Hydrology, Water Quality, and Aquatic Communities of Selected Springs in the St. Johns River Water Management District, Florida

By Stephen J. Walsh, Leel Knowles, Jr., Brian G. Katz, and Douglas G. Strom

Prepared in cooperation with the

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Detailed Geographic Information System (GIS) data for the St. Johns River Water Management District are available on the District's spatial data website (*http://sjr.state.fl.us/gisdevelopment/docs/themes.html*). Due to the way certain land-use codes were combined in this study, and differences in coding between years of available data, some differences exist between codes used for land-use and land-cover categories. For example, some of the percentages provided on figure 4 reflect a different overall pattern than would be evident from a broad landscape-scale area of coverage. Readers of this report and land-use and land-coverage data users are encouraged to utilize the original GIS sources for any indepth applications requiring detailed spatial data.

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Conversion factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square inch (in^2)	6.452	square centimeter (cm^2)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Acronyms and Abbreviations

BMM	binary mixing model
CFC	chlorofluorocarbon
EFM	exponential flow model
EPM	exponential and piston flow model
FDEP	Florida Department of Environmental Protection
FSI	Florida Springs Initiative
FI	Florida Index
FSTF	Florida Springs Task Force
GWML	global meteoric water line
ln	natural logarithm
LPIL	lowest practicable identification level
MDS	multidimensional scaling
MFLs	minimum flows and levels
MWL	meteoric water line
NOAA	National Oceanic and Atmospheric Administration
NTU	nephelometric turbidity units
PCA	principal components analysis
PFM	piston flow model
pmc	percent modern carbon
ppm	parts per million
ppt	parts per thousand
pptv	parts per trillion by volume
SCI	stream condition index
SJRWMD	St. Johns River Water Management District
TU	tritium units
TL	total length
USGS	U.S. Geological Survey
µg	microgram
µm	micrometer

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By Stephen J. Walsh[1], Leel Knowles, Jr.[2], Brian G. Katz[3], and Douglas G. Strom[4]

Abstract

Hydrologic, physicochemical, and aquatic community data were collected and compiled by the U.S. Geological Survey (USGS) for selected springs within the St. Johns River Water Management District (SJRWMD) from January 2004 to October 2007. Nine springs were included in this study: Alexander, Apopka, Bugg, De Leon, Gemini, Green, Rock, Silver Glen, and Wekiwa. In addition, hydrologic and water-quality data are provided for Fern Hammock, Juniper, and Silver Springs from a supplemental study. Particle tracking analysis was used to delineate the 100-year springshed for each of the targeted springs. Land-use data were compiled for the surface area contributing recharge to each springshed and are reported in general categories (urban, agriculture, forested, open-water/wetlands, and non-forested) to evaluate change for a 31-year period from 1973 and 2004 data sets. Retrospective hydrologic and physicochemical data for each spring were summarized from records of the USGS, SJRWMD, Florida Department of Environmental Protection, and a private landowner. Water-quality data collected by the USGS during the period of study consisted of quarterly physicochemical, chlorophyll-*a*, and pheophytin-*a* measurements taken simultaneously with the collection of benthic macroinvertebrate samples. Aquatic community data are summarized for collections of benthic macroinvertebrates made quarterly at Apopka, Bugg, Rock, and Wekiwa Springs in 2006, at Alexander and Silver Glen Springs in 2007, and for fish collections made once at each of these sites. In addition, benthic macroinvertebrate data collected from Gemini, Green, and De Leon Springs in 2004 are reanalyzed following re-identification of organisms to a finer taxonomic scale.

Predominant land use varied among all of the target springsheds, and notable changes occurred within several springsheds during the period of record. Alexander, Apopka, De Leon, Gemini, Green, and Wekiwa springsheds became increasingly urbanized, with a concomitant loss of forested and/or agricultural lands occurring in most springsheds. Forested cover increased and open surface waters and wetlands decreased in the Bugg and Rock springsheds. Land use in the Silver Glen springshed remained relatively unchanged. Land-use data were unavailable for Fern Hammock and Juniper Springs, but ground-based observations indicated relatively little change. Both springsheds consist of mostly forested land cover, with lesser amounts of the other land-use categories.

No significant trends were observed in rainfall records within each springshed. However, analysis of spring discharge records revealed a decreasing trend for De Leon, Fern Hammock, Rock, Silver, and Wekiwa Springs. Decreasing discharges may be associated, in part, with land-use changes that reduce springshed recharge and increased ground-water pumping. Nevertheless, climate cannot be dismissed as a major, if not primary, factor acting in conjunction with other variables that have contributed to the apparent decreasing trends in spring discharge.

Nitrate concentrations showed a significant increasing trend with time in water samples from Apopka, Fern Hammock, Gemini Springs run, and Juniper Springs. Conversely, nitrate concentrations showed a significant decreasing trend with time for Alexander Spring, Bugg Spring run, Rock Springs, and Wekiwa Springs. Phosphorus concentrations generally were low and relatively constant over time for most springs. However, water from Juniper Springs showed a significant increase in phosphorus with time, whereas significant decreases in phosphorus occurred with time at Apopka, De Leon, Rock, Silver Glen, and Wekiwa Springs.

Benthic macroinvertebrate communities among the targeted springs ranged from relatively low diversity assemblages, such as at Green Spring, to assemblages with high taxonomic richness, diversity, and dominance, such as at Rock and De Leon Springs. Mean values of the Shannon-Wiener diversity index among samples pooled by spring were lowest for Apopka Spring and greatest for Rock, Bugg, and Silver Glen Springs.

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The Stream Condition Index (SCI), a multimetric measure of ecosystem health based on the benthic macroinvertebrate community profile, was very low for all springs and all seasonal sampling events. SCI values ranged from 6 to 34; mean SCI for pooled samples per spring was lowest for De Leon and Gemini Springs and highest for Rock and Wekiwa Springs. Low SCI scores were probably the result of a combination of factors, including lack of natural association of taxa used in calculation of the SCI with spring habitats (for example, ephemeropteran, trichopteran, and sensitive species) and water-quality constituents (for example, low dissolved oxygen, high conductivity). Springs with extensive land-use changes exhibited the greatest visible signs of nutrient enrichment, as evidenced by abundant algal growth, and in some cases, these springs had proportionally high numbers of taxa considered to be very tolerant. Mean percentage of very tolerant taxa was lowest for Alexander Spring (less than 4 percent), modest (10-20 percent) for Gemini, De Leon, Rock, Silver Glen, and Wekiwa Springs, and highest (greater than 40 percent) for Bugg and Green Springs. In general, most springs had high dominance of relatively few species; dominant taxa differed among seasonal samples for some springs but most often consisted of gastropods (especially hydrobiids, for example, *Amnicola dalli*, *Aphaostracon* sp.), amphipods (*Hyalella* and *Gammarus* spp.), and oligochaetes.

Richness of fish communities was lowest for Green Spring (only two species observed) and greatest for Alexander Spring run (29 species of 31 historically recorded) and Silver Glen Springs (24 species). A combined total of 45 fish species representing 35 genera and 23 families were collected or observed from all springs in this study. Samples were dominated by centrarchids (23.7 percent), cyprinids (22.0 percent), fundulids (14.5 percent), atherinopsids (13.9 percent), and poeciliids (12.4 percent).

Introduction

The springs and spring runs of Florida are renowned for their intrinsic beauty, value as ground-water resources, and their cultural, recreational, and ecological importance (Rosenau and others, 1977; Scott and others, 2002; 2004). Threats to springs, including declining flow rates and increased nutrient and contaminant concentrations, have escalated over time as the human population of Florida expands and land-use patterns change (Miller 1997; Upchurch and Randazzo 1997). Ground water that discharges from most Florida springs originates from the Floridan aquifer system, which is the main source of water supply in the central part of the State and elsewhere.

Projections by water managers of the St. Johns River Water Management District (SJRWMD) and ground-water flow models developed by the SJRWMD and U.S. Geological Survey (USGS) indicate that increased pumping of ground water likely will result in decreased discharge from many Florida springs (Knowles and others, 2002; Sepúlveda 2002); in some cases, the decreases have been documented previously. Nitrate concentrations have increased in many springs in central Florida over time (Spechler and Halford 2001; Florida Department of Environmental Protection, 2007; Stevenson and others, 2007; Brown and others, 2008), and Florida ground-water resources are especially vulnerable to pesticides and other organic compounds (Katz 1992; Upchurch and Randazzo 1997). The ecological effects of decreased discharge and the presence of nutrients and contaminants in Florida springs are of increasing concern to natural resource managers. Consequently, in recent years much effort has focused on studying Florida spring ecosystems to improve knowledge about their structure and function. In 2001, the Florida Springs Initiative (FSI) was established by the Florida Department of Environmental Protection (FDEP) in response to recommendations made by the Florida Springs Task Force (FSTF) and growing public awareness of the declining condition of Florida springs. This initiative was a pivotal point in the history of research, monitoring, and management of Florida springs, resulting in an unprecedented level of involvement in vital assessments of springs throughout the State by multiple agencies, nongovernmental organizations, and the public and private sectors. Priority recommendations of the FSI call for collaborative actions by stakeholders to delineate springshed and recharge areas, identify relations between nutrients and ecological conditions, understand how water quantity and quality affect ecosystem structure and function, and apply a multi-pronged approach to managing, protecting, and restoring Florida springs (Florida Department of Environmental Protection, 2007).

The USGS, in cooperation with the SJRWMD, conducted a 4-year study to investigate the status and conditions of aquatic resources of selected springs identified as high priority for baseline ecological assessment. The USGS provides relevant scientific data to aid in understanding the condition of natural resources and the factors that affect them. This study is applicable to the major science strategies within the mission of the USGS (U.S. Geological Survey, 2007); in particular, the study includes elements of assessing the structure, patterns, and function of ecosystems, and evaluating and quantifying the status of freshwater resources.

Purpose and Scope

The purpose of this report is to describe selected springs in the SJRWMD, delineate their basins, summarize historic land use within each, and provide assessments of the hydrology, water chemistry, and benthic macroinvertebrate and fish communities. Data collected by the USGS during 2004-07 are provided in addition to compiled retrospective information on discharge and water chemistry obtained from multiple sources for variable periods of record. Nine springs were included in this study: Alexander, Apopka, Bugg, De Leon, Gemini, Green, Rock, Silver Glen, and Wekiwa Springs. In addition, comparative hydrologic and water-quality information is included for three additional springs (Fern Hammock, Juniper, and Silver Springs) as the result of an ancillary study to compile data for the FDEP. The present study was designed to provide baseline data and augment existing information of potential use in establishing or assessing Minimum Flows and Levels (MFLs) and assisting in the evaluation of water-resource value assessments for these springsheds. The project was initiated in 2004 with trimester collections of physicochemical and biological data for De Leon, Gemini, Green, and Silver Springs, as summarized by Phelps and others (2006). In 2006, data on physicochemical parameters, benthic macroinvertebrates, fishes, and chlorophyll-*a* and pheophytin-*a* concentrations were collected quarterly for Apopka, Bugg, Rock, and Wekiwa Springs, and were summarized in an interim report by Walsh and Kroening (2007). In 2007, similar data were collected quarterly at Alexander and Silver Glen Springs.

Environmental Setting

Springs are abundant in Florida because the peninsula is underlain by limestone and dolomite, both of which are dissolved relatively easily by rain water that seeps into the ground (Spechler and Schiffer, 1995). Carbon dioxide dissolved in aquifer-recharging rain water forms carbonic acid, a weak acid that slowly dissolves subsurface rock, creating cavities and caverns. The process results in a landform known as karst, which is characterized by the presence of springs and sinkholes (Lane 1986; Scott and others, 2004). The springs examined in this study are representative of many springs in central Florida, and are popular recreational destinations for residents and tourists (fig. 1, table 1). The study springs are located in the St. Johns River surface-water basin of north-central Florida within Orange, Lake, Marion, and Volusia Counties. Water from these springs discharges from the extensive Floridan aquifer system, one of the largest and most productive aquifers of the world (Miller 1990).

Following Meinzer (1927), Rosenau and others (1977) and Scott and others (2002; 2004), springs are classified, among other factors, by their average rate of discharge of water: a first magnitude spring is defined as having a discharge rate of greater than 100 ft^3/s (65 Mgal/d), a second magnitude spring has an average discharge rate of 10 to 100 ft^3/s (6.5 to 65 Mgal/d), and a third magnitude spring has an average discharge rate of 1 to 10 ft^3/s (0.65 to 6.5 Mgal/d). The rate of discharge from a spring depends on many factors, including the size of caverns in the rocks, water pressure in the aquifer, size of the area contributing recharge to the spring (the springshed), and amount of preceding rainfall (Spechler and Schiffer, 1995). Of the springs examined in this study, 3 were first magnitude (Alexander, Silver, Silver Glen), 7 were second magnitude (Apopka, Bugg, De Leon, Fern Hammock, Juniper, Rock, Wekiwa), and 2 were third magnitude (Gemini, Green). Spring discharge responds mostly to rainfall occurring within a springshed; however, local pumping can reduce spring flow by intercepting water that would otherwise flow to a spring. The short-term effects of pumping on spring flow are greatest during intensive consumptive periods of water use, such as for agricultural irrigation and freeze protection.

The climate in the study area is subtropical and characterized by warm, humid, rainy summers and temperate dry winters. The 30-year average for annual daily temperature is about 22°C (71°F) at DeLand and 23°C (73°F) at Sanford, Florida (National Oceanic and Atmospheric Administration, 1930-2007). Within the study area, average annual rainfall (1930-2007) is about 49 in. at Leesburg, Eustis and Lisbon; 50 in. at Orlando; 51 in. at Bushnell, Clermont, Mt. Plymouth, Plymouth, and Zellwood; 52 in. at Sanford and Crescent City; and 56 in. at DeLand. Typically, more than 50 percent of the annual rainfall occurs from June through September. About 70 to 75 percent of the rainfall commonly returns to the atmosphere as evapotranspiration (Sumner, 1996; Knowles, 1996).

Acknowledgments

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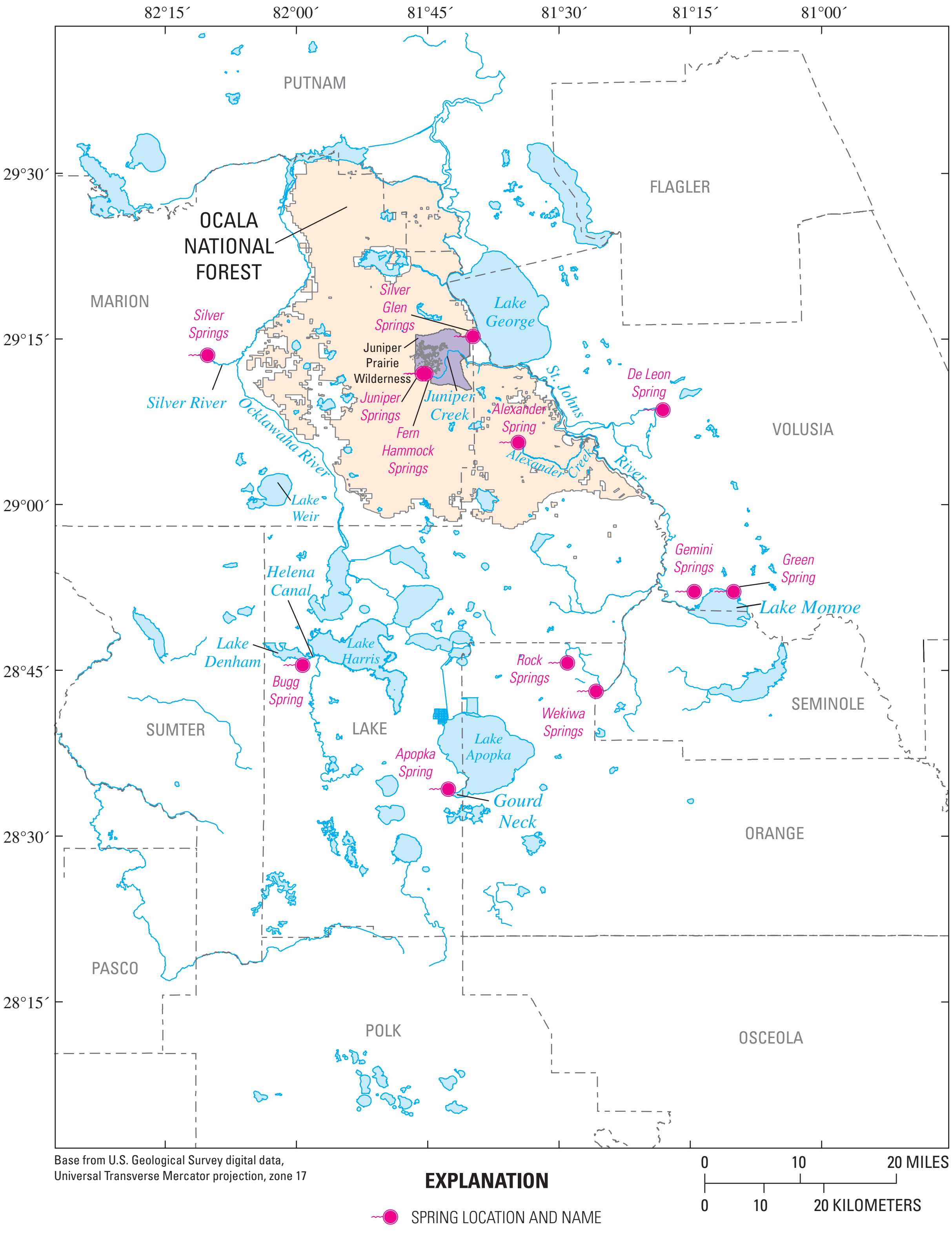
Methods of Investigation

This section contains information about (1) the procedures used to delineate springsheds and (2) how flow, water chemistry and age, and aquatic community data were collected or compiled for the springs examined in this study. Summaries of spring discharge were compiled from data sets maintained by the SJRWMD and the USGS, including measurements obtained at the time of this study as detailed in individual spring accounts. Water-chemistry data, including nutrient and contaminant constituents, were compiled from data



Base from U.S. Geological Survey digital data,
Universal Transverse Mercator projection, zone 17

Figure 1. Location of springs within the study area in central Florida.

Table 1. Springs in the study area.

[Coordinates for springs are from Scott and others (2004). Beginning of record indicates starting year of discharge measurements collected by agency listed under source of data. SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey; dd mm ss.ss, degrees, minutes, seconds]

Site name	Latitude (dd mm ss.ss)	Longitude (dd mm ss.ss)	Source of data	Beginning of record	Location and access information
Alexander	29° 04′ 52.68″	81° 34′ 33.18″	USGS, SJRWMD, FDEP	1931	About 6 mi south of Astor Park and about 17 mi northwest of De Land. The spring and spring run are within the Alexander Spring Recreation Area in Ocala National Forest.
Apopka (Gourdneck)	28° 33′ 59.77″	81° 40′ 50.41″	USGS, SJRWMD, FDEP	1971	At the southwestern shoreline of Lake Apopka in an area referred to as the Gourd Neck, a narrow cove of the lake. The spring is accessible only by boat.
Bugg	28° 45′ 07.15″	81° 54′ 05.46″	USGS, SJRWMD, FDEP	1943	About 0.4 mi northwest of Okahumpka and 3.5 mi south-southwest of Leesburg. The spring is on private property and is not accessible to the public; it is leased to the U.S. Navy, which maintains a research laboratory used for underwater calibration of sonar systems.
De Leon	30° 43′ 16.33″	85° 55′ 50.47″	USGS, SJRWMD, FDEP	1932	In De Leon Springs State Park, northwest of the municipality of De Leon Springs and about 7 mi northwest of the City of De Land.
Fern Hammock	29° 11′ 00.86″	81° 42′ 29.50″	USGS, SJRWMD, FDEP	1935	In the Juniper Springs Recreational Area in Ocala National Forest.
Gemini	28° 51′ 45.98″	81° 18′ 41.06″	USGS, SJRWMD, FDEP	1966	In Gemini Springs County Park.
Green	28° 51′ 46.04″	81° 14′ 50.92″	USGS, SJRWMD, FDEP	1932	Spring is along the north shore of Lake Monroe near the town of De Bary.
Juniper	29° 11′ 01.34″	81° 42′ 44.68″	USGS, SJRWMD, FDEP	1935	In the Juniper Springs Recreational Area in Ocala National Forest about 10 mi west of Astor Park.
Rock	28° 45′ 23.20″	81° 30′ 06.25″	USGS, SJRWMD, FDEP	1931	In Dr. Howard A. Kelly Park, approximately 6 mi north of the City of Apopka. The spring and spring run are within the boundaries of the Wekiva River Aquatic Preserve.
Silver	29° 12′ 58.34″	82° 03′ 09.47″	USGS	1932	East of Ocala in Marion County.
Silver Glen	29° 14′ 45.04″	81° 38′ 36.50″	USGS, SJRWMD, FDEP	1931	About 11 mi south of the city of Salt Springs and 30 mi northeast of Ocala in eastern Marion County. The spring head and part of the run are in the Silver Glen Springs Recreational Area of the Ocala National Forest.
Wekiwa	28° 42′ 42.79″	81° 27′ 37.52″	USGS, SJRWMD, FDEP	1932	About 4 mi northeast of the City of Apopka. The spring pool and run are located within Wekiwa Springs State Park.

sets downloaded from databases maintained by the USGS, SJRWMD, and FDEP. Age-dating data, including tritium (^{3}H) concentration, gases (helium, ^{3}He, ^{4}He), sulfur hexafluoride (SF$_{6}$), and nutrient isotopes (δ^{1}) were compiled from a database maintained by the USGS.

Delineation of Springsheds

The procedure used to delineate 100-year springsheds or areas contributing recharge to springs involved particle-tracking analyses (Pollock, 1994) using the output from a ground-water flow model (Knowles and others, 2002). The particle-tracking analyses for each spring was performed using the MODPATH program (Pollock, 1994) and required steps including (1) assigning effective porosity values to the hydrogeologic units, (2) using forward and backward particle tracking, (3) determining the number of particles to use and assigning starting locations for each particle, (4) determining how particles interact with weak sinks such as specified-flux, specified-head, or head-dependent flux internal boundaries that do not discharge all of the ground water entering the model cell, and (5) selecting ground-water flow model grid cells having travel times of less than 100 years. The term “springshed” used in this report is defined as the contributing area of ground-water flow to the spring head with a travel time of less than 100 years.

Given the uncertainties in effective porosity, uniform values were assigned to each layer in the model (Knowles and others, 2002). A value of 0.4 each was assigned to the surficial aquifer system and intermediate confining unit model layers. A value of 0.2 each was assigned to the Upper Floridan aquifer and the middle semiconfining unit model layers. The value of effective porosity affects only particle travel time, but has no effect on particle paths calculated by MODPATH (Shoemaker and others, 2004). This procedure for delineating springsheds accounts for the slight difference in the Silver Springs springshed presented in this report and the springshed presented in Shoemaker and others (2004).

Forward particle tracking was used to delineate areas contributing recharge, because the complex discontinuous areas were more clearly defined by using forward (rather than backward) tracking. Forward tracking was performed by first identifying extensive areas surrounding each spring cell where particles would initially be placed to encompass all potential areas. Using the maximum number of particles, these particles initially were placed at the water-table surface in active surficial aquifer system cells. The areas contributing recharge for each spring were then delineated by noting the location of model cells with forward particles that entered the spring cell. Backward tracking was used to compute the percent of total spring discharge as a function of particle travel time. Particles were allowed to pass through weak sinks during forward and backward tracking, because many pumping wells simulated as weak sinks were located within the areas contributing recharge to each spring. Stopping particles at these pumping wells would have reduced the areas contributing recharge to unrealistic zone limits. In addition, particles were allowed to pass through weak sinks because discharge from many weak sinks was negligible compared to the total inflow to the model cell.

Land Use Data Compilation

To determine approximate 30-year land-use changes for each springshed, land-use data from 1973 and 2004 for areas contributing recharge to each spring (100-year springshed) were compiled from geographic information system (GIS) data sets provided by the SJRWMD and the Southwest Florida Water Management District (SWFWMD). At the time of this study, the 1973 land-use data set was the earliest available that covered the entire study area. Land-use changes for each springshed were determined in ArcMap by overlaying and comparing land-use and springshed data sets. Land-use types are consolidated from land-use codes contained in the data sets and are presented for simplicity herein as the following general land-use types: urban/mining/recreation/transportation, agriculture/pastureland/rangeland, non-forested (barren) land, forestland, and open-water surfaces/wetlands.

Hydrologic Data Compilation

The period of record used herein for the analysis of spring discharge and associated rainfall begins in 1930, although a few measurements were collected at some springs prior to 1930. Hydrologic data, including flow and stage data, were collected by the USGS and SJRWMD. Continuous flow was calculated for Rock and Wekiwa Springs by the SJRWMD, and measured at Silver Glen Springs by the USGS. Noncontinuous flow measurements were made weekly at Bugg Spring by a qualified observer for the SJRWMD since 1990, monthly at Alexander by the USGS and SJRWMD since 1982, quarterly at Apopka by a contractor for the SJRWMD since 1997, and intermittently at Juniper and Fern Hammock Springs by the USGS and SJRWMD since 1908 and 1935, respectively. Annual discharge values for each spring were computed by averaging all of the measurements made during each year for that spring.

Kendall's tau (τ) test (Helsel and Hirsch, 1992) was used to determine if variations in spring discharge and rainfall were statistically significant trends rather than random occurrences. The Kendall test is a nonparametric procedure that measures the strength of a monotonic relation, whether linear or nonlinear, between x and y. Distribution of discharge and rainfall data was assumed to be monotonic for the period of record in this study.

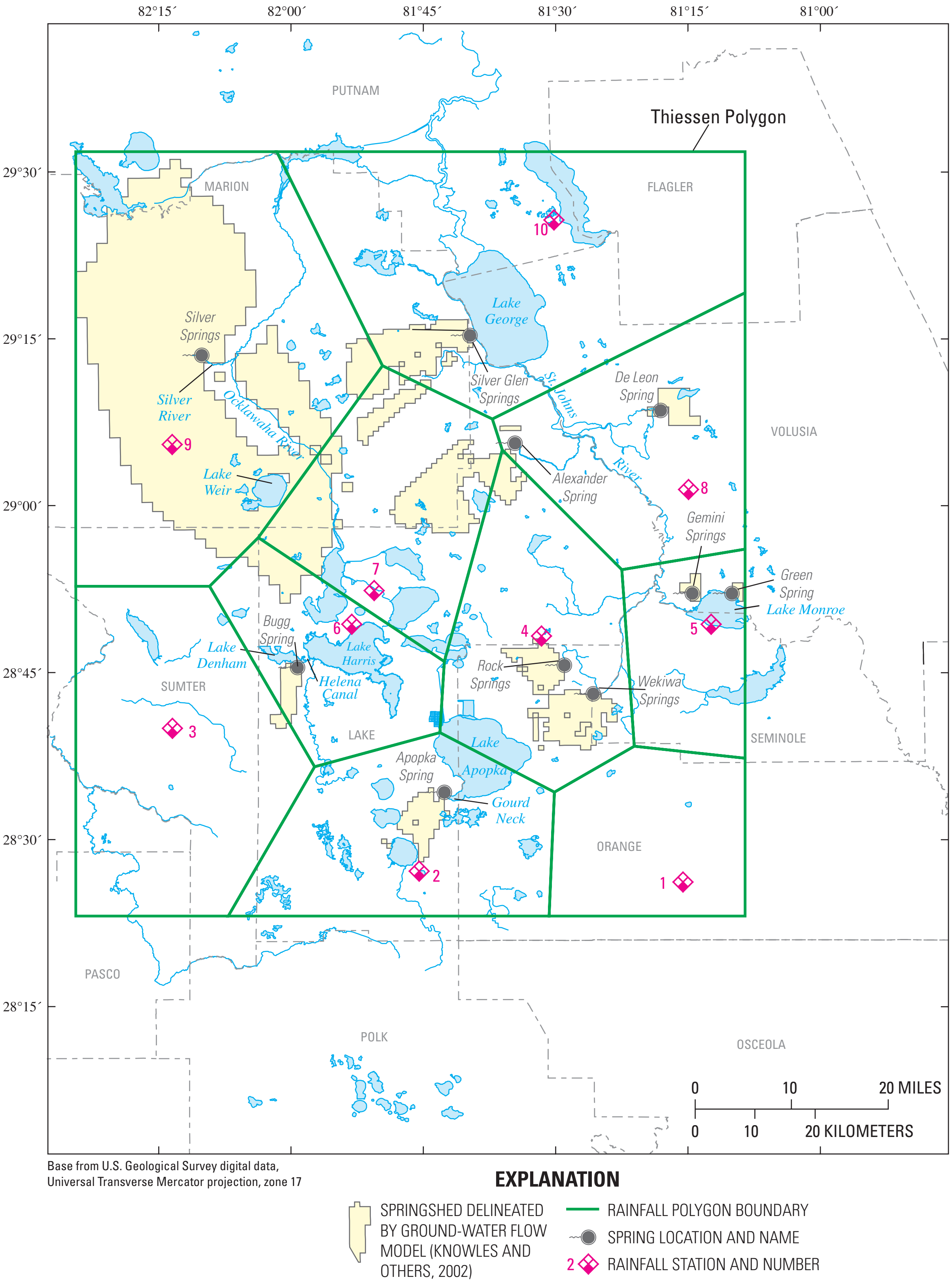
Rainfall for each springshed was determined areally in ArcMap using the Thiessen method for a set of 10 polygons with each polygon representing a single rain-gage station (Fetter 1980) (table 2, fig. 2). Weighted rainfall values, which were computed for the percentage of total springshed area in each Thiessen polygon, were summed to determine the total rainfall for each springshed.

Table 2. Rainfall stations in the study area.

[Station locations are shown in figure 2. Coordinates are from agency station records. Beginning of record is 1930 for all stations. All rainfall data collected by National Oceanic and Atmospheric Administration (NOAA), except where indicated; dd mm ss.ss, degrees, minutes, seconds]

Site number	Site name	Latitude (dd mm ss.ss)	Longitude (dd mm ss.ss)
1	Orlando	28° 26′ 02″	81° 19′ 30″
2	Clermont	28° 27′ 00″	81° 43′ 00″
3	Bushnell	28° 39′ 43″	82° 04′ 58″
4	Mt. Plymouth/Plymouth/Zellwood[1]	28° 47′ 56″	81° 32′ 06″
5	Sanford	28° 49′ 00″	81° 17′ 00″
6	Leesburg/Eustis	28° 49′ 00″	81° 49′ 00″
7	Lisbon	28° 52′ 00″	81° 47′ 00″
8	De Land	29° 01′ 00″	81° 19′ 00″
9	Ocala	29° 05′ 00″	82° 05′ 00″
10	Crescent City	29° 25′ 42″	81° 31′ 00″

[1] Data collected by NOAA and private observer.



Base from U.S. Geological Survey digital data,
Universal Transverse Mercator projection, zone 17

Figure 2. Thiessen rainfall polygons and springsheds for selected springs of the St. Johns River drainage. Rainfall station information is provided in table 2.

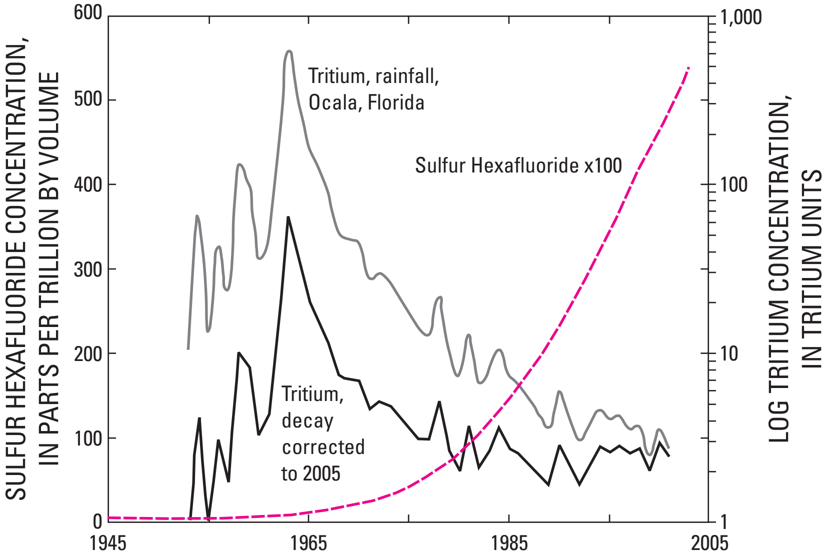


Figure 3. Input of sulfur hexafluoride to the atmosphere in the northern hemisphere and tritium concentrations in rainfall from Ocala, Florida during 1950-2006 (modified from Katz and others, 2007).

Collection and Analysis of Spring Water

Water samples were collected by the USGS, SJRWMD, and FDEP using an electric submersible stainless-steel pump with Teflon discharge tubing by immersion into the spring pool as close to the vent as possible (Phelps and others, 2006). In the spring runs, the pump was placed at approximately one-half the depth of water in the run (Phelps and others, 2006). Water samples were collected after field constituents (pH, specific conductance, temperature, and dissolved oxygen) had stabilized, and were collected according to U.S. Geological Survey (1997-2006) protocols as described in Phelps and others (2006). The USGS National Water Quality Laboratory in Lakewood, Colorado, analyzed water samples for major ions, nutrients, pesticides, and organic wastewater compounds. Samples for nitrogen and oxygen isotopes of nitrate were analyzed at the USGS Stable Isotope Laboratory in Reston, Virginia. Isotopic values are reported using the standard delta (δ) notation (Gonfiantini, 1981). Chlorophyll-*a* and pheophytin-*a* were measured following the methods of Arar and Collins (1997).

Kendall’s tau (τ) test (Helsel and Hirsch, 1992) was used to determine if variations in nitrate-N and phosphorus concentrations in spring waters showed significant trends over the time period of sampling. A probability level of 5 percent ($p < 0.05$) was used as the criterion for significance, which indicated that the probability of a correlation trend between nitrate-N or phosphorus concentration and time occurring by chance was less than 5 percent.

The saturation index of minerals that are present in the aquifer matrix (calcite, dolomite, and gypsum) is used to determine if spring water is in thermodynamic equilibrium with a given mineral. When spring water is undersaturated with respect to a mineral (saturation index < 0), the mineral has the thermodynamic potential to dissolve. When water is saturated with respect to a mineral (saturation index = 0 ± 0.1), the mineral is in equilibrium with the aqueous phase. When the saturation index is greater than zero, the mineral has the thermodynamic potential to precipitate from the water phase.

Age Dating of Spring Water

To better understand the age of water discharging from springs, water samples were analyzed for the transient environmental tracers sulfur hexafluoride (SF_6), tritium (^3H), and its radioactive decay product helium-3 (^3He). Anthropogenic activities, such as industrial processes and atmospheric testing of thermonuclear devices, have released SF_6, and ^3H into the atmosphere in low but measurable concentrations (fig. 3). Precipitation that incorporates SF_6, and ^3H from the atmosphere infiltrates into the ground and carries a particular chemical or isotopic signature related to atmospheric conditions at the time of recharge to the Upper Floridan aquifer. The dating methods assume that gas exchange between the unsaturated zone and air is rapid, but that shallow ground water remains closed to gas exchange after recharge (Schlosser and others, 1989; Plummer and Busenberg, 2000; Busenberg and Plummer, 2000). Sampling and analytical procedures for SF_6 sampling are described by Busenberg and Plummer (2000).

Water samples for the determination of ^{3}H, ^{3}He, ^{4}He, and neon were collected in pinched-off copper tubes (10-mm [0.39 in.] diameter, 80-cm [3.15 in.] length, approximately 40-mL volume) while applying back pressure to prevent formation of gas bubbles. These samples were analyzed at the Noble Gas Laboratory of Lamont-Doherty Earth Observatory by using quantitative gas extraction followed by mass spectrometry techniques (Schlosser and others, 1989; Ludin and others, 1998).

Lumped parameter models have been used to estimate the age distribution of spring waters and spring-water mixtures in previous studies in the St. Johns Water Management District (Toth and Katz, 2006) and elsewhere in Florida (Katz and others, 1999; Katz, 2004). In this study, lumped parameter models were used to estimate the age distribution of spring water from the Upper Floridan aquifer. These models treat the aquifer system as a homogeneous compartment in which tracer input concentrations are converted to tracer output concentrations according to the system response function used (Zuber, 1986). By fitting measured tracer concentrations to modeled output curves, the response function accounts for the distribution of ages at a sampled site (Zuber and others, 2001). No detailed information is needed regarding the flow system, such as boundary conditions, porosity, and hydraulic conductivity—all of which are necessary for numerical models based on Darcy's law. Lumped parameter models assume a steady-state flow system and assume that the selected tracers behave like water molecules. Although this assumption typically is valid for ^{3}H, which is part of the water molecule, the gas tracer SF_6 may or may not be transported in the same exact manner as the water.

Ground-water flow system characteristics are represented by two end-member lumped-parameter models: piston flow and exponential flow. The piston-flow model (PFM) assumes that after a tracer is isolated from the atmosphere at the time of ground-water recharge, it becomes incorporated in a parcel of water that moves from the recharge area with the mean velocity of ground water. All flow lines are assumed to have similar velocities, and hydrodynamic dispersion and molecular diffusion of the tracer are assumed to be negligible.

The exponential flow model (EFM) represents an aquifer system in which the mean residence time of ground water is exponentially distributed. Ground-water flow is composed of recharge from all past years. Ground-water contributions to well discharge, however, decrease exponentially from the most recent recharge to that which has occurred in the distant past. Although the exponential model may provide a reasonable approximation of homogeneous unconsolidated aquifers, it may not be as useful in karst systems where ground water moves slowly through small openings in the carbonate matrix, fractures or fissures, and much more rapidly through large conduits or caverns.

Other lumped parameter models that account for mixing include the combined exponential and piston flow model (EPM). The EPM has one additional fitted parameter, which is the ratio of the PFM to the EMM.

In addition to the above models, simple binary mixing models (BMM) are used to evaluate mixing scenarios that involve relatively young water (recharged within the past 5 years) with older water (decades), presumably from deeper parts of the Upper Floridan aquifer. In principle, both end members of a binary mixture can be of any age, but the calculation is greatly simplified if it is assumed that one or both end members is either "young" (assumed to represent recharge that occurred after 1995) or "old" (recharged before 1950 with undetectable SF_6 concentrations). Ground-water ages were determined using combinations of tracers including SF_6 and ^{3}H, and SF_6 and $^{3}H/^{3}H(0)$. The $^{3}H(0)$ tracer represents the initial tritium concentration at the time of recharge and is the sum of the measured concentrations of ^{3}H and ^{3}He. The ratio of $^{3}H/^{3}H(0)$ is a surrogate for the relative age of water, in that values near 0.0 represent old waters, and conversely, values near 1.0 represent young waters. The computer program TRACERMODEL1 (Böhlke, 2006) was used in this study to calculate theoretical curves for the different lumped parameter models using atmospheric input data for the various tracers.

Aquatic Community Data Collection and Analysis

Aquatic macroinvertebrates were collected with a D-frame dip net (500-µm mesh, 0.3-m width) and Wildco™ petite ponar dredge. Dip net sampling was based on a multi-habitat approach (Barbour and others, 1999) to determine richness and diversity metrics and to calculate the Stream Condition Index (SCI; Barbour and others, 1996b; Fore and others, 2007). Collections made with the petite ponar dredge were done to estimate abundance as density of organisms per square meter. Dip net collections and those made with the petite ponar dredge followed standard operating procedures used by the Florida Department of Environmental Protection (2004). Sampling was done within wadeable reaches downstream of main spring vents or on the periphery of spring pools in those systems with a spring run (Alexander, Bugg, De Leon, Gemini, Green, Rock, Silver Glen, and Wekiwa). Sampling in Apopka Spring was limited to deploying a petite ponar dredge from a boat in close proximity to the surface boil. Microhabitats selected for sampling were based on areas inferred to provide suitable conditions of substrate and cover to support macroinvertebrate communities (for example, Barbour and others, 1999).

Each dip net sample consisted of 20 sweeps or scrapes taken from leaf packs, aquatic macrophytes (submersed and emergent), root mats, undercut banks, unconsolidated sediment (muck or sand), rock, and woody snag microhabitats in proportion to the approximate percent coverage of each habitat type estimated visually. Each sweep or scrape consisted of collecting epifauna from a 0.5-m (1.64 ft) section of substrate or cover by scraping or jabbing the dip net, or manually agitating or brushing in a manner to allow benthic macroinvertebrates and organic matter to flow into the net held stationary downstream or into a bucket that was then strained through the net. Material was rinsed through a series of sieves to remove coarse debris, vegetation, detritus and sediment. Three replicate samples were taken with the petite ponar dredge at each site and on individual sampling dates. Rinsed dip net samples and the entire contents of each ponar grab were preserved in a 10-percent solution of formalin containing Rose Bengal dye.

Freshly preserved samples were transferred to the USGS laboratory in Gainesville, Florida, soaked and rinsed in water for 24 to 48 hours following a fixation period of at least 2 days, and placed in a solution of 70-percent ethanol. Samples were then transferred to Water and Air Research, Inc., in Gainesville, where macroinvertebrates were sorted, identified, and enumerated. Subsampling procedures were applied to randomly select a minimum target number of 100 to 110 organisms per collection (Florida Department of Environmental Protection, 2004). Taxonomic identifications were made to the lowest practicable identification level (LPIL). A voucher collection of representative taxa is maintained at the USGS facility in Gainesville. A list of all macroinvertebrates collected in this study and taxonomic authorities are provided in appendix 1. Taxonomic authorities were obtained from the Integrated Taxonomic Information System (*http://www.itis.gov/*, accessed October 1, 2008), Epler (2001), Bright (2007), and Wetzel and others (2008).

For individual dip net samples, raw data were "upward collapsed" using FDEP standard operating procedures. Specifically, closely related organisms in a sample that were identified to different supraspecific categories were allocated among presumed congeneric or species-level taxa. For example, Chironomidae LPIL and/or *Dicrotendipes* sp. would be combined with *Dicrotendipes modestus*. Data from ponar samples were pooled for each set of replicates taken at an individual spring on the same date.

Standard community metrics for benthic macroinvertebrates were calculated using "Warstat" (proprietary software of Water and Air Research Inc.), PRIMER® (Version 6.1.6; Clarke and Warwick, 2001; Clarke and Gorley, 2006), and PC-ORD® (Version 5.0; McCune and Grace, 2002; McCune and Mefford, 2006). Kwak and Peterson (2007) recommend providing explicit equations used in reporting community indices of species diversity, equitability, and dominance, because there are numerous alternative forms and occasional inconsistent use of terminology. The Shannon-Wiener diversity index, H' (Shannon, 1948), was calculated as:

$$H' = -\sum_{i=1}^{s} p_i \log_e p_i \qquad (1)$$

where H' (index of diversity) is the information content of the sample (nits/individual), s is the number of species, and p_i is the proportion of the total sample belonging to the ith species. Calculation of H' is with a logarithmic base of e, 2, or 10; conversion factors are provided by Krebs (1999), Zar (1999), and others. The logarithmic base 2 for calculation of H' is specified in Florida Statutes Chapter 62-30 of the Florida Biological Integrity Rule. Therefore, calculated values using each of the logarithmic bases are included in table summaries.

The Shannon-Wiener diversity index may also be expressed as units of numbers of species (MacArthur, 1965; Krebs, 1999):

$$N_1 = e^{H'} \qquad (2)$$

where N_1 is the number of equally common species that would produce the same diversity as H' and e is the natural log base; N_1 has been suggested to be among the best heterogeneity measures that are sensitive to abundances of rare species in a community (Peet, 1974).

Evenness or equitability (Pielou, 1966) was calculated as:

$$J' = \frac{H'}{H'_{\max}} = \frac{H'}{\log S} \qquad (3)$$

where J' is evenness and $H'_{\max}$ is the maximum possible value of the Shannon-Wiener index, a value that would be achieved if all species were equally abundant (= log S, where S is the number of species) (Clarke and Warwick, 2001).

Simpson's index of diversity was calculated as:

$$1 - D = 1 - \sum (p_i)^2 \qquad (4)$$

where (1-D) is the Simpson's index of diversity (that is, complement of the original index, D; Simpson, 1949) and p_i is the proportion of individuals of species i in the community (that is, 1-D = probability of selecting two organisms at random that are different taxa). Simpson's index of diversity emphasizes more abundant species in a sample and ranges from 0 (low diversity) to near 1 (that is, 1[1-1/s] where s is the number of species in the sample).

The Stream Condition Index (SCI) is a multimetric index used to evaluate the relative condition of the water quality of a water body based on characteristics of the benthic invertebrate community (Barbour and others, 1996a and 1996b; Fore and others, 2007). The index is a summation of macroinvertebrate metrics that are responsive to environmental disturbance. The SCI has been modified (recalibrated) since first established and currently includes the following core metrics: (1) taxonomic richness; (2) numbers of Ephemeroptera, Trichoptera, Tanytarsini, clinger taxa, long-lived taxa, sensitive taxa; and, (3) percentages of filter feeders, dominant taxa, and very tolerant taxa (Fore and others, 2007). The index is calibrated for three ecoregions of Florida and is normalized to a scale of 0 to 100 by multiplying by 0.9. Threshold values of SCI scores are interpreted to define biocriteria for classification of aquatic life use categories as: "exceptional" = 71 to 100; "healthy" = 35 to 70; and "impaired" = 0 to 34. Details on the calculation of the SCI are provided in FDEP Standard Operating Procedure LT7200, Stream Condition Index Determination (*http://www.dep.state.fl.us/labs/qa/sops.htm*, accessed October 1, 2008). At the time of this study, subsampling to calculate the SCI was based on a target number of 100 to 110 individual organisms selected by a randomization process; the SCI procedures were subsequently modified to include subsampling of a larger number of organisms (140-160) based on average scores from two subsamples per site or date.

Scores for the Florida Index (FI; Ross and Jones, 1979) were assigned to Class I and II taxa and calculated for each spring using the formula:

$$\text{FI} = 2 \times \text{number of Class I taxa} + \text{number of Class II taxa} \qquad (5)$$

The FI is a composite metric that was developed for Florida based on taxa sensitive to environmental perturbation, especially insects and crustaceans (Beck, 1954); it represents the weighted sum of the least tolerant taxa (that is, most sensitive, which are assigned a score of 2) and more tolerant taxa (less sensitive, assigned a score of 1).

Multivariate ordinations of benthic macroinvertebrate data for dip net collections were used to examine assemblages among springs and to associate observed relationships with environmental data using PRIMER® version 6.1.6 (Clarke and Warwick, 2001; Clarke and Gorley, 2006). Agglomerative hierarchical clustering using Bray-Curtis similarities of means for each spring and nonmetric multidimensional scaling (MDS) were used to identify groups. Physicochemical data were analyzed with principal components analysis (PCA) and the resulting vectors then compared with the assemblage ordination using the BioEnv procedure of PRIMER®.

Fishes were collected using an electroshocking boat equipped with a Smith-Root™ GPP 9.0 controller. Frequency and voltage settings on the controller were adjusted in the range of 60 to 120 Hz and 100 to 680 volts to produce about 2 to 14 amps. Two netters at the front of the boat retrieved fish with dip nets and placed them in a live well. Large fish were identified, measured (total length, TL, in millimeters), and released near the site of capture. Small fish (less than about 75 mm [2.95 in.]) were fixed in a 10-percent formalin solution and returned to the laboratory for identification and enumeration. Accessibility to head spring areas by boat or using other gears to catch fish was precluded in some instances; consequently, most fish collections were made in spring runs, occasionally a considerable distance downstream from the main spring vent(s). Snorkeling and seining was also used in some cases to observe and/or catch fish in habitats inaccessible by boat. Voucher specimens of representative fishes were deposited in the ichthyology collection of the Florida Museum of Natural History, University of Florida, Gainesville (*http://www.flmnh.ufl.edu/fish/collection/collection.htm*, accessed October 1, 2008). Scientific and common names of fishes collected during this study are listed in appendix 2 and follow the nomenclature of Nelson and others (2004).

Hydrology, Water Quality, and Aquatic Communities of Selected Springs

Individual spring descriptions provided herein are based on those presented by Rosenau and others (1977), Scott and others (2002; 2004), Phelps and others (2006), and personal observations made at the time of this study. No biological sampling was conducted at Fern Hammock, Juniper, or Silver Springs during this study; hydrologic and land-use data for these springs are summarized from the results of an ancillary investigation for the FDEP (Munch and others, 2006) conducted simultaneously with the present study.

Spring accounts describe boil and spring pool characteristics, related surface-water attributes, vegetation abundance in the spring pool and spring run, and surrounding land features.

Springshed land-use characterization and percentage of each category for the years covered are summarized in individual spring accounts, and land-use changes from 1973 to 2004 for the springsheds included in this study are presented in figure 4. Wastewater treatment and disposal systems are characterized for each springshed in terms of current use and changes that have occurred between 1973 and 2004.

Discharge data for individual springs are presented in each spring account as annual means. Discharge ranges are presented as minimum and maximum annual means and instantaneous values.

Physicochemical data collected simultaneously with macroinvertebrates for springs sampled during 2004-07 are summarized in appendix 3. Data that were collected at the spring vent or boil and in stream sections downstream in the spring runs where benthic macroinvertebrates were sampled include the following: water temperature, specific conductance, dissolved oxygen, pH, turbidity, and chlorophyll-*a* and pheophytin-*b*. Summaries of these data are presented in each of the spring accounts. Median values of physicochemical data reported in individual springs and table 3 were derived from the entire period of record for each spring as compiled from the sources listed in the “Methods of Investigation” section.

Detailed summaries of benthic macroinvertebrate samples are provided in each spring account, and a comparison among all springs in the “Comparison of Aquatic Communities” section. Benthic macroinvertebrate data are presented as richness (total taxa), percent composition, and dominance for subsamples of collections made with both petite ponar dredge and dip net. Density estimates, reported herein as the number of organisms per square meter, are provided for benthic macroinvertebrates collected by petite ponar dredge. Diversity indices, represented by the Shannon-Wiener index (to natural log base, 2, and 10), Pielou’s evenness, and Simpson’s index of diversity, are presented in individual spring accounts and tables 4 and 5. In addition, the Florida Index is provided for samples collected by petite ponar dredge, and the SCI and percent very tolerant taxa are reported for collections made with dip net.

Total numbers of fishes collected or estimated to have been observed at each spring are summarized in each account and in tabular format, where appropriate, listed by family, species, and percent composition of each sample.

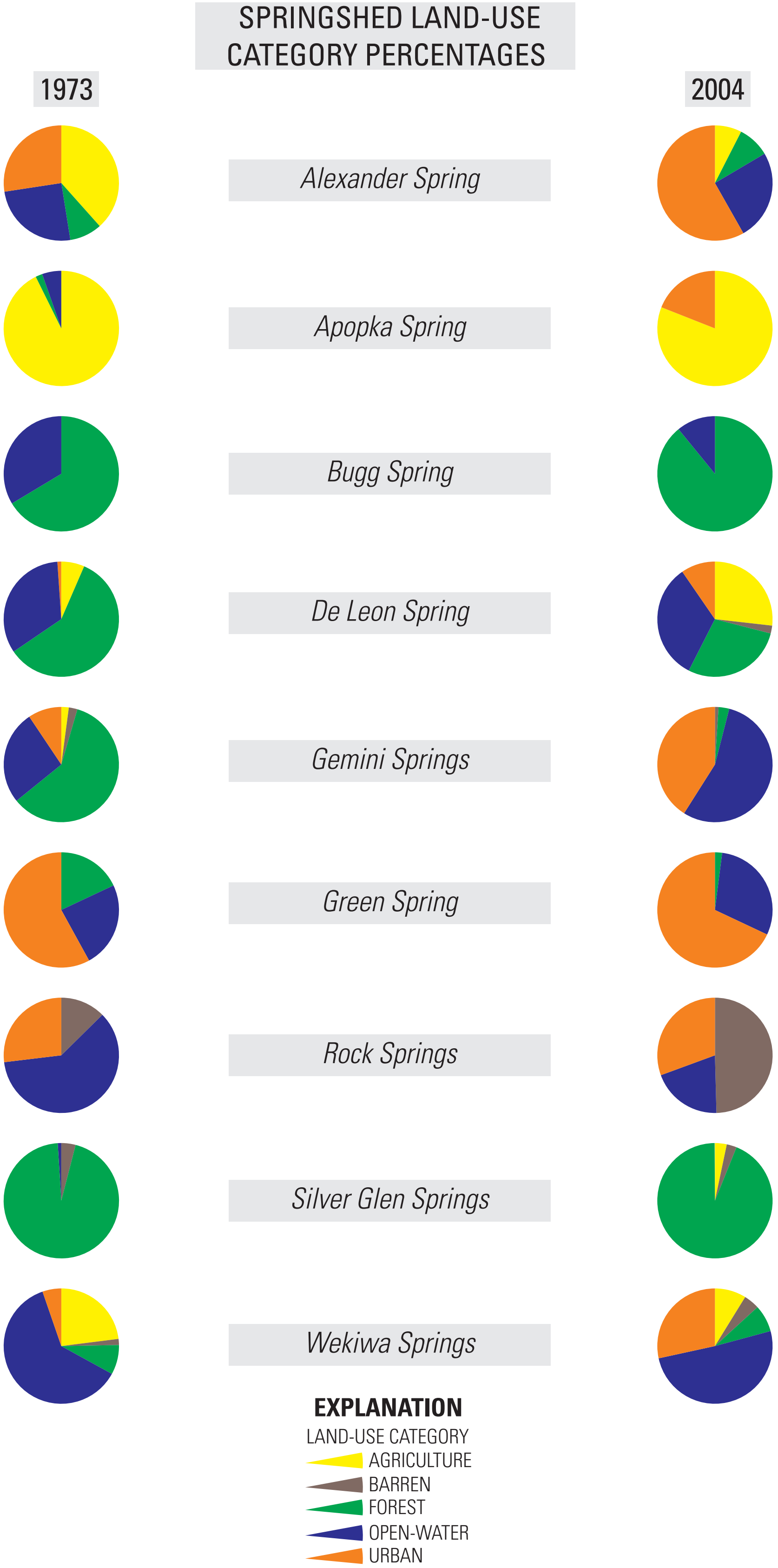


Figure 4. Relative proportions of springshed land-use categories for the years 1973 and 2004.

Table 3. Median values for physical and chemical characteristics, and saturation indices with respect to calcite, dolomite, gypsum, and carbon dioxide partial pressure for selected springs in the St. Johns River Water Management District.

