INFLUENCES ON THE DISTRIBUTION AND OCCURRENCE OF NITRATE-NITROGEN AND TOTAL PHOSPHORUS IN THE WATER RESOURCES OF THE SUWANNEE RIVER WATER MANAGEMENT DISTRICT

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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To my wife, Jennifer, my children Lauren, Jenna, and Kyra, and the Suwannee River

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LIST OF ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
BMP	best management practice
C	carbon
°C	degrees Celsius
CAFO	confined animal feeding operation
CFC	chloroflurocarbons
cfs	cubic feet per second
d	day
DACS	Florida Department of Agriculture and Consumer Services
DO	dissolved oxygen
DOC	dissolved organic carbon
EPA	United States Environmental Protection Agency
F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FDER	Florida Department of Environmental Regulation
FLUC	Florida Land Use Code
GPS	global positioning system
HRS	Department of Health and Rehabilitative Services
IFAS	Institute of Food and Agricultural Sciences
K	potassium
kg	kilogram
km	kilometer

L	liter
$L\ s^{-1}$	liter per second
LSRB	Lower Suwannee River Basin
LSFRB	Lower Santa Fe River Basin
m	meter
$\mu g\ g^{-1}$	micrograms per gram
$mg\ L^{-1}$	milligram per liter
$\mu g\ L^{-1}$	micrograms per liter
MLRA	Major Land Resource Area
msl	mean sea level
MSRB	Middle Suwannee River Basin
N	nitrogen
NAWQA	National Water Quality Assessment
NH_4^+	ammonium
NO_2^-	nitrite
NO_3^-	nitrate
NO_3-N	nitrate-nitrogen
NO_x-N	nitrate plus nitrite nitrogen
NRCS	Natural Resource Conservation Service
OFW	Outstanding Florida Water
OM	organic matter
P	phosphorus
PCA	principal component analysis

PCU	platinum cobalt unit
PO_4^{3-}	phosphate
SRB	Suwannee River Basin
SRBNMWG	Suwannee River Basin Nutrient Management Working Group
SRWMD	Suwannee River Water Management District
TDS	total dissolved soilds
TKN	total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TOC	Total organic carbon
TP	total phosphorus
U.S.	United States
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WARN	Water Assessment Regional Network
y	year

Abstract of Dissertation Presented to the Graduate School
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In Florida, the Suwannee River is highly influenced by the interconnection with groundwater. This relationship affects the quality and quantity of water in the river. An increasing temporal trend in nitrate-nitrogen (NO_3-N) concentration and a declining temporal trend for total phosphorus (TP) concentrations has been identified in the river. Loadings of NO_3-N were consistently highest in the Middle Suwannee River Basin (MSRB) and the Lower Santa Fe River Basin (LSFRB).

The research objectives were to indentify changes in riverine TP and NO_3-N concentrations and relate to anthropogenic influences, characterize groundwater/surfacewater interaction in the MSRB and LSFRB and locate segment(s) with the greatest NO_3-N load entering the river, delineate groundwater domains in the Suwannee River Water Management District (SRWMD) using potentiometric surface maps and hydrochemical facies analysis, and determine relationships of groundwater domain TP and NO_3-N concentrations to domain landuse/landcover.

The increasing temporal trend in NO_3-N concentrations and declining temporal trend in TP concentrations are still present in the river. The declining trend in TP is related to

management of a phosphate mining discharge. The NO_3-N concentration observed in the Suwannee River at Branford is likely related to fertilizer sales/use in Suwannee and Lafayette counties. The increase in NO_3-N loading in the MSRB and LSFRB occurred over small segments of each river. The NO_3-N load increases in the MSRB and LSFRB appear to be due to groundwater inputs based on riverine chemical signature and river discharge. Eight groundwater domains were delineated from the SRWMD potentiometric surface maps and were refined to nine domains using hydrochemical facies analysis. Groundwater domain landuse/landcover was related to observed groundwater domain TP and NO_3-N concentrations. When crop and pasture land was greater than 12 % of the land area of the groundwater domain elevated groundwater NO_3-N concentrations were observed. These landuses receive much of the fertilizer used in the basins. Groundwater domains with elevated NO_3-N concentrations are adjacent to the MSRB and LSFRB. Groundwater domains with elevated NO_3-N concentrations are affecting the surfacewater quality that receives discharge from these groundwater domains and the most likely source of the NO_3-N is fertilizer use in the groundwater domains.

CHAPTER 1
INTRODUCTION

The Suwannee River Basin (SRB) is shared by two states: Georgia and Florida (Figure 1-1). The SRB covers 9,950 square miles [25,770 km^2] of land drained by the Suwannee, Alapaha, Withlacoochee, and Santa Fe rivers in Florida and Georgia. The SRB in Florida covers 4,230 square miles [10,955 km^2] (Katz and DeHan, 1996). The Suwannee River is the State River of Florida. The Florida Legislature in 1979 designated the Suwannee River in Florida an Outstanding Florida Water which means the river has significant cultural and ecological value to the State of Florida. Also, the Suwannee River is one of the last rivers in the United States that flows unimpeded by dams, dikes, or levees and is the second largest discharging river in Florida (FDEP, 2001). The SRB consists of three major tributaries: the Withlacoochee River (and its tributary Little River), Alapaha River, and Santa Fe River (Berndt, 1996) as shown in Figure 1-1.

The SRB has been farmed since the 1700's, and the present road patterns reflect historic travel routes. River and stream corridors and larger wetland areas have, for the most part, remained relatively undeveloped and provide excellent wildlife habitat (Fernald and Purdum, 1998). National Wildlife Refuges managed by the United States Fish and Wildlife Service occupy both the headwaters and delta of the Suwannee River.

Agriculture constitutes most of the developed land uses within the SRB in Florida, including pine plantations, row crops, and pastures. Irrigated acreage has increased considerably in the SRB over the last several decades as technologies have improved and market conditions have changed (Marella, 2004). The primary water source is ground water from the Floridan aquifer system in Florida (Fernald and Purdum, 1998). Trends over the last decade indicate a general shift towards more intensive production of food and forage crops as well as animal husbandry. Agricultural crops and products from the SRB include dairy and poultry, fruits and

vegetables, grains, pasture, hay, and forestry products. Forestry, primarily pine plantations, covers large areas of the SRB and provides timber and fiber for mills within and outside the SRB.

In recent years, water quality data have indicated an increasing temporal trend for nitrate-nitrogen (NO_3-N) in the Suwannee River. The rate of increase is 0.02 mg N L^{-1} y^{-1} (Ham and Hatzell, 1996). Possible sources of the NO_3-N in the SRB are atmospheric deposition, septic tanks, fertilizer, and animal waste (Andrews, 1994). Data have shown that NO_3-N loadings are consistently highest in the Middle Suwannee River and the Lower Santa Fe River basins.

This Dissertation contributes the following:

1. An understanding of the changes in concentrations of total phosphorus (TP) and NO_3-N in the Suwannee River due to possible anthropogenic influences.

2. Summary of recent ground and surface water quality data in the Suwannee River Water Management District (SRWMD).

3. Characterization of groundwater/surfacewater interactions in the Middle Suwannee River Basin (MSRB) and the Lower Santa Fe River Basin (LSFRB). This characterization located the segment (s) of the river where the greatest NO_3-N load enters the river system from ground water.

4. Determination of the groundwater domains within the SRWMD using potentiometric surface maps and principal component analysis of groundwater quality. Groundwater domain TP and NO_3-N concentrations were statistically evaluated to ensure that each groundwater domain was statistically different from each other and a summary of groundwater quality by groundwater domain was generated.

5. Landcover/Landuse was clipped to each groundwater domain and correlations will be run to determine relationship to groundwater domain TP and NO_3-N concentrations and level 2 Florida Land Use Codes (FLUC) landuses.

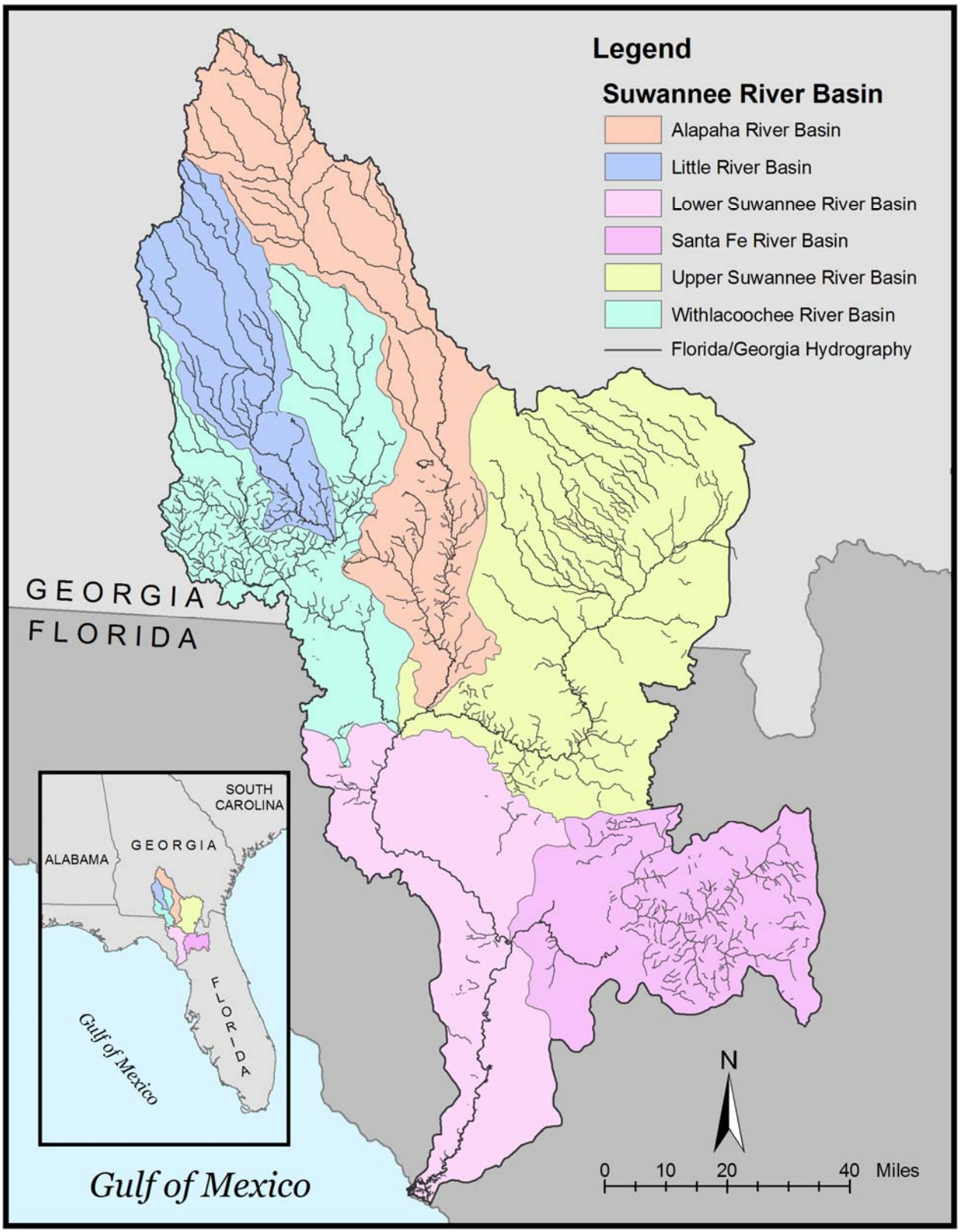

Figure 1-1. Basins of the Suwannee River System (Hornsby and Raulston, 2000).

CHAPTER 2
LITERATURE REVIEW

Overview of the Suwannee River Basin

Location

The Suwannee River Basin (SRB) is located within the Coastal Plain physiographic region of the southeastern U. S., extending from near Cordele, Georgia, to Cedar Key, Florida, in the Gulf of Mexico (Fernald and Purdum, 1998). The Okefenokee Swamp contains the headwaters of both the Suwannee and St. Marys Rivers (Fernald and Purdum, 1998). The SRB covers part of South Georgia and North Florida (Figure 1-1), and has at least 60 units of government with jurisdiction (Hornsby and Raulston, 2000). Valdosta, Georgia is the largest city within the SRB, followed by Lake City, Florida. Interstate 75 traverses the length of the SRB; Interstate 10 crosses the southern third.

Hydrology

The SRB hydrology is highly varied in terms of flows, water quality, aquatic habitat, and related values. The SRB includes freshwater swamp, small surfacewater streams, large rivers, extensive tidal salt marshes, and interior-drained karst areas with extensive spring discharge. The character of the Suwannee River changes dramatically as it progresses down stream, reflecting the geology, physiography, and land cover of the region it drains (Fernald and Purdum, 1998).

Surface drainage characteristics dominate the upper two-thirds of the SRB. The dendritic pattern of the stream drainage is also evidenced by the forested stream corridors. Surface drainage exists where soils contain more clays and fine sediments that are more resistant to infiltration. Streams, lakes, and wetlands are more abundant in the upper Suwannee River, and in the upper Santa Fe River basins. Water quality conditions in these areas reflect the dominant

influence of surfacewater systems which contain low dissolved minerals and generally acidic conditions due to low buffering (FDEP, 2001).

In the southern third of the SRB, a relatively thin layer of highly porous sand overlies the Floridan aquifer system, and the Suwannee River takes on more groundwater quality characteristics (Hornsby and Ceryak, 1999). Rainfall in these areas percolates directly to the aquifer. The relative absence of surfacewater features such as streams, lakes, and wetlands indicates areas where recharge to the aquifer is direct. The transition between these areas includes many stream-to-sink sub-basins, where surface stream flow is abruptly captured by sinkholes and is directed to the aquifer. This transition zone lies along a feature in Florida known as the Cody Escarpment or Cody Scarp (Fernald and Purdum, 1998). These areas, as well as the numerous springs along the lower river reaches, act as points of interaction between surface water and ground water (Scott et al., 2004).

Water quality conditions in the Suwannee and its tributaries reflect the physical setting of the SRB. Areas dominated by surface drainage typically have more acidic water, higher levels of sediment and particulate matter, and higher variability in flow regime. Downstream of White Springs, Florida, the Suwannee River receives inflow from over 200 known springs (Scott et al., 2004; Hornsby and Ceryak, 1998). The influx of ground water from the upper Floridan aquifer system buffers the acidity and darker color of the surface water with relatively constant flow of clear, mineral-rich ground water which provides base flow to the Suwannee River (Hornsby and Ceryak, 1999). Base flow in a river system is a natural condition of ground water discharge to the river and is the primary source of flow in the system during low flow (Pittman et al., 1997). Ground water influence on water quality in the river is more pronounced during low flow and in the river reaches having the greatest number of springs and the least tributary inflow (Hull et al.,

1981). The upper Floridan aquifer will receive recharge from the Suwannee River when the surface water levels are above the adjacent aquifer potentiometric level. This results in the spring to estevelle, which is the cessation of discharge due to the surfacewater head overcoming the groundwater head. This results in reverse flow of springs or surfacewater entering the aquifer.

Physiography

Hydrogeology within the SRB is directly related to the physiography. The SRB can be divided into three general physiographic regions: Northern Highlands, Gulf Coastal Lowlands, and River Valley Lowlands as shown in Figure 2-1 (White, 1970).

The Northern Highlands region is mainly characterized by altitude and thick, clayey strata that overlie the Floridan aquifer system. The land surface throughout the area is greater than 100 feet (30.5 m) above mean sea level (msl) and reaches heights up to 230 feet (70.1 m) msl (White, 1970; Hornsby and Ceryak, 1999; Fernald and Purdum, 1998).

The area to the west and southwest is the Gulf Coastal Lowlands. The land surface of this area is less than 100 feet (30.5 m) msl and the majority of the clayey sediments have been eroded away (White, 1970; Hornsby and Ceryak, 1999; Fernald and Purdum, 1998). Limestone is at or near land surface throughout the Gulf Coastal Lowlands.

The most persistent topographic feature in the State of Florida is the Cody Scarp, which is the boundary between the Highlands and Lowlands (Puri and Vernon, 1964; Hornsby and Ceryak, 1999; Fernald and Purdum, 1998). It is a very significant feature as it pertains to hydrogeology of the SRB. Every river or stream (except the Suwannee River) that originates in the Highlands disappears underground as it crosses the Cody Scarp (White, 1970; Hornsby and Ceryak, 1999; Fernald and Purdum, 1998). The few streams that exist in the Gulf Coastal

Lowlands have eroded downward into the upper Floridan aquifer system and have intersected the unconfined upper Floridan aquifer. Base flow to Gulf Coastal Lowland streams is supplied by artesian spring flow from the upper Floridan aquifer system (Scott et al., 2002; Scott et al., 2004; Pittman et al., 1997).

The third physiographic region is the River Valley Lowlands. River Valley Lowlands are erosional/depositional features formed by the rivers that originate in the Highlands and pass through the River Valley Lowlands to the Gulf of Mexico (White, 1970; Hornsby and Ceryak, 1999).

Soils

The Natural Resource Conservation Service (NRCS) formerly known as the Soil Conservation Service (SCS), a branch of the United States Department of Agriculture (USDA), has defined three major land resource areas (MLRAs) within the SRB in the Suwannee River Water Management District (SRWMD). The three MLRAs are Southern Coastal Plain, North-Central Florida Ridge, and Eastern Gulf Coast Flatwoods (Soil Survey Staff, 1997). The Southern Coastal Plain's soils are predominantly Udults. These soils are characterized as deep and have a thermic temperature regime, an udic moisture regime, a loamy or sandy surface layer. The North-Central Florida Ridge's soils are predominantly Udults and Psamments. These soils are characterized by having a thermic temperature regime and an udic moisture regime. The soils range from well drained to poorly drained and generally sandy. The predominant Eastern Coast Flatwood's soils are Aquults, Aquepts, and Aquods. These soils are characterized by having a thermic temperature regime and an aquic moisture regime. The soils are generally sandy and poorly drained or very poorly drained (Soil Survey Staff, 1997). Nair et al. (2004) noted the sandy soils of the SRB in Florida have little ability to absorb phosphorus (P) and that

many animal husbandry operations were applying P-rich lagoon effluent to permanent sprayfields. This application of P-rich lagoon effluent increased the P loading to the sites and may result in P loss via surfacewater runoff or leaching to ground water. Furthermore, Obreza and Means (2006) noted that the sandy soils of the SRB were vulnerable to nutrient and agrichemical leaching, especially under excessive rainfall or irrigation conditions.

The Middle Suwannee River Basin (MSRB) is a sub-basin of the SRB which is located in Suwannee and Lafayette counties in Florida. Generally, soils in the MSRB are sandy well drained to excessively drained. For agricultural production, these soils present issues with irrigation and leaching of nutrients from the root zone (USDA, 1993). Furthermore, these soils have medium to high potential for nitrogen (N) leaching to ground water. Most agricultural production in the MSRB occurs primarily on Entisols and Ultisols (Obreza and Means, 2006). Entisols are soils that do not display evidence of pedogenic horizon development (Brady and Weil, 2000). Entisols are able to support any vegetation and occur in any climate. Entisols form in inert parent materials such as quartz sand or slowly soluble rock such as limestone (Carlisle et al., 1985). The properties unique to Florida Entisols are a dominance of mineral soil and an absence of distinct pedogenic horizons except for an ochric epipedon, an albic horizon, and a spodic or argillic diagnostic subsurface horizon that is below 80 inches[203 cm] (Collins, 2003). Ultisols occur in humid regions and formation is from weathering and leaching that results in subsurface horizons of illuvial accumulations, such as, quartz, kaolinite, and iron oxides (Brady and Weil, 2000; Soil Survey Staff, 2007). Generally, Ultisols are acidic with nutrients concentrated within a few centimeter of the land surface and have a relatively low capacity to retain fertilizers (Soil Survey Staff, 2007).

Soil orders with high leaching potential in the SRWMD are shown in Figure 2-2. These soil orders include Ultisols, Spodosols, Inceptisols and Entisols with Entisols being the majority of the high leaching soils. High leaching Ultisols in the SRWMD are Apopka (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) and Valdosta (siliceous, thermic Psammentic Paleudults) [Houston et al., 1965; Carlisle, 1985 and Soil Survey Staff, 2007]. High leaching Spodosols are Cassia (sandy, siliceous, hyperthermic Oxyaquic Alorthods), Hurricane (sandy, siliceous, thermic Oxyaquic Alorthods), Mandarin (sandy, siliceous, thermic Oxyaquic Alorthods), and Ridgeland (sandy, siliceous, thermic Oxyaquic Alorthods) [Soil Survey Staff, 2007]. High leaching Inceptisol are Fort Meade (siliceous, hyperthermic humic Psammentic Dystrudepts), Orlando (siliceous, hyperthermic humic Psammentic Dystrudepts), Pickney (sandy, siliceous, thermic Cumulic Humaquepts) and Placid (sandy, siliceous, hyperthermic typic Humaquepts). The high leaching Entisols are Adamsville (hyperthermic, uncoated aquic Quartzipsamments), Alaga (thermic, coated typic Quartzipsamments), Alpin (thermic, coated Lamellic Quartzipsamments), Astatula (hyperthermic, uncoated typic Quartzipsamments), Bigbee (thermic, coated typic Quartzipsamments), Candler (hyperthermic, uncoated Lamellic Quartzipsamments), Chipley (thermic, coated aquic Quartzipsamments), Clara (siliceous, thermic spodic Psammaquents), Foxworth (thermic, coated typic Quartzipsamments), Gainesville (hyperthermic, coated typic Quartzipsamments), Kershaw (thermic, uncoated typic Quartzipsamments), Lake (hyperthermic, coated typic Quartzipsamments), Lakeland (thermic, coated typic Quartzipsamments), Orsino (hyperthermic, uncoated spodic Quartzipsamments), Ortega (thermic, uncoated typic Quartzipsamments), Osier (siliceous, thermic typic Psammaquents), Ousley (thermic, uncoated aquic Quartzipsamments), Paola (hyperthermic, uncoated spodic Quartzipsamments), Penney (thermic, uncoated Lamellic Quartzipsamments),

Pompano (siliceous, hyperthermic typic Psammaquents), Resota (thermic, coated spodic Quartzipsamments), Ridgewood (thermic, uncoated aquic Quartzipsamments), and Tavares (hyperthermic, uncoated typic Quartzipsamments) [Houston et al., 1965; Carlisle, 1985 and Soil Survey Staff, 2007].

The dominant Entisols soils in the MSRB are Alpin and Penney (Figure 2-2). The Alpin series consists of very deep, excessively drained, moderately rapidly permeable soils on uplands and river terraces of the Coastal Plain. The soils formed in thick beds of sandy eolian or marine deposits. (Soil Survey Staff, 2007). The Penney series consists of very deep, excessively drained, rapidly permeable soils on uplands. The soils formed in thick beds of sandy eolian or marine deposits (Soil Survey Staff, 2007). These soils have leaching potential.

Sabasan (2004) identified NO_3-N concentrations in various landuse on Entisols, Ultisols, and Spodosols in the Santa Fe River Watershed. For landuse pine plantations, the NO_3-N concentrations for Entisols, Ultisols, and Spodosols were 0.05, 0.33 and 0.28 μg N $g^{-1}$of soil, respectively. For landuse improved pasture, the NO_3-N concentrations for Entisols, Ultisols, and Spodosols were 0.51, 1.80 and 1.65 μg N $g^{-1}$of soil, respectively. For landuse crops, the NO_3-N concentrations for Entisols, Ultisols, and Spodosols were 2.70, 2.60 and 0.56 μg N $g^{-1}$of soil, respectively.

Hydrogeology

A highly productive regional aquifer exists within the SRB that is capable of producing thousands of gallons of water per minute to wells. This aquifer is referred to as the Floridan Aquifer system (Miller, 1997). The upper Floridan aquifer system is the primary source of drinking water and base flow in the SRB (FDEP, 2001). The Floridan aquifer system is made up of limestone and dolostone. Carbonate rock (limestone and/or dolostone) as much as 5,000 feet

(1,524 m) thick exists in the subsurface of the SRB. These strata, which are primarily Tertiary in age, make up the Florida Platform. The Floridan aquifer system is found within these strata in the Florida Platform (Figure 2-3) and in similar strata in the Carolinas and portions of Alabama. The permeable portion of this carbonate-rock platform ranges from about 600 feet (182.9 m) to 1,700 feet (518.2 m) in thickness (Miller, 1982).

Water that recharges the Floridan aquifer system comes from rainfall and focused recharge through leaky sediments at the base of the upper aquifers, at the edge of the upper aquifers where the clayey base becomes discontinuous, or through sinkholes that penetrate into the aquifer system (Ceryak et al., 1983; Hornsby and Ceryak, 1999). There are two distinct regions of the upper Floridan aquifer within the SRB in Florida: a confined region and an unconfined region (Figure 2-4). The confined regions are where there is a layer of clay over limestone, thus reducing/retarding the recharge of rainwater and fostering surface water runoff. The unconfined regions are where limestone is at or near land surface and are recharged directly from percolating rainfall, since the only sediment overlying the aquifer is porous sand (Hornsby and Ceryak, 1999). These unconfined regions allow for direct recharge of the upper Floridan aquifer and allows for the contamination of the upper Floridan aquifer by water-soluble contaminants such as nitrates (NO_3^-).

Land Use Overview

The land use patterns that have evolved within the SRB reflect the opportunities and constraints of the land. Most of the developed land uses in the SRB historically have been located on the upland, better-drained regions. The SRB has been farmed since the 1700's and the present road patterns reflect historic travel routes. River and stream corridors and larger wetland areas have, for the most part, remained relatively undeveloped and provide excellent

wildlife habitat (Fernald and Purdum, 1998). National Wildlife Refuges managed by the United States Fish and Wildlife Service bracket both the headwaters and delta of the Suwannee River.

Growth and development within the Florida side of the SRB has been steady since the 1960s, but at a relatively slower rate than other areas in Florida (Fernald and Purdum, 1998). Most of the urban development has occurred near the Interstate 75 corridor, and in proximity to cities and towns. The estimated population in 2006 in the SRB within Florida is 350,000 (K. Webster, 2007, Personal Communication). Growth projections for the SRB indicate a 13 to 15 % increase in the population over the coming decade (Fernald and Purdum, 1998).

Agriculture defines most of the developed land uses within the SRB in Florida, including pine plantations, row crops, and pastures. Irrigated acreage has increased considerably in the SRB over the last several decades as technologies have improved and market conditions have changed (Marella, 2004). Drinking water source is primarily ground water from the Floridan aquifer system in Florida (Fernald and Purdum, 1998). Agriculture acreages within the SRB over the last decade indicate a declining trend, which indicates a general shift towards more intensive production of food, forage crops and animal husbandry on less acreage. Agricultural crops and products from the SRB include dairy and poultry, fruits and vegetables, grains, pasture, hay, and forestry products. Forestry, primarily pine plantations, covers large areas of the SRB and provides timber and fiber for mills within and outside the SRB.

Water Quality Characteristics

The Suwannee River system's hydrology and water chemistry is influenced by physiographic characteristics (FDER, 1985). The geologic and physiographic changes that the Suwannee River undergoes as it traverses through north central Florida results in dramatic longitudinal changes in water chemistry (Ceryak et al., 1983; FDER, 1985). The changes in

these characteristics may best be described by recognizing six reaches of the Suwannee River in Florida, as shown in Figure 2-5 (Hornsby et al., 2000). A description of the reaches is given in Table 2-1.

Water chemistry in the Suwannee River changes in a unique way from upstream to downstream (Bass and Cox, 1985). Hornsby and Mattson (1998) used water chemistry and stream structure to define six distinct reaches of the Suwannee River; the upper river (Reaches 1 and 2) is a soft, acidic, blackwater stream, with waters of low mineral content and high color (Figures 2-6 and 2-7). As the river progresses downstream (Reaches 3, 4, 5 and 6), it receives increasing amounts of water from the upper Floridan aquifer, which changes river water quality to a clear, slightly colored, alkaline stream (Figures 2-6 and 2-7). These natural chemical gradients influence the ecology of the river in many ways. In terms of overall biological production, the upper river tends to be more oligotrophic, while the lower river is more productive.

Total organic carbon (TOC) concentrations are higher in the upper reaches of the river (Hornsby et al., 2000), largely due to the dissolved organic carbon (C) associated with the high water color. Nutrient concentrations (dissolved N and P) are low in the uppermost reach (Reach 1), generally near detection limits of less than 0.05 mg N L^{-1} and 0.04 mg P L^{-1} (Hornsby et al., 2000). The low levels of nutrients in the upper reach contribute to its low biological productivity. Dissolved N and P concentrations both generally increase going downstream. Peak P levels are seen in Reach 2, partly due to the geology, as the river crosses the exposed Hawthorn Group that contains high levels of phosphate in the form of carbonate-fluorapatite (Maddox et al., 1992), and partly due to discharges from phosphate mining and processing. Highest NO_3-N levels are seen in the middle and lower reaches (Reaches 3,4,5 and 6), and a

historical trend of increasing NO_3-N has been identified in the middle and Lower Suwannee and Lower Santa Fe rivers (Ham and Hatzell, 1996). Much of NO_3-N increase comes from groundwater discharges via springs along the river corridor (Katz et al., 1999; Pittman et al., 1997). Areas of elevated NO_3-N have been identified in the upper Floridan aquifer in these regions (Hornsby et al., 2005B). Sources of this N are diverse and include agricultural operations, sewage spray fields, areas with dense concentrations of septic tank drain fields, and stormwater runoff to sinkholes.

The 2004 State Water Quality Assessment 305(b) Report prepared by the Florida Department of Environmental Protection (FDEP) indicates generally "good" water quality in the SRB. Portions of the lower river and most of the estuary are designated as "impaired" and are candidates for Total Maximum Daily Load (TMDL) establishment. Portions of the upper Suwannee and Santa Fe sub-basins are indicated to be "potentially impaired". These assessments appear to be based largely on low dissolved oxygen (which is partly natural due to groundwater discharge), nutrients, and/or elevated fecal coliform levels.

Nutrients

For water quality concerns, the two nutrients that receive the most attention in water are P and N. The most common forms of P and N that plants uptake are $H_2PO_4^-$ and HPO_4^{2-} for P and NO_3^- and NH_4^+ for N (Brady and Weil, 2000).

Phosphorus

Phosphorus is second only to N in its importance in the production of healthy plants and profitable yields (Brady and Weil, 2000). Phosphorus is needed for the production of adenosine triphosphate (ATP) that is the energy source for most biochemical process, a component of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Native soils are generally low in

available P thus soil amendments have been used to promote crop yields (Havlin et al., 1999). Unfortunately, more P is often added to the soil than is removed by plant uptake (Brady and Weil, 2000). This results in excess P in the soil and allows for the movement of the P via erosion or leaching.

Phosphorus cycle

Phosphorus is a macronutrient for primary producers. The availability of P for biological uptake has little to no relationship to the total P (TP) content in soils (Havlin et al., 1999). Factors which control $H_2PO_4^-$ and HPO_4^{2-} in the soil solution are pH, adsorption, desorption, mineralization and immobilization, precipitation, dissolution, fertilization, soil organic matter, leaching and plant uptake.

The sources for P in the environment are fertilizer, soil organic matter, primary minerals and secondary minerals. Secondary minerals are formed when P complexes with cations and precipitates out of the soil solution. Primary and secondary minerals can dissolve to supply the soil solution P. Soil organic matter is both a source and a sink of P. Soil organic matter can complex with P or the P can be incorporated in to the soil microbial mass. This is immobilization of P. The release of P into the soil solution by the soil organic matter is mineralized. Fertilization with P results in the increase of soil solution P by increasing the amount of P in the soil, which saturates the possible adsorption sites in the soil.

The pH of the soil solution determines the form(s) of P available. At low pH, between 2 and 6, $H_2PO_4^-$ is the domiant form while at higher pH, 8 to 12, HPO_4^{2-} is the domiant form. At pH 7.2 there are equal amounts of $H_2PO_4^-$ and HPO_4^{2-} in solution (Havlin et al., 1999).

Adsorption of P is a process in which P in soil solution is removed and accumulated at the interface of the soil (minerals and clays) and solution. The adsorption of P reduces the

availability of the P for plant uptake. The reverse process, desorption, is the release of adsorbed P into the solution.

The P cycle in soils is shown in Figure 2-8. However, the P cycle can be reduced to the following relationship (Havlin et al., 1999):

$$\text{Soil solution P} \leftrightarrow \text{labile P} \leftrightarrow \text{nonlabile P}$$

Soil solution P is the P which is dissolved in soil pore water. Labile P is the P that is readily available to the soil solution to replace P, which is removed by biological uptake. Nonlabile P is the P in the soil, which is not available to the soil solution due to chemical or biological immobilization (Havlin et al., 1999; Brady and Weil, 2000).

Occurrence of phosphorus in groundwater

Maddox et al. (1992) defined the background concentration of ortho-phosphate ($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}) in the upper Floridan aquifer to be less than 0.10 mg P L^{-1} while surface water within the SRWMD ranges in concentration of TP and ortho-phosphate from 0.001 to 26.6 mg P L^{-1} and 0.001 to 26.2 mg P L^{-1}, respectively (Hornsby and Mattson, 1998). The P concentrations in the Suwannee River vary as the river traverses from the headwaters to the Gulf of Mexico. The high concentrations of P in the Suwannee River is observed in the upper river where the river comes in contact with the Hawthorne Group, a P bearing unit, and also, receives discharge from a phosphate mining operation. From the upper Suwannee River to Gulf of Mexico, the P concentrations decline in the river (Hornsby and Mattson, 1998).

Concerns with phosphorus

The primary concern with P is eutrophication of surface water bodies. The input of P into these surface waters results in increased bio-activity, favoring organisms able to adapt to the environmental changes in the water. Thus, the bio-diversity will be reduced. Also, harmful algae

such as blue green can produce toxins that can cause fish kills and prevent the water from being suitable for human consumption (Brady and Weil, 2000).

Water quality standards for phosphorus

Currently, there is no groundwater standard for P (in any form) and no numeric surfacewater standard for P (in any form) for the State of Florida. Florida Administrative Code (F.A.C.) 62-302.530 for surface water has a narrative standard for nutrients, which states, "that nutrients shall not cause an imbalance to flora or fauna". The only surfacewater body with a numeric standard for P is the Everglades which has a standard of 10 μg P L^{-1} per Florida Administrative Code (F.A.C.) 62-302.540.

The FDEP uses a screening concentration for total N and TP of 0.45 and 0.1 mg L^{-1}, respectively (T. Greenhalgh, 2005, Personal Communication). The screening concentrations are based on total N and TP concentrations in surfacewater bodies that will support a chlorophyll *a* concentration of 20 μg L^{-1} (J. Hand, 2005, Personal Communication). These screening concentrations for total N and TP are used to determine impaired water bodies by nutrients. These impaired water bodies are reported biannually to the United States Environmental Protection Agency (EPA) and are placed on the State's TMDL list for development of TMDLs for nutrients.

Nitrogen

Nitrogen is the most commonly deficient nutrient in crop production (Havlin et al., 1999). Therefore, most crops require the addition of N for optimum yield. Nitrogen is needed by organisms for the production of protein. The most mobile form of N in the environment is nitrate (NO_3^-). Nitrate is completely soluble in water. The movement of nitrates in the environment can pose risks to humans and animal health as well as impact the quality of the environment.

Nitrogen cycle

Nitrogen is a macronutrient for primary producers. The N cycle is shown in Figure 2-9. The four general steps in this cycle are 1) N fixation, 2) ammonification, 3) nitrification, and 4) denitrification (Havlin et al., 1999):

Nitrogen fixation can be a biological or chemical process. The biological process converts atmospheric nitrogen gas [$N_{2(g)}$] to organic nitrogen (N) matter while chemical fixation can occur naturally by lighting in the atmosphere converting $N_{2(g)}$ to nitric acid (HNO_3) or by man converting $N_{2(g)}$ to NH_3, NH_2^-, NO_3^- used in synthetic fertilizers.

Ammonification is the decomposition of soil organic matter by soil organisms to release ammonium ion (NH_4^+) from organic matter. The released NH_4^+ can then be used by nitrifying organisms in a process called nitrification if conditions are suitable or immobilized by soil organisms or available for plant uptake. Also, in high pH in soils and waters, the NH_4^+ can volatize to $NH_{3(g)}$ or become fixed in a biologically unavailable form in some clay mineral lattices.

Nitrification is the conversion of NH_4^+ to NO_3^- by a biological mediated reaction that oxidizes the N. The process in the conversion NH_4^+ to NO_3^- is a two step reaction. The first step is the conversion of NH_4^+ to NO_2^-. Bacteria called *nitrosomonas* mediate this reaction. The second step is the conversion of NO_2^- to NO_3^-. Bacteria called *nitrobacter* mediate this reaction. The rate limiting step is the conversion of NH_4^+ to NO_2^-.

Denitrification is the conversion of NO_3^- to gaseous forms of nitrogen ($N_{2(g)}$, $N_2O_{(g)}$). The process occurs under anaerobic conditions. Denitrifying bacteria (*Pseudomonas, Baccillus* and *Paracoccus*) in anaerobic conditions have the ability to use NO_3^- as the terminal electron

acceptor in place of $O_{2(g)}$ for respiration. Through the biological mediated reactions, N (in NO_3^-) goes from an oxidation state of +5 to 0.

The amount of decomposable organic matter (OM) strongly influences denitrification. The NO_3^- is used in place of $O_{2(g)}$ in the respiration process by the denitrifying bacteria. Thus, OM is the food source and the amount of C available defines the amount of denitrification that will occur to produce energy for the denitrifying bacteria.

Soil water content determines the amount of denitrification by impeding $O_{2(g)}$ diffusion into the soil by the soil pore spaces being filled with water. Thus, water fills pore spaces and promotes anaerobic conditions by creating regions in the soil where the concentration $O_{2(g)}$ is reduced or $O_{2(g)}$ is removed from the system

The process of denitrification will only occur when the concentration of $O_{2(g)}$ is too low to meet biological requirements for aerobic respiration. However, in well aerated soils, denitrification can occur due to development of anaerobic microsites.

Occurrence of nitrate-nitrogen

Nitrate is a widespread contaminant of shallow ground water and the levels of contamination are increasing (Spalding and Exner, 1993). Nationally, Spalding and Exner (1993) conducted an evaluation of the occurrence of NO_3-N in groundwater. The percentage of wells sampled with NO_3-N concentrations higher than the 10 mg N L^{-1} found in the following states were: 18 % in Iowa, 27 % in Kansas, 17 % in Nebraska, 3 % in North Carolina, Ohio, and Arkansas, 7 % of the wells sampled in Texas, 13 % in California, 25 % in Delaware, 9 % in Pennsylvania, 22 % in Washington, 20 % in Minnesota, and 37 % in South Dakota. Furthermore, the National Water Quality Assessment (NAWQA) program of the United States Geological Survey (USGS) has assessed the water quality of aquifer systems that cover the water resources of greater than sixty

percent of the population in the contiguous Unites States. The findings were that approximately fifteen percent of shallow groundwater sampled beneath agricultural and urban areas had NO_3-N concentration above 10 mg N L^{-1} (Manassaram et al., 2006). The concentrations of NO_3-N in groundwater are associated with source availability, regional environmental factors [i.e., rainfall, organic C, dissolved O_2] (Madison and Brunett, 1985) and man-induced factors [i.e., agricultural activities] (Spalding and Exner, 1993). The NO_3-N concentrations in the nation's river are shown in Table 2-2. The percentiles were determined from 383 different rivers through the United States.

Maddox et al. (1992) defined the background concentration of NO_3-N in the Floridan aquifer system to be 0.05 mg N L^{-1} while surface water within the SRWMD ranged in concentration of NO_3-N from 0.05 to 4.8 mg N L^{-1} (Hornsby and Mattson, 1998).

Concerns with nitrate-nitrogen

Methemoglobinemia which affects infants, is a result of NO_3^- being reduced to nitrite (NO_2^-) in the gastrointestinal tract. The reduced species nitrite (NO_2^-), then oxidizes the ferrous iron (Fe^{2+}) in hemoglobin to ferric iron (Fe^{3+}) which inhibits the hemoglobin from releasing oxygen to the cells of the body (Kreitler, 1975). The cells of the body are thereby oxygen deprived, resulting in the blue color of the skin of the effected infant; hence, the name "blue baby" disease.

Methemoglobinemia also affects animals (i.e., livestock). In the rumen, the bacteria convert NO_3^- to NO_2^- when excess NO_3^- is introduced into the rumen and causes NO_2^- to build up. NO_2^- can be adsorbed through the oral and/or GI tract into the blood and affects the hemoglobin similarly as in human (MPCAMDA, 1991). The result is methemoglobinemia in livestock.

Another human health problem associated with NO_3-N is the carcinogenic properties of N compounds which are created in the digestive tract. The elevated concentrations NO_3-N in drinking watger has been correlated to either mortality or incidence of stomach cancer

(MPCAMDA, 1991). Just like in methemoglobinemia, NO_3^- is reduced to NO_2^- in the gastrointestinal tract. The acidic conditions in the gastrointestinal tract is conducive to the formation of N-nitroso compounds (MPCAMDA, 1991). The EPA has classified N-nitroso compounds as probable human carcinogens (EPA, 1991).

Nitrogen also causes eutrophication in surface water where N is the limiting nutrient. The input of NO_3-N into these surface waters results in increased bio-activity, favoring organisms able to adapt to the environmental changes in the water (MPCAMDA, 1991). Thus, the bio-diversity will be reduced.

In surface waters, nitrate provides the N, which is a macronutrient, needed by primary producers. In surface waters where N is the limiting nutrient, the additional N introduced can result in over production by the primary producers and result in a condition called eutrophication. The over production by primary producers generates increased biomass in a system which results in the depletion of available oxygen in the system to organisms for respiration. Eutrophication results in the reduction of species in a water body and ultimately can result in a dead water body. Nutrients delivered by the Mississippi River have been shown to contribute to the "dead zone" in the Gulf of Mexico and nutrients (primarily P) are the main problem in Lake Okeechobee (Zagier, 2003; Hey, 2002).

Water quality standards for nitrate-nitrogen

There is a numeric groundwater standard for NO_3-N of 10 mg N L^{-1} which is for the protection of human health. However, there is no numeric surface water standard for NO_3-N in the State of Florida. The Florida Administrative Code (F.A.C.) 62-302.530 for surface water narrative standard for nutrients states "that nutrients shall not cause an imbalance to flora or

fauna". U.S. Department of Agriculture (1991) developed water quality indices for tidal and freshwater based on NO_3-N concentration. The water quality indices are presented in Table 2-3.

Water Quality Assessments

In 1979, the FDEP identified the Middle Suwannee River Basin (MSRB) as one of five watersheds within the State of Florida for potential groundwater contamination by nonpoint sources due to agricultural practices (FDEP, 1979). However, the ranking was based on professional judgment due to the paucity of groundwater data within the watershed. Furthermore, in Florida, ground water has few regulations in place to protect it from nutrient contamination from non-point sources of pollution such as agriculture runoff (Hauserman, 2000).

In the late 1980's, a shift in agricultural practices occurred in dairy operations in the SRB in Florida, primarily in Suwannee and Lafayette counties. The number of dairy operations and the number of dairy cows increased. It was perceived that the dairy cow population was increasing in the SRB due to the dairy buyouts in the Lake Okeechobee Basin in south Florida and that the dairy operations from the Lake Okeechobee Basin were shifting to the SRB. The dairy buyouts in the Okeechobee were designed to reduce surface runoff loadings of P, a macronutrient, to Lake Okeechobee which was impacting the water quality of the lake due to the lake being P limited. The loading of P was accelerating the eutrophication of the lake. This perceived increase in dairy cows populations resulted in concern among local public health officials as to the effects of the waste from the dairy operations in Suwannee and Lafayette counties would have on groundwater quality. Since the Floridan aquifer is unconfined in Suwannee and Lafayette counties, it is easily contaminated with water soluble contaminates, such as, NO_3-N (E. Wilson, 2004, Personal Communication).

The state health officials with the Florida Department of Health and Rehabilitative Services (HRS) started private well surveys near dairy operations in Suwannee and Lafayette counties (these counties comprise a region known as the MSRB) in 1990 (E. Wilson, 2004, Personal Communication). These surveys revealed that 20 to 30 percent of the wells near dairy operations had NO_3-N concentrations in excess of the State Drinking Water Standard of 10.0 mg N L^{-1}. Some of the wells sampled by the HRS in the MSRB in 1990-92 had NO_3-N concentrations in excess of 20 mg N L^{-1} (USDA, 1993). The NO_3-N contamination in excess of the Drinking Water Standard was observed in ten wells located on dairy operations (HRS, 1992). At the same time, ambient monitoring for NO_3-N in the surface water resources and springs in the MSRB indicated a statistically significant increasing trend (Ham, 1996) while Mueller et al. (1995) identified increasing concentrations of NO_3-N in the upper Floridan aquifer system in the same region. The results of these monitoring activities prompted the FDEP to start requiring industrial wastewater permits for any new dairy operations in the SRWMD in 1992 (E. Wilson, 2004, Personal Communication). Also, under the Clean Water Act the U. S. Environmental Protection Agency (EPA) in 2002 began regulating through the state's Department of Environmental Protection confined animal feeding operations (CAFO). A dairy is considered a confined animal feeding operations if it has more than 700 dairy cows. In the MSRB, the implementation of confined animal feeding operations regulation only affected seven of the dairies since the majority of the dairy operations had less than 700 dairy cows (D. Smith, 2004, Personal Communication).

In 1993, the United States Department of Agriculture – Soil Conservation Service (now known as the Natural Resource Conservation Service) submitted a watershed protection plan and environmental assessment under the authority of the Watershed Protection and Flood Prevention

Act and in accordance with the National Environmental Policy Act to Secretary of Agriculture (USDA, 1993). The objective of the plan was to reduce the potential for NO_3-N leaching to the Floridan aquifer from animal operations through the installation of best management practices (BMPs) in the MSRB. The watershed protection plan setup public law 566 (PL-566) projects that receive federal assistance with the implementation of projects that are consistence with the actions outlined in the plan. Furthermore, in 1996 the Florida Legislature provided line item funds to assist in the implementation of the Soil Conservation Services Watershed Protection Plan. Federal and state funds are used to cost share the implementation of BMPs on animal operations to help prevent leaching of NO_3-N in to the upper Floridan aquifer.

A follow up study of private drinking water wells conducted in 1997 by the FDEP found that wells near animal husbandry operation were 29 percent more likely to have NO_3-N concentrations greater than the Drinking Water Standard for NO_3-N (Copeland et al., 1999). The EPA has found that nutrients are the leading cause of water quality impairment in estuaries and the second leading cause of water quality impairment in lakes and rivers (EPA, 1994). Also, the EPA defined the number one source of impairment to rivers and lakes are from agriculture and agriculture is the third source of impairment for estuaries (EPA, 1994).

The SRWMD ambient monitoring identified the MSRB as the largest contributor of the NO_3-N load to the Suwannee River. Figure 2-10 shows the loadings by sub-basins in the Suwannee River system. The highest percentage of the NO_3-N loading is derived from the MSRB. In this region, ground water from the upper Floridan aquifer enters the Suwannee River via springs and seeps. The ground water provides the base flow to the Suwannee River in this region. Under base flow conditions, the flow in the Suwannee River doubles in volume from the top of the MSRB (near Dowling Park, Florida) to the bottom the MSRB (near Branford, Florida).

In the MSRB, there are no tributaries to the river, thus, the increase in flow is directly due to ground water influx from the upper Floridan aquifer via springs and seeps.

A series of studies added to the knowledge that NO_3-N contamination of the upper Floridan aquifer was occurring and the NO_3-N contamination of the upper Floridan aquifer was impacting the water quality of the springs along the Suwannee River and the river itself. The average NO_3-N concentration in the upper Floridan aquifer was observed to be 30 to 40 mg N L^{-1} under dairy lagoons and high intensity areas, 30 mg N L^{-1} under spray fields which receive dairy effluent, 6.2 mg N L^{-1} on dairy pastures, and on average 4.25 mg N L^{-1} under property adjoining dairy farms (USDA, 1993; Andrews, 1994). During base flow in the MSRB, Pittman et al. (1997) observed a 160 percent increase in the NO_3-N concentration in the Middle Suwannee River (Dowling Park to Branford). Springs in the MSRB have NO_3-N concentrations that range from 10 to 300 times greater than the background concentration for NO_3-N of 0.05 mg N L^{-1} (Maddox et al., 1992; Scott et al., 2002, Scott et al., 2004, Katz et al., 1999, Berndt et al., 1998, Hornsby and Mattson, 1998; and Hornsby and Ceryak, 1999). Also, when the Suwannee River was compared to the Altamaha River, St. Johns River, Satilla River, Ogeechee River, Withlacoochee River (South), and the Ochlockonee River, the Suwannee River had the highest in-stream TP and NO_3-N load km^{-2} of basin of the seven rivers (Asbury and Oaksford, 1997). Based on N estimation from potential sources in the SRWMD, there are multiple sources of N in the MSRB with fertilizer being the largest potential contributor, poultry the second largest potential contributor, and dairy cows the third largest potential contributors as shown in Figures 2-11 and 2-12 (Hornsby and Mattson, 1998). Furthermore, the Suwannee River and its estuary have been shown to be N limited (Quinlan, 2003). A study conducted by Katz et al. (1999 and 2001) showed that the mean age of the water discharging from the springs was between 12 and

25 years old in the MSRB. This study indicates that the observed NO_3-N concentration in the ground water, rivers and springs represents NO_3-N that may have entered the aquifer under land uses that occurred 12 to 25 years ago and from mixed sources.

All the sources of N within the MSRB (Suwannee and Lafayette counties) are anthropogenic. Thus, the NO_3-N from the MSRB accounts for 45 percent of the annual NO_3-N load for the Suwannee River for water year 1998 (Figure 2-10); there are multiple sources of N within the basin and the travel time within the upper Floridan aquifer is between 12 and 25 years (Katz et al., 1999).

The FDEP classified the waters of the MSRB as being impaired due to nutrients, primarily NO_3-N, in the FDEP Water Quality Assessment - 305(b) Report to the U.S. EPA in 1998 (FDEP, 1998). The Water Quality Assessment - 305(b) Report is required to be submitted to the EPA every two years by the State's environmental assessment agency under the authority of the Clean Water Act. The listing of the Suwannee River in the 305(b) report resulted in the Suwannee River being listed on the FDEP, 2002 Section 303(d) List of Impaired Waters for the development of TMDL. The listing of the Suwannee River on the 303(d) will result in FDEP allocation of pollutants (i.e., nitrates) to permittees within the Florida portion of the SRB.

Groundwater Domain Delineation

Understanding the region/area from which ground water is derived aids in the management of the resource. Groundwater studies have used various techniques to define contributing areas (or basins) to the ground water. The two commonly used methods are utilizing groundwater level or potentiometric surface and geochemical fingerprinting or hydrochemical facies. The first method utilizes contours of potentiometric surface of groundwater levels. This method used ground water moving perpendicular to the contours and

defines the basin at bend points in the potentiometric contour. Jones and Upchurch (1993) used this method to define a study area for the contributing groundwater domain to Lithia and Buckhorn springs. Davis (1996) used potentiometric surfaces to determine groundwater basins in North Central Florida and Southwest Georgia. The basins defined by Davis delineated the groundwater basins (spring sheds) for Spring Creek spring group, Wakulla spring, Saint Marks spring, and Wacissa spring group. Also, Upchurch et al. (2001) referenced this method for defining a preliminary groundwater domain (springshed) for springs within the SRWMD. Furthermore, Upchurch et al. (2001) referenced the uses of geochemical fingerprinting to refine groundwater domains.

Geochemical factor analysis (fingerprinting) has been used in the SRWMD to identify recharge areas within the upper Floridan aquifer (Lawrence and Upchurch, 1982). From the factor analysis, four distinct chemical distinct water masses were identified as well as the impacts of the quality of the recharge water entering the upper Floridan aquifer. Factor analysis was employed due to the combining of variables that are correlated into clusters in order of the amount of variance explained (Lawrence and Upchurch, 1978; Lawrence and Upchurch, 1982). Jones et al. (1996) used hydrochemical facies analysis (geochemical fingerprinting) to determine groundwater quality domains to Rainbow Springs to ascertain distinctive water quality and relate the observed water quality within the domain to specific spring vents within the Rainbow springs group. The hydrochemical facies placed a series of water quality analyses into a spatial context that allowed for patterns to be determined. Also, hydrochemical facies analyses were used by Maddox et al. (1992) when determining the quality of waters within the Florida's aquifers. Variations in NO_3-N concentrations within the groundwater domain of Rainbow Springs were due to anthropogenic sources such as inorganic fertilizer (Jones et al., 1996).

In most published studies by geologists, the term factor analysis is used when the actual analysis is Principal Component Analysis (Davis, 1973). Principal Component Analysis (PCA) is used to interpret the structure within the variance-covariance matrix of a multivariate data set (Davis, 1973). The PCA is a method that simplifies a dataset (Lawrence and Upchurch, 1982). PCA is also called Karhunen-Loeve transform.

Based on this literature review, additional evaluation of water quality issues in the SRB are needed to define the extent of nutrients, NO_3-N and TP, and relationships between the water resources, nutrients and possible sources of the nutrients. This dissertation will address the interaction of ground and surface water, extent and changes over time of nutrients, NO_3-N and TP, in the water resources of the SRWMD and evaluate relationships of the possible sources of the nutrients, NO_3-N and TP, with observed concentrations in the water resources with the goal of determining anthropogenic factors effecting NO_3-N and TP concentrations in the water resources.

Table 2-1. Reaches of the Suwannee River (Hornsby et al., 2000).

Reach	Description
1	Upper River Blackwater
2	Cody Scarp Transitional
3	Middle River Calcareous
4	Lower River Calcareous
5	Tidal Riverine
6	Estuary (same as 5 with salinity)

Table 2-2. National NO_3-N concentrations in 383 U.S. Rivers (USDA, 1991).

Percentile	Concentrations
25^{th}	0.21 mg N L^{-1}
50^{th}	0.40 mg N L^{-1}
75^{th}	0.89 mg N L^{-1}

Table 2-3. Tidal-freshwater water quality indices based on NO_3-N concentration (USDA, 1991).

Condition	Nitrate-Nitrogen (mg N L^{-1})
Healthy and High Quality	< 0.6
Fair	0.6 to 1.0
Fair to Poor	1.0 to 1.8
Poor	> 1.8

Note: For higher salinity levels N is more limiting and optimum N concentrations are much lower than 0.6 mg N L^{-1}

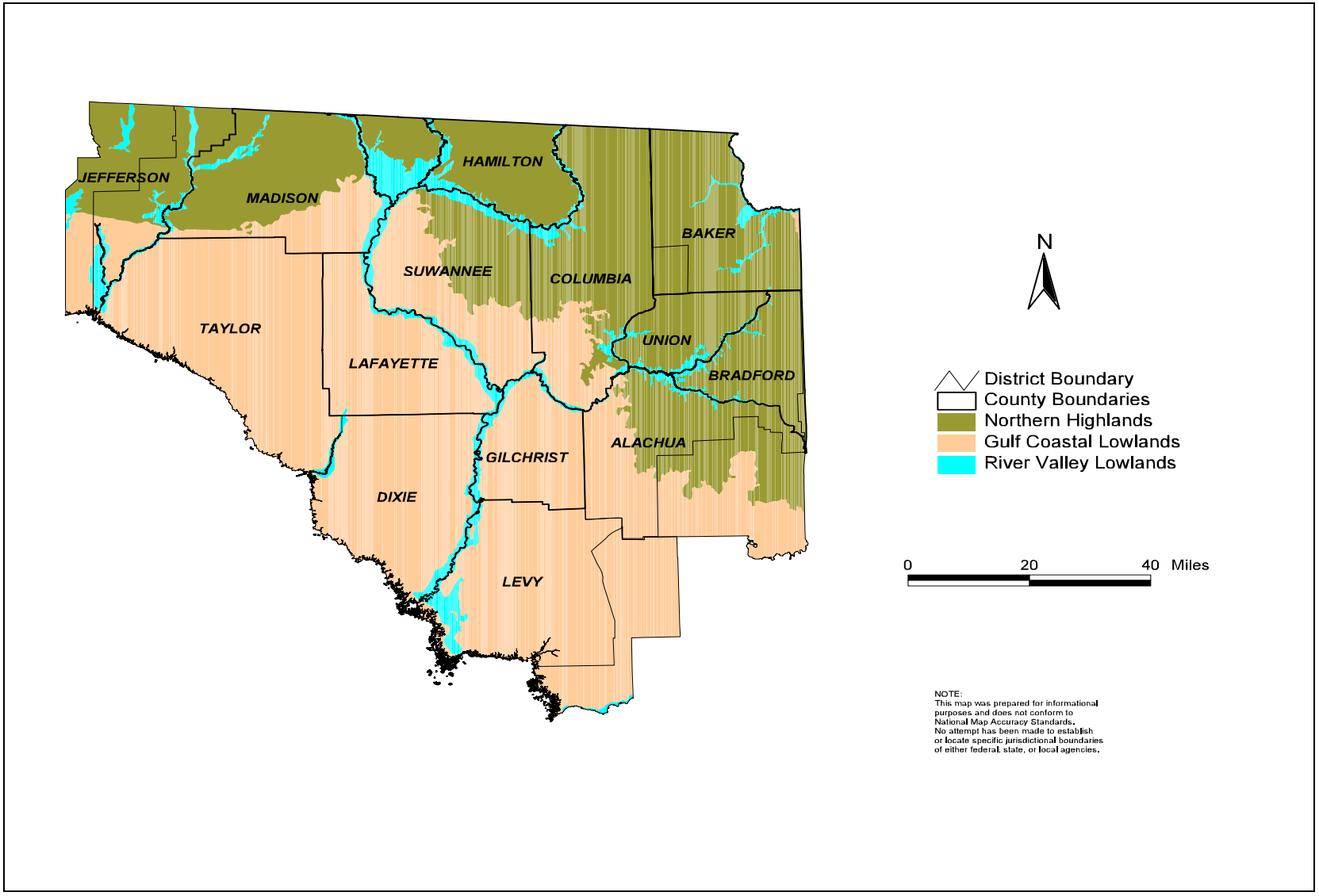

Figure 2-1. Physiography regions of the Suwannee River Water Management District (Hornsby and Ceryak, 1999).

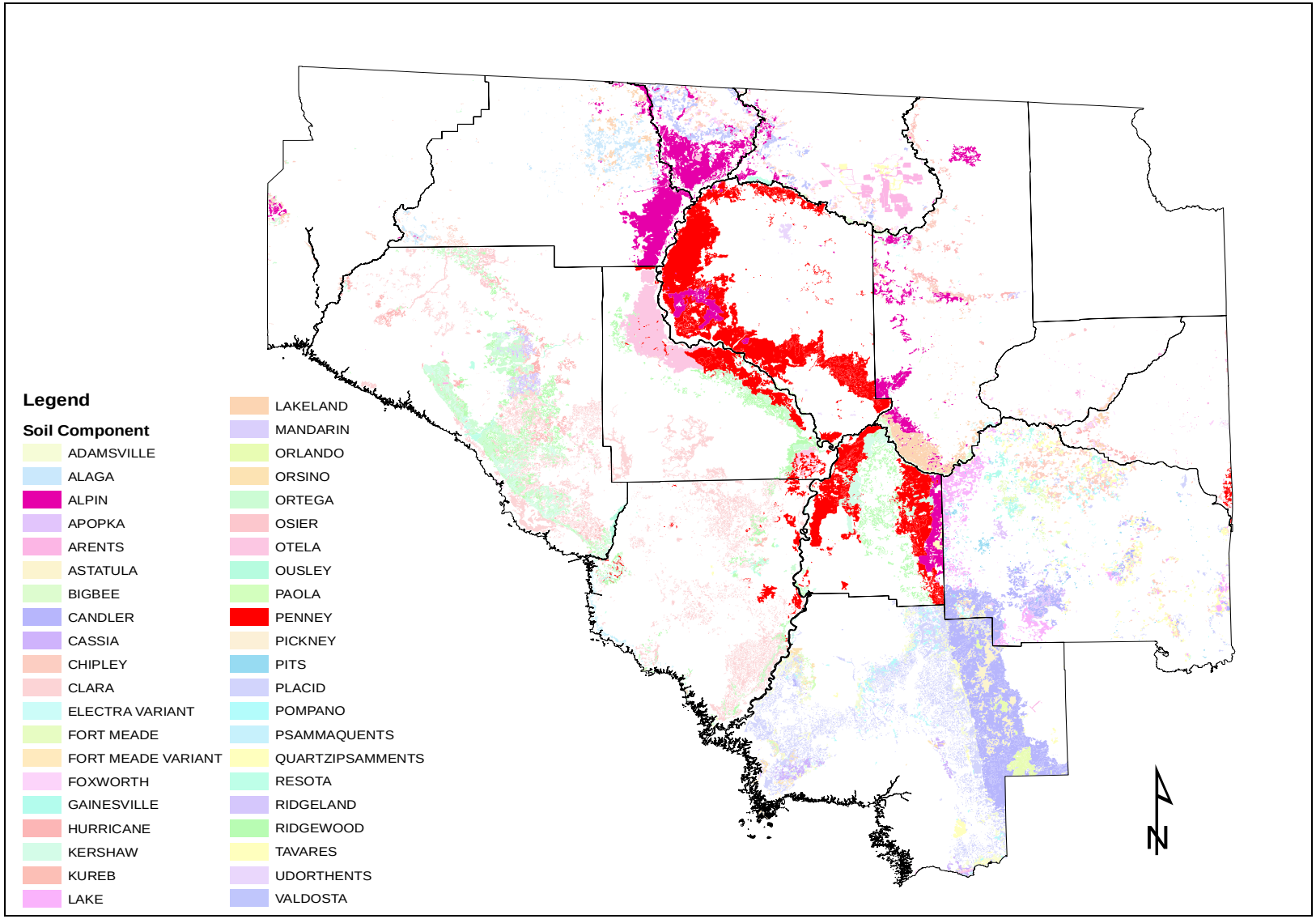

Figure 2-2. High leaching soils in the Suwannee River Water Management District.

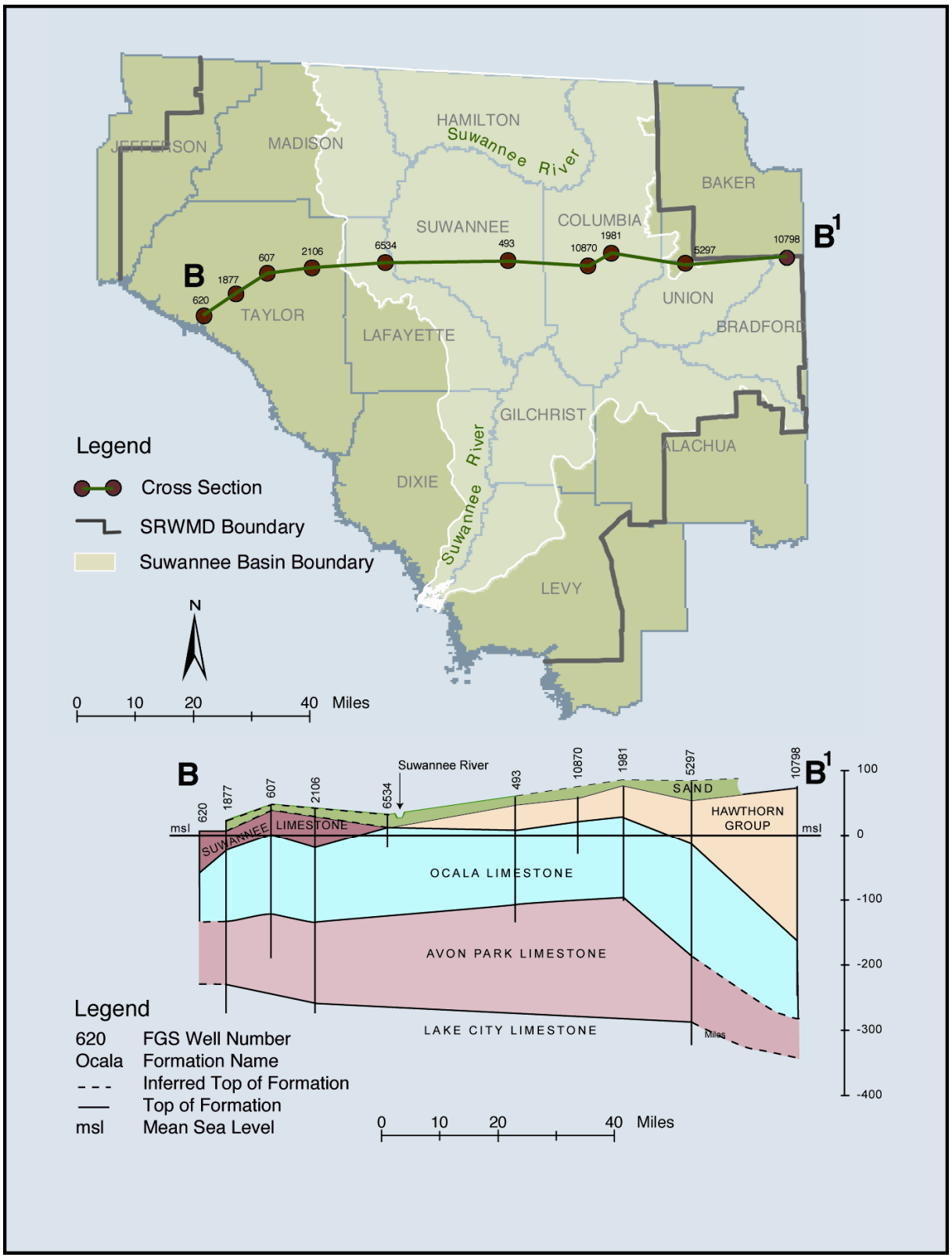

Figure 2-3. Generalized geologic cross section of the region (modified from Ceryak et al., 1983).

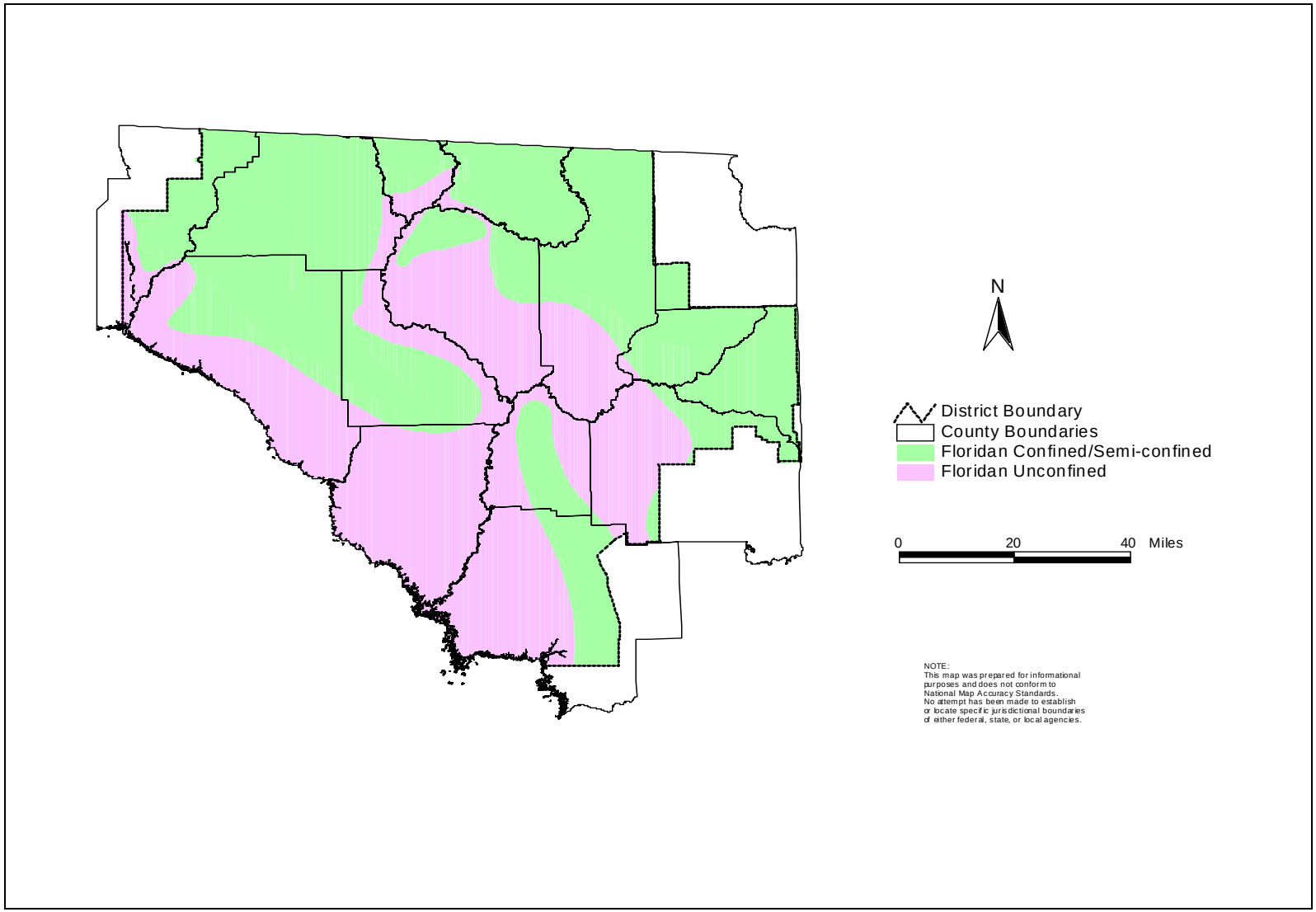

Figure 2-4. Confined and unconfined regions of the Floridan aquifer system (Hornsby and Ceryak, 1999).

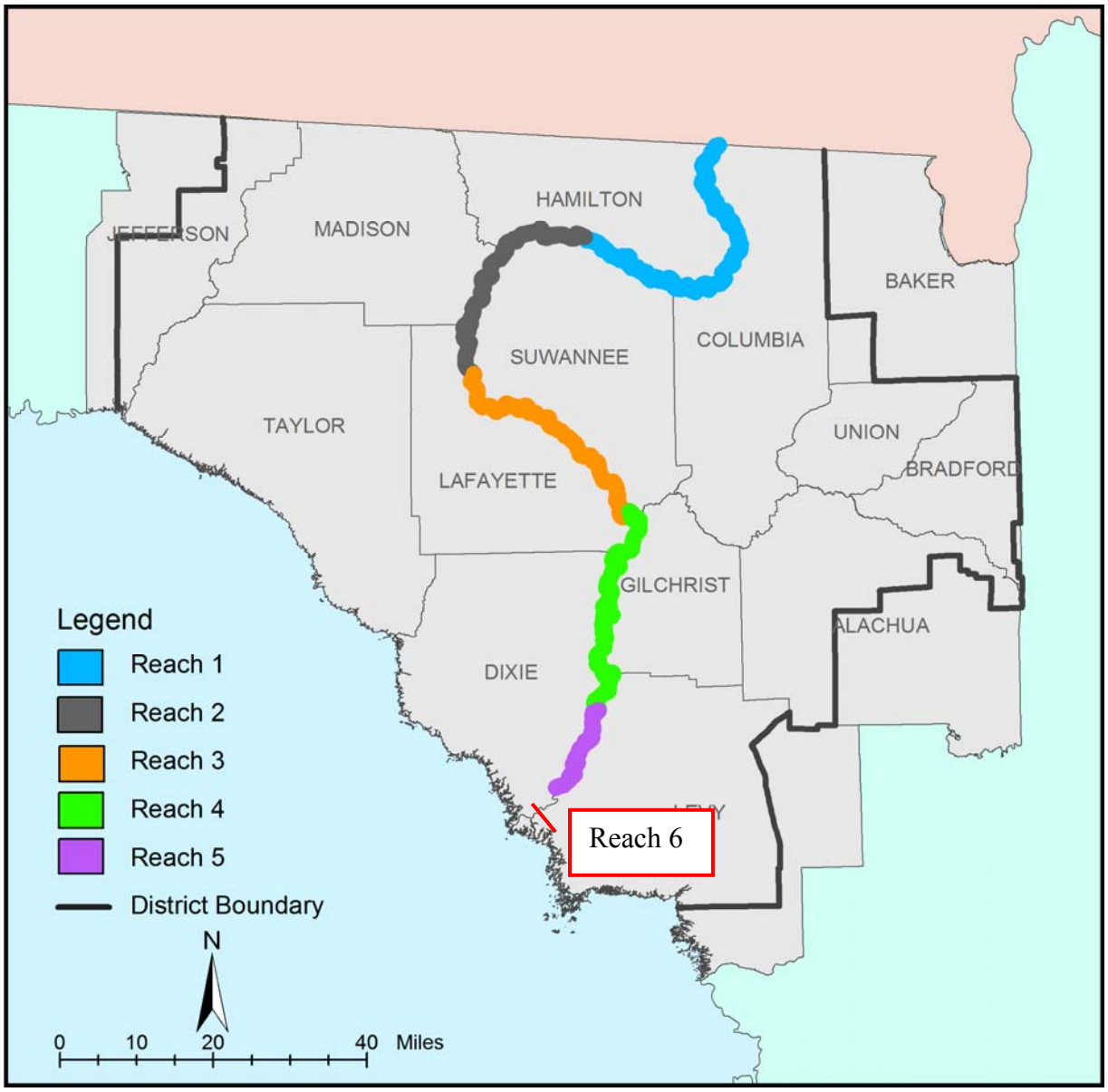

Figure 2-5. Map showing the reaches of the Suwannee River in Florida (Hornsby et al., 2000).

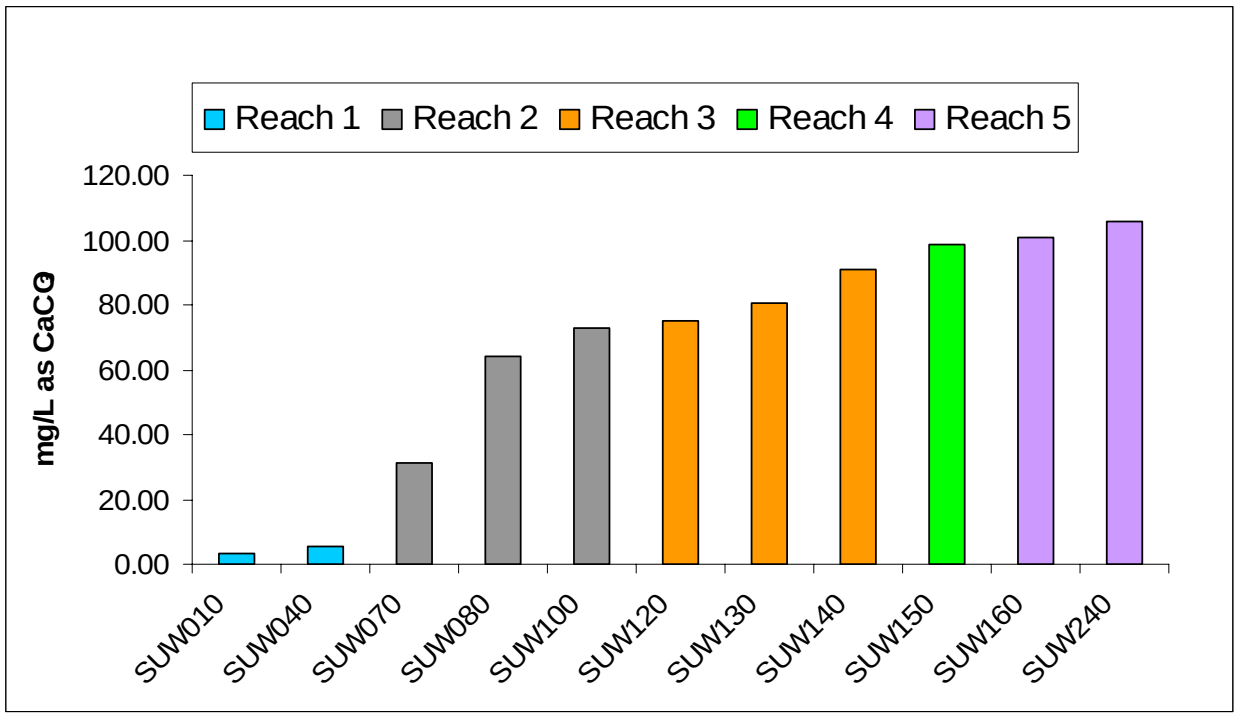

Figure 2-6. Plot of mean alkalinity (mg L^{-1} as $CaCO_3$) in the five reaches of the Suwannee River in Florida (Hornsby et al., 2000).

