Final Report

An Ecosystem-Level Study of Florida's Springs

FWC Project Agreement No. 08010

Prepared for

Florida Fish and Wildlife Conservation Commission
St. Johns River Water Management District
Southwest Florida Water Management District
Florida Park Service
Florida Springs Initiative
Three Rivers Trust, Inc.

Prepared by

Wetland Solutions, Inc.

February 26, 2010

WSI
Wetland Solutions, Inc.

Final Report

An Ecosystem-Level Study of Florida's Springs

FWC Project Agreement No. 08010

Prepared for

Florida Fish and Wildlife Conservation Commission
St. Johns River Water Management District
Southwest Florida Water Management District
Florida Park Service
Florida Springs Initiative
Three Rivers Trust, Inc.

Prepared by

Wetland Solutions, Inc.

February 26, 2010

This report is funded in part by the Florida Fish and Wildlife Conservation Commission (FWC) through FWC Agreement Number 08010. The views expressed herein are those of the authors and do not necessarily reflect the views of the State of Florida, Fish and Wildlife Conservation Commission.

Executive Summary

The Florida Fish and Wildlife Conservation Commission (FWC), with support from the Florida Department of Environmental Protection (FDEP), the St. Johns River Water Management District (SJRWMD), the Southwest Florida Water Management District (SWFWMD), and Three Rivers Trust, Inc. sponsored this synoptic ecosystem study of twelve of Florida's artesian springs. Wetland Solutions, Inc. (WSI) was selected to conduct this work.

The twelve springs selected for this state-wide comparison include three in each of four water management districts: Jackson Blue (Jackson Co.), Ponce de Leon (Holmes Co.), and Wakulla (Wakulla County) in the Northwest Florida Water Management District (NWFWMD); De Leon (Volusia Co.), Silver (Marion Co.), and Silver Glen (Marion Co.) in the SJRWMD; Madison Blue (Madison Co.), Ichetucknee (Columbia Co.), and Manatee (Levy Co.) in the Suwannee River Water Management District (SRWMD); and Homosassa (Citrus Co.), Rainbow (Marion Co.), and Weeki Wachee (Hernando Co.) in the SWFWMD.

All field work for this project was completed during 2008 and 2009, including: receipt of permits to sample state (10), federal (1), and county (1) managed springs; reconnaissance trips to each of the springs, and synoptic sampling and data analysis of a broad range of ecological indices at the twelve springs. Syntheses of new data and previously published information for the twelve springs are provided in this final report.

Selected parameters measured at the 12 springs during 2008-2009 are summarized in **Table ES-1**. Findings described in this report indicate that while specific springs display remarkable consistency over various temporal periods, there may be large differences between individual springs in their physical, chemical, and biological properties. Artesian springs vary greatly in their physical dimensions and in the quantity of the water they discharge. The spring boils of the twelve study springs ranged in size from about 1,700 m^3 (2,220 cubic yards) at Ponce de Leon to 50,000 m^3 (65,000 cubic yards) for Wakulla Springs. The volume of the spring pool is in part a function of the existing and historical spring discharge, with smaller spring pools resulting from lower discharge rates (*e.g.*, Ponce de Leon with a pool of about 1,700 m^3 [2,220 cubic yards] and a measured flow of 0.33 m^3/s [12 cfs]) and larger boils such Wakulla Springs associated with higher discharge rates (measured in this study following locally high rainfall at 30.8 m^3/s [1,086 cfs]). Large spring size and high flows are in turn the basis for high levels of primary productivity and food-chain support for wildlife.

TABLE ES-1
Selected spring ecosystem parameters (average pool station values unless noted) measured during 2008-2009.

Water Management District	Spring (County)	Spring Pool Volume (m^3)	Discharge (m^3/s)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH (SU)	NO_x-N (mg/L)	NH_4-N (mg/L)	PO_4 (mg/L)	Maximum Horizontal Secchi (m)*	Gross Primary Productivity ($gO_2/m^2/d$)	Net Primary Productivity ($gO_2/m^2/d$)	Community Respiration ($gO_2/m^2/d$)	Photosynthetic Efficiency (%)
NWFWMD	**Blue (Jackson)**	4,081	3.42	262	6.8	7.55	3.32	0.05	0.02	64	2.88	-0.16	3.04	1.30
	Ponce de Leon (Holmes)	1,708	0.33	218	3.6	7.62	0.28	0.08	0.02	33	2.67	2.46	0.21	0.80
	Wakulla (Wakulla) [a]	49,607	30.78 [b]	282	2.1	7.32	0.48	0.03	0.03	3	2.71	1.82	0.89	8.55
SJRWMD	**De Leon (Volusia)**	4,898	0.84	945	0.7	7.44	0.78	0.11	0.06	14	4.32	-5.45	9.78	1.85
	Silver (Marion)	11,969	12.04	447	2.1	7.25	1.11	0.01	0.04	76	24.89	6.02	18.88	6.62
	Silver Glen (Marion)	1,875	2.21	1,810	3.1	7.86	0.05	0.02	0.02	70	11.10 [c]	9.26 [c]	1.84 [c]	4.56 [c]
SRWMD	**Blue (Madison)**	2,457	3.50	280	1.4	7.60	1.45	0.09	0.05	19	2.82 [c]	-1.74 [c]	4.56 [c]	4.43 [c]
	Ichetucknee (Columbia) [d]	5,644	2.31	312	3.6	7.48	0.66	0.03	0.03	32	9.09	5.01	4.08	2.26
	Manatee (Levy)	3,683	2.57	499	1.1	7.07	2.00	0.005	0.03	31	14.92	7.72	7.20	4.05
SWFWMD	**Homosassa (Citrus)**	5,578	2.04	4,755	3.7	7.90	0.55	0.03	0.02	11	1.26	-0.23	1.48	1.03
	Rainbow (Marion)	8,245	3.87	179	6.9	8.01	1.75	0.15	0.03	59	18.58	-0.15	18.73	4.42
	Weeki Wachee (Hernando)	5,867	2.53	328	1.6	7.51	0.74	0.10	0.01	87	6.98	2.15	4.83	2.76

** horizontal Secchi visibility exceeded maximum dimensions of Jackson Blue and Silver spring pool; Wakulla Spring pool was flooded and tannin stained when surveyed*
[a] *includes clear and tannin stained water periods*
[b] *discharge made at SR61 overpass of Wakulla River*
[c] *values from pool and run combined*
[d] *values from upper sonde station (24 m below confluence of Blue Spring and Ichetucknee River)*

The twelve study springs illustrated the normal range of electrical conductivities (due to dissolved cations and anions), ranging from a low specific conductance of 125 µS/cm at Madison Blue Spring in the Central Highlands of north Florida to a high of 4,755 µS/cm at Homosassa Springs in Citrus County, adjacent to the Gulf Coast. While artesian springs have long been categorized by their quantity and quality of salts and other inorganic ions, the importance of dissolved oxygen concentration variability with respect to their aquatic ecology has not been widely appreciated. The spring pool average dissolved oxygen concentrations recorded in this study ranged from a high of 6.9 mg/L at Rainbow Springs in Marion County to a low of 0.7 mg/L at De Leon Springs in Volusia County, with a relatively even distribution of values between these two extremes. Nitrate nitrogen concentrations which are primarily the result of anthropogenic pollution ranged from a low of 0.05 mg/L at Silver Glen Spring in the Ocala National Forest in Marion County to a high of 3.32 mg/L at Jackson Blue Spring located in an area of intensive row crop agriculture. Measured concentrations of total phosphorus among the twelve study springs ranged between 0.01 to 0.06 mg/L.

A variety of biological data were collected during this study, including observations of the percent cover and dominance of submerged aquatic macrophytes and benthic and attached algae, populations and occurrence of snails, turtles, aquatic insects, and manatees (primary and secondary consumers of plants and algae), and fish, bird, and reptile species at higher trophic levels. Monitoring also included detailed observations of human use at each spring.

In addition to these population-level study methods, this project quantified the overall functioning of these spring ecosystems as a response to their chemical and physical forcing functions. These top-down study methods included the estimation of overall assimilation of nutrients; system export of organic and inorganic matter; light attenuation due to suspended matter, turbidity, and dissolved color; and community or ecosystem metabolism (primary productivity, respiration, and photosynthetic efficiency.

Table ES-1 indicates that these springs have a relatively wide range of community-wide metabolic rates with gross primary productivity (GPP) ranging from a low of about 1.26 g $O_2/m^2/d$ at Homosassa Springs to a high of about 25 g $O_2/m^2/d$ at Silver Springs. GPP is the best available measure of a natural ecosystem's "gross domestic product" or the total amount of organic carbon fixed by photosynthesis within that system and available to meet the respiratory requirements of all plants, microbes, invertebrates, and vertebrates living in that ecosystem. GPP magnitude reflects the overall ability of a natural ecosystem to support life.

Overall community respiration (CR) was also estimated for these twelve springs and ranged from about 0.21 g $O_2/m^2/d$ at Ponce de Leon to a high of about 18.8 g $O_2/m^2/d$ at Silver Springs. CR is an independent estimate of the size and function of the biological community and is analogous to the caloric metabolic rate of a human or other animal.

The difference between GPP and CR is termed net primary productivity (NPP) and reflects the amount of fixed carbon that is utilized in the spring ecosystem for increasing living biomass or is available for export to downstream systems. It is analogous to the net profit earned by a company that is available for growth of that company or expenditures on outside projects. A prolonged period of negative NPP indicates that a natural ecosystem is living off of internal storages and may ultimately "starve to death". The estimated NPP during limited sampling in these twelve springs ranged from -5.45 g $O_2/m^2/d$ at De Leon Springs pool to 9.26 g $O_2/m^2/d$ at Silver Glen Springs for the combined pool and run segments.

The final measure summarized in **Table ES-1** is the ratio between GPP and photosynthetically active radiation (PAR), defined as photosynthetic efficiency (PE), the efficiency of the aquatic ecosystem in the conversion of useable sunlight into GPP. The average PE (%) across the twelve spring boils included in this study was 3.4%, with a range of values between 0.8 and 8.6%. These findings can be roughly compared to the observation made by Dr. Howard Odum (deceased) in his study of eleven artesian springs in Florida in the 1950s where he found a trend line equivalent to a PE of about 4% (Odum 1957b). Odum concluded that this consistency in the PE observed over a wide range of incident light intensities indicated that springs' biota were highly adapted to their relatively constant environments and able to maximize their production at rates higher than many other natural ecosystems with less favorable water and nutrient availability.

Continuing data analysis will help to paint a more complete picture of the current range of conditions in typical artesian springs in Florida. This data set is not a pristine baseline description but rather a snapshot of current conditions in springs, many of which have been highly altered by recent and historic cultural practices. Some springs, including most of those included in this study have seen reductions in their flows and increases in their nitrate nitrogen concentrations. They are also subject to increasing levels of direct human disturbances from recreation and management practices. It is hoped that the results of this study will be useful to establish a baseline for the future as improved management measures are taken to help restore ecological functions in Florida's artesian springs to pre-impact levels.

Contents

List of Figures

List of Tables

List of Appendices

Acknowledgements

Wetland Solutions, Inc. (WSI) gratefully acknowledges the following individuals for their assistance provided over the course of this project: Shea Armstrong, Wildlife Legacy Biologist and Brian Branciforte and Laura Morse, State Wildlife Grants Program Coordinators with the Florida Fish and Wildlife Conservation Commission (FWC) provided overall project guidance and contract management. Erich Marzolf, Ph.D., Technical Program Manager with the St. Johns River Water Management District (SJRWMD) provided contract and project assistance. Veronica Craw, Environmental Section Manager, and Gary Williams, Ph.D., Senior Environmental Scientist with the Southwest Florida Water Management District (SWFWMD) provided contract and project assistance. Dana Bryan, Environmental Policy Coordinator, with the Florida Park Service (FPS), Florida Department of Environmental Protection (FDEP) provided contract and project assistance. Connie Bersok, FDEP Springs Coordinator, provided contract and project assistance. Jim Stevenson and Richard Hamann, Ph.D., chair members of Three Rivers Trust, Inc. provided funding and project assistance.

Staff members of the Florida Park Service and the Division of Recreation and Parks (FDEP) were instrumental in the performance of this project through their contributions towards sampling and research efforts. We particularly thank: Brian Polk, Manager, Roger Reynolds, Assistant Manager, and Graham Williams, District Biologist for assistance at De Leon Springs State Park; Art Yerian, Manager, and Susan Lowe, Animal Operations Manager for assistance at the Ellie Schiller Homosassa Springs Wildlife State Park; Sherry McGowan, Manager, Sam Cole, Park Service Specialist, Rick Hughes, Park Ranger, and Ginger Morgan, Park Biologist, for assistance at Ichetucknee Springs State Park; Craig Liney, Manager, and Myra Carter, Park Ranger, for assistance at Madison Blue Springs; Sally Lieb, Manager, Bill Roberson, Assistant Manager, and Rick Owen, District Biologist, for assistance at Manatee Springs State Park; Ronnie Hudson, Manager, Jacob Strickland and Aaron Miller, Park Rangers, for assistance at Ponce de Leon Springs State Park; Joe Smyth, Manager and Jeff Sowards, Aquatic Preserve Manager, for assistance at Rainbow Springs State Park; Brian Fugate, Manager, Bonnie Allen, Assistant Manager, Scott Savery, Park Biologist, and Bob Thompson, Park Ranger, for assistance at Edward Ball Wakulla Springs State Park; Tommy Ervin, Manager, John Athanason, Marketing Manager, facilitated site access and arranged a boat tour at Weeki Wachee Springs; and John Reynolds for his assistance with the collation of state park attendance data. The assistance of Alicia Wilson and Mike Heyn with FDEP for identification of adult aquatic insects is especially appreciated.

Chuck Hatcher, Parks and Recycling Director for Jackson County, facilitated access and a boat tour of Jackson Blue Spring. US Forest Service staff Bobby Grinstead, Fisheries Biologist, provided a boat tour, while Patricia Tooley, Special Uses Coordinator, aided in data and permit acquisition at Silver Glen Springs. Private business contributed to this project as well. Dennis Mellen, Operations Manager and Terry Turner, General Manager facilitated access and provided boat tours at the Silver Springs Attraction.

Funding for this project was contributed from FWC, SJRWMD, SWFWMD, FDEP, and Three Rivers, Inc. This project was completed under project number 08010 between the FWC and WSI.

Introduction

Project Background

Importance of Springs

The large number and diversity of springs in Florida represents a globally significant concentration of these ecosystems. It is likely that many of the larger spring ecosystems have been in existence for up to 15,000 to 30,000 years, since the end of the last major ice age (Martin 1966, Munch *et al.* 2006). This extended time period has allowed the evolution of highly adapted and productive plant and animal communities (Odum 1957a).

Springs represent an important resource for human utilization as well, both by ancient inhabitants as supported by archeological evidence, and by present day populations who utilize them for a variety of recreational purposes (Bonn 2004, Scott *et al.* 2002). There is little doubt that the intrinsic aesthetics of clear, cool water vigorously emanating from the underground will continue to interest and fascinate humans. Many of Florida's oldest tourist attractions (*e.g.*, Weeki Wachee mermaids, Homosassa fish bowl, and Silver Springs glass bottom boats – see **Figure 1**) utilize spring ecosystems as their main draw. In addition, numerous spring boil areas have been modified to facilitate swimming, recreation, and even "health spas". Today all of the largest springs in Florida, whether privately or publicly owned, are managed as recreational parks, which, in turn, attract a large number of visitors and generate many millions of dollars in revenue on an annual basis. Correspondingly, many springs have suffered declines (often unintentional) in their condition (*e.g.,* up-rooting of vegetation, bank erosion, litter, *etc*.) due to visitation by ever increasing numbers of people.

Springs and their associated spring runs are a unique class of aquatic ecosystems. Since their principal water source is groundwater, many springs have water that is crystal clear, yet rich with dissolved nutrients and gases. Often this water quality provides the basis for a diverse and abundant assemblage of aquatic flora and fauna whose productivity is primarily determined by light availability and secondarily affected by the availability of macro and micro nutrients and by the ambient groundwater temperature. Additional factors that may affect spring productivity include external forcing functions such as diffusion of atmospheric gases, rainfall inputs of water and nutrients, immigration of fauna, and anthropogenic perturbations.

Over the last two decades other more serious stressors, with the potential to permanently alter Florida's spring ecosystems, have been increasingly recognized. Two of the most apparent anthropogenic factors that may be causing significant changes in spring ecosystems are: 1) the reduction in discharge, resulting from a reduction in groundwater supply through consumptive human withdrawals; and 2) the simultaneous pollution of groundwater, principally with nitrate-nitrogen, resulting from human population growth and associated land use changes. The full spectrum of the combined effects associated with flow reductions and nutrient enrichment on spring ecosystems is not yet clear. However, there is justifiable concern for potential negative consequences due to the obvious degradation of other aquatic habitats worldwide subjected to declining flows and water levels, and increased nutrient loading. The potential consequences of nutrient enrichment in springs include: an increase in opportunistic primary producers and organic matter deposition, an increase in nuisance algae species biomass, a decline in native submersed aquatic vegetation, a decrease in overall plant and animal productivity and diversity, an increase in downstream nutrient loading and not insignificantly, a reduction of the aesthetics these ecosystems have long provided.

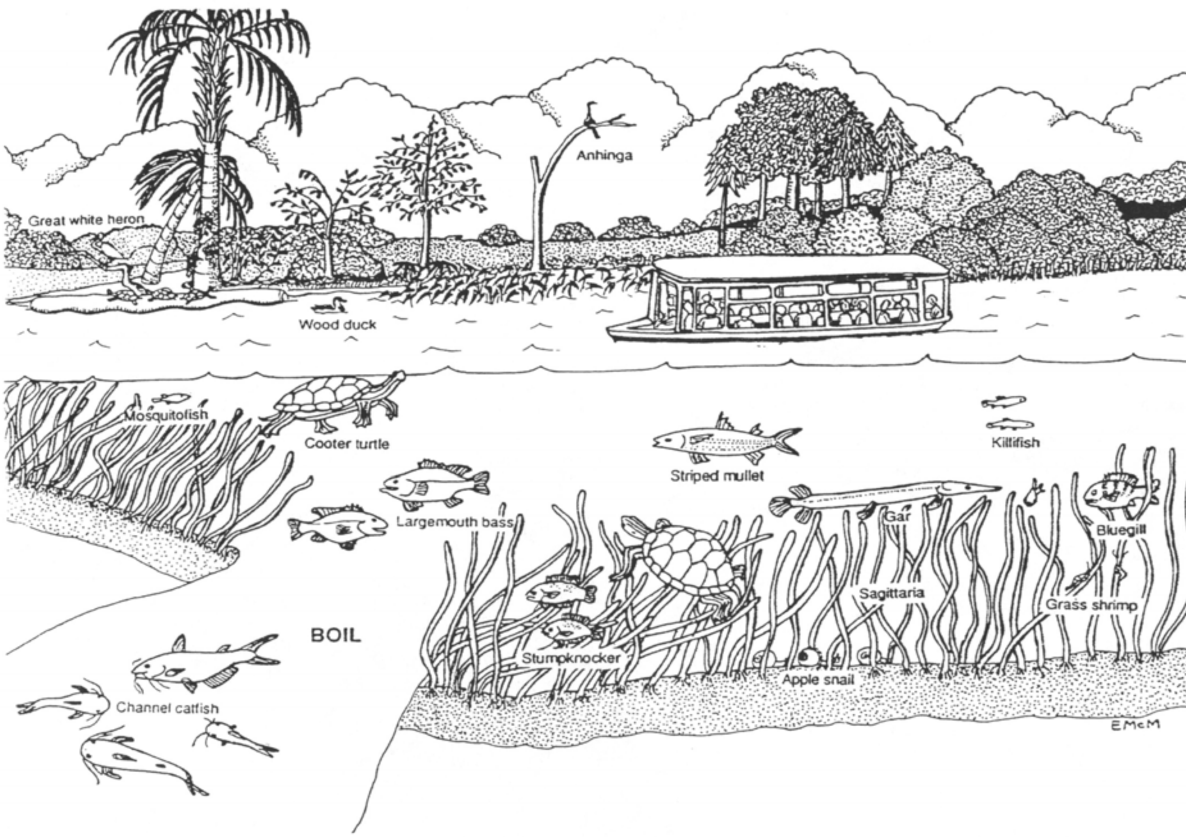


FIGURE 1
An artist's representation of Silver Springs at the time of H.T. Odum's 1957 landmark study (illustration by Elizabeth A. McMahan, from Odum *et al*. 1998).

Springs as Ecosystem Laboratories

Spring ecosystems have been the focus of some notable ecological studies, due to their diverse flora and fauna, and because their stable environmental characteristics generate natural controlled settings suitable for general ecological research. Springs research is broad and varied, ranging from descriptive classifications based on water discharge and chemistry, to observations of endemic flora and fauna, to studies of community ecology through whole system measurements.

The study of community ecology generally follows one of two methodologies. The first, the "reductionist" method, in which single species and their associated ecological controls are studied, in turn may be combined with other species-centric studies to assemble a working community model. This approach is generally limited to the study of dominant species, and even if multiple components are quantified and combined, the resulting sum of the parts is unlikely to represent a functional community. The second method, the "holistic" or "systems-level" approach, attempts to study the community in its entirety. The major challenge to the holistic approach is the concern that not enough useful information is obtained concerning the fate of individual species and resources that might be of greatest practical interest to managers and the public. Clearly, a comprehensive knowledge of ecosystems can only be obtained using both holistic and reductionist studies. A central theme of this report is that understanding of spring ecology and how to apply effective management and protection to spring ecosystems should be based on both types of studies together.

As first described by H.T. Odum in his landmark study of Silver Springs in the 1950s, spring ecosystems (or, simply springs), are highly suitable for the study of community ecology and ecosystem function at a holistic level. This is because the external forcing functions that determine spring structure and function are more stable than for many other aquatic ecosystems. This environmental stability, in turn, results in less temporal complexity in springs than in other aquatic ecosystems and more consistent food webs based on relatively stable groups of primary producers. In addition, springs offer a range of different community structures as a response to their differences in physical and chemical condition, creating a natural experimental platform for understanding the relationships between ecosystem form and function.

Another important reason to study spring ecosystems is that springs provide an opportunity to characterize the groundwater upon which both wildlife and humans are so dependent. A better understanding of land use changes and their resulting effects on groundwater quantity and quality changes has emerged through the study of springs (Cohen *et al*. 2007). An appropriate analogy that supports the need for increased emphasis on springs monitoring and ecological research is that these environments are comparable to the "canary in the coal mine" used to warn miners of unhealthy air. Wildlife populations in some springs are experiencing significant declines (*e.g.*, fish populations in Silver Springs [Munch *et al.* 2006]). A greater emphasis on ecological research and monitoring of springs could provide a better understanding of just how impaired existing spring biological communities are compared to historic conditions and whether recovery efforts are able to restore the ecological functions of our formerly pristine springs.

Springs as Ecosystems

Spring and spring run ecosystems are products of their environments and may be evaluated by considering their surroundings and their relationship with this environment. A complete understanding of the forces working to shape a spring's ecology must include consideration of forces acting at multiple spatial scales.

Florida's springs are a part of the global and continental environment and economy. Their location between north latitudes 31 and 27 (decimal degrees) puts them in the southern temperate zone of North America, an area rich in rainfall and groundwater, influenced by moderate temperatures, and subject in coastal areas to salt water influences.

As global and national economies influence land use changes in this region of Florida, springs are affected. For example, agricultural products in the Suwannee River area of Florida include dairy products and row crops, both industries that are subject to regional market factors. These land uses, in turn, alter spring hydrology and water quality through their irrigation requirements and increased loads of nitrogen and other pollutants to the underlying groundwater.

A second regional influence on spring ecology results from their unique aesthetic and recreational opportunities for humans. Several of Florida's springs are economic engines, attracting a high rate of international and interstate visitation (5% and 31.5% of visitors, respectively at multiple state-owned springs [Bonn 2004]). These visitors spend money that fuels local economies that have the potential to affect the springs' ecologies through mechanisms such as groundwater pumping, increased surface water runoff pollutant transport, and the direct and indirect effects of recreational use and aquatic weed control.

The life-blood of Florida's artesian springs is groundwater, principally derived from the Floridan aquifer which is largely supplied by regional rainfall. The quantity and quality of this groundwater determines the basis for much of the aquatic ecology of Florida's springs. Just as surface water features rely on a watershed, springs are dependant upon their "springshed", the area of land that constitutes the majority of their source of water to the aquifer, and can also be called the capture zone, catchment basin, or contributory area.

Figure 2 illustrates the springshed delineations of many of Florida's largest spring ecosystems. These springshed delineations were produced by the Florida Geological Survey (FGS) using multiple methods using many data sets including surface water and ground-water flows, potentiometric levels, subsurface conduit maps and dye trace studies and other hydrogeologic information (FGS 2007). The inset portion of **Figure 2** shows an image of the Ichetucknee Springs springshed located in north central Florida. A large number of anthropogenic activities within this springshed have the potential to affect the ecology of these springs.

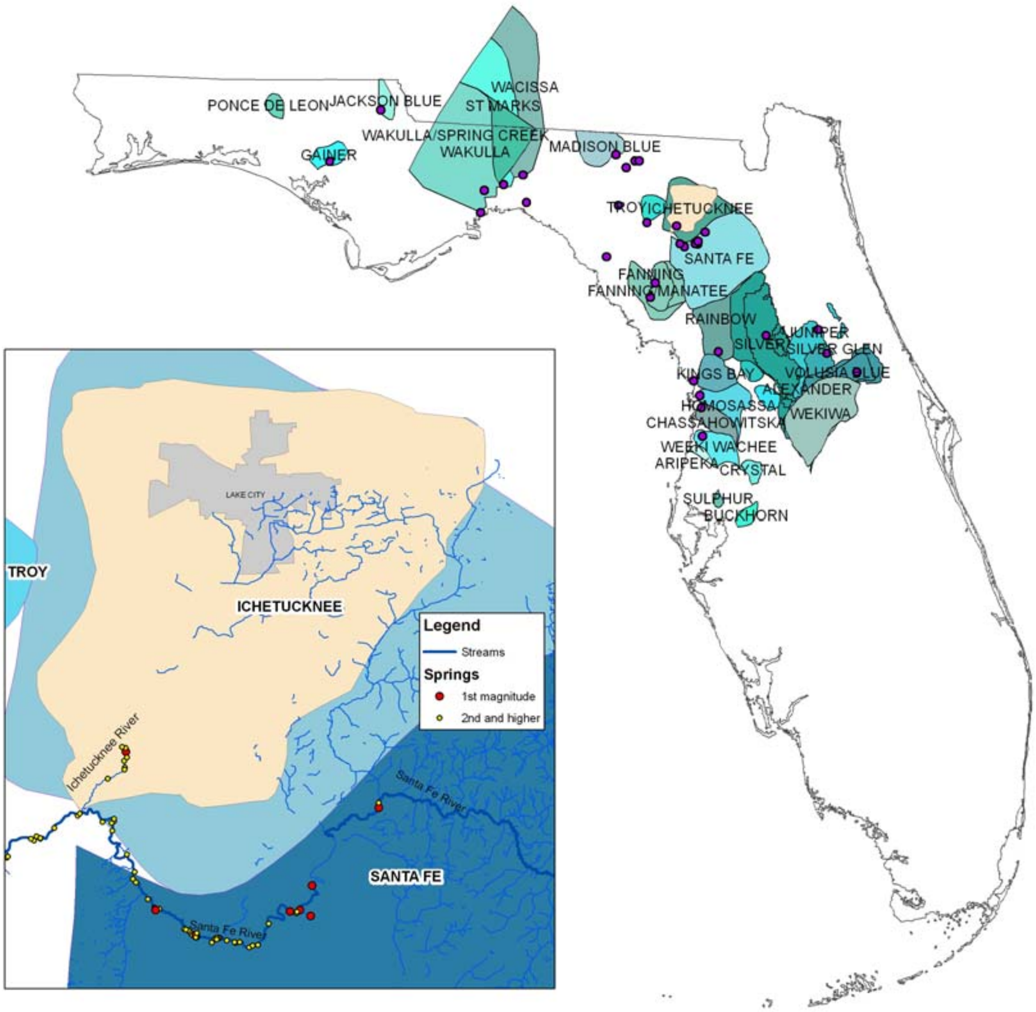


FIGURE 2
Florida springshed delineations, with an inset of the Ichetucknee springshed in North Central Florida (FGS 2007).

Recent work by the U.S. Geological Survey (Grubbs and Crandall 2007) has illustrated the fact that springshed boundaries are not fixed and may change radically over a period of time due to increased groundwater consumptive uses. In their study, USGS found that by

1980 an area of about 1,250 square miles that formerly recharged the springs in the Suwannee River Water Management District (SRWMD) was now sending groundwater to a major pumping center in Duval and Nassau Counties in the St. Johns River Water Management District (SJRWMD) on the east coast of the state. Presumably, this unintentional inter-basin transfer of potential springflow from the SRWMD to the SJRWMD has increased markedly in the ensuing three decades. Pipelines are not needed to transfer water away from springs when all wells pump from a single massive aquifer.

Figure 3 presents a conceptual diagram that illustrates the linkage between terrestrial ecosystems, developed land uses, and groundwater within a Florida artesian spring at the regional scale using the symbolic "energese" language of H.T. Odum (1998). The diagram includes the major forcing functions of sunlight, atmospheric inputs (wind, rain, and storms), with associated water and nutrients, and economic drivers (tourism, markets, and goods) interacting with developed land use changes. This conceptual energy and materials diagram focuses on flows of water, nitrogen, and energy, with counter flows of money for those pathways mediated by human activities. Variables in the diagram include: natural lands and low intensity land uses that do not receive significant inputs of nitrogen from anthropogenic uses; developed lands that include all other land uses; the water and nitrogen associated with the natural and developed lands; the artesian groundwater within the basin; and the physical and biological structure of a spring. Key system-level exports in the diagram include evapotranspiration, outflows of goods (recreational services), and downstream exports of water and organic material.

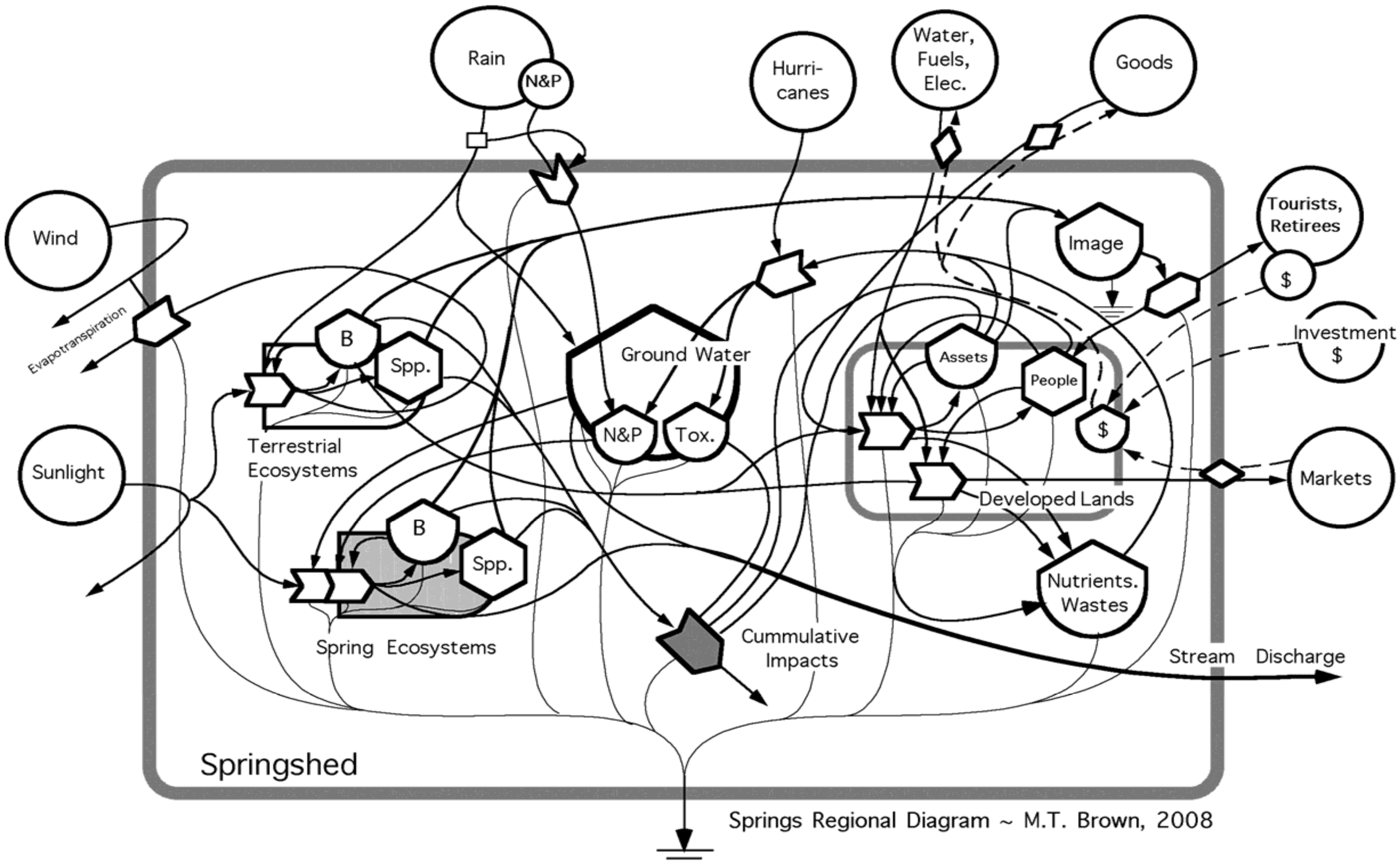


FIGURE 3
Conceptual springs regional diagram (M.T. Brown 2008). Key forcing functions at the regional scale include: sunlight, wind, precipitation, and associated nutrients, hurricanes, and human goods and services. Springsheds are in turn influenced and modified by their associated undeveloped and developed terrestrial environments with fertilizer and waste nutrient inputs and cumulative synergistic impacts resulting from consumptive water uses, recreation, and various resource management activities.

Documentation of the effects of regional land use changes in springshed basins on water quality changes in major springs (especially nitrate concentrations) has substantially improved in the past five years (Munch *et al.* 2006; Cohen *et al*. 2007). Munch *et al.* (2006) conducted a detailed evaluation of land use changes in a five-mile radius around Silver Springs and nitrate concentrations in the Silver Springs system. This analysis found that approximately 75% of the water discharging from Silver Springs originates within a two-year capture zone contained in a 6.4 km (4 mi) radius around the spring covering about 135 km^2 (52 mi^2). Analysis of aerial photos taken during the past fifty years suggests that land cover within the two-year capture zone has changed from a predominantly natural landscape to a mostly urban/agricultural area. This change corresponds to increased nitrogen loading, principally as a result of increased groundwater nitrate concentrations. **Figure 4** provides another example of the observed correlation between increases in human population and increases in nitrate concentration of the ground water discharging from Weeki Wachee Spring in Hernando County.

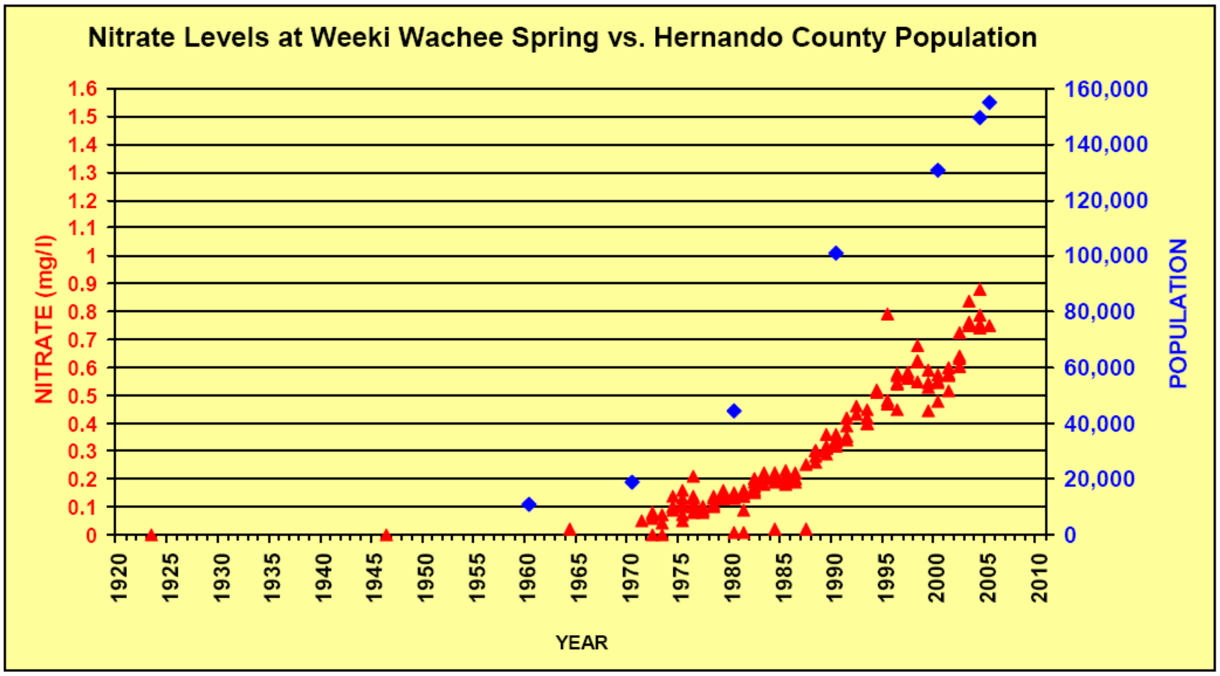


FIGURE 4
Graph of population growth (diamonds) in Hernando County, Florida and nitrate nitrogen concentration (triangles) at Weeki Wachee Spring from 1923 to 2006 (from FDEP 2006).

A typical spring ecosystem exhibits a large amount of physical, chemical, and biological complexity. The proximal external factors affecting this complexity are sunlight, artesian groundwater inputs, biological exchanges, and human activities. Springs in Florida occur where the underlying aquifer is at or near the surface allowing groundwater with net positive head pressure to be discharged. Springs are also found where surface water features have incised into the underlying karst geological formations. In general, a spring ecosystem includes all the internal abiotic and biotic components typical of most aquatic ecosystems including: aquatic macrophytes (higher plants) that support a diverse assemblage of attached algae (periphyton, benthic algae, and pseudo-plankton), detritus (dead plant and animal material generally associated with benthic organic sediments), associated animals feeding on detritus, and a faunal food web of herbivores, omnivores, and carnivores. Because of their continuous discharge, springs commonly serve as headwaters for streams, rivers, and sometimes lakes and ultimately contribute a great deal of freshwater to downstream inland and coastal aquatic ecosystems. Many of Florida's springs are found along the banks or the bottom of streams, and are therefore integral components of larger stream systems.

Figure 5 provides a systems diagram illustrating some of the immense complexity inherent in a relatively unaltered Florida artesian spring ecosystem. This model provides a summary of the major external forcing functions, internal energy storages and processes, and interactions between the spring ecology and the human economy. Functional groups within trophic levels illustrate the potential complexity of a spring ecosystem and the multiple interactive linkages.

Figure 6 provides an aggregated diagram of a spring ecosystem modified by human activities. Aggregation of functional groups is useful for the sake of combining elements of like structure and function into larger wholes. At this level of diagram aggregation illustrated forcing functions include: sunlight, atmospheric inputs of water and nutrients, groundwater inputs of water and nutrients, sediment derived inputs of nutrients, and anthropogenic inputs such as management actions, goods, services, and people. Aggregated outflows in the diagram include evapotranspiration, surface water discharges with downstream particulate matter and nutrient export. The spring ecosystem diagram illustrated in **Figure 6** is entirely included within the springshed landscape diagram illustrated above in **Figure 3**.

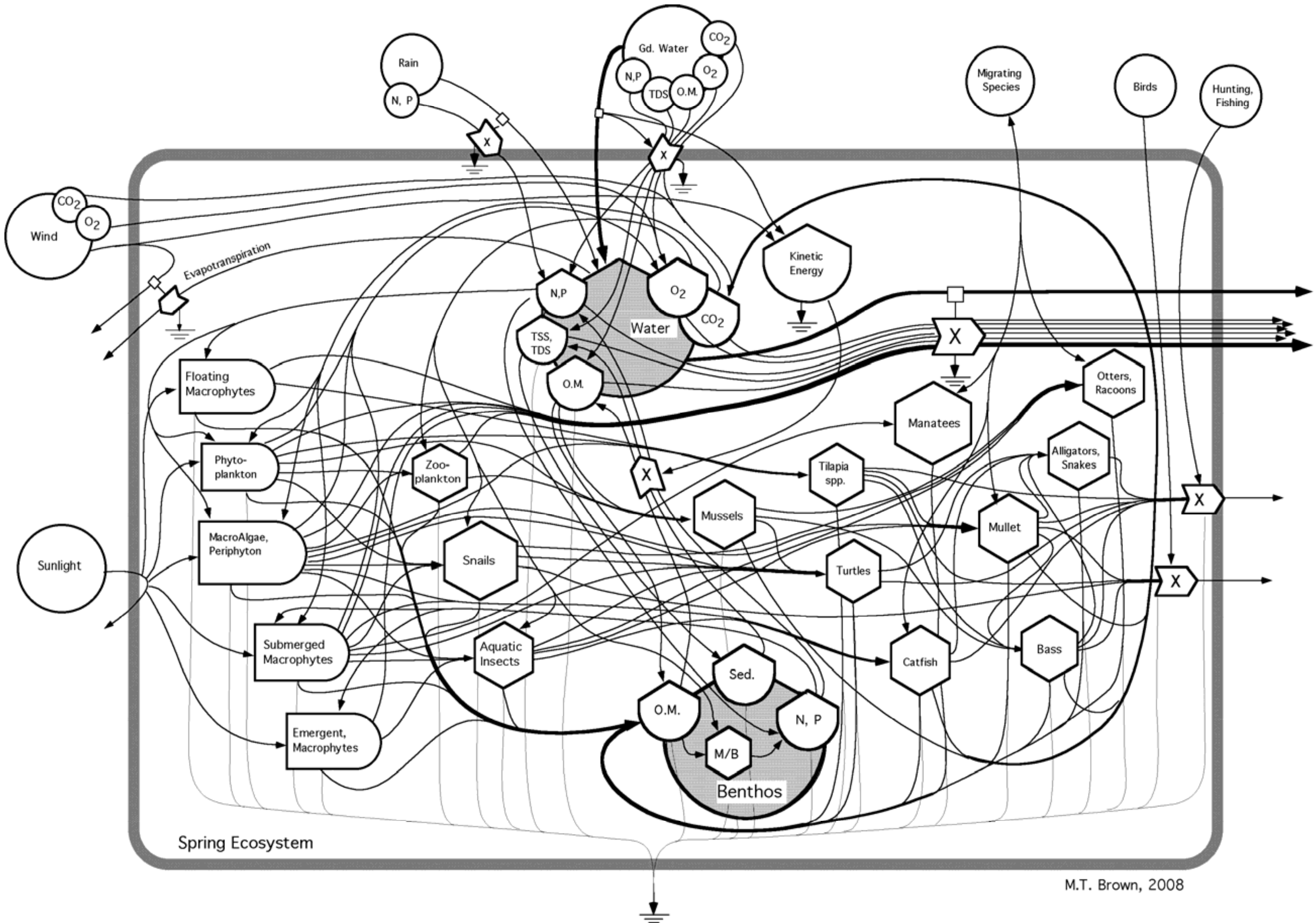


FIGURE 5
Detailed conceptual diagram of a Florida artesian spring ecosystem (M.T. Brown 2008).

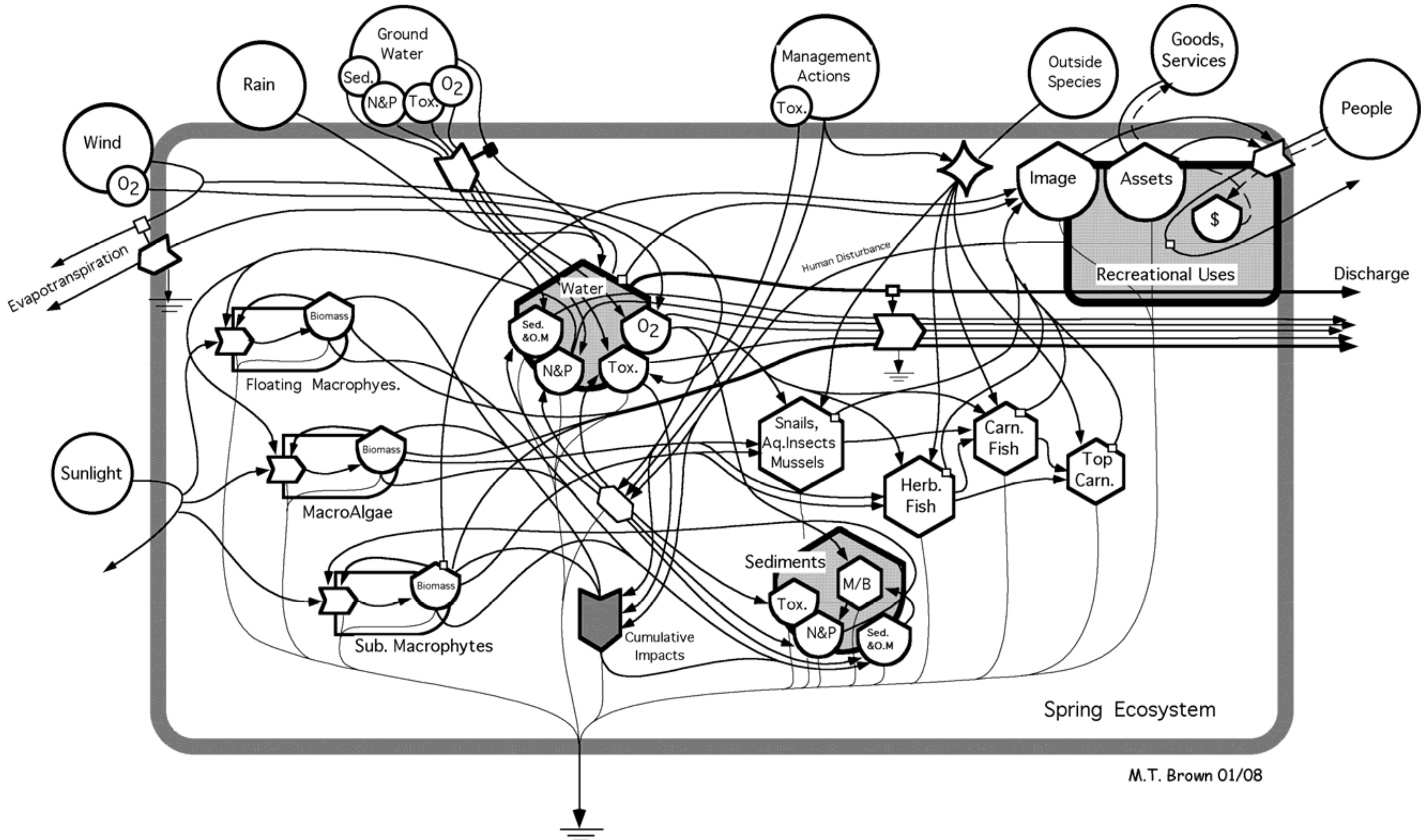


FIGURE 6
Aggregated spring ecosystem diagram that incorporates human recreation and management activities (M.T. Brown 2008).

Project Scope

Wetland Solutions, Inc. with funding and assistance from the Florida Fish and Wildlife Conservation Commission (FWC), Three Rivers Trust, Inc., the St. Johns River Water Management District (SJRWMD), the Southwest Florida Water Management District (SWFWMD), and the Florida Department of Environmental Protection (FDEP) has completed six project quarterly periods of ecological data collection and analysis for twelve key artesian springs located in Florida. This study is the first ecosystem-level comparison of multiple springs in Florida since the work conducted by H.T. Odum (1957b).

This project was divided into three general tasks; 1) project planning and mobilization, 2) synoptic sampling of spring ecosystems, and 3) data analysis and reporting. Work on this project required a total of 18 months (six quarters) to complete as follows:

- Quarter 1 – project planning and mobilization
- Quarters 2 – 5 – synoptic sampling of springs
- Quarter 6 – data analysis and reporting

During the first project period (Contract Execution – September 30, 2008), WSI developed a detailed plan of study, visited twelve springs for preliminary reconnaissance and data collection, and began a review and summary of existing historical data from each spring. Activities completed during this period were summarized in the First, Second, Third Interim Reports, Annual Report, and Draft Final Report (WSI 2008, WSI 2009a, WSI 2009b, WSI 2009c, and WSI 2009d, respectively). The reader of this final project report is referred to WSI (2008) for additional background about the objectives of the project, the occurrence of springs in the area of study, and the sampling and data analysis methods utilized for this springs ecosystem study.

This final project report summarizes activities completed by WSI during the time period spanning September 1, 2008 to December 31, 2009. Detailed field work was completed at all twelve study springs (**Figure 7**) during this time period: De Leon (Volusia Co.), Homosassa (Citrus Co.), Ichetucknee (Columbia Co.), Jackson Blue (Jackson Co.), Madison Blue (Madison Co.), Manatee (Levy Co.), Ponce de Leon (Holmes Co.), Rainbow (Marion Co.), Silver Glen (Marion Co.), Silver (Marion Co.), Wakulla (Wakulla Co.), and Weeki Wachee (Hernando Co.). Final data and analyses from each of these springs are summarized and compared in this report.

While the scope of this project was extensive, data collection at individual springs was not intensive due to budgetary and time constraints. For this reason it is important to consider the data and analyses included in this report as somewhat preliminary and suitable for a general comparison or "range-finding" understanding of these springs. Similarities and differences between springs are illustrated by these data but detailed temporal and spatial variability is not documented. Nevertheless, the data collected and analyzed for this project will be vital for future retrospective studies of the responses of individual springs to improved management activities.

Study Methodology

The twelve spring systems that were selected for sampling are physically quite different. Some are less than an acre in spatial extent while others are dozens of acres in size. Some have shallow depths throughout while others are several meters in depth throughout. All have differing dominant plant and animal species. Due to the duration and scope of this project, intensive sampling in each spring was only conducted for about one week during the study year.

Ecological sampling efforts were applied to this diverse group of springs in as consistent a fashion as practicable within these project constraints. Biological systems are known to vary considerably due to seasonal variation in sunlight, temperature, and precipitation. This factor is fortunately reduced in spring-fed aquatic ecosystems due to the buffering effect of the groundwater reservoir water temperature, volume, and quality on the dependent surface water plant and animal populations (Odum 1957). The only major environmental factor that typically is variable in springs is the input of sunlight. In this study this variation is partially controlled by the normalization of primary productivity data based on measured incident light energy. This photosynthetic or "ecological" efficiency provides a comparable measure of overall spring function regardless of season and latitude. Nevertheless, seasonal variability is a factor that was considered in project design and data analysis. With this variability in mind the following overall protocols were applied to this study to maximize comparability between the twelve sites:

- The focus of each ecological study site was the spring pool, including the spring vent and pool area and the defining basin, as well as the upstream-most portion of the spring run;
- The selected study area was generally extensive enough to allow a significant and measurable change in dissolved oxygen concentrations due to plant productivity;
- Sampling segments for collection of continuous field parameter data, as well as water quality, discharge, export, and plant and animal diversity and population data

typically included: Segment 1 - the spring vent area to the downstream edge of the spring pool or an intermediate point in the spring run that integrates all principal spring vents in a spring group, and Segment 2 – from the edge of the spring pool or the midpoint in the spring run area extending to a downstream spring run location that allows measurement of a relatively homogenous area of spring run habitat with constant flow and physical characteristics (such as shading by trees, water depths, channel width, dominant plant communities, etc.). Sampling points were selected on a case-by-case basis and are described in the next section.

The following ecological metrics were measured in each of the spring segments:

Physical Environment

- Total insolation and photosynthetically active radiation (PAR)
- Stream discharge (water level and flow) and current velocity
- Underwater light transmission (PAR)
- Segment morphometry (area and volume)
- Atmospheric oxygen diffusion coefficient as a function of velocity
- Water quality field parameters (temperature, pH, dissolved oxygen, specific conductance)

Water Chemistry

- Water chemistry (total Kjeldahl nitrogen [TKN-T], nitrate+nitrite nitrogen [NOx-N], ammonia nitrogen [NH_3-D], soluble reactive phosphorus [PO_4-D], total phosphorus [TP-T], chloride, chlorophyll [Chl *a*], color, and turbidity)

Biology

- Plant community characterization
- Faunal observations
- Human uses

Ecosystem Level

- Ecosystem metabolism metrics (gross primary productivity, net primary productivity, community respiration, P/R ratio, photosynthetic efficiency)
- Nutrient assimilation
- Community export (fine particulate export)

Methods used for measurement of these parameters are described in detail in **Appendix A** and briefly described in the results section below.

Description of the Study Springs

Detailed site descriptions and summaries of existing data for the twelve study springs have been provided in previous interim reports and are included in this report as appendices. This section summarizes the key descriptive information for each of the twelve study springs (**Figure 7**). **Figures 8** through **19** illustrate the area studied for each of the aforementioned spring systems, with sampling locations shown as red icons. **Table 1** lists the sampling stations for each the twelve study springs with latitude and longitude coordinates for continuous water quality monitoring locations.

Table 2 summarizes the physical location of each of the twelve study spring study sites and their reported historical discharge rates. The spring pool areas range in size from about 440 to 15,700 m^2 (0.1 to 3.9 ac) and have volumes ranging from 1,700 to 49,600 m^3 (8.4 to 246 cy). Measured average spring discharges ranged from 28,500 to 2.65 million m^3/d (12 to 1,087 cfs). The smallest spring in terms of spring pool volume and discharge was Ponce de Leon in Holmes County while the largest was Wakulla Springs in Wakulla County.

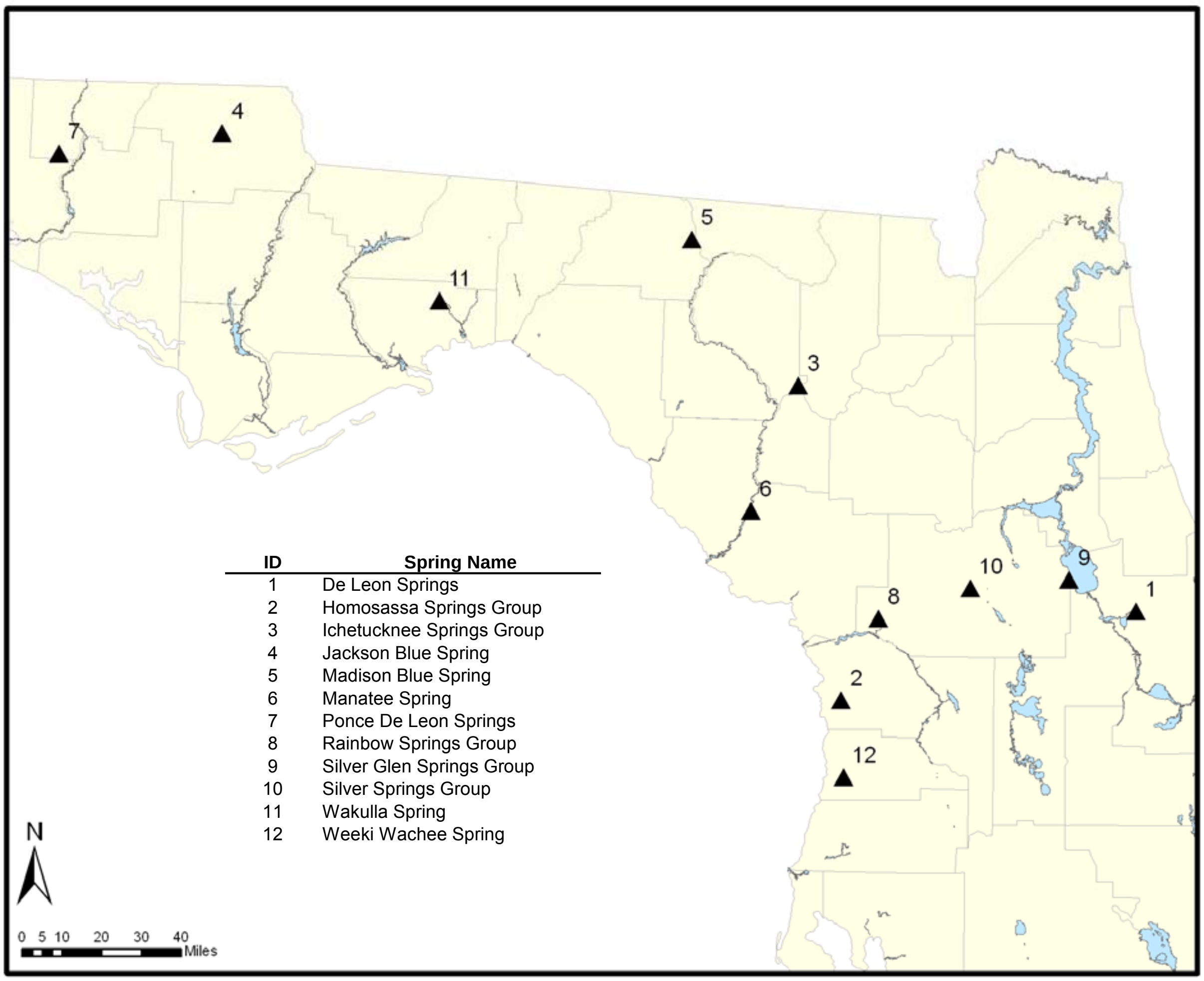


FIGURE 7
Locations of the twelve spring systems of this project.

TABLE 1
Sampling station locations for the twelve study springs.

Water Management District	Spring	County	Station Name	Latitude	Longitude	Site Visit Date	Synoptic Sampling Dates	Notes
Northwest	**Jackson Blue**	Jackson	JBS-1	30.790440°	-85.140029°	08/18/08	01/12/09 - 01/15/09	In mouth of vent (~ 10 ft depth)
			JBS-2	30.790029°	-85.140431°			from fence across pool, in flow path
			JBS-3	30.787597°	-85.145097°			from idle speed buoy
	Ponce de Leon	Holmes	PDL-1	30.721082°	-85.930715°	08/18/08	09/8/09 - 9/11/09	by main vent,12' depth
			PDL-2	30.720779°	-85.930826°			just upstream weir, 2.5' depth
			PDL-3	30.719350°	-85.929910°			20' upstream Sandy Creek confluence, 3.4' depth
	Wakulla	Wakulla	WAK-1	30.235410°	-84.302360°	08/18/08	04/13/09 - 04/16/09	downstream of main vent (~ 15 ft depth)
			WAK-2	30.235598°	-84.301366°			on dock near USGS sonde
			WAK-3	30.234072°	-84.294293°			in main channel by service takeout ramp
St. Johns River	**De Leon**	Volusia	VDL-1	29.134328°	-81.362696°	07/29/08	10/06/08 - 10/09/08	near vent (~ 20 ft depth)
			VDL-2	29.134313°	-81.362938°			at upstream side of weir grate
			VDL-3	29.136303°	-81.365641°			on old piling near park boundary
	Silver	Marion	SS-1	29.21613°	-82.05266°	07/29/08	05/4/09 - 05/8/09	in main boil, about 34' water
			SS-2	29.21601°	-82.04697°			at turtle meadows, about 350 m, about 12'
			SS-3	29.21552°	-82.04153°			at 1,200 m, about 10'
	Silver Glen	Marion	SGS-a	29.245693°	-81.643773°	07/29/08	02/16/09 - 02/19/09	at middle post of barrier to "The Well" spring vent
			SGS-1	29.245819°	-81.643442°			downstream side of main spring vent (~ 10 ft depth)
			SGS-2	29.244966°	-81.643288°			at middle post of boat barrier line
			SGS-3	29.246130°	-81.639730°			from green channel marker #11 in run
Suwannee River	**Ichetucknee**	Columbia	IS-1	29.979743°	-82.758784°	07/28/08	07/6/09 - 07/9/09	upstream sonde, 80' below confluence of Blue Hole and run
			IS-2	29.964140°	-82.763630°		07/14/09	Mid-Point Tube Launch
			IS-3	29.960360°	-82.770956°			Dampier's Landing
			IS-4	29.954783°	-82.784478°			US27 final take-out point
	Madison Blue	Madison	MBS-1	30.480481°	-83.244427°	07/28/08	12/01/08 - 12/02/08	near vent (~ 25 ft depth)
			MBS-2	30.480586°	-83.244202°		01/02/09 - 01/06/09	from blue-white float line
			MBS-3	30.480736°	-83.243978°			from white float line at river interface
	Manatee	Levy	MS-1	29.489613°	-82.976743°	07/28/08	08/3/09 - 08/06/09	near vent at 26' depth
			MS-2	29.489398°	-82.977674°			just downstream swim area rope at 5' depth
			MS-3	29.489177°	-82.979996°			at 5' depth
Southwest	**Homosassa**	Citrus	HS-1	28.799161°	-82.588324°	08/13/08	11/03/08 - 11/06/08	from east side of fish bowl (~ 20 ft depth)
			HS-2	28.799618°	-82.589067°			from downstream side of foot bridge
			HS-3	28.799098°	-82.589770°			from bacteria warning sign post
	Rainbow	Marion	RS-1	29.101606°	-82.436950°	08/13/08	06/8/09 - 06/11/09	just upstream from park canoe launch area, about 10' depth
			RS-2	29.098430°	-82.436020°			at sign prohibiting further upstream motor boating, about 7' depth
			RS-3	29.093622°	-82.432912°			at 1,100 m downstream from swim area, about 12' depth
	Weeki Wachee	Hernando	WWS-1	28.517559°	-82.573367°	08/13/08	03/9/09 - 03/12/09	north of vent by metal post (~ 10 ft depth)
			WWS-2	28.519053°	-82.573949°			attached to sign post "No Vessels Upstream" sign
			WWS-3	28.518920°	-82.579090°			just upstream of Frazer Project Coast St. 2

TABLE 2
The twelve study springs with selected previously published physical, chemical, and ownership characteristics.

WMD	Name	County	Magnitude	Management	Previously Studied [b]	Discharge (ft^3/s) *	pH	SpCond (uS/cm)	DO (mg/L)	NO_3-N (mg/L)	TP (mg/L)	NO_3/TP Ratio (wt)	Latitude (N)	Longitude (W)
NWFWMD	**Jackson Blue Spring**	Jackson	1st	County Park	F, S	61*	7.58	243	7.26	3.30	0.020	165	30.8203	85.2450
	Ponce de Leon Springs	Holmes	2nd	State Park	F, S	20	7.53	180	3.44	0.20	0.100	2	30.7211	85.9308
	Wakulla Spring	Wakulla	1st	State Park	F, S	129*	7.20	328	2.39	1.00	0.030	33	30.2347	84.3028
SJRWMD	**De Leon Springs**	Volusia	2nd	State Park	F,O	28	7.53	821	0.46	1.14	0.050	23	29.1343	81.3627
	Silver Glen Springs Group	Marion	1st (Group)	US Forest Service	F, S	109*	7.42	1,141	3.02	0.05	0.020	3	29.2508	81.6436
	Silver Springs Group	Marion	1st	Private Attraction [a]	F, O, S, W	556*	7.23	461	3.09	1.30	0.040	33	29.2158	82.0531
SRWMD	**Ichetucknee Springs Group**	Columbia	1st	State Park	F, S	186*	7.73	306	1.95	0.53	0.039	16	29.9525	82.7861
	Madison Blue Spring	Madison	1st	State Park	F, S	71*	7.75	277	1.76	1.40	0.040	35	30.4803	83.2444
	Manatee Spring	Levy	1st	State Park	F, O, S	154*	7.04	430	1.60	1.80	0.020	90	29.4892	82.9769
SWFWMD	**Homosassa Springs Group**	Citrus	1st (Group)	State Park	F, O, S	87*	7.70	4,520	3.97	0.52	0.028	19	28.7994	82.5889
	Rainbow Springs Group	Marion	1st (Group)	State Park	F, O, S	634*	7.67	274	5.53	1.13	0.032	35	29.1025	82.4375
	Weeki Wachee Spring	Hernando	1st	State Park	F, O, S	161*	7.68	320	1.29	0.70	0.007	100	28.5167	82.5736

[b] Researchers

F = Florida Geological Survey (water quality)

O = H.T. Odum (1950s)

S = Jan Stevenson (FDEP algae study)

W = Wetland Solutions, Inc. (ecosystem metabolism)

* Fall 2001 measures by FGS, (Scott, T.M., G.H. Means, R.C. Means, and R.P. Meegan. 2002. First magnitude springs of Florida. Florida Geological Survey. Open File Report No. 85. Tallahassee, Fl. 138 pp.)

[a] Silver Springs is managed as a private attraction under a lease from the state.

Jackson Blue Springs

Jackson Blue Springs is located about 5 miles east of Marianna in Jackson County. This spring is the headspring for Merritt's Mill Pond, a reservoir containing an aggregation of springs. Lands surrounding Jackson Blue Spring are owned by the state and the park facilities are county-owned and operated under lease from the Board of Trustees. **Figure 8** illustrates the study area and the two segments, the spring pool (JBS-1 to JBS-2) and spring run (JBS-2 to JBS-3), utilized in this study. The spring pool segment has a surface area of approximately 4,080 m^2 (1.0 ac) while the spring run segment has an area of 103,300 m^2 (25.5 ac). The spring pool is highly modified as a swimming area and encircled by concrete walls. Along the east of the spring run, uplands are relatively natural, while along the west side of the spring run, private residences are common. The reservoir in the upper spring run is formed by a weir at US 90 in Marianna.

Period-of-record data describing Jackson Blue Spring are summarized in **Appendix R**. These data indicate that the average discharge for Jackson Blue Springs is 4.8 m^3/s (171 cfs), the average nitrate nitrogen concentration is 3.24 mg/L, the average total phosphorus concentration is 0.021 mg/L, the average dissolved oxygen concentration is 7.33 mg/L, and the average specific conductance is 248 µS/cm.

FIGURE 8
Illustration of the general area studied at Jackson Blue Springs (with data sonde locations as red icons).

Ponce de Leon Springs

Ponce de Leon Springs is located in southern Holmes County, just north of Interstate 10. The springs are located in the Ponce de Leon Springs State Park managed by the Florida State Park System. **Figure 9** illustrates the study area and the two segments, the spring pool (PDL-1 to PDL-2) and spring run (PDL-2 to PDL-3), utilized in this study. The spring pool has a surface area of approximately 1,600 m^2 (0.4 ac) while the spring run segment has an area of 1,870 m^2 (0.5 ac). The spring pool is a highly modified swimming area, encircled by concrete walls and utilizing a weir to maintain water levels. The spring run is small and travels through a natural forested area. Both the spring pool and run are regularly flooded by Sandy Creek and the Choctawhatchee River.

Period-of-record data describing Ponce de Leon Springs are summarized in **Appendix U**. These data indicate that the average discharge for Ponce de Leon Springs is 0.47 m^3/s (16.5 cfs), the average nitrate nitrogen concentration is 0.24 mg/L, the average total phosphorus concentration is 0.029 mg/L, the average dissolved oxygen concentration is 4.3 mg/L, and the average specific conductance is 205 µS/cm.

FIGURE 9
Illustration of the general area studied at Ponce de Leon Springs in Holmes County (with data sonde locations as red icons).

Wakulla Springs

Wakulla Springs is located about 22.5 km (14 mi) south of Tallahassee in Wakulla County. The springs and upper 4.8 km (3 mi) portion of the spring run are managed by the Florida State Park System as the Edward Ball Wakulla Springs State Park. **Figure 10** illustrates the study area and the two segments, the spring pool (WAK-1 to WAK-2) and spring run (WAK-2 to WAK-3), utilized in this study. The spring pool has a surface area of approximately 15,700 m^2 (3.9 ac) while the spring run segment has an area of 60,300 m^2 (14.9 ac). The spring pool is partially modified with a dive platform, swim platforms, and boat docks. The spring run is relatively unaltered except for the boat docks and a downstream boat maintenance facility.

Period-of-record data describing Wakulla Springs are summarized in **Appendix Y**. These data indicate that the average discharge for Wakulla Springs is 17.9 m^3/s (632 cfs), the average nitrate nitrogen concentration is 0.76 mg/L, the average total phosphorus concentration is 0.03 mg/L, the average dissolved oxygen concentration is 2.1 mg/L, and the average specific conductance is 308 µS/cm.

FIGURE 10
Illustration of the general area studied at Wakulla Springs (with data sonde locations as red icons).

De Leon Springs

De Leon Springs is located just west of De Land in Volusia County. This spring and majority of the spring run (with several vents) are located in the De Leon Springs State Park managed by the Florida State Park System. **Figure 11** illustrates the study area and two segments, the spring pool (VDL-1 to VDL-2) and spring run (VDL-2 to VDL-3), utilized in this study. The spring pool has a surface area of approximately 2,750 m^2 (0.7 ac) while the spring run segment has an area of 38,000 m^2 (9.4 ac). The spring pool is highly modified as a swimming area being completely encircled by a concrete wall with a weir spillway. The spring run is relatively unaltered except for a boat ramp at the southeast (upstream) end.

Period-of-record data describing De Leon Springs are summarized in **Appendix O**. These data indicate that the average discharge for De Leon Springs is 0.8 m^3/s (28 cfs), the average nitrate nitrogen concentration is 0.80 mg/L, the average total phosphorus concentration is 0.087 mg/L, the average dissolved oxygen concentration is 1.4 mg/L, and the average specific conductance is 738 µS/cm.

FIGURE 11
Illustration of the general area studied at De Leon Springs in Volusia County (with data sonde locations as red icons).

Silver Springs

Silver Springs is located about 10 km (6 mi) northeast of Ocala in Marion County where numerous springs create the Silver River. Surrounding the pool and upper run is a privately operated tourism enterprise which leases the land from the state Board of Trustees, while the Silver River is managed as the Silver River State Park by the Florida State Park System. **Figure 12** illustrates the study area and two segments, the spring pool (SS-1 to SS-2) and spring run (SS-2 to SS-3), utilized in this study. The spring pool has a surface area of approximately 5,600 m^2 (1.4 ac) while the spring run segment has an area of 73,800 m^2 (18.2 ac). The spring pool is highly modified for tourism with boat docks and an encircling concrete wall. The upper spring run has been modified with tourism attractions and a parallel canal.

Period-of-record data describing Silver Springs are summarized in **Appendix W**. These data indicate that the average discharge for Silver Springs is 21.6 m^3/s (763 cfs), the average nitrate nitrogen concentration is 0.94 mg/L, the average total phosphorus concentration is 0.048 mg/L, the average dissolved oxygen concentration is 4.5 mg/L, and the average specific conductance is 448 µS/cm.

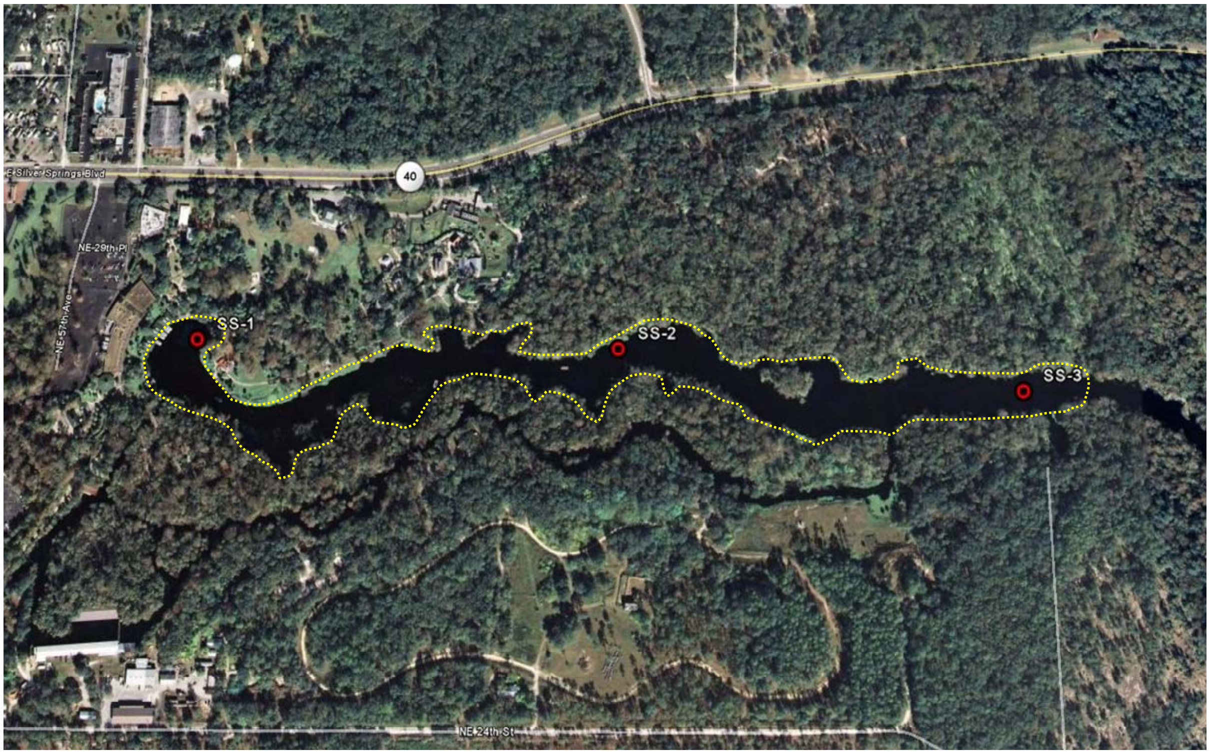


FIGURE 12
Illustration of the general area studied at Silver Springs in Marion County (with data sonde locations as red icons).

Silver Glen Springs

Silver Glen Springs is located 48 km (30 mi) northeast of Ocala in Marion County on the west side of Lake George. Two spring vents supply the system; the lands surrounding the pool are owned by the US Forest Service and the site is managed by private concession. **Figure 13** illustrates the study area and two segments, the spring pool (SGS-1 to SGS-2) and spring run (SGS-2 to SGS-3), utilized in this study. The spring pool has a surface area of approximately 2,400 m^2 (0.6 ac) while the spring run segment has an area of 35,800 m^2 (8.8 ac). The spring pool is partially modified for swim access. Lands along the spring run are natural except for the private hunt/fish camp along the lower run. The benthic vegetation in the spring run is impacted by motor boat usage by the visiting public.

Period-of-record data describing Silver Glen Springs are summarized in **Appendix X**. These data indicate that the average discharge for Silver Glen Springs is 2.9 m^3/s (102 cfs), the average nitrate nitrogen concentration is 0.05 mg/L, the average total phosphorus concentration is 0.03 mg/L, the average dissolved oxygen concentration is 2.9 mg/L, and the average specific conductance is 1,860 µS/cm.

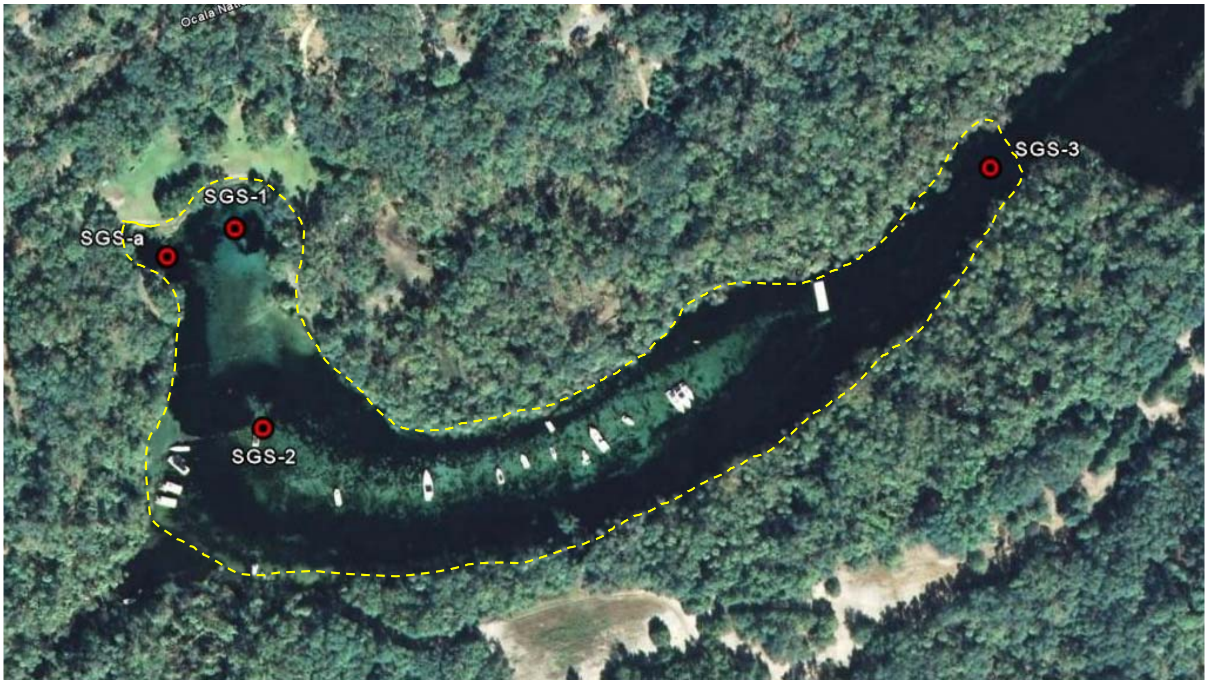


FIGURE 13
Illustration of the general area studied at Silver Glen Springs in Marion County (with data sonde locations as red icons).