[In shaded cells, period of water-quality data are shown below each spring name and number of observations are shown in parentheses. All concentration units are milligrams per liter unless otherwise noted. Temp, water temperature in degrees Celsius; SC, specific conductance in microsiemens per centimeter; DO, dissolved oxygen; DS, dissolved solids; HCO_3, bicarbonate; NO_2-NO_3-N, nitrite plus nitrate as nitrogen; o-PO_4, orthophosphate, as P; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Cl, chloride; SO_4, sulfate; F, fluoride; SiO_2, silica; log pCO_2(g), log partial pressure of carbon dioxide in atmospheres; SI, saturation index with respect to calcite, dolomite, and gypsum calculated using median chemistry (unitless)]

Spring	Temp	SC	DO	pH	DS	HCO_3	NO_2-NO_3-N	o-PO_4	Ca	Mg	Na	K	Cl	SO_4	F	SiO_2	log pCO_2 (g)	Calcite SI	Dolo-mite SI	Gypsum SI
Alexander	23.5	1,100	2.12	7.80	596	82	0.04	0.05	46	20.3	137	4.0	252	66	0.12	8.8	-2.92	-0.16	-0.34	-2.00
1960-2007	(113)	(97)	(16)	(92)	(77)	(76)	(70)	(34)	(79)	(80)	(80)	(80)	(82)	(79)	(49)	(7)				
Apopka	24.2	249	3.76	8.09	146	74	4.41	0.09	29	8.0	5.5	1.5	12	9.9	0.08	4.9	-3.23	0.01	-0.19	-2.83
1972-2007	(99)	(101)	(34)	(92)	(89)	(89)	(84)	(84)	(101)	(100)	(100)	(93)	(91)	(89)	(10)	(26)				
Bugg	23.6	293	1.43	7.60	167	125	0.58	0.07	48	3.0	5.9	0.93	11	6.1	0.10	8.6	-2.52	-0.05	-0.97	-2.84
1972-2006	(18)	(17)	(11)	(17)	(12)	(10)	(9)	(191)	(12)	(12)	(12)	(12)	(12)	(11)	(9)	(5)				
Bugg Run	23.6	290	3.58	7.56	172	125	0.50	0.08	50	3.2	7.7	1.1	13	8.8		9.2	-2.48	-0.08	-1.01	-2.68
1991-2007	(43)	(43)	(24)	(43)	(25)	(38)	(39)	(221)	(25)	(24)	(24)	(22)	(35)	(35)		(14)				
De Leon	23.0	640	1.48	7.60	416	120	0.90	0.16	50	12.8	79	4.4	115	27	0.10	6.6	-2.55	-0.12	-0.50	-2.28
1932-2007	(220)	(201)		(89)	(77)	(79)	(63)	(5)	(80)	(81)	(81)	(79)	(180)	(81)	(61)	(15)				
De Leon Run	23.1	900	5.52	7.46	546		0.63	0.16	52	16.7	121	5.7	227	38	0.10	6.6	-2.42	-0.27	-0.71	-2.17
2004-2007	(5)	(5)	(5)	(5)	(3)		(4)	(2)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)				
Fern Hammock	21.9	118	6.20	8.17	68	45	0.08	0.02	13	4.7	2.7	0.30	4.5	6.9	0.07	9.6	-3.53	-0.46	-1.06	-3.25
1972-2007	(92)	(89)	(12)	(81)	(66)	(67)	(65)	(17)	(70)	(70)	(47)	(18)	(67)	(69)	(46)	(2)				
Gemini N Boil	23.1	2,508	1.01	7.25	1,523		1.07	0.18	104	41.0	346	8.4	660	124	0.14	9.7	-2.12	-0.19	-0.45	-1.56
2004-2006	(7)	(7)	(7)	(7)	(2)		(2)	(2)	)	(2)	(2)	(2)	(2)	(2)	(2)	(2)				

Table 3. Median values for physical and chemical characteristics, and saturation indices with respect to calcite, dolomite, gypsum, and carbon dioxide partial pressure for selected springs in the St. Johns River Water Management District.—Continued

[In shaded cells, period of water-quality data are shown below each spring name and number of observations are shown in parentheses. All concentration units are milligrams per liter unless otherwise noted. Temp, water temperature in degrees Celsius; SC, specific conductance in microsiemens per centimeter; DO, dissolved oxygen; DS, dissolved solids; HCO_3, bicarbonate; NO_2-NO_3-N, nitrite plus nitrate as nitrogen; o-PO_4, orthophosphate, as P; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Cl, chloride; SO_4, sulfate; F, fluoride; SiO_2, silica; log pCO_2(g), log partial pressure of carbon dioxide in atmospheres; SI, saturation index with respect to calcite, dolomite, and gypsum calculated using median chemistry (unitless)]

Spring	Temp	SC	DO	pH	DS	HCO_3	NO_2-NO_3-N	o-PO_4	Ca	Mg	Na	K	Cl	SO_4	F	SiO_2	log pCO_2 (g)	Calcite SI	Dolomite SI	Gypsum SI
Gemini S Boil	23.3	2,579	0.86	7.23	1,572		1.06	0.19	104	40.9	349	8.6	671	124	0.14	9.7	-2.10	-0.21	-0.49	-1.57
2004-2006	(7)	(7)	(7)	(7)	(2)		(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)				
Gemini Run	22.9	2,412	3.20	7.35	1,420	136	0.91	0.08	101	39.0	334	8.3	633	120	0.12	9.2	-2.28	-0.15	-0.39	-1.58
1972-2007	(50)	(49)	(7)	(47)	(45)	(42)	(47)	(20)	(48)	(48)	(48)	(48)	(48)	(50)	(33)	(6)				
Green	22.7	2,480	0.41	7.36	1,500	158	0.03	0.07	87	40.6	357	11	682	102	0.09	7.4	-2.22	-0.14	-0.29	-1.71
1960-2007	(43)	(43)	(9)	(43)	(33)	(34)	(18)	(17)	(35)	(35)	(35)	(35)	(35)	(35)	(16)	(2)				
Green Run	22.8	2,716	0.60	7.30	1,490		0.02	0.07	89	41.9	360	12	690	104	0.10	7.8	-2.16	-0.19	-0.39	-1.70
2004	(3)	(3)	(3)	(3)	(3)		(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)				
Juniper	22.0	117	6.60	8.43	66	45	0.08	0.02	13	4.4	2.7	0.30	4.4	6.0	0.07	8.8	-3.80	-0.21	-0.58	-3.31
1908-2007	(110)	(110)	(11)	(102)	(84)	(91)	(77)	(33)	(95)	(92)	(94)	(27)	(91)	(92)	(53)	(8)				
Rock	23.8	251	1.38	7.65	144	93	1.45	0.08	30	9.1	5.1	1.3	8.6	18	0.15	9.4	-2.69	-0.32	-0.83	-2.56
1931-2007	(203)	(140)	(16)	(122)	(107)	(107)	(87)	(37)	(112)	(113)	(112)	(111)	(114)	(114)	(80)	(23)				
Silver Glen	23.2	1,951	3.68	7.84	1,070	68	0.04	0.02	71	34.5	250	8.7	453	179	0.12	8.8	-3.06	-0.10	-0.18	-1.51
1972-2007	(94)	(89)	(16)	(85)	(62)	(65)	(60)	(12)	(68)	(37)	(67)	(68)	(67)	(66)	(50)	(4)				
Wekiwa	23.7	314	0.40	7.42	179	120	1.30	0.12	39	11.0	9.0	1.5	14	19	0.16	9.3	-2.36	-0.35	-0.91	-2.46
1956-2007	(200)	(150)	(20)	(127)	(108)	(110)	(93)	(45)	(115)	(116)	(115)	(114)	(117)	(117)	(81)	(22)				

Table 4. Diversity indices for macroinvertebrates by pooled petite ponar dredge samples from selected springs of the St. Johns River drainage, 2004-07.

[N_1, power function of base of the natural log to *H′*]

Spring	Date	Number of taxa (S)	Number of individuals (n)	Shannon Wiener diversity Index (*H′*)			N_1	Pielou's evenness (*J′*)	Simpson's index of diversity (1-*D*)	Florida Index
				$H'(\log_e)$	$H'(\log_2)$	$H'(\log_{10})$				
Alexander	2/1/2007	22	16,206	2.020	2.915	0.878	7.538	0.654	0.797	4
	5/10/2007	16	31,955	0.996	1.437	0.433	2.707	0.359	0.407	0
	8/7/2007	5	1,207	1.393	2.010	0.605	4.027	0.866	0.708	0
	10/10/2007	21	11,077	1.490	2.150	0.647	4.437	0.490	0.621	2
Apopka	12/30/2005	10	13,806	0.463	0.667	0.201	1.588	0.201	0.169	2
	3/28/2006	7	8,706	0.391	0.564	0.170	1.479	0.201	0.142	1
	7/13/2006	13	10,775	1.482	2.138	0.644	4.402	0.578	0.604	1
	9/21/2006	10	13,619	1.349	1.946	0.586	3.854	0.586	0.587	2
Bugg	12/30/2005	12	2,959	2.090	3.016	0.908	8.085	0.841	0.845	0
	3/17/2006	17	3,280	2.606	3.759	1.132	13.545	0.920	0.914	0
	7/12/2006	14	10,443	1.539	2.221	0.669	4.660	0.583	0.624	0
	9/21/2006	15	9,773	2.260	3.260	0.981	9.583	0.834	0.860	0
De Leon	2/11/2004	7	530	1.169	1.687	0.508	3.219	0.601	0.561	2
	5/11/2004	23	4,062	1.622	2.340	0.704	5.063	0.517	0.703	1
	8/18/2004	46	12,622	1.595	2.301	0.693	4.928	0.417	0.651	7
Gemini	2/10/2004	17	2,470	1.563	2.255	0.679	4.773	0.552	0.595	2
	5/11/2004	11	4,598	1.569	2.263	0.681	4.802	0.654	0.740	1
	8/17/2004	11	1,752	1.820	2.626	0.790	6.172	0.759	0.800	1
Green	2/10/2004	3	115	0.897	1.294	0.390	2.452	0.816	0.534	0
	5/11/2004	13	4,396	1.533	2.211	0.666	4.632	0.598	0.640	0
	8/17/2004	17	20,630	0.938	1.354	0.408	2.556	0.331	0.466	0
Rock	12/6/2005	13	2,497	1.880	2.712	0.816	6.554	0.733	0.803	4
	3/27/2006	20	8,838	1.962	2.830	0.852	7.114	0.655	0.786	2
	6/21/2006	37	5,339	3.152	4.548	1.369	23.383	0.873	0.939	11
	9/27/2006	39	8,095	3.034	4.377	1.318	20.780	0.828	0.922	10
Silver Glen	1/31/2007	22	22,875	2.089	3.014	0.907	8.077	0.676	0.816	6
	5/10/2007	24	26,122	1.995	2.879	0.867	7.352	0.628	0.704	4
	8/7/2007	21	12,646	1.897	2.736	0.824	6.666	0.623	0.669	5
	10/10/2007	19	21,152	2.003	2.889	0.870	7.411	0.680	0.798	2
Wekiwa	12/7/2005	17	23,706	1.613	2.327	0.701	5.018	0.569	0.729	2
	3/27/2006	17	13,451	2.121	3.060	0.921	8.339	0.749	0.776	1
	6/22/2006	12	6,438	1.927	2.779	0.837	6.869	0.775	0.798	0
	9/27/2006	23	35,802	1.416	2.043	0.615	4.121	0.452	0.509	1

Table 5. Diversity indices for macroinvertebrates collected by dip net from selected springs of the St. Johns River drainage, 2004-07.

[N_1, power function of base of the natural log to H']

Spring	Date	Number of taxa (S)	Shannon Wiener diversity index (H')			N_1	Pielou's evenness (J')	Simpson's index of diversity (1-D)	Stream condition index (SCI)	Percent very tolerant taxa (%VTT)
			$H'(\log_e)$	$H'(\log_2)$	$H'(\log_{10})$					
Alexander	2/1/2007	10	1.127	1.626	0.490	3.086	0.490	0.499	13	1.8
	5/10/2007	8	0.433	0.625	0.188	1.542	0.208	0.157	12	0.9
	8/7/2007	10	1.366	1.970	0.593	3.920	0.593	0.625	8	7.2
	10/10/2007	17	2.114	3.051	0.918	8.281	0.746	0.833	22	5.4
Bugg	12/30/2005	11	1.809	2.609	0.785	6.104	0.754	0.759	7	77.8
	3/17/2006	26	2.834	4.088	1.231	17.013	0.870	0.926	34	38.1
	7/12/2006	22	1.768	2.550	0.768	5.859	0.572	0.630	13	19.3
	9/21/2006	22	2.444	3.526	1.061	11.519	0.791	0.863	23	36.3
De Leon	2/11/2004	12	1.131	1.631	0.491	3.099	0.455	0.440	10	3.6
	5/11/2004	14	1.647	2.376	0.715	5.191	0.624	0.690	10	14.5
	8/18/2004	11	1.289	1.860	0.560	3.629	0.538	0.591	9	6.3
Gemini	2/10/2004	7	1.052	1.517	0.457	2.863	0.541	0.490	9	5.5
	5/11/2004	14	2.234	3.224	0.970	9.337	0.847	0.872	13	39.1
	8/17/2004	6	0.850	1.226	0.369	2.339	0.474	0.516	8	2.7
Green	2/10/2004	9	1.664	2.401	0.723	5.280	0.758	0.783	6	53.6
	5/11/2004	18	2.250	3.246	0.977	9.488	0.778	0.852	15	43.7
	8/17/2004	10	1.077	1.554	0.468	2.936	0.468	0.526	6	26.3
Rock	12/6/2005	15	1.700	2.453	0.738	5.474	0.628	0.721	19	4.6
	3/27/2006	14	1.712	2.470	0.744	5.540	0.649	0.708	13	16.3
	6/21/2006	25	2.777	4.007	1.206	16.071	0.863	0.919	33	22.9
	9/27/2006	16	1.350	1.948	0.587	3.857	0.487	0.515	12	11.8
Silver Glen	1/31/2007	14	2.008	2.897	0.872	7.448	0.761	0.818	16	2.7
	5/10/2007	19	2.383	3.438	1.035	10.837	0.809	0.884	16	23.6
	8/7/2007	15	1.815	2.618	0.788	6.141	0.670	0.760	14	6.4
	10/10/2007	16	2.078	2.998	0.902	7.988	0.749	0.837	25	5.4
Wekiwa	12/7/2005	15	1.711	2.468	0.743	5.534	0.632	0.665	10	19.1
	3/27/2006	13	1.820	2.626	0.791	6.172	0.710	0.792	32	9.9
	6/22/2006	11	1.318	1.901	0.572	3.736	0.550	0.555	15	4.5
	9/27/2006	12	1.422	2.052	0.618	4.145	0.572	0.624	22	2.7

Alexander Spring

Alexander Spring (figs. 1 and 5, table 1) is a first magnitude spring (mean and median discharge 104 and 102 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004). The spring and spring run are within the Ocala National Forest and are maintained by the U.S. Forest Service as a multiple-use recreation area open to the public. The spring pool measures about 300 ft from north to south and about 258 ft from east to west. Maximum depth is about 25 to 28 ft to a conical depression containing multiple clustered vents within a mix of sand and limestone outcrop, boulders, and a rock ledge that extends north to south along the downstream edge of the main vent. A large boil is visible at the surface. The south shoreline of the spring pool consists of a concrete retaining wall and two sets of stairs adjacent to a sandy beach and picnic area. Aquatic vegetation surrounds the main spring vent and is present throughout most of the run in the upstream reaches where there is open tree canopy; the pool bottom near the beach is mostly open sand. Mats of algae accumulate during the winter and spring months in the pool and run areas when recreational activity in the spring is at a minimum; later during the spring and summer months when swimming activity is high, much of the algae that has accumulated during the previous season becomes dislodged and drifts down the run. The pool discharges to Alexander Spring run (fig. 6), which flows westward from the spring vent for a few hundred yards and then flows eastward about 8 mi to the St. Johns River. Riparian areas surrounding Alexander Spring and Alexander Spring run are mixed hardwood, pine, and palm forest and wetlands. The areal extent of the Alexander springshed is 58.5 mi^2.

Land Use

Land use in the Alexander springshed changed markedly from 1973 to 2004 as a result of the conversion of agricultural lands to urban use, which approximately doubled in area over the 31-year period; by 2004 more than half of the Alexander springshed was urbanized (fig. 4). Land use in the springshed in 1973 consisted of agriculture (38.4 percent), urban/mining/transportation/recreation (27.4 percent), open-water/wetlands (25.1 percent), and forestland (9.1 percent). Land use of the springshed in 2004 consisted of urban/mining/transportation/recreation (58.2 percent), open-water/wetlands (25.3 percent), agriculture (7.5 percent), and forestland (9.0 percent). As of 2007, no wastewater treatment facilities were active in the Alexander springshed and septic systems were the only method of wastewater treatment and disposal.

Discharge

Discharge from Alexander Spring has been measured intermittently by the USGS since 1931, with more frequent measurements made since 1982 (fig. 7). During this study, the SJRWMD and the USGS measured the discharge of Alexander Springs at least monthly. Discharge was measured in the uppermost part of the run about 150 ft downstream of the vent. Discharge of Alexander Spring averaged 104 ft^3/s annually and varied with rainfall that averaged 52.10 in/yr within the springshed. Average annual discharge ranged from 79 ft^3/s in 1977 to 136 ft^3/s in 1956. Measured (instantaneous) discharge from Alexander Spring ranged from 55.9 ft^3/s in May 1986 to 202 ft^3/s in January 1984 (fig. 8).

Figure 5. Aerial view of Alexander Spring. Photograph courtesy of the St. Johns River Water Management District, used with permission.

Figure 6. Alexander Spring run immediately downstream of spring pool. The spring run contains extensive floating and submerged algae. Photograph by S.J. Walsh, May, 9, 2007.

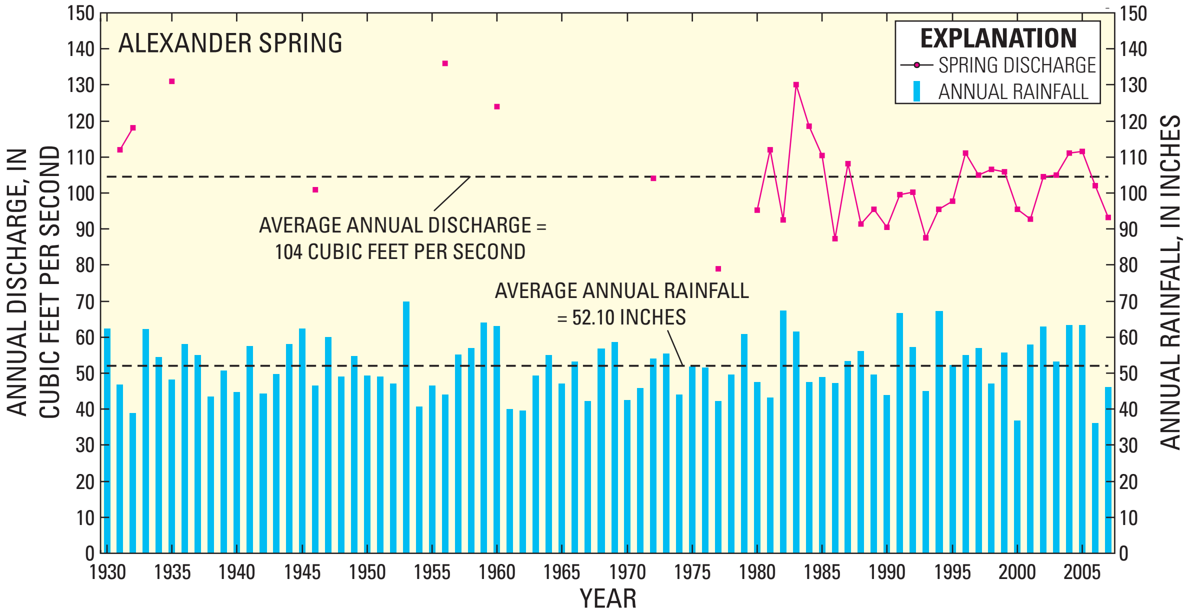


Figure 7. Average annual discharge for Alexander Spring and rainfall for the springshed.

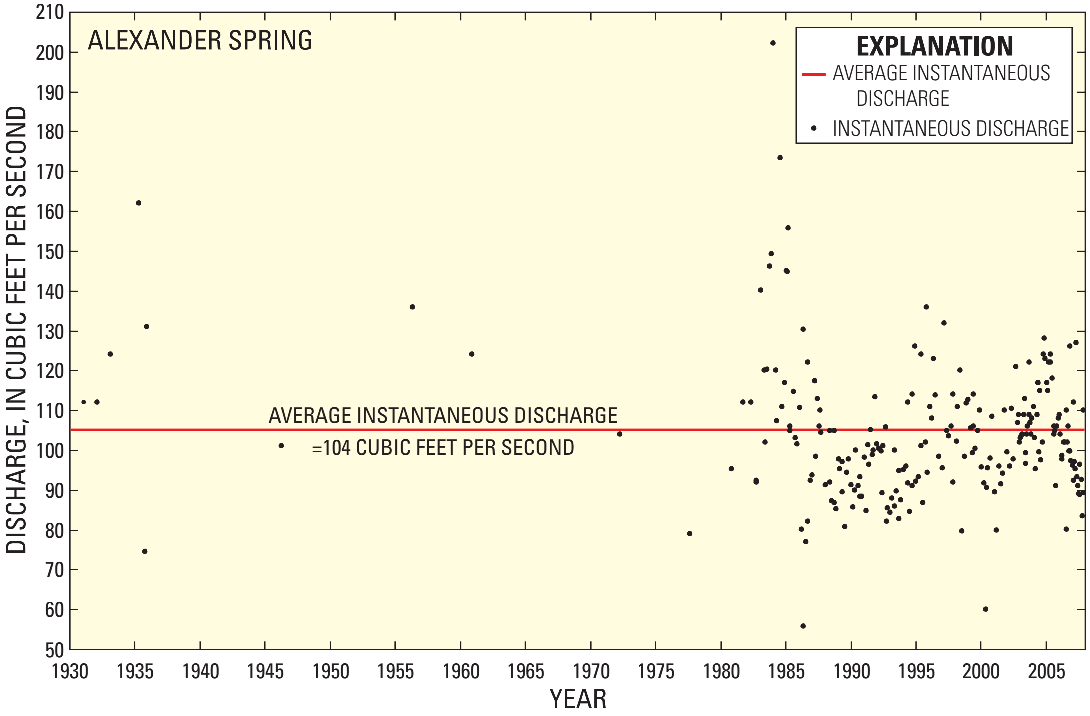


Figure 8. Periodic discharge data for Alexander Spring, 1931-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

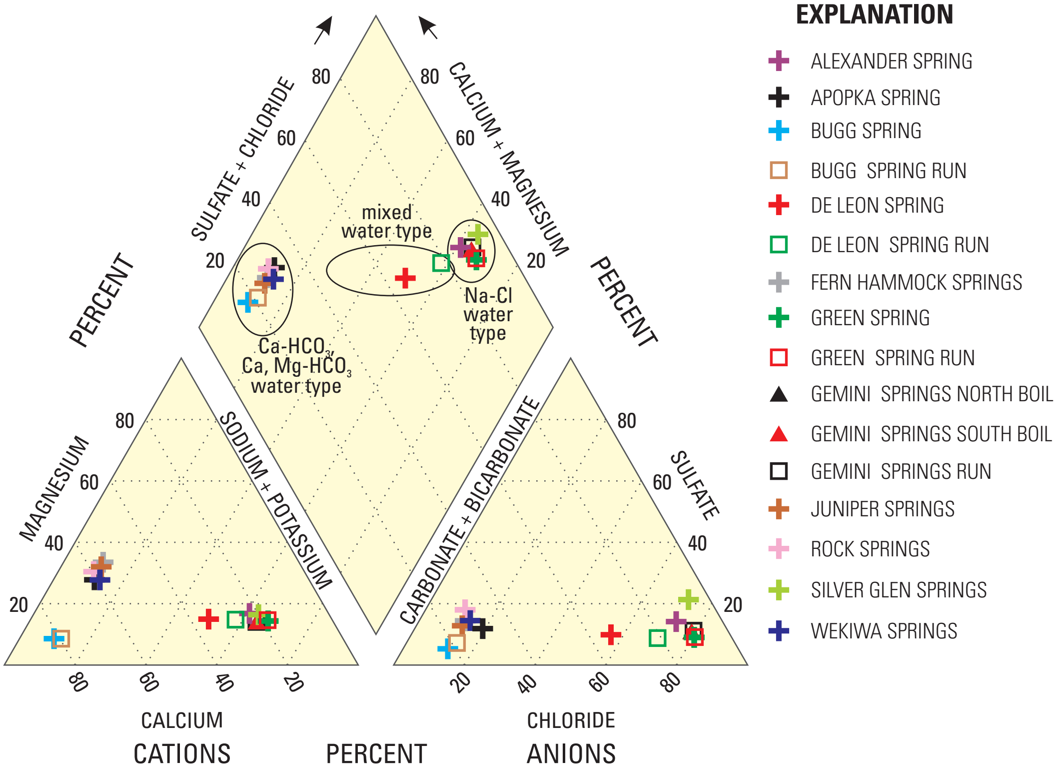


Figure 9. Trilinear plot showing the major-ion composition of spring waters and water types of selected springs in the St. Johns River drainage.

Water Chemistry and Age

The water quality of Alexander Spring has been sampled periodically by the USGS since 1931 and sampled by the SJRWMD since 1983. At the time of this study, the SJRWMD and the USGS jointly sampled Alexander Spring at least four times per year.

Alexander Spring has a Na-Cl water type (fig. 9), and the spring water is slightly undersaturated with respect to calcite and dolomite (table 3). The Na-Cl water type for Alexander Spring likely originates from vertical upconing of water from the Lower Floridan aquifer (Knowles and others, 2002). Median values of pH, dissolved oxygen, and dissolved solids were 7.8, 2.1 mg/L, and 596 mg/L, respectively, for the period of record (1960-2007).

Nitrate-N concentrations have remained below 0.1 mg/L over the past 30 years (fig. 10), and from 1960 to 2007, nitrate-N concentrations showed a significant decreasing trend ($p < 0.01$) (table 6). Total phosphorus (P) concentrations remained relatively constant over time as indicated by samples collected sporadically during the past 35 years (fig. 11). The P concentration in Alexander Spring was 0.04 mg/L in April 1972 and September 1977, and 0.06 mg/L in January 1985. From November 2003 to October 2007, P concentrations remained relatively constant at 0.04 to 0.05 mg/L, which were slightly higher than P concentrations measured in other springs in the Ocala National Forest (Silver Glen, Fern Hammock, and Juniper Springs) (fig. 11). In 2007, the USGS sampled Alexander Spring for chlorophyll-*a* and pheophytin-*a* to determine the richness of suspended photosynthetic organisms in the run approximately 100 ft downstream of the spring vent. Chlorophyll-*a* values ranged from less than 0.1 to 0.88 μL (May and February, respectively), and pheophytin values ranged from 0.15 to 1.5 μL (October and February, respectively) (app. 3).

Data for the stable isotopes of water (delta ^{18}O and ^{2}H) plot along the Global Meteoric Water Line (GMWL) or local Meteoric Water Line (MWL) that is parallel to the GMWL (Toth, 1999), indicating that recharge to the spring does not undergo evaporation. The ^{3}H concentration of 2.7 TU (Toth, 1999) indicates that recharge occurred during the past 30 years. The delta ^{34}S composition was 21.0 per

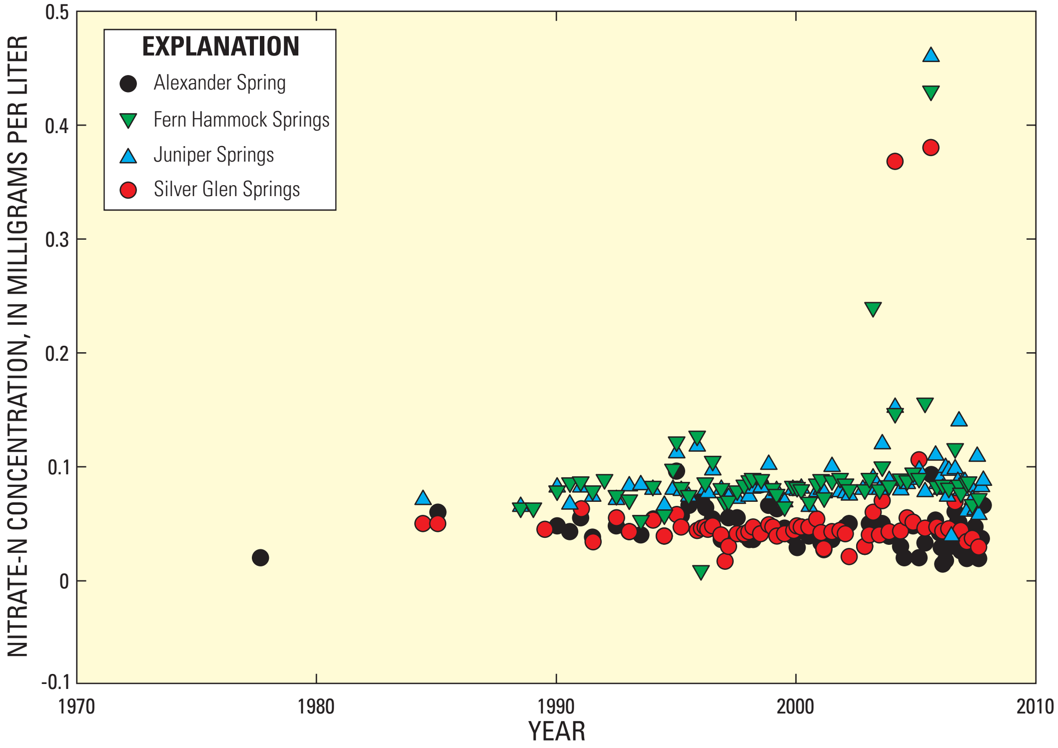


Figure 10. Nitrate-N concentrations in water from Alexander, Silver Glen, Fern Hammock, and Juniper springs located in Ocala National Forest.

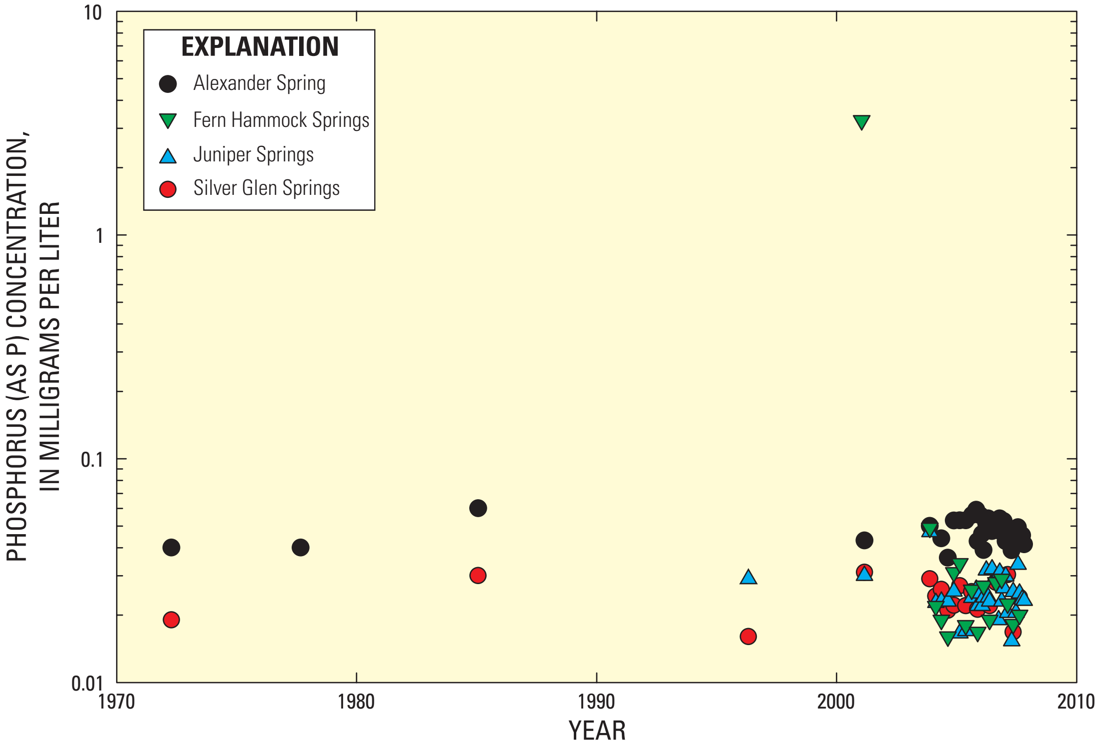


Figure 11. Phosphorus concentrations in water from Alexander, Silver Glen, Fern Hammock and Juniper Springs located in Ocala National Forest.

Table 6. Statistically significant (*p* less than 0.05) trends of nitrite plus nitrate as N, orthophosphate as PO_4, and phosphorus with time.

[NS, not statistically significant; Kendall tau; Kendall tau correlation coefficient; *p*, probability value of exceeding null hypothesis; <, less than value. Significant increasing trends are highlighted in dark gray; significant decreasing trends are highlighted in light gray]

Spring	Nitrite plus nitrate as N			Orthophosphate as PO_4-unfiltered			Orthophosphate as PO_4-filtered			Phosphorus (P)-unfiltered		
	N	Kendall tau	*p* value	N	Kendall tau	*p* value	N	Kendall tau	*p* value	N	Kendall tau	*p* value
Alexander	70	-0.23	0.005	28	0.07	NS	0		NS	34	-0.13	NS
Apopka	84	0.21	0.005	5	-0.40	NS	1		NS	84	-0.16	0.036
Bugg	9	0.00	NS	1	1.00	NS	1		NS	191	-0.003	NS
Bugg Run	39	-0.32	0.004	13	0.33	NS	0		NS	221	0.03	NS
De Leon	63	0.02	NS	15	-0.79	<0.001	5	-0.32	NS	17	-0.23	NS
De Leon Run	4	0.00	NS	2	0.00	NS	2		NS	4	0.67	NS
Fern Hammock	65	0.21	0.016	10	-0.18	NS	0		NS	17	-0.20	NS
Gemini N Boil	2		NS	2		NS	1		NS	2		NS
Gemini S Boil	2		NS	2		NS	1		NS	2		NS
Gemini Run	47	0.63	<0.001	11	-0.33	NS	3	0.33	NS	20	-0.09	NS
Green	18	0.11	NS	11	-0.35	NS	0		NS	17	-0.24	NS
Green Run	3	-0.82	NS	2		NS	1		NS	3	0.81	NS
Juniper	77	0.17	0.033	20	0.35	0.030	1		NS	33	-0.03	NS
Rock	87	-0.17	0.021	1		NS	3	-0.33	NS	37	-0.54	<0.001
Silver Glen	60	-0.03	NS	12	-0.53	0.016	12			20	0.02	NS
Wekiwa	93	-0.34	<0.001	3	-0.82	NS	4	0.72	NS	45	-0.25	0.022

mil (Toth, 1999), which is similar to that for modern sulfate evaporite minerals likely present in the aquifer matrix. Based on concentrations of ^{3}H, ^{3}He, and chlorofluorocarbons (CFCs) measured in water samples from Alexander Springs in 2001, spring water represents a mixture containing approximately 30 percent of water from the Lower Floridan aquifer and about 70 percent of water from the Upper Floridan aquifer with a mean residence time of about 15 years (Toth and Katz, 2006). Previous water samples were collected in July 1995 to assess the age of water discharging from Alexander Springs by measuring the concentration of ^{3}H, delta ^{13}C, and ^{14}C. The ^{3}H concentration of 2.7 TU for Alexander Spring indicated that the younger fraction of the water likely was less than 42 years old, whereas the ^{3}H/^{3}He age indicated an age of 25 years for the young-water fraction. Alexander Spring had a delta ^{13}C value of -9.50 per mil and a ^{14}C concentration of 28 percent modern carbon (pmc), which likely indicates mixing of Upper and Lower Floridan aquifer water. The adjusted ^{14}C age is recent (Toth and Katz, 2006).

Aquatic Communities

A total of 47 macroinvertebrate taxa were collected by petite ponar dredge from Alexander Spring across four sampling dates (table 7). By season, the number of taxa collected from Alexander Spring with this gear ranged from 5 in August 2007 to 22 in February 2007. Combined, samples were dominated by gastropods (70.2 percent, most of which were hydrobiids) and oligochaetes (22.1 percent). Density of all organisms ranged from approximately 1.2×10^{3} per m^{2} (12.9×10^{3} per ft^{3}) in August 2007 to 32.0×10^{3} per m^{2} (34.4×10^{3} per ft^{3}) in May 2007. The few taxa and low number of total organisms collected in May were likely the result of inefficient grabs for one or more of the three replicate petite ponar samples. For petite ponar samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 1.44 to 2.92, Simpson's index of diversity ranged from 0.41 to 0.80, Pielou's evenness ranged from 0.36 to 0.87, and the Florida Index ranged from 0 to 4 with a mean of 1.5 (table 4).

Table 7. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Alexander Spring, February-October 2007.

[LPIL, lowest practicable identification level]

Clade	Taxon	Feb. 1, 2007		May 10, 2007		Aug. 7, 2007		Oct. 10, 2007	
		n	%	n	%	n	%	n	%
Turbellaria	Tricladida (LPIL)	115	0.7						
Gastropoda	*Amnicola dalli*	3,218	19.9						
	Aphaostracon sp.					115	9.5		
	cf. *Aphaostracon* sp.			1,034	3.2	345	28.6		
	cf. *Tarebia* sp.	1,207	7.4	460	1.4			158	1.4
	Elimia floridensis					115	9.5		
	Hydrobiidae (LPIL)	345	2.1	3,908	12.2				
	Hydrobiidae sp. C Line			24,253	75.9			1,451	13.1
	Melanoides turricula	115	0.7					29	0.3
	Planorbella scalaris	115	0.7						
	Spilochlamys gravis	5,575	34.4						
Hirudinea	cf. *Helobdella fusca*			345	1.1				
	Erpobdellidae (LPIL)							14	0.1
	Gloiobdella elongata							29	0.3
	Glossiphoniidae (LPIL)			115	0.4				
	Hirudinea (LPIL)			115	0.4				
	Mooreobdella microstoma							14	0.1
Oligochaeta	*Dero digitata* complex			345	1.1				
	Dero pectinata							14	0.1
	Dero sp.	57	0.4						
	Limnodrilus hoffmeisteri	115	0.7	115	0.4			1,609	14.5
	Naididae (LPIL)			345	1.1			115	1.0
	Pristina leidyi							14	0.1
	Pristina sp.			115	0.4				
	Slavina appendiculata	115	0.7						
	tubificoid Naididae immature sp. A (LPIL)	3,103	19.1	345	1.1	517	42.8	6,451	58.2
Arachnida	*Neumania* sp.	115	0.7						
	Amphipoda (LPIL)			115	0.4				
	Gammarida (LPIL)							14	0.1
	Gammarus cf. *tigrinus* LeCroy	287	1.8					72	0.6
	Gammarus sp.							72	0.6
	Hyalella azteca complex Lecroy	115	0.7			115	9.5	187	1.7
Diptera	*Ablabesmyia mallochi*	115	0.7						
	Chironominae (LPIL)			115	0.4				
	Chironomus sp.	230	1.4					345	3.1
	Cladopelma sp.							115	1.0
	Dicrotendipes sp. (immature)			115	0.4				
	Polypedilum halterale group Epler	690	4.3						
	Polypedilum scalaenum group Epler	172	1.1						
	Polypedilum sp.	115	0.7						
	Tanypus carinatus							115	1.0
	Tanypus sp.							115	1.0
	Tanytarsus sp. L Epler	115	0.7						
Ephemeroptera	*Caenis diminuta*	115	0.7					29	0.3
	Caenis sp.			115	0.4				
Odonata	*Epitheca princeps regina*							115	1.0
Trichoptera	Leptoceridae (LPIL)	57	0.4						
Total		**16,206**		**31,955**		**1,207**		**11,077**	
Number of Taxa		**22**		**16**		**5**		**21**	

A total of 27 macroinvertebrate taxa were identified in subsamples collected by dip net from Alexander Spring (table 8). The number of taxa ranged from 8 in May 2007 to 17 in October 2007. Similar to the petite ponar samples, combined dip net subsamples were numerically dominated by hydrobiid snails (74.8 percent), although tubificoid (Naididae) worms constituted a smaller overall proportion (2.3 percent) in these samples than in pooled petite ponar samples. Amphipods constituted 11.4 percent of the total number of organisms subsampled across all dates. For dip net samples among dates, the $\log_2$ Shannon-Wiener index ranged from 0.63 to 3.05, Simpson's index of diversity ranged from 0.16 to 0.83, Pielou's evenness ranged from 0.21 to 0.75, the SCI ranged from 8 to 22 with a mean of 14, and percent very tolerant taxa ranged from 0.9 to 7.2 with a mean of 3.8 (table 5). The dominant taxon in both ponar and dip net samples, *Spilochlamys gravis*, is a hydrobiid snail that is limited in distribution to the upper St. Johns River drainage (Thompson, 2004) and also previously recorded from Alexander, Rock, and Wekiwa Springs (Shelton, 2005); in this study, specimens from Alexander Spring were identified to this species, whereas many hydrobiids from Rock and Wekiwa Springs were not identified beyond the family level.

Efforts were made to use a boat electroshocker to collect fishes from Alexander Spring run in the vicinity of the State Road 445 bridge (about 1.3 mi downstream from the head spring) on May 10 and 24, 2007. However, low water levels, abundant macrophyte and algae growth, and high water conductivity precluded effective sampling with either boat or backpack electroshocking equipment. Therefore, on August 28, 2007, a crew of eight people used a variety of qualitative gears (seines, cast nets, dip nets, mask and snorkel) to collect and observe fishes near the highway bridge and within several hundred yards upstream along the spring run. A total of 1,674 fish specimens were collected or recorded by visual observation, representing 29 species of 23 genera and 14 families (table 9). The sample was dominated by cyprinids (35.4 percent, especially *Notropis petersoni*), atherinopsids (29.8 percent, especially *Menidia beryllina*), fundulids (17.0 percent, especially *Lucania goodei*), and poeciliids (9.7 percent, especially *Poecilia latipinna*). An examination of the holdings of the ichthyology collection in the Florida Museum of Natural History revealed that only two species historically recorded from this site were not collected nor observed on the sampling date during this study: *Notropis chalybeus* and *Pteronotropis welaka*. Although no nonindigenous fishes were taken or observed along the spring run during dates of general sampling, numerous adult *Pterygoplichthys disjunctivus* were observed resting on the substrate in close proximity to the Alexander Spring vent during the spring and early summer months of 2007 (fig. 12). These fish retreated to crevices in the rock when swimmers approached them, and when not disturbed were observed "piping" for air by (1) slowly swimming toward the surface of the boil, (2) rapidly ascending within the last few feet of the surface, (3) gulping a bubble of air, and (4) slowly swimming back to the substrate.

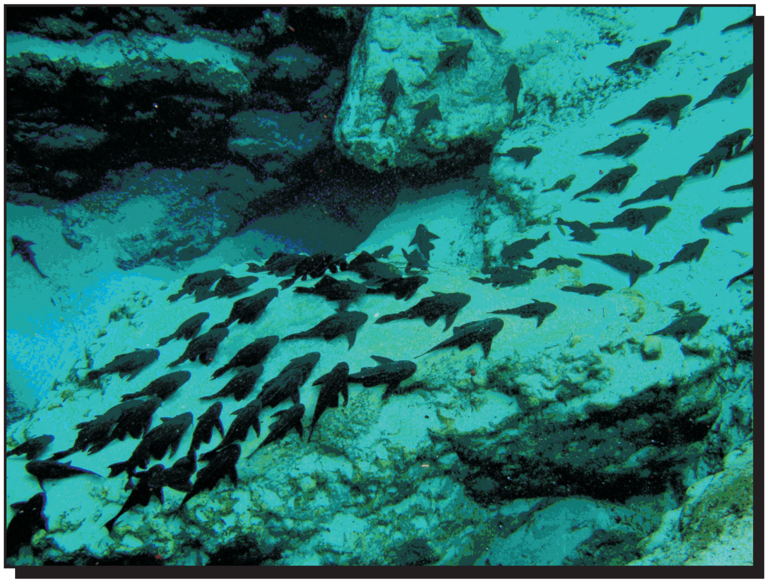


Figure 12. Aggregation of adults of the nonindigenous vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*) above the Alexander Spring vent, February 2007. Photograph courtesy of Brian MacGregor, used with permission.

Table 8. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Alexander Spring, February-October 2007.

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Clade	Taxon	Feb. 1, 2007		May 10, 2007		Aug. 7, 2007		Oct. 10, 2007	
		n	%	n	%	n	%	n	%
Gastropoda	*Amnicola dalli*	17	15.5					11	10.0
	Aphaostracon sp.					62	56.4		
	cf. *Aphaostracon* sp.			101	91.8	26	23.6		
	cf. *Tarebia* sp.	4	3.6			6	5.5	6	5.5
	Haitia cubensis	1	0.9	1	0.9				
	Hydrobiidae sp. C Line							36	32.7
	Melanoides turricula					5	4.5		
	Planorbella scalaris	1	0.9			2	1.8		
	Pomacea paludosa							1	0.9
	Spilochlamys gravis	76	69.1						
Hirudinea	*Gloiobdella elongata*							1	0.9
Oligochaeta	tubificoid Naididae immature sp. A (LPIL)			1	0.9	2	1.8	7	6.4
Amphipoda	*Gammarus* cf. *tigrinus* LeCroy					2	1.8	16	14.5
	Gammarus sp.	3	2.7	1	0.9				
	Hyalella azteca complex LeCroy	4	3.6	3	2.7	3	2.7	18	16.4
Isopoda	*Cassidinidea ovalis*	1	0.9						
Decapoda	*Palaemonetes paludosus*	2	1.8	1	0.9			1	0.9
	Procambarus sp. (immature)							2	1.8
Diptera	*Chironomus* sp.					1	0.9	4	3.6
	Cladopelma sp.							1	0.9
	Dicrotendipes sp. A Epler							2	1.8
	Polypedilum halterale group Epler			1	0.9				
	Polypedilum nubifer							1	0.9
	Pseudochironomus sp.			1	0.9			1	0.9
Ephemeroptera	*Caenis* sp.	1	0.9						
	Callibaetis floridanus					1	0.9	1	0.9
Hemiptera	*Trepobates subnitidus*							1	0.9
Total		**110**		**110**		**110**		**110**	
Number of Taxa		**10**		**8**		**10**		**17**	

Table 9. Fishes collected or observed in Alexander Spring and Silver Glen Springs in 2007.

[n, total number of specimens; %, percent composition; >, greater than value. Relative abundances are considered qualitative based on visual estimates for several species]

Family	Species	Alexander Spring		Silver Glen Springs	
		n	%	n	%
Lepisosteidae	*Lepisosteus osseus*	1	0.06		
	Lepisosteus platyrinchus	2	0.12		
Amiidae	*Amia calva*	2	0.12	7	0.86
Anguillidae	*Anguilla rostrata*			1	0.12
Cyprinidae	*Notemigonus crysoleucas*	15	0.90		
	Notropis harperi			>100	12.33
	Notropis petersoni	526	31.42	75	9.25
	Opsopoeodus emiliae	18	1.08		
	Pteronotropis metallicus	34	2.03		
Catostomidae	*Erimyzon sucetta*	17	1.02	21	2.59
Ictaluridae	*Ameiurus nebulosus*	1	0.06		
	Noturus gyrinus	4	0.24		
Callichthyidae	*Hoplosternum littorale* [1]			2	0.25
Loricariidae	*Pterygoplichthys disjunctivus* [1]			1	0.12
Aphredoderidae	*Aphredoderus sayanus*	3	0.18		
Mugilidae	*Mugil cephalus*	30	1.79	±36	4.44
Atherinopsidae	*Labidesthes sicculus*	23	1.37		
	Menidia beryllina	476	28.43		
Belonidae	*Strongylura marina*	5	0.30	1	0.12
Fundulidae	*Fundulus seminolis*	44	2.63	4	0.49
	Lucania goodei	195	11.65	12	1.48
	Lucania parva	46	2.75	>224	27.62
Poeciliidae	*Gambusia holbrooki*	25	1.49	>52	6.41
	Heterandria formosa	10	0.60	1	0.12
	Poecilia latipinna	127	7.59		
Moronidae	*Morone saxatilis*			>200	24.66
Centrarchidae	*Lepomis auritus*	25	1.49	5	0.62
	Lepomis gulosus			1	0.12
	Lepomis macrochirus	3	0.18	10	1.23
	Lepomis marginatus	2	0.12		
	Lepomis microlophus	5	0.30		
	Lepomis punctatus	9	0.54	28	3.45
	Micropterus salmoides	12	0.72	6	0.74
Percidae	*Percina nigrofasciata*	12	0.72		
Lutjanidae	*Lutjanus griseus*			±20	2.47
Elassomatidae	*Elassoma okefenokee*	2	0.12	1	0.12
Cichlidae	*Oreochromis aureus* [1]			2	0.25
Gobiidae	*Gobiosoma bosc*			1	0.12
Total		**1,674**		**811**	
Number of Taxa		**29**		**24**	

[1] Nonindigenous species.

Apopka Spring

Apopka Spring (figs. 1 and 13, table 1) is a second magnitude spring (mean and median discharge 28.1 and 26.8 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004). The spring discharges at the bottom of Lake Apopka from a deep bowl-shaped depression into a circular spring pool approximately 180 ft in diameter. The vent opening is about 45 ft below the water surface of the lake. The spring emerges from an underground cave system; the vent opening narrows vertically downward into the limestone for 16 ft, and then slopes northward at about 45 degrees to a depth of 90 ft as determined by cave divers. The spring discharge pool is clear when springflow is high and clouded by lake water when flow is low. When the lake is quiescent, a gentle boil may be visible at the pool surface. Emergent vegetation and an organic muck bottom surround the pool perimeter in the cove area, which is buffered by marsh and lowland swamp forests along the western shoreline. Hurricanes that affected the area in 2004 deposited debris and a thick floating mass of vegetation, blanketing the western shoreline, so that the distance between the spring vent and the new shoreline was reduced to about 10 to 15 ft during this study. The areal extent of the Apopka springshed is 17.7 mi^2.

Land Use

Land use in the Apopka springshed remains predominantly agricultural; however, increased urban land use from 1973 to 2004 resulted in the decline of other land-use types (fig. 4). Open-water/wetlands had decreased by more than 5 percent during the 31-year period and were nearly nonexistent by 2004. Land use in the springshed in 1973 consisted of agriculture (92.7 percent), open-water/wetlands (5.4 percent), forestland (1.9 percent), and urban/mining/transportation/recreation (less than 0.1 percent). Land use in the springshed in 2004 consisted of agriculture (80.6 percent), urban/mining/transportation/recreation (19.3 percent), and open-water/wetlands (0.1 percent). By 2004, municipal and centralized sewer systems, currently the primary means of wastewater treatment and disposal, had replaced most of the septic systems in the Apopka springshed. By 2005, treated (reclaimed) wastewater was being applied to 5.7 mi^2 of land surface in the southern half of the Apopka springshed.

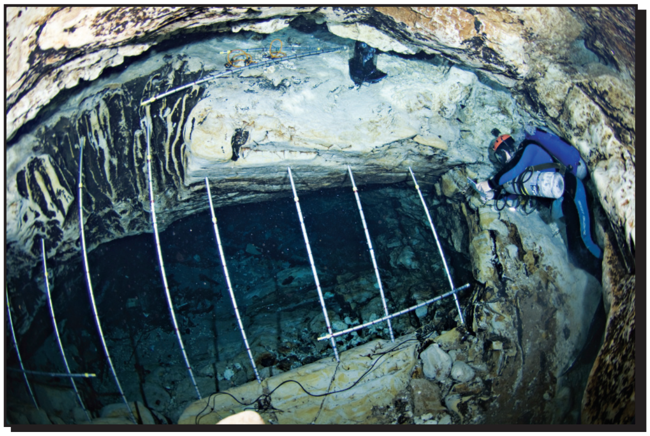


Figure 13. Diver taking discharge measurements at Apopka Spring vent. Photograph is courtesy of Jill Heinreth, Karst Environmental Services, Inc., and the SJRWMD, used with permission.

Discharge

Apopka Spring is a submerged spring, and accurate discharge measurements must be made at the vent opening by scuba divers. The USGS measured the spring discharge seven times from 1971 to 1992. Since 1997, a contractor for the SJRWMD has measured discharge at least four times per year. Spring discharge is controlled mostly by the regulated water level in Lake Apopka, with discharge diminished by higher lake levels. Annual discharge for Apopka Spring and rainfall in the springshed averaged 28.1 ft^3/s and 51.22 in., respectively (fig. 14). Average annual discharge for Apopka Spring ranged from 23.9 ft^3/s in 2001 to 66.8 ft^3/s in 1989. Measured (instantaneous) discharge from Apopka Spring averaged 27.2 ft^3/s, and ranged from 21.0 ft^3/s in September 2001 to 70.4 ft^3/s in November 1988 (fig. 15). The highest discharge measurements for Apopka Spring made in 1988-89 likely are erroneous and may have resulted from an undocumented decrease in the size of the vent opening. Occasionally, tree debris and anchors partially block the Apopka Spring vent, which results in a higher flow velocity until the spring vent is cleared. Diving at Apopka Spring is dangerous and visibility is restricted to the immediate area just above the vent; therefore, any vent obstructions could have easily been unobserved at the time when abnormally high measurements were made. Using artificially high flow velocities with the original cross-sectional opening area of the vent would elevate the value of mean discharge calculations. Therefore, average discharges shown for Apopka Spring reported here do not include those measurements made in 1988-89.

Water Chemistry and Age

Water-quality samples were collected from Apopka Spring once in 1972, periodically from 1986 to 1990, and quarterly from 1995 to the present by the SJRWMD and/or USGS. Apopka Spring has a $Ca\text{-}Mg\text{-}HCO_3$ water type (fig. 9), low dissolved solids (137 mg/L), and is at equilibrium (saturated) with respect to calcite and slightly undersaturated with respect to dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids were 8.1, 3.8 mg/L, and 146 mg/L, respectively. The ^3H concentration of 2.3 TU (Toth, 2003) indicates recent recharge. Apopka spring water

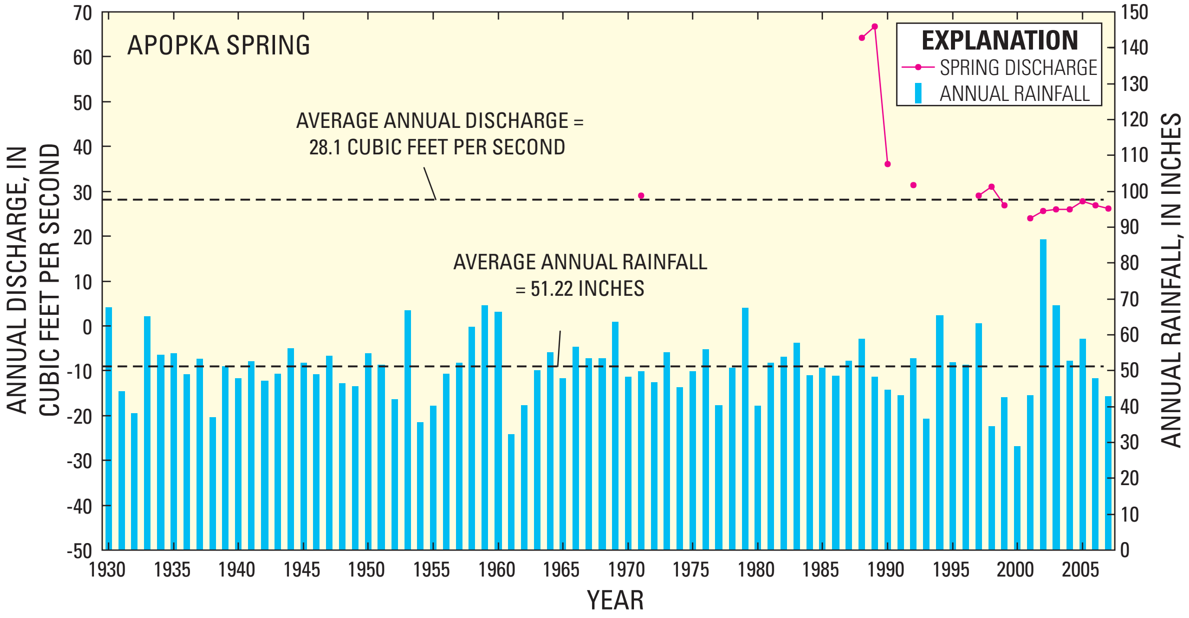


Figure 14. Average annual discharge for Apopka Spring and rainfall for the Apopka springshed.

