Characterization of the Hydrology, Water Chemistry, and Aquatic Communities of Selected Springs in the St. Johns River Water Management District, Florida, 2004

By G.G. Phelps, Stephen J. Walsh, Robert M. Gerwig, and William B. Tate

Prepared in cooperation with the
St. Johns River Water Management District

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
centimeter (cm)	0.3937	inch (in.)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.646	million gallons per day (Mgal/d)
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:

$$°F=(1.8\times°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8.$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

Ar	argon
BOD	biochemical oxygen demand
CH_4	methane
CIAT	2-chloro-4-isopropylamino-6-amino-s-triazine
CO_2	carbon dioxide
DEET	N,N′-diethyl-methyl-toluamide
DO	dissolved oxygen
EPT	Ephemeroptera, Plecoptera, and Trichoptera taxa
ETO	Ephemeroptera, Trichoptera, and Odonata taxa
FDEP	Florida Department of Environmental Protection
FI	Florida Index
FLMNH	Florida Museum of Natural History
GIS	geographic information system
H_2S	hydrogen sulfide
m	meter
μm	micrometer
μS/cm	microsiemens per centimeter at 25 °C
NWIS	U.S. Geological Survey National Water Data Information System
NO_3^-	nitrate
NO_2^-	nitrite
N	nitrogen
N_2	nitrogen gas
O_2	oxygen
P	phosphorus
RSIL	Reston Stable Isotope Laboratory
r	richness
SJRWMD	St. Johns River Water Management District
SCI	Stream Condition Index
SAV	submerged aquatic vegetation
SF_6	sulfur hexafluoride
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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Abstract

The hydrology, water chemistry, and aquatic communities of Silver Springs, De Leon Spring, Gemini Springs, and Green Spring in the St. Johns River Water Management District, Florida, were studied in 2004 to provide a better understanding of each spring and to compile data of potential use in future water-management decisions. Ground water that discharges from these and other north-central Florida springs originates from the Upper Floridan aquifer of the Floridan aquifer system, a karstic limestone aquifer that extends throughout most of the State's peninsula. This report summarizes data about flow, water chemistry, and aquatic communities, including benthic invertebrates, fishes, algae, and aquatic macrophytes collected by the U.S. Geological Survey, the St. Johns River Water Management District, and the Florida Department of Environmental Protection during 2004, as well as some previously collected data.

Differences in water chemistry among these springs reflect local differences in water chemistry in the Upper Floridan aquifer. The three major springs sampled at the Silver Springs group (the Main Spring, Blue Grotto, and the Abyss) have similar proportions of cations and anions but vary in nitrate and dissolved oxygen concentrations. Water from Gemini Springs and Green Spring has higher proportions of sodium and chloride than the Silver Springs group. Water from De Leon Spring also has higher proportions of sodium and chloride than the Silver Springs group but lower proportions of calcium and bicarbonate. Nitrate concentrations have increased over the period of record at all of the springs except Green Spring. Compounds commonly found in wastewater were found in all the springs sampled. The most commonly detected compound was the insect repellant N,N'-diethyl-methyl-toluamide (DEET), which was found in all the springs sampled except De Leon Spring. The pesticide atrazine and its degradate 2-chloro-4-isopropylamino-6-amino-s-triazine (CIAT) were detected in water from the Silver Springs group and in both boils at Gemini Springs. No pesticides were detected in water samples from De Leon Spring and Green Spring. Evidence of denitrification was indicated by the presence of excess nitrogen gas in water samples from most of the springs.

Aquatic communities varied among the springs. Large floating mats of cyanobacteria (blue-green algae), identified as *Lyngbya wollei*, were observed in De Leon Spring during all sampling events in 2004. At Gemini Springs, the dominant periphyton was *Rhizoclonium* sp. Of the three springs sampled for benthic invertebrates, De Leon Spring had the highest overall species richness and most disturbance intolerant species (Florida Index = 4). Green Spring had the lowest species richness of the springs sampled. Based on qualitative comparisons, overall macroinvertebrate species richness seemed to be negatively related to magnesium, potassium, sodium, and specific conductance. Invertebrate abundance was greatest when dissolved oxygen and nitrate were high but phosphorus and potassium concentrations were low. Dipteran abundance seemed to be positively associated with specific conductance and total organic carbon but negatively associated with nitrate-N. Amphipods were the numerically dominant group collected in most (six of nine) collections. Shifts in amphipod abundance of the two species collected (*Gammarus* sp. and *Hyalella azteca*) varied by season among the three springs, but there were no trends evident in the variation. Fish populations were relatively species-rich at the Silver Springs group, De Leon Spring, and Gemini Springs, but not at Green Spring. Nonindigenous fish species were observed at all springs except Green Spring.

Introduction

Florida's springs are important natural features, many of which are headwaters of spring runs or streams that support fragile ecosystems containing diverse biotas and endemic, rare, or unique species or assemblages. The springs also are important recreational, cultural, and economic assets to the State. All of the ground water that discharges from the largest springs and nearly all of the smaller springs comes from the Floridan aquifer system (a thick sequence of carbonate rocks of Eocene age); the water is recharged entirely within the State. In much of central and north-central Florida, the limestone of the Upper Floridan aquifer (the upper unit of the Floridan aquifer system) is at or near land surface, so recharge occurs rapidly. The landscape is characterized by gently rolling topography formed by a combination of karst depressions and hills capped with clastic sediments; sinkholes and springs are abundant.

Demand for water for public supply, irrigation, and other uses continues to increase as Florida's population grows. Ground water from the Floridan aquifer system traditionally has been the main source of water supply. Projections by water managers of the St. Johns River Water Management District (SJRWMD) and ground-water flow models developed by the SJRWMD and the U.S. Geological Survey (USGS) indicate that the increased pumping of ground water is likely to result in decreased discharge from many of Florida's springs. Droughts place additional stress on ground-water resources. There have been recent periods of low flows associated with droughts; many Florida springs had record low discharge in 2000. The ecological effects of decreased discharge are largely unknown because the aquatic ecosystems of many of Florida's springs have received little study.

Florida's springs vary substantially in such attributes as length of channel and size of adjacent wetlands, effects of backwater from other streams, water chemistry, land use in the springshed, and other factors. A standard or uniformly applied set of criteria to monitor water chemistry and biotic communities may not include all of the properties necessary to evaluate ecological integrity. For example, in some springs protection of adjacent wetlands may be an important priority, whereas in other springs the depth of water in the spring run may be an important factor for maintaining habitat for such prominent animals as fishes and manatees. A better understanding of the hydrologic and ecological conditions of Florida's springs is needed in order to adequately assess the effects of land-use changes on ground-water resources and the biological communities that are dependent upon them.

This study summarizes preliminary assessments of water chemistry and components of the aquatic communities of four springs in the St. Johns River drainage. Similar studies of other springs are in progress and results of these investigations are intended to provide baseline data for a subset of springs within the basin. The primary purpose of these studies is to present comparative data that can be used to evaluate interactions among flow, water chemistry, and ecological conditions.

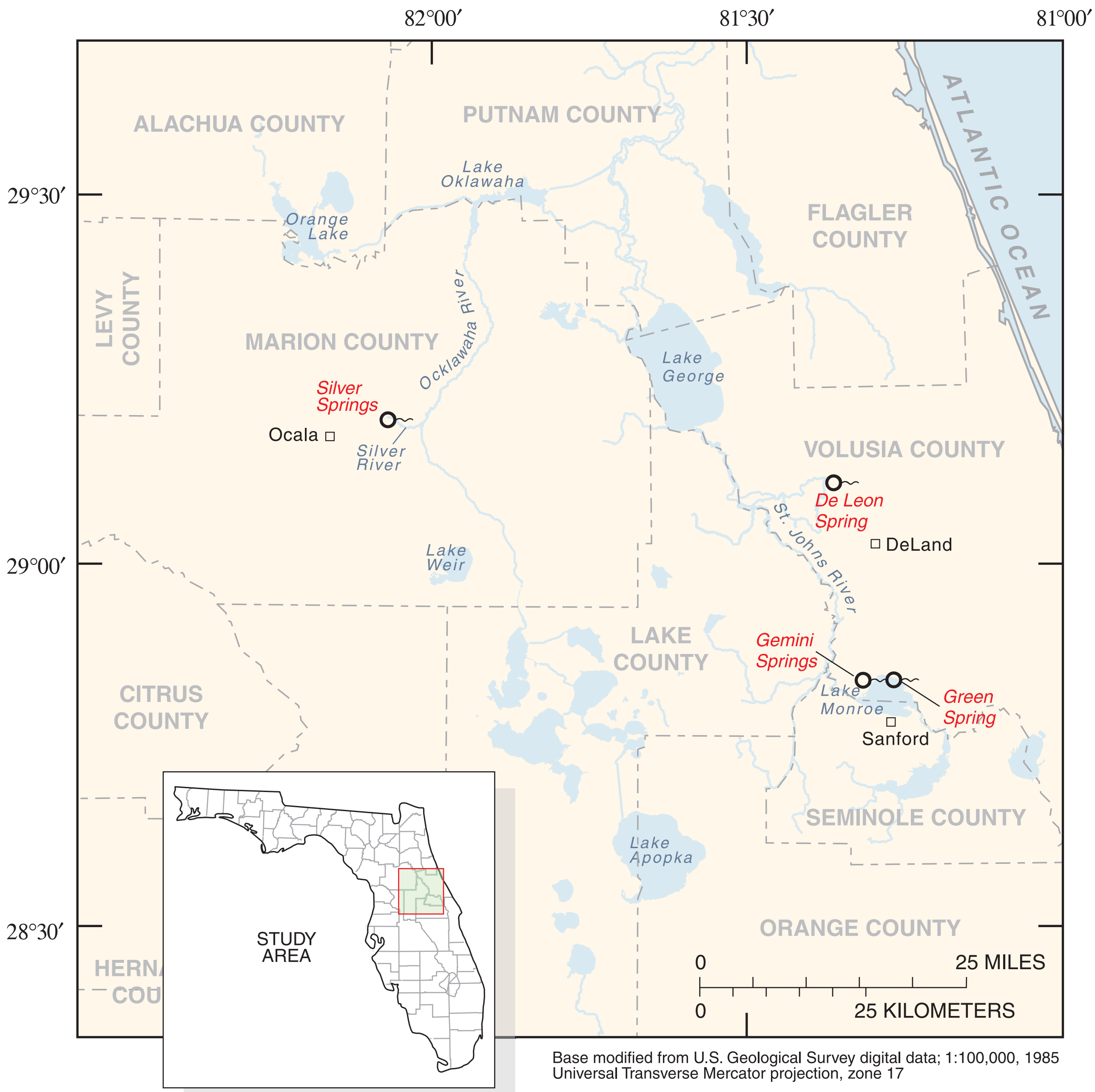
Purpose and Scope

This report summarizes data collected during the first year of the study (2004) so that water managers can assess the sampling methodologies and plan future sampling of additional springs. The purpose of the report is to provide a baseline assessment of the aquatic ecosystems of the springs. Data were collected three times during the year by the USGS, the SJRWMD, and the Florida Department of Environmental Protection (FDEP) at the Silver Springs group (Marion County), De Leon Spring (Volusia County; formerly called Ponce de Leon Spring), Gemini Springs (Volusia County), and Green Spring (Volusia County) from October 1, 2003 to September 30, 2004. Data include discharge, water chemistry, and aquatic-community data for benthic invertebrates, fishes, algae, and aquatic macrophytes. Water-chemistry data were collected by the USGS to complement data collected by other agencies. The spring vents were sampled three times for physicochemical properties (specific conductance, dissolved oxygen (DO) concentration, temperature, and pH), and twice for concentrations of chlorophyll-*a* and –*b*, pesticides, and a suite of compounds commonly found in wastewater. The spring runs were sampled three times for the physicochemical properties and for concentrations of chlorophyll-*a* and –*b,* major anions and cations, and nutrients. Samples were collected for analysis of benthic invertebrate populations at De Leon Spring, Gemini Springs, and Green Spring on the same dates as the USGS water-chemistry sampling. Fish population, vegetation, and periphyton surveys were done once at each of the three springs during the study. Three springs of the Silver Springs group were sampled twice for the same constituents as the other spring vents; biological data were not collected because the aquatic ecosystem at this system was studied by other investigators (Wetland Solutions, Inc., 2004; Stevenson and others, 2004). The water-chemistry data collected by FDEP and SJRWMD that are described in this report include dissolved major anion and cation and nutrient concentrations for each spring vent.

Previous Studies

Rosenau and others (1977) provided a detailed description of more than 200 of Florida's springs. Scott and others (2002; 2004) revisited many of those springs, updated site descriptions, and collected water samples. Smaller springs such as Gemini Springs and Green Spring, however, were not included in either study by Scott and others (2002; 2004).

Silver Springs, the largest non-tidal spring group in Florida, is a group consisting of at least 16 springs that form the headwaters of the Silver River in Marion County, FL (fig. 1). Annual mean discharge of the group for 1934-2004 is about 780 cubic feet per second (ft^3/s) (U.S. Geological Survey, 2005). Studies of the aquatic ecosystems of Silver Springs include Hubbs and Allen (1943) and Odum (1957). A recent study (Wetland Solutions, Inc., 2004) provided an updated evaluation of the Silver Springs ecosystem. Surveys of fish and mussel populations were summarized recently by Walsh and Williams (2003) and portions of their results are included in this report. Those surveys were augmented by additional information from literature sources and databases of the Florida Museum of Natural History (FLMNH), University of Florida, Gainesville, FL. The influence of



Base modified from U.S. Geological Survey digital data; 1:100,000, 1985
Universal Transverse Mercator projection, zone 17

Figure 1. Locations of Upper Floridan aquifer springs.

wastewater on water quality in three of the larger springs of the group (the Main Spring, the Abyss, and the Blue Grotto) was discussed by Phelps (2004), who also estimated ages of about 30 years or less for at least some portion of the water discharging from the Main Spring at Silver Springs.

The other springs included in this study are smaller than the Silver Springs group and have been the subject of relatively little research. De Leon Spring (mean annual discharge about 30 ft^3/s) is located at De Leon Springs State Park. A description of De Leon Spring by Rosenau and others (1977) was updated by Scott and others (2004). Green Spring and Gemini Springs were described by Rosenau and others (1977). Results of fish and mussel population surveys in the spring run of De Leon Spring (Walsh and Williams, 2003) were augmented by additional observations made during this study and updated in this report.

Acknowledgments

Identification of algae specimens to species was made by Peter D'Aiuto (Green Water Laboratories, Palatka, FL). Douglas G. Strom (Water and Air Research, Inc., Gainesville, FL) provided selected taxonomic identifications of benthic invertebrates.

Site-Numbering System

The USGS National Water Data Information System (NWIS) uses a 15-digit number (site identification number) based on latitude and longitude to identify wells and miscellaneous surface-water data-collection sites. The first six digits denote the degrees, minutes, and seconds of latitude; the next seven digits denote the degrees, minutes, and seconds of longitude; and the last two digits denote a sequential number for a site within a one-second grid. Well-site identification numbers generally end in "01" or "02." Miscellaneous surface-water quality data-collection sites generally end in sequence number "00." Surface-water sites that are part of the USGS data-collection network are identified by an 8-digit downstream order number. The 8-digit site identification number for the main Silver Springs data-collection site is 0229500 and for De Leon Spring is 02236110.

Environmental Setting

Central Florida has an abundance of springs because the Florida peninsula is underlain by a thick sequence of limestone and dolomite, both of which are relatively easily dissolved by rainwater that seeps into the ground (Spechler and Schiffer, 1995). Carbon dioxide dissolved in recharging rainwater forms carbonic acid, a weak acid that dissolves the rocks, thus creating cavities and caverns. The result is a landform called karst, which is characterized by the presence of springs and sinkholes.

Springs can be classified on the basis of the amount of water that discharges from them. A first-magnitude spring discharges 100 ft^3/s (65 million gallons per day (Mgal/d)) or more. A second magnitude spring discharges from 10 to 100 ft^3/s (6.5 to 65 Mgal/d), and a third magnitude spring from 1 to 10 ft^3/s (0.65 to 6.5 Mgal/d). The amount of water discharging from a spring depends on many factors, including the size of caverns in the rocks, the water pressure in the aquifer, the size of the area contributing recharge to the spring (also called the springshed), and the amount of rainfall (Spechler and Schiffer, 1995).

Climate in the study area is subtropical and is characterized by warm, humid, rainy summers and temperate, dry winters. Average annual (30 years) daily temperature is about 71 degrees Fahrenheit (^oF) (22^o C) at DeLand and 73 ^oF at Sanford, FL (National Oceanic and Atmospheric Administration, 2004). Average annual rainfall (1971-2000) is about 57 inches (in.) at DeLand, 51 in. at Sanford, and 50 in. at Ocala. Most of the rainfall occurs in June-September, with some months having as much as 20 in. of rainfall (figs. 2 and 3). About 70-75 percent of the rainfall commonly returns to the atmosphere as evapotranspiration (Sumner, 1996; Knowles, 1996).

Methods

The following sections describe the methods and techniques used to collect and analyze flow, water chemistry, and aquatic community data collected from the four springs. Unless noted otherwise, hydrologic, water chemistry, and aquatic community data all were collected on the same day for each sampling event.

Hydrologic and Water-Chemistry Data

Hydrologic data, including flow and stage data, are collected by the USGS and the SJRWMD. Continuous flow is calculated at Silver Springs by the USGS. Continuous flow data are not available for De Leon Spring, Gemini Springs, and Green Spring; however, monthly flow measurements are made by SJRWMD at De Leon Spring and Green Spring and quarterly flow measurements are made at Gemini Springs. Flow measurements also were made by the USGS at both vents of Gemini Springs on dates when water samples were collected.

Water-chemistry data were collected by the USGS, the SJRWMD, and the FDEP. Water samples were collected

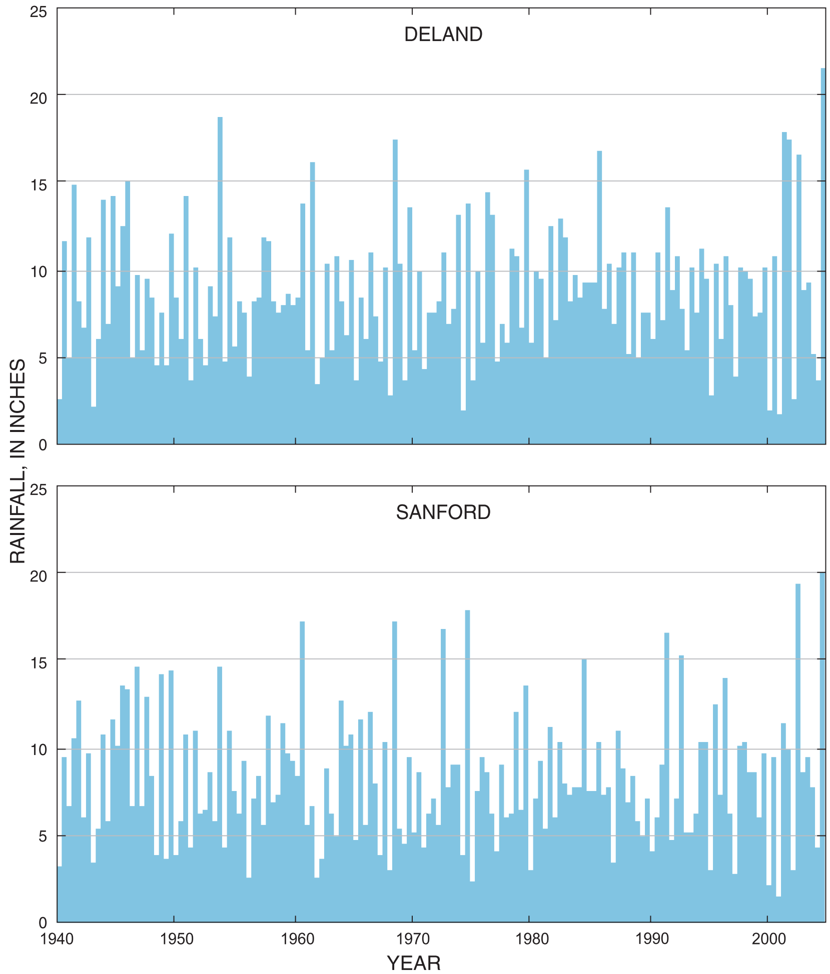


Figure 2. Monthly rainfall at DeLand and Sanford, Florida, 1940-2004.