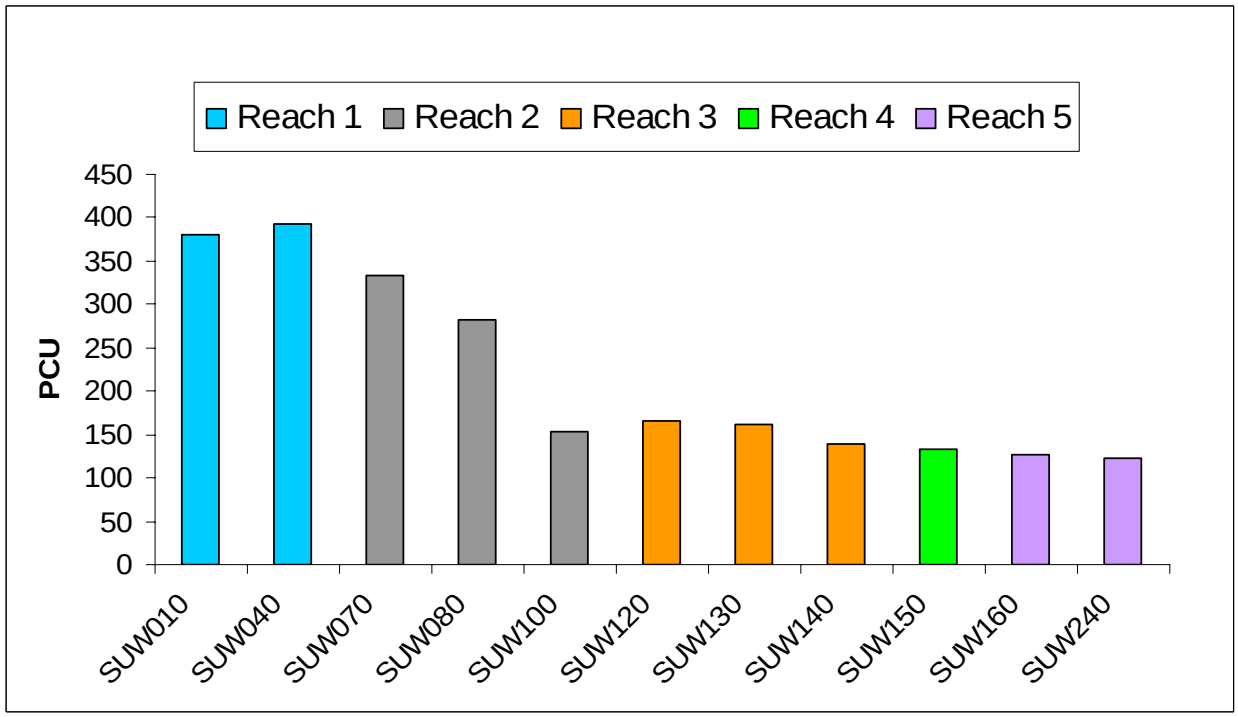

Figure 2-7. Plot of mean color (PCU) in the five reaches of the Suwannee River in Florida (Hornsby et al., 2000).

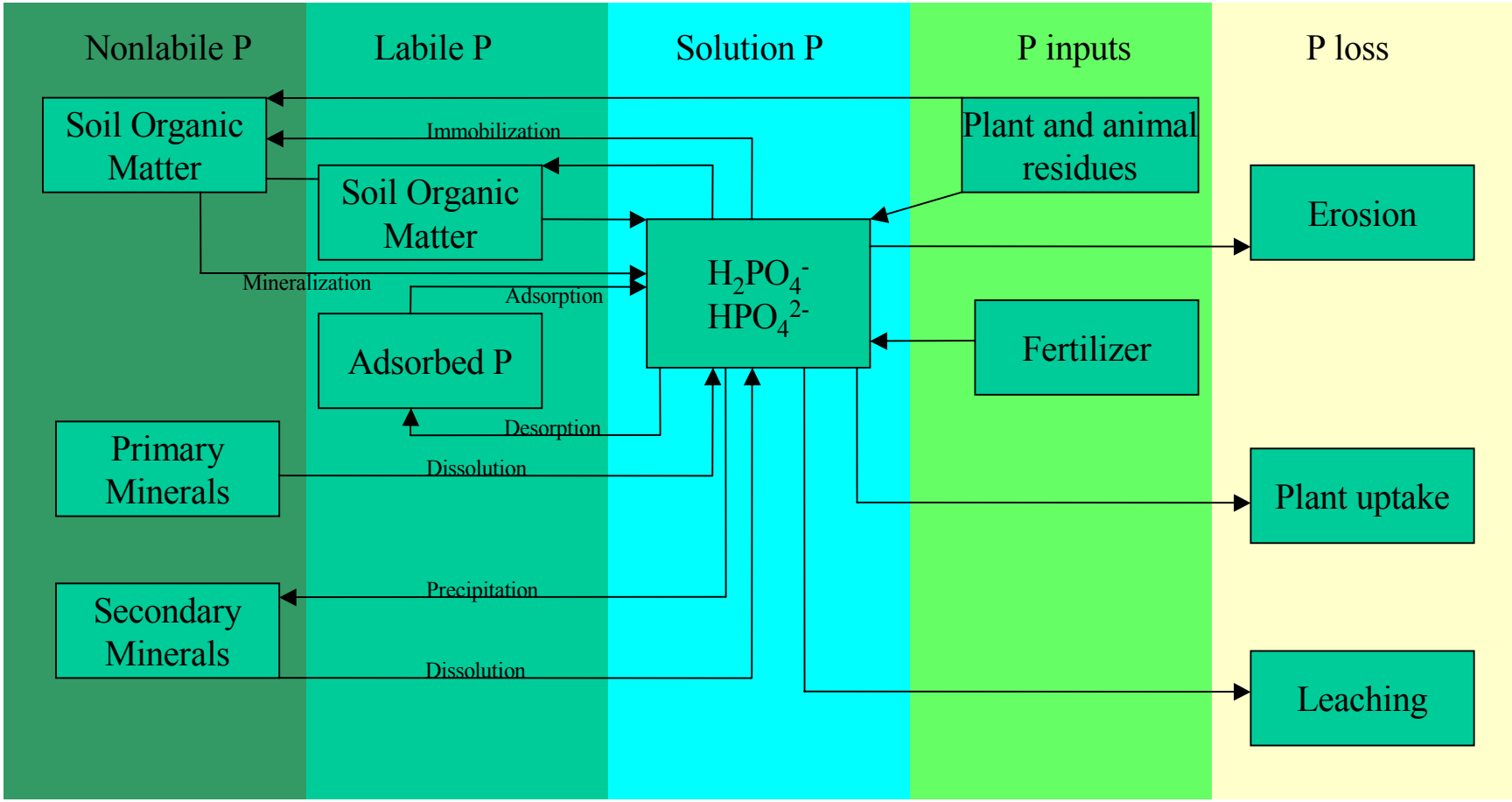

Figure 2-8. P cycle in soils.

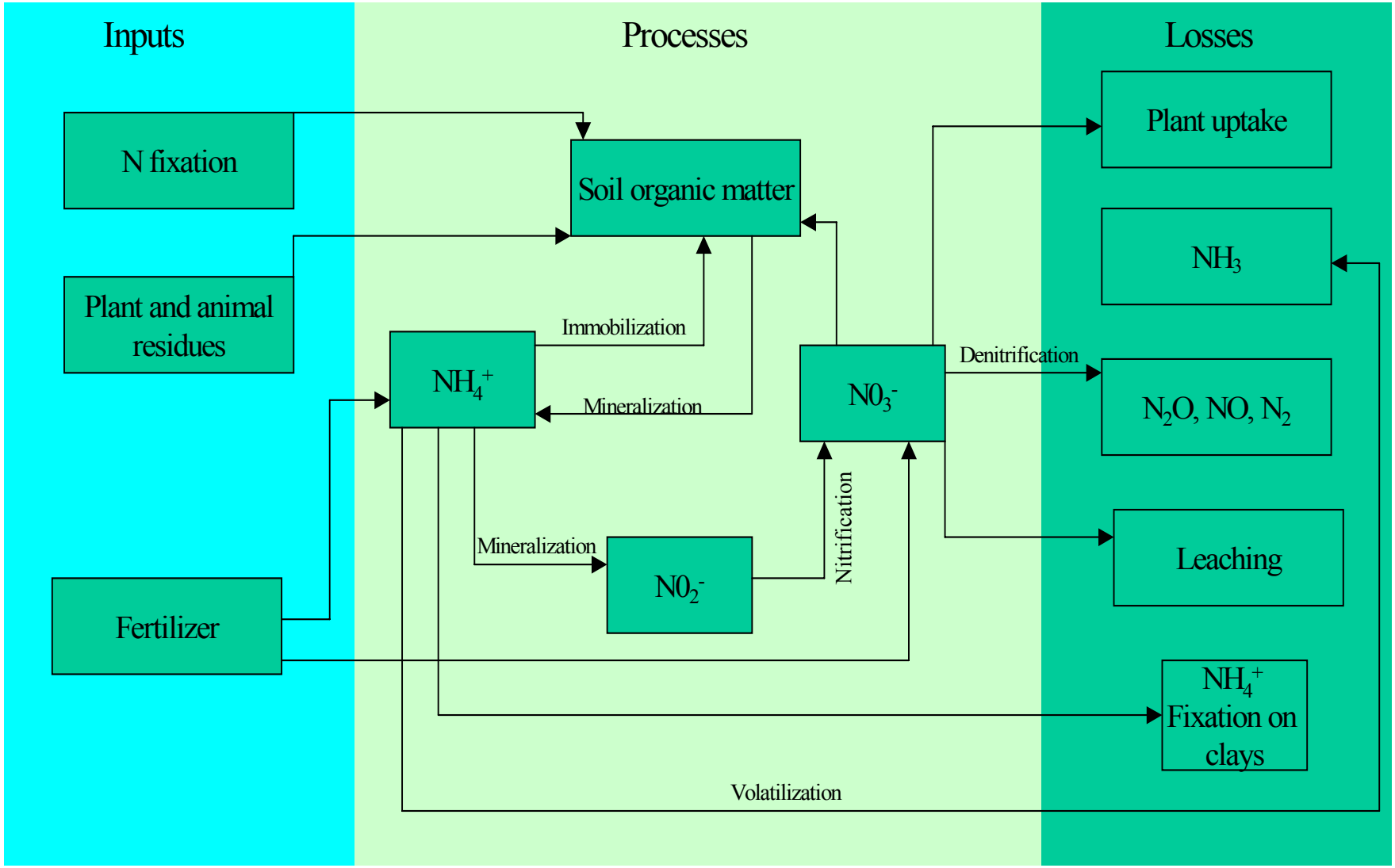

Figure 2-9. N cycle in soils.

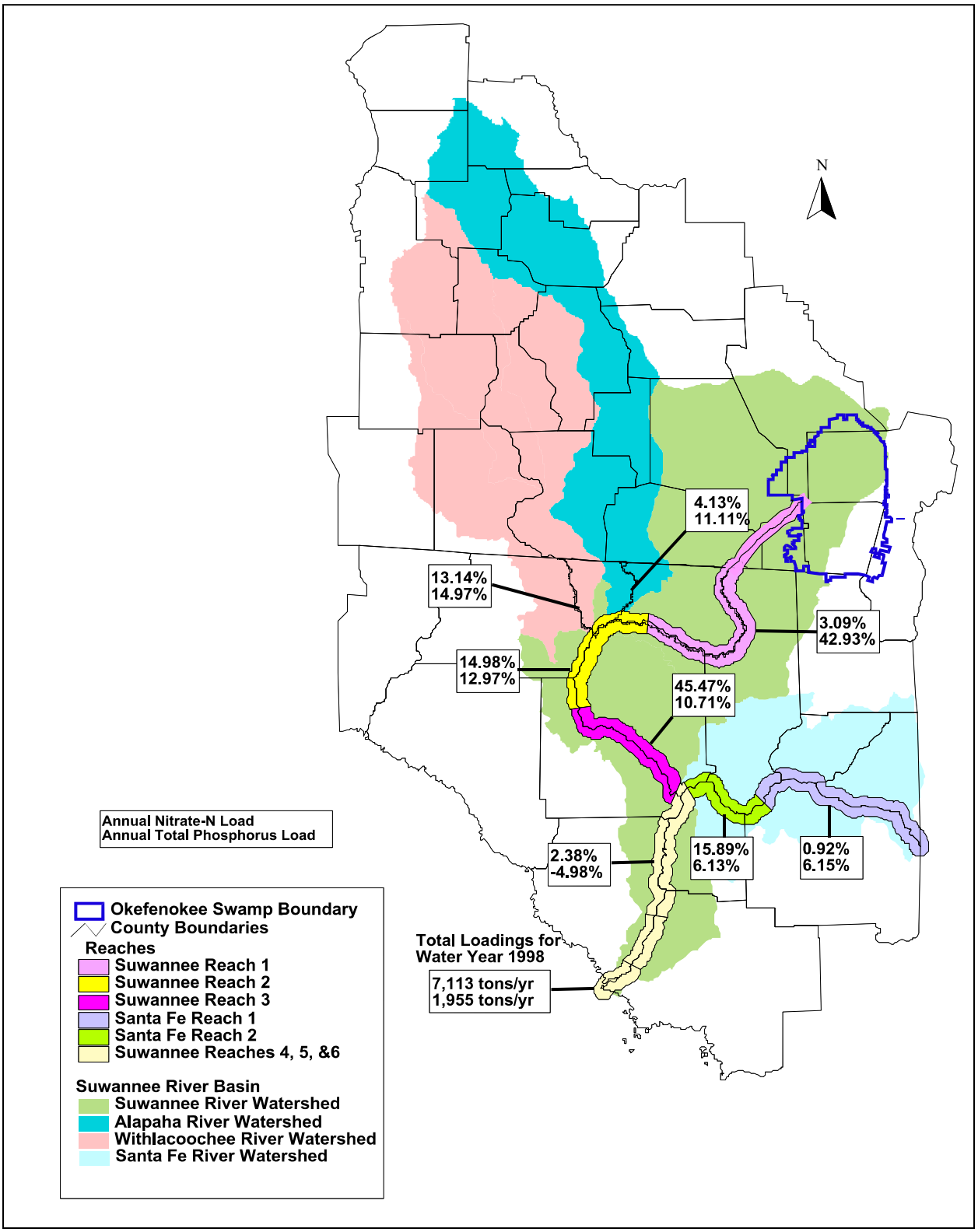

Figure 2-10. Nutrient loadings by watershed/reach in the Suwannee River System for water year 1998 (Hornsby and Mattson, 1998).

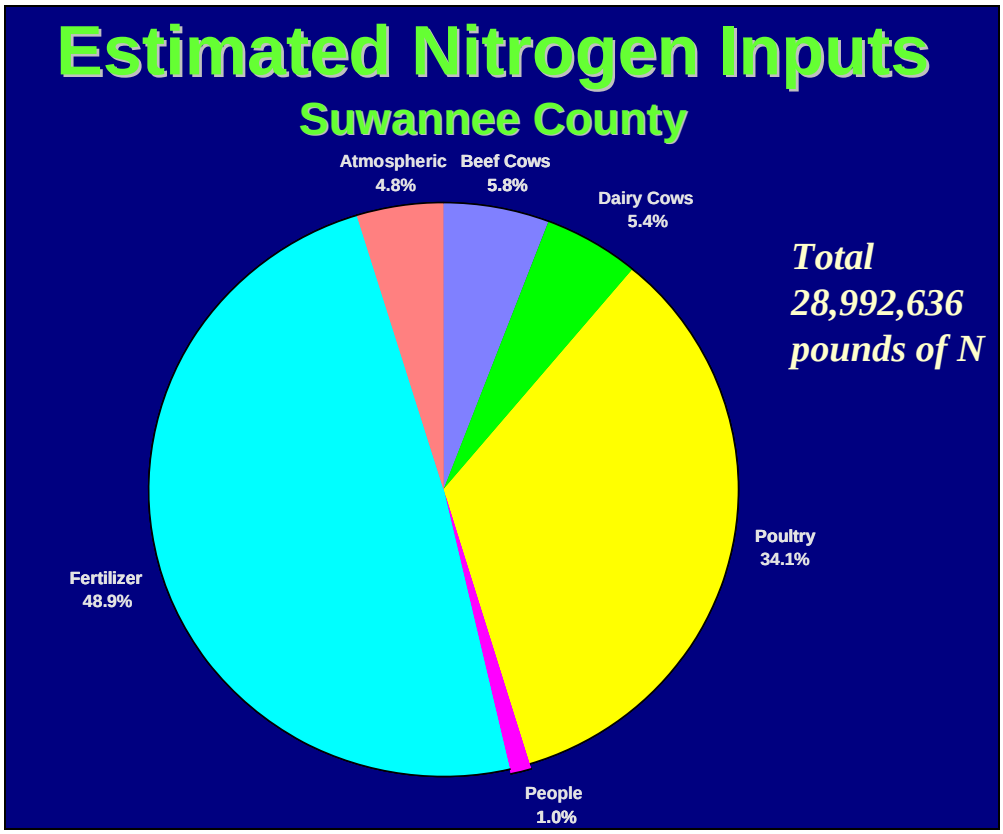

Figure 2-11. Estimated N inputs for Suwannee County (Hornsby and Mattson, 1998).

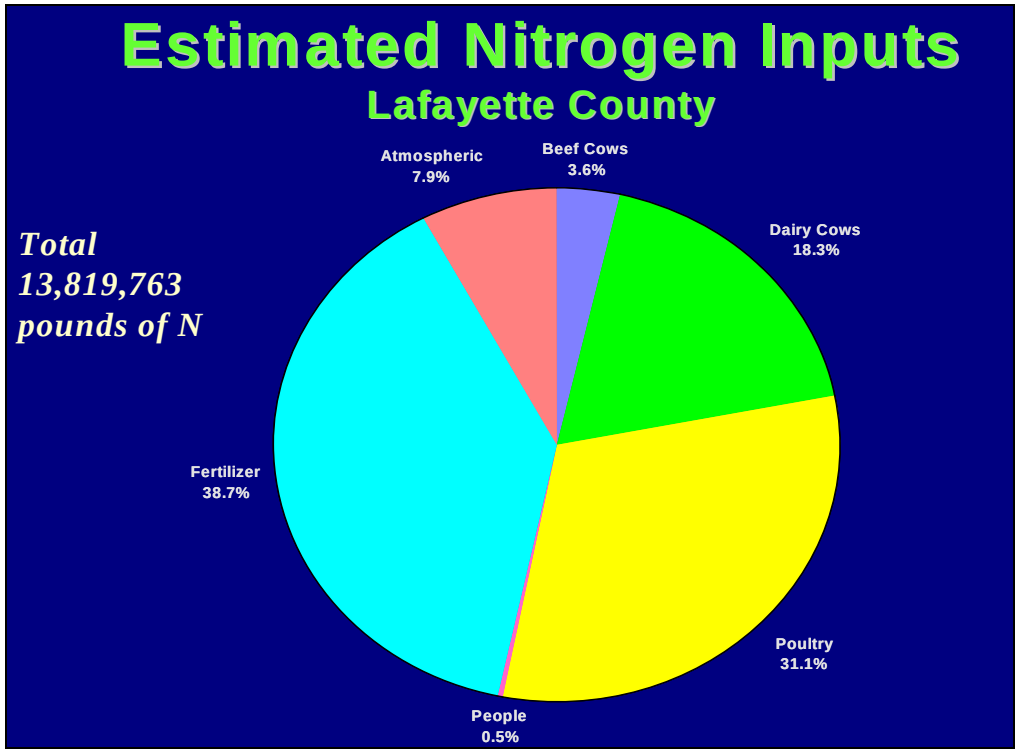

Figure 2-12. Estimated N inputs for Lafayette County (Hornsby and Mattson, 1998).

CHAPTER 3
COMPARISONS OF PRE AND POST OUTSTANDING FLORIDA WATER CONCENTRATIONS, TRENDS AND RECENT OCCURRENCES OF NITRATE-NITROGEN AND TOTAL PHOSPHORUS

Introduction

The Florida Legislature in 1979 designated the Suwannee River in Florida an Outstanding Florida Water (OFW) which means the River has significant cultural and ecological value to the State of Florida. The Florida Department of Environmental Protection (FDEP) was directed by Florida Statues Chapter 403.061 (27) which states "Establish rules which provide for a special category of water bodies within the State, to be referred to as Outstanding Florida Waters, which water bodies shall be worthy of special protection because of their natural attributes. Nothing in this subsection shall affect any existing rules of the department." Thus, the FDEP developed a rule 62-302.700 Florida Administrative Code (F.A.C.). Rule 62-302.700 (1) F.A.C. states "It shall be the Department policy to afford the highest protection to Outstanding Florida Waters and Outstanding National Resource Waters. No degradation of water quality, other than that allowed in subsections 62-4.242(2) and (3), F.A.C., is to be permitted in Outstanding Florida Waters and Outstanding National Resource Waters, respectively, not withstanding any other Department rules that allow water quality lowering." This rule focuses on point source discharges into an OFW. Furthermore, rule 62-302.700 (8) F.A.C. establishes the baseline definition for water bodies designated OFWs, as stated in the following: "For each Outstanding Florida Water listed under subsection 62-302.700(9), F.A.C., the last day of the baseline year for defining the existing ambient water quality (paragraph 62-4.242(2)(c), F.A.C.) is March 1, 1979, unless otherwise indicated. Where applicable, Outstanding Florida Water boundary expansions are indicated by date(s) following "as mod." under subsection 62-302.700(9), F.A.C. For each Outstanding Florida Water boundary which

expanded subsequent to the original date of designation, the baseline year for the entire Outstanding Florida Water, including the expansion, remains March 1, 1979, unless otherwise indicated." The Suwannee River falls in the initial induction into the OFW status; therefore, the last day of the baseline year is March 1, 1979.

The Suwannee River at Branford, Florida, has been monitored for water quality analytes by the United States Geological Survey (USGS) since 1954 and the Suwannee River Water Management District (SRWMD) since 1989. Concurrently, with water quality monitoring, the USGS monitors daily discharge for the Suwannee River at Branford (station number 02320500) since 1931 to present. Due to the paucity of historical data for the Santa Fe River only the Suwannee River at Branford will be discussed in this Chapter for long trend analysis and comparisons to pre-OFW, baseline, and post-OFW concentrations of total phosphorus (TP) and nitrate-nitrogen (NO_3-N).

The SRWMD Water Assessment Regional network (WARN) has 67 surface water quality stations (47 river and 20 spring stations) and 251groundwater quality stations as shown in Figures 3-1 and 3-2, respectively (Hornsby et al., 2005C). The WARN data will be used to determine the recent distribution and occurrences of TP and NO_3-N in the SRWMD. The WARN surfacewater quality stations have a period of record of sixteen years (Hornsby et al., 2005A) and the WARN groundwater quality stations have a period of record of six years (Hornsby et al., 2005B). The WARN surfacewater quality monitoring was started in 1989 while the WARN groundwater quality monitoring was started in 2000. The WARN water quality data provides a dataset that has been collected and analyzed in a consistent manner. This reduces variation in the data due to collection and analyzed method differences.

The objectives of this chapter are to analyze and interpret changes in the TP and NO_3-N concentrations in the Suwannee River at Branford from pre-OFW conditions to post-OFW conditions by combining several data sets, relate possible anthropogenic factors to observed changes, and determine the recent occurrences of TP and NO_3-N in surface water, springs and ground water in the upper Floridan aquifer within the SRWMD using WARN data.

Materials and Methods

Long Term Trend Analysis

Data was collected from the USGS for the station on the Suwannee River at Branford, Florida and the SRWMD. The USGS has been monitoring water quality at this site since 1954. The USGS data contains NO_3-N and potassium (K) concentrations from 1954 to 1989 and TP concentration from 1971 to 1989. The SRWMD data contains NO_3-N, K, and TP data from 1989 to 2006 for the Suwannee River at Branford. The data from the USGS and the SRWMD were combined to form a time series (or period of record) from 1954 to 2006.

Period of record graphs were produced for TP, K, and NO_3-N. The period of record for NO_3-N, K and TP were analyzed for linear correlation. Post-OFW median water year values for NO_3-N and TP were compared to median pre-OFW values using a Mann-Whitney test. The anthropogenic factors, such as, fertilizer sales, crop acreages, and population, were gathered for the period of record for correlation with riverine TP and NO_3-N concentrations.

Recent Distribution and Occurrences of Total Phosphorus and Nitrate-Nitrogen

The SRWMD WARN data was analyzed using MiniTab© to generate descriptive statistics (mean, standard deviation, median, 25^{th} percentile, 75^{th} percentile) for ground water (upper Floridan aquifer and springs) and surfacewater quality. Surface water was further subdivided by river basin. Annual mean upper Floridan aquifer concentrations contours of TP

and NO_3-N were generated using Surfer© with the kriging option with linear interpolation and zero nugget.

Annual surfacewater basin loading was determined using water quality data collected by the SRWMD, under my supervision, and discharge volume collected by the USGS and SRWMD. Loads for TP and NO_3-N were calculated by sub-basin.

Results and Discussion

Long Term Trends

The median annual TP concentration in the Suwannee River at Branford for the period of record (1971 to 2006) ranged from 0.13 to 0.34 mg P L^{-1} as shown in Appendix A, Figure A-1. Based on the data, there was an increasing trend from 1971 to 1985 and a declining trend starting in 1986 in the Suwannee River at Branford for TP as seen in Figure 3-3. The TP concentrations dropped in water years 1985 and 1986 and have continued to decline. The range of TP concentrations observed by water year is shown in Figure 3-4. This drop in TP concentration in 1985-1986 and the declining trend is associated with the regulation of a point source discharge for phosphate mining operations in northern Columbia and eastern Hamilton counties (J. Owens, 1998. Personal Communication). Also, the variations in the riverine concentrations observed have been reduced since 1986 due to regulation of the point source. The Suwannee River has a background concentration of TP of 0.3 mg L^{-1} due to the river coming into contact with the Hawthorne Group that contains high levels of P (FDER, 1985). Thus, the TP concentration in the Suwannee River is decreasing due to better management practices by the phosphate mining operation.

The median annual NO_3-N concentrations in the Suwannee River at Branford for the period of record (1954 to 2006) ranged from 0.14 to 1.21 mg N L^{-1} as shown in Appendix A,

Figure A-2. Based on the data, there is an increasing trend in the Suwannee River at Branford for NO_3-N (Figure 3-5). Ham and Hatzell (1996) documented this increasing trend for NO_3-N for the period of 1954 to 1995 for the Suwannee River at Branford. Recent data (1996 to 2006) indicates that the increasing trend is still present. The range of NO_3-N concentrations observed by water year is shown in Figure 3-6.

Comparison of Pre and Post OFW Water Quality

The OFW language in F.A.C. establishes 1979 as the baseline year for water quality for the Suwannee River and that the water quality should not degrade from the baseline water quality. Changes in water quality in the Suwannee River can be determined by comparing the water quality of a point in time to the water quality during the baseline year. Using the water quality data prior to and including the baseline year defines the pre-OFW and water quality data after the baseline year defined the post-OFW. A comparison of annual median NO_3-N and TP concentrations to 1979, the year the River was designated an OFW are given in Table 3-1. The baseline annual median concentrations for NO_3-N and TP are 0.50 mg N L^{-1} and 0.235 mg P L^{-1}, respectively; and post-OFW annual median concentrations for NO_3-N and TP are 0.72 mg N L^{-1} and 0.152 mg P L^{-1}, respectively. The comparison of baseline to post-OFW concentration shows a decreasing trend at greater than the 99.9 % confidence level for TP and a increasing trend at greater than the 99.9 % confidence level for NO_3-N. Also, a comparison of water years 1954 to 1979 or pre-OFW designation median concentrations of NO_3-N and TP of 0.14 mg N L^{-1} and 0.21 mg P L^{-1}, respectively; and water years 1979 to 2006 or post-OFW designation annual median concentrations of NO_3-N and TP of 0.72 mg N L^{-1} and 0.152 mg P L^{-1}, respectively, yielded similar results to the pre-OFW to the post-OFW. The annual NO_3-N loads for 1979 and 1998 to 2005 (post-OFW) are presented in Table 3-2. The annual NO_3-N load for 1979 was

3,548,981 kg N yr^{-1} while the annual NO_3-N load for water year 2005 was 6,197,855 kg N yr^{-1}. This shows an approximately 75 percent increase in the annual NO_3-N load for the Suwannee River to the Gulf of Mexico from 1979 to 2005 and is indicative of the increasing trend in NO_3-N concentrations in the river.

Anthropogenic Factors

The counties adjacent to the Suwannee River at Branford are Suwannee and Lafayette. The reach of the Suwannee River that borders Suwannee and Lafayette counties receives little to no surface water inputs due to the internal drainage of the counties; however, the River picks up flow from groundwater discharge via springs and seeps in the riverbed during base flow conditions. This pickup in flow from groundwater inputs can almost double the volume in the River from upstream to down stream under certain flow conditions (T. Mirti, 2003, Personal Communication). Data has shown that the reach of the Suwannee River, also known as the Middle Suwannee River Basin (MSRB), bordering Suwannee and Lafayette counties has the largest increase in NO_3-N concentration than any other sub-basin in the Suwannee River system and the NO_3-N was associated with flow conditions that are dominated by groundwater inputs (Hornsby et al., 2005A).

The population began increasing between 1970 to 1980 for Suwannee and Lafayette counties (Figure 3-7). The combined populations for Suwannee and Lafayette counties were plotted against annual median NO_3-N and TP concentrations for the Suwannee River at Branford as shown in Figures 3-8 and 3-9, respectively. The plot of population versus NO_3-N concentrations in the Suwannee River at Branford shows as population increases so does the riverine NO_3-N concentration. The increase in riverine NO_3-N concentration associated with the increase in population may be due to increased densities of onsite domestic systems (septic

tanks) and/or increased use of fertilizers associated with improved pasture and agricultural production. Based on the data for TP, there is an inverse relationship with TP concentration and population; however, this is a spurious correlation because the concentration of TP in the Suwannee River is dominated by the mining discharge in the upper River.

Fertilizer sales data (N, K, P) for Suwannee and Lafayette counties from 1941 to 2006 are shown in Figure 3-10. Florida Department of Agriculture and Consumer Services (DACS) Fertilizer sales data represents the sale and use of fertilizer within a county (W. Cox, 1997, Personal Communication). Florida Department of Agriculture and Consumer Services tracks the sales and the designation of N fertilizers in the State as required by Chapter 576.041(7), Florida Statues. Reports on fertilizer sales and destination county are reported to DACS on a monthly basis as required by Chapter 576, Florida Statues. Thus, DACS can generate annual reports by county that represents the fertilizer sales as well as fertilizer applied in each county within the State. Figure 3-11 presents the annual median TP concentration in the Suwannee River at Branford and P sales for 1971 to 2006. There is no correlation with sales data and riverine TP concentrations. Based on the P sales data, a sharp increase in P sales occurred in 1998 and has remained well above historic sales data from 1971 to 1998. The increase in P sales that occurred in 1998 maybe attributed to reapplication of P to crops during the growing season due to El Niño conditions; however, this is not the case for 1999 to 2006. The departure from historical sales data is most likely associated with a change in the DACS methodology for the collection of P sales data. A possible reason for the P sales remaining above the historical level since 1998 may be a result of a change in reporting format that occurred in 1994 which the fertilizer dealers submit to DACS (W. Cox, 2007, Personal Communication). Furthermore, since 1998, DACS does not compile the fertilizer sales data or develop the annual fertilizer sales report. Florida

Department of Agriculture and Consumer Services now contracts the data management and development of the annual report of fertilizer sales to the University of Kentucky (D. Terry, 2007, Personal Communication). Therefore, the potential exists that the historical P sales data have been under reported. Figure 3-12 presents the annual median NO_3-N concentrations in the Suwannee River at Branford and N sales for 1954 to 2006. There was a linear increasing trend in fertilizer sales and riverine NO_3-N concentrations from 1954 to 1982. From 1982 to 1992, sales data indicates dramatic fluctuations in N sales; however, the sales were lower than the time period from1954 to 1982. The riverine NO_3-N concentrations began dropping in 1988 and shows similar fluctuations as the sales data. This drop in riverine concentrations reflects the drop in total crop acres, primarily corn acreage, in Suwannee and Lafayette counties as shown in Figure 3-13. In 1998, a spike in sales for N was reported similar to the spike of P in 1998. Also, Figure 3-13 shows that from 1960 to 1999 N fertilizer sales data tracked the total crop acres in Suwannee and Lafayette counties; however, since 1988, N fertilizer sales data has diverted from the total cropped acres indicating that more fertilizer is being applied per acre than in the period 1960 to 1988. The correlation of the N fertilizer sales and riverine NO_3-N concentration was analyzed using Minitab© time series analysis with cross correlation. Based on a cross correlation of N fertilizer sales and riverine NO_3-N concentration, there is a one to six year time lag between the relationship of N sales data and the observed riverine NO_3-N concentrations (Table 3-3). This time lag or residence time in sales data and riverine NO_3-N concentrations is most likely a result of rainfall and the path from the application through the upper Floridan aquifer to river via springs and seeps in the riverbed. The variation in rainfall from year to year greatly influences the rate at which NO_3-N will be leached from the root zone and vadose zone and reach the underlying aquifer. Furthermore, the residence time is related to tortuosity of the

flow path and aquifer properties, such as, head, porosity and transmissivity (Maddox et al., 1992).

The annual median potassium (K) concentrations in the Suwannee at Branford were plotted for water years1954 to 2006 in Appendix A, Figure A-3. An increasing trend for riverine K was observed (Figure 3-14). The trend for K was similar to the trend observed for NO_3-N. The riverine annual median for K and NO_3-N were plotted form 1954 to 2006 in Figure 3-15. Figure 3-16 presents the annual median K concentrations in the Suwannee River at Branford and K sales for 1954 to 2006. The K sales data shows that prior to 1998 the amount of K sold in Suwannee and Lafayette counties was less than 100,000 kg y^{-1}; however, in 1998 a spike in sales occurred, sales for 1998 were ~500,000 kg and since 1998 have ranged between 225,000 to 300,000 kg. The increases in 1998 for K also occurred for P and N. This was possibly due the heavy rainfall in the spring of 1998 that was generated by a strong El Niño. The heavy springtime rains result in leaching events and farmers reapplied fertilizer to replace the leached nutrients. As with P and N, the reported K sales have been greater than historical levels since 1998. This might be attributed to a change in reporting format in 1994 that the fertilizer dealers submit to DACS and different data management and report format developed by DACS contractor, the University of Kentucky (W. Cox, 2007, Personal Communication)

Recent Distribution and Occurrences of Total Phosphorus and Nitrate-Nitrogen

Upper Floridan aquifer water quality

Background concentrations for TP and NO_3-N in the upper Floridan aquifer is < 0.1 mg P L^{-1} and <0.05 mg N L^{-1}, respectively (Maddox et al., 1992). The mean upper Floridan aquifer concentrations for TP and NO_3-N are 0.219 mg P L^{-1} and 0.94 mg N L^{-1}, respectively (Table 3-4). These concentrations (2001-2006) are three times above background and 23 times above

background concentrations for TP and NO_3-N, respectively. Annual mean distributions for water years 2001 to 2005 of TP, NO_3-N, and K in the upper Floridan aquifer are presented in Appendix B, Figures B-1A to B-1E, B-2A to B-2E, and B-3A to B-3E, respectively. The annual mean distribution for water year 2006 for TP, NO_3-N, and K are presented in Figures 3-17, 3-18, and 3-19, respectively. Lower TP concentrations are observed in the regions where the upper Floridan aquifer is confined while the higher concentrations were observed in the unconfined regions of the upper Floridan aquifer (Figure 3-17). Since the unconfined region receives recharge almost directly from rainfall events, the pH of the recharge water is still slightly acidic; thus, mobilizing TP. Thus, the distribution of TP in the upper Floridan aquifer seems to be controlled by whether the upper Floridan aquifer is confined or unconfined. The highest NO_3-N concentrations were observed in the unconfined regions of the upper Floridan aquifer; while, the lowest NO_3-N concentrations are observed in the confined regions of the upper Floridan aquifer (Figure 3-18). Nitrogen applied to the land surface in the unconfined regions leached into the upper Floridan aquifer when recharge events occur. Thus, NO_3-N concentrations seem to be controlled by both geology and land use practices. The mean upper Floridan aquifer concentration for K was 1.23 mg K L^{-1} compared to the background concentration of 1.1 mg K L^{-1}. The concentration of K observed in the upper Floridan aquifer has no relationship to geology (Figure 3-19). Both the unconfined and confined regions have similar concentrations. There are regions within the unconfined upper Floridan aquifer that show K depletion that may correlate to zones where the ground water is discharging (i.e., conduct flow) and possibly represents a groundwater basin.

A summary of all collected water quality parameters for the upper Floridan aquifer is presented in Appendix B, Table B-1 and contour concentrations for TP, NO_3-N, and K are

graphically presented in Appendix B, Figures B-1A to B-1E for TP, Figures B-2A to B-2E for NO_3-N, and Figures B-3A to B-3E for K.

Spring water quality

Spring water quality data are presented by specific river basin. The mean TP for the springs of Aucilla River Basin is 0.053 mg P L^{-1}, for the springs of Coastal Rivers Basin is 0.075 mg P L^{-1}, for the springs of Lower Suwannee River Basin (LSRB) is 0.051 mg P L^{-1}, for the springs of Santa Fe River Basin is 0.083 mg P L^{-1}, for the springs of Upper Suwannee River Basin is 0.102 mg P L^{-1}, for the springs of Waccasassa River Basin is 0.045 mg P L^{-1}, and the springs of Withlacoochee River Basin is 0.054 mg P L^{-1} (Table 3-5). The TP observed in the springs reflect the concentrations of TP observed in the upper Floridan aquifer which supplies water to the springs. Springs in the unconfined regions of the upper Floridan aquifer have higher TP concentrations than the springs in the confined region.

The mean NO_3-N for springs of the Aucilla River Basin is 0.16 mg N L^{-1}, for the springs of Coastal Rivers Basin is 0.05 mg N L^{-1}, for the springs of LSRB is 3.01 mg N L^{-1}, for the springs of Santa Fe River Basin is 0.90 mg N L^{-1}, for the springs of Upper Suwannee River Basin is 0.40 mg N L^{-1}, for the springs of Waccasassa River Basin is 0.43 mg N L^{-1}, and the springs of Withlacoochee River Basin is 1.34 mg N L^{-1} (Table 3-5). Similarly, to TP, the NO_3-N concentrations in the springs are a reflection of the concentrations in the upper Floridan aquifer. The unconfined regions of the upper Floridan aquifer are producing springs with the highest concentrations of NO_3-N. The unconfined regions of the upper Floridan are subject to contamination by water soluble contaminants, such as NO_3-N.

A summary of all collected water quality parameters for the springs of Aucilla River Basin is presented in Appendix B, Table B-2, for the springs of Coastal Rivers Basin is presented

in Appendix B, Table B-3, for the springs of LSRB is presented in Appendix B, Table B-4, for the springs of Santa Fe River Basin is presented in Appendix B, Table B-5, for the springs of Upper Suwannee River Basin is presented in Appendix B, Table B-6, for the springs of Waccasassa River Basin is presented in Appendix B, Table B-7, and the springs of Withlacoochee River Basin is presented in Appendix B, Table B-8.

Surface water quality

The mean TP for the Alapaha River Basin is 0.127 mg P L^{-1}, for the Aucilla River Basin is 0.026 mg P L^{-1}, for the Coastal Rivers Basin is 0.169 mg P L^{-1}, for the LSRB is 0.115 mg P L^{-1}, for the Santa Fe River Basin is 0.151 mg P L^{-1}, for the Upper Suwannee River Basin is 0.253 mg P L^{-1}, for the Waccasassa River Basin is 0.075 mg P L^{-1}, and the Withlacoochee River Basin is 0.137 mg P L^{-1} (Table 3-6). The exception of the Upper Suwannee River Basin which is influenced by a point discharge and geological formation, the TP concentration seems to be influenced by geological formation.

The mean NO_3-N for the Alapaha River Basin is 0.48 mg N L^{-1}, for the Aucilla River Basin is 0.05 mg N L^{-1}, for the Coastal Rivers Basin is 0.07 mg N L^{-1}, for the LSRB is 0.57 mg N L^{-1}, for the Santa Fe River Basin is 0.34 mg N L^{-1}, for the Upper Suwannee River Basin is 0.15 mg N L^{-1}, for the Waccasassa River Basin is 0.10 mg N L^{-1}, and the Withlacoochee River Basin is 0.39 mg N L^{-1} (Table 3-6). The riverine NO_3-N concentration seems to be influenced by the NO_3-N concentrations in the ground water of the upper Floridan aquifer adjacent to the rivers.

A summary of all collected water quality parameters for the Alapaha River Basin is presented in Appendix B, Table B-9, for the Aucilla River Basin is presented in Appendix B, Table B-10, for the Coastal Rivers Basin is presented in Appendix B, Table B-11, for the LSRB is presented in Appendix B, Table B-12, for the Santa Fe River Basin is presented in Appendix

B, Table B-13, for the Upper Suwannee River Basin is presented in Appendix B, Table B-14, for the Waccasassa River Basin is presented in Appendix B, Table B-15, and the Withlacoochee River Basin is presented in Appendix B, Table B-16.

Annual TP and NO_3-N loads for the Suwannee River to the Gulf of Mexico for water years 1990 to 2005 are presented in Figures 3-20 and 3-21, respectively. Asbury and Oaksford (1997) comparison of the Suwannee River to the Altamaha River, St. Johns River, Satilla River, Ogeechee River, Withlacoochee River (South), and the Ochlockonee River, showed the Suwannee River had the highest in-stream TP and NO_3-N load km^{-2} of basin of the seven rivers. Quinlan (2003) demonstrated that the Suwannee River and its estuary are N limited. Thus, increases in NO_3-N loads in the Suwannee River and the estuary will increase the potential for eutrophication. Figures 3-22 and 3-23 present the TP and NO_3-N for water years 1998 to 2005 with annual rainfall. The TP loads increased with increased rainfall. This is likely due to surfacewater runoff from the headwater in the Okefenokee Swamp that lowers the pH and results in leaching of P from the Hawthorne Group and other sites where P is bound. The NO_3-N loads increases with rainfall is most likely due to the flushing of the NO_3-N from the soil profile into the upper Floridan aquifer that is connected to the rivers. Based on the regionalization of the SRB developed by Hornsby and Mattson (1998), the mainstem of the Suwannee and Santa Fe rivers are subdivided into six and two reaches, respectively. Annual TP loads for the sub-basins of the SRB for each water year from 1998 to 2004 are presented in Appendix B, Tables B-17A to B-17F and graphically presented in Appendix B, Figures B-4A to B-4G. The annual TP and NO_3-N loads for the sub-basins of the SRB for water year 2005 are presented in Table 3-7 and graphically presented in Figure 3-24. The sub-basin that contributed the largest percentage of the TP load is Reach 1 of the Suwannee River, followed by the Alapaha and Withlacoochee

rivers for water years 1998 to 2005. This is the region where the Suwannee River intersects the Hawthorne Group and where a phosphate mining operation discharges to the Suwannee River. The sub-basin that contributed the largest percentage of the NO_3-N load is Reach 3 of the Suwannee River, followed by Reach 2 of the Santa Fe River for water years 1998 to 2005.

Summary and Conclusions

The observed concentrations of TP and NO_3-N in the Suwannee River at Branford has significantly (>95% confidence level) changed since its designation as an Outstanding Florida Water in 1979. The annual median TP concentrations in the Suwannee River have significantly decreased from 0.235 mg P L^{-1} in water year 1979 to 0.148 mg P L^{-1} in water year 2006. The decrease in the annual median TP concentration in the Suwannee River that started in 1985 coincides with the increased regulation of a phosphate mining operation in Hamilton and Columbia counties. The annual median NO_3-N concentrations in the Suwannee River have significantly increased from 0.50 mg N L^{-1} in water year 1979 to 1.21 mg N L^{-1} in water year 2006. There is an observed time lag between the sales data and riverine NO_3-N concentrations of one to six years. The increasing trend for NO_3-N in the Suwannee River is supported by the increased use of inorganic fertilizer. Therefore, anthropogenic factors are driving the changes in water quality for TP and NO_3-N from pre-OFW to post-OFW concentrations.

The mean upper Floridan aquifer concentrations for TP and NO_3-N are three times above background and 23 times above background concentrations, respectively, as defined by Maddox et al (1992). Surfacewater NO_3-N concentrations reflect the upper Floridan aquifer groundwater concentrations for NO_3-N in the adjacent surfacewater basin. Surfacewater basin concentrations of TP are driven by geological formations, point sources and surface runoff. While, surfacewater basins with low concentrations of NO_3-N in the upper Floridan aquifer have low concentrations

of NO_3-N observed in the surface water and surfacewater basins with high concentrations of NO_3-N in the upper Floridan aquifer have high concentrations of NO_3-N observed in the surface water. The basin with the highest percentage load of TP is Reach 1 of the Suwannee River. This is a region of the Suwannee River where a point source discharges and where the River comes in contact with a P bearing Hawthorne Group. The basins with the highest percentage loads of NO_3-N is Reach 3 of the Suwannee River and Reach 2 of the Santa Fe River. These are regions that have high concentrations of NO_3-N in the upper Floridan aquifer and the Suwannee and Santa Fe rivers receives ground water from numerous springs and riverbed seeps during base flow conditions. Thus, ground water from the upper Floridan aquifer plays a major role on the quality of surface water in regions where the River intersects the top of the upper Floridan aquifer.

Table 3-1. Comparison of pre and post OFW concentrations of TP and NO_3-N to OFW baseline concentrations of TP and NO_3-N for the Suwannee River at Branford.

Water Year	Median NO_3-N (mg N L^{-1})	Trend	Significant	Median TP (mg P L^{-1})	Trend	Significant
1954 to 1979 (pre - OFW)	0.14			0.21		
1979 to 2006 (post-OFW)	0.72	increasing	<0.0001	0.152	decreasing	<0.0001
1979 (Baseline)	0.50			0.235		
Annual water year comparison to Baseline						
1998	0.49	Neutral	0.6474	0.109	decreasing	<0.0001
1999	1.05	increasing	<0.0001	0.118	decreasing	<0.0001
2000	0.835	increasing	0.0001	0.129	decreasing	<0.0001
2001	0.680	increasing	0.0346	0.123	decreasing	<0.0001
2002	0.875	increasing	0.0003	0.216	decreasing	0.0215
2003	0.595	increasing	0.6711	0.160	decreasing	<0.0001
2004	0.97	increasing	0.0051	0.167	decreasing	<0.0001
2005	0.43	decreasing	0.3218	0.153	decreasing	<0.0001
2006	1.21	increasing	0.0040	0.151	decreasing	<0.0001

Table 3-2. Comparison of OFW baseline annual NO_3-N load to water years 1998 to 2005 annual NO_3-N load.

Water Year	Annual NO_3-N Load (kg N yr^{-1})	Departure from Baseline	Mean Discharge [cfs/L s^{-1})]
1979	3,548,981	Baseline	8,657(245,139)
1998	6,402,033	Greater than	15,476(438,232)
1999	4,270,788	Greater than	6,415(181,653)
2000	2,358,000	Less than	3,406(96,447)
2001	2,356,146	Less than	5,339(151,183)
2002	2,674,080	Less than	3,275(92,738)
2003	4,036,590	Greater than	10,088(285,660)
2004	4,789,350	Greater than	6,467(183,125)
2005	6,197,855	Greater than	16,310(461,848)

Table 3-3. Cross correlation of N fertilizer sales and annual median riverine NO_3-N concentration for the Suwannee River at Branford.

Lag time (years)	Cross correlation function
-8	-0.0596
-7	-0.0567
-6	0.0228
-5	0.0719
-4	0.1256
-3	0.2065
-2	0.2917
-1	0.4014
0	0.4312
1	0.5200
2	0.5547
3	0.5456
4	0.5540
5	0.4681
6	0.5090
7	0.4028
8	0.3469

Table 3-4. Summary of NO_3-N and TP concentrations in the upper Floridan aquifer for the Suwannee River Water Management District (2001 to 2006).

Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
NO_3-N	mg L^{-1}	0.94	2.73	0.00	0.17	1.00	0.000	52.0
TP	mg L^{-1}	0.219	1.558	0.000	0.07	0.156	0.000	45.0

Table 3-5. Summary of NO_3-N and TP concentrations for the Springs by River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Aucilla	NO_3-N	mg L^{-1}	0.17	0.14	0.05	0.13	0.26	0.00	0.46
Aucilla	TP	mg L^{-1}	0.054	0.053	0.036	0.043	0.056	0.009	0.319
Coastal	NO_3-N	mg L^{-1}	0.05	0.07	0.02	0.03	0.05	0.00	0.38
Coastal	TP	mg L^{-1}	0.075	0.020	0.068	0.072	0.078	0.047	0.128
Lower Suwannee	NO_3-N	mg L^{-1}	3.01	3.11	1.30	1.91	3.45	0.00	21.80
Lower Suwannee	TP	mg L^{-1}	0.051	0.031	0.032	0.047	0.064	0.004	0.430
Santa Fe	NO_3-N	mg L^{-1}	0.91	1.60	0.39	0.58	1.01	0.00	26.00
Santa Fe	TP	mg L^{-1}	0.084	0.058	0.048	0.077	0.101	0.004	0.820
Upper Suwannee	NO_3-N	mg L^{-1}	0.40	0.40	0.02	0.29	0.70	0.00	1.91
Upper Suwannee	TP	mg L^{-1}	0.102	0.046	0.060	0.111	0.136	0.004	0.220
Waccasassa	NO_3-N	mg L^{-1}	0.44	0.25	0.42	0.43	0.65	0.03	0.65
Waccasassa	TP	mg L^{-1}	0.046	0.006	0.044	0.046	0.048	0.039	0.053
Withlacoochee	NO_3-N	mg L^{-1}	1.35	0.35	1.17	1.40	1.58	0.27	1.94
Withlacoochee	TP	mg L^{-1}	0.054	0.016	0.044	0.050	0.060	0.040	0.140

Table 3-6. Summary of NO_3-N and TP concentrations for each River Basin in the Suwannee River Water Management District (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Alapaha	NO_3-N	mg L^{-1}	0.48	0.44	0.14	0.31	0.72	0.00	2.00
Alapaha	TP	mg L^{-1}	0.191	0.097	0.110	0.180	0.250	0.041	0.567
Aucilla	NO_3-N	mg L^{-1}	0.05	0.05	0.01	0.03	0.07	0.00	0.44
Aucilla	TP	mg L^{-1}	0.054	0.027	0.037	0.048	0.070	0.011	0.150
Coastal	NO_3-N	mg L^{-1}	0.07	0.11	0.02	0.05	0.06	0.00	0.71
Coastal	TP	mg L^{-1}	0.285	0.707	0.054	0.091	0.139	0.010	9.600
Lower Suwannee	NO_3-N	mg L^{-1}	0.57	0.33	0.31	0.56	0.81	0.00	2.44
Lower Suwannee	TP	mg L^{-1}	0.161	0.094	0.111	0.140	0.181	0.004	1.320
Santa Fe	NO_3-N	mg L^{-1}	0.34	0.32	0.07	0.26	0.56	0.00	4.80
Santa Fe	TP	mg L^{-1}	0.204	0.368	0.080	0.124	0.210	0.001	6.000
Upper Suwannee	NO_3-N	mg L^{-1}	0.15	0.31	0.03	0.05	0.20	0.00	8.04
Upper Suwannee	TP	mg L^{-1}	0.299	0.535	0.100	0.168	0.280	0.004	8.900
Waccasassa	NO_3-N	mg L^{-1}	0.10	0.09	0.02	0.09	0.16	0.00	0.49
Waccasassa	TP	mg L^{-1}	0.075	0.036	0.050	0.068	0.098	0.023	0.350
Withlacoochee	NO_3-N	mg L^{-1}	0.39	0.28	0.20	0.32	0.51	0.00	2.36
Withlacoochee	TP	mg L^{-1}	0.137	0.098	0.093	0.115	0.147	0.010	1.100

Table 3-7. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 2005.

		Annual Load Contribution (kg/year)			
Contributing Basin	Area (mi²)	Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee River Reach 1	2,430	41,589.9	0.7%	340,891.6	14.6%
Alapaha River	1,801	155,304.6	2.5%	297,750.6	12.7%
Withlacoochee River	2,382	1,166,049.5	18.8%	507,256.9	21.7%
Withlacoochee - GA	2,118	441,407.9	7.1%	340,207.0	14.5%
Withlacoochee – FL	264	724,641.6	11.7%	167,049.8	7.1%
Suwannee River Reach 2	443	208,815.9	3.4%	748,258.8	31.9%
Suwannee River Reach 3	824	2,362,408.1	38.1%	201,830.1	8.6%
Santa Fe River Reach 1	820	48,107.4	0.8%	237,689.3	10.1%
Santa Fe River Reach 2	564	1,133,998.0	18.3%	145,558.5	6.2%
Suwannee River Reach 4	342	-421,452.7	-6.8%	-106,884.5	-4.6%
Suwannee River Reaches 5 & 6	344	1,503,034.7	24.3%	-29,667.8	-1.3%
Total	*9,950*	*6,197,855.5*	*100%*	*2,342,683.5*	*100.0%*

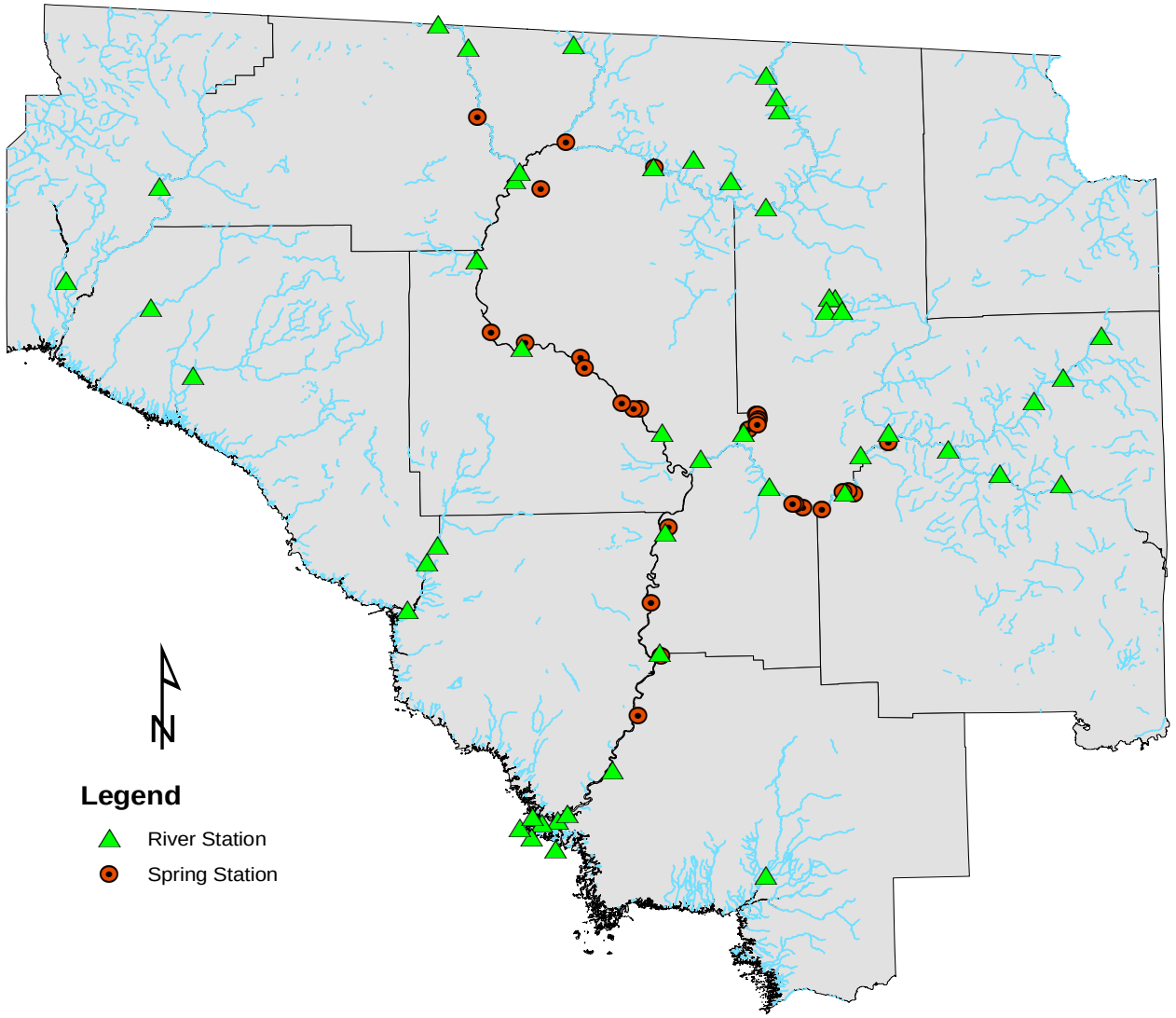

Figure 3-1. Suwannee River Water Management District surfacewater quality monitoring network.

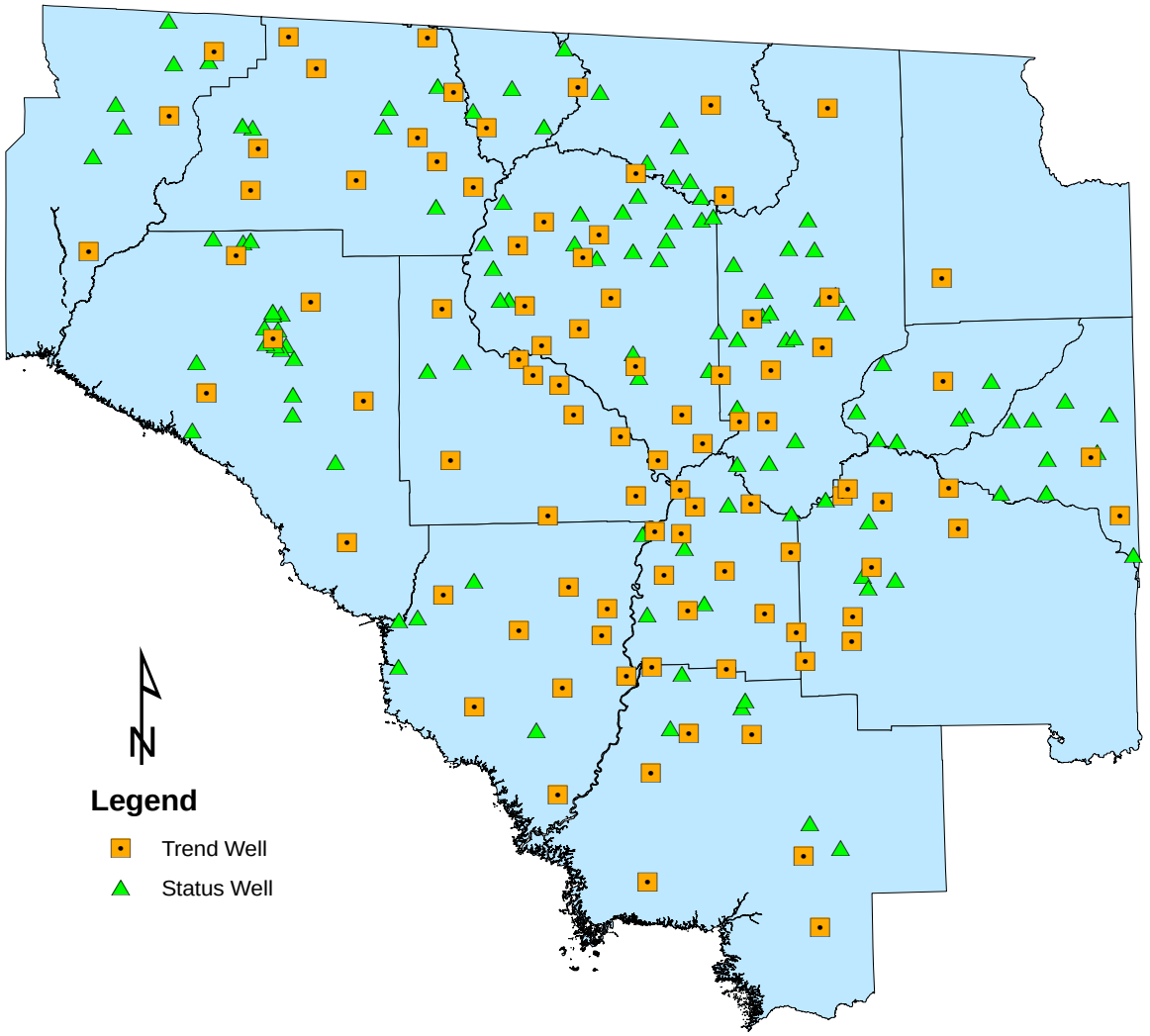

Figure 3-2. Suwannee River Water Management District groundwater quality monitoring network.

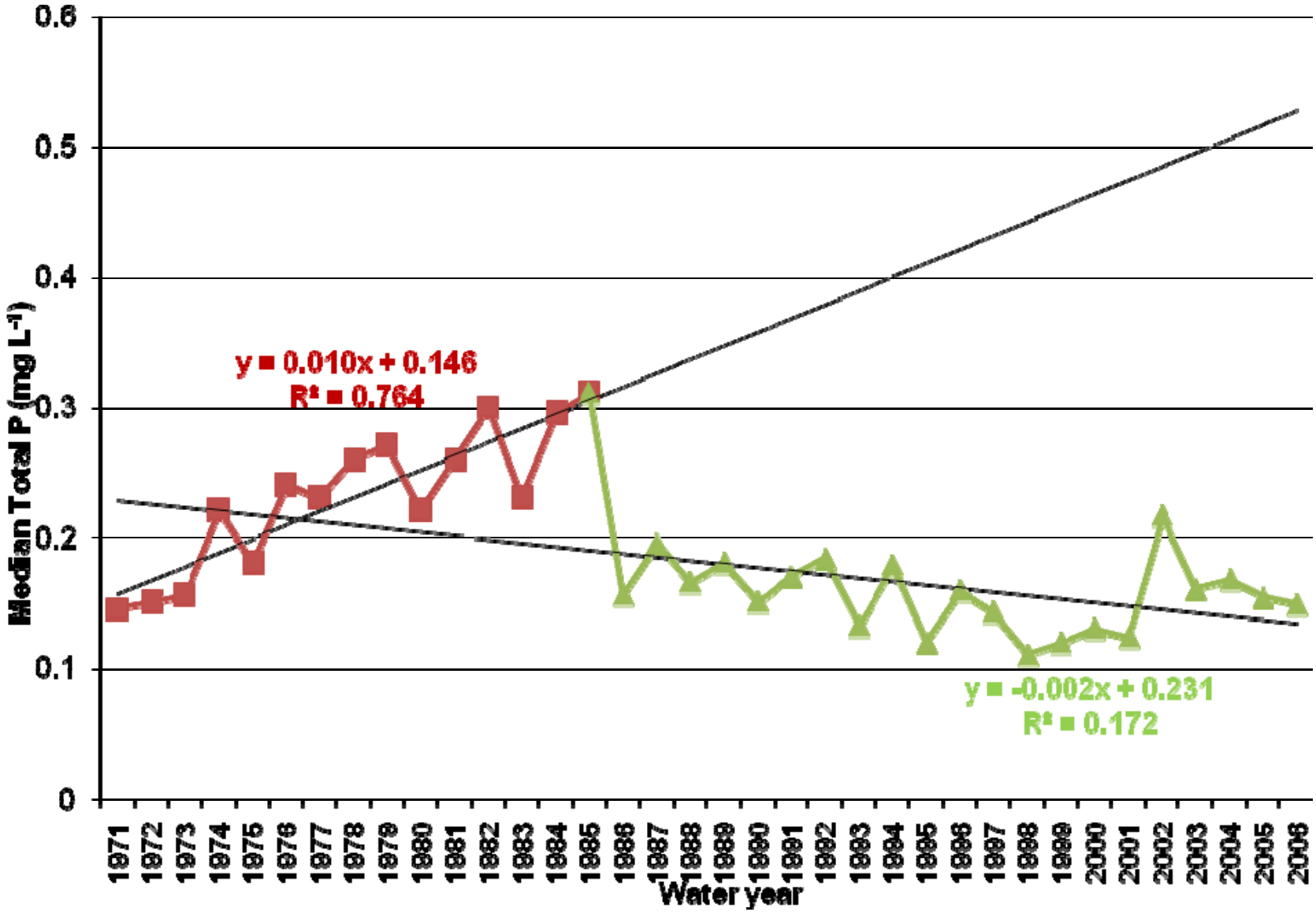

Figure 3-3. Median TP for the Suwannee River at Branford with linear trend lines.

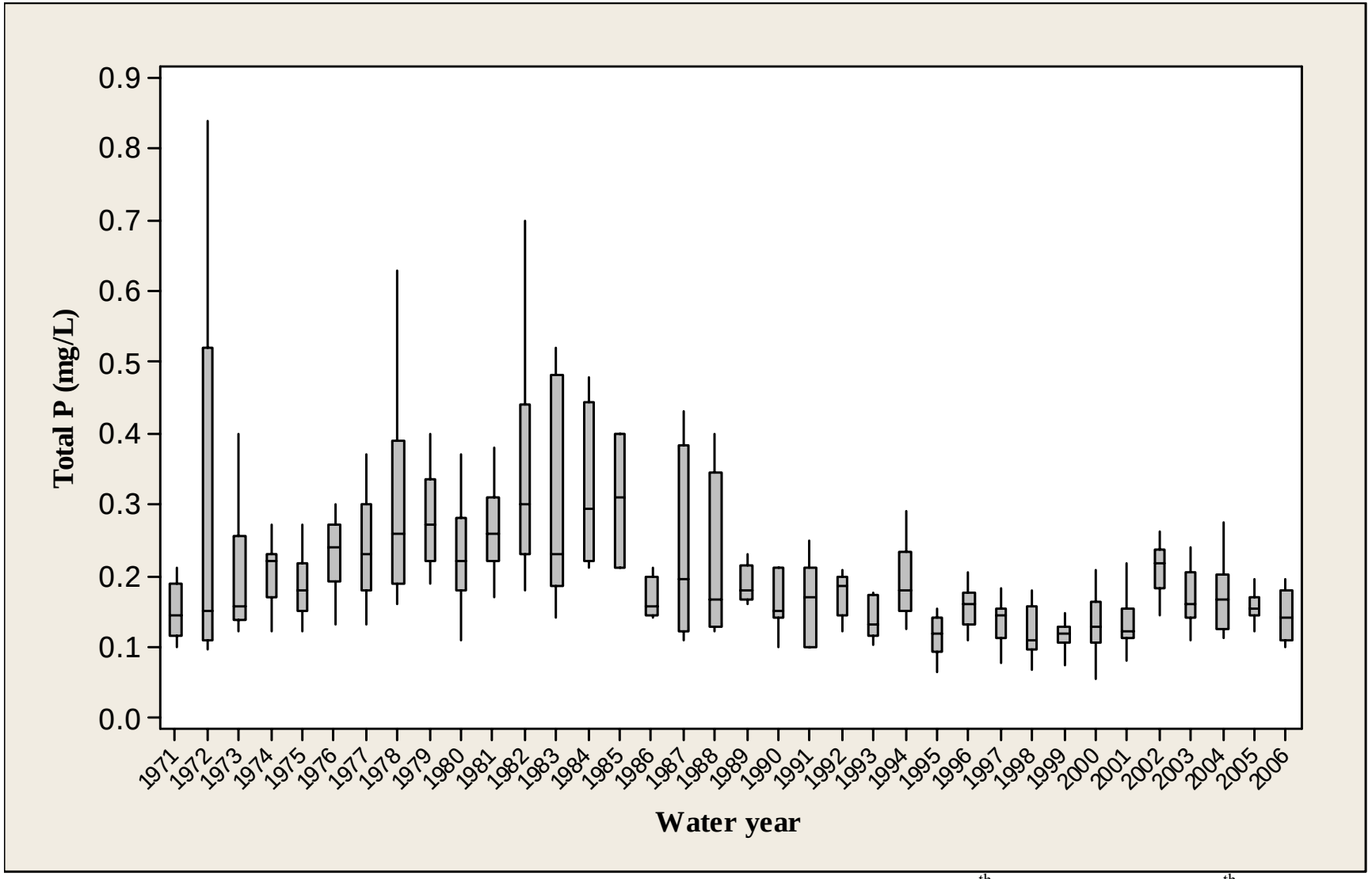

Figure 3-4. TP concentration by water year for Suwannee River at Branford. Box represents 25th percentile, median, 75th percentile and whiskers represents the upper and lower observed value.

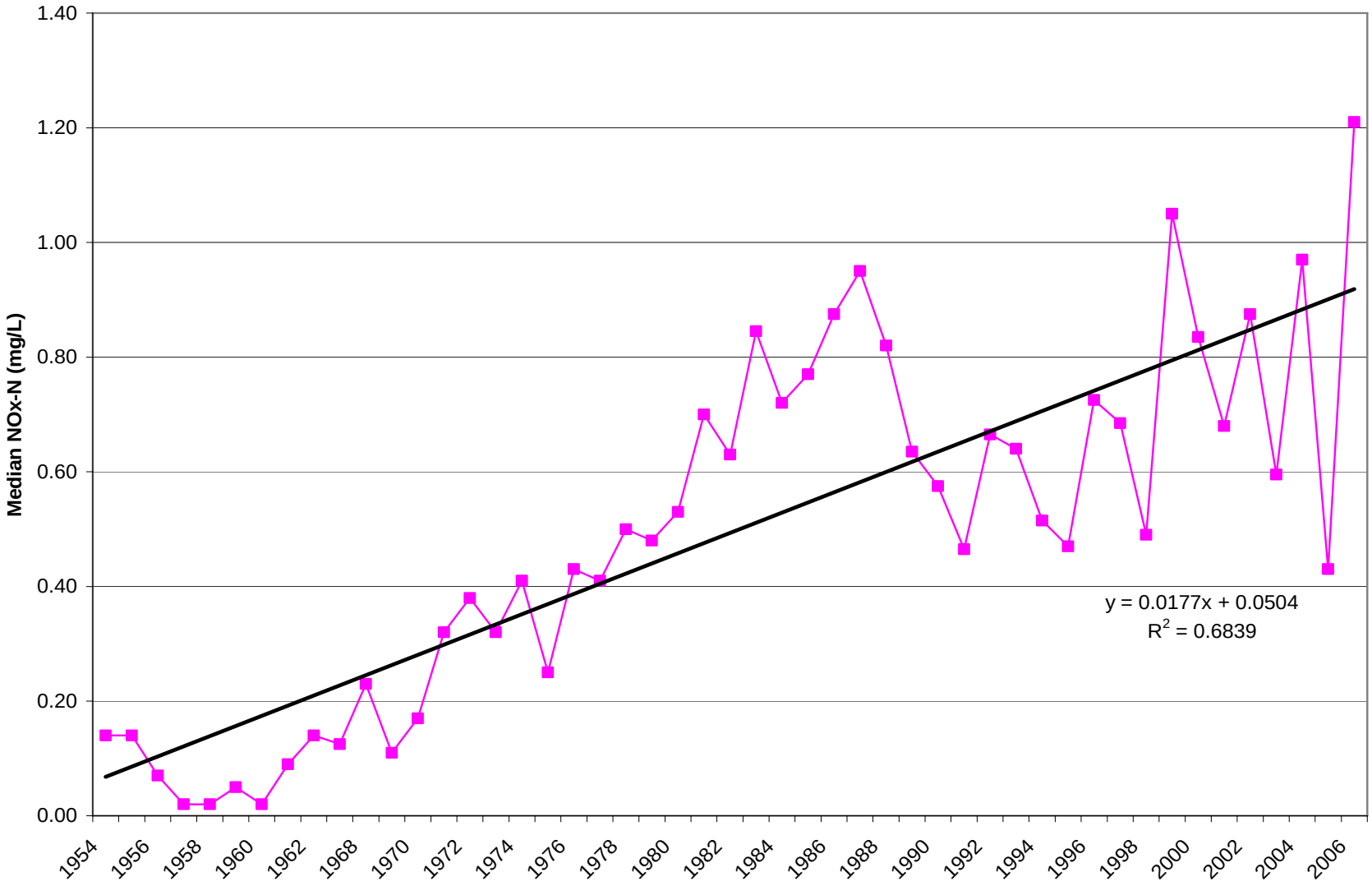

Figure 3-5. Median NO_3-N for the Suwannee River at Branford with linear trend line.