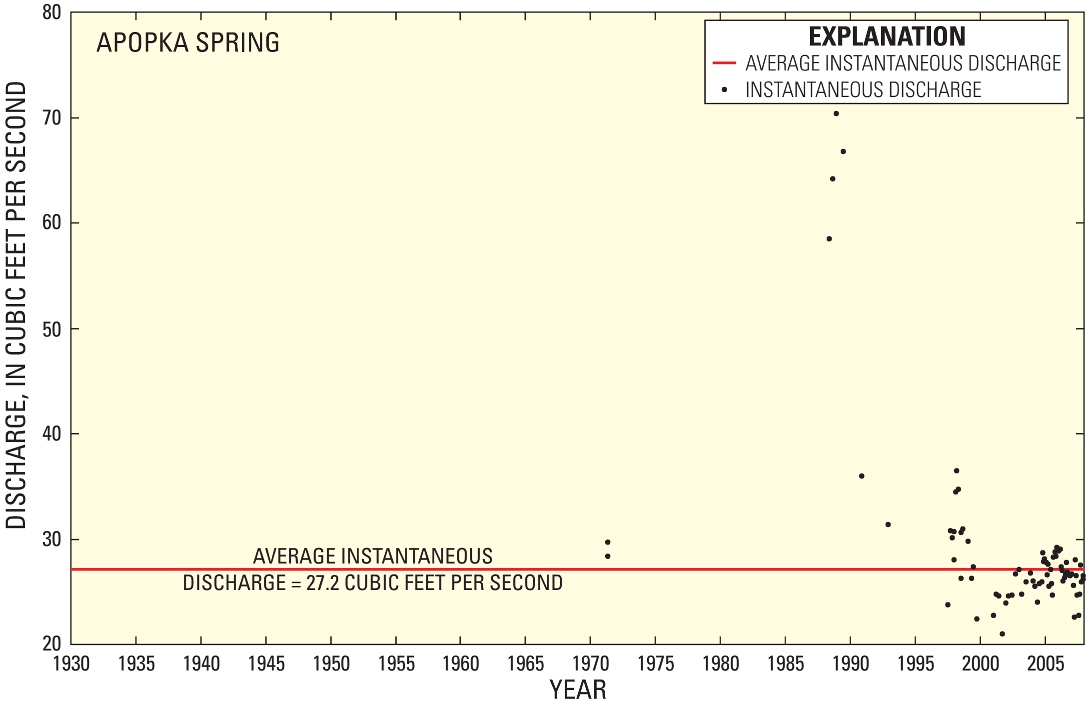


Figure 15. Periodic discharge data for Apopka Spring,1971-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

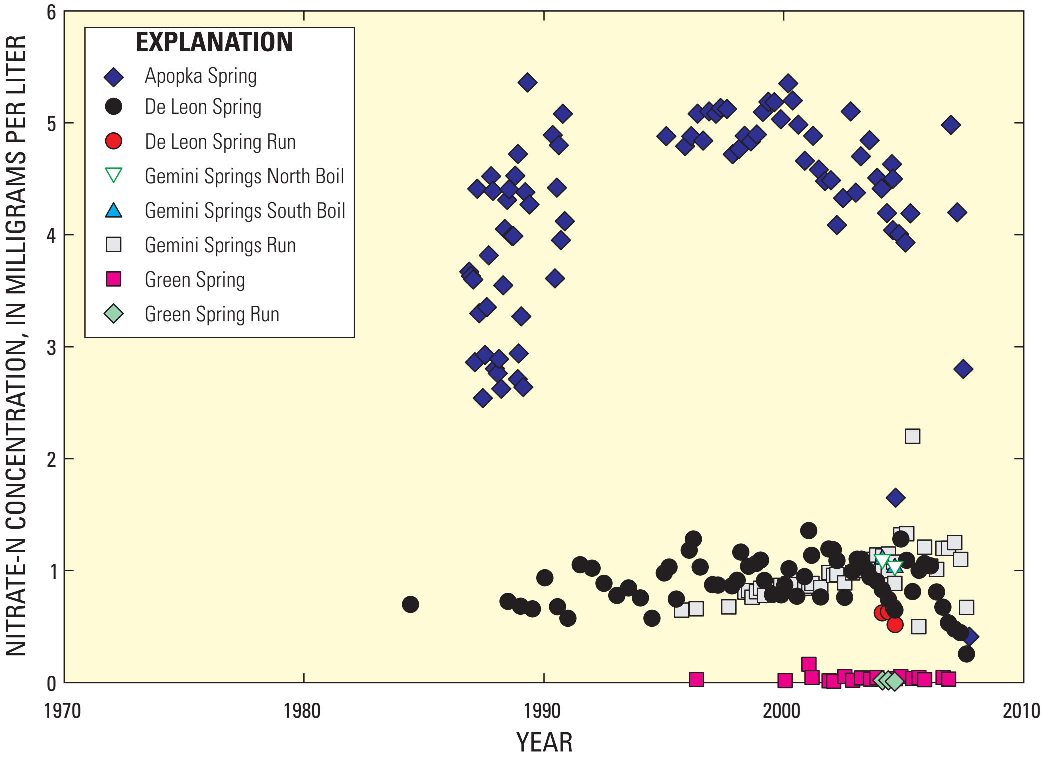


Figure 16. Nitrate-N concentrations in water from Apopka, De Leon, Gemini, and Green Springs.

has a slightly enriched delta ^{18}O and ^{2}H composition that plots along an evaporation trend line for lakes (Toth, 2003), indicating that recharge has undergone some evaporation.

Nitrate-N concentrations in Apopka Spring were the highest of all springs in this study (median 4.4 mg/L during 1986-2007), and nitrate-N concentrations showed large fluctuations over time, from 0.42 to 5.4 mg/L (fig. 16, table 3). From May 1986 to November 1989, nitrate-N concentrations ranged from 2.5 to 5.4 mg/L. Since May 1990, nitrate-N concentrations ranged from 0.4 to 5.4 mg/L. Nitrate-N concentrations showed a significant ($p < 0.01$) increase from 1972 to 2007 (table 6). Phosphorus (total P) concentrations in Apopka Spring also fluctuated widely over the past 20 years; the earliest sample had a P concentration of 0.033 mg/L in October 1986. Although most water samples from Apopka Spring had P concentrations that fluctuated from 0.02 to 0.06 mg/L, several spikes in P concentration as high as 0.6 mg/L have occurred sporadically over the past 20 years (fig. 17); however, phosphorus concentrations showed a significant ($p < 0.04$) decreasing trend from 1972 to 2007 (table 6). Elevated nitrate-N concentrations and several spikes in phosphorus concentrations in Apopka Spring likely are related to the springshed having more than 50 percent agricultural land use. In 2005-06 the USGS sampled Apopka Spring on two occasions for chlorophyll-*a* and pheophytin-*a* to determine the richness of suspended photosynthetic organisms in the boil approximately 45 ft above the spring vent; chlorophyll-*a* values ranged from 13.9 to 18.4 µg/L and pheophytin-*a* values ranged from to 3.2 to 5.8 µg/L (app. 3).

The age of water discharging from Apopka Spring was determined by measuring the concentration of ^{3}H, ^{3}He, ^{4}He, and neon in the spring discharge in August 1999. Apopka Spring had a ^{3}H concentration of 2.9 TU, which indicates that the younger fraction of the water likely is less than 46 years old, whereas the ^{3}H /^{3}He age indicated an age of 25 years for the younger fraction.

Aquatic Communities

Due to the location of Apopka Spring at the bottom of Lake Apopka, sampling of the benthos could only be accomplished using a petite ponar dredge. On each of four sampling occasions, four replicate grabs were made. The dredge often had to be deployed numerous times to obtain a

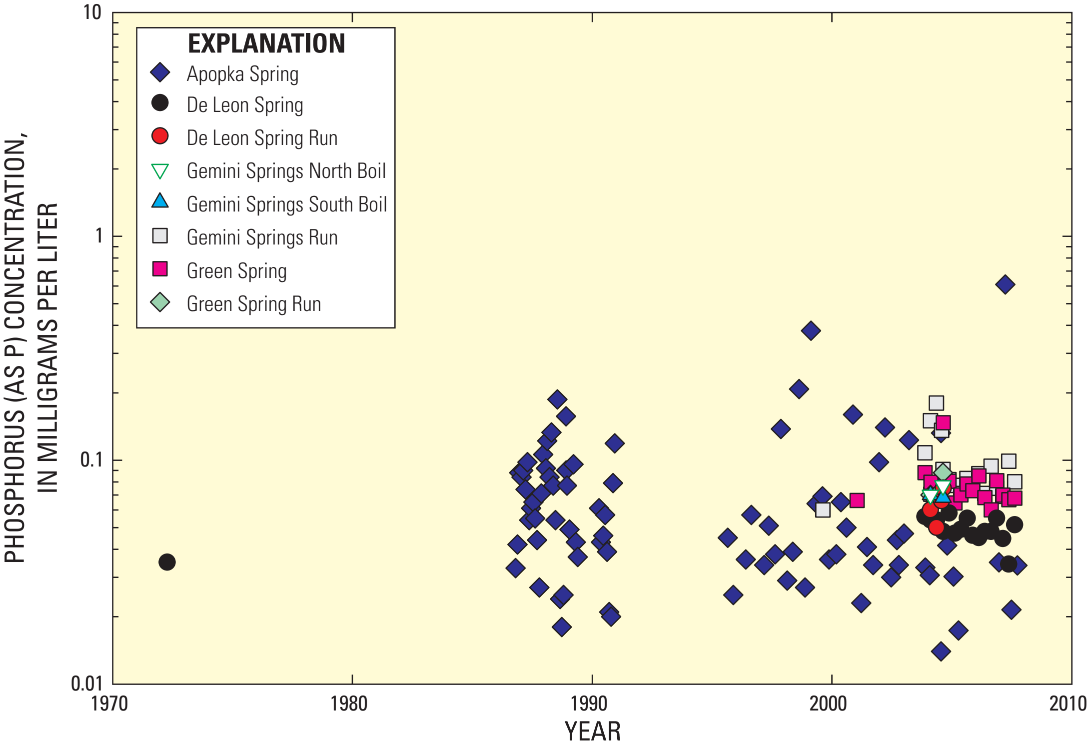


Figure 17. Phosphorus concentrations in water from De Leon, Gemini, Green, and Apopka Springs.

suitable collection, because large snags and other debris often prevented the jaws of the dredge from closing completely. An effort was made to drop the dredge over the vent (that is, lower it within the water column over the boil). The substrate mostly consisted of coarse decayed wood and organic matter.

A total of 29 macroinvertebrate taxa were collected from Apopka Spring, with the number of taxa from each sampling event ranging from 7 in March 2006 to 13 in July 2006 (table 10). The overall density of organisms ranged from 8.7 × 10^3 per m^2 (93.7 × 10^3 per ft^2) in March 2006 to 13.8 × 10^3 per m^2 (148.6 × 10^3 per ft^2) in December 2005. Samples were dominated by amphipods (76.0 percent; *Hyallela azteca* complex) and isopods (7.2 percent; *Caecidotea racovitzai australis* and/or *Caecidotea* sp.). Across all sampling dates, the $\log_2$ Shannon-Wiener index ranged from 0.56 to 2.14, Simpson's index of diversity ranged from 0.14 to 0.60, Pielou's evenness ranged from 0.20 to 0.59, and the Florida index ranged from 1 to 2 with a mean of 1.5 (table 4).

A boat-mounted electroshocker was used on May 25, 2006, to sample fishes along the shoreline of Lake Apopka around Apopka Spring and in the Gourd Neck cove of the lake. A total of 554 specimens were collected representing 22 species of 16 genera and 11 families (table 11). Specimens were dominated by centrarchids (82.5 percent, especially *Lepomis macrochirus*, *Micropterus salmoides*, and *L. auritus*), poeciliids (6.5 percent, especially *Gambusia holbrooki*), and the atherinopsid *Labidesthes sicculus* (4.9 percent). These common species are typical of both lotic waters and margins of vegetated lakes. During most sampling events, a large aggregation of *L. sicculus* was observed schooling at the surface in the clear water of the spring boil. A few large adults of the nonindigenous *Oreochromis aureus* were collected; one or more of these were mouthbrooding females that disgorged a large number of young-of-the-year fry into a cooler used as a holding well (these individuals are not included in the summary total). Three passes with the electroshocking boat were made along most of the shoreline of Gourd Neck, and qualitative field observations suggested that fish appeared to be most abundant (and many of the largest adults present) in closest proximity to the spring outflow. Catch per-unit-effort was lowest along the shallow northern margin of Gourd Neck (25 fish/min for all species) and greatest in the two passes along the western and southern shoreline nearest the spring (40-45 fish/min).

Table 10. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 4 per date) from Apopka Spring, December 2005-September 2006.

[LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 30, 2005		Mar. 28, 2006		July 13, 2006		Sept. 21, 2006	
		n	%	n	%	n	%	n	%
Porifera	*Spongilla* sp.			86	1.0				
Turbellaria	Tricladida (LPIL)	345	2.5			1,379	12.8		
	Turbellaria (LPIL)							1,034	7.6
Gastropoda	*Amnicola dalli*			86	1.0	431	4.0	431	3.2
	cf. *Floridobia* sp.					172	1.6		
	cf. *Notogillia wetherbyi*					86	0.8		
	Hydrobiidae (LPIL)							86	0.6
	Melanoides tuberculata					259	2.4		
	Planorbella scalaris					86	0.8		
Bivalvia	Bivalvia (LPIL)					86	0.8		
	cf. *Musculium* sp.					86	0.8		
	Pisidiidae (LPIL)							86	0.6
Hirudinea	*Desserobdella phalera*	57	0.4						
	Helobdella stagnalis	115	0.8						
	Helobdella triserialis					517	4.8	776	5.7
	Myzobdella lugubris	57	0.4						
Oligochaeta	*Dero trifida*			86	1.0				
	Eclipidrilus palustris					259	2.4		
	Pristina leidyi							86	0.6
	Psammoryctides convolutus					172	1.6		
	tubificoid Naididae immature sp. A (LPIL)			216	2.5				
Amphipoda	*Hyalella azteca* complex Lecroy	12,572	91.1	8,060	92.6	6,552	60.8	8,448	62.0
Isopoda	*Caecidotea racovitzai australis*	14	0.1					948	7.0
	Caecidotea sp.	72	0.5	86	1.0	690	6.4	1,552	11.4
Diptera	*Chironomus* sp.			86	1.0				
	Glyptotendipes meridionalis group							172	1.3
	Glyptotendipes paripes	402	2.9						
	Goeldichironomus amazonicus	115	0.8						
Odonata	*Perithemis tenera seminole*	57	0.4						
Total		**13,806**		**8,706**		**10,775**		**13,619**	
Number of Taxa		**10**		**7**		**13**		**10**	

Table 11. Fishes collected by boat electroshocker in vicinity of Apopka, Bugg, Rock, and Wekiwa springs in 2006.

[n, total number of specimens; %, percent composition per sample]

Family	Species	Apopka Spring		Bugg Spring		Rock Springs		Wekiwa Springs	
		n	%	n	%	n	%	n	%
Lepisosteidae	*Lepisosteus osseus*	1	0.18						
	Lepisosteus platyrinchus	7	1.26	2	0.56	5	5.49	5	1.57
Amiidae	*Amia calva*	2	0.36	9	2.53	7	7.69	13	4.09
Anguillidae	*Anguilla rostrata*					2	2.20		
Clupeidae	*Dorosoma petenense*	1	0.18						
Cyprinidae	*Notemigonus crysoleucas*	3	0.54			8	8.79	49	15.41
	Notropis maculatus	1	0.18						
	Notropis petersoni							6	1.89
Catostomidae	*Erimyzon sucetta*			3	0.84	13	14.29	32	10.06
Ictaluridae	*Ameiurus catus*	1	0.18			1	1.10		
	Ameiurus natalis							2	0.63
	Ameiurus nebulosus	4	0.72			2	2.20		
Callichthyidae	*Hoplosternum littorale* [1]					1	1.10		
Loricariidae	*Pterygoplichthys disjunctivus* [1]					2	2.20	16	5.03
Esocidae	*Esox americanus*			6	1.69				
Atherinopsidae	*Labidesthes sicculus*	27	4.87			1	1.10		
Fundulidae	*Fundulus seminolis*	3	0.54	7	1.97	3	3.30		
	Lucania goodei	3	0.54	2	0.56			5	1.57
	Lucania parva							2	0.63
Poeciliidae	*Gambusia holbrooki*	35	6.32	[2]156	43.82	1	1.10	1	0.31
	Heterandria formosa	1	0.18	5	1.40				
	Poecilia latipinna			56	15.73				
Centrarchidae	*Lepomis auritus*	34	6.14	4	1.12	16	17.58	45	14.15
	Lepomis gulosus	13	2.35	4	1.12			15	4.72
	Lepomis macrochirus	336	60.65	9	2.53			39	12.26
	Lepomis marginatus	2	0.36						
	Lepomis microlophus	17	3.07	26	7.30			23	7.23
	Lepomis punctatus			52	14.61	18	19.78	36	11.32
	Micropterus salmoides	46	8.30	13	3.65	11	12.09	27	8.49
	Pomoxis nigromaculatus	9	1.62						
Percidae	*Etheostoma fusiforme*	1	0.18						
	Percina nigrofasciata							2	0.63
Cichlidae	*Oreochromis aureus*[1]	[3]7	1.26	2	0.56				
Total		**554**		**356**		**91**		**318**	
Number of Taxa		**22**		**16**		**15**		**17**	

[1] Nonindigenous species.

[2] Disproportionately large number of specimens collected as schooling adults at the surface.

[3] An additional 288 small fry collected when disgorged from buccal cavities of adult mouthbrooding females, not included.

Bugg Spring

Bugg Spring (figs. 1 and 18, table 1) is a second magnitude spring (mean and median discharge 11.2 and 10.3 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004). Bugg Spring discharges into a spring run (fig. 19) that flows about 1.5 mi north and east into Helena canal, which connects Lake Denham and Lake Harris. The spring has a deep circular pool about 400 ft in diameter. Water discharges from a cave at the bottom of the spring pool at a depth of approximately 170 ft below the water surface. The limestone walls of the spring pool are almost vertical and extend to the vent on all sides except the western shoreline. No boil is evident on the pool surface due to the substantial depth of the spring vent and large pool diameter. Except for algae, there is little aquatic vegetation in the spring pool; algae and macrophytes (mostly emergent and floating) are present in the spring run. Low-lying areas around the spring are densely forested, with sand hills present along the southern shoreline. The areal extent of Bugg springshed is 10.1 mi^2.

Land Use

Land use in the Bugg springshed changed little from 1973 to 2004, with some transition of open-water/wetlands to forestland as a result of land-surface drying and enhanced drainage (fig. 4). Land use in the springshed in 1973 consisted of forestland (66.4 percent), open-water/wetlands (33.6 percent), and urban/mining/transportation/recreation (less than 0.1 percent). Land use in the springshed in 2004 consisted of forestland (89.1 percent), open-water/wetlands (10.9 percent), and urban/mining/transportation/recreation (less than 0.1 percent). By 2004, a municipal sewer system was the primary mean of wastewater treatment and disposal, having replaced many of the relatively few septic systems in the northern part of the Bugg springshed prior to that time. Reclaimed wastewater, mostly imported from outside the springshed, was being applied as spray irrigation to 0.77 mi^2 of the land surface in the northern part of the Bugg springshed within 1 mi of the spring head.

Discharge

Discharge from Bugg Spring was measured intermittently by the USGS from 1943 to 1985. Since 1990, discharge has been measured at least monthly by the landowner. Discharge for Bugg Spring averaged 11.2 ft^3/s annually and varied greatly with rainfall, which averaged 50.22 in/yr in the springshed (fig. 20). Average annual discharge for Bugg Spring ranged from 8.1 ft^3/s in 2000 to 18.6 ft^3/s in 1960. Spring discharge is affected in winter months by nearby pumping of the Floridan aquifer system, particularly for freeze protection of local agricultural and horticultural crops (J. Branham, oral commun., 2005). Measured (instantaneous) discharge from Bugg Spring averaged 11.0 ft^3/s, and ranged from a pumping-affected minimum of 3.70 ft^3/s in December 2000 to 19.8 ft^3/s in July 1991 (fig. 21).

Water Chemistry and Age

Bugg Spring has been sampled intermittently by the USGS since 1967. The SJRWMD sampled the spring three times in 1991 and at least two to four times per year since

Figure 18. Surface view of Bugg Spring pool. Large structure is U.S. Navy sonar testing facility. Photograph by S.J. Walsh, September 21, 2006.

Figure 19. Bugg Spring run downstream of spring pool. Photograph by S.J. Walsh, May 25, 2006.

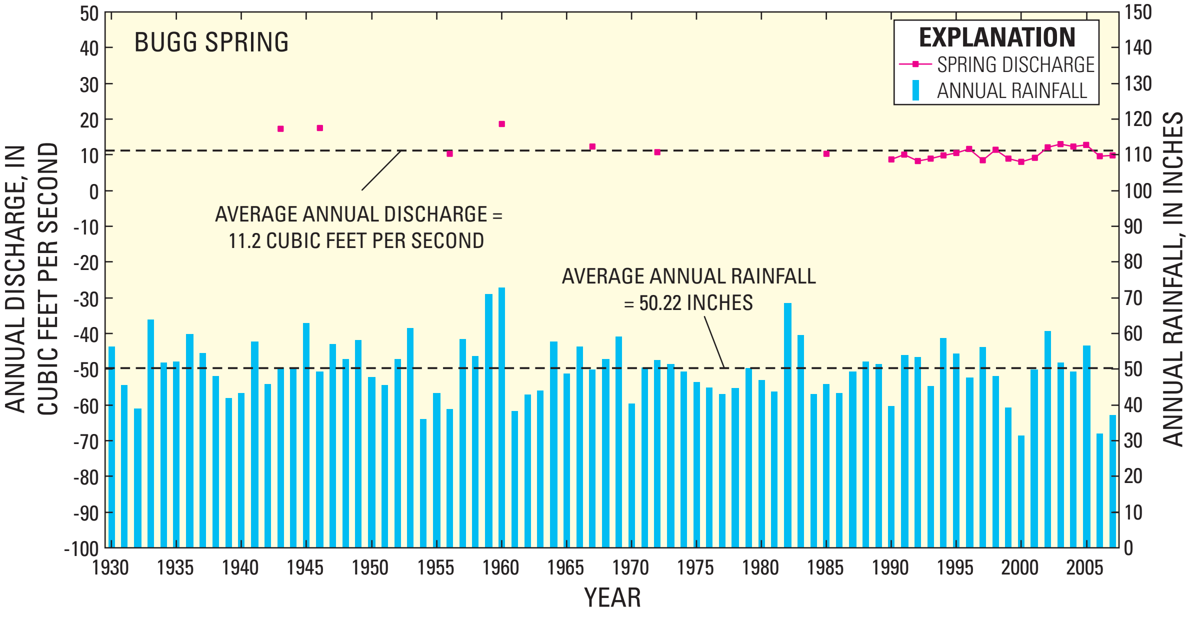


Figure 20. Average annual discharge for Bugg Spring and rainfall for the Bugg springshed.

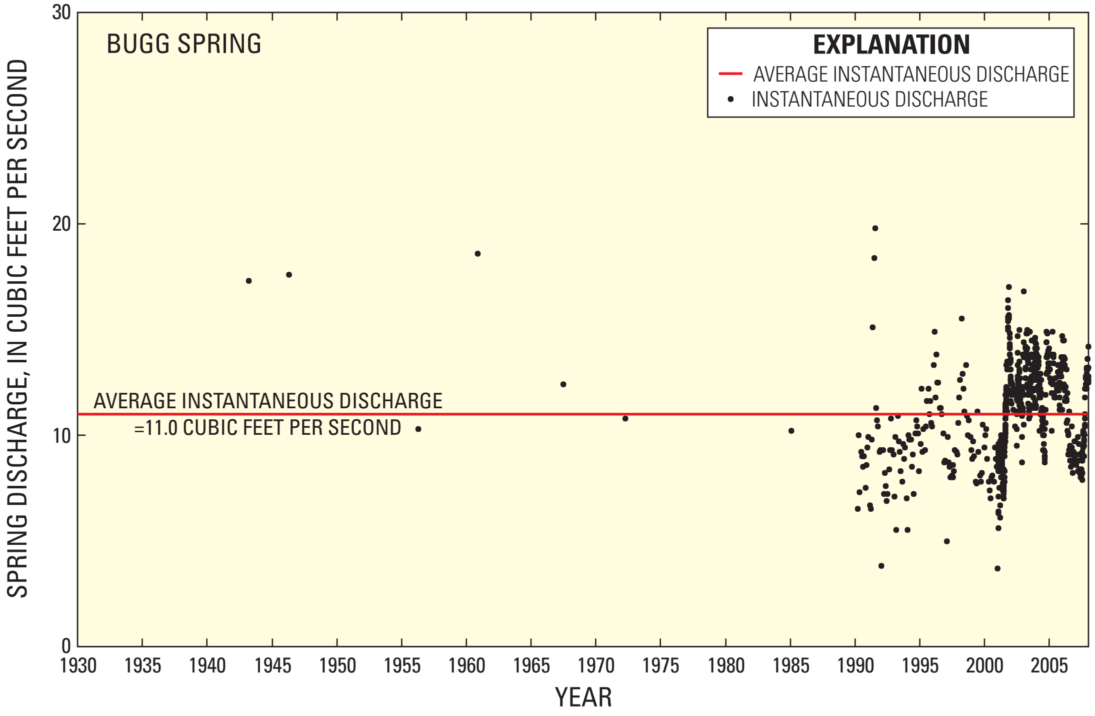


Figure 21. Periodic discharge data for Bugg Spring, 1943-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

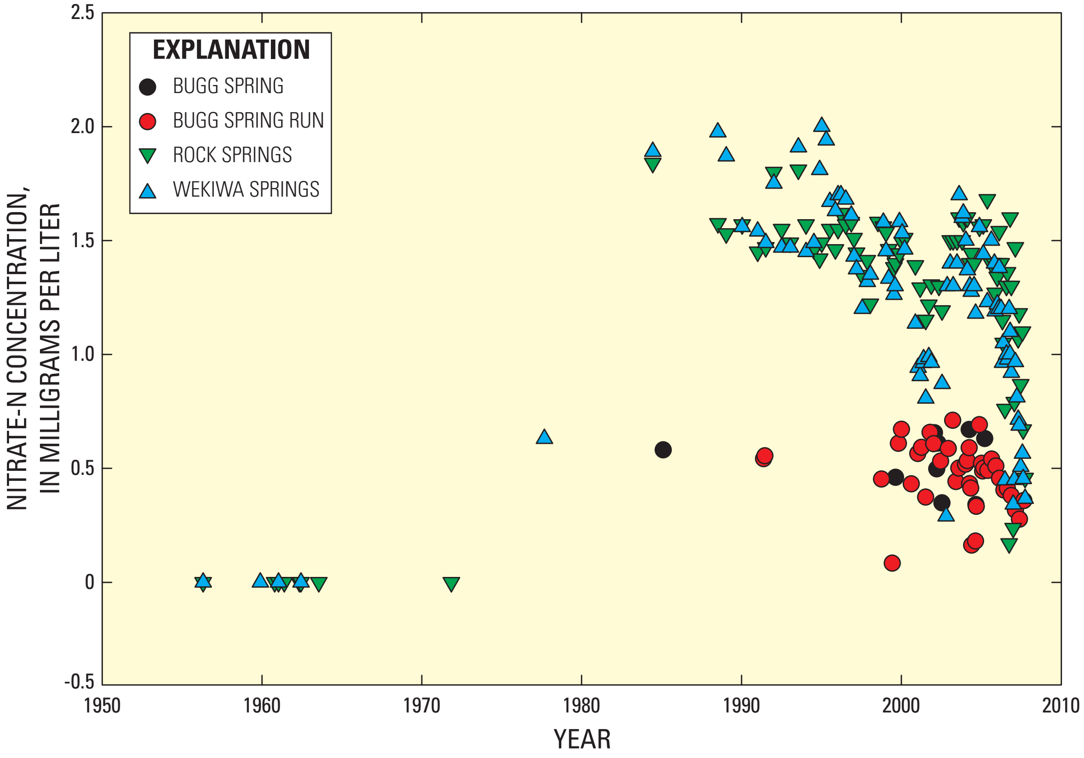


Figure 22. Nitrate-N concentrations in water from Bugg, Rock, and Wekiwa Springs.

1997. At the time of this study, the SJRWMD and USGS jointly sampled Bugg Spring at least four times per year.

Bugg Spring has a Ca-HCO_3 water type (fig. 9) and is at equilibrium (saturated) with respect to calcite and slightly undersaturated with respect to dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids were 7.6, 1.4 mg/L, and 167 mg/L, respectively. A ^{3}H concentration of greater than 2.3 TU was reported by Toth (2003). Delta ^{18}O and ^{2}H values were slightly enriched and plot along an evaporation trend line for lakes (Toth 2003), indicating that Bugg Spring receives recharge from surface water. Nutrient concentrations, such as nitrate-N, total P, and orthophosphate, have remained slightly higher than background conditions for the period of record (Maddox and others, 1992). Nitrate-N concentrations in Bugg Spring have remained relatively constant over time (fig. 22). In May 1985, the nitrate-N concentration was 0.58 mg/L, and nitrate-N concentrations ranged from 0.46 mg/L in August 1999 to 0.63 mg/L in March 2005 (fig. 22). Median concentrations of nitrate-N and total P for the period from 1972 to 2006 were 0.58 and 0.07 mg/L, respectively. Phosphorus (total P) concentrations in Bugg Spring generally have fluctuated between 0.04 to 0.09 mg/L (fig. 23), with a median value of 0.07 mg/L; however, there were large spikes in P concentrations above 0.2 mg/L in June 2002 and March 2004. In 2006, the USGS sampled Bugg Spring for chlorophyll-*a* and pheophytin-*a* to determine the richness of suspended photosynthetic organisms in the run where discharge measurements are made, approximately 200 ft downstream of the spring vent.

The age of water discharging from Bugg Spring was determined by measuring the concentration of ^{14}C and ^{13}C in the spring discharge in April 2001. Bugg Spring had a ^{14}C concentration of 42 pmc and a delta ^{13}C value of -9.95 per mil. Based on the ^{14}C results, and the use of the Fontes and Garnier (1979) model, the estimated age of water from Bugg Spring is less than 50 years.

Aquatic Communities

Because of the pool depth at Bugg Spring, the collection of macroinvertebrates was limited to a reach extending about 150 m (492 ft) downstream of the U.S. Navy fence, which spans the head of the run. Substrate along the spring run consisted of sand, soft organic detritus, muck, mats of filamentous algae, encrusting periphyton, and an abundance of dead gastropod shells.

A total of 39 macroinvertebrate taxa were collected by petite ponar dredge from Bugg Spring across four sampling dates (table 12). It is possible that five taxa, *Dero* sp., *Goeldichironomus* sp., immature *Dicrotendipes* sp., immature *Melanoides* sp., and *Spirosperma* sp., represented congeneric taxa identified to species; therefore, richness may have been lower than the 39 recorded. The number of taxa collected

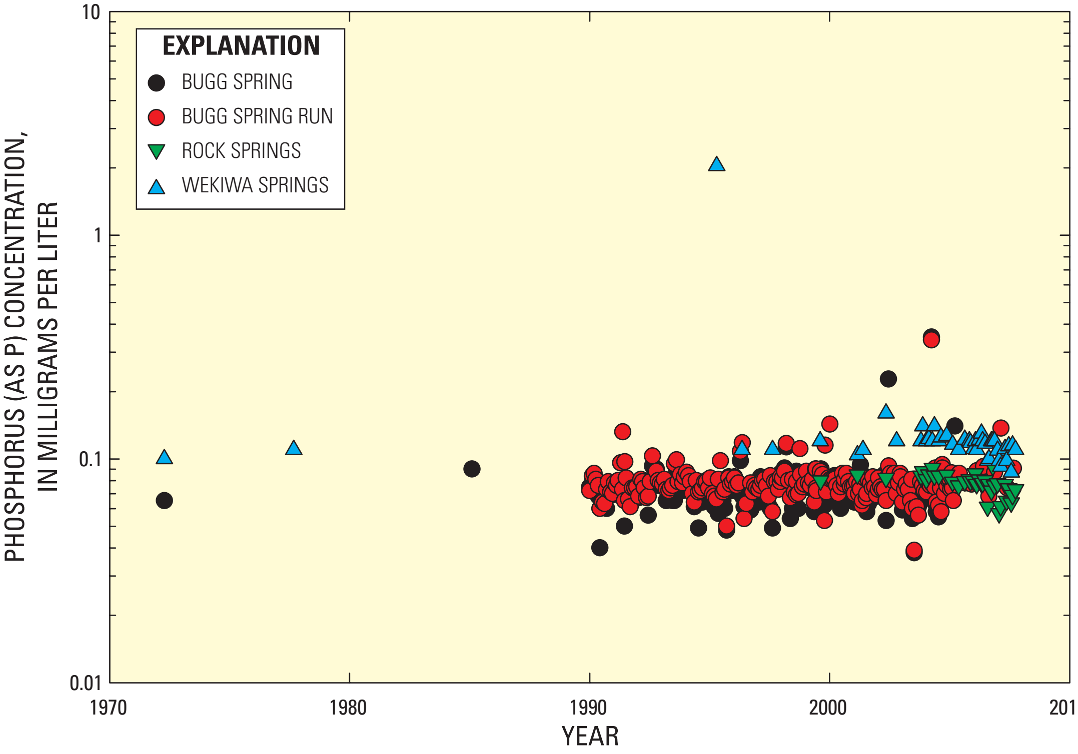


Figure 23. Phosphorus concentrations in water from Bugg, Rock, and Wekiwa Springs.

with this gear ranged from 12 in December 2005 to 17 in March 2006. Pooled samples were dominated by oligochaetes (41.7 percent of all organisms collected, consisting of 10 or fewer taxa, including immature forms and those not identifiable to species), amphipods (27.4 percent; *Hyalella azteca* complex), and gastropods (15.8 percent; 6 or fewer taxa, primarily *Melanoides tuberculata* and immature *Melanoides*). Density of all organisms ranged from approximately 2.9×10^3 per m^2 (31.9×10^3 per ft^2) in December 2005 to 10.4×10^3 per m^2 (112.4×10^3 per ft^2) in July 2006. For petite ponar samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.21 to 3.76, Simpson's index of diversity ranged from 0.62 to 0.91, Pielou's evenness ranged from 0.58 to 0.92, and the Florida index was consistently zero (table 4).

A total of 58 macroinvertebrate taxa were identified in subsamples collected by dip net from Bugg Spring (table 13); the fewest (11) were collected in the December 2005 sample and the most (26) in the March 2006 sample. The target number of organisms (110) was not obtained during sorting of the December 2005 (n = 45), March 2006 (n = 97), or July 2006 (n = 108) collections; the especially low number for the December 2005 sample likely accounts for the minimum number of taxa collected on that date and may have been the result of ineffective sampling. Subsamples from all dates combined were numerically dominated by amphipods (28.9 percent; all *Hyallela azteca* complex), oligochaetes (18.3 percent), and gastropods (15.3 percent). The nonindigenous snails *Melanoides tuberculata* and *M. turricula* dominated the December 2005 dip net sample (57.8 percent) and constituted a substantial proportion (15.4 percent) of the September 2006 sample. For dip net samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.55 to 4.09, Simpson's index of diversity ranged from 0.63 to 0.93, Pielou's evenness ranged from 0.57 to 0.87, the SCI ranged from 7 to 34 with a mean of 19.25, and percent very tolerant taxa ranged from 19.3 to 77.8 (table 5).

An attempt to collect or observe fishes in the Bugg Spring pool was impractical due to the spring depth and prohibited motorized boat access near the U.S. Navy sonar calibration facility. However, the spring run was accessed on June 7, 2006, with an electroshocker boat launched at Lake Harris. Two electroshocking passes (with a total of 30 minutes power output) were made from the U.S. Navy fence just downstream of the spring pool to near the mouth of the spring run. Margins of the spring run were shallow and contained large amounts of thick brush, overhanging branches, floating logs, and submerged or partially exposed large woody debris, making electrofishing difficult and somewhat inefficient. It is likely that the number of fallen trees and amount of woody debris in the spring run was increased by hurricanes in 2004.

A total of 356 fish specimens were collected, representing 16 species of 12 genera and 8 families (table 11). Specimens were dominated by poeciliids (61 percent, mostly

Table 12. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Bugg Spring, December 2005-September 2006.

[LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 30, 2005		Mar. 17, 2006		July 12, 2006		Sept. 21, 2006	
		n	%	n	%	n	%	n	%
Porifera	Porifera (LPIL)							230	2.4
	Ephydatia sp.							115	1.2
Turbellaria	Tricladida (LPIL)					115	1.1		
Gastropoda	*Amnicola dalli*							115	1.2
	Ancylidae (LPIL)			144	4.4				
	Hebetancylus excentricus	115	3.9			345	3.3		
	Melanoides sp. (immature)							805	8.2
	Melanoides tuberculata	29	1.0			575	5.5	1,724	17.6
	Viviparus georgianus	316	10.7						
Bivalvia	Bivalvia (LPIL)					129	1.2		
	Pisidiidae (LPIL)			230	7.0				
	Sphaerium striatinum	115	3.9	144	4.4				
Hirudinea	*Erpobdella punctata*	172	5.8						
	Helobdella stagnalis	172	5.8						
	Helobdella triserialis							345	3.5
	Mooreobdella tetragon			29	0.9			115	1.2
Oligochaeta	*Dero digitata*							805	8.2
	Dero sp.							690	7.1
	Dero trifida			29	0.9				
	Ilyodrilus templetoni	402	13.6	431	13.1	86	0.8	690	7.1
	Limnodrilus hoffmeisteri	718	24.3	101	3.1	402	3.8		
	Naididae (LPIL)							230	2.4
	Spirosperma ferox					546	5.2		
	Spirosperma sp.							230	2.4
	tubificoid Naididae immature sp. A (LPIL)	690	23.3	532	16.2	1,494	14.3	2,644	27.1
	tubificoid Naididae immature sp. B (LPIL)	144	4.9			172	1.6		
Arachnida	*Piona* sp.			230	7.0				
Amphipoda	*Hyalella azteca* complex Lecroy	29	1.0	158	4.8	6,149	58.9	920	9.4
Decapoda	Cambaridae (LPIL)					86	0.8		
Diptera	*Chironomus* sp.			144	4.4	86	0.8		
	Dicrotendipes modestus					86	0.8		
	Dicrotendipes sp. (immature)			259	7.9				
	Einfeldia natchitocheae			230	7.0				
	Goeldichironomus carus	57	1.9						
	Goeldichironomus sp.							115	1.2
	Palpomyia/Sphaeromias group Brigham			259	7.9	172	1.6		
	Tanytarsus sp. G Epler			101	3.1				
	Zavreliella marmorata			230	7.0				
Ephemeroptera	*Caenis diminuta*			29	0.9				
Total		**2,959**		**3,280**		**10,443**		**9,773**	
Number of Taxa		**12**		**17**		**14**		**15**	

Table 13. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Bugg Spring, December 2005-September 2006.

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 30, 2005		Mar. 17, 2006		July 12, 2006		Sept. 21, 2006	
		n	%	n	%	n	%	n	%
Gastropoda	*Hebetancylus excentricus*					1	0.9		
	Laevapex sp.	1	2.2						
	Melanoides sp. (immature)					1	0.9		
	Melanoides tuberculata	21	46.7					2	1.8
	Melanoides turricula	5	11.1					15	13.6
	Planorbella scalaris					4	3.7		
	Viviparus georgianus	3	6.7					2	1.8
Bivalvia	Bivalvia (LPIL)					3	2.8		
	Corbicula fluminea							1	0.9
	Sphaerium striatinum	3	6.7	2	2.1			6	5.5
	Utterbackia imbecilis	1	2.2						
Hirudinea	Erpobdellidae (LPIL)	1	2.2						
	Glossiphoniidae (LPIL)			1	1.0				
	Helobdella stagnalis							1	0.9
	Mooreobdella tetragon							1	0.9
Oligochaeta	*Aulodrilus pigueti*			3	3.1	3	2.8	5	4.5
	Bratislavia unidentata					1	0.9	3	2.7
	Dero flabelliger			3	3.1				
	Dero pectinata			2	2.1				
	Ilyodrilus templetoni			1	1.0			5	4.5
	Limnodrilus hoffmeisteri	5	11.1	8	8.2	8	7.4	10	9.1
	Nais communis complex					1	0.9		
	Nais elinguis							1	0.9
	Pristina leidyi					1	0.9		
	Spirosperma ferox					1	0.9	5	4.5
Arachnida	Acariformes (LPIL)	3	6.7						
	Limnesia sp.							1	0.9
Amphipoda	*Hyalella azteca* complex LeCroy			4	4.1	65	60.2	35	31.8
Decapoda	*Palaemonetes* sp.					1	0.9		
	Procambarus sp. (immature)							2	1.8

Table 13. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Bugg Spring, December 2005-September 2006.—Continued

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 30, 2005		Mar. 17, 2006		July 12, 2006		Sept. 21, 2006	
		n	%	n	%	n	%	n	%
Diptera	*Beardius truncates*					1	0.9		
	Bezzia/Palpomyia complex Brigham					3	2.8		
	Chironomus sp.	1	2.2	5	5.2	3	2.8	7	6.4
	Cladotanytarsus sp. A Epler			1	1.0	1	0.9		
	Clinotanypus sp.			1	1.0				
	Cryptochironomus sp.			1	1.0				
	Dicrotendipes modestus			9	9.3				
	Dicrotendipes sp. (immature)					1	0.9		
	Einfeldia natchitocheae			7	7.2			2	1.8
	Glyptotendipes sp.	1	2.2						
	Larsia decolorata					5	4.6		
	Monopelopia boliekae			1	1.0				
	Palpomyia/Sphaeromias group Brigham			1	1.0				
	Parachironomus supparilis			1	1.0				
	Polypedilum illinoense group Epler			1	1.0				
	Polypedilum tritum			1	1.0				
	Pseudochironomus sp.					1	0.9		
	Tanypus carinatus			6	6.2				
	Tanypus sp.					1	0.9	1	0.9
	Tanytarsus sp.							2	1.8
	Tanytarsus sp. G Epler			20	20.6	1	0.9		
	Tanytarsus sp. L Epler			2	2.1				
	Zavreliella marmorata			2	2.1				
Ephemeroptera	*Caenis diminuta*			7	7.2	1	0.9		
	Caenis sp.							2	1.8
	Callibaetis floridanus			4	4.1				
Hemiptera	*Mesovelia* sp. (immature)			3	3.1				
Odonata	Coenagrionidae (LPIL)							1	0.9
Total		**[1]45**	**100**	**[1]97**	**100**	**108**	**100**	**110**	**100**
Number of Taxa		**11**		**26**		**22**		**22**	

[1] Failed to obtain target number of subsampled organisms (100-110) during sorting process.

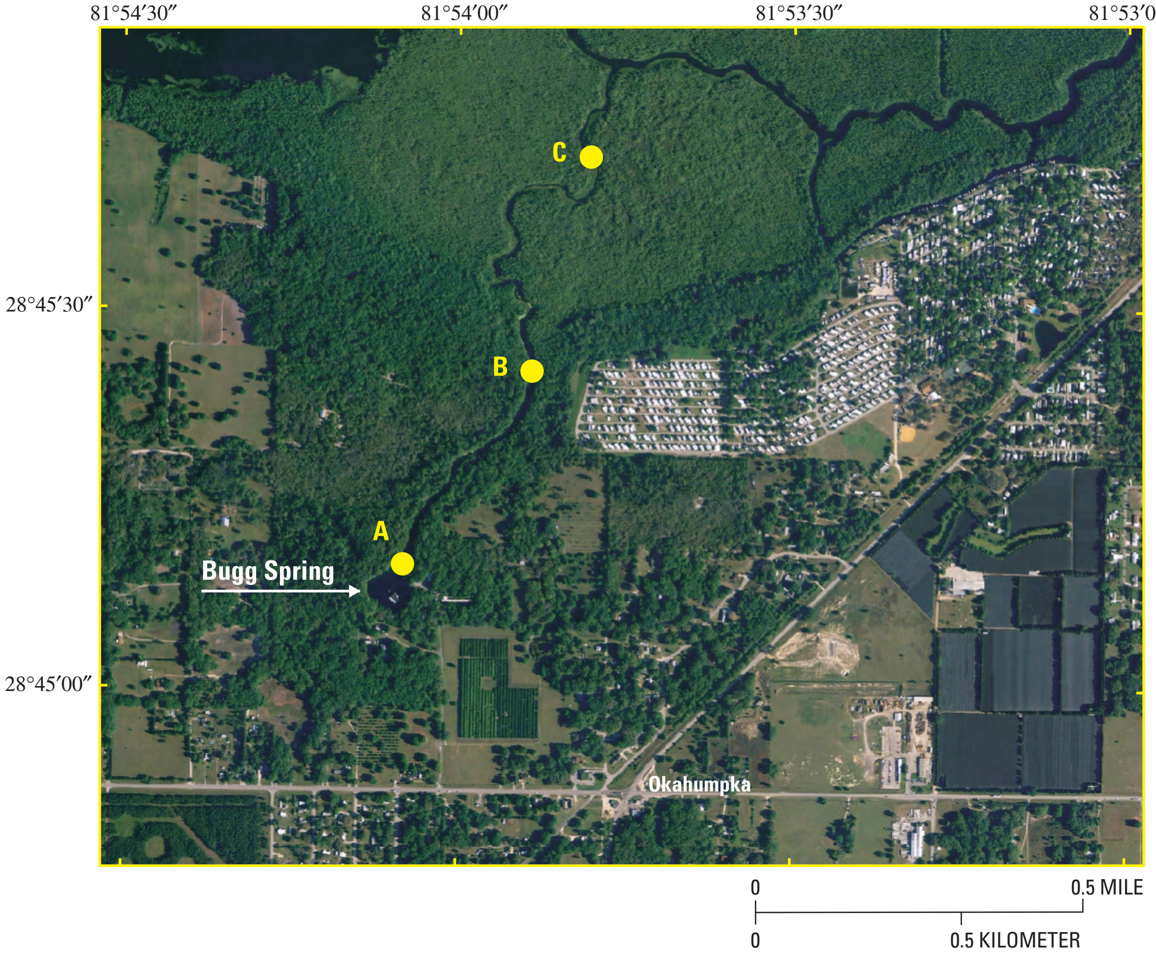


Figure 24. Aerial view of Bugg Spring and run showing differences in land use and riparian vegetation between upper and lower sections of the run. Circles A and B represent endpoints of upstream electrofishing pass, and circles B and C represent endpoints of downstream electrofishing pass in this study.

Gambusia holbrooki) and centrarchids (30.3 percent, mostly *Lepomis punctatus*). Two specimens of the nonindigenous *Oreochromis aureus* were collected in the spring run, and the landowner of the spring-head property indicated that adults were common in the spring pool. The fish community in the spring run was relatively depauperate and overall abundance was low. Qualitative field observations indicated that total fish abundance was greatest in the upstream portion of the spring run and diminished in the lower section. Excluding *G. holbrooki* (all of which were collected in the first upstream pass), catch per-unit-effort for all other species was 9.0 fish/min in the upstream section (a distance of about 580 m [0.36 mi], shown in figure 24) and was 4.5 fish/min in the downstream section (a distance of about 790 m [0.49 mi]).

The observed difference in relative abundance between the upstream and downstream sections of the spring run may be related to gear efficiency, habitat variation, or a combination of both. The upstream section was characterized by a heavy tree canopy, more in-stream woody debris, undercut banks with root mats and other structurally complex microhabitats (but devoid of aquatic macrophytes), and greater spring-water influence as evidenced by water clarity. The lower section of the spring run had a relatively open canopy, very shallow depth, extensive submergent, emergent, and floating marsh vegetation on the shoreline with a less defined bank, as well as lower water clarity. The substrate throughout the run was flocculent muck and detritus, in the upstream section overlain by leaf packs, branches, and dead gastropod shells. Large mats of floating algae were observed in several areas of the spring run. Differences in riparian vegetation and land use between the upstream and downstream sections of the sinuous spring run are evident in an aerial photograph of the site (fig. 24).

De Leon Spring

De Leon Spring (fig. 1) is a second magnitude spring (mean and median discharge 27.9 and 26.4 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004; Phelps and others, 2006). Although this spring is listed as “Ponce de Leon Springs” in the USGS Geographic Names Information System (*http://geonames.usgs.gov*), that name is not in general usage to avoid confusion with Ponce de Leon Springs in Holmes County, Florida. Discharge is from a cavern and chimney opening in the central part of a semicircular pool, forming a boil above the vent. The spring pool of De Leon Spring is impounded by a large concrete weir along the west wall, where discharge measurements were made; spring outflow then flows over a 3-ft drop and into a wide natural spring run that flows toward the west and discharges at about 0.25 mi into Lake Woodruff. The bottom of the spring pool is sand with exposed rock near the vent. Aquatic macrophytes are absent in the pool, although patches of algae are present seasonally. A concrete walkway with numerous ladders and access points encircles the spring pool. The spring is a popular recreational attraction and is used extensively for swimming and boating. Direct effects of human disturbance to the pool bottom necessitated collecting macroinvertebrate samples from the dam overflow area and in the broad section of the run immediately downstream of the dam, which was heavily vegetated with submergent, emergent, and floating macrophytes encrusted by abundant periphyton. The substrate where macroinvertebrates were collected varied extensively from rock and artificial hard surfaces, sand, and areas of extensive organic muck and detritus. The areal extent of the De Leon springshed is 10.8 mi^2.

Land Use

Land use in the De Leon springshed changed from 1973 to 2004, mainly as a transition from forestland to agriculture, but the springshed remains mostly rural in character (fig. 4). Land use in the springshed in 1973 consisted of forestland (59.0 percent), open-water/wetlands (33.4 percent), agriculture (6.5 percent), and urban/mining/transportation/recreation (1.1 percent). Land use in the springshed in 2004 consisted of open-water surface/wetlands (32.9 percent), forestland (28.5 percent), agriculture (26.8 percent), urban/mining/transportation/recreation (9.5 percent), and non-forested/barren land (2.3 percent). As of 2004, a municipal sewer system had replaced septic systems in a 1.0-mi^2 area along the southern edge of the De Leon springshed, and no reclaimed wastewater was applied to the land surface within the springshed. Septic systems remain the primary means of wastewater treatment and disposal in the De Leon springshed.

Discharge

Discharge from De Leon Spring was measured by the USGS from 1929 to 2002. The SJRWMD measured discharge bimonthly from 1983 to 2005, and monthly since 2005. Discharge for De Leon Spring averaged 27.9 ft^3/s annually, and varied greatly with rainfall that averaged 56.02 in/yr within the springshed (fig. 25). Average annual discharge for De Leon Spring ranged from 19.2 ft^3/s in 2000 to 43.1 ft^3/s in 2006. Measured (instantaneous) discharge for De Leon Spring averaged 32.5 ft^3/s, and ranged from 12.2 ft^3/s in November 1997 to 61.6 ft^3/s in August 2004 following Hurricane Charley (fig. 26).

Water Chemistry and Age

De Leon Spring has been sampled periodically by the USGS since 1932, with the highest sampling frequency occurring from 1956 to 1990. The SJRWMD sampled De Leon Spring from 1984 to 2005, and currently samples the spring four times per year.

De Leon Spring has a mixed water type (fig. 9), and is slightly undersaturated with respect to calcite and dolomite. Median values of pH, dissolved oxygen, and dissolved solids were 7.6, 1.5 mg/L, and 416 mg/L, respectively (table 3). The delta ^{18}O and ^{2}H composition plotted along the GMWL, or local MWL parallel to the GMWL, and the ^{3}H concentration was 2.1 TU (Toth, 1999). The delta ^{34}S concentration was 13.9 per mil, which typically corresponds to low sulfate concentrations and indicates variable sources of sulfate, including rainfall, mixtures of shallow and deep ground water, and geochemical reactions along ground-water flow paths (Toth, 1999).

Nitrate-N concentrations increased from 1984 to 2005 (0.7-1.4 mg/L), but decreased below 1.0 mg/L from May 2006 to August 2007 (fig. 16). The median nitrate-N concentration from 1984 to 2007 was 0.9 mg/L. Excess dissolved nitrogen concentrations of about 1.5 mg/L were found during previous sampling events during May 2004 and August 2004 (Phelps and others, 2006). Water samples collected in 2005 (January 28, May 17, June 30, and September 1) also had excess dissolved nitrogen concentrations of about 1 mg/L. It is likely that denitrification was occurring in the Upper Floridan aquifer in the vicinity of De Leon Spring. Additional evidence for denitrification was indicated by the fractionation of nitrogen and oxygen isotopes of nitrate, which had elevated values relative to other spring-water samples (Phelps and others, 2006). Phosphorus (total P) concentrations in De Leon Spring generally have been uniform (0.03-0.06 mg/L) with a median concentration of 0.05 mg/L (fig. 17), although orthophosphate concentrations showed a significant ($p < 0.001$) decreasing trend over time (1968-2007) (table 6).

Water samples collected from De Leon Spring in May and August 2004 were analyzed for 64 organic chemicals commonly associated with wastewater sources and 52 pesticides. The following organic wastewater compounds were detected (in microgram per liter concentrations) in the May 2004 samples: phenol (E0.4), indole (E0.4), and p-cresol (2) (app. 4). Here, “E” denotes estimated concentrations reported by the laboratory that are quantifiable between the method detection limit and the method reporting level. No pesticides were detected in water samples from De Leon Spring (app. 5).

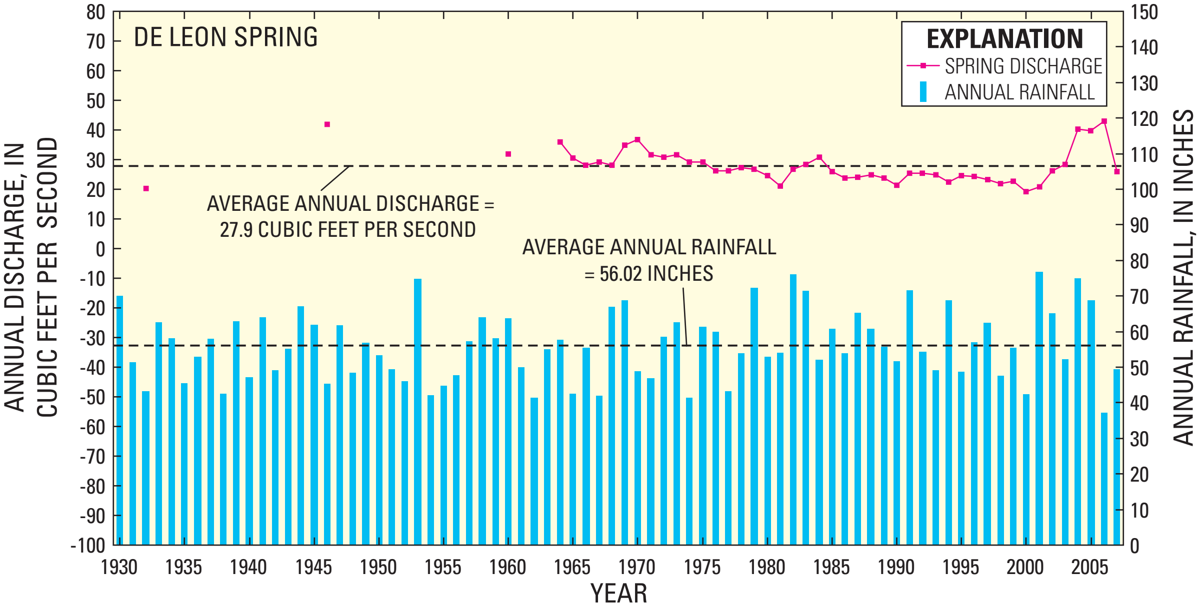


Figure 25. Average annual discharge for De Leon Spring and rainfall for De Leon springshed.

