NITRATE LOADING AS AN INDICATOR OF NONPOINT SOURCE POLLUTION IN THE LOWER ST. MARKS-WAKULLA RIVERS WATERSHED

PREPARED BY :

NORTHWEST FLORIDA
WATER MANAGEMENT DISTRICT

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AS AN
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IN THE
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Water Resources Special Report 02-1

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS [cont]

Page

LIST OF FIGURES

LIST OF FIGURES [cont.]

LIST OF FIGURES [cont.]

LIST OF TABLES

Table **Page**

Appendix A Tables **Page**

LIST OF TABLES [cont.]

Appendix A Tables **Page**

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The cover photograph was taken inside the conduit system looking up at a glass bottom boat floating on the surface of the spring. Daniel Wagner, who graciously agreed to its use, took the photograph.

REVISION June 2003 – As part of the District's lower St. Marks/Wakulla rivers watershed nitrate investigation, water levels were measured in the study area and potentiometric surfaces contoured (report Figures 22 through 24). Three maps were prepared; January 1999, August 1999 and March 2000. One criterion for inclusion on the final map was a surveyed wellhead elevation. Seven measured wells were not surveyed during the study period due to time constraints. Data from these wells were not included in the original contouring efforts. Funding provided by the FDEP Florida Springs Initiative (2002-2003) allowed for two of the unsurveyed wells (NWF ID# 7238 and 7239) to be professionally surveyed to ±0.1 ft, NGVD. Correctly adjusted ground water elevation data from these two well points were inserted into Figures 22 through 24 and the potentiometric surface contours revised accordingly.

INTRODUCTION

Purpose and Scope

This report is being submitted to provide Leon and Wakulla counties, the City of Tallahassee, the Florida Department of Environmental Protection and other interested parties with a means of assessing the risk posed to drinking water wells (existing and proposed) and surface water bodies by NO_3-N contamination. It is the intent of this study to augment the St. Marks River Surface Water Improvement and Management (SWIM) Program in its effort focusing on the restoration and long-term preservation of the St. Marks and Wakulla rivers watershed. This is an integral component of the State of Florida's Watershed Management Program. This work was performed under Florida Department of Environmental Protection (FDEP) Contract Number WM695. Specifically, the scope of this work includes the following activities:

- Relying on an existing USGS-developed numerical model of the Floridan Aquifer, develop a steady-state water budget for the study area. Quantify the horizontal flux into the study area from up-gradient portions of the Floridan Aquifer. Estimate ground water inputs from principal sinking streams. Quantify areally distributed recharge rates to Woodville karst plain. Quantify losses through springs and rivers. Quantify losses to the Gulf of Mexico.

- Develop a project-specific network of approximately 40 existing wells. Develop criteria for including wells in network. Review Northwest Florida Water Management District (NWFWMD) databases for wells suitable for inclusion. Visit well sites and determine their locations via global positioning system (GPS).

- Develop a network of surface water sampling sites comprised of rivers, springs, sinking streams, and sinkholes. In conjunction with DEP, develop criteria for including sites in network, parameter lists and sampling frequency. Site visit and GPS sites.

- Construct a supplemental network of approximately six Floridan Aquifer wells suitable for isotopic sampling. Develop criteria for choosing site locations. Obtain necessary easements. Obtain contractor services and construct wells. Locate wells with GPS.

- Conduct sampling of karst features, springs and sinkholes.

- Sample project-specific network wells for field parameters, major ions, nutrients, silica, and dissolved organic carbon (DOC). The U.S. Geological Survey Water Quality and Research Laboratory in Ocala, FL analyzed samples for major ions. Prepare maps showing the spatial distribution of selected parameters. Prepare corresponding potentiometric-surface map from water-level data collected at time of sample collection. Sample supplemental network twice in one year for the same parameters, as well as isotopes $^{18}O/^{16}O$, D/H, $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{3}H/^{3}He$.

- Develop geographic information systems (GIS) coverages of karst features within the study area including, sinkholes, springs, sinking streams, etc.

- Examine all data to delineate areal distribution of NO_3-N, isotopes and other water quality parameters. Perform geochemical modeling using WATEQF and NETPATH. Integrate and interpret geochemical data to determine flow paths, flow rates, ground water ages and NO_3-N flux through the system.

- Compile NO_3-N concentration and load data for the principal input sources to the Floridan Aquifer in study area including stormwater runoff; horizontal flux into study area from up-gradient areas; and effective concentration of rainfall recharge, recharge from wastewater treatment facilities, and leaching from fertilizer application.

- Conduct an inventory of septic tank sites in the study area using available census data, land-use data, areal photographs and Department of Health (DOH) septic tank permitting records. Develop GIS coverages representing current spatial distribution of septic tanks in study area. Based on available literature, develop estimates of NO_3-N loading rates from septic tanks. Combine data on septic tank loading rates with cumulative tank numbers to estimate total load to Floridan Aquifer from this source.

- Develop STELLA application. Perform and document sensitivity analyses. Document usefulness and limitations associated with this approach. Transfer STELLA application to interested local governments. Provide an integrated technology transfer and training program to local decision-makers and affected stakeholders interested in understanding and using the application.

Project deliverables consist of this report and Katz et al. (in preparation). This project and the preparation of this report were funded in part by a Section 319 Nonpoint Source Management Program grant from the U.S. Environmental Protection Agency (USEPA) through a contract with the Nonpoint Source Management and Water Quality Standards Section of the Florida Department of Environmental Protection. The total cost of the project was $503,700 of which $291,966, or 58 percent was provided by the USEPA. The project described here is a component of the District's St. Marks Surface Water Improvement and Management Program. From FY96-97 through FY00-01, expenditures on the St. Marks SWIM program (exclusive of the 319h grant) totaled approximately $574,000.

Area of Investigation

The focus of this study is those portions of Leon and Wakulla counties where the Floridan Aquifer is under either semi-confined or under unconfined conditions (Figure 1). This includes approximately the eastern two-thirds of Leon County and the eastern half of Wakulla County. Tallahassee, Woodville, Crawfordville and St. Marks all lie within the study area. The vast majority of residents in both counties live within the study area. This area was selected because of the relatively good hydraulic connection between the land surface and the underlying Floridan Aquifer. Further, much of the water that flows south to points of discharge either originates in or flows beneath this area. The area identified as being under semi-confined conditions generally coincides with the Tallahassee Hills physiographic subdivision as mapped by Hendry and Sproul (1966), Puri and Vernon (1964) and Brooks (1981). It also corresponds to what Davis (1996) mapped as Floridan Aquifer "overlain but not confined by low-permeability Miocene-and Pliocene age sediments."

The area identified as being under unconfined conditions generally corresponds to what Brooks (1981) mapped as the Lake Munson Hills and Woodville Karst Plain physiographic subdivisions. It also corresponds to the Woodville Karst Plain as mapped by Rupert (1988) and Lane (1986) and to what Davis mapped as where the Floridan Aquifer is "unconfined and the top of the aquifer is at (or near) land surface". The boundary between the semi-confined and unconfined areas corresponds to the Cody Scarp, as mapped by Puri and Vernon (1964). The remainder of Leon and Wakulla counties are described by Davis as being under confined conditions.

The study area is imbedded within a larger Floridan Aquifer zone-of-contribution for the significant ground water discharge occurring in Wakulla Springs, the lower St. Marks River and beneath the Gulf of Mexico (Figure 1). Potentiometric surface mapping by Davis (1996) was used to delineate this larger zone-of-contribution. Land use for the coastal Wakulla County Floridan Aquifer zone-of-contribution delineation is provided in Figure 2.

Rainfall

During the study period 1998-2000, rainfall was abnormally low. The 50-year (1951-2000) average annual rainfall at the Tallahassee Airport is 62.6 inches. The 10-year (1991-2000) average annual rainfall declines to 60 inches, reflecting drought conditions during the latter part of this period. Comparisons between the Tallahassee Airport 50-year average annual and yearly totals for 1998, 1999 and 2000 are given in Figure 3. Data from the River Sink rainfall station are only available for 1999 and 2000. During 1998, the airport recorded a deficit of 3.8 inches (6.1 percent of the 50-year average). In 1999, the deficit was 12.5 inches (two-year cumulative deficit of 16.3 inches, or 13.1 percent of two years average rain). During 2000, the deficit was 17.5 inches, yielding a three-year cumulative deficit of 33.8 inches, or 18.0 percent of three years average rain. Not only did dry conditions persist for much of the three-year study period, but also the severity of the drought worsened during the latter half of the period. The persistent lack of rainfall during the study period yielded a lowering of the Floridan Aquifer potentiometric surface, low or no inflows to sinkholes and sinking streams, lower than normal discharge from springs, low lake levels and diminished or nonexistent surface streamflows.

Mean monthly rainfall totals for the 10-year period 1991-2000 were calculated for the Tallahassee Airport. These monthly averages are compared with monthly rainfall during the same period in Figure 4. A ten-year cumulative departure from normal is given in Figure 5. For the entire 36-month period (January 1998 through December 2000), monthly rainfall exceeded the 10-year monthly average in only eight months (February 1998, March 1998, July 1998, September 1998, May 1999, June 1999, August 2000 and September 2000). Two monthly average exceedances are attributable to tropical storms. In September 1998, Hurricane Earl (9/3/1998) dropped 5.07 inches of rain at Tallahassee Airport and Hurricane Georges (9/30/1998) dropped 5.32 inches. In September 2000, Hurricane Gordon (9/18/00) dropped 0.71 inches of rain at the Airport and Tropical Storm Helene (9/22/00) dropped 8.2 inches.

The National Oceanographic and Atmospheric Administration, Drought Information Center has published the weekly U.S. Drought Monitor http://www.drought.noaa.gov/ since May 20, 1999. The study area was classified as being under drought conditions for the entirety of 2000. The beginning of 2000 found the study area under D2 (severe drought) conditions, which persisted for all of January. February was characterized as being at D1 (moderate drought) status. D2 conditions persisted from the end of February until the end of May. From the beginning of June until September 11, the study area was under either D3 (extreme drought) or D4 (exceptional drought) conditions. The D1 conditions that prevailed from September 19 through October 30 were associated with the passage of tropical storms through the area. From the first of November until the end of the year, the study area was again under D2 conditions.

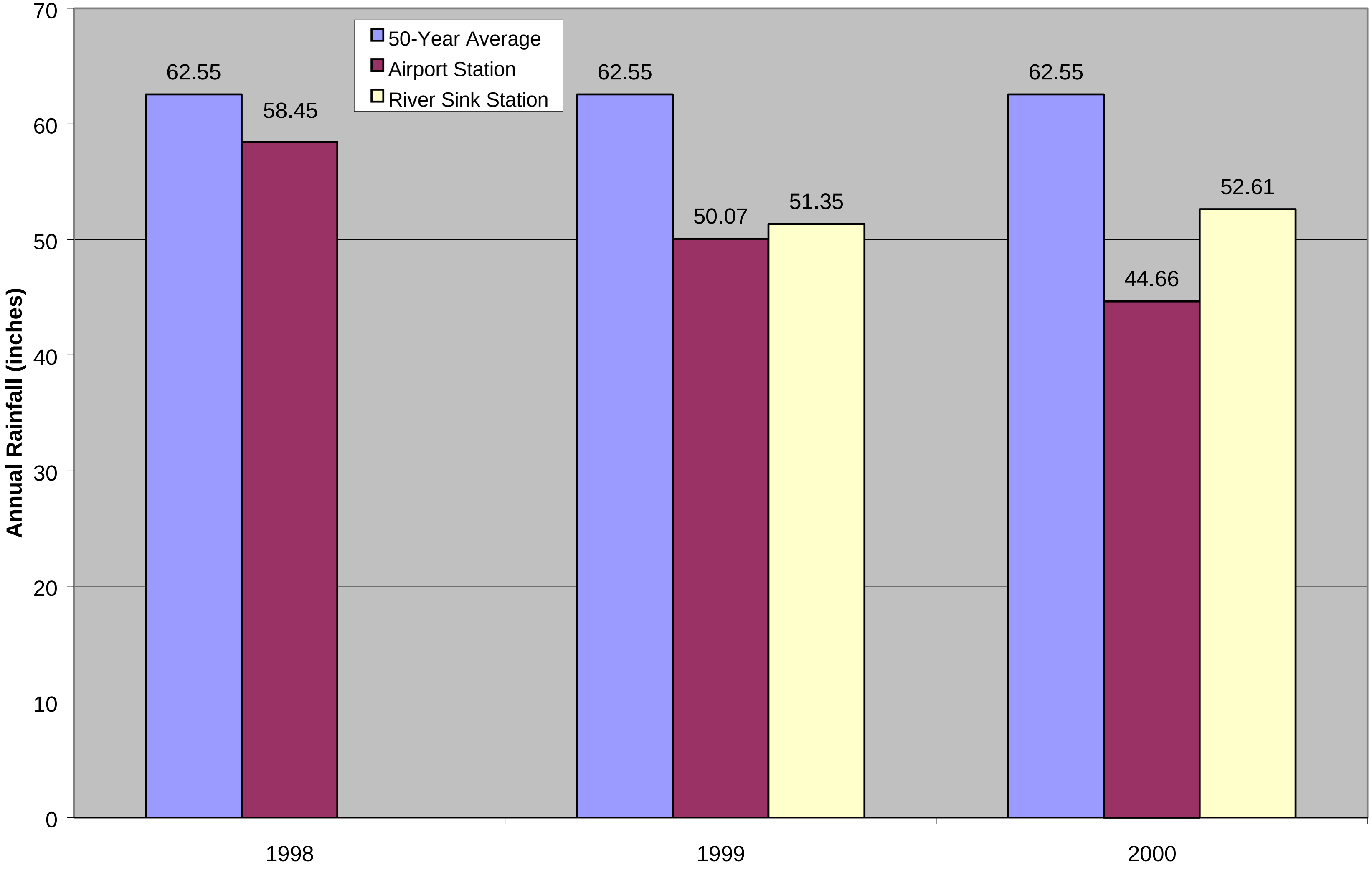


Figure 3. Annual Rainfall Deficit (1998-2000) versus 50-Year Average (1951-2000) at Tallahassee Airport.

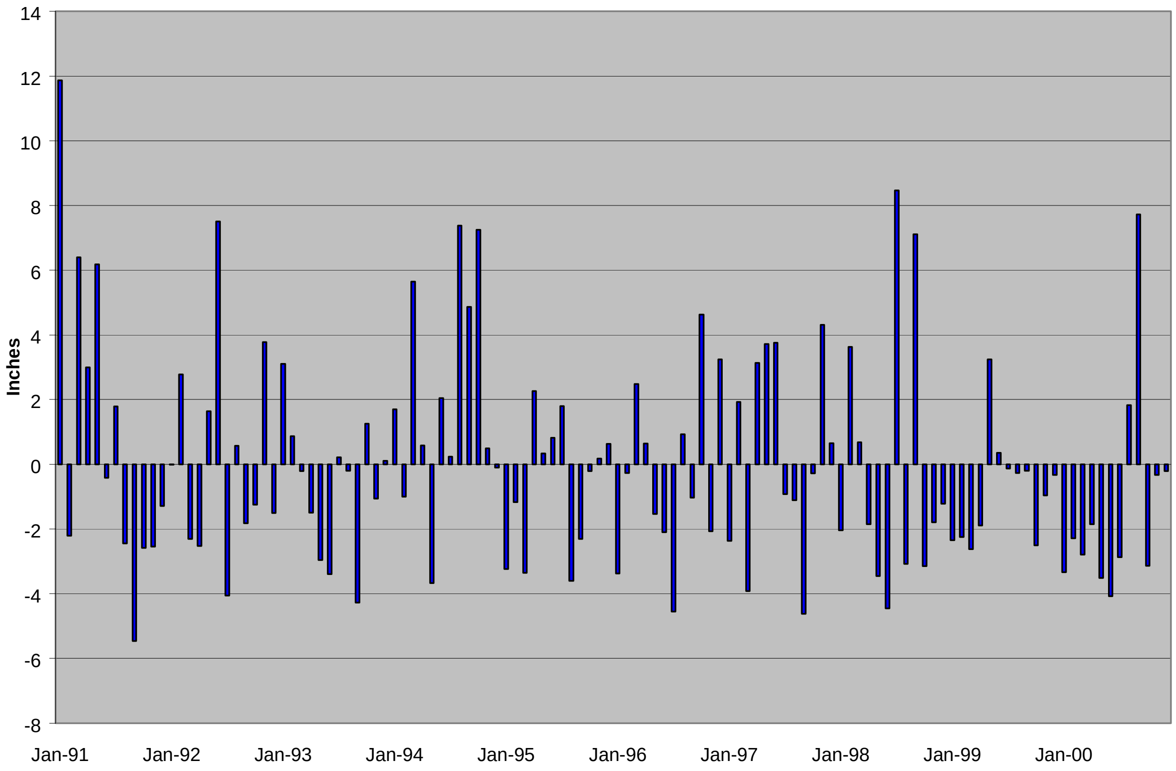


Figure 4. 1991-2000 Monthly Rainfall Deviation from Monthly Mean.

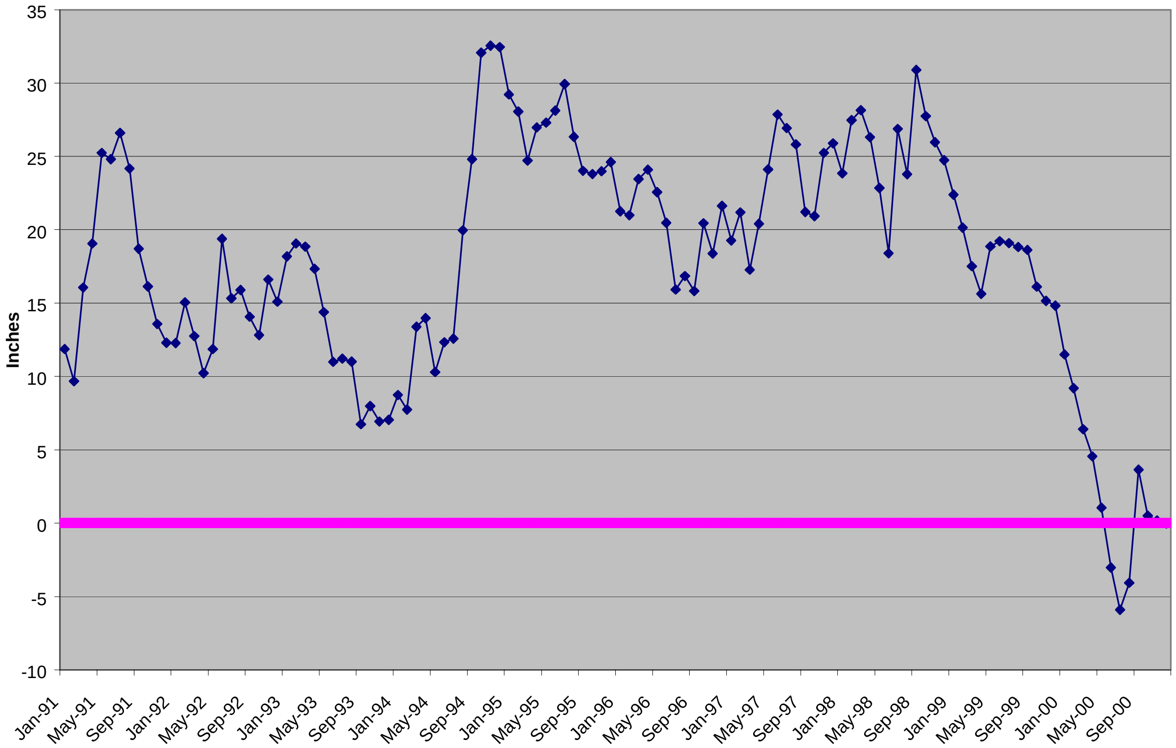


Figure 5. 1991-2000 Cumulative Deviation from Normal Rainfall.

Study period dry conditions had a profound effect on both surface and ground waters, although impacts on surface waters were most evident. Lake Jackson stood at an elevation of 86 ft (MSL) in March 1998. By May 1999, the lake had declined to 81 ft (MSL). On September 9, the lake stood at an elevation of 78.6 ft. On September 16, 1999 Porter Hole Sink drained, leaving the southern half of the lake mostly dry. During the summer of 2000, evaporation and leakage removed much of the remaining water in the northern half of the lake. Lime Sink drained during April and May 2000, leaving the lake effectively dry. The lake remained dry through the remainder of 2000 and the first half of 2001. Heavy rains associated with tropical storm Allison in June 2001 re-flooded much of the lake bottom to a depth of several feet. The lake has not experienced dry conditions for this length of time since the mid- to late 1950s.

Water levels in the Floridan and Intermediate aquifers experienced period-of-record (1966-2001) lows during the study period (Figures 6 and 7). Water levels in both aquifer systems mirror the cumulative departure from normal, rising in relatively wet periods and declining when it is dry. During the extreme dryness of 2000, ground water levels declined to elevations not see for more than 30 years, and likely not since the 1950s.

Ground Water Use in Leon and Wakulla Counties

Effectively, all of the water used for public supply, domestic, agriculture, commercial/industrial, and recreation/landscape uses comes from the Floridan Aquifer. Only in the case of power generation in Wakulla County does a substantial portion of the water use come from surface water. This water is not consumptively used, being almost entirely returned to the St. Marks River after passing through the Purdom Power Generation Station's cooling system. Tables 1 and 2 summarize the most recent water use figures for Leon and Wakulla counties, respectively. The uses are disaggregated by use classification and by source. Table 3 details public water supply use by system in each county.

Table 1. Leon County Estimated Average Ground Water Use, 1995.

Use Classification	Ground Water (Mgal/d)	Surface Water (Mgal/d)	Total (Mgal/d)
Public Supply	27.66	0.0	27.66
Self-supplied Domestic	4.61	0.0	4.61
Agriculture	1.01	0.0	1.01
Recreation/Landscape	0.95	0.0	0.95
Commercial/Industrial	0.23	0.0	0.23
Power Generation	2.64	0.0	2.64
Total	37.10	0.0	37.10

Source: Ryan, P.L., Macmillian, T.L., Pratt, T.R., Chelette, A.R., Richards, C.J., Countryman, R.A., and Marchman, G.L. District Water Supply Assessment. Northwest Florida Water Management District WRA 98-2. 1998.

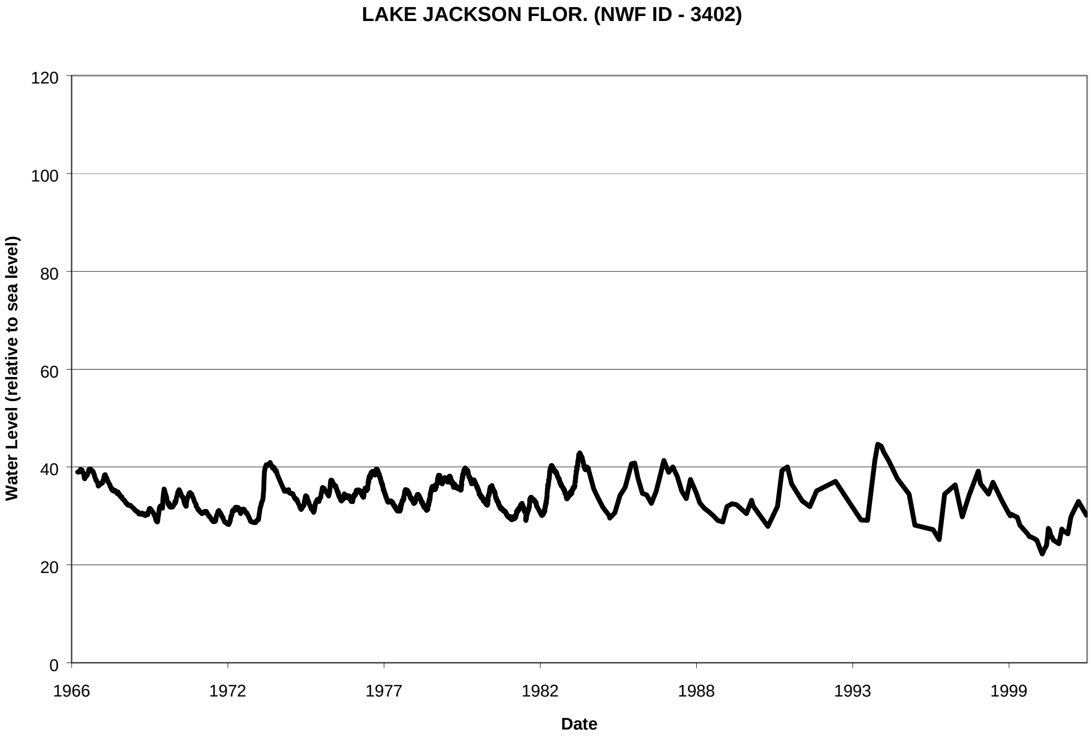


Figure 6. Hydrograph of Lake Jackson Floridan Aquifer Monitor Well, Northern Leon County. (data from USGS and NWFWMD)

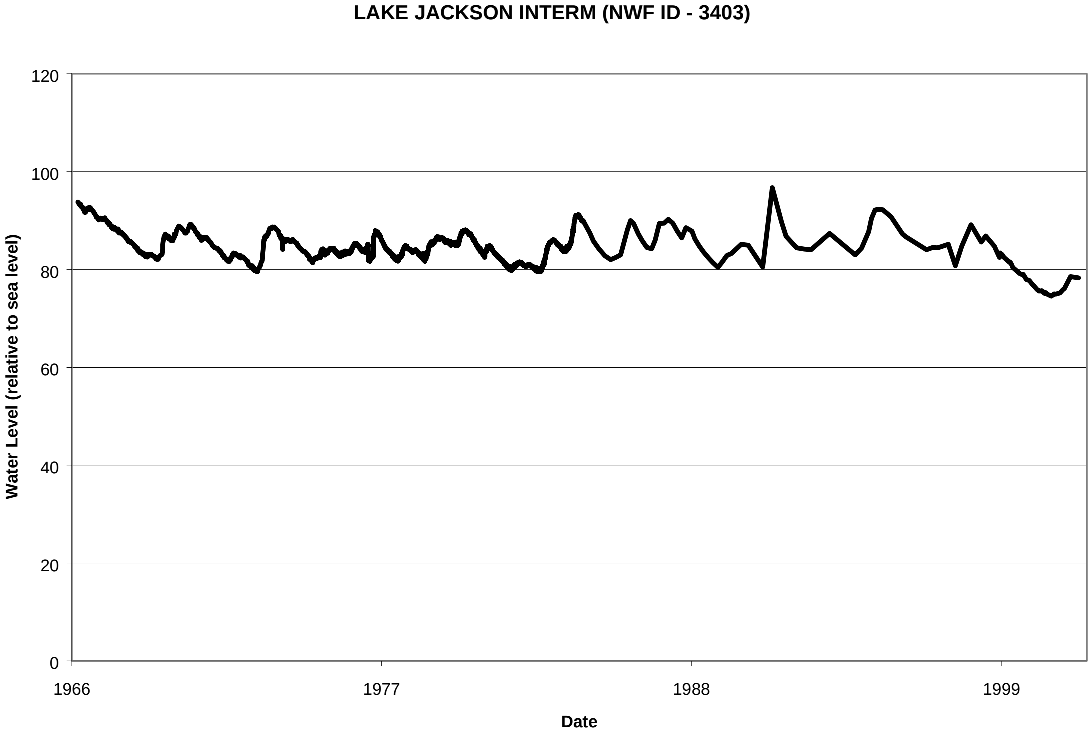


Figure 7. Hydrograph of Lake Jackson Intermediate Aquifer Monitor Well, Northern Leon County. (data from USGS and NWFWMD)

Table 2. Wakulla County Estimated Average Surface and Ground Water Use, 1995.

Use Classification	Ground Water (Mgal/d)	Surface Water (Mgal/d)	Total (Mgal/d)
Public Supply	1.05	0.0	1.05
Self-supplied Domestic	0.93	0.0	0.93
Agriculture	0.0	0.0	0.0
Recreation/Landscape	0.10	0.0	0.10
Commercial/Industrial	0.63	0.0	0.63
Power Generation	0.29	68.84*	69.13
Total	3.00	68.84*	71.84

Sources:
Ryan, P.L., Macmillan, T.L., Pratt, T.R., Chelette, A.R., Richards, C.J., Countryman, R.A., and Marchman, G.L. District Water Supply Assessment. Northwest Florida Water Management District WRA 98-2. 1998.

Marella, R.L., M.F. Mokray and M.J. Hallock-Solomon, 1998. Water Use Trends and Projections in the Northwest Florida Water Management District. U.S. Geological Survey. Open File Report 98-269, 35 pp.

*Almost all of this water is returned to the St. Marks River.

Table 3. Estimated Average Public Water Supply Use by System, 1995.

Public Supply System	Ground Water Use (Mgal/d)	Percent of Leon/Wakulla Public Supply Total
Leon County		
City of Tallahassee	25.32	88.2
TEC/Bradfordville Regional	0.79	2.8
TEC/Meadows at Woodrun	0.32	1.1
TEC/Lake Jackson	1.17	4.1
Pine Ridge Estates	0.06	0.2
Wakulla County		
TEC/Gulf Coast Water System	0.28	1.0
Panacea Area Water System	0.23	0.8
St. Marks	0.10	0.3
Sopchoppy	0.44	1.5
Total	28.71	100

Source: Ryan, P.L., Macmillan, T.L., Pratt, T.R., Chelette, A.R., Richards, C.J., Countryman, R.A., and Marchman, G.L. District Water Supply Assessment. Northwest Florida Water Management District WRA 98-2. 1998.

METHODS

Floridan Aquifer Potentiometric Surface Mapping

The focus of potentiometric surface mapping was that portion of the study area south of the Cody Scarp (in southern Leon County and eastern Wakulla County). In order to determine general flow directions within the Floridan Aquifer in this area, a network of water level monitoring wells was established. 54 wells were identified as being suitable for water level data collection (Appendix A, Table A1 and Figure 8). Wells were selected from records maintained at the District and were chosen to provide as dense a network as was reasonably practicable to monitor. Only Floridan Aquifer wells were included in the water level monitoring effort. Given the flatness of the potentiometric surface, wellhead and land surface elevations were established by survey (NGVD) for all wells included on the potentiometric surface maps. All wells that had not previously been surveyed were instrument leveled to an accuracy of ±0.1 ft. Previous potentiometric surface mapping efforts in this area have been based (predominantly) on elevations estimated from topographic maps. Horizontal locations were determined using differential GPS location techniques.

Drilling

Six Floridan Aquifer monitor wells were constructed as a part of this project. Wells were constructed in three pairs. At each site a deep well and a shallow well were constructed. All wells were constructed using flush-threaded PVC well casing and were grouted with neat cement grout. All were constructed using conventional hydraulic rotary drilling techniques. Well locations and other construction details are found in Appendix A, Table A1.

Ground and Surface Water Sampling

A second network of 41 Floridan Aquifer wells was established for the purpose of ground water sampling (Appendix A, Table A2 and Figure 9). 35 were pre-existing domestic supply, public supply and irrigation wells. The remaining six were constructed specifically for the project. In addition, surface water samples were collected at seven sites (Lost Creek, Fisher Creek, Ames Sink, Middle River Sink, Sally Ward Spring, Wakulla Springs and McBride Slough). Samples were collected by USGS and NWFWMD personnel and were analyzed for major ions, nutrients, silica, DOC and isotopes. Sample collection protocols and analytical methods are discussed in greater detail in Katz et al. (in preparation). The USGS Water Quality and Research Laboratory in Ocala, FL analyzed major ions. The USGS Isotope Fractionation Laboratory in Reston, VA, analyzed O, H and N isotopes. Carbon isotope analyses were performed at the University of Waterloo. Tritium and ^{3}He analyses were performed at the Noble Gas Laboratory of the Lamont-Dougherty Earth Observatory in Palisades, NY.

Ground and surface water sampling was conducted in several mobilizations. Results from the initial ground water sampling were used to guide location selection for the six monitor wells constructed for the project. Once these wells were completed, isotopic sampling was conducted in them and at Middle River Sink and Wakulla Springs. Analyses for this event include $^{15}N/^{14}N$; $^{18}O/^{16}O$; D/H; $^{13}C/^{12}C$; and $^{3}H/^{3}He$. A key project objective was to conduct isotopic sampling under low-flow and high-flow conditions. The first isotopic sampling occurred in February 2000 and is considered to represent the low-flow condition. Due to drought conditions that persisted through 2000, it was only following Tropical Storm Helene in September 2000 that conditions were appropriate for high-flow sampling. The project wells, Middle River Sink and Wakulla Springs were sampled again in October 2000 for that purpose.

Nitrogen isotope data gathered to establish the ratio of organic to inorganic nitrogen in the samples were inconclusive for four wells. This was due to nitrate concentrations being below detection limits. Due to this, four alternate wells with elevated nitrate concentrations were selected for additional sampling. These wells were sampled on April 25, 2001.

Surface Water Monitoring

The study plan included collection of continuous hydrologic data to help characterize the dynamics of the hydrologic cycle and the interaction between surface water and ground water resources in the study area. The automated monitoring equipment utilized on the project included an automated rainfall station, a current meter (water velocity) and in-situ water-quality data-sonde meters (water temperature and conductivity). Continuous streamflow monitoring was beyond the scope of the project. Site locations are shown in Figure 10.

Rainfall

An automated rainfall station was established at a central location in Wakulla County (at the River Sink Water Tower located on Highway 319 near the intersection with SR 267 (30°16‘38”/ 84°21’22” NAD27). The station consisted of a rainfall tipping bucket sensor and a data logger, which recorded rainfall data on a ten-minute time interval. The tipping bucket rain gage includes a funnel and a tipping mechanism. Rainfall passes through the funnel onto the tipping mechanism which causes a switch contact closure for each 0.01 inches of accumulated rainfall. The data logger stores the number of tips and records the accumulated rainfall depth. The tipping bucket has an accuracy of ± 2 percent for rainfall rates of less than 1 inch per hour and ± 3 percent for rates above 1 inch per hour. The station was visited each month to retrieve data, perform routine maintenance and insure proper functioning. Annual field calibrations were performed to insure sensor accuracy. The station was installed in May 15, 1999.

Rainfall data was also utilized from two long-term rainfall stations located in Leon County. These included a station operated by NWFWMD located near Lake Munson in southern Leon County and data collected by the National Weather Service at the Tallahassee Regional Airport.

Current Meter

The NWFWMD operates and maintains a self-contained electro-magnetic current meter in the main spring vent of Wakulla Springs. InterOcean Systems, Inc manufactured the meter (S4 model). It has the capability to continuously measure and record velocity and direction components of water movement, water temperature and conductivity. The meter is installed in the main discharge tunnel (A-tunnel) at a depth of approximately 190 ft below the surface of the spring. The meter was installed in May 1997. The geometry of the vent opening has been measured (Figure 11) and the opening area used, with the velocity data and a calibration factor, to calculate continuous discharge data.

The current meter is a ten-inch diameter sphere with four electro-magnetic sensors located symmetrically around the central axis of the sensor. The meter has an internal compass to provide directional information with the velocity data. Conductivity and temperature sensors are also located along the center axis of the meter. The current meter collects data on a three-hour

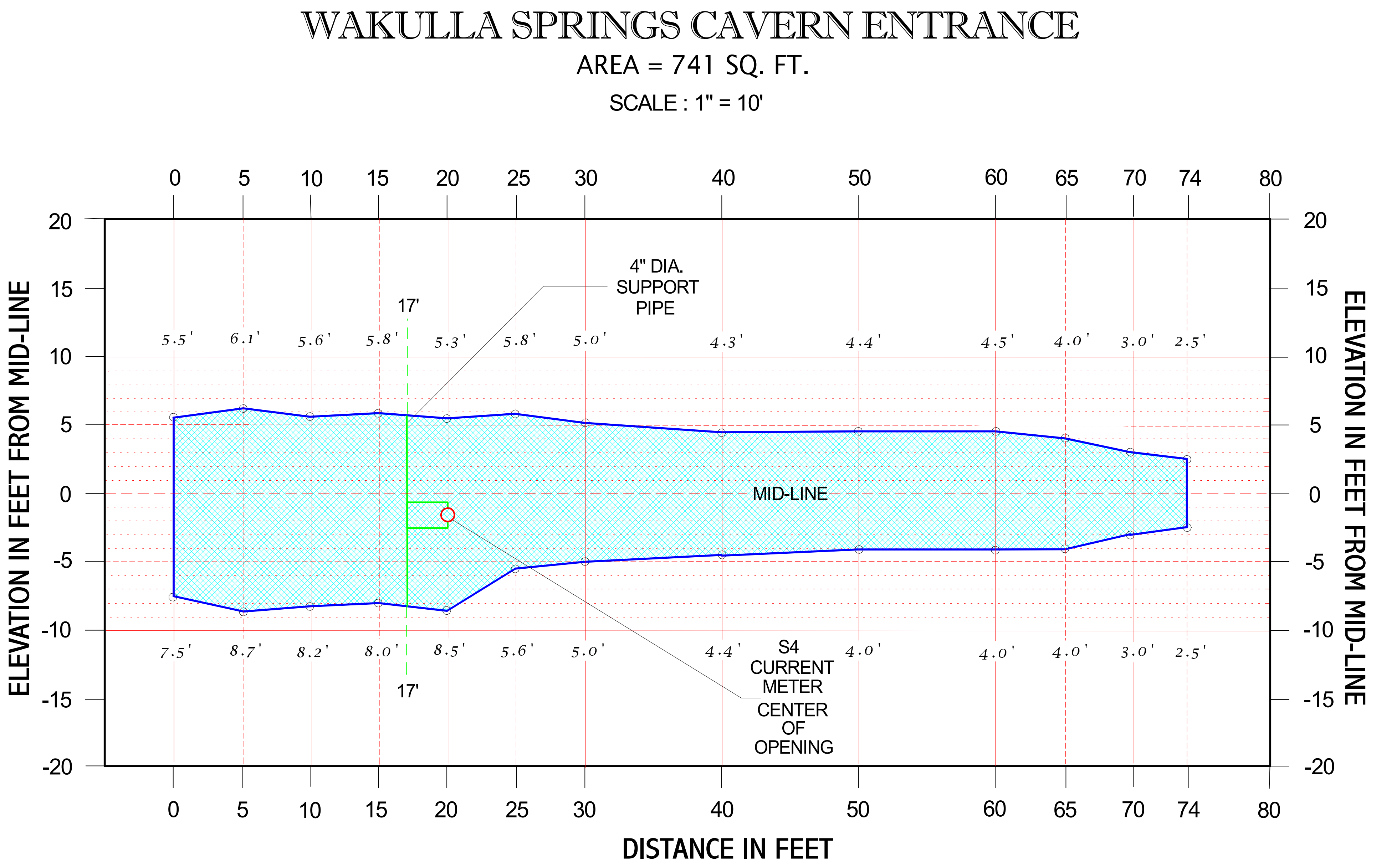


FIGURE 11
CROSS-SECTION OF WAKULLA SPRINGS PRINCIPLE CONDUIT SHOWING S4 EMPLACEMENT

recording cycle and stores it internally. The meter is brought to the surface every eight to twelve months to retrieve data and service the meter.

The meter is installed in the center of a limestone constriction at the mouth of the main spring vent (Figure 11). The mooring system consists of telescoping aluminum pipes that extend between the roof and floor of the spring vent. Two arms extend from the side of the aluminum pipes to support the meter. The mooring system was designed to minimize disturbance of the spring flow, prevent damage to the limestone surfaces of the spring vent opening and facilitate easy removal and installation of the current meter. The cross-sectional area of the conduit at the point where the meter is installed is 741 ft^2.

Main vent discharge has been estimated as the product of observed point velocity in A-tunnel and A-tunnel cross-sectional area at the point of velocity measurement. These estimates have been verified with five conventional channel discharge measurements at the CR 365 bridge and the other three major inflows (Sally Ward Spring and two McBrides Slough inflows) that discharge to the river above the CR 365 bridge. The conventional channel discharge measurements were completed during one-day measuring events. A variable time lag was assumed between the main vent and the CR 365 bridge based on a distance of 2.75 miles and an average channel velocity for the measuring period. Discharges from Sally Ward Spring and the McBrides Slough inflow were subtracted from the Wakulla River discharge at CR 365 to approximate discharge from the main vent. Discharge from small springs and seeps along the river was estimated to contribute little to the total river flow and were excluded. Observed main vent discharge versus calculated discharge is given in Figure 12.

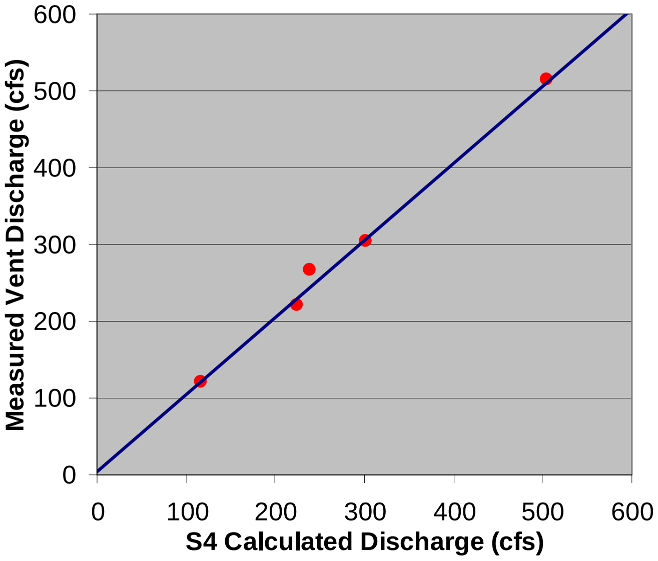


Figure 12. Wakulla Springs Main Vent Measured Discharge versus Calculated Discharge.

In-situ Water Quality Meters

Self-contained water quality data loggers were installed at six locations (stations 1—6 below, Figure 10) to continuously measure surface water conductivity and temperature. The water quality data loggers were programmed to collect data on an hourly time interval at the six stations. The station locations are described below. Three stations, Middle River Sink Spring, Wakulla Springs and Spring Creek #2 had moving water for the entirety of their respective data collection periods. Due to drought conditions, Fisher Creek, Lost Creek and Ames Sink intermittently had conditions of very low to zero flow. However, there was continuous standing water at each of these sites. Time series data for these stations should be evaluated with this in mind. Continuous mean daily flow data for Lost Creek during 1999 and 2000 were obtained from the USGS and are presented later in this report. Collection of continuous stream flow data at Fisher Creek Sink and Ames Sink was beyond the scope of this investigation.

1. Fisher Creek Sink at Leon Sink Geological Area—Fisher Creek is a black-water stream that originates in the Apalachicola National Forest. Fisher Creek disappears underground and re-emerges at several locations along its length below the Springhill Road Bridge. The meter was installed on a walkway in a six-inch diameter PVC support pipe at the point where Fisher Creek disappears underground for the last time (30°18'35.115"/84°21'22.783" NAD83).

