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FIFTY-YEAR RETROSPECTIVE STUDY OF THE ECOLOGY OF SILVER SPRINGS, FLORIDA

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

Fifty-Year Retrospective Study of the Ecology of Silver Springs, Florida

Prepared for

Florida Department of Environmental Protection

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Executive Summary

THE PROJECT

The St Johns River Water Management District (SJRWMD), in collaboration with Wetland Solutions Inc. (WSI) and the University of Florida Department of Fisheries and Aquatic Sciences (UFDFAS) conducted an evaluation of the ecological health of Silver Springs located in Marion County, Florida. The field work was conducted from late 2003 through early 2005. This effort was funded by the Florida Department of Environmental Protection (FDEP) as part of the Florida Springs Initiative.

This Fifty-Year Retrospective Study of the Ecology of Silver Springs was intended to provide an assessment of land use and water quality changes in Silver Springs and a development of cause-and-effect relationships, if any, to the springs' ecology. The scope of this study was to review and summarize the data that are currently available for the upper 0.75 miles (1,200 m) of the Silver River, collect additional data as needed for comparison to historical data, and develop linkages between springshed land use changes and the ecology of Silver Springs. This study was explicitly limited in spatial extent to the upper 1,200 m of the Silver Springs run beginning at the Main Spring Boil (Mammoth Spring, Figure ES-1). This area includes all of the major spring boils and was the focus of the work conducted by Dr. Howard T. Odum and Dr. Robert L. Knight for their biological and ecosystem metabolism studies of the 1950s and 1970s, respectively.

THE SPRINGS

Silver Springs, the largest of Florida's first magnitude springs, (Scott *et al.* 2004; Scott *et al.* 2002; Osburn *et al*. 2002; Rosenau *et al.* 1977) discharges approximately 766 cubic feet per second (cfs) (514 million gallons per day [mgd]) from the Floridan Aquifer (Osburn *et al*. 2002) and is also likely the largest limestone spring in the United States (Meinzer 1927; Rosenau *et al.* 1977). It forms the headwaters of the Silver River, which eventually becomes part of the Ocklawaha River. It is also the center of the Silver Springs tourist attraction, which has been a popular destination for over one hundred years (Crum 1954; Martin 1966) and continues to receive a million or more visitors each year, generating an estimated annual economic impact of about $65 million (Bonn, 2004).

Silver Springs was the focal point of an extensive effort of data collection and analysis of springs throughout Florida conducted by Dr. Howard Tom Odum, a young faculty member at the University of Florida in the 1950s. Dr. Odum's springs research lasted for a period of five years and he published information on a total of eleven Florida springs in addition to Silver Springs. H.T. Odum's landmark paper on the research conducted in cooperation with numerous colleagues on the energy flows and biological hierarchy of Silver Springs was published in

Ecological Monographs (Odum 1957). Odum's team studied water quality, productivity, ecosystem structure, and energy flows for the Silver Springs system.

A second ecological study of Silver Springs was conducted by Robert L. Knight for a doctoral dissertation under the supervision of H.T. Odum in the late 1970s. Knight (1980, 1983) re-examined the system metabolism, productivity, and consumer control structure of Silver Springs approximately twenty-five years following the earlier work by Odum.

The research at Silver Springs by Odum, Knight, and numerous other scientists provides the most thorough overview and detail of a spring's ecology reported to date in the scientific literature. For this reason it is possible to utilize quantitative data from studies conducted during the early 1950s as a baseline or benchmark to compare to existing conditions. A fifty-year time interval has occurred since Dr. Odum studied Silver Springs, offering a long-enough historical perspective to possibly detect environmental changes that might be difficult to recognize over shorter time intervals.

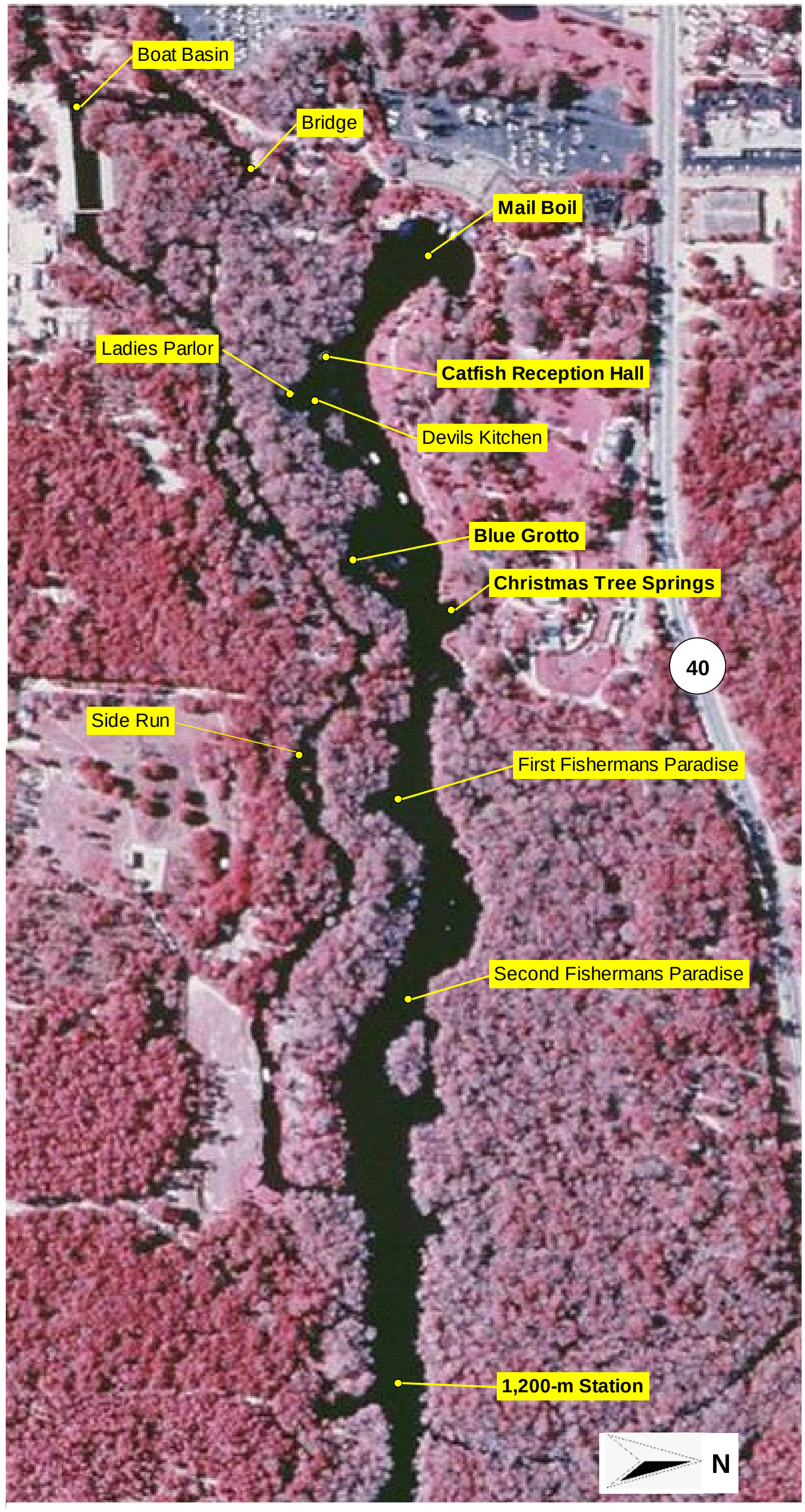

Figure ES-1 Silver Springs Fifty-Year Retrospective Study area

RESULTS

Due to the comprehensive nature of an ecology study, a number of disciplines were applied to this project, including biology, geology, hydrology, land use analysis and more. Modeling was employed to produce a prediction of future conditions at the spring, based on land use plans for the springshed. Following are the major hydrological and hydrogeological findings.

- Historical spring flows at Silver Springs have been measured at several locations in the spring run. However, a majority of the discharge data collected was obtained from a location approximately 0.75 mi downstream from the Main Spring Boil. This point is referred to as the 1,200-m station. Approximately 50% of the flow at the 1,200-m station is derived from the Main Spring Boil. The remaining discharge occurs throughout the spring run at specific locations or as diffuse upward leakage. (Karst Environmental Services, 2005; Appendix T and Appendix V).
- The US Geological Survey (USGS) has performed manual discharge measurements at Silver Springs three hundred ninety-nine times between 1906 and 2004. The mean and median discharge measurements for this period are 766 and 762 cubic feet per second (cfs), respectively. A maximum discharge of 1,290 cfs was measured in September 1960. A minimum discharge of 250 cfs was measured in January 2001. While statistical analysis shows a minor decline in overall discharge, this decline is also consistent with recorded declines in rainfall in the central Florida area.
- The Silver Springs springshed covers an area of 1,200 square miles (3,100 km^2). Comparison of previously published delineations of the springshed and work performed in this study show very similar results. An evaluation of the areas contributing to the spring flow utilizing the SJRWMD North-central Florida Regional Groundwater Flow Model (NCF) coupled with the USGS MODPATH code indicates that approximately 75% of water discharging from Silver Springs originates within a two-year capture zone. Model results also indicate that the two-year capture zone covers approximately a 4-mile radius around the spring and constitutes about 52 square miles (Figure ES-2).
- USGS MODPATH simulation was also performed to estimate the extension of the groundwater contributing area for the 10-year and 100-year particle travel times. The extensions of the 10-year particle lines range from approximately 5.5 miles to a maximum of 11.1 miles from Silver Springs. The extensions of the 100-year particle lines range from approximately 6.8 miles to 27.5 miles from the springs.
- The NCF groundwater model was also used to evaluate the impacts of the estimated 1957 and 1979 as well as the projected 2025 and 2055 water demand on the discharge of Silver Springs. The estimated 1957 and 1979 spring discharges are 716.5 and 710.8 cfs, respectively. Projected spring discharges for 2025 and 2055 are estimated to be 674.3

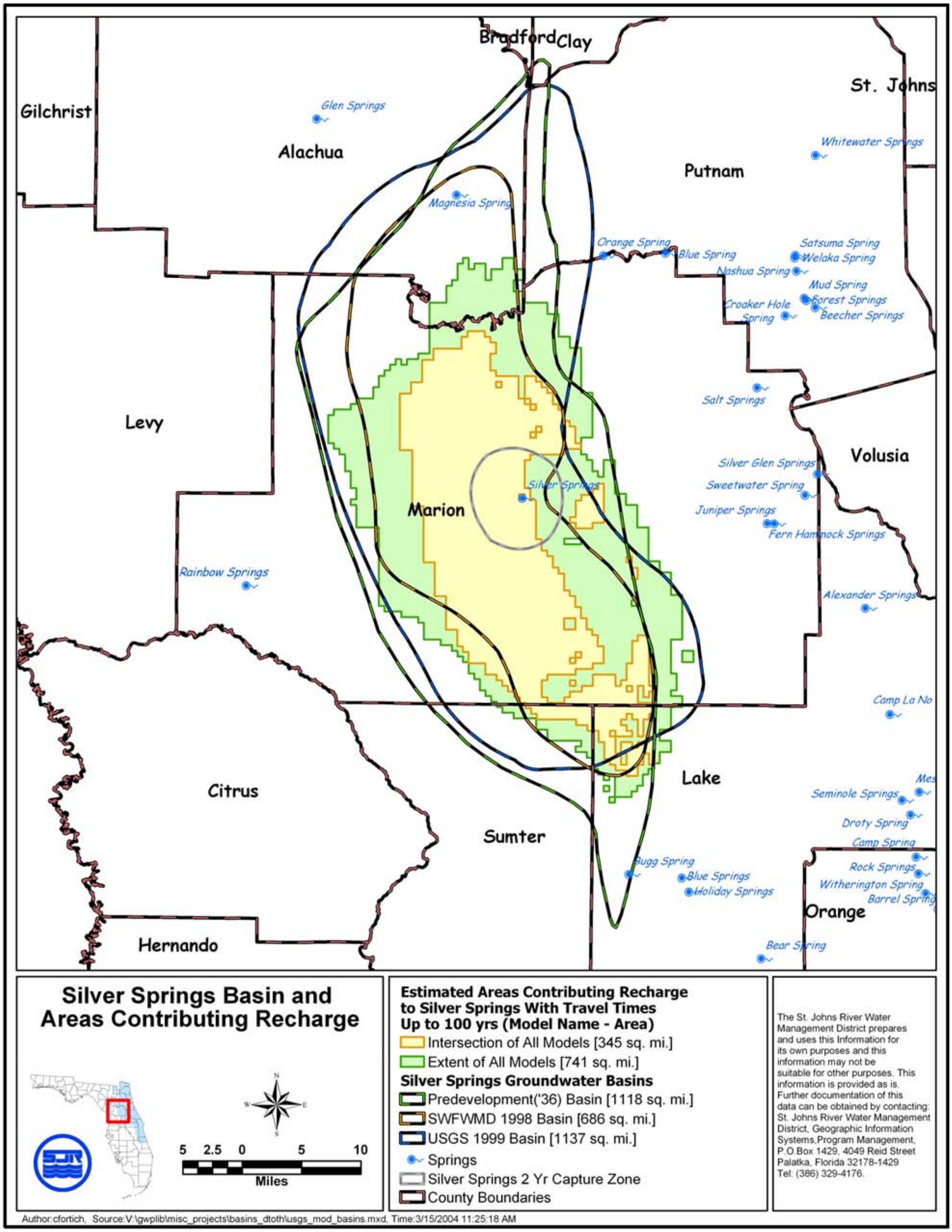

Figure ES-2 Silver Springs springshed and two-year capture zone and 589.14 cfs. Aerial thermography surveys and seismic profiling were performed in order to detect previously unknown groundwater discharge sites at Silver Springs. Aerial thermography was used to identify thermal anomalies at a 2-meter pixel resolution in the Silver River. Such thermal anomalies indicate sites of groundwater discharge. Timber Springs, one of the discharge points revealed by aerial thermography, is presented in Figure ES-3. Seismic profiling was used to identify subsurface features that may provide a pathway for groundwater discharge into the Silver River. These techniques produced the following results:

- Three new sites of discharge upstream of the 1,200-m station were detected by thermography and field verified.
- All of the thermal anomalies detected above the 1,200-m gaging station have been correlated with identified spring vent groups.
- Other sites with thermal anomalies have been detected downstream of the 1,200-m station. These sites may indicate groundwater flow into the Silver River. The quantity and quality of water flowing from these probable discharge areas are unknown.
- In most cases, seismic profiles showed evidence of subsurface features such as cavities or collapse structures associated with thermal anomalies.

Based on the groundwater model estimates of recharge to the Floridan Aquifer and the relative magnitude with which that recharge eventually discharges at Silver Springs, the two-year capture zone was selected for a detailed determination of nutrient loading rates to the springs. Analysis of aerial photos dating to 1947 shows that land cover within the two-year capture zone has changed from a predominantly natural landscape to a mostly urban/agricultural area during the past fifty years. Due to data limitations, land use/land cover (LULC) classes and the applied nitrogen-loading rates were generalized to a great extent (for instance, farming, pasture, and improved pasture were grouped together). This limitation was imposed due to the LULC classes that could be determined from 1940 – 1957 aerial imagery. A summary of historic and projected land coverage and land uses within the Silver Springs two-year capture zone is presented in Table ES-1.

The conversion of land cover within the two-year capture zone is a potential cause for increased nitrogen loading rates to the springs. Observed and projected nitrate- nitrogen (nitrate-N) loading rates, in pounds per year (lbs/yr) for Silver Springs are presented in Table ES-2.

Loading rates and estimated discharge rates at Silver Springs for the years 1957, 1979, 1995, 2025 and 2055 were key components of the development of the Linked Landscape-Ecosystem Model presented in the report. Table ES-3 contains a summary of historic and projected future nitrate-N concentrations at Silver Springs. Figure ES-4 presents a summary of nitrate-N concentrations at the Main Spring Boil from the early 1900s through 2005.

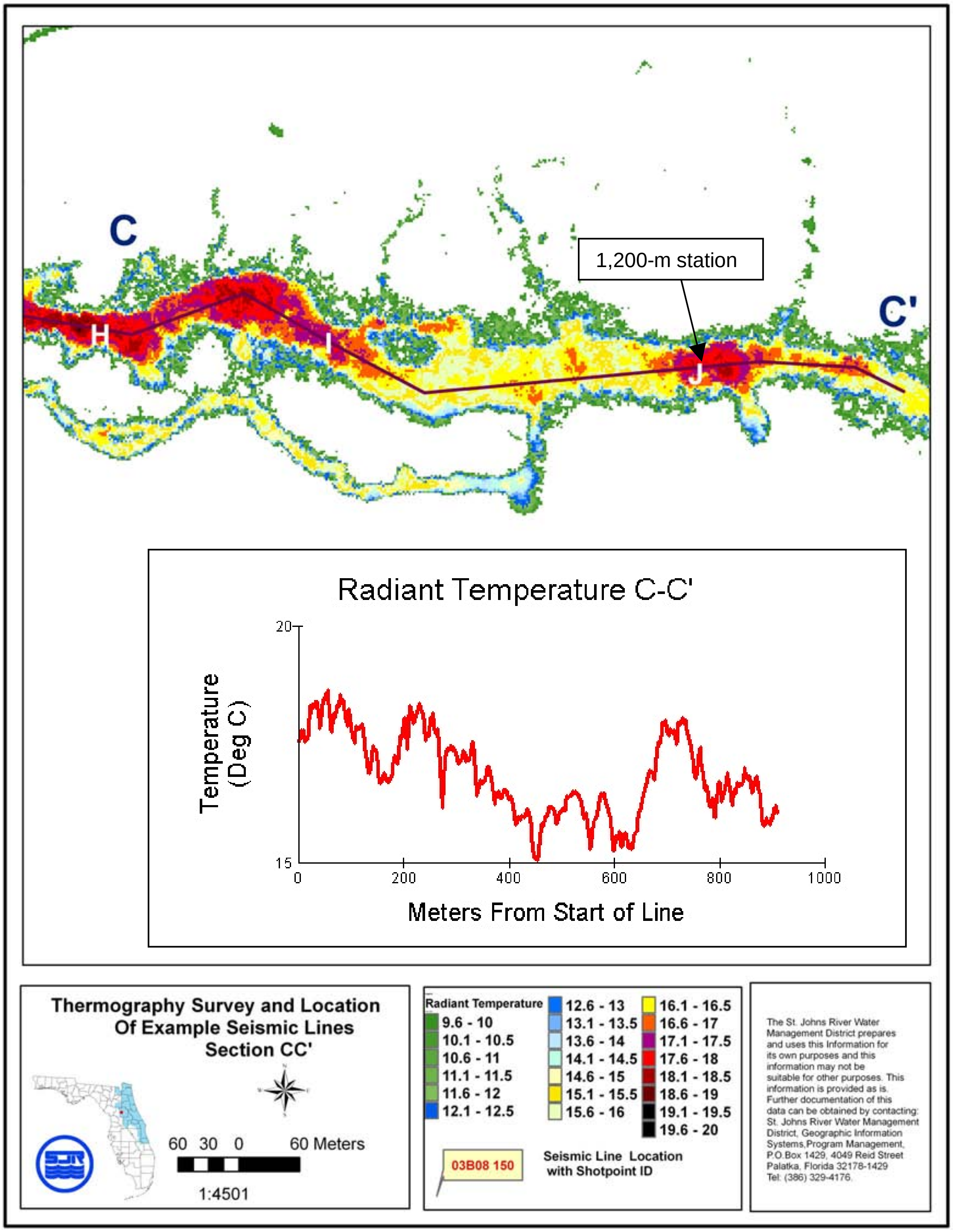

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Figure ES-3 Aerial thermography survey and temperature profile for Section C-C' of the Silver River, including sites known as First Fisherman's Paradise Spring (H), Second Fisherman's Paradise Spring (I), and the 1,200-m station (J). Several vents were observed discharging at site J (recently given the name Timber Springs).

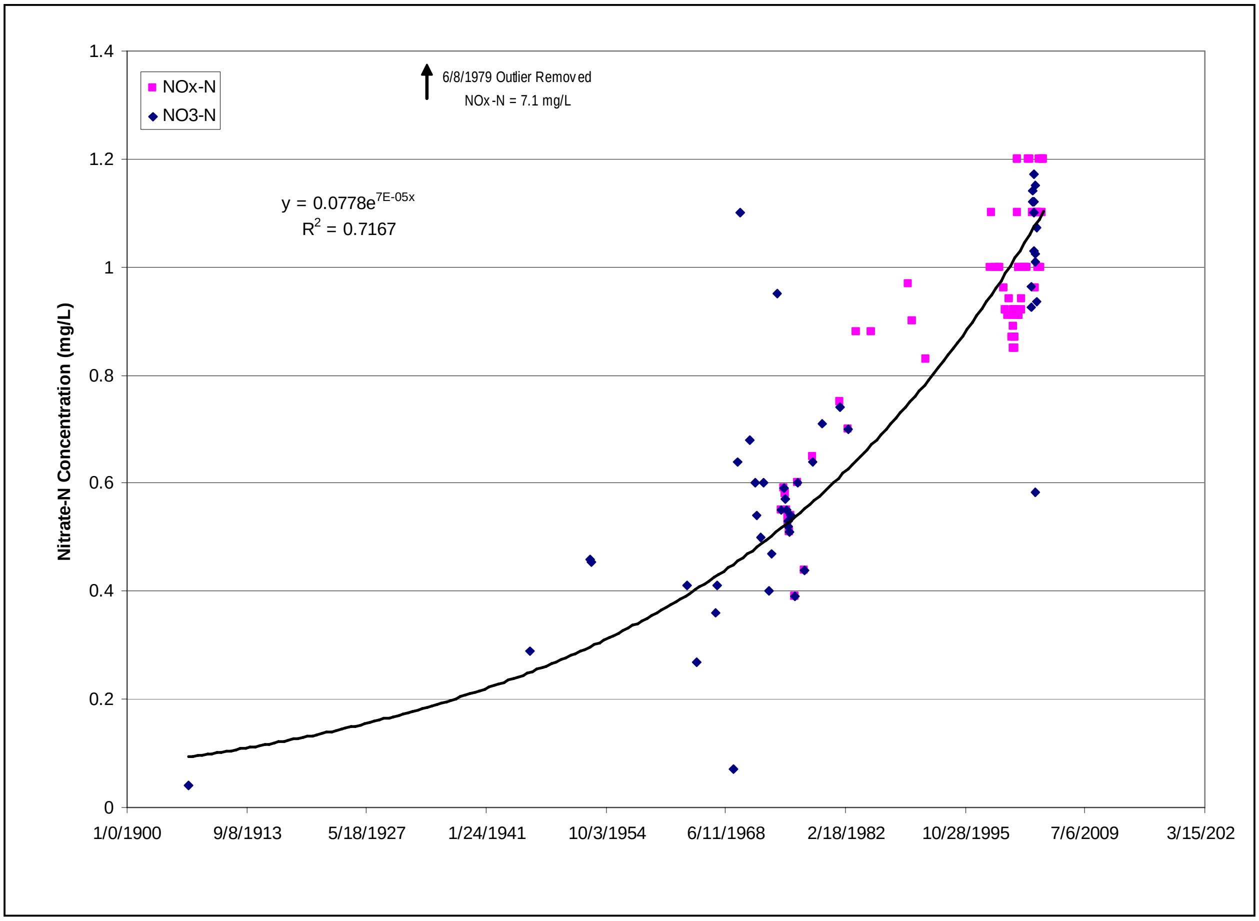

Figure ES-4 Summary of observed nitrate-N concentrations at the Silver Springs Main Boil

Table ES-1 Land cover and land use in the Silver Springs two-year capture zone, 1949-2055

Land Use / Land Cover	Acres 1949	Acres 1957	Acres 1964	Acres 1972	Acres 1989	Acres 1995	Acres 2005	Acres 2055
Urban	143.48	797.72	688.68	3460.62	3816.44	6238.29	7081.93	12327.37
Agriculture / Pasture	6060.38	6863.84	7483.66	9463.61	8310.07	8011.64	8235.47	9130.75
Forested / Vegetated	24178.41	22927.31	21148.22	15799.47	13354.65	12333.11	10754.89	4487.9
N/A	3299.93	3093.32	4361.64	4958.5	8201.03	7099.14	7609.91	7736.17

Land Use / Land Cover	Acres % 1949	Acres % 1957	Acres % 1964	Acres % 1972	Acres % 1989	Acres % 1995	Acres % 2005	Acres % 2055
Urban	0.43	2.37	2.04	10.27	11.33	18.52	21.03	36.6
Agriculture / Pasture	18.01	20.4	22.24	23.2	24.7	23.81	24.48	27.11
Forested / Vegetated	71.87	68.15	62.86	57.33	39.69	36.66	31.97	13.34
N/A	9.80%	9.18%	12.95%	14.72%	24.35%	21.08%	22.59%	22.97%

* Forested / Vegetated also includes Bare Soil & Clearcut
* N/A includes Transportation Right-of-Ways and Trails or areas that could not be classified

Table ES-2 Silver Springs Observed and Projected Nitrogen Loading Rates, 1957 - 2055

year	loading rate, pounds per year (lbs/yr)
1957	94,400
1979	814,900
1995	956,000
2005	1,058,000
2055 (projected)	1,760,000

Table ES-3 Nitrate-N concentrations at Silver Springs, 1907-2055

year	(source)	nitrate-N concentration (mg/l)
1907	USGS	0.04
1946	USGS	0.29
1953	Odum	0.46 (average)
1957	USGS	0.1
1979	USGS	0.71
1995	USGS	0.90
2005	this study	1.07
2055 (projected)	this study	2.02

Given the historical changes in land use and the relationship between nitrogen loading and the limited observation of increased nitrate-N concentrations from the Main Spring Boil, nitrate-N concentrations are expected to continue to increase into the future.

Aside from the increase in nitrate-N, water quality at Silver Springs has generally remained stable during the past fifty years, with the exception of light transmission and estimated nighttime dissolved oxygen (DO) concentration:

- Horizontal secchi distance has decreased and vertical light attenuation coefficients have increased during the past fifty years, indicating a general decline in the overall water clarity within the Main Spring Boil and the spring run.
- Average estimated nighttime DO concentration at the 1,200-m station has declined from about 3.1 milligrams per liter (mg/l) during the 1950s to about 2.8 mg/l during the 1970s to about 2.5 mg/l during this study. A comparison of the average diurnal DO curves during Odum's study, Knight's work, and this project is presented in Figure ES-5.

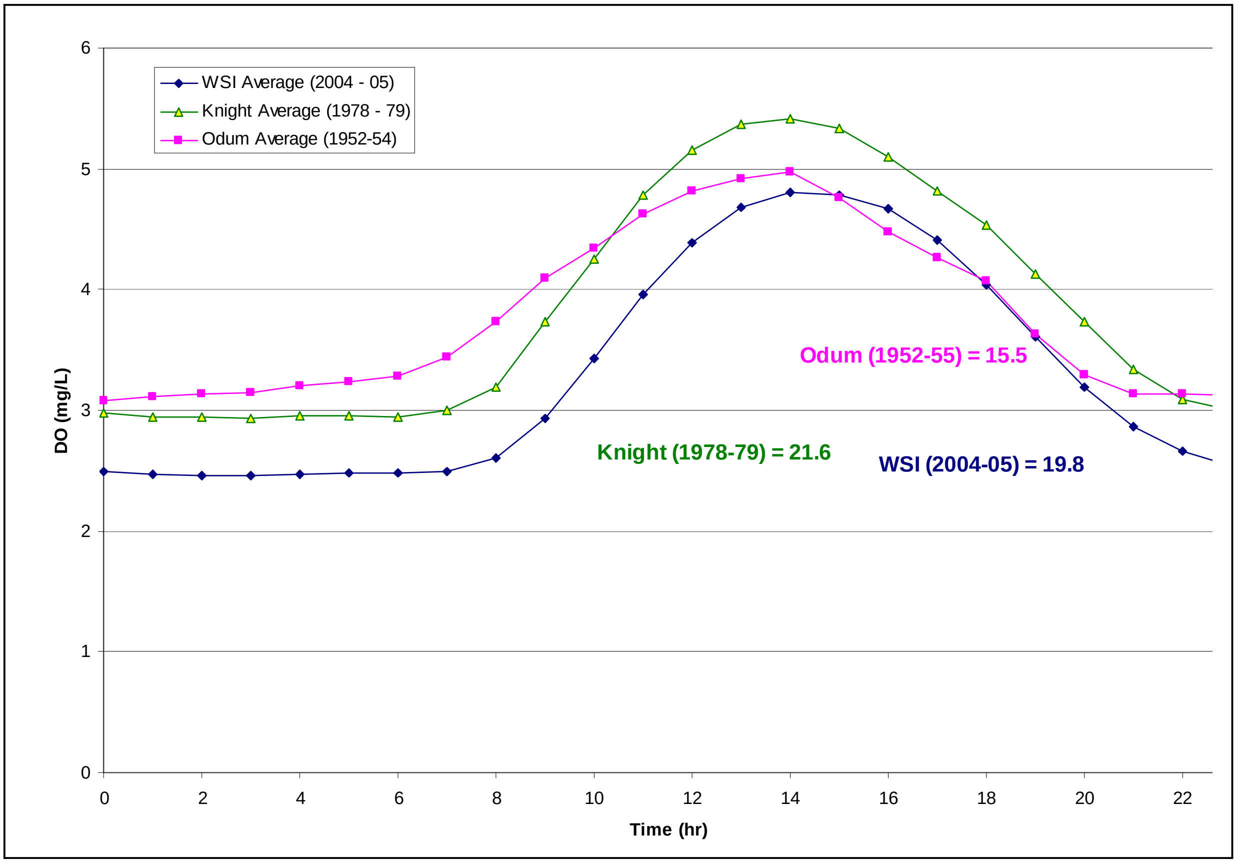

Figure ES-5 Comparison of Silver Springs average diurnal oxygen curves at the 1,200-m station; estimated gross primary productivity in units of ppm-hrs. Higher total GPP estimates for Knight (1978-79) and WSI (2004-05) are a result of increased submerged area in Silver Springs Run above the 1,200-m station due to the addition of the Back Channel Extension in the late 1970s.

Aquatic plants, including epiphytes, benthic algae mats, and macrophytes were sampled, characterized, and analyzed. The following is a summary of the significant results of the aquatic plant sampling and analysis:

- *Sagittaria* remains the dominant submerged aquatic plant species in Silver Springs and represents one of the main physical features of the ecosystem.
- Biomass estimates for submerged aquatic plants in the summer season were not significantly different from estimates made by Odum in the early 1950s. However, estimates for winter biomass were 31% lower than Odum's, who reported no seasonal difference in submerged aquatic plant biomass.
- Biomass estimates for the epiphyte community in the summer were approximately three-fold higher than those reported by Odum, while winter values were not significantly different between the two studies.
- The largest disparity between the current estimates of primary producer community biomass and those of Odum from the 1950s was the substantial values for the benthic algal mat community biomass in this current study. While Odum discounted the importance of algal mats, in terms of biomass, the current study showed biomass estimates similar to those observed for epiphytes and submerged aquatic plants. However, it is important to note that these estimates may not be an accurate indicator of primary productivity attributable to benthic mats, since mat biomass includes large proportions of bacteria, fauna, dead algae and other detrital material.

The populations of birds, fish, turtles and alligators at Silver Springs were assessed and compared to the results of previous investigations. Table ES-4 summarizes the bird and reptile species observed in Odum's study and in this study. Table ES-5 presents the fish species biomass estimates observed by Odum, Knight, and in this study. The following observations were made concerning vertebrate populations at Silver Springs:

- Total species richness for birds, fish, and reptiles were similar in 2004 compared to historical records at the Silver River.
- Visual observations of turtles present in Silver Springs found that dominant populations of cooters observed during the early 1950s were still present as were smaller populations of soft shelled turtles; however, musk turtles were observed during the Odum study and although likely to be present today, were not observed here.
- Alligator populations were not estimated by Odum in the 1950s but were estimated at night at a density of about 3.4 per hectare (/ha) by Knight (1980) and in the day at 0.91/ha during the current study.
- Populations of fish-eating birds such as the double-crested cormorant have apparently increased at Silver Springs since the 1950s study period.
- Largemouth bass and bluegill sunfish continue to be among the most dominant larger fish present in Silver Springs based on data during the past fifty years.

Table ES-4 Species of birds and reptiles observed (indicated by "+") in the spring run of Silver River, Florida studies by Odum (1957) and this study

	Common	Species	Odum	This study
Birds	American coot	*Fulica americana*	+	
	Anhinga	*Anhinga anhinga*		+
	Common moorhen	*Gallinula chloropus*	+	+
	Double-crested cormorant	*Phalacrocorax auritus*		+
	Florida mottled duck	*Anas fulvigula*		+
	Grackle	*Quiscalus quiscula*		+
	Great blue heron	*Ardea herodias*	+	+
	Green heron	*Butorides virescens*	+	
	Little blue heron	*Egretta caerulea*	+	+
	Osprey	*Pandion haliaetus*		+
	Pied-billed grebe	*Podilymbus podiceps*		+
	Snowy egret	*Egretta thula*		+
	White ibis	*Eudocimus albus*		+
	Wood duck	*Aix sponsa*		+
Reptiles	Alligator	*Alligator mississippiensis*	+	+
	Common musk turtle	*Sternotheris odoratus*	+	
	Florida cooter	*Pseudemys floridana*	+	+
	Florida red-bellied cooter	*Pseudemys nelsoni*	+	+
	Florida softshell turtle	*Apalone ferox*	+	+
	Loggerhead musk turtle	*Sternotheris minor*	+	
	Snapping turtle	*Chelydra serpentina*	+	+

Table ES-5 Comparison of biomass estimates (kg live weight/ha) of fishes in the Silver River, Florida based on results of visual surveys from Odum (1957), Knight (1980), and this study. Methods used for visual surveys were different among studies. *Anguilla rostrata* was listed as *A. bostoniensis* in Odum (1957). Biomass was derived from grams dry weight per meter [2] estimates in in Odum (1957) and in Knight (1980) using standard wet weight/dry weight conversion factors.

Family	**Common Name**	**Scientific Name**	**Biomass (kg/ha)**		
			Odum	**Knight**	**This Study**
Amiidae	Bowfin	*Amia calva*		0.58	2.79
Anguillidae	American eel	*Anguilla rostrata*			0.01
Belonidae	Atlantic needlefish	*Strongylura marina*		0.01	
Catostomidae	Lake chubsucker	*Erimyzon sucetta*		1.97	1.10
Centrarchidae	Redbreast sunfish	*Lepomis auritus*			0.26
Centrarchidae	Bluegill	*Lepomis macrochirus*			10.99
Centrarchidae	Redear sunfish	*Lepomis microlophus*			2.42
Centrarchidae	Spotted sunfish	*Lepomis punctatus*			0.04
Centrarchidae	Sunfish sp.	*Lepomis sp.*	47.62	15.56	
Centrarchidae	Largemouth bass	*Micropterus salmoides*	27.14	18.65	11.10
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*		0.02	0.01
Cichlidae	Blue tilapia	*Tilapia aurea*			0.23
Clupeidae	Gizzard shad	*Dorosoma cepedianum*		66.28	2.57
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*		6.32	0.59
Cyprinodontidae	Golden topminnow	*Fundulus chrysotus*			0.00007
Cyprinodontidae	Bluefin killifish	*Lucania goodei*	18.57		0.002
Esocidae	Chain pickerel	*Esox niger*		1.34	2.61
Ictaluridae	Channel catfish	*Ictalurus punctatus*			0.03
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	1.43		2.06
Lepisosteidae	Florida gar	*Lepisosteus platyrhincus*	44.29	1.33	3.52
Mugilidae	Striped mullet	*Mugil cephalus*	266.67	2.57	1.55
Percidae	Swamp darter	*Etheostoma fusiforme*			0.00007
Poeciliidae	Gambusia sp	*Gambusia sp.*	21.43		0.00003
Poeciliidae	Least killifish	*Heterandria formosa*	3.33		0.00003
	Catfish		95.24		
	Shiners		0.95		0.01
TOTAL FISH BIOMASS			526.7	114.6	41.90

- Catfish and mullet were present in high abundance in Silver Springs fifty years ago and had largely disappeared during Knight's 1978-79 study and also were observed in low abundance in the current study.
- Knight found gizzard shad to be the most abundant fish species twenty-five years ago whereas the current study found much lower abundance of this species. Gizzard shad were not reported by Odum in the 1950s.
- Overall estimated annual average fish live-weight biomass has declined in Silver Springs since Odum's study in the early 1950s by about 96%; and by 61% since Knight's 1978-79 study. The declines in total biomass were due to large reductions in a few species (i.e., catfish, mullet, gizzard shad), but other species were found in similar abundance across the fifty-year span.

Ecological measurements made during this study resulted in the following observations:

- Annual average gross primary productivity (GPP) declined from about 15.6 grams oxygen per square meter per day (g $O_2/m^2/d$) in the 1950s and late 1970s to about 11.2 g $O_2/m^2/d$ during the current study, a decline of about 27% (Table ES-6).
- Community respiration also declined from about 14.8 g $O_2/m^2/d$ during the earlier studies to about 10.9 g $O_2/m^2/d$ during the current study, a 26% reduction.
- Resulting net community primary productivity declined from about 1.0 g $O_2/m^2/d$ in the 1950s, to 0.80 g $O_2/m^2/d$ in the late 1970s, to about 0.42 g $O_2/m^2/d$ during the current study, a decline of about 59% over the past fifty years.
- The production to respiration (P/R) ratio remained relatively consistent between the three studies, ranging from about 1.11 during Odum's study in the 1950s to about 1.06 during Knight's study in the late 1970s, and 1.06 in the current study.
- Ecological efficiency declined from about 1.09 gram of oxygen per mol (g O_2/mol) of Photosynthetically Active Radiation (PAR) during Odum's study to about 0.94 g O_2/mol of PAR during the current study, a decline of about 13%.
- Average particulate export rates were found to be 72% lower during the current study compared to data published by Odum (1957).

Although daily emergence of aquatic insects still occurs at Silver Springs year-around as previously observed by Odum (1957) and Knight (1980), measured rates of emergence were lower during the current study with an apparent decrease of about 72% since the early 1950s.

Table ES-6 Comparison of Silver Springs gross primary productivity estimates

Odum (1957)		Knight (1980)		WSI (this study)	
Date	GPP ($gO_2/m^2/d$)	Date	GPP ($gO_2/m^2/d$)	Date	GPP ($gO_2/m^2/d$)
2/19/1953	12.4	8/31/1978	19.3	Feb-04	8.2
3/7/1953	14.0	10/5/1978	13.6	Mar-04	11.4
3/25/1953	17.5	12/13/1978	7.8	Apr-04	13.2
1/7/1954	10.1	3/7/1979	10.7	May-04	13.9
5/23/1954	24.4	4/15/1979	16.8	Jun-04	12.7
7/12/1955	12.1	5/16/1979	23.4	Jul-04	13.6
8/11/1955	19.7	6/19/1979	20.7	Aug-04	12.3
		7/17/1979	11.2	Sep-04	10.9
		8/15/1979	17.1	Oct-04	11.7
				Nov-04	9.8
				Dec-04	8.5
				Jan-05	8.6
				Feb-05	11.1
				Mar-05	10.8
Average	15.7		15.6		11.2

Historical data for land use changes in the Silver Springs springshed were analyzed using aerial photo interpretation, pollutant load models, groundwater flow and pollutant attenuation models, and geographical information system tools to construct a nitrate nitrogen mass balance by decade for the past fifty years. This analysis found a close correspondence between the sum of agricultural and urban land uses (percent developed land) and the resulting predicted and actual nitrate concentrations in Silver Springs.

When these models were utilized in combination with the most realistic springshed land use projections for the year 2055, it is estimated that average nitrate concentration at Silver Springs could potentially increase to a level of 2.02 mg/l. The model predictions are presented in Table ES-7.

Developed land percentage was found to be highly positively correlated with actual nitrate concentrations while spring discharge was found to be inversely correlated with nitrate. Correlation models were also developed between nitrate concentration and spring discharge with the following dependent variables: insect emergence, macrophyte export, particulate export, fish biomass, epiphytic algal biomass, macrophyte biomass, and community metabolism metrics. These regressions were used in turn to predict

Table ES-7 Spatial Land Use Model Results for the Silver Springs Two-Year Capture Zone

Year	Observed Spring Flow	MODFLOW Simulated Spring Flow	Observed Nitrogen Load (lbs/yr)	Land Use / Land Cover Model Est N Load (lbs/yr)	Observed Spring Nitrogen Concentration (mg/L)	Land Use / Land Cover Model Estimated N Concentation (mg/l)
1957	640.0	716.5	94,416.0	399,054.10	0.10	0.38
1979	778.0	710.8	814,898.6	802,633.06	0.71	0.76
1995	720.0	708.3	955,962.0	1,036,198.93	0.90	0.99
2005	680.0	687.6	1,057,606.7	1,120,813.63	1.07	1.10
2055	NA	687.6		1,760,000.00	N/A	2.02

N Concentration Change (Model Predictions)	
1957 -1979	102.75%
1979 - 1995	29.56%
1995 - 2005	11.42%
2005 - 2055	84.00%

future structure and function of the Silver Springs ecosystem if the future land use development estimates for 2055 are indeed realized:

- This predictive model analysis suggests that there may be continuing changes to the biological integrity of this ecosystem, including increased algal biomass, reduced macrophyte biomass, reduced consumer biomass (continuing losses of pollution-intolerant insects and fish), and overall reduced ecosystem metabolism and ecological efficiency.
- Model predictions of nitrate-N concentration at the Silver Springs complex reflect current land use and development regulations. Emerging state and local regulations should attenuate the increase predicted by the model. However, continued monitoring and springs ecosystem evaluations will help in assessing the effectiveness of these regulations.

These estimates represent extrapolations well beyond existing data from Silver Springs and therefore are very tentative. However, review of data from other Florida spring systems with elevated nitrate levels, decreased discharge rates, and highly altered aquatic ecosystems dominated by filamentous algae and devoid of normal spring water clarity and faunal communities provide some level of validation of these projections. A comparison of nitrate-N concentrations in one hundred thirty Florida reference springs, including Silver Springs, is presented in Figure ES-6.

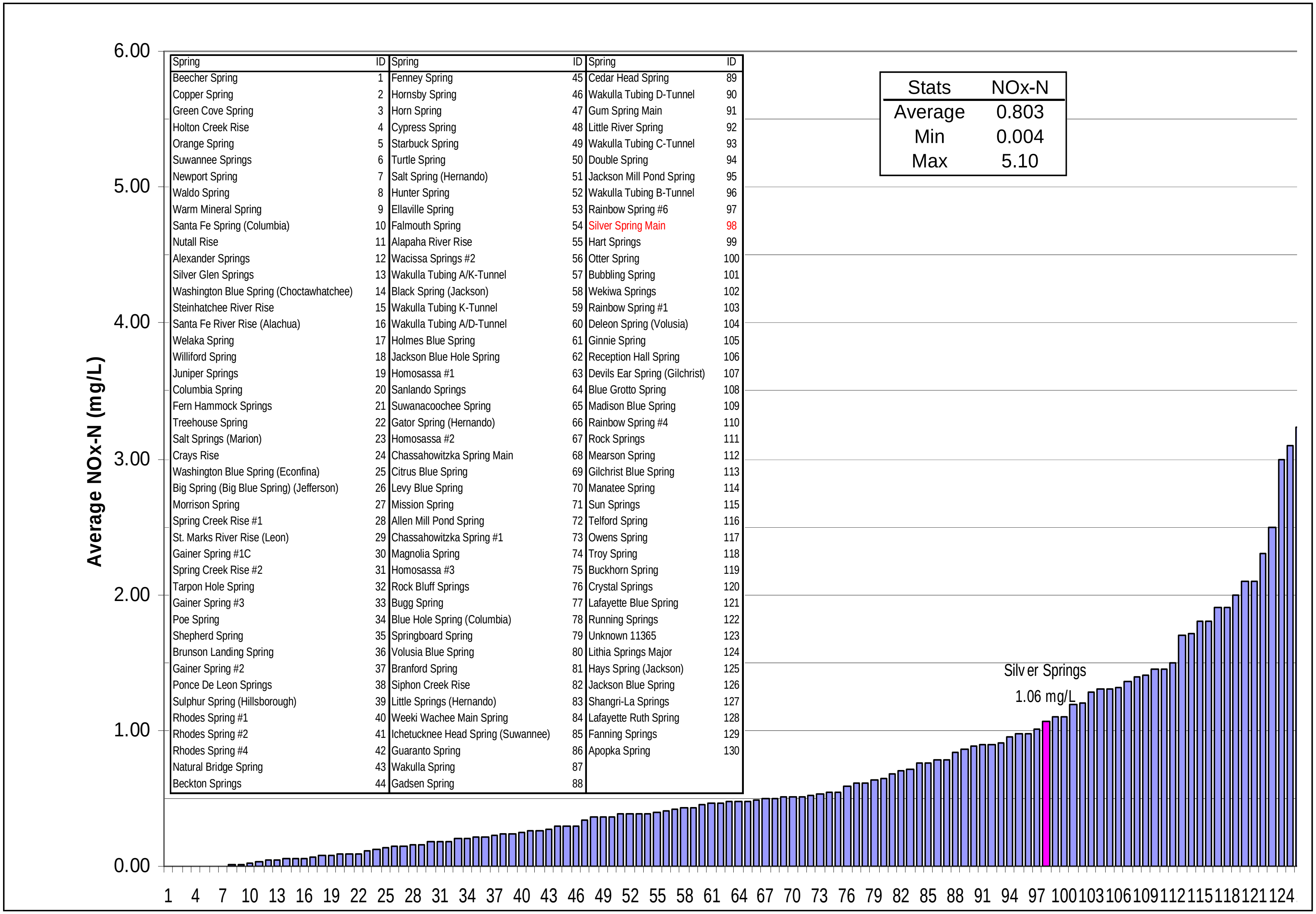

Figure ES-6 Average NOx-N concentrations for Florida Springs with a comparison to Silver Springs in Marion County

SUGGESTED FUTURE RESEARCH PRIORITIES

The fifty-year Silver Springs retrospective study has illustrated historic and possible future changes in the Silver Springs ecosystem as a result of land use alteration in the springshed. As with most studies, this one resulted in a realization that historic baseline data are not adequate to answer all of the pressing questions concerning the ecological health of Silver Springs. These findings lead to the following suggested research priorities:

- Collect additional local hydrological and hydraulic data to support a finer-grid model design to improve simulation performance.
- Collect samples from all sites where thermal anomalies have been detected and analyze them for strontium isotopes. The results may help in the identification of areas of diffuse flow and in confirming that the discharge is from the Floridan Aquifer.
- When groundwater flow modeling is performed, incorporate the information from the newly-discovered discharge sites within the Silver River, as they affect the configuration of the potentiometric surface and flow paths.
- Collect and analyze water quality samples, particularly for dissolved oxygen and nitrates, on a periodic schedule, from all the vent groups in the upper 1,200 m of the Silver River.
- Compare water quality results from each vent group with wells in the Silver Springs springshed. The results may aid in the process of identifying areas that contribute nitrates to the springs.
- Perform discharge measurements at each vent group in the upper 1,200 m of the Silver River so that a more detailed evaluation of loading estimates can be performed.
- Use divers to perform field investigations of thermal anomalies in order to ground truth the location and physical characteristics of discharge points downstream of the 1,200-m station.
- Perform flow measurements to assess the volume of water being contributed to the Silver River from the thermal anomalies downstream of the 1,200-m station.
- Collect and analyze water quality samples both upstream and downstream of the thermal anomalies. This will help in assessing the impact of the additional flow.
- Apply the estimated spring discharge rates from 1957, 1979, 1995 and 2025 with the estimated nutrient loading rates to calculate nutrient concentrations in spring discharge. This will allow researchers to assess the impact of springshed land use changes on the nutrient concentration of the discharge at Silver Springs.
- With regard to future use of the LULC data sets, restrict the development of the LULC dataset by utilizing contemporary data, beginning with the development of parcel

databases around 1990. This data, combined with improved infrared and color imagery, will greatly increase the relative accuracy in the LULC classification and the associated loading rates.

- Determine the most accurate estimates of nitrogen loading per LULC category.
- Install permanent *in situ* data loggers (minimum of three to five) at multiple locations within the Silver River to provide a continuous record of changing water quality conditions, including temperature, dissolved oxygen (concentration and percent saturation), pH, and specific conductance; estimate and tabulate ecosystem metabolism daily and release the results in an annual report.
- Routinely quantify insect emergence rates and diversity.
- Conduct comprehensive plant community studies in the Silver River on a three-to-five-year schedule.
- Quantify floating plant and particulate export over daily and seasonal time frames.
- Determine the role nutrient limitation plays in the growth of epiphytes and benthic algae at Silver Springs. The central question to be answered is whether future increases or decreases of nutrient levels will result in responses by the primary producer community.
- Determine the impact of changes in light availability on the structure and function of the Silver Springs ecosystem. Light availability can be affected by seasonal patterns of incident irradiance, canopy cover and floating plant communities, and may have a role in the changes noted at Silver Springs.
- Conduct a comprehensive study on the Back Channel (added to the spring run in the late 1970s) in order to determine its impact on estimates of gross primary production (GPP), community respiration (CR) and net primary production (NPP).
- Determine the respiratory and photosynthetic potentials of epiphyte and benthic mat communities of different thicknesses. Current estimates of biomass for these two components may not be good indicators of their contributions to GPP, CR and NPP.
- Continue to monitor fish, birds, and reptiles in Silver Springs on a monthly basis (twelve events per year) for at least one year during each five-year period for the foreseeable future.
- Schedule monitoring events throughout the year to elucidate seasonal trends within the year.
- Monitor alligators at night during warm months (April-September) and in the day during cold months (October-March) for a twelve-month period during one year of each five-year period.

- Conduct a study for channel catfish. Channel catfish should be experimentally radio-tagged and placed in the Silver River to monitor habitat use and movement. Such a study would reveal factors influencing the decline in channel catfish in the system.
- Inventory human use activities on a routine basis (including number of glass-bottom and jungle boat trips per day, wildlife feeding activities, pleasure boating use of the river, etc.).
- Evaluate and document stormwater effects on the Silver River by conducting a watershed evaluation and focused storm sampling of flows and loads.

RECOMMENDATIONS

- It is recommended that the State of Florida set up a permanent funding source for the establishment of a "Florida Springs Aquatic Ecology Research Center" (FSAERC) at Silver Springs within the Silver River State Park in order to develop a consistent base of scientific knowledge for this and other Florida first magnitude spring ecosystems. Many of the research priorities identified in this document could be conducted under the direction of the FSAERC.
- It is recommended that Marion County explore the development of a springs protection plan that addresses such components as land development regulations and land acquisition, along with other groundwater and spring protection measures in order to halt and, if possible, reverse the observed increases in nitrate nitrogen concentrations in Silver Springs.
- It is recommended that the FDEP direct SJRWMD to undertake a project to develop Pollutant Load Reduction Goals (PLRGs) for nitrogen in Silver Springs and the Silver River. These PLRGs should then form the basis for a Total Maximum Daily Load (TMDL) nitrogen limit for the spring and spring run to be developed by the FDEP. TMDLs will provide a basis for the State and Marion County to enforce stringent nitrogen mass loading limits on all existing and future point and non-point sources in the Silver Springs springshed.

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Acknowledgements

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1.0 Introduction and Purpose

1.1 Purpose and Significance

Springs are an important water resource in Florida. Some springs are the source for rivers and maintain river flows, especially during dry periods. They provide a unique habitat for a large, diverse environmental community and a location for human recreational activities. Some springs contribute significantly to local economic activity by creating tourism-related jobs.

The largest spring in the St. Johns River Water Management District (SJRWMD) is Silver Springs. It is a first-magnitude spring and forms the headwaters of the Silver River, which eventually becomes part of the Ocklawaha River. It is also the center of the Silver Springs tourist attraction, which provides glass-bottom boat rides and has long been the setting for movies and television shows. Silver Springs is the largest spring in Florida based on discharge (Rosenau *et al.* 1977) and is also likely the largest limestone spring in the United States (Meinzer 1927; Rosenau *et al.* 1977).

The SJRWMD, in collaboration with Wetland Solutions Inc. (WSI) and the University of Florida Department of Fisheries and Aquatic Sciences (UFDFAS) conducted an evaluation of the ecological health of Silver Springs located in Marion County, Florida from February 2004 through March 2005. This work was a collaborative project between the SJRWMD and the Florida Department of Environmental Protection (FDEP) under contract as part of the Florida Springs Initiative.

Silver Springs is of particular importance in Florida because it is considered to be the largest of Florida's first magnitude springs (Scott *et al.* 2004; Scott *et al.* 2002; Osburn *et al*. 2002; Rosenau *et al.* 1977), discharging approximately 1.9 million cubic meters per day (hm^3/d) (514 million gallons per day [mgd]) from the Floridan Aquifer (Osburn *et al*. 2002). Silver Springs is important not only as an environmental resource, but also as a tourist attraction. The Silver Springs attraction, at the headwaters of the Silver River, has been a popular tourist attraction for over one hundred years (Crum 1954; Martin 1966) and continues to receive an estimated million-plus visitors each year, generating an estimated annual economic impact of about $65 million (Bonn 2004). Also, many additional people make the trip upriver by motorboat, kayak, or canoe to catch a glimpse of the crystal-clear springs, their wildlife, and the mystique of the glass-bottom boats seemingly floating in the air.

In spite of its very high and relatively constant flow rate, Silver Springs is undergoing ecological changes (Knight 1980; 1983). Water quality studies have documented a significant trend of increasing nitrate nitrogen (NO_3-N) and chloride concentrations in Silver Springs (Osburn *et al.*

2002). Based on anecdotal information from long-term residents, unsightly blooms of filamentous algae that cover the submerged aquatic strap-leaf sagittaria (*Sagittaria kurziana*) have apparently been increasing in the Main Spring Boil (Mammoth Spring), the area with highest tourist use. The source of the increasing dissolved nitrogen is assumed to be historically-increasing applications of fertilizer, greater agricultural use, and increasing numbers of septic systems in the springshed during the past few decades (Phelps 2004; FDEP 2000; Florida Springs Task Force 2000). The high public use of Silver Springs as well as the increasing awareness of the fragility of Florida's spring ecosystems in general has created heightened awareness of these apparent changes. Thus, development and groundwater withdrawal in the springshed are all of particular concern to the fate of this truly magnificent spring/river system.

The Fifty-Year Retrospective Study of the Ecology of Silver Springs was intended to provide an assessment of land use and water quality changes in Silver Springs and development of cause-and-effect relationships, if any, to the spring's ecology. The scope of this study was to review and summarize the data that are currently available for the Silver River, collect additional data as needed for comparison to historical data, and develop linkages between springshed land use changes and the ecology of Silver Springs. This study was explicitly limited in spatial extent to the upper 1,200 meters (m) (3/4 miles) of the Silver Springs run beginning at the Main Spring Boil and ending at the 1,200-m station. This area includes all of the major spring boils and was the focus of the work conducted by Drs. Odum and Knight for their biological and ecosystem metabolism studies.

The Silver Springs Fifty-Year Retrospective Study project was completed in two phases. The first phase focused on collection, review, and summarization of existing published and unpublished information and on collection of additional field data over a five-month period from February through June 2004. An interim report was prepared to summarize preliminary findings from this Phase 1 period (SJRWMD *et al.* 2004). The second project phase continued field measurements over an additional seven-month period to complete an annual cycle and then draw connections between current surrounding land use and the ecosystem's health. The second project phase culminated with the preparation of this final summary report.

The project team included the following organizations and principal investigators:

- St. Johns River Water Management District – Doug Munch (Project Manager and Senior Hydrogeologist)
- Wetland Solutions, Inc. – Robert Knight (Co-Principal Investigator and Systems Ecologist)
- University of Florida DFAS – Ed Phlips (Co-Principal Investigator and Aquatic Botanist)

- University of Florida DFAS – Mike Allen (Co-Principal Investigator and Fisheries Ecologist)

Numerous project assistants and graduate students were also active in the successful completion of this project.

1.2 A Half Century of Ecosystem Monitoring

Silver Springs offers a unique historical perspective on spring ecology and the effects of surrounding urbanization. This spring was the focal point of an extensive effort of data collection and analysis of springs throughout Florida conducted by Dr. Howard Tom Odum, a young faculty member at the University of Florida in the 1950s. Dr. Odum's springs research lasted for a period of five years and he published information on a total of eleven Florida springs in addition to Silver Springs. While Odum's published papers from this period of his career compare and contrast the ecological structure and function of a variety of spring-fed rivers and other clear-water habitats such as coral reefs and shallow coastal waters, his greatest emphasis was placed on Silver Springs. H.T. Odum's landmark paper on the research conducted in cooperation with numerous colleagues on the energy flows and biological hierarchy of Silver Springs was published in *Ecological Monographs* (Odum 1957). Odum's team studied water quality, productivity, ecosystem structure, and energy flows for the spring system.

H.T. Odum returned to the University of Florida in 1970 to finish out his long and productive career in science. This gave him the opportunity to revisit the ecology of Silver Springs through a series of field trips associated with his ecology courses. This renewed interest in Silver Springs and its apparent chemostatic nature was culminated by completion of a second ecological study of Silver Springs by Robert L. Knight for a doctoral dissertation under the supervision of H.T. Odum in the late 1970s. Knight (1980, 1983) re-examined the system metabolism, productivity, and consumer control structure of Silver Springs approximately twenty-five years following the earlier work by Odum. While Knight used the methods originally employed by Odum for measurement of the overall stream metabolism and estimation of fish populations in the river, he also conducted manipulative mesocosm experiments in the Silver River to test theories on the importance of consumers for ecosystem control and maintenance.

While there are published papers that mention a variety of Florida springs from a historical perspective, the research at Silver Springs by Odum, Knight, and numerous other researchers provides the most thorough overview and detail of a spring's ecology reported to date in the scientific literature. For this reason it is possible to utilize quantitative data from studies conducted during the early 1950s as a baseline or benchmark to compare to existing conditions. A fifty-year time interval has occurred since Dr. Odum studied Silver Springs, offering a long-enough historical perspective to possibly detect environmental changes that might be difficult to recognize over shorter time intervals.

1.3 Linkages between Land Use Practices and Spring Ecology

Silver Springs and the Silver River are products of their environment. Like a gem in a fancy gold setting, Silver Springs can best be evaluated by considering its surroundings and its relationship with its immediate environment. The life blood of the Silver River is the groundwater issuing from the Floridan Aquifer at Mammoth Springs and the rest of the Silver Springs Group downstream. The quantity and quality of this groundwater is truly the basis for most of the ecology of Silver Springs. In recent years the extent of the "springshed," the area of land that constitutes the majority of the source of water to the aquifer that feeds this spring, has been delineated (Figure 1-1). This springshed encompasses approximately 3,100 km^2 (768,000 ac) of land in Marion, Alachua, Putnam, Lake and Sumter Counties in central Florida (Phelps 2004).

1.3.1 Silver Springs Conceptual Nitrogen Landscape Model

Figure 1-2 presents a highly simplified conceptual model of the environment surrounding and influencing Silver Springs. The symbolic environmental modeling language of H.T. Odum used in this diagram is explained in Appendix A. The model boundary in Figure 1-2 encompasses the active springshed as well as the upper 1,200-m portion of the Silver River. Lands in the springshed are defined as undeveloped or developed to designate the intensity of human alterations. The general trend in this area of Florida is a rapid increase in commercial and residential development with conversion of relatively passive agricultural and forested uplands to paved and landscaped environments. The major "forcing functions," (external factors that influence the modeled area) of importance are sunlight, rain, and economic "goods & services" that are active in landscape modification from rural to urban.

1.3.2 Silver Springs Ecosystem Model

Figure 1-3 presents a close-up-view conceptual model of Silver Springs and the upper 1,200-m reach of the Silver River using the Odum modeling language. The principal features of this ecosystem that are considered important enough to illustrate in this model are the limestone spring basin that is constantly eroding on a geological time scale, the water that supports the aquatic environment, actively-growing submerged aquatic plants and algae, dead plant and animal material known as "detritus", and the various trophic levels of consumers including herbivores, primary, and secondary carnivores such as fish and alligators. The glass-bottom and

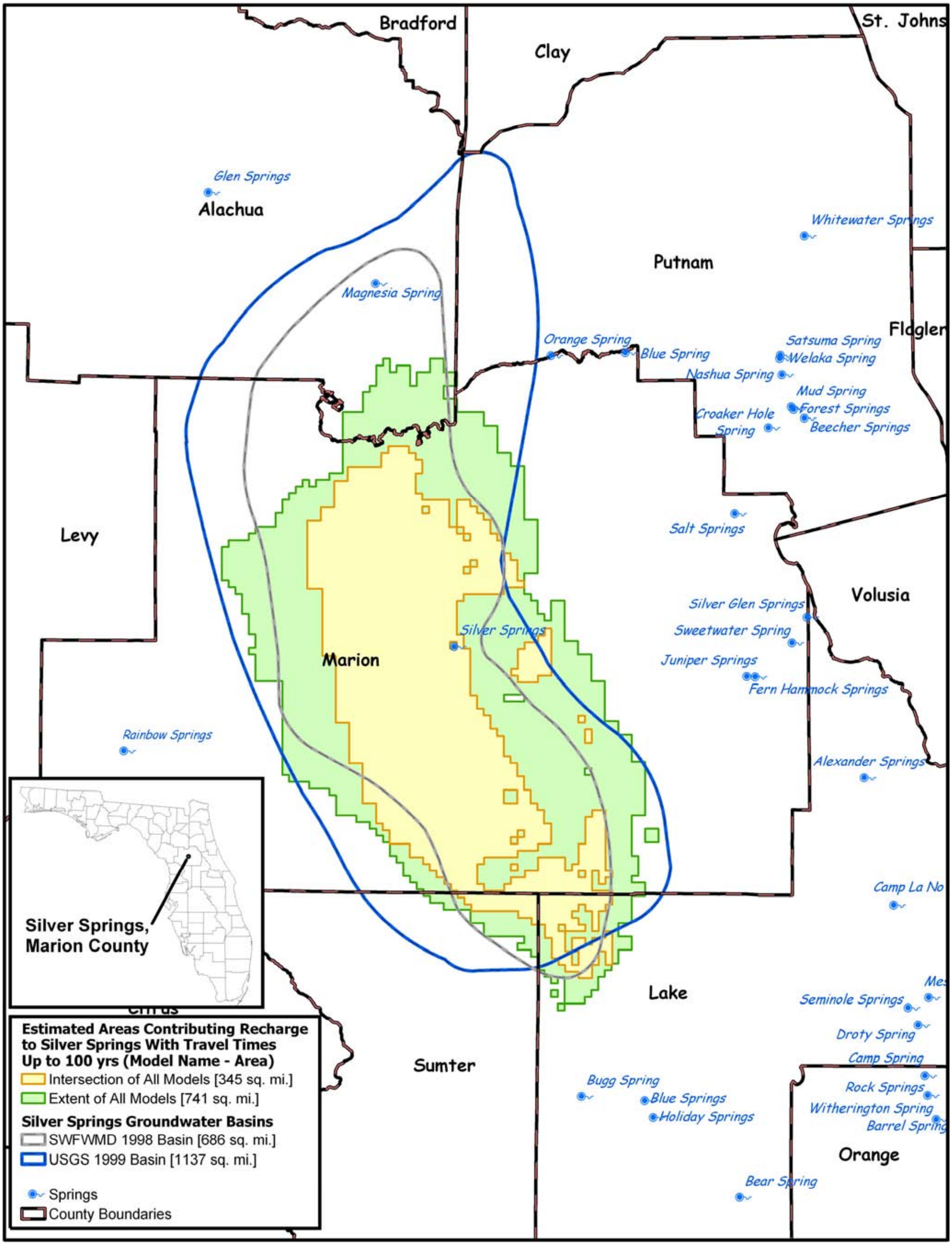


Figure 1-1 Silver Springs basin and areas contributing recharge (SJRWMD 2004)

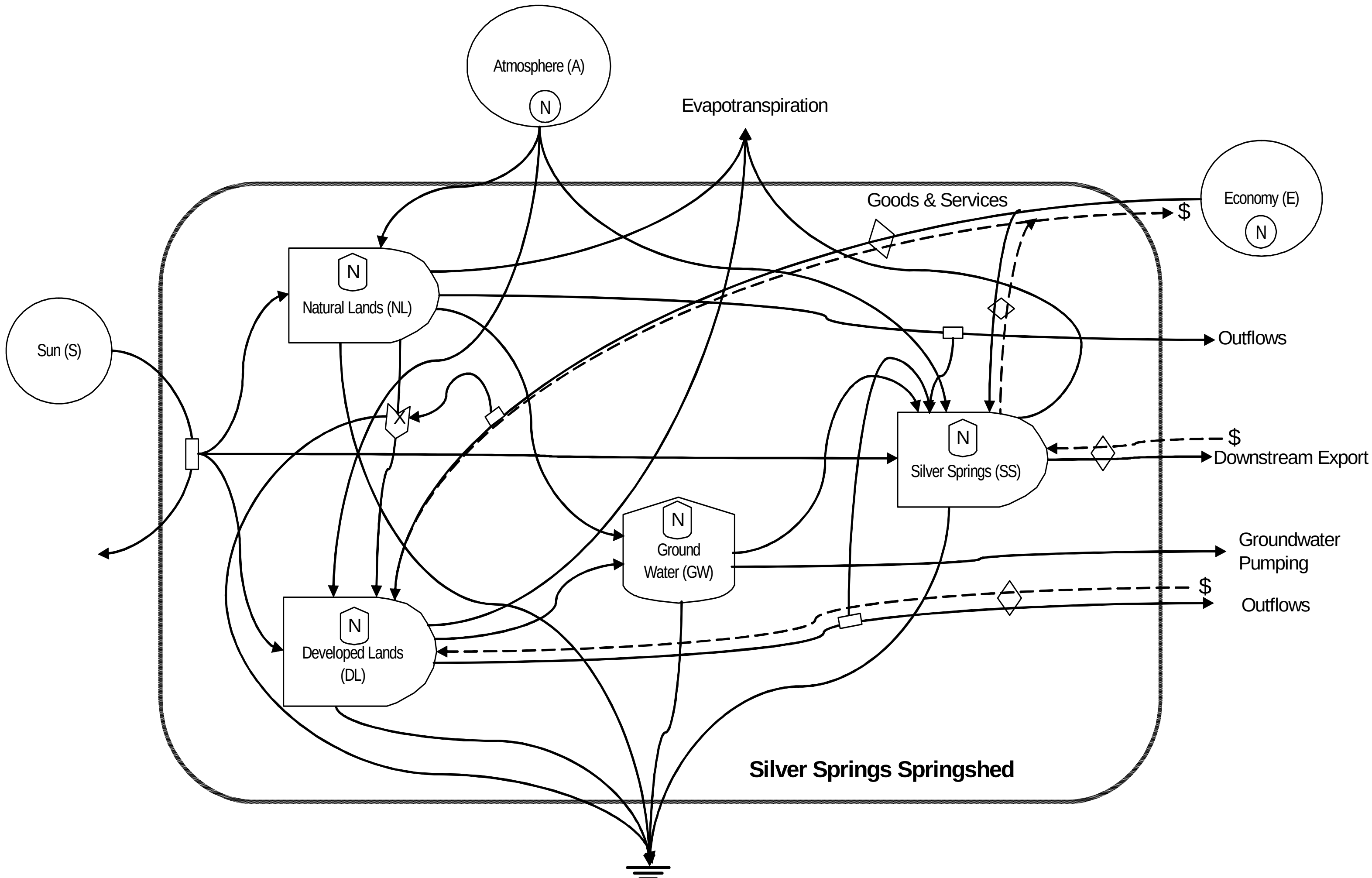


Figure 1-2 Silver Springs conceptual nitrogen landscape model

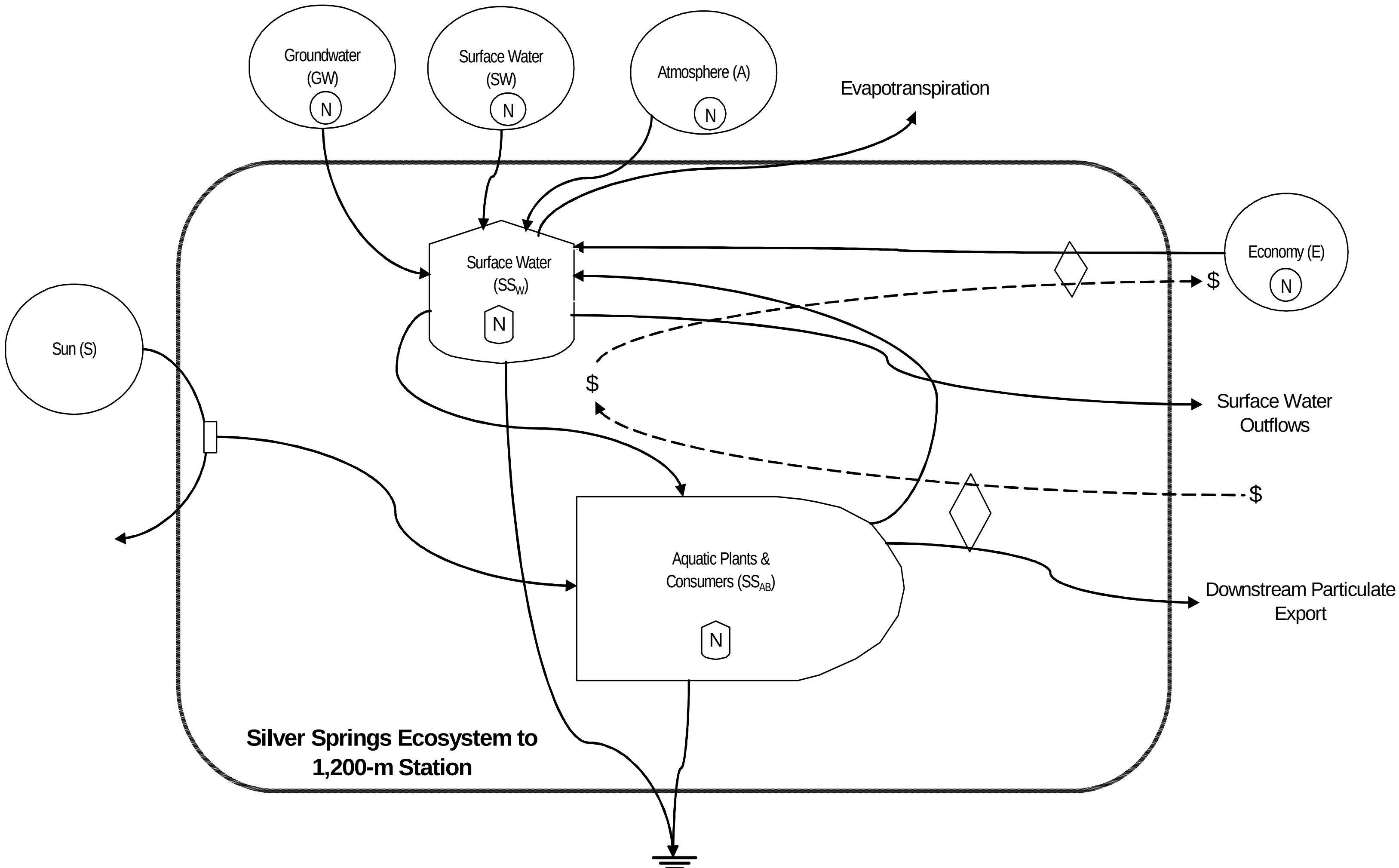


Figure 1-3 Silver Springs ecosystem model (Main Spring Boil to 1,200-m Station)

Jungle Boats operated for the tourists have been an important part of the spring ecosystem for over one hundred years.

1.3.3 Links Between Land Use and the Quantity and Quality of Spring Discharge

As illustrated in the two models just described, the quantity of water discharging at Silver Springs is entirely dependent upon the net water balance within this springshed. This balance is comprised of rainfall, evapotranspiration, storage, and groundwater losses. As land uses change in the springshed and as various portions of this water balance shift due to natural or human-induced causes, the amount of water discharged from the Floridan Aquifer to the Silver Springs Group varies. Increased groundwater pumping and inter-basin water transfers have the potential to reduce the daily discharge at Silver Springs. Conversions of rural to developed land have the potential to increase impervious areas, resulting in increased runoff to surface-water features and increased water losses to evapotranspiration. This effect can also result in a decrease in associated spring flows.

The quality of the water discharged from the Floridan Aquifer to the Silver Springs Group is likewise totally affected by chemical mass balances within the springshed. Nutrients such as nitrogen and phosphorus that are added to developed landscapes and not fully assimilated on site eventually find their way to the aquifer and, if conservative from the standpoint of minimal transformation and degradation, they ultimately are released from the aquifer at Silver Springs. As more fully described in the following pages, continuing work has found that oxidized forms of nitrogen (nitrate and nitrite) are especially mobile in area soils and in the groundwater (Osburn *et al.* 2002; Phelps 2004) and their concentrations have risen dramatically over the past century in groundwater wells near Silver Springs and in Silver Springs itself. This increase in dissolved nitrogen is clearly linked to anthropogenic nitrogen sources from agricultural and developed landscapes.

The linkages between Silver Springs and the surrounding springshed have been identified prior to this study. The purpose of the present study was: to attempt to detect any significant ecological effects of these linkages as they relate to ongoing land use changes; and to provide a preliminary basis for identifying thresholds on land use changes that will not result in unacceptable ecological changes to Silver Springs.

2.0 The Silver Springs Ecosystem

2.1 Geographical Setting

Silver Springs is Florida's largest freshwater spring. It is located in Marion County in northern central Florida (Figure 2-1). The group of springs that form the Silver River discharge an estimated average of 1.9 to 2.0 hm^3/d (514 to 530 million gallons per day [mgd]) from the Floridan Aquifer (Rosenau *et al.* 1977; Scott *et al.* 2002; Scott *et al.* 2004; Osburn *et al.* 2002). The largest of these is Mammoth Spring, located at the Main Spring Boil at the top of the Silver River, which discharges approximately half of the total flow (Ferguson *et al.* 1947). All of the major spring vents are thought to be included in the upper 1,200 m of the Silver River. Many of the spring vents have been named and these common names are used in this report when available (Figure 2-2).

The upper 1,200 m of the Silver River currently has a wetted surface area of about 116,750 m^2 (Figure 2-3). This area includes about 79,075 m^2 in the Main Spring Boil and spring run and an additional area of about 37,675 m^2 in a man-made boat basin and in the Back Channel. A 10,125 m^2 portion of the Back Channel was present in the early 1950s when H.T. Odum conducted his ecosystem studies at Silver Springs. He noted that it included several boat houses, was largely shaded by overhanging trees, had a different variety of insects and algae, and had an average current velocity significantly slower (0.14 m/s) compared to the average current he estimated in the main channel of the Silver River (0.21 m/s). A review of historic aerial photographs of Silver Springs indicates that additional dredging occurred sometime around 1972 with construction of a large boat basin to provide covered storage of the glass-bottom boats and other equipment related to the tourist attraction. Also the Back Channel was extended and connected to the Silver River further downstream by about 1979. The overall area of the Back Channel and boat basin increased from the 10,125 m^2 in Odum's time to about 37,675 m^2 by the time of Knight's research in 1979 and 1980. This configuration has not changed appreciably during the past twenty-five years except that populations of penned large exotic animals have recently been removed from the banks of the Back Channel.

A bathymetric map of the upper 1,200-m reach of the Silver River was prepared for the current study by the UFDFAS team (Figure 2-4). In addition a total of four transects were surveyed to develop stream cross-sections in the project area by the SJRWMD for a related project (Figure 2-5). Data from these two studies indicate that the mean depth of the Main Spring Boil/Spring Run area down to the 1,200-m station is about 2.38 m over the period-of-record (POR) data for the river and that the mean volume is about 194,000 m^3. The Boat Basin and Back Channel area

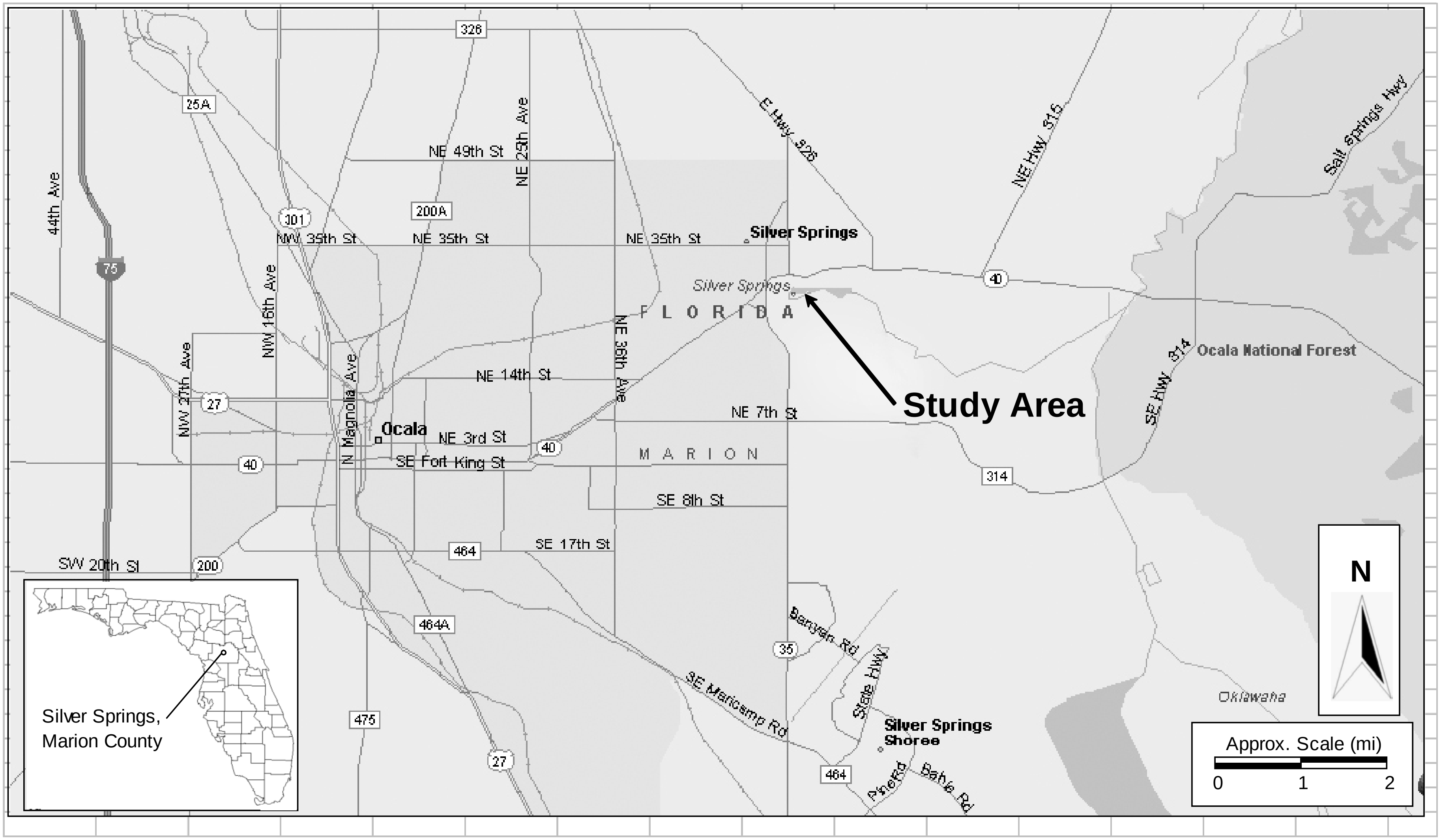


Figure 2-1 Location map for the Silver Springs study site in Marion County, Florida

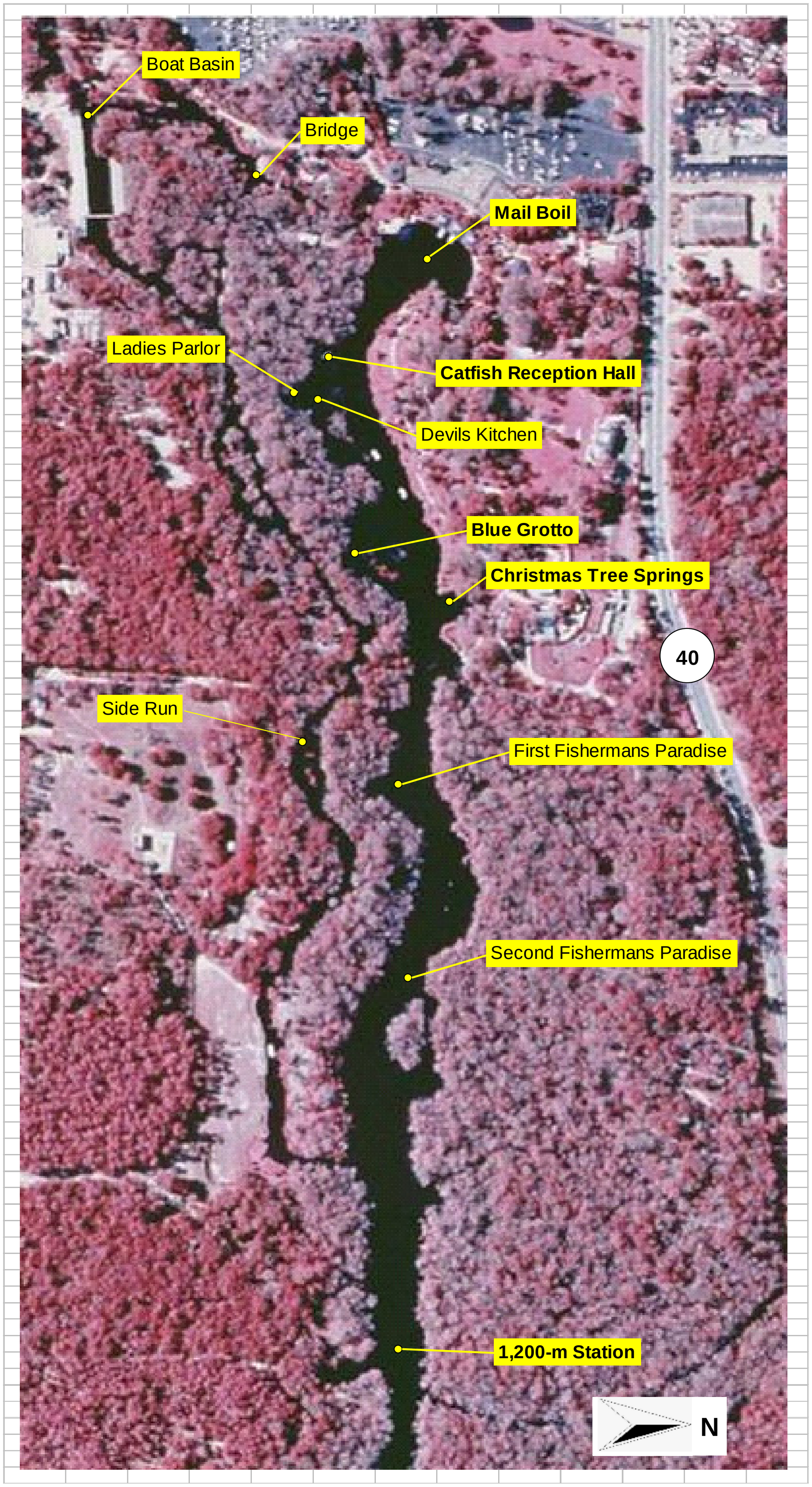


Figure 2-2 Some of the named sites in the Silver Springs 50-year retrospective study area

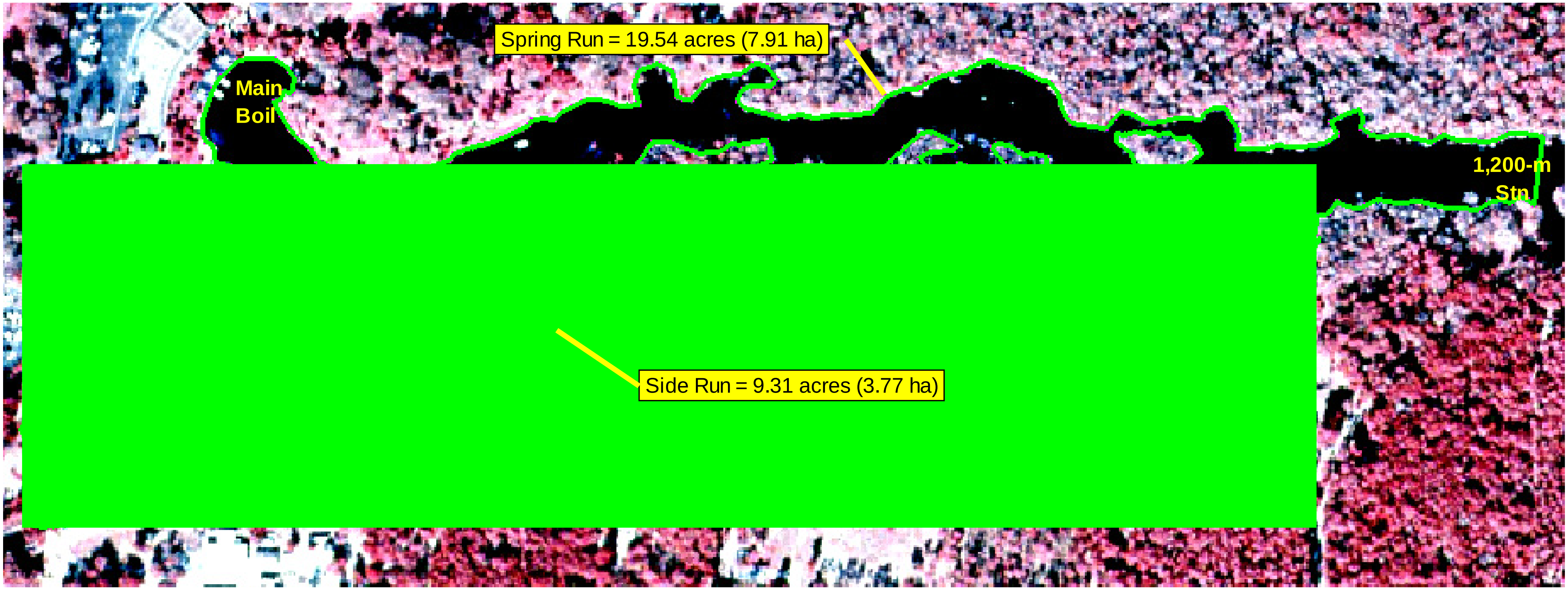


Figure 2-3 Estimated wetted area in the upper 1,200 m of the Silver River and in the parallel Side Run (Back Channel)

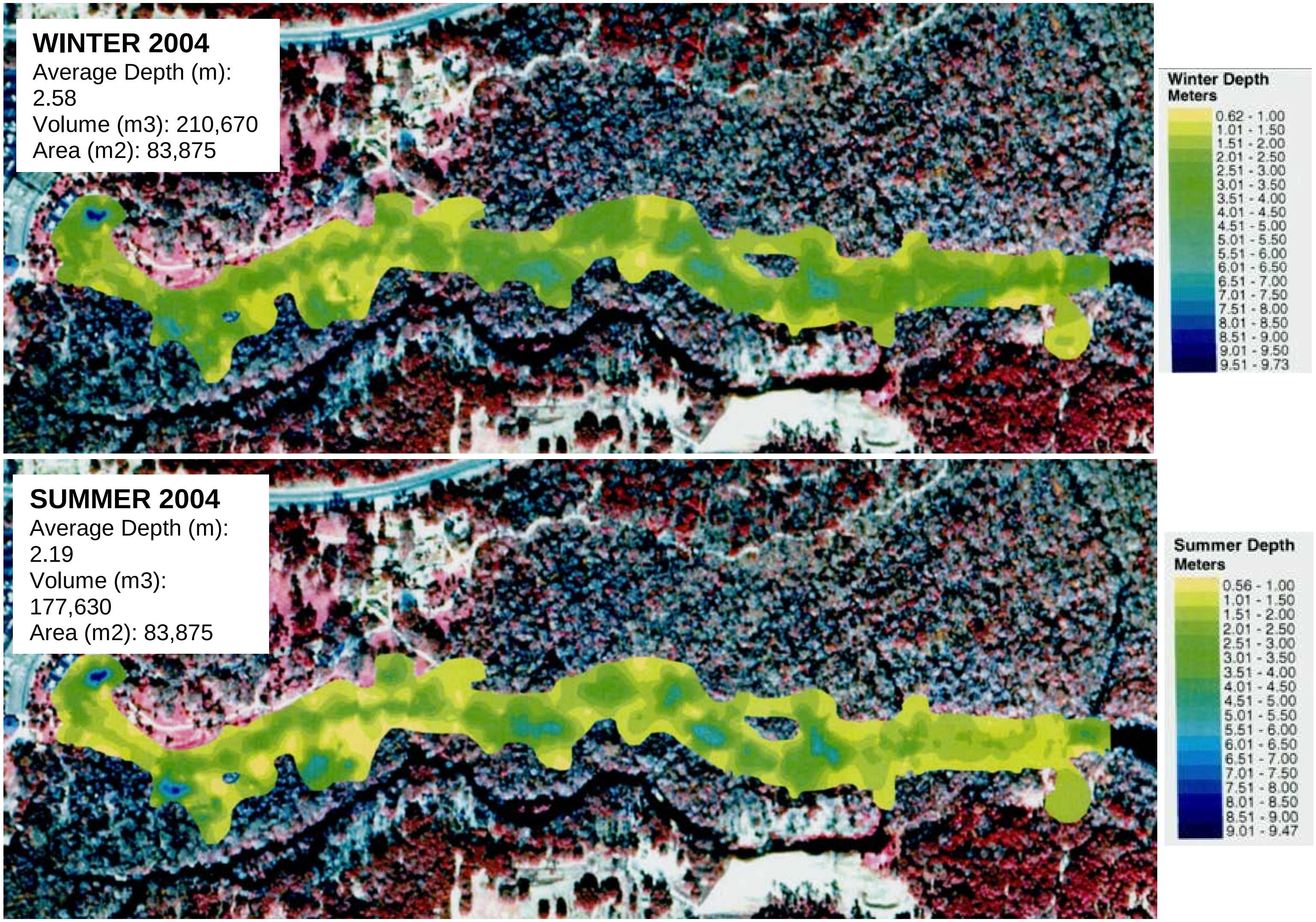


Figure 2-4 Silver River winter and summer bathymetric maps for the upper 1,200 meters (UFDFAS)

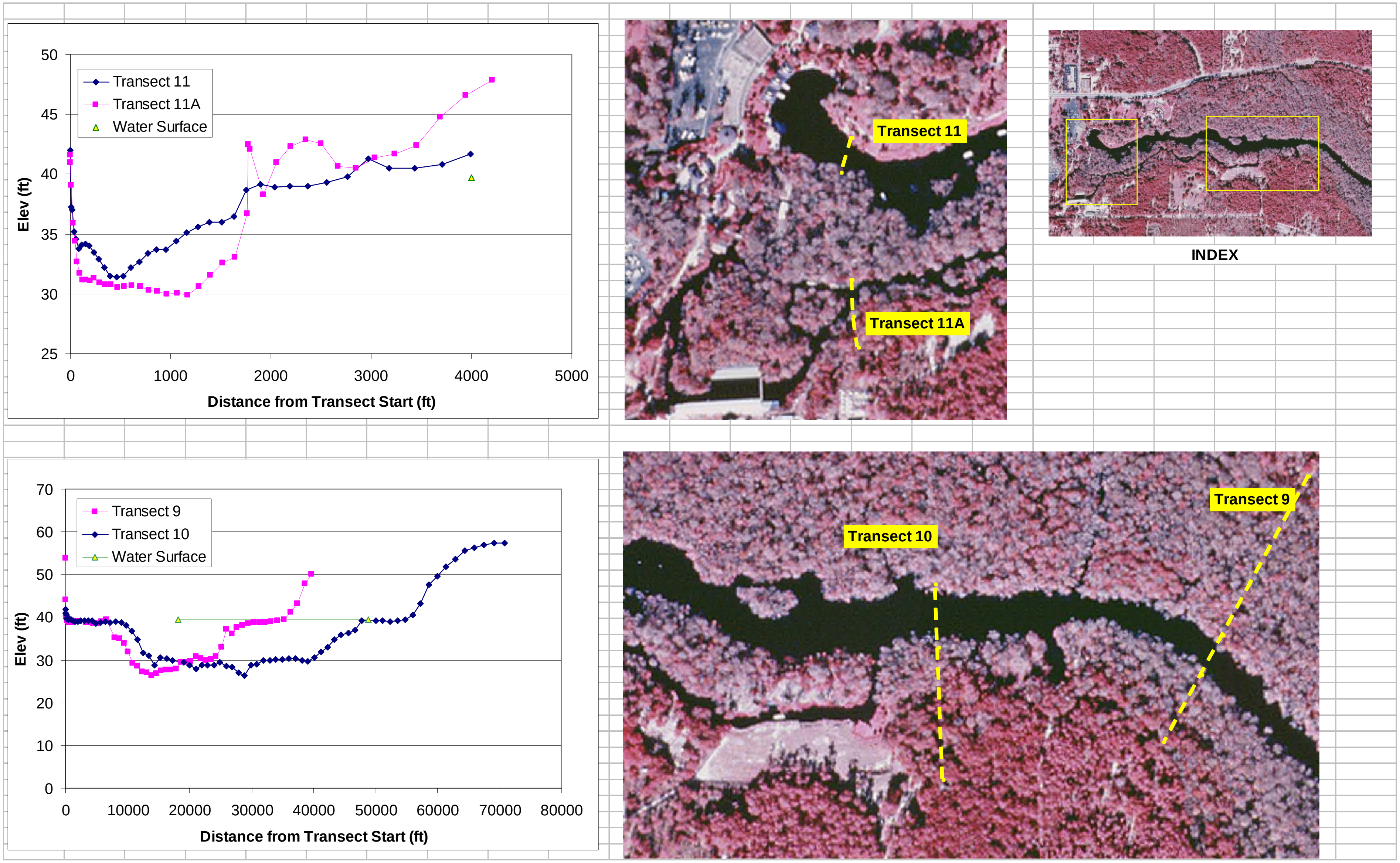


Figure 2-5 Minimum flow and level transects in the Silver Springs 50-year retrospective study area (SJRWMD data)

has an estimated mean depth of about 1.3 m and an estimated mean volume of about 48,000 m^3. The methods used to develop the bathymetric maps are described in Appendix B.