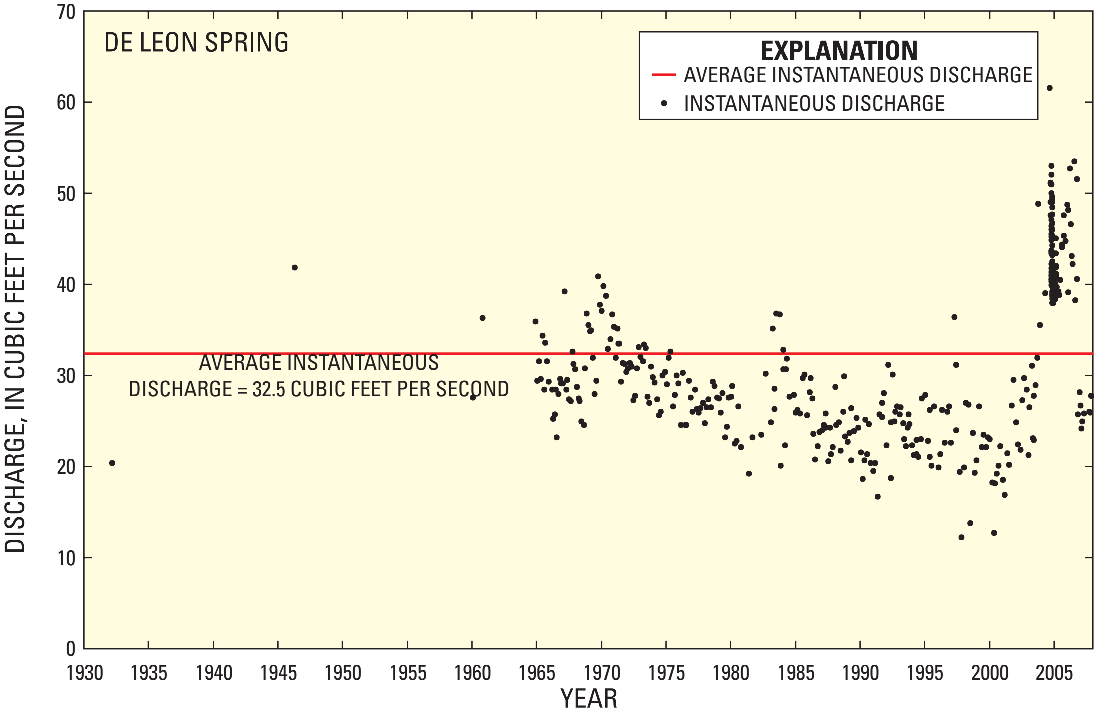


Figure 26. Periodic discharge data for De Leon Spring, 1929-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

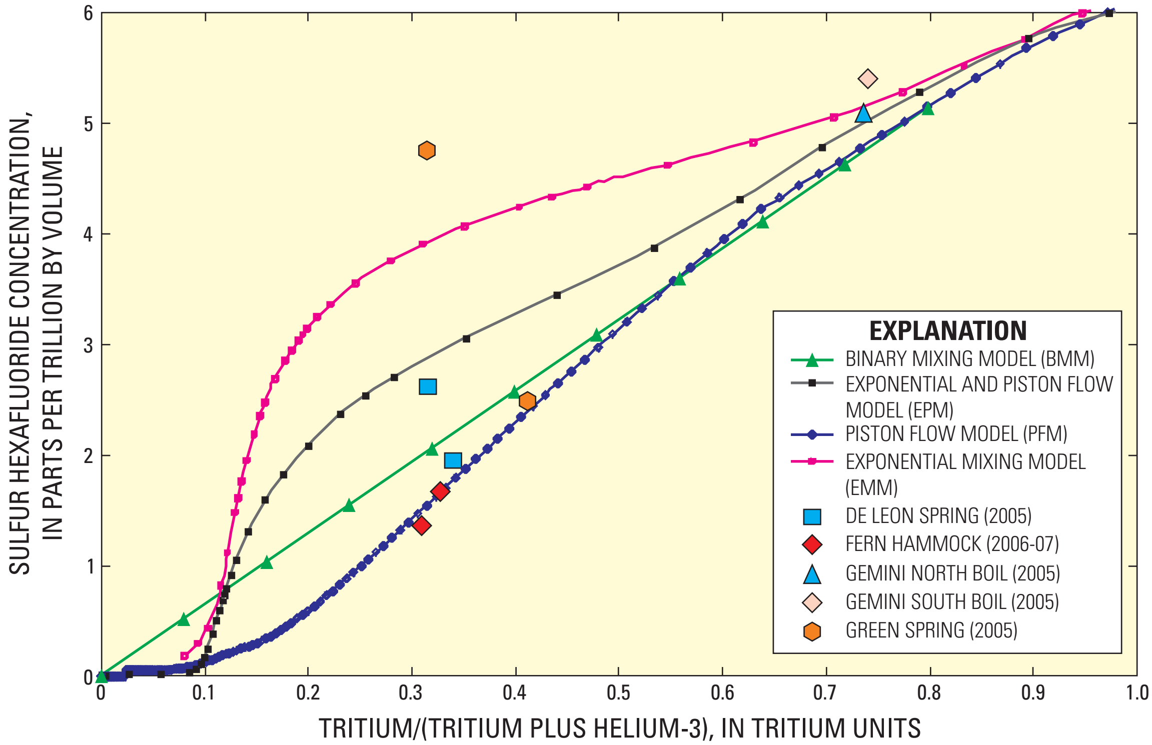


Figure 27. Measured concentrations of sulfur hexafluoride (SF$_6$, y-axis) and the ratio of measured tritium (^{3}H) to the initial tritium (measured concentrations of tritium plus helium-3 (^{3}He) radioactive decay product of tritium) in water samples from selected springs, and output curves from various lumped parameter models for various scenarios of ground-water flow to springs.

Based on concentrations of ^{3}H, ^{3}He (daughter product of tritium decay), SF$_6$ and chlorofluorocarbons (CFCs) measured in water samples from De Leon Spring in 2001, the age of spring water represents an exponential mixture containing approximately 30 percent old water (greater than 60 years) and about 70 percent younger water having a mean residence time of 14 years (Toth and Katz, 2006). The SF$_6$, ^{3}H, and ^{3}He data from recent water samples from De Leon Spring collected in 2005 were plotted, along with the output curves showing age distributions for various lumped-parameter models (fig. 27). The modeled output curves are based on various assumptions of ground-water flow in the spring contributing area and atmospheric concentrations of SF$_6$, ^{3}H, and ^{3}He over time (fig. 3). The tracer data indicated a similar exponential mixture of old and young waters from the Floridan aquifer system (fig. 27). The age of water discharging from De Leon Spring also was determined by measuring the concentration of ^{3}H, delta ^{13}C, and ^{14}C in the spring discharge in May 1995 and ^{3}H and ^{3}He in July 1995. De Leon Spring had a ^{3}H concentration of 2.1 TU, which indicates that the younger fraction of water likely is less than 42 years old. The ^{3}H /^{3}He age of the water was 28.6 years. De Leon Spring had a delta ^{13}C value of -7.96 per mil and a ^{14}C concentration of 35 pmc, which is indicative of mixing of Upper and Lower Floridan aquifer water. The adjusted ^{14}C age is recent.

Aquatic Communities

General descriptions of the aquatic macroinvertebrate and fish assemblages of De Leon Spring were presented by Phelps and others (2006). Previously, macroinvertebrate samples were sorted, identified, and enumerated, but the oligochaetes and most dipterans (families Chironomidae and Ceratopogonidae) were not identified beyond family or higher level taxonomic categories. These specimens were subsequently identified to species or lowest practicable identification level. The macroinvertebrate data were, therefore, reanalyzed and are reported here in greater detail.

A total of 61 macroinvertebrate taxa were collected by petite ponar dredge from De Leon Spring across three sampling dates (table 14). The number of taxa collected with this gear ranged from 7 in February 2004 to 46 in August 2004. The total number of organisms collected in February was much lower than the numbers collected on the other dates. Pooled samples across all dates were dominated by amphipods (78.9 percent, *Hyalella azteca* complex and *Gammarus* cf. *tigrinus*), gastropods (8.3 percent, most of which were hydrobiids), and dipterans (5.4 percent). Density of all organisms ranged from 530 per m^2 (5.7 × 10^3 per ft^2) in February 2004 to 12.6 × 10^3 per m^2 (135.9 × 10^3 per ft^2) in August 2004. The

Table 14. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from De Leon Spring, February-August 2004.

[LPIL, lowest practicable identification level]

Clade	Taxon	Feb. 11, 2004		May 11, 2004		Aug. 18, 2004	
		n	%	n	%	n	%
Porifera	Porifera (LPIL)					14	0.1
Turbellaria	Tricladida (LPIL)			29	0.7		
Gastropoda	Ancylidae (LPIL)					29	0.2
	Elimia floridensis	14	2.6	43	1.1	72	0.6
	Haitia sp.					115	0.9
	Hydrobiidae (LPIL)			29	0.7	776	6.1
	Melanoides tuberculata			14	0.3		
	Micromenetus floridensis			14	0.3		
	Planorbella scalaris			14	0.3	302	2.4
	Viviparus georgianus					14	0.1
Hirudinea	cf. *Actinobdella inequiannulata*			14	0.3		
	Glossiphoniidae (LPIL)	29	5.5				
	Helobdella sp.					43	0.3
	Helobdella stagnalis			172	4.2	86	0.7
	Helobdella triserialis					14	0.1
	Mooreobdella tetragon					43	0.3
Oligochaeta	*Aulodrilus pigueti*					14	0.1
	cf. *Lumbriculus* sp.					14	0.1
	Dero digitata complex			14	0.3	29	0.2
	Dero nivea					29	0.2
	Dero pectinata					29	0.2
	Dero sp.					29	0.2
	Eclipidrilus sp.					14	0.1
	Enchytraeidae (LPIL)					14	0.1
	Limnodrilus hoffmeisteri	14	2.6	14	0.3		
	Spirosperma ferox					86	0.7
	Spirosperma sp.			14	0.3		
	tubificoid Naididae immature sp. A (LPIL)			57	1.4	101	0.8
Arachnida	Acariformes (LPIL)					115	0.9
Amphipoda	*Gammarus* cf. *tigrinus* LeCroy	330	62.3	1,480	36.4	3,621	28.7
	Hyalella azteca complex Lecroy	115	21.7	1,580	38.9	6,451	51.1
Isopoda	*Caecidotea* sp.	14	2.6				
	Cassidinidea ovalis					14	0.1
Decapoda	*Palaemonetes paludosus*					14	0.1
	Procambarus sp.			14	0.3		
Coleoptera	*Helocombus* sp.			14	0.3		

Table 14. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from De Leon Spring, February-August 2004.—Continued

[LPIL, lowest practicable identification level]

Clade	Taxon	Feb. 11, 2004		May 11, 2004		Aug. 18, 2004	
		n	%	n	%	n	%
Diptera	*Bezzia/Palpomyia* complex Brigham					14	0.1
	Chironomidae (LPIL)			14	0.3		
	Chironomus sp.					14	0.1
	Cladotanytarsus sp.					14	0.1
	Cryptochironomus sp.			29	0.7		
	Dicrotendipes modestus			417	10.3	14	0.1
	Labrundinia neopilosella					14	0.1
	Larsia decolorata					230	1.8
	Monopelopia boliekae					14	0.1
	Odontomyia/Hedriodiscus group Merritt and Cummins			29	0.7		
	Paratanytarsus sp.					14	0.1
	Pseudochironomus sp.			14	0.3	14	0.1
	Tabanidae (LPIL)	14	2.6				
	Tanypodinae (LPIL)					14	0.1
	Tanytarsini (LPIL)			14	0.3		
	Tanytarsus sp. F Epler					14	0.1
	Tanytarsus sp. G Epler					29	0.2
Ephemeroptera	*Caenis diminuta*					43	0.3
	Callibaetis floridanus					14	0.1
	Ephemeroptera (LPIL)			29	0.7	14	0.1
Hemiptera	*Mesovelia* sp.					14	0.1
	Pelocoris sp.					14	0.1
Odonata	*Argia* sp.					14	0.1
	Libellulidae (LPIL)					14	0.1
Trichoptera	*Orthotrichia* sp.					14	0.1
Total		**530**		**4,062**		**12,622**	
Number of Taxa		**7**		**23**		**46**	

Table 15. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from De Leon Spring, February-August 2004.

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index]

Gastropoda	*Elimia floridensis*	5	4.5	6	5.5	3	2.7
	Hydrobiidae (LPIL)	4	3.6	3	2.7	7	6.4
	Pomacea paludosa	1	0.9				
	Viviparus georgianus	2	1.8	1	0.9	1	0.9
Bivalvia	*Corbicula fluminea*			1	0.9		
Hirudinea	*Gloiobdella elongata*					1	0.9
	Helobdella stagnalis			3	2.7		
Oligochaeta	*Allonais inaequalis*	1	0.9				
	Bratislavia unidentata					1	0.9
	Limnodrilus hoffmeisteri					4	3.6
	Spirosperma ferox	1	0.9				
	tubificoid Naididae immature sp. A (LPIL)			2	1.8		
Amphipoda	*Gammarus* cf. *tigrinus* LeCroy	5	4.5	24	21.8	24	21.8
	Hyalella azteca complex LeCroy	82	74.5	56	50.9	66	60.0
Decapoda	*Procambarus* sp. (immature)					1	0.9
Coleoptera	Chrysomelidae (LPIL)	2	1.8				
Diptera	*Chironomus* sp.			2	1.8		
	Cricotopus politus			3	2.7		
	Dicrotendipes modestus	4	3.6	6	5.5	1	0.9
	Pseudochironomus sp.			1	0.9		
	Tanytarsus sp.			1	0.9		
Odonata	*Argia* sp.	2	1.8				
	Enallagma sp.			1	0.9	1	0.9
	Erythemis plebeja	1	0.9				

ratio of *Hyalella* to *Gammarus* was 1:0.3, 1:1.1, and 1:1.8 in February, March, and August, respectively. For petite ponar samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 1.69 to 2.34, Simpson's index of diversity ranged from 0.56 to 0.70, Pielou's evenness ranged from 0.42 to 0.60, and the Florida Index ranged from 1 to 7 with a mean of 3.3 (table 4).

A total of 24 macroinvertebrate taxa were identified in subsamples collected by dip net from De Leon Spring; over three sampling dates, the number of taxa collected ranged from 11 in August 2004 to 14 in May 2004 (table 15). Although far fewer taxa were collected with this gear than by petite ponar dredge, subsamples from all dates combined were numerically dominated by amphipods (77.9 percent), followed by gastropods (10.0 percent), and dipterans (5.5 percent). The taxonomic composition of the most abundant taxa, therefore, was similar to the composition of samples collected by petite ponar dredge. For dip net samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 1.63 to 2.38, Simpson's index of diversity ranged from 0.44 to 0.69, Pielou's evenness ranged from 0.45 to 0.62, SCI ranged from 9 to 10 with a mean of 10, and percent very tolerant taxa ranged from 3.6 to 14.5, with a mean of 8.1 (table 5).

Fern Hammock Springs

Fern Hammock Springs (figs. 1, 28, and 29, table 1), also known as "The Aquarium," is a second-magnitude spring (mean and median discharge 13.0 and 12.7 ft^3/s, respectively) located in the Ocala National Forest (Rosenau and others, 1977; Scott and others, 2004). The irregularly shaped main pool measures about 160 ft by 75 ft, with a depth ranging from 2 to 6 ft. The bottom of the pool contains over 25 sand boils, and is mostly fine, white sand with patches of aquatic macrophytes, and muck. A wooden footbridge spans the spring pool near its center, with the largest sand boil in the pool situated directly under the footbridge (fig. 29). The clear, bluish spring water has exceptionally low mineralization (mean and median specific conductance: 125 and 118 µS/cm, respectively) among Floridan aquifer system springs, which typically have a specific conductance of greater than about 300 µS/cm. Discharge from Fern Hammock Springs flows about 600 ft through a gently meandering run to Juniper Creek. The head of Fern Hammock Springs is located downgradient of a low-volume wastewater treatment facility (used for the recreation area) that may potentially affect the water quality in the spring. Swimming is prohibited in Fern Hammock Springs because of ecological, human-health, and safety considerations. The areal extent of the Fern Hammock springshed has not been determined.

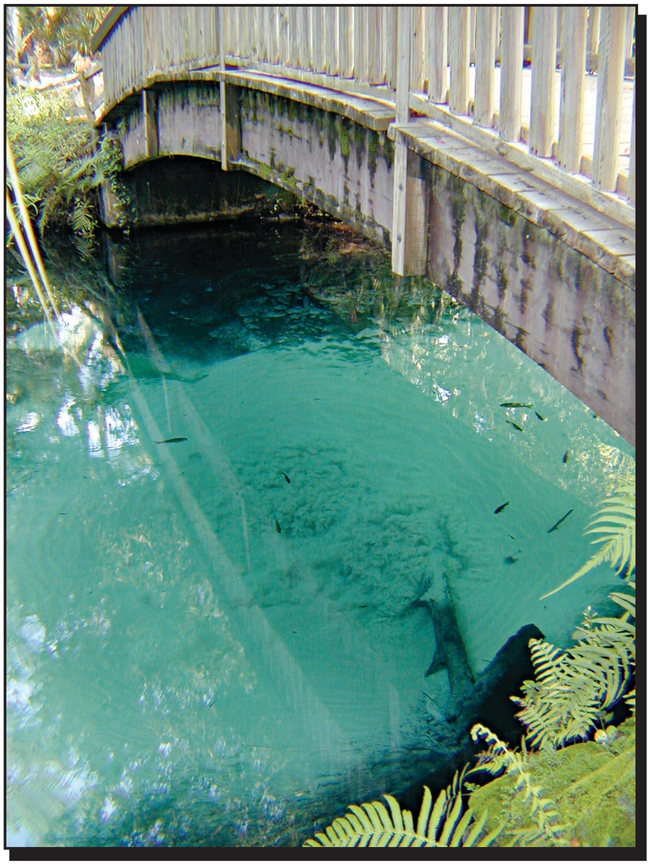


Figure 29. Large sand boil at Fern Hammock Springs that was sampled for this study. Photograph by L. Knowles, Jr., March 29, 2007.

Land Use

Land-use data for the Fern Hammock springshed were not available at the time of this study. Based on personal observations of the Fern Hammock springshed, land use from 1973 to 2004 was estimated to be relatively unchanged, and consisted mostly of forestland, some open-water surface/wetlands, and lesser areas of non-forested/barren land with small tracts for urban/mining/transportation/recreation mostly near the spring head. A few existing septic systems are the only means of wastewater treatment and disposal in the Fern Hammock springshed.

Figure 28. Main pool of Fern Hammock Springs. Photograph by L. Knowles, Jr., March 29, 2007.

Discharge

Discharge at Fern Hammock Springs was measured by the USGS from 1935 to 1984, and by the SJRWMD from 1985 to the present. At the time of this study, the USGS and SJRWMD jointly measured discharge of Fern Hammock Springs at least once per month. Discharge for Fern Hammock Springs averaged 13.0 ft^3/s annually, and varied with rainfall that averaged 49.33 in/yr within the springshed (fig. 30). Average annual discharge for Fern Hammock Springs ranged from 9.3 ft^3/s in 2000 to 19.9 ft^3/s in 1936. Measured (instantaneous) discharge for Fern Hammock Springs averaged 12.7 ft^3/s and ranged from 9.3 ft^3/s in May 2000 to 19.9 ft^3/s in September 1936 (fig. 31).

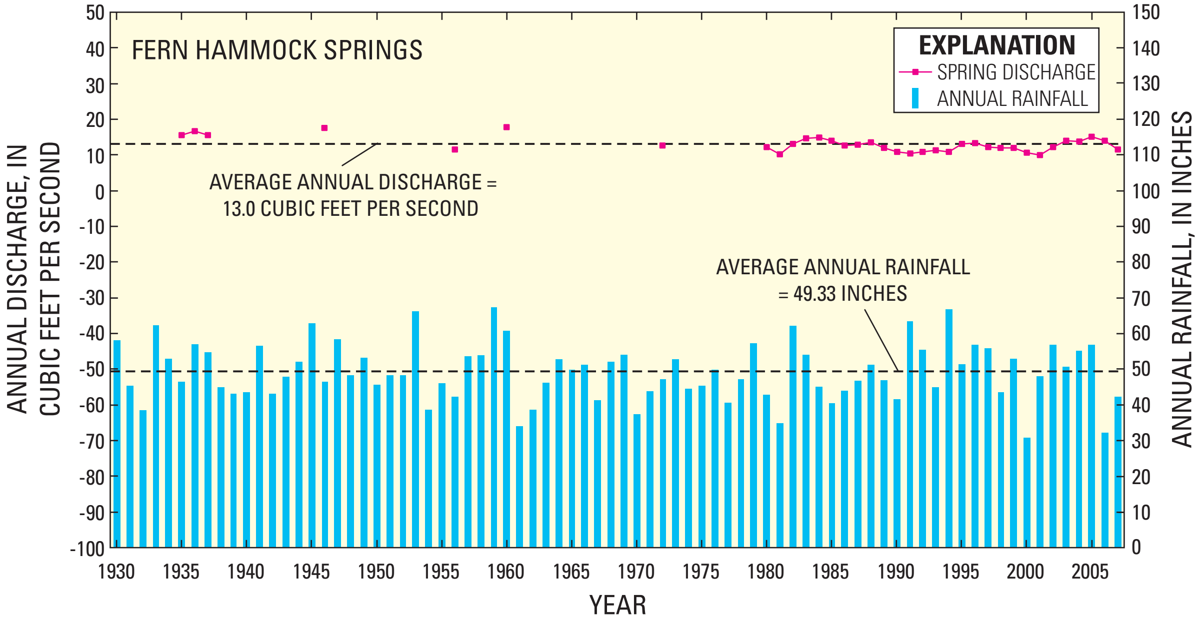


Figure 30. Average annual discharge for Fern Hammock Springs and rainfall for the Fern Hammock springshed.

Water Chemistry and Age

Fern Hammock Springs was sampled once per year by the USGS in 1972 and 1980, with periodic field measurements made from 1980 to the present. The SJRWMD has sampled the spring quarterly from 1985 to 2005, and at the time of this study, sampled the spring four times per year.

Fern Hammock Springs has a Ca-Mg-HCO_3 water type (fig. 9) and is undersaturated with respect to calcite and dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids were 8.2, 6.2 mg/L, and 68 mg/L, respectively. The ^3H concentration was reported as greater than 2.3 TU by Toth (2003). Delta ^{18}O and ^2H values plot along the GMWL (Toth, 2003), indicating that isotopic fractionation of rain water during recharge was not occurring.

Nitrate-N concentrations from 1990 to 2006 generally were uniform and less than 0.2 mg/L, although some recent spikes in concentration of up to 0.4 mg/L have been observed (fig. 10). Nitrate-N concentrations showed a significant ($p < 0.02$) increasing trend with time from 1972 to 2007 (table 6). Phosphorus (total P) concentrations generally were uniform, averaging approximately 0.02 mg/L during 2004-07 (fig. 11). Concentrations of dissolved nitrogen and argon in water samples from Fern Hammock Springs were consistent with atmospheric equilibration during ground-water recharge with the addition of minor amounts of excess air. Values of delta ^{15}N (5.93 per mil) and delta ^{18}O (1.84 per mil) of nitrate in water samples collected in October 2006 did not indicate any isotopic fractionation. This result indicates that active denitrification likely was not occurring in the Upper Floridan aquifer in the vicinity of Fern Hammock Springs. Water samples collected from Fern Hammock Springs on October 19, 2006, were analyzed for antibiotics, and all compounds were below method reporting levels. Water samples collected from Fern Hammock Springs in October 2006 and March 2007 were analyzed for 64 organic chemicals commonly associated with wastewater sources, plus 52 pesticides. Tritethyl citrate (E0.1 µg/L) was the only compound detected and quantified in the October 2006 samples (app. 4). No pesticides were detected in samples from Fern Hammock Springs (app. 5).

Concentrations of ^3H, ^3He, and SF_6 measured in water samples from Fern Hammock Spring in 2006-07 can be described by a piston model curve, and the apparent springwater age ranged from 20 to 23 years (fig. 27). Fern Hammock Springs had a delta ^{13}C value of -8.4 per mil and a ^{14}C concentration of 26 pmc. Based on an adjusted initial value of ^{14}C using the Fontes and Garnier (1979) model, the age of the older fraction of water was approximately 2,000 years.

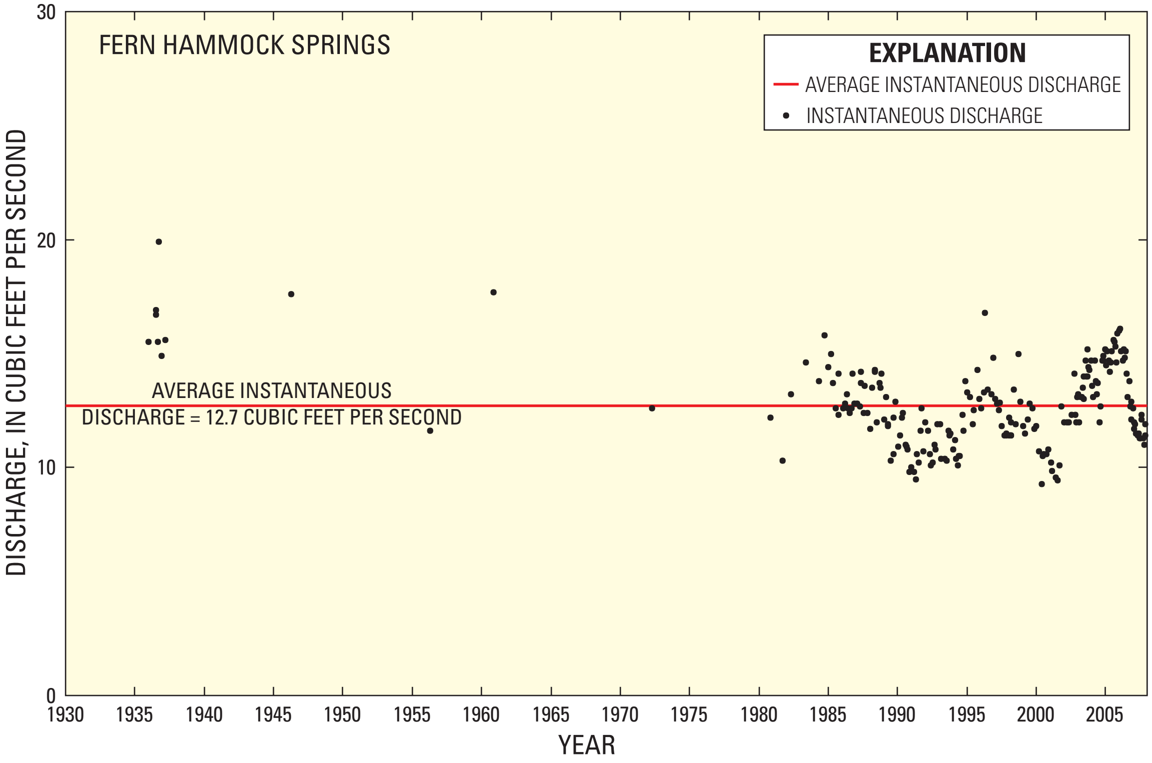


Figure 31. Periodic and continuous discharge data for Fern Hammock Springs, 1935-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

Gemini Springs

Gemini Springs (fig. 1, table 1) is a third-magnitude system (mean and median discharge 9.9 and 9.8 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004; Phelps and others, 2006). The springs consist of two primary vents (north and south) plus an additional vent and seepage from an adjacent hillside. Flows from the springs converge to form a run that is impounded by a low-head dam. Flow from the south boil emanates from a small cavern under a rock ledge about 3 ft below the water surface and forms a circular pool (pool 1). Discharge from the north vent emanates from a horizontal cavern opening in limestone rock and forms a circular pool (pool 2) about 15 ft in diameter. The cavern opening is about 6 ft high and 8 ft wide, with the cavern appearing to extend laterally underground to the north or northeast. Discharge from the north boil flows about 150 ft to the east-southeast and converges with the flow from the south boil at the west end of the reservoir. The reservoir is impounded on its east end by an earthen dam with a concrete weir outlet. Flow is through the weir and then to the east-northeast for about 150 ft through a marsh area to Lake Monroe. Collections of macroinvertebrates were made in sections of the run flowing from the north vent and adjacent to, and just downstream of, the south vent (Phelps and others, 2006). Substrate consisted primarily of sand, cobble, and submergent macrophytes, overlain with periphyton and filamentous algae in some areas. The areal extent of the Gemini springshed is 3.59 mi^2.

Land Use

Land use in the Gemini springshed changed considerably from 1973 to 2004. During this period, the areal extent of urbanized areas increased four-fold, open-water/wetland areas doubled in size, and forestland decreased 95 percent (fig. 4). Land use in the springshed in 1973 consisted of forestland (59.7 percent), open-water/wetlands (26.4 percent), urban/mining/transportation/recreation (9.4 percent), non-forested/barren land (2.4 percent), and agriculture (2.1 percent). Land use in the springshed in 2004 consisted of open-water/wetlands (54.7 percent), urban/mining/transportation/recreation (40.9 percent), forestland (3.0 percent), non-forested/barren land (0.8 percent), and agriculture (0.6 percent). As of 2004, two municipal sewer systems were the primary means of wastewater treatment and disposal in the Gemini springshed, replacing preexisting septic systems. Reclaimed wastewater is applied to 1.2 mi^2, or about a third of the land surface in the Gemini springshed.

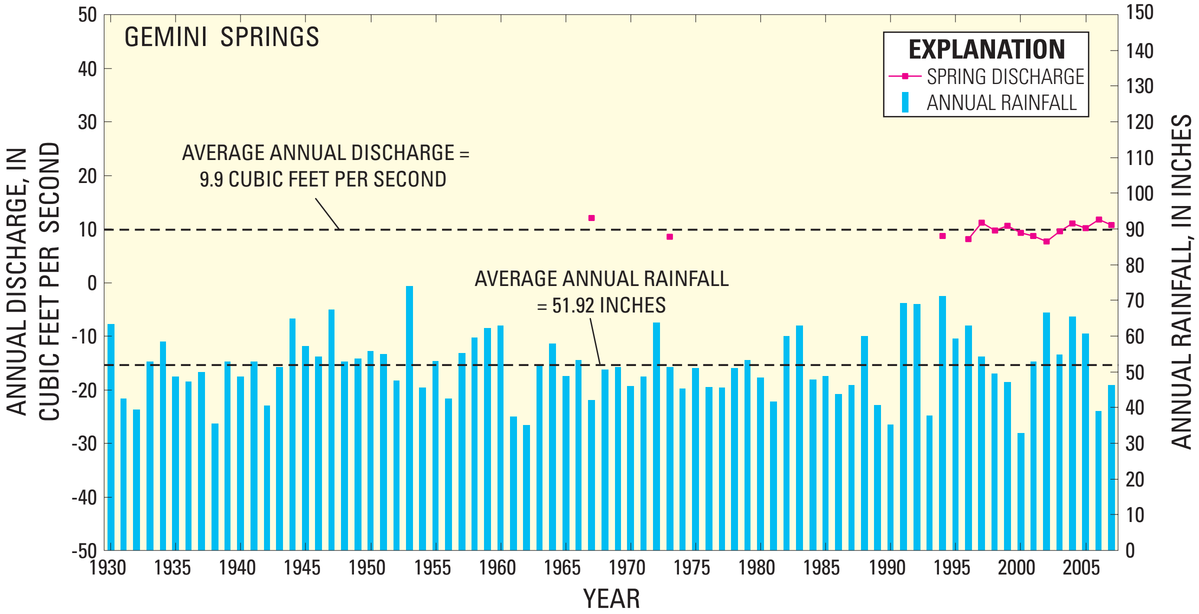


Figure 32. Average annual discharge for Gemini Springs and rainfall for the Gemini springshed.

Discharge

Discharge at Gemini Springs was measured by the USGS from 1966 to 1999, and has been measured by the SJRWMD since 1996; at the time of this study, measurements were made by the SJRWMD at least four times per year. Spring discharge is controlled mostly by the water level in the reservoir. Occasionally the stage is high enough in Lake Monroe or the St. Johns River to elevate the water level in the reservoir and results in a reduction in spring discharge. Discharge for Gemini Springs averaged 9.9 ft^3/s annually and varied with rainfall, which averaged 51.92 in/yr in the springshed (fig. 32). Average annual discharge for Gemini Springs ranged from 7.6 ft^3/s in 2002 to 12.0 ft^3/s in 1967. Measured (instantaneous) discharge for Gemini Springs averaged 10.1 ft^3/s and ranged from 6.2 ft^3/s in June 1995 to 15.3 ft^3/s in November 2005 (fig. 33).

Water Chemistry and Age

Gemini Springs has been sampled periodically by the USGS since 1972 and by the SJRWMD since 1986. At the time of this study, the SJRWMD sampled the spring four times per year. In 2006, the USGS sampled Gemini Springs for human antibiotics and hormones.

The north and south boils of Gemini Springs have a Na-Cl water type (fig. 9) and are undersaturated with respect to calcite and dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids in water from the north boil were 7.3, 1.0 mg/L, and 1,520 mg/L, respectively. Median values of pH, dissolved oxygen, and dissolved solids in water from the south boil were 7.2, 0.9 mg/L, and 1,570 mg/L, respectively. Values of ^{18}O and ^{2}H plotted along the GMWL or local MWL, parallel to the GMWL (Toth, 1999). The ^{3}H concentration was 3.3 TU (Toth, 1999). Only two water samples were collected from the north and south boils of Gemini Springs during 2004, and nitrate-N concentrations were about 1.0 mg/L. Concentrations of dissolved nitrogen and argon in water samples from Gemini Springs (both north and south boils) were consistent with atmospheric equilibration during ground-water recharge with the addition of minor amounts of excess air. Based on nitrogen and argon data in water samples collected in January, May, June, and August 2005, the calculated recharge temperature was 22 to 23°C (assuming a recharge elevation of 50 ft and 100-percent humidity at the water table). One water sample collected from the south boil at Gemini Springs in May 2004 (Phelps and others, 2006) had a slightly elevated dissolved nitrogen concentration (0.5 mg/L), indicating that some denitrification may have been occurring in the Upper Floridan aquifer in the vicinity of the south boil at Gemini Springs. Nitrite plus nitrate concentration within Gemini Springs run showed a significant increasing trend over time (table 6). Phosphorus (total P) concentrations were approximately 0.07 mg/L, based on two water samples collected in 2004 from the north and south boils.

Water samples collected from the north and south boils in May and August 2004 were analyzed for 64 organic chemicals commonly associated with wastewater sources, plus 52 pesticides. The following organic wastewater compounds were detected in water samples from the north boil: phenol (0.7 μg/L), benzophenone (E0.1 μg/L), DEET

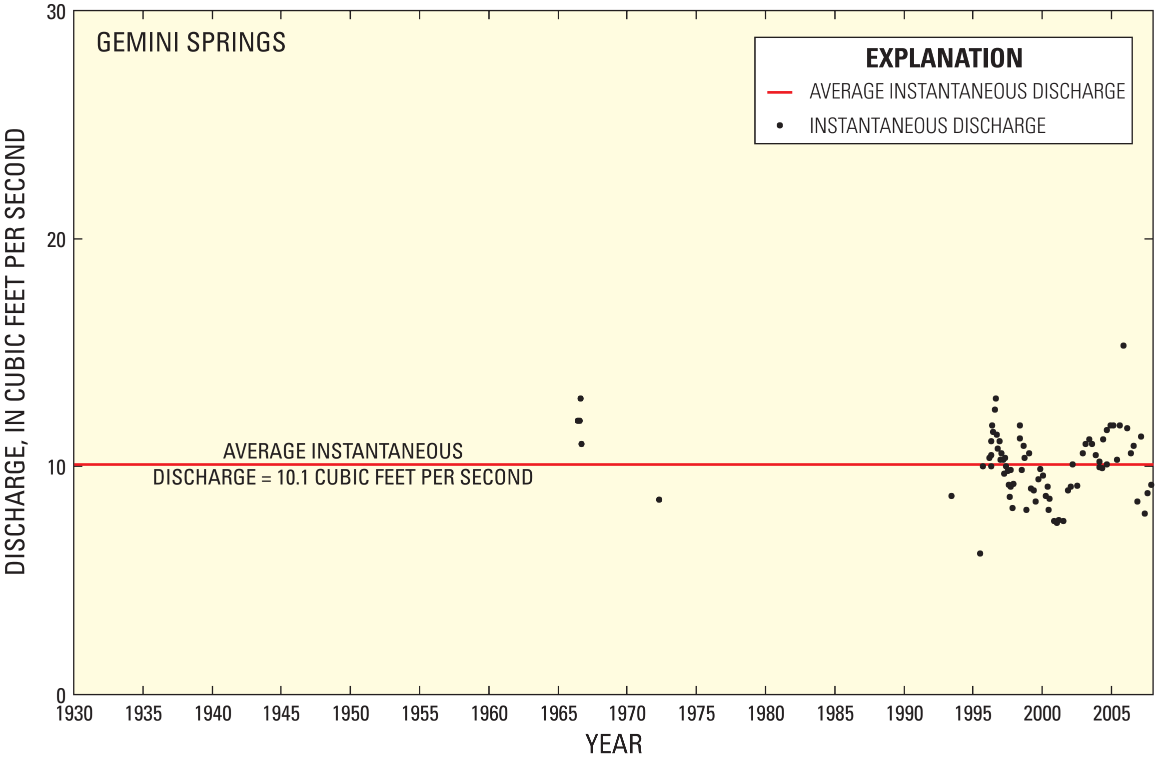


Figure 33. Periodic discharge data for Gemini Springs, 1966-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

(E0.1 µg/L), and triphenyl phosphate (E0.1 µg/L) (app. 4). The following compounds were detected in water samples from the south boil: benzophenone (E0.1 µg/L), DEET (E0.1 µg/L), and triphenyl phosphate (E0.1 µg/L) (app. 4). The following pesticides were detected in water samples from the north boil: atrazine (0.015-0.017 µg/L), and an atrazine degradate (2-chloro-4-isopropylamino-6-amino-s-triazine, CIAT) (E0.011-E0.012 µg/L) (app. 5). Both atrazine (0.013-0.019 µg/L) and CIAT (E0.010-E0.013 µg/L) also were detected in water samples from the south boil (app. 5).

The age of water from the north and south boils at Gemini Springs appeared to be young (less than 5 years) as indicated by SF_6 and ^3H concentrations that are similar to recent atmospheric concentrations. However, the high concentrations of SF_6 (10-12 pptv) in some of the 2005 samples greatly exceeded atmospheric levels and likely indicated contamination from non-atmospheric SF_6 sources, which render SF_6 concentrations unusable for age dating. Water samples also were collected for ^3H, ^{13}C, and ^{14}C in the spring discharge in May 1996, and for $^3H/^3He$ in August 1999. Gemini Springs had a ^3H concentration of 3.3 TU, which indicates that the younger fraction of water was less than 43 years old. The $^3H/^3He$ results indicate that the younger fraction of water from Gemini Springs was 19 years old. Gemini Springs had a delta ^{13}C value of –10.4 ppm and a ^{14}C concentration of 41 pmc, which indicates mixing of Upper and Lower Floridan aquifer water.

Gemini Springs run has a Na-Cl water type (fig. 9). Median values of pH, dissolved oxygen, and dissolved solids were 7.4, 3.2 mg/L, and 1,420 mg/L, respectively (table 3). Nitrate concentrations from 1995 to 2007 showed large fluctuations (0.05-2.2 mg/L, median 0.91 mg/L) (fig. 16). Phosphorus concentrations ranged from 0.06 to 0.18 mg/L during 1999-2007, with a median concentration of 0.08 mg/L (fig. 17).

Aquatic Communities

General descriptions of aquatic macroinvertebrate and fish assemblages of Gemini Springs are presented in Phelps and others (2006). Prior to that report, macroinvertebrates were enumerated but oligochaetes and most dipterans (Chironomidae) were not identified beyond family or higher level taxonomic categories. These specimens were subsequently identified to species or lowest practicable identification level. The macroinvertebrate data were, therefore, reanalyzed and are reported here in greater detail.

Table 16. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Gemini Springs, February-August 2004.

[LPIL, lowest practicable identification level]

Turbellaria	Tricladida (LPIL)	158	6.4	144	3.1	72	4.1
	Turbellaria (LPIL)			14	0.3		
Gastropoda	Ancylidae (LPIL)	14	0.6				
	Haitia sp.	43	1.7				
	Hydrobiidae (LPIL)	14	0.6	101	2.2	489	27.9
Hirudinea	*Gloiobdella elongata*	43	1.7	14	0.3	14	0.8
	Helobdella fusca	14	0.6				
	Helobdella sp.	29	1.2				
	Helobdella stagnalis	43	1.7				
	Helobdella triserialis	29	1.2				
	Myzobdella lugubris	29	1.2	101	2.2		
Oligochaeta	*Dero digitata* complex			14	0.3		
	Dero sp.					14	0.8
	Dero trifida					86	4.9
	Eclipidrilus palustris	14	0.6				
	Eclipidrilus sp.			14	0.3		
	Limnodrilus hoffmeisteri	216	8.7	848	18.4	474	27.1
	tubificoid Naididae immature sp. A (LPIL)	144	5.8	1,595	34.7	259	14.8
Amphipoda	*Gammarus* cf. *tigrinus* LeCroy	1,537	62.2	1,451	31.6	259	14.8
	Hyalella azteca complex Lecroy			302	6.6	14	0.8
Isopoda	*Caecidotea* sp.	43	1.7				
Diptera	*Chironomus decorus* group Epler	43	1.7			14	0.8
	Chironomus sp.	57	2.3			57	3.3

A total of 23 macroinvertebrate taxa were collected by petite ponar dredge from Gemini Springs across three sampling dates (table 16). The number of taxa collected with this gear ranged from 11 in May and August 2004 to 17 in February 2004. The total numbers of organisms collected in February and August were considerably lower than the number collected in May. Pooled samples across all dates were dominated by oligochaetes (41.7 percent; mostly tubificoid Naididae immature sp. A and *Limnodrilus hoffmeisteri*), amphipods (40.4 percent, *Gammarus* cf. *tigrinus* complex and *Hyalella azteca* complex), gastropods (7.5 percent, mostly hydrobiids), and turbellarians (4.4 percent). Density of all organisms ranged from 1.8×10^3 per m^2 (18.9×10^3 per ft^2) in August 2004 to 4.6×10^3 per m^2 (49.5×10^3 per ft^2) in May 2004. For petite ponar samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.26 to 2.63, Simpson's index of diversity ranged from 0.59 to 0.80, Pielou's evenness ranged from 0.55 to 0.76, and the Florida Index ranged from 1 to 2 with a mean of 1.3 (table 4).

Table 17. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Gemini Springs, February-August 2004.

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Turbellaria	Tricladida (LPIL)	10	9.1	1	0.9		
Gastropoda	*Haitia* sp.			1	0.9	1	0.9
	Hydrobiidae (LPIL)	12	10.9	16	14.5	41	37.3
	Planorbella scalaris					1	0.9
Hirudinea	*Helobdella* sp.					1	0.9
Oligochaeta	*Dero digitata* complex			10	9.1		
	Eclipidrilus palustris			3	2.7		
	Eclipidrilus sp.	1	0.9				
	Limnodrilus hoffmeisteri	6	5.5	19	17.3		
Amphipoda	*Gammarus cf. tigrinus* LeCroy			6	5.5	65	59.1
	Gammarus mucronatus complex LeCroy	77	70.0				
	Hyalella azteca complex LeCroy	3	2.7	27	24.5	1	0.9
Decapoda	*Procambarus* sp. (immature)	1	0.9				
Diptera	Ceratopogonidae (LPIL)			8	7.3		
	Chironomus sp. A Line			5	4.5		
	Culicoides group Brigham			3	2.7		
	Goeldichironomus holoprasinus			7	6.4		
	Larsia decolorata			1	0.9		
	Tanytarsus sp. V Epler			3	2.7		

A total of 19 macroinvertebrate taxa were identified in subsamples collected by dip net from Gemini Springs (table 17); the number of taxa ranged from 6 in August 2004 to 14 in May 2004. The overall composition of organisms in samples collected by dip nets was similar to the composition of samples collected by petite ponar dredge. Specifically, the dip net samples were dominated by amphipods (54.2 percent) and gastropods (21.8 percent), but dipterans constituted a slightly greater proportion (8.2 percent). For dip net samples collected across all dates, the $\log_2$ Shannon-Wiener index ranged from 1.23 to 3.22, Simpson's index of diversity ranged from 0.52 to 0.87, Pielou's evenness ranged from 0.47 to 0.85, the SCI ranged from 8 to 13 with a mean of 10, and percent very tolerant taxa ranged from 2.7 to 39.1 (table 5).

The fish community of Gemini Springs was summarized by Phelps and others (2006), who recorded a total of 11 species by visual survey of the impounded spring pool. Crayfish traps were relatively inefficient at capturing fish, but a moderate number of *Fundulus seminolis* and *Lucania goodei* were collected with this gear. In the qualitative visual surveys, other native species observed, all in relatively low abundance, included *Gambusia holbrooki*, *Micropterus salmoides*, *Lepomis macrochirus*, *L. microlophus*, and *Dorosoma cepedianum*. Three nonindigenous fish species were observed: *Cyprinus carpio*, *Oreochromis aureus*, and *Pterygoplichthys disjunctivus*. Of the nonindigenous species, *C. carpio* is unknown to be established in the St. Johns River drainage.

Green Spring

Green Spring (fig. 1) is a third-magnitude spring (mean and median discharge both 1.1 ft^3/s) (Rosenau and others, 1977; Scott and others, 2004; Phelps and others, 2006). Green Spring discharges from a 125-ft deep, conical limestone vent into a nearly circular pool about 90 ft in diameter. Water in the pool generally is milky green with poor visibility of less than 0.5 ft; however, the water occasionally becomes clear with visibility of 10 ft or more, as observed during a visit on June 14, 2006. An eastward extension of the pool is bordered on the north and east by a concrete retaining wall where a shallow run from 3 to 6 ft wide begins. The run flows toward the southeast for about 200 ft and discharges into a small creek that flows south for about 0.25 mi and discharges into Lake Monroe. Sampling of the macroinvertebrate fauna was conducted at three sites within the spring run. The substrate consisted of detritus and leaf packs with submergent and emergent macrophytes covered by cyanobacteria. The areal extent of the Green springshed is 1.79 mi^2.

Land Use

Urbanization of the Green springshed from 1973 to 2004 replaced much of the forestland urban and open-water/wetland areas (fig. 4). Forestland only remains around the immediate vicinity of Green Spring. Land use in the springshed in 1973 consisted of urban/mining/transportation/recreation (58.1 percent), open-water/wetlands (24.0 percent), forestland (17.7 percent), non-forested/barren land (0.2 percent), and agriculture (less than 0.1 percent). Springshed land use in 2004 consisted of urban/mining/transportation/recreation (68.4 percent), open-water/wetlands (29.9 percent), forestland (1.7 percent), non-forested/barren land (less than 0.1 percent), and agriculture (less than 0.1 percent). As of 2005, two municipal sewer systems, currently the primary means of wastewater treatment and disposal, had replaced septic systems in the Green springshed. Reclaimed wastewater is applied to 0.39 mi^2 of the land surface in the springshed.

Discharge

Discharge at Green Spring has been measured periodically by the USGS since 1932. The SJRWMD has been measuring discharge since 1995, and at the time of this study, measured discharge at least monthly. Discharge for Green Spring averaged 1.1 ft^3/s annually and varied with rainfall that averaged 51.92 in/yr within the springshed (fig. 34). Average annual discharge for Green Spring ranged from 0.0 ft^3/s (no flow) in 1981 and 2001 to 3.6 ft^3/s in 2006. Measured (instantaneous) discharge for Green Spring averaged 1.4 ft^3/s and ranged from 0.0 ft^3/s in April 1981, June-July 2000, and January-July 2001 to 3.6 ft^3/s in February 2006 (fig. 35).

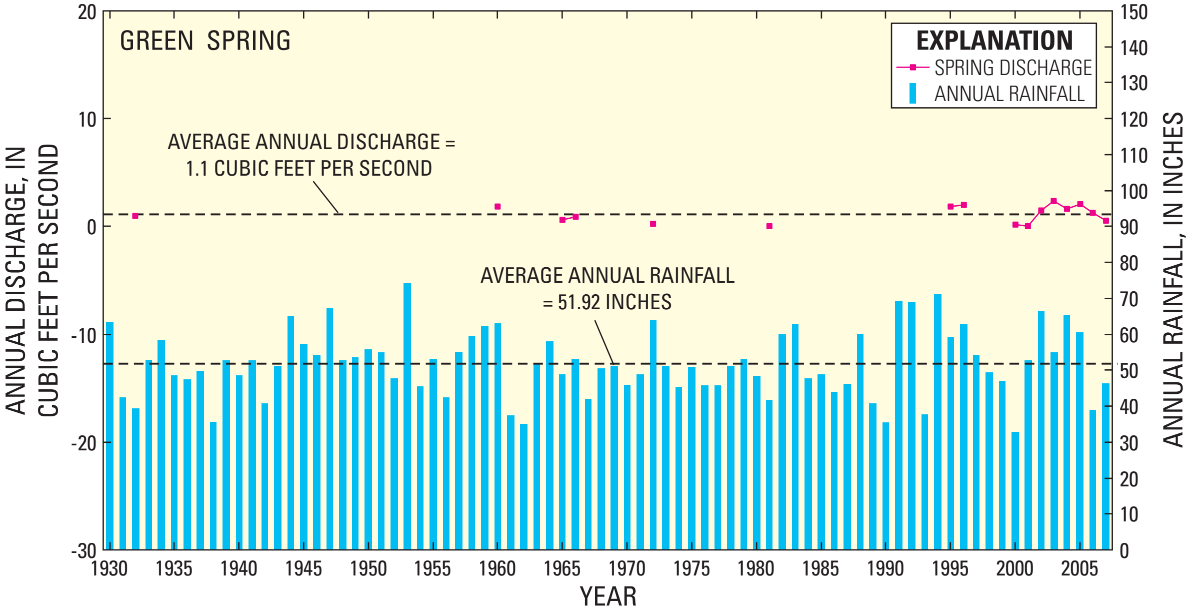


Figure 34. Average annual discharge for Green Spring and rainfall for the Green springshed.

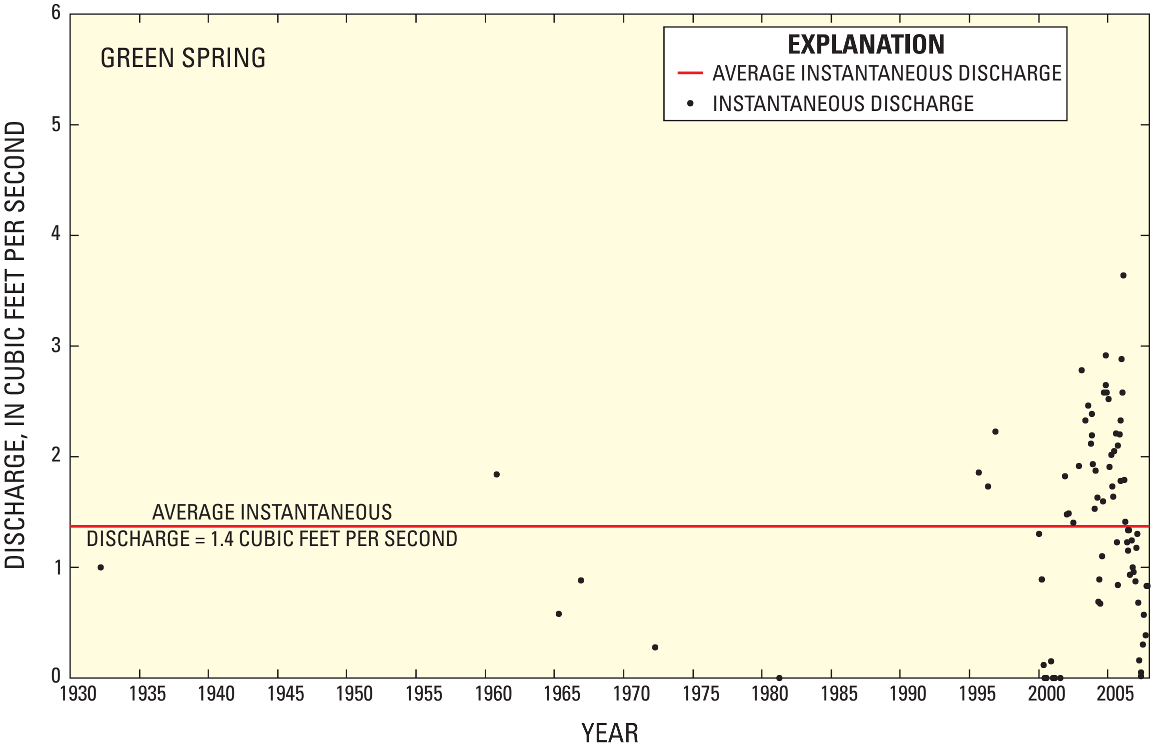


Figure 35. Periodic discharge data for Green Spring, 1932-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

Water Chemistry and Age

Green Spring was first sampled by the USGS in 1972, and was sampled frequently by the SJRWMD from 1995 to 2005, including at least four times per year during this study. In 2006, the USGS sampled Green Spring for human antibiotics and hormones.

Green Spring has a Na-Cl water type (fig. 9) and is slightly undersaturated with respect to calcite and dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids in water were 7.4, 0.4 mg/L, and 1,500 mg/L, respectively. Spring water had a ^{3}H concentration greater than 2.3 TU and a slightly enriched ^{18}O and ^{2}H composition that plots along an evaporation trend line for lakes (Toth, 2003). Water samples collected from Green Spring since May 1996 generally had nitrate-N concentrations less than 0.06 mg/L, with the exception of a January 2001 sample that had a nitrate-N concentration of 0.16 mg/L (fig. 16).

Concentrations of dissolved nitrogen and argon in water samples from Green Spring (January, May, June 2005) were consistent with atmospheric equilibration during groundwater recharge with the addition of minor amounts of excess air. However, dissolved gas analyses of water samples collected in May and August 2004 (Phelps and others, 2006) and August 2005 indicated a slight excess of dissolved nitrogen (0.5-1.0 mg/L), which indicates that denitrification likely was occurring in the Upper Floridan aquifer in the vicinity of Green Spring during those time periods. Based on nitrogen and argon data in water samples collected in 2004-05 (Phelps and others, 2006), the calculated recharge temperature was 22 to 23°C (assuming a recharge elevation of 60 ft and 100-percent humidity at the water table). Dissolved phosphorus (total P) concentrations in water samples collected from January 2001 to August 2007 ranged from 0.06 to 0.15 mg/L (fig. 17).

Water samples collected from Green Spring in May and August 2004 were analyzed for 64 organic chemicals commonly associated with wastewater sources, plus 52 pesticides. The following compounds were detected in water samples from Green Spring: phenol (E0.2 µg/L, E0.3 µg/L), benzophenone (E0.1 µg/L), and DEET (E0.2 µg/L) (app. 4). No pesticides were detected in water samples from Green Spring (app. 5).

Water from Green Spring was estimated to be about 20 years in age, based on concentrations of SF_6, ^{3}H, and ^{3}He. Concentrations of SF_6 in the two samples collected in January and May 2005 varied considerably (2.5-4.7 pptv); the higher concentration may indicate some contamination occurred during sampling.

Table 18. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Green Spring, February-August 2004.

[LPIL, lowest practicable identification level]

Gastropoda	Hydrobiidae (LPIL)					201	1.0
Oligochaeta	*Dero digitata*			230	5.2	144	0.7
	Dero digitata complex			29	0.7	115	0.6
	Dero furcata					14	0.1
	Dero sp.					14	0.1
	Dero trifida			115	2.6	57	0.3
	Dero vaga					14	0.1
	Eclipidrilus palustris					14	0.1
	Haemonais waldvogeli					29	0.1
	Limnodrilus hoffmeisteri	29	25.2	704	16.0	4,626	22.4
	tubificoid Naididae immature sp. A (LPIL)	72	62.6	2,500	56.9	14,325	69.4
Amphipoda	*Hyalella azteca* complex Lecroy			115	2.6	14	0.1
Diptera	*Bezzia/Palpomyia* complex Brigham			14	0.3		
	Ceratopogonidae (LPIL)					805	3.9
	Chironomini (LPIL)			14	0.3		
	Chironomus decorus group Epler			14	0.3		
	Chironomus sp.	14	12.2	129	2.9	43	0.2
	Chironomus sp. A Line			115	2.6	43	0.2
	Culicoides group Brigham			72	1.6	101	0.5
	Goeldichironomus holoprasinus			273	6.2	57	0.3
	Goeldichironomus sp.			72	1.6		
	Larsia sp.					14	0.1

Aquatic Communities

General descriptions of the aquatic macroinvertebrate and fish assemblages of Green Spring were presented in Phelps and others (2006). Prior to that report, macroinvertebrates were enumerated, but oligochaetes and dipterans (Chironomidae and Ceratopogonidae) were not identified beyond family or higher level taxonomic categories. These specimens were subsequently identified to species or lowest practicable identification level. The macroinvertebrate data were, therefore, reanalyzed and are reported here in greater detail.