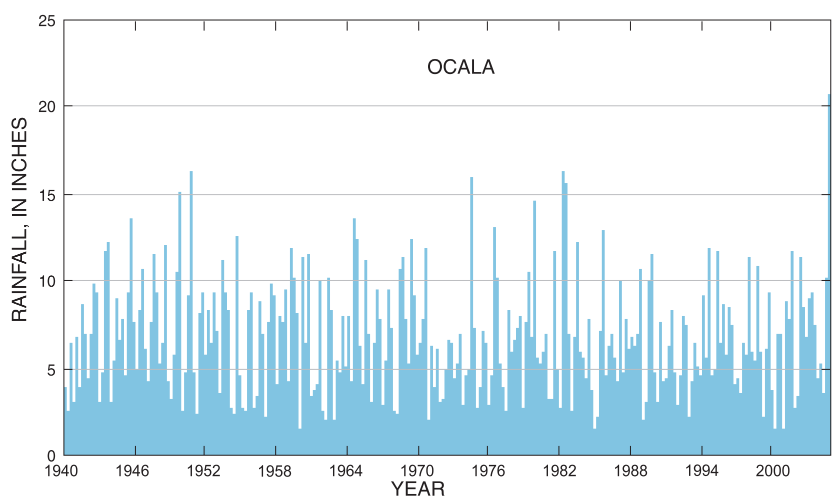


Figure 3. Monthly rainfall at Ocala, Florida, 1940-2004.

by the USGS from each spring by lowering an electric submersible stainless-steel pump (Fultz pump) with Teflon discharge tubing into the spring pool as close to the vent as possible. In the spring runs, the pump was placed at approximately half the depth of the run. Samples were collected when temperature, pH, and specific conductance had stabilized. Water samples for major ions and nutrients were collected according to U.S. Geological Survey (1997-2003) protocols and analyzed at the USGS laboratories in Ocala, FL and Denver, CO. Water samples for anion and cation analysis were filtered by using 0.45 micrometer (µm) Gelman capsule filters. Cation samples were collected in acid-washed bottles and acidified with 70 percent nitric acid. Samples analyzed for nutrients were held in the field at 4° C before delivery to the laboratory. Because of changes in laboratory methodologies, nutrient samples collected after July 2004 were filtered. Generally, for ground water and spring water, concentrations of nutrients in filtered and unfiltered water samples are comparable. Appendix A contains cation, anion, and nutrient data collected during this study.

Nitrogen (N) occurs as anions in water as nitrite (NO_2^-) or nitrate (NO_3^-). Both species are mobile and NO_3^- is stable over a wide range of conditions (Hem, 1985). The NO_2^- ion is unstable in aerated water and generally is present in negligible concentrations compared to NO_3^-. In this report, the combined concentration of nitrite-plus-nitrate reported by the analytic laboratory is referred to as nitrate-N.

Samples for N isotope analysis were filtered and collected in 1-liter (L) plastic bottles, kept chilled at 4° C and shipped to the USGS Stable Isotope Laboratory (RSIL) in Reston, VA, for analysis. Analytical techniques are described by Böhlke and Denver (1995) and Böhlke and Coplen (1995). Isotopic values are reported with the standard delta notation (δ) (Gonfiantini, 1981) as defined by the expression:

$$\delta \text{ (per mil)} = [(R_{sample}/R_{standard})-1] \times 1{,}000,$$

for $\delta^{15}N$, $R = {}^{15}N/{}^{14}N$. Values of $\delta^{15}N$ for nitrate-N concentrations greater than 0.5 milligrams per liter (mg/L) are normalized to values of +0.4 per mil for International Atomic Energy Agency standard IAEA-N1 and +180.0 per mil for USGS-32 (Böhlke and Coplen, 1995), with analytical uncertainties of about ±0.25 per mil.

Water samples analyzed for organic compounds commonly found in wastewater (app. B) and pesticides (app. C) were filtered through a 0.7-µm nominal pore size glass-fiber filter and collected in baked 1-L amber glass bottles, chilled at 4 °C and shipped to the USGS laboratory in Denver, CO. For quality-assurance purposes, replicate samples and field blank samples were collected during each sampling trip. Because caffeine and insecticides were included in the chemical analysis, field personnel neither consumed caffeine nor used personal insecticides on sampling days. Samples for organic wastewater compounds were analyzed by using gas chromatography and mass spectrometry, as described by Zaugg and others (2002). Pesticides were analyzed by using solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring (Zaugg and others, 1995). Acetophenone, phenol, and tetrachloroethylene were detected in one or more of the field blanks, so detections of those compounds less than 10 times the concentration determined in the blanks were not reported in this report. Water samples for dissolved gas analysis were collected in septum glass vials and samples for sulfur hexafluoride (SF_6) analysis were collected in glass bottles and shipped to USGS Chlorofluorocarbon Laboratory in Reston, VA, for analysis.

Land-use data for 2000 for the areas contributing recharge to each spring (springshed) were compiled from geographic information system (GIS) coverages provided by the SJRWMD (St. Johns River Water Management District, 2002). Approximate springshed areas were calculated by adding backwards particle tracking to a calibrated model of ground-water flow developed by Sepúlveda (2002), using a maximum travel time of 500 years.

Aquatic Community Data

Aquatic macroinvertebrate samples were collected with a D-frame dip net (500 µm mesh, 0.3 meter (m) width) and a petite ponar dredge. Dip net sampling was based on a multihabitat approach outlined in the U.S. Environmental Protection Agency (USEPA) rapid bioassessment manual (Barbour and others, 1999). Collections using a petite ponar dredge followed methods used as standard operating procedures by the Florida Department of Environmental Protection (2004a). Sampling was conducted to coincide with dates of water-chemistry sampling at Green Spring, Gemini Springs, and De Leon Spring and to represent seasonal conditions during winter (February), spring (May), and summer (August) 2004. All samples were taken downstream of main spring vents in each system, generally at a distance where low DO was not expected to limit diversity, and in spring pools or runs where benthic habitats provided suitable habitats for macroinvertebrates.

A dip net sample consisted of 20 sweeps taken from leaf packs, snags, aquatic macrophytes (submersed and emergent), roots or undercut banks, sediment (muck or sand) and rock habitats in proportion to the approximate percent coverage of each habitat type estimated visually. Each sweep consisted of a 0.5-m sweep, jab, or the substrate was disturbed by kicking or agitating with hands and allowing invertebrates and organic matter to flow into the net held stationary 0.5 m downstream. Material was rinsed in a 500 µm sieve after two or three individual sweeps for removal of large debris, vegetation, detritus, and sediment. The combined material from all 20 sweeps was preserved in a solution of 10 percent formalin, containing a small amount of Rose Bengal dye for ease of processing in the laboratory.

Three separate samples were collected at each site with a Wildco® petite ponar dredge. Samples were taken in areas with suitable substrate to ensure complete closure of the device, and to prevent loss of course material and invertebrates from the dredge. Each sample was rinsed in a 500 µm sieve and transferred into a 0.5 or 1 gallon jar and preserved with a 10 percent formalin solution containing Rose Bengal dye.

All preserved samples were transferred to the USGS laboratory in Gainesville, FL for taxonomic identification and enumeration. Each sample (i.e., combined dip net sweeps or individual ponar dredge collection) was treated on an individual basis depending on the number of organisms present. Samples that contained large numbers of organisms were subsampled for a target of approximately 100±10 percent individuals. Subsampling procedures followed commonly applied techniques (Rosenberg and Resh, 1993) as outlined in the USEPA rapid bioassessment protocols, FDEP standard operating procedures, and methods developed for Florida benthic assessments (Barbour and others, 1999; Florida Department of Environmental Protection, 2004b; Fore, 2004). The entire sample was spread evenly across a gridded pan (30 centimeters (cm) x 36 cm) with 30 grids (6 cm x 6 cm). Grids were selected four at a time with the use of a random numbers table. If the four grids chosen still contained far greater than 100 (+10 percent) organisms, a second subsample was made using the same method. This was repeated until a target of approximately 100-110 individuals was obtained. All organisms picked for identification and enumeration were placed in vials with 75 percent ethanol. The remainder of the sample material was rinsed, transferred to a jar, and stored in 75 percent ethanol.

All organisms were identified to the lowest practical taxonomic level with the use of an Olympus SZH10 dissecting microscope and enumerated with the use of a hand counter (for a discussion of the merits of identifications to different taxonomic scales, see Bailey and others, 2001). Primary aids used in invertebrate identifications included Thompson (1984), Berner and Pescador (1988), Daigle (1991, 1992), Pescador and Rasmussen (1995), Epler (1996), Merritt and Cummins (1996), Smith (2001), and Thorp and Covich (2001). No effort was made to identify chironomids or oligochaetes to species. A list of taxonomic names and authorities (for genera and species) is provided in appendix D. Higher taxonomic groups are listed in approximate phylogenetic order (app. D). Voucher specimens are archived at the USGS laboratory in Gainesville, FL.

Macroinvertebrate community richness and relative abundance metrics of taxa were calculated for Green Spring, Gemini Springs, and De Leon Spring. Seasonal taxonomic lists were tabulated for each spring and included organisms collected in combined ponar and sweep samples. Three community richness (r) measures were determined from the lists: richness, i.e., total number of taxa at the lowest level of identification; EPTr (number of Ephemeroptera, Plecoptera, and Trichoptera taxa); and ETOr (number of Ephemeroptera, Trichoptera, and Odonata taxa). All three richness measures were simple counts of distinct taxa. Scores for the Florida Index (FI) (Ross and Jones, 1979) were assigned to Class I and II taxa and the FI calculated for each spring using the formula:

$$FI = (2 \text{ x number Class I taxa}) + \text{number of Class II taxa}.$$

The FI is a composition 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 least tolerant taxa (i.e., most sensitive, assigned a score of 2) and tolerant taxa (less sensitive, scored 1). Because relatively few organisms from either FI class were collected in seasonal samples during this study, calculations were made by using pooled taxonomic data for all seasons for each spring.

For dip net samples, abundance estimates of taxa for each sample were extrapolated from the number of organisms in each taxon from subsamples; for example, by multiplying the count data by a factor of 7.5 for each subsample (i.e., in cases where one subsample was sufficient to obtain the target of 100-110 individuals). The following indices were determined to be important in Florida waters based on Resh and Jackson (1993), Graves and others (1998), and Barbour and others (1999): total number of organisms (=total abundance); most commonly occurring (dominant) taxon based on number of individuals; total individuals of EPT and EPO taxa; and percent (of total organism number) of dipterans and odonates. The values generated from these estimates were used to determine relative abundances for select orders, combinations of taxa, and dominant groups. Because amphipods were numerous in most samples, the calculations were repeated excluding amphipods.

Passive diffusion periphytometers were placed in De Leon Spring and Gemini Springs for 2 weeks during the summer of 2004. These devices consisted of vials containing solutions enriched in N, phosphorus (P), both N and P, and deionized water as a control. Glass microfiber filters were placed on the open ends of each vial so that differential colonization of periphyton species relative to a particular nutrient could be determined.

Recent surveys of fish and mussel populations in the Silver Springs system and De Leon Spring as reported by Walsh and Williams (2003) are summarized in this report. Those surveys were augmented by additional information from literature sources, databases of the FLMNH, and observations made during this study. Sampling of fishes was done by using boat electro-shocking, seines, dip nets, and underwater observation by divers using mask and snorkel. Mussel sampling was accomplished by dip netting, grubbing, and snorkeling; details of sampling methodology was provided by Walsh and Williams (2003). Scientific and common names of fishes reported in this study (app. E) follow Nelson and others (2004).

Fish surveys at Green Spring and Gemini Springs were limited by conditions at the respective springs. The vent at Green Spring is too deep to effectively sample with conventional gears. Modified crayfish traps (Johnson and Barichivich, 2004) were deployed on August 17, 2004, at both springs. On the same date, three snorkelers visually surveyed Gemini Springs, including the impounded pool, and recorded species presence and general abundance.

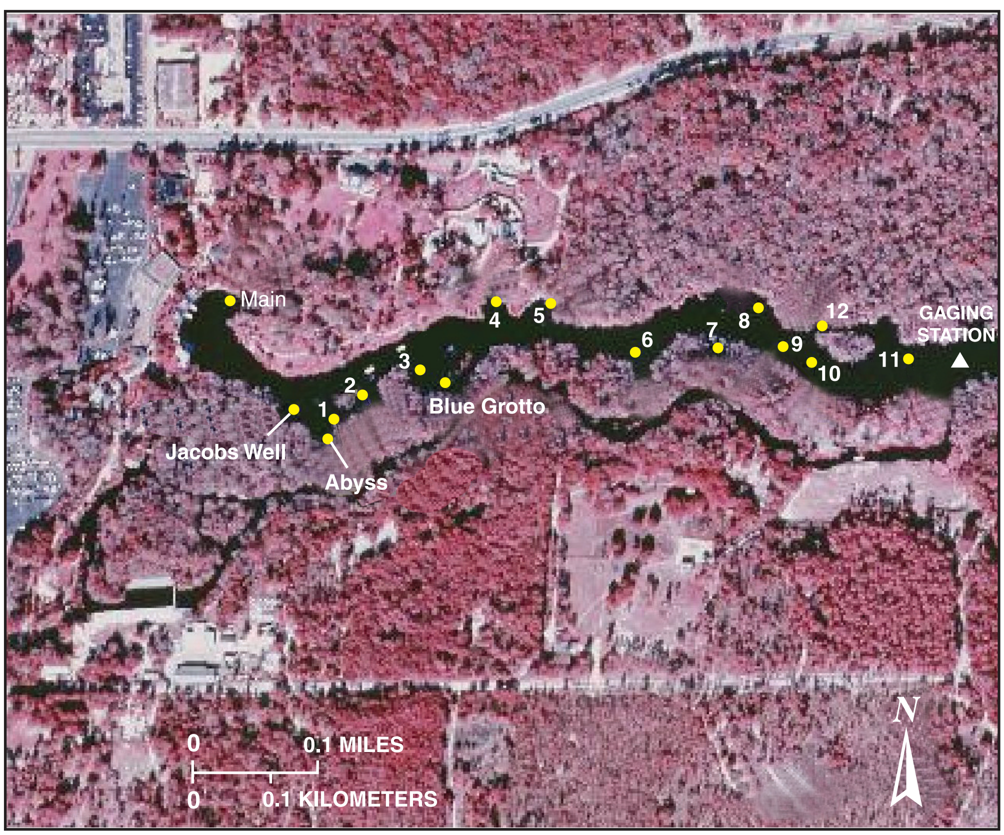
Characterization of Springs

The springs selected for study are representative of the many springs in central Florida. The Silver Springs group, one of the largest spring groups in Florida, is well-known as a recreational destination for tourists and residents alike. De Leon Spring is reputed to have been discovered by Ponce de Leon as the possible “Fountain of Youth” and is a popular recreation area. Even smaller springs, such as the twin springs of Gemini Springs and Green Spring, also attract human visitors. The areas surrounding all four springs studied were at one time privately owned but are now (2006) in public ownership by the State or by local government. The data collected during this study include a broad range of chemical and biological information. Each spring is discussed individually; to facilitate comparisons, all the data are included in the appendixes.

Silver Springs

The Silver Springs group is recognized as an hydrologically important feature in north-central Florida since its discovery by the first human residents of the area. Early indigenous people regarded Silver Springs as the home of their “water gods” because of the abundance of food and freshwater found at the spring (Wetland Solutions, Inc., 2004).

The Silver Springs group consists of at least 16 springs (fig. 4). Flows from the springs combine to form the Silver River. For consistency in terminology, “Silver Springs group” is used to designate the combination of all springs contributing to flow at the USGS gaging station. “Main Spring” is used to designate the primary headspring and often is referred to as Silver Spring or Mammoth Spring. The Main Spring has at least two caverns that produce water with differing chemical quality (A. Biddlecomb, Jones, Edmonds, Associates, written commun., 1997).



Photograph from Florida Department of Environmental Protection.

Figure 4. Silver Springs group.

This conclusion is based on data from hourly measurements of temperature, DO, pH and specific conductance from each of the vents in May 1997. The “left vent” had an average temperature of about 22.7 °C, specific conductance of about 445 microsiemens per centimeter (μS/cm), and DO of 1.18 mg/L, whereas the “right vent” had an average temperature of about 23.3 °C, average specific conductance of about 487 μS/cm, and DO of about 3.34 mg/L (Wetland Solutions, 2004, fig. 2-5). Variations in water chemistry from the Main Spring also were reported by Phelps (2004) who observed differences in nitrate concentration and $\delta^{15}N$ values during different sampling events.

A bathymetric map of the Silver River was prepared by Phlips and Allen (2004), based on fathometer surveys completed during February-March 2004. Maximum depth was about 30 feet (ft) at the Main Spring. Depth was about 21 ft at the Jacob’s well spring. Much of the Silver River is about 9 ft deep or less.

Analysis of land-use data for the Silver Springs springshed in 2000 (St. Johns River Water Management District, 2002) indicates that the springshed consisted of about 28 percent forest, 25 percent agriculture, 22 percent urban, 18 percent water or wetlands, 6 percent rangeland, and 1 percent other uses. Urban land use in the springshed has increased by about 12 percent since 1973.

Hydrology and Water Chemistry

The Silver Springs group is the largest non-tidal spring group in Florida, with a combined average discharge of about 780 ft^3/s for the period of record, 1932-2004 (fig. 5) (U.S. Geological Survey, 2005). Flow measurements are made at a site about 1.5 mile (mi) downstream from the Main Spring (fig. 4). Continuous flow is calculated based on a relation between the water stage at the gaging site and the head in the Upper Floridan aquifer at a nearby well and takes into account back-water from the Ocklawaha River. A drought in 2000-2002 resulted in the lowest flow measurement on record for the Silver Springs group, 350 ft^3/s in June 2001 (U.S. Geological Survey, 2002).

Water-chemistry data have been collected by the USGS at Silver Springs since 1956. Concentrations of nitrate-N in water from the Main Spring have increased from about 0.1 mg/L in 1956 to about 1.2 mg/L (fig. 6). The concentration of calcium also has an increasing trend (ranging from 48 to 78 mg/L, all values since 1996 have been greater than 70 mg/L). Sulfate concentration, however, does not show an increasing trend (Phelps, 2004). Nitrogen isotope-data indicated that the sources of N generally are mixed organic and inorganic and also that the isotope signature of the water from the Main Spring

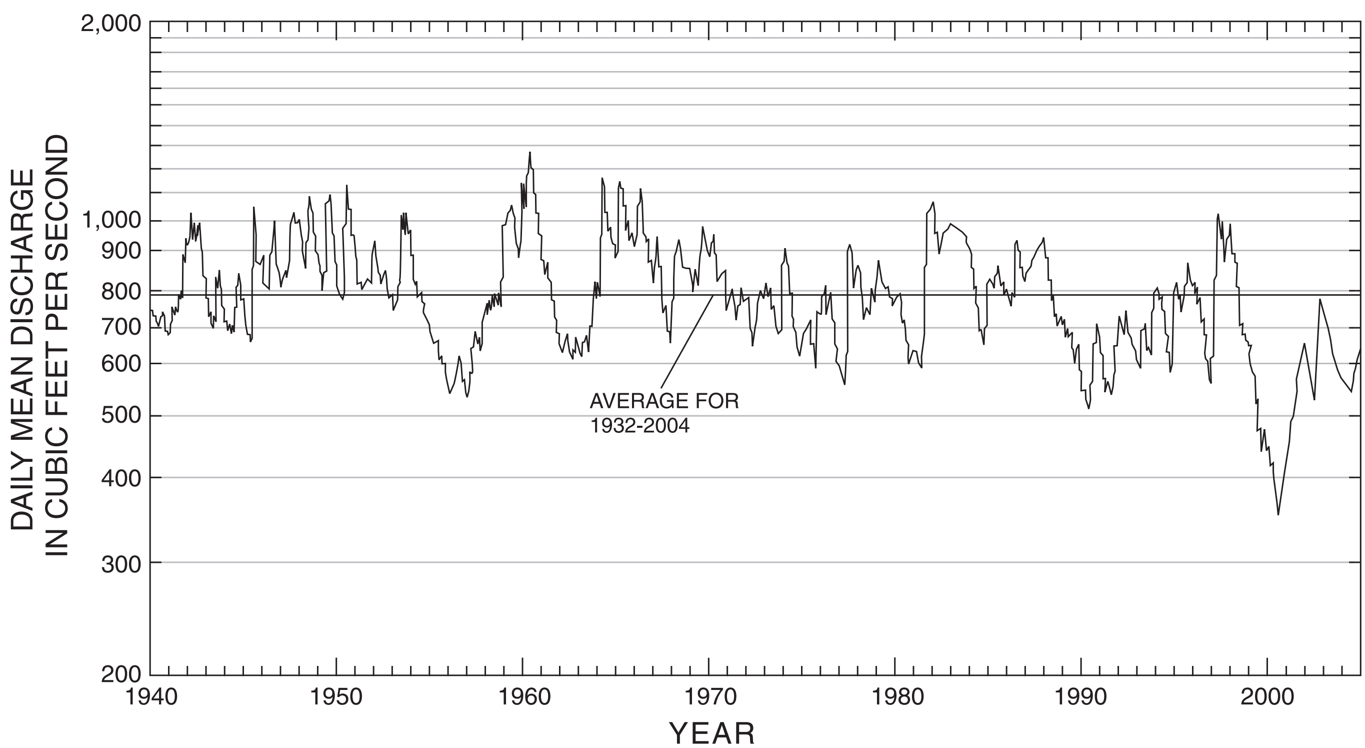


Figure 5. Discharge from the Silver Springs group, 1940-2004.