The upper 1,200 m of the Silver River is also the area that is devoted to the Silver Springs attraction. In the upper area (first 300 m) visitors ride the famous battery-powered glass-bottom boats in order to enjoy the clarity of the spring run (Figure 2-6). Additional trips are offered on battery-powered Jungle Boats (Figure 2-6) down to a wildlife viewing station (Lost River Outpost) located just downstream of the 1,200-m station and adjacent to the new USGS gaging station (Figure 2-7). In the upper 1,200 m of the river no swimming is currently allowed. Swimming in the vicinity of the Main Spring Boil was allowed during Odum's time. Access to the head spring is also possible via kayak, canoe, or powerboat from a public boat ramp located approximately 8.2 km (5.1 mi) downstream on the Silver River and just upstream of its confluence with the Oklawaha River.

2.2 Cultural Setting

One of the most complete records of the history of Silver Springs is included in the book titled *Eternal Spring: Man's 10,000 Years of History at Florida's Silver Springs* (Martin 1969). Martin's book details much of the history of Silver Springs, including early accounts of visitors who made the difficult journey to the spring. Martin also describes the Main Spring Boil as having two separate sources. Jack McEarchern, a professional diver at Silver Springs, noted this after finding a temperature difference of nearly ten degrees between the two outlets. The water is supplied from five major "rivers" according to McEarchern. The author also mentioned Bruce Mozert, a prominent photographer at Silver Springs known for his underwater photography of the spring. Mozert documented many of the wonders of the spring run including the fish, divers, fossils, and the clarity of the spring water.

2.2.1 Prior to 1900

The fossil and artifact history of Silver Springs are also described by Martin. Ben Waller, a well-known underwater amateur archaeologist, along with Bill Franklin discovered a mammoth that was buried in the channel of the river. The skeleton was later exhumed by Waller, Franklin, and Robert Allen (Figure 2-8). Archaeological resources in and adjacent to the Silver River were also described by Neill (1958, 1964, and 1971). Neill (1958) describes a Paleolithic Period stratified site on the south side of the spring run about 1,000 m downstream of the Main Spring Boil. A number of the earliest known artifacts from North America, Clovis projectile points, which are often found in association with extinct mega fauna such as mastodon and mammoth remains, have been found in and adjacent to Silver Springs (Figure 2-9). In his 1971 paper, Neill

Figure 2-6 Typical glass-bottom and jungle boats used by the Silver Springs tourist attraction

Figure 2-7 USGS stream gaging station located just downstream of the Silver River 1,200-m station

Figure 2-8 Divers recovering mammoth remains in the Silver River in the 1960s

Figure 2-9 Silver Springs dive instructor and amateur archaeologist Ben Waller with a fluted projectile point found underwater in the Silver River

described two late Paleolithic artifacts recovered from the inside of the Cavern site within the Mammoth Spring (or Main Spring Boil) cavern. He indicated that it is thought that during that late Pleistocene period when humans were first in evidence in North America, sea level and the water table in the vicinity of Silver Springs were low enough to expose this cave for direct human habitation. Fossils of extinct mega fauna such as the giant ground sloth were also recovered from this cave. According to early records the Indians regarded Silver Springs as the home of their "water gods." The area was regarded as sacred because of the abundance of food and fresh water. The Seminole Indians later settled around Silver Springs. The waters were used for hunting, fishing, recreation, and as a sacred shrine.

Silver Springs later came into the ownership of James Rogers who purchased eighty acres surrounding the spring from the United States government for $1.25 per acre. The Indians who lived in the area were reportedly evicted from Silver Springs at that time. One of the earliest written accounts was by Lady Amelia Murray, lady-in-waiting to Queen Victoria, who was appalled by the "primitive accommodations" in Ocala and Silver Springs. Hubbard L. Hart is described as the man who "put Silver Springs on the world tourist map." Hart began the first steamboat lines along the Ocklawaha River to Silver Springs in the early 1800s (Figure 2-10). The boats attracted many tourists to the spring. Word of mouth traveled quickly and Hart had a difficult time trying to accommodate the travelers who came to visit the springs. However, tourism temporarily ended with the beginning of the Civil War in 1861. Both of the steamboats were seized for use by the Confederacy in 1861 for transporting supplies. After the Civil War Hart resumed his steamboat line to Silver Springs, including their use for clearing the blockades put in place on the Ocklawaha River by Union troops.

2.2.2 After 1900

Tourism continued to do well into the early 1900s when the steamboats began to disappear. In the 1920s Silver Springs began to be marketed as a tourist attraction unlike any other. A road was built between Ocala and Silver Springs in the 1920s and a large hotel and bathhouse were constructed at the Main Spring Boil. Phillip Morrell is credited with inventing the glass-bottom boat. The glass-bottom boat ride has since become a staple, and is in place to this day in the upper Silver Springs run. Ownership of the spring changed hands in the late 1860s when the upper spring area was purchased by Captain Samuel O. Howse, who held ownership until 1898 when the property was sold to H.L. Anderson. In 1909 the property once again changed hands, and was purchased by C. Carmichael for less than $3,000. In the same year that the first road was constructed, the first motion picture was also filmed at Silver Springs ("The Seven Swans," 1916).

Figure 2-10 Steamboat Okeehumkee that traveled on the Silver River in the 1800s (Florida Archives)

In 1924 W.C. Ray and Captain W. M. Davidson leased the springs for fifty years. They greatly improved the springs' tourist attraction by building glass-bottom boats, which they outfitted with electric motors in 1932, replacing the earlier gas motors. Tourism at Silver Springs sky-rocketed as new forms of advertising were used to promote the springs (Figure 2-11). The movie industry also began to make movies using the beautiful scenery, and ultimately made underwater movies at the spring. At this time Ross Allen and Newton Perry gained popularity for wrestling with alligators and snakes underwater (Figure 2-12). In 1929 the biggest break for Silver Springs came with the first "talkie" movie filmed there. In the 1930s several of the Tarzan movies featuring Johnny Weissmuller and Maureen O'Sullivan made their home at Silver Springs (Figure 2-13). The extremely clear water made the filming of underwater exploits a possibility that thrilled audiences. Six of the Tarzan films were made in Silver Springs, and after completion of the last, some monkeys escaped from the set and made their residence in the woods adjacent to Silver Springs. Many movies were shot at Silver Springs and one movie even

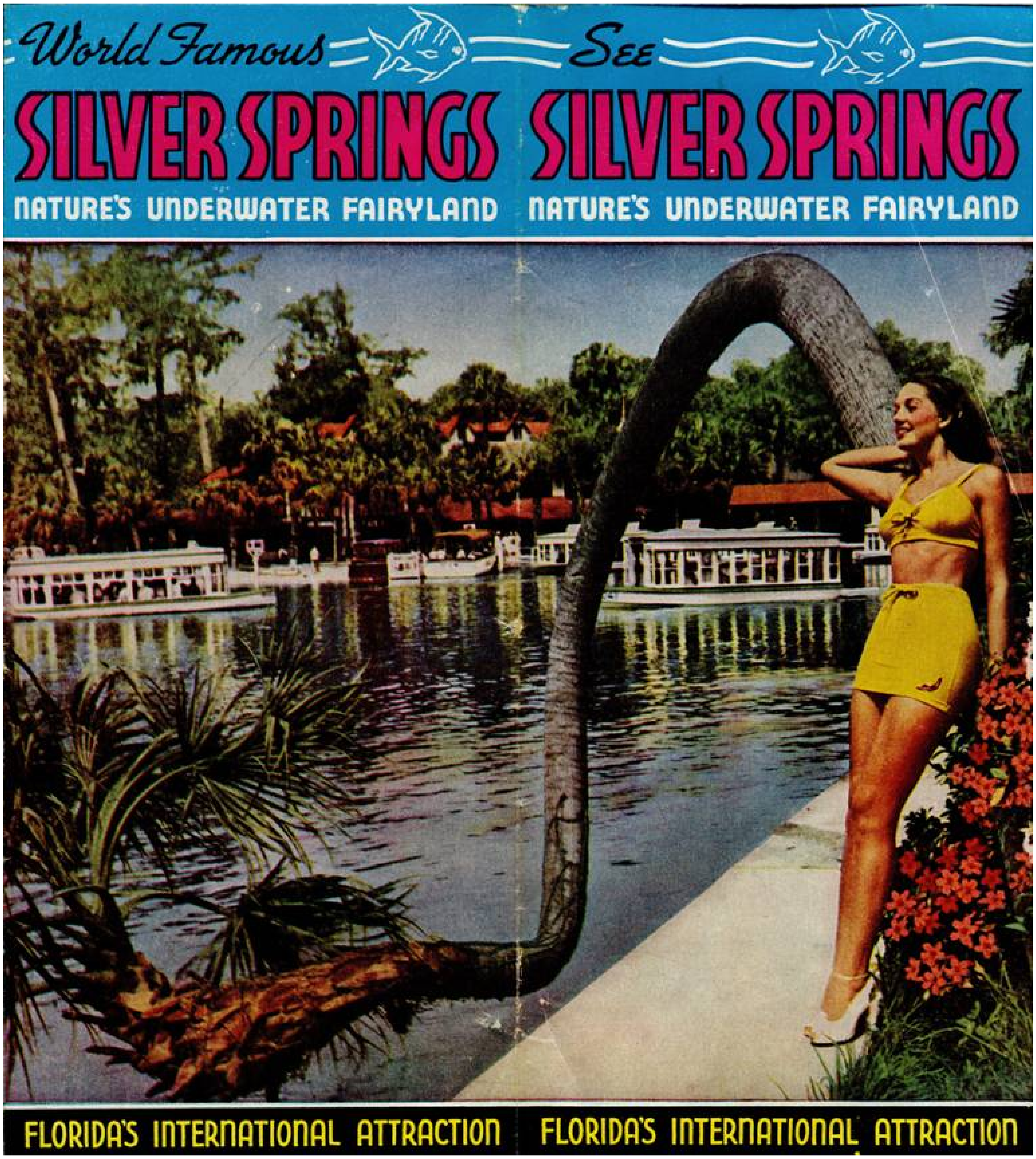


Figure 2-11 Silver Springs tourist attraction advertisement (no date)

Figure 2-12 Ross Allen was a famous snake handler and alligator wrestler at the Silver Springs tourist attraction from the 1930s through the 1960s

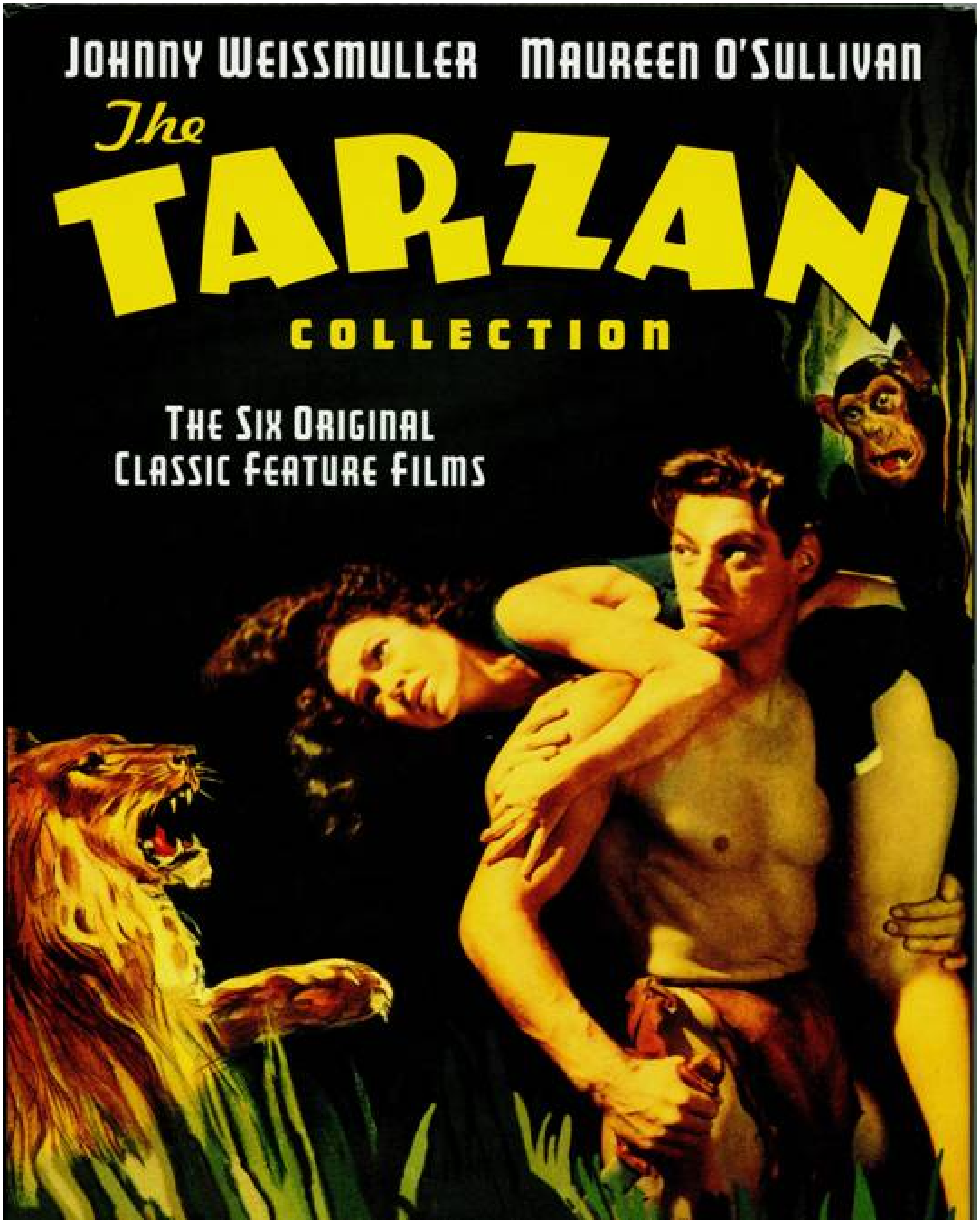


Figure 2-13 Six of the original Johnny Weissmuller Tarzan movies were filmed at Silver Springs in the 1930s

premiered there underwater. Many other documentary and military training films were also shot in the clear water of Silver Springs. Several television shows had their underwater portions shot at the springs. The television series “Sea Hunt” had over one hundred underwater clips taken at Silver Springs, and “Aquanauts” also had some underwater portions filmed at the springs. Then in 1962 the American Broadcasting Corporation acquired control of Silver Springs and 3,900 acres surrounding the Silver River. During this period, the infrastructure on site was greatly expanded.

Lou Jean Crum (1954), in her thesis about the Oklawaha River, made many references to the Silver River and Silver Springs. In 1954 she described the business at Silver Springs as booming. In 1952 concessions of over one million dollars were reported. She also described the importance of Silver Springs as a shipping port for goods to be transported to Palatka and Waldo. Crum also made reference to the history of the glass-bottom boats, saying that Phillip Morrell may not have been the inventor, but that “Doc,” the operator who conducted passengers to the Brown House, was the original developer of the idea.

2.2.3 History of Land Use Changes in the Springshed

For land use analyses, the two-year capture zone, an area of 33,720 acres, was designated as the Silver Springs springshed (Figure 2-14). Between 1949 and 1989, land use/land cover within the Silver Springs two-year capture zone changed from a predominately natural landscape to a more urbanized one (Figures 2-15 and 2-16). In 1949, the predominant land cover designation (Figure 2-17) was forested and vegetative areas (including a large variety of forests, dry prairies, scrub and brush land), which covered 68% of the area. When included with other natural land covers such as wetlands and open water, the portion of the two-year capture zone covered by natural areas was 74% in 1949. Urban areas covered only 3.3% of the area in 1949. The only other significant land uses in 1949 were rural in nature, with 9% and 7% of the area covered by various agricultural land and pastures, respectively.

By 1989, the portion of the area with forested and/or vegetative land cover had decreased to 38%, while urban areas increased to 29% of the study area. All natural land covers declined from 74% to 45% of the two-year capture zone between the years 1949 and 1989 (Table 2-1). The percentages of land covered by agriculture and pasture remained fairly constant, with declines of 1.5% each.

The trend to urbanization continued during the period from 1989 to 2005. During this time, forested and vegetative areas declined from 38% to 31%. When the areas covered by wetlands and open water are combined with forested and vegetative areas, the total area of natural land cover, at 36%, had reached parity with the urban areas, which covered 37% of the springshed in

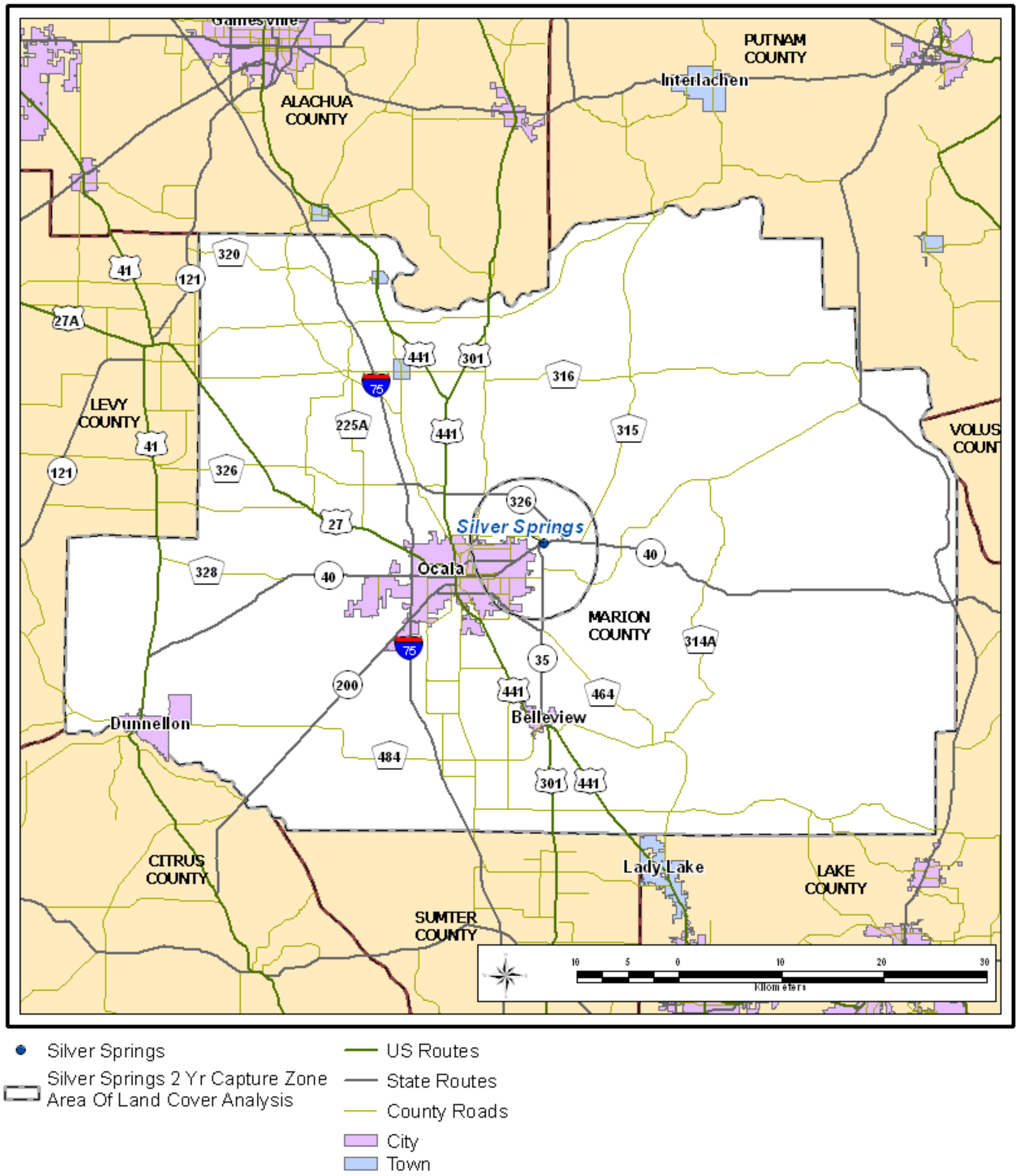
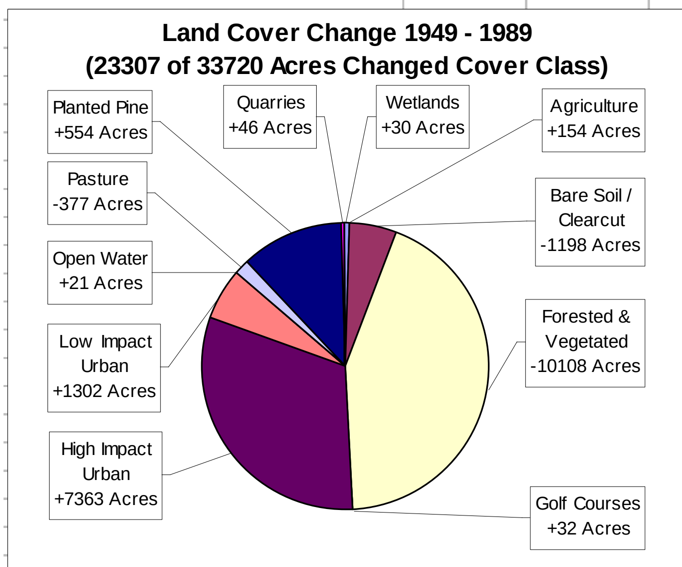


Figure 2-14 Area of Land Cover Analysis. Land Cover analysis utilized aerial photographs from 1949, 1957, 1964, 1972, 1979, and 1989. Digital orthophoto quarter quadrangles (DOQQs) were utilized in 1995 and 2005

Land Cover Class	1949 - 1989 Change in Acres	1949 -1989 Percent Change	1989 - 2005 Change in Acres	1989 - 2005 Percent Change	1949 - 1989 ABS Acres Change	1989 - 2005 ABS Acres Change
Agriculture	153.69	5.10	-527.35	-19.97	153.69	527.35
Bare Soil / Clearcut	-1198.15	-74.74	-257.76	-175.25	1198.15	257.76
Forested & Vegetated	-10108.72	-43.94	-2303.85	-0.44	10108.72	2303.85
Golf Courses	32.08	30.24	0.60	0.44	32.08	0.60
High Impact Urban	7363.58	1700.19	3086.87	28.36	7363.58	3086.87
Low Impact Urban	1302.97	228.73	-452.41	-31.86	1302.97	452.41
Open Water	21.27	28.56	-0.72	-0.76	21.27	0.72
Pasture	-377.10	-15.85	-564.31	-39.26	377.10	564.31
Planted Pine	2734.38	554.76	969.94	23.11	2734.38	969.94
Quarries	45.67	0.00	10.97	19.37	45.67	10.97
Wetlands	30.33	1.49	38.02	1.80	30.33	38.02
			Total Acreage Change		23367.95	8212.81



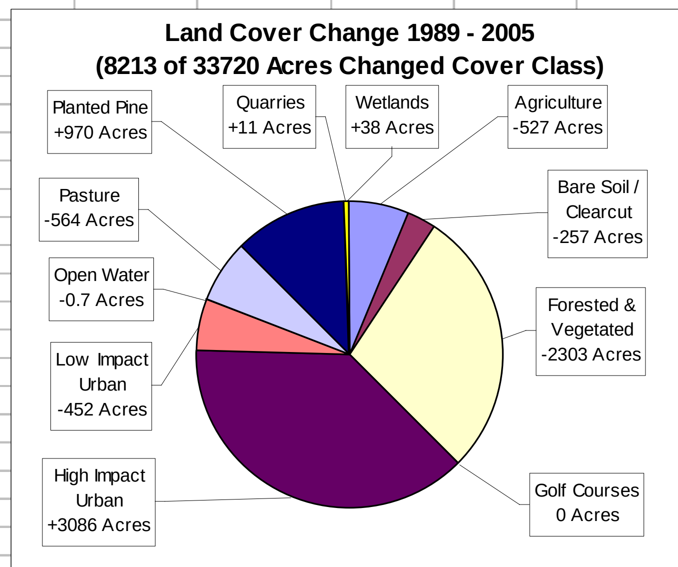


Figure 2-15 Land Cover Change (1949 – 1989 & 1989 – 2005)

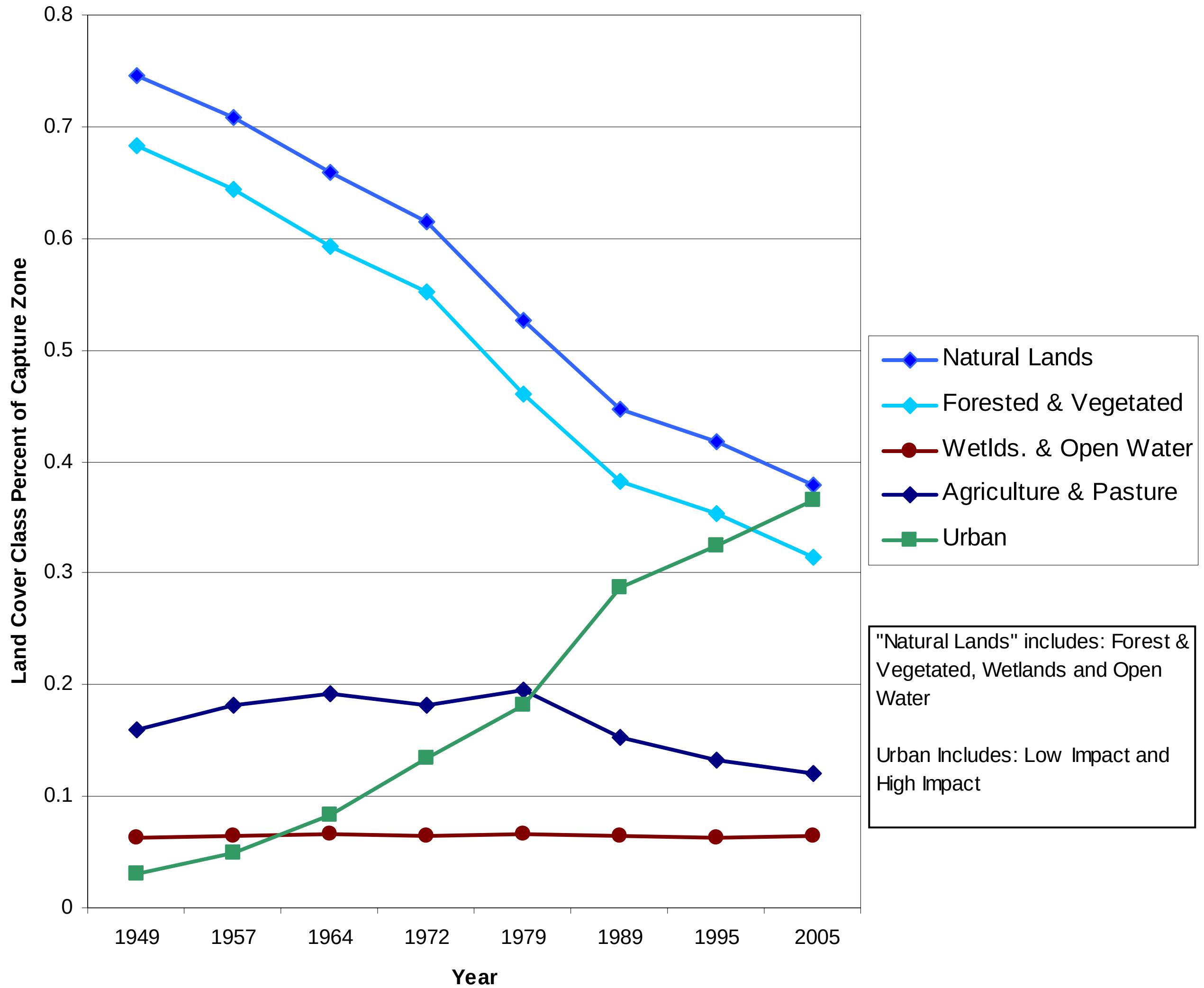


Figure 2-16 Historic Land Cover Change 1949 – 2005

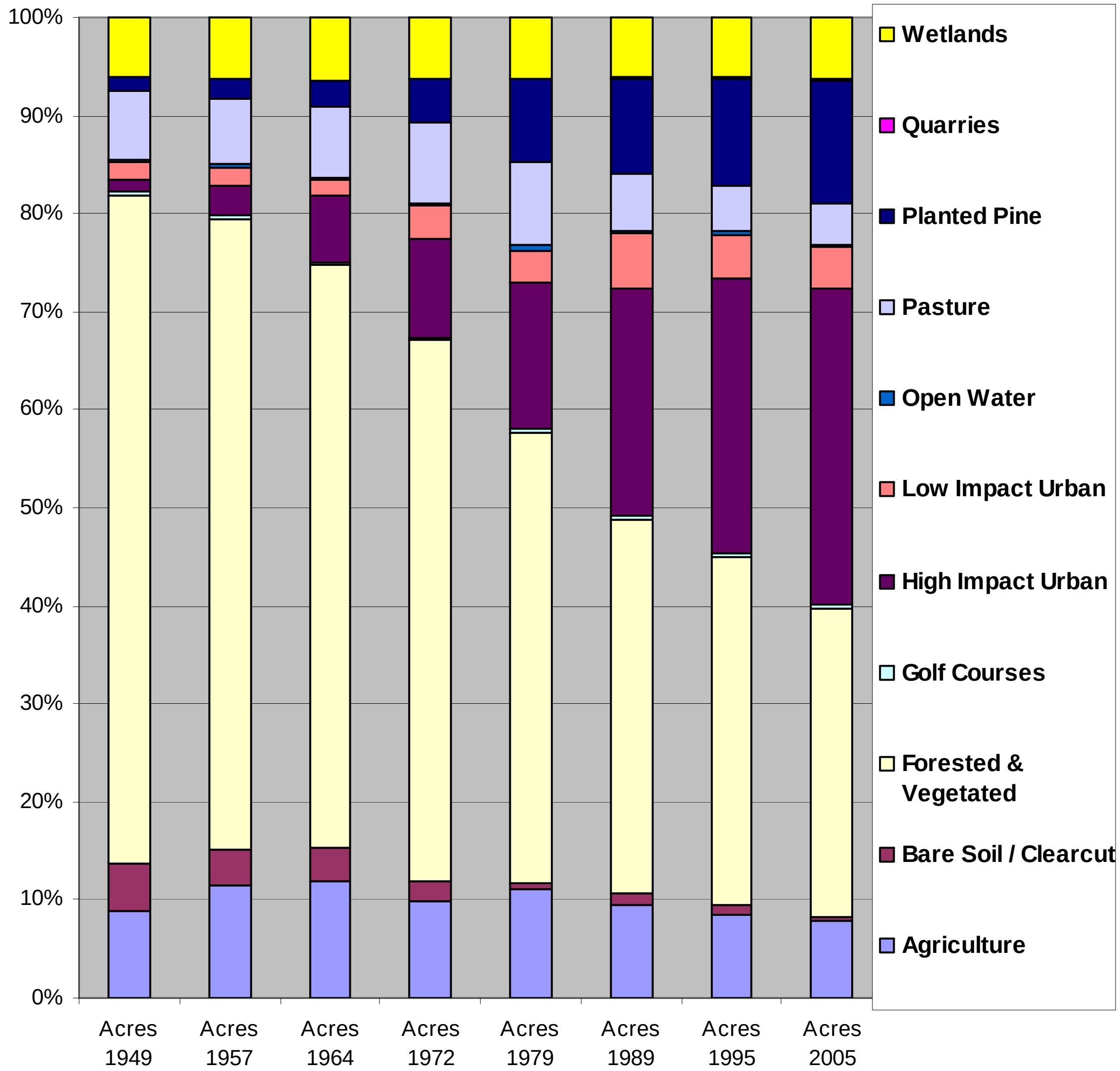


Figure 2-17 Land Use/Land Cover Categories – Percent Coverage 1949 – 2005

Table 2-1 Land Cover - Raw Acreage (by Aerial Photo Date)

Land Cover Class	Acres 1949	Acres 1957	Acres 1964	Acres 1972	Acres 1979	Acres 1989	Acres 1995	Acres 2005
Agriculture	3014.90	3843.75	4020.90	3365.17	3719.25	3168.59	2857.32	2641.24
Bare Soil / Clearcut	1602.99	1271.97	1175.42	648.04	198.18	404.84	362.06	147.08
Forested & Vegetated	23016.22	21701.36	20003.84	18595.16	15517.47	12899.60	11929.89	10595.75
Golf Courses	106.09	106.09	106.09	106.04	138.77	138.17	135.26	138.77
High Impact Urban	433.10	1041.40	2263.53	3418.25	5010.99	7796.68	9445.34	10883.56
Low Impact Urban	569.64	619.88	547.51	1103.91	1142.58	1872.61	1517.46	1420.20
Open Water	66.59	73.84	76.93	78.11	141.62	95.76	106.10	95.04
Pasture	2378.70	2304.22	2436.16	2776.54	2893.78	2001.60	1602.76	1437.29
Planted Pine	492.90	665.57	932.31	1529.30	2866.94	3227.28	3668.74	4197.21
Quarries	0.00	0.00	0.00	11.56	11.56	45.67	55.21	56.64
Wetlands	2039.14	2092.19	2157.57	2088.17	2079.13	2069.47	2040.13	2107.49
Total Acres	33720.27	33720.27	33720.27	33720.27	33720.27	33720.27	33720.27	33720.27

Land Cover - Percentage of Total Area

Land Cover Class	1949	1957	1964	1972	1979	1989	1995	2005
Agriculture	8.94%	11.40%	11.92%	9.98%	11.03%	9.40%	8.47%	7.83%
Bare Soil / Clearcut	4.75%	3.77%	3.49%	1.92%	0.59%	1.20%	1.07%	0.44%
Forested & Vegetated	68.26%	64.36%	59.32%	55.15%	46.02%	38.25%	35.38%	31.42%
Golf Courses	0.31%	0.31%	0.31%	0.31%	0.41%	0.41%	0.40%	0.41%
High Impact Urban	1.28%	3.09%	6.71%	10.14%	14.86%	23.12%	28.01%	32.28%
Low Impact Urban	1.69%	1.84%	1.62%	3.27%	3.39%	5.55%	4.50%	4.21%
Open Water	0.20%	0.22%	0.23%	0.23%	0.42%	0.28%	0.31%	0.28%
Pasture	7.05%	6.83%	7.22%	8.23%	8.58%	5.94%	4.75%	4.26%
Planted Pine	1.46%	1.97%	2.76%	4.54%	8.50%	9.57%	10.88%	12.45%
Quarries	0.00%	0.00%	0.00%	0.03%	0.03%	0.14%	0.16%	0.17%
Wetlands	6.05%	6.20%	6.40%	6.19%	6.17%	6.14%	6.05%	6.25%

Land Cover Class Groups

Class Group	1949	1957	1964	1972	1979	1989	1995	2005
Natural Lands	74.50%	70.78%	65.95%	61.57%	52.60%	44.68%	41.74%	37.95%
Forested & Vegetated	68.26%	64.36%	59.32%	55.15%	46.02%	38.25%	35.38%	31.42%
Wetlds. & Open Water	6.24%	6.42%	6.63%	6.42%	6.59%	6.42%	6.36%	6.53%
Agriculture & Pasture	16.00%	18.23%	19.15%	18.21%	19.61%	15.33%	13.23%	12.10%
Urban	2.97%	4.93%	8.34%	13.41%	18.25%	28.68%	32.51%	36.49%

Natural Lands Includes Forested & Vegetated, Open Water and Wetlands; Urban contains High & Low Impact Urban

2005. The area of land covered by agricultural uses and pastures has remained fairly constant with declines of 1.5% each. These trends can be seen as continuous, with few exceptions, from 1947 to 2005.

2.3 Climatological Setting

2.3.1 Insolation, Air Temperature, and Pan Evaporation

Insolation is defined as the incoming solar radiation that reaches a planet and its atmosphere or, by extension, any object exposed to solar rays, and is measured in watts per square meter. On Earth's surface, the sun's rays are attenuated by the atmosphere. The midday insolation on clear days in temperate latitudes may be estimated as 1,000 watts per square meter directly facing the sun. The actual figure varies with the sun angle at different times of year and with atmospheric haze and cloud cover. Long-term time-averaged insolation in sunny locations is closer to 250 watts per square meter, taking into account the lower insolation in early morning and evening, and the presence of night (Wikipedia).

The closest Florida automated weather network (FAWN) station to Silver Springs where solar radiation is measured is called Ocklawaha. It is located southwest of Silver Springs at Carney Island County Park (29.020 degrees north, 81.968 degrees west) in Marion County. In 2000 the highest and lowest daily average solar radiation at the Ocklawaha FAWN station occurred in May and December, respectively. At those times the highest and lowest daily solar radiation was 336 and 0 watts per square meter. The average daily ranges for insolation values, in watts per square meter, for the year 2000, were as follows:

- 29 – 198 in January
- 13 – 247 in February
- 94 – 297 in March
- 40 – 330 in April
- 219 – 336 in May
- 89 – 306 in June
- 62 – 311 in July
- 120 – 298 in August
- 21 – 275 in September
- 114 – 248 in October
- 19 – 197 in November, and
- 0 – 174 in December

Climate in the study area is subtropical and marked by long, warm humid summers and mild, dry winters. The mean annual air temperature at Ocala is 70.8^{o} F for 1971-2000 (National Climatic Data Center [NCDC]). Mean monthly air temperature ranges from 58.1^{o} F in January to 81.7^{o} F in July. Diurnal temperature variation is modest, typically about 20^{o} F in summer and about 25^{o} F in winter.

Regional average pan-evaporation rates range from 60 to 66 inches per year; 36 to 40 inches during the warm season (May to October) and 24 to 26 inches during the cool season (November to April) (Farnsworth *et al*. 1982). Pan-evaporation data typically is used to estimate potential evapotranspiration (PET), which is the water loss when there is not a deficiency of water in the soil for use by vegetation.

2.3.2 Precipitation Trends

Over the 30-year period 1975 – 2004, the average annual rainfall at Ocala was 51.12 inches (NCDC). During a typical year, rainfall in the Silver Springs area can be characterized by two distinct seasons: a wet season (June through September) and a much longer dry season (October through May). More than 50% of the rainfall falls during the wet season. Diurnal thunderstorm activity is most prominent during the summer months when moist tropical air moving in from the Gulf of Mexico and the Atlantic Ocean is uplifted by differential solar heating of the land surface. These thunderstorms can produce several inches of rain in one location and little or no rain a mile or even a few hundred feet away. Tropical systems, such as tropical storms and hurricanes, can generate copious amounts of rainfall over a much larger part of Marion County. Generally these systems occur in the wet season; however, occasionally tropical activity can extend into the first few months of the dry season. Rainfall during the dry season is usually associated with frontal systems and is more evenly distributed geographically than rainfall during the wet season (Knowles, Jr. 1996).

Over the period 1891 – 2004, the lowest annual rainfall of 28.58 inches occurred in 2000, whereas the highest annual rainfall of 74.71 inches occurred in 1982. Annual rainfall at Ocala, Florida, has declined since 1980. The annual average rainfall from 1891 to 1980 is 53.30 inches, whereas the annual average rainfall from 1981 to 2004 is 50.53 inches.

2.4 Hydrogeological Setting

2.4.1 Geologic formations

The geologic formations of interest in ascending order from deepest and oldest to shallowest and youngest are the Avon Park Formation, the Ocala limestone, the Hawthorn Group, and surficial, unconsolidated post-Miocene deposits. The Avon Park Formation consists of alternating layers of hard dolomite and softer limestone. It is fractured and cavernous. It is overlain by the Ocala Limestone. An erosional unconformity separates the Avon Park Formation from the Ocala Limestone. The Ocala consists of soft cream to white fossiliferous limestone. The Ocala crops out over much of central Marion County. It is at or near land surface north, south, and west of Silver Springs. In the southwestern portion of Marion County, the Avon Park Formation occurs closer to the surface, due to erosion of the overlying Ocala Formation near the crest of the Ocala platform.

The Hawthorn Group unconformably overlies the Ocala Limestone. It consists of sand, silt, clay, and hard limestone and dolostone interbeds. It ranges in thickness from a few feet to about 100 feet in eastern Marion County. In central and western Marion County most of the Hawthorn has been removed by erosion. Here it occurs on the tops of hills. East of the Oklawaha River, the Hawthorn is present as a continuous layer; this results in a change in the landscape from rolling karst hills in the western part of the county to a more flat, open, poorly-drained landscape in the eastern part of the county. Surficial post-Miocene deposits overlie the Hawthorn Group. They vary in thickness from zero to about 100 feet. In most of the Silver Springs springshed the thickness of deposits above the Ocala Limestone is generally less than 50 feet.

2.4.2 Hydrogeology

The principal hydrogeologic unit in the springshed is the Upper Floridan Aquifer. It is about 300 feet thick and occupies the Avon Park Formation and Ocala Limestone, where present. Because both units have a high porosity, flow is from both matrix and conduits. Transmissivity, which is a measure of flow, has been calculated from flow nets for the entire Upper Floridan Aquifer and ranges from 10,700 to 25,500,000 feet squared per day (ft^2/day), with an average value of 2,000,000 ft^2/day (Faulkner, 1973). The high transmissivity values result in the rapid flow of water in the springshed.

2.5 Characteristics of the Springshed, Groundwater, and Spring Run

2.5.1 Contributing Area

The contributing area for Silver Springs occurs in Marion, Lake, Sumter, Putnam, and Alachua Counties. Previous studies of the groundwater resources of Marion County and the Silver Springs area include investigations focused on the potential effects of the proposed cross-Florida barge canal (Faulkner 1973). Knochenmus (1967) investigated groundwater travel times by using dye traces. Faulkner (1973) conducted a detailed study of the stratigraphy, structural geology, groundwater flow system, and groundwater chemistry in central Marion County. Tibbals (1975) conducted aquifer tests in the Upper Floridan Aquifer in the proposed canal right-of-way. Phelps (1994) described the hydrogeology, groundwater quality, and potential for contamination of the Upper Floridan Aquifer in the Silver Springs springshed. Knowles (1996) estimated basin shapes and evapotranspiration rates for both the Silver Springs and the Rainbow Springs springsheds. Shoemaker *et al*. (2004) presented delineations of the Silver Springs groundwater contributing area by comparing results of three different numerical groundwater flow models. These models included Sepulveda (2002), Knowles *et al*. (2002), and Motz and Dogan (2002), where each mapped the shape of the springshed for Silver Springs. However, because of different calibration periods and different hydrogeologic parameters, the shape and size of the springshed delineated by each model differs somewhat.

2.5.2 Springshed Boundaries

The Silver Springs springshed is defined as the land surface area that acts as a source of groundwater that contributes to the discharge of the springs. It is generally defined on the basis of the direction of groundwater flow, and is sometimes referred to as the groundwater basin. The movement of groundwater within an aquifer can be affected by many variables including such things as climate and locations and quantities of water withdrawals. Hence the springshed boundaries can be dynamic and vary over time.

Figure 2-18 provides an overview of some delineations of the Silver Springs Floridan Aquifer contributing area. The size of the springshed mapped by Phelps (2004) by drawing orthogonal lines on the May 1999 potentiometric surface is about 1,140 square miles. This area is assumed to represent the approximate current size of the springshed. For comparison, the total area covered by all three models of Sepulveda (2002), Knowles *et al*. (2002), and Motz and Dogan (2002) is 741 square miles, which represents the one-hundred-year travel time. A particle of water originating from the outermost reaches of that one-hundred-year zone will discharge from the spring one hundred years later. This area is similar to the springshed area (686 square miles) determined by the Southwest Florida Water Management District (draft) by drawing orthogonal lines on the May 1998 potentiometric surface, which represented a modern dry period.

The area common to all three numerical models described above is only 345 square miles, which is a good indicator of the area likely to contribute the most to spring flow. Based on the results derived from the orthogonal approaches and three MODPATH numerical models, the 741-

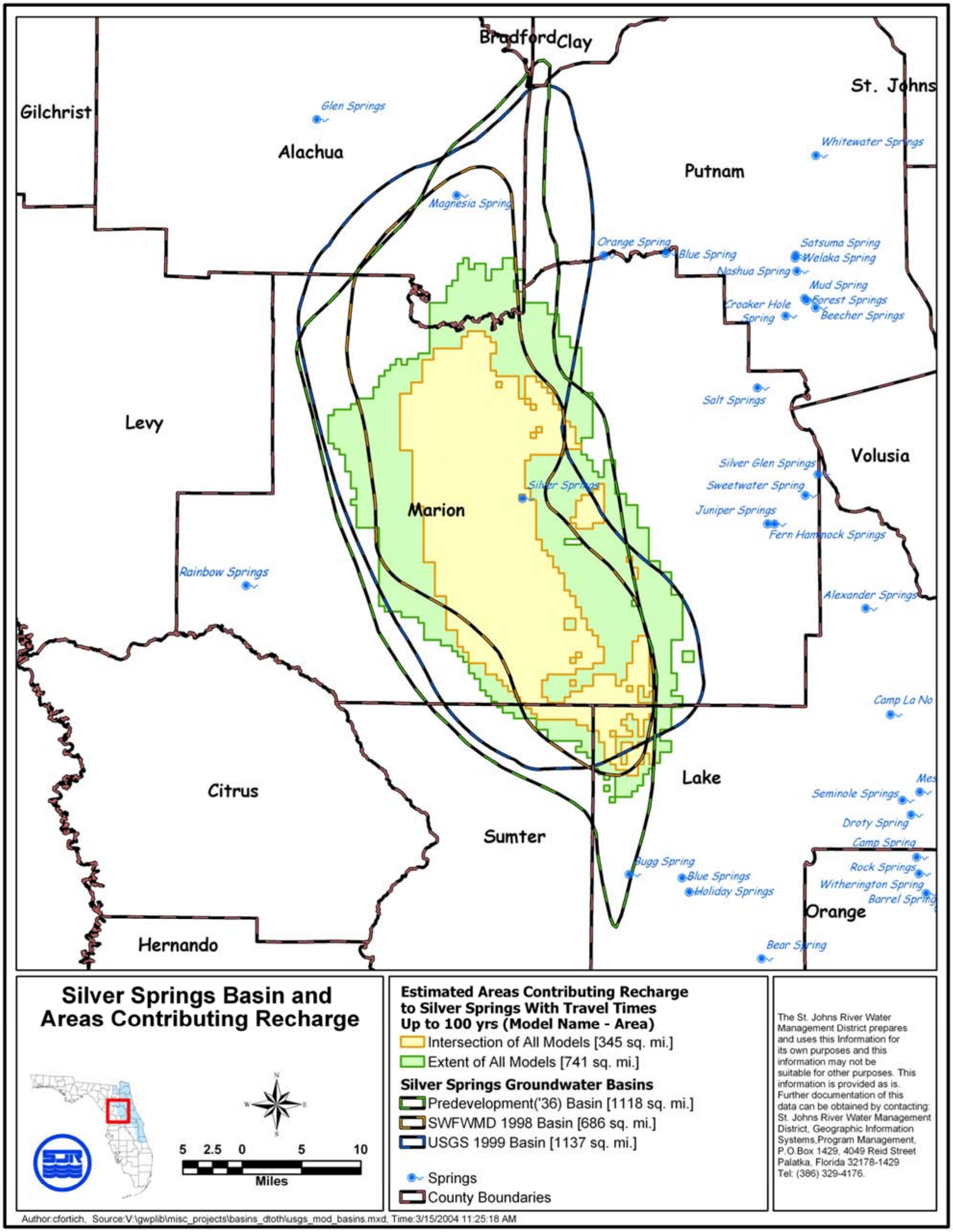


Figure 2-18 Delineations of Silver Springs Springshed

square-mile contributing area would impose the most significant impacts to groundwater flow and groundwater quality on the discharge at Silver Springs.

2.5.3 Isotope Age Estimates and Source of Groundwater

Phelps (2004) investigated the chemical quality of groundwater in the Silver Springs springshed and looked at the relationship between nitrate concentrations and land use. Findings from this report estimate the age of the water issuing from Silver Springs to be less than thirty years. Toth (2003) measured water quality and isotopes in Silver Springs. He inferred an age for the spring water as young (less than one hundred years) from isotope and carbon-14 analysis. Because of the karst nature of the Floridan Aquifer known to exist in the Marion County area and the relatively young age of the waters, the groundwater within the uppermost parts of the aquifer likely provides a large portion of the springs' discharge.

2.5.4 Area of the Spring Run

Because no shoreline survey has been conducted, aerial imagery was considered, at this time, to be the best way to construct a digital approximation of the Silver Springs run boundary area. However, since much of the shoreline is obscured by vegetation, the area could only be approximated. A 1995 Infra-red Digital Orthophoto Quarter Quadrangle, which allowed more of the shoreline to be identified, was used to delineate the run boundary. From this snapshot, the Silver Springs run measures 1,200 m and covers an area of approximately $83{,}875^2$ m, or 20.72 acres, as presented previously in Figure 2-4.

Aerial imagery indicates that the boat basin was begun prior to 1964 and completed prior to 1972 (Figure 2-19). The basin has an area of $8{,}088^2$ m (0.186 acres). The back channel was extended to just above the 1,200-m station. Aerial imagery indicates that this was completed between 1972 and 1979 (Figures 2-19 and 2-20).

2.6 Spring and Stream Discharge Estimates

2.6.1 History of discharge measurement methods at Silver Springs, USGS Station 02239500

Discharge measurements at Silver Springs near Ocala, USGS station 02239500 can be classified by periods as follows:

A: May 1906 – March 1932: thirteen discharge measurements were made at irregular intervals and at various locations, most frequently 300 feet downstream from the Main Spring Boil (Mammoth Spring). These measurements are considered "not official" by USGS due to a lack of documentation regarding the quality of the measurements.

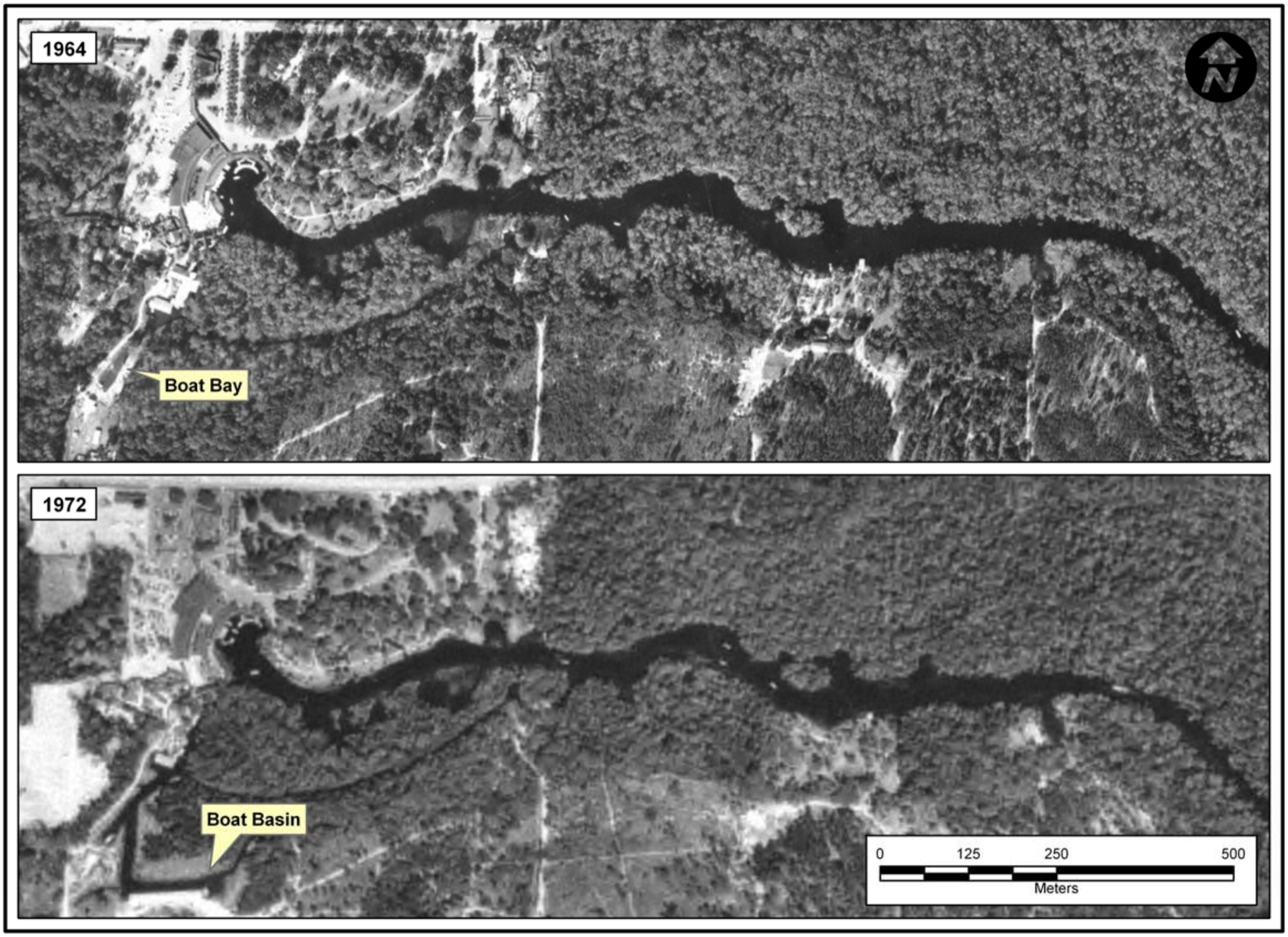


Figure 2-19 Spring Run Area Changes 1964 – 1972 – Bay Area and Boat Basin Added

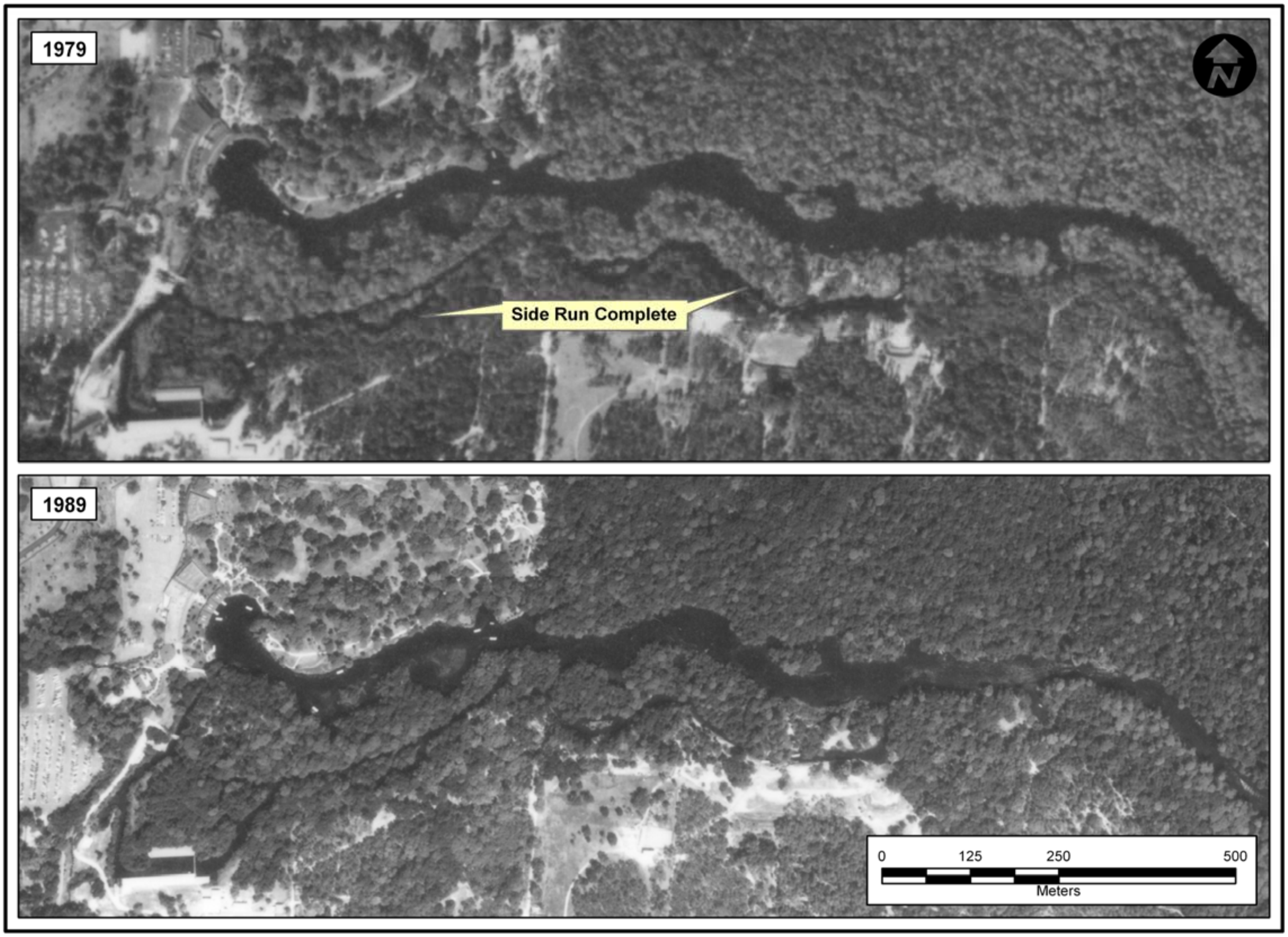
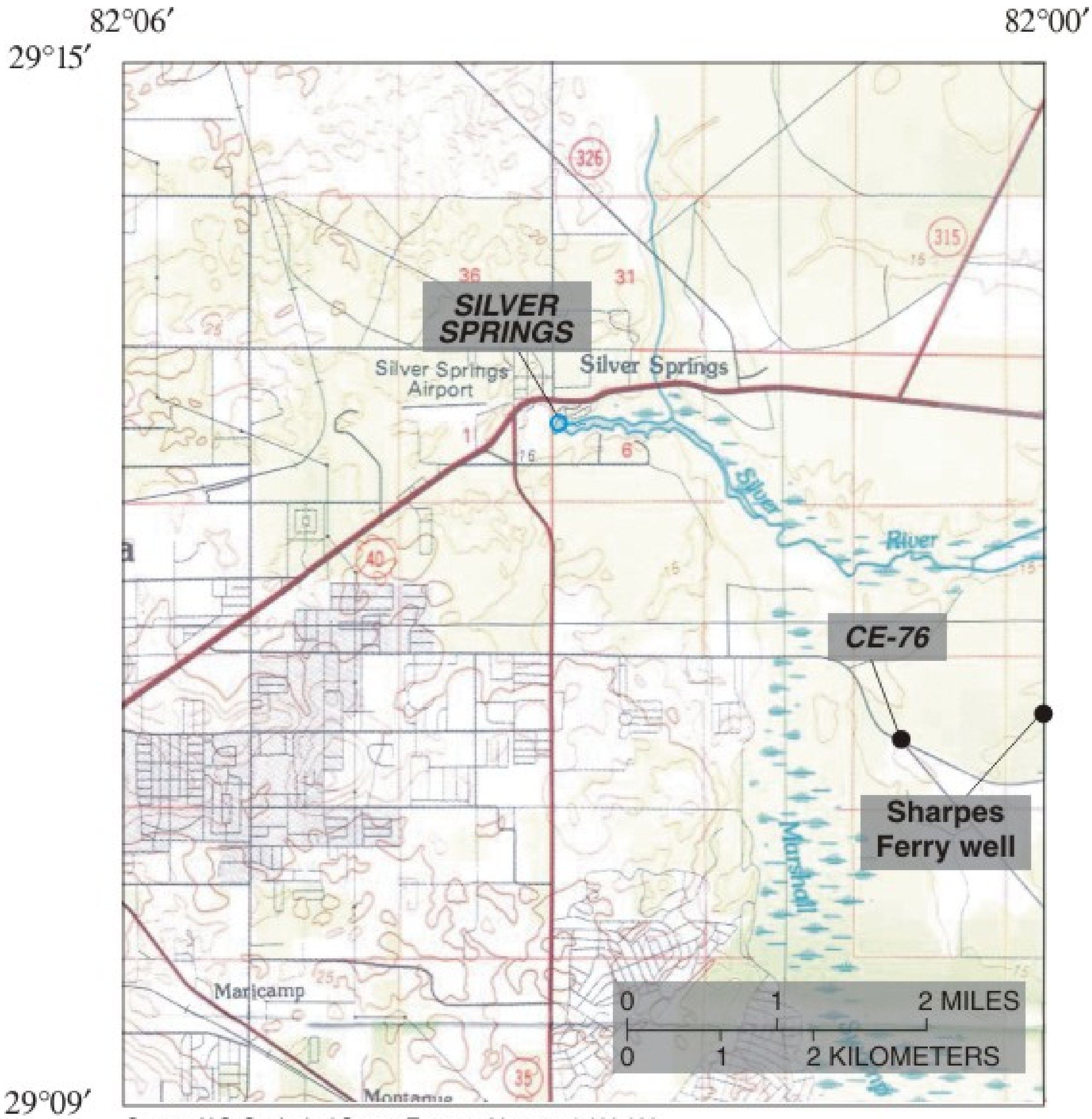


Figure 2-20 Spring Run Area Changes 1979 – 1989 – Side Run (Back Channel) Completed Between 1972 and 1979

B: October 1932 – September 1947: Monthly discharge measurements were made.

C: October 1947 – November 20, 1959: Weekly discharge measurements were made at a site 0.7 mile downstream from the head of the springs; surface inflow between the head of the springs and the measuring site was subtracted when measured. Daily mean discharge values were computed from the relation between artesian pressure at Sharpes Ferry Well (USGS 291115081592501; Figure 2-21) and discharge measured at a site downstream from the head of the springs.



Source: U.S. Geolocical Survey Topographic map; 1:100,000

Figure 2-21 Location of Silver Springs and observation wells near Silver Springs

D: Nov. 21, 1959 – Sept. 2002: Weekly discharge measurements were made 2 to 5 miles downstream from the head of the springs; surface inflow between the head of the springs and the measuring site was subtracted when measured. Daily mean discharge values were computed from the relation between artesian pressure at Sharpes Ferry Well (USGS 291115081592501) and discharge measured at a site downstream from the head of the springs.

E: Oct. 2002 – Sept. 2005: Weekly discharge measurements were made 4 to 5 miles downstream from the head of the springs; surface inflow between the head of the springs and the measuring site was subtracted when measured. Daily mean discharge values were computed from the relation between artesian pressure at CE-76 Well (USGS 291100082010003; Fig. 2-21), the Silver Springs pool elevation, and discharge measured at a site downstream from the head of the springs. Flow velocities obtained from an acoustic velocity meter (AVM) at Silver Springs are not yet being used to compute spring discharge listed in the USGS Data Reports.

F: Oct. 2005 – Present (September 2006): An Acoustic Flowmeter For Remote Areas (AFFRA) AVM is being used to measure flow velocity in the channel from the difference in time a sound wave takes to travel upstream and downstream in the channel. More sophisticated AVMs require a higher water turbidity to accurately detect the scattered wave used to measure the velocity profile. There are two AVM sites, one at Silver River near Ocala and the second at Silver River near Conner. The Silver Springs discharge is being measured at a downstream site 0.7 mile from the head springs and the entire flow is being measured at these two additional sites.

2.6.2 Record of Manual Measurements

The USGS has manually measured the discharge of Silver Springs from 1906 to the present (Figure 2-22). The irregular manual measurements taken from January 1933 to the present have been utilized to calibrate a groundwater stage vs. spring discharge relationship. The result was used to estimate mean daily discharge of the spring (Figure 2-23). The period of record (POR) statistics for the two sets of measurements are presented in Table 2-2. The minimum of the manual measurements was observed on January 9, 2001, and the maximum on September 28, 1960. The minimum estimated daily mean discharge occurred June 27, 2001 and the maximum on October 7, 1960.

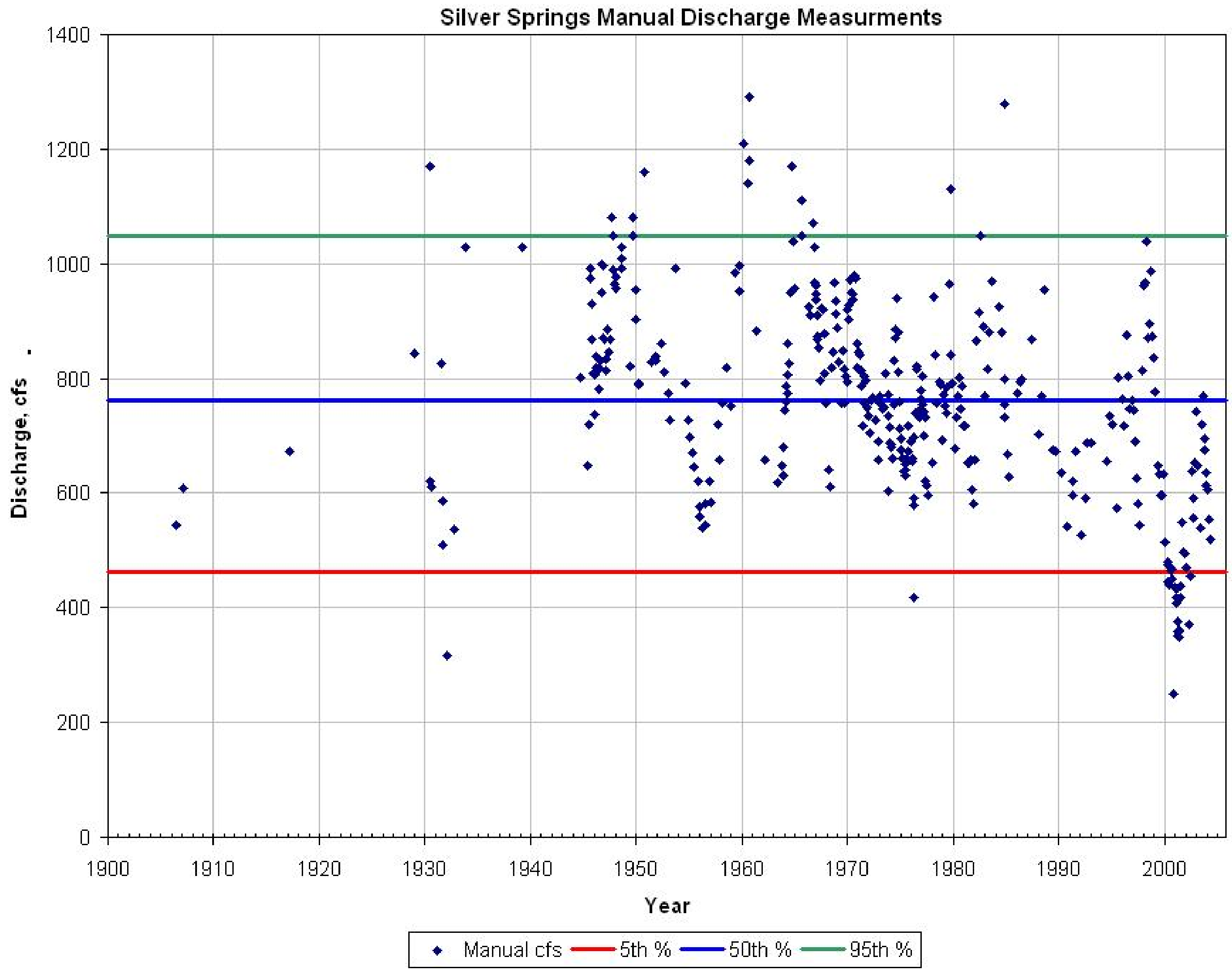


Figure 2-22 Silver Springs Manual Discharge Measurements (from USGS data)

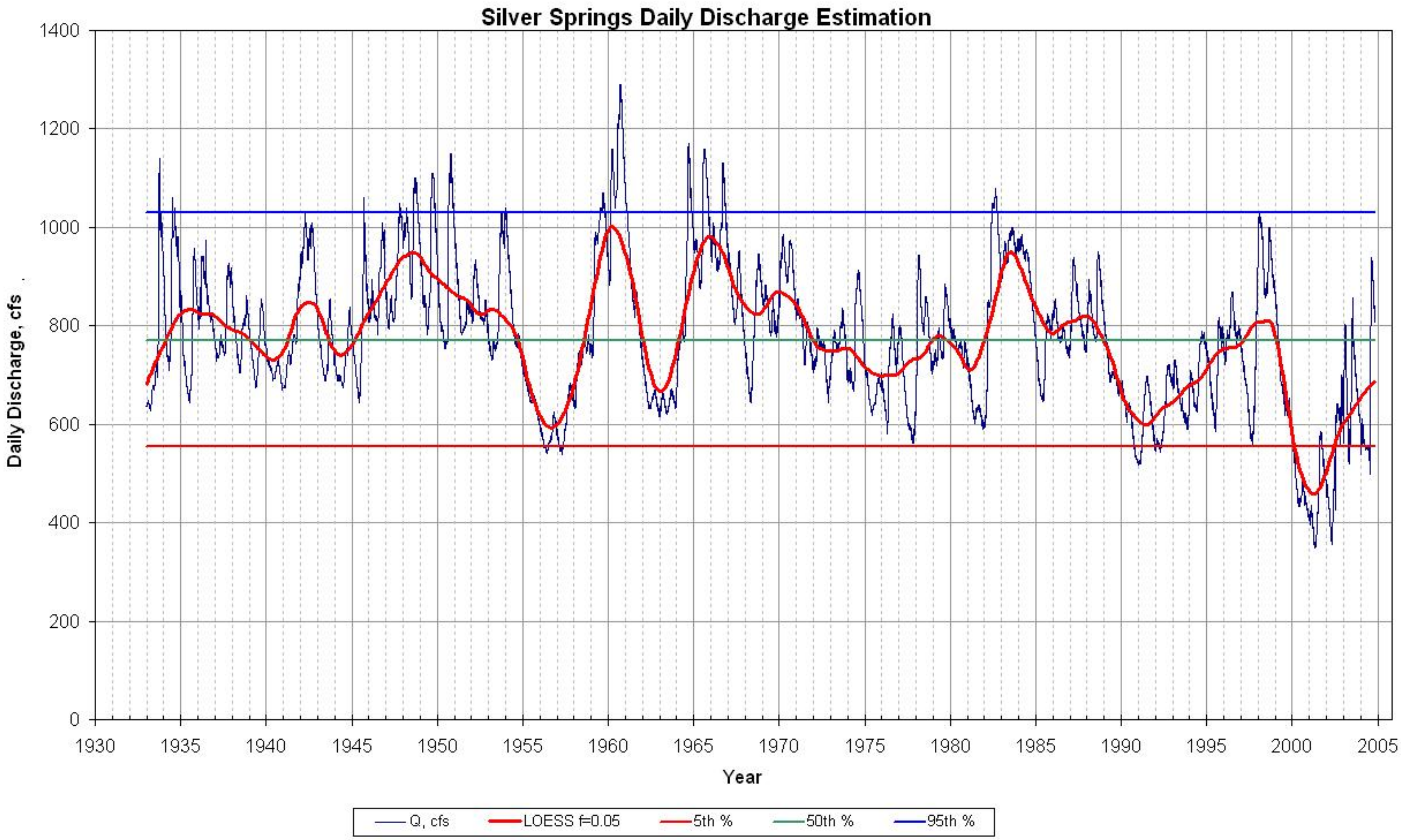


Figure 2-23 Silver Springs Daily Discharge Estimation

Table 2-2 Summary of Silver Springs period of record discharge measurements

	Min	Average	Median	Max	Count	Range	Period
Manual	250	766	762	1,290	399	1,040	1906-2004
Daily	350	778	770	1,290	26,298	940	1933-2004

2.6.3 Discharge trends

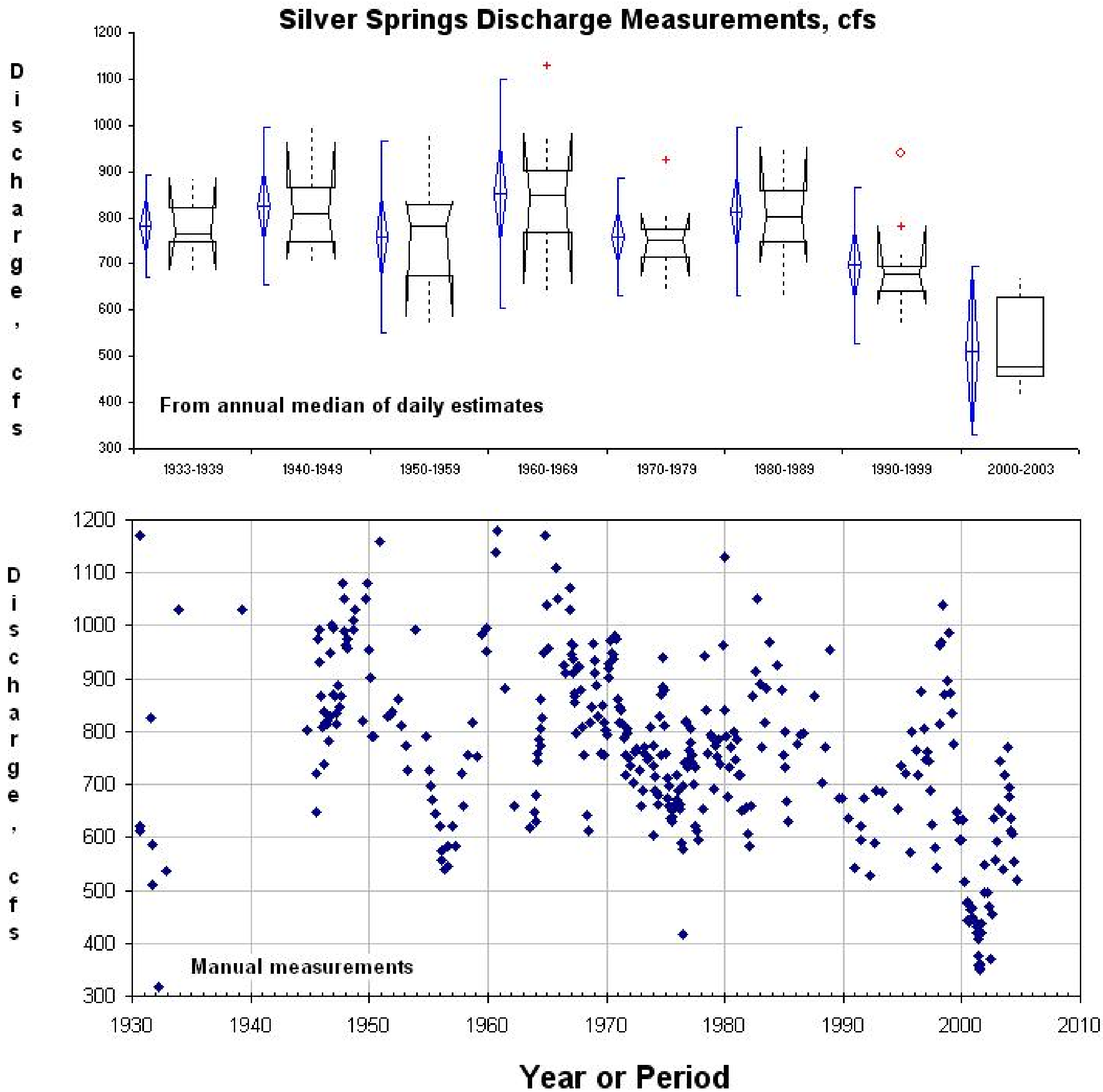
Both the daily estimates and manual measures show a decreasing trend in spring flow – especially since the 1960s (Figure 2-24). It should be noted that the manual measurements, calibrating the stage vs. discharge relationship, have been taken at various distances from the main vent: from 350 feet to greater than 19,000 feet (3.6 miles) downstream (German, 2004). German went on to demonstrate that due to numerous vents, seeps and surface water inflows, discharge in the Silver River downstream of the main vents can increase by nearly 40% to 50%. No further investigation to determine whether "corrections" must be applied to the USGS stage vs. discharge relationship estimations has been done.

A double-mass analysis of the relationship between Silver Springs flow and Ocala rainfall suggest that long-term changes in rainfall are responsible for changes in flow over the period 1933 to 2000 (Figure 2-25). After 2000 the double-mass relationship between the two variables changed and the curve indicates there is less spring flow occurring per unit of rain than prior to 2000. However, this change in relationship occurred the same year there was a revision in the stage vs. discharge rating used to compute the daily mean discharge. Thus the 2001 change in 1933-2000 double-mass relationship may be an artifact of the revision of the stage vs. discharge rating.

2.7 Ecological Setting

Silver Springs constitutes a complex aquatic ecosystem displaying most of the structural and functional features identified in aquatic ecology (Odum 1957, Odum 1971). This aquatic ecosystem includes all abiotic and biotic components typical of aquatic ecosystems including: aquatic macrophytes (higher plants) that support a diverse assemblage of attached algae (periphyton), detritus (dead plant and animal material associated with benthic organic sediments) and associated animals feeding on detritus – a food chain of herbivores and omnivores.

Odum's biomass "pyramid" is reproduced in Figure 2-26. This figure illustrates the predominance of the *Sagittaria* and associated periphytic algae as the biological flywheel of this ecosystem. Average standing stock (dry weight biomass) of these plants was estimated by Odum as about 809 grams per square meter (g/m^2). Herbivores, including especially turtles, midges, snails, and herbivorous fish such as mullet (*Mugil cephalus*) are the next step up on the biomass pyramid with an estimated average biomass of only 37 g/m^2. Higher trophic levels include



Explanation of symbols in upper graph

Figure 2-24 Silver Springs daily estimates and manual measurements of spring discharge

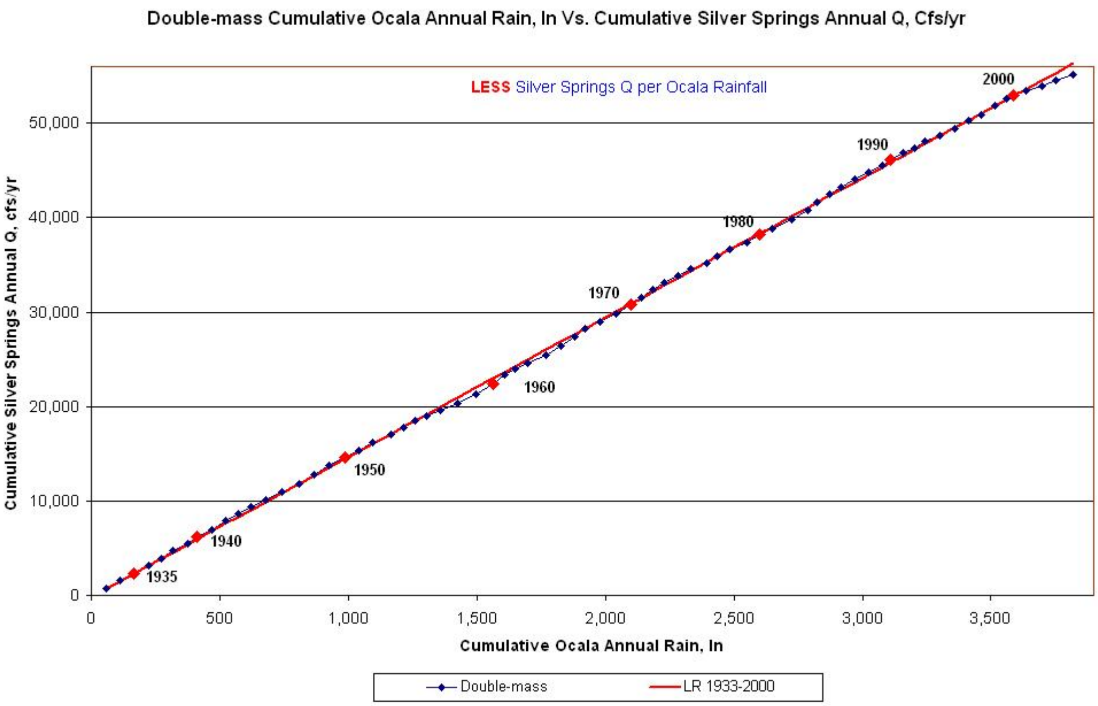


Figure 2-25 Double-mass analysis of the relationship between Silver Springs flow and Ocala rainfall

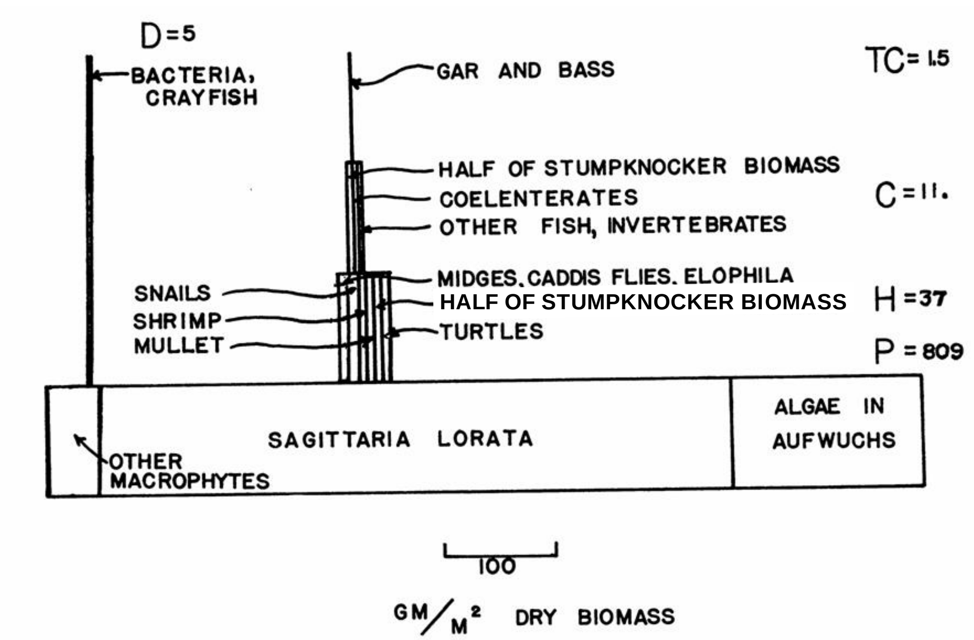


Figure 2-26 Pyramid of biomass for the Silver Springs community (Odum 1957)

primary and secondary consumers such as carnivorous fish, alligators, and numerous fish-eating birds such as the double-crested cormorant (*Phalacrocorax auritus*), anhinga (*Anhinga anhinga*), herons, and egrets. The biomass of the primary consumers was estimated as 11 g/m^2 while the top consumers had an estimated biomass of only 1.5 g/m^2. An important parallel metabolic track occurs in the detrital food chain that includes decomposer organisms such as bacteria, aquatic insects, and crayfish.

H.T. Odum summed up his ecological study of Silver Springs in what is perhaps the first published energy flow diagram (Figure 2-27). In this diagram energy flows are depicted as tubes with widths proportional to the estimated average annual energy flow in units of kilocalories (kcal) per area ($kcal/m^2/yr$). The predominant external energy forcing function for Silver Springs is sunlight with an estimated annual average input of 1,700,000 $kcal/m^2/yr$. About 24% of this light is absorbed by the plant community and an estimated 1.2% of the total incoming solar energy is converted to useable plant production by photosynthesis. Of this trapped energy (about 20,810 $kcal/m^2/yr$) an estimated 58% is lost through plant respiration and the rest (42%) is passed on to the ecosystem for support of the aquatic animals living either within the upper 1,200-m section of the river or downstream.

H.T. Odum recognized that Silver Springs and similar spring communities are especially unique in ecological studies because they are in a "quasi-steady state", a condition of unchanging environmental forcing functions that provide the foundation for the "emergent" ecosystem properties of form and function. Due to the large volume of spring water, consistent water clarity and temperature, and relatively stable water quality over many decades of human observation, H.T. Odum concluded that Silver Springs is in steady state except for the annual variation in solar radiation entering the surface of the water. Odum observed in his 1957 paper that this rare environmental condition allows for the replication of measurements of ecological properties over the course of time, for the purpose of ecosystem quantification and in any effort to detect changes due to changing forcing functions. The data collected during the ecosystem study by Knight in the late 1970s and by the current study fifty years after Odum's work are a test of this observation.