A total of 22 macroinvertebrate taxa were collected by petite ponar dredge from Green Spring across three sampling dates (table 18). The number of taxa collected with this gear ranged from 3 in February 2004 to 18 in August 2004. The number of taxa and density of organisms in pooled samples varied considerably among the collection dates. This result may indicate variation in sampling efficiency of the petite ponar grabs, patchiness of the benthic fauna, and/or seasonal variation; the very low number of organisms collected in February 2004 was likely the result of ineffective grabs. Pooled samples across all dates were dominated by oligochaetes (91.6 percent; consisting of no fewer than seven and possibly as many as nine taxa), with dipterans constituting 7.1 percent of the remaining organisms; the only other taxon collected with this gear consisted of one amphipod (*Hyalella azteca* complex) and unidentified hydrobiid snails. Density of all organisms ranged from 115 per m^2 (1,238 per ft^2) in February 2004 to 20.6 × 10^3 per m^2 (222.1 × 10^3 per ft^2) in May 2004. For petite ponar samples pooled across all dates, the log$_2$ Shannon-Wiener index ranged from 1.29 to 2.21, Simpson's index of diversity ranged from 0.47 to 0.64, and Pielou's evenness ranged from 0.33 to 0.82; the Florida index was zero on all dates (table 4).

Table 19. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Green Spring, February-August 2004.

[Values represent material as subsampled to obtain target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Gastropoda	*Haitia* sp.			1	1.1		
	Hydrobiidae (LPIL)			1	1.1	1	0.9
Oligochaeta	*Dero digitata* complex			4	4.5	1	0.9
	Dero trifida	1	0.9	5	5.6		
	Eclipidrilus palustris	1	0.9			1	0.9
	Limnodrilus hoffmeisteri	35	31.8	19	21.3	27	24.5
Amphipoda	*Hyalella azteca* complex LeCroy	7	6.4	26	29.2	71	64.5
Decapoda	*Procambarus* sp. (immature)			1	1.1		
Coleoptera	Chrysomelidae (LPIL)					1	0.9
Diptera	*Bezzia/Palpomyia* complex Brigham			1	1.1		
	Ceratopogonidae (LPIL)	29	26.4	7	7.9		
	Chironomus decorus group Epler	1	0.9				
	Chironomus sp. A Line	20	18.2	2	2.2		
	Culicoides group Brigham	14	12.7	7	7.9		
	Einfeldia sp. A Epler			1	1.1		
	Ephydridae (LPIL)			1	1.1		
	Goeldichironomus holoprasinus			7	7.9		
	Goeldichironomus sp.	2	1.8				
	Larsia decolorata			1	1.1		
	Polypedilum tritum					1	0.9
	Ptychoptera sp.			1	1.1		
	Stratiomys sp.					4	3.6
	Tanytarsus sp. V Epler			2	2.2	2	1.8
Hemiptera	*Belostoma* sp.					1	0.9
	Lethocerus sp.			2	2.2		

[1] Failed to obtain target number of subsampled organisms (100-110) during sorting process.

A total of 25 macroinvertebrate taxa were identified in subsamples of dip net collections from Green Spring, ranging from 9 in February 2004 to 18 in May 2004 (table 19). Subsampling of the May dip net collection failed to obtain the target number (110) of organisms, even though the May collection had the greatest taxonomic richness by season. The lower number of taxa collected by dip net in February corresponded to a lower number also collected in the petite ponar samples, thus suggesting a possible seasonal difference in the assemblage composition. Dip net collections differed notably from petite ponar dredge samples in percent composition of subsampled organisms. Dip net subsamples combined for all dates were more evenly represented by amphipods (33.7 percent; *Hyalella azteca* complex), dipterans (33.3 percent; no fewer than 13 total taxa, greatest richness in May with 10 taxa), and oligochaetes (30.4 percent). For dip net samples across all dates, the $\log_2$ Shannon-Wiener index ranged from 1.55 to 3.25, Simpson's index of diversity ranged from 0.53 to 0.85, Pielou's evenness ranged from 0.47 to 0.78, the SCI ranged from 6 to 15 with a mean of 9, and percent very tolerant taxa ranged from 26.3 to 53.6 (table 5).

Phelps and others (2006) reported that Green Spring has relatively low fish diversity and abundance; the only species observed were the poeciliids *Gambusia holbrooki* and *Poecilia latipinna*, which were present in moderate abundance near the shoreline of the spring pool. Crayfish traps submerged near the edges of the spring pool captured few fish. Although Phelps and others (2006) speculated that other species could be present (such as other poeciliids, centrarchids, cyprinids, or ictalurids), the spring depth, nearly vertical walls of the spring pool, and low water clarity prevented any other practical means of effective sampling. No fish were observed or collected in the spring run. The isolated nature of the spring and unusual water chemistry (very low dissolved O_2 and high H_2S concentrations) are likely limiting factors responsible for the depauperate fish fauna.

Juniper Springs

Juniper Springs (fig. 1), located in the Ocala National Forest, is a second-magnitude spring (mean and median discharge 10.8 and 10.9 ft^3/s, respectively) and forms an oval-shaped pool that measures about 120 by 90 ft (Rosenau and others, 1977; Scott and others, 2004). Multiple vents are present on the pool bottom; the substrate is sand, limestone bedrock is exposed near the vents, and scattered patches of aquatic macrophytes are present. The clear, bluish water has a lower dissolved solids concentration than most other Florida springs. The largest vent, which was sampled for this study, is located on the east side of the pool next to a limestone retaining wall that surrounds most of the pool. A historical millhouse and spillway are located on the east side of the pool. The pool drains into the spring run, Juniper Creek, which meanders to the east-northeast through the Juniper Prairie Wilderness area of Ocala National Forest for about 10 mi, where it discharges into Lake George on the St. Johns River. Fern Hammock Springs is located about 0.25 mi downstream from Juniper Springs.

Near its headwaters, Juniper Creek historically had numerous additional small boils. Most of the sand boils located in the run downstream of the pool disappeared during this study as a result of pumping sand that had filled in the main spring vents over a 20-year period. In early 2006, spring boils had begun to undercut the banks, threatening to undermine the millhouse and create a safety risk. Therefore, in late 2006 the U.S. Forest Service had the sand pumped from the spring vents, which had become boils themselves, in the pool area to reduce the pressure head on the spring system. After nearly 20 ft of sand was pumped from each of two vents in the pool area, hydrostatic pressure on the system was reduced enough to eliminate many of the boils in the spring run immediately downstream of the pool. The areal extent of the Juniper springshed has not been determined.

Land Use

Land-use data for the Juniper springshed were estimated based on observations made during this study. Because the spring is located deep within the Ocala National Forest, land use in the springshed during 1973-2004 was considered to be unchanged, and consisted mostly of forestland, some open-water/wetlands, and lesser areas of non-forested/barren land with small tracts for urban/mining/transportation/recreation mainly near the spring head. A few existing septic systems are the only means of wastewater treatment and disposal in the springshed.

Discharge

Discharge at Juniper Springs has been measured by the USGS and the SJRWMD since 1908 and 1983, respectively. At the time of this study, the USGS and SJRWMD jointly measured the discharge of Juniper Springs at least monthly. Discharge for Juniper Springs averaged 10.5 ft^3/s annually and varied with rainfall that averaged 49.33 in/yr within the springshed (fig. 36). Average annual discharge for Juniper Springs ranged from 6.0 ft^3/s in 1931 to 14.1 ft^3/s in 1946. Measured (instantaneous) discharge from Juniper Springs averaged 10.7 ft^3/s, and ranged from 5.6 ft^3/s in May 1991 to 16.3 ft^3/s in July 1936 (fig. 37). Upper Floridan aquifer pumping for water supply at the Juniper Springs Recreation Area has an unknown effect on spring discharge.

Water Chemistry and Age

Juniper Springs has a $Ca\text{-}Mg\text{-}HCO_3$ water type (fig. 9) and is slightly undersaturated with respect to calcite and dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids in spring water were 8.4, 6.6 mg/L, and 66 mg/L, respectively. Values of ^{18}O and ^{2}H plot along the GMWL or local MWL parallel to the GMWL (Toth, 1999). The delta ^{34}S concentration was 17.0 ppm, similar to that for modern sulfate evaporite minerals, and the ^{3}H concentration was 4.2 TU (Toth, 1999).

Nitrate-N concentrations from 1990 to 2006 generally were uniform and less than 0.2 mg/L, but recent spikes in concentration of up to 0.5 mg/L have occurred (fig. 10). Nitrate-N concentrations showed a significant ($p < 0.04$) increasing trend with time for samples collected during 1984-2007 (table 6). Concentrations of dissolved nitrogen and argon in water samples from Juniper Springs were consistent with atmospheric equilibration during ground-water recharge with the addition of minor amounts of excess air. Based on nitrogen and argon data in water samples collected in October 2006 and March 2007, the calculated recharge temperature was 20 to 21°C (assuming a recharge elevation of 80 ft and 100 percent humidity at the water table). Values of delta ^{15}N (5.35 per mil) and delta ^{18}O (1.34 per mil) of nitrate in water samples collected in October 2006 did not indicate any isotopic fractionation; therefore, active denitrification likely was not occurring in the Upper Floridan aquifer in the vicinity of Juniper Springs. Phosphorus (total P) concentrations in water samples collected during 2004-07 were uniformly low, averaging approximately 0.02 mg/L (fig. 11).

Water samples collected from Juniper Springs in October 2006 and March 2007 were analyzed for 64 organic chemicals commonly associated with wastewater sources, plus 52 pesticides. Triethyl citrate (E0.1 µg/L) was the only compound detected and quantified in the October 2006 water sample (app. 4). No pesticides were detected in water samples from Juniper Springs (app. 5). Water samples collected from Juniper Springs on October 19, 2006, were analyzed for antibiotics and all compounds were below method reporting levels.

Based on concentrations of CFCs in water samples collected from Juniper Springs in 2001, the age of spring water likely indicates a mixture of water recharged during 1980-90 with 60 to 80 percent of old (greater than 60 years) tracer-free water (Toth and Katz 2006). Water samples also were collected in April 1996 and analyzed for ^{3}H, delta ^{13}C, and ^{14}C. Juniper Springs had a ^{3}H concentration of 4.2 TU, which indicated that the age of water was less than 43 years. Juniper Springs had a delta ^{13}C of –9.5 per mil and a ^{14}C concentration of 31 pmc. The adjusted ^{14}C age is recent, and recharge likely occurred after about 1960.

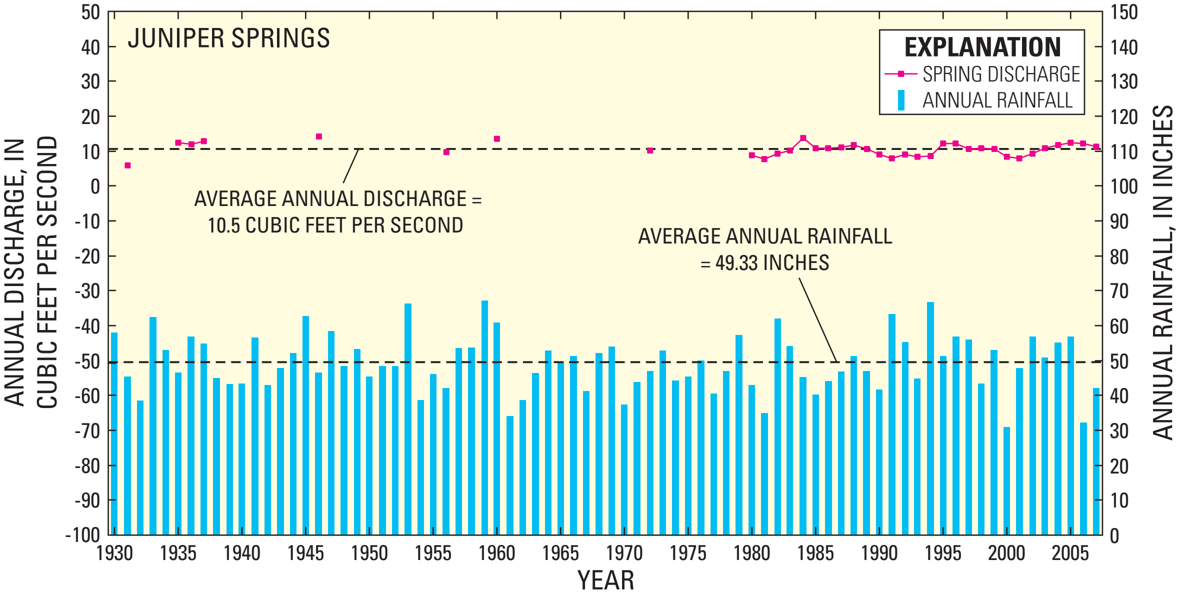


Figure 36. Average annual discharge for Juniper Springs and rainfall for the Juniper springshed.

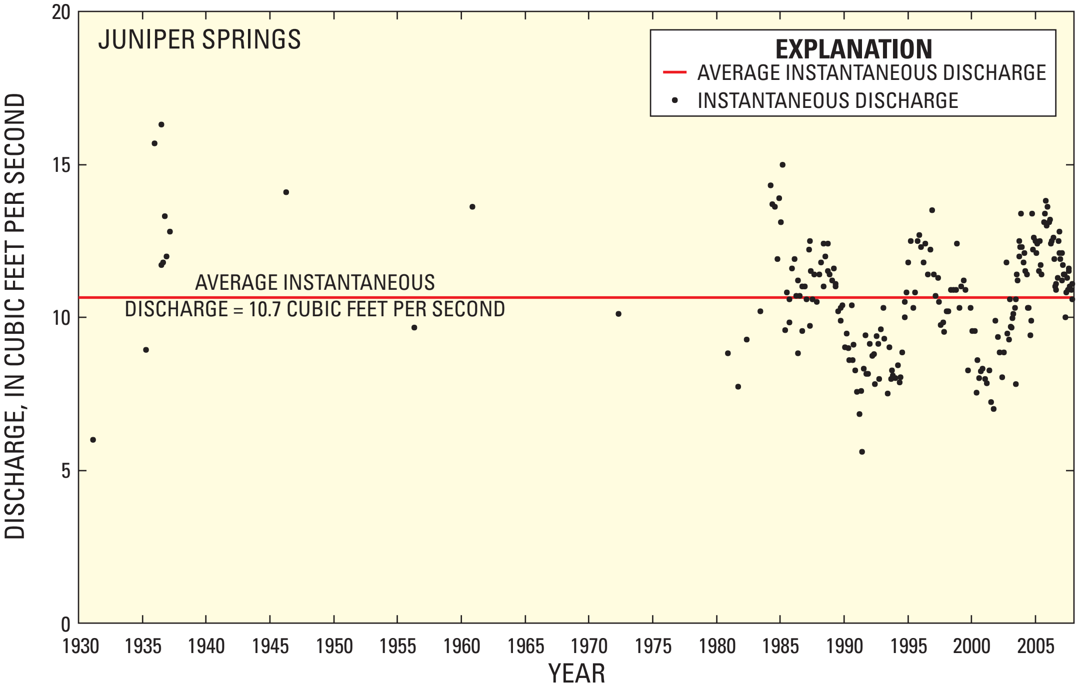


Figure 37. Periodic and continuous discharge data for Juniper Springs, 1931-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

Rock Springs

Rock Springs (figs. 1, 38, 39, table 1) is a second magnitude spring (mean and median annual discharge 59.3 and 58.5 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004). The spring is a popular recreational site, and the spring run is used extensively by swimmers, snorkelers, and tubers. Spring water discharges from two partly submerged caves at the base of a 20-ft limestone and sand bluff (fig. 38). Clear, bluish water discharges from the caves with considerable velocity and has substantially eroded the limestone along the initial part of the spring run. In contrast to most large springs in peninsular Florida, Rock Springs has no well-defined large pool at the spring head. About 10 ft downstream from the cavern opening, additional water is discharged through a submerged opening in the channel bottom. Rock ledges protrude from the banks of the run for about 100 ft downstream of the cavern opening. A boardwalk spans the spring run about 120 ft downstream from the cavern. About 1,000 ft downstream from the spring cavern, part of the spring flow is diverted from the spring run into a large swimming area mostly surrounded by concrete retaining walls (fig. 39). Overflow from the swimming area rejoins the run after passing through a concrete weir. The areal extent of the Rock springshed is 16.8 mi^2.

Macroinvertebrate samples were taken from several distinctly different sites in Rock Springs run to characterize, to the maximum extent possible, the fauna influenced by the spring outflow. The uppermost site was sampled between 30 and 150 ft downstream of the cavern opening, where the substrate consisted of bare and periphyton-encrusted rock, mixed gravel, sand, crushed fossil shells, organic detritus and leaf pack, and rooted macrophytes (*Valisneria*). Along the middle reach, samples were collected near the swimming and picnic area on the east shoreline, and in the channelized sections just upstream of the swimming pool, in locations with minimal human disturbance. The substrate in these areas consisted of coarse sand, cobble, bare rock, snags, filamentous algae, and submergent, emergent, and floating macrophytes. The third sampling site was near the downstream boundary of the park, along a reach between 10 and 75 ft upstream of the boardwalk that spans the spring run. Substrate along this reach consisted of sand, submergent and floating macrophytes, snags, and detritus, with minimal algae cover due to moderate flow velocities caused by narrow channel morphology.

Land Use

Land use in the Rock springshed from 1973 to 2004 shifted primarily from open-water/wetlands to non-forested/barren and urban lands, probably as a result of enhanced drainage and consequent drying of the land surface (fig. 4). Land use in the springshed in 1973 consisted of open-water/wetlands (60.5 percent), urban/mining/transportation/recreation (26.9 percent), and non-forested/barren land (12.6 percent). Land use in the springshed in 2004 consisted of non-forested/barren land (49.6 percent), urban/mining/transportation/recreation (30.6 percent), and open-water/wetlands (19.8 percent). As of 2005, municipal and centralized sewer systems, which are currently the primary means of wastewater treatment and disposal, replaced slightly more than 50 percent of the septic systems, primarily in the southern half of the springshed. Reclaimed wastewater, which is applied to 3.2 mi^2 of the land surface, and discharge from the remaining septic units both augment ground-water recharge in the springshed.

Figure 38. Rock Springs cavern. Photograph by S.J. Walsh, September 27, 2006.

Figure 39. Rock Springs run at central swimming area in Kelly Park. Photograph by S.J. Walsh, June 20, 2006.

Discharge

Discharge from Rock Springs has been measured by the USGS and SJRWMD since 1931 and 1983, respectively. At the time of this study, the SJRWMD and USGS jointly measured the discharge of Rock Springs at least bimonthly. Discharge for Rock Springs averaged 59.3 ft^3/s annually and varied greatly with rainfall that averaged 51.18 in/yr within the springshed (fig. 40). Average annual discharge for Rock Spring ranged from 45.9 ft^3/s in 2001 to 80.7 ft^3/s in 1960. The lowest periods of discharge corresponded to periods of well-below average rainfall in the springshed. During periods of extremely low spring discharge, particularly in late spring and early summer, the Rock Springs swimming area is closed because of high bacteria counts. Reduced flushing action in the swimming area of the run, caused by low spring discharge, encourages the proliferation of animal fecal bacteria in the run that can present a public health risk to those who come in contact with contaminated water. Continued urbanization in the springshed of Rock Springs likely will slowly continue to reduce spring flow while adversely affecting the water quality of the spring. Measured (instantaneous) discharge from Rock Springs averaged 59.2 ft^3/s and ranged from 34.1 ft^3/s in July 1998 to 83.2 ft^3/s in October 1960 (fig. 41).

Water Chemistry and Age

Rock Springs has been sampled periodically by the USGS since 1956, with most samples collected during discharge measurements made until 1983; the SJRWMD has sampled Rock Springs since 1987. At the time of this study, the SJRWMD and the USGS jointly sampled Rock Springs at least four times per year.

Rock Springs has a $Ca\text{-}Mg\text{-}HCO_3$ water type (fig. 9) that is undersaturated with respect to calcite and dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids were 7.7, 1.4 mg/L, and 144 mg/L, respectively. Values of ^{18}O and ^{2}H plot along the GMWL or local MWL parallel to the GMWL (Toth, 1999). The ^{3}H concentration was 3.1 TU (Toth, 1999), and the concentration of delta ^{34}S was 9.4 per mil, which typically corresponds to low sulfate concentrations and indicates variable sources of sulfate, including rainfall and geochemical reactions along ground-water flow paths (Toth, 1999).

Nitrate-N concentrations in Rock Springs showed large fluctuations (0.17 to 1.8 mg/L) during 1984-2007, but especially during 2006-07 (fig. 22). The median nitrate-N concentration was 1.4 mg/L during 1984-2007. Nitrate concentrations showed a significant ($p = 0.02$) decreasing trend with time for samples collected during 1956-2007 (table 6). Phosphorus (total P) concentrations in Rock Springs were generally uniform (0.06-0.09 mg/L) during 2001-07 (fig. 23), but showed a significant ($p < 0.001$) decreasing trend with time for samples collected during 1999-2007 (table 6).

Based on concentrations of CFCs, ^{3}H, and ^{3}He in water samples collected from Rock Springs in 2001, the age of spring water likely indicates a mixture of about 80 percent water recharged in 1980 with about 20 percent old (greater than 60 years) tracer-free water (Toth and Katz, 2006). Water samples also were collected in July 1995 and analyzed in 1995 for ^{3}H, delta ^{13}C, and ^{14}C. The water samples had a ^{3}H concentration of 3.1 TU, which indicated that the young fraction of water was less than 42 years old. Rock Springs had a delta ^{13}C value of -9.08 per mil and a ^{14}C value of 41 pmc. The adjusted ^{14}C age of Rock Springs is less than 50 years (recharge occurred after about 1960).

Aquatic Communities

A total of 70 macroinvertebrate taxa were collected by petite ponar dredge from Rock Springs across four sampling dates (table 20). The number of taxa collected with this gear ranged from 13 in December 2005 to 39 in September 2006. Numerically dominant taxa in pooled samples across all dates were amphipods (32.5 percent; *Gammarus* cf. *tigrinus*, *Gammarus* sp., and *Hyalella azteca* complex), dipterans (26.7 percent; no fewer than 22 taxa), gastropods (19.9 percent; no fewer than 10 taxa), and oligochaetes (13.6 percent, no fewer than 14 taxa). Density of all organisms ranged from 2.5×10^3 per m^2 (26.9×10^3 per ft^2) in December 2005 to 8.8×10^3 per m^2 (95.1×10^3 per ft^2) in March 2006. For petite ponar samples across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.71 to 4.55, Simpson's index of diversity ranged from 0.79 to 0.94, Pielou's evenness ranged from 0.65 to 0.87, and the Florida Index ranged from 2 to 11 with a mean of 5.7 (table 4).

A total of 45 macroinvertebrate taxa were identified in subsamples of dip net collections from Rock Springs; the fewest was 14 in March 2006 and the greatest was 37 in June 2006 (table 21). The percent composition of subsampled organisms combined for all collection dates was dominated by gastropods (52.6 percent, mostly the hydrobiid *Amnicola dalli*), amphipods (17.8 percent), and dipterans (17.8 percent). For dip net samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.45 to 4.01, Simpson's index of diversity ranged from 0.71 to 0.92, Pielou's evenness ranged from 0.49 to 0.86, the SCI ranged from 12 to 33 with a mean of 19, and percent very tolerant taxa ranged from 4.6 to 22.9 (table 5).

Rock Springs run in Kelly Park could not be electrofished due to a lack of boat access and heavy recreational use by park visitors. Therefore, an electroshocking boat was used on August 25, 2006, to sample a reach of the spring run downstream from Kelly Park (at approximately 28°46′17.04″N, 81°30′11.52″W). The spring run in this section is moderately wide (20-100 ft), deep (3-6 ft), and heavily forested on both shorelines, but with a relatively open canopy. The water was moderately tannic and the substrate consisted of soft muck, detritus, fallen trees, and branches; areas of the spring run had patches of submergent and emergent macrophytes. Three passes were made with the electroshocking boat for a combined total of 30 min power output.

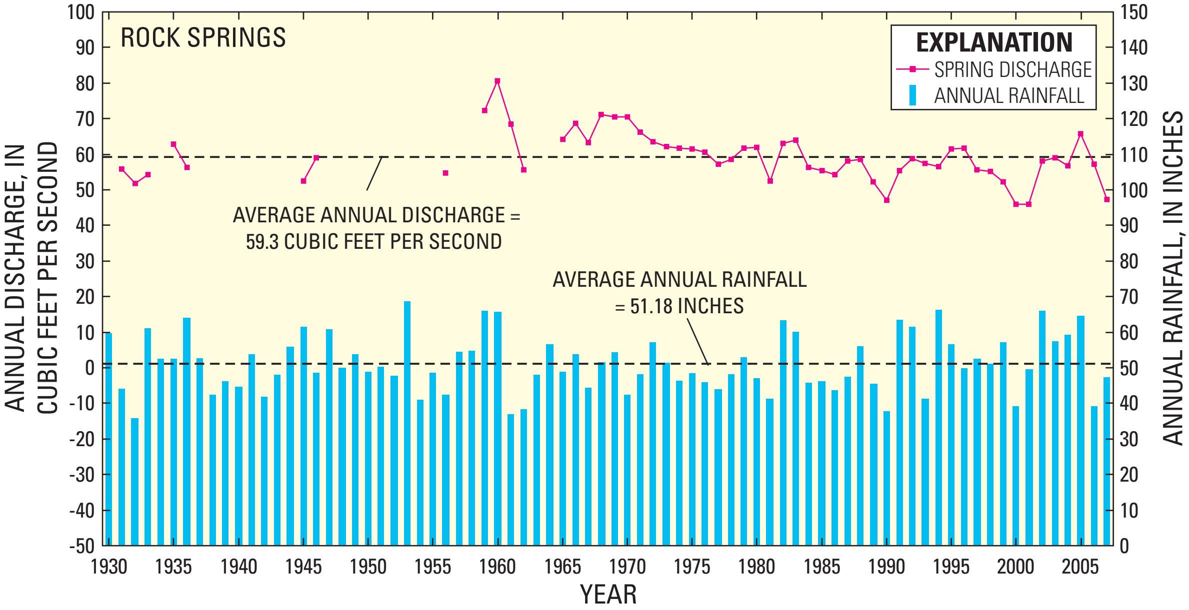


Figure 40. Average annual discharge for Rock Springs and rainfall for the Rock springshed.

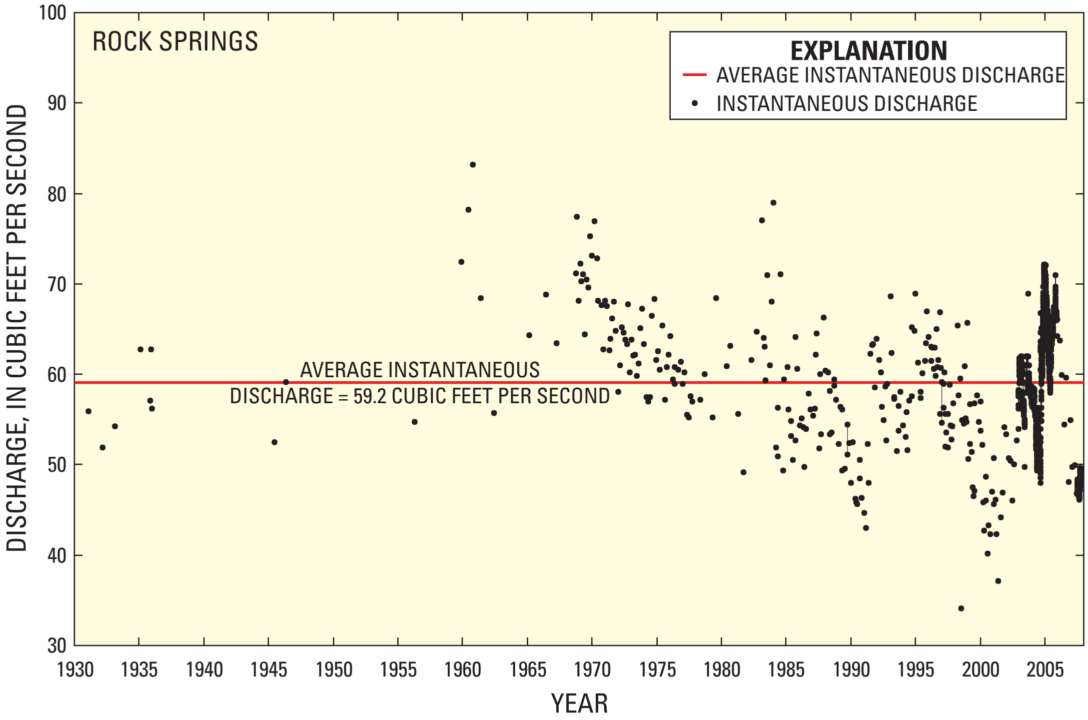


Figure 41. Periodic and continuous discharge data for Rock Springs, 1931-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

Table 20. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Rock Springs, December 2005-September 2006.

[LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 6, 2005		Mar. 27, 2006		June 21, 2006		Sept. 27, 2006	
		n	%	n	%	n	%	n	%
Hydrozoa	*Hydra* sp.					57	1.1		
Turbellaria	Tricladida (LPIL)			920	10.4	115	2.2		
	Turbellaria (LPIL)							57	0.7
Gastropoda	*Amnicola dalli*	747	29.9	115	1.3	129	2.4	1,494	18.5
	Ancylidae (LPIL)			14	0.2				
	Campeloma floridense					43	0.8		
	cf. *Floridobia* sp.							57	0.7
	cf. *Tarebia* sp.							575	7.1
	Elimia floridensis							57	0.7
	Hydrobiidae (LPIL)			14	0.2	790	14.8		
	Laevapex peninsulae					57	1.1		
	Melanoides sp. (immature)					172	3.2		
	Melanoides tuberculata					158	3.0		
	Melanoides turricula							460	5.7
	Pomacea paludosa					43	0.8		
Hirudinea	*Helobdella stagnalis*							115	1.4
Oligochaeta	*Allonais inaequalis*							57	0.7
	Dero digitata							57	0.7
	Dero furcata							115	1.4
	Dero sp.							57	0.7
	Eclipidrilus palustris	14	0.6					115	1.4
	Eclipidrilus sp.							57	0.7
	Haber speciosus					43	0.8		
	Ilyodrilus templetoni							115	1.4
	Limnodrilus hoffmeisteri	172	6.9	29	0.3	43	0.8	57	0.7
	Lumbriculus sp.					129	2.4		
	Lumbriculus variegatus	14	0.6	14	0.2				
	Naididae (LPIL)							57	0.7
	Nais communis complex					43	0.8	57	0.7
	Nais sp.			115	1.3				
	Slavina appendiculata					43	0.8	57	0.7
	tubificoid Naididae immature sp. A (LPIL)	273	10.9	29	0.3	489	9.2	230	2.8
	tubificoid Naididae immature sp. B (LPIL)	690	27.6			129	2.4	57	0.7
	Varichaetadrilus angustipenis	14	0.6						
Amphipoda	*Gammarus* cf. *tigrinus* LeCroy	187	7.5	2,730	30.9	86	1.6	402	5.0
	Gammarus sp.	14	0.6	2,773	31.4	460	8.6	517	6.4
	Hyalella azteca complex Lecroy			115	1.3	302	5.7	460	5.7
Isopoda	*Caecidotea* sp.					57	1.1		
Decapoda	*Procambarus* sp. (immature)	14	0.6						
Diptera	*Ablabesmyia rhamphe* group Epler					57	1.1	57	0.7
	Bezzia/Palpomyia complex Brigham					43	0.8	57	0.7
	cf. *Cricotopus* sp.					43	0.8		

Table 20. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Rock Springs, December 2005-September 2006.—Continued

[LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 6, 2005		Mar. 27, 2006		June 21, 2006		Sept. 27, 2006	
		n	%	n	%	n	%	n	%
	Chironomidae (LPIL)					57	1.1		
	Chironomus sp.			101	1.1	345	6.5	172	2.1
	Cricotopus bicinctus					302	5.7		
	Cricotopus politus							115	1.4
	Cryptochironomus sp.					43	0.8	57	0.7
	Dicrotendipes neomodestus					86	1.6		
	Dicrotendipes sp. (immature)					129	2.4	57	0.7
	Larsia decolorata					43	0.8		
	Orthocladiinae (LPIL)			690	7.8				
	Paralauterborniella nigrohalteralis			115	1.3	86	1.6	115	1.4
	Pentaneura inconspicua							115	1.4
	Polypedilum flavum			230	2.6				
	Polypedilum scalaenum group Epler					388	7.3	1,092	13.5
	Pseudochironomus sp.			230	2.6	43	0.8	115	1.4
	Stempellinella sp.							115	1.4
	Stenochironomus sp.	14	0.6			57	1.1		
	Tanytarsus sp.			230	2.6				
	Tanytarsus sp. C Epler			115	1.3	129	2.4	460	5.7
	Tanytarsus sp. G Epler			230	2.6				
	Tanytarsus sp. L Epler					86	1.6		
	Tanytarsus sp. V Epler	172	6.9						
	Tribelos sp.			29	0.3				
Ephemeroptera	*Caenis diminuta*							57	0.7
	Tricorythodes albilineatus							115	1.4
Odonata	*Macromia* sp.							57	0.7
Trichoptera	*Cernotina* sp.	172	6.9						
	Cheumatopsyche sp.							57	0.7
	Nectopsyche pavida					14	0.3		
Total		**2,497**		**8,838**		**5,339**		**8,095**	
Number of Taxa		**13**		**20**		**37**		**39**	

A total of 91 fish specimens were collected representing 15 species of 14 genera and 12 families (table 11). The community appeared to be relatively depauperate and abundance was low; catch per-unit-effort for each of the passes ranged from 2.1 to 4.6 fish/min and averaged 3.1 fish/min. The sample was dominated by centrarchids (49.4 percent, similar equitability for *Lepomis auritus*, *L. punctatus*, and *Micropterus salmoides*) and the catostomid *Erimyzon sucetta* (14.3 percent). *Notemigonus crysoleucas*, *Lepisosteus platyrinchus*, and *Amia calva* each constituted over 5 percent of the sample. Thus, six species accounted for 78 percent of the specimens collected. Two species of nonindigenous armored catfishes (*Hoplosternum littorale* and *Pterygoplichthys disjunctivus*) were collected; both species have colonized widely throughout the St. Johns drainage in recent years. Large adults of *P. disjunctivus* were observed in the swimming area of Kelly Park, and a park attendant indicated that this species was first observed in low numbers about 5 years earlier (circa 2000), and was seen by the hundreds in 2005-06. A midden of dead partial carcasses of this species was found in the park and was presumed to have been the result of predation by one or more otters (*Lutra canadensis*).

Table 21. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Rock Springs, December 2005-September 2006.

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 6, 2005		Mar. 27, 2006		June 21, 2006		Sept. 27, 2006	
		n	%	n	%	n	%	n	%
Gastropoda	*Amnicola dalli*	52	47.3	56	50.9	24	21.8	76	69.1
	cf. *Tarebia* sp.			2	1.8			1	0.9
	Melanoides tuberculata	2	1.8						
	Melanoides turricula			14	12.7			2	1.8
	Pyrgophorus platyrachis			1	0.9				
	Rissoidea (LPIL)					3	2.7		
Hirudinea	*Helobdella stagnalis*			1	0.9				
Oligochaeta	*Allonais inaequalis*							2	1.8
	Bratislavia unidentata					1	0.9	1	0.9
	Dero digitata complex					3	2.7		
	Limnodrilus hoffmeisteri			1	0.9				
	Nais communis complex					6	5.5		
	Pristina leidyi							1	0.9
	tubificoid Naididae immature sp. A (LPIL)	2	1.8			1	0.9		
Arachnida	*Hydrodroma* sp.					1	0.9		
	Lebertia sp.					8	7.3	1	0.9
	Limnesia sp.							1	0.9
Amphipoda	*Gammarus* cf. *tigrinus* LeCroy	21	19.1	12	10.9	7	6.4	1	0.9
	Hyalella azteca complex LeCroy	16	14.5	7	6.4	11	10.0	3	2.7
Isopoda	*Cassidinidea ovalis*					1	0.9		
Decapoda	*Palaemonetes paludosus*	6	5.5	1	0.9	3	2.7		
Diptera	*Chironomus* sp.			1	0.9	7	6.4		
	Cricotopus bicinctus					2	1.8		
	Cricotopus politus							1	0.9
	Cryptochironomus sp.					1	0.9		
	Dicrotendipes modestus					3	2.7		
	Dicrotendipes neomodestus							9	8.2
	Paralauterborniella nigrohalteralis	2	1.8						
	Pentaneura inconspicua							1	0.9
	Polypedilum flavum			6	5.5	1	0.9		
	Polypedilum scalaenum group Epler	1	0.9	6	5.5	7	6.4	2	1.8
	Polypedilum tritum	1	0.9						
	Pseudochironomus sp.					4	3.6	2	1.8
	Stempellinella fimbriata	1	0.9						
	Tanytarsus sp.			1	0.9				
	Tanytarsus sp. C Epler	1	0.9			7	6.4	6	5.5
	Tanytarsus sp. L Epler	2	1.8						
	Thienemanniella sp.					1	0.9		
	Tipulidae (LPIL)					1	0.9		
Ephemeroptera	*Tricorythodes albilineatus*			1	0.9	1	0.9		
Hemiptera	*Merragata* sp.	1	0.9						
	Mesovelia mulsanti	1	0.9						
Odonata	*Argia* sp.	1	0.9						
	Enallagma sp.					2	1.8		
Trichoptera	Hydropsychidae (LPIL)					4	3.6		
Total		**110**		**110**		**110**		**110**	
Number of Taxa		**15**		**14**		**25**		**16**	

Silver Springs Group

The Silver Springs group (fig. 1, table 1) has the largest discharge (mean and median annual discharge 767 and 771 ft^3/s, respectively) of all inland first-magnitude springs in Florida. The Silver Springs group forms the headwaters of the Silver River (Marion County), which flows into the Ocklawaha River (Rosenau and others, 1977; Scott and others, 2004). Silver Springs has been a major tourist attraction for over 100 years (Munch and others, 2006). The upper 3,937 ft (1,200 m) of the river includes numerous named major spring vents and the majority of the smaller vents, the combined total of which may exceed 150 in number. The headspring consists of two vents, Mammoth East and West, which combined, contribute about half of the total flow of the springs group (Munch and others, 2006). A springshed area of 33,720 acres (52.7 mi^2) was delineated by Munch and others (2006) on the basis of the 2-year capture zone.

Limited physicochemical samples were collected during the initial year (2004) of this study because of the amount of previous and ongoing research by other investigators. In a collaborative effort between the SJRWMD, University of Florida, and Wetland Solutions, Inc., Munch and others (2006) assessed the Silver Springs ecosystem in the context of a retrospective comparison with the benchmark studies of Odum (1957) and Knight (1980; 1983). The benchmark studies represent the most in-depth analyses of a first-magnitude spring in evaluating the complex linkages between land use, hydrology, water quality, and ecosystem function. Recent conditions and changes that have occurred over several decades are documented in the comprehensive assessment by Munch and others (2006).

Land Use

Munch and others (2006) provided detailed analyses of land use within the Silver Springs springshed, including identification of threats, high-risk areas, and a spatial land-use model to associate nitrogen loading rates with land cover. Between 1949 and 1989, the springshed (2-year capture zone) shifted from a predominantly natural to more urbanized land use. In 1949, natural land cover (including forest and vegetative areas, wetlands, and open water) accounted for 74 percent of the surface area for the 2-year capture zone, whereas urban areas covered only 3.3 percent. By 1989, natural land cover had diminished to 45 percent, and the urban areas increased to 29 percent. From 1989 to 2005, the trend in urbanization continued, with natural and urban lands constituting a total of 36 percent and 37 percent of springshed area, respectively. The percentages of land covered by agriculture and pasture remained fairly constant over the entire 1949-2005 period, with declines of about 1.5 percent for each land-use category.

Discharge

Discharge from Silver Springs has been measured by the USGS since 1932. Continuous, daily discharge record is computed from the relationship among artesian pressure at a local well (CE-76), spring-pool elevation, and discharge measured at a site 0.7 mi downstream from the head of the springs on the Silver River. Discharge for Silver Springs averaged 767 ft^3/s annually and varied greatly with rainfall that averaged 50.86 in/yr within the springshed (fig. 42). Average annual discharge for Silver Springs ranged from

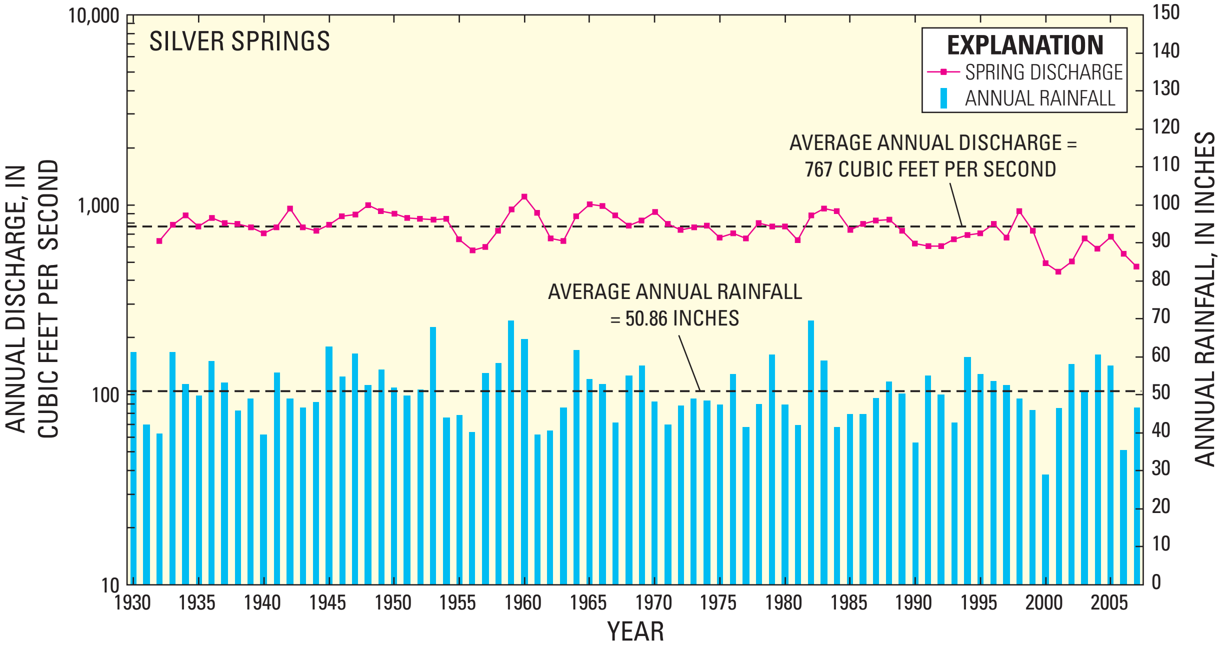


Figure 42. Average annual discharge for Silver Springs and rainfall for the Silver springshed.

445 ft^3/s in 2001 to 1,108 ft^3/s in 1960. Measured (instantaneous) discharge from Silver Springs averaged 768 ft^3/s and ranged from 350 ft^3/s in June 2001 to 1,290 ft^3/s in October 1960 (fig. 43).

Water Chemistry and Age

Descriptions of the water chemistry and synoptic water-quality data for the Silver Springs group were summarized by Phelps (1994), Scott and others (2002; 2004), Phelps and others (2006), and Munch and others (2006). The Silver Springs group has a $Ca\text{-}HCO_3$ water type. Average values of pH, dissolved oxygen, and specific conductance at the Main Spring Boil reported by Munch and others (2006) were 7.3, 2.2 mg/L, and 452 µS/cm, respectively. Average dissolved oxygen concentrations in surface water varied between sampling stations and ranged from 1.3 mg/L at Christmas Tree Spring to 4.1 mg/L at a station 0.74 mi (1,200 m) downstream from the Main Spring Boil. The following constituents were found to decline from the farthest upstream to farthest downstream stations, as summarized by Munch and others (2006): average total alkalinity (184 to 169 mg/L as $CaCO_3$), total Kjeldahl nitrogen (0.05 to 0.04 mg/L), total ammonia nitrogen (0.015 to 0.013 mg/L), total nitrogen (1.19 to 1.17 mg/L), calcium (77 to 72 mg/L), turbidity (0.16 to 0.10 NTU), total fluoride (0.19 to 0.17 mg/L), and total potassium (0.62 to 0.57 mg/L). Constituent concentrations that increased, on average, between the upstream and downstream stations included sulfate (44 to 54 mg/L), sodium (5.9 to 6.4 mg/L), total dissolved solids (277 to 281 mg/L), nitrate plus nitrite nitrogen (1.10 to 1.14 mg/L), total phosphorus (0.046 to 0.060 mg/L), total coliforms (7.1 to 131 col/100 mL), and fecal coliforms (1.7 to 77 col/100 mL). No differences were observed between these stations in average concentrations of total suspended solids and orthophosphorus, or in average color.

The average concentration of nitrate nitrogen values in Silver Springs waters has increased over 200 percent during the last 50 years (Munch and others, 2006). Odum (1957) reported an average nitrate nitrogen concentration in the Main Spring Boil of 0.46 mg/L in 1953. Data collected during 1978-79 and 2003-05 indicated average values of about 0.67 mg/L and 1.14 mg/L, respectively (Munch and others, 2006). No similar increase in any other form of nitrogen or phosphorus was observed over the 50-year period examined by Munch and others (2006).

In a study of nitrate concentrations and land-use patterns, Phelps (2004) estimated water issuing from Silver Springs to be less than 30 years old. Toth (2003) examined water quality and measured isotopes, and concluded that the age of the spring water was less than 100 years. Thus, the geology of the springshed recharge zone suggests that ground water within the uppermost part of the Floridan aquifer system provides a large percentage of total Silver Springs discharge (Munch and others, 2006).

Aquatic Communities

The aquatic communities of Silver Springs were not examined in this study. Collectively, the fauna and flora of the Silver River is the best studied of any spring or spring-fed river in Florida and was summarized in detail by Munch and others (2006).

The FDEP sampled benthic macroinvertebrates biannually at Silver Springs each year from 2002 to 2007, except in 2005 when only one sample was collected. These samples were collected using standardized FDEP protocols with D-frame dip net for calculation of the SCI. During this time period, recalibration of the SCI procedures yielded different numbers of targeted organisms and replicate samples, depending on the year of collection. For combined samples, total number of benthic macroinvertebrate taxa ranged from 18 to 31 with a mean of 22.4. The SCI ranged from 19 to 46 (mean = 27.2), percent dominant taxon ranged from 24.3 to 73.1 (mean = 45.9 percent), percent very tolerant taxa ranged from 0 to 32.4 (mean = 11.3), and the Florida Index ranged from 5 to 14 (mean = 8). Most samples were dominated by the amphipod *Hyalella azteca*; however, samples in October 2002 and November 2004 were dominated by the chironomid *Tanytarsus* sp. C Epler, and samples in June 2006 and October 2007 were co-dominated, respectively, by the chironomid *Rheotanytarsus* sp. (*exiguus* group) and the hydrobiid *Spilochlamys gravis*.

Several fish surveys of the Silver River have used qualitative and quantitative methods (Hubbs and Allen, 1943; Odum, 1957; Knight, 1980; Walsh and Williams, 2003; Munch and others, 2006). Although approximately 41 species have been recorded among these surveys, the number of species collected during each study is imprecise due to questionable identifications and nomenclature reported by previous authors. Some taxa reported in early studies, but not verified in more recent surveys, suggest misidentifications (for example, *Hybopsis* sp., *Mugil curema*); other taxa, however, may represent species that were historically present and likely still present but not recently detected due to small body size, low abundance, habitat preference, or other factors (for example, *Leptolucania ommata*, *Jordanella floridae*, *Enneacanthus* sp., *Elassoma evergladei*). There is evidence of a recent shift in the community structure of fish populations in the Silver River due to the greater biomass of carnivorous species in comparison to omnivores, with three historically dominant species (*Mugil cephalus*, *Ictalurus punctatus*, and *Dorosoma cepedianum*) having been reduced in abundance by approximately 92 percent over a 50-year time span (Munch and others, 2006). Two nonindigenous fish species, *Pterygoplichthys disjunctivus* and *Oreochromis aureus*, were recently recorded (Walsh and Williams, 2003; Munch and others, 2006); however, the effects of their presence on native communities, if any, are unknown. A few individuals of an unidentified species of pacu (probably *Colossoma macropomum* or *Piaractus brachypomus*) were observed in upper reaches of the Silver River in 2008 (R.L. Knight, Wetlands Solutions, Inc., oral commun., 2008). *Pterygoplichthys disjunctivus* and *O. aureus* are well established in the St. Johns River, but there is no evidence that any species of pacu is. Additional studies of the Silver River fish fauna are warranted to better document and quantify the diversity and relative abundances of populations, and to evaluate the potential effects of changes to the springshed.

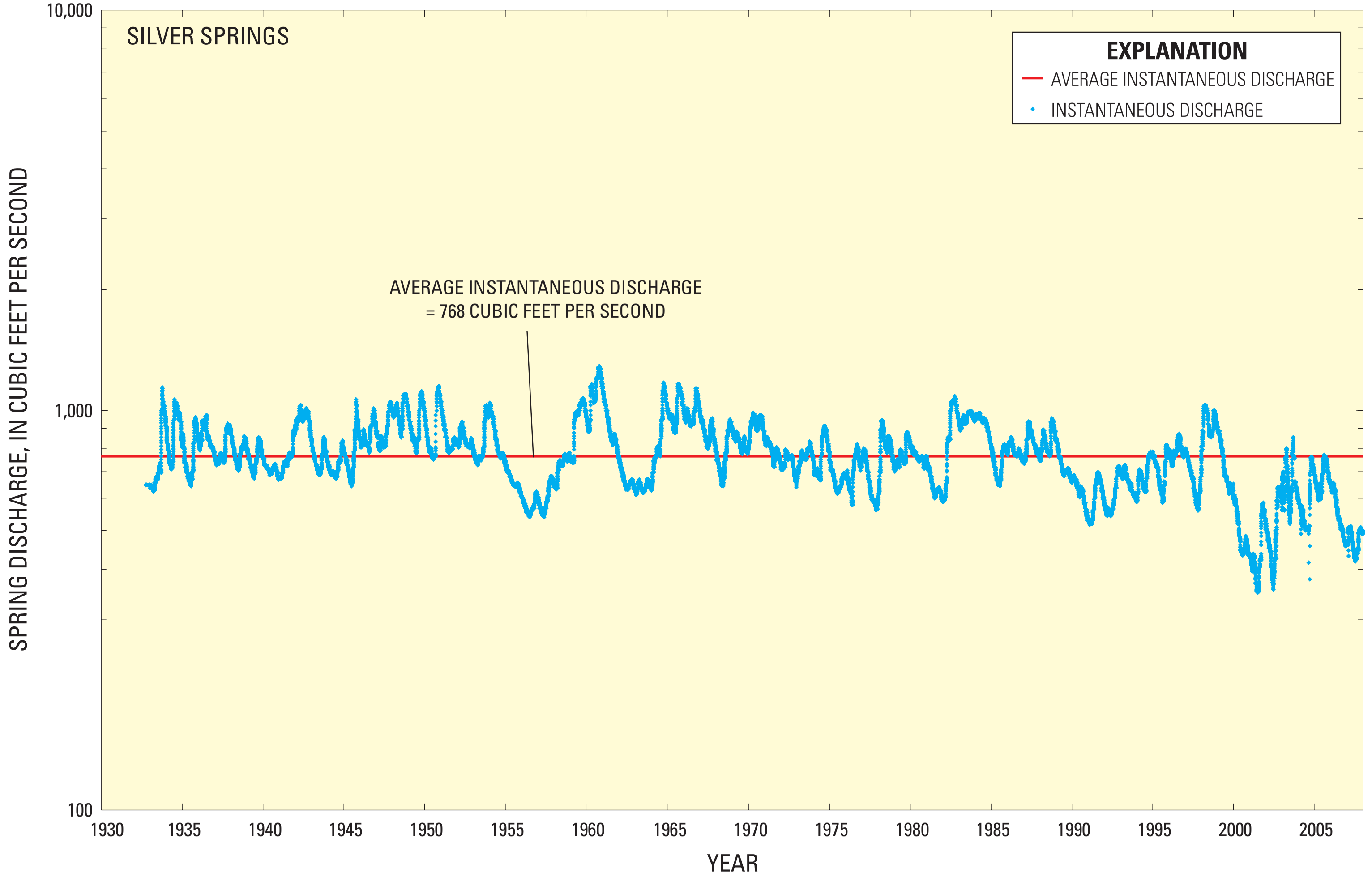


Figure 43. Continuous discharge data for Silver Springs, 1932-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

Silver Glen Springs

Silver Glen Springs (figs. 1, 44, 45, table 1) is a first magnitude spring (mean and median discharge 104 and 102 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004). The spring head and a portion of the run are located in a multi-use recreation area in the Ocala National Forest. Two vents contribute discharge that coalesces to form a large pool measuring about 200 ft across from north to south and about 175 ft east to west. Boils are evident at the surface above both of the main spring vents. The primary vent (fig. 44) is northeast of the secondary vent and lies in a conical depression of exposed limestone at a depth of about 18 ft. The secondary vent is in a vertical, limestone cave opening at a depth of about 40 ft with a pool diameter of about 12 to 15 ft; this vent is sometimes referred to as the "Natural Well" (Scott and others, 2004). The secondary vent is roped off near where its short run joins the main spring pool, and is inaccessible to recreational users. Water that issues from the secondary vent is more mineralized than that of the primary vent. Additional flow is supplied from sand boils in the bottom of the spring run downstream from the head of the spring vents. Most of the large pool area is shallow and has a sand substrate with limestone outcrops and patches of submergent vegetation. The north and west edge of the spring pool consists of an extensive limestone ledge. The "Natural Well" spring run and sections of the main spring pool, especially on the southwest side, are densely vegetated with submergent rooted macrophytes. The spring pool receives heavy use by swimmers and snorkelers, and the run downstream of the spring pool is often crowded with boats and people during peak periods of recreational use. A cable extends across the entire spring run downstream of the spring pool to prevent boat traffic from entering the vent areas. The spring run (fig. 45) is about 200 ft wide and flows easterly about 0.75 mi into the west side of Lake George. Large schools of fish congregate in the spring pool, especially near the vents. Thick mats of algae cover the substrate and rooted macrophytes in extensive areas of the spring pool and spring run, and partly cover the water surface when mats float to the top of the water column as a result of off-gassing. Algae are more prevalent in the spring and early summer prior to heavy recreational activity that dislodges and redistributes them downstream along the spring run.

Land Use

Land use in the Silver Glen springshed remained relatively unchanged from 1973 to 2004, and consisted primarily of forested land. Slight changes were attributed to a decrease in open-water/wetlands, a decrease in non-forested/barren land, and a small increase in lands used for agriculture (fig. 4). Land use in the springshed in 1973 consisted of forestland (95.2 percent), non-forested/barren land (4.4 percent), open-water/wetlands (0.4 percent), and urban/mining/transportation/recreation (less than 0.1 percent). Land use in the springshed in 2004 consisted of forestland (93.8 percent), agriculture (3.3 percent), non-forested/barren land (2.8 percent), open-water/wetlands (less than 0.1 percent), and urban/mining/transportation/recreation (less than 0.1 percent). As of 2007, no wastewater services were active in the Silver Glen springshed, and septic systems were the only method of wastewater treatment and disposal.

Discharge

Discharge from Silver Glen Springs has been measured by the USGS since 1931 and by the SJRWMD since 1983. At the time of this study, the SJRWMD and the USGS measured the discharge from Silver Glen Springs at least monthly. Continuous discharge record was computed using the relation between artesian pressure at a nearby well, spring-pool elevation, and

Figure 44. Main vent of Silver Glen Springs. Photograph by S.J. Walsh, January 31, 2007.

Figure 45. Silver Glen Springs and upper section of run. Photograph courtesy of the St. Johns River Water Management District, used with permission.