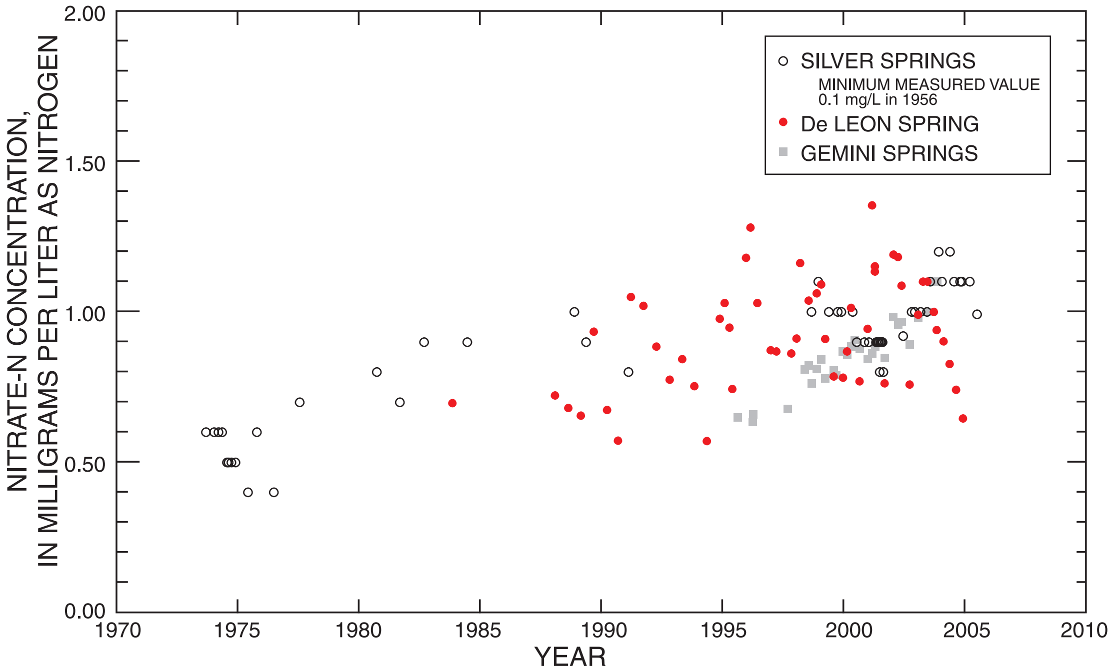


Figure 6. Nitrate-nitrogen concentrations for Silver Springs, De Leon Spring, and Gemini Springs.

can vary, sometimes strongly indicating inorganic (fertilizer) sources but other times indicating mixed sources with a strong influence of organic N (Phelps, 2004). The Main Spring, the Abyss, and the Blue Grotto were sampled for organic constituents commonly found in wastewater in January 2001 (Phelps, 2004). N,N'-diethyl-methyl-toluamide (DEET) was detected in the Main Spring and the Blue Grotto. Para-nonylphenol, a detergent metabolite, was detected in water from the Main Spring and isophorone, a solvent, in water from the Abyss. None of these compounds was detected in field blanks. These data indicate that human activities have influenced the water chemistry of the springs.

Water samples were collected during this study from the Main Spring, the Blue Grotto, the Abyss, and at a site in the Silver River near the USGS gaging station at times to coincide with data collection by FDEP (app. A). Water chemistry differed slightly among the three springs, mostly with respect to concentrations of DO and nitrate-N. Concentrations of DO in water from the Main Spring ranged from 1.7-2.7 mg/L but was higher in water from the Abyss (3.4-4.4 mg/L) and the Blue Grotto (3.6-4.5 mg/L). Concentrations of nitrate-N were about 0.96-1.2 mg/L in water from the Main Spring, about 1.2-1.5 mg/L in water from the Abyss, and about 1.4 mg/L in water from the Blue Grotto. Differences in DO and nitrate-N concentrations among springs of the Silver Springs group probably result from differences in source areas for recharge and the relative contributions of N originating from different sources. Total P concentrations were about the same in water from the three springs. Sulfate was lower in water from the Main Spring (median value about 38 mg/L) compared to the Abyss (about 69 mg/L) and the Blue Grotto (64 mg/L), probably because water discharging from these springs moves along different flow paths in the aquifer. Water in the Silver River differed from the spring-water samples mainly with respect to concentrations of DO, which ranged from 5.0-5.7 mg/L. Concentration of nitrate-N in the river samples ranges from 0.96-1.2 mg/L. Neither chlorophyll-*a* nor –*b* was detected in any of the samples from the Silver Springs group or the Silver River.

Water samples collected from the three springs in April and July 2004 were analyzed for organic compounds commonly found in wastewater (app. B) and for pesticides (app. C). Four wastewater compounds and two pesticides were detected in the Main Spring (table 1); the insect repellent DEET was detected in the Main Spring during both sampling events. Six wastewater compounds and one pesticide were detected in water samples from the Abyss, including DEET during one sampling. At the Blue Grotto, 15 wastewater compounds and one pesticide were detected, although none of the compounds were detected during both sampling events. Diethoxy-octylphenol, a known endocrine disruptor, was detected once in each of the three springs.

Table 1. Wastewater compounds, pesticides, and number of detections, 2004.

[P, pesticide. All other compounds are wastewater compounds. Endocrine disrupting potential: S, suspected; K, known]

Compound names	Endocrine disrupting potential	Silver Springs Group			De Leon	Green	Gemini North	Gemini South
		Main	Blue Grotto	Abyss				
1,4-Dichlorobenzene	S		1					
1-Methylnaphthalene			1			1		
2,6-Dimethylnaphthalene			1					
2-Chloro-4-isopropylamino-6-amino-s-triazine (CIAT) (P)		1	1	1			2	2
2-Methylnaphthalene			1			1	1	
3-Methyl-1(H)-indole (skatol)					1			
Atrazine (P)		1					2	2
Benzophenone	S	1				1	1	1
Bisphenol A	K	1	1	1		1		
Caffeine			1					
Camphor				1				
d-Limonene			1					
Indole				1	1			
Isopropylbenzene (cumene)			1					
Methyl salicylate			1			1	1	
N,N'-diethyl-methyl-toluamide (DEET)		2	1	1		2	2	1
Naphthalene			1			1	1	
Octylphenol, diethoxy-	K	1	1	1	1			
para-Cresol	S		1	1	1	1		
para-Nonylphenol (total)	K		1			1		
Phenanthrene			1					
Triphenyl phosphate								1

The presence of these constituents indicates that wastewater is affecting the water discharged from all three springs sampled at the Silver Springs group. The pesticide degradate 2-chloro-4-isopropylamino-6-amino-s-triazine (CIAT) was detected at all three springs during both sampling events and its parent compound atrazine was detected in the Main Spring in April 2004.

Water samples collected during this study from the Main Spring, the Abyss, and the Blue Grotto also were analyzed for dissolved gases and SF_6 (table 2). There was no evidence of excess nitrogen gas (N_2) dissolved in the water samples from the Main Spring and the Abyss, indicating that denitrification had not occurred. A small amount of excess N_2 gas was detected in the sample from the Blue Grotto, possibly indicating the occurrence of some denitrification. The SF_6 results from this study were not consistent with previous results (Phelps, 2004). For example, the sample collected from the Main Spring in 2002 indicated a recharge year of 1986-87 (Phelps, 2004), whereas the sample collected in July 2004 indicated a recharge year of 1994. The discrepancies may have resulted because sampling in 2004 was disrupted by boat traffic, possibly allowing the water to be contaminated with atmospheric SF_6 during the sampling process. The inconsistencies also could result from the varying concentrations of SF_6 in wastewater that has entered the aquifer and subsequently discharged at the springs.

Water from the springs generally is a mixture of varying proportions of younger water from shallow flow paths and older water from deeper flow paths. Tritium-helium dating of water from the Silver Springs group generally indicated older ages than SF_6 (Phelps, 2004). The young fraction of water from the Main Spring was about 27 years old (compared to about 15 years based on SF_6) and from the Blue Grotto about 18 years (compared to 6 years). For the Abyss, the tritium-helium and SF_6 ages were the same, about 10 years, possibly indicating that flow to the Abyss is relatively rapid and shallow.

Table 2. Dissolved gas and sulfur hexafluoride (SF_6) data.

[mg/L, milligrams per liter; pptv, parts per trillion volume; STP, standard temperature and pressure; c, cannot date sample because concentration is greater than 2004 atmospheric value; s, sample lost. Dissolved gas samples were collected and analyzed in duplicate]

Spring name	Date collected	Field temperature °C	N_2, mg/L	Ar, mg/L	O_2, mg/L	CO_2, mg/L	CH_4, mg/L	Excess N_2, mg/L	Recharge elev. ft.	Estimated recharge temperature °C	Excess air cm_3 at STP	Uncorrected SF_6 (pptv)	SF_6 corrected for excess air (pptv)	Piston flow model recharge year
Silver Springs Group														
Main	7/14/2004	23.1	16.20	0.55	1.18	14.90	0.00		55	23.3	2.1	4.6	3.3	1994.0
	7/14/2004	23.1	16.07	.55	1.34	14.59	.00		55	23.3	2.0			
Blue Grotto	7/14/2004	23.7	15.43	.53	2.76	11.12	.00	0.8	55	22.1	.2	6.8	6.6	c
	7/14/2004	23.7	15.15	.53	2.67	11.28	.00	.8	55	21.8	-.1			
Abyss	7/14/2004	23.7	15.52	.54	2.87	11.86	.00		55	23.4	1.5	6.9	5.6	2003.5
	7/14/2004	23.7	15.13	.54	2.70	12.14	.00		55	23.3	1.1			
De Leon Spring	5/12/2004	23	19.38	.59	.07	6.79	.00	1.5	50	22.6	3.7	3.0	1.8	1987.0
	5/12/2004	23	18.95	.58	.05	9.25	.00	1.5	50	22.4	3.2			
	8/23/2004	23.5	18.46	.57	.04	6.81	.00	1.5	50	23.0	2.8	2.7	1.8	1987.0
	8/23/2004	23.5	18.13	.57	.04	6.86	.00	1.5	50	22.7	2.4			
Gemini Spring North	5/11/2004	23	17.16	.57	.05	11.33	.00	.5	50	22.4	2.4	52.2	36.8	c
	5/11/2004	23	16.86	.56	.06	10.92	.00	.5	50	22.8	2.2			
	8/18/2004	24.25	16.84	.56	.05	12.02	.00	.8	50	22.0	1.6	91.7	71.3	c
	8/18/2004	24.25	s	s	s	s	s	s	s	s	s	s	s	s
Gemini Spring South	5/12/2004	23	17.32	.57	.05	11.14	.00	.8	50	22.2	2.2	59.4	42.1	c
	5/12/2004	23	17.60	.57	.04	10.99	.00	.8	50	22.0	2.4			
	8/18/2004	24.2	17.02	.57	.05	12.24	.00	.8	50	21.6	1.8	97.6	76.1	c
	8/18/2004	24.2	16.61	.56	.05	12.25	.00	.8	50	21.7	1.3			
Green Spring	5/11/2004	23	17.45	.57	.00	10.57	.23	.5	60	22.4	2.7	2.5	1.7	1986.5
	5/11/2004	23	17.57	.58	.00	10.63	.23	.5	60	22.0	2.7			
	8/18/2004	26	17.75	.57	.19	11.01	.27	1.0	60	22.9	2.6	2.0	1.3	1984.0
	8/18/2004	26	17.95	.57	.18	11.06	.27	1.0	60	22.8	2.8			

Aquatic Communities

Fishes in the Silver River were sampled in October 2001 (Walsh and Williams, 2003). A total of 29 species representing 22 genera and 15 families was collected from sites near the source of the Silver River downstream to its confluence with the Ocklawaha River (table 3). Previous collections of fishes in the Silver River by various investigators included 22 species of 15 genera and 11 families deposited in the FLMNH. The most complete historical survey of the fishes in any of Florida's first magnitude springs recorded a total of 35 species of 25 genera and 18 families in this system (Hubbs and Allen, 1943). Based on these combined sources, at least 45 fish species have been documented from the Silver River, although some of Hubbs and Allen's (1943) records were invalidated or represent species that have undergone subsequent taxonomic changes. USGS personnel (Walsh and Williams, 2003) did not collect 16 species that were represented by material in the FLMNH collection or reported by Hubbs and Allen (1943), probably because of limitations of the gear used (boat electrofishing) and the likely presence of these species in backwater and shallow, well-vegetated habitats where collection efforts were not targeted. Species collected in 2001 (Walsh and Williams, 2003) that were not present in the museum material or recorded by Hubbs and Allen (1943) included pugnose minnow (*Opsopoeodus emiliae*), brown bullhead (*Ameiurus nebulosus*), vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*), and swamp darter (*Etheostoma fusiforme*). Hubbs and Allen (1943) also reported the possible occurrence of white mullet (*Mugil curema*), smallmouth bass (*Micropterus dolomieu*), and a species of *Enneacanthus*. The white mullet observation was provisional and the authors suggested the possibility of a misidentification. Smallmouth bass were introduced into Lake Weir, which is connected to the Ocklawaha River by a canal, and records of this species in the Silver River were based on visual reports; however, there is no evidence that this species is established in the drainage. Specimens of *Enneacanthus* were reported to have been collected, but Hubbs and Allen (1943) did not examine them and were unable to render identification; two species are likely to be present in backwater areas, the banded sunfish (*E. obesus*) and the bluespotted sunfish (*E. gloriosus*). The most diverse families in the Silver River are centrarchids (8 species), ictalurids (6 species), fundulids (5 species), and cyprinids (4 species).

Specimens from the Silver River in the FLMNH collection were dominated by rainwater killifish (*Lucania parva*), redeye chub (*Notropis harperi*), bluefin killifish (*L. goodei*), and sailfin molly (*Poecilia latipinna*), accounting for a combined total of nearly three-fourths of all museum specimens; however, the proportions of specimens of different taxa deposited as museum specimens may not reflect overall relative abundances of species over time. Four species taken in the 2001 survey (Walsh and Williams, 2003) accounted for a combined 45 percent of the sample composition: redeye chub, mosquitofish (*Gambusia holbrooki*), sailfin molly, and spotted sunfish (*Lepomis punctatus*). Families represented by the greatest numbers of specimens were centrarchids (32.1 percent combined percent composition of all fish), poeciliids (22.8 percent), cyprinids (16.1 percent), and fundulids (13 percent). The greatest fish biomass consisted of gar (*Lepisosteus* spp.), lake chubsuckers (*Erimyzon sucetta*), and centrarchids. The most abundant species noted in visual surveys by Phlips and Allen (2004) during two counting events in March and April 2004 was the bluegill (*Lepomis macrochirus)*.

Silver Springs has at least one nonindigenous species, the vermiculated sailfin catfish. This South American species was introduced into west-central Florida and has spread rapidly in recent years to colonize the upper St. Johns River drainage, including several other large-magnitude springs and their spring runs. This represents the first known occurrence in an Ocklawaha River tributary.

Mussels were surveyed in August 2002 in four areas: from about 0.5 mi downstream of the Main Spring pool to 1.5 mi downstream in the Silver River; at another site downstream from the extent of this segment; in the spring-influenced section of the river near its mouth; and at one site in the Ocklawaha River near the confluence with the Silver River (Walsh and Williams, 2003). Mussels were located at all sites in the Silver River but were low in abundance. Conversely, mussels were more common at the single site in the Ocklawaha River, and species composition at that site differed from those collections made in the spring-influenced sites. Five species of native unionids were collected in the Silver River (table 4), with samples dominated (89 percent of total number of specimens) by a species of *Elliptio* that warrants further taxonomic study. All other native mussels from spring habitats were represented by fewer than five specimens, and two of these (variable spike, *Elliptio icterina* and iridescent lilliput, *Toxolasma paulus*) were represented by single specimens. These two species plus one other (Florida pondhorn, *Uniomerus carolinianus*) were found in the Silver River but were not present in the collection made in the Ocklawaha River. In contrast, the sample from the Ocklawaha River had three species not present in the Silver River: barrel floater (*Anodonta couperiana*), Florida shiny spike (*E. buckleyi*), and paper pondshell (*Utterbackia imbecillis*). Variation in species composition between these sites is attributed to habitat conditions and probable differences in ecological requirements of the individual species. The site in the Ocklawaha River was characterized by warmer, more tannic, turbid water and a substrate of mud

Table 3. Fishes collected or observed in Silver Springs State Park (Walsh and Williams, 2003), deposited in the Florida Museum of Natural History (FLMNH), and reported (x) by Hubbs and Allen (1943).

Family	Species	USGS		FLMNH ichthyological collection		Hubbs & Allen (1943)
		Number of specimens	Percent composition	Number of specimens	Percent of material	
Lepisosteidae	*Lepisosteus osseus*	11	1.2	--	--	X
	Lepisosteus platyrhincus	23	2.4	--	--	X
Amiidae	*Amia calva*	3	.3	--	--	X
Anguillidae	*Anguilla rostrata*	5	.5	1	.1	X
Clupeidae	*Dorosoma cepedianum*	10	1.1	--	--	X
	Dorosoma petenese	--	--	--	--	X
Cyprinidae	*Notemigonus crysoleucas*	1	.1	--	--	X
	Notropis harperi	126	13.3	200	22.4	--
	Notropis petersoni	20	2.1	44	4.9	--
	Opsopoeodus emiliae	6	.6	--	--	--
Catostomidae	*Erimyzon sucetta*	19	2.0	--	--	X
Ictaluridae	*Ameiurus catus*	--	--	2	.2	X
	Ameiurus natalis	--	--	1	.1	X
	Ameiurus nebulosus	1	.1	--	--	---
	Ictalurus punctatus	--	--	--	--	X
	Noturus gyrinus	5	.5	3	.3	--
	Noturus leptacanthus	--	--	6	.7	--
Loricariidae*	*Pterygoplichthys disjunctivus*	7	.7	--	--	--
Esocidae	*Esox americanus*	--	--	--	--	X
	Esox niger	2	.2	--	--	X
Aphredoderidae	*Aphredoderus sayanus*	--	--	--	--	X
Mugilidae	*Mugil cephalus*	--	--	--	--	X
Atherinopsidae	*Labidesthes sicculus*	27	2.8	2	.2	X
Belonidae	*Strongylura marina*	--	--	2	.2	X
Fundulidae	*Fundulus chrysotus*	--	--	--	--	X
	Fundulus lineolatus	--	--	--	--	X
	Jordanella floridae	--	--	--	--	X
	Lucania goodei	55	5.8	106	11.9	X
	Lucania parva	68	7.2	258	29.0	X
Poeciliidae	*Gambusia holbrooki*	109	11.5	40	4.5	X
	Heterandria formosa	12	1.3	18	2.0	X
	Poecilia latipinna	95	10.0	99	11.1	X
Centrarchidae	*Lepomis auritus*	30	3.2	11	1.2	X
	Lepomis gulosus	10	1.1	4	.4	X
	Lepomis macrochirus	57	6.0	--	--	X
	Lepomis marginatus	--	--	1	.1	--
	Lepomis microlophus	36	3.8	--	--	X
	Lepomis punctatus	96	10.1	71	8.0	X
	Micropterus salmoides	75	7.9	7	.8	X
	Pomoxis nigromaculatus	--	--	--	--	X
Percidae	*Etheostoma fusiforme*	1	.1	--	--	--
	Percina nigrofasciata	30	3.2	9	1.0	X
Elassomatidae	*Elassoma evergladei*	--	--	--	--	X
	Elassoma okefenokee	8	.8	1	.1	--
Achiridae	*Trinectes maculatus*	--	--	5	.6	X
	Total number of species	**29**		**22**		**35**
	Total number of specimens	**948**		**891**		

*nonindigenous species

and organic detritus, in comparison with the clear, cool water of the Silver River and substrate dominated by hard-packed sand with abundant growth of submerged aquatic plants and filamentous algae. The nonindigenous Asian clam (*Corbicula fluminea*) was relatively common in both systems.

The Silver Springs group was one of 28 Florida springs studied in 2003 by Stevenson and others (2004) to document and increase understanding of the ecological condition and relations between algae and nutrients. They reported that macroalgal cover at Silver Springs was about 70 percent in fall 2003, of which about 70 percent was *Lyngbya majuscule. Lyngbya* species are N-fixing, blue-green algae (cyanobacteria), some of which produce saxitoxins that can cause symptoms ranging from skin irritation to nausea in humans. Stevenson and others (2004) reported that the taxonomic status of *Lyngbya majuscula* is not clear. It may be a nonindigenous species in a phase of range expansion, possibly a marine species that can adapt to fresh water. *Lyngbya majuscule* is not affected by low N levels (Lundgren and others, 2003) and grows well in low-light conditions (Rossi and others, 1997). *Lyngbya majuscula* was associated with high-nutrient and high-discharge springs; however, overall nutrient concentrations in the 28 springs studied were not directly related to cover by *Lyngbya majuscula* (Stevenson and others, 2004). Control of nutrients could indirectly constrain *Lyngbya* because *Lyngbya* has no direct method of attaching to surfaces except by becoming entangled with rough surfaces or other objects attached to the bottom. *Lyngbya* generally was found attached to *Vaucheria* and aquatic plants, the proliferation of which could be constrained by nutrient reduction. Cowell and Botts (1994) suggested that *Lyngbya* colonizes areas after a disturbance such as removal of nuisance vegetation or after hurricanes. Thus, disturbance of aquatic vegetation by human activities in spring habitats may promote invasion by macroalgae during subsequent periods of low human activity (Stevenson and others, 2004).