Madison Blue Springs

Madison Blue Spring is located about 16 km (10 mi) east of Madison in Madison County on the west bank of the Withlacoochee River. The spring and surrounding lands are managed by the Florida State Park System as the Madison Blue Springs State Park. **Figure 14** illustrates the study area and two segments, the spring pool (MBS-1 to MBS-2) and spring run (MBS-2 to MBS-3), utilized in this study. The spring pool has a surface area of approximately 440 m^2 (0.11 ac) while the spring run segment has an area of 630 m^2 (0.16 ac). The spring pool is partially modified for swimming with stairs and walkways. The spring pool and run are regularly flooded by the Withlacoochee River as illustrated in **Figure 14**.

Period-of-record data describing Madison Blue Spring are summarized in **Appendix S**. These data indicate that the average discharge for Madison Blue Spring is 2.9 m^3/s (101 cfs), the average nitrate nitrogen concentration is 1.40 mg/L, the average total phosphorus concentration is 0.05 mg/L, the average dissolved oxygen concentration is 2.0 mg/L, and the average specific conductance is 270 µS/cm.

FIGURE 14
Illustration of the general area studied at Madison Blue Spring (image shows flooded conditions with data sonde locations as red icons).

Ichetucknee Springs

Ichetucknee Springs is located about 16 km (10 mi) northeast of Branford in Columbia County (headspring in Suwannee Co.). A collection of nine named and many unnamed springs form the Ichetucknee River, which together with surrounding lands are managed by the Florida State Park System as the Ichetucknee Springs State Park. **Figure 15** illustrates the study area and segments, the upper run (upstream sonde (IS-1) to mid-point sonde (IS-2)) and the lower run (mid-point sonde (IS-2) to US27 sonde (IS-4)), utilized in this study. The upper spring run has a surface area of approximately 103,400 m^2 (25.6 ac) while the lower spring run segment has an area of 56,800 m^2 (14 ac). The headspring pool is partially modified for swimming with retaining walls, stairs, and walkways. The spring run (Ichetucknee River) is natural with docks at three locations (for tubing access) and flows into the Santa Fe River. Due the presence of multiple spring pools in the upper portion of the Ichetucknee Springs System, no pool was directly sampled but rather the whole upper segment of the spring run.

Period-of-record data describing Ichetucknee Springs are summarized in **Appendix Q**. These data indicate that the average discharge for the Ichetucknee River at US27 is 8.9 m^3/s (313 cfs), the average nitrate nitrogen concentration is 0.492 mg/L, the average total phosphorus concentration is 0.086 mg/L, the average dissolved oxygen concentration is 5.88 mg/L, and the average specific conductance is 310 µS/cm.

FIGURE 15
Illustration of the general area studied at Ichetucknee Springs (with data sonde locations as red icons).

Manatee Springs

Manatee Springs is located about 11.3 km (7 mi) west of Chiefland in Levy County on the east bank of the Suwannee River. The springs and surrounding lands are managed by the Florida State Park System as the Manatee Springs State Park. **Figure 16** illustrates the study area and two segments, the spring pool (MS-1 to MS-2) and spring run (MS-2 to MS-3), utilized in this study. The spring pool has a surface area of approximately 2,600 m^2 (0.65 ac) while the spring run segment has an area of 5,350 m^2 (1.3 ac). The spring pool is partially modified for swimming with retaining walls, stairs, and walkways along the south shore. The spring pool and run are occasionally flooded by the Suwannee River.

Period-of-record data describing Manatee Springs are summarized in **Appendix T**. These data indicate that the average discharge for Manatee Spring is 4.1 m^3/s (145 cfs), the average nitrate nitrogen concentration is 1.73 mg/L, the average total phosphorus concentration is 0.033 mg/L, the average dissolved oxygen concentration is 1.7 mg/L, and the average specific conductance is 465 µS/cm.

FIGURE 16
Illustration of the general area studied at Manatee Springs in Levy County (with data sonde locations as red icons).

Homosassa Springs

Homosassa Springs is located in the town of Homosassa Springs in Citrus County. These springs and the spring run are located in the Ellie Schiller Homosassa Springs Wildlife State Park managed by the Florida State Park System. **Figure 17** illustrates the study area and two segments, the spring pool (HS-1 to HS-2) and spring run (HS-2 to HS-3), utilized in this study. The spring pool has a surface area of approximately 5,100 m^2 (1.3 ac) while the spring run segment has an area of 6,300 m^2 (1.5 ac). The spring pool is partially filled by an observation platform located over the three spring vents and by a foot bridge that crosses the spring run. The spring pool is modified for manatee containment and wildlife viewing. The spring is tidal and feeds the Homosassa River.

Period-of-record data describing Homosassa Springs are summarized in **Appendix P**. These data indicate that the average discharge for Homosassa Springs is 2.5 m^3/s (90 cfs), the average nitrate nitrogen concentration is 0.523 mg/L, the average total phosphorus concentration is 0.08 mg/L, the average dissolved oxygen concentration is 3.86 mg/L, and the average specific conductance is 4,100 µS/cm.

FIGURE 17
Illustration of the general area studied at Homosassa Springs (with data sonde locations as red icons).

Rainbow Springs

Rainbow Springs is located about 6.4 km (4 mi) north of Dunnellon in Marion County. A collection of numerous named and unnamed springs create the Rainbow River. These springs and the upper river are located in the Rainbow Springs State Park managed by the Florida State Park System. **Figure 18** illustrates the study area and two segments, the spring pool (RS-1 to RS-2) and spring run (RS-2 to RS-3), utilized in this study. The spring pool has a surface area of approximately 5,070 m^2 (1.2 ac) while the spring run segment has an area of 45,300 m^2 (11.2 ac). The headspring pool is modified along the western shoreline for swimming. The Rainbow River has state lands along the east and private residences along the west banks.

Period-of-record data describing Rainbow Springs are summarized in **Appendix V**. These data indicate that the average (at SR 484) discharge for Rainbow Springs is 20.2 m^3/s (714 cfs), the average nitrate nitrogen concentration is 1.06 mg/L, the average total phosphorus concentration is 0.043 mg/L, the average dissolved oxygen concentration is 8.17 mg/L, and the average specific conductance is 263 µS/cm.

FIGURE 18
Illustration of the general area studied at Rainbow Springs in Marion County (with data sonde locations as red icons).

Weeki Wachee Springs

Weeki Wachee Springs is located in the town of Weeki Wachee on the west side of US 19 in Hernando County. The main spring and several smaller feeder springs, create the Weeki Wachee River. The main spring and the upper river are located in the newly formed Weeki Wachee Springs State Park managed by the Florida State Park System. **Figure 19** illustrates the study area and two segments, the spring pool (WWS-1 to WWS-2) and spring run (WWS-2 to WWS-3), utilized in this study. The spring pool has a surface area of approximately 1,930 m^2 (0.5 ac) while the spring run segment has an area of 19,500 m^2 (4.8 ac). The headspring pool is heavily modified with swim beaches, slides, and an underwater viewing theater. The Weeki Wachee River has state lands along the upper most portion and private residences along lower reaches.

Period-of-record data describing Weeki Wachee are summarized in **Appendix Z**. These data indicate that the average discharge for Weeki Wachee Springs is 4.4 m^3/s (157 cfs), the average nitrate nitrogen concentration is 0.615 mg/L, the average total phosphorus concentration is 0.019 mg/L, the average dissolved oxygen concentration is 2.8 mg/L, and the average specific conductance is 289 µS/cm.

FIGURE 19
Illustration of the general area studied at Weeki Wachee Springs (with data sonde locations as red icons).

Project Findings

Introduction

The twelve study springs were sampled during the interval from October 2008 through September 2009. Each spring was intensively sampled during a one-week period using the methods described below in **Appendix A**. One spring was sampled during each month of the overall 12 month sampling period. One spring from each of the four water management districts was sampled during each quarter of the study. **Table 3** provides a summary of the sampling that was completed at each spring.

Environmental data are inherently variable due to natural conditions and measurement inaccuracies. Fortunately, environmental conditions in springs are known to be less variable compared to most aquatic ecosystems. Since data for this project were collected over a relatively short time span with limited replication, their inherent variability cannot be precisely estimated. For these reasons all findings in this report should be considered as approximate until they can be validated through additional long-term sampling.

A summary of the ecological data collected is provided below to allow for comparison of these twelve spring ecosystems. For consistency, these data are arranged by the general region (water management district) in which each spring occurs.

TABLE 3
Summary of the sampling tasks completed by spring.

TASK	De Leon	Homosassa	Madison Blue	Jackson Blue	Silver Glen	Weeki Wachee	Wakulla	Silver	Rainbow	Ichetucknee	Manatee	Ponce de Leon
Sample Start Date	10/6/08	11/3/08	12/1/08	1/12/09	2/16/09	3/9/09	3/16/09	5/4/09	6/8/09	7/6/09	8/3/09	9/8/09
Sample End Date	10/9/08	11/6/08	1/2/09	1/15/09	2/19/09	3/12/09	4/16/09	5/7/09	6/11/09	7/9/09	8/6/09	9/11/09
Aquatic vegetation sampling	X	X	X	X	X	X	X	X	X	X	X	X
Bathymetry mapping	X	X	X	X	X	X	X	X	X	X	X	X
Data sonde deployment	X	X	X	X	X	X	X	X	X	X	X	X
Diffusion measurements	X	X	X	X	X	X	X	X	X	X	X	X
Discharge measurements	X	X	X	X	X	X	X	X	X	X	X	X
Faunal counts	X	X	X	X	X	X	X	X	X	X	X	X
Field parameter sampling	X	X	X	X	X	X	X	X	X	X	X	X
Human use observations	X	X	X	X	X	X	X	X	X	X	X	X
Light attenuation measurements	X	X	X	X	X	X	X	X	X	X	X	X
Macroinvertebrate sampling	X	X	X	X	X	X	X	X	X	X	X	X
Particulate export sampling	X	X	X	X	X	X	X	X	X	X	X	X
Secchi disk measurements	X	X	X	X	X	X	X	X	X	X	X	X
Water chemistry sampling	X	X	X	X	X	X	X	X	X	X	X	X

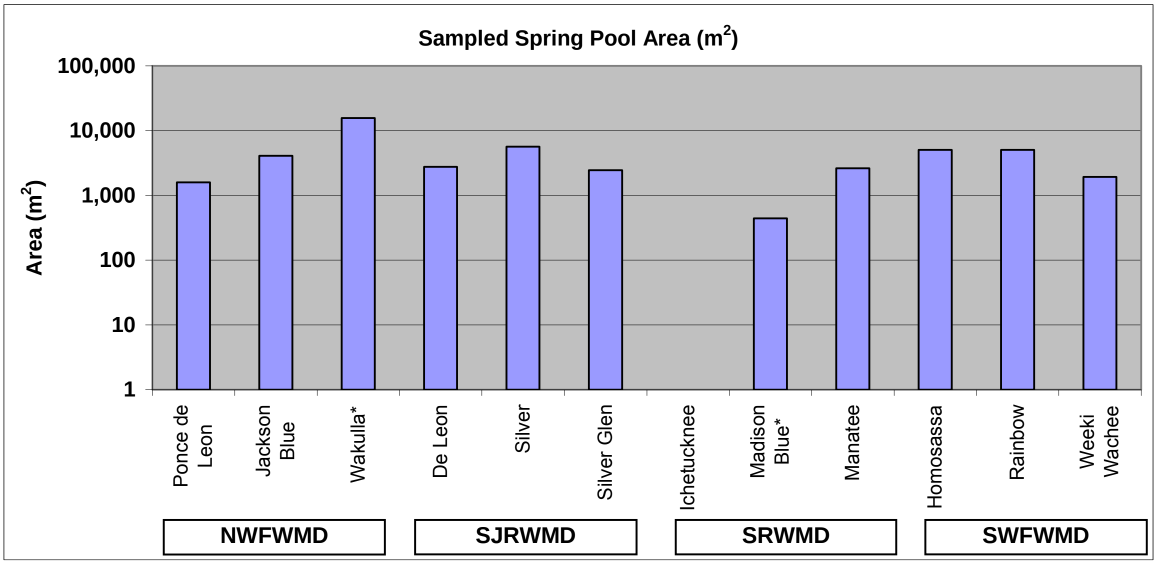
Physical Parameters

Bathymetry

Spring size provides an important record of the discharge history of a spring and an index of the springs' potential to support a biological community. Segment depth, area, and water volume were estimated by use of a recording depth finder linked to a global positioning system (GPS). Wetted surface area and volume of each spring segment were estimated based on these three dimensional data. Nominal hydraulic residence time was estimated for each spring segment based on these estimated water volumes and the upstream and downstream flow estimates.

Figure 20 illustrates the wetted areas of each spring by the pool and run (for the sampled portions only, Ichetucknee pools not sampled). The smallest spring pool and run surface areas were observed at Madison Blue Spring, with 441 m^2 in the pool and 643 m^2 in the run. Largest spring surface areas were 15,685 m^2 for the pool segment of Wakulla and 171,680 m^2 for the run segment of Ichetucknee. **Figure 21** illustrates the volume of each spring by pool and run (for the sampled portions only). The smallest spring pool and run volumes were observed at Ponce de Leon Springs, with 1,708 m^3 for the pool segment and 868 m^3 for the run segment. Largest spring volumes were 49,607 m^3 for the pool segment of

Wakulla Springs and 108,306 m³ for the run segment of Silver Springs. **Table 4** provides the area, volume, minimum, maximum depths and dimensions, as well as average depths for each spring by the sampled portions of the pool and run.



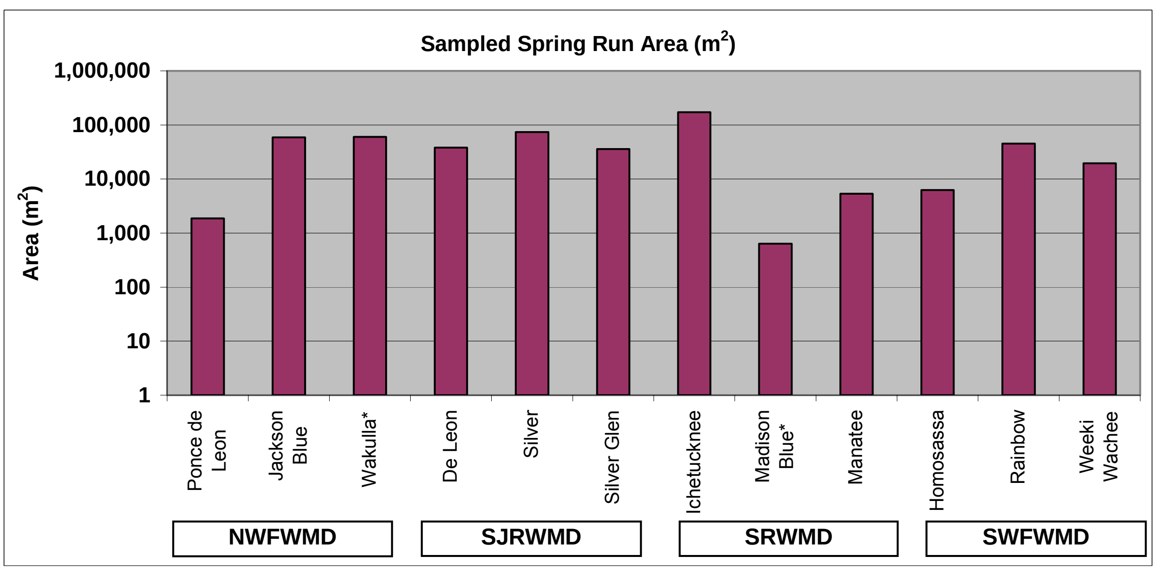
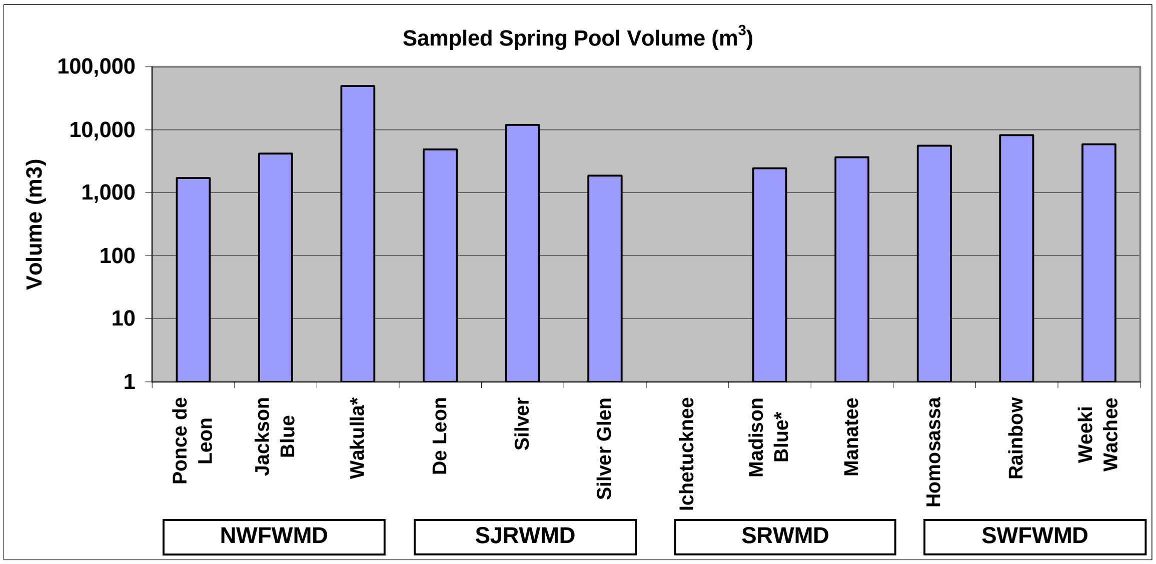


FIGURE 20
Wetted area (m^2) of the pool and run by spring (sampled portions only, Ichetucknee pool not sampled, *flooded during bathymetry survey).



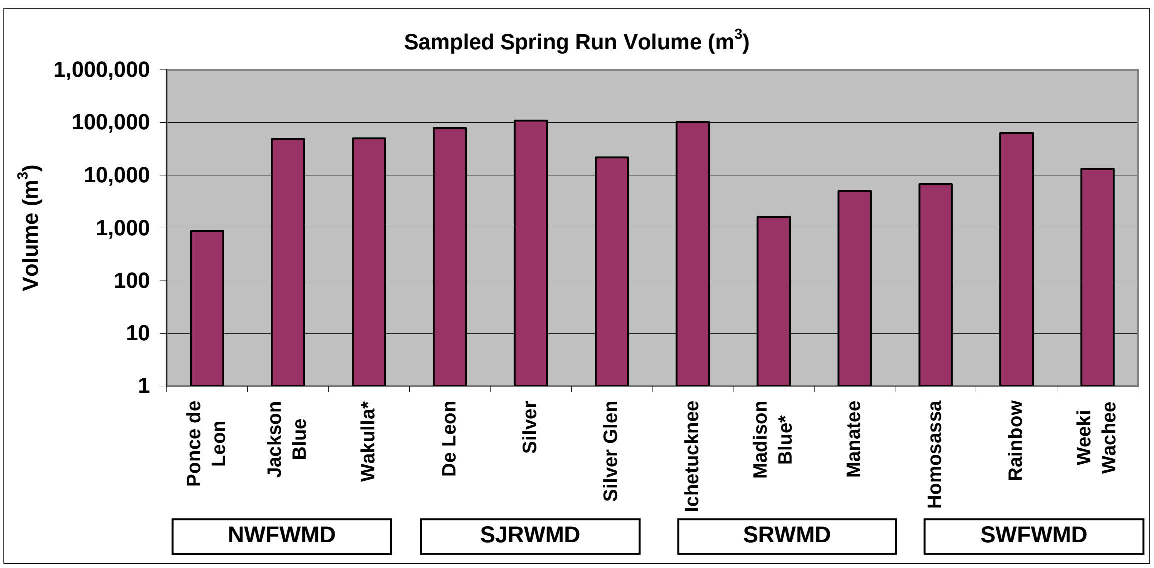


FIGURE 21
Summary of the sampled volume (m^3) by spring (sampled portions only, Ichetucknee pool not sampled, *flooded during bathymetry survey).

TABLE 4
Physical characteristics of the pool and run by spring (sampled portions only, Ichetucknee pool not sampled).

Water Management District	Spring	Location	Volume (m³)	Area (m²)	Maximum Width (m)	Maximum Length (m)	Minimum Depth (m)	Maximum Depth (m)	Average Depth (m)	Stage (ft)
NWFWMD	**Ponce de Leon**	Pool	1,708	1,595	23	42	0.30	4.67	1.18	n/a
		Run	868	1,869	15	171	0.34	1.67	0.58	n/a
	Jackson Blue	Pool	4,175	4,081	76.6	62.8	0.32	5.10	1.33	n/a
		Run	48,529	58,723	217	534	0.29	3.70	1.21	13.27
	Wakulla*	Pool	49,607	15,685	91	176	0.32	27.09	4.82	3.18
		Run	50,237	60,318	108	800	0.30	3.06	1.07	4.06
SJRWMD	**De Leon**	Pool	4,898	2,752	56	54	0.6	8.3	2.19	n/a
		Run	77,777	37,959	118	344	0.7	3.9	2.22	n/a
	Silver	Pool	11,969	5,643	70	101	0.34	13.53	1.18	n/a
		Run	108,306	73,754	111	1100	0.25	8.25	1.94	0.67
	Silver Glen	Pool	1,875	2,442	90	115	0.32	5.10	1.18	0.38
		Run	21,766	35,836	105	395	0.24	3.13	1.21	n/a
SRWMD	**Ichetucknee**	Pool	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Run	101,843	171,680	30	5,103	0.31	6.36	0.93	14.60
	Madison Blue*	Pool	2,457	441	19.1	18.8	0.34	9.99	6.12	n/a
		Run	1,618	634	9.8	35.8	0.34	4.17	2.28	17.02
	Manatee	Pool	3,683	2,618	25	96	0.32	8.17	1.17	1.48
		Run	5,015	5,352	40	234	0.31	2.49	0.88	n/a
SWFWMD	**Homosassa**	Pool	5,578	5,068	31.9	132.6	0.44	7.48	1.21	3.01
		Run	6,775	6,251	59.3	98.1	0.40	2.76	1.14	n/a
	Rainbow	Pool	8,245	5,033	68	155	0.46	3.74	2.07	n/a
		Run	62,713	45,255	118	983	0.27	4.09	1.91	4.09
	Weeki Wachee	Pool	5,867	1,929	43	112	0.34	38.91	7.14	n/a
		Run	13,340	19,477	31	809	0.31	0.94	0.71	n/a

** flooded during bathymetry survey*

Discharge

Spring discharge is possibly the single most important forcing function that regulates overall spring habitat support of plant, fish, and wildlife communities. Stream discharge and velocity were measured at the downstream ends of each spring segment using a portable flow meter (Marsh-McBirney Flo-Mate). Discharge measurements were collected on multiple dates and locations for each spring (USGS data reported for Silver Springs).

Figure 22 and **23** provides a visual comparison of these discharge data. **Table 5** provides a summary of velocity, discharge, and hydraulic residence time (HRT) values by spring and station, while **Appendix C** provides detailed discharge measurements by spring.

Light Transmission

The influx of light is the most important determinant of overall ecosystem primary productivity in clear-water springs. Light attenuation by dissolved and particulate matter in spring waters limits the magnitude of this forcing function. Light attenuation/transmittance measurements, in the wavelength range of photosynthetically active radiation (PAR, 300 to

700 nm), were collected on multiple dates and locations for each spring. Shading from riparian vegetation was estimated for both the pool and run segments of each spring.

Figures 24 and **25** provide a visual comparison of these light attenuation data for the pool and run sections of each spring, respectively. **Table 6** provides a summary of the percent of light transmittance by spring and station, and **Appendix D** provides detailed light measurements by spring. Higher transmittance values indicate clearer water and more solar energy available to submersed aquatic plants and other primary producers. Highest average light transmittance was typically measured in the spring pool stations and lowest average light transmittance was typically measured in the lower spring run, particularly in those systems subject to back-flooding by dark water rivers (*e.g.*, De Leon and Madison Blue) or from dark water entrained through swallets upstream of the spring vent (e.g., Wakulla Springs). Riparian shading data are presented in the aquatic vegetation section below.

Secchi Visibility

Horizontal Secchi disk visibility measurements were collected on multiple dates and locations for each spring. These measurements provide additional information concerning water clarity and the light attenuation properties of springs. Secchi disk visibility declines in proximity to intensive human recreation due to an increase in the suspension of particulate matter.

Figures 26 and **27** provide a visual comparison of maximum horizontal Secchi readings by spring for the pool and run portions, respectively. **Table 7** provides a summary of horizontal Secchi disk measurements by spring and location, which have been completed through this reporting period.

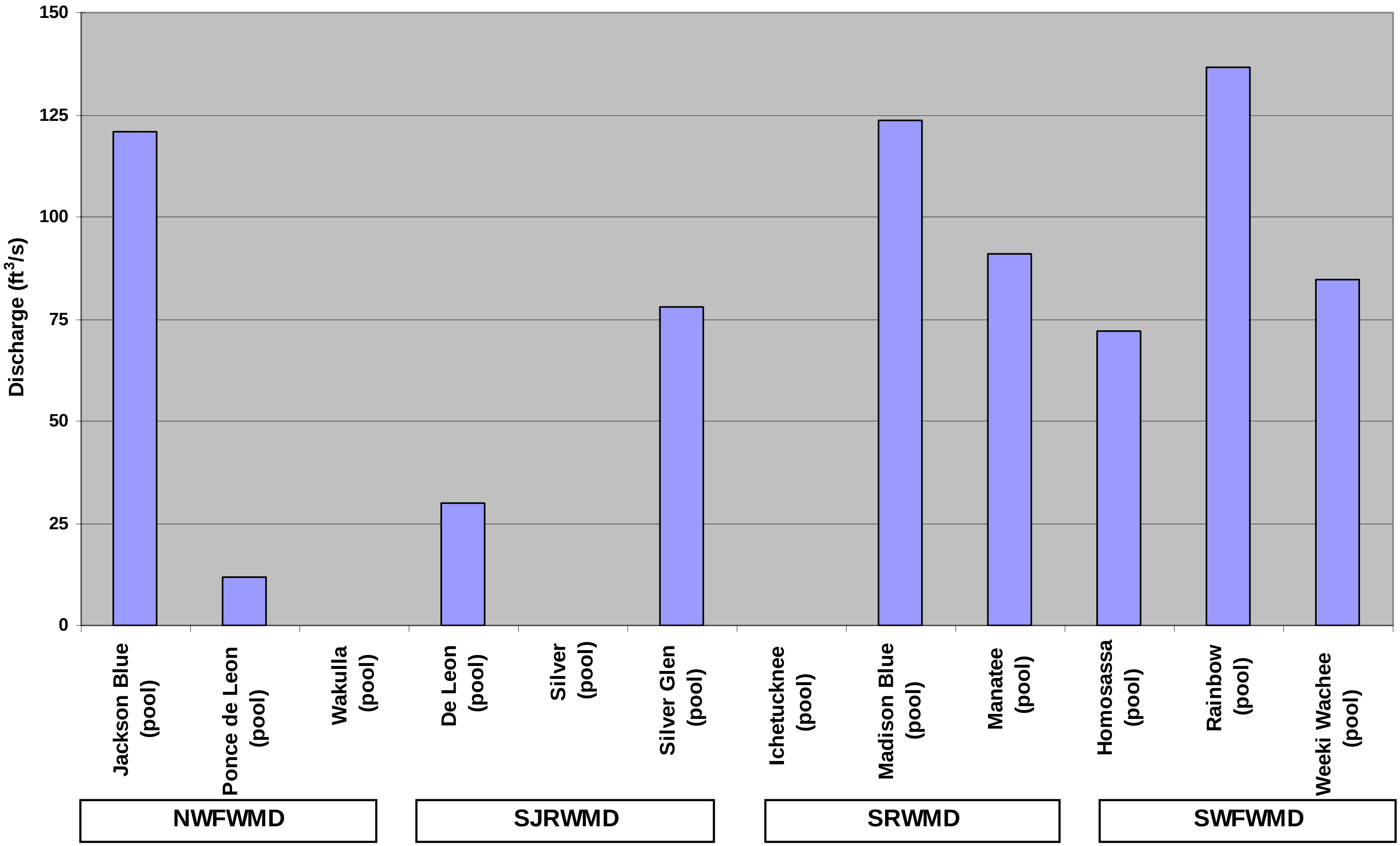


FIGURE 22
Summary of pool discharge (cfs) by spring (Wakulla, Silver, and Ichetucknee pool segments not measured).

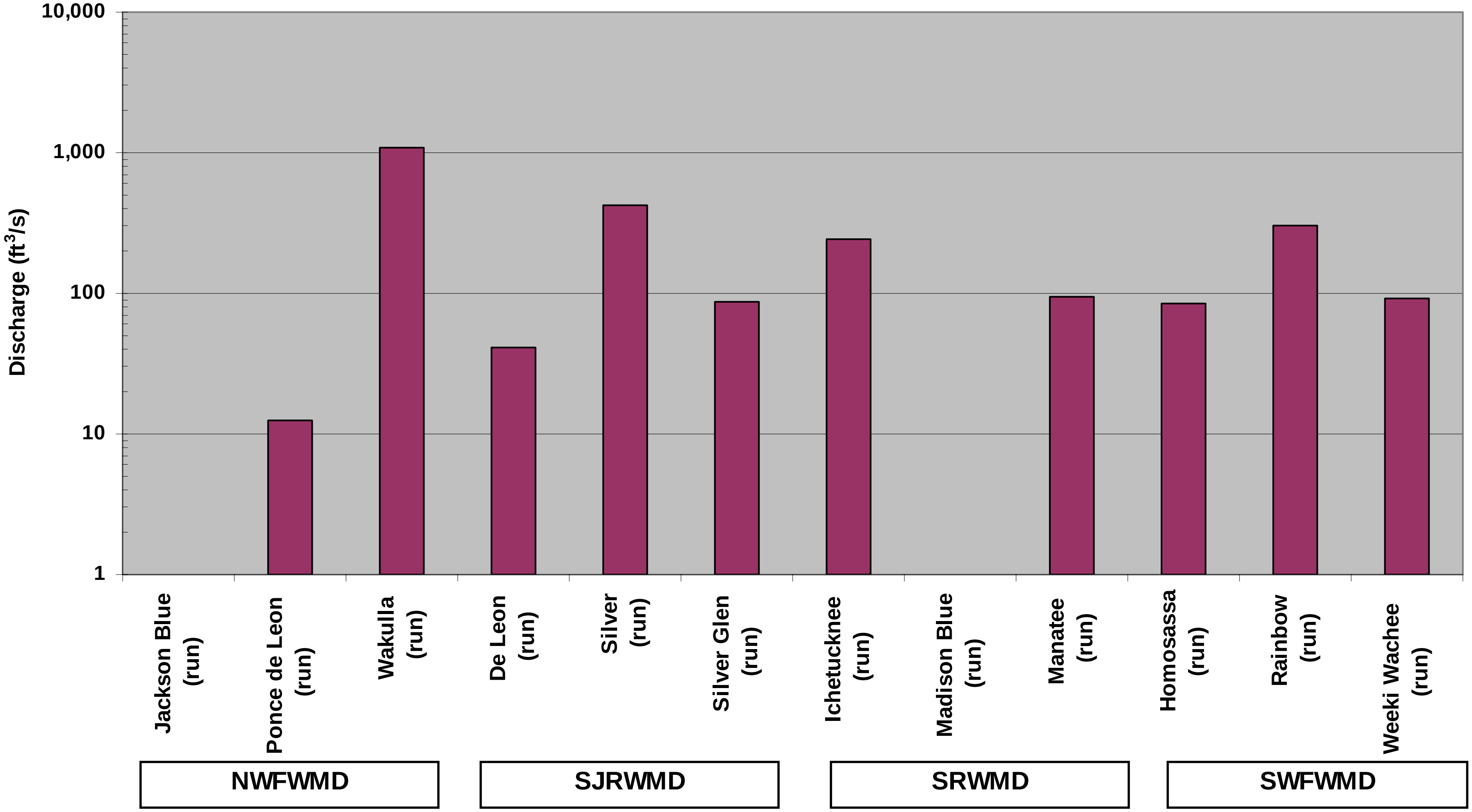


FIGURE 23
Summary of run discharge (cfs) by spring (Jackson Blue and Madison Blue run segments not measured).

TABLE 5
Summary of velocity, discharge, and hydraulic residence time by spring and location.

Water Management District	Spring	Date	Location	Segment Width (ft.)	Average Depth (ft.)	Velocity (ft/s)			Discharge			Hydraulic Residence Time (HRT, hrs)
						0.2 x depth	0.6 x depth	0.8 x depth	(ft^3/s)	(m^3/d)	(MGD)	
NWFWMD	**Jackson Blue**	Jan 13 to 14, 2009	pool	211	4.4	0.16	0.01	0.07	120.9	295,727	78.1	0.40
			run	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.07
	Ponce de Leon	Sep 8 to 11, 2009	pool	31	1.8	0.24	0.12	0.25	11.6	28,497	7.5	1.42
			run	35	1.6	0.25	0.18	0.26	12.4	30,353	8.0	0.72
	Wakulla	Apr 14 to 15, 2009	pool	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.21
			run	424	3.7	0.88	0.17	0.62	1,087	2,659,239	702.5	4.27
SJRWMD	**De Leon**	Oct 6 to 9, 2008	pool	12	1.5	0.37	0.34	0.34	29.7	72,752	19.2	1.69
			run	220	7.0	0.04	---	0.02	41.0	100,223	26.5	26.84
	Silver*	May 4 to 8, 2009	pool	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.55
			run	N/A	N/A	N/A	N/A	N/A	425.2	1,040,284	274.8	1.23
	Silver Glen	Feb 16 to 18, 2009	pool	174	2.4	0.24	0.10	0.21	77.9	190,569	50.3	N/A
			run	120	3.8	0.38	0.12	0.04	87.7	214,645	56.7	2.19 [§]
SRWMD	**Ichetucknee**	Jul 6 to 9, 2009	pool	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
			run	79	3.6	1.41	0.11	0.43	240.4	588,102	155.4	4.47
	Madison Blue	Dec 12, 2008 / Jan 2, 2009	pool	51	5.5	1.10	0.49	0.51	123.6	302,377	79.9	N/A
			run	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.22 [§]
	Manatee	Aug 3 to 6, 2009	pool	84	3.7	0.34	0.02	0.27	90.8	222,098	58.7	0.27
			run	95	4.2	0.22	0.04	0.24	93.6	228,958	60.5	0.37
SWFWMD	**Homosassa**	Nov 3 to 6, 2008	pool	107	3.0	0.26	0.04	0.20	72.0	176,044	46.5	0.63
			run	212	4.2	0.10	0.01	0.08	84.1	205,860	54.4	0.75
	Rainbow	Jun 6 to 8, 2009	pool	101	8.4	0.19	N/A	0.08	136.6	334,221	88.3	1.23
			run	136	7.0	0.42	0.08	0.11	302.7	740,517	195.6	1.00
	Weeki Wachee	Mar 9 to 12, 2009	pool	59	3.4	0.54	0.28	0.72	84.8	207,444	54.8	0.80
			run	66	2.3	0.85	0.31	0.81	93.3	228,206	60.3	0.75

** USGS discharge data from 1,200 m station (# 02239501), [§] pool and run HRT combined, N/A - data not available due to site-specific sampling constraints*

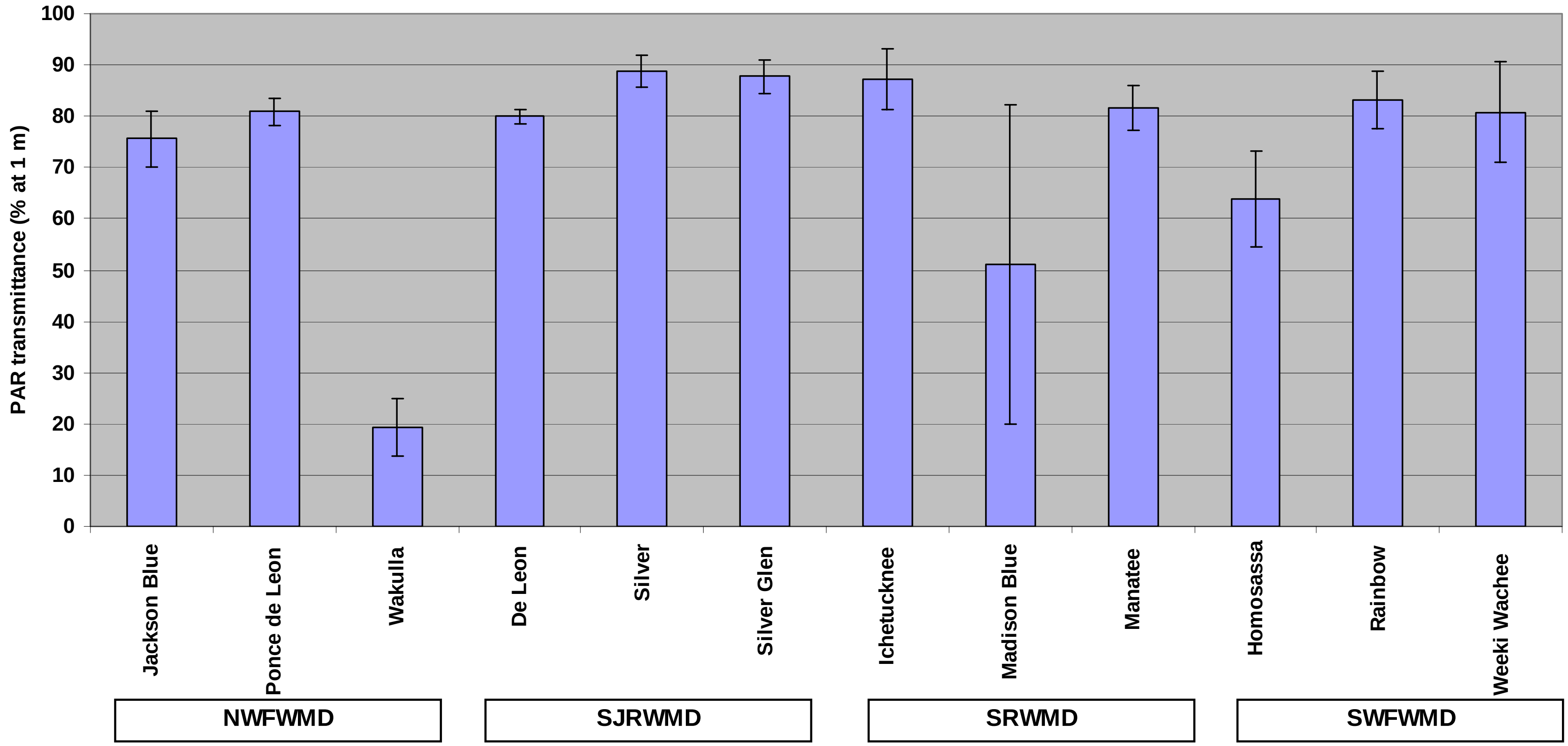


FIGURE 24
Summary of light (PAR) transmittance (% at 1 m) in spring pool (Wakulla and Madison Blue tannin colored and flooded during portions of sampling).

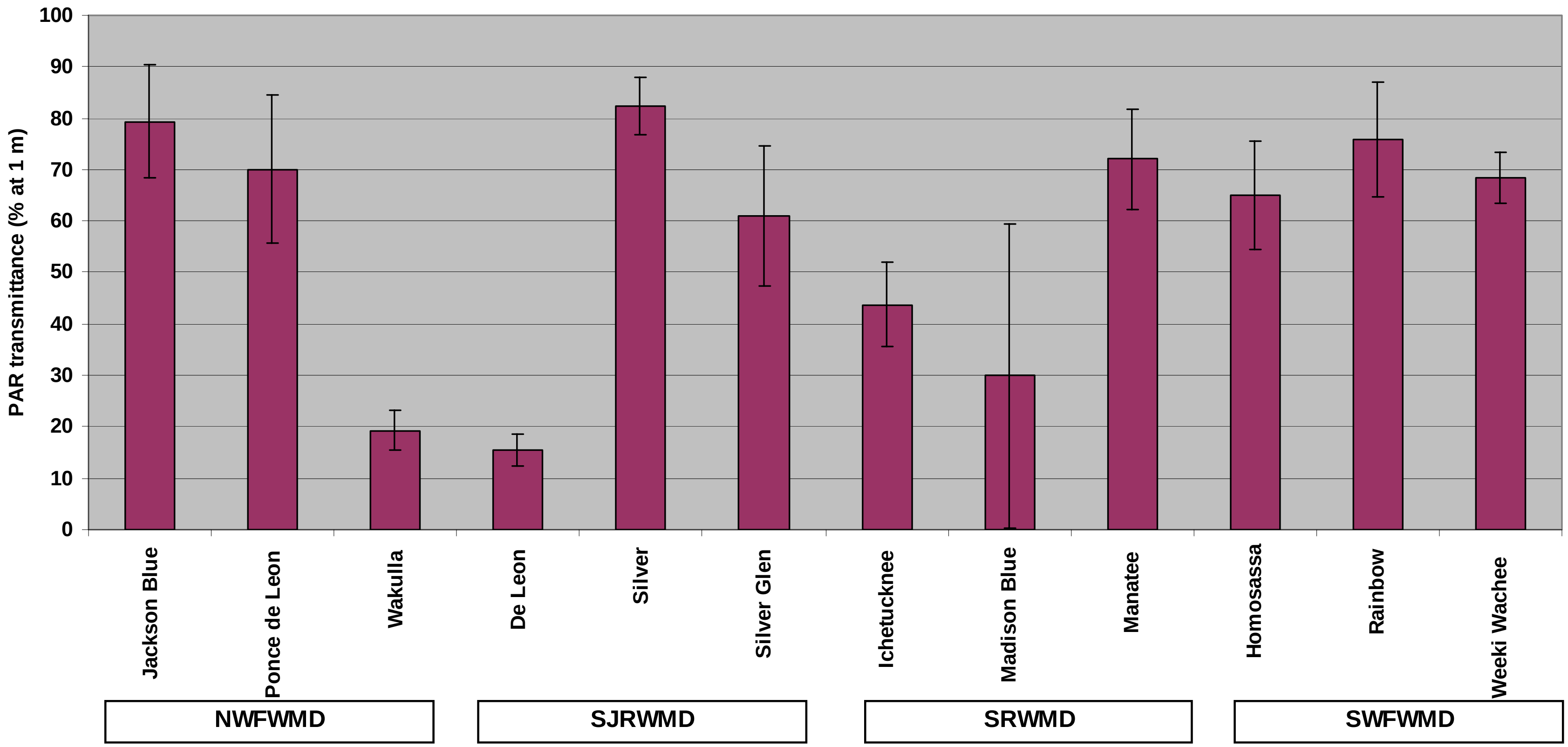


FIGURE 25
Summary of light (PAR) transmittance (% at 1 m) in spring run (Wakulla and Madison Blue tannin colored and flooded during portions of sampling).

TABLE 6
Summary of light (PAR) transmittance (% at 1 m) by spring and station (PDL-2 not measured).

Water Management District	Spring	STATION	Average	Minimum	Maximum	Std Dev	N	Min Date	Max Date
NWFWMD	**Jackson Blue**	JBS-1	75.6	66.2	83.6	5.5	8	01/12/09	01/14/09
		JBS-3	79.3	63.0	94.9	11.0	8	01/12/09	01/14/09
	Ponce de Leon	PDL-1	81.8	78.1	84.0	2.6	4	09/09/09	09/10/09
		PDL-2	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		PDL-3	70.0	58.6	89.5	14.4	4	09/09/09	09/10/09
	Wakulla	WAK-1	19.3	12.3	26.4	5.7	6	04/13/09	04/15/09
		WAK-2	18.2	13.6	21.5	2.8	6	04/13/09	04/15/09
		WAK-3	19.3	12.3	23.9	4.0	6	04/13/09	04/15/09
SJRWMD	**De Leon**	VDL-1	79.9	77.9	81.4	1.5	4	10/06/08	10/08/08
		VDL-2	71.2	63.5	83.8	6.0	10	10/06/08	10/09/08
		VDL-3	15.5	12.1	19.9	3.0	6	10/07/08	10/08/08
	Silver	SS-1	88.8	83.1	91.2	3.0	6	05/04/09	05/08/09
		SS-2	83.0	73.2	91.0	5.9	8	05/04/09	05/08/09
		SS-3	82.3	70.5	87.2	5.5	8	05/04/09	05/08/09
	Silver Glen	SGS-1	87.8	84.3	92.1	3.2	4	02/17/09	02/18/09
		SGS-2	55.6	22.0	83.8	26.6	4	02/16/09	02/18/09
		SGS-3	61.0	46.5	78.2	13.6	6	02/16/09	02/18/09
SRWMD	**Ichetucknee**	IS-1	87.3	83.2	91.4	5.8	2	07/07/09	07/07/09
		IS-2	82.6	82.2	83.1	0.6	2	07/07/09	07/07/09
		IS-3	68.9	61.1	76.7	11.0	2	07/06/09	07/06/09
		IS-4	43.8	40.1	57.8	8.1	4	07/06/09	07/07/09
	Madison Blue	MBS-1	51.0	3.9	83.6	31.1	6	12/01/08	01/02/09
		MBS-2	36.4	7.7	78.5	30.2	6	12/01/08	01/02/09
		MBS-3	30.0	4.2	57.5	29.5	4	12/01/08	01/02/09
	Manatee	MS-1	81.5	77.2	85.8	4.4	4	08/04/09	08/06/09
		MS-2	70.7	48.0	81.8	11.3	8	08/03/09	08/06/09
		MS-3	72.0	55.0	83.8	9.7	10	08/03/09	08/06/09
SWFWMD	**Homosassa**	HS-1	63.8	52.2	72.8	9.4	4	11/03/08	11/05/08
		HS-2	62.2	44.9	77.5	13.1	6	11/03/08	11/05/08
		HS-3	65.1	52.5	80.7	10.5	6	11/03/08	11/05/08
	Rainbow	RS-1	83.2	76.4	91.7	5.7	8	06/08/09	06/11/09
		RS-2	80.4	74.5	89.5	5.0	8	06/08/09	06/11/09
		RS-3	75.8	53.9	88.5	11.1	8	06/08/09	06/11/09
	Weeki Wachee	WWS-1	80.8	69.2	93.0	9.8	6	03/09/09	03/11/09
		WWS-2	46.7	15.8	85.8	24.6	6	03/09/09	03/11/09
		WWS-3	68.5	62.4	77.1	5.0	6	03/09/09	03/11/09

N/A - data not available due to site-specific sampling constraints

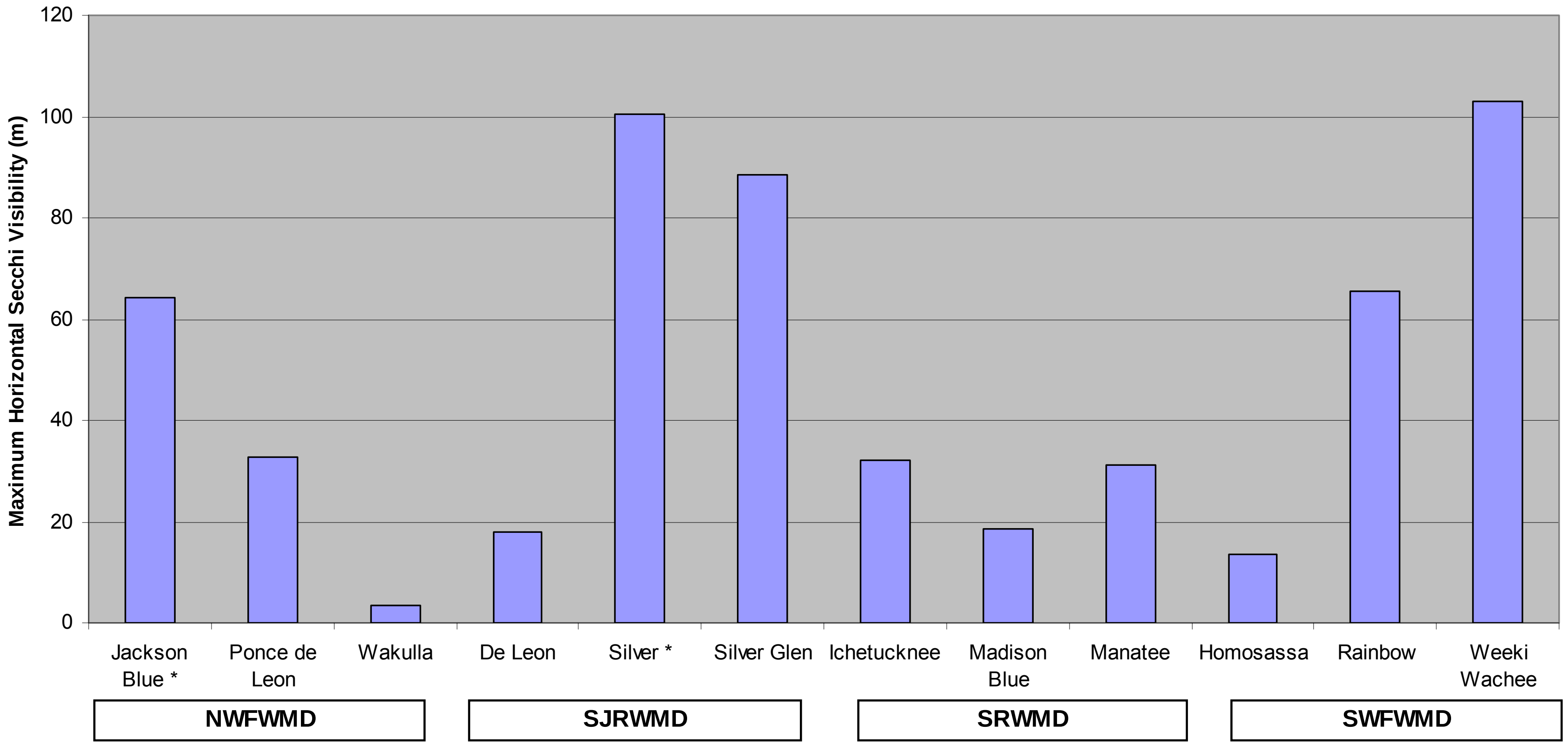


FIGURE 26
Summary of maximum horizontal Secchi disk visibility (m) in spring pool (* horizontal Secchi visibility exceeded maximum dimensions of spring pool, Wakulla flooded and tannin colored during sampling).

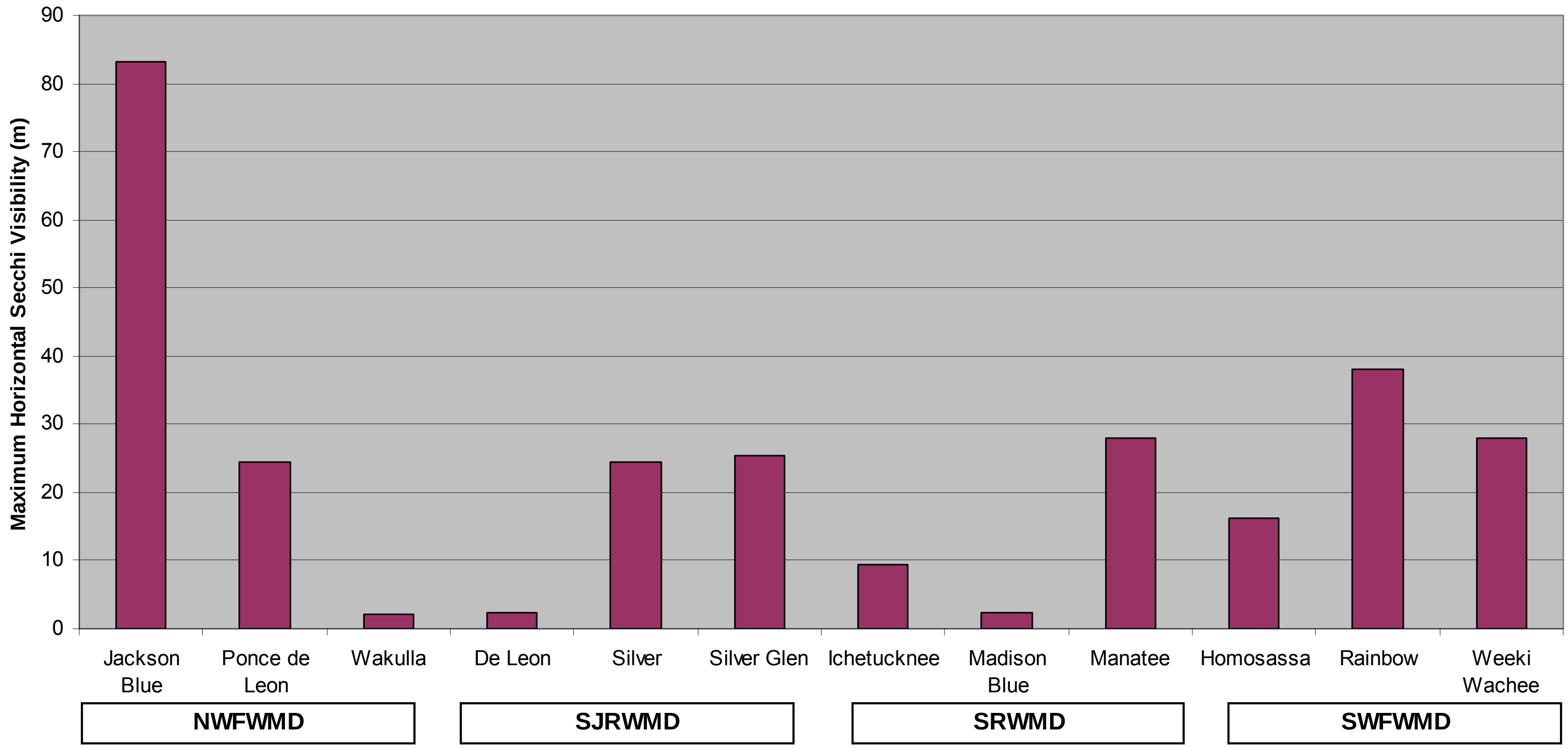


FIGURE 27
Summary of maximum horizontal Secchi disk visibility (m) in spring run (Wakulla and Madison Blue flooded and tannin colored during sampling).

TABLE 7
Summary of horizontal Secchi disk visibility (m) by spring and location.

Water Management District	Spring	Location	Secchi visibility (m)	
			average	maximum
NWFWMD	**Jackson Blue**	pool*	64	*N/A*
		run	78.8	83.2
	Ponce de Leon	pool	27.8	32.9
		run	22.9	24.4
	Wakulla	pool §	2.8	3.4
		run §	2.1	2.2
SJRWMD	**De Leon**	pool	14.0	17.9
		run	1.9	2.4
	Silver	pool*	100.6	100.6
		run	20.1	24.4
	Silver Glen	pool	69.7	88.4
		run	25.3	25.3
SRWMD	**Ichetucknee**	pool	28.7	32.0
		run	7.0	9.3
	Madison Blue	pool	15.0	18.6
		run §	1.1	2.3
	Manatee	pool	27.7	31.1
		run	23.6	28.0
SWFWMD	**Homosassa**	pool	10.8	13.4
		run	11.5	16.2
	Rainbow	pool	59.3	65.5
		run	31.3	38.1
	Weeki Wachee	pool	87.4	103.0
		run	18.4	28.0

§ *Madison Blue Spring run flooded by Withlacoochee River when measured*

§ *Wakulla Springs flooded and tannin stained when measured*

** Horizontal Secchi visibility exceeded maximum dimensions of spring pool*

Oxygen Diffusion

To estimate spring ecosystem metabolism using diel changes in dissolved oxygen, the diffusion rate of this gas between spring waters and the atmosphere must be accounted for (gas exchanges between the air and emergent/floating plants were not measured). Oxygen diffusion rates are especially high in springs with naturally low concentrations of dissolved oxygen and in springs with high current velocities. Field diffusion measurements (see **Appendix A** for a description of the methodology) were made using the floating dome technique at multiple locations for each spring system. For each study segment, the average oxygen diffusion coefficient was interpolated from the average study segment velocity.

Results confirm that oxygen diffusion rates are similar between springs and positively correlated to the velocity of the spring water (**Figure 28** and **Table 8**). **Appendix E** provides detailed diffusion measurements by spring.

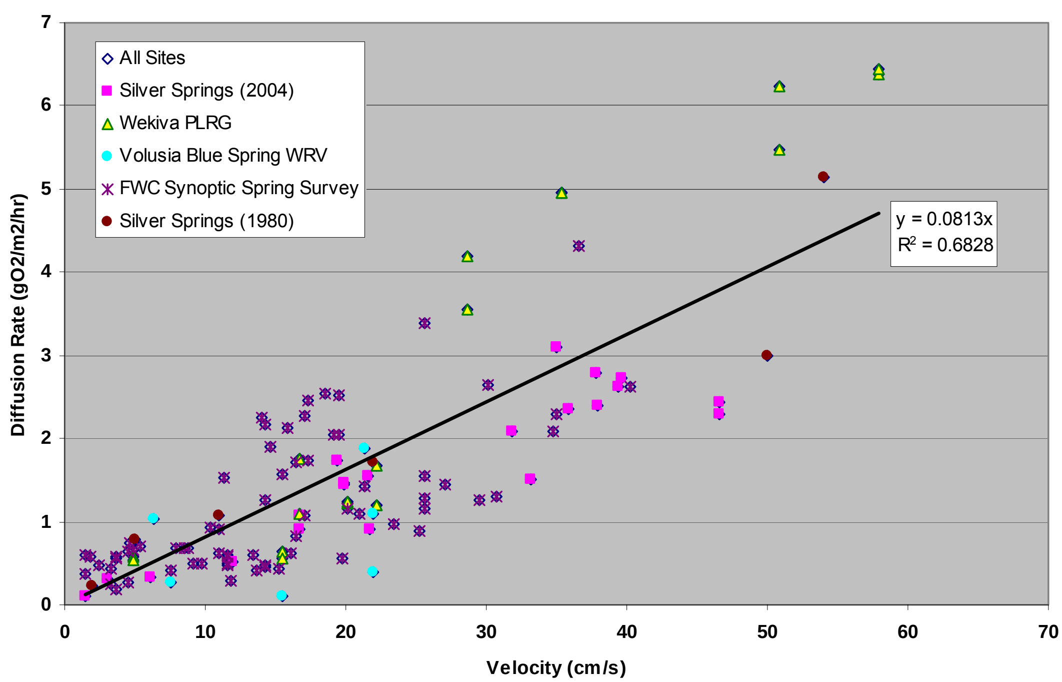


FIGURE 28
Linear relationship between measured water velocity and oxygen diffusion rate, data points from all stations and springs.

TABLE 8
Summary of measured oxygen diffusion rates and corresponding ambient dissolved oxygen, depth, and velocity readings by spring and station.

Water Management District	Spring	Date	Station Name	Ambient Dissolved Oxygen (mg/L)	Depth (m)	Velocity (cm/s)	K Rate ($gO_2/m^2/hr$)
NWFWMD	Jackson Blue	01/12/09	JBS-1	7.03	2.23	16.46	1.71
		01/13/09	JBS-1	6.58	2.16	17.37	1.73
		01/14/09	JBS-1	6.30	2.19	15.54	1.57
		01/15/09	JBS-1	5.75	2.16	17.07	2.28
	Ponce de Leon	09/10/09	PDL-2.5	4.82	0.27	9.75	0.50
		09/10/09	PDL-2.5	4.65	0.24	8.84	0.69
		09/09/09	PDL-3	5.00	0.91	7.62	0.40
	Wakulla	04/13/09	WAK-2	2.29	2.41	35.05	2.30
		04/13/09	WAK-2	2.22	2.41	36.58	4.31
		04/14/09	WAK-2	2.15	2.96	40.23	2.63
		04/15/09	WAK-2	2.31	2.13	1.83	0.58
		04/15/09	WAK-2	2.02	1.19	25.60	3.39
		04/16/09	WAK-2	2.17	1.19	14.33	2.17
SJRWMD	De Leon	10/06/08	VDL-2	0.95	0.85	14.02	2.25
		10/06/08	VDL-2	0.91	0.82	15.85	2.13
		10/07/08	VDL-2	0.91	0.85	14.33	1.27
		10/08/08	VDL-2	0.76	0.84	19.51	2.53
		10/08/08	VDL-2	0.80	0.84	19.51	2.05
		10/09/08	VDL-2	0.81	0.84	14.63	1.90
	Silver	05/04/09	SS-BB	4.47	1.11	2.44	0.48
		05/05/09	SS-2.5	4.89	1.59	14.33	0.48
		05/05/09	SS-2.5	4.96	1.59	14.33	0.45
		05/07/09	SS-3	5.55	3.35	34.75	2.09
		05/07/09	SS-2	4.57	2.59	19.20	2.04
		05/08/09	SS-BB	2.76	0.75	3.35	0.26
	Silver Glen	02/18/09	SGS-1	2.81	0.64	25.60	1.15
		02/18/09	SGS-1	2.54	0.64	25.60	1.56
		02/19/09	SGS-1	2.79	0.73	29.57	1.26
SRWMD	Ichetucknee	07/09/09	IS-1	4.23	0.82	11.89	0.30
		07/09/09	IS-1	4.14	1.01	21.34	1.42
		07/07/09	IS-2	5.30	1.58	19.81	0.55
		07/07/09	IS-2	6.52	0.92	20.12	1.15
		07/07/09	IS-2	6.40	0.72	11.58	0.58
		07/06/09	IS-4	5.27	1.44	4.57	0.26
		06/05/08	IS-4	5.31	1.62	11.58	0.61
		06/05/08	IS-4	7.12	1.62	11.58	0.50
		06/05/08	IS-4	8.48	1.62	11.58	0.48
	Madison Blue	12/01/08	MBS-2	1.48	1.01	4.88	0.66
		12/02/08	MBS-2	7.42	0.27	3.66	0.20
	Manatee	08/04/09	MS-2	1.17	1.28	30.18	2.64
		08/04/09	MS-2	1.20	1.34	18.59	2.53
		08/05/09	MS-2	1.33	1.40	17.37	2.46
		08/05/09	MS-2	1.31	1.55	8.53	0.69
		08/06/09	MS-2	1.24	1.52	23.47	0.97
		08/04/09	MS-2.5	2.22	0.79	4.57	0.63
SWFWMD	Homosassa	11/04/08	HS-2	3.97	1.72	5.36	0.70
		11/04/08	HS-2	3.99	1.55	11.34	1.52
		11/05/08	HS-2	3.86	1.79	3.66	0.57
		11/06/08	HS-2	4.16	1.77	4.66	0.75
	Rainbow	06/08/09	RS-1	7.90	2.84	3.35	0.43
		06/09/09	RS-1	7.85	2.32	7.92	0.69
		06/10/09	RS-1	6.54	2.62	13.41	0.60
		06/11/09	RS-1	6.38	3.54	16.46	0.82
		06/08/09	RS-2	7.07	2.37	16.15	0.62
		06/08/09	RS-2	7.97	1.95	15.24	0.43
		06/09/09	RS-2	8.66	2.41	10.36	0.93
		06/10/09	RS-2	7.31	2.38	13.72	0.41
		06/11/09	RS-2	6.37	2.16	17.07	1.08
		06/08/09	RS-3	9.26	3.20	25.60	1.28
		06/09/09	RS-3	10.04	3.08	21.03	1.09
		06/10/09	RS-3	8.78	3.14	30.78	1.30
		06/11/09	RS-3	7.01	2.83	27.13	1.44
	Weeki Wachee	03/09/09	WWS-1	1.61	3.41	9.14	0.49
		03/10/09	WWS-1.5	1.97	0.81	1.52	0.37
		03/10/09	WWS-1.5	1.97	0.81	1.52	0.60
		03/11/09	WWS-2	2.12	0.47	3.66	0.56
		03/11/09	WWS-2	2.12	0.47	10.97	0.91
		03/11/09	WWS-2	2.12	0.47	10.97	0.62
		03/12/09	WWS-2	2.32	0.67	25.30	0.89

Particulate Export

Spring ecosystems are typically autotrophic – they are net producers of organic matter that is transferred downstream to dependent ecosystems (Odum 1957). Particulate export rates were measured in each of the study springs using a plankton net technique (**Appendix A**) to quantify the amount of organic material being transported downstream for each spring system. The Ichetucknee spring pools were not sampled for particulate export.

Particulate export rates are expressed as dry matter (inorganic + organic) and organic matter (loss on ignition) in both grams per day (g/d) and grams per square meter per day (g/m^2/d) in **Figures 29, 30, 31**, and 3**2,** respectively. Positive values indicate a net production of detrital material (material leaving the study segment), while negative values indicate a net accrual of detrital material (material being deposited in the study segment, **Table 9**). **Appendix F** provides detailed particulate measurement data by spring.

TABLE 9
Summary of ecosystem particulate export rates by spring and station (Ichetucknee pool not sampled).

		3 day average values from individual worksheets							
Water Management District	Spring	Dry Matter (g/d)		Organic Matter (g/d)		Dry Matter (g/m^2/d)		Organic Matter (g/m^2/d)	
		pool	run	pool	run	pool	run	pool	run
NWFWMD	Jackson Blue	2,866	-418	570	254	0.70	0.00	0.14	0.00
	Ponce de Leon	1,445	-1,186	222	-97	0.91	-0.63	0.14	-0.05
	Wakulla	18,716	93,524	1,877	40,004	1.19	1.55	0.12	0.66
SJRWMD	De Leon	9,451	7,942	1,839	6,267	3.43	0.20	0.67	0.15
	Silver	98,610	43,979	39,970	21,992	2.24	0.55	0.91	0.28
	Silver Glen	6,866	12,254	3,826	6,978	2.81	0.34	1.57	0.19
SRWMD	Ichetucknee	n/a	128,622	n/a	54,569	n/a	7.30	n/a	2.37
	Madison Blue	7,894	28,103	3,195	4,372	17.89	26.13	7.24	4.07
	Manatee	3,617	3,803	1,650	2,702	1.38	0.71	0.63	0.50
SWFWMD	Homosassa	9,102	11,881	1,308	3,617	1.80	1.90	0.26	0.58
	Rainbow	16,048	13,842	7,761	4,503	3.19	0.53	1.54	0.18
	Weeki Wachee	34,815	-18,187	2,821	4,437	5.30	-0.85	0.43	0.21

N/A - data not available due to site-specific sampling constraints

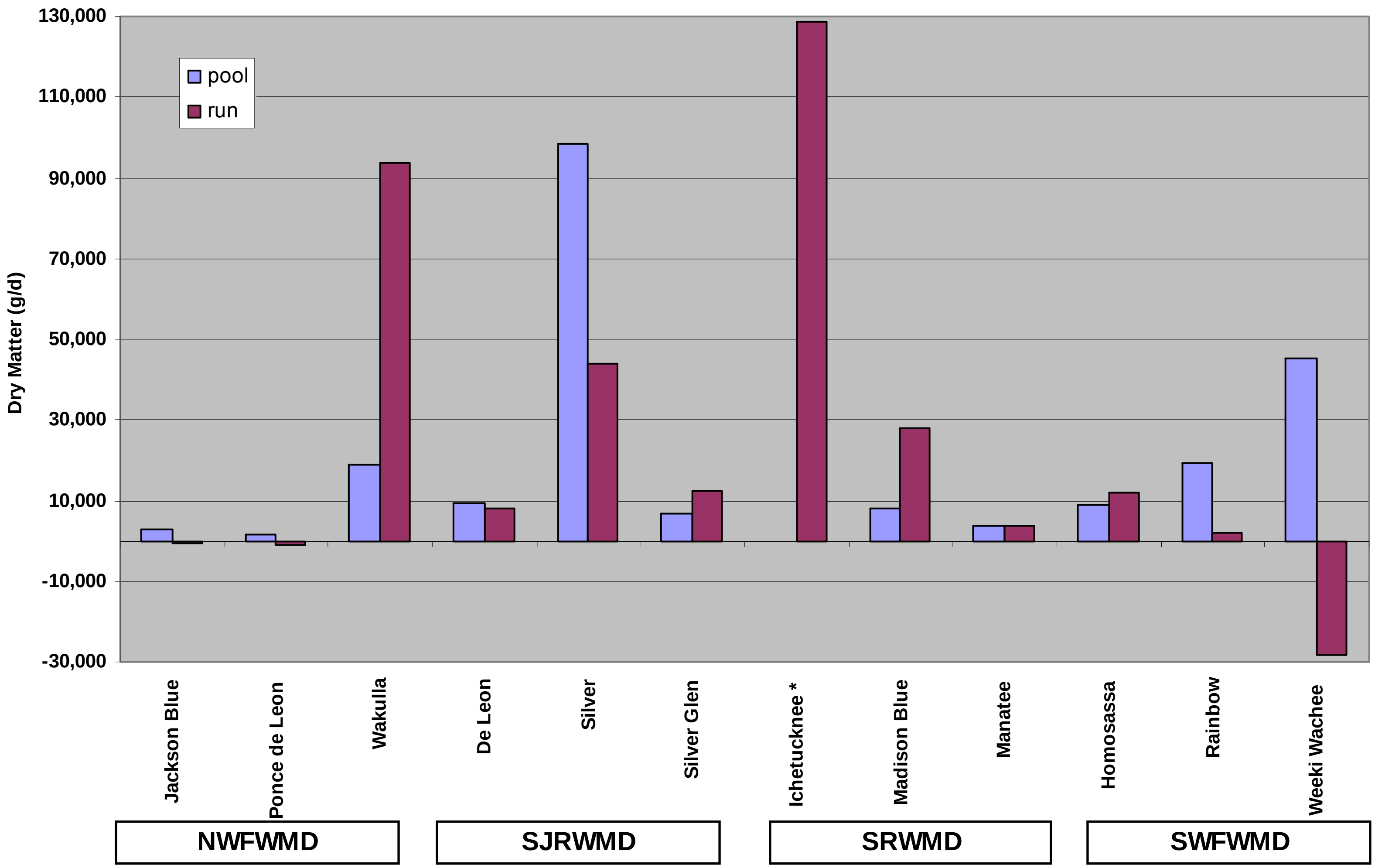


FIGURE 29
Average ecosystem particulate export (dry matter, g/d) by spring and location (* Ichetucknee pool not sampled).

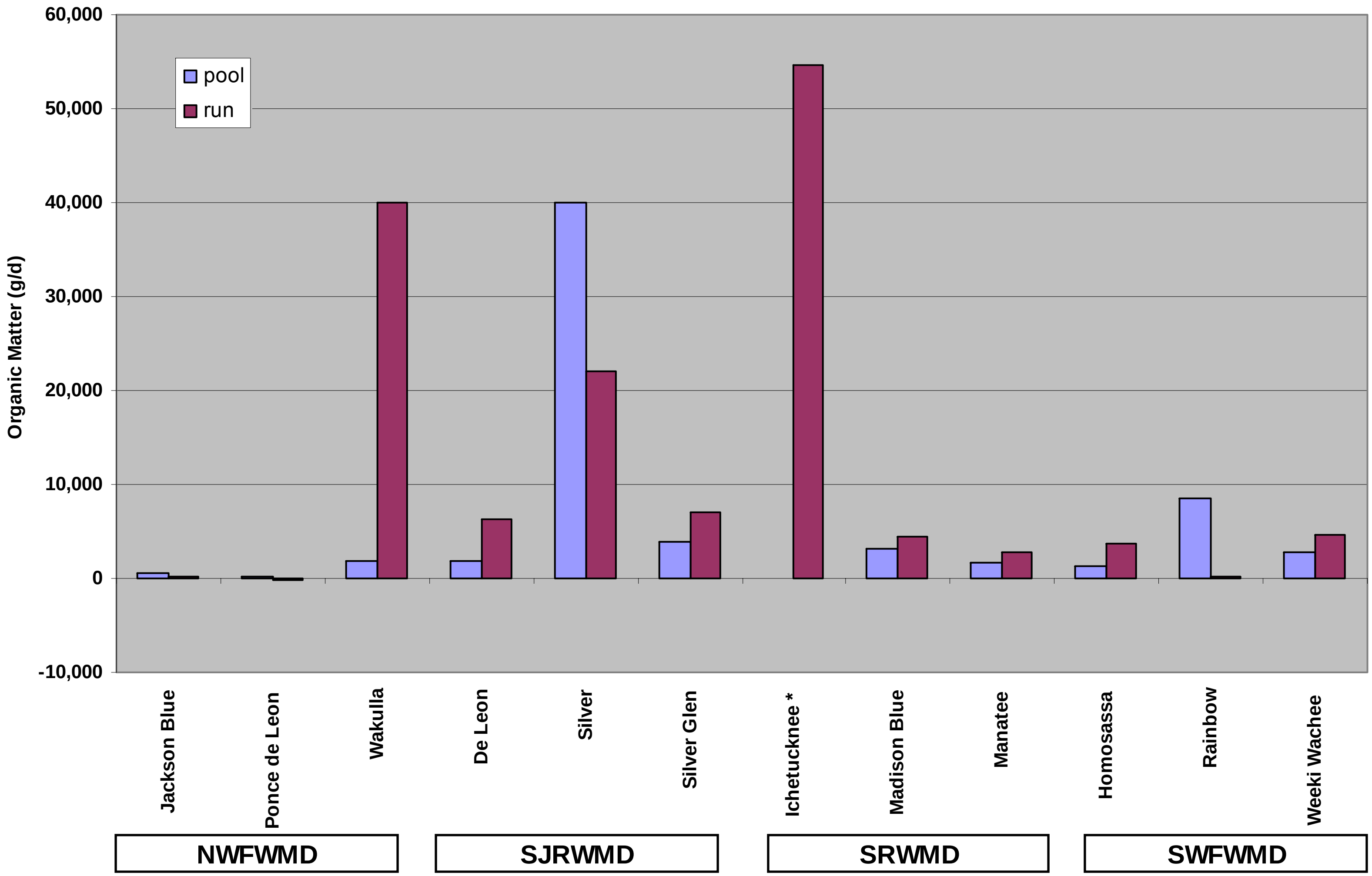


FIGURE 30
Average ecosystem particulate export (organic matter, g/d) by spring and location (* Ichetucknee pool not sampled).

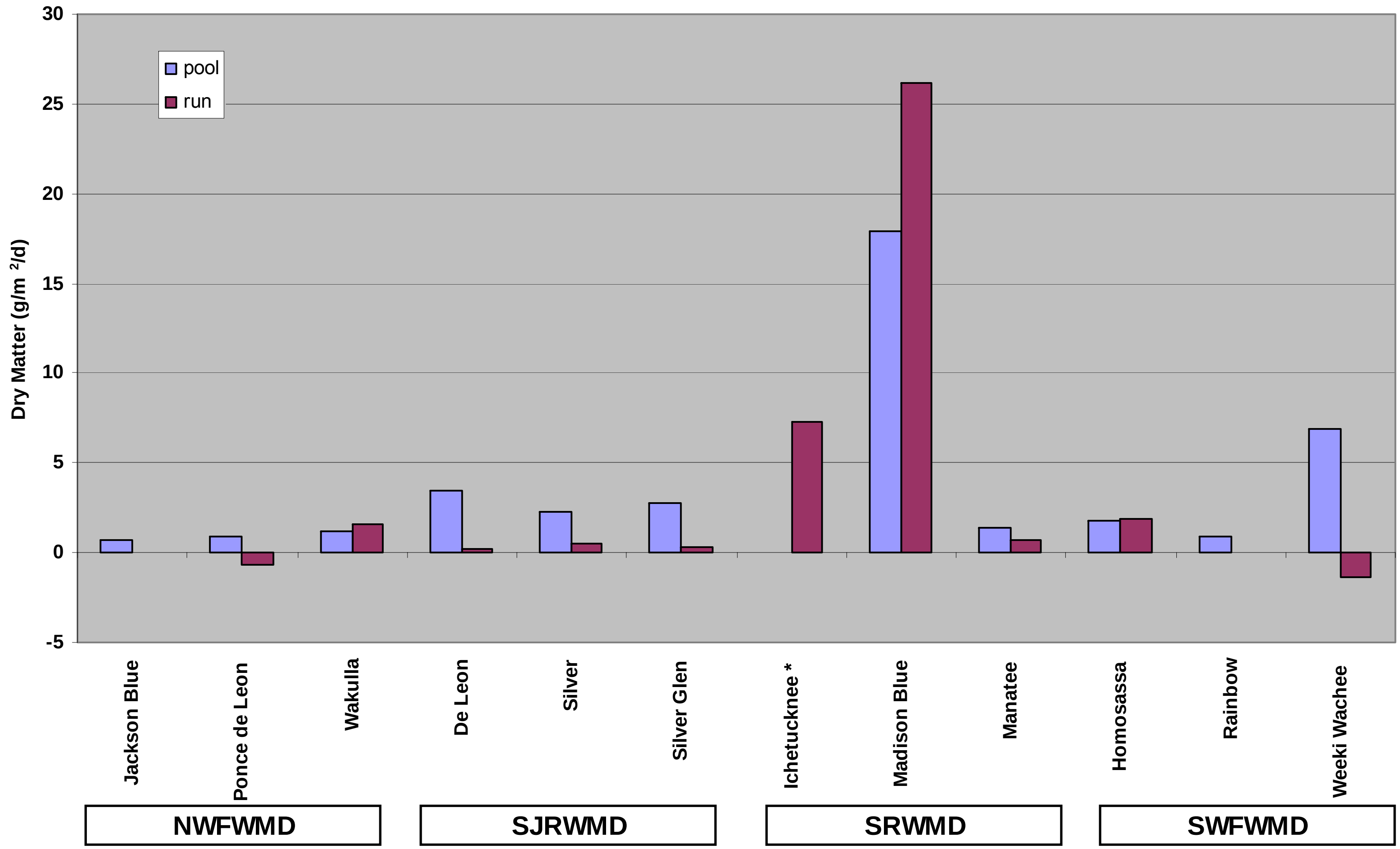


FIGURE 31
Average ecosystem particulate export (dry matter, $g/m^2/d$) by spring and location (* Ichetucknee pool not sampled, Madison Blue flooded by Withlacoochee).