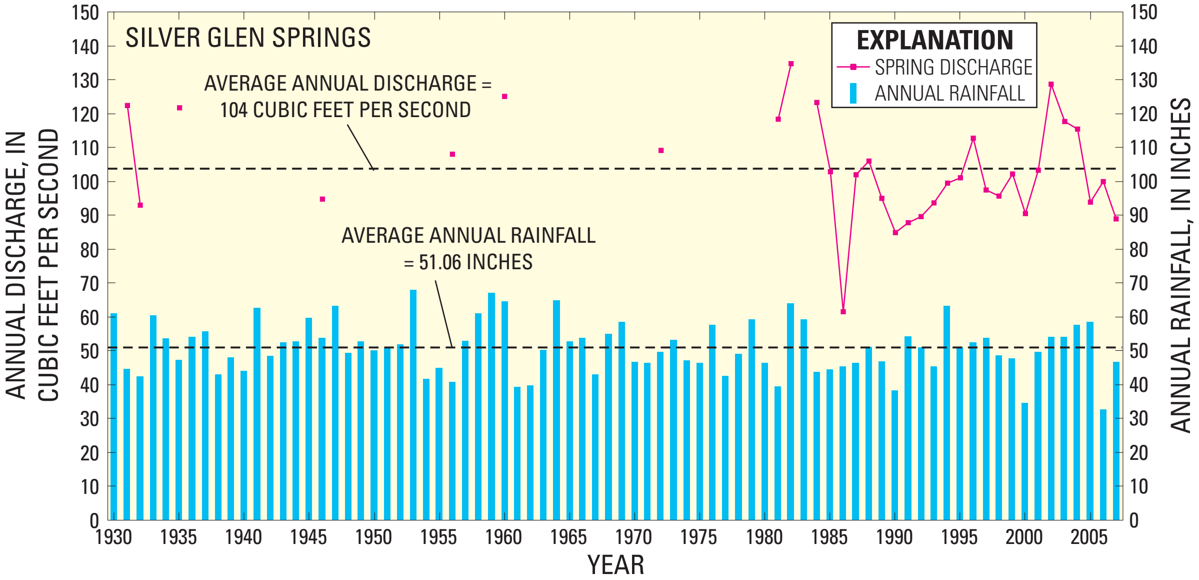


Figure 46. Average annual discharge for Silver Glen Springs and rainfall for the Silver Glen springshed.

discharge measured approximately 50 ft downstream of both vents. Discharge for Silver Glen Springs averaged 104 ft^3/s annually, and varied greatly with rainfall that averaged 51.06 in/yr within the springshed (fig. 46). Average annual discharge for Silver Glen Springs ranged from 61.5 ft^3/s in 1986 to 135 ft^3/s in 1982. Flow in the spring run is tidally affected and controlled by stage in the St. Johns River (Lake George), which occasionally is high enough to cause backwater in the run, elevate pool stage, and consequently, suppress spring discharge. Measured (instantaneous) discharge from Silver Glen Springs averaged 103 ft^3/s, and ranged from 57.0 ft^3/s in June 2007 to 259 ft^3/s in September 2004 (fig. 47).

Water Chemistry and Age

Silver Glen Springs has been sampled by the USGS since 1972, with field measurements made periodically through 1999. The SJRWMD has sampled Silver Glen Springs since 1984. At the time of this study, the SJRWMD and the USGS jointly sampled the main vent of Silver Glen Springs at least four times per year.

Silver Glen Springs has a Na-Cl water type (fig. 9) and is at equilibrium (saturated) with respect to calcite and slightly undersaturated with respect to dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids in water were 7.8, 3.7 mg/L, and 1,070 mg/L, respectively. Delta ^{18}O and ^{2}H plot along the GMWL or local MWL parallel to the GMWL (Toth, 1999). Delta ^{34}S was 20.2 ppm, similar to that for modern sulfate evaporite minerals (Toth, 1999).

Nitrate-N concentrations generally were uniform and less than 0.2 mg/L from 1990 to 2006, although recent spikes in concentration of up to 0.5 mg/L have occurred (fig. 10). Phosphorus (total P) concentrations were generally uniform, averaging approximately 0.02 mg/L during 2004-07 (fig. 11); however, orthophosphate concentrations showed a significant ($p < 0.02$) decreasing trend with time for samples collected from 1972 to 2007 (table 6). Median concentrations of nitrate-N and total P were 0.04 and 0.02 mg/L, respectively, for the 1972-2007 period. Concentrations of dissolved nitrogen and argon in water samples from Silver Glen Springs were consistent with atmospheric equilibration during ground-water recharge with the addition of minor amounts of excess air. Based on nitrogen and argon data in water samples collected in October 2006 and March 2007, the calculated recharge temperature was 22 to 23°C (assuming a recharge elevation of 75 ft and 100-percent humidity at the water table). Values of delta ^{15}N (5.63 per mil) and delta ^{18}O (-0.68 per mil) of nitrate in water samples collected in October 2006 did not indicate any isotopic fractionation; therefore, active denitrification likely was not occurring in the Upper Floridan aquifer in the vicinity of Silver Glen Springs.

Water samples collected from Silver Glen Springs on October 19, 2006, were analyzed for antibiotics, and all compounds were below method reporting levels. Water samples collected from Silver Glen Springs in October 2006 and March 2007 were analyzed for 64 organic chemicals commonly associated with wastewater sources, plus 52 pesticides. Phenol (E0.17 µg/L) was the only compound detected in the

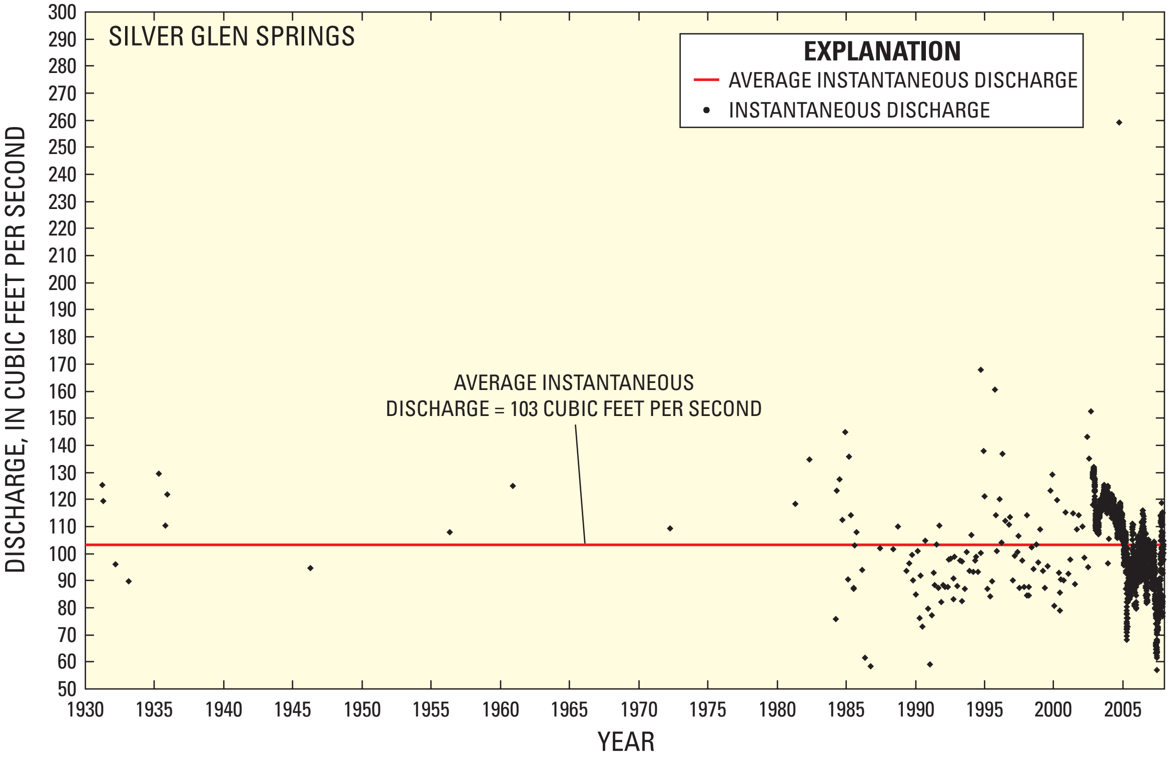


Figure 47. Periodic and continuous discharge data for Silver Glen Springs, 1931-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

March 2007 water sample (app. 4). No pesticides were detected in water samples from Silver Glen Springs (app. 5). In 2006-07, the USGS sampled the main vent at Silver Glen Springs for chlorophyll-*a*, pheophytin-*a*, wastewater compounds, pesticides, antibiotics, and dissolved gases. Chlorophyll-*a* and pheophytin-*a* concentrations in 2007 ranged from 0.1 to 0.66 µg/L and 0.1 to 1.77 µg/L, respectively. No wastewater compounds, pesticides, or antibiotics were detected in water samples from Silver Glen Springs. Dissolved gas concentrations (nitrogen and argon) were consistent with atmospheric equilibration, and no excess nitrogen gas was measured.

Based on concentrations of CFCs in water samples collected from Silver Glen Springs in 2001, the age of spring water likely indicates a mixture of about 20 percent of water recharged in about 1980 and about 80 percent older tracer-free water (greater than 60 years) (Toth and Katz 2006). The $^3H/^3He$ age indicated an age of 26 years for the young fraction. Silver Glen Springs had a delta ^{13}C value of –7.70 per mil and a ^{14}C concentration of 20 pmc, which results from the mixing of Upper and Lower Floridan aquifer water. The adjusted ^{14}C age is less than 50 years, with recharge occurring after about 1960.

Aquatic Communities

A total of 47 macroinvertebrate taxa were collected by petite ponar dredge from Silver Glen Springs across four sampling dates (table 22). The number of taxa collected with this gear ranged from 19 in October 2007 to 24 in May 2007. Numerically dominant taxa for samples pooled across all dates were mostly amphipods (57.1 percent; no fewer than four taxa) and gastropods (18.2 percent; no fewer than six taxa), with oligochaetes and dipterans comprising most of the remaining taxa (12.4 percent and 4.4 percent, respectively). The density for all organisms ranged from 12.6×10^3 per m^2 (136.1×10^3 per ft^2) in August 2007 to 26.1×10^3 per m^2 (281.2×10^3 per ft^2) in May 2007. For petite ponar samples for all dates, the $\log_2$ Shannon-Wiener index ranged from 2.74 to 3.01, Simpson's index of diversity ranged from 0.67 to 0.82, Pielou's evenness ranged from 0.62 to 0.68, and the Florida Index ranged from 2 to 6 with a mean of 4.25 (table 4).

A total of 36 macroinvertebrate taxa were identified in subsamples of dip net collections from Silver Glen Springs (table 23). The number of taxa ranged from 14 in January 2007 to 19 in March 2007. The percent composition of subsampled organisms combined for all collection dates was dominated by amphipods (45.7 percent) and gastropods (31.8 percent, mostly cf. *Aphaostracon* sp. and cf. *Tarebia* sp.), with lesser numbers of oligochaetes (7.3 percent) and dipterans (6.4 percent). For dip net samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.62 to 3.44, Simpson's index of diversity ranged from 0.76 to 0.88, the SCI ranged from 14 to 25 with a mean of 18, and percent very tolerant taxa ranged from 2.7 to 23.6 (table 5).

The benthic macroinvertebrate fauna of Silver Glen Springs includes several taxa that are most commonly associated with estuarine or nearshore waters: the amphipods *Gammarus mucronatus* complex, *G.* cf. *tigrinus*, *Grandidierella bonnieroides*, and unidentified species of the family Aoridae; the isopods *Cassidinidea ovalis* and *Uromunna reynoldsi*; and the decapod *Palaemonetes vulgaris*. The occurrence of these taxa at Silver Glen Springs is probably due to the high water conductivity, relict connate saltwater reserves in the vicinity of the spring, and connection of Lake George with the Atlantic Ocean by way of the St. Johns River. Specimens provisionally assigned to the *G. mucronatus* complex may be a disjunct population of an undescribed form known from the northern Gulf of Mexico, or a newly discovered species.

Fishes were sampled by electroshocking boat in the Silver Glen Spring run downstream of the spring pool on May 15, 2007. Collecting with this gear was relatively inefficient due to the depth of the spring run and high water conductivity; thus, assessment of the fish community was augmented by using mask and snorkel in the spring pool to visually observe species presence and relative abundances on May 15 and August 7, 2007. At least 811 specimens were collected or observed, representing 24 species of 19 genera and 16 families (table 9). Numerical estimates were made for species visually recorded but not collected (for example, *Morone saxatilis*, *Lutjanus griseus*, *Mugil cephalus*, *Lucania parva*, and *Notropis* spp.).

The fish assemblage was dominated by fundulids (29.6 percent, especially *L. parva*), the moronid *M. saxatilis* (24.7 percent), and cyprinids (21.6 percent, *Notropis harperi* and *N. petersoni*). Relative abundances are considered qualitative, however, given the large area of unsurveyed habitat and the presumably large margin of error in visual count estimates. Three nonindigenous species, *Hoplosternum littorale*, *Pterygoplichthys disjunctivus*, and *Oreochromis aureus*, were observed or collected, but they appeared to be in lower abundance here than in other springs where they were recorded during this study.

A notable characteristic of the Silver Glen Springs ichthyofauna was the presence of diadromous and/or euryhaline species of marine derivation: *M. saxatilis*, *L. griseus*, *M. cephalus*, *Anguilla rostrata*, *Menidia beryllina*, and *Gobiosoma bosc*. These species likely inhabit this system due to the high carbonate and other ionic content of the spring water. The large numbers of *M. saxatilis* fluctuated seasonally; in early spring, numerous large adults were observed rheophilically oriented in and around the main spring vent, but many apparently dispersed from the spring pool during summer months when recreational use peaked. Most if not all individuals of this species were presumed to have originated as hatchery-reared, stocked fish. Small schools of *M. cephalus* were observed and videotaped grazing on abundant mats of algae in the spring pool.

Table 22. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Silver Glen Springs, January-October 2007.

[LPIL, lowest practicable identification level]

Clade	Taxon	Jan. 31, 2007		May 10, 2007		Aug. 7, 2007		Oct. 10, 2007	
		n	%	n	%	n	%	n	%
Turbellaria	Tricladida (LPIL)	115	0.5	115	0.4				
	Turbellaria (LPIL)			115	0.4	460	3.6		
Gastropoda	cf. *Pyrgophorus platyrachis*							345	1.6
	cf. *Tarebia* sp.							5,862	27.7
	Elimia floridensis	115	0.5						
	Hydrobiidae (LPIL)			690	2.6				
	Hydrobiidae sp. C Line							6,437	30.4
	Laevapex sp.					115	0.9		
	Melanoides sp. (immature)			1,149	4.4				
	Melanoides turricula							345	1.6
Hirudinea	*Gloiobdella elongata*			115	0.4	460	3.6		
Oligochaeta	*Chaetogaster diaphanus*			805	3.1				
	Dero digitata complex					115	0.9	230	1.1
	Dero lodeni					115	0.9		
	Dero sp.	230	1.0			115	0.9		
	Eclipidrilus palustris					115	0.9	115	0.5
	Ilyodrilus templetoni					115	0.9		
	Limnodrilus hoffmeisteri	230	1.0	230	0.9	345	2.7	920	4.3
	Pristina breviseta	115	0.5						
	Pristina leidyi	115	0.5	805	3.1				
	Pristina sp.					460	3.6		
	tubificoid Naididae immature sp. A (LPIL)	345	1.5	374	1.4	460	3.6	3,448	16.3
	tubificoid Naididae immature sp. B (LPIL)					230	1.8	230	1.1
Amphipoda	Amphipoda (LPIL)	575	2.5	575	2.2				
	Aoridae (LPIL)	345	1.5	115	0.4			345	1.6
	Gammarus cf. *tigrinus* LeCroy	5,517	24.1	805	3.1	115	0.9	115	0.5
	Gammarus mucronatus complex LeCroy	5,747	25.1	1,149	4.4	115	0.9	575	2.7
	Gammarus sp.	920	4.0	1,379	5.3	460	3.6	805	3.8
	Grandidierella bonnieroides					575	4.5		
	Hyalella azteca complex Lecroy	5,402	23.6	13,793	52.8	7,126	56.3	690	3.3
Isopoda	*Caecidotea racovitzai australis*	230	1.0			230	1.8		
	Caecidotea sp.	1,264	5.5	345	1.3	690	5.5		
	Cassidinidea ovalis	230	1.0	115	0.4				
	Cyathura polita			115	0.4			115	0.5
	Uromunna reynoldsi	230	1.0	1,494	5.7				
Decapoda	Cambaridae (LPIL)					115	0.9		
Diptera	cf. *Cricotopus* sp.			115	0.4				
	Chironomus sp.							115	0.5
	Cricotopus politus	115	0.5	1,264	4.8	115	0.9		0.0
	Cryptochironomus sp.							115	0.5
	Dicrotendipes sp. (immature)							115	0.5
	Goeldichironomus carus			115	0.4				
	Polypedilum tritum/illinoense group Epler			230	0.9				
	Pseudochironomus sp.	690	3.0	115	0.4			230	1.1
	Tanypodinae (LPIL)	115	0.5						
	Tanytarsus sp.	115	0.5						
	Tanytarsus sp. C Epler	115	0.5						
Total		**22,875**		**26,122**		**12,646**		**21,152**	
Number of Taxa		**22**		**24**		**21**		**19**	

Table 23. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Silver Glen Springs, January-October 2007

[Values represent material as subsampled to obtain target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Clade	Taxon	31 Jan 2007		10 May 2007		7 Aug 2007		10 Oct 2007	
		n	%	n	%	n	%	n	%
Turbellaria	Tricladida (LPIL)	2	1.8						
Gastropoda	cf. *Aphaostracon* sp.	4	3.6	3	2.7	39	35.5		
	cf. *Floridobia* sp.					1	0.9		
	cf. *Spilochlamys* sp.			3	2.7				
	cf. *Tarebia* sp.	26	23.6	24	21.8	36	32.7		
	Melanoides sp. (immature)			1	0.9				
	Melanoides tuberculata	1	0.9						
	Planorbella scalaris	1	0.9	1	0.9				
Oligochaeta	*Dero digitata* complex					7	6.4	1	0.9
	Limnodrilus hoffmeisteri			13	11.8			2	1.8
	Lumbriculus sp.			2	1.8				
	Pristina leidyi			2	1.8				
	tubifoid Naididae immature sp. A (LPIL)	4	3.6			1	0.9		
Arachnida	*Arrenurus* sp.					1	0.9		
Amphipoda	Aoridae (LPIL)	4	3.6	9	8.2	2	1.8	3	2.7
	Gammarus cf. *tigrinus* LeCroy	8	7.3	3	2.7	1	0.9	22	20.0
	Gammarus mucronatus complex LeCroy	35	31.8	15	13.6	3	2.7	27	24.5
	Hyalella azteca complex LeCroy	16	14.5	19	17.3	9	8.2	25	22.7
Isopoda	*Caecidotea racovitzai australis*					2	1.8		
	Caecidotea sp.							1	0.9
	Cassidinidea ovalis	2	1.8	1	0.9	3	2.7	2	1.8
Decapoda	*Palaemonetes paludosus*					2	1.8	13	11.8
	Palaemonetes vulgaris	3	2.7						
	Procambarus sp. (immature)							4	3.6
Diptera	*Bezzia/Palpomyia* complex Brigham					1	0.9		
	Chironomus sp.							3	2.7
	Cladotanytarsus cf. *daviesi* Epler			1	0.9			2	1.8
	Cricotopus politus	1	0.9	6	5.5				
	Cryptochironomus sp.			1	0.9				
	Dicrotendipes sp. A Epler							2	1.8
	Polypedilum illinoense group Epler			4	3.6				
	Pseudochironomus sp.	3	2.7	1	0.9	2	1.8		
	Tanytarsus limneticus							1	0.9
Ephemeroptera	*Caenis* sp.			1	0.9				
	Callibaetis sp.							1	0.9
Hemiptera	Heteroptera (LPIL)							1	0.9
Total		**110**		**110**		**110**		**110**	
Number of Taxa		**14**		**19**		**15**		**16**	

Wekiwa Springs

Wekiwa Springs (figs. 1, 48, 49, table 1) is a second magnitude spring (mean and median discharge 68.0 and 66.5 ft^3/s, respectively) (Rosenau and others, 1977; Scott and others, 2004). Wekiwa Springs is listed in the USGS Geographic Names Information System (*http://geonames.usgs.gov/domestic/index.html*) as "Wekiva Springs." Although the name used herein follows Scott and others (2004), the plural form ("springs") is used because there are two main vents. The spring pool is located in a semitropical forest at the base of a northeastern-sloping, grassy hillside. The spring pool is used for swimming and snorkeling, and the area surrounding the spring pool and upper reach of the spring run is developed as a recreation area with concession facilities and boardwalks. Two areas of discharge in Wekiwa Springs produce surface boils in the southeastern half of the pool near its edge. The strongest boil (fig. 49) is over a large, irregularly shaped vent about 35 ft long by 5 ft wide in the limestone bottom and about 15 ft below the surface. The other boil is above a rock ledge along the extreme southeastern edge of the pool. The pool substrate is mostly sand, except for the limestone rock bottom in the southeastern part of the pool. The spring pool is kidney-shaped, about 200 ft long and 100 ft wide, and elongated toward the southeast. A sidewalk surrounds the pool and a wooden footbridge crosses the run immediately downstream of the pool. A limerock retaining wall encloses the pool and extends a short distance down the run. At its widest point, the upper section of the Wekiwa Springs run expands into a large slow-flowing pool about 320 ft across and 490 ft long; the run then narrows to about 20-40 ft wide and flows approximately 2,900 ft (0.55 mi) to its confluence with Rock Springs run (fig. 50). The combined discharge from Rock and Wekiwa Springs forms the headwaters of the Wekiva River, a National Wild and Scenic River that is designated as an Outstanding Florida Water by the FDEP. The areal extent of the Wekiwa springshed is 31.6 mi^2.

Figure 49. Close-up view of Wekiwa Springs main vent. Photograph courtesy of the St. Johns River Water Management District, used with permission.

Land Use

The Wekiwa springshed shifted from predominantly agricultural toward urbanized land use from 1973 to 2004 (fig. 4). Drying and enhanced drainage of the land surface probably

Figure 48. Upstream view of Wekiwa Springs pool from footbridge spanning upper section of spring run. Photograph by S.J. Walsh, August 21, 2002.

Figure 50. Wekiwa Springs run near confluence with Rock Springs Run. Photograph by S.J. Walsh, July 17, 2006.

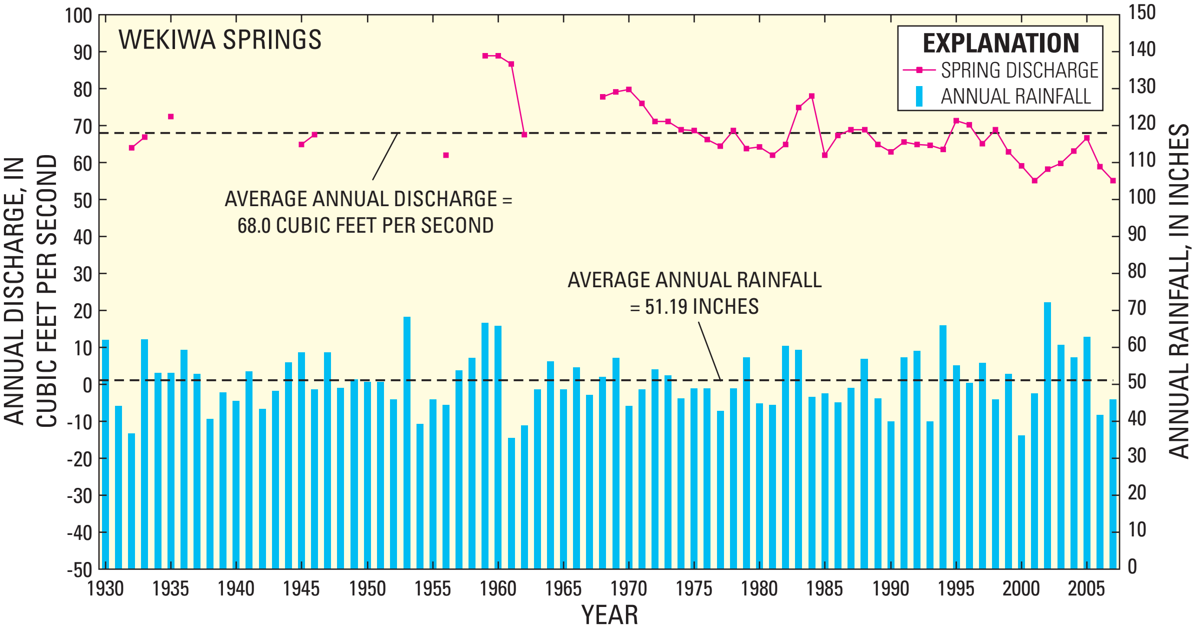


Figure 51. Average annual discharge for Wekiwa Springs and rainfall for the Wekiwa springshed.

contributed to a substantial decrease in open-water/wetlands and a slight increase in non-forested/barren lands. These changes, combined with a reduction in agriculture, yielded available land for development. Land use in the springshed in 1973 consisted of open-water/wetlands (61.7 percent), agriculture (23.0 percent), forestland (8.3 percent), urban/mining/transportation/recreation (5.3 percent), and non-forested/barren land (1.7 percent). Land use in the springshed in 2004 consisted of open-water/wetlands (50.8 percent), urban/mining/transportation/recreation (28.4 percent), agriculture (8.8 percent), forestland (7.6 percent), and non-forested/barren land (4.4 percent). As of 2005, municipal and centralized sewer systems were the primary means of wastewater treatment and disposal, and had replaced most of the septic systems in the Wekiwa springshed. Reclaimed wastewater (applied to 2.8 mi^2 of the springshed) and discharge from the remaining septic units augment groundwater recharge in the Wekiwa springshed.

Discharge

Discharge from Wekiwa Springs has been measured by the USGS since 1932. The SJRWMD has measured discharge since 1983. At the time of this study, the SJRWMD and the USGS jointly measured the discharge of Wekiwa Springs at least bimonthly. Discharge for Wekiwa Springs averaged 68.0 ft^3/s annually, and varied with rainfall that averaged 51.19 in/yr within the springshed (fig. 51). Average annual discharge for Wekiwa Springs ranged from 55.1 ft^3/s in 2007 to 88.9 ft^3/s in 1960. Spring discharge is occasionally affected by localized pumping of the Upper Floridan aquifer within the Wekiwa springshed. Measured (instantaneous) discharge from Wekiwa Springs averaged 63.5 ft^3/s, and ranged from 38.6 ft^3/s in July 1998 to 91.7 ft^3/s in October 1960 (fig. 52).

Water Chemistry and Age

Wekiwa Springs has been sampled by the USGS and SJRWMD since 1956 and 1984, respectively. At the time of this study, the SJRWMD and the USGS jointly sampled Wekiwa Springs at least four times per year. In 2006-07, the USGS sampled Wekiwa Springs for chlorophyll-*a*, pheophytin-*a*, wastewater compounds, pesticides, antibiotics, and dissolved gases.

Wekiwa Springs has a Ca-Mg-HCO$_3$ water type (fig. 9) and is undersaturated with respect to calcite and dolomite (table 3). Median values of pH, dissolved oxygen, and dissolved solids of water were 7.4, 0.4 mg/L, and 180 mg/L, respectively. Delta ^{18}O and ^{2}H of water from Wekiwa Springs plots along the GMWL or local MWL parallel to the GMWL (Toth, 1999), indicating no evaporation during recharge. The ^{3}H concentration was 3.0 TU (Toth, 1999), indicating that recharge has occurred during the past 20 years. Delta ^{34}S equaled 5.7 ppm, typically corresponding to low sulfate concentrations and indicating variable sources of sulfate including rainfall and geochemical reactions along groundwater flow paths (Toth, 1999).

The median nitrate concentration from 1977 to 2007 was 1.3 mg/L. Nitrate-N concentrations showed a significant (less

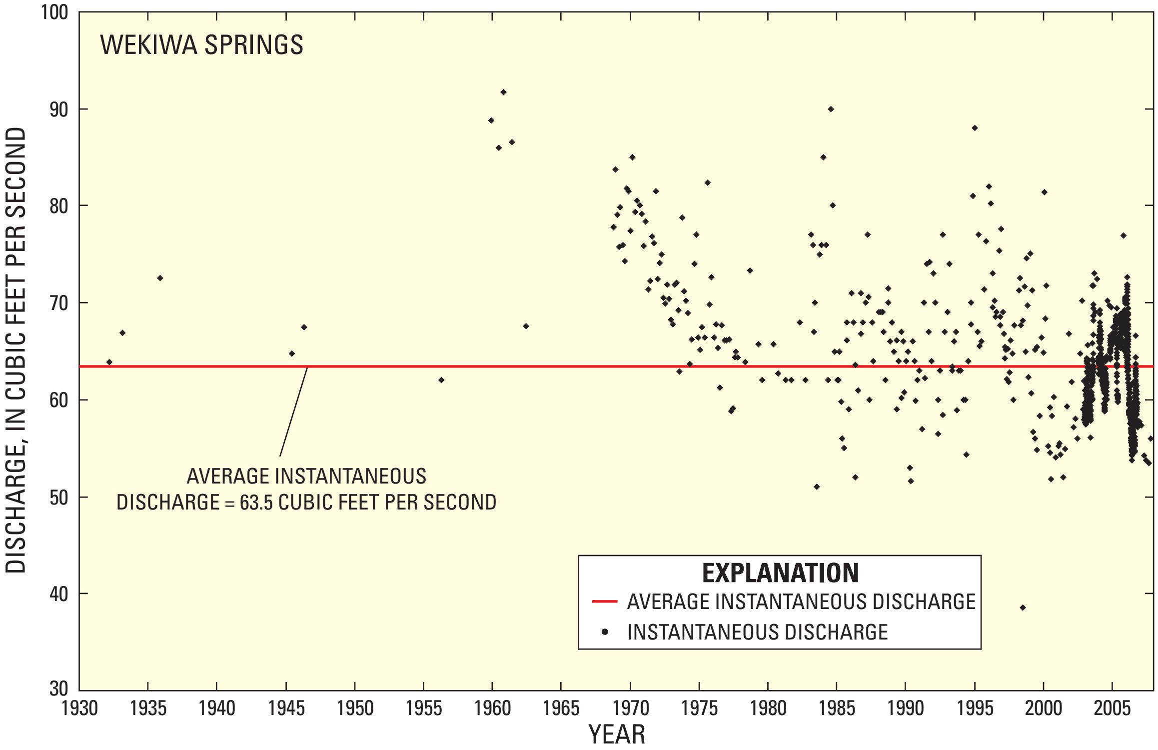


Figure 52. Periodic and continuous discharge data for Wekiwa Springs, 1932-2007. Data collected by the St. Johns River Water Management District (SJRWMD) and U.S. Geological Survey. SJRWMD data used with permission.

than 0.001) decreasing trend with time for samples collected during 1970-2007 (table 6). Excess dissolved nitrogen concentrations of about 3 mg/L were found in water samples collected in October 2006 and March 2007, indicating that denitrification was occurring in the Upper Floridan aquifer in the vicinity of Wekiwa Springs. Elevated values of delta ^{15}N and delta ^{18}O of nitrate (14.7 and 12.9 per mil, respectively) were indicative of isotopic fractionation due to denitrification. In addition, low dissolved methane concentrations (0.006 mg/L) were indicative of reducing conditions in the Upper Floridan aquifer in the vicinity of Wekiwa Springs. Dissolved oxygen concentrations generally were less than 0.5 mg/L, which is indicative of anoxic conditions. Phosphorus concentrations in Wekiwa Springs generally were uniform around 0.1 mg/L from 1970 to 2007, although spikes in concentration have occurred (up to 2 mg/L) (fig. 23). The phosphorus (total P) median concentration was 0.12 mg/L from 1972 to 2007. Phosphorus concentrations showed a significant ($p = 0.02$) decreasing trend with time for samples collected from 1970 to 2007 (table 6).

Water samples collected from Wekiwa Springs in October 2006 and March 2007 were analyzed for 64 organic chemicals commonly associated with wastewater sources, plus 52 pesticides. Of the organic wastewater compounds analyzed, triethyl citrate (E0.1 µg/L) was detected in the October 2006 water sample, and phenol (E0.1 µg/L) was detected in the March 2007 water sample (app. 4). Pesticides detected in water samples from Wekiwa Springs included atrazine (E0.007, E0.008 µg/L), an atrazine degradate (2-chloro-4-isopropylamino-6-amino-s-triazine) (E0.008 µg/L), fipronil (E0.005-E0.007 µg/L), and simazine (E0.004-E0.005 µg/L) (app. 5).

Based on concentrations of ^{3}H and ^{3}He in water samples collected from Wekiwa Springs in 2001, the age of spring water indicates a mixture dominated by relatively young water (less than 9 years old) (Toth and Katz 2006). More recent samples collected in October 2006 and March 2007 had concentrations of ^{3}H and ^{3}He that indicated an apparent age of 16 to 20 years. Concentrations of SF_6 were considerably higher than atmospheric concentrations, indicating that ground water discharging from Wekiwa Spring has been affected by non-atmospheric sources of SF_6 and thus, cannot be dated using this technique. Water samples collected in April 1995 were analyzed for ^{3}H, ^{13}C, and ^{14}C. Wekiwa Springs had a ^{3}H concentration of 3.0 TU, which indicated that the young fraction of water was less than 42 years old. Wekiwa Springs had a delta ^{13}C value of –10.1 per mil and a ^{14}C of 50 pmc. The adjusted ^{14}C age of Wekiwa Springs is recent, with recharge likely occurring after about 1960.

Aquatic Communities

A total of 41 macroinvertebrate taxa were collected by petite ponar dredge from Wekiwa Springs across four sampling dates (table 24). The number of taxa collected with this gear ranged from 12 in June 2006 to 23 in September 2006. Numerically dominant taxa in pooled samples across all dates were gastropods (51.2 percent, mostly *Amnicola dalli* and unidentified hydrobiids, but at least four species total), chironomids (22.2 percent, at least nine species), and oligochaetes (14.1 percent, at least seven species). Density of all organisms ranged from 6.4×10^3 per m^2 (69.3×10^3 per ft^2) in June 2006 to 35.8×10^3 per m^2 (385.4×10^3 per ft^2) in September 2006. For petite ponar samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 2.04 to 3.06, Simpson's index of diversity ranged from 0.51 to 0.80, Pielou's evenness ranged from 0.45 to 0.77, and the Florida Index ranged from 0 to 2 with a mean of 1 (table 4).

A total of 31 macroinvertebrate taxa were identified in subsamples of dip net collections from Wekiwa Springs (table 25). The number of taxa ranged from 11 in June 2006 to 15 in December 2005. The percent composition of subsampled organisms combined for all collection dates was dominated by gastropods (56.9 percent, mostly *Amnicola dalli* and *Aphaostracon monas*), with most of the remaining specimens comprising chironomids (15.9 percent), ephemeropterans (11.0 percent, all *Caenis diminuta*), amphipods (6.9 percent, all *Hyalella azteca* complex), and oligochaetes (5.4 percent). The Wekiwa Springs endemic hydrobiid *Floridobia wekiwae* constituted 2.4 percent of the subsampled specimens collected by dip net. For dip net samples pooled across all dates, the $\log_2$ Shannon-Wiener index ranged from 1.90 to 2.63, Simpson's index of diversity ranged from 0.55 to 0.79, Pielou's evenness ranged from 0.55 to 0.71, the SCI ranged from 10 to 32 with a mean of 20, and percent very tolerant taxa ranged from 2.7 to 19.1 (table 5).

Fishes were sampled by electroshocking boat in the Wekiwa Springs run downstream of the spring pool on July 27, 2006. Three passes were made with the boat in the broadest portion of the spring run upstream of its sinuous course through a narrow, closed canopy section. Power was applied for 30 min during the sampling effort. A total of 318 specimens were collected or observed, representing 17 species of 12 genera and 10 families (table 11). The sample was dominated by centrarchids (58.2 percent, six species), cyprinids (17.3 percent, mostly *Notemigonus crysoleucas*), and the catostomid *Erimyzon sucetta* (10.1 percent). The nonindigenous *Pterygoplichthys disjunctivus* was estimated to constitute approximately 5 percent of the sample (not all individuals were netted); this species is common in the spring pool and park personnel routinely remove adults from the swimming area (R. Owen, Florida Park Service, oral commun., 2006). Composition of the sample was considered to be under-representative of the entire fish community based on the limited effort and gear used. A previous survey of fishes in the Wekiwa Springs run (including a longer reach that extended downstream of the confluence with Rock Springs run) resulted in the collection or observation of 24 species, although based on fewer (n = 275) total specimens (Walsh and Williams, 2003). Species collected by Walsh and Williams (2003) but not in this study were *Lepisosteus osseus*, *Notropis maculatus*, *Opsopoeodus emiliae*, *Pteronotropis metallicus*, *Labidesthes sicculus*, *Fundulus seminolis*, *Heterandria formosa*, and *Poecilia latipinna*. Except for *L. osseus*, all of these species are small-bodied fishes and cannot be sampled reliably using boat electroshocking gear. In this study, two specimens of *Ameiurus natalis* were collected, a species not recorded by Walsh and Williams (2003).

Land-Use Changes among Springsheds

Springsheds examined in this study range in area from about 1.8 mi^2 (Green Spring) to 52.7 m^2 (Silver Springs), and land use within each varied considerably for the 1973 to 2004 period. The Bugg and Silver Glen springsheds remained primarily rural in character, consisting mostly of forest and wetlands (fig. 4). Urban land tracts have increased substantially within the Alexander, Apopka, Gemini, Green, and Wekiwa springsheds. Although urban lands in the Apopka springshed increased by about 20 percent, most of the springhsed has remained agricultural. In contrast, the Alexander and Wekiwa springsheds lost agricultural lands, whereas land-use changes in the De Leon springshed resulted in the conversion of nearly 35 percent of forest land to tracts of agricultural and, to a lesser extent, urban lands. The Rock springshed had a slight increase in urban area and a large loss of open-water/wetlands accompanied by increased barren lands. The Gemini springshed had a marked change from predominantly forest to urban land and open water.

Trends in Spring Discharge and Rainfall

Temporal trends in annually averaged measurements of spring discharge and springshed rainfall were evaluated with Kendall's tau (τ) (Helsel and Hirsch, 1992) for the 12 springs included in this study using weighted rainfall from 10 rainfall sites (table 26). Five of the springs (De Leon, Fern Hammock, Rock, Silver, and Wekiwa Springs) exhibited statistically significant decreases in discharge, whereas none of the weighted rainfall data for the springsheds exhibited any statistically significant trends. These tests assume a monotonic distribution of data across the period of coverage. Springs exhibiting putative decreases in discharge may be those most affected by human activities such as increased ground-water withdrawals and land-use alterations that decrease recharge to the springs. Nevertheless, climate cannot be dismissed as a major, if not primary, factor acting in conjunction with other variables that have contributed to the apparent decreasing trends in spring discharge.

Table 24. Number of specimens (n) and percent density (%) per square meter of macroinvertebrates collected by pooled petite ponar dredge samples (n = 3 per date) from Wekiwa Springs, December 2005-September 2006.

[LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 7, 2005		Mar. 27, 2006		Jun. 22, 2006		Sept. 27, 2006	
		n	%	n	%	n	%	n	%
Turbellaria	Tricladida (LPIL)	43	0.2	690	5.1	345	5.4		
	Turbellaria (LPIL)							1,379	3.9
Gastropoda	*Amnicola dalli*			5,977	44.4			24,885	69.5
	Aphaostracon monas							115	0.3
	cf. *Floridobia* sp.							115	0.3
	Floridobia wekiwae							1,034	2.9
	Hydrobiidae (LPIL)	6,207	26.2	230	1.7	1,724	26.8		
	Melanoides turricula							345	1.0
Hirudinea	*Desserobdella phalera*	43	0.2						
	Helobdella stagnalis	2,644	11.2	1,149	8.5	115	1.8		
	Helobdella triserialis	43	0.2			115	1.8		
Oligochaeta	*Dero botrytis*							172	0.5
	Dero digitata	57	0.2	575	4.3				
	Dero digitata complex					345	5.4		
	Dero pectinata					115	1.8		
	Dero sp.							115	0.3
	Limnodrilus hoffmeisteri	517	2.2	460	3.4	805	12.5	57	0.2
	Naidinae (LPIL)	273	1.2			115	1.8	115	0.3
	Nais communis complex					345	5.4		
	Nais elinguis							402	1.1
	Nais variabilis							230	0.6
	tubificoid Naididae immature sp. A (LPIL)	2,974	12.5	690	5.1	2,069	32.1	805	2.2
Amphipoda	*Hyalella azteca* complex Lecroy	345	1.5					57	0.2
Isopoda	*Caecidotea racovitzai australis*	43	0.2						
	Caecidotea sp.	72	0.3					115	0.3
Decapoda	*Procambarus* sp. (immature)	57	0.2						
Diptera	Chironomidae (LPIL)							57	0.2
	Chironomini (LPIL)			230	1.7				
	Chironomus sp.	244	1.0			230	3.6	1,379	3.9
	Cladopelma sp.					115	1.8	1,149	3.2
	Dicrotendipes modestus			460	3.4				
	Dicrotendipes sp. (immature)			460	3.4			115	0.3
	Polypedilum halterale group Epler			115	0.9				
	Polypedilum scalaenum group Epler			230	1.7				
	Rheotanytarsus sp.			115	0.9				
	Tanytarsus sp.			575	4.3			172	0.5
	Tanytarsus sp. C Epler			115	0.9				
	Tanytarsus sp. T Epler	9,871	41.6	460	3.4			1,494	4.2
	Tribelos jucundum	43	0.2						
Ephemeroptera	*Caenis diminuta*	230	1.0	920	6.8			690	1.9
	Caenis sp.							805	2.2
Total		**23,706**		**13,451**		**6,438**		**35,802**	
Number of Taxa		**17**		**17**		**12**		**23**	

Table 25. Number of specimens (n) and percent composition (%) of macroinvertebrates collected by dip net from Wekiwa Springs, December 2005-September 2006.

[Values represent material as subsampled to obtain the target number of organisms required for calculation of the Stream Condition Index. LPIL, lowest practicable identification level]

Clade	Taxon	Dec. 7, 2005		Mar. 27, 2006		June 22, 2006		Sept. 27, 2006	
		n	%	n	%	n	%	n	%
Turbellaria	Tricladida (LPIL)					2	1.8		
	Turbellaria (LPIL)							3	2.7
Gastropoda	*Amnicola dalli*	62	56.4	30	27.3			64	58.2
	Aphaostracon monas	2	1.8	2	1.8	72	65.5		
	Floridobia wekiwae							11	10.0
	Melanoides sp. (immature)					1	0.9		
	Melanoides turricula	2	1.8						
	Planorbella scalaris	1	0.9						
Hirudinea	*Helobdella stagnalis*	2	1.8					1	0.9
Oligochaeta	*Dero digitata* complex			3	2.7				
	Limnodrilus hoffmeisteri	5	4.5						
	Nais communis complex					4	3.6		
	Nais elinguis							1	0.9
	Nais variabilis			1	0.9				
	Pristina sp.	2	1.8						
	tubificoid Naididae immature sp. A (LPIL)			1	0.9	4	3.6	3	2.7
Amphipoda	*Hyalella azteca* complex LeCroy	11	10.0	6	5.5	9	8.2	4	3.6
Isopoda	*Caecidotea racovitzai australis*	5	4.5						
	Caecidotea sp.			1	0.9	1	0.9		
Diptera	*Chironomus* sp.	4	3.6	2	1.8			1	0.9
	Cladopelma sp.	2	1.8					1	0.9
	Cladotanytarsus cf. *daviesi* Epler					1	0.9		
	Dicrotendipes sp. (immature)			4	3.6				
	Polypedilum halterale group Epler					1	0.9		
	Pseudosmittia sp.			1	0.9				
	Stenochironomus sp.	1	0.9						
	Tanytarsus sp. C Epler							1	0.9
	Tanytarsus sp. T Epler	2	1.8	27	24.5	4	3.6	19	17.3
	Tribelos sp.	1	0.9						
Ephemeroptera	*Caenis diminuta*	8	7.3	30	27.3	11	10.0	1	0.9
Odonata	*Enallagma* sp.			2	1.8				
Total		**110**		**110**		**110**		**110**	
Number of Taxa		**15**		**13**		**11**		**12**	

Table 26. Results of trend testing of annually averaged spring discharge and springshed rainfall.

[NOAA, National Oceanic and Atmospheric Administration; ft^3/s, cubic foot per second]

Alexander	1931-2007	-0.1943	-0.1508	0.2003	No	DeLand/Lisbon/Plymouth	0.0190	0.0436	0.5749	No
Apopka	1971-2007	-0.2673	-0.4103	0.0586	No	Clermont	-0.0128	-0.0193	0.8057	No
Bugg	1943-2007	-0.0303	-0.1367	0.3501	No	Leesburg/Bushnell	-0.0541	-0.0942	0.2237	No
De Leon	1930-2007	-0.2000	-0.3404	0.0008	Decreasing	DeLand	0.0568	0.0783	0.3127	No
Fern Hammock	1935-2007	-0.0500	-0.2336	0.0500	Decreasing	Crescent City/Lisbon	-0.0169	-0.0296	0.7042	No
Gemini	1966-2007	0.0650	0.1619	0.4285	No	Sanford	0.0040	0.0073	0.9278	No
Green	1932-2007	0.0065	0.0917	0.6522	No	Sanford	0.0040	0.0073	0.9278	No
Juniper	1908-2007	0.0000	0.0016	1.0000	No	Crescent City/Lisbon	-0.0169	-0.0296	0.7042	No
Rock	1931-2007	-0.1538	-0.2572	0.0057	Decreasing	Plymouth/Leesburg/Clermont	0.0119	0.0190	0.8091	No
Silver	1932-2007	-2.7762	-0.2905	0.0002	Decreasing	Ocala/Lisbon/Leesburg	-0.0412	-0.0696	0.3695	No
Silver Glen	1931-2007	-0.1835	-0.1402	0.2580	No	Crescent City/Ocala/Lisbon	-0.0378	-0.0729	0.3469	No
Wekiwa	1932-2007	-0.2087	-0.3639	0.0002	Decreasing	Plymouth/Clermont	0.0191	0.0287	0.7151	No

Comparison of Aquatic Communities

Numerous benthic invertebrates and fishes were collected from springs in this study. Their characteristics and differences in assemblages among springs are discussed in the subsequent sections.

Benthic Macroinvertebrates

A total of 249 benthic macroinvertebrate taxa were collected from springs in this study; of these, 60 taxa were represented solely in dip net samples, 84 solely in ponar grab samples, and the remaining 105 represented in both (app. 1). The number of taxa collected using combined gears was variable among dates for each spring (fig. 53A). Cumulative numbers of taxa were lowest for Apopka Spring (29), Gemini Springs (32), and Green Spring (33); intermediate for Wekiwa Springs (48), Alexander Spring (57), and Silver Glen Springs (65); and greatest for De Leon Spring (71), Bugg Spring, (76), and Rock Springs (89) (fig. 53B). Rank-order plots for both dip net and ponar samples indicated log-normal distributions, with relatively few species dominant in abundance (fig. 54). Many additional taxa would likely have been obtained with greater sampling effort, as evidenced by species-accumulation curves (fig. 55).

Numerous richness estimators are commonly applied to community data; figure 55 includes nonparametric approaches dependent on simple functions of the number of taxa observed in only one or two samples (Jacknife1), number of taxa with only one or two individuals in the entire pool of samples (Chao1), set of proportions of samples that contain each species (Bootstrap), and a parametric model (Michaelis-Menton) (Colwell and Coddington, 1994; Clarke and Gorley, 2006; Colwell, 2006). For dip net subsamples, eight taxa represented 58.7 percent of all specimens recorded: *Hyalella azteca* complex (19.6 percent), *Amnicola dalli* (12.2 percent), *Gammarus* cf. *tigrinus* (6.8 percent), cf. *Aphaostracon* sp. (5.6 percent), *Limnodrilus hoffmeisteri* (5.1 percent), *Gammarus mucronatus* complex (5.0 percent), Hydrobiidae sp. (3.6 percent), and cf. *Tarebia* sp. (3.3 percent). For ponar samples, eight taxa as mean abundance across samples for each spring represented 62.2 percent of specimens recorded: Hydrobiidae sp. (21.4 percent), *Hyalella azteca* complex (12.0 percent), *Amnicola dalli* (11.2 percent), immature tubificoid Naididae sp. (7.0 percent), cf. *Tarebia* sp. (4.2 percent), *Gammarus* cf. *tigrinus* (3.2 percent), and *Spilochlamys gravis* (3.2 percent).

Differences in assemblages among springs were attributable to both natural dissimilarity in community structure and to variation in ecological conditions among sites. Diversity indices for benthic macroinvertebrates collected by petite ponar dredge and dip net are summarized in tables 4 and 5. Pielou's evenness index and mean Shannon-Wiener (ln) diversity index for each spring are shown in figure 56. For combined gears, greatest diversity was represented in samples from Rock, Bugg, and Silver Glen Springs, with Bugg Spring also exhibiting greatest evenness. Apopka Spring had the lowest diversity and evenness. The SCI values and percent

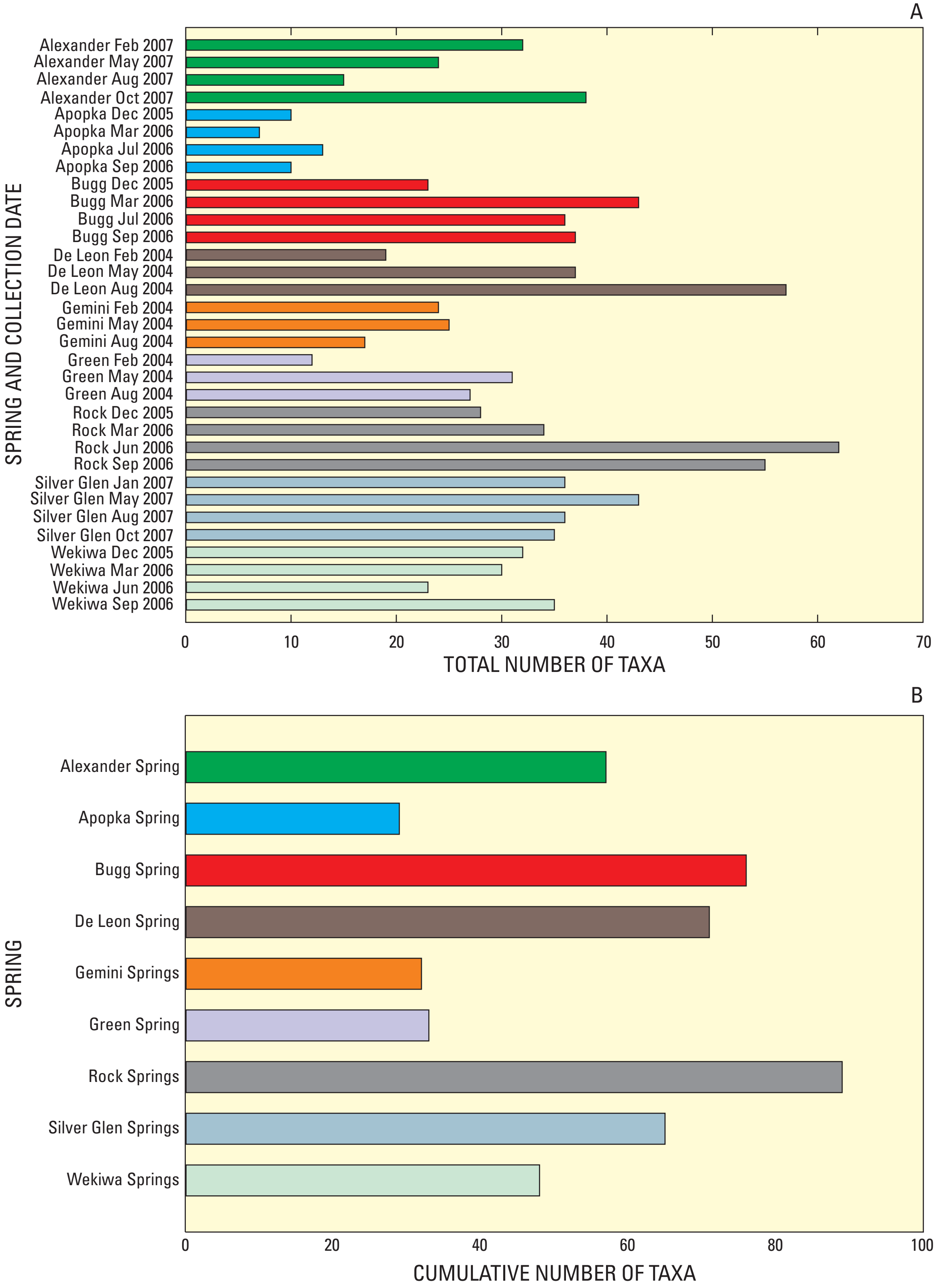


Figure 53. Number of macroinvertebrate taxa collected by dip net and petite ponar dredge from selected springs of the St. Johns River drainage, 2004-07. Taxa are shown by (A) date (month and year) and (B) cumulative number per spring.

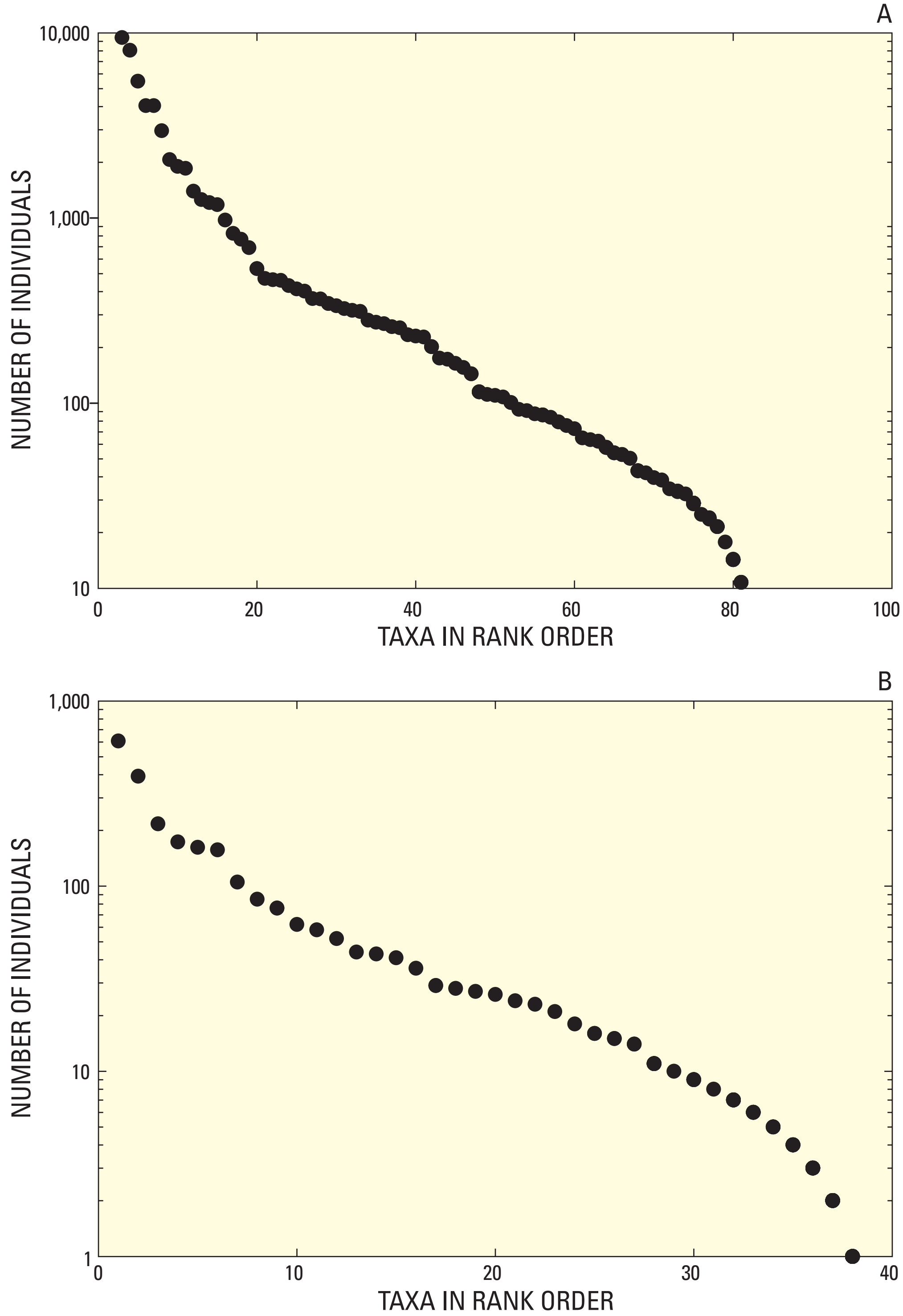


Figure 54. Lognormal ranked species abundance curves for macroinvertebrate taxa collected by (A) petite ponar dredge and (B) dip net from springs in the St. Johns River drainage, 2004-07. Number of individuals for ponar samples are from means pooled by spring. Dip-net data are based on raw numbers.