A survey of the aquatic communities in the Silver River was made in December 2003-January 2004 (Phlips and Allen, 2004). These investigators observed submerged aquatic vegetation (SAV), algal, and vertebrate communities and compared the results to descriptions by Odum (1957). The dominant SAV, both as observed by Odum (1957) and Phlips and Allen (2004), was strap-leaf sagittaria (*Sagittaria kurtziana*). Algae blooms covered the SAV (Wetland Solutions, Inc., 2004). The dominant epiphytic algae based on biomass were the green alga *Ulothrx*, the diatom *Aulocosira* (=*Melosira*), and a variety of other diatoms. The dominant benthic algal species was *Lyngbya* sp., which covered 100 percent of the substrate in some parts of the study area. The predominance of *Lyngbya* in the benthic algal assemblage of the Silver River is an important change from the observations by Odum in 1957, when *Lyngbya* was not observed (Phlips and Allen, 2004). Whitford (1954; 1956) also described the algal assemblage in the Silver River and noted that the dominant species was the diatom *Cocconeis placentula*—similar to Odum's (1957) observation. Odum (1957) also reported small mats of *Spirogyra* sp., *Oedogonium* sp. and *Rhizoclonium* sp. in Silver Springs. According to Whitford (1954; 1956), the most important factor for distribution of algal communities was water velocity rather than temperature or light levels. Martin (1966) described dense filamentous growths of *Spirogyra* in the Main Spring and epiphytic *Lyngbya* attached to exposed surfaces in the Main Spring.

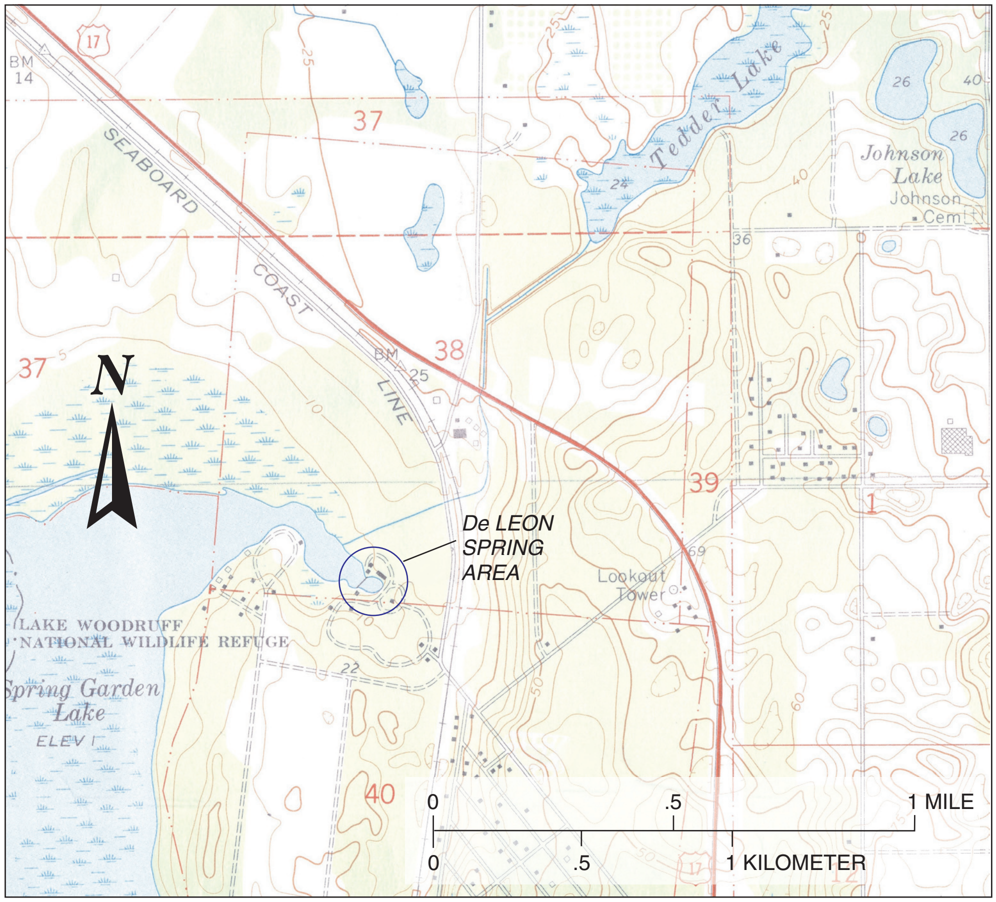
Table 4. Mussels collected in Silver River State Park and the Ocklawaha River at the mouth of the Silver River, 2002.

[Data from Walsh and Williams, 2003]

Species	Common name	Number for each subsample	Percent for each subsample
Silver River			
Corbicula fluminea	Asian clam	31	8.8
Elliptio icterina	variable spike	1	.3
Elliptio sp.	unidentified spike	315	89.0
Toxolasma paulus	iridescent lilliput	1	.3
Uniomerus carolinianus	Florida pondhorn	2	.6
Villosa amygdala	Florida rainbow	4	1.1
Total number of specimens		**354**	
Ocklawaha River			
Anodonta couperiana	barrel floater	1	1.1
Corbicula fluminea	Asian clam	14	15.4
Elliptio buckleyi	Florida shiny spike	36	39.6
Elliptio sp.	unidentified spike	1	1.1
Utterbackia imbecillis	paper pondshell	9	9.9
Villosa amygdala	Florida rainbow	30	33.0
Total number of specimens		**91**	

De Leon Spring

De Leon Spring, located near the town of De Leon Springs in Volusia County, is a 603-acre State park popular as a site for swimming, scuba diving, and other recreational activities. Downstream from the spring is a boat ramp with public access to the Lake Woodruff National Wildlife Refuge (fig. 7). In 2000, land use in the springshed was about 7 percent urban, 16 percent agricultural, 5 percent rangeland, 38 percent forest, 33 percent water or wetlands and 1 percent other types.



Source: U.S. Geological Survey Topographic map; 1:24,000

Figure 7. Location of De Leon Spring.

Hydrology and Water Chemistry

The spring pool is an almost circular, conical depression measuring 189 ft north to south and 168 ft east to west (fig. 8). The pool depth measures 28 ft over the spring vent (Scott and others, 2004). The pool is surrounded by a low concrete wall bordered by a concrete walk. A dam was constructed at the west side of the pool to maintain the water level in the spring pool (figs. 9 and 10). Two weir outlets in the


Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 8. De Leon Spring pool.


Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 9. De Leon Spring dam.

dam can be used to regulate the water level in the pool, and a flume at the southwest side of the pool diverts some flow to a large water wheel that formerly was used to operate a sugar mill. A boil usually is visible over the spring vent. Spring flow originates from a single cavern with a chimney vent in the north-central part of the pool (Rosenau and others, 1977).

The mean discharge of De Leon Spring, based on 244 measurements from 1929 to 2000, was 27.2 ft^3/s (U.S. Geological Survey, 2001) (fig. 11). Discharge measurements less than 20 ft^3/s were recorded during droughts in the early 1990s and in 2000; the minimum discharge recorded by the USGS was 12.7 ft^3/s on May 25, 2000 (U.S. Geological Survey, 2001). A discharge of 61.6 ft^3/s was measured by the SJRWMD on August 25, 2004 (St. Johns River Water Management District, 2005). Almost 22 in. of rain fell at DeLand, FL, in August 2004 partly as a result of hurricanes (National Oceanic and Atmospheric Administration, 2004). Discharge from De Leon Spring is difficult to measure because of the dam. Mats of algae and aquatic vegetation can partially block the culverts that carry flow through the dam, causing the water level in the spring pool to rise. Flows that are measured immediately after the vegetation is cleared reflect ponded water in the spring pool in addition to actual spring flow. Also, the shape of the spring vent does not allow good access for divers to make underwater measurements.

Water samples were collected from the spring vent by both the USGS and the SJRWMD and by the USGS from a site about 100 ft downstream from the dam. Concentration of DO in the spring water generally was low (0.8 to 1.5 mg/L) whereas the concentration was higher (1.5 to 6.7 mg/L) at the downstream site owing to turbulence and reaeration from the atmosphere. Specific conductance was similar at the vent and the downstream site: about 800 to 1,100 µS/cm. Chloride and sulfate concentrations also were similar at the two sites, ranging from about 140 to 240 mg/L for chloride and for sulfate from 28 to 38 mg/L. Nitrate-N concentration was only slightly higher at the spring vent (0.64 to 0.83 mg/L) compared to the downstream site (0.52 to 0.67 mg/L). Total P concentration was slightly higher in the spring run: 0.05 to 0.08 mg/L, compared to 0.05 in the spring. Total organic carbon (TOC) concentration ranged from 1.1 to 1.3 mg/L at the vent and from 1.1 to 3.9 downstream. Concentration of biochemical oxygen demand (BOD) ranged from 0.3 to 1.2 mg/L at both sites. On two sampling days,

Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 10. View downstream from De Leon Spring to Spring Garden Lake.

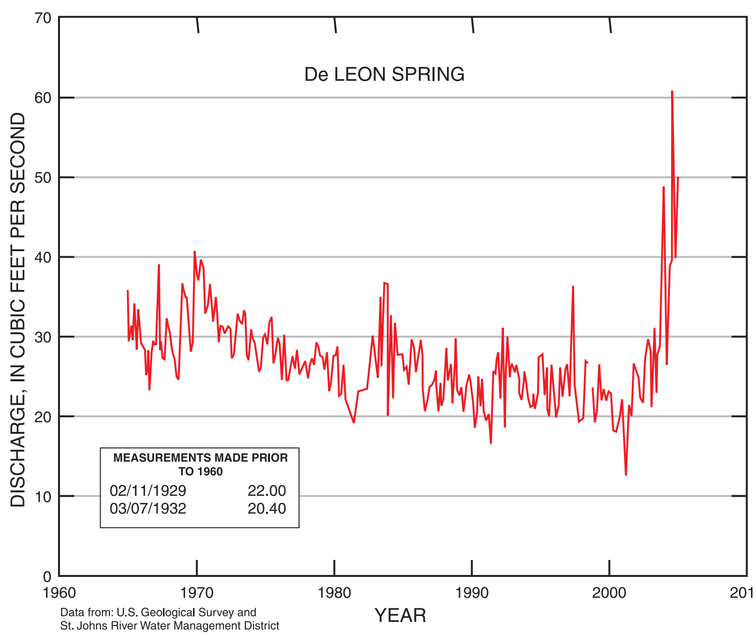


Figure 11. Discharge from De Leon Spring, 1965-2004.

chlorophyll-*a* was not detected in the vent but was 5.7 mg/L in May 2004; at the downstream site, chlorophyll-*a* was undetected in March 2004 but as high as 21 mg/L in February, on a day it was not detected at the spring vent. Chlorophyll-*b* was detected once at this spring during the study, in August 2004 at the downstream site. Chlorophyll-*a* is found in all plants, green algae, and cyanobacteria that photosynthesize whereas chlorophyll-*b* occurs only in plants and green algae (University of California Berkeley, 2005) so the relative amounts of the two types of chlorophyll may be helpful in understanding the periphyton community in a water body.

Historic nitrate-N data indicate an apparent increasing trend in concentration in the water from De Leon Spring (fig. 6) from about 1985 to 2004, although the concentrations fluctuated during this period. There are insufficient paired nitrate-N and discharge data to determine the relation (if any) between the two, but the low concentration in November 2004, when flow was high, could indicate that nitrate-N concentration is inversely related to discharge at De Leon Spring. Total P apparently has not increased since data collection began in 1972.

Excess dissolved N_2 concentrations of about 1.5 mg/L during both USGS sampling events indicate that denitrification was taking place in the Upper Floridan aquifer in the vicinity of De Leon Spring (table 2). Four conditions must be met for denitrification to occur (Korom, 1992): presence in the water of NO_3^-; presence of denitrifying bacteria; an electron donor (such as organic carbon); and anaerobic conditions (low DO). Nitrogen and oxygen isotope data for the dissolved NO_3^- indicate that N isotopes likely were being fractionated by denitrification (fig. 12). The SF_6 data indicate a recharge year of about 1987 for some fraction of the spring water, assuming that flow through the Upper Floridan aquifer to the spring can be approximated by piston flow.

Sampling for organic compounds commonly found in wastewater resulted in detections of four compounds (table 1) including para-Cresol (a wood preservative) at a level of 1.7 micrograms per liter (µg/L). Pesticides were not detected in water samples from De Leon Spring during either sampling. Water-chemistry data from De Leon Spring generally indicate the springshed has been affected by human activities.

Aquatic Communities

An estimated total of 42,335 macroinvertebrates was collected from ponar and sweep samples at De Leon Spring during three sampling events in 2004 (table 5). From those samples, 45 distinct taxa were identified. Taxon richness was highest in the sample collected in summer (August) and lowest in spring (May) but always greater than 10 total taxa (table 6). Ponar samples accounted for 18 taxa not collected in sweeps. Richness of EPT taxa varied from 0 (spring) to 3 (summer). Richness of ETO taxa ranged from 1 (spring) to 7 (summer); however, the relative abundance of odonates collected was highest in winter (table 6).

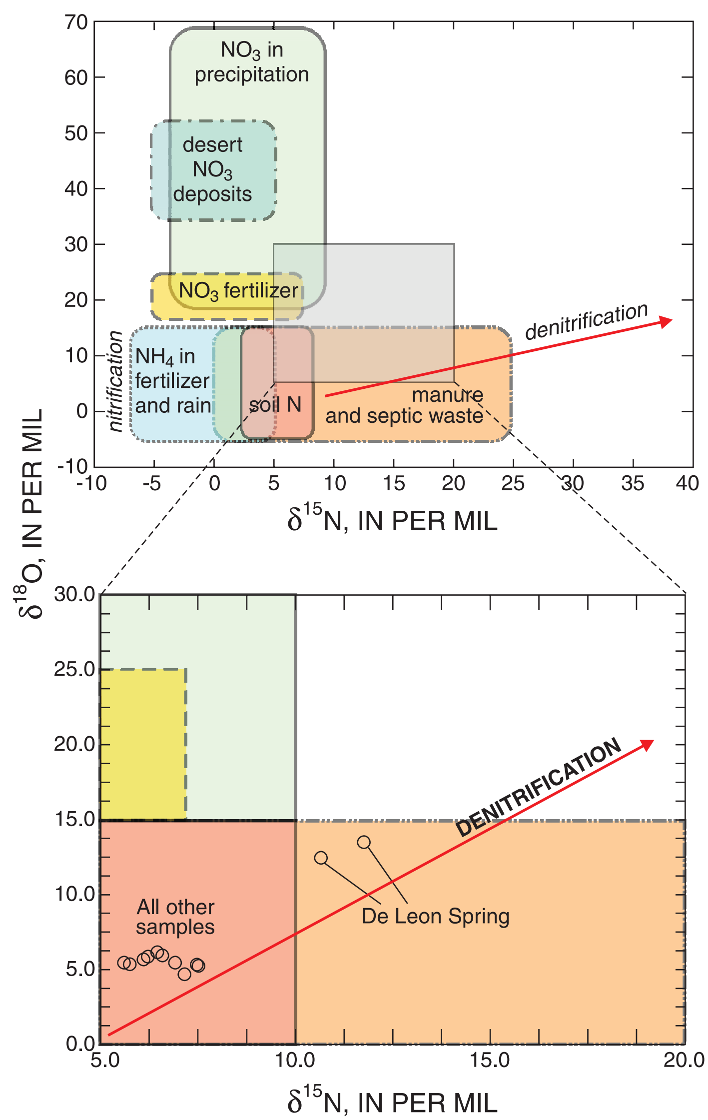


Figure 12. Delta ^{18}O of nitrate as a function of delta ^{15}N of nitrate for samples collected in 2004.

Table 5. Percent composition of total number of benthic macroinvertebrates (combined ponar and dip net sweep samples for all seasons) collected in De Leon, Gemini, and Green Springs, 2004.

[--, not differentiated or not observed]

Major taxon	Family	Species	Percent composition		
			De Leon	Gemini	Green
Porifera	--	--	0.018	--	--
Tricladida	--	--	.035	2.052	--
Nematoda	--	--	.135	.327	0.068
Oligochaeta	--	--	3.780	20.310	48.950
Hirudinea	Erpobdellidae	--	.005	--	--
Hirudinea	Glossiphoniidae	--	1.337	.270	--
Gastropoda	Ampullaridae	*Pomacea paludosa*	.133	--	--
Gastropoda	Ancylidae	--	.005	.016	--
Gastropoda	Hydrobiidae	--	4.790	11.888	.685
Gastropoda	Physidae	*Physella* sp.	.019	.297	.452
Gastropoda	Planorbidae	*Micromenetus floridensis*	.009	--	--
Gastropoda	Planorbidae	*Planorbella scalaris*	.067	.097	--
Gastropoda	Planorbidae	*Planorbella trivolvis intertextum*	.133	--	--
Gastropoda	Pleuroceridae	*Elimia floridensis*	2.733	--	--
Gastropoda	Thiaridae	*Melanoides tuberculata*	.142	--	--
Gastropoda	Viviparidae	*Viviparus georgianus*	1.214	--	--
Pelecypoda	Corbiculidae	*Corbicula fluminea*	.133	--	--
Pelecypoda	Unionidae	*Uniomerus carolinianus*	.133	--	--
Hydracarina	--	--	.019	--	--
Arachnida	Pisauridae	*Dolomedes* sp.[1]	--	.014	--
Ephemeroptera	--	--	.029	--	--
Ephemeroptera	Baetidae	*Callibaetis floridanus*	.002	--	--
Ephemeroptera	Caenidae	*Caenis diminuta*	.273	.014	--
Odonata	Coenagrionidae	*Enallagma* sp.	.266	--	--
Odonata	Coenagrionidae	*Nehalennia* sp.	.268	--	--
Odonata	Coenagrionidae	*Telebasis byersi*	--	.014	--
Odonata	Corduliidae	*Epitheca princeps regina*	.133	--	--
Odonata	Libellulidae	--	.002	--	--
Odonata	Libellulidae	*Erythemis plebeja*	.133	--	--
Hemiptera	Belostomatidae	--	--	.208	--
Hemiptera	Belostomatidae	*Belostoma* sp.	--	--	.120
Hemiptera	Belostomatidae	*Lethocerus* sp.	--	--	.904
Hemiptera	Gerridae	--	--	.104	--
Hemiptera	Mesoveliidae	*Mesovelia* sp.	.002	--	--
Hemiptera	Naucoridae	*Pelocoris* sp.	.135	.028	.060
Homoptera	--	--	.133	--	--
Trichoptera	Hydroptilidae	*Neotrichia* sp.	--	.014	--
Trichoptera	Hydroptilidae	*Orthotrichia* sp.	.002	--	--
Coleoptera	Chrysomelidae	--	.266	--	.060
Coleoptera	Dryopidae	*Pelonomus obscurus*	--	.014	--
Coleoptera	Haliplidae	*Peltodytes* sp.	--	.327	--
Coleoptera	Hydrophilidae	*Helocombus* sp.	.018	--	--
Diptera	Ceratopogonidae	--	.133	--	5.987
Diptera	Chironomidae	--	3.553	19.541	19.202
Diptera	Ephydridae	--	--	--	.452
Diptera	Ptychopteridae	--	--	--	.452

Table 5. Percent composition of total number of benthic macroinvertebrates (combined ponar and dip net sweep samples for all seasons) collected in De Leon, Gemini, and Green Springs, 2004—Continued.

[--, not differentiated or not observed]

Major taxon	Family	Species	Percent composition		
			De Leon	Gemini	Green
Diptera	Stratiomyidae	--	.035	--	.422
Diptera	Tabanidae	--	.002	--	--
Cladocera[1]	--	--	.019	--	--
Ostracoda[1]	--	--	.085	8.964	1.428
Isopoda	Asellidae[2]	--	.002	.006	--
Isopoda	Asellidae	*Lirceus lineatus*	.266	--	--
Isopoda	Sphaeromatidae	*Cassidinidea ovalis*	.135	--	--
Amphipoda	--	--	--	1.980	--
Amphipoda	Gammaridae	*Gammarus* sp.	18.496	18.152	--
Amphipoda	Hyalellidae	*Hyalella azteca*	60.502	15.087	20.309
Decapoda	Cambaridae	*Procambarus* sp.	.135	.236	.452
Decapoda	Palaemonidae	*Palaemonetes paludosus*	.135	.042	--
		Total number	**42,335**	**53,968**	**12,451**

[1]Not regarded as a component of the benthic macroinvertebrate fauna by the Florida Department of Environmental Protection.

[2]Possibly a terrestrial form.

Table 6. Richness and community measures for De Leon Spring.