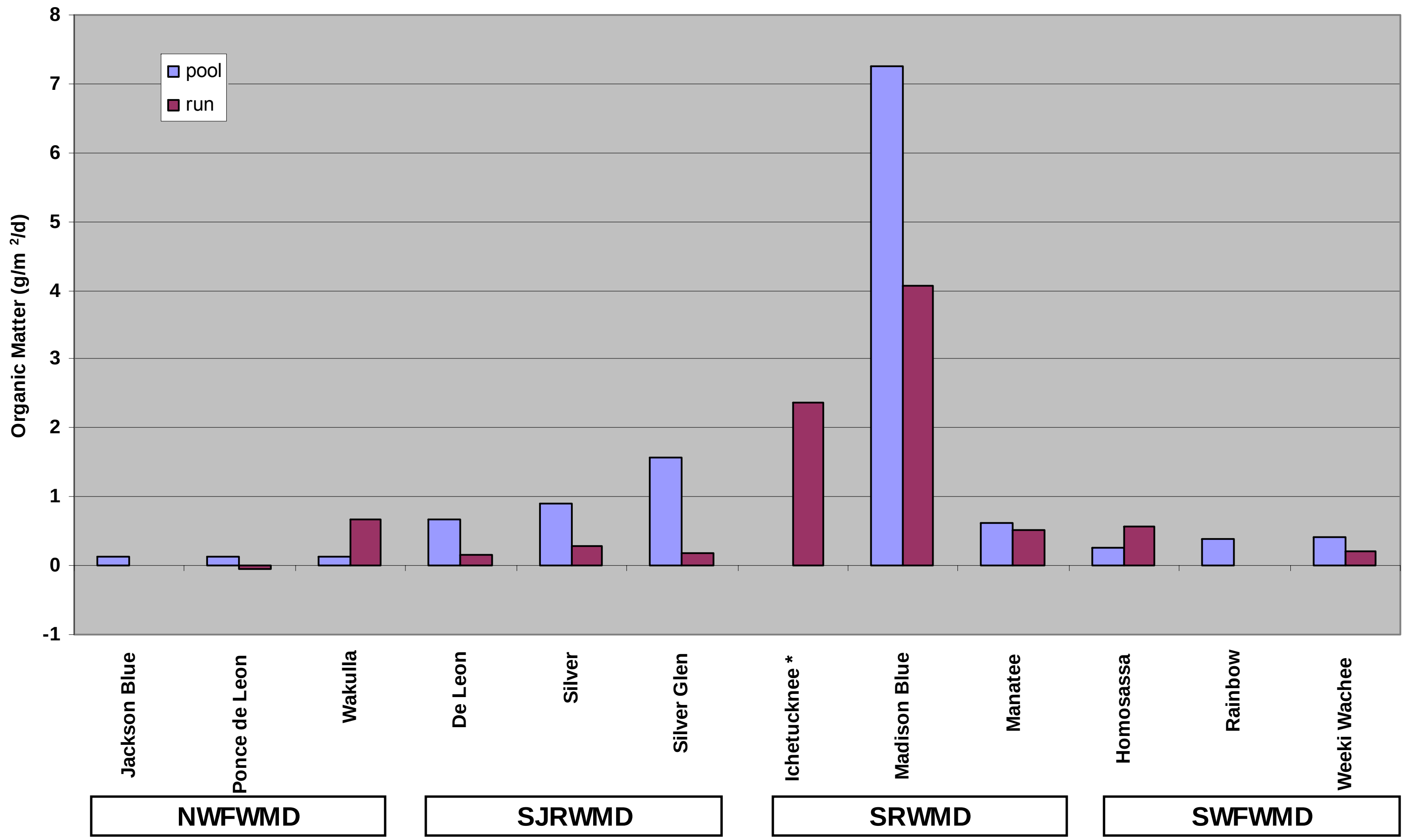


FIGURE 32
Average ecosystem particulate export (organic matter, $g/m^2/d$) by spring and location (* Ichetucknee pool not sampled, Madison Blue flooded by Withlacoochee).

Chemical Parameters

Consistent water chemistry provides a signature of sorts for spring ecosystems. Biological communities in springs are in turn dependent upon these chemical signatures. Water quality field parameters and grab samples for water chemistry analyses were collected at multiple locations and dates during the synoptic sampling for each spring system. These parameters were collected to characterize water quality conditions concurrent with the other intensive sampling, to estimate nutrient uptake rates, to compare nutrient ratios, and to correlate with biological parameters. Methods for chemical data collection are described in **Appendix A**.

Field Parameters

Figure 33 provides a visual comparison of field parameter data including water temperature, dissolved oxygen, pH, and specific conductance (average of the spring pool station) by spring. **Table 10** provides a more detailed summary of these field parameter statistics (N, mean, minimum, maximum, and standard deviation) by spring and sampling station. **Appendix G** provides detailed field parameter measurements by spring.

Temperature varies between springs depending on latitude and depth of the source water but is generally very consistent over an annual basis for a given spring. Mean temperature of the 12 study springs varied between about 20 and 24 ° C with warmer temperatures in the southernmost springs. The only exception was observed in Madison Blue Spring when the colored Withlacoochee River was flowing into the spring estavelle (suck hole) during flooding conditions.

Average pool dissolved oxygen concentrations (near the spring vents) ranged from 0.1 to 3.7 mg/L for 10 of the 12 springs, which is below the state standard for Class III surface waters (5 mg/L). Rainbow and Jackson Blue Springs exhibited highest dissolved oxygen concentrations at their upper vents (at 6.9 and 6.8 mg/L, respectively). Within spring runs, average dissolved oxygen concentrations ranged from 1.5 to 9.5 mg/L.

All twelve of the study springs were circum-neutral with pH values between 7 and 8 standard units.

Specific conductance was variable between springs as a result of their source water quality. Ten of the springs had average specific conductance values less than 1,000 µS/cm while Silver Glenn had an average conductance of about 1,900 µS/cm and Homosassa had a measured value of about 4,800 µS/cm.

Water Chemistry

Figure 34 provides a visual comparison of water chemistry data including total chloride, color, turbidity, total Kjeldahl nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, organic nitrogen (calculated as TKN – NH_4), total nitrogen (calculated as TKN + NO_X), orthophosphate, total phosphorus, and chlorophyll *a- corrected* (average of the spring pool station) by spring. **Figure 35** illustrates average spring pool (upper sonde at Ichetucknee) nitrogen components by spring. **Table 11** provides a summary of water chemistry results by spring and station. **Appendix G** provides detailed water chemistry data by spring.

Average total chloride concentrations in the 12 spring pools ranged from 3 mg/L at Ponce de Leon in Holmes County to 1,250 mg/L in Homosassa Springs near the Gulf of Mexico in Citrus County. Nine of the study springs had total chloride concentrations less than 10 mg/L and the remaining three (De Leon, Silver Glen, and Homosassa) were above 100 mg/L.

Color is naturally low in most artesian springs and was generally in the range from 3 to 6 CPU. The only exception to this rule was at Wakulla Springs in Wakulla County when color increased to 60 CPU following a significant rainfall event during the middle of the study.

Turbidity is also typically low in artesian springs with most measured values less than about 0.25 NTU. The only exception in this study was Homosassa Springs with an average recorded turbidity of 0.76 NTU at the upstream station.

Average concentrations of chlorophyll *a* were low at all upstream spring pool locations, ranging from 0.55 to 1.33 µg/L. Phosphorus concentrations were typical of springs with concentrations of soluble reactive phosphorus (SRP) ranging from a low of 0.009 mg/L at Weeki Wachee in Hernando County to a high of 0.061 mg/L at De Leon in Volusia County. Total phosphorus was only slightly higher, ranging from 0.013 to 0.059 mg/L, indicating the general absence of organic phosphorus in these spring waters.

Nitrogen species in each spring pool area are summarized in **Figure 35**. Total nitrogen in these springs ranged from 0.132 mg/L at Silver Glen to a high of 3.405 mg/L at Jackson Blue. The predominant form of nitrogen in all of the springs was nitrate with a low concentration of 0.052 mg/L at Silver Glen to a high of 3.315 mg/L at Jackson Blue.

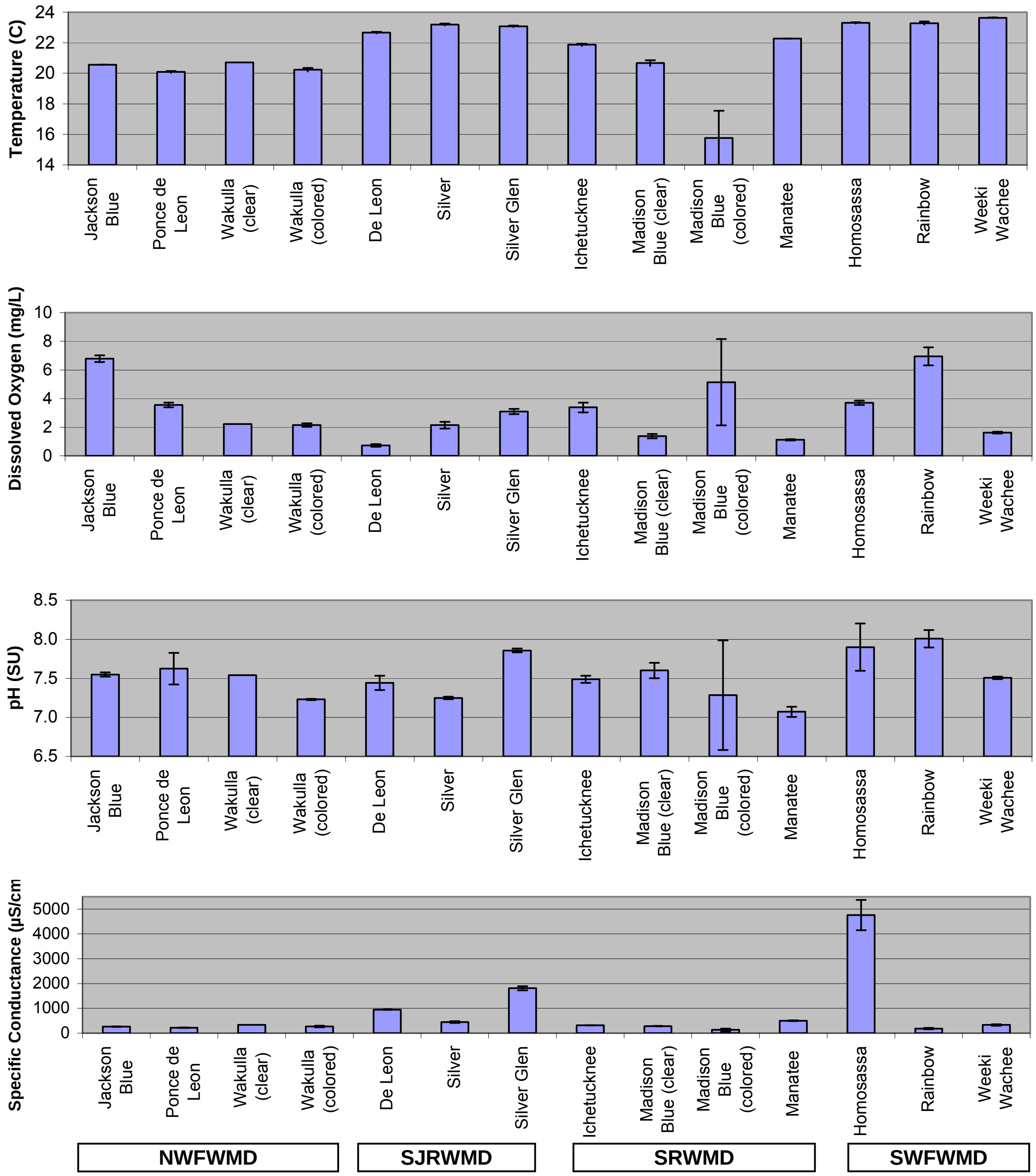


FIGURE 33
Comparison of average (± standard deviation) spring pool field parameters by spring (Madison Blue and Wakulla Springs flooded with colored water during sampling).

TABLE 10
Summary of field parameters (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
DISSOLVED OXYGEN	DO	%	Homosassa	HS-1	44.0	41.3	48.8	1.71	34	11/03/08	11/06/08
			Homosassa	HS-2	48.2	45.5	50.8	1.70	9	11/03/08	11/06/08
			Homosassa	HS-3	50.4	45.8	56.1	3.84	11	11/03/08	11/06/08
			Ichetucknee	ICH_MAIN	41.3	39.0	43.3	1.68	5	01/19/09	07/09/09
			Ichetucknee	ICH_BLUE_HOLE	18.3	16.6	21.4	2.16	4	01/19/09	07/09/09
			Ichetucknee	ICH_MISSION	4.7	2.2	6.1	2.17	3	07/06/09	07/09/09
			Ichetucknee	ICH_DEVILS	1.4	1.1	2.0	0.51	3	07/06/09	07/09/09
			Ichetucknee	ICH_MILLPOND	10.6	7.8	12.5	2.48	3	07/06/09	07/09/09
			Ichetucknee	IS-1	41.5	34.2	46.9	4.23	6	06/19/09	07/09/09
			Ichetucknee	IS-2	68.4	52.7	83.3	10.79	8	01/19/09	07/09/09
			Ichetucknee	IS-3	63.3	46.1	87.0	13.58	9	11/11/08	07/09/09
			Ichetucknee	IS-4	65.9	48.2	89.6	13.82	10	11/11/08	07/09/09
			Jackson Blue	JBS-1	75.5	69.1	79.1	2.60	15	01/12/09	01/15/09
			Jackson Blue	JBS-2	74.4	69.8	77.5	3.38	4	01/12/09	01/15/09
			Jackson Blue	JBS-3	105.2	94.5	114.6	7.98	6	01/12/09	01/15/09
			Madison Blue	MBS-1	60.6	13.9	73.4	22.66	21	12/01/08	01/06/09
			Madison Blue	MBS-2	19.0	14.6	31.2	8.14	4	12/01/08	01/06/09
			Madison Blue	MBS-3	16.8	15.1	19.9	2.69	3	12/01/08	01/06/09
			Manatee	MS-1	12.8	12.3	13.3	0.44	4	08/03/09	08/06/09
			Manatee	MS-2	14.6	13.7	15.7	0.69	6	08/03/09	08/06/09
			Manatee	MS-3	23.0	19.8	25.2	2.30	5	08/03/09	08/06/09
			Ponce de Leon	PDL-1	40.0	38.5	40.7	1.00	4	09/08/09	09/11/09
			Ponce de Leon	PDL-2	42.8	40.4	43.8	1.60	4	09/08/09	09/11/09
			Ponce de Leon	PDL-3	55.4	52.5	59.0	2.83	4	09/08/09	09/11/09
			Rainbow	RS-1	81.5	72.4	92.8	7.49	6	06/08/09	06/11/09
			Rainbow	RS-2	82.6	74.0	101.9	10.61	6	06/08/09	06/11/09
			Rainbow	RS-3	74.8	12.0	104.8	36.29	5	06/08/09	06/11/09
			Silver Glen	SGS-1	36.4	33.5	39.9	2.18	8	02/16/09	02/19/09
			Silver Glen	SGS-2	56.2	39.5	72.3	13.68	5	02/16/09	02/19/09
			Silver Glen	SGS-3	73.2	45.5	95.6	19.89	9	02/16/09	02/19/09
			Silver Glen	SGS-A	33.2	32.1	34.2	0.93	4	02/16/09	02/19/09
			Silver	SS-1	24.9	21.7	29.1	2.72	5	05/04/09	05/08/09
			Silver	SS-2	53.5	50.0	56.0	2.18	5	05/04/09	05/08/09
			Silver	SS-3	58.7	50.9	66.5	6.97	7	05/04/09	05/08/09
			De Leon	VDL-1	8.3	6.1	10.6	1.08	10	10/06/08	10/09/08
			De Leon	VDL-2	9.6	8.1	12.4	2.45	3	10/06/08	10/09/08
			De Leon	VDL-3	35.5	8.1	76.3	17.71	10	10/06/08	10/09/08
			Wakulla	WAK-1	23.5	21.6	24.9	1.46	5	03/16/09	04/16/09
			Wakulla	WAK-2	26.3	23.1	39.6	4.17	13	03/16/09	04/16/09
			Wakulla	WAK-3	48.1	32.9	79.5	19.14	5	03/16/09	04/16/09
			Weeki Wachee	WWS-1	19.0	18.4	19.7	0.67	3	03/09/09	03/12/09
			Weeki Wachee	WWS-2	28.2	26.9	30.0	1.59	3	03/09/09	03/12/09
			Weeki Wachee	WWS-3	49.6	47.5	51.6	2.90	2	03/09/09	03/12/09
DISSOLVED OXYGEN	DO	mg/L	Homosassa	HS-1	3.7	3.5	4.1	0.15	34	11/03/08	11/06/08
			Homosassa	HS-2	4.1	3.9	4.3	0.14	9	11/03/08	11/06/08
			Homosassa	HS-3	4.3	3.9	4.8	0.33	11	11/03/08	11/06/08
			Ichetucknee	ICH_MAIN	3.6	3.4	3.8	0.16	5	01/19/09	07/09/09
			Ichetucknee	ICH_BLUE_HOLE	1.6	1.5	1.9	0.19	4	01/19/09	07/09/09
			Ichetucknee	ICH_MISSION	0.4	0.2	0.5	0.19	3	07/06/09	07/09/09
			Ichetucknee	ICH_DEVILS	0.1	0.1	0.2	0.05	3	07/06/09	07/09/09
			Ichetucknee	ICH_MILLPOND	0.9	0.7	1.1	0.21	3	07/06/09	07/09/09
			Ichetucknee	IS-1	3.6	3.0	4.1	0.37	6	06/19/09	07/09/09
			Ichetucknee	IS-2	6.0	4.6	7.1	0.95	8	01/19/09	07/09/09
			Ichetucknee	IS-3	5.6	4.1	7.4	1.17	9	11/11/08	07/09/09
			Ichetucknee	IS-4	5.8	4.2	7.6	1.13	10	11/11/08	07/09/09
			Jackson Blue	JBS-1	6.8	6.2	7.1	0.23	15	01/12/09	01/15/09
			Jackson Blue	JBS-2	6.7	6.3	7.0	0.31	4	01/12/09	01/15/09
			Jackson Blue	JBS-3	9.5	8.6	10.4	0.71	6	01/12/09	01/15/09
			Madison Blue	MBS-1	6.1	1.3	7.5	2.38	21	12/01/08	01/06/09
			Madison Blue	MBS-2	1.8	1.3	3.0	0.84	4	12/01/08	01/06/09
			Madison Blue	MBS-3	1.5	1.4	1.8	0.25	3	12/01/08	01/06/09
			Manatee	MS-1	1.1	1.1	1.2	0.04	4	08/03/09	08/06/09
			Manatee	MS-2	1.3	1.2	1.4	0.06	6	08/03/09	08/06/09
			Manatee	MS-3	2.0	1.7	2.2	0.20	5	08/03/09	08/06/09
			Ponce de Leon	PDL-1	3.6	3.3	3.7	0.17	4	09/08/09	09/11/09
			Ponce de Leon	PDL-2	3.9	3.7	4.0	0.14	4	09/08/09	09/11/09
			Ponce de Leon	PDL-3	5.0	4.8	5.3	0.25	4	09/08/09	09/11/09
			Rainbow	RS-1	6.9	6.2	7.9	0.63	6	06/08/09	06/11/09
			Rainbow	RS-2	7.0	6.3	8.6	0.91	6	06/08/09	06/11/09
			Rainbow	RS-3	8.2	6.9	10.1	1.29	5	06/08/09	06/11/09
			Silver Glen	SGS-1	3.1	2.9	3.4	0.18	8	02/16/09	02/19/09
			Silver Glen	SGS-2	4.8	3.4	6.1	1.16	5	02/16/09	02/19/09
			Silver Glen	SGS-3	6.2	4.0	8.0	1.63	9	02/16/09	02/19/09
			Silver Glen	SGS-A	2.8	2.7	2.9	0.08	4	02/16/09	02/19/09
			Silver	SS-1	2.1	1.9	2.5	0.24	5	05/04/09	05/08/09
			Silver	SS-2	4.5	4.2	4.7	0.19	5	05/04/09	05/08/09
			Silver	SS-3	5.0	4.3	5.6	0.58	7	05/04/09	05/08/09
			De Leon	VDL-1	0.7	0.5	0.9	0.09	10	10/06/08	10/09/08
			De Leon	VDL-2	0.8	0.7	1.1	0.21	3	10/06/08	10/09/08
			De Leon	VDL-3	3.0	0.7	6.2	1.43	10	10/06/08	10/09/08
			Wakulla	WAK-1	2.1	2.0	2.2	0.11	5	03/16/09	04/16/09
			Wakulla	WAK-2	2.4	2.1	3.5	0.37	13	03/16/09	04/16/09
			Wakulla	WAK-3	4.3	3.0	7.1	1.70	5	03/16/09	04/16/09
			Weeki Wachee	WWS-1	1.6	1.6	1.7	0.06	3	03/09/09	03/12/09
			Weeki Wachee	WWS-2	2.4	2.3	2.5	0.13	3	03/09/09	03/12/09
			Weeki Wachee	WWS-3	4.2	4.0	4.3	0.21	2	03/09/09	03/12/09

TABLE 10 (CONTINUED)
Summary of field parameters (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
PHYSICAL	pH	SU	Homosassa	HS-1	7.90	6.99	8.27	0.30	34	11/03/08	11/06/08
			Homosassa	HS-2	7.87	7.30	8.20	0.33	9	11/03/08	11/06/08
			Homosassa	HS-3	7.93	7.52	8.20	0.23	11	11/03/08	11/06/08
			Ichetucknee	ICH_MAIN	7.37	6.67	7.81	0.43	5	01/19/09	07/09/09
			Ichetucknee	ICH_BLUE_HOLE	7.41	7.35	7.54	0.09	4	01/19/09	07/09/09
			Ichetucknee	ICH_MISSION	7.42	7.34	7.51	0.09	3	07/06/09	07/09/09
			Ichetucknee	ICH_DEVILS	7.49	7.41	7.53	0.07	3	07/06/09	07/09/09
			Ichetucknee	ICH_MILLPOND	7.48	7.37	7.56	0.10	3	07/06/09	07/09/09
			Ichetucknee	IS-1	7.48	7.43	7.54	0.04	6	06/19/09	07/09/09
			Ichetucknee	IS-2	7.80	7.50	8.00	0.18	8	01/19/09	07/09/09
			Ichetucknee	IS-3	7.89	7.36	8.73	0.42	9	11/11/08	07/09/09
			Ichetucknee	IS-4	7.80	7.32	8.51	0.33	10	11/11/08	07/09/09
			Jackson Blue	JBS-1	7.55	7.51	7.60	0.03	15	01/12/09	01/15/09
			Jackson Blue	JBS-2	7.55	7.48	7.59	0.05	4	01/12/09	01/15/09
			Jackson Blue	JBS-3	7.97	7.86	8.12	0.10	6	01/12/09	01/15/09
			Madison Blue	MBS-1	6.95	6.70	7.68	0.33	21	12/01/08	01/06/09
			Madison Blue	MBS-2	7.64	7.47	7.78	0.13	4	12/01/08	01/06/09
			Madison Blue	MBS-3	7.61	7.48	7.72	0.12	3	12/01/08	01/06/09
			Manatee	MS-1	7.07	6.98	7.13	0.07	4	08/03/09	08/06/09
			Manatee	MS-2	7.09	7.00	7.18	0.07	6	08/03/09	08/06/09
			Manatee	MS-3	7.14	7.09	7.19	0.04	5	08/03/09	08/06/09
			Ponce de Leon	PDL-1	7.62	7.45	7.90	0.20	4	09/08/09	09/11/09
			Ponce de Leon	PDL-2	7.62	7.32	8.01	0.29	4	09/08/09	09/11/09
			Ponce de Leon	PDL-3	7.67	7.55	7.71	0.08	4	09/08/09	09/11/09
			Rainbow	RS-1	8.01	7.89	8.18	0.11	6	06/08/09	06/11/09
			Rainbow	RS-2	7.80	7.59	8.05	0.19	6	06/08/09	06/11/09
			Rainbow	RS-3	7.91	7.76	8.08	0.14	4	06/08/09	06/11/09
			Silver Glen	SGS-1	7.86	7.84	7.91	0.02	8	02/16/09	02/19/09
			Silver Glen	SGS-2	8.16	7.86	8.50	0.25	5	02/16/09	02/19/09
			Silver Glen	SGS-3	8.28	7.67	8.76	0.36	9	02/16/09	02/19/09
			Silver Glen	SGS-A	7.81	7.76	7.85	0.04	4	02/16/09	02/19/09
			Silver	SS-1	7.25	7.23	7.27	0.01	5	05/04/09	05/08/09
			Silver	SS-2	7.35	7.31	7.39	0.04	5	05/04/09	05/08/09
			Silver	SS-3	7.38	7.32	7.47	0.05	7	05/04/09	05/08/09
			De Leon	VDL-1	7.44	7.23	7.50	0.09	10	10/06/08	10/09/08
			De Leon	VDL-2	7.40	7.35	7.44	0.05	3	10/06/08	10/09/08
			De Leon	VDL-3	7.54	7.29	8.12	0.22	10	10/06/08	10/09/08
			Wakulla	WAK-1	7.32	7.22	7.54	0.13	5	03/16/09	04/16/09
			Wakulla	WAK-2	7.31	7.16	7.64	0.12	13	03/16/09	04/16/09
			Wakulla	WAK-3	7.43	7.20	7.91	0.28	5	03/16/09	04/16/09
			Weeki Wachee	WWS-1	7.51	7.49	7.52	0.02	3	03/09/09	03/12/09
			Weeki Wachee	WWS-2	7.57	7.52	7.63	0.06	3	03/09/09	03/12/09
			Weeki Wachee	WWS-3	7.65	7.64	7.65	0.01	2	03/09/09	03/12/09
PHYSICAL	SpCond	umhos/cm	Homosassa	HS-1	4755	3425	5611	610	34	11/03/08	11/06/08
			Homosassa	HS-2	4110	3305	4593	498	9	11/03/08	11/06/08
			Homosassa	HS-3	3720	2662	4522	685	11	11/03/08	11/06/08
			Ichetucknee	ICH_MAIN	326	324	328	2	5	01/19/09	07/09/09
			Ichetucknee	ICH_BLUE_HOLE	309	307	312	2	4	01/19/09	07/09/09
			Ichetucknee	ICH_MISSION	339	336	341	3	3	07/06/09	07/09/09
			Ichetucknee	ICH_DEVILS	363	362	365	2	3	07/06/09	07/09/09
			Ichetucknee	ICH_MILLPOND	400	397	402	3	3	07/06/09	07/09/09
			Ichetucknee	IS-1	312	307	317	4	6	06/19/09	07/09/09
			Ichetucknee	IS-2	329	321	337	6	8	01/19/09	07/09/09
			Ichetucknee	IS-3	332	323	339	6	9	11/11/08	07/09/09
			Ichetucknee	IS-4	331	324	338	5	10	11/11/08	07/09/09
			Jackson Blue	JBS-1	262	245	268	6	15	01/12/09	01/15/09
			Jackson Blue	JBS-2	257	246	265	10	4	01/12/09	01/15/09
			Jackson Blue	JBS-3	262	246	269	9	6	01/12/09	01/15/09
			Madison Blue	MBS-1	125	88	284	76	21	12/01/08	01/06/09
			Madison Blue	MBS-2	251	166	284	57	4	12/01/08	01/06/09
			Madison Blue	MBS-3	278	274	284	6	3	12/01/08	01/06/09
			Manatee	MS-1	499	478	513	15	4	08/03/09	08/06/09
			Manatee	MS-2	501	478	513	12	6	08/03/09	08/06/09
			Manatee	MS-3	500	478	513	13	5	08/03/09	08/06/09
			Ponce de Leon	PDL-1	218	209	228	8	4	09/08/09	09/11/09
			Ponce de Leon	PDL-2	217	209	229	9	4	09/08/09	09/11/09
			Ponce de Leon	PDL-3	217	209	228	8	4	09/08/09	09/11/09
			Rainbow	RS-1	179	141	204	26	6	06/08/09	06/11/09
			Rainbow	RS-2	256	190	313	54	6	06/08/09	06/11/09
			Rainbow	RS-3	244	220	259	17	4	06/08/09	06/11/09
			Silver Glen	SGS-1	1810	1608	1862	83	8	02/16/09	02/19/09
			Silver Glen	SGS-2	1828	1703	1903	75	5	02/16/09	02/19/09
			Silver Glen	SGS-3	1859	1674	1941	107	9	02/16/09	02/19/09
			Silver Glen	SGS-A	1969	1768	2050	134	4	02/16/09	02/19/09
			Silver	SS-1	447	420	489	35	5	05/04/09	05/08/09
			Silver	SS-2	463	428	490	32	5	05/04/09	05/08/09
			Silver	SS-3	442	415	475	30	7	05/04/09	05/08/09
			De Leon	VDL-1	945	944	948	1	10	10/06/08	10/09/08
			De Leon	VDL-2	946	944	948	2	3	10/06/08	10/09/08
			De Leon	VDL-3	988	974	1022	13	10	10/06/08	10/09/08
			Wakulla	WAK-1	282	246	327	34	5	03/16/09	04/16/09
			Wakulla	WAK-2	281	245	326	25	13	03/16/09	04/16/09
			Wakulla	WAK-3	290	245	323	28	5	03/16/09	04/16/09
			Weeki Wachee	WWS-1	328	295	345	29	3	03/09/09	03/12/09
			Weeki Wachee	WWS-2	327	294	345	29	3	03/09/09	03/12/09
			Weeki Wachee	WWS-3	318	292	343	36	2	03/09/09	03/12/09

TABLE 10 (CONTINUED)
Summary of field parameters (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
TEMPERATURE	**Wtr Temp**	C	Homosassa	HS-1	23.3	23.1	23.3	0.04	34	11/03/08	11/06/08
			Homosassa	HS-2	23.2	23.0	23.3	0.08	9	11/03/08	11/06/08
			Homosassa	HS-3	23.1	22.3	23.6	0.33	11	11/03/08	11/06/08
			Ichetucknee	ICH_MAIN	21.7	21.7	21.8	0.05	5	01/19/09	07/09/09
			Ichetucknee	ICH_BLUE_HOLE	24.4	21.6	32.7	5.51	4	01/19/09	07/09/09
			Ichetucknee	ICH_MISSION	21.7	21.7	21.7	0.02	3	07/06/09	07/09/09
			Ichetucknee	ICH_DEVILS	21.8	21.8	21.8	0.00	3	07/06/09	07/09/09
			Ichetucknee	ICH_MILLPOND	21.9	21.9	21.9	0.02	3	07/06/09	07/09/09
			Ichetucknee	IS-1	21.9	21.8	22.0	0.06	6	06/19/09	07/09/09
			Ichetucknee	IS-2	21.7	20.5	23.5	0.96	8	01/19/09	07/09/09
			Ichetucknee	IS-3	21.2	20.0	23.3	1.13	9	11/11/08	07/09/09
			Ichetucknee	IS-4	21.3	19.5	23.5	1.52	10	11/11/08	07/09/09
			Jackson Blue	JBS-1	20.6	20.5	20.6	0.01	15	01/12/09	01/15/09
			Jackson Blue	JBS-2	20.6	20.6	20.6	0.01	4	01/12/09	01/15/09
			Jackson Blue	JBS-3	20.5	20.1	20.7	0.23	6	01/12/09	01/15/09
			Madison Blue	MBS-1	15.7	14.5	20.9	2.48	21	12/01/08	01/06/09
			Madison Blue	MBS-2	19.8	17.0	20.9	1.84	4	12/01/08	01/06/09
			Madison Blue	MBS-3	20.6	20.5	20.6	0.05	3	12/01/08	01/06/09
			Manatee	MS-1	22.3	22.3	22.3	0.01	4	08/03/09	08/06/09
			Manatee	MS-2	22.3	22.3	22.3	0.02	6	08/03/09	08/06/09
			Manatee	MS-3	22.4	22.3	22.5	0.08	5	08/03/09	08/06/09
			Ponce de Leon	PDL-1	20.1	20.0	20.2	0.07	4	09/08/09	09/11/09
			Ponce de Leon	PDL-2	20.2	20.1	20.4	0.13	4	09/08/09	09/11/09
			Ponce de Leon	PDL-3	20.3	20.2	20.4	0.09	4	09/08/09	09/11/09
			Rainbow	RS-1	23.3	23.2	23.5	0.11	6	06/08/09	06/11/09
			Rainbow	RS-2	23.4	23.1	23.6	0.17	6	06/08/09	06/11/09
			Rainbow	RS-3	23.7	23.3	24.2	0.46	5	06/08/09	06/11/09
			Silver Glen	SGS-1	23.1	23.0	23.2	0.05	8	02/16/09	02/19/09
			Silver Glen	SGS-2	23.1	22.8	23.3	0.19	5	02/16/09	02/19/09
			Silver Glen	SGS-3	22.8	20.9	23.9	0.90	9	02/16/09	02/19/09
			Silver Glen	SGS-A	23.1	23.1	23.1	0.01	4	02/16/09	02/19/09
			Silver	SS-1	23.2	23.1	23.3	0.06	5	05/04/09	05/08/09
			Silver	SS-2	23.7	23.3	23.8	0.21	5	05/04/09	05/08/09
			Silver	SS-3	23.8	23.5	24.1	0.23	7	05/04/09	05/08/09
			De Leon	VDL-1	22.7	22.6	22.8	0.05	10	10/06/08	10/09/08
			De Leon	VDL-2	22.7	22.6	22.9	0.14	3	10/06/08	10/09/08
			De Leon	VDL-3	24.0	23.4	25.7	0.67	10	10/06/08	10/09/08
			Wakulla	WAK-1	20.3	20.2	20.7	0.23	5	03/16/09	04/16/09
			Wakulla	WAK-2	20.3	20.1	20.9	0.19	13	03/16/09	04/16/09
			Wakulla	WAK-3	20.6	20.3	21.3	0.41	5	03/16/09	04/16/09
			Weeki Wachee	WWS-1	23.6	23.6	23.7	0.02	3	03/09/09	03/12/09
			Weeki Wachee	WWS-2	23.8	23.7	23.9	0.06	3	03/09/09	03/12/09
			Weeki Wachee	WWS-3	23.9	23.6	24.2	0.39	2	03/09/09	03/12/09

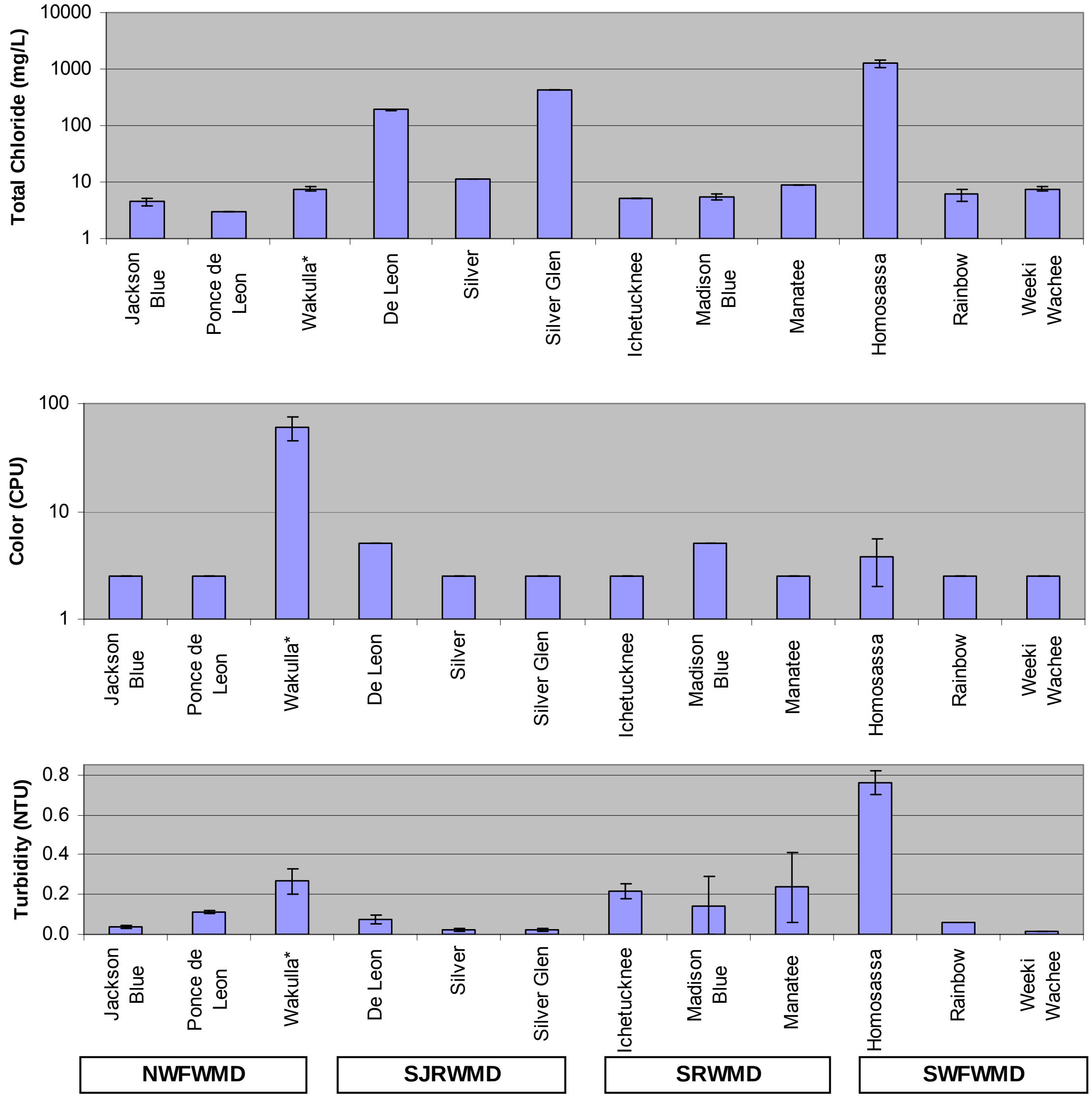


FIGURE 34
Comparison of average (± standard deviation) spring pool (upper sonde at Ichetucknee) water chemistry parameters by spring (* systems flooded with colored water during sampling).

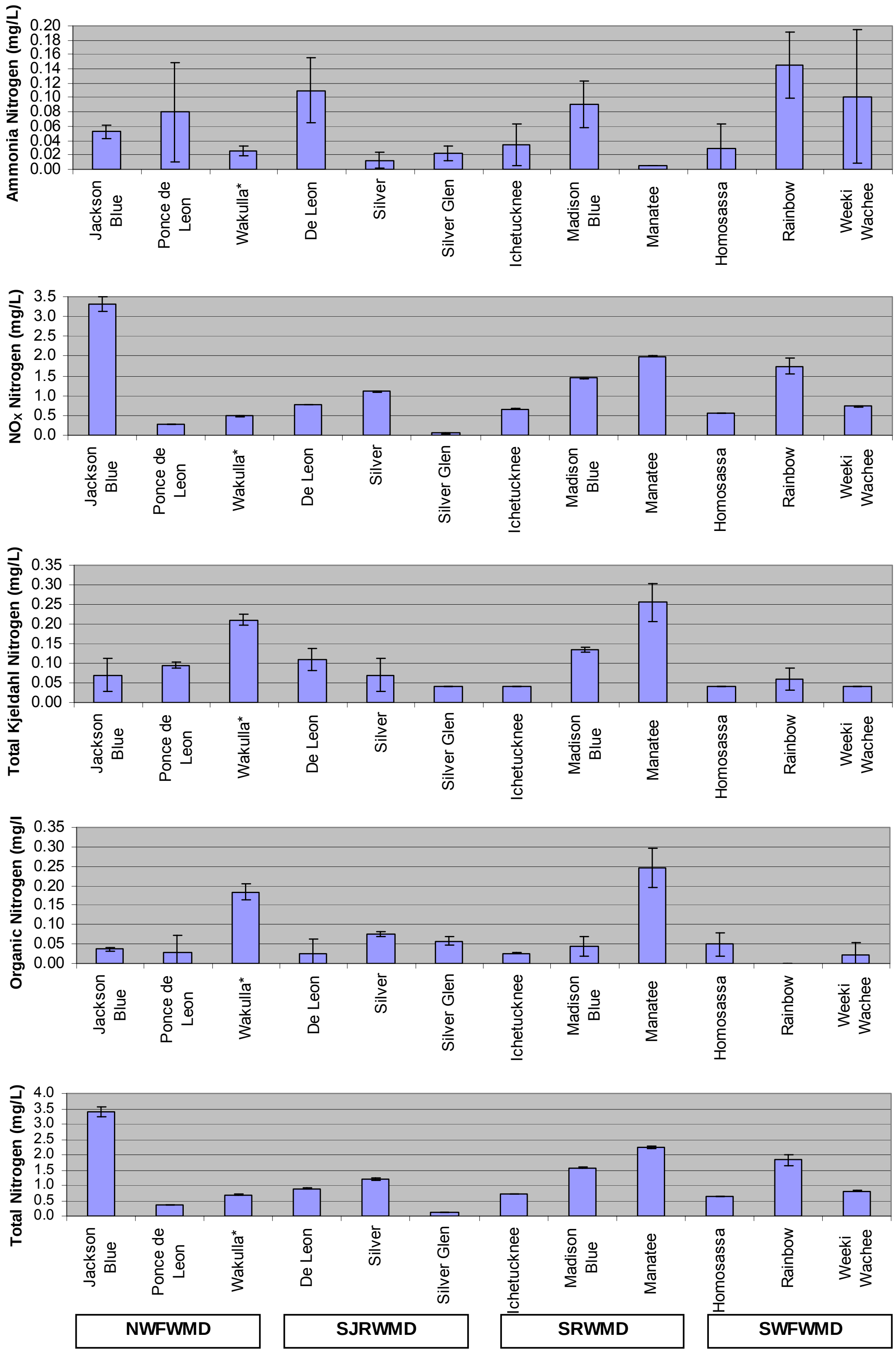


FIGURE 34 (CONTINUED)
Comparison of average (± standard deviation) spring pool (upper sonde at Ichetucknee) water chemistry parameters by spring (* systems flooded with colored water during sampling).

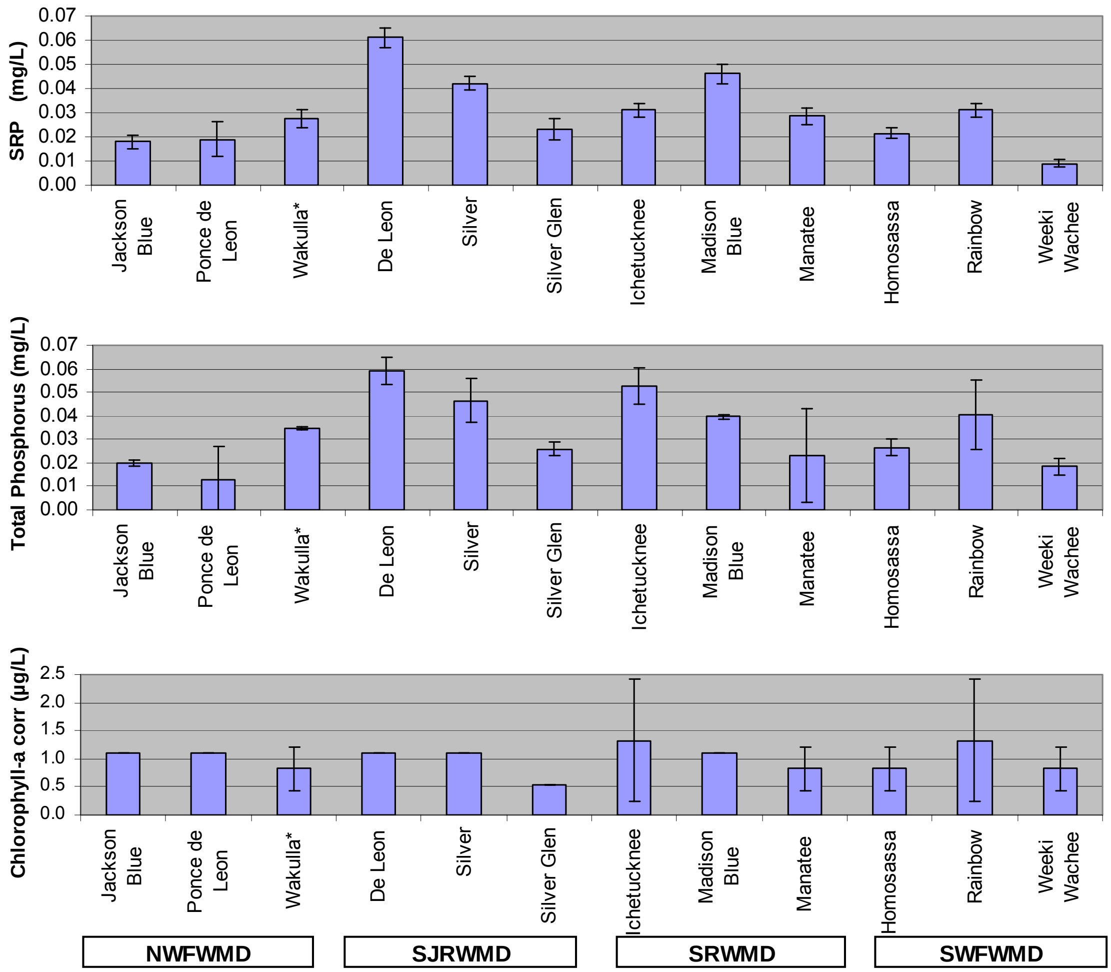


FIGURE 34 (CONTINUED)
Comparison of average (± standard deviation) spring pool (upper sonde at Ichetucknee) water chemistry parameters by spring (* systems flooded with colored water during sampling).

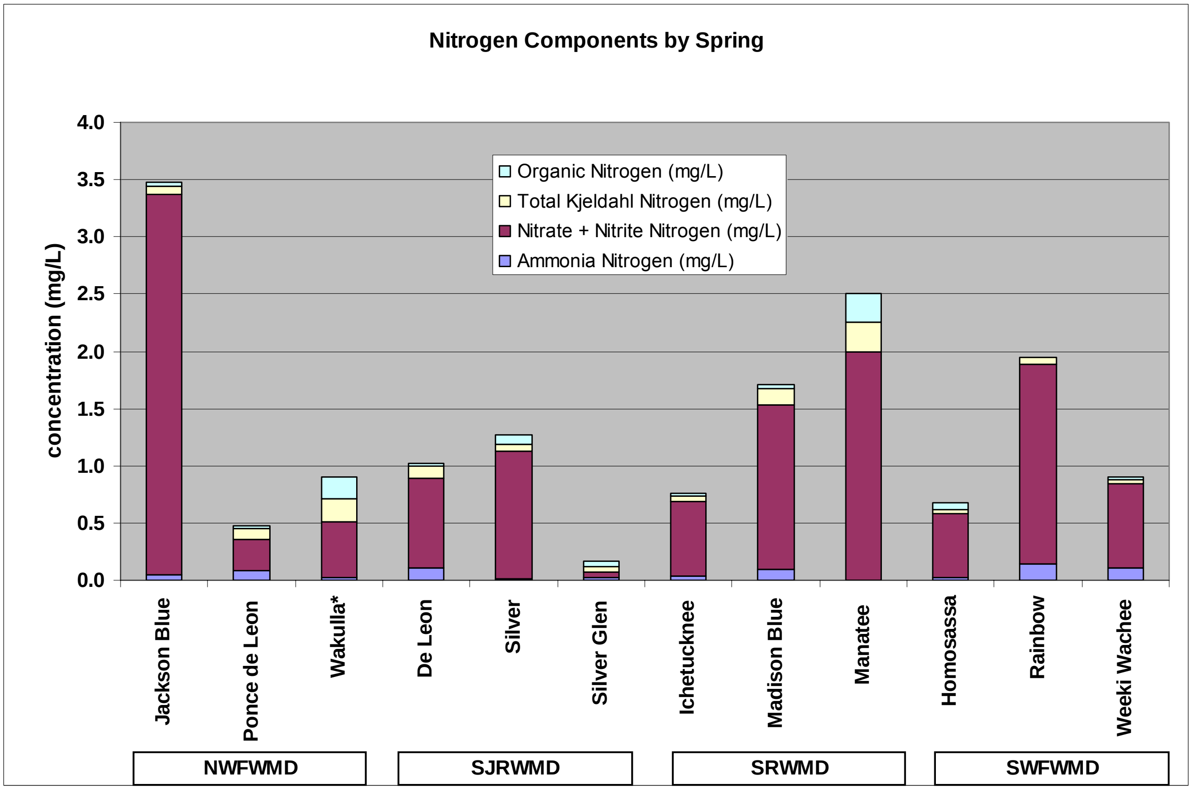


FIGURE 35
Comparison of average spring pool (upper run at Ichetucknee) nitrogen components (* system flooded with colored water during sampling).

TABLE 11
Summary of water chemistry (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
BIOLOGICAL	**Chl-a corr**	**µg/L**	Homosassa	HS-1	0.83	0.55	1.10	0.39	2	11/03/08	11/06/08
			Homosassa	HS-2	1.33	0.55	2.10	1.10	2	11/03/08	11/06/08
			Homosassa	HS-3	1.33	0.55	2.10	1.10	2	11/03/08	11/06/08
			Ichetucknee	IS-1	1.33	0.55	2.10	1.10	2	07/06/09	07/09/09
			Ichetucknee	IS-2	2.10	2.10	2.10	0.00	2	07/06/09	07/09/09
			Ichetucknee	IS-4	2.10	2.10	2.10	0.00	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	1.10	1.10	1.10	0.00	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	1.10	1.10	1.10	0.00	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	1.10	1.10	1.10	0.00	2	01/13/09	01/15/09
			Madison Blue	MBS-1	1.10	1.10	1.10	0.00	2	12/01/08	01/02/09
			Madison Blue	MBS-2	1.10	1.10	1.10	0.00	2	12/01/08	12/10/08
			Madison Blue	MBS-3	1.60	1.10	2.10	0.71	2	12/01/08	01/02/09
			Manatee	MS-1	0.83	0.55	1.10	0.39	2	08/03/09	08/06/09
			Manatee	MS-2	0.55	0.55	0.55	0.00	2	08/03/09	08/06/09
			Manatee	MS-3	0.83	0.55	1.10	0.39	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	1.10	1.10	1.10	0.00	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	1.33	0.55	2.10	1.10	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.83	0.55	1.10	0.39	2	09/08/09	09/11/09
			Rainbow	RS-1	1.33	0.55	2.10	1.10	2	06/08/09	06/11/09
			Rainbow	RS-2	1.10	1.10	1.10	0.00	2	06/08/09	06/11/09
			Rainbow	RS-3	1.60	1.10	2.10	0.71	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.55	0.55	0.55	0.00	2	02/17/09	02/19/09
			Silver Glen	SGS-2	1.60	1.10	2.10	0.71	2	02/17/09	02/19/09
			Silver Glen	SGS-3	1.60	1.10	2.10	0.71	2	02/17/09	02/19/09
			Silver	SS-1	1.10	1.10	1.10	0.00	2	05/04/09	05/07/09
			Silver	SS-2	1.60	1.10	2.10	0.71	2	05/04/09	05/07/09
			Silver	SS-3	0.55	0.55	0.55	0.00	2	05/04/09	05/07/09
			De Leon	VDL-1	1.10	1.10	1.10	0.00	2	10/06/08	10/09/08
			De Leon	VDL-2	0.83	0.55	1.10	0.39	2	10/06/08	10/09/08
			De Leon	VDL-3	12.30	10.70	13.90	2.26	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.83	0.55	1.10	0.39	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.83	0.55	1.10	0.39	2	04/13/09	04/16/09
			Wakulla	WAK-3	1.10	1.10	1.10	0.00	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.83	0.55	1.10	0.39	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.55	0.55	0.55	0.00	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.55	0.55	0.55	0.00	2	03/09/09	03/12/09
GENERAL INORGANIC	**Cl-T**	**mg/L**	Homosassa	HS-1	1250	1100	1400	212	2	11/03/08	11/06/08
			Homosassa	HS-2	1175	1020	1330	219	2	11/03/08	11/06/08
			Homosassa	HS-3	358	320	396	54	2	11/03/08	11/06/08
			Ichetucknee	IS-1	5	5	5	0	2	07/06/09	07/09/09
			Ichetucknee	IS-2	7	7	7	0	2	07/06/09	07/09/09
			Ichetucknee	IS-4	7	6	7	1	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	5	4	5	1	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	5	4	5	1	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	5	4	5	1	2	01/13/09	01/15/09
			Madison Blue	MBS-1	6	5	6	1	2	12/01/08	01/02/09
			Madison Blue	MBS-2	7	5	8	2	2	12/01/08	12/10/08
			Madison Blue	MBS-3	6	6	6	0	2	12/01/08	01/02/09
			Manatee	MS-1	9	9	9	0	2	08/03/09	08/06/09
			Manatee	MS-2	9	9	9	0	2	08/03/09	08/06/09
			Manatee	MS-3	9	9	9	0	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	3	3	3	0	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	3	3	3	0	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	3	3	3	0	2	09/08/09	09/11/09
			Rainbow	RS-1	6	5	7	1	2	06/08/09	06/11/09
			Rainbow	RS-2	6	5	6	1	2	06/08/09	06/11/09
			Rainbow	RS-3	6	5	6	1	2	06/08/09	06/11/09
			Silver Glen	SGS-1	427	419	435	11	2	02/17/09	02/19/09
			Silver Glen	SGS-2	441	440	441	1	2	02/17/09	02/19/09
			Silver Glen	SGS-3	459	454	463	6	2	02/17/09	02/19/09
			Silver	SS-1	11	11	11	0	2	05/04/09	05/07/09
			Silver	SS-2	11	11	11	0	2	05/04/09	05/07/09
			Silver	SS-3	12	11	12	1	2	05/04/09	05/07/09
			De Leon	VDL-1	190	188	191	2	2	10/06/08	10/09/08
			De Leon	VDL-2	191	190	191	1	2	10/06/08	10/09/08
			De Leon	VDL-3	209	204	213	6	2	10/06/08	10/09/08
			Wakulla	WAK-1	8	7	8	1	2	04/13/09	04/16/09
			Wakulla	WAK-2	8	7	8	1	2	04/13/09	04/16/09
			Wakulla	WAK-3	8	7	8	1	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	8	7	8	1	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	8	8	8	0	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	8	8	8	0	2	03/09/09	03/12/09

TABLE 11 (CONTINUED)
Summary of water chemistry (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
NITROGEN	NH4-N	mg/L	Homosassa	HS-1	0.029	0.005	0.053	0.034	2	11/03/08	11/06/08
			Homosassa	HS-2	0.022	0.005	0.040	0.025	2	11/03/08	11/06/08
			Homosassa	HS-3	0.011	0.005	0.017	0.009	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.034	0.013	0.054	0.029	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.030	0.005	0.056	0.036	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.059	0.019	0.098	0.056	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	0.053	0.046	0.059	0.009	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	0.007	0.005	0.009	0.003	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	0.082	0.064	0.100	0.025	2	01/13/09	01/15/09
			Madison Blue	MBS-1	0.091	0.068	0.113	0.032	2	12/01/08	01/02/09
			Madison Blue	MBS-2	0.044	0.031	0.056	0.018	2	12/01/08	12/10/08
			Madison Blue	MBS-3	0.072	0.057	0.086	0.021	2	12/01/08	01/02/09
			Manatee	MS-1	0.005	0.005	0.005	0.000	2	08/03/09	08/06/09
			Manatee	MS-2	0.008	0.005	0.012	0.005	2	08/03/09	08/06/09
			Manatee	MS-3	0.005	0.005	0.005	0.000	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.080	0.031	0.128	0.069	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.020	0.005	0.036	0.022	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.034	0.029	0.039	0.007	2	09/08/09	09/11/09
			Rainbow	RS-1	0.145	0.112	0.178	0.047	2	06/08/09	06/11/09
			Rainbow	RS-2	0.109	0.099	0.119	0.014	2	06/08/09	06/11/09
			Rainbow	RS-3	0.089	0.072	0.105	0.023	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.022	0.015	0.029	0.010	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.023	0.021	0.024	0.002	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.021	0.020	0.022	0.001	2	02/17/09	02/19/09
			Silver	SS-1	0.012	0.005	0.020	0.011	2	05/04/09	05/07/09
			Silver	SS-2	0.007	0.005	0.009	0.003	2	05/04/09	05/07/09
			Silver	SS-3	0.010	0.005	0.016	0.008	2	05/04/09	05/07/09
			De Leon	VDL-1	0.110	0.078	0.142	0.045	2	10/06/08	10/09/08
			De Leon	VDL-2	0.081	0.054	0.108	0.038	2	10/06/08	10/09/08
			De Leon	VDL-3	0.052	0.018	0.086	0.048	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.026	0.021	0.031	0.007	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.023	0.022	0.023	0.001	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.021	0.017	0.024	0.005	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.102	0.036	0.167	0.093	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.019	0.018	0.019	0.001	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.036	0.035	0.036	0.001	2	03/09/09	03/12/09
NITROGEN	NOx-N	mg/L	Homosassa	HS-1	0.554	0.548	0.560	0.008	2	11/03/08	11/06/08
			Homosassa	HS-2	0.539	0.523	0.554	0.022	2	11/03/08	11/06/08
			Homosassa	HS-3	0.533	0.532	0.534	0.001	2	11/03/08	11/06/08
			Ichetucknee	ICH_BLUE_HOLE	0.800	0.800	0.800	0.000	2	07/06/09	07/09/09
			Ichetucknee	ICH_DEVILS	0.400	0.400	0.400	0.000	2	07/06/09	07/09/09
			Ichetucknee	ICH_MAIN	1.050	1.000	1.100	0.071	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.382	0.367	0.396	0.021	2	07/06/09	07/09/09
			Ichetucknee	ICH_MILLPOND	0.200	0.200	0.200	0.000	2	07/06/09	07/09/09
			Ichetucknee	ICH_MISSION	0.500	0.500	0.500	0.000	2	07/06/09	07/09/09
			Ichetucknee	IS-1	0.659	0.644	0.674	0.021	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.355	0.341	0.369	0.020	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	3.315	3.190	3.440	0.177	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	3.450	3.440	3.460	0.014	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	3.380	3.340	3.420	0.057	2	01/13/09	01/15/09
			Madison Blue	MBS-1	1.445	1.430	1.460	0.021	2	12/01/08	01/02/09
			Madison Blue	MBS-2	0.872	0.264	1.480	0.860	2	12/01/08	12/10/08
			Madison Blue	MBS-3	1.450	1.440	1.460	0.014	2	12/01/08	01/02/09
			Manatee	MS-1	1.995	1.990	2.000	0.007	2	08/03/09	08/06/09
			Manatee	MS-2	1.675	1.330	2.020	0.488	2	08/03/09	08/06/09
			Manatee	MS-3	1.645	1.320	1.970	0.460	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.275	0.270	0.280	0.007	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.280	0.267	0.292	0.018	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.282	0.276	0.287	0.008	2	09/08/09	09/11/09
			Rainbow	RS-1	1.745	1.610	1.880	0.191	2	06/08/09	06/11/09
			Rainbow	RS-2	1.725	1.640	1.810	0.120	2	06/08/09	06/11/09
			Rainbow	RS-3	1.635	1.600	1.670	0.049	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.052	0.047	0.056	0.006	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.031	0.024	0.038	0.010	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.020	0.019	0.020	0.001	2	02/17/09	02/19/09
			Silver	SS-1	1.110	1.100	1.120	0.014	2	05/04/09	05/07/09
			Silver	SS-2	1.150	1.140	1.160	0.014	2	05/04/09	05/07/09
			Silver	SS-3	1.175	1.160	1.190	0.021	2	05/04/09	05/07/09
			De Leon	VDL-1	0.776	0.768	0.784	0.011	2	10/06/08	10/09/08
			De Leon	VDL-2	0.767	0.758	0.776	0.013	2	10/06/08	10/09/08
			De Leon	VDL-3	0.235	0.133	0.337	0.144	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.481	0.475	0.486	0.008	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.469	0.458	0.479	0.015	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.455	0.445	0.465	0.014	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.737	0.724	0.750	0.018	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.722	0.707	0.737	0.021	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.695	0.693	0.696	0.002	2	03/09/09	03/12/09

TABLE 11 (CONTINUED)
Summary of water chemistry (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
NITROGEN	OrgN	mg/L	Homosassa	HS-1	0.049	0.027	0.071	0.031	2	11/03/08	11/06/08
			Homosassa	HS-2	0.081	0.060	0.101	0.029	2	11/03/08	11/06/08
			Homosassa	HS-3	0.097	0.093	0.101	0.006	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.027	0.026	0.027	0.001	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.028	0.024	0.031	0.005	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.011	0.000	0.021	0.015	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	0.038	0.034	0.041	0.005	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	0.071	0.071	0.071	0.000	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	0.008	0.000	0.016	0.011	2	01/13/09	01/15/09
			Madison Blue	MBS-1	0.045	0.027	0.062	0.025	2	12/01/08	01/02/09
			Madison Blue	MBS-2	0.382	0.149	0.614	0.329	2	12/01/08	12/10/08
			Madison Blue	MBS-3	0.224	0.163	0.284	0.086	2	12/01/08	01/02/09
			Manatee	MS-1	0.246	0.211	0.281	0.049	2	08/03/09	08/06/09
			Manatee	MS-2	0.270	0.218	0.321	0.073	2	08/03/09	08/06/09
			Manatee	MS-3	0.246	0.221	0.271	0.035	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.030	0.000	0.059	0.042	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.058	0.044	0.071	0.019	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.046	0.041	0.051	0.007	2	09/08/09	09/11/09
			Rainbow	RS-1	0.000	0.000	0.000	0.000	2	06/08/09	06/11/09
			Rainbow	RS-2	0.021	0.000	0.041	0.029	2	06/08/09	06/11/09
			Rainbow	RS-3	0.004	0.000	0.008	0.006	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.058	0.051	0.065	0.010	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.073	0.056	0.089	0.023	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.094	0.060	0.128	0.048	2	02/17/09	02/19/09
			Silver	SS-1	0.076	0.071	0.080	0.006	2	05/04/09	05/07/09
			Silver	SS-2	0.071	0.071	0.071	0.000	2	05/04/09	05/07/09
			Silver	SS-3	0.068	0.064	0.071	0.005	2	05/04/09	05/07/09
			De Leon	VDL-1	0.026	0.000	0.052	0.037	2	10/06/08	10/09/08
			De Leon	VDL-2	0.013	0.000	0.026	0.018	2	10/06/08	10/09/08
			De Leon	VDL-3	0.648	0.492	0.804	0.221	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.184	0.169	0.199	0.021	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.128	0.098	0.157	0.042	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.195	0.146	0.243	0.069	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.022	0.000	0.044	0.031	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.053	0.044	0.062	0.013	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.075	0.044	0.105	0.043	2	03/09/09	03/12/09
NITROGEN	TKN	mg/L	Homosassa	HS-1	0.040	0.040	0.040	0.000	2	11/03/08	11/06/08
			Homosassa	HS-2	0.105	0.100	0.110	0.007	2	11/03/08	11/06/08
			Homosassa	HS-3	0.110	0.110	0.110	0.000	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.040	0.040	0.040	0.000	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.040	0.040	0.040	0.000	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.040	0.040	0.040	0.000	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	0.070	0.040	0.100	0.042	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	0.040	0.040	0.040	0.000	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	0.040	0.040	0.040	0.000	2	01/13/09	01/15/09
			Madison Blue	MBS-1	0.135	0.130	0.140	0.007	2	12/01/08	01/02/09
			Madison Blue	MBS-2	0.425	0.180	0.670	0.346	2	12/01/08	12/10/08
			Madison Blue	MBS-3	0.295	0.220	0.370	0.106	2	12/01/08	01/02/09
			Manatee	MS-1	0.255	0.220	0.290	0.049	2	08/03/09	08/06/09
			Manatee	MS-2	0.280	0.230	0.330	0.071	2	08/03/09	08/06/09
			Manatee	MS-3	0.255	0.230	0.280	0.035	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.095	0.090	0.100	0.007	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.040	0.040	0.040	0.000	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.040	0.040	0.040	0.000	2	09/08/09	09/11/09
			Rainbow	RS-1	0.060	0.040	0.080	0.028	2	06/08/09	06/11/09
			Rainbow	RS-2	0.100	0.040	0.160	0.085	2	06/08/09	06/11/09
			Rainbow	RS-3	0.040	0.040	0.040	0.000	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.040	0.040	0.040	0.000	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.075	0.040	0.110	0.049	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.095	0.040	0.150	0.078	2	02/17/09	02/19/09
			Silver	SS-1	0.070	0.040	0.100	0.042	2	05/04/09	05/07/09
			Silver	SS-2	0.060	0.040	0.080	0.028	2	05/04/09	05/07/09
			Silver	SS-3	0.040	0.040	0.040	0.000	2	05/04/09	05/07/09
			De Leon	VDL-1	0.110	0.090	0.130	0.028	2	10/06/08	10/09/08
			De Leon	VDL-2	0.090	0.080	0.100	0.014	2	10/06/08	10/09/08
			De Leon	VDL-3	0.700	0.510	0.890	0.269	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.210	0.200	0.220	0.014	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.150	0.120	0.180	0.042	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.215	0.170	0.260	0.064	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.040	0.040	0.040	0.000	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.070	0.040	0.100	0.042	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.090	0.040	0.140	0.071	2	03/09/09	03/12/09

TABLE 11 (CONTINUED)
Summary of water chemistry (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
NITROGEN	TN	mg/L	Homosassa	HS-1	0.634	0.628	0.640	0.008	2	11/03/08	11/06/08
			Homosassa	HS-2	0.644	0.623	0.664	0.029	2	11/03/08	11/06/08
			Homosassa	HS-3	0.643	0.642	0.644	0.001	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.719	0.714	0.724	0.007	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.442	0.436	0.447	0.008	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.415	0.409	0.421	0.008	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	3.405	3.290	3.520	0.163	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	3.530	3.520	3.540	0.014	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	3.460	3.420	3.500	0.057	2	01/13/09	01/15/09
			Madison Blue	MBS-1	1.580	1.560	1.600	0.028	2	12/01/08	01/02/09
			Madison Blue	MBS-2	1.297	0.934	1.660	0.513	2	12/01/08	12/10/08
			Madison Blue	MBS-3	1.745	1.660	1.830	0.120	2	12/01/08	01/02/09
			Manatee	MS-1	2.250	2.220	2.280	0.042	2	08/03/09	08/06/09
			Manatee	MS-2	1.955	1.560	2.350	0.559	2	08/03/09	08/06/09
			Manatee	MS-3	1.900	1.550	2.250	0.495	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.370	0.370	0.370	0.000	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.360	0.347	0.372	0.018	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.362	0.356	0.367	0.008	2	09/08/09	09/11/09
			Rainbow	RS-1	1.825	1.690	1.960	0.191	2	06/08/09	06/11/09
			Rainbow	RS-2	1.845	1.800	1.890	0.064	2	06/08/09	06/11/09
			Rainbow	RS-3	1.715	1.680	1.750	0.049	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.132	0.127	0.136	0.006	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.126	0.118	0.134	0.011	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.135	0.099	0.170	0.050	2	02/17/09	02/19/09
			Silver	SS-1	1.200	1.180	1.220	0.028	2	05/04/09	05/07/09
			Silver	SS-2	1.230	1.220	1.240	0.014	2	05/04/09	05/07/09
			Silver	SS-3	1.255	1.240	1.270	0.021	2	05/04/09	05/07/09
			De Leon	VDL-1	0.886	0.874	0.898	0.017	2	10/06/08	10/09/08
			De Leon	VDL-2	0.857	0.838	0.876	0.027	2	10/06/08	10/09/08
			De Leon	VDL-3	0.935	0.847	1.023	0.124	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.691	0.675	0.706	0.022	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.619	0.599	0.638	0.028	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.670	0.635	0.705	0.049	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.817	0.804	0.830	0.018	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.812	0.807	0.817	0.007	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.805	0.773	0.836	0.045	2	03/09/09	03/12/09
PHOSPHORUS	OrthoP	mg/L	Homosassa	HS-1	0.022	0.020	0.023	0.002	2	11/03/08	11/06/08
			Homosassa	HS-2	0.023	0.022	0.024	0.001	2	11/03/08	11/06/08
			Homosassa	HS-3	0.023	0.022	0.024	0.001	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.031	0.029	0.033	0.003	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.041	0.036	0.045	0.006	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.040	0.039	0.041	0.001	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	0.018	0.016	0.020	0.003	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	0.023	0.016	0.030	0.010	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	0.016	0.016	0.016	0.000	2	01/13/09	01/15/09
			Madison Blue	MBS-1	0.046	0.043	0.049	0.004	2	12/01/08	01/02/09
			Madison Blue	MBS-2	0.049	0.047	0.051	0.003	2	12/01/08	12/10/08
			Madison Blue	MBS-3	0.045	0.040	0.049	0.006	2	12/01/08	01/02/09
			Manatee	MS-1	0.029	0.026	0.031	0.004	2	08/03/09	08/06/09
			Manatee	MS-2	0.029	0.026	0.031	0.004	2	08/03/09	08/06/09
			Manatee	MS-3	0.033	0.027	0.038	0.008	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.019	0.014	0.024	0.007	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.029	0.023	0.035	0.008	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.018	0.012	0.024	0.008	2	09/08/09	09/11/09
			Rainbow	RS-1	0.031	0.029	0.033	0.003	2	06/08/09	06/11/09
			Rainbow	RS-2	0.032	0.031	0.033	0.001	2	06/08/09	06/11/09
			Rainbow	RS-3	0.031	0.031	0.031	0.000	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.023	0.020	0.026	0.004	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.021	0.016	0.026	0.007	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.023	0.021	0.024	0.002	2	02/17/09	02/19/09
			Silver	SS-1	0.042	0.040	0.044	0.003	2	05/04/09	05/07/09
			Silver	SS-2	0.035	0.034	0.036	0.001	2	05/04/09	05/07/09
			Silver	SS-3	0.036	0.035	0.036	0.001	2	05/04/09	05/07/09
			De Leon	VDL-1	0.061	0.058	0.064	0.004	2	10/06/08	10/09/08
			De Leon	VDL-2	0.060	0.059	0.060	0.001	2	10/06/08	10/09/08
			De Leon	VDL-3	0.042	0.036	0.048	0.008	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.028	0.025	0.030	0.004	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.025	0.023	0.027	0.003	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.027	0.025	0.028	0.002	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.009	0.008	0.010	0.001	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.008	0.006	0.010	0.003	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.007	0.006	0.008	0.001	2	03/09/09	03/12/09

TABLE 11 (CONTINUED)
Summary of water chemistry (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
PHOSPHORUS	TP	mg/L	Homosassa	HS-1	0.027	0.024	0.029	0.004	2	11/03/08	11/06/08
			Homosassa	HS-2	0.027	0.024	0.030	0.004	2	11/03/08	11/06/08
			Homosassa	HS-3	0.022	0.019	0.024	0.004	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.053	0.047	0.058	0.008	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.071	0.068	0.073	0.004	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.086	0.076	0.096	0.014	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	0.020	0.019	0.021	0.001	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	0.019	0.019	0.019	0.000	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	0.018	0.016	0.019	0.002	2	01/13/09	01/15/09
			Madison Blue	MBS-1	0.040	0.039	0.040	0.001	2	12/01/08	01/02/09
			Madison Blue	MBS-2	0.059	0.038	0.079	0.029	2	12/01/08	12/10/08
			Madison Blue	MBS-3	0.040	0.039	0.040	0.001	2	12/01/08	01/02/09
			Manatee	MS-1	0.023	0.009	0.037	0.020	2	08/03/09	08/06/09
			Manatee	MS-2	0.019	0.003	0.035	0.023	2	08/03/09	08/06/09
			Manatee	MS-3	0.023	0.003	0.042	0.028	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.013	0.003	0.023	0.014	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.016	0.003	0.029	0.018	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.015	0.003	0.026	0.016	2	09/08/09	09/11/09
			Rainbow	RS-1	0.041	0.030	0.051	0.015	2	06/08/09	06/11/09
			Rainbow	RS-2	0.032	0.030	0.033	0.002	2	06/08/09	06/11/09
			Rainbow	RS-3	0.037	0.035	0.038	0.002	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.026	0.024	0.028	0.003	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.027	0.024	0.030	0.004	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.029	0.024	0.033	0.006	2	02/17/09	02/19/09
			Silver	SS-1	0.047	0.040	0.053	0.009	2	05/04/09	05/07/09
			Silver	SS-2	0.038	0.033	0.043	0.007	2	05/04/09	05/07/09
			Silver	SS-3	0.040	0.038	0.041	0.002	2	05/04/09	05/07/09
			De Leon	VDL-1	0.059	0.055	0.063	0.006	2	10/06/08	10/09/08
			De Leon	VDL-2	0.062	0.060	0.063	0.002	2	10/06/08	10/09/08
			De Leon	VDL-3	0.088	0.087	0.089	0.001	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.035	0.034	0.035	0.001	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.032	0.029	0.035	0.004	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.031	0.029	0.033	0.003	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.019	0.016	0.021	0.004	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.016	0.016	0.016	0.000	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.016	0.016	0.016	0.000	2	03/09/09	03/12/09
PHYSICAL	Color	CPU	Homosassa	HS-1	4	3	5	2	2	11/03/08	11/06/08
			Homosassa	HS-2	4	3	5	2	2	11/03/08	11/06/08
			Homosassa	HS-3	4	3	5	2	2	11/03/08	11/06/08
			Ichetucknee	IS-1	3	3	3	0	2	07/06/09	07/09/09
			Ichetucknee	IS-2	3	3	3	0	2	07/06/09	07/09/09
			Ichetucknee	IS-4	4	3	5	2	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	3	3	3	0	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	3	3	3	0	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	3	3	3	0	2	01/13/09	01/15/09
			Madison Blue	MBS-1	5	5	5	0	2	12/01/08	01/02/09
			Madison Blue	MBS-2	53	5	100	67	2	12/01/08	12/10/08
			Madison Blue	MBS-3	5	5	5	0	2	12/01/08	01/02/09
			Manatee	MS-1	3	3	3	0	2	08/03/09	08/06/09
			Manatee	MS-2	3	3	3	0	2	08/03/09	08/06/09
			Manatee	MS-3	3	3	3	0	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	3	3	3	0	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	3	3	3	0	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	3	3	3	0	2	09/08/09	09/11/09
			Rainbow	RS-1	3	3	3	0	2	06/08/09	06/11/09
			Rainbow	RS-2	3	3	3	0	2	06/08/09	06/11/09
			Rainbow	RS-3	3	3	3	0	2	06/08/09	06/11/09
			Silver Glen	SGS-1	3	3	3	0	2	02/17/09	02/19/09
			Silver Glen	SGS-2	3	3	3	0	2	02/17/09	02/19/09
			Silver Glen	SGS-3	4	3	5	2	2	02/17/09	02/19/09
			Silver	SS-1	3	3	3	0	2	05/04/09	05/07/09
			Silver	SS-2	3	3	3	0	2	05/04/09	05/07/09
			Silver	SS-3	3	3	3	0	2	05/04/09	05/07/09
			De Leon	VDL-1	5	5	5	0	2	10/06/08	10/09/08
			De Leon	VDL-2	8	5	10	4	2	10/06/08	10/09/08
			De Leon	VDL-3	50	40	60	14	2	10/06/08	10/09/08
			Wakulla	WAK-1	60	50	70	14	2	04/13/09	04/16/09
			Wakulla	WAK-2	55	50	60	7	2	04/13/09	04/16/09
			Wakulla	WAK-3	65	50	80	21	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	3	3	3	0	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	4	3	5	2	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	3	3	3	0	2	03/09/09	03/12/09

TABLE 11 (CONTINUED)
Summary of water chemistry (from grab samples) by spring and station.