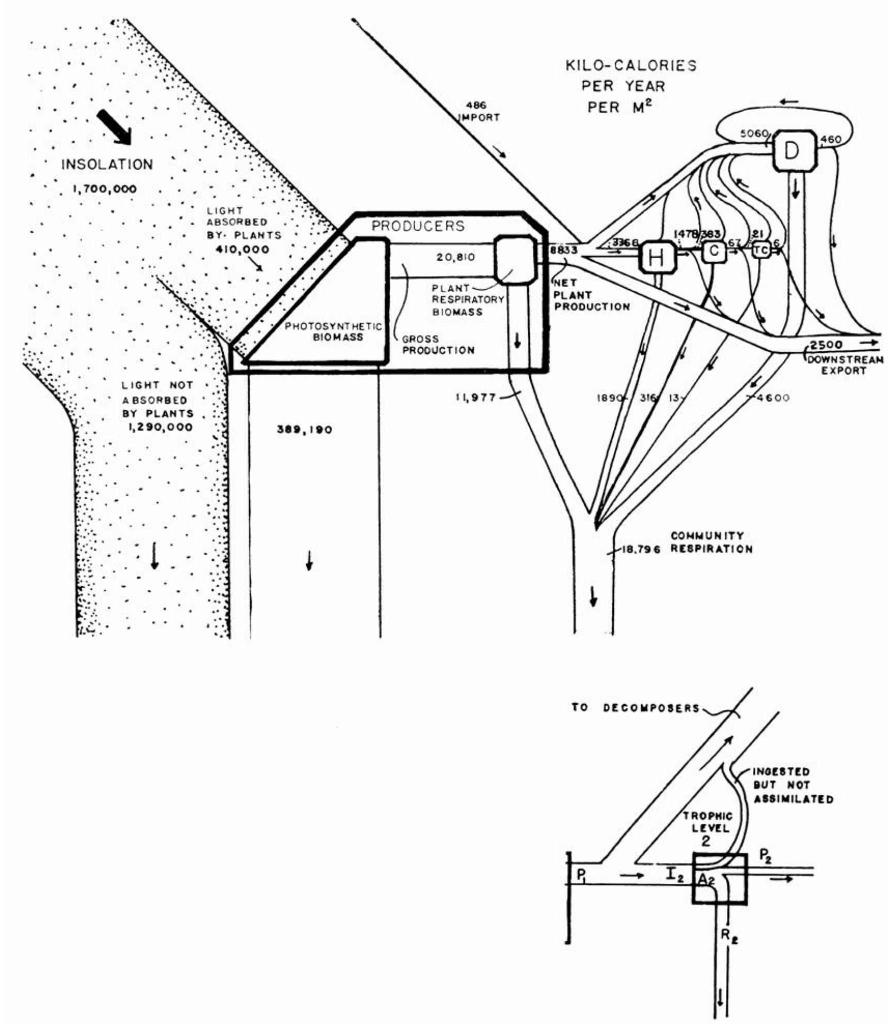


Figure 2-27 Energy flow diagram with estimates of energy flows in kilo-calories per square meter per year in the Silver Springs community (Odum 1957)

3.0 Previous Studies and Data Sources

3.1 Introduction

Silver Springs and the Silver River have been in the public eye for a long time. This attention has resulted in an extensive literature both published and unpublished available about this aquatic ecosystem. These studies range widely in scope from historical accounts to detailed studies on the optical properties of Mammoth Spring. Published reports on Silver Springs date back at least as far as the 1860s when early accounts of the river were made by people living nearby or traveling through the area. Other than a few water quality measurements, no reports were located that describe Silver Springs during the first half of the 20th century. As described earlier, numerous studies were conducted in Silver Springs during the late 1940s and early 1950s. Since that time there has been a fairly intensive series of limited studies in Silver Springs and the Silver River. In addition to the Silver Springs research published in peer-reviewed scientific journals there are a variety of unpublished data available from the USGS, the Florida Fish and Wildlife Commission (FWC), the U.S. Environmental Protection Agency (USEPA), and the Florida Geological Survey (FGS).

3.2 Early Scientific Accounts

The earliest records for the Silver River were made by several individuals who visited the spring in the mid 1800s. Early accounts of Silver Springs were made by John LeConte (1861), Brinton (1859), and a Confederate soldier (*Letters from the Frontier*, 1868). LeConte wrote a paper in the American Journal of Science describing the optical characteristics of the spring. This included measuring the depth of the Main Spring Boil (Mammoth Spring) as 11 m (36 feet), an average flow velocity of 0.89 meters per second (m/s) (2 miles/hour), the width of the river at various locations from 14 to 30 m (45-100 feet), and various other descriptions of the optical nature of the water. Observations about the spring were also made by Brinton (1859) who measured the depth of the Main Spring Boil as 12.5 m (41 feet), the water temperature as 22.9 ^{o}C (73.2 ^{o}F), and the spring discharge as 1.1 million cubic meters per day (hm^3/d) (300 million gallons per day [mgd]). His measurements and records about the fish species and vegetation remain largely true today, illustrating the relative consistency of the Silver Springs' ecosystem.

3.3 Hydrology and Water Quality

The FGS has released three reports titled *Springs of Florida* (Ferguson, *et al*., 1947; Rosenau, *et al*., 1977; and Scott, *et al*,. 2004). The first of these (Ferguson *et al*. 1947) provided historical data from 1907 for Silver Springs, including measurements of nitrate, alkalinity, etc. Ferguson *et al*. (1947) and Rosenau *et al*. (1977) duplicated many of these measurements and found similar values in 1946. Table 3-1 compares the data reported by Rosenau *et al.* (1977) and by Odum (1957). Numbers for nitrate show a clear increase from 1907 to the levels measured in 1947 and 1955.

The SJRWMD published a description of all of the significant springs in their jurisdiction (Osburn *et al.* 2002). The Main Spring Boil at Silver Springs is described as a pool about 76 m (250 ft) in diameter with a ledge at 7.6 to 9.1 m (25 to 30 ft) below the surface and a cavern mouth about 1.5 m high and 41 m wide. Mean daily discharge downstream near the 1,200-m station for the period from 1932 through 1999 was reported as 22.5 m^3/s (795 cubic feet per second [cfs]). This report identified significant increasing trends for total chloride and nitrate+nitrite nitrogen (NO_3+NO_2-N) at Silver Springs. Median chloride concentration was 9 mg/L with an increasing trend since 1956 of about 0.036 mg/L per year. Median NO_3+NO_2-N concentrations for the years 1932 through 1999 were 0.70 mg/L with an average increase of 0.018 mg/L per year. There was no significant trend observed for sulfate concentration (median value 41 mg/L).

The FGS also released an Open File Report in 2002 characterizing all of the first magnitude springs of Florida (Scott *et al.* 2002). Table 3-2 displays the data comparison for Silver Springs reported in 2002 compared to the historical levels of 1907 and 1947. The 2002 report clearly notes the "layer of algae" that covers most surfaces in the Main Spring Boil.

Scott *et al.* (2004) produced a revised version of the *Springs of Florida* previously authored by Ferguson *et al.* (1947) and Rosenau *et al.* (1977). The Main Spring Boil area is described as being 91.4 by 59.4 m (300 by 195 ft) in length and width, with a depth of 10.1 m (33 ft) over the vent opening.

Recent attention to groundwater withdrawal and contamination led the FDEP to create a Florida Springs Task Force. In November 2000, the Springs Task Force released *Strategies for Protection and Restoration of Florida's Springs* (Florida Springs Task Force, 2000). This report lists Silver Springs as one of a group of first magnitude springs in Florida requiring special protection.

The USGS reported on the *Large Springs in the United States* in 1927. This book provided brief descriptions of "large springs" which it described as varying by area or definition. This book also made reference to the classification of springs based on magnitude. Silver Springs was reported to have a discharge of between 0.84 and 2.01 hm^3/d (342 and 822 cfs). It was also reported that single rainfall events did not appear to have a large effect on the discharge of the spring in any characteristic way. It was found that discharge and water level tended to increase during the rainy season and decline during the dry season.

Table 3-1 Silver Springs historic water quality data

Parameter	**12/16/1907**[1]	**10/21/1946**[2]	**1950-1955**[3]
Color (PCU)	---	4	---
Nitrate-N (mg/L)	0.04	0.29	0.46
Sulfate-SO4 (mg/L)	44	34	---
Total Alkalinity-HCO3 (mg/L)	220	200	195
Total Chlorides (mg/L)	7.7	7.8	9.6
Total Coliform (col/100mL)	---	---	99
Total Dissolved Solids (mg/L)	274	237	241
Total Kjeldahl N (mg/L)	---	---	0.02
Total Phosphorus (mg/L)	---	---	0.05
Fluoride (mg/L)	---	0.1	---
Silica (mg/L)	13	9.2	---
pH (Standard Units)	---	7.8	7.53
Calcium (mg/L)	73	68	72
Magnesium (mg/L)	9.2	9.6	---
Potassium (mg/L)	9.8	4	---
Sodium (mg/L)		1.1	---

[1] as reported by Rosenau, Faulkner, Hendry, and Hull (1977)
[2] as reported by Rosenau, Faulkner, Hendry, and Hull (1977)
[3] H. T. Odum (1957)

Table 3-2 Recent Summary of Florida Geologic Survey Chemistry Data for Silver Springs (Scott *et al.*, 2002)

Analytes	1907	1946	1972	Main 2001		Blue Grotto 2001		Reception Hall 2001	
				Unfilt.	Filter	Unfilt.	Filter	Unfilt.	Filter
Field Measures									
Temperature	-	-	23.5	23.2	-	23.5	-	23.6	-
DO	-	-	-	2.38	-	3.16	-	3.73	-
pH	-	7.8	8.1	7.20	-	7.26	-	7.24	-
Sp. Cond.	-	401	420	471	-	443	-	468	-
Lab Analytes									
BOD	-	-	0.1	0.2 U	-	0.2 AU	-	0.2 U	-
Turbidity	-	-	0	0.05 U	-	0.05 U	-	0.05 U	-
Color	-	4	0	5 U	-	5 U	-	5 U	-
Alkalinity	-	-	170	176	176	153	153	158	157
Sp. Cond.	-	-	-	510	-	480	-	500	-
TDS	-	-	-	285	-	273	-	292	-
TSS	-	-	-	4 U	-	4 U	-	4 U	-
Cl	7.7	7.8	8.0	9.1	9.2	8.9	9	8.8	8.9
SO_4	44	34	39	59	60	63	64	73	74
F	-	0.1	0.2	0.17	0.17	0.15	0.15 A	0.16	0.16
Nutrients									
TOC	-	-	8.0	1 U	-	1 U	-	1 U	-
NO_3+ NO_2	-	-	2.6	1.2	1.1	1.5	1.4	1.4	1.4
NH_3+NH_4	-	-	-	0.01 U	0.01 U	0.01 U	0.025 A	0.011 I	0.01 U
TKN	-	-	-	0.06 U	0.06 U	0.06 U	0.06 U	0.06 U	0.06 U
P	-	-	0.14	0.042 A	0.044	0.038	0.039	0.037	0.038
PO_4	-	-	0.14	0.03 J	-	0.042 J	-	0.045 J	-
Metals									
Ca	73	68	68	73.3	76.5	68.2 A	70	73	74.3
K		1.1	0.2	0.61	0.68	0.65	0.67	0.64	0.68
Na		4.0	4.3	5.92	6.87	5.91 A	6.48	6.04	6.39
Mg	9.2	9.6	9.3	10.7	11.1	11.3 A	11.4	12	12.2
As	-	-	-	3 U	3 U	3 U	3 U	3 U	3 U
Al	-	-	-	-	75 U	-	75 U	-	75 U
B	-	-	0	25 U	-	25 U		25 U	-
Cd	-	-	0	0.75 U	0.75 U	0.75 U	0.75 U	0.75 U	0.75 U
Co	-	-	0	0.75 U	-	0.75 U	-	0.75 U	-
Cr	-	-	0	2 U	2 U	2 U	2 U	2 U	2 U
Cu	-	-	0	2.5 U	2.5 U	2.5 U	2.5 U	2.5 U	2.5 U
Fe	-	-	20	35 U	35 U	35 U	35 U	35 U	35 U
Mn	-	-	0	1 U	1 U	1 U	1 U	1 U	1 U
Ni	-	-	-	2 U	2 U	2 U	2 U	2 U	2 U
Pb	-	-	2	5 U	4 U	5 U	4 U	5 U	4 U
Se	-	-	-	4 U	4 U	4 U	4 U	4 U	4 U
Sn	-	-	-	10 U	-	10 U	-	10 U	-
Sr	-	-	500	693	-	676 A	-	782	-
Zn	-	-	1	5 U	5 U	5 U	5 U	12 I	5 U

A=Average Value U,K=Compound not detected, value shown is the method detection limit
I=Value is less than practical quantitation limit J=Estimated value Q=Exceeding holding time limit

An Information Circular was printed by the USGS (1971) providing flow characteristics and summaries of flows for selected Florida streams. The extremes reported for the Silver River for the period from 1932 to 1965 were a maximum of 3.16 hm^3/d (1,290 cfs) in October 1960 and a minimum of 1.32 hm^3/d (539 cfs) for May 1957. The maximum relative gage height recorded was 1.67 m (5.50 feet) in September 1933 and the minimum was -0.30 m (-0.99 feet) in June 1956.

The USGS (Phelps, 1994) compiled a report on the hydrogeology, water quality, and potential for contamination in the Silver Springs springshed. This report examined the influence of the karst geology on the potential for groundwater contamination, which could then affect Silver Springs. At the time of the study no major water quality problems were discovered.

Phelps (2004) published an updated evaluation of the Silver Springs springshed water chemistry with a special emphasis on nitrate nitrogen. She noted that the concentration of NO_3+NO_2-N at the Silver Spring Main Spring Boil had increased from about 0.5 mg/L to 1.0 mg/L in 2003. This water arises from the Upper Floridan Aquifer and elevated nitrogen concentrations are derived from nutrients leached from the ground surface. Sources for these nutrient inputs include atmospheric deposition, fertilizer applications on both agricultural and urban lands, and human and animal wastes. Groundwater sampled from wells in agricultural areas had the highest median NO_3+NO_2-N concentration (1.7 mg/L) while median nitrate concentrations in water collected from urban area wells (1.15 mg/L), and rangeland and forest area wells (0.09 mg/L) were lower. Two distinct nitrogen isotope values were detected in the Main Spring Boil at Silver Springs indicating that there are both fertilizer influences from agricultural and urban areas as well as inputs of organic nitrogen primarily from urban areas. A common insecticide (DEET) was frequently detected in wells and in Silver Springs discharge, indicating the likely influence of sanitary wastewater on the nitrogen content of these water samples. Typical estimated groundwater travel times to the springs that comprise the Silver Springs Group are less than 30 years, indicating that current groundwater contamination at the springs is of relatively recent origin.

Knowles (1996) reported on the evapotranspiration of the Silver Springs and Rainbow Springs basins. In this report a water budget analysis of the Silver Springs springshed was compiled including inflows and outflows. This analysis allowed for calculation of evapotranspiration for the area. The study included rainfall, change in aquifer storage, lake storage, spring flow, stream flow, and withdrawal from the Floridan Aquifer.

Detailed water quality and hydrological data for Silver Springs and the Silver River are available from the USEPA's online STORET database and USGS's National Water Information System (NWIS). The STORET and NWIS databases contain data collected at multiple stations located in or near the Silver River. These stations include monitoring stations at the Main Spring Boil, several secondary spring vents, and multiple downstream stations both in the Silver and Ocklawaha Rivers (Figure 3-1). Included in these measurements are water quality parameters for the Silver River and the surrounding area, including part of the Ocklawaha River. These databases also provide some historical data for water quality parameters at many of the same locations. Table 3-3 summarizes all of these historic data by decade. Statistics are reported in Appendix C. The only clear water quality trend evident in this data summary is a steady increase in nitrate-nitrogen concentrations from <0.1 mg/L in the early 1900s to about 1.0 mg/L in the latest decade.

Additional water quality data were received from Alan Biddlecomb of Jones Edmunds in Gainesville, Florida. Using two Hydrolab data sondes, Biddlecomb collected hourly field measurements of temperature, dissolved oxygen (DO), DO% saturation, pH, and specific conductance at the head spring from the two separate vents in May 1997. Biddlecomb's data indicate that there are two distinctly different water masses issuing from the Main Spring Boil. His "Left Vent" had an average DO of 1.18 mg/L and 13.7% saturation while his "Right Vent" had an average DO concentration of 3.34 mg/L and an average DO percent saturation of 39.2%. Temperature, pH, and specific conductance were also significantly different between the two vents (Figure 3-2). Biddlecomb's data also document the highly consistent quality of the groundwater issuing from this spring within the limited timeframe of his study. No diurnal patterns were observed for any of the field parameters recorded by Biddlecomb.

The USGS provided data for gage height and discharge of Silver Springs as early as 1932. Figure 3-3 illustrates data for gage height at the Silver Springs Boat Basin for the period from 1932 through 2004. Figure 3-4 illustrates the estimated Silver River discharge data for the same period. For this dataset, stream flow averaged 1.91 hm^3/d (779 cfs) and relative gage height averaged 0.35 m (1.14 ft). Both of these plots appear to have a downward trend over this period-of-record with an observed average decline of about 19% for discharge between 1932 and 2004.

Figure 3-5 illustrates the available annual average rainfall data reported by the National Climatic Data Center for the nearby City of Ocala weather station between 1948 and 2001. Rainfall data since 2001 are from the FAWN Ocklawaha station and the WSI 2004 total from the Silver River State Park is also shown for comparison. Average annual rainfall declined over this shorter period-of-record by about 20%. This declining rainfall trend may adequately explain the declining trend in stream discharge in the Silver River during this period-of-record.

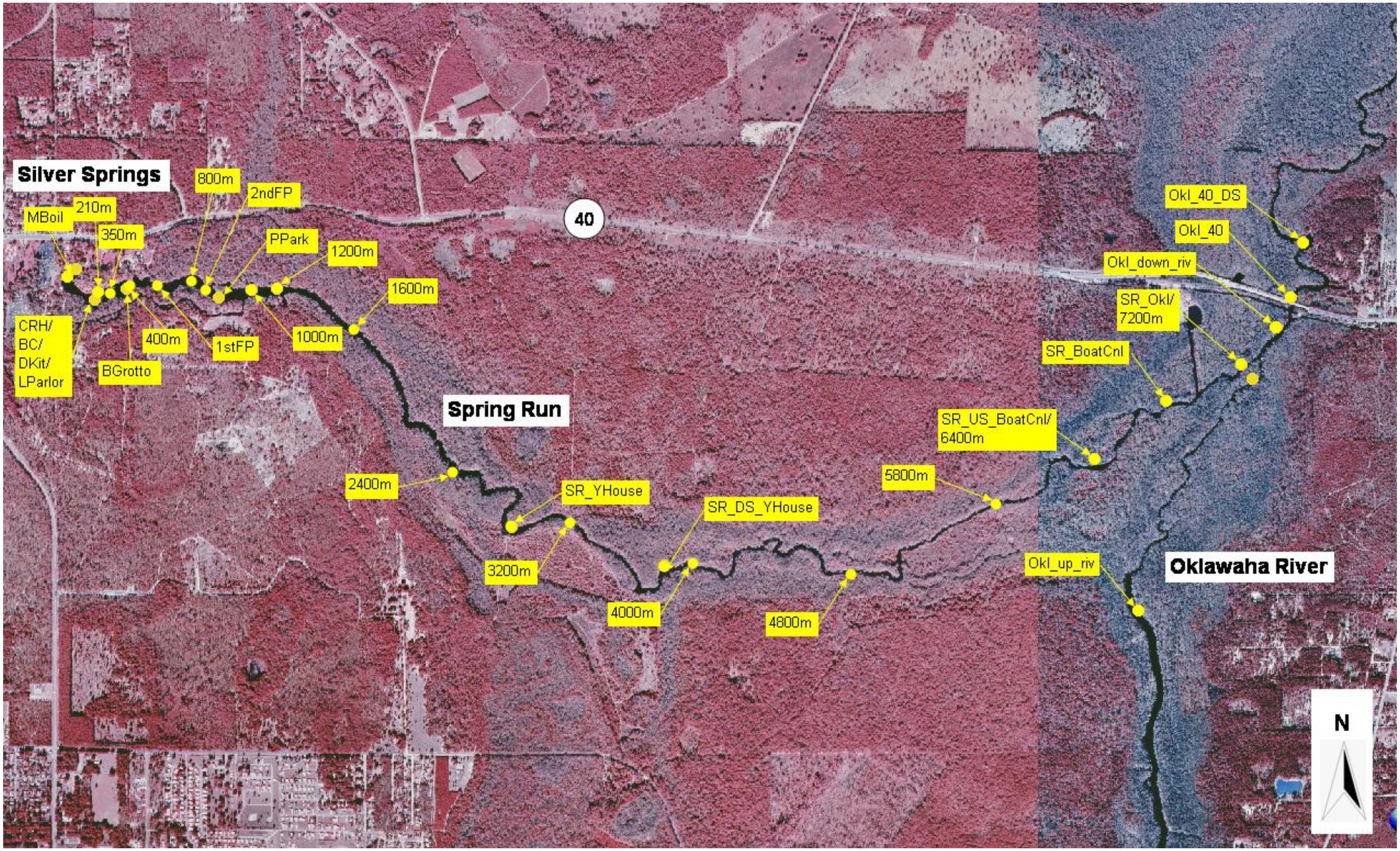


Figure 3-1 Historic water quality stations in Silver Springs and the Silver River

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
Temperature	WTemp (C)	SS_MBoil	23.1	23.3	23.2	23.6	23.0	23.2
		SR<1200m		23.7	23.5	23.9		23.4
		SR>1200m			23.3	23.1	23.1	23.3
		SR_Okl				22.7	21.5	23.7
		Okl_down			24.4	22.7	22.4	24.6
		Okl_up				21.1	28.5	25.6
Physical	Color (CPU)	SS_MBoil	8.00	1.09	2.70	1.25	3.33	2.34
		SR<1200m		0.259		6.00		2.22
		SR>1200m			37.3	6.46	7.95	0.00
		SR_Okl				10.9	30.0	10.0
		Okl_down			36.7	29.4	48.9	
		Okl_up				110	80.0	200
	Cond (uS/cm)	SS_MBoil			466			446
		SR<1200m			462			440
	Depth (m)	SS_MBoil						5.10
		SR<1200m						3.08
		SR_Okl				2.20	3.00	
		Okl_down				6.80	2.87	
	pH (SU)	SS_MBoil	7.54	7.50	6.75	7.52	7.65	7.34
		SR<1200m		7.50	6.60	7.79		7.42
		SR>1200m			7.68	7.83	7.58	7.48
		SR_Okl				7.38	6.97	7.48
		Okl_down			7.67	7.56	7.26	7.32
		Okl_up				7.41	7.34	7.00
	SpCond (uS/cm)	SS_MBoil	425	403	419	428	466	453
		SR<1200m		398		3,499		442
		SR>1200m			379	409	419	400
		SR_Okl				393	432	411
		Okl_down			369	384	413	349
		Okl_up				335	289	286
	Turb (JTU)	SS_MBoil		0.222	0.789			
		SR<1200m		0.219				
		SR>1200m			26.1	25.0		
		Okl_down			26.4			
	Turb (NTU)	SS_MBoil			1.00	0.767		0.108
		SR<1200m				0.853		0.123
		SR>1200m				0.664	0.702	0.060
		SR_Okl				0.727	0.800	1.14
		Okl_down				1.87	2.08	
		Okl_up				7.02	21.0	6.70
	Turb SiO2 (ppm as SiO2)	SS_MBoil		1.96				

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
Oxygen Demand	BOD (mg/L)	SS_MBoil		0.635	0.427	0.600		0.100
		SR<1200m		0.834		0.429		0.100
		SR>1200m			2.10	0.331	0.495	
		SR_Okl				1.07		
		Okl_down			1.60	1.11	0.543	
		Okl_up				2.28		
	BOD5 (mg/L)	SS_MBoil						0.100
		SR<1200m						0.100
Dissolved Oxygen	DO (%)	SS_MBoil		27.9	34.7	33.0	26.4	26.2
		SR<1200m		42.6		63.6		43.2
		SR>1200m			54.4	61.0	63.3	
		SR_Okl				56.9	56.6	
		Okl_down			63.8	54.4	49.2	
		Okl_up				46.6	34.2	
	DO (mg/L)	SS_MBoil	2.53	2.40	2.37	3.63	2.26	2.13
		SR<1200m	3.81	3.64	4.14	5.20		3.55
		SR>1200m			4.69	5.31	6.10	4.76
		SR_Okl				4.99	5.09	4.37
		Okl_down			5.40	4.79	4.56	4.09
		Okl_up				4.36	2.70	2.55
General Inorganic	Acid (mg/L as CaCO3)	SS_MBoil		5.60		166	179	185
		SR<1200m		5.67				
		SR>1200m			3.55			
		Okl_down			4.30			
	Alk (mg/L as CaCO3)	SS_MBoil	182	146	165	171		184
		SR<1200m	144	151		151		163
		SR>1200m			123	150	154	
		SR_Okl				138	149	157
		Okl_down			132	137	147	
		Okl_up				103	95.9	
	Cl-D (mg/L)	SS_MBoil	9.50					9.90
		SR<1200m	8.70					10.0
	Cl-T (mg/L)	SS_MBoil	12.0	10.0	9.28	10.3	9.83	10.2
		SR<1200m		9.25		11.7		10.3
		SR>1200m			12.0	11.3	9.19	9.10
		SR_Okl				10.4	11.0	52.5
		Okl_down			16.5	15.7	12.1	
		Okl_up				30.9	26.0	33.0
	CO2 (mg/L)	SS_MBoil	9.15	5.93	8.70	26.0		
	F-D (mg/L)	SS_MBoil		0.250	0.253	0.200	0.200	0.197
		SR<1200m						0.176

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
	F-T (mg/L)	SS_MBoil						0.188
		SR<1200m						0.172
		SR>1200m			0.175	0.171		
		Okl_up						0.200
General Inorganic	HARD (mg/L as CaCO3)	SS_MBoil	220	208	212	215		228
		SR<1200m	205					
		SR>1200m			162		217	
		SR_Okl				189		210
		Okl_down				170	191	
	SI-D (mg/L)	SS_MBoil	11.0	10.3	9.93	10.1	10.1	10.2
		SR_Okl						10.4
	SI-T (mg/L)	SS_MBoil						10.6
		SR<1200m						10.1
		SR>1200m						9.95
		SR_Okl						8.91
		Okl_down						8.37
		Okl_up						6.57
	SO4 (mg/L as SO4)	SS_MBoil	45.0	40.5	41.2	45.0	39.5	45.3
		SR<1200m				51.8		66.4
		SR>1200m			43.0	51.1	51.5	49.0
		SR_Okl				45.5	63.0	226
		Okl_down				44.9	42.6	
		Okl_up				35.4	12.0	12.0
	SO4-D (mg/L as SO4)	SS_MBoil						43.4
		SR<1200m						69.7
General Organic	TOC (mg/L)	SS_MBoil		4.00	1.82	0.380	0.050	0.481
		SR<1200m						0.500
		SR>1200m			7.50	3.06	0.885	
		SR_Okl					7.60	3.72
		Okl_down					6.00	
		Okl_up						28.0
Solid	TDS (mg/L)	SS_MBoil	267	264	257	259	289	275
		SR<1200m						283
		SR_Okl				247	276	264
		Okl_down			280	267	246	
		Okl_up						229
	TSS (mg/L)	SS_MBoil						1.71
		SR<1200m				2.27		2.17
		SR>1200m			5.38	2.83	0.919	
		SR_Okl				2.67	2.00	5.07
		Okl_down			13.7	5.21	3.21	
		Okl_up				13.5		15.0

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
Nitrogen	DN (mg/L)	SS_MBoil						1.17
		SR<1200m						1.26
		SR>1200m						1.16
		SR_Okl						1.29
		Okl_down						1.37
		Okl_up						1.86
Nitrogen	NH3 (mg/L as NH3)	SS_MBoil						0.005
		SR<1200m						0.012
		SR>1200m					0.008	0.017
		Okl_down					0.038	
		Okl_up						1.10
	NH3-N (mg/L)	SS_MBoil		0.00				
		SR<1200m				0.001		
		SR>1200m			0.0009	0.0008	0.0003	
		SR_Okl				0.0003	0.0001	
		Okl_down			0.002	0.0007	0.0006	
		Okl_up				0.003	0.006	
	NH4-D (mg/L as NH4)	SS_MBoil		0.020	0.313			
	NH4-N (mg/L)	SS_MBoil		0.00	0.014	0.018	0.009	0.009
		SR<1200m				0.060		0.011
		SR>1200m			0.075	0.030	0.015	
		SR_Okl				0.022		0.045
		Okl_down			0.110	0.101	0.103	
		Okl_up				0.250	0.300	
	NH4-N-D (mg/L)	SS_MBoil		0.017	0.287			0.007
		SR<1200m						0.007
		SR_Okl				0.039	0.026	0.007
		Okl_down				0.030		
	NO2-N (mg/L)	SS_MBoil		0.00	0.006	0.006	0.007	0.005
		Okl_down			0.017			
	NO2-N-D (mg/L)	SS_MBoil		0.012	0.089			0.005
		SR>1200m			0.006			
	NO2-T (mg/L as NO2)	SS_MBoil			0.00			
	NO2-T (mg/L)	SS_MBoil	0.002					
		SR<1200m	0.00					
	NO3-D (mg/L as NO2)	SS_MBoil		0.040	0.255			
	NO3-D (mg/L as NO3)	SS_MBoil	0.600	2.19	2.55			
	NO3-N (mg/L)	SS_MBoil		0.360	0.566	0.720		1.03
		SR<1200m						1.20
		SR>1200m						1.07
		SR_Okl						0.845
		Okl_down			0.560			0.703
		Okl_up						0.156

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
	NO3-N-D (mg/L)	SS_MBoil	0.140	0.621	0.563			
		SR>1200m			0.337			
	NO3-T (mg/L as NO3)	SS_MBoil			1.10			
	NO3-T (mg/L)	SS_MBoil	0.453					
Nitrogen	NOx-N (mg/L)	SS_MBoil			1.04	0.847	0.988	1.00
		SR<1200m				0.766		1.28
		SR>1200m			0.478	0.785	0.948	0.936
		SR_Okl				0.764		0.893
		Okl_down				0.688	0.827	
		Okl_up				0.186	0.021	0.041
	NOX-N-D (mg/L)	SS_MBoil						1.01
		SR<1200m						1.32
		SR_Okl					0.960	0.950
	TKN (mg/L)	SS_MBoil			0.075	0.152	0.100	0.088
		SR<1200m				0.089		0.063
		SR>1200m			0.352	0.122	0.080	0.098
		SR_Okl				0.297	0.340	0.361
		Okl_down				0.498	0.634	
		Okl_up				2.16	3.40	3.80
	TKN-D (mg/L)	SS_MBoil						0.060
		SR<1200m						0.049
		SR_Okl				0.370	0.270	0.128
		Okl_down				1.10		
	TN (mg/L)	SS_MBoil			0.995	0.845		1.25
		SR<1200m						1.32
		SR>1200m						1.19
		SR_Okl						1.35
		Okl_down						1.46
		Okl_up						2.06
	TON (mg/L)	SS_MBoil		0.045	0.176	0.095		
		SR<1200m				0.120		
		SR>1200m			0.840	0.050		
		Okl_down			0.913	0.560		
		Okl_up				1.51		
Phosphorus	DP (mg/L)	SS_MBoil						0.044
		SR<1200m						0.042
		SR_Okl				0.048	0.047	0.036
		Okl_down				0.048		
	IPO4 (mg/L)	SS_MBoil	0.053					
		SR<1200m	0.049					
	OrthoP (mg/L)	SS_MBoil		0.035	0.042	0.042	0.040	0.044
		SR<1200m						0.044
		SR>1200m			0.055			0.039
		SR_Okl				0.039	0.039	0.034
		Okl_down			0.035	0.042	0.028	0.025

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
		Okl_up						0.013
	Ortho-PO4 (mg/L as PO4)	SS_MBoil		0.155	0.122			
		SR>1200m					0.044	0.038
		SR_Okl						0.029
		Okl_down			0.030		0.048	
Phosphorus	TP (mg/L)	SS_MBoil		0.010	0.045	0.050	0.042	0.045
		SR<1200m				0.045		0.052
		SR>1200m			0.054	0.044	0.038	0.050
		SR_Okl				0.054	0.051	0.046
		Okl_down			0.100	0.066	0.112	0.052
		Okl_up				0.078	0.120	0.066
	TPO4 (mg/L as PO4)	SS_MBoil	0.047	0.140	0.146			
	TSP (mg/L)	SS_MBoil						0.054
		SR<1200m						0.048
		SR>1200m						0.048
		SR_Okl						0.042
		Okl_down						0.037
		Okl_up						0.036
Bacteriological	Bacteria (col/cc)	SS_MBoil	99.0					
		SR<1200m	988					
	Ecoli (#/100ml)	SS_MBoil						5.00
		SR<1200m						33.3
		Okl_up						48.0
	Enterococcus (#/100ml)	SS_MBoil			30.0			40.4
		SR<1200m						14.2
		Okl_up						200
	FColi (#/100ml)	SS_MBoil			7.14			2.74
		SR<1200m						29.5
		SR>1200m			54.5	42.4	48.0	68.7
		Okl_down					93.2	
		Okl_up						80.0
	TColi (#/100ml)	SS_MBoil		110	145			50.4
		SR<1200m		306				70.2
		SR>1200m			293	158	550	1,489
		Okl_down			460		3,000	
		Okl_up						560
Biological	Chl a (ug/L)	SS_MBoil	0.267					0.050
		SR>1200m			4.23	1.71	0.874	4.63
		SR_Okl				1.68	3.19	4.09
		Okl_down				6.16	10.4	
		Okl_up						11.0
	Chl a corr (ug/L)	SR<1200m				0.812		
		SR>1200m				1.41	1.13	
		SR_Okl				0.891	2.41	3.69
		Okl_down				3.94	7.93	

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
		Okl_up				22.7		
	Chl b (ug/L)	SR>1200m			0.535	0.278		
		SR_Okl				0.446	0.015	0.320
		Okl_down				0.648	0.363	
Biological	Chl c (ug/L)	SR>1200m			1.60	0.688		
		SR_Okl				0.956	0.075	0.201
		Okl_down				0.970	1.27	
	Pheo a (ug/L)	SR<1200m				0.958		
		SR>1200m			0.852	0.699	1.04	3.68
		SR_Okl				2.47	1.15	0.548
		Okl_down				3.49	4.91	
		Okl_up				7.98		0.00
Metal	Ag-T (ug/L)	SS_MBoil				0.500		
		SR>1200m					1.50	
		Okl_down					0.103	
	Al-D (ug/L)	SS_MBoil						4.38
		SR<1200m						4.38
		SR>1200m					25.0	
	Al-T (ug/L)	SS_MBoil			0.00	5.00	5.00	12.1
		SR<1200m						12.1
		SR_Okl						29.0
		Okl_down					74.4	
	As-D (ug/L)	SS_MBoil			0.00	0.500		2.40
		SR<1200m						3.29
	As-T (ug/L)	SS_MBoil			0.778	1.70	0.500	2.57
		SR<1200m						2.57
		SR>1200m					10.0	
		SR_Okl						1.01
		Okl_down					1.32	
	Ba-T (ug/L)	SS_MBoil				50.0		3.10
		SR<1200m						4.26
		SR_Okl						5.65
		Okl_down					8.86	
	B-D (ug/L)	SS_MBoil						20.8
		SR<1200m						21.4
	Be-T (ug/L)	SR>1200m					0.250	
	B-T (ug/L)	SS_MBoil						15.4
		SR<1200m						15.9
	Ca-D (mg/L)	SS_MBoil	72.0	67.3	69.0	71.5	73.7	75.7
		SR<1200m						75.8
		SR_Okl				61.5		
		Okl_down				53.7		
	Ca-T (mg/L)	SS_MBoil						76.5
		SR<1200m						74.6
		SR>1200m			49.6			

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
		SR_Okl						67.6
		Okl_down					59.2	
		Okl_up						40.3
Metal	Cd-D (ug/L)	SS_MBoil			0.00			0.275
		SR<1200m						0.275
	Cd-T (ug/L)	SS_MBoil			0.800	0.500	0.500	0.339
		SR<1200m						0.339
		SR>1200m			4.00	0.200	0.850	
		SR_Okl						0.070
		Okl_down					0.306	
	Co-D (ug/l)	SS_MBoil			0.00			0.600
		SR<1200m						0.438
	Co-T (ug/L)	SS_MBoil			0.00			0.542
		SR<1200m						0.542
	Cr-D (ug/L)	SS_MBoil						1.00
		SR<1200m						1.31
	Cr-H (ug/l)	SS_MBoil			0.00			
	Cr-T (ug/L)	SS_MBoil			3.33	0.500		1.07
		SR<1200m						1.64
		SR>1200m			70.0	15.0	5.00	
		SR_Okl						0.772
		Okl_down					0.967	
	Cu-D (ug/L)	SS_MBoil			3.14	0.500	0.500	1.65
		SR<1200m						1.65
	Cu-T (ug/L)	SS_MBoil			0.00			1.75
		SR<1200m						1.75
		SR>1200m			139	12.5	2.50	
		Okl_down					1.69	
	Fe-D (ug/L)	SS_MBoil		0.00	9.62	12.0	10.0	7.50
		SR<1200m						7.50
		SR_Okl				62.2		
		Okl_down				59.5		
	Fe-T (ug/L)	SS_MBoil			29.0	44.0	20.0	10.5
		SR<1200m						13.5
		SR>1200m			77.0	57.5	2.00	
		SR_Okl						24.2
		Okl_down					71.4	
	Hg-D (ug/l)	SS_MBoil			0.100			
	Hg-T (ug/L)	SS_MBoil			0.175	0.083	0.050	
		SR>1200m			0.110	0.120	0.075	

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
	K-D (mg/L)	SS_MBoil	0.500	1.55	0.540	0.550	0.600	0.587
		SR<1200m						0.647
		SR_Okl				0.550		
		Okl_down				1.40		
Metal	K-T (mg/L)	SS_MBoil						0.596
		SR<1200m						0.621
		SR>1200m			1.13			
		SR_Okl						1.12
		Okl_down					1.94	
		Okl_up						7.10
	Mg-D (mg/L)	SS_MBoil	9.40	36.3	9.03	9.33	9.00	9.74
		SR<1200m						11.9
		SR_Okl				9.37		
		Okl_down				10.9		
	Mg-T (mg/L)	SS_MBoil						10.2
		SR<1200m						11.4
		SR>1200m			9.27			
		SR_Okl						10.1
		Okl_down					9.90	
		Okl_up						10.8
	Mn-D (ug/L)	SS_MBoil		0.00	4.09	5.10	10.0	0.225
		SR<1200m						0.225
	Mn-T (ug/L)	SS_MBoil			10.5	8.00	10.0	0.286
		SR<1200m						0.321
		SR>1200m					0.500	
		SR_Okl						2.91
		Okl_down					7.19	
	Na-D (mg/L)	SS_MBoil	7.50	23.5	6.03	5.95	5.83	6.29
		SR<1200m						6.37
		SR_Okl				6.18		
		Okl_down				7.03		
	Na-T (mg/L)	SS_MBoil						6.35
		SR<1200m						6.26
		SR>1200m			6.27			
		SR_Okl						7.16
		Okl_down					7.08	
		Okl_up						14.9
	Ni-D (ug/L)	SS_MBoil						0.900
		SR<1200m						0.900
	Ni-T (ug/L)	SS_MBoil			1.00	0.500	0.500	1.11
		SR<1200m						1.74
		SR>1200m					2.50	
		SR_Okl						1.06
		Okl_down					3.89	
	Pb-D (ug/L)	SS_MBoil			50.0	1.00	2.00	4.02

Table 3-3 Silver Springs historic water quality summary

Group	Parameter Units	Location	1950	1960	1970	1980	1990	2000
		SR<1200m						2.96
Metal	Pb-T (ug/L)	SS_MBoil			100	1.17	4.00	2.43
		SR<1200m						2.64
		SR>1200m			10.0	3.18	0.825	
		SR_Okl						0.440
		Okl_down					1.43	
	Se-D (ug/L)	SS_MBoil				0.500		3.10
		SR<1200m						3.10
	Se-T (ug/L)	SS_MBoil						2.93
		SR<1200m						2.93
		SR>1200m					15.0	
		SR_Okl						0.906
		Okl_down					8.27	
	Sn-D (ug/L)	SS_MBoil						14.5
		SR<1200m						15.1
	Sn-T (ug/L)	SS_MBoil						6.83
		SR<1200m						6.83
	Sr-D (ug/L)	SS_MBoil		615	593	622	545	561
		SR<1200m						823
	Sr-T (ug/L)	SS_MBoil						606
		SR<1200m						775
	Tl-T (ug/L)	SR>1200m					25.0	
	Zn-D (ug/L)	SS_MBoil			42.9	80.4	10.0	3.08
		SR<1200m						3.38
	Zn-T (ug/L)	SS_MBoil			0.00			2.51
		SR<1200m						3.84
		SR>1200m			82.5	14.2	2.50	
		SR_Okl						1.67
		Okl_down					10.9	

Notes:
SS_Mboil = Silver Springs Main Spring Boil
SR<1200m = All Stations < 1200 meters from Main Spring Boil (does not include Main Spring Boil)
SR>1200m = All Stations > 1200 meters from Main Spring Boil (does not include Main Spring Boil)
SR_Okl = Spring Run Station before confluence with the Ocklawaha River
Okl_down = Ocklawaha Station downstream of Spring Run confluence
Okl_up = Ocklawaha Station upstream of Spring Run confluence
Averages calculated using one half the detection limit when reported as below detection limit

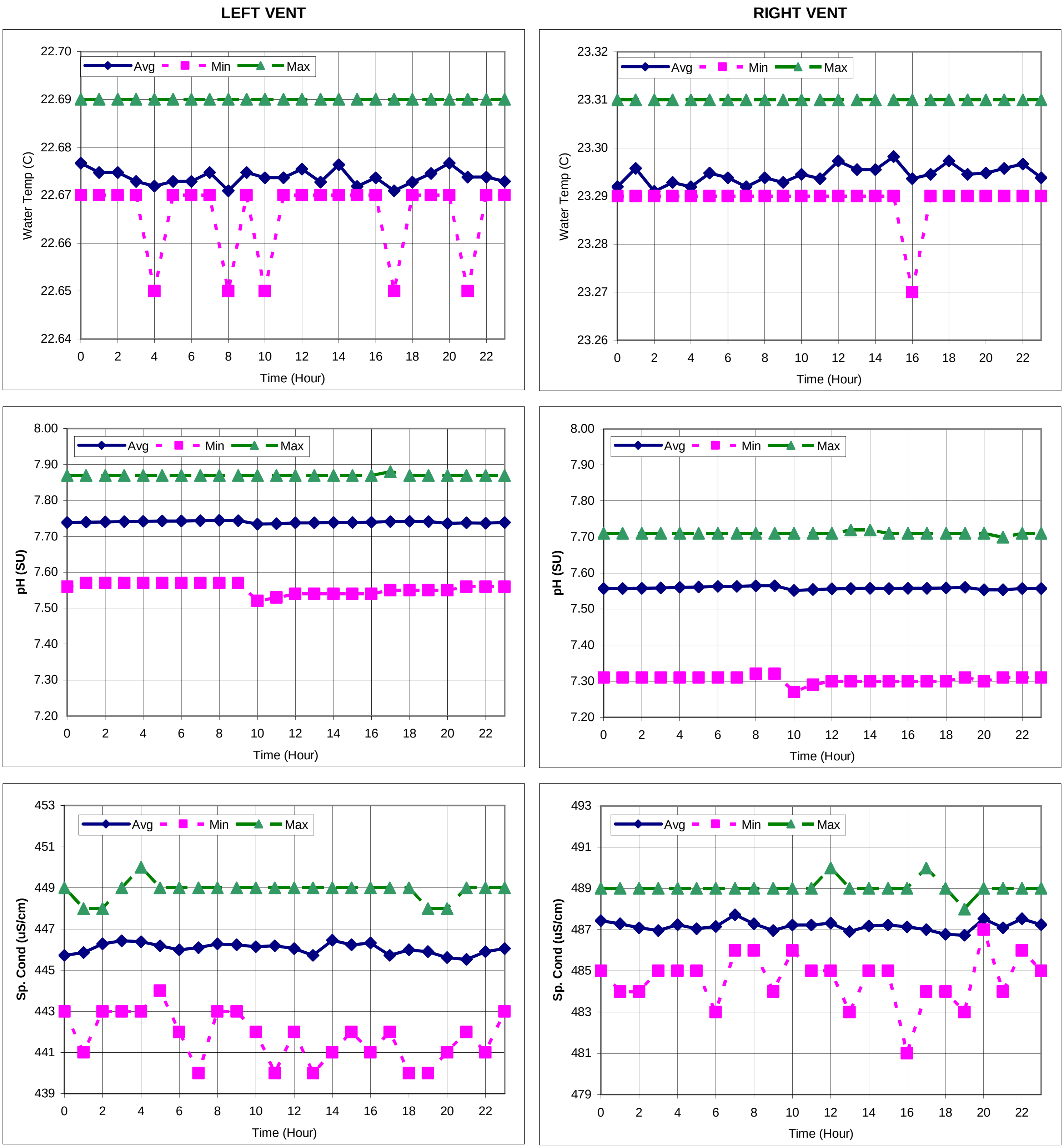
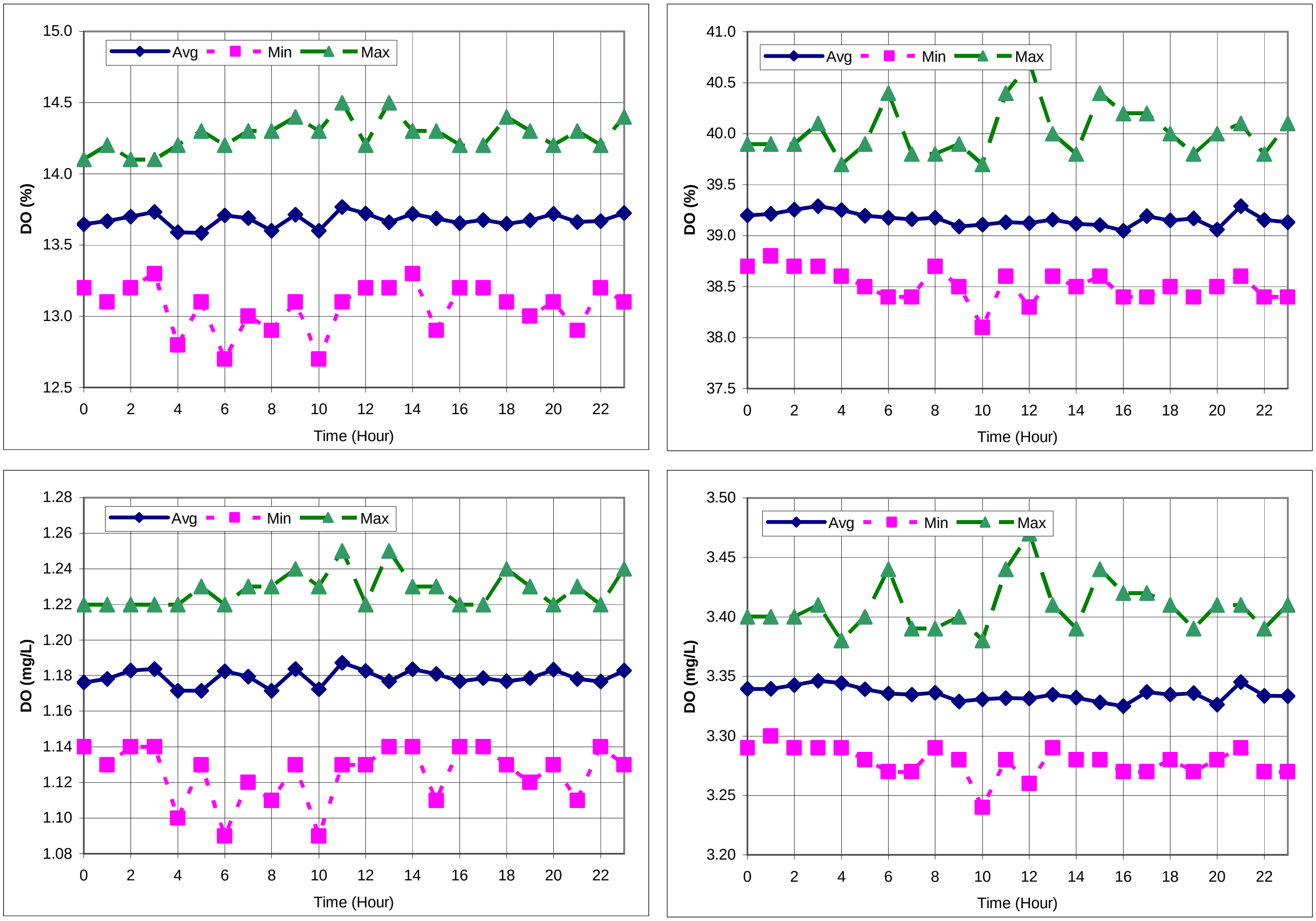


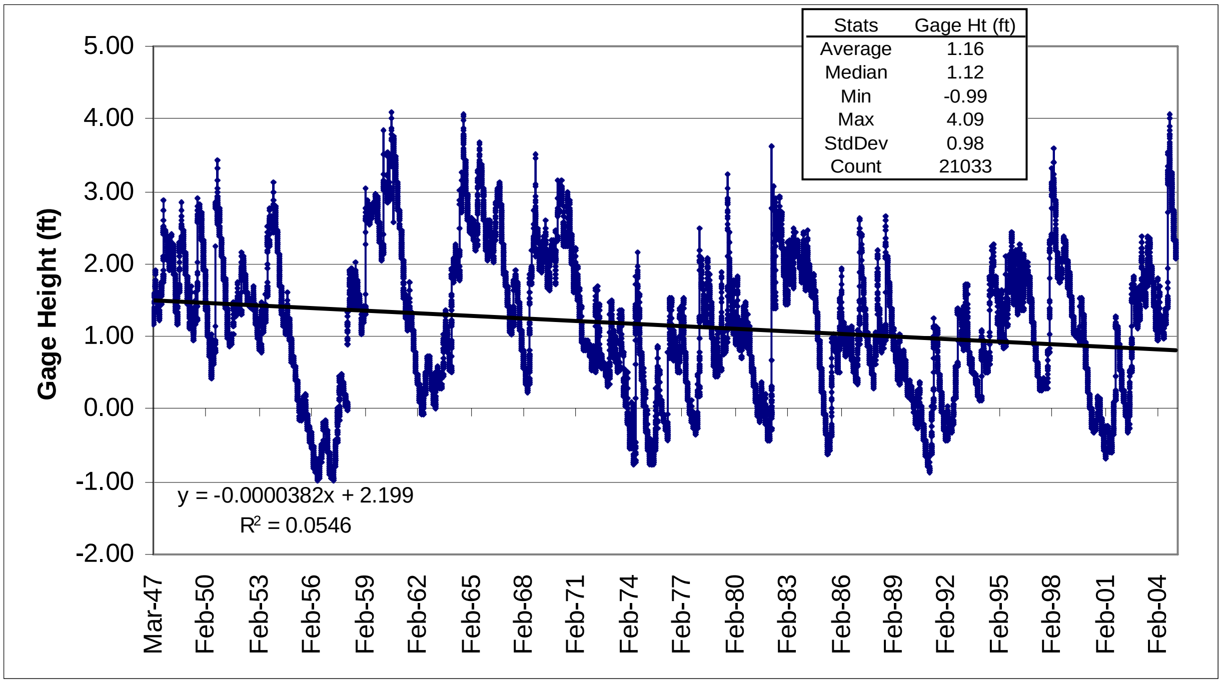
Figure 3-2 Diurnal summary of field parameters measured hourly for twenty-one days at two discrete vents in Silver Springs Main Spring Boil during May 1997

LEFT VENT RIGHT VENT



Source: Biddlecomb, unpublished data

Figure 3-2 (cont.)



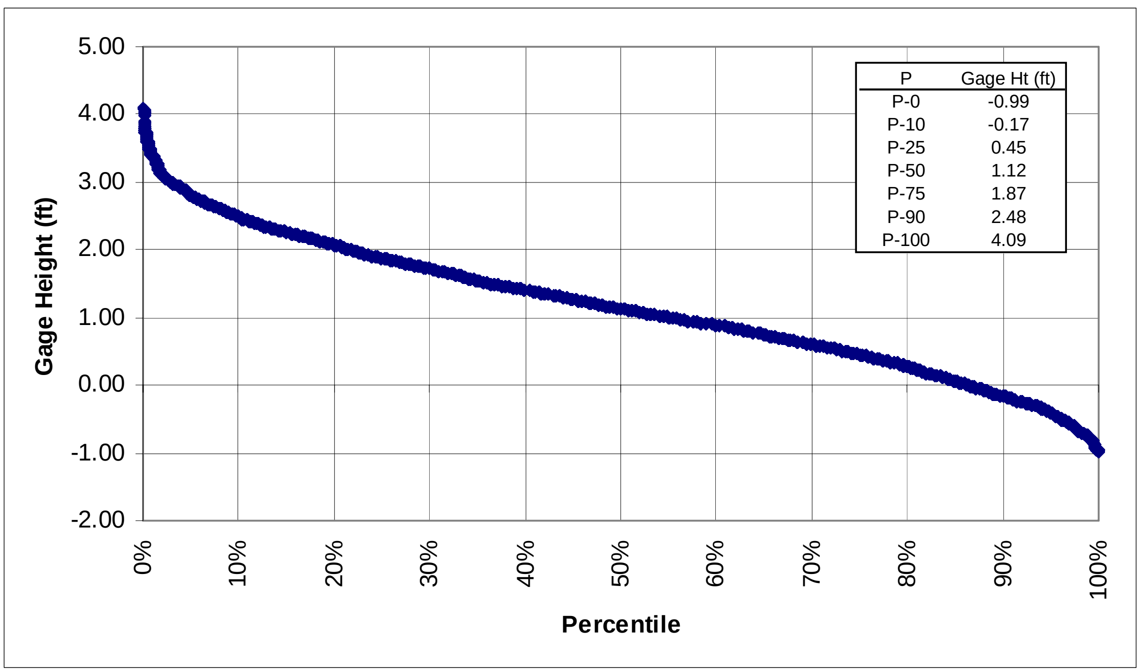
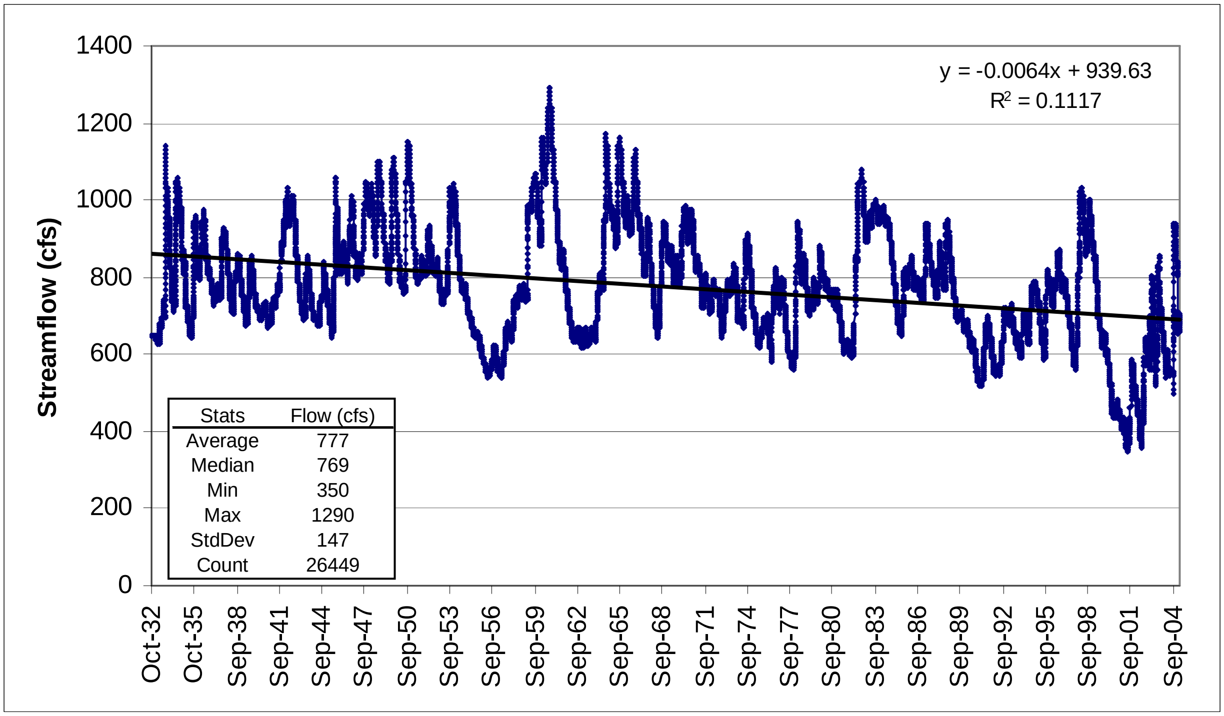


Figure 3-3 Silver Springs USGS 02239500 gage height (1947 – 2005)



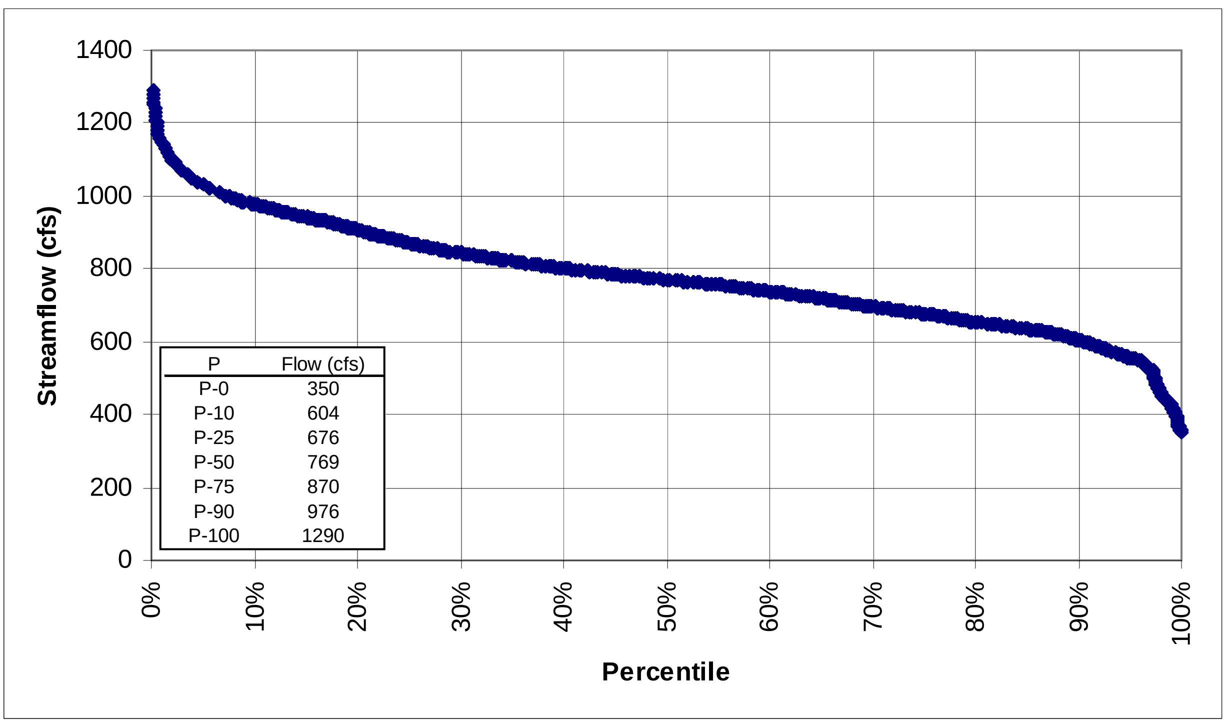


Figure 3-4 Silver Springs USGS 02239500 streamflow (1932 – 2005) (Note: 10/03 – 2/05 preliminary data)

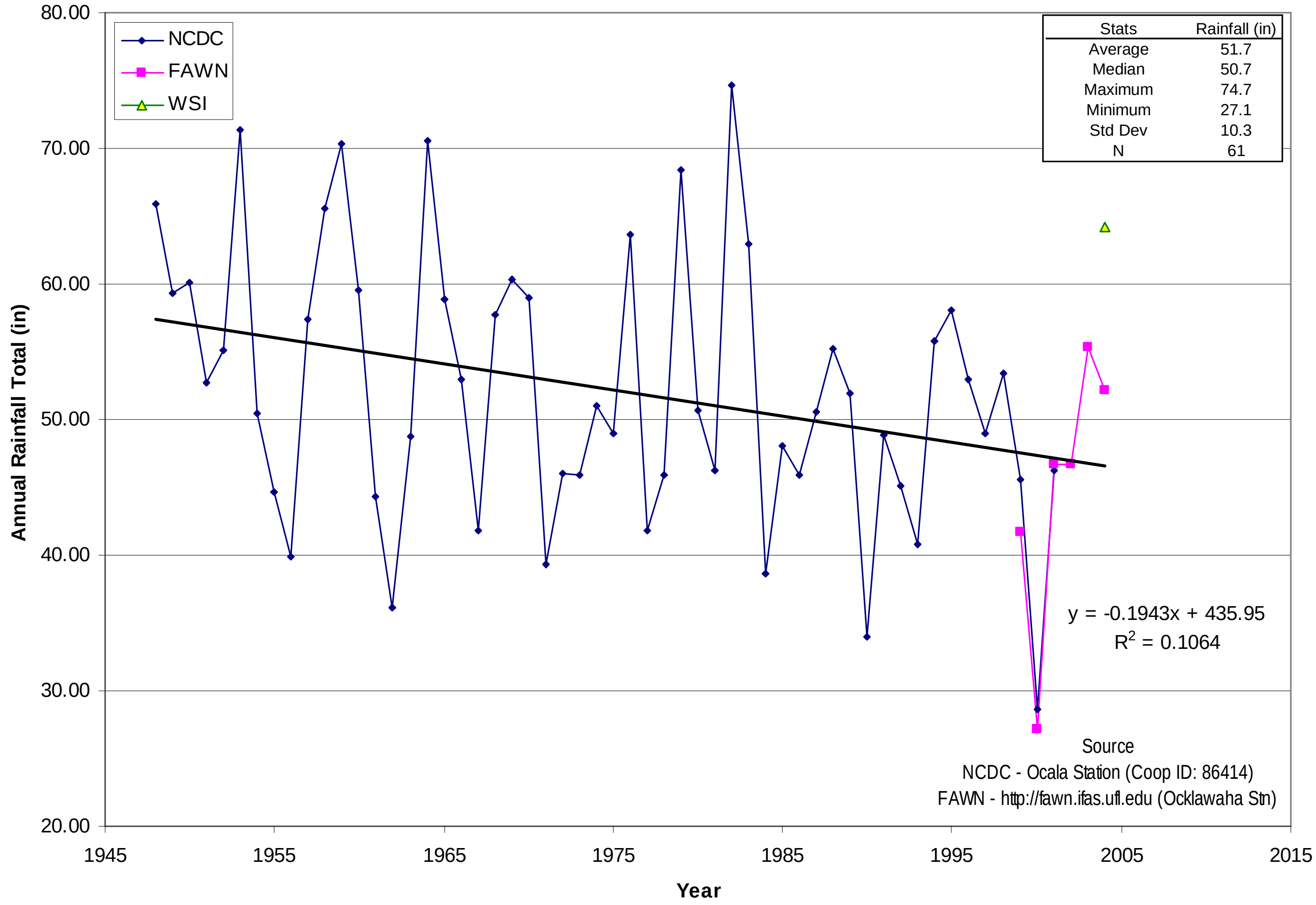


Figure 3-5 Historic Annual Rainfall Totals in Ocala, Florida (1948 – 2004)

3.4 Algae and Macrophytes

Whitford (1954, 1956) examined the different algae species common in spring runs and boils in Florida. He specifically examined Silver Springs and found similar communities to those found in other springs in Florida. In all of the springs examined by Whitford, 107 species of algal flora were identified, and five types of springs were identified. Each type of spring had different flora and water quality characteristics. Silver Springs was identified as a hard, freshwater spring. The dominant algal taxa in Silver Springs were identified as *Cocconeis placentula*, *Synedra ulna*, *Achnanthes lanceolata*, *Gomphonema longiceps*, *Gomphonema sphaerophorum*, *Amphitrix* sp., and *Plectonema wollei (*also known as *Lyngbya wollei)*. The most important controlling factor for the distribution of algal plant communities in springs was identified as water velocity rather than temperature or light effects.

Martin (1969) described the plants of Silver Springs. He specifically mentioned dense filamentous growths of the alga *Spirogyra* in the Main Spring Boil and *Lyngbya* attached to exposed surfaces in the Main Spring Boil.

Stevenson (2004) conducted a survey of the condition of algae as related to nutrient levels in twenty-eight springs in north and central Florida. The purpose of this study was to provide a systematic comparison of algal communities in these springs and to relate those communities to macro-nutrient (nitrogen and phosphorus) concentrations in those springs. Five sampling locations were selected in the Silver River starting at the Main Spring Boil, downstream in the Devils Kitchen area, at the Birds of Prey site near the 1,200-m station, and at two points farther downstream. Water quality and algae were quantified along nine transects at each station during the spring and fall of 2003. Dominant macroalgae in this portion of the Silver River were reported to be *Lyngbya majuscula*, *Vaucheria* sp., *Rhizoclonium hieroglyphicum*, and *Oscillatoria* sp. Macroalgae were observed in 19% of the Main Spring Boil sampling points with an average thickness of 0.8 cm. At Devil's Kitchen macroalgae occurred in 51% of the sampling points with an average thickness of 9.8 cm. At the Birds of Prey transects macroalgae was observed at 34% of the sampling points and had an average thickness of 6.5 cm. General conclusions in this study of twenty-eight springs were that macroalgae are found in all springs (including low nutrient sites such as Alexander Springs) and covered about half of the bottom area of all springs studied. *Vaucheria* and *Lyngbya* were the two most common macroalgae species observed. Percent cover by *Vaucheria* was related to total nitrogen concentrations in these springs but no similar relationship was found for *Lyngbya*. Traditional diatom indicators of water quality were not found to be predictive of spring nutrient conditions.

3.5 Fish and Mussels

Ross Allen, the well-known herpetologist at Silver Springs, wrote a book titled *Fishes of Silver Springs, Florida* (Allen, 1946). This book contains information on most of the species of fish that occur in the spring run. Detailed descriptions of many of the fish are given, as well as pictures of many more common species.

There is literature on many other Florida springs and much of the literature for springs in general is directly applicable to Silver Springs. Odum and Caldwell (1955) and Caldwell *et al.* (1955, 1956) described fish respiration in an anaerobic Florida spring. Beecher Spring, the setting for their study, is an anaerobic spring located in Welaka, Florida. For this study oxygen tension of the spring water was related to the density and species makeup of fish. This study provides insight into the diffusion of oxygen into springs and the release of oxygen by photosynthetic organisms.

Walsh and Williams (2003) surveyed fish and mussel populations in springs and spring runs in sixteen state parks and trustee-owned lands in north central Florida. Their study was designed to provide a baseline inventory for comparison and analysis of differences in fish and mussel populations between springs and for future reference. Fish were sampled by electroshocking, seines, dip nets, and underwater observation with mask and snorkel. Snorkeling, dip nets, and hand grubbing techniques were used to collect live and dead mussels. Museum data were also reviewed to establish occurrence of other fish and mussel species in individual springs. Museum collections included ninety-nine fish species from Florida springs. The most common species in these collections was the redeye chub (*Notropis harperi*), which has a recognized close association with spring habitats. Fish families in museum collections in order of abundance were minnow (Cyprinidae), sunfishes and basses (Centrarchidae), topminnows and livebearers (Fundulidae and Poecillidae), and seven other families. During their own sampling, Walsh and Williams (2003) collected seventy-nine fish species, with twenty-nine species collected in Silver Springs and the Silver River. The Silver River Museum collection includes twenty-two species. Hubbs and Allen (1943) reported twenty-five fish species. A combined species total for the Silver River is forty-one different fish. Walsh and Williams (2003) found a new exotic fish species established in Silver Springs, the vermiculated sailfin catfish (*Pterygoplichys disjunctivus*) introduced from South America. The redeye chub was the dominant fish in the museum collections and in the Walsh and Williams collections from the Silver River.

Mussels had relatively low population densities in the Silver River (Walsh and Williams 2003). Five species of native unionid mussels were collected in the Silver River. The non-indigenous Asiatic clam (*Corbicula fluminea)* was relatively common in the Silver River.

3.6 Ecological Studies

3.6.1 H.T. Odum's Ecosystem Studies

The first large scale study of Silver Springs was performed by Howard T. Odum (1957) of the University of Florida. In the period from 1951 to 1955 Odum completed the first comprehensive ecological assessment of Silver Springs and the upper 1,200 m of the Silver River system. This research was funded in part by a contract with the United States Office of Naval Research and in part by the University of Florida. During this period, Odum and his colleagues studied the productivity of several Florida springs. Silver Springs received a large portion of the attention of Odum's research. Odum examined the physical and chemical water quality of Silver Springs, the biological community, the trophic structure of the aquatic ecosystem, energy flows, and overall system metabolism (primary productivity and ecosystem respiration). A list of the parameters, sampling methods, and sampling locations used during Odum's study is provided in Table 3-4. Internal reports and references generated by Odum and his colleagues include the following: Nateleson (1955), Odum (1953; 1954a,b; 1955a,b,c,d; and 1956b,c,d), Odum and Johnson (1955), Odum and Yount (1955), Yount (1955, 1956a,b), and Yount and Odum (1956). Available copies of Odum's original field notes, spring diagrams, and Navy progress reports are provided as Appendix D.

In his water quality assessment Odum examined temperature, dissolved oxygen (DO), carbon dioxide, nutrients, metals, pH, clarity, light, and bacterial counts. When possible Odum compared the values he measured with historical conditions from previous reports.

The focus area was the upper 1,200 m of the river below the Main Spring Boil. Table 3-5 summarizes the water quality parameters that were measured by Odum at the Main Spring Boil, several side vents, and at the 1,200-m station.

In order to study the Silver Springs biological community Odum's research team counted and characterized the flora and fauna. This included plants, fish, carnivores, invertebrates, bacteria, decomposers, and parasites. These counts of species and estimates of biomass were used to assemble a relatively complete food web and trophic pyramid for the ecological community and estimates of the overall productivity and respiration of the Silver Springs aquatic ecosystem. Table 3-6 summarizes Odum's data for the different components of the Silver Springs' flora and fauna.

An important component of Odum's study was his estimation of ecosystem metabolism and production. Odum was one of the first scientists to apply upstream-downstream measurements of DO and carbon dioxide (CO_2) to the estimation of the metabolism of an entire ecological community of plants and animals. As part of his metabolism calculations Odum also quantified

Table 3-4 Parameters, sampling methods, and sampling locations at Silver Springs reported by H.T. Odum (1957)

Parameter	Method	Station *				
		1	2	3	4	5
Mixing	Dye (Fluorescein)				X	
Dissolved Oxygen	Winkler 125 cc Bottles	X	X	X	X	X
Carbon Dioxide	250 cc Phenolphthalein Oxidation Method	X	X	X	X	X
Nitrate-N	Phenol-Disulfuric Acid & Strychnidine	X	X	X	X	
Phosphate-P	Ammonium Molybdate	X	X		X	
Versenate Hardness	Taylor Co. Reagent	X			X	X
Alkalinity	Methyl Purple	X	X		X	X
pH	Beckman Model G	X	X		X	
Chlorophyll	Beckman spectrophotometer, Foerst Centrifuge, Millepore Filter	X	X		X	
Temperature	Thermistor bridge	X	X		X	X
Current Velocity	USGS measurement	X			X	X
Discharge	USGS measurement	X			X	
Sr, B, Mg, Na, K, Fe, Al, Mn, Cu, Ag, Bs, Ca, Mo, Co, Sn, Hg, Si, Zn, Pb, Be, As, Ni, Pa, Cd, Ge, In	Spectrographic Analysis	X				
Cl	Mohr method	X			X	
Radioactivity	Survey Meter	X				
Oxidation Potential	Beckman Model G Platinum Calomel	X	X			
Dissolved Solids	not stated	X				
Color	USGS Scale	X				
Clarity/Light Transmission	Secchi Disk	X			X	
Light	Photometer (Weston cell 594YR)	X			X	X
Ecosystem Metabolism	Upstream-downstream oxygen and CO2 changes	X	X	X	X	X
Algae	Dr. A.M. Laessle & Dr. L. Whitford, biomass by clipping and drying, growth rate by tags in leaves				X	
Producers	Visual Inspection and quadrats clip studies				X	
Herbivores	Visual Inspection, counts, and biomass estimates				X	
Carnivores, Secondary Carnivores	Visual Inspection, counts, and biomass estimates				X	
Decomposers	Visual Inspection, counts, and biomass estimates				X	
Bacteria	1. Agar Plates, 2. Slide Count, 3. Direct Count, 4. Chromogens & Types of Colonies (colonies/cc)	X	X		X	
Floating Clumps of Sagittaria	Gill net		X			
Net Seston	Dye and Net Method (No. 10)	X	X			
Sand & Seston	Millepore Filter	X	X			
Algal Cells	Millepore Filter and No. 10 net	X	X			
Organic Matter	Acid Permanganate, Alkaline Permanganate, BOD	X	X			
Fungi/Slime Molds	Hemp Seeds (no fungi found)				X	
Nitrogen in Mud	Kjeldahl method				X	
Mud Thickness	Probe				X	
Organic Matter Settling	Cage for 6 months with glass container				X	
Snails	10ft x 10ft Count Area				X	
Turtles	Tag and Recapture (estimated from Rainbow				X	

Table 3-4 Parameters, sampling methods, and sampling locations at Silver Springs reported by H.T. Odum (1957)

	Springs)					
Others	Net and Scraping				X	
Fish	Visual Inspection				X	
Jellyfish	Slides				X	
Parasites	Counted on Fish				X	
Plankton	Culture Work					X
Diffusion	Estimated by use of Fluorescein and by calculation				X	
Photosynthesis	Glass Tube with *Sagittaria*				X	
Plant and Epiphyte Metabolism	Bell Jar over *Sagittaria* for 3 days				X	
Bacterial Metabolism	Bell Jar				X	
Sagittaria growth rates	Cages 3'x4'x6' weigh plants before and after replanting in the cage (snails, sun and current are problematic)				X	
Respiration	Capturing insects for a short time				X	
Insect Emergence	Inverted funnel and centrifuge tube	X				

*1=Main Boil
2=1,200-m Station
3=Side Boils
4=Main Channel
5=Side Run

Table 3-5 Summary of Silver Springs water quality data, reported by Odum (1957)

Parameter	Units	Sampling Date	Average	Maximum	Minimum	Count
Main Spring Boil						
Temperature	^oC	12/3/1952-5/23/1954	23.1	23.4	23.0	3
DO	ppm	7/1952-8/1955	2.53	3.60	1.17	76
Chloride	ppm	2/12/1953	9.5	9.5	9.5	1
Carbon Dioxide	ppm	12/1952-7/1955	9.4	12.6	6.5	54
Nitrate-N	ppm	2/1953-11/1953	0.46	0.59	0.28	58
Nitrite-N	ppm	2/12/1953	0.002	0.002	0.002	1
Hardness	ppm	2/12/1953	200.5	200.5	200.5	1
Total Alkalinity	ppm	2/12/1953	162	162	162	1
Inorganic Phosphorus-P	ppm	8/1952-11/1953	0.05	0.09	0.01	56
Total Phosphorus-P	ppm	8/9/1952	0.05	0.05	0.05	1
Oxidation Potential	EV	5/28/1954	0.436	0.438	0.433	5
Chlorophyll	mg/M^3	7/1953-8/1955	0.27	0.48	0.03	3
pH	standard	12/3/1952	7.48	7.70	7.25	2
Bacteria	colonies/cc	10/15/1953	99	130	64	10
Other Boils						
DO	ppm	2/1954-5/1954	3.72	4.86	1	35
Carbon Dioxide	ppm	2/1954-5/1954	8.6	12.1	5.2	34
Nitrate-N	ppm	2/1954-5/1954	0.40	0.56	0.18	29
1,200-m Station						
Temperature	^oC	6/8/1955	23.4	23.4	23.4	1
DO	ppm	5/23-24/1954	2.53-6.3	6.3	2.53	64
Chloride	ppm	2/12/1953	8.7	8.7	8.7	1
Carbon Dioxide	ppm	5/23-24/1954	4.5-11.9	11.9	4.5	73
Nitrate-N	ppm	2/19/1953-10/22/1953	0.45	0.47	0.41	115
Nitrite-N	ppm	2/12/1953	0	0	0	1
Hardness	ppm	2/12/1953	205.4	205.4	205.4	1
Total Alkalinity	ppm	2/12/1953	144	144	144	1
Inorganic Phosphorus-P	ppm	8/9/1952-11/27/1953	0.05	0.10	0.03	84
Oxidation Potential	EV	5/28/1954	0.432	0.433	0.431	5
Chlorophyll	mg/M^3	7/12/1955	1-2.1	2.1	1	7
Bacteria	colonies/cc	10/15/1953	988	1926	277	10

Table 3-6 Summary of historic Silver Springs data, reported by Odum (1957)

Parameter	Units	Value
Producers & Consumers		
Primary Producers Dominant	# of species	12
Primary Producers Others	# of species	55
Herbivores Dominant	# of species	20
Herbivores Others	# of species	24
Carnivores Dominant	# of species	15
Carnivores Others	# of species	61
Secondary Carnivores Dominant	# of species	2
Secondary Carnivores Others	# of species	4
Decomposers	# of species	22
Primary Producers Biomass	g/m^2	809
Herbivores Biomass	g/m^2	36.8
Carnivores Biomass	g/m^2	10.7
Secondary Carnivores Biomass	g/m^2	1.53
Decomposers Biomass	g/m^2	4.6
Insect Emergence	g/m^2/day	0.01
Bacterial Metabolism	g/m^2/hr	0.079
System-Level Metrics		
Gross Primary Production, dry weight	g/m^2/yr	6390
Standing Crop Biomass, dry weight	g/m^2/yr	819
Community Respiration, dry weight	g/m^2/yr	6000
Plant Export, dry weight	g/hr	216
Particulate Organic Matter Export, dry weight	g/m^2/yr	766-1280
Other Measurements		
Gas Transfer Coefficient	g/m^2/hr	0.92
Light Extinction Coefficient	1 m	0.06
Secchi Reading	m	105
Oxygen Loss (Bubbles)	mL/m^2/day	224

the oxygen bubbles released by individual submerged plants using an inverted funnel apparatus. This funnel design also served the unexpected secondary purpose of capturing emerging aquatic insects. Odum also employed other methods for determination of the amount of respiration in the spring system. These methods included use of light and dark bell jars, bacterial counts, and diffusion estimates using the rate of mixing of fluoresine dye. Table 3-6 includes a summary of Odum's estimates for system level metrics.

The metabolism and respiration of the Silver Springs ecosystem were used to determine a community budget and annual cycle of production. This incorporated total plant and particulate organic matter export and respiration of the system. Plant export was measured at the 1,200-m station by stretching a gill net across the width of the river to catch all floating and some submerged (<1 m deep) vegetation. From the determination of export and the measurements of production and respiration Odum created a balance sheet to examine the accuracy of his methods, since inputs should equal outputs from the system. Odum found a slight difference (4%) between the inputs and outputs, indicating a remarkable accuracy of estimates considering the relatively crude methods used. After determining an estimate for overall metabolism Odum examined the energy flows of the system and the production efficiencies. Efficiencies were calculated by relating visible light reaching the plants and gross primary production, as well as efficiencies of assimilation, ingestion, and growth. The turnover for the system was calculated based on the gross primary production during the year and standing biomass at any given time.

Odum's experiments compared the Boat Basin, located in a backwater area from the main channel with little current, to the main spring run. Here Odum found water that was not as well mixed, and had a temperature difference between the surface and one meter depth. The productivity was also somewhat lower with an estimated value of 7.5 grams of oxygen per square meter per day (gm O_2/m^2/day) compared with an average of 12 gm O_2/m^2/day for the main channel due to the lower production efficiency.

H.T. Odum continued to refer to his work at Silver Springs throughout the remainder of his scientific career (e.g. Odum *et al*., 1998). He refined his summary energy flow model for the springs illustrated in Figure 3-6 in his "Energese" modeling language in Odum *et al*. (1998). In that text his friend and long-time collaborator, Dr. Elizabeth McMahan provided an interesting drawing depicting the principal ecological components in Silver Springs in 1967, before the construction of the Rodman Dam downstream (Figure 3-7).

Other studies of spring ecology and ecosystem metabolism were also reported by Odum and Hoskin (1957) and Odum (1956, 1957, 1960). Odum and Hoskin examined the use of an experimental microcosm to study a larger system. As part of the productivity experiment, metabolism and nutrient uptake were studied. A blade of eel grass from Silver Springs covered with *aufwuchs* was used in one of the test runs, and the observed change in algal dominance and lowering of production demonstrated succession of the algal communities. This study defined a new apparatus with which to test metabolism of a stream in a laboratory setting. Odum (1956) also examined the physical and chemical factors controlling primary production in flowing

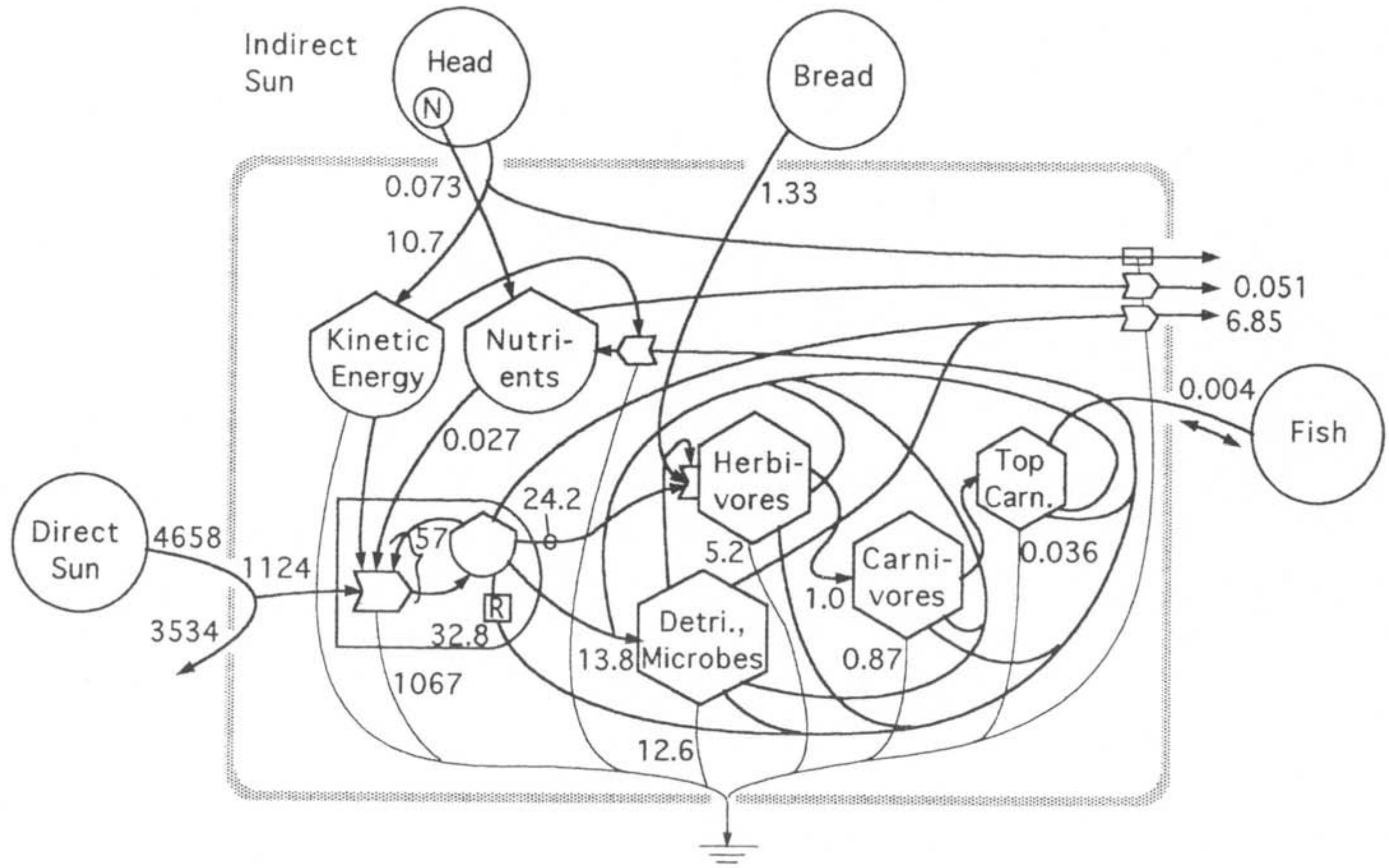


Figure 3-6 Summary model of the Silver Springs ecosystem including average flows of energy in kilocalories per square meter per day

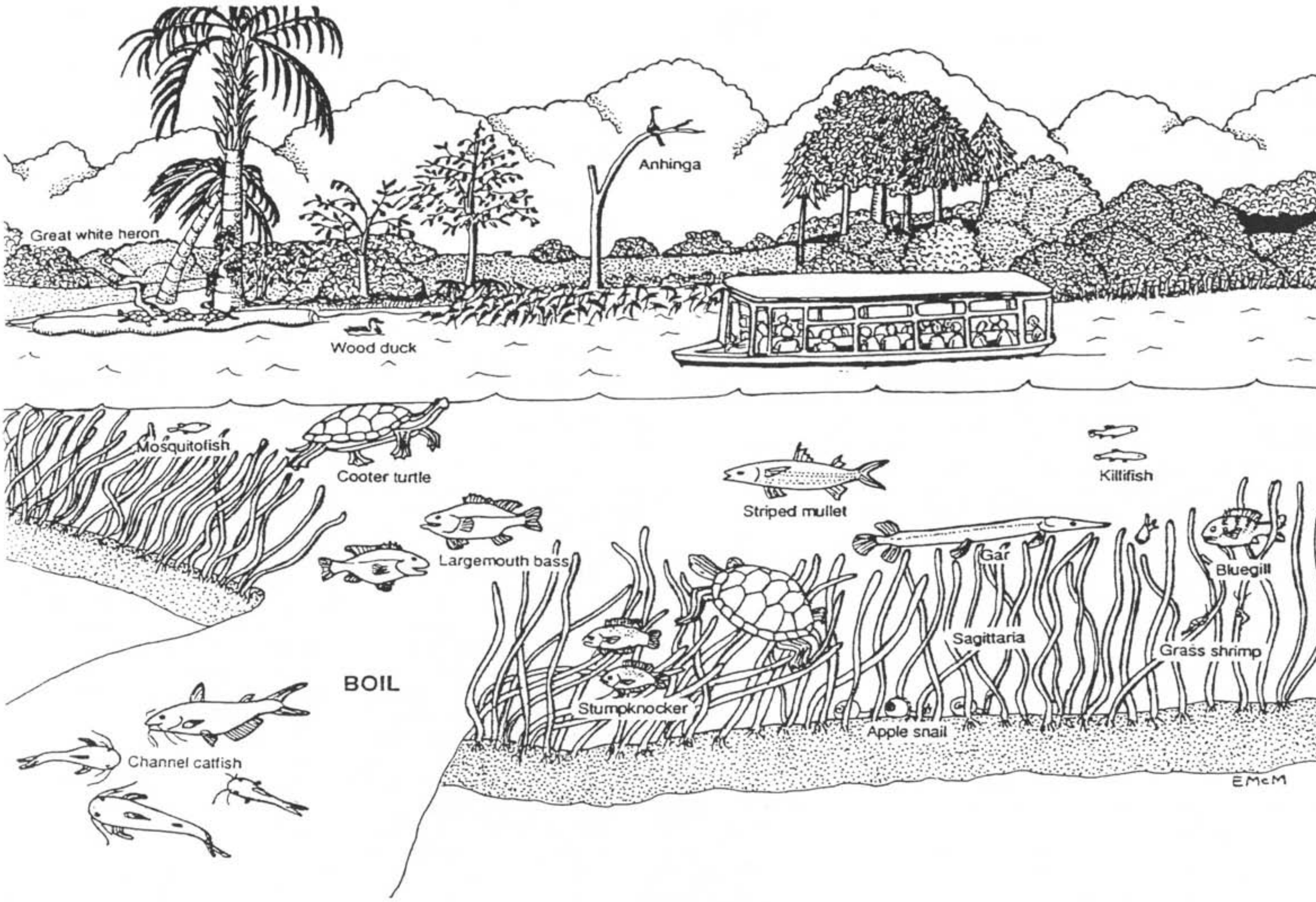


Figure 3-7 Life in Silver Springs before 1967 (original artwork by Elizabeth A. McMahan)

waters. His study reevaluated the information available on productivity and respiration using diurnal oxygen curves for upstream and downstream stations. Odum questioned the use of the light and dark bottle method in flowing waters because it eliminates the effect of current on primary production. Silver Springs was identified as an easy test case because the temperature is constant day and night. From his study of eleven Florida springs, Odum (1957) found primary production ranging from 0.6 to 59 gm dry organic matter/m^2/day. The average primary production measured at Silver Springs was estimated as 18 gm dry organic matter/m^2/day. Also reported was the excess of production over respiration for Silver Springs. This results in the export of organic material downstream and the increase in particulate organic content of the water.

3.6.2 Knight's Consumer Control Study

A similar but less comprehensive study of Silver Springs was performed by Robert Knight for his University of Florida doctoral dissertation under the supervision of H.T. Odum approximately twenty-four years after Odum's work (Knight 1980, 1983). A copy of Knight's original field notes is included in Appendix E. Knight re-examined the metabolism of the community and how it had changed in the period between 1955 and 1979 (Figure 3-8). This analysis indicated that estimated maximum metabolism rates were remarkably close to Odum's estimates with the exception of two winter values. Knight found an average annual gross primary productivity of about 21 g O_2/m^2/d compared to Odum's 16 g O_2/m^2/d and a substantially higher photosynthetic efficiency than that measured by Odum (2.8% vs. 1.7%).