[--, not calculated. EPT, Ephemeroptera, Plecoptera, and Trichoptera taxa; ETO, Ephemeroptera, Trichoptera, and Odonata taxa. Richness measures (taxon richness, EPTr, ETOr, and Florida Index) were tabulated from taxonomic lists from combined petite ponar dredge and dip net sweep samples. All other measures (# individuals; percentages) were calculated using total abundance estimates derived from dip net sweep collections only]

	Winter	Spring	Summer	Combined
Taxon Richness (total # taxa)	15	11	18	45
Total Abundance	8,944	7,425	22,275	38,644
EPTr (# taxa)	1	0	3	4
EPT (# individuals)	56	0	56	112
Odonata (# taxa)	2	1	4	5
ETOr (# taxa)	3	1	7	9
ETO (# individuals)	225	56	169	350
Florida Index	--	--	--	4
Dominant Taxon	Amphipoda	Amphipoda	Amphipoda	Amphipoda
Percent Dominant Taxon	77.4	75	81.3	79
Percent Diptera	4.4	10.6	.8	3.5
Percent Odonata	1.9	.8	.5	.9
Amphipoda excluded				
Total Abundance	2,025	1,856	4,163	8,044
Dominant Taxon	Gastropoda	Diptera	Gastropoda	Gastropoda
Percent Dominant Taxon	52.8	42.5	48.6	45
Percent Diptera	19.5	42.5	4.1	16.8
Percent Odonata	8.3	3	2.7	4.1

Table 7. Fishes observed or collected in De Leon Springs State Park (Walsh and Williams, 2003), and deposited in the Florida Museum of Natural History (FLMNH).

[--, not observed]

Family	Species	USGS		FLMNH ichthyological collection	
		Number of specimens	Percent composition	Number of specimens	Percent of material
Dasyatidae	*Dasyatis sabina*	3	0.4	--	--
Lepisosteidae	*Lepisosteus osseus*	1	.1	--	--
Amiidae	*Amia calva*	1	.1	--	--
Anguillidae	*Anguilla rostrata*	3	.4	--	--
Clupeidae	*Dorosoma cepedianum*	2	.3	--	--
Cyprinidae	*Notemigonus crysoleucas*	17	2.5	2	3.2
Catostomidae	*Erimyzon sucetta*	29	4.3	--	--
Ictaluridae	*Ameiurus natalis*	1	.1	--	--
	Noturus leptacanthus	--	--	1	1.6
Esocidae	*Esox niger*	1	.1	--	--
Mugilidae	*Mugil cephalus*	15	2.2	--	--
Belonidae	*Strongylura marina*	2	.3	--	--
Fundulidae	*Fundulus chrysotus*	3	.4	--	--
	Fundulus rubrifrons	--	--	3	4.8
	Fundulus seminolis	12	1.8	8	12.7
	Lucania goodei	49	7.3	20	31.7
	Lucania parva	42	6.3	1	1.6
Poeciliidae	*Gambusia holbrooki*	69	10.3	--	--
	Heterandria formosa	22	3.3	--	--
	Poecilia latipinna	15	2.2	--	--
Centrarchidae	*Enneacanthus gloriosus*	1	.1	4	6.3
	Lepomis auritus	11	1.6	5	7.9
	Lepomis gulosus	9	1.3	4	6.3
	Lepomis macrochirus	196	29.3	5	7.9
	Lepomis microlophus	69	10.3	7	11.1
	Lepomis punctatus	9	1.3	--	--
	Micropterus salmoides	76	11.4	1	1.6
	Pomoxis nigromaculatus	5	.7	1	1.6
Percidae	*Etheostoma fusiforme*	5	.7	--	--
Cichlidae	*Oreochromis aureus**	1	.1	--	--
Achiridae	*Trinectes maculatus*	--	--	1	1.6
	Total number of species	**28**		**14**	
	Total number of specimens	**669**		**63**	

*nonindigenous species

None of five odonate taxa (including an unidentified species of Libellulidae) collected at De Leon Spring was collected at Gemini Springs or Green Spring. Based on all samples combined, De Leon Spring had an FI value of 4. Given this FI score, De Leon Spring would receive a “moderate” score when calculating the Stream Condition Index (SCI) for a peninsular Florida stream (Barbour and others, 1996). Amphipods dominated sweep samples from all three sampling events, with relative abundances by season of 75 to 82 percent. Dipteran abundance was relatively low during summer, highest in spring, and intermediate in winter. When amphipods were omitted from calculations of relative abundance, gastropods dominated in winter and summer and dipterans dominated in spring. Seasonal differences in relative abundances of different macroinvertebrate groups and overall densities did not show any obvious trends. It is possible that greater relative abundances of certain insect groups (i.e., dipterans and odonates) during winter and spring months and lower abundance during summer may have been the result of emergences from aquatic stages to winged adults.

Shelton (2005) reported two notable hydrobiid snails from De Leon Spring: *Tryonia aequicostata*, a species endemic to the St. Johns River, and an unidentified species of *Aphaostracon*. The samples collected during this study contained gastropods, in order of descending abundance, of hyrobiids (presumably the species identified by Shelton), the pleurocerid *Elimia floridensis*, and the viviparid *Viviparus georgianus*. Collectively, gastropods comprised 9.2 percent of all invertebrates collected from De Leon Spring.

Descriptions of the fish populations at De Leon Spring are based on the FLMNH collection and on data collected in 2002 by the USGS (Walsh and Williams, 2003). The FLMNH collection included 14 species representing 9 genera and 5 families from De Leon Spring (table 7).

The 2002 survey resulted in 28 species comprising 23 genera and 16 families collected or observed from the headspring area (Walsh and Williams, 2003). Species represented in the FLMNH collection that were not found in the 2002 survey were speckled madtom (*Noturus leptacanthus*), redface topminnow (*Fundulus rubrifrons*), and hogchoker (*Trinectes maculatus*). In contrast, 17 species were found in the 2002 survey that were not represented by museum material; thus, a total of 31 species of fishes has been recorded from De Leon Spring. This includes four species of marine derivation (Atlantic stingray, *Dasyatis sabina*; striped mullet, *Mugil cephalus*; Atlantic needlefish, *Strongylura marina*; hogchoker, *Trinectes maculatus*), although populations of the Atlantic stingray within parts of the St. Johns River drainage may reside year-round in fresh water.

One nonindigenous species, the blue tilapia (*Oreochromis aureus*), was found in the 2002 survey of De Leon Spring (Walsh and Williams, 2003). During this study, several individuals of an introduced armored catfish, the brown hoplo (*Hoplosternum littorale*), were observed in the spring run below the dam on February 11, 2004; this species was not reported from this location by Walsh and Williams (2003). *Hoplosternum littorale* has rapidly colonized parts of the St. Johns River and other drainages in Florida. It is usually associated with marshes, lakes, canals, and wetlands with an abundance of macrophytes (including the invasive *Hydrilla verticillata*) that are used to construct bubble nests (Nico and others, 1996; Nico and Muench, 2004). In this study, USGS personnel observed individuals of *Hoplosternum littorale* hiding in benthic vegetation, rapidly ascending to the surface to "pipe" (gulp air), and then quickly returning to the substrate. In addition to the above, Davis and Herring (2005) observed nonindigenous "suckermouth catfish" in the spring run; these were likely the vermiculated sailfin catfish noted to be widely distributed elsewhere in the drainage (see discussion of Silver Springs group and Gemini Spring).

Fish species at De Leon Spring represented by the most specimens in the FLMNH collection were the bluefin killifish (*Lucania goodei*), Seminole killifish (*Fundulus seminolis*), and redear sunfish (*Lepomis microlophus*), together representing 56 percent of museum specimens. Other species of centrarchids accounted for an additional 32 percent of the museum material. Walsh and Williams' (2003) samples were dominated by bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), redear sunfish, and eastern mosquitofish (*Gambusia holbrooki*), each totaling more than 10 percent of the total number of specimens and, combined, representing 61 percent of all specimens. Other relatively common species collected included bluefin killifish, rainwater killifish (*L. parva*), and lake chubsucker (*Erimyzon sucetta*).

Mussels were collected in August 2002 from the main spring pool area (near the west shore downstream from the sugar mill) by snorkeling and by using seines and dip nets (Walsh and Williams, 2003). The substrate was muck bottom with thick mats of filamentous algae, which made sampling difficult and provided few suitable areas for live mussels. Dead valves of five native species were found: barrel floater (*Anodonta couperiana*, N=2); Florida shiny spike (*Elliptio buckleyi*, N=1); flat spike (*E. jayensis*, N=1); paper pondshell (*Utterbackia imbecillis*, N=13); and downy rainbow (*Villosa amygdala*, N=2). A few shells of the nonindigenous Asian clam (*Corbicula fluminea*) were collected. The number of dead specimens indicates that native mussels formerly existed or may persist in low numbers within the spring run. Water-chemistry conditions, habitat perturbation, or limiting abiotic and/or biotic factors may account for the apparent lack of mussel populations within the spring run.

Large floating mats of filamentous algae, identified as *Lyngbya wollei*, were observed in the spring during all sampling events. Stevenson and others (2004) identified another *Lyngbya* species, *Lyngbya majuscule*, in other springs in central Florida, although the distinction between *L. wollei* and *L. masjuscule* has not been clearly defined in the literature (Shannon and others, 1992; Speziale and Dyck, 1992). Recent molecular work (Joyner, 2004) indicates that *L. wollei* is not related to *L. masjuscule*.

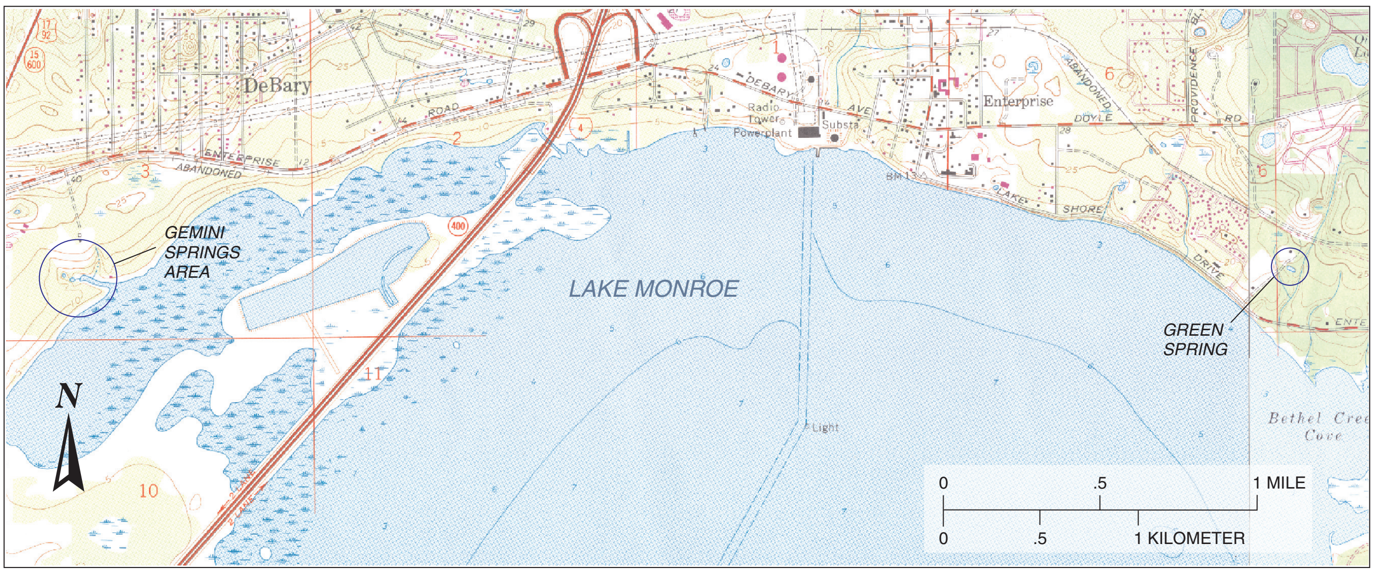
Two passive periphyton sampling devices were placed in De Leon Spring, one on the dam spillway and the other about 50 ft downstream from the dam, from July 28-August 11, 2004. Both samplers were recovered but large mats of floating *Lyngbya* were attached to the samplers so that smaller periphyton had little opportunity to grow in the filters (fig. 13). No determinations of periphyton density as related to the N or P content of the solution in the vials could be made.

Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 13. Periphyton sampler at De Leon Spring, August 11, 2004.

Gemini Springs

Gemini Springs consist of two small vents near the north shore of Lake Monroe and is operated as a park by Volusia County (figs. 14 and 15). A previous owner built a dam to create an impoundment for swimming (fig. 16); water from the springs and pool discharges at a shallow weir into the lake. A third feature at the far west end of the impoundment may be an old spring head and a seep is located north of the primary vents. Park personnel reported that another spring is located in the center of the impoundment.



Source: U.S. Geological Survey Topographic map; 1:24,000

Figure 14. Locations of Gemini Springs and Green Spring.

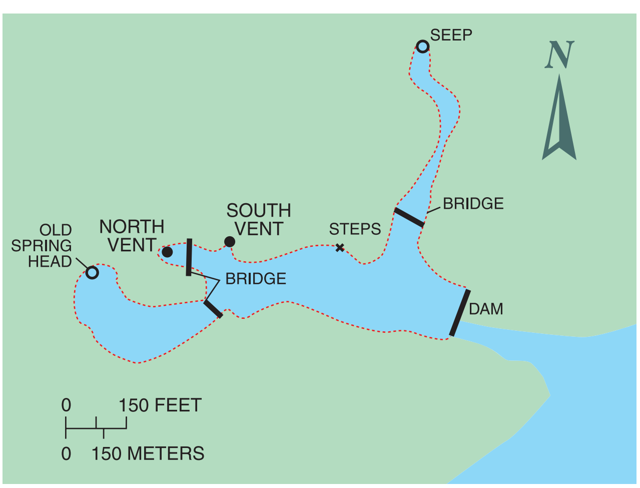


Figure 15. Gemini Springs.

Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 16. View from Gemini Springs to the dam and Lake Monroe.

Hydrology and Water Chemistry

Flow measurements are made quarterly by SJRWMD at the downstream end of the dam. Total flow at the dam ranged from about 7.5 ft^3/s during the drought of 2001 to about 13 ft^3/s during the summer of 1996, which was during a wet period (fig. 17). During this study, individual measurements were made at each boil and at the dam to determine if additional springs were discharging into the impoundment. On February 10, 2004, measured flow from the north boil was 6.74 ft^3/s and from the south boil, 3.52 ft^3/s. Flow at the dam was 10.2 ft^3/s. On August 19, 2004, flow from the north vent was 6.74 ft^3/s and from the south boil (fig. 18), 3.05 ft^3/s. Flow at the dam was 10.1 ft^3/s. The fact that flow at the dam is about equal to the total flow from both boils indicates that it is unlikely that other springs are contributing flow to the impoundment. Flow measurements at the dam were 11.6 ft^3/s on August 24, 2004, and 11.8 ft^3/s on December 1, 2004.

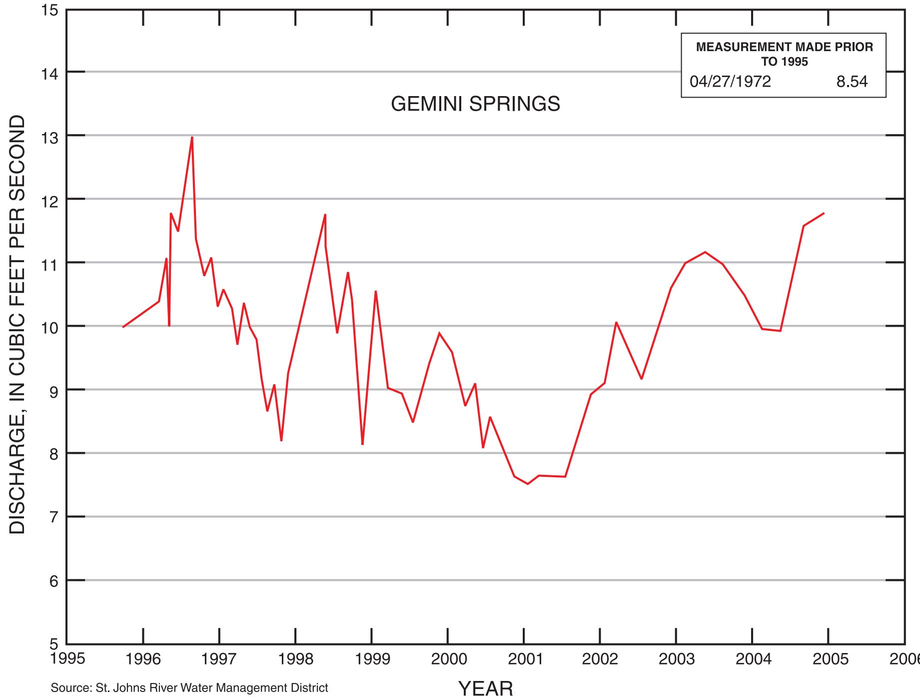


Figure 17. Total combined discharge from Gemini Springs, 1995-2004.

Water-chemistry data have been collected at the dam at Gemini Springs by SJRWMD since 1995. Nitrate-N concentrations increased from about 0.65 mg/L in 1995 to 1.1 mg/L in 2004 (fig. 6). During this study, samples were collected by the USGS from both spring vents and at the dam. Water chemistry at both vents and at the dam was similar, except that DO was higher at the dam (app. A). Concentration of DO of water from the spring vents was less than 1.0 mg/L and ranged from 2.2 to 4.8 mg/L at the dam. Specific conductance ranged from about 2,400 to 2,700 µS/cm at all sites. Major constituents showed little spatial or seasonal variability: calcium concentration was about 100 mg/L, magnesium concentration about 40 mg/L, potassium concentration about 8 mg/L, and sodium concentration about 340 mg/L. Chloride concentration ranged from about 600 to about 690 mg/L and sulfate concentration from 110 to 129 mg/L. Concentration of nitrate-N ranged from 0.88 to 1.13 mg/L and total P from 0.07 to 0.14 mg/L. The maximum value of total P concentration was measured in July 2004 at the dam. Concentrations of TOC ranged from 0.8 to 4.34 mg/L; the highest value was in water from the north vent on August 18, 2004. BOD concentrations ranged from 0.2 to 0.5 mg/L. Chlorophyll-*a*

Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 18. Gemini Springs south vent.

was detected in the samples collected at the dam in May and August 2004, but not in the February sample. Chlorophyll-*b* was not detected in any of the samples.

Both vents at Gemini Springs were sampled in May and August 2004 for pesticides and compounds commonly found in wastewater. Atrazine and its degradate CIAT were detected in water from both vents during both USGS sampling events. DEET was detected at the north vent during both sampling events (table 1) and at the south vent once. Four other compounds were detected at the north vent and two others at the south vent.

Water samples from both vents at Gemini Springs contained SF_6 concentration much higher than atmospheric levels, indicating the influence of excess SF_6, probably from wastewater sources (table 2). Thus, the water samples cannot be dated by the SF_6 method. Dissolved gas results show small concentrations of excess N_2 (table 2), indicating that denitrification probably was taking place in the Upper Floridan aquifer near the springs.

Aquatic Communities

An estimated total of 53,968 macroinvertebrates was collected from ponar and sweep samples at Gemini Springs during 2004; from these samples, 24 distinct taxa were identified (table 5; unidentified amphipods were presumed to be either *Gammarus* sp. or *Hyalella azteca*). Species richness was highest in the summer sample and lowest in winter (table 8). No EPT or ETO taxa were collected during winter or spring; richness values for EPTr and ETOr were 2 and 3, respectively, during summer. One trichopteran species (*Neotrichia* sp.) and one odonate species (*Telebasis byersi*) collected at Gemini Springs were not collected at De Leon Spring or Green Springs (app. D). Based on all samples combined, Gemini Springs had an FI =2. Barbour and others (1996) indicate that a peninsular stream with an FI < 4 receives the lowest score when calculating the stream condition index. Amphipods dominated sweep samples during winter (71 percent) and summer (61 percent), and dipterans were the most abundant organisms collected during spring (table 8). Relative abundance of dipterans was very low during winter (0 percent) and summer (0.3 percent), but dipterans dominated the macroinvertebrate samples during spring (28 percent). When amphipods were excluded, oligochaetes and gastropods were dominant in winter and summer samples, respectively. Gemini Springs had the highest total species richness, EPTr, and ETOr values in summer. The May sample had the greatest overall abundance of invertebrates; excluding amphipods, this sample was dominated by large numbers of dipterans (Chironomidae), oligochaetes, and hydrobiid snails.

Crayfish traps were inefficient at capturing fishes in Gemini Springs, possibly because of clear water and aversion by fishes to enter the traps. A moderate number of Seminole killifish (*Fundulus seminolis*) and bluefin killifish (*Lucania goodei*) were captured in traps.

Table 8. Richness and community measures for Gemini Springs.

[--, not calculated. Richness measures (taxon richness, EPTr, ETOr, and Florida index) were tabulated from taxonomic lists from combined petite ponar dredge and dip net sweep samples. All other measures (# individuals; percentages) were calculated using total abundance estimates derived from dip net sweep collections only]

	Winter	Spring	Summer	Combined
Taxon Richness (total # taxa)	8	14	20	25
Total Abundance	9,394	37,912	5,130	52,436
EPTr (# taxa)	0	0	2	2
EPT (# individuals)	0	0	16	56
Odonata (# taxa)	0	0	1	1
ETOr (# taxa)	0	0	3	3
ETO (# individuals)	0	0	24	67
Florida Index	--	--	--	2
Dominant Taxon	Amphipoda	Diptera	Amphipoda	Amphipoda
Percent Dominant Taxon	70.7	27.7	61.0	35
Percent Diptera	0	27.7	0.3	20
Percent Odonata	0	0	0.16	0.01
Amphipoda excluded				
Total Abundance	2,756	29,250	2,003	34,009
Dominant Taxon	Oligochaeta	Diptera	Gastropoda	Diptera
Percent Dominant Taxon	40.8	36	90.3	30
Percent Diptera	0	36	0.7	31
Percent Odonata	0	0	0.4	0.1

Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 19. View toward old springhead at Gemini Springs.