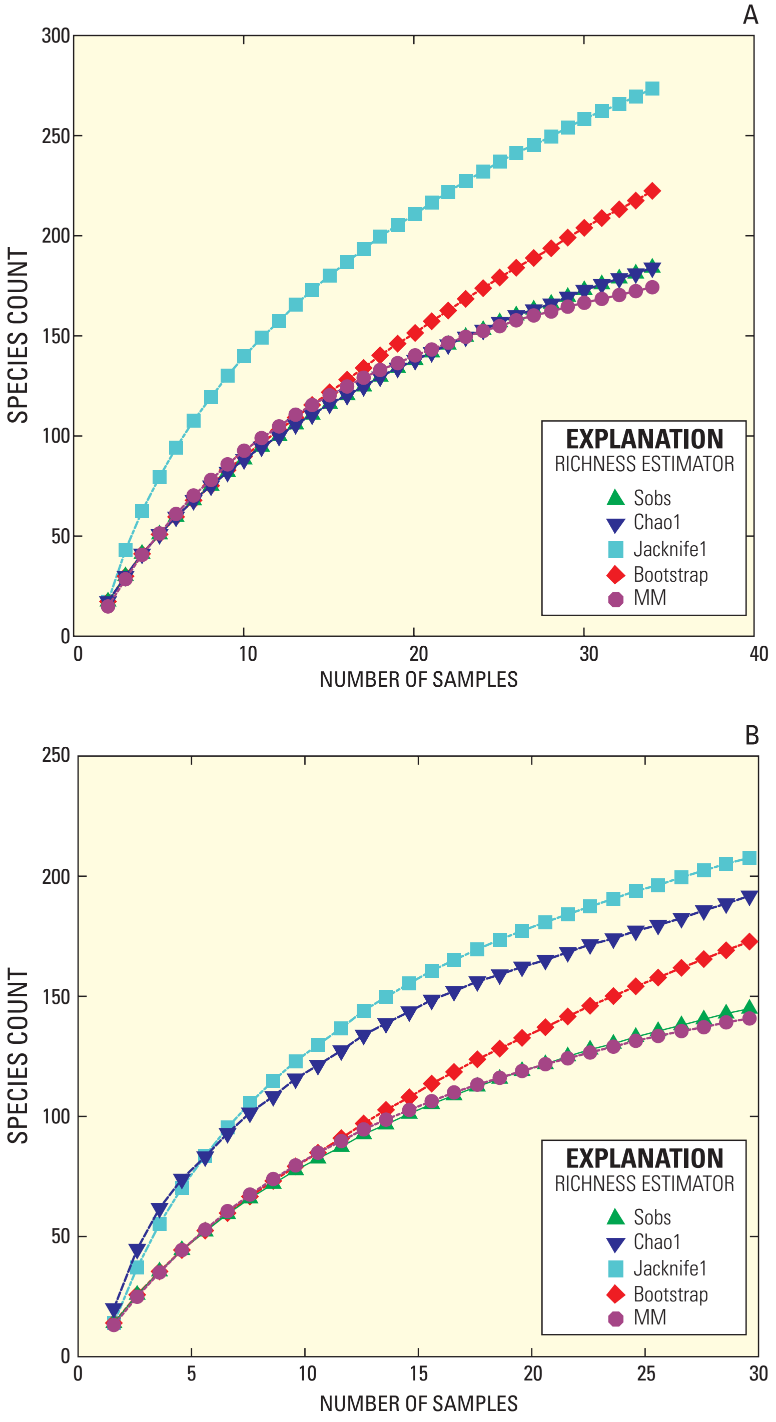


Figure 55. Species accumulation curves for macroinvertebrates collected by (A) petite ponar dredge and (B) dip net from springs of the St. Johns River drainage, 2004-07. Richness estimators are as follows: Sobs, observed number of taxa in sample; Chao1, Jacknife 1, and Bootstrap are nonparametric models; MM (Michaelis-Menten) is a parametric model (see text).

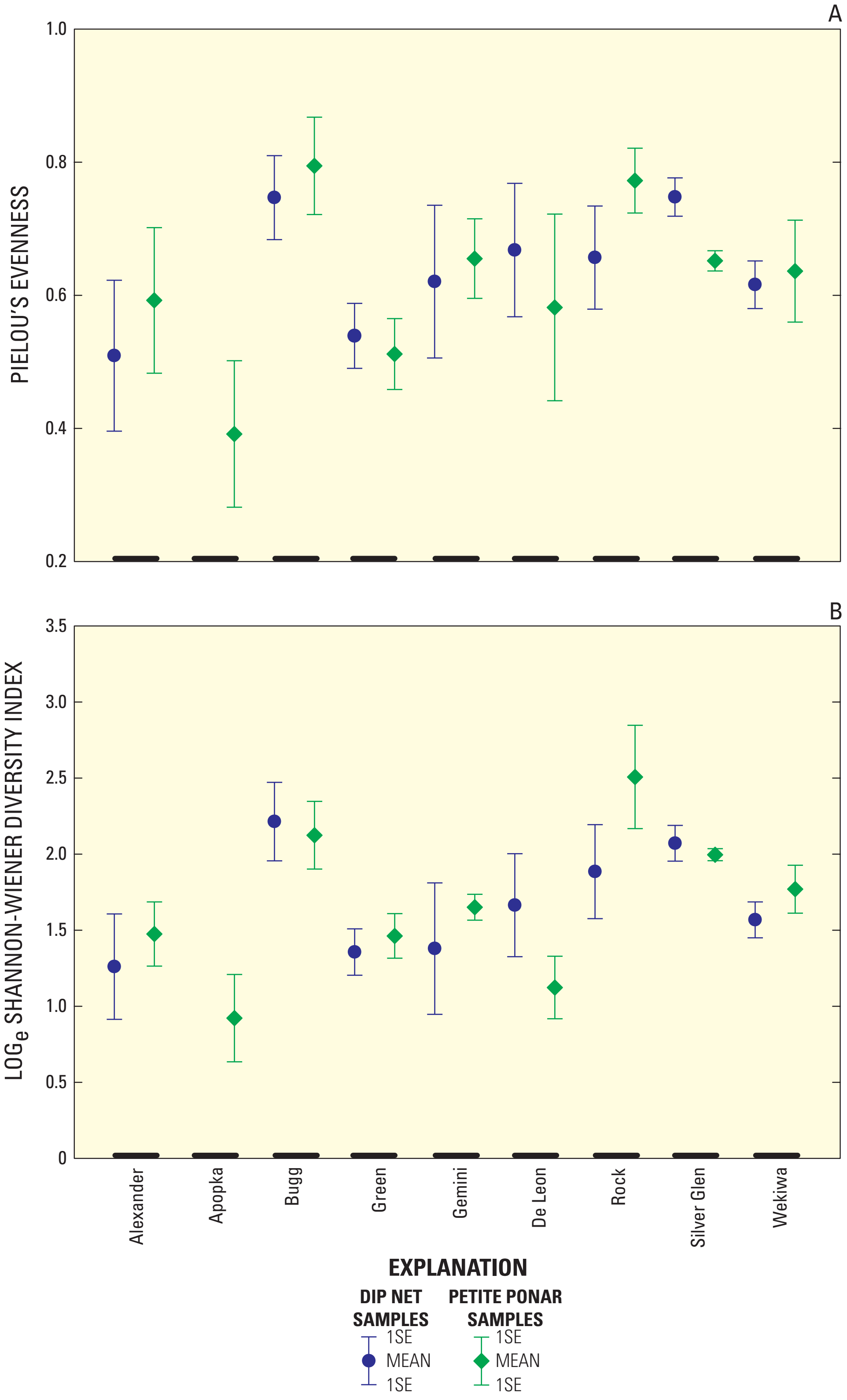


Figure 56. (A) Pielou's evenness (J') and (B) $\log_e$ Shannon-Wiener diversity index (H') for macroinvertebrate samples from selected springs of the St. Johns River drainage, 2004-07. SE is standard error.

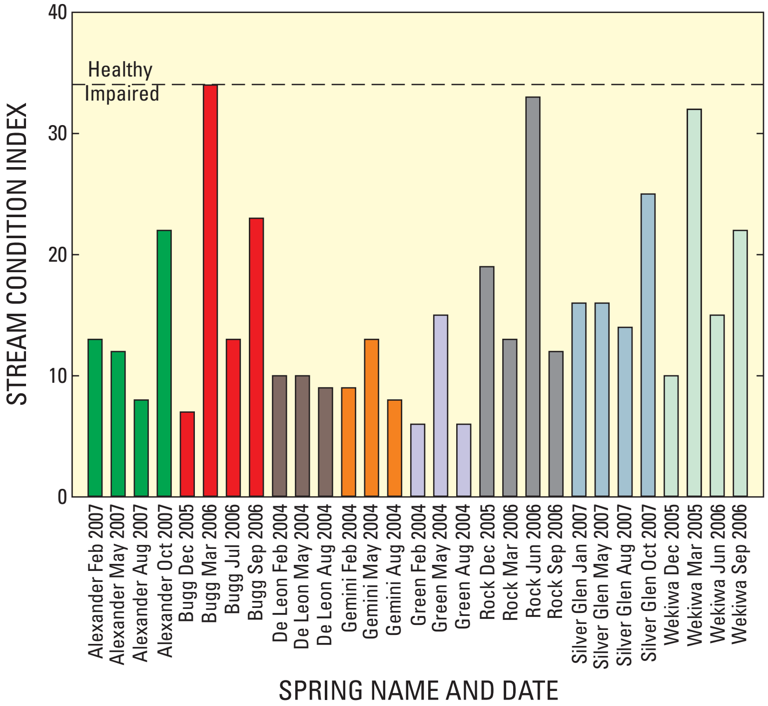


Figure 57. Stream Condition Index (SCI) values for dip net samples of macroinvertebrates collected from selected springs of the St. Johns River drainage, 2004-07. Horizontal dashed line indicates SCI value separating categories classified as “impaired” (0-34) and “healthy” (35-70) as recognized by the Florida Department of Environmental Protection (Fore and others, 2007).

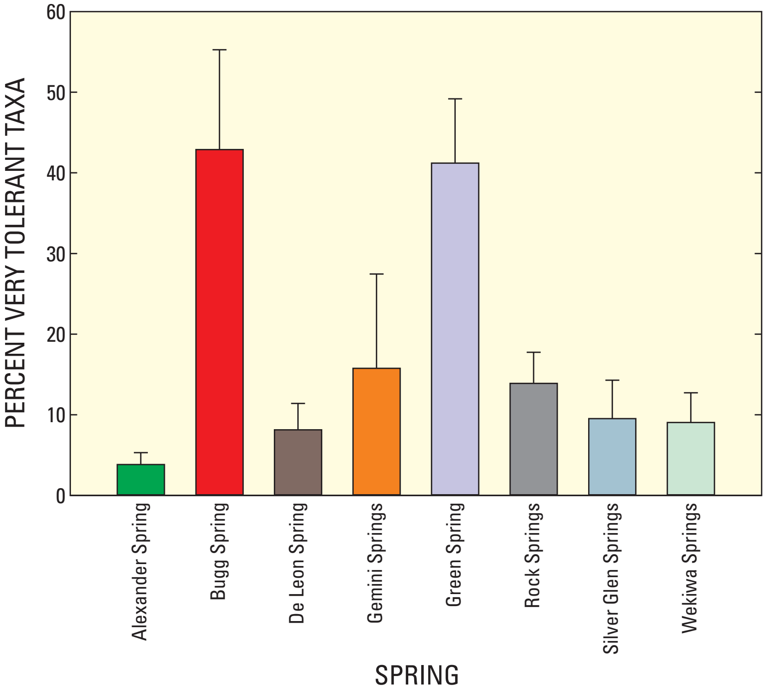


Figure 58. Percent very tolerant macroinvertebrate taxa collected by dip net from selected springs of the St. Johns River drainage, 2004-07. Solid bars represent means +1 SE (vertical line) for 3-4 samples per spring. SE is standard error.

very tolerant taxa per spring and date are summarized in table 5, and figures 57 and 58. The SCI scores for all dip net samples ranged from 6 to 34, and thus, fell within the “impaired” category as recognized by the FDEP (Fore and others, 2007). Mean percent very tolerant taxa values ranged from less than 4 percent for Alexander Spring to greater than 40 percent for Bugg and Green Springs (fig. 58).

Multivariate Analysis of Spring Communities and Environmental Parameters—Mean dip net data across sampling dates for each spring were analyzed for relationships between benthic macroinvertebrate assemblages and environmental parameters. An agglomerative hierarchical cluster analysis of Bray-Curtis similarities derived from square-root transformed means (fig. 59) and a nonmetric multidimensional scaling (MDS) plot of the same data matrix (fig. 60) indicated two major groupings of springs, each with two sub-clusters consisting of paired springs: [(Alexander + Silver Glen) + (Rock + Wekiwa)] and [(Bugg + De Leon) + (Green + Gemini)].

Median values of environmental data for each spring (table 3) were examined using draftsman plots in PRIMER® to identify correlated variables. Specific conductance, Ca, Mg, Na, K, Cl, total dissolved solids, and gypsum saturation index were highly correlated (*r* greater than 0.95); therefore, all of these variables except specific conductance were omitted from the data matrix prior to principal components analysis (PCA).

A PCA plot of the normalized data matrix of environmental variables indicated similar groupings of paired springs corresponding to the assemblage cluster plot, but with different separation of sub-clusters along the horizontal axis (principal component 1; PC1), the vertical axis (principal component 2; PC2), or both (fig. 61). Cumulative percent variation on the first three principal components was 46.6 percent, 75.0 percent, and 91.4 percent, respectively. Loadings on the first two principal components were relatively low. Factors with greatest positive loadings on PC1 were specific conductance (0.367), SiO_2 (0.363), dolomite saturation index (0.350), o-PO_4 (0.336), and log pCO_2 (0.330); greatest negative loadings on PC1 were temperature (-0.368), HCO_3 (-0.281), and NO_2-NO_3-N (-0.266). Factors with greatest positive loadings on PC2 were calcite saturation index (0.491) and NO_2-NO_3-N (0.350); greatest negative loadings on PC2 were pH (-0.486), mean discharge (-0.431), and dissolved oxygen (-0.214). The BioEnv (“Best”) procedure of PRIMER® was used to perform 99 random permutations of sample combinations, linking the environmental data with the assemblage matrix. The resulting ranked Spearman correlation (ρ) value was significant ($p \leq 0.01$), indicating concordance in multivariate patterns observed between the data sets. Greatest agreement ($r > 0.80$) between the MDS assemblage ordination and the PCA of environmental variables was attributed to combinations of SO_4 + SiO_2 + mean discharge (0.813), followed by specific conductance + SO_4 + mean discharge (0.804).

Fishes

A total of 45 species of fishes representing 35 genera and 23 families were collected from target springs in this study (app. 2). Greatest species richness was within the Centrarchidae, Cyprinidae, Ictaluridae, Fundulidae, and Poeciliidae. Greatest relative abundance, accounting for over 85 percent of more than 3,800 specimens collected or observed, was limited to five families: Centrarchidae (23.7 percent), Cyprinidae (21.9 percent), Fundulidae (14.5 percent), Atherinopsidae (13.8 percent), and Poeciliidae (12.4 percent) (fig. 62). Eight species accounted for 68.9 percent of fish specimens collected or observed among all springs: *Notropis petersoni* (16.0 percent), *Menidia beryllina* (12.5 percent), *Lepomis macrochirus* (10.4 percent), *Lucania parva* (7.2 percent), *Gambusia holbrooki* (7.1 percent), *Lucania goodei* (5.7 percent), *Morone saxatilis* (5.3 percent), and *Poecilia latipinna* (4.8 percent). However, relative abundances (as percent composition of samples) of *N. petersoni*, *M. beryllina*, *L. parva*, *L. goodei*, and *M. saxatilis* were skewed due to intensive sampling at Alexander Spring and visual observations at Silver Glen Springs.

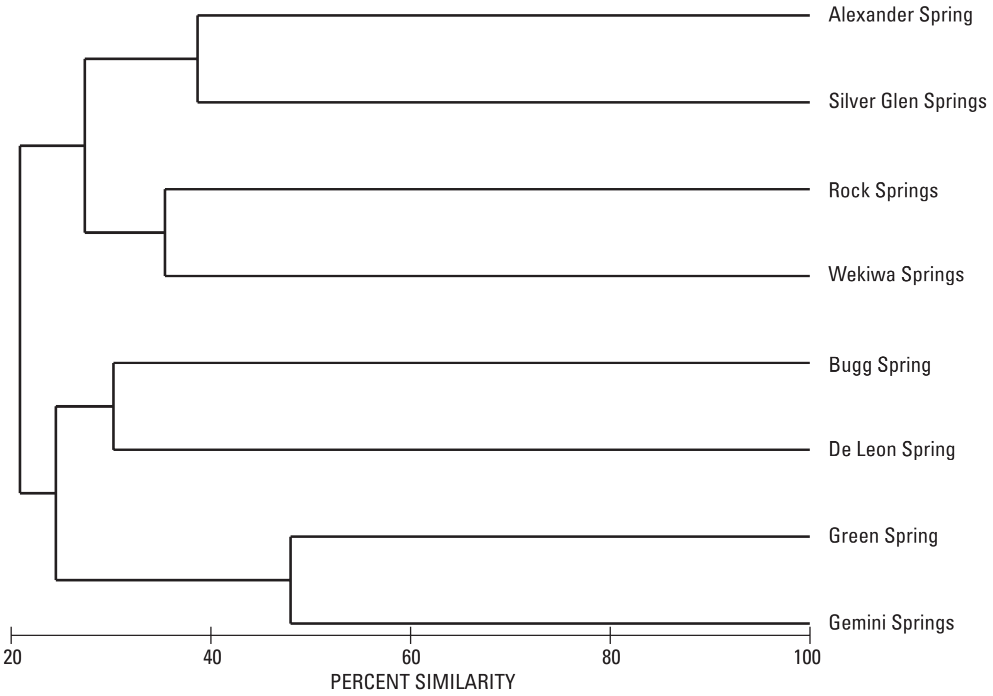


Figure 59. Agglomerative hierarchical cluster of selected springs in the St. Johns River drainage based on square-root transformed Bray-Curtis similarity values of macroinvertebrates collected by dip net, 2004-07.

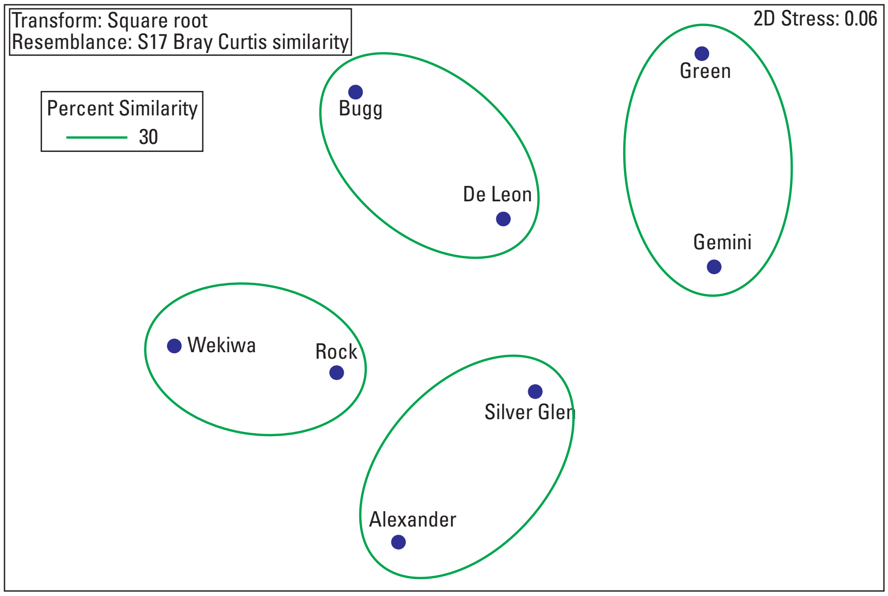


Figure 60. Nonmetric multidimensional scaling ordination based on Bray-Curtis similarity values derived from square-root transformed means of macroinvertebrate samples collected by dip net from selected springs in the St. Johns River drainage, 2004-07. Ellipses indicate springs clustered at 30 percent similarity; stress values less than 0.1 are considered a measure of good fit (Clarke and Warwick, 2001; Clarke and Gorley, 2006).

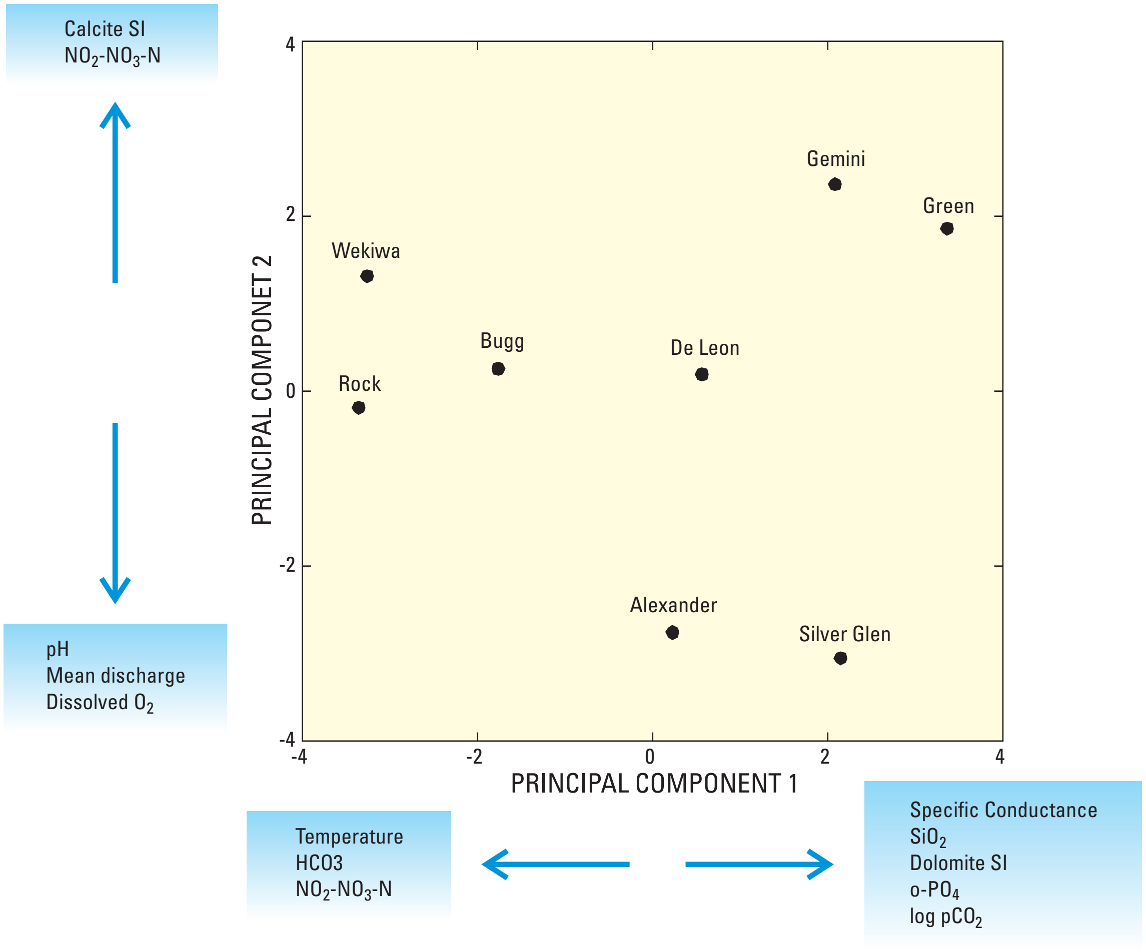


Figure 61. Principal components analysis (PCA) scatter plot of environmental variables for selected springs of the St. Johns River drainage. Variables shown on the PC axes are those that loaded most heavily (described in text).

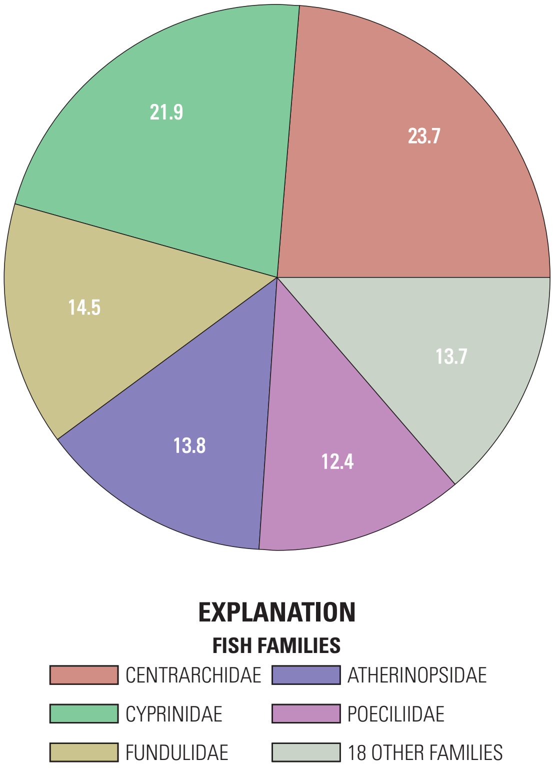


Figure 62. Relative abundance (as percent composition of collective samples) of fish families in springs of the St. Johns River drainage surveyed in 2004-07.

Concluding Discussion

The SJRWMD identified the following nine springs for this study based on priorities for establishing or evaluating minimum flows and levels (MFLs): Alexander, Apopka, Bugg, De Leon, Gemini, Green, Rock, Silver Glen, and Wekiwa Springs. Three additional springs (Fern Hammock, Juniper, and Silver Springs) were included, based on ancillary data collection for water chemistry and discharge parameters as part of a separate study for the FDEP or other investigations in progress. This report augments existing information and compiles additional baseline data to assist the SJRWMD in developing guidelines for a long-term strategy for evaluating, monitoring, and protecting these springs.

Springs of the St. Johns River drainage examined herein exhibit a wide range of physical, chemical, and biological characteristics that are representative of springs in north-central Florida. Much of the variation observed from data collected and compiled for these springs is reflected in (1) diverse natural characteristics, ranging from large, first-magnitude springs with substantial discharge and springshed area (such as Silver and Silver Glen Springs) to those with smaller recharge areas (such as Gemini and Green Springs), (2) land-use within each springshed, (3) differences in water chemistry, and (4) composition of the biological communities. Current land use within the springsheds examined varies from being predominately forested (Bugg, Silver Glen, and Wekiwa), agricultural (Apopka), to mixed (all others). Notable land-use changes over the 30-year period of record were documented for all springsheds except Fern Hammock, Juniper, and Silver Glen, which remain mostly forested. Urban lands increased substantially within the Alexander, Gemini, and Wekiwa springsheds, and to a lesser extent, in the Apopka, De Leon, Green, and Rock springsheds. The increase in urban lands was accompanied by a considerable loss of forested lands in the De Leon, Gemini, and Green springsheds, whereas forested lands remained relatively unchanged in the Alexander, Silver Glen, and Wekiwa springsheds. Although the Apopka springshed lost virtually all forested lands during the last 35 years, this land-use category composed a small percentage of total land use in 1973 within that springshed. Among the springsheds combined, most land-use changes over time correspond to increased loss of forested, open/wetland, and agricultural lands accompanied by increased conversion to urban lands within large corridors of the St. Johns River drainage. However, some exceptions to this general trend were noted; specifically, the Gemini and Green springsheds gained open/wetland lands, and agricultural lands increased in the De Leon and Silver Glen springsheds, although by a relatively small percentage for the latter.

Land-use changes and accompanying increases in water withdrawals are presumed to be important factors affecting the diminished discharge for some of these springs. Past and future trends of increased consumptive use can be expected to contribute to changes in ground-water quantity and quality within portions of the basin, and these changes are likely to be accompanied by ecological effects.

Four primary water types ($Ca\text{-}HCO_3$, $Ca\text{-}Mg\text{-}HCO_3$, mixed, and Na-Cl) were identified in the springs included in this study based on the composition of major ions. Most springs were of the $Ca\text{-}Mg\text{-}HCO_3$ water type (Apopka, Fern Hammock, Juniper, Rock, and Wekiwa Springs). Bugg and Silver Springs had a $Ca\text{-}HCO_3$ water type, De Leon Spring and De Leon run had a mixed water type, and four springs (Alexander, Gemini, Green, and Silver Glen Springs) had a Na-Cl water type. Early classifications of Florida springs based on water chemistry included those of Whitford (1956) and Slack and Rosenau (1979). To provide finer resolution, Woodruff (1993) used an average linkage cluster analysis to compare 170 Florida springs based on ionic composition and recognized four major water types: low ionic, calcium bicarbonate, mixed, and salt. The study further recognized three types within the $Ca\text{-}HCO_3$ category: low ($Ca \leq 20$ mg/L; $HCO_3 \leq 75$ mg/L), medium ($Ca \leq 45$ mg/L; $HCO_3 \leq 150$ mg/L), and high ($Ca \leq 75$ mg/L; $HCO_3 \leq 255$ mg/L). According to the Woodruff (1993) classification scheme, springs examined in this study belong to the following categories: low $Ca\text{-}HCO_3$ (Apopka, Fern Hammock, and Juniper Springs); medium $Ca\text{-}HCO_3$ (Bugg, Rock, and Wekiwa Springs); high $Ca\text{-}HCO_3$ (Silver Springs); mixed (Alexander and De Leon Springs), and salt (Green, Gemini, and Silver Glen Springs). The terminology used herein utilizes a trilinear plot that explicitly separates springs based on combinations of all major ions. Nevertheless, it is useful to recognize springs in general terms that are meaningful relative to major characteristics; for example, calcium-bicarbonate or salt, insofar as distinguishing larger groupings based on other factors such as their biotic assemblages. The classification scheme of Woodruff (1993) was associated with karstic geology and geography; salt and mixed springs emerge nearer coastal regions, whereas calcium-bicarbonate springs are more typical of river down-cutting areas (such as the Suwannee River), although all three partially overlap in distribution.

Increased nutrient input to Florida springs is the single greatest threat to the ecology of these systems. In particular, nitrate-N loading has been identified for many springs (Brown and others, 2008), where it promotes eutrophication (Stevenson and others, 2007) and can have direct toxic as well as sublethal effects on aquatic organisms (Guillette and Edwards, 2005; Edwards and Guillette, 2007; Mattson and others, 2007; Jacoby and others, 2008). Waters with nitrate levels above about 0.2 mg/L are considered to be enriched by human activities (Toth, 1999; Cohen and others, 2007). Based on a review of the literature, Mattson and others (2007) reported nitrate toxicity threshold minima of 0.23, 1.1, and 5 mg/L NO_3-N for invertebrates, fishes, and amphibians, respectively. Mattson and others (2007) suggested that nitrate levels found in Rock Springs Run may contribute to chironomid larval mortality and may be chronically toxic to caddisflies and the amphipod *Hyalella* sp. Because these macroinvertebrates are important food sources as both larvae and adults for a variety of animals, there are implications of broad adverse effects on spring system food webs in general.

As noted by these authors, food-web related effects may result from interactions between grazers and primary producers, especially periphytic and filamentous algae. Therefore, nitrate enrichment may have bottom-up effects (greater nutrient levels promoting algal growth), top-down effects (reduced grazer abundance or activity allowing for greater algal growth and biomass), or a combination of both.

Nitrate concentrations varied spatially among springs examined in this study, and temporally within several springs. For the springs examined in this study, only Apopka Spring had a median nitrate level above 2 mg/L; however, several of the springs exhibited nitrate levels elevated over presumed historical levels, and in some cases showed spikes in nitrate concentration. Lowest median nitrate levels were observed for Alexander, Fern Hammock, Green, Juniper, and Silver Glen Springs, all below 0.1 mg/L. The low levels for these springs are likely due to their location within the Ocala National Forest (except for Green Spring). Gemini, Rock, and Wekiwa Springs had median levels above 1.0 mg/L. Bugg and De Leon Springs had median levels between 0.5 and 1.0 mg/L. Nitrate concentrations showed a statistically significant ($p < 0.05$) increasing trend with time in water samples from Apopka, Fern Hammock, Gemini run, and Juniper Springs. Conversely, several other springs showed a statistically significant ($p < 0.05$) decreasing trend with time (Alexander, Bugg run, Rock and Wekiwa Springs). Phosphorus concentrations generally were low and relatively constant over time for most springs. However, water from Juniper Springs showed a statistically significant increase in phosphorus with time, whereas other spring waters showed statistically significant decreasing phosphorus trends with time (Apopka, De Leon, Rock, Silver Glen, and Wekiwa Springs). In many cases, these trends are based on limited sampling data, and continued sampling for phosphorus compounds would be desirable for establishing trends over time.

Spring-water ages and residence times of water discharging from springs were estimated using measured concentrations of various transient tracers in water samples. These tracers have been released into the atmosphere during the past 50 years as CFCs, SF_6, ^3H, and ^3He (the decay product of tritium). Concentrations of the various tracers in spring waters are consistent with various mixtures of young and old waters. For example, waters from Juniper and Silver Glen Springs are a mixture of 60 to 80 percent old (tracer-free) water (greater than 60 years), with 20 to 40 percent young water (recharged after 1980). In contrast, water from Alexander, De Leon, and Wekiwa Springs contains mixtures that are dominated by young waters, and waters discharging from these springs have residence times that are 20 years or less.

Springs of the St. Johns River drainage harbor unique assemblages of benthic macroinvertebrates. In this study, considerable variation in richness, diversity, and abundance was documented among springs as well as between independent samples from each spring. Based on combined gear types used to collect benthic macroinvertebrates, a total of approximately 249 taxa were identified among all springs surveyed: 60 taxa were limited to dip net samples, 84 to petite ponar samples, and 105 were common to both. Cumulative number of taxa pooled among samples per spring ranged from 29 to 89 in Apopka and Rock Springs, respectively. Greatest taxonomic richness and diversity was found in Alexander, Bugg, De Leon, Rock, Silver Glen, and Wekiwa Springs, whereas lowest was in Apopka, Gemini, and Green Springs. Bugg, Rock, and Silver Glen Springs exhibited the greatest diversity and evenness for dip net and ponar samples combined. For most of the springs, relatively few taxa dominated dip net and petite ponar samples as either percent composition or abundance (density as organisms per square meter). Eight taxa represented 58.7 percent of all subsampled individuals for combined dip net samples across all springs. Eight taxa, as mean abundance across samples for each spring, represented 62.2 percent of specimens recorded from petite ponar samples. Collectively, the benthic macroinvertebrate fauna was dominated by gastropods, amphipods, oligochaetes, and dipterans.

The gastropod fauna of the St. Johns River drainage, especially species of the family Hydrobiidae, is notable due to endemism of many taxa, some of which are confined to a single spring (Walsh, 2001; Thompson, 2004; Shelton, 2005). Hydrobiid snails are diminutive and require special preservation methods and expertise in identification; therefore, many of the specimens collected in the present study were provisionally identified only to genus or family. *Spilochlamys gravis* is restricted in distribution to the mid- to upper St. Johns River; we collected this species, or specimens identified as cf. *Spilochlamys* sp., from Alexander Spring, where this taxon dominated both dip net and petite ponar samples, and Silver Glen Springs. Shelton (2005) also reported *S. gravis* from Rock and Wekiwa Springs; it is possible that this species was represented among the numerous unidentified hydrobiids collected from these springs during this study. *Floridobia alexander* is endemic to Alexander Spring; no specimens explicitly identified as this taxon were collected, although a large number of hydrobiids from petite ponar samples were not identified below family level. *Floridobia petrifons* is endemic to Rock Springs, and in the current study, specimens of cf. *Floridobia* sp. were collected from Rock Springs in petite ponar samples from September 2006. *Aphaostracon pycnum* is endemic to Alexander and Silver Glen Springs, and specimens identified as cf. *Aphaostracon* sp. were recorded from both of these springs. *Floridobia wekiwae* and *Aphaostracon monas* are endemic to Wekiwa Springs; in this study, both species were collected in low numbers in dip net samples, and were absent in petite ponar samples on three of the four sampling dates, but were collected using this gear in September 2006. Shelton (2005) did not report any rare or endemic snails from Apopka Spring, although specimens of cf. *Floridobia* sp. were collected in this study in July 2006. None of the other rare taxa reported by Shelton (2005) were documented from the same springs in this study.

The Silver Glen Springs benthic macroinvertebrate fauna exhibits unique characteristics in comparison to other springs examined in this study. Several species were collected that are typically associated with estuarine or nearshore habitats: the amphipods *Gammarus mucronatus* complex, *G*. cf. *tigrinus*, *Grandidierella bonnieroides*, and unidentified species of the family Aoridae; the isopods *Cassidinidea ovalis* and *Uromunna reynoldsi*; and the decapod *Palaemonetes vulgaris*. The water chemistry of Silver Glen Springs accounts for the presence of these taxa, particularly the high specific conductance and ionic content, with high values of Na, Ca, Cl, and SO_4. Although Alexander Spring exhibits similar water chemistry as Silver Glen Springs, only two of the taxa previously mentioned (*G*. cf. *tigrinus* and *C. ovalis*) were collected from both springs. Nevertheless, the grouping of these two springs in the multivariate ordinations of community assemblage and water chemistry indicates that their biotas are strongly influenced by the latter, especially the high degree of mineralization within the aquifer (Katz, 1992) and connate relict saltwater reserves within this part of the basin.

The importance of water chemistry in structuring the benthic macroinvertebrate communities of the springs examined in this study was further evidenced by results of the ordination analyses. Alexander and Silver Glen Springs were separated from the other springs on principal components that loaded most negatively for pH, dissolved O_2, and discharge. Gemini and Green Springs clustered together and loaded positively for several parameters, including nitrate and specific conductance. Gemini and Green Springs may also show faunistic similarities due to their geographic location, isolation, and low-flow characteristics. Rock and Wekiwa Springs clustered together and were separated from the other springs on the basis of negative principal component loadings for temperature and median concentrations of bicarbonate and nitrate. Bugg and De Leon Springs clustered together and were generally intermediate among other springs for loadings on the physical and chemical parameters. Further study is needed to elucidate the assemblage patterns and to identify the full suite of environmental parameters that characterize or influence the faunal composition of these springs.

The characterization of Florida springs as chemostatic systems (Odum, 1957) has been challenged over time with accumulation of long-term data sets and evidence of fluxes in water chemistry. Although changes involving such parameters as dissolved oxygen or total dissolved solids may not be unexpected based on diel variation or under different flow regimes (Munch and others, 2006), changes in ion concentrations or their ratios over time may be more subtle, yet potentially could affect ecological conditions. In addition to nitrate-N concentrations, which have demonstrable ecological effects (Brown and others, 2008), changes in other ion constituents are of interest in monitoring springs and their biological communities relative to establishing or assessing MFLs. Considering the importance of water chemistry in structuring benthic macroinvertebrate assemblages (and other fauna and flora), potential long-term changes in discharge that can alter historical conditions, such as increased salinity, have potential consequences for aquatic communities.

The SCI values for all samples in this study fell within the "impaired" category as recognized by the FDEP (Fore and others, 2007). Beginning in 2000, the FDEP has conducted regular water-quality monitoring at 18 major springs in north-central Florida, including 5 of the springs sampled in this study (Florida Department of Environmental Protection, 2007). As part of the FDEP monitoring program, benthic macroinvertebrate communities are assessed at most of the sites using the SCI protocol. Results of FDEP springs monitoring are summarized as "EcoSummaries," and made available online (*http://www. dep.state.fl.us/*, accessed October 1, 2008). Similar to the results of this study, FDEP scored many of the same springs as "impaired" based on SCI evaluations. It is possible that low SCI values for many of these springs may be attributable to individual metrics within the SCI scoring procedure that are strongly affected by community characteristics. For example, hydrobiid snails can exert strong dominance, yet they are not considered to represent impaired conditions. In the case of springs considered to be good reference sites in this study, Alexander and Silver Glen, SCI scores indicating impairment could be due, in part, not only to the abundance of hydrobiids, but also to the high specific conductance and low dissolved oxygen, both factors that would reduce the number of sensitive organisms (Florida Department of Environmental Protection, 2007). Samples from all springs in this study contained very few sensitive taxa (as listed by the FDEP; *http://www.dep.state.fl.us/labs/cgi-bin/sbio/keys.asp#keys*, accessed October 1, 2008).

Taxonomic richness of fish assemblages observed at each of the springs varied from 2 species in Green Spring to 29 species in Alexander Spring. For most of the springs it is likely that taxonomic richness was underestimated due to limited sampling efforts and habitat inaccessibility. A combined total of 45 fish species, representing 35 genera of 23 families, was collected from all springs. Fish communities of the springs in this study were dominated by centrarchids (23.7 percent), cyprinids (22.0 percent), fundulids (14.5 percent), atherinopsids (13.9 percent), and poeciliids (12.4 percent). The communities studied were characteristic of springs throughout north-central Florida and shared species composition and relative abundances similar to those of many others surveyed by Walsh and Williams (2003). Green Spring showed very low richness and abundance, likely due to its isolation and unusual water chemistry, most notably its high hydrogen sulfide content. Gemini Springs also had relatively low richness and abundance, probably due in part to its isolation from the mainstem St. Johns River by an artificial weir. The large magnitude springs generally had the greatest taxonomic richness as well as overall biomass of fishes. Silver Glen Springs was most notable among these; large numbers of striped bass (*Morone saxatilis*) were observed in the spring pool, as were schools of striped mullet (*Mugil cephalus*). As with the benthic macroinvertebrate fauna, Silver Glen Springs also supports a characteristic fish assemblage. Three species were observed that are most commonly associated with salt water but are known to penetrate into inland Florida waters, especially springs:

Atlantic needlefish (*Strongylura marina*), gray snapper (*Lutjanus griseus*), and naked goby (*Gobiosoma bosc*). The inland silverside (*Menidia beryllina*) was collected from Alexander Spring but not from Silver Glen Springs, although it is likely to occur in the latter and was probably undetected due to sampling limitations. Although striped bass populations in the St. Johns River are augmented by artificial stocking, this species is native and presumably utilized many springs historically as thermal refugia; the striped bass is considered to be potadromous or diadromous in that it migrates seasonally within river systems and estuaries. Fish surveys conducted during this study confirmed that two nonindigenous species, the vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*) and brown hoplo (*Hoplosternum littorale*), continue to increase their range and population size throughout the St. Johns River drainage. Blue tilapia (*Oreochromis aureus*) is also widely established throughout the watershed. Other reported nonindigenous species require further survey and monitoring.

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Appendixes 1-5

Appendix 1. Macroinvertebrate taxa collected by dip net (D) and petite ponar dredge (P) from selected springs in the St. Johns River drainage, 2004-07.

[Authorities are listed for lowest practicable identification level (LPIL) indicated. Taxa are listed in approximate phylogenetic order by suprafamilial categories and alphabetically by genus and species]

Phylum	Class	Order	Family	Taxon	Authority	D	P
Porifera	--	--	--	Porifera (LPIL)	Grant 1836		x
Porifera	Demospongiae	Haplosclerida	Spongillidae	*Ephydatia* sp.	Lamouroux 1816		x
Porifera	Demospongiae	Haplosclerida	Spongillidae	*Spongilla* sp.	Lamarck 1816		x
Cnidaria	Hydrozoa	Anthoathecatae	Hydridae	*Hydra* sp.	Linnaeus 1758		x
Platyhelminthes	Turbellaria	Tricladida	--	Tricladida (LPIL)	--	x	x
Platyhelminthes	Turbellaria	--	--	Turbellaria (LPIL)	--	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	*Amnicola dalli*	(Pilsbry and Beecher 1892)	x	x
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ancylidae (LPIL)	--		x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	*Aphaostracon monas*	(Pilsbry 1899)	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	*Aphaostracon* sp.	Thompson 1968	x	x
Mollusca	Gastropoda	Architaenioglossa	Viviparidae	*Campeloma floridense*	Call 1886		x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	cf. *Amnicola dalli*	(Pilsbry and Beecher 1892)	x	
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	cf. *Aphaostracon* sp.	Thompson 1968	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	cf. *Floridobia* sp.	Thompson and Hershler 2002	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	cf. *Notogillia wetherbyi*	(Dall 1885)		x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	cf. *Pyrgophorus platyrachis*	Thompson 1968		x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	cf. *Spilochlamys* sp.	Thompson 1968	x	
Mollusca	Gastropoda	Neotaenioglossa	Thiaridae	cf. *Tarebia* sp.	H. Adams and A. Adams 1854	x	x
Mollusca	Gastropoda	Neotaenioglossa	Pleuroceridae	*Elimia floridensis*	(Reeve 1860)		x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	*Floridobia wekiwae*	(Thompson 1968)	x	x
Mollusca	Gastropoda	Basommatophora	Physidae	*Haitia cubensis*	(Pfeiffer 1839)	x	
Mollusca	Gastropoda	Basommatophora	Physidae	*Haitia* sp.	Taylor 2003	x	x
Mollusca	Gastropoda	Basommatophora	Ancylidae	*Hebetancylus excentricus*	(Morelet 1851)	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	Hydrobiidae (LPIL)	Simpson 1865	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	Hydrobiidae sp. C Line	Simpson 1865	x	x
Mollusca	Gastropoda	Basommatophora	Ancylidae	*Laevapex peninsulae*	(Pilsbry 1903)		x
Mollusca	Gastropoda	Basommatophora	Ancylidae	*Laevapex* sp.	Walker 1903	x	x
Mollusca	Gastropoda	Neotaenioglossa	Thiaridae	*Melanoides* sp. (immature)	Olivier 1804	x	x
Mollusca	Gastropoda	Neotaenioglossa	Thiaridae	*Melanoides tuberculata*	(Müller 1774)	x	x
Mollusca	Gastropoda	Neotaenioglossa	Thiaridae	*Melanoides turricula*	(Lea 1862)	x	x
Mollusca	Gastropoda	Basommatophora	Planorbidae	*Micromenetus floridensis*	(Baker 1945)		x
Mollusca	Gastropoda	Basommatophora	Planorbidae	*Planorbella scalaris*	(Jay 1839)	x	x
Mollusca	Gastropoda	Basommatophora	Planorbidae	*Planorbella trivolvis intertexta*	(Sowerby 1878)	x	
Mollusca	Gastropoda	Architaenioglossa	Ampullariidae	*Pomacea paludosa*	(Say 1829)	x	x
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	*Pyrgophorus platyrachis*	Thompson 1968	x	
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	Rissoidea (LPIL)	--	x	
Mollusca	Gastropoda	Neotaenioglossa	Hydrobiidae	*Spilochlamys gravis*	Thompson 1968	x	x
Mollusca	Gastropoda	Architaenioglossa	Viviparidae	*Viviparus georgianus*	(Lea 1834)	x	x
Mollusca	Bivalvia	--	--	Bivalvia (LPIL)	Linnaeus 1758	x	x
Mollusca	Bivalvia	Veneroida	Pisidiidae	cf. *Musculium* sp.	Link 1807		x
Mollusca	Bivalvia	Veneroida	Corbiculidae	*Corbicula fluminea*	Müller 1774	x	
Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidiidae (LPIL)	Gray 1857	x	x
Mollusca	Bivalvia	Veneroida	Pisidiidae	*Sphaerium striatinum*	(Lamarck 1818)	x	x

Appendix 1. Macroinvertebrate taxa collected by dip net (D) and petite ponar dredge (P) from selected springs in the St. Johns River drainage, 2004-07.—Continued

[Authorities are listed for lowest practicable identification level (LPIL) indicated. Taxa are listed in approximate phylogenetic order by suprafamilial categories and alphabetically by genus and species]

Phylum	Class	Order	Family	Taxon	Authority	D	P
Mollusca	Bivalvia	Unionoida	Unionidae	*Uniomerus caroliniana*	(Bosc 1801)	x	
Mollusca	Bivalvia	Unionoida	Unionidae	*Utterbackia imbecilis*	(Say 1829)	x	
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	cf. *Actinobdella inequiannulata*	Moore 1901		x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	cf. *Helobdella fusca*	(Castle 1900)		x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	*Desserobdella phalera*	(Graf 1899)		x
Annelida	Clitellata	Arhynchobdellida	Erpobdellidae	*Erpobdella punctata*	(Leidy 1870)		x
Annelida	Clitellata	Arhynchobdellida	Erpobdellidae	Erpobdellidae (LPIL)	Blanchard 1894	x	x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	*Gloiobdella elongata*	(Castle 1900)	x	x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	Glossiphoniidae (LPIL)	Vaillant 1890	x	x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	*Helobdella fusca*	(Castle 1900)		x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	*Helobdella* sp.	Blanchard 1896	x	x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	*Helobdella stagnalis*	Linnaeus 1758	x	x
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae	*Helobdella triserialis*	(Blanchard 1849)		x
Annelida	Clitellata	--	--	Hirudinea (LPIL)	Lamarck 1818		x
Annelida	Clitellata	Arhynchobdellida	Erpobdellidae	*Mooreobdella microstoma*	(Moore 1901)		x
Annelida	Clitellata	Arhynchobdellida	Erpobdellidae	*Mooreobdella tetragon*	Sawyer and Shelley 1976	x	x
Annelida	Clitellata	Rhynchobdellida	Piscicolidae	*Myzobdella lugubris*	Leidy 1851		x
Annelida	Clitellata	Haplotaxida	Naididae	*Allonais inaequalis*	(Stephenson 1911)	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Aulodrilus pigueti*	Kowalewski 1914	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Bratislavia unidentata*	(Harman 1973)	x	
Annelida	Clitellata	Lumbriculida	Lumbriculidae	cf. *Lumbriculus* sp.	Grube 1844		x
Annelida	Clitellata	Haplotaxida	Naididae	*Chaetogaster diaphanus*	(Gruithuisen 1828)		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero botrytis*	Marcus 1943		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero digitata*	(Müller 1773)		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero digitata* complex	(Müller 1773)	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero flabelliger*	(Stephenson 1931)	x	
Annelida	Clitellata	Haplotaxida	Naididae	*Dero furcata*	(Müller 1773)		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero lodeni*	Brinkhurst 1986		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero nivea*	Aiyer 1930		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero pectinata*	Aiyer 1930	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero* sp.	Okem 1815		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero trifida*	Loden 1979		x
Annelida	Clitellata	Haplotaxida	Naididae	*Dero vaga*	(Leidy 1880)		x
Annelida	Clitellata	Lumbriculida	Lumbriculidae	*Eclipidrilus palustris*	(Smith 1900)		x
Annelida	Clitellata	Lumbriculida	Lumbriculidae	*Eclipidrilus* sp.	Eisen 1881		x
Annelida	Clitellata	Haplotaxida	Enchytraeidae	Enchytraeidae (LPIL)	--		x
Annelida	Clitellata	Haplotaxida	Naididae	*Haber speciosus*	(Hrabe 1931)		x
Annelida	Clitellata	Haplotaxida	Naididae	*Haemonais waldvogeli*	Bretscher 1900	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Ilyodrilus templetoni*	(Southern 1909)	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Limnodrilus hoffmeisteri*	Claparède 1862	x	x
Annelida	Clitellata	Lumbriculida	Lumbriculidae	*Lumbriculus* sp.	Grube 1844	x	x
Annelida	Clitellata	Lumbriculida	Lumbriculidae	*Lumbriculus variegatus*	(Müller 1774)		x
Annelida	Clitellata	Haplotaxida	Naididae	Naididae (LPIL)	--	x	x

Appendix 1. Macroinvertebrate taxa collected by dip net (D) and petite ponar dredge (P) from selected springs in the St. Johns River drainage, 2004-07.—Continued

[Authorities are listed for lowest practicable identification level (LPIL) indicated. Taxa are listed in approximate phylogenetic order by suprafamilial categories and alphabetically by genus and species]

Phylum	Class	Order	Family	Taxon	Authority	D	P
Annelida	Clitellata	Haplotaxida	Naididae	*Nais communis* complex	Piquet 1906	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Nais elinguis*	Müller 1773	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Nais* sp.	Müller 1773		x
Annelida	Clitellata	Haplotaxida	Naididae	*Nais variabilis*	Piquet 1906	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Pristina breviseta*	Bourne 1891		x
Annelida	Clitellata	Haplotaxida	Naididae	*Pristina leidyi*	Smith 1896	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Pristina* sp.	Ehrenberg 1828	x	x
Annelida	Clitellata	Haplotaxida	Naididae	*Psammoryctides convolutus*	Loden 1978		x
Annelida	Clitellata	Haplotaxida	Naididae	*Slavina appendiculata*	(D'udekem 1855)		x
Annelida	Clitellata	Haplotaxida	Naididae	*Spirosperma ferox*	Eisen 1879		x
Annelida	Clitellata	Haplotaxida	Naididae	*Spirosperma* sp.	Eisen 1879	x	x
Annelida	Clitellata	Haplotaxida	Naididae	tubificoid Naididae immature sp. A (LPIL)	--	x	x
Annelida	Clitellata	Haplotaxida	Naididae	tubificoid Naididae immature sp. B (LPIL)	--		x
Annelida	Clitellata	Haplotaxida	Naididae	*Varichaetadrilus angustipenis*	(Brinkhurst & Cook 1966)		x
Arthropoda	Arachnida	Acariformes	--	Acariformes (LPIL)	--	x	x
Arthropoda	Arachnida	Trombidiformes	Arrenuridae	*Arrenurus* sp.	Duges 1835	x	
Arthropoda	Arachnida	Trombidiformes	Hydrodromidae	*Hydrodroma* sp.	Koch 1837	x	
Arthropoda	Arachnida	Trombidiformes	Lebertiidae	*Lebertia* sp.	Neumann 1880	x	
Arthropoda	Arachnida	Trombidiformes	Limnesiidae	*Limnesia* sp.	Koch 1835	x	
Arthropoda	Arachnida	Trombidiformes	Unionicolidae	*Neumania* sp.	Trouessart 1888		x
Arthropoda	Arachnida	Trombidiformes	Pionidae	*Piona* sp.	Koch 1842		x
Arthropoda	Malacostraca	Amphipoda	--	Amphipoda (LPIL)	Latreille 1816	x	x
Arthropoda	Malacostraca	Amphipoda	Aoridae	Aoridae (LPIL)	Walker 1908	x	x
Arthropoda	Malacostraca	Amphipoda	--	Gammarida (LPIL)	Latreille 1802	x	x
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammaridae (LPIL)	Latreille 1802	x	
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus* cf. *tigrinus* LeCroy	Sexton 1939	x	x
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus mucronatus* complex LeCroy	(Say 1818)	x	x
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus* sp.	Fabricius 1775	x	x
Arthropoda	Malacostraca	Amphipoda	Aoridae	*Grandidierella bonnieroides*	Coutière 1904		x
Arthropoda	Malacostraca	Amphipoda	Hyalellidae	*Hyalella azteca* complex Lecroy	Saussure 1858	x	x
Arthropoda	Malacostraca	Isopoda	Asellidae	*Caecidotea racovitzai australis*	(Williams 1970)	x	x
Arthropoda	Malacostraca	Isopoda	Asellidae	*Caecidotea* sp.	Packard 1871	x	x
Arthropoda	Malacostraca	Isopoda	Sphaeromatidae	*Cassidinidea ovalis*	(Say 1818)	x	x
Arthropoda	Malacostraca	Isopoda	Anthuridae	*Cyathura polita*	(Stimpson 1855)		x
Arthropoda	Malacostraca	Isopoda	Asellidae	*Lirceus lineatus*	(Say 1818)	x	
Arthropoda	Malacostraca	Isopoda	Munnidae	*Uromunna reynoldsi*	(Frankenberg and Menzies 1966)		x
Arthropoda	Malacostraca	Decapoda	Cambaridae	Cambaridae (LPIL)	Hobbs 1942		x
Arthropoda	Malacostraca	Decapoda	Palaemonidae	*Palaemonetes paludosus*	(Gibbes 1850)	x	x
Arthropoda	Malacostraca	Decapoda	Palaemonidae	*Palaemonetes* sp.	Heller 1869	x	
Arthropoda	Malacostraca	Decapoda	Palaemonidae	*Palaemonetes vulgaris*	(Say 1818)	x	