Parameter Group	Parameter	Units	Spring	Station Code	Average	Minimum	Maximum	Std Dev	Count	Min Date	Max Date
PHYSICAL	**Turb**	**NTU**	Homosassa	HS-1	0.76	0.72	0.80	0.06	2	11/03/08	11/06/08
			Homosassa	HS-2	0.72	0.61	0.82	0.15	2	11/03/08	11/06/08
			Homosassa	HS-3	0.28	0.28	0.28	0.00	2	11/03/08	11/06/08
			Ichetucknee	IS-1	0.22	0.19	0.24	0.04	2	07/06/09	07/09/09
			Ichetucknee	IS-2	0.35	0.33	0.37	0.03	2	07/06/09	07/09/09
			Ichetucknee	IS-4	0.84	0.39	1.29	0.64	2	07/06/09	07/09/09
			Jackson Blue	JBS-1	0.04	0.03	0.04	0.01	2	01/13/09	01/15/09
			Jackson Blue	JBS-2	0.05	0.03	0.06	0.02	2	01/13/09	01/15/09
			Jackson Blue	JBS-3	0.48	0.04	0.92	0.62	2	01/13/09	01/15/09
			Madison Blue	MBS-1	0.15	0.04	0.25	0.15	2	12/01/08	01/02/09
			Madison Blue	MBS-2	4.25	0.05	8.44	5.93	2	12/01/08	12/10/08
			Madison Blue	MBS-3	0.16	0.02	0.31	0.21	2	12/01/08	01/02/09
			Manatee	MS-1	0.24	0.11	0.36	0.18	2	08/03/09	08/06/09
			Manatee	MS-2	0.22	0.10	0.33	0.16	2	08/03/09	08/06/09
			Manatee	MS-3	0.26	0.18	0.34	0.11	2	08/03/09	08/06/09
			Ponce de Leon	PDL-1	0.12	0.11	0.12	0.01	2	09/08/09	09/11/09
			Ponce de Leon	PDL-2	0.42	0.13	0.70	0.40	2	09/08/09	09/11/09
			Ponce de Leon	PDL-3	0.24	0.19	0.28	0.06	2	09/08/09	09/11/09
			Rainbow	RS-1	0.06	0.06	0.06	0.00	2	06/08/09	06/11/09
			Rainbow	RS-2	0.15	0.08	0.22	0.10	2	06/08/09	06/11/09
			Rainbow	RS-3	0.08	0.04	0.11	0.05	2	06/08/09	06/11/09
			Silver Glen	SGS-1	0.02	0.02	0.03	0.01	2	02/17/09	02/19/09
			Silver Glen	SGS-2	0.01	0.01	0.02	0.00	2	02/17/09	02/19/09
			Silver Glen	SGS-3	0.04	0.02	0.06	0.03	2	02/17/09	02/19/09
			Silver	SS-1	0.02	0.02	0.03	0.01	2	05/04/09	05/07/09
			Silver	SS-2	0.04	0.02	0.06	0.03	2	05/04/09	05/07/09
			Silver	SS-3	0.04	0.02	0.06	0.03	2	05/04/09	05/07/09
			De Leon	VDL-1	0.08	0.06	0.09	0.02	2	10/06/08	10/09/08
			De Leon	VDL-2	0.09	0.06	0.12	0.04	2	10/06/08	10/09/08
			De Leon	VDL-3	1.82	1.51	2.13	0.44	2	10/06/08	10/09/08
			Wakulla	WAK-1	0.27	0.22	0.31	0.06	2	04/13/09	04/16/09
			Wakulla	WAK-2	0.34	0.29	0.38	0.06	2	04/13/09	04/16/09
			Wakulla	WAK-3	0.45	0.42	0.47	0.04	2	04/13/09	04/16/09
			Weeki Wachee	WWS-1	0.02	0.02	0.02	0.00	2	03/09/09	03/12/09
			Weeki Wachee	WWS-2	0.02	0.02	0.03	0.01	2	03/09/09	03/12/09
			Weeki Wachee	WWS-3	0.15	0.08	0.21	0.09	2	03/09/09	03/12/09

Nitrogen to Phosphorus Ratios

The ratio of nitrogen to phosphorus is typically of interest when examining what nutrient may be limiting the growth of phytoplankton. Although phytoplankton biomass is expected to be low in spring ecosystems due to the limited residence time of flowing spring pools and runs, it is of interest to examine nitrogen to phosphorus ratios given the impact these nutrients have on the productivity of aquatic ecosystems. By way of comparison, historical N:P ratios for spring waters were reported by Odum (1957b) and Odum *et al.* (1953) and were generally below 7:1 (by weight) but not always, suggesting that historically most springs had the potential for nitrogen limitation. By way of comparison, N:P ratios can be reported by weight or by atomic (*i.e.,* molar) ratio, the commonly reported Redfield ratio for N:P of 16:1 is expressed in atomic units and represents an N:P ratio of approximately 7:1 by weight (Redfield *et al*. 1963, Duarte 1992).

With the exception of Silver Glen, the study springs N:P ratios strongly indicate a presumption of limitation by phosphorus (greater than 16:1 (atomic) or greater than 7:1 (weight), **Table 12** and **Appendix G**). Silver Glen has a ratio of about 3 (atomic), indicating the possibility of nitrogen limitation.

TABLE 12
Average nitrogen to phosphorus ratios (by atoms and by weight) by spring and station.

Water Management District	Spring	Station	N	Mean NOX-N : OrthoP (atomic)	Mean NOX-N : OrthoP (weight)	Mean TN : TP (weight)
NWFWMD	Jackson Blue	JBS-1	2	411	186	170
		JBS-2	2	366	165	186
		JBS-3	2	467	211	199
	Ponce de Leon	PDL-1	2	34	15	70
		PDL-2	2	22	10	68
		PDL-3	2	39	18	68
	Wakulla	WAK-1	2	39	18	20
		WAK-2	2	42	19	19
		WAK-3	2	38	17	22
SJRWMD	De Leon	VDL-1	2	28	13	15
		VDL-2	2	29	13	14
		VDL-3	2	12	5	11
	Silver	SS-1	2	59	27	26
		SS-2	2	73	33	33
		SS-3	2	73	33	32
	Silver Glen	SGS-1	2	5	2	5
		SGS-2	2	3	1	5
		SGS-3	2	2	1	5
SRWMD	Ichetucknee	IS-1	2	47	21	14
		IS-2	2	21	10	6
		IS-4	2	20	9	5
	Madison Blue	MBS-1	2	70	32	40
		MBS-2	2	41	18	28
		MBS-3	2	73	33	44
	Manatee	MS-1	2	156	71	154
		MS-2	2	129	58	294
		MS-3	2	111	50	285
SWFWMD	Homosassa	HS-1	2	57	26	24
		HS-2	2	52	23	24
		HS-3	2	51	23	30
	Rainbow	RS-1	2	126	57	47
		RS-2	2	120	54	59
		RS-3	2	117	53	47
	Weeki Wachee	WWS-1	2	183	83	45
		WWS-2	2	212	96	51
		WWS-3	2	224	101	50

N:P ratios can be reported by weight or by atomic (i.e. molar) ratio, the commonly reported Redfield ratio for N:P of 16:1 is expressed in atomic units and represents an N:P ratio of approximately 7:1 by weight.

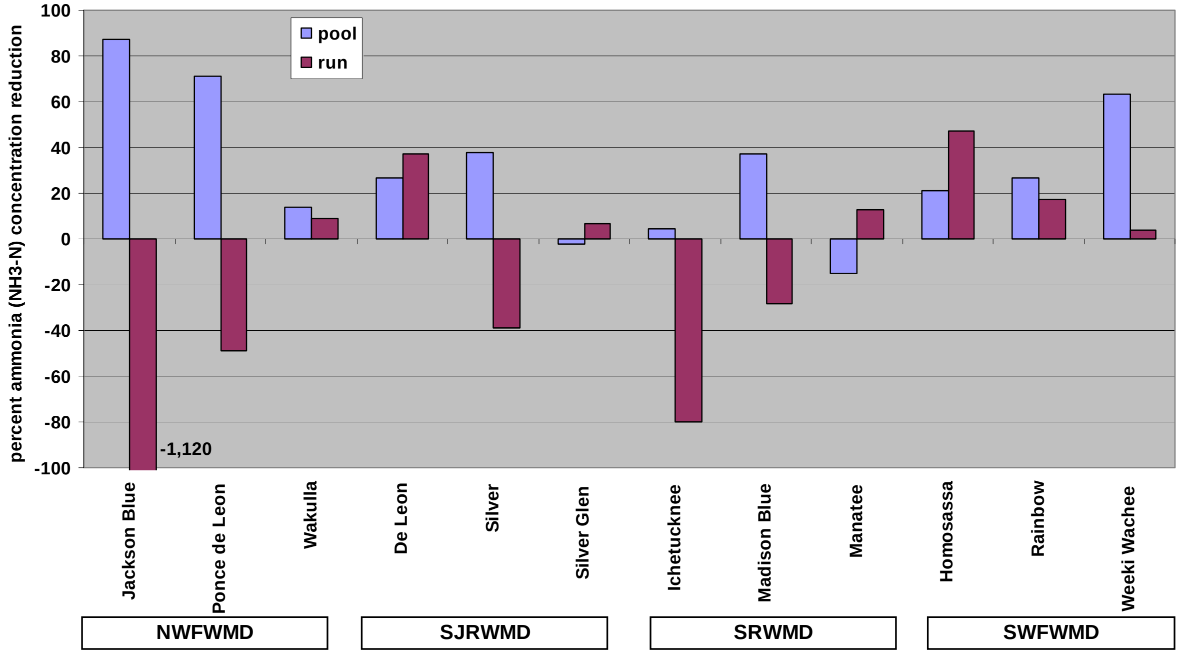
Nutrient Assimilation

Upstream-downstream changes in nutrient masses provide an overview of the spring ecosystem's metabolism. Nutrient uptake might be due to assimilation and/or dissimilation processes. Downstream nutrient increases can result from nutrient transformations, through releases from internal nutrient storages, and through inputs from multiple vents within a spring segment (*e.g.*, Silver and Rainbow Springs). By comparison of the water chemistry values at the upstream and downstream ends of each spring segment, changes in concentration and mass were calculated for both the pool and run sections. Mass balance changes for six water chemistry parameters were calculated, including: ammonia, nitrate, total Kjeldahl nitrogen, total nitrogen, soluble reactive phosphorus, and total phosphorus. **Figures 36** to **41** and **Table 13** present visual and tabular summary of these data. Note that in **Figures 36** to **41** the upper graph illustrates percent changes in nutrient concentrations while the lower graph illustrates the estimated mass changes. These are not always in the same direction due to the possible measured upstream-downstream differences in measured discharge. **Appendix H** provides detailed water chemistry mass balance values by spring.

The mass of ammonia nitrogen was reduced in the upstream segment of 8 of the 12 springs. Estimated mass removal rates ranged from about 1.3 to 193 kg/ha/d. Estimated ammonia mass removal rates were generally lower in the spring runs.

The concentration of nitrate nitrogen was reduced in 18 of the 24 spring pool and run segments studied. Mass reductions of nitrate were observed in 14 of those segments and ranged from 0.43 to 244 kg/ha/d. Downstream increases in nitrate mass at Rainbow, Jackson Blue, and Silver Springs were presumably due to the input of additional nitrate-rich water from the multiple spring vents in those spring runs.

Average concentrations and masses of SRP and total phosphorus were just as likely to increase downstream in these spring runs as to decrease. Estimated total phosphorus mass changes in these springs segments ranged between about -3 and +4 kg/ha/d.



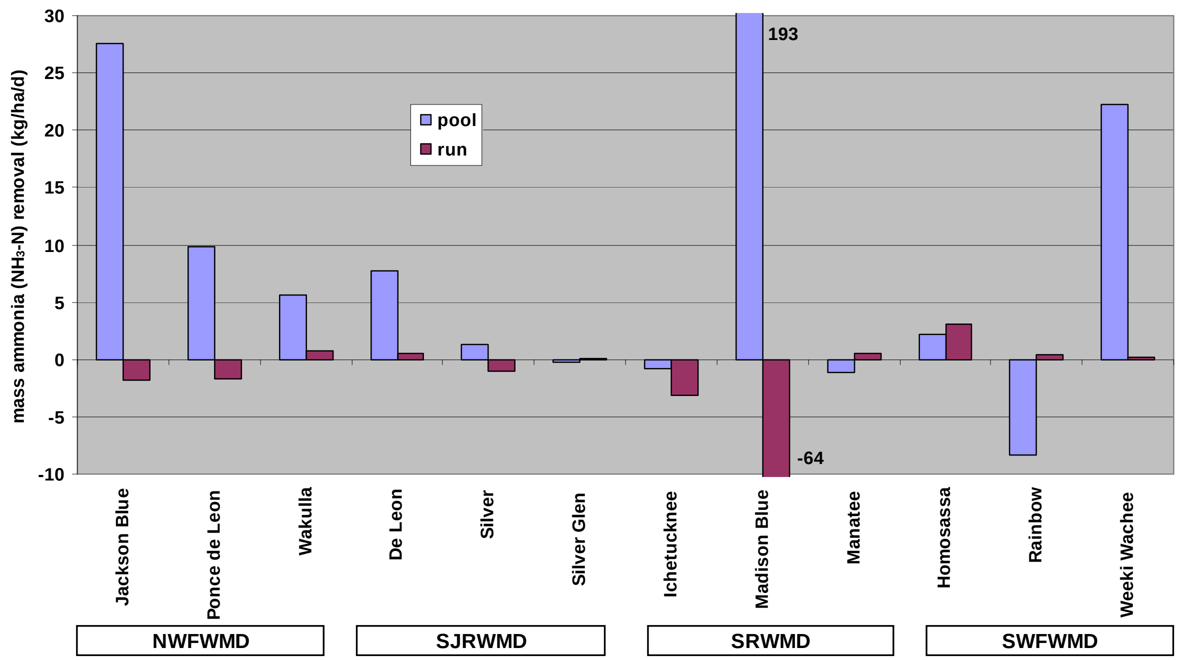


FIGURE 36
Summary of upstream-downstream ammonia (NH_3-N) percent concentration reduction (+) or increase (-) (%, top) and mass removals (+) or gains (-) (kg/ha/d, bottom) by spring and location.

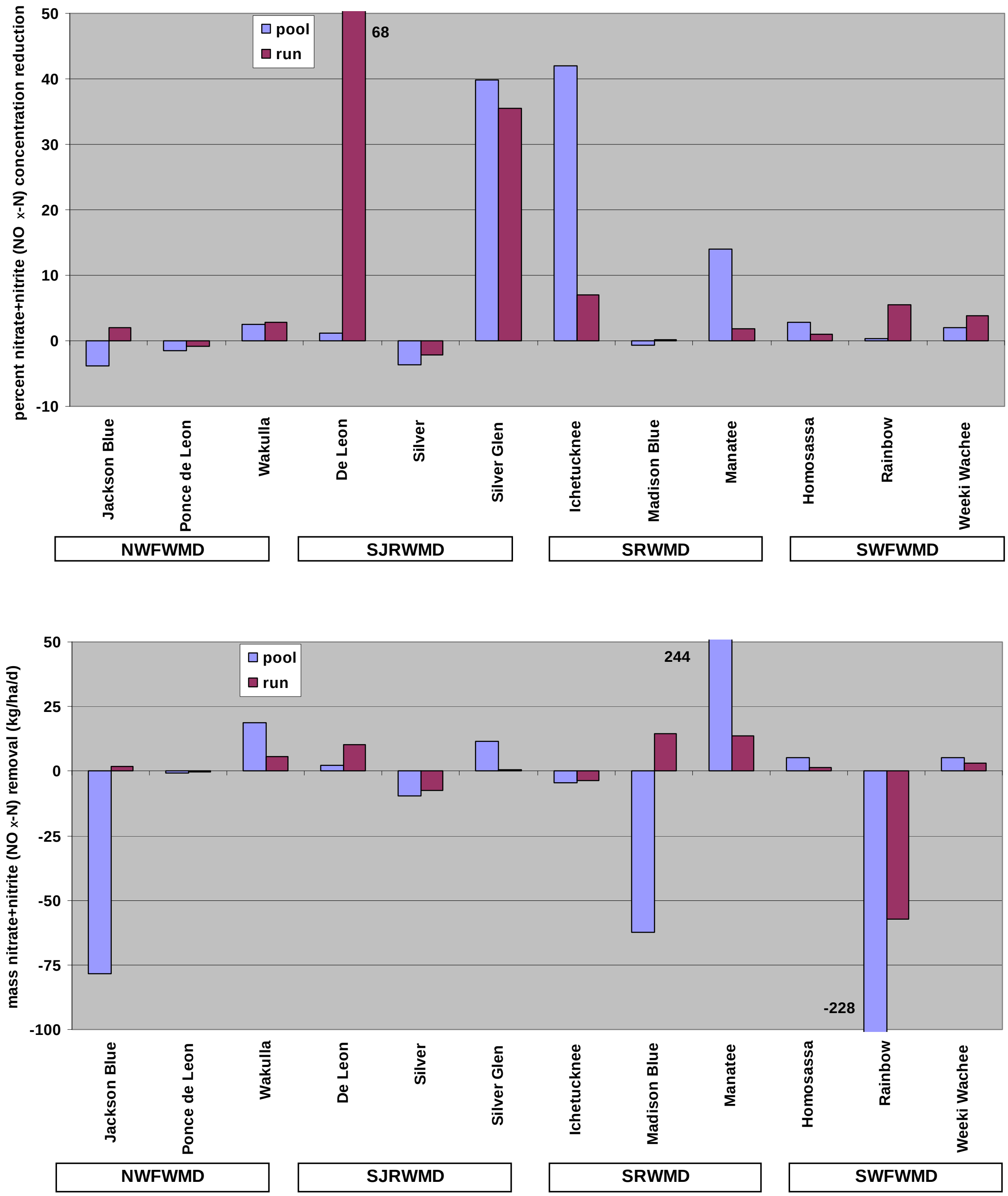


FIGURE 37
Summary of upstream-downstream nitrate+nitrite (NO_X-N) percent concentration reduction (+) or increase (-) (%, top) and mass removals (+) or gains (-) (kg/ha/d, bottom) by spring and location.

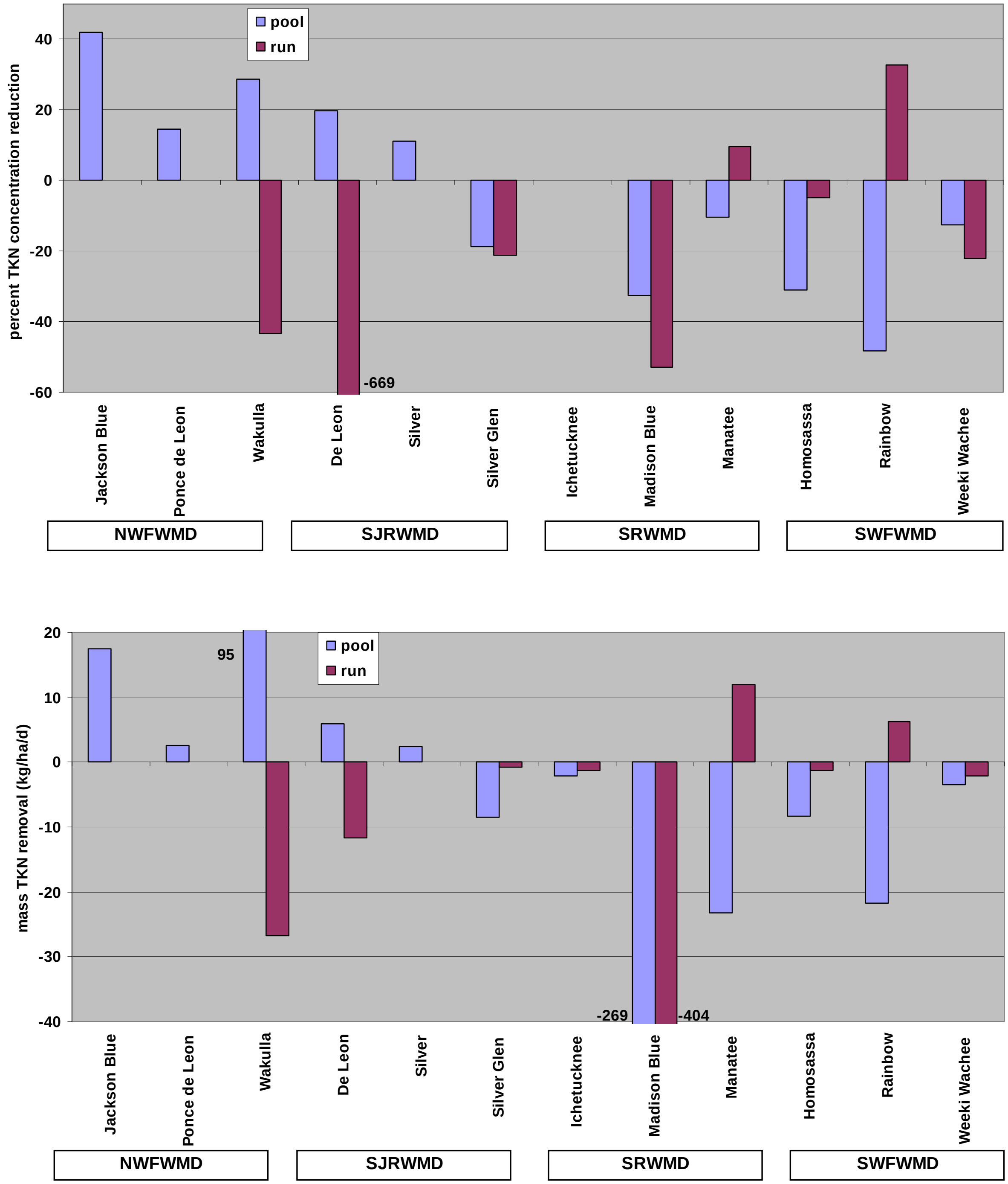
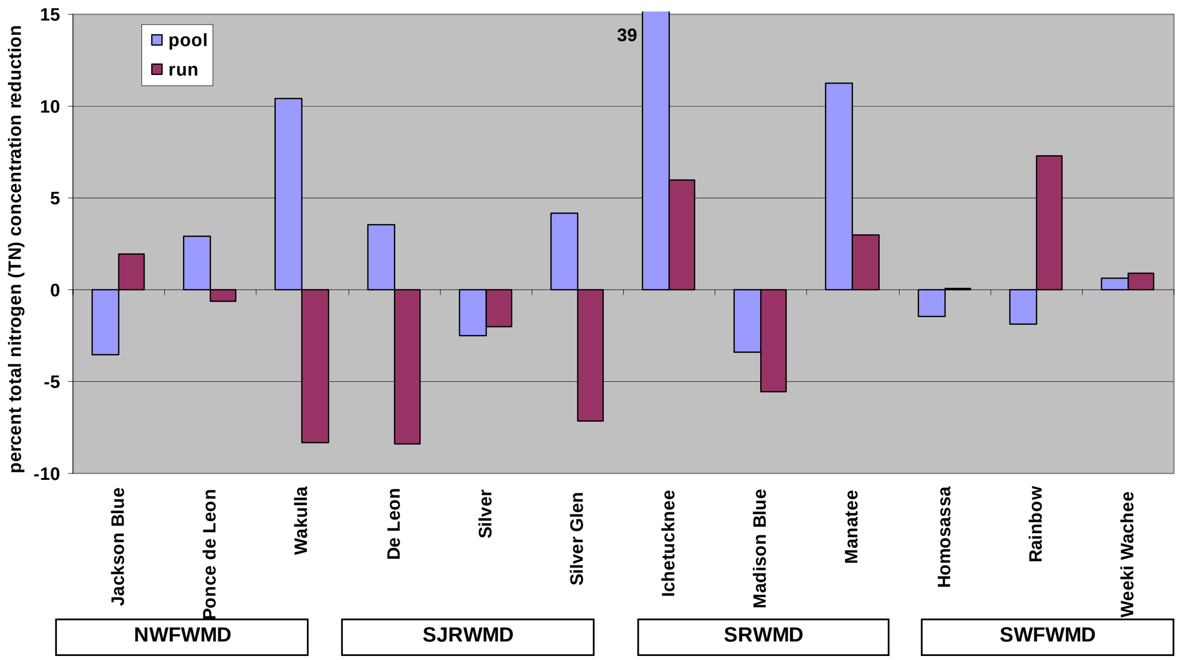


FIGURE 38
Summary of upstream-downstream total Kjeldahl nitrogen (TKN) percent concentration reduction (+) or increase (-) (% top) and mass removals (+) or gains (-) (kg/ha/d, bottom) by spring and location.



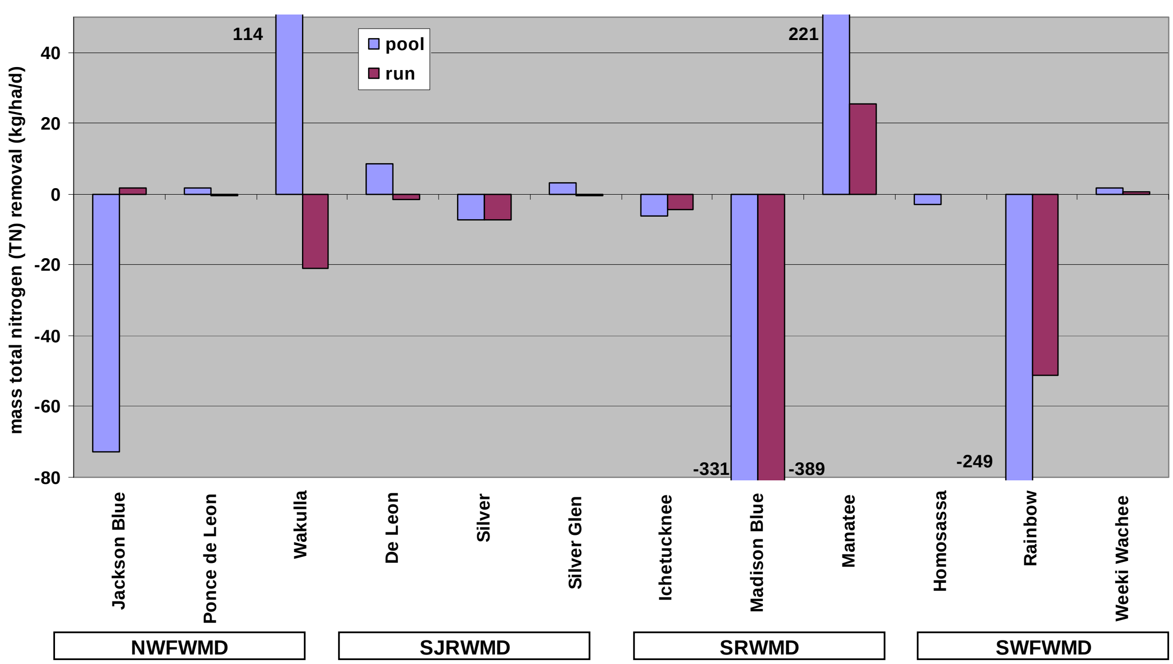
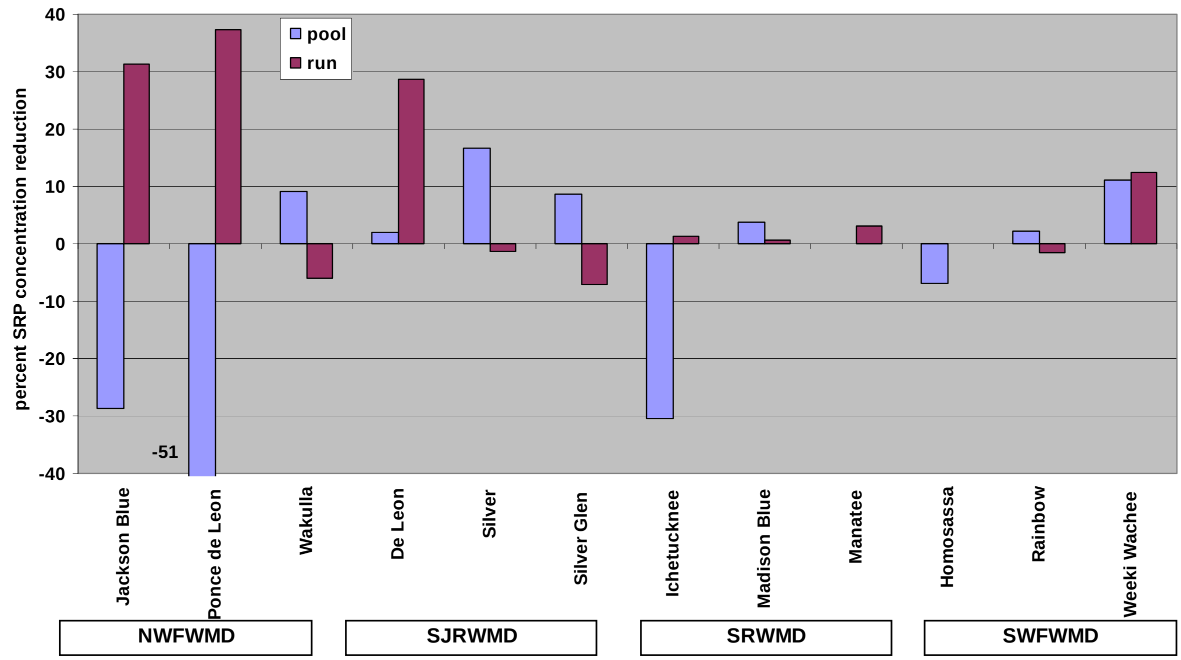


FIGURE 39
Summary of upstream-downstream total nitrogen (TN) percent concentration reduction (+) or increase (-) (%, top) and mass removals (+) or gains (-) (kg/ha/d, bottom) by spring and location.



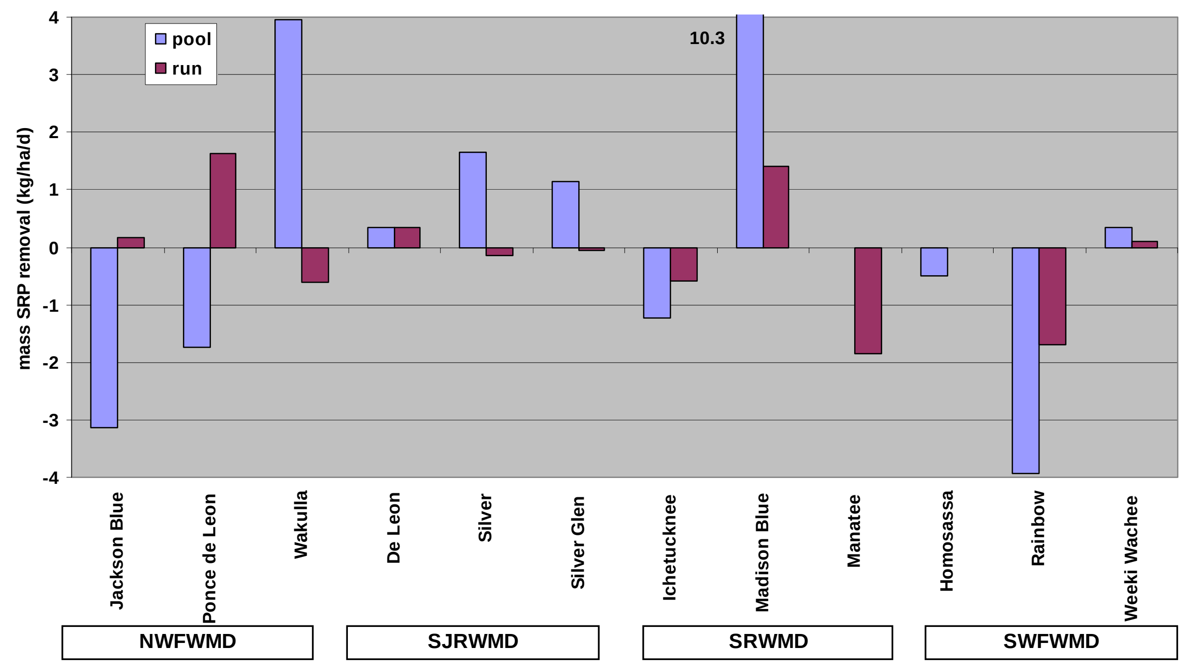


FIGURE 40
Summary of upstream-downstream soluble reactive phosphorus (SRP) percent concentration reduction (+) or increase (-) (%, top) and mass removals (+) or gains (-) (kg/ha/d, bottom) by spring and location.

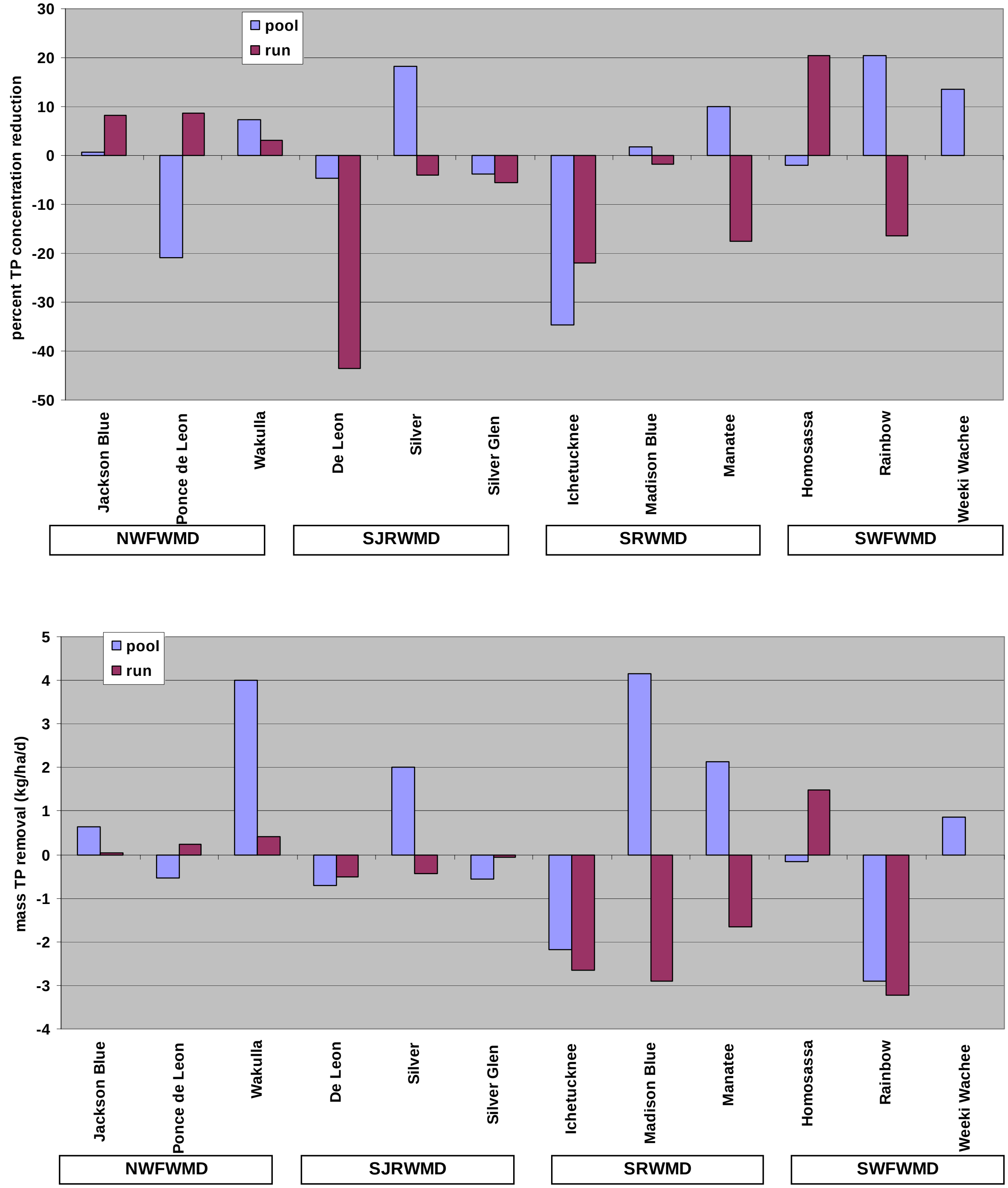


FIGURE 41
Summary of upstream-downstream total phosphorus (TP) percent concentration reduction (+) or increase (-) (%, top) and mass removals (+) or gains (-) (kg/ha/d, bottom) by spring and location.

TABLE 13
Summary of upstream-downstream nutrient percent concentration and mass removal by spring, location, and chemical parameter.

Parameter	Water Management District	Spring	Median Date	Location	Segment Area (ha)	Inflow Conc. (mg/L)	Inflow Flow (m^3/d)	Inflow Mass (kg/d)	Inflow Mass (kg/ha/d)	Outflow Conc. (mg/L)	Outflow Flow (m^3/d)	Outflow Mass (kg/d)	Outflow Mass (kg/ha/d)	Removal Conc. (mg/L)	Removal Conc. (%)	Removal Mass (kg/d)	Removal Mass (kg/ha/d)
NH_3-N	NWFWMD	Jackson Blue	01/14/09	pool	0.41	0.052	247,181	12.91	31.65	0.007	247,181	1.65	4.04	0.046	87.2	11.27	27.61
				run	10.33	0.007	247,181	1.65	0.16	0.081	247,181	20.10	1.95	-0.075	-1120.3	-18.45	-1.79
				both	10.74	0.052	247,181	12.91	1.20	0.081	247,181	20.10	1.87	-0.029	-55.6	-7.18	-0.67
		Ponce de Leon	09/10/09	pool	0.16	0.079	28,236	2.22	13.91	0.023	28,236	0.64	4.03	0.056	71.0	1.58	9.88
				run	0.19	0.023	28,236	0.64	3.44	0.034	28,236	0.96	5.12	-0.011	-48.9	-0.31	-1.68
				both	0.35	0.079	28,236	2.22	6.40	0.034	28,236	0.96	2.76	0.045	56.8	1.26	3.64
		Wakulla	04/14/09	pool	1.57	0.026	2,482,892	64.71	41.25	0.022	2,482,892	55.85	35.61	0.004	13.7	8.86	5.65
				run	6.03	0.022	2,482,892	55.85	9.26	0.021	2,482,892	51.01	8.46	0.002	8.7	4.84	0.80
				both	7.60	0.026	2,482,892	64.71	8.51	0.021	2,482,892	51.01	6.71	0.006	21.2	13.70	1.80
	SJRWMD	De Leon	10/08/08	pool	0.28	0.108	74,141	7.99	29.02	0.079	74,141	5.86	21.30	0.029	26.6	2.12	7.72
				run	3.80	0.079	74,141	5.86	1.54	0.050	74,141	3.68	0.97	0.029	37.3	2.19	0.58
				both	4.07	0.108	74,141	7.99	1.96	0.050	74,141	3.68	0.90	0.058	54.0	4.31	1.06
		Silver	05/06/09	pool	4.41	0.014	1,042,292	15.09	3.42	0.009	1,042,292	9.38	2.13	0.005	37.8	5.71	1.29
				run	3.53	0.009	1,042,292	9.38	2.66	0.012	1,042,292	13.01	3.69	-0.003	-38.7	-3.63	-1.03
				both	7.94	0.014	1,042,292	15.09	1.90	0.012	1,042,292	13.01	1.64	0.002	13.8	2.08	0.26
		Silver Glen	02/18/09	pool	0.24	0.022	139,398	3.07	12.56	0.023	139,398	3.14	12.84	-0.0005	-2.3	-0.07	-0.29
				run	3.58	0.023	139,398	3.14	0.88	0.021	139,398	2.93	0.82	0.002	6.7	0.21	0.06
				both	3.83	0.022	139,398	3.07	0.80	0.021	139,398	2.93	0.76	0.001	4.5	0.14	0.04
	SRWMD	Ichetucknee	07/08/09	upper run	10.34	0.034	199,980	6.80	0.66	0.033	468,202	15.22	1.47	0.002	4.5	-8.41	-0.81
				lower run	5.68	0.033	468,202	15.22	2.68	0.059	558,606	32.73	5.76	-0.026	-80.3	-17.51	-3.08
				both	16.02	0.034	199,980	6.80	0.42	0.059	558,606	32.73	2.04	-0.025	-72.2	-25.92	-1.62
		Madison Blue	12/02/08	pool	0.04	0.083	273,774	22.75	515.58	0.052	273,774	14.22	322.35	0.031	37.5	8.52	193.23
				run	0.06	0.052	273,774	14.22	224.23	0.067	273,774	18.27	288.01	-0.015	-28.4	-4.04	-63.78
				both	0.11	0.083	273,774	22.75	211.51	0.067	273,774	18.27	169.86	0.016	19.7	4.48	41.66
		Manatee	08/04/09	pool	0.26	0.009	228,435	2.06	7.85	0.010	228,435	2.36	9.01	-0.001	-14.8	-0.30	-1.16
				run	0.54	0.010	228,435	2.36	4.41	0.009	228,435	2.06	3.84	0.001	12.9	0.30	0.57
				both	0.80	0.009	228,435	2.06	2.58	0.009	228,435	2.06	2.58	0.000	0.0	0.00	0.00
	SWFWMD	Homosassa	11/04/08	pool	0.51	0.031	167,867	5.25	10.36	0.025	167,867	4.15	8.18	0.007	21.0	1.10	2.18
				run	0.63	0.025	167,867	4.15	6.63	0.013	167,867	2.19	3.50	0.012	47.2	1.95	3.13
				both	1.13	0.031	167,867	5.25	4.64	0.013	167,867	2.19	1.94	0.018	58.3	3.06	2.70
		Rainbow	06/10/09	pool	2.17	0.148	334,221	49.48	22.77	0.109	621,485	67.54	31.09	0.039	26.6	-18.06	-8.31
				run	2.35	0.109	621,485	67.54	28.71	0.090	740,517	66.65	28.33	0.019	17.2	0.89	0.38
				both	4.53	0.148	334,221	49.48	10.93	0.090	740,517	66.65	14.73	0.058	39.2	-17.17	-3.79
		Weeki Wachee	03/10/09	pool	0.66	0.101	226,464	22.97	35.00	0.037	226,464	8.38	12.77	0.064	63.5	14.59	22.23
				run	2.14	0.037	226,464	8.38	3.91	0.036	226,464	8.04	3.76	0.002	4.1	0.34	0.16
				both	2.80	0.101	226,464	22.97	8.21	0.036	226,464	8.04	2.87	0.066	65.0	14.93	5.34

TABLE 13 (CONTINUED)
Summary of upstream-downstream nutrient percent concentration and mass removal by spring, location, and chemical parameter.

Parameter	Water Management District	Spring	Median Date	Location	Segment Area (ha)	Inflow Conc. (mg/L)	Inflow Flow (m^3/d)	Inflow Mass (kg/d)	Inflow Mass (kg/ha/d)	Outflow Conc. (mg/L)	Outflow Flow (m^3/d)	Outflow Mass (kg/d)	Outflow Mass (kg/ha/d)	Removal Conc. (mg/L)	Removal Conc. (%)	Removal Mass (kg/d)	Removal Mass (kg/ha/d)
NO_x-N	NWFWMD	Jackson Blue	01/14/09	pool	0.41	3.320	247,181	820.60	2,010.79	3.450	247,181	852.68	2,089.38	-0.130	-3.9	-32.07	-78.59
				run	10.33	3.450	247,181	852.68	82.53	3.382	247,181	835.85	80.90	0.068	2.0	16.82	1.63
				both	10.74	3.320	247,181	820.60	76.41	3.382	247,181	835.85	77.83	-0.062	-1.9	-15.25	-1.42
		Ponce de Leon	09/10/09	pool	0.16	0.275	28,236	7.77	48.70	0.279	28,236	7.89	49.44	-0.004	-1.5	-0.12	-0.74
				run	0.19	0.279	28,236	7.89	42.19	0.281	28,236	7.95	42.51	-0.002	-0.8	-0.06	-0.32
				both	0.35	0.275	28,236	7.77	22.42	0.281	28,236	7.95	22.94	-0.006	-2.3	-0.18	-0.51
		Wakulla	04/14/09	pool	1.57	0.480	2,482,892	1,192.86	760.51	0.469	2,482,892	1,163.55	741.83	0.012	2.5	29.31	18.69
				run	6.03	0.469	2,482,892	1,163.55	192.90	0.455	2,482,892	1,130.02	187.34	0.014	2.9	33.53	5.56
				both	7.60	0.480	2,482,892	1,192.86	156.95	0.455	2,482,892	1,130.02	148.68	0.025	5.3	62.84	8.27
	SJRWMD	De Leon	10/08/08	pool	0.28	0.775	74,141	57.49	208.91	0.766	74,141	56.82	206.46	0.009	1.2	0.67	2.44
				run	3.80	0.766	74,141	56.82	14.97	0.242	74,141	17.96	4.73	0.524	68.4	38.86	10.24
				both	4.07	0.775	74,141	57.49	14.12	0.242	74,141	17.96	4.41	0.533	68.8	39.53	9.71
		Silver	05/06/09	pool	4.41	1.110	1,042,292	1,156.90	262.36	1.150	1,042,292	1,198.68	271.83	-0.040	-3.6	-41.79	-9.48
				run	3.53	1.150	1,042,292	1,198.68	339.57	1.175	1,042,292	1,224.62	346.92	-0.025	-2.2	-25.94	-7.35
				both	7.94	1.110	1,042,292	1,156.90	145.71	1.175	1,042,292	1,224.62	154.24	-0.065	-5.9	-67.73	-8.53
		Silver Glen	02/18/09	pool	0.24	0.052	139,398	7.18	29.40	0.031	139,398	4.32	17.70	0.021	39.8	2.86	11.70
				run	3.58	0.031	139,398	4.32	1.21	0.020	139,398	2.79	0.78	0.011	35.5	1.53	0.43
				both	3.83	0.052	139,398	7.18	1.88	0.020	139,398	2.79	0.73	0.032	61.2	4.39	1.15
	SRWMD	Ichetucknee *	07/08/09	pool	10.34	0.659	199,980	131.71	12.73	0.382	468,202	178.62	17.27	0.277	42.1	-46.91	-4.53
				run	5.68	0.382	468,202	178.62	31.45	0.355	558,606	198.29	34.92	0.027	7.0	-19.67	-3.46
				both	16.02	0.659	199,980	131.71	8.22	0.355	558,606	198.29	12.38	0.304	46.1	-66.58	-4.16
		Madison Blue	12/02/08	pool	0.04	1.440	273,774	394.25	8,936.61	1.450	273,774	396.99	8,998.84	-0.010	-0.7	-2.75	-62.22
				run	0.06	1.450	273,774	396.99	6,259.78	1.447	273,774	396.07	6,245.20	0.003	0.2	0.92	14.58
				both	0.11	1.440	273,774	394.25	3,666.21	1.447	273,774	396.07	3,683.13	-0.007	-0.5	-1.82	-16.93
		Manatee	08/04/09	pool	0.26	1.994	228,435	455.60	1,740.25	1.714	228,435	391.65	1,495.97	0.280	14.0	63.95	244.28
				run	0.54	1.714	228,435	391.65	731.78	1.682	228,435	384.27	717.99	0.032	1.9	7.38	13.78
				both	0.80	1.994	228,435	455.60	571.64	1.682	228,435	384.27	482.15	0.312	15.7	71.33	89.50
	SWFWMD	Homosassa	11/04/08	pool	0.51	0.554	167,867	92.99	183.49	0.538	167,867	90.36	178.32	0.016	2.8	2.62	5.17
				run	0.63	0.538	167,867	90.36	144.57	0.533	167,867	89.47	143.14	0.005	1.0	0.89	1.43
				both	1.13	0.554	167,867	92.99	82.16	0.533	167,867	89.47	79.05	0.021	3.8	3.51	3.11
		Rainbow	06/10/09	pool	2.17	1.733	334,221	579.06	266.53	1.728	621,485	1,073.78	494.24	0.005	0.3	-494.71	-227.71
				run	2.35	1.728	621,485	1,073.78	456.37	1.632	740,517	1,208.38	513.58	0.096	5.6	-134.61	-57.21
				both	4.53	1.733	334,221	579.06	127.96	1.632	740,517	1,208.38	267.02	0.101	5.8	-629.32	-139.06
		Weeki Wachee	03/10/09	pool	0.66	0.737	226,464	166.90	254.27	0.722	226,464	163.50	249.09	0.015	2.0	3.40	5.18
				run	2.14	0.722	226,464	163.50	76.38	0.694	226,464	157.28	73.47	0.027	3.8	6.23	2.91
				both	2.80	0.737	226,464	166.90	59.67	0.694	226,464	157.28	56.23	0.042	5.8	9.62	3.44

TABLE 13 (CONTINUED)

Summary of upstream-downstream nutrient percent concentration and mass removal by spring, location, and chemical parameter.

Parameter	Water Management District	Spring	Median Date	Location	Segment Area (ha)	Inflow Conc. (mg/L)	Inflow Flow (m^3/d)	Inflow Mass (kg/d)	Inflow Mass (kg/ha/d)	Outflow Conc. (mg/L)	Outflow Flow (m^3/d)	Outflow Mass (kg/d)	Outflow Mass (kg/ha/d)	Removal Conc. (mg/L)	Removal Conc. (%)	Removal Mass (kg/d)	Removal Mass (kg/ha/d)
TKN	NWFWMD	Jackson Blue	01/14/09	pool	0.41	0.069	247,181	17.01	41.69	0.040	247,181	9.89	24.23	0.029	41.9	7.13	17.46
				run	10.33	0.040	247,181	9.89	0.96	0.040	247,181	9.89	0.96	0.000	0.0	0.00	0.00
				both	10.74	0.069	247,181	17.01	1.58	0.040	247,181	9.89	0.92	0.029	41.9	7.13	0.66
		Ponce de Leon	09/10/09	pool	0.16	0.095	28,236	2.68	16.80	0.080	28,236	2.26	14.16	0.015	15.7	0.42	2.64
				run	0.19	0.080	28,236	2.26	12.09	0.080	28,236	2.26	12.09	0.000	0.0	0.00	0.00
				both	0.35	0.095	28,236	2.68	7.74	0.080	28,236	2.26	6.52	0.015	15.7	0.42	1.21
		Wakulla	04/14/09	pool	1.57	0.210	2,482,892	521.10	332.23	0.150	2,482,892	371.53	236.87	0.060	28.7	149.58	95.36
				run	6.03	0.150	2,482,892	371.53	61.59	0.214	2,482,892	532.46	88.28	-0.065	-43.3	-160.93	-26.68
				both	7.60	0.210	2,482,892	521.10	68.56	0.214	2,482,892	532.46	70.06	-0.005	-2.2	-11.36	-1.49
	SJRWMD	De Leon	10/08/08	pool	0.28	0.111	74,141	8.26	30.02	0.089	74,141	6.62	24.06	0.022	19.9	1.64	5.96
				run	3.80	0.089	74,141	6.62	1.74	0.686	74,141	50.90	13.41	-0.597	-668.8	-44.28	-11.66
				both	4.07	0.111	74,141	8.26	2.03	0.686	74,141	50.90	12.50	-0.575	-516.1	-42.64	-10.47
		Silver	05/06/09	pool	4.41	0.090	1,042,292	93.76	21.26	0.080	1,042,292	83.38	18.91	0.010	11.1	10.38	2.35
				run	3.53	0.080	1,042,292	83.38	23.62	0.080	1,042,292	83.38	23.62	0.000	0.0	0.00	0.00
				both	7.94	0.090	1,042,292	93.76	11.81	0.080	1,042,292	83.38	10.50	0.010	11.1	10.38	1.31
		Silver Glen	02/18/09	pool	0.24	0.080	139,398	11.15	45.67	0.095	139,398	13.24	54.23	-0.015	-18.8	-2.09	-8.56
				run	3.58	0.095	139,398	13.24	3.70	0.115	139,398	16.03	4.47	-0.020	-21.1	-2.79	-0.78
				both	3.83	0.080	139,398	11.15	2.91	0.115	139,398	16.03	4.19	-0.035	-43.8	-4.88	-1.27
	SRWMD	Ichetucknee *	07/08/09	pool	10.34	0.080	199,980	16.00	1.55	0.080	468,202	37.46	3.62	0.000	0.0	-21.46	-2.07
				run	5.68	0.080	468,202	37.46	6.60	0.080	558,606	44.69	7.87	0.000	0.0	-7.23	-1.27
				both	16.02	0.080	199,980	16.00	1.00	0.080	558,606	44.69	2.79	0.000	0.0	-28.69	-1.79
		Madison Blue	12/02/08	pool	0.04	0.133	273,774	36.51	827.54	0.177	273,774	48.37	1,096.40	-0.043	-32.5	-11.86	-268.86
				run	0.06	0.177	273,774	48.37	762.68	0.270	273,774	73.99	1,166.71	-0.094	-53.0	-25.62	-404.02
				both	0.11	0.133	273,774	36.51	339.50	0.270	273,774	73.99	688.07	-0.137	-102.7	-37.48	-348.57
		Manatee	08/04/09	pool	0.26	0.259	228,435	59.17	226.00	0.286	228,435	65.27	249.31	-0.027	-10.3	-6.10	-23.31
				run	0.54	0.286	228,435	65.27	121.95	0.258	228,435	58.90	110.06	0.028	9.8	6.36	11.89
				both	0.80	0.259	228,435	59.17	74.24	0.258	228,435	58.90	73.91	0.001	0.4	0.26	0.33
	SWFWMD	Homosassa	11/04/08	pool	0.51	0.080	167,867	13.43	26.50	0.105	167,867	17.62	34.76	-0.025	-31.2	-4.19	-8.26
				run	0.63	0.105	167,867	17.62	28.18	0.110	167,867	18.47	29.54	-0.005	-4.8	-0.85	-1.36
				both	1.13	0.080	167,867	13.43	11.87	0.110	167,867	18.47	16.31	-0.030	-37.5	-5.04	-4.45
		Rainbow	06/10/09	pool	2.17	0.080	334,221	26.74	12.31	0.119	621,485	73.77	33.95	-0.039	-48.4	-47.03	-21.65
				run	2.35	0.119	621,485	73.77	31.35	0.080	740,517	59.24	25.18	0.039	32.6	14.53	6.17
				both	4.53	0.080	334,221	26.74	5.91	0.080	740,517	59.24	13.09	0.000	0.0	-32.50	-7.18
		Weeki Wachee	03/10/09	pool	0.66	0.080	226,464	18.12	27.60	0.090	226,464	20.38	31.05	-0.010	-12.5	-2.27	-3.45
				run	2.14	0.090	226,464	20.38	9.52	0.110	226,464	24.91	11.63	-0.020	-22.2	-4.52	-2.11
				both	2.80	0.080	226,464	18.12	6.48	0.110	226,464	24.91	8.90	-0.030	-37.5	-6.79	-2.43

TABLE 13 (CONTINUED)
Summary of upstream-downstream nutrient percent concentration and mass removal by spring, location, and chemical parameter.

Parameter	Water Management District	Spring	Median Date	Location	Segment Area (ha)	Inflow Conc. (mg/L)	Inflow Flow (m^3/d)	Inflow Mass (kg/d)	Inflow Mass (kg/ha/d)	Outflow Conc. (mg/L)	Outflow Flow (m^3/d)	Outflow Mass (kg/d)	Outflow Mass (kg/ha/d)	Removal Conc. (mg/L)	Removal Conc. (%)	Removal Mass (kg/d)	Removal Mass (kg/ha/d)
TN	NWFWMD	Jackson Blue	01/14/09	pool	0.41	3.409	247,181	842.75	2,065.07	3.530	247,181	872.45	2,137.84	-0.120	-3.5	-29.70	-72.77
				run	10.33	3.530	247,181	872.45	84.44	3.462	247,181	855.63	82.81	0.068	1.9	16.82	1.63
				both	10.74	3.409	247,181	842.75	78.47	3.462	247,181	855.63	79.67	-0.052	-1.5	-12.87	-1.20
		Ponce de Leon	09/10/09	pool	0.16	0.370	28,236	10.45	65.50	0.359	28,236	10.14	63.60	0.011	2.9	0.30	1.90
				run	0.19	0.359	28,236	10.14	54.27	0.361	28,236	10.20	54.60	-0.002	-0.6	-0.06	-0.32
				both	0.35	0.370	28,236	10.45	30.16	0.361	28,236	10.20	29.46	0.009	2.3	0.24	0.70
		Wakulla	04/14/09	pool	1.57	0.690	2,482,892	1,713.97	1,092.74	0.618	2,482,892	1,535.08	978.69	0.072	10.4	178.89	114.05
				run	6.03	0.618	2,482,892	1,535.08	254.50	0.670	2,482,892	1,662.48	275.62	-0.051	-8.3	-127.40	-21.12
				both	7.60	0.690	2,482,892	1,713.97	225.51	0.670	2,482,892	1,662.48	218.74	0.021	3.0	51.49	6.77
	SJRWMD	De Leon	10/08/08	pool	0.28	0.887	74,141	65.75	238.93	0.856	74,141	63.44	230.52	0.031	3.5	2.31	8.41
				run	3.80	0.856	74,141	63.44	16.71	0.927	74,141	68.75	18.11	-0.072	-8.4	-5.32	-1.40
				both	4.07	0.887	74,141	65.75	16.15	0.927	74,141	68.75	16.89	-0.040	-4.6	-3.00	-0.74
		Silver	05/06/09	pool	4.41	1.200	1,042,292	1,250.66	283.62	1.230	1,042,292	1,282.07	290.74	-0.030	-2.5	-31.41	-7.12
				run	3.53	1.230	1,042,292	1,282.07	363.19	1.255	1,042,292	1,308.01	370.54	-0.025	-2.0	-25.94	-7.35
				both	7.94	1.200	1,042,292	1,250.66	157.52	1.255	1,042,292	1,308.01	164.74	-0.055	-4.6	-57.35	-7.22
		Silver Glen	02/18/09	pool	0.24	0.132	139,398	18.33	75.06	0.126	139,398	17.56	71.93	0.006	4.2	0.77	3.14
				run	3.58	0.126	139,398	17.56	4.90	0.135	139,398	18.82	5.25	-0.009	-7.1	-1.25	-0.35
				both	3.83	0.132	139,398	18.33	4.79	0.135	139,398	18.82	4.92	-0.004	-2.7	-0.49	-0.13
	SRWMD	Ichetucknee *	07/08/09	pool	10.34	0.719	199,980	143.81	13.90	0.442	468,202	206.71	19.98	0.278	38.6	-62.90	-6.08
				run	5.68	0.442	468,202	206.71	36.40	0.415	558,606	231.83	40.82	0.026	6.0	-25.12	-4.42
				both	16.02	0.719	199,980	143.81	8.98	0.415	558,606	231.83	14.47	0.304	42.3	-88.02	-5.49
		Madison Blue	12/02/08	pool	0.04	1.573	273,774	430.76	9,764.16	1.627	273,774	445.36	10,095.24	-0.053	-3.4	-14.61	-331.08
				run	0.06	1.627	273,774	445.36	7,022.46	1.717	273,774	470.06	7,411.90	-0.090	-5.5	-24.70	-389.44
				both	0.11	1.573	273,774	430.76	4,005.70	1.717	273,774	470.06	4,371.20	-0.144	-9.1	-39.30	-365.50
		Manatee	08/04/09	pool	0.26	2.253	228,435	514.76	1,966.25	2.000	228,435	456.91	1,745.28	0.253	11.2	57.85	220.97
				run	0.54	2.000	228,435	456.91	853.73	1.940	228,435	443.17	828.05	0.060	3.0	13.74	25.67
				both	0.80	2.253	228,435	514.76	645.88	1.940	228,435	443.17	556.05	0.313	13.9	71.59	89.82
	SWFWMD	Homosassa	11/04/08	pool	0.51	0.634	167,867	106.41	209.99	0.643	167,867	107.98	213.08	-0.009	-1.5	-1.56	-3.09
				run	0.63	0.643	167,867	107.98	172.75	0.643	167,867	107.94	172.68	0.000	0.0	0.04	0.07
				both	1.13	0.634	167,867	106.41	94.02	0.643	167,867	107.94	95.37	-0.009	-1.4	-1.52	-1.34
		Rainbow	06/10/09	pool	2.17	1.813	334,221	605.80	278.84	1.846	621,485	1,147.55	528.19	-0.034	-1.9	-541.75	-249.35
				run	2.35	1.846	621,485	1,147.55	487.72	1.712	740,517	1,267.63	538.76	0.135	7.3	-120.08	-51.03
				both	4.53	1.813	334,221	605.80	133.87	1.712	740,517	1,267.63	280.11	0.101	5.6	-661.82	-146.24
		Weeki Wachee	03/10/09	pool	0.66	0.817	226,464	185.02	281.87	0.812	226,464	183.89	280.15	0.005	0.6	1.13	1.72
				run	2.14	0.812	226,464	183.89	85.90	0.804	226,464	182.18	85.11	0.008	0.9	1.70	0.80
				both	2.80	0.817	226,464	185.02	66.15	0.804	226,464	182.18	65.14	0.013	1.5	2.83	1.01

TABLE 13 (CONTINUED)
Summary of upstream-downstream nutrient percent concentration and mass removal by spring, location, and chemical parameter.

Parameter	Water Management District	Spring	Median Date	Location	Segment Area (ha)	Inflow Conc. (mg/L)	Inflow Flow (m^3/d)	Inflow Mass (kg/d)	Inflow Mass (kg/ha/d)	Outflow Conc. (mg/L)	Outflow Flow (m^3/d)	Outflow Mass (kg/d)	Outflow Mass (kg/ha/d)	Removal Conc. (mg/L)	Removal Conc. (%)	Removal Mass (kg/d)	Removal Mass (kg/ha/d)
SRP	NWFWMD	Jackson Blue	01/14/09	pool	0.41	0.018	247,181	4.47	10.95	0.023	247,181	5.75	14.10	-0.005	-28.7	-1.28	-3.15
				run	10.33	0.023	247,181	5.75	0.56	0.016	247,181	3.95	0.38	0.007	31.2	1.80	0.17
				both	10.74	0.018	247,181	4.47	0.42	0.016	247,181	3.95	0.37	0.002	11.5	0.51	0.05
		Ponce de Leon	09/10/09	pool	0.16	0.019	28,236	0.54	3.38	0.029	28,236	0.82	5.11	-0.010	-51.2	-0.28	-1.73
				run	0.19	0.029	28,236	0.82	4.36	0.018	28,236	0.51	2.74	0.011	37.3	0.30	1.63
				both	0.35	0.019	28,236	0.54	1.56	0.018	28,236	0.51	1.48	0.001	5.1	0.03	0.08
		Wakulla	04/14/09	pool	1.57	0.027	2,482,892	68.20	43.48	0.025	2,482,892	62.01	39.54	0.002	9.1	6.19	3.95
				run	6.03	0.025	2,482,892	62.01	10.28	0.026	2,482,892	65.75	10.90	-0.002	-6.0	-3.74	-0.62
				both	7.60	0.027	2,482,892	68.20	8.97	0.026	2,482,892	65.75	8.65	0.001	3.6	2.45	0.32
	SJRWMD	De Leon	10/08/08	pool	0.28	0.061	74,141	4.51	16.38	0.060	74,141	4.41	16.04	0.001	2.1	0.09	0.34
				run	3.80	0.060	74,141	4.41	1.16	0.042	74,141	3.15	0.83	0.017	28.7	1.27	0.33
				both	4.07	0.061	74,141	4.51	1.11	0.042	74,141	3.15	0.77	0.018	30.2	1.36	0.33
		Silver	05/06/09	pool	4.41	0.042	1,042,292	43.79	9.93	0.035	1,042,292	36.48	8.27	0.007	16.7	7.30	1.66
				run	3.53	0.035	1,042,292	36.48	10.34	0.036	1,042,292	37.00	10.48	0.000	-1.4	-0.52	-0.15
				both	7.94	0.042	1,042,292	43.79	5.51	0.036	1,042,292	37.00	4.66	0.007	15.5	6.78	0.85
		Silver Glen	02/18/09	pool	0.24	0.023	139,398	3.21	13.13	0.021	139,398	2.93	11.99	0.002	8.7	0.28	1.14
				run	3.58	0.021	139,398	2.93	0.82	0.023	139,398	3.14	0.88	-0.002	-7.1	-0.21	-0.06
				both	3.83	0.023	139,398	3.21	0.84	0.023	139,398	3.14	0.82	0.001	2.2	0.07	0.02
	SRWMD	Ichetucknee *	07/08/09	pool	10.34	0.031	199,980	6.21	0.60	0.041	468,202	18.96	1.83	-0.009	-30.4	-12.75	-1.23
				run	5.68	0.041	468,202	18.96	3.34	0.040	558,606	22.35	3.93	0.000	1.2	-3.38	-0.60
				both	16.02	0.031	199,980	6.21	0.39	0.040	558,606	22.35	1.39	-0.009	-28.8	-16.14	-1.01
		Madison Blue	12/02/08	pool	0.04	0.045	273,774	12.32	279.33	0.043	273,774	11.87	268.98	0.002	3.7	0.46	10.35
				run	0.06	0.043	273,774	11.87	187.11	0.043	273,774	11.78	185.69	0.000	0.8	0.09	1.41
				both	0.11	0.045	273,774	12.32	114.59	0.043	273,774	11.78	109.51	0.002	4.4	0.55	5.08
		Manatee	08/04/09	pool	0.26	0.029	228,435	6.58	25.12	0.029	228,435	6.58	25.12	0.000	0.0	0.00	0.00
				run	0.54	0.029	228,435	6.58	12.29	0.033	228,435	7.57	14.14	-0.004	-15.1	-0.99	-1.85
				both	0.80	0.029	228,435	6.58	8.25	0.033	228,435	7.57	9.50	-0.004	-15.1	-0.99	-1.24
	SWFWMD	Homosassa	11/04/08	pool	0.51	0.022	167,867	3.61	7.13	0.023	167,867	3.86	7.62	-0.001	-6.9	-0.25	-0.49
				run	0.63	0.023	167,867	3.86	6.18	0.023	167,867	3.86	6.18	0.000	0.0	0.00	0.00
				both	1.13	0.022	167,867	3.61	3.19	0.023	167,867	3.86	3.41	-0.001	-6.9	-0.25	-0.22
		Rainbow	06/10/09	pool	2.17	0.031	334,221	10.42	4.80	0.031	621,485	18.97	8.73	0.001	2.1	-8.54	-3.93
				run	2.35	0.031	621,485	18.97	8.06	0.031	740,517	22.96	9.76	0.000	-1.6	-3.99	-1.70
				both	4.53	0.031	334,221	10.42	2.30	0.031	740,517	22.96	5.07	0.000	0.6	-12.53	-2.77
		Weeki Wachee	03/10/09	pool	0.66	0.009	226,464	2.04	3.10	0.008	226,464	1.81	2.76	0.001	11.1	0.23	0.35
				run	2.14	0.008	226,464	1.81	0.85	0.007	226,464	1.59	0.74	0.001	12.5	0.23	0.11
				both	2.80	0.009	226,464	2.04	0.73	0.007	226,464	1.59	0.57	0.002	22.2	0.45	0.16

TABLE 13 (CONTINUED)

Summary of upstream-downstream nutrient percent concentration and mass removal by spring, location, and chemical parameter.

Parameter	Water Management District	Spring	Median Date	Location	Segment Area (ha)	Inflow Conc. (mg/L)	Inflow Flow (m^3/d)	Inflow Mass (kg/d)	Inflow Mass (kg/ha/d)	Outflow Conc. (mg/L)	Outflow Flow (m^3/d)	Outflow Mass (kg/d)	Outflow Mass (kg/ha/d)	Removal Conc. (mg/L)	Removal Conc. (%)	Removal Mass (kg/d)	Removal Mass (kg/ha/d)
TP	NWFWMD	Jackson Blue	01/14/09	pool	0.41	0.020	247,181	4.95	12.14	0.019	247,181	4.70	11.51	0.001	5.2	0.26	0.63
				run	10.33	0.019	247,181	4.70	0.45	0.017	247,181	4.31	0.42	0.002	8.2	0.39	0.04
				both	10.74	0.020	247,181	4.95	0.46	0.017	247,181	4.31	0.40	0.003	13.0	0.64	0.06
		Ponce de Leon	09/10/09	pool	0.16	0.015	28,236	0.41	2.60	0.018	28,236	0.50	3.14	-0.003	-20.9	-0.09	-0.54
				run	0.19	0.018	28,236	0.50	2.68	0.016	28,236	0.46	2.45	0.002	8.6	0.04	0.23
				both	0.35	0.015	28,236	0.41	1.20	0.016	28,236	0.46	1.32	-0.002	-10.4	-0.04	-0.12
		Wakulla	04/14/09	pool	1.57	0.034	2,482,892	85.64	54.60	0.032	2,482,892	79.36	50.60	0.003	7.3	6.28	4.01
				run	6.03	0.032	2,482,892	79.36	13.16	0.031	2,482,892	76.91	12.75	0.001	3.1	2.45	0.41
				both	7.60	0.034	2,482,892	85.64	11.27	0.031	2,482,892	76.91	10.12	0.004	10.2	8.74	1.15
	SJRWMD	De Leon	10/08/08	pool	0.28	0.059	74,141	4.35	15.82	0.061	74,141	4.55	16.54	-0.003	-4.6	-0.20	-0.72
				run	3.80	0.061	74,141	4.55	1.20	0.088	74,141	6.53	1.72	-0.027	-43.5	-1.98	-0.52
				both	4.07	0.059	74,141	4.35	1.07	0.088	74,141	6.53	1.60	-0.029	-50.0	-2.18	-0.53
		Silver	05/06/09	pool	4.41	0.047	1,042,292	48.50	11.00	0.038	1,042,292	39.63	8.99	0.009	18.3	8.87	2.01
				run	3.53	0.038	1,042,292	39.63	11.23	0.040	1,042,292	41.18	11.67	-0.001	-3.9	-1.55	-0.44
				both	7.94	0.047	1,042,292	48.50	6.11	0.040	1,042,292	41.18	5.19	0.007	15.1	7.32	0.92
		Silver Glen	02/18/09	pool	0.24	0.026	139,398	3.62	14.84	0.027	139,398	3.76	15.41	-0.001	-3.8	-0.14	-0.57
				run	3.58	0.027	139,398	3.76	1.05	0.029	139,398	3.97	1.11	-0.002	-5.6	-0.21	-0.06
				both	3.83	0.026	139,398	3.62	0.95	0.029	139,398	3.97	1.04	-0.003	-9.6	-0.35	-0.09
	SRWMD	Ichetucknee *	07/08/09	pool	10.34	0.052	199,980	10.47	1.01	0.071	468,202	33.01	3.19	-0.018	-34.6	-22.54	-2.18
				run	5.68	0.071	468,202	33.01	5.81	0.086	558,606	48.05	8.46	-0.016	-22.0	-15.04	-2.65
				both	16.02	0.052	199,980	10.47	0.65	0.086	558,606	48.05	3.00	-0.034	-64.3	-37.58	-2.35
		Madison Blue	12/02/08	pool	0.04	0.039	273,774	10.77	244.10	0.039	273,774	10.59	239.94	0.001	1.7	0.18	4.16
				run	0.06	0.039	273,774	10.59	166.91	0.039	273,774	10.77	169.80	-0.001	-1.7	-0.18	-2.89
				both	0.11	0.039	273,774	10.77	100.14	0.039	273,774	10.77	100.14	0.000	0.0	0.00	0.00
		Manatee	08/04/09	pool	0.26	0.025	228,435	5.62	21.47	0.022	228,435	5.06	19.33	0.002	9.9	0.56	2.13
				run	0.54	0.022	228,435	5.06	9.46	0.026	228,435	5.95	11.12	-0.004	-17.6	-0.89	-1.66
				both	0.80	0.025	228,435	5.62	7.05	0.026	228,435	5.95	7.47	-0.001	-5.9	-0.33	-0.42
	SWFWMD	Homosassa	11/04/08	pool	0.51	0.027	167,867	4.45	8.79	0.027	167,867	4.54	8.96	-0.001	-1.9	-0.08	-0.17
				run	0.63	0.027	167,867	4.54	7.26	0.022	167,867	3.61	5.78	0.006	20.4	0.92	1.48
				both	1.13	0.027	167,867	4.45	3.94	0.022	167,867	3.61	3.19	0.005	18.8	0.84	0.74
		Rainbow	06/10/09	pool	2.17	0.040	334,221	13.21	6.08	0.031	621,485	19.55	9.00	0.008	20.4	-6.33	-2.92
				run	2.35	0.031	621,485	19.55	8.31	0.037	740,517	27.13	11.53	-0.005	-16.5	-7.58	-3.22
				both	4.53	0.040	334,221	13.21	2.92	0.037	740,517	27.13	5.99	0.003	7.3	-13.92	-3.08
		Weeki Wachee	03/10/09	pool	0.66	0.018	226,464	4.19	6.38	0.016	226,464	3.62	5.52	0.002	13.5	0.57	0.86
				run	2.14	0.016	226,464	3.62	1.69	0.016	226,464	3.62	1.69	0.000	0.0	0.00	0.00
				both	2.80	0.018	226,464	4.19	1.50	0.016	226,464	3.62	1.30	0.002	13.5	0.57	0.20

Biological Parameters

Aquatic Vegetation

Microscopic and macroscopic plants provide the principal basis of the aquatic food chain in spring ecosystems. Both micro and macro algae occur in springs, however the microscopic periphytic forms (commonly diatoms) are most characteristic of undisturbed springs. Rooted submersed vascular aquatic macrophytes, such as tape grass and strap-leaved sagittaria, are typically the most abundant plants in undisturbed springs on a weight and cover basis (Odum 1957a). Increasing cover by benthic, attached, and floating macroscopic algae is a recognized symptom of spring disturbance (Stevenson *et al.* 2007).

Aquatic vegetation components were quantified at each spring. Within the surveyed pool and run portions of each spring system the submersed aquatic, the emergent aquatic, and the riparian plant species were quantified and identified to the lowest practical taxonomic level.

Riparian shading (canopy cover of shoreline trees) ranged from 0% to 85%at the study springs. The amount of riparian shading was related to the physical dimensions of the spring pool and run, especially the width, as the relative amount of riparian shading declines in the bigger spring systems. In addition, the amount of riparian shading was influenced by the degree of development which had occurred in the vicinity of the spring with the pool areas typically had a lesser amount of canopy cover due to development for recreational access. Within spring runs, the width of the run influenced canopy cover, as wider run systems had a smaller percentage of shading possible from shoreline trees.

The percent area covered (PAC) by submersed aquatic vegetation (SAV) ranged from 1% to 85% in the study springs, with the pool typically having lower values than the run. The

PAC included both filamentous algae and vascular plants combined. This trend was most prevalent in Homosassa Springs, which was nearly devoid of SAV in the pool due to the captive manatees in this area. However, both Madison Blue and Ponce de Leon Springs had higher PAC values in their pools than in their runs, likely due to rocky substrate combined with high water velocity and heavy riparian shading, respectively. The PAC in the pool of Silver Springs was slightly higher than the run, due to the high degree of benthic filamentous algae found in the pool. In the remaining spring systems, higher PAC values for the run portion were likely due to in-water recreation being dispersed over a greater area, a general reduction in human use, or lack of in-water access (such as at Wakulla Springs).

The percent volume inhabited (PVI) by SAV (including both filamentous algae and vascular plants combined) ranged from 1% to 68%. As was the case with PAC, the pool areas were typically lower. As with PAC, this trend is likely the result of human use or management. The exception was Madison Blue Springs, where greater depth and lower water velocity in the pool, allow a somewhat greater amount of filamentous algae to accumulate (*i.e.*, 2% in the pool versus 1% in the run).

The thickness of benthic filamentous algae ranged from 0.1 cm to 9.1 cm (**Table 15**). Lowest filamentous algae thickness was measured at in Jackson Blue and Wakulla Springs, while higher ranging values were measured at Homosassa, Manatee, and Silver Glen Springs. Filamentous algae thickness should not be related to chemical or physical factors in areas were in-water recreation occurs as this disturbance will obscure any correlations. Manatee and Silver Glen Springs are prime examples of this: where human recreation (primarily wading) occurs, the accumulation of filamentous algae is reduced.

There were ten different genera of four divisions of filamentous algae observed (**Table 16**). Seven of these genera belonged to the Chlorophyta division (green algae), with one of the most commonly observed genera (11 of 12 springs), *Spirogyra*, in this grouping. *Lyngbya*, a member of the blue-green algae (Cyanophyta division) was equally common (11 of 12 springs). The third most common filamentous algae, found in 7 of 12 springs were *Vaucheria*, a yellow-green algae (Xanthophyta division). The remaining filamentous algae division belonged to the red algae (Rhodophyta), and was represented by *Compsopogon* and *Batrachospermum* which were found in Wakulla and Ponce de Leon Springs, respectively.

The plant communities of the study springs were categorized into three functional groups: riparian (canopy forming trees and shrubs), emergent and floating aquatic species (non-woody species), and submersed aquatic vegetation (SAV, macroalgae and vascular species). A comparison of the percentage of these groups by spring is shown in **Figure 42**. Combining both the pool and run study segments, there were generally more riparian species, followed by emergent and then SAV species. Detailed vegetation observations by spring are provided in **Appendix I**.

Among all twelve springs, the total number of riparian plant species was 33 in the pool areas and 40 in the run areas. The number of riparian plant species at individual springs ranged from 5 to 23 (**Table 15** and **Figure 43**). Jackson Blue Springs had five riparian plant species and was predominately composed of bald cypress (*Taxodium distichum*). Weeki Wachee Springs had 23 riparian species, largely a function of the presence of both wetland and upland species. In general, more riparian species were observed in the run segments versus the pool segments. The most commonly occurring riparian species by spring pools were live oak (*Quercus virginiana*) and bald cypress, each occurring in 50% of the springs studied. The most common specie growing by spring runs was bald cypress at 92% of springs, followed by red maple (*Acer rubrum*) at 83% of the springs (**Figure 47**).

Among all twelve springs, the total number of emergent and floating plant species was 21 in the pool areas and 43 in the run areas. The number of emergent and floating aquatic species for individual springs ranged from zero to 15 species (**Table 15** and **Figure 44**). Madison Blue Spring had zero species in this category, which was likely a result of the large range in water levels that this spring is subjected to from riverine flooding. At the upper end of the range was De Leon Springs with 15 emergent and floating aquatic species, all of which where found in the run portion. The most commonly occurring emergent and floating species in spring pools were duckweed (*Lemna sp.*) and water pennywort (*Hydrocotyle sp.*), each occurring in 25% of the springs studied. The most common emergent plant specie growing in spring runs was water pennywort at 67% of the springs (**Figure 44**).

Among all twelve springs, the total number of SAV plant species was 22 in the pool areas and 29 in the run areas. The number of SAV species for individual springs ranged from four to 14 species (**Table 15** and **Figure 45**). Madison Blue Spring had four species of SAV, composed of three genera of filamentous algae and a moss (*Fontinalis sp.*), and is likely the result of regular riverine flooding. Rainbow Springs had 14 species of SAV composed of both vascular plants and filamentous algae; most of which were found in the spring run study segment and likely due to the consistent water clarity and protection from physical damage in this area. The most commonly occurring SAV vascular specie in spring pools was southern naiad (*Najas guadalupensis*) occurring in 50% of the springs studied; while the most common SAV algal species were muskgrass (*Chara sp.*) and *Spirogyra sp.*, each occurring in 42% of the spring pools. The most commonly occurring SAV vascular species growing in spring runs was tape grass (*Vallisneria americana*) at 67% of springs; while the algal species *Spirogyra sp*. occurred at 75% of the springs runs (**Figure 45**).

TABLE 14
Quantitative description of riparian shading, submersed aquatic vegetation (SAV, includes filamentous algae and vascular plants), and benthic filamentous algae thickness by spring and location.