2. Ames Sink—Ames Sink is located about eight miles south of Tallahassee and funnels water from Munson Slough underground as it flows south. The meter was installed in a six-inch diameter PVC pipe mounted on the SW bank of the sink near the inflow channel into the sink (30°19'08.859"/84°17'54.916" NAD83).

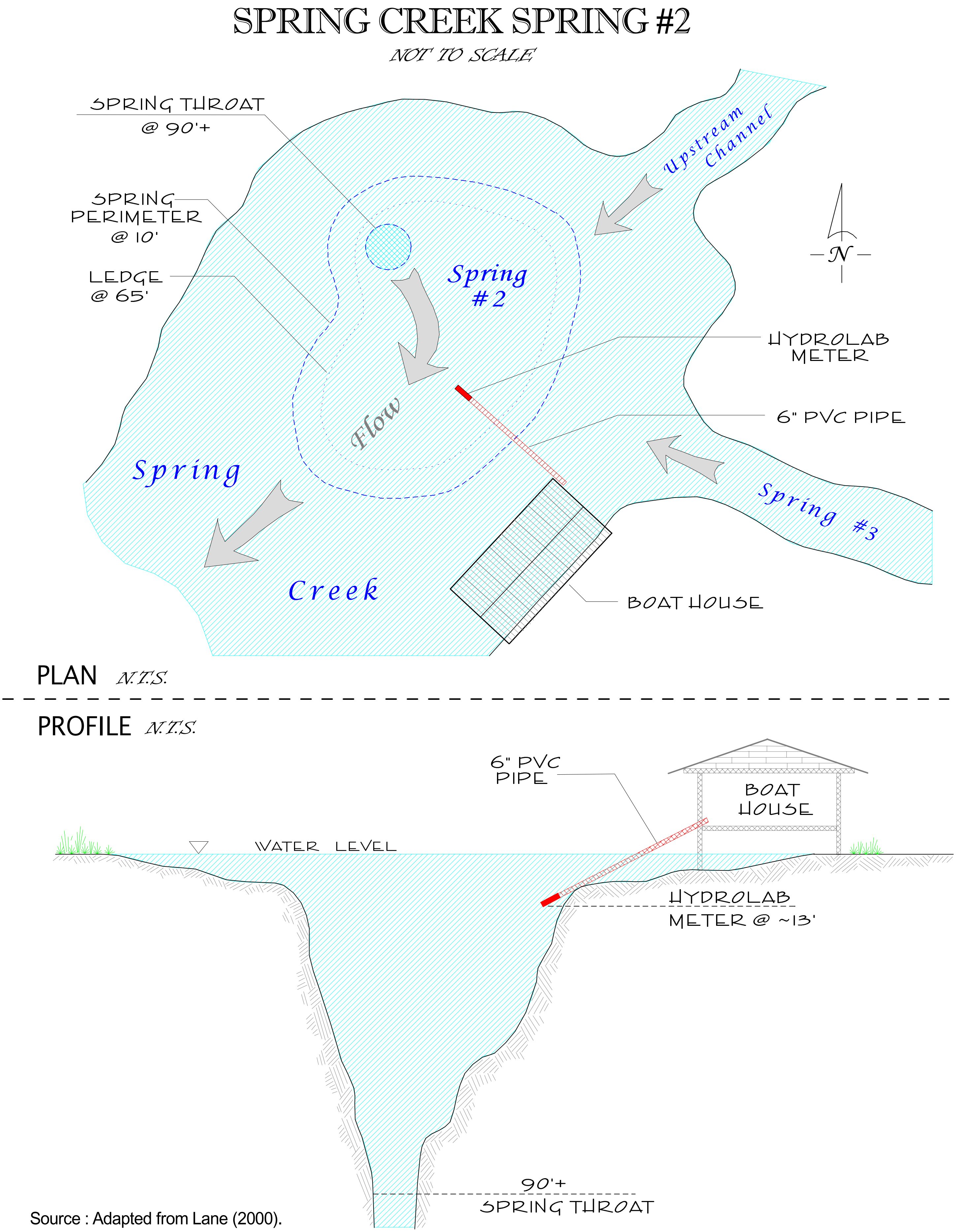
3. Lost Creek below FR 13—Lost Creek is a black-water stream originating in the Apalachicola National Forest. The creek meanders through the forest before disappearing underground south of Crawfordville. The meter was installed in a six-inch PVC pipe extending into the creek about 0.5 miles upstream from the point where it flows underground (30°10'33.014"/ 84°24'00.696" NAD83).

4. Wakulla River at Boat Dock—The Wakulla River begins at a basin created by the main Wakulla Spring vent located at the Wakulla Springs State Park. The meter was installed on a concrete slab, with a vertical support pipe, below the tour boat dock located about 500 feet downstream of the main spring vent (30°14'08.381"/84°18'05.199" NAD83).

5. Spring Creek Vent #2—Spring Creek Vent #2 is one of several springs that discharge into the estuary near the Spring Creek community. The meter was installed in a six-inch diameter pipe on the upper edge of the sink in the path of the spring flow (Figure 13). The meter was installed in about 13 feet of water (30°04'53.687"/84°19'47.141" NAD83). A schematic representation of the geometry of Spring Creek Vent #2 sink and pool is also given in Figure 13. This figure is adapted from Lane (2001). Lane also gives a map depicting the location of the 13 mapped vents in the Spring Creek group.

Specific conductivity versus time data for this station is given in Figure 14. These data show that, for most of the data collection period, the conductivity at the measurement point was rarely less than 2,000 µmhos/cm. Specific conductivity values daily ranged between about 2,000 µmhos/cm to well in excess of 9,000 µmhos/cm, apparently reflecting the mixing of saline surface water with fresher ground water discharge within the spring pool itself. Only once were waters in the spring pool consistent with what should be expected for Floridan Aquifer water uncontaminated by saline surface water. This occurred for about a week in early November 1999 following heavy rains associated with Hurricane Floyd.

6. River Sink Group—The River Sink area is a series of sinks and karst features in northern Wakulla County. The meter was installed on a concrete slab, with a vertical support pipe, in



Source : Adapted from Lane (2000).

FIGURE 13

CROSS-SECTION OF SPRING CREEK VENT #2 SHOWING HYDROLAB EMPLACEMENT

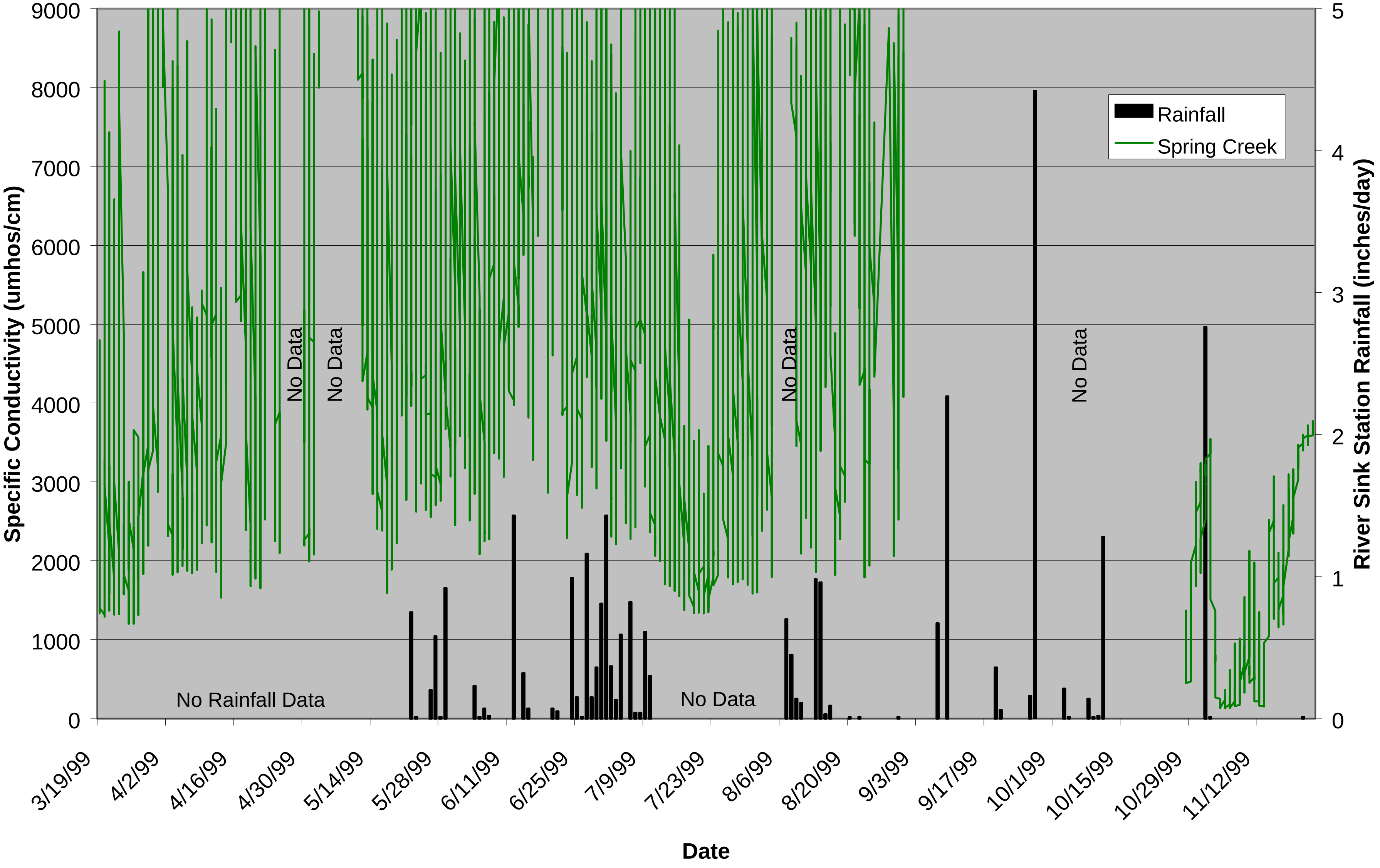


Figure 14. Specific Conductivity and Rainfall versus Time for Spring Creek Vent #2, 1999.

7. the center of a section of collapsed conduit where ground water emerges to create a stream that flows about 200 feet before disappearing underground into a sink (30°16’36.24” 84°20’27.396” NAD83).

Data from three additional stations (Figure 10) were also used in this investigation.

8. USGS Lost Creek Gaging Station—The USGS maintains a continuous stream flow gaging station on Lost Creek. The station is located on the downstream side of the Highway 368 bridge, 0.5 miles east of Arran (30°11‘17”/84°24’30” NAD27). This station is located about 1.8 miles north (linearly) of the point where Lost Creek goes underground and about one mile (linearly) above the NWFWMD water quality data logger site (station #3 above).

Continuous daily mean flow versus conductivity data from the NWFWMD Lost Creek station are given in Figure 15, for the period 3/99 to 11/00. For most of this period, conductivities range between 40 to 70 µmhos/cm. During three low-flow periods (04/99 to 06/99, 12/99, and 04/00 to 08/00) surface water conductivities rose to as high as 200 µmhos/cm. Conductivities this high appear to reflect base flow discharge from the Floridan Aquifer into Lost Creek. Along the lower reach of Lost Creek, Floridan Aquifer heads are above stream channel elevations. Accordingly, it is quite plausible that Floridan Aquifer waters are discharging to the channel above the point where Lost Creek goes underground.

9. USGS St. Marks River Gaging Station—The USGS maintains a continuous streamflow gaging station on the St. Marks River about 0.65 miles below the St. Marks River rise. The station is located on the east bank of the river, about 0.4 miles south of the Leon/Wakulla county line (30°16‘00”/84°09’00” NAD27).

10. Munson Slough north of Lake Munson (S3)—The NWFWMD maintains a continuous stream flow station on Munson Slough. The station is located at the point where Munson Slough crosses under Highway 319 (30°23‘14”/84°18’49” NAD27). This station is located about 0.95 mile north of Lake Munson and about 5.24 miles north of the continuous recording water quality logger in Ames Sink (station #2).

Continuous daily mean flow (station #9) versus conductivity data from the Ames Sink hydrolab station (station #2) are given in Figure 16, for the period 3/99 to 9/00. For most of this period, conductivities range between 57 and 261 µmhos/cm. During relatively dry periods surface water conductivities rose. High conductivities within Ames Sink may reflect re-circulation of Floridan Aquifer water into the sink or discharge of Floridan Aquifer water into lower Munson Slough during periods of minimal surface water inflow.

Four sites had meters installed within six-inch diameter PVC support pipes. For these stations PVC support pipes were installed to protect the meters. Each pipe had vent holes drilled around the perimeter of the pipe to ensure good water flow around the sensors. Two stations were installed on concrete anchor slabs having two-inch diameter PVC support pipes vertically mounted in the center. The two-inch diameter support pipe extended about three feet above the channel bottom. Water quality meters were installed on the two-inch vertical support pipe within the water column.

The water quality meter stations were visited monthly to retrieve data and re-calibrate the meters. The sensor arrays were cleaned monthly and the meters were monthly re-calibrated using appropriate conductivity calibration standards. The temperature probes were monthly

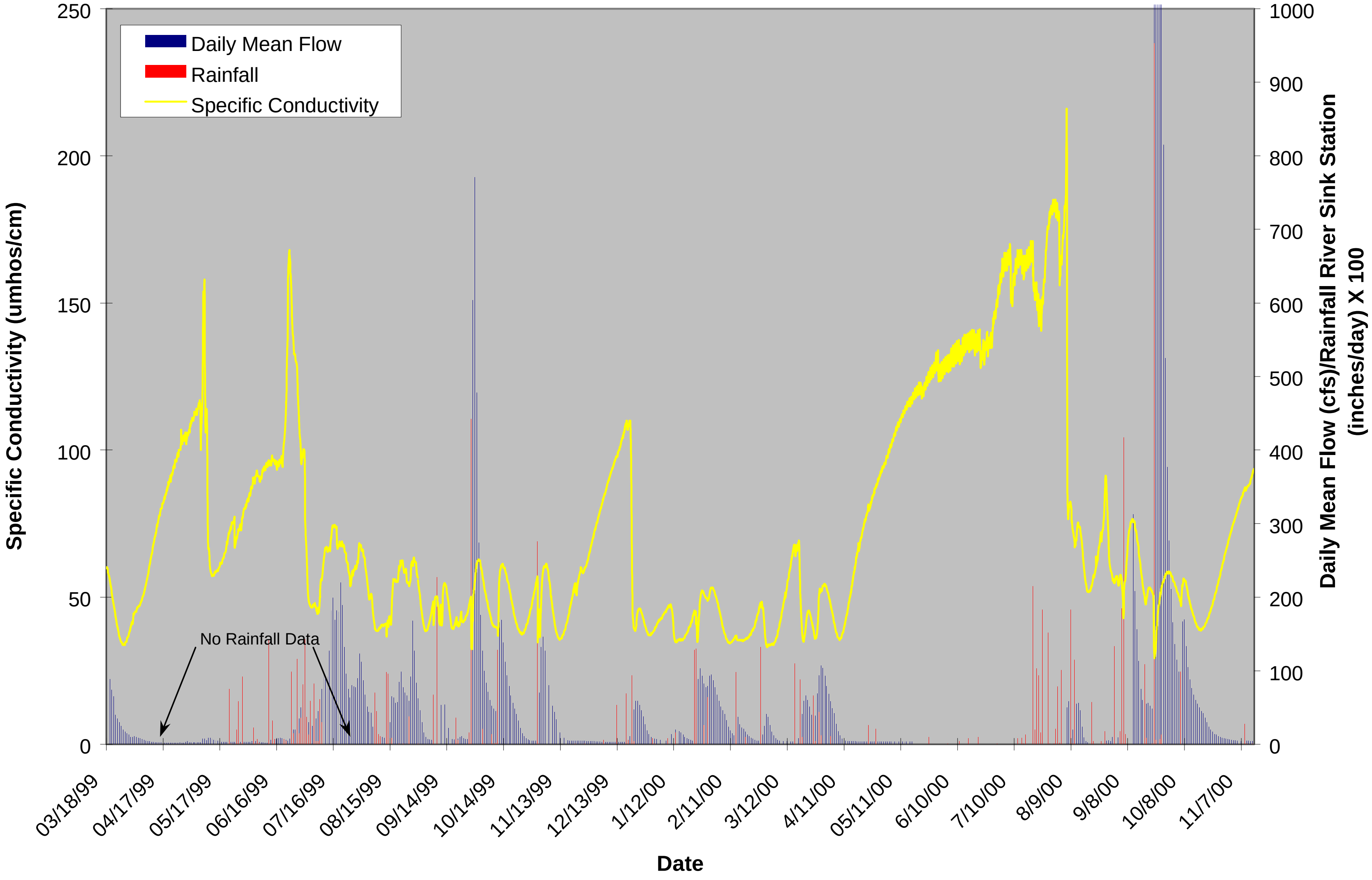


Figure 15. Lost Creek Specific Conductivity, Rainfall and Daily Mean Flow versus Time (flow data from USGS).

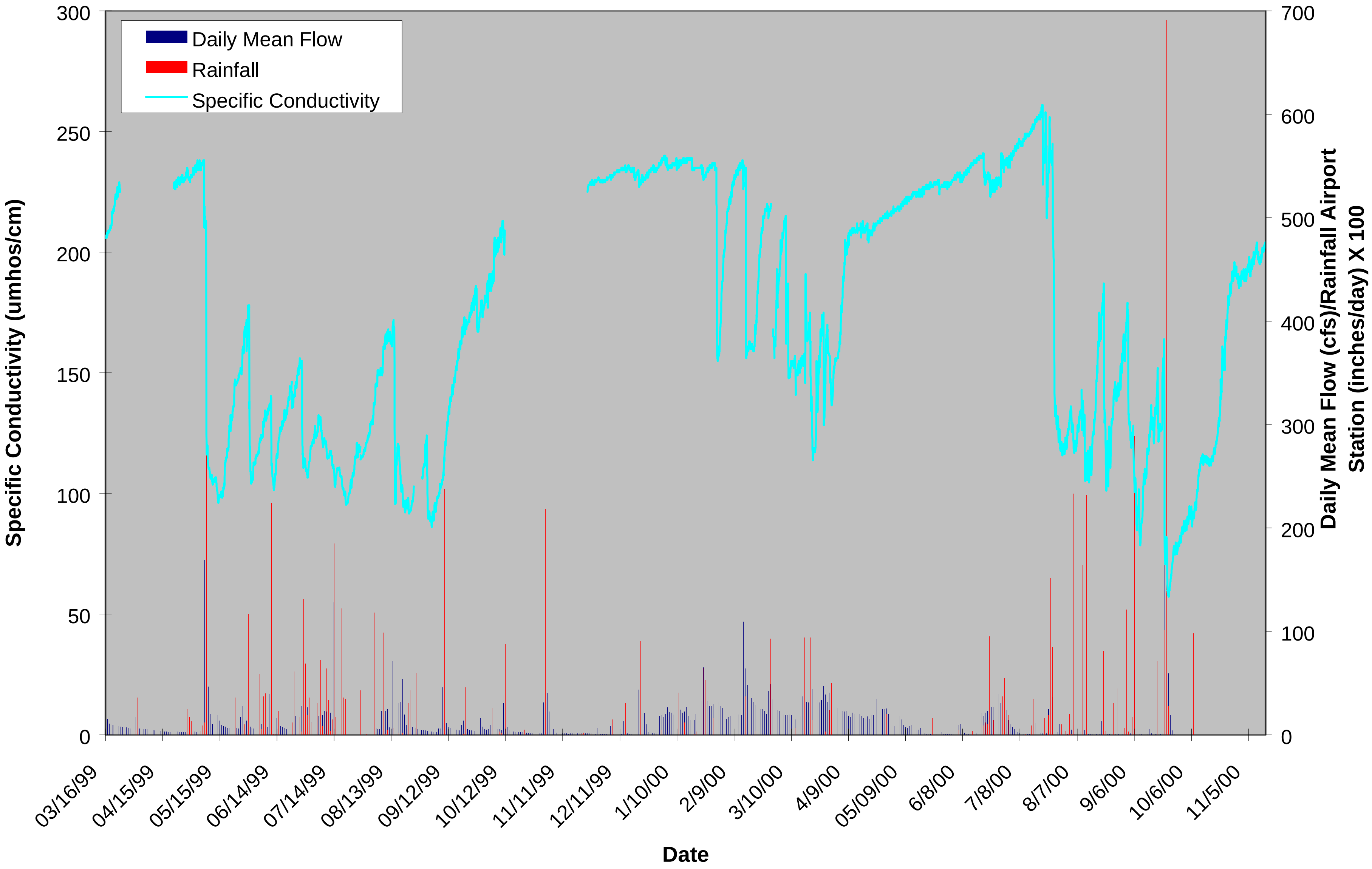


Figure 16. Ames Sink Specific Conductivity, Rainfall and Munson Slough @ Highway 319 Daily Mean Flow versus Time.

calibrated to an external thermometer reading. The meters experienced minimal sensor fouling at all six locations throughout the data collection period. They also experienced minimal drift with respect to both temperature and conductivity. Calibration adjustments for temperature ranged from 0.01 to 4.86 degree Celsius with an average adjustment of 0.35 degrees. The adjustments required for conductivity ranged from zero to 29 μmhos/cm with an average of 6.1 μmhos/cm.

Temperature readings from the hydrolabs under identical conditions were compared once to assure data consistency. Results are as follows:

Fisher Creek @ Leon Sink	Serial #15588	19.6°C
Ames Sink	#15591	19.8°C
Lost Creek below FR13	#18253	19.4°C
Middle River Sink Spring	#15589	19.8°C
External thermometer reading		19.7°C

HYDROLOGY OF THE ST. MARKS-WAKULLA RIVERS WATERSHED

Physiography and Geology

The study area principally lies within the Tallahassee Hills and the Gulf Coastal Lowlands physiographic divisions (Figure 17). The northern two-thirds of Leon County lie within the Tallahassee Hills. The southern third of Leon County and all of Wakulla County lie within the Gulf Coastal Lowlands. The northern portion of Jefferson County lies in the Tallahassee Hills, the southern portion in the coastal lowlands. Elevations in the Tallahassee Hills are quite variable, being as high as 250 ft above sea level and as low as 50 ft above sea level. Elevations on the Gulf Coastal Lowlands are much more uniform and lower, being generally less than 50 ft above sea level.

The Cody Scarp divides these two physiographic divisions and is defined by a fairly abrupt decrease in elevation from the Tallahassee Hills onto the coastal lowlands (Figure 17). It is most evident in eastern Leon County. In the western part of the county, the break in topography is more gentle and the scarp more difficult to map. It represents the landward edge of a transgressional marine erosion event.

South of the Tallahassee Hills, the Woodville Karst Plain forms a subdivision of the Gulf Coastal Lowlands. The Woodville Karst Plain lies in southeast Leon County and eastern Wakulla County. It is an erosional surface bounded on the north by the Cody Scarp and on the west by a second, lower scarp (Figure 17). Land surface elevations on the Woodville Karst Plain are low, rarely more than 50 ft above sea level. The overlying confining units have been stripped away by sea level fluctuations, leaving only a thin veneer of unconsolidated sediments covering the St. Marks Formation. Sinkholes, shallow closed depressions, cenotes, springs, other karst landforms, and an almost complete lack of surface streams dominate the landscape.

Most of the Tallahassee Hills in Leon County lie within one of four large closed lake basins (Figure 18). These are the Lake Iamonia, Lake Jackson, Lake Lafayette and Lake Miccosukee basins. The basins within which Lakes Jackson and Iamonia lie were originally tributary to the Ochlockonee River. Erosion improved the hydraulic connection to the underlying Floridan Aquifer to the point where the drainage became internal and the basins closed. Lake Jackson is effectively completely closed. Lake Iamonia is still hydraulically connected to the Ochlockonee River floodplain under high flow conditions. Under low flow conditions, it is a closed basin. Both lakes have active sinkholes in their beds.

Similarly, Lakes Lafayette and Miccosukee were originally tributary to the St. Marks River. Erosion and internal drainage have more or less closed both of these basins. An intermittent overland hydraulic connect exists between the Lake Lafayette basin and the St. Marks River floodplain. The Lake Miccosukee basin is effectively completely closed by a system of sinks that capture any outflow along the relic stream channel. These include Lake Drain sink and Creek sink. Both lakes have active sinks in their beds as well.

Smaller closed basins lying in the Tallahassee Hills include the Fred George basin draining to Fred George sink, the Patty Sink basin, and the Black Creek basin draining to Bird and Copeland sinks. The Lake Munson basin lies on both the Tallahassee Hills and on the Gulf Coastal Lowlands. Surface waters originating in the Lake Munson basin flow south onto the coastal lowlands, through Lake Munson and eventually drain underground at Ames Sink.

The Tallahassee Hills are underlain by (in descending order) the Miccosukee Formation, the Torreya Formation of the Hawthorn Group, the St. Marks Formation, the Suwannee Limestone and older, more deeply lying units. Hendry and Sproul (1966) first described the geology of Leon County. Scott (1988) describes the lithostratigraphy of the Hawthorn Group in Florida, including Leon County. The Hawthorn Group is absent in southeast Leon County and eastern Wakulla County, having been removed by the marine transgression that formed the Cody Scarp. Within the Tallahassee Hills the Miccosukee Formation is limited to the higher elevations found on inter-stream divides (Figures 19 and 20). Elsewhere, it has been removed by erosion. The Torreya Formation is near the surface along lower elevations within the Tallahassee Hills. These include the many stream channels that dissect the hills and in the bottoms of the large lakes that dot the landscape. Torreya Formation is frequently seen in scoured stream channels and drainage ditches found throughout Tallahassee and the surrounding urbanized area. Lying immediately south of the Tallahassee Hills, fairly thick deposits of undifferentiated sand mantle the northern edge of the Gulf Coastal Lowlands. These consist of relict beach and dune deposits. One portion of this sequence is known as the Lake Munson Hills.

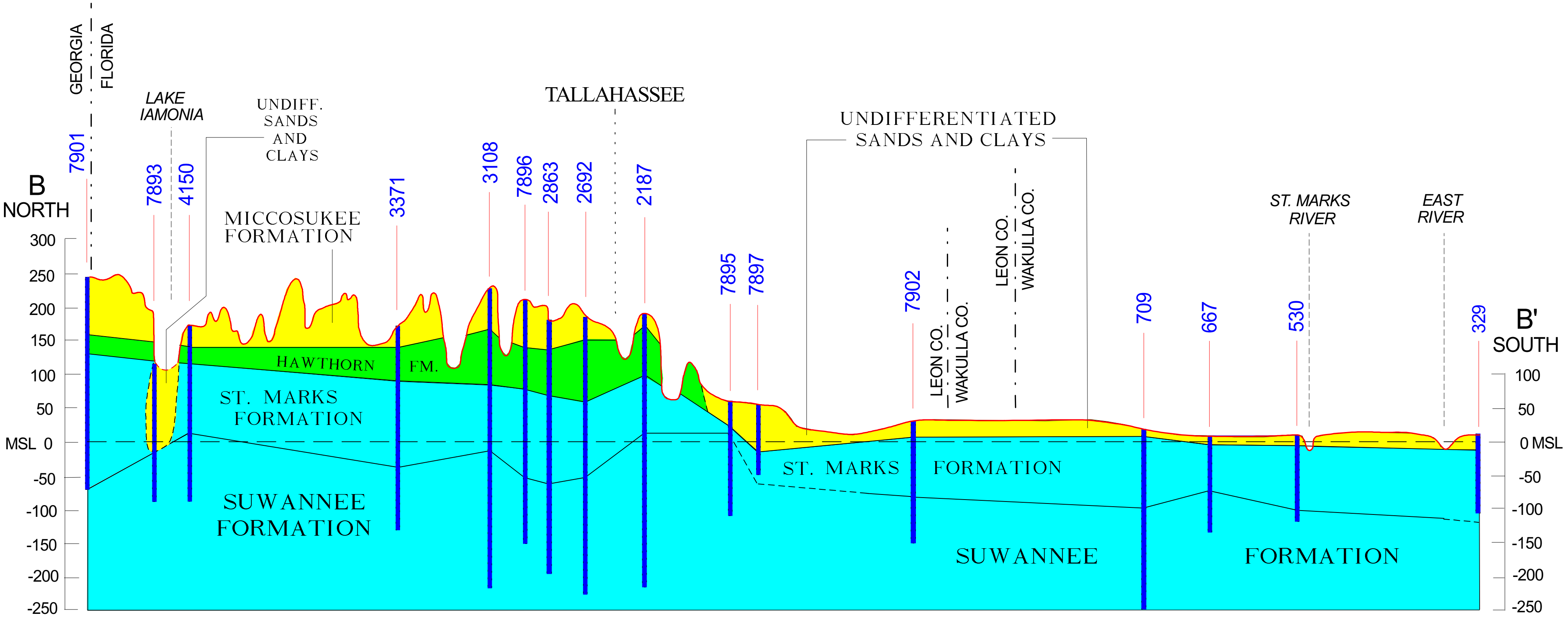
Undifferentiated sands, Jackson Bluff Formation, Intracoastal Formation, Torreya Formation, St. Marks Formation, Suwannee Limestone and older, more deeply lying units underlie the Gulf Coastal Lowlands south of the Tallahassee Hills. Rupert and Spencer (1988) describe the geology of Wakulla County. The area of occurrence of the Intracoastal and Torreya Formations is limited to approximately the western half of the county (Figure 21). The relatively low hydraulic conductivity of the Intracoastal and Torreya formations hydraulically isolates the surficial sands from the underlying Floridan Aquifer. Given the flatness of the terrain, the thinness of the surficial sands and the low permeability of the underlying sediments, broad expanses of wet pine flatwoods dominate the landscape. The Ochlockonee River and Fisher, Black and Lost creeks drain these flatwoods. Fisher, Black and Lost creeks flow from west to east. Once they encounter the western edge of the Woodville Karst Plain, they disappear underground. Their waters drain either to Wakulla Springs or to the Gulf of Mexico. On the karst plain itself, the stratigraphy consists of the thin veneer of sands lying directly on top of the St. Marks and older formations (Figures 20 and 21).

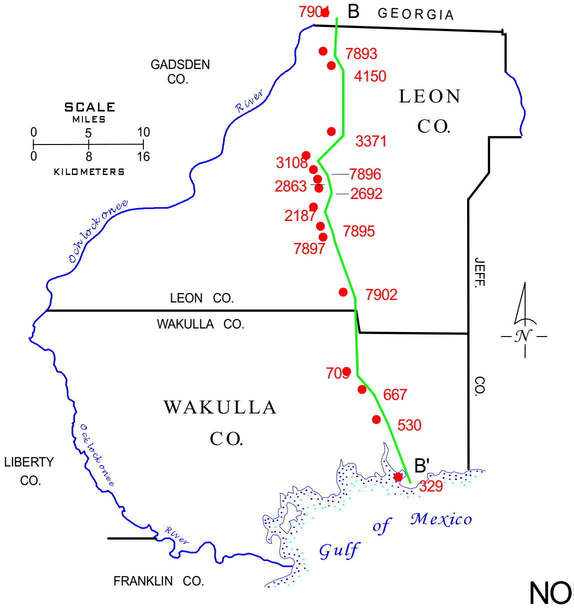
Hydrology of the Floridan Aquifer

The work of Davis (1996) provides a comprehensive overview of the Floridan Aquifer flow system beneath Leon and Wakulla counties. Davis calibrated and applied a Floridan Aquifer flow model to a large study area in southwest Georgia and north Florida (including Leon and Wakulla counties). Based on potentiometric surface mapping, Davis defined an approximate recharge area for the coastal Wakulla County discharge features (Wakulla Springs, Spring Creek, lower St. Marks River and other submerged lands beneath the Gulf of Mexico). That area includes all or portions of Leon, Gadsden and Jefferson counties in Florida and Thomas, Grady, Colquitt, Mitchell and Decatur counties in Georgia. The Florida portion of this area is delineated in Figure 1. In both Georgia and Florida the total recharge area for these features is about 2,200 mi^2.

As a part of his conceptual model development, Davis divided Leon County into three areas: unconfined where the Floridan Aquifer is near land surface; unconfined where the Floridan Aquifer is overlain but not confined by low-permeability sediments; and confined. The first two of these areas generally correspond to areas identified as unconfined and semi-confined, respectively, in Figure 1. In Wakulla County, Davis conceptualized the Floridan Aquifer as being either unconfined and near land surface, or confined. Davis' unconfined area generally

GEOLOGIC CROSS-SECTION B-B' IN LEON AND WAKULLA COUNTIES





Source : Wakulla County - After Rupert and Spencer,
Bulletin 60, Florida Geological Survey, 1988.
Leon County - After Hendry and Sproul,
Bulletin 47, Florida Geological Survey, 1966.

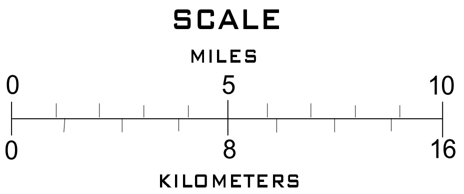
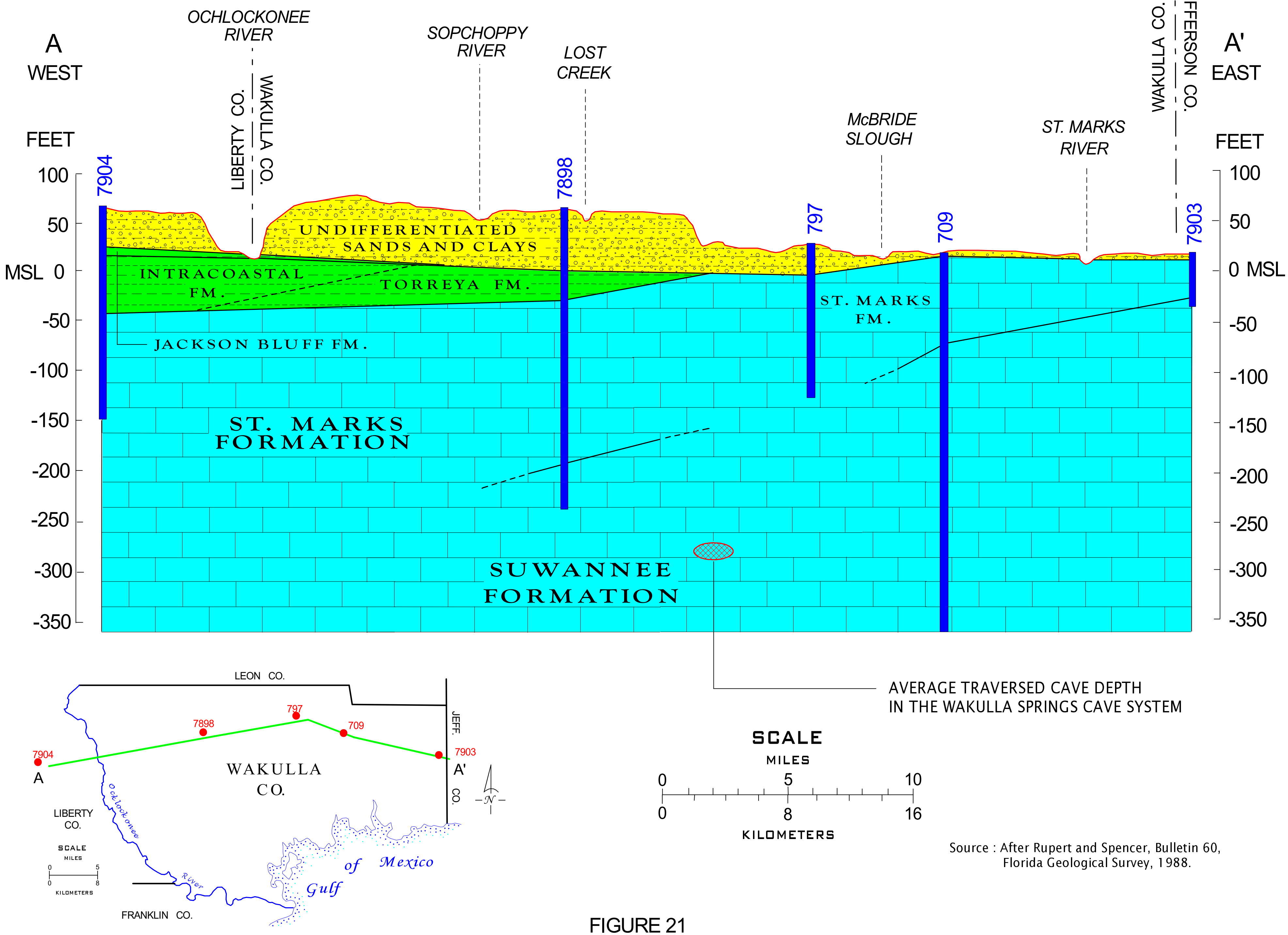


FIGURE 20
NORTH-SOUTH HYDROGEOLOGIC CROSS-SECTION

GEOLOGIC CROSS-SECTION A-A' IN WAKULLA COUNTY



Source : After Rupert and Spencer, Bulletin 60, Florida Geological Survey, 1988.

FIGURE 21
EAST-WEST HYDROGEOLOGIC CROSS-SECTION

corresponds to what is mapped as unconfined on Figure 1. This also corresponds to what was mapped as the Woodville Karst Plain by Hendry and Sproul (1966), Lane (1986), Rupert and Spencer (1988) and Rupert (1988).

Davis calibrated his model to conditions in October and November 1991. Based on the calibration results, Davis developed Floridan Aquifer recharge rates for each of these three areas. For that portion of Leon County overlain by low-permeability sediments but not confined, he calibrated a recharge rate of 7.9 in/yr. For that portion of Leon and Wakulla counties under unconfined conditions, he calibrated a recharge rate of 18 in/yr. For the two sprayfields operated by the City of Tallahassee he applied recharge rates of 62 in/yr (reflecting the volume of effluent applied to the sprayfield). For confined portions of both counties, he calibrated fluxes into the Floridan Aquifer (recharge across the confining unit) as high as 10 in/yr and out of the aquifer (discharge) as high as 10 in/yr. Discharge across the confining unit was simulated to occur in the immediate vicinity of the Ochlockonee River. The highest recharge rates occurred immediately adjacent to the unconfined parts of the model.

Davis measured discharge from the Floridan Aquifer at several sites in Wakulla County. On November 1, 1991 the following flows were measured: Spring Creek sub-aqueous spring group—307 cfs, Wakulla Springs—350 cfs, St. Marks River south of Leon/Wakulla county line—602 cfs. The total discharge from these three features is 1,259 cfs, virtually all of which comes from the Floridan Aquifer. Davis' calibrated model simulated a discharge from these features of 1,246 cfs. Diffuse discharge to the Gulf of Mexico (the only other discharge sink for the coastal Wakulla County recharge area) was simulated as being minimal.

Ground water flowing beneath Leon County in the Floridan Aquifer flows in a generally north to south direction. Because of extremely high transmissivities, pumping by the City of Tallahassee has relatively little effect on the potentiometric surface and no significant cone of depression has formed. The potentiometric surface at the State line stands at an elevation of about 70 ft above sea level. This declines to about 10 ft above sea level at the Leon-Wakulla county line. Water that flows across the state line is augmented by water that leaks into the Floridan Aquifer within the county.

In spite of fact that the Floridan Aquifer rarely outcrops within Leon County, it is well connected to the overlying land surface. Downward leakage occurs in the base of closed depressions, through lakebeds and sinkholes, and through the confining unit. Sediments of the St. Marks Formation are rarely observed in Leon County, but they are not far beneath the surface. Sediments that comprise the Torreya Formation are relatively thin. In the eastern two-thirds of the county, they are typically 100-ft thick or less. In many low-lying areas they have been significantly thinned by erosion. In the northern part of the county the top of the St. Marks Formation stands at elevations as high as 100 to 120 ft above sea level, resulting in a significant thickness of unsaturated carbonate rock north of the Cody Scarp. Unsaturated thicknesses of St. Marks sediments in this area are as great as 80 ft.

Katz et al. (1997a) conducted an investigation into ground water/surface water interactions at two sites in Leon County, near Fred George Sink within the Tallahassee Hills and near Lake Bradford, on the Gulf Coastal Lowlands. They also collected samples from 11 City of Tallahassee public supply wells open to significant portions of the highly permeable uppermost Floridan Aquifer. Katz et al. observed that ground waters from five City wells are, in part, composed of surface waters enriched with ^{18}O and D. In the case of two wells (CW-19 and CW-26), and based on mixing model studies, up to 32 percent lake water (subjected to evaporation prior to recharging the Floridan Aquifer) is required to provide the chemical and isotopic composition observed in ground water from these wells. They postulate Fred George Sink and Lake Jackson as plausible sources for this evaporated surface water.

Floridan Aquifer water that flows into Wakulla County flows in a southerly direction toward points of discharge. These include Wakulla Springs, Spring Creek springs group, the lower St. Marks River and the Gulf of Mexico. Water that flows into the county subterraneanly is augmented by downward leakage of local rainfall and sinking streams. These include Lost, Black and Fisher creeks and Munson Slough. Lost, Black and Fisher creeks drain pine flatwoods lying west of the Woodville Karst Plain. Munson Slough drains the Lake Munson basin, which lies on both the Tallahassee Hills and the Woodville Karst Plain. Beginning with an elevation of 10 ft at the Leon-Wakulla county line, water levels in the Floridan Aquifer decline to near zero at the coastline.

Potentiometric Surface of the Floridan Aquifer on the Woodville Karst Plain

Based on water-level data collected during the term of the project, three Floridan Aquifer potentiometric surface maps of the Woodville Karst Plain were prepared. Maps (Figures 22 through 24) are representative of conditions in January 1999, August 1999, and March 2000. Numbers of control points included on the maps ranged from 42 to 48. All wellhead elevations were leveled to NGVD. Water level values given on these maps are reliable to ± 0.1 ft, NGVD.

All three maps show basically the same potentiometric surface contour pattern. Contours are closest together immediately south of the Cody Scarp. Within about four miles of the scarp, the potentiometric surface begins to flatten. From the point where the flattening becomes apparent (just north of the Leon/Wakulla County line), water levels decline very gently toward the south. Over eastern Wakulla County they decline as little as a foot over distances of as much as 10 miles (0.0001). Wakulla Springs is situated more or less at the center of this flattening, although it imparts no visible (from these data) perturbation to the potentiometric surface. Rather, the potentiometric surface continues to slope away from the spring to the southwest. The Big Dismal—Turner Sink conduit system is imbedded in the zone of low hydraulic gradient. The extremely high Floridan Aquifer transmissivities associated with this feature undoubtedly facilitate potentiometric surface flattening. However, flatness is not limited to the axis of the conduit system, as it also extends to the north and to the northeast, in the direction of Woodville.

These data imply that an eight to 10-mile wide highly transmissive band of the Floridan Aquifer is situated in central Wakulla County. This zone of high conductivity locally perturbs the general north to south flow regime and funnels water to Wakulla Springs from the northwest, north and northeast. It includes the mapped conduit system, a paleo surface drainage channel connecting Munson Slough and McBride Slough, and presumes the existence of other, unmapped conduits north and northeast of Wakulla Springs. Using other lines of evidence, Werner (2000) postulates the existence of a second, significant conduit system due north of Wakulla Springs. The calibrated transmissivity distribution of Davis (1996) is consistent with this interpretation, as it shows a band of very high transmissivity (as high as 10M ft^2d) aligned north/south through the center of Wakulla County.