Photograph by S.J. Walsh, U.S. Geological Survey.

Figure 20. View toward Gemini Springs south vent.

Photograph by R. M. Spechler, U.S. Geological Survey.

Figure 21. Periphyton sampler at Gemini Springs near the dam, August 11, 2004.

In addition to these two species, the following fishes were observed by snorkelers on August 17, 2004: eastern mosquitofish (*Gambusia holbrooki*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), redear sunfish (*L. microlophus*), redbreast sunfish (*L. auritus*), gizzard shad (*Dorosoma cepedianum*), blue tilapia (*Oreochromis aureus*), common carp (*Cyprinus carpio*), and vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*). The last three species are nonindigenous. Common carp are not known to be established in the St. Johns River, hence their presence at Gemini Springs is of concern. The SJWRMD and Florida Fish and Wildlife Conservation Commission were notified of the observation. Presence of the vermiculated sailfin catfish in other springs of the St. Johns is known and this species was observed in large numbers at Gemini Springs during this study. Armored catfishes are of particular concern because of their potential to alter existing habitats (through nest borrowing) and possible interactions with native species.

Perhaps because of low flow velocities and relatively high nitrate-N and P concentrations, the water at Gemini Springs contains large amounts of aquatic vegetation (which is mechanically harvested twice a year by park personnel) and algae (figs. 19 and 20). At Gemini Springs, the dominant periphyton was *Rhizoclonium* sp., a green alga with no known toxin-producing capabilities. Periphyton samplers also were placed at Gemini Springs from July 28-August 11, 2004. One sampler was placed just downstream of the confluence of the spring runs from the north and south boils and the other was placed near the dam (fig. 21). Both samplers were covered by floating mats of filamentous algae, which prevented meaningful analysis of any preference of the periphyton for either N or P solutions.

Green Spring

Green Spring is a third-magnitude spring located along the north shore of Lake Monroe, near the town of DeBary, FL (figs. 14 and 22); the spring is owned by Volusia County. The spring pool is about 90 ft in diameter and has

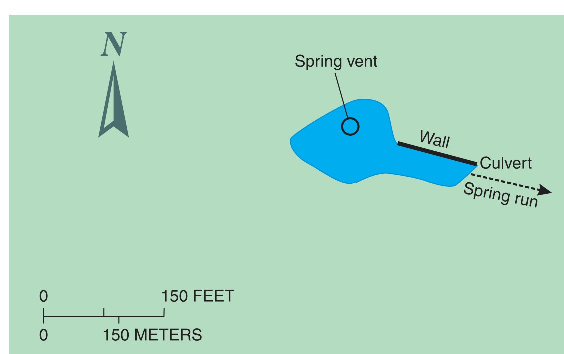


Figure 22. Green Spring.

a reported depth of 125 ft (Rosenau and others, 1977). A concrete retaining wall and steps were built along the north edge of the spring run when the spring was privately owned (fig. 23). A concrete culvert was built about 100 ft downstream from the spring pool, modifying the natural spring run (fig. 24).

Hydrology and Water Chemistry

Discharge measurements have been made by SJRWMD since 2000. Flow ranges from about 0.2 to 2.9 ft^3/sec (fig. 25). During the study, flow ranged from a minimum of 0.67 ft^3/s on June 16, 2004, to a maximum of 2.58 ft^3/s on September 30, 2004.

Photograph by G.G. Phelps, U.S. Geological Survey.

Figure 23. View from culvert to Green Spring pool.

Photograph by S.J. Walsh, U.S. Geological Survey.

Figure 24. View from steps at Green Spring toward culvert.

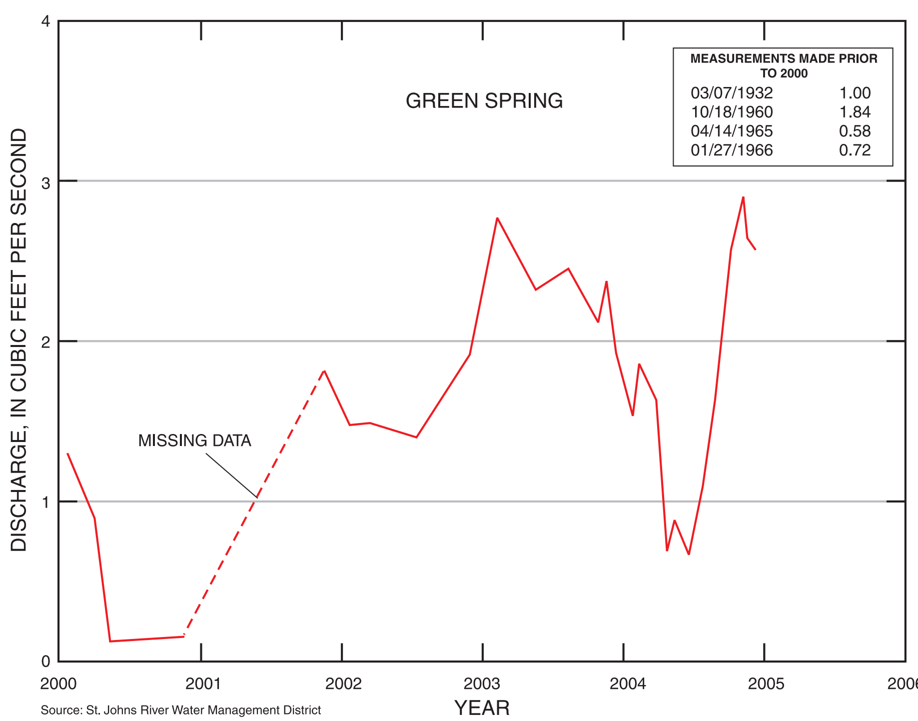


Figure 25. Green Spring discharge, 2000-2004.

Photograph by G.G. Phelps, U.S. Geological Survey.

Figure 26. Green Spring (water is murky).

Photograph by S.J. Walsh, U.S. Geological Survey.

Figure 27. Green Spring (water is clear).

Photograph by G. G. Phelps, U.S. Geological Survey

Figure 28. Sulfur-reducing bacteria form light gray plumes around the edges of Green Spring pool.

Green Spring presumably derives its name from water that usually appears murky green, although on rare occasions, the water is clear but still appears dark green (figs. 26 and 27). The water usually has a hydrogen sulfide (H_2S) odor. Concentration of DO in water from the spring vent was very low—about 0.1 mg/L. At the culvert downstream from the vent, DO concentrations ranged from 0.4 to 0.6 mg/L. Specific conductance from the vent water ranged from 2,430 to 2,700 µS/cm and at the culvert from 2,620 to 2,670 µS/cm. The sample collected on August 18, 2004, may be anomalous, based on the low major ion concentrations compared with other samples, so the values from that sample are not considered to be the actual minimum values. Calcium concentrations ranged from 84-88 mg/L in water from the vent and from 88-91 mg/L at the culvert. Magnesium concentrations ranged from 39-45 mg/L at the vent and from 42-46 mg/L at the culvert. Concentrations of potassium and sodium were about the same at both the vent and at the culvert: potassium concentrations ranged from 11-12 mg/L at the vent to 11-13 mg/L at the culvert; sodium concentrations ranged from 345-400 mg/L at the vent to 350-430 mg/L at the culvert. Chloride concentration generally was slightly lower at the culvert, ranging from 620-764 mg/L at the vent to 690-740 mg/L at the culvert. Sulfate concentration was about the same at the vent and the culvert: 100-110 mg/L at the vent and 104-110 at the culvert. The spring water was not analyzed for sulfide but the odor of hydrogen sulfide (H_2S) and the presence of sulfur-reducing bacteria in the spring pool (fig. 28) and spring run indicate high H_2S concentration in the water, which probably accounts for the murky appearance of the water.

At Green Spring, nitrate-N concentrations usually are too low to be detected; the highest reported concentration was 0.03 mg/L from a sample collected by SJRWMD at the vent; no nitrate-N could be detected in any of the samples collected at the culvert. Total P values ranged from 0.07 to 0.15 at the vent and from 0.07 to 0.09 at the culvert. Concentrations of TOC ranged from 2.1 to 2.5 mg/L at the vent and from 2.2 to 2.7 mg/L at the culvert. The concentration of BOD was 0.7 mg/L at the vent and ranged from 0.8 to 1.2 at the culvert. Neither chlorophyll-*a* nor –*b* was detected in water from the vent. At the culvert, chlorophyll-*b* was not detected during the study; chlorophyll-*a* was not detected in the winter sample, but the concentration was 1.6 mg/L in May 2004 and 0.5 mg/L in August 2004. Dissolved gas results indicated excess dissolved N_2 in a concentration of about 0.5 mg/L in the May 2004 sample (table 2), and 1.0 mg/L in August 2004, indicating denitrification likely was occurring in the aquifer.

No pesticides were detected at Green Spring during the study. Nine compounds commonly found in wastewater were detected in water from Green Spring, including DEET during both sampling events (table 1). Data for SF_6 from

Green Spring indicated a recharge year of about 1984-1986 for some fraction of the water discharging from the spring.

Aquatic Communities

An estimated total of 12,451 macroinvertebrates was collected at Green Spring from ponar and sweep samples during 2004; of these, 16 distinct taxa were identified (table 5). Green Spring was not taxonomically rich and macroinvertebrate abundance was generally low. Species richness was highest in the spring (10 taxa) and lowest in winter (5 taxa) (table 9). No ephemeropterans or odonates were collected during any sampling at Green Spring. Based on all samples combined, Green Spring had an FI=0. Overall, oligochaetes were the first-, second-, or third-most abundant taxon in spring, summer, and winter, respectively. When amphipods were omitted from tabulations, oligochaetes represented their highest percentage composition in summer and lowest in spring. Relative abundance of dipterans was highest during winter (52 percent) and spring (32 percent) and declined during summer (9 percent). Dipteran abundance consisted mainly of chironomids (72 percent of all dipterans) and ceratopogonids (22 percent). Amphipods composed 27 percent of all invertebrates taken by sweep samples at Green Spring. Combined, oligochaetes, dipterans, and amphipods made up 95 percent of all specimens collected (fig. 29). Shelton (2005) reported a species of hydrobiid snail (*Aphaostracon* sp.) from Green Spring and speculated that this could be an endemic and undescribed species.

Species richness and the total number of macroinvertebrates collected in Green Spring were lowest of the three springs sampled and EPTr, ETOr, and the FI were consistently zero in all seasons. The apparent low richness and relative abundance of aquatic invertebrates may have been attributable, in part, to sampling restricted to the short spring run, because of the steep-sided nature and inaccessibility of the main pool. Substrate in the spring run consisted mainly of flocculent detritus without aquatic macrophytes. Submerged aquatic vegetation, woody debris, and filamentous algae were noted in deep areas near the edges of the cavern, and likely provide additional habitat for benthic invertebrates. Water chemistry, however, especially the low concentrations of DO and high concentrations of

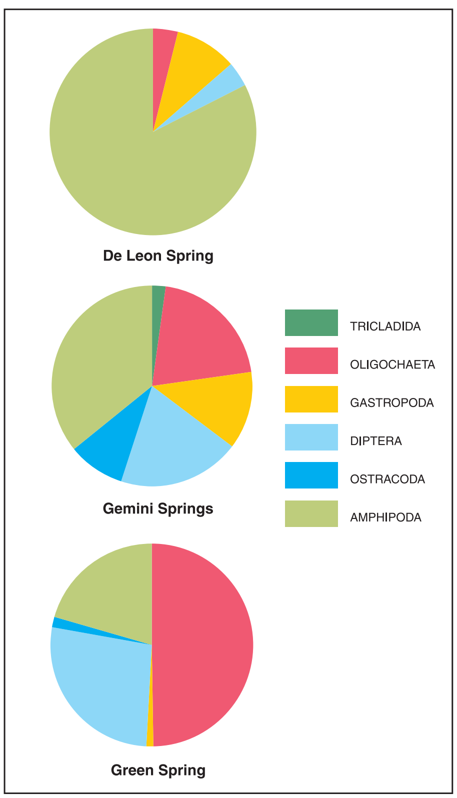


Figure 29. Relative proportions of benthic invertebrates per order collected in De Leon Spring, Gemini Springs, and Green Spring, 2004.

Table 9. Richness and community measures for Green Spring.

[--, not calculated. Richness measures (taxon richness, EPTr, ETOr, and Florida index) were tabulated from taxonomic lists from combined petite ponar dredge and dip net sweep samples. All other measures (# individuals; percentages) were calculated using total abundance estimates derived from dip net sweep collections only]

	Winter	Spring	Summer	Combined
Taxon Richness (total # taxa)	5	10	9	16
Total Abundance	1,928	5,906	1,628	9,461
EPTr (# taxa)	0	0	0	0
EPT (# individuals)	0	0	0	0
Odonata (# taxa)	0	0	0	0
ETOr (# taxa)	0	0	0	0
ETO (# individuals)	0	0	0	0
Florida Index	--	--	--	0
Dominant Taxon	Diptera	Oligochaeta	Amphipoda	Oligochaeta
Percent Dominant Taxon	51.8	34.9	57.6	35.8
Percent Diptera	51.8	32.1	8.8	32.2
Percent Odonata	0	0	0	0
Amphipoda excluded				
Total Abundance	1,807	4,387	690	6,941
Dominant Taxon	Diptera	Oligochaeta	Oligochaeta	Oligochaeta
Percent Dominant Taxon	55.2	47.4	72.9	48.8
Percent Diptera	55.2	43.6	20.7	32.2
Percent Odonata	0	0	0	0

H_2S, also may be a major factor for the relatively depauperate invertebrate community. Further study is needed to determine relations between all aspects of the macroinvertebrate assemblage (richness, taxonomic composition, and relative abundance) and environmental variables at Green Spring.

Green Spring does not seem to have a substantial fish fauna, with the exception of a dense population of mosquitofish and other poeciliids. The only fishes visually observed and captured by minnow traps and petite ponar dredge at Green Spring were eastern mosquitofish (*Gambusia holbrooki*) and sailfin molly (*Poecilia latipinna*). It is possible that other poeciliids were present (e.g., *Heterandria formosa*) in the spring run and the margins of the spring vent and that centrarchids, cyprinids, or ictalurids were present in deeper parts of the spring. The isolated nature of this spring accounts, in part, for the apparent absence of other fishes. Moreover, hypoxic conditions may be a limiting factor. Additional sampling efforts would require use of other gear types, such as hook-and-line or visual surveys.

No macroalgae were observed in Green Spring. The occurrence of chlorophyll-*a* in May and August 2004, however, indicates some growth of periphyton in summer.

Green Spring had limited communities of macroinvertebrates and fishes. This is likely related to the unique water chemistry characterized by the relatively high specific conductance, low DO, and the presence of H_2S.

Comparisons among Springs

The springs sampled during this study are representative of the wide range of characteristics exhibited by springs in central Florida. This diversity reinforces the conclusion that study of individual springs is desirable to provide water managers with adequate data to support their decisions.

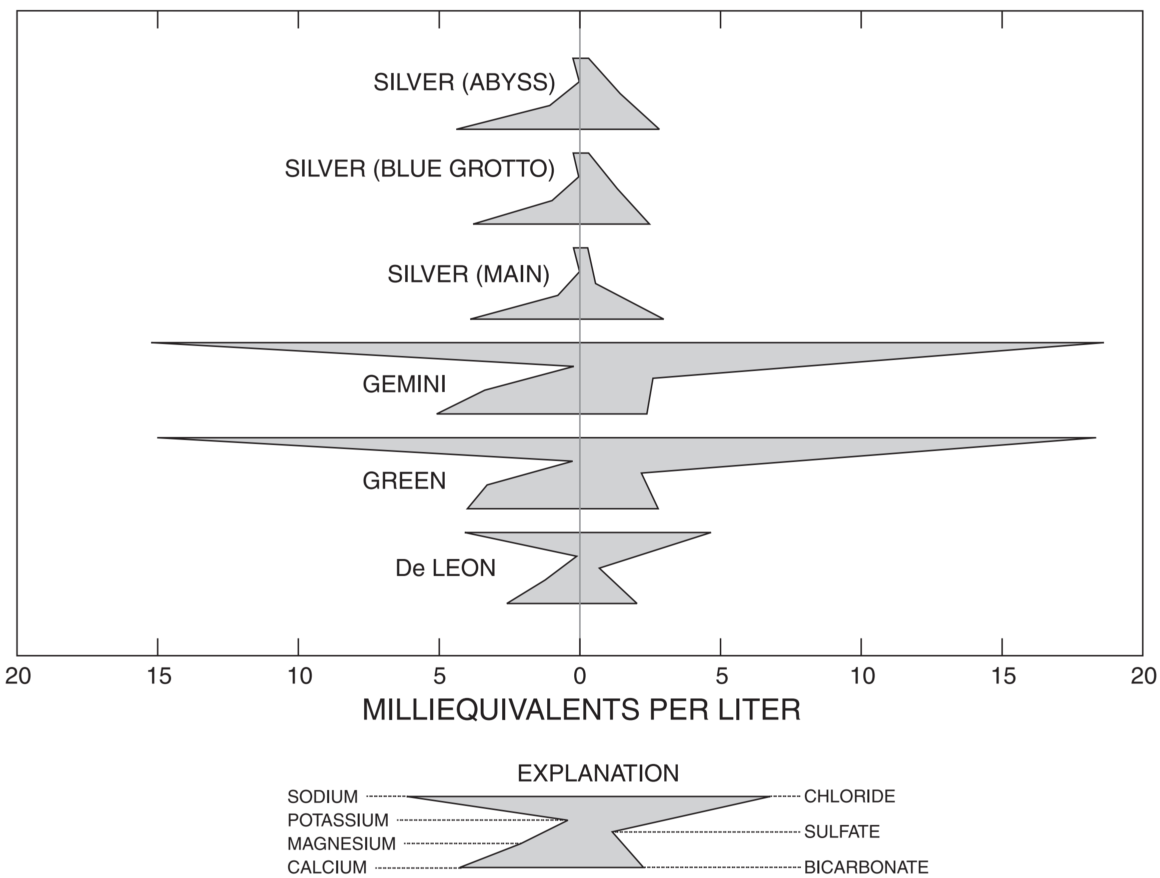


Figure 30. Relative proportions of cations and anions in spring-water samples, 2004.

Hydrology and Water Chemistry

The springs studied range from the first-magnitude Silver Springs group, with an average discharge of about 780 ft^3/s to Green Spring, a third magnitude spring, with an average discharge of about 2 ft^3/s. Silver Springs has the least disturbed natural flow system, whereas the spring runs at De Leon Spring, Gemini Springs, and Green Spring have been modified by water-control structures.

Differences in water chemistry among the springs sampled reflect local differences in water chemistry in the Upper Floridan aquifer. Total dissolved solids concentrations ranged from about 270 mg/L at the Silver Springs group and 450 mg/L at De Leon Spring to about 1,500 to 1,550 mg/L at Gemini Springs and Green Spring. The three springs sampled in the Silver Springs group (the Main Spring, Blue Grotto, and Abyss) have similar proportions of cations and anions (fig. 30). The water from Gemini Springs and Green Spring has higher proportions of sodium and chloride. The water from De Leon Spring has higher proportions of sodium and chloride than water from Silver Springs, but lower proportions of calcium and bicarbonate than Silver Springs.

All of the springs studied are affected by human activities, based on the presence of organic compounds found in wastewater in all the spring-water samples, as well as qualitative observations of algae and periphyton. The most commonly detected compound was DEET, which was found in all the springs sampled except De Leon Spring. The pesticide atrazine and its degradate CIAT were detected in water from Silver Springs and in both vents at Gemini Springs. No pesticides were detected in water samples from De Leon Spring and Green Spring. Levels of wastewater compounds and pesticides were low and likely not high enough to cause direct harm to organisms (U.S. Environmental Protection Agency, 2004), but little information exists about possible effects of mixtures of various chemicals.

Aquatic Communities

Available habitats for macroinvertebrates varied greatly from site to site. Green Spring run contained nearly all leaf pack and snag material with a thin band of water pennywort (*Hydrocotyle* sp.) and an abundance of detritus. Gemini Springs contained areas of bare sand, muck, extensive beds of algae, and submersed and emergent vegetation along the margins of the run. De Leon Spring run contained an abundance of submersed and emergent vegetation and an artificial waterfall at the outflow of the spring pool that was covered with algae.