Knight made measurements of dissolved oxygen (DO), temperature, and conductivity at the Main Spring Boil and at the 1,200-m station. Knight reproduced the visual counts for fish species while being towed by boat. This evaluation of fish species documented a change in the dominant fish species from mullet and catfish to gizzard shad (*Dorosoma cepedianum*). These changes were attributed to the construction of Rodman Dam downstream on the Ocklawaha River. Quantification of the snail population biomass was reported by Knight at the 1,200-m station in a side cove of the river. Snail populations were considered to be important for regulation of energy flows because of their consumption of periphytic algae on the strap-leaf sagittaria that dominates the spring run.

Knight's research built on Odum's earlier work by employing *in situ* mesocosms within the river channel to test the influence of consumer organisms on ecosystem metabolism (Figure 3-9). Knight manipulated the number of consumers in these mesocosms (*Elimia floridensis* – river horn snails and *Gambusia affinis* – mosquitofish) to test the effects of varying consumer populations on upstream/downstream DO change productivity estimates. The mesocosms were

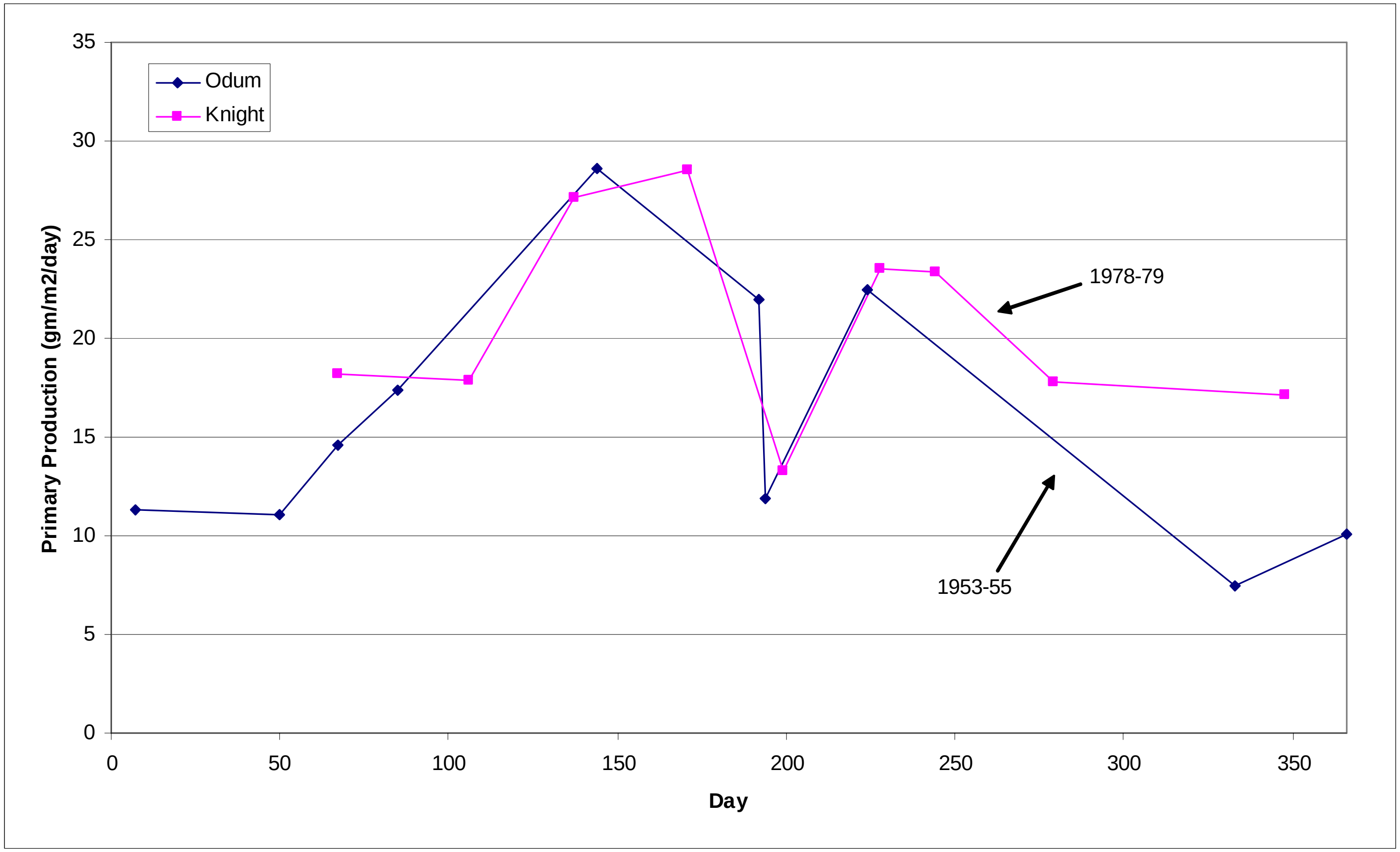


Figure 3-8 Comparison of Silver Springs ecosystem metabolism from the early 1950s and late 1970s (Odum, 1957; Knight, 1980)

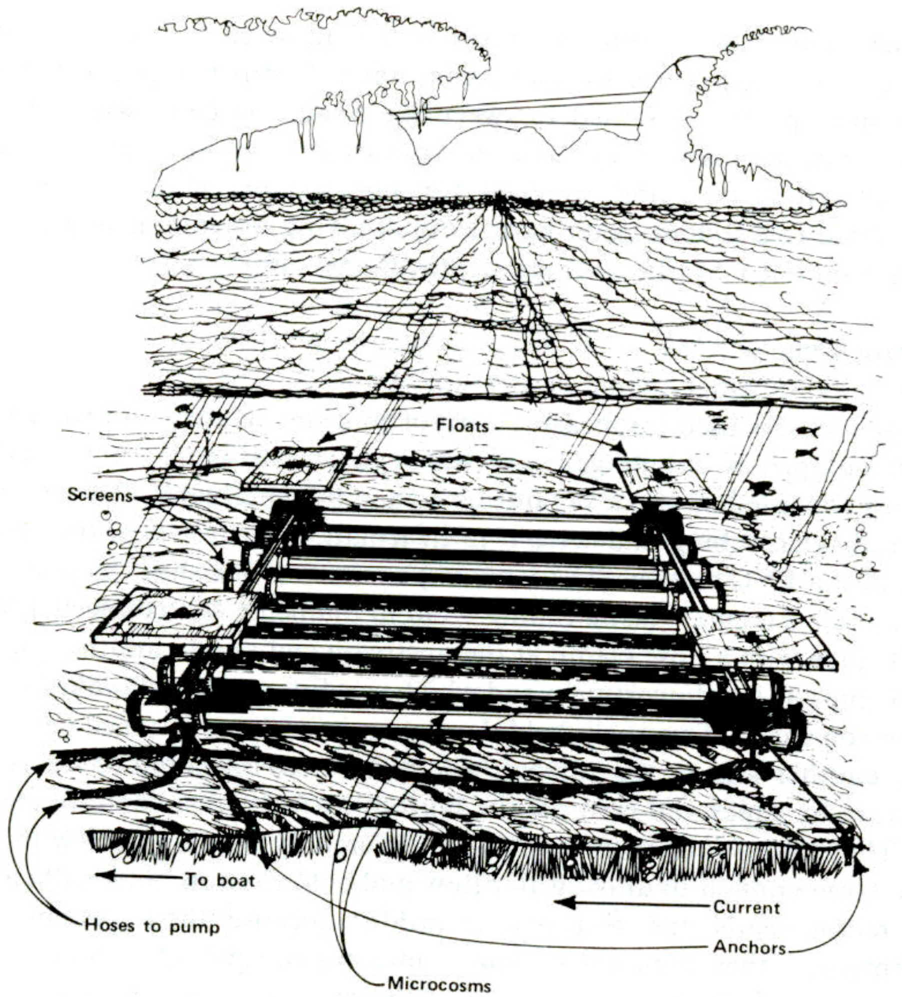


Figure 3-9 Flow-through experimental mesocosms used by Knight to study consumer control in the Silver River (Knight 1983)

deployed two meters below the surface at the 1,200-m station, and because they were submerged, they did not require correction for diffusion. Knight found that consumers, when present at relatively low densities similar to those that actually occurred in Silver Springs enhanced system productivity, and at higher and lower densities primary production was diminished. This finding was repeated for low concentrations of a toxic metal, cadmium, which was also placed in some of the mesocosms. This research supported the Maximum Power Principle proposed by Odum (1955), the Subsidy-Stress proposal by E.P. Odum *et al.* (1979), and was observed to be consistent with a wide range of research on the controlling effects of top consumers and toxins in ecosystems.

3.7 Economic Value

In 2004 the SJRWMD contracted with Bonn Marketing Research Group, Inc. (BMRG) to undertake research to establish a current-day economic baseline for eight springs within the District. The intent, in establishing this baseline, was to address socioeconomic and market-based values as well as recreational and aesthetic values. The purpose behind this evaluation was to use the results of the research in the decision-making process as part of the criteria to establish minimum flows and levels in accordance with Chapter 373, Florida Statutes. Silver Springs is one of the eight springs on which BMRG reported in the study entitled “Visitor Profiles, Economic Impacts and Recreational Aesthetic Values Associated with Eight Priority Florida Springs Located in the St. Johns River Water Management District”(Appendix F).

In its current state, the Silver Springs nature theme park encompasses approximately 350 acres of land surrounding the Silver Springs spring group and spring run. Not only does the theme park continue the tradition of the glass-bottom boat tours, but has expanded its operation to include a water park and weekend music concert series of nationally-known artists. While the recreational and aesthetic values were not developed in this report, it is obvious that because of the spring group and run the theme park business has remained a destination for tourists and entertainment seekers. While this report focused on the spring itself, no mention was made of the recreational or eco-tourism values of the spring run, which develops into the Silver River. The Silver River provides significant recreational boating, fishing and eco-tourism opportunities to this area.

Economic data collected during 2003 and 2004 indicate that the Silver Springs attraction accounts for approximately $61 million in direct spending, which creates $12.61 million in wages paid, creating a little over 1,000 jobs.

4.0 Methods

4.1 Introduction

The following types of samples and measurements were collected for the Silver Springs Fifty-Year Retrospective Study:

- Delineation of historic and current springshed boundaries
- Continuous insolation and photosynthetically active radiation (PAR)
- Underwater light (PAR) transmission and absorbance
- Daily rainfall
- Stream discharge, water stage, and current velocity
- Oxygen diffusion rate
- Water quality
- Epiphytic algae
- Benthic macroalgae
- Macrophyte community
- Downstream particulate matter export
- Downstream macrophytic plant export
- Insect emergence
- Vertebrate population survey
- Fish biomass estimation, total fish standing crop, and total species richness for fish
- Ecosystem metabolism

The following modeling tools were employed for this study:

- USGS MODFLOW numerical groundwater flow model
- MODPATH water particle reverse tracking model
- Spatial Land Use Model
- Linked Landscape Ecosystem Model

A planning review audit of the approved standard operating procedures (SOPs) for sample collection and handling was conducted during each of the two phases of the Silver Springs study

(Appendix G). All methods used during this retrospective study are briefly described in the following pages, with detailed methodology descriptions provided in Appendix B.

4.2 Solar Insolation and PAR

Measurements of solar insolation and PAR were made through the use of LI-COR light sensors models LI-190SA (pyranometer) and LI-200SA (PAR). Data collected by these light sensors were recorded using an LI-1000 data logger that was downloaded using a Rugged Reader Pocket PC. These data were transferred to a computer and summarized using a Microsoft Excel spreadsheet and Microsoft Access database (Appendix W). The data logger was programmed to take readings every minute and average the values to output integrated hourly data at the end of each hour. For data analysis these average hourly data were shifted to correspond to the half hour before the recorded time. Figure 4-1 shows the installation of the light sensors and the data logger. A complete, detailed description of the solar insolation and PAR measurement methodologies is provided in Appendix B.

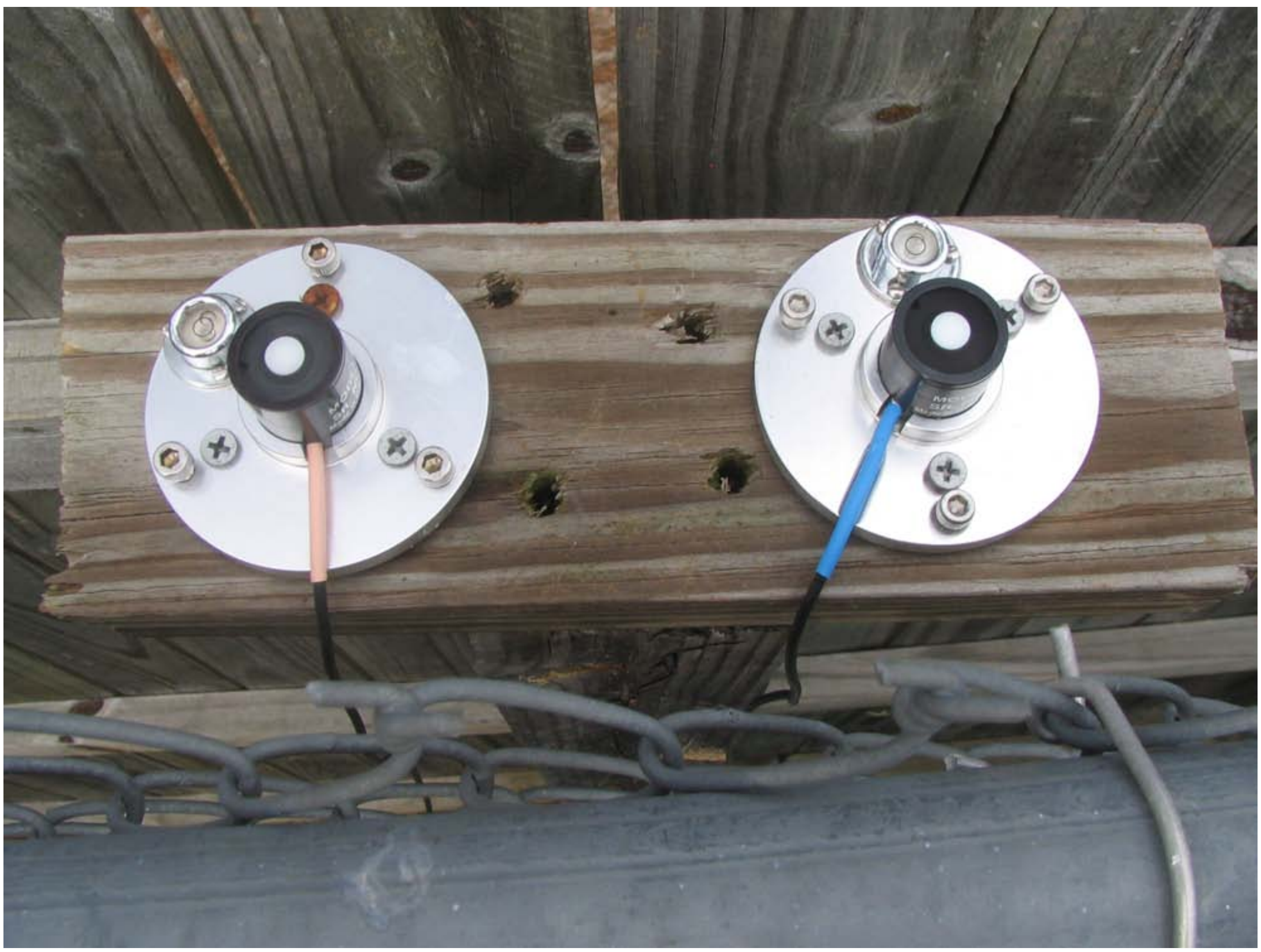


Figure 4-1 WSI's total insolation and PAR sensors located at the Silver River Museum

4.3 Precipitation

Precipitation was measured with a recording tipping-bucket rain gauge manufactured by Infinities, USA. The rain gauge was installed at the same location as described previously for the LI-COR unit and is shown in Figure 4-2. This gauge recorded rain amounts in 0.25 mm (0.01 inch) increments. Data from the rain gauge were summed over a twenty-four hour period to provide daily data. These rain data were used to provide a real-time summary of rainfall contributions to Silver Springs during the course of the study. The rain gauge data were downloaded using a Hewlett-Packard HP-48G+ calculator with an installed interface from Infinities, USA. The data were then outputted to a desktop computer in the office and summarized in a Microsoft Excel spreadsheet and stored in a Microsoft Access database.

Figure 4-2 WSI's recording rainfall gauge located near the Silver River Museum

4.4 Delineation of historic and current springshed boundaries

The predevelopment potentiometric surface of the Floridan Aquifer as described by Johnston and others (1980) is a composite of many other maps: recent potentiometric surface maps in areas where pumping has been light and older maps or modifications of them where groundwater development has been extensive. The predevelopment potentiometric map shows the best estimate of the configuration of the average predevelopment potentiometric surface of the Upper Floridan Aquifer.

The process of delineating the historic and current springshed boundaries consisted of two steps. First, a map of the predevelopment springshed for Silver Springs was prepared, utilizing the predevelopment potentiometric surface of the Floridan Aquifer. Second, an existing subregional numerical groundwater flow model (NCF MODFLOW model, Motz and Dogan, 2004) and the USGS MODPATH particle-tracking routine (Pollack, 1994) were used to perform the simulations necessary to determine the current springshed boundaries.

The NCF MODFLOW model (Motz and Dogan, 2004), was also used to delineate the springshed. The NCF MODFLOW model is calibrated to the average groundwater hydrologic conditions that existed in May 1995. The USGS MODPATH (Pollack, 1994) particle tracking routine was used to delineate the Silver Springs springshed. The springshed has been delineated for three different travel-time periods: a two-year period, a ten-year period, and one hundred years (Shoemaker and others, 2004). The one hundred-year time period is assumed to represent steady-state. Further discussion of the springshed delineation methods used for this study is provided in Appendix B.

4.5 Modeling Tools

4.5.1 Introduction

A number of models were used to characterize the movement of groundwater in the springshed and to quantify the effects of springshed land use practices on groundwater quality at Silver Springs.

4.5.2 Groundwater Model Description

4.5.2.1 Introduction

The USGS numerical groundwater flow model, MODFLOW (Harbaugh and McDonald, 1996) and water particle reverse tracking model, MODPATH (Pollock, 1994), were applied for this study. Based on the results of the calibrated 1995 North Central Florida (NCF) MODFLOW and MODPATH models, the following were simulated and delineated by SJRWMD: the hydraulic head distribution within the Floridan Aquifer groundwater flow system, and the two-, ten-, and one hundred-year groundwater contribution areas to Silver Springs in Marion County.

4.5.2.2 MODFLOW

The NCF MODFLOW model was developed for SJRWMD by the University of Florida (Motz and Dogan, 2004) and calibrated to the average 1995 groundwater hydrological conditions. The first step of this study was to utilize the calibrated 1995 NCF model (Figure 4-3) to evaluate

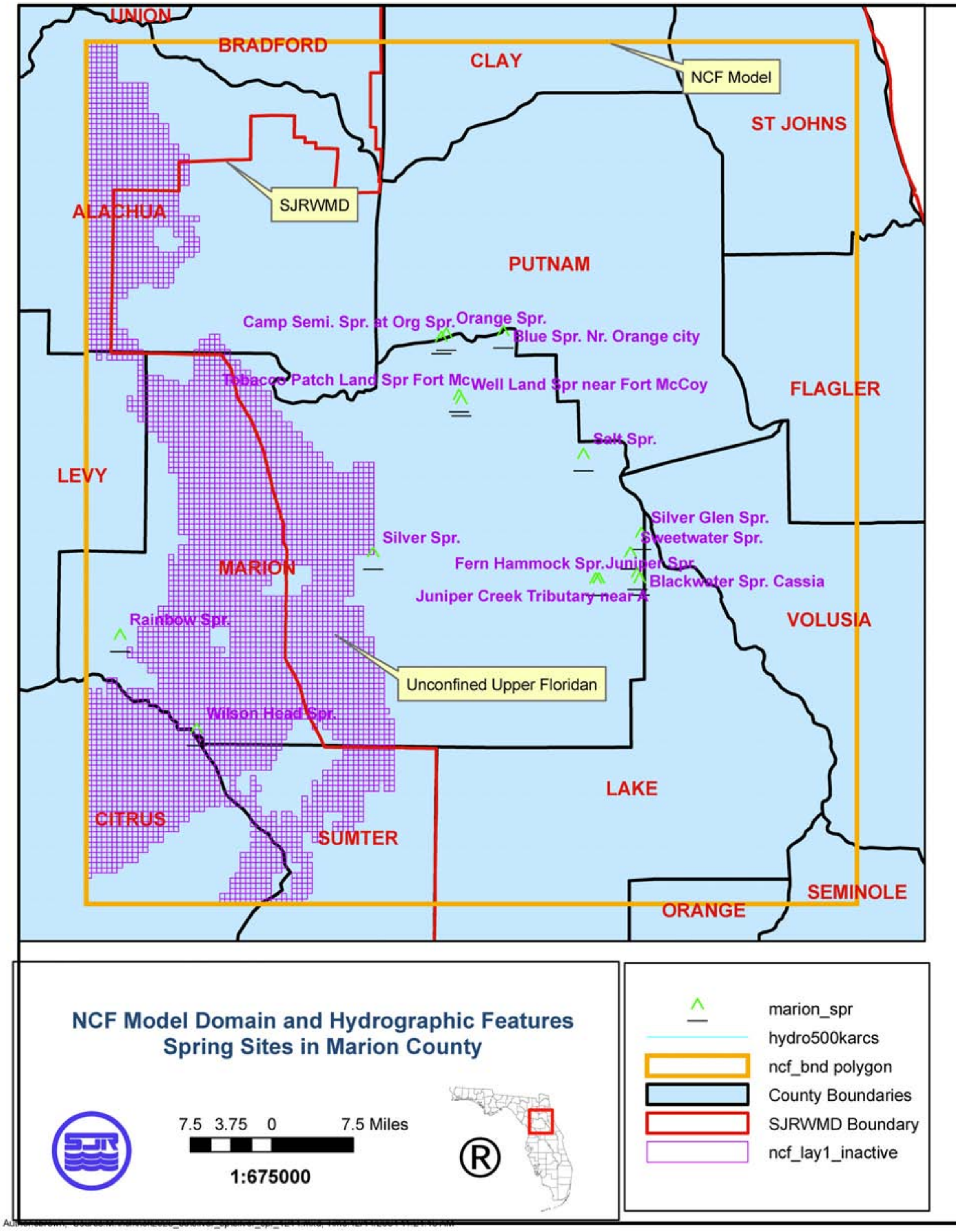


Figure 4-3 NCF model domain, hydrographic features, and spring sites in Marion County

hydraulic heads, groundwater flow fluxes and velocity distributions in the Floridan aquifer system. After that, the results of the evaluation of groundwater heads and flow fluxes and the calibrated model parameters and boundary conditions with starting particle positions at Silver Springs were applied to the MODPATH model. The model produced estimates of the groundwater contribution areas to Silver Springs for the two-, ten- and one hundred-year travel time periods (Figure 4-4).

4.5.2.3 MODPATH

The USGS MODPATH (Pollock, 1994) particle tracking model was applied in this study to delineate the groundwater contributing zones to the Silver Springs complex. The backward track method was selected to track the travel distance of water particles for two-, ten- and one hundred-years' travel time. In this study, the MODPATH model automatically generated particles required for this simulation. Effective porosity had to be estimated. Detailed geological data are required to determine a representative porosity value for dual porosity karst limestone where primary and secondary porosity occur. Phelps (1994) described the dual porosity characteristics of the Upper Floridan Aquifer in the vicinity of Ocala. Usually, the effective porosity for the Ocala limestone ranges from 0.17 to 0.49. A complete discussion of the methods employed, and the rationale for choosing them, is provided in Appendix B.

4.5.3 Delineation of Risk Areas within the Two-Year Groundwater Contribution Zone

The NCF regional groundwater flow model developed by the University of Florida (Motz and Dogan, 2004) was used to determine the hydraulic heads and flow field direction to Silver Springs. The calibrated 1995 NCF MODFLOW head distributions and hydrological parameters were applied to the USGS MODPATH particle tracking model to determine the positions and distances of the particles as they are tracked backward from Silver Springs during two years of travel time. Results of the MODPATH particle tracks analyses indicated about 75% of water discharging from Silver Springs originates from this two-year contributing zone. Figure 4-5 displays the two-year groundwater contribution zone, the contour of hydraulic heads in the Upper Floridan Aquifer and the groundwater flow field in the vicinity of Silver Springs. A complete explanation of the methods used to assign risk designations to the areas within the two-year groundwater capture zone for Silver Springs, including figures illustrating the risk potential zones for vertical and horizontal flux, is provided in Appendix B.

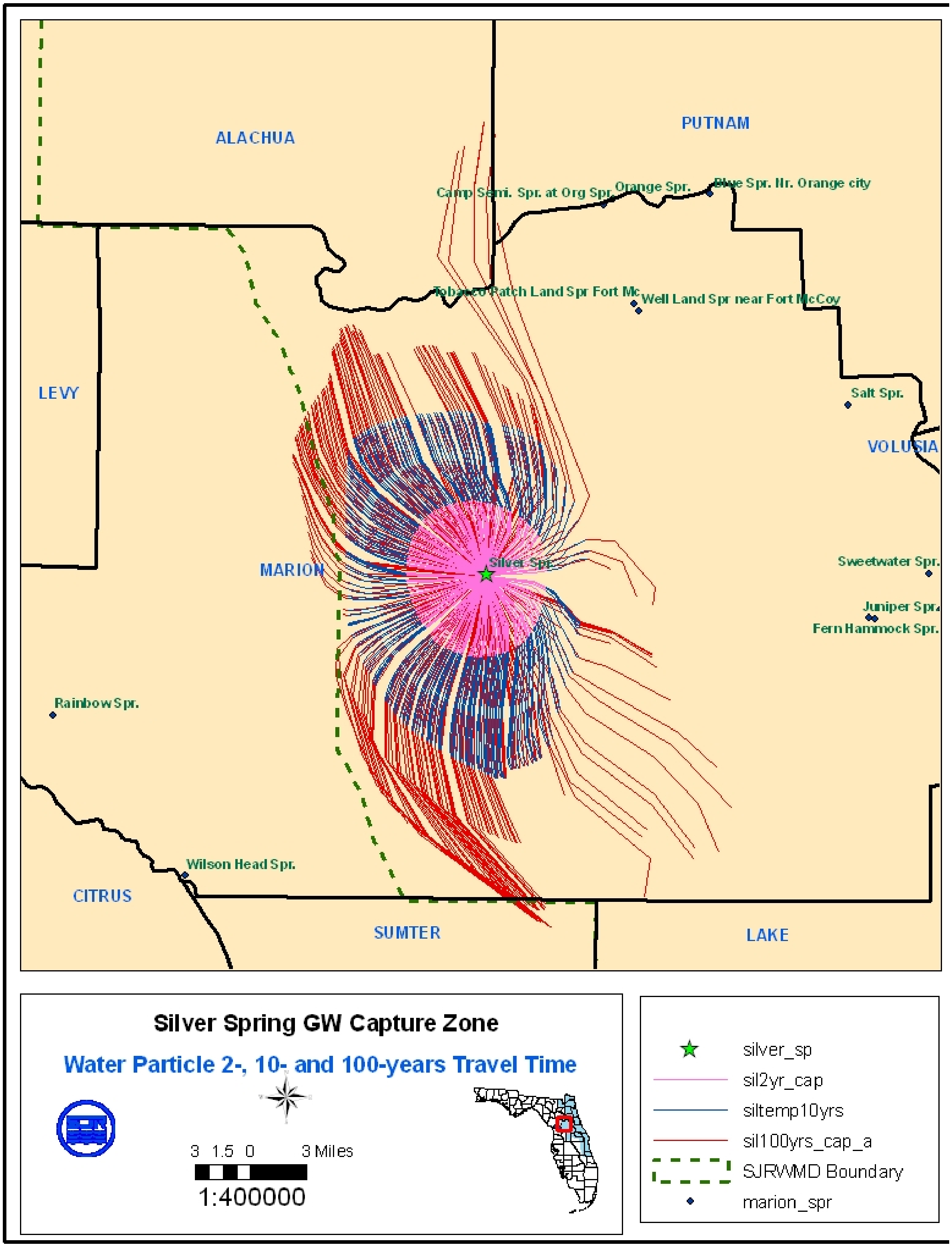


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Figure 4-4 Two, ten and one hundred years' water particle travel distance

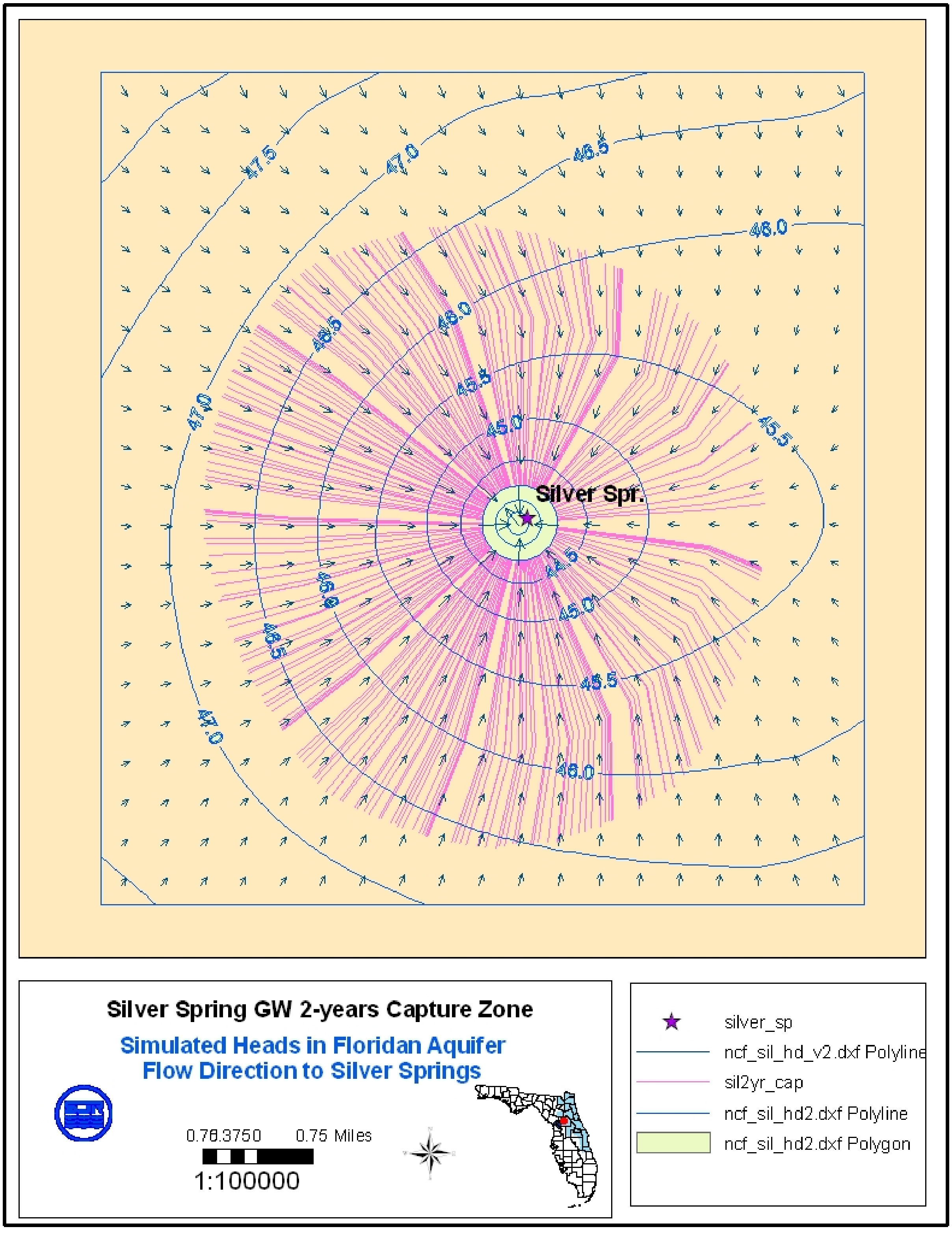


Figure 4-5 Simulated Heads in the Floridan Aquifer

4.5.4 Spatial Land Use Model

4.5.4.1 Introduction

A Spatial Land Use/Land Cover (LULC) Model was developed to simulate the impacts, or effects, of land use and land cover on nitrogen loading to groundwater. As stated, nitrogen, from decomposition on natural landscapes and manual deposition on developed landscapes, when not assimilated on site, is introduced to groundwater. The amount of nitrogen introduced is defined as the load. The load from any unit of land can be estimated from the land use/land cover type of the unit.

Spatial feature classes (classifications and representations of geographic features – here, polygons representing land use/land cover classes) were created to represent the LULC distribution pattern within the two-year capture zone for several discrete time periods (1949, 1957, 1964, 1972, 1979, 1989, 1995 and 2005). Each polygon in the dataset describes a homogenous area identified as one class, or category, of LULC. Each LULC class specifies the relative impact on nitrogen loading to groundwater for the area described (expressed in pounds/acre/year). The output of each simulation is a prediction of nitrogen discharged at the Silver Springs complex for that year, based on the sum of the polygon (class) loads in the two-year capture zone.

As stated in the previous section, MODPATH analysis determined that 75% of groundwater discharged at the Silver Springs complex originated within the two-year capture zone (Figure 4-6). For the purposes of this study, it is assumed that 75% of the nitrogen discharged at the complex was deposited within the two-year capture zone. Accordingly, the Spatial LULC Model nitrogen discharge estimates represent 75% of total nitrogen discharged. Water quality analyses measured total nitrogen discharges in 1957, 1979, 1989, 1995, and 2005. A comparison of observed loads with model predictions will be used to assess model performance. The results of the simulations, including a simulation of nitrogen loading in the year 2025, should provide a basis to identify land management practices intended to ameliorate nitrogen impacts at the Silver Springs complex.

4.5.4.2 Model Development

The term land cover refers to the surface cover on the ground (i.e. water, urban infrastructure, forest, ground vegetation, bare soil, etc). Land use refers to the purpose for which the land is utilized and is often determined by parcel information (i.e. agriculture, pasture, recreation, dwelling units, etc). The model design is an attempt to capture both cover and use. A Spatial LULC Model designed to simulate the effects of LULC on nitrogen loading requires accurate characterization of the LULC distribution pattern over several time periods. LULC patterns for

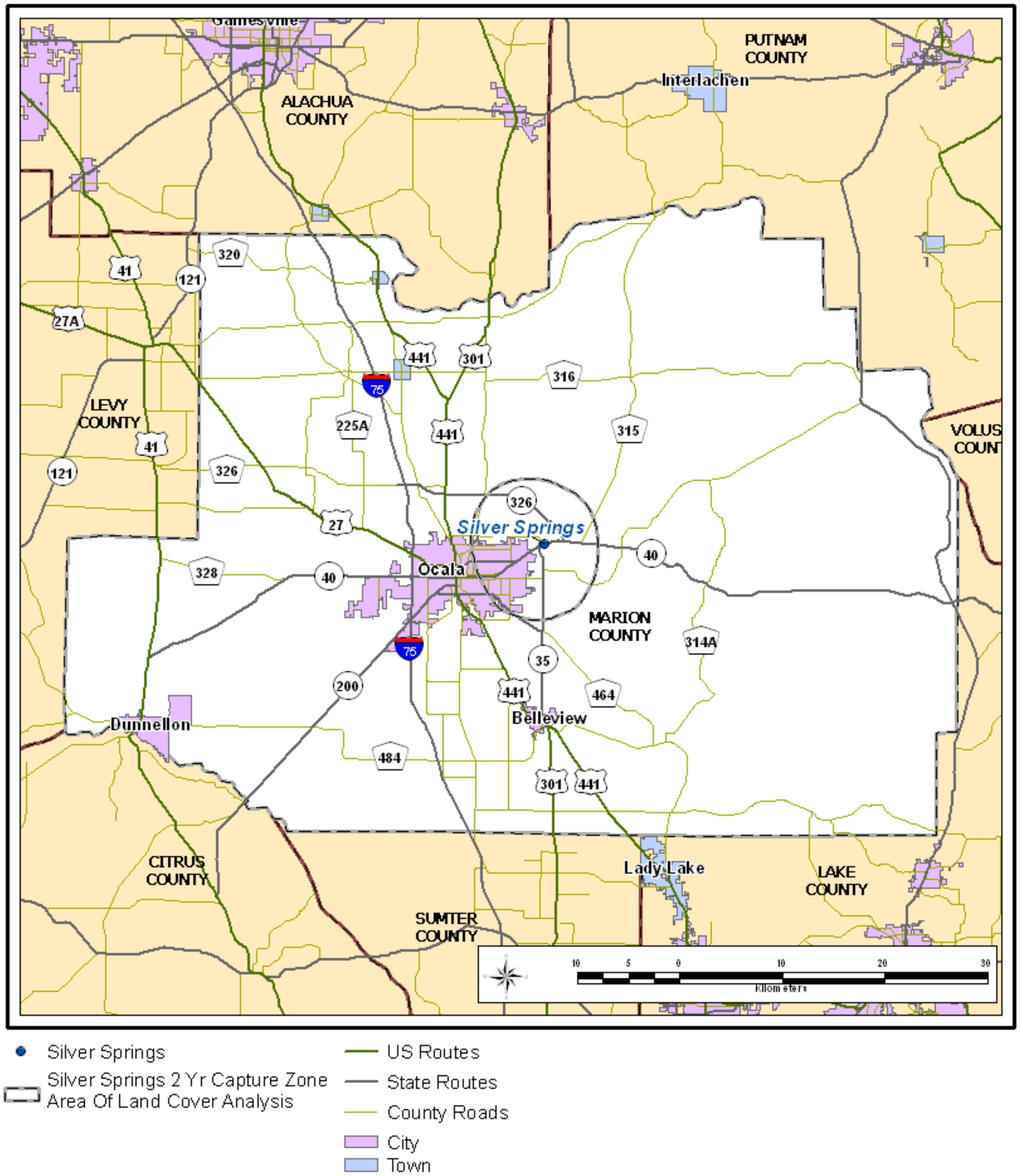


Figure 4-6 Silver Springs two-year capture zone

the capture zone were initially developed from an analysis of aerial imagery. These images included black and white aerial photographs for the years 1949, 1957, 1964, 1972, 1979, 1989 and Digital Orthographic Quarter-Quads (DOQQs) for 1995 and 2005 (Tables 4-1 and 4-2). Unlike DOQQs, that have been fitted to a standard projection and can be used like maps, the

Table 4-1 Imagery Utilized for Land Cover Analysis

Photo Year	Scale	Source	Source Media	Georeferencing Medthod
1949	1:20000	University of Florida	B&W Photo	ArcGIS Geo-reference
1959	1:20000	University of Florida	B&W Photo	ArcGIS Geo-reference
1964	1:20000	University of Florida	B&W Photo	ArcGIS Geo-reference
1972	1:40000	University of Florida	B&W Photo	ArcGIS Geo-reference
1979	1:40000	University of Florida	B&W Photo	ArcGIS Geo-reference
1989	1:24000	SJRWMD	B&W Photo	ArcGIS Geo-reference
1995	1:24000	SJRWMD	Infra-Red DOQQ	By Definition
2005	1:24000	SJRWMD	True Color DOQQ	By Definition

Table 4-2 Image List

Aerial Imagery ID			
1949 - Photo ID	**1957 - Photo ID**	**1964 - Photo ID**	**1972 - Photo ID**
12083_1949_3f_121	12083_1956_3r_194	12083_1964_1ee_178	272_11
12083_1949_3f_122	12083_1956_3r_195	12083_1964_1ee_179	272_147
12083_1949_3f_124	12083_1956_3r_196	12083_1964_1ee_180	272_9
12083_1949_3f_125	12083_1956_3r_197	12083_1964_1ee_181	372_2
12083_1949_3f_126	12083_1956_3r_198	12083_1964_1ee_182	372_4
12083_1949_3f_41	12083_1956_3r_200	12083_1964_1ee_224	
12083_1949_3f_43	12083_1957_3r_157	12083_1964_1ee_225	
12083_1949_3f_45	12083_1957_3r_159	12083_1964_1ee_226	
12083_1949_3f_46	12083_1957_3r_160	12083_1964_1ee_227	
12083_1949_3f_82	12083_1957_3r_161	12083_1964_1ee_228	
12083_1949_3f_84	12083_1957_3r_162	12083_1964_1ee_230	
12083_1949_3f_86	12083_1957_4r_16	12083_1964_1ee_264	
12083_1949_3f_87	12083_1957_4r_17	12083_1964_1ee_265	
12083_1949_4F_113	12083_1957_4r_18	12083_1964_1ee_266	
12083_1949_4F_114	12083_1957_4r_19	12083_1964_1ee_267	
12083_1949_4F_115	12083_1957_4r_206	12083_1964_1ee_268	
12083_1949_4F_116	12083_1957_4r_207	12083_1964_1ee_269	
	12083_1957_4r_208	12083_1964_1ee_270	
	12083_1957_4r_21	12083_1964_1ee_271	
	12083_1957_4r_22	12083_1964_2ee_61	
	12083_1957_5r_136	12083_1964_4ee_18	
		12083_1964_4ee_19	
		12083_1964_4ee_20	
		12083_1964_4ee_22	
		12083_1964_4ee_24	
1979 - Photo ID	**1989 - Photo ID**	**1995 - DOQQ ID**	**20055 - DOQQ ID**
12083_1979_179_254	89_14-15	dq4216nw	dq4216nw
12083_1979_179_255	89_14-17	dq4216sw	dq4216sw
12083_1979_179_256	89_14-19	dq4217ne	dq4217ne
12083_1979_179_276	89_14-21	dq4217nw	dq4217nw
12083_1979_179_277	89_15-17	dq4217se	dq4217se
12083_1979_179_278	89_15-19	dq4217sw	dq4217sw
	89_15-21	dq4218ne	dq4218ne
	89_15-23	dq4218se	dq4218se
	89_16-12	dq4316sw	dq4316sw
	89_16-14	dq4317ne	dq4317se
	89_16-16	dq4317se	dq4317sw
	89_16-18	dq4317sw	dq4318se
	89_17-16	dq4318se	
	89_17-18		
	89_17-20		
	89_17-22		

aerial photographs had no information to locate them in a coordinate system. The photos were georeferenced (Figure 4-7) to make them suitable for the classification of LULC in the capture zone. Since black and white aerial imagery comprised the majority of the imagery available, the land cover classification system for the model was limited to groups of land cover that could be discerned from the black and white aerial images (Table 4-3). Land use nitrogen loading rates were supplied for the three residential land use categories (from parcel data) and land cover (from imagery) only (Table 4-4). A full description of the method used to develop the Spatial LULC Model is provided in Appendix B.

4.5.4.3 Land Use Analysis and Development of Input Land Use Data

After each aerial photographic image was georeferenced, the images were assembled to create a mosaic covering the entire zone (Figure 4-8), and the LULC classification process began with the classification or conversion of the image information into a feature class. Using the imagery as a background base dataset, polygon features around homogenous areas were created through a process known as “head-up” digitizing. Each polygon was attributed with an LULC class from the schema presented in Table 4-3. Once the LULC feature class for 1949 was created, it was copied to create the initial base feature class for 1957. Features from 1949 were edited to conform to any changes in land use captured in the imagery. The process continued until a feature class representing the LULC regimes from all image years had been created. This initial process resulted in eight datasets representing the changing LULC regime as captured with imagery (Figure 4-9). A full description of the methods used to analyze land use in the two-year capture zone, and to convert the LULC information into a grid, is provided in Appendix B.

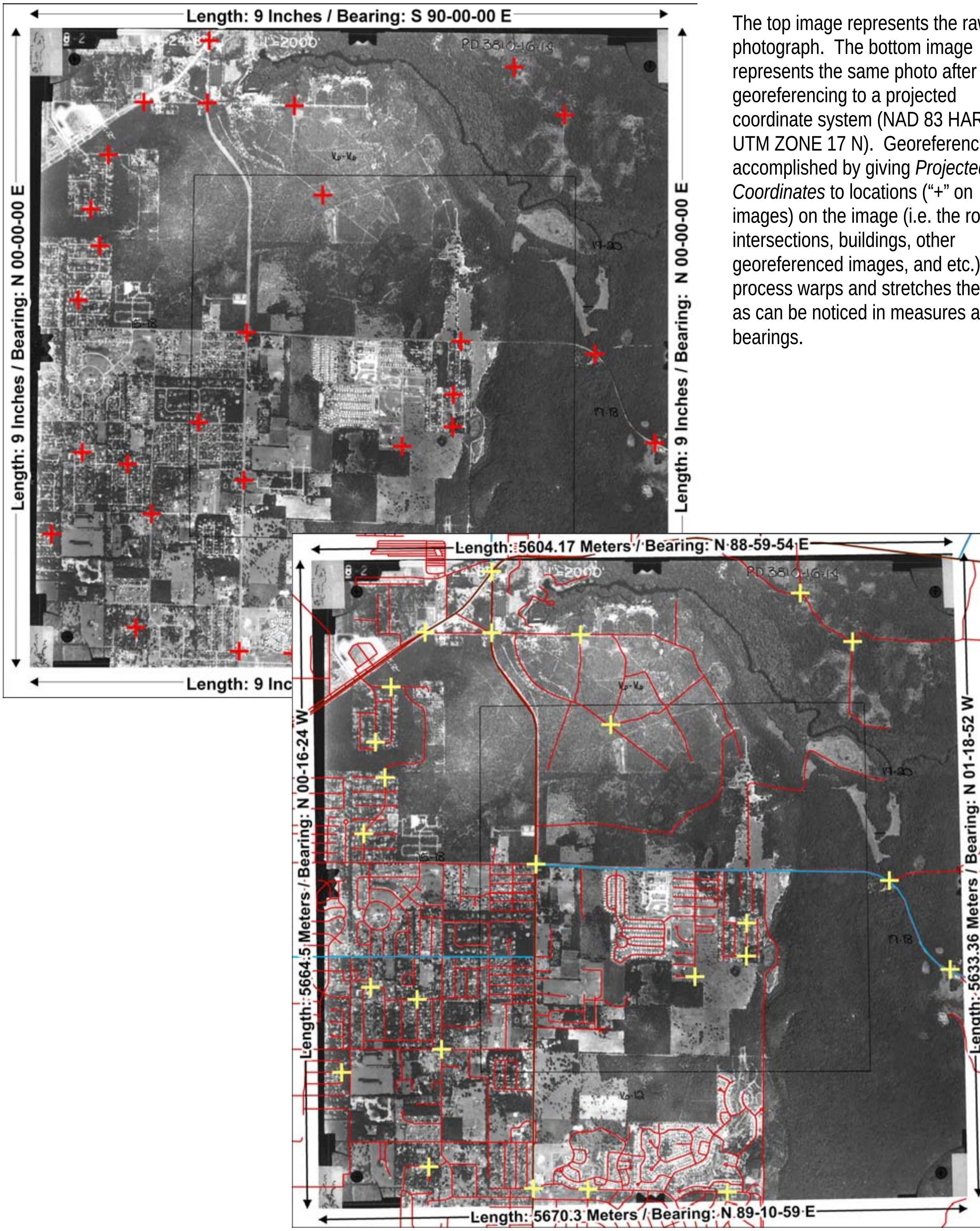
4.5.4.4 Development of Nitrogen Loading Estimates by Land Use Category

The nitrate-N loading estimates used for this study are from several sources, including a March 2005 Marion County Water Resource Assessment and Management Study. It was assumed that 10% of the atmospheric deposition reached the groundwater. Within the 1,200 square mile area of the Silver Springs springshed, that was calculated to be 200,000 kilograms per year (kg/yr) or 0.57 pounds per acre per year (lbs/acre/yr) (Phelps, 2004). That loading rate was assumed for the portion of the springshed falling within the forested and vegetated land use category. A complete discussion of the methods used to develop nitrate-N loading estimates is presented in Appendix B.

4.5.5 Linked Landscape Ecosystem Model

4.5.5.1 Introduction

Historic data concerning land use in the Silver Springs groundwater springshed were analyzed to provide a quantitative record of changing nutrient loading rates. Nutrient loading rates indirectly



The top image represents the raw photograph. The bottom image represents the same photo after georeferencing to a projected coordinate system (NAD 83 HARN, UTM ZONE 17 N). Georeferencing is accomplished by giving *Projected Coordinates* to locations ("+" on images) on the image (i.e. the road intersections, buildings, other georeferenced images, and etc.). The process warps and stretches the image as can be noticed in measures and bearings.

Figure 4-7 Georeferencing

Table 4-3 Land Cover Class Schema

Land Cover designations were based on the Florida Fish and Wildlife Conservation Commission (FWC) land cover using 1985-89 Landsat Thematic Mapper satellite imagery. These classes were grouped into categories that are reasonably discernable from black and white aerial imagery.

Silver Springs Land Cover Class	FWC Classes In Group	Description
Pasture	**Improved Pasture**	Land that has been cleared, tilled, reseeded with specific grass types, and periodically improved with brush control and fertilizer application. There is no method to distinguish between "improved" and "unimproved" pastures. While the parcel based land use does distinguish between these uses, there is no digital use information available prior to 1990. Further, especially with the B&W imagery, there is no method to distinguish between row crops, pasture, improved pasture, and other agricultural uses. Additionally, as these uses could have been easily changed during the study era, these uses/covers are not reliable. Therefore the nitrogen loading rates applied to these classes are identical (see figure 4.6.4-4).
Pasture	**Unimproved Pasture (And Woodland Pasture)**	Cleared land with major stands of trees and brush where native grasses have been allowed to develop. Normally, unimproved pastures are not managed with brush control or fertilizer application.
Agriculture	**Row and Field Crops**	Row crops are agricultural fields in which rows remain well defined even after crops have been harvested. Typical row crops in Florida include corn, tomatoes, potatoes, cotton, and beans. Field crops are agricultural croplands not planted in rows. Typical field crops in Florida include hay and grasses.
Agriculture	**Other Agriculture**	Agricultural lands other than pasture land, sugar cane fields, citrus groves, and croplands. Types of agricultural lands included in this category are peach orchards, pecan and avocado groves, nurseries and vineyards, specialty farms, aquaculture, fallow cropland, and unidentified agricultural uses.

Table 4-4 Estimated nitrogen loading rates according to land use/land cover

Land Cover	Nitrogen Loading to Groundwater (lbs/acre)
Bare Soil / Clearcut	0.57
Forested & Vegetated	0.57
Golf Courses	260.00
Agriculture / Pasture / Silviculture*	48.25
Land Use	
Low Density Residential (Less than 2 Du/Acre)	14.80
Medium Density Residential (2 - 5 Du/Acre)	66.00
High Density Residential (Greater than 5 Du/Acre)	29.60
* Agriculture / Pasture / Silviculture is average for the following land uses. Prior to 1992, no digital parcel information is available. Image analysis cannot distinquish between agriculture, pasture and improved pasture. The average of land use depostion for these uses has been applied to any cover that is designated agriculture or pasture	
Pasture	62
Other Agriculture	46
Field and Field Crops	46
Horse Farms	39
Average	48.25

Land Use / Land Cover	1949	1957	1964	1972	1989	1995
Acreage Total	33682.19	33682.19	33682.19	33682.19	33682.19	33682.19
Acreage With N Loads	30382.27	30588.87	29320.55	28723.70	25481.16	26583.05
Percent Area with N Loads	90.20	90.82	87.05	85.28	75.65	78.92

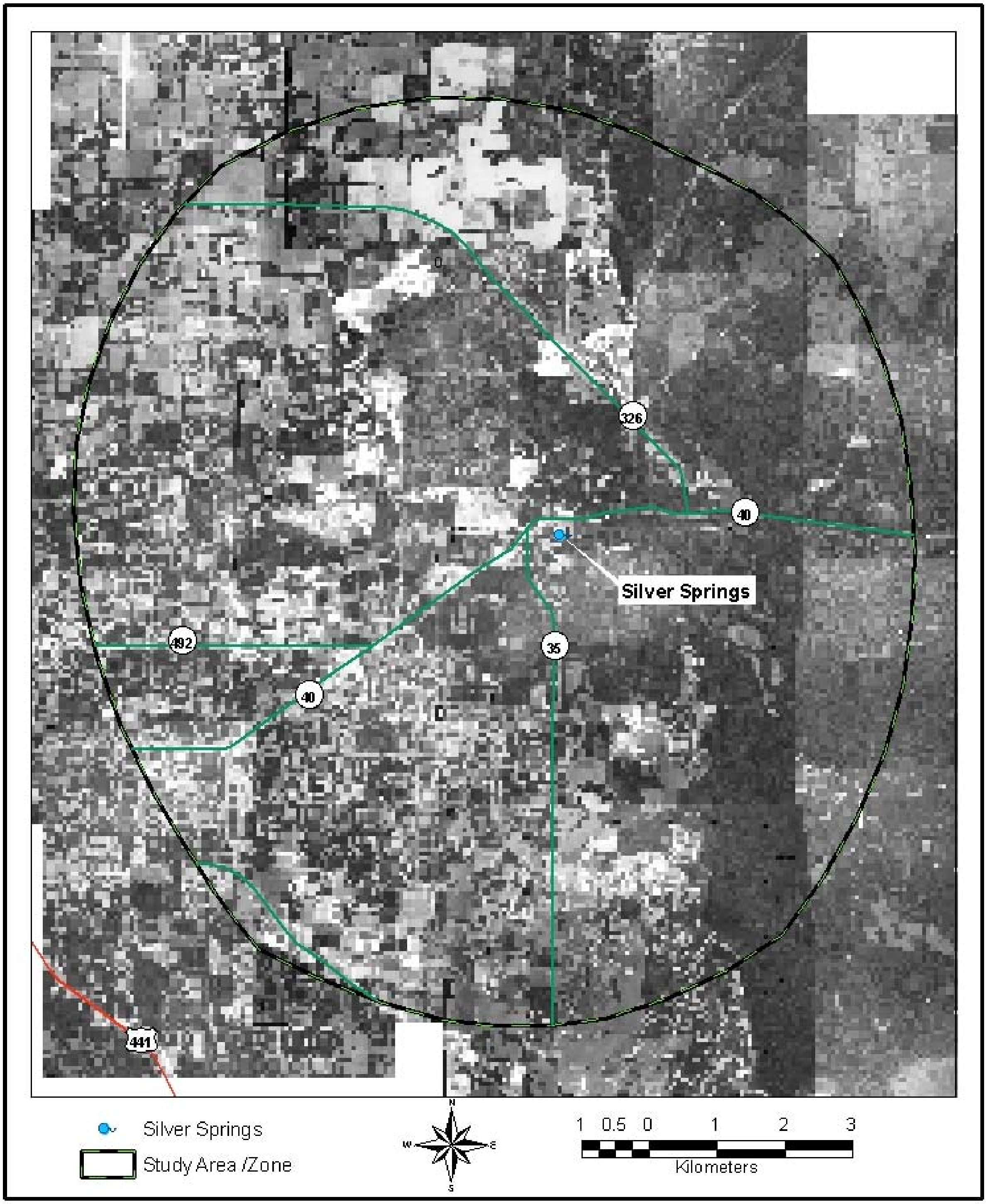


Figure 4-8 Image Mosaics:

Once all of the images from a year group were georeferenced, they were assembled into a mosaic that seamlessly covered the two-year capture zone (1989 imagery)

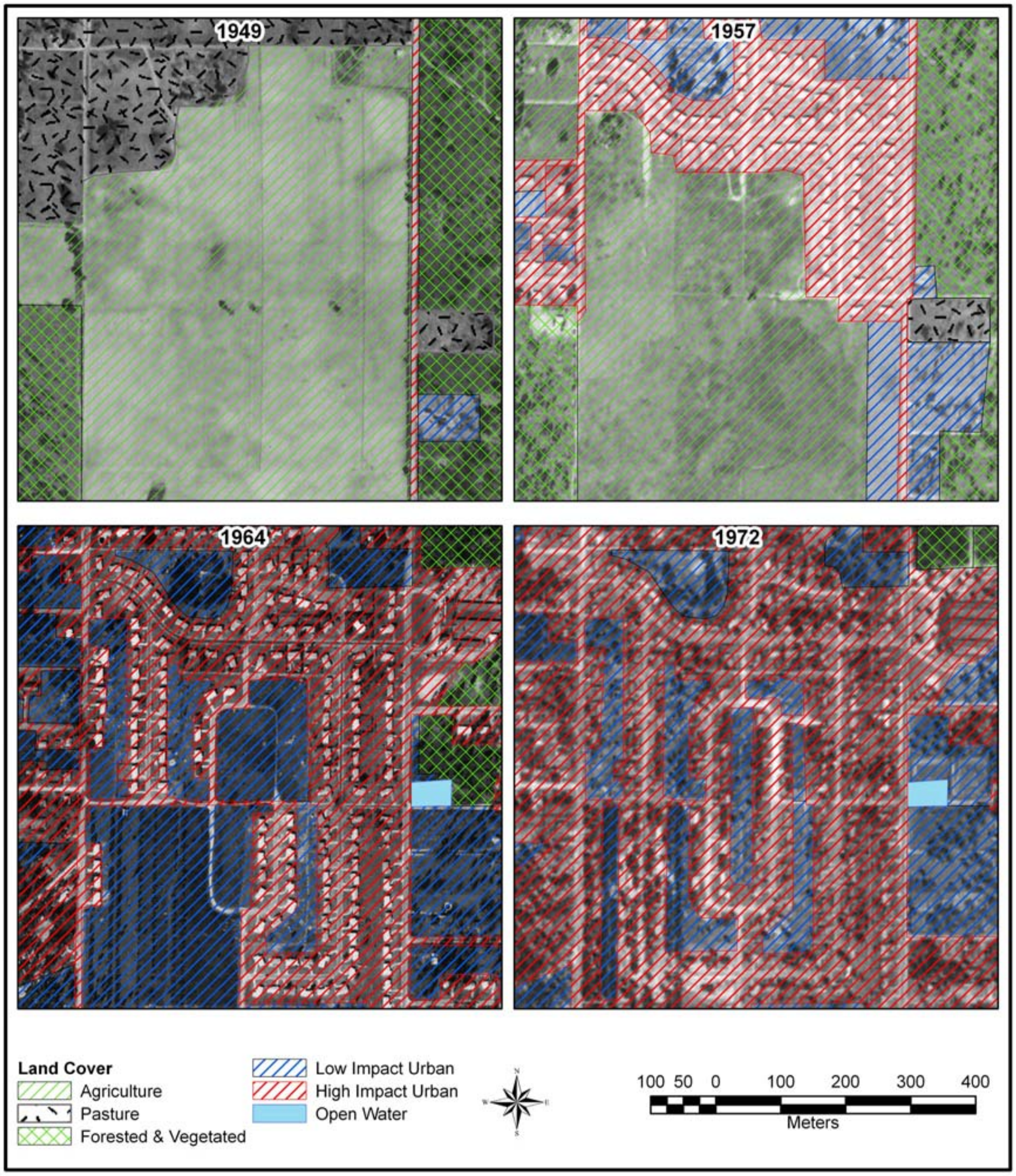


Figure 4-9 An example of the land cover classification process.

Once agriculture/pasture areas are in line for development, they are classified as low impact urban.

affect the Silver Springs ecosystem via the artesian groundwater flow path. This section describes the model structure and the methods used for determination of model input data and rate coefficients.

4.5.5.2 Description of the Silver Springs Landscape Model

Figure 4-10 illustrates the landscape model used for this evaluation. Forcing functions, state variables, and key energy flows in the model are identified in Table 4-5. Numbered pathways on the conceptual model refer to specific rate equations detailed in Table 4-5.

The landscape model has three principal forcing functions including sunlight (S), atmospheric inputs (A) with associated water and nitrogen, and economic drivers (E). Due to the historic observation that nitrogen is the only water quality constituent that has consistently changed in the Silver River over the period-of-record, the landscape model focuses on flows of nitrogen and

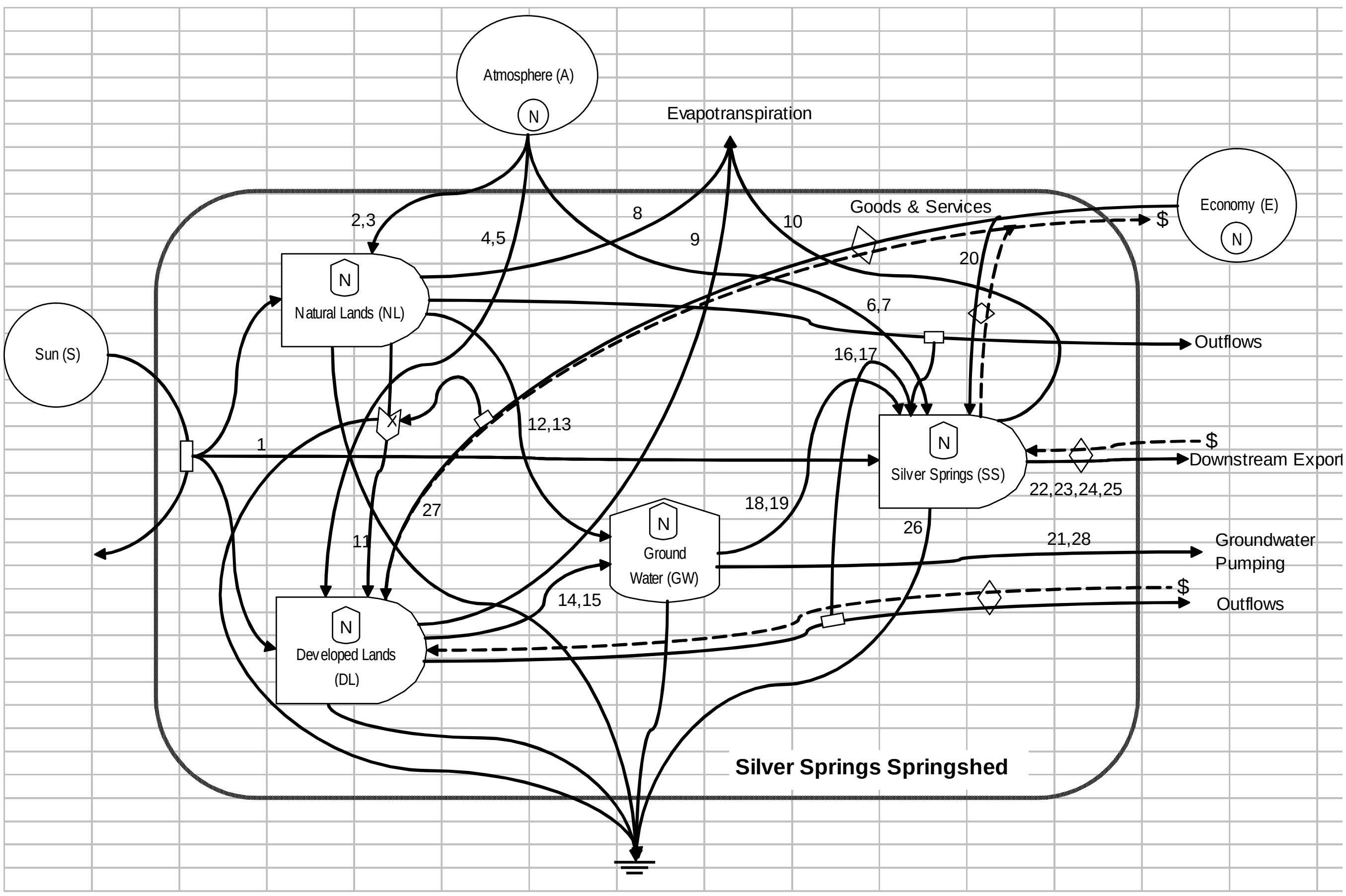


Figure 4-10 Silver Springs conceptual nitrogen landscape model

Table 4-5 Silver Springs Conceptual Nitrogen Landscape Model

Forcing Functions

S	photosynthetically active radiation (µM/s/m^2)
A	atmospheric inputs (m/yr)
A_N	TN in total precipitation (g/m^2/yr)
E	economic health (GNP)
E_N	anthropogenic TN inputs (g/m^2/yr)

Storages

NL	natural lands (km^2)
NL_W	natural land water (km_3)
NL_N	natural land available TN (kg)
DL	developed lands (km^2)
DL_W	developed land water (km_3)
DL_N	developed land available TN (kg)
GW	groundwater (m)
GW_N	TN in groundwater (g/m^3)
SS	Silver Springs area in upper 1,200-m segment (m^2)
SS_W	mean water depth in Silver Springs upper 1,200 m (m)
SW_N	TN in Silver Springs surface water in upper 1,200 m (g/m^3)
SS_{AB}	aquatic plant & consumer biomass in Silver Springs upper 1,200 m (g dw/m^2)
AB_N	TN in aquatic plants & algae biomass in Silver Springs upper 1,200 m (g/m^2)

Flows

1	gross primary productivity in Silver Springs (g dw/m^2/d)	$J_1 = k_{GPP}(S)(SW_N)(SS_{AB})$
2	direct precipitation to natural lands (km^3/yr)	$J_2 = 0.001(A)(NL)$
3	TN in direct precipitation to natural lands (kg/yr)	$J_3 = 1{,}000(A_N)(NL)$
4	direct precipitation to developed lands (km^3/yr)	$J_4 = 0.001(A)(DL)$
5	TN in direct precipitation to developed lands (kg/yr)	$J_5 = 1{,}000(AN)(DL)$
6	direct precipitation to Silver Springs (km^3/yr)	$J_6 = 0.000001(A)(SS)$
7	TN in direct precipitation to Silver Springs (kg/yr)	$J_7 = 0.001(A_N)(SS)$
8	evapotranspiration from natural lands (km^3/yr)	$J_8 = k_1(PE)(NL)$
9	evapotranspiration from developed lands (km^3/yr)	$J_9 = k_2(PE)(DL)$
10	evapotranspiration from Silver Springs (km^3/yr)	$J_{10} = k_3(PE)(SS)$
11	rate of conversion of natural lands to developed lands (km^2/yr)	$J_{11} = k_4(NL)(E)$
12	infiltration from natural lands to groundwater (km^3/yr)	$J_{12} = J_2\text{-}J_8$
13	TN in infililtrating water from natural lands to groundwater (kg/yr)	$J_{13} = k_5(NL)$
14	infiltration from developed lands to groundwater (km^3/yr)	$J_{14} = J_4\text{-}J_9$
15	TN in infililtrating water from developed lands to groundwater (kg/yr)	$J_{15} = k_6(DL)$
16	surface water inputs to Silver Springs (km3/yr)	$J_{16} = k_7A$
17	TN in surface water inputs to Silver Springs (kg/yr)	$J_{17} = k_8A$

Table 4-5 Silver Springs Conceptual Nitrogen Landscape Model

18	groundwater inputs into Silver Springs (km^3/yr)	$J_{18} = k_9(GW)$
19	TN in groundwater inputs to Silver Springs (kg/yr)	$J_{19} = J_{18}(GW_N)$
20	anthropogenic TN inputs to Silver Springs (kg/yr)	$J_{20} = k_{10}(E)$
21	groundwater pumping out of springshed (km^3/yr)	$J_{21} = k_{11}(E)(GW)$
22	Silver Springs downstream flows (km^3/yr)	$J_{22} = J_{18}+J_6-J_{10}$
23	Silver Springs downstream surface water TN outflows (kg/yr)	$J_{23} = J_{22}(SW_N)$
24	Silver Springs downstream particulate export (g dw/m^2/yr)	$J_{24} = J_1-J_{26}$
25	Silver Springs downstream particulate TN export (kg/yr)	$J_{25} = J_{24}(AB_N)$
26	Silver Springs community respiration (gm dw/m^2/yr)	$J_{26} = k_{12}(SS_{AB})$
27	anthropogenic TN inputs to developed lands (kg/yr)	$J_{27} = k_{13}(E)$
28	TN in groundwater pumping out of springshed (kg/yr)	$J_{28} = J_{21}(GW_N)$

Differential Equations

$NL = -6$
$NL_W = 2-8-12$
$NL_N = 3-13$
$DL = 6$
$DL_W = 4-9-14$
$DL_N = 5+27-15$
$GW = 12+14-18-21$
$GW_N = 13+15-19-28$
$SS_W = 16+18-10-22$
$SS_N = 17+19-23-25$
$SS_{AB} = 1-24-26$

energy, with counter flows of money for those pathways mediated by human society. There are thirteen state variables in the model, including: natural lands (NL), which include land characterized by any low intensity land uses that do not receive significant inputs of nitrogen from anthropogenic uses, developed lands (DL) that include areas impacted by all other land uses, the water and nitrogen associated with the natural and developed lands, the groundwater within the basin (GW), and the structure of Silver Springs (SS) including the surface water (SW) and its associated nitrogen (SS_N) and biota (SS_{AB}) and its associated nitrogen (AB_N). Key exports in the model include evapotranspiration, outflows of products, seeds, water, and wildlife from natural and developed lands, groundwater pumping out of the basin, and downstream exports in the Silver River. A total of twenty-eight rate equations with fourteen adjustable rate constants and eleven differential equations comprise the mathematical model.

4.5.5.3 Description of the Silver Springs Ecosystem Model

The Silver Springs Ecosystem Model is entirely included within the landscape model just described. The boundary for the ecosystem model is the immediate surface watershed of the upper 1,200-m segment of the Silver River. The spatial area of this watershed basin is about 2,945 km^2.

Figure 4-11 provides a diagram of the conceptual ecosystem model. Table 4-6 provides a list of the forcing functions, state variables, rate equations, and differential equations that comprise the mathematical simulation model. There are nine forcing functions including: the PAR portion of sunlight, atmospheric inputs of water and nitrogen, groundwater inputs of water and nitrogen, surface water (stormwater) inputs of water and nitrogen, and anthropogenic inputs such as goods and services. There are five state variables in the ecosystem model including: the land area and associated uplands, spring boils, and river channel, the water in the channel and associated nitrogen, and the aquatic plant and consumer biomass and associated nitrogen. There are five outflows from the model including: evapotranspiration, surface water outflow in the Silver River with dissolved nitrogen, and downstream particulate matter and nitrogen export. The Silver Springs Ecosystem Model has twenty-six rate equations, eight adjustable constants, and three differential equations.

4.6 Water Stage and Discharge

4.6.1 Water Stage and Discharge Measurements with Gauges and Flow Meters

Water stage was recorded using existing USGS staff gages. There are two existing staff gages within the study area, one in the covered boat house located in the Boat Basin, and the other immediately below the 1,200-m station near the Birds-of-Prey exhibit area. The vertical datum

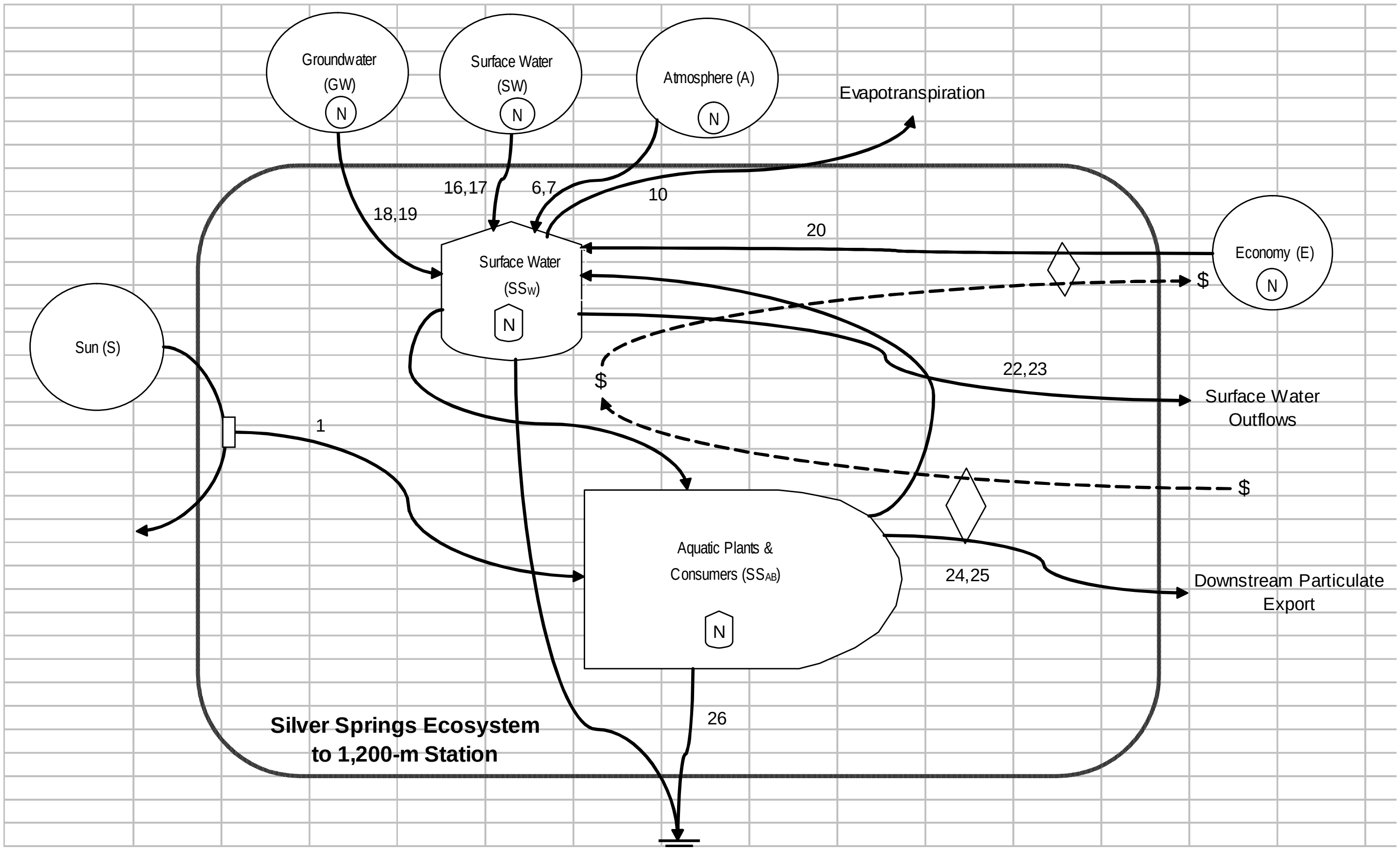


Figure 4-11 Silver Springs ecosystem model (Main Spring Boil to 1,200-m Station)

Table 4-6 Silver Springs Ecosystem Model (Main Boil to 1,200-m station)

Forcing Functions

S	photosynthetically active radiation (µM/s/m^2)
A	atmospheric inputs (m/yr)
A_N	TN in total precipitation (g/m^2/yr)
GW	groundwater inputs (km^3/yr)
GW_N	TN in groundwater (g/m^3)
SW	surface water inputs (km^3/yr)
SW_N	TN in surface water (g/m^3)
E	economic health (GNP)
E_N	anthropogenic TN inputs (g/m^2/yr)

Storages

SS	Silver Springs area in upper 1,200-m segment (m^2)
SS_W	mean water depth in Silver Springs upper 1,200 m (m)
SW_N	TN in Silver Springs surface water in upper 1,200 m (g/m^3)
SS_{AB}	aquatic plant & consumer biomass in Silver Springs upper 1,200 m (g dw/m^2)
AB_N	TN in aquatic plants & algae biomass in Silver Springs upper 1,200 m (g/m^2)

Flows

1	gross primary productivity in Silver Springs (g dw/m^2/d)
6	direct precipitation to Silver Springs (km^3/yr)
7	TN in direct precipitation to Silver Springs (kg/yr)
10	evapotranspiration from Silver Springs (km^3/yr)
11	rate of conversion of natural lands to developed lands (km^2/yr)
16	surface water inputs to Silver Springs (km3/yr)
17	TN in surface water inputs to Silver Springs (kg/yr)
18	groundwater inputs into Silver Springs (km^3/yr)
19	TN in groundwater inputs to Silver Springs (kg/yr)
20	anthropogenic TN inputs to Silver Springs (kg/yr)
22	Silver Springs downstream flows (km^3/yr)
23	Silver Springs downstream surface water TN outflows (kg/yr)
24	Silver Springs downstream particulate export (g dw/m^2/yr)
25	Silver Springs downstream particulate TN export (kg/yr)
26	Silver Springs community respiration (gm dw/m^2/yr)

Differential Equations

$$SS_W = 16+18-10-22$$
$$SS_N = 17+19-23-25$$
$$SS_{AB} = 1-24-26$$

for the Boat Basin staff gage is reported as 11.88 m (38.96 ft) above mean sea level (msl) (1929 National Geodetic Vertical Datum [NGVD]). The vertical datum for the downstream station gage is reported as 11.66 m (38.27 ft) above msl (1929 NGVD). Water stage at both staff gage stations was recorded during each field trip. Detailed daily records of water stage at these two stations were provided by the SJRWMD and the USGS.

Periodic discharge measurements were made for the Main Spring Boil outlet channel, Back Channel, Boat Basin Channel, and at the 1,200-m station. Discharge measurements were taken in an effort to determine the relative proportion of the flow entering the Back Channel and Boat Basin, in order to better understand the importance of water quality changes in that area. A detailed description of the methods used to measure water stage and discharge with gages and flow meters can be found in Appendix B.

4.6.2 Discharge Detection by Aerial Thermal Infrared Imagery

Thermal infrared imagery was obtained during February 2003 to identify temperature anomalies that may be indicative of groundwater discharge into the Silver River. Throughout the Silver River, numerous vents provide pathways for artesian water to flow from the Floridan Aquifer to the surface. Much of this discharge is obvious and can be seen as boils on the water surface. Other discharge is less obvious and can only be detected by techniques such as diving, water chemistry, flow measurements, or remote sensing techniques. The thermography surveys can be complemented by high resolution single channel seismic reflection profiling (see 4.6.3), which can confirm the existence of potential pathways for groundwater discharge. An aerial thermography survey was used to identify temperature anomalies that would be caused by warmer groundwater entering the cooler surface water of the river. The SJRWMD has obtained aerial thermography surveys for more than 1,200 line kilometers over lakes and rivers. All known springs that were surveyed could be identified in the resulting imagery. All of the aerial thermography data for the different sites were collected through contracts with SenSyTech, Inc. based in Ann Arbor, Michigan. Silver Springs was included in a cooperative agreement with the Florida Geological Survey (FGS) in which the FGS contracted directly with SenSyTech, Inc. Coordination of surveys is more cost effective since mobilization costs can be shared. A complete description of the aerial thermal infrared imagery methodology is provided in Appendix B.

4.6.3 Detection of Subsurface Pathways for Discharge using High Resolution Single Channel Seismic Reflection Profiling

The SJRWMD has utilized Joint Funding Agreements with the USGS Center for Coastal and Wetlands Studies to perform high resolution single channel seismic reflection profiles (HRSCS) on over sixty sites within the SJRWMD. Features that have been identified include buried sinkholes, spring vents, breaches in the confining units, and multiple episodes of subsidence that has deformed the confining units (Kindinger and others, 1994). Data from HRSCS surveys conducted at Silver Springs were used to identify potential pathways for flow by detecting breaches or disturbances in the confining units above the Floridan Aquifer. Seismic profiles were obtained along the entire length of the river and additional short profiles were obtained at specific points of interest identified from the thermal anomalies discussed in the previous subsection of this report. Detailed HRSCS methodologies are presented in Appendix B.

4.7 Oxygen Diffusion

Oxygen diffuses from the air to the water in the Silver River due to the unsaturated nature of the groundwater as it emerges from the Floridan Aquifer. This source of oxygen to the water column must be determined to correctly estimate ecosystem metabolism by the upstream-downstream dissolved oxygen (DO) method used in this study. Oxygen diffusion rate was estimated by use of the floating dome technique of Copeland and Duffer (1964) and as refined and described by McKellar (1975). This method determines the rate of diffusion of oxygen from the water with known oxygen percent saturation into a floating dome with essentially zero oxygen percent saturation. The rate of oxygen diffusion through the water surface is assumed to be equal regardless of the direction of movement and is assumed to be linearly related to the saturation deficit between the water and the air. The technique is described in detail in Appendix B.

4.8 Water Quality

Water quality measurements of the individual spring vents and the upper 1,200 m of the Silver River were made for field parameters, analytical constituents, and physical conditions. Each of these parameters was measured with varying frequency and in different locations as described in the following paragraphs. Water quality sampling field notes are included in Appendix H.

4.8.1 Field Parameters

Monthly field parameters were measured at eleven stations shown in Figure 4-12. This included DO, temperature, conductivity, specific conductance, and pH. All measurements of DO and temperature were made with a Yellow Springs Instruments (YSI) 550 DO meter.

Conductivity, specific conductance, and pH were recorded using a YSI 63 meter. As with the YSI 550 DO meter, calibration was performed on each field trip. Once calibrated the YSI 63 meter was used to record conductivity, specific conductance, and pH at each of the eleven stations shown in Figure 4-12. Descriptions of the calibration and measurement methodologies used for the YSI 550 and YSI 63 meters can be found in Appendix B.

4.8.2 Water Sample Collection

Collection of water samples was performed by WSI, the FDEP, and the SJRWMD. Grab samples were taken by FDEP personnel quarterly (January, April, July, and October 2004, and January 2005) and the remaining monthly samples were collected by WSI staff. In addition, SJRWMD staff collected water quality samples on March 24, 2005. WSI and FDEP collected water quality samples from four spring vents (Main Spring Boil, Catfish Reception Hall, Blue Grotto, and Christmas Tree Spring, also known as Spanish Spring and Cypress Spring) and from one river station (1,200-m). In addition, the SJRWMD collected water quality samples from the following locations: two vents (A and B) at the Main Spring Boil, the Abyss (also known as Bridal Chamber), Blue Grotto, and Christmas Tree Springs. The locations of the water quality sampling stations are shown in Figure 4-13. A summary of field and laboratory water quality methods and detection limits is provided in Table 4-7. A full discussion of the collection, transportation, and analysis of water quality grab samples is provided in Appendix B.

4.8.3 Continuous Water Quality Monitoring

Continuous records for temperature, DO, specific conductance, and pH were made at the Main Spring Boil, Turtle Meadows, and at the 1,200-m station using a Troll-9000 data-logging sonde (Figure 4-14). The 1,200-m station was monitored throughout the duration of the study (February 2004 through March 2005) while data sonde deployment in the Main Spring Boil and at Turtle Meadows was more limited in duration (February to March 2005). Complete details of the calibration and downloading of data from the data sondes can be found in Appendix B.

4.8.4 Secchi Distance

Secchi distance was measured with a standard 20 centimeter diameter black and white secchi disk. Due to extreme clarity of the water (>20 meters) in combination with the relatively shallow depths (<15 meters) secchi disk readings were taken horizontally in the river channel. The secchi disk was attached to the end of a tape measure and aligned in the sampling area parallel to the orientation of the sun with the sunlight shining toward the disk. A skin diver then extended the tape until the disk was no longer visible. The diver then swam back and forth several times to determine the average distance from which the disk could be observed. All measurements were made before 10 A.M. when the Silver Springs attraction opens its glass-bottom boat rides. Measurements of secchi distance were recorded for three stations: the Main Spring Boil, Turtle Meadows, and the 1,200-m station.

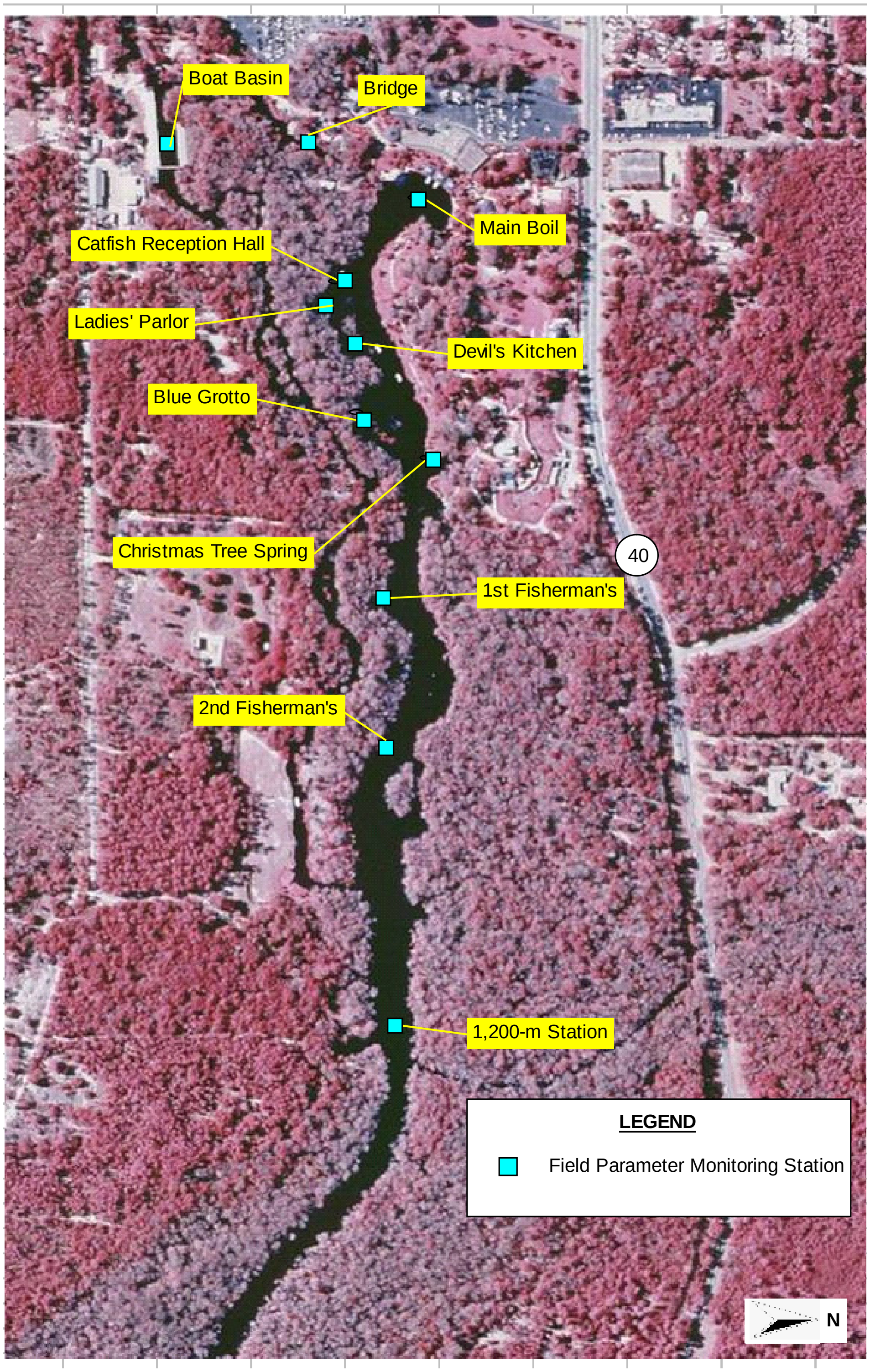


Figure 4-12 WSI's field parameter sampling stations in the upper 1,200-m reach of the Silver River during the retrospective study

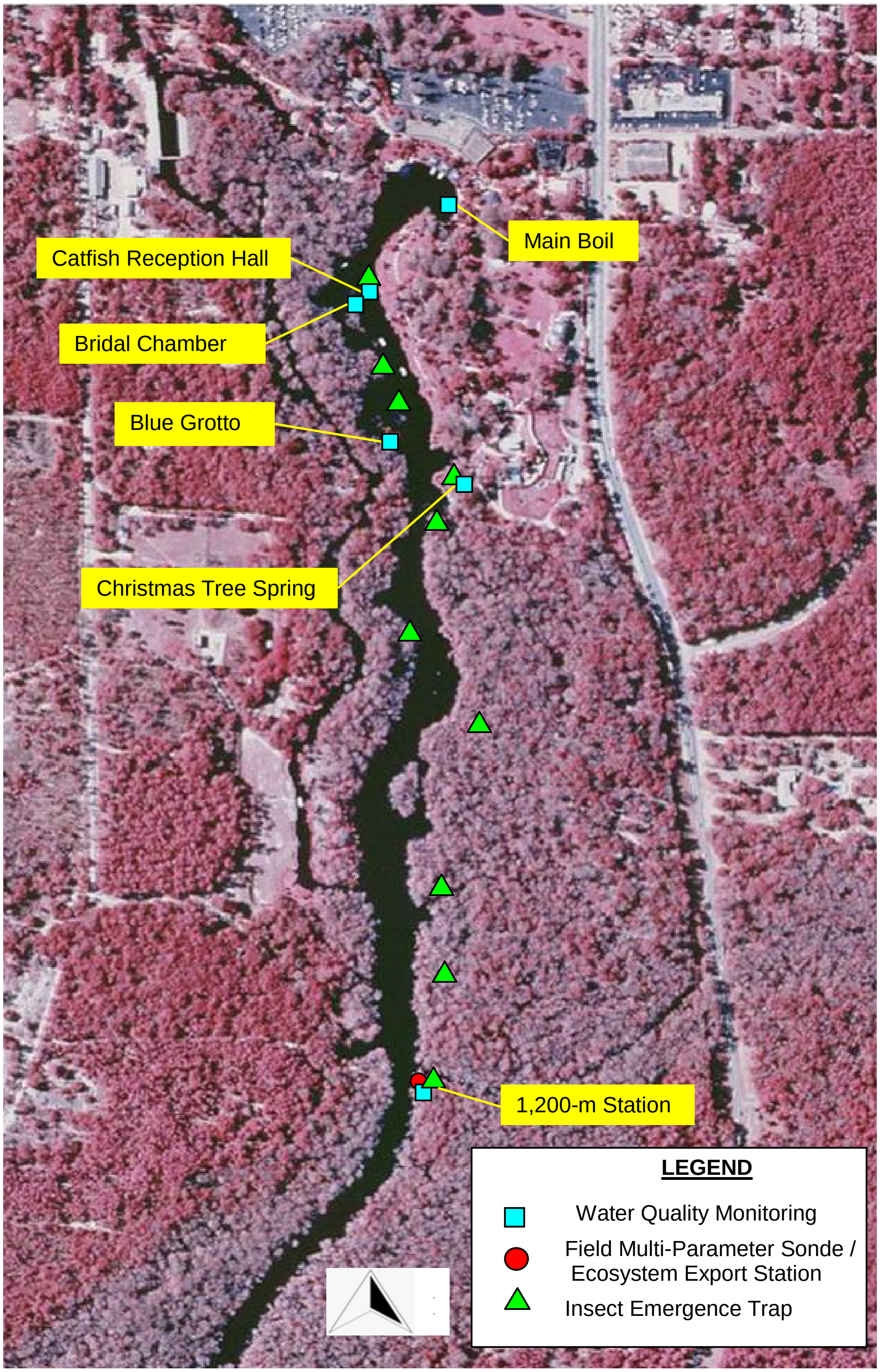


Figure 4-13 Water quality sampling stations in the upper 1,200 m of Silver Springs run during the fifty-year retrospective study

Table 4-7 Summary of field and laboratory water quality methods and detection limits for the Silver Springs Fifty-Year Retrospective Study

Parameter	Method [1]	Detection limit (mg/L)	Holding time	Preservative
Temperature (^oC)	FT 1400	---	---	---
Dissolved Oxygen	FT 1500	---	---	---
pH (SU)	FT 1100	---	---	---
Specific Conductance (umhos/cm)	FT 1200	---	---	---
Chlorides	EPA 325.1	2.5	28 days	---
Sulfate	EPA 375.4	2.5	28 days	<4^oC
Fluoride	SM4500FC	0.05	28 days	---
Calcium	EPA 200.7	0.014	28 days	HNO_3
Magnesium	EPA 200.7	0.0074	28 days	HNO_3
Sodium	EPA 200.7	0.0084	28 days	HNO_3
Potassium	EPA 200.7	0.024	28 days	HNO_3
Alkalinity	EPA 310.1	5	14 days	<4^oC
Nitrate + Nitrite –N	EPA 353.2	0.05	28 days	H_2SO_4, <4^oC
Ammonia-N	EPA 350.1	0.02	28 days	H_2SO_4, <4^oC
Total Kjeldahl Nitrogen	EPA 351.2	0.05	28 days	H_2SO_4, <4^oC
Total Phosphorus	EPA 365.4	0.02	28 days	H_2SO_4, <4^oC
Ortho Phosphorus	EPA 365.2	0.015	48 hours	Field filtered, <4^oC
Total Dissolved Solids	EPA 160.1	2	7 days	Lab filtered, <4^oC
Total Suspended Solids	EPA 160.2	2	7 days	<4^oC
Turbidity (NTU)	EPA 180.1	1	48 hours	<4^oC
Color (PCU)	EPA 110.2	5	48 hours	<4^oC
Total Coliform (#/100mL)	SM 9222B	1	6 hours	<4^oC
Fecal Coliform (#/100mL)	SM9222D	1	6 hours	<4^oC

[1] All methods for environmental waters from Methods for Chemical Analysis of Water and Wastes, EPA-600-79-020, Revised March 1983, and /or Standard Methods for the Examination of Water and Wastewater, 18th Edition, Revised 1992 and /or DEP SOPs.