The potentiometric surface data also imply that Wakulla Springs incompletely captures ground water flow moving from north to south to the west of the spring. The prevailing wisdom is that the Big Dismal—Turner Sink conduit system is connected to Wakulla Springs. However, this hypothesis has yet to be proved by direct exploration. While there is, likely, some connection, the completeness with which the conduit system captures and conveys ground water flow to Wakulla Springs is unknown. These head data imply some significant quantity of bypass flow.

Based on the potentiometric surface mapping conducted for this investigation, general flow directions on the karst plain are identified (Figure 25). Werner (2000) gives information on the position of a stagnation point within the Wakulla Springs conduit system. He notes that a separation between north-flowing and south-flowing waters is observable in the main conduit system and that it occurs at distances ranging between 2,100 ft and 7,500 ft south of the spring, depending on flow conditions.

Data collected on and near the City of Tallahassee southeast sprayfield (SESF) indicate a southwesterly flow direction into the zone of high conductivity. Such an interpretation is counterintuitive, given the proximity of the sprayfield to the St. Marks River. St. Marks Rise (located near the Leon/Wakulla county line and about half the distance between the SESF and Wakulla Springs) is a significant source of ground water outflow from the Floridan Aquifer. Presumably, the drain effect of the St. Marks Rise should perturb Floridan Aquifer flow directions in southeast Leon County to the southeast. This does not seem to be the case, although the reason for this is not clear. A southwesterly flow direction near the sprayfield, while based in this instance on a limited number of wells is substantiated by previous potentiometric surface mapping at the sprayfield itself (Pruitt et al., 1988 and Berndt, 1990). Additional water level data along the lower St. Marks River would be of value in refining localized flow directions.

Surface Waters

Wakulla Springs and River

Wakulla Springs is a major Floridan Aquifer ground water discharge point within the St. Marks and Wakulla rivers basin. The output from the spring is sufficient to form the Wakulla River, which flows southeast about nine miles and discharges into the Gulf of Mexico. Based on USGS data, the period of record median flow from Wakulla Springs is 340 cfs (n=297, mean=397, stdev=266, Figure 26). The lowest observed flow was 25.2 cfs, on June 18, 1931. The largest observed flow, 1,910 cfs, occurred on April 11, 1973. Beneath the spring pool of Wakulla Springs lies an extensive network of large-diameter conduits. The main trunk of the conduit system lies more or less horizontally at depths ranging between 230 ft and 280 ft below sea level. This conduit system runs northeast and south away from the spring, consists of multiple branches, and has been extensively traversed and mapped by divers.

Another large conduit system has been mapped by divers starting in the Leon Sinks Geologic Area. This system connects Big Dismal Sink on the north end, with Cheryl Sink, River Sink Group and Turner Sink on the south end (Werner, 2000). It also receives surface water inflow from Fisher Creek. River Sink Group is a collection of three tunnel collapse features that have a significant perennial flow. In each case, water emerges from the ground on the upstream end of the sink, flows along the length of the sink and disappears into the ground on the downstream end. Middle River Sink, which has been measured seven times, has a median discharge of 160 cfs, or about 47 percent of the median discharge of Wakulla Springs. Cave divers have explored several smaller conduit systems on the karst plain including Chip's Hole, Indian Springs, Sally Ward Spring, McBride's Slough (Werner, 2000). Though the Big Dismal-Turner Sink and Wakulla Springs systems have not been shown to connect through direct exploration, it is reasonable to presume some degree of interconnection.

In the last 25 years, Wakulla Springs has experienced a significant increase in NO_3 concentrations (Figure 27). These data were gleaned from USGS and EPA STORET databases and represent a compilation of analyses for (1) NO_3, total (as N); (2) NO_3, dissolved (as N); (3) NO_2+NO_3, total (as N); (4) and NO_2+NO_3, dissolved (as N). These analyses were considered to yield relatively equivalent results for the purpose of illustrating the increase in NO_3 experienced at Wakulla Springs. Historically, there has been no measurable NO_2 in the ground waters of the study area and, presumably, all detectable NO_3 in ground water is dissolved.

Based on data from 1971 through 1977, the median NO_3 concentration was 0.26 mg-N/L (n=22). Based on data from 1989 through 2000, the median concentration had increased to 0.89 mg-N/L (n=26). Concentrations appear to have peaked in the early 1990s and have declined slightly since. Over similar periods, the NO_3 concentration in Middle River Sink increased from a median of 0.06 mg-N/L (n=14) to 0.19 mg-N/L (n=3). The postulated increases are considered accurate, as the data from the 1970s are reported as NO_3-N, total and the data from the 1980s and 1990s are reported as NO_3-N, dissolved. Based on a median flow of 340 cfs (3.04×10^{11} L/yr), and a median NO_3 concentration of 0.89 mg-N/L, the NO_3 load discharged from Wakulla Springs is 270,000 kg-N/yr.

The difference in the NO_3 concentration histories of Wakulla Springs and Middle River Sink is of note. Both show increases with time. River Sink had what are generally considered background concentrations during the 1970s. Currently, River Sink nitrate concentrations are similar to what Wakulla Springs experienced 25 years previously. River Sink lies northwest of Wakulla Springs and, presumably, passes water to the spring from the western edge of the area contributing water to the spring. This water has a much lower nitrate concentration than

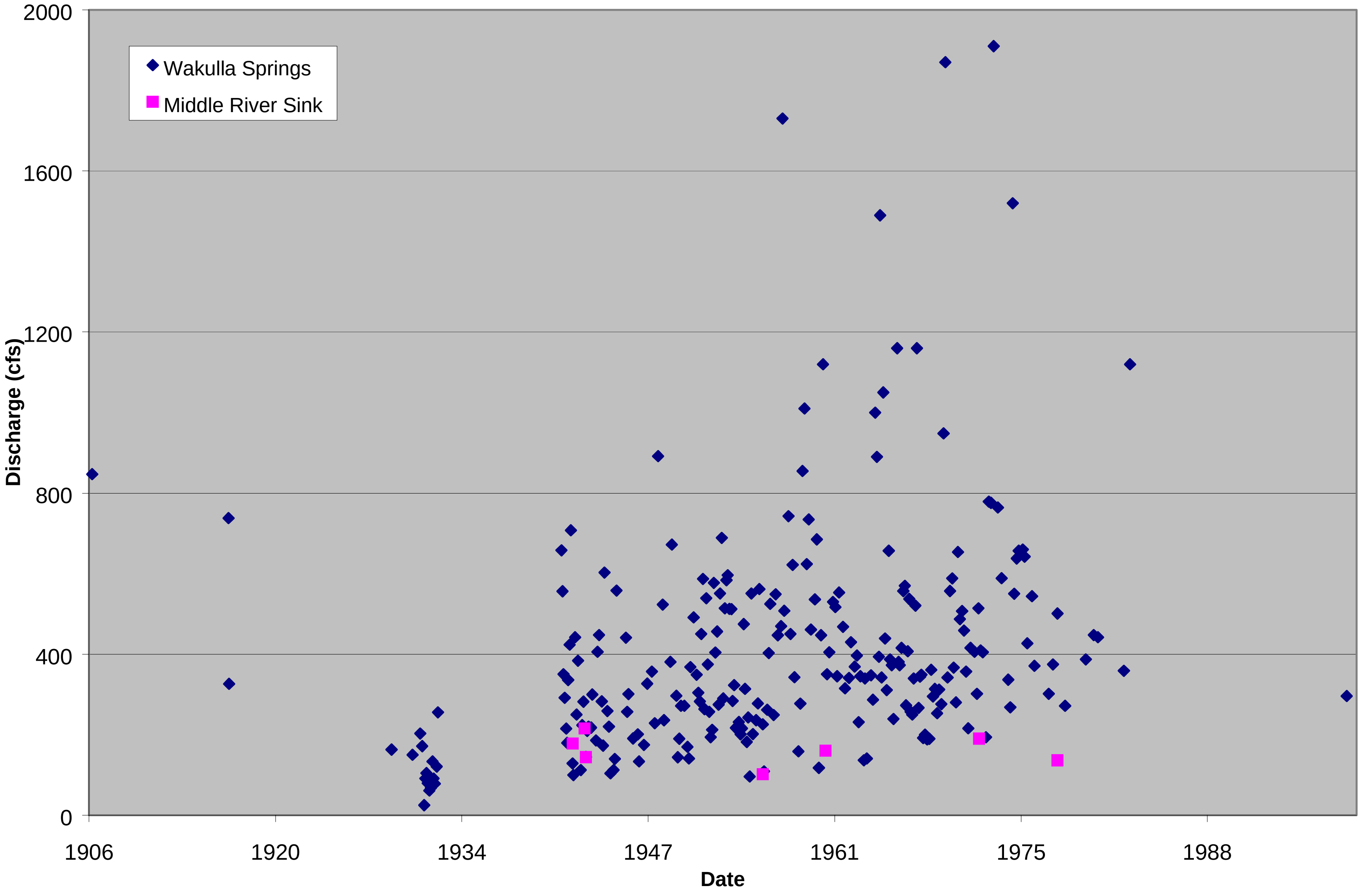


Figure 26. Wakulla Springs and Middle River Sink Spring Historic Discharge (data from USGS).

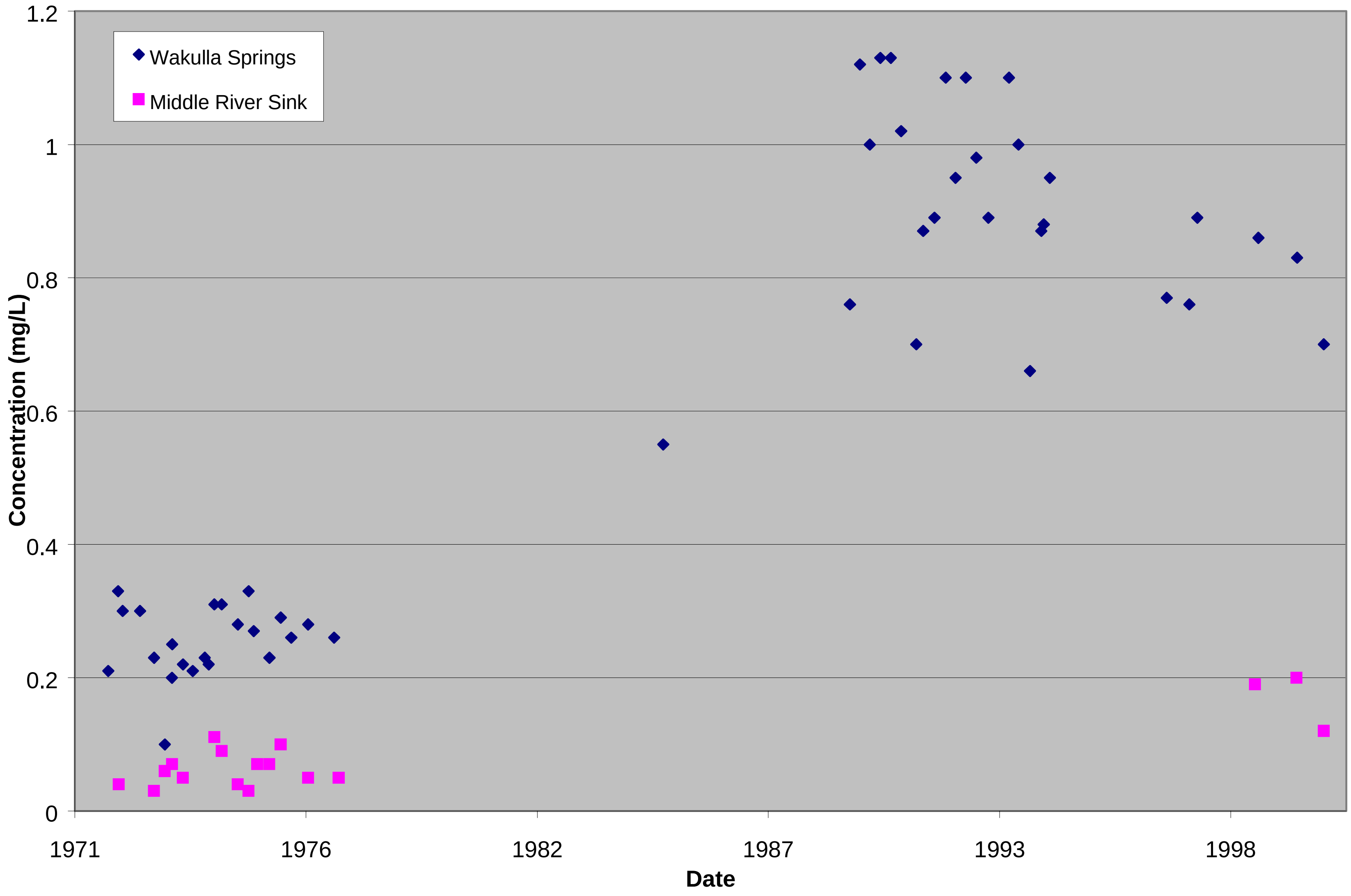


Figure 27. Compilation of NO_3-N and NO_2+NO_3-N Concentration Data for Wakulla Springs and Middle River Sink Spring.

Wakulla Springs itself. If it is true that River Sink discharges to Wakulla Springs, and if the three recent River Sink nitrate concentration measurements are representative of current conditions, the source of elevated nitrates in Wakulla Springs must lie north and east of the Big Dismal—Turner Sink conduit system. If the flow through River Sink bypasses Wakulla Springs, the same conclusion is true.

NO_3 concentrations in waters currently discharging from the spring are promoting the growth of undesirable vegetation. *Hydrilla* and filamentous algae are particularly problematic. According to the FDEP EcoSummary (FDEP, 2000) for Wakulla Springs, "nitrate-nitrite concentrations (ranging from 0.77-0.84 mg/L) at the sampling site were consistently higher than the values found in 90% of Florida streams." Based on four determinations made during 2000, "the stream condition index (SCI) ranked the site 'very poor' once, 'poor' twice, and at the lowest end of 'good' category once" during 2000. The report further observes that the periphyton community is dominated by taxa that are tolerant of nutrient enriched conditions. Further, they conclude that "the poor macroinvertebrate health was related to the habitat and dissolved oxygen problems caused by *Hydrilla*, which in turn was due to high nitrate levels" (FDEP, 2000).

Katz (2001) performed sampling and isotopic analysis of ground and surface waters from the Woodville Karst Plain, including Wakulla Springs, Fisher Creek, Lost Creek and Munson Slough. Water from most sampled wells and from Wakulla Springs had δ^{15} N-NO_3 values ranging between 6.8 and 8.9 per mil, indicating that their NO_3 originates from a blend of organic and inorganic sources. Using $^3H/^3He$ age-dating techniques, Katz (2001) determined that the average residence time of ground water discharging from Wakulla Springs was 38.7 +/-1.07 years. He also concluded that surface water inflows from sinking streams contributed little NO_3-N to ground waters on the karst plain.

St. Marks River

The St. Marks River is a second major source of Floridan Aquifer discharge on the Woodville Karst Plain. The St. Marks River originates in the Tallahassee Hills physiographic subdivision. The river headwaters were originally what are now the Lakes Miccosukee and Lafayette drainage basins. Erosion modified the headwater basins to the point where drainage became predominantly internal and the basins closed. Between these basins and the St. Marks River Rise, overland surface flows are intermittent, depending on the amounts of rainfall and overland runoff.

In periods of low flow, the St. Marks Rise is the head of the perennial St. Marks River (Rosenau et al., 1977). Based on 42 years of record, the USGS St. Marks River gage (0.65 miles south of the rise) has the following statistics; Q_{10}—1090 cfs; Q_{50}—635 cfs; Q_{90}—408 cfs. Median stage at this station is 8.9 ft, NGVD (Marvin Franklin, personal communication, 2001).

Interaction between Wakulla Springs and Up-gradient Surface Water Features

Ames Sink

Ames Sink lies about 5.5 miles due north of Wakulla Springs and is within the capture zone of the spring. Accordingly, waters that enter Ames Sink eventually discharge from the spring. Ames Sink is on the downstream end of Munson Slough, which conveys surface waters from the lake to the sink. In turn, Lake Munson receives water from the urban drainage system that drains much of the southern part of the City of Tallahassee.

Conductivity data collected at Ames Sink and flow data collected on Munson Slough above Lake Munson are given in Figure 16. Collection of flow data at Ames Sink was beyond the scope of this investigation. Conductivity and flow data are given for the period 03/99 to 11/00, which includes the very dry summer of 2000. For much of this period, inflows at the sink were minimal to nonexistent. However, the water quality meter used to collect these data was continually submerged. Measured conductivity values ranged from 60 and 250 μmhos/cm. Typically, conductivities dipped after rainfall events and rose during dry periods. It is possible that the elevated conductivities observed during dry periods reflect re-circulation of Floridan Aquifer waters into the sink in the absence of surface water inflows. Otherwise, conductivity decreases during rainy periods seem to reflect the inflow of stormwater derived from low conductivity rainfall.

1999 Surface Water Conductivity Data

During 1999, specific conductivities of water from Wakulla Springs ranged between 275 and 340 μmhos/cm (Figure 28). These data are typical of Floridan Aquifer conductivities found up-gradient of Wakulla Springs. 238 conductance samples collected in Leon County between 1986 and 1999 had a median conductance of 247 μmhos/cm (mean=241, stdev=62). Elevated conductivity is primarily due to dissolved carbonate from the limestone aquifer. As a function of time, the 1999 Wakulla Springs conductivity data exhibit relatively little variability.

1999 conductivities in the three other surface water features were lower (Figure 28). Fisher Creek is a black-water sinking stream whose watershed lies within the Apalachicola National Forest. During 1999, it had the lowest range of conductivity values, between 30 and 75 μmhos/cm and exhibited little variability during the year. Fisher Creek conductivities were lowest during dry periods and (curiously) rose following rain events. Lowest observed values for Lost Creek (another black-water sinking stream draining the national forest) were similar to Fisher Creek, in the vicinity of 30 μmhos/cm. However, during dry periods, conductivities in Lost Creek rose well above those of Fisher Creek, to about 170 μmhos/cm. This increase is likely attributable to the discharge of Floridan Aquifer water into Lost Creek during low-flow periods. Conductivities in Ames Sink were typically higher than in either Fisher or Lost creeks.

2000 Surface Water Conductivity Data

During much of 2000, conductivities in Wakulla Springs were similar (>300 μmhos/cm) to the previous year (Figure 29). However, September rains were sufficient to perturb the prevailing pattern. During September a total of 19.29 inches of rain fell at the River Sink Station. Of this, 8.31 inches fell during the first week, 1.09 inches fell on September 17 and an additional 9.53 inches were associated with the passage of Tropical Storm Helene on September 22. During September, conductivities in Wakulla Springs declined rather sharply from 310 μmhos/cm to 250 μmhos/cm, or by about 20 percent. Within about three weeks of Tropical Storm Helene's passage through the area, conductivities in the spring rebounded to 320 μmhos/cm.

Middle River Sink had a 2000 conductivity history similar to that of Wakulla Springs. During much of the year values varied through a small range (between 220 to 240 μmhos/cm). These high values reflect the high proportion of Middle River Sink water originating in the Floridan Aquifer. Rains occurring around the first of September were sufficient to reduce the conductivity by about 20 percent. A precipitous decline followed Tropical Storm Helene (Figure 30). During a six-day period, conductivities fell from 220 μmhos/cm to 60 μmhos/cm. For a short period of time, flow through Middle River Sink consisted entirely of surface water, much of it undoubtedly originating from Fisher Creek. The high surface water inflow following rains associated with

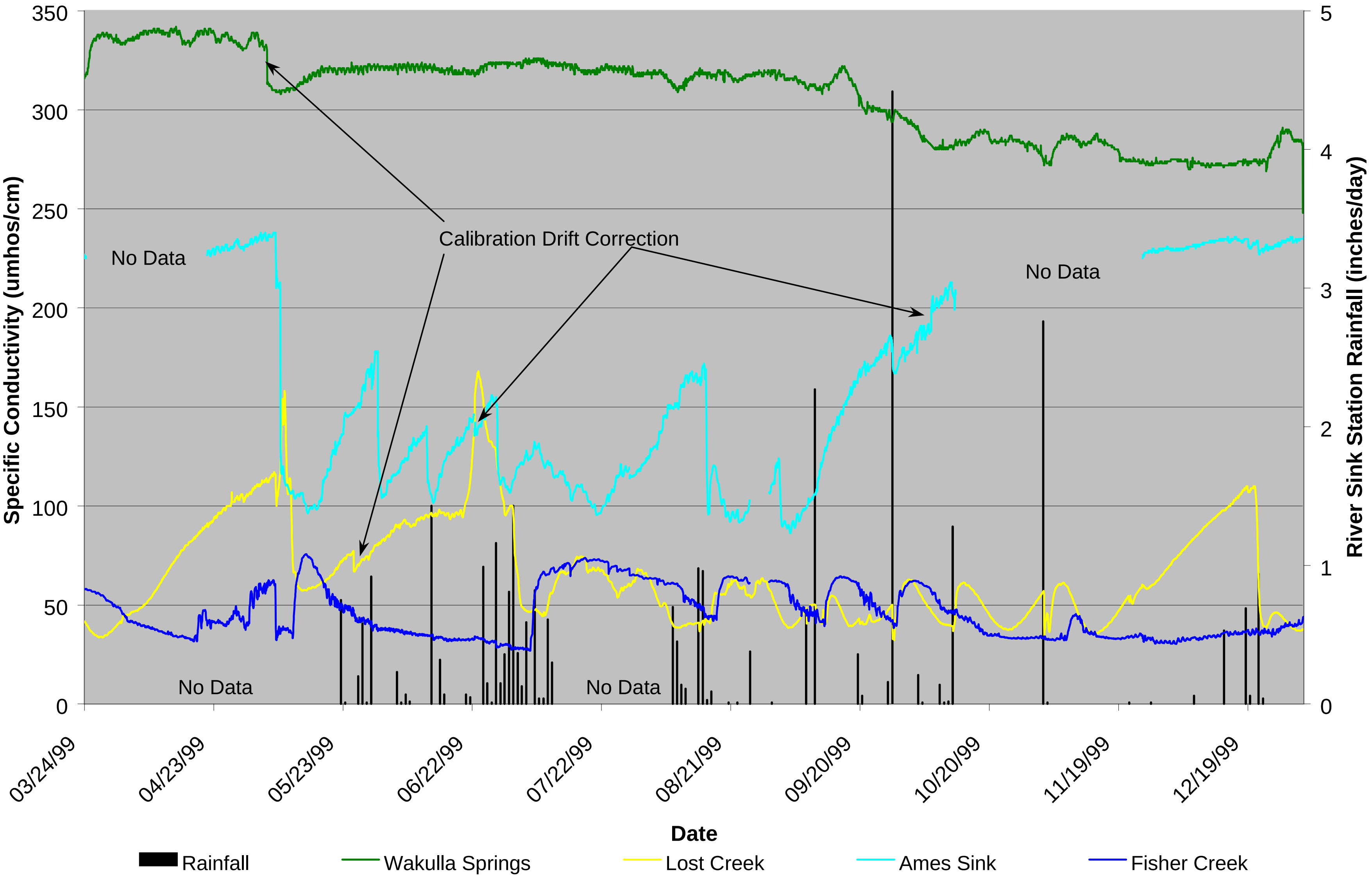


Figure 28. 1999 Specific Conductivity and Rainfall versus Time for Fisher Creek, Ames Sink, Lost Creek and Wakulla Springs.

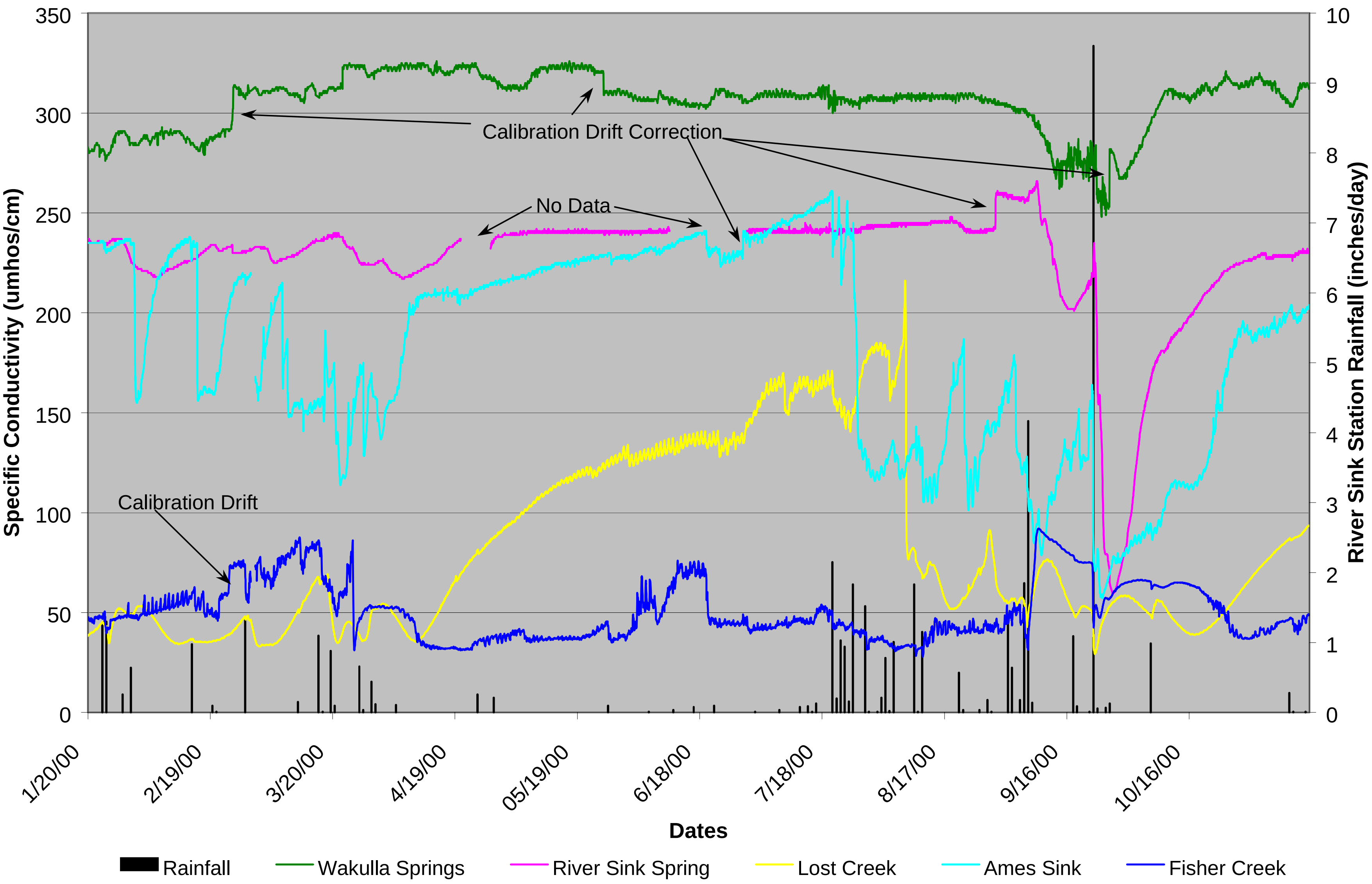


Figure 29. 2000 Specific Conductivity and Rainfall versus Time for Fisher Creek, Ames Sink, Lost Creek, Middle River Sink and Wakulla Springs.

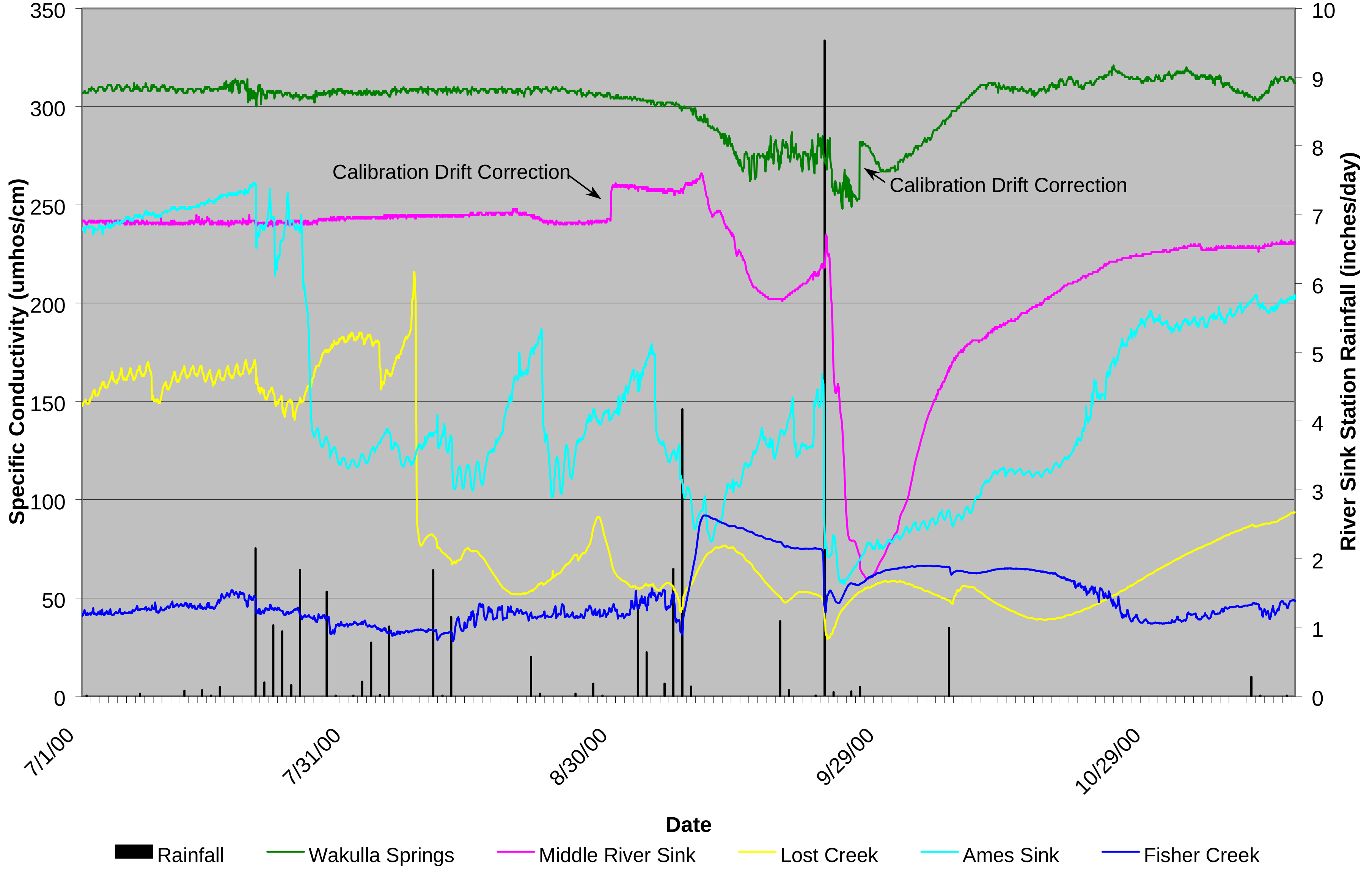


Figure 30. Specific Conductivity and Rainfall versus Time Prior to and Following Tropical Storm Helene, July-November, 2000.

Tropical Storm Helene completely overwhelmed the ground water component of Middle River Sink Spring. During this period, waters in Ames Sink, Fisher Creek, Middle River Sink and Lost Creek all had similar conductivities, on the order of 60 µmhos/cm. By late October, Middle River Sink returned to its typical, Floridan Aquifer dominated flow regime. Wakulla Springs recovered to its typical conductivities over the same period.

In Ames sink, Fisher Creek and Lost Creek, conditions during 2000 were similar to 1999. During the prolonged dry period that began around the first of April and ended around mid-July, conductivities in Lost Creek and Ames sink rose well above typical wet period values. For the year Fisher Creek had a fairly narrow range of values, between 30 and 90 µmhos/cm.

Surface Water Temperature Data

Figures 31 and 32 give temperature versus time data for Fisher Creek, Ames Sink, Lost Creek, Middle River Sink, Spring Creek and Wakulla Springs for 1999 and 2000. The Wakulla Springs temperature data given in these figures were collected with the S4 meter inside A-tunnel. Mean-daily air temperature data from the Tallahassee Airport are also given. For both years, the temperature profile of Wakulla Springs is virtually invariant. During the entire period the only perturbation followed Tropical Storm Helene and that disturbance was slight. Middle River Sink (for which only 2000 data was collected) is only slightly less invariant. The two most significant disturbances occurred in mid-January 2000, during a period of very cold air temperatures, and in September 2000, during periods of high rainfall. In contrast, temperature data for the surface water features closely follow the average daily air temperature, being cooler than Wakulla Springs in winter and warmer in summer.

The invariant nature of the temperature data from Wakulla Springs partially substantiates the observation that the spring is deeply imbedded in the regional flow system. Likely, much of the seasonal temperature signal is removed from recharge water by the time it reaches the Floridan Aquifer. There are observations of seasonal temperature fluctuations in individual Floridan Aquifer wells on the order of 2 °C. Wakulla Springs undoubtedly integrates waters over a wide range of temporal scales. In the process, any remaining seasonal (or other) temperature signals are almost completely removed.

Wakulla Springs Velocity and Conductivity Data

Specific conductivity and velocity data from Wakulla Springs are given in Figures 33 and 34 for 1999 and 2000. Specific conductivity data were collected from the data logger installed beneath the boat dock (Station #4, above). These data show a generally inverse relationship between conductivity and velocity. Inflows of relatively low conductivity rainfall via sinking streams will undoubtedly mix with and dilute Floridan Aquifer waters discharging from the spring, reducing conductivity in the process.

Hurricane Floyd and Tropical Storm Helene passed through the area in September 1999, contributing to a monthly total rainfall of 13.31 inches at the Tallahassee Airport and 19.29 inches at the River Sink Station. In August, A-tunnel velocities were on the order of 8 cm/s and specific conductivities were on the order of 325 µmhos/cm. In mid-September, tunnel velocities increased to ~17 cm/s. Concurrently, the conductivity declined to ~300 µmhos/cm. The observed increase in velocity from 8 cm/s to 17 cm/s should represent roughly a doubling of the spring discharge. Assuming that 325 µmhos/cm represents 100 percent Floridan Aquifer water and assuming a surface water conductivity of about 40 µmhos/cm, a blending ratio of 93 percent Floridan Aquifer water to 7 percent surface water is required to reduce the conductivity from 325 to 300 µmhos/cm. This mixing ratio is independent of spring flow.

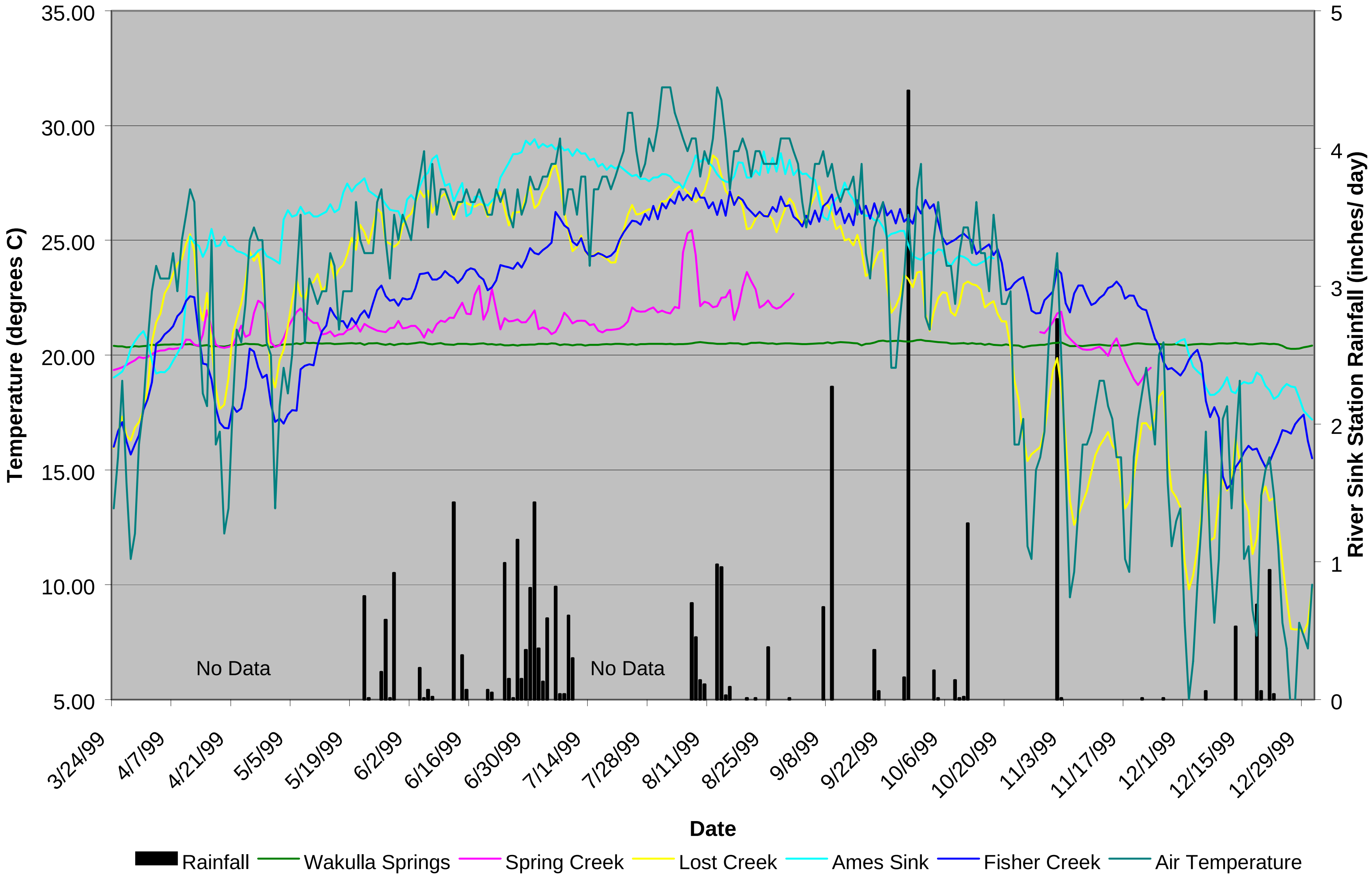


Figure 31. 1999 Temperature and Rainfall versus Time for Fisher Creek, Ames Sink, Lost Creek and Wakulla Springs.

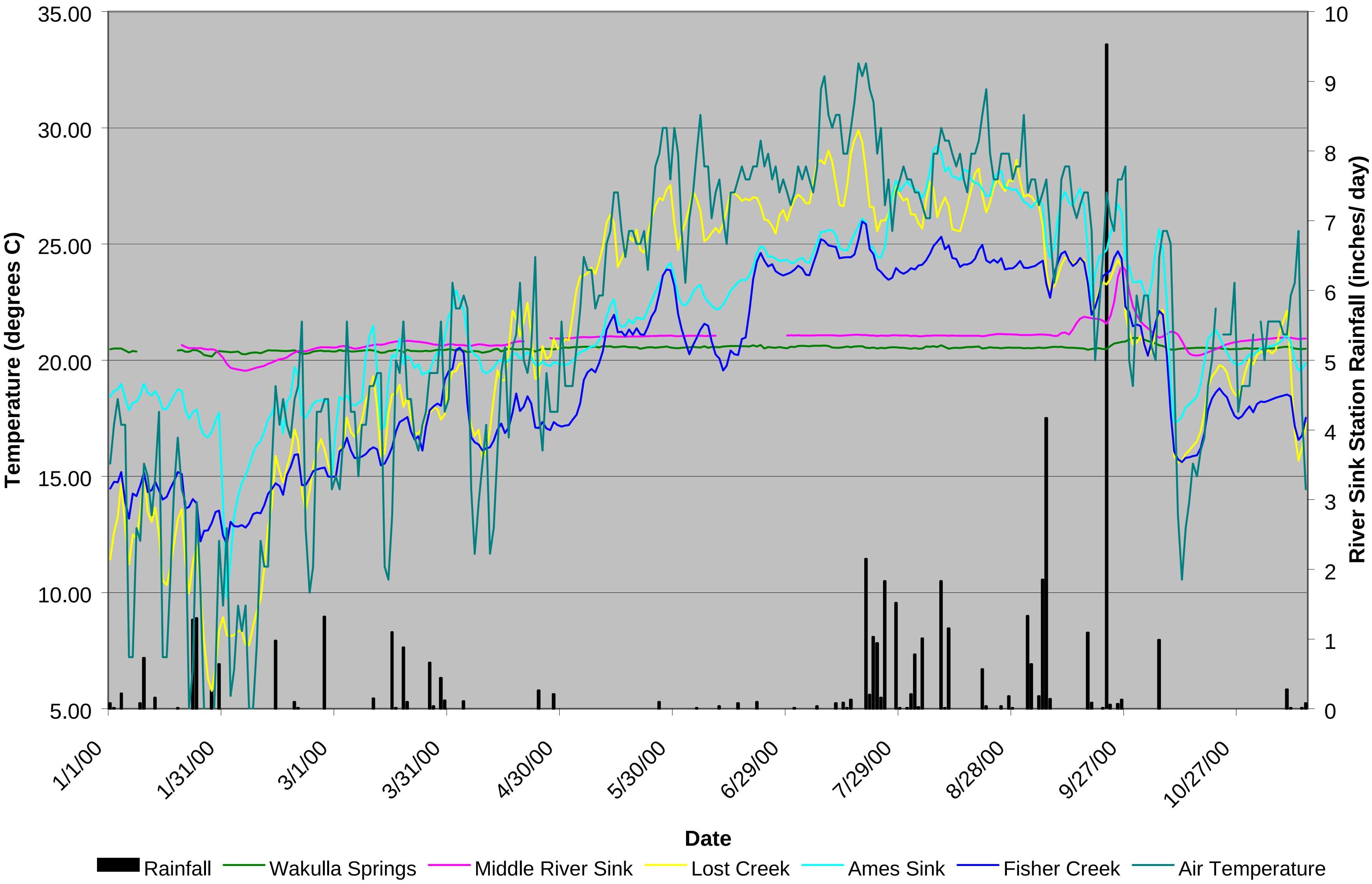


Figure 32. 2000 Temperature and Rainfall versus Time for Fisher Creek, Ames Sink, Lost Creek, Middle River Sink and Wakulla Springs.