The macroinvertebrate data indicated some differences among De Leon Spring, Gemini Springs, and Green Spring. None of the five odonate taxa collected at De Leon Spring were collected at either Gemini Springs or Green Spring (table 5). One species each of an odonate (*Telebasis byersi*) and a trichopteran (*Neotrichia* sp.) was collected from Gemini Springs, but not from the other springs. No plecopteran taxa were collected during this study. Of the three springs sampled, De Leon Spring had the highest overall species richness, EPTr, and ETOr, and had the most disturbance-intolerant assemblage (FI = 4) (table 6). Gemini Springs had high relative abundances of oligochaetes, chironomids, amphipods, hydrobiids, and ostracods (fig. 29). The impounded pool and presence of zooplankton, phytoplankton, and attached algae at Gemini Springs are somewhat indicative of eutrophic conditions in comparison to most relatively oligotrophic spring runs in close proximity to source vents. It is also notable that during visits to Gemini Springs in 2004, the impounded pool was closed to swimming and a sign was posted warning of high coliform bacteria levels in the water. Green Spring had the lowest species richness, no EPT or ETO taxa, and a community dominated by three organisms (collectively comprising 88 percent of all animals collected): oligochaetes, amphipods, and chironomids. The unusual water chemistry of Green Spring and the spring morphology (deep vent and shallow, short run modified by an impoundment) are hypothesized to be limiting factors in terms of richness and abundance of the benthic fauna.

Amphipods are commonly associated with karst habitats of Florida and may often occur in great abundance (Woodruff, 1993; Mattson and others, 1995; Walsh, 2001). In De Leon Spring and Gemini Springs, amphipods made up the largest percentage of any invertebrate group collected (fig. 31) and were consistently dominant in all months of the study except for a shift in dipteran abundance at Gemini Springs in spring (May)

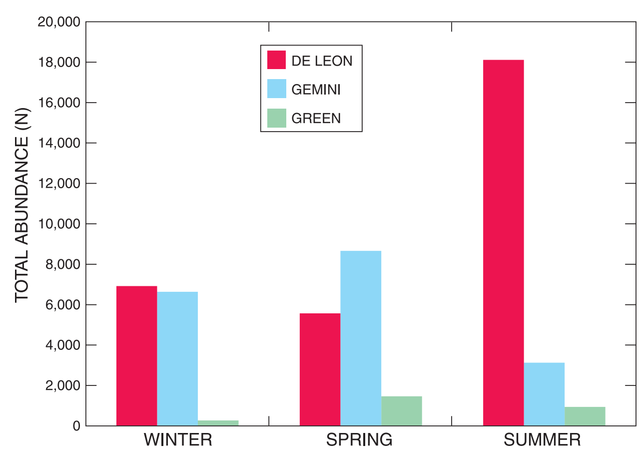


Figure 31. Total number of all amphipods collected by season in De Leon Spring, Gemini Springs, and Green Spring, 2004.

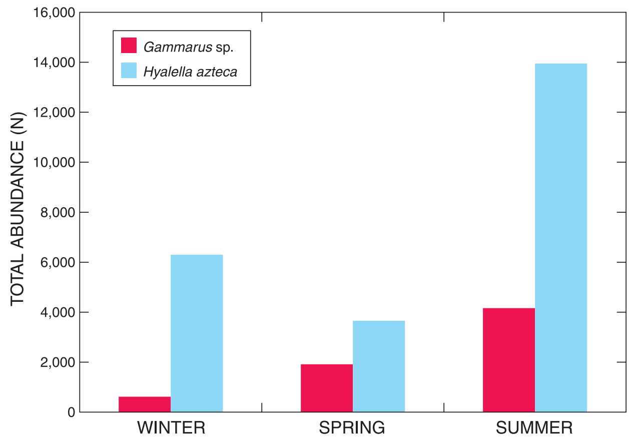


Figure 32. Total number of *Gammarus* sp. and *Hyallela azteca* by season at De Leon Spring, 2004.

(tables 6 and 8). At De Leon Spring, both amphipod species peaked in abundance in summer (August), but the lowest abundance of *Gammarus* sp. occurred in winter (February) whereas *Hyalella azteca* was least abundant in spring (fig. 32). Only one amphipod species (*H. azteca*) was identified in samples from Green Spring.

Sample sizes of invertebrates collected in this study were too limited to allow for detailed quantitative or statistical analysis of trends or correlations with water-quality properties; however, some qualitative observations suggested possible associations between biological metrics and water chemistry. Species richness appeared to be negatively related to magnesium, potassium, sodium, and specific conductance. More invertebrates were collected when DO and nitrate-N were high but phosphorus and potassium concentrations were low. The relative abundance of dipterans was positively associated with specific conductance and TOC but negatively associated with nitrate-N.

Invertebrate assemblages observed in springs of the St. Johns River were consistent with communities that have been studied in other north-central springs and spring-fed streams or rivers. Beck (1965) characterized benthic communities of calcareous streams in Florida as consisting primarily of mollusks, chironomids, ephemeropterans (e.g., baetids and heptageniids), trichopterans (e.g., *Cheumatopsyche*), and crustaceans (e.g., *Palaemonetes paludosus* and *Hyalella azteca*). Woodruff (1993) found that benthic sediments of Manatee Spring (lower Suwannee River drainage) had a community dominated by oligochaetes, amphipods, leeches, and isopods. The study by Mattson and others (1995) provided the most detailed tabulation of aquatic invertebrate communities in Florida karst habitats. Mattson and others (1995) noted that species richness and/or relative abundance generally increased in association with hard, alkaline spring water. Moreover, substrata of limestone outcrops, wood, and submerged macrophytes provide important habitat for benthic invertebrates in these systems. In the present study, sampling of rock and wood habitats was not feasible; thus, it is likely that species richness of the aquatic communities at De Leon, Gemini, and Green Springs is greater than reported herein.

Fish assemblages in Silver Springs and De Leon Spring had the greatest species richness of the springs surveyed. Centrarchids and poeciliids generally were in greatest abundance during surveys by USGS personnel (Walsh and Williams 2003) (tables 3, 7). Silver Springs had centrarchids and poeciliids in greatest abundance (32.1 percent and 22.8 percent composition, respectively), followed by cyprinids (16.1 percent) and fundulids (13.0 percent) (table 3). Centrarchids (56 percent) dominated in De Leon Spring and were followed by poeciliids and fundulids in numerical abundance (15.8 percent) (table 7). Fish collections at Gemini Springs and Green Spring were limited to the use of crayfish traps, minnow traps, and visual surveys. Taxonomic composition of the fishes in Gemini Springs was similar to the fauna of De Leon Spring. The fish assemblage at Green Spring was dominated by poeciliids (possibly the only family represented), presumably because of the water chemistry (low DO and presence of H_2S), small size, and isolation from Lake Monroe. The presence of nonindigenous fishes in three of the four springs surveyed is of particular concern. Three nonindigenous fish species were observed in Gemini Springs, two in De Leon Spring (and a third reported by Davis and Herring, 2005), and one in Silver Springs.

Summary

The hydrology, water chemistry, and aquatic communities of Silver Springs, De Leon Spring, Gemini Springs, and Green Spring in the St. Johns River Water Management District, Florida, were studied in 2004 to provide a better understanding of each spring and to provide baseline data that may be useful in water-management decisions. Ground water that discharges from the springs studied flows from the Upper Floridan aquifer of the Floridan aquifer system; the water is recharged entirely within the State. This report summarizes data about flow, water-chemistry, and aquatic communities (benthic invertebrates, fishes, algae, and selected aquatic macrophytes) collected by the U.S. Geological Survey, the St. Johns River Water Management District, and the Florida Department of Environmental Protection during 2004, as well as previously collected data.

The physical size and flow of the springs varies greatly. Silver Springs consists of a group of at least 16 springs located along about 0.5 mile of the Silver River. Maximum depth of the springs in the group is about 33 feet. The average combined discharge from the Silver Springs group is about 780 cubic feet per second. De Leon Spring is a single conical pool about 170 feet across and about 28 feet deep. Average discharge from De Leon Spring is about 27 cubic feet per second. Gemini Springs consists of two small vents; flow from the springs is impounded and discharge totals about 10 cubic feet per second. Green Spring is a single pool about 90 feet in diameter with a reported depth of about 125 feet and discharge of about 2 cubic feet per second.

Differences in water chemistry among the springs sampled reflect differences in local water chemistry in the Upper Floridan aquifer as well as differences in anthropogenic inputs (agricultural or wastewater effects). The three springs sampled at the Silver Springs group (the Main Spring, Blue Grotto, and the Abyss) have similar proportions of cations and anions. The water from Gemini Springs and Green Spring has higher proportions of sodium and chloride. Water from De Leon Spring has higher proportions of sodium and chloride than at the Silver Springs group but lower proportions of calcium and bicarbonate. Nitrate nitrogen concentrations have increased with time at Silver Springs, De Leon Spring, and Gemini Springs, but apparently not at Green Spring. Evidence of denitrification in the Upper Floridan aquifer was indicated by the presence of excess nitrogen gas in water samples from most of the springs. Organic compounds found in wastewater were detected in all the springs sampled, indicating the effects of human activities in the springsheds. The most commonly detected compound was N,N'-diethyl-methyl-toluamide (DEET), which was found in all the springs sampled except De Leon. The pesticide atrazine and its degradate 2-chloro-4-isopropylamino-6-amino-s-triazine (CIAT) were detected in water from Silver Springs and in both boils at Gemini Springs. No pesticides were detected in water samples from De Leon Spring and Green Spring.

Macroinvertebrate communities were sampled at De Leon Spring, Gemini Springs and Green Spring. Amphipods were the dominant group in most benthic invertebrate collections. A total of 57 taxa was identified from all springs combined. De Leon Spring had the greatest species richness (45 taxa), followed by Gemini Springs (24) and Green Spring (16). Five odonate taxa were collected only from De Leon Spring, and samples from Gemini Springs had a single species each of an odonate and a trichopteran that were not collected at the other springs. Total abundance of invertebrates was greatest at Gemini Springs primarily because of the large numbers of oligochaetes, dipterans, and hydrobiids.

Fish assemblages in the Silver River and De Leon Spring were similar; both were dominated by centrarchids, poeciliids, and fundulids. Gemini Springs could not be sampled adequately, but the fish population is moderately species-rich and seems to be similar in composition to the large springs. The fish assemblage in Green Spring is heavily dominated by poeciliids, possibly because of the spring's unique water chemistry, small size, and/or isolation from Lake Monroe. The presence of nonindigenous fishes in Silver Springs, De Leon Spring, and Gemini Springs is of concern and is indicative of the rapid colonization of certain invasive species throughout the St. Johns River drainage.

Assemblages of aquatic plants and algae varied among the springs, perhaps influenced by physical characteristics of the springs and water chemistry. The dominant submerged aquatic vegetation in the Silver River is strap-leaf sagittaria (*Sagittaria kurtziana*). Algae blooms generally cover the vegetation. The dominant epiphytic algae, based on biomass, were the green alga *Ulothrx*, the diatom *Aulocosira* (*Melosira*), and a variety of other diatoms. The dominant benthic algal species was *Lyngbya* sp. In De Leon Spring, large floating mats of filamentous algae, identified as *Lyngbya wollei,* were observed during all sampling events in 2004. Two passive periphyton sampling devices placed in De Leon Spring from July 28-August 11, 2004, had large mats of floating *Lyngbya* attached to the samplers so that smaller periphyton had little opportunity to grow in the filters. Gemini Springs contains large quantities of aquatic vegetation, perhaps because of low flow velocities and relatively high nitrogen and phosphorus concentrations in the water. The dominant periphyton at Gemini Springs was *Rhizoclonium* sp., a green alga with no known toxin-producing capabilities. Periphyton samplers also were placed at Gemini Springs from July 28-August 11, 2004. Both samplers were covered by floating mats of filamentous algae. No macroalgae were observed in Green Spring, although occurrence of chlorophyll-*a* in some water samples may indicate the growth of periphyton in summer. The water at Green Spring usually is murky green in appearance, although on rare occasions, the water is clear but appears dark green.

The short duration of this study, the low number of samples, and variability of the invertebrate data preclude drawing anything but general comparisons within and among the springs. Long-term monitoring would elucidate trends and allow statistical comparisons of biological, environmental, and physical data within and among springs. Additional monitoring and research of Florida's springs is essential to the long-term preservation of these natural treasures.

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Appendixes A-E

Appendix A. Water-chemistry data, 2004.

[<, less than; *, sample lost. Yellow shading indicates data obtained from the St. Johns River Water Management District; blue shading indicates data obtained from the Florida Department of Environmental Protection; pink shading indicates filtered samples]

Site name	Site ID	Date	Color	Turbidity	Dissolved oxygen	pH	Specific conductance, laboratory	Specific conductance, field	Temperature	Calcium	Magnesium	Potassium	Sodium	Acid neutralizing capacity
De Leon Spring	2236110	2004/02/11	5	0.12	0.8	7.52	810	886	22.5	51	14	4.2	94	119
	2236110	2004/03/18			1.5	7.4		884	23					
	2236110	2004/05/12	<5	.62	.8	7.4	758	801	22.7	50	13	4.4	78	130
	2236110	2004/08/23	8		1.2	6.8	1,030	1,127	23.5	59	19	5.6	128	124
De Leon run	290804081214800	2004/02/11	5	.22	6.7	7.7	1,140	1,060	21.3	55	18	5.8	130	122
	290804081214800	2004/03/18			5.5	7.5		900	22.9					
	290804081214800	2004/05/12	7	.67	6	7.6	865	869	23.1	50	14	4.6	94	124
	290804081214800	2004/07/28			1.5	7.2		832	23.1					
	290804081214800	2004/08/23			3.6	7	949	969	23.8	52	17	5.7	121	114
Green Spring	285145081145500	2004/02/10	<5	.13	.1	7.4	2,700	2,900	22.5	88	45	12	400	410
	285145081145500	2004/03/18			.1	7.3		2,920	22.6					
	285145081145500	2004/05/11	5	.62	.1	7.2	2,430	2,640	22.6	84	39	11	345	179
	285145081145500	2004/08/18	8		.4	7	1,725	2,760	23.2	34	10	1.6	5.4	109
Green run	285146081145100	2004/02/10	5	.16	.4	7.4	2,900	2,920	22.5	91	46	13	430	156
	285146081145100	2004/05/11	5	.43	.6	7.3	2,620	2,630	22.8	89	40	12	360	159
	285146081145100	2004/08/18	12		.6	7.2	2,670	2,720	23.2	88	42	11	350	158
Gemini Spring North	285146081184100	2004/02/10	<5	.19	.8	7.2	2,510	2,620	22.9	102	41	8.6	360	139
	285146081184100	2004/05/11	<5		.6	7.2		2,510	22.9					
	285146081184100	2004/08/18			1	7	2,590	2,710	24.2	106	41	8.2	333	144
Gemini Spring South	285147081184000	2004/02/10	<5	.2	.9	7.1	2,640	2,650	22.9	105	41	8.7	370	140
	285147081184000	2004/03/18			.6	7.2		2,690	22.9					
	285147081184000	2004/05/12	<5	*	.6	7.2	*	2,541	22.9	*	*	*	*	*
	285147081184000	2004/08/18	5		.8	7	2,620	2,740	24.1	103	41	8.5	327	145
Gemini Dam	285144081183900	2004/02/10	<5	.38	3.2	7.4	2,430	2,650	22.9	104	41	8.6	360	139
	285144081183900	2004/02/16					2,166	2,500	22.6	103	41	8.4	351	135
	285144081183900	2004/03/18			4.8	7.3		2,710	23.7					
	285144081183900	2004/05/11	6	.57	3.8	7.3	2,480	2,540	23.4	103	38	8	330	140
	285144081183900	2004/05/13				7.4	2,370	2,445	24	100	38	8	324	148
	285144081183900	2004/07/28			2.2	7		2,620	22.9					
	285144081183900	2004/08/18	10	<2	3	7.1	2,670	2,730	26.6	107	41	8.4	340	143

Appendix A. Water-chemistry data, 2004—Continued.

[<, less than; *, sample lost. Yellow shading indicates data obtained from the St. Johns River Water Management District; blue shading indicates data obtained from the Florida Department of Environmental Protection; pink shading indicates filtered samples]

Site name	Site ID	Date	Color	Turbidity	Dissolved oxygen	pH	Specific conductance, laboratory	Specific conductance, field	Temperature	Calcium	Magnesium	Potassium	Sodium	Acid neutralizing capacity
Silver Springs Group														
Main	2239500	2003/09/08	<5		2.6	7.1	446	483	23.4					185
	2239500	2003/10/21	<5		2.2	7.2	464	456	23.1					187
	DEP	2003/10/23	5	.1	1.7	7.32	430	425	23.3	78	9.5	0.52	5.3	182
	2239500	2004/02/19	5		2.7	6.8	457	475	23.2					189
	2239500	2004/04/14			2.5	7.2		470	23.2					
	2239500	2004/04/14	5		2.5	7.2	416	470	23.2					189
	2239500	2004/07/14	<5	.12	1.9	7		382	23.1					
	2239500	2004/08/02												
Blue Grotto	DEP	2003/10/23	5	.05	3.6	7.36	449	465	23.7	76	12	1.59	5.4	151
	291255082030000	2004/04/14			4.5	7.3		473	23.5					
	291255082030000	2004/07/14	<5	.13	3.9	7.1		390	23.7					
Abyss	DEP	2003/10/23	5	.15	3.4	7.31	497	509	23.6	88	13	0.63	5.7	172
	291253082030600	2004/04/14			4.4	7.2		491	23.5					
	291253082030600	2004/07/14	<5	.16	3.9	7.1		404	23.7					
Silver River	291256082022800	2004/01/15	<5	.1	5.4	7.4	454	465	23.4	74	10	0.6	6.2	172
	291256082022800	2004/04/14	5	.17	5.7	7.2	449	451	23.4	68	9.4	0.8	6.4	170
	291256082022800	2004/07/14	<5	.16	5	6.9	450	373	23.8	68	9.3	0.6	6.3	168

Appendix A. Water-chemistry data, 2004—Continued.

[<, less than; *, sample lost. Yellow shading indicates data obtained from the St. Johns River Water Management District; blue shading indicates data obtained from the Florida Department of Environmental Protection; pink shading indicates filtered samples]

Site name	Chloride	Fluoride	Silica	Sulfate	Residue on evaporation	Nitrite plus nitrate	Orthophosphate	Phosphorus	Organic carbon	Biochemical oxygen demand	Chlorophyll-*a*	Chlorophyll-*b*	Iron	Strontium
De Leon Spring	165			33	466	0.83	0.06	0.05	1.3	0.3	<0.1	<0.1		
											<.1	<.1		
	140			28	415	.74	.05	.05	1.1	1	5.7	<.1		
	217			37	603	.64	.05	.05						
De Leon run	240	<0.1	6.5	38	627	.62	.04	.06	2.5	1.2	21	<.1	17	460
											<.1	<.1		
	170	<.1	6.6	30	476	.63	.04	.05	1.1	.6	8.3	<.1	10	370
						.67	.048	.07						
	227	<.17	7.2	38	546	.52	.055	.073	3.9		7.8	.6	48	408
Green Spring	764			110	1,570		.106	.08	2.5	.7	<.1	<.1		
											<.1	<.1		
	620			100	1,450		.06	.07	2.1	.7	<.1	<.1		
	431			62	1,060	.03	.115	.15	2.5					
Green run	740	<.1	7.8	110	1,690	<.02	.06	.07	2.5	1.2	<.1	<.1	27	1,740
	670	<.1	7.8	100	1,490	<.02	.11	.07	2.2	.8	1.6	<.1	14	1,550
	690	<.17	8.1	104	1,420	.01	.075	.09	2.7		.5	<.1	26	1,560
Gemini Spring North	650	.1	9.5	120	1,540	1.1	.06	.07	1.1	.2	<.1	<.1	98	1,660
							.06		.8	.3	<.1	<.1		
	670		9.9	128	1,510	1.04	.058	.078	4.34				85	1,660
Gemini Spring South	650	.1	9.6	120	1,610	1.1	.06	.07	1.3	.2	<.1	<.1	76	1,710
											<.1	<.1		
	*	*	*	*	*	*	.06	*	.9	.4	<.1	<.1	*	*
	692		9.9	129	1,530	1.02	.061	.07	1.67				62	1,680
Gemini Dam	670	.1	9.4	120	1,560	1	.05	.07	1.1	.2	<.1	<.1	85	1,700
	641			118	1,470		.124	.07						
						1.13		.07			<.1	<.1		
	640	.1	9	110	1,420	1	.06	.06	1	.5	2.2	<.1	63	1,610
	586			118	1,450	1.15	.07	.07						
						1.07	.057	.14						
	686	<.17	9.6	128	1,480	.88	.065	.09	3.04		.5	<.1	71	1,700

Appendix A. Water-chemistry data, 2004—Continued.