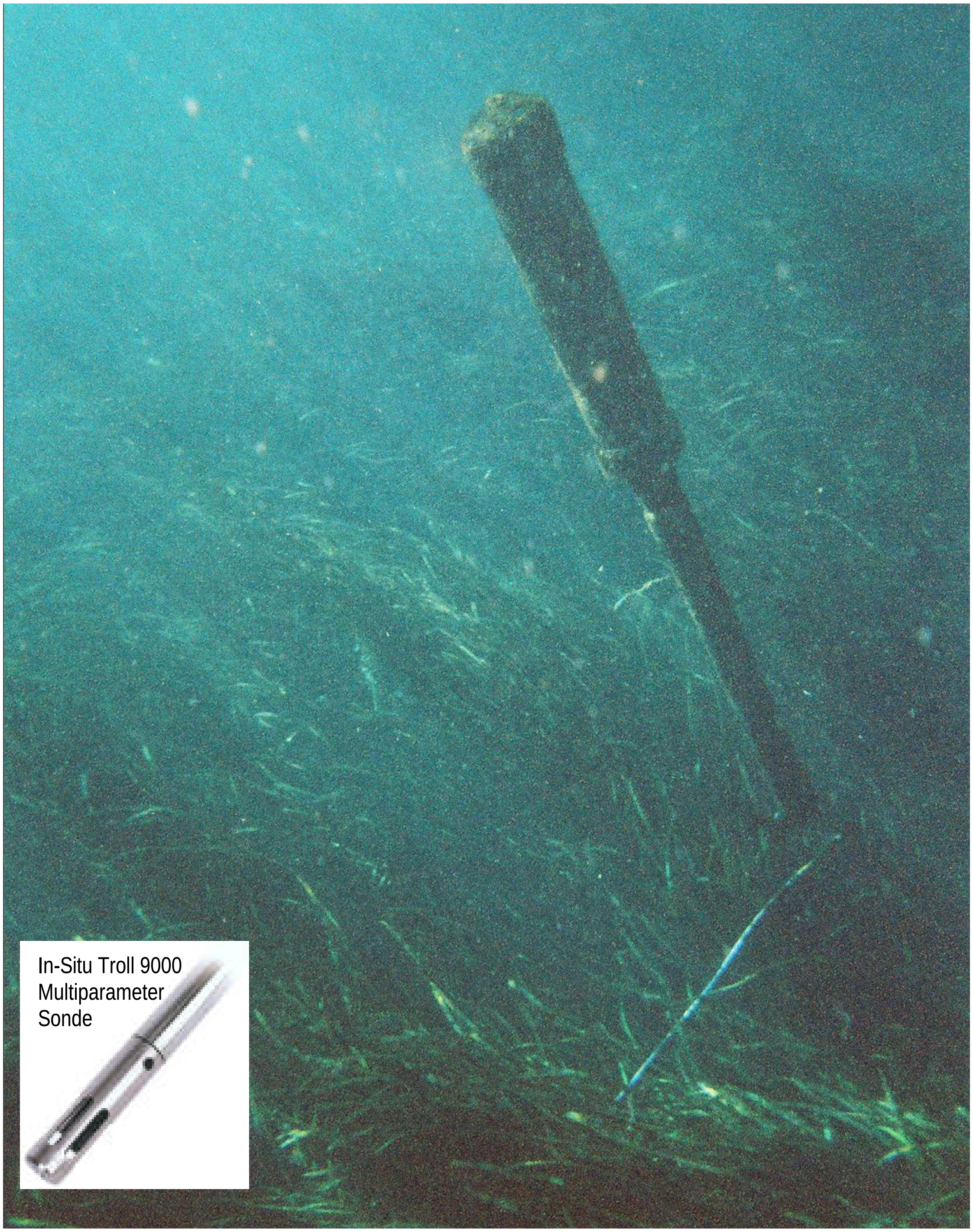


Figure 4-14 WSI's In-Situ Troll 9000 recording datasonde installation at the 1,200-m station in Silver Springs.

The upper portion of the PVC outer case provides flotation without capturing drifting plants. The lower portion contains the stainless steel datasonde. The whole apparatus is anchored to the river bottom with a stainless steel cable.

4.9 Epiphytic Algae

Epiphyte samples were collected, analyzed and characterized at thirty-seven sites in the Silver River during the winter of 2003 – 2004. The resulting data were entered into a database format to be used in a geographical information system (GIS) program (ArcGIS 8.3). Layered coverage maps were generated for each season to quantify the spatial distribution of epiphytic algae in the Silver Springs system. From these maps, estimations of epiphyte biomass per area (g dry weight epiphytes /m^2) and total epiphyte biomass were generated. The mean epiphyte biomass and standard deviation were also calculated. A detailed description of the methodologies used in sampling, analysis, and characterization of epiphytes algae is presented in Appendix B.

4.9.1 Benthic Macroalgae

Benthic algae mats were sampled, analyzed, and characterized during the winter of 2003 – 2004, and in the summer of 2004 and winter of 2004. The results of this analysis were entered into a database format to be used in ArcGIS 8.3. Layered data maps were generated for each season. From these maps, estimations of total algae mat biomass, total benthic algae mat biomass, mean algae mat biomass and standard deviation were produced. Detailed descriptions of the methodologies used are presented in Appendix B.

4.9.2 Macrophyte Community

The following five paragraphs provide brief descriptions of the methodologies used to quantify and characterize the Silver Springs macrophyte community. Complete details of the macrophyte community characterization methods can be found in Appendix B.

4.9.2.1 Macrophyte Biomass

Macrophyte biomass was calculated by counting the number of *Sagittaria* blades within a given area, collecting blades randomly from six plants at each site, and then determining dry weight and ash-free dry weight using laboratory methods. Biomass estimates were reported as dry and ash-free weight (g) per meter squared in a database format and as a macrophytes biomass coverage map (g dry weight per meter squared). Detailed descriptions of these methodologies are presented in Appendix B.

4.9.2.2 Macrophyte Distribution

The distribution of macrophytes was determined with high density transect sampling. Transects were sampled in close proximity to provide accurate depth and *Sagittaria* blade length. Boundaries of distinct aquatic habitats were marked on the chart tracing, along with details observed during a visual survey. A buoy was dropped randomly while sampling and the site marked on the tracing paper. After a transect was completed, the buoy was retrieved and the depth and *Sagittaria* plant height at the site were recorded to reference the fathometry data. Complete details of the methods used are provided in Appendix B.

4.9.2.3 Macrophyte Percent Coverage

Macrophyte percent coverage throughout the system was characterized visually on a Braun-Blanquet scale (Braun-Blanquet 1932). The visual survey allowed for the rapid assessment of macrophytes coverage from a boat using a viewing box and/or snorkel. At each geo-referenced site (n=107), a 0.25m^2 quadrat was lowered through the water column and percent coverage determined. Depth and plant height were also recorded at each site.

4.9.2.4 Macrophyte Coverage and Blade Density Relationships

The relationship between macrophytes percent coverage and the number of blades within the quadrat was determined with SCUBA divers. The divers counted the number of blades per 0.25m^2 quadrat representing the Braun-Blanquet scale. For example, the scale was divided into the following coverages: 0, 10, 25, 50, 75 and 100% and from each of these divisions; blades were counted in ten different quadrats.

4.9.3 Coverage Maps

Macrophyte coverage maps were generated with the use of ArcGIS 8.3. Coverage maps were created for each season to quantify the spatial distribution of macrophytes in the Silver Springs system (Appendix X). Macrophyte biomass based on blade length was determined from the winter biomass surveys. The following estimations were generated from the maps: macrophyte biomass per area (g dry weight *Sagittaria* /m^2); total macrophyte biomass; mean algal biomass; and standard deviation. “False” macrophyte biomass was taken into account. Complete details of the methods used are provided in Appendix B.

4.10 Particulate Export of Organic Material

Particulate export was measured periodically during the study period in an effort to quantify particulate organic carbon outputs to the Silver River system. This measurement provides a comparative check on net primary productivity estimated by the upstream-downstream DO change method. The plankton net used to measure fine particulate export is presented in Figure 4-15. The methods used to collect and quantify particulate export of organic material are described in Appendix B.

4.11 Floating Aquatic Plant Export

Floating plant export was estimated monthly with a device that captured any floating and drifting plants within approximately 20 cm of the water surface (Figure 4-16). The purpose of these traps was to quantify the export of floating and submerged aquatic vegetation from the upper Silver Springs area. This export number, in addition to the suspended organic material sampling results described in the previous section, provided an independent measure of ecosystem net primary productivity. Appendix B includes a description of the method used to estimate floating plant export for this study.

4.12 Insect Emergence

Insect emergence was measured through the use of floating pyramidal traps, each with a sampling area of 0.5x0.5 meters (0.25 m^2). The design of this trap was based on traps used for midge and mosquito sampling from wetland and aquatic environments (Walton *et al.* 1999). Each trap was constructed of wood and had four sides covered with fiberglass window screen. Flotation was provided by foam “noodles” attached along the bottom wooden supports. The traps worked under the premise that insects emerging into the trap generally seek the highest spot and in the process travel through an inverted funnel into a 500 mL jar inverted over the end of the funnel. A total of ten pyramidal traps were typically deployed at locations along the periphery of the spring run monthly (refer to Figure 4-13 for trap locations). Each trap was tethered near the shoreline by rope to a branch or log. Bottom plant cover (benthic algae, shelly bottom, or *Sagittaria*) was noted for each trap. A typical trap installation is illustrated in Figure 4-17. Complete details about the frequency and method of trap sampling, sample analysis, and the use of an alternative insect emergence sampling technique employed in this study are provided in Appendix B.

4.13 Vertebrate Population Survey

UF researchers conducted visual surveys at the spring run for fishes, turtles, alligators and birds. Surveys were conducted on four dates: March 4th, April 16th, June 4th, and June 17th in 2004. The sample area included the spring run from the Main Spring Boil down to the USGS station, a stretch of 1,200 m. Fish and turtles were counted along three underwater transects encompassing the entire 1,200 m stretch. Fish populations were also sampled using electrofishing on July 22nd, 2004 to compare with visual surveys. Electrofishing was used because of difficulty counting spotted sunfish (*Lepomis punctatus)* in visual surveys (Odum 1957).

Alligators and birds were assessed by idling downstream and entering spring heads. In one pass, alligators were tallied and all bird species were identified and tallied by three observers. Submerged alligators were easily observed due to the high clarity of the water. Detailed methodologies are provided in Appendix B.

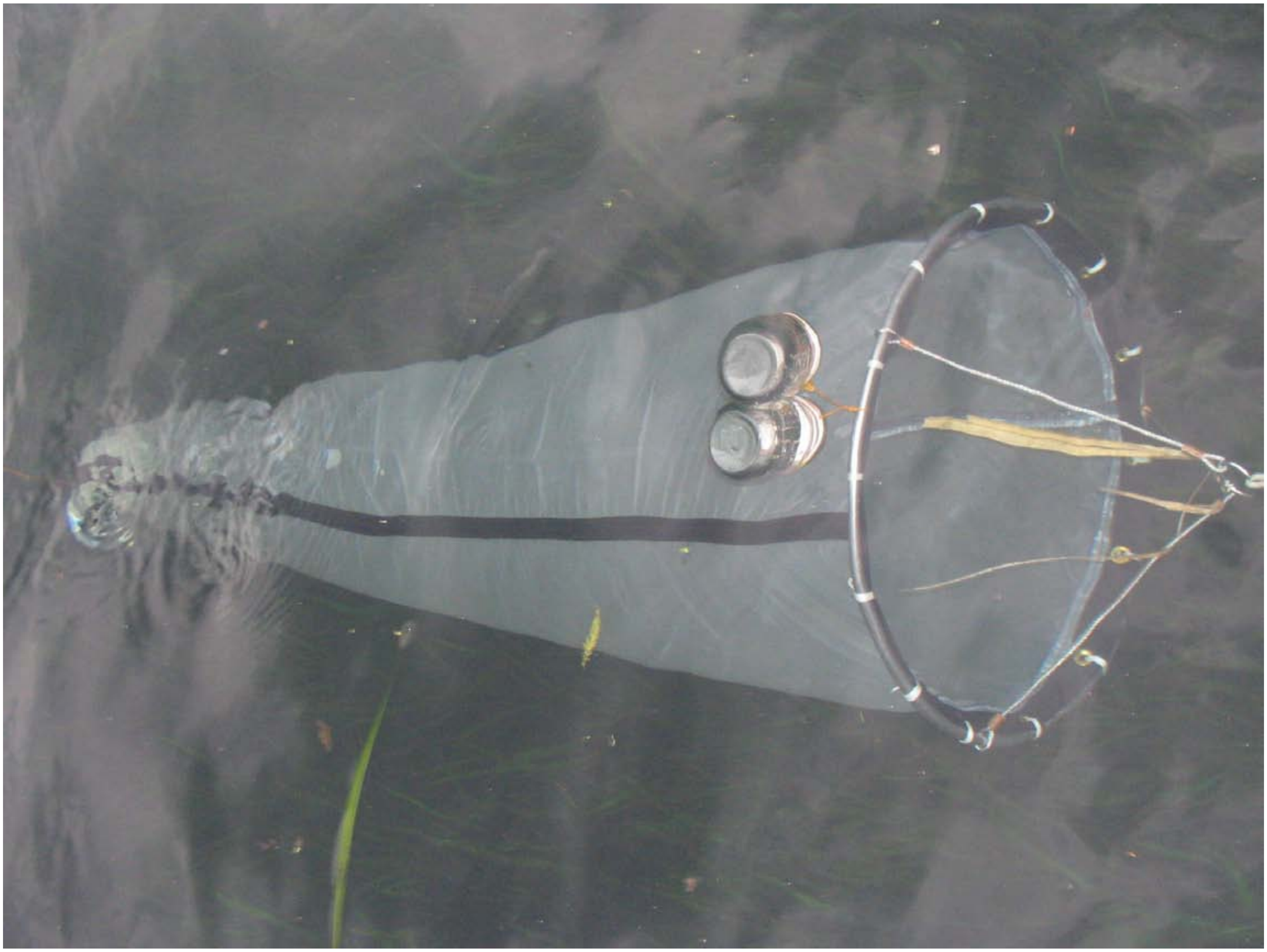


Figure 4-15 Plankton net used to measure fine particulate export in the upper Silver River

Figure 4-16 Typical plant export trap deployed in the Silver River.

Each trap has a capture length of 1 meter.

Figure 4-17 Typical pyramidal insect emergence trap and inverted glass funnel deployed at Silver Springs

Biomass of all fish species from the three transects of each visual sample was totaled and an average total fish standing crop in kilograms per hectare (kg/ha) was estimated. To compare fish biomass levels at Silver Springs to other Florida springs and rivers, the average total standing crop was plotted versus total phosphorus (µg/l) of Silver Springs along with fifteen other Florida rivers and spring runs (Hoyer and Canfield 1991). Species richness was determined by combining the results of all the sampling efforts, including visual estimates and electrofishing.

4.14 Ecosystem Metabolism

A detailed description of the methods used to measure ecosystem metabolism, including a thorough discussion of the rationales employed to select the methodologies, is presented in Appendix B. Ecosystem metabolism was estimated using a spreadsheet adaptation (Microsoft Excel) of the upstream/downstream DO method developed by H.T. Odum (1956; 1960) and Odum and Hoskins (1957). This method (see Figure 4-18) estimates and subtracts upstream from downstream DO fluxes to determine the metabolic oxygen rate-of-change of the aquatic ecosystem. For the case of Silver Springs, DO mass inputs are the result of spring discharges, atmospheric diffusion into the water column, and the release of DO as a by-product of aquatic plant productivity. Oxygen losses include the metabolic respiration of the plant and animal communities including sediment oxygen demand.

4.15 Silver Springs Fifty-Year Retrospective Ecosystem Study Database

4.15.1 Description of the Silver Springs Fifty-Year Retrospective Ecosystem Study Database

All historical and new data collected for the Silver Springs Fifty-Year Retrospective Ecosystem Study were electronically stored and organized with Microsoft Access 2003 (Appendix W). Microsoft Access was selected because of its ability to organize and analyze data easily. The Silver Springs Database (SSDB) contains the following primary database tables titled:

- Lab Field Data
- Troll 9000 Infinities Rainfall
- LiCor Data
- USGS Flow
- USGS Stage
- UF Fish

Date: 3/22/2004

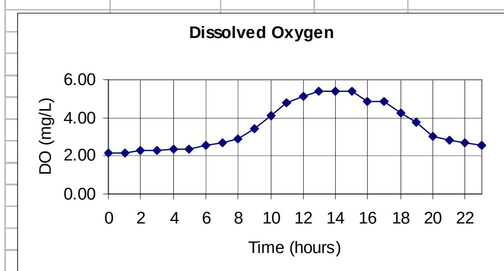
Spring Run		
Area:	76000	m^2
Water Depth:	1.8	m
Flow:	2040000	m^3/d
Diff Rate:	1.72	$g/m^2/hr$

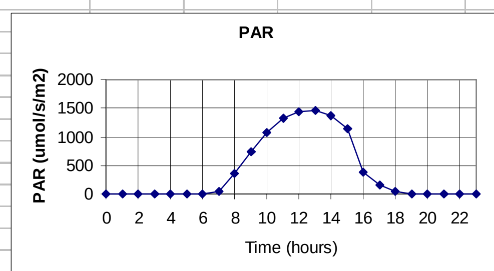
Mail Boil		
Water Temp:	23.1	C
DO:	2.6	mg/L
DO sat:	28.7	%
Diffusion:	1.23	$g/m^2/hr$

Accrual		
DO:	-0.2	mg/L
DO:	-0.22	$g/m^2/hr$

	1,200-m Station									
Time	Temp	DO	DO	Diffusion	Average Diffusion	DO Rate of Change	Corrected DO Rate of Change	Average PAR	Nighttime Respiration (Qnight)	Nighttime Diffusion (Dinnight)
	C	mg/L	%	$g/m^2/hr$	$g/m^2/hr$	$g/m^2/hr$	$g/m^2/hr$	$umol/s/m^2$	$g/m^2/hr$	$g/m^2/hr$
0:00	23.21	2.15	25.1	1.3	1.3	-0.50	-1.54	0.00	-1.54	1.26
1:00	23.20	2.17	25.3	1.3	1.3	-0.48	-1.51	0.00	-1.51	1.26
2:00	23.17	2.27	26.5	1.3	1.2	-0.37	-1.39	0.00	-1.39	1.25
3:00	23.14	2.29	26.7	1.3	1.2	-0.35	-1.37	0.00	-1.37	1.24
4:00	23.09	2.35	27.4	1.2	1.2	-0.28	-1.29	0.00	-1.29	1.24
5:00	23.07	2.38	27.7	1.2	1.2	-0.25	-1.26	0.00	-1.26	1.23
6:00	23.04	2.53	29.4	1.2	1.2	-0.08	-1.07	0.16	-1.07	1.22
7:00	23.00	2.72	31.6	1.2	1.2	0.13	-0.84	49.65		
8:00	23.00	2.90	33.7	1.1	1.2	0.34	-0.62	355.60		
9:00	23.05	3.47	40.4	1.0	1.1	0.97	0.07	738.40		
10:00	23.16	4.12	48.0	0.9	1.1	1.70	0.86	1076.00		
11:00	23.32	4.80	56.2	0.8	1.0	2.46	1.69	1324.00		
12:00	23.49	5.12	60.1	0.7	1.0	2.82	2.09	1438.00		
13:00	23.64	5.41	63.6	0.6	0.9	3.14	2.44	1454.00		
14:00	23.74	5.40	63.6	0.6	0.9	3.13	2.43	1362.00		
15:00	23.76	5.36	63.3	0.6	0.9	3.09	2.38	1151.00		
16:00	23.71	4.87	57.4	0.7	1.0	2.54	1.78	371.10		
17:00	23.58	4.88	57.4	0.7	1.0	2.55	1.79	152.20		
18:00	23.42	4.24	49.7	0.9	1.0	1.83	1.01	47.34		
19:00	23.26	3.75	43.8	1.0	1.1	1.29	0.41	4.14		
20:00	23.13	3.02	35.3	1.1	1.2	0.47	-0.48	0.00	-0.48	1.17
21:00	23.06	2.85	33.2	1.1	1.2	0.28	-0.68	0.00	-0.68	1.19
22:00	23.02	2.73	31.8	1.2	1.2	0.15	-0.83	0.00	-0.83	1.20
23:00	23.01	2.54	29.6	1.2	1.2	-0.07	-1.06	0.00	-1.06	1.22

GPP =	30.26	$g/m^2/d$	N24+R
NPP24 =	3.01	$g/m^2/d$	average (corrQ)
R24 =	27.25	$g/m^2/d$	average (Qnight)
Din (night) =	29.39	$g/m^2/d$	average(Dinnight)
Q (night) =	-27.25	$g/m^2/d$	average(Qnight)
CM (24hr)=	30.26	$g/m^2/d$	
PAR (24 hr) =	34.28	$mol/m^2/d$	
Efficiency (%) =	16.9	percent	
NPPday =	16.97	$g/m^2/d$	
Rnight=	13.96	$g/m^2/d$	
GPP=	30.92	$g/m^2/d$	





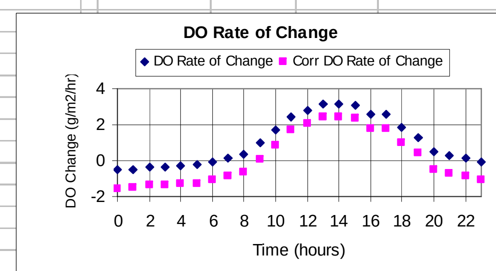


Figure 4-18 Example Silver Springs ecosystem metabolism worksheet using the parameter values previously used by Odum (1957) and Knight (1980)

- UF Winter Fathometry
- UF Summer Fathometry
- UF Macroalgae Coverage Thickness
- UF Macroalgae Biomass
- UF Braun Blanquet Coverages – *Sagittaria kurziana*
- UF Braun Blanquet Coverage Blade
- UF Braun Blanquet Blade Counts

The remaining database tables are supplemental to support the tables listed above.

- WQ Stations
- Parameter Codes
- Parameter Groups
- FAWN Ocklawaha Stn
- UF Fish Codes
- UF Macrophyte/Algae Species

A brief description of each of the tables created for this project, with field details (field names, field type, and field description), is provided in Appendix I. Appendix I also includes a 'screen-shot' of the data summary form used to generate summary statistics and charts for data included in this database.

The *Lab Field Data* database table contains historic and new data collected for this project on water, sediment, insect emergence, particulate organic carbon export, and wildlife tissue. Data entered into this table are identified by the station name, sampling date (or date range), sample matrix type and the sample parameter. STORET Parameter Codes are included for release of water quality data to the public via STORET. The researcher and data source are identified for each database record. There are twenty-seven fields, not including two memo fields for record comments and edit notes, in the Lab Field Data database file.

There are three supplemental database tables that are linked to the *Lab Field Data* database table including *WQ Stations*, *Parameter Codes*, and *Parameter Groups*. The *WQ Stations* database table lists each station in the *Lab Field Data* database table along with the researcher, station identification and name, and latitude/longitude, if available. The *Parameter Codes* and

Parameter Groups database tables list the STORET parameter codes, parameter long name and short name, and parameter groups for all water quality parameters in the *Lab Field Data* tables.

The *Troll 9000* database table contains continuous field parameter data measured during this study with an *in situ* multi-function sonde (TROLL 9000 In-Situ, Inc.) including water temperature, dissolved oxygen, pH, and specific conductance. Data entered into this table are identified by the station name, sampling date and time, and equipment serial number. Database records in the table have been adjusted for any calibration shifts during sonde deployment. The original "raw" continuous field parameter data are included in another database table named *Troll 9000 Raw* with identical database structure. Each database table contains sixteen fields, not including one memo field for database record edit notes.

The *Infinities Rainfall* database table contains daily total rainfall measured using an Infinities USA, Inc. Rain Gauge Data Logger located in the Silver River State Park. Data entered into this table are identified by the sampling date and time. There are seven fields, not including the memo field for record edit notes, in the *Infinities Rainfall* database file.

The *Licor Data* database table contains hourly average measurements of solar insolation and photosynthetically active radiation (PAR) made through the use of LI-COR light sensors models LI-190SA (pyranometer) and LI-200SA (PAR) located in the Silver River State Park. Data entered into this table are identified by the sampling date and time. There are nine fields, not including two memo fields for record comments and edit notes, in the Licor Data database file.

The *FAWN Ocklawaha Stn* database table contains weather data (air temperature, rainfall, relative humidity, solar radiation, wind speed, and wind direction) for the FAWN Ocklawaha station. These data were used to supplement existing rainfall and PAR data being collected during this study. Data are reported every fifteen minutes and include a total of ten database fields.

The *USGS Flow* database table contains daily average flow estimates provided by the USGS using existing USGS staff gages within the study area. Data entered into this table are identified by the staff gage site and sampling date. There are seven fields, not including a memo field for record edit notes, in the *USGS Flow* database file.

The *USGS Stage* database table contains daily average stage estimates provided by the USGS using existing USGS staff gages within the study area. Data entered into this table are identified by the staff gage site and sampling date. There are nine fields, not including the memo field for record edit notes, in the *USGS Stage* database file.

The *UF Fish* database table contains a count and estimated length of fish species observed during visual counts and electrofishing events within the study by UFDFAS. Data entered into this table are identified by the sampling date, transect, and sampling method. The *UF Fish Codes* table is used to link the Species field to the common and scientific names.

The *UF Summer Fathometry* and *UF Winter Fathometry* database tables contain bathymetric, plant height, and plant dry and ash-free dry weight data collected by UFDFAS within the study area. Data entered into this table are identified by the transect location and GPS coordinates. There are a total of seven fields in each database table.

The *UF Macroalgae Coverage Thickness* database table contains benthic macroalgae community coverage (on a Braun-Blanquet scale) and benthic mat thickness data collected by UFDFAS within the study area. Data entered into this table are identified by the date, waypoint, and GPS coordinates. There are a total of seven fields in the *UF Macroalgae Coverage Thickness* database table.

The *UF Macroalgae Biomass* database table contains benthic macroalgae community biomass data collected by UFDFAS within the study area. Data entered into this table are identified by the date and sample zone. There are a total of fourteen fields in the *UF Macroalgae Biomass* database table.

The *UF Braun Blanquet Coverages – Sagittaria kurziana* database table contains *Sagittaria kurziana* coverage (on a Braun-Blanquet scale) collected by UFDFAS within the study area. Data entered into this table are identified by the date, waypoint, and GPS coordinates. There are a total of thirteen fields in the *UF Braun Blanquet Coverages – Sagittaria kurziana* database table.

The *UF Braun Blanquet Coverages Blades* database table contains *Sagittaria kurziana* Braun-Blanquet coverage estimates and the number of blades per m^2 collected by UFDFAS within the study area. Data entered into this table are identified by the waypoint and GPS coordinates. There are a total of five fields in the *UF Braun Blanquet Coverages Blades* database table.

The *UF Braun Blanquet Blade Counts* database table contains *Sagittaria kurziana* Braun-Blanquet coverage estimates and the number of blades counted within a 0.25m quadrat collected by UFDFAS within the study area. Data entered into this table are identified by the sampling quad. There are a total of four fields in the *UF Braun Blanquet Blade Counts* database table.

5.0 Results

5.1 Introduction

Formal field work at Silver Springs for the Fifty-Year Retrospective Study began following FDEP approval of the Sampling and Analysis Plan on February 18, 2004. Sample collection continued through March 12, 2005.

5.2 Solar Insolation and PAR

Total insolation and photosynthetically active radiation (PAR) were measured between February 2004 and March 2005 at a protected location adjacent to the Silver River Museum and are reported in Figure 5-1 and in Table 5-1. These data are considered to be representative of the incident solar radiation to the upper Silver River in relatively unshaded locations.

Total insolation during the approximately 394-day measurement period averaged 13.5 million joules per square meter per day (MJ/m^2/d), with maximum and minimum daily values of 27.0 and 0.41 MJ/m^2/d, respectively. Total insolation followed a general sinusoidal pattern through the monitoring period with the maximum monthly average in May 2004 (20.8 MJ/m^2/d) and a minimum monthly average in December 2004 (7.10 MJ/m^2/d). Day-to-day variation in total insolation was great throughout the annual period.

PAR generally mirrored total insolation (Figure 5-1). The period-of-record average PAR was 19.3 E/m^2/d and the maximum and minimum daily values were 38.8 and 0.58 E/m^2/d, respectively. PAR rose gradually from February through May 2004 with an average monthly value of 28.9 E/m^2/d in May and a minimum average value of 10.1 E/m^2/d in December 2004.

Figure 5-2 provides a typical daily trace of total insolation and PAR at this station for April 24, 2004. On that date solar energy inputs were observed to begin at about 0730 AM and to increase smoothly until about 2:00 PM, about one hour after true noon. Solar energy inputs then decreased gradually until full darkness at about 0800 PM. Some shading by trees near the recorder site is indicated by the irregular light recorded just before sunset.

5.3 Precipitation

Total daily precipitation amounts recorded at the rain gauge located at the Silver River Museum are graphically presented in Figure 5-1 and averages are summarized in Table 5-1. Average daily precipitation during the project period-of-record was about 0.44 cm for an annual rate of about 160.6 cm (about 63 in/yr). The 2004 – 2005 annual period was wetter than average for central Florida, especially due to several hurricanes that passed near the project area during the normally dry months of September and October 2004.

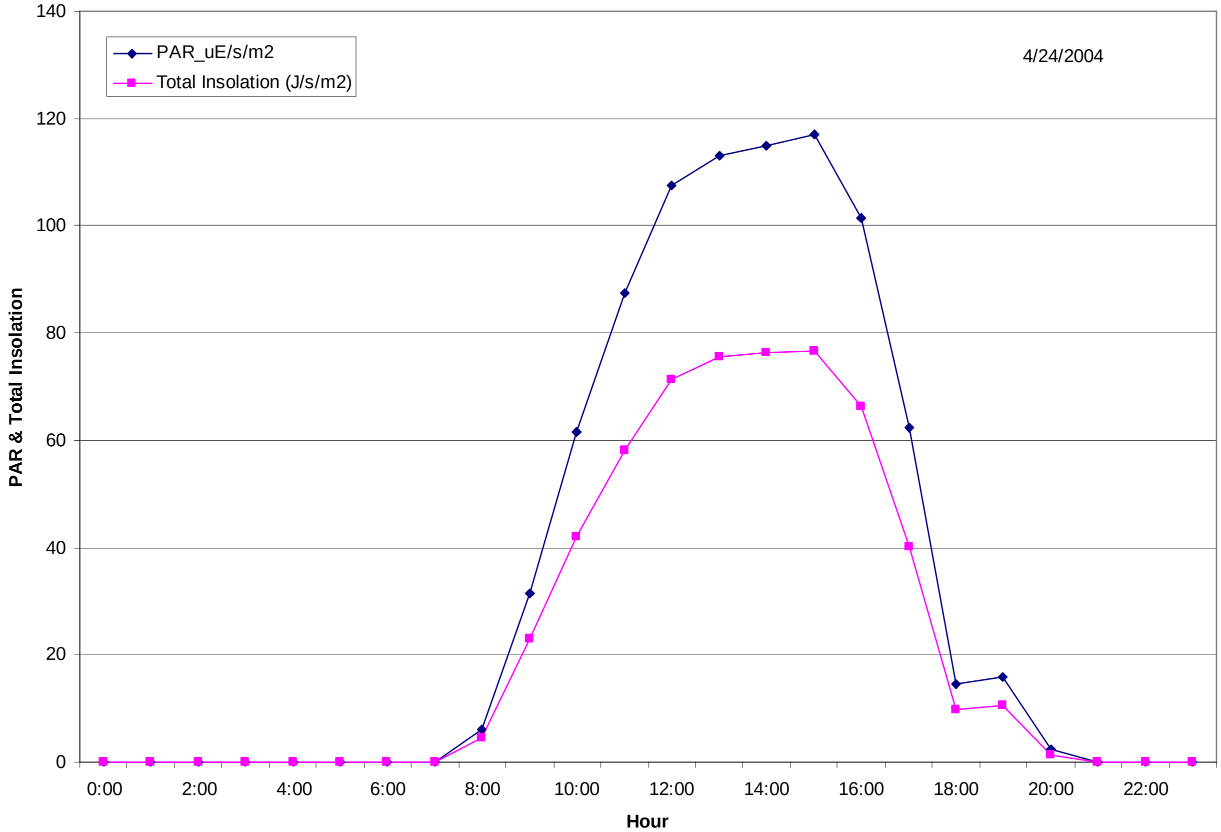


Figure 5-1 Typical daily pattern of total solar radiation and photosynthetically active radiation at Silver Springs

Table 5-1 Summary of average monthly photosynthetically active radiation, total solar radiation, and rainfall measured at the Silver River State Park during the current study period

Month	Rainfall (cm)	PAR ($E/m^2/d$)	Total Insolation ($MJ/m^2/d$)
Feb-04	16.0	15.8	8.7
Mar-04	9.73	25.2	16.7
Apr-04	11.5	27.5	20.0
May-04	18.7	29.0	20.9
Jun-04	19.2	28.5	19.8
Jul-04	18.0	22.1	16.4
Aug-04	19.1	17.9	13.9
Sep-04	28.5	17.0	12.3
Oct-04	12.2	16.9	11.7
Nov-04	5.11	15.6	9.1
Dec-04	3.25	10.1	7.1
Jan-05	2.97	13.1	8.0
Feb-05	5.54	15.6	9.8
Mar-05	4.06	20.9	15.5
Total	173.9		
Average Daily	0.44	19.3	13.4
Maximum Daily	14.78	38.8	27.0
Minimum Daily	0.00	0.58	0.4
Count	394	395	380

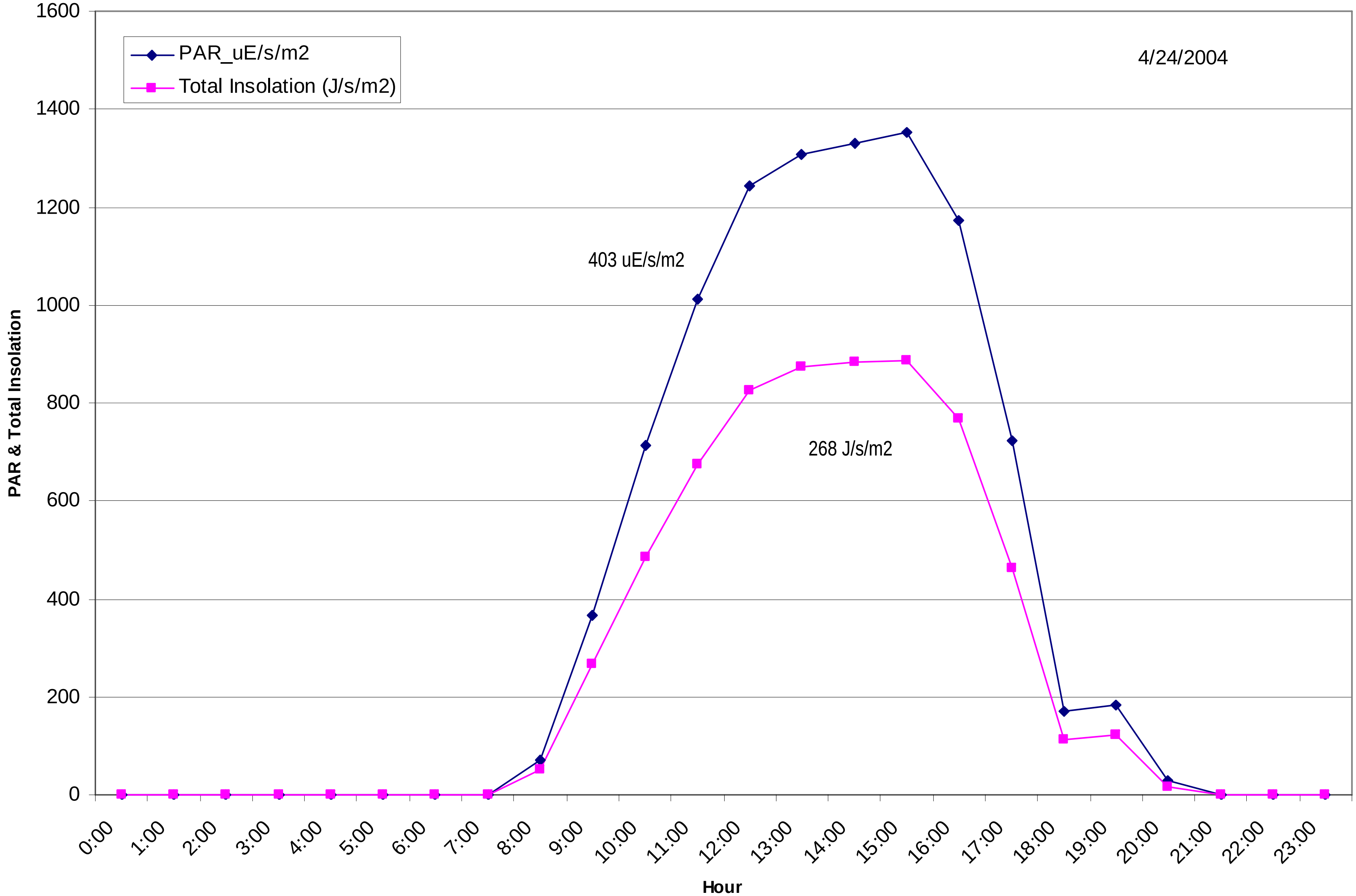


Figure 5-2 Typical daily pattern of total solar radiation and photosynthetically active radiation at Silver Springs

5.4 Historic and Current Springshed Boundaries

Figure 5-3 provides a graphical representation of the groundwater contributing area to Silver Springs based upon the flow-net method. The overall predevelopment area includes seven counties and is approximately 1,120 square miles. In general, most of the water discharged at Silver Springs comes from the west, north, and south and very little is flowing from the east. The product of delineating the groundwater basin by particle tracking supports the conclusion inferred from measuring environmental tracers. That is: the mean age of water from Silver Springs is relatively young and a significant portion of the waters are derived locally.

5.5 Results from Groundwater Modeling, Land Use Analysis, and Loading Estimates

5.5.1 Groundwater Numerical Modeling Results

Results of the 1995 NCF model in the vicinity of Silver Springs were selected to determine the hydraulic heads and flow field direction for Silver Springs. The contour of hydraulic heads in the Upper Floridan Aquifer and groundwater flow field near Silver Springs was presented in Figure 4-5. The simulated 1995 discharge at Silver Springs from the Upper Floridan Aquifer was 708.3 cfs. The 1995 estimated discharge (Motz and Dogan, 2004) at Silver Springs was 707.2 cfs.

Based on an expected increase in groundwater demands, SJRWMD projected the 2025 water use data within the NCF domain. Using estimated 2025 groundwater use data, SJRWMD applied the calibrated 1995 NCF model to determine the impact of the estimated 2025 water use on the discharge of Silver Springs. The simulated 2025 groundwater discharge from the Upper Floridan Aquifer at Silver Springs is 674.3 cfs. A decrease in spring discharge of 34 cfs can be expected to occur by 2025 based on the predicted additional groundwater withdrawal.

The calibrated 1995 NCF model was used to estimate the 1957, 1979 and 2025 pumping effect on the groundwater flow system. In general, the response of water level elevations indicates that groundwater was flowing from east to west in the NCF model domain and groundwater in Marion County was converging at Silver Springs as shown in Figure 5-4. Because of the high transmissivity and low hydraulic gradients in the springshed, the particle pathlines extending from the center of Silver Springs for the two-year travel time range from 16,750 feet to 23,510 feet. The estimated 1957, 1979, 1995 and 2025 spring discharges of, respectively, 716.5 cfs, 710.8 cfs, 708.3 cfs and 674.3 cfs, in combination with the nutrient loading rates can be used to delineate the nutrient variations in the spring water system for a variety of conditions.

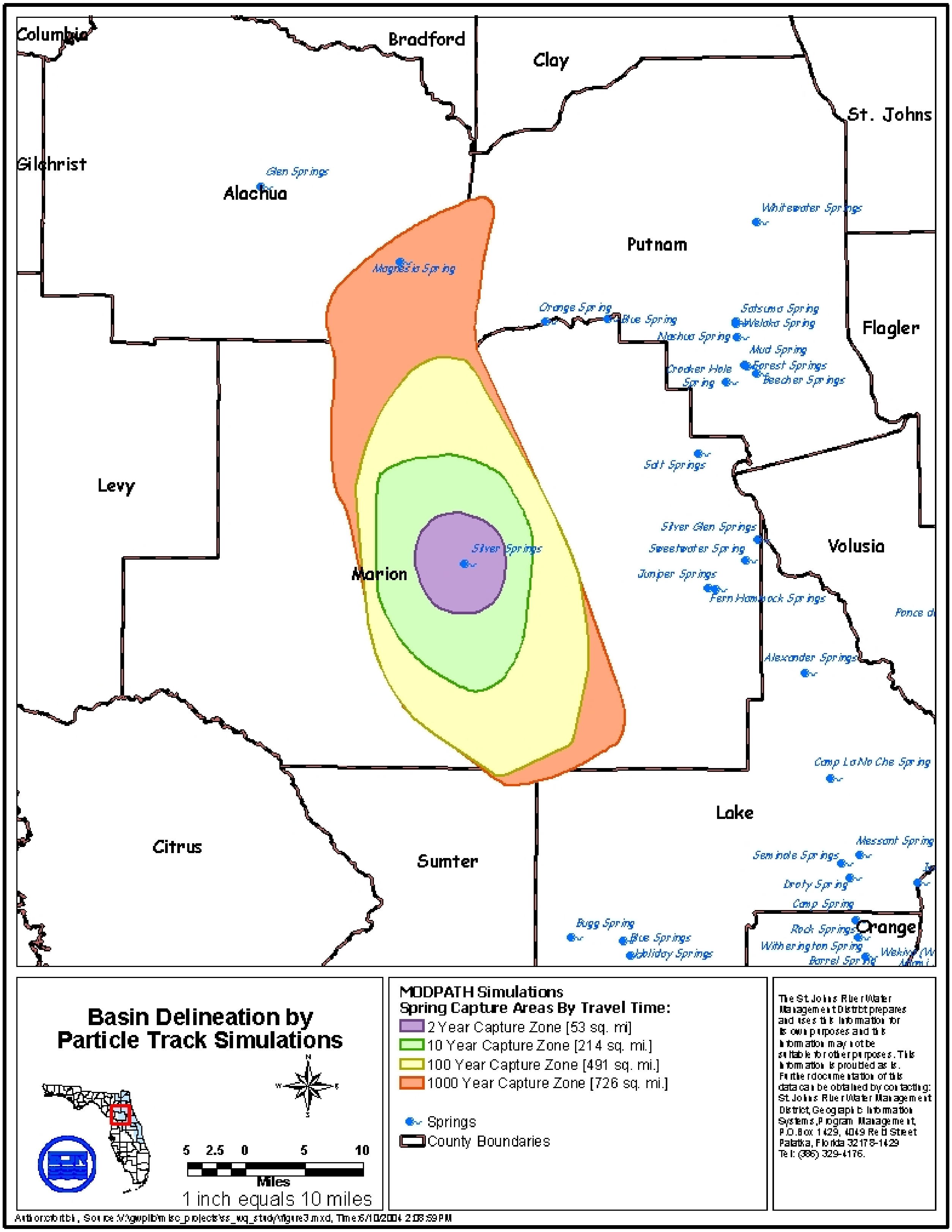


Figure 5-3 Groundwater Contributing Area to Silver Springs Based on the Flow-Net Method

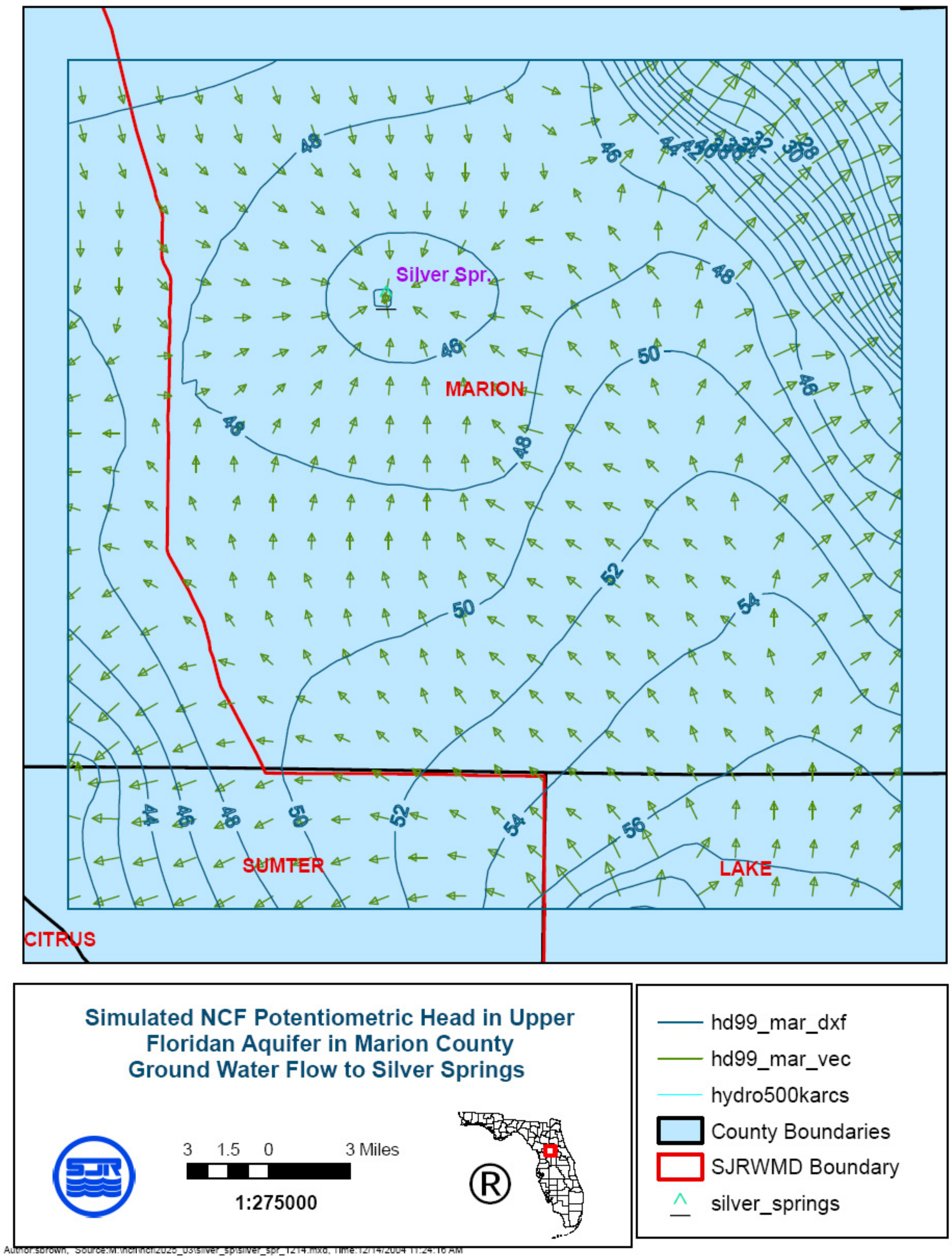


Figure 5-4 Simulated NCF Potentiometric Head in Upper Floridan Aquifer of Marion County

5.5.2 Delineation of Changes in Land Use and Land Cover Within "High Risk" Areas

As detailed in section 4.5.3, risk designations were determined for areas within the springshed. The composite map of the risk potentials for the two-year groundwater contribution to Silver Springs, based on the high, medium, and low risk levels, is presented as Figure 5-5. Once the high risk areas were delineated, these areas could be extracted from the land use/land cover (LULC) feature datasets created for the springshed. The LULC maps of the "high risk" areas are presented in Figures 5-6 through 5-13.

5.5.3 Land Use Analysis

As discussed in section 2.2.3, History of Land Use Changes in the Springshed, the springshed has changed from a natural landscape (i.e. no land uses) to one dominated by land uses. Analysis of aerial photos dating to the year 1947 shows a transition from this absence of land use to an area dominated by urban and agricultural land uses. Table 5-2 shows that the springshed, which once had an area greater than 71% with no apparent land uses (logging and recreation may have been prevalent), now has only 13% of its land area with no apparent land uses. The overall trend of this area continues the transition from a natural landscape to an urban/agricultural area.

5.5.4 Nitrogen Loading Estimates

Loading rates from the Marion County study that were applied in this study were previously presented in Table 4-4. These estimates indicate the highest loading rates result from golf courses and that loading rates from medium and high density residential areas with turf grass fertilization are comparable to those from horse farms and agriculture. Table 5-3 presents historic estimated loading rates for the two-year capture zone, and includes notes on how the population estimates were created. An abstract of a presentation on sources of nitrate-nitrogen in the Silver Springs group of springs is provided as Appendix J.

5.6 Water Stage and Discharge Results from Gauges and Flow Meters

Water stage was recorded continuously and by intermittent staff gauge readings at the Boat Basin and at the downstream 1,200-m station (Figure 5-14). At the USGS Boat Basin Station stage averaged 40.92 ft msl based on the continuous recorder data provided by USGS. Intermittent WSI staff gauge readings are also plotted in Figure 5-14. Maximum and minimum stage records at that station for this period were 43.01 and 39.91 ft msl for an observed range of about 3.1 ft. Average water stage observed at the 1,200-m (downstream) USGS station averaged 40.31 ft msl

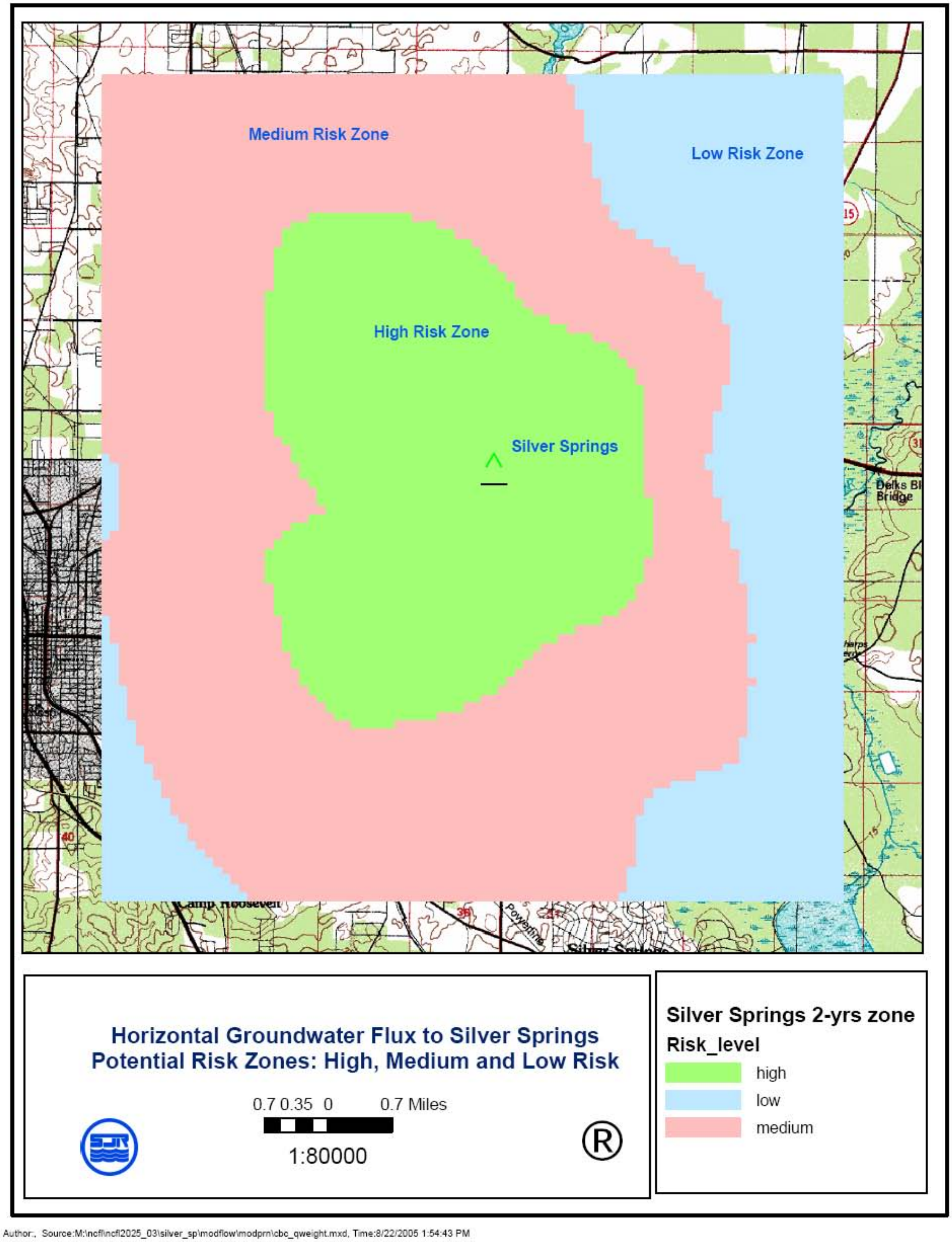


Figure 5-5 Composite risk potential for two-year capture zone

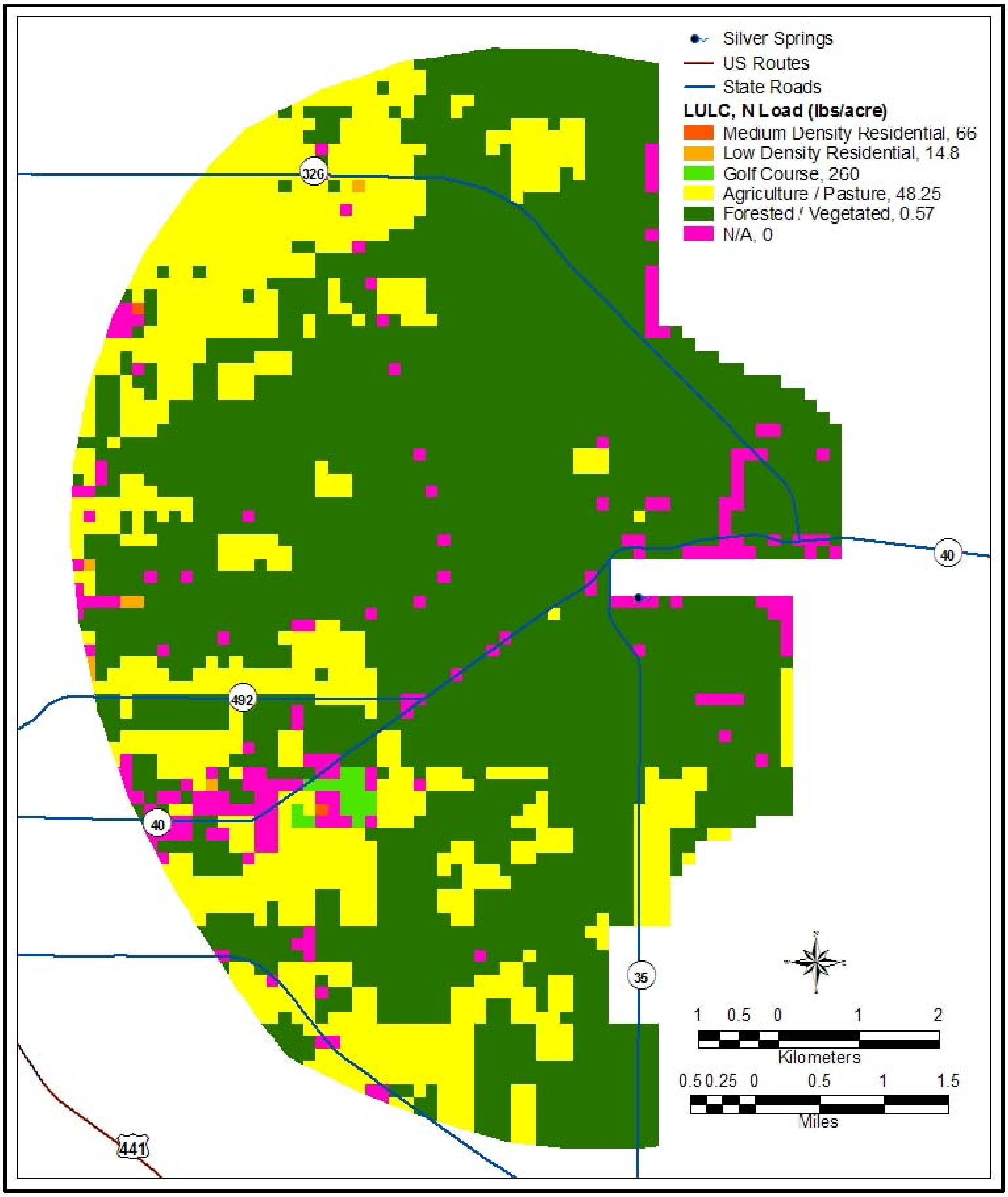


Figure 5-6 1949 Land Use / Land Cover in High Risk Areas

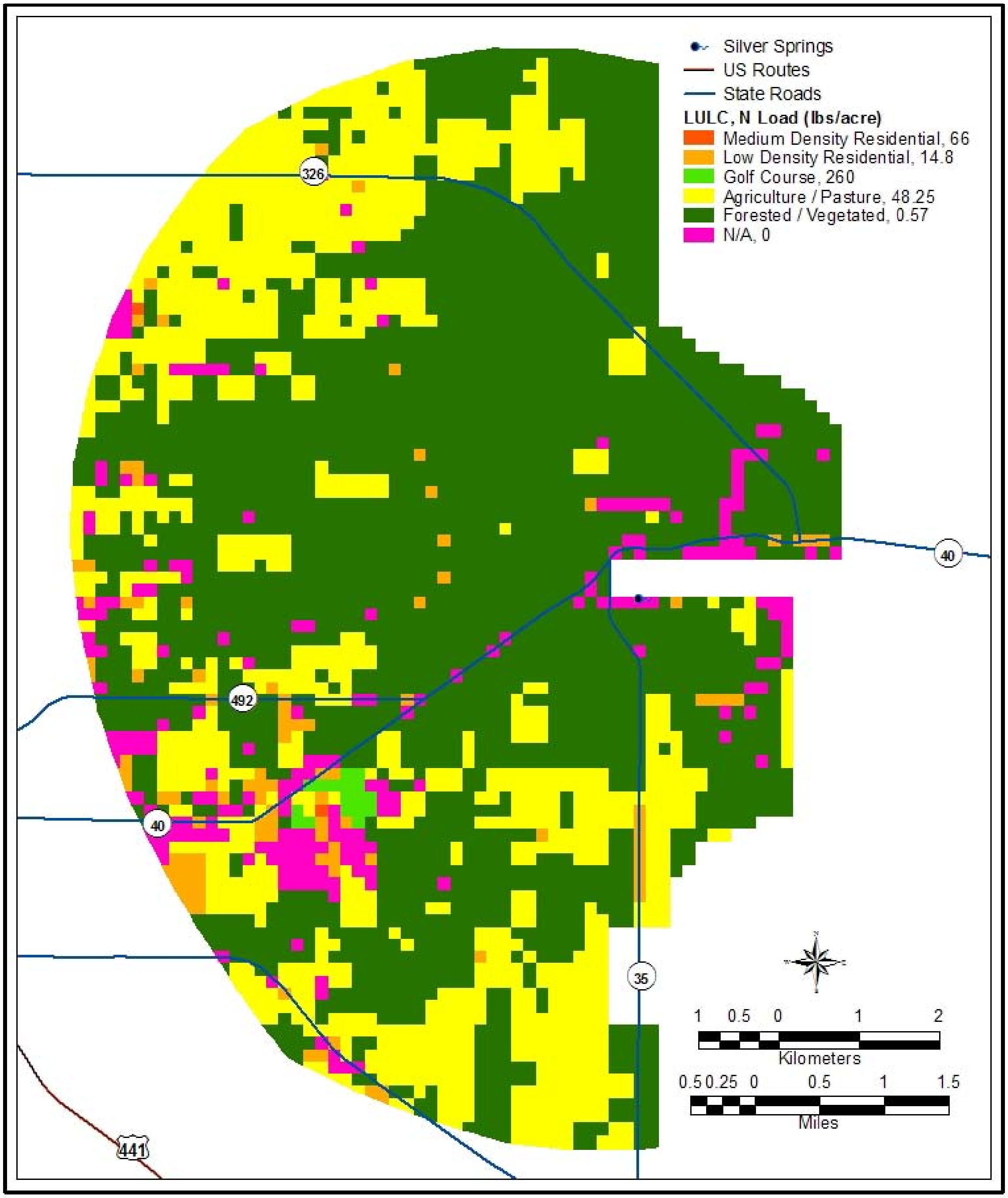


Figure 5-7 1957 Land Use / Land Cover in High Risk Areas

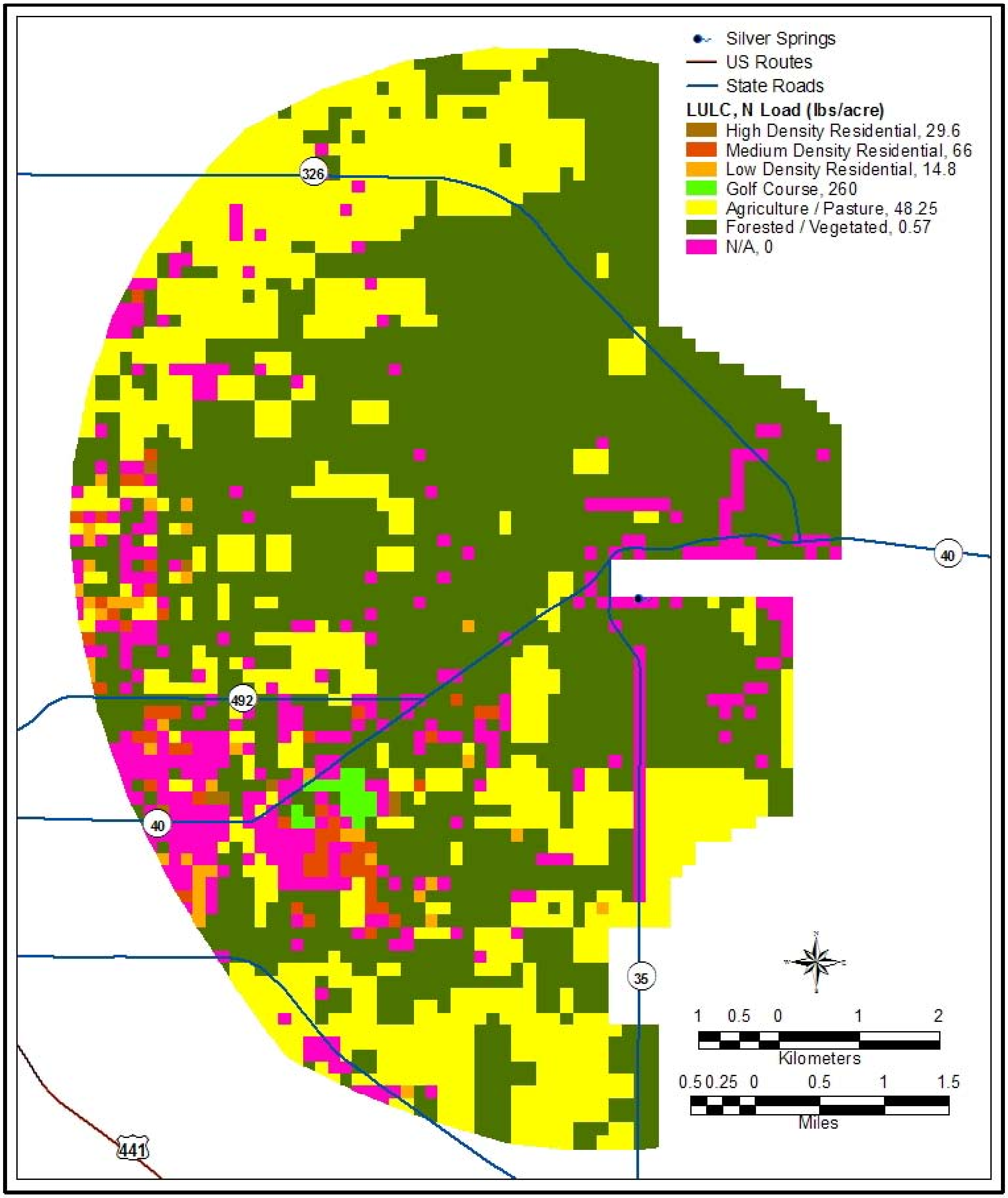


Figure 5-8 1964 Land Use / Land Cover in High Risk Areas

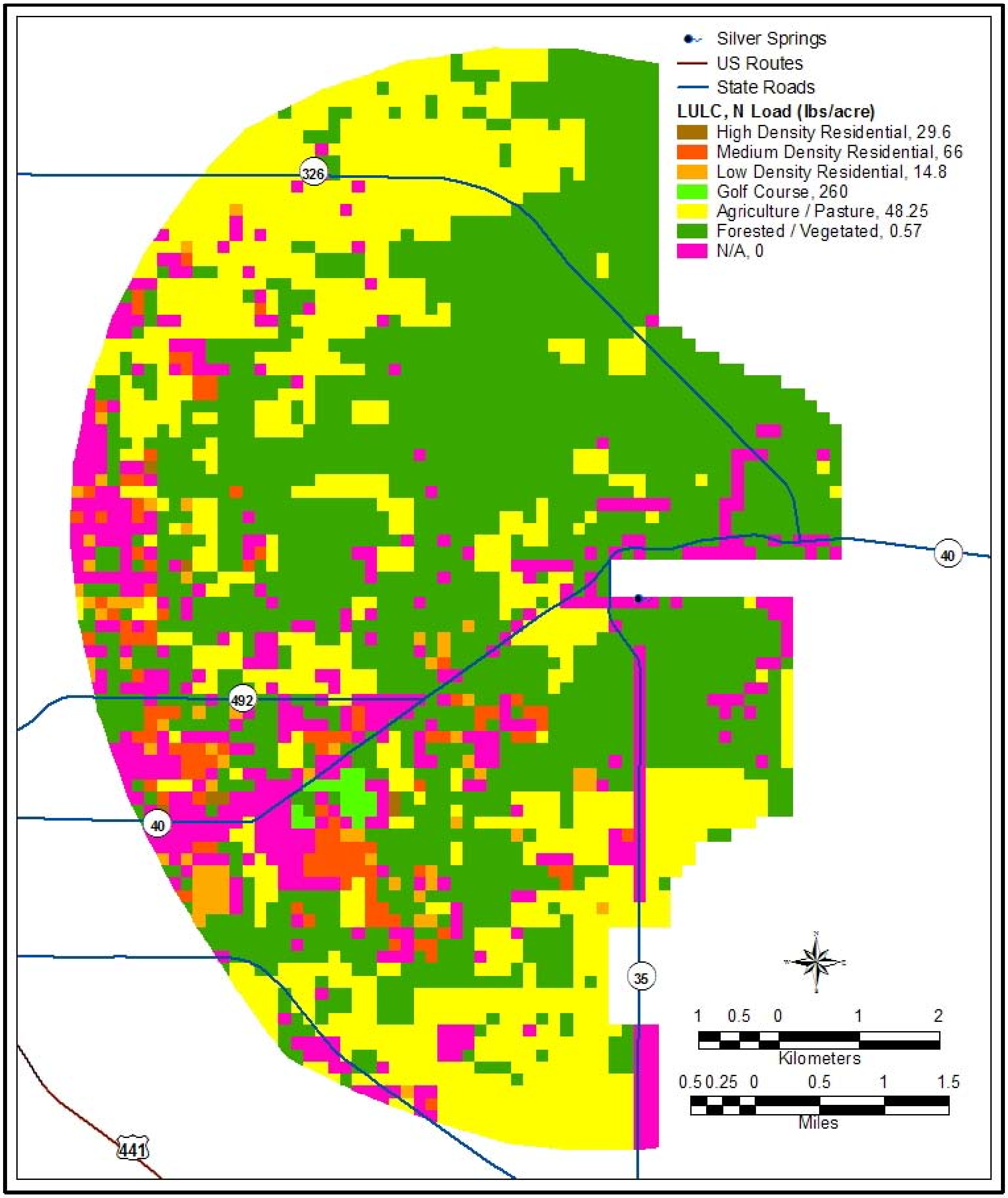


Figure 5-9 1972 Land Use / Land Cover in High Risk Areas

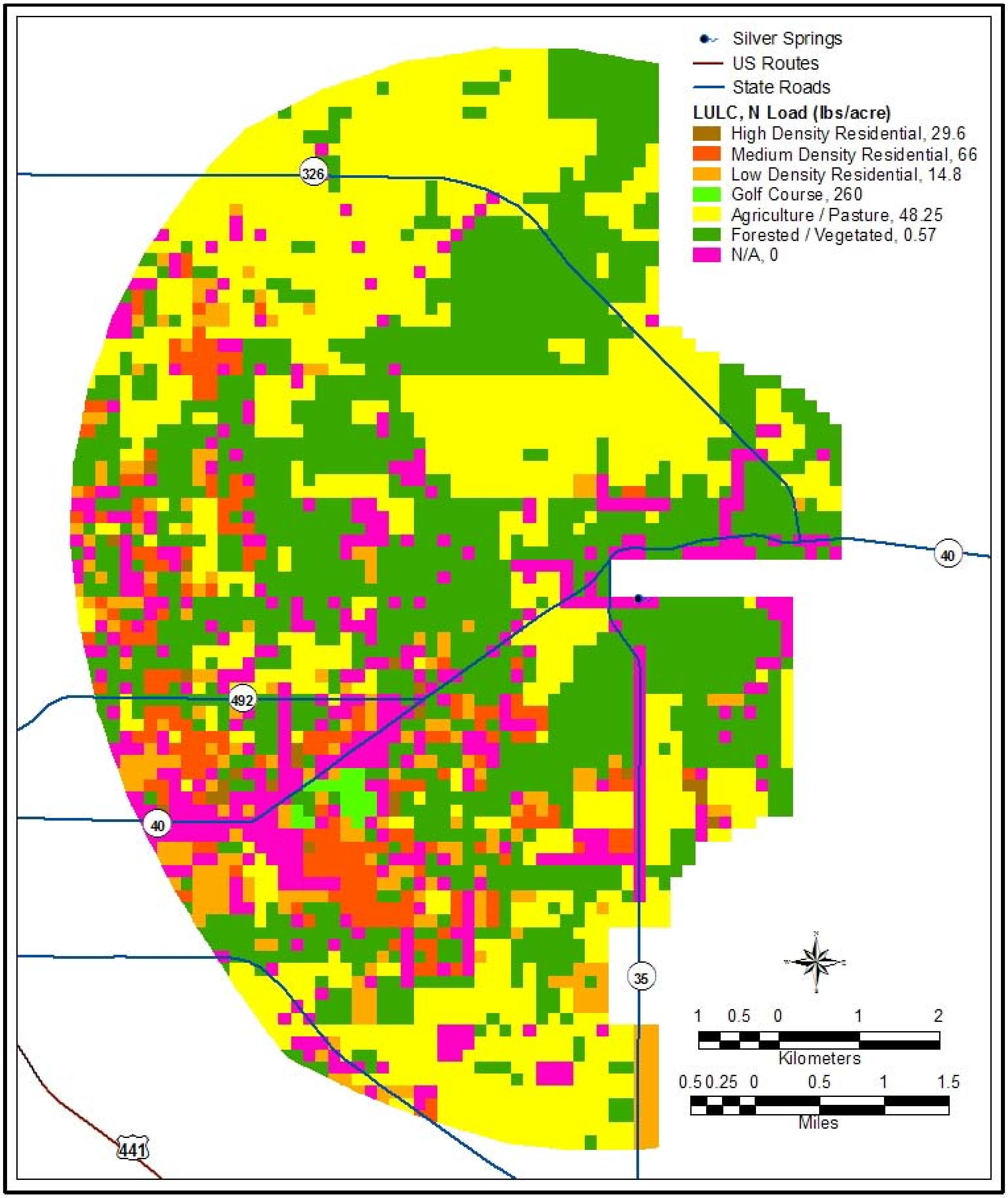


Figure 5-10 1979 Land Use / Land Cover in High Risk Areas

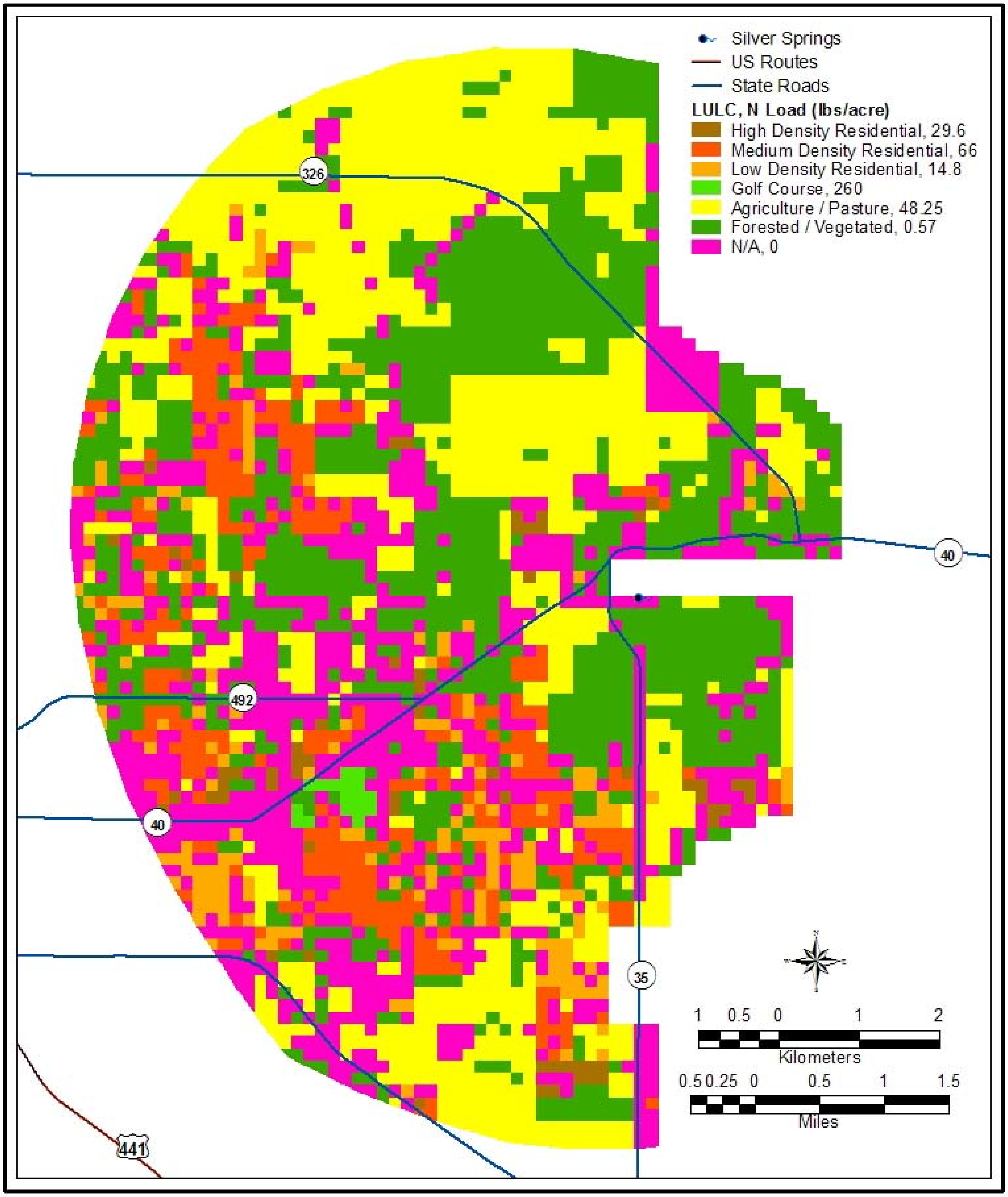


Figure 5-11 1989 Land Use / Land Cover in High Risk Areas

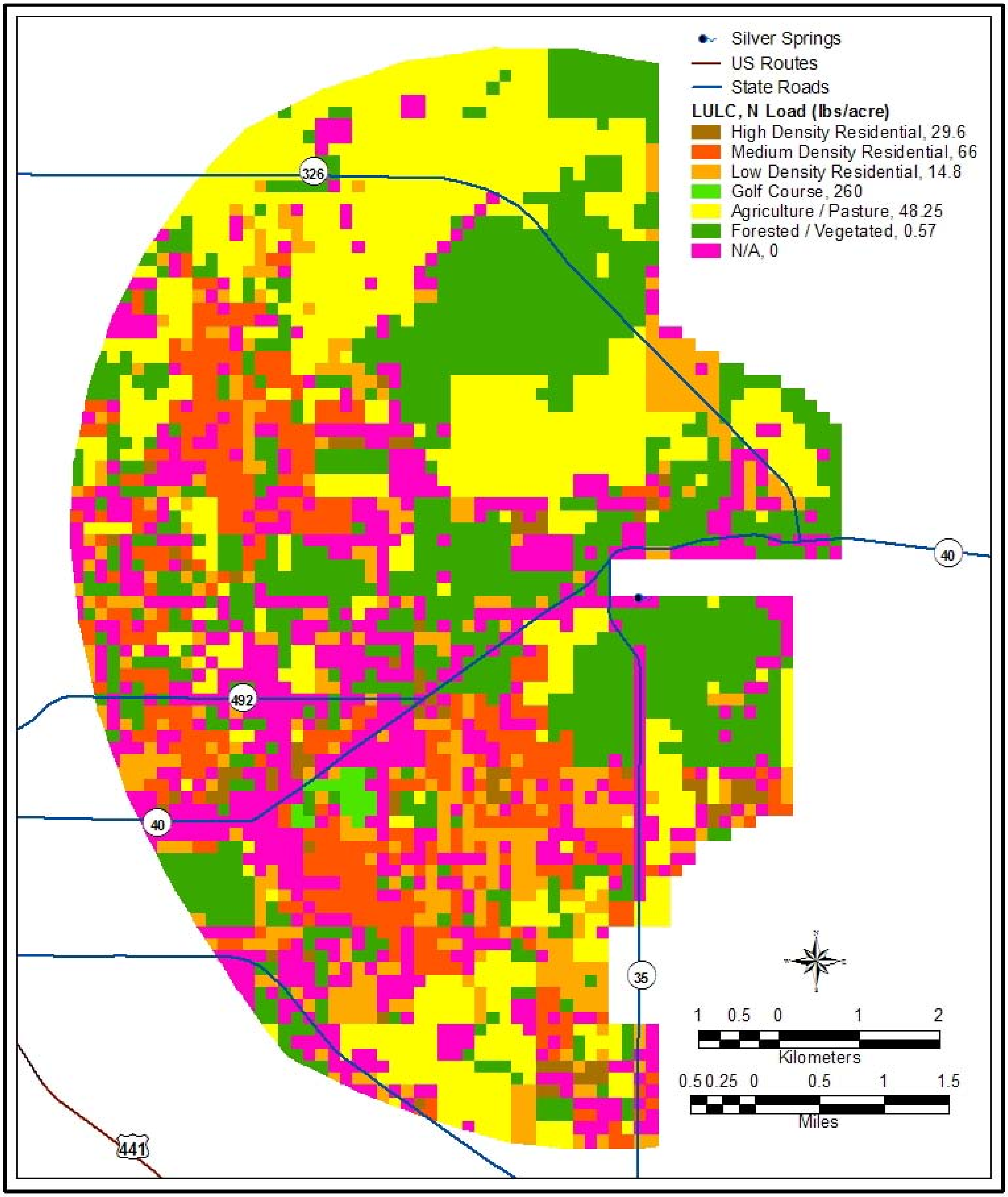


Figure 5-12 1995 Land Use / Land Cover in High Risk Areas

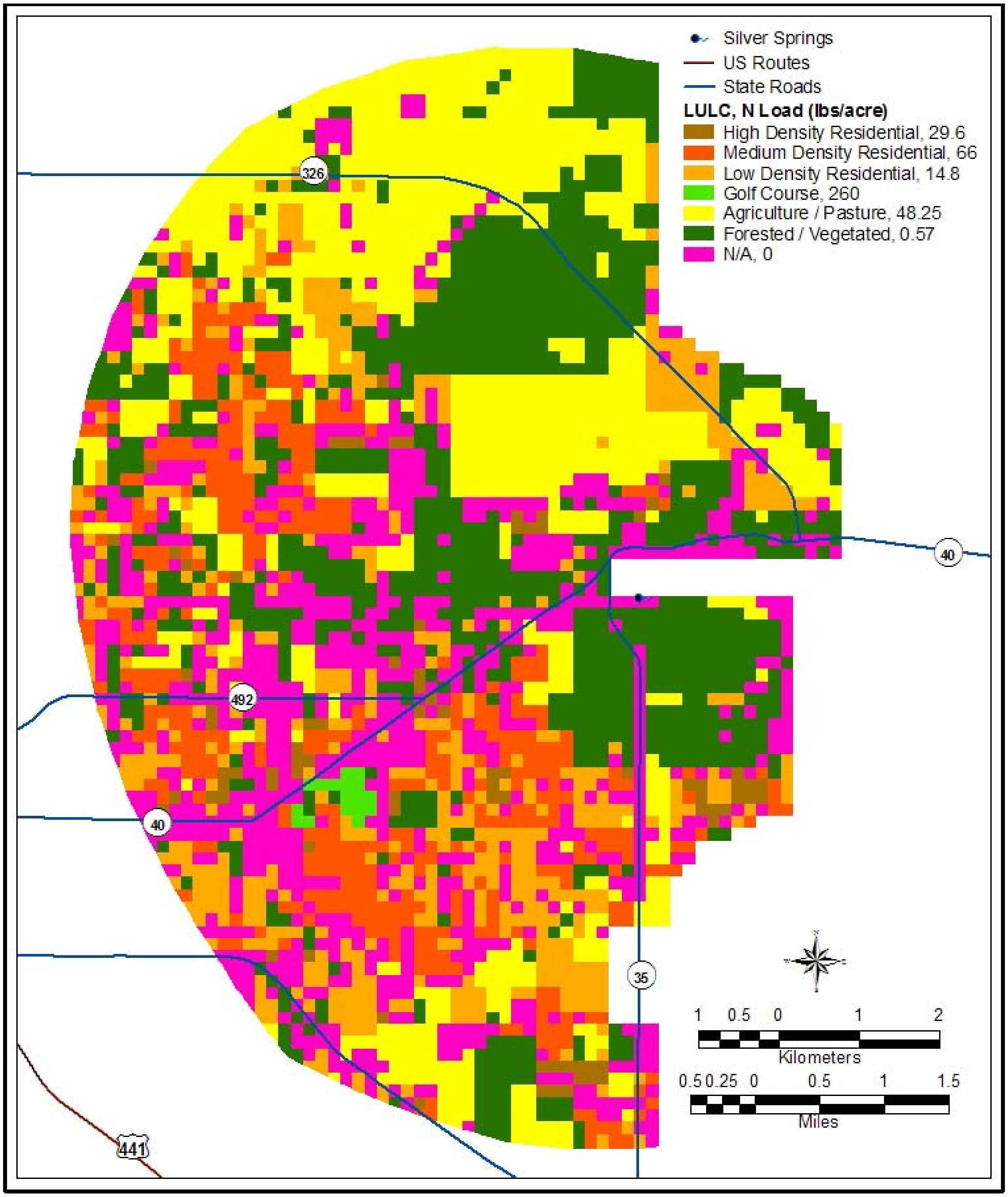


Figure 5-13 2005 Land Use / Land Cover in High Risk Areas

Table 5-2 Land Use and Land Cover for the Silver Springs two-year capture zone, 1949 – 2055

Land Use / Land Cover	Acres 1949	Acres 1957	Acres 1964	Acres 1972	Acres 1989	Acres 1995	Acres 2005	Acres 2055
Urban	143.48	797.72	688.68	3460.62	3816.44	6238.29	7081.93	12327.37
Agriculture / Pasture	6060.38	6863.84	7483.66	9463.61	8310.07	8011.64	8235.47	9130.75
Forested / Vegetated	24178.41	22927.31	21148.22	15799.47	13354.65	12333.11	10754.89	4487.9
N/A	3299.93	3093.32	4361.64	4958.5	8201.03	7099.14	7609.91	7736.17

Land Use / Land Cover	Acres % 1949	Acres % 1957	Acres % 1964	Acres % 1972	Acres % 1989	Acres % 1995	Acres % 2005	Acres % 2055
Urban	0.43	2.37	2.04	10.27	11.33	18.52	21.03	36.6
Agriculture / Pasture	18.01	20.4	22.24	23.2	24.7	23.81	24.48	27.11
Forested / Vegetated	71.87	68.15	62.86	57.33	39.69	36.66	31.97	13.34
N/A	9.80%	9.18%	12.95%	14.72%	24.35%	21.08%	22.59%	22.97%

* Forested / Vegetated also includes Bare Soil & Clearcut
* N/A includes Transportation Right-of-Ways and Trails or areas that could not be classified

Table 5-3 Estimated Historic Loading Rates for the Silver Springs Two-Year Capture Zone

Year	**1949**	**1957**	**1964**	**1972**	**1979**	**1989**	**1995**	**2005**	**2055**
LULC N Loading	332843.7125	380582.5	424409.2	465098.9	617765.9	618448.4	668455.3	706298.8	857946.9
Population									
Condo Units	0	0	18	19	176	815	846	861	
Single Family Units	224	707	1987	4138	6632	10476	11930	13652	
MF Units									
2F	2	10	27	42	76	148	150	155	
3F	0	2	4	5	5	7	7	14	
4F	0	0	0	1	13	229	230	242	
<9 (9 du)	0	0	0	1	1	4	4	4	
>10(20 du)	0	0	1	4	15	27	27	29	
	228	733	2091	4349	7336	13100	14593	16449	35782
Population (DU Total * 2.8)	638.4	2052.4	5854.8	12177.2	20540.8	36680	40860.4	46057.2	100189.6
Total N Loading (LU Total + (P0P * 9 lbs)	338589.3125	399054.1	477102.4	574693.7	802633.1	948568.4	1036199	1120814	1759653

POP/DU Estimates (2.8) from average of (1995, 2000, & 2004 Population Data Divided by Parcel DU count in corresponding year.