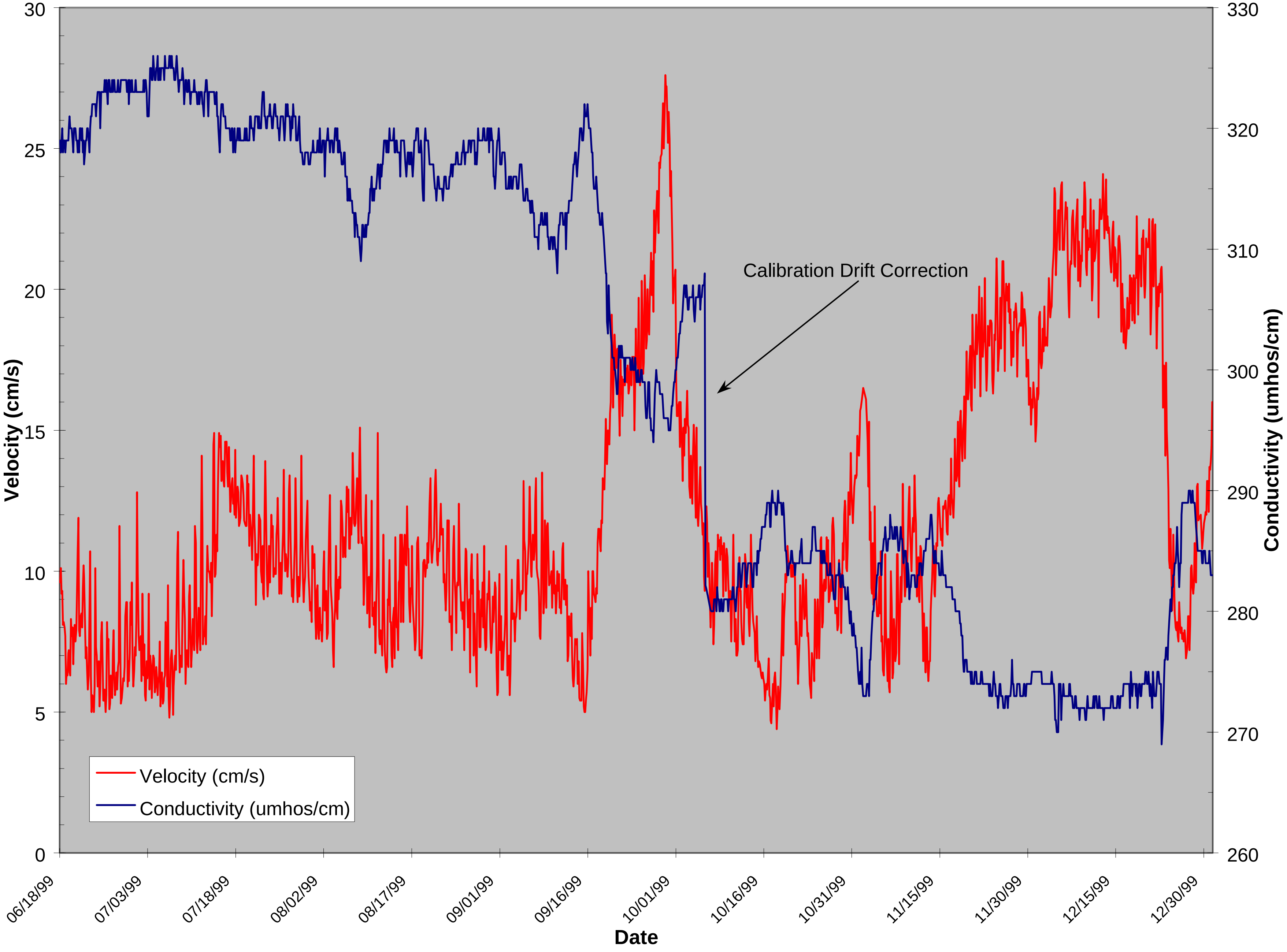


Figure 33. 1999 Wakulla Springs Velocity versus Specific Conductivity.

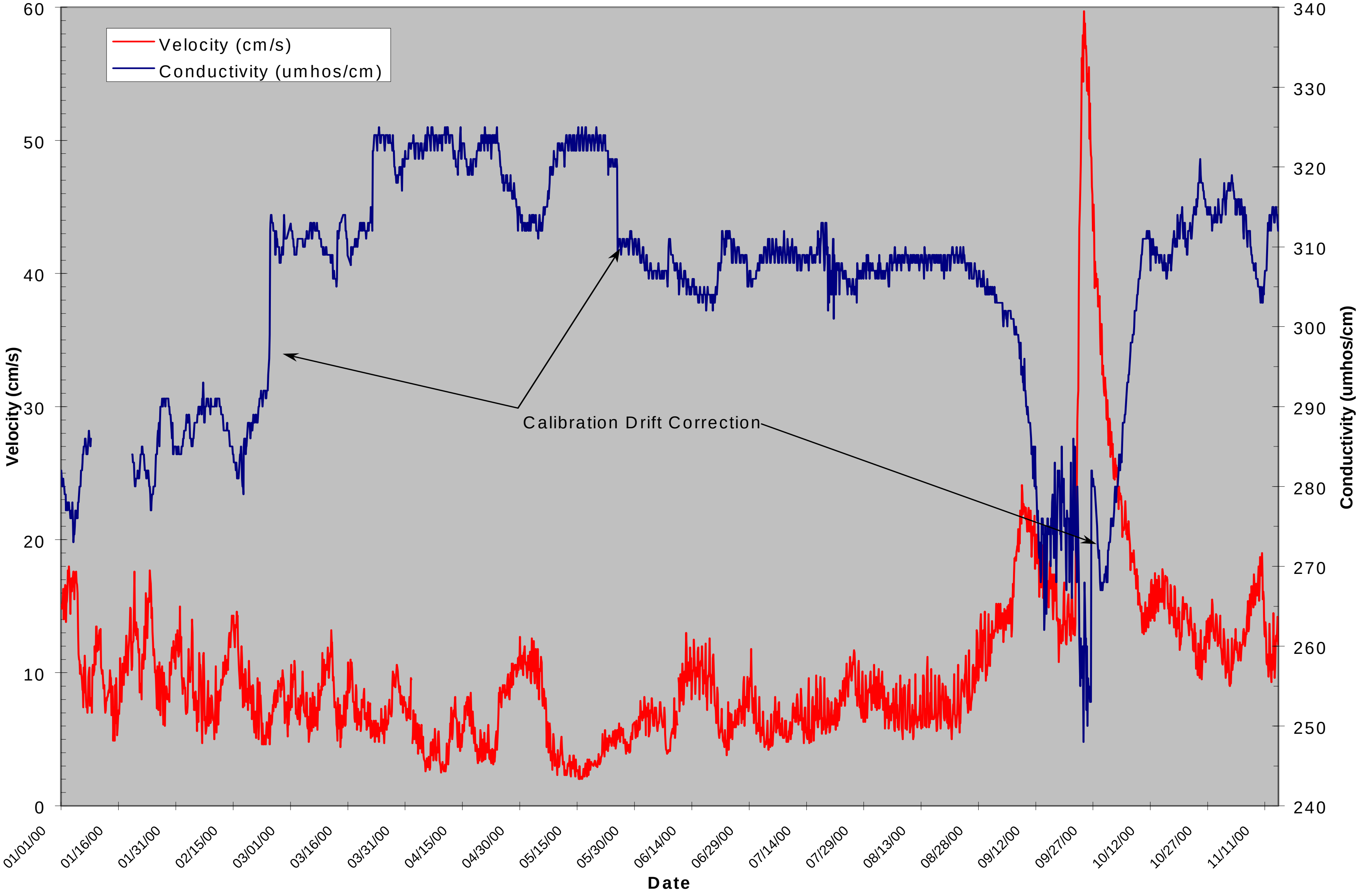


Figure 34. 2000 Wakulla Springs Velocity versus Specific Conductivity.

The addition of surface water inflow from sinking streams is not sufficient to double discharge from the spring. Rather, the increase in flow is mostly accounted for by additional discharge from the Floridan Aquifer. The increase in Floridan Aquifer discharge through the spring results from a slight increase in Floridan Aquifer water levels attributable to short-term, relatively intense rainfall events. Given the extremely high hydraulic conductivity of the Floridan Aquifer, it is not surprising that small increases in hydraulic head result in a significant increase in discharge.

WATER QUALITY IN THE FLORIDAN AQUIFER

Historic Nitrate Concentrations

Two previous studies (1986 and 1997) by the Department of Health (DOH) provide insight into historic NO_3 concentrations in the Floridan Aquifer. Wells used in these studies are described in Table 5. One study performed in 1986 concentrated on Leon County. When these data were examined, it appeared that they had significant quality assurance problems. For this reason NO_3 data obtained by the DOH in 1986 were not mapped. The data are included in time series representations for several wells.

The second DOH study, performed in 1997, focused on Wakulla County (Figures 35 and 36). Data from the FDEP GWIS data set, USGS databases and the City of Tallahassee were combined with the DOH data to produce data sets as complete as possible for 1997. The data represent a compilation of analyses for (1) NO_3, total (as N); (2) NO_3, dissolved (as N); (3) NO_2+NO_3, total (as N); (4) and NO_2+NO_3, dissolved (as N). These analyses were considered to yield relatively equivalent results for the purpose of illustrating NO_3 concentrations in the Floridan Aquifer. Historically, there has been no measurable NO_2 in the ground waters of the study area and, presumptively, all detectable NO_3 in ground water is dissolved.

Results of the 1997 study show that NO_3 concentrations are quite variable over the study area. Most results from the semi-confined and unconfined areas are above detection limits, reflecting a widespread distribution of NO_3 from anthropogenic sources. There is a scattering of values below detection limits (BDLs) in the unconfined portions of Leon and Wakulla counties. BDLs are even more prevalent in Wakulla County where the Floridan Aquifer is under confined conditions (western half of county). This reflects the relatively low population density in this area and the greater degree of aquifer confinement.

Project-specific Ground and Surface Water Sampling

Six surface water sites and 41 Floridan Aquifer wells were sampling as part of the project (Figure 9, Appendix A, Table A3). A complete list of sampling results is presented in Table 7. Six of the sampled wells were constructed for the project. They, along with Middle River Sink and Wakulla Springs were sampled twice more—during low-flow and high-flow conditions—for various isotopes. Analytical results from these data collection efforts are described in greater detail in Katz et al. (in preparation).

NO_2+NO_3

The overall distribution of NO_2+NO_3-N (Figure 37) is consistent with the historical data—few BDL concentrations and a variable distribution on the karst plain, with concentrations below detection limits in the undeveloped eastern portion of Wakulla County and along the coast. Concentrations in ground water ranged from below the detection limit of 0.020 mg-N/L to 7.3 mg-N/L. The primary drinking water standard for nitrate is 10 mg/L. In surface water inflows (Lost Creek, Fisher Creek and Munson Slough) NO_2+NO_3-N concentrations are below detection limits. In surface water outflows (Wakulla Springs, Sally Ward Spring, Middle River Sink Spring, and McBride Slough) NO_2+NO_3-N concentrations ranged from 0.19 mg-N/L to 1.0 mg-N/L.

The six wells constructed for the project, Middle River Sink and Wakulla Springs were sampled for nitrogen isotopes to obtain a $\delta^{15}N$-NO_3 value. $\delta^{15}N$-NO_3 values are helpful in distinguishing between organic and inorganic sources of nitrate. Low values (0 to 3 per mil) indicate an inorganic nitrate source such as artificial fertilizer. Higher values (10 to 20 per mil) indicate an organic nitrate source such as septic tanks, waste disposal or manure spreading (Katz et al., 1999). With four of six wells constructed for the project having BDL NO_3-N concentrations, four additional wells from the sampling network with elevated NO_3-N concentrations were selected to replace them. Values for $\delta^{15}N$-NO_3 are shown below:

Table 4. $\delta^{15}N$-NO_3 Values.

Site name (NWF ID)	$\delta^{15}N$-NO_3 (per mil)
Wakulla Springs (749)	6.3
Middle River Sink (7757)	4.5
Nitrate #1 (7492)	4.6
Nitrate #5 (7498)	7.4
Claycomb (6493)	2.6
Johnson (674)	0.6
Garcia (663)	3.1
Blackstead (641)	7.6

Wakulla Springs data are consistent with previous sampling results (Katz, 2001) and indicate a mixture of nitrogen sources. Middle River Sink, Nitrate #1 and Garcia also indicate a mixing of sources, tending toward the inorganic. Claycomb and Johnson, both adjacent to agricultural land uses, have a strong inorganic source indication. Nitrate #5 and Blackstead indicate a mixture of sources.

Previous $\delta^{15}N$ analysis in the study area was perfomed by the USGS (Berndt, 1990) at the SESF. Sampling for $\delta^{15}N$ analyses in Floridan and surficial aquifer was conducted during January 1988 and the reported median $\delta^{15}N$ ratio was 7.2 per mil (n=13, mean=8.1, stdev=2.3, range=5.9 to 12.4). From this data, Berndt concluded that the application of inorganic fertilizer at the SESF was influencing N isotopic ratios in ground waters at the site.

Dissolved Organic Carbon

Dissolved organic carbon (DOC) values ranged from below a detection limit of 0.1 mg-C/L to 31.0 mg-C/L (Figure 38). Highest levels occurred in surface water inflows (Fisher Creek, Munson Slough and Lost Creek). Concentrations in ground water were generally low. However, some wells had concentrations sufficiently elevated to indicate a possible influence from surface water.

Dissolved Oxygen

Dissolved oxygen (DO) was determined as a field parameter at the time laboratory samples were collected. DO values ranged from zero mg-O/L (in one of the wells constructed for the project) to 11.9 mg-O/L (Figure 39). Surface water and ground water concentrations are scattered throughout this range, although the lowest values (<1.0 mg/L) are all from ground waters.

pH

Values for pH were measured in the field at the time of sample collection. Values ranged from 3.5 to 8.5 standard units (Figure 40). Surface water inflow sites (Fisher Creek, Munson Slough and Lost Creek) generally had low pH, ranging from 3.5 to 6.4 standard units (su). One ground water site (Seminole Golf Course) had a pH indicative of surface water influence (5.3 su).

All remaining ground water sites had pH values between 6.8 to 8.5 su. pH was generally higher with increasing well depth.

Specific Conductance

Specific conductance levels were measured in the field coincident with sampling. Levels ranged from 41 to 130 µmhos/cm in surface water inflows (Lost Creek, Fisher Creek, Ames Sink, Figure 41). Levels in surface water outflows (Middle River Sink, Wakulla Springs, Sally Ward Spring and McBride Slough) range from 211 to 337 µmhos/cm. Ground water levels ranged from 60 to 1,180 µmhos/cm. The ground water median specific conductance was 291 µmhos/cm.

Orthophosphate

Samples were analyzed for orthophosphate (PO_4-P) in the laboratory. Levels ranged from 0.01 to 0.64 mg/L with a median value of 0.03 mg/L (Figure 42). The median value for ground water (0.02 mg/L) is lower than the median value for surface water (0.04 mg/L), but the highest values were in some wells near the coast.

Nitrate Concentrations as a Function of Time

City of Tallahassee Public Supply Wells

The City of Tallahassee provided NO_2+NO_3-N data for 29 Floridan Aquifer public supply wells in their system (Appendix A, Table A5, Figure 43). Due to their relatively long open-hole intervals, regular pumping, long periods of record, large zones of contribution and high discharge volumes, these wells are of particular interest. Specifically, the data represent the best available insight into the spatial distribution of NO_2+NO_3-N in the Floridan Aquifer beneath the semi-confined portion of the study area. Data collection for some wells began in the early 1980s. Others began at various times since. Data given in Figure 44 for Woodville #1 and #2 were supplemented by three data points (Woodville #1 on 7/14/1980 and Woodville #2 on 1/19/1978 and 7/14/1980) obtained from FDEP (Cliff McKeown, personal communication, 2001).

NO_2+NO_3-N concentrations in individual wells are relatively invariant as a function of time (Figure 44). Statistical analyses of these time series were performed using Spearman and Kendall tau correlation statistics (Katz, personal communication, 2001). Seventeen of the 29 wells showed no statistically significant trend. Seven wells (#10, #12, #17, #20, #21, #22, and #27) showed a slight increasing trend ($p<0.05$) in NO_2+NO_3-N levels over time. Five wells (#7, #13, #15, #19, and #23) showed a slight decreasing trend ($p<0.05$). Wells #12, #17 and #27 are located in the southeast quadrant of the city, within the city limits. Wells #20, #21 and #22 are located near the intersection of Highway 90E and I-10 and lie within about one mile of each other. There is a high concentration of septic tanks in the immediate vicinity of these wells. The declining wells lie in the northwest quadrant of the city, south and east of Lake Jackson.

Data from the 29 City of Tallahassee wells were then aggregated in several subsets based on location. The semi-confined well data set (716 values from 27 wells, excluding the two Woodville wells) showed no significant trend in NO_2+NO_3-N concentration over time. The median concentration from this set of wells is 0.33 mg-N/L (n=716, mean=0.35, stdev=0.17). For the 20 City of Tallahassee wells south of I-10, the median concentration was 0.36 mg-N/L (n=556, mean=0.38, stdev=0.16). Lastly, the six southernmost wells (south of Tram Road/Orange Avenue and adjacent to the Cody Scarp) had a median concentration of 0.48 mg-N/L (n=208, mean=0.48, stdev=0.16). These results show an increasing trend in NO_2+NO_3-N from north to south in Leon County under the semi-confining unit.

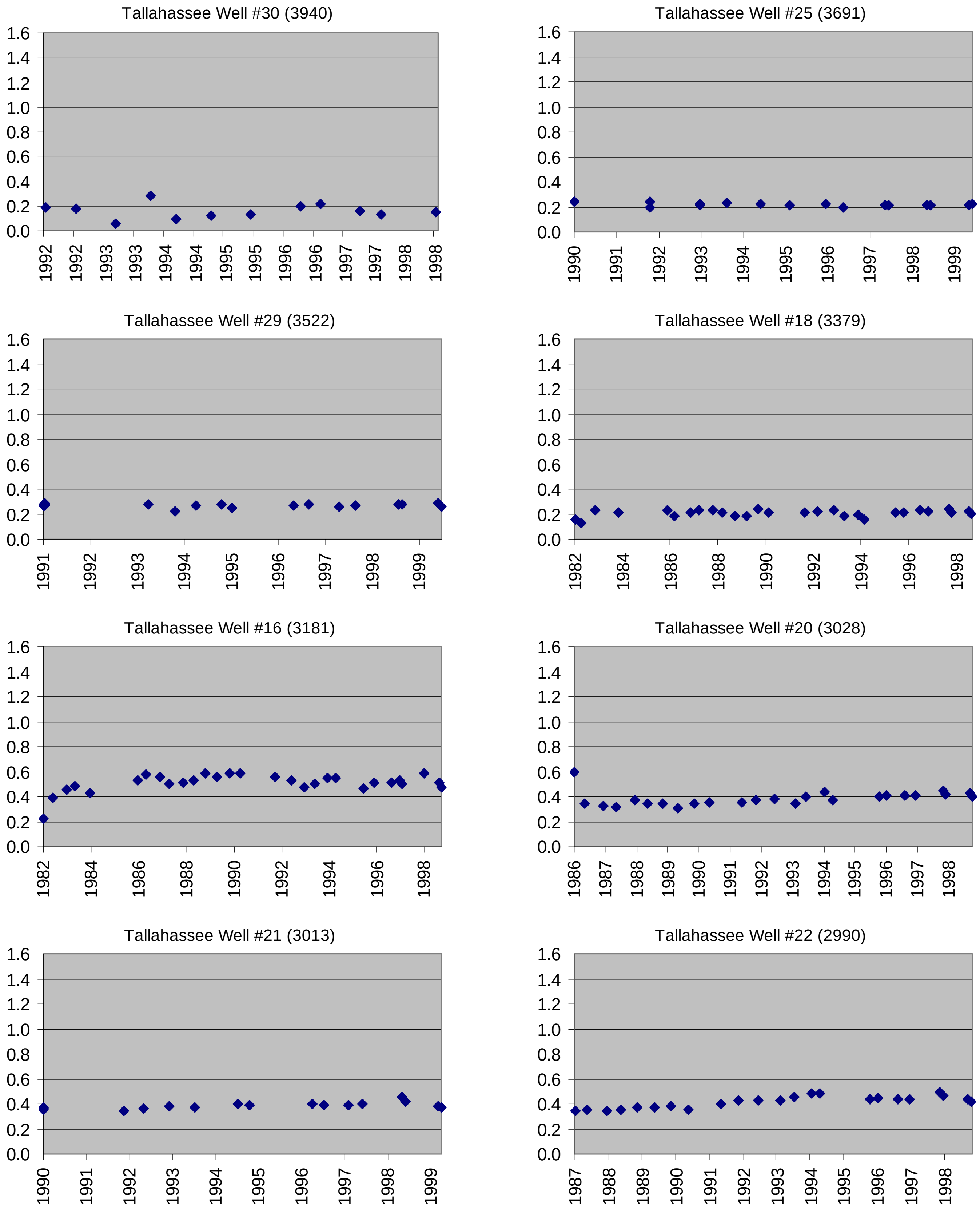


Figure 44. City of Tallahassee Public Supply Well NO_2+NO_3-N Concentrations (mg/L).

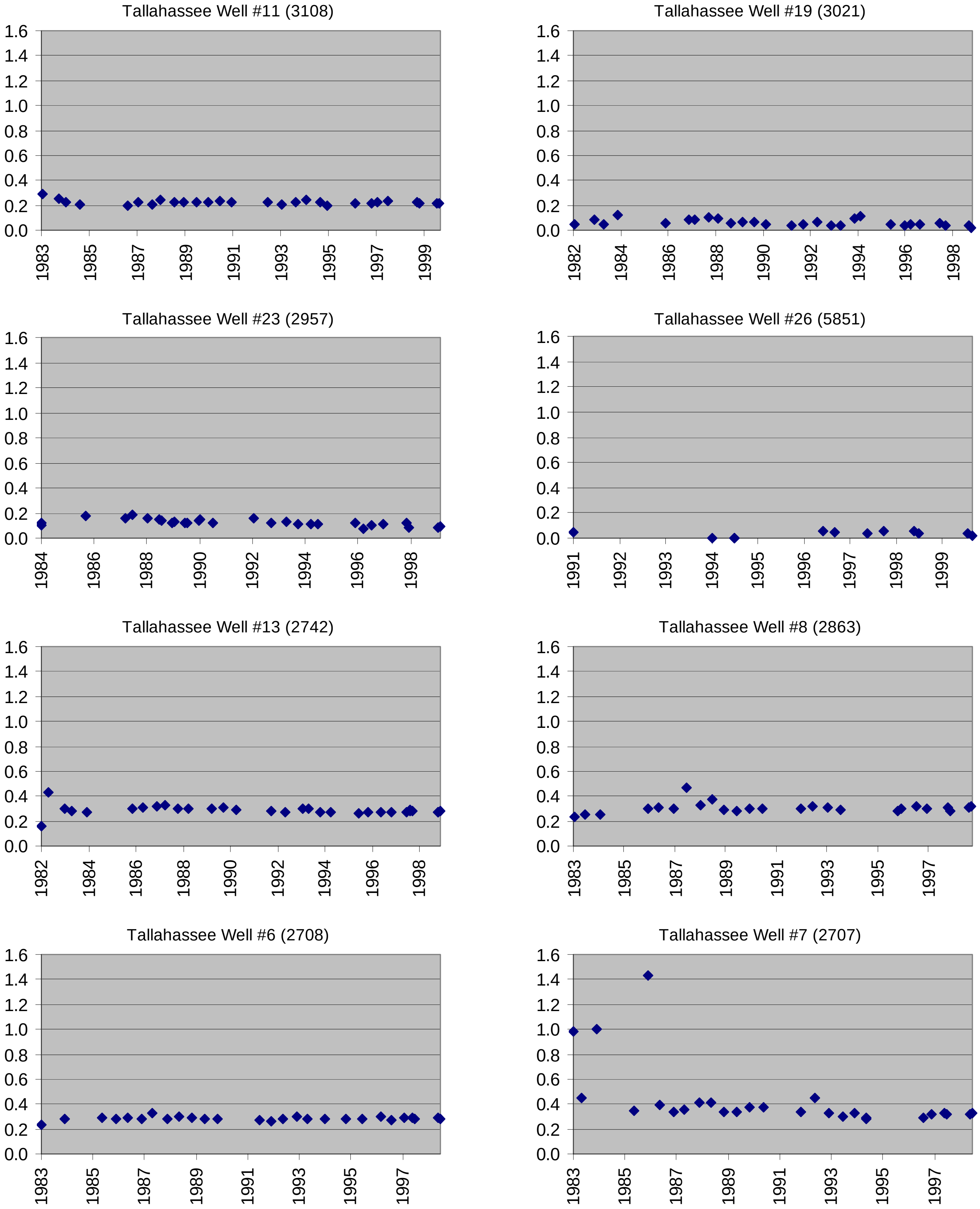
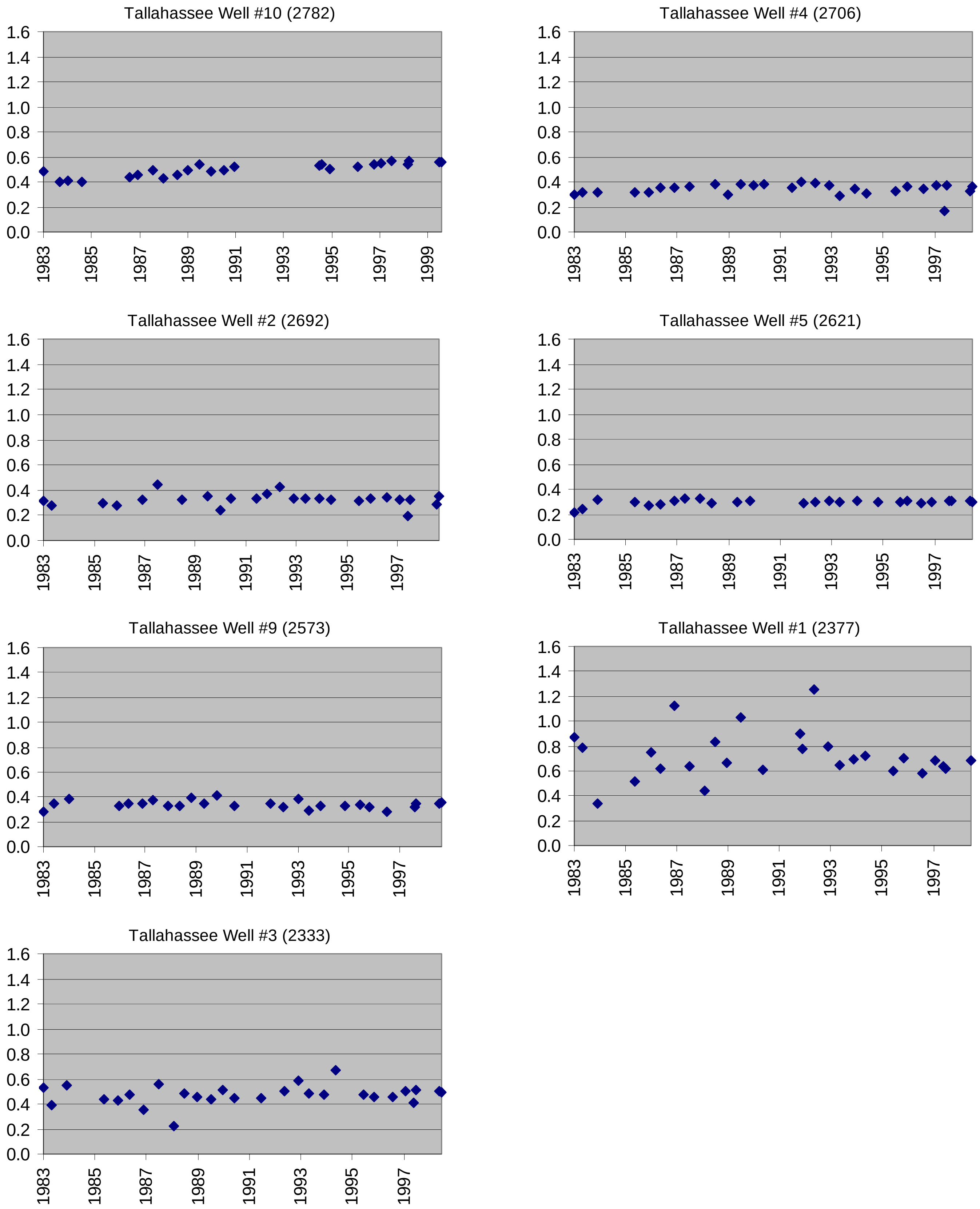


Figure 44. City of Tallahassee Public Supply Well NO_2+NO_3-N Concentrations (mg/L) [cont.]


Tallahassee Well #10 (2782)

Tallahassee Well #4 (2706)

Tallahassee Well #2 (2692)

Tallahassee Well #5 (2621)

Tallahassee Well #9 (2573)

Tallahassee Well #1 (2377)

Tallahassee Well #3 (2333)

Figure 44. City of Tallahassee Public Supply Well NO_2+NO_3-N Concentrations (mg/L) [cont.]

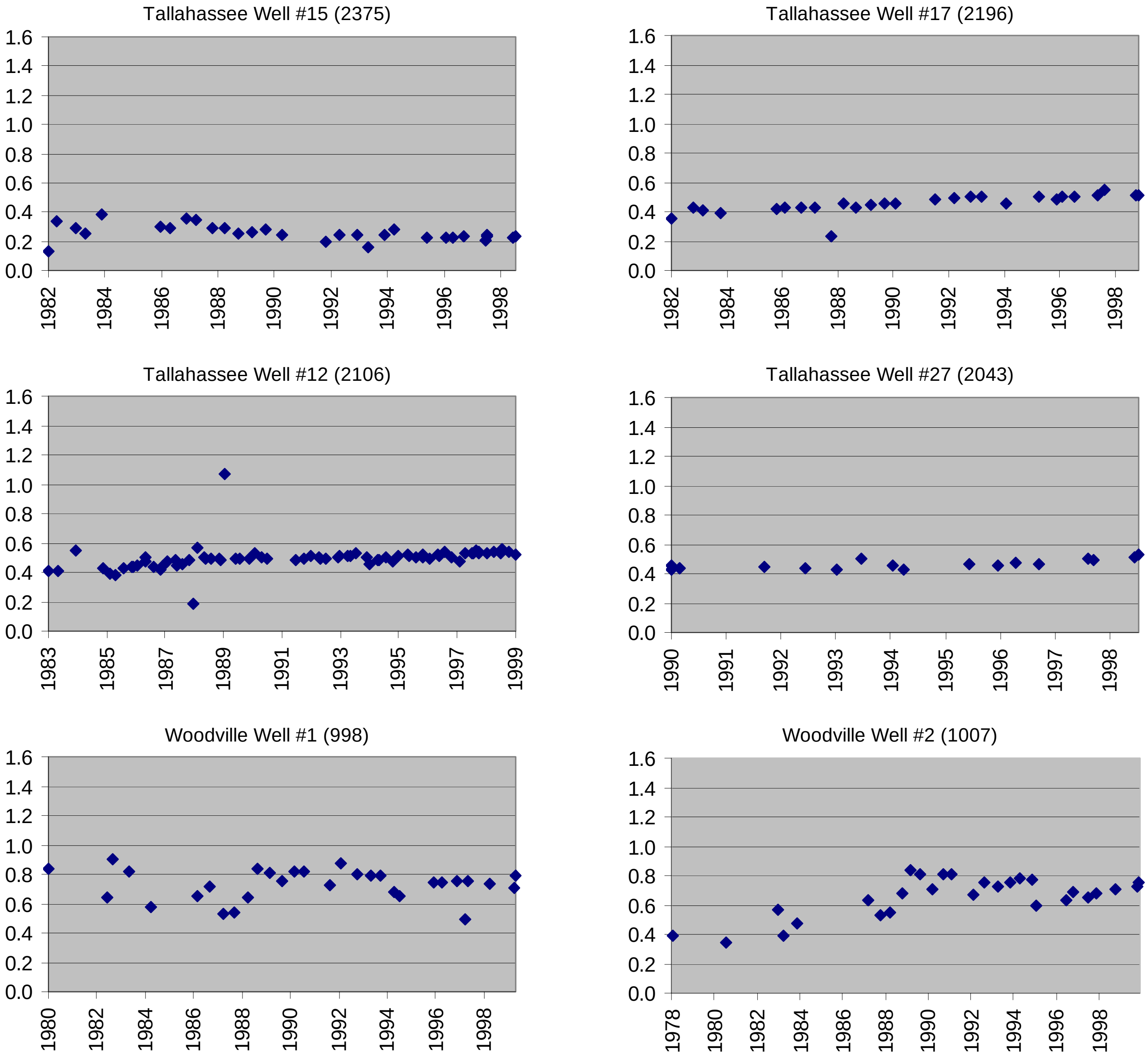


Figure 44. City of Tallahassee Public Supply Well NO_2+NO_3-N Concentrations (mg/L) [cont.]

NITROGEN SOURCE INVENTORY

One of the primary objectives of this study was to quantify the various inputs of nitrogen to the landscape of Leon and Wakulla counties. Six principal nitrogen inputs to the hydrosphere were investigated: atmospheric deposition, wastewater treatment facilities (WWTF), on-site domestic disposal systems (OSDS), commercial fertilizer application, livestock and sinking streams. Nitrogen derivative of atmospheric deposition is predominantly inorganic (IN) and has both a dissolved and a particulate aspect. Commercial fertilizers are also predominantly inorganic. They are typically applied to the landscape in particulate form. However, to be bio-available, the N they contain is water-soluble. Solubility makes this source of inorganic N available for dispersal in the environment via surface water runoff and rainfall infiltration to ground water. WWTFs and OSDS take what is predominantly particulate organic N (ON) suspended in water and treat it by (1) providing partial denitrification, (2) converting organic N to inorganic forms (predominately NO_3), and (3) sequestering some N in particulate form. WWTF are more efficient at providing denitrification than are OSDS. N-containing wastewater from these systems is applied either to or beneath the land surface for disposal. In the case of a WWTF, land application provides opportunities for vegetative N uptake, microbial transformation and other forms of N removal. Eventually, the disposed water reaches the water table, carrying some fraction of its original N load. Livestock apply organic N directly to the landscape. Sinking streams carry nitrogen in predominantly organic form. Further, this load is partitioned between dissolved and particulate forms.

For each source the total nitrogen load (as N) was estimated and is presented here. As applicable to the particular source, these estimates represent the summation of constituent forms (DIN, PIN, DON, and PON). For each source, most of the N is presumed to be present in one or two of these forms. However, the exact partitioning among DIN, DON, PIN and PON is poorly understood. Annual loads were estimated during the period 1970 through 1999 (Figure 45). Conditions as of 1999 are summarized below.

A number of different data sources were used to prepare the nitrogen load estimates given below. Consequently, the quality of data underlying the estimates is quite variable. Some data (WWTFs) are generally complete, accurate and reliable. Other data are either incomplete (primarily) or of poor quality. This necessitated estimation and/or interpolation strategies in order to prepare load estimates. Estimation and interpolation techniques are described in the relevant text sections. Such approaches were unavoidable. Future nitrogen inventory efforts will benefit from accurate record keeping pertaining to all sources, not just WWTF.

The sources characterized through this investigation represent a continuum of “intensities” that range from relatively low, when expressed on a mass per unit area basis, to direct introductions into the Floridan Aquifer. At the scale of the study area, atmospheric deposition provides the largest total N load but probably the lowest mass per unit area (M/L^2) application, ~5 kg-N/ha-yr. Relatively low M/L^2 application rates provide the greatest opportunity for denitrification via vegetative uptake, microbial transformations, etc. This is particularly true when the N is applied to the soil surface. Given the lack of concentrated livestock feeding operations in the study area and the direct application of the existing application to the top of the soil profile, livestock N loading also represents (on a M/L^2 basis) a relatively low intensity application.

WWTF represent a relatively intense N application. Based on effluent N loading estimates at the City of Tallahassee SESF and an estimated application area of 600 ha (1,500 acres), effluent spraying delivers N at a rate of about 550 kg-N/ha-yr. This does not account for the additional load derivative of IN application to support crop production at the SESF.

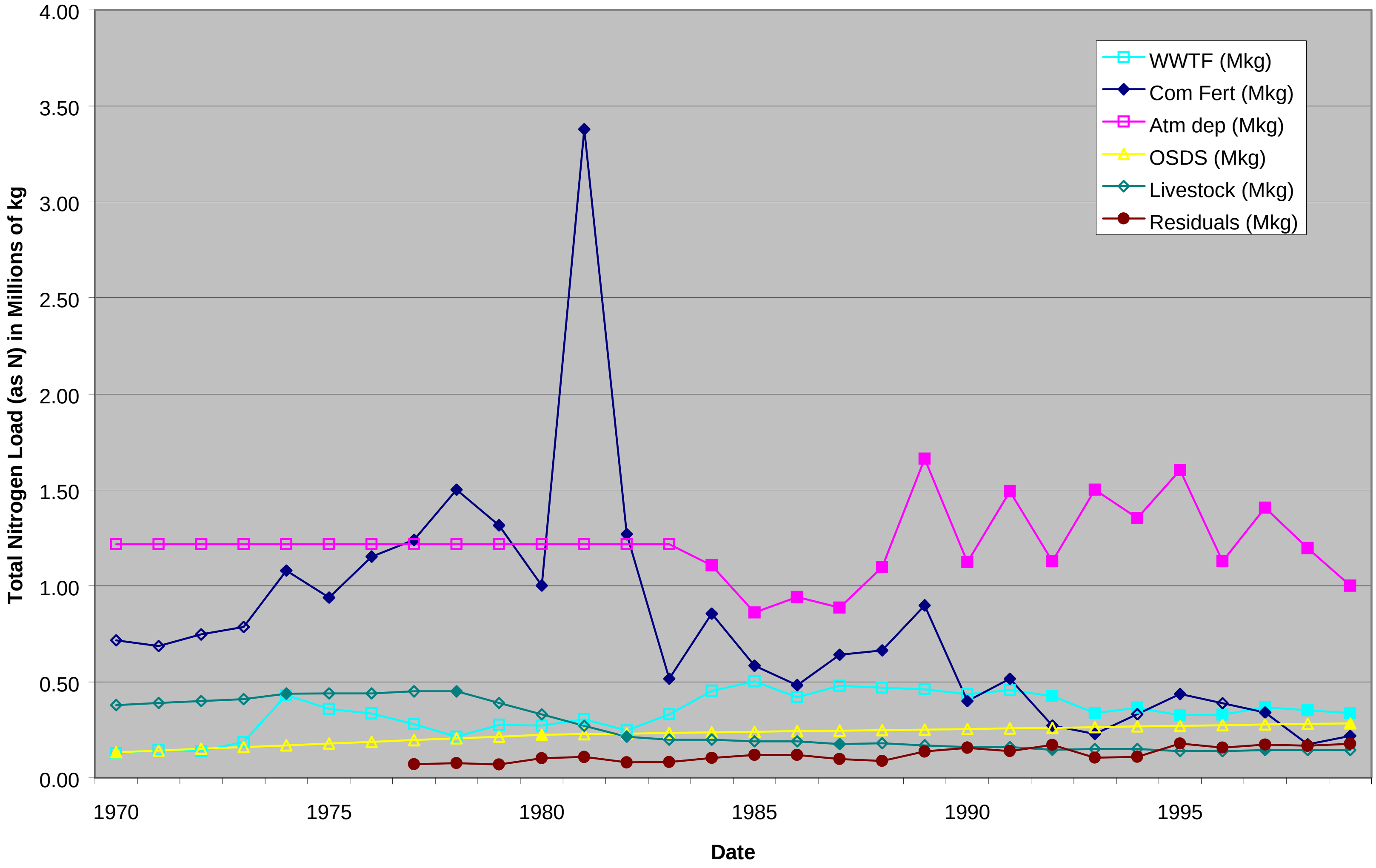


Figure 45. Summary of Nitrogen Loading to the Semi-confined and Unconfined Areas as a Function of Time

OSDS represent an intense N application. Based on estimated OSDS annual N loads between 2 and 6 kg-N/year per capita and a drain field area of 625 ft^2, ODSD application rates equate to between 800 and 2,400 kg-N/ha-yr. OSDS are know to be effective at both nitrifying and at delivering NO_3 to ground water. Release of wastewater beneath the most biologically active portion of the soil profile facilitates NO_3 delivery to ground water.

Commercial fertilizer applications also represent a significant step up in application intensity. In farming operations, application rates are in the 100s of kg-N/ha-yr. Residential application rates are similar. This N source is available for leaching into the soil profile where it is subject to vegetative uptake, microbial transformation, etc. and/or transport to the underlying ground water, or off-site removal via surface water runoff. Given the large number of closed lake basins in Leon County, some (unknown) fraction of N from this source is being sequestered in lakes and lake-bottom sediments. Historically, the majority of the IN fertilizer load applied in the study area was on semi-confined Leon County. Presumably, the fraction of this load that reached the Floridan Aquifer is reflected in the 0.2 to 0.4 mg/L NO_2+NO_3 presently seen in Floridan Aquifer water beneath semi-confined Leon County.

It is important to recognize that application of nitrogen to the landscape is not the same as its introduction into the Floridan Aquifer. Nitrogen is a highly reactive element. Further, depending on the source, the pathways N travels to reach Floridan Aquifer ground water are quite variable. Various natural processes act on anthropogenic N to provide denitrification. Numerous transformations, reaction pathways and uptakes can either temporarily sequester nitrogen in vegetation, lake-bottom sediments or the subsurface, or return it to the atmosphere. Only part of the nitrogen introduced to the landscape eventually reaches the Floridan Aquifer. Given the current state of knowledge, little is known about source-specific or pathway-specific nitrogen removal efficiencies in this environment. Based on data presented here, it appears that much of the total nitrogen load applied to these two counties is either being sequestered or returned to the atmosphere.

Atmospheric Deposition

The Earth’s atmosphere is approximately 78.93 percent nitrogen. The amount of atmospheric nitrogen is affected by human activities—primarily the burning of fossil fuels (e.g. automobiles, power production, etc.). Nitrogen from the atmosphere is deposited on the land surface both dissolved in rain and as dry deposition.

To monitor nitrogen deposition rates, the National Atmospheric Deposition Program (NADP) was established in the late 1970s. An NADP wet-deposition site has been operated in Quincy since 1984, with chemical analyses being performed by the USGS. Annual (1984 to 1999) wet deposition loading rates for inorganic nitrogen (NO_3-N and NH_4-N, dissolved) ranged between 2.03 kg/ha and 3.92 kg/ha. These rates equate to annual average dissolved inorganic nitrogen (DIN) concentrations in rainfall between 0.15 mg/L and 0.28 mg/L. The observed 1999 DIN load was 2.36 kg/ha. The period of record average load was 2.87 kg-N/ha-yr.

Dry deposition is not measured at the NADP site. Rather, for the purposes of this study it was estimated as 96 percent of wet deposition (Baker, 1991). 1.96 times the observed 1999 wet load was used as the annual total inorganic N (TIN) load for 1999, 4.63 kg-N/ha-yr. 1.96 times the period-of-record average annual wet load was used as the period-of-record TIN load, or 5.63 kg-N/ha-yr. This average was used to estimate annual loads prior to 1984, during which no observations were available.