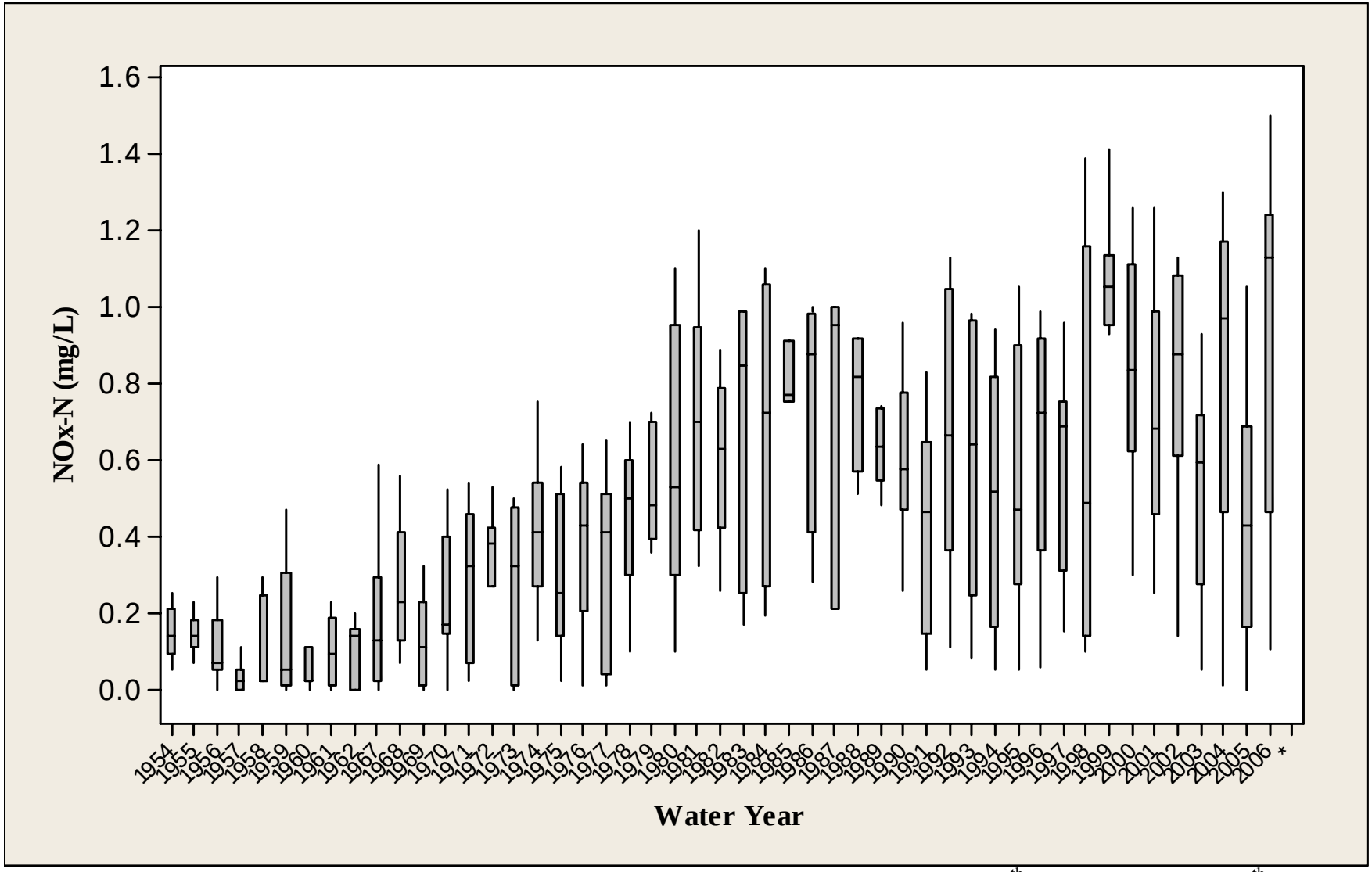

Figure 3-6. NO_3-N concentration by water year for Suwannee River at Branford. Box represents 25th percentile, median, 75th percentile and whiskers represents the upper and lower observed value.

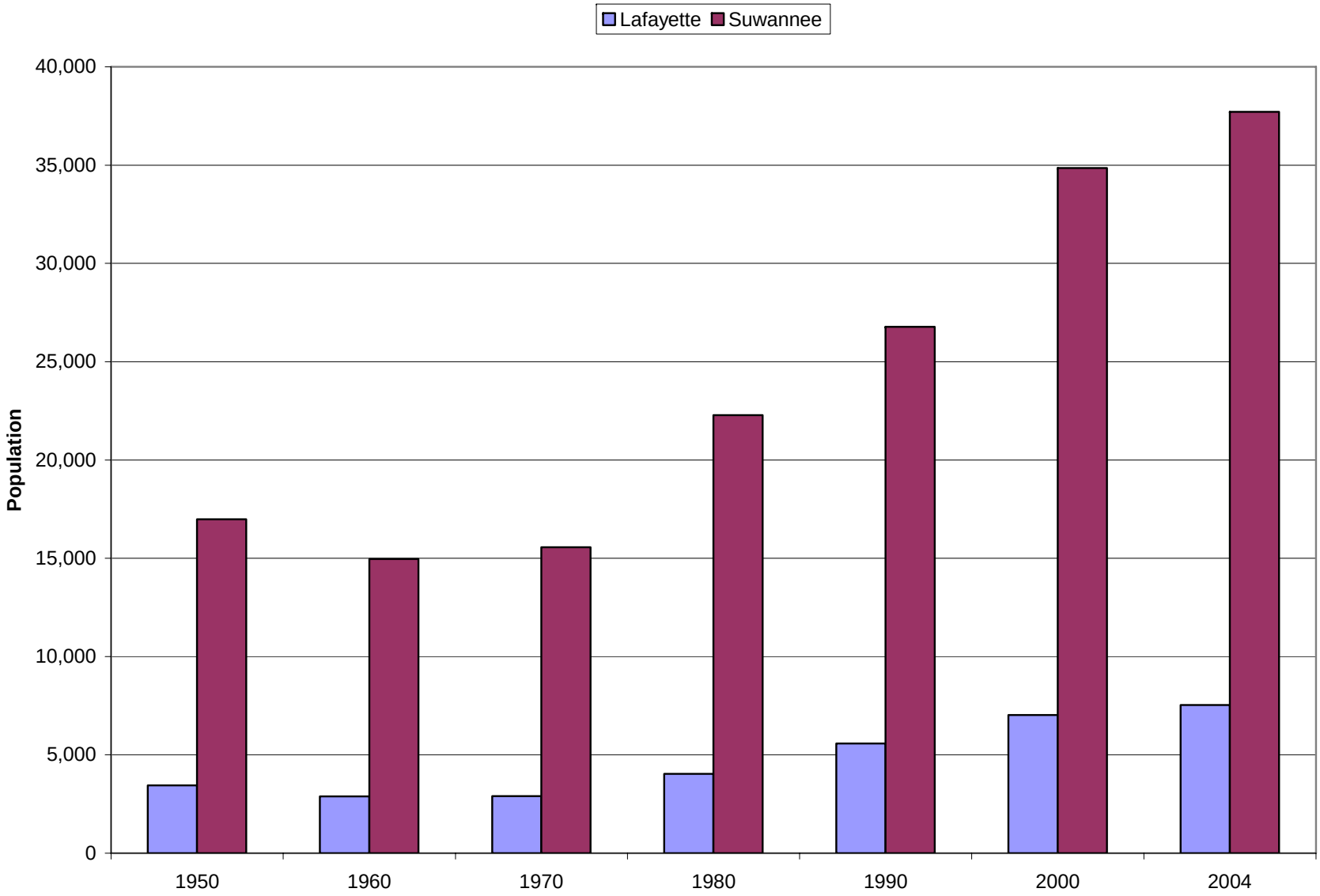

Figure 3-7. Population for Lafayette and Suwannee Counties, 1950 through 2004 (BEBR, 2001; BEBR, 2004).

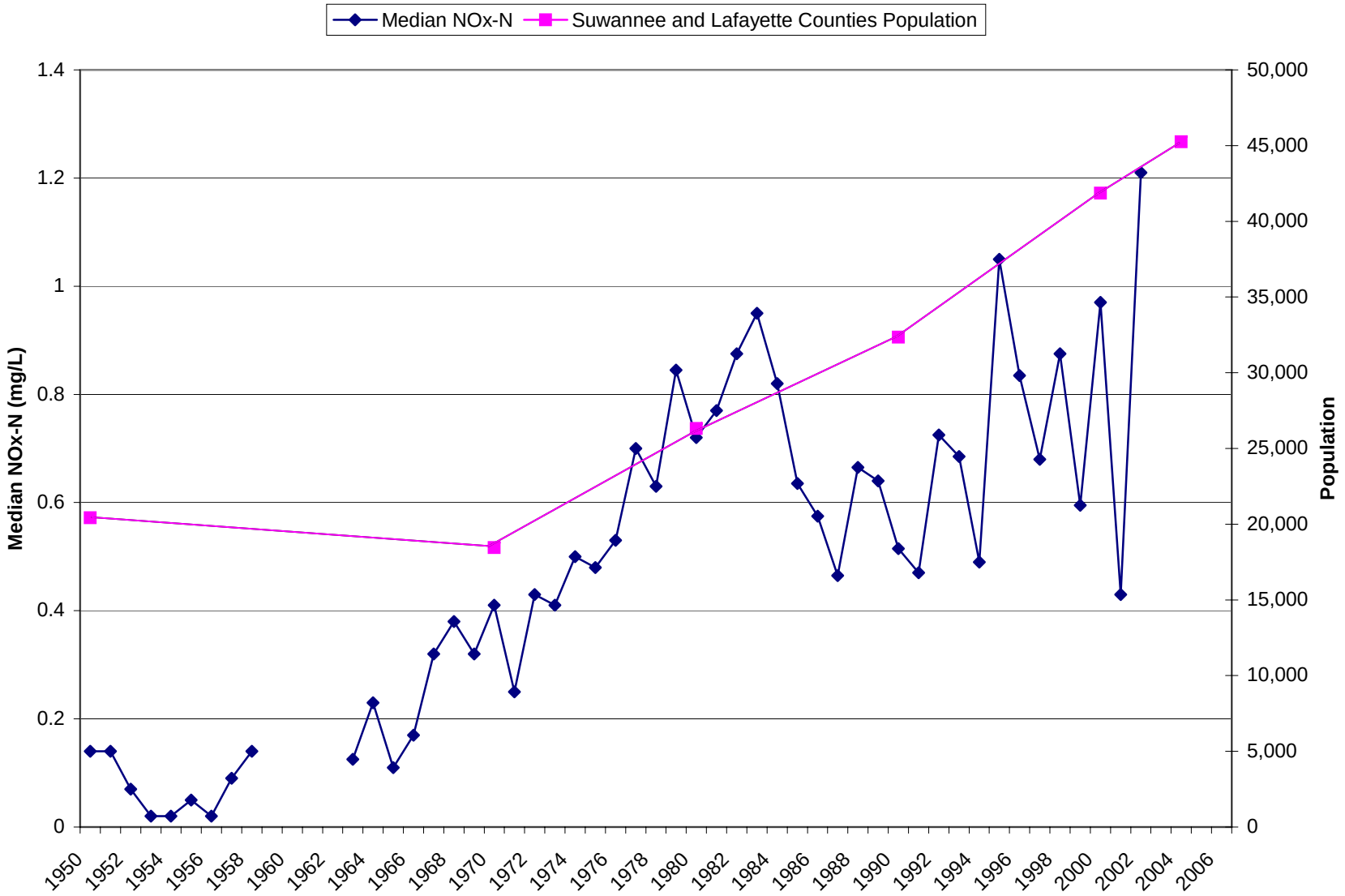

Figure 3-8. Median NO_3-N concentration for the Suwannee River at Branford and population for Lafayette and Suwannee counties (BEBR, 2001; BEBR, 2004).

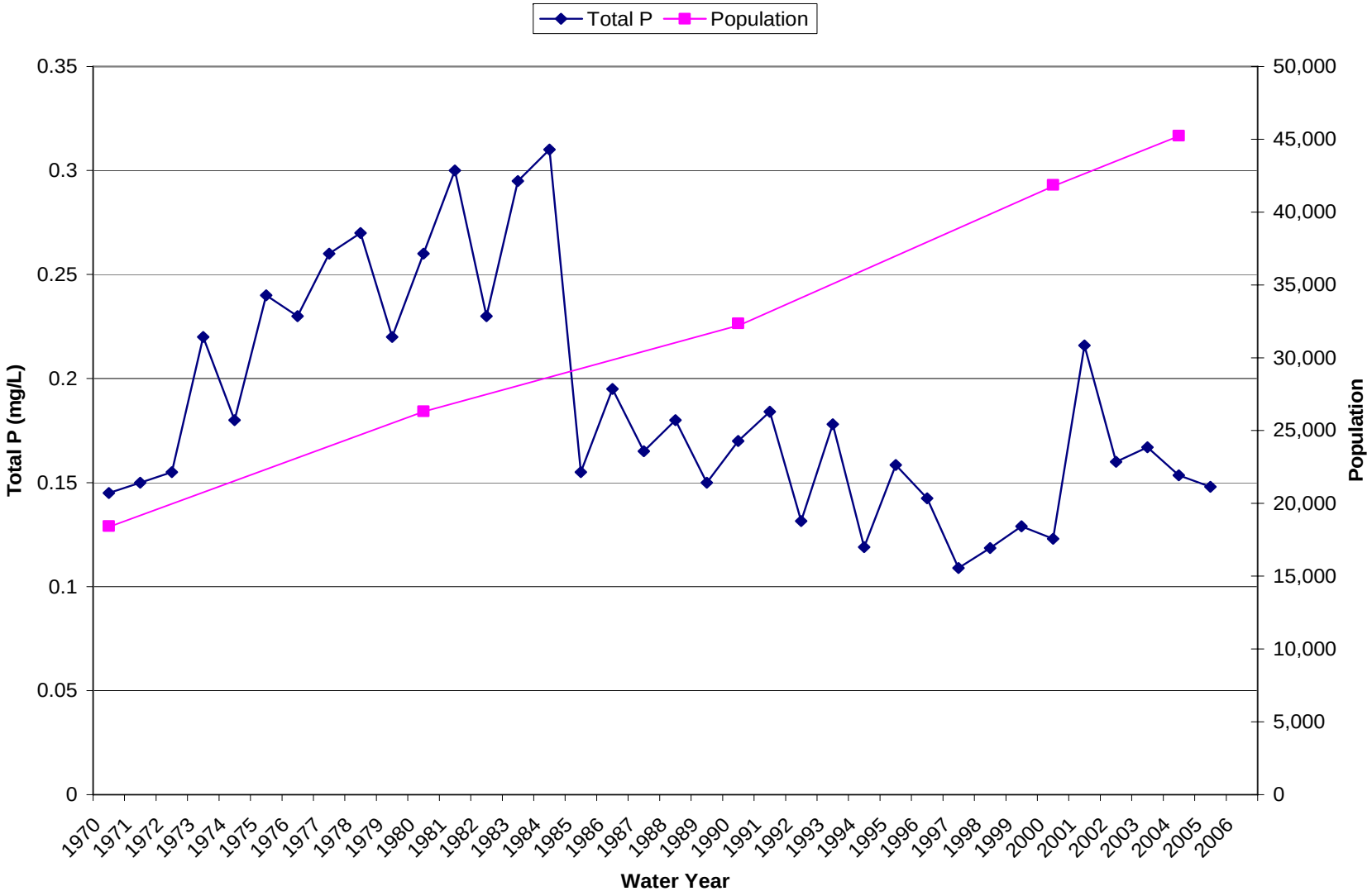

Figure 3-9. Median TP concentration for the Suwannee River at Branford and population for Lafayette and Suwannee counties (BEBR, 2001; BEBR, 2004).

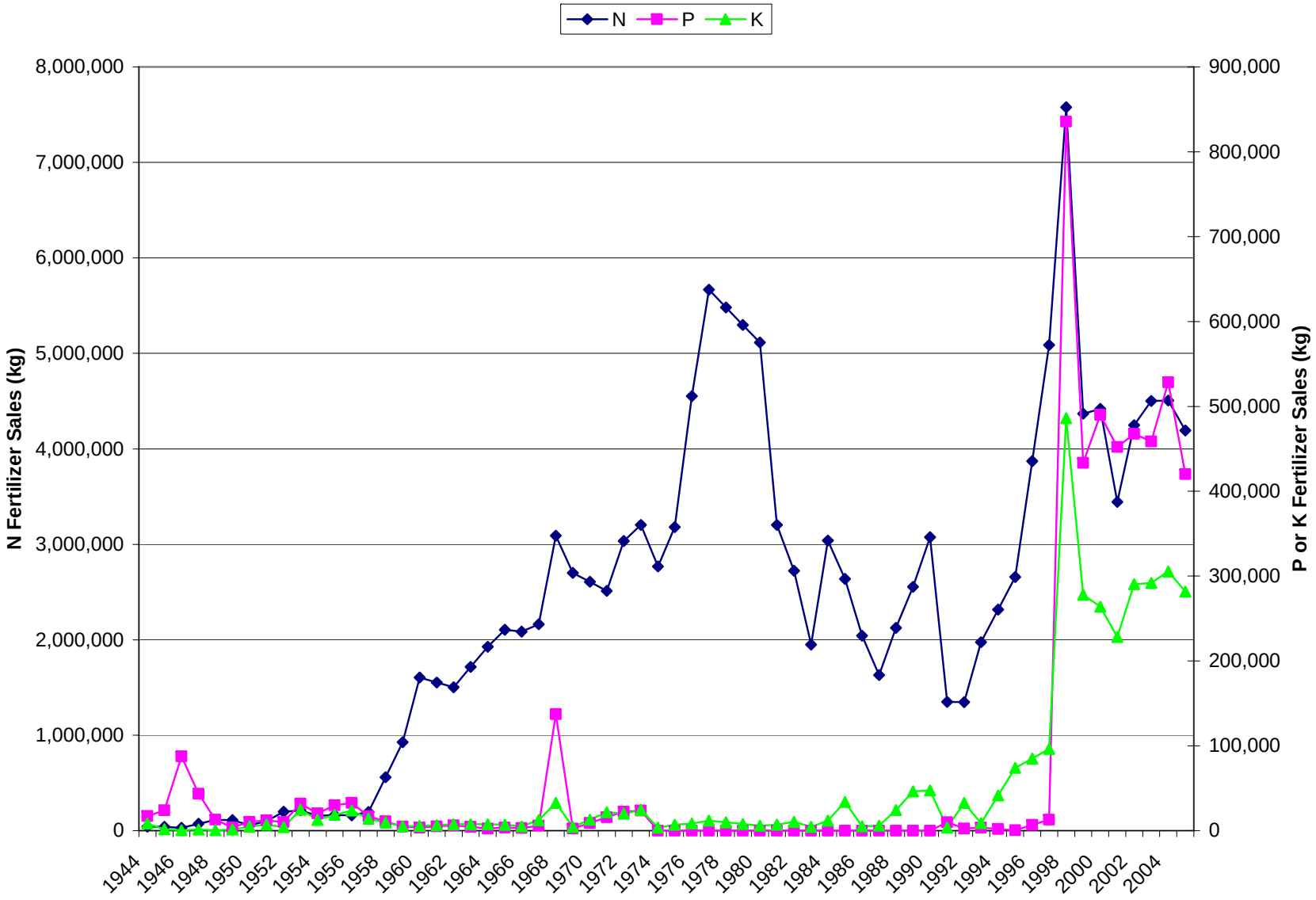

Figure 3-10. Fertilizer sales data for Suwannee and Lafayette counties.

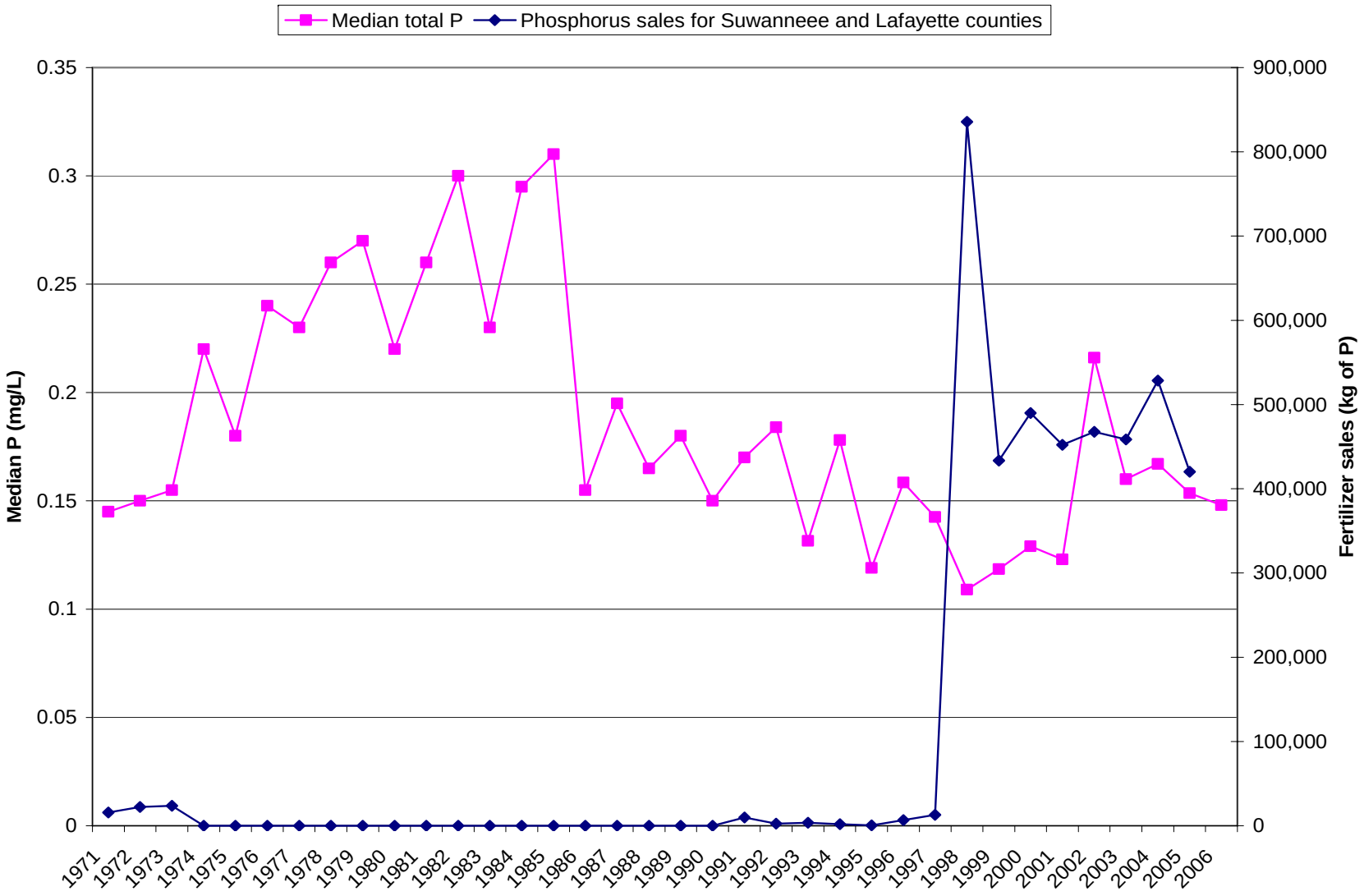

Figure 3-11. Median TP concentration for the Suwannee River at Branford and N fertilizer sale for Suwannee and Lafayette counties.

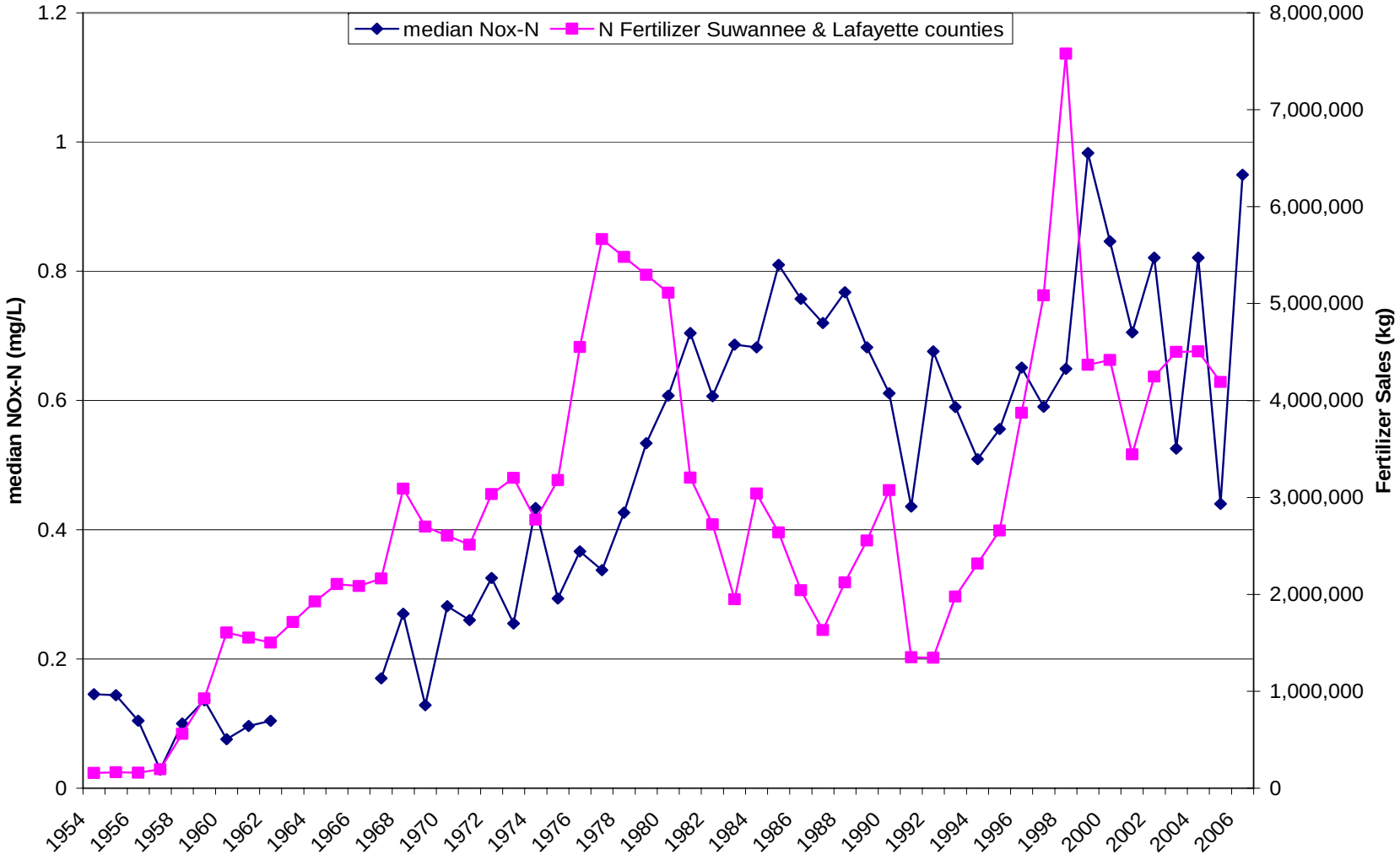

Figure 3-12. Median NO_3-N concentration for the Suwannee River at Branford and N fertilizer sales for Suwannee and Lafayette counties.

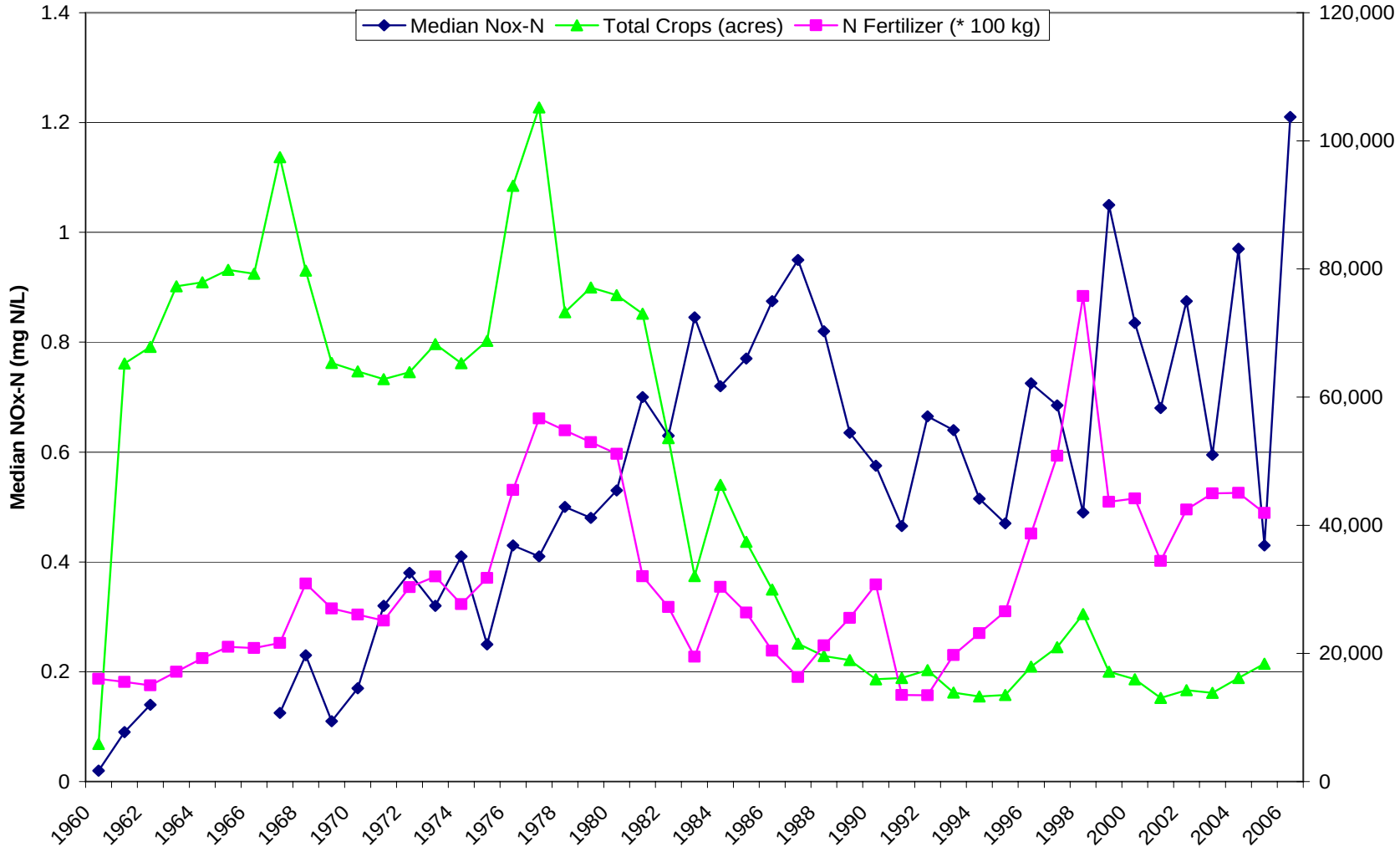

Figure 3-13. Median NO_3-N concentration for the Suwannee River at Branford and N fertilizer sales and total crop acres for Suwannee and Lafayette counties.

Figure 3-14. Median K concentration for the Suwannee River at Branford with linear trend line.

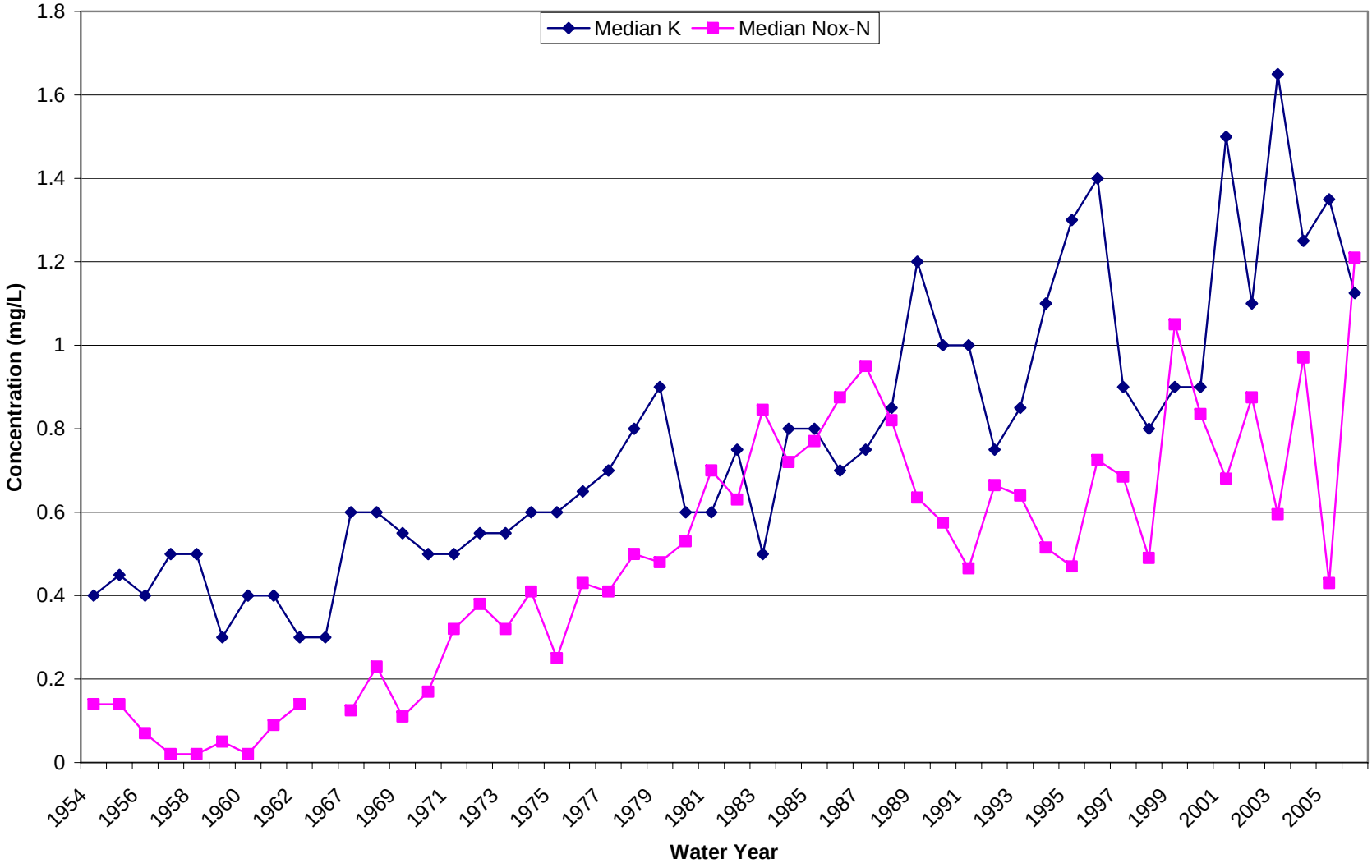

Figure 3-15. Median K and median NO_3-N concentrations for the Suwannee River at Branford.

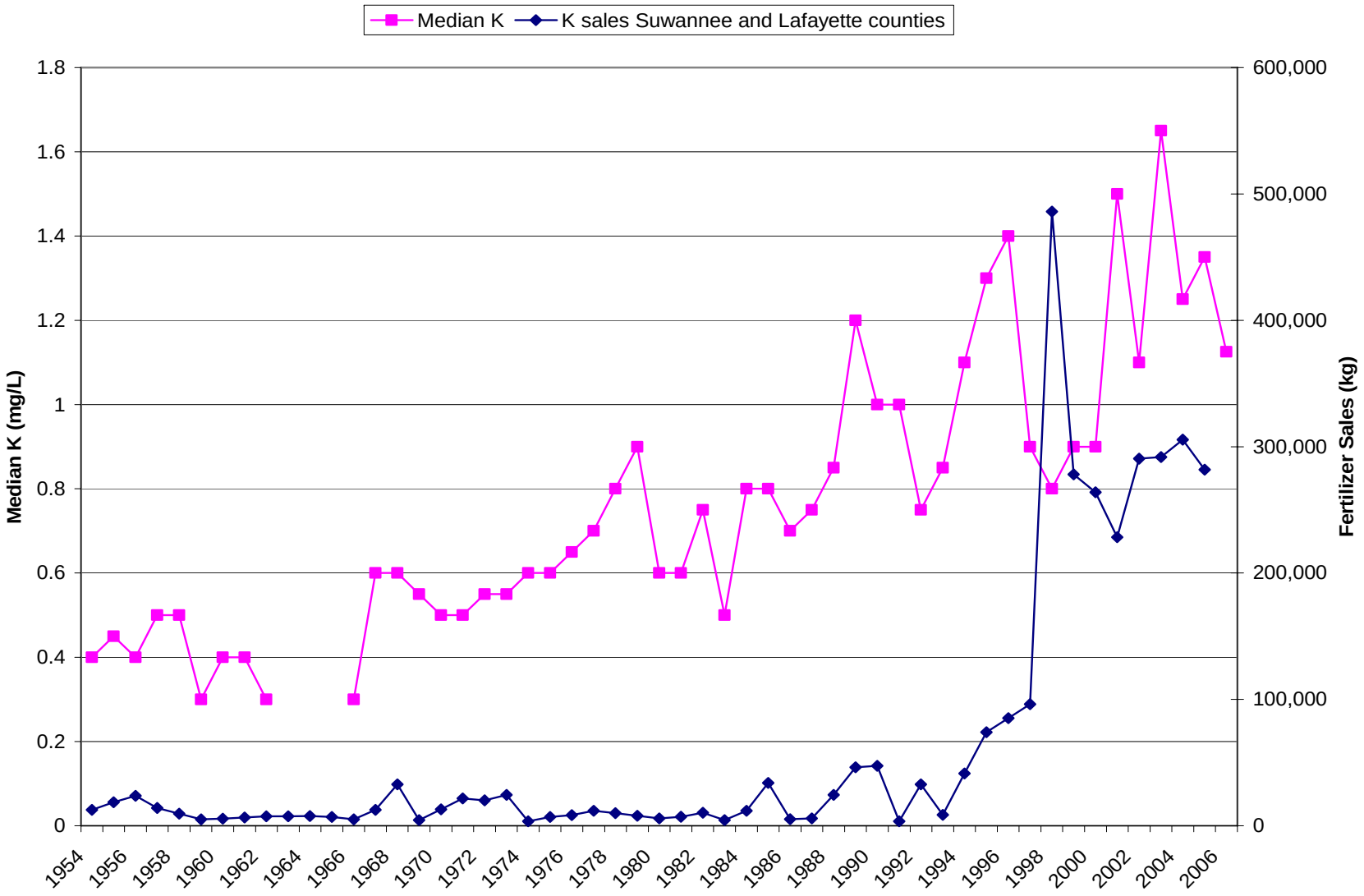

Figure 3-16. Median K concentration for the Suwannee River at Branford and K fertilizer sale for Suwannee and Lafayette counties.

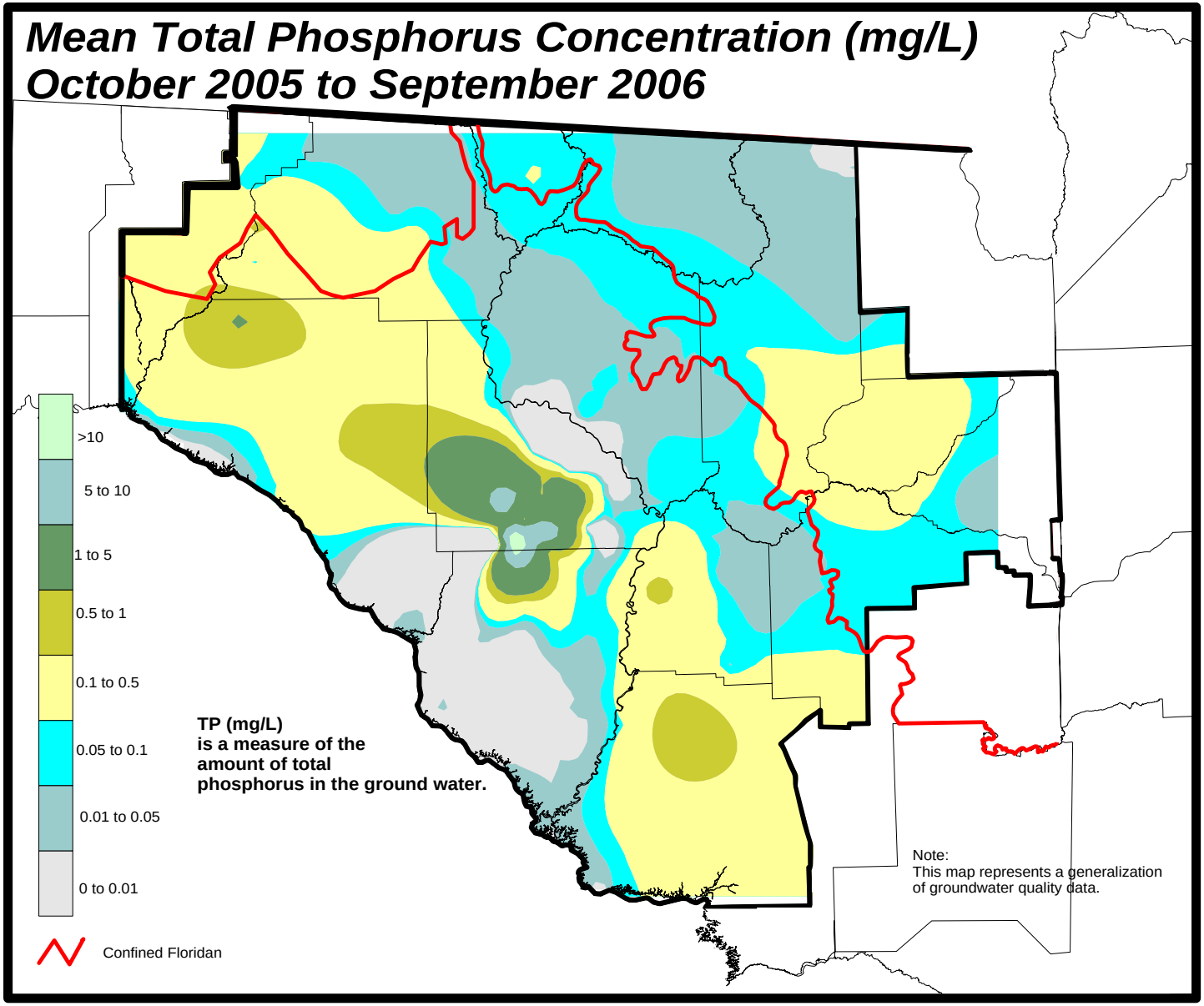

Figure 3-17. Mean upper Floridan aquifer TP concentration contour map for water year 2006.

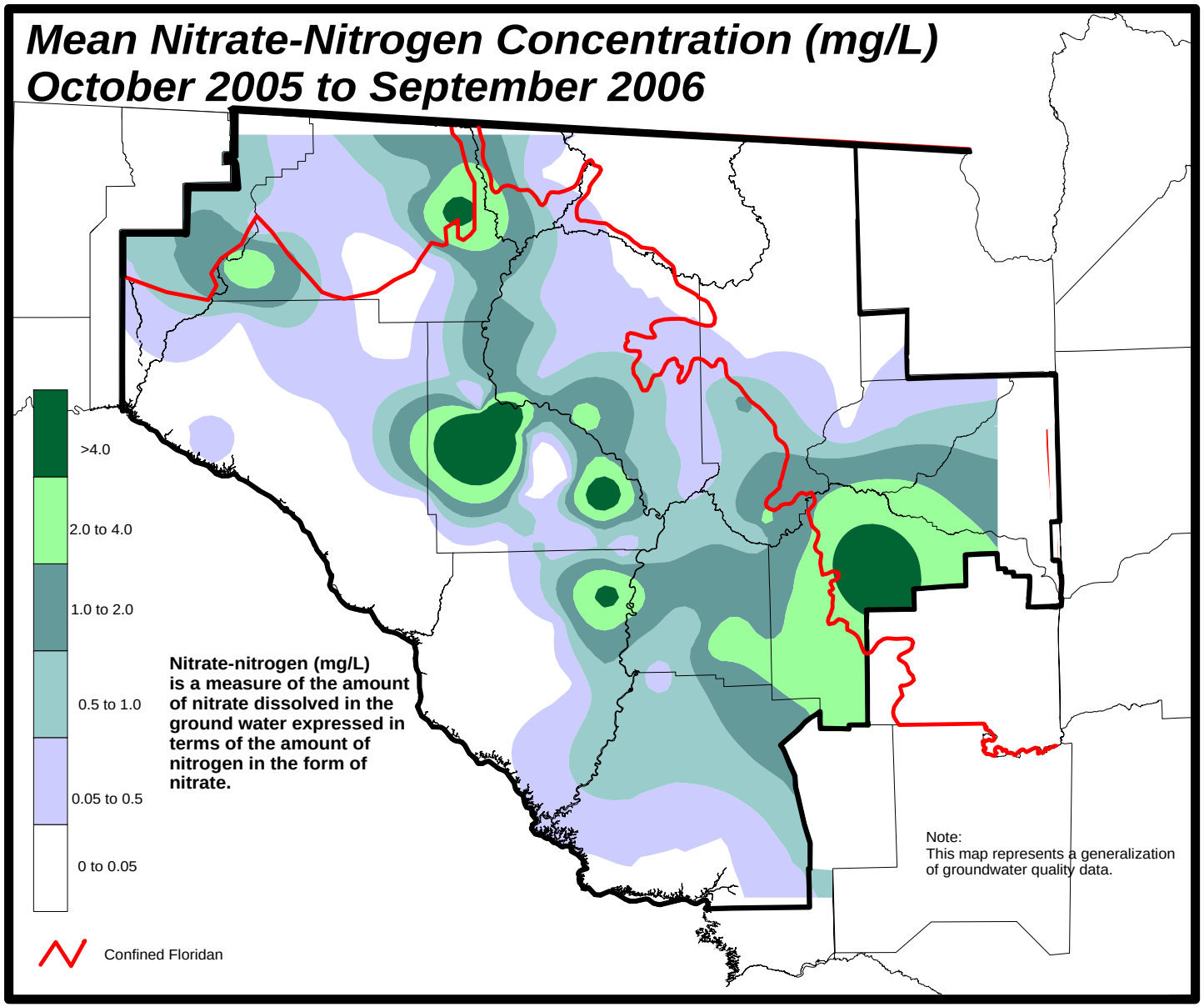

Figure 3-18. Mean upper Floridan aquifer NO_3-N concentration contour map for water year 2006.

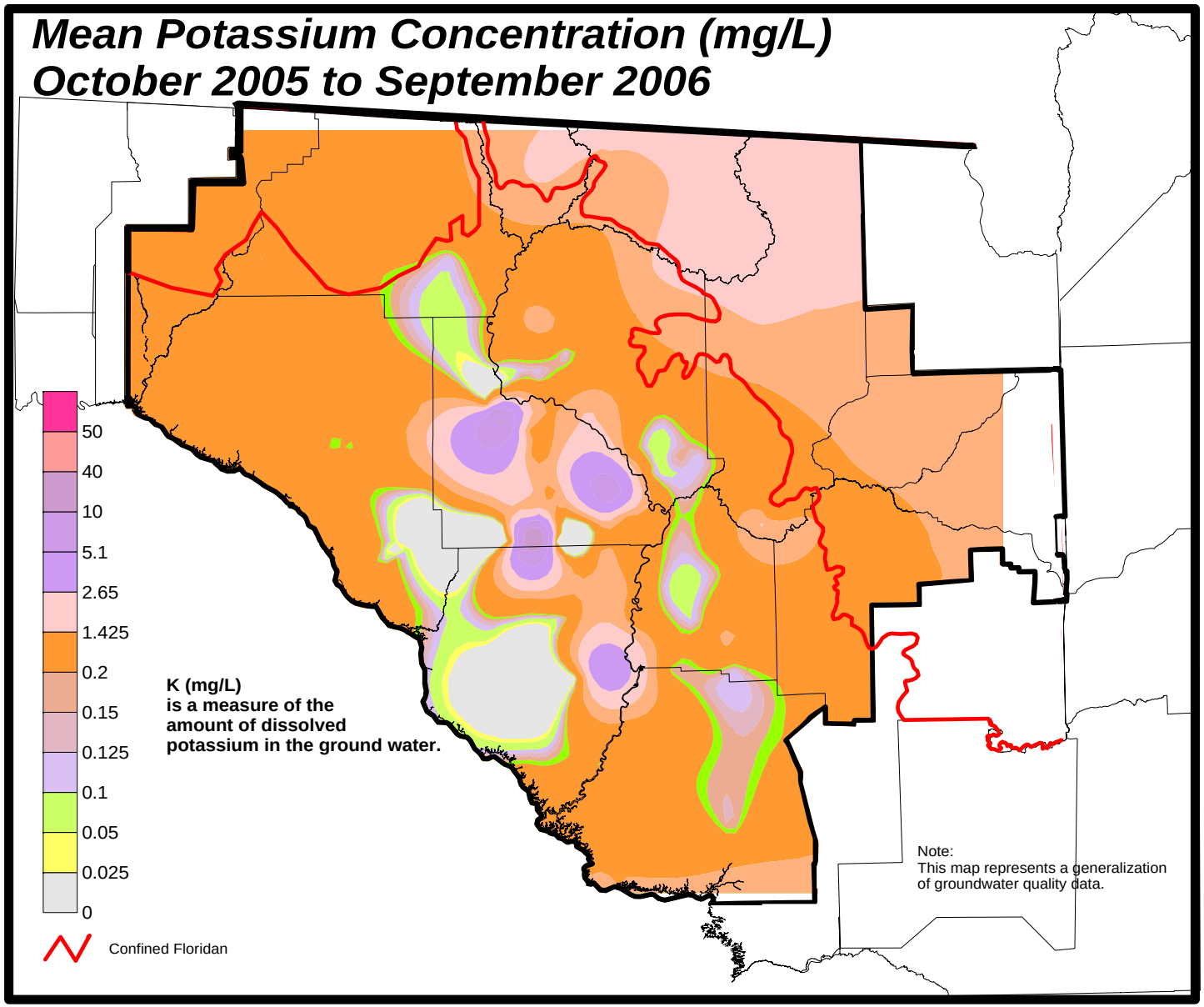

Figure 3-19. Mean upper Floridan aquifer K concentration contour map for water year 2006.

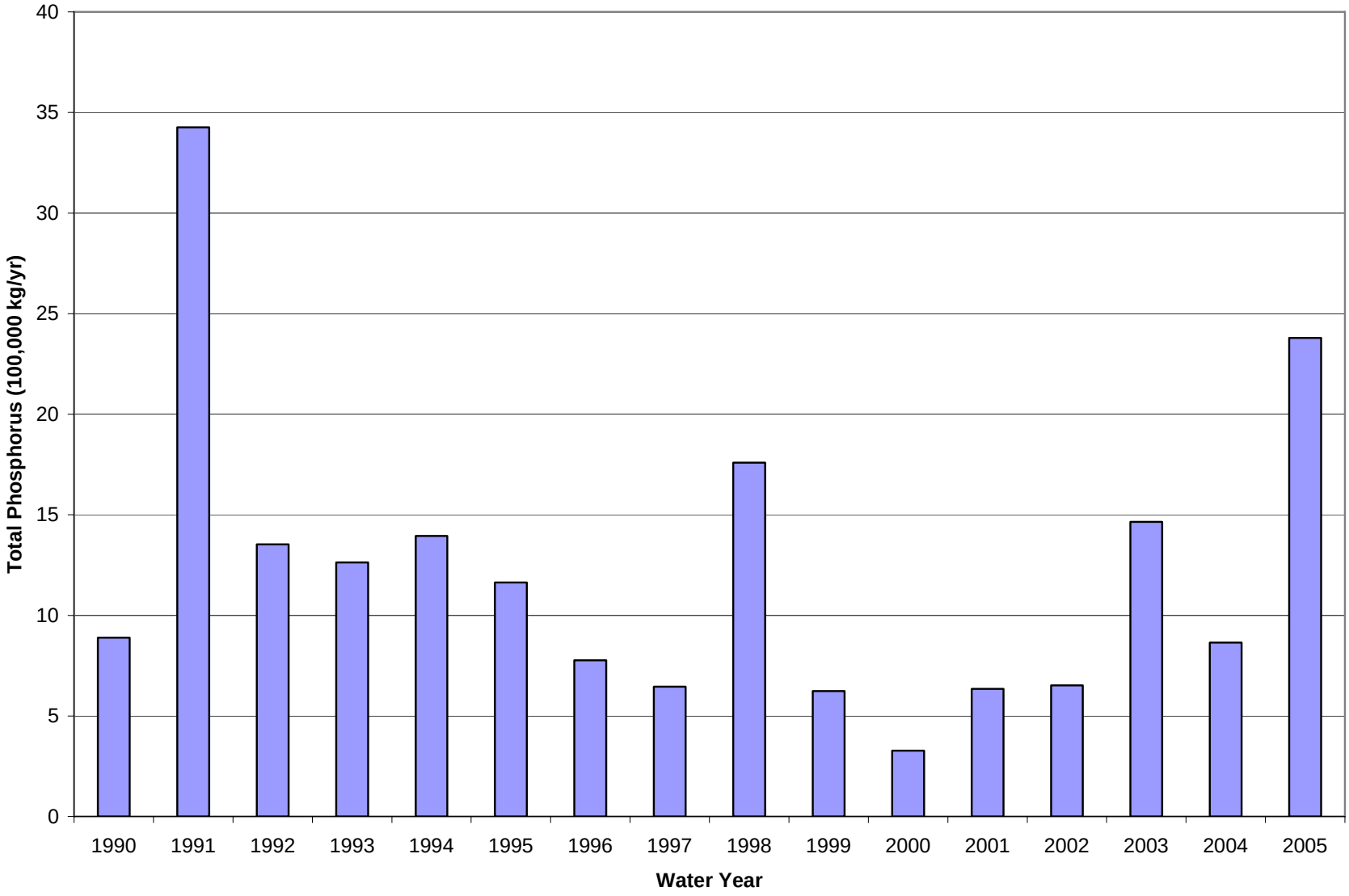

Figure 3-20. TP loads for the Suwannee River to the Gulf of Mexico for water years 1990 to 2005.

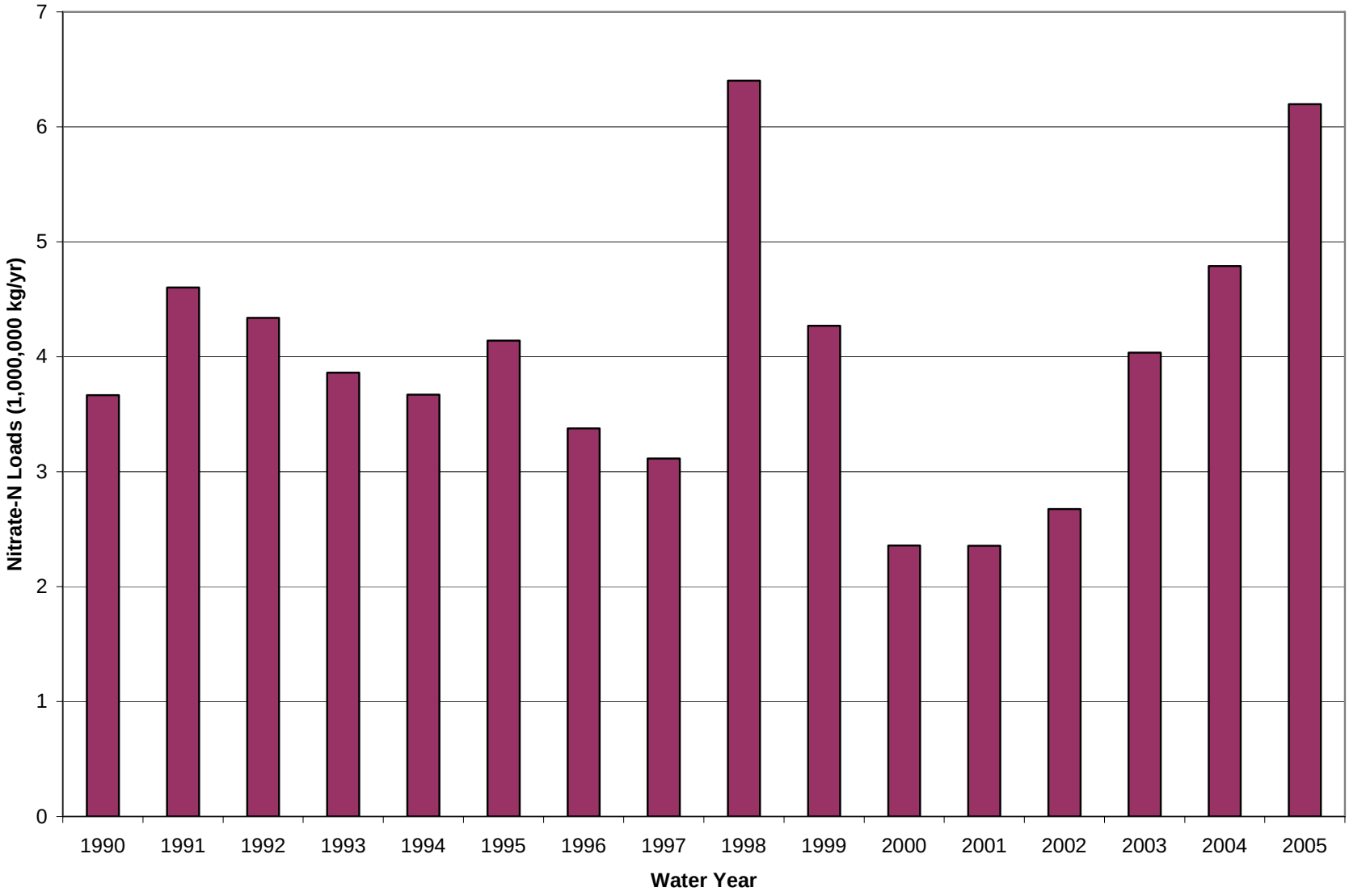

Figure 3-21. NO_3-N loads for the Suwannee River to the Gulf of Mexico for water years 1990 to 2005.

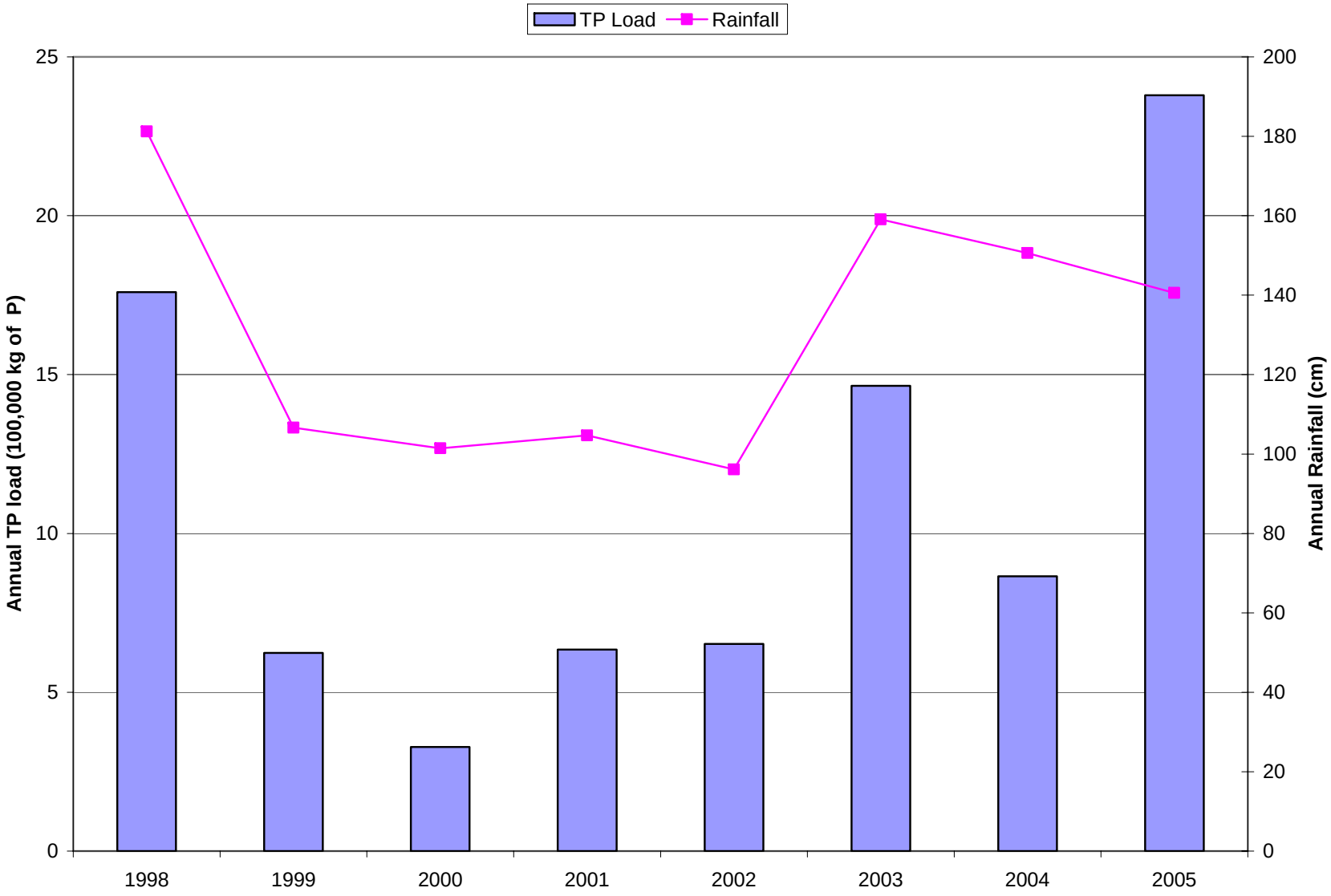

Figure 3-22. Annual TP loads and rainfall by water year for the Suwannee River.

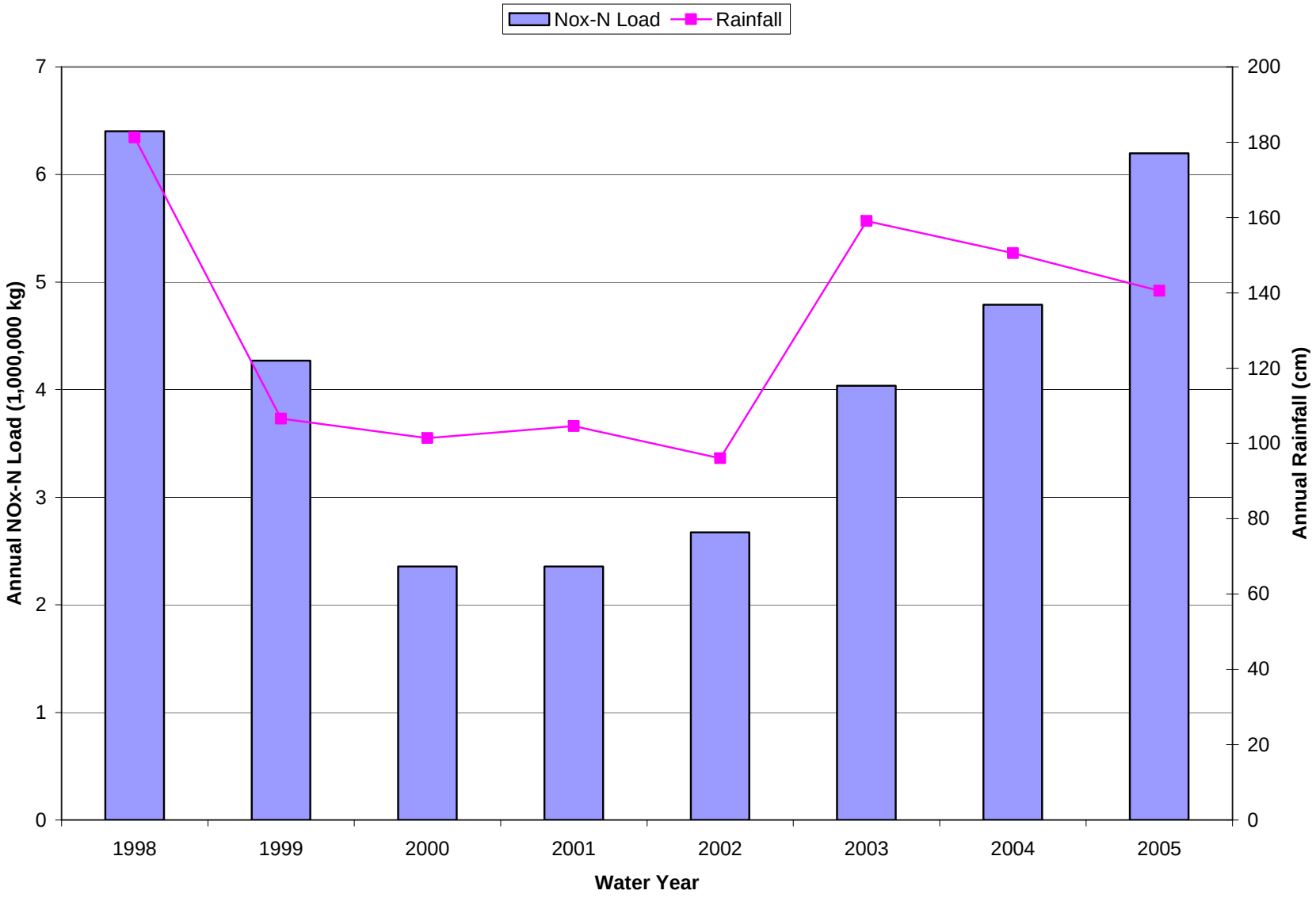

Figure 3-23. Annual NO_3-N loads and rainfall by water year for the Suwannee River.

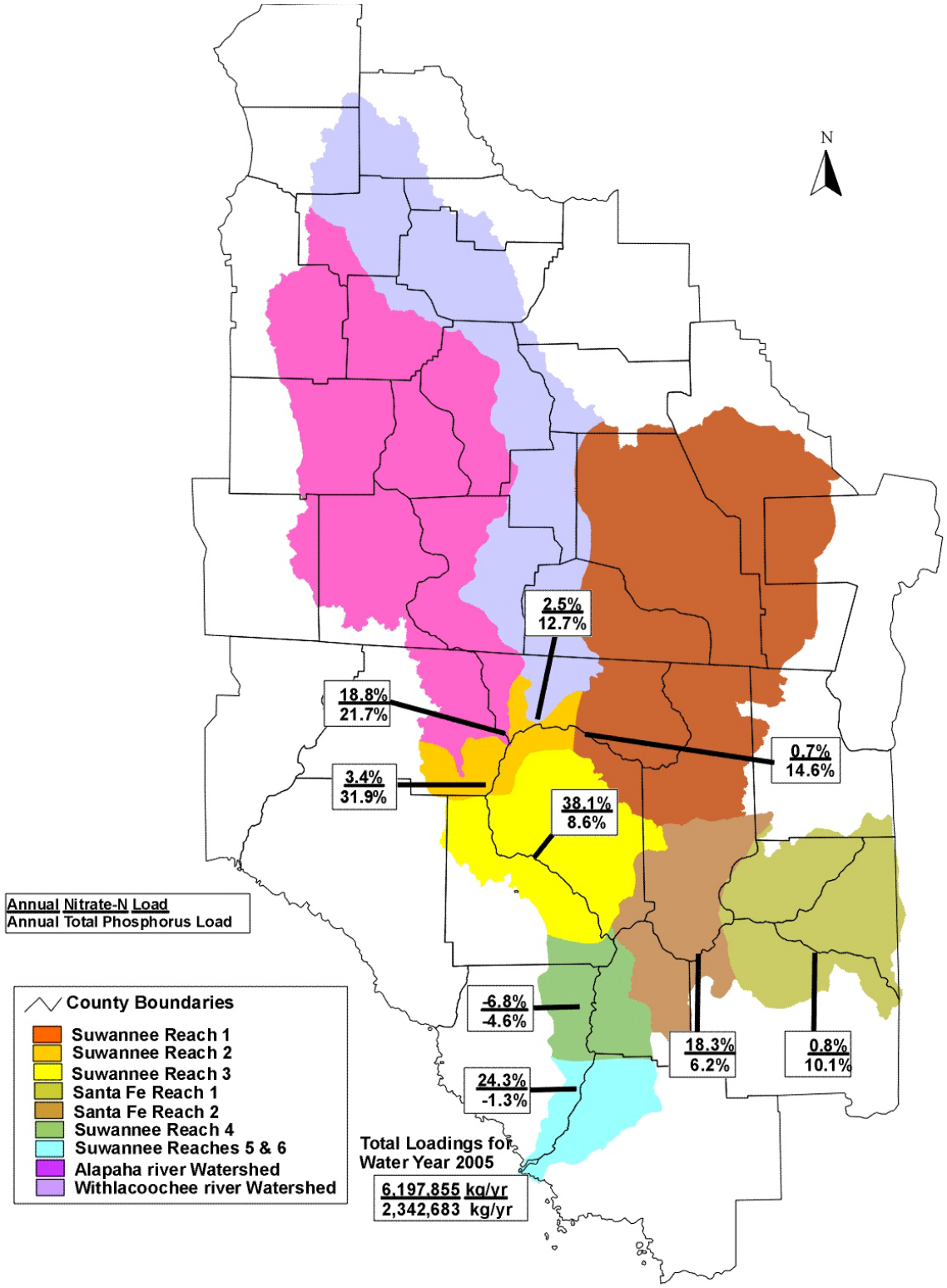

Figure 3-24. Suwannee River Basin loading by watershed/reach for water year 2005.

CHAPTER 4
NITROGEN LOADING FROM GROUD WATER TO SELECTED REACHES OF THE SUWANNEE AND SANTA FE RIVERS

Introduction

Ground water can either contribute positively to river flow through riverbed inflows and spring discharge or negatively by river water seepage through the riverbed and reverse spring discharge, depending on hydrologic conditions (Winter et al., 1998; Dingman, 2002). Hornsby et al. (2004) demonstrated that the Suwannee River has reaches that receive ground water from the upper Floridan aquifer and reaches which lose surface flow to the aquifer. Water loss from the Suwannee River to the upper Floridan aquifer occurs when the stage of the river is higher than the adjacent groundwater levels. This results in a cessation of flow from the springs along the Suwannee River and reverses flow or estevelle, which results in focus recharge. The river has incised into the top of the upper Floridan aquifer in the lower reaches of the Suwannee River. Under base flow conditions, the Suwannee River stage is lower than the adjacent groundwater levels in the upper Florida aquifer. This results in the ground water discharging through the springs and seeps along the riverbed. The numerous springs and the amount of ground water that discharges to the river indicate the interaction of the Suwannee River and the upper Floridan aquifer (Hull et al., 1981).

The Middle Suwannee River Basin (MSRB) has karstic geology and the region is internally drained. The internal drainage results in karst features, such as sinkholes that capture the surface water from streams. The result is that surface waters, such as streams, do not flow for long distances and are directly connected to the underlying upper Floridan aquifer. In some cases, surfacewater features, such as Rose Creek in the Lower Santa Fe River Basin (LSFRB),

that are captured by sinkholes have been shown to be directly connected by conduits in the upper Floridan aquifer to springs within the surfacewater basin (FDEP, 2000).

The Lower Suwannee and the Lower Santa Fe Rivers and their associated springs flows depend on the groundwater levels in the contiguous upper Floridan aquifer (Grubbs and Crandall, 2007). This interaction of the ground water and surface water results in the ground water having dramatic impacts of the surfacewater quality of the rivers (Hull et al., 1981).

Pittman et al. (1997) conducted a study of a 33 mile (53 km) reach of the MSRB (Dowling Park to Branford), that was divided into an upstream and downstream segment, to assess the impact of groundwater discharge on the quantity and quality of water in the Suwannee River. The study was conducted under base flow conditions. The objective of the study was to determine whether the measured springs and other groundwater inflows and NO_3-N contributions were similar in each segment. They found that 11 % of the 3,700 kg N d^{-1} of NO_3-N load in the study area was from the upstream segment and 89 % was from the downstream segment. Furthermore, in the upstream segment, the four springs accounted for 92 % of the 350 cubic feet per second (cfs) [9,911 L s^{-1}] flow pickup with the remaining 8 % consisting of riverbed seepage; while, the downstream segment the springs accounted for 41 % of the 600 cfs (16,990 L s^{-1}) flow pickup and the remaining 59 % flow pickup was associated with riverbed seepage.

The Suwannee River Water Management District (SRWMD) monitoring stations on the Suwannee and Santa Fe rivers are shown in Figures 4-1 and 4-2, respectively. Data from the monitoring network for the period 1989 to 2006 has shown an increasing trend for NO_3-N concentrations in the Suwannee and Santa Fe rivers as they traverse from their headwaters to

downstream. The increase in the NO_3-N concentrations is associated with regions of the river that receive ground water inputs.

The largest increase in NO_3-N concentration in the SRB occurred between Dowling Park and Branford (MSRB), a 60.8 kilometer (km) segment of SRB (Figure 4-3). The largest increase in NO_3-N concentration occurred in the Santa Fe River between US 441 and State Road 47 (Figure 4-4).

To date, no study has identified the exact area within the MSRB or the LSFRB where the NO_3-N load is entering the river system from the groundwater system. This study will expand on the work of Pittman at al. (1997) and the SRWMD monitoring program by sampling the Suwannee River in the MSRB on 1.6 km segments from Dowling Park to Branford. Also, this study will be expanded to include the LSFRB (River Rise to the confluence with the Suwannee River). The initial sampling will identify the river segment where NO_3-N concentrations currently increase in the rivers. The sampling increment lengths will be decreased and in-stream discharge measurements of the river and discharge measurement for the springs will be conducted to define the segment or segments with the greatest increase in NO_3-N load. The results of this study will identify the segment(s) and springs within MSRB and LSFRB associated with groundwater inputs that are contributing to the increase in NO_3-N loads in the surface water and qualitatively relate adjacent landuse to the segment(s) with the greatest increase in NO_3-N loads.

Materials and Methods

Water quality sampling and discharge measurements were performed over an approximately 61 km stretch of the Middle Suwannee River from Dowling Park, Florida, downstream to Branford, Florida on July 21 and 22, 2000; and an approximately 42 km stretch of

the Lower Santa Fe River, from its re-emergence in River Rise State Park to its confluence with the Suwannee River on June 7, 2000. Measurements were made on subsequent sampling dates on selected segments of the above reaches as indicated in Table 4-1. Sampling locations were chosen at intervals not exceeding 2.2 km and at all inflow points (i.e., springs).

The distance between locations was determined using a global positioning system (GPS) where the path between points was nearly straight. Where the curvature of the river made straight-line distances difficult to determine, a combination of a USGS topographic map for the area, a 1:24,000 scale mileage template, and site recognition of mapped features were used. GPS points were collected in 1983 North American Datum (NAD83) and differentially corrected to provide a 3-5 meter (m) accuracy range to ensure sampling locations.

Vertical-axis meter discharge measurements (i.e., Price AA and Pygmy current meters) were conducted in springs, such that, no partial section contained more than five percent of the flow from the spring; consequently, approximately 25 partial sections were used at each measurement (Buchanan and Somers, 1969). The two-point method (velocity measurements at the 0.2 and 0.8 tenths depths) was used primarily for velocity measurement in a partial section. The six-tenths method, is where the velocity meter is placed six-tenths of the total depth from the surface of the water being measured, was employed as necessary and appropriate to instrument capabilities, velocity profile characteristics, and the partial section depth. Data obtained from the spring discharge measurements included the spring name, date of measurement, beginning and ending times of measurement, beginning and ending reference water level measurements, width of measurement, total cross-sectional area, mean velocity, and discharge. Discharge measurements were conducted on the river using Teledyne Workhorse Rio Grande Acoustic Doppler Current Profiler (ADCP) and were performed by the FDEP. Discharge measurements

were performed using the ADCP following the guidelines established in ADCP manuals by RD Instruments. The discharge measurements with the ADCP included five cross-sectional traverses of the stream. The discharge from each traverses were sum and a mean was calculated to determine the discharge. For springs discharging less than one cfs (28.3 L s^{-1}), field estimates were made.