Water Management District	Spring	Location	Riparian Shading (%)	SAV PAC (%) *	SAV PVI (%) *	Filamentous Algae Thickness (cm)
NWFWMD	Jackson Blue	Pool	5	25	13	0.1
		Run	5	78	41	0.1
	Ponce de Leon	Pool	35	25	8	2.3
		Run	85	7	5	1.5
	Wakulla	Pool	2	35	10	0.1
		Run	10	85	68	0.1
SJRWMD	De Leon	Pool	0	5	1	1.9
		Run	7	20	5	2.5
	Silver	Pool	0	80	5	2.0
		Run	10	75	45	2.6
	Silver Glen	Pool	5	40	12	5.6
		Run	5	57	28	2.0
SRWMD	Ichetucknee	Pool	49	66	45	1.8
		Run	65	78	59	0.8
	Madison Blue	Pool	25	31	2	5.4
		Run	50	17	1	1.2
	Manatee	Pool	30	56	5	7.3
		Run	50	83	20	9.1
SWFWMD	Homosassa	Pool	20	1	1	0.3
		Run	15	56	15	7.6
	Rainbow	Pool	5	40	8	0.8
		Run	5	80	47	1.2
	Weeki Wachee	Pool	1	15	2	1.5
		Run	10	43	17	5.8

** SAV- Submersed Aquatic Vegetation, includes filamentous algae and vascular plants*
** PAC- Percent Area Coverage*
** PVI- Percent Volume Inhabited*

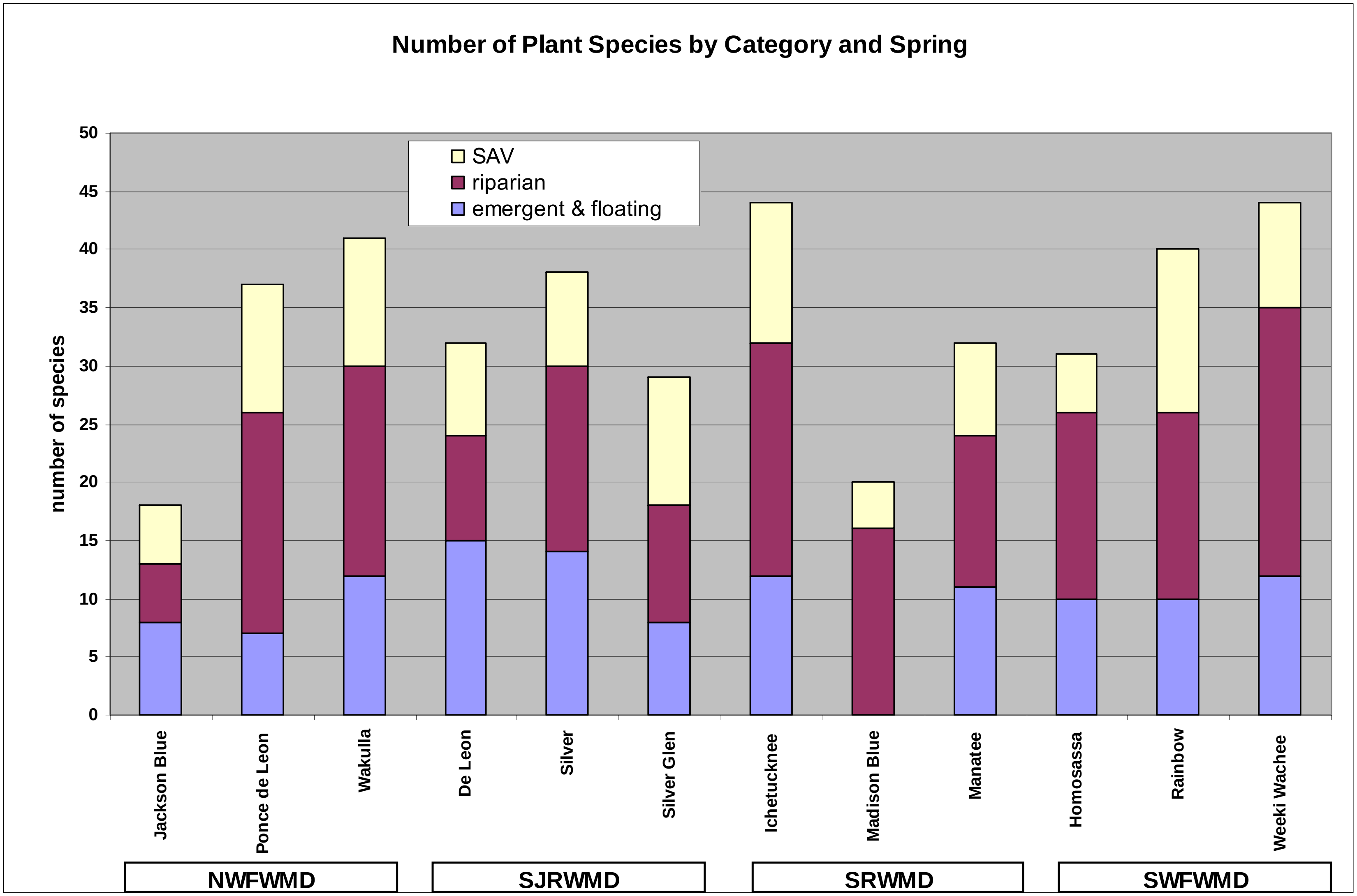


FIGURE 42
Summary of the number of plant species by plant growth type category and spring.

TABLE 15

Vegetation observed by group (emergent [and floating], riparian or submersed aquatic vegetation [SAV]), species, and spring (X denotes occurrence in either pool and/or run).

Group	Species	Common name	NWFWMD			SJRWMD			SRWMD			SWFWMD			12 Spring Percent Occurrence
			Jackson Blue	Ponce de Leon	Wakulla	De Leon	Silver	Silver Glen	Ichetucknee	Madison Blue	Manatee	Homosassa	Rainbow	Weeki Wachee	
emergent	*Acrostichum danaeifolium*	giant leather fern										X			8%
	Alternanthera philoxeroides	alligator weed	X								X	X			25%
	Azolla caroliniana	mosquito fern										X			8%
	Carex sp.	caric sedge	X	X					X		X				33%
	Cicuta maculata	water hemlock			X	X	X		X			X	X	X	58%
	Cladium jamaicense	saw grass	X		X		X					X	X	X	50%
	Colocasia esculenta	wild taro											X	X	17%
	Commelina sp.	day flower										X			8%
	Crinum americanum	swamp lily			X		X				X		X		33%
	Cyperus involucratus	umbrella flat sedge											X	X	17%
	Cyperus sp.	cyperus sedge							X						8%
	Cyperus sp.	flat sedge			X		X								17%
	Dichromena colorata	white-top sedge									X				8%
	Eichhornia crassipes	water hyacinth				X		X				X			25%
	Hydrocotyle sp.	pennywort	X	X		X	X	X	X		X		X	X	75%
	Hygrophila lacustris	lake hygrophila		X											8%
	Hygrophila polysperma	east Indian hygrophila									X				8%
	Hymenocallis sp.	spider lily							X			X			17%
	Kosteletzkya virginica	salt marsh mallow				X									8%
	Lemna sp.	duckweed	X		X	X	X	X	X		X				58%
	Lobelia cardinalis	cardinal flower		X			X		X						25%
	Ludwigia peruviana	water primrose				X									8%
	Ludwigia repens	red ludwigia		X											8%
	Mikania scandens	climbing hemp vine				X							X	X	25%
	Nuphar luteum	spatterdock				X	X	X			X				33%
	Nymphaea odorata	fragrant water lily			X										8%
	Panicum hemitomon	maidencane					X						X		17%
	Panicum repens	torpedo grass						X						X	17%
	Panicum sp.	panic grass									X				8%
	Paspalidium geminatum	Egyptian paspalidium											X		8%
	Peltandra sagittifolia	spoonflower		X											8%
	Phragmites australis	common reed										X			8%
	Pistia stratiotes	water lettuce				X		X	X					X	33%
	Polygonum sp.	smartweed			X	X	X							X	33%
	Pontederia cordata	pickerelweed	X		X	X	X	X							42%
	Sacciolepis striata	American cupscalegrass				X									8%
	Sagittaria lancifolia	arrowhead			X	X	X						X		33%
	Sagittaria latifolia	duck potato			X										8%
	Salvinia minima	water fern				X			X		X				25%
	Saururus cernuus	lizard's tail		X							X				17%
	Scirpus pungens	three-square bulrush												X	8%
	Scirpus sp.	bulrush			X		X		X						25%
	Scirpus sp.	sedge										X			8%
	Thelypteris palustris	marsh fern												X	8%
	Typha sp.	cat-tail	X		X	X	X	X	X					X	58%
	Wolffia sp.	water-meal	X												8%
	Zizania aquatica	wild rice							X						8%
		Species count:	8	7	12	15	14	8	12	0	11	10	10	12	

TABLE 15 (CONTINUED)

Vegetation observed by group (emergent [and floating], riparian or submersed aquatic vegetation [SAV]), species, and spring (X denotes occurrence in either pool and/or run).

Group	Species	Common name	NWFWMD			SJRWMD			SRWMD			SWFWMD			12 Spring
			Jackson Blue	Ponce de Leon	Wakulla	De Leon	Silver	Silver Glen	Ichetucknee	Madison Blue	Manatee	Homosassa	Rainbow	Weeki Wachee	Percent Occurrence
riparian	*Acer rubrum*	red maple		X	X	X	X	X	X		X	X	X	X	83%
	Ampelopsis arborea	pepper vine		X							X				17%
	Aster carolinianus	climbing aster										X	X		17%
	Baccharis halimifolia	saltbush		X	X			X	X			X			42%
	Berchemia scandens	rattan vine												X	8%
	Berchemia scandens	supplejack vine													0%
	Carpinus caroliniana	hornbeam		X					X						17%
	Carya sp.	hickory	X			X				X					25%
	Celtis laevigata	sugarberry								X					8%
	Cephalanthus occidentalis	buttonbush			X		X		X	X	X		X		50%
	Cornus foemina	Florida dogwood			X	X	X				X	X	X	X	58%
	Cyrilla racemiflora	titi		X											8%
	Decumaria barbara	wild hydrangea			X		X		X						25%
	Diospyros virginiana	persimmon			X		X		X		X	X			42%
	Ficus pumila	climbing fig								X					8%
	Fraxinus sp.	ash		X	X	X	X		X		X		X		58%
	Ilex cassine	Dahoon holly		X	X	X	X		X			X	X	X	67%
	Ilex opaca	American holly		X											8%
	Itea virginica	Virginia willow			X				X						17%
	Juniperus silicicola	southern red cedar	X	X				X	X			X			42%
	Liquidambar styraciflua	sweetgum				X	X	X		X				X	42%
	Lonicera japonica	Japanese honeysuckle								X					8%
	Lyonia lucida	fetterbush												X	8%
	Magnolia grandiflora	southern magnolia		X										X	17%
	Mikania scandens	climbing hemp vine		X								X			17%
	Myrica cerifera	wax myrtle		X	X	X	X	X	X		X	X	X	X	83%
	Nephrolepis exaltata	Boston fern										X			8%
	Nyssa sp.	tupelo		X					X		X	X			33%
	Parthenocissus quinquefolia	Virginia creeper					X						X		17%
	Persea palustris	swamp bay	X		X		X	X				X	X	X	58%
	Philodendron bipinnatifidum	split-leaf philodendron												X	8%
	Pinus clausa	sand pine												X	8%
	Pinus elliottii	slash pine												X	8%
	Pinus taeda	loblolly pine		X						X					17%
	Platanus occidentalis	sycamore		X											8%
	Quercus laurifolia	laurel oak						X	X	X			X	X	42%
	Quercus lyrata	overcup oak							X						8%
	Quercus nigra	water oak										X			8%
	Quercus sp.	oak	X		X										17%
	Quercus virginiana	live oak		X				X	X	X	X	X	X	X	67%
	Rhapis excelsa	lady palm												X	8%
	Rhododendron sp.	azalea												X	8%
	Rhus radicans	poison ivy			X		X		X		X			X	42%
	Rosa palustris	swamp rose			X										8%
	Sabal minor	blue-stem palm		X	X				X	X					33%
	Sabal palmetto	cabbage palm			X	X	X	X		X		X	X	X	67%
	Salix sp.	willow			X		X				X		X	X	42%
	Sambucus canadensis	American elderberry					X						X	X	25%
	Serenoa repens	saw palmetto								X				X	17%
	Smilax sp.	green briar								X					8%
	Taxodium distichum	bald cypress	X	X	X	X	X	X	X	X	X		X	X	92%
	Tilia caroliniana	Carolina basswood										X			8%
	Tillandsia bartramii	Bartram's airplant							X		X				17%
	Ulmus sp.	elm								X					8%
	Vitis sp.	grape		X					X	X			X	X	42%
		Species count:	5	19	18	9	16	10	20	16	13	16	16	23	

TABLE 15 (CONTINUED)
Vegetation observed by group (emergent [and floating], riparian or submersed aquatic vegetation [SAV]), species, and spring (X denotes occurrence in either pool and/or run).

Group	Species	Common name	NWFWMD			SJRWMD			SRWMD			SWFWMD			12 Spring
			Jackson Blue	Ponce de Leon	Wakulla	De Leon	Silver	Silver Glen	Ichetucknee	Madison Blue	Manatee	Homosassa	Rainbow	Weeki Wachee	Percent Occurrence
SAV	*Batrachospermum sp.*	filamentous red algae		X											8%
	Brachelyma sp.	water moss		X											
	Cabomba caroliniana	fanwort									X				8%
	Ceratophyllum demersum	coontail	X			X	X	X	X				X		50%
	Chaetomorpha sp.	filamentous green algae										X			8%
	Chara sp.	muskgrass	X	X	X	X	X	X	X					X	67%
	Cladophora sp.	filamentous green algae			X			X	X				X		33%
	Compsopogon sp.	filamentous red algae			X										8%
	Enteromorpha sp.	filamentous green algae						X							8%
	Fontinalis sp.	water moss								X			X		17%
	Hydrilla verticillata	hydrilla			X	X		X			X		X	X	50%
	Hydrocotyle sp.	pennywort							X						8%
	Hydrodictyon sp.	filamentous green algae		X							X			X	25%
	Ludwigia repens	red ludwigia		X					X				X		25%
	Lyngbya sp.	filamentous cyanobacteria		X	X	X	X	X	X	X	X	X	X	X	92%
	Mougeotia sp.	filamentous green algae												X	8%
	Myriophyllum heterophyllum	variable-leaf milfoil											X		8%
	Najas guadalupensis	southern naiad	X	X	X	X	X	X			X	X	X		75%
	Nasturtium officinale	water cress							X						8%
	Nuphar luteum	spatterdock									X				8%
	Porella pinnata	liverwort		X											8%
	Potamogeton illinoensis	Illinois pondweed		X	X								X		25%
	Ruppia maritima	widgeon grass				X		X				X			25%
	Sagittaria kurziana	strap-leaf sagittaria			X		X		X				X	X	42%
	Spirogyra sp.	filamentous green algae	X	X	X	X	X	X	X	X	X		X	X	92%
	Ulothrix sp.	filamentous green algae		X											8%
	Utricularia sp.	bladderwort											X		8%
	Vallisneria americana	tape grass	X		X	X	X	X	X				X	X	67%
	Vaucheria sp.	filamentous yellow-green algae			X		X		X	X	X		X	X	58%
	Zannichellia palustris	horned pondweed						X				X			17%
	Zizania aquatica	wild rice							X						8%
		Species count:	**5**	**11**	**11**	**8**	**8**	**11**	**12**	**4**	**8**	**5**	**14**	**9**	
		All groups species count:	**18**	**37**	**41**	**32**	**38**	**29**	**44**	**20**	**32**	**31**	**40**	**44**	

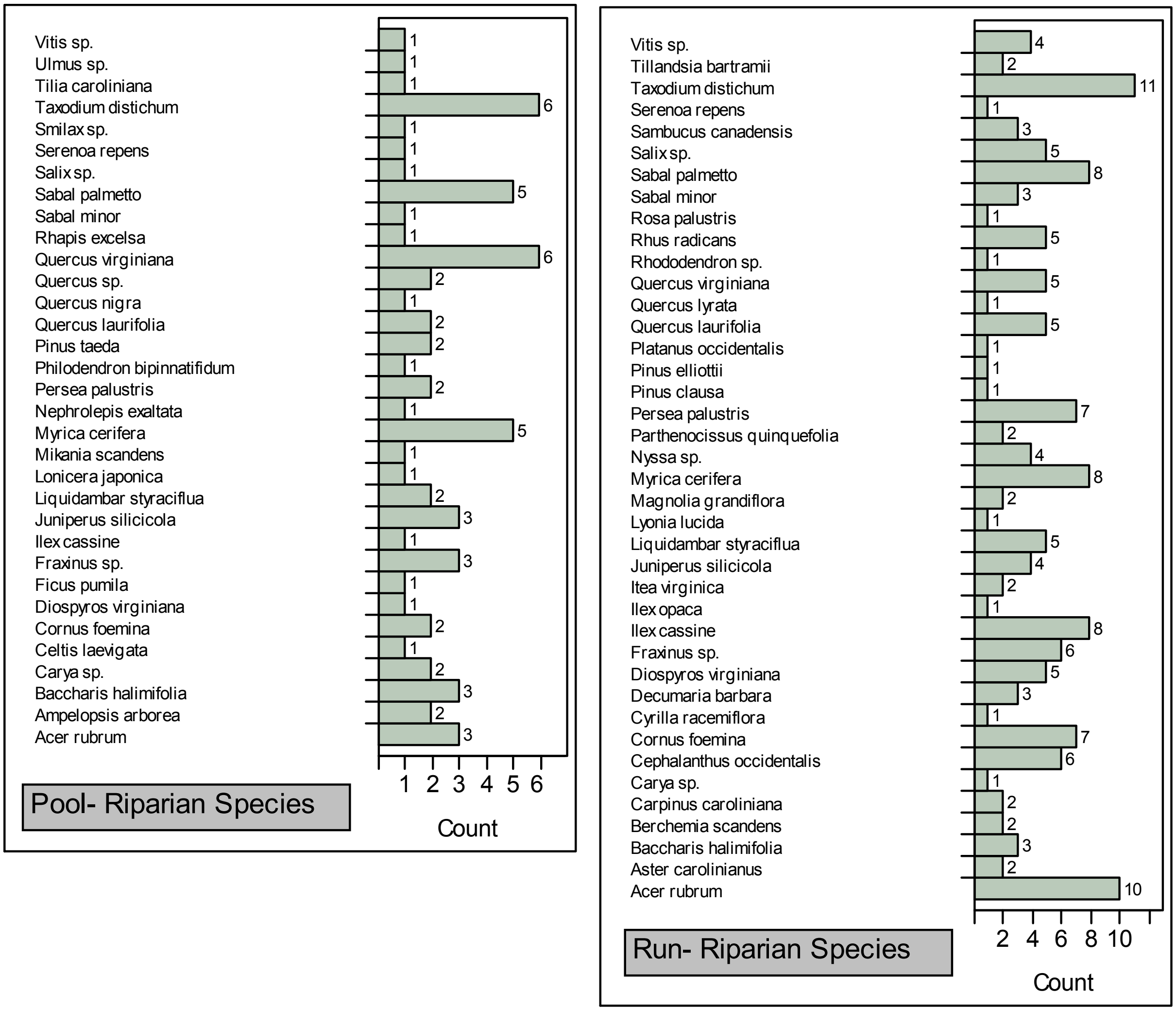
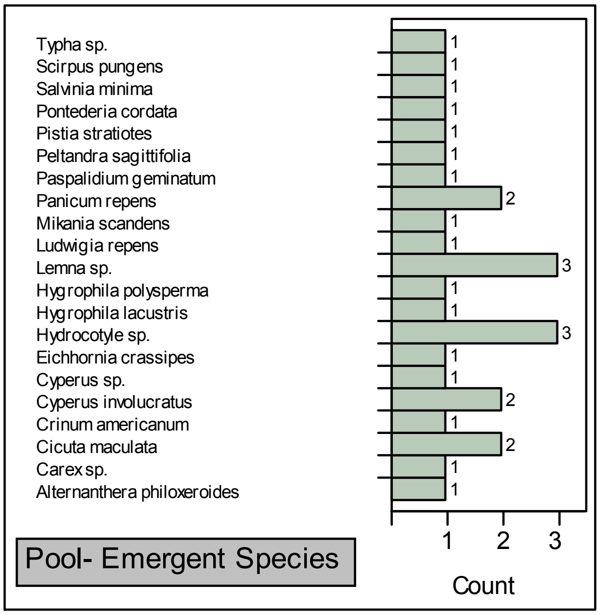


FIGURE 43
The numbers of springs in which the listed riparian plant species were observed for the pool and run areas.



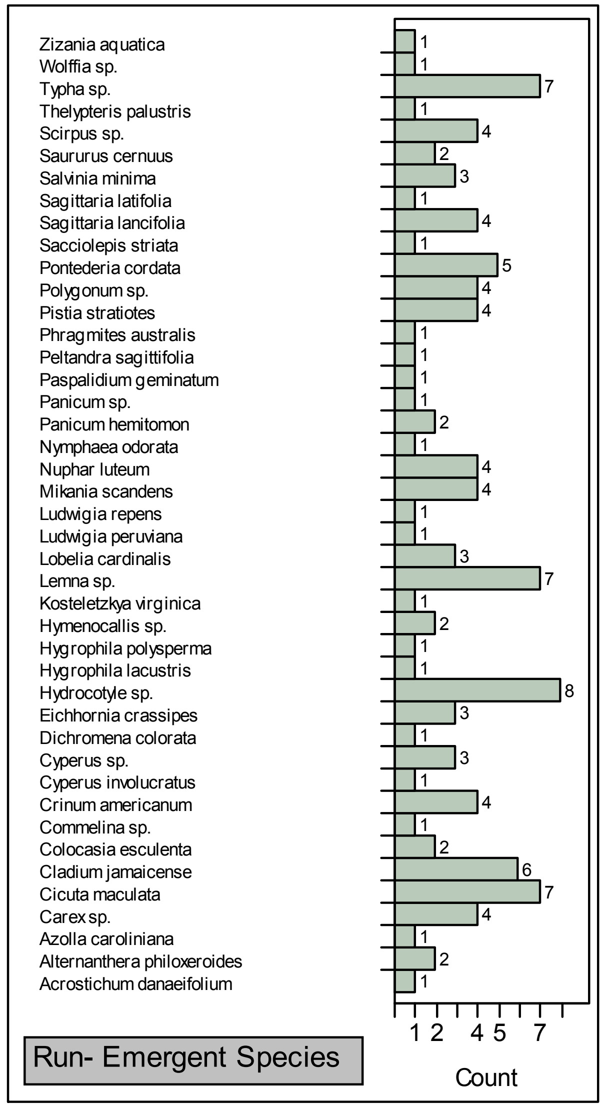


FIGURE 44
The numbers of springs in which the listed emergent and floating aquatic plant species were observed for the pool and run areas.

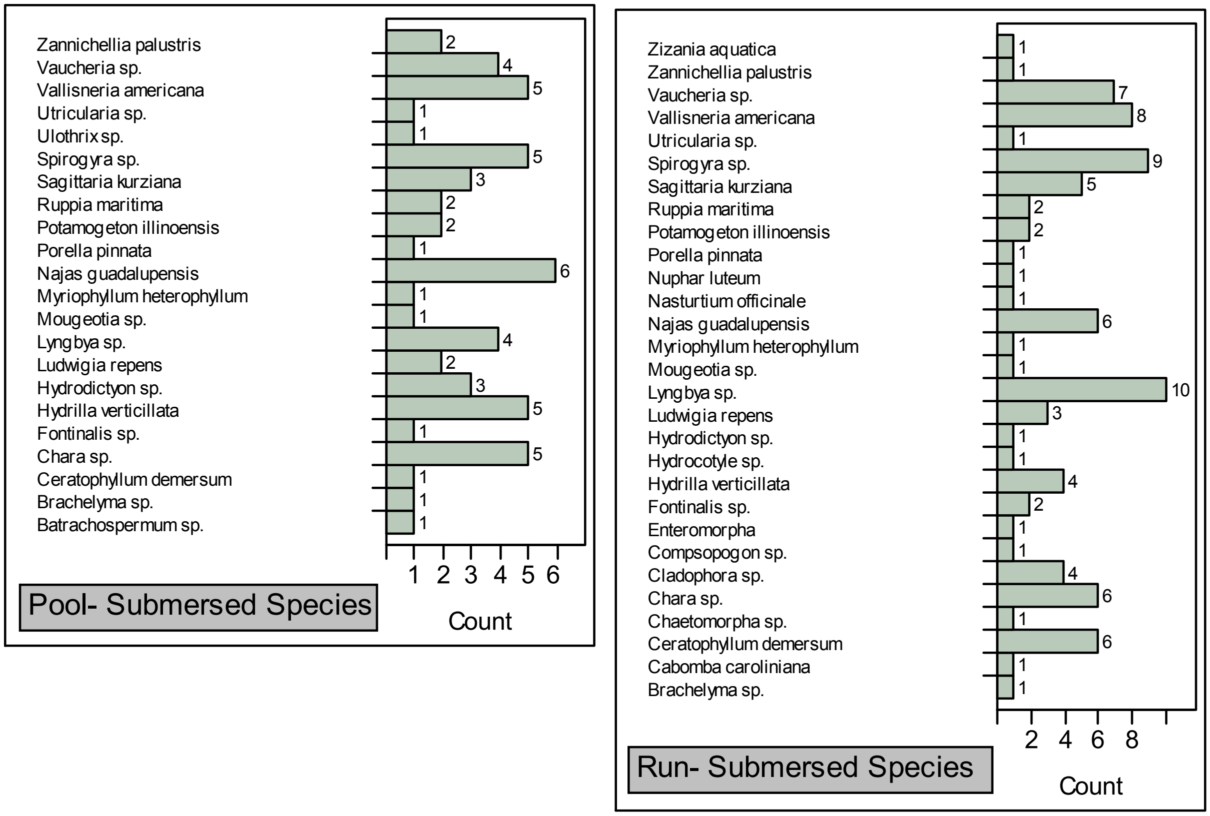


FIGURE 45
The numbers of springs in which the listed submersed aquatic vegetation (SAV) species were observed for the pool and run areas.

Aquatic Emergent Insects

Aquatic insects (especially in the Diptera, Trichoptera, and Ephemeroptera orders), have been found to fill an important role as primary consumers in spring ecosystems (Warren *et al*. 2000). Typical sampling of these organisms includes the use of submerged artificial and natural substrates as well as benthic sampling. However, one characteristic property of many springs is the synchronous emergence of vast numbers of these insects on a daily basis, year-round (Odum 1957a). This emergence facilitates measurement of the rate of production of these insects rather than just their standing stock as measured by traditional sampling methods. The emergence traps used to capture emerging aquatic insects are described in **Appendix A**. **Appendix J** provides detailed insect emergence data by spring.

Adult aquatic insects (imago stage) were trapped as they emerged from the waters' surface to quantify emergence rates and document the species present. Insect emergence rates are presented in **Figures 46** and **47** and **Table 16**. Greatest measured insect emergence rates were measured at Silver and Rainbow Springs. Overall average insect emergence rates were higher in the spring runs (44 organisms/m^2/d) compared to the pools (26 organisms/m^2/d).

A listing of the aquatic insect species collected by order, family, tribe, and lowest practical taxonomy for each spring is shown in **Table 17**. The most commonly collected insects were non-biting midges (Diptera: Chironomidae), with 81% of the sample belonging to this family of insects. The most common midge species, collected in nine of the twelve springs, was *Dicrotendipes modestus*, which belongs to the gatherer/collector functional group. In spring ecosystems, the dominance of Chironomidae has been widely documented (Mattson *et al*. 1995, Lobinske *et al*. 1997, Warren *et al*. 2000, and Steigerwalt 2005).

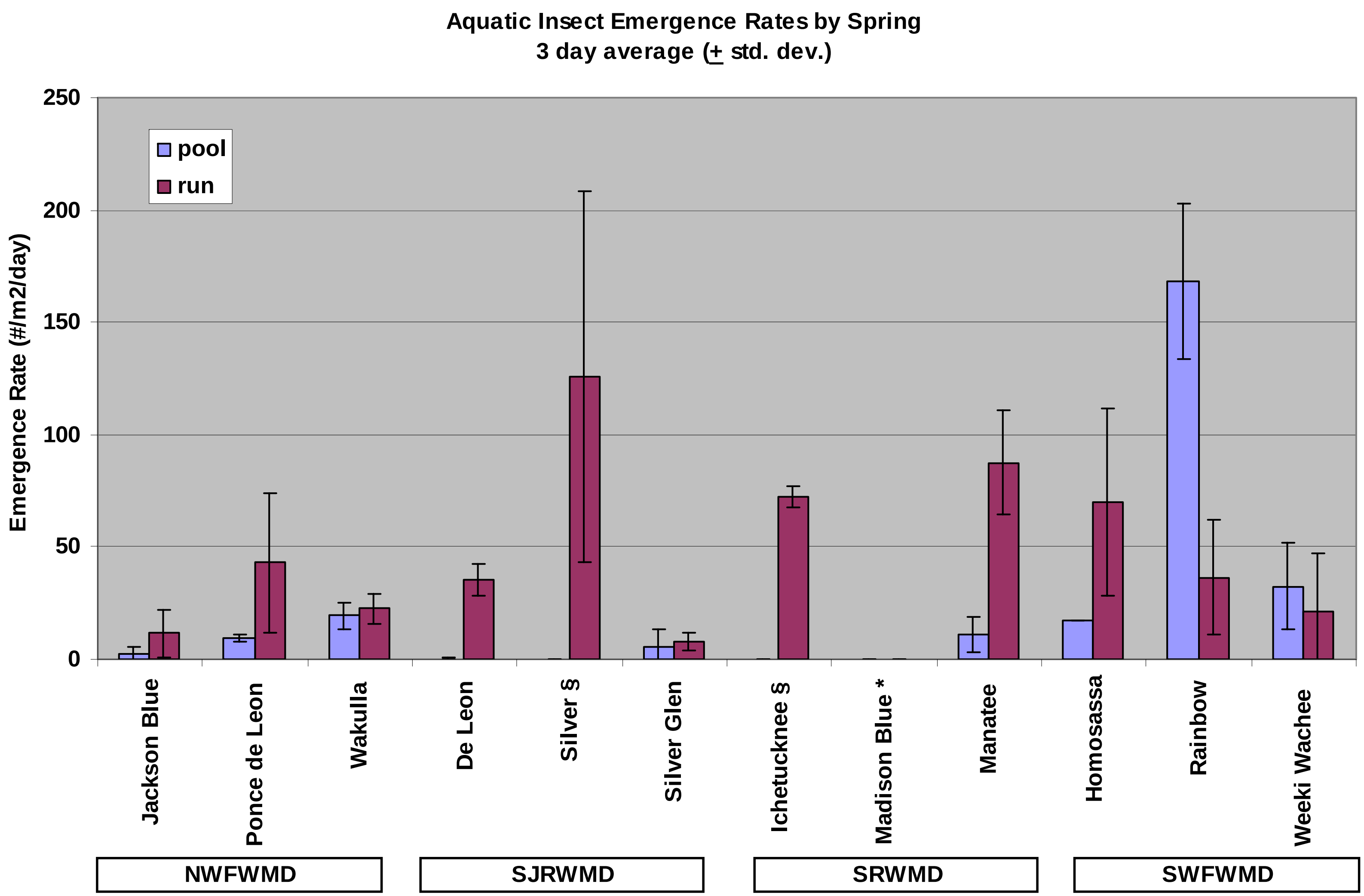


FIGURE 46
Summary of aquatic insect emergence rates ± standard deviation (#/m2/d) by spring and location (* Madison Blue flooded with no captured insects, § Silver and Ichetucknee Springs main pool areas not sampled).

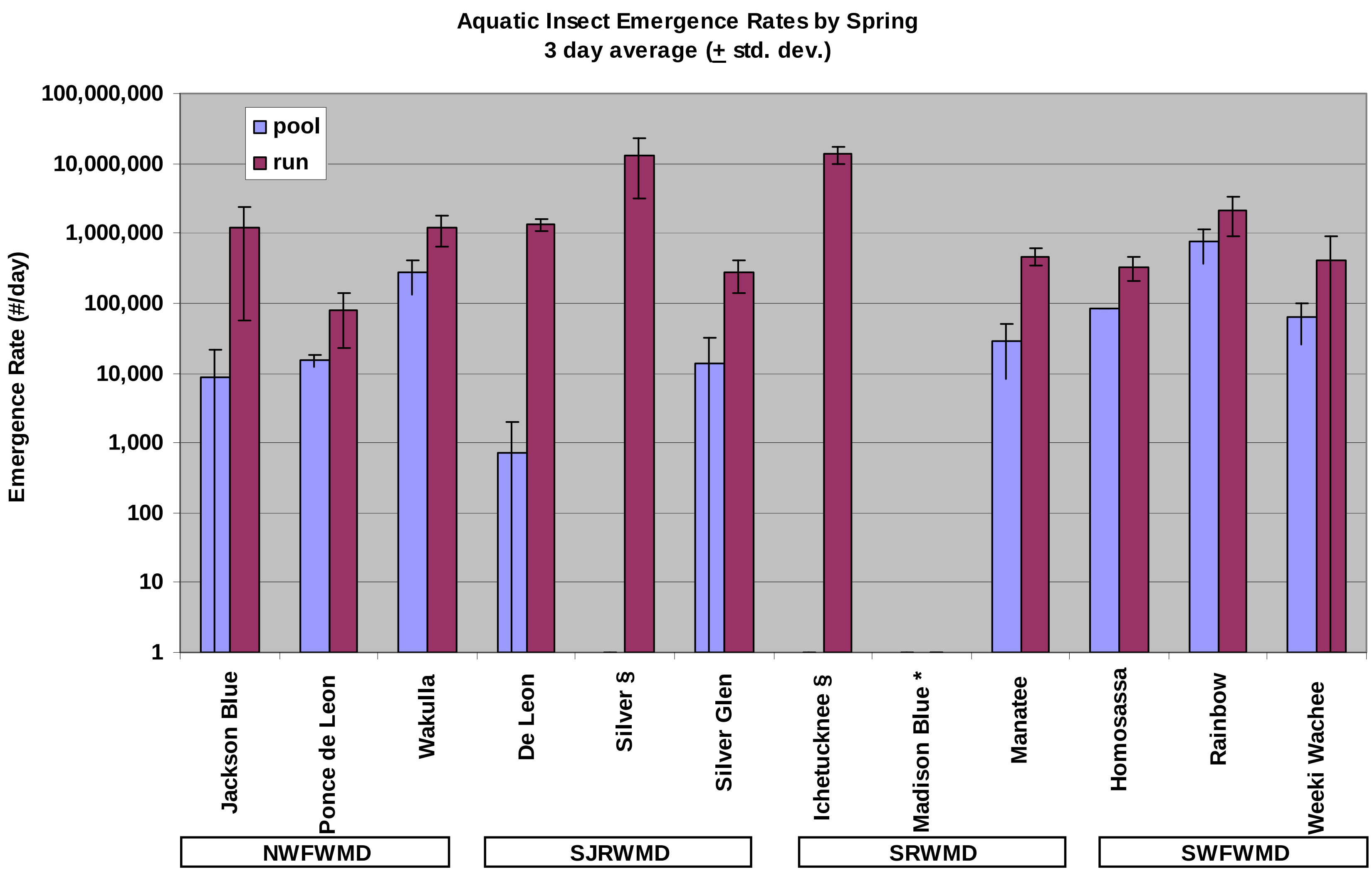


FIGURE 47
Summary of aquatic insect emergence rates ± standard deviation (#/d) by spring and location (* Madison Blue flooded with no captured insects, § Silver and Ichetucknee Springs main pool areas not sampled).

TABLE 16
Summary of average (n=3) adult aquatic insect emergence rates by spring and location.

Water Management District	Spring	Sampling Date	Emergence Rate ($\#/m^2/day$)		Emergence Rate (#/day)	
			pool	run	pool	run
NWFWMD	**Jackson Blue**	Jan-09	2	11	8,706	1,184,725
	Ponce de Leon	Sep-09	9	43	14,887	80,242
	Wakulla	Apr-09	19	23	271,873	1,234,508
SJRWMD	**De Leon**	Oct-08	0.3	35	734	1,346,279
	Silver §	May-09	*N/A*	126	*N/A*	12,917,330
	Silver Glen	Feb-09	6	8	13,675	277,132
SRWMD	**Ichetucknee §**	Jul-09	*N/A*	72	*N/A*	13,631,619
	Madison Blue *	Dec-08	0	0	0	0
	Manatee	Aug-09	11	87	29,089	467,918
SWFWMD	**Homosassa**	Nov-08	17	70	86,149	331,693
	Rainbow	Jun-09	168	37	746,480	2,117,580
	Weeki Wachee	Mar-09	33	21	62,757	410,315

** Madison Blue Spring flooded by Withlacoochee River.*
§ Silver and Ichetucknee Springs main pool areas not sampled.

TABLE 17
Adult (imago) aquatic insects collected by order, family, tribe, and lowest practical taxonomy for each spring (X denotes occurrence in either pool and/or run).

				NWFWMD			SJRWMD			SRWMD			SWFWMD			
Order	**Family**	**Tribe**	**Lowest Practical Taxonomy**	**Jackson Blue**	**Ponce de Leon**	**Wakulla**	**De Leon**	**Silver**	**Silver Glen**	**Ichetucknee**	**Madison Blue**	**Manatee**	**Homosassa**	**Rainbow**	**Weeki Wachee**	**12 Spring Percent Occurrence**
Coleoptera	Coccinellidae	---	Coccinellidae			X										8%
			Count:	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Diptera	---	---	Diptera					X								8%
Diptera	Cecidomyiidae	---	Cecidomyiidae							X						8%
Diptera	Chaoboridae	---	*Chaoborus sp.*				X									8%
Diptera	Chironomidae	---	Chironomidae	X				X	X				X	X	X	50%
Diptera	Chironomidae	---	*Cricotopus bicinctus*							X				X		17%
Diptera	Chironomidae	---	*Cricotopus sp.*	X				X	X	X				X	X	50%
Diptera	Chironomidae	---	Tanypodinae			X		X		X				X		33%
Diptera	Chironomidae	Chironomini	*Apedilum elachistus*	X												8%
Diptera	Chironomidae	Chironomini	*Beardius sp.*							X						8%
Diptera	Chironomidae	Chironomini	*Beardius truncatus*	X		X		X						X	X	42%
Diptera	Chironomidae	Chironomini	Chironomini		X	X		X		X		X	X	X		58%
Diptera	Chironomidae	Chironomini	*Chironomus decorus*												X	8%
Diptera	Chironomidae	Chironomini	*Chironomus sp.*	X				X		X		X	X	X		50%
Diptera	Chironomidae	Chironomini	*Cladopelma collator*	X												8%
Diptera	Chironomidae	Chironomini	*Cryptochironomus fulvus*			X				X					X	25%
Diptera	Chironomidae	Chironomini	*Cryptochironomus sp.*	X		X				X						25%
Diptera	Chironomidae	Chironomini	*Dicrotendipes modestus*		X	X		X	X	X		X	X	X	X	75%
Diptera	Chironomidae	Chironomini	*Dicrotendipes neomodestus*							X			X	X		25%
Diptera	Chironomidae	Chironomini	*Glyptotendipes sp.*				X									8%
Diptera	Chironomidae	Chironomini	*Goeldichironomus amazonicus*				X									8%
Diptera	Chironomidae	Chironomini	*Goeldichironomus holoprasinus*				X									8%
Diptera	Chironomidae	Chironomini	*Microtendipes sp.*		X											
Diptera	Chironomidae	Chironomini	*Parachironomus directus*				X									8%
Diptera	Chironomidae	Chironomini	*Parachironomus potamogeti*	X												8%
Diptera	Chironomidae	Chironomini	*Paracladopelma sp.*		X											
Diptera	Chironomidae	Chironomini	*Paralauterborniella nigrohalterale*												X	8%
Diptera	Chironomidae	Chironomini	*Polypedilum flavum*							X						8%
Diptera	Chironomidae	Chironomini	*Polypedilum halterale*	X					X	X			X			33%
Diptera	Chironomidae	Chironomini	*Polypedilum illinoense*		X	X			X				X		X	42%
Diptera	Chironomidae	Chironomini	*Polypedilum scalaenum*	X	X					X		X	X			42%
Diptera	Chironomidae	Chironomini	*Polypedilum sp.*		X								X			17%
Diptera	Chironomidae	Chironomini	*Stenochironomus sp.*		X	X				X						25%
Diptera	Chironomidae	Chironomini	*Tribelos sp.*							X						8%
Diptera	Chironomidae	Coelotanypodini	*Clinotanypus pinguis*												X	8%
Diptera	Chironomidae	Pentaneurini	*Ablabesmyia mallochi*	X												8%
Diptera	Chironomidae	Pentaneurini	*Ablabesmyia sp.*		X	X		X		X		X		X	X	58%
Diptera	Chironomidae	Pentaneurini	*Labrundinia declorata*			X										8%
Diptera	Chironomidae	Pentaneurini	*Labrundinia pilosella*					X		X				X		25%
Diptera	Chironomidae	Pentaneurini	*Labrundinia sp.*									X				
Diptera	Chironomidae	Pentaneurini	*Pentaneura inconspicua*					X		X		X			X	33%
Diptera	Chironomidae	Pentaneurini	*Thienemannimyia sp.*											X		8%
Diptera	Chironomidae	Pentaneurini	*Zavrelimyia varipennis*												X	8%
Diptera	Chironomidae	Procladiini	*Procladius sp.*							X		X		X		25%
Diptera	Chironomidae	Procladiini	*Procladius sublettei*											X		8%
Diptera	Chironomidae	Pseudochironomini	*Pseudochironomus fulviventris*											X		8%
Diptera	Chironomidae	Pseudochironomini	*Pseudochironomus richardsoni*	X		X			X	X			X	X	X	58%
Diptera	Chironomidae	Pseudochironomini	*Pseudochironomus sp.*		X			X		X				X		33%
Diptera	Chironomidae	---	Tanypodinae									X				
Diptera	Chironomidae	Tanytarsini	Tanytarsini		X	X		X	X	X		X	X	X	X	75%
Diptera	Chironomidae	Tanytarsini	*Zavreliella marmorata*			X						X	X			25%
Diptera	Chloropidae	---	Chloropidae						X							8%
Diptera	Empididae	---	Empididae								X					8%
Diptera	Empididae	Hemerodromiini	*Hemerodromia sp.*					X						X		17%
Diptera	Ephydridae	---	Ephydridae									X				
Diptera	Sciaridae	---	Sciaridae			X									X	17%
			Count:	**12**	**11**	**14**	**5**	**14**	**8**	**23**	**1**	**12**	**12**	**19**	**15**	
Ephemeroptera	---	---	Ephemeroptera							X						8%
Ephemeroptera	Baetidae	---	Baetidae												X	8%
			Count:	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	
Hymenoptera	---	---	Hymenoptera											X		8%
			Count:	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	
Lepidoptera	Pyralidae	---	Pyralidae							X						8%
			Count:	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	
Trichoptera	---	---	Trichoptera												X	8%
Trichoptera	Hydropsychidae	---	Hydropsychidae		X	X		X		X					X	42%
Trichoptera	Hydroptilidae	---	Hydroptilidae	X	X	X				X		X	X		X	58%
Trichoptera	Leptoceridae	---	Leptoceridae			X				X				X		25%
			Count:	**1**	**2**	**3**	**0**	**1**	**0**	**3**	**0**	**1**	**1**	**1**	**3**	
			All orders count:	**13**	**13**	**18**	**5**	**15**	**8**	**28**	**1**	**13**	**13**	**21**	**19**	

Fish

Fish populations in clear spring waters are one of the most visible components of consumers in these ecosystems. These fish fill multiple niches as primary, secondary, and tertiary consumers.

Fish were visually surveyed using snorkel and/or SCUBA gear at each of the spring systems sampled (Wakulla fish observations from boat, see **Appendix A**). A total of 63 fish species were observed among the twelve springs (including one unknown shiner species), with individual springs ranging from eight species at Jackson Blue and Madison Blue to 28 species at Ichetucknee and Silver Springs (**Figure 48** and **Table 18**). Largemouth bass and mosquito fish were observed at 100% of the springs sampled, while 27 species were only observed at one spring or 8% of the springs **(Figure 49**).

At least one marine fish species was observed in all but two of the study springs (**Table 18**). Those lacking marine species were Jackson Blue Spring which has a substantial dam with a spillway preventing upstream access beyond Spring Creek; while Ponce de Leon Springs is about 89 km (55 mi) upstream of marine waters. Homosassa Springs had the most marine fish species at 16 of 22 total species. The high number (and density) of marine fish at Homosassa Springs is likely a combination of factors: the proximity to the Gulf of Mexico, the protection from fishing within the upper run and pool, and the warm-water thermal refuge it provides. Among the twelve study springs the most common marine fish were striped mullet (*Mugil cephalus*) observed at 75% of the springs, followed by Atlantic needlefish (*Strongylura marina*) observed at 42% of the springs, and ladyfish (*Elops saurus*) and Crevalle jack (*Caranx hippos*) each observed at 25% of the springs.

Among the twelve study springs there were two non-indigenous fish species observed (**Table 18**). Blue tilapia (*Oreochromis aurea*) and vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*) were present in both Silver and Silver Glen Springs. Both of these species have become common within the St. Johns River drainage and it should be expected that the associated springs of this drainage will continue to become inhabited by these species.

Fish density and biomass data are presented in **Figure 50** and **Table 19**. Lowest average fish counts were made in Madison Blue Springs which averaged less than 600 fish (**Table 19**). However, when fish density is calculated based on the surveyed area of the spring (*i.e.*, #/ha), Madison Blue Spring has the second highest densities preceded only by Ponce de Leon Springs (the second smallest spring surveyed). This is a consequence of the size of the spring affecting the density estimates. In these smaller springs, densities are also higher because fish are more visible (less able to flee) and there was a minimal amount of aquatic vegetation for fish to hide in. **Appendix K** provides detailed fish data by spring.

Among the study springs fish biomass ranged from a low value of about 31 kg in the pool of Madison Blue Springs to about 4,800 kg at Homosassa Springs. The estimated biomass for Homosassa Springs, based on multiple fish surveys which averaged nearly 6,800 fish, was due to the thousands of gray snapper and multiple hundreds of large snook observed in the pool. At Homosassa Springs, it should be noted that fish smaller than 10 cm (4 in) were almost entirely absent from the upper run and pool and that the piscivorous fish observed there must be feeding within the greater Homosassa River (and beyond) as their biomass cannot be supported by the spring ecosystem alone. **Appendix K** provides detailed fish data by spring.

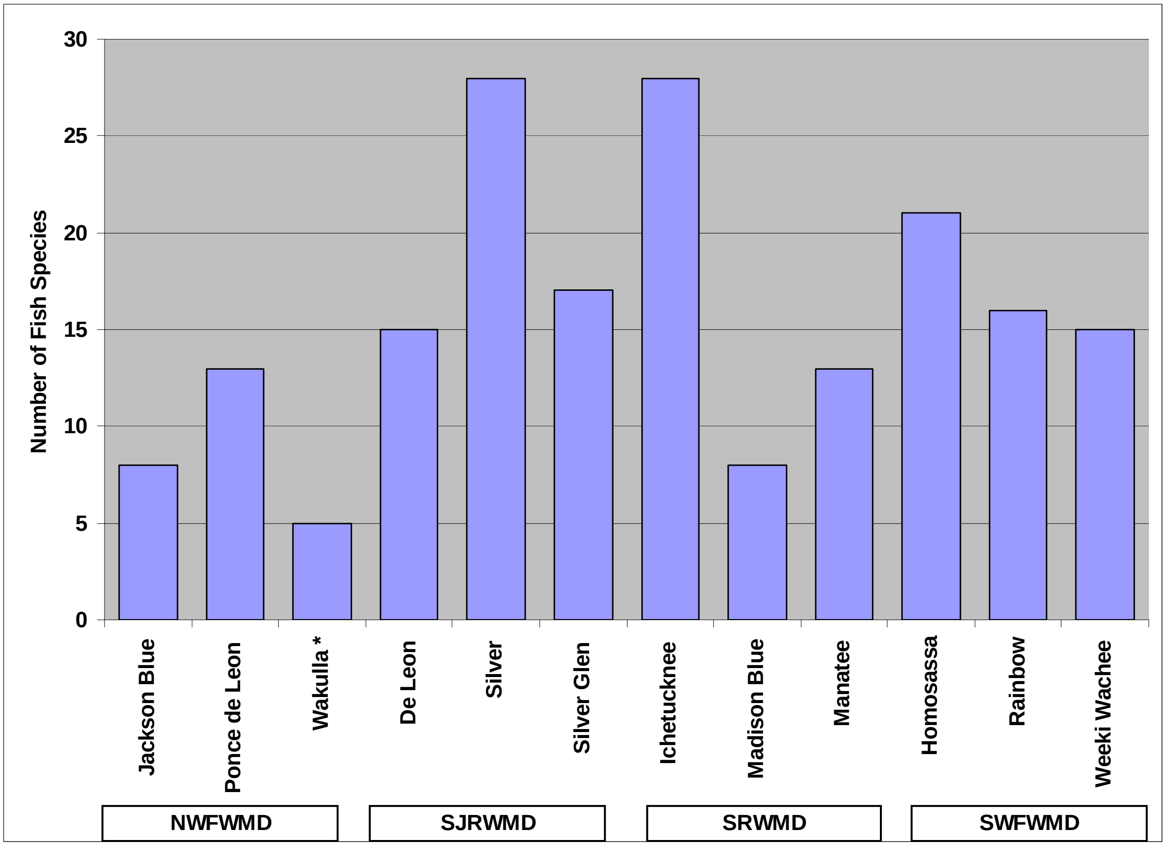


FIGURE 48
Number of fish species observed by spring (includes pool and run, * snorkeling prohibited at Wakulla).

TABLE 18
Fish species observed by spring (X denotes occurrence).

		NWFWMD			SJRWMD			SRWMD			SWFWMD			
Species	**Common Name**	**Jackson Blue**	**Ponce de Leon**	**Wakulla**	**De Leon**	**Silver**	**Silver Glen**	**Ichetucknee**	**Madison Blue**	**Manatee**	**Homosassa**	**Rainbow**	**Weeki Wachee**	**12 Spring Percent Occurrence**
Agonostomus monticola	mountain mullet							X						8%
Ameiurus nebulosus	brown bullhead					X								8%
Amia calva	bowfin					X					X	X		25%
Archosargus probatocephalus	sheepshead										X		X	17%
Bagre marinus	Gafftop sail sea catfish										X			8%
Caranx hippos	Crevalle jack						X				X		X	25%
Centropomus undecimalis	snook										X			8%
Ctenopharyngodon idella	grass carp	X												8%
Dasyatis sabina	Atlantic stingray						X							8%
Dorosoma cepedianum	gizzard shad											X		8%
Echeneis naucrates	sharksucker										X			8%
Elassoma okefenokee	Okefenokee pygmy sunfish					X								8%
Elops saurus	ladyfish				X		X				X			25%
Erimyzon sucetta	lake chubsucker				X	X		X				X		33%
Esox americanus	redfin pickerel		X											8%
Esox niger	chain pickerel		X			X								17%
Etheostoma colorosum	coastal darter		X											8%
Etheostoma edwini	brown darter							X						8%
Etheostoma fusiforme	swamp darter		X			X								17%
Eucinostomus harengulus	tidewater mojarra										X		X	17%
Eugerres plumieri	striped mojarra										X			8%
Fundulus escambiae	eastern starhead minnow							X						8%
Fundulus seminolis	Seminole killifish				X		X	X				X	X	42%
Gambusia holbrooki	eastern mosquitofish	X	X	X	X	X	X	X	X	X	X	X	X	100%
Heterandria formosa	least killifish					X		X						17%
Ictalurus punctatus	channel catfish					X								8%
Labidesthes sicculus	brook silverside		X			X			X			X		33%
Lepisosteus osseus	longnose gar			X		X		X	X			X		42%
Lepisosteus platyrhincus	Florida gar					X	X				X			25%
Lepomis auritus	redbreast sunfish		X		X	X		X	X	X	X	X		67%
Lepomis gulosus	warmouth	X			X									17%
Lepomis macrochirus	bluegill	X	X		X	X	X	X		X	X	X	X	83%
Lepomis marginatus	dollar sunfish				X	X		X						25%
Lepomis microlophus	redear sunfish	X	X		X	X	X	X		X		X	X	75%
Lepomis punctatus	spotted sunfish	X	X	X	X	X	X	X		X		X	X	83%
Lucania goodei	bluefin killifish					X		X		X		X		33%
Lucania parva	rainwater killifish					X	X				X		X	33%
Lutjanus griseus	gray snapper										X		X	17%
Menidia beryllina	inland silverside										X			8%
Microgobius gulosus	clown goby										X			8%
Micropterus notius	Suwannee bass							X						8%
Micropterus salmoides	largemouth bass	X	X	X	X	X	X	X	X	X	X	X	X	100%
Minytrema melanops	spotted sucker							X	X	X				25%
Morone saxatilis	striped bass						X							8%
Mugil cephalus	striped mullet			X	X	X	X	X	X	X	X		X	75%
Notemigonus chrysoleucas	golden shiner				X	X		X		X		X		42%
Notropis chalybaeus	ironcolor shiner								X					8%
Notropis cummingsae	dusky shiner	X					X							17%
Notropis harperi	redeye chub		X			X		X		X		X		42%
Notropis petersoni	coastal shiner					X		X		X				25%
Notropis sp.	shiner sp.												X	8%
Notropis texanus	weed shiner		X											8%
Oreochromis aurea *	blue tilapia *					X	X							17%
Percina nigrofasciata	blackbanded darter					X		X						17%
Poecilia latipinna	sailfin molly					X		X					X	25%
Pogonias cromis	black drum										X			8%
Pomoxis nigromaculatus	black crappie							X						8%
Pteronotropis metallicus	sailfin shiner							X						8%
Pterygoplichthys disjunctivus *	vermiculated sailfin catfish *					X	X							17%
Sciaenops ocellatus	red drum										X			8%
Strongylura marina	Atlantic needlefish				X			X			X	X	X	42%
Syngnathus scovelli	Gulf pipefish						X	X						17%
Trinectes maculatus	hogchoker				X			X		X				25%
	Species count:	**8**	**13**	**5**	**15**	**28**	**17**	**28**	**8**	**13**	**22**	**16**	**15**	
	*** non-indigenous species count**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	

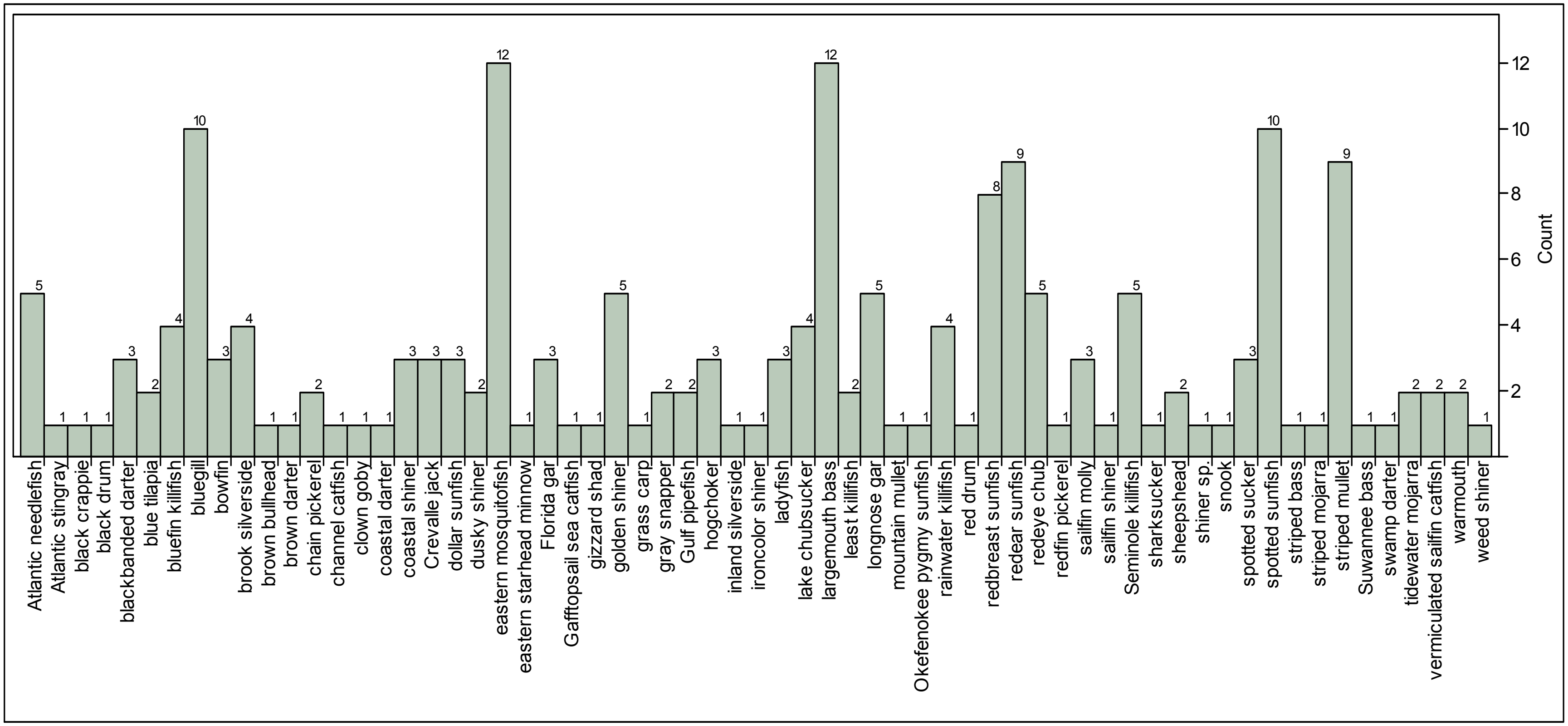


FIGURE 49
The numbers of springs in which the listed fish species were observed.

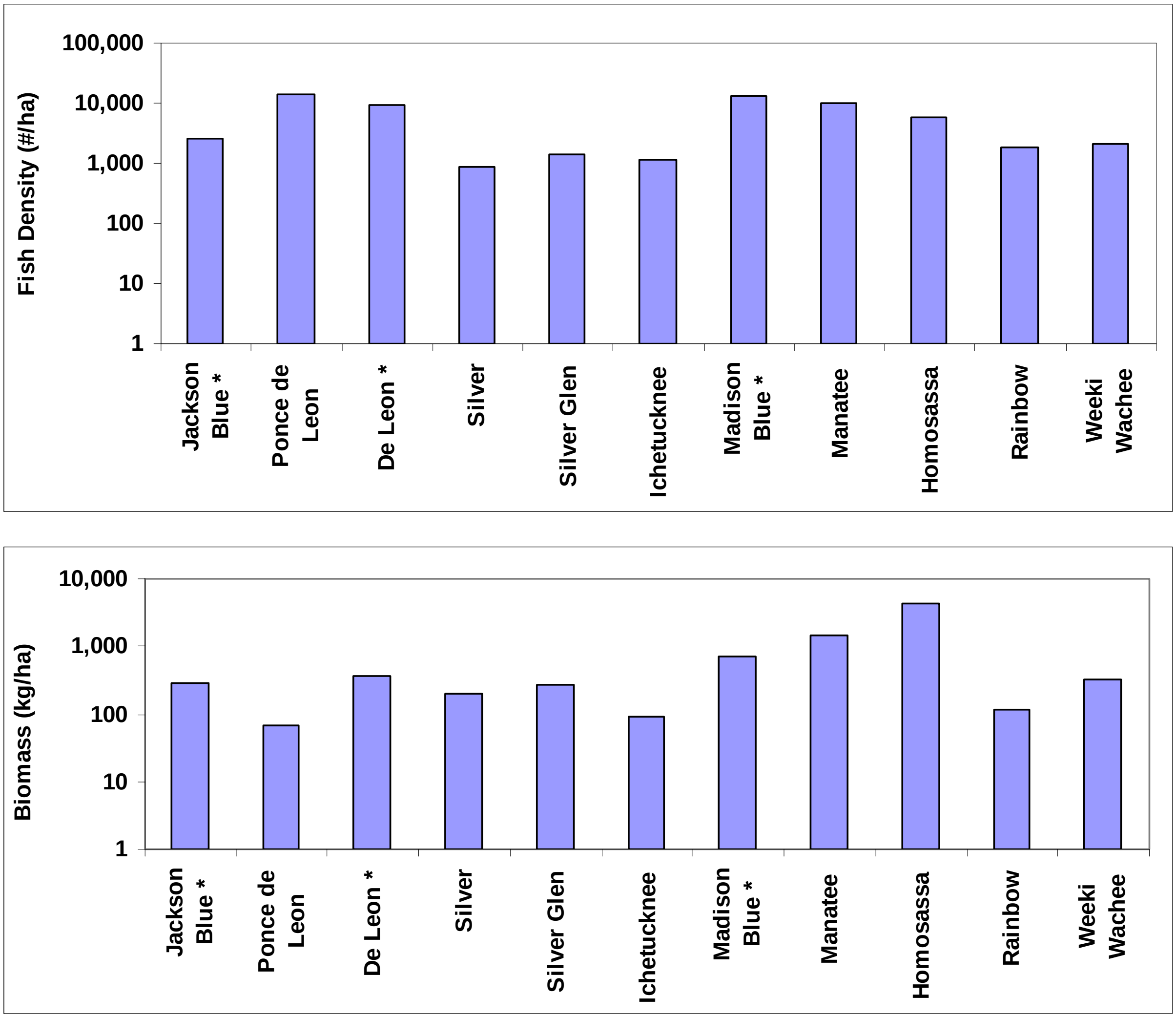


FIGURE 50
Average density (#/ha, top) and fresh-weight biomass (kg/ha, bottom) by spring (* only pool sampled).

TABLE 19
Summary of fish density (#/ha, top) and biomass (kg/ha, bottom) by spring.

Water Management District	Spring Name	Sampled Area (ha)	Total Fish	Density (#/ha)
NWFWMD	Jackson Blue *	0.41	1,087	2,663
	Ponce de Leon	0.16	2,165	13,571
SJRWMD	De Leon *	0.28	2,635	9,575
	Silver	7.94	6,905	870
	Silver Glen	3.83	5,518	1,441
SRWMD	Ichetucknee	10.85	12,343	1,137
	Madison Blue *	0.04	597	13,521
	Manatee	0.66	6,492	9,891
SWFWMD	Homosassa	1.13	6,788	5,997
	Rainbow	5.03	9,502	1,889
	Weeki Wachee	2.14	4,399	2,055

Water Management District	Spring Name	Sampled Area (ha)	Total Biomass (kg)	Biomass (kg/ha)
NWFWMD	Jackson Blue *	0.41	117.3	287.4
	Ponce de Leon	0.16	10.6	66.6
SJRWMD	De Leon *	0.28	98.2	356.7
	Silver	7.94	1,554.2	195.8
	Silver Glen	3.83	1,004.6	262.4
SRWMD	Ichetucknee	10.85	975.7	89.9
	Madison Blue *	0.04	31.3	710.5
	Manatee	0.66	965.4	1,470.9
SWFWMD	Homosassa	1.13	4,820.3	4,259.0
	Rainbow	5.03	571.2	113.6
	Weeki Wachee	2.14	684.0	319.6

* Only pool sampled.

Macrofauna

The presence of reptiles, birds, and mammals is a part of the normal ecology of Florida springs. These higher level consumers are important both for the roles they are known to play in controlling energetics and maximizing productivity of spring ecosystems (Knight 1980) and for their contribution to the aesthetics of springs and their attractive appearance.

During sampling of each spring system the observed birds, mammals, reptiles, amphibians, and crustaceans were qualitatively identified (**Figure 51** and **Table 20**). **Appendix L** provides detailed macrofauna observations by spring.

Among the twelve study springs there was a total of 66 bird species observed (**Table 20**). Wakulla Springs alone had 42 species of birds observed including the run, pool, and upland areas. Springs with the lowest number of bird species observed were Madison Blue and Ponce de Leon Springs, with two and three species, respectively. The most commonly occurring bird species were Red-shouldered Hawk (*Buteo lineatus*) observed at 92% of the springs; followed by Great Blue Heron (*Ardea herodias*) observed at 75% of the springs, and American Black Vulture (*Coragyps atratus*) and American White Ibis (*Eudocimus albus*) each of which were observed at 67% of the springs.

Among the twelve study springs there was a total of nine mammal species observed (**Table 20**). Ichetucknee and Silver Glen each had four mammal species observed, while Ponce de Leon and Rainbow Springs had no mammal species observed. The most common mammals among all springs were eastern gray squirrels (*Sciurus carolinensis*) observed at 75% of springs, followed by raccoon (*Procyon lotor*) observed at 33% of springs, and nine-banded armadillo (*Dasypus novemcinctus*) which were observed in the uplands of 25% of the springs. Florida manatees (*Trichechus manatus latirostrus*) were observed at Wakulla and Homosassa Springs only.

Among the twelve study springs there was a total of 19 reptile and three amphibian species observed (**Table 20**). Springs with the most observed reptile species were Manatee with nine species, Ichetucknee with eight species, and Wakulla with six species. Amphibians were relatively uncommon at the study springs, with members of the *Rana* and

Hyla genera only noted at two springs. The reduced occurrence of amphibians is likely due to daytime sampling and the presence of fish which would prey upon amphibian larvae (Sudol *et al*. 2009). The most common reptiles among all study springs were Florida cooter (*Pseudemys floridana floridana*) observed at 75% of springs, followed by loggerhead musk turtle (*Sternotherus minor minor*) observed at 67% of springs. American alligator (*Alligator mississippiensis*) were observed at 33% of the study springs, and most abundantly at Silver Springs.

Among the study springs, two crustacean species, both believed to be members of the *Procambarus* genus were observed (**Table 20**). Ichetucknee, Jackson Blue, and Ponce de Leon each had members of this crayfish genus regularly observed during daylight hours.

Among the twelve study springs there were a variety of non-indigenous macrofauna species observed (**Table 20**). Among birds, the Muscovy duck (*Cairina moschata*) was observed at Weeki Wachee Springs. Among mammals, the house cat (*Felis catus*) was observed near the pool at De Leon Springs, along with wild boar (*Sus scrofa*) feeding along the run of Ichetucknee Springs, and family groups of rhesus macaque (*Macaca mulatta*) along the upper run of Silver Springs. Among reptiles, only the brown anole (*Anolis sagrei*) was observed among riparian vegetation at Manatee and Weeki Wachee Springs.

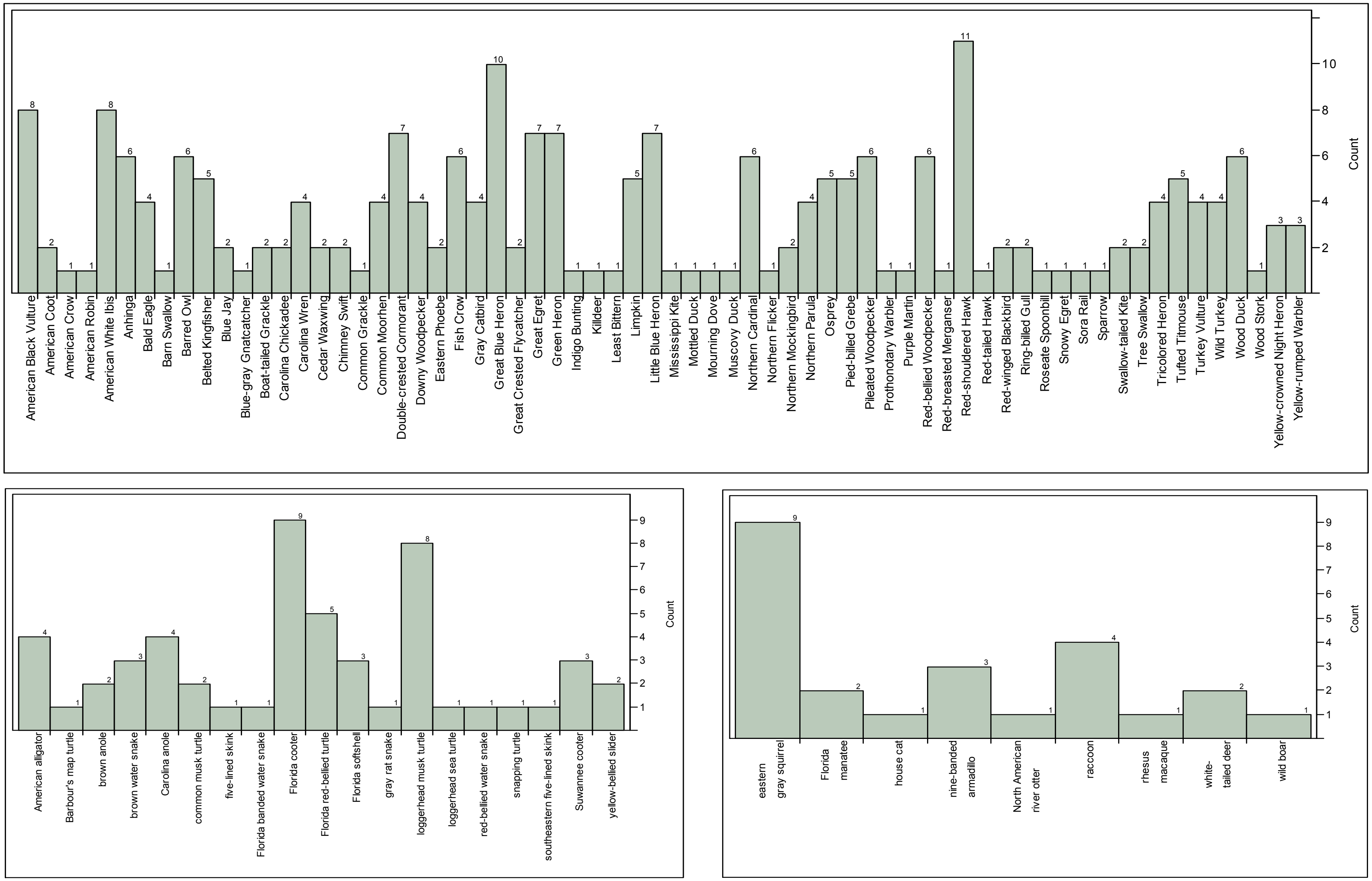


FIGURE 51
The number of springs in which the listed bird, reptile, and mammal species were observed.

TABLE 20
Macrofauna observed by group, species, and spring (X denotes occurrence in either pool, run, or surrounding uplands).

Group	Species	Common Name	NWFWMD			SJRWMD			SRWMD			SWFWMD			12 Spring
			Jackson Blue	Ponce de Leon	Wakulla	De Leon	Silver	Silver Glen	Ichetucknee	Madison Blue	Manatee	Homosassa	Rainbow	Weeki Wachee	Percent Occurrence
Bird	*Agelaius phoeniceus*	Red-winged Blackbird			X								X		17%
	Aix sponsa	Wood Duck			X		X		X			X	X	X	50%
	Anas fulvigula	Mottled Duck												X	8%
	Anhinga anhinga	Anhinga			X	X	X	X				X	X		50%
	Aramus guarauna	Limpkin				X	X		X		X			X	42%
	Ardea alba	Great Egret	X		X	X			X			X	X	X	58%
	Ardea herodias	Great Blue Heron	X		X	X	X	X	X			X	X	X	75%
	Baeolophus bicolor	Tufted Titmouse	X	X	X		X							X	42%
	Bombycilla cedrorum	Cedar Waxwing	X		X										17%
	Buteo jamaicensis	Red-tailed Hawk	X												8%
	Buteo lineatus	Red-shouldered Hawk	X	X	X	X	X	X	X	X	X		X	X	92%
	Butorides virescens	Green Heron	X		X	X	X		X		X			X	58%
	Cairina moschata *	Muscovy Duck *												X	8%
	Cardinalis cardinalis	Northern Cardinal			X	X	X	X					X	X	50%
	Cathartes aura	Turkey Vulture	X				X	X			X				33%
	Chaetura pelagica	Chimney Swift			X		X								17%
	Charadrius vociferus	Killdeer												X	8%
	Colaptes auratus	Northern Flicker	X												8%
	Coragyps atratus	American Black Vulture	X		X	X		X			X	X	X	X	67%
	Corvus brachyrhynchos	American Crow								X					8%
	Corvus ossifragus	Fish Crow	X		X	X	X	X					X		50%
	Cyanocitta cristata	Blue Jay	X	X											17%
	Dendroica coronata	Yellow-rumped Warbler	X					X						X	25%
	Dryocopus pileatus	Pileated Woodpecker	X		X	X	X	X			X				50%
	Dumetella carolinensis	Gray Catbird			X			X				X		X	33%
	Egretta caerulea	Little Blue Heron			X	X	X		X			X	X	X	58%
	Egretta thula	Snowy Egret							X						8%
	Egretta tricolor	Tricolored Heron			X	X							X	X	33%
	Elanoides forficatus	Swallow-tailed Kite					X						X		17%
	Emberizidae	Sparrow												X	8%
	Eudocimus albus	American White Ibis			X		X	X	X		X	X	X	X	67%
	Fulica americana	American Coot	X		X										17%
	Gallinula chloropus	Common Moorhen			X	X	X						X		33%
	Haliaeetus leucocephalus	Bald Eagle			X	X		X						X	33%
	Hirundo rustica	Barn Swallow			X										8%
	Ictinia mississippiensis	Mississippi Kite							X						8%
	Ixobrychus exilis	Least Bittern			X										8%
	Larus delawarensis	Ring-billed Gull	X					X							17%
	Megaceryle alcyon	Belted Kingfisher	X		X	X		X						X	42%
	Melanerpes carolinus	Red-bellied Woodpecker	X		X			X	X				X	X	50%
	Meleagris gallopavo	Wild Turkey			X			X	X		X				33%
	Mergus serrator	Red-breasted Merganser												X	8%
	Mimus polyglottos	Northern Mockingbird			X									X	17%
	Mycteria americana	Wood Stork							X						8%
	Myiarchus crinitus	Great Crested Flycatcher			X		X								17%
	Nyctanassa violacea	Yellow-crowned Night Heron			X	X	X								25%
	Pandion haliaetus	Osprey			X	X		X	X			X			42%
	Parula americana	Northern Parula			X		X						X	X	33%
	Passerina cyanea	Indigo Bunting			X										8%
	Phalacrocorax auritus	Double-crested Cormorant	X		X	X	X	X				X	X		58%
	Picoides pubescens	Downy Woodpecker					X	X					X	X	33%
	Platalea ajaja	Roseate Spoonbill							X						8%
	Podilymbus podiceps	Pied-billed Grebe	X		X	X		X					X		42%
	Poecile carolinensis	Carolina Chickadee	X		X										17%
	Polioptila caerulea	Blue-gray Gnatcatcher	X												8%
	Porzana carolina	Sora Rail			X										8%
	Progne subis	Purple Martin											X		8%
	Protonotaria citrea	Prothonotary Warbler			X										8%
	Quiscalus major	Boat-tailed Grackle			X	X									17%
	Quiscalus quiscula	Common Grackle			X										8%
	Sayornis phoebe	Eastern Phoebe	X					X							17%
	Strix varia	Barred Owl	X		X		X		X		X			X	50%
	Tachycineta bicolor	Tree Swallow			X			X							17%
	Thryothorus ludovicianus	Carolina Wren	X				X				X		X		33%
	Turdus migratorius	American Robin	X												8%
	Zenaida macroura	Mourning Dove			X										8%
		Species count:	**26**	**3**	**42**	**20**	**23**	**22**	**16**	**2**	**10**	**10**	**21**	**26**	
Amphibian	*Hyla cinerea*	green tree frog											X		8%
	Rana catesbeiana	bull frog											X		8%
	Rana grylio	pig frog					X								8%
		Species count:	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	
Crustacean	*Procambarus sp.*	crayfish		X											8%
	Procambarus spiculifer	crayfish	X						X						17%
		Species count:	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	
Mammal	*Dasypus novemcinctus*	nine-banded armadillo						X	X		X				25%
	Felis catus *	house cat *				X									8%
	Lontra canadensis	North American river otter	X												8%
	Macaca mulatta *	rhesus macaque *					X								8%
	Odocoileus virginianus	white-tailed deer						X			X				17%
	Procyon lotor	raccoon	X				X	X	X						33%
	Sciurus carolinensis	eastern gray squirrel			X	X	X	X	X	X	X	X		X	75%
	Sus scrofa *	wild boar *							X						8%
	Trichechus manatus latirostrus	Florida manatee			X							X			17%
		Species count:	**2**	**0**	**2**	**2**	**3**	**4**	**4**	**1**	**3**	**2**	**0**	**1**	
Reptile	*Alligator mississippiensis*	American alligator			X		X	X					X		33%
	Anolis carolinensis	Carolina anole			X		X	X			X				33%
	Anolis sagrei *	brown anole *									X			X	17%
	Apalone ferox	Florida softshell					X						X	X	25%
	Caretta caretta	loggerhead sea turtle										X			8%
	Chelydra serpentina	snapping turtle					X								8%
	Elaphe obsoleta spiloides	gray rat snake									X				8%
	Eumeces fasciatus	five-lined skink									X				8%
	Eumeces inexpectatus	southeastern five-lined skink		X											8%
	Graptemys barbouri	Barbour's map turtle			X										8%
	Nerodia erythrogaster erythrogaster	red-bellied water snake									X				8%
	Nerodia fasciata pictiventris	Florida banded water snake					X								8%
	Nerodia taxispilota	brown water snake			X				X		X				25%
	Pseudemys concinna suwanniensis	Suwannee cooter							X		X		X		25%
	Pseudemys floridana floridana	Florida cooter	X	X	X	X	X	X		X		X		X	75%
	Pseudemys nelsoni	Florida red-bellied turtle					X	X	X		X			X	42%
	Sternotherus minor minor	loggerhead musk turtle	X	X			X	X	X	X	X		X		67%
	Sternotherus odoratus	common musk turtle											X	X	17%
	Trachemys scripta	yellow-bellied slider			X				X						17%
		Species count:	**2**	**3**	**6**	**1**	**8**	**5**	**5**	**2**	**9**	**2**	**5**	**5**	
		All groups species count	**31**	**7**	**50**	**23**	**35**	**31**	**26**	**5**	**22**	**14**	**28**	**32**	
		*** non-indigenous species count**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**2**	

Human Use

Detailed observations of human use were made for each spring. Human use activity was characterized by location (pool versus run and in-water versus out-of-water) in terms of number of person-hours, number of persons, and persons per hectare (**Appendix M**). The methods used to collect and report these data are detailed in **Appendix A**. Human-use densities could not be accurately estimated at Ichetucknee, Homosassa, and Weeki Wachee Springs. Each spring was sampled on week-days during a different month; hence comparisons between springs do not take into account the seasonal or weekend usage of these ecosystems. However, these observations record the types of human use for each spring and the relative percentage of those uses.