Appendix 1. Macroinvertebrate taxa collected by dip net (D) and petite ponar dredge (P) from selected springs in the St. Johns River drainage, 2004-07.—Continued

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Phylum	Class	Order	Family	Taxon	Authority	D	P
Arthropoda	Malacostraca	Decapoda	Cambaridae	*Procambarus* sp.	Ortmann 1905	x	x
Arthropoda	Malacostraca	Decapoda	Cambaridae	*Procambarus* sp. (immature)	Ortmann 1905	x	x
Arthropoda	Insecta	Coleoptera	Chrysomelidae	Chrysomelidae (LPIL)	Latreille 1802	x	
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Helocombus* sp.	Horn 1890		x
Arthropoda	Insecta	Coleoptera	Dryopidae	*Pelonomus obscurus*	LeConte 1852	x	
Arthropoda	Insecta	Coleoptera	Haliplidae	*Peltodytes* sp.	Regimbart 1878	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Ablabesmyia mallochi*	(Walley 1925)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Ablabesmyia rhamphe* group Epler	Sublette 1964		x
Arthropoda	Insecta	Diptera	Chironomidae	*Beardius truncatus*	Reiss and Sublette 1985	x	
Arthropoda	Insecta	Diptera	Ceratopogonidae	*Bezzia/Palpomyia* complex Brigham	Kieffer 1899 (*Bezzia*); Meigen 1818 (*Palpomyia*)	x	x
Arthropoda	Insecta	Diptera	Ceratopogonidae	Ceratopogonidae (LPIL)	--	x	x
Arthropoda	Insecta	Diptera	Chironomidae	cf. *Cricotopus* sp.	Wulp 1874		x
Arthropoda	Insecta	Diptera	Chironomidae	Chironomidae (LPIL)	--	x	x
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae (LPIL)	--		x
Arthropoda	Insecta	Diptera	Chironomidae	Chironomini (LPIL)	--	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus decorus* group Epler	Johannsen 1905	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus* sp.	Meigen 1803	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus* sp. A Line	Meigen 1803	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Cladopelma* sp.	Kieffer 1921	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Cladotanytarsus* cf. *daviesi* Epler	Bilyj 1989	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Cladotanytarsus* sp.	Kieffer 1921		x
Arthropoda	Insecta	Diptera	Chironomidae	*Cladotanytarsus* sp. A Epler	Kieffer 1921	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Clinotanypus* sp.	Kieffer 1913	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Cricotopus bicinctus*	(Meigen 1818)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Cricotopus politus*	(Coquillett 1902)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Cryptochironomus* sp.	Kieffer 1918	x	x
Arthropoda	Insecta	Diptera	Ceratopogonidae	*Culicoides* group Brigham	Latreille 1809	x	x
Arthropoda	Insecta	Diptera	Ceratopogonidae	*Dasyhelea* sp.	Kieffer 1911	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Dicrotendipes modestus*	(Say 1823)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Dicrotendipes neomodestus*	(Malloch 1915)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Dicrotendipes* sp. A Epler	Kieffer 1913	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Dicrotendipes* sp. (immature)	Kieffer 1913	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Einfeldia natchitocheae*	(Sublette 1964)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Einfeldia* sp. A Epler	Kieffer 1924	x	
Arthropoda	Insecta	Diptera	Ephydridae	Ephydridae (LPIL)	--	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Glyptotendipes meridionalis* group	Dendy and Sublette 1959		x
Arthropoda	Insecta	Diptera	Chironomidae	*Glyptotendipes paripes*	(Edwards 1929)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Glyptotendipes* sp.	Kieffer 1913	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Goeldichironomus amazonicus*	(Fittkau 1965)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Goeldichironomus carus*	(Townes 1945)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Goeldichironomus holoprasinus*	(Goeldi 1905)	x	x

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Phylum	Class	Order	Family	Taxon	Authority	D	P
Arthropoda	Insecta	Diptera	Chironomidae	*Goeldichironomus* sp.	Fittkau 1965		x
Arthropoda	Insecta	Diptera	Chironomidae	*Labrundinia neopilosella*	Beck and Beck 1966		x
Arthropoda	Insecta	Diptera	Chironomidae	*Larsia decolorata*	(Malloch 1915)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Larsia* sp.	Wiedemann 1824	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Monopelopia boliekae*	Beck and Beck 1966	x	x
Arthropoda	Insecta	Diptera	Stratiomyidae	*Odontomyia/Hedriodiscus* group Merritt and Cummins	Meigen 1803; Enderlein 1914		x
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae (LPIL)	Lenz 1921	x	x
Arthropoda	Insecta	Diptera	Ceratopogonidae	*Palpomyia/Sphaeromias* group Brigham	Meigen 1818 (*Palpomyia*); Curtis 1829 (*Sphaeromias*)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Parachironomus supparilis*	Edwards 1931	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Paralauterborniella nigrohalteralis*	(Malloch 1915)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Paratanytarsus* sp.	Thienemann and Bause 1913		x
Arthropoda	Insecta	Diptera	Chironomidae	*Pentaneura inconspicua*	(Malloch 1915)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum flavum*	(Johannsen 1905)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum halterale* group Epler	(Coquillett 1901)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum illinoense* group Epler	(Malloch 1915)	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum scalaenum* group Epler	(Schrank 1803)	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum nubifer*	Kieffer 1913	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum* sp.	Kieffer 1913	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum tritum*	(Walker 1856)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum tritum/illinoense* group Epler	(Walker 1856) for *tritum*; (Malloch 1915 for *illinoense*)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Pseudochironomus* sp.	Malloch 1915	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Pseudosmittia* sp.	Goetghebuer 1932	x	
Arthropoda	Insecta	Diptera	Ptychopteridae	*Ptychoptera* sp.	Meigen 1803	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Rheotanytarsus* sp.	Bause and Thienemann 1913		x
Arthropoda	Insecta	Diptera	Chironomidae	*Stempellinella* sp.	Brundin 1947		x
Arthropoda	Insecta	Diptera	Chironomidae	*Stempellinella fimbriata*	Ekrem 2007	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Stenochironomus* sp.	Kieffer 1919	x	x
Arthropoda	Insecta	Diptera	Stratiomyidae	*Stratiomys* sp.	Geoffroy 1762	x	
Arthropoda	Insecta	Diptera	Tabanidae	Tabanidae (LPIL)	--		x
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae (LPIL)	--		x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanypus carinatus*	Sublette 1964	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanypus* sp.	Meigen 1803	x	x
Arthropoda	Insecta	Diptera	Chironomidae	Tanytarsini (LPIL)	--		x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus limneticus*	Sublette 1964	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp.	Wulp 1874	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp. C Epler	Wulp 1874	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp. F Epler	Wulp 1874		x

Appendix 1. Macroinvertebrate taxa collected by dip net (D) and petite ponar dredge (P) from selected springs in the St. Johns River drainage, 2004-07.—Continued

[Authorities are listed for lowest practicable identification level (LPIL) indicated. Taxa are listed in approximate phylogenetic order by suprafamilial categories and alphabetically by genus and species]

Phylum	Class	Order	Family	Taxon	Authority	D	P
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp. G Epler	Wulp 1874	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp. L Epler	Wulp 1874	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp. T Epler	Wulp 1874	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp. V Epler	Wulp 1874		x
Arthropoda	Insecta	Diptera	Chironomidae	*Thienemanniella* sp.	Kieffer 1911	x	
Arthropoda	Insecta	Diptera	Tipulidae	Tipulidae (LPIL)	--	x	
Arthropoda	Insecta	Diptera	Chironomidae	*Tribelos jucundum*	(Walker 1848)		x
Arthropoda	Insecta	Diptera	Chironomidae	*Tribelos* sp.	Townes 1945	x	x
Arthropoda	Insecta	Diptera	Chironomidae	*Zavreliella marmorata*	Kieffer 1920	x	x
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis diminuta*	Walker 1853	x	x
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis* sp.	Stephens 1835	x	x
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Callibaetis floridanus*	Banks 1900	x	x
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Callibaetis* sp.	Eaton 1881	x	
Arthropoda	Insecta	Ephemeroptera	--	Ephemeroptera (LPIL)	--		x
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	*Tricorythodes albilineatus*	Berner 1946	x	x
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Belostoma* sp.	Latreille 1807	x	
Arthropoda	Insecta	Hemiptera	Belostomatidae	Belostomatidae (LPIL)	Leach 1815	x	
Arthropoda	Insecta	Hemiptera	--	Heteroptera (LPIL)	Latreille 1810	x	
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Lethocerus* sp.	Mayr 1853	x	
Arthropoda	Insecta	Hemiptera	Hebridae	*Merragata* sp.	White 1877	x	
Arthropoda	Insecta	Hemiptera	Mesoveliidae	*Mesovelia mulsanti*	White 1879	x	
Arthropoda	Insecta	Hemiptera	Mesoveliidae	*Mesovelia* sp.	Mulsant and Rey 1852		x
Arthropoda	Insecta	Hemiptera	Mesoveliidae	*Mesovelia* sp. (immature)	Mulsant and Rey 1852	x	
Arthropoda	Insecta	Hemiptera	Naucoridae	*Pelocoris* sp.	Stål 1876	x	x
Arthropoda	Insecta	Hemiptera	Gerridae	*Trepobates subnitidus*	Esaki 1926	x	
Arthropoda	Insecta	Heteroptera	Gerridae	Gerridae (LPIL)	Leach 1815	x	
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia* sp.	Rambur 1842	x	x
Arthropoda	Insecta	Odonata	Coenagrionidae	Coenagrionidae (LPIL)	--	x	
Arthropoda	Insecta	Odonata	Coenagrionidae	*Enallagma* sp.	Charpentier 1840	x	
Arthropoda	Insecta	Odonata	Corduliidae	*Epitheca princeps regina*	(Hagens in Selys 1871)	x	x
Arthropoda	Insecta	Odonata	Libellulidae	*Erythemis plebeja*	(Burmeister 1839)	x	
Arthropoda	Insecta	Odonata	Libellulidae	Libellulidae (LPIL)	--		x
Arthropoda	Insecta	Odonata	Corduliidae	*Macromia* sp.	Rambur 1842		x
Arthropoda	Insecta	Odonata	Libellulidae	*Perithemis tenera seminole*	(Say 1839)		x
Arthropoda	Insecta	Odonata	Coenagrionidae	*Telebasis byersi*	Westfall 1957	x	
Arthropoda	Insecta	Trichoptera	Polycentropodidae	*Cernotina* sp.	Ross 1938		x
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche* sp.	Wallengren 1891		x
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsychidae (LPIL)	Curtis 1835	x	
Arthropoda	Insecta	Trichoptera	Leptoceridae	Leptoceridae (LPIL)	Leach in Brewster 1815		x
Arthropoda	Insecta	Trichoptera	Leptoceridae	*Nectopsyche pavida*	(Hagen 1861)		x
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Neotrichia* sp.	Ross 1956	x	
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Orthotrichia* sp.	Eaton 1873		x

Appendix 2. Fish species recorded from selected springs sampled in the St. Johns River drainage, 2004-07.

[Scientific and common names follow Nelson and others (2004)]

Family	Scientific name	Common name	Family	Scientific name	Common name
Lepisosteidae	*Lepisosteus platyrhincus*	Florida gar	Belonidae	*Strongylura marina*	Atlantic needlefish
	Lepisosteus osseus	longnose gar	Fundulidae	*Lucania parva*	rainwater killifish
Amiidae	*Amia calva*	bowfin		*Lucania goodei*	bluefin killifish
Anguillidae	*Anguilla rostrata*	American eel		*Fundulus seminolis*	Seminole killifish
Clupeidae	*Dorosoma petenense*	threadfin shad	Poeciliidae	*Gambusia holbrooki*	eastern mosquitofish
Cyprinidae	*Notropis petersoni*	coastal shiner		*Poecilia latipinna*	sailfin molly
	Notropis harperi	redeye chub		*Heterandria formosa*	least killifish
	Notemigonus crysoleucas	golden shiner	Moronidae	*Morone saxatilis*	striped bass
	Pteronotropis metallicus	sailfin shiner	Centrarchidae	*Lepomis macrochirus*	bluegill
	Opsopoeodus emiliae	pugnose minnow		*Lepomis punctatus*	spotted sunfish
	Notropis maculatus	taillight shiner		*Lepomis auritus*	redbreast sunfish
Catostomidae	*Erimyzon sucetta*	lake chubsucker		*Micropterus salmoides*	largemouth bass
Ictaluridae	*Ameiurus nebulosus*	brown bullhead		*Lepomis microlophus*	redear sunfish
	Noturus gyrinus	tadpole madtom		*Lepomis gulosus*	warmouth
	Ameiurus catus	white catfish		*Pomoxis nigromaculatus*	black crappie
	Ameiurus natalis	yellow bullhead		*Lepomis marginatus*	dollar sunfish
Callichthyidae	*Hoplosternum littorale*	brown hoplo	Percidae	*Percina nigrofasciata*	blackbanded darter
Loricariidae	*Pterygoplichthys disjunctivus*	vermiculated sailfin catfish		*Etheostoma fusiforme*	swamp darter
Esocidae	*Esox americanus*	redfin pickerel	Lutjanidae	*Lutjanus griseus*	gray snapper
Aphredoderidae	*Aphredoderus sayanus*	pirate perch	Elassomatidae	*Elassoma okefenokee*	Okefenokee pygmy sunfish
Mugilidae	*Mugil cephalus*	striped mullet	Cichlidae	*Oreochromis aureus*	blue tilapia
Atherinopsidae	*Menidia beryllina*	inland silverside	Gobiidae	*Gobiosoma bosc*	naked goby
	Labidesthes sicculus	brook silverside			

Appendix 3. Physicochemical data for springs on dates that benthic macroinvertebrate samples were collected in 2004-07.

[DO, dissolved oxygen; DS, downstream; NTU, nephelometric turbidity units; LB, left bank; RB, right bank; --, not available]

Spring	Location	Date	Time	Depth (feet)	Temper ature (degrees C)	Specific conductance (µS/cm)	DO (mg/L)	pH	Turbidity (NTU)	Chlorophyll-*a*, phytoplankton (µg/L)	Pheophytin-*a*, phytoplankton (µg/L)
Alexander	100 ft DS of boil; 25 ft from LB	2/2/2007	1100	2	23.5	1,117	2	7.8	0		
Alexander	100 ft DS of boil; 60 ft from LB	2/2/2007	1103	2	23.4	1,101	2	7.9	0		
Alexander	100 ft DS of boil; 100 ft from LB	2/2/2007	1109	2	23.4	1,095	1.9	7.9	0		
Alexander	100 ft DS of boil; 125 ft from LB	2/2/2007	1113	2	23.4	1,125	1.4	7.8	0		
Alexander	100 ft DS of boil; 150 ft from LB	2/2/2007	1117	2	23.5	1,138	2.4	7.9	0		
Alexander		2/2/2007	1150		23.5	1,117	2.03	7.9	0	0.88	1.5
Alexander		5/10/2007	1000		23.4	1,097	1.73	7.9	0	<0.1	0.19
Alexander	100 ft DS of boil; 25 ft from LB	5/10/2007	1001	2	23.5	1,121	1.9	7.9	0.2		
Alexander	100 ft DS of boil; 60 ft from LB	5/10/2007	1004	2.2	23.4	1,058	1.5	7.9	0		
Alexander	100 ft DS of boil; 100 ft from LB	5/10/2007	1008	2.5	23.4	1,085	1.4	7.9	0		
Alexander	100 ft DS of boil; 125 ft from LB	5/10/2007	1012	2.5	23.4	1,098	1.7	7.9	0		
Alexander	100 ft DS of boil; 150 ft from LB	5/10/2007	1015	1	23.4	1,097	2.1	7.9	0		
Alexander	100 ft DS of boil; 10 ft from LB	8/7/2007	900	1	23.5	1,167	--	7.6	--		
Alexander	100 ft DS of boil; 40 ft from LB	8/7/2007	903	2	23.3	1,148	--	7.6	--		
Alexander	100 ft DS of boil; 70 ft from LB	8/7/2007	907	2	23.2	1,120	--	7.7	--		
Alexander	100 ft DS of boil; 100 ft from LB	8/7/2007	910	2	23.2	1,110	--	7.8	--		
Alexander	100 ft DS of boil; 125 ft from LB	8/7/2007	914	2	23.2	1,116	--	7.8	--		
Alexander		8/7/2007	930		23.2	1,118	--	7.7	--	0.78	0.32
Alexander		10/10/2007	1000		23.3	1,167	1.49	7.8	0.2	0.15	0.15
Alexander	100 ft DS of boil; 10 ft from LB	10/10/2007	1042	1	23.4	1,210	1.8	7.7	0.3		
Alexander	100 ft DS of boil; 40 ft from LB	10/10/2007	1045	2	23.3	1,195	1.8	7.7	0.2		
Alexander	100 ft DS of boil; 70 ft from LB	10/10/2007	1047	3	23.2	1,142	1.4	7.8	0.3		
Alexander	100 ft DS of boil; 100 ft from LB	10/10/2007	1049	3	23.2	1,174	1.6	7.8	0.2		
Alexander	100 ft DS of boil; 125 ft from LB	10/10/2007	1052	2	23.4	1,185	2.3	7.9	0.2		
Apopka	Boil	12/30/2005	1530	28	18.6	297	6.8	8	--		
Apopka		12/30/2005	1530		--	--	--	--	--	18.39	5.76
Apopka		3/28/2006	1200		22.4	286	4.88	8.3	--	13.91	3.23
Apopka	Boil	3/28/2006	1237	4.9	22.4	285	4.8	8.4	--		
Apopka	Boil	3/28/2006	1239	1.1	22.4	286	4.9	8.3	--		
Apopka	Boil	3/28/2006	--	18	22	288	5	8.5	--		
Apopka	Boil	3/28/2006	--	15	22.1	288	5	8.5	--		
Apopka	Boil	3/28/2006	--	10	22.1	287	5	8.4	--		
Apopka	Boil	7/13/2006	1013	22	23.9	266	2.7	7.9	0		
Apopka	Boil	7/13/2006	1017	20	24.2	267	3.2	8	0		
Apopka	Boil	7/13/2006	1019	15	24.4	271	3.4	8	0		
Apopka	Boil	7/13/2006	1020	10	24.4	271	3.4	8	0.1		
Apopka	Boil	7/13/2006	1022	5	24.7	283	4.3	8.2	1.2		
Apopka	Boil	7/13/2006	1027	1	24	263	4	8.1	0		

Appendix 3. Physicochemical data for springs on dates that benthic macroinvertebrate samples were collected in 2004-07.—Continued

[DO, dissolved oxygen; DS, downstream; NTU, nephelometric turbidity units; LB, left bank; RB, right bank; --, not available]

Spring	Location	Date	Time	Depth (feet)	Temperature (degrees C)	Specific conductance (µS/cm)	DO (mg/L)	pH	Turbidity (NTU)	Chlorophyll-*a*, phytoplankton (µg/L)	Pheophytin-*a*, phytoplankton (µg/L)
Apopka		7/13/2006	1030		24	263	4.04	7.9	0	5.91	1.27
Apopka		9/21/2006	1430		24.4	265	2.5	8	0.2	0.63	0.17
Apopka	Boil	9/21/2006	1440	22	24.4	265	2.5	8	0.2		
Apopka	Boil	9/21/2006	1444	20	24.2	261	2.3	8	0		
Apopka	Boil	9/21/2006	1446	15	24.2	262	2.3	8	0		
Apopka	Boil	9/21/2006	1448	10	24.2	261	2.2	8	0		
Apopka	Boil	9/21/2006	1450	5	24.4	262	2.5	8	0		
Apopka	Boil	9/21/2006	1451	1	24.4	261	2.8	8.3	0		
Bugg	Head of run	12/30/2005	1210	1.6	22	283	2.6	7.6	0		
Bugg		12/30/2005	1210		--	--	--	--	--	0.66	0.42
Bugg	Head of run	3/17/2006	1250	1	23.9	312	5.3	7.4	--		
Bugg		3/17/2006	1250		23.9	312	5.33	7.4	--	2.19	1.43
Bugg	300 ft DS	7/12/2006	930	1	24.3	307	7.4	7.8	3.4		
Bugg	150 ft DS	7/12/2006	945	1	24.1	307	7.7	8	2		
Bugg	Head of run	7/12/2006	1000	1	24	308	7	7.9	0.4		
Bugg		7/12/2006	1000		24.1	307	7.38	7.9	2	41.2	24.9
Bugg	Boil	7/12/2006	1040	25	23.2	311	0.6	7.3	0		
Bugg	Boil	7/12/2006	1041	20	23.2	311	0.7	7.3	0		
Bugg	Boil	7/12/2006	1043	15	23.2	311	0.8	7.3	0		
Bugg	Boil	7/12/2006	1044	10	23.2	311	1.1	7.4	0		
Bugg	Boil	7/12/2006	1046	5	23.6	310	4.8	7.7	0		
Bugg	Boil	7/12/2006	1048	1	24.1	308	7.8	8.1	0.4		
Bugg	Boil	9/21/2006	926	24	23.4	315	1.4	7.4	0		
Bugg	Boil	9/21/2006	931	20	23.4	315	1.3	7.4	0		
Bugg	Boil	9/21/2006	933	15	23.4	314	2	7.5	0		
Bugg	Boil	9/21/2006	935	10	23.4	314	2.2	7.5	0		
Bugg	Boil	9/21/2006	937	5	23.5	314	2.4	7.5	0		
Bugg	Boil	9/21/2006	938	1	23.6	314	2.7	7.6	0		
Bugg	300 ft DS	9/21/2006	1000	1	23.8	312	3.6	7.6	0.2		
Bugg		9/21/2006	1000		23.8	312	3.56	7.6	0.2	24.8	13.4
Bugg	450 ft DS	9/21/2006	1015	1	24.1	312	3.7	7.6	0.2		
Bugg	600 ft DS	9/21/2006	1020	1	24	313	3.5	7.7	0.3		
De Leon	Vent, inside 5 ft	2/11/2004	1035	33	22.5	886	0.8	7.5	0.1		
De Leon		2/11/2004	1035		22.5	886	0.8	7.5	0.1	<0.1	<0.1
De Leon	Run, 100 ft DS of dam	2/11/2004	1133	2	21.3	1,060	6.7	7.7	0.2		
De Leon	Vent, inside 5 ft	3/18/2004	1145	33	23	884	1.5	7.4	--		
De Leon		3/18/2004	1145		23	884	1.5	7.4	--	<0.1	<0.1
De Leon	Run, 100 ft DS of dam	3/18/2004	1210	2	22.9	900	5.5	7.5	--		

Appendix 3. Physicochemical data for springs on dates that benthic macroinvertebrate samples were collected in 2004-07.—Continued

[DO, dissolved oxygen; DS, downstream; NTU, nephelometric turbidity units; LB, left bank; RB, right bank; --, not available]

Spring	Location	Date	Time	Depth (feet)	Temper ature (degrees C)	Specific conduc-tance (µS/cm)	DO (mg/L)	pH	Turbidity (NTU)	Chloro-phyll-*a*, phyto-plankton (µg/L)	Pheophy-tin-*a*, phyto-plankton (µg/L)
De Leon	Vent, inside 5 ft	5/12/2004	1100	33	22.7	801	0.8	7.4	0.6		
De Leon		5/12/2004	1100		22.7	801	0.8	7.4	0.6	5.7	<0.1
De Leon	Run, 100 ft DS of dam	5/12/2004	1300	2	23.1	869	6	7.6	0.7		
De Leon	Run, 100 ft DS of dam	7/28/2004	1430	2	23.1	832	1.5	7.2	--		
De Leon	Vent, inside 5 ft	8/23/2004	1040	33	23.5	1,127	1.2	6.8	--		
De Leon	Run, 100 ft DS of dam	8/23/2004	1200	2	23.8	969	3.6	7	--		
De Leon		8/23/2004	1200		23.5	1,127	1.2	6.8	--	--	--
Gemini	Vent, South Boil	2/10/2004	1312	5	22.9	2,650	0.9	7.1	0.2		
Gemini	Vent, North Boil	2/10/2004	1341	4	22.9	2,620	0.8	7.2	0.2		
Gemini	Dam, run	2/10/2004	1430	2	22.9	2,650	3.2	7.4	0.4		
Gemini	Dam, run	2/16/2004	--	2	22.6	2,500	--	--	--		
Gemini	Vent, South Boil	3/18/2004	1450	4	22.9	2,690	0.6	7.2	--		
Gemini	Dam, run	3/18/2004	1525	2	23.7	2,710	4.8	7.3	--		
Gemini	Vent, North Boil	5/11/2004	1435	5	22.9	2,510	0.6	7.2	--		
Gemini	Dam, run	5/11/2004	1710	2	23.4	2,540	3.8	7.3	0.6		
Gemini	Vent, South Boil	5/12/2004	1600	4	22.9	2,541	0.6	7.2	--		
Gemini	Dam, run	5/13/2004	--	2	24	2,445	--	7.4	--		
Gemini	Dam, run	7/28/2004	1330	2	22.9	2,620	2.2	7	--		
Gemini	Dam, run	8/18/2004	1400	2	26.6	2,730	3	7.1	<2		
Gemini	Vent, North Boil	8/18/2004	1500	5	24.2	2,710	1	7	--		
Gemini	Vent, South Boil	8/18/2004	1600	5	24.1	2,740	0.8	7	--		
Gemini	Vent, North Boil	2/10/2004	1341		22.9	2,620	0.8	7.2	0.2	<0.1	<0.1
Gemini	Vent, North Boil	5/11/2004	1435		22.9	2,510	0.6	7.2	--	<0.1	<0.1
Gemini	Vent, North Boil	8/18/2004	1500		24.2	2,710	1	7.2	--	--	--
Gemini	Vent, South Boil	2/10/2004	1312		22.9	2,650	0.9	7.1	0.2	<0.1	<0.1
Gemini	Vent, South Boil	3/18/2004	1450		22.9	2,690	0.6	7.2	--	<0.1	<0.1
Gemini	Vent, South Boil	5/12/2004	1600		22.9	2,541	0.6	7.2	--	<0.1	<0.1
Gemini	Vent, South Boil	8/18/2004	1600		24.1	2,740	0.8	7	--	--	--
Green	Run	2/10/2004	1341	2	22.5	2,920	0.4	7.4	0.2		
Green	Vent	2/10/2004	1600	20	22.5	2,900	0.1	7.4	0.1		
Green		2/10/2004	1600		22.5	2,900	0.1	7.4	0.1	<0.1	<0.1
Green	Vent	3/18/2004	1420	20	22.6	2,920	0.1	7.3	--		
Green		3/18/2004	1420		22.6	2,920	0.1	7.3	--	<0.1	<0.1
Green	Vent	5/11/2004	1035	20	22.6	2,640	0.1	7.2	0.6		
Green		5/11/2004	1035		22.6	2,640	0.1	7.2	0.6	<0.1	<0.1
Green	Run	5/11/2004	1435	2	22.8	2,630	0.6	7.3	0.4		
Green	Vent	8/18/2004	1100	20	23.2	2,760	0.4	7	--		
Green		8/18/2004	1100		23.2	2,760	0.4	7	--	--	--

Appendix 3. Physicochemical data for springs on dates that benthic macroinvertebrate samples were collected in 2004-07.—Continued

[DO, dissolved oxygen; DS, downstream; NTU, nephelometric turbidity units; LB, left bank; RB, right bank; --, not available]

Spring	Location	Date	Time	Depth (feet)	Temperature (degrees C)	Specific conductance (µS/cm)	DO (mg/L)	pH	Turbidity (NTU)	Chlorophyll-*a*, phytoplankton (µg/L)	Pheophytin-*a*, phytoplankton (µg/L)
Green	Run	8/18/2004	1500	2	23.2	2,720	0.6	7.2	--		
Rock	Boil	12/6/2005	1310	0.6	23.7	236	1.1	7.6	0		
Rock	Swimming area	12/6/2005	1500	0.4	23.6	237	2.1	7.7	0		
Rock	Lower section (end tube run)	12/6/2005	1615	0.4	23.4	237	2.8	7.7	0		
Rock		12/6/2005	1615		--	--	--	--	--	0.19	0.17
Rock	Boil; 5 ft from RB	3/17/2006	1147	1.6	23.6	258	1.1	7.5	--		
Rock	Boil; 10 ft from RB	3/17/2006	1149	1.7	23.7	258	1	7.6	--		
Rock	Boil; 15 ft from RB	3/17/2006	1150	1.6	23.7	258	1	7.6	--		
Rock	Boil; 20 ft from RB	3/17/2006	1152	1.5	23.7	258	1	7.6	--		
Rock	Midreach; 3 ft from RB	3/17/2006	1242	2	23.8	257	2.1	7.8	--		
Rock	Midreach; 6 ft from RB	3/17/2006	1244	2.1	23.8	257	2.2	7.8	--		
Rock	Midreach; 10 ft from RB	3/17/2006	1247	1	23.8	258	3	7.8	--		
Rock	Lower section; 5 ft from RB	3/17/2006	1335	1.5	24	250	4.1	8	--		
Rock	Lower section; 10 ft from RB	3/17/2006	1337	1.5	24.1	257	4.1	8	--		
Rock	Lower section; 15 ft from RB	3/17/2006	1339	1.7	24.1	258	3.7	8	--		
Rock	Lower section; 20 ft from RB	3/17/2006	1341	1.7	24.1	258	3.6	8	--		
Rock	Lower section; 25 ft from RB	3/17/2006	1342	1.3	24.1	258	3.7	8	--		
Rock	Lower section; 30 ft from RB	3/17/2006	1344	0.4	24.1	258	3.7	8	--		
Rock		3/27/2006	1318		23.8	257	2.23	7.8	--	0.57	0.71
Rock	Boil	6/21/2006	1117	0.4	23.7	265	0.9	7.5	6.5		
Rock	Swimming area; RB footbridge	6/21/2006	1238	0.5	23.9	265	2	7.9	16.5		
Rock	Swimming area; LB footbridge	6/21/2006	1242	0.5	23.9	265	2.1	8	6.7		
Rock	Lower section (end tube run)	6/21/2006	1347	0.3	24.3	265	3	7.9	30.3		
Rock		6/28/2006	1015		23.7	259	1.74	7.6	--	0.23	0.42
Rock	Boil	9/27/2006	940	1.5	23.8	262	1.3	7.6	0		
Rock	Swimming area; RB footbridge	9/27/2006	1100	1	23.9	262	2.4	7. 8	0		
Rock	Swimming area; LB footbridge	9/27/2006	1105	1	23.9	262	2.3	7.8	0		
Rock	Swimming area; steps	9/27/2006	1130	1	24.1	262	2.9	7.9	0		
Rock		9/27/2006	1140		24.1	262	2.89	7.9	0	0.4	0.66
Rock	Lower section (end tube run)	9/27/2006	1210	1	24.2	262	3.5	8	0		
Silver Glen		10/19/2006	1600		23.3	1,917	3.5	7.8	0	--	--
Silver Glen		10/30/2006	1145		23.5	1,921	3.55	7.8	0	--	--
Silver Glen	100 ft DS of both vents; 5 ft from LB	1/31/2007	1100	1	23.2	2,022	4.1	8	0		
Silver Glen	100 ft DS of both vents; 25 ft from LB	1/31/2007	1103	2	23.2	2,016	3.6	7.9	0		
Silver Glen	100 ft DS of both vents; 50 ft from LB	1/31/2007	1107	2.5	23.2	1,894	3.7	7.9	0		
Silver Glen	100 ft DS of both vents; 75 ft from LB	1/31/2007	1110	3	23.2	1,870	3.6	7.8	0		
Silver Glen	100 ft DS of both vents; 100 ft from LB	1/31/2007	1114	3.5	23.2	1,843	3.5	7.8	0		
Silver Glen		1/31/2007	1135		23.2	1,894	3.65	7.9	0	0.1	<0.1

Appendix 3. Physicochemical data for springs on dates that benthic macroinvertebrate samples were collected in 2004-07.—Continued

[DO, dissolved oxygen; DS, downstream; NTU, nephelometric turbidity units; LB, left bank; RB, right bank; --, not available]

Spring	Location	Date	Time	Depth (feet)	Temperature (degrees C)	Specific conductance (µS/cm)	DO (mg/L)	pH	Turbidity (NTU)	Chlorophyll-*a*, phytoplankton (µg/L)	Pheophytin-*a*, phytoplankton (µg/L)
Silver Glen		3/15/2007	1530		23.8	1,951	2.8	7.6	0	--	--
Silver Glen	100 ft DS of both vents; 5 ft from LB	5/10/2007	1320	1	23.3	1,887	2.8	7.8	0		
Silver Glen	100 ft DS of both vents; 25 ft from LB	5/10/2007	1324	2	23.2	1,909	2.7	7.8	0		
Silver Glen	100 ft DS of both vents; 50 ft from LB	5/10/2007	1328	2.5	23.2	1,936	2.7	7.8	0		
Silver Glen		5/10/2007	1330		23.2	1,936	2.81	7.8	0	0.66	1.09
Silver Glen	100 ft DS of both vents; 75 ft from LB	5/10/2007	1332	3	23.2	1,997	2.8	7.9	0		
Silver Glen	100 ft DS of both vents; 100 ft from LB	5/10/2007	1336	3.5	23.2	2,001	2.8	7.9	0.1		
Silver Glen	100 ft DS of both vents; 5 ft from LB	8/7/2007	1200	1	23	1,894	--	7.2	--		
Silver Glen	100 ft DS of both vents; 25 ft from LB	8/7/2007	1204	2	23	1,903	--	7.5	--		
Silver Glen	100 ft DS of both vents; 50 ft from LB	8/7/2007	1208	2.5	23.1	1,898	--	7.6	--		
Silver Glen	100 ft DS of both vents; 75 ft from LB	8/7/2007	1212	3	23.1	1,928	--	7.7	--		
Silver Glen	100 ft DS of both vents; 100 ft from LB	8/7/2007	1216	3.5	23	2,054	--	7.7	--		
Silver Glen		8/7/2007	1230		23	1,928	--	7.6	--	0.21	1.77
Silver Glen	100 ft DS of both vents; 10 ft from LB	10/10/2007	1220	2	23.1	1,953	3.3	7.8	0.2		
Silver Glen	100 ft DS of both vents; 25 ft from LB	10/10/2007	1221	2	23	1,961	3.2	7.8	0.1		
Silver Glen	100 ft DS of both vents; 75 ft from LB	10/10/2007	1223	3	23.1	1,974	3.3	7.8	0.1		
Silver Glen	100 ft DS of both vents; 100 ft from LB	10/10/2007	1225	3	23.1	1,984	3.6	7.8	0.1		
Silver Glen	100 ft DS of both vents; 125 ft from LB	10/10/2007	1227	4	23.2	2,083	4.1	8	0.1		
Silver Glen		10/10/2007	1300		23.1	1,929	3.31	7.8	0.1	0.37	0.17
Silver Springs Group											
Abyss	Boil	10/23/2003	--	40	23.6	509	3.4	7.3	0.2		
Abyss	Boil	4/14/2004	1030	40	23.5	491	4.4	7.2	--		
Abyss	Boil	7/14/2004	925	40	23.7	404	3.9	7.1	0.2		
Blue Grotto	Boil	10/23/2003	--	30	23.7	465	3.6	7.4	0.1		
Blue Grotto	Boil	4/14/2004	1120	30	23.5	473	4.5	7.3	--		
Blue Grotto	Boil	7/14/2004	1000	30	23.7	390	3.9	7.1	0.1		
Silver (Mammoth)	Boil	9/8/2003	945	20	23.4	483	2.6	7.1	--		
Silver (Mammoth)	Boil	10/21/2003	1100	20	23.1	456	2.2	7.2	--		
Silver (Mammoth)	Boil	10/23/2003	--	20	23.3	425	1.7	7.3	0.1		
Silver (Mammoth)	Boil	2/19/2004	1145	20	23.2	475	2.7	6.8	--		
Silver (Mammoth)	Boil	4/14/2004	810	20	23.2	470	2.5	7.2	--		
Silver (Mammoth)	Boil	8/2/2004	1230	20	--	--	--	--	--		
Silver (Mammoth)	Boil	7/14/2004	840	20	23.1	382	1.9	7	0.1		
Silver River	Run, 0.25 miles DS of Mammoth	1/15/2004	1420	10	23.4	465	5.4	7.4	0.1		
Silver River	Run, 0.25 miles DS of Mammoth	4/14/2004	1200	10	23.4	451	5.7	7.2	0.2		
Silver River	Run, 0.25 miles DS of Mammoth	7/14/2004	1045	10	23.8	373	5	6.9	0.2		
Wekiwa	Foot bridge	12/7/2005	1100	0.4	23.7	317	0.7	7.3	0		
Wekiwa		12/7/2005	1100		--	--	--	--	--	<0.1	<0.1

Appendix 3. Physicochemical data for springs on dates that benthic macroinvertebrate samples were collected in 2004-07.—Continued

[DO, dissolved oxygen;; DS, downstream; NTU, nephelometric turbidity units; LB, left bank; RB, right bank; --, not available]

Spring	Location	Date	Time	Depth (feet)	Temper ature (degrees C)	Specific conduc-tance (µS/cm)	DO (mg/L)	pH	Turbidity (NTU)	Chloro-phyll-*a*, phyto-plankton (µg/L)	Pheophy-tin-*a*, phyto-plankton (µg/L)
Wekiwa	Foot bridge; 5 ft from RB	3/27/2006	1540	0.3	23.8	342	0.8	7.3	--		
Wekiwa	Foot bridge; 10 ft from RB	3/27/2006	1541	0.8	23.8	344	0.6	7.3	--		
Wekiwa	Foot bridge; 15 ft from RB	3/27/2006	1542	0.8	23.7	344	0.6	7.3	--		
Wekiwa	Foot bridge; 20 ft from RB	3/27/2006	1543	0.9	23.7	344	0.5	7.3	--		
Wekiwa	Foot bridge; 25 ft from RB	3/27/2006	1544	0.8	23.7	339	0.6	7.3	--		
Wekiwa		3/27/2006	1605		23.8	344	0.61	7.3	--	<0.31	<0.31
Wekiwa	Foot bridge; RB	6/22/2006	1021	0.2	23.9	355	0.7	6.7	12.6		
Wekiwa	Foot bridge; middle	6/22/2006	1023	0.2	23.8	354	0.7	7	5.7		
Wekiwa	Foot bridge; LB	6/22/2006	1029	0.2	23.8	355	0.5	7.2	5.9		
Wekiwa		6/28/2006	840		23.7	342	0.82	7.2	--	<0.1	<0.1
Wekiwa	Foot bridge; 40 ft from LB	9/27/2006	1310	0.5	23.9	344	1.2	7.3	0		
Wekiwa	Foot bridge; center	9/27/2006	1312	1	23.9	344	1.2	7.3	0		
Wekiwa	Foot bridge; 60 ft from LB	9/27/2006	1315	1	23.9	344	1.1	7.3	0		
Wekiwa		9/27/2006	1345		23.9	344	1.14	7.3	0	0.15	0.13
Wekiwa		10/18/2006	1300		24.5	344	--	7.3	0	--	--
Wekiwa		3/22/2007	1100		23.7	347	0.4	7.3	0.1	--	--

Appendix 4. Concentrations of organic wastewater compounds detected in water samples from selected springs in the St. Johns River drainage.

[Concentrations are in micrograms per liter; E, estimated value reported by laboratory that is between the method reporting level and the method detection level; M, presence verified but not quantified]

Organic compound	Spring																	
	De Leon		Fern Hammock			Gemini-N Boil		Gemini-S Boil		Green		Juniper		Silver Glen			Wekiwa	
Date	5/12/04	8/23/04	10/19/06	10/30/06	3/15/07	5/11/04	8/18/04	5/12/04	8/18/04	5/11/04	8/18/04	10/19/06	3/15/07	10/19/06	10/30/06	3/15/07	10/18/06	3/22/07
Sample start time	1100	1040	1330	930	930	1435	1500	1600	1600	1035	1100	1045	1300	1600	1145	1530	1300	1100
Medium code	6	6	6	6	6	6	6	6	6	9	9	6	6	6	6	6	6	6
1,4-Dichlorobenzene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
1-Methylnaphthalene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	M	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
2,6-Dimethylnaphthalene	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
2-Methylnaphthalene	<0.5	<0.5	<0.1		<0.1	M	<0.5	<0.5	<0.5	M	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
3-beta-Coprostanol	<2	<2	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2	<2	<2
3-Methyl-1H-indole	M	<1	<0.08		<0.08	<1	<1	<1	<1	<1	<1	<0.08	<0.08	<0.08		<0.08	<0.08	<0.08
3-tert-Butyl-4-hydroxyanisole	<5	<5	<0.6		<0.6	<5	<5	<5	<5	<5	<5	<0.6	<0.6	<0.6		<0.6	<0.6	<0.6
4-Cumylphenol	<1	<1	<0.14		<0.14	<1	<1	<1	<1	<1	<1	<0.14	<0.14	<0.14		<0.14	<0.14	<0.14
4-Nonylphenol	<5	<5	<2		<2	<5	<5	<5	<5	M	<5	<2	<2	<2		<2	<2	<2
4-Octylphenol	<1	<1	<0.16		<0.16	<1	<1	<1	<1	<1	<1	<0.16	<0.16	<0.16		<0.16	<0.16	<0.16
4-tert-Octylphenol	<1	<1	<0.10		<0.10	<1	<1	<1	<1	<1	<1	<0.10	<0.10	<0.10		<0.10	<0.10	<0.10
5-Methyl-1H-benzotriazole	<2	<2	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2	<2	<2
9,10-Anthraquinone	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Acetophenone	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Acetyl hexamethyl tetrahydro naphthalene	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5
Anthracene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Benzo[a]pyrene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Benzophenone	<0.5	<0.5	<0.2		<0.2	E0.1	<0.5	E0.1	<0.5	E0.1	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
beta-Sitosterol	<2	<2	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2	<2	<2
beta-Stigmastanol	<2	<2	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2	<2	<2
BisA	<1	<1				<1	<1	<1	<1	M	<1							
Bisphenol A-d3, surrogate, % recovery	104	54.7	5.8		55.6	66.7	37	82.6	70.6	133	58.9	9.6	61.7	26		50	7.3	71.9
Bromacil	<0.5	<0.5	<0.4		<0.4	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4		<0.4	<0.4	<0.4
Caffeine	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2

Appendix 4. Concentrations of organic wastewater compounds detected in water samples from selected springs in the St. Johns River drainage.—Continued

[Concentrations are in micrograms per liter; E, estimated value reported by laboratory that is between the method reporting level and the method detection level; M, presence verified but not quantified]

Organic compound	Spring																	
	De Leon		Fern Hammock			Gemini-N Boil		Gemini-S Boil		Green		Juniper		Silver Glen			Wekiwa	
Caffeine-13C, surrogate, % recovery	109	90.7	80.5		80.6	121	73.9	135	82.5	129	81.9	80.7	85	82.2		81	79.3	94.1
Camphor	<0.5	<0.5	M		M	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Carbaryl	<0.041	<0.041	<1	<0.060	<0.060	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.060	<0.060	<1	<0.060	<0.060	<0.060	<0.060
Carbazole	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Chlorpyrifos	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005
Cholesterol	<2	<2	<1		<1	<2	<2	<2	<2	<2	<2	<1	<1	<1		<1	<1	<1
Cotinine	<1.00	<1.00	<0.400		<0.400	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<0.400	<0.400	<0.400		<0.400	<0.400	<0.400
Decafluorobiphenyl, surrogate, % recovery	73.9	37.2	50.5		66.4	83.3	55.7	78.3	41	75	48	49.4	62.3	47.6		61.2	43.3	78.1
DEET	<0.5	<0.5	<0.2		<0.2	E0.1	E0.1	E0.1	<0.5	E0.2	E0.1	<0.2	M	<0.2		<0.2	<0.2	<0.2
Diazinon	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005
Diethoxynonylphenol	<5	<5	<5		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5		<5	<5	<5
Diethoxyoctylphenol	<1	<1	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1
D-Limonene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Fluoranthene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Fluoranthene-d10, surrogate, filtered, % recovery	109	97.5	80.2		76.8	125	83.7	135	95.1	125	89.2	81.1	82.6	79.2		80.1	77.4	102
Hexahydrohexamethyl cyclopentabenzo-pyran	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5
Indole	E0.4	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Isoborneol	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Isophorone	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Isopropylbenzene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.2
Isoquinoline	<0.5	<0.5	<0.4		<0.4	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4		<0.4	<0.4	<0.4
Menthol	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Metalaxyl	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Methyl salicylate	<0.5	<0.5	<0.2		<0.2	M	<0.5	<0.5	<0.5	M	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Metolachlor	<0.013	<0.013	<0.2	<0.010	<0.010	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.010	<0.010	<0.2	<0.010	<0.010	<0.010	<0.010

Appendix 4. Concentrations of organic wastewater compounds detected in water samples from selected springs in the St. Johns River drainage.—Continued

[Concentrations are in micrograms per liter; E, estimated value reported by laboratory that is between the method reporting level and the method detection level; M, presence verified but not quantified]

Organic compound	Spring																	
	De Leon		Fern Hammock			Gemini-N Boil		Gemini-S Boil		Green		Juniper		Silver Glen			Wekiwa	
Monoethoxyoctyl-phenol	<1	M	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1
Naphthalene	<0.5	<0.5	<0.1		<0.1	M	<0.5	<0.5	<0.5	M	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
p-Cresol	2	<1	<0.18		<0.18	<1	<1	<1	<1	M	<1	<0.18	<0.18	<0.18		<0.18	<0.18	<0.18
Pentachlorophenol	<2	<2				<2	<2	<2	<2	<2	<2							
Phenanthrene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Phenol	E0.4	<0.5	<0.4		<0.4	<0.5	0.7	<0.5	<0.5	E0.3	E0.2	<0.4	<0.4	<0.4		E0.2	<0.4	E0.1
Prometon	<0.01	<0.01	<0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.4	<0.01	<0.01	<0.01	<0.01
Pyrene	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Sample volume, wastewater method, water, filtered, milliliters	877	893	926		907	832	889	866	858	834	886	924	908	938		900	942	861
Tetrachloroethene	M	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Tribromomethane	<0.5	<0.5	<0.1		<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Tributyl phosphate	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Triclosan	<1	<1	<0.2		<0.2	<1	<1	<1	<1	<1	<1	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Triethyl citrate	<0.5	<0.5	E0.1		<0.4	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	E0.1	<0.4	<0.4		<0.4	E0.1	<0.4
Triphenyl phosphate	<0.5	<0.5	<0.2		<0.2	E0.1	<0.5	E0.1	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Tris(2-butoxyethyl) phosphate	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5
Tris(2-chloroethyl) phosphate	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
Tris(dichloroisopropyl) phosphate	<0.5	<0.5	<0.2		<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2

Appendix 5. Concentrations of pesticides analyzed in water samples from selected springs in the St. Johns River drainage, 2004-07.

[Concentrations are in micrograms per liter; E, estimated concentration reported by laboratory that is quantifiable below the method reporting level]

Pesticide	Spring																	
	De Leon		Fern Hammock			Gemini-N Boil		Gemini-S Boil		Green		Juniper		Silver Glen			Wekiwa	
Sample date	5/12/04	8/23/04	10/19/06	10/30/06	3/15/07	5/11/04	8/18/04	5/12/04	8/18/04	5/11/04	8/18/04	10/19/06	3/15/07	10/19/06	10/30/06	3/15/07	10/18/06	3/22/07
Sample time	1100	1040	1330	930	930	1435	1500	1600	1600	1035	1100	1045	1300	1600	1145	1530	1300	1100
Medium code	6	6	6	6	6	6	6	6	6	9	9	6	6	6	6	6	6	6
Sample type code	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
alpha-HCH	<0.005	<0.005				<0.005	<0.005	<0.005	<0.005	<0.005	<0.005							
Acetochlor	<0.006	<0.006		<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006		<0.006	<0.006	<0.006	<0.006
Alachlor	<0.005	<0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	<0.005	<0.005	<0.005
2,6-Diethylaniline	<0.006	<0.006		<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006		<0.006	<0.006	<0.006	<0.006
Atrazine	<0.007	<0.007		<0.007	<0.007	0.015	0.017	0.013	0.019	<0.007	<0.007	<0.007	<0.007		<0.007	<0.007	0.008	E0.007
Azinphos-methyl	<0.050	<0.050		<0.080	<0.080	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.080	<0.080		<0.080	<0.080	<0.080	<0.080
Benfluralin	<0.010	<0.010		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010		<0.010	<0.010	<0.010	<0.010
Butylate	<0.004	<0.004				<0.004	<0.004	<0.004	<0.004	<0.004	<0.004							
Carbaryl	<0.041	<0.041	<1	<0.060	<0.060	<0.041	<0.041	<0.041	<0.041	<0.041	<0.041	<0.060	<0.060	<1	<0.060	<0.060	<0.060	<0.060
Carbofuran	<0.020	<0.020				<0.020	<0.020	<0.020	<0.020	<0.020	<0.020							
Chlorpyrifos	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005
cis-Permethrin	<0.006	<0.006		<0.010	<0.010	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.010	<0.010		<0.010	<0.010	<0.010	<0.010
Cyanazine	<0.018	<0.018				<0.018	<0.018	<0.018	<0.018	<0.018	<0.018							
DCPA	<0.003	<0.003		<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003		<0.003	<0.003	<0.003	<0.003
2-Chloro-4-isopropylamino-6-amino-s-triazine	<0.006	<0.006		<0.014	<0.014	E0.011	E0.012	E0.010	E0.013	<0.006	<0.006	<0.014	<0.014		<0.014	<0.014	E0.008	E0.008
Diazinon	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.2	<0.005	<0.005	<0.005	<0.005
Dieldrin	<0.009	<0.009		<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009		<0.009	<0.009	<0.009	<0.009
Disulfoton	<0.02	<0.02				<0.02	<0.02	<0.02	<0.02	<0.02	<0.02							
EPTC	<0.004	<0.004				<0.004	<0.004	<0.004	<0.004	<0.004	<0.004							
Ethalfluralin	<0.009	<0.009				<0.009	<0.009	<0.009	<0.009	<0.009	<0.009							
Ethoprop	<0.005	<0.005				<0.005	<0.005	<0.005	<0.005	<0.005	<0.005							
Desulfinylfipronil amide	<0.029	<0.029		<0.029	<0.029	<0.029	<0.029	<0.029	<0.029	<0.029	<0.029	<0.029	<0.029		<0.029	<0.029	<0.029	<0.029

Appendix 5. Concentrations of pesticides analyzed in water samples from selected springs in the St. Johns River drainage, 2004-07.—Continued

[Concentrations are in micrograms per liter; E, estimated concentration reported by laboratory that is quantifiable below the method reporting level]

Pesticide	Spring																	
	De Leon		Fern Hammock			Gemini-N Boil		Gemini-S Boil		Green		Juniper		Silver Glen			Wekiwa	
Fipronil sulfide	<0.013	<0.013		<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013		<0.013	<0.013	<0.013	<0.013
Fipronil sulfone	<0.024	<0.024		<0.024	<0.024	<0.024	<0.024	<0.024	<0.024	<0.024	<0.024	<0.024	<0.024		<0.024	<0.024	<0.024	<0.024
Desulfinylfipronil	<0.012	<0.012		<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012		<0.012	<0.012	<0.012	<0.012
Fipronil	<0.016	<0.016		<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016		<0.016	<0.016	E0.007	E0.005
Fonofos	<0.003	<0.003		<0.006	<0.006	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.006	<0.006		<0.006	<0.006	<0.006	<0.006
Lindane	<0.004	<0.004				<0.004	<0.004	<0.004	<0.004	<0.004	<0.004							
Linuron	<0.035	<0.035				<0.035	<0.035	<0.035	<0.035	<0.035	<0.035							
Malathion	<0.027	<0.027		<0.016	<0.016	<0.027	<0.027	<0.027	<0.027	<0.027	<0.027	<0.016	<0.016		<0.016	<0.016	<0.016	<0.016
Methylparathion	<0.015	<0.015		<0.008	<0.008	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.008	<0.008		<0.008	<0.008	<0.008	<0.008
Metolachlor	<0.013	<0.013	<0.2	<0.010	<0.010	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.010	<0.010	<0.2	<0.010	<0.010	<0.010	<0.010
Metribuzin	<0.006	<0.006		<0.012	<0.012	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.012	<0.012		<0.012	<0.012	<0.012	<0.012
Molinate	<0.003	<0.003				<0.003	<0.003	<0.003	<0.003	<0.003	<0.003							
Napropamide	<0.007	<0.007				<0.007	<0.007	<0.007	<0.007	<0.007	<0.007							
p,p'-DDE	<0.003	<0.003				<0.003	<0.003	<0.003	<0.003	<0.003	<0.003							
Parathion	<0.010	<0.010				<0.010	<0.010	<0.010	<0.010	<0.010	<0.010							
Pebulate	<0.004	<0.004				<0.004	<0.004	<0.004	<0.004	<0.004	<0.004							
Pendimethalin	<0.022	<0.022		<0.020	<0.020	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.020	<0.020		<0.020	<0.020	<0.020	<0.020
Phorate	<0.011	<0.011		<0.020	<0.020	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.020	<0.020		<0.020	<0.020	<0.020	<0.020
Prometon	<0.01	<0.01	<0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.4	<0.01	<0.01	<0.01	<0.01
Propyzamide	<0.004	<0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004		<0.004	<0.004	<0.004	<0.004
Propachlor	<0.025	<0.025				<0.025	<0.025	<0.025	<0.025	<0.025	<0.025							
Propanil	<0.011	<0.011				<0.011	<0.011	<0.011	<0.011	<0.011	<0.011							
Propargite	<0.02	<0.02				<0.02	<0.02	<0.02	<0.02	<0.02	<0.02							
Simazine	<0.007	<0.005		<0.006	<0.006	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.006	<0.006		<0.006	<0.006	E0.005	E0.004
Tebuthiuron	<0.02	<0.02		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02		<0.02	<0.02	<0.02	<0.02
Terbacil	<0.034	<0.034				<0.034	<0.034	<0.034	<0.034	<0.034	<0.034							
Terbufos	<0.02	<0.02		<0.01	<0.01	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01
Thiobencarb	<0.010	<0.010				<0.010	<0.010	<0.010	<0.010	<0.010	<0.010							
Triallate	<0.002	<0.002				<0.002	<0.002	<0.002	<0.002	<0.002	<0.002							

Appendix 5. Concentrations of pesticides analyzed in water samples from selected springs in the St. Johns River drainage, 2004-07.—Continued

[Concentrations are in micrograms per liter; E, estimated concentration reported by laboratory that is quantifiable below the method reporting level]

Pesticide	Spring																	
	De Leon		Fern Hammock			Gemini-N Boil		Gemini-S Boil		Green		Juniper		Silver Glen			Wekiwa	
Trifluralin	<0.009	<0.009		<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009		<0.009	<0.009	<0.009	<0.009
Sample volume, Schedule 2001, milliliters	879	888				903	876	880	860	902	814							
Diazinon-d10, surrogate, water, filtered (0.7-micron glass fiber filter), percent recovery	120	107				103	96.9	113	108	103	102							
alpha-HCH-d6, surrogate, percent recovery	94.4	97.1				100	90.1	95.6	97.6	101	91.9							