Water chemistry samples were collected in mid channel and at a depth of 0.5 m while spring samples were collected as near as possible to the spring vent. Samples were preserved in accordance with FDEP Standard Operating Procedures (011/01) and analyzed using EPA methods (EPA, 1983).

Results and Discussion

Middle Suwannee River Basin (MSRB)

The MSRB was sampled from Dowling Park to Branford at 1.6 km intervals for NO_3-N on July 21 and 22, 2000 (Figure 4-5). The NO_3-N concentration increased from 0.32 mg N L^{-1} at Dowling Park to 0.52 mg N L^{-1} at Branford (Figure 4-6). The highest rate of increase in NO_3-N concentration in the river was observed over a 12.8-km stretch sampling points 19 to 28 (circled area on Figure 4-6). The NO_3-N concentrations in the springs in the MSRB for July 21 and 22, 2000, ranged from 0.02 to 13.8 mg N L^{-1} (Table 4-2). The flow increased from 1,030 cfs (29,166 L s^{-1}) at Dowling Park to 1,480 cfs (41,908 L s^{-1}) at Branford. The springs accounted for 277 cfs (7,844 L s^{-1}) of the flow increase or 62 % at low flow conditions (Table 4-2). Since, there are no surfacewater inflow points in this stretch of the river; the increase not accounted for by measured springs is presumably due to groundwater inputs through the riverbed. The NO_3-N load increased by 1,080 kg N d^{-1} from Dowling Park to Branford and the springs in the reach accounted for approximately 1,080 kg N d^{-1} or 100 % of the load increase (Table 4-2). This

indicates that the NO_3-N concentration in the adjacent upper Floridan aquifer is greater than the NO_3-N concentration in the Suwannee River. Based on the loading increase, the concentration of NO_3-N in the upper Floridan aquifer is 2 to 30 times that of the concentration observed in the Suwannee River.

Pittman et al. (1997) study consisted of three river sites which had discharge gages (Suwannee River near Dowling Park, FL station number 301259083143700, Suwannee River at Luraville, FL station number 02320000, and Suwannee River at Branford, FL station number 02320500) and three springs in the upstream segment and eight (8) springs in the downstream segment. The study area (Dowling Park to Branford) was divided into an upstream segment (Dowling Park to Luraville) and a downstream segment (Luraville to Branford). The study concluded that 11 % of the 3,700 kg N d^{-1} of NO_3-N load in the study area was from the upstream segment and 89 % was from the downstream segment. Furthermore, the study found that in the upstream segment the four springs accounted for 92 % of the 350 cfs (9,911 L s^{-1}) flow pickup with the remaining eight percent consisting of riverbed seepage; while, the downstream segment the springs accounted for 41 % of the 600 cfs (16,990 L s^{-1}) flow pickup and the remaining 59 % flow pickup was associated with riverbed seepage. The findings of the July 2000 sampling confirmed the findings of Pittman et al. (1997) that the major of flow and NO_3-N increase occurred in the MSRB below Luraville gage. This indicates that there is a consistent supply of ground water and NO_3-N entering the MSRB below Luraville gage.

Additional samplings were conducted from Luraville to Branford on October 24, 2000 and September 19, 2006. This river segment covers the area where the greatest increases in NO_3-N were observed in the July 2000 sampling event (Figure 4-5). In the MSRB on October 24, 2000, the highest rate of increase in NO_3-N concentration in the river was observed over a

4.8 km stretch (Figure 4-7). The September 19, 2006 sampling yielded similar results (Figure 4-8). Since there are no surfacewater inflow points in this stretch of the river, the increase not accounted by measured springs is presumably due to groundwater inputs through the riverbed. The NO_3-N concentration increased from 0.61 mg N L^{-1} at Luraville to 1.07 mg N L^{-1} at Branford on October 24, 2000 and 0.70 mg N L^{-1} at Luraville to 1.10 mg N L^{-1} at Branford on September 19, 2006 (Figure 4-8). The increase in riverine NO_3-N concentration is associated with the increase in groundwater discharge. Figure 4-9 shows an inverse relationship of river discharge and NO_3-N concentration in the Suwannee River at Branford. Thus, as the flow decreases the NO_3-N concentration increases. Also, as ground water enters the river system, the specific conductance of the river increases. Typically, surface water has specific conductance of less than 100 μohms cm^{-1}; while ground water has specific conductance generally greater than 250 μohms cm^{-1}. As discharge increases the specific conductance in the Suwannee River at Branford decreases (Figure 4-10). This is a result of the stage of the river overcoming the groundwater head. The hydraulic gradient in the upper Floridan aquifer is toward the Suwannee River during low flow conditions and away from the river during high flow conditions (Hirten, 1996). Hirten (1996) identified that the impacts of the high river stage on the potentiometric surface during high flow conditions extended outward from the river for approximately 3 km. As the specific conductance in the Suwannee River at Branford increases so does the NO_3-N concentration in the river (Figure 4-11). The increase in groundwater discharge is a result of the river stage beginning lower in 2006 than 2000; thus, allowing more groundwater into the river.

Since discharge was measured in the river at six locations (as indicated by the red lines in Figure 4-12), it is possible to calculate loading for each segment (Table 4-3). The load change for each segment was calculated by subtracting the upstream segment load from the load for the

given segment. The highest NO_3-N load change per m of river for both the 2000 and 2006 sampling events were observed in segment 3 (Figure 4-13).

The major landuse adjacent to segment 3 is row crops on the Suwannee County side. On the Lafayette County side of segment 3, animal husbandry operations and improved pasture are the major landuses. The recommended University of Florida, Institute of Foods and Agricultural Science (IFAS) recommend N fertilizer rates for typical crops, corn, potatoes and watermelon, grown in the MSRB are 200 lb acre^{-1} (222 kg hectare^{-1}), 200 lb acre^{-1} (222 kg hectare^{-1}) and 150 lb acre^{-1} (168 kg hectare^{-1}), respectively (Hochmuth and Hanlon, 2000). For hay, the IFAS recommendation for N is 80 lb acre^{-1} (89 kg hectare^{-1}) in the spring and 80 lb acre^{-1} (89 kg hectare^{-1}) following each cutting except for the final fall cutting (Mylavarapu et al., 2007). Generally, hay fields are cut four times per year (M. Randall, 2004, Personal Communication). Thus, hay fields may receive 320 lb acre^{-1} (359 kg hectare^{-1}) based on IFAS recommended rates. While, IFAS N fertilizer recommendation for improved pasture range between 50 lb acre^{-1} (56 kg N hectare^{-1}) and up to 160 lb acre^{-1} (179 kg N hectare^{-1}) [Mylavarapu et al., 2007]. The landuses are occurring primarily on Alpin and Penney soils. Both soils are Entisols. The Alpin series consists of very deep, excessively drained, moderately rapidly permeable soils on uplands and river terraces of the Coastal Plain. The soils formed in thick beds of sandy eolian or marine deposits. (Soil Survey Staff, 2007). The Penney series consists of very deep, excessively drained, rapidly permeable soils on uplands. The soils formed in thick beds of sandy eolian or marine deposits (Soil Survey Staff, 2007). These landuse uses are occurring over the unconfined Floridan aquifer on Entisols (Alpin and Penney) which have high leaching potential.

The contributions of the springs for October 2000 and September 2006 are given in Table 4-2. Also, Table 4-2 presents the discharge, NO_3-N loading and percent of NO_3-N load increase

in the segment that the spring discharges. The NO_3-N concentration of the springs ranged from 0.09 to 18.6 mg N L^{-1} in 2000 and 0.33 to 15.0 mg N L^{-1} in 2006. The two springs (SUW718971 and SUW725971) with the highest NO_3-N concentrations discharge in segment 3. These two third magnitude springs were sampled by Katz et al. (1999 and 2001) and yielded NO_3-N concentrations of 29 and 38 mg N L^{-1} for SUW718971 and SUW725971, respectively. Katz et al. (1999) used isotopic ratios of ^{14}N and ^{15}N to determine the source of the NO_3-N in the spring water from springs SUW718971 and SUW725971. Katz et al. (1999) findings showed that the NO_3-N was from an inorganic source. Also, Katz et al. (1999) used chlorofluorocarbons (CFC) to date the spring water from springs SUW718971 and SUW725971. The findings of the age dating were that the youngest water had a mean age of less than nine years reported by Katz et al. (1999). This corresponds with the observed time lag in Chapter 3 of fertilizer sales data and riverine NO_3-N concentration of one to six years. Also, the Florida Department of Environmental Protection (FDEP) on an every other week schedule from March 15, 2000 to January 10, 2001 sampled these two springs (SUW718971 and SUW725971) for NO_3-N and K (T. Greenhalgh, 2005, Personal Communication). The springs SUW718971 and SUW725971 show a clear linear relationship between the concentration of NO_3-N and K, which indicates an inorganic (fertilizer) source as shown in Appendix C, Figures C-1 and C-2, respectively. There is a major agricultural operation (row crop) within 1.6 km of these springs. Based on the findings that inorganic fertilizer is correlated to the increasing NO_3-N trend in the Suwannee River at Branford (Chapter 3), the activities that occur adjacent to segment 3 (Figure 4-12) of the MSRB should be investigated.

Lower Santa Fe River Basin (LSFRB)

The LSFRB begins at River Rise, which is where the Santa Fe River re-emerges from the upper Floridan aquifer after traveling approximately 3.2 km underground from River Sink. River Sink is located in O'Leno State Park and is a karst feature, which captures the entire Santa Fe River during all but extremely high flow conditions. The LSFRB has 58 identified spring and six siphons (Hornsby and Ceryak, 1998). Thus, the LSFRB is highly connected to the upper Floridan aquifer. This connection with the upper Floridan aquifer has impacts on the water quality and quantity of the LSFRB.

Unlike the springs in the MSRB, the springs in LSFRB do not typically reverse flow or estevelle. Due to the morphology of the river system, the surface stage cannot overcome the head in the upper Floridan aquifer. Also, should the river overcome the groundwater head at a spring vent, the groundwater pressure is relieved by discharging from karst features within the floodplain. Thus, the observed decrease in riverine NO_3-N concentrations in high flow conditions is related to dilution of ground water by surface water not by excluding the ground water from the surface water, as is the case for the MSRB.

On June 7, 2000, the LSFRB was sampled on 1.6 km intervals for NO_3-N (Figure 4-14). There was little discharge at River Rise due to the drought conditions and limited flow in the upper Santa Fe River. This created a base flow condition that was virtually all ground water with little surface water inputs from the upper Santa Fe River. This allowed for the sampling of the LSFRB to determine the impacts of groundwater discharge on the NO_3-N concentration in the river. The highest rate of increase in NO_3-N concentration in the LSFRB was observed over a 4.8 km stretch (Figure 4-15). The NO_3-N concentration increased from 0.09 mg N L^{-1} at the Santa Fe Rise to 0.88 mg N L^{-1} near Fort White, with the concentration decreasing to the

confluence with the Suwannee River. Ground water inputs accounted for 100 % of the flow increase. The NO_3-N concentrations in the springs in the LSFRB for June 7, 2000, ranged from 0.11 to 4.8 mg N L^{-1}.

Based on the sampling results from June 2000 sampling event, the sampling intervals were reduced and the sampling reach of the LSFRB was reduced to the Santa Fe River above Rum Island to the USGS gage near Fort White and the sampling was conducted on September 5, 2001 and October 10, 2006. In the LSFRB, the highest rate of increase in NO_3-N concentration in the river was observed over a 0.3 km stretch (Figure 4-16) for September 5, 2001 and October 10, 2006. The NO_3-N concentration increased from 0.28 mg N L^{-1} above Rum Island to 0.79 mg N L^{-1} near Fort White on September 5, 2001 and 0.26 mg N L^{-1} above Rum Island to 0.82 mg N L^{-1} near Fort White on October 10, 2006. As the case for the MSRB, the flow in the Santa Fe River was lower in 2006 than 2000. This results in less dilution of ground water by surface water in 2006 than 2000. Also, the percentage of flow increase in the river from the springs was greater in 2006 than 2000. Therefore, the riverine NO_3-N concentration increased due to less quantity of the receiving surface water to dilute the NO_3-N concentration in the groundwater that was discharge into the surfacewater system.

Since discharge was measured in the river at three transects (as indicated by the red lines in Figure 4-17) on September 5, 2001 and at seven transects on October 10, 2006 (as indicated by the red lines in Figure 4-18), it is possible to calculate loading for each segment (Tables 4-4 and 4-5). The set of transects used in 2006 incorporated the three transects for 2001 by adding additional transects between the 2001 transects to better define the NO_3-N inputs. A comparison of 2001 to 2006 loading increase per m of river is shown in Table 4-4 and Figure 4-19. The greatest increase in NO_3-N loads change per m of river was observed in segment 1 for 2001 and

2006 when the sampling reach was divided into three segments. The refined seven segments for 2006 segments indicated that segment 4 as the highest NO_3-N load change per m of river for 2006 sampling events (Table 4-5 and Figure 4-20). The discharge contribution of the springs for September 5, 2001 and October 10, 2006 are given in Table 4-6. The NO_3-N concentration of the springs ranged from 0.55 to 1.59 mg N L^{-1} in 2001 (Table 4-6) and 0.27 to 1.9 mg N L^{-1} in 2006 (Table 4-6). Segment 1 (for the 3 segment sampling) and segment 4 (for the 7 segment sampling) had the highest increase in NO_3-N loads and contain the lotus of springs known as the Devil's complex. Based on the 2006 sampling, the NO_3-N load is associated with the Devil's complex that consists of two first magnitude springs (Devil's Ear and July).

The landuses adjacent to segments 1 in 2001 and 4 in 2006 are improved pasture, recreational park, and low density residential. These landuse uses are occurring over the unconfined Floridan aquifer on Entisols (Lakeland and Penney) with high leaching potential. Sabasan (2004) identified NO_3-N concentrations in various landuse on Entisols, Ultisols, and Spodosols in the Santa Fe River Watershed. For landuse improved pasture, the NO_3-N concentrations for Entisols, Ultisols, and Spodosols were 0.51, 1.80 and 1.65 µg N $g^{-1}$of soil, respectively. The Entisols which are in landuse improve pasture have lower soil NO_3-N due to the leaching of the NO_3-N. And where these Entisols are over the unconfined Floridan aquifer there is potential for leaching of NO_3-N into the upper Floridan aquifer.

Katz et al. (1999) sampled the July and Ginnie Springs for ^{15}N and ^{14}N. The result of Katz's study indicated that the NO_3-N was from an inorganic source (i.e., fertilizer). As with the MSRB springs, the springs in the LSFRB in the segment where the NO_3-N load in the river increases are discharging NO_3-N whose source is inorganic fertilizer.

Summary and Conclusions

The regions of the Middle Suwannee and Lower Santa Fe rivers where the greatest increase in NO_3-N concentrations occur are relatively small segments of studied river reach. The greatest increase in NO_3-N load occurs in segment 3 of the MSRB, which is 3,408 m of river channel, and Segment 4 of the LSFRB, which is 425 m of river channel. The NO_3-N is moving into the surfacewater system via ground water through springs and seeps in the riverbed during base flow conditions. The soils adjacent to these segments are Entisols that have high leaching potential. Furthermore, the upper Floridan aquifer is unconfined in these regions. The coupling of the upper Floridan aquifer being unconfined and overlain by soil with high leaching potential with landuses that are adding NO_3-N via fertilizer creates the potential for contamination of the upper Floridan aquifer and ultimately the Suwannee and Santa Fe river which receive base flow from the upper Floridan aquifer by the NO_3-N.

Two springs sampled in segment 3 of the MSRB, where the highest increase in NO_3-N loading occurred, showed a linear relationship with K and NO_3-N. Also, these two springs were sampled by the USGS for NO_3-N sourcing and age dating. The result from the USGS sampling showed the NO_3-N source as inorganic and the age of the water was less than nine years (Katz et al., 1999) which is similar to the results observed in the lag time between fertilizer sales and riverine NO_3-N concentrations in the Suwannee River at Branford in Chapter 3. Furthermore, for the Suwannee River at Branford, this confirms that fertilizer is the major component of the observed increasing NO_3-N trend in the Suwannee River at Branford (see Chapter 3). Segment 4 of the LSFRB springs was also sampled by Katz et al. (1999). The results indicated that the major springs in segment 4 were discharging NO_3-N that was primarily from inorganic fertilizer. The MSRB and LSFRB showed increased NO_3-N concentrations from 2000-2001 to 2006

sampling events. This indicates that the NO_3-N loading from the ground water to the surface water is increasing for the studied areas of the Suwannee and Santa Fe rivers and the NO_3-N is primarily from inorganic fertilizer. Thus, understanding of fertilizer use and contribution areas to the upper Floridan aquifer, which supplies the water to segment 3 of the MSRB and segment 4 of the LSFRB, is needed to focus management activities.

Table 4-1. Suwannee River and Santa Fe River segments used in this study along with sampling dates and other pertinent information.

River Segment	Sampling Date	Comments
	Middle Suwannee River Basin	
Dowling Park to Branford See Figure 4-5 for locations.	July 21-22, 2000	Water samples and discharge measurements taken at 1.6 km intervals and at all identified springs of 61 km river segment.
Luraville to Branford See Figure 4-12 for locations.	October 24, 2000	Water samples and discharge measurements taken at the segment (34 km) of the river showing high NO_3-N input. Samples were taken at irregular intervals ranging from 2 km down to 0.7 km. The sampling interval was based on the previous sampling event (i.e., in the segments with the greatest NO_3-N increase the interval was reduced).
Luraville to Branford	September 19, 2006	Repeat of the October 24, 2000 sampling.
	Lower Santa Fe River Basin	
River Rise State Park to confluence with the Suwannee River. See Figure 4-14 for locations.	July 7, 2000	Water samples and discharge measurements taken at 1.6 km intervals of 42 km river segment and at all identified springs.
Above Rum Island spring to USGS discharge gage near Fort White. See Figure 4-17 for locations.	September 5, 2001	Water samples taken at 0.3 km intervals of 5.4 km river segment and at all identified springs. Discharge measurements were taken at 3 transects and all flowing springs.
River Rise State Park to confluence with the Suwannee River. See Figure 4-18 for locations.	October 10, 2006	Water samples taken at 0.3 km intervals of 5.4 km river segment and at all identified springs. Discharge measurements were taken at 7 transects and all flowing springs.

Table 4-2. Middle Suwannee River Basin spring comparison 2000 to 2006 of discharge, NO_3-N concentration, NO_3-N load and contribution of the total NO_3-N load increase in the study reach.

River Segment	Spring	Discharge[cfs/(L s^{-1})) 2000	2006	NO_3-N (mg L^{-1}) 2000	2006	NO_3-N Load (kg d^{-1}) 2000	2006	NO_3-N Load change (%) 2000	2006
1									
	LAF924971	15(425)	12(340)	3.05	4.9	111	143	2.43	4.09
	Telford	38(1,076)	25(708)	1.93	2.7	175	163	3.84	4.69
	Running	49(1,388)	45(1,274)	2.32	2.3	275	251	6.02	7.21
2									
	LAF919972	1.5(43)	2(57)	1.36	2.00	4.95	9.71	0.11	0.28
	Bathtub	6(170)	3(85)	1.34	1.4	19.5	10.2	0.43	0.29
	Convict	2.3(65)	3(85)	7.9	9.4	44.5	68.4	0.98	1.96
	SUW919971	4(113)	7(198)	0.52	0.56	5.05	9.51	0.11	0.27
	Suwannee Blue	18(510)	3.6(102)	6.5	3.6	282	79.1	6.19	2.27
3									
	SUW718971	8(226)	5(226)	18.6	14	361	169	7.92	4.87
	SUW725971	5(142)	4(142)	16.6	15	201	145	4.42	4.18
4									
	Mearson	62.4(1,767)	55(1,557)	2.13	2.1	323	280	7.07	8.04
5									
	LAF718972	15(425)	15(425)	2.18	1.3	79.4	47.3	1.74	1.36
	Troy	111.9(3,169)	87.4(2,475)	2.05	2.2	557	467	12.21	13.39
	LAF1024001	0.5(14)	1(28)	0.12	0.33	0.15	0.80	0.00	0.02
6									
	Ruth	10.9(309)	1.6(45)	5.5	4.7	145	18.5	3.19	0.53
	Little River	63.7(1,804)	51(1,444)	1.12	1.2	173	149	3.80	4.26
	LAF93971	0.5(14)	0(0)	0.09	Dry	0.11	Dry	<0.01	Dry
	LAF718971	15(425)	8(226)	1.1	0.44	40.0	8.54	0.88	0.25

Table 4-3. Middle Suwannee River Basin NO_3-N change profile 2000 and 2006.

MSRB Segment	River Segment (m)	NO_3-N Load change (kg d^{-1}) 2000	2006	NO_3-N Load change per meter of river (kg d^{-1} m^{-1}) 2000	2006
1	6,361	284	1,043	0.045	0.164
2	6,220	903	494	0.145	0.079
3	3,408	1,663	937	0.488	0.275
4	5,152	523	98	0.101	0.019
5	5,477	995	403	0.182	0.074
6	7,502	192	510	0.026	0.068

Table 4-4. Lower Santa Fe River Basin NO_3-N change profile 2001 and 2006.

LSFR Segment	River Segment (m)	NO_3-N Load change (kg d^{-1}) 2001	2006	NO_3-N Load change per meter of river 2001	2006
1	2,171	894.6	1,171.0	0.412	0.539
2	2,127	309.2	108.2	0.145	0.051
3	813.8	-725.9	22.0	-0.892	0.027

Table 4-5. Lower Santa Fe River Basin refined NO_3-N change profile for 2006.

LSFR Segment	River Segment (m)	NO_3-N Load change (kg d^{-1}) 2006	NO_3-N Load change per meter of river 2006
1	914.5	-20.5	-0.022
2	351.2	176.9	0.504
3	481.0	-20.2	-0.042
4	424.7	1,034.8	2.437
5	1,141	188.7	0.165
6	985.9	-80.5	-0.082
7	813.8	22.0	0.027

Table 4-6. Lower Santa Fe River Basin spring comparison 2000 to 2006 of discharge, NO_3-N concentration, NO_3-N Load and contribution of the total NO_3-N load increase in the study reach.

River Segment	Springs	Discharge [cfs/(L s^{-1})] 2001	2006	NO_3-N (mg L^{-1}) 2001	2006	NO_3-N Load (kg d^{-1}) 2001	2006	% NO_3-N Load change 2001	2006
1									
	Rum Island	30(850)	14.3(405)	1.06	1.5	77.2	52.2	16.2	4.01
	Blue	50(1,416)	14.1(399)	1.59	1.9	193	64.9	40.6	4.99
2									
	July	75(2,124)	70(1,982)	1.28	1.6	233	271.8	49.0	20.89
	Devil's Ear	100(2,831)	ns	1.37	ns	332	ns	70.0	ns
3									
	Ginnie	40(1,133)	13.5(382)	1.24	1.3	120	42.7	25.3	3.28
	Dogwood	15(425)	5.2(146)	0.86	0.79	31.3	10.1	6.59	0.77
	Sawdust	7(198)	4(113)	0.82	0.78	13.9	7.57	2.93	0.58
	Twin	15(425)	2.5(71)	0.55	0.27	20.0	1.61	4.21	0.12

ns = no sample

Table 4-7. Discharge, NO_3-N concentration, NO_3-N Load and contribution of the total NO_3-N load increase in the study reach for Lower Santa Fe River Basin springs in refined segments (October 10, 2006).

River Segments	Springs	Discharge [cfs/ L s^{-1})]	NO_3-N (mg L^{-1})	NO_3-N Load (kg d^{-1})	% NO_3-N Load change
1					
	Rum Island	14.3(405)	1.5	52.2	4.01
	Blue	14.1(399)	1.9	64.9	4.99
2					
	No springs				
3					
	No springs				
4					
	July	70(1,982)	1.6	271.8	20.9
5					
	Ginnie	13.5(382)	1.3	42.7	3.28
	Dogwood	5.2(147)	0.79	10.0	0.77
	Sawdust	4(113)	0.78	7.57	0.58
	Twin	2.5(71)	0.27	1.61	0.12
6					
	No springs				
7					
	No springs				

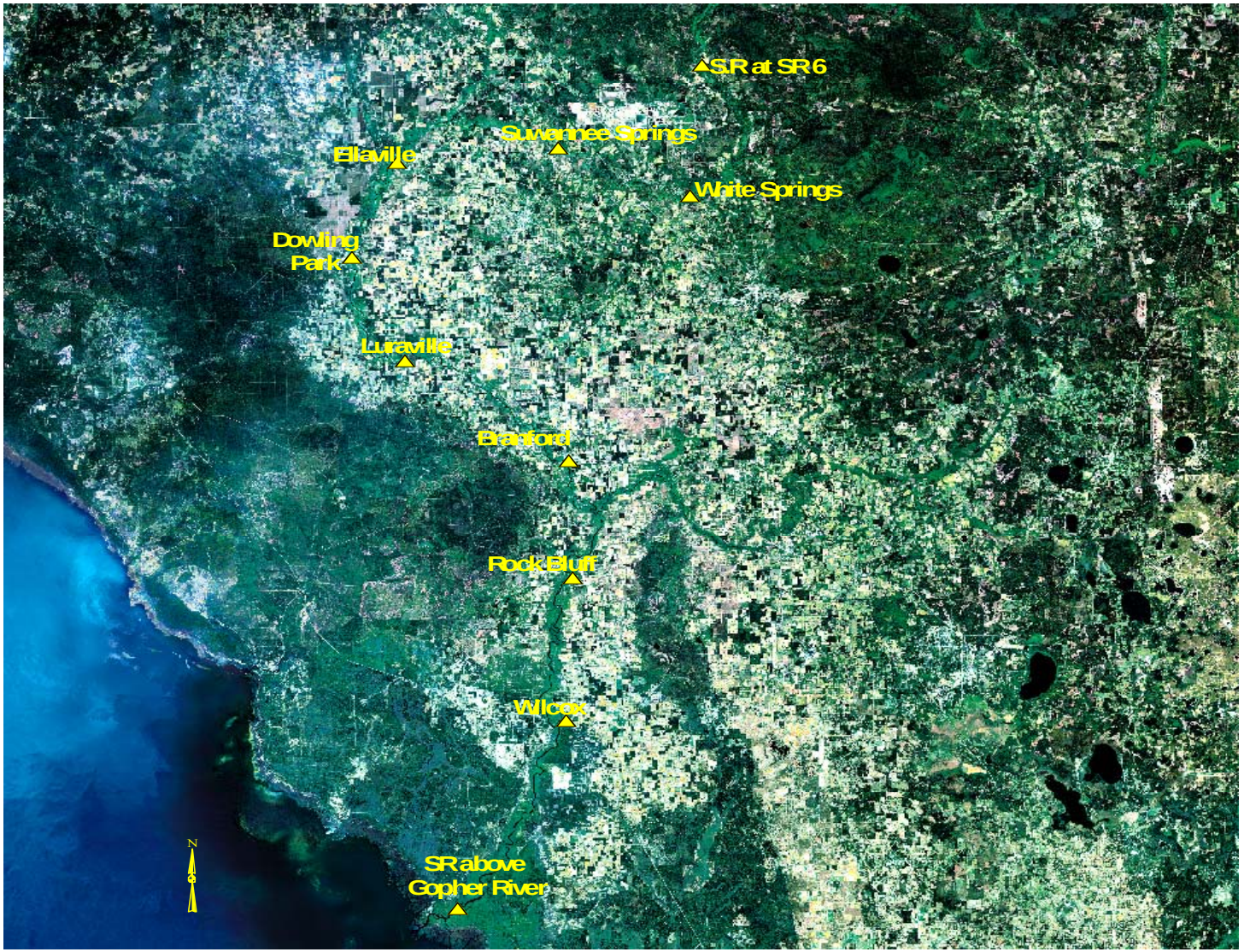

Figure 4-1. Suwannee River Water Management District stations on the Suwannee River with aerial photography.

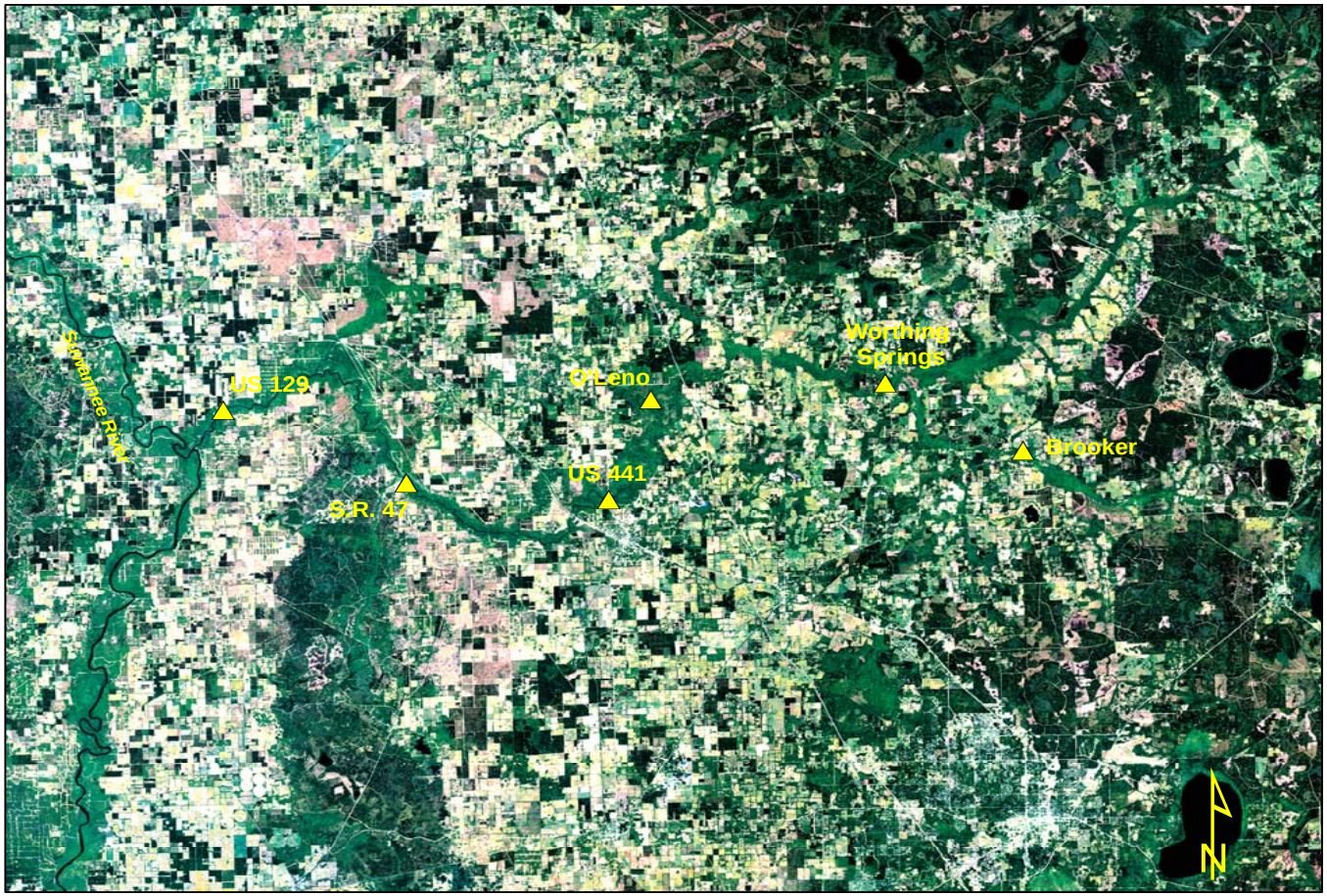

Figure 4-2. Suwannee River Water Management District stations on the Santa Fe River with aerial photography.

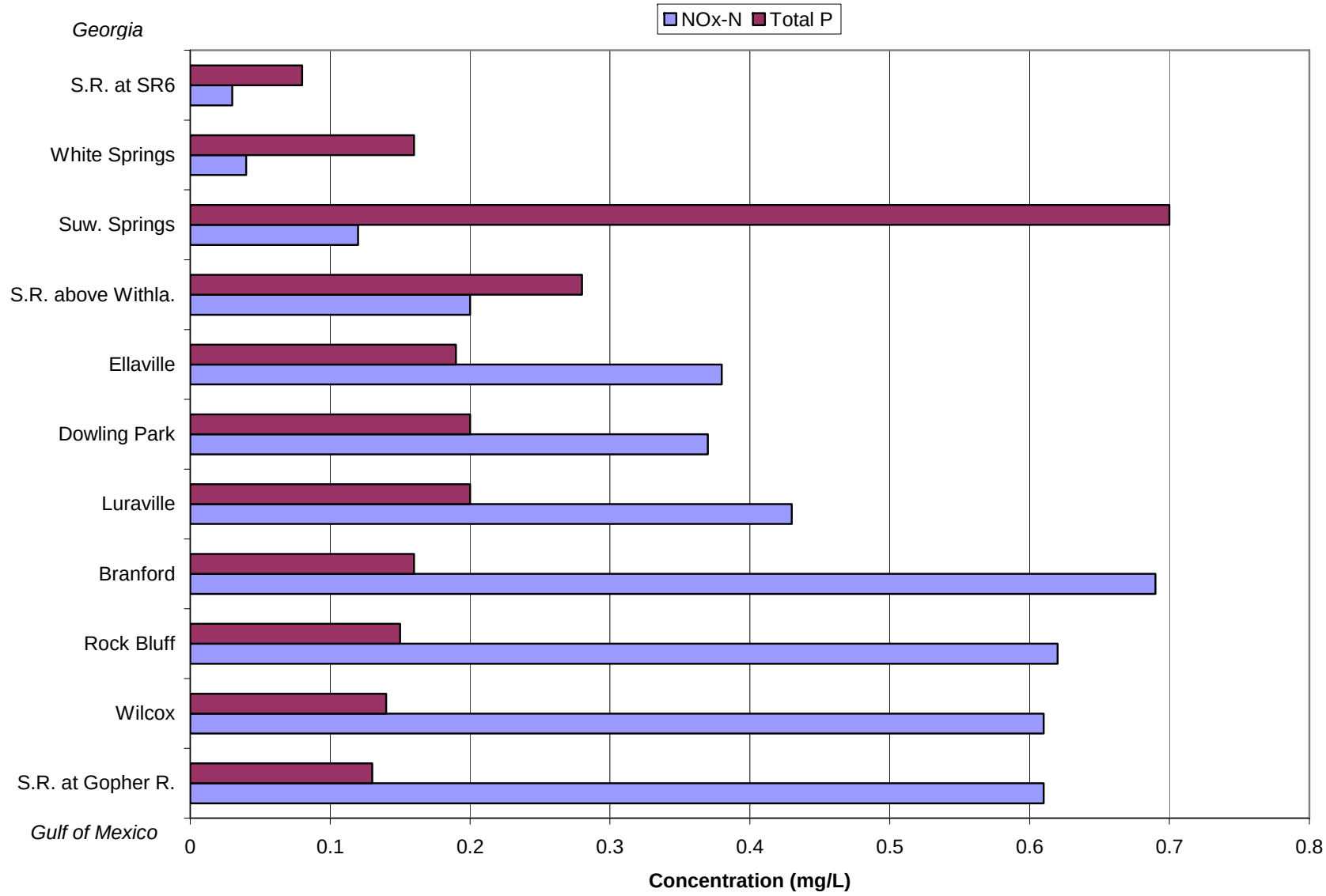

Figure 4-3. Mean NO_3-N and TP for Suwannee River Water Management District Suwannee River stations (1989 to 2006).

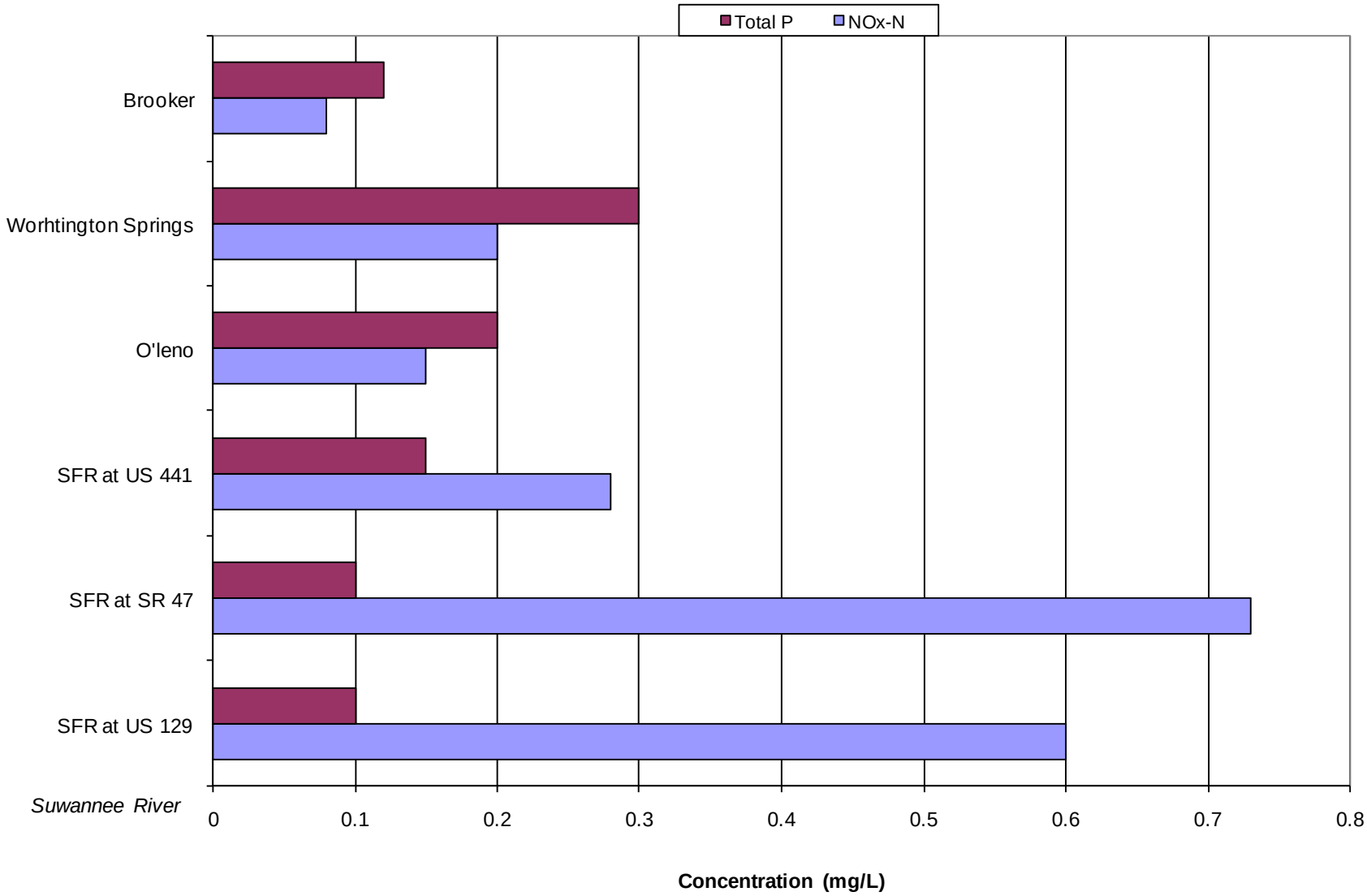

Figure 4-4. Mean NO_3-N and TP for Suwannee River Water Management District Santa Fe River stations (1989 to 2006).

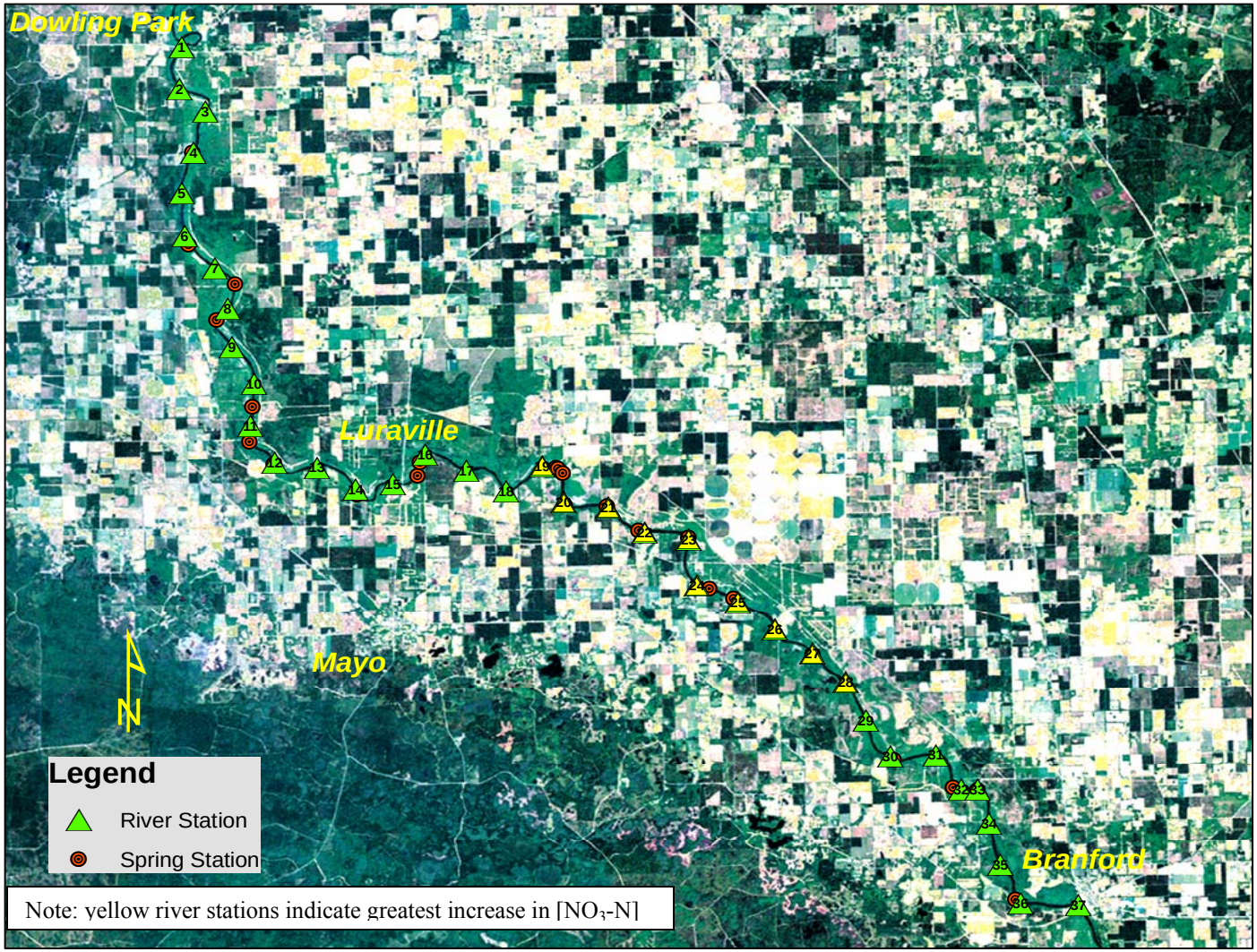

Figure 4-5. Middle Suwannee River Basin sampling points (July 21, 2000) for NO_3-N profile.

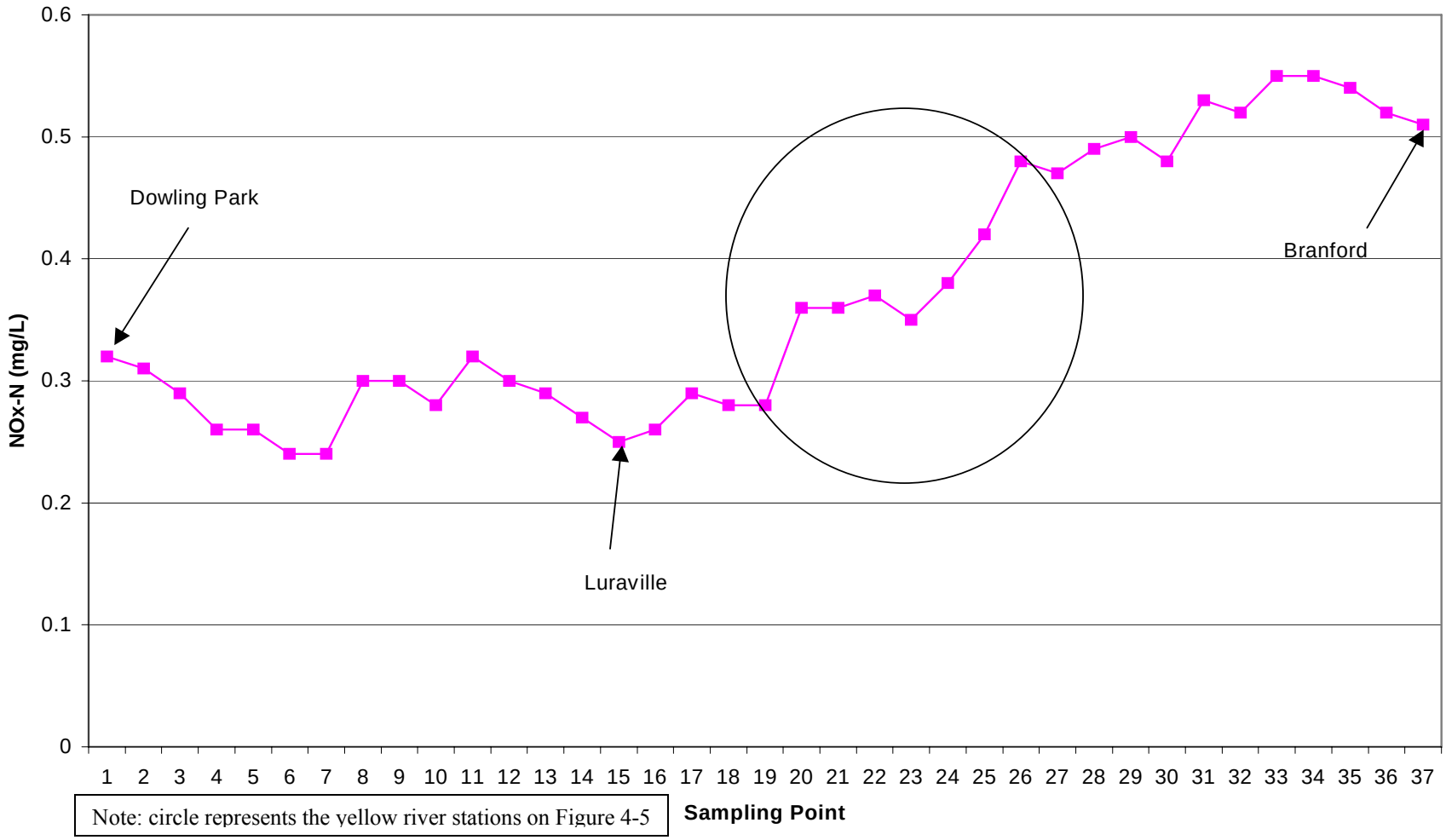

Figure 4-6. Middle Suwannee River Basin (Dowling Park to Branford) NO_3-N profile on July 21, 2000.

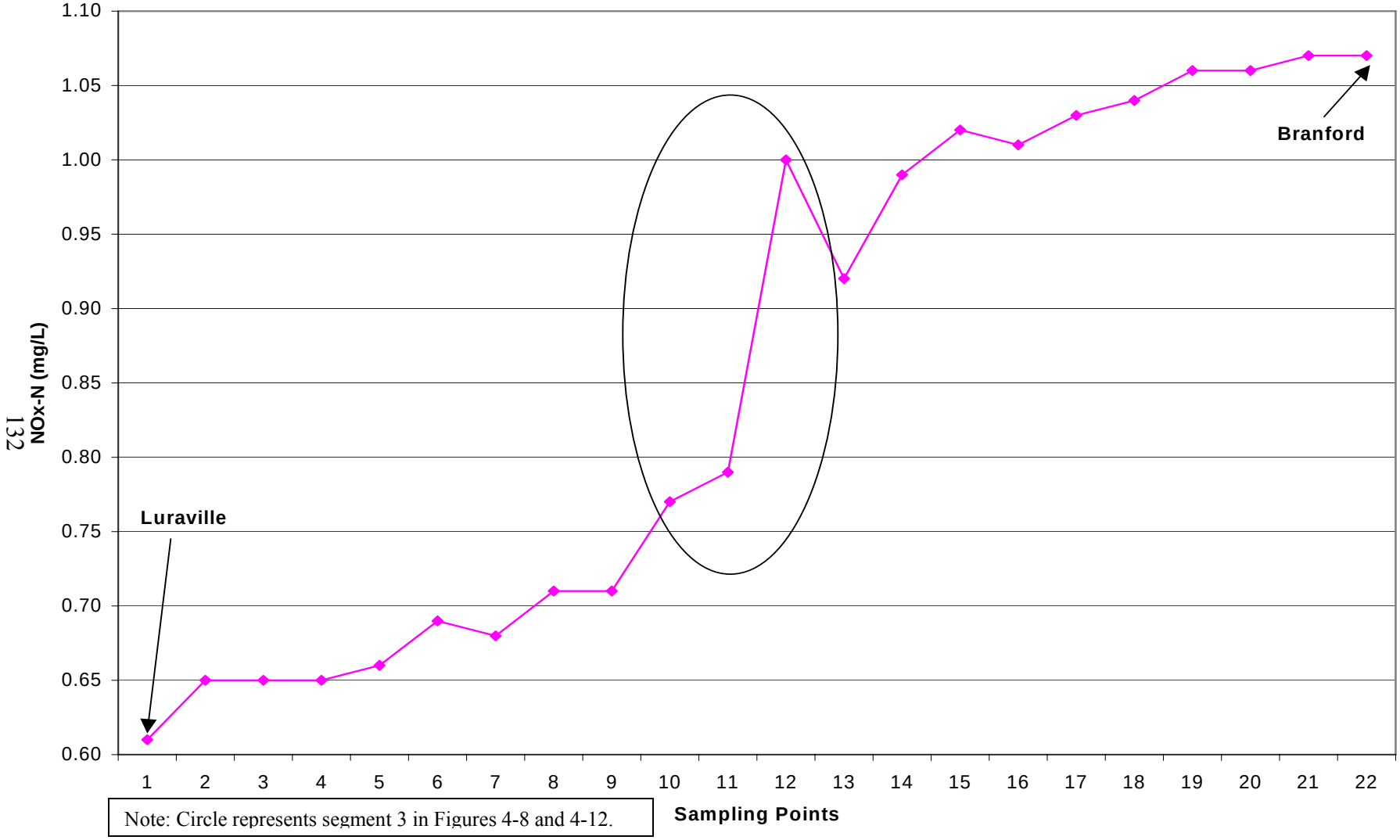

Figure 4-7. NO_3-N profile of the Middle Suwannee River Basin (October 2000).

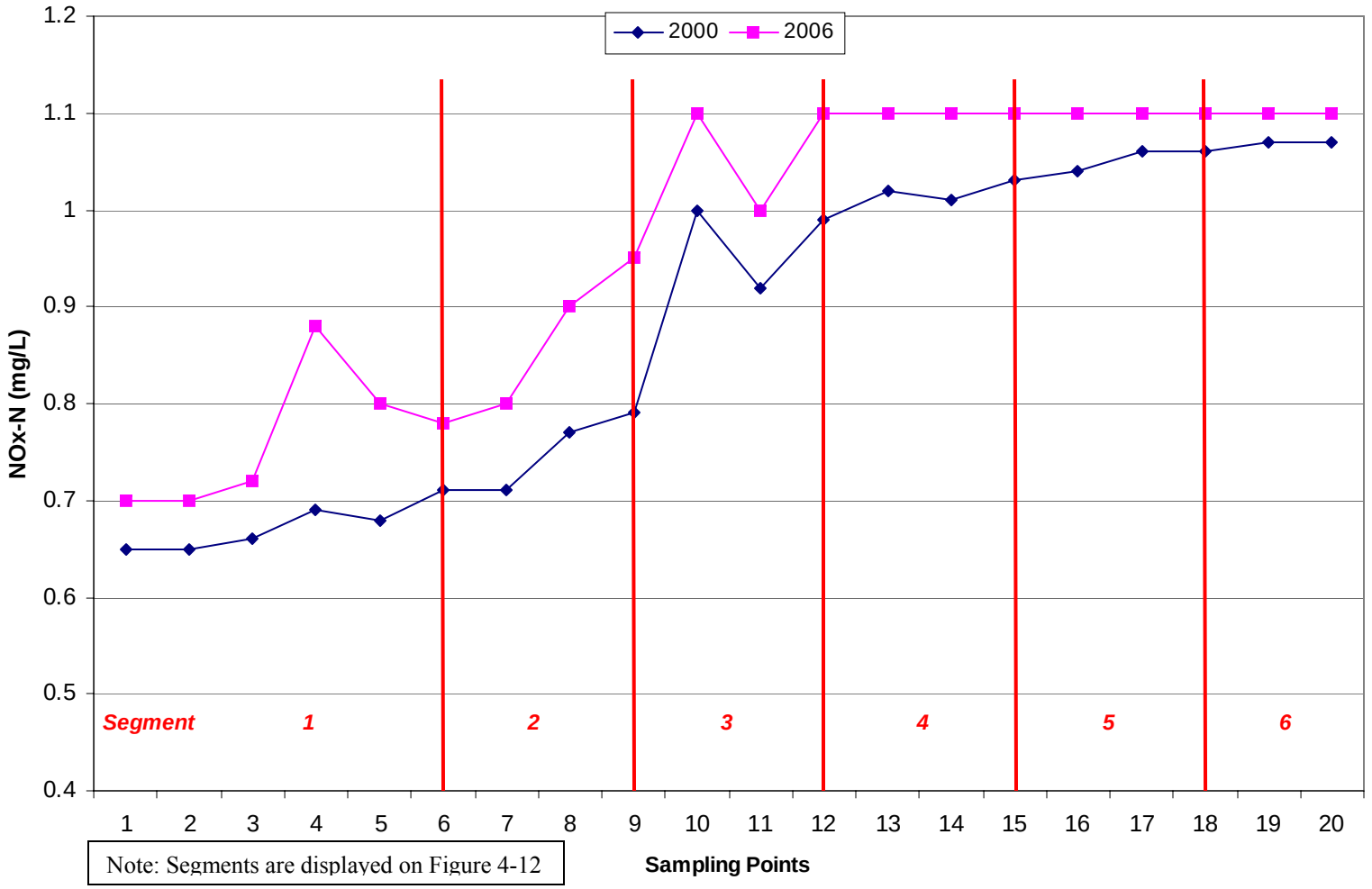

Figure 4-8. NO_3-N profiles of Middle Suwannee River Basin (October 2000 and September 2006).

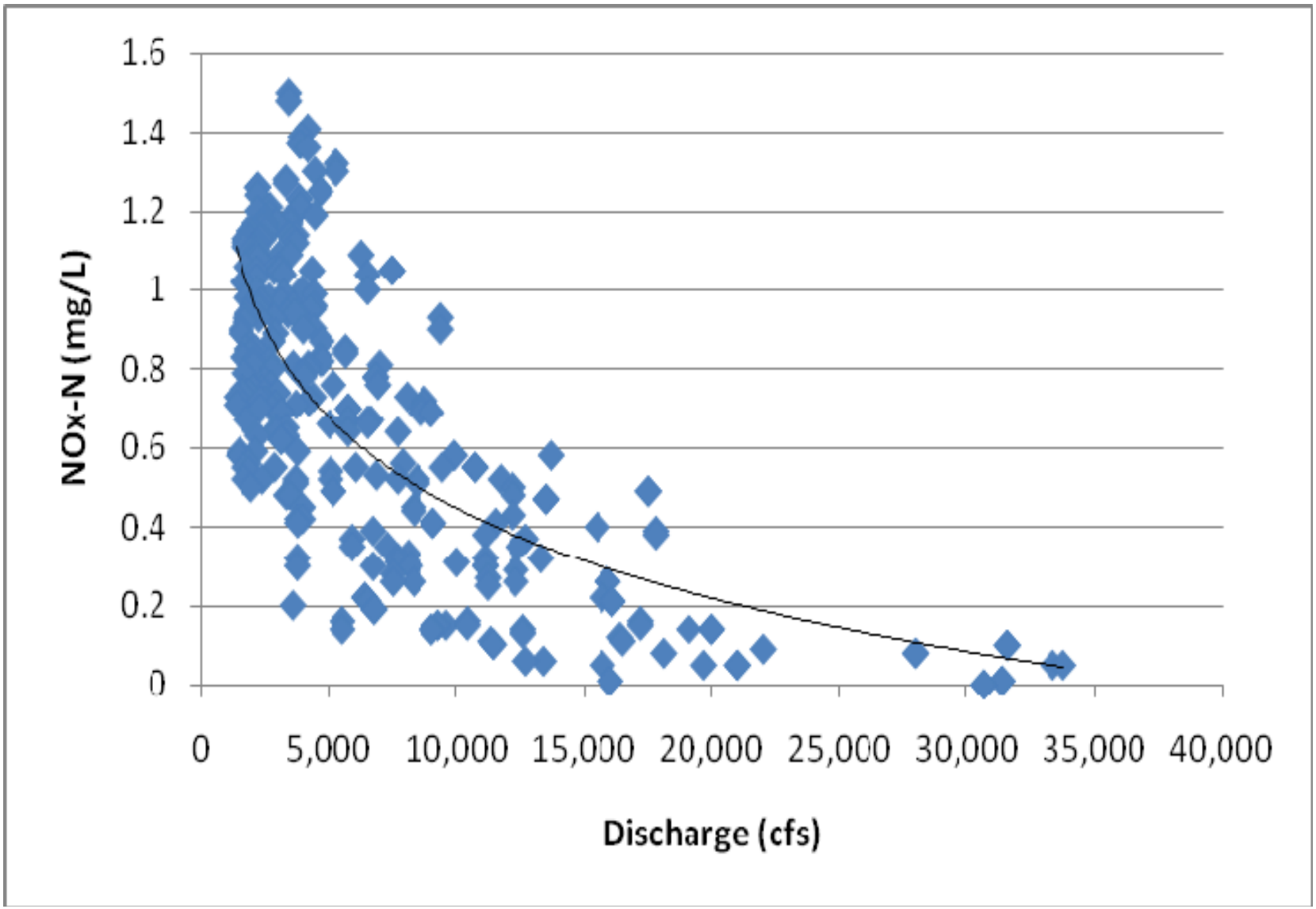

Figure 4-9. The relationship of discharge and NO_3-N concentration for the Suwannee River at Branford (1989 to 2006).

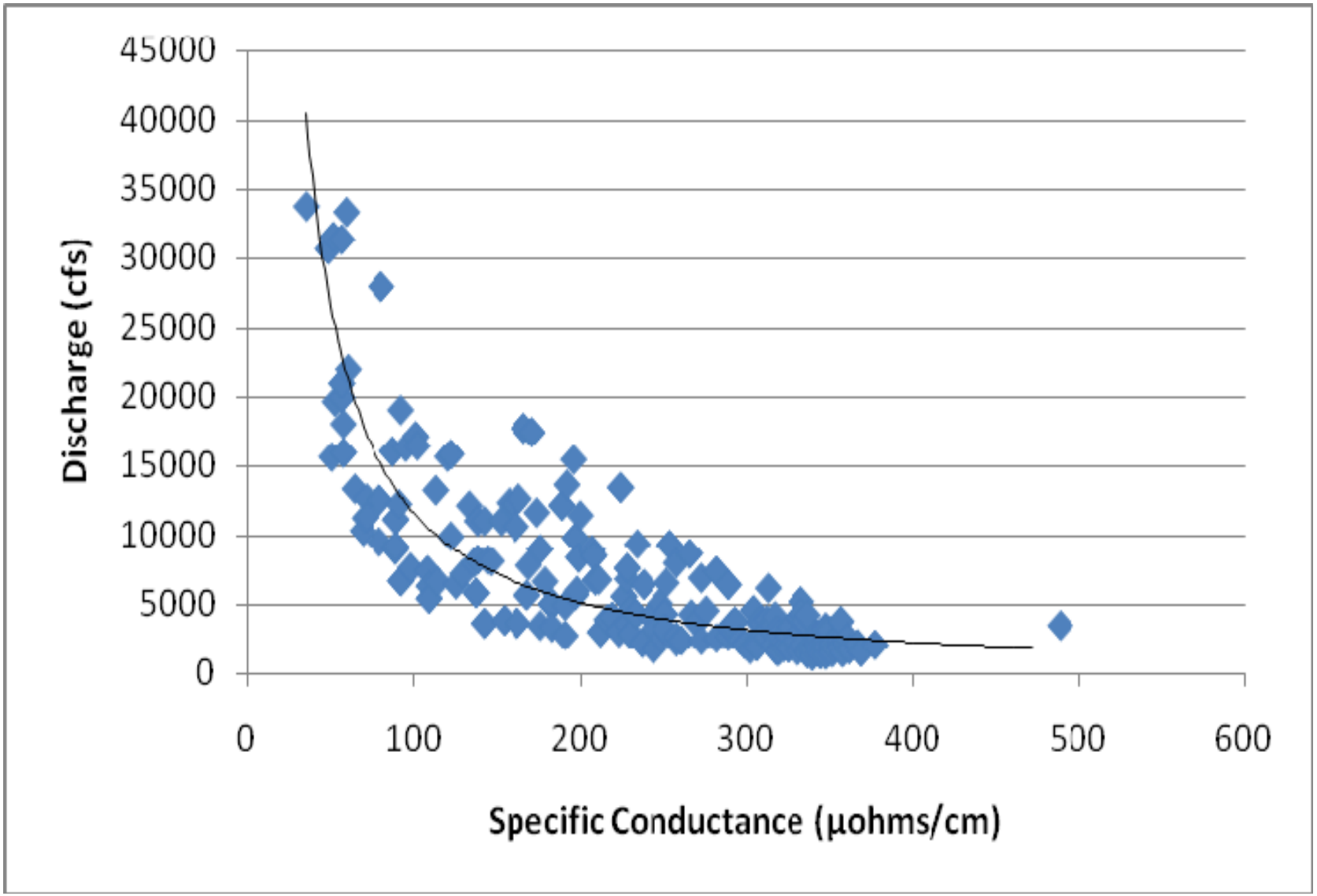

Figure 4-10. The relationship of specific conductance and discharge for the Suwannee River at Branford (1989 to 2006).

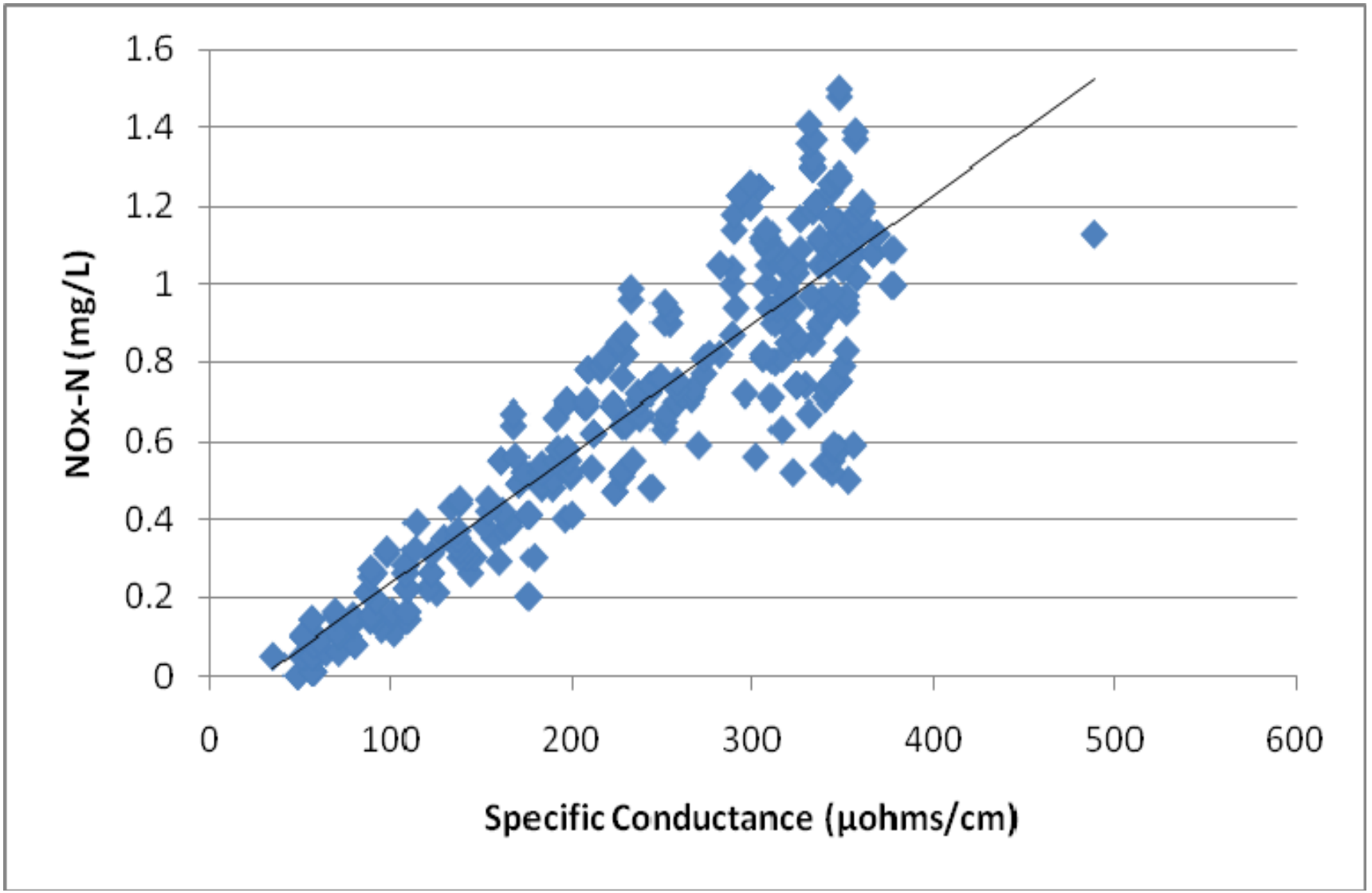

Figure 4-11. The relationship of specific conductance and NO_3-N concentration for the Suwannee River at Branford (1989 to 2006).

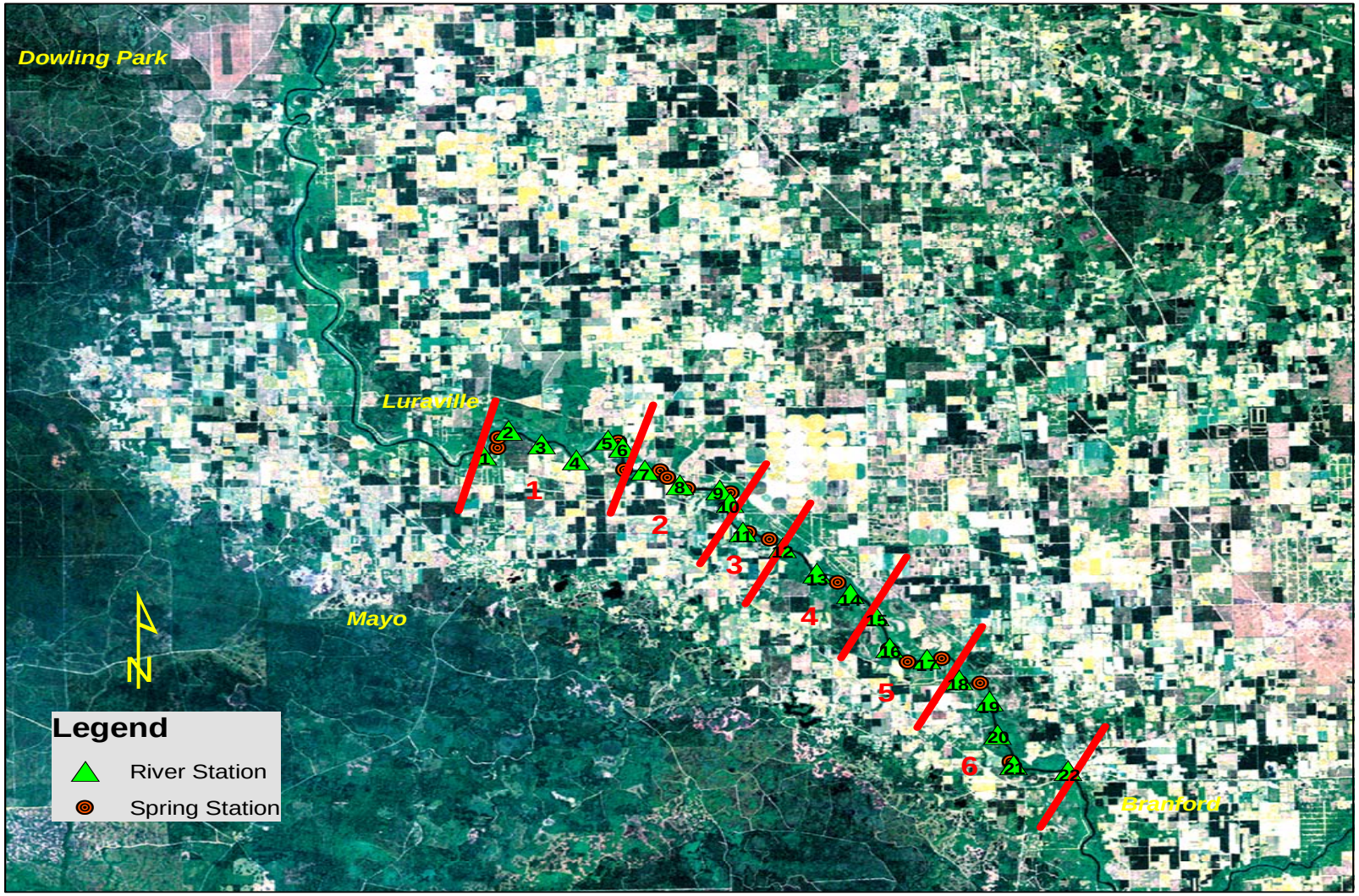

Figure 4-12. Middle Suwannee River Basin sampling points and discharge cross-sections [segments] (October 2000 and September 2006).

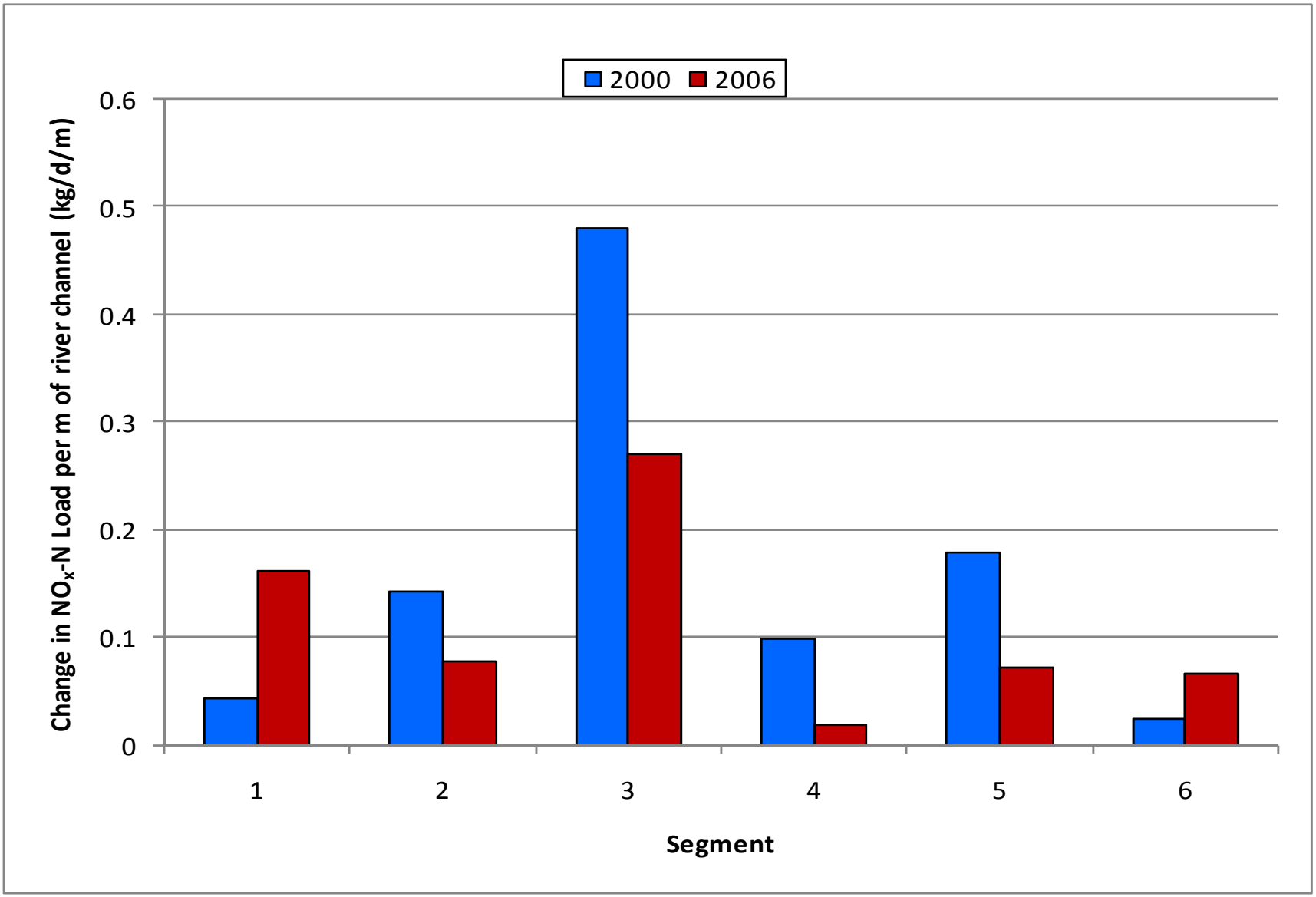

Figure 4-13. Comparison of segment NO_3-N load change per m of river in the Middle Suwannee River Basin (October 2000 and September 2006).