The highest average observed in-water human use density on the dates of our sampling in spring pools (**Table 23**) were measured at Madison Blue Springs (30 persons/ha, SCUBA divers) and at Manatee Springs (16 persons/ha, primarily swimming and snorkeling). Silver Springs had the highest observed in water use of the downstream spring runs (3.3 persons/ha, primarily in tour boats), followed by Manatee Springs (1.9 persons/ha, canoes and kayaks), Madison Blue Springs (1.1 persons/ha, canoes and kayaks), and Rainbow River (1.1 persons/ha, canoes, kayaks, and power boats). Out-of-water uses were dominated by sitting and walking on the days of our observations. The highest average out-of-water human use densities were recorded at Manatee Springs (22 persons/ha, Volusia De Leon Springs (20.5 persons/ha), and Rainbow Springs (16 persons/ha). The highest average overall human-use densities were observed at Manatee Springs (40 persons/ha), Rainbow Springs (30 persons/ha), and Volusia De Leon Springs (27 persons/ha). The lowest average densities were recorded at Jackson Blue Springs (0.71 persons/ha), Wakulla Springs (2.7 persons/ha), and Silver Springs (3.3 persons/ha). Ichetucknee Springs had the highest level of tubing activity observed while Homosassa Springs had the highest estimated out-of-water use (fish and manatee watching), followed by Weeki Wachee Springs (viewing the live mermaid show) (**Appendix M**). **Figures 52** and **53** illustrate diversity of human uses observed at these springs, both in the pool areas and in the run segments.

Overall recorded attendance records for 2008 were also assembled for each spring from state and county data. For a comparison of each spring's overall human utilization, the total number of visitors during 2008 is presented in **Figure 54**. Highest usage during 2008 was for Homosassa with over 338,000 visitors and lowest usage was for Jackson Blue Springs with about 28,000 visitors.

TABLE 22
Average amount of observed human-use density (persons/ha) by location, activity, and category.

Location	Category	Activity	De Leon Springs	Jackson Blue Springs	Madison Blue Springs	Manatee Springs	Ponce de Leon Springs	Rainbow Springs	Silver Glen Springs	Silver Springs	Wakulla Springs
Spring Pool	In Water	Wading	1.15	0.00	0.00	0.00	1.18	0.29	0.72	---	0.08
		Bathing	0.86	0.00	0.00	0.00	0.00	0.76	0.12	---	0.00
		Tubing	0.00	0.00	0.00	2.05	0.20	2.23	0.00	---	0.00
		Snorkeling	0.33	0.00	0.00	3.53	0.00	0.35	0.18	---	0.00
		Swimming	3.29	0.00	0.00	10.31	3.09	8.31	0.69	---	0.06
		SCUBA	1.10	0.71	29.95	0.37	0.00	0.00	0.00	---	0.00
	Out of Water	Sitting	6.28	0.00	0.00	21.72	0.78	14.01	0.24	---	0.23
		Walking	12.72	0.00	0.10	0.00	1.10	1.02	0.51	---	0.79
		Sunbathing	1.51	0.00	0.00	0.00	0.87	1.40	0.31	---	0.34
		Viewing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.57
	In Water		6.72	0.71	29.95	16.27	4.46	11.95	1.72	---	0.14
	Out of Water		20.50	0.00	0.10	21.72	2.75	16.44	1.07	---	1.92
Spring Run	In Water	Canoe / Kayak	0.04	0.00	1.13	1.80	0.00	0.83	0.02	0.10	0.00
		Power-boating	0.02	0.00	0.00	0.03	0.00	0.28	1.00	0.07	0.00
		Tour Boats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.09	0.59
		Tubing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Snorkeling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Swimming	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Fishing	0.03	0.00	0.00	0.05	0.00	0.03	0.08	0.00	0.00
	Out of Water	Sitting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Walking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	In Water		0.09	0.00	1.13	1.88	0.00	1.14	1.09	3.26	0.60
	Out of Water		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Entire Spring		27.31	0.71	31.18	39.86	7.21	29.54	3.88	3.26	2.66

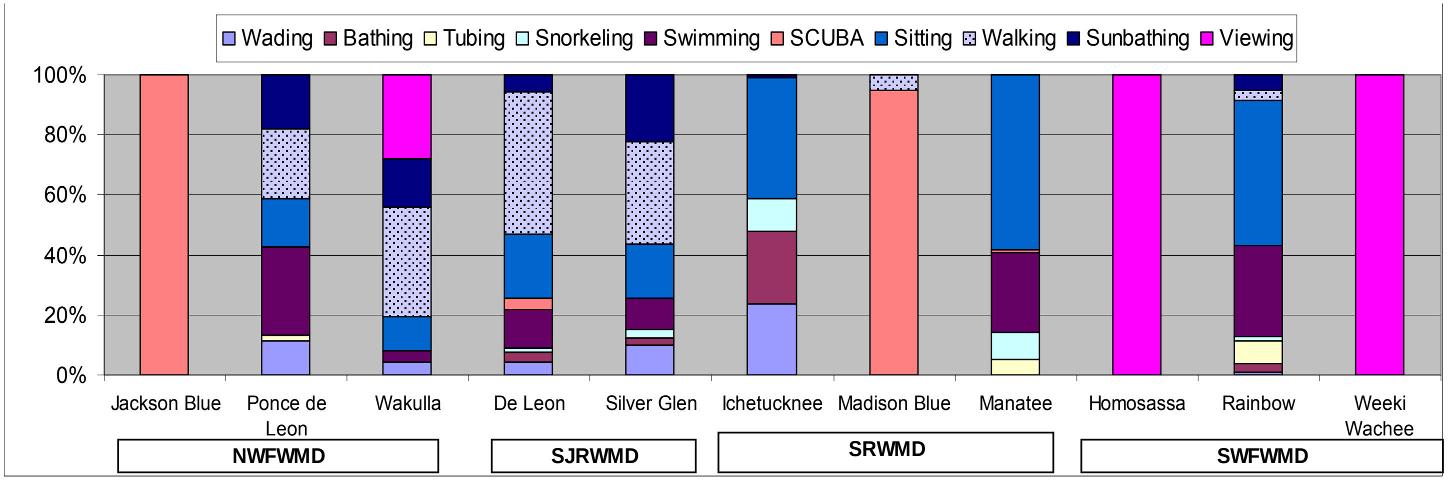


FIGURE 52
The percentage of various human-use activities for the spring pool areas (in water activity prohibited in Homosassa and Silver Springs pools, Weeki Wachee pool closed during sampling).

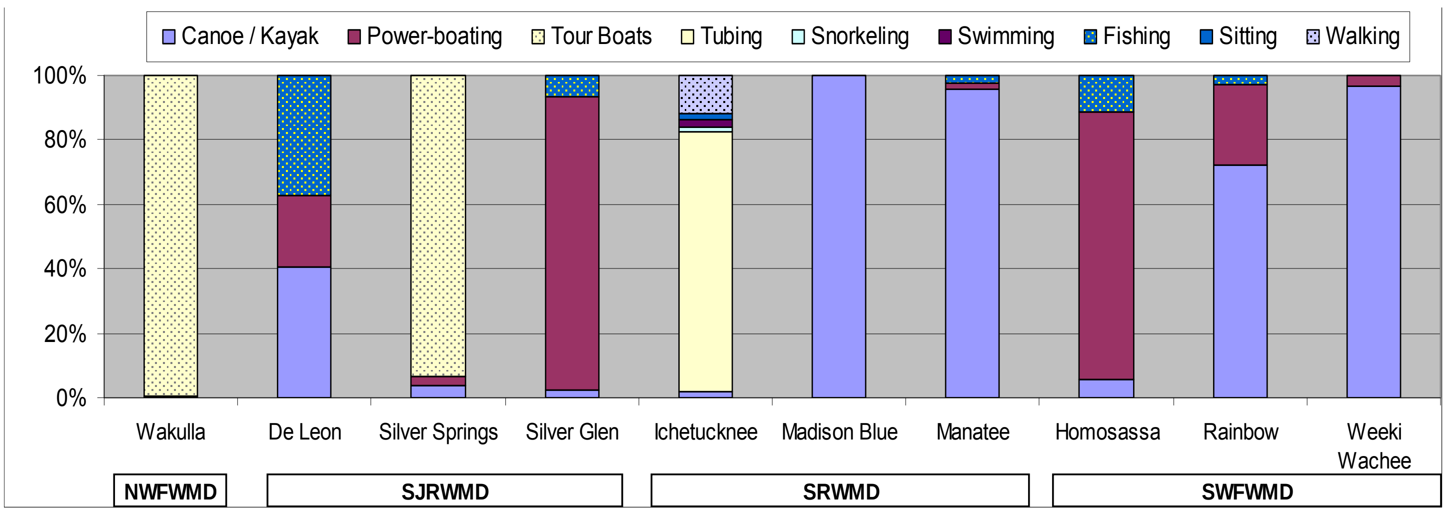


FIGURE 53
The percentage of various observed human-use activities for the spring run areas (Jackson Blue and Ponce de Leon had no run activity during sampling).

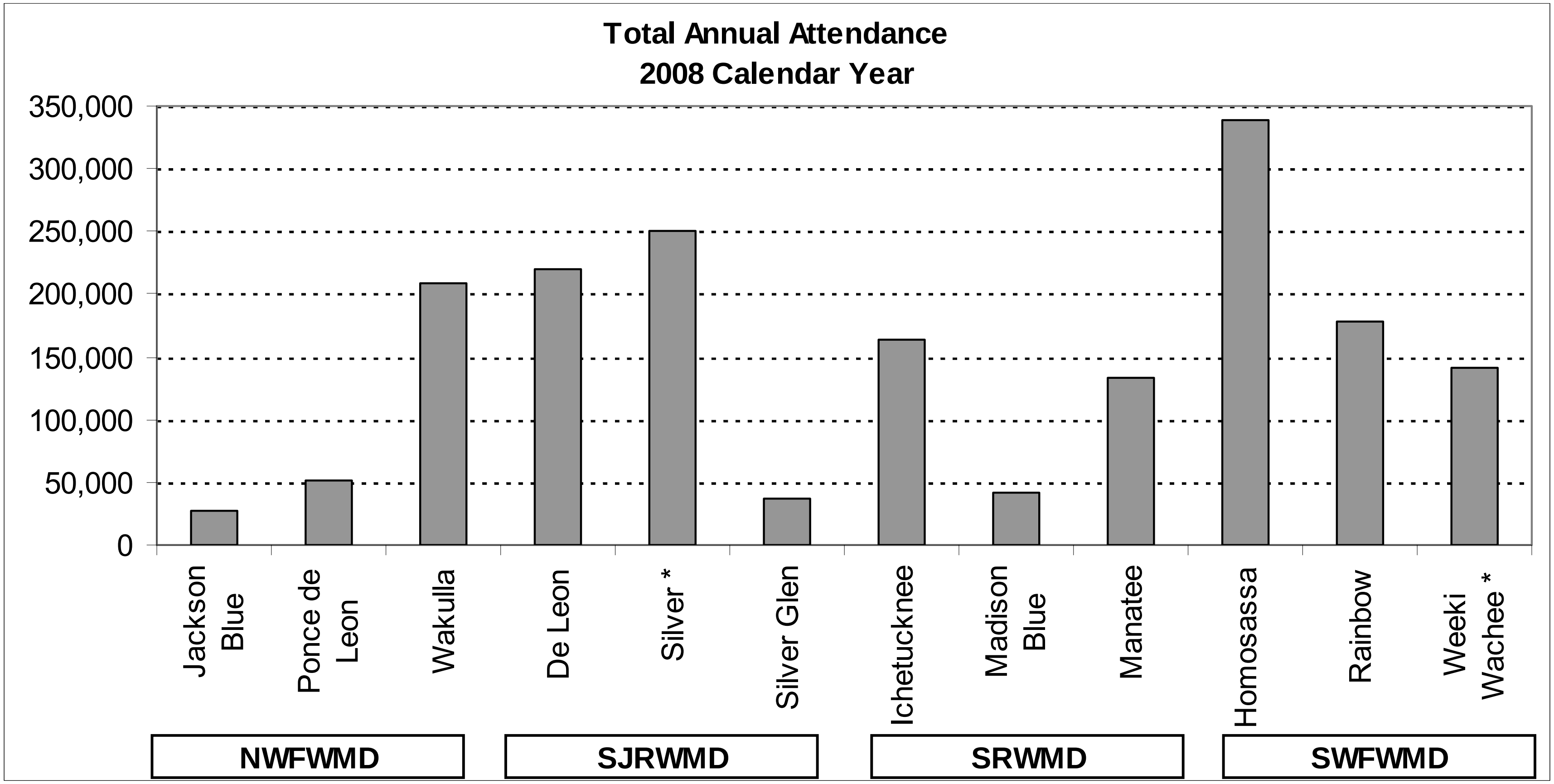


FIGURE 54
The total number of visitors by spring during the 2008 calendar year. *Silver is privately managed and data were not provided (Silver River State Park data used). *Weeki Wachee became state park in November 2008 and reported value derived from November 2008 to October 2009 total. Manatee, Rainbow, and Wakulla have overnight usage; all other springs are day use only. Jackson Blue numbers are from summer months only; the park is closed the rest of the year except to cave divers.

Ecosystem Metabolism

Metabolism Parameters

Ecosystem metabolism is an estimate of the overall function of an aquatic ecosystem. The consumption and production of oxygen by all spring flora and fauna are included in these measurements. Just as individual organisms have a measurable metabolism; spring ecosystems utilize oxygen for aerobic metabolism and exhale carbon dioxide throughout the day. At night they consume oxygen to meet the needs of their metabolism and during the day the plants in the ecosystem “exhale” more oxygen into the water column than they consume in their respiration. Daily variations in dissolved oxygen and carbon dioxide in the spring water column look surprising like the heart beat and respiration of individual plants and animals. Springs are especially well suited for these estimates because of their chemostatic (constant chemistry) character, including steady upstream concentrations of dissolved oxygen.

Ecosystem metabolism (primary production and community respiration) was determined from data collected over a 72 hour period (at least) from each spring. **Figures 55** through **61** provide a visual comparison of the following ecosystem metabolism parameters: gross primary productivity, net primary productivity, community respiration, productivity to respiration ratio, photosynthetically active radiation, and ecosystem efficiency (% and g O_2/mol) for each spring. **Table 23** provides a summary of each of these ecosystem metabolism parameters for all twelve springs. **Appendix N** provides detailed ecosystem metabolism measurements by spring.

Estimated rates of gross primary productivity (GPP) in the spring pools ranged from a low of 0.58 g $O_2/m^2/d$ at Wakulla Springs under dark water conditions to a high of 25 g

O_2/m^2/d at Silver Springs during sampling on a very sunny day in May 2009 (**Figure 59** and **Table 24**). Rates of GPP were higher in the pool segments at 4 of 9 springs where both segments were sampled and higher in the run segments for the other 5 springs. The highest GPP recorded during this study was in the downstream segment at Rainbow Springs (26.7 g O_2/m^2/d). Under clear water conditions seven of the 12 springs sampled had GPP values over 5 g O_2/m^2/d.

Estimated rates of community respiration (CR) varied from about 0.21 to 29.7 g O_2/m^2/d (**Figure 57** and **Table 23**). Higher CR rates were generally found in the spring run segments downstream from the spring pools. Silver, Rainbow, and Jackson Blue springs had similar rates of CR in their upstream and downstream segments, while Ichetucknee, Manatee, Weeki Wachee, Ponce de Leon, and Wakulla springs had much higher respiration rates in their downstream segments.

The difference between GPP and CR is termed net primary productivity (NPP) and provides an estimate of the excess fixed carbon produced by a spring that goes into biomass growth, sediment storage, and/or downstream export. Rates of NPP between springs were highly variable. In six of ten springs the upstream NPP was higher than the downstream NPP. In eleven of the 21 segments studied under clear water conditions (roughly half) the NPP was positive. Spring segments with negative NPP values are presumably utilizing internal storages of fixed carbon to meet their metabolic needs. It has been observed in other spring studies (Munch *et al.* 2008) that rates of NPP fluctuate greatly in response to daily variations in light inputs.

The ratio of GPP to CR (P:R ratio) varied in the spring segments between 0.17 and 13.3 with the majority of the observed spring segment ratios between 0.5 and 1.5 (62%). The ideal ratio for a well adapted/balanced autotrophic spring ecosystem is 1.0. The observed variability in these values reflects the short-term nature of the estimates and would be expected to decrease markedly with a longer period of data collection.

Figure 59 summarizes the estimated PAR levels received by the plant community in each of the 12 springs that were studied. The average depths of the submersed aquatic vegetation (SAV) plays a role in the estimation of photosynthetic efficiency and these values are presented in **Table 24**. The amount of PAR and average SAV depth values are used in conjunction with the GPP estimates summarized in **Figure 55** to estimate the photosynthetic (ecosystem) efficiency in **Figures 60** and **61**, presented in two different units. Estimated efficiencies ranged from 0.8 to 13% (0.10 to 1.64 g O_2/mol) for the spring pools and from 0.17 to 5.83% (0.02 to 0.72 g O_2/mol) in the spring run segments. H.T. Odum identified an average efficiency of about 4% as being typical of the springs he studied in the early 1950s. Photosynthetic efficiencies less than 2% (about 0.20 g O_2/mol) may indicate poorly adapted spring ecosystems as a result of natural or anthropogenic stressors and in this study included: Jackson Blue, Ponce de Leon, De Leon, the Homosassa pool, and Wakulla under dark water conditions. Efficiencies between 2% and 4% might tentatively be considered to be in the normal range of natural spring ecosystems and in this study included: Wakulla in clear water conditions, the Homosassa run (not the pool), and Weeki Wachee. Springs with photosynthetic efficiencies above 4% (0.50 g O_2/mol) might be considered to be healthy or adapted to anthropogenic stressors. This group includes Silver, Silver Glen, Madison Blue, Manatee, and Rainbow Springs.

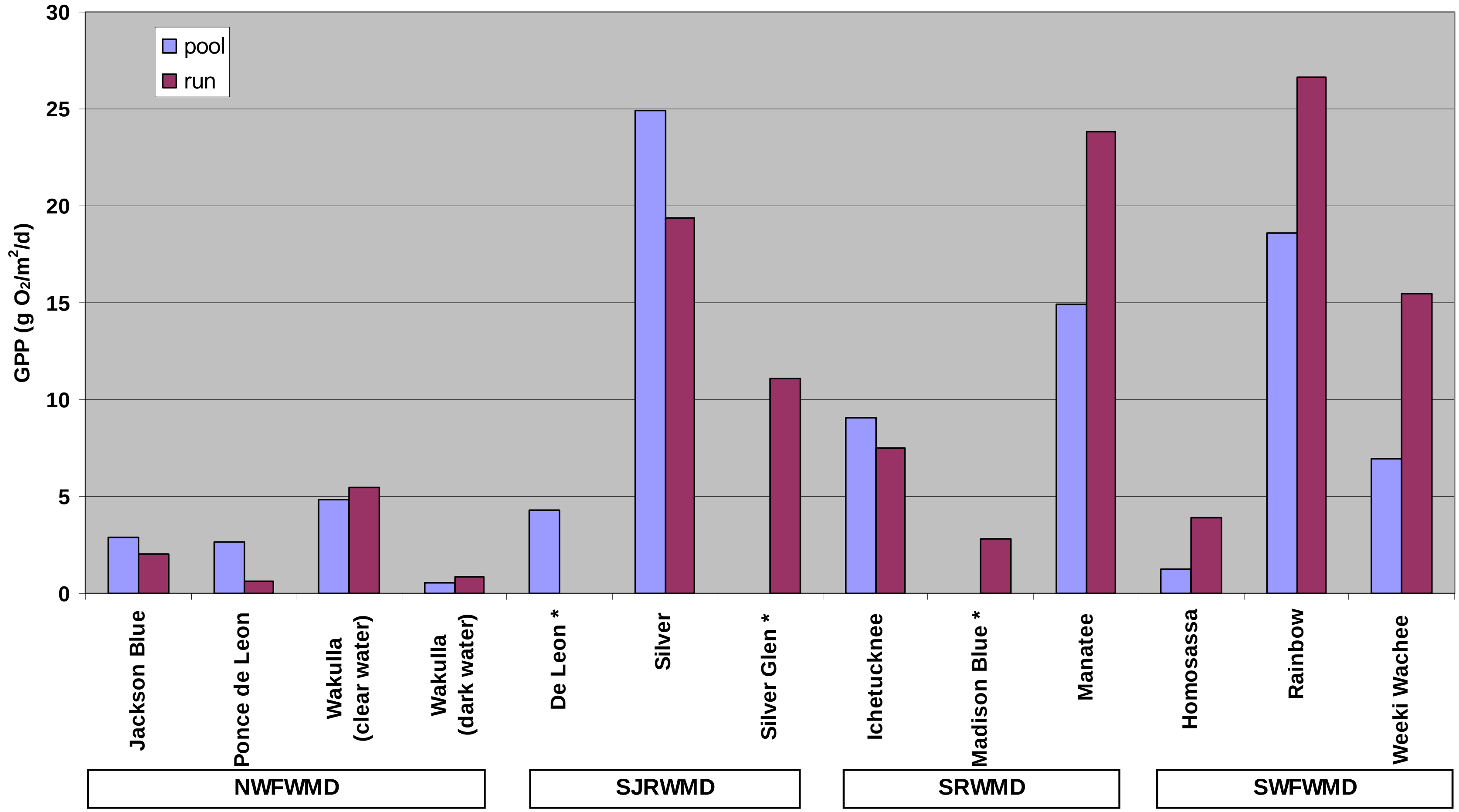


FIGURE 55
Average ecosystem metabolism gross primary productivity (GPP, g $O_2/m^2/d$) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

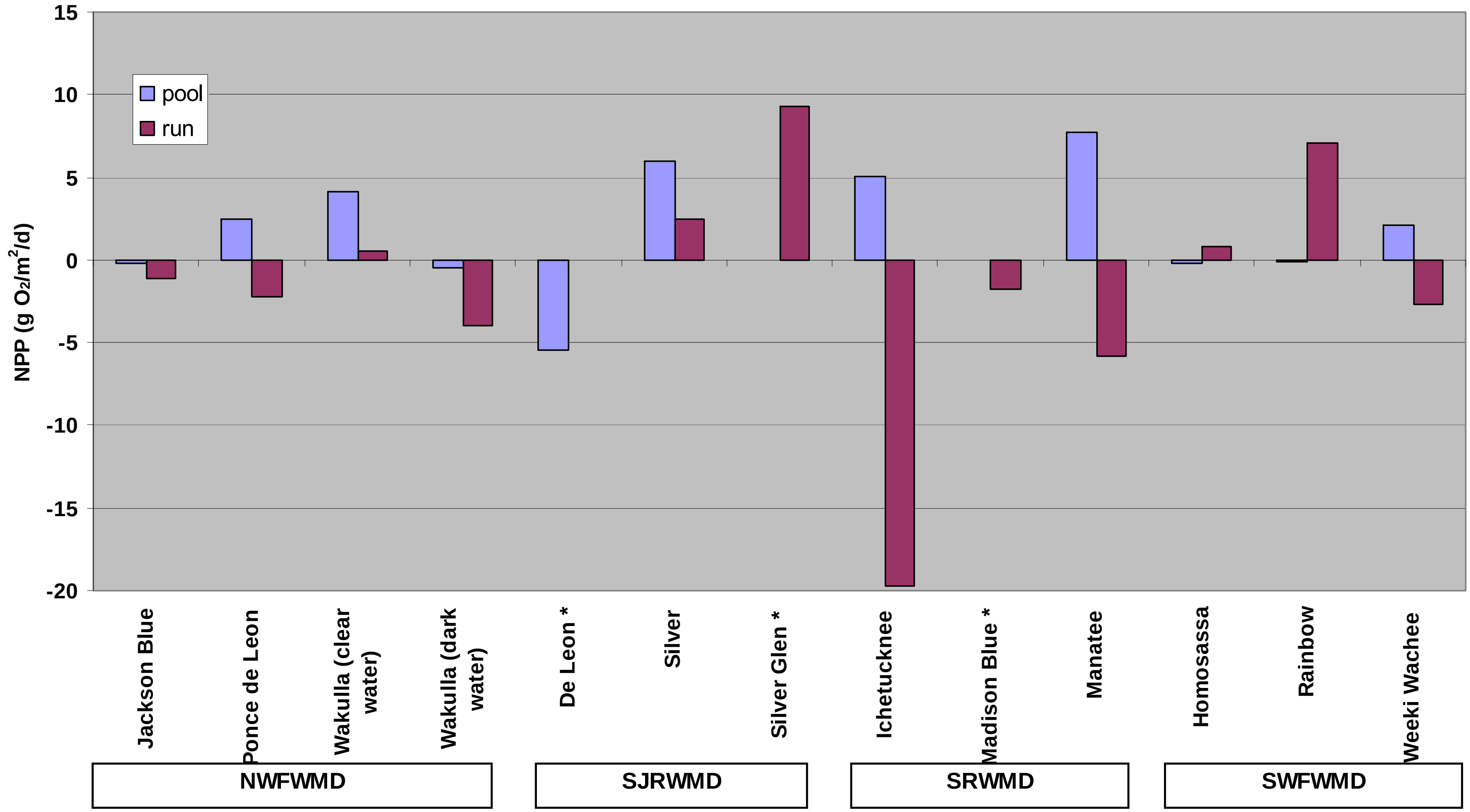


FIGURE 56
Average ecosystem net primary productivity (NPP, g $O_2/m^2/d$) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

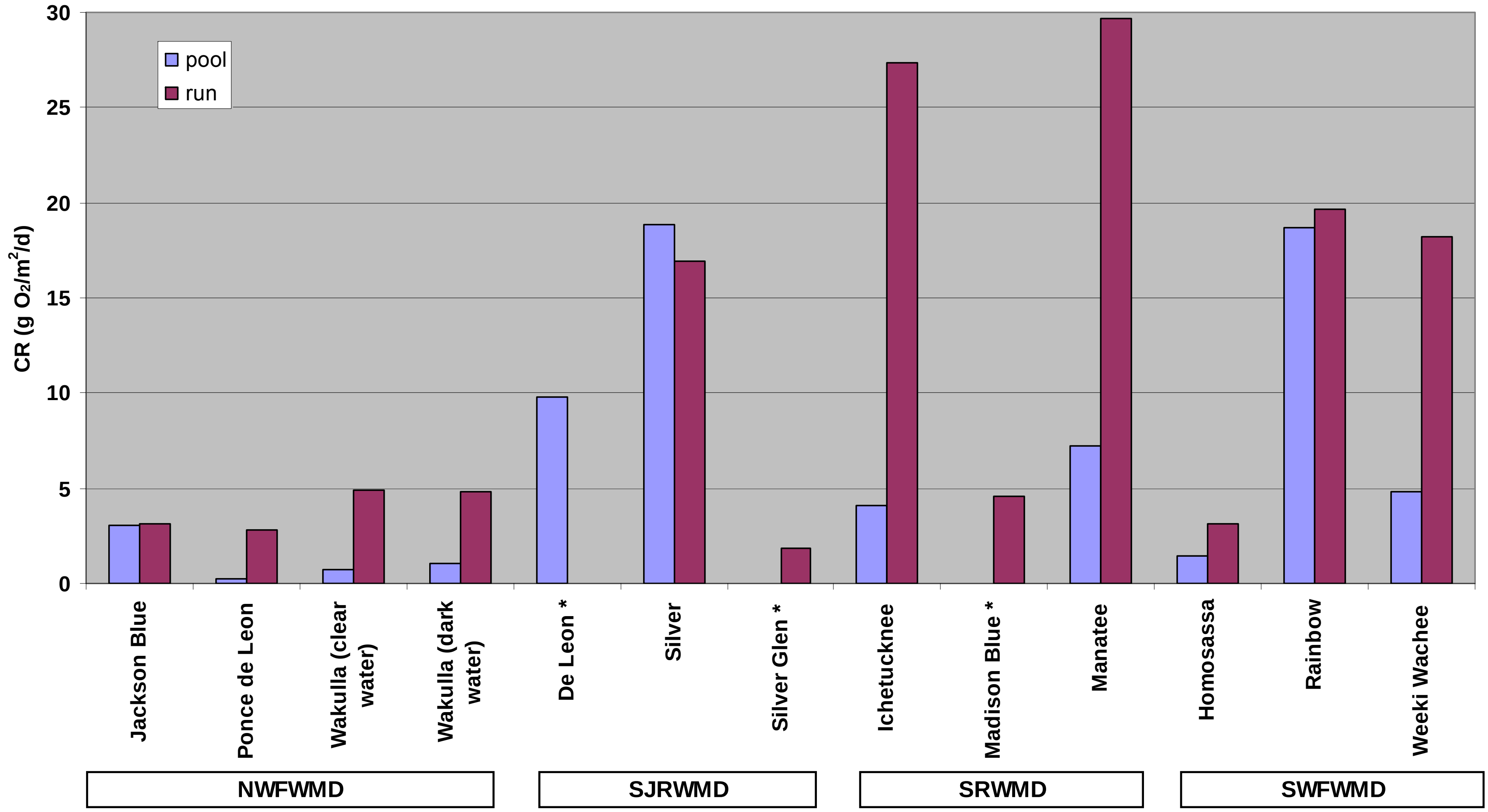


FIGURE 57
Average ecosystem community respiration (CR) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

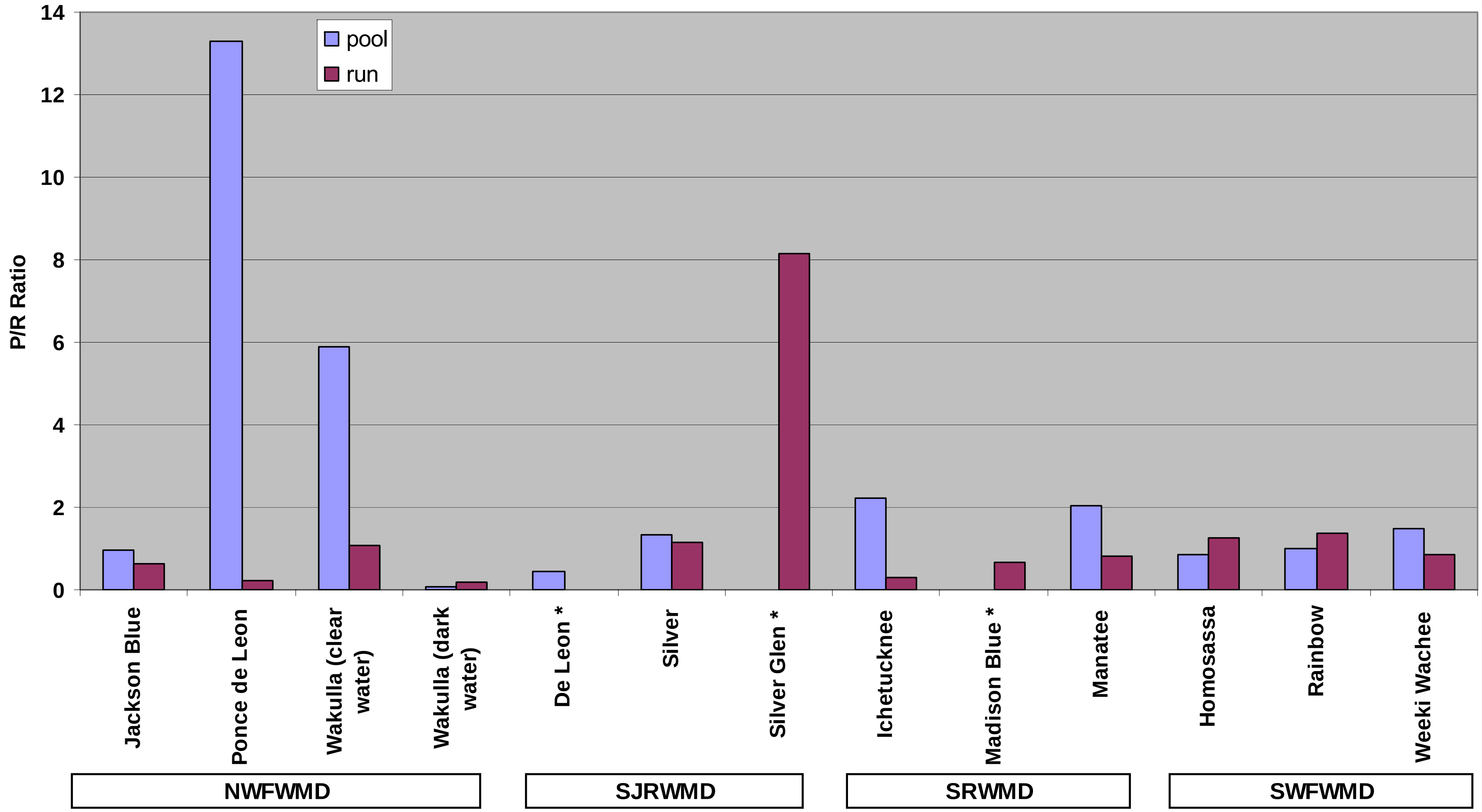


FIGURE 58
Average ecosystem productivity to respiration ratio (P/R) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

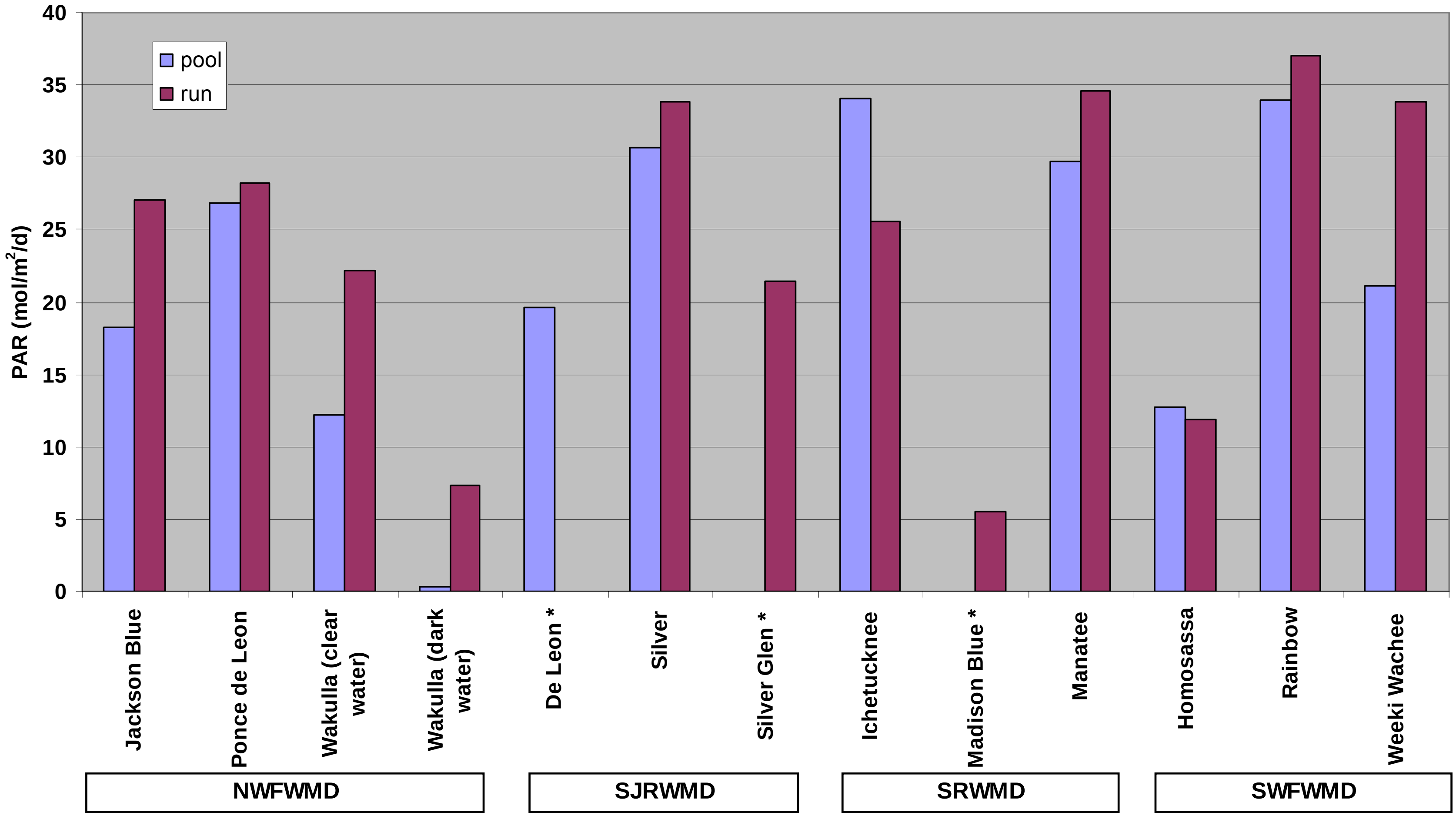


FIGURE 59
Average ecosystem photosynthetically active radiation (PAR) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

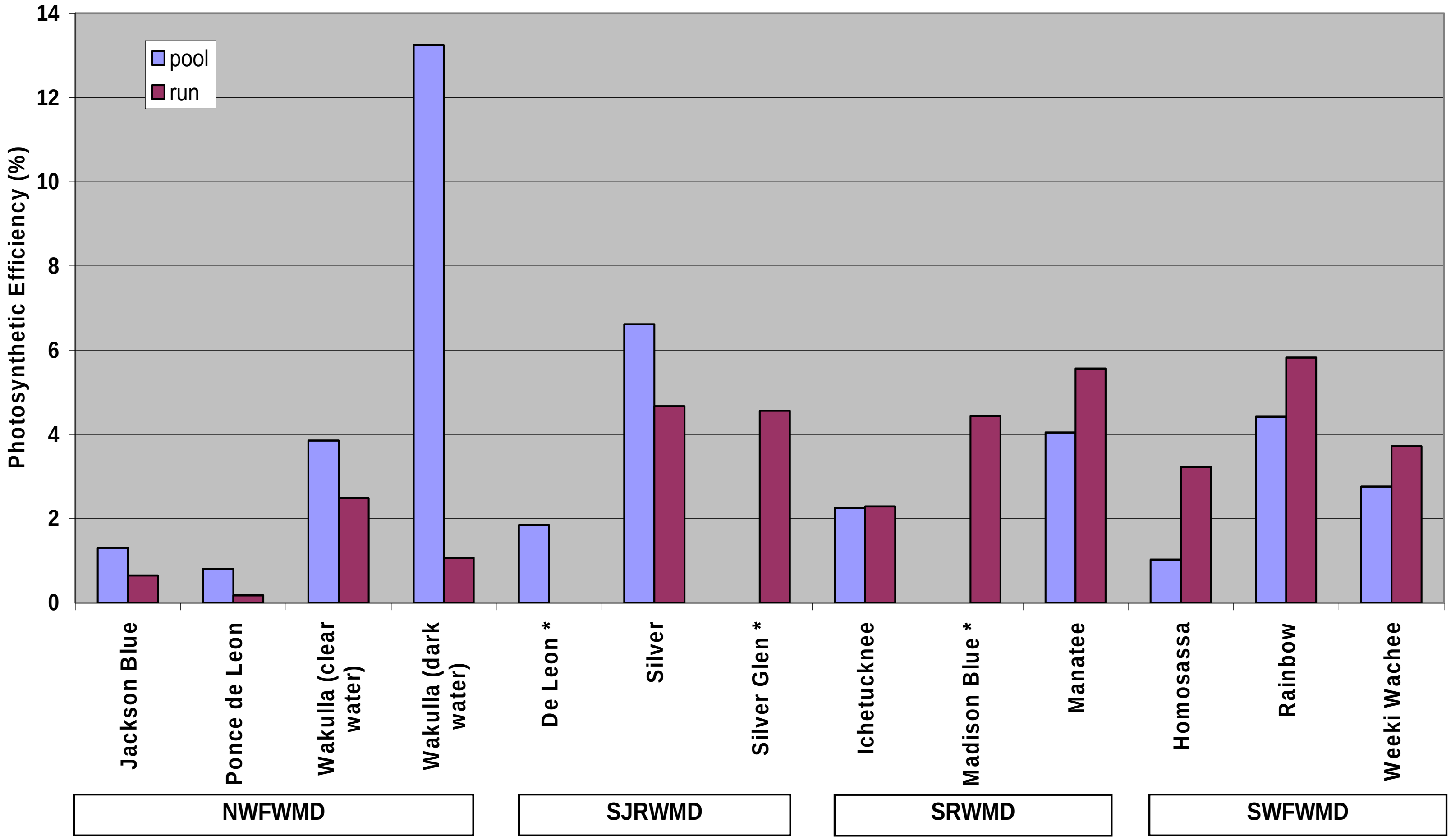


FIGURE 60
Average photosynthetic efficiency (%) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

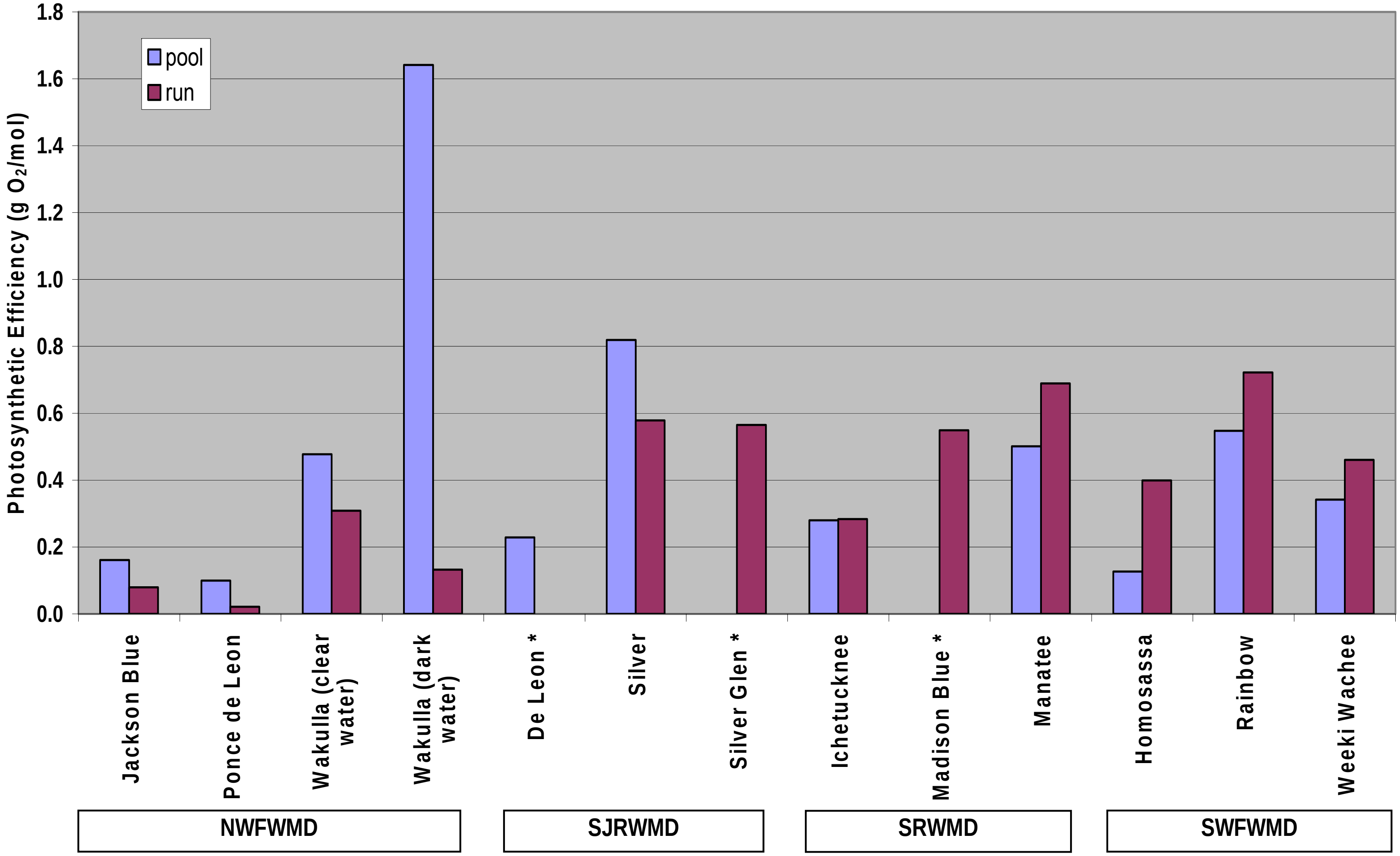


FIGURE 61
Average photosynthetic efficiency (g O_2/mol) by spring and location (* spring run flooded at De Leon, no productivity noted in pool at Madison Blue, sonde failure at Silver Glen pool segment).

TABLE 23
Summary of ecosystem metabolism data by spring and station.

Water Management District	Spring	Date Range	Location	GPP ($g\ O_2/m^2/d$)	NPP ($g\ O_2/m^2/d$)	CR ($g\ O_2/m^2/d$)	P/R Ratio	PAR (24hr) ($mol/m^2/d$)	Photosynthetic Efficiency (%)	Photosynthetic Efficiency ($g\ O_2/mol$)
NWFWMD	**Jackson Blue**	01/12/09 - 01/15/09	pool	2.88	-0.16	3.04	0.96	18.24	1.30	0.16
			run	2.02	-1.09	3.11	0.64	27.03	0.65	0.08
			both	1.61	0.17	1.44	1.12	25.49	0.32	0.04
	Ponce de Leon	09/08/09 - 09/11/09	pool	2.67	2.46	0.21	13.31	26.88	0.80	0.10
			run	0.60	-2.18	2.78	0.22	28.21	0.17	0.02
			both	1.36	1.18	0.18	16.00	27.08	0.41	0.05
	Wakulla (clear water)	03/17/09 - 04/01/09	pool	4.83	4.13	0.70	5.90	12.23	3.85	0.48
			run	5.44	0.51	4.93	1.08	22.14	2.49	0.31
			both	4.82	1.85	2.97	1.69	23.61	2.05	0.25
	Wakulla (dark water)	04/02/09 - 04/14/09	pool	0.58	-0.49	1.07	0.06	0.33	13.25	1.64
			run	0.84	-3.95	4.79	0.17	7.30	1.07	0.13
			both	0.69	-2.91	3.60	0.19	10.32	0.64	0.08
SJRWMD	**De Leon** [a]	10/06/08 - 10/09/08	pool	4.32	-5.45	9.78	0.44	19.62	1.85	0.23
	Silver	05/04/09 - 05/08/09	pool	24.89	6.02	18.88	1.32	30.70	6.62	0.82
			run	19.40	2.51	16.89	1.15	33.90	4.67	0.58
			both	19.00	1.60	17.40	1.09	32.67	4.76	0.59
	Silver Glen [b]	02/16/09 - 02/19/09	both	11.10	9.26	1.84	8.15	21.39	4.56	0.56
SRWMD	**Ichetucknee** [c]	06/20/09 - 07/07/09	upper run	9.09	5.01	4.08	2.23	34.05	2.26	0.28
			lower run	7.47	-19.77	27.36	0.28	25.54	2.29	0.28
			both	8.28	-7.38	15.72	1.26	29.79	2.27	0.28
	Madison Blue [d]	01/02/09 - 01/06/09	both	2.82	-1.74	4.56	0.68	5.49	4.43	0.55
	Manatee	08/03/09 - 08/06/09	pool	14.92	7.72	7.20	2.05	29.74	4.05	0.50
			run	23.84	-5.83	29.67	0.80	34.64	5.56	0.69
			both	21.33	0.11	21.22	1.00	33.13	5.21	0.64
SWFWMD	**Homosassa**	11/03/08 - 11/06/08	pool	1.26	-0.23	1.48	0.87	12.73	1.03	0.13
			run	3.87	0.77	3.10	1.26	11.83	3.22	0.40
			both	2.69	1.39	1.31	2.08	12.31	2.19	0.27
	Rainbow	06/08/09 - 06/11/09	pool	18.58	-0.15	18.73	0.99	33.98	4.42	0.55
			run	26.67	7.05	19.62	1.36	37.01	5.83	0.72
			both	22.98	4.64	18.34	1.25	34.78	5.34	0.66
	Weeki Wachee	03/09/09 - 03/12/09	pool	6.98	2.15	4.83	1.46	21.07	2.76	0.34
			run	15.50	-2.70	18.20	0.85	33.87	3.72	0.46
			both	12.20	4.26	7.93	1.54	31.32	3.16	0.39

[a] *spring run not flowing at De Leon (flooded)*
[b] *middle sonde failure at Silver Glen (unable to split spring into pool and run segments)*
[c] *upper run defined as below Blue Spring confluence to mid-point tube launch, lower run is mid-point tube launch to US27 dock*
[d] *no productivity noted in pool at Madison Blue (very short residence time, minimal aquatic vegetation, and relatively deep)*

TABLE 24
Summary of physical and submersed aquatic vegetation (SAV) data used to estimate photosynthetically active radiation (PAR) efficiency by spring and metabolism segment. The calculated average depth was derived from volume divided by area estimates; the calculated plant depth is water depth less the percentage occupied by SAV (*i.e.*, PVI- percent volume inhabited, PAC- percent area coverage).

Water Management District	Spring	Location	Volume (m^3)	Area (m^2)	Calculated Avg. Depth (m)	Riparian Shading (%)	SAV PAC (%)	SAV PVI (%)	Calculated Plant Depth (m)
NWFWMD	**Jackson Blue**	Seg 1	4,175	4,081	1.02	5	25	13	0.89
		Seg 2	104,116	103,319	1.01	5	78	41	0.59
		Both	108,291	107,401	1.01	5	51	27	0.73
	Ponce de Leon	Seg 1	1,708	1,595	1.07	35	25	8	0.99
		Seg 2	868	1,869	0.46	85	7	5	0.44
		Both	2,576	3,464	0.74	60	16	7	0.70
	Wakulla	Seg 1	49,607	15,685	3.16	2	35	10	2.85
		Seg 2	50,237	60,318	0.83	10	85	68	0.27
		Both	99,844	76,003	1.31	6	60	39	0.80
SJRWMD	**De Leon**	Seg 1	4,898	2,752	1.78	0	5	1	1.76
		Seg 2	77,777	37,959	2.05	7	20	5	1.95
		Both	82,675	40,711	2.03	4	13	3	1.97
	Silver	Seg 1	67,134	44,096	1.52	0	80	5	1.45
		Seg 2	53,140	35,300	1.51	10	75	45	0.83
		Both	120,274	79,396	1.51	5	78	25	1.14
	Silver Glen	Seg 1	1,875	2,442	0.77	5	40	12	0.68
		Seg 2	21,766	35,836	1.64	5	57	28	1.18
		Both	23,640	38,278	1.20	5	49	20	0.96
SRWMD	**Ichetucknee**	Seg 1	67,940	103,442	1.25	55	74	72	0.51
		Seg 2	28,259	56,790	1.67	75	82	46	0.68
		Both	96,199	160,231	1.46	65	78	59	0.60
	Madison Blue	Seg 1	2,457	441	4.07	25	31	2	3.99
		Seg 2	1,618	634	1.05	50	17	1	1.04
		Both	4,075	1,075	2.56	38	24	2	2.52
	Manatee	Seg 1	3,683	2,618	1.41	30	56	5	1.34
		Seg 2	5,015	5,352	0.94	50	83	20	0.75
		Both	8,698	7,970	1.09	40	70	13	0.95
SWFWMD	**Homosassa**	Seg 1	5,578	5,068	1.10	20	1	1	1.09
		Seg 2	6,775	6,251	1.08	15	56	15	0.92
		Both	12,353	11,318	1.09	18	29	8	1.00
	Rainbow	Seg 1	31,952	21,726	1.47	5	40	8	1.35
		Seg 2	30,761	23,529	1.31	5	80	47	0.69
		Both	62,713	45,255	1.39	5	60	28	1.00
	Weeki Wachee	Seg 1	9,887	6,564	1.51	1	15	2	1.48
		Seg 2	9,320	14,842	0.63	10	43	17	0.52
		Both	19,207	21,406	0.90	6	29	10	0.81

Discussion

Historic Spring Discharge Comparisons

The volume of water discharged from a spring is one of the key physical features and has profound impacts on the overall ecosystem. Concerns over reductions in spring discharge have become increasingly warranted as declines in spring flow have become increasingly common. Discharge data (cfs) for the twelve springs examined in this project are presented in **Table 25** and **Figure 62**. Percentile data are shown for the period-of-record (POR) and for the last decade (year 2000 to present) in **Table 25**. The number of records used to calculate percentile data is shown for both time periods; and of note, Jackson Blue, Madison Blue, and Manatee Springs have a limited amount of historic data. The median discharge values are shown for both time periods as well as the relative percentage change between them in **Figure 62**.

These exhibits show that discharge has declined for eleven of the twelve springs examined (the exception being Wakulla, which shows an 87% increase). The spring with the lowest decline in discharge is Silver Glen (1% decline), a possible consequence of a springshed with minimal withdrawals and other anthropogenic impacts. Observed declines in discharge are a result of climatic variation in rainfall and human groundwater withdrawals. The degree to which climate and/or withdrawals influence spring discharge needs to be better quantified by state water management districts.

The large increase in median discharge noted for Wakulla Springs may correspond to the increased occurrence of dark water discharge from this spring (discussed below). There may also be a relationship between Wakulla Springs and the Springs Creek Springs Group located in coastal Wakulla County. Wakulla Springs and the Springs Creek Group are believed to share portions of the aquifer conduit system and an inverse relationship may exist in the discharge of these two spring systems. It has been hypothesized that a decline in discharge at the Springs Creek Group will produce an increase in discharge at Wakulla Springs. This could occur as a back-water effect of the southerly located Springs Creek Group on the upstream Wakulla Springs. Elevated coastal water levels may exacerbate this back-water effect. It should be noted that the Springs Creek Group is approximately 16 km (10 mi) south of Wakulla Springs and this explanation does not account for the increase in colored water observed to be discharging from Wakulla Springs.

Historic Metabolism Comparisons

Historic ecosystem metabolism data exist for 11 different Florida springs from the work of H.T. Odum (1957a, 1957b). Of these springs, five of them were re-visited by this study: Homosassa, Manatee, Rainbow, Silver, and Weeki Wachee. The data for the 11 springs studied by Odum (1957b) were gathered from measurements taken over the course of one day, with the exception of Silver Springs. The metabolism of Silver Springs has also been measured in the intervening time-period, during 1979 to 1980 by Knight (1980) and during 2004 to 2005 by Munch *et al.* (2006). In conjunction, these earlier studies allow for a historic comparison of metabolism data.

TABLE 25
Discharge percentile data for the period-of-record (POR) and the last decade (year 2000 to present) by spring.

Spring	Period of Record								2000 to present								Period of Record	
	P-0	P-5	P-25	P-50	P-75	P-95	P-100	N	P-0	P-5	P-25	P-50	P-75	P-95	P-100	N		
Jackson Blue	27.9	34.5	100.6	125.1	176.2	280.2	308.8	54	27.9	34.3	100.4	122.4	164.7	281.5	308.8	53	2/1985	9/2008
Ponce de Leon	12.7	20.9	25.3	27.8	30.8	36.5	41.8	173	12.7	18.9	20.2	21.8	26.8	30.6	31.9	21	2/1929	7/2009
Wakulla	25.0	123.6	244.0	344.0	513.0	903.6	1,910.0	305	203.0	318.0	505.7	643.5	787.0	1,495.0	1,670.0	21	2/1907	11/2007
De Leon	12.2	19.8	23.3	27.0	30.7	37.1	44.3	295	15.9	18.2	22.2	26.5	31.1	40.5	44.3	69	2/1929	8/2008
Silver Glen	58.0	79.6	92.9	102.0	115.9	134.7	168.0	122	67.1	78.6	92.5	101.3	115.7	126.8	152.0	75	3/1931	6/2008
Silver	358.1	503.0	656.7	760.3	864.4	1,015.2	1,279.7	918	358.1	411.0	464.9	516.3	598.5	718.6	764.2	111	10/1932	3/2009
Ichetucknee	241.0	276.2	320.0	347.0	393.0	487.9	578.0	383	164.3	189.4	232.5	285.0	353.7	466.7	516.8	92	1/1929	9/2009
Madison Blue	-73.8	-18.3	60.5	85.9	139.0	252.3	407.5	83	-73.8	-21.6	59.8	83.8	140.6	262.8	407.5	78	11/1973	6/2008
Manatee	75.4	84.4	101.7	134.4	185.9	256.9	317.1	118	75.4	84.3	101.3	126.3	166.8	265.8	317.1	104	3/1932	9/2009
Homosassa	67.7	75.5	86.8	95.7	111.0	140.0	280.0	266	67.7	72.3	79.3	88.0	95.7	111.0	119.1	105	10/1930	9/2008
Rainbow	525.1	570.0	633.4	693.0	781.1	914.0	1,039.0	420	477.5	501.3	557.1	585.9	645.2	765.4	819.9	111	1/1965	3/2009
Weeki Wachee	101.0	117.1	145.0	166.0	192.0	237.0	275.0	646	105.5	115.3	131.8	151.0	177.9	232.9	253.4	108	10/1904	12/2008

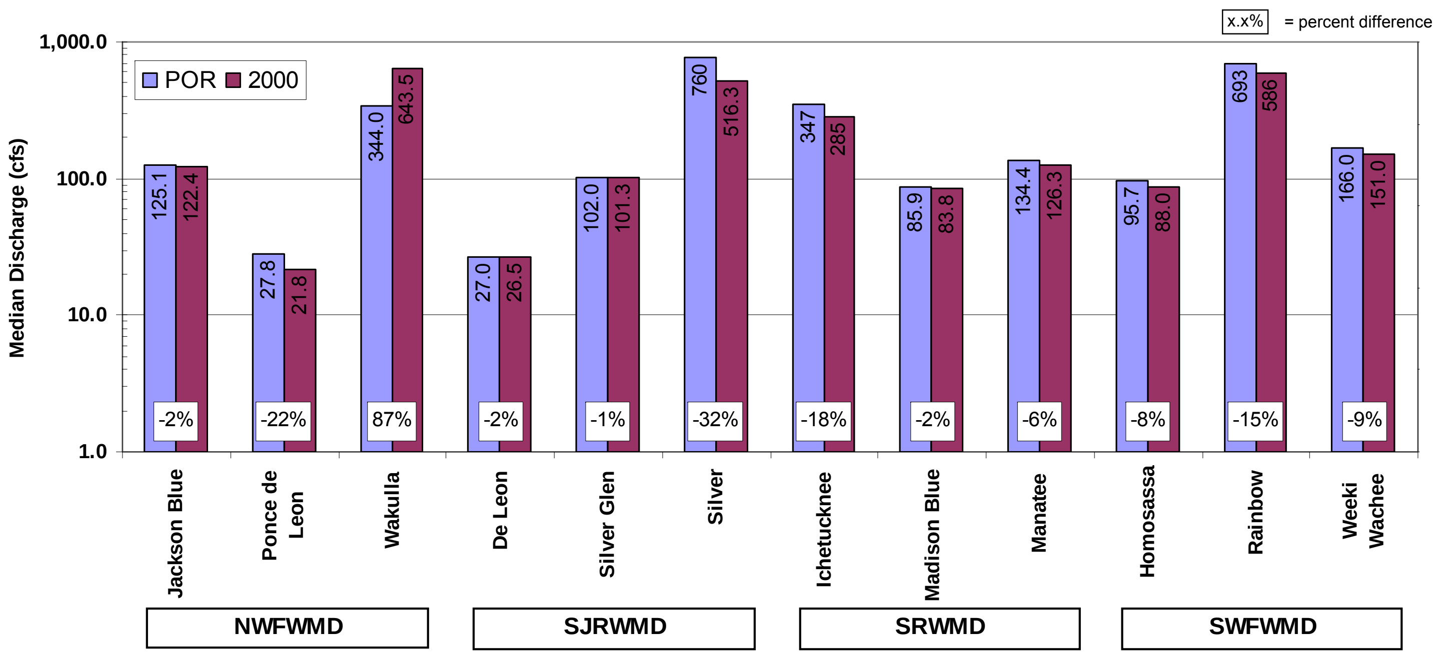


FIGURE 62
Median discharge data for the period-of-record (POR), the last decade (year 2000 to present) by spring, and the percent difference between these time periods.

The historic and modern gross primary production (GPP) values for Homosassa, Manatee, Rainbow, and Weeki Wachee Springs are shown in **Table 26**. Among these four springs, the GPP increased for all except for Homosassa Springs which had dramatically lower GPP than historically estimated. The observation of a dramatic reduction in Homosassa Springs is not unexpected. Odum measured productivity at the foot bridge in July 1955, during which time the submersed aquatic vegetation was abundant. Our measures were made at the same location, but during the intervening time period the pool of Homosassa Springs had been converted to a holding pen for Manatees and submersed aquatic vegetation is now absent.

For Manatee, Rainbow, and Weeki Wachee, the increase between Odum's measurements and ours range from about 23%, 12%, and 45%, respectively. Time of year could explain some difference between the two studies, as only Manatee Spring was sampled during the same month. Another possible cause for these increased rates of GPP is the observed increase in nitrate nitrogen concentrations. However, it is possible that the number of samples is responsible for some of the differences, as Odum collected data from a single day, while our reported measures are the average of four days. Because of the variability observed in daily metabolism values, it is possible that the difference observed between Odum (1957b) and this study are partially a function of the number of samples. As can be seen in **Figure 63**, day-to-day variation in ecosystem metabolism is evident (in that case driven by clear versus sunny skies and clear versus colored water). Daily variation was also noted by Munch *et al*. (2006) at Silver Springs and can be observed in the data collected during this study (**Appendix N**).

TABLE 26
Comparison of historic ecosystem metabolism estimates with modern estimates for Homosassa, Manatee, Rainbow, and Weeki Wachee Springs.

		Odum (1957)			This Study		
Spring	Location	GPP ($g\ O_2/m^2/d$)	Period-of-Record (POR)	N (Days)	GPP ($g\ O_2/m^2/d$)	Period-of-Record (POR)	N (Days)
Homosassa	Pool	63.8	07/19/1955	1	1.3	11/03/08 to 11/06/08	4
Manatee	Run	19.4	08/15/1955	1	23.8	08/03/09 to 08/06/09	4
Rainbow	Run	23.9	08/16/1955	1	26.7	06/08/09 to 06/11/09	4
Weeki Wachee	Run	10.7	07/26/1955	1	15.5	03/09/09 to 03/12/09	4

Odum, H.T. 1957. Primary production measurements in eleven Florida springs and a marine turtle-grass community. Limnology and Oceanography 2: 85-97.

In the Odum (1957b) study of 11 Florida springs one key finding was that the primary production of these systems was positively correlated to solar energy (**Figure 64**). This relationship can also be described as photosynthetic efficiency (PE), or as used in this study, the efficiency of conversion of photosynthetically active radiation (PAR) into GPP reported in units of g O_2/mol of photons or as % (see Appendix A for detailed methods). In Odum (1957b), the studied springs averaged 4% efficiency (Silver Springs had an estimated efficiency of 5.2% [Odum 1957a], recalculated as 8.8% by Munch *et al.* 2006). Data from the current study were also plotted to examine this relationship and are shown in **Figure 65**. Plotting data points from each spring's pool, run, and the average of both, with PAR energy on the x-axis and GPP on the y-axis, a significant positive correlation (R^2 = 0.51, P = 0.0001) was observed. As was observed by Odum (1957b), increasing light availability is correlated to increasing primary production in these spring ecosystems. Photosynthetic efficiency data from the current study averaged 3.26%, a value slightly less to the 4% efficiency estimated by Odum (1957b). Examining photosynthetic efficiency from pool, run, and the combined segments of the twelve springs of this study, values ranged from 0.13% for the run segment of Ponce de Leon Springs (with 85% riparian shading) to about 13% at the Wakulla Springs pool segment under dark water conditions (with 10% riparian shading).

A more robust historic data set is available for Silver Springs (**Table 27**). From Odum (1957a) there were seven days, Knight (1980) had nine days, Munch *et al*. (2006) had 373 days, and this study had five days of metabolism data. Comparing these four time-periods, GPP estimates were higher during this study at 19.4 g $O_2/m^2/d$ than previously measured. Lowest values were measured during 2004 to 2005, with an average of 11.4 g $O_2/m^2/d$. Differences in net primary production (NPP) and community respiration (CR) are also evident, with highest values for both measured in the current study (**Table 27**). Photosynthetic efficiency apparently declined between Odum's work in the 1950s and the current study. However, productivity to respiration (P/R) ratios were all very similar and above one, indicating that this spring ecosystem maintains positive net primary production. Again differences in metabolism parameters for these four time-periods may be influenced by the time of sampling and the number of samples. In the current study, sampling at Silver Springs took place in May. Based on records of annual solar energy available, May is the peak period of the year for this geographic location (Munch *et al*. 2006). In turn, ecosystem metabolism varies over the course of the year in response to variation in solar inputs. An example of this is shown in **Figure 63**, which illustrates Silver Springs run GPP data with a sinusoidal model fit. Therefore, part of the higher GPP, NPP, and CR values observed in this study at Silver Springs may be attributed to seasonal effects. Other reasons for differences in historical metabolism values include changes in water chemistry, discharge rate, and aquatic plant community changes (increase in benthic algae biomass) which have taken place.

TABLE 27
Comparison of historic ecosystem metabolism estimates for the upper run (above 1,200 m) segment of Silver Springs.

Study	GPP ($g\ O_2/m^2/d$)	NPP ($g\ O_2/m^2/d$)	CR ($g\ O_2/m^2/d$)	P/R Ratio	PAR (24hr) ($mol/m^2/d$)	Photosynthetic Efficiency (%)	Photosynthetic Efficiency ($g\ O_2/mol$)	Period-of-Record (POR)	N (Days)
Odum (1957)	15.75	1.02	14.73	1.11	n/a	8.82	1.09	1952 to 1955	7
Knight (1980)	15.64	0.80	14.84	1.06	n/a	8.53	1.06	1979 to 1980	9
Munch (2005)	11.37	0.42	10.95	1.06	13.86	7.63	0.95	02/13/04 to 03/12/05	373
this study	19.40	2.51	16.89	1.15	33.90	4.67	0.58	05/04/09 to 05/08/09	5

Munch, D.A., D.J. Toth, C. Huang, J.B. Davis, C.M. Fortich, W.L. Osburn, E.J. Phlips, E.L. Quinlan, M.S. Allen, M.J. Woods, P. Cooney, R.L. Knight, R.A Clarke, and S.L. Knight. 2006. Fifty-year retrospective study of the ecology of Silver Springs, Florida. Report prepared for the Department of Environmental Protection. St. Johns River Water Management District, Palatka, Fl. Special Publication SJ2007-SP4. 314 pp.

Knight, R.L. 1980. Energy Basis of Control in Aquatic Ecosystems. Ph.D. Dissertation. University of Florida, Gainesville. Fl. 200 pp.

Odum, H.T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecological Monographs 27(1): 55-112.

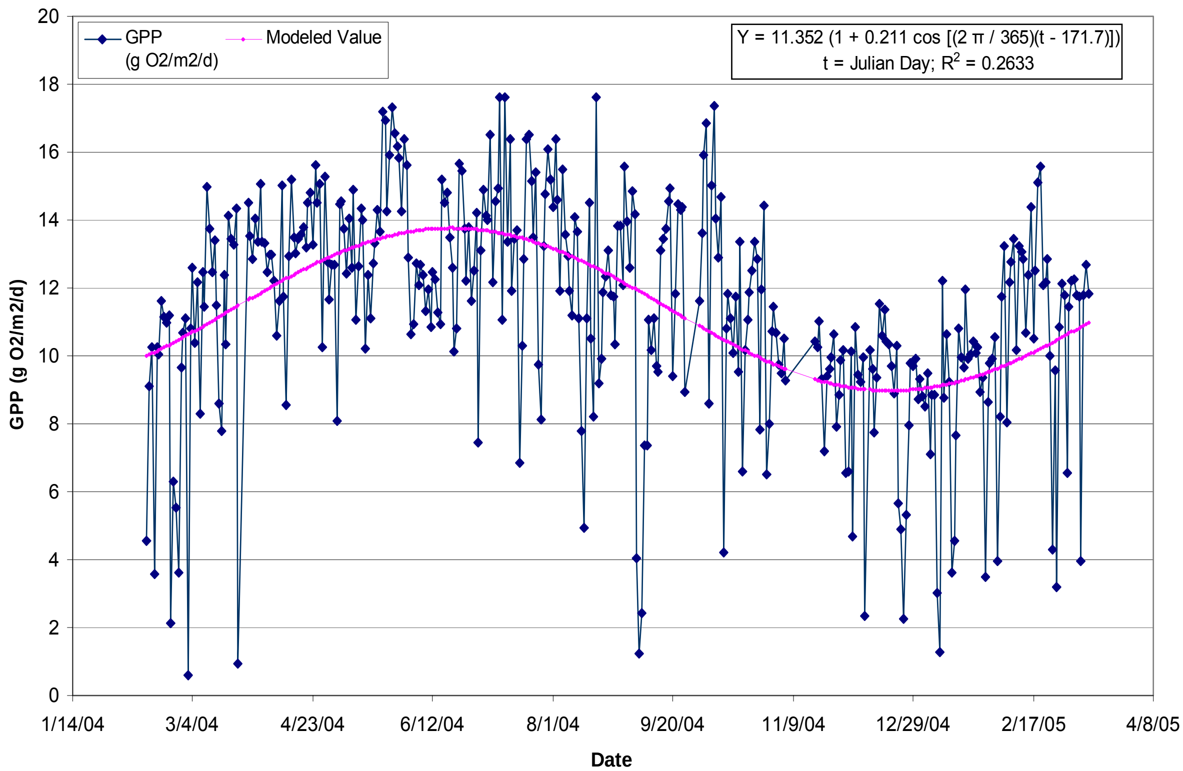


FIGURE 63
Annual Silver Springs run gross primary production (GPP, $g\ O_2/m^2/d$) data with sinusoidal model fit (from Munch *et al.* 2006).

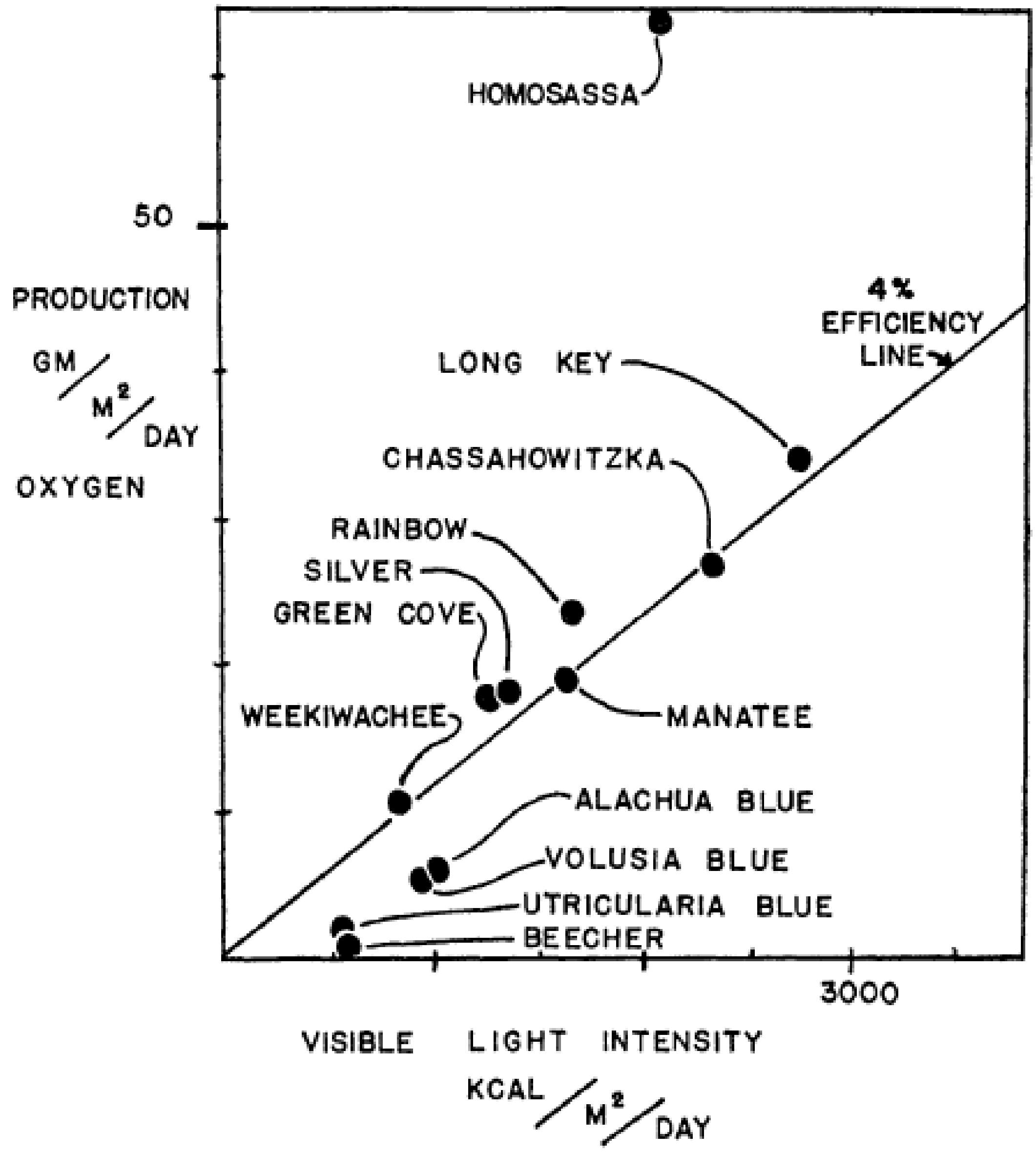
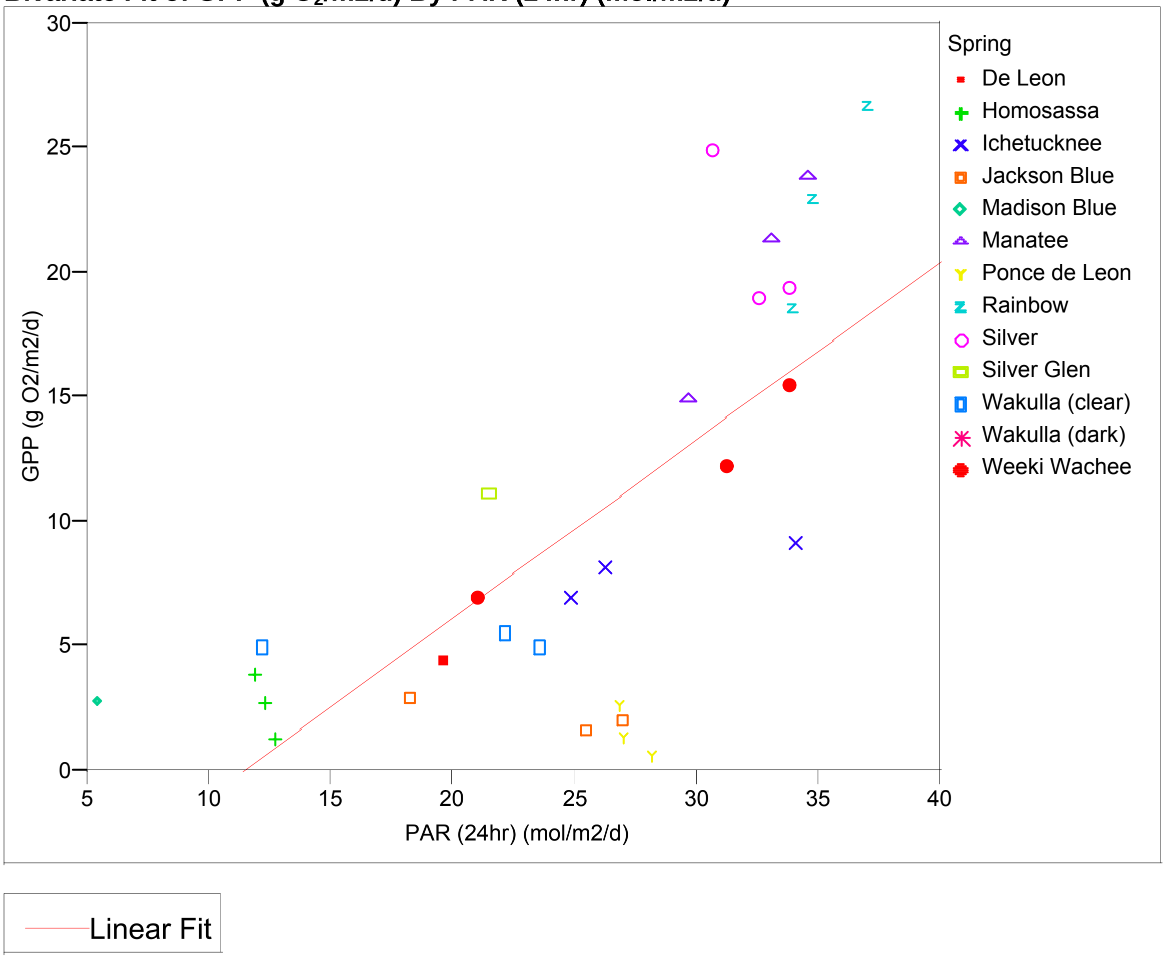


FIGURE 64
Gross primary production (GPP, g $O_2/m^2/d$) as a function of visible light intensity for 11 Florida springs measured in 1955 (from Odum 1957b).

