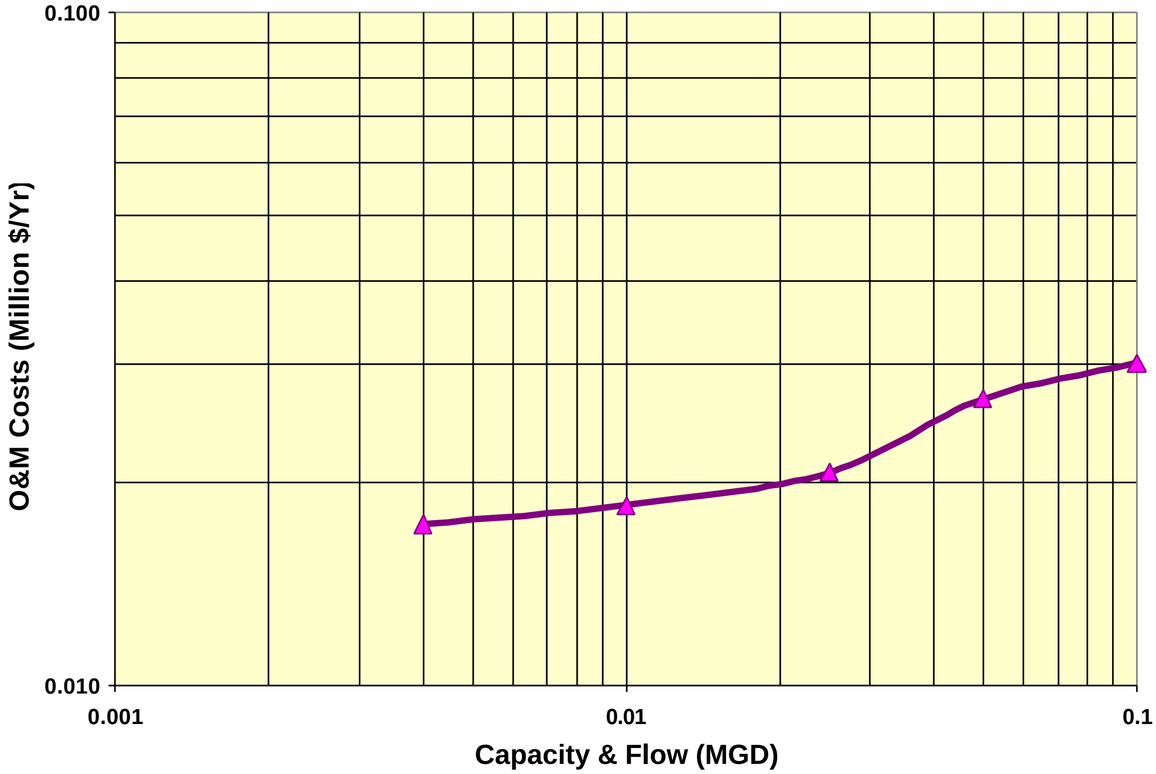

Figure 3. Capital Costs for Denitrification Filter