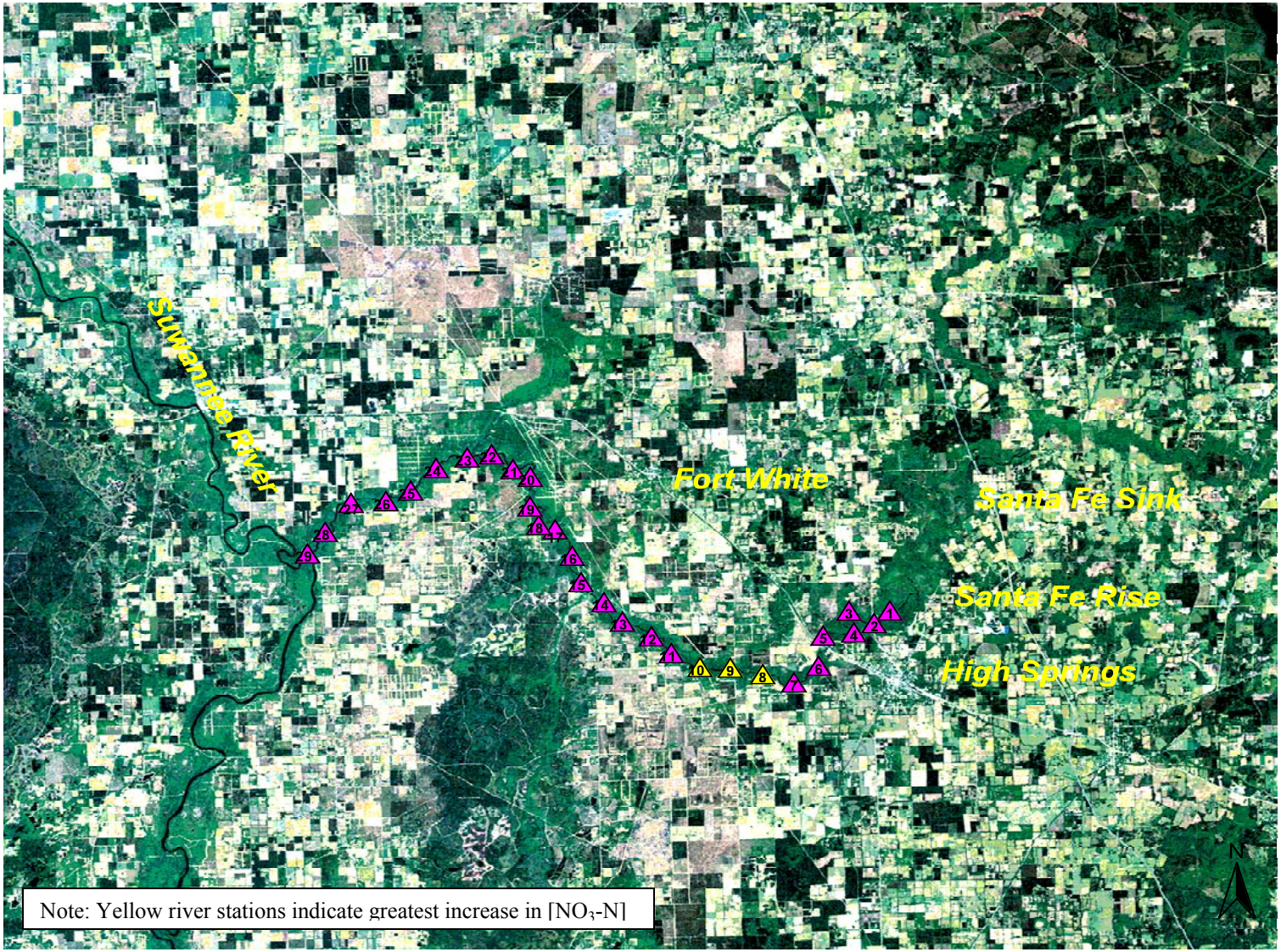

Figure 4-14. Lower Santa Fe River Basin sampling points (June 7, 2000) for NO_3-N profile.

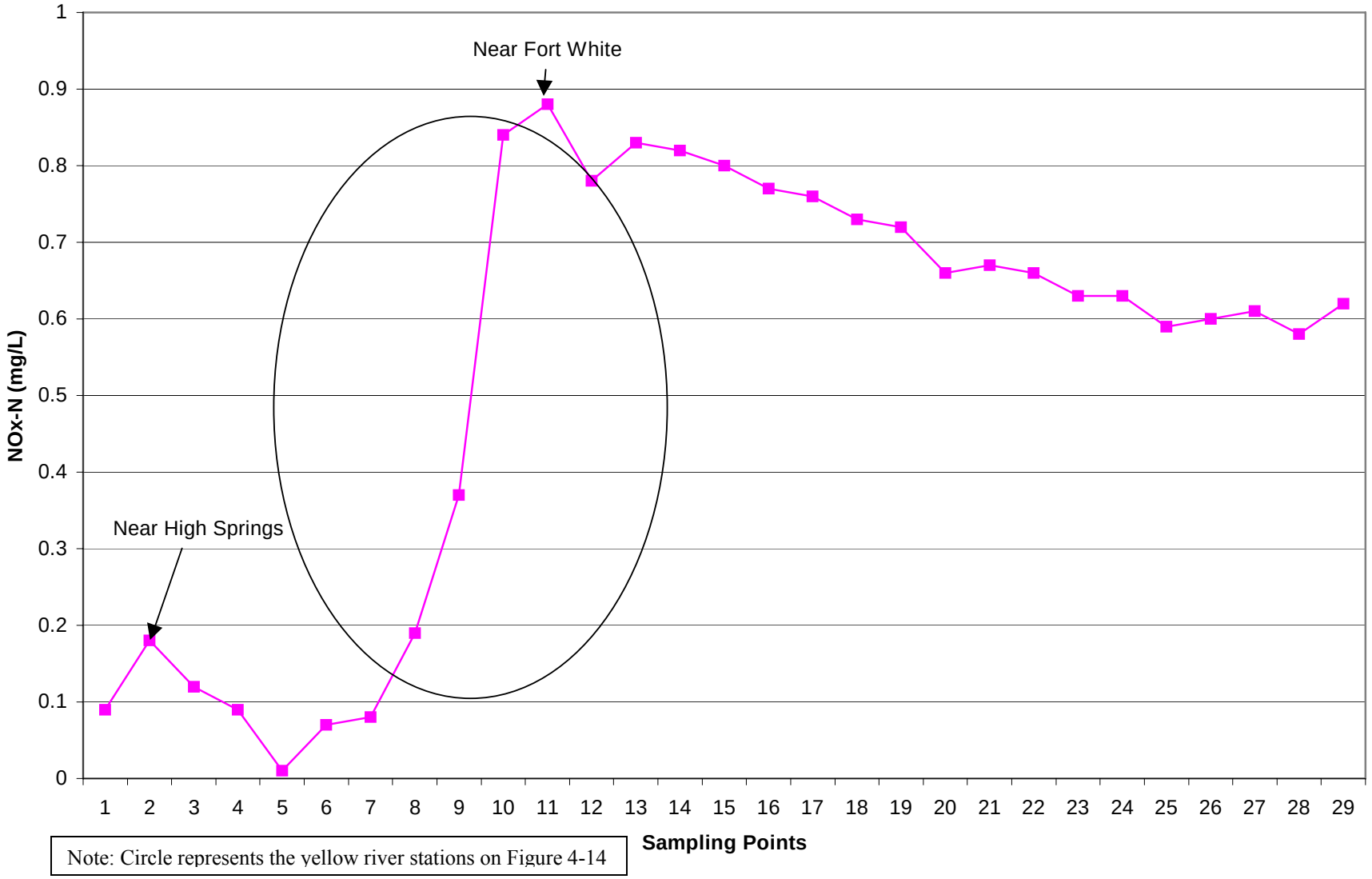

Figure 4-15. NO_3-N profile of the Lower Santa Fe River Basin on June 7, 2000.

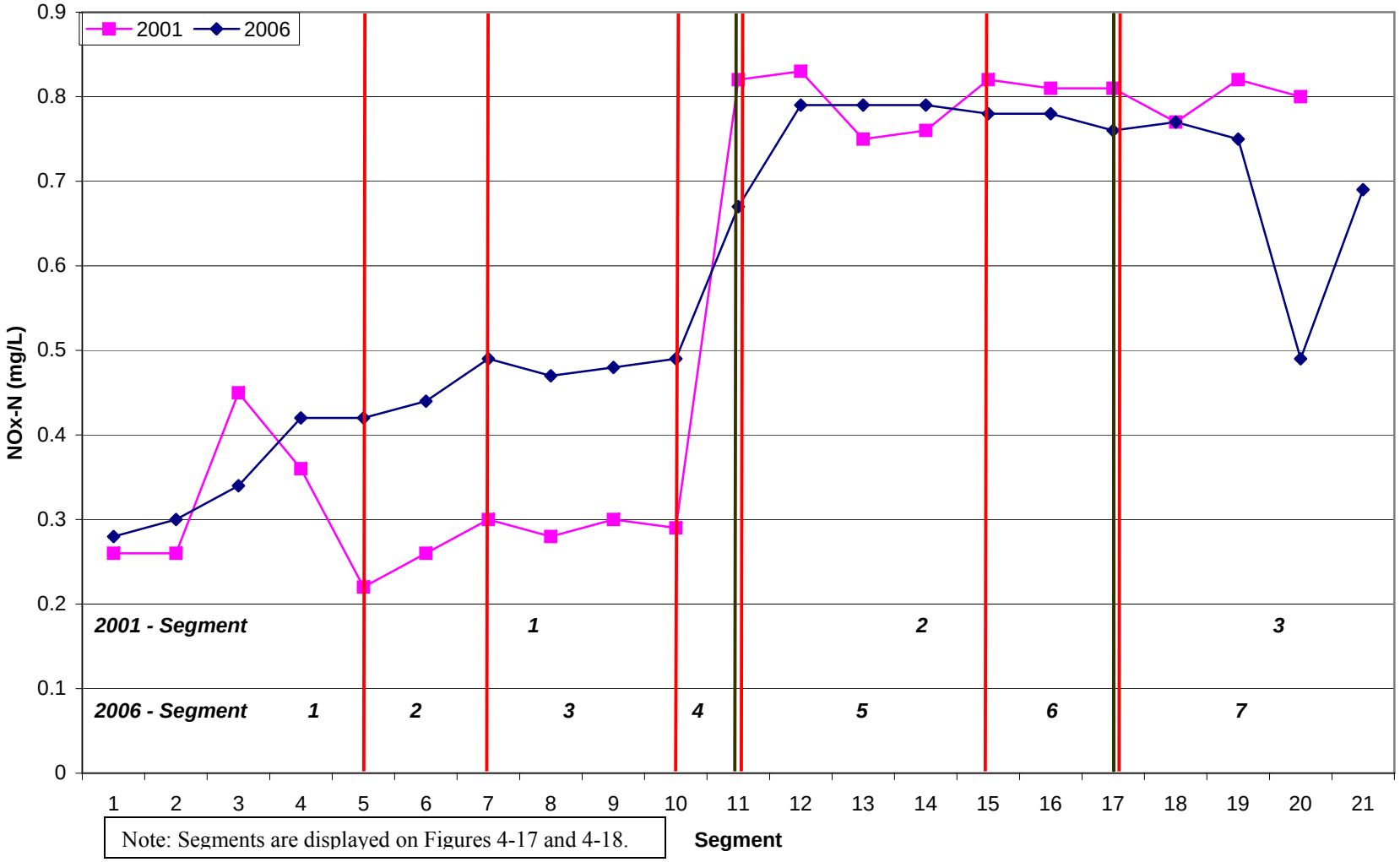

Figure 4-16. NO_3-N profile of the Lower Santa Fe River Basin (September 2001 and October 2006).

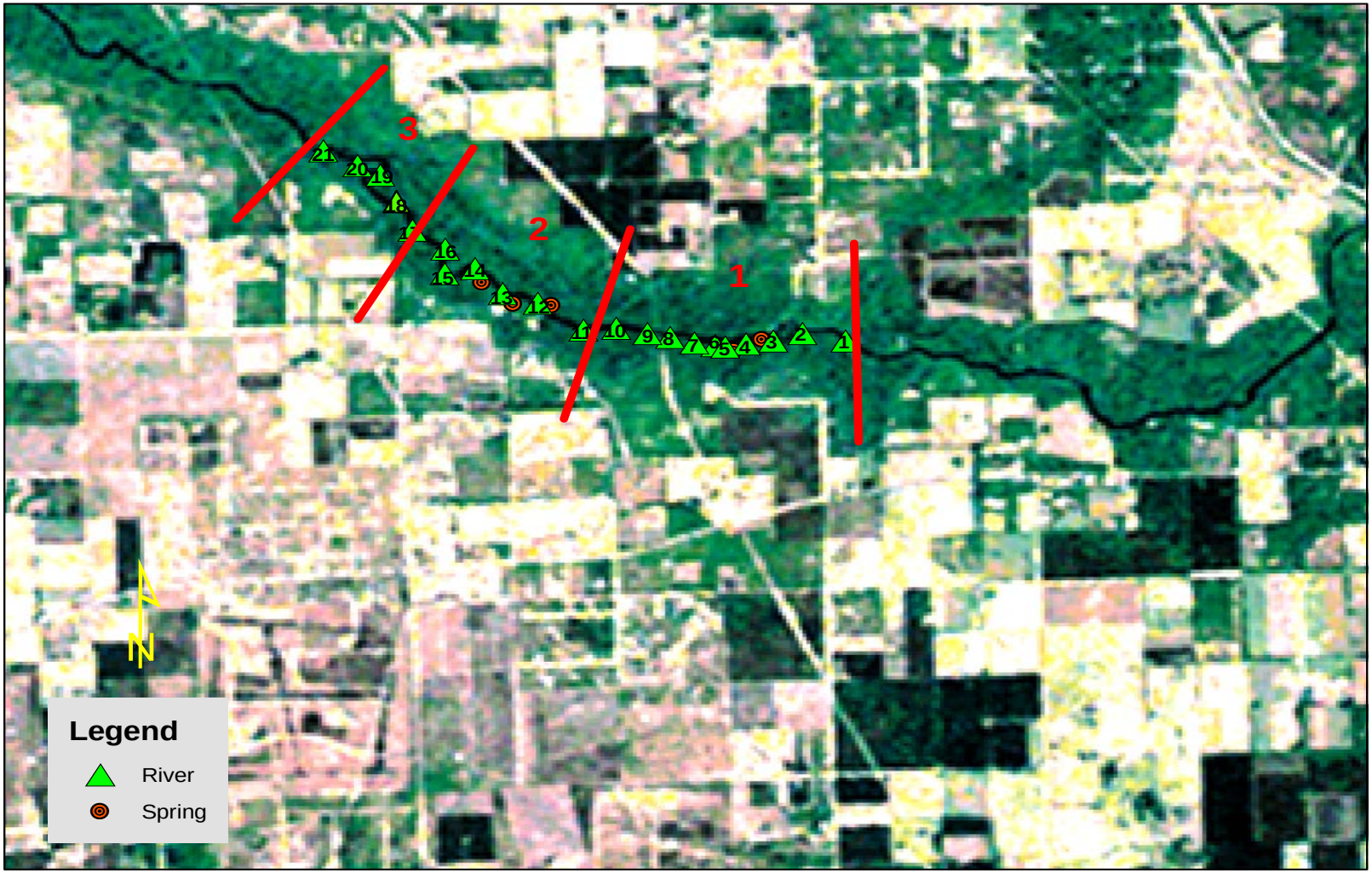

Figure 4-17. Lower Santa Fe River Basin segments for September 2001 NO_3-N profile.

Figure 4-18. Refined Lower Santa Fe River Basin segments for October 2006 NO_3-N profile.

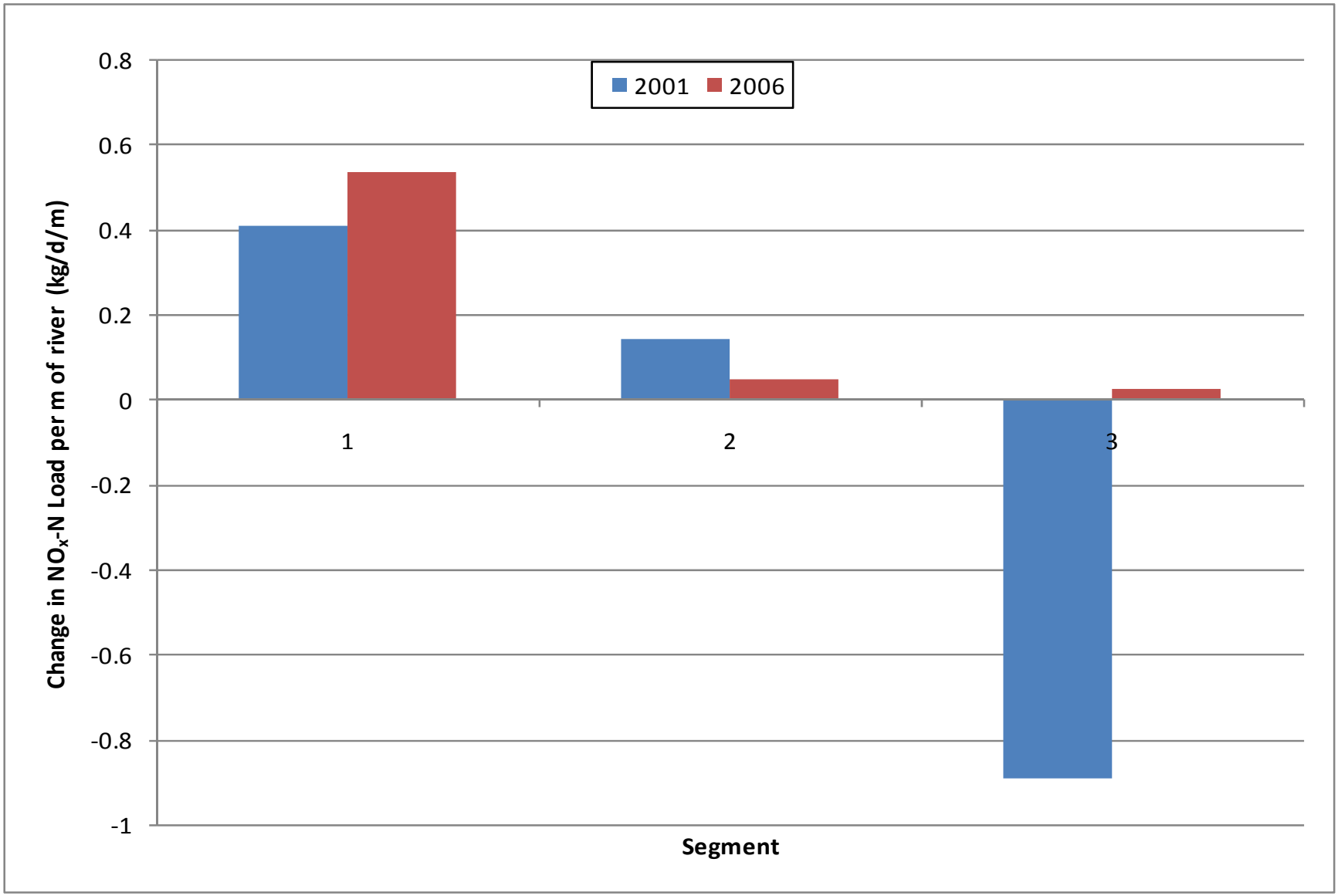

Figure 4-19. Comparison of segment NO_3-N load change per m of river in the Lower Santa Fe River Basin (September 2001 to October 2006).

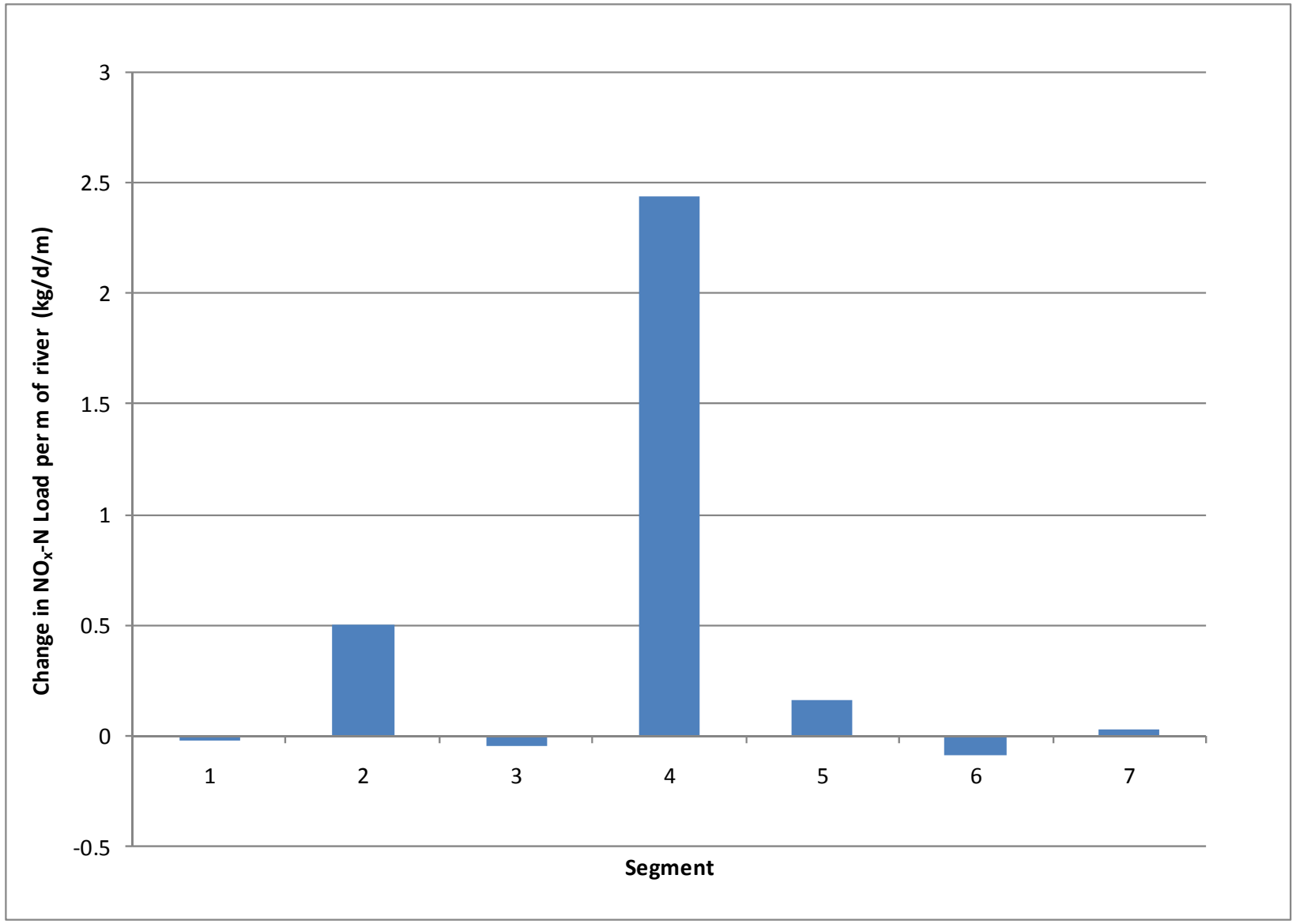

Figure 4-20. Refined segments NO_3-N load change per m of river in the Lower Santa Fe River Basin in October 2006.

CHAPTER 5
GROUNDWATER DOMAIN DELINEATION AND LANDUSE INFLUENCES ON GROUNDWATER QUALITY

Introduction

A Chinese proverb states "When you drink the water, remember the spring". This statement is a good way to think about the influences of human activities on the land surface and the ultimate impacts to the ground water beneath the landuse. The springs are the sentinels of the Floridan aquifer's overall status with respect to water quality. The geologic conditions in the Suwannee River Water Management District (SRWMD) are karstic which means that there are interconnections of surface and ground water. The landuse can be reflected in the ground water of the underlying Floridan aquifer. Also, agricultural activities and other landuses have impaired the quality of springs by contributing large quantities of nutrients to groundwater recharge in parts of the world (Katz et al., 2001; Dietrich and Hebert, 1997; Focazio et al., 1998; Burg and Heaton, 1998; Buzek et al., 1998).

The SRWMD operates the Water Assessment Regional Network (WARN) which has 181 wells monitored monthly for groundwater levels (Hornsby et al., 2005C). Also, the WARN network monitors 251 groundwater quality stations. About half of the WARN groundwater quality stations were randomly located and the remaining wells were placed to define regional trends (Upchurch and Goodwin, 2000). Also, approximately every five years the SRWMD and the United States Geological Survey (USGS) collect groundwater levels from approximately 1,000 wells to develop a potentiometric surface map of the Floridan aquifer in the SRWMD.

Groundwater domains can be approximated using potentiometric surface(s) of the aquifer or by using computer model(s) to simulate the groundwater domain (Scott et al., 2004). The approximation of a groundwater domain is determined by using potentiometric surface(s) to

delineate groundwater divides and assumes that groundwater movement is perpendicular to the potentiometric surface isopleths (Freeze and Cherry, 1979).

Groundwater flow modeling provides a valuable tool in understanding the hydrologic system, assessing the needs for additional data and information, and providing water managers a means to determine effects of changing hydrologic conditions (Planert, 2007). Groundwater computer models are mathematical representations of an aquifer and have been used to simulate groundwater flow and solute transport (Fetter, 1988). Most computer models for groundwater quality assumes a source of a water quality constituent and models transport rates, reactions and flow paths within the aquifer system. These transport models use theoretical leaching and uptake coefficients to simulate observed conditions. Thus, computer models are useful for conceptual understanding of the groundwater system.

The computer model MODFLOW simulates an aquifer system by assuming that the aquifer has saturated flow, Darcy's Law applies, and constant groundwater density within the aquifer (USGS, 1997). MODFLOW has been used to characterize the regional groundwater flow of the SRWMD (Planert, 2007; Grubbs and Crandall, 2007). Also, Davis (1996) used MODFLOW to assist in the delineating capture zones of well fields in the Woodville Karst plain areas of the panhandle of Florida.

Shoemaker et al. (2004) to identify areas contributing recharge to the springs in north-central Florida used groundwater flow models. The results yielded springshed and time based capture zones. Also, springsheds of Silver and Rainbow Springs in Marion County, Florida, were developed using two different flow models by indentified areas of groundwater that could be expected to reach the springs in 10 and 100 years (WRA and SDII, 2005). The identified land

area associated with the groundwater was classified a Spring Protection Zone for land use planning and management.

Other studies try to relate observed isotopic nitrogen (N) ratios in NO_3-N to the source of the NO_3-N and the landuse that possibly can be associated with the observed isotopic composition. Gormly and Spalding (1979) collected ground water samples from Buffalo, Hall and Merrick counties in the Central Platte Region of Nebraska and compared the isotopic values of the ground water samples to those of potential NO_3-N sources. The potential sources were inorganic fertilizer, soil organic N and animal waste with $\delta^{15}N$ ranges of -2.1 to +1.9 ‰, +5.9 to +9.0 ‰ and +10.0 to +18.0 ‰, respectively. The ground water in the Central Platte Region during 1976-1977 had 183 of 256 ground water samples in excess of 10 mg N L^{-1} of NO_3-N. The study indicated that the primary source of NO_3-N contamination in the ground water was due to fertilizers and a small fraction of the samples indicated NO_3-N contamination due to animal waste. Samples for which the source could not be identified were assumed to be a combination of two or more sources of contamination.

Kreitler and Browning (1983) used N isotope analyses in ground water samples from Cretaceous Edwards aquifer in Texas, U.S.A. and Pleistocene Ironshore Formation on Grand Cayman Island, West Indies. Both aquifers are carbonate aquifers. The $\delta^{15}N$ classification ranges used were -2.0 to +1.9 ‰ (inorganic fertilizer), +2.0 to +8 ‰ (soil cultivation without fertilizer) and +10.1 to +22.0 ‰ (animal waste). The ground water samples from Cretaceous Edwards aquifer had $\delta^{15}N$ values that ranged from +1.9 to +10.0 ‰; while, the sample from Pleistocene Ironshore Formation had $\delta^{15}N$ values that ranged from +18 to 23.9 ‰. Cretaceous Edwards aquifer $\delta^{15}N$ values indicate fertilizer and mineralization of soil organic matter as the sources of the NO_3-N in the

ground water; while, Pleistocene Ironshore Formation $\delta^{15}N$ values indicates animal wastes as the source of NO_3-N contamination in the ground water.

Flipse and Bonner (1985) used isotopic ratios for the identification of NO_3-N in the ground water under fertilized fields. Two sites were used. Site one was a potato farm where the fertilizer applied had an average $\delta^{15}N$ value of 0.2 ‰ and the NO_3-N had an average $\delta^{15}N$ value of +6.2 ‰. Site two was a golf course where the fertilizer applied had an average $\delta^{15}N$ value of -5.9 ‰ and the NO_3-N had an average $\delta^{15}N$ value of +6.5 ‰. The difference between the $\delta^{15}N$ of the fertilizer and the $\delta^{15}N$ of the NO_3-N was possibly due to the isotopic fractionation in the volatile loss of NH_3 during (or after) application of ammonium fertilizer. The $\delta^{15}N$ values are consistent with characteristic range determined for NO_3-N resulting from agricultural operations (non-animal waste).

Kreitler (1975) used $^{15}N/^{14}N$ ratios of groundwater NO_3-N to determine the source(s) of NO_3-N. $\delta^{15}N$ value ranges were -3 to +2 ‰ (inorganic fertilizer), +2 to +8 ‰ (unfertilized cultivated fields) and +10 to +20 ‰ (animal waste). From the isotopic ratios of NO_3^-, the source of NO_3-N indicates a mixed source of NO_3-N (mean $\delta^{15}N$ value +6.8 ‰). Due to the age of the water in the aquifer, the $\delta^{15}N$ value is representative of older landuse pattern where agriculture was widely practiced and both inorganic fertilizer and manure were used.

Mytyk and Delfino (2004) reviewed a 50-year period of record for NO_3-N concentrations in the Ocklawaha Basin and linked changes to landuse based on isotopic composition. While Katz et al. (2001) used isotopic composition of NO_3-N and age dating techniques from collected spring water to link landuse within the basin and estimate travel times. Isotopic studies were able to show relative composition of the sources of N in the form of NO_3-N. However, the potential sources of N for the isotopic studies were inorganic, organic or mixed.

In hydrochemical studies, classification on the basis of water quality serves the purpose of identification of representative clusters (hydrochemical facies) of samples that reflect the processes generating the natural variability found in hydrochemical parameters (Guler and Thyne, 2004). The use of hydrochemical facies was demonstrated by Back (1961), Back and Hanshaw (1965), Morgan and Winner (1962), Seaber (1962), Jones et al. (1996), and Maddox et al. (1992) to indicate distinct regions of ground water which contain similar composition of cations and anions. The use of hydrochemical facies analysis depends on pattern recognition. Methods for defining and displaying hydrochemical facies patterns range from the use of Piper diagrams, Stiff diagrams, and star diagrams to statistical methods, such as fuzzy c-mean clustering or factor analysis or principal component analysis (Kwansirikul et al., 2005; Guler and Thyne, 2004; Lawrence and Upchurch, 1982). Lawrence and Upchurch (1982) used factor analysis to delineate regions of similar groundwater quality in Northern Suwannee County. For small data sets, graphical methods are useful to display the relative patterns among hydrochemical facies; while, for large data sets, statistical techniques are used to filter the data set and identify patterns.

This study will identify groundwater domains based on potentiometric surface maps from 1985, 1990, 1995, 2002, and 2005. Hydrochemical facies analysis will be used to refine the groundwater domains determined from the potentiometric surface data. Water quality statistics of the upper Floridan aquifer water will be determined for each groundwater domain. Then each groundwater domain will be related to the observed groundwater domain median TP and NO_3-N concentrations to percent of the groundwater domain in specific level 2 Florida Landuse Code (FLUC). This study will provide an examination of relationships of groundwater quality and land uses on a groundwater domain wide analysis.

Materials and Methods

The groundwater domains for potentiometric surface maps from 1985, 1990, 1995, 2002 and 2005 were approximated by using the methods outlined by Freeze and Cherry (1979) and Upchurch et al. (2001). Principal components analysis (PCA) of the WARN groundwater quality monitoring well data was used to confirm and refine the groundwater domains which were delineated from the potentiometric surfaces. The PCA used potassium (K), sodium (Na), magnesium (Mg), calcium (Ca), chloride (Cl), sulfate (SO_4^{2-}) and NO_3-N to cluster samples according to the hydrochemical facies, or geochemical fingerprints, of the groundwater domains within the upper Floridan aquifer (Back, 1961; Lawrence and Upchurch, 1982). The PCA used Eigen analysis that created a correlation matrix for the components. The resulting component scores were imported into Surfer© and contoured using the kriging option with a linear interpolation and zero nugget. The resulting contours were imported into ArcGIS. In ArcGIS, the groundwater domains from delineated potentiometric surface data were overlaid with the component score contours to delineate the final groundwater domains.

The WARN well coverage was clipped to groundwater domains. Mean, standard deviation, median, 25th percentile, 75th percentile, maximum, and minimum for groundwater quality were generated for each groundwater domain. The median NO_3-N and TP were compared using a series of Kruskal-Wallis tests (Ott and Longnecker, 2001) to ensure that each basin was statistically different at the 95% confidence level.

The 1995 landuse/landcover (SRWMD, 1997) coverage for the SRWMD was clipped to the groundwater domains using ArcGIS. The hectares of basin in landuse/landcover at level 2 Florida landuse codes (FLUCs) were determined for each groundwater domain. The median

groundwater domain concentrations of TP and NO_3-N were correlated to each of the level 2 Florida landuse codes.

Results and Discussion

The potentiometric surface maps for SRWMD for 1985, 1990, 1995, 2002 and 2005 are presented in Appendix D, Figures D-1 through D-5. Figures 5-1 to 5-5 present the groundwater domains based on the potentiometric surface maps for 1985, 1990, 1995, 2002 and 2005, respectively. In the 1985 groundwater domains, a east-west domain was not delineated in the center of Taylor County due to the groundwater withdrawals in the region causing an artificial bend in the potentiometric surface. The groundwater domains for 1985, 1990, 1995, 2002 and 2005 potentiometric surface maps were overlaid and the maximum extent of each basin was used to determine the composite potentiometric surface groundwater domains.

The PCA revealed two distinct water types based on water quality parameters potassium (K), sodium (Na), magnesium (Mg), calcium (Ca), chloride (Cl), sulfate (SO_4), and NO_3-N. The PCA yielded two principal components that were significant and accounted for 77.8 % of the total variability (Table 5-1). Principal component 1 includes K, Na, Mg, Cl, and SO_4, which are positively correlated Figure 5-6 shows the component contours for principal component 1. The higher contours are associated with the regions of the upper Floridan aquifer that has a confining unit. Principal component 1 represents geological influences on recharge and weathering of the Hawthorne Group. Therefore, principal component 1 represents the confined Floridan aquifer. Principal component 2 includes Ca and NO_3-N, which are negatively correlated. Figure 5-7 shows the component contours for principal component 2. The higher component contours indicate recharge or surfacewater influences. The region in the southwest corner of Dixie County indicates water quality that is different from the surrounding ground water. This resulted

in the delineation of a ninth groundwater domain. The difference in the groundwater quality in southwest Dixie County may be associated with sand/limestone mining. Principal component 2 represents more rapid recharge of the upper \Floridan through karst features. Therefore, principal component 2 represents the unconfined Floridan aquifer.

The results from the composite potentiometric surface groundwater domains yielded eight distinct groundwater domains. The eight potentiometric surface groundwater domains were coupled with the component contours. The component contours were used to confirm that the potentiometric surface groundwater domains did not contain water quality differences. The component contours for principal component 2 identified two groundwater domains in Dixie County instead of one groundwater domain as identified from the potentiometric surface. This resulted in the delineation of a ninth groundwater domain, Dixie, which is the smallest groundwater domain delineated in the SRWMD. The potentiometric surface groundwater domain most likely did not account for the ninth basin due to the resolution of the potentiometric surface and the density of wells in the region used to create the potentiometric surface maps. The refined groundwater domains were adjusted to include the additional basin identified from the component contours. The refined groundwater domains map for the SRWMD are shown in Figure 5-10. Names were assigned to the groundwater domains based on their relationship to surfacewater features (Alapaha, Aucilla, Coastal, Dixie, Ichetucknee, Santa Fe, Suwannee, Steinhatchee, and Waccasassa).

The statistical summary by groundwater domain for NO_3-N and TP are presented in Table 5-2. A statistical summary for the period of record of the remaining groundwater quality parameters from the WARN network (temperature, specific conductance, pH, DO, turbidity,

TDS, alkalinity, TOC, DOC, K, Na, Mg, Ca, Cl, F, SO_4^{2-}, Fe, TKN, NH_4^+-N) is presented in Appendix D, Table D-1.

A series of Kruskal-Wallis tests were conducted on the median TP and NO_3-N concentrations to show that each groundwater domain was statistically different at the 95 percent confidence level (Appendix D, Tables D-2A to D-2H). The median TP and NO_3-N concentrations for each of the groundwater domains were examined. The first test included all nine basins. The model was found to be significant at the 95 % confidence level. The groundwater domain with the highest concentrations was removed and the remaining basins were analyzed using the Kruskal-Wallis test. This process was continued until all the basins were determined to be statistically different at the 95 % confidence level for TP and NO_3-N. These results provide a method for evaluating the groundwater conditions for TP and NO_3-N on a regional scale.

Figure 5-9 shows the median TP concentration with Kruskal-Wallis statistical separation for each groundwater domain. The groundwater domain with the highest TP concentration was the Waccasassa. Waccasassa groundwater TP may be associated with the weathering of carbonate-hydroxylapatite [$Ca_5(PO_4 \bullet CO_3)_3 \bullet (OH)$] in the Waccasassa Flats (Maddox et al., 1992). Carbonate-hydroxylapatite is the mineral produced by precipitation of phosphate which was liberated by weathering of carbonate-fluorapatite [$Ca_5(PO_4 \bullet CO_3)_3 \bullet F$] under acidic conditions. The precipitation of carbonate-hydroxylapatite occurs when the phosphate rich water encounters an alkaline environment, such as the upper Floridan aquifer (Maddox et al., 1992).

Furthermore, the groundwater domains closest to the Gulf of Mexico had the highest TP concentrations in the SRWMD. The possible sources of the P are organic rich recharge water containing P or leaching from the geological formations providing P as the acidic water is

recharging to the upper Floridan aquifer. The groundwater domains adjacent to the Gulf of Mexico have large areas of swamps which are groundwater discharge zones. The swamps result from low lying topography and in some case, overlying clayey sands and the high potentiometric surface which results in surficial waters being unable to infiltrate into the ground (Arthur, 1991). The surface water conditions in these swamps result in an acidic environment, largely due to organic acids, in which P may be dissolved in the water column or suspended with organic material. As the water in the swamps move to the edge of the swamps which have karst features which can provide recharge points into the underlying upper Floridan aquifer. The ortho-P fraction of the TP will precipitate when it comes in contact with the alkaline water of the upper Floridan aquifer (Maddox et al., 1992). The organic P fraction of TP may precipitate or remain suspended or dissolved. Lawrence and Upchurch (1982) demonstrated that recharge water containing P could maintain the P in solution for several kilometers within karst features, such as conduits in the upper Floridan aquifer, due to the lack of contact with limestone. Also, Lawrence and Upchurch (1982) noted that the weathering of apatite minerals from the Hawthorn Group introduced phosphate into surface and ground water. Erosion of the Hawthorn Group in the Highlands during various sea level stands and deposition of the erosion products from the Hawthorn Group within the groundwater domains adjacent to the Gulf of Mexico may account for the P bearing materials within the groundwater domains.

Figure 5-10 shows the median NO_3-N concentration with Kruskal-Wallis statistical separation for each groundwater domain. The groundwater domain with the highest median NO_3-N concentration was the Santa Fe. Three groundwater domains, Santa Fe, Ichetucknee, and Suwannee, had elevated NO_3-N concentrations. The elevated NO_3-N is due to anthropogenic factors, such as atmospheric deposition, septic tanks, wastewater spray fields, or fertilization

(Andrews, 1994). Also, there are no known natural sources of NO_3-N in the upper Floridan aquifer. Katz et al. (1999) sampled springs within Santa Fe, Ichetucknee, and Suwannee groundwater domains. Nitrate-nitrogen in two springs in the Suwannee groundwater domain with NO_3-N concentrations greater than 10 mg L^{-1} was from an inorganic source; while other springs had mixed or organic source signatures based on the $^{15}N/^{14}N$ isotopic ratio. The results for the Santa Fe groundwater domain yielded that one spring (GIL917971) with NO_3-N concentrations greater than 10 mg N L^{-1} was from a mixed source; while other springs had inorganic or organic source signatures. Only one spring was sampled in the Ichetucknee groundwater domain and it had an inorganic signature. Furthermore, the limitation of using $^{15}N/^{14}N$ ratio is potential sources are limited to inorganic, organic and mixed and that it cannot be traced to a specific landuse practice on a specific site.

The groundwater domains, as shown in Figure 5-8, were used to clip the 1995 landuse/landcover (Figure 5-11) to determine the landuse/landcover for each groundwater domain. The 1995 landuse/landcover coverage is the best available source of landuse data available at the time of this study. Level 2 FLUC landuse/landcover for each groundwater domain is presented in Table 5-3 to 5-11. The single largest landuse/landcover for all the groundwater domains is tree plantations, which confirms the rural nature of the SRWMD.

The percentage of each level 2 FLUC landuse/landcover was correlated to the median groundwater domain concentrations of TP and NO_3-N. The only level 2 FLUC landuse/landcover with a correlation was crop and pasture land to NO_3-N (Figure 5-12). No correlation was observed for TP for crop and pasture land landuse/landcover (Figure 5-13) or any other landuse/landcover, which suggests that either TP is not influenced by landuse/landcover at this time or the ortho-P component of TP is precipitated in the upper Floridan aquifer, so

concentration in the groundwater is a result of the chemical equilibrium. Figure 5-14 shows the median groundwater domain NO_3-N and the percentage of the domain in crop and pasture land. Based on the correlation of median NO_3-N concentrations and percent of the basin in level 2 FLUC crop and pasture land landuse/landcover there are elevated NO_3-N concentrations in the upper Floridan aquifer within the groundwater domain when the groundwater domain has greater than 12 percent of the groundwater domain in crop and pasture land landuse/landcover. The Santa Fe groundwater domain has the highest median NO_3-N concentration and the highest percentage of the domain in crop and pasture land landuse/landcover followed by the Suwannee and Ichetucknee (Figure 5-14). The landuse crop and pasture land in Santa Fe, Suwannee and Ichetucknee domains are occurring over the unconfined Floridan aquifer on primarily Entisols with high leaching potential. Sabasan (2004) identified NO_3-N concentrations in various landuse on Entisols, Ultisols, and Spodosols in the Santa Fe River Watershed. For landuse improved pasture, the NO_3-N concentrations for Entisols, Ultisols, and Spodosols were 0.51, 1.80 and 1.65 $\mu g\ N\ g^{-1}$of soil, respectively. The Entisols which are in landuse improved pasture have lower soil NO_3-N due to the leaching of the NO_3-N. Furthermore, where these Entisols are over the unconfined Floridan aquifer there is potential for leaching of NO_3-N into the upper Floridan aquifer. For the Santa Fe, Suwannee and Ichetucknee groundwater domain, the level 2 FLUC crop and pasture land landuse/landcover is composed of improved pasture, row crop and woodland pasture. The improved pasture makes up greater than 65 percent of the level 2 FLUC crop and pasture land landuse/landcover as shown in Figure 5-15. Also, hay fields are classified as improved pasture in the level 2 FLUC system which receives applications of N fertilizers.

Summary and Conclusions

There are nine distinct groundwater domains in the upper Floridan aquifer within the SRWMD based on groundwater levels (potentiometric surface) and groundwater quality. The Santa Fe, Ichetucknee and Suwannee groundwater domains have the highest median NO_3-N concentrations of the groundwater domains within the SRWMD. Variation in the concentrations of TP is most likely due to geological properties of the upper Floridan aquifer while the variation in the concentrations of NO_3-N is due to anthropogenic factors, such as, fertilizer use in the groundwater domain.

Median concentrations of TP and NO_3-N was related to various level 2 FLUC landuse/landcover classes in each groundwater domain. The only correlation was observed for crop and pasture land for groundwater domain NO_3-N concentration. Based on the observed relationship in the SRWMD, when the percentage of a groundwater domain is greater than 12 percent crop and pasture land, the groundwater domain will have elevated NO_3-N concentrations. The landuse crop and pasture land in Santa Fe, Suwannee and Ichetucknee domains are occurring over the unconfined Floridan aquifer on primarily Entisols with high leaching potential. The major component of the level 2 FLUC crop and pasture land class is improved pasture. Furthermore, improved pasture can also be fields for the production of hay that can receive N fertilizer to maximize hay crop yields and protein content. Thus, this study identified for the SRWMD a direct relationship tool for determining when a groundwater domain may be impacted by NO_3-N concentrations in the upper Floridan aquifer by landuse crop and pasture lands.

Table 5-1. Principal component analysis showing significant components.

Variable	Units	Principal Component 1	Principal Component 2
Sodium	mg L^{-1}	0.463	-0.099
Chloride	mg L^{-1}	0.461	-0.099
Potassium	mg L^{-1}	0.456	-0.065
Sulfate	mg L^{-1}	0.421	0.061
Magnesium	mg L^{-1}	0.419	0.043
Calcium	mg L^{-1}	0.112	0.654
Nitrate-nitrogen	mg L^{-1}	0.006	0.737
Eigenvalue		4.418	1.030
Accounted percent of variability		63.1	14.7

Table 5-2. Statistical summary for NO_3-N and TP by groundwater domain.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
NO_3-N	mg L^{-1}	Alapaha	0.18	0.56	0.00	0.01	0.09	0.00	3.94
		Aucilla	0.62	1.12	0.01	0.03	0.62	0.00	4.16
		Coastal	0.09	0.17	0.00	0.02	0.11	0.00	1.05
		Dixie	0.02	0.02	0.00	0.02	0.03	0.00	0.07
		Ichetucknee	0.62	1.74	0.01	0.25	0.73	0.00	27.20
		Santa Fe	1.41	1.73	0.02	1.21	1.62	0.00	10.60
		Steinhatchee	0.03	0.09	0.00	0.01	0.03	0.00	0.73
		Suwannee	1.32	3.56	0.00	0.31	1.31	0.00	52.0
		Waccasassa	0.01	0.02	0.00	0.01	0.01	0.00	0.09
TP	mg L^{-1}	Alapaha	0.087	0.087	0.040	0.070	0.109	0.000	0.598
		Aucilla	0.325	0.545	0.050	0.133	0.480	0.000	4.870
		Coastal	0.258	0.228	0.081	0.151	0.522	0.000	0.814
		Dixie	0.028	0.019	0.010	0.030	0.042	0.000	0.056
		Ichetucknee	0.144	0.359	0.035	0.053	0.100	0.000	3.640
		Santa Fe	0.102	0.204	0.040	0.055	0.105	0.000	2.240
		Steinhatchee	1.005	3.936	0.040	0.068	0.461	0.000	25.000
		Suwannee	0.248	1.781	0.044	0.070	0.145	0.000	45.000
		Waccasassa	0.195	0.037	0.189	0.196	0.209	0.078	0.303

Table 5-3. 1995 level 2 Florida Landuse Code for the Alapaha groundwater domain.

Land Cover	Hectares
Tree Plantations	160,459
Wetland Forested	30,762
Crop and Pasture Land	26,808
Wetland Coniferous	17,515
Wetland Hardwood	8,353
Upland Hardwood	5,145
Extractive	3,167
Streams and Waterways	929
Freshwater or Salt Marshes	625
Upland Coniferous	332
Industrial	314
Residential, Medium Density	310
Residential, Low Density	272
Utilities	232
Commercial and Services	229
Transportation	96
Recreational	57
Animal Feeding Operation	40
Specialty Farms	20
Nurseries and Vineyards	8.3
Residential, High density	8.0
Disturbed land	7.8
Major Springs	1.2

Table 5-4. 1995 level 2 Florida Landuse Code for the Aucilla groundwater domain.

Land Cover	Hectares
Tree Plantations	105,890
Wetland Forested	105,017
Embayments opening directly into the Gulf of Mexico	40,470
Crop and Pasture Land	31,021
Wetland Coniferous	13,049
Wetland Hardwood	7,478
Freshwater or Salt Marshes	4,266
Upland Hardwood	4,097
Upland Coniferous	663
Utilities	533
Residential, Low Density	414
Extractive	393
Residential, Medium Density	326
Nurseries and Vineyards	244
Streams and Waterways	198
Commercial and Services	184
Transportation	173
Recreational	107
Industrial	93.0
Specialty Farms	37.1
Disturbed land	20.5
Animal Feeding Operation	17.9
Open Land	15.0
Residential, High density	9.78
Non-Vegetated Wetland	6.49
Major Springs	4.64
Oyster Bars	0.91

Table 5-5. 1995 level 2 Florida Landuse Code for the Coastal groundwater domain.

Land Cover	Hectares
Embayments opening directly into the Gulf of Mexico	145,729
Tree Plantations	117,688
Freshwater or Salt Marshes	10,068
Wetland Forested	9,375
Wetland Coniferous	9,072
Crop and Pasture Land	4,216
Wetland Hardwood	3,386
Upland Hardwood	1,164
Residential, Low Density	808
Utilities	755
Upland Coniferous	586
Residential, Medium Density	484
Industrial	380
Commercial and Services	231
Non-Vegetated Wetland	176
Extractive	79.1
Streams and Waterways	68.2
Recreational	50.8
Coastal Scrub	48.9
Open Land	29.6
Animal Feeding Operations	27.5
Embayments not opening directly into the Gulf of Mexico	20.4
Residential, High Density	14.6
Major Springs	1.51
Disturbed Land	0.95

Table 5-6. 1995 level 2 Florida Landuse Code for the Dixie groundwater domain.

Land Cover	Hectares
Embayments opening directly into the Gulf of Mexico	105,241
Tree Plantations	22,006
Freshwater or Salt Marshes	6,613
Wetland Forested	5,076
Wetland Coniferous	1,135
Residential, Low Density	341
Crop and Pasture Land	230
Non-Vegetated Wetland	206
Residential, Medium Density	196
Upland Hardwood	108
Commercial and Services	66.9
Wetland Hardwood	50.8
Embayments not opening directly into the Gulf of Mexico	41.5
Recreational	12.2
Upland Coniferous	10.3
Coastal Scrub	7.22
Open Land	3.16
Residential, High Density	1.97
Disturbed land	1.37
Utilities	1.17

Table 5-7. 1995 level 2 Florida Landuse Code for the Ichetucknee groundwater domain.

Land Cover	Hectares
Tree Plantations	276,578
Crop and Pasture Land	66,861
Wetland Forested	40,965
Upland Hardwood	19,916.
Wetland Coniferous	13,968
Upland Coniferous	10,089
Wetland Hardwood	3,726
Residential, Low Density	3,292
Residential, Medium Density	1,754
Utilities	1,040
Commercial and Services	716
Extractive	390
Recreational	339
Freshwater or Salt Marshes	319
Nurseries and Vineyards	250
Industrial	247
Streams and Waterway	224
Disturbed land	214
Transportation	199
Animal Feeding Operations	173
Open Land	142
Residential, High Density	113
Specialty Farms	69.7
Tree Crops	30.3
Palmetto Prairies	19.3
Major Springs	1.47

Table 5-8. 1995 level 2 Florida Landuse Code for the Santa Fe groundwater domain.

Land Cover	Hectares
Tree Plantations	86,217
Crop and Pasture Land	68,046
Upland Hardwood	28,252
Wetland Forested	18,924
Residential, Medium Density	6,726
Residential, Low Density	6,465
Wetland Coniferous	5,033
Upland Coniferous	2,460
Freshwater or Salt Marshes	2,221
Wetland Hardwood	1,755
Commercial and Services	1,495
Utilities	1,353
Residential, High Density	1,142
Recreational	902
Extractive	718
Industrial	509
Transportation	499
Specialty Farms	449
Nurseries and Vineyards	307
Open Land	263
Streams and Waterway	176
Disturbed Land	60.8
Animal Feeding Operations	60.0
Tree Crops	12.8
Major Springs	1.81

Table 5-9. 1995 level 2 Florida Landuse Code for the Steinhatchee groundwater domain.

Land Cover	Hectares
Tree Plantations	166,446
Embayments opening directly into the Gulf of Mexico	105,222
Wetland Forested	62,042
Wetland Coniferous	11,709
Freshwater or Salt Marshes	4,706
Wetland Hardwood	2,440
Upland Hardwood	797
Crop and Pasture Land	443
Residential, Low Density	407
Non-Vegetated Wetland	318
Residential, Medium Density	184
Upland Coniferous	99.1
Streams and Waterways	97.6
Commercial and Services	20.7
Embayments not opening directly into the Gulf of Mexico	18.9
Recreational	16.5
Industrial	9.68
Disturbed land	5.95
Open Land	3.90
Coastal Scrub	2.45
Utilities	1.56
Extractive	1.52
Major Springs	0.34

Table 5-10 1995 level 2 Florida Landuse Code for the Suwannee groundwater domain.

Land Cover	Hectares
Tree Plantations	283,108
Crop and Pasture Land	145,374
Upland Hardwood	90,396
Wetland Forested	86,362
Residential, Low Density	31,182
Wetland Coniferous	26,164
Wetland Hardwood	15,387
Open Land	9,153
Shrub and Brush Land	7,468
Upland Coniferous	4,340
Lakes	4,020
Other Open Lands	3,340
Streams and Waterway	3,299
Residential, Medium Density	1,698
Non-Vegetated Wetlands	1,082
ODC - Institutional (Education, religious, health, military)	1,080
Commercial and Services	1,035
Extractive	965
Reservoirs	934
Tree Crops	929
Specialty Farms	737
Nurseries and Vineyards	687
Animal Feeding Operations	668
Industrial	360
Residential, High Density	106
Disturbed Lands	81.4
Major Springs	12.9
Bays and Estuaries	8.07

Table 5-11. 1995 level 2 Florida Landuse Code for the Waccasassa groundwater domain.

Land Cover	Hectares
Embayments opening directly into the Gulf of Mexico	105,233
Tree Plantations	57,782
Wetland Forested	12,706
Crop and Pasture Land	10,060
Upland Hardwood	7,647
Freshwater or Salt Marshes	7,443
Upland Coniferous	3,013
Wetland Hardwood	2,305
Wetland Coniferous	1,759
Extractive	473
Nurseries and Vineyards	242
Residential, Low Density	207
Utilities	46.3
Commercial and Services	34.9
Recreational	23.9
Specialty Farms	22.9
Streams and Waterway	12.9
Open Land	8.25
Embayments not opening directly into the Gulf of Mexico	7.87
Coastal Scrub	7.64
Palmetto Prairies	5.31
Residential, Medium Density	2.81
Residential, High Density	1.45
Disturbed Land	0.70

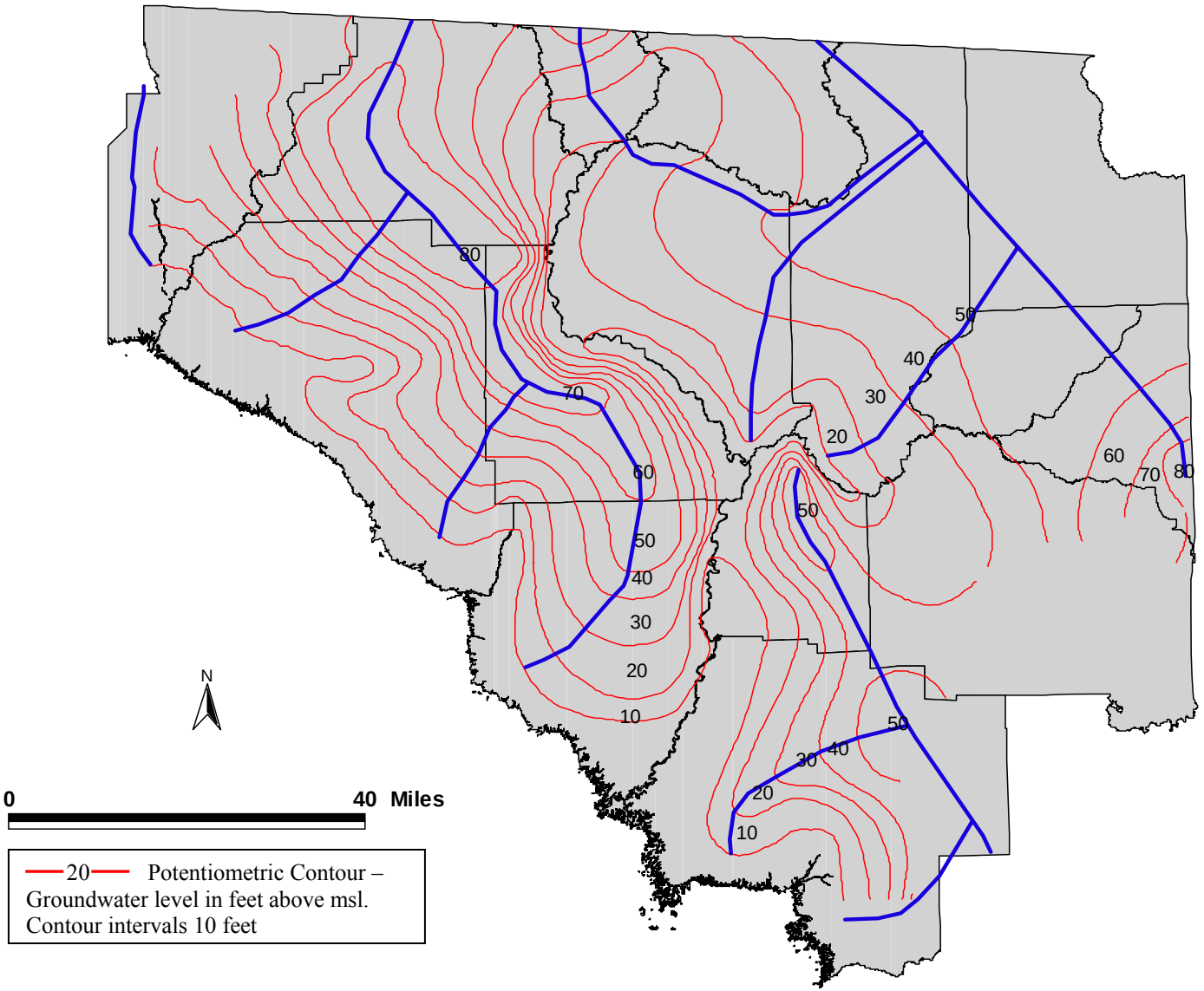

Figure 5-1. Groundwater domians based on 1985 potentiometric surface (Rosenau and Meadows, 1986).

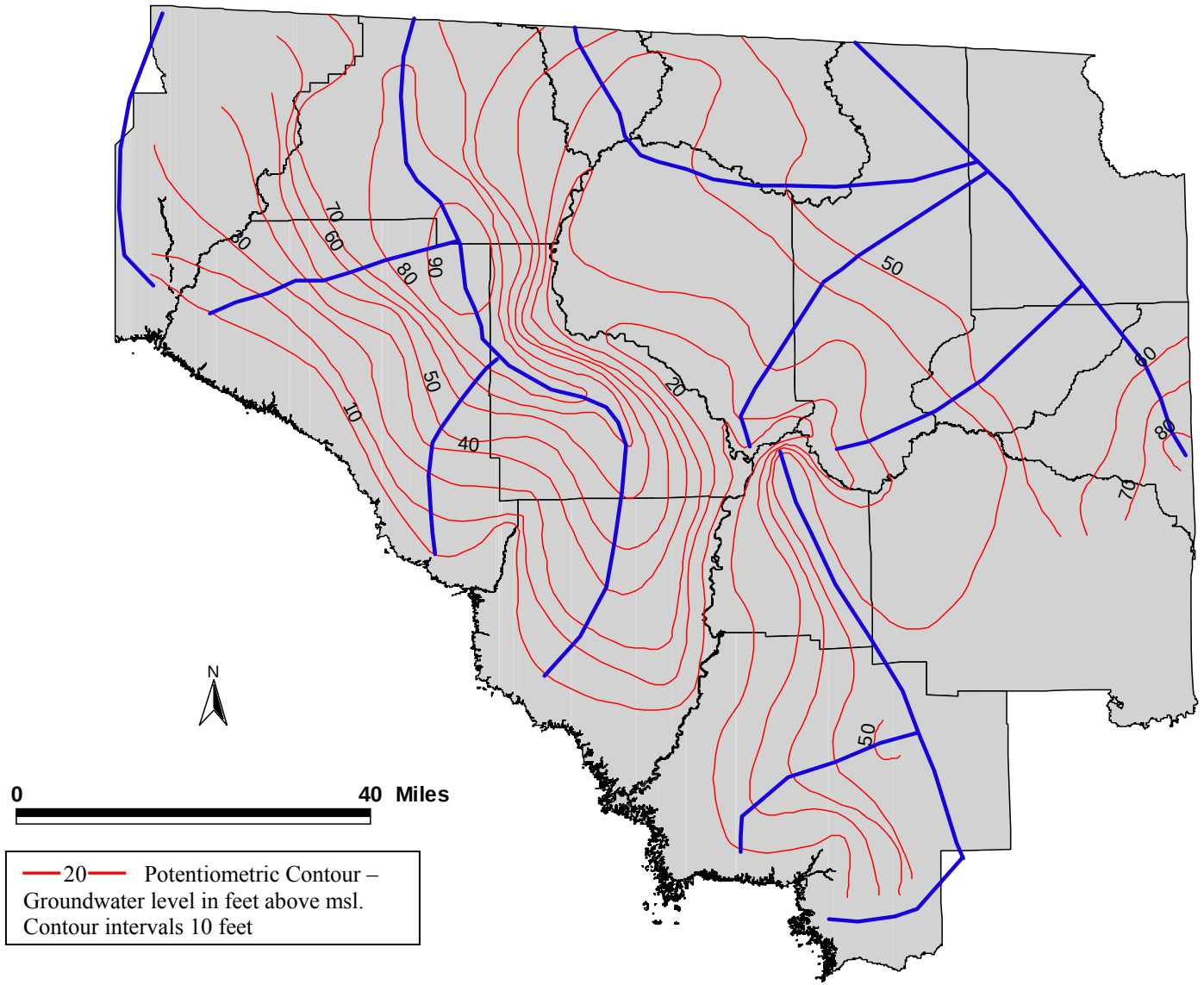

Figure 5-2. Groundwater domains based on 1990 potentiometric surface (Meadows, 1991).

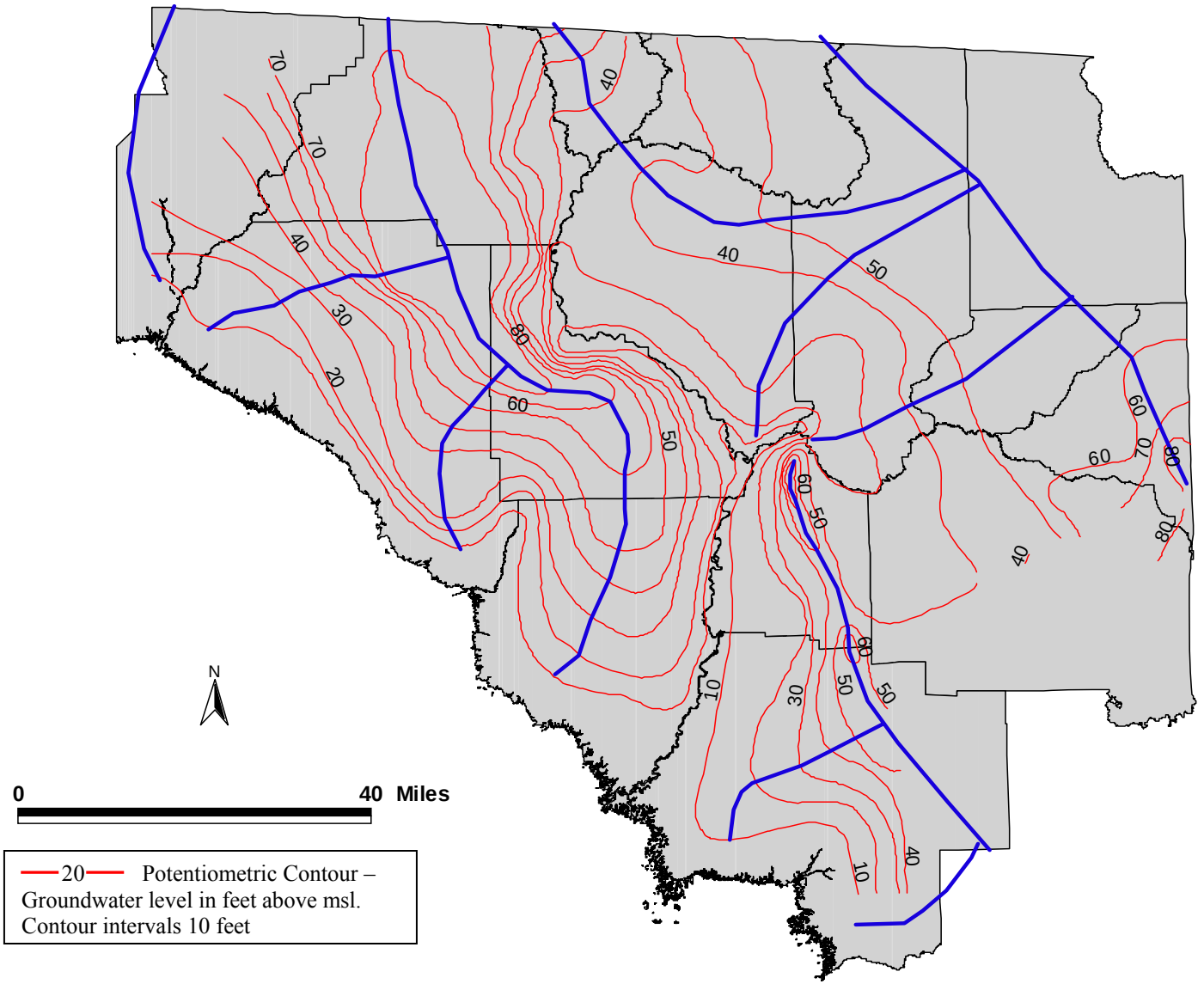

Figure 5-3. Groundwater domains based on 1995 potentiometric surface (Mahon et al., 1997).

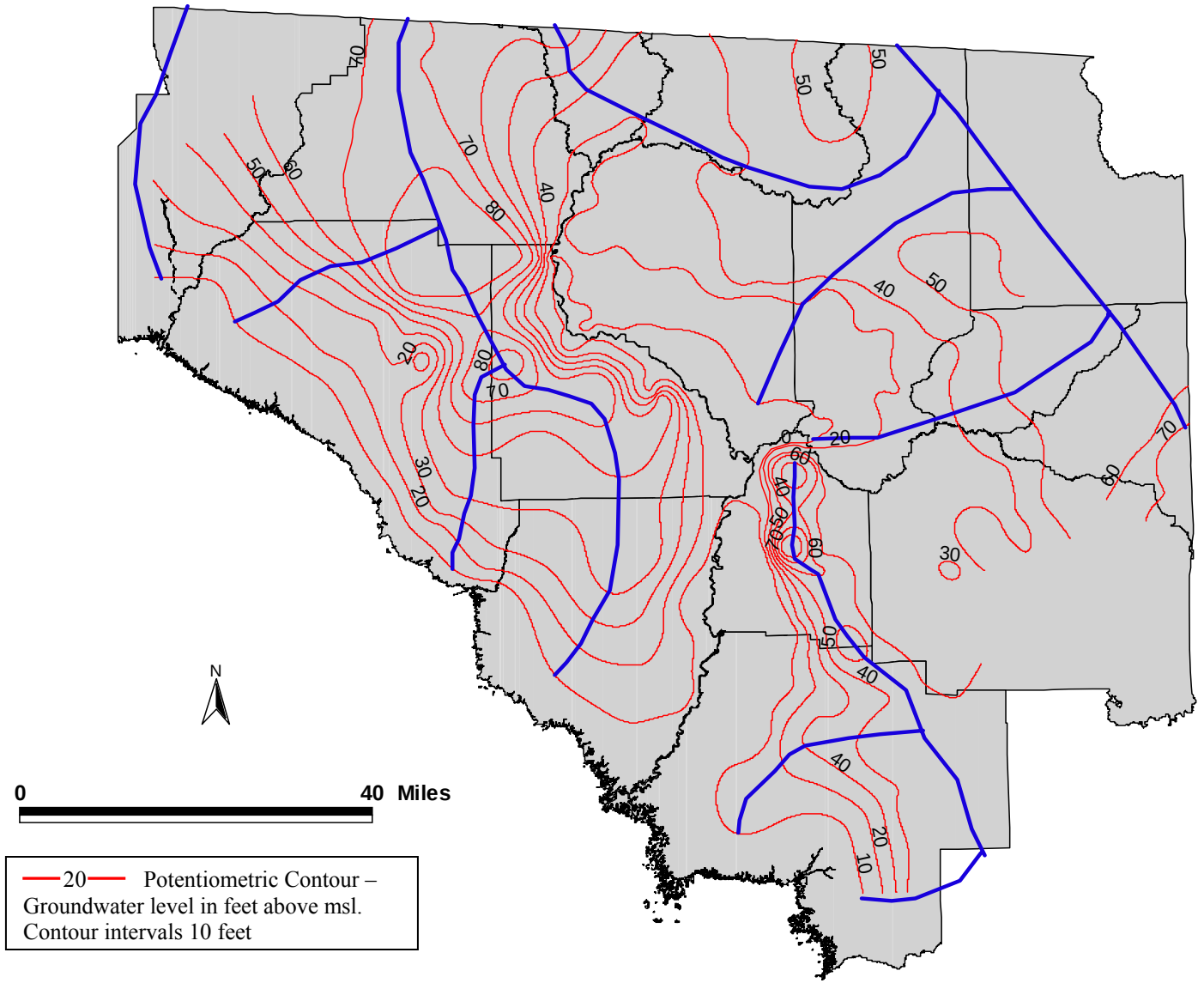

Figure 5-4. Groundwater domains based on 2002 potentiometric surface (SRWMD, 2002).

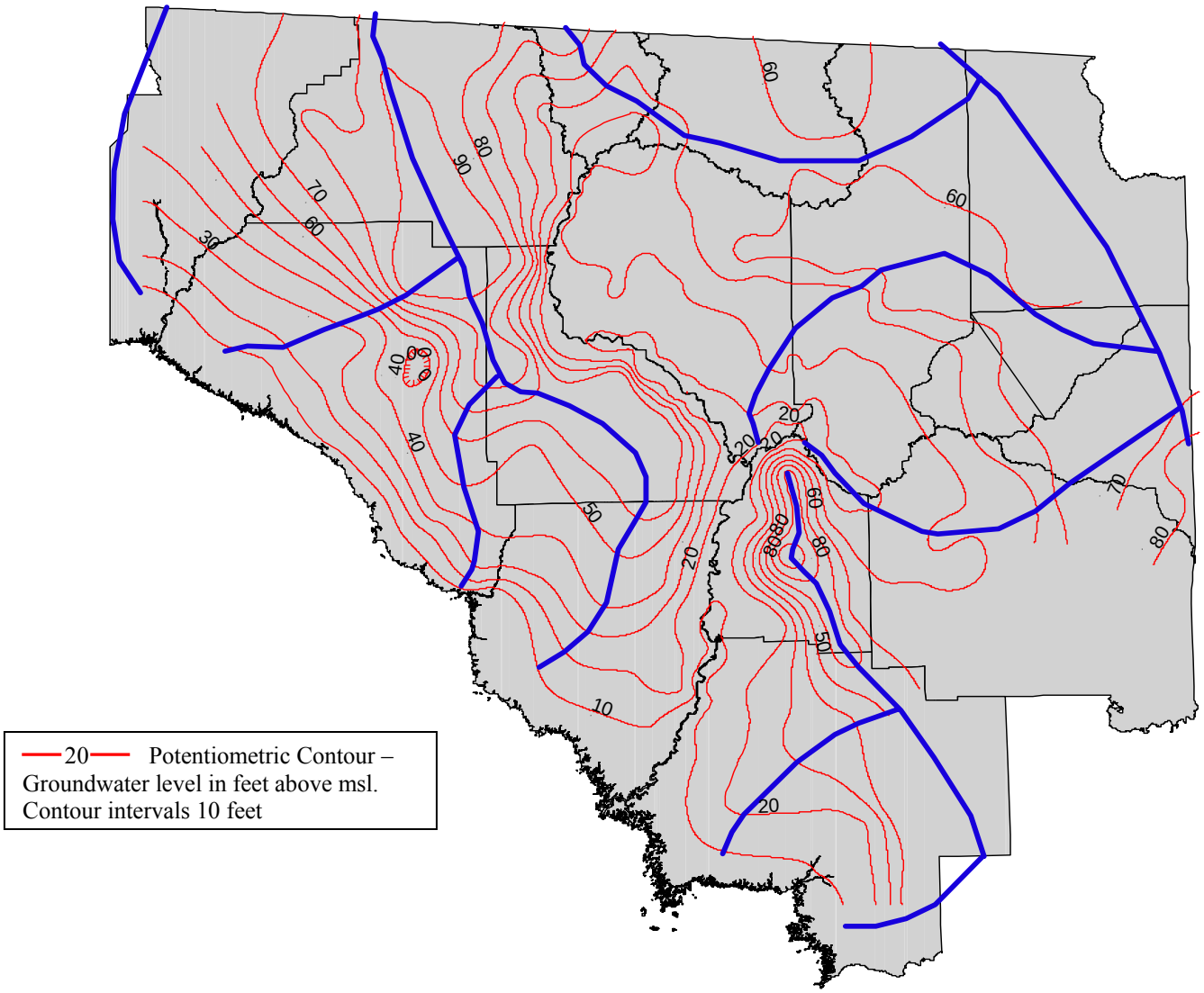

Figure 5-5. Groundwater domains based on 2005 potentiometric surface (SRWMD, 2005).