Bivariate Fit of GPP (g O_2/m2/d) By PAR (24hr) (mol/m2/d)



Linear Fit

GPP (g O2/m2/d) = -8.192559 + 0.7157265 PAR (24hr) (mol/m2/d)

Summary of Fit

RSquare	0.509432
RSquare Adj	0.491912
Root Mean Square Error	5.980946
Mean of Response	10.08733
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1040.1252	1040.13	29.0767
Error	28	1001.6082	35.77	Prob > F
C. Total	29	2041.7334		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-8.192559	3.561537	-2.30	0.0291
PAR (24hr) (mol/m2/d)	0.7157265	0.132732	5.39	<.0001

FIGURE 65

Gross primary production (GPP, g $O_2/m^2/d$) as a function of photosynthetically active radiation (PAR, $mol/m^2/d$) for the current study.

Flooding Effects

During the course of the study, several of the spring systems were impacted by colored water events. De Leon Springs (Volusia County) was sampled in early October 2008 following Tropical Storm Fay's late August passage which delivered nearly 18 inches of rainfall to the nearby city of DeLand (Stewart and Beven 2009). The back water effect resulting from flooding of the St. Johns River and the receiving waters of the spring, *i.e.*, Spring Garden and Woodruff Lakes, dramatically changed the nature of this system's spring run. Instead of a flowing, clear water environment, the spring run of De Leon was tannic colored, quiescent, and unsuitable for metabolism estimation. The pool at De Leon Springs is encircled with concrete and raised so that water spills out, likely to prevent colored water from intruding into the pool (the spring was observed to be covered by tannic waters during William Bartram's 1773-77 travels of Florida). The main impact on the pool was the large number of fish (shad, shiner, sunfish, and hogchoker) which gained access to the pool. Many of these fish returned to the spring run, however large schools of golden shiner (*Notropis chrysoleucas*) were still present during our sampling.

Similarly the flooding observed at Madison Blue Spring (Madison County) during December 2008, represents a phenomenon common to springs along the banks of rivers (**Figures 66** and **67**). Rainfall in the extensive watershed of the Withlacoochee River (north) caused river stage at Madison Blue Springs to increase by over 3 m (10 ft). During our sampling we observed the spring reverse flow and behave as an estavelle. The net effect of this flow reversal was that a large volume of colored water with low dissolved solids typical of surface runoff measured at 26.5 million gallons a day on December 2, 2008 (water levels peaked five days later) was delivered to the aquifer (see Madison Blue Springs discharge details in **Appendix C**).

FIGURE 66
Northerly view across the pool of Madison Blue Springs on April 27, 2008; USGS gage height was 9.53'.

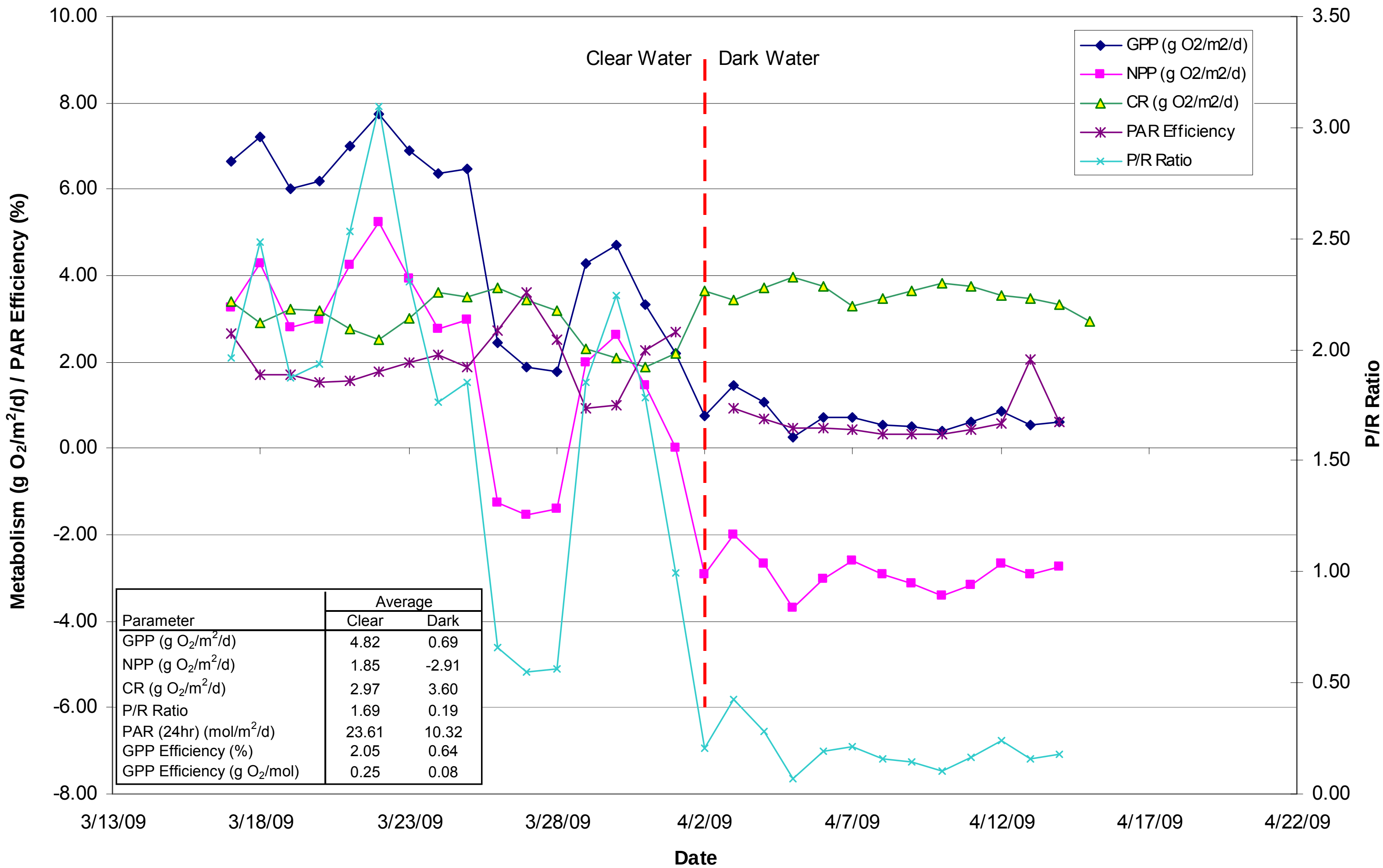
FIGURE 67
Northerly view across the pool of Madison Blue Springs on December 10, 2008; USGS gage height was 17.00'.

Flooding events strongly affect the ecology of a spring and typically include a significant change in the water chemistry from artesian to surface water, the absence of light available for primary production due to the dissolved tannic compounds in the colored water, and in some cases and increase in the load of sediments to the spring boil and run. Spring systems such as Madison Blue (and Ponce de Leon in Holmes County, and many others along the Suwannee and Santa Fe Rivers) are regularly flooded by their neighboring surface water streams.

Wakulla Spring is another system subject to dark water periods; however the mechanism of introducing colored water to the spring system appears to be different. Nearby forested wetlands do have the ability to introduce colored water to Wakulla Springs during flood conditions; however, colored water is also being discharged from the underground spring source. This implies that the aquifer in the vicinity of Wakulla Springs has direct conduits that readily transfer surface water runoff, through the limestone, back to surface waters at the spring boil. This is not unusual in karst geology and is also well documented at Ichetucknee Springs (**Appendix Q**) but without the tannic water inputs.

It appears that the occurrence of colored water discharging at Wakulla Springs has dramatically increased in the last several years. The glass-bottom boat tours at this spring are regularly cancelled due to inadequate visibility. A long-term record of these cancellations has been kept by park staff and the frequency of these events has markedly increased. During this project, upstream and downstream data sondes were deployed for an extended period at Wakulla Springs (March 16 to April 16, 2009) which captured periods of both clear water and colored water. Heavy rainfall in the springshed during the last week of March resulted in colored (dark tannin stained) water discharging from this system by

April 2, 2009. This resulted in a drop in ecosystem productivity, contrasting clear versus colored water periods, average gross primary production (GPP) changed from 4.82 to 0.69 g $O_2/m^2/d$, net primary production (NPP) changed from 1.85 to -2.91 g $O_2/m^2/d$, and community respiration (CR) changed from 2.97 to 3.60 g $O_2/m^2/d$ (**Figure 68**). These results illustrate the obvious, the productivity of spring ecosystems are directly related to photosynthetic inputs (Canfield and Hoyer 1988a, 1988b). In spring ecosystems, primary production is dependent on attached and benthic primary producers (*e.g.*, vascular plants, algae, and epiphytes). While light energy passing through water is greatly reduced (Kirk 1994), primary producers in clear water can flourish. Reductions in water clarity (*e.g.*, from tannins, phytoplankton, or sediments) all significantly reduce the amount of energy available to benthic primary producers (Kirk 1994). This conclusion is clearly supported by the data shown in **Figure 68**. The phenomenon of colored water discharging from Wakulla Springs has both aesthetic impacts through a reduction in water clarity and biological impacts through a lowering of primary production and food chain support for wildlife.



Parameter	Average Clear	Average Dark
GPP (g $O_2/m^2/d$)	4.82	0.69
NPP (g $O_2/m^2/d$)	1.85	-2.91
CR (g $O_2/m^2/d$)	2.97	3.60
P/R Ratio	1.69	0.19
PAR (24hr) (mol/m^2/d)	23.61	10.32
GPP Efficiency (%)	2.05	0.64
GPP Efficiency (g O_2/mol)	0.25	0.08

FIGURE 68
Comparison of Wakulla Springs ecosystem metabolism parameters under different water clarity regimes. A clear water period existed up to April 2, 2009 and was followed by a dark water period due to heavy rains within the springshed.

Physical Factors Influencing Metabolism

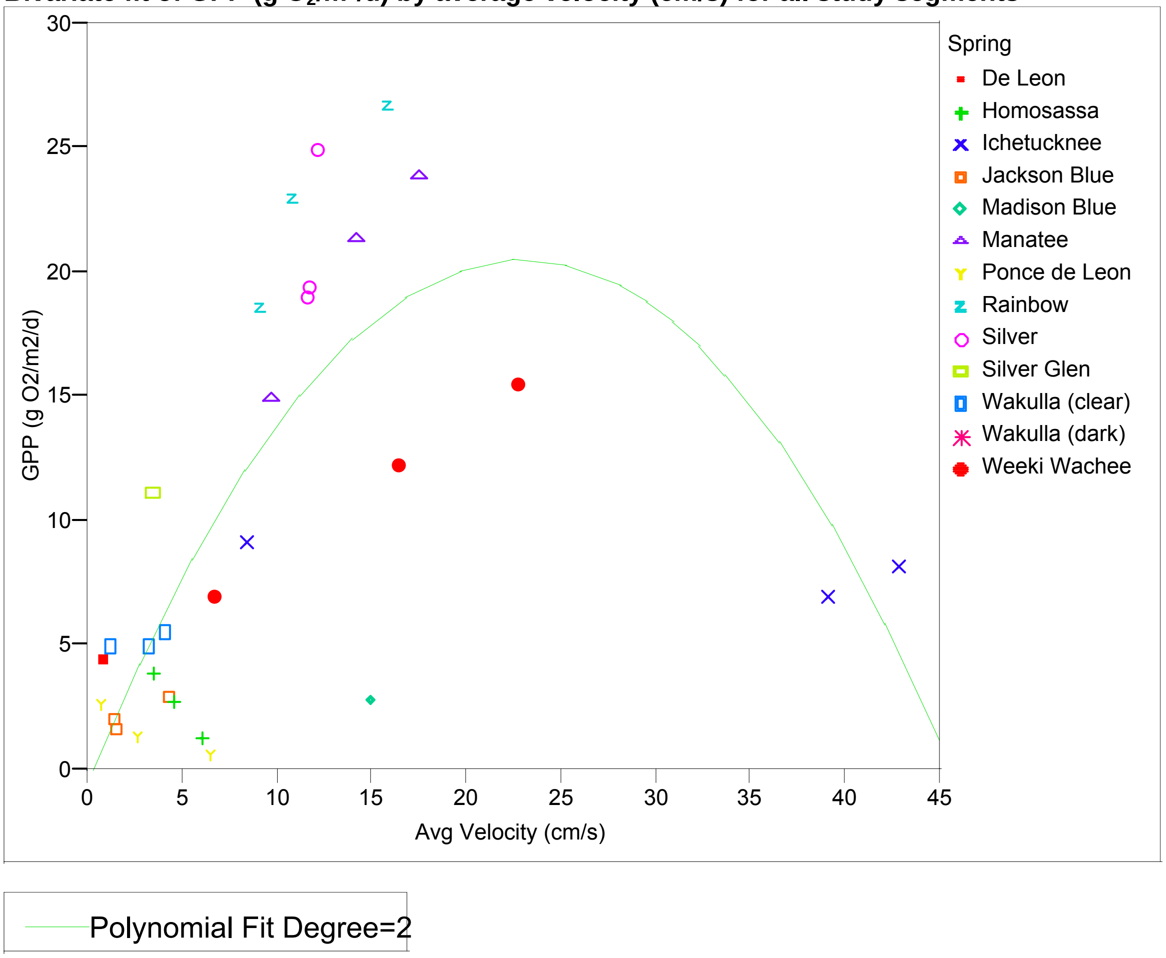
Physical factors affecting ecosystem metabolism were examined. It is known that water velocity has strong deterministic impacts on submersed aquatic vegetation (SAV). In a high-flow system, continuous flow reduces the residence time of the water and the likelihood of extensive phytoplankton development (Hynes 1970). Stream flow can also expel floating macrophytes such as water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*), that might otherwise block the light essential for SAV. Continuous flow supplies nutrients (including CO_2) and reduces the thickness of the boundary layer around leaves and increases the gradient for nutrient and gas diffusion (Westlake 1967). Stream velocity is also interrelated with sediment composition (Butcher 1933, Hynes 1970). Favorable sediments for macrophyte growth, such as sandy clays (Power 1996), may be scoured away at velocities greater than 30 cm/s (Hynes 1970). Sand substrates begin to give way to gravel and large rocks at stream velocities of 60 cm/s or greater (Butcher 1933).

Within the springs examined in this study, highest average velocity was observed in the lower run of the Ichetucknee (about 43 cm/s). This value appears well below that necessary to scour the substrate or dislodge rooted plants (see Butcher 1933). Nilsson (1987) reported that peak macrophyte species diversity was observed at surface velocities of 30 cm/s. Detrimental aspects of flow are generally encountered at higher velocities; Chambers *et al.* (1989) reported that plant biomass was inversely correlated with stream velocities between 1 to 100 cm/s. As flow rates increase, the ability of macrophytes to remain attached to the substrate is reduced. Large amounts of sand continuously shifting may also bury established macrophyte communities while remaining too unstable to allow re-colonization.

In spring ecosystems, SAV are key components of the primary producer community. The periphyton or epiphytic community is likely of equal importance, and much of this epiphytic community is found on the SAV community (both leaves of vascular plants and filaments of benthic algae). Examining the relationship between GPP and spring velocity and discharge supports the research findings discussed above in regard to SAV and stream velocity. Modeled GPP is positively correlated ($R^2 = 0.56$, $P < 0.0001$) to average spring velocity; at current velocities up to about 25 cm/s GPP increases, while at velocities greater than this, GPP declines (**Figure 69**). While it is clear that the polynomial fit illustrated in this figure provides a better fit to these data than a linear model ($R^2 = 0.15$), additional data within the range of average velocities between 25 and 40 cm/s are needed to determine if the measured response of the primary producers in Ichetucknee Springs is anomalous or is indeed indicative of a subsidy-stress effect of spring run velocity on GPP.

When the relationship between GPP and average discharge is examined, a linear model provides a relatively strong fit ($R^2 = 0.48$, $P < 0.0001$, **Figure 70**). From the point-of-view of SAV, stream velocity appears to be beneficial up to a certain point (around 30 cm/s) after which, physical conditions reduce habitat suitability. GPP seems to mimic this pattern, largely due to the role that SAV plays as a key component of primary production in spring ecosystems. Since discharge and velocity are generally positively correlated in spring habitats, the beneficial nature of increased discharge rates is expected on ecosystem metabolism (**Figure 70**). Although not shown, photosynthetic efficiency was similarly correlated to average velocity and discharge as discussed above.

Bivariate fit of GPP (g $O_2/m^2/d$) by average velocity (cm/s) for all study segments



Polynomial Fit Degree=2

GPP (g O2/m2/d) = 3.6012678 + 1.0151815 Avg Velocity (cm/s) - 0.0398747 (Avg Velocity (cm/s)-10.2933)^2

Summary of Fit

RSquare	0.556973
RSquare Adj	0.524156
Root Mean Square Error	5.788057
Mean of Response	10.08733
Observations (or Sum Wgts)	30

Analysis of Variance

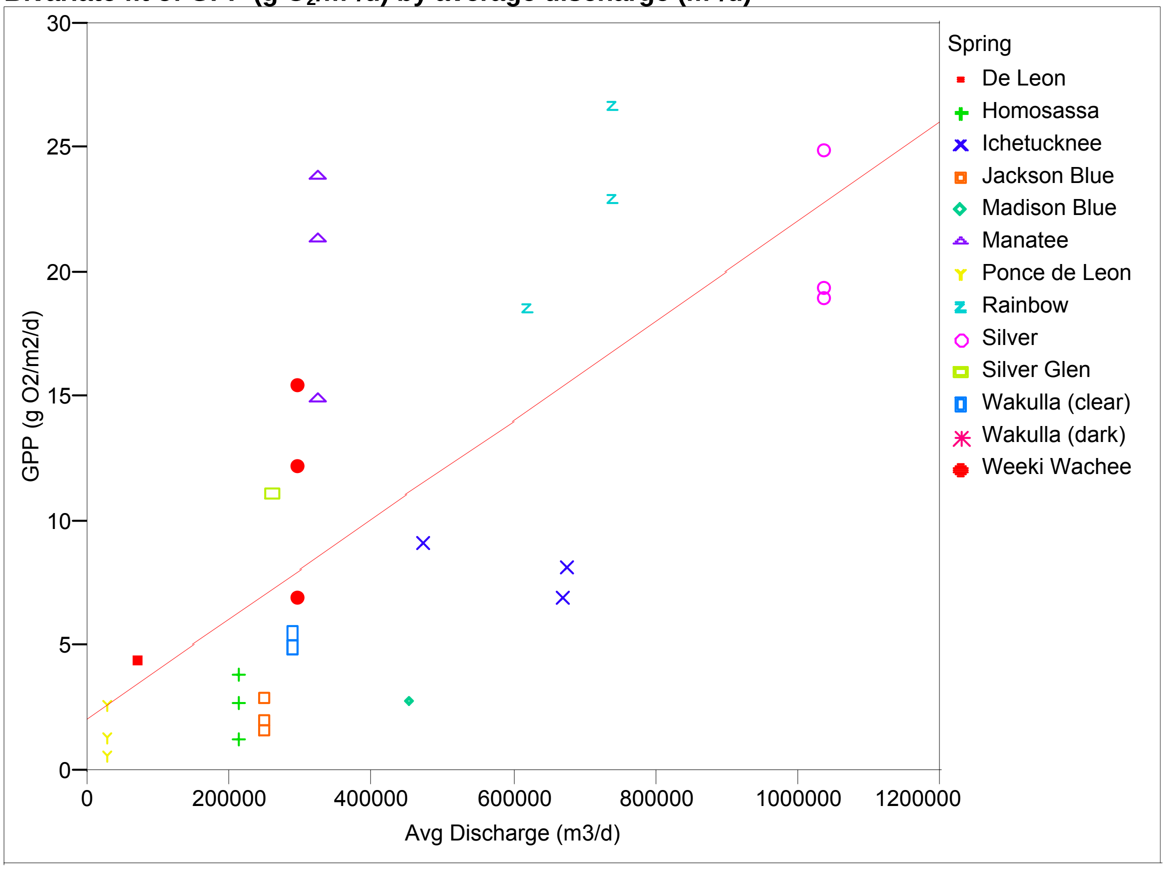
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1137.1900	568.595	16.9722
Error	27	904.5434	33.502	Prob > F
C. Total	29	2041.7334		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.6012678	1.670829	2.16	0.0402
Avg Velocity (cm/s)	1.0151815	0.176935	5.74	<.0001
(Avg Velocity (cm/s)-10.2933)^2	-0.039875	0.007668	-5.20	<.0001

FIGURE 69
Relationship between average velocity (cm/s) and GPP (g $O_2/m^2/d$) from pool, run, and combined study segments.

Bivariate fit of GPP (g $O_2/m^2/d$) by average discharge (m^3/d)



Linear Fit

Linear Fit

GPP (g O2/m2/d) = 2.0830632 + 0.00002 Avg Discharge (m3/d)

Summary of Fit

RSquare	0.481258
RSquare Adj	0.462732
Root Mean Square Error	6.150298
Mean of Response	10.08733
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	982.6009	982.601	25.9768
Error	28	1059.1325	37.826	Prob > F
C. Total	29	2041.7334		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.0830632	1.930607	1.08	0.2898
Avg Discharge (m3/d)	0.00002	0.000004	5.10	<.0001

FIGURE 70
Relationship between average spring discharge (m^3/d) and GPP (g $O_2/m^2/d$) from pool, run, and combined segments.

In previous studies of Florida's spring runs and streams, it was determined that light availability was the key determinant factor in biomass of submersed aquatic vegetation (SAV, the combination of vascular plants and filamentous algae) (Canfield and Hoyer 1988a, 1988b). We examined this relationship for the springs examined in this study and found it to be generally supported (non-significantly though, P = 0.15) for percent area coverage (PAC) and significantly (P = 0.035) for percent volume inhabited (PVI) of SAV (**Figures 71** and **72**). In both instances, riparian shading was negatively correlated to the amount of SAV (both aerial and vertical abundance). In the case of SAV PAC, the combined pool and run segment correlation to riparian shading had an R^2 value of 0.24 (**Figure 71**). In the case of SAV PVI and riparian shading, the combined pool and run segment correlation to riparian shading had an R^2 value of 0.45 (**Figure 72**).

Filamentous algae were a conspicuous component of the SAV communities in many of the springs examined in this study (see **Appendix I**). As such we examined the correlation between benthic filamentous algae thickness (cm) with riparian shading. In this case, no significant relationship was observed. This is likely due to the ability of algae to compensate for lower light levels better than vascular plants and the role that human recreation plays on the accumulation of filamentous algae in some spring pools.

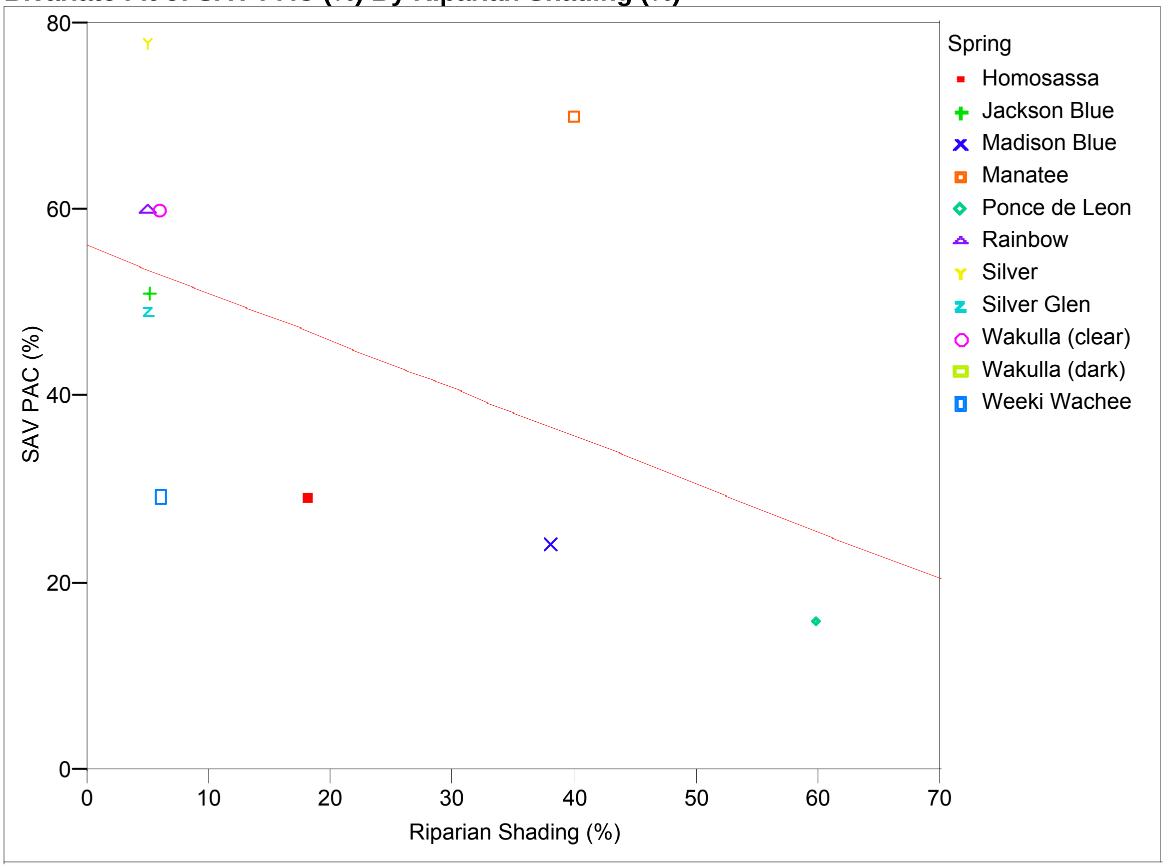
Examining the relationship between riparian shading and GPP reveals that these parameters were not strongly correlated (**Figure 73**). This implies that despite the negative relationship between SAV abundance and riparian shading, the gross primary productivity of the examined springs was not dependent on the degree of shading they experience. The relationships between SAV percent area covered (PAC) with GPP are examined in **Figures 74** to **76**. SAV PAC is significantly positively correlated to GPP in the pool segments (R^2 =

0.75, P = 0.0024, **Figure 74**), the combination of pool and run segments (R^2 = 0.49, P = 0.024, **Figure 75**), but not in the run segments alone (R^2 = 0.13, P = 0.27, **Figure 76**). The lack of a significant correlation between SAV PAC and GPP in the run segments may be due to the limited range of SAV PAC values; which mostly cluster around 75% to 85%. It should also be observed that it was not practical within the constraints of this project to separate the relative fractions of macrophytes and macroalgae in the SAV PAC estimates. The proportional contributions of these two classes of photosynthetic organisms on GPP in springs were not quantified in this study.

Examining the relationship between SAV percent volume inhabited (PVI) and GPP revealed no significant correlation between these parameters. This suggests that aerial plant coverage (PAC) is a more important factor than vertical plant abundance (*i.e.*, PVI). Examining the relationships between filamentous algae thickness and GPP reveals a weak but significant correlation (R^2 = 0.13, P = 0.046, **Figure 77**) when all data points (pool, run, and combination segment data) are examined.

Location=Pool & Run

Bivariate Fit of SAV PAC (%) By Riparian Shading (%)



Linear Fit

Linear Fit

SAV PAC (%) = 56.208564 - 0.5110939 Riparian Shading (%)

Summary of Fit

RSquare	0.236383
RSquare Adj	0.140931
Root Mean Square Error	19.50178
Mean of Response	46.6
Observations (or Sum Wgts)	10

Analysis of Variance

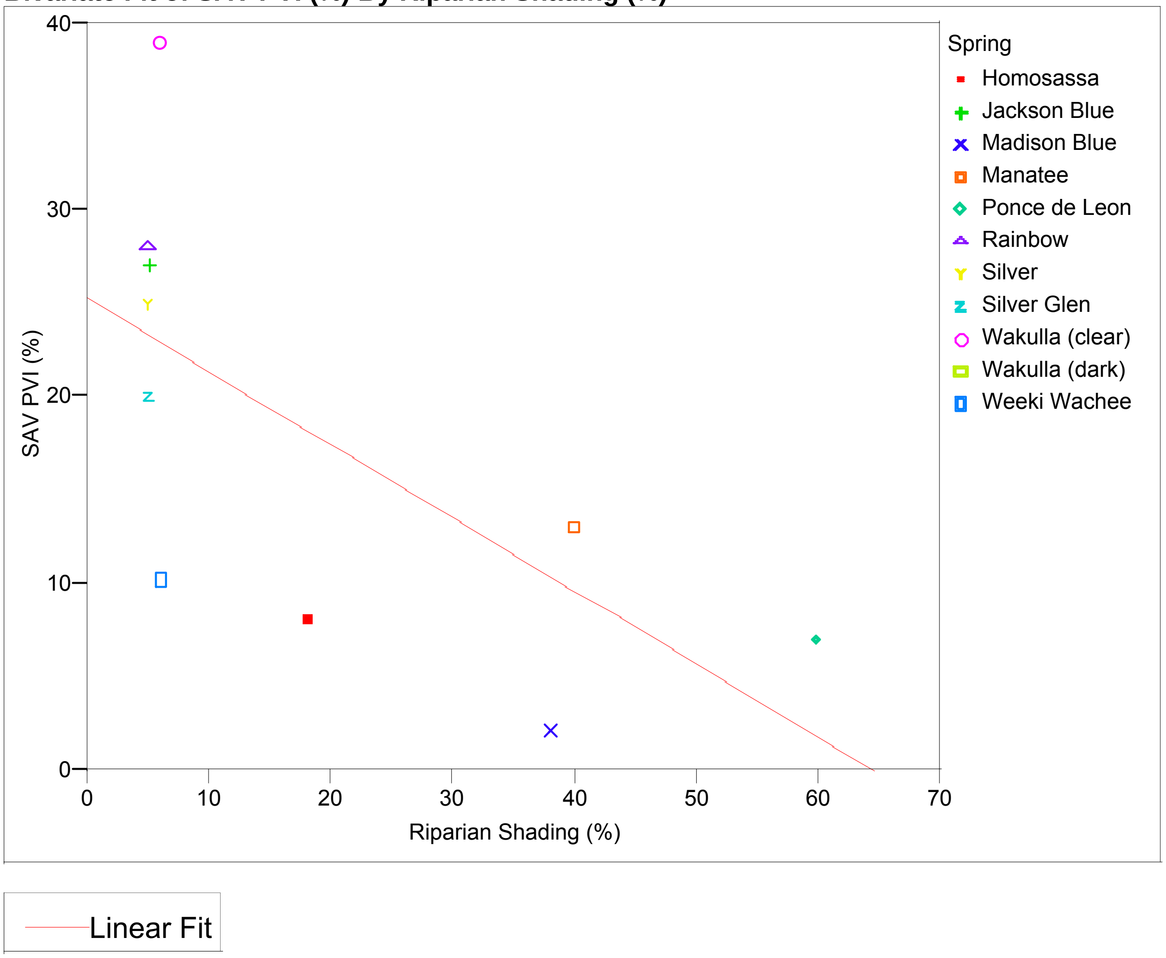
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	941.8438	941.844	2.4765
Error	8	3042.5562	380.320	Prob > F
C. Total	9	3984.4000		0.1542

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	56.208564	8.6783	6.48	0.0002
Riparian Shading (%)	-0.511094	0.324777	-1.57	0.1542

FIGURE 71
Relationship between riparian shading (%) and submersed aquatic vegetation (SAV) percent area coverage (PAC, %).

Location=Pool & Run
Bivariate Fit of SAV PVI (%) By Riparian Shading (%)



Linear Fit

SAV PVI (%) = 25.258154 - 0.3913912 Riparian Shading (%)

Summary of Fit

RSquare	0.445105
RSquare Adj	0.375744
Root Mean Square Error	9.277451
Mean of Response	17.9
Observations (or Sum Wgts)	10

Analysis of Variance

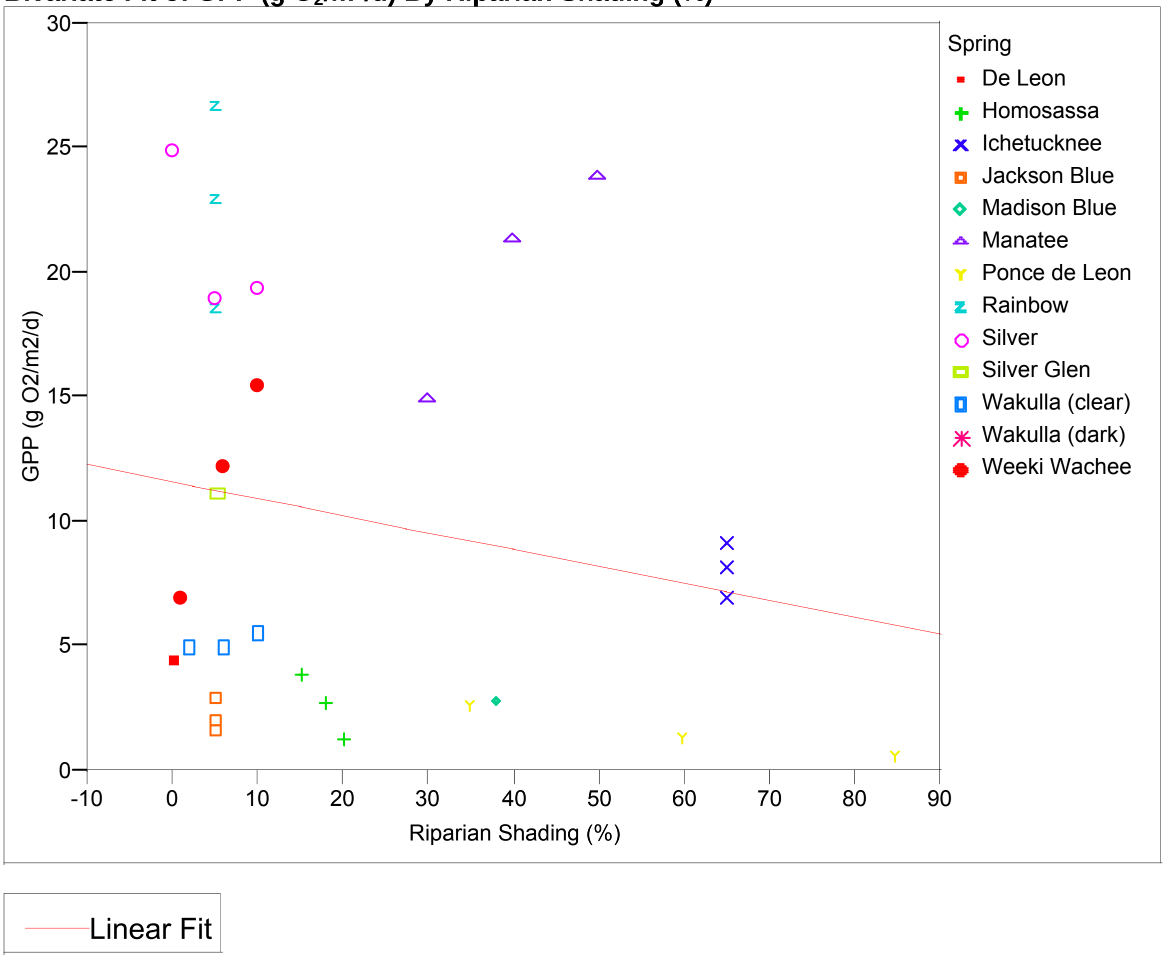
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	552.3312	552.331	6.4172
Error	8	688.5688	86.071	Prob > F
C. Total	9	1240.9000		0.0351

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	25.258154	4.128469	6.12	0.0003
Riparian Shading (%)	-0.391391	0.154504	-2.53	0.0351

FIGURE 72
Relationship between riparian shading (%) and submersed aquatic vegetation (SAV) percent volume inhabited (PVI, %).

Bivariate Fit of GPP (g $O_2/m^2/d$) By Riparian Shading (%)



Linear Fit

GPP (g O2/m2/d) = 11.607314 - 0.0679574 Riparian Shading (%)

Summary of Fit

RSquare	0.040006
RSquare Adj	0.005721
Root Mean Square Error	8.36671
Mean of Response	10.08733
Observations (or Sum Wgts)	30

Analysis of Variance

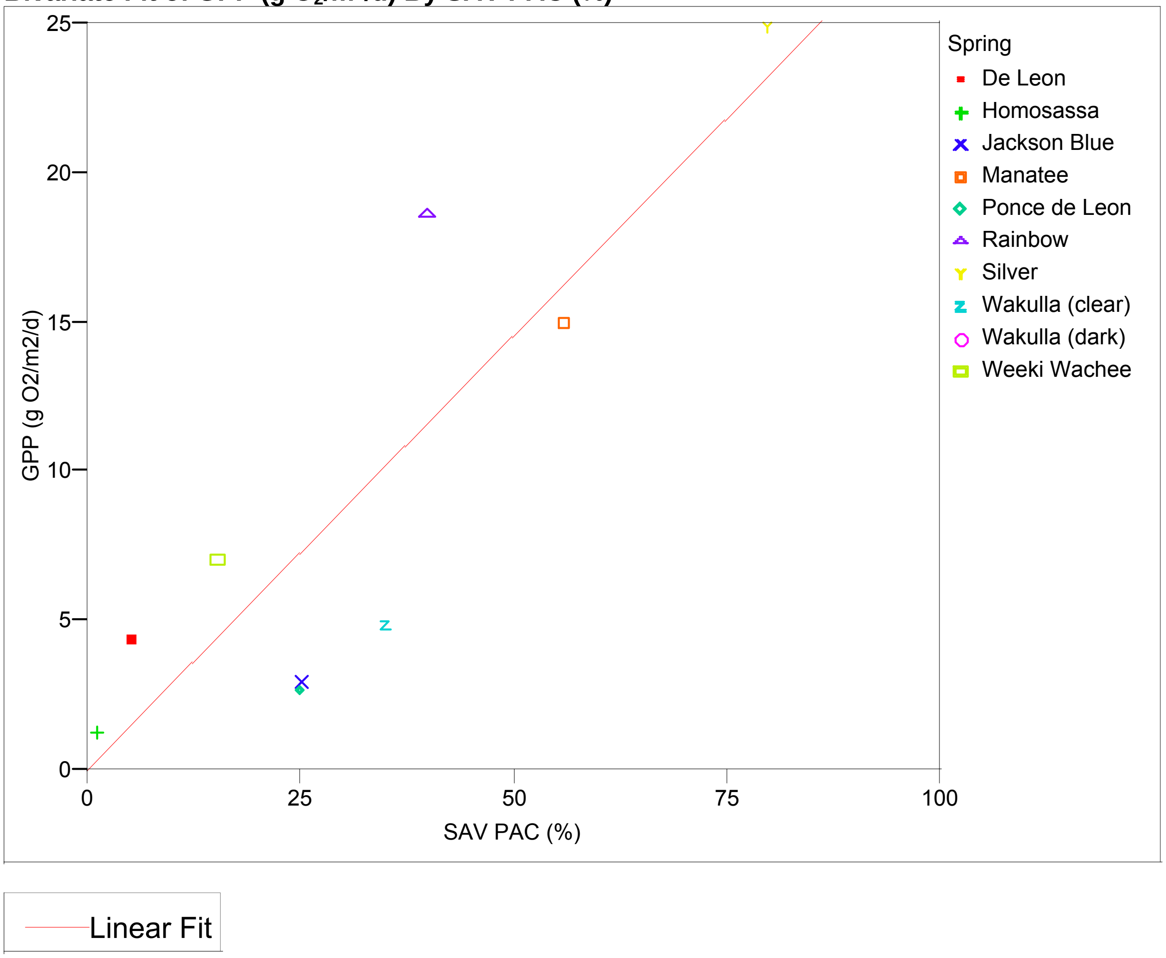
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	81.6821	81.6821	1.1669
Error	28	1960.0512	70.0018	Prob > F
C. Total	29	2041.7334		0.2893

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.607314	2.076864	5.59	<.0001
Riparian Shading (%)	-0.067957	0.062911	-1.08	0.2893

FIGURE 73
Relationship between riparian shading (%) and GPP (g $O_2/m^2/d$) from pool, run, and combined segments.

Location=Pool
Bivariate Fit of GPP (g $O_2/m^2/d$) By SAV PAC (%)



Linear Fit

GPP (g O2/m2/d) = -0.046259 + 0.2898806 SAV PAC (%)

Summary of Fit

RSquare	0.754034
RSquare Adj	0.718896
Root Mean Square Error	4.436323
Mean of Response	9.036667
Observations (or Sum Wgts)	9

Analysis of Variance

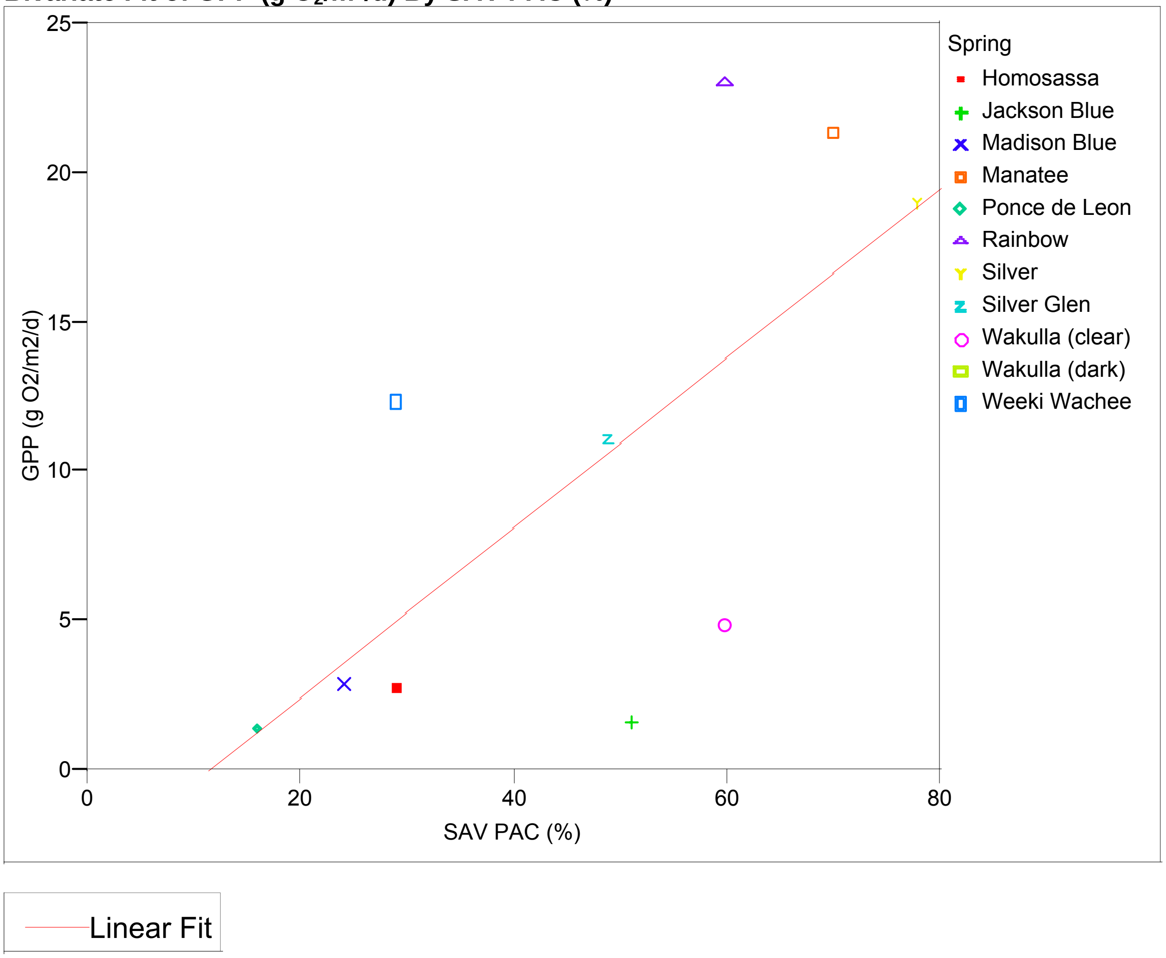
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	422.33867	422.339	21.4593
Error	7	137.76673	19.681	Prob > F
C. Total	8	560.10540		0.0024

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.046259	2.45586	-0.02	0.9855
SAV PAC (%)	0.2898806	0.062577	4.63	0.0024

FIGURE 74
Relationship between SAV Percent Area Coverage (PAC, %) and GPP (g $O_2/m^2/d$) from spring pool segments.

Location=Pool & Run
Bivariate Fit of GPP (g $O_2/m^2/d$) By SAV PAC (%)



Linear Fit

GPP (g O2/m2/d) = -3.278304 + 0.284749 SAV PAC (%)

Summary of Fit

RSquare	0.488926
RSquare Adj	0.425042
Root Mean Square Error	6.497095
Mean of Response	9.991
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	323.06314	323.063	7.6533
Error	8	337.69795	42.212	Prob > F
C. Total	9	660.76109		0.0244

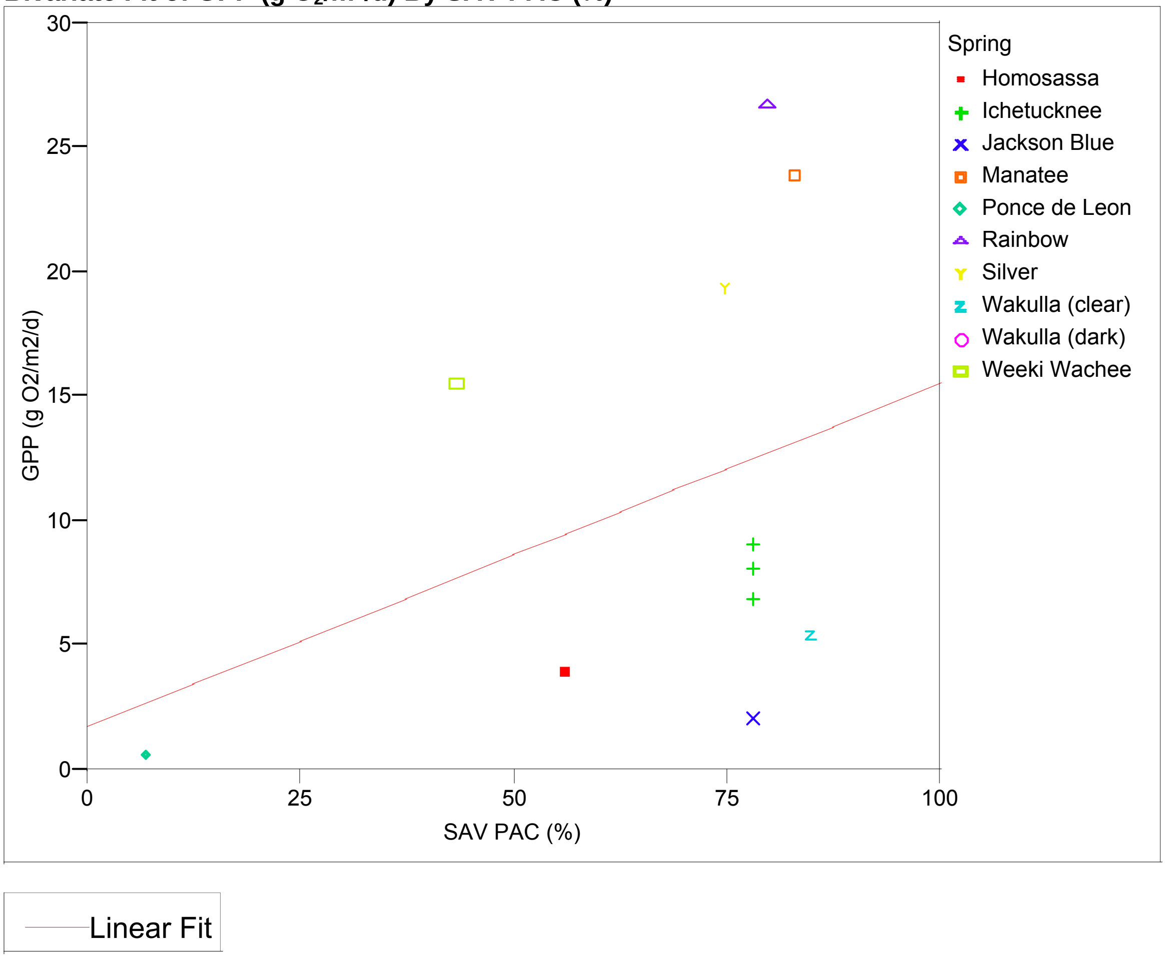
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3.278304	5.218003	-0.63	0.5473
SAV PAC (%)	0.284749	0.102929	2.77	0.0244

FIGURE 75
Relationship between SAV Percent Area Coverage (PAC, %) and GPP (g $O_2/m^2/d$) from spring pool and run segments combined.

Location=Run

Bivariate Fit of GPP (g $O_2/m^2/d$) By SAV PAC (%)



Linear Fit

GPP (g O2/m2/d) = 1.7208914 + 0.1382594 SAV PAC (%)

Summary of Fit

RSquare	0.13347
RSquare Adj	0.037189
Root Mean Square Error	8.781701
Mean of Response	11.03455
Observations (or Sum Wgts)	11

Analysis of Variance

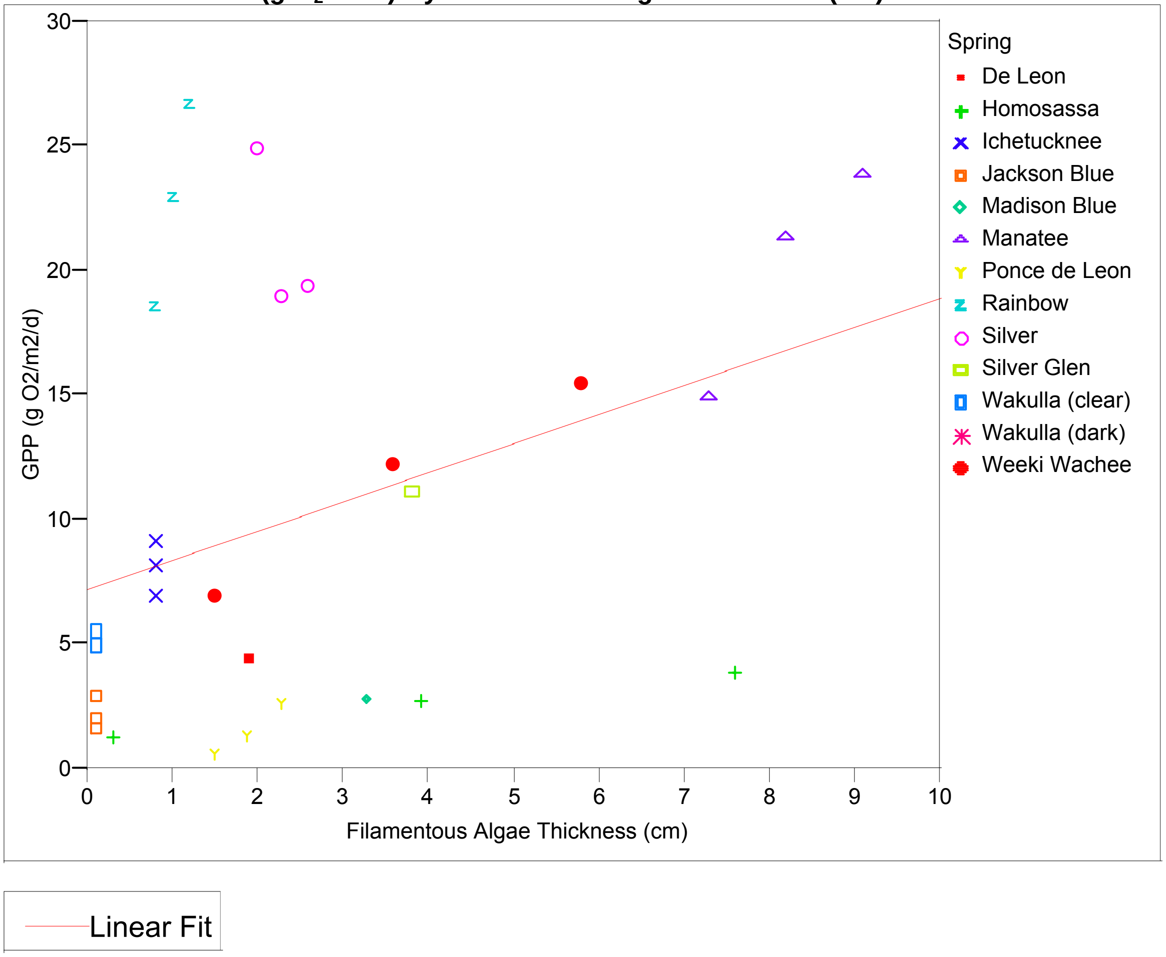
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	106.90516	106.905	1.3862
Error	9	694.06451	77.118	Prob > F
C. Total	10	800.96967		0.2692

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.7208914	8.34179	0.21	0.8411
SAV PAC (%)	0.1382594	0.117429	1.18	0.2692

FIGURE 76
Relationship between SAV Percent Area Coverage (PAC, %) and GPP (g $O_2/m^2/d$) from spring run segments.

Bivariate Fit of GPP (g $O_2/m^2/d$) By Filamentous Algae Thickness (cm)



Linear Fit

GPP (g O2/m2/d) = 7.1547342 + 1.1746058 Filamentous Algae Thickness (cm)

Summary of Fit

RSquare	0.134778
RSquare Adj	0.103877
Root Mean Square Error	7.942995
Mean of Response	10.08733
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	275.1805	275.180	4.3616
Error	28	1766.5529	63.091	Prob > F
C. Total	29	2041.7334		0.0460

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.1547342	2.018616	3.54	0.0014
Filamentous Algae Thickness (cm)	1.1746058	0.562429	2.09	0.0460

FIGURE 77
Relationship between filamentous algae thickness (cm) and GPP (g $O_2/m^2/d$) from pool, run, and combination segments.

Chemical Factors Influencing Metabolism

While not strictly chemical parameters, the relationships between dissolved oxygen and specific conductance with productivity were examined. Dissolved oxygen concentrations (at the upstream portion of the segment) were found to have no significant correlation with GPP (g $O_2/m^2/d$). This suggests that the primary productivity of a spring ecosystem is not dependent of the concentration of oxygen coming out of the spring vents. This is not unexpected, given that aquatic primary producers are less dependent on oxygen concentrations, and more influenced by light energy and carbon dioxide and macro nutrients for productivity. As many of the springs examined in this study discharge water with low oxygen concentrations (see **Appendix G**), their ability to support animal life would be severely diminished if it were not for the presence of primary producers (vascular plants and algae).

The relationship between specific conductance (at the upstream portion of the segment) and productivity was found to have a non-significant correlation with GPP (g $O_2/m^2/d$) and not examined further.

The relationship between total phosphorus concentrations (at the upstream portion of the segment) and productivity in the combined pool and run segments was found to have a non-significant positive correlation with GPP (**Figure 78**). While phosphorus concentrations are commonly positively correlated to aquatic ecosystem productivity, this relationship is typically observed in phytoplankton-dominated systems. This finding indicates that phosphorus is not limiting productivity in these SAV-dominated spring systems in spite of the high N:P ratios described earlier.

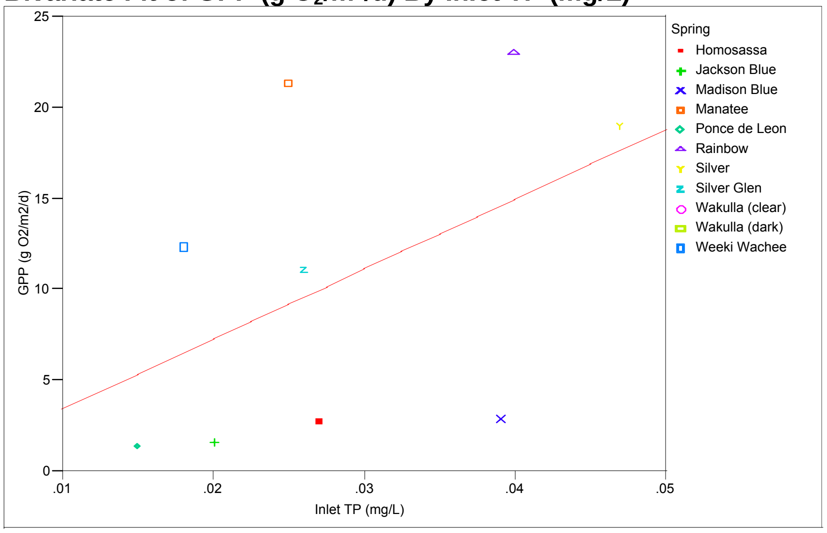
None of the studied springs had elevated chlorophyll *a* concentrations that would indicate the occurrence of a significant rate of productivity attributable to pseudo-plankton. Within these study springs there was no significant correlation between nitrogen or phosphorus concentrations and the abundance of primary producers. This was likely due to vascular plants collecting most of their required nutrients from sediments and the surplus of nutrients to filamentous algae and vascular plant leaves by the continuous flow of water passing through these ecosystems.

The relationship between nitrate+nitrite nitrogen (NO_X-N) concentrations (at the upstream portion of the segment) and productivity were found to have a significant correlation with GPP (**Figures 83** to **85**). When examining only pool segments the correlation was best modeled by a second degree polynomial fit (R^2 = 0.66, P = 0.069, **Figure 79**). When examining only run segments, the same modeled fit had even stronger correlation and significance level (R^2 = 0.94, P = 0.0002, **Figure 80**). Examining all data points (pool, run, and a combination), the relationship between (NO_X-N concentrations and GPP was significant as well (R^2 = 0.57, P = 0.0001, **Figure 81**). While it is clear that the polynomial fit illustrated in these figures provides a better fit to these data than a linear model (pool R^2 = 0.05; run R^2 = 0.04; and combined R^2 = 0.04), additional data within the NO_X-N range between 2 and 3 mg/L are needed to determine if the observed response of the primary producers in artesian springs is anomalous or is indicative of a subsidy-stress effect of NO_X-N concentration on GPP.

There were no significant relations observed in this study between net primary productivity (NPP) and nitrate-nitrite concentrations.

Location=Pool & Run

Bivariate Fit of GPP (g $O_2/m^2/d$) By Inlet TP (mg/L)



Linear Fit

Linear Fit

GPP (g O2/m2/d) = -0.427647 + 384.97595 Inlet TP (mg/L)

Summary of Fit

RSquare	0.227863
RSquare Adj	0.117558
Root Mean Square Error	8.343155
Mean of Response	10.56556
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	143.79322	143.793	2.0658
Error	7	487.25760	69.608	Prob > F
C. Total	8	631.05082		0.1938

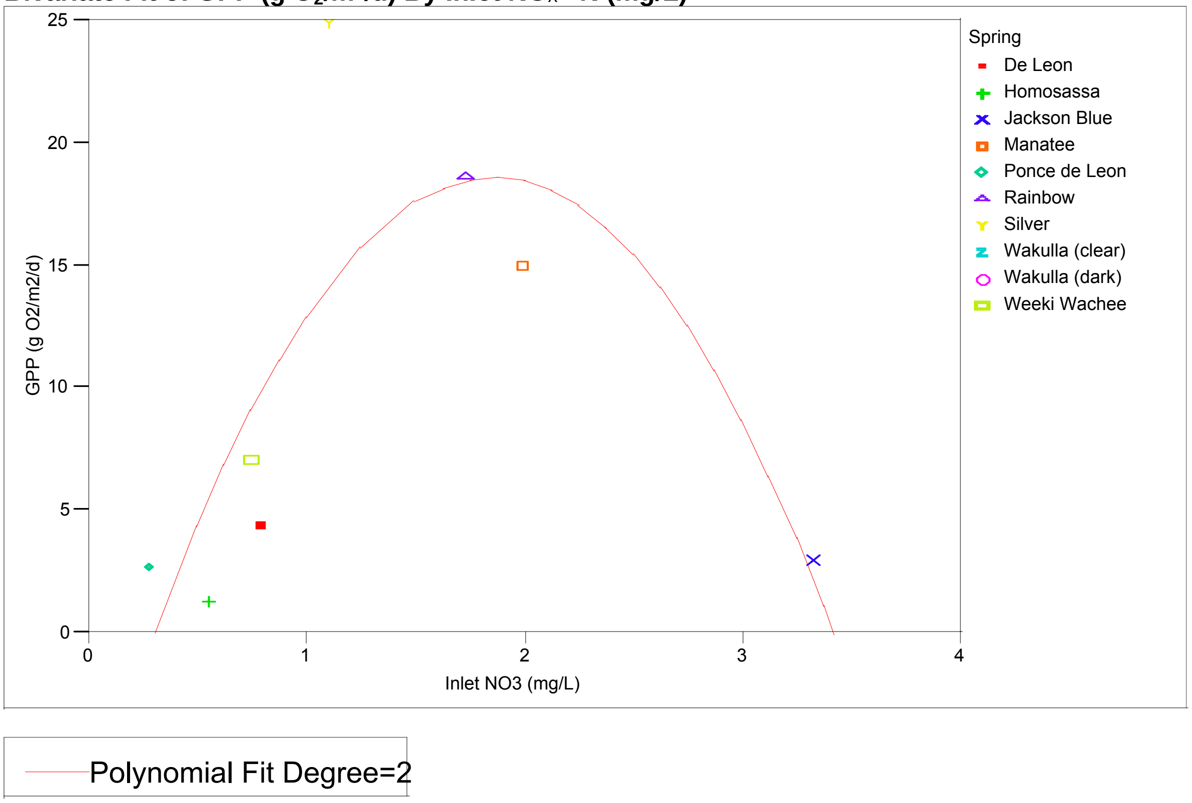
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.427647	8.138564	-0.05	0.9596
Inlet TP (mg/L)	384.97595	267.8519	1.44	0.1938

FIGURE 78
Relationship between inlet total phosphorus concentration (mg/L) and GPP (g $O_2/m^2/d$) for combined pool and run segments.

Location=Pool

Bivariate Fit of GPP (g $O_2/m^2/d$) By Inlet NO_X –N (mg/L)



Polynomial Fit Degree=2

GPP (g O2/m2/d) = 5.1049266 + 8.4761271 Inlet NO3 (mg/L) - 7.6601462 (Inlet NO3 (mg/L)-1.3125)^2

Summary of Fit

RSquare	0.656369
RSquare Adj	0.518917
Root Mean Square Error	6.093087
Mean of Response	9.5625
Observations (or Sum Wgts)	8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	354.56881	177.284	4.7752
Error	5	185.62854	37.126	Prob > F
C. Total	7	540.19735		0.0692

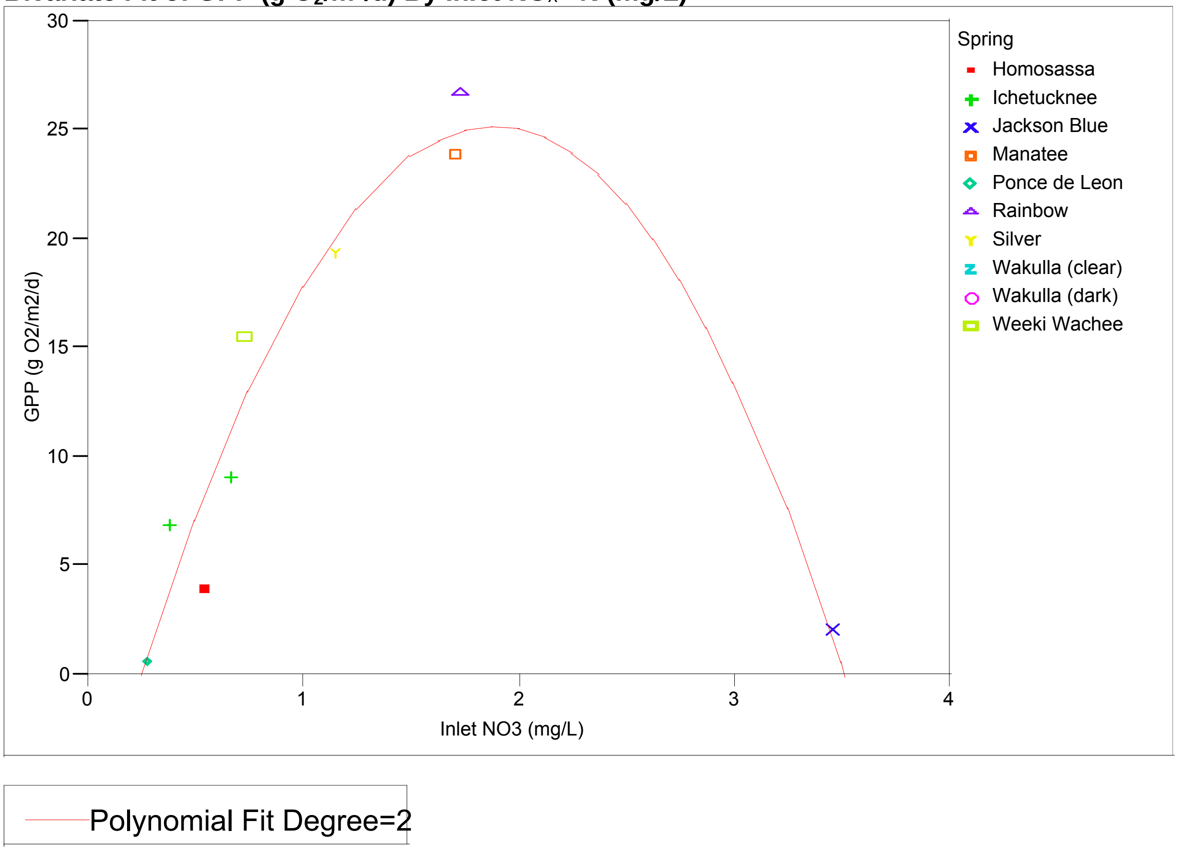
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.1049266	3.833371	1.33	0.2404
Inlet NO3 (mg/L)	8.4761271	3.315519	2.56	0.0509
(Inlet NO3 (mg/L)-1.3125)^2	-7.660146	2.516619	-3.04	0.0286

FIGURE 79
Relationship between inlet nitrate+nitrite (NO_X-N) concentration (mg/L) and GPP (g $O_2/m^2/d$) from pool segments.

Location=Run

Bivariate Fit of GPP (g $O_2/m^2/d$) By Inlet NO_X –N (mg/L)



Polynomial Fit Degree=2

GPP (g O2/m2/d) = 4.6982393 + 13.360071 Inlet NO3 (mg/L) - 9.4442372 (Inlet NO3 (mg/L)-1.18)^2

Summary of Fit

RSquare	0.939569
RSquare Adj	0.919426
Root Mean Square Error	2.753443
Mean of Response	11.98556
Observations (or Sum Wgts)	9

Analysis of Variance

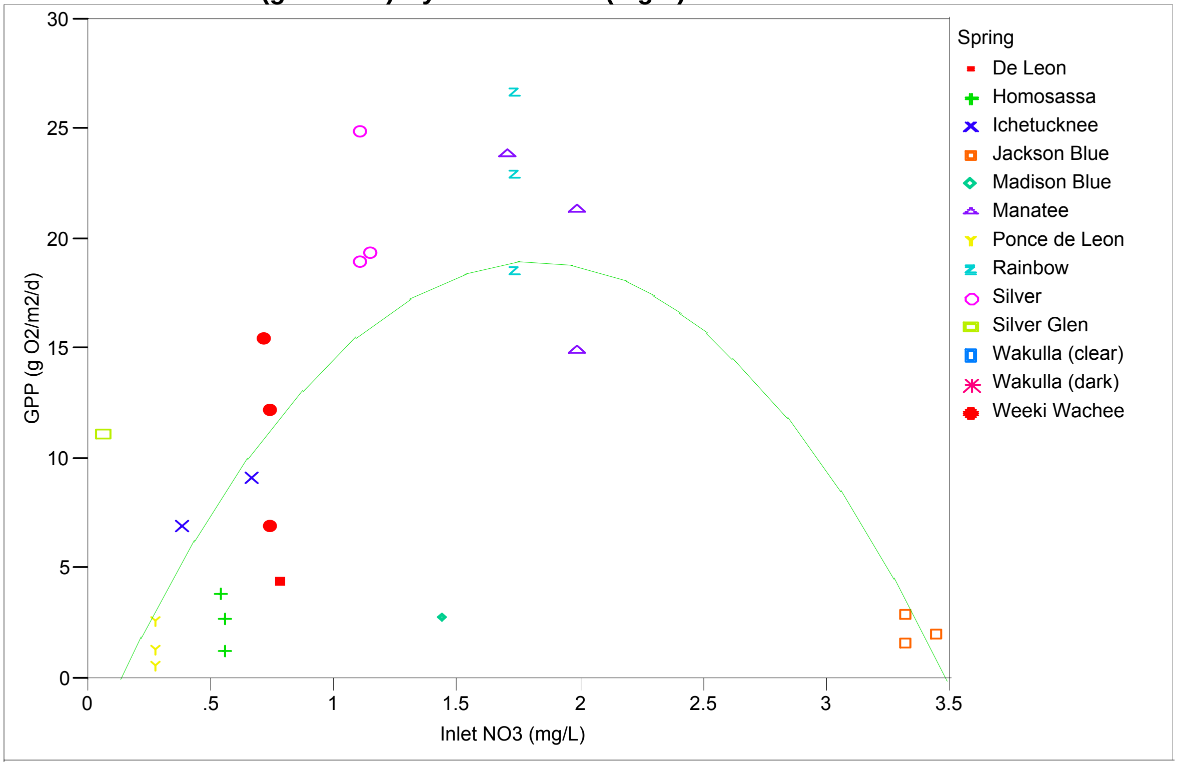
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	707.25373	353.627	46.6437
Error	6	45.48869	7.581	Prob > F
C. Total	8	752.74242		0.0002

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.6982393	1.582292	2.97	0.0250
Inlet NO3 (mg/L)	13.360071	1.586477	8.42	0.0002
(Inlet NO3 (mg/L)-1.18)^2	-9.444237	0.988196	-9.56	<.0001

FIGURE 80
Relationship between inlet nitrate+nitrite (NO_X-N) concentration (mg/L) and GPP (g $O_2/m^2/d$) from run segments.

Bivariate Fit of GPP (g O_2/m^2/d) By Inlet NO_X –N (mg/L)



Polynomial Fit Degree=2

Polynomial Fit Degree=2

GPP (g O2/m2/d) = 7.2248569 + 7.6871145 Inlet NO3 (mg/L) - 6.7154031 (Inlet NO3 (mg/L)-1.24346)^2

Summary of Fit

RSquare	0.566616
RSquare Adj	0.52893
Root Mean Square Error	6.060575
Mean of Response	10.74846
Observations (or Sum Wgts)	26

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1104.5142	552.257	15.0354
Error	23	844.8032	36.731	Prob > F
C. Total	25	1949.3173		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.2248569	2.00401	3.61	0.0015
Inlet NO3 (mg/L)	7.6871145	1.755853	4.38	0.0002
(Inlet NO3 (mg/L)-1.24346)^2	-6.715403	1.23835	-5.42	<.0001

FIGURE 81
Relationship between inlet nitrate+nitrite (NO_X-N) concentration (mg/L) and GPP (g O_2/m^2/d) from pool, run, and combined segments.

The observed relationship between nitrate-nitrite concentrations and GPP in springs fits the subsidy-stress model proposed by E.P. Odum *et al.* (1979). This concept originated in the paper by E. P. Odum *et al*. titled: Perturbation Theory and the Subsidy-Stress Gradient, in which the model of "too much of a good thing" is examined in the context of ecosystem response to perturbation (**Figure 82**). An example of a subsidy-stress gradient is the productivity of hardwood forested swamps in response to flooding, in which forested swamp productivity was observed to increase under seasonal flooding conditions but to decline under permanent flooding (Conner and Day 1992). This model describes the whole-system effects of many stressors as being positive at lower levels (subsidy) and negative at higher levels (stress).

It is important to remember that thresholds exist for the capacity of all aquatic ecosystems to productively assimilate increased nutrient loads and that if these thresholds are exceeded, harmful ecological consequences may occur. With regard to spring ecosystems, it is likely that a variety of physical, biological, and chemical inputs may operate individually or simultaneously within subsidy-stress gradients. For instance, stream velocity can replace nutrients and remove waste products at low velocities, but is capable of scouring at high velocities, and grazing of primary producers may promote algal productivity at moderate levels but a reduction in primary production at higher levels. Knight (1980) found evidence of this principal (often referred to in the current literature as hormesis) in a variety of aquatic ecosystems, including Silver Springs where he quantified the effects of herbivorous snails, carnivorous fish, and a trace metal (elemental cadmium) on primary productivity in stream mesocosms.

For this 12 spring data set it appears that increasing average inflow nitrate-nitrite nitrogen concentrations in these springs up to approximately 1.5 mg/L were stimulatory. Earlier work conducted at two impacted springs and spring runs in central Florida (Wekiwa and Rock) reported an apparent stress effect of nitrate on GPP (WSI 2007a) with no observation of the apparent stimulatory affect at lower or intermediate concentrations recorded in this study. In terms of assessing impairment of spring ecosystems by nitrate, this relationship needs additional quantification and validation by continuing studies at these and additional springs that encompass the entire range of observed nitrate concentrations.

A large amount of inherent variability occurs in measures of whole ecosystem productivity as well as in other metrics of spring structure and function. Robust data sets are needed to identify the amount of variability and the cause-and-effect relationships between independent and dependent variables. Such a data set over a range of springs does not yet exist. Never-the-less, the relationship observed in this initial sample of large artesian springs provides the basis for developing hypotheses needed to direct future spring research efforts. Based on the data collected in this study it is hypothesized that spring ecosystems respond to nitrate-nitrite nitrogen concentrations along a subsidy-stress gradient. At extremely low concentrations overall system productivity of plant and animal life is low; as nutrient concentrations increase, so too does primary and secondary productivity, but at some point, productivity may decrease. Within aquatic ecosystems, nutrient subsidy-stress gradients are likely to have unique performance curves for primary producers by functional group, *i.e.* algae vs. vascular plant, or even by species within these groups. Additional data collections using holistic measures such as GPP are recommended to further test this hypothetical construct or to offer alternate interpretations of spring function as related to chemical pollutants.

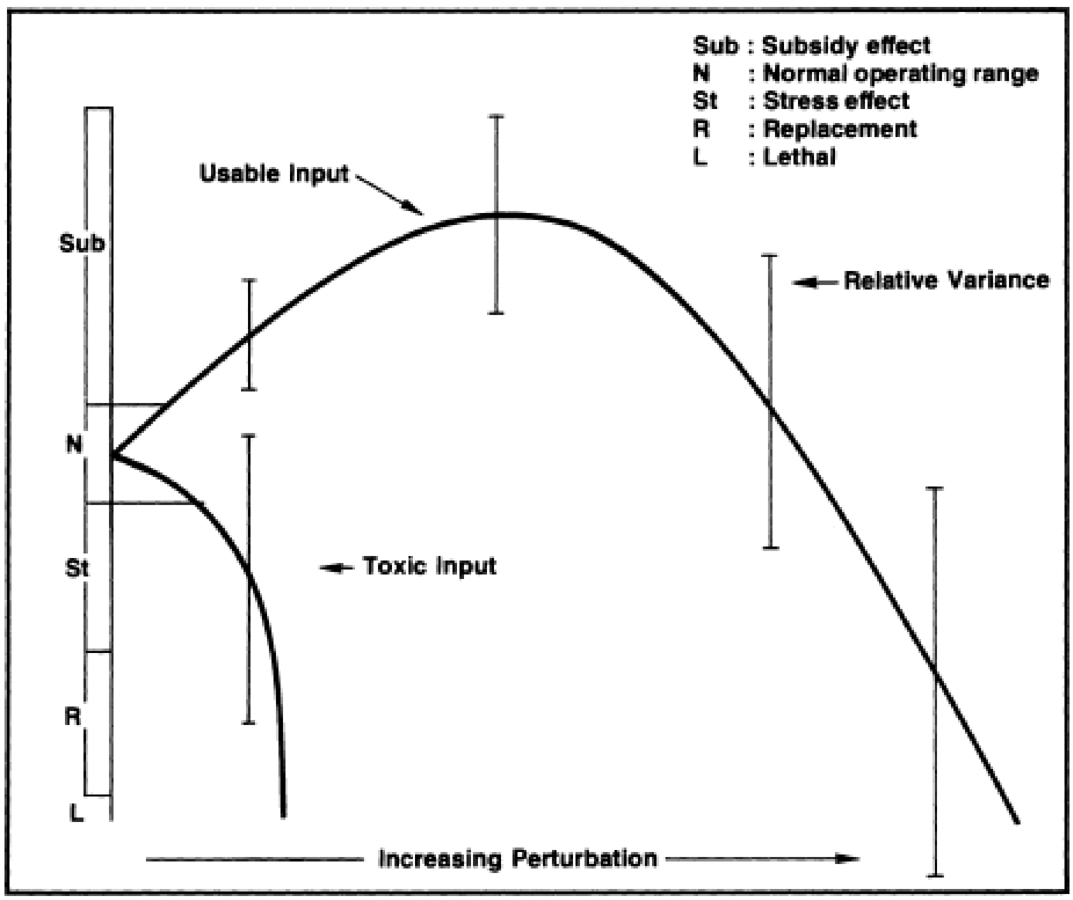


FIGURE 82
A hypothetical example of two types of inputs and their resulting ecosystem perturbations due to increasing input levels. Nutrients and nitrate in particular could be viewed as an example of a usable input (top curve), which have a subsidy effect on ecosystem productivity to a point beyond which stress is incurred (from E. P. Odum *et al*. 1979).