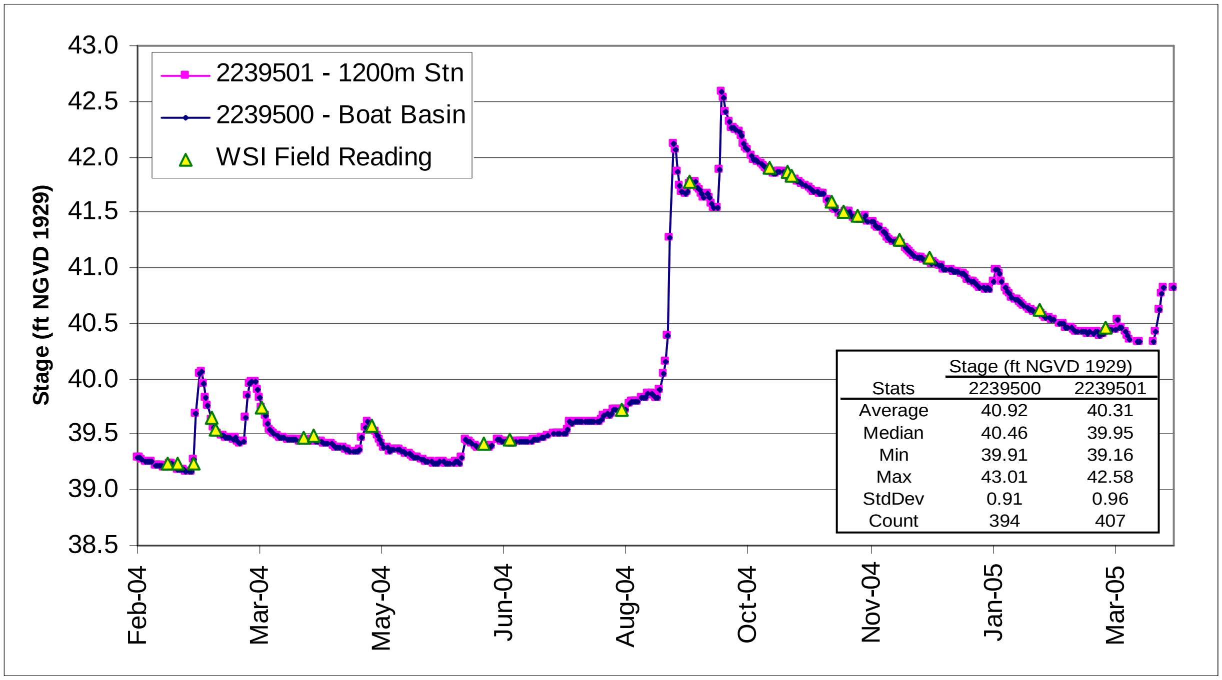
However, even at block level, some blocks were split, making population estimates difficult.

*2000 Census pop/du = 2.91789

(in Study Area)

2055 Data from GIS Associates 2055 Population Density Projections

2055 GIS predicts 2.36/du



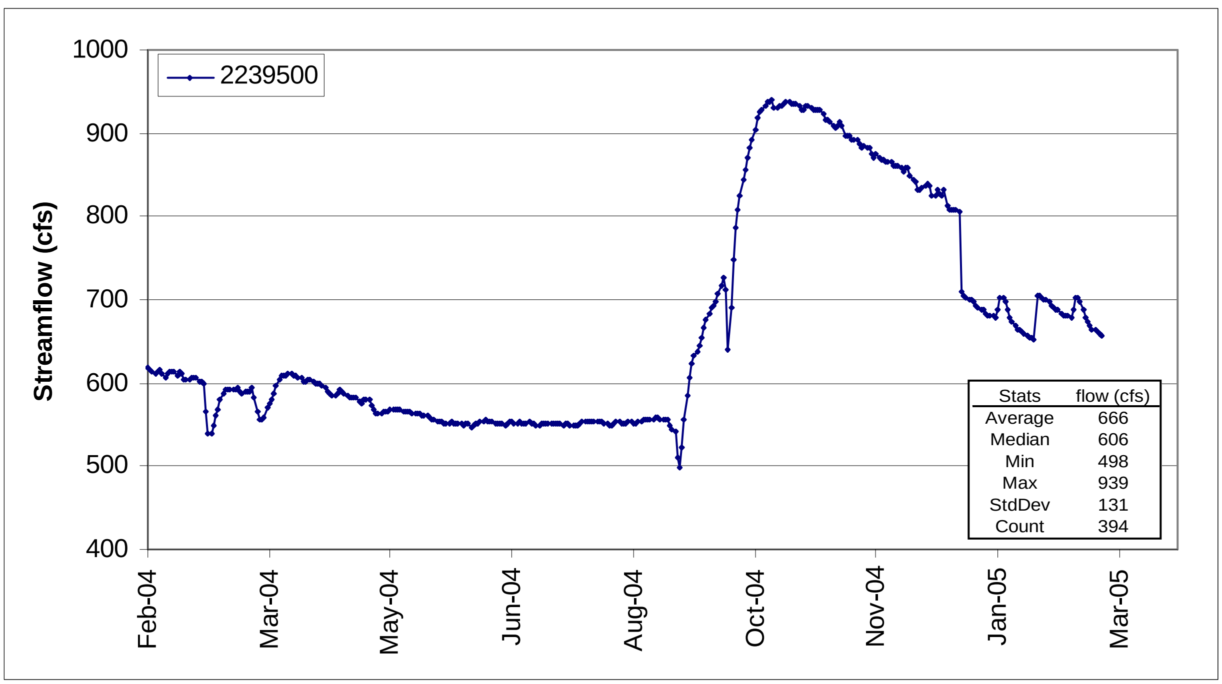


Figure 5-14 Silver Springs USGS gage height and flows for study period

over this period-of-record. Maximum and minimum stages recorded at that station were 42.58 and 39.16 ft msl, respectively for a range of 3.42 ft. Based on these measurements, the average water surface slope between the Boat Basin and the 1,200-m station was about 0.016%.

Stream discharge data for the period of this fifty-year retrospective study are also graphically presented in Figure 5-14. The average recorded discharge at the 1,200-m station during this period was 1.63 hm^3/d (666 cfs). The maximum recorded flow was 2.30 hm^3/d (939 cfs) in early October 2004 shortly after three hurricanes traveled through central Florida and the minimum flow of 1.21 hm^3/d (498 cfs) occurred in late August 2004 just before the hurricanes.

Detailed flow measurements were conducted on a few occasions to provide an indication of how much flow was issuing from individual springs and how much flow was traveling down the Back Channel. WSI's measurements of flow proportions between the main channel and the Back Channel indicated that an average of about 12% of the total flow took the Back Channel route while the rest reached the 1,200-m station via the main channel. Detailed measurements made by Hydrogage Inc, and Karst Environmental Services (KES) on March 24, 2005 are summarized in Figure 5-15 and in Appendices U and V. On that date it was determined that about 0.83 hm^3/d (341 cfs) of artesian water was issuing from the Main Spring Boil (sum of 231 cfs and 110cfs) and 0.11 hm^3/d (45 cfs) was coming from one secondary spring, Catfish Reception Hall. The flow downstream at Turtle Meadows was higher, measured at 1.21 hm^3/d (494 cfs) and was 1.63 hm^3/d (670 cfs) at the 1,200-m station. About 12% to 16% of the 1,200-m station flow was going down the Back Channel with some of this flow leaking back into the main channel somewhere upstream of the Back Channel terminus. On that day the Main Spring Boil flow was roughly 51% of the 1,200-m station flow, similar to the 50% ratio reported previously by Rosenau *et al.* (1977).

5.7 Detection of Discharge Points and Subsurface Features by Thermography and Seismic Surveys

5.7.1 Overview of Thermography and Seismic Survey Results

This report provides examples from the thermography and seismic surveys from the Main Spring Boil (Mammoth Spring) to just past the 1,200-m station. The examples from the thermography surveys were selected to show locations of the major thermal anomalies and hence the most likely points of groundwater discharge to the Silver River. Examples from the seismic profiles were selected to show key features that best characterize the subsurface of a particular section of the river or a subsurface feature at a potential discharge point. In Figure 5-16, the sections of the river that are discussed include A-A', B-B', and C-C'. For examples and discussion of seismic profiles and thermography surveys on the rest of the Silver River, the reader is referred to Davis, 2006 (in review at time of publication).

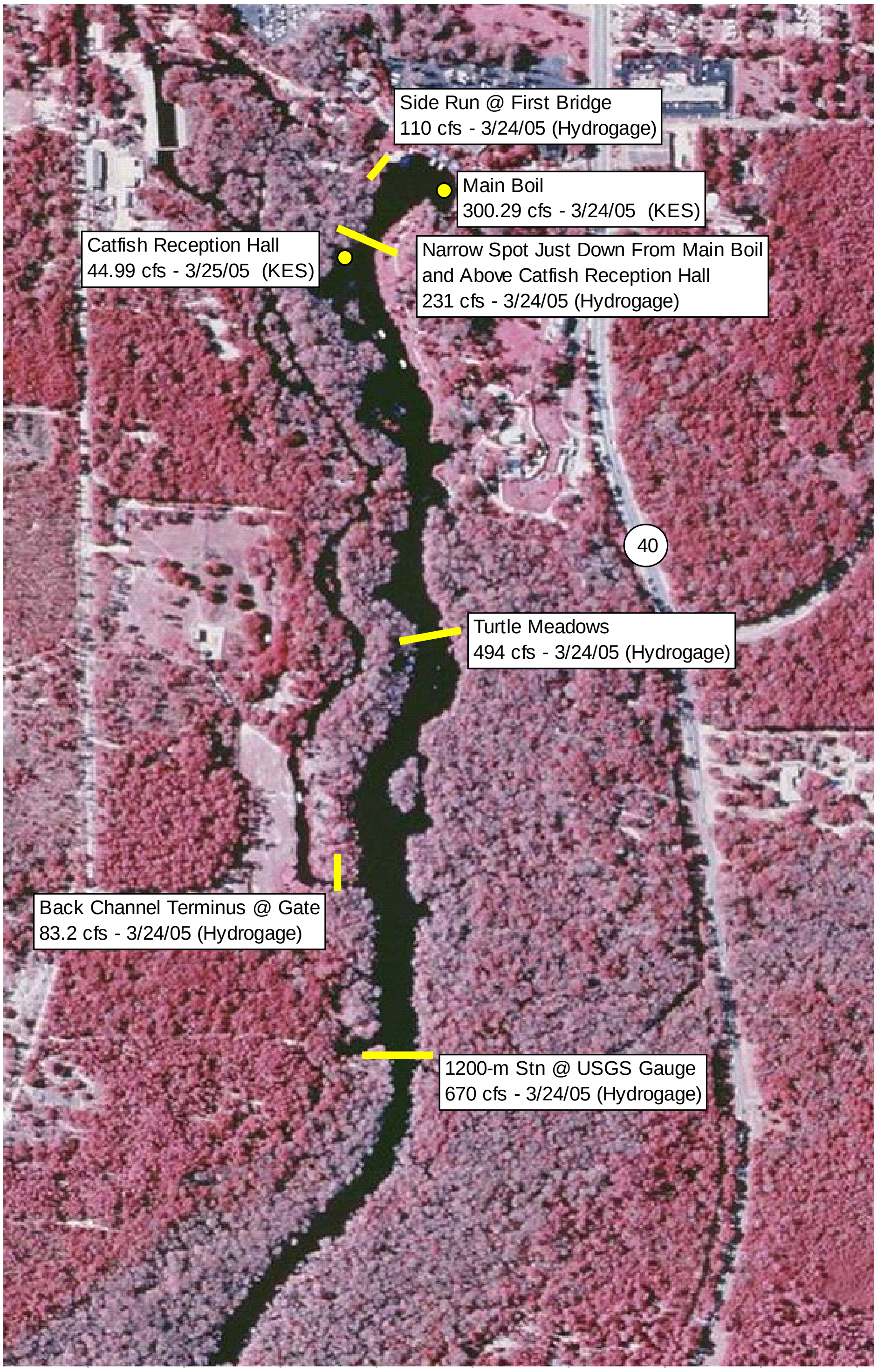


Figure 5-15 Detailed flow estimates conducted in the Silver Springs 50-year retrospective study area on March 24, 2005 (SJRWMD data)

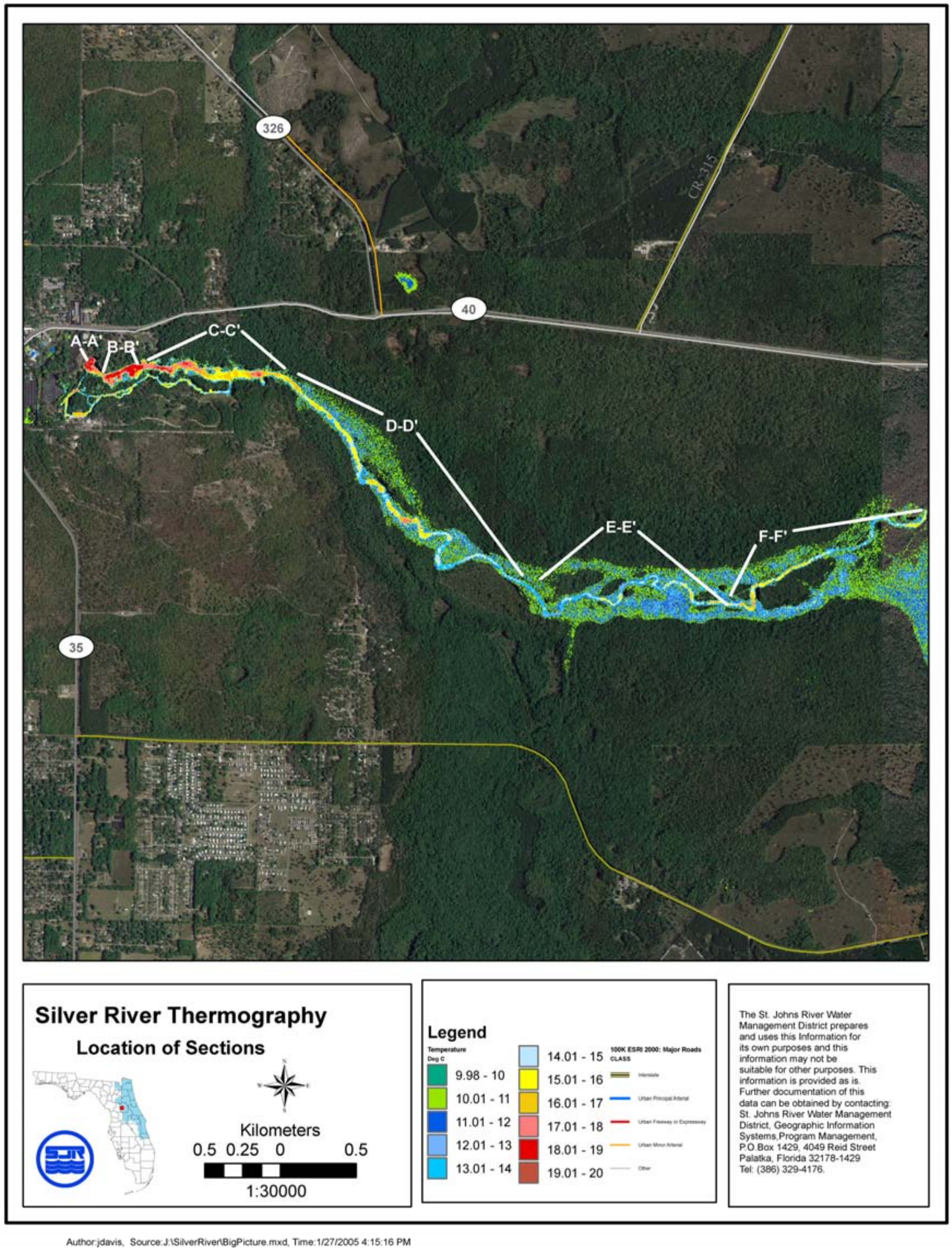


Figure 5-16 Overview of Thermography in the Silver River and Section Location Reference Map

The features that may provide a pathway for groundwater discharge range from the most likely, such as a vent connected to a cave, to the more subtle such as discontinuous or disrupted bedding, evidence of subsidence, or buried sinkholes and solution pipes. Reflectors that may provide an indication of the subsurface structure are highlighted in the seismic figures and are shown in green or blue based on the probable lithostratigraphic unit they belong to. The transitional nature of some of the contacts and lack of substantiating core data preclude marking exact lithostratigraphic boundaries on most figures.

The imagery shown in Figure 5-16 has the thermography data superimposed on it to show only those areas where the temperature exceeded 9.5^0 C. This value was chosen to eliminate the land areas. Figure 5-16 presents an overview of the locations of the major thermal anomalies; discussions and figures for sections A-A’, B-B’, and C-C’ are presented later in this report. For each detailed section that follows, the temperature values for each two-meter pixel can be seen. The detailed figures also show the location of shot point intervals of selected seismic profiles that are presented as examples of the seismic data. The figures show how the thermal anomalies may be related to subsurface features. Within each section numerous hot spots are evident that correlate not only to known spring discharge but to probable new discharge points as well. Certain sites in the river have been named as springs (e.g. Christmas Tree Spring, also known as Spanish Spring or Cypress Spring) or named in reference to some characteristic that the site is known for (e.g. First Fisherman’s Paradise). All of the previously named sites occur within the upper 1,200 m of the spring run, which includes Section A-A’, Section B-B’, and Section C-C’. The following named sites are identified on the detailed section figures presented later in this report: Main Spring Boil, Catfish Reception Hall, Devils Kitchen, Blue Grotto, Christmas Tree Springs, First Fisherman’s Paradise, Second Fisherman’s Paradise, and the 1,200-m station.

The thermography surveys were flown at night over the Silver River when the ambient air temperature was about 6 °C so there is a rather large contrast between the ambient air temperature and the temperature radiated from the water surface. Most features on land were recorded by the thermography system as less than 9.5 °C.

Field measurements of temperature at the Main Spring Boil (Retrospective Interim Report, 2004) taken between January 29, 2004 and May 4, 2004 ranged from a minimum of 23.00 °C to a maximum of 23.4 °C and averaged 23.23 °C. Hourly temperature measurements taken at the 1,200-m station ranged from a minimum of 22.7 °C to a maximum of 23.99 °C . These samples indicated that over a 24-hour period temperatures fluctuated the most during the day and stabilized to a constant value during the night. This pattern is consistent with other lakes and rivers where continuous temperature recordings are made.

5.7.2 Silver River Section A-A'

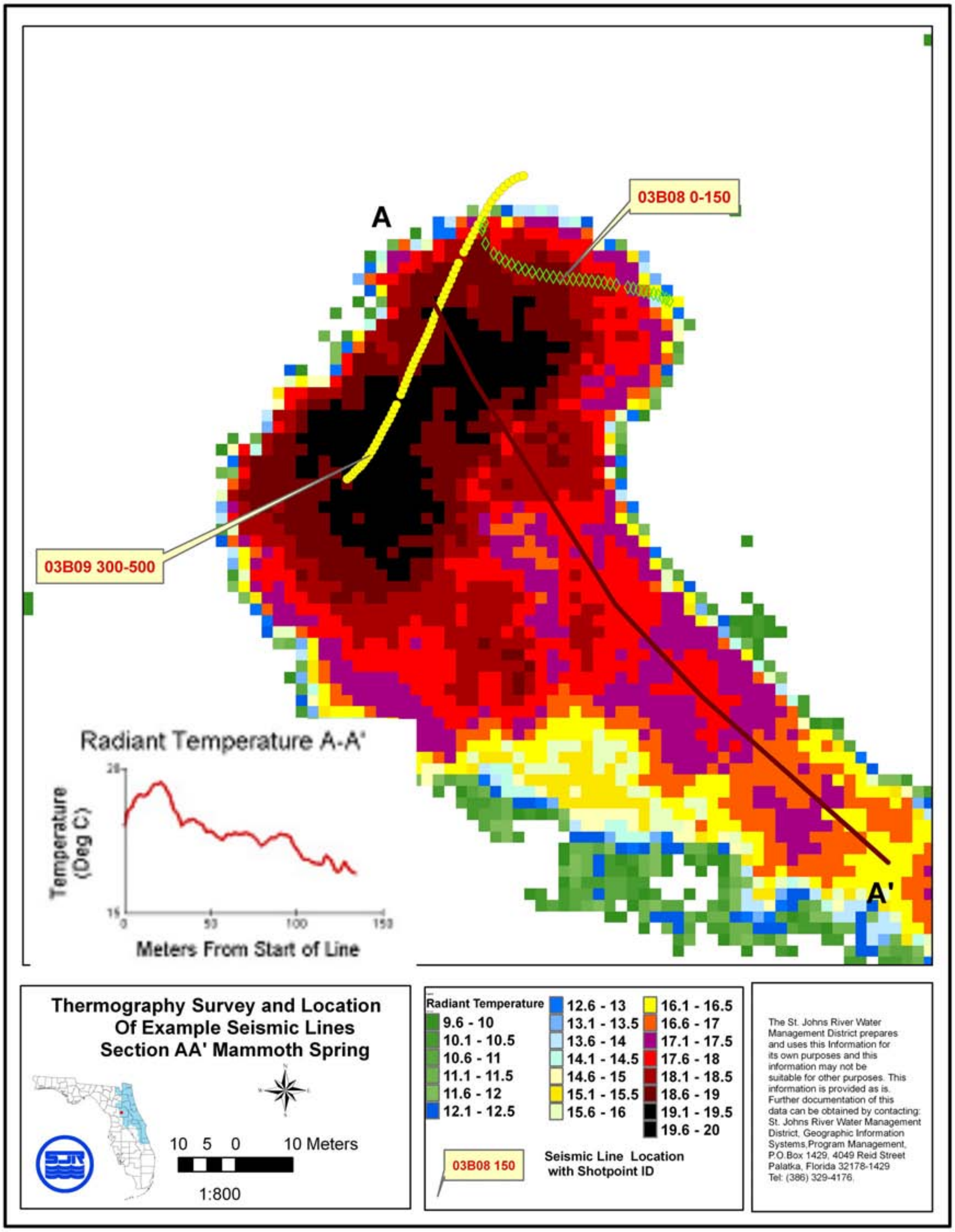
5.7.2.1 Thermography - Main Spring Boil

The Main Spring Boil area comprises the most western spring vent. The maximum temperature values from all of the Silver River were encountered here. The water flows from 40-feet-deep vents with sufficient force to maintain a constant boil on the basin surface. Jack McEarchem, a professional diver at Silver Springs, noted temperature differences for two vents in the Main Spring area. It has been suggested that the source waters for different vents are coming from different depths within the Floridan Aquifer. The dual nature of the thermal sources was confirmed when a dive team from Karst Environmental Services, Inc. (KES) re-sampled and made flow measurements at the two vents in 2005. Video taken (Appendix T) of the vents also indicated evidence of bacterial growth at the east vent, where the highest temperature and conductivity readings were recorded. Since the geothermal gradient normally increases with depth, the higher temperature sites may indeed represent a deeper source of discharge water. The thermography surveys may indicate different radiant temperatures at different spring sites, but there are other factors that would have to be verified before an interpretation of different source waters could be based on thermography alone.

Since lateral flow is only on the downstream side of the spring basin and there is sufficient flow for most of the discharge to reach the surface, the radiant temperature is close to the actual field temperature. Radiant temperature declines within a short distance of the discharge point. This characteristic is well illustrated in a graph of temperature along a transect A-A' that goes from the west side of the spring through the Main Spring Boil to a distance of 135 meters downstream (Figure 5-17). The KES dive team also recorded video (Appendix T) that demonstrated the leaky nature of the river bottom. While divers were in the caves at the Main Spring Boil, the air bubbles they created could be seen flowing from the river bottom in numerous minute vents which would be very difficult to detect without the bubbles. This provides a good example of how pathways for diffuse flow can be present but be very difficult to detect without the use of thermal imaging.

The water depth is much shallower than in the spring vent and there is no other water source to dilute the flow so the warm spring water is not being masked by external features. The temperature drops from a high of 19.7 °C at the Main Spring Boil to 18 °C in less than 30 meters. Even with the large volume of water being discharged the temperature drops to less than 16 °C after 130 meters downstream, where the water is considerably shallower.

Thermography results from the Main Spring Boil provide an excellent example of how radiant temperature measured in thermography surveys can detect discharge sources more effectively



Author:jdavis, Source:J:\SilverRiver\seismic.mxd, Time:1/25/2005 11:29:58 AM

Figure 5-17 Thermography Survey, Temperature Profile, and Location of Seismic Profiles for Section A-A' than field measurements with a thermometer. Field measurements taken on October 25, 2004 at 6 inches below the surface at various points around the Main Spring Boil varied from a minimum of 22.0 °C to a maximum of 22.5 °C. A variation in radiant temperature of 3.7 degrees can be seen in the graph in Figure 5-17. The effects of warm water cooling as it flows downstream can be seen for a distance of about 150 m (just past A') at which point the temperature reaches a minimum and then begins to increase where discharge from other spring vents begins to show.

The difference between the two techniques is that thermography surveys are a response to the thermal radiation emitted from the water's surface, while a temperature measurement, made with a standard thermometer, is a response to the water's internal kinetic temperature. In other words, as a spring discharges 23-degree water it is constantly heating the water surface and therefore is constantly emitting thermal radiation. The kinetic water temperature may only decrease slightly as the water flows downstream but the radiant temperature will decrease greatly because there is no new heat source.

5.7.2.2 Selected Seismic Profiles – Main Spring Boil

High-resolution single channel seismic (HRSCS) reflection profiles were recorded over the Main Spring Boil. Seismic profile lines were designed to parallel the long axis of the spring vent and to cross perpendicular to the vent. For this section and all other sections to follow, all seismic lines were reviewed to choose intervals of shot points that best demonstrate the subsurface features or characterize a particular section of the river. Reflectors that have been highlighted show the angular relationship between specific bedding planes and therefore show the subsurface structure. The different colors highlight the lithostratigraphic units that the reflectors are within and in some cases may represent boundaries between different lithostratigraphic units.

Of the three primary lithostratigraphic units that are exposed in the Silver River region, sediments of the Undifferentiated Pleistocene-Holocene surficial sediments and the underlying Hawthorn Group are the most similar in composition. The seismic expression of the surficial sediments is therefore very similar to the Hawthorn Group. In some sections, cross bedding in the upper sediments can be distinguished, as well as where they make contact with the underlying horizontal beds. These cross beds are probably undifferentiated Pleistocene-Holocene surficial sediments. Since additional data from cores are needed for confirmation, both these units and the Hawthorn Group sediments are considered together and highlighted in green. The contact between the Hawthorn Group sediments and the underlying Ocala Limestone can be identified in many seismic sections by a change from distinct horizontal, sub-parallel reflectors that may extend laterally for some distance to a more chaotic uneven pattern with minimal lateral continuity. These reflector patterns occur because the Hawthorn Group has interbeds of changing lithologies that provide velocity contrasts, whereas the Ocala Limestone has more massive bedding with features such as cavities, chert boulders, and solution-enlarged fractures that may be filled with chert or other sediment.

The reflectors that are within the Ocala Limestone are highlighted in blue in the figures. In places the Hawthorn Group reflectors are truncated by the underlying Ocala Limestone reflectors and the truncation helps identify the contact between the two units. The Hawthorn Group-Ocala Limestone contact is an unconformity with a paleokarst surface that may exhibit large elevation differences over small distances. The contacts shown in the figures were also compared to nearby geophysical log data where possible.

The location of shot points from two of the lines is shown in Figure 5-17. The lines were chosen to show the general character of the subsurface below the main spring (03b08 shot points 0 – 150) and to show the undisturbed area on the west side of the spring (03b09 shot points 300-560). They are cut to 0.05 second two way time (TWT) to show the best quality data.

Line 03b08 Shots 0-150 (Figure 5-18) crosses perpendicular to the vent axis and provides a bathymetric profile of the spring vent. Reflectors in the subsurface have been highlighted to emphasize the orientation of strata at depth. Line 03b08 shows some sub-parallel horizontal bedding from the bottom of the bathymetric low at around 13 milliseconds (ms) to 20ms TWT. Below that there is a major down-warping underlain by a series of convex upward layers (60' below water level). These hyperbolic reflections continue to 40 ms. Divers (Hutchenson *et al*. 1993) have mapped an extensive cave system at the spring vent near this depth. Below 40 ms there is a large (35 meters across) set of convex downward reflectors that may represent the base of a debris pile. Within this system numerous debris piles were observed (by divers) where the roof of the cave had collapsed. This debris will also disrupt any horizontal reflector pattern and may cause high amplitude reflectors if chert boulders are present. The hyperbolic reflection pattern is similar to a response from underground storage tanks or mine shafts. Additional seismic processing beyond the current capabilities of the SJRWMD could be used to verify caves by identifying phase reversals caused by velocity changes between the rock and a fluid-filled cavity. A similar reflection pattern has been observed at other sites where known caves have been documented by divers, such as the Croaker Hole in the St. Johns River.

In contrast to Figure 5-18 line 03b08, the second set of seismic data, also shown in Figure 5-18 03b09, shows an undisturbed section along the west side of the Main Spring Boil basin. The parallel horizontal reflectors of the Hawthorn Group continue to about 30ms at shot point 300 but rise to about 25ms at shot point 560. There are no high amplitude reflectors at depth or any other anomalies that would suggest a subsurface structure.

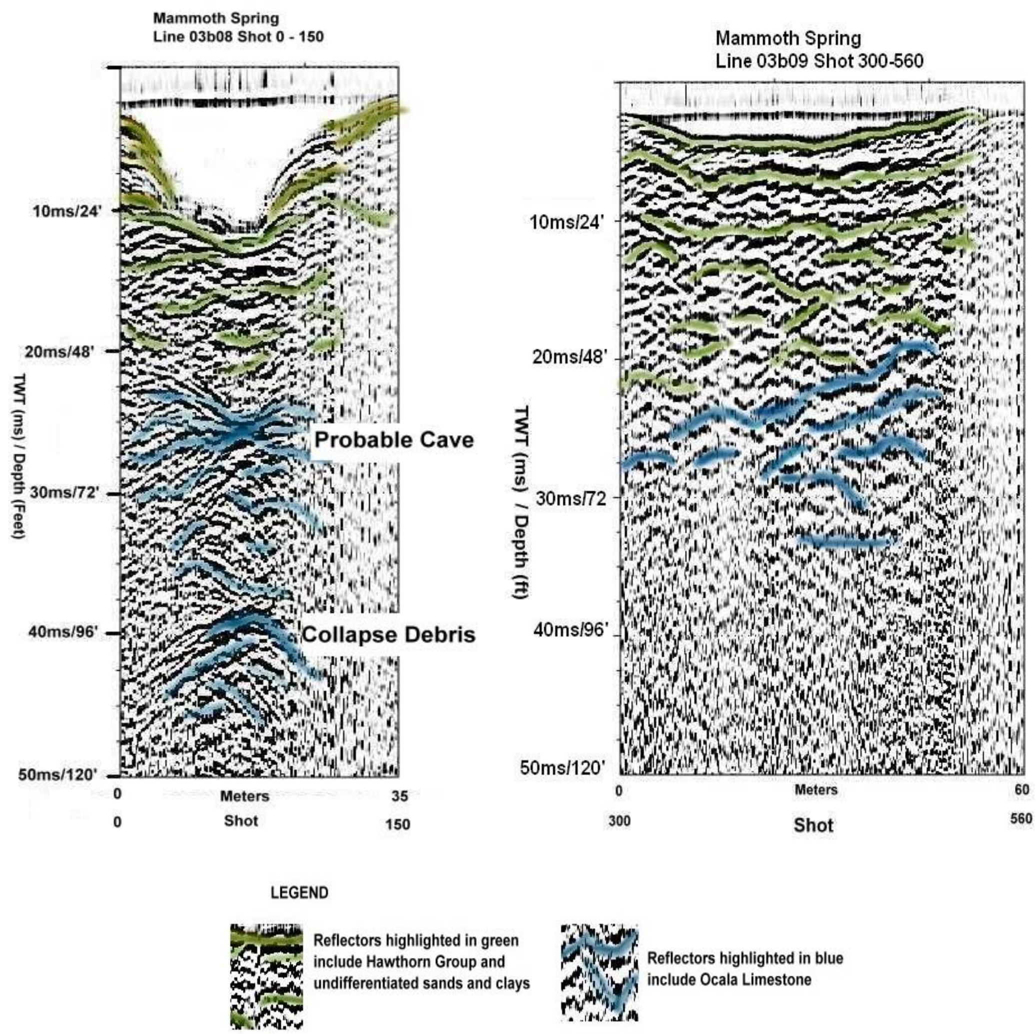


Figure 5-18 Seismic profiles from Line 03b08 shot 0-150 and Line 03b09 shot 300-560 at the Mammoth Spring.

Location of lines is shown in Figure 5-17. Highlighted reflectors indicate the subsurface orientation of individual beds. Line 03b08 is near the entrance to the cave system and shows deformed bedding and evidence of cave and collapse debris. Line 03b09 is west of the cave entrance and shows a relatively undisturbed bedding sequence.

5.7.3 Silver River Section B-B'

5.7.3.1 Thermography – Catfish Reception Hall Spring, Ladies Parlor Spring (aka Florida Snowstorm), Devils Kitchen Spring, Blue Grotto Spring, and Christmas Tree Springs

Downstream from A-A' in Figure 5-16, the next group of named springs and features are encountered. As before, a temperature profile and a plan view of the thermography survey are shown to identify thermal anomalies. The previously named sites are identified by the letters A through E in Figure 5-19. The temperature profile is shown for Section B-B'.

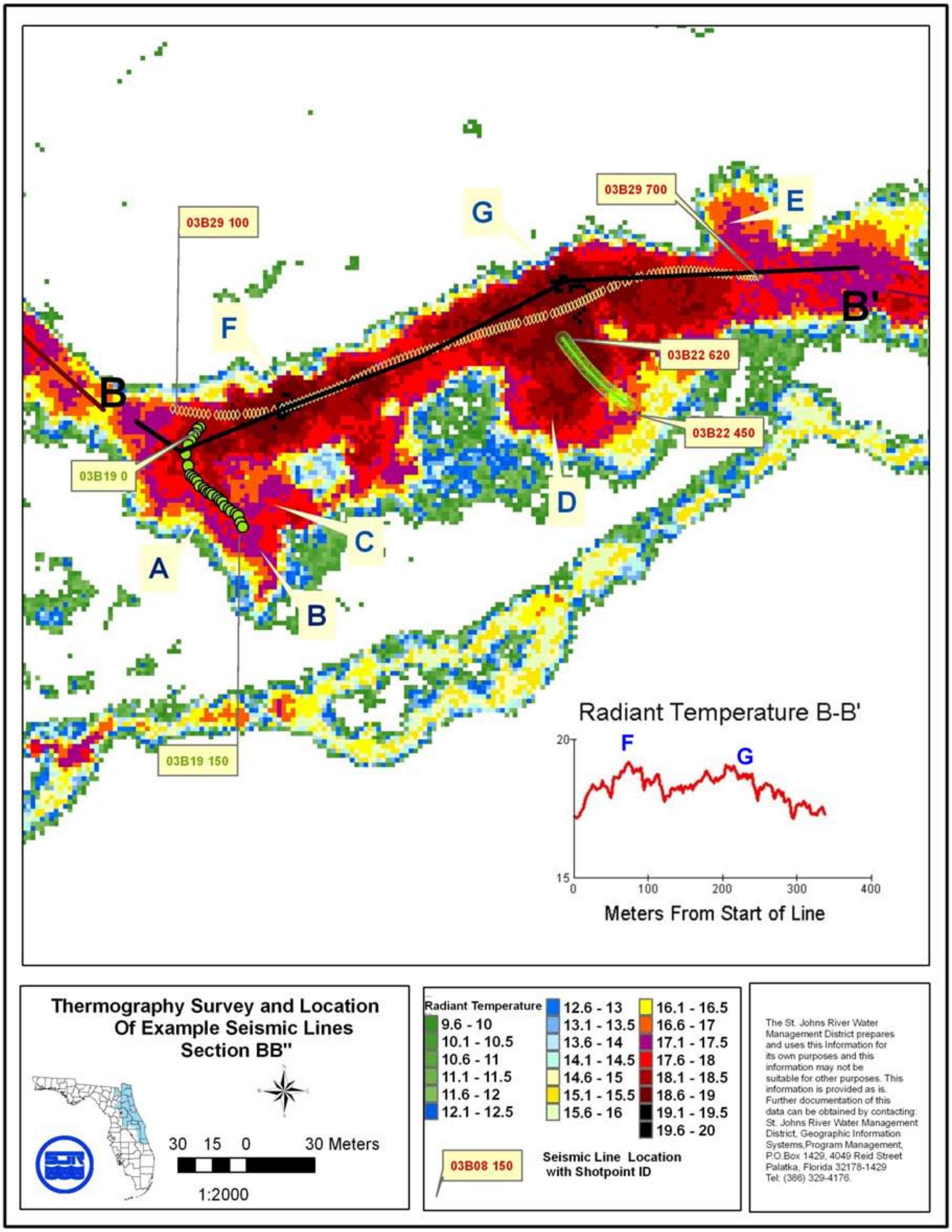


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Figure 5-19 Thermography survey and location of example seismic lines, section B-B'

Temperature values for most of the area range from 17.3 °C to 19.0 °C but a few areas (F and G) are greater than 19.0 °C. Interestingly, the highest values do not occur at the named sites. Discharge from the five named sites has been confirmed by the KES diving team (2005). The high values shown near the labeled areas F and G may represent spring discharge that has not been previously identified or named. The temperature profile graph of B-B' (Figure 5-19) shows the high values associated with those sites. The temperature values for the named sites may be low due to the depth of water at the discharge points and the volume of water being discharged. All of the sites A through E show steep-sided bathymetric lows and provide exciting viewing for the patrons on the glass-bottom boat rides. The two unnamed sites with the highest radiant temperature, F and G, have some change in bathymetry but are not nearly as dramatic as the named sites. Divers confirmed flow from a fracture at site G but could not identify a discharge detected at the site F thermal anomaly. Later, during a ground-truthing cruise using a glass-bottom boat, a vent was identified at the F site and named (in honor of the long-time Silver Springs boat operator) Oscar Spring. Mastodon Bone Spring (site G) was named for a bone seen in the fracture by the KES dive team. These names are included in the SJRWMD springs publication (Osburn, et al. 2006).

5.7.3.2 Seismic Profile Examples – Catfish Reception Hall Spring, Ladies Parlor Spring, Devils Kitchen Spring, and Blue Grotto Spring

The seismic profiles were obtained over all of the thermal anomalies within the Section B-B' river area except Christmas Tree Spring ("E" in Figure 5-19). The cove was too small to tow the equipment over. Both river bottom and subsurface structure can be seen in the seismic data for the sites with known vents. In the example from the Catfish Reception Hall (Figure 5-20) a collapse feature and debris pile can be seen in the central area above 15ms. Below 22 ms the signal is scattered and is suggestive of a transitional contact with the underlying limestone. The reflectors in the central area between shot 50 and 100 are either oriented at different angles or curved as would be expected in a collapse debris pile. The majorities of reflectors below 22 ms are too weak to discern and are an indication of the massive bedding of the limestone.

Seismic lines were run near the two thermal anomalies F and G in the main channel of the Silver River north of the Catfish Reception Hall Spring. No previous reports of vents or discharge have been recorded at these points and the river bathymetry is relatively flat. Seismic lines showed little evidence of subsurface structure at point F that could provide a pathway for spring discharge (Figure 5-21). The reflectors are mostly parallel and laterally continuous down to about 15 ms, which would tend to retard flow. At point G, however, there is lateral discontinuity in the bedding reflectors as would be expected in a solution-enlarged fracture. There are no

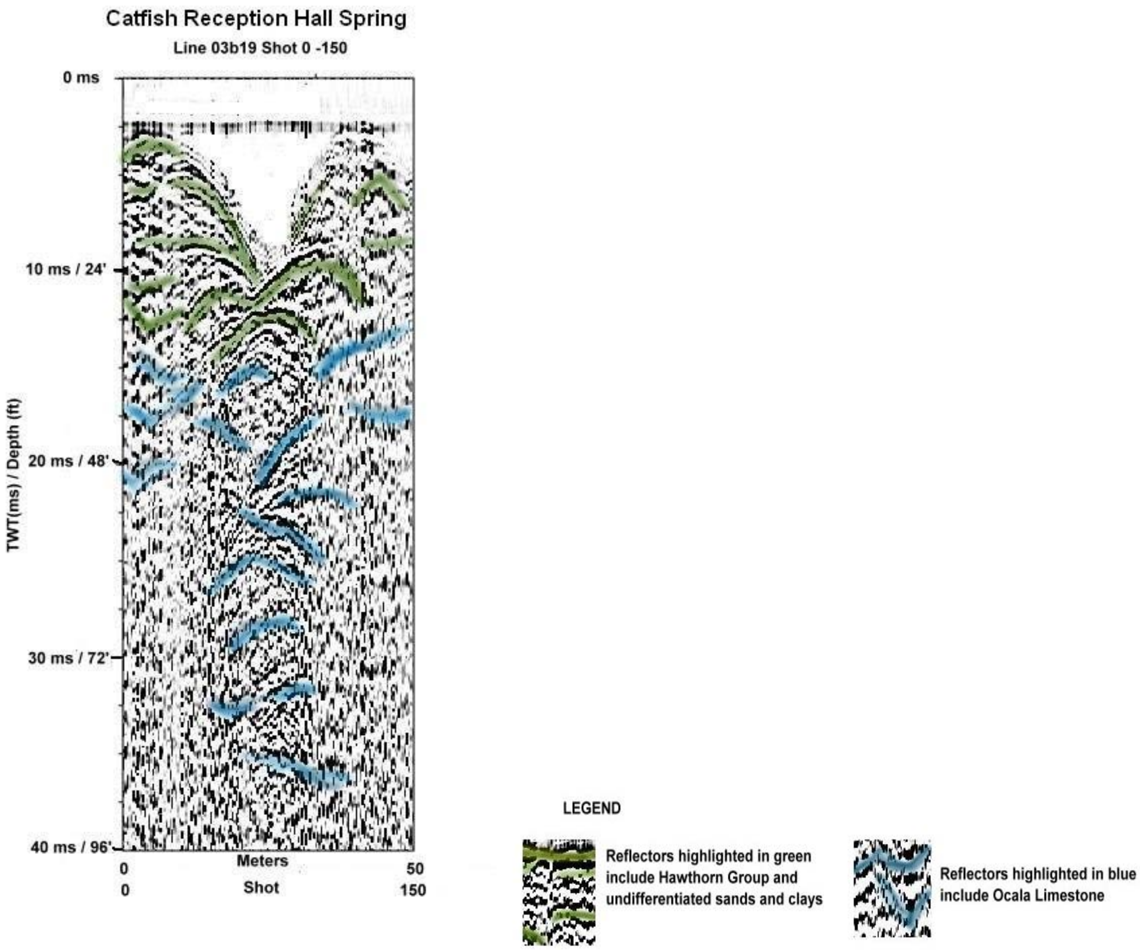

Figure 5-20 Seismic profile Line 03b19 shot 0 to shot 150 within section B-B' by Catfish Reception Hall Spring

Location of profile is shown in Figure 5-19. Highlighted reflectors indicate the subsurface orientation of individual beds. The central region is highly deformed, suggesting collapse into a void.

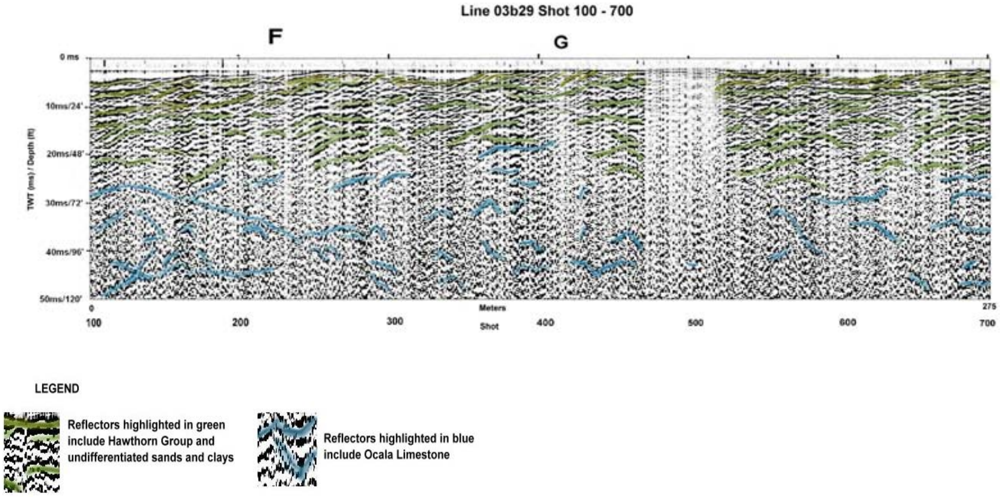

Figure 5-21 Seismic profile Line 03b29 shot 100 to shot 700 within section B-B' north of the Catfish Reception Hall

Location of shot points are shown in Figure 5-19. Highlighted reflectors indicate the subsurface orientation of individual beds. Sites F and G where thermal anomalies were detected are shown. Site F provides no indication of subsurface features that could provide a pathway for flow. Site G shows some lateral discontinuity in the bedding such as would be expected with a solution-enlarged fracture but no evidence of collapse.

down-warped reflectors to indicate collapse or subsidence into a cavity. The KES dive team identified a fracture that crosses the river at this point and filmed water discharging.

No obvious subsurface structure is apparent at the general location of point F thermal anomaly; however, point G shows a lateral discontinuity of bedding reflectors down into the limestone. Highlighted reflectors indicate the subsurface orientation of individual beds. Green highlighted reflectors are within the Hawthorn Group and Undifferentiated Sand and Shell Units. Blue highlighted reflectors are within the Ocala Limestone.

Additional named areas within Section B-B' include the Devils' Kitchen Spring and Blue Grotto Spring. Both of these show evidence of subsurface features. Blue Grotto Spring seismic data is presented in Figure 5-22. Blue Grotto Spring shows high amplitude reflectors to around 17ms, where they begin to attenuate and lose lateral continuity. The discordant orientation of reflectors suggests this is a site of a collapse feature. Unlike the Main Spring Boil example in Figure 5-18, there is no evidence of a debris pile.

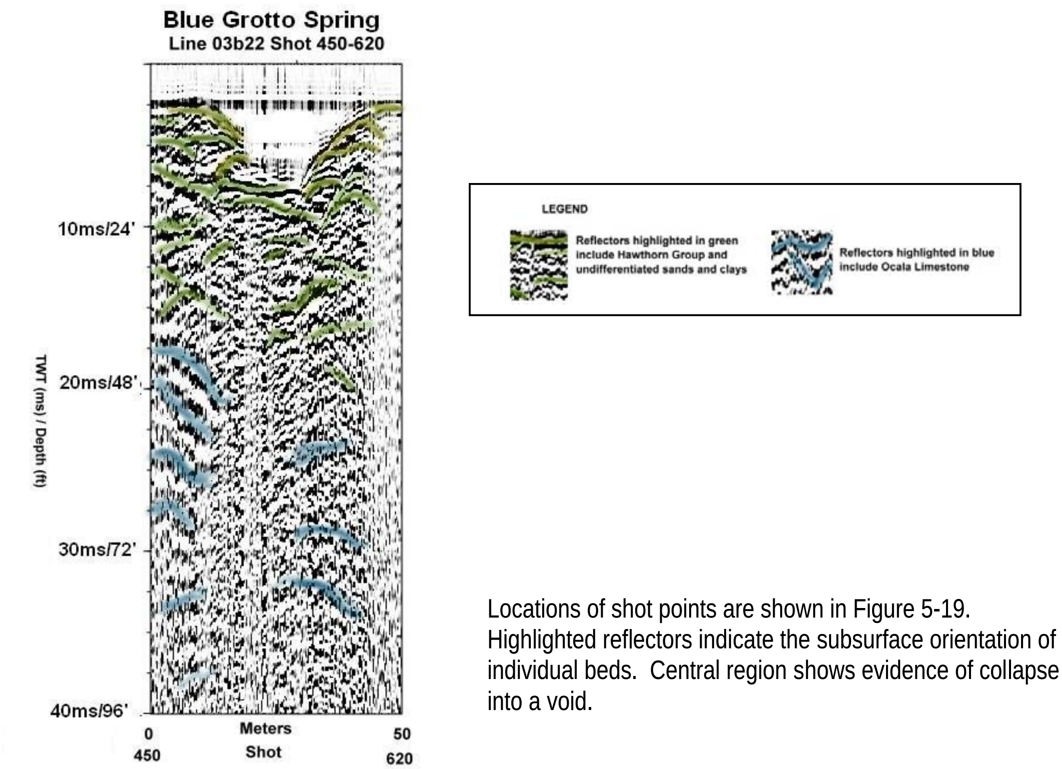

Figure 5-22 Seismic profile Line 03b22 shot 450 to shot 620 within section B-B’ showing the profile of Blue Grotto Spring.

5.7.4 Silver River Section C-C’

5.7.4.1 Thermography – First Fisherman’s Paradise Spring, Second Fisherman’s Paradise Spring, and the 1,200 Meter Station

Continuing downstream, Section C-C’ (Figure 5-23) encompasses the last of the named sites, including First Fisherman’s Paradise Spring, Second Fisherman’s Paradise Spring, and the 1,200-m Station. These are labeled H, I, and J respectively in Figure 5-23. The thermal profiles suggest that all three sites are points of discharge. There is an approximate 300 m run between the Second Fisherman’s Paradise Spring and the 1,200-m station where the radiant temperature stays below 16 °C. It then increases sharply to over 17.5 °C at the 1,200-m station at site J. During the aforementioned ground-truthing cruise, discharge from this site was also verified and was subsequently named Timber Springs (Osburn and others, 2006) due to a piece of timber that was jammed into one of the vents.

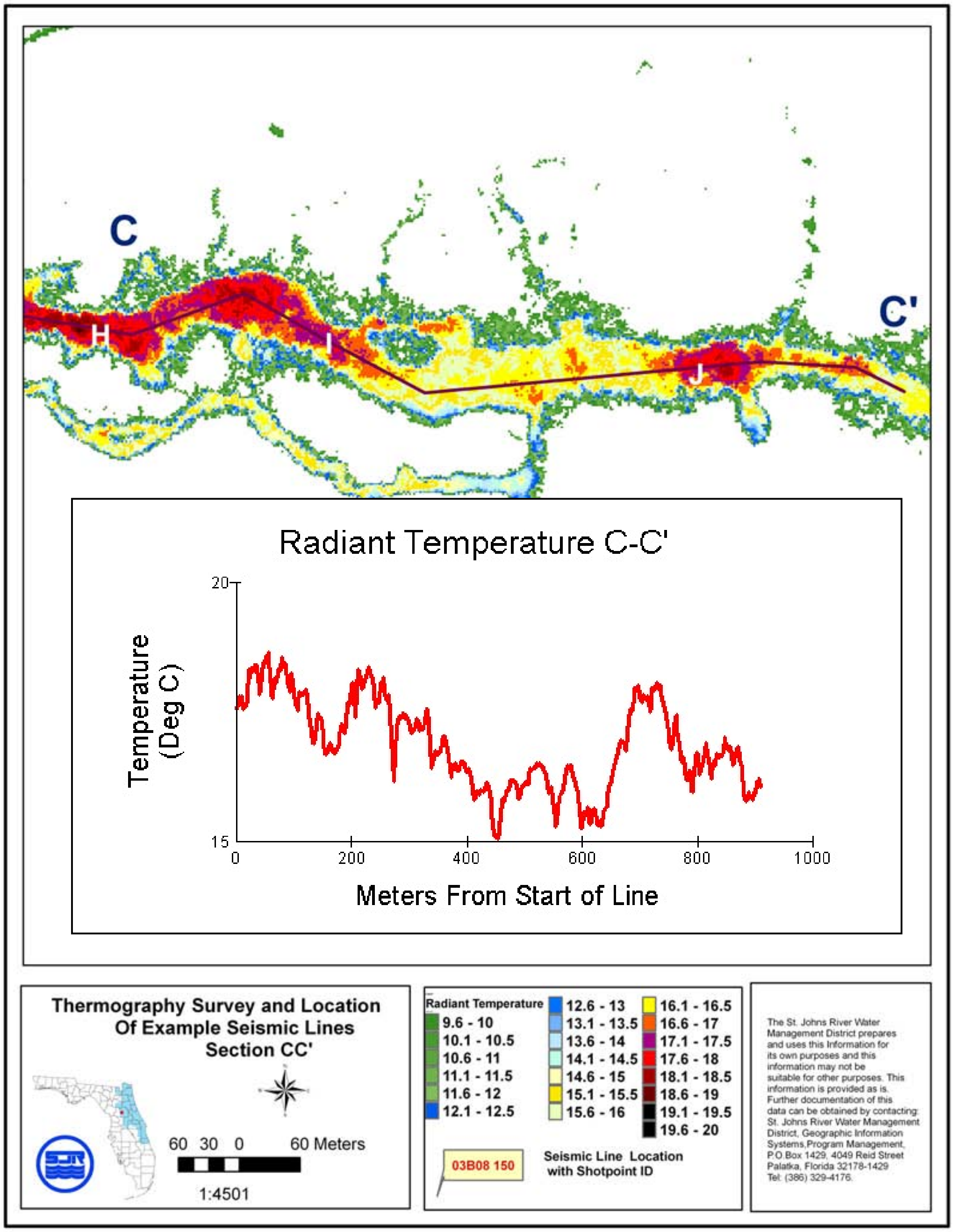

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Figure 5-23 Thermography Survey and Temperature Profile for Section C-C.

It includes sites on the Silver River known as First Fisherman's Paradise Spring (H), Second Fisherman's Paradise Spring (I), and the 1,200-m station (J). Several vents were observed discharging at site J (recently given the name Timber Springs).

5.7.5 Summary of Thermography and Seismic Profiles Findings

The thermography survey over the Silver River was very successful at identifying the location of all of the known springs and many new discharge areas have been mapped. A typical observed trend is a rise in temperature over the discharge point if there is sufficient flow to bring the waters to the surface before they are carried downstream by the existing current. The best example is at the Main Spring where the water shows a peak directly over the boil and drops several degrees after flowing about 130 meters downstream. A new spring was identified by the thermography data at point "G" in Figure 5-19 and subsequently documented with video camera by divers of Karst Productions, Inc. Another probable discharge area was identified upstream from "G" and is labeled "F" in Figure 5-19. Though divers did not find a discrete vent at this area a subsequent ground-truthing cruise with a glass-bottom boat confirmed this discharge. Evidence of the leaky nature of the river bottom was seen at the Main Spring Boil when the divers' air bubbles filtered through small holes in the river bottom as they swam in the cave below. The holes were not noticeable until the bubbles started rising.

It is quite evident that discharge of groundwater into the Silver River is not concentrated solely at the Main Spring Boil area as previously supposed. Downstream of the Main Spring Boil there are numerous thermal anomalies that range from less than 100 m to over 1,000 m of river length. Within these zones high peaks may indicate a point source. Areas of even but relatively high temperatures may represent diffuse flow. All of the thermal anomalies in the A-A', B-B', and C-C' sections were field verified. The technique has successfully identified every known discharging spring that has been flown over within SJRWMD. Though the temperature response is in itself direct evidence of groundwater discharge, additional verification such as underwater videos, direct flow measurements, or water quality indicators can provide additional confirmation if there is a question.

5.8 Oxygen Diffusion

Oxygen diffusion rate was estimated twenty-one times using the floating dome technique. Diffusion rate was measured in areas with differing flow velocities ranging from about 1.5 to 47 cm/s. Figure 5-24 illustrates the observed relationship between the measured rate of oxygen diffusion and current velocity at Silver Springs. Data collected by Knight (1980) at Silver Springs are also included on this graph for comparison. A fairly strong relationship was found between current velocity and diffusion rate with a regression coefficient of 0.84. This relationship was used for estimating diffusion rate as a function of flow in the upper 1,200 m of the Silver River as part of the metabolism estimates described in section 5.14.

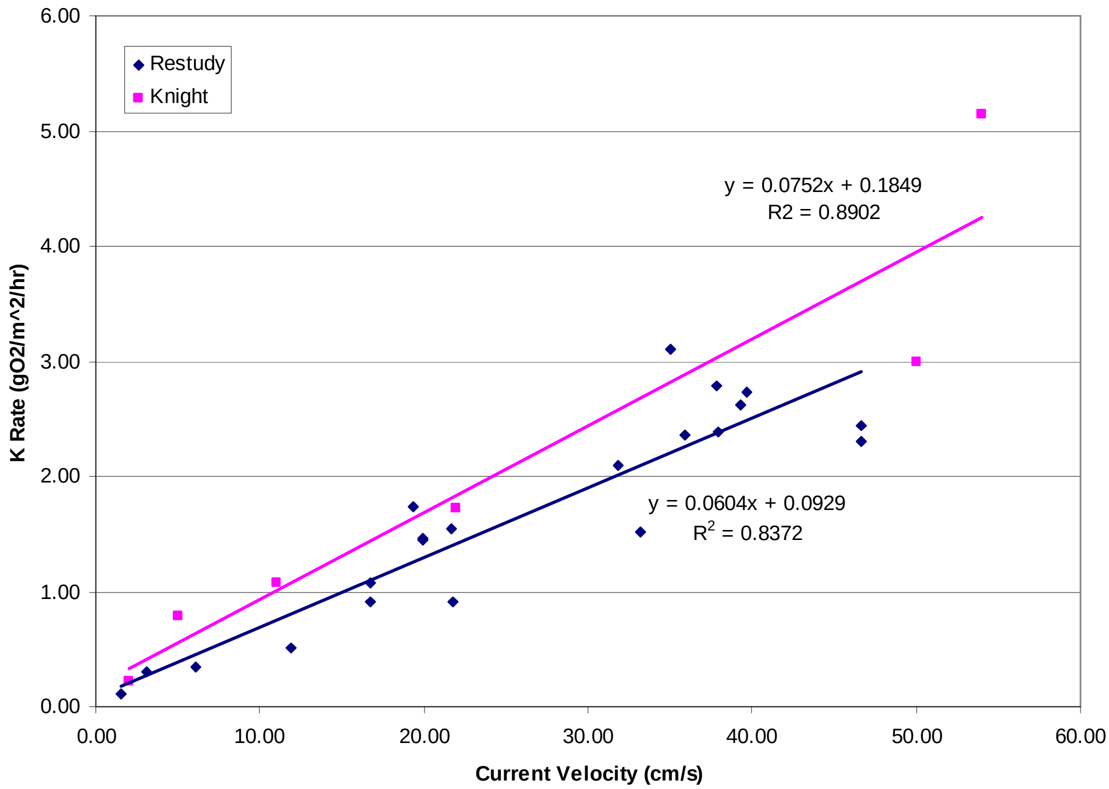


Figure 5- 24 Summary of Silver Springs oxygen diffusion rates as a function of current velocity during the retrospective study and by Knight (1980)

5.9 Water Quality

5.9.1 Introduction

Water quality recorded in Silver Springs over the duration of this study was relatively constant. A summary of the field data for eleven stations visited during this study is provided in Table 5-4. Upstream/downstream water quality for field and laboratory parameters is summarized in Table 5-5. Table 5-6 provides a summary of field parameters measured with the Troll 9000 Datalogger at the 1,200-m station. Figure 5-25 illustrates the average diurnal time series for these 1,200-m station field data. Laboratory reports for the water sample analyses are provided as Appendix K. Detailed water quality data collected for this study are provided in Appendix L. Appendix M contains water quality results for samples collected at five spring vents on March 24, 2005. Table 5-7 summarizes the water quality data for three additional spring boils.

Table 5-4 Silver Springs water quality summary of field parameters by station

Location	Statistics	Wtr Temp (C)	pH (SU)	DO (mg/L)	DO (%)	SpCond (uS/cm)
Boat Basin	Average	23.18	7.44	3.55	40.35	449
	Maximum	24.10	7.81	5.65	68.30	500
	Minimum	22.60	7.14	2.08	24.30	419
	Std Dev	0.49	0.17	1.06	12.28	26
	N	15	15	15	14	15
Bridge	Average	23.22	7.41	2.92	29.71	451
	Maximum	23.50	7.60	7.32	38.90	500
	Minimum	23.00	7.19	1.96	23.00	427
	Std Dev	0.15	0.12	1.29	4.21	26
	N	15	15	15	14	15
Main Boil	Average	23.28	7.32	2.22	26.08	452
	Maximum	23.90	7.56	4.16	49.30	499
	Minimum	22.60	6.91	1.25	20.20	389
	Std Dev	0.20	0.16	0.50	4.53	25
	N	46	24	48	41	28
Catfish Reception Hall	Average	23.67	7.37	3.31	39.33	496
	Maximum	24.02	7.54	6.17	72.70	539
	Minimum	23.50	7.16	2.58	31.80	436
	Std Dev	0.14	0.11	0.70	9.03	31
	N	23	24	25	19	28
Ladies Parlor	Average	23.68	7.45	3.66	43.12	474
	Maximum	23.90	7.59	4.24	50.00	518
	Minimum	23.20	7.22	3.18	38.10	441
	Std Dev	0.16	0.09	0.27	3.11	27
	N	16	16	16	16	16
Devils Kitchen	Average	23.70	7.45	3.86	45.73	485
	Maximum	24.20	7.64	6.28	74.40	532
	Minimum	23.40	7.23	2.82	33.90	447
	Std Dev	0.20	0.10	0.85	9.98	29
	N	17	17	17	17	17
Blue Grotto	Average	23.60	7.44	3.52	42.60	457
	Maximum	24.10	7.62	4.51	53.10	497
	Minimum	23.10	7.23	2.77	35.90	408
	Std Dev	0.21	0.13	0.42	4.97	25
	N	23	24	25	19	28
Christmas Tree Spring	Average	23.10	7.56	1.26	14.82	373
	Maximum	23.30	7.69	2.74	33.30	404
	Minimum	22.90	7.31	0.64	7.50	335
	Std Dev	0.11	0.10	0.46	5.66	22
	N	19	18	19	19	18
First Fisherman's Paradise	Average	23.43	7.49	3.48	40.66	458
	Maximum	23.90	7.64	4.73	55.70	496
	Minimum	23.20	7.23	2.55	30.10	427
	Std Dev	0.20	0.11	0.50	6.12	26

Table 5-4 Silver Springs water quality summary of field parameters by station

Location	Statistics	Wtr Temp (C)	pH (SU)	DO (mg/L)	DO (%)	SpCond (uS/cm)
	N	18	18	18	18	18
Second Fisherman's Paradise	Average	23.45	7.50	3.73	43.76	443
	Maximum	24.10	7.64	5.37	62.80	484
	Minimum	23.10	7.26	2.60	30.30	420
	Std Dev	0.27	0.11	0.80	9.58	23
	N	17	17	17	17	17
1200-m Station	Average	23.38	7.55	4.13	48.41	453
	Maximum	24.20	7.75	9.26	100.10	482
	Minimum	19.10	7.22	2.59	30.60	412
	Std Dev	0.59	0.12	1.09	12.25	26
	N	173	29	173	173	29
Period-of-Record		1/14/04	1/14/04	1/14/04	1/29/04	1/14/04
		1/22/05	12/9/04	1/22/05	1/22/05	12/9/04

Note: Water Quality Samples Collected by WSI and FDEP
DO is dissolved oxygen; SpCond is specific conductance

Table 5-5 Silver Springs Upstream/Downstream Water Quality Summary

Parameter_Units	Main Spring Boil					1200-m Station					Field Blank	Period-of-Record	
	Average	Max	Min	Std Dev	N	Average	Max	Min	Std Dev	N			
Water Temp (C)	23.3	23.9	22.6	0.196	46	23.4	24.2	19.1	0.587	173	---	1/14/04	1/22/05
Stage (Ft)	2.08	3.46	1.01	1.04	19	2.03	3.63	0.960	1.10	21	---	1/29/04	12/9/04
Secchi (m)	72.9	96.0	46.4	19.2	5	27.5	32.1	23.5	3.24	5	---	4/9/04	10/17/04
Color (CPU)	2.50	2.50	2.50	0.00	12	2.50	2.50	2.50	0.00	8	5u	1/14/04	12/9/04
Sp. Cond (uS/cm)	452	499	389	24.7	28	453	482	412	26.0	29	---	1/14/04	12/9/04
DO (mg/L)	2.22	4.16	1.25	0.500	48	4.13	9.26	2.59	1.09	173	---	1/14/04	1/22/05
DO (%)	26.1	49.3	20.2	4.53	41	48.4	100	30.6	12.3	173	---	1/29/04	1/22/05
pH (SU)	7.32	7.56	6.91	0.157	24	7.55	7.75	7.22	0.123	29	---	1/14/04	12/9/04
Alkalinity (mg/L)	184	201	170	7.87	12	169	170	160	3.54	8	5u	1/14/04	12/9/04
TDS (mg/L)	277	300	254	15.7	12	281	320	260	19.6	8	10u, 11u	1/14/04	12/9/04
TSS (mg/L)	1.33	2.00	1.00	0.492	12	1.00	1.00	1.00	0.00	8	2u, 3.4u	1/14/04	12/9/04
NH_4-N (mg/L)	0.015	0.053	0.005	0.014	11	0.013	0.017	0.013	0.001	8	0.026u, 0.041i (8/17/04)	1/14/04	12/9/04
TKN (mg/L)	0.046	0.190	0.024	0.048	12	0.039	0.140	0.024	0.041	8	0.048u	1/14/04	12/9/04
NOx-N (mg/L)	1.10	1.20	1.00	0.085	12	1.14	1.20	0.920	0.100	8	0.015u	1/14/04	12/9/04
TN (mg/L)	1.19	1.61	1.02	0.190	9	1.17	1.24	0.940	0.109	7	0.032u	1/14/04	12/9/04
TP (mg/L)	0.046	0.067	0.022	0.017	12	0.060	0.220	0.022	0.079	6	0.043u, 0.027i (8/17/04)	1/14/04	9/14/04
Ortho P (mg/L)	0.045	0.055	0.026	0.008	13	0.044	0.074	0.026	0.014	8	0.015u, 0.04i (3/23/04)	1/14/04	12/9/04
Ca-T (mg/L)	77.3	83.0	72.0	3.12	12	71.6	75.0	69.0	2.13	8	0.068u, 70u, 0.034iv (11/11/04)	1/14/04	12/9/04
Mg-T (mg/L)	9.83	11.0	8.90	0.651	12	10.0	11.0	9.60	0.414	8	0.0074u, 0.033u, 10u	1/14/04	12/9/04
Na-T (mg/L)	5.87	7.20	0.680	1.72	12	6.43	6.80	6.10	0.282	8	6.3u, 0.079v (8/17/04), 0.0086i (11/11/04)	1/14/04	12/9/04
K-T (mg/L)	0.617	0.730	0.540	0.057	12	0.565	0.700	0.060	0.210	8	0.024u, 0.7u, 0.037i (8/17/04)	1/14/04	12/9/04
Cl-T (mg/L)	11.1	12.0	9.50	1.01	12	12.1	14.0	11.0	0.835	8	1.3u, 2.5u	1/14/04	12/9/04
SO_4 (mg/L)	43.9	60.0	25.0	11.9	12	53.9	64.0	44.0	5.72	8	1.4u	1/14/04	12/9/04
F-T (mg/L)	0.191	0.230	0.160	0.016	12	0.174	0.220	0.150	0.021	8	0.061u	1/14/04	12/9/04
TColi (#/100mL)	7.08	16.0	1.00	5.60	12	131	560	1.00	186	8	1u	1/14/04	12/9/04
FColi (#/100mL)	1.67	6.00	0.500	1.70	12	76.9	440	1.00	150	8	1u	1/14/04	12/9/04
Turbidity (NTU)	0.160	0.700	0.050	0.184	12	0.103	0.270	0.065	0.075	8	0.13u	1/14/04	12/9/04

Note(s):
Water Quality Samples Collected by WSI and DEP
Main Spring Boil Stage from USGS at Boat Basin
Statistics calculated using 0.5 times the detection limit when reported as below the detection limit
u = indicates that the compound was analyzed for but not detected
I = the reported value is between the lab method detection limit and the lab practical quantitation limit
v = indicates that the analyte was detected in both the sample and the associated method blank
Period-of-Record identifies the date range of samples included in summary

Table 5-6 Silver Springs Hourly Measurements at the 1,200-m Station using the In-Situ Troll 9000 Datasonde

Parameter	Average	Minimum	Maximum	StDev	N
DO (mg/L)	3.30	1.39	6.41	1.02	8911
DO (%)	38.5	16.1	74.4	12.1	8911
Wtr Temp (C)	23.1	22.1	24.2	0.345	9297
pH (SU)	7.38	7.12	7.69	0.101	9297
Sp Cond (uS/cm)	415	329	459	32.6	9201

Period of Record: 2/13/04 - 3/13/05

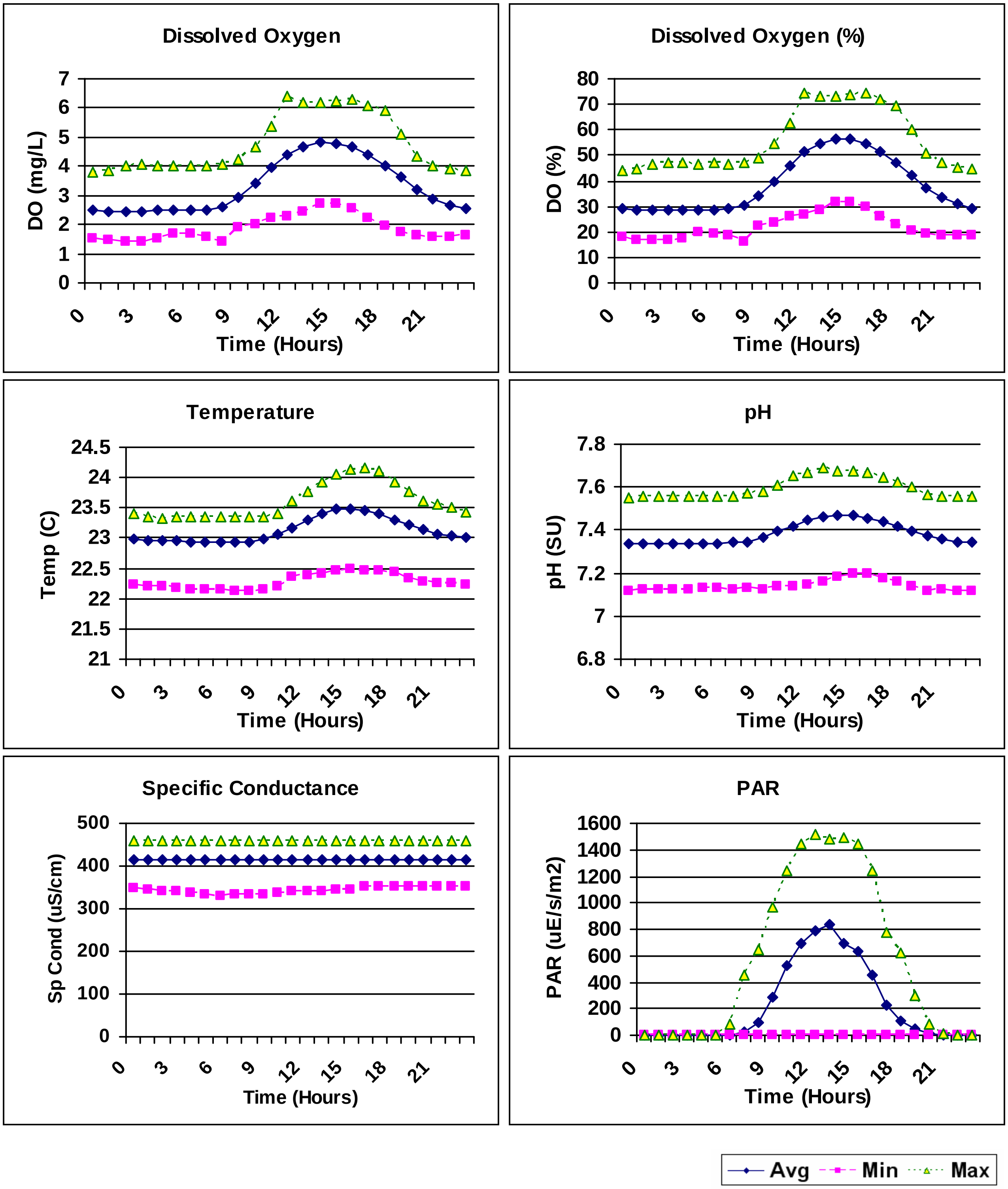


Figure 5- 25 Diurnal summary of Silver Springs recording datasonde measurements at the 1,200-m station, February 2004 to March 2005

Table 5-7 Silver Springs water quality summary

Parameter_Units	Catfish Reception Hall					Blue Grotto					Christmas Tree Spring					Period-of-Record	
	Average	Max	Min	Std Dev	N	Average	Max	Min	Std Dev	N	Average	Max	Min	Std Dev	N		
Water Temp (C)	23.7	24.0	23.5	0.144	23	23.6	24.1	23.1	0.211	23	23.1	23.3	22.9	0.106	19	1/14/04	12/9/04
Color (CPU)	2.50	2.50	2.50	0.00	4	2.50	2.50	2.50	0.00	4	2.50	2.50	2.50	---	1	1/14/04	7/22/04
Sp. Cond (uS/cm)	496	539	436	31.1	28	457	497	408	24.9	28	373	404	335	22.4	18	1/14/04	12/9/04
DO (mg/L)	3.31	6.17	2.58	0.703	25	3.52	4.51	2.77	0.419	25	1.26	2.74	0.640	0.459	19	1/14/04	12/9/04
DO (%)	39.3	72.7	31.8	9.03	19	42.6	53.1	35.9	4.97	19	14.8	33.3	7.50	5.66	19	1/29/04	12/9/04
pH (SU)	7.37	7.54	7.16	0.113	24	7.44	7.62	7.23	0.126	24	7.56	7.69	7.31	0.104	18	1/14/04	12/9/04
Alkalinity (mg/L)	174	180	168	5.51	4	160	164	157	2.87	4	160	160	160	---	1	1/14/04	7/22/04
TDS (mg/L)	317	350	298	23.9	4	244	278	160	56.1	4	230	230	230	---	1	1/14/04	7/22/04
TSS (mg/L)	1.75	2.00	1.00	0.500	4	1.75	2.00	1.00	0.500	4	1.00	1.00	1.00	---	1	1/14/04	7/22/04
NH_4-N (mg/L)	0.007	0.013	0.005	0.004	4	0.027	0.070	0.005	0.031	4	0.013	0.013	0.013	---	1	1/14/04	7/22/04
TKN (mg/L)	0.036	0.060	0.024	0.016	4	0.047	0.073	0.024	0.024	4	1.10	1.10	1.10	---	1	1/14/04	7/22/04
NOx-N (mg/L)	1.43	1.50	1.30	0.096	4	1.43	1.50	1.30	0.096	4	0.900	0.900	0.900	---	1	1/14/04	7/22/04
TN (mg/L)	1.46	1.56	1.32	0.112	4	1.47	1.57	1.32	0.119	4	2.00	2.00	2.00	---	1	1/14/04	7/22/04
TP (mg/L)	0.053	0.085	0.041	0.022	4	0.042	0.049	0.038	0.005	4	0.022	0.022	0.022	---	1	1/14/04	7/22/04
Ortho P (mg/L)	0.042	0.048	0.037	0.005	4	0.040	0.045	0.037	0.004	4	0.048	0.048	0.048	---	1	1/14/04	7/22/04
Ca-T (mg/L)	82.4	91.5	76.6	6.38	4	74.0	79.1	71.5	3.50	4	61.0	61.0	61.0	---	1	1/14/04	7/22/04
Mg-T (mg/L)	12.5	13.3	12.0	0.591	4	11.6	12.1	11.0	0.497	4	6.90	6.90	6.90	---	1	1/14/04	7/22/04
Na-T (mg/L)	6.30	6.60	5.70	0.404	4	6.16	6.49	5.40	0.513	4	5.30	5.30	5.30	---	1	1/14/04	7/22/04
K-T (mg/L)	0.663	0.690	0.630	0.025	4	0.625	0.630	0.610	0.010	4	0.610	0.610	0.610	---	1	1/14/04	7/22/04
Cl-T (mg/L)	11.3	12.0	11.0	0.500	4	10.5	11.0	10.0	0.577	4	9.60	9.60	9.60	---	1	1/14/04	7/22/04
SO_4 (mg/L)	79.0	86.0	76.0	4.76	4	64.5	74.0	59.0	6.66	4	26.0	26.0	26.0	---	1	1/14/04	7/22/04
F-T (mg/L)	0.185	0.200	0.170	0.013	4	0.165	0.180	0.150	0.013	4	0.140	0.140	0.140	---	1	1/14/04	7/22/04
TColi (#/100mL)	5.3	17.0	1.0	7.85	4	9.8	35.0	1.0	16.8	4	20.0	20.0	20.0	---	1	1/14/04	7/22/04
FColi (#/100mL)	2.75	7.00	1.00	2.87	4	3.5	10.0	1.0	4.36	4	0.500	0.500	0.500	---	1	1/14/04	7/22/04
Turbidity (NTU)	0.104	0.150	0.065	0.035	4	0.066	0.100	0.050	0.024	4	0.065	0.065	0.065	---	1	1/14/04	7/22/04

Note(s):
Water Quality Samples Collected by WSI and DEP
Statistics calculated using 0.5 times the detection limit when reported as below the detection limit

5.9.2 Water Temperature

The average water temperature recorded in the Main Spring Boil was 23.3 °C with a range of observed values between 22.6 and 23.9 °C. Average temperatures at all eleven stations ranged from a low of 23.1 °C at Christmas Tree Spring to a high of 23.7 °C recorded at Devil's Kitchen. Maximum and minimum temperature records were recorded at the 1,200-m station as 24.2 and 19.1 °C. Temperature varied diurnally at the 1,200-m station as illustrated in Figure 5-25.

5.9.3 Hydrogen Ion

Average pH recorded at the Main Spring Boil was 7.3 s.u. and individual maximum and minimum pH values at that station were 7.6 and 6.9 s.u. Average pH ranged from a low of 7.32 s.u. at the Main Spring Boil to a high of 7.56 s.u. recorded at Christmas Tree Spring. The diurnal variation in pH at the 1,200-m station is illustrated in Figure 5-25.

5.9.4 Dissolved Oxygen

Surface measurements of dissolved oxygen at the Main Spring Boil station remained relatively constant over the period of sampling with an average of 2.22 mg/L and a range of observed values from 1.2 to 4.2 mg/L. Average surface water DO was rather variable between stations with the lowest average of 1.3 mg/L recorded at Christmas Tree Spring and the highest average of 4.1 mg/L recorded downstream at the 1,200-m station. The 1,200-m station had the widest range of measured DO concentrations from a low of 1.39 mg/L measured by the Troll 9000 meter and a surface reading of 9.3 mg/L. The typical diurnal pattern of DO concentrations and percent saturation is illustrated for the 1,200-m station in Figure 5-25. The average DO concentration from measurements taken during water quality sampling was higher than those collected with the Troll 9000. This finding can be explained by looking at the average diurnal pattern in Figure 5-25. Water quality sampling typically took place during daylight hours when the DO concentrations were higher and the Troll 9000 average was calculated using hourly readings for the entire day/night cycle.

5.9.5 Specific Conductance

Specific conductance at the Main Spring Boil station averaged 452 µS/cm. Maximum and minimum recorded values during the period-of-record were 499 and 389 µS/cm. Average specific conductance varied from a low of 373 µS/cm at the Christmas Tree Spring station to a high of 496 µS/cm at Catfish Reception Hall. Measured specific conductance values ranged from 329 to 482 µS/cm at the 1,200-m station. There was very little diurnal variation in specific conductance as indicated in Figure 5-25.

5.9.6 Secchi Distance and Light Transmission

Secchi disk readings were made on five occasions during this period-of-record. The river bottom was clearly visible from the surface at all stations and under all conditions except during a heavy rain shower and during the night. Average horizontal secchi distance varied from a maximum average value of 73 m in the Main Spring Boil area, to 37 m in the vicinity of Turtle Meadows, and 28 m at the 1,200-m station. The highest recorded secchi distance during this study was 96 m taken in the vicinity of the Main Spring Boil on July 2, 2004. The minimum reading was 24 m taken at the 1,200-m station March 26, 2004.

Light (PAR) transmittance and attenuation was measured with an underwater photometer at the Main Spring Boil, Turtle Meadows, and at the 1,200-m station on December 21, 2004 (Figure 5-26). The PAR diffuse attenuation coefficient increased downstream from a low value of 0.161 m^{-1} at the Main Spring Boil, to 0.211 m^{-1} at Turtle Meadows, to 0.336 m^{-1} at the 1,200-m station. Estimated percent PAR transmittance at 1 m decreased between these stations from 85.1% at the Main Spring Boil to 71.5% at the 1,200-m station.

5.9.7 Additional Parameters

Laboratory data are summarized for eight surface water quality sampling events conducted by WSI and four events by FDEP. These data for the Main Spring Boil and 1,200-m stations have been summarized in Table 5-5 and detailed laboratory data are provided in Appendix K. A brief description contrasting the upstream (Main Spring Boil) and downstream (1,200-m) averages for each measured parameter is provided below.

Average total alkalinity declined from about 184 to 169 mg/L as $CaCO_3$ between the upstream and downstream stations. Other chemical components that also declined on average between these two stations included: total Kjeldahl nitrogen (0.05 to 0.04 mg/L), total ammonia nitrogen (0.015 to 0.013 mg/L), total nitrogen (1.19 to 1.17 mg/L), calcium (77 to 72 mg/L), turbidity (0.16 to 0.10 NTU), total fluoride (0.19 to 0.17 mg/L), and total potassium (0.62 to 0.57 mg/L). Constituent concentrations that increased on average between the upstream and downstream stations included sulfate (44 to 54 mg/L), sodium (5.9 to 6.4 mg/L), total dissolved solids (277 to 281 mg/L), nitrate+nitrite nitrogen (1.10 to 1.14 mg/L), total phosphorus (0.046 to 0.060 mg/L), total coliforms (7.1 to 131 col/100mL), and fecal coliforms (1.7 to 77 col/100/mL). Parameters

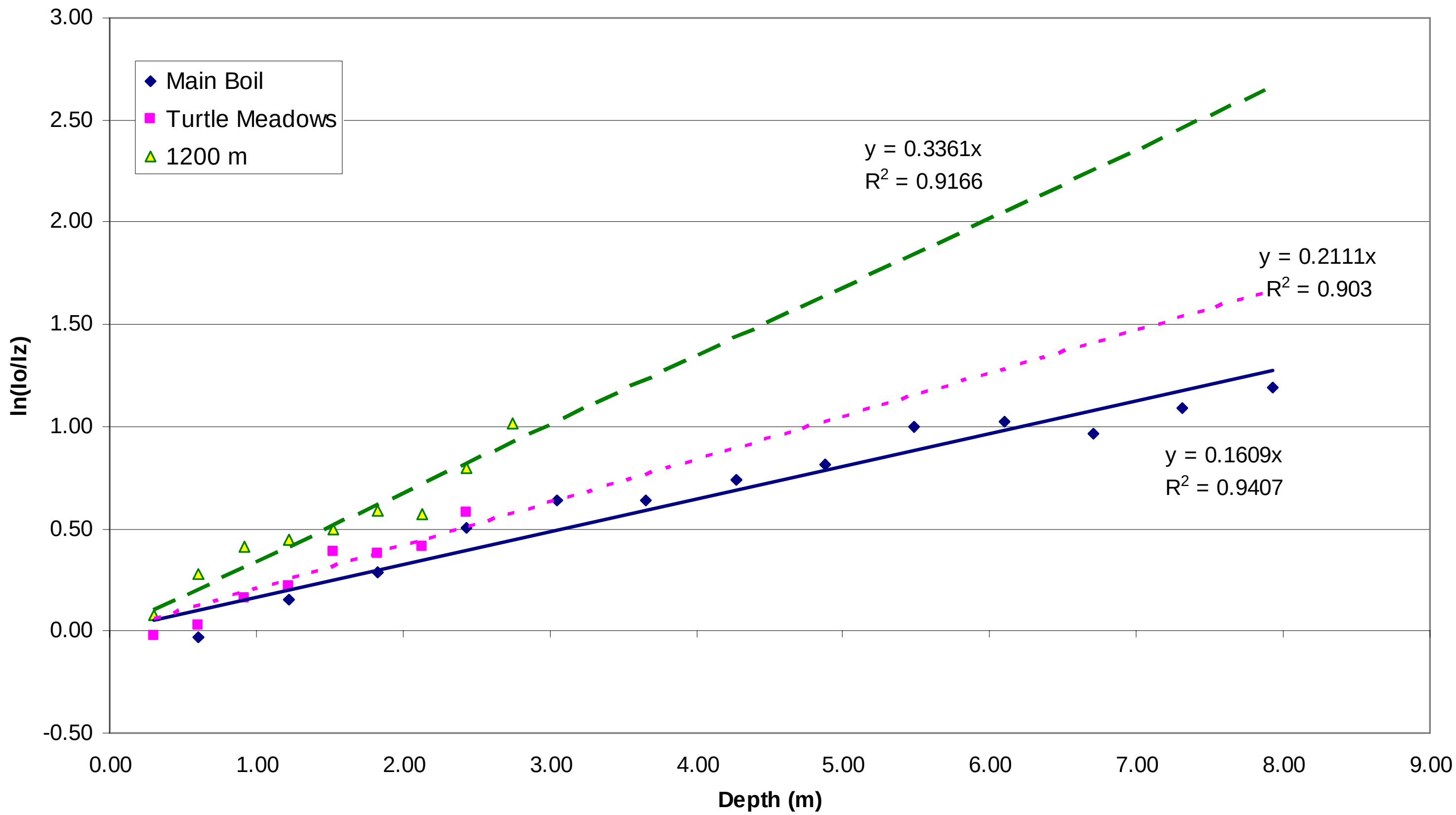


Figure 5-26 Silver Springs light (PAR) attenuation estimates at the Main Spring Boil, Turtle Meadows, and 1,200-m station - December 21, 2004; PAR estimates are in µmol/s/m2

with average concentrations that did not change noticeably between these stations included total suspended solids (1.0 mg/L), ortho-phosphorus (0.044 mg/L), and color (2.5 CPU).

There were several apparent differences in water quality between the various spring boils (see Tables 5-5 and 5-7). In addition to the differences in field parameters discussed above, nitrate+nitrite nitrogen concentrations were somewhat lower at Christmas Tree Spring than at Catfish Reception Hall and Blue Grotto and total Kjeldahl nitrogen concentrations were higher in Christmas Tree than in the others. The Main Spring Boil value was intermediate between these extremes.

Isotope analyses were conducted on samples collected from inside the spring vents. The analytical results of the isotope analyses are provided in Appendix N.

5.10 Epiphytes and Macrophytes

5.10.1 Macrophytes

The macrophyte community was dominated by the submerged aquatic plant *Sagittaria kurziana*. A wide range of submersed, emergent and floating aquatic macrophytes were observed within the spring run (Table 5-8), but altogether represented less than 5% of the total macrophyte biomass. All of these species were observed throughout the study period. Two species of submerged macrophytes were observed in significant quantities at multiple sites along the study reach during the course of the study, *Ceratophyllum demersum* (coontail) and *Cabomba caroliniana* (fanwort) (Figure 5-27). However, even these two taxa were never observed to cover more than 50% of the bottom at the sites where they occurred and the areal extent of their distribution was limited.

Four GIS layers of information collected in the field were used to estimate the biomass of macrophytes in the Silver River: percent plant cover, plant height, plant blade density and conversion coefficients for plant abundance to dry weight and ash-free dry weight relationships. Average *Sagittaria* biomass for the region of Silver Springs included in this study was estimated to be 547 g dry weight m^{-2} (std. dev. 235 g dry wt. m^{-2}) for the summer survey and 379 g dry weight m^{-2} (std. dev. 183 g dry wt. m^{-2}) for the winter survey. Extrapolated over the entire study reach, the total *Sagittaria* biomass was estimated to be 47.2 x 10^6 g dry weight in the summer and 33.1 x 10^6 g dry weight in the winter. The seasonal differences in plant biomass are clearly discernible in the GIS images of plant biomass distribution in the summer (Figure 5-28) and winter (Figure 5-29). Patches of exceptionally high biomass were distributed along the entire length of the study reach.