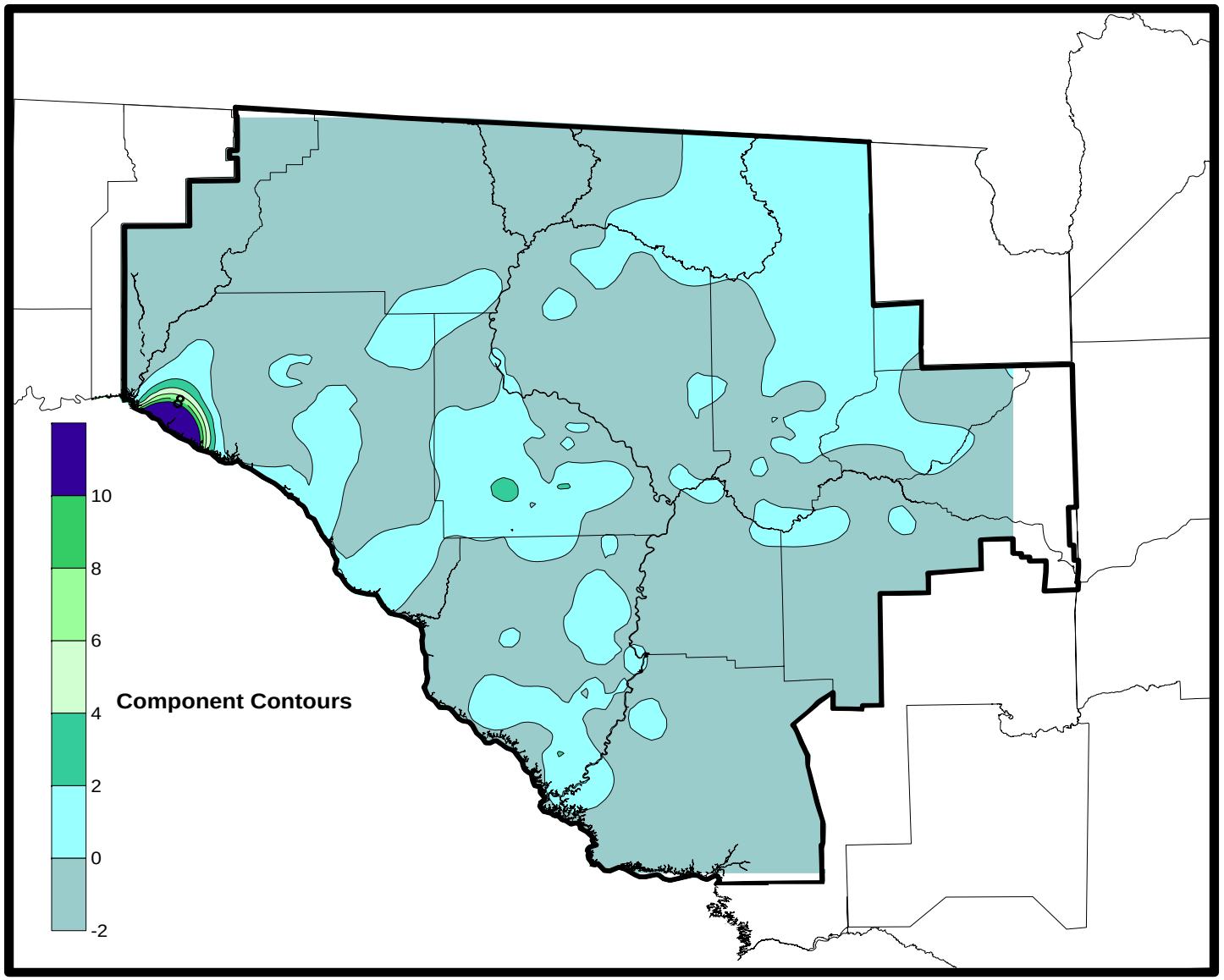

Figure 5-6. Principal component 1 contours for hydrochemical facies analysis.

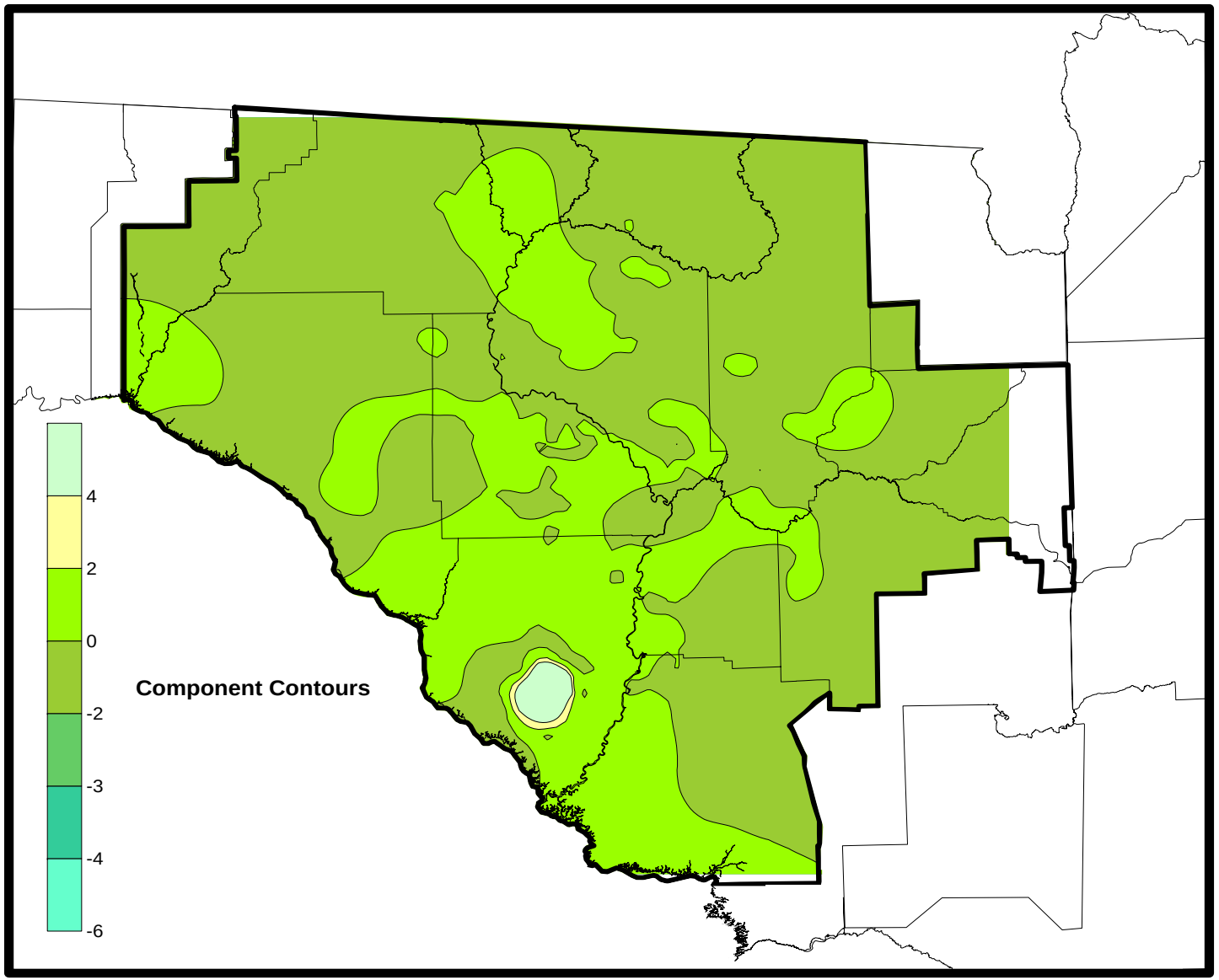

Figure 5-7. Principal component 2 contours for hydrochemical facies analysis.

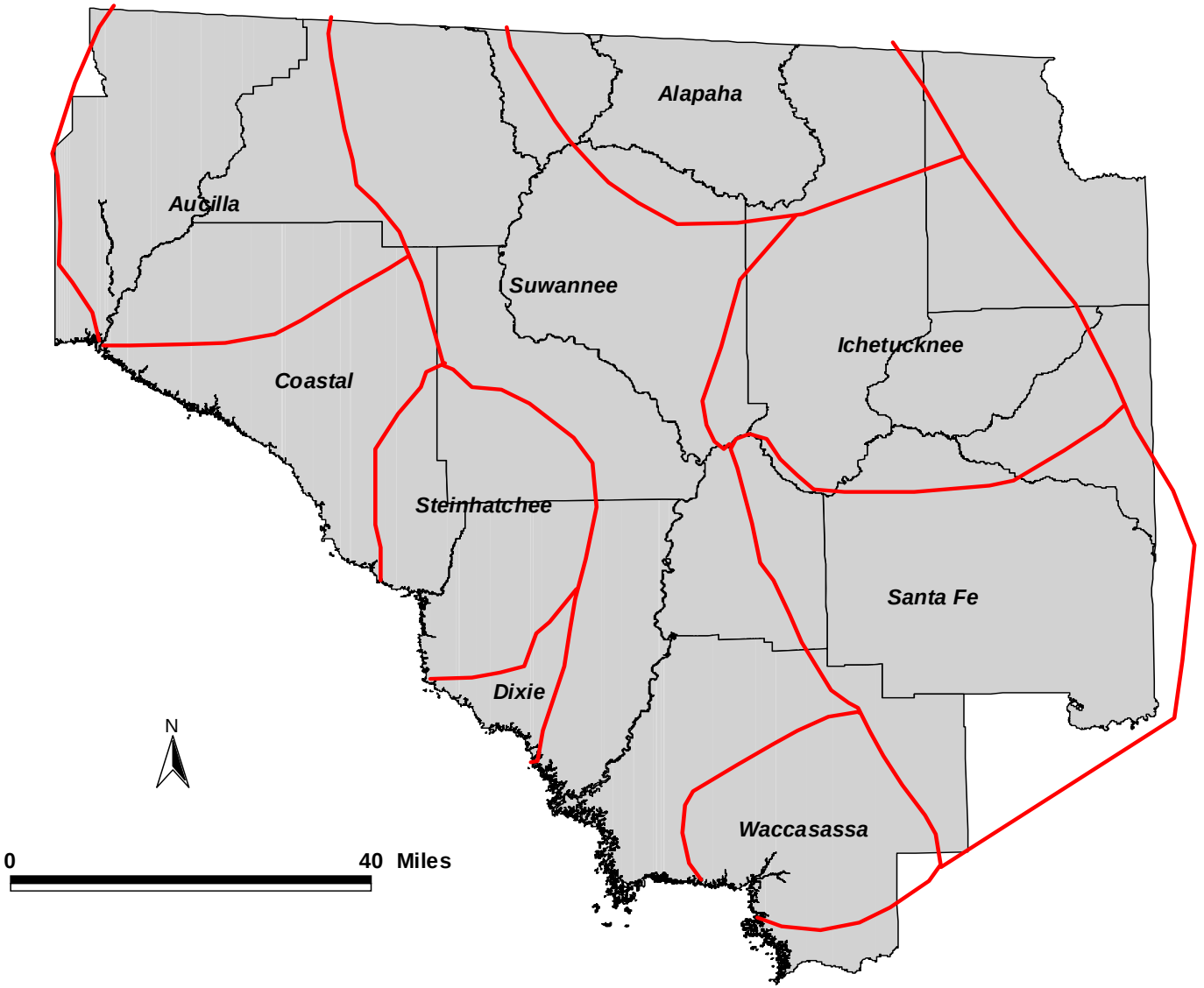

Figure 5-8. Refined groundwater domains based on composite potentiometric surfaces basins and hydrochemical facies analysis.

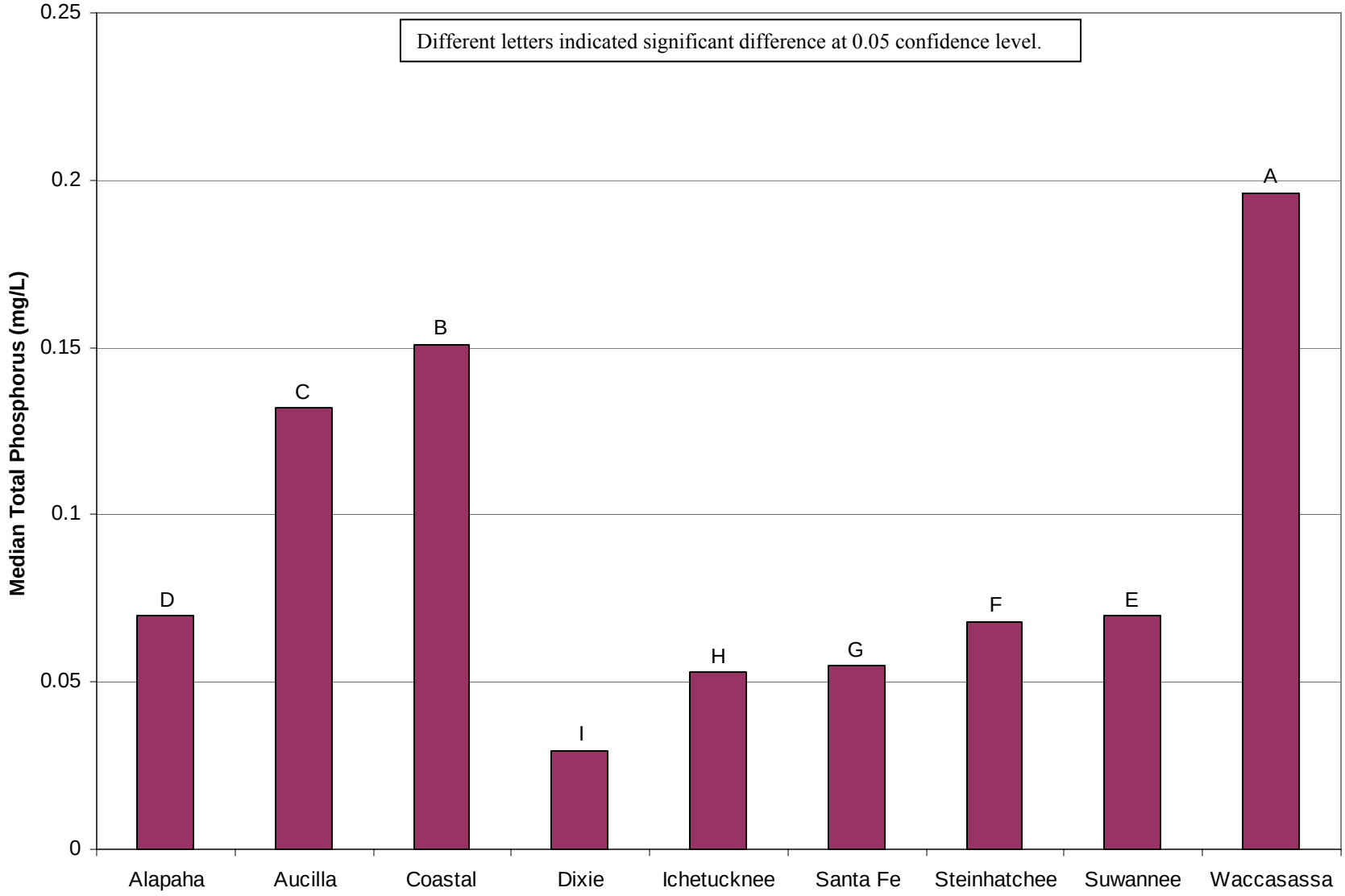

Figure 5-9. Median groundwater TP concentration by groundwater domains. (

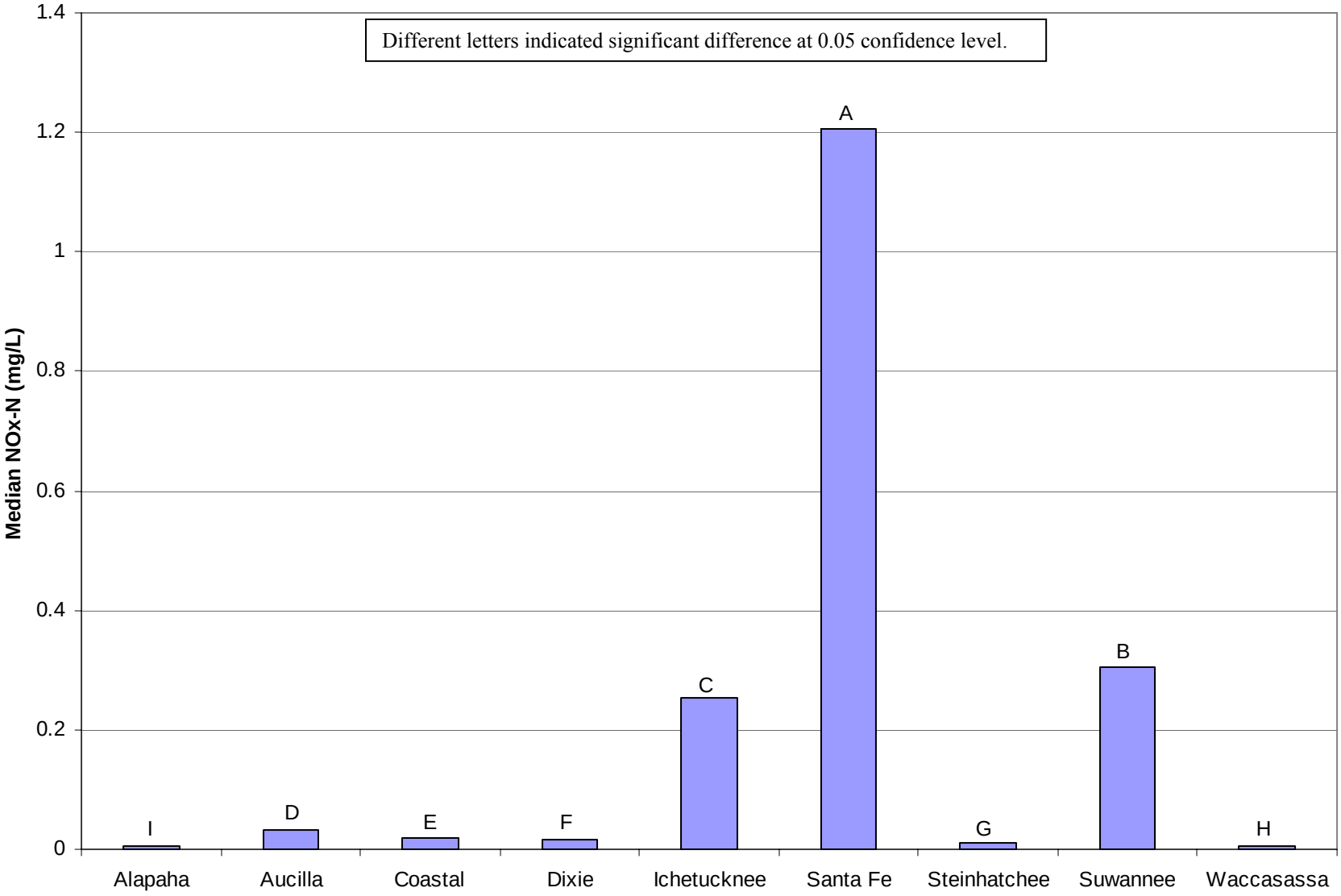

Figure 5-10. Median groundwater NO_3-N concentration by groundwater domains.

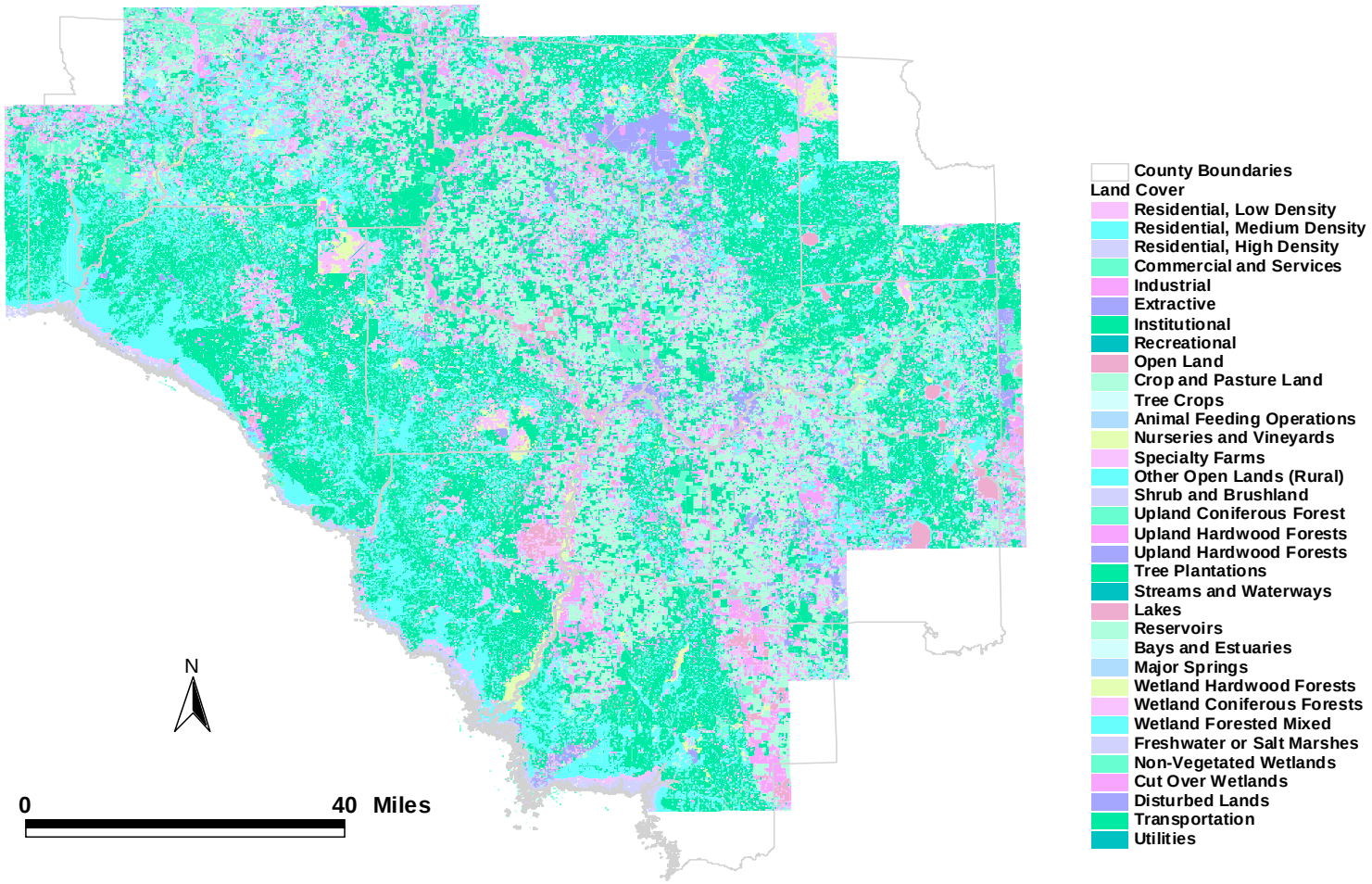

Figure 5-11. 1995 level 2 Florida Landuse Code landuse/landcover for the Suwannee River Water Management District.

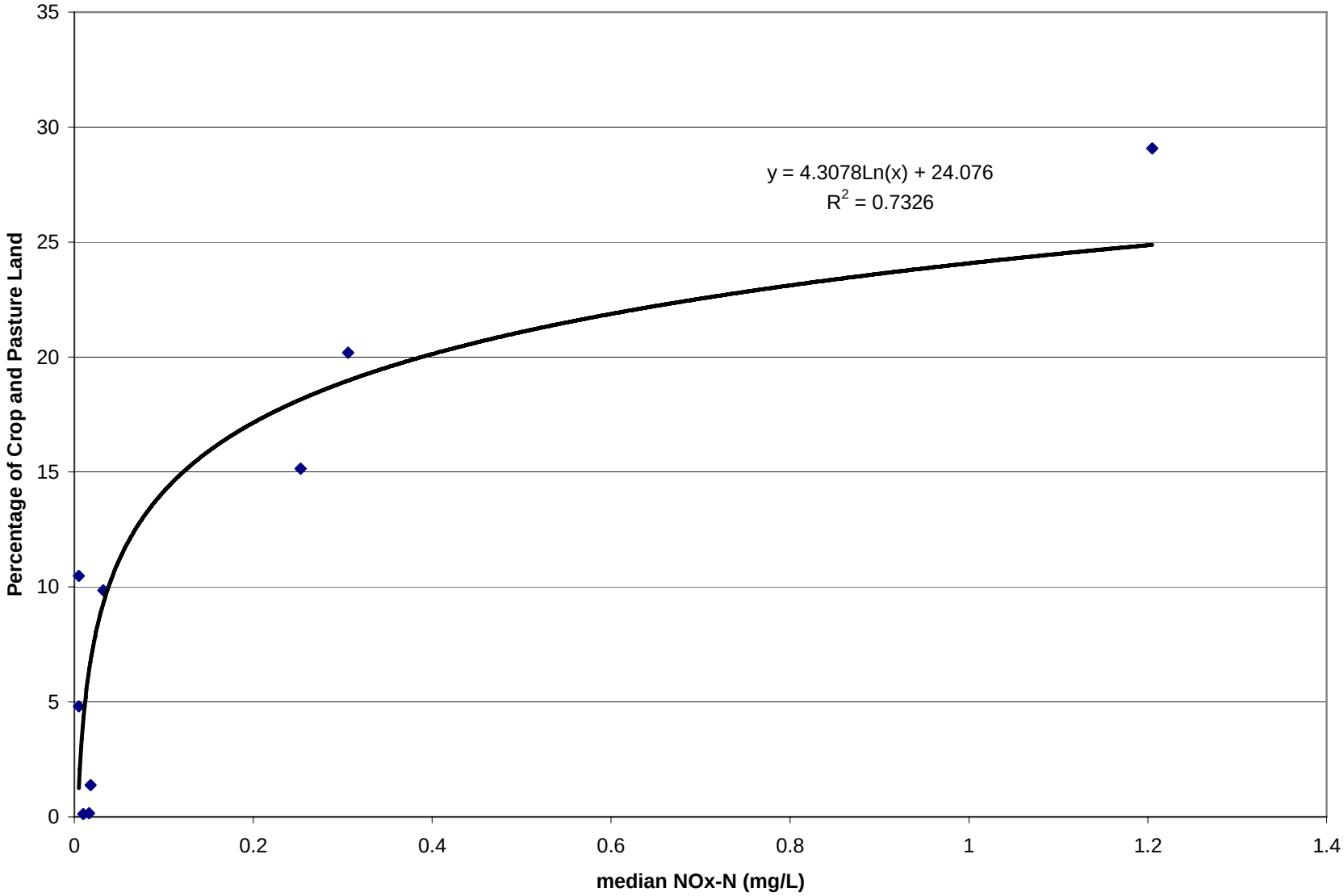

Figure 5-12. Median groundwater NO_3-N concentration versus percentage of groundwater domains in crop and pasture lands.

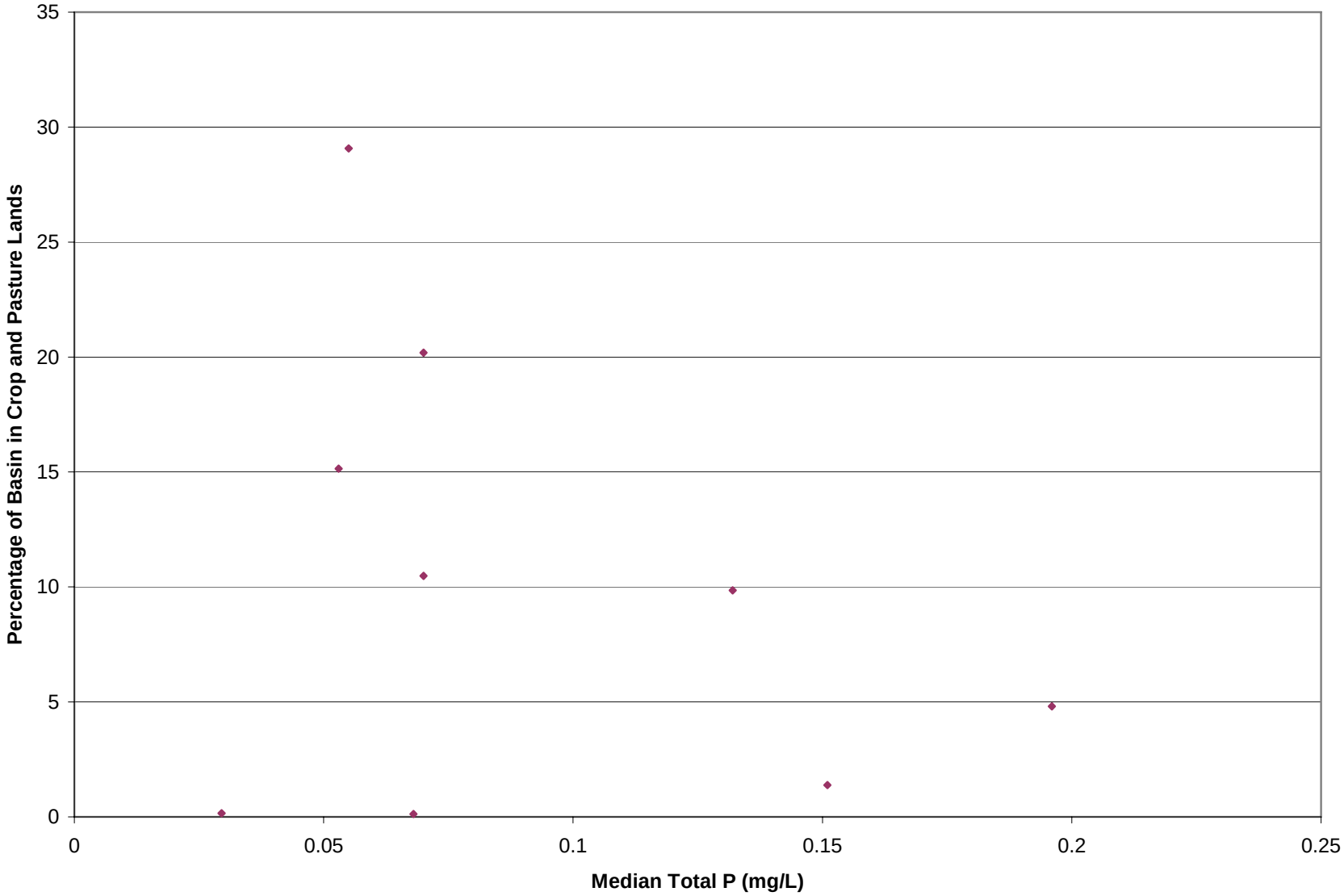

Figure 5-13. Median groundwater TP concentration versus percentage of groundwater domains in crop and pasture lands.

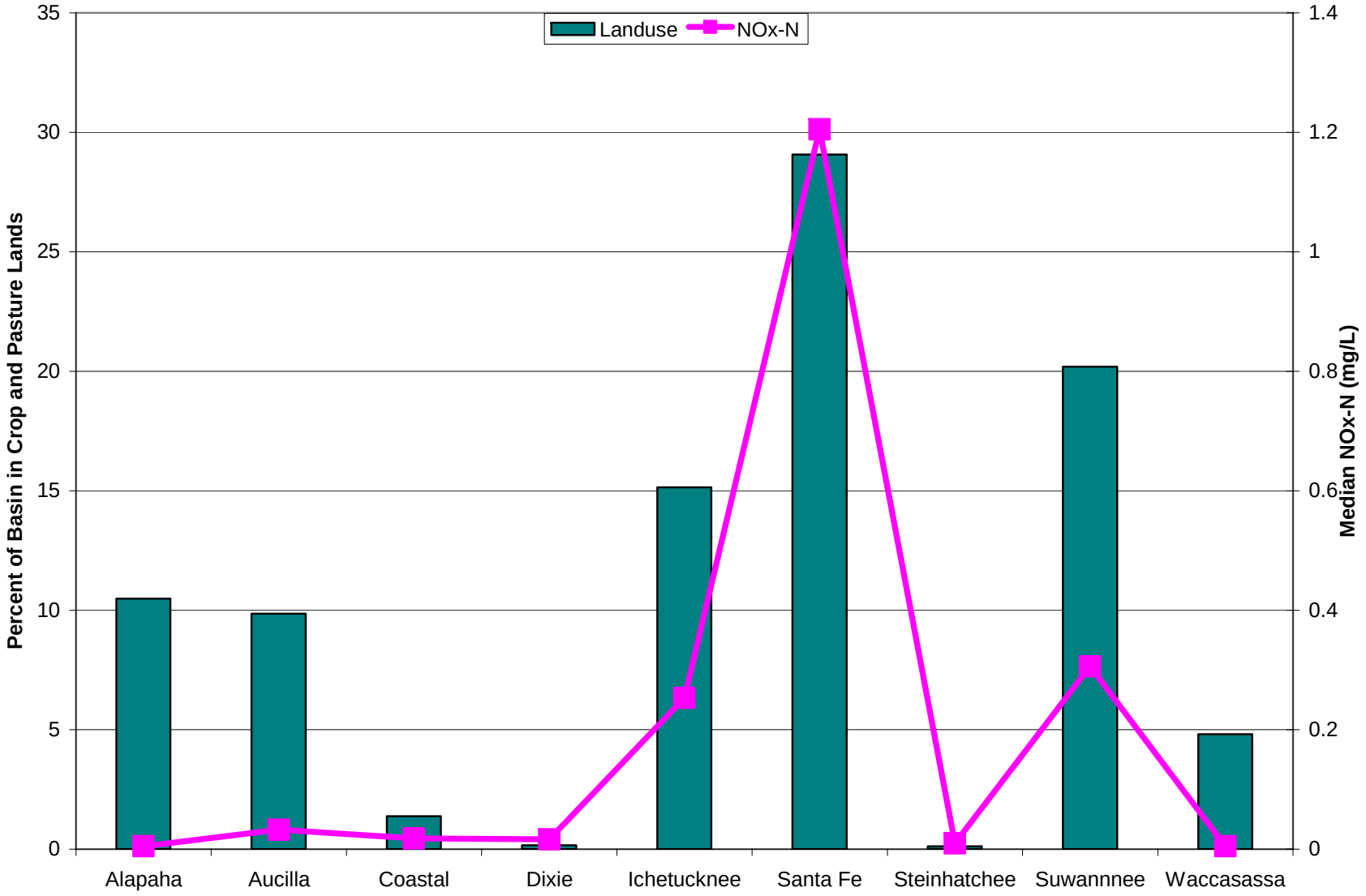

Figure 5-14. Median groundwater NO_3-N concentration and percentage of groundwater domains in crop and pasture lands.

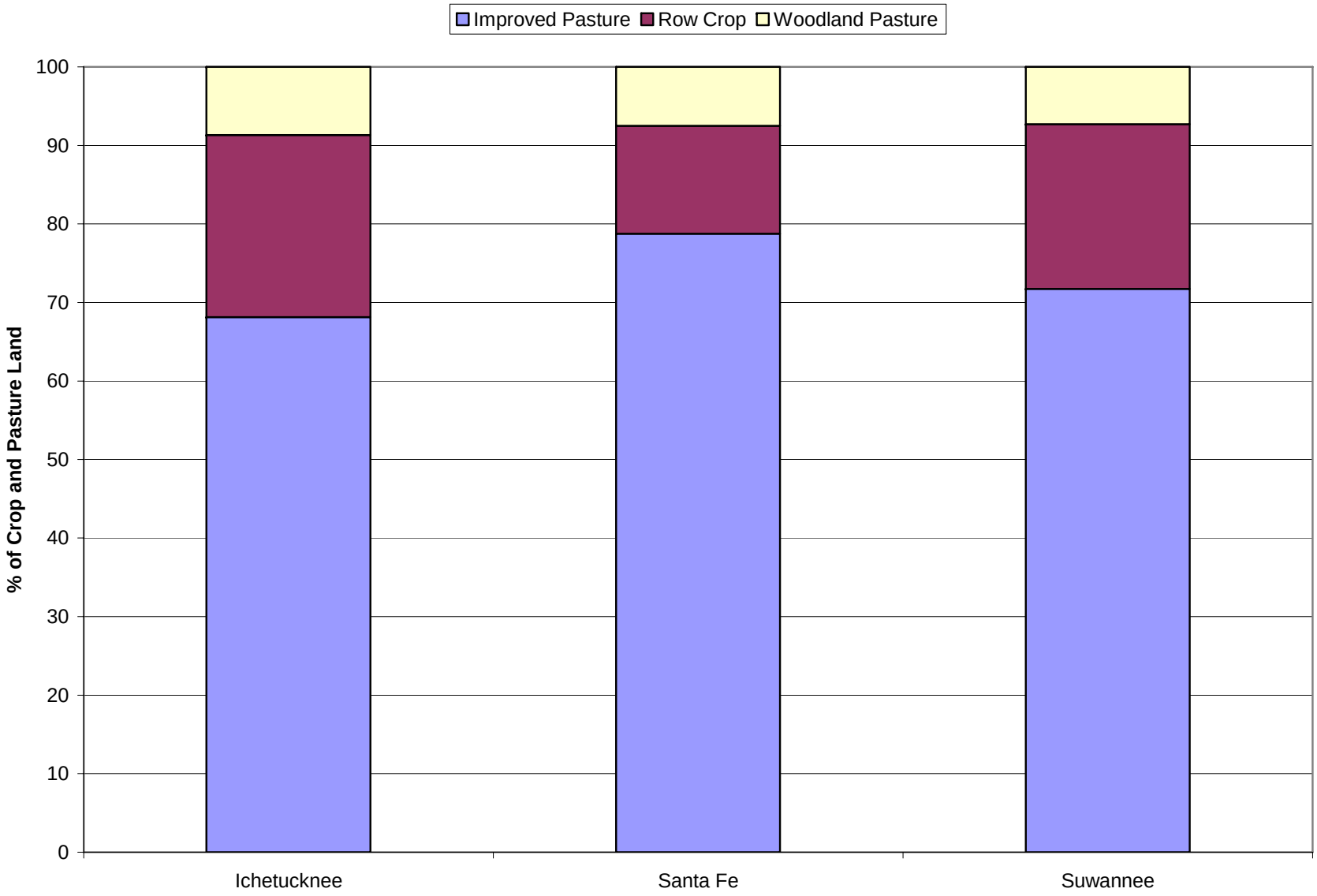

Figure 5-15. Landuses within crop and pasture lands code for the groundwater domains with elevated median NO_3-N.

CHAPTER 6
SYNTHESIS

The station on the Suwannee River at Branford is a sentinel or integrator station for the Suwannee River. This station has been monitored for water quality since 1954. Total phosphorus (TP) concentration has significantly (>99.9% confidence level) declined since the river was designated an Outstanding Florida Water (OFW) in 1979. The decrease in the TP concentrations that started in 1985 coincides with increased regulation of a phosphate mining operation in Hamilton and Columbia counties. Nitrate-nitrogen (NO_3-N) concentrations have significantly increased since its designation as an OFW in 1979. Also, there was an observed increasing trend for potassium (K). The increases in NO_3-N and K concentrations suggest a fertilizer signature. There was an observed time lag between N fertilizer sales data for Suwannee and Lafayette counties and riverine NO_3-N concentrations of one to six years. This increasing trend is supported by the increased use of inorganic fertilizer in Suwannee and Lafayette counties. This suggests that the NO_3-N concentration observed at the Branford station was likely related to fertilizer use in the groundwater domains that feed ground water to the Suwannee River via the numerous springs and seeps in the Middle Suwannee River Basin (MSRB). The MSRB was consistently the highest contributor of the annual NO_3-N load from water years 1998 to 2005 and reach 1 of the Suwannee River was consistently the highest contributor of the annual TP load from water years 1998 to 2004 excluding 2005 when it was the third largest contributor. The range of the annual NO_3-N loading for the MSRB was 29.3 to 46.9 percent of the annual NO_3-N load for the entire Suwannee River Basin (SRB) from 1998 to 2005. The range of the annual TP loading for reach 1 of the Suwannee River was 14.6 to 100 percent of the annual TP load for the entire SRB from 1998 to 2005. This suggests that anthropogenic factors are driving the changes in water quality from pre-OFW to post-OFW conditions for TP and NO_3-N.

The current mean upper Floridan aquifer concentrations for TP and NO_3-N were three times above background (or <0.10 mg P L^{-1}) and 23 times above background (or <0.10 mg N L^{-1}) concentrations, respectively, as defined by Maddox et al. (1992). Surfacewater NO_3-N concentrations reflected the adjacent Floridan aquifer's groundwater concentrations for NO_3-N. Surfacewater basin concentrations of TP were driven by geological formations, point sources, and surface runoff. Thus, ground water from the upper Floridan aquifer plays a major role on the quality of surface water in regions where the Suwannee and Santa Fe rivers intersects the top of the upper Floridan aquifer.

The regions of the MSRB and Lower Santa Fe River Basin (LSFRB) where the greatest increase in NO_3-N concentrations occur are relatively small segments of river channel within each river system. The NO_3-N was likely moving into the surfacewater system via ground water through springs and seeps in the riverbed. The soils adjacent to these segments were Entisols that have high leaching potential. Furthermore, the upper Floridan aquifer is unconfined in these regions. The coupling of the upper Floridan aquifer being unconfined and overlain by soil with high leaching potential with landuses that are adding NO_3-N via fertilizer creates the potential for contamination of the upper Floridan aquifer. This resulted in increased NO_3-N concentrations in reaches of the Suwannee and Santa Fe river which receive base flow from the upper Floridan aquifer. Two springs sampled in the segment of the MSRB where the highest increase in NO_3-N loading occurred showed a linear relationship with K and NO_3-N. Results from a USGS study showed that the NO_3-N was from an inorganic source and the age of the water was less than nine years (Katz et al., 1999). This is similar to the observed relationship of N fertilizer sales data and riverine NO_3-N concentration and the apparent lag time of one to six years. Furthermore, for the Suwannee River this suggests that fertilizer is the major component of the observed increasing

NO_3-N trend in the Suwannee River at Branford. The Middle Suwannee and Lower Santa Fe rivers showed increased NO_3-N concentrations from 2000-2001 to 2006 sampling events. This suggests that the NO_3-N loading from the ground water to the surface water was increasing for the studied areas of the MSRB and LSFRB. Thus, understanding the aerial extent of the groundwater domains of the upper Floridan aquifer that supplies the water to the MSRB and the LSFRB and landuses that occur within the domains is needed to focus management activities.

Groundwater domains were defined in the Suwannee River Water Management District (SRWMD) using potentiometric surface maps and water quality data of the upper Floridan aquifer. Nine distinct groundwater domains were indentified in the upper Floridan aquifer within the SRWMD. The Santa Fe, Ichetucknee and Suwannee domains had the highest median NO_3-N concentrations of the groundwater domains within the SRWMD. These domains generally occurred in areas where the unconfined Floridan aquifer underlies Entisols with high leaching potential. Variation in the concentrations of NO_3-N was due to anthropogenic factors, primarily the use of inorganic fertilizer.

Relating landuse in a groundwater domain to observed upper Floridan NO_3-N and TP concentrations yielded a correlation for level 2 Florida landuse codes (FLUC) for crop and pasture land and groundwater domain median NO_3-N concentration. No other correlations with TP and NO_3-N concentrations and other level 2 FLUC were identified. When the percentage of a groundwater domain area was greater than 12 percent crop and pasture land, the domain generally had elevated NO_3-N concentrations. The major component of the level 2 FLUC crop and pasture land class is improved pasture which also includes areas used for forage production.

It is important that the regulating agencies continue to work with the point source discharges associated with phosphate mining in the upper Suwannee River Basin to maintain the

declining trend in TP concentrations. Reducing NO_3-N concentration in the Suwannee River will require continued implementation of best management practices (BMPs) by the agricultural producers. The Floridan aquifer is especially vulnerable in areas where the aquifer is unconfined and soils have high leaching potential. Development/implementation of BMPs on these areas should be given priority.

APPENDIX A
HISTORICAL TOTAL PHOSPHORUS AND NITRATE-NITROGEN

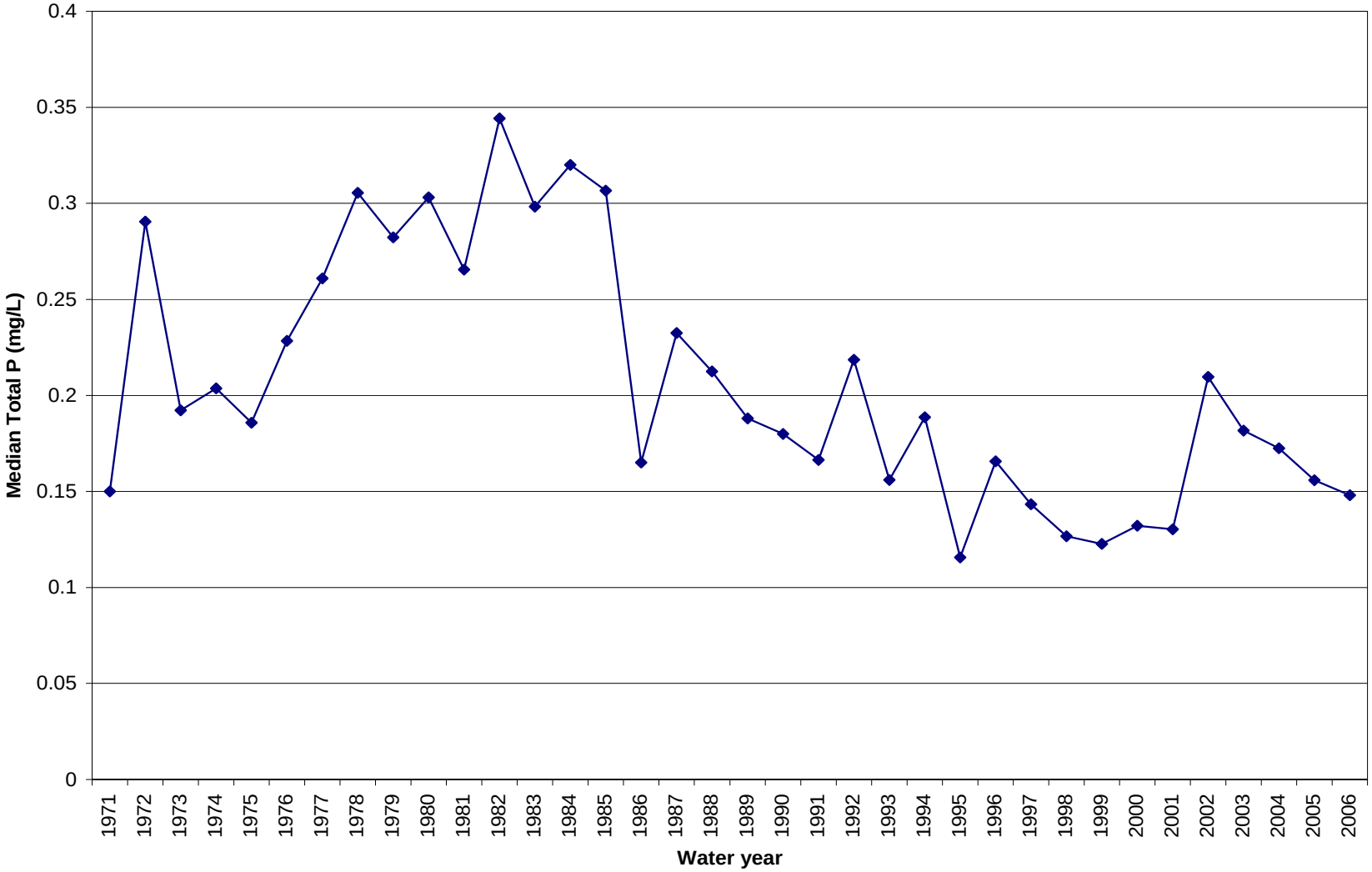

Figure A-1. Median TP concentration for the Suwannee River at Branford.

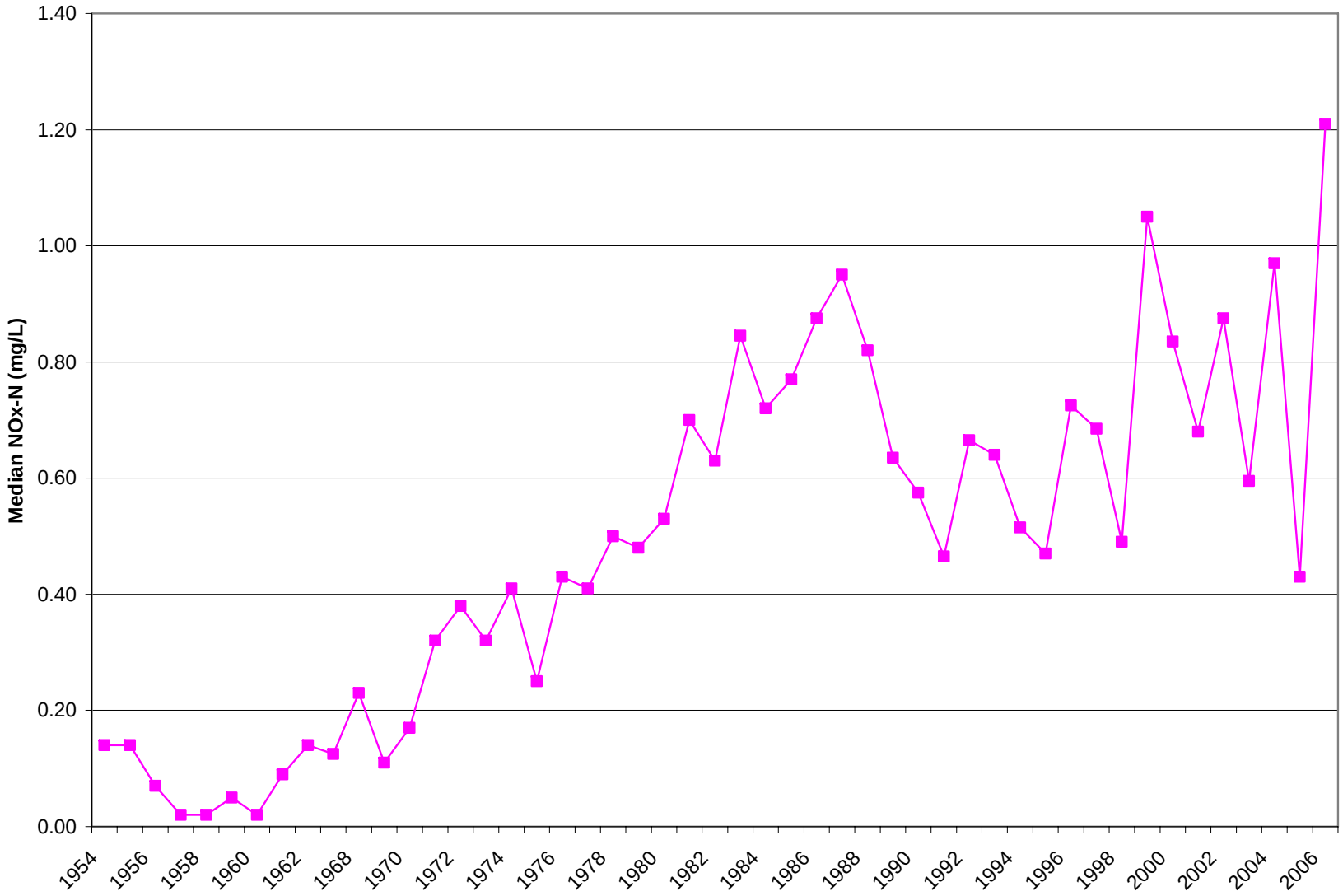

Figure A-2. Median NO_3-N concentration for the Suwannee River at Branford.

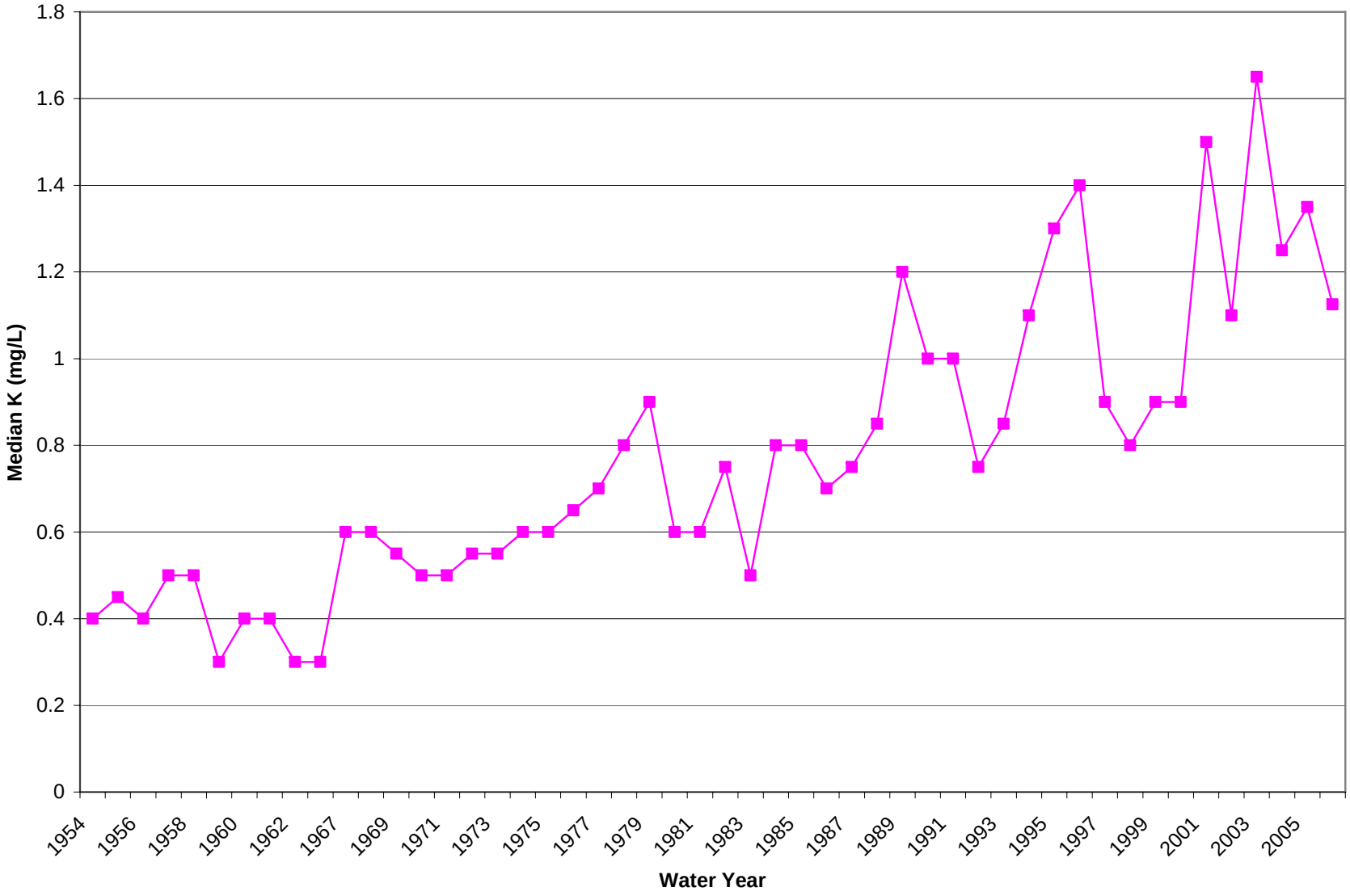

Figure A-3. Median K concentration for the Suwannee River at Branford.

APPENDIX B
WATER QUALITY SUMMARY

Table B-1. Summary of upper Floridan groundwater quality for the SRWMD (2001 to 2006).

Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Temperature	°C	22.0	4.21	21.2	21.9	22.7	13.23	225
Specific Conductance	µmhos cm^{-1}	369	171.6	282	352	437		2714
pH	su	7.64	17.14	6.85	7.15	7.4	3.45	586
Dissolve Oxygen	mg L^{-1}	2.68	10.67	0.4	1.37	3.73		373
Turbidity (NTU)	NTU	11.57	47.12	0.5	1.9	8.4	0.04	986
Total Dissolved Solids	mg L^{-1}	251.8	856	162	205	260	4	36800
Alkalinity	mg L^{-1}	171.44	64.36	133	170	207	0.3	660
Total Organic Carbon	mg L^{-1}	3.45	5.83	0.638	1.4	3.68	0.38	79.6
Dissolve Organic Carbon	mg L^{-1}	4.05	5.67	0.85	2.08	5	0.07	61.6
Potassium	mg L^{-1}	1.23	8.56	0.19	0.401	0.824	0.007	243
Sodium	mg L^{-1}	11.14	148.51	2.64	3.4	5.24	0.044	4800
Magnesium	mg L^{-1}	8.61	17.27	2.37	5.1	11.8	0.004	536
Calcium	mg L^{-1}	62.78	36.20	43.1	58.5	79.225	0.004	913
Chloride	mg L^{-1}	18	281.63	4.45	5.65	8.02	0.15	9870
Fluoride	mg L^{-1}	0.17	0.60	0.07	0.12	0.2	0.02	29.9
Sulfate	mg L^{-1}	12.75	46.24	2.16	5.17	10.8	0.11	1140
Iron	mg L^{-1}	0.94	3.30	0.031	0.159	0.909	0.003	131
Nitrate +Nitrite-nitrogen	mg L^{-1}	0.94	2.73	0.00	0.17	1.00	0.002	52.0
TKN	mg L^{-1}	0.33	0.43	0.11	0.2	0.4	0.04	8.5
Ammonia-nitrogen	mg L^{-1}	0.10	0.29	0.037	0.04	0.100	0.016	10.1
Total Phosphorus	mg L^{-1}	0.219	1.558	0.000	0.07	0.156	0.005	45.0

Table B-2. Summary of water quality parameters for the Springs of Aucilla River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Aucilla	Temperature	°C	20.4	2.85	20.1	20.5	21.4	13.3	26.6
	Specific Conductance	µmhos cm^{-1}	263	84.9	224.5	279.5	318	72	459
	pH	su	7.20	0.36	6.91	7.25	7.52	6.49	7.79
	Dissolved Oxygen	mg L^{-1}	4.66	1.92	3.3	4.75	5.68	0.7	9.7
	Total Organic Carbon	mg L^{-1}	11.96	11.52	0.4	6.5	24.4	0.3	31.7
	Dissolved Organic Carbon	mg L^{-1}	1.1	1.82	0.38	0.45	0.63	0.3	5.6
	Potassium	mg L^{-1}	0.54	0.44	0.3	0.4	0.7	0	2.3
	Sodium	mg L^{-1}	4.05	3.14	2.9	3.2	4.1	2.1	19.1
	Magnesium	mg L^{-1}	6.89	3.28	4.4	6.7	8.6	1.5	16.2
	Calcium	mg L^{-1}	35.61	17.25	20.4	41.4	45.4	3.5	73.5
	Chloride	mg L^{-1}	6.43	5.27	4.3	5.3	7	0.5	32
	Fluoride	mg L^{-1}	0.09	0.05	0.06	0.08	0.12	0.04	0.26
	Sulfate	mg L^{-1}	5.9	4.2	2	5	9	0.1	15
	TKN	mg L^{-1}	0.39	0.29	0.14	0.36	0.63	0.04	0.93
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.16	0.14	0.05	0.13	0.26	0	0.46
	Ammonia-nitrogen	mg L^{-1}	0.024	0.015	0.02	0.02	0.027	0	0.07
	Total Phosphorus	mg L^{-1}	0.053	0.052	0.036	0.043	0.056	0.009	0.319
	Soluble reactive Phosphorus	mg L^{-1}	0.031	0.009	0.029	0.032	0.037	0.016	0.05

Table B-3. Summary of water quality parameters for the Springs of Coastal Rivers Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Coastal	Temperature	°C	21.3	2.67	20.3	21.3	22.3	10.5	25.5
	Specific Conductance	µmhos cm^{-1}	2927	5511.3	428	755	878	213	23700
	pH	su	6.99	0.24	6.84	6.96	7.12	6.4	7.65
	Dissolved Oxygen	mg L^{-1}	2.89	2.58	0.5	2.8	4.7	0.1	8.7
	Total Organic Carbon	mg L^{-1}	14.23	8.60	10.4	10.7	12.95	8.1	35.8
	Dissolved Organic Carbon	mg L^{-1}	18.3	9.09	11.7	13.9	23.3	10.7	31.9
	Potassium	mg L^{-1}	0.53	0.34	0.4	0.5	0.575	0	1.5
	Sodium	mg L^{-1}	6.24	1.47	5.4	5.7	6.75	4.2	9.9
	Magnesium	mg L^{-1}	16.09	3.513	15.73	16.15	17.75	5.9	20.3
	Calcium	mg L^{-1}	115.07	22.93	113.5	120.5	127.5	42.9	132
	Chloride	mg L^{-1}	10.04	4.90	5.5	11.2	14.15	1	16
	Fluoride	mg L^{-1}	0.27	0.06	0.27	0.29	0.31	0.08	0.35
	Sulfate	mg L^{-1}	56.59	18.51	50.5	62.8	68.23	3	74
	TKN	mg L^{-1}	0.43	0.14	0.37	0.43	0.48	0.16	0.82
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.05	0.06	0.02	0.025	0.05	0	0.38
	Ammonia-nitrogen	mg L^{-1}	0.14	0.05	0.119	0.16	0.186	0.01	0.216
	Total Phosphorus	mg L^{-1}	0.075	0.019	0.068	0.072	0.078	0.047	0.128
	Soluble reactive Phosphorus	mg L^{-1}	0.057	0.018	0.054	0.063	0.066	0.002	0.087

Table B-4. Summary of water quality parameters for the Springs of Lower Suwannee River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Lower Suwannee	Temperature	°C	21.6	0.82	21.4	21.7	22.1	10.2	25.9
	Specific Conductance	µmhos cm^{-1}	407	59.5	366	412	455	77	543
	pH	su	7.25	0.18	7.16	7.26	7.38	6.05	7.95
	Dissolved Oxygen	mg L^{-1}	1.85	1.31	1	1.6	2.3	0.1	8
	Total Organic Carbon	mg L^{-1}	3.77	4.84	0.7	1.8	5.4	0	54.8
	Dissolved Organic Carbon	mg L^{-1}	4.01	4.90	0.9	2.2	5.92	0.2	47.6
	Potassium	mg L^{-1}	1.30	1.24	0.5	0.8	1.6	0	8.6
	Sodium	mg L^{-1}	3.66	1.41	2.7	3.5	4.4	0.1	28.7
	Magnesium	mg L^{-1}	8.92	4.29	6	7.3	11.6	0	28.7
	Calcium	mg L^{-1}	63.5	13.69	54.4	61.6	71.1	0	119
	Chloride	mg L^{-1}	7.39	3.06	5.4	7	9	0	39
	Fluoride	mg L^{-1}	0.11	0.051	0.08	0.11	0.15	0.02	0.39
	Sulfate	mg L^{-1}	19.9	11.11	12	16.3	24.1	0.2	54.7
	TKN	mg L^{-1}	0.16	0.64	0.04	0.1	0.16	0	17.8
	Nitrate+Nitrite-nitrogen	mg L^{-1}	3.01	3.11	1.3	1.91	3.45	0	21.8
	Ammonia-nitrogen	mg L^{-1}	0.035	0.030	0.02	0.02	0.04	0.001	0.205
	Total Phosphorus	mg L^{-1}	0.051	0.030	0.032	0.047	0.064	0.004	0.43
	Soluble reactive Phosphorus	mg L^{-1}	0.034	0.017	0.022	0.031	0.045	0.002	0.129

Table B-5. Summary of water quality parameters for the Springs of Santa Fe River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Santa Fe	Temperature	°C	22.2	0.93	21.7	22.2	22.4	17.1	28.1
	Specific Conductance	µmhos cm^{-1}	382	67.2	334	370.5	426.3	86	675
	pH	su	7.33	0.24	7.22	7.34	7.49	5.71	8.25
	Dissolved Oxygen	mg L^{-1}	2.28	2.11	0.3	1.7	4	0.1	9.5
	Total Organic Carbon	mg L^{-1}	4.36	7.20	0.52	1.6	5.3	0	52.9
	Dissolved Organic Carbon	mg L^{-1}	4.30	6.64	0.8	1.9	5.6	0.1	53.9
	Potassium	mg L^{-1}	0.67	0.48	0.3	0.5	1	0	5.4
	Sodium	mg L^{-1}	5.76	3.08	2.9	5.2	8.4	1.8	19.8
	Magnesium	mg L^{-1}	7.45	2.49	5.6	6.8	8.9	2.2	15.7
	Calcium	mg L^{-1}	60.13	10.08	52.8	59.4	66.85	10.6	103
	Chloride	mg L^{-1}	9.38	4.95	5.5	8	13.2	3	62
	Fluoride	mg L^{-1}	0.15	0.067	0.1	0.15	0.19	0.02	0.66
	Sulfate	mg L^{-1}	30.6	104.7	9.47	16.5	38.5	3.2	2550
	TKN	mg L^{-1}	0.19	0.23	0.05	0.1	0.23	0	1.56
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.90	1.60	0.39	0.58	1.01	0	26
	Ammonia-nitrogen	mg L^{-1}	0.035	0.034	0.02	0.02	0.04	0.001	0.369
	Total Phosphorus	mg L^{-1}	0.083	0.057	0.048	0.077	0.101	0.004	0.82
	Soluble reactive Phosphorus	mg L^{-1}	0.064	0.038	0.033	0.06	0.088	0.004	0.309

Table B-6. Summary of water quality parameters for the Springs of Upper Suwannee River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Upper Suwannee	Temperature	°C	21.0	1.29	20.5	20.8	21.3	17	27.6
	Specific Conductance	µmhos cm^{-1}	312	68.6	285.3	320	370	126	458
	pH	su	7.20	0.24	7.14	7.22	7.32	6.57	8.66
	Dissolved Oxygen	mg L^{-1}	0.75	1.20	0.2	0.4	0.7	0	10.2
	Total Organic Carbon	mg L^{-1}	8.04	6.59	2.9	6.3	10.8	0	24.8
	Dissolved Organic Carbon	mg L^{-1}	8.38	6.10	3.6	6.7	10.8	0.8	26.4
	Potassium	mg L^{-1}	0.73	0.51	0.4	0.6	1.25	0	3
	Sodium	mg L^{-1}	4.17	3.82	2.8	3.4	4.1	0	37.7
	Magnesium	mg L^{-1}	6.71	2.46	4.6	6.7	8.55	0	11.6
	Calcium	mg L^{-1}	47.02	13.72	37.3	50	56.1	0.1	72
	Chloride	mg L^{-1}	5.51	1.91	4.8	5.3	6.77	1	11.1
	Fluoride	mg L^{-1}	0.14	0.04	0.11	0.13	0.16	0.02	0.32
	Sulfate	mg L^{-1}	13.23	8.11	8.85	10.4	15.1	1	35.9
	TKN	mg L^{-1}	0.36	0.33	0.105	0.28	0.48	0	1.8
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.40	0.39	0.02	0.29	0.7	0	1.91
	Ammonia-nitrogen	mg L^{-1}	0.064	0.10	0.02	0.04	0.099	0.001	1.1
	Total Phosphorus	mg L^{-1}	0.102	0.045	0.060	0.110	0.136	0.004	0.22
	Soluble reactive Phosphorus	mg L^{-1}	0.077	0.039	0.041	0.08	0.112	0.002	0.146

Table B-7. Summary of water quality parameters for the Springs of Waccasassa River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Waccassasa	Temperature	°C	22.4	0.30	22.1	22.3	22.7	22.1	22.7
	Specific Conductance	µmhos cm^{-1}	207	11.6	194	213	216	194	216
	pH	su	6.86	0.25	6.59	7.03	7.05	6.59	7.05
	Dissolved Oxygen	mg L^{-1}	3.32	0.89	2.4	3.7	3.7	2.4	4.4
	Total Organic Carbon	mg L^{-1}							
	Dissolved Organic Carbon	mg L^{-1}							
	Potassium	mg L^{-1}							
	Sodium	mg L^{-1}							
	Magnesium	mg L^{-1}							
	Calcium	mg L^{-1}							
	Chloride	mg L^{-1}	4.25	0.50	4	4	4.25	4	5
	Fluoride	mg L^{-1}							
	Sulfate	mg L^{-1}							
	TKN	mg L^{-1}							
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.436	0.25	0.42	0.43	0.65	0.03	0.65
	Ammonia-nitrogen	mg L^{-1}	0.02	0.00	0.02	0.02	0.02	0.02	0.02
	Total Phosphorus	mg L^{-1}	0.045	0.01	0.043	0.045	0.048	0.039	0.053
	Soluble reactive Phosphorus	mg L^{-1}	0.0317	0.00	0.0295	0.032	0.034	0.028	0.035

Table B-8. Summary of water quality parameters for the Springs of Withlacoochee River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Withlacoochee	Temperature	°C	20.9	0.3	20.8	20.9	21	19.6	22.8
	Specific Conductance	µmhos cm^{-1}	287	17.2	278.3	286	289.2	237	383
	pH	su	7.50	0.21	7.42	7.55	7.63	6.78	7.92
	Dissolved Oxygen	mg L^{-1}	1.85	1.03	1	1.7	2.3	0.2	5.3
	Total Organic Carbon	mg L^{-1}	1.18	1.23	0.5	0.65	1.1	0.3	5.8
	Dissolved Organic Carbon	mg L^{-1}	1.48	1.51	0.8	0.85	1.35	0.3	7.1
	Potassium	mg L^{-1}	0.51	0.39	0.4	0.4	0.5	0.2	3
	Sodium	mg L^{-1}	4.20	4.49	3.2	3.4	3.9	2.9	35.4
	Magnesium	mg L^{-1}	8.33	0.64	7.95	8.4	8.9	6.3	9.8
	Calcium	mg L^{-1}	40.9	2.80	39.5	41.1	42.7	33.1	48.9
	Chloride	mg L^{-1}	5.74	0.88	5	5.7	6.2	4.3	7.7
	Fluoride	mg L^{-1}	0.14	0.043	0.13	0.15	0.17	0.05	0.25
	Sulfate	mg L^{-1}	12.8	1.4	11.75	12.7	13.65	10.6	16.4
	TKN	mg L^{-1}	0.19	0.15	0.11	0.12	0.25	0.04	0.627
	Nitrate+Nitrite-nitrogen	mg L^{-1}	1.34	0.34	1.17	1.39	1.58	0.27	1.94
	Ammonia-nitrogen	mg L^{-1}	0.05	0.04	0.02	0.04	0.099	0.02	0.235
	Total Phosphorus	mg L^{-1}	0.054	0.016	0.044	0.05	0.06	0.04	0.14
	Soluble reactive Phosphorus	mg L^{-1}	0.035	0.01	0.0277	0.034	0.0435	0.019	0.056

Table B-9. Summary of surfacewater quality parameters for the Alapaha River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Alapaha	Temperature	°C	20.6	4.74	17.0	21.50	24.50	8.20	27.10
	Specific Conductance	µmhos cm^{-1}	84	36.7	56.5	77	104		210
	pH	su	6.14	0.70	5.60	6.25	6.7	3.98	7.51
	Dissolved Oxygen	mg L^{-1}	7.78	1.53	6.7	7.5	8.7	3.8	11.9
	Total Organic Carbon	mg L^{-1}	18.622	8.384	12.3	17.15	23.575	0.8	46.1
	Potassium	mg L^{-1}	1.93	0.74	1.50	1.80	2.20	0.30	5.90
	Sodium	mg L^{-1}	7.91	5.60	3.90	6.20	10.30	1.50	27.00
	Magnesium	mg L^{-1}	2.04	0.74	1.50	1.90	2.50	0.40	7.10
	Calcium	mg L^{-1}	4.64	5.61	3.00	3.90	4.90	1.40	62.50
	Chloride	mg L^{-1}	9.65	2.76	8.00	9.80	11.30	0	18.20
	Fluoride	mg L^{-1}	0.13	0.06	0.09	0.11	0.18	0.02	0.32
	Sulfate	mg L^{-1}	7.7	6.5	3.0	6.0	10.4	0.8	45.3
	TKN	mg L^{-1}	0.79	0.32	0.56	0.79	0.96	0	2.00
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.48	0.44	0.14	0.31	0.72	0	2.00
	Ammonia-nitrogen	mg L^{-1}	0.04	0.03	0.02	0.03	0.04	0	0.33
	Total Phosphorus	mg L^{-1}	0.191	0.097	0.110	0.180	0.250	0.041	0.567
	Soluble Reactive Phosphorus	mg L^{-1}	0.127	0.085	0.056	0.105	0.193	0.014	0.460

Table B-10. Summary of surfacewater quality parameters for the Aucilla River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Aucilla	Temperature	°C	19.7	5.3	15.4	20.7	23.8	4.4	28.8
	Specific Conductance	µmhos cm^{-1}	194	109.4	69	257	293	28	330
	pH	su	7.03	0.98	6.35	7.31	7.86	4.67	8.32
	Dissolved Oxygen	mg L^{-1}	7.37	1.80	6.1	7.4	8.9	2.5	10.9
	Total Organic Carbon	mg L^{-1}	16.73	14.41	4.38	10.9	26.48	0.5	55.2
	Potassium	mg L^{-1}	0.56	0.35	0.30	0.40	0.78	0	1.90
	Sodium	mg L^{-1}	3.05	0.77	2.60	3.00	3.30	1.70	8.10
	Magnesium	mg L^{-1}	5.15	2.77	2.13	6.40	7.60	0.80	10.60
	Calcium	mg L^{-1}	28.65	17.55	8.60	37.85	44.55	0.40	51.70
	Chloride	mg L^{-1}	5.62	1.36	5.00	5.50	6.18	0.5	11.10
	Fluoride	mg L^{-1}	0.11	0.05	0.07	0.12	0.15	0.02	0.29
	Sulfate	mg L^{-1}	3.4	2.5	0.8	4.0	5.4	0.1	12.3
	TKN	mg L^{-1}	0.68	0.53	0.22	0.51	1.09	0.05	2.50
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.05	0.05	0.01	0.03	0.07	0	0.44
	Ammonia-nitrogen	mg L^{-1}	0.04	0.03	0.02	0.04	0.06	0	0.12
	Total Phosphorus	mg L^{-1}	0.054	0.027	0.037	0.048	0.070	0.011	0.150
	Soluble Reactive Phosphorus	mg L^{-1}	0.026	0.014	0.018	0.025	0.032	0.002	0.078

Table B-11. Summary of surfacewater quality parameters for the Coastal Rivers Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Coastal	Temperature	°C	20.6	4.86	17	21.15	24.3	6.2	32.3
	Specific Conductance	µmhos cm^{-1}	2485	7331	170	364	586	33	4084
	pH	su	6.86	0.89	6.77	7.1	7.33	3.29	8.41
	Dissolved Oxygen	mg L^{-1}	4.92	1.99	3.8	5.1	6.3	0.2	10.4
	Total Organic Carbon	mg L^{-1}	42.41	33.07	18.9	36	53.6	2.5	213
	Potassium	mg L^{-1}	13.58	52.18	0.20	0.50	1.00	0	570.00
	Sodium	mg L^{-1}	377.40	1385.30	2.90	3.92	13.10	1.00	15050.00
	Magnesium	mg L^{-1}	50.90	285.90	3.65	7.20	13.60	0.20	6890.00
	Calcium	mg L^{-1}	56.76	51.01	26.00	47.20	70.93	1.00	352.00
	Chloride	mg L^{-1}	704.00	4710.00	5.90	8.70	13.70	0	118000.00
	Fluoride	mg L^{-1}	0.20	0.88	0.09	0.13	0.20	0.02	24.00
	Sulfate	mg L^{-1}	119.6	349.2	2.1	8.0	29.1	0.1	4360.0
	TKN	mg L^{-1}	1.46	1.94	0.57	1.00	1.53	0.09	26.00
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.07	0.11	0.02	0.05	0.06	0	0.71
	Ammonia-nitrogen	mg L^{-1}	0.39	1.22	0.02	0.04	0.10	0	17.00
	Total Phosphorus	mg L^{-1}	0.285	0.707	0.054	0.091	0.139	0.010	9.600
	Soluble Reactive Phosphorus	mg L^{-1}	0.169	0.389	0.027	0.050	0.082	0.000	4.000

Table B-12. Summary of surfacewater quality parameters for the Lower Suwannee River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Lower Suwannee	Temperature	°C	21.2	4.6	17.5	21.6	25.3	9	29.4
	Specific Conductance	µmhos cm^{-1}	247	105.8	163	263	337	29	918
	pH	su	7.15	0.62	6.82	7.24	7.6	3.79	9.83
	Dissolved Oxygen	mg L^{-1}	6.43	1.41	5.5	6.4	7.37	1.2	26.3
	Total Organic Carbon	mg L^{-1}	16.14	10.59	7.6	14	23.2	0.8	69
	Potassium	mg L^{-1}	1.18	0.89	0.80	1.00	1.40	0.10	27.10
	Sodium	mg L^{-1}	6.00	4.80	4.40	5.40	6.60	0.70	110.00
	Magnesium	mg L^{-1}	5.86	2.78	3.50	6.00	7.90	0.60	28.40
	Calcium	mg L^{-1}	32.94	15.91	20.00	34.40	46.20	2.30	85.20
	Chloride	mg L^{-1}	8.07	8.25	6.50	7.50	8.50	0	170.00
	Fluoride	mg L^{-1}	0.14	0.05	0.11	0.13	0.18	0.02	0.53
	Sulfate	mg L^{-1}	16.4	8.0	9.8	17.0	22.6	0.8	47.3
	TKN	mg L^{-1}	0.58	0.39	0.28	0.53	0.80	0	5.90
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.57	0.33	0.31	0.56	0.81	0	2.44
	Ammonia-nitrogen	mg L^{-1}	0.04	0.03	0.02	0.03	0.04	0	0.35
	Total Phosphorus	mg L^{-1}	0.161	0.094	0.111	0.14	0.181	0.004	1.320
	Soluble Reactive Phosphorus	mg L^{-1}	0.115	0.068	0.078	0.1	0.134	0.002	1.290

Table B-13. Summary of surfacewater quality parameters for the Santa Fe River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Santa Fe	Temperature	°C	20.5	4.3	18.1	21.3	23.6	5	31.3
	Specific Conductance	µmhos cm^{-1}	245	129.2	125	250	350	22	1948
	pH	su	6.81	0.92	6.41	7.09	7.45	3.21	8.36
	Dissolved Oxygen	mg L^{-1}	5.70	1.71	4.6	5.5	6.7	0.5	14.4
	Total Organic Carbon	mg L^{-1}	21.09	18.29	6.1	15.9	32.4	0	139.6
	Potassium	mg L^{-1}	1.01	2.53	0.50	0.80	1.10	0	98.80
	Sodium	mg L^{-1}	7.25	4.48	4.90	6.25	8.40	1.80	94.10
	Magnesium	mg L^{-1}	5.80	3.01	3.30	6.00	7.40	0.10	15.70
	Calcium	mg L^{-1}	31.45	21.89	11.00	25.70	52.20	0.90	111.00
	Chloride	mg L^{-1}	14.06	8.53	9.00	12.20	16.70	0	88.30
	Fluoride	mg L^{-1}	0.15	0.08	0.10	0.14	0.20	0.02	1.30
	Sulfate	mg L^{-1}	17.6	16.2	5.2	13.0	25.0	0.8	105.0
	TKN	mg L^{-1}	0.71	0.61	0.22	0.60	1.04	0	5.25
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.34	0.32	0.07	0.26	0.56	0	4.80
	Ammonia-nitrogen	mg L^{-1}	0.05	0.12	0.02	0.03	0.05	0	2.70
	Total Phosphorus	mg L^{-1}	0.204	0.368	0.080	0.124	0.210	0.001	6.000
	Soluble Reactive Phosphorus	mg L^{-1}	0.151	0.274	0.053	0.092	0.159	0.001	3.800

Table B-14. Summary of surfacewater quality parameters for the Upper Suwannee River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Upper Suwannee	Temperature	°C	20.8	5.6	16.5	21.5	25.3	5.6	32.5
	Specific Conductance	µmhos cm^{-1}	124	93.8	65.25	79	161.3	34	1570
	pH	su	5.47	1.45	4.01	5.38	6.93	2.34	8.05
	Dissolved Oxygen	mg L^{-1}	6.14	1.92	5	6	7.3	0	22.4
	Total Organic Carbon	mg L^{-1}	38.89	18.51	24.7	40.9	52	2.8	98
	Potassium	mg L^{-1}	0.68	0.65	0.20	0.50	1.00	0	5.90
	Sodium	mg L^{-1}	5.02	2.91	3.40	4.20	5.60	0	46.30
	Magnesium	mg L^{-1}	2.81	2.51	1.00	1.80	4.10	0	15.00
	Calcium	mg L^{-1}	11.48	12.93	1.80	4.90	18.28	0.10	55.00
	Chloride	mg L^{-1}	7.53	2.64	6.00	7.60	8.70	0	65.00
	Fluoride	mg L^{-1}	0.17	0.21	0.08	0.12	0.20	0.02	4.90
	Sulfate	mg L^{-1}	9.9	11.3	1.1	5.5	15.0	0.2	120.0
	TKN	mg L^{-1}	1.25	5.04	0.70	0.99	1.22	0.04	128.00
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.15	0.31	0.03	0.05	0.20	0	8.04
	Ammonia-nitrogen	mg L^{-1}	0.05	0.07	0.02	0.03	0.06	0	1.10
	Total Phosphorus	mg L^{-1}	0.299	0.535	0.100	0.168	0.280	0.004	8.900
	Soluble Reactive Phosphorus	mg L^{-1}	0.253	0.531	0.060	0.128	0.230	0.000	8.800

Table B-15. Summary of surfacewater quality parameters for the Waccasassa River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Waccasassa	Temperature	°C	20.6	4.74	17	21.5	24.5	8.2	27.1
	Specific Conductance	µmhos cm^{-1}	409	369.2	273	358	434	52	3792
	pH	su	7.30	0.35	7.115	7.34	7.53	5.36	7.83
	Dissolved Oxygen	mg L^{-1}	6.23	1.56	5.2	5.8	7.4	2.8	10.6
	Total Organic Carbon	mg L^{-1}	16.64	10.97	7.2	14.8	24.5	1.6	45.9
	Potassium	mg L^{-1}	1.16	3.75	0.20	0.40	0.80	0	37.70
	Sodium	mg L^{-1}	26.32	101.85	4.54	6.40	10.35	1.80	1030.00
	Magnesium	mg L^{-1}	10.25	12.69	6.10	8.70	10.40	1.40	133.00
	Calcium	mg L^{-1}	50.93	18.54	38.20	49.30	60.05	8.40	140.00
	Chloride	mg L^{-1}	30.48	73.87	8.55	12.00	17.00	2.7	554.00
	Fluoride	mg L^{-1}	0.14	0.06	0.10	0.13	0.17	0.03	0.38
	Sulfate	mg L^{-1}	17.4	8.8	10.1	15.7	45.5	3.0	318.0
	TKN	mg L^{-1}	0.66	0.44	0.29	0.59	0.90	0.10	2.80
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.10	0.09	0.02	0.09	0.16	0	0.49
	Ammonia-nitrogen	mg L^{-1}	0.04	0.03	0.02	0.03	0.04	0	0.16
	Total Phosphorus	mg L^{-1}	0.075	0.036	0.050	0.068	0.098	0.023	0.350
	Soluble Reactive Phosphorus	mg L^{-1}	0.039	0.015	0.028	0.038	0.050	0.002	0.083

Table B-16. Summary of surfacewater quality parameters for the Withlacoochee River Basin (1989 to 2006).