Rainfall, together with its DIN load, falls on the landscape and is subject to evaporation, transpiration, runoff and infiltration. Inorganic nitrogen being transported through the soil as a component of recharge is subject to uptake by plants, microbial transformations and other processes that remove nitrogen from the infiltrating water. Some sense of the efficiency of the soil at removing nitrogen from recharge can be obtained by comparing rainfall DIN concentrations with concentrations in ground water lying immediately beneath the land surface and otherwise unaffected by anthropogenic nitrogen inputs. The processes controlling the fate of dry deposition N are somewhat different. This N must be re-mobilized by infiltrating rainfall before it becomes available for uptake or transformation in the soil, or recharge to ground water.

NO_2+NO_3-N (dissolved) and NH_4-N (dissolved) data from surficial aquifer wells in Leon and Wakulla counties were examined to gain insight into the fate of N applied to the landscape via atmospheric deposition. Data from 9 wells, having depths ranging between 15 and 58 ft, were evaluated. Six wells are completed in undifferentiated sands overlying the confined Floridan Aquifer in western Leon and Wakulla counties. Land use in this area is predominantly silvaculture and, presumably, these wells should be little affected by septic tanks or other sources of anthropogenic nitrogen. The remaining three are completed in sandy intervals within the Miccosukee formation in semi-confined Leon County.

A total of 48 NO_2+NO_3-N (dissolved) and analyses were available. Sample collection dates ranged between 07/89 and 07/99. 16 of 48 NO_2+NO_3-N analyses were below their respective method detection limits. Of the 32 above MDL analyses, three samples (from one well located in semi-confined Leon County) seemed to reflect the impact of a local source of NO_2+NO_3-N on ground water. These data ranged between 1.7 mg/L-N and 2.1 mg/L-N and were excluded from further analysis. The remaining 29 values had a median concentration of 0.02 mg/L-N (mean=0.038, stdev=0.052).

From the same set of wells and for the period 06/93 to 07/99, 26 NH_4-N (dissolved) analyses were available. Of these, 10 were below the minimum detection limit. Three analyses (all from the same well and ranging between 0.8 and 1.3 mg/L) appeared to be outliers and were excluded from further analysis. This well was also located in semi-confined Leon County. The remaining 12 values had a median of 0.019 mg/L (mean=0.028, stdev=0.024).

Annual average rainfall DIN concentrations ranged between 0.15 and 0.28 mg/L at the Quincy NADP site (1984 to 1999). During the same period ground waters from the surficial aquifer had NO_2+NO_3 and NH_4 concentrations generally below or slightly above their respective method detection limits. Comparing medians for these parameters to DIN concentrations in rainfall suggests that the soil profile is capable of removing about 80 percent of the DIN in rainfall. If the impact of re-mobilized N from dry deposition is included, the soil’s N removal efficiency is even greater.

Approximately 103,491 hectares (ha) lie in the semi-confined part of Leon County and 112,903 ha in the unconfined part of Leon and Wakulla counties (Figure 1). Using these areas, the observed annual wet deposition loading rate, and the assumed constant ratio of wet to dry deposition, annual total loads were calculated for 1984 through 1999. For years prior to 1984, the period-of-record average annual total load was used. For 1999 the total loading rate is 4.63 kg-N/ha-yr, resulting in a total load to the semi-confined area of 479,000 kg-N/yr. The total load to the unconfined area is 523,000 kg-N/yr.

Table 5. Estimated 1999 Nitrogen Loading from Atmospheric Deposition.

Area	Area (ha)	kg-N/ha-yr	kg-N/yr
Semi-confined	103,491	4.63	479,000
Unconfined	112,903	4.63	523,000

Wastewater Treatment Facilities

According to FDEP records, there are 69 wastewater treatment facilities (WWTFs) in Leon and Wakulla counties (Appendix A, Table A6, Figure 46). Of the 59 within the semi-confined and unconfined areas, 21 are domestic WWTF and 38 are industrial WWTFs. The total design capacity of the WWTFs, domestic and industrial, is 38.05 Mgal/d. The majority of this capacity (32.06 Mgal/d) is for domestic plants operated by the City of Tallahassee. The remaining facilities have a combined capacity of slightly less than six Mgal/d.

Industrial WWTF Effluent

The industrial WWTFs discharge from systems used for vehicle washing, ground water remediation or for non-contact heating/cooling purposes. These facilities are not monitored for nitrogen because elevated concentrations are not anticipated as a result of their operations. Most water quality concerns at the industrial WWTFs center around volatile organic compounds (VOCs) rather than nutrients. With the exception of one industrial facility, no estimates were made of nitrogen contributions from these facilities.

The one industrial WWTF that is an exception is Primex, a large black-powder production facility located in southern Wakulla County. Presently, Primex discharges effluent with elevated nitrogen levels to surface waters in Wakulla County. Primex is located near St. Marks and is adjacent to the lower Wakulla River. Effluent is held in a polishing pond prior to being sprayed onto an eight-acre sprayfield. Overland flow from the sprayfield passes through a swampy area and enters a ditch leading to Big Boggy Branch and, eventually, into the Wakulla River just north of its confluence with the St. Marks River.

FDEP provided monthly averages of total nitrogen concentration (as N) and effluent flows at the point where it discharges into Big Boggy Branch. From 1992 to 2000 monthly average nitrogen concentrations varied from 1.5 to 56.9 mg/L. Estimated annual loads for this period ranging between 4,819 and 31,096 kg-N/yr entered Big Boggy Branch, with recent loads being highest. Mitigation of this source will occur when Primex begins diverting its effluent to the City of Tallahassee Purdom Generating Station for use in the power station's cooling system. This action is anticipated during 2001. Any effluent remaining after this diversion will go to an evaporation unit at the power plant where the nitrogen will be volatilized. This will effectively remove from surface waters of the basin any direct nitrogen discharge from the Primex industrial WWTF.

Domestic WWTF Effluent

Domestic facilities receive wastewater, treat it using any of several methods and then discharge the treated effluent largely to percolation ponds or sprayfields for disposal (Figure 46). Domestic WWTFs have much more (and better) nitrogen discharge data available than do industrial WWTFs. The City of Tallahassee provided average annual TN concentrations and annual facility flows back to 1970. Data from other facilities were much less complete. Data for facilities other than City of Tallahassee were not readily available prior to 1992. Sufficient data were not available to make estimates for all facilities for all years between 1992 and 1999. For the domestic facilities other than City of Tallahassee and Winco Utilities, Inc. the most complete data set was for 1993. Winco Utilities is located south of Woodville in Wakulla County and provides water for prison and the industrial park.

Using available FDEP compliance data and data provided by the City of Tallahassee, annual TN loads were estimated (Appendix A, Table A7) for 21 domestic WWTF for 1992 through 1999. When estimating annual loads, average monthly values of flow and TN concentration were used where possible. In some cases, maximum monthly concentrations were used, as they were the only data available. Six of 21 facilities had sufficient monthly flow and concentration data from which to calculate monthly N loads. For these cases monthly N loads were then aggregated into the annual loads given in Appendix A, Table A7. Six facilities had monthly flow data but no monthly total N concentration data. For these cases monthly TN data from another facility were used as an estimate of the unavailable data. Eight facilities had neither flow nor concentration data. For these cases, total monthly N load from similar facilities was scaled up or down according to the ratio of design flow capacities of the two respective facilities. City of Tallahassee annual load estimates (1970 to 1999) were the product of average annual TN and annual flow.

TN and flow data were most complete for the small WWTFs in 1993. In this year the small WWTFs contributed about 4 percent of the total TN load with the City of Tallahassee contributing the remainder. Annual TN load estimates from WWTF effluent (Figure 45) consist of calculated City of Tallahassee loads from 1970 to 1999, calculated loads from small WWTF from 1992 to 1999 and estimated small WWTF loads prior to 1992. Between 1970 and 1992 the annual TN load for both the City of Tallahassee and the small WWTFs was estimated as 104 percent of the City of Tallahassee annual load.

1999 TN loads by semi-confined and unconfined areas are summarized in Table 6. Small WWTF loads from 1993 were used to estimate 1999 conditions. For City of Tallahassee and Winco Utilities, Inc. 1999 data were available and are used in the totals below.

Table 6. Estimated 1999 Nitrogen Loading from WWTF Effluent

Area	Industrial (kg-N/yr)	Domestic (kg-N/yr)	Total (kg-N/yr)
Leon Semi-confined	--	8,700	8,700
Leon Unconfined	--	326,000	326,000
Wakulla Unconfined	31,000	4,800	35,800

City of Tallahassee WWTF Development History

The largest WWTF total N load originates from facilities operated by the City of Tallahassee. This is not surprising given the scale of total flow through City of Tallahassee facilities as compared to other, smaller facilities. City of Tallahassee facilities serve a significant percentage of the population in Leon County. Their facilities represent about 80 percent of the total design flow capacity for domestic and industrial WWTFs in Leon and Wakulla counties and 96 percent of the estimated domestic WWTF total N load. Given the relative scale of the City of Tallahassee discharge, the significance of this discharge to the total nitrogen budget of the study area, and the high quality of available data characterizing the discharge, it was possible to assemble a more complete picture of the history of N discharges from City of Tallahassee facilities.

A number of environmental laws passed in the late 1960s and early 1970s were aimed at improving and protecting surface water quality. A significant component of this effort involved the removal of point source discharges from surface waters. In Leon County, Federal regulators assigned Lake Munson a Waste Load Allocation of “zero” pollutants. The Water Pollution Control Act Amendments of 1972 (P.L. 92-500) mandated “no discharge of pollutants to navigable water by 1985". Also in this time period, USEPA implemented the NPDES program. Federal grant funds were made available to local communities to convert surface water effluent discharges to land application. These programs and environmental concerns associated with discharge of domestic waste to Munson Slough prompted the City of Tallahassee to move forward with the spray irrigation facility that could eventually handle all the City's effluent (Keith Turner, City of Tallahassee, personal communication, 2001; Pruitt et. al, 1988).

The first central sewers in Tallahassee were installed in 1904 to serve the downtown commercial district and the Florida State College for Women (now Florida State University). These sewers discharged to two septic tanks for treatment. The first WWTF (1.0 Mgal/d) was constructed on Lake Bradford Road in 1933 and discharged to a tributary of Lake Munson. The Federal Correctional Institution constructed their own WWTF at Capital Circle and Park Avenue which discharged into Lake Lafayette until 1967, when the facility connected to the City of Tallahassee sewer. Effluent discharge in the Lake Munson Basin increased in 1941 with the U.S. Army's construction of a WWTF (1 Mgal/d) to serve Dale Mabry Field. After deactivation of the military post, the City took over the WWTF and continued to operate it through 1982. Lake Munson was impounded in 1950 to alleviate downstream flooding problems (Bocz and Hand, 1985) and a new, higher capacity plant (4.5 Mgal/d) was constructed on Lake Bradford road in 1951. In 1961, a 0.06 Mgal/d capacity high-rate trickling filter system was constructed at the municipal airport to process effluent, which was discharged to rapid infiltration basins (Keith Turner, City of Tallahassee, personal communication, 2001).

Lake Munson showed the effects of the increasing amounts of stormwater and effluent it received from the City of Tallahassee with massive algal blooms reported as early as 1956 and 1963 (Beck, 1963). In 1964 the City completed a land exchange with the US Forest Service that gave them the area at Capital Circle and Springhill Road for a WWTF site. Construction of the Southwest Plant (2.5 Mgal/d) was completed in 1966 with effluent discharge to Munson Slough. A 6.5 ha (16 acre) experimental irrigation system was also provided for effluent disposal at the site and research began into the effects and benefits of spray application. This sprayfield represented the beginning of what is now the Southwest Sprayfield (SWSF) and all flow through the plant was disposed of through spray application. The sprayfield area was expanded in 1972 to 15.6 ha (38.5 acres) and again in 1977 to 48 ha (118.5 acres) (Keith Turner, City of Tallahassee, personal communication, 2001). Spray effluent disposal to uplands provided the opportunity to mitigate adverse impacts experienced by Lake Munson as a result of surface water discharge. Since the diversion of effluent out of the lake occurred, it has experienced a significant improvement in water quality.

Spray application of treated wastewater effluent at the Southwest plant averaged 0.25 Mgal/d in 1966. By 1969 the average flow through the plant had risen to one Mgal/d and by 1974 the average flow had increased to 3.5 Mgal/d—exceeding the plant capacity. As a result, plant capacity was increased to 10 Mgal/d in 1974 and the WWTF was officially named Thomas P. Smith Plant. This new plant used an activated sludge method of treatment, which resulted in immediate changes in effluent water quality. Total nitrogen in the effluent did not change but NO_3-N increased to approximately four times levels in the high-rate trickling filter process. This conversion of ammonia and Kjeldahl nitrogen to NO_3-N prior to land application ensures that the nitrogen is in a form to be utilized by vegetation and prevents potentially more harmful ammonia from entering ground water (Overman, 1979).

Southeast Sprayfield

In 1981, the Southeast Sprayfield (SESF) was put into operation on Tram Road approximately 1.6 miles east of Capital Circle SE. The site is located just south of the Cody Scarp on the Gulf Coastal Lowlands. It originally consisted of 405 ha (1,000 acres). In 1982, 202 ha (500 acres) were added. 160 ha (396 acres) were added in 1986. With the 1986 expansion, all treated effluent discharge to the Lake Munson Drainage basin ceased. In 1999, another 106 ha (266 acres) were added to the SESF, bringing the total acreage to 873 ha (2,159 acres). The latest addition is referred to as the SESF extension. Since its inception, the SESF has been actively farmed. Over the years and as a part of farming operations, inorganic fertilizers have been applied to promote crop growth.

There are records of 69 monitor wells having been constructed at the SESF (Appendix A, Table A8, Figure 47). All are Floridan Aquifer wells except SE28 through SE36 (nine surficial aquifer wells) and SE54 through SE70 (17 surficial aquifer wells).

Given the scope of activities conducted at the SESF, a number of wells are presently being sampled, as required by permit or at the discretion of the City of Tallahassee. As required by permit, eleven wells (eight Floridan Aquifer, SE2, SE15, SE16, SE17, SE19, SE22A, SE52, SE53, and three surficial aquifer wells, SE30, SE31 and SE34) are currently being sampled. The City is also required, by permit, to sample 10 Floridan Aquifer wells (SE75 through SE84) at the SESF extension. SE85 and SE86 are presently sampled at the discretion of the City of Tallahassee.

Sampling results from eight SESF monitor wells are given in Figure 48. All data were obtained from USGS and City of Tallahassee databases and represent analyses for NO_2+NO_3-N, total. Data from these wells are quite variable, as would be expected given the wide variability in N application rates over short spatial and temporal scales. SE16 and SE17 are consistently below 0.6 mg/L. SE15 shows a slight increasing trend with time; concentrations are typically less that 1 mg/L. SE02 shows a strongly increasing trend with time, going from about 0.5 mg/L in the early 1980s to between 4 and 5 mg/L now. SE22A is clearly under the influence of effluent disposal and/or IN fertilizer application. SE19, SE52 and SE53 are of interest, in that they show a rapid concentration run-up from the mid-1980s to 1990. Around 1990 concentrations peaked in the range of 6 to 8 mg/L. Since 1990, they have declined slightly and are now in the 4 to 6 mg/L range, where they have been since about 1994.

Results from six SESF extension monitor wells (SE77, SE78, SE79, SE80, SE81 and SE86) are also given in Figure 48. Data from these wells are variable, with no concentration exceeding 2 mg/L-N. SE75, SE76, and SE82 through SE85 are not presented, as they are largely below detection limits. Among SE75, SE76 and SE82 through SE85 there were only 8 detections in 42 samples. Excluding the initial samples, which appear to be anomalous, the highest NO_2+NO_3-N result obtained from these wells was 0.052 mg/L.

Sampling of City of Tallahassee public supply well CW-12 is required for background purposes. “SES”, the Floridan Aquifer potable supply well for the facility, is presently sampled quarterly. The City has recently begun to sample the “SE Farmers Well” as well. Two off-site privately owned domestic wells are also being sampled. The “Messer” well has been sampled since 1975. Sampling of the “Barker” well began in 1999. Both wells are up-gradient of the SESF and show NO_3-N levels ranging from below detection limits to 0.44 mg/L.

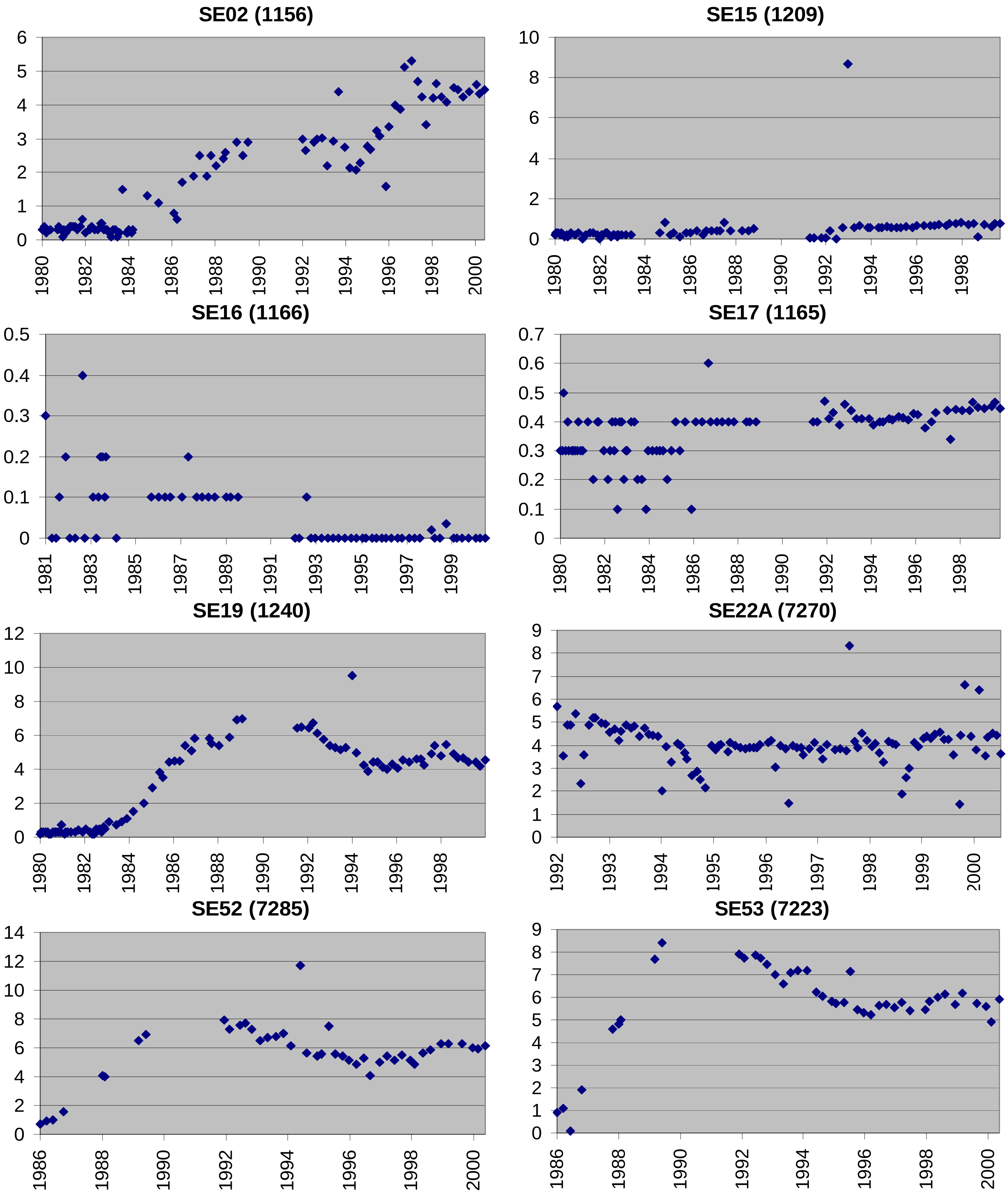


Figure 48. Southeast Sprayfield Monitor Well NO_2+NO_3-N Concentrations (mg/L)

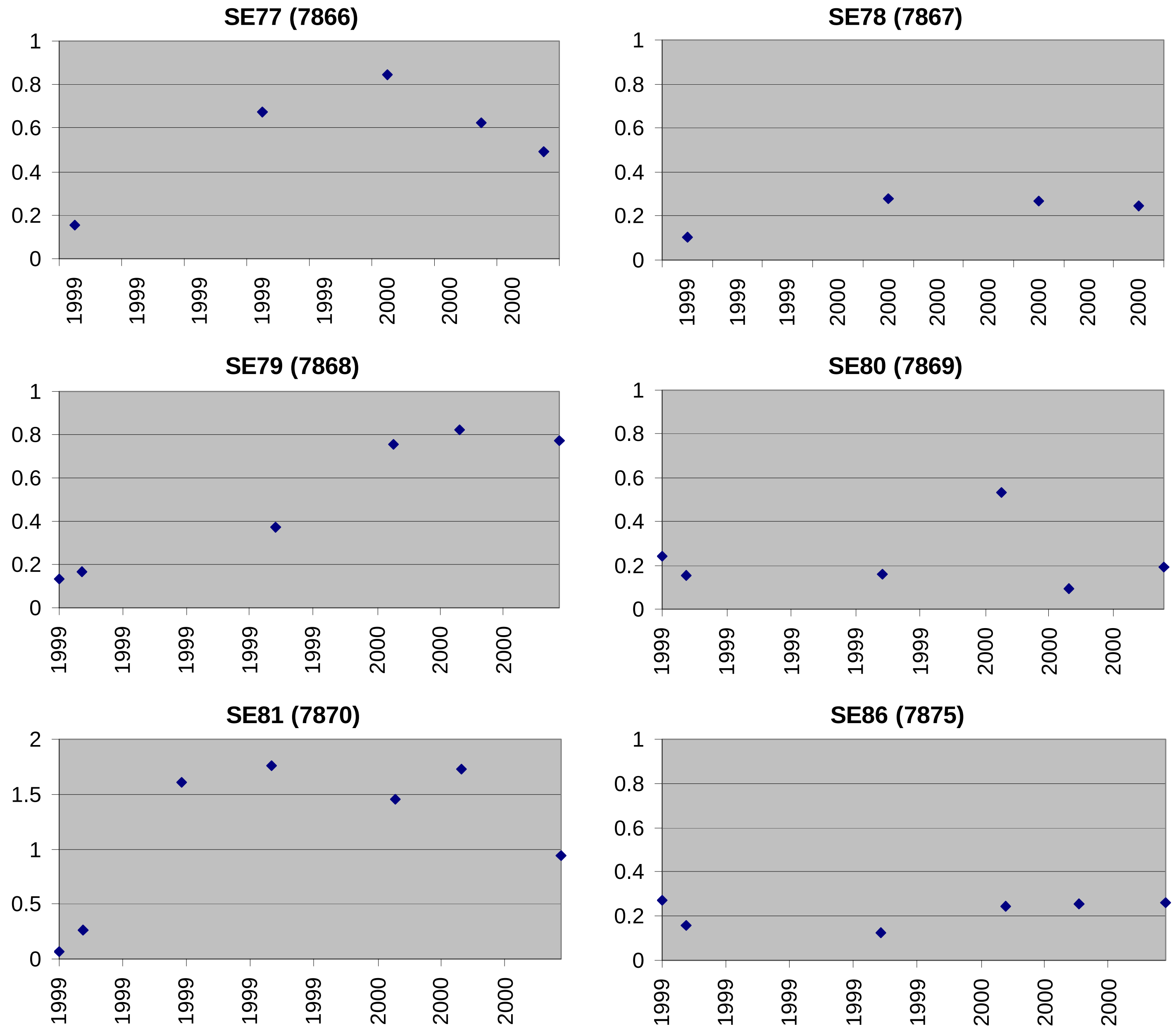


Figure 48. Southeast Sprayfield Monitor Well NO_2+NO_3-N Concentrations (mg/L) [cont.]

Southwest Sprayfield

SWSF has shrunk in the years since 1977 and its spray application area is currently 36 ha (89 acres). There are 43 monitor wells on record as having been constructed at or near the site (Appendix A, Table A9, Figure 49). The City is presently required to sample three Floridan Aquifer wells at the SWSF (LS21, LS25, BOG 6-5 [also called LS32]). Analytical results from these wells have been presented in Figure 50. The data were gleaned from USGS and City of Tallahassee databases and represent analyses for NO_3-N (total), NO_2+NO_3-N (total) and NO_2+NO_3-N (dissolved). These analyses were considered as yielding relatively equivalent results for the purpose of reporting this data. Historically there has been no measurable NO_2 in the ground water of the study area and, presumptively, all detectable NO_3 in ground water is dissolved. LS21 shows a decreasing trend with time; presently concentrations are below 1 mg/L. LS25 and LS32 both show a rapid concentration run-up during the 1980s. Concentrations peaked in excess of 10 mg/L and have since declined to the 6 to 8 mg/L range.

WWTF Residual Disposal

In addition to effluent disposal, the City of Tallahassee also disposes of solidified wastewater residuals, which remain following treatment. The City of Tallahassee provided annual residual TN loads applied to city disposal sites (in pounds) and the area (in acres) where residuals were spread at each site. TN load data and disposal site acreage were provided for the period 1977 through 2000. The annual total N load from all the City of Tallahassee's residual facilities ranged from a low of 70,252 kg-N/yr in 1979 to a high of 185,851 kg-N/yr in 2000.

In the mid-1960s, when the City of Tallahassee beginning began experimental spray application of wastewater effluent, spreading of wastewater residuals was also begun at the Tallahassee Municipal Airport. Currently, using a belt-press or screw press method, water content of the residuals is reduced to 18-20 percent. The solids are then spread with a manure spreader or a pressurized spray truck. The spreading areas (198 ha or 490 ac) at the airport are mostly planted in Bermuda grass, which takes up nitrogen in its growth and is subsequently harvested as hay. A smaller portion of the total spreading area is in planted pines (81.7 ha or 202 ac).

The City of Tallahassee monitors five wells adjacent to the residual disposal sites at the airport. NO_2+NO_3-N concentration data from these wells are given in Figure 51, well construction details are summarized in Appendix A, Table A10. Concentrations in SF01, presently around 15 mg/L, are highest and show the greatest variability over time. SF01 is immediately adjacent to and south of the airport. SF05, located about 0.6 miles south of the airport shows a modest increasing trend, going from 0.9 mg/L in 1992 to 1.3 mg/L in 2000. SF04 also shows an increasing trend, 0.3 mg/L in 1993 to 0.5 mg/L in 2000. Concentrations in SF06 peaked in 1997 and have declined since.

In 1996, the City of Tallahassee began spreading residuals on three farms in Wakulla County as well (Figure 46). Recent ground water sampling at those sites yielded NO_2+NO_3-N concentrations ranging from 0.5 mg/L-N to 8.26 mg/L-N. Having no pre-spreading water quality data from these sites, however, it is difficult to determine how much of this N is the result of residual disposal and how much is the result of previous farming practices. As of 2001, the spreading of residuals in Wakulla County by the City of Tallahassee has been discontinued.

According to FDEP records, the majority of the small WWTFs within the study area dispose of their residuals outside Leon and Wakulla counties. Their residuals go to farms near Wewahitchka in Gulf County. Because of a general lack of data for most of the other WWTF, the diversion of some of their residuals to outside the study area, and the relatively small

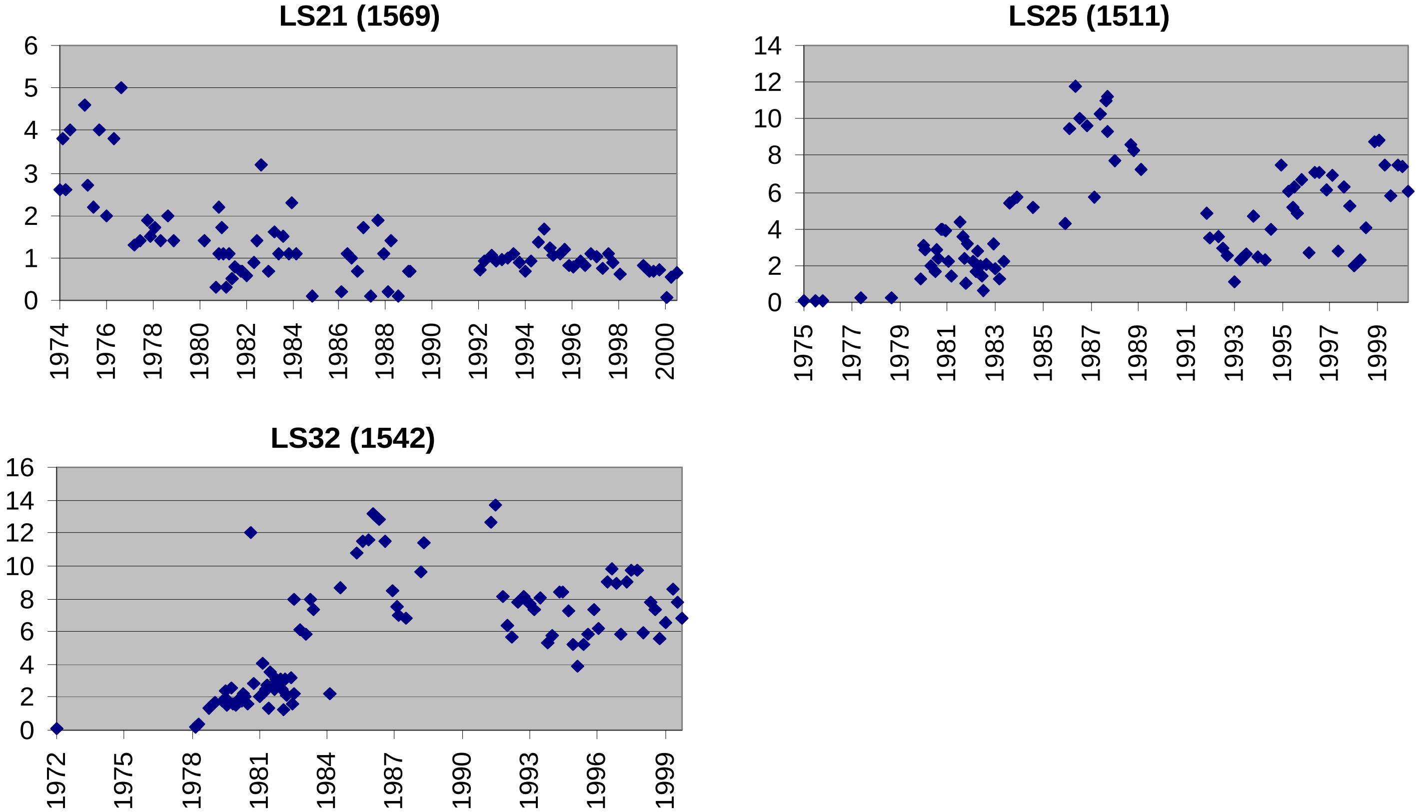


Figure 50. Southwest Sprayfield Monitor Well Nitrate Concentrations (as N, mg/L).

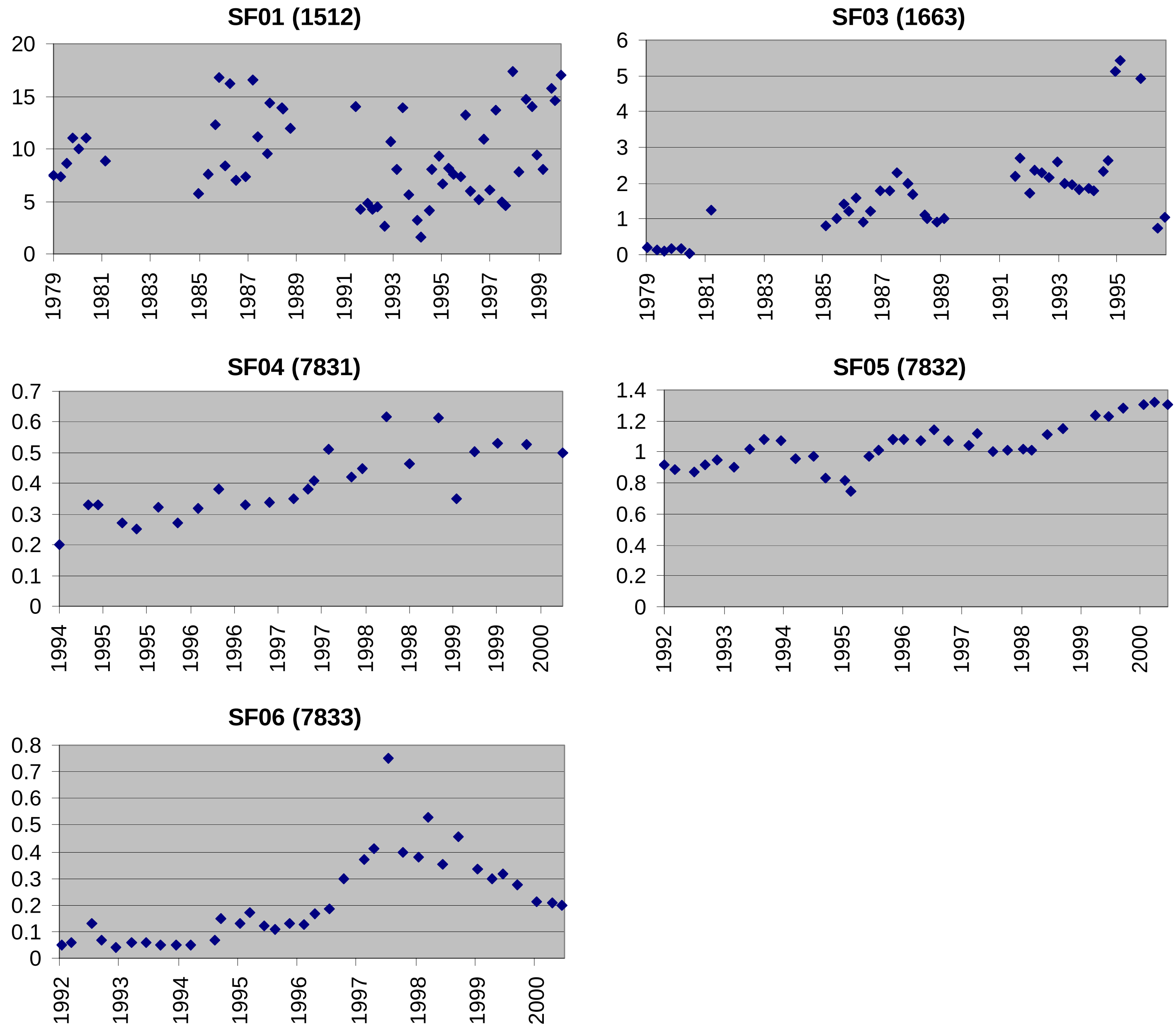


Figure 51. Residual Disposal Area Monitor Well NO_2+NO_3-N Concentrations (mg/L).

percentage of the total WWTF flow that they represent, no attempt was made to estimate the residual nitrogen loading from facilities other than the City of Tallahassee.

Table 7. Estimated 1999 Nitrogen Loading from WWTF Residuals.

Area	Residuals (kg-N/Yr)
Leon Semi-confined	0
Leon Unconfined	78,000
Wakulla Unconfined	99,000

On-Site Disposal Systems

OSDS include septic tanks, cesspits and other non-sewered disposal of domestic wastewater. One of the objectives of this study was to estimate the current number of OSDS in Leon and Wakulla counties and to quantify the role of these systems in the nitrogen budget of the study area. While the City of Tallahassee is fully sewered, much of surrounding Leon County is not. Virtually none of Wakulla County is sewered, the exceptions being St. Marks, Panacea and Crawfordville. St. Marks and Panacea have been sewered since the late 1980s. Crawfordville recently made use of grant funds to sewer their main commercial/industrial area. Residential hook-ups to the Crawfordville system are made on voluntary basis.

According to U.S. Census Bureau data, the population in Leon County grew by 24 percent between 1990 and 2000, from 192,493 to 239,452 (Figure 52). During the same period, the population in Wakulla County increased by 61 percent, from 14,202 to 22,863. The 1990 Census provides the number of OSDS operating in each county but the 2000 OSDS census figures were not available in time to assist with this project. However, using population, per capita and OSDS data from 1990 and population and per capita data from 2000, an estimate of the number of OSDS in both counties in 2000 was made.

According to the 1990 Census, Leon County had 22,090 active OSDS and a household occupancy rate of 2.42 persons. Wakulla County had 5,645 OSDS and a household occupancy rate of 2.71. These numbers were multiplied together to estimate the number of persons using an OSDS in each county in 1990. In Leon County the estimated 1990 population dependent on an OSDS was 53,460. The 1990 OSDS population estimate for Wakulla County was 15,300. These estimates were then compared to the 1990 total population of each county to determine the percentage of the population reliant on an OSDS. These percentages were applied to the 2000 census population data and the results were divided by the 2000 census occupancy rates (2.34 in Leon County and 2.57 in Wakulla County). Based on this approach, during 2000 an estimated 28,417 OSDS were in use in Leon County and 8,896 were in use in Wakulla County.

In order to get the required sense of the spatial distribution of OSDS; a second estimation technique was employed. This approach was based on tax roll parcel data. It was presumed that all parcels with improvements (valued at $400 or greater) required the disposal of sewage. For Leon County, two GIS coverages were obtained from the City of Tallahassee/Leon County Geographic Information Systems department. The first was a map coverage showing both parcels with improvements (valued at $400 or greater) and parcels codes institutional. The second was a point coverage of geo-coded City of Tallahassee sewer billing addresses. The geo-coded billing addresses were intersected with the parcel coverage. All parcels with a City of Tallahassee sewer billing address were presumed not to have an OSDS. A scattering of parcels without a geo-coded billing address remained within the city limits. These were presumed to be sewered and were excluded. This process yielded a total of 27,404 parcels in Leon County that are potential OSDS sites. Of these an estimated 3,100 are known to be served by the sewer services of Talquin Electric Cooperative (TEC). TEC operates three WWTF serving Killearn Lakes, neighborhoods on the southwest side of Lake Jackson and Fallschase. Deletion of households served by TEC yields an estimate of 24,304 OSDS in Leon County (as of 1999) by the parcel-counting technique.

In Wakulla County, a different approach was required. 1999 tax data were obtained from the Florida Department of Revenue. Hardcopy plat maps were obtained from the Wakulla County Property Appraiser's Office. In 1999 there were a total of 8,267 improved parcels in Wakulla County. Of these, only those in the study area were of interest. Using 1994 digital orthoquads

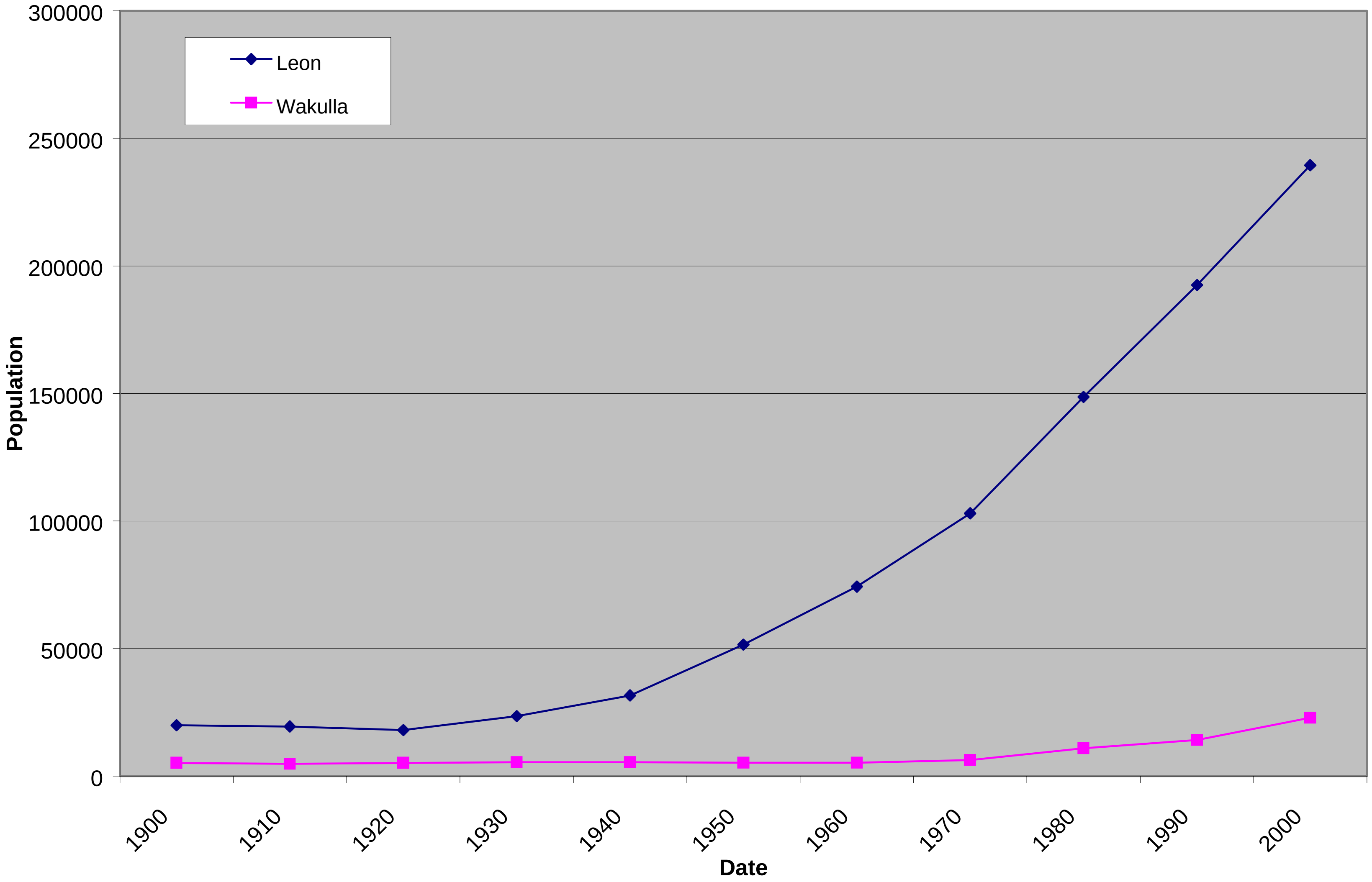


Figure 52. Population Increase in Leon and Wakulla Counties since 1900.

as a base map, the locations of all improved parcels in the study area were manually geo-referenced using parcel identification numbers and hardcopy plat maps. The result was point coverage of all improved parcels in the study area (6,632 parcels). Of these, 119 were served by a WWTF. The remaining 6,513 parcels were presumed to have an OSDS. The number of improved parcels outside the study area was 1,635.