Table 5-8 Commonly observed aquatic plant species in Silver Springs, Florida, USA, 2003 – 2005

Submerged Aquatic Species
Sagittaria kurziana (strap-leaf *Sagittaria*)
Ceratophyllum demersum (coontail)
Cabomba caroliniana (fanwort)
Vallisneria americana (eel-grass)
Najas guadalupensis (southern naiad)
Floating Aquatic Species
Pistia stratiotes (water lettuce)
Nuphar luteum (spatterdock)
Eichornia crassipes (water hyacinth)
Lemna minor (duckweed)
Emergent Species
Pontederia cordata (pickerelweed)
Ludwigia octovalvis (water primrose)
Typha sp. (cattail)
Cicuta mexicana (water hemlock)
Colocasia esculenta (wild taro)
Panicum hemitomon (maidencane)

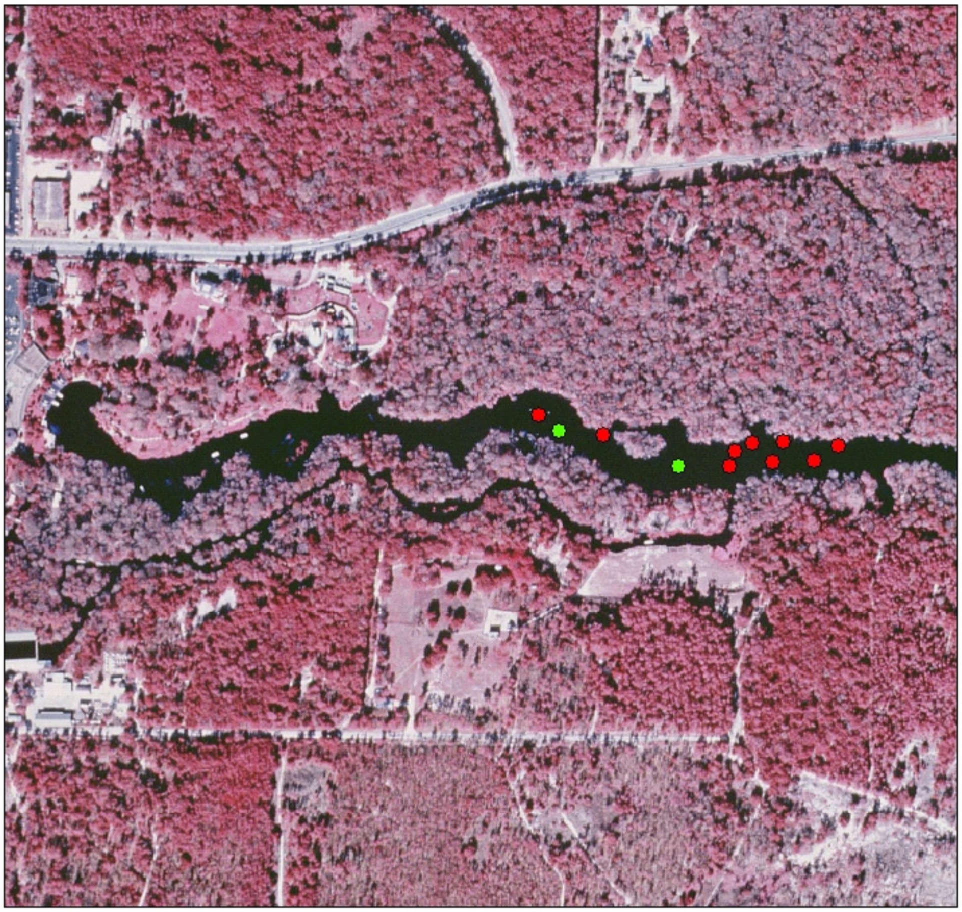


Figure 5-27 Locations of Ceratophyllum (red circles) and Cabomba (green circles) beds

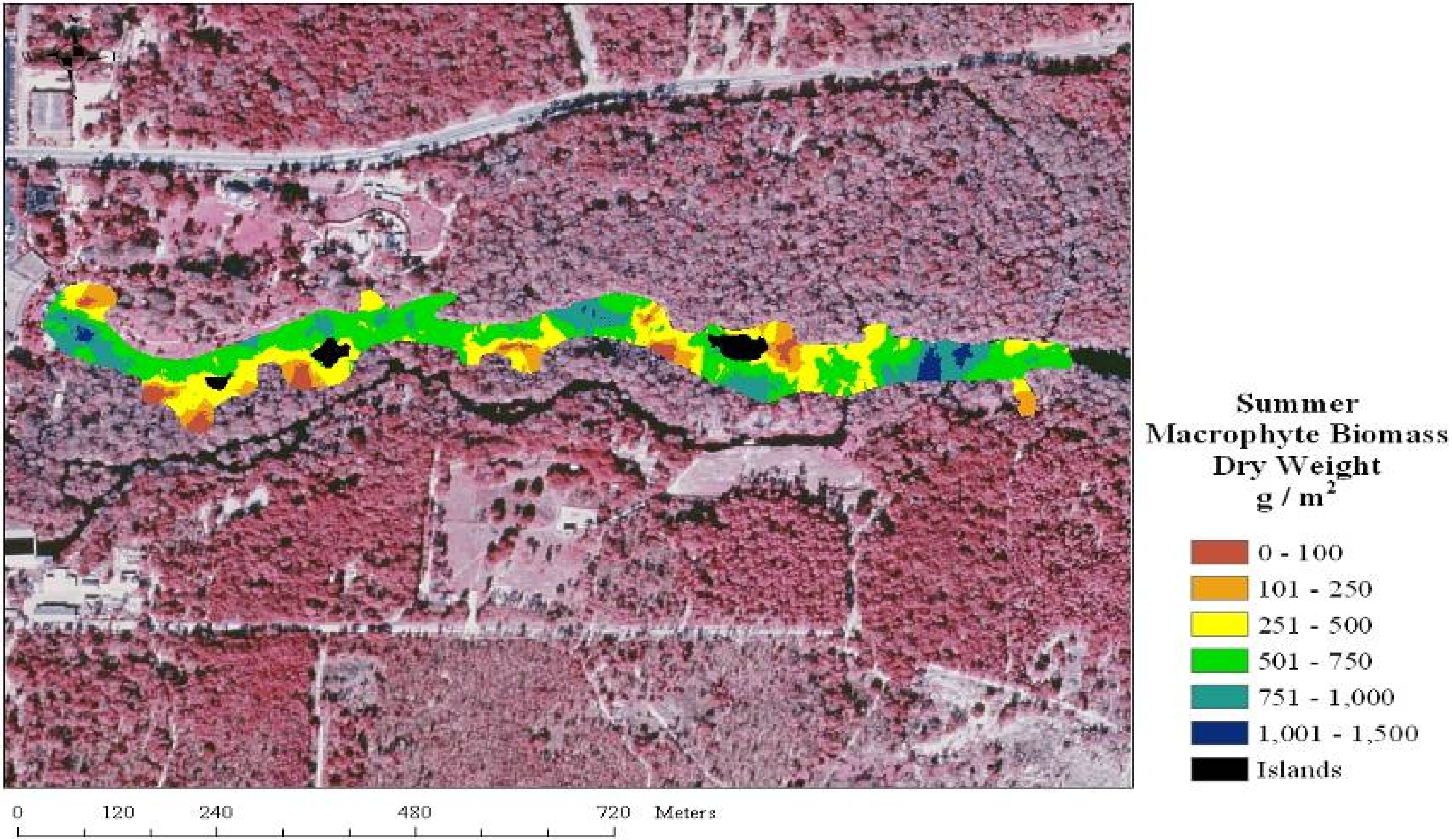


Figure 5-28 Average summer dry weight (g m^{-2}) distribution of macrophytes in Silver Springs, Florida, USA (2004)

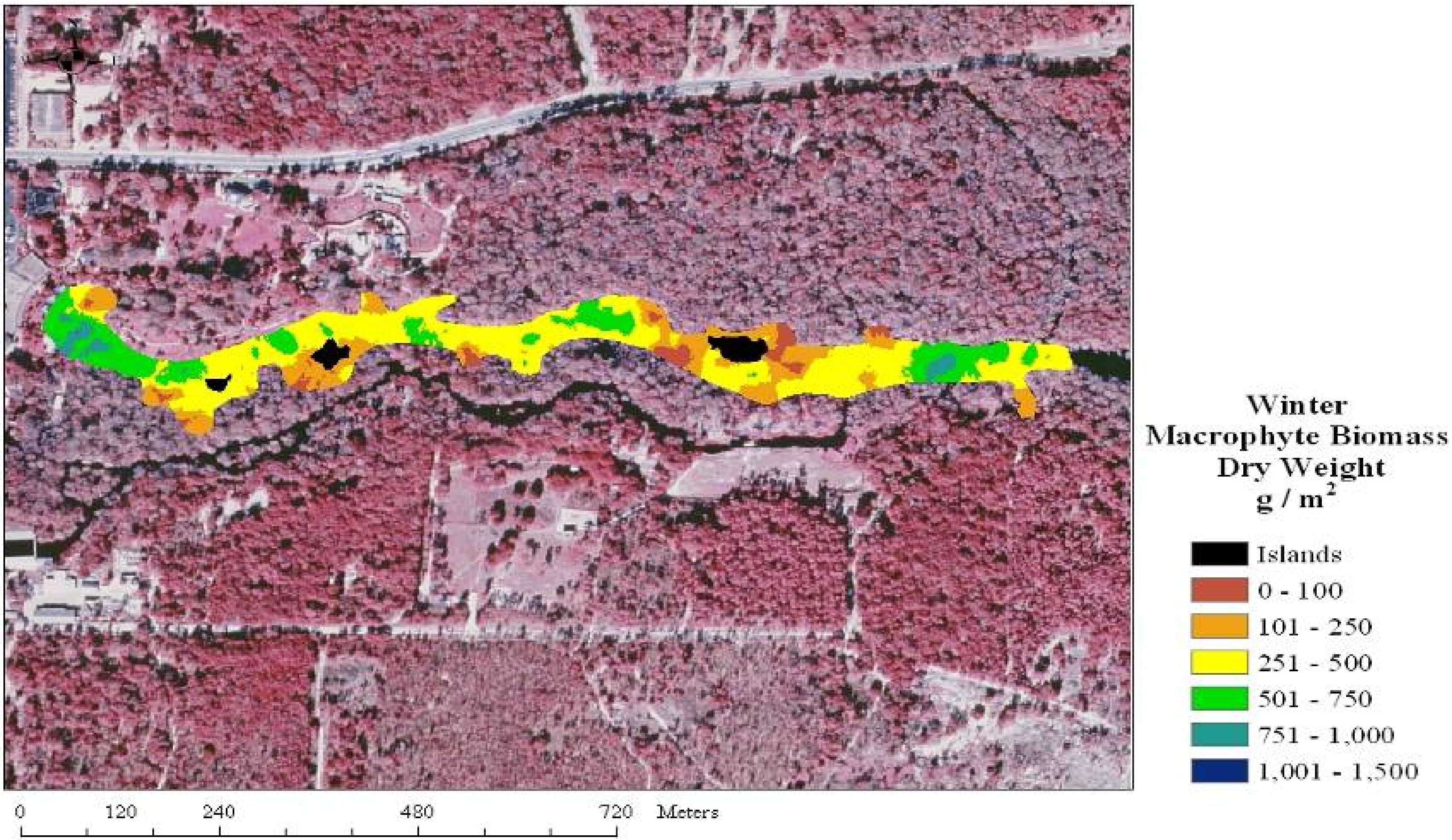


Figure 5-29 Average winter dry weight (g m^{-2}) distribution of macrophytes in Silver Springs, Florida, USA (2004)

It was further estimated that the contribution of other macrophytes to total plant density was no more than 5% of the *Sagittaria* biomass, yielding a system-wide maximum of 2.8 x 10^6 g dry weight in the summer and 2 x 10^6 g dry weight in the winter. The relatively minor contribution of macrophytes other than *Sagittaria* is illustrated by the maximum biomass values for the two most commonly observed species in the ‘other’ category, *Ceratophyllum* and *Cabomba*. The densest patches of *Ceratophyllum* observed in the study had biomasses of up to 550 g dry weight m^{-2} and densest patches of *Cabomba* had biomasses up to 565 g dry weight m^{-2}, however the total biomass of both macrophytes were orders of magnitude below the average dry weights of *Sagittaria* previously described (0.095 x 10^6 g DW and 0.042 x 10^6 g DW respectively).

In terms of ash-free dry weight (AFDW), the averages for the spring run were 405 g AFDW m^{-2} (std. dev. 183 g AFDW m^{-2}) in the summer and 304 g AFDW m^{-2} (std. dev. 142 g AFDW m^{-2}) in the winter. Extrapolated over the entire study reach, the total *Sagittaria* AFDW was estimated to be 37.2 x 10^6 g AFDW in the summer and 26.6 x 10^6 g AFDW in the winter. The spatial distribution of *Sagittaria* AFDW (Figures 5-30 and 5-31) was analogous to the distribution of dry weight. Although the overall biomass of *Sagittaria* was higher in the summer than in the winter, certain regions of the spring had higher winter than summer *Sagittaria* biomass (Figure 5-32). Many of the latter regions were located near the shore of the spring. This may be associated with the winter loss of tree canopy, which provides additional light for aquatic plant production.

5.10.2 Algal Mats

The benthic algal mat communities observed over the study period were dominated by the blue-green alga *Lyngbya wollei* (Table 5-9). However, other blue-green algae were found in the mats, including *Oscillatoria* and *Phormidium*. Meroplanktonic forms of diatoms were also common components of the mats, particularly *Aulacoseira* and *Terpsinoe musica*. The xanthophyte *Vaucheria* was associated with mats in certain regions of the spring, particularly in the summer and fall.

Three GIS layers of information collected in the field were used to estimate the biomass of algal mats in the Silver River: percent mat cover, mat depth, and conversion coefficients for dry weight per unit volume of mat. Average algal mat biomass for the region of Silver Springs included in this study was estimated to be 601 g dry weight m^{-2} (std. dev. 248 g dry wt. m^{-2}) for the summer survey and 379 g dry weight m^{-2} (std. dev. 299 g dry wt. m^{-2}) for the winter survey. Spatially, the average algal mat dry weights were higher in the lower third of the sampling reach (Figures 5-33 and 5-34). Mat biomasses tended to be lowest near the areas where obvious

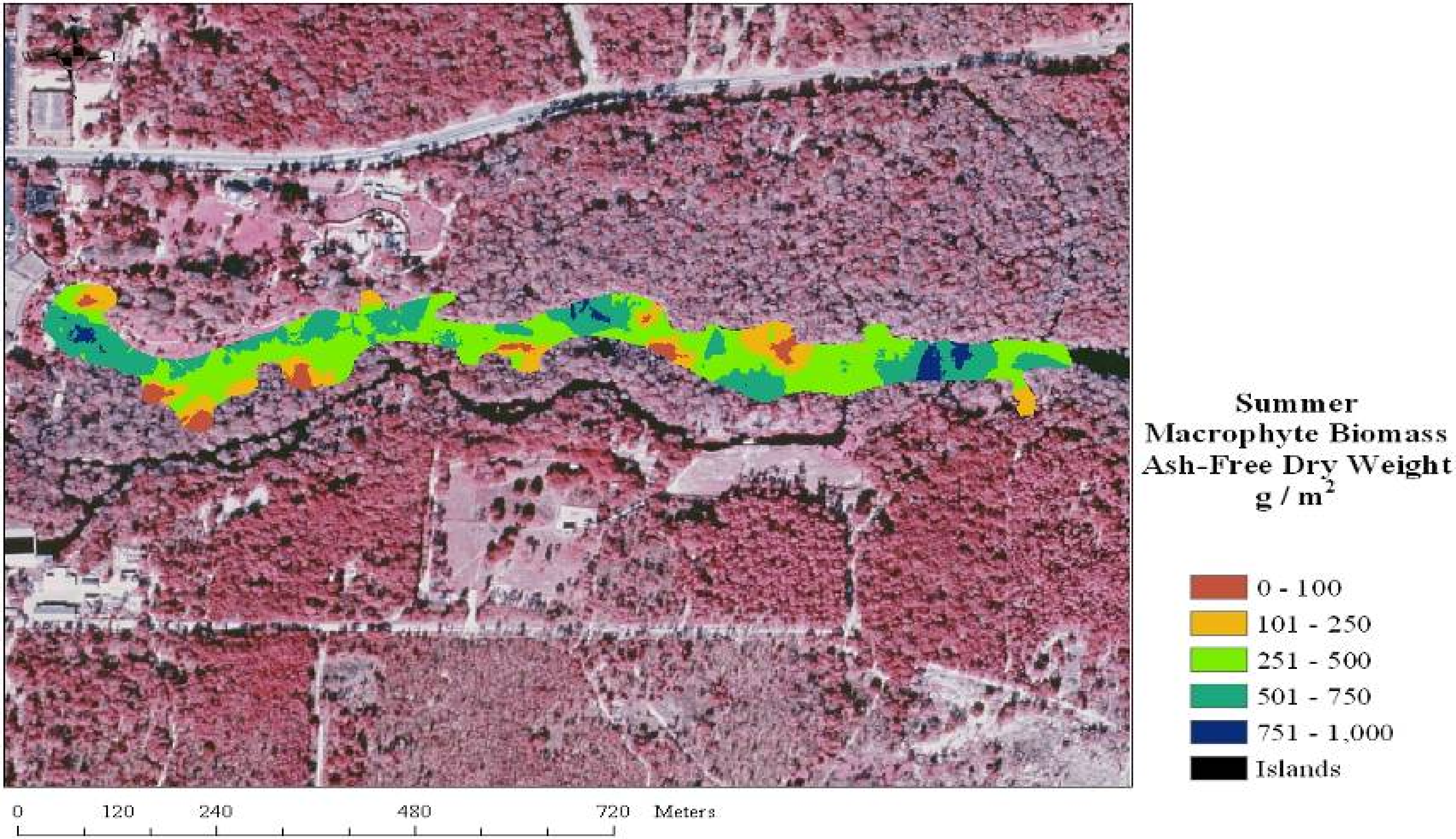


Figure 5-30 Average summer ash-free dry weight (g m-2) distribution of macrophytes in Silver Springs, Florida, USA (2004)

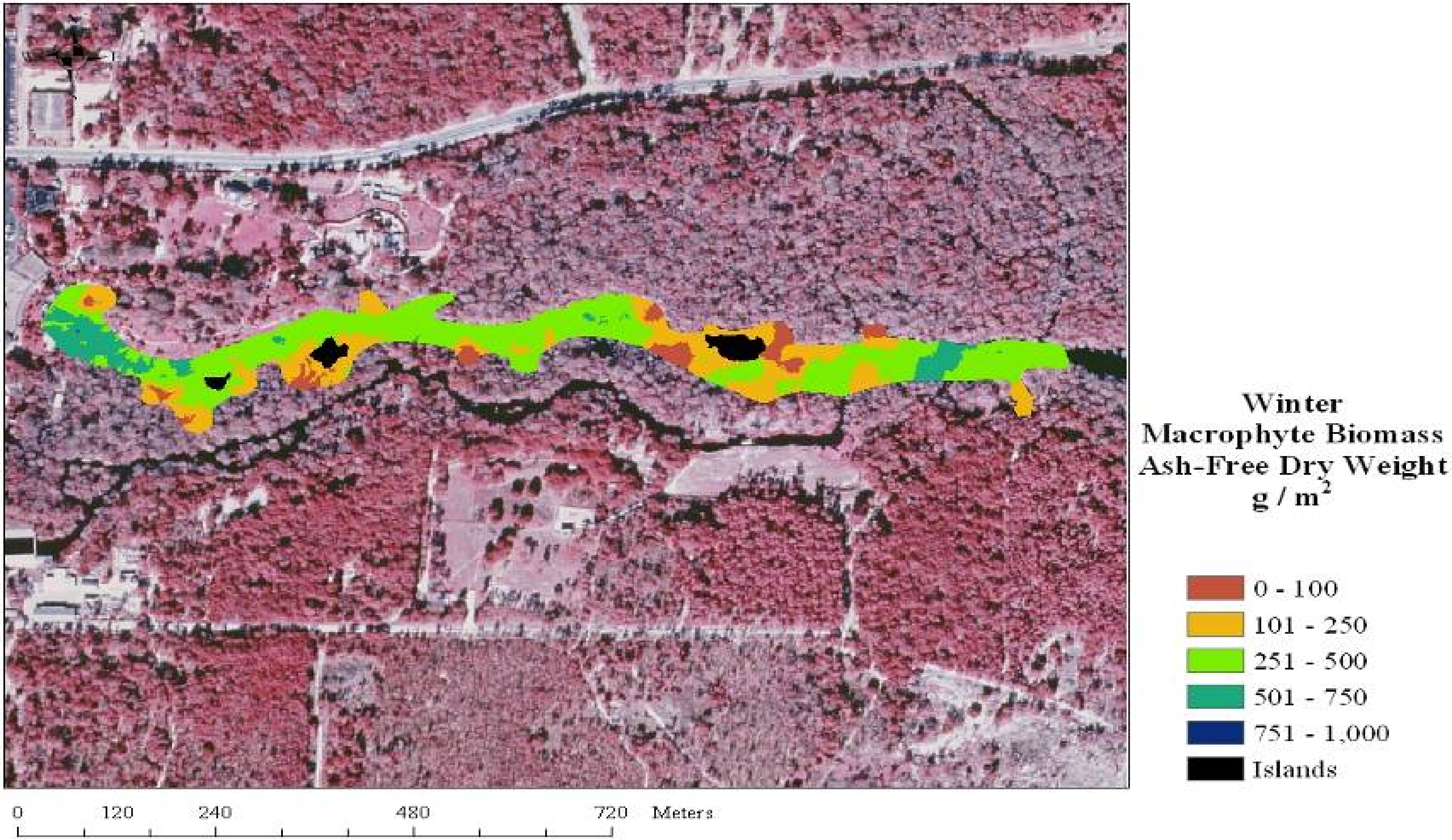


Figure 5-31 Average winter ash-free dry weight (g m^{-2}) distribution of macrophytes in Silver Springs, Florida, USA (2004)

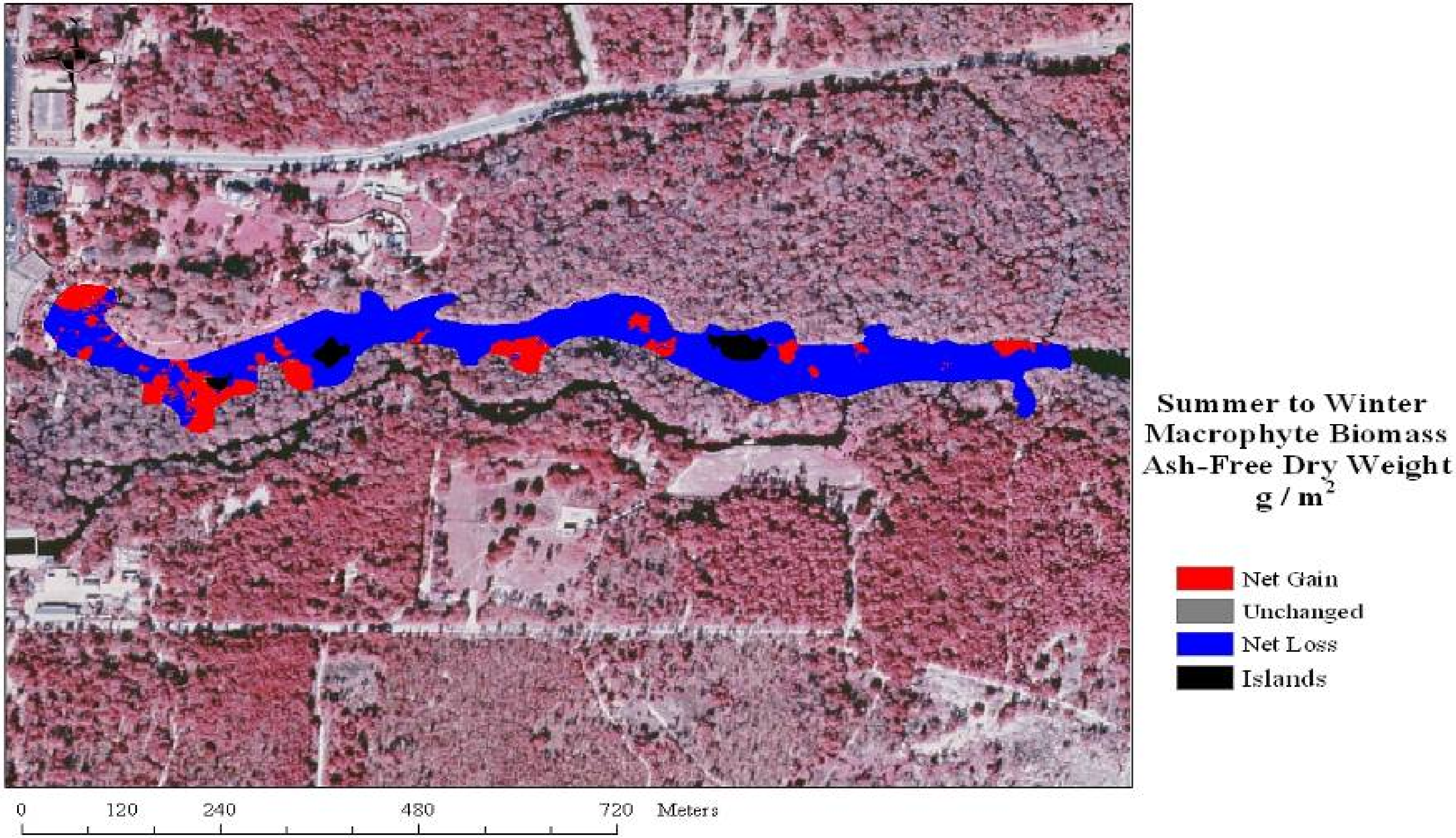


Figure 5-32 Overall seasonal changes in macrophyte biomass distribution (AFDW g m^{-2}) from summer to winter in Silver Springs, Florida, USA (2004)

Table 5-9 Major benthic algal species encountered in Silver Springs, Florida 2003 – 2005

Spring	Summer	Fall	Winter
Cyanophyta - blue green algae - cyanobacteria			
Lyngbya wollei	*Lyngbya wollei*	*Lyngbya wollei*	*Lyngbya wollei*
Phormidium sp	*Oscillatoria sp.*	*Oscillatoria sp.*	*Oscillatoria sp.*
Chlorophyta - green algae			
Ulothrix sp.	*Cladophora sp.*	*Cladophora sp.*	*Cladophora sp.*
	Mougeotia sp.	*Mougeotia sp.*	
Xanthophyceae			
	Vaucheria sp.	*Vaucheria sp.*	*Vaucheria sp.*
Baccillariophyta - diatoms			
Pennate			
Gomphonema	*Synedra ulna*	*Fragilaria*	*Gomphonema*
Cymbella sp.	*Cymbella*	*Cymbella*	*Fragilaria*
Synedra ulna	*Gomphonema*	*Gomphonema*	*Cymbella*
Fragilaria crotoninsis	*Navicula*	*Synedra ulna*	*Navicula*
Fragilaria sp.	*Fragilaria*		*Synedra ulna*
Centric			
Aulacoseira italica	*Cocconesis*	*Aulacoseira varians*	*Aulacoseira varians*
Aulacoseira varians	*Aulacoseira varians*	*Terpsinoe musica*	*Terpsinoe musica*
Aulacoseira			*Aulacoseira italica*
Terpsinoe musica			*Cocconesis*
Cocconeis sp.			

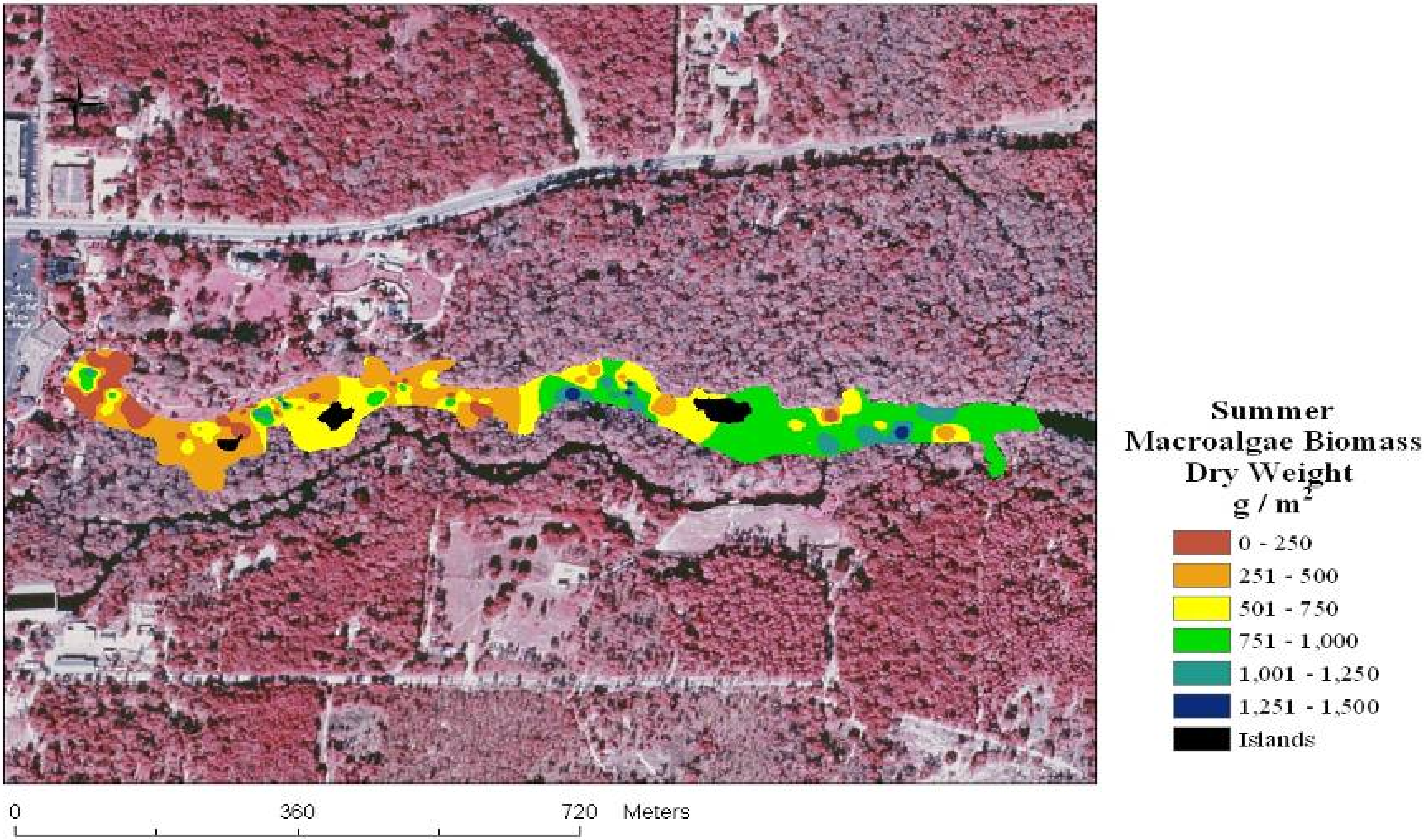


Figure 5-33 Average summer dry weight (g/m^{-2}) distribution of benthic algal mats in Silver Springs, Florida, USA (2004)

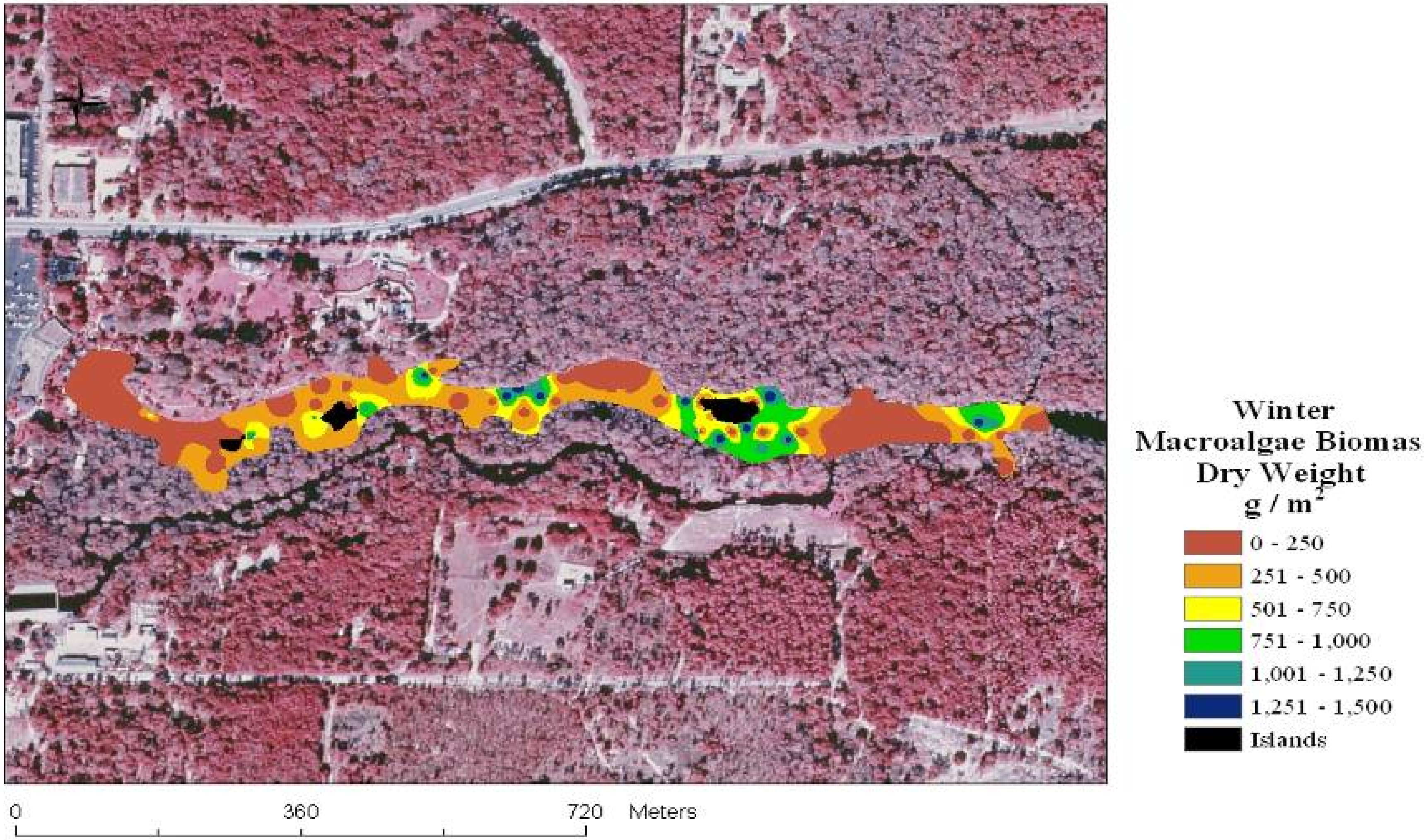


Figure 5-34 Average winter dry weight (g/m^{-2}) distribution of benthic algal mats in Silver Springs, Florida, USA (2004)

surface boils were evident and highest in topographic depressions along the spring run where flow rates were diminished. The spatial differences in mat biomass were a result of both percent coverage and mat thickness. The thickness of mats varied widely, from less than a centimeter to over 40 centimeters. Extrapolated over the entire study reach, the total algal mat biomass was estimated to be 53.3 x 10^6 g dry weight in the summer and 32.2 x 10^6 g dry weight in the winter.

In terms of AFDW, the averages for the spring run were 266 g AFDW m^{-2} (std. dev. 108g AFDW m^{-2}) in the summer and 169 g AFDW m^{-2} (std. dev. 83 g AFDW m^{-2}) in the winter. Extrapolated over the entire study reach, the total algal mat AFDW was estimated to be 23.6 x 10^6 g AFDW in the summer and 14.4 x 10^6 g AFDW in the winter. The spatial distribution of algal mat AFDW (Figures 5-35 and 5-36) was analogous to the distribution of dry weight.

5.10.3 Epiphytes

The epiphytic community observed on the surface of aquatic plants in the spring consisted of both closely attached and loosely associated species. The most commonly observed species in the latter group included pennate diatoms, such as *Cymbella*, *Gomphonema*, *Synedra*, *Fragilaria* and *Navicula* (Table 5-9). Among the loosely attached species, filamentous green algae were common, including *Cladophora*, *Mougeotia* and *Ulothrix*. Filamentous blue-green algae were commonly observed in the epiphytic community, including *Lyngbya wollei* and *Oscillatoria*. The chain-forming centric diatoms *Aulacoseira* and *Terpsinoe* were also common in the epiphytic community.

Three GIS layers of information collected in the field were used to estimate the biomass of epiphytes in the Silver River: percent epiphytic cover, density of epiphytic cover and conversion coefficients for dry weight per density of epiphyte cover. Average epiphyte biomass for the region of Silver Springs included in this study was estimated to be 572 g dry weight m^{-2} (std. dev. 302 g dry wt. m^{-2}) for the summer survey and 221 g dry weight m^{-2} (std. dev. 191 g dry wt. m^{-2}) for the winter survey. The large seasonal difference in epiphyte biomass is clearly shown in the GIS representations of biomass distribution (Figures 5-37 and 5-38). Spatially, the average epiphyte dry weights were higher in the lower third of the sampling reach (Figures 5-37 and 5-38). Extrapolated over the entire study reach, the total epiphyte biomass was estimated to be 48.6 x 10^6 g dry weight in the summer and 18.8 x 10^6 g dry weight in the winter.

In terms of AFDW, the averages for the spring run were 294 g AFDW m^{-2} (std. dev. 161 g AFDW m^{-2}) in the summer and 73 g AFDW m^{-2} (std. dev. 70 g AFDW m^{-2}) in the winter. Extrapolated over the entire study reach, the total epiphyte AFDW was estimated to be 26.1 x 10^6 g AFDW in the summer and 6.2 x 10^6 g AFDW in the winter. The spatial distribution of epiphyte AFDW (Figures 5-39 and 5-40) was analogous to the distribution of dry weight.

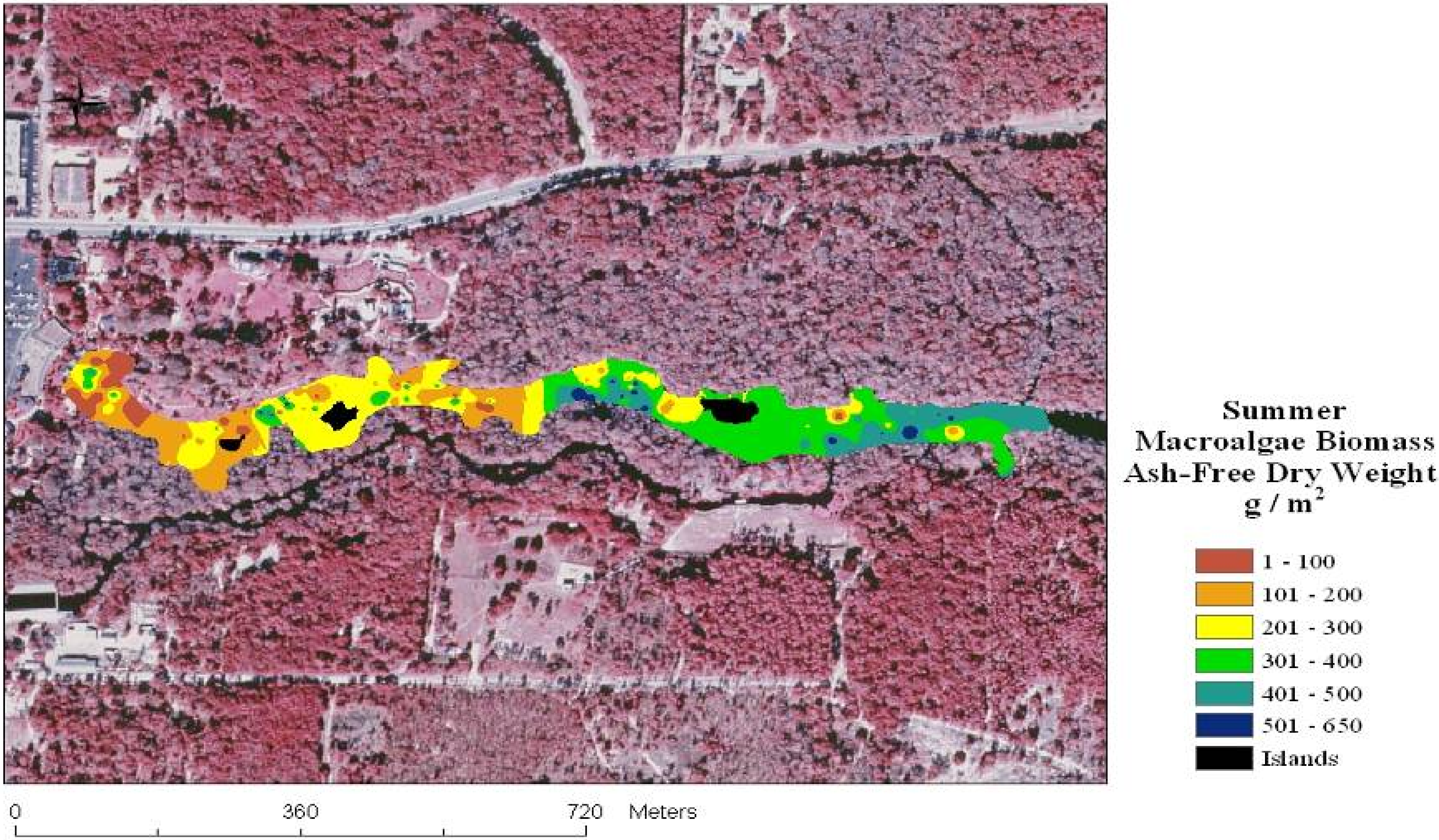


Figure 5-35 Average summer ash-free dry weight (g/m^{-2}) distribution of benthic algae mats in Silver Springs, Florida, USA (2004)

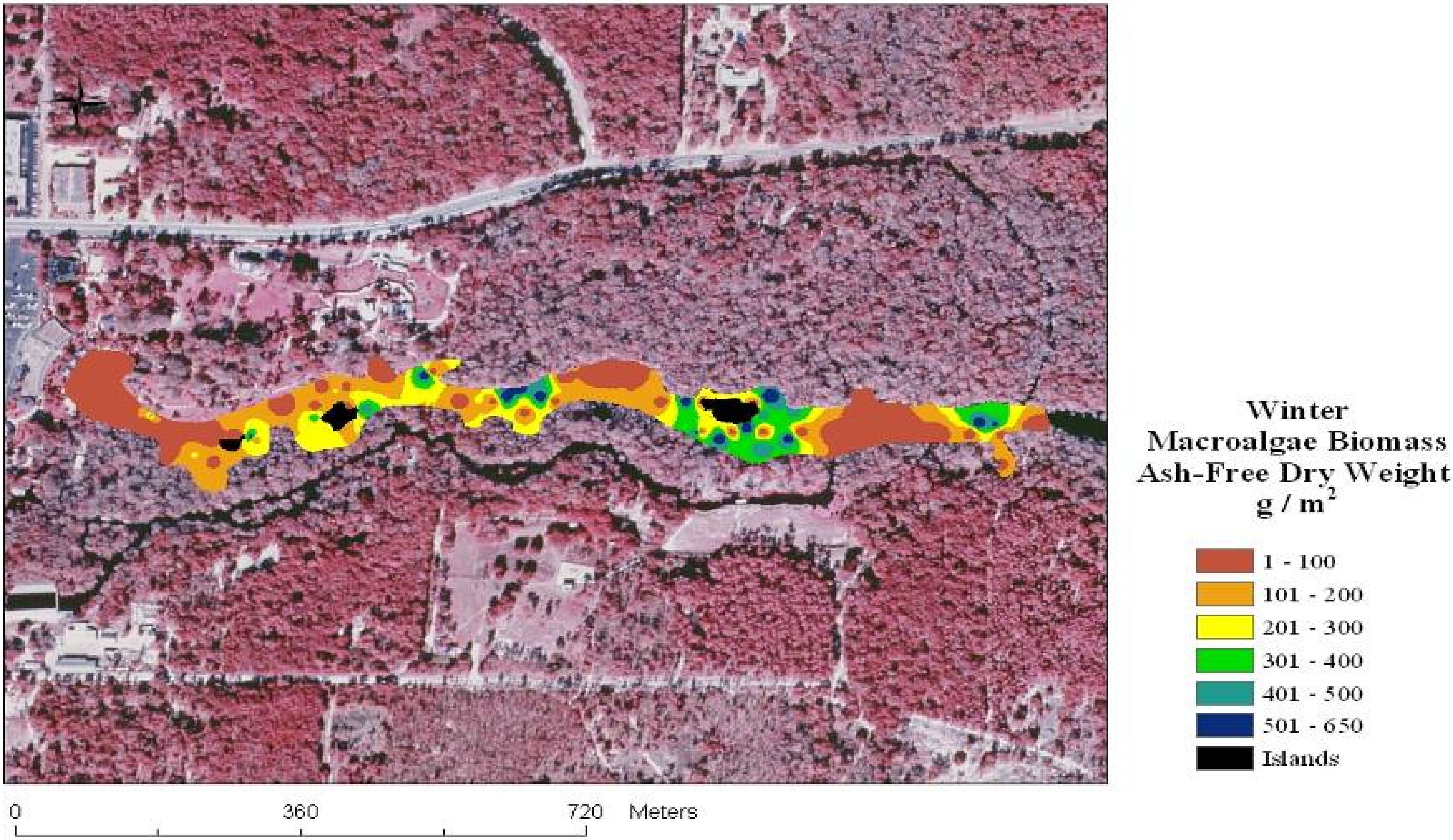


Figure 5-36 Average winter ash-free dry weight (g/m^{-2}) distribution of benthic algae mats in Silver Springs, Florida, USA (2004)

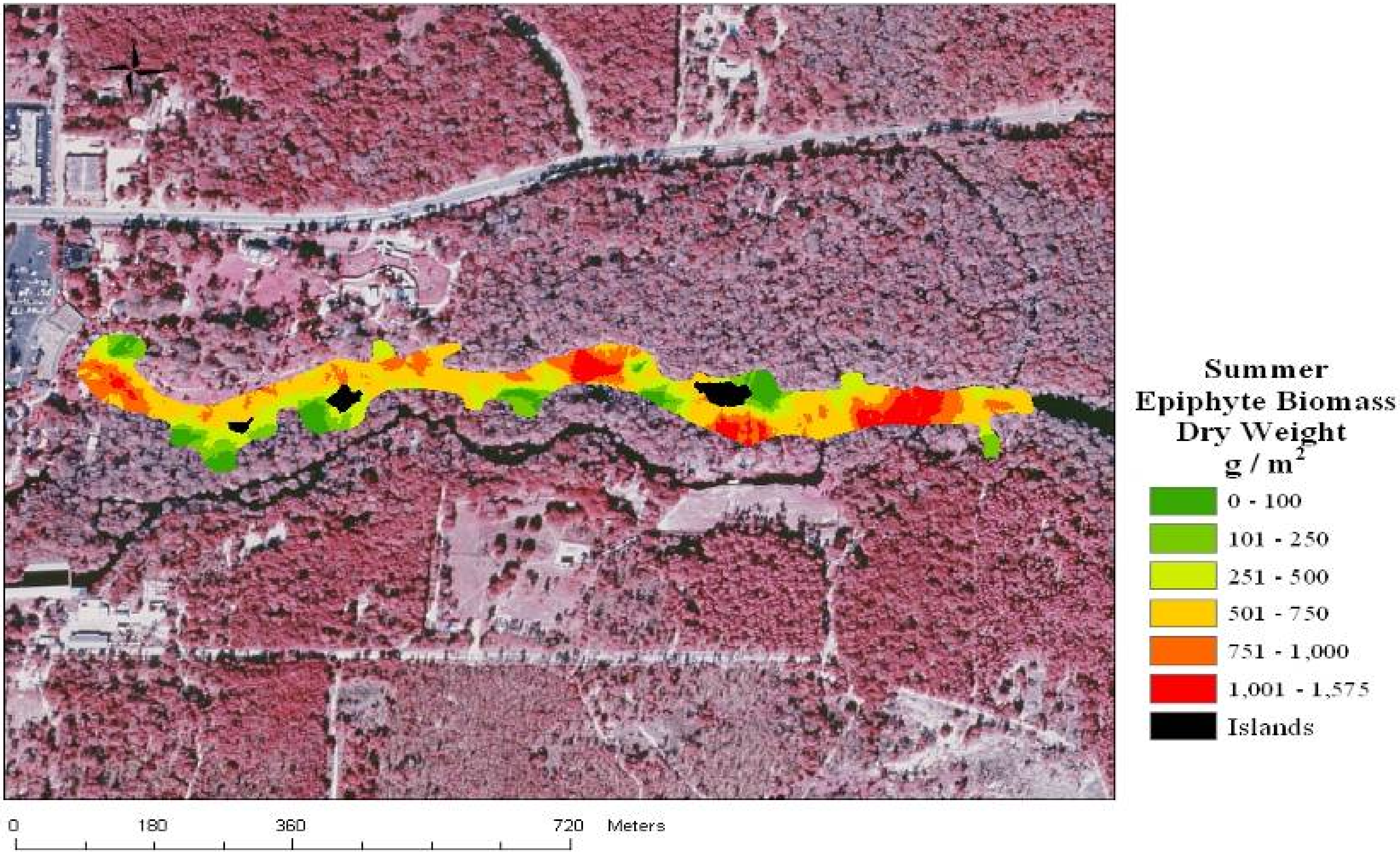


Figure 5-37 Average summer dry weight (g/m^{-2}) distribution of epiphytes in Silver Springs, Florida, USA (2004)

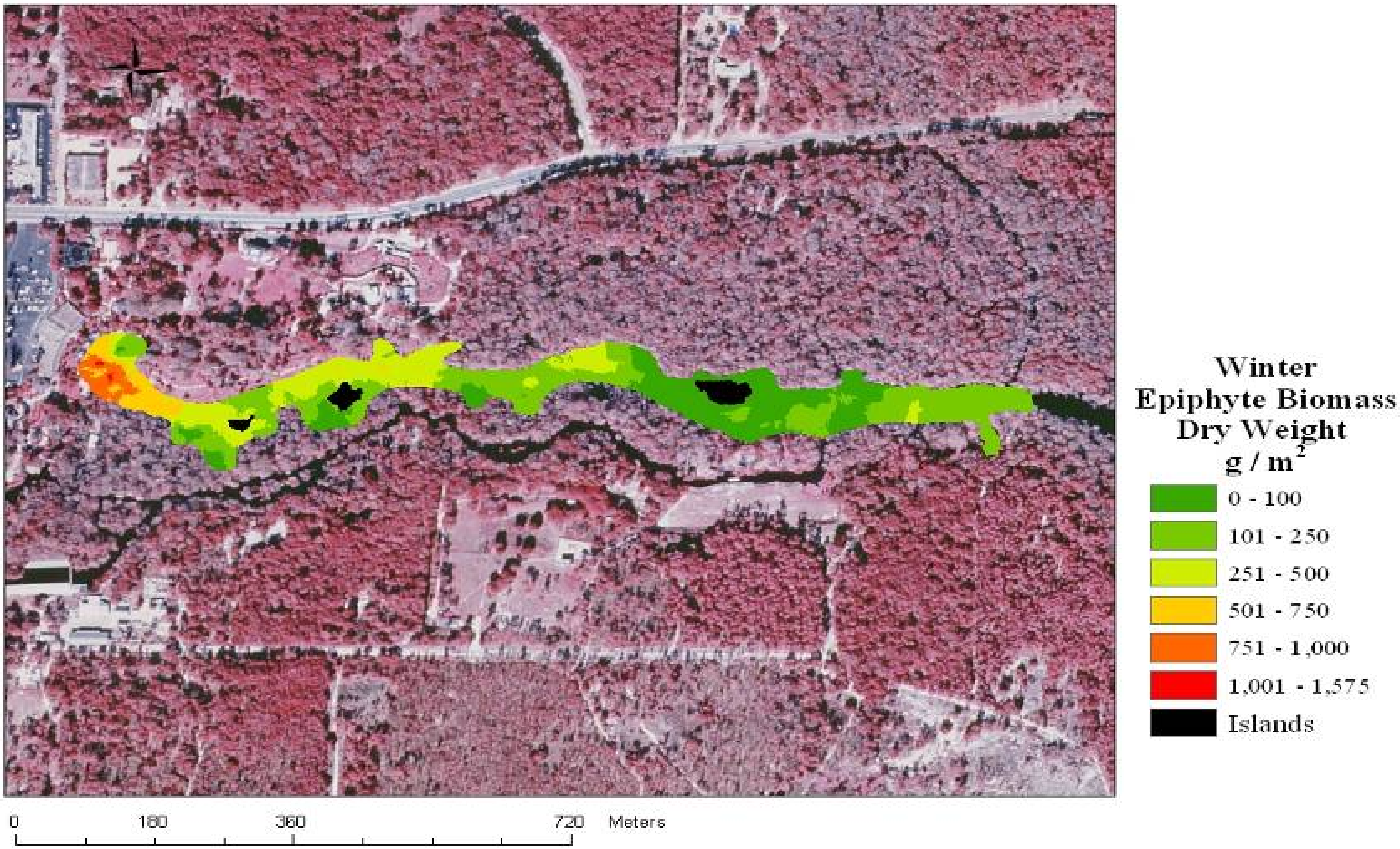


Figure 5-38 Average winter dry weight (g m^{-2}) distribution of epiphytes in Silver Springs, Florida, USA (2004)

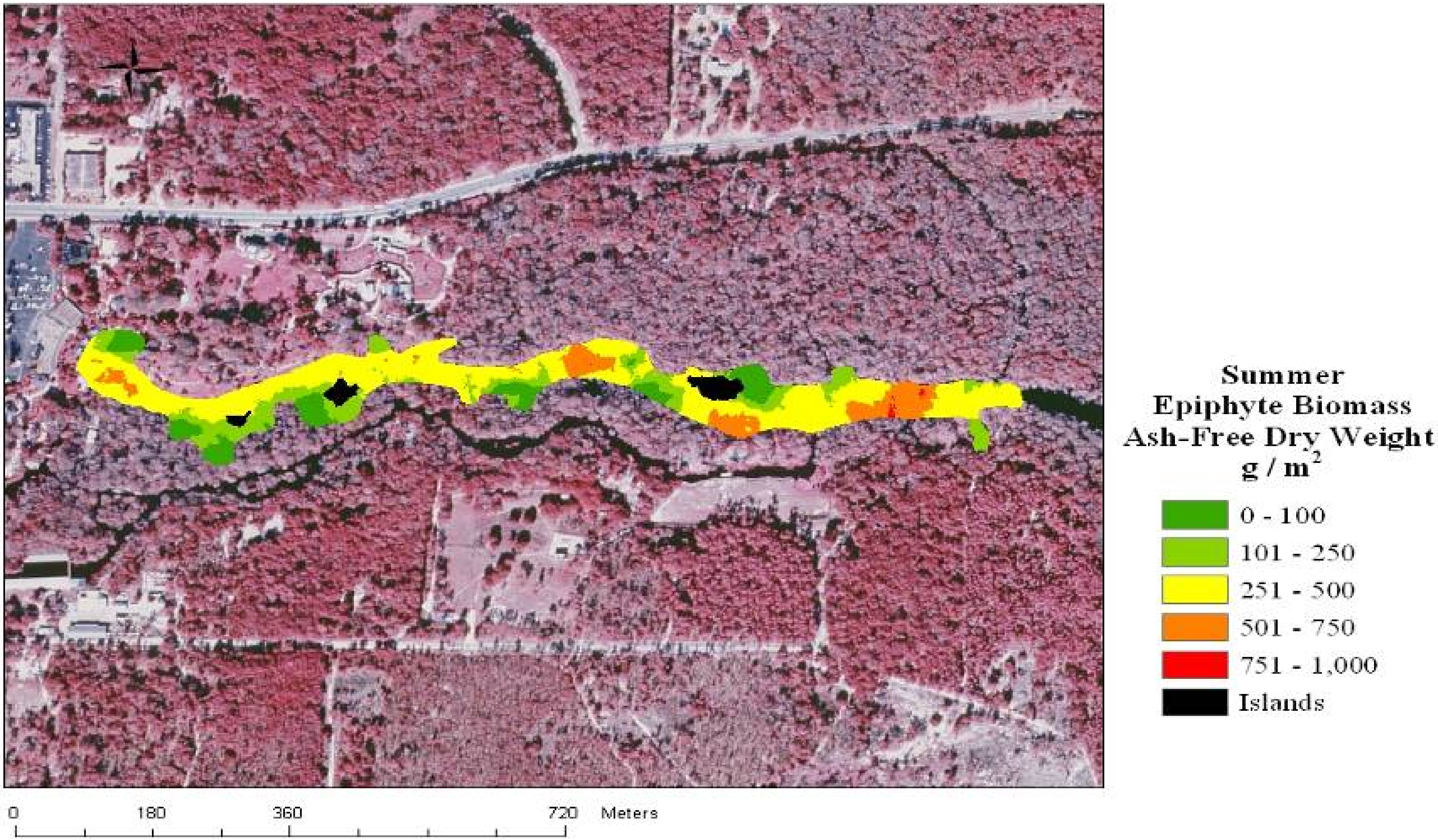


Figure 5-39 Average summer ash-free dry weight (g m^{-2}) distribution of epiphytes in Silver Springs, Florida, USA (2004)

Figure 5-40 Average winter ash-free dry weight (g m^{-2}) distribution of epiphytes in Silver Springs, Florida, USA (2004)

As might be expected, the spatial distribution of epiphyte biomass mimicked the macrophyte distribution. Temporally, epiphytic biomass was observed to increase rapidly in the early spring with a bloom of the filamentous green alga *Ulothrix*. The green algae were loosely associated with the macrophytes and were displaced by the time of the summer survey by a mixture of other filamentous green algae, blue green algae and epiphytic diatoms (Table 5-9).

5.11 Plant and Particulate Export

Plant export traps were deployed and harvested fourteen times during the period of record. Appendix O summarizes the detailed data including deployment date and time, pickup date and time, and approximate weights for each trap for each date. Overall average floating plant export was estimated as 22.4 kg dry weight (dw)/d during this period-of-record. Based on an estimated total aquatic area of about 116,750 m^2 this is equivalent to an average areal export rate of about 0.19 g dw/m^2/d. The maximum and minimum recorded export rates during individual events were 87 kg dw/d and 10 kg dw/d, respectively (Figure 5-41). Figure 5-41 also illustrates the approximate proportion of various plant species that were collected on these traps. Strap-leaf sagittaria was typically the dominant plant being exported with an average export rate of 13.4 kg dw/d, followed by coontail with an average export rate of 8.5 kg dw/d.

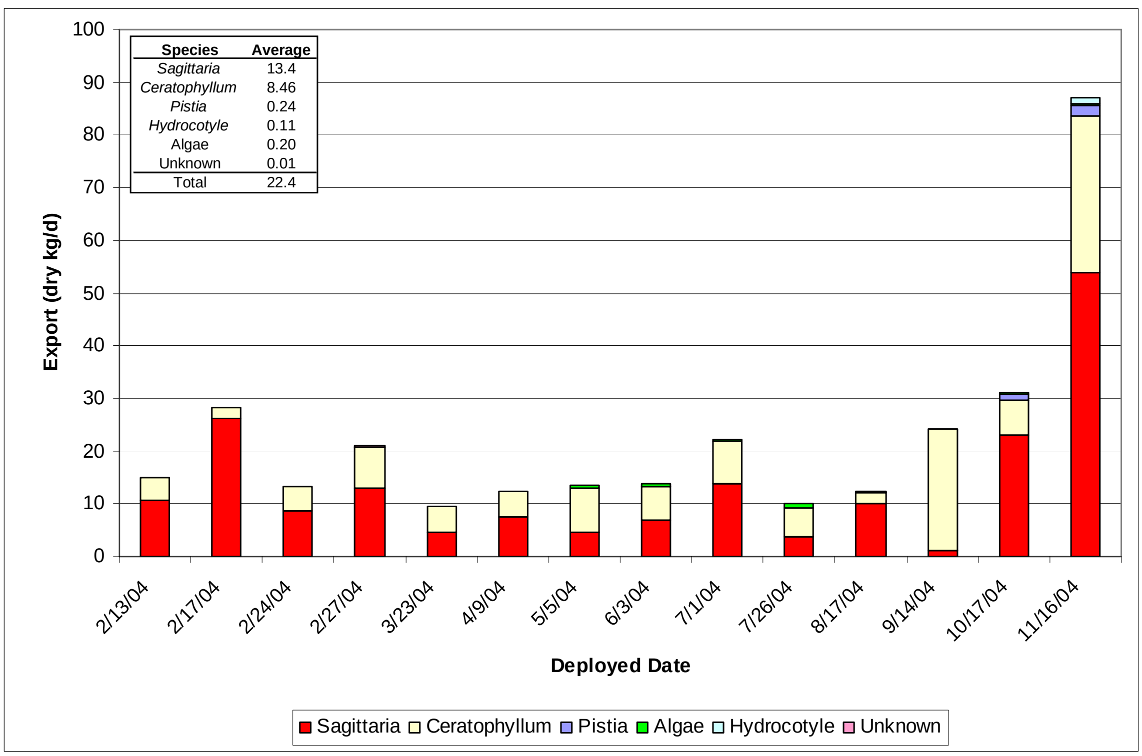


Figure 5-41 Silver Springs macrophyte export at the 1,200-m station

Particulate export was measured at three stations in the upper portion of the Silver River: just below the Main Spring Boil, at the upstream end of Turtle Meadows, and downstream at the 1,200-m station (Appendix P). All measurements were made between June 2004 and January 2005. No seasonal patterns were evident; however a slight diurnal pattern of increasing particulate export in the middle to late afternoon was observed (Figure 5-42). Overall average particulate export rates expressed as dry matter and as organic matter (ash-free dry weight) are summarized in Table 5-10. Although particulate export increased markedly downstream from about 9.3 kg dw/d just below the Main Spring Boil to 78 kg dw/d at the 1,200-m station, the average particulate export on a per-area basis was higher just below the Main Spring Boil, with an average of 1.15 g dw/m^2/d than the average rate of 0.67 g dw/m^2/d measured at the 1,200-m station.

5.12 Insect Emergence

Insect emergence traps were deployed on the same fourteen dates as the plant export traps. Typical deployment periods were between one and seven days. Table 5-11 summarizes the average deployment time and total insect emergence estimate for each of these deployments. Appendix Q summarizes the detailed data including deployment date and time, pickup date and time, and overall insect estimates by group for each trap for each date. The overall average insect emergence rate for this period-of-record was 66.9 organisms/m^2/d. Variability between sampling events and between traps was fairly large (Figures 5-43 and 5-44). The range of average event totals was 10.3 to 368 organisms/m^2/d. The minimum and maximum trap numbers were 0 and 1,646 organism/m^2/d.

Figure 5-43 illustrates the average total insect emergence and the breakdown by taxonomic group for the fourteen sampling events. Total insect emergence numbers were fairly consistent throughout the study period except for one particularly high event in October 2004 when about three times the mean emergence was recorded. The predominant insect taxonomic groups that were represented in these traps were midges (Chironomidae), black flies (Simuliidae), other unidentified flies (Diptera), aquatic moths (Lepidopteran – *Petrophila santafealis*), and caddis flies (Trichopteran - *Hydroptilidae*). Midge species identified in a few selected samples by Water and Air Research, Inc. included the following: *Ablabesmyia mallochi, Cricotopus bicinctus, Dicrotendipes neomodestus, Labrudinia johannseni, Microtendipes pedellus, Polypedilium illinoense, Pseudochironomus sp., Rheotantarsus exiguous, Stenochironomus maceteei, Tanytarsus buckleyi, T. pathudsoni, and Tribelos fuscicorne*. A full taxonomic list of macroinvertebrate species occurring in the Silver River was not determined for this study; however, considerable diversity appeared to be present based on the insects observed in these samples.

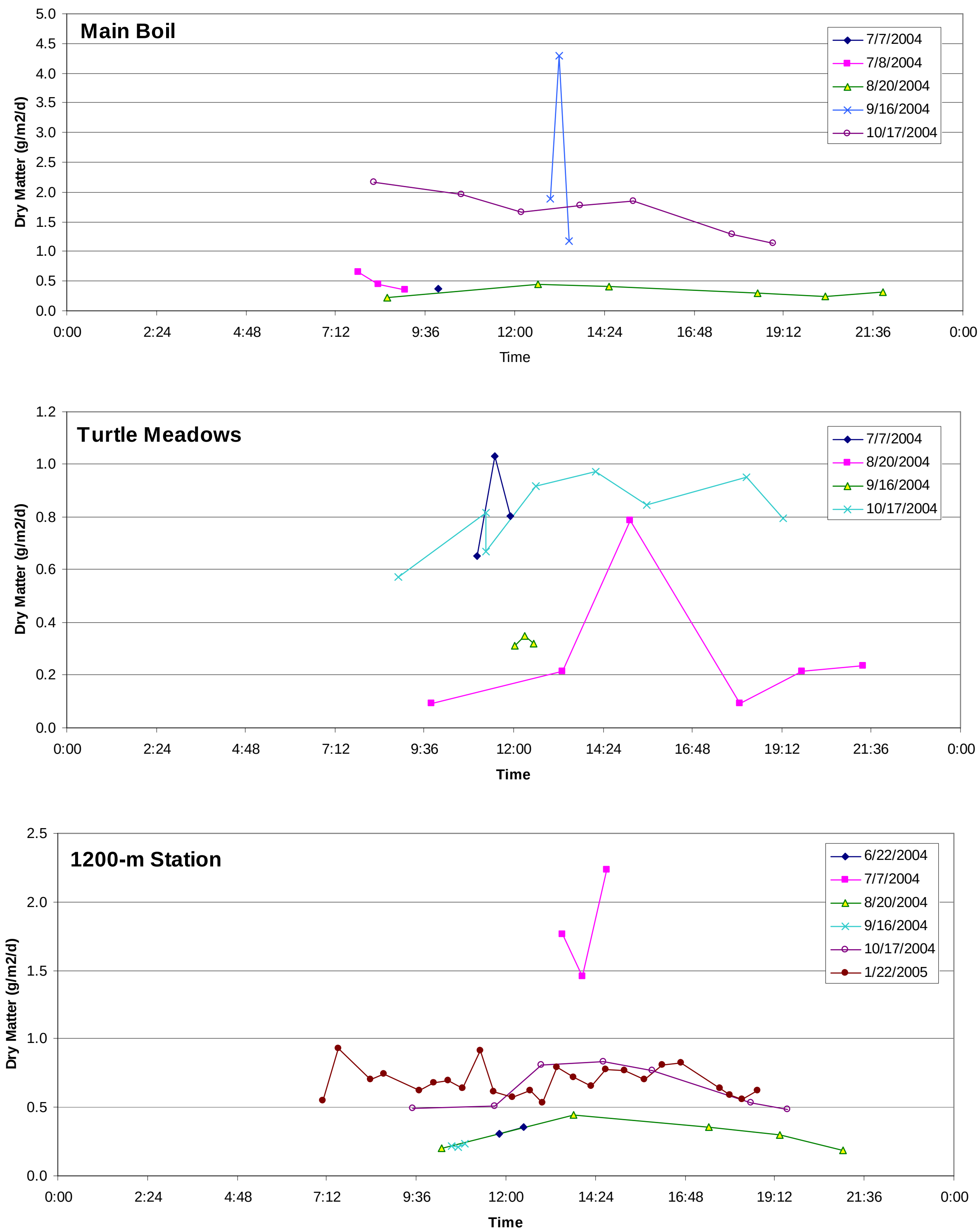


Figure 5-42 Silver Springs diurnal export of fine particulate matter at the Main Spring Boil, Turtle Meadows, and 1,200-m stations

Table 5-10 Silver Springs average downstream export of suspended organic material at the Main Spring Boil, Turtle Meadows, and 1,200-m Station

Station	Estimated Segment Areas (m^2)	Dry Matter (g/d)	Organic Matter (g/d)	Dry Matter ($g/m^2/d$)	Organic Matter ($g/m^2/d$)
Main Spring Boil	8,094	9,293	3,088	1.15	0.382
Turtle Meadows	48,643	28,322	12,744	0.582	0.262
1200m	116,750	77,802	34,114	0.666	0.292

Table 5-11 Summary of Silver Springs insect emergence trap data by sample date

Deploy Date	No. Traps	Deployment Time (d)	Emergence ($\#/m^2/d$)
2/13/2004	3	4.04	44.63
2/17/2004	9	6.95	33.09
2/24/2004	10	2.86	10.30
2/27/2004	10	6.11	36.67
3/23/2004	10	2.82	42.57
4/9/2004	8	4.16	22.32
5/5/2004	9	1.99	60.97
6/3/2004	10	1.02	98.14
7/1/2004	10	1.02	19.65
7/26/2004	10	1.83	22.83
8/17/2004	10	3.02	63.05
9/14/2004	10	1.86	21.45
10/17/2004	10	2.02	368.31
11/16/2004	10	1.07	92.68
AVERAGE		2.91	66.90

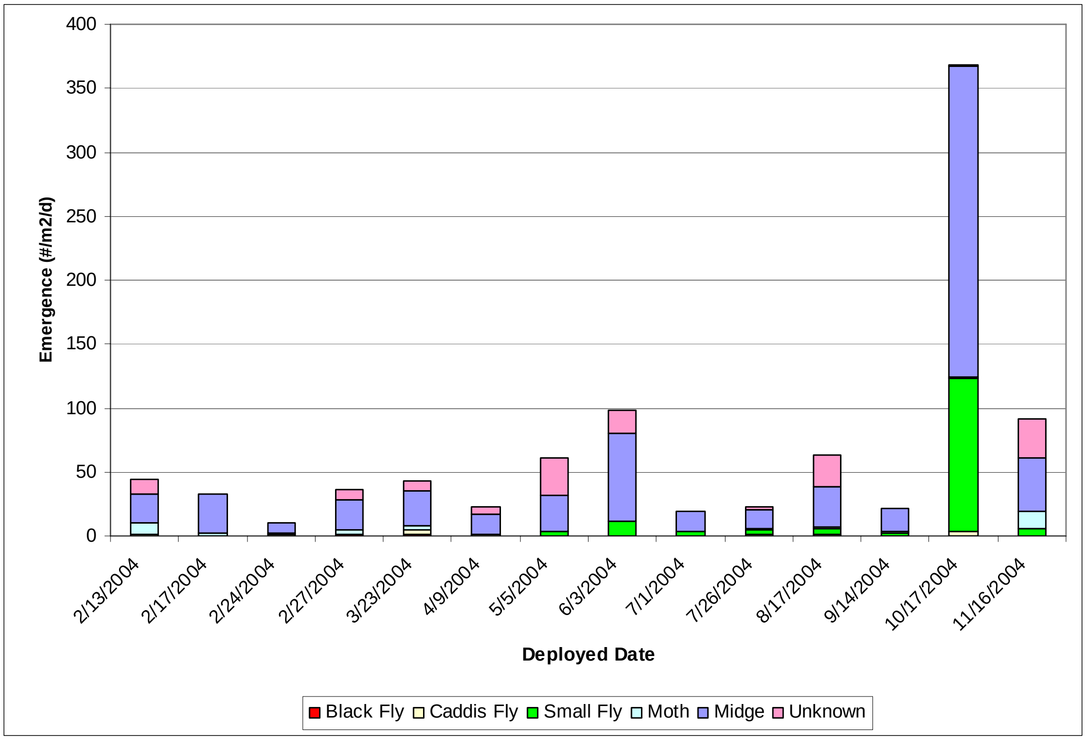


Figure 5-43 Summary of Silver Springs insect emergence trap data by sampling date

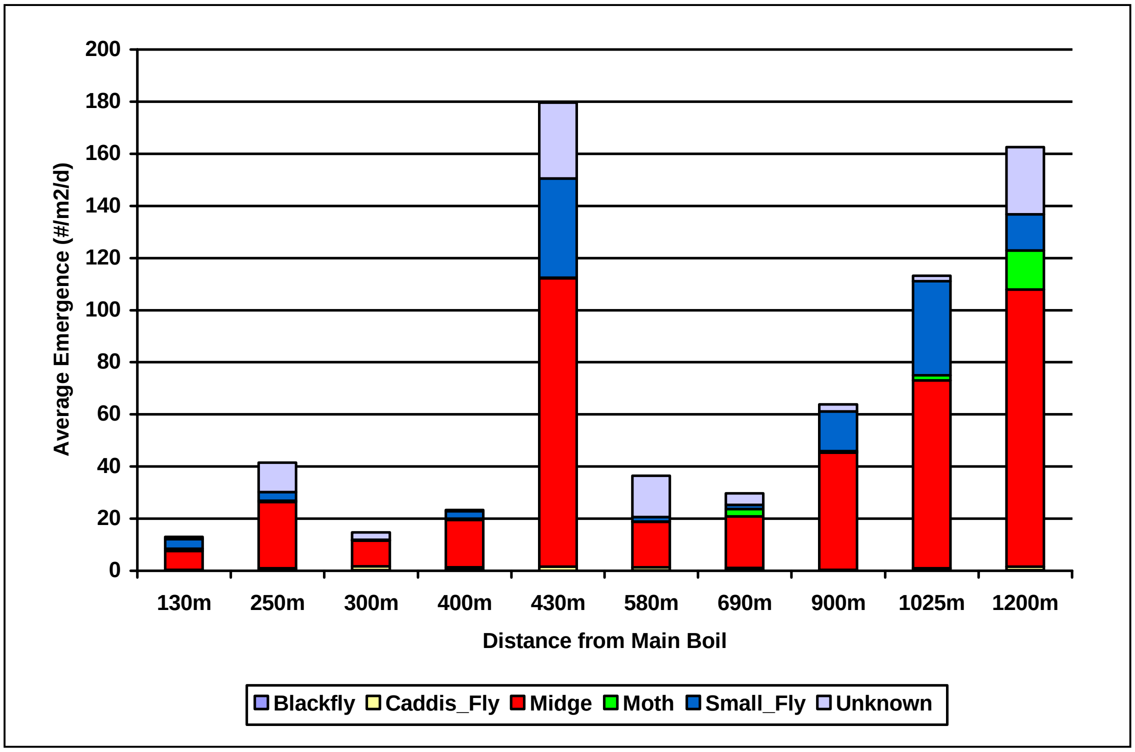


Figure 5-44 Silver Springs period-of-record insect emergence as a function of distance downstream from the Main Spring Boil

5.13 Vertebrates

Appendix R contains vertebrate sampling data. On all four visual sample dates, the peninsula cooter (*Pseudemys peninsularis*) was the most abundant species of turtle identified, followed by Florida red-bellied cooter (*Pseudemys nelsoni*) and the softshell turtle (*Apalone ferox*) (Table 5-12).

The number of American alligators (*Alligator mississippiensis*) observed ranged from three to thirteen across sample dates (Table 5-12). The alligators had a large size range and included juveniles and large adults. Several alligators, one a very large adult, were seen during every sampling event in the Reception Hall Spring, where glass-bottom boat operators and tourists often stop and feed fish.

Of the total number of birds observed along the sample area, the double crested cormorant (*Phalacrocorax auritus*) was the most abundant for the first three sample dates and the Florida mottled duck (*Anas fulvigula*) was the most abundant on the final sample date (Table 5-12). A small island on the studied stretch of spring run was used as a rookery by the double crested cormorant, contributing to their high relative abundance to other bird species. The white ibis (*Eudocimus albus*) was the only other bird species observed in relatively high abundance on any of the sample dates (Table 5-12).

The total number of fish observed was similar for all four sample dates and ranged from 4,286 to 5,208 (Tables 5-13 – 5-16). Variation depended mostly on the number of bluegill sunfish (*Lepomis macrochirus*) and unidentifiable shiners. The highest count of fish observed on each sample date was found along the southern shore transect, followed by the northern shore transect, and then the center transect (Tables 5-13 – 5-16). An unidentified shiner, most likely the coastal shiner (*Notropis petersoni*), taillight shiner (*N. maculates*) or golden shiner (*Notemigonus crysoleucas*) was the second most-abundant fish species in our study. Shiners were difficult to identify to species in the visual surveys due to their small size and the difficulty in approaching them closely for visual inspection. The total number of bluegill and unidentifiable shiners comprised over 75% of observed fish on each sampling date. Largemouth bass (*Micropterus salmoides*) and redear sunfish (*L. microlophus*) were also observed in relatively high abundance compared to the remaining fish species on all sample dates (Tables 5-13 – 5-16). Bluefin killifish (*Lucania goodei*), golden shiner, striped mullet (*Mugil cephalus*), gizzard shad (*Dorosoma cepedianum*) and Florida gar (*Lepisosteus platyrhincus*) were found in lesser abundance and their abundance varied across sample dates (Tables 5-13 – 5-16).

Table 5-12 Individual and total count of alligator, turtle and bird species visually observed on the spring run of Silver Springs, Florida on each sample date

Common Name	Scientific Name	Number Observed			
		3/4/2004	4/16/2004	6/4/2004	6/17/2004
American Alligators	*Alligator mississippiensis*	**7**	**3**	**13**	**6**
Turtles					
Common snapping turtle	*Chelydra serpentina*	0	0	1	0
Florida red bellied cooter	*Pseudemys nelsoni*	8	4	5	5
Peninsula cooter	*Pseudemys peninsularis*	25	17	20	17
Soft shelled turtle	*Apalone ferox*	0	1	2	1
Unidentified turtle		11	12	9	7
Total		**44**	**34**	**37**	**30**
Birds					
Anhinga	*Anhinga anhinga*	4	1	0	1
Common moorhen	*Gallinula chloropus*	4	2	3	2
Double crested cormorant	*Phalacrocorax auritus*	14	13	8	2
Florida Mottled Duck	*Anas fulvigula*	0	0	3	5
Grackle	*Quiscalus quiscula*	0	1	0	0
Great blue heron	*Ardea herodias*	3	1	2	2
Little blue heron	*Egretta caerulea*	2	1	3	1
Osprey	*Pandion haliaetus*	0	1	0	0
Pied-billed grebe	*Podilymbus podiceps*	2	0	0	0
Snowy egret	*Egretta thula*	2	1	3	2
White ibis	*Eudocimus albus*	13	0	1	2
Wood duck	*Aix sponsa*	0	2	4	0
Total		**54**	**23**	**27**	**17**

Table 5-13 Number and estimated lengths (range and mean) and weights of fish species visually observed from three transects (south, center and north) at the spring run of Silver Springs, Florida on March 4th of 2004

Date	Species	Scientific Name	Number				Length (mm)		Weight (g) Total
			South	Center	North	Total	Range	Mean	
3/4/2004	Blue tilapia	*Tilapia aurea*	4	0	1	5	350-450	400	2460
	Bluefin killifish	*Lucania goodei*	58	100	285	443	25-50	25	34
	Bluegill sunfish	*Lepomis macrochirus*	827	701	1420	2948	25-250	125	110411
	Bowfin	*Amia calva*	5	4	5	14	375-800	625	15613
	Chain pickerel	*Esox niger*	6	0	1	7	400-775	600	10360
	Channel catfish	*Ictalurus punctatus*	1	0	0	1	625	625	803
	Florida gar	*Lepisosteus platyrhincus*	67	0	2	69	300-750	700	25875
	Gambusia	*Gambusia sp.*	1	0	0	1	50	50	1
	Gizzard shad	*Dorosoma cepedianum*	4	61	3	68	300-350	325	22016
	Golden topminnow	*Fundulus chrysotus*	24	0	0	24	25	25	2
	Lake chubsucker	*Erimyzon sucetta*	12	11	10	33	75-400	325	8019
	Largemouth bass	*Micropterus salmoides*	75	49	53	177	102-610	350	105533
	Least killifish	*Heterandria formosa*	6	0	0	6	25	25	1
	Longnose gar	*Lepisosteus osseus*	2	3	1	6	925-1225	1050	8857
	Redbreast sunfish	*Lepomis auritus*	4	0	2	6	150-175	170	635
	Redear sunfish	*Lepomis microlophus*	72	28	29	129	50-325	200	26975
	Striped mullet	*Mugil cephalus*	62	69	4	135	400-600	475	47250
	Unidentifiable Shiner		751	93	150	994	25-50	34	76
	Total		1981	1119	1966	5066			384920

Table 5-14 Number and estimated lengths (range and mean) and weights of fish species visually observed from three transects (south, center and north) at the spring run of Silver Springs, Florida on April 16th of 2004

Date	Species	Scientific Name	Number				Length (mm)		Weight (g)
			South	Center	North	Total	Range	Mean	Total
4/16/2004	Blue tilapia	*Tilapia aurea*	0	2	6	8	250-375	350	3936
	Bluefin killifish	*Lucania goodei*	64	82	30	176	25	25	14
	Bluegill sunfish	*Lepomis macrochirus*	1021	596	1463	3080	25-250	100	71155
	Bowfin	*Amia calva*	12	10	3	25	400-825	625	27880
	Chain pickerel	*Esox niger*	2	3	4	9	450-925	675	21826
	Florida gar	*Lepisosteus platyrhincus*	113	0	1	114	450-925	750	42750
	Gizzard shad	*Dorosoma cepedianum*	0	11	5	16	250-300	300	4349
	Golden shiner	*Notemigonus crysoleucas*	12	0	15	27	100-125	125	567
	Lake chubsucker	*Erimyzon sucetta*	11	13	9	33	150-650	375	8019
	Largemouth bass	*Micropterus salmoides*	41	42	141	224	25-650	350	84125
	Longnose gar	*Lepisosteus osseus*	4	2	5	11	600-1225	1075	15975
	Redbreast sunfish	*Lepomis auritus*	2	0	11	13	75-150	125	372
	Redear sunfish	*Lepomis microlophus*	31	11	7	49	50-350	200	10551
	Swamp darter	*Etheostoma fusiforme*	1	0	0	1	50	50	1
	Unidentifiable Shiner		738	70	160	968	25	25	74
	Total		2052	842	1860	4754			291594

Table 5-15 Number and estimated lengths (range and mean) and weights of fish species visually observed from three transects (south, center and north) at the spring run of Silver Springs, Florida on June 4th of 2004

Date	Species	Scientific Name	Number				Length (mm)		Weight (g)
			South	Center	North	Total	Range	Mean	Total
6/4/2004	Blue tilapia	*Tilapia aurea*	0	0	1	1	400	400	492
	Bluefin killifish	*Lucania goodei*	35	20	8	63	25	25	5
	Bluegill sunfish	*Lepomis macrochirus*	1034	524	607	2165	50-225	100	62409
	Bowfin	*Amia calva*	7	4	7	18	350-775	525	20074
	Chain pickerel	*Esox niger*	3	2	3	8	400-775	600	14932
	Florida gar	*Lepisosteus platyrhincus*	0	0	59	59	457-742	700	22125
	Gizzard shad	*Dorosoma cepedianum*	0	0	1	1	350	350	514
	Golden shiner	*Notemigonus crysoleucas*	400	0	200	600	150-200	175	12600
	Lake chubsucker	*Erimyzon sucetta*	10	13	13	36	200-400	300	8748
	Largemouth bass	*Micropterus salmoides*	29	40	44	113	100-500	250	36581
	Longnose gar	*Lepisosteus osseus*	4	2	2	8	925-1225	1050	11618
	Redbreast sunfish	*Lepomis auritus*	54	29	10	93	75-200	100	2452
	Redear sunfish	*Lepomis microlophus*	59	21	36	116	75-300	125	10474
	Spotted sunfish	*Lepomis punctatus*	7	3	40	50	75-150	100	919
	Swamp darter	*Etheostoma fusiforme*	0	1	0	1	25	25	1
	Unidentifiable Shiner		436	477	963	1867	25-50	34	144
	Total		2078	1136	1994	5208			204088

Table 5-16 Number and estimated lengths (range and mean) and weights of fish species visually observed from three transects (south, center and north) at the spring run of Silver Springs, Florida on June 17th of 2004

Date	Species	Scientific Name	Number				Length (mm)		Weight (g)
			South	Center	North	Total	Range	Mean	Total
6/17/2004	American eel	*Anguilla rostrata*	0	1	0	1	600	600	300
	Black crappie	*Pomoxis nigromaculatus*	0	0	1	1	250	250	267
	Bluefin killifish	*Lucania goodei*	0	0	6	6	25	25	1
	Bluegill sunfish	*Lepomis macrochirus*	1301	871	801	2973	50-250	100	90223
	Bowfin	*Amia calva*	6	7	6	19	450-925	675	21189
	Chain pickerel	*Esox niger*	5	1	1	7	600-1025	825	32080
	Florida gar	*Lepisosteus platyrhincus*	43	0	0	43	500-925	675	16125
	Gizzard shad	*Dorosoma cepedianum*	100	0	0	100	350	350	51351
	Golden shiner	*Notemigonus crysoleucas*	5	0	228	233	100-250	250	4893
	Lake chubsucker	*Erimyzon sucetta*	14	12	10	36	250-600	400	8748
	Largemouth bass	*Micropterus salmoides*	66	56	31	153	50-575	325	111342
	Longnose gar	*Lepisosteus osseus*	11	0	7	18	775-1525	1150	26141
	Redbreast sunfish	*Lepomis auritus*	30	12	10	52	50-300	125	4589
	Redear sunfish	*Lepomis microlophus*	18	20	43	81	100-350	200	25475
	Spotted sunfish	*Lepomis punctatus*	3	6	9	18	75-125	100	341
	Unidentifiable Shiner		130	120	295	545	25-50	34	42
		Total	1732	1106	1448	4286			393107

The range and average lengths of individual fish were similar within a species for all sample dates (Tables 5-13 – 5-16).

The total estimated weight of all fish for the four visual sample dates ranged from 204 to 393 kilograms with the lowest and highest values coming from June 4th and June 17th , respectively (Tables 5-13 – 5-16). Bluegill and largemouth bass were found to have the highest total estimated biomass, and comprised approximately 50% of the total estimated biomass of observed fish for each of the four sample dates. Therefore, the total amount of estimated biomass for each date depended highly on the number and average length of bluegill sunfish and largemouth bass.

Bluegill sunfish, largemouth bass, redear sunfish and bluefin killifish were also found in relatively high abundance in the electrofishing samples compared to other species (Table 5-17). These same species were visually surveyed in relatively high abundance (Tables 5-13 – 5-16), displaying similarities in results between the two techniques for these fishes. The lack of a high abundance of the unidentifiable shiner in the electrofishing transects is due to the inability of electrofishing techniques to sample very small-bodied fish (Reynolds 1996). The total biomass collected with electrofishing was not comparable to the visual surveys due to the fact that the electrofishing transects did not cover the entire sample stretch and were done on a timed basis.

The only *Notropis spp.* collected with electrofishing in this study was the taillight shiner, with only two collected in thirty minutes. However, coastal shiner was collected in the historic electrofishing samples, and golden shiner was observed in the historic (Knight 1980) and the current visual surveys, suggesting that they could be coastal shiner or juvenile golden shiner. Thus, the visual surveys and low catch of shiners via electrofishing made separating shiners to species level not possible in this study.

Total species richness for fish varied between visual surveys and electrofishing. Visual surveys ranged from fifteen species (Table 5-14) to eighteen species (Table 5-13), and electrofishing surveys ranged from eight species to fifteen species (Table 5-17). Total species richness for each survey method, with all observations combined, was greater for visual counts (thirty-two species) than electrofishing (fifteen species). Eight species of fish, including American eel *Anguilla rostrata*, channel catfish *Ictalurus punctatus*, gizzard shad, longnose gar, and striped mullet, which were found in the deep spring areas where electrofishing equipment was ineffective, were included in the visual surveys but not by electrofishing. Many of the other species observed visually but not collected by electrofishing were simply too small or occupying a habitat in which they were not effectively collected by the sampling gear. An inventory of all fish observed is included in Appendix R.

Table 5-17 Number and estimated lengths (range and mean) and weights of fish species collected from three electrofishing transects (north, center and north; 10 minutes each) on the spring run of Silver Springs, Florida on July 22nd of 2004

Date	Species	Scientific Name	Number				Length (mm)		Weight (g)
			South	Center	North	Total	Range	Mean	Total
7/22/2004	Black crappie	*Pomoxis nigromaculatus*	0	0	1	1	200	200	141
	Blue tilapia	*Tilapia aurea*	0	0	1	1	350	350	492
	Bluegill sunfish	*Lepomis macrochirus*	31	6	24	61	50-250	150	5510
	Bowfin	*Amia calva*	3	0	0	3	250-775	550	2883
	Brown bullhead	*Ameiurus nebulosus*	0	1	0	1	250	250	233
	Chain pickerel	*Esox niger*	1	0	1	2	475-525	500	1707
	Florida gar	*Lepisosteus platyrhincus*	11	2	0	13	425-650	550	4875
	Lake chubsucker	*Erimyzon sucetta*	4	5	2	11	250-400	325	2673
	Largemouth bass	*Micropterus salmoides*	16	11	14	41	75-500	250	14805
	Redbreast sunfish	*Lepomis auritus*	0	0	3	3	125-150	134	142
	Redear sunfish	*Lepomis microlophus*	9	1	9	19	125-275	150	1843
	Spotted sunfish	*Lepomis punctatus*	84	23	57	164	50-175	100	3473
	Taillight shiner	*Notropis maculatus*	2	0	0	2	50	50	1
	Warmouth	*Lepomis gulosus*	0	0	1	1	200	200	180
	Yellow bullhead	*Ameiurus natalis*	0	1	1	2	275	275	492
		Total	161	50	114	325			53252

As with the visual surveys, the highest abundance of fish collected while electrofishing was on the south shore transect, followed by the north shore transect and center transect, indicating consistency between the two sampling methods. Also, as in the visual surveys, largemouth bass and bluegill had the highest total estimated biomass of the fish species collected by electrofishing, despite spotted sunfish having the highest relative abundance.

5.14 Ecosystem Metabolism

Estimates of ecosystem metabolism are dependent upon diffusion rates, stream discharges, water stage, stream volume, and accrual of oxygen from side boils. New estimates of diffusion rates, stream depths and volumes, contributing areas, and upstream DO concentrations were collected during this study. These new measurements allow refinements to estimates of ecosystem metabolism at Silver Springs. However they do not provide total certainty concerning the absolute values of these metabolism parameters. Figure 5-45 presents a time-series of estimated values for GPP, NPP24, R24, and PAR for the operational period from February 2004 through February 2005. Table 5-18 provides a summary table of the monthly averages, maxima, and minima for the Silver Springs community metabolism measurements.

An apparent seasonal pattern of GPP was observed for this period generally tracking PAR, with an overall average rate of 11.4 g $O_2/m^2/d$ and a maximum monthly rate of 13.9 g $O_2/m^2/d$ in May 2004. Figure 5-46 provides a sinusoidal model fit to these data ($R^2 = 0.26$) with an estimated maximum GPP on June 23 and a minimum on December 22.

Estimated average R24 also followed an apparent seasonal pattern similar to GPP but with a dampened amplitude (Figure 5-47) with an average rate of 11.0 g $O_2/m^2/d$ and a monthly maximum and minimum of 12.0 and 10.2 g $O_2/m^2/d$. The sinusoidal model ($R^2 = 0.04$) estimated July 22 as the date of maximum R24 and January 20 as the date with minimum R24.