Basin	Parameter	Units	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Withlacoochee	Temperature	°C	19.9	5.03	16.15	21	24.1	5.7	29
	Specific Conductance	µmhos cm^{-1}	194	107.22	105.5	177	264	41	786
	pH	su	6.96	0.60	6.56	7	7.42	4.84	8.15
	Dissolved Oxygen	mg L^{-1}	6.30	1.46	5.3	6	7.05	3	11.2
	Total Organic Carbon	mg L^{-1}	11.39	6.44	6.2	10.8	16	0.1	45.5
	Potassium	mg L^{-1}	2.17	1.15	1.50	2.10		0.10	
	Sodium	mg L^{-1}	10.42	10.23	4.50	6.60	11.75	2.10	74.00
	Magnesium	mg L^{-1}	4.13	2.43	2.40	3.70	5.20	0.90	26.00
	Calcium	mg L^{-1}	19.99	12.60	8.21	17.80	32.00	2.60	52.10
	Chloride	mg L^{-1}	8.81	2.84	7.00	8.40	10.10	0	23.30
	Fluoride	mg L^{-1}	0.14	0.06	0.10	0.13	0.18	0.02	0.74
	Sulfate	mg L^{-1}	14.2	12.1	6.2	10.0	18.6	1.0	79.8
	TKN	mg L^{-1}	0.57	0.33	0.30	0.56	0.77	0.04	2.10
	Nitrate+Nitrite-nitrogen	mg L^{-1}	0.39	0.28	0.20	0.32	0.51	0	2.36
	Ammonia-nitrogen	mg L^{-1}	0.04	0.06	0.02	0.03	0.05	0	0.86
	Total Phosphorus	mg L^{-1}	0.137	0.098	0.093	0.115	0.147	0.010	1.100
	Soluble Reactive Phosphorus	mg L^{-1}	0.082	0.058	0.048	0.067	0.095	0.015	0.461

Table B-17A. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 1998.

		Annual Loads kg/year)			
Contributing Basin	Area (mi²)	Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee Reach 1	2,430	197,791.5	3.09	755,461.8	42.93
Alapaha River	1,801	264,561.0	4.13	195,610.3	11.11
Withlacoochee	2,382	841,213.9	13.14	263,494.5	14.97
Suwannee Reach 2	443	959,161.3	14.98	228,319.3	12.97
Suwannee Reach 3	824	2,910,823.9	45.47	188,536.7	10.71
Santa Fe Reach 1	820	59,007.1	0.92	108,270.9	6.15
Santa Fe Reach 2	564	1,017,344.3	15.89	107,829.0	6.13
Suwannee Reach 4,5, & 6	686	152,126.8	2.38	-87,569.7	-4.98
Total Load	*9,950*	*6,402,029.7*	*100.00*	*1,759,952.8*	*100.00*

Table B-17B. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 1999.

		Annual Loads (kg/year)			
Contributing Basin	Area (mi²	Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee Reach 1	2,430	75,192.5	1.76	206,590.9	33.12
Alapaha River	1,801	175,187.9	4.10	62,560.6	10.03
Withlacoochee	2,382	508,185.2	11.90	74,562.0	11.95
Suwannee Reach 2	443	383,006.3	8.97	64,285.4	10.31
Suwannee Reach 3	824	2,005,222.0	46.95	62,619.6	10.04
Santa Fe Reach 1	820	19,245.9	0.45	30,083.4	4.82
Santa Fe Reach 2	564	884,718.9	20.72	68,190.7	10.93
Suwannee Reach 4,5, & 6	686	220,026.0	5.15	54,856.9	8.79
Total	*9,950*	*4,270,784.8*	*100.00*	*623,749.4*	*100.00*

Table B-17C. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 2000.

Contributing Basin	Area (mi²)	Annual Load (kg/year) Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee River Reach 1	2,430	36,900.6	1.6%	82,096.2	25%
Alapaha River	1,801	158,688.2	6.7%	71,765.6	22%
Withlacoochee River	2,382	256,733.5	10.9%	39,748.6	12%
Suwannee River Reach 2	443	281,498.4	11.9%	61,740.0	19%
Suwannee River Reach 3	824	848,107.2	36.0%	0.0	0%
Santa Fe River Reach 1	820	2,671.4	0.1%	5,748.8	2%
Santa Fe River Reach 2	564	705,113.7	29.9%	52,714.2	16%
Suwannee River Reaches 4, 5, & 6	686	69,110.1	2.9%	13,634.3	4%
Total	*9,950*	*2,358,000.0*	*100.0%*	*327,600.0*	*100%*

Table B-17D. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 2001.

Contributing Basin	Area (mi²)	Annual Load (kg/year) Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee River Reach 1	2,430	30,716.1	1.1%	241,761.3	38%
Alapaha River	1,801	344,868.4	12.8%	142,372.5	22%
Withlacoochee River	2,382	543,940.1	20.2%	128,279.3	20%
Suwannee River Reach 2	443	45,340.7	1.7%	-112,024.0	-18%
Suwannee River Reach 3	824	1,227,440.1	45.5%	103,347.9	16%
Santa Fe River Reach 1	820	3,748.2	0.1%	10,820.0	2%
Santa Fe River Reach 2	564	427,311.4	15.8%	26,890.0	4%
Suwannee River Reaches 4, 5, & 6	686	75,818.6	2.8%	93,448.0	15%
Total	*9,950*	*2,699,183.5*	*100.0%*	*634,895.1*	*100%*

Table B-17E. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 2002.

		Annual Load (kg/year)			
Contributing Basin	Area (mi²)	Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee River Reach 1	2,430	17,576.2	0.7%	268,841.5	41.3%
Alapaha River	1,801	96,958.3	3.6%	50,264.8	7.7%
Withlacoochee River	2,382	236,861.6	8.9%	49,680.2	7.6%
Withlacoochee - GA	2,118	72,453.6	2.7%	53,895.0	8.3%
Withlacoochee - FL	264	164,408.0	6.1%	-4,214.8	-0.6%
Suwannee River Reach 2	443	174,178.7	6.5%	-10,530.3	-1.6%
Suwannee River Reach 3	824	783,503.0	29.3%	18,312.5	2.8%
Santa Fe River Reach 1	820	2,698.4	0.1%	6,447.7	1.0%
Santa Fe River Reach 2	564	522,922.8	19.6%	54,320.7	8.3%
Suwannee River Reach 4	342	-161,535.1	-6.0%	6,461.7	1.0%
Suwannee River Reaches 5 & 6	344	1,000,872.2	37.4%	207,890.2	31.9%
Total	*9,950*	*2,674,036.1*	*100%*	*651,689.0*	*100.0%*

Table B-17F. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 2003.

		Annual Load Contribution (kg/year)			
Contributing Basin	Area (mi²)	Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee River Reach 1	2,430	30,913.9	0.8%	792,541.7	54.1%
Alapaha River	1,801	491,223.4	12.2%	271,328.3	18.5%
Withlacoochee River	2,382	960,163.0	23.8%	346,609.1	23.7%
Withlacoochee - GA	2,118	801,011.6	19.8%	337,420.6	23.0%
Withlacoochee - FL	264	159,151.4	3.9%	9,188.5	0.6%
Suwannee River Reach 2	443	-64,733.3	-1.6%	-145,933.2	-10.0%
Suwannee River Reach 3	824	1,386,940.1	34.4%	158,491.5	10.8%
Santa Fe River Reach 1	820	26,674.5	0.7%	129,706.1	8.9%
Santa Fe River Reach 2	564	626,407.0	15.5%	86,853.1	5.9%
Suwannee River Reach 4	342	-184,172.2	-4.6%	-121,628.5	-8.3%
Suwannee River Reaches 5 & 6	344	763,194.1	18.9%	-53,499.8	-3.7%
Total	*9,950*	*4,036,610.7*	*100%*	*1,464,468.5*	*100.0%*

Table B-17G. TP and NO_3-N loadings by watersheds/reach in the Suwannee River for water year 2004.

		Annual Load Contribution (kg/year)			
Contributing Basin	Area (mi²)	Nitrate-N	% of Load	Total Phosphorus	% of Load
Suwannee River Reach 1	2,430	66,713.9	1.4%	867,015.6	100.2%
Alapaha River	1,801	464,351.4	9.7%	174,172.1	20.1%
Withlacoochee River	2,382	891,320.4	18.6%	172,898.5	20.0%
Withlacoochee - GA	2,118	309,349.1	6.5%	148,264.2	17.1%
Withlacoochee - FL	264	581,971.4	12.2%	24,634.3	2.8%
Suwannee River Reach 2	443	-240,949.5	-5.0%	-491,391.4	-56.8%
Suwannee River Reach 3	824	1,660,115.3	34.7%	116,851.5	13.5%
Santa Fe River Reach 1	820	13,469.1	0.3%	118,561.1	13.7%
Santa Fe River Reach 2	564	1,014,996.9	21.2%	50,334.5	5.8%
Suwannee River Reach 4	342	15,550.1	0.3%	-121,249.5	-14.0%
Suwannee River Reaches 5 & 6	344	903,821.5	18.9%	-22,290.9	-2.6%
Total	*9,950*	*4,789,389.1*	*100%*	*864,901.4*	*100.0%*

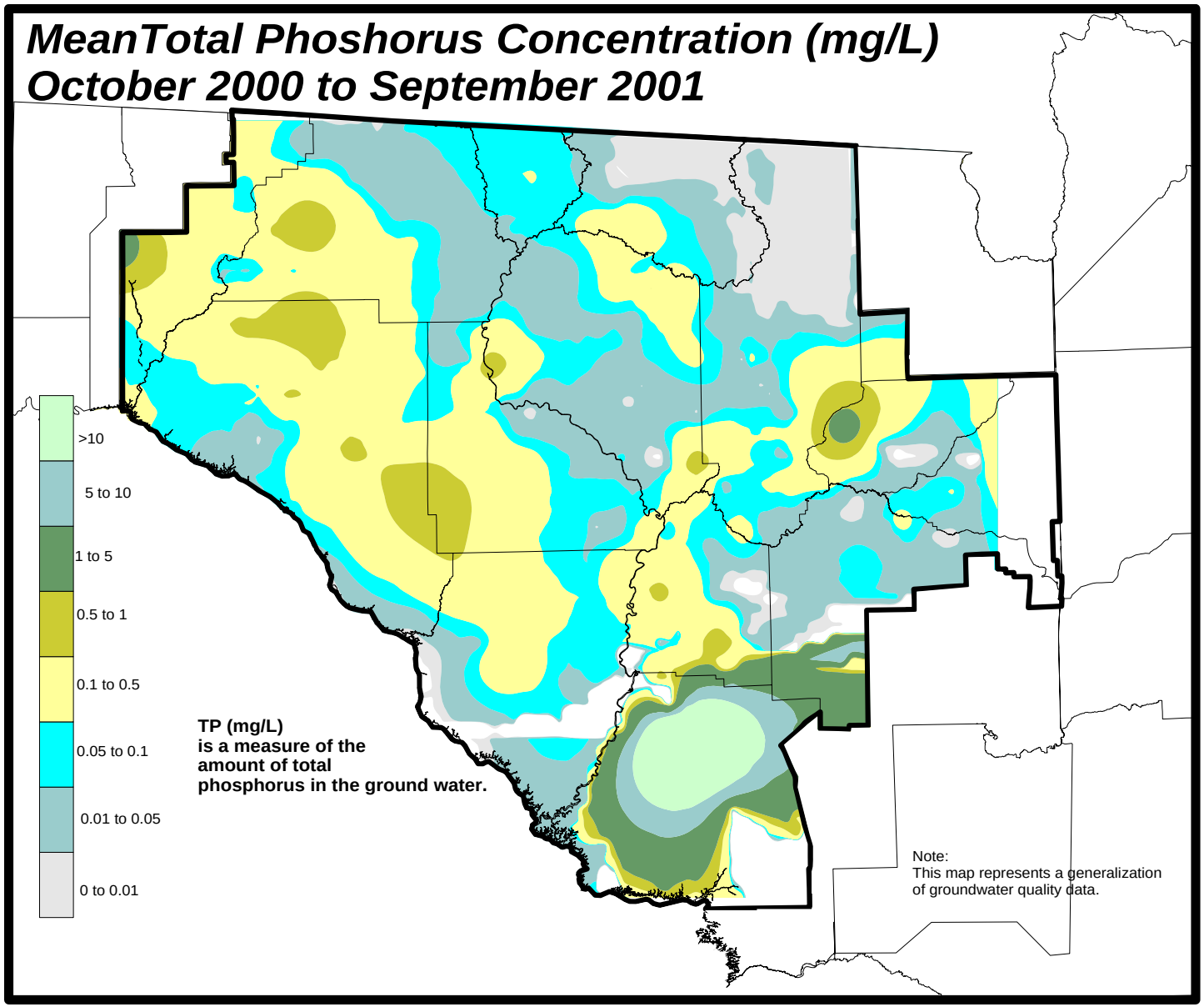

Figure B-1A. Mean upper Floridan aquifer TP concentration contour map for water year 2001.

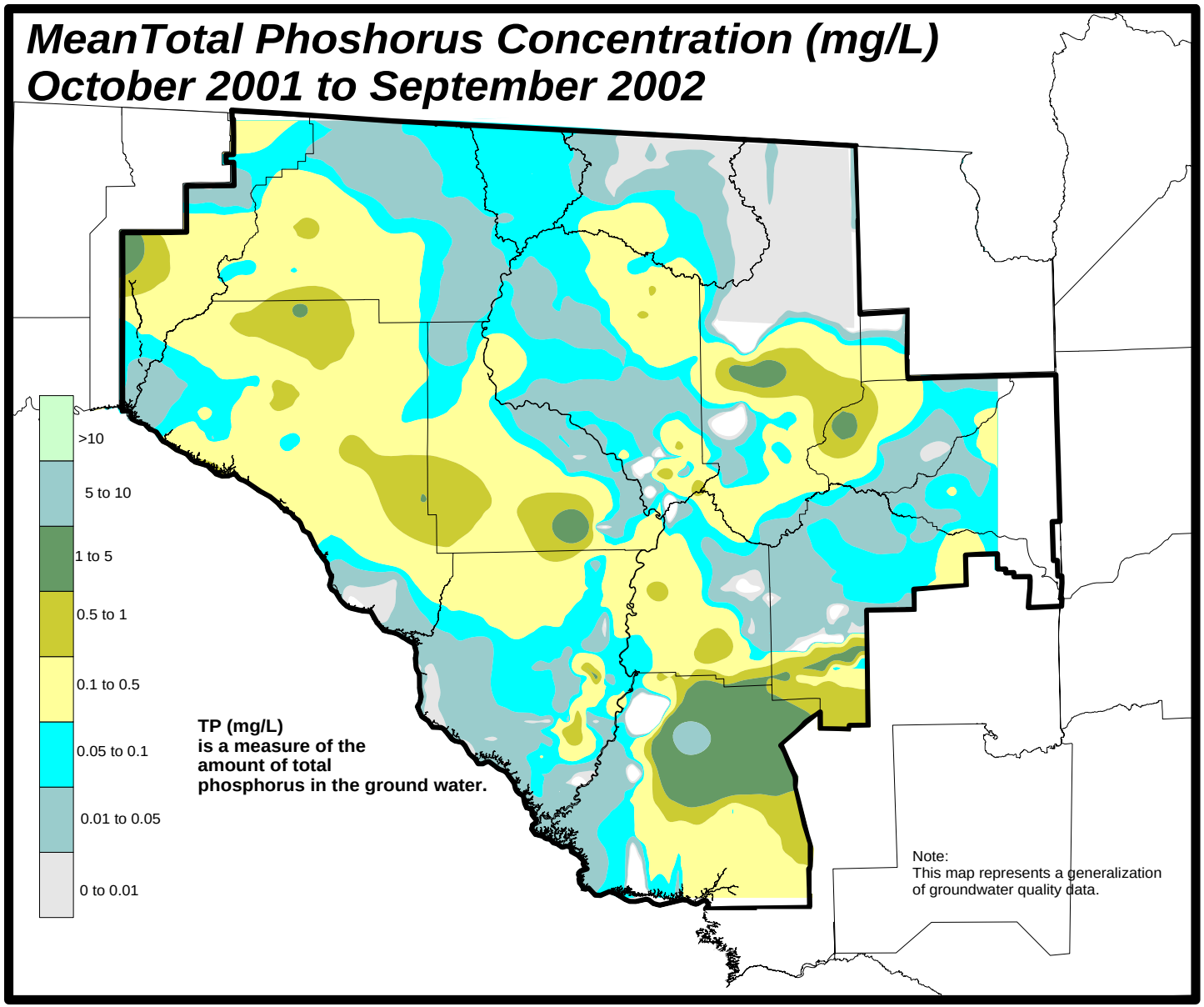

Figure B-1B. Mean upper Floridan aquifer TP concentration contour map for water year 2002.

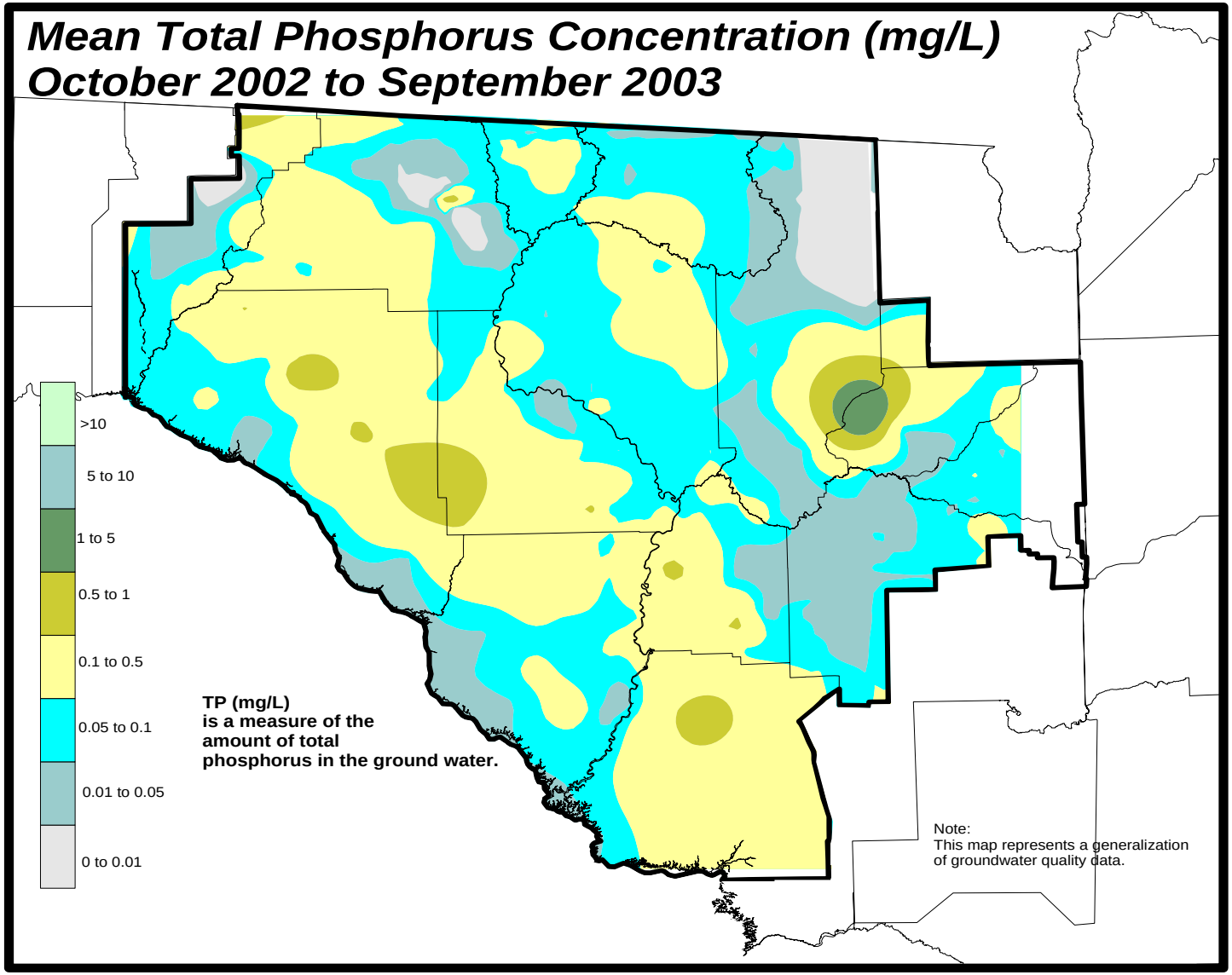

Figure B-1C. Mean upper Floridan aquifer TP concentration contour map for water year 2003.

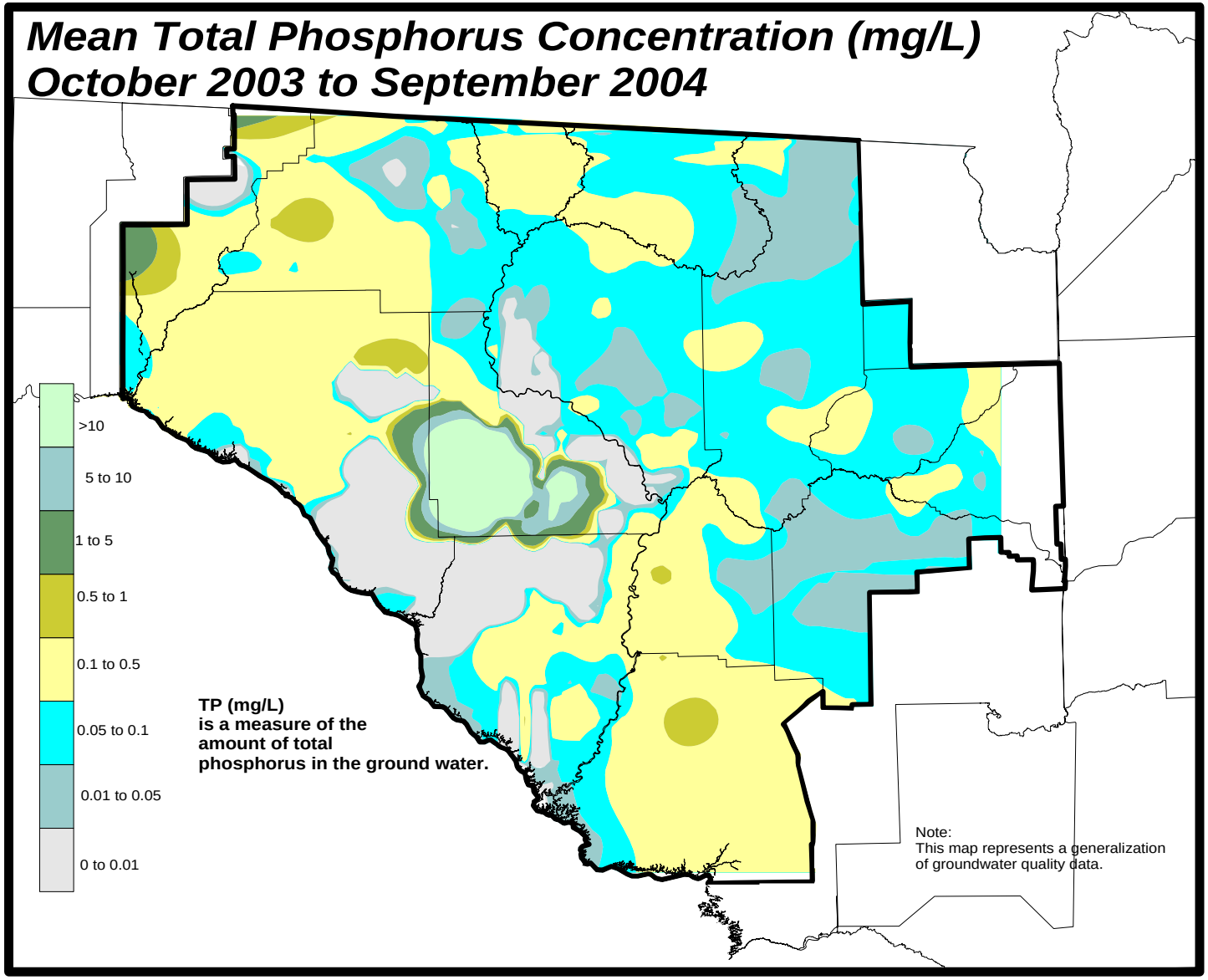

Figure B-1D. Mean upper Floridan aquifer TP concentration contour map for water year 2004.

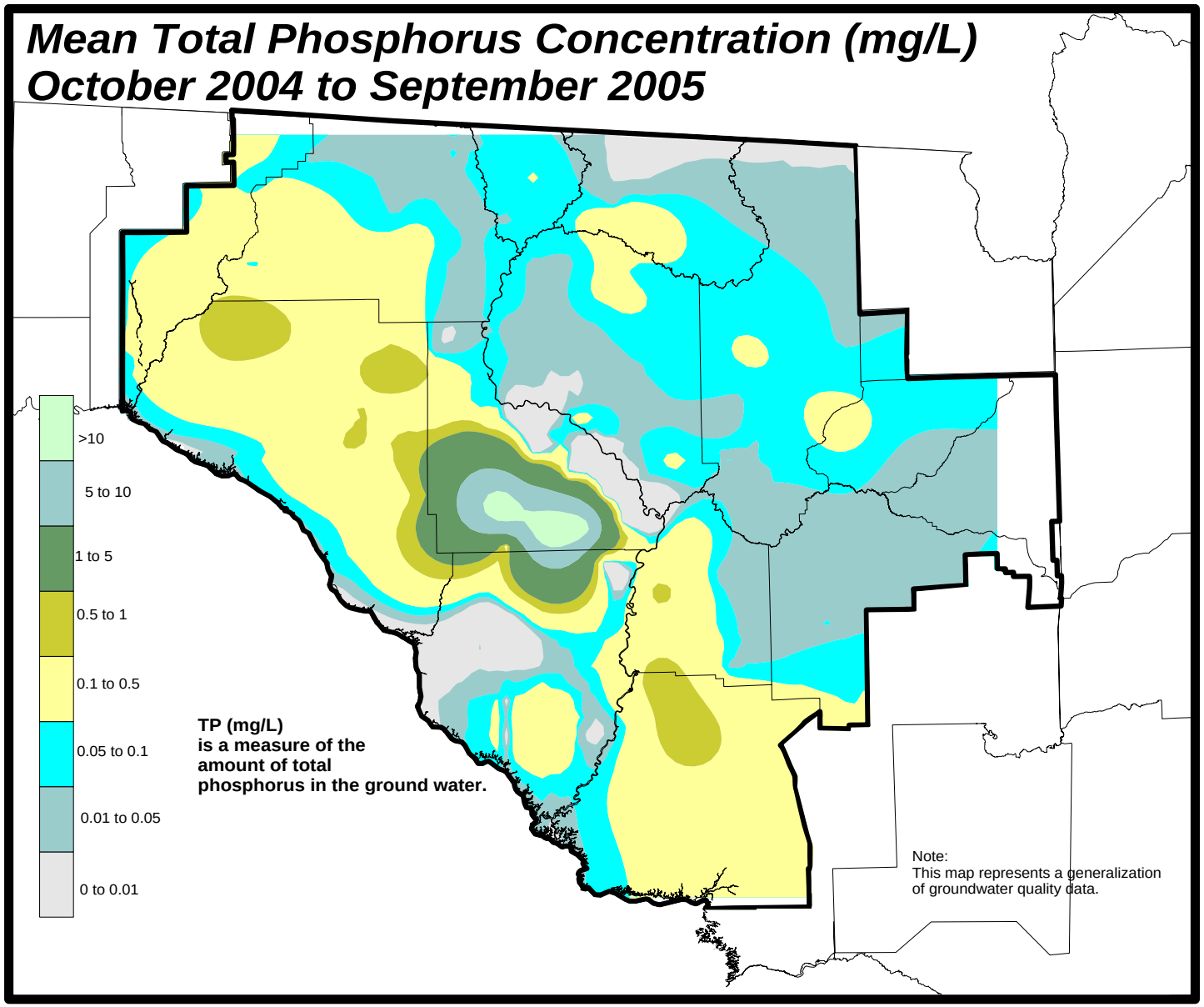

Figure B-1E. Mean upper Floridan aquifer TP concentration contour map for water year 2005.

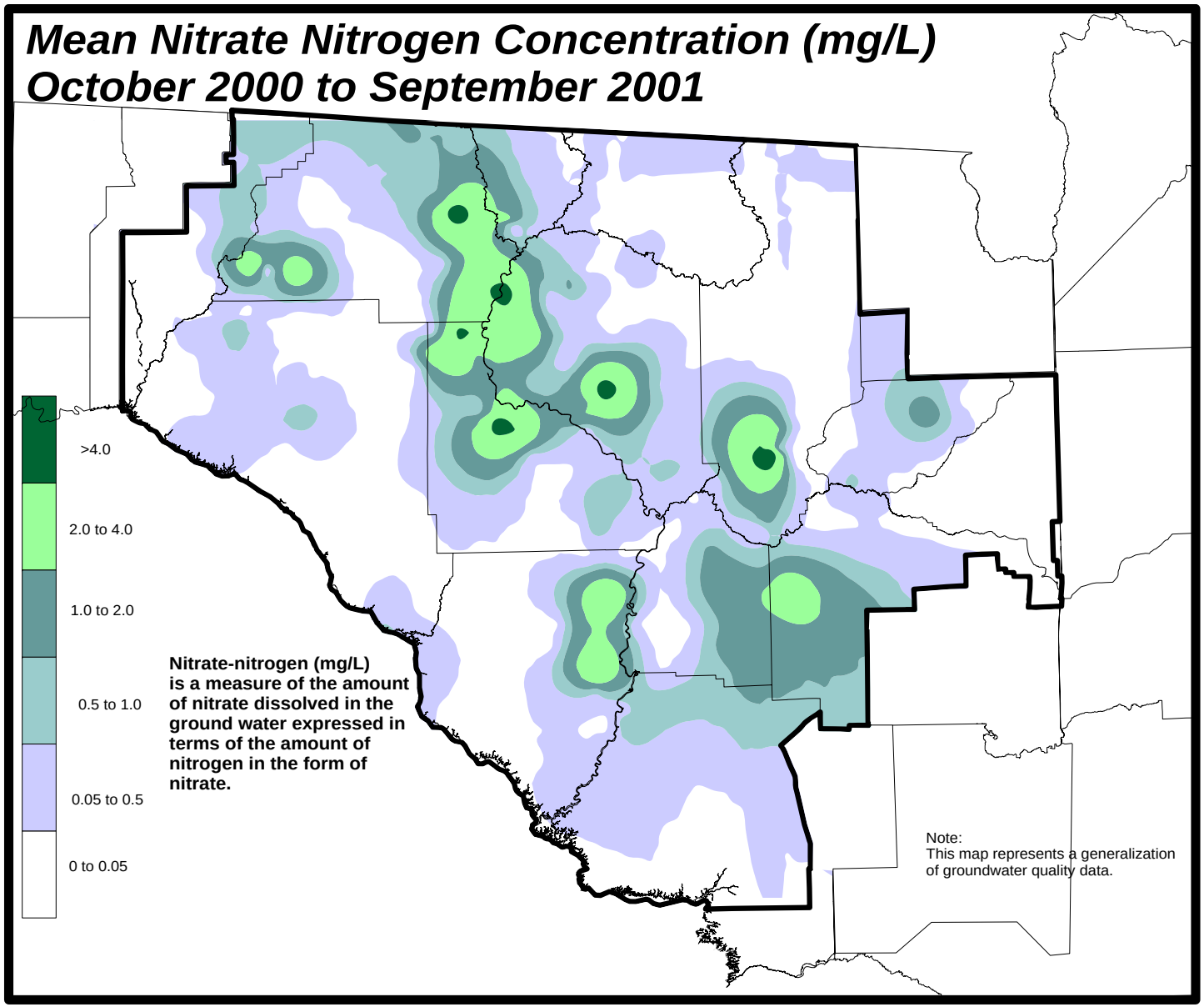

Figure B-2A. Mean upper Floridan aquifer NO_3-N concentration contour map for water year 2001.

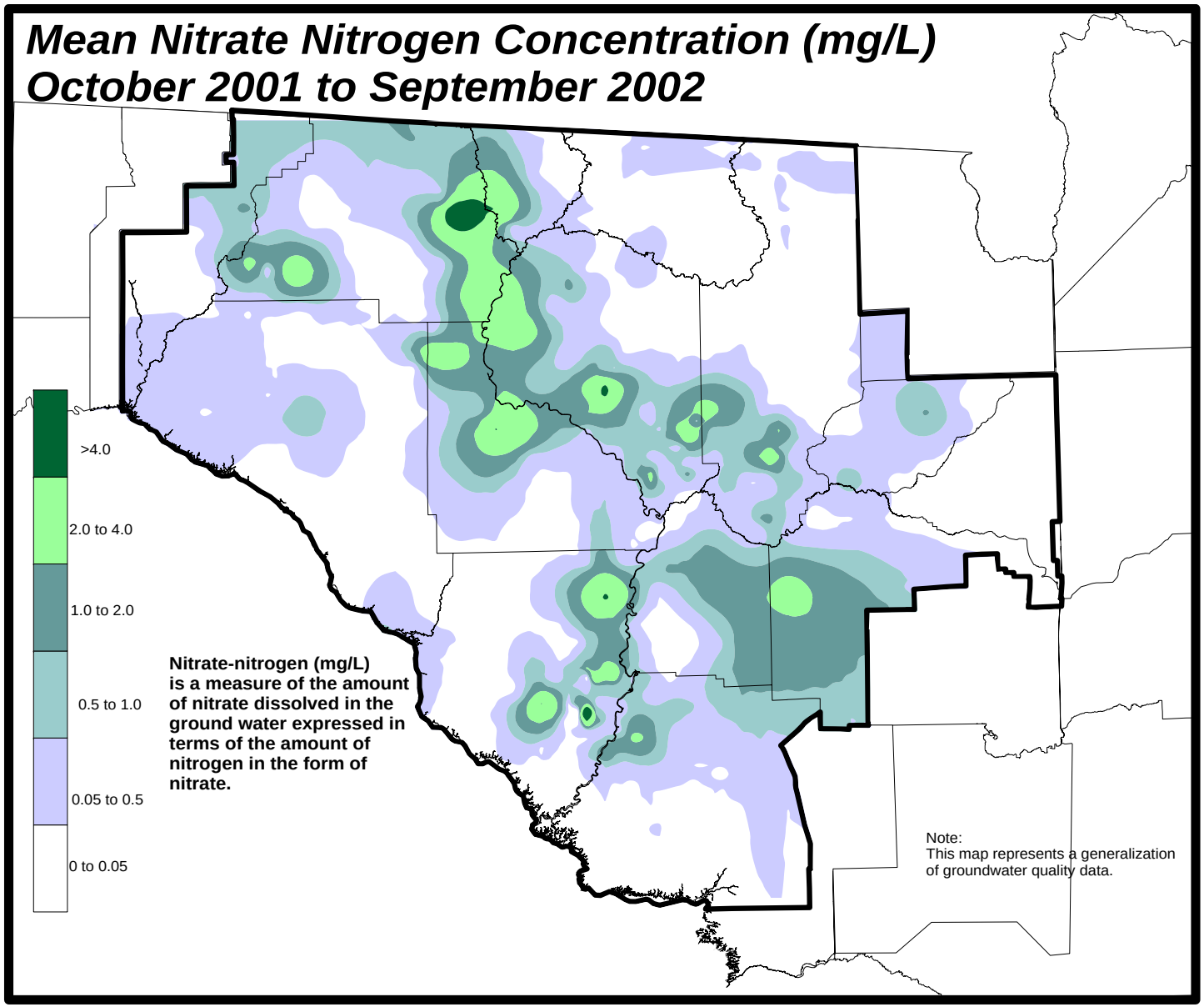

Figure B-2B. Mean upper Floridan aquifer NO_3-N concentration contour map for water year 2002.

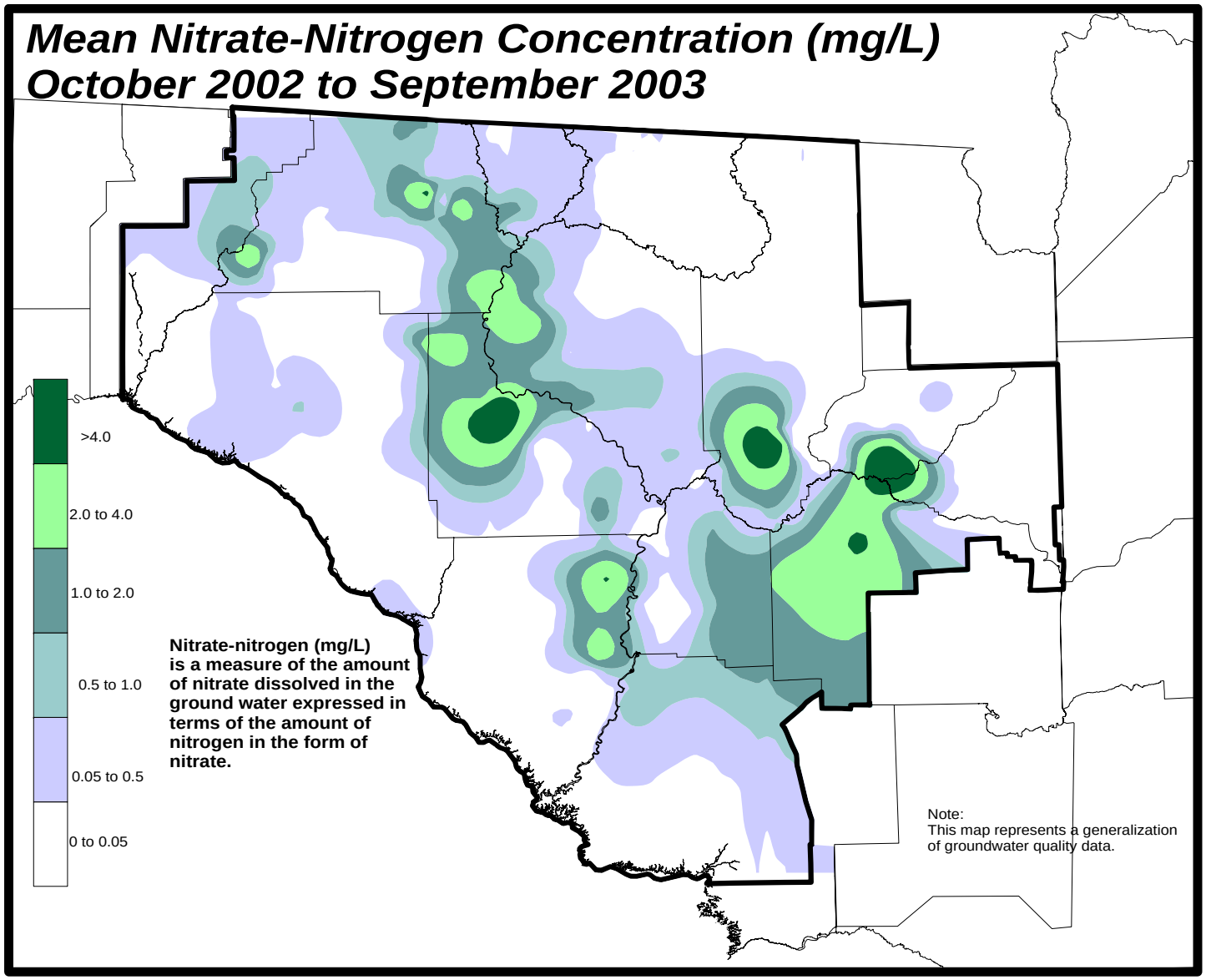

Figure B-2C. Mean upper Floridan aquifer NO_3-N concentration contour map for water year 2003.

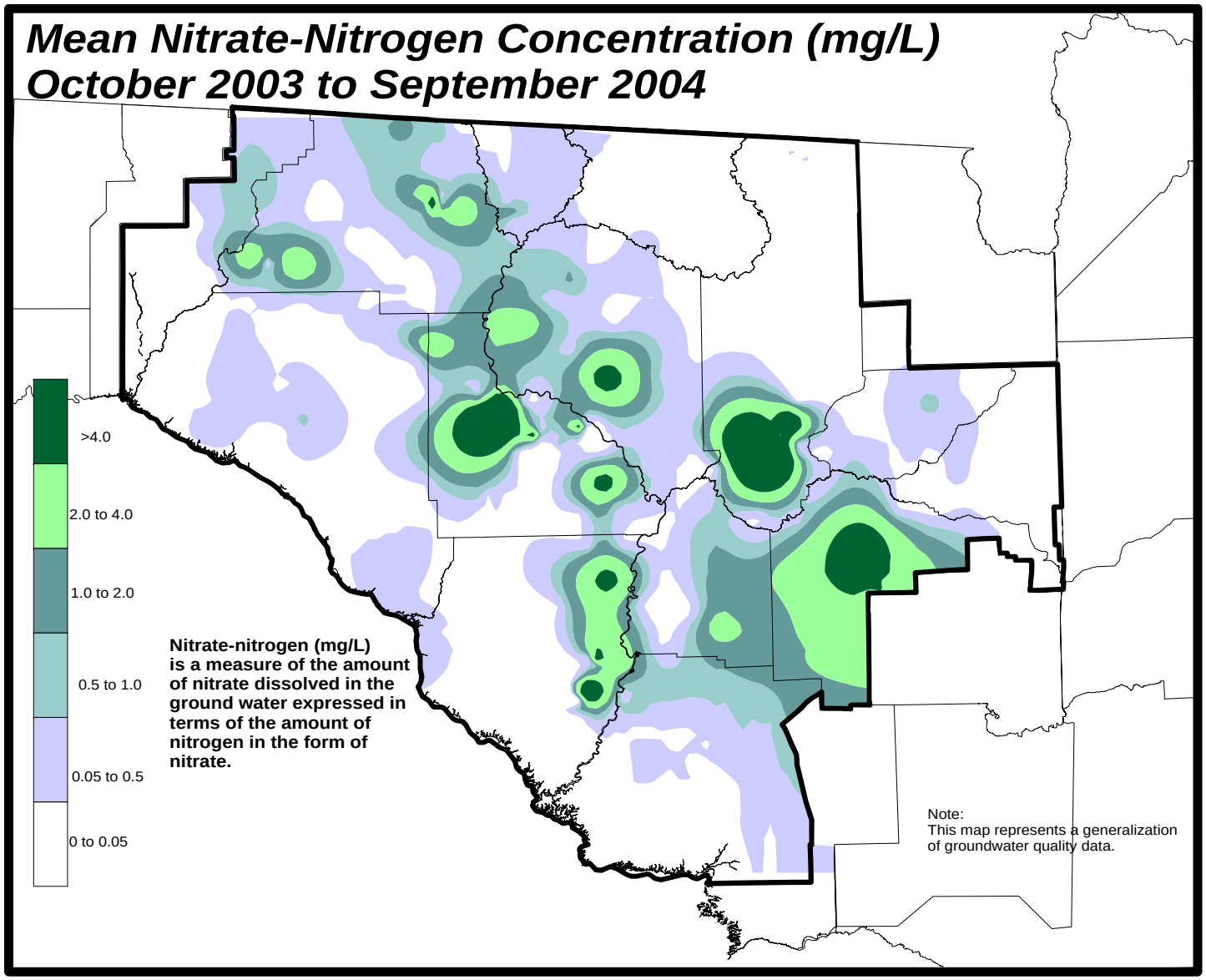

Figure B-2D. Mean upper Floridan aquifer NO_3-N concentration contour map for water year 2004.

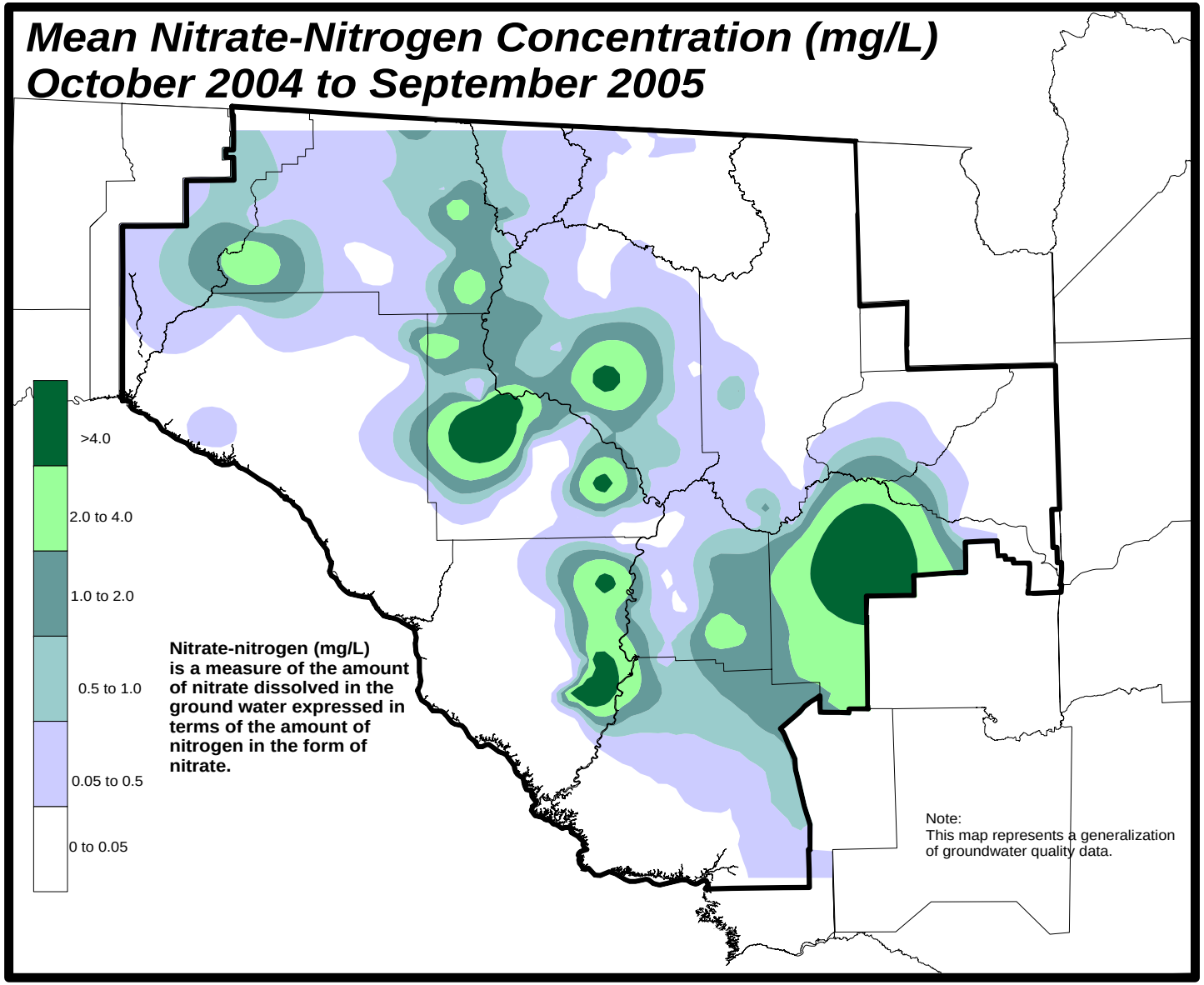

Figure B-2E. Mean upper Floridan aquifer NO_3-N concentration contour map for water year 2005.

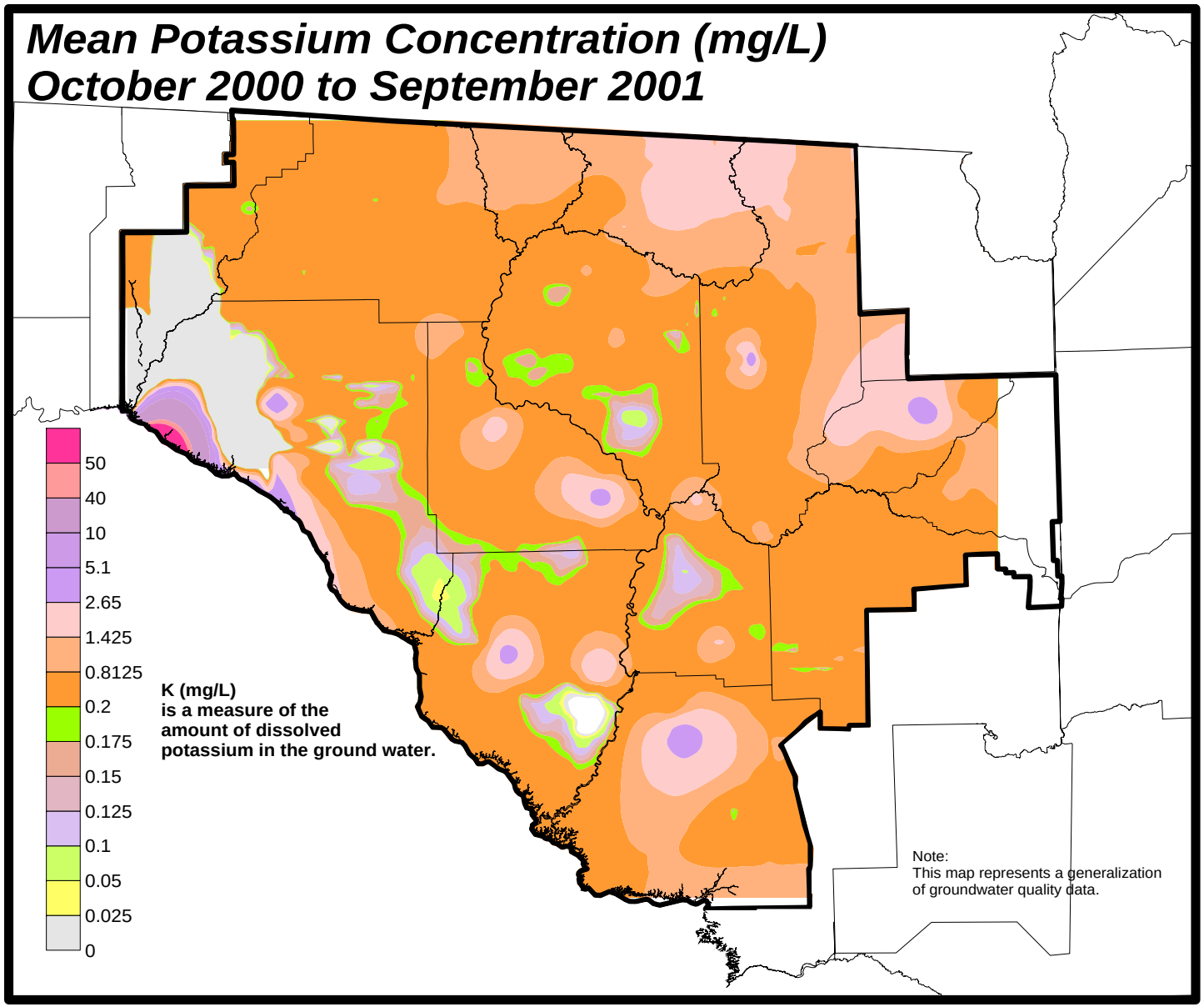

Figure B-3A. Mean upper Floridan aquifer K concentration contour map for water year 2001.

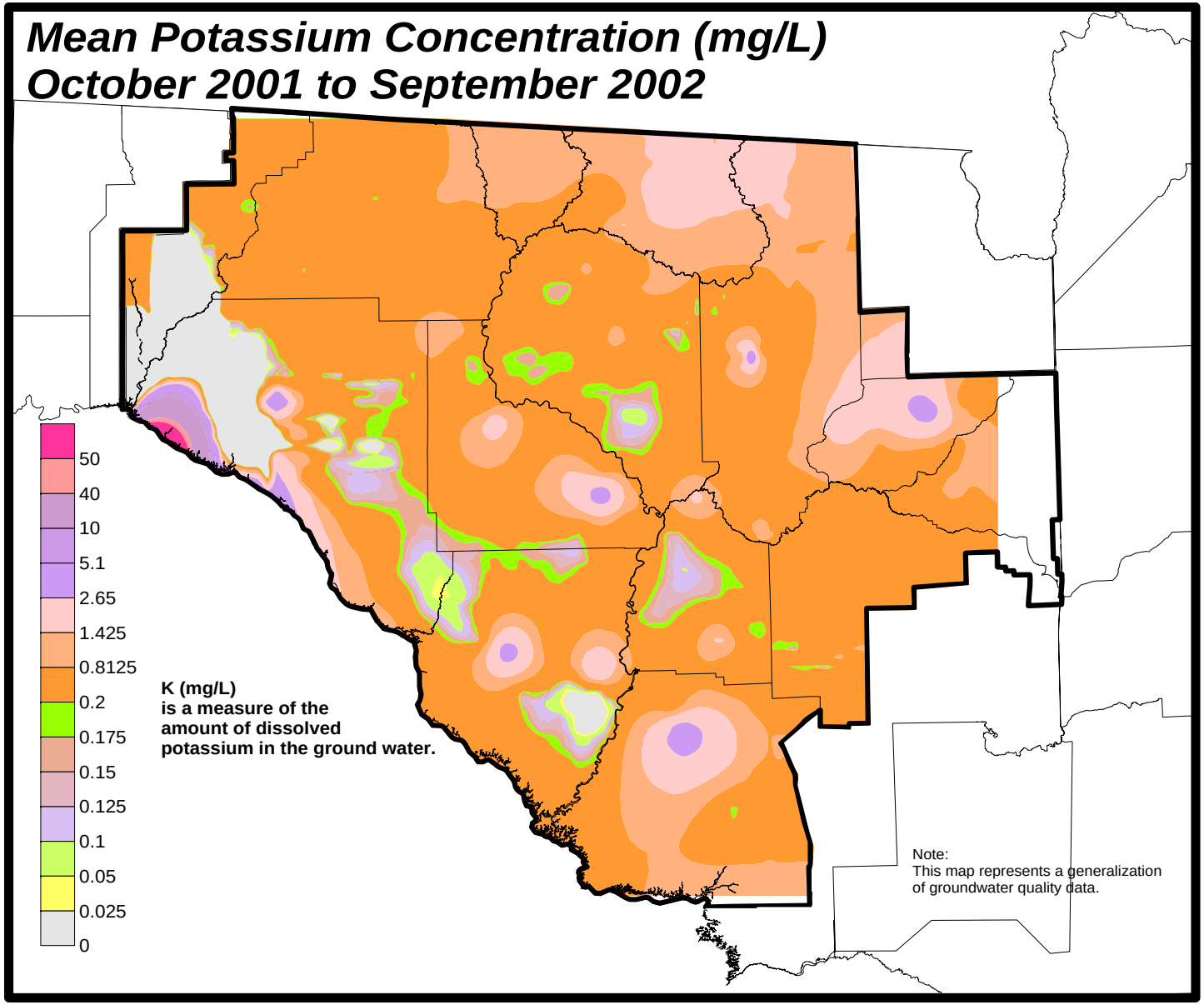

Figure B-3B. Mean upper Floridan aquifer K concentration contour map for water year 2002.

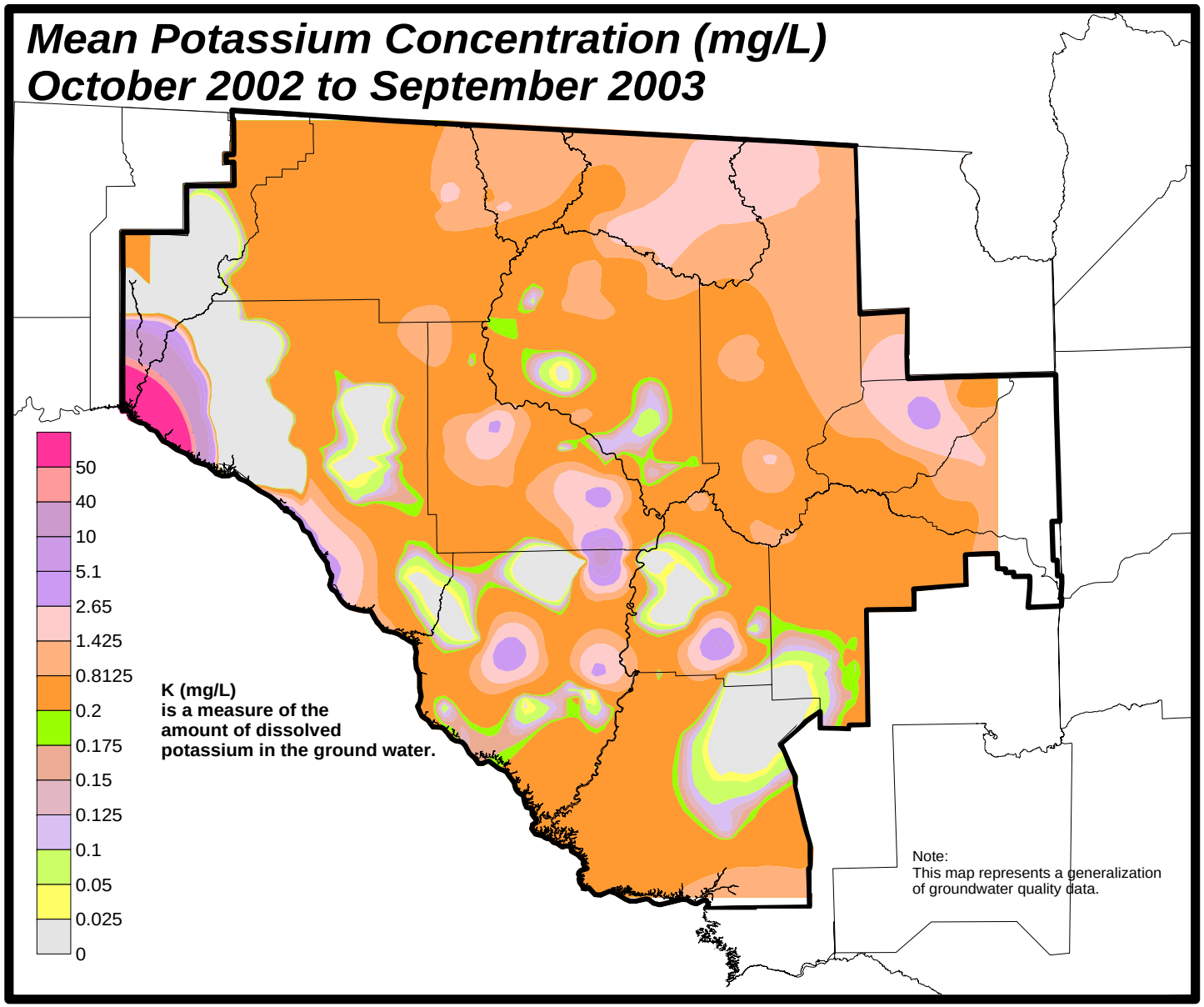

Figure B-3C. Mean upper Floridan aquifer K concentration contour map for water year 2003.

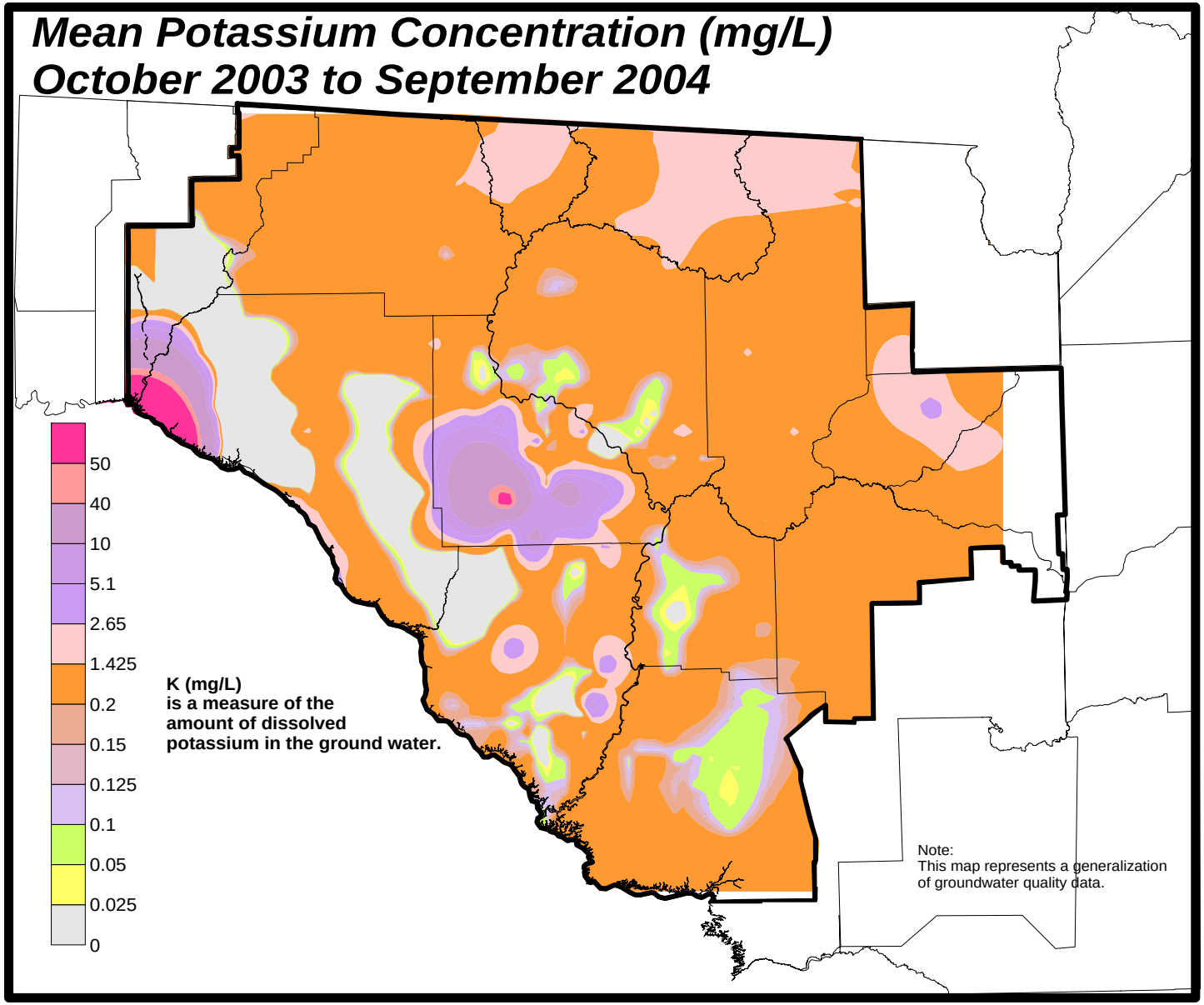

Figure B-3D. Mean upper Floridan aquifer K concentration contour map for water year 2004.

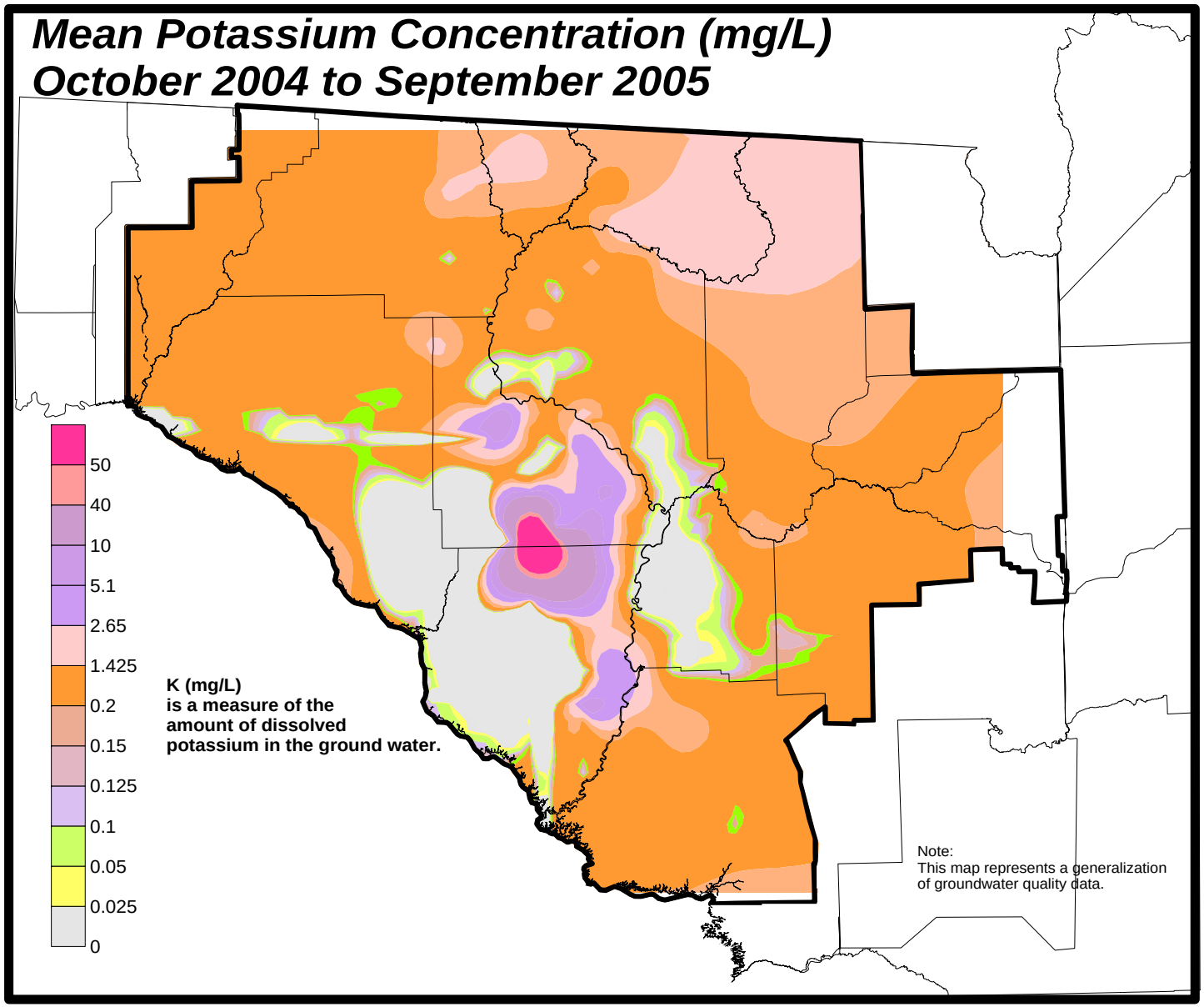

Figure B-3E. Mean upper Floridan aquifer K concentration contour map for water year 2005.

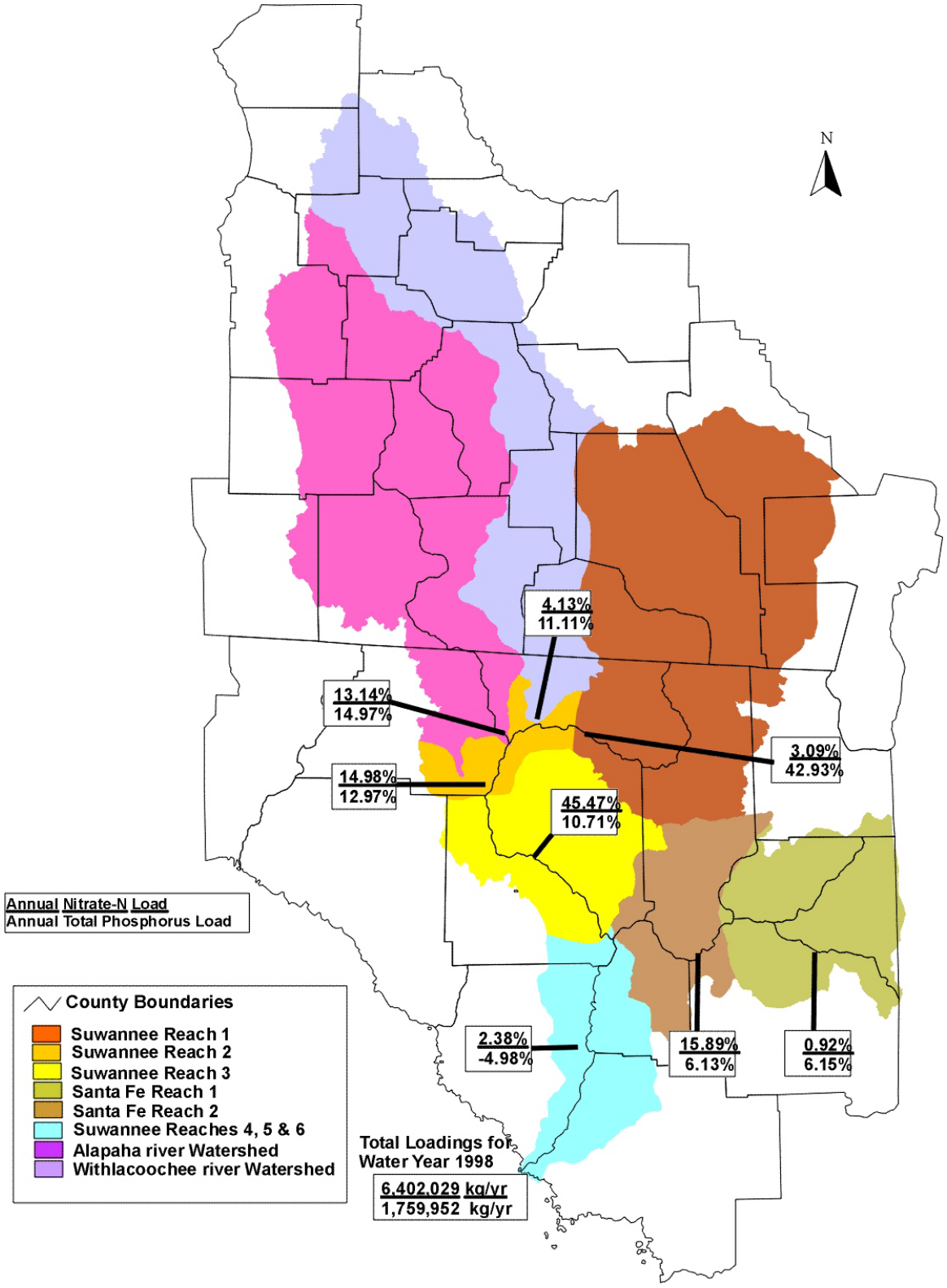

Figure B-4A. Suwannee River Basin loading by watershed/reach for water year 1998.