Because the OSDS were given a geographic location, it was possible to disaggregate them according to whether they overlay semi-confined, unconfined or confined portions of the Floridan Aquifer (Figure 53). Leon County was divided into three areas according to the relative permeability of the sediments overlying the Floridan Aquifer. The eastern portion of the county (north of the Cody Scarp) is considered to be under conditions of semi-confinement of the Floridan Aquifer. Southeast Leon County (south of the Cody Scarp) is considered to be under unconfined conditions. Southwest Leon County is considered to be under confined conditions. Based on the delineations found in Figure 53: 17,498 OSDS in Leon County lie in the semi-confined area; 4,290 OSDS lie in the unconfined area; 2,516 OSDS lie in the confined area of the county (total of 24,304). Wakulla County was divided into either unconfined or confined areas (Figure 1). Within the study area in Wakulla County, 6,429 OSDS lie in the unconfined area and 84 lie in the confined area (total of 6,513).

Sarac et al. (2001) examined the behavior of 20 OSDS at a study site in New South Wales, Australia. Based on sampling data from six systems, they calculated annual per capita TN generation rates “at the outlet of the septic tank” averaging 4.0 kg-N/year per capita. They also cite Griffiths (1997) as giving annual TN loading rates ranging between 4.2 and 5.5 kg-N/year per capita.

Horsley and Witten (2000), citing six papers, give a range of total nitrogen concentrations in OSDS effluent of between 23 mg/L and 40 mg/L. They define “in effluent” based on samples taken “from the leaching area or from ground water immediately below the leaching area”. Based on a wastewater flow rate of 208 l/d per capita (55 gal/d per capita) and an average effluent total nitrogen concentration of 35 mg/L, they estimated an OSDS effluent load of 7 gm-N/d per capita (2.6 kg/N/year per capita). Based on a comparison of estimated nitrogen inputs and observed ground water concentrations at six sites (containing 55 residential lots and 34 OSDS), they estimated a 45 percent to 98 percent attenuation of nitrogen contributed to their study area. Ninety-three percent of the total nitrogen load was estimated to come from the 34 OSDS in their study area.

Otis et al. (1993) give a literature-based range of TN concentrations in OSDS influent of between 35 mg/L and 100 mg/L. Based on a wastewater flow rate of 170 l/d per capita (45 gal/d per capita), these concentrations yield OSDS influent load estimates of between 6 and 17 gm-N/d per capita. These equate to annual loads ranging between 2.2 kg-N/year per capita and 6.2 kg-N/year per capita. Otis et al. cite others to observe that OSDS effluent can undergo denitrification in soils beneath the drain field that removes up to 20 percent of the effluent nitrogen. They also observe that fine-grained and/or organic rich soils facilitate denitrification.

Based on Otis et al. (1993), Katz et al. (1999) used 4.09 kg-N/year per capita to estimate nitrogen loads emanating from OSDS within the Suwannee River Basin. The midpoint of the Otis et al. range (4.2 kg-N/year per capita) is used below to estimate OSDS loads in Leon and Wakulla counties (Table 8).

Table 8. Estimated 1999 Nitrogen Loads from OSDS.

Area	# OSDS	Household occupancy	Kg-N/cap/yr	Kg-N/Yr
Leon Semi-confined	17,498	2.34	4.2	172,000
Leon Unconfined	4,290	2.34	4.2	42,000
Wakulla Unconfined	6,429	2.57	4.2	69,000

Annual OSDS TN load estimates (Figure 45) were prepared by linearly interpolating between the 1970 census OSDS count, the 1980 census OSDS count and the 1999 OSDS parcel-based count described above. The 1970 and 1980 OSDS counts represent the number of OSDS in the entirety of Leon and Wakulla counties whereas the 1999 OSDS number is only for the semi-confined and unconfined portions of each county. The number of persons per household was acquired from the census for years 1970, 1980, 1990 and 1999. All other years were interpolated from these. The number of OSDS multiplied by the number of persons per household yields the population utilizing OSDS. Multiplying the population times the per capita load gives the total load for each year.

Commercial Fertilizer Application

Commercial fertilizers represent a significant source of inorganic nitrogen (IN) in the study area. Department of Commerce (DoC) Census of Agriculture (CoA) census data for fertilized acres and for harvested acres show a growth of agriculture in Leon and Wakulla counties from the early 1900s to a peak in the early to mid-1980s. The United States Department of Agriculture (USDA), the DoC CoA, and the Florida Department of Agriculture and Consumer Services (DACS) maintain records of fertilizer sales and distributions within the state. USDA records, covering the period 1945 through 1973, provide annual statewide total fertilizer distributions, as nitrogen in tons. CoA data for 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997 provide fertilizer expenditures on a county-by-county and statewide basis. DACS records, from 1974 through 1999, give statewide total fertilizer distributions on a county-by-county basis. Annual TN load estimates based on these data are given in Figure 45.

With no by-county fertilizer sales data prior to 1974, countywide loads were estimated using the same method as Battaglin and Goolsby (1994). State tonnages of total N for each year were obtained from the USDA and converted to kg/yr. These data were then multiplied by the ratio of county expenditures to state expenditures. For example, in 1964 the Leon County expenditure for nitrogen fertilizer was $314,648 and the Wakulla County expenditure was $22,967. Dividing these numbers by the statewide expenditure of $84,570,575 yields county/state ratios of 3.72 $X10^{-3}$ for Leon County and $2.72x10^{-4}$ for Wakulla County. Multiplying the USDS statewide nitrogen total (117,729,907 kg-N) by these ratios results in an approximate application of 438,073 kg-N in Leon County and 32,022 kg-N in Wakulla County in 1964. For the years 1945 to 1964, the 1964 expenditure ratios were used. From 1965 to 1973, the 1969 county/state expenditure ratios of $3.85x10^{-3}$ for Leon County and $2.73x10^{-4}$ for Wakulla County were used.

More recent data, from 1974 to present, are derived from reported county tonnages for different types of fertilizer, as reported by fertilizer distributors to DACS. Multi-nutrient fertilizer tonnages were multiplied by the percent nitrogen in each to estimate total N. Assumptions were required regarding the percent nitrogen in: liquid fertilizers, nitrogen solutions, and miscellaneous formulations (20 percent each); urea (46 percent); and ammonium nitrate, anhydrous ammonia and ammonium Poly-P (32 percent each) (Bill Cox, DACS, personal communication, 2000). The resulting nitrogen tonnages were subsequently converted to kg/yr.

Both the USDA and DACS numbers are reported distribution amounts from fertilizer distributors/manufacturers and are reported by fertilizer years (July 1 to June 30). The numbers do not account for fertilizer sold in one county and used in another. They assume that fertilizer distributed to a particular county is used in that county. There is also no differentiation between fertilizer used for agriculture purposes and that used for lawn, golf course, recreation area, or other purposes. It is assumed that the predominant use is agricultural in nature. However, to the extent that large, non-farm retailers purchase fertilizer through distributors reporting to DACS, these figures capture fertilizer sold for application in residential settings. It is believed that most of the fertilizer destined for residential application is included in the DACS data. DACS data for the 1992, 1994, and 1996 fertilizer years were incomplete and no values are provided for those years.

To apportion the nitrogen fertilizer application between the unconfined and semi-confined portions of the study area, GIS land-use maps were used to calculate the total area of “pasture and cropland” land use within each county. Land use data were as of 1994-1995. The total area in “pasture and cropland” was further disaggregated into what lies within the semi-confined, unconfined and confined portions of the two counties. Leon County had a total of

14,272 ha of “pasture and cropland”, with 13,002 ha (91 percent) lying in the semi-confined area and 1,071 ha (7.5 percent) in the unconfined area. The remainder (199 ha or 1.5 percent) lies in the confined portion of the county. The attribution of most of the county’s pasture and cultivable land to the semi-confined area is consistent with the disparity in soil suitability for agriculture between unconfined and semi-confined areas. These areal weightings were subsequently applied to the 1999 DACS countywide nitrogen application of 197,000 kg-N. This approach resulted in an estimated 179,000 kg-N having been applied to the semi-confined portion of Leon County and 15,000 kg-N in the unconfined portion of the county in 2000.

This disaggregation of commercial fertilizer use between semi-confined and unconfined underestimates the actual application to the unconfined area, as based on fertilizer application data for the SESF (provided by the City of Tallahassee). According to the “pasture and cropland” land use data available for the unconfined portion of Leon County, SESF is the only such land use. City of Tallahassee records indicate a 1999 nitrogen application of 44,000 kg-N to 691 ha at their facility. Since SESF is the only area designated “pasture and cropland” in the unconfined portion of the Leon County, the nitrogen application to SESF is assumed to represent the entirety of commercial fertilizer applied to this area (Table 9). Inherent in this approach is the assumption that there is no other significant fertilizer application in the unconfined portion of Leon County. The application to the semi-confined portion of Leon County was estimated at 150,000 kg-N. This is the result of 194,000 kg-N (98.5 percent of the countywide total) less that previously attributed to the unconfined portion of the county (44,000 kg-N).

2,294 ha (82 percent) of Wakulla County’s total 2,787 ha of “pasture and cropland” lie within the unconfined portion of the county. The estimated nitrogen application to this area was 18,000 kg-N (82 percent) of the county total 1999 application of 22,000 kg-N.

Table 9. Estimated 1999 Nitrogen (IN) Loads from Commercial Fertilizer.

Area	Kg-N/Yr
Leon Semi-confined	150,000
Leon Unconfined	44,000
Wakulla Unconfined	18,000

Livestock

Animal waste is a source of organic nitrogen (ON). In other areas of the state, elevated levels of nitrogen in ground water have been seen beneath concentrated animal populations such as dairies, feed lots and chicken sheds. To estimate the total nitrogen load from this source, CoA livestock population data were multiplied by the estimated nitrogen mass discharged in waste for each type of livestock. Annual total ON load estimates based on these data are given in Figure 45.

Due to the small number of livestock operations in Leon and Wakulla counties, CoA withheld data for many years to avoid disclosure of information for individual farms. The most recently available data were used to provide estimates of "current" N loads from this source. This means that, in Leon County, 1992 data were used to estimate current populations of beef cattle, 1992 data for dairy cattle, 1987 data for broiler chickens, 1997 data for layer chickens, and 1997 data for swine. In Wakulla County, 1987 data were used to estimate populations of beef cattle, 1982 data for dairy cattle, 1992 data for broiler chickens, 1992 data for layer chickens, and 1997 data for swine. Empirically, this approach probably overestimates "current" N loads from this source, given land use changes that have occurred in Leon and Wakulla counties since these population data were collected. Uncertainty in estimates based on these data is an unavoidable consequence of the limitations associated with these data.

Based on 454 kg (1,000 pounds) of each type of animal, the following daily nitrogen discharges were estimated (American Society of Agricultural Engineers, 1996): (1) dairy cattle—0.18 kg-N/day; (2) beef cattle and broiler chickens—0.5 kg/N/day; (3) egg-laying chickens—0.38 kg-N/day; (4) swine—0.24 kg-N/day. The following average animal masses, in kg, were also assumed: (1) dairy cattle—635 kg; (2) beef cattle—364 kg; (3) broiler chickens—0.9 kg; (4) egg-laying chickens—1.4 kg; (5) swine—61 kg (American Society of Agricultural Engineers, 1996). Combining numbers of animals, average animal mass and N yield per unit animal mass, annual total N loads from this source were estimated.

Using land use mapping and GIS techniques described previously, the countywide total "pasture and cropland" acreage in each county was disaggregated into those portions lying within the semi-confined and unconfined areas. In Leon County 91 percent of "pasture and cropland" lies in the semi-confined area and 7.5 percent in the unconfined area. In Wakulla County 82 percent of the "pasture and cropland" lies in the unconfined area. In Leon County, the countywide total livestock N load was linearly apportioned to semi-confined and unconfined areas based on the above percentages (Table 10). In Wakulla County, this entire load was empirically attributed to the unconfined area.

Table 10. Estimated "Recent" Nitrogen (ON) Loads from Livestock.

Area	% of County LU Pasture Land	Kg-N/Yr
Leon Semi-confined	91	124,000
Leon Unconfined	7.5	10,000
Wakulla Unconfined	82	23,000

Sinking Streams

Four significant sinking streams flow into the Floridan Aquifer from the surrounding landscape. These include Munson Slough and Fisher, Black and Lost creeks. Munson Slough drains much of the southern portion of the City of Tallahassee, eventually sinking at Ames Sink. There are 13 years of continuous streamflow data for Munson Slough at Capital Circle (1987-2000), one mile north of Lake Munson. These data were collected by the NWFWMD. Fisher, Black and Lost creeks flow east through wet pine flatwoods west of the Woodville Karst Plain, eventually sinking on the plain's western edge. Lost Creek has a short period of USGS continuous stream flow data. Fisher and Black creeks have no continuous data and only a few instantaneous data.

Nitrogen is present in these sinking surface waters, almost exclusively in organic form. Inorganic nitrogen is typically present at only very low concentrations. It is believed that the conversion of organic nitrogen to inorganic forms is relatively inefficient within the Floridan Aquifer. As a consequence, sinking streams were not considered to represent a significant loading of inorganic nitrogen to ground waters. Nonetheless, and in attempt to be complete, an effort was made to estimate the total nitrogen load from these sources using existing, limited flow and concentration data (Table 11).

Munson Slough and Ames Sink

Much of the water conveyed south through Munson Slough is stormwater runoff originating from the southern portion of the City of Tallahassee. Ultimately, Munson Slough discharges to the Floridan Aquifer via Ames Sink in southern Leon County. Prior to discharging to the Floridan Aquifer, surface waters flow through Lake Munson and, further south, through Eightmile Pond. Lake Munson is about four miles north of Ames Sink. Eightmile Pond is about a mile north of the sink.

The Lake Munson Basin has an area of 17,800 ha or 68.75 mi^2 (Bartel et al., 1991). Of this area, only about 75 percent (13,350 ha) is thought to contribute stormwater runoff to the lake. The remainder of the basin consists of sub-basins closed in all but the most extreme hydrologic conditions. Bartel et al. (1991) state that, based on long-term hydrologic modeling, only about 12 percent of the total volume of water entering the basin leaves as surface water runoff through Eightmile Pond. The remaining 88 percent evaporates, transpires or recharges ground water as leakage through the beds of Lake Munson and Eightmile Pond.

The majority of water leaving Eightmile Pond flows into the Floridan Aquifer via Ames Sink. Assuming an effective basin area of 13,350 ha and an average rainfall depth of 63 inches, this equates to an average runoff of 29 cfs or 7.6 inches per year. The observed daily mean flow at the point where Munson Slough crosses Highway 319 (about one mile north of the lake) is 44.7 cfs (period of record 1987—2000). Considering evaporation and subsurface infiltration from the lake, the lower of these two estimations was considered more accurate and 30 cfs was used to estimate the long-term surface water inflow at this point to the Floridan Aquifer.

Nitrogen samples were collected from Munson Slough at Oak Ridge Road by the NWFWMD between 02/00 to 01/01. These data had a median total nitrogen concentration of 0.51 mg-N/L (mean=0.57, stdev=0.16, n=7). The median NH_4-N concentration was 0.018 mg/L (mean=0.039, stdev=0.042). The median TKN-N concentration was 0.50 mg/L (mean=0.55, stdev=0.15). The median NO_2+NO_3-N concentration was 0.015 mg/L (mean=0.014, stdev=0.011). The TN median concentration was multiplied by the estimated long-term average flow of 30 cfs to yield an annual load estimate of 13,600 kg-N/yr.

Fisher Creek

Fisher Creek has a basin area of about 11,084 ha (42.8 mi^2). It sinks at a sinkhole located within the Leon Sinks Geologic Area, approximately 0.7 miles due west of Crawfordville Hwy. (30°18'35.115"/84°21'22.783"). Through mid-2001, no continuous streamflow monitoring has been conducted on Fisher Creek. However, a limited number of instantaneous discharge measurements are available. These data were collected by the NWFWMD in the early 1980s at various locations along the lower end of the creek, at or east of the Springhill Road Bridge and by the FDEP at the Springhill Road Bridge. Flow data collection during the study period was beyond the scope of this investigation. Fisher Creek is believed to discharge to the Floridan Aquifer within the Wakulla Springs capture zone.

Fisher Creek at Springhill Road Bridge	03.04.1982	19.8 cfs
Fisher Creek at Springhill Road Bridge	04.07.1982	20.7 cfs
Fisher Creek at Springhill Road Bridge	05.06.1982	3.1 cfs
Fisher Creek 2.7 miles east of Springhill Rd	06.10.1982	4.7 cfs
Fisher Creek at Springhill Road Bridge*	03.07.1997	18.5 cfs
Fisher Creek at Springhill Road Bridge*	08.04.1999	26.6 cfs
Fisher Creek at Springhill Road Bridge*	02.29.2000	4.1 cfs

*Obtained from Richard Wieckowicz, FDEP, personal communication, 2001.

Nitrogen samples were collected from Fisher Creek at Springhill Road by the NWFWMD between 02/00 to 01/01. These data had a median total nitrogen concentration of 0.74 mg-N/L (mean=0.74, stdev=0.18, n=9). The median NH_4-N concentration was 0.017 mg/L (mean=0.016, stdev=0.005). The median TKN-N concentration was 0.72 mg/L (mean=0.73, stdev=0.18). The median NO_2+NO_3-N concentration was 0.004 mg/L (mean=0.008, stdev=0.008). The median of six flow measurements at the Springhill Road Bridge is 19.2 cfs. Multiplying the estimated long-term average flow of 20 cfs by the observed median TN concentration (0.74 mg/L) resulted in a total N load estimate for Fisher Creek of 13,200 kg-N/yr.

Black Creek

Black Creek has a basin area of about 3,800 ha (14.7 mi^2). It sinks at a sinkhole located approximately two miles northwest of the intersection of Crawfordville Hwy and Bloxham Cutoff (30°17'15"/84°22'39"). To date, no continuous flow data has been collected on Black Creek; however, a few miscellaneous measurements are available. Black Creek is believed to discharge to the Floridan Aquifer within the Wakulla Springs capture zone.

Black Creek above sink at culvert	03.03.1982	7.1 cfs
Black Creek above sink at culvert	04.06.1982	14.2 cfs
Black Creek near New Light Church	05.05.1982	1.9 cfs
Black Creek near New Light Church	06.08.1982	0.0 cfs
Black Creek at SR 267*	02.29.2000	6.5 cfs

*Obtained from Richard Wieckowicz, FDEP, personal communication, 2001.

Nitrogen samples were collected from Black Creek by the NWFWMD between 02/00 to 01/01. These data had a median total nitrogen concentration of 1.0 mg-N/L (mean=1.06, stdev=0.23, n=9). The median NH_4-N concentration was 0.017 mg/L (mean=0.072, stdev=0.126). The median TKN-N concentration was 1.0 mg/L (mean=1.05, stdev=0.23). The median NO_2+NO_3-N concentration was 0.008 mg/L (mean=0.014, stdev=0.01). The median of the above five flow measurements is 6.5 cfs. Multiplying the estimated long-term average flow of 6.5 cfs by the median TN concentration (1.0 mg/L) yields an estimated N load of 5,800 kg-N/yr from Black Creek.

Lost Creek

Lost Creek has a basin area of about 18,130 ha (70.4 mi^2). It drains into a sinkhole located on the north side of County Road 374 (30°09'57"/84°23'43"). The USGS has made miscellaneous discharge measurements since 1928. Daily mean flows have been collected since October 1998. For water year 1999, the annual mean flow was 57 cfs (Franklin et al., 1999). This estimated flow may be somewhat low due to low rainfall conditions. At the Tallahassee Airport, 1998 and 1999 experienced a two-year cumulative deficit of 16.6 inches (13 percent of normal rainfall).

Water quality data for Lost Creek are extremely limited. In order to estimate the total N load in the stream, the median TN concentration from Fisher Creek was used to estimate that for Lost Creek. Multiplying the Fisher Creek concentration (0.74 mg/L) by a flow of 60 cfs resulted in an annual TN load of 39,600 kg-N/yr for Lost Creek. Lost Creek is believed to discharge to the Floridan Aquifer outside the Wakulla Springs capture zone.

From anecdotal data and observation, Floridan Aquifer inflow from the sinking streams is quite variable. These streams are often dry during periods of below normal rainfall. During and directly following periods of intense rainfall, the streams may flood and drown the sinks. The water subsides rapidly, however, and inflow returns to relatively low levels. Wakulla Springs' reaction to high inflows from sinking streams is muted by an overall discharge increase caused by rising ground water levels associated with intense rainfall. Figure 29 shows that the conductivity of water discharging from Wakulla Springs dropped 20 percent while the velocity/discharge more than tripled following Tropical Storm Helene. If this increase in discharge had been caused by a significant influx of surface water, conductivity would have been depressed to a value nearer that of surface water.

Ammonia and NO_3-N levels are typically very low in the sinking inflow from surface water bodies. Most of the total nitrogen present in sinking streams is organic in nature and is believed to be mechanically removed from the flow system. The organic N is usually bound up in large-molecule tannins and lignins. These humics are sensitive to pH and tend to flocculate when the surface water encounters more alkaline ground water. Some of the organic N sorbs readily onto colloids. Only a small percentage of the organic N associated with sinking streams is believed to be transformed, through bacterial digestion, into ammonia and made available for nitrification within the Floridan Aquifer.

As part of the study, a high-flow sampling event was conducted at Wakulla Springs. It was found that nitrate concentrations in water discharging from Wakulla Springs was slightly reduced when compared to the low-flow sampling event. This was despite (or perhaps due to) a relatively high inflow rate from sinking streams. All indications are that water entering the ground water flow system from sinking streams travels quickly and its affect on Wakulla Springs water quality is ephimeral. The transient, variable influx from these sinking streams is believed to have a minor effect on the quality of water discharging from Wakulla Springs.

Table 11. Estimated “Recent” Nitrogen Loads from Sinking Streams.

Area	Surface Water Body	Flow (cfs)	Median Concentration (mg-N/L)	Load (kg-N/yr)
Leon Semi-confined	none	0	--	0
Leon Unconfined	Munson Slough	30	0.51	13,600
Wakulla Unconfined	Fisher Creek	20	0.74	13,200
Wakulla Unconfined	Black Creek	6.5	1.0	5,800
Wakulla Unconfined	Lost Creek	60	0.74	39,600

Landfills

There are 31 active landfills in Leon and Wakulla counties. Twenty-four (24) are construction and demolition landfills and three are household garbage disposal sites (the Highway 27 landfill in Leon County and the Lower Bridge and Medart landfills in Wakulla County). There is also a waste tire disposal facility, a transfer station, a land clearing debris disposal, and an unclassified landfill (total of 31). For the 31 active landfills, there are a total of 29 ground water monitoring wells and two surface water monitoring sites. These monitoring sites are located at the three household garbage disposal sites. In addition, there are 26 ground water wells monitoring 33 inactive or closed landfills.

Forty-nine landfills, active and inactive, lie within the semi-confined and unconfined portions of the study area. Seventeen are in the semi-confined area and 32 are in the unconfined area plain. Ground water quality sampling results indicate that the landfills contribute nitrogen to ground water in the form of NH_4 and NO_3. However, no data are available with which to estimate a total nitrogen load emanating from any of these sites. Accordingly, no effort to do so was made as a part of this investigation. At the scale of the study area, landfills are not believed to be a significant source of nitrogen in the Floridan Aquifer.

Summary

TN loads to the landscape in the semi-confined and unconfined portions of the study area under recent conditions are summarized in Table 12. The various approaches used to spatially apportion load estimates to these areas were discussed previously. Figures in this table summarize N loads contributed to the landscape (but not necessarily to the Floridan Aquifer) within the semi-confined and unconfined portions of the study area.

Table 12. Estimated 1999 Nitrogen Loading to the Study Area by Geographic Subdivision.

Source	Predominant form	Semi-confined (kg-N/yr)	Unconfined (kg-N/yr)	Total (kg-N/yr)
Atmospheric Deposition	IN	479,000	523,000	1,002,000
WWTF Effluent	IN	9,000	331,000	340,000
WWTF Residuals	indeterminate	0	177,000	177,000
OSDS	IN	172,000	111,000	283,000
Commercial Fertilizer	IN	150,000	62,000	212,000
Livestock	ON	124,000	33,000	157,000
Sinking Streams	ON	0	72,000	72,000
Total		934,000	1,309,000	2,243,000

For each loading class (excepting OSDS, sinking streams and livestock), the average annual load (1990 through 1999) was calculated (Table 13). Figure 54 includes the estimated contributions attributable to atmospheric deposition and sinking streams; Figure 55 does not. OSDS and livestock data were heavily interpolated during that period. As a result, their respective 1999 values are cited in the above table. Effluent data for the small WWTFs were not readily available for 1990 and 1991. Instead, the 1992 small WWTF value was substituted for the two missing years. Average values for atmospheric deposition, WWTF (effluent and residuals) and commercial fertilizer were calculated directly from previously described data.

Table 13. Ten-Year Average Annual Nitrogen Load to the Study Area by Geographic Subdivision.

Source	Predominant form	Semi-confined (kg-N/yr)	Unconfined (kg-N/yr)	Total (kg-N/yr)
Atmospheric Deposition	IN	619,000	675,000	1,294,000
WWTF Effluent	IN	8,000	363,000	371,000
WWTF Residuals	indeterminate	0	154,000	154,000
OSDS*	IN	172,000	111,000	283,000
Commercial Fertilizer	IN	211,000	104,000	315,000
Livestock*	ON	124,000	33,000	157,000
Sinking Streams*	ON	0	72,000	72,000
Total		1,134,000	1,512,000	2,646,000

*1999 values.

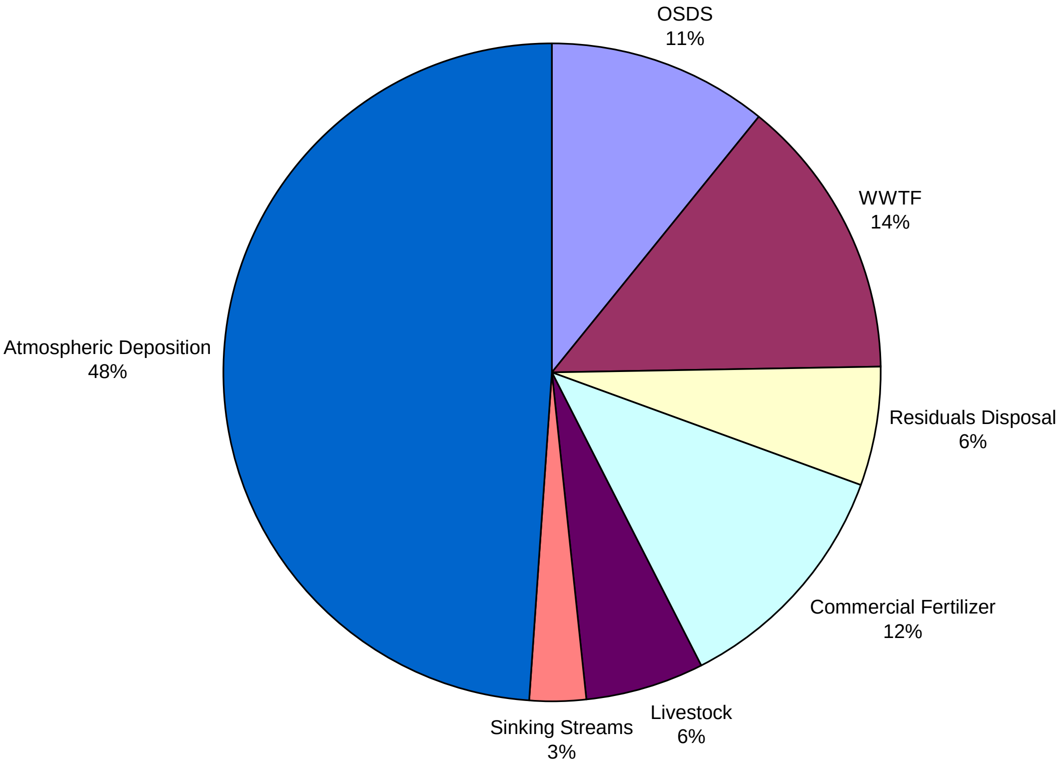


Figure 54. Relative Contribution from Inventoried Nitrogen Sources to 1990-1999 Average N Loading in Semi-confined and Unconfined Portions of Leon and Wakulla Counties.

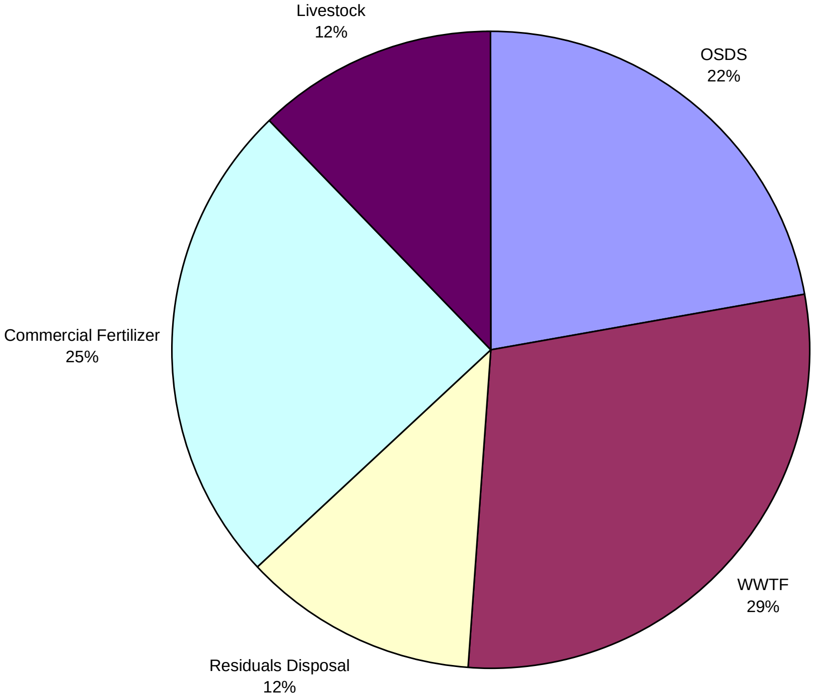


Figure 55. Relative Contribution from Anthropogenic Sources to 1990-1999 Average N Loading in Semi-confined and Unconfined Portions of Leon and Wakulla Counties.

Total nitrogen load by source from 1970 to 1999 is given in Figure 45. Open markers on the timelines represent interpolated or estimated data. Atmospheric deposition data prior to 1984 is represented by the period-of-record median. The commercial fertilizer data has several early years of data calculated from State of Florida data, as explained previously. OSDS and livestock time series involve interpolation between decadal census data. Early WWTF effluent data calculations required assumptions that lent uncertainty. Early residuals data was not available and no attempt was undertaken to estimate it. Flow and sampling data from sinking streams were not sufficient to estimate a time series.

NITROGEN FATE MODELING

One task of this project was to integrate Floridan Aquifer water budget data and information on the fate of nitrogen applied to the landscape into a simple descriptive model. Key aspects of the model are the water budget of a specified aquifer volume, the nitrogen load advected into this volume from up-gradient, and the nitrogen load that originates within the volume. The intent of the model is to anticipate how changes in the nitrogen loading to the landscape could translate into impacts on receiving surface waters. The approach is constrained by the assumptions inherent to the water budget and by an empirically derived model of the landscape's capacity to provide denitrification. Of necessity, this capacity is reduced to a linear relationship. Further, denitrification of all anthropogenic nitrogen sources is modeled by the same linear relationship.

The model is developed for an area in relatively close proximity to Wakulla Springs. This choice removes a number of assumptions required if a larger volume of the aquifer is evaluated. The area of interest is bounded on the north by the Cody Scarp and on the east, south and west by a line that defines the downgradient limit of the Wakulla Springs "contributory zone". This is the aquifer volume thought to contribute and/or convey ground water to the spring. Definition of the volume is based on the observed and simulated Floridan Aquifer potentiometric surfaces in near proximity to the spring. Limitations on the flow system conceptualization around the spring are discussed in the following sections.

Water Budget for Wakulla Springs

Davis (1996) describes a calibrated, steady state regional model of the Floridan Aquifer centered on Leon County. That work serves as the basis of efforts to develop a ground water budget for Wakulla Springs below the Cody Scarp. Davis' work was regional in nature. He did not specifically attempt to develop the capability to simulate local-scale flow in the immediate vicinity of the spring. Attempting to do so here goes somewhat beyond the limits of Davis' model. However, there presently exists no better representation of the near-vicinity Floridan Aquifer ground-water flow around the spring. Davis' model was calibrated to October and November 1991 conditions. At this time, generally dry conditions prevailed and inflows to sinking streams were minimal (Davis, personal communication, 2001).

The program "Zonebudget" (Harbaugh, 1990) was used to estimate ground water inflows and outflows to the area around Wakulla Springs. Application of Zonebudget requires the definition of an aquifer volume of interest. The model uses the simulated cell-by-cell flow terms from the MODFLOW output file to summate inflows and outflows to the volume of interest. The volume of interest (contributory area) is outlined in Figure 56 and has an area of 38,825 ha. It consists of the Floridan Aquifer bounded by the Cody Scarp on the north, by the boundary between confined and unconfined Floridan Aquifer in Wakulla County on the west and by what was initially conceptualized as a no-flow boundary on the south and east. Wakulla Springs is located within the volume of interest. The eastern boundary was positioned on the basis of potentiometric surface maps described earlier. Key to positioning a no-flow boundary in the Floridan Aquifer west of Wakulla Springs is the assumption that the Big Dismal—Turner Sink conduit system eventually flows to Wakulla Springs and, further, that it completely captures Floridan Aquifer ground water flow in its vicinity. This volume was, accordingly, considered to constitute the Wakulla Springs ground water capture zone in the near vicinity of the spring. Obviously, the Wakulla Springs capture zone extends far to the northeast, north and northwest, beneath semi-confined Leon County and confined portions of Leon and Wakulla counties.

The conceptualization of the southern and eastern boundary as no-flow was overturned when Davis' simulated two-ft contours were plotted over the volume (Figure 56). Compared to the contours of Davis, there is good agreement between his flow field and the volume boundary defined east of Wakulla Springs. The conceptualization breaks down west of the spring. Here Davis' model shows significant flow of ground water to the south, past Wakulla Springs and toward Spring Creek. This outflow is consistent with the mapped Floridan Aquifer potentiometric surfaces given earlier. All show a hydraulic gradient to the southwest, away from a line connecting Big Dismal and Wakulla Springs. Indeed, Wakulla Springs itself imparts no perturbation to the potentiometric surface, given the data available to map it.

Likely, ground water flow on the western edge of the Woodville Karst Plain is quite convoluted. Sinking streams have provided large quantities of acidic recharge to the Floridan Aquifer for long periods of time. This has undoubtedly enhanced the development of complex, three-dimensional cavern systems along the boundary where the sinking occurs. The Big Dismal—Turner Sink conduit system may be but one of several systems along this physiographic boundary. It may be that flow in this system entirely bypasses Wakulla Springs. It is possible that the ground water capture zones for Wakulla Springs and Spring Creek overlap in this area with Wakulla capturing water from shallow portions of the Floridan Aquifer and Spring Creek drawing flow from the deeper portions (Figure 57).

Under the presumption that at least part of the water flowing through the Big Dismal—Turner Sink system discharges in Wakulla Springs, positioning a no-flow boundary west of the conduit system is reasonable. However, given the complexity of flow in such a system, the entire concept of being able to locate the two-dimensional expression of a "no-flow" boundary over a complex three-dimensional system may be of limited utility. Thus, while the volume defined earlier is not, in the strictest sense, a "capture zone", it is deemed to be of some utility in defining the area in which land-surface activities influence the quality of water discharged from Wakulla Springs.

Davis simulated the Floridan Aquifer as consisting of two layers. With Zonebudget the layers were aggregated together into one zone and layer inflows and outflows combined. Per Davis' model, four sources of water contribute inflow to the designated volume:

- up-gradient underflow across the Cody Scarp—201 cfs;
- direct recharge within the designated volume—178 cfs;
- leakage through the confining unit on the western edge of the volume—9 cfs;
- up-gradient underflow from beneath the confining unit in western Wakulla County—7 cfs.

Inflows equate to 395 cfs. The bulk of the inflow is derived from two sources, underflow across the Cody Scarp and recharge on the karst plain within the designated volume. Inflows are balanced by:

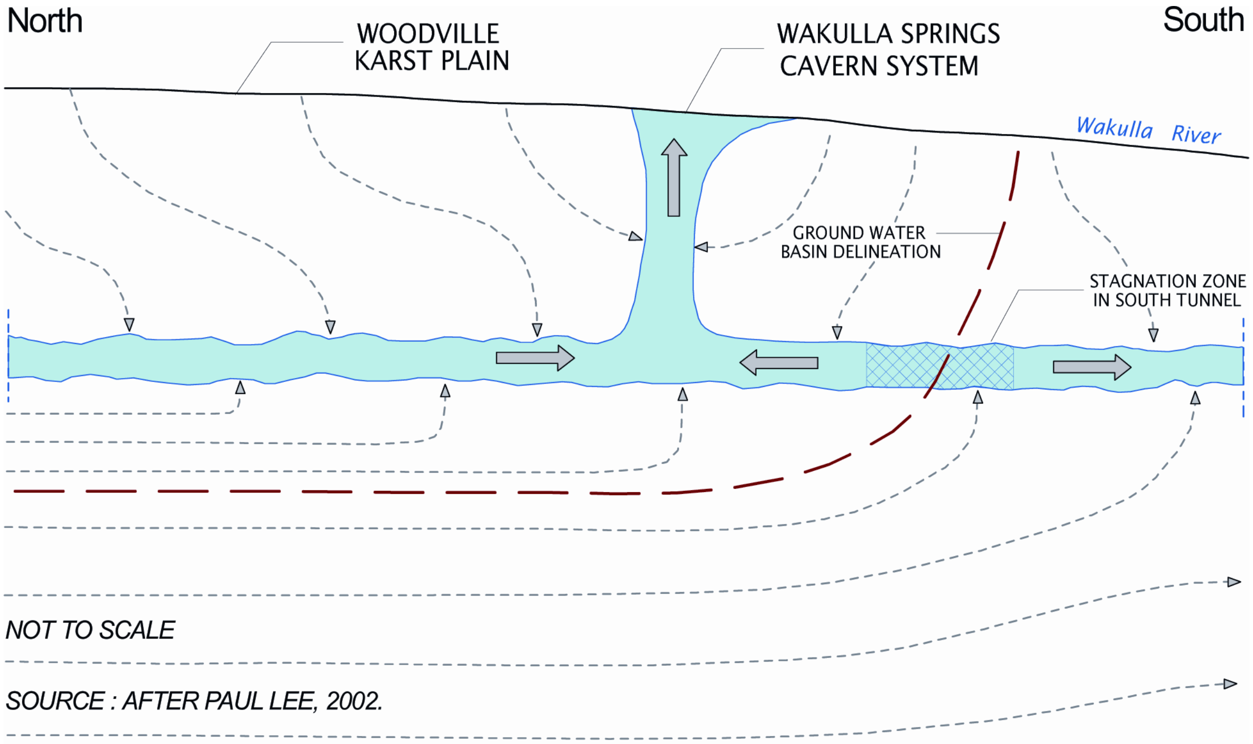
- outflow within the estimated contributory area to river nodes simulating Wakulla Springs—160 cfs;
- outflow that bypasses the drain cells that represent Wakulla Springs—234 cfs.

These outflows equal the simulated inflow.

Davis conceptualized the Wakulla River as a collection of drain (river) cells extending several miles from the headspring toward the confluence of the Wakulla and St. Marks rivers. The aggregate discharge to these cells is 356 cfs. As noted in Figure 56, some of this discharge occurs within the designated contribution area and some occurs outside. However, in aggregation, the simulated Wakulla Springs/River discharge equates to the observed calibration target of 350 cfs. Recalling the regional scale of the model, it was quite sufficient to have the discharge from the spring occur along the reach of the river, as opposed to being concentrated at the headspring. In reality, most of the discharge to the river does occur at the main spring vent.

One way to reconcile the difference between the simulated spring discharge within the contributory area (160 cfs) and the observed discharge (~350 cfs), is to assume that some water simulated as bypassing the spring on the west actually discharges through the spring. This is as opposed to it flowing further south and discharging into the gulf. This equates to assuming that some fraction of the simulated by-pass water eventually discharges from the model via drain (river) cells south of (and outside) the defined aquifer volume. In the absence of a re-calibration of Davis' model (or development of a new model) to the local vicinity of Wakulla Springs, this question is impossible to answer.

For the present discussion, the relevant question is how much of the 200 cfs simulated as crossing the Cody Scarp actually discharges through Wakulla Springs. The most conservative approach is to assume the majority of it discharges through the spring. In this way the nitrogen it carries also discharges through the spring. To the extent this water bypasses the spring, both the water volume and nitrogen mass originating within the contributory area must increase, to balance the spring outflow. To the extent this water bypasses the spring on the west, the contributory area must rotate to the east and/or get smaller to facilitate the by-pass flow.



SOURCE : AFTER PAUL LEE, 2002.

FIGURE 57. CONCEPTUAL GROUND WATER FLOW CROSS-SECTION.

Nutrient Budget for Wakulla Springs

Developing a nutrient budget for a discrete volume of the Floridan Aquifer entails a number of conceptual difficulties. In addition, a number of simplifying assumptions are required. Given the assumptions and limitations associated with this effort, the budget presented here should be viewed as a first-order approximation of a highly complicated, generally poorly understood hydrodynamic system. Key processes known to be highly variable in time and/or space are (of necessity) reduced to simple approximations. In spite of this, the general framework (distribution of nitrogen sources, nitrate concentrations in ground water and ground water fluxes) is believed to be sufficiently well understood to permit construction of a simple nutrient budget for Wakulla Springs.

Inventoried nitrogen sources include predominantly inorganic sources, predominantly organic sources and mixtures of the two. The nitrogen load discharged from Wakulla Springs is predominantly inorganic, in the form of NO_3. Predominantly inorganic sources include atmospheric deposition, commercial fertilizer, OSDS and WWTF effluent. Predominantly organic sources include livestock, WWTF residuals and sinking streams. In addition to being partitioned between organic and inorganic forms, nitrogen goes onto the landscape at various locations throughout the study area. Some of it goes onto the ground in places where the Floridan Aquifer is poorly confined or unconfined. In these areas it is reasonable to presume short vertical travel times for infiltrating water and relatively efficient delivery of dissolved nitrogen to the water table. In other areas, low-permeability materials that slow the vertical transit of water overburden the Floridan Aquifer.

In addition, there are a host of uptakes, transformations and sequestrations that act on mobilized N as it transits the environment. However, little is known about the relative efficiency of these processes at denitrifying various forms of mobilized N at the scale of this particular study area. Presumptively, organic N is relatively inefficiently converted to inorganic forms within the hydrosphere and, by inference, is less likely to become part of the inorganic N load being discharged from the Floridan Aquifer. Presumptively, N applied to the unconfined Floridan Aquifer is relatively more efficiently delivered further down-gradient than is N applied on the semi-confined areas. Presumptively, atmospheric deposition, with its low application rate per unit area, is more efficiently denitrified in the soil than are other sources. However, the veracity of these assumptions is difficult to assess.