Productivity and Animal Communities

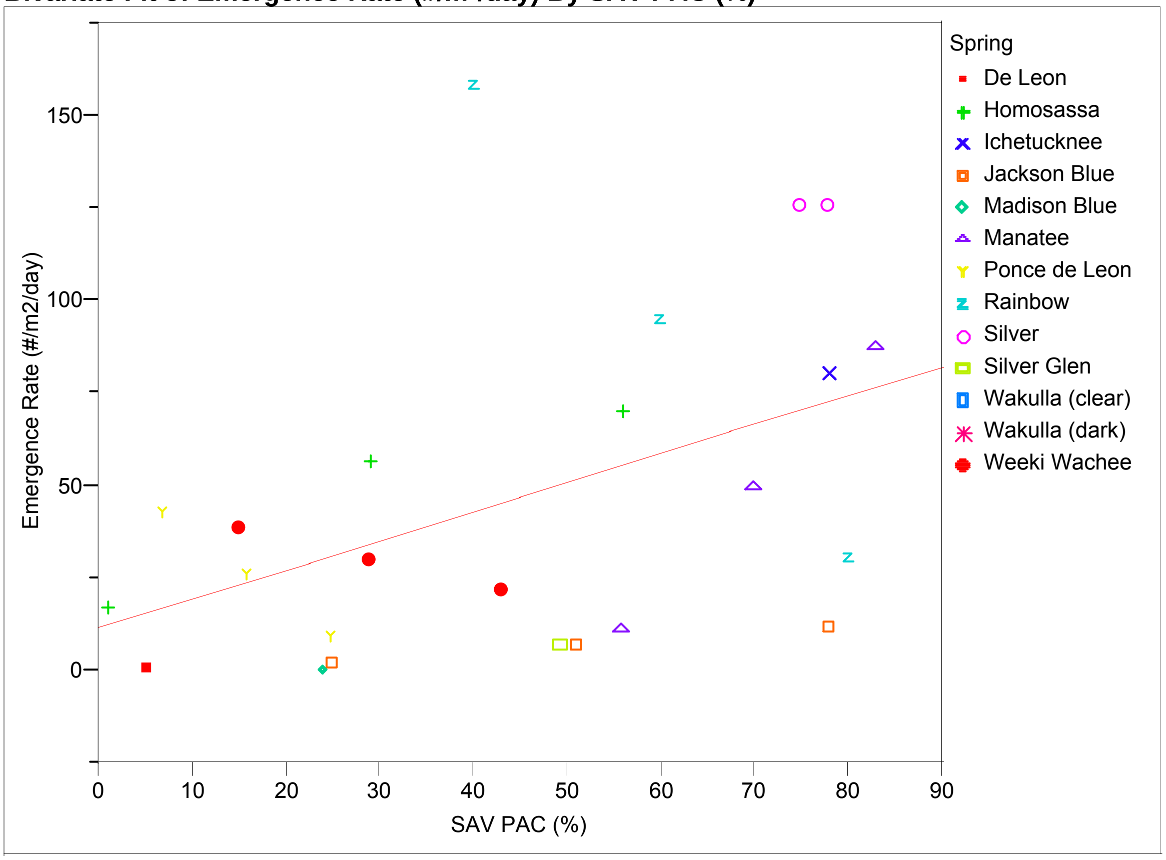
Average insect emergence rates measured at these twelve springs in this study were found to be higher downstream in the spring runs (44 organisms/m^2/d) than upstream in the spring pools (26 organisms/m^2/d). This difference is presumably due to the observed higher GPP downstream in these spring runs (see discussion below). A general increase in insect emergence rates using these same methods was previously noted at Silver Springs (Munch *et al.* 2006). The overall average insect emergence rate measured during the twelve-month Silver Springs study was about 67 organisms/m^2/d (Munch *et al.* 2006). That study also noted that insect emergence rates did not show a significant seasonal response.

The relationship between aquatic insect emergence rates and SAV percent area coverage was examined and found to be significantly positively correlated (R^2 = 0.24, P = 0.012, **Figure 83**). This suggests that abundant aquatic insect populations are enhanced by abundant SAV. This is intuitive, given that the aquatic (immature) life stages of these insects are typically composed of shredder, filter, grazer, and gather feeding groups (Steigerwalt 2005).

Insect emergence as a function of GPP (g O_2/m^2/d) was observed to be significantly correlated (R^2 = 0.28, P = 0.006, **Figure 84**). Again this relationship is expected given the positive correlations between SAV and GPP, and aquatic insects and SAV. From an ecosystem perspective, higher levels of gross primary production (GPP) should support higher production rates of primary consumers, of which aquatic insects (and other aquatic invertebrates) play a large role.

Insect emergence as a function of discharge was also observed to be significantly positively correlated (R^2 = 0.50, P = 0.0001, **Figure 85**). This suggests that bigger springs produce more aquatic insects per unit area, likely a function of the greater abundance of SAV found in the larger spring systems studied. Many of the large springs were sampled during the summer, making it uncertain whether size or season was the primary determinant of insect emergence rate. See **Appendix J** for insect emergence by date of sampling.

Bivariate Fit of Emergence Rate (#/m²/day) By SAV PAC (%)



Linear Fit

Linear Fit

Emergence Rate (#/m2/day) = 11.329143 + 0.7885617 SAV PAC (%)

Summary of Fit

RSquare	0.235845
RSquare Adj	0.204005
Root Mean Square Error	39.43769
Mean of Response	48.60385
Observations (or Sum Wgts)	26

Analysis of Variance

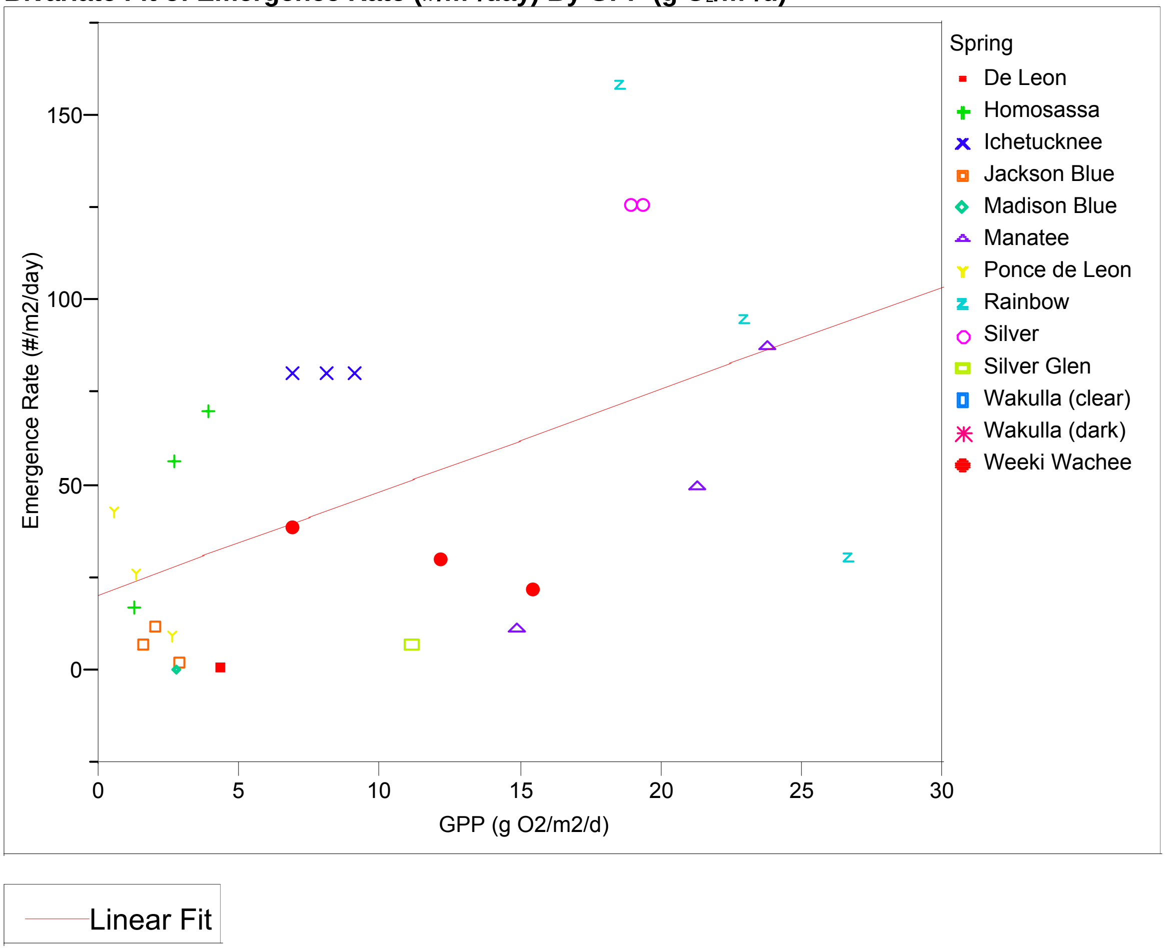
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11520.707	11520.7	7.4072
Error	24	37327.963	1555.3	Prob > F
C. Total	25	48848.670		0.0119

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.329143	15.72877	0.72	0.4783
SAV PAC (%)	0.7885617	0.289739	2.72	0.0119

FIGURE 83
Relationship between SAV percent area coverage (PAC, %) and insect emergence rates (#/m²/day).

Bivariate Fit of Emergence Rate ($\#/m^2/day$) By GPP ($g\ O_2/m^2/d$)



Linear Fit

Emergence Rate (#/m2/day) = 20.492402 + 2.7828874 GPP (g O2/m2/d)

Summary of Fit

RSquare	0.276752
RSquare Adj	0.246616
Root Mean Square Error	38.36759
Mean of Response	48.60385
Observations (or Sum Wgts)	26

Analysis of Variance

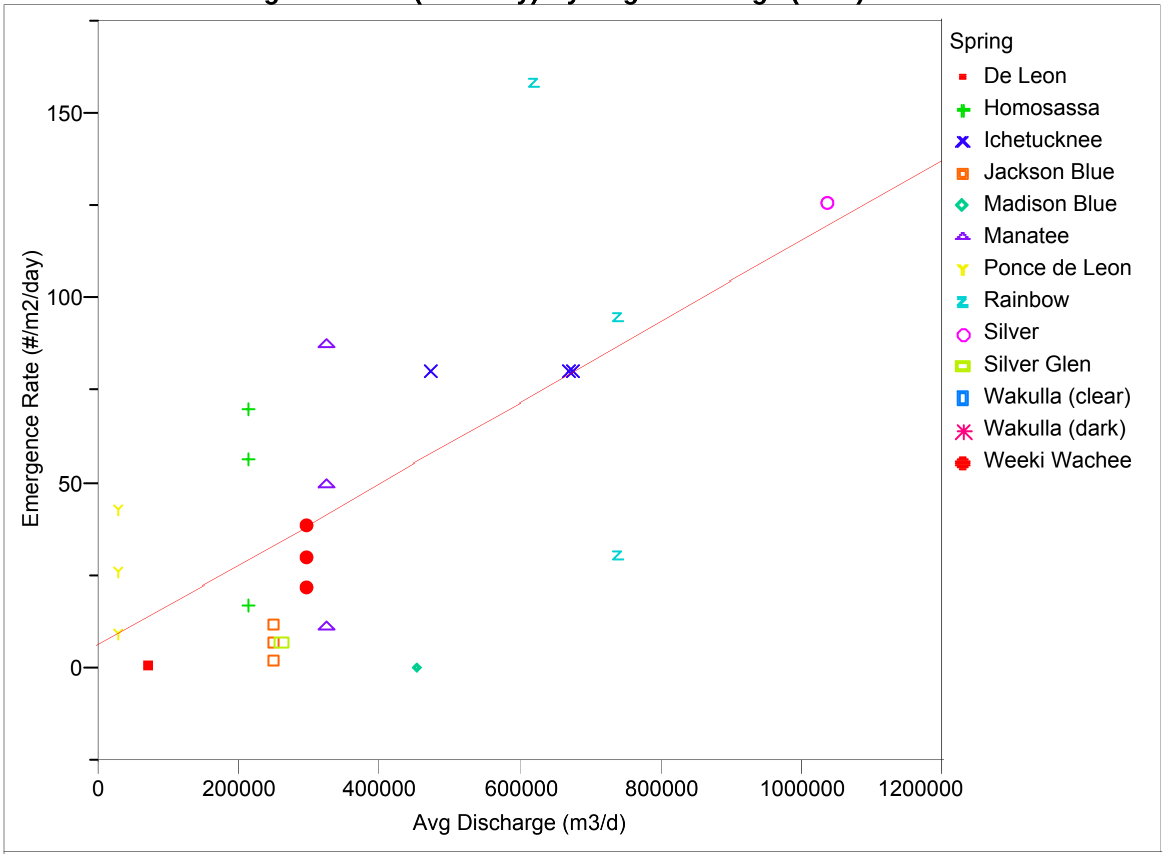
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	13518.944	13518.9	9.1836
Error	24	35329.726	1472.1	Prob > F
C. Total	25	48848.670		0.0058

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	20.492402	11.94439	1.72	0.0991
GPP (g O2/m2/d)	2.7828874	0.918309	3.03	0.0058

FIGURE 84
Relationship between GPP ($g\ O_2/m^2/d$) and insect emergence rates ($\#/m^2/day$).

Bivariate Fit of Emergence Rate (#/m^2/day) By Avg. Discharge (m^3/d)



Linear Fit

Linear Fit

Emergence Rate (#/m2/day) = 5.905202 + 0.0001097 Avg Discharge (m3/d)

Summary of Fit

RSquare	0.496804
RSquare Adj	0.475837
Root Mean Square Error	32.0029
Mean of Response	48.60385
Observations (or Sum Wgts)	26

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	24268.211	24268.2	23.6951
Error	24	24580.459	1024.2	Prob > F
C. Total	25	48848.670		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.905202	10.78586	0.55	0.5891
Avg Discharge (m3/d)	0.0001097	0.000023	4.87	<.0001

FIGURE 85
Relationship between average spring discharge (m^3/d) and insect emergence rates (#/m^2/day).

Fish density and biomass as a function of GPP, spring discharge, or insect emergence rates were not found to be significantly correlated (Homosassa Springs excluded from analyses). This suggests that fish density and biomass are controlled by other factors and/or that short term estimates of fish communities and ecosystem productivity are inadequate to model these relationships. Fish have a high degree of mobility, and this may explain some of the lack of correlation with GPP.

Among the twelve springs examined in this study, historic fish data are most available from Silver Springs. The fish species observed in this study were similar to those observed in past fish population studies of Silver Springs (**Table 28**). Forty six species were observed in at least one study, 28 of which were detected in this study. In this study, sunfish (*Lepomis sp*.) were most abundant, followed by rainwater killifish (*Luciana parva*), and largemouth bass (*Micropterus salmoides*). These three species combined accounted for about 70% of the observed specimens.

A comparison of the fish wet-weight biomass estimates from historic studies: Hubbs and Allen (1943), Odum (1953), Knight (1980), Munch *et al*. (2006), and this study was made for the upper 1,200 m of Silver Springs (**Table 29**). The estimated range and average lengths of individual fish in this study were similar to those observed in Munch *et al*. (2006) and our biomass estimates were calculated for each individual fish species based on published length to weight regressions (Schneider *et al*. 2000). Average values for all species resulted in a biomass value of about 196 kg/ha for this study. This value is lower than Odum (1953) which was about 527 kg/ha, and higher than the values estimated by Knight (1980) and Munch *et al*. (2006) at approximately 115 and 42 kg/ha, respectively. In this study, species biomass estimates were highest for the longnose gar (*Lepisosteus osseus*) which averaged

37.6 kg/ha, followed by lake chubsucker (*Erimyzon sucetta*) averaging 37 kg/ha, and sunfish (*Lepomis sp*.) at 36 kg/ha. In the Odum (1953) study, highest biomass estimates by species were for striped mullet (*Mugil cephalus*) at about 267 kg/ha, followed by catfish (*Ameiurus* and *Ictalurus sp*.) at about 95 kg/ha, and sunfish at about 48 kg/ha. For the Knight (1980) study highest biomass was noted for gizzard shad (*Dorosoma cepedianum*) at about 66 kg/ha, followed by largemouth bass at about 19 kg/ha, and sunfish at about 16 kg/ha. In the Munch *et al.* (2006) highest biomass was estimated for sunfish at about 14 kg/ha, followed by largemouth bass at about 11 kg/ha, and Florida gar at about 3.5 kg/ha.

Biomass values varied greatly between past studies and this one (**Table 29**); with the greatest difference between the most recent study by Munch *et al*. (2006). This study's total fish biomass estimate of 196 kg/ha was nearly five-times greater than the value presented in the report of Munch *et al*. (2006) and nearly two-times greater than the Knight (1980) estimate. In this study, the biomass of the longnose gar contributed an average of about 20% to the total biomass estimate. Conversely, this species accounted for less than 5% of the total biomass value presented by Munch *et al*. (2006). Estimated total lengths for this particular species were very similar between the two studies, leading us to believe that the number of individual fish observed is responsible for the difference. These fish were easily observed during our visual surveys, and the size of the larger individuals may have been under estimated during electro-shocking sampling of the Munch *et al*. (2006) study.

Two other fish species which greatly contributed to our biomass estimates made in this study were lake chubsucker and bowfin (*Amia calva*). Both of these fish species were abundant and easily visually sampled due to their size and slow movement when not disturbed. In this study, lake chubsucker and bowfin both had biomass estimates an order-of-magnitude greater than in Munch *et al*. (2006). This was due to the larger number of these individual species encountered and a greater weight estimated in this study. We estimated the chubsucker to weigh approximately 0.805 kg per fish, while Munch *et al*. (2006) estimated 0.2423 kg per fish. In the case of bowfin, we counted approximately 10 times more of them, and estimated their weight to be about 135% greater than did Munch *et al*. (2006).

Thus we attribute the great difference in total biomass estimates between Munch *et al*. (2006) and this study primarily as a result of observing more fish, and secondarily estimating a greater biomass per fish for large species (especially longnose gar, lake chubsucker, and bowfin). Another factor likely contributing to the differences between these studies is related to methodology. Munch *et al*. (2006) used electro-shocking to capture fish for biomass estimates. In our study we estimated fish lengths while in the water and then used published relationships between length and weight. While each of these survey methods has advantages and disadvantages, we feel that electro-shocking particularly at Silver Springs may have preferentially sampled smaller fish, resulting in a smaller estimated mean length and weight applied to the actual visual density estimates. This may be due to the depth of this system which precludes the likelihood of effectively stunning and netting fish, as well as the active avoidance that fish tend to exhibit from electro-shocking gear in large clear-water systems.

TABLE 28
Fish species occurrence from the upper 1,200 m of Silver Springs by study.

Family	Species	Common Name	FLMNH ichthyologic collection	Hubbs and Allen (1943)	Odum (1957a)	Knight (1980)	Walsh and Williams (2003)	Munch *et al*. (2006)	This Study
						Occurrence			
Lepisosteidae	*Lepisosteus osseus*	longnose gar		X	X		X	X	X
	Lepisosteus platyrhincus	Florida gar		X	X	X	X	X	X
Amiidae	*Amia calva*	bowfin		X	X	X	X	X	X
Anguillidae	*Anguilla rostrata*	American eel	X	X	X		X	X	
Cichlidae	*Oreochromis aurea*	blue tilapia						X	X
Clupeidae	*Dorosoma cepedianum*	gizzard shad		X	X	X	X	X	
	Dorosoma petenense	threadfin shad		X	X				
Cyprinidae	*Notemigonus chrysoleucas*	golden shiner		X	X	X	X	X	X
	Notropis harperi	redeye chub	X				X		X
	Notropis petersoni	coastal shiner	X				X		X
	Opsopoeodus emiliae	pugnose minnow					X		
Catostomidae	*Erimyzon sucetta*	lake chubsucker		X	X	X	X	X	X
Ictaluridae	*Ameiurus catus*	white catfish	X	X	X				
	Ameiurus natalis	yellow bullhead	X	X	X			X	
	Ameiurus nebulosus	brown bullhead					X	X	X
	Ictalurus punctatus	channel catfish		X	X			X	X
	Noturus gyrinus	tadpole madtom	X				X	X	
	Noturus leptacanthus	speckled madtom	X						
Loricariidae	*Pterygoplichthys disjunctivus*	vermiculated sailfin catfish					X		X
Esocidae	*Esox americanus*	redfin pickerel		X	X			X	
	Esox niger	chain pickerel		X	X	X	X	X	X
Aphredoderidae	*Aphredoderus sayanus*	pirate perch		X	X			X	
Mugilidae	*Mugil cephalus*	striped mullet		X	X	X		X	X
Atherinopsidae	*Labidesthes sicculus*	brook silverside	X	X	X		X		X
Belonidae	*Strongylura marina*	Atlantic needlefish	X	X	X	X			
Fundulidae	*Fundulus chrysotus*	golden topminnow		X	X			X	
	Fundulus lineolatus	lined topminnow		X					
	Jordanella floridae	flagfish		X	X				
	Lucania goodei	bluefin killifish	X	X	X		X	X	X
	Lucania parva	rainwater killifish	X	X	X		X	X	X
Poeciliidae	*Gambusia holbrooki*	eastern mosquitofish	X	X	X		X	X	X
	Heterandria formosa	least killifish	X	X	X		X	X	X
	Poecilia latipinna	sailfin molly	X	X	X		X	X	X
Centrarchidae	*Lepomis auritus*	redbreast sunfish	X	X	X		X	X	X
	Lepomis gulosus	warmouth	X	X	X		X	X	
	Lepomis macrochirus	bluegill		X	X	X	X	X	X
	Lepomis marginatus	dollar sunfish	X						X
	Lepomis microlophus	redear sunfish		X	X	X	X	X	X
	Lepomis punctatus	spotted sunfish	X	X	X	X	X	X	X
	Micropterus salmoides	largemouth bass	X	X	X	X	X	X	X
	Pomoxis nigromaculatus	black crappie		X	X	X		X	
Percidae	*Etheostoma fusiforme*	swamp darter					X	X	X
	Percina nigrofasciata	blackbanded darter	X	X			X		X
Elassomatidae	*Elassoma evergladei*	Everglades pygmy sunfish		X	X				
	Elassoma okefenokee	Okefenokee pygmy sunfish	X				X	X	X
Achiridae	*Trinectes maculatus*	hogchoker	X	X					
		Total number of species	**22**	**35**	**32**	**13**	**29**	**31**	**28**

TABLE 29
Comparison of historic and modern fish wet-weight biomass estimates for Silver Springs.

			Biomass (kg/ha)			
Family	**common name**	**Scientific name**	**Odum (1953)**	**Knight (1980)**	**Munch *et al.* (2006)**	**This Study**
Amiidae	bowfin	*Amia calva*		0.58	2.79	32.51
Anguillidae	American eel	*Anguilla rostrata*			0.01	
Atherinopsidae	brook silverside	*Labidesthes sicculus*				0.0005
Belonidae	Atlantic needlefish	*Strongylura marina*		0.01		
Catostomidae	lake chubsucker	*Erimyzon sucetta*		1.97	1.10	36.96
Centrarchidae	black crappie	*Pomoxis nigromaculatus*		0.02	0.01	
	largemouth bass	*Micropterus salmoides*	27.14	18.65	11.10	25.25
	sunfish sp.*	*Lepomis sp.*	47.62	15.56	13.71	35.99
Cichlidae	blue tilapia	*Oreochromis aurea*			0.23	0.95
Clupeidae	gizzard shad	*Dorosoma cepedianum*		66.28	2.57	
Cyprinidae	golden shiner	*Notemigonus crysoleucas*		6.32	0.59	0.19
	shiner sp.	*Notropis sp.*	0.95		0.01	0.32
	golden topminnow	*Fundulus chrysotus*			0.0001	
Esocidae	chain pickerel	*Esox niger*		1.34	2.61	4.65
Fundulidae	rainwater killifish	*Lucania parva*				0.12
	bluefin killifish	*Lucania goodei*	18.57		0.0020	0.0714
Lepisosteidae	Florida gar	*Lepisosteus platyrhincus*	44.29	1.33	3.52	15.77
	longnose gar	*Lepisosteus osseus*	1.43		2.06	37.55
Loricariidae	vermiculated sailfin catfish	*Pterygoplichthys disjunctivus*				2.23
Mugilidae	striped mullet	*Mugil cephalus*	266.67	2.57	1.55	2.95
Percidae	blackbanded darter	*Percina nigrofasciata*				0.0021
	swamp darter	*Etheostoma fusiforme*			0.0001	
Poeciliidae	mosquitofish	*Gambusia sp.*	21.43		0.00003	0.1013
	least killifish	*Heterandria formosa*	3.33		0.00003	0.0333
	sailfin molly	*Poecilia latipinna*				0.60
Ictaluridae	catfish*	*Ameiurus* and *Ictalurus sp.*	95.24		0.03	0.15
		TOTAL FISH BIOMASS (kg/ha)	**526.67**	**114.63**	**41.89**	**196.43**

*sunfish species include bluegill, redear, spotted, redbreast, and warmouth.
*catfish species include brown bullhead, channel catfish, and white.

Relationships within Metabolism Parameters

In the correlations between ecosystem metabolism and physical, chemical, and biological parameters discussed above, gross primary productivity (GPP, g $O_2/m^2/d$) was the primarily metabolism parameter utilized. The use of this metabolism parameter was appropriate because GPP is the underlying basis of ecosystem metabolism. To see how other metabolism parameters were related to GPP, we present several metabolism parameter correlations below.

The relationship between GPP (g $O_2/m^2/d$) and net primary productivity (NPP, g $O_2/m^2/d$) was found to be non-significant ($R^2 = 0.05$, P = 0.23, **Figure 86**). NPP in these spring systems is highly variable, primarily in response to daily variation in solar energy inputs.

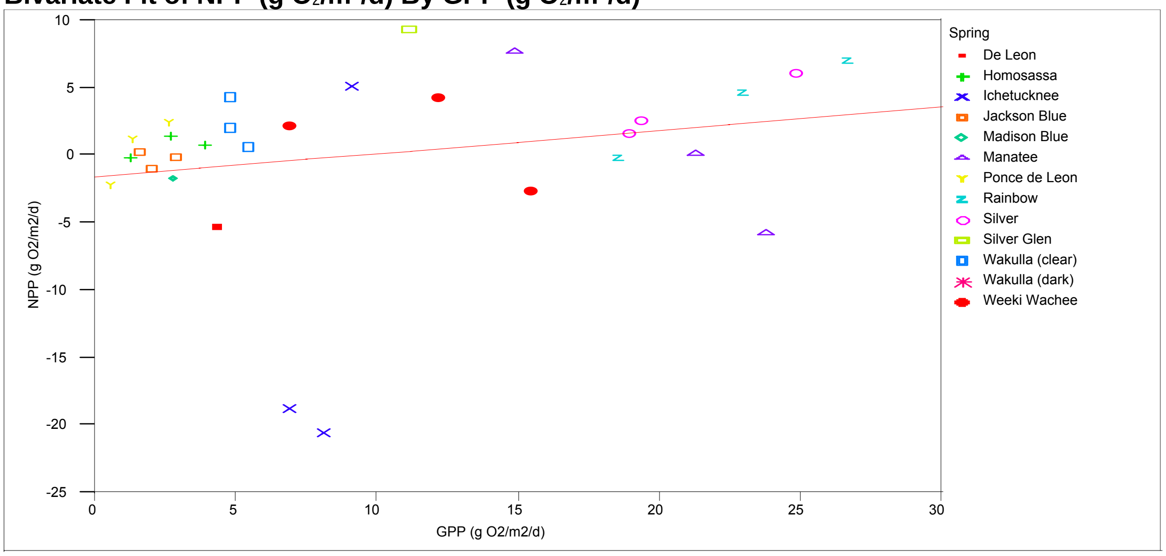
The relationship between GPP (g $O_2/m^2/d$) and community respiration (CR, g $O_2/m^2/d$) was found to be significantly positively correlated ($R^2 = 0.55$, P = 0.0001, **Figure 87**). CR has commonly been used as a surrogate for whole ecosystem metabolism and in balanced ecosystems is essentially identical to GPP.

The relationship between GPP (g $O_2/m^2/d$) and production to respiration (P/R) ratio was found to be non-significant ($R^2 = 0.06$, P = 0.20, **Figure 88**).

The relationship between GPP (g $O_2/m^2/d$) and photosynthetic efficiency (%) was found to be significantly positively correlated ($R^2 = 0.78$, P = 0.0001, **Figure 89**). These parameters are auto correlated which may account for this relationship.

In addition, the average GPP (g $O_2/m^2/d$) of the pool and the run study segments was compared (**Figure 90**). Average GPP values for all study springs were 9.04 and 11.71 g $O_2/m^2/d$ for the pool and run, respectively. Comparison of these values using ANOVA reveals that the difference is not significant (P = 0.5), due to the large range in values observed between systems. This reduction in GPP within pool study segments is relatively intuitive given the degree of physical disturbance (from recreational impacts) and the corresponding reductions in plant life.

Bivariate Fit of NPP (g $O_2/m^2/d$) By GPP (g $O_2/m^2/d$)



Linear Fit

Linear Fit

NPP (g O2/m2/d) = -1.61837 + 0.1727615 GPP (g O2/m2/d)

Summary of Fit

RSquare	0.050667
RSquare Adj	0.016762
Root Mean Square Error	6.385777
Mean of Response	0.124333
Observations (or Sum Wgts)	30

Analysis of Variance

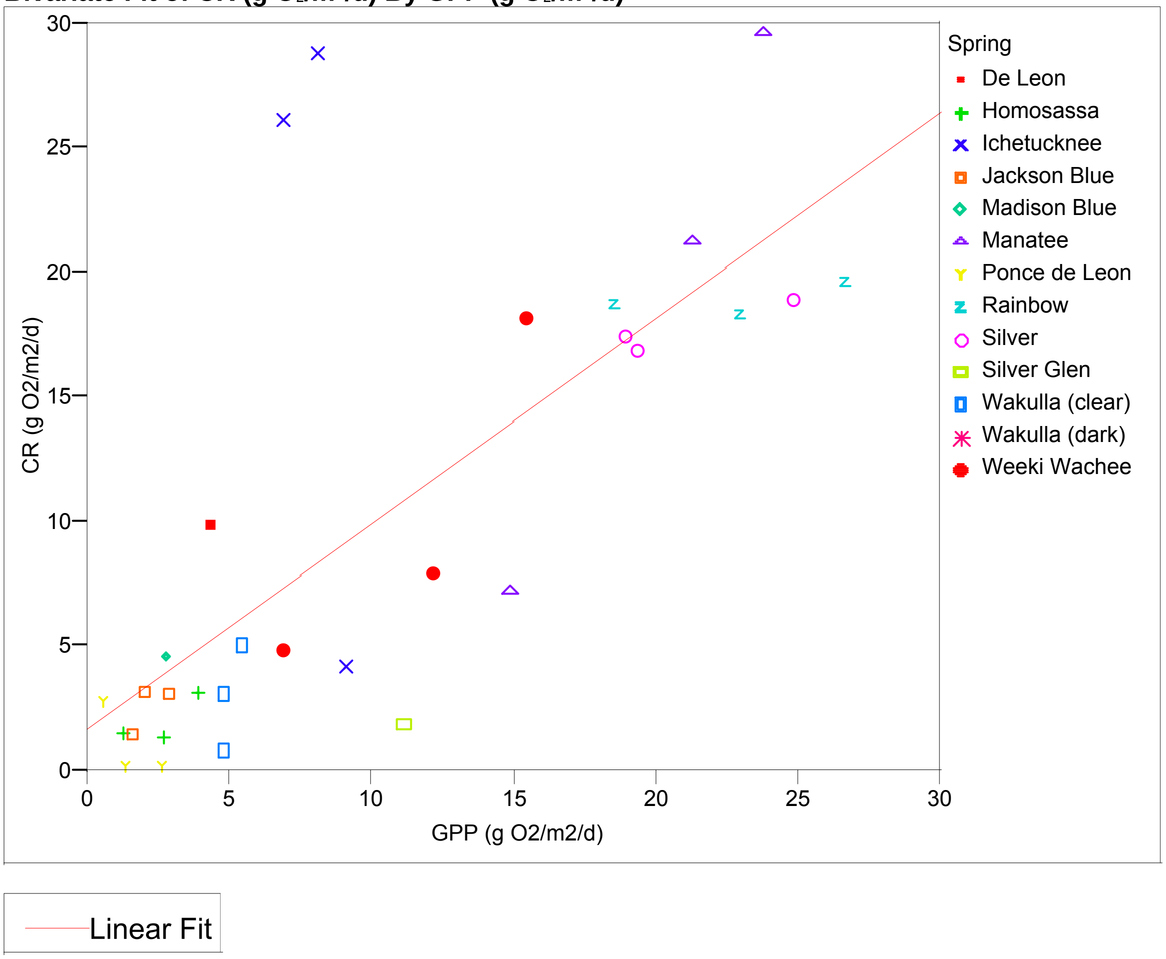
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	60.9387	60.9387	1.4944
Error	28	1141.7881	40.7781	Prob > F
C. Total	29	1202.7267		0.2317

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.61837	1.841614	-0.88	0.3870
GPP (g O2/m2/d)	0.1727615	0.141323	1.22	0.2317

FIGURE 86
Relationship between GPP (g $O_2/m^2/d$) and NPP (g $O_2/m^2/d$) for pool, run, and combined segments.

Bivariate Fit of CR (g $O_2/m^2/d$) By GPP (g $O_2/m^2/d$)



Linear Fit

CR (g O2/m2/d) = 1.6305851 + 0.8268867 GPP (g O2/m2/d)

Summary of Fit

RSquare	0.548066
RSquare Adj	0.531926
Root Mean Square Error	6.411907
Mean of Response	9.971667
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1396.0180	1396.02	33.9560
Error	28	1151.1514	41.11	Prob > F
C. Total	29	2547.1694		<.0001

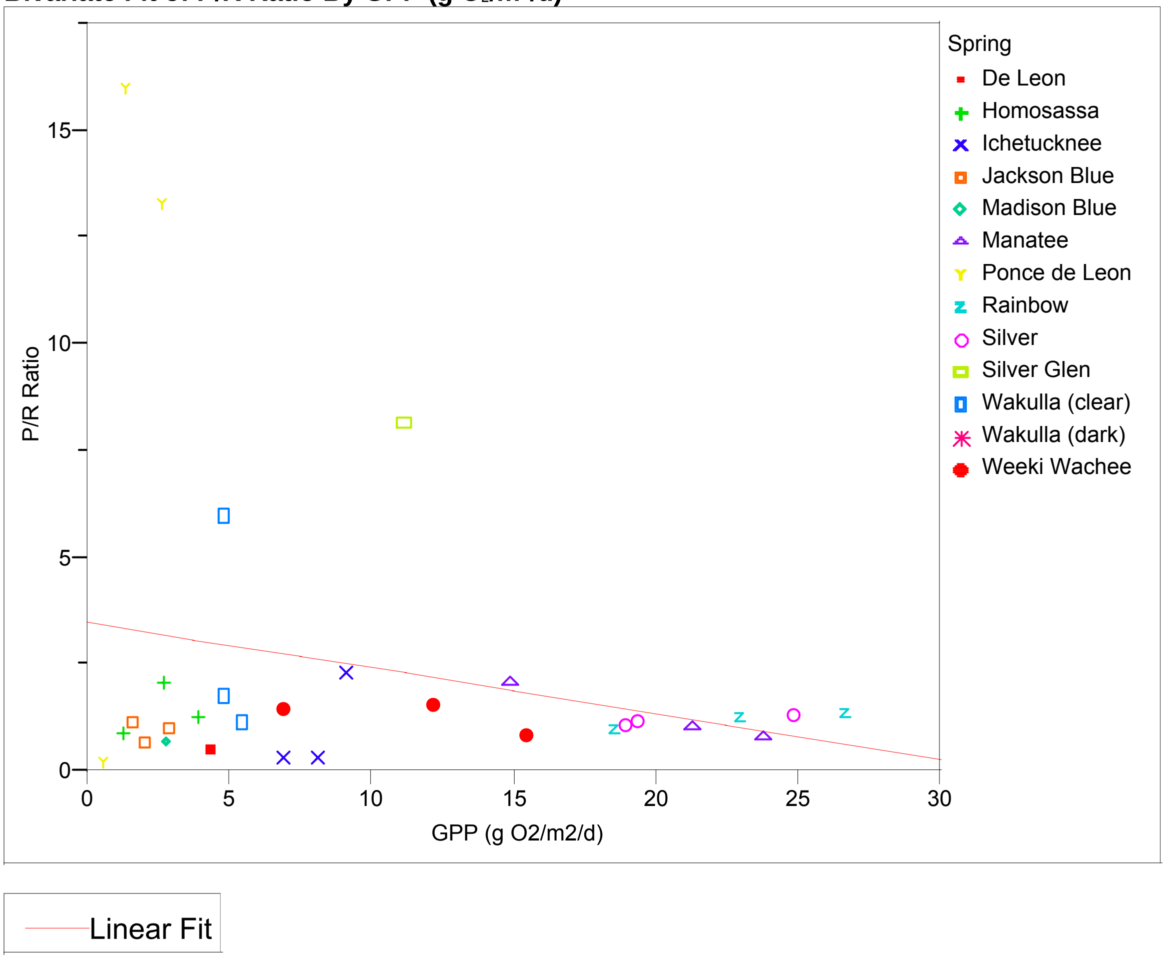
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.6305851	1.849149	0.88	0.3854
GPP (g O2/m2/d)	0.8268867	0.141902	5.83	<.0001

FIGURE 87

Relationship between GPP (g $O_2/m^2/d$) and CR (g $O_2/m^2/d$) for pool, run, and combined segments.

Bivariate Fit of P/R Ratio By GPP (g $O_2/m^2/d$)



Linear Fit

P/R Ratio = 3.4795497 - 0.1068881 GPP (g O2/m2/d)

Summary of Fit

RSquare	0.058286
RSquare Adj	0.024653
Root Mean Square Error	3.668839
Mean of Response	2.401333
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	23.32696	23.3270	1.7330
Error	28	376.89059	13.4604	Prob > F
C. Total	29	400.21755		0.1987

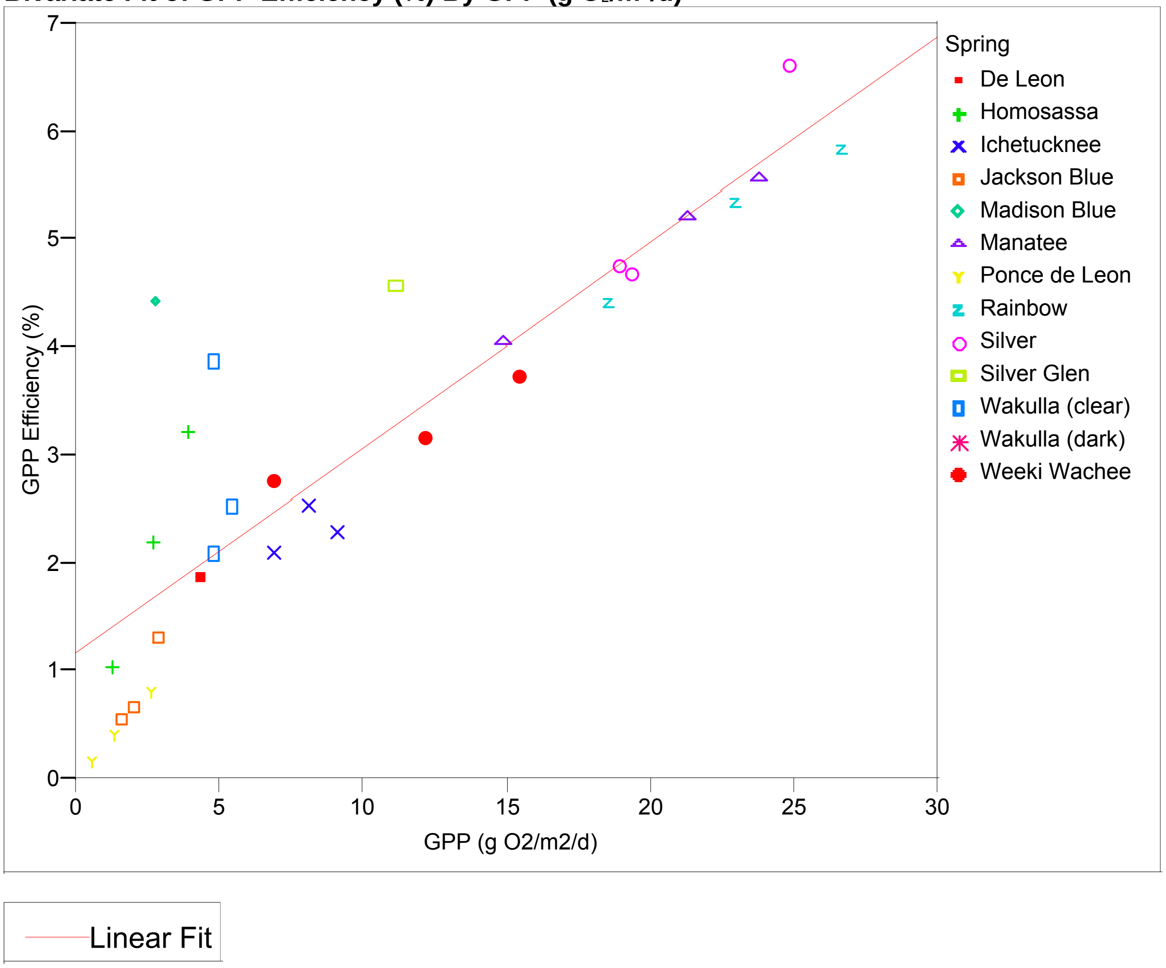
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.4795497	1.058068	3.29	0.0027
GPP (g O2/m2/d)	-0.106888	0.081195	-1.32	0.1987

FIGURE 88

Relationship between GPP (g $O_2/m^2/d$) and P/R ratio for pool, run, and combined segments.

Bivariate Fit of GPP Efficiency (%) By GPP (g $O_2/m^2/d$)



Linear Fit

GPP Efficiency (%) = 1.1596865 + 0.1906662 GPP (g O2/m2/d)

Summary of Fit

RSquare	0.778661
RSquare Adj	0.770756
Root Mean Square Error	0.868058
Mean of Response	3.083
Observations (or Sum Wgts)	30

Analysis of Variance

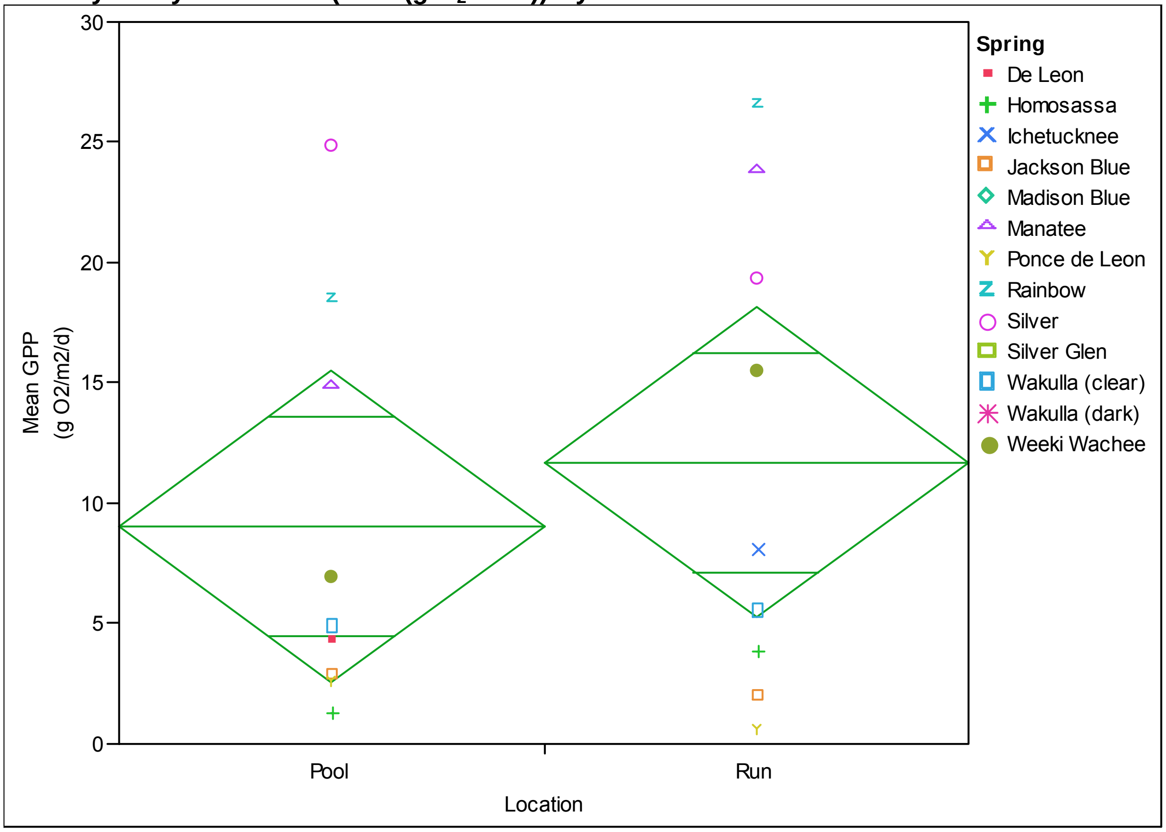
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	74.224356	74.2244	98.5030
Error	28	21.098674	0.7535	Prob > F
C. Total	29	95.323030		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.1596865	0.250342	4.63	<.0001
GPP (g O2/m2/d)	0.1906662	0.019211	9.92	<.0001

FIGURE 89
Relationship between GPP (g $O_2/m^2/d$) and GPP efficiency (%) for pool, run, and combined segments.

Oneway Analysis of Mean(GPP (g $O_2/m^2/d$)) By Location



Excluded Rows
13

Oneway Anova

Summary of Fit

Rsquare	0.023431
Adj Rsquare	-0.0376
Root Mean Square Error	9.138914
Mean of Response	10.3713
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Location	1	32.0623	32.0623	0.3839	0.5443
Error	16	1336.3160	83.5197		
C. Total	17	1368.3782			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Pool	9	9.0367	3.0463	2.5788	15.495
Pool & Run	0	.	.	.	.
Run	9	11.7059	3.0463	5.2480	18.164

Std Error uses a pooled estimate of error variance

FIGURE 90
Comparison of average spring system GPP (g $O_2/m^2/d$) between pool and run study segments.

Human Use of Springs

Recorded human uses at the study springs were generally low, because observations were made on week days (except for Wakulla) and springs were each sampled at different times throughout the year. Spring pool densities ranged from 0 persons/ha at Silver to 30 persons/ha at Madison Blue with an overall average of about 8 persons/ha. In the spring runs the average in water use was about 0.74 persons/ha. These observations provide average human densities made on week days and throughout the year, including many days of rain, cloudiness, and cool air temperatures. The numbers published in this report indicate that the average non-weekend human use density on the water in these twelve springs was about 4 humans/ha. Based on these estimated human-use densities, these springs do not appear to be receiving a high level of disturbance by humans, at least on average week days.

To further explore this issue, detailed human use data were collected at Wakulla Springs head pool area for six months from January through June 2009 (**Figure 91**). Two counts were made each month over an entire diurnal period with one on a week day and one on a weekend day. Based on these more detailed data it is clear that certain areas of these springs, typically in the head pool but also often in the run, receive higher levels of human activity and that the intensity of this activity is seasonal with higher pressure during the warmer months. At Wakulla Springs the human activity was essentially at zero persons/ha during the winter months and nearly 60 persons/ha during a mid-summer weekend. The average annual in-water density at the swim area at Wakulla Springs during this period was 6.5 persons/ha on weekdays and 20 persons/ha on weekend days. As a result the amount of SAV living in this area varies throughout the year. At Wakulla Springs, portions of the swim area are also treated with herbicide annually to control hydrilla. The link between human use and SAV disturbance was well documented by DuToit (1979) for Ichetucknee Springs. Visual patterns of SAV absence in the swim areas are evident at the study springs, for example at Rainbow Springs the roped-off swim area identifies the areas absent of SAV.

A similar pattern of intensive human use in another state park, Wekiwa Springs, was recorded by WSI (2007b) on Sunday, August 12, 2007 (**Figure 92**). The estimated average human density in this swim area was 290 persons/ha. It was observed that the spring water was highly turbid under these conditions and there was no evidence of any macrophytic vegetation other than some filamentous algae in the Wekiwa spring pool. A similar human intensity value of 121 persons/ha was measured by WSI (2007b) in the main swim area in Rock Springs.

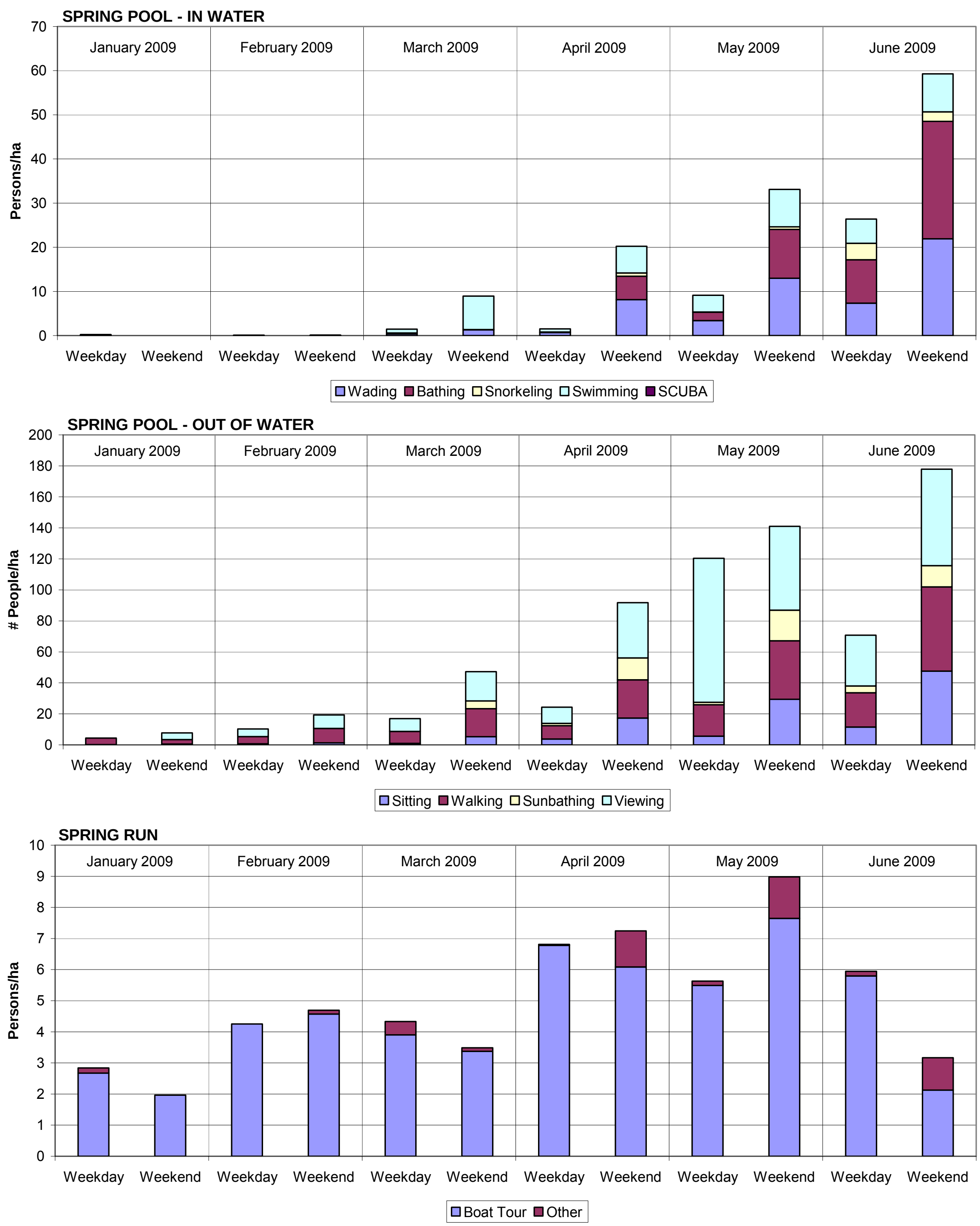


FIGURE 91
Wakulla Springs human use (persons/ha) by location, category, activity, and time period.

TABLE 30
Wakulla Springs human use (persons/ha) by location, category, activity, and time period.

Location	Category	Activity	1/19/2009 Weekday	1/25/2009 Weekend	2/26/2009 Weekday	2/28/2009 Weekend	3/29/2009 Weekend	3/31/2009 Weekday	4/26/2009 Weekend	4/30/2009 Weekday	5/29/2009 Weekday	5/31/2009 Weekend	6/28/2009 Weekend	6/30/2009 Weekday	Average Weekday	Average Weekend
			# Person/ha													
Spring Pool	In Water	Wading	0.12	0.02	0.11	0.08	1.28	0.41	8.14	0.71	3.42	12.99	21.92	7.33	2.02	7.40
		Bathing	0.00	0.00	0.00	0.00	0.00	0.17	5.32	0.13	1.86	11.04	26.59	9.84	2.00	7.16
		Snorkeling	0.06	0.00	0.00	0.00	0.11	0.00	0.74	0.00	0.05	0.60	2.15	3.74	0.64	0.60
		Swimming	0.06	0.00	0.00	0.04	7.56	0.87	6.03	0.69	3.80	8.49	8.58	5.48	1.82	5.12
		SCUBA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Out of Water	Sitting	0.24	0.58	0.65	1.32	5.31	1.01	17.34	3.81	5.62	29.39	47.62	11.48	3.80	16.93
		Walking	4.10	2.90	4.67	9.29	18.09	7.66	24.65	8.63	20.31	37.75	54.27	22.20	11.26	24.49
		Sunbathing	0.00	0.00	0.00	0.00	5.04	0.00	14.07	1.36	1.51	19.78	13.71	4.34	1.20	8.77
		Viewing	0.00	4.28	4.91	8.78	18.88	8.33	35.68	10.53	92.85	54.10	62.31	32.75	24.90	30.67
	In Water		0.2	0.0	0.1	0.1	8.9	1.4	20.2	1.5	9.1	33.1	59.2	26.4	6.47	20.28
	Out of Water		4.3	7.8	10.2	19.4	47.3	17.0	91.8	24.3	120.3	141.0	177.9	70.8	41.16	80.86
Spring Run	In Water	Boat Tour	2.68	1.96	4.25	4.57	3.37	3.90	6.08	6.78	5.49	7.65	2.13	5.80	4.82	4.29
		Other	0.17	0.00	0.00	0.12	0.11	0.43	1.16	0.03	0.14	1.34	1.04	0.15	0.15	0.63
	In Water		2.8	2.0	4.3	4.7	3.5	4.3	7.2	6.8	5.6	9.0	3.2	5.9	4.97	4.92
Entire Spring			7.4	9.7	14.6	24.2	59.7	22.8	119.2	32.7	135.1	183.1	240.3	103.1	52.61	106.06

Note(s):

Hours of Observations:		5.5	9.5	8.5	8.0	7.0	5.5	6.5	6.3	6.3	4.0	6.0	7.5
Spring Pool Wetted Area (ha):	1.569												
Spring Pool Upland Area (ha):	1.353												
Spring Run Area (ha):	6.032												

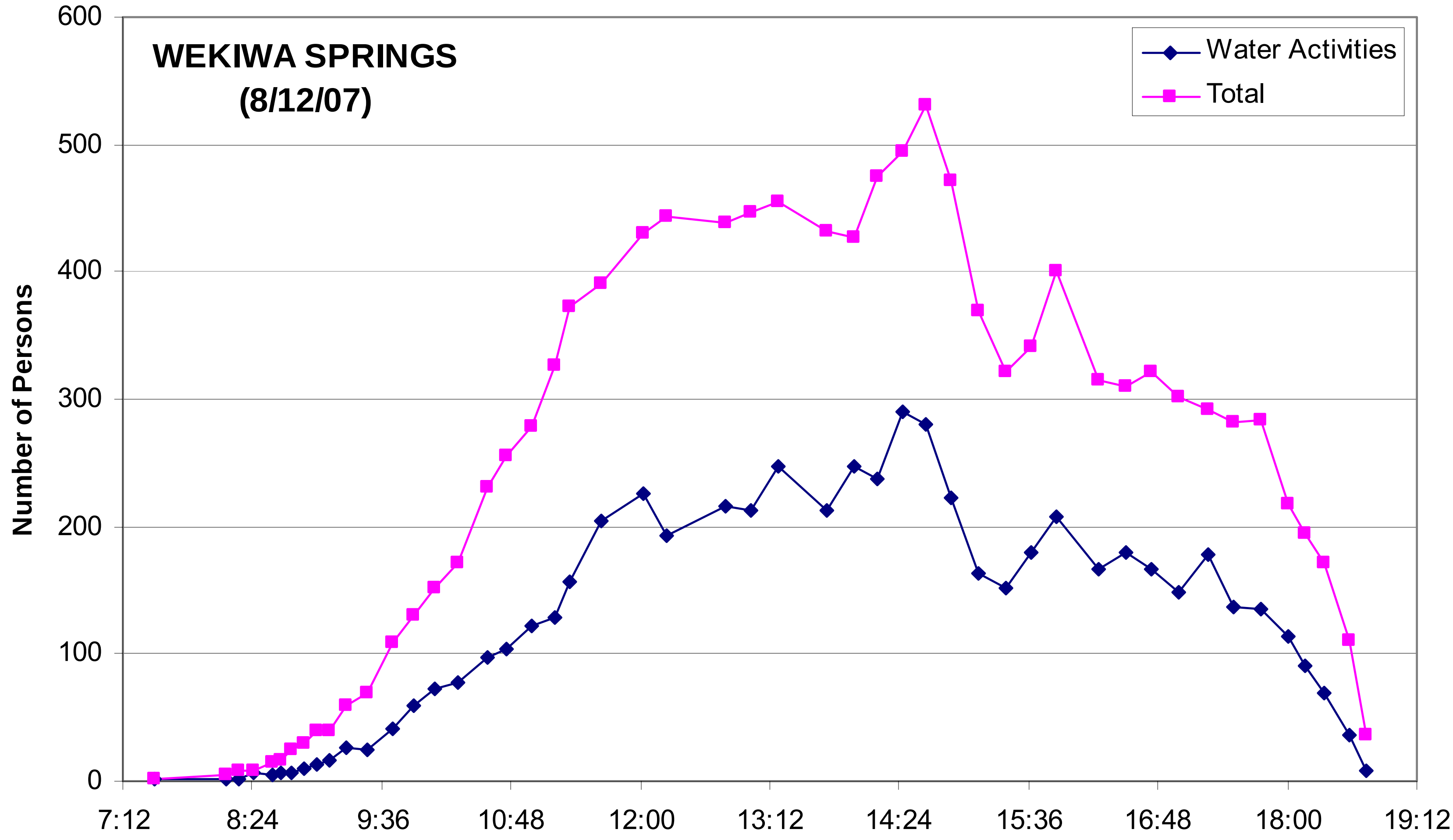


FIGURE 92
Daily pattern of water-dependent human use observed at Wekiwa Springs on Sunday, August 12, 2007 (from WSI 2007b).

Conclusions and Recommendations

Springs and the Ecological Steady State

Historical Perspective

H.T. Odum (1957a) described Silver Springs as thermostatic, chemostatic, and biostatic; referring to the essentially unvarying water temperature, dissolved constituents in the inflow water, and apparently constant biomass or standing stock of plants and animals he observed in that spring over his three-year study. Dr. Odum considered Silver Springs to be an ideal living laboratory in which conditions were close to a steady state with annual and diel light variations being the only pulsing forcing function acting on the aquatic ecosystem. In this relatively unchanging environment he concluded that complex adaptations of plants and animals had been perfected through natural selection based on the maximization of overall system productivity (*i.e.*, community metabolism). He concluded that if the Silver Springs ecosystem was constant, then any experiment conducted at some time in the past could be reproduced some time in the future using similar methods (Odum 1957a).

This theoretical conclusion was put to the test when Silver Springs was restudied in 1979-80 (Knight 1980), in 2004-05 (Munch *et al.* 2006), and again during the study described in this report (2009). These follow-up studies found that many aspects of Silver Springs have remained surprisingly constant over the past 55 years. Water temperatures at the spring boil and for a considerable distance downstream remain constant and approximately equal to the values measured by Odum in the 1950s. Dissolved oxygen at the boil is relatively unchanged as is total phosphorus, specific conductance, and most of the measured cations and anions. Water clarity and light inputs remain about the same and even the dominant submerged aquatic plant in the spring run (strap-leaved sagittaria) is still prevailing. The only significant measured changes for the forcing functions powering the Silver Springs aquatic ecosystem are overall spring discharge (reduced about 20 to 30% in the past 55 years) and nitrate nitrogen (increased by about 3x during that period). This discussion acknowledges the likely possibility that other important forcing functions or properties that were not explicitly measured [*e.g*., the completion of the Rodman Dam, the introduction of exotic species such as armored catfish and tilapia, and the removal of turtles and fish through legal and illegal hunting in the Silver River] may have changed during this same period.

Based on results of the detailed study of Silver springs reported by Munch *et al.* (2006), noted biological changes over the past 50 years include a doubling of plant biomass, mostly in the form of benthic filamentous algae, a small decline in primary productivity and photosynthetic efficiency in spite of this increase in plant material, a possible decline in the secondary productivity of aquatic insects, and an apparent decline in fish biomass. These findings originally reported in Munch *et al* (2006) and generally confirmed in this project, indicate a possible cause-and-effect relationship between changes for spring discharge and nitrate and the resulting biological changes. Odum's steady-state hypothesis for springs would predict that the structure and function of the springs' biota would be likely to change if key forcing functions have changed in the interim. This study and the previous study of Munch *et al.* (2006) demonstrate that external forcing functions and internal ecosystem functional rates (the "type, nature, and function") have changed since the Silver Springs ecosystem was initially described in the 1950s.

Application to the Synoptic Spring Study

H.T. Odum also published ecological information about a number of other Florida artesian springs in the 1950s (Odum 1957b). Several of those springs have been restudied in the past decade and four were included in this study. Observations from two of the systems visited by Odum in central Florida, Wekiwa and Rock Springs in Orange County, were that the physical and biological nature at Rock Springs was essentially unchanged over the intervening fifty years while Wekiwa Springs had been totally encircled by a concrete retaining wall and converted into an intensive swimming area during that fifty year span (WSI 2007b). Plant communities, fish occurrence and, ecosystem metabolism were severely reduced in Wekiwa Spring while the ecology of Rock Spring was found to be relatively unchanged.

Results of the current study summarized above found relatively minor changes in Rainbow Springs, Weeki Wachee Springs, and Silver Springs, with the exception of flow reductions and nitrate increases. All four of these springs had relatively small increases in GPP compared to numbers estimated by Odum in the 1950s (Odum 1957b). These increases, if real, are presumably due to the increased availability of nitrate nitrogen at these springs. Homosassa Springs had a much lower GPP measured during the current study than measured by Odum in July 1955. This decline is in part due to the very high GPP reported by Odum of 63.8 g $O_2/m^2/d$, a value which was not observed in any of the study springs of this project. A decline in GPP was however not unexpected due to the loss of macrophytic vegetation in this spring pool and upper run area. In 1955 Odum produced a sketch of the SAV pool area at Homosassa Springs, showing dense coverage of tape grass, pond weed, and southern naiad. This SAV has been eliminated from the same area by manatee feeding from animals which are housed in this area (see detailed discussion in **Appendix P**).

These results offer support to Odum's conclusion that springs are an excellent natural laboratory for studying the ecological properties of quasi-steady-state aquatic ecosystems. When the external and internal factors affecting springs are relatively unchanged, their ecology is also unchanging and plant and animal structure and functions are stable. When forcing functions change and biological communities in these springs are severely altered due to anthropogenic activities, ecosystem-level measurements such as GPP and photosynthetic efficiency can be used to provide an assessment of the effects on the plant and animal community as a whole, without the need to study populations of individual species in great detail.

Efforts to provide wise management of springs and their associated wildlife are dependent upon a good understanding of cause and effect. An adequate baseline of routine ecological data (physical, chemical, and biological) from individual springs is needed to be able to detect impairment caused by worsening environmental conditions. Likewise, a continuing monitoring program in those same springs has the ability to detect improvement in ecological conditions once stressors such as flow reductions and increasing nitrate concentrations are reversed by regulatory programs.

Recommendations for Springs' Management

Spring's Conservation and Monitoring

A large number of first and second magnitude artesian springs in Florida are within state and federal ownership (Scott *et al*. 2002). Whenever possible, springs' conservation through public ownership should be extended to the remainder of these important ecosystems. Public ownership should include as much of the spring watershed and springshed as possible so that less intensive land management activities would have the benefits of reduced nutrient and contaminant loading and increased groundwater recharge.

With public ownership comes the responsibility for wise management. Management of springs and their contributing basins can be relatively easy if human uses are limited. However, when recreation is excessive, springs may be impacted even when under state or federal management. A few examples of these effects described in this report include recreational boating impacts on vegetation and wildlife in Silver Glen, human trampling and turbidity effects on SAV in Ichetucknee, and modifications to the spring pool at Volusia De Leon Springs. Examples of human recreational effects on the structure and function of all of the twelve studied springs were noted during this research effort. Recommended monitoring of these recreational side-effects includes frequent human-use counts and surveys, examination of the ecological changes resulting from structural modifications present in many springs, and implementation of baseline monitoring programs that focus on human effects on turbidity and water clarity in springs. Careful consideration of allowable human uses and human carrying capacities should be based on better data and is needed to protect and preserve the ecological functions of these sensitive habitats.

This project provides an overview of available quantitative assessment methods that are potentially useful for making these springs' management decisions. In general, more holisitic measurements such as water chemistry, spring discharge and current velocities, and whole ecosystem metabolism (GPP and CR) are recommended as indicators of spring condition and their potential to support faunal food chains. When possible, trophic-level studies should be conducted to help fill in the overall picture of spring health. Of particular interest are assessments of biomass and species dominance at each trophic level. For example, plant communities should be fractionated into algal and macrophytic cover and dominance when possible with less emphasis on species diversity. Primary consumer standing stocks and productivity (e.g., insects, molluscs, crayfish, turtles, mullet, etc.) should be quantified using quantitative, area-based assessment methods. The biomass and productivity of key secondary and tertiary consumer populations should also be assessed quantitatively (predaceous fish, alligators, birds, etc.).

Springs's Restoration

As this and previous studies have demonstrated, many of the artesian springs in Florida have already been altered. Water quality as indicated by increasing nitrate nitrogen concentrations is degraded in the majority of Florida's artesian springs. Flow declines are becoming evident in a growing number of springs independent of variations caused by weather and climate patterns. Partially as a result of these stressors as well as recreational uses and the occurrence of invasive plants and resulting aquatic plant management activities, plant communities have been altered in a large number of springs. The resulting effects on wildlife populations have not been well studied, but based on current information, faunal populations at all levels of the food chain appear to be altered in many springs.

Restoration of these observed ecological changes in springs requires two responses by the general public and their resource managers: first - stopping the increasing intensity of these changes (e.g., no new nitrogen loads or consumptive water uses in affected springsheds) and second - restoring of water quality and quantity to historic levels that will allow the eventual recovery and restoration of spring ecosystems. The U.S. Environmental Protection Agency and the Florida Department of Environmental Protection are currently evaluating and implementing numeric nutrient criteria in springs. Simultaneously, the water management districts are developing minimum flows and levels for many first and second magnitude springs. These two regulatory programs seek to establish criteria for pollutants and water flow, beyond which, natural aquatic ecosystems such as springs are considered to be "harmed" or "impaired".

These regulatory decisions set the bar for evaluating ecological recovery in springs. If these bars are set too low, then regulatory protections may not be strong enough to allow recovery to the historic ecological structure and function. Based on the convincing theory that spring ecology is a function of the principal external forcing functions that act on each spring, these regulatory goals cannot be assumed to restore springs alone. As recommended above, more detailed measurement of the ecological structure and function of our most pristine springs should be combined with comprehensive baseline data collection at each impaired spring to evaluate success along the path to recovery.

Literature Cited

Bonn, M.A. 2004. Visitor profiles, economic impacts and recreational aesthetic values associated with eight priority Florida springs located in the St. Johns River Water Management District. Special Publication SJ2004-SP35.

Brown, M.T. 2008. Original conceptual spring's regional diagrams used in Figures 3, 5, and 6. Department of Environmental Engineering Sciences. University of Florida. Gainesville, FL.

Butcher, R.W. 1933. Studies on the ecology of rivers. I. On the distribution of macrophytic vegetation in the rivers of Britain. Journal of Ecology. 21: 58-91.

Canfield, D.E., Jr., and M.V. Hoyer. 1988a. Influence of nutrient enrichment and light availability on the abundance of aquatic macrophytes in Florida streams. Canadian Journal of Fisheries and Aquatic Sciences. 45: 1467-1472.

Canfield, D.E., Jr., and M.V. Hoyer. 1988b. The nutrient assimilation capacity of the Little Wekiva River. Final Report. Director of Public Works, City of Altamonte Springs, Altamonte Springs, Florida. 288 pp.

Chambers, P. A., E. E. Prepas, M. L. Bothwell, and H. R. Hamilton. 1989. Roots versus shoots in nutrient uptake by aquatic macrophytes in flowing waters. Canadian Journal of Fisheries and Aquatic Sciences. 46: 435-439.

Cohen, M.J., S. Lamsal, and L.V. Korhnak. 2007. Sources, Transport and Transformations of Nitrate-N in the Florida Environment. St. Johns River Water Management District SJ2007-SP10. 125 pp

Conner, W.H. and J.W. Day. 1992. Water level variability and litterfall productivity of forested freshwater wetlands in Louisiana. American Midland Naturalist 128: 237-245.

Duarte, C.M. 1992. Nutrient concentration of aquatic plants: patterns across species. Limnology and Oceanography 37(4): 882-889.

DuToit, C.H. 1979. The carrying capacity of the Ichetucknee Springs and River. M.S. Thesis. University of Florida. Gainesville, FL. 176 pp.

Florida Department of Environmental Protection (FDEP). 2000. Florida Water Quality Assessment: 305(b) Report. Florida Department of Environmental Protection. Division of Water Resource Management. Bureau of Watershed Management. Tallahassee, FL. 99 pp.

Florida Department of Environmental Protection. 2006. Florida's Springs. Strategies for Protection and Restoration. Report by the Florida Springs Task Force. Florida Department of Environmental Protection, Tallahassee, FL.

Florida Geological Survey (FGS). 2007. Florida Springsheds. Geographical information system data file. Florida Department of Environmental Protection. Florida Geological Survey. Tallahassee, FL.

Grubbs, J.W. and C.A. Crandall. 2007. Exchanges of Water between the Upper Floridan Aquifer and the Lower Suwannee and Lower Santa Fe Rivers, Florida. U.S. Geological Survey. Professional Paper 1656-C. 83 pp.

Hubbs, C.L. and E.R. Allen. 1943. Fishes of Silver Springs. Proceedings of the Florida Academy of Sciences 6: 110-130.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press.

Kirk, J. T. O. 1994. Light and photosynthesis in Aquatic ecosystems. 2nd Edition. Cambridge University Press. Great Britain.

Knight, R.L. 1980. Energy Basis of Control in Aquatic Ecosystems. Ph.D. Dissertation. University of Florida, Gainesville. Fl. 200 pp.

Lobinske, R.J., A. Ali, and I.J. Stout. 1997. Benthic macroinvertebrates and selected physico-chemical parameters in two tributaries of the Wekiva River, Central Florida, USA. Medical Entomology and Zoology 48 (3): 219-231.

Martin, R.A. 1966. Eternal Spring: Man's 10,000 Years of History at Florida's Silver Springs. Great Outdoors Press, Inc., St. Petersburg, FL.

Mattson, R.A., J.H. Epler, and M.K. Hein. 1995. Description of benthic communities in karst, spring-fed streams of north central Florida. Journal of the Kansas Entomological Society 68(2):18-41.

Munch, D.A., D.J. Toth, C. Huang, J.B. Davis, C.M. Fortich, W.L. Osburn, E.J. Phlips, E.L. Quinlan, M.S. Allen, M.J. Woods, P. Cooney, R.L. Knight, R.A Clarke, and S.L. Knight. 2006. Fifty-year retrospective study of the ecology of Silver Springs, Florida. Report prepared for the Department of Environmental Protection, Special Publication SJ2007-SP4. Palatka: St. Johns River Water Management District. 314 pp. From: http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2007-SP4.pdf; accessed December 2007.

Nilsson, C. 1987. Distribution of stream-edge vegetation along a gradient of current velocity. Journal of Ecology. 75: 513-522.

Odum, E.P., J.T. Finn, and E.H. Franz. 1979. Perturbation theory and the subsidy-stress gradient. BioScience 29: 349-352.

Odum, H.T. 1957a. Trophic structure and productivity of Silver Springs, Florida. Ecological Monographs 27(1): 55-112.

Odum, H.T. 1957b. Primary Production Measurements in Eleven Florida Springs and a Marine Turtle-Grass Community. Limnology and Oceanography 2: 85-97.

Odum, H.T., O. Galindo, B. Parrish, R. Pinkerton, W.C. Sloan, and L.A. Whitford. 1953. Productivity of Florida Springs Factors controlling marine invasion in Florida fresh waters. Third semi-annual report to the Biology Division, Office of Naval Research 3: 134-156.

Odum, H.T., E.C. Odum, and M.T. Brown. 1998. Environment and Society in Florida. Lewis Publishers. Boca Raton, FL.

Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The influence of organisms on the composition of sea-water. p. 26-77, v. 2. In M.N. Hill, E.D. Goldberg, C. O'D. Iselin, and W.H. Munk (*Eds*.). The sea. Interscience, London.

Schneider, J.C., P.W. Larrman, and H. Gowing. 2000. Length-weight relationships, Chapter 17, In Schneider, J.C. [*Ed*.] Manual of Fisheries Survey Methods II: With Periodic Updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor, MI.

Scott, T.M., G.H. Means, R.C. Means, and R.P. Meegan. 2002. First magnitude springs of Florida: Florida Geological Survey Open File Report 85, 138 9p.

Steigerwalt, N.M. 2005. Environmental factors affecting aquatic invertebrate community structure on snags in the Ichetucknee River, Florida. MSc Thesis, University of Florida, Gainesville, Florida. 96 pp.

Stevenson, R.J., A. Pinowska, A. Albertin and J.O. Sickman. 2007. Ecological condition of algae and nutrients in Florida Springs. The Synthesis Report WM 858 Florida Department of Environmental Protection, Tallahassee, Florida. 58 pp.

Stewart, S.R. and J.L. Beven, II. 2009. Tropical Cyclone Report, Tropical Storm Fay (AL062008), 15-26 August 2008. National Hurricane Center, National Weather Service. 29 pp. Accessed December 2009 at: http://www.nhc.noaa.gov/pdf/TCR-AL062008_Fay.pdf .

Sudol, T.A., E.V. Willcox, and W. Giuliano. 2009. Isolated Wetlands and Breeding Amphibians. University of Florida, IFAS Extension EDIS document WEC 268. Web link: http://edis.ifas.ufl.edu/pdffiles/UW/UW31300.pdf

Walsh, S.J. and J.D. Williams. 2003. Inventory of Fishes and Mussels in Springs and Spring Effluents of North-Central Florida State parks. Final Report submitted to the Florida Park Service. Prepared by the U.S. Geological Survey, Gainesville, Florida. 94 pp.

Warren, G.L., D.A. Holt, C. Cichra, and D. VanGenecten. 2000. Fish and aquatic invertebrate communities of the Wekiva and Little Wekiva Rivers: a baseline evaluation in the context of Florida's minimum flows and levels statues. St. Johns River Water Management District Special Publication SJ2000-SP4, Palatka, FL.

Westlake, D.F. 1967. Some effects of low-velocity currents on the metabolism of aquatic macrophytes. Journal of Experimental Botany. 18: 187-205.

Wetland Solutions, Inc (WSI). 2007a. Phase 3 Final Report. Pollutant Load Reduction Goal (PLRG) Analysis for the Wekiva River and Rock Springs Run, Florida. Report prepared for the St. Johns River Water Management District, Palatka, FL. 418 pp.

Wetland Solutions, Inc. (WSI). 2007b. Human Use and Ecological Water Resource Values Assessments of Rock and Wekiwa Springs (Orange County, Florida) Minimum Flows and Levels. St. Johns River Water Management District, Palatka, FL. Special Publication SJ2008-SP2. 192 pp.

Wetland Solutions, Inc. (WSI). 2008. An Ecosystem-Level Study of Florida's Springs. Interim Report No. 1. September 30, 2009. Prepared for the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. FWC Project Agreement No. 08010. 164. pp.

Wetland Solutions, Inc. (WSI). 2009a. An Ecosystem-Level Study of Florida's Springs. Interim Report No. 2. January 15, 2009. Prepared for the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. FWC Project Agreement No. 08010. 166. pp.

Wetland Solutions, Inc. (WSI). 2009b. An Ecosystem-Level Study of Florida's Springs. Interim Report No. 3. May 15, 2009. Prepared for the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. FWC Project Agreement No. 08010. 164. pp.

Wetland Solutions, Inc. (WSI). 2009c. An Ecosystem-Level Study of Florida's Springs. Annual Report. July 15, 2009. Prepared for the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. FWC Project Agreement No. 08010. 135. pp.

Wetland Solutions, Inc. (WSI). 2009d. An Ecosystem-Level Study of Florida's Springs. Draft Final Report. October 15, 2009. Prepared for the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. FWC Project Agreement No. 08010. 138. pp.