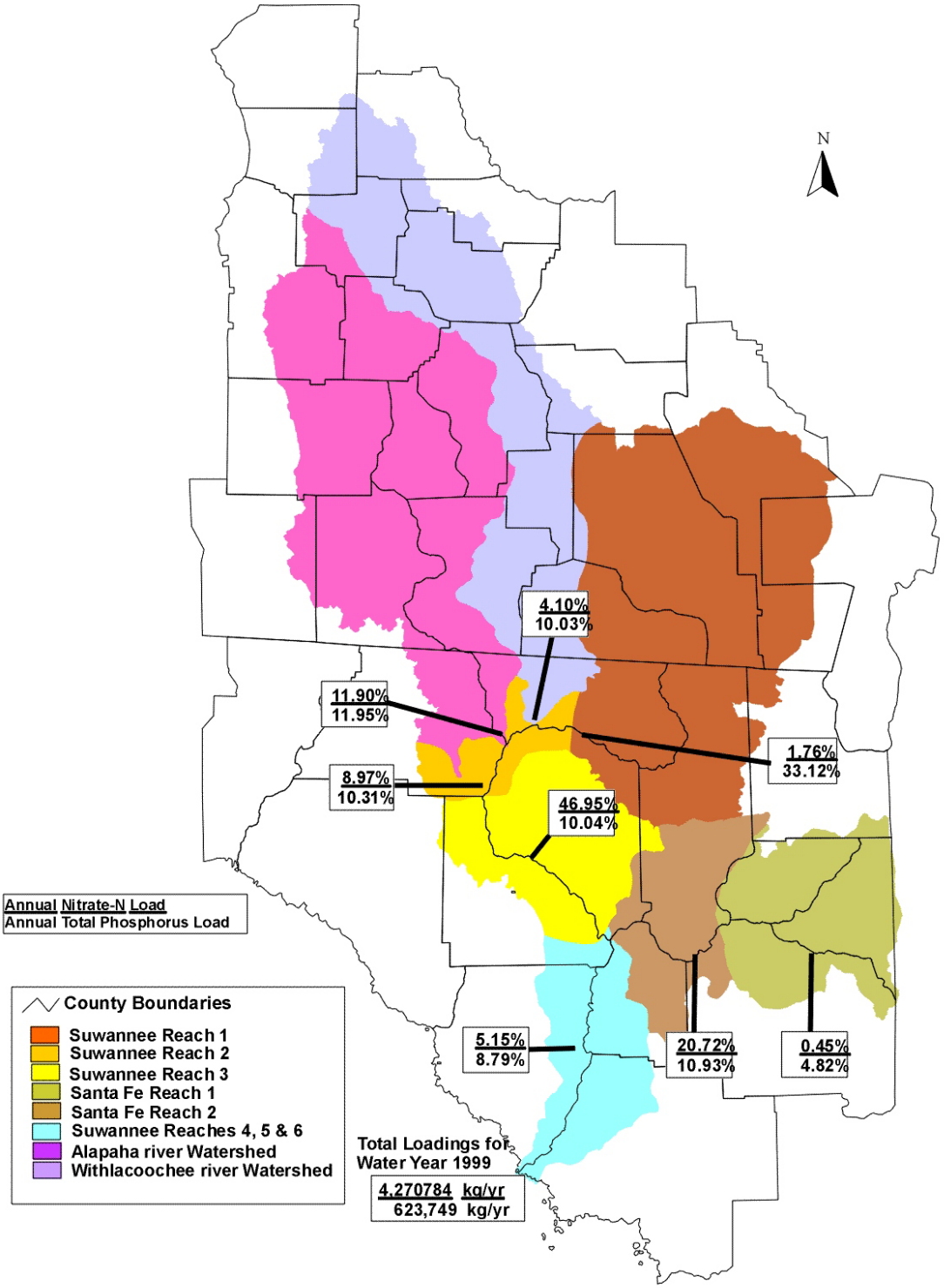

Figure B-4B. Suwannee River Basin loading by watershed/reach for water year 1999.

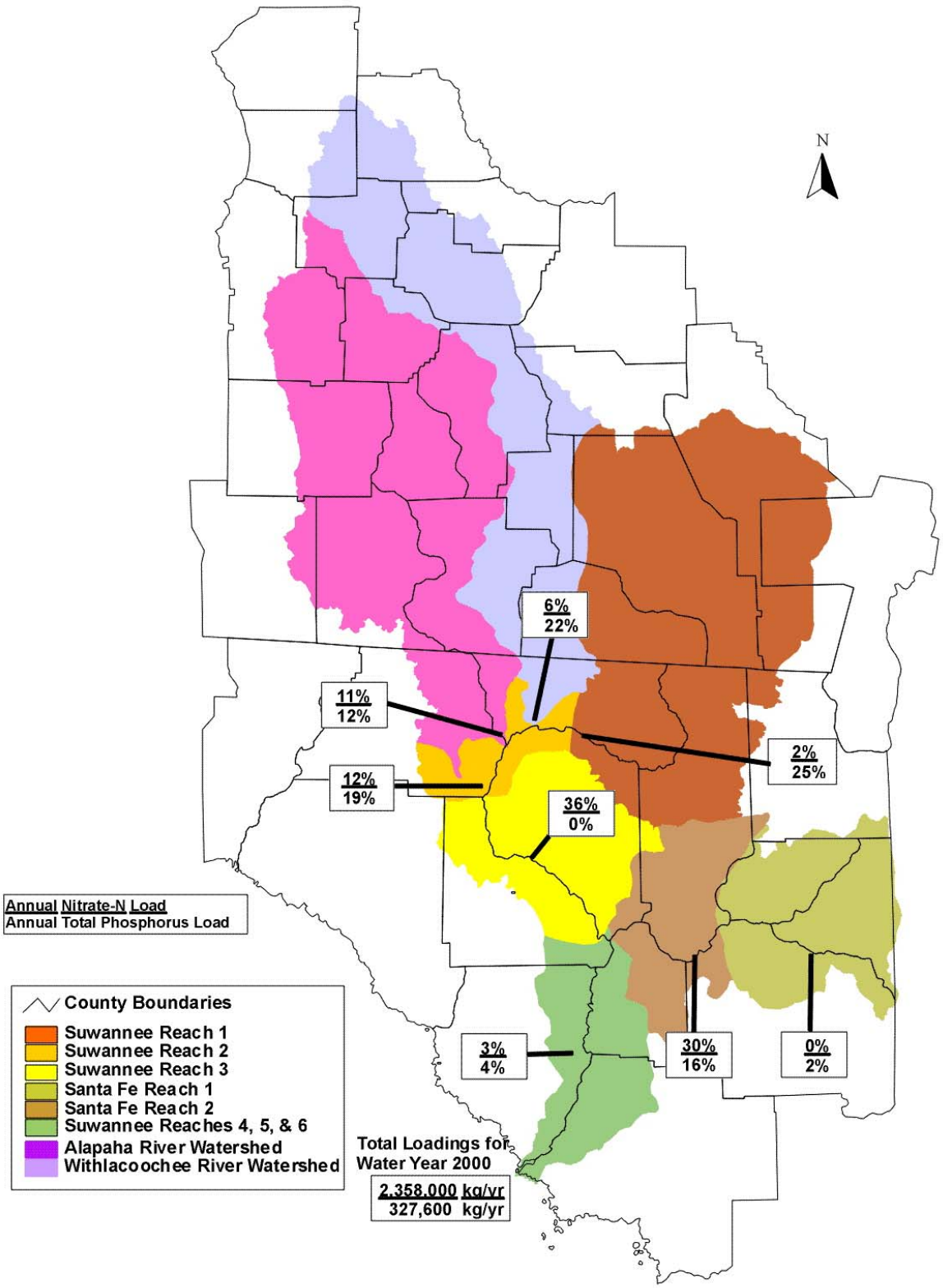

Figure B-4C. Suwannee River Basin loading by watershed/reach for water year 2000.

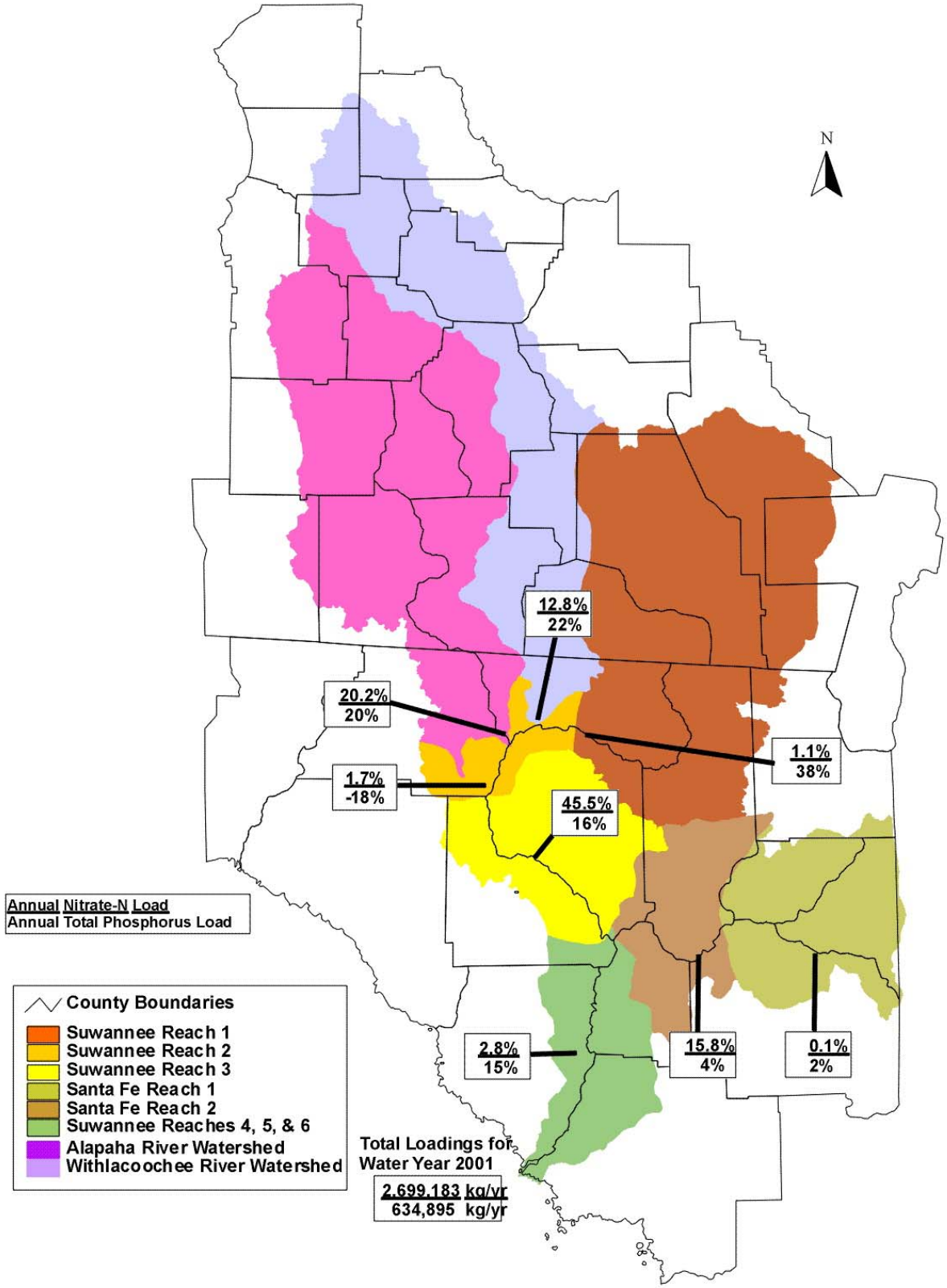

Figure B-4D. Suwannee River Basin loading by watershed/reach for water year 2001.

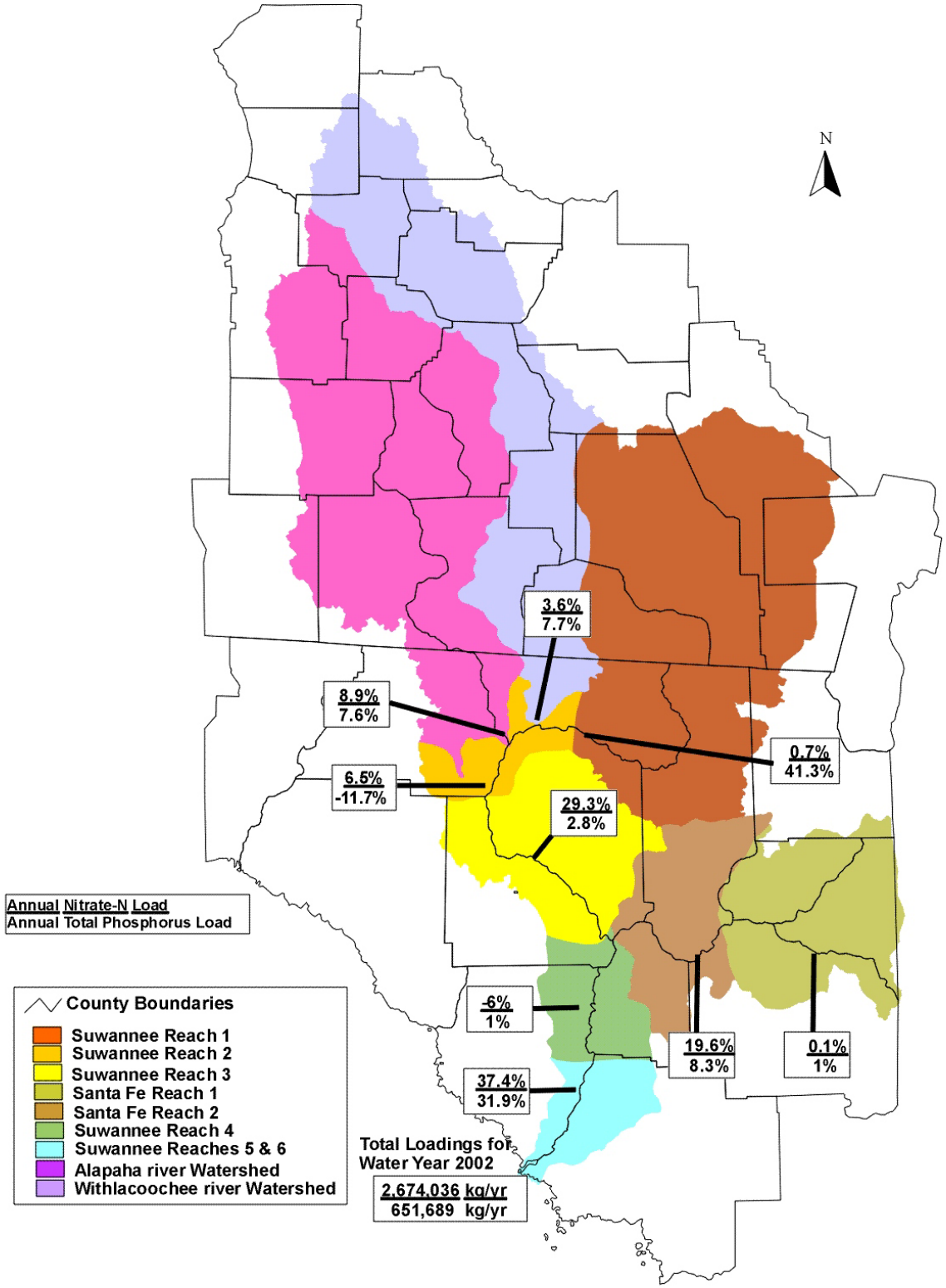

Figure B-4E. Suwannee River Basin loadings by watershed/reach for water year 2002.

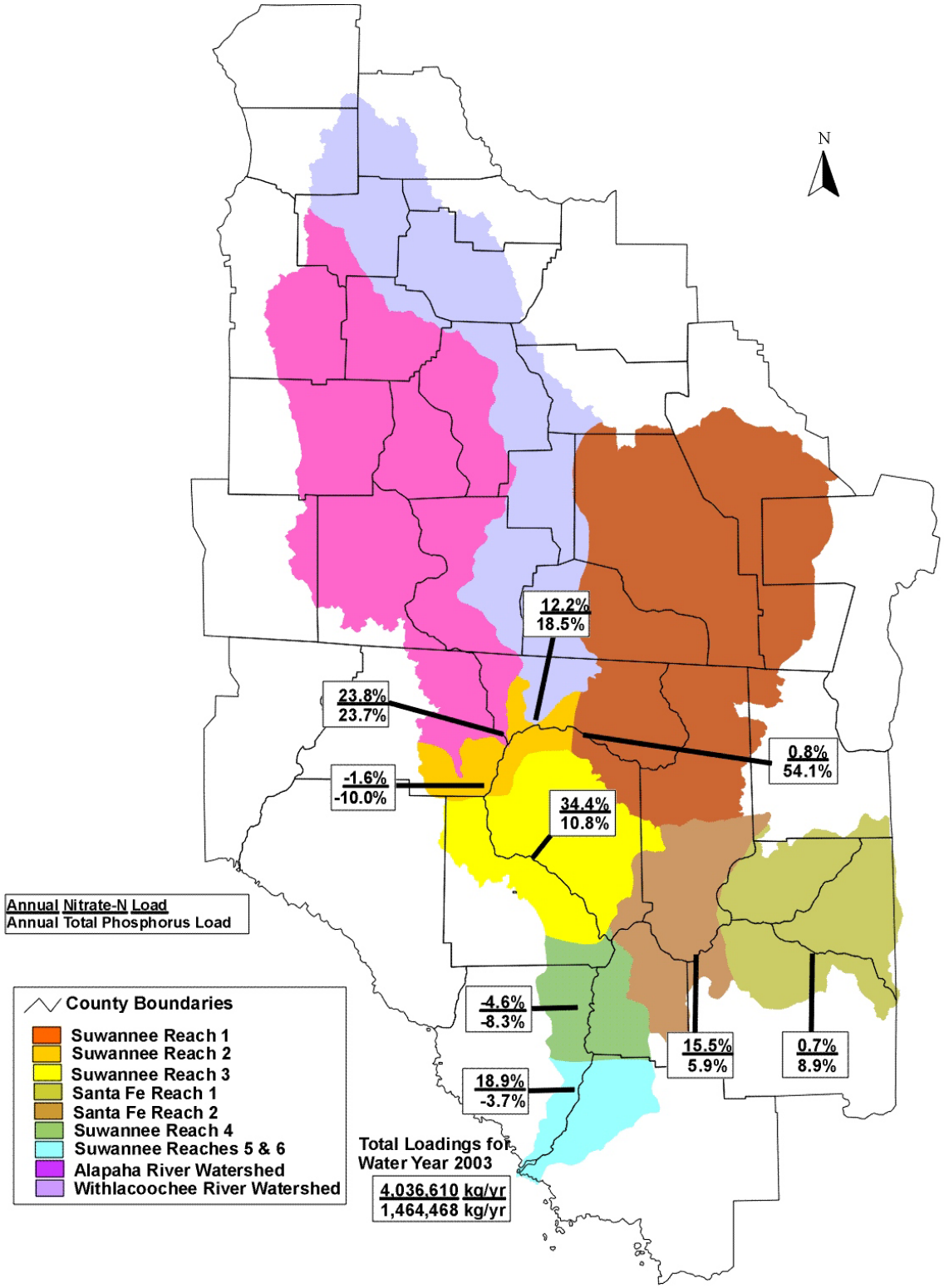

Figure B-4F. Suwannee River Basin loading by watershed/reach for water year 2003.

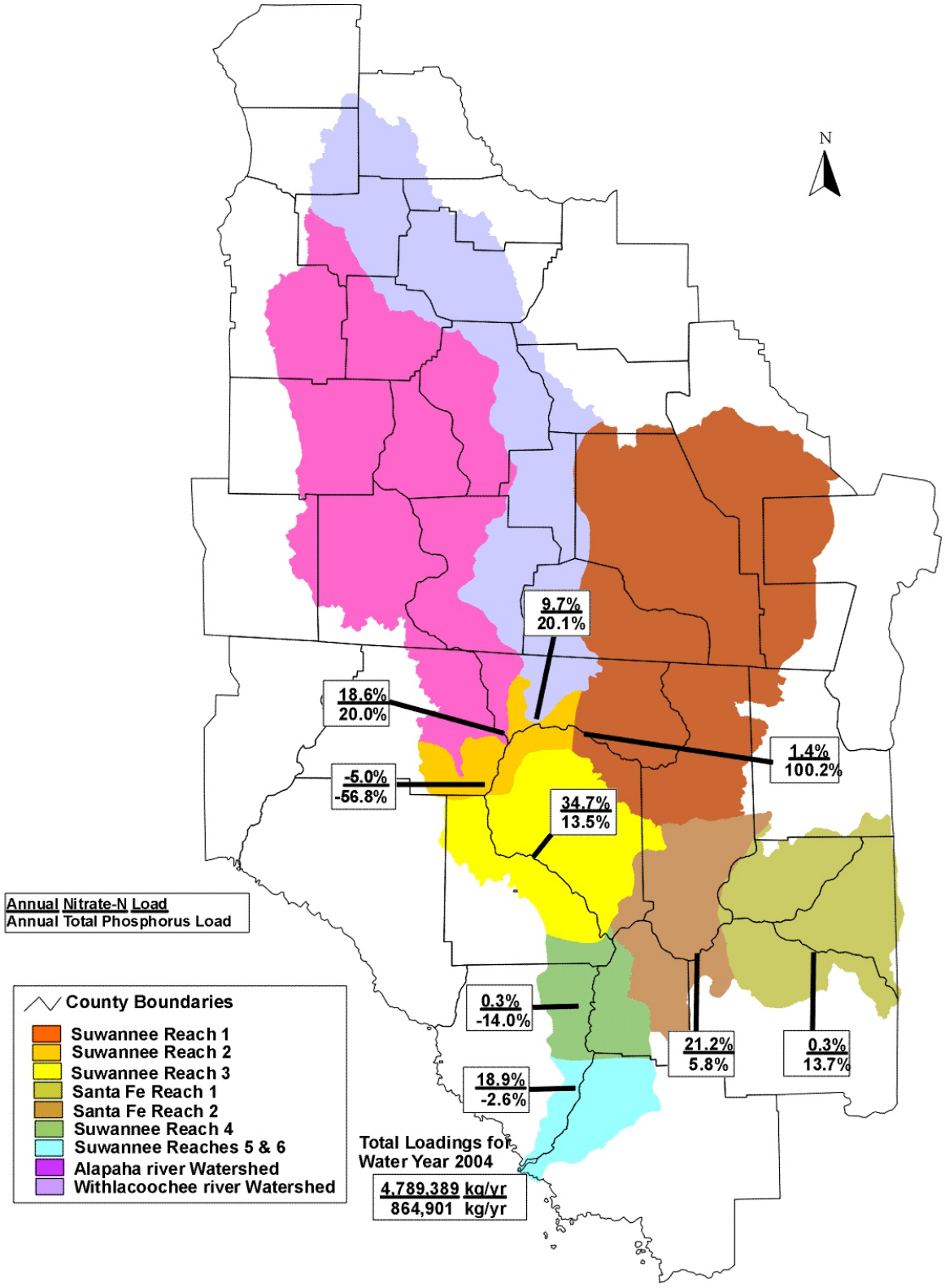

Figure B-4G. Suwannee River Basin loading by watershed/reach for water year 2004.

APPENDIX C
SELECTED MIDDLE SUWANNEE SPRINGS

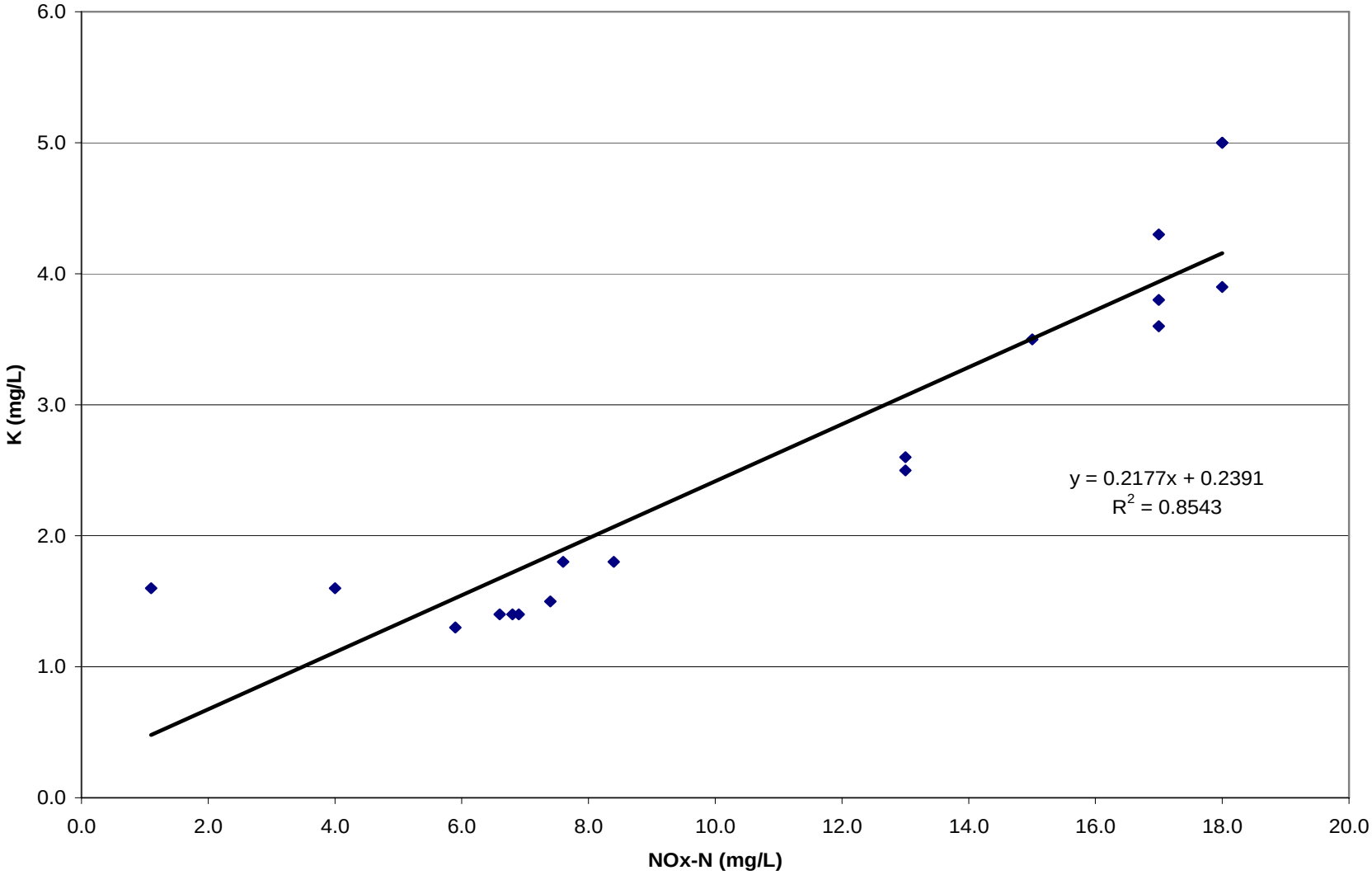

Figure C-1. Plot of NO_3-N versus K concentrations for spring SUW718971.

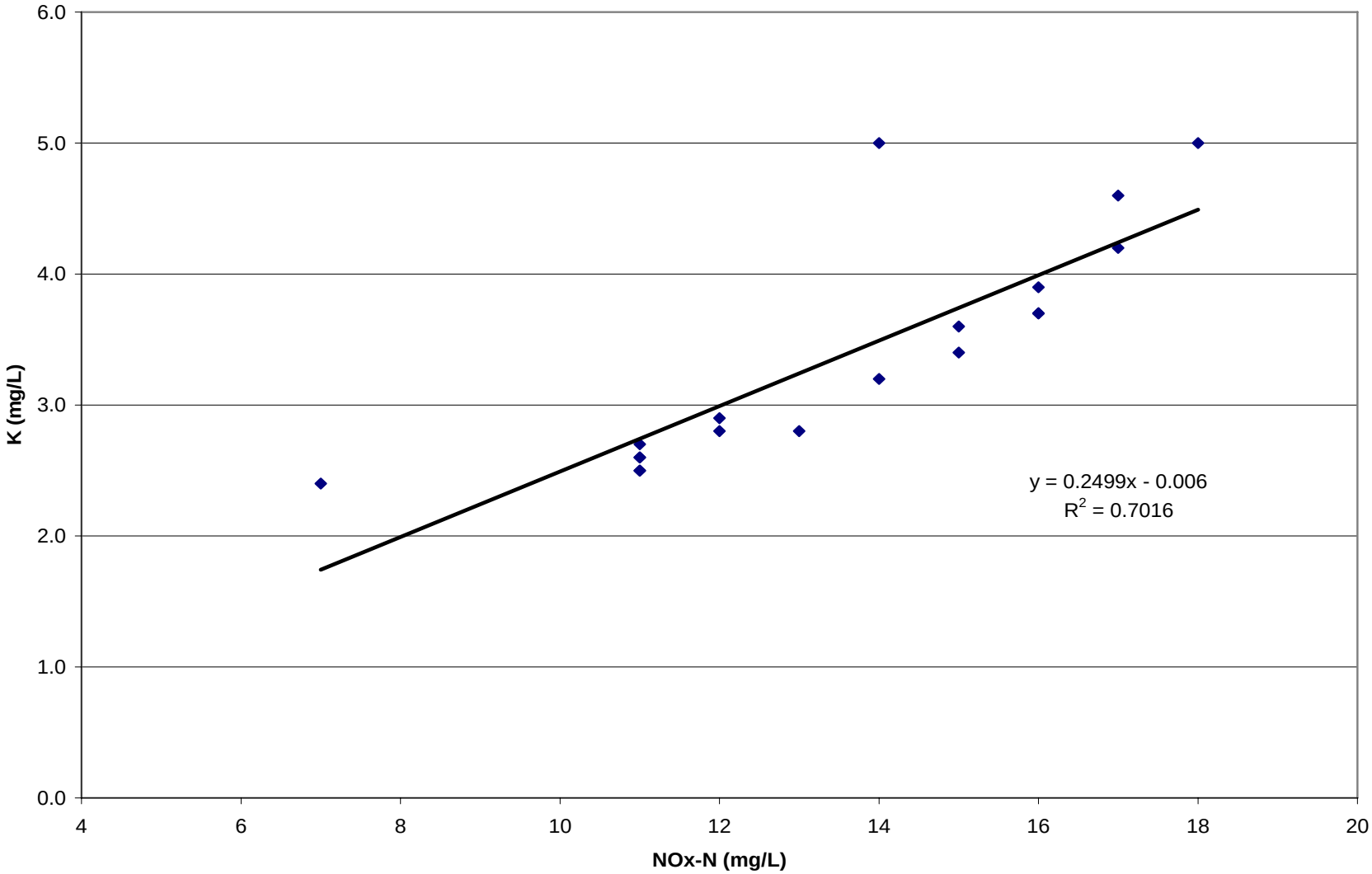

Figure C-2. Plot of NO_3-N versus K concentrations for spring SUW725971.

APPENDIX D
WATER QUALITY SUMMARY BY GROUNDWATER DOMAINS

Table D-1. Groundwater quality statistical summary by groundwater domain.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Temperature	°C	Alapaha	21.42	1.08	20.90	21.20	21.70	17.70	24.00
		Aucilla	20.72	2.31	20.40	21.00	21.40	0.00	23.60
		Coastal	21.56	1.40	20.60	21.80	22.40	16.90	27.50
		Dixie	22.22	1.67	20.93	21.90	23.70	18.80	24.30
		Ichetucknee	21.17	4.02	21.60	22.00	22.56	0.00	24.14
		Santa Fe	19.60	7.77	21.77	22.64	23.17	0.00	24.56
		Steinhatchee	20.18	5.25	20.90	21.20	21.80	0.00	25.83
		Suwannee	20.80	7.93	21.20	21.99	22.70	0.00	225.00
		Waccasassa	21.26	6.89	22.89	23.08	23.57	0.00	30.02
Specific Conductance	µmho cm^{-1}	Alapaha	375.1	141.9	240.0	363.0	498.0	6.0	695.0
		Aucilla	273.1	129.4	217.0	258.5	344.5	0.0	695.0
		Coastal	499.9	373.0	340.0	396.0	497.0	174.0	2301.0
		Dixie	474.7	62.4	410.5	475.5	534.0	385.0	590.0
		Ichetucknee	361.8	140.0	284.0	334.0	420.0	0.0	1170.0
		Santa Fe	294.2	103.7	258.8	301.5	355.0	0.0	617.0
		Steinhatchee	461.8	273.0	341.0	469.0	541.0	0.0	2714.0
		Suwannee	360.9	171.6	284.0	358.5	440.0	0.0	1815.0
		Waccasassa	370.2	183.5	329.5	353.0	537.0	0.0	588.0
pH	su	Alapaha	7.33	0.29	7.14	7.24	7.50	6.58	8.05
		Aucilla	9.60	39.05	6.52	6.90	7.31	0.00	542.00
		Coastal	6.88	0.43	6.70	6.85	7.14	5.50	8.02
		Dixie	6.77	0.44	6.53	6.80	6.99	5.72	7.76
		Ichetucknee	7.03	1.30	7.01	7.33	7.53	0.00	8.67
		Santa Fe	7.04	1.59	7.18	7.37	7.53	0.00	8.42
		Steinhatchee	6.63	0.91	6.47	6.77	6.98	0.00	7.64
		Suwannee	7.58	19.33	6.81	7.10	7.33	0.00	586.00
		Waccasassa	6.86	0.69	6.75	7.01	7.24	4.22	7.68

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Turbidity	NTU	Alapaha	2.34	3.30	0.15	0.85	3.60	0.00	18.20
		Aucilla	12.28	45.98	0.55	4.63	10.33	0.00	508.00
		Coastal	14.86	19.86	1.00	11.00	16.50	0.00	110.00
		Dixie	1.14	1.19	0.28	0.85	1.68	0.00	4.90
		Ichetucknee	3.94	11.22	0.24	0.75	3.00	0.00	175.00
		Santa Fe	2.33	7.53	0.24	0.64	1.65	0.00	77.50
		Steinhatchee	29.50	103.38	3.80	9.00	18.10	0.00	986.00
		Suwannee	13.30	51.95	0.35	1.55	7.80	0.00	750.00
		Waccasassa	8.62	9.46	1.72	4.03	15.45	0.00	44.50
Total Dissolved Solids	mg L^{-1}	Alapaha	230.20	86.85	149.50	217.00	293.00	102.00	480.00
		Aucilla	168.47	80.83	123.00	145.00	204.50	22.00	440.00
		Coastal	1002.00	4395.00	201.00	234.00	291.00	120.00	36800.00
		Dixie	239.40	91.90	232.80	265.00	295.00	0.00	325.00
		Ichetucknee	222.09	100.08	169.00	204.00	250.00	0.00	972.00
		Santa Fe	170.29	45.55	144.00	173.00	201.00	40.00	312.00
		Steinhatchee	326.80	359.50	211.00	319.00	345.00	0.00	4040.00
		Suwannee	231.40	299.10	168.30	208.00	260.00	0.00	10200.00
		Waccasassa	228.70	79.30	176.50	200.50	302.00	26.00	341.00
Alkalinity	mg L^{-1}	Alapaha	190.99	75.20	125.00	174.00	243.00	52.50	369.00
		Aucilla	135.80	77.38	89.03	124.50	178.75	0.30	359.00
		Coastal	197.62	57.95	141.50	190.00	265.00	88.00	310.00
		Dixie	208.40	76.00	201.80	237.50	255.80	0.00	270.00
		Ichetucknee	161.38	48.62	132.00	164.00	188.00	0.00	294.00
		Santa Fe	141.23	41.10	127.75	142.00	163.00	15.00	343.00
		Steinhatchee	234.48	89.45	184.00	275.00	293.00	0.00	660.00
		Suwannee	171.03	62.57	139.00	176.00	211.00	0.00	486.00
		Waccasassa	211.20	76.20	173.50	184.50	283.00	5.60	293.00

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Total Organic carbon	mg L^{-1}	Alapaha	2.54	2.78	0.68	1.70	3.71	0.00	15.90
		Aucilla	3.33	5.36	0.64	1.13	3.48	0.00	33.20
		Coastal	4.40	4.75	0.75	2.48	7.94	0.00	21.20
		Dixie	1.31	1.03	0.60	1.18	2.07	0.00	3.99
		Ichetucknee	1.76	3.13	0.38	0.71	1.79	0.00	35.20
		Santa Fe	1.47	2.18	0.38	0.64	1.63	0.00	20.64
		Steinhatchee	11.44	12.29	3.07	8.30	16.60	0.00	79.60
		Suwannee	2.93	5.45	0.59	1.10	3.00	0.00	57.20
		Waccasassa	3.24	2.67	1.06	2.68	5.61	0.00	10.80
Dissolved Organic carbon	mg L^{-1}	Alapaha	3.11	2.75	1.00	2.37	4.29	0.38	16.00
		Aucilla	4.14	5.76	0.91	2.08	4.92	0.38	48.40
		Coastal	5.44	4.45	1.53	4.44	8.08	0.80	19.50
		Dixie	3.39	4.22	0.85	1.69	4.51	0.85	19.10
		Ichetucknee	2.52	3.47	0.85	1.14	2.92	0.00	34.70
		Santa Fe	2.82	2.66	0.85	1.82	4.20	0.38	21.07
		Steinhatchee	11.74	9.87	4.04	8.30	17.54	0.00	56.76
		Suwannee	3.98	5.93	0.85	1.96	4.71	0.00	61.60
		Waccasassa	4.74	3.67	1.51	5.04	6.45	0.85	18.70
Potassium	mg L^{-1}	Alapaha	1.13	0.59	0.49	1.31	1.62	0.14	2.80
		Aucilla	0.37	0.35	0.21	0.33	0.44	0.01	4.22
		Coastal	7.57	38.75	0.17	0.26	0.40	0.05	243.00
		Dixie	0.08	0.05	0.04	0.05	0.15	0.02	0.16
		Ichetucknee	0.76	2.29	0.28	0.51	0.90	0.05	49.30
		Santa Fe	0.67	1.62	0.16	0.30	0.68	0.01	16.70
		Steinhatchee	1.08	6.00	0.11	0.18	0.51	0.00	68.10
		Suwannee	1.26	6.07	0.20	0.41	0.81	0.00	200.00
		Waccasassa	0.63	0.60	0.13	0.17	1.27	0.05	1.55

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Sodium	mg L^{-1}	Alapaha	7.25	6.01	3.14	4.30	10.45	0.94	21.50
		Aucilla	5.82	15.67	2.36	2.80	3.39	0.71	107.00
		Coastal	156.10	785.20	3.13	3.54	4.67	2.77	4800.00
		Dixie	8.08	2.50	6.90	7.92	9.52	1.79	13.60
		Ichetucknee	5.79	4.43	2.97	4.30	6.52	0.38	23.00
		Santa Fe	4.00	2.10	2.47	2.98	6.04	0.42	13.50
		Steinhatchee	14.65	67.51	3.94	4.45	5.00	0.00	722.00
		Suwannee	5.44	16.04	2.52	3.11	4.56	0.04	329.00
		Waccasassa	3.95	1.11	2.99	3.18	5.16	2.20	5.64
Magnesium	mg L^{-1}	Alapaha	14.12	11.77	3.63	10.50	25.50	1.17	41.10
		Aucilla	7.94	8.60	2.41	4.50	7.32	0.00	41.70
		Coastal	32.35	74.05	16.05	18.40	20.25	10.50	536.00
		Dixie	1.34	0.22	1.20	1.37	1.46	0.87	1.86
		Ichetucknee	8.81	7.56	2.81	5.45	14.80	0.03	32.80
		Santa Fe	5.21	4.68	1.48	3.53	7.72	0.35	17.80
		Steinhatchee	7.77	4.76	3.86	7.86	10.40	0.00	28.80
		Suwannee	7.02	11.27	1.98	4.27	9.05	0.03	290.00
		Waccasassa	8.83	2.32	9.01	9.30	9.75	0.49	10.40
Calcium	mg L^{-1}	Alapaha	54.16	17.62	40.20	59.90	66.75	7.14	86.30
		Aucilla	43.18	23.11	32.10	39.10	62.60	0.09	112.00
		Coastal	64.60	26.80	47.65	56.50	80.15	22.70	221.00
		Dixie	94.98	9.89	89.90	96.15	101.75	67.80	108.00
		Ichetucknee	59.27	27.59	40.40	52.30	74.30	3.52	215.00
		Santa Fe	51.54	16.41	39.83	52.90	63.98	6.70	118.00
		Steinhatchee	80.67	35.03	67.60	95.10	107.00	0.00	138.00
		Suwannee	67.48	43.37	48.30	62.70	83.80	0.02	913.00
		Waccasassa	69.46	27.61	54.30	58.50	96.23	0.66	105.00

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Chloride	mg L^{-1}	Alapaha	6.36	3.58	3.65	6.07	8.46	1.56	30.10
		Aucilla	4.94	1.88	3.97	4.51	5.43	1.62	18.20
		Coastal	292.00	1496.00	5.32	5.99	6.96	3.22	9870.00
		Dixie	11.66	5.63	10.13	11.70	15.13	0.00	21.90
		Ichetucknee	9.41	11.29	4.66	5.93	8.46	0.00	76.10
		Santa Fe	6.93	3.64	4.80	5.48	7.37	0.15	24.30
		Steinhatchee	17.93	56.51	6.97	8.15	9.43	0.00	457.00
		Suwannee	7.66	11.64	4.19	5.44	7.87	0.00	222.00
		Waccasassa	6.06	1.44	4.98	5.54	7.44	3.00	9.02
Fluoride	mg L^{-1}	Alapaha	0.29	0.18	0.11	0.32	0.45	0.02	0.78
		Aucilla	0.21	0.14	0.11	0.16	0.27	0.02	0.76
		Coastal	0.61	3.15	0.14	0.20	0.25	0.03	29.90
		Dixie	0.05	0.04	0.02	0.04	0.06	0.00	0.17
		Ichetucknee	0.20	0.15	0.07	0.15	0.31	0.00	0.84
		Santa Fe	0.14	0.09	0.07	0.10	0.22	0.02	0.51
		Steinhatchee	0.12	0.09	0.06	0.11	0.15	0.00	0.53
		Suwannee	0.11	0.09	0.05	0.10	0.15	0.00	1.14
		Waccasassa	0.15	0.05	0.11	0.14	0.18	0.05	0.25
Sulfate	mg L^{-1}	Alapaha	9.28	14.22	2.05	5.27	11.50	0.00	99.10
		Aucilla	2.25	2.56	0.40	1.72	3.09	0.00	18.30
		Coastal	53.40	191.00	1.01	6.38	40.20	0.00	1140.00
		Dixie	7.93	4.39	6.99	7.82	9.89	0.00	18.70
		Ichetucknee	15.80	40.20	1.92	4.86	10.60	0.00	271.00
		Santa Fe	3.92	2.55	1.88	4.18	5.51	0.00	13.20
		Steinhatchee	2.34	3.71	0.18	0.96	3.53	0.00	22.40
		Suwannee	11.85	3.56	2.48	6.37	13.30	0.00	52.00
		Waccasassa	1.18	2.93	0.18	0.53	1.30	0.00	19.60

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Iron	mg L^{-1}	Alapaha	0.25	0.43	0.02	0.08	0.36	0.00	2.84
		Aucilla	1.26	4.55	0.03	0.49	1.48	0.00	54.10
		Coastal	1.32	1.63	0.04	0.72	2.45	0.01	9.01
		Dixie	0.21	0.88	0.01	0.01	0.02	0.00	3.94
		Ichetucknee	0.31	0.91	0.02	0.06	0.23	0.00	12.50
		Santa Fe	0.31	1.46	0.03	0.10	0.25	0.00	16.70
		Steinhatchee	2.70	2.47	1.28	1.68	3.57	0.00	15.50
		Suwannee	1.02	4.07	0.03	0.13	0.97	0.00	131.00
		Waccasassa	1.62	1.14	0.50	1.72	2.63	0.42	4.46
Lead	mg L^{-1}	Alapaha	0.003	0.002	0.002	0.003	0.003	0.000	0.025
		Aucilla	0.004	0.006	0.002	0.003	0.003	0.000	0.043
		Coastal	0.003	0.001	0.002	0.003	0.003	0.000	0.009
		Dixie	0.002	0.001	0.002	0.003	0.003	0.000	0.003
		Ichetucknee	0.003	0.003	0.002	0.003	0.003	0.000	0.064
		Santa Fe	0.002	0.002	0.002	0.003	0.003	0.000	0.010
		Steinhatchee	0.003	0.007	0.002	0.003	0.003	0.000	0.064
		Suwannee	0.005	0.058	0.002	0.003	0.003	0.000	2.100
		Waccasassa	0.002	0.001	0.002	0.003	0.003	0.000	0.006
Nitrate+Nitrite-Nitrogen	mg L^{-1}	Alapaha	0.18	0.56	0.00	0.01	0.09	0.00	3.94
		Aucilla	0.62	1.12	0.01	0.03	0.62	0.00	4.16
		Coastal	0.09	0.17	0.00	0.02	0.11	0.00	1.05
		Dixie	0.02	0.02	0.00	0.02	0.03	0.00	0.07
		Ichetucknee	0.62	1.74	0.01	0.25	0.73	0.00	27.20
		Santa Fe	1.41	1.73	0.02	1.21	1.62	0.00	10.60
		Steinhatchee	0.03	0.09	0.00	0.01	0.03	0.00	0.73
		Suwannee	1.69	13.79	0.02	0.31	1.31	0.00	488.00
		Waccasassa	0.01	0.02	0.00	0.01	0.01	0.00	0.09

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
TKN	mg L^{-1}	Alapaha	0.36	0.37	0.14	0.26	0.50	0.04	2.43
		Aucilla	0.33	0.37	0.11	0.24	0.37	0.04	3.00
		Coastal	0.52	0.87	0.16	0.30	0.56	0.05	6.00
		Dixie	0.20	0.13	0.11	0.17	0.25	0.05	0.60
		Ichetucknee	0.24	0.23	0.11	0.18	0.31	0.04	2.00
		Santa Fe	0.24	0.33	0.11	0.15	0.27	0.04	3.70
		Steinhatchee	0.69	0.70	0.30	0.53	0.91	0.00	5.22
		Suwannee	0.32	0.44	0.11	0.20	0.38	0.00	8.50
		Waccasassa	0.40	0.23	0.20	0.37	0.60	0.05	0.94
Ammonia-nitrogen	mg L^{-1}	Alapaha	0.13	0.30	0.04	0.04	0.10	0.00	2.40
		Aucilla	0.06	0.08	0.02	0.04	0.05	0.00	0.50
		Coastal	0.18	0.58	0.02	0.04	0.20	0.00	5.25
		Dixie	0.03	0.03	0.02	0.04	0.04	0.00	0.10
		Ichetucknee	0.06	0.10	0.02	0.04	0.06	0.00	1.01
		Santa Fe	0.06	0.22	0.02	0.04	0.04	0.00	3.54
		Steinhatchee	0.16	0.15	0.04	0.12	0.22	0.00	0.59
		Suwannee	0.09	0.33	0.02	0.04	0.09	0.00	10.10
		Waccasassa	0.19	0.16	0.04	0.18	0.31	0.00	0.61
Total Phosphorus	mg L^{-1}	Alapaha	0.087	0.087	0.040	0.070	0.109	0.000	0.598
		Aucilla	0.325	0.545	0.050	0.133	0.480	0.000	4.870
		Coastal	0.258	0.228	0.081	0.151	0.522	0.000	0.814
		Dixie	0.028	0.019	0.010	0.030	0.042	0.000	0.056
		Ichetucknee	0.144	0.359	0.035	0.053	0.100	0.000	3.640
		Santa Fe	0.102	0.204	0.040	0.055	0.105	0.000	2.240
		Steinhatchee	2.610	9.960	0.040	0.068	0.461	0.000	25.000
		Suwannee	0.321	1.758	0.044	0.070	0.145	0.000	45.100
		Waccasassa	0.195	0.037	0.189	0.196	0.209	0.078	0.303

Table D-1. continued.

Variable	Units	Basin	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Minimum	Maximum
Cadmium	mg L^{-1}	Alapaha	0.002	0.001	0.000	0.002	0.003	0.000	0.004
		Aucilla	0.002	0.002	0.000	0.002	0.003	0.000	0.007
		Coastal	0.002	0.001	0.000	0.001	0.003	0.000	0.004
		Dixie	0.002	0.001	0.000	0.002	0.003	0.000	0.004
		Ichetucknee	0.002	0.001	0.000	0.002	0.003	0.000	0.004
		Santa Fe	0.002	0.002	0.000	0.002	0.003	0.000	0.005
		Steinhatchee	0.002	0.002	0.000	0.002	0.003	0.000	0.010
		Suwannee	0.002	0.007	0.000	0.002	0.003	0.000	0.257
		Waccasassa	0.002	0.002	0.000	0.002	0.003	0.000	0.004
Arsenic	mg L^{-1}	Alapaha	0.009	0.006	0.005	0.010	0.010	0.000	0.023
		Aucilla	0.011	0.007	0.009	0.010	0.010	0.000	0.050
		Coastal	0.010	0.006	0.007	0.010	0.010	0.000	0.023
		Dixie	0.009	0.006	0.005	0.010	0.010	0.000	0.023
		Ichetucknee	0.010	0.007	0.005	0.010	0.010	0.000	0.037
		Santa Fe	0.009	0.008	0.005	0.010	0.010	0.000	0.050
		Steinhatchee	0.011	0.014	0.005	0.010	0.010	0.000	0.100
		Suwannee	0.011	0.013	0.005	0.010	0.010	0.000	0.286
		Waccasassa	0.010	0.006	0.009	0.010	0.010	0.000	0.023

Table D-2A. The Kruskal-Wallis Test for the groundwater domains differences using nine domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha	137	0.005	794.4	-8.45
Aucilla	188	0.033	1180.2	-2.90
Coastal	93	0.018	822.6	-6.55
Dixie	20	0.017	657.5	-3.95
Ichetucknee	479	0.253	1318.3	-0.60
Santa Fe	262	1.205	1681.9	7.60
Steinhatchee	131	0.010	684.7	-9.92
Suwannee	1320	0.306	1495.0	10.41
Waccasassa	44	0.005	476.6	-7.46
Overall	2674		1337.5	
H = 388.20	DF = 8	P = 0.000		
H = 388.93	DF= 8	P = 0.000	(adjusted for ties)	

Table D-2B. The Kruskal-Wallis Test for the groundwater domains differences using eight domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha	137	0.005	738.8	-8.09
Aucilla	188	0.033	1097.5	-2.23
Coastal	93	0.018	767.4	-6.20
Dixie	20	0.017	609.2	-3.85
Ichetucknee	479	0.253	1232.2	0.90
Steinhatchee	131	0.010	635.7	-9.65
Suwannee	1320	0.306	1383.4	13.71
Waccasassa	44	0.005	442.4	-7.35
Overall	2414		1206.5	
H = 344.82	DF = 7	P = 0.000		
H = 345.52	DF = 7	P = 0.000	(adjusted for ties)	

Table D-2C. The Kruskal-Wallis Test for the groundwater domains differences using seven domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha	137	0.005	604.4	-7.89
Aucilla	188	0.033	884.2	-2.14
Coastal	93	0.018	631.9	-5.93
Dixie	20	0.017	504.9	-3.72
Steinhatchee	131	0.010	525.5	-9.38
Suwannee	1320	0.306	1110.9	16.64
Waccasassa	44	0.005	365.1	-7.24
Overall	1933		967.0	
H = 330.08	DF = 6	P = 0.000		
H = 330.77	DF = 6	P = 0.000	(adjusted for ties)	

Table D-2D. The Kruskal-Wallis Test for the groundwater domains differences using six domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha	137	0.005	287.4	-1.47
Aucilla	188	0.033	376.1	6.42
Coastal	93	0.018	307.1	0.00
Dixie	20	0.017	264.6	-1.09
Steinhatchee	131	0.010	271.4	-2.60
Waccasassa	44	0.005	198.1	-4.23
Overall	613		307.0	
H = 53.36 DF =	DF= 5	P = 0.000		
H = 53.99 DF =	DF= 5	P = 0.000	(adjusted for ties)	

Table D-2E. The Kruskal-Wallis Test for the groundwater domains differences using five domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha	137	0.005	221.0	0.92
Coastal	93	0.018	236.9	2.12
Dixie	20	0.017	203.7	-0.35
Steinhatchee	131	0.010	209.0	-0.45
Waccasassa	44	0.005	154.0	-3.37
Overall	425		213.0	
H = 14.50	DF = 4	P= 0.006		
H = 14.73	DF = 4	P= 0.005	(adjusted for ties)	

Table D-2F. The Kruskal-Wallis Test for the groundwater domains differences using four domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha	137	0.005	176.8	1.63
Dixie	20	0.017	166.2	-0.01
Steinhatchee	131	0.010	169.9	0.52
Waccasassa	44	0.005	124.6	-3.11
Overall	332		166.5	
H = 10.11	DF = 3	P= 0.018		
H = 10.29	DF = 3	P= 0.016	(adjusted for ties)	

Table D-2G. The Kruskal-Wallis Test for the groundwater domains differences using three domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha 1	37 0	0.005	165.9	1.64
Steinhatchee 1	31 0	0.010	159.8	0.55
Waccasassa	44 0	0.005	117.3	-3.11
Overall 3	12		156.5	
H = 9.98	DF = 2	P= 0.007		
H = 10.16	DF = 2	P= 0.006	(adjusted for ties)	

Table D-2H. The Kruskal-Wallis Test for the groundwater domains differences using two domains.

Groundwater Domain	N	Median	Ave Rank	Z
Alapaha 137	0	5000.000	97.2	2.81
Waccasassa 44	0	5000.000	-71.7	2.81
Overall 181			91.0	
H = 7.88	DF = 1	P= 0.005		
H = 8.10	DF = 1	P= 0.004 (	(adjusted for ties)	

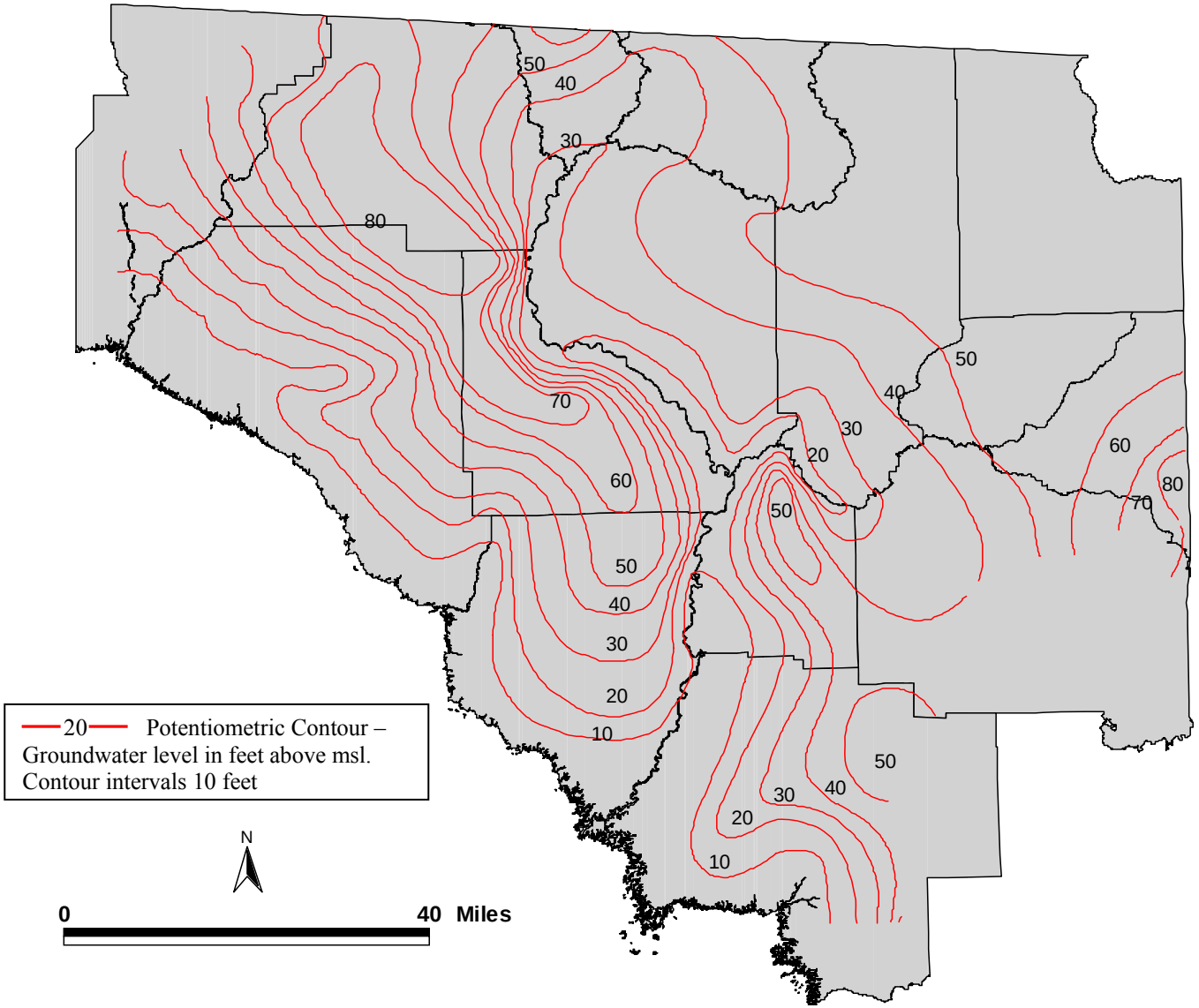

Figure D-1. 1985 potentiometric surface map for the Suwannee River Water Management District (Rosenau and Meadows, 1986).

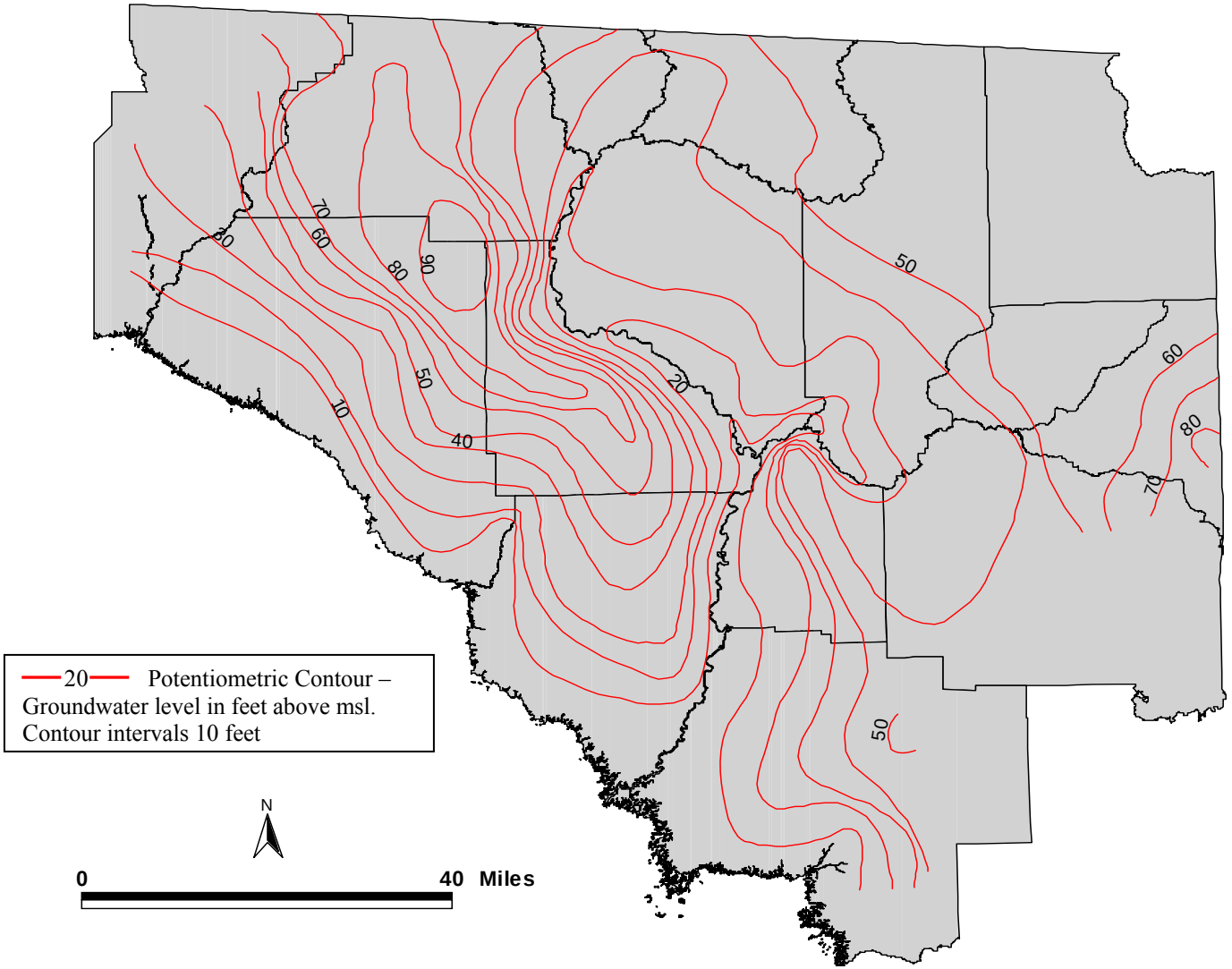

Figure D-2. 1990 potentiometric surface map for the Suwannee River Water Management District (Meadows, 1991).

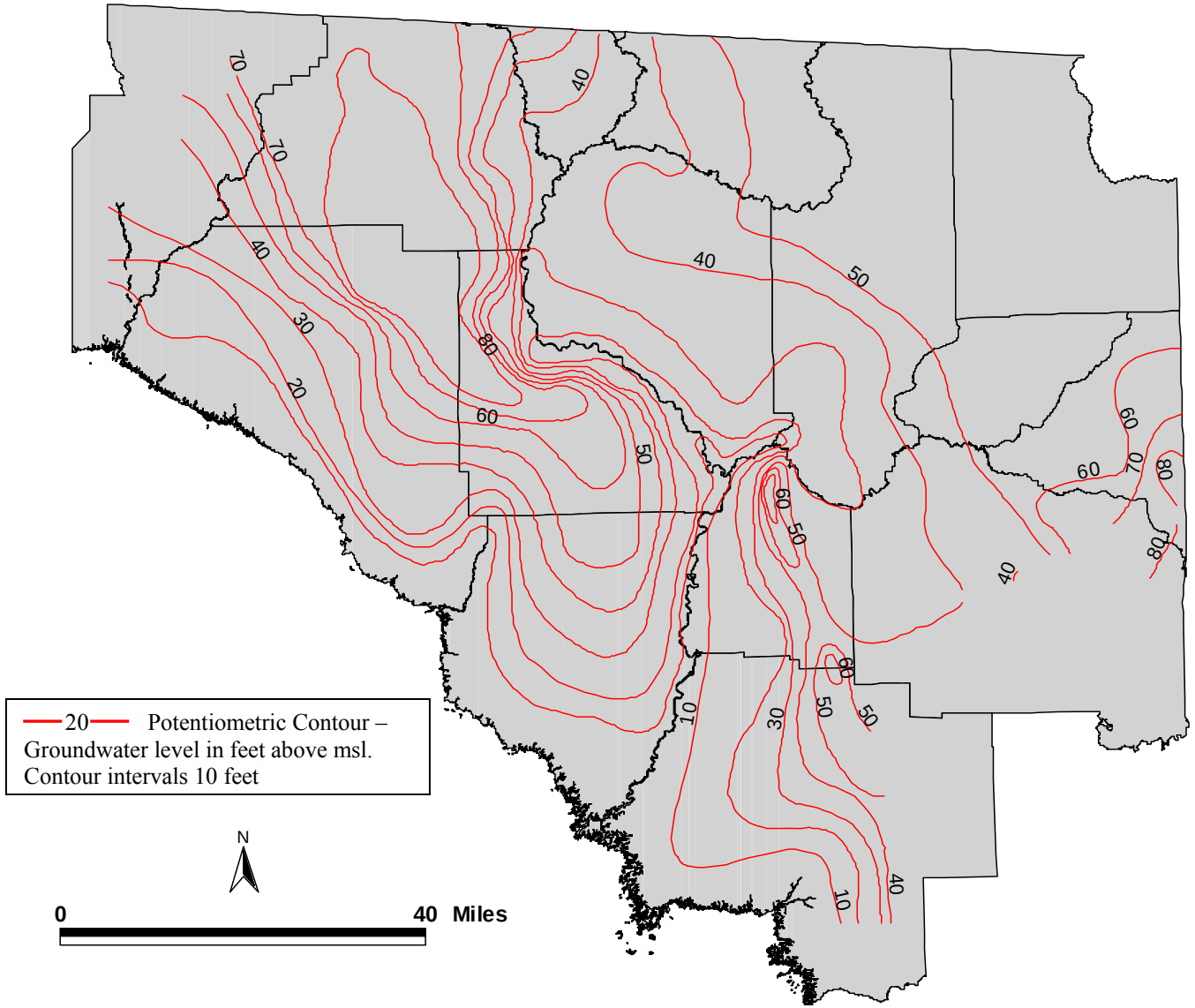

Figure D-3. 1995 potentiometric surface map for the Suwannee River Water Management District (Mahon et al., 1996).

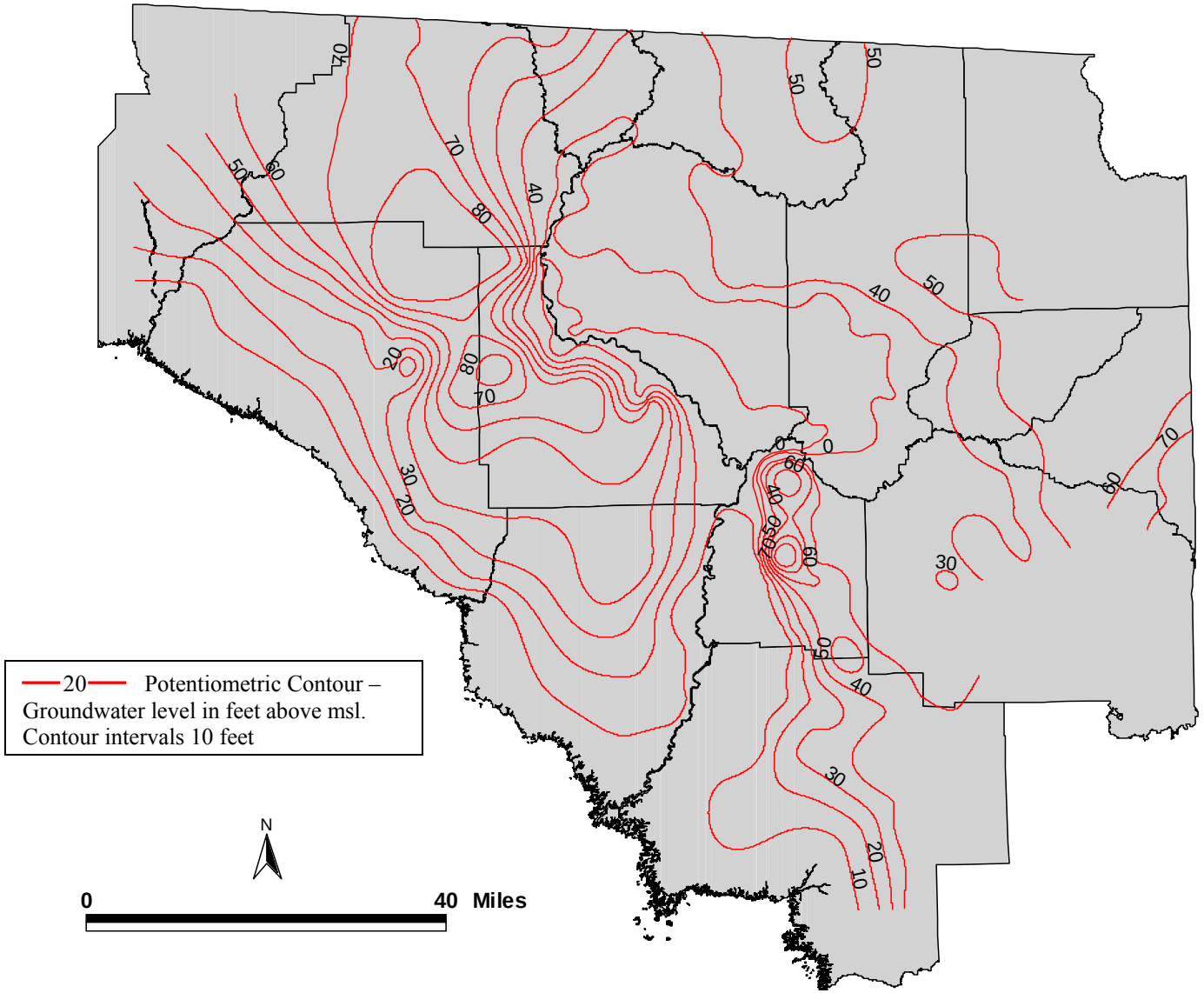

Figure D-4. 2002 potentiometric surface map for the Suwannee River Water Management District (SRWMD, 2002).

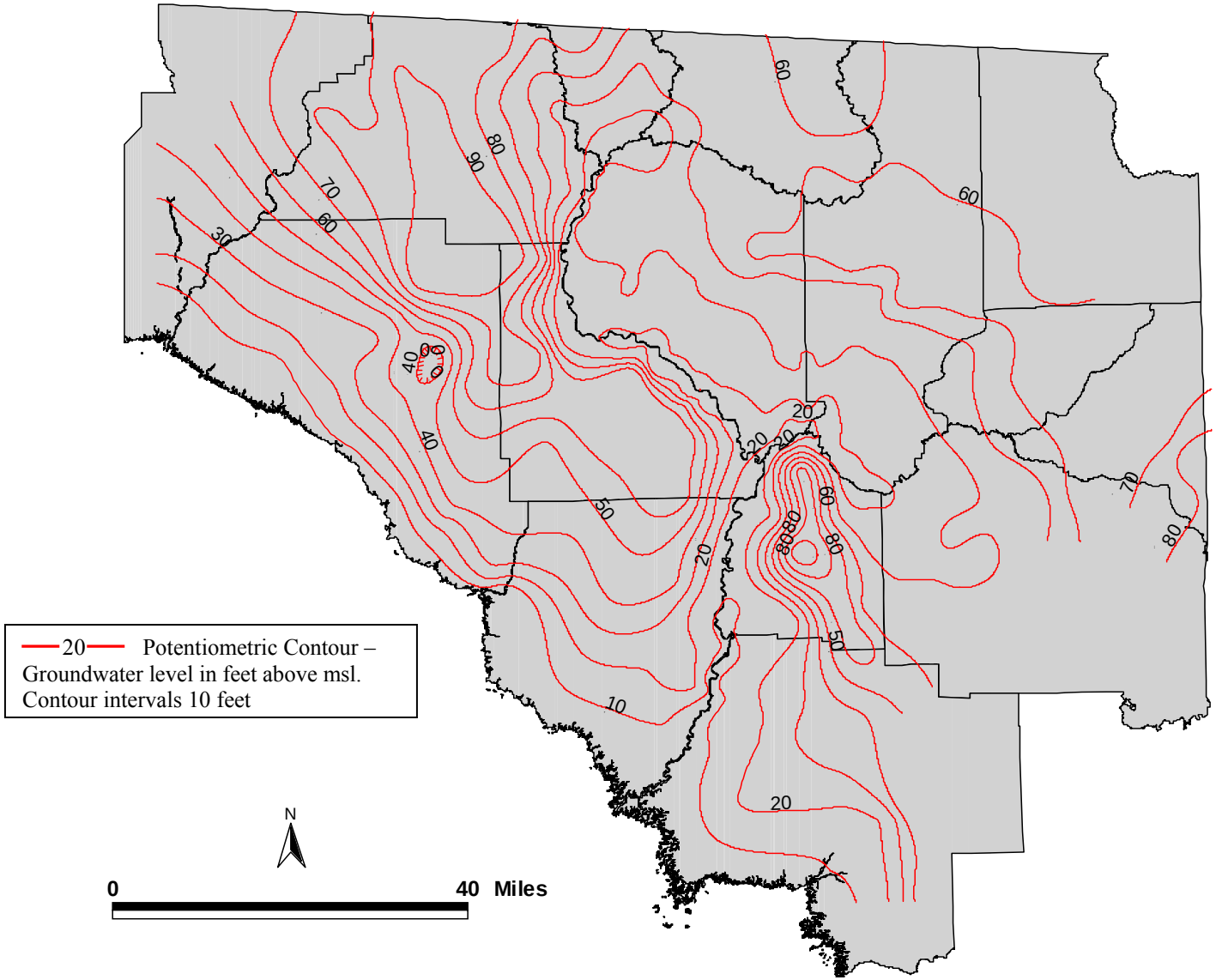

Figure D-5. 2005 potentiometric surface map for the Suwannee River Water Management District (SRWMD, 2005).

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