[<, less than; *, sample lost. Yellow shading indicates data obtained from the St. Johns River Water Management District; blue shading indicates data obtained from the Florida Department of Environmental Protection; pink shading indicates filtered samples]

Site name	Chloride	Fluoride	Silica	Sulfate	Residue on evaporation	Nitrite plus nitrate	Orthophosphate	Phosphorus	Organic carbon	Biochemical oxygen demand	Chlorophyll-*a*	Chlorophyll-*b*	Iron	Strontium
Silver Springs Group														
Main	11			47	318	1.2	.04	.04						
	11			42	276	1.1	.04	.04						
	9.8	.2		27	251	.96		.04	1				15	441
	10			38	278	1.2	.03	.05						
	10			37	270	1.1	.03	.04						
						1.1	.04	.04	.5	<.1				
								.04						
Blue Grotto	11	.16		64	273	1.4		.04	1				.16	669
						1.4	.03	.03	.4	.2				
Abyss	11	.19		69	299	1.2		.05	1					823
						1.5	.04	.03	.4	.3				
Silver River	11	.2	10	49	278	1.2	.04	.04	.3	<.1	<.1	<.1	3	630
	11	.2	9.8	48	275	1.2	.03	.03	.3	.4	<.1		3.1	570
	10	.2	10	46	271	.96	.03	.02	.5	.1	<.1	<.1	2	590

Appendix B. Compounds commonly detected in wastewater.

[%, percent; >, greater than. Endocrine disrupting potential: K, known, S, suspected. CAS, Chemical Abstract Service; F, fungicide; H, herbicide; I, insecticide; GUP, general use pesticide; FR, flame retardant]

Compound names	Endocrine disrupting potential	CAS number	Common use, application, or occurrence
1,4-Dichlorobenzene	S	106-46-7	moth repellent, fumigant, deodorant
1-Methylnaphthalene		90-12-0	nearly equal concentrations (2-5%) in gasoline/diesel/crude
2,6-Dimethylnaphthalene		58-14-2	indicator of diesel, kerosene (not much in gasoline)
2-Methylnaphthalene		91-57-6	nearly equal concentrations (2-5%) in gasoline/diesel/crude
3-beta-Coprostanol		360-68-9	usually a carnivore fecal indicator
3-Methyl-1(H)-indole (skatol)		83-34-1	fragrance: odor in feces and coal tar
3-tert-Butyl-4-hydroxy anisole (BHA)	K	25013-16-5	antioxidant, preservative
4-Cumylphenol	K	599-64-4	nonionic detergent metabolite
4-n-Octylphenol	K	1806-26-4	nonionic detergent metabolite
4-tert-Octylphenol	K	140-66-9	nonionic detergent metabolite
5-Methyl-1H-benzotriazole		136-85-6	antioxidant in antifreeze, deicers
Acetophenone		98-86-2	fragrance: soap, detergent, tobacco; flavor: beverages
Acetyl hexamethyl tetrahydronaphthalene (AHTN)		21145-77-7	fragrance: musk; widespread usage; persistent in ground water
Anthracene		120-12-7	wood preservative, in tar/diesel/crude (not gasoline)
Anthraquinone		84-65-1	manufacture of dye/textiles, seed treatment, bird repellent
Benzo(a)pyrene	K	50-32-8	regulated polychlorinated aromatic hydrocarbon, used in cancer research
Benzophenone	S	119-61-9	fixative for perfumes and soaps
beta-Sitosterol		83-46-5	generally a plant sterol
beta-Stigmastanol		19466-47-8	generally a plant sterol
Bisphenol A	K	80-05-7	FR, manufacture of polycarbonate resins, antioxidant,
Bromacil		314-40-9	H, GUP, >80% non-crop grass/brush control
Bromoform		75-25-2	by-product of wastewater ozonation, military uses/explosives
Caffeine		58-08-2	medical: diuretic, highly mobile/biodegradable
Camphor		76-22-2	flavor, odorant, in ointments
Carbaryl	K	63-25-2	I, crop and garden uses, low environmental persistence
Carbazole		86-74-8	I, manufacture of dyes, explosives, and lubricants
Chlorpyrifos	K	2921-88-2	domestic pest/termite control, highly restricted (2000)
Cholesterol		57-88-5	often a fecal indicator, also a plant sterol
Cotinine		486-56-6	primary nicotine metabolite
Diazinon	K	333-41-5	I, > 40% non-agricultural uses, ants, flies, etc.
Dichlorvos	S	62-73-7	I, pet collars, fly spray; breakdown of naled & trichlofon
d-Limonene		5989-27-5	F, antimicrobial, antiviral, fragrance in aerosols
Fluoranthene		206-44-0	common in coal tar/asphalt (not gasoline/diesel)
Hexahydrohexamethyl Cyclopentabenzopyran (HHCB)		1222-05-5	fragrance: musk; widespread usage; persistent in ground water
Indole		120-72-9	pesticide inert, fragrance: coffee
Isoborneol		124-76-5	fragrance: perfumery, disinfectants
Isophorone		78-59-1	solvent for lacquers, plastics, oils, silicon, resins
Isopropylbenzene (cumene)		98-82-8	manufacture of phenol/acetone, component of fuels/paint thinner
Isoquinoline		119-65-3	flavors and fragrances

Appendix B. Compounds commonly detected in wastewater—Continued.

[%, percent; >, greater than. Endocrine disrupting potential: K, known, S, suspected. CAS, Chemical Abstract Service; F, fungicide; H, herbicide; I, insecticide; GUP, general use pesticide; FR, flame retardant]

Compound names	Endocrine disrupting potential	CAS number	Common use, application, or occurrence
Menthol		89-78-1	cigarettes, cough drops, liniment, mouthwash
Metalaxyl		57837-19-1	H, F, GUP, soil pathogens, mildew, blight, golf turf
Methyl salicylate		119-36-8	liniment, food, beverage, UV-adsorbing lotions
Metolachlor		51218-45-2	H, GUP, indicator of agricultural drainage
N,N’-diethyl-methyl-toluamide (DEET)		134-62-3	I, urban uses, mosquito control
Naphthalene		91-20-3	fumigant, moth repellent, about 10% of gasoline
Nonylphenol, diethoxy- (total)	K	26027-38-3	nonionic detergent metabolite
Octylphenol, diethoxy-	K	26636-32-8	nonionic detergent metabolite
Octylphenol, monoethoxy-	K	26636-32-8	nonionic detergent metabolite
para-Cresol	S	106-44-5	wood preservative
para-Nonylphenol (total)	K	84852-15-3	nonionic detergent metabolite
Pentachlorophenol	S	87-86-5	H, F, wood preservative, termite control
Phenanthrene		85-01-8	manufacture of explosives, in tar/diesel/crude (not gasoline)
Phenol		108-95-2	disinfectant, manufacture of several products, leachate
Prometon		1610-18-0	H, only non-crop areas, applied prior to blacktop
Pyrene		129-00-0	common in coal tar/asphalt (not gasoline/diesel)
Tetrachloroethylene		127-18-4	solvent, degreaser; veterinary: anthelminic
tri(2-Chloroethyl) phosphate	S	115-96-8	FR, plasticizer
tri(Dichlorisopropyl) phosphate	S	13674-87-8	FR
Tributylphosphate		126-73-8	FR, antifoaming agent
Triclosan	S	3380-34-5	disinfectant, antimicrobial (concern: induced resistance)
Triethyl citrate (ethyl citrate)		77-93-0	cosmetics, pharmaceuticals, widely used
Triphenyl phosphate		115-86-6	FR, plasticizer, resins, waxes, finishes, roofing paper
tris(2-Butoxyethyl) phosphate		78-51-3	FR

Appendix C. Pesticides analyzed.

[CAS, Chemical Abstract Service; µg/L, microgram per liter]

Analyte	CAS number	Reporting limit	Units
2,4-D	94-75-7	0.0218	µg/L
2,4-D methyl ester	1928-38-7	.0086	µg/L
2,4-DB	94-82-6	.016	µg/L
3(4-Chlorophenyl)-1- methyl	5352-88-5	.0242	µg/L
3-Ketocarbofuran	16709-30-1	1.5	µg/L
Acifluorfen	50594-66-6	.0066	µg/L
Aldicarb	116-06-3	.04	µg/L
Aldicarb sulfone	1646-88-4	.02	µg/L
Aldicarb sulfoxide	1646-87-3	.0082	µg/L
Chloramben, methyl ester	7286-84-2	.018	µg/L
Atrazine	1912-24-9	.009	µg/L
2-Hydroxyatrazine	2163-68-0	.008	µg/L
Deethylatrazine	6190-65-4	.0282	µg/L
Deethyldeisopropylatrazine	3397-62-4	.01	µg/L
Deisopropylatrazine	1007-28-9	.044	µg/L
Bendiocarb	22781-23-3	.0252	µg/L
Benomyl	17804-35-2	.0038	µg/L
Bensulfuron-methyl	83055-99-6	.0158	µg/L
Bentazon	25057-89-0	.011	µg/L
Bromacil	314-40-9	.033	µg/L
Bromoxynil	1689-84-5	.017	µg/L
Caffeine	58-08-2	.0096	µg/L
Carbaryl	63-25-2	.0284	µg/L
Carbofuran	1563-66-2	.0056	µg/L
3-Hydroxycarbofuran	16655-82-6	.0058	µg/L
Chlorimuron-ethyl	90982-32-4	.0096	µg/L
Chlorothalonil	1897-45-6	.035	µg/L
Clopyralid	1702-17-6	.0138	µg/L
Cycloate	1134-23-2	.013	µg/L
Dacthal monoacid	887-54-7	.0116	µg/L
Dicamba	1918-00-9	.0128	µg/L
Dichlorprop	120-36-5	.0138	µg/L
Dinoseb	88-85-7	.012	µg/L
Diphenamid	957-51-7	.0264	µg/L

Appendix C. Pesticides analyzed—Continued.

[CAS, Chemical Abstract Service; µg/L, microgram per liter]

Analyte	CAS number	Reporting limit	Units
Diuron	330-54-1	.015	µg/L
Fenuron	101-42-8	.0316	µg/L
Flumetsulam	98967-40-9	.011	µg/L
Fluometuron	2164-17-2	.031	µg/L
Imazaquin	81335-37-7	.016	µg/L
Imazethapyr	81335-77-5	.017	µg/L
Imidacloprid	138261-41-3	.0068	µg/L
Linuron	330-55-2	.0144	µg/L
MCPA	94-74-6	.0162	µg/L
MCPB	94-81-5	.015	µg/L
Metalaxyl	57837-19-1	.02	µg/L
Methiocarb	2032-65-7	.008	µg/L
Methomyl	16752-77-5	.0044	µg/L
Metsulfuron methyl	74223-64-6	.025	µg/L
Neburon	555-37-3	.012	µg/L
Nicosulfuron	111991-09-4	.013	µg/L
Norflurazon	27314-13-2	.016	µg/L
Oryzalin	19044-88-3	.0176	µg/L
Oxamyl	23135-22-0	.0122	µg/L
Picloram	1918-02-1	.0198	µg/L
Propham	122-42-9	.0096	µg/L
Propiconazole	60207-90-1	.021	µg/L
Propoxur	114-26-1	.008	µg/L
Siduron	1982-49-6	.0168	µg/L
Sulfometuron-methyl	74222-97-2	.0088	µg/L
Tebuthiuron	34014-18-1	.0062	µg/L
Terbacil	5902-51-2	.0098	µg/L
Tribenuron-methyl	101200-48-0	.0088	µg/L
Triclopyr	55335-06-3	.0224	µg/L

Appendix D. Macroinvertebrate taxa reported in this study.

[--, not differentiated. Major taxa (phyla through orders) are in approximate ascending phylogenetic sequence, with families, genera, and species in each listed alphabetically. Authorities and dates are for lowest level of identification (i.e., genus or species). Authorities listed for genera and species were obtained from the Integrated Taxonomic Information System, 2006]

Major taxon	Family	Species
Porifera	--	--
Nematoda	--	--
Oligochaeta	--	--
Hirudinea	Erpobdellidae	--
Hirudinea	Glossiphoniidae	--
Gastropoda	Ampullariidae	*Pomacea paludosa* (Say, 1829)
Gastropoda	Ancylidae	--
Gastropoda	Hydrobiidae	--
Gastropoda	Physidae	*Physella* sp. Haldeman, 1842
Gastropoda	Planorbidae	*Micromenetus floridensis* Baker, 1945
Gastropoda	Planorbidae	*Planorbella scalaris* (Jay, 1839)
Gastropoda	Planorbidae	*Planorbella trivolvis intertextum* (Sowerby, 1878)
Gastropoda	Pleuroceridae	*Elimia floridensis* (Reeve, 1860)
Gastropoda	Thiaridae	*Melanoides tuberculata* (Müller, 1774)
Gastropoda	Viviparidae	*Viviparus georgianus* (Lea, 1834)
Pelecypoda	Corbiculidae	*Corbicula fluminea* Müller, 1774
Pelecypoda	Unionidae	*Anodonta couperiana* Lea, 1840
Pelecypoda	Unionidae	*Elliptio* sp. Rafinesque, 1819
Pelecypoda	Unionidae	*Elliptio buckleyi* (Lea, 1843)
Pelecypoda	Unionidae	*Elliptio icterina* (Conrad, 1834)
Pelecypoda	Unionidae	*Toxolasma paulus* (Lea, 1840)
Pelecypoda	Unionidae	*Uniomerus carolinianus* (Bosc, 1801)
Pelecypoda	Unionidae	*Utterbackia imbecillis* (Say, 1829)
Pelecypoda	Unionidae	*Villosa amygdala* (Lea, 1843)
Hydracarina	--	--
Arachnida	Pisauridae	*Dolomedes* sp. Latreille, 1804
Ephemeroptera	--	--
Ephemeroptera	Baetidae	*Callibaetis floridanus* Banks, 1900
Ephemeroptera	Caenidae	*Caenis diminuta* Walker, 1853
Odonata	Coenagrionidae	*Enallagma* sp. Charpentier, 1840
Odonata	Coenagrionidae	*Nehalennia* sp. Selys, 1850
Odonata	Coenagrionidae	*Telebasis byersi* Westfall, 1957
Odonata	Corduliidae	*Epitheca princeps regina* (Hagen *in* Selys, 1871)
Odonata	Libellulidae	--
Odonata	Libellulidae	*Erythemis plebeja* (Burmeister, 1839)
Hemiptera	Belostomatidae	--
Hemiptera	Belostomatidae	*Belostoma* sp. Latreille, 1807
Hemiptera	Belostomatidae	*Lethocerus* sp. Mayr, 1853
Hemiptera	Gerridae	--
Hemiptera	Mesoveliidae	*Mesovelia* sp. Mulsant and Rey, 1852
Hemiptera	Naucoridae	*Pelocoris* sp. Stal, 1876
Homoptera	--	--
Trichoptera	Hydroptilidae	*Neotrichia* sp. Morton, 1905
Trichoptera	Hydroptilidae	*Orthotrichia* sp. Eaton, 1873
Coleoptera	Chrysomelidae	--

Appendix D. Macroinvertebrate taxa reported in this study—Continued.

[--, not differentiated. Major taxa (phyla through orders) are in approximate ascending phylogenetic sequence, with families, genera, and species in each listed alphabetically. Authorities and dates are for lowest level of identification (i.e., genus or species). Authorities listed for genera and species were obtained from the Integrated Taxonomic Information System, 2006]

Major taxon	Family	Species
Coleoptera	Dryopidae	*Pelonomus obscurus* Leconte, 1852
Coleoptera	Haliplidae	*Peltodytes* sp. Regimbart, 1878
Coleoptera	Hydrophilidae	*Helocombus* sp. Horn, 1890
Diptera	Ceratopogonidae	--
Diptera	Chironomidae	--
Diptera	Ephydridae	--
Diptera	Ptychopteridae	--
Diptera	Stratiomyidae	--
Diptera	Tabanidae	--
Cladocera	--	--
Ostracoda	--	--
Isopoda	Asellidae	--
Isopoda	Asellidae	*Lirceus lineatus* (Say, 1818)
Isopoda	Sphaeromatidae	*Cassidinidea ovalis* (Say, 1818)
Amphipoda	--	--
Amphipoda	Gammaridae	*Gammarus* sp. Fabricius, 1775
Amphipoda	Hyalellidae	*Hyalella azteca* Saussure, 1858
Decapoda	Cambaridae	*Procambarus* sp. Ortmann, 1905
Decapoda	Palaemonidae	*Palaemonetes paludosus* (Gibbes, 1850)

Appendix E. Scientific names, authorities and dates of original descriptions, and common names of fishes reported in this study.

[Families are organized in approximate phylogenetic order; genera and species within families are listed alphabetically. Species designated by an asterisk are nonindigenous. Names follow Nelson and others (2004)]

Family	Scientific name	Common name
Dasyatidae	*Dasyatis sabina* (Lesueur, 1824)	Atlantic stingray
Lepisosteidae	*Lepisosteus osseus* (Linnaeus, 1758)	longnose gar
Lepisosteidae	*Lepisosteus platyrhincus* DeKay, 1842	Florida gar
Amiidae	*Amia calva* Linnaeus, 1766	bowfin
Anguillidae	*Anguilla rostrata* (Lesueur, 1817)	American eel
Clupeidae	*Dorosoma cepedianum* (Lesueur, 1818)	gizzard shad
Clupeidae	*Dorosoma petenese* (Günther, 1867)	threadfin shad
Cyprinidae	*Cyprinus carpio* Linnaeus, 1758*	common carp
Cyprinidae	*Notemigonus crysoleucas* (Mitchill, 1814)	golden shiner
Cyprinidae	*Notropis harperi* Fowler, 1941	redeye chub
Cyprinidae	*Notropis petersoni* Fowler, 1942	coastal shiner
Cyprinidae	*Opsopoeodus emiliae* Hay, 1881	pugnose minnow
Catostomidae	*Erimyzon sucetta* (Lacepède, 1803)	lake chubsucker
Ictaluridae	*Ameiurus catus* (Linnaeus, 1758)	white catfish
Ictaluridae	*Ameiurus natalis* (Lesueur, 1819)	yellow bullhead
Ictaluridae	*Ameiurus nebulosus* (Lesueur, 1819)	brown bullhead
Ictaluridae	*Ictalurus punctatus* (Rafinesque, 1818)	channel catfish
Ictaluridae	*Noturus gyrinus* (Mitchill, 1817)	tadpole madtom
Ictaluridae	*Noturus leptacanthus* Jordan, 1877	speckled madtom
Callichthyidae	*Hoplosternum littorale* (Hancock, 1828)*	brown hoplo
Loricariidae	*Pterygoplichthys disjunctivus* (Weber, 1991)*	vermiculated sailfin catfish
Esocidae	*Esox americanus* Gmelin, 1789	redfin pickerel
Esocidae	*Esox niger* Lesueur, 1818	chain pickerel
Aphredoderidae	*Aphredoderus sayanus* (Gilliams, 1824)	pirate perch
Mugilidae	*Mugil cephalus* Linnaeus, 1758	striped mullet
Atherinopsidae	*Labidesthes sicculus* (Cope, 1865)	brook silverside
Belonidae	*Strongylura marina* (Walbaum, 1792)	Atlantic needlefish
Fundulidae	*Fundulus chrysotus* (Günther, 1866)	golden topminnow
Fundulidae	*Fundulus lineolatus* (Agassiz, 1854)	lined topminnow
Fundulidae	*Fundulus rubrifrons* (Jordan, 1880)	redface topminnow
Fundulidae	*Fundulus seminolis* Girard, 1859	Seminole killifish
Fundulidae	*Lucania goodei* Jordan, 1880	bluefisn killifish
Fundulidae	*Lucania parva* (Baird & Girard, 1855)	rainwater killifish
Poeciliidae	*Gambusia holbrooki* Girard, 1859	eastern mosquitofish
Poeciliidae	*Heterandria formosa* Agassiz, 1855	least killifish
Poeciliidae	*Poecilia latipinna* (Lesueur, 1821)	sailfin molly
Cyprinodontidae	*Jordanella floridae* Goode & Bean, 1879	flagfish
Centrarchidae	*Enneacanthus gloriosus* (Holbrook, 1855)	bluespotted sunfish
Centrarchidae	*Lepomis auritus* (Linnaeus, 1758)	redbreast sunfish
Centrarchidae	*Lepomis gulosus* (Cuvier, 1829)	warmouth
Centrarchidae	*Lepomis macrochirus* Rafinesque, 1819	bluegill
Centrarchidae	*Lepomis marginatus* (Holbrook, 1855)	dollar sunfish
Centrarchidae	*Lepomis microlophus* (Günther, 1859)	redear sunfish
Centrarchidae	*Lepomis punctatus* (Valenciennes, 1831)	spotted sunfish
Centrarchidae	*Micropterus salmoides* (Lacepède, 1802)	largemouth bass
Centrarchidae	*Pomoxis nigromaculatus* (Lesueur, 1829)	black crappie

Appendix E. Scientific names, authorities and dates of original descriptions, and common names of fishes reported in this study—Continued.

[Families are organized in approximate phylogenetic order; genera and species within families are listed alphabetically. Species designated by an asterisk are nonindigenous. Names follow Nelson and others (2004)]

Family	Scientific name	Common name
Percidae	*Etheostoma fusiforme* (Girard, 1854)	swamp darter
Percidae	*Percina nigrofasciata* (Agassiz, 1854)	blackbanded darter
Elassomatidae	*Elassoma evergladei* Jordan, 1884	Everglades pygmy sunfish
Elassomatidae	*Elassoma okefenokee* Böhlke, 1956	Okefenokee pygmy sunfish
Cichlidae	*Oreochromis aureus* (Steindachner, 1864)*	blue tilapia
Achiridae	*Trinectes maculatus* (Block & Schneider, 1801)	hogchocker