Clearly, the water quality of Wakulla Springs has been adversely influenced by anthropogenic impacts. NO_3 concentrations have tripled since the late 1970s. Over the same period it is reasonable to assume that the N load discharged through the spring has also tripled. Further, the increase has occurred over a fairly short time period, on the order of ten years or less. These changes represent a significant impact. Key (and obvious) assumptions are that the nitrogen load discharging through the spring is the product of nitrogen additions to the landscape up-gradient of the spring and that N loadings to the landscape have increased with time.

Because NO_3 comprised the greatest fraction of mobilized N in the Floridan Aquifer, the nitrogen balance is expressed in terms of NO_3. The budget presented here consists of the following components: (1) defining a volume of the Floridan Aquifer that contributes water to the spring, (2) estimating the mass of NO_3 passing into the aquifer volume from up-gradient portions of the Floridan Aquifer, (3) estimating the mass of NO_3 discharging from the spring (4) defining the NO_3 load originating within the volume as the difference between the mass discharged from the spring and that advected in from up-gradient, and (5) assuming that the NO_3 mass originating within the aquifer volume is derivative of the total N mass applied to the landscape on top of the volume. Conceptual limitations and assumptions associated with this effort are outlined below.

Conceptual limitations

- Nitrogen is highly reactive in the hydrosphere.
- Wakulla Springs integrates flow system components over a wide range of time scales.
- The efficiency of de-nitrification processes acting on various anthropogenic N sources is poorly understood.
- The impact of conduit systems on ground-water flow and contaminant transport is poorly understood.

Assumptions

- Water discharging from Wakulla Springs is almost exclusively derived from the Floridan Aquifer much of the time and predominantly from the Floridan Aquifer all of the time.
- Nitrogen sources applied to the landscape in Leon and Wakulla counties are adequately characterized in both time and space.
- Lacking discrete removal efficiencies for each anthropogenic source, removal efficiencies were assumed to be uniform.
- Under steady-state conditions, the flux of Floridan Aquifer water crossing the Cody Scarp that ultimately discharges from Wakulla Springs is about 200 cfs. This is assumed to be about half the steady-state discharge from the spring.
- Within the designated area around Wakulla Springs, recharge to the Floridan Aquifer that ultimately discharges from Wakulla Springs is about 180 cfs. This is assumed to be about half the steady-state discharge from the spring.
- 0.48 mg-N/L is representative of nitrate concentrations in Floridan Aquifer water crossing the Cody Scarp, both presently and in the recent past.
- 0.89 mg-N/L is representative of nitrate concentrations in Floridan Aquifer ground waters discharging from Wakulla Springs, both presently and in the recent past.
- In the near vicinity of Wakulla Springs, nutrients reaching the water table relatively quickly transit the Floridan Aquifer and discharge to surface waters. The presence of conduit flow shortens contaminant travel times relative to a porous media conceptualization.
- The area designated around Wakulla Springs adequately characterizes that portion of the Woodville Karst plain where land use can affect the quality of water discharged from the spring.

- Underflow from beneath the confining unit on the western edge of the karst plain contributes relatively little flow or nutrients to the discharge of Wakulla Springs.

Conceptual Model of Nutrient Budget

The nutrient budgeting effort reduced to an attempt to balance (on a mass basis) the inflow of nitrate into the area defined around Wakulla Springs with the outflow from the spring. The inflow is further divided into two components; underflow from beneath the Cody Scarp and recharge occurring on the karst plain within the contributory area defined around the spring.

$$C_{\text{semi-confined}}V_{\text{semi-confined}} + C_{\text{local}}V_{\text{local}} = C_{\text{spring}}V_{\text{spring}}$$

In this expression C is concentration (mass/volume) and V is ground water flux (volume/time). The expression defines a steady state, instantaneous mixing model of flow and solute transport in an aquifer volume containing Wakulla Springs. In a greatly simplified manner, it approximates the flux of mass into and out of the volume of interest.

One presumptive “known” is the mass of NO_3 discharged from Wakulla Springs ($C_{\text{spring}}V_{\text{spring}}$). Based on 266 instantaneous discharge measurements made between 1907 and 1999, Wakulla Springs has a median flow of 340 cfs. For the purpose of budget development, this flow is used as V_{spring}. As the balance is steady state, use of this flow constrains the inflow ($V_{\text{semi-confined}}$ + V_{local}) to the same value. For comparison, Davis (1996) calibrated a steady state Floridan Aquifer discharge to the Wakulla River of 356 cfs. For the recent past (1989 to 2000) the median Wakulla Springs NO_3 concentration (C_{spring}) is 0.89 mg-N/L (n=26). Combining these data (340 cfs and 0.89 mg/L) gives an estimate of the current annual NO_3 load ($C_{\text{spring}}V_{\text{spring}}$) discharging from the spring, 270,000 kg-N/yr.

A second presumptive known is the NO_3 mass ($C_{\text{semi-confined}}V_{\text{semi-confined}}$) flowing south of the Cody Scarp. Combining the model-simulated flow across this boundary with the estimated representative concentration yields an estimate of this mass. The median NO_3 concentration of 0.48 mg-N/L (n=208, mean=0.48, stdev=0.16) from the six southernmost City of Tallahassee wells in the semi-confined portion of the Floridan Aquifer is used for $C_{\text{semi-confined}}$. Reasons why these data are considered to be broadly representative of conditions in the ground water discharging from beneath the semi-confining unit in Leon County include: relatively long open-hole intervals; wide dispersal of wells; regular pumping at high rates; relatively time-invariant data going as far back as 20 years and relatively small variance in space.

The previously described water budget (Davis, 1996) for the area defined around the spring was 395 cfs, of which 201 cfs represents underflow from the semi-confined area and 178 cfs represents direct recharge. As V has already been constrained to 340 cfs, the model simulated underflow (201 cfs) and local recharge (178 cfs) cannot be directly applied to the balance. For the purpose of budget development and referencing Davis’ approximate 50-50 split between underflow and recharge, 340 cfs was equally divided between underflow and direct recharge. Using the NO_3 median concentration ($C_{\text{semi-confined}}$) of 0.48 mg-N/L and 170 cfs ($V_{\text{semi-confined}}$), a load ($C_{\text{semi-confined}}V_{\text{semi-confined}}$) of 73,000 kg-N/yr was estimated to discharge across the Cody Scarp into the Wakulla Springs contributory area.

The discrepancy ($C_{\text{local}}V_{\text{local}}$ or 197,000 kg-N/yr) between the NO_3 mass originating from beneath the semi-confined area and the mass discharged at the spring vent, of necessity, means that a significant portion of the mass discharged from the spring originates on the karst plain (Figure 56). Whereas, the recharge rate for the contributory area is estimated to be 170 cfs (V_{local}), there is no equivalent area-wide median NO_3 concentration associable with this recharge. However, the combination of this mass flux and volumetric flux equates to an effective NO_3 recharge concentration (distributed over the entire contributory area) of 1.3 mg-N/L.

In an effort to gain insight into nitrate-contributing sources, each of the seven principal nitrogen sources was spatially apportioned as being either inside the Wakulla Springs contributory area or outside it according to the following (Table 24).

- WWTF effluent is the annual average (1990-1999) N load discharged from the City of Tallahassee facilities and three small package plants located within the contributory area. The average load from these facilities is 360,000 kg-N/yr.

- Atmospheric deposition is the contributory area (38,825 ha) multiplied by the estimated average (1990-1999) N deposition (wet + dry) per unit area (5.98 kg-N/yr), or 232,000 kg-N/yr. The median loading rate over the same period was 5.89 kg-N/yr.

- The WWTF residuals load is the (1990-1999) average of N amounts reported by the City of Tallahassee as being spread at the airport sites within the contributory area, or 130,000 kg-N/yr.

- OSDS is the estimated total number of systems presently found in the contributory area (5,600) multiplied by a loading rate of 4.2 kg-N/yr per capita multiplied by an occupancy rate of 2.4, or 56,000 kg-N/yr.

- Commercial fertilizer is based on N amounts sold in Wakulla County, as reported by DACS and actual SESF usage obtained from the City of Tallahassee. The load applied to the Wakulla County portion of the contributory area is estimated by calculating the percentage of the total countywide agricultural land area in the contributory area and multiplying that percentage by the county total average N sales for 1990-1999. The load applied to the Leon County portion of the contributory area is solely the average (1990-1999) N load applied at the SESF as reported by the farm manager. The (1990-1999) estimated average N load applied to the contributory area in both counties is 60,000 kg-N/yr.

- Sinking streams is the sum of the estimated annual load for Munson Slough at Ames Sink, and Fisher and Black creeks, or 32,600 kg-N/yr.

- Livestock is the number of each type of livestock in each county (per the Census of Agriculture) multiplied by literature based loads per animal. These amounts were then disaggregated using the percent of county pastureland within the contributory area in each county. The total for both counties is 14,000 kg-N/yr.

Within the contributory area the 1990-1999 average aggregate load from the above seven sources is about 885,000 kg-N/yr (Table 14). For the purposes of comparison, 1990-1999 median values were calculated and are also presented in this table. The percent apportionment of this load is illustrated in Figure 58.

Table 14. Ten-Year Average and Median Annual Nitrogen Loads to the Wakulla Springs Contributory Area.

Source	Average N Load (kg/yr)	Median N Load (kg/yr)	Percent of Total
WWTF Effluent	360,000	345,000	40
Atmospheric Deposition	232,000	229,000	26
WWTF Residuals	130,000	126,000	15
OSDS	56,000	56,000	6
Commercial Fertilizer	60,000	65,000	7
Sinking Streams	33,000	33,000	4
Livestock	14,000	14,000	2
Total	885,000	868,000	100

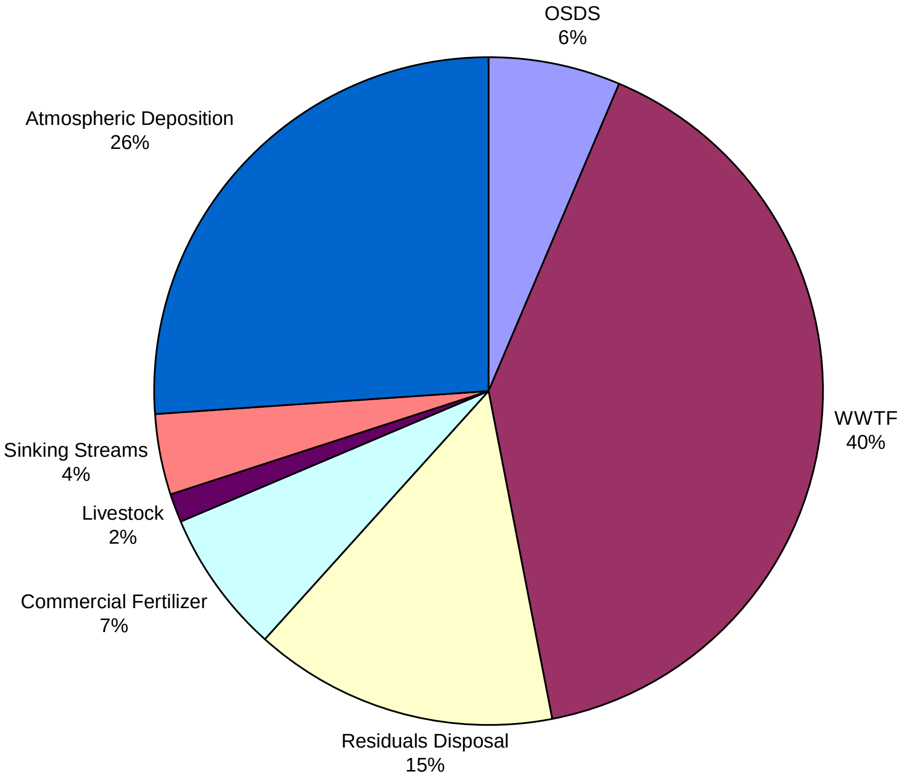


Figure 58. Relative Contribution from Inventoried Nitrogen Sources to 1990-1999 Average N Loading in the Wakulla Springs Contributory Area.

885,000 kg-N/yr represents the 1990-1999 average nitrogen load applied to the landscape within the contributory area. Obviously, this load is subject to de-nitrification as it reacts with the landscape and the hydrosphere. Under the presumption that the nitrogen load applied to the landscape is responsible for nitrate load applied to the underlying ground water, it is possible to estimate the nitrogen removal efficiency of the landscape and the hydrosphere.

Katz et al. (1999) conducted a study of the sources and fate of anthropogenic nitrogen in a similar hydrologic setting within the Suwannee River Water Management District. Specifically, they undertook a comparison of long-term nitrate concentrations in Floridan Aquifer ground water discharging from springs and estimated nitrogen inputs to the landscape up-gradient of the springs. Nitrogen loads identified in their study were principally derivative of agricultural fertilizers. By assuming that the entire fertilizer N load applied to the landscape was converted to nitrate and dissolved in recharge water, they estimated nitrogen removal efficiencies between the point of application and the point of discharge ranging between 50 and 66 percent. When all nitrogen sources (including atmospheric deposition) were considered, they estimated N removal efficiencies ranging between 66 and 75 percent. Under a similar set of assumptions, and assuming that both the estimated annual N landscape load and the estimated annual Wakulla Springs N discharge load are representative of the recent past, the N removal efficiency within the Wakulla Springs contributory area is approximately 78 percent.

That portion of the total Wakulla Springs N load estimated to derive from the contributory area ($C_{local}V_{local}$ or 197,000 kg-N/yr) is assumed to originate from the N load applied to this area. Further, when estimating the removal efficiency it is assumed that local N sources have fully broken through into the spring. That is, sufficient time has elapsed for plumes derivative of these sources to reach the spring and become part of the discharged N load. Put another way, no N released from these local sources is going into storage within the Floridan Aquifer. While there is no way to prove the hypothesis regarding the in=out nature of local N loading to the Floridan Aquifer, to assume otherwise implies that N loads discharged through the spring will increase as more sources break through.

As noted above, nitrogen is applied to the contributory area in a variety of forms (DIN, DON, PIN, and PON). Depending on the form, some sources have a greater potential to impact ground waters than others do. However, little is known about source specific removals. Atmospheric deposition (DIN and PIN) appears to be subject to removals of at least 80 percent between the land surface and immediately underlying ground waters. Based on comparisons between TN in WWTF effluent and DIN in underlying ground waters, effluent is subject to at least a 50-percent removal efficiency between land surface and the water table. PON applied to the land surface is presumed to be inefficiently converted to DIN that eventually reaches ground water, but how poorly is unknown. OSDS are efficient at converting ON to DIN. They are less efficient at de-nitrifying and are relatively efficient at delivering DIN to ground water, particularly in the unconfined part of the sturdy area. The efficiency of de-nitrification within the Floridan Aquifer is virtually unknown. The 77 percent removal efficiency estimated here is an integration of all processes (conversion to DIN and de-nitrification) acting on N applied to the landscape. It appears to be consistent with both the limited information regarding local-scale, source-specific removals and with global-scale removals estimated elsewhere in similar settings.

Based on the load magnitudes involved it seems reasonable to assume that all available sources are required to account for the N load discharged from Wakulla Springs. Three individual sources (OSDS, commercial fertilizer and livestock) are collectively insufficient to account of the spring load, even assuming 100 percent conversion to DIN and zero de-nitrification. If atmospheric deposition were a principal source, DIN concentrations in Middle River Sink would be more similar to those observed in Wakulla Springs. Although the apportionment of impacts at Wakulla Springs to specific sources is beyond both the scope of this work and the limitations of existing data, there is evidence development (including WWTFs and OSDS in Leon and Wakulla counties) is having an impact on the quality of water discharged from the spring.

CONCLUSIONS AND RECOMMENDATIONS

- *The quality of water discharged from Wakulla Springs is predominantly determined by the quality of ground water in the Floridan Aquifer. Under low-flow conditions, discharge from Wakulla Springs is composed almost entirely of ground water from the Floridan Aquifer. Under high-flow conditions, discharge from Wakulla Springs is still primarily composed of Floridan Aquifer ground water. Surface water inputs (via sinking streams and other direct, conduit-type inputs to the Floridan Aquifer) at all times constitute a relatively small fraction of the total discharge from the spring.*

- *The capture zone for Floridan Aquifer discharge features in coastal Wakulla County extends as far north as Mitchell County in southwest Georgia. Volumetrically, most of the water discharged through Wakulla Springs is recharge that occurs on the Woodville Karst plain near the spring or further north in Leon County. The spring is imbedded in a zone of very high Floridan Aquifer hydraulic conductivity that funnels water to the spring from the northwest, north and northeast. The cities of Tallahassee and Woodville, suburbanized Leon County and developing portions of Wakulla County overlie the spring capture zone.*

- *Given its proximity to both the spring and to the high hydraulic conductivity zone lying north of the spring, it is a virtual certainty that Ames Sink contributes water to Wakulla Springs. Fisher and Black creeks, which lie near the presumptive western edge of the capture zone probably contribute water to Wakulla Springs. Lost Creek sinks too far south to contribute water to the spring. This water likely discharges through the Spring Creek group.*

- *Potentiometric surface mapping efforts suggest a significant ground water bypass flow occurring west of Wakulla Springs. To date, efforts to prove the existence of a direct connection between the Big Dismal—Turner Sink conduit system and Wakulla Springs have been unsuccessful. Management and protection efforts for Wakulla Springs will benefit from resolution of this question.*

- *Based on measurements of stream condition index and other observations, the biota of Wakulla Springs and the upper river have been adversely perturbed by anthropogenic impacts. These appear to result from the introduction of invasive exotic plants and increased nutrient discharge from the spring. Effective efforts to manage Wakulla Springs as an esthetic and recreational resource require an improved understanding of the complex interrelationship between nutrient concentrations in spring water and attendant biological perturbations.*

- *Existing data indicate that nitrate concentrations in waters discharging from Wakulla Springs have increased threefold in the past 25 years. This represents a tripling of the total nitrate-N mass discharged from the spring, from an estimated 80,000 kg-N/yr in the mid- to late 1970s to an estimated 270,000 kg-N/yr presently. Isotopic analyses indicate that both inorganic and organic sources contribute to the nitrogen load discharged by the spring.*

- *Assuming that removal efficiencies remain at present levels, the nitrogen load discharged through the spring will increase as the population of Leon and Wakulla counties increases.*

- *Existing data indicate that nitrate concentrations in Floridan Aquifer ground waters beneath the semi-confined potion of Leon County have been constant or slightly increasing over the* *past 20 years. This implies that the flux of nitrate-N from the semi-confined Floridan Aquifer into the unconfined Floridan Aquifer (along the Cody Scarp) has been relatively constant over this period. The estimated nitrate-N mass flux across this boundary under present conditions is 73,000 kg-N/yr.*

- *Analyses presented here indicate that the increase in nitrate-N output from Wakulla Springs over the past 25 years is largely attributable to nitrogen inputs that have occurred south of the Cody Scarp.*

- *At the scale of the entire study area and under current conditions, atmospheric deposition accounts for about half the total N load applied to the landscape. OSDS, WWTF, commercial fertilizer, livestock and sinking streams account for the other half. Ignoring atmospheric deposition and sinking stream inputs, OSDS, livestock and commercial fertilizers are estimated to contribute about 60 percent of the total nitrogen load applied to the landscape. WWTFs contribute the remaining 40 percent.*

- *At the scale of the Wakulla Springs contributory area and under current conditions, WWTFs are estimated to contribute just over half of the nitrogen load applied to the landscape. Atmospheric deposition, OSDS, livestock, commercial fertilizer and sinking streams contribute the remainder.*

- *The analysis presented here presumes a state of quasi-equilibrium between nitrogen applications to the landscape and nitrogen loads discharged through downgradient springs. Assuming that the ability of the landscape and hydrosphere to provide de-nitrification is more or less constant, decreasing the nutrient discharge from springs will require reducing nitrogen loads to the landscape.*

- *Technologies that provide for OSDS de-nitrification (beyond what currently applied technologies give) should be encouraged, particularly south of the Cody Scarp and within the Wakulla Springs contributory area. To the extent they reduce potential numbers of OSDS (or other pollution sources), land acquisitions provide positive water quality benefits.*

- *If additional de-nitrification of large, more concentrated sources (e.g. WWTFs) is contemplated, this should be preceded by consideration of the benefit likely to be derived. Effective cost-benefit analysis presumes a better understanding of both the fate and transport of nutrients derivative of these facilities and the adverse effect of elevated nutrient levels on receiving surface waters.*

- *Nitrogen introduced to the environment via WWTF effluent and residuals disposal comprises a relatively large fraction of the total nutrient budget of the study area. The fate of nitrogen introduced to ground water from these sites is poorly understood, beyond the immediate site perimeters. While the nitrogen budget presented here assumes this nitrogen is reaching Wakulla Springs, there is no direct evidence for this. Additional data collection and monitoring will be required to prove this hypothesis.*

- *Monitoring the evolution of nutrient plumes emanating from concentrated points of application is not a trivial undertaking. The effort is significantly complicated by the length scales involved and by the cryptic way in which conduit flow in a karst environment influences contaminant transport.*

- *Continuing, long-term monitoring of streamflow and water quality (potentially Munson Slough, Black, Fisher and Lost creeks, and St. Marks River) and spring flow (Wakulla Springs and St. Marks Rise) will provide a better understanding of ground-water/surface-water interactions on the Woodville Karst Plain.*

- *The age dating of ground and surface waters is an important tool in the identification ground water/surface water interactions (and associated time scales). Continued speciation of nitrogen isotopes will further elucidate the significance of various inputs of organic and inorganic nitrogen to ground waters.*

- *This study greatly benefited from accurate and precise data on effluent and residual loads. Future studies in this (and other areas) will benefit from similar high quality data for other nitrogen streams, in addition to effluent and residuals.*

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APPENDIX A

Table A1. Construction Details of Wells Used for Water Level Monitoring.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
372	300645084223701	AAA0525	WAKULLA PK REC WELL	120	35	32.14	300654.83	842236.93
467	300907084172701		WELCH WELL	185	26	20.64	300904.695	841727.756
507	300930084210301	AAA6529	R. BREG	100	28	20.72	300931.168	842105.795
554	301008084123801	AAA0526	PURDOM #4	106	71	11	301008.08	841238.12
556	301011084190401	AAA6514	P. HAND	90	19	25.54	301008.561	841859.923
585	301032084144001	AAA6530	T&T HIDEAWAY	100	60	3.95	301033.448	841440.886
607	301053084192101	AAA6769	N. WOOTEN	98	40	20.94	301053.145	841923.184
613	301059084204002	AAA6499	D. BRAZIER	35		13.87	301104.351	842040.028
635	301115084241201	AAA0523	USGS ARRAN WORK CTR	129	75	32.23	301114.08	842412.23
654	301130084215801	AAA6526	R. WARREN	70	60	27.56	301125.886	842155.712
663	301145084192201	AAA6527	N. GARCIA	60	38	23.39	301144.655	841925.53
671	301156084103501	AAA0527	NEWPORT RECREATION	69	12	6.96	301156.1	841035.73
705	301300084152501	AAA0245	GODARD PLANTATION	48	21	21.04	301258.45	841524.41
713	301315084202801	AAA6506	CLEMENS / HICKS	60	40	15.58	301311.397	842026.961
715	301323084133001		RUTHERFORD WELL	0	0	14.53	301319.582	841327.906
728	301337084204001	AAA6522	R. MCKEITHON	75	36	18.32	301335.989	842039.067
746	301402084222801	AAA6521	P. CAUSSEAUX	60	23	21.26	301402.922	842227.469
769	301427084144601	AAA6534	PENNINGTON,DAU-VAUSE	65	37	18.08	301426.367	841439.587
802	301505084200801	AAA6516	C WELCH	57	25	14.96	301503.678	842017.345
876	301700084205201	AAA6519	MARSHALL WELL	70	42	20.17	301701.015	842052.088
900	301725084122601	AAA0296	WALTER GERREL	70	40	30.26	301725.62	841227.07
977	301844084173501	AAA6984	CHARLES DONAHUE	80	56	25.69	301840.88	841738.27
978	301844084173502	AAA6985	C DONAHUE DEEP	157	113	25.21	301839.49	841738.07
1003	301857084180401	AAA0262	SPRIGGS AG WELL	148	110	25.04	301857.52	841804.01
1017	301904084183601	AAA6778	S CAMPELL	80	36	23.27	301903.86	841835.75
1028	301910084174901	AAA0260	J. LEWIS	50	35	23.03	301909.74	841748.59
1164	302051084120901	AAA2999	SE22 (1164)	127	102	27.96	302051.093	841208.793
1204	302109084154701	AAA0281	BIKE TRAIL WELL	90	80	37.33	302110.05	841543.34
1276	302135084202001	AAA0258	LS20 (1276)	145	145	29.24	302133.76	842019.13
1344	302203084110001	AAA2976	SE48 (1344)	95	89	54.18	302148.151	841039.476
1417	302235084190301	AAA0255	LS04 (1417)	53	38	44.56	302235.53	841902.33
1427	302237084211301		BETTY KELLY	160		33.1	302236.977	842112.247
1569	302315084192801	AAA2936	LS21 (1569)	248	247	58.32	302317.474	841927.976
6101	301230084215001	AAA2122	JIMMIE PETTY	80	29	18.54	301238.69	842147.05
6102	301322084204001	AAA2121	DENHARDT	140	32	19.34	301324.65	842040.19
6105	300755084211301	AAB2403	JAMES EMMONS	60	38	20.43	300750.85	842121.78
6108	301104084255401	AAB2406	RICHARD SANDERS	74	52	44.87	301059.8	842546.52
6127	301242084213201	AAB2407	J.W. COOPER	80	28	24.85	301744.96	842132.05
6128	301736084194601	AAB2408	J.J. FLORES	60	20	17.22	301742.67	841950.64
6135	301712084211401	AAB2409	A. SCOTT	28	22	24.05	301714.09	842115.9
6200	301819084134001	AAA3053	DISC VILLAGE	140	40	44.13	301819.865	841340.22
6282	301050084150101	AAB2413	CHRIS RACKLEY	80	60	10.52	301050.04	841501.09
6311	301230084214001	AAB2411	MARK SMITH	65	55	24.91	301226.4	842131.96
7105	301422084183601	AAA6779	WAKULLA SPRINGS PARK	65	57	16.01	301423.212	841837.263
7221	301546084163001		ROBERT SMITH	100	30	34.83	301617.703	841542.005
7222	301158084135501	AAA3011	MARTHA DINGLER	100	21	13.99	301158.51	841355.74
7223	302050084110502		SE53 (7223)	100	93	27.9	302050.127	841105.812

Table A1. Construction Details of Wells Used for Water Level Monitoring [cont].

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
7234	301550084153001	AAA7793	KATHY CAUSSEAX	99	42	26.96	301550.14	841530.16
7238	301815084092601	AAG8892	DICK WEST	56	26	21.30	301829.703	840926.607
7239	301548084130301	AAA7822	WINCO #1	150	60	41.2	301548.337	841303.009
7492	300911084162301	AAB2437	NITRATE #1	247	229	16.97	300911.978	841623.956
7493	300915084162501	AAB2438	NITRATE #2	120	105	16.36	300915.464	841625.286
7494	301446084184601	AAB2439	NITRATE #3	270	250	13.12	301446.984	841846.815
7495	301448084184601	AAB2440	NITRATE #4	70	50	13.46	301448.235	841846.882
7498	302037084082701	AAB2441	NITRATE #5	270	253	28.56	302037.881	840827.329
7499	302039084082601	AAB2442	NITRATE #6	90	70	28.35	302039.364	840826.19

Table A2. Construction Details for Wells Used in 1997 Sampling Event.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
231	295953084290101	AAA0524	OCHLOCKONEE ST PK #1	74	41	11.54	295957.743	842859.776
251	300117084330501	AAA6504	J. GLOW	142	116	10	300120.271	843303.995
276	300320084285201	AAA6775	GRIFFIN HM & CRM STR	110	60	17	300319.068	842850.962
278	300328084292201	AAA6770	REVELL WELL BACKYARD	181	131	28	300328.311	842920.746
280	300330084301501	AAA6502	B. PORTER	100	97	12	300327.271	843013.751
313	300422084304001	AAA6771	F. LAWHON	153	123	30	300441.358	843103.182
325	300500084232001	AAA6776	BROWN TRLR & SEAFOOD	95	78	34	300500.706	842319.066
326	300500084373501	AAA6512	L ROBERTS	210	166	35	300501.748	843740.395
330	300516084311101	AAA6772	J CRAIG	98	65	15	300511.885	843108.078
334	300526084300301	AAA6503	PATRICK HARRINGTON	140	66	40	300520.051	842956.618
338	300529084321501	AAA6773	MCCAULEY FLOWER SHOP	139	88	43	300527.213	843215.796
339	300530084221501	AAA6508	MCDONALD #2	63	52	32	300534.588	842220.049
343	300550084224401		M. WIGGINS	120	60	37	300550	842244
344	300550084315201	AAA6501	B. AREND	123	100	35	300550.623	843156.107
351	300618084193801	AAA7842	TEC-GULF COAST 1	205	131	14.07	300614.746	841936.133
354	300628084213801	AAA6538	J. EWING	127	68	27	300622.036	842143.617
356	300629084294701	AAA6510	LYNN FORMERLY QUIGG	120	70	45	300626.297	842948.062
363	300638084223101	AAA6537	GAIL DEFEND	190	37	35	300643.443	842227.557
372	300645084223701	AAA0525	WAKULLA PK REC WELL	120	35	32.14	300654.83	842236.93
381	300705084220901	AAA6774	CRONAN	80	40	28	300708.737	842207.477
391	300740084235201	AAA6536	D. SHORES	41	32	25	300739.691	842354.6
399	300755084184801	AAA6531	C. COOMBS	150	38	23	300754.644	841848.801
402	300757084240501	AAA6524	R. GILLESPIE	70	58	43	300751.153	842422.741
412	300810084202501	AAA6532	R. HUGUENIN	90	87	10	300812.514	842030.139
507	300930084210301	AAA6529	R. BREG	100	28	20.72	300931.168	842105.795
527	300943084234301	AAA6535	W. HARVEY	55	23	23	300940.245	842342.519
544	300957084240901	AAA6539	J. REEVES	118	97	32	300956.55	842409.692
547	300959084244701	AAA6513	VIRGO IS THE BUILDER	106	66	37	301005.715	842435.674
564	301018084242301	AAA6498	S. EDWARDS	95	55	35	301017.629	842424.071
607	301053084192101	AAA6769	N. WOOTEN	98	40	20.94	301053.145	841923.184
613	301059084204002	AAA6499	D. BRAZIER	35		13.87	301104.351	842040.028
635	301115084241201	AAA0523	USGS ARRAN WORK CTR	129	75	32.23	301114.08	842412.23
641	301119084210601	AAA6525	D. BLACKSTAD	60	44	18	301120.086	842103.815
648	301124084153701		GODDARD PLANT. #1	45	18	6	301124	841537
653	301128084251401	AAA6515	DONNIE SPARKMAN WELL	105	76	41	301134.741	842520.629
654	301130084215801	AAA6526	R. WARREN	70	60	27.56	301125.886	842155.712
658	301135084183402	AAA7841	TEC-GULF COAST #3	322	140	27	301134.067	841833.519
663	301145084192201	AAA6527	N. GARCIA	60	38	23.39	301144.655	841925.53
674	301200084183601	AAA6528	JOHNSON, THOMAS	86	22	25.46	301201.552	841835.776
698	301252084214101	AAA6523	G. RUIS	48	36	18	301251.137	842141.247
701	301256084202001	AAA6500	A. CONNER	49	25	17	301253.909	842028.474
702	301256084202501	AAA6509	K. KEY	50	16	16	301253.123	842028.908
710	301310084402001	AAA6511	M. BERG	170	94	60	301311.632	844020.202
713	301315084202801	AAA6506	CLEMENS / HICKS	60	40	15.58	301311.397	842026.961
717	301324084132601	AAA6517	S. B. SMITH	50	18	17	301323.868	841427.306
728	301337084204001	AAA6522	R. MCKEITHON	75	36	18.32	301335.989	842039.067
746	301402084222801	AAA6521	P. CAUSSEAUX	60	23	21.26	301402.922	842227.469
769	301427084144601	AAA6534	PENNINGTON,DAU-VAUSE	65	37	18.08	301426.367	841439.587

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
801	301505084080401	AAA6505	NETTLES	43		12	301505.123	840905.821
802	301505084200801	AAA6516	C WELCH	57	25	14.96	301503.678	842017.345
831	301609084145201	AAA6518	J. MCCABE	115	39	43	301604.597	841453.6
977	301844084173501	AAA6984	CHARLES DONAHUE	80	56	25.69	301840.88	841738.27
978	301844084173502	AAA6985	C DONAHUE DEEP	157	113	25.21	301839.49	841738.07
998	301855084145001	AAA3056	WOODVILLE #1	199	117	35	301900.12	841449.564
1007	301900084141801	AAA3055	WOODVILLE #2	200	122	35	301859.579	841419.674
1020	301905084201701		TEC-SOUTHERN PINES	287	286	35	301905.23	842018.305
1056	301930084185801		TEC-FOREST PARK #1	200	112	27	301941.204	841923.219
1103	302007084231901	AAA0290	TROUT POND	340	307	92	302008.47	842317.96
1156	302049084120901	AAA2994	SE02 (1156)	46	42	26.05	302049.917	841208.043
1164	302051084120901	AAA2999	SE22 (1164)	127	102	27.96	302051.093	841208.793
1166	302051084123502	AAA2996	SE16 (1166)	70	60	29.84	302052.148	841234.927
1233	302116084123701	AAA2960	SE01 (1233)	71	57	20.38	302115.897	841237.083
1240	302117084113801	AAA2989	SE19 (1240)	74	52	46.88	302117.909	841137.766
1290	302141084123602	AAA2962	SE15 (1209)	102	96	34.8	302141.996	841234.172
1511	302303084190901	AAA2937	LS25 (1511)	69	54	65	302303.984	841909.125
1512	302303084213701		SF01 (1512)	40	26	35.28	302304.129	842136.789
1542	302309084185701	AAA8325	LS32 (1542)	80	58	64.05	302317.474	841927.976
1569	302315084192801	AAA2936	LS21 (1569)	248	247	58.32	302334	842229
1663	302334084222901		SF03 (1663)	88	60	76.73	302442.119	841536.721
2043	302445084154501	AAA3695	TALLAHASSEE #27	316	150	70	302454	842004
2106	302513084160901	AAA3697	TALLAHASSEE #12	365	192	125	302536.846	841328.567
2196	302535084132902	AAA3702	TALLAHASSEE #17	483	314	210	302559.878	841628.907
2333	302558084162601	AAA3698	TALLAHASSEE #3	380	185	150	302609.601	841853.267
2375	302607084185201	AAA3696	TALLAHASSEE #15	315	127	116	302609.243	841640.086
2377	302608084164101	AAA3084	TALLAHASSEE #1	341	176	125	302644.516	841701.674
2573	302644084170101	AAA3704	TALLAHASSEE #9	347	187	140	302655	840730
2621	302655084175502	AAA3707	TALLAHASSEE #5	390	222	141	302710.797	841633.961
2692	302710084163002	AAA3083	TALLAHASSEE #2	415	213	186.82	302713.682	841627.121
2706	302714084162701	AAA3703	TALLAHASSEE #4	424	228	193	302713.684	841709.227
2707	302714084170701	AAA3705	TALLAHASSEE #7	355	170	162	302713.684	841723.288
2708	302714084172301	AAA3706	TALLAHASSEE #6	281	150	137.5	302723.4	841838.16
2742	302722084184101	AAA3157	TALLAHASSEE #13	365	192	157	302727	841111
2782	302731084154301	AAA3699	TALLAHASSEE #10	442	242	192	302802.278	841632.149
2863	302801084163401	AAA3082	TALLAHASSEE #8	466	233	187	302829	841233
2957	302838084204302	AAA3087	TALLAHASSEE #23	410	250	120	302858.44	841146.667
2990	302856084112101	AAA3694	TALLAHASSEE #22	190	101	90	302905.283	841009.465
3013	302903084101001	AAA3085	TALLAHASSEE #21	280	180	110	302940.199	842018.96
3021	302908084202002	AAA3700	TALLAHASSEE #19	428	290	193	302909.603	841054.482
3028	302910084105601	AAA3693	TALLAHASSEE #20	245	151	145	302936.243	841710.326
3108	302939084164301	AAA3692	TALLAHASSEE #11	454	274	230	303010.799	841354.468
3181	303012084135302	AAA3088	TALLAHASSEE #16	310	257	180	303030	841734
3379	303126084141302	AAA3086	TALLAHASSEE #18	388	267	185	303206	840744
3522	303225084103001	AAA3089	TALLAHASSEE #29	405	250	158	303228	841827
3691	303335084163701	AAA3691	TALLAHASSEE #25	450	305	235	303347	841938
3946	303522084154401	AAA3090	TALLAHASSEE #31—AH2	317	190	206	302847.275	841903.349
5851	302847084190502	AAA3156	TALLAHASSEE #26	407	309	135	302050.127	841105.812
7223	302050084110502		SE53 (7223)	100	93	27.9	302146	841103
7268	302146084110301	AAA3011	SE11N (7268)	70		55.23	302146	841103
7269	302146084110302	AAA3012	SE11S (7269)	88		55.21	302051.303	841205.68

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
7270	302051084120501	AAA2969	SE22A (7270)	121		31.87	302050.365	841105.868
7285	302050084110501	AAA2972	SE52 (7285)	53		29.41	302838.317	840422.761
7796	301408084180501		WAKULLA BOAT DOCK			2	301900	841835
7831	302325084221701		SF04 (7831)	98	90	100.02	302230.12	842131.32
7832	302230084213101		SF05 (7832)	29		35.17	302303.84	842110.86
7833	302303084211001		SF06 (7833)	63		60.26	302304.05	841857.76

Table A3. Construction Details for Project Sampling Sites.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
318	300436084251902	AAA0244	SOPCHOPPY #2	200	85	25.35	300437.24	842511.27
329	300516084094801	AAA0528	REFUGE HEADQUARTERS	65	45	13	300532.287	840942.005
351	300618084193801	AAA7842	TEC-GULF COAST #1	205	131	14.07	300614.746	841936.133
372	300645084223701	AAA0525	WAKULLA PK REC WELL	120	35	32.14	300654.83	842236.93
391	300740084235201	AAA6536	D. SHORES	41	32	25	300739.691	842354.6
544	300957084240901	AAA6539	J. REEVES	118	97	32	300956.55	842409.692
564	301018084242301	AAA6498	S. EDWARDS	95	55	35	301017.629	842424.071
607	301053084192101	AAA6769	N. WOOTEN	98	40	20.94	301053.145	841923.184
635	301115084241201	AAA0523	USGS ARRAN WORK CTR	129	75	32.23	301114.08	842412.23
641	301119084210601	AAA6525	D. BLACKSTAD	60	44	18	301120.086	842103.815
650	301126084050601	AAB2427	GAME CHECK STATION	36	14	14.78	301128.601	840505.59
653	301128084251401	AAA6515	DONNIE SPARKMAN WELL	105	76	41	301134.741	842520.629
658	301135084183402	AAA7841	TEC-GULF COAST #3	322	140	27	301134.067	841833.519
663	301145084192201	AAA6527	N. GARCIA	60	38	23.39	301144.655	841925.53
674	301200084183601	AAA6528	THOMAS JOHNSON	86	22	25.46	301201.552	841835.776
705	301300084152501	AAA0245	GODARD PLANTATION	48	21	21.04	301258.45	841524.41
713	301315084202801	AAA6506	CLEMENS / HICKS	60	40	15.58	301311.397	842026.961
717	301324084132601	AAA6517	S. B. SMITH	50	18	17	301323.868	841427.306
774	301430084184001		SALLY WARD	55		5	301430	841840
801	301505084080401	AAA6505	NETTLES	43		12	301505.123	840905.821
900	301725084122601	AAA0296	WALTER GERREL	70	40	30.26	301725.62	841227.07
1020	301905084201701		TEC-SOUTHERN PINES	287	286	35	301905.23	842018.305
1056	301930084185801		TEC-FOREST PARK #1	200	112	27	301941.204	841923.219
1176	302056084214901		BRATCHER	80		45.9	302055.312	842150.846
1261	302125084182301		HIERS	100		27	302126.483	841822.072
1399	302229084064902	AAA0297	TUNNINGTON NEW	211	150	150	302231.686	840644.565
1427	302237084211301		BETTY KELLY	160		33.1	302236.977	842112.247
2045	302445084194101	AAA6767	GOLF COURSE WELL	80	60	38.38	302445.46	841940.72
2562	302642084041501		WINDHAM	73	66	151.27	302641.718	840412.345
2749	302724084114501	AAA3064	MEADOW HILL S/D	253	123	135	302736.426	841150.216
2923	302829084123301		JIM GREGORY	187	97	120	302829	841233
6493	301542084213501	AAA1786	K.L. CLAYCOMB	180		25	301542.415	842135.071
7240	301547084131101	AAA7823	WINCO #2	160	60	20	301547.687	841311.714
7261	300007084283801	AAA7844	OCHLOCKONEE ST PK #2	80	66	10	300007.797	842838.855
7348	300826084175301	AAB1683	STEVE GRANTHAM	142	25	13	300826.9	841753.49
7353	300844084183001		CHARLIE MILLER	151	148	25	300846.008	841831.956
7492	300911084162301	AAB2437	NITRATE #1	247	229	16.97	300911.978	841623.956
7493	300915084162501	AAB2438	NITRATE #2	120	105	16.36	300915.464	841625.286
7494	301446084184601	AAB2439	NITRATE #3	270	250	13.12	301446.984	841846.815
7495	301448084184601	AAB2440	NITRATE #4	70	50	13.46	301448.235	841846.882
7498	302037084082701	AAB2441	NITRATE #5	270	253	28.56	302037.881	840827.329
7499	302039084082601	AAB2442	NITRATE #6	90	70	28.35	302039.364	840826.19
7734	301421084161201		MCBRIDE SLOUGH			7	301421	841612
7735	301033084240101		LOST CREEK @FR13			17	301033	842401
7736	301926084182001		MUNSON SL@OAKRIDGE R			13	301926	841820
7737	301848084233601		FISHER CR@SPGHILL R			37	301848	842336
7757	301636084202701		MIDDLE RIVER SINK			5	301636.24	842027.396
7796	301408084180501		WAKULLA BOAT DOCK			2	301408.381	841805.199

Table A4. Project Sampling Results.