Estimated average NPP24 was 0.42 g $O_2/m^2/d$ with maximum and minimum monthly averages of 2.5 and -3.2 g $O_2/m^2/d$. Figure 5-48 illustrates the observed seasonal pattern for NPP24 (R2 = 0.16) with maximum NPP24 estimated for June 16 and minimum NPP24 on December 16.

Measured GPP in Silver Springs was found to be positively correlated with PAR estimated at the plant level (Figure 5-49). A logarithmic model relating PAR and GPP had a correlation coefficient of 0.56 with measured GPP leveling off around a daily average incident PAR of about 23 mol/m^2/d. The period-of-record average GPP efficiency was 0.95 g O_2/mol, equivalent to an estimated PAR efficiency of 7.6% using the conversion factors described in the methods section. PAR efficiency was found to be seasonal (Figure 5-50) with the highest monthly average value of 10.5% (1.30 g O_2/mol) estimated in December 2004 and the lowest value of 5.5%

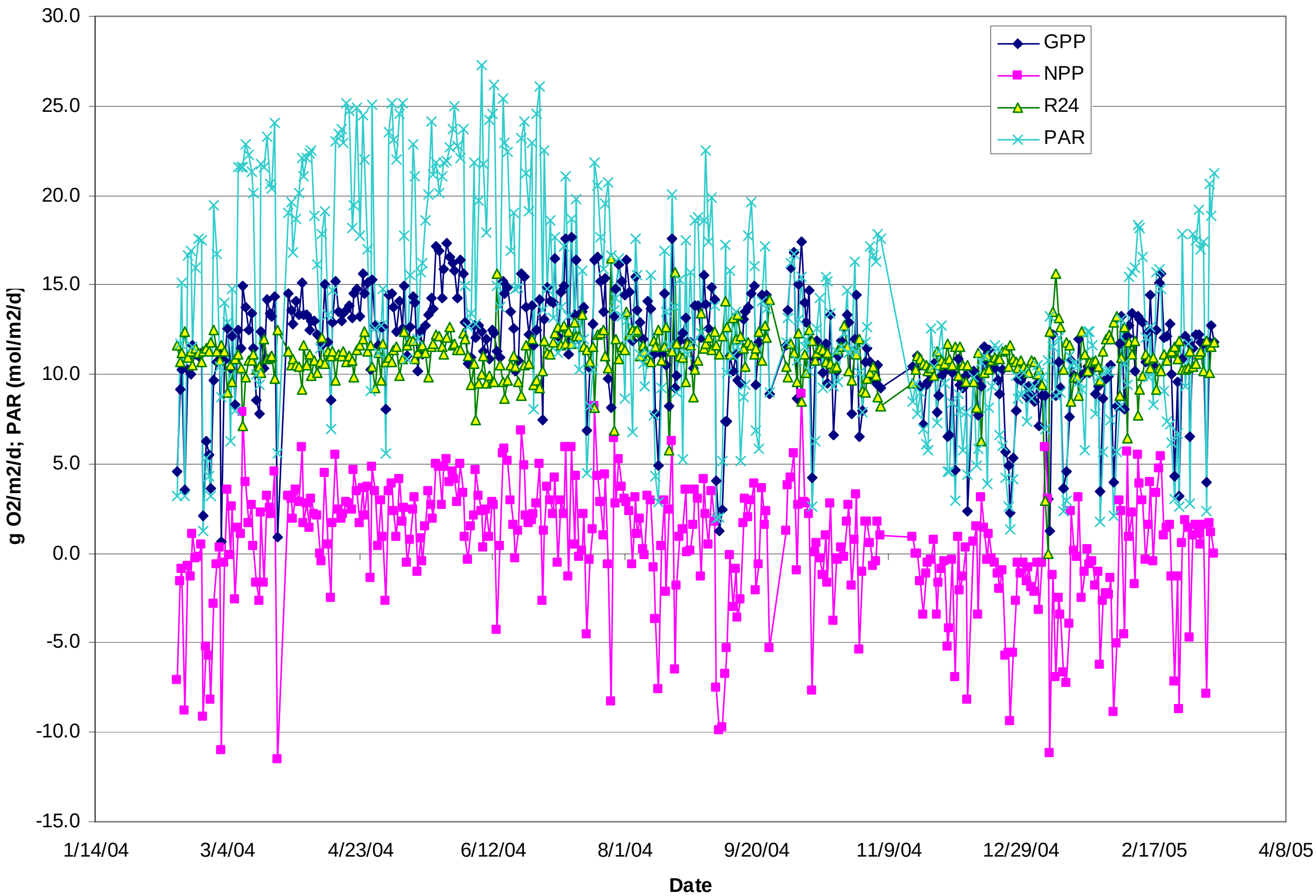


Figure 5-45 Summary of Silver Springs preliminary community metabolism estimates

Table 5-18 Summary of Silver Springs community metabolism estimates

Parameter	Stats	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	POR
NPP24 (g O2/m2/d)	Average	-3.18	0.832	2.32	2.52	2.41	1.93	0.861	-1.13	0.798	-0.415	-2.02	-1.88	0.327	-0.065	0.421
	Max	1.08	7.86	5.88	5.28	6.86	8.25	6.29	3.86	8.93	1.76	3.10	5.89	5.70	1.84	8.93
	Min	-9.13	-11.5	-2.52	-2.62	-4.31	-8.31	-7.58	-9.88	-7.65	-3.43	-9.36	-11.1	-8.91	-7.89	-11.5
R24 (g O2/m2/d)	Average	11.3	10.6	10.9	11.4	10.3	11.6	11.5	12.0	10.9	10.2	10.5	10.4	10.7	10.9	10.9
	Max	12.5	12.4	12.4	12.6	15.6	16.4	15.7	14.2	12.7	11.3	11.7	15.7	13.2	11.8	16.4
	Min	10.5	7.12	9.20	9.68	7.47	6.83	5.74	10.4	8.44	8.25	6.27	-0.051	6.47	10.1	-0.051
GPP (g O2/m2/d)	Average	8.16	11.4	13.2	13.9	12.7	13.6	12.3	10.9	11.7	9.77	8.47	8.55	11.1	10.8	11.4
	Max	11.6	15.0	15.6	17.3	15.6	17.6	17.6	15.0	17.4	11.4	11.5	12.2	15.6	12.7	17.6
	Min	2.12	0.614	8.54	8.09	10.1	6.84	4.93	1.22	4.20	7.17	2.25	1.27	3.19	3.95	0.614
P/R Ratio	Average	0.727	1.11	1.22	1.22	1.26	1.19	1.09	0.917	1.08	0.967	0.827	0.879	1.07	1.003	1.06
	Max	1.10	2.10	1.64	1.44	1.78	2.01	1.56	1.35	2.06	1.20	1.49	3.00	1.88	1.18	3.00
	Min	0.189	0.053	0.772	0.755	0.724	0.494	0.394	0.110	0.354	0.678	0.194	0.102	0.268	0.334	0.053
PAR (24hr) (mol/m2/d)	Average	11.2	17.0	19.1	19.9	19.8	15.4	12.4	12.2	11.9	11.3	7.07	9.17	10.9	14.6	13.9
	Max	19.5	24.1	25.2	25.2	27.2	22.5	20.1	22.5	16.7	17.9	11.7	13.2	18.3	21.3	27.2
	Min	1.25	5.59	6.94	5.57	8.03	4.46	2.87	1.94	2.57	5.72	1.31	1.77	2.08	2.38	1.25
PAR Efficiency (%)	Average	7.38	5.65	5.95	5.95	5.50	7.51	8.93	8.16	8.20	7.79	10.5	8.29	9.30	7.75	7.63
	Max	13.7	13.4	9.93	11.7	11.7	12.4	18.9	16.8	14.0	13.6	21.9	15.9	15.4	19.3	21.9
	Min	4.00	0.570	4.36	4.04	3.61	3.80	5.41	3.46	5.06	4.26	4.29	0.776	4.92	4.49	0.570
GPP Efficiency (g O2/mol)	Average	0.914	0.700	0.737	0.737	0.681	0.931	1.11	1.01	1.02	0.965	1.30	1.03	1.15	0.960	0.945
	Max	1.70	1.66	1.23	1.45	1.45	1.54	2.35	2.08	1.73	1.68	2.71	1.97	1.91	2.39	2.71
	Min	0.495	0.071	0.539	0.500	0.447	0.470	0.671	0.428	0.626	0.528	0.531	0.096	0.610	0.556	0.071

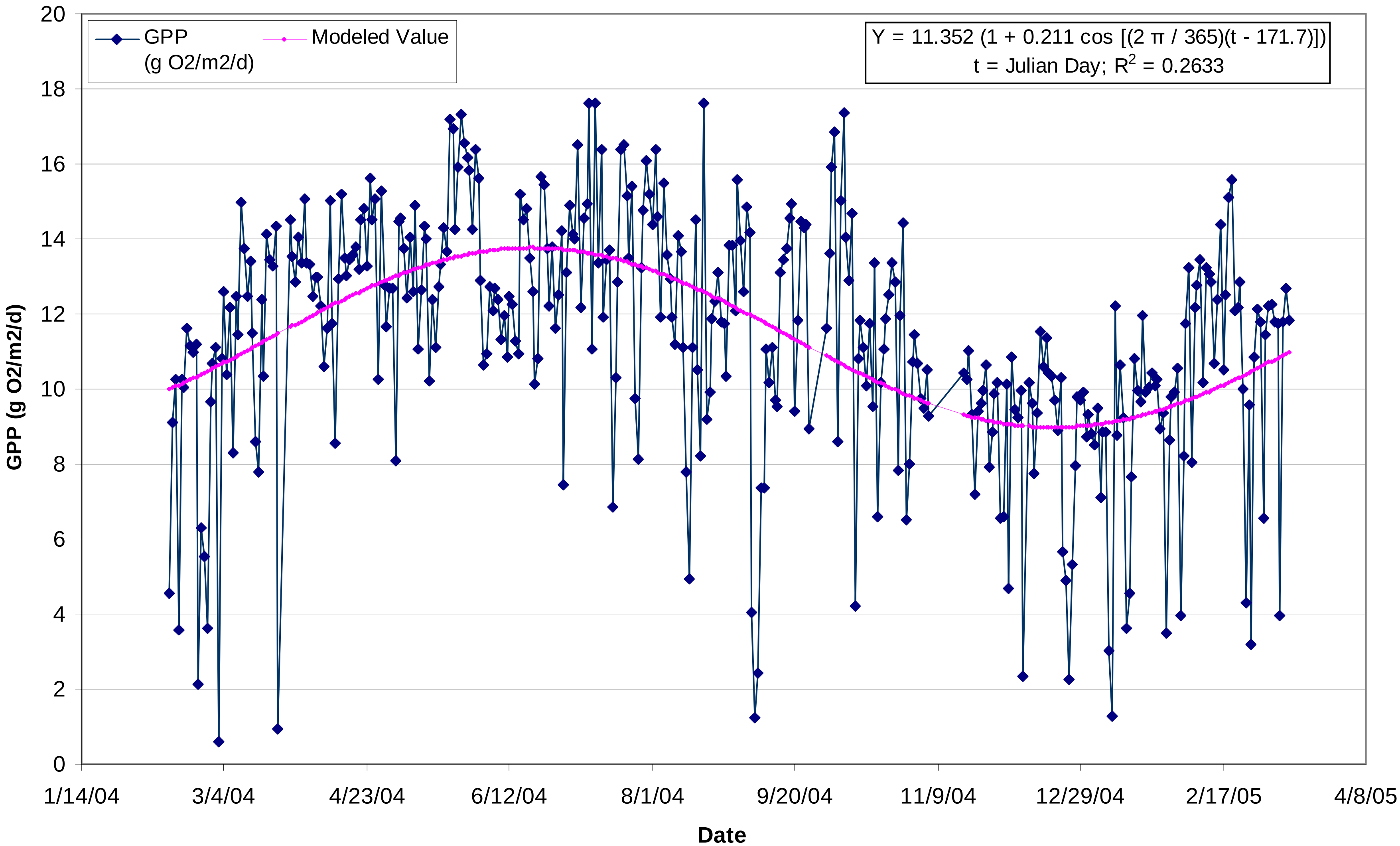


Figure 5-46 Silver Springs Run metabolism worksheet GPP (Gross Primary Productivity) sinusoidal model fit

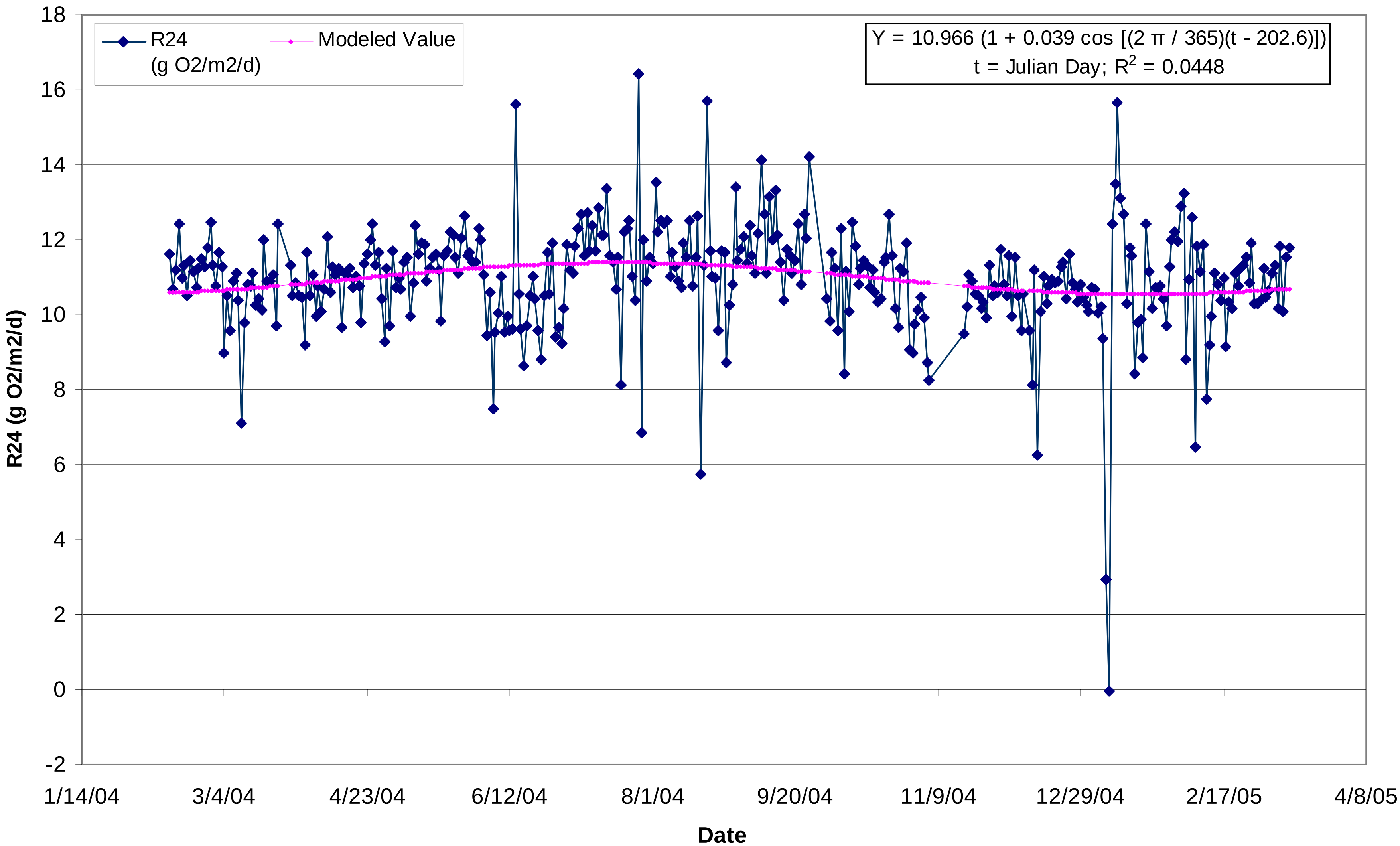


Figure 5-47 Silver Springs Run metabolism worksheet R24 (Community Respiration) sinusoidal model fit

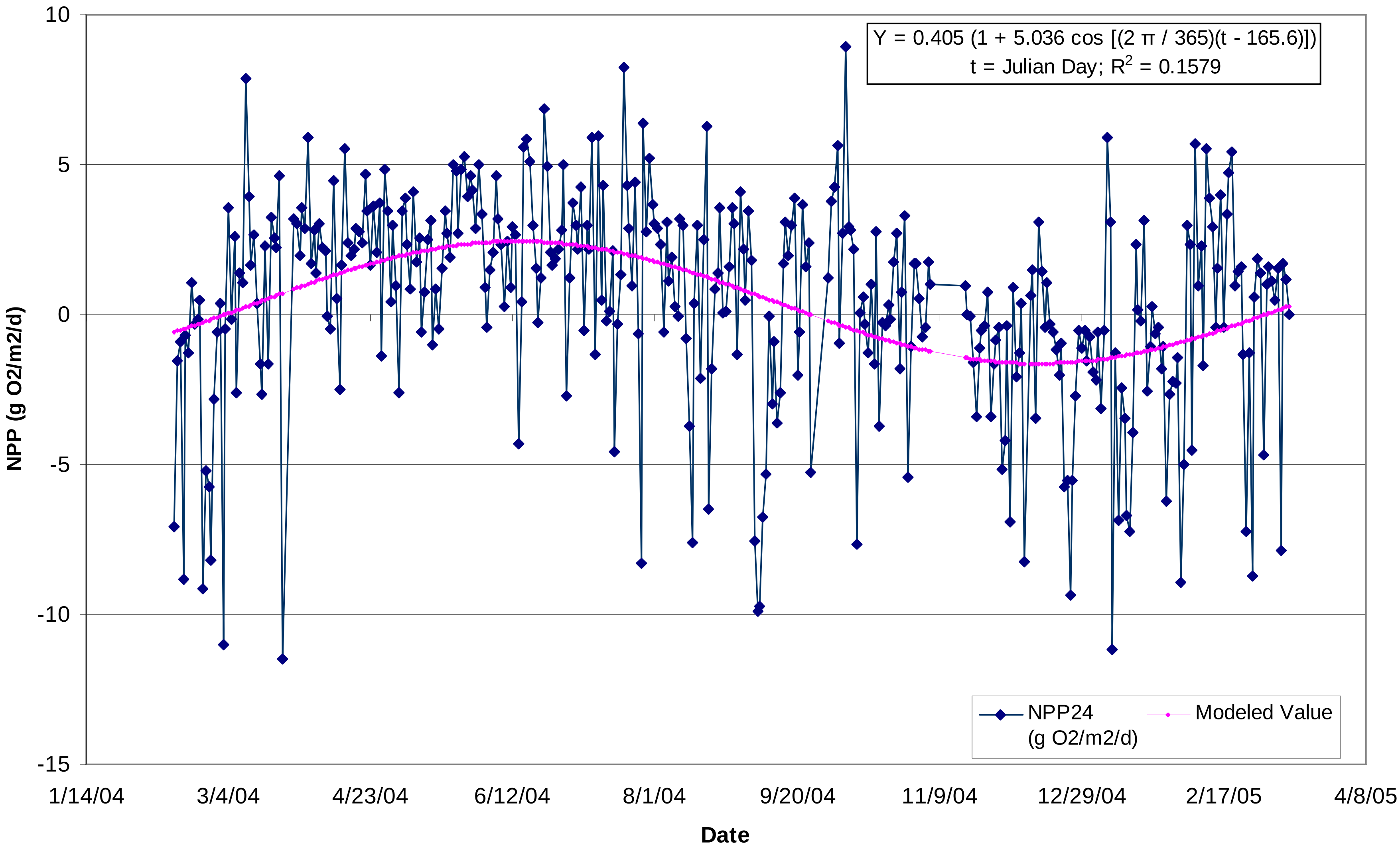


Figure 5-48 Silver Springs Run metabolism worksheet NPP (Net Primary Productivity) sinusoidal model fit

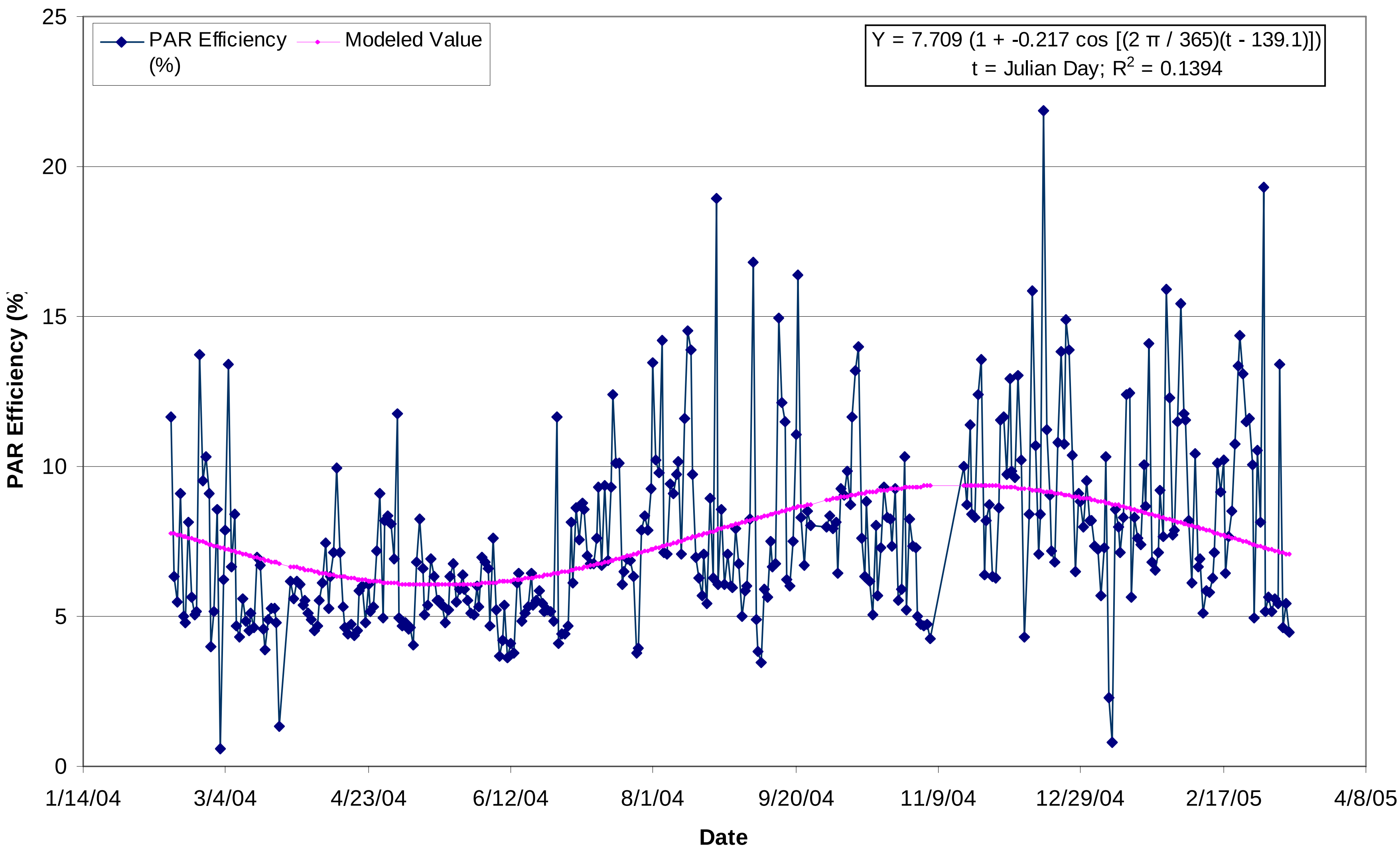


Figure 5-49 Silver Springs Run metabolism worksheet PAR Efficiency sinusoidal model fit

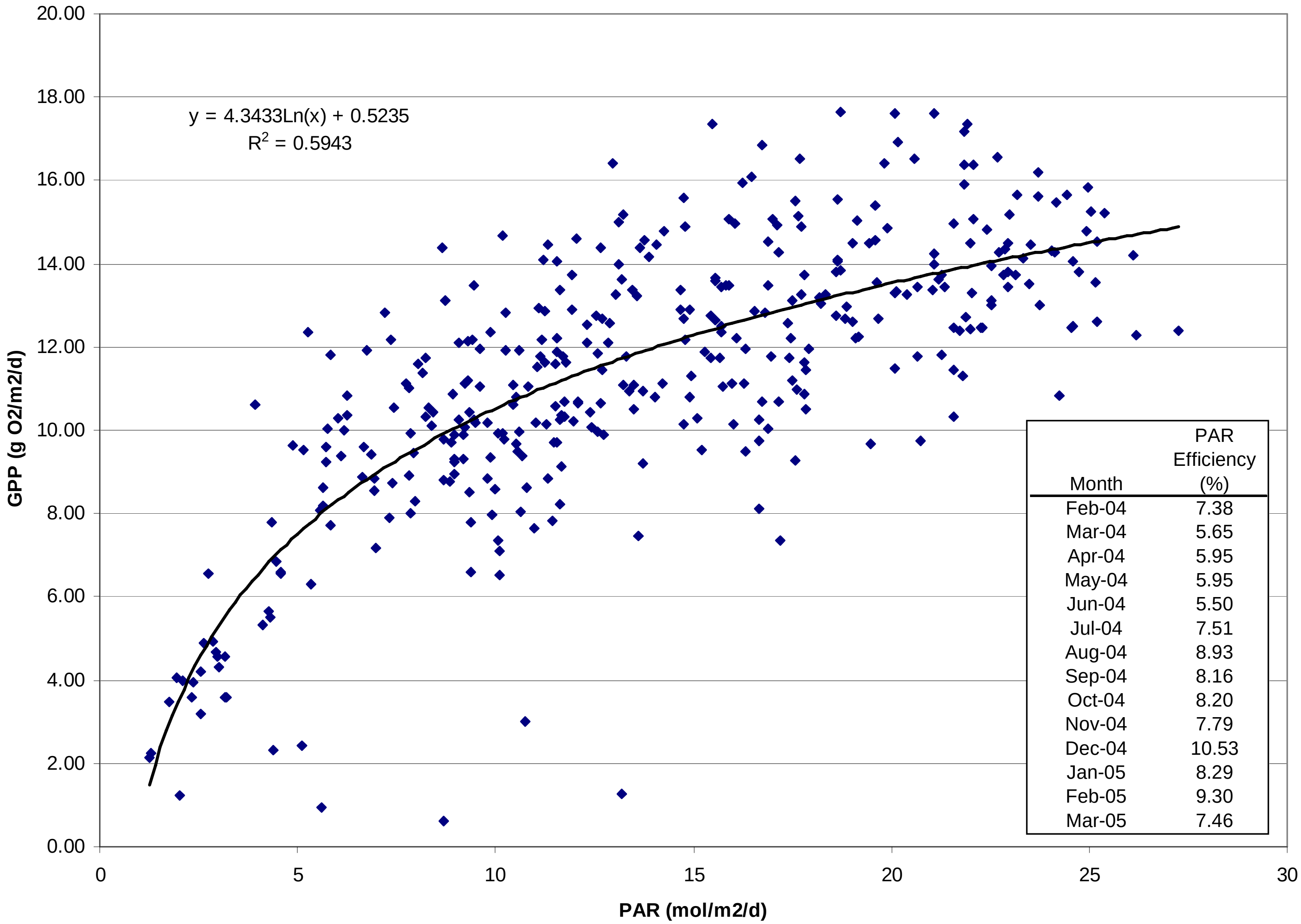


Figure 5- 50 Silver Springs Run metabolism worksheet PAR (Photosynthetically Active Radiation) / GPP (Gross Primary Productivity) relationship

(0.68 g O_2/mol) measured in June 2004. The sinusoidal model (R^2 = 0.14) predicted a minimum PAR efficiency on May 19 and a maximum on November 18.

The period-of-record average P/R ratio at Silver Springs during the current study was estimated as 1.06 (Table 5-18). The monthly maximum P/R ratio was 1.26 in June 2004 and the minimum monthly average was 0.73 in February 2004.

6.0 Changes in the Silver Springs Ecosystem

6.1 Introduction

The Silver River is an excellent ecosystem for comparison between current and historic conditions. Odum described the Silver River as a "ready-made natural laboratory in which whole communities can be studied under controlled conditions." He went on to say that: "Most terrible and healthy for the poor ecologist is the realization that anyone can check his field work at any later time ..." These observations remain largely true today with certain caveats. Water still issues forth from the Main Spring Boil with similar characteristics to Odum's time. Water temperature remains at approximately 23.2 °C, virtually identical to both Brinton's and Odum's measurements in 1856 and 1951, respectively. Average flow rates are still similar to those measured historically. With a few notable exceptions, other water quality estimates are also quite similar to values recorded by previous studies. The following discussion provides a summary of similarities and changes noted between historic and current conditions in Silver Springs.

6.2 Physical/Climatic

6.2.1 Recharge Contribution Area and Springshed Boundary

Although the exact shape of the Silver Springs springshed changes as hydrologic conditions change, the total areal extent of the basin, determined by drawing orthogonal lines on potentiometric surfaces, hasn't changed significantly since the area was developed.

6.2.2 Insolation

Insolation data from the Ocala area prior to Knight's study in 1978-79 could not be located for this comparison. Odum (1957) estimated total insolation at ground surface from methods described by Kennedy (1949), adjusted for observed cloud cover and season. To estimate ecological efficiency, Odum estimated useful light absorbed at the plant level by taking 50% of the total insolation as energy of useable wavelengths, 40% attenuation through the water column, and from 10 to 30% shading based on estimated tree cover between July and December. Odum published two curves of measured light intensity at the water surface and at 2.4 m depth at an unspecified site within the upper Silver River. Both graphs have reduced insolation in the morning due to tree shading and possibly fog (a common occurrence during the early morning and late evening hours during the colder months). Odum (1957) provided an approximate microampere to ft-candle conversion on these figures and Figure 6-1 provides a comparison between Odum's measured light data and data collected during the current study on cloudless

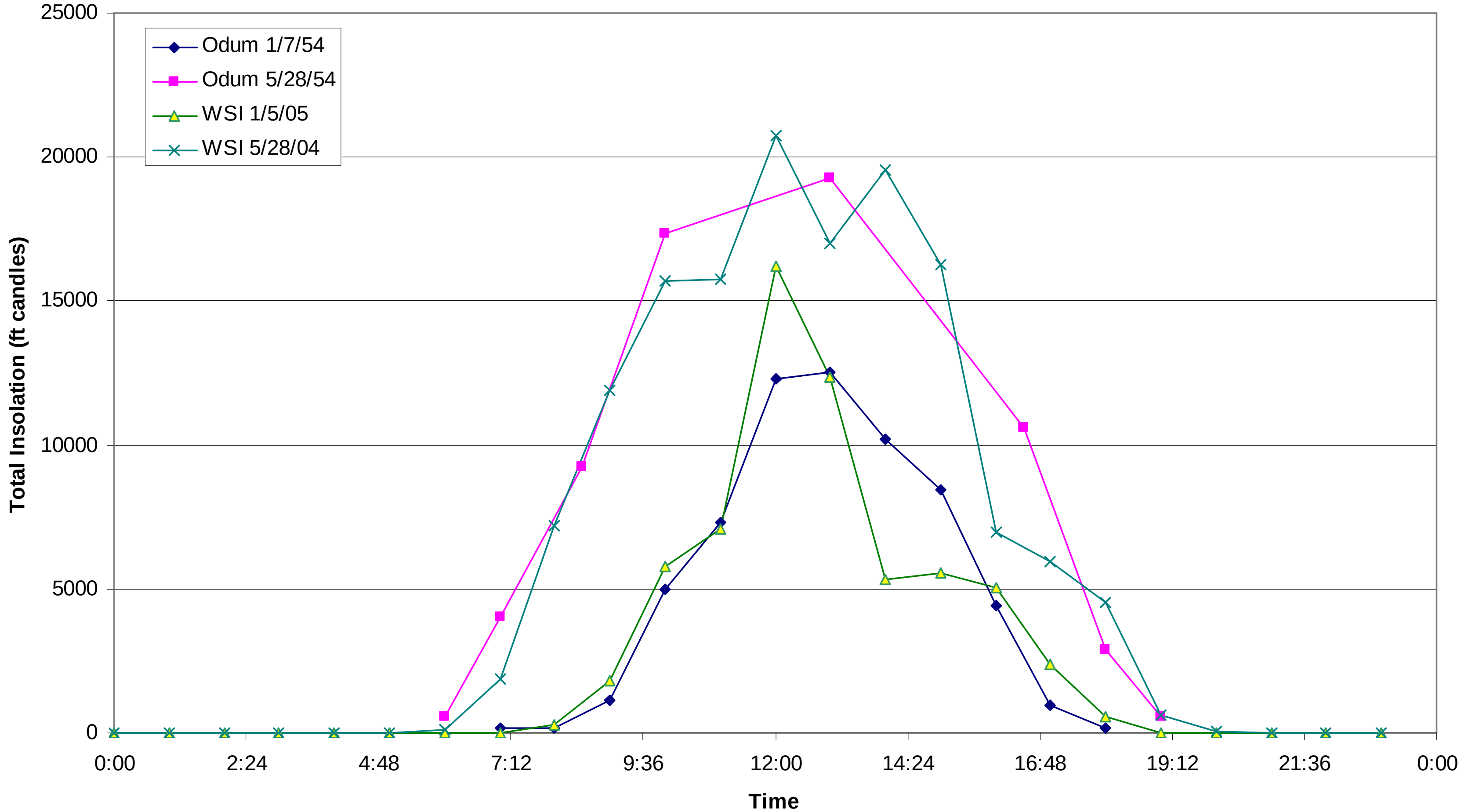


Figure 6-1 Comparison of Silver Springs winter and summer total insolation diurnal curves from Odum (1957) and WSI

days as close as possible to the dates Odum reported. This figure illustrates a close similarity between total insolation patterns in these two studies at Silver Springs.

Knight (1980) measured total insolation at ground level by use of a recording pyranometer. Total insolation was computed by estimating the area under the daily insolation plots. Nine daily insolation values were reported ranging from 2,228 to 5,119 kcal/m^2/d. Figure 6-2 provides a correlation between Knight's total insolation measurements from 1978-79 and measurements from the current study for the same dates. Cloud cover, fog, and shading are likely to be different between the two study periods; however, the correspondence between the two data sets generally indicates that there have been no substantial changes in total insolation over the past twenty-five years at Silver Springs.

6.2.3 Water Stage/Discharge

Period-of-record stage and discharge data for Silver Springs were previously summarized in Section 3. That analysis indicated that average long-term flow in the river has been about 1.91 hm^3/d (779 cfs) and that actual flows have been showing a fairly steady rate of decline throughout the period-of-record (about 0.3% per year), possibly explainable by a similar rate of decline in area precipitation. Table 6-1 provides a summary of flow and estimated average water depth data for the three ecosystem study periods described in this report. Average flow during these three periods declined from 1.97 hm^3/d (804 cfs) for the period from 1952-55 to 1.61 hm^3/d (658 cfs) during the most recent study in 2004-05. On the other hand, estimated water depth in the upper portion of the Silver River actually increased some between Odum's study (1.8 m) and the current study (2.0 m) due to the prolonged backwater effects resulting from the fall 2004 hurricanes.

6.3 Water Quality

6.3.1 Light Transmission

Odum (1957) described the "extreme clarity" of Silver Springs and how that clarity allows intense insolation to reach the luxurious underwater plant community. He measured a horizontal secchi distance of "about 105 m" in the Main Spring Boil in the early 1950s. However, Odum did not provide any details on his estimate so it is not known if it was a single or replicated reading, the size of the secchi disk employed, or light conditions on the date of measurement. Odum (1957) reported a visible light extinction coefficient of 0.06 m^{-1} for the Main Spring Boil. This appears to be his lowest extinction value (highest clarity) and curves shown for three measurements of light extinction in the Main Spring Boil show some variability. He also measured light extinction curves farther downstream but did not report the extinction coefficients

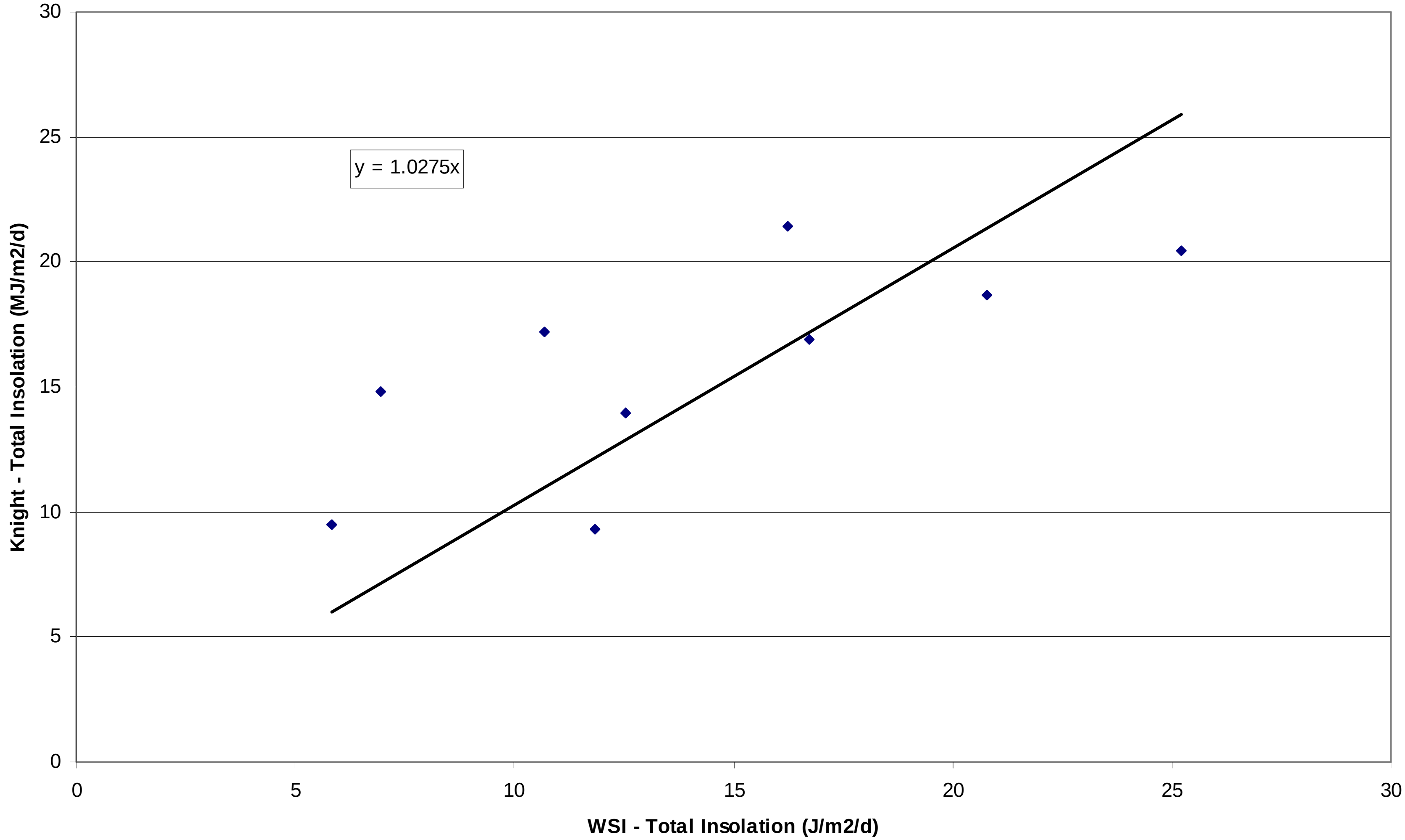


Figure 6-2 Total Insolation relationship between Knight (1980) and WSI for the same calendar day

Table 6-1 Summary of flow and estimated average water depth data for the three ecosystem study periods

Parameter	Odum 1952-1955	Knight 1979-1980	WSI 2004-2005
Flow (m^3/d)			
Average	1,967,191	1,866,493	1,610,972
Maximum	2,544,439	2,104,055	2,297,335
Minimum	1,575,595	1,717,496	1,218,395
Std Error	9,386	5,601	16,039
N	904	350	373
Depth (m)			
Average	1.80	1.66	2.00
Maximum	2.39	1.98	2.61
Minimum	1.31	1.51	1.66
Std Error	0.01	0.01	0.01
N	900	350	373
Area (m^2)	89,200	116,751	116,751

associated with those curves. His curves for the First Fisherman's Paradise boil area and for the 1,200-m station indicate greater light extinction (lower clarity) than in the Main Spring Boil. Knight (1980) did not measure light extinction or secchi distance at Silver Springs.

The current study has measured horizontal secchi distance in the vicinity of the Main Spring Boil on three occasions with a maximum recorded reading of 96 m, about 9% lower than the single value reported by Odum. Measurements taken during this study showed a PAR diffuse attenuation coefficient of about 0.16 m^{-1} in the Main Spring Boil, 0.21 m^{-1} at Turtle Meadows, and 0.34 m^{-1} at the 1,200-m station. The measurement for the Main Spring Boil was considerably higher than the value Odum reported, indicating greater light attenuation (less water clarity) during this study.

If the single values for secchi distance and light extinction published by Odum can be believed to be representative and not maximum observed values, then it appears that light transmission has declined in the Main Spring Boil area during the past fifty years. Additional readings collected during this study downstream of the Main Spring Boil indicate that this measure of light transmission is very sensitive to increasing concentrations of fine particulate matter with distance from the Main Spring Boil. The apparent decrease in water clarity documented in this study during the past fifty years may be a result of higher sediment suspension rates due to boat traffic upstream or increased net production of periphyton and the resulting fine particulate export associated with that increased net production.

6.3.2 Nitrate Nitrogen

Odum (1957) reported an average nitrate nitrogen concentration in the Main Spring Boil area of Silver Springs of 0.46 mg/L in 1953. Nitrite nitrogen measurements reported by Odum found only a trace of this reactive compound. Historic USGS records (Rosenau *et al*. 1977) indicate a concentration of 0.04 mg/L for nitrate nitrogen in 1907, 0.29 mg/L in 1946, and 0.38 by 1949-57. Knight (1980) did not conduct measurements of nitrate or nitrite nitrogen. Data collected by others during the time of Knight's research (1978-79) indicated that the nitrate concentration was about 0.67 mg/L. The average nitrate+nitrite nitrogen concentration measured during the current retrospective study was 1.14 mg/L.

Figure 6-3 illustrates a time series of all of the nitrate nitrogen values currently in the Silver Springs Access database. It is clear that one highly significant change in the water quality of Silver Springs is a marked increase in nitrate nitrogen levels, with more than a doubling of the average concentration observed over the past fifty years. There was no similar increase observed for any other form of nitrogen or for any form of phosphorus during this time period.

6.3.3 Dissolved Oxygen

Odum (1957) and Knight (1980) conducted their research under the assumption that the concentration of dissolved oxygen (DO) was relatively constant in the artesian flow from the individual spring boils. While both researchers noted that there were significant water quality differences between the springs, they did not have data available to detect day-to-day variations in the mixture of those discrete artesian flow sources. The current research study has found some interesting patterns of variability in these artesian flows that not only affect metabolism estimates but also may influence the overall ecology of the Silver River aquatic ecosystem.

Figures 6-4 and 6-5 illustrate the detailed diurnal DO concentration curves at the 1,200-m station reported by Odum and Knight. Considerable variation in the position of each curve is visible in both data sets with average nighttime DO concentrations ranging from about 2 mg/L to about 3.5 mg/L. Figure 6-6 provides a similar graph for the current study period with average diurnal DO variation illustrated by month. The detailed curves of maxima and minima measured during the current study were presented earlier in this report (Figure 5-24). Figure 6-7 provides a comparison of the average diurnal pattern of DO concentrations for all of the data reported by Odum (1957), by Knight (1980), and for this retrospective study by WSI. This figure indicates that the average nighttime DO concentration apparently declined between the 1950s and the current decade from about 3.1 mg/L during Odum's work, to about 2.8 mg/L during Knight's

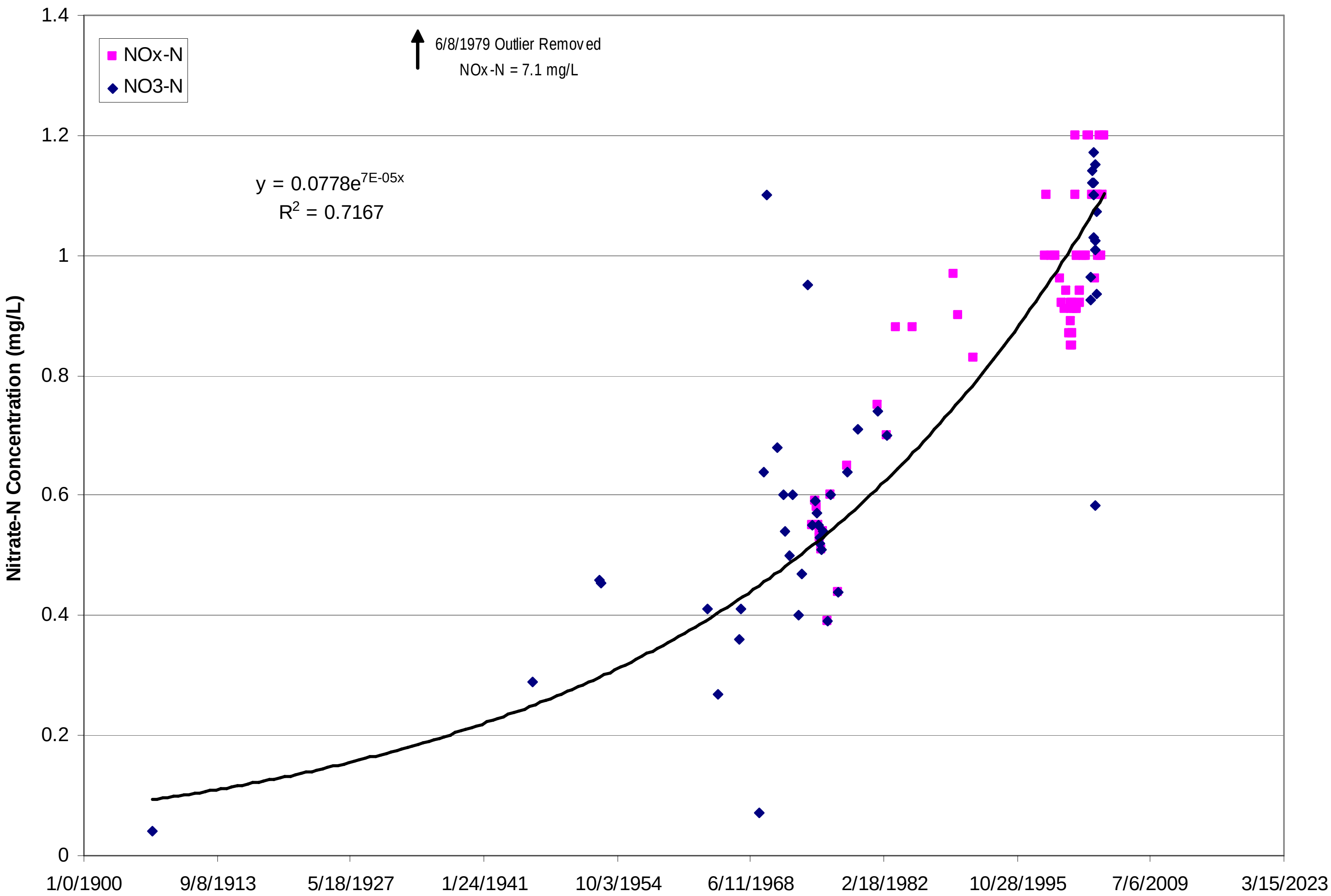


Figure 6-3 Summary of observed nitrate nitrogen concentrations at the Silver Springs Main Spring Boil

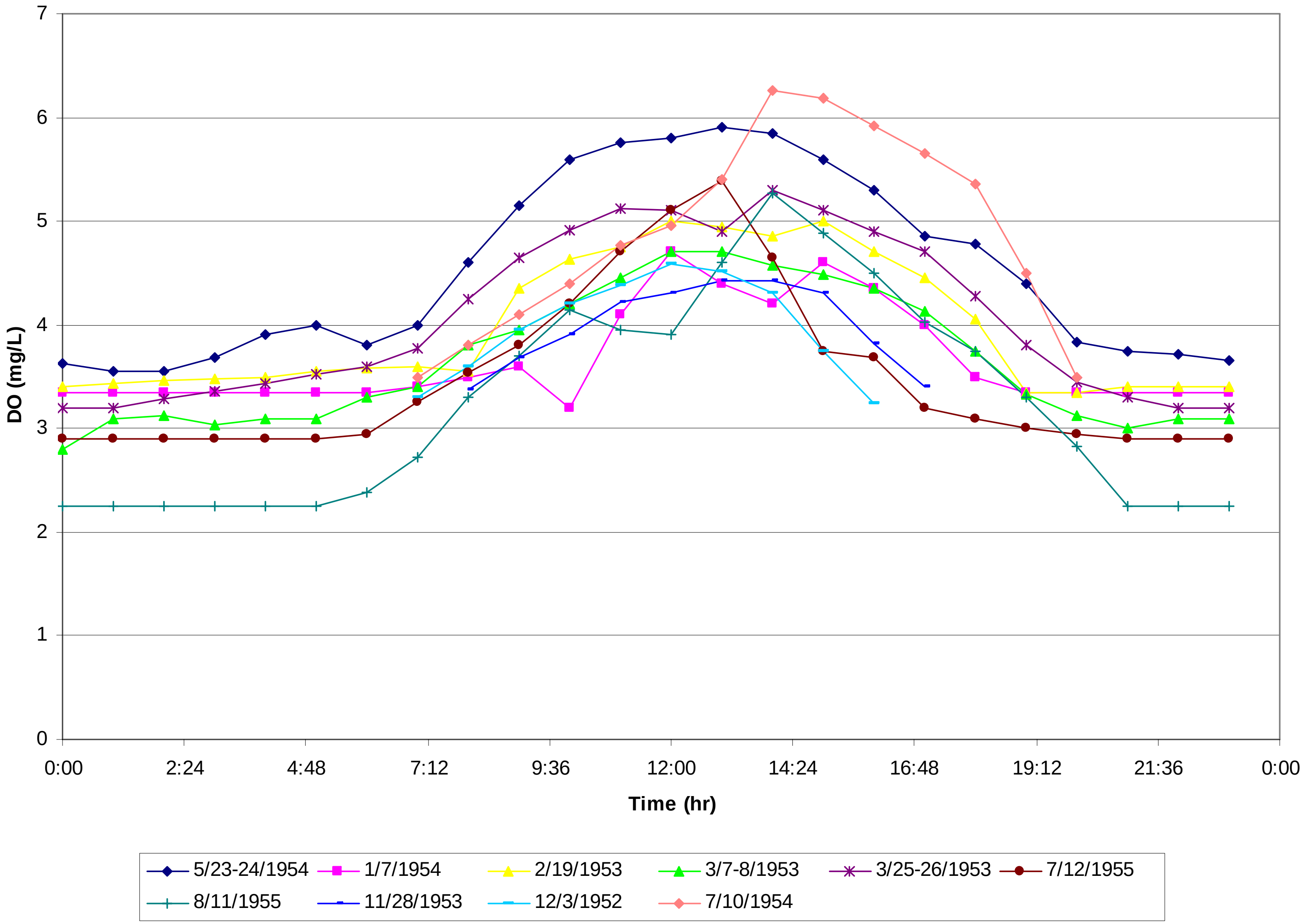


Figure 6-4 Summary of Silver Springs diurnal dissolved oxygen data for the 1,200-m station during ten sampling periods (Odum, 1957)

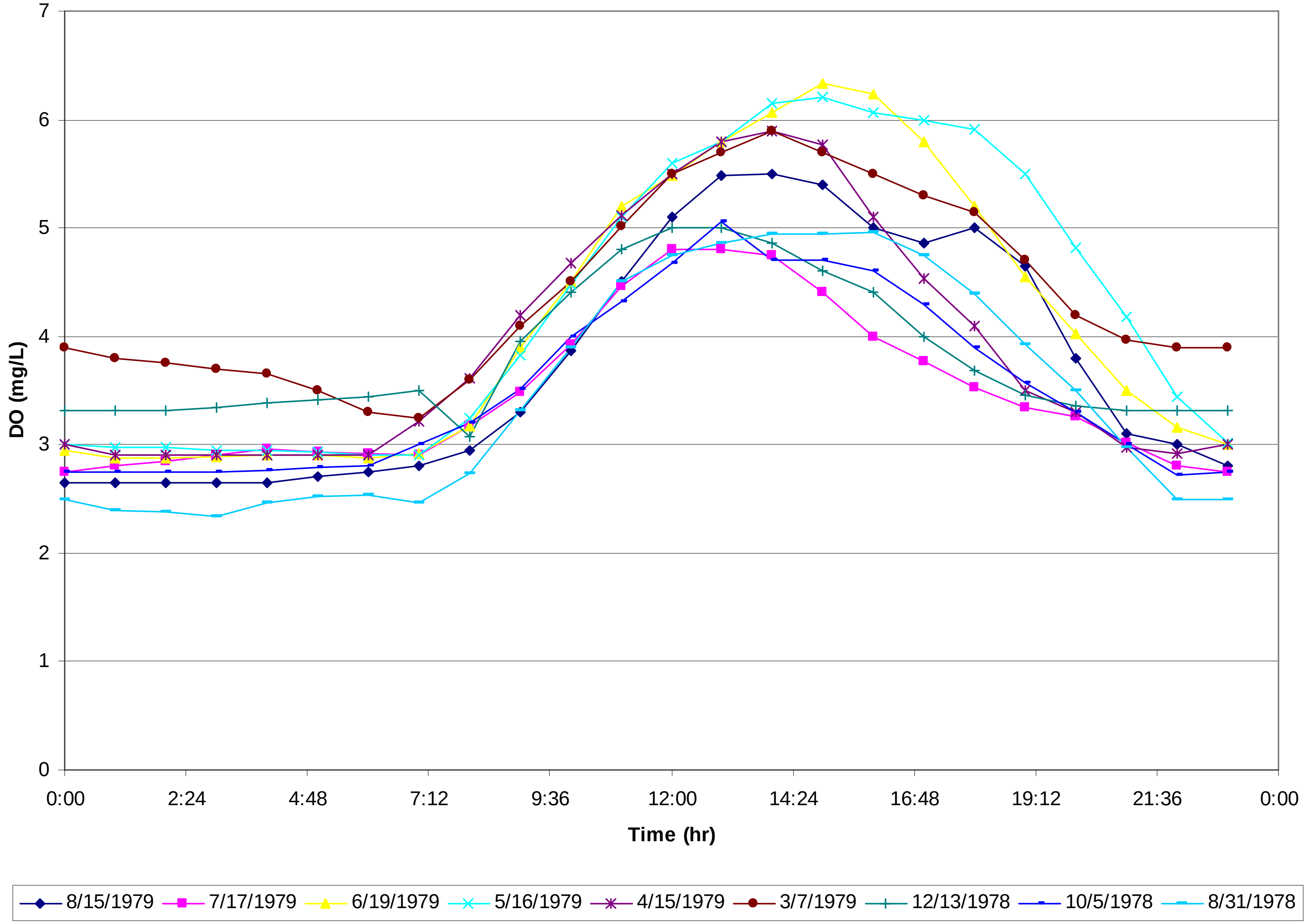


Figure 6-5 Summary of Silver Springs diurnal dissolved oxygen data for the 1,200-m station during nine sampling periods (Knight 1980)

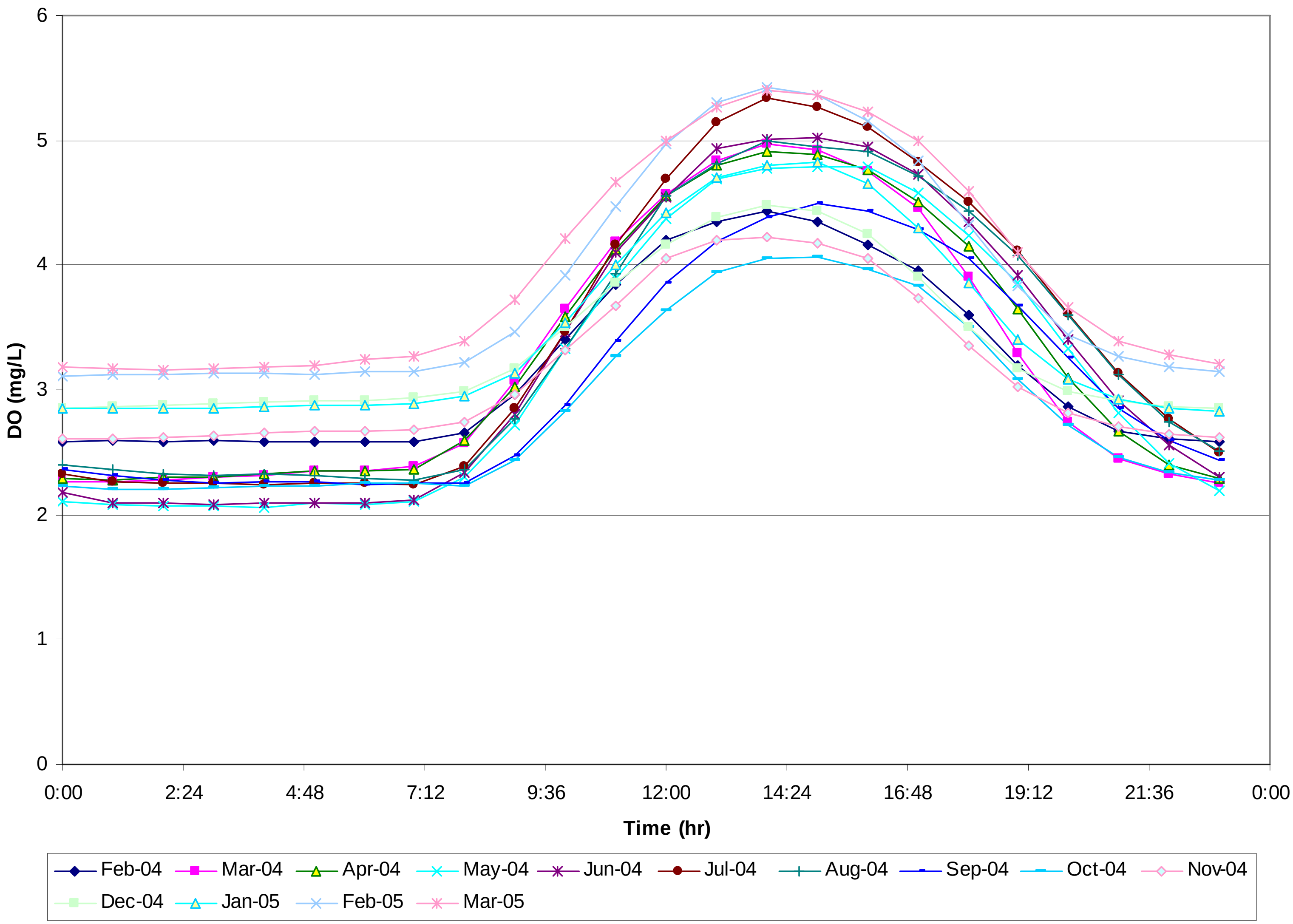


Figure 6-6 Summary of Silver Springs monthly average diurnal dissolved oxygen data for the 1,200-m station during this study (WSI)

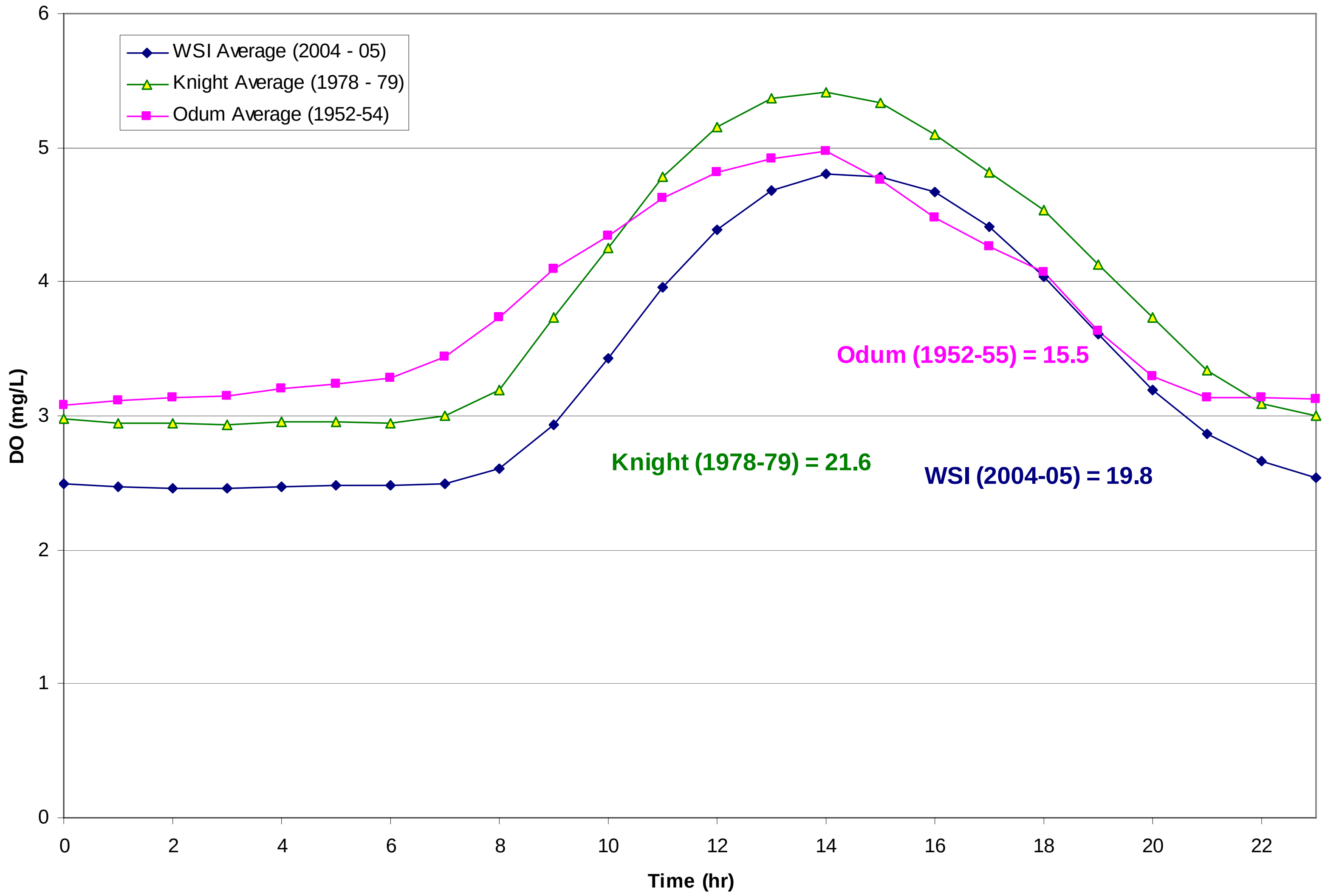


Figure 6-7 Comparison of Silver Springs average diurnal oxygen curves at the 1,200-m station; estimated gross primary productivity in units of ppm-hrs

research, to about 2.5 mg/l during the current study. Dissolved oxygen is an inherently variable water quality parameter affected by temperature, biological activity, time-of-day, and to some extent methods for analysis. The Florida Department of Environmental Protection recognizes this variability and generally considers a measured DO change greater than 0.3 mg/L as being biologically significant (Russ Frydenborg, personal communication). With this criterion in mind, it appears that the observed changes in average nighttime DO in the Silver River over the past fifty years are likely to be biologically significant. These lower DO concentrations can be explained by two differing phenomena that may be occurring independently or simultaneously: the upstream DO concentration in the artesian flow has declined over this time period and/or the absolute amount of community respiration has increased in the aquatic ecosystem. The updated average estimated DO accrual rates at the 1,200-m station in the Silver River for the three studies were: Odum – 111 kilograms per hour (kg/hr), Knight – 100 kg/hr, and WSI – 69 kg/hr. As indicated by the relative distances between the curves in Figure 6-7 and this apparent decline in DO accrual from side boils, the rate of lowering of these nighttime DO concentrations (and therefore the lowering of upstream DO concentrations at the spring boils) appears to be accelerating with time.

6.4 Biological/Ecological

6.4.1 Introduction

Odum (1957) measured and recorded many of the biological indices of Silver Springs during his studies fifty years ago. Knight (1980) provided biomass estimates for snails and fish in the upper portion of the Silver River. Those data provide a baseline for comparison to more recent measurements made during this retrospective study.

6.4.2 Epiphytes and Macrophytes

Silver Springs has long been recognized as an ecosystem with an abundant community of primary producers (Odum 1957). As noted by Odum (1957), empirical accounts of the spring dating back to the mid-1800s describe a system with extensive “moss-like plants on long waving grass blades” (Brinton 1859, Leconte 1861). Subsequent studies of Silver Springs by Odum (1957), Knight (1983), Stevenson (2004) and the current research group all suggest that the overriding structure of the primary producer community has retained many of its basic characteristics. The aquatic macrophyte *Sagittaria* has been the most clearly defined biotic feature of the spring over the period of record and epiphytic algae have been a major element of the community, even though early accounts refer to it as “moss” (Leconte 1961). Based on the results of a comprehensive study of Silver Springs in the early 1950s, Odum (1957) highlighted the temporal stability of the primary producer community, on both seasonal and inter-annual scales. He concluded that the major elements of primary producer standing crop, *Sagittaria* and epiphytic algae, did not exhibit measurable seasonal or inter-annual variation. However, he did temper that conclusion by pointing out the inherent limitations of the techniques used for the analyses, as well as his concerns about the potential impacts of future changes in external inputs to the system. Odum (1957) also stressed the fact that the dynamics of the primary producer community were incompletely understood. One of the key issues arising from Odum's primary production research was the reconciliation between the putative seasonal stability of standing crop and the disparity between summer and winter net primary production, with strong positive NPP in the summer and negative NPP in the winter. As stated by Odum (1957): "It will be noted that the gross primary production in winter does not equal community losses so that there must be some retrenchment in total community biomass and sediments, although it is not conspicuous enough to be noted in rough biomass measurements made so far." Odum (1957) suggested two possible explanations for these observations, with the first most closely matching his observations of the system:

> Thus the Silver Springs community may maintain its great mass of individual producers if they maintain a production over their individual compensation points all the year. This is possible by exporting organic matter representing the excess production of summer. This situation suggests that communities in order to be stable in a region of large annual light variation must store or export considerable organic matter during the summer. Alternatively the communities must die out during the winter in the familiar way of many environments.

The objective of the current study was to re-examine the characteristics and dynamics of primary producer communities of Silver Springs with two goals in mind: 1) to compare the existing structure of the community with that observed by Odum (1957) fifty years ago, as a means of evaluating the impacts of changes that have occurred over time, and 2) Re-examine the alternative hypotheses presented by Odum (1957) regarding the abundance and dynamics of primary producers, as a means of gaining a better understanding of the factors that may drive future changes in the system.

6.4.2.1 Structure of the Primary Producer Community

The unifying element of all studies carried out over time in Silver Springs is the structural importance of the aquatic plant *Sagittaria*. It is clear that this "waving grass-like" species is now and has long been an integral part of the physical structure and biological function of the Silver Springs ecosystem. Similarly, the epiphytic community living on the *Sagittaria* has been a major element of the ecosystem over the past century. The lists of epiphytic species provided by Odum (1957) and Whitford (1956) contain many of the same species observed in the current study.

The largest apparent shift in dominant species in the system over the past fifty years is the rise in prominence of the algal-mat-forming filamentous blue-green alga (i.e. cyanobacterium) *Lyngbya*. While a similar filamentous blue-green alga, *Plectonema*, was observed in the 1950s, it was not identified as forming extensive benthic algal mats. In fact, Odum (1957) largely discounted the importance of benthic algal mats in Silver Springs. The importance of *Lyngbya* in Silver Springs is corroborated by a contemporaneous study of the system by Stevenson (2004). Stevenson (2004) further highlights the widespread importance of this taxon throughout the spring systems of Florida.

Another algal phenomenon observed during the course of the current study of Silver Springs was a spring bloom of epiphytic filamentous green algae, dominated by *Ulothrix*. Spring blooms of filamentous green algae were not documented during the 1950s (Whitford 1956, Odum 1957), although the importance of filamentous green algae is clearly described by Whitford (1956). Similarly, the abundance of diatoms like *Aulacoseira* (*Melosira*) in the epiphytic community is a long-standing feature of Silver Springs (Whitford 1956, Odum 1957). As noted by Whitford (1956), the species assemblages of Silver Springs exhibit spatial heterogeneity that in part can be attributed to spatial differences in flow, light regime and benthic substrate. Certain firmly attached filamentous green algae, like *Cladophora*, are common components of the epiphytic community in high flow regions of the spring, while loosely attached species, like *Mougeotia*, are more common in regions of lower flow. For the most part, with the exception of the prominence of *Lyngbya*, the general components of the algal community observed by Whitford in 1956 remain in the system today.

6.4.2.2 Abundance and Dynamics of Primary Producers

In the early 1950s Odum (1957) described two major components of primary producer standing crop in Silver Springs, *Sagittaria* and the epiphytes growing on *Sagittaria*. The average standing crop of the two components was estimated to be 578 g dry wt. m^2 and 188 g dry wt. m^2, respectively. The biomass of other macrophytes was estimated at 43 g dry wt. m^2. Benthic algal mats were also observed "in a few places but were not large enough to figure in the overall community estimates" (Odum 1957). Based on multiple year and year-round observations of these four components Odum (1957) concluded that the community biomass was in steady state, i.e. constant over time, seasonally and inter-annually.

The results of the current study also recognize *Sagittaria* and the epiphyte community as major primary producers in Silver Springs. Estimates of biomass of *Sagittaria* were almost identical in the summer to those reported by Odum (1957), but were lower in the winter, which runs contrary to Odum's conclusion of temporal uniformity of primary producer biomass. The average total macrophyte biomass observed in the winter was 70% of the summer average, i.e. 402 g dry wt.

m^2, in contrast to Odum's conclusion of no seasonal differences (Table 6-2). The fact that current estimates of summer *Sagittaria* biomass are only 5% different than Odum's is remarkable, especially considering the differences in methods used in the two studies.

Estimates of epiphytic biomass from the current study also deviated from Odum's observations. Average summer biomass estimates were nearly three times that observed by Odum (1957), i.e., 572 g dry wt. m^2 compared to 188 g dry wt. m^2 (Table 6-2). In the winter, the average epiphytic biomass was 221 g dry wt. m^2, close to the value reported by Odum (1957).

Table 6-2 A Comparison of Average Dry Weights (g dry weight m^{-2}) for Major Primary Producer Components Observed by Odum (1957) and in the Current Study

Primary Producer	Season	Odum (1957)	Current Study
Macrophytes	Winter	621	402
	Summer	621	580
Epiphytes	Winter	188	221
	Summer	188	572
Benthic Mats	Winter	negligible*	379
	Summer	negligible*	601

*not measured

It is noteworthy that summer epiphyte dry weight rivals *Sagittaria* biomass. However, care must be taken in interpreting the relative meaning of the biomass values for macrophytes and epiphytes. For example, the similarity in the summer dry weight values for macrophytes and epiphytes may not indicate a similarity in primary producer biomass. The epiphytic community contains many living and non-living elements other than algae. In part, this is reflected in the large ash content of epiphyte community biomass, which averaged 49% ash, compared to an average ash content of 26% for *Sagittaria*. From another perspective, the relative rates of primary production by macrophytes and epiphytes must be viewed within the context of the turnover rates of epiphytic algae, which can be much higher than for macrophytes, as noted by Odum (1957). Odum (1957) reported productivity values for epiphytes of 4,490 grams m^{-2} yr^{-1}, compared to 1,900 grams m^{-2} yr^{-1} for *Sagittaria*, which, given the relative standing crops of these two elements, demonstrates the difference in turnover rates.

One of the major departures from the observations of Odum in the early 1950s is the extensive benthic algal mats observed in this study. While Odum (1957) discounted the importance of benthic algal mats to the overall primary producer biomass in Silver Springs, the results of the current study indicate a significant role. Estimated average biomass of benthic algal mats was 379 g dry wt. m^2 in the winter and 601 g dry wt. m^2 in the summer, both very substantial in relation to the estimated values for *Sagittaria* and the epiphytic elements of the primary producer community. The strong presence of benthic algae is corroborated by the results of a recent contemporaneous study by Stevenson (2004), which reports substantial biomass levels of benthic algae at individual sampling sites within Silver Springs, although a spring-wide average was not determined.

The large algal mat biomass in Silver Springs must be viewed within the context of the composition of the mat. While the average dry weight for the mats was similar to the average macrophyte dry weights, the biomass of active primary producers represented by these values may be substantially different. While benthic mats ranged in depth from less than 1 to 40 cm, it is likely that only the top cm receives enough light to support net photoautotrophic photosynthesis. Benthic algal mat dry weight also includes a large non-photosynthetic component: including bacteria, dead algae, other detritus, sediment and fauna, as indicated by the 44% ash content. The use of AFDW for comparisons helps to eliminate some interference from non-volatile solids, but even this figure may overestimate the biomass of active primary producers, due to the presence of organic detritus and non-photosynthetic organisms (e.g. bacteria and invertebrates). Direct microscopic analysis of algal biovolumes, in combination with pigment analysis, may provide a better measure of primary producer biomass. Actual measures of photosynthesis and respiration activity of mats in different regions of the spring would also provide a better estimate of gross and net primary productivity attributable to benthic algae mats.

The results of the current study suggest that the *Sagittaria* component of Silver Springs has remained relatively stable over the past fifty years, but epiphyte and benthic algal mat community biomass may have expanded. However, it is important to note that a portion of these differences may be attributable to methodological disparities between the current and earlier studies, as well as inherent variances in mean values. For example, the results of the current study demonstrate that epiphyte biomass is subject to considerable spatial and temporal variability. Large differences in epiphyte coverage and density were observed between high flow and low flow regions of the spring. On a temporal scale, an over three-fold change was recorded in winter and summer epiphyte biomass. In addition, other shifts in epiphyte abundance were observed over shorter time scales, but were not fully quantified due to limitations in the scope of the research project. It is difficult to believe that similar variations did not occur in the 1950s, despite Odum's (1957) preliminary conclusion of temporal stability. If

Odum's conclusion is correct, the temporal variability in epiphyte abundance in the current study would represent a major change in the ecology of the system.

A more difficult disparity to explain, between Odum's observations and the results of the current study, is the relative lack of macroalgal mats observed by Odum (1957), relative to the extensive mats observed in the current study. The presence of benthic algal communities in Silver Springs dates back to the 1950s (Whitford 1956), but no efforts were made to quantify the extent of the mats. From a visual perspective, the extent of the mats is somewhat masked by the thin layer of loose sediments that blanket much of the mats. The mats only become more obvious by dusting off the surface layer. It is possible that former studies of the spring may have underestimated the scope of benthic algal mats due to problems with visual recognition. It is also important to recognize that the high benthic algal mat biomass observed in the current study may not be associated with a proportionally large increase in primary production, since only the upper layers of mat receive sufficient light to generate net photosynthesis.

The results of the current study may also help to resolve another issue brought up by Odum (1957), namely the dynamic character of the primary producer community in Silver Springs. The results of the current study indicate that the community is not in a seasonal steady state, as evidenced by higher summer biomass than winter biomass for most elements of the community. This observation favors the alternative hypothesis of primary producer dynamics put forth by Odum (1957), that there is a winter decline in standing crop of photosynthetic organisms and a spring/summer resurgence in consort with elevated light availability. Many of the seasonal and spatial patterns of primary producer biomass observed in the current study support the importance of light availability in defining productivity of the system.

Another issue raised by the results of this study is the apparent contradiction between the increase in primary producer standing crop, in terms of epiphytes and benthic algae, and the decline in GPP, CR and NPP. Assuming that the observed decline in the latter three parameters is significant within the confidence intervals of the applied measurements, it is difficult to reconcile these observations with the data available. This also points out the need for additional information on the structure and function of key elements of the Silver Springs ecosystem. These additional needs can be viewed within the context of several important questions, including:

1. How are the oxygen balances used to estimate GPP, CR and NPP impacted by the addition of back channels to the spring run in the 1970s?

2. What are the respiratory and photosynthetic potentials of benthic mat communities of different thicknesses? Current estimates of algal mat biomass may not be good indicators of oxygen balances in the mats.
3. What are the respiratory and photosynthetic potentials of epiphyte communities of different thicknesses?
4. How are different components of the primary producer community impacted by changes in light availability resulting from seasonal patterns of incident irradiance, canopy cover and floating plant communities? In other words, what role does light limitation play in defining primary production?
5. What role does nutrient limitation play in the growth of epiphytes and benthic algae? The important question is whether future increases or decreases of nutrient levels will result in responses by the primary producer community.

6.4.3 Aquatic Insects

Odum (1957) inadvertently captured emerging insects in inverted funnels suspended below the water surface for measurement of bubble release rates from submerged aquatic vegetation (SAV). Apparently this measurement was made by Odum on only a few occasions over a diurnal period at four stations arranged at varying depths at a location just below the Main Spring Boil. He typically only captured emerging insects during his nighttime sampling events. Odum reported an average insect emergence rate of about 236 insects/m^2/d. The emergence traps utilized in this study on six dates returned a lower average emergence rate of about 67 insects/m^2/d with a maximum value of about 368 insects/m^2/d. Side-by-side comparisons between the pyramid traps used for this study and funnel traps similar to those used by Odum found similar emergence rates. Estimated insect emergence was also calculated based on insects trapped in plankton tows and revealed similar levels to those recorded in the emergence traps.

Since Odum's data are based on very small sampling areas and fewer traps, it cannot be determined with certainty whether these two estimates are significantly different. Large insect emergence events were observed every evening that researchers were on the river during this study period. Qualitatively these emergence events are very similar to those witnessed by Knight in the late 1970s. Although the absolute numbers appear to be significantly lower than those previously reported, it is clear that the overall phenomenon of insect emergence is still very important in Silver Springs. Based on taxonomic composition of the emerging insect samples it appears that there has been relatively little change in the dominant families of aquatic insects using this portion of the Silver River.

6.4.4 Vertebrates

6.4.4.1 Turtles

In a broad 1970s study assessing the impacts of the Cross Florida Barge Canal along the Silver River, peninsula cooter and Florida red-bellied cooter were, as in this study, found to be the most abundant species (GFC 1976). Odum (1957) also noted that the peninsula cooter and the Florida red-bellied cooter were dominant herbivores in his survey. Although no softshell turtles were observed in the 1970s (GFC 1976), they were observed by Hubbs and Allen (1943), Odum (1957), and in this study (Table 6-3). Odum's (1957) study had the most thorough presentation of turtles surveyed and the only species he observed that were not found in this study were the common musk turtle (*Sternotheris odoratus*) and the loggerhead musk turtle (*S. minor*) (Table 6-3). Notably these two species are fairly small (about one third the size of other turtles listed here when fully grown and the largest are 5 inches in diameter), rarely leave the bottom sediment, and are nocturnal. On all of the sample dates for this study, there were numerous turtles that were covered by algae, making them difficult to identify to species. These unidentified turtles were counted and probably were peninsula cooter and Florida red-bellied cooter and likely some musk (K. Bjorndal, UF Zoology, personal communication).

6.4.4.2 Alligators

On the night of March 7, 1979, Knight (1980) observed an average of 27.3 alligators for the same 1.2-km stretch of Silver River sampled for the current study. An average of 7.3 alligators was observed during the four survey dates in 2004. The 2004 surveys, however, were during daylight hours, whereas Knight (1980) was able to search the system during the nighttime when the alligators' eyes reflect in the dark making them relatively easy to find. Had this study team been able to make nighttime observations, the resulting estimates likely would be much higher.

6.4.4.3 Birds

All birds encountered during this study were also surveyed along the spring runs of the Ocklawaha River in the 1970s (Florida Game and Freshwater Fish Commission, 1976). All of the bird species observed by Odum (1957) were also seen during this survey, or are known to still be common to the Silver Springs region today (e.g., green heron (*Butorides virescens*), Table 6-3. Similar to Odum's observations (1957), Hubbs and Allen (1943) noted that fish-eating birds (e.g., double crested cormorant) were not common and were only occasionally found around the spring run at the time of their survey.

6.4.4.4 Fish

Similar to the findings of Hubbs and Allen (1943) at Silver Springs, bluegill sunfish was the most abundant fish species for each sample date in this study. Odum (1957) also listed bluegill sunfish as a dominant carnivore in the system. Knight (1980) reported sunfish (*Lepomis spp*., classified to genus level) to be among the most dominant fishes in his study.

Table 6-3 Species of birds and reptiles observed (indicated by "+") in the spring run of Silver River, Florida studies by Odum (1957) and this study

	Common	Species	Odum	This study
Birds	American coot	*Fulica americana*	+	
	Anhinga	*Anhinga anhinga*		+
	Common moorhen	*Gallinula chloropus*	+	+
	Double-crested cormorant	*Phalacrocorax auritus*		+
	Florida mottled duck	*Anas fulvigula*		+
	Grackle	*Quiscalus quiscula*		+
	Great blue heron	*Ardea herodias*	+	+
	Green heron	*Butorides virescens*	+	
	Little blue heron	*Egretta caerulea*	+	+
	Osprey	*Pandion haliaetus*		+
	Pied-billed grebe	*Podilymbus podiceps*		+
	Snowy egret	*Egretta thula*		+
	White ibis	*Eudocimus albus*		+
	Wood duck	*Aix sponsa*		+
Reptiles	Alligator	*Alligator mississippiensis*	+	+
	Common musk turtle	*Sternotheris odoratus*	+	
	Florida cooter	*Pseudemys floridana*	+	+
	Florida red-bellied cooter	*Pseudemys nelsoni*	+	+
	Florida softshell turtle	*Apalone ferox*	+	+
	Loggerhead musk turtle	*Sternotheris minor*	+	
	Snapping turtle	*Chelydra serpentina*	+	+

The fish species visually observed during this study were similar to those observed in past studies (Table 6-4). Hubbs and Allen (1943) reported thirty-three species. Odum (1957) reported thirty-five, and this group observed thirty-three. Of the forty-one combined species identified among studies past and present, Hubbs and Allen (1943), Odum (1957), and the participants in this study all observed twenty-six of the same species, and ten species were common among all four studies. The only species not observed in this study that was documented in the other three visual surveys (Hubbs and Allen 1943, Odum 1957, Knight 1980) was the Atlantic needlefish (*Strongylura marina).* Hubbs and Allen (1943) and Odum (1957) both observed the dominant carnivores spotted sunfish, redear sunfish, bluegill sunfish, channel catfish (*Ictalurus punctatus*), and the dominant fish herbivore striped mullet. They also observed many gambusia and white catfish (*Ameiurus catus*) in visual surveys, in contrast to this study, in which these species were not documented. In addition, Odum (1957) did not find the abundance of golden shiner observed during this study.

The large total lengths observed for several species, including largemouth bass, longnose gar (*Lepisosteus osseus*), bowfin (*Amia calva*), and chain pickerel (*Esox niger*), were high and possibly due to the ban on fishing along this stretch of river, and related to the high abundance of prey fish from supplemental feeding by tourists and park employees (Hubbs and Allen 1943). These four species also were noted to have individuals of exceptional size and length in Hubbs and Allen's (1943) survey. Odum (1957) listed largemouth bass, longnose gar, and Florida gar as the top carnivores and noted their significant size in the spring area, but did not discuss sizes of bowfin.

Odum (1957) reported that striped mullet, followed by catfish and *Lepomis spp*., represented the greatest biomass during his observations. More recently, Knight (1980) also found that largemouth bass and *Lepomis spp*. had high relative biomass levels, ranking second and third respectively of those species observed. However, gizzard shad had the highest total biomass for each of his four sample dates (Knight 1980). Allen and Hubbs (1943) and Odum (1957) observed a low abundance of gizzard shad in their surveys. In the current study, gizzard shad had high total biomass relative to other species on only the final sample date, when it ranked third behind largemouth bass and bluegill.

In this study, the visual sampling methods for fish were similar to methods used by Odum (1957) and Knight (1980), but all the studies obtained only qualitative estimates of fish biomass without associated error. Visual surveys representing a single transect were conducted at Silver Springs by Odum (1957) and Knight (1980). Odum (1957) and Knight (1980) had an observer hanging on the bow of the boat wearing a face mask while the boat motored in crisscrossing circuits down the 1,200 m spring run. Knight (1980) noted that his survey took approximately an hour

Table 6-4 Fish Species observed (indicated by "+") at the spring run of Silver River, Florida studies by Hubbs and Allen (1943), Odum (1957), Knight (1980), and this study

Several species were listed under different names in the historical studies. *Anguilla rostrata* was known as *A. bostoniensis* in both Hubbs and Allen and in Odum; *Lepomis gulosus* was listed as *Chaenobryttus coronarius* in Hubbs and Allen and in Odum; *Dorosoma petenense* was listed as *Signalosa petenensis* in Odum; *Ictalurus punctatus* was listed as *I. lacustris* in Odum; *Ameiurus catus* was listed as *I. catus* in both Hubbs and Allen and in Odum; *Percina nigrofasciata* was listed as *Hadropterus nigrofasciatus* in Hubbs and Allen and in Odum; Prior to 1980, *Gambusia holbrooki* was *G. affinis*; *Poecilia latipinna* was listed as *Mollienesia latipinna* in Hubbs and Allen and in Odum.

Family	Common Name	Scientific Name	Hubbs & Allen	Odum	Knight	This Study
Amiidae	Bowfin	*Amia calva*	+	+	+	+
Anguillidae	American eel	*Anguilla rostrata*	+	+		+
Aphredoderidae	Pirate perch	*Aphredoderus sayanus*	+	+		+
Atherinidae	Brook silverside	*Labidesthes sicculus*		+		
Belonidae	Atlantic needlefish	*Strongylura marina*	+	+	+	
Catostomidae	Lake chubsucker	*Erimyzon sucetta*	+	+	+	+
Centrarchidae	Everglades pygmy sunfish	*Elassoma evergladei*	+	+		
	Elassoma sp.	*Elassoma sp.*				+
	Sunfish	*Enneacanthus sp.*	+			
	Redbreast sunfish	*Lepomis auritus*	+	+		+
	Warmouth	*Lepomis gulosus*	+	+		+
	Bluegill	*Lepomis macrochirus*	+	+		+
	Redear sunfish	*Lepomis microlophus*	+	+		+
	Spotted sunfish	*Lepomis punctatus*	+	+		+
	Sunfish sp.	*Lepomis sp.*	+	+	+	+
	Largemouth bass	*Micropterus salmoides*	+	+	+	+
	Black crappie	*Pomoxis nigromaculatis*	+	+	+	+
Cichlidae	Blue tilapia	*Tilapia aurea*				+
Clupeidae	Gizzard shad	*Dorosoma cepedianum*	+	+	+	+
	Threadfin shad	*Dorosoma petenense*	+	+		
Cyprinidae	Shiner sp.	*Hybopsis sp.*		+		
	Golden shiner	*Notemigonus crysoleucas*	+	+	+	+
	Florida shiner	*Notropsis sp.*	+	+		
	Taillight shiner	*Notropsis maculatus*				+
Cyprinodontidae	Starhead topminnow	*Fundulus dispar*	+	+		
	Golden topminnow	*Fundulus chrysotus*	+	+		+
	American flagfish	*Jordanella floridae*	+	+		
	Pygmy killifish	*Leptolucania ommata*		+		
	Bluefin killifish	*Lucania goodei*		+		+
	Rainwater killifish	*Lucania parva*	+	+		+
Esocidae	Redfin pickerel	*Esox americanus americanus*	+	+		+
	Chain pickerel	*Esox niger*	+	+	+	+
Ictaluridae	Yellow bullhead	*Ameiurus natalis*	+	+		+
	Brown bullhead	*Ameiurus nebulosus*				+
	Channel catfish	*Ictalurus punctatus*	+	+		+
	White catfish	*Ameiurus catus*	+	+		
	Tadpole madtom	*Noturus gyrinus*				+
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	+	+		+
	Florida gar	*Lepisosteus platyrhincus*	+	+	+	+

Table 6-4 Fish Species observed (indicated by "+") at the spring run of Silver River, Florida studies by Hubbs and Allen (1943), Odum (1957), Knight (1980), and this study

Family	Common Name	Scientific Name	Hubbs & Allen	Odum	Knight	This Study
Mugilidae	Striped mullet	*Mugil cephalus*	+	+	+	+
	White mullet	*Mugil curema*		+		
Percidae	Swamp darter	*Etheostoma fusiforme*				+
	Blackbanded darter	*Percina nigrofasciata*	+	+		+
Poeciliidae	Eastern mosquitofish	*Gambusia holbrooki*	+	+		+
	Gambusia sp.	*Gambusia sp*				+
	Least killifish	*Heterandria formosa*		+		+
	Sailfin molly	*Poecilia latipinna*	+	+		+

and was performed beginning around 1730 hours. During this study the observer was towed while holding onto a rope behind the boat and was pulled along three transects, each about 30 minutes, to cover the 1,200 m stretch of spring run. The use of three transects introduced the potential for fish recounts. However, the water clarity was not great enough to see from one bank to the other, and the width of the Silver River was adequate for three transects to be conducted. The use of a single crisscrossed transect would likely underestimate fish abundance due to river width and lower detection with long distances. Most fish encountered during this survey remained in the sample area as the boat and snorkeler approached, with what appeared to be a low occurrence of recounts. Odum (1957) and Knight (1980) both estimated biomass based on their visual estimates (g/m^2). In this study, weights of fishes were estimated based on standard weight equations applied to approximate fish lengths.