NWF ID	STATION NAME	DATE	Tempera- ture oC	SC	DO	pH	CA	MG	NA	K	NH4-N	NH4+ON-N	NO2+NO3-N	CL	SO4	HCO3	F	PO4-P	DOC	SIO2
7261	OCHLOCKONEE STATE PARK 2	03/08/99	25.0	530	0.1	7.2	66	7.7	28	1.7	0.10	<0.20	<0.02	39.0	1.7	257	<0.10	0.02	1.9	6.8
318	SOPCHOPPY WELL 2	03/08/99	20.5	238	0.1	7.8	43	1	3.4	0.7	0.10	<0.20	<0.02	5.6	2.8	135	0.13	0.18	0.5	11.0
329	REFUGE HEADQUARTERS	03/17/99	21.6	635	0.1	7.2	55	7.8	58	2.7	0.30	0.52	<0.02	83.0	7.7	222	<0.10	0.64	9.0	8.5
351	TEC GULF COAST	03/10/99	20.9	356	0.1	7.6	48	3.4	16	0.8	0.04	<0.20	<0.02	30.0	11.0	149	<0.10	0.07	0.5	5.5
372	WAKULLA PARKS AND REC	03/08/99	22.7	204	8.3	7.8	36	0.7	1.6	0.4	<0.01	<0.20	4.00	6.3	7.6	84	<0.10	0.04	<0.1	6.0
391	DANIEL SHORES	03/08/99	21.1	224	5.0	7.8	39	1.4	3.8	0.4	<0.01	<0.20	0.24	6.7	4.2	122	<0.10	0.02	<0.1	5.9
7348	STEVE GRANTHAM	08/11/99	20.6	354	0.7	7.3	64	2.8	3.8	1.4	0.20	<0.20	<0.02	7.9	8.5	199	0.41	0.27	1.8	16.0
7353	CHARLIE MILLER	08/11/99	21.0	264	0.4	7.5	50	1.2	3	0.7	0.20	0.21	<0.02	4.1	1.0	158	0.55	0.24	1.0	9.5
7492	NITRATE #1	02/14/00	21.1	583	0.6	7.6	62	11	33	1.5	0.02	<0.20	0.66	62.0	18.0	207	0.13	0.07	0.2	8.4
7492	NITRATE #1	10/11/00	21.1	635	0.7	7.6	69	11	39	1.9	<0.01	<0.20	1.10	71.0	20.0	235	0.1	0.06	0.5	8.5
7493	NITRATE #2	02/14/00	20.8	454	0.1	7.2	78	6.2	5.3	1.6	0.08	<0.20	<0.02	10.0	1.9	268	0.35	0.03	1.6	24.0
7493	NITRATE #2	10/11/00	20.7	455	0.2	7.1	76	6.5	5.3	1.8	0.06	<0.20	<0.02	10.0	1.7	272	0.3	0.02	2.1	24.0
544	JERRY REEVES WELL	03/11/99	20.8	359	0.1	7.4	69	0.9	2.7	0.4	0.05	<0.20	<0.02	3.9	0.1	223	<0.10	0.07	1.5	9.2
564	STEVE EDWARDS JR WELL	03/11/99	21.0	226	11.9	7.5	41	0.5	3.5	0.7	0.06	<0.20	0.04	3.8	5.1	129	<0.10	0.04	0.6	7.9
7735	LOST CREEK AT ARRAN FL	02/17/99	13.0	41	9.3	5.3	6.2	0.4	2	0.05	0.02	0.72	<0.02	3.9	1.2	10	<0.10	0.04	31.0	7.1
607	NICK WOOTEN	03/11/99	20.2	382	3.6	7.4	71	2.6	2.9	0.4	0.02	<0.20	0.52	6.2	5.4	228	0.11	0.04	<0.1	10.0
635	ARRAN WORK CENTER	03/18/99	22.7	274	0.1	7.5	53	0.7	2.7	0.5	0.05	<0.20	<0.02	3.6	1.9	166	<0.10	0.04	1.6	7.8
641	DUANE BLACKSTEAD WELL	03/11/99	20.5	291	1.3	7.7	53	1	3.1	0.6	<0.01	0.280	1.40	7.0	11.0	149	<0.10	0.01	<0.1	5.7
650	GAME CHECK STATION	03/31/99	20.9	519	0.1	7.1	95	5.3	4	0.4	0.20	<0.20	<0.02	8.5	0.1	322	0.17	0.02	7.5	16.0
653	DONNIE SPARKMAN WELL	03/11/99	21.1	182	0.2	7.9	34	0.5	1.7	0.6	0.03	<0.20	<0.02	3.3	3.5	104	<0.10	0.03	0.2	6.8
658	TEC GULF COAST 3	03/10/99	20.8	304	0.1	7.6	46	7.2	3.8	0.4	<0.01	<0.20	0.05	6.6	8.2	173	0.12	0.03	0.5	9.3
663	N. GARCIA	03/18/99	21.1	306	3.9	7.4	53	4.1	3.6	0.4	<0.01	<0.20	0.34	6.2	9.5	169	<0.10	0.03	0.3	8.5
674	THOMAS JOHNSON	03/18/99	21.5	321	7.3	7.5	54	3.4	2.9	1.4	<0.01	<0.20	7.30	9.1	7.4	138	<0.10	0.02	0.3	9.0
705	GODDARD PLANTATION	03/17/99	21.0	318	1.1	7.4	54	5.3	3.1	0.3	0.02	<0.20	0.18	5.0	7.7	184	0.1	0.02	0.5	9.4
713	LINDA CLEMENS/HICKS	03/10/99	21.1	358	10.6	7.4	63	3.1	4.5	0.6	<0.01	<0.20	0.34	8.1	11.0	200	<0.10	0.02	0.2	8.6
717	STEVE SMITH	03/18/99	20.3	503	1.5	7.1	97	2.7	4.4	0.6	<0.01	<0.20	0.97	8.0	6.8	301	0.11	0.02	0.6	14.0
7796	WAKULLA SPRINGS	03/19/99	20.7	211	1.0	7.0	43	9.7	5.5	0.5	0.20	<0.20	0.86	8.1	9.9	169	0.14	0.04	0.2	12.0
7796	WAKULLA SPRINGS	02/17/00	20.6	268	6.2	7.9	42	9.3	5.4	0.6	0.02	<0.20	0.83	7.8	11.0	171	0.14	0.03	0.5	11.0
7796	WAKULLA SPRINGS	10/05/00	20.9	282	1.8	7.5	41	8.90	4.70	0.50	0.02	<0.20	0.70	7.7	9.2	156	0.10	0.02	3.7	11.0

Table A4. Project Sampling Results [cont].

NWF ID	STATION NAME	DATE	Tempera- ture oC	SC	DO	pH	CA	MG	NA	K	NH4-N	NH4+ON- N	NO2+NO3- N	CL	SO4	HCO3	F	PO4-P	DOC	SIO2
7734	MCBRIDE SLOUGH	02/17/99	20.0	337	4.0	6.7	53	7.1	4.2	0.5	0.02	<0.20	0.58	6.5	10.3	190	0.13	0.05	0.1	11.0
774	SALLY WARD SPRING	03/19/99	20.9	211	1.5	7.5	42	10	5.5	0.5	<0.01	<0.20	1.00	8.1	9.6	167	0.14	0.03	0.3	12.0
7494	NITRATE #3	02/15/00	21.1	268	0.1	8.1	37	8.5	3.6	1.1	0.02	<0.20	<0.02	5.0	8.8	146	0.16	0.02	<0.1	11.0
7494	NITRATE #3	10/11/00	21.2	269	0.1	8.2	35	8.5	4.2	3.7	0.02	<0.20	<0.02	5.5	11.0	149	0.2	0.02	0.4	11.0
7495	NITRATE #4	02/15/00	20.4	385	0.1	7.3	71	3.5	2.6	1	0.02	<0.20	<0.02	4.2	2.5	232	0.1	0.02	0.2	10.0
7495	NITRATE #4	10/11/00	20.6	377	0.1	7.3	68	3.6	2.6	1	<0.01	<0.20	<0.02	4.5	2.9	232	0.1	0.01	0.3	11.0
801	LEON NETTLES	03/17/99	20.0	1180	0.1	6.8	130	8.1	84	1.2	0.06	0.26	<0.02	210.0	2.4	337	0.2	0.01	5.8	20.0
6493	CLAYCOMB WELL	03/18/99	22.1	274	6.2	7.5	42	6.6	2.8	0.5	<0.01	<0.20	1.60	4.8	7.1	149	<0.10	0.03	0.2	7.2
7240	WINCO-2 WELL	06/23/99	20.2	282	0.3	7.4	44	6.4	3.3	0.4	0.02	<0.20	0.14	4.8	8.3	160	0.12	0.04	0.5	11.0
7757	MIDDLE RIVERSINK	02/19/99	20.0	226	1.6	7.2	29	6.80	5.00	0.30	0.02	<0.20	0.19	8.0	11.0	110	<0.10	0.04	1.8	7.3
7757	MIDDLE RIVERSINK	02/14/00	20.0	222	3.5	7.7	30	6.8	4.9	0.3	0.02	<0.20	0.20	7.5	11.0	113	<0.10	0.02	2.6	7.1
7757	MIDDLE RIVERSINK	10/05/00	21.1	151.0	1.6	6.8	22	4.5	3.7	0.3	0.02	<0.20	0.12	5.9	6.8	76	<0.10	<0.01	18.0	6.6
900	WALTER GERREL	03/17/99	21.2	332	2.2	7.5	50	8.2	3.7	0.5	<0.01	0.30	0.59	6.1	9.5	184	0.17	0.02	0.1	14.0
7737	FISHER CREEK	02/16/99	12.5	56	9.2	3.5	0	0.2	1.8	0.05	0.02	0.61	<0.02	3.6	0.7	1	<0.10	0.04	24.0	7.5
1020	TEC SOUTHERN PINES	03/10/99	21.2	204	1.2	7.8	28	6.4	3	0.2	<0.01	<0.20	0.24	5.3	6.0	112	<0.10	0.02	<0.1	6.9
7736	MUNSON SLOUGH-8	02/18/99	16.0	130	3.7	6.4	12	3	6.9	2.5	0.03	0.40	<0.02	10.7	1.3	55	<0.10	0.06	6.6	0.3
1056	TEC FOREST PARK 1	03/10/99	21.0	169	3.4	7.9	26	3.6	1.8	0.2	<0.01	<0.20	0.31	3.0	1.1	99	<0.10	0.01	<0.1	5.7
7498	NITRATE #5	02/15/00	21.1	291	0.3	7.6	43	7.4	3.5	0.9	0.03	<0.20	0.17	4.5	13.0	158	0.16	0.04	0.6	12.0
7498	NITRATE #5	10/12/00	20.9	298	0.2	7.5	44	7.9	3.4	0.5	<0.01	<0.20	0.19	5.3	12.0	166	0.2	0.04	1.3	13.0
7499	NITRATE #6	02/15/00	20.6	293	0.1	7.4	54	2.6	1.8	0.4	0.02	<0.20	<0.02	2.7	1.0	232	0.11	0.01	0.7	11.0
7499	NITRATE #6	10/12/00	20.6	294	0.2	7.4	53	2.7	1.9	0.4	<0.01	<0.20	<0.02	3.0	1.0	232	0.11	0.01	1.6	11.0
1176	HENRY BRATCHER	03/05/99	21.7	193	7.0	8.1	25	6.5	3.3	0.3	<0.01	<0.20	0.68	4.9	2.0	107	<0.10	0.01	<0.1	8.8
1261	CARMEN HIERS	03/05/99	20.9	219	2.8	7.9	35	2.8	4.2	0.3	<0.01	<0.20	0.76	6.7	1.6	121	<0.10	0.02	<0.1	6.0
1399	FRED TUNNINGTON WELL	03/04/99	21.3	170	6.3	8.2	25	4.1	2.4	0.3	<0.01	<0.20	1.20	4.8	4.9	85	0.1	0.02	<0.1	10.0
1427	BETTY KELLY WELL	03/05/99	21.8	215	1.8	8.0	28	7.8	2.7	0.3	<0.01	<0.20	0.63	3.8	6.4	118	<0.10	0.02	<0.1	7.4
2045	SEMINOLE GOLF COURSE	04/12/99	21.3	60	0.1	5.3	4	1.3	3.2	1.1	0.02	<0.20	0.07	9.7	0.7	12	<0.10	0.02	1.5	9.4
2562	WINDHAM WELL	03/31/99	20.7	152	8.5	7.9	20	4.9	2.5	0.6	<0.01	<0.20	0.70	4.0	0.5	84	0.3	0.02	<0.1	32.0
2749	MEADOWHILL SUBDIVISION	04/12/99	21.0	280	5.6	7.8	36	11	2.9	0.4	<0.01	<0.20	0.58	4.5	12.0	154	0.16	0.05	0.2	13.0
2923	JIM GREGORY	03/04/99	20.7	288	7.2	7.7	43	7.9	3.2	0.5	<0.01	<0.20	0.38	5.6	2.0	172	0.11	0.03	<0.1	14.0

Table A5. Construction Details for City of Tallahassee Public Supply Wells.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
998	301855084145001	AAA3056	WOODVILLE #1	199	117	35	301900.12	841449.564
1007	301900084141801	AAA3055	WOODVILLE #2	200	122	35	301859.579	841419.674
2043	302445084154501	AAA3695	TALLAHASSEE #27	316	150	70	302442.119	841536.721
2106	302513084160901	AAA3697	TALLAHASSEE #12	365	192	125	302513.796	841609.845
2196	302535084132902	AAA3702	TALLAHASSEE #17	483	314	210	302536.846	841328.567
2333	302558084162601	AAA3698	TALLAHASSEE #3	380	185	150	302559.878	841628.907
2375	302607084185201	AAA3696	TALLAHASSEE #15	315	127	116	302609.601	841853.267
2377	302608084164101	AAA3084	TALLAHASSEE #1	341	176	125	302609.243	841640.086
2573	302644084170101	AAA3704	TALLAHASSEE #9	347	187	140	302644.516	841701.674
2621	302655084175502	AAA3707	TALLAHASSEE #5	390	222	141	302655.673	841754.244
2692	302710084163002	AAA3083	TALLAHASSEE #2	415	213	186.82	302710.797	841633.961
2706	302714084162701	AAA3703	TALLAHASSEE #4	424	228	193	302713.682	841627.121
2707	302714084170701	AAA3705	TALLAHASSEE #7	355	170	162	302713.684	841709.227
2708	302714084172301	AAA3706	TALLAHASSEE #6	281	150	137.5	302713.684	841723.288
2742	302722084184101	AAA3157	TALLAHASSEE #13	365	192	157	302723.4	841838.16
2782	302731084154301	AAA3699	TALLAHASSEE #10	442	242	192	302731.677	841541.39
2863	302801084163401	AAA3082	TALLAHASSEE #8	466	233	187	302802.278	841632.149
2957	302838084204302	AAA3087	TALLAHASSEE #23	410	250	120	302836.487	842041.646
2990	302856084112101	AAA3694	TALLAHASSEE #22	190	101	90	302858.44	841146.667
3013	302903084101001	AAA3085	TALLAHASSEE #21	280	180	110	302905.283	841009.465
3021	302908084202002	AAA3700	TALLAHASSEE #19	428	290	193	302940.199	842018.96
3028	302910084105601	AAA3693	TALLAHASSEE #20	245	151	145	302909.603	841054.482
3108	302939084164301	AAA3692	TALLAHASSEE #11	454	274	230	302936.243	841710.326
3181	303012084135302	AAA3088	TALLAHASSEE #16	310	257	180	303010.799	841354.468
3379	303126084141302	AAA3086	TALLAHASSEE #18	388	267	185	303126.4	841413.197
3522	303225084103001	AAA3089	TALLAHASSEE #29	405	250	158	303227.239	841033.61
3691	303335084163701	AAA3691	TALLAHASSEE #25	450	305	235	303344.997	841636.844
3940	303520084153501		TALLAHASSEE #30	315	186	224	303520	841535
5851	302847084190502	AAA3156	TALLAHASSEE #26	407	309	135	302847.275	841903.349

Table A6. WWTFs in Leon and Wakulla Counties (from FDEP permitting records)

FACILITY NAME	PERMIT NO.	COUNTY	FACILITY TYPE	OWNER TYPE	DESIGN CAPACITY	DISPOSAL METHOD	FACILITY STATUS*	DD_LAT	DD_LONG	DATUM
ARVAH B. HOPKINS GENERATING STATION	FL0025518	Leon	Industrial	City	1.87	Surface water	Active	30.4509	-84.3997	83
WOODVILLE ELEM SCHOOL	FLA010136	Leon	Domestic	Public	0.01	Reuse system	Active	30.3139	-84.2466	83
DISC VILLAGE WWTP	FLA010137	Leon	Domestic	Public	0.02	Spray	Active	30.3046	-84.2285	83
FORT BRADEN ELEMENTARY SCHOOL	FLA010138	Leon	Domestic	Public	0.011	Percolation	Active	30.4404	-84.5161	83
T P SMITH WATER RECLAMATION FACILITY	FLA010139	Leon	Domestic	Public	27.5	Spray	Active	30.3915	-84.3225	83
LAKE BRADFORD ROAD WWTP	FLA010140	Leon	Domestic	Public	4.5	Spray	Active	30.4262	-84.3014	83
TALLAHASSEE MUNICIPAL AIRPORT STP	FLA010141	Leon	Domestic	Public	0.06	Percolation	Active	30.4076	-84.3557	83
BORDEN INC. DISTRIBUTION CENTER	FLA010143	Leon	Industrial	Private				30.4306	-84.3361	
BUDGET RENT A CAR	FLA010144	Leon	Industrial	Private				30.4303	-84.3528	
CAPITAL EUROCARS, INC.	FLA010145	Leon	Industrial	Private				30.4569	-84.3572	
WESTVIEW MOBILE HOME PARK	FLA010146	Leon	Domestic	Private	0.015			30.4428	-84.4033	
LAKE BRADFORD ESTATES STP	FLA010148	Leon	Domestic	Private	0.036	Percolation	Active	30.4067	-84.3240	83
RAINBOW CAR WASH	FLA010149	Leon	Industrial	Private		Drainfield		30.4351	-84.3729	
PROCTOR ACURA	FLA010150	Leon	Industrial	Private				30.4585	-84.4543	
SOUTHERN BELL TRAILER PARK	FLA010151	Leon	Domestic	Private	0.015	Reuse system	Active	30.4579	-84.3737	83
WESTERN ESTATES MHP	FLA010152	Leon	Domestic	Private	0.02	Reuse system	Active	30.4351	-84.3729	83
LAFAYETTE KENNELS	FLA010153	Leon	Industrial	Private				30.4314	-84.1886	
COURTESY CARS	FLA010154	Leon	Industrial	Private	0.001	Drainfield	Active	30.4566	-84.3704	83
LEWISWOOD CENTER & SELF SVC STORAGE	FLA010155	Leon	Industrial	Private	0.0013	Drainfield	Active	30.3266	-84.2498	83
MIKE'S LAUNDRY	FLA010156	Leon	Industrial	Private	0.0027	Drainfield	Active	30.3181	-84.2486	83
LAKE JACKSON ANIMAL HOSPITAL	FLA010158	Leon	Industrial	Private	0.0005	Drainfield	Active	30.4940	-84.3255	83
MEADOWS-AT-WOODRUN WWTF	FLA010159	Leon	Domestic	Private	0.07	Reuse system	Active	30.4216	-84.1362	83
FLINT EQUIPMENT CO.	FLA010160	Leon	Industrial	Private		Recycle	Active	30.4582	-84.3817	83
ISLAND FOOD STORE, LTD.	FLA010161	Leon	Industrial	Private		Recycle	Active	30.4403	-84.3141	83
ISLAND FOOD STORE, LTD	FLA010162	Leon	Industrial	Private		Recycle	Active	30.4377	-84.2701	83
DOLLAR RENT A CAR	FLA010163	Leon	Industrial	Private		Recycle	Active	30.4025	-84.3518	83
JACKSON-COOK INC.	FLA010164	Leon	Industrial	Private				30.4389	-84.3347	
AMOCO/SING OIL CO.	FLA010165	Leon	Industrial	Private		Closed	Active	30.5648	-84.2145	83
G.W. HUNTER, INC. # 337 (CHEVRON)	FLA010166	Leon	Industrial	Private				30.4000	-84.2667	
SANDSTONE RANCH WWTF	FLA010167	Leon	Domestic	Private	0.0707	Percolation	Active	30.4347	-84.3954	83
SOUTHDOWN, INC. / TALLAHASSEE	FLA010168	Leon	Industrial	Private	0.8146	Percolation	Active	30.4344	-84.2988	83
DAVIS REFINING CORPORATION	FLA010169	Leon	Industrial	Private				30.4117	-84.3036	
LAKE JACKSON WWTF (AKA LAKEWOOD)	FLA010171	Leon	Domestic	Private	0.3	Reuse system	Active	30.5357	-84.3668	83
FALLSCHASE	FLA010172	Leon	Domestic	Private	0.175	Percolation	Active	30.4632	-84.2129	83
KILLEARN LAKES SUBDIVISION	FLA010173	Leon	Domestic	Private	0.7	Spray/perc	Active	30.5931	-84.2202	83

Table A6. WWTFs in Leon and Wakulla Counties (from FDEP permitting records) [cont]

FACILITY NAME	PERMIT NO.	COUNTY	FACILITY TYPE	OWNER TYPE	DESIGN CAPACITY	DISPOSAL METHOD	FACILITY STATUS	DD_LAT	DD_LONG	DATUM
NATIONAL HIGH MAGNETIC FIELD LAB – FSU	FLA016533	Leon	Industrial	State	0.075	Spray	Active	30.4246	-84.3265	83
SOUTHDOWN, INC. / TALLAHASSEE	FLA016653	Leon	Industrial	Private		Percolation	Active	30.4350	-84.2969	83
SOUTHERN CONCRETE – TALLAHASSEE PLANT	FLA016709	Leon	Industrial	Private		Percolation	Active	30.3770	-84.2731	83
HERTZ EQUIPMENT RENTAL CORPORATION	FLA016876	Leon	Industrial	Private		Recycle	Under Construction	30.4359	-84.3639	83
ENTERPRISE CAR RENTAL	FLA016985	Leon	Industrial	Private		Recycle	Under Construction	30.4370	-84.3499	83
DIVISION OF FORESTRY DISTRICT OFFICE	FLA017296	Leon	Industrial	State		Recycle	Under Construction	30.4566	-84.3999	83
HYCREST DAIRY, INC.	FLA181803	Leon	Industrial	Private			Active	30.5263	-84.0254	83
NEFF RENTAL – TALLAHASSEE	FLA188590	Leon	Industrial	Private			Under Construction	30.3863	-84.2746	
BP OIL COMPANY	FLG910291	Leon	Industrial	Private		Drainfield	Active	30.4802	-84.3039	83
FDOT KATE IRELAND/FOSHALEE FARM	FLG910616	Leon	Industrial	State		Drainfield	Active	30.6605	-84.1897	83
FORMER NORTHSIDE CITGO	FLG910976	Leon	Industrial	Private		Drainfield	Active	30.4699	-84.3609	83
PRIMEX TECHNOLOGIES, INC.	FL0002518	Wakulla	Industrial	Private	0.79	Surface wat	Active	30.1810	-84.2201	83
SAM O. PURDOM GEN STATION	FL0025526	Wakulla	Industrial	City			Active	30.1630	-84.1992	83
MURPHY OIL CORPORATION	FL0032433	Wakulla	Industrial	Private		Spray	Active	30.1670	-84.2006	83
ST MARKS REFINERY	FL0035220	Wakulla	Industrial	Private	0.03	Surface wat	Active	30.1647	-84.2065	83
MCKENZIE SERVICE CO. INC.	FL0042161	Wakulla	Industrial	Private		Surface wat	Active	30.1600	-84.1992	83
WAKULLA COUNTY WWTF	FLA010225	Wakulla	Domestic	Public	0.2	Sprayfield	Active	30.0821	-84.4168	83
WAKULLA CO HIGH SCHOOL	FLA010226	Wakulla	Domestic	Public	0.018		Active	30.1063	-84.3749	83
SHADEVILLE ELEMENTARY WWTF	FLA010227	Wakulla	Domestic	Public	0.016	Percolation	Active	30.2150	-84.3203	83
WAKULLA COUNTY LAW ENFORCEMENT CTR	FLA010228	Wakulla	Domestic	Public	0.02			30.1929	-84.3722	83
WAKULLA MIDDLE SCHOOL	FLA010229	Wakulla	Domestic	Public	0.018	Reuse system	Active	30.1268	-84.3722	83
ACE COIN LAUNDRY	FLA010232	Wakulla	Industrial	Private	0.0068		Active	30.1846	-84.3745	83
MUDBUSTERS	FLA010233	Wakulla	Industrial	Private				30.2114	-84.3703	
OYSTER BAY ESTATES STP	FLA010237	Wakulla	Domestic	Private	0.06	Reuse system	Active	30.0670	-84.2967	83
WAKULLA MANOR	FLA010238	Wakulla	Domestic	Private	0.024	Reuse system	Active	30.0849	-84.3869	83
LAND OF WAKULLA D.B.A. QUIK LUBE	FLA010239	Wakulla	Industrial	Private			Active	30.2066	-84.3660	83
HANNON LIMESTONE PIT	FLA010240	Wakulla	Industrial	Private			Active	30.1603	-84.2918	83
RIVER PLANTATION ESTATES WWTP	FLA010241	Wakulla	Domestic	Private	0.025	Percolation	Active	30.2050	-84.2517	83
SHELL POINT STP	FLA010242	Wakulla	Domestic	Private	0.024	Percolation	Active	30.0587	-84.2895	83
WINCO UTILITIES, INC.	FLA016544	Wakulla	Domestic	Private	0.495	Sprayfield	Active	30.2566	-84.2184	83
ST. MARKS WWTF	FLA102318	Wakulla	Domestic	City	0.05	Industrial reuse		30.1532	-84.2076	
WAKULLA STATION CNTY CAFÉ & LAUNDROMAT	FLA185965	Wakulla	Industrial	Private	0.003		Under Construction	30.2329	-84.2304	83
SANDERS & SON INC CRAB PROCESSING FACILITY	FLA188824	Wakulla	Industrial	Private	0.0005		Active	30.0608	-84.4897	83
BROOKS CONCRETE	FLG110265	Wakulla	Industrial	Private			Active	30.0363	-84.2882	

Table A7. Domestic WWTF Effluent Total Nitrogen (kg-N/yr) Loading Rates.

FACILITY NAME	PERMIT NO.	COUNTY	METHOD	DATA SOURCE	FACTOR USED**	1992	1993	1994	1995	1996	1997	1998	1999
DISC VILLAGE WWTP	FLA010137	LEON	design flow factor	Wakulla High School	2	343	390	254	284	512	235		
FALLSCHASE	FLA010172	LEON	design flow factor	Wakulla County	0.87						1025*	2367*	
KILLEARN LAKES SUBDIVISION	FLA010173	LEON	design flow factor	Lake Jackson	1.17	5221	3676	4288	3916	3532	3076		
LAKE BRADFORD ESTATES STP	FLA010148	LEON	design flow factor	Shadeville Elem	2.25	346	634	235	204				
LAKE JACKSON WWTF	FLA010171	LEON	concentration sub	T.P. Smith		4462	3142	3665	3347	3018	2629		
MEADOWS-AT-WOODRUN WWTF	FLA010159	LEON	design flow factor	St. Marks	1.2		231						
T.P. SMITH	FLA010139	LEON				283431	193830	253445	202634	226619	258305	213391	222624
LAKE BRADFORD ROAD WWTP	FLA010140	LEON				127932	128941	96726	108424	87554	95080	124146	102184
TALLAHASSEE MUNICIPAL AIRPORT	FLA010141	LEON				1186	1436	1191	1179	1129	1058		
WOODVILLE ELEM SCHOOL	FLA010136	LEON	design flow factor	Shadeville Elem	0.62	95	175	65	56				
OYSTER BAY ESTATES STP	FLA010237	WAKULLA	design flow factor	St. Marks	1		193						
RIVER PLANTATION ESTATES WWTP	FLA010241	WAKULLA	design flow factor	Shell Point	1	220	147	96	100	206	141		
SHELL POINT STP	FLA010242	WAKULLA	concentration sub	T.P. Smith		220	147	96	100	206	141		
WAKULLA COUNTY WWTF	FLA010225	WAKULLA	concentration sub	T.P. Smith		2087	1861	1881	1963	1827	2085	1059	1853
SHADEVILLE ELEMENTARY WWTF	FLA010227	WAKULLA				154	282	104	90				
ST. MARKS WWTF	FL0040835	WAKULLA					193						
WAKULLA CO HIGH SCHOOL	FLA010226	WAKULLA	concentration sub	Shadeville Elem		172	195	127	142	256	118		
WAKULLA COUNTY LAW ENFORCEMENT CTR	FLA010228	WAKULLA				147	81	80	290	182	146	173*	
WAKULLA MANOR	FLA010238	WAKULLA				202*	301						
WAKULLA MIDDLE SCHOOL	FLA010229	WAKULLA	concentration sub	Shadeville Elem		190	230	112	82	78	122	108*	
WINCO UTILITIES, INC.	FLA016544	WAKULLA	concentration sub	T.P. Smith							478*	1313	1219

*Calculated from less than six months data

**Conversion factor based on design capacity

Table A8. Construction Details for Southeast Sprayfield Monitor Wells.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
1148	302045084120901	AAA2956	SE04 (1148)	47	42	27.57	302044.638	841207.691
1149	302045084123701	AAA2955	SE23 (1149)	57	48	32.48	302047.191	841235.817
1150	302045084123702	AAA2953	SE50 (1150)	129	125	32.93	302047.313	841235.897
1153	302046084113801	AAA2954	SE24 (1153)	58	56	24.55	302046.749	841137.816
1154	302046084113802	AAA2952	SE51 (1154)	170	146	25.67	302046.916	841137.904
1156	302049084120901	AAA2994	SE02 (1156)	46	42	26.05	302049.917	841208.043
1162	302051084113801	AAA2992	SE21 (1162)	139	125	27	302051.579	841138.048
1163	302051084113802	AAA2991	SE20 (1163)	53	50	30.22	302051.808	841138.317
1164	302051084120901	AAA2999	SE22 (1164)	127	102	27.96	302051.093	841208.793
1165	302051084123501	AAA2998	SE17 (1165)	122	112	31.38	302051.713	841235.515
1166	302051084123502	AAA2996	SE16 (1166)	70	60	29.84	302052.148	841234.927
1171	302053084115101	AAA3023	SE09 (1171)	52	51	36.99	302052.479	841151.201
1172	302053084115102	AAA3022	SE10 (1172)	133	124	39.2	302052.57	841151.771
1183	302058084105101	AAA3018	SE46 (1183)	174	171	27.41	302059.351	841051.024
1184	302058084105102	AAA3019	SE47 (1184)	45	31	27.71	302059.351	841051.024
1185	302058084105103		SE57 (1185)	25	20	29.32	302058	841051
1208	302110084110601	AAA2975	SE43 (1208)	183	174	40.3	302112	841107
1209	302110084110602	AAA2974	SE44 (1209)	120	109	41.67	302112	841107
1210	302110084110603	AAA2973	SE45 (1210)	72	55	42.39	302112	841107
1223	302114084105201	AAA3015	SE37 (1223)	240	191	32.17	302118.416	841052.563
1224	302114084105202	AAA3017	SE38 (1224)	115	101	32.73	302118.254	841052.177
1225	302114084105203	AAA3016	SE39 (1225)	73	63	32.28	302118.038	841052.56
1232	302116084120701	AAA2957	SE03 (1232)	62	54	42.02	302115.355	841203.194
1233	302116084123701	AAA2960	SE01 (1233)	71	57	20.38	302115.897	841237.083
1240	302117084113801	AAA2989	SE19 (1240)	74	52	46.88	302117.909	841137.766
1288	302141084114001	AAA2965	SE18 (1288)	62	52	59.44	302141.89	841139.696
1289	302141084123601	AAA2963	SE14 (1289)	51	47	35.44	302142.681	841234.201
1290	302141084123602	AAA2962	SE15 (1209)	102	96	34.8	302141.996	841234.172
1291	302141084123603	AAA2961	SE68 (1291)	35	35	36.28	302142.166	841234.472
1307	302150084103801	AAA3014	SE49 (1307)	55	47	33.41	302148.119	841039.432
1311	302151084111901	AAA2906	SE40 (1311)	194	164	47.2	302149.645	841120.318
1312	302151084111902	AAA2907	SE41 (1312)	134	120	47.27	302149.458	841120.009
1313	302151084111903	AAA2908	SE42 (1313)	65	43	47.84	302149.328	841120.355
1333	302157084115101	AAA2968	SE06 (1333)	102	101	50.16	302159.494	841151.288
1334	302157084115102	AAA2967	SE07 (1334)	242	214	51.11	302159.468	841151.772
1344	302203084110001	AAA2976	SE48 (1344)	95	89	54.18	302148.151	841039.476
1348	302204084102401		SE05 (1348)	122	120	40	302204	841024
1352	302208084123801	AAA2964	SE12 (1352)	55	51	46.56	302208.894	841236.845
7223	302050084110502		SE53 (7223)	100	93	27.9	302050.127	841105.812
7268	302146084110301	AAA3011	SE11N (7268)	70		55.23	302146	841103
7269	302146084110302	AAA3012	SE11S (7269)	88		55.21	302146	841103
7270	302051084120501	AAA2969	SE22A (7270)	121		31.87	302051.303	841205.68
7279	302115084120501	AAA2958	SE28 (7279)	23		42	302115.361	841205.867
7280	302051084113803	AAA2993	SE29 (7280)	22		30.21	302051.58	841138.098
7281	302049084120902	AAA3000	SE30 (7281)	12		29.64	302050.58	841208.6
7282	302118084113701	AAA2990	SE31 (7282)	22		49.16	302118.086	841137.566
7283	302101084123701	AAA2995	SE33 (7283)	17		26.95	302104.299	841237.055
7284	302051084123503	AAA2997	SE34 (7284)	22		33.77	302051.972	841235.078

Table A8. Construction Details for Southeast Sprayfield Monitor Wells [cont].

7285	302050084110501	AAA2972	SE52 (7285)	53		29.41	302050.365	841105.868
7290	302157084115104	AAA2966	SE54 (7290)	43		52.89	302159.744	841151.771
7291	302045084120902	AAA2951	SE55 (7291)	34		29.39	302044.723	841207.765
7292	302053084115103	AAA3021	SE56 (7292)	35		39.09	302052.661	841151.623
7293	302114084105204		SE58 (7293)	36		33.45	302114	841052
7294	302150084103802	AAA3013	SE59 (7294)	30		34.65	302148.06	841039.423
7295	302117084113803	AAA2988	SE60 (7295)	36		44	302117.732	841137.152
7296	302125084120601	AAA2956	SE61 (7296)	35	29	47	302210.84	841143.83
7297	302212084114402	AAA3010	SE62 (7297)	35	26	45	302210.845	841143.83
7298	302209084123601	AAA2935	SE63 (7298)			46	302209.044	841236.278
7299	302123084120901	AAA2950	SE64 (7299)	32	27	38	302117.359	841207.807
7300	302110084110604		SE65 (7300)	30	25	42.28	302110	841106
7301	302050084115101	AAA3020	SE66 (7301)	35	30	33.27	302049.772	841151.545
7302	302050084110503	AAA2970	SE67 (7302)	35	30	29	302050.312	841106.025
7303	302048084115101	AAA2909	SE69 (7303)	30	25	22.9	302047.489	841151.558
7304	302046084113803	AAA2949	SE70 (7304)	17	12	27.13	302046.81	841137.788
7836	302212084114401		SES (7836)	200	84	46.61	302210.5	841144.04
7864	302129084091701		SE75 (7864)	32	22	36.69	302129.52	840917.94
7865	302129084091801		SE76 (7865)	57	47	36.04	302129.46	840918.78
7866	302053084100401		SE77 (7866)	57	47	32.17	302053.76	841004.56
7867	302153084100402		SE78 (7867)	127	105	32.9	302053.64	841004.74
7868	302104084094801		SE79 (7868)	43	34	45.35	302104.2	840948.6
7869	302102084094801		SE80 (7869)	57	47	44.97	302102.76	840948.3
7870	302149084094201		SE81 (7870)	37	27	33.7	302149.32	840942.48
7871	302148084094101		SE82 (7871)	50	40	33.41	302148.06	840941.58
7872	302202084091901		SE83 (7872)	27	17	36.77	302202.04	840919.2
7873	302204084091901		SE84 (7873)	45	35	36.22	302204.32	840919.5
7874	302100084092401		SE85 (7874)	17	7	28.65	302100.48	840924
7875	302100084092001		SE86(7875)	127	105	30.33	302100	840920
7888	302208084114101		SE FARMERS (7888)			50	302208.478	841141.726
7889	302209084084801		MESSER WELL (7889)			40	302209.628	840848.056
7890	302236084075601		BARKER WELL (7890)			120	302236.119	840756.475

Table A9. Construction Details for Southwest Sprayfield Monitor Wells.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
1253	302122084194001		LS19 (1253)	80	78	39.34	302122	841940
1276	302135084202001	AAA0258	LS20 (1276)	145	145	29.24	302133.76	842019.13
1351	302206084194001		LS13 (1351)	37	35	42.2	302206	841940
1411	302233084194101		LS05 (1411)	51	33	50.37	302256	841935
1412	302234084193901		LS14 (1412)	55	53	44.52	302234	841939
1417	302235084190301	AAA0255	LS04 (1417)	53	38	44.56	302235.53	841902.33
1460	302252084192901		LS22 (1460)	268	268	48.64	302252	841929
1466	302256084185801		LS02 (1466)	75	51	52.05	302256	841858
1470	302257084191101		LS26 (1470)	185	185	55	302257	841911
1474	302258084193001		LS17 (1475)	152	152	48.73	302258	841930
1496	302301084192901		LS10 (1496)	43	41	58	302301	841929
1497	302301084192902		LS18 (1497)	160	54	58.25	302301	841929
1511	302303084190901	AAA2937	LS25 (1511)	69	54	65	302303.984	841909.125
1534	302308084185601		BOG 2-7 (1534)	36	34	63.7	302308	841856
1535	302308084195301		LS06 (1535)	45	35	40.58	302308	841953
1542	302309084185701	AAA8325	LS32 (1542)	80	58	64.05	302304.059	841857.765
1543	302309084191101		LS12 (1543)	50	48	58.36	302309	841911
1550	302310084191901		LS23 (1550)	240	240	52.48	302310	841919
1554	302313084191001		BOG 2-1 (1554)	25	23	55.57	302313	841910
1555	302313084191301		LS01 (1555)	61	45	56.32	302313	841913
1556	302313084191302		LS15 (1556)	47	45	55.6	302313	841913
1557	302313084192201		LS09 (1557)	42	40	48.54	302313	841922
1559	302314084190901		BOG 6-4 (1559)	43	41	55.57	302314	841909
1560	302314084190902		BOG 4-2 (1560)	70	60	55	302314	841909
1561	302314084192201		BOG 2-2 (1561)	22	20	69	302314	841922
1568	302315084192401		BOG 2-3 (1568)	26	24	56.6	302315	841924
1569	302315084192801	AAA2936	LS21 (1569)	248	247	58.32	302317.474	841927.976
1573	302316084191101		LS08 (1573)	49	47	57.3	302316	841911
1584	302318084192801		BOG 6-3 (1584)	52	44	60.21	302318	841928
1590	302319084220601		LS24 (1590)	260	260	105.5	302319	842206
1595	302320084192901		BOG 2-4 (1595)	48	46	55.95	302320	841929
1599	302321084193001		BOG 4-1 (1599)	89	87	57.37	302321	841930
1608	302322084193201		BOG 2-5 (1608)	49	47	54.75	302322	841932
1609	302322084193601		LS07 (1609)	35	27	37.42	302322	841936
1613	302323084191201		LS11 (1613)	40	38	51.72	302323	841912
1614	302323084193001		BOG 2-6 (1614)	50	48	61.15	302323	841930
1625	302325084191601		LS16 (1625)	67	65	58.54	302325	841916
1640	302328084192701		BOG 6-1 (1640)	292	80	67.43	302328	841927
1656	302332084191901		LS03 (1656)	104	93	69	302332	841919
7860	302314084191501		LS27 (7860)	150		54	302315	841915
7861	302314084191502		LS28 (7861)	158	145	54	302314	841915
7862	302312084191301		LS29 (7862)	250	153	54	302312	841916
7863	302206084194002		LS30 (7863)	150	148	42	302206	841940

Table A10. Construction Details for Residual Disposal Monitor Wells.

NWF ID	Site ID	FLUID	Well Name	Total Depth	Casing Depth	Land Surface Elevation	Latitude	Longitude
1512	302303084213701		SF01 (1512)	40	26	35.28	302304.129	842136.789
1663	302334084222901		SF03 (1663)	88	60	76.73	302334	842229
1685	302341084222501		SF02 (1685)	102	94	40	302341	842225
7831	302325084221701		SF04 (7831)	98	90	100.02	302325.98	842217.34
7832	302230084213101		SF05 (7832)	29		35.17	302230.12	842131.32
7833	302303084211001		SF06 (7833)	63		60.26	302303.84	842110.86
7838	302351084200701		T01 (7838)	62		72.9	302351.24	842007.62
7839	302341084195201		T02 (7839)	79		44.96	302342.96	841953.58
7840	302336084201101		T03 (7840)	31		50	302336	842011
7841	302335084193801		T04 (7841)	44		60	302335	841938
7842	302324084194501		T05 (7842)	39		40	302324	841945
7843	302323084195401		T06 (7843)	40		35.83	302322.56	841949.44
7844	302325084201001		T07 (7844)	65		40	302325	842010
7845	302327084200801		T08 (7845)	40		40	302327	842008
7846	302327084200802		T09 (7846)	16		40	302327	842008
7847	302328084201201		T10 (7847)	42		40	302328	842012
7848	302336084201301		T12 (7848)	56		50	302336	842013
7849	302335084193601		T13 (7849)	50		60	302335	841936
7850	302335084193602		T14 (7850)	45		60	302335	841936
7851	302321084194701		T15 (7851)	47		30	302321	841947
7852	302321084194702		T16 (7852)	29		30	302321	841947
7853	302320084194401		T17 (7853)	31		30	302320	841944
7854	302320084194402		T18 (7854)	16		30	302320	841944
7855	302318084194901		T19 (7855)	34		30	302318	841949
7856	302318084194902		T20 (7856)	14		50	302318	841945
7857	302328084201203		T23 (7857)	99		35.4	302325.38	842012.12
7858	302343084195101		T24 (7858)	81		70	302343	841951
7859	302343084195102		T25 (7859)	52		70	302342	841951
7879	300904084212001		YOUNG FARM (7879)			15	300903.598	842119.924
7880	300833084214401		DAVIS FARM (7880)			20	300832.997	842144.419
7881	300859084215501		COUNCIL #1 (7881)			15	300859.743	842155.49
7882	300848084215101		COUNCIL #2 (7882)			15	300848.291	842151.568
7883	301410084210601		RAKER FARM (7883)			20	301409.894	842106.477
7884	300844084172701		LAWHON WELL			15	300844.13	841727.396
7885	300901084175401		PETTY #1 (7885)			25	300900.872	841753.735
7886	300906084174101		PETTY #2 (7886)			25	300906.068	841741.803
7887	300941084172201		PETTY #3 (7887)			25	300941.748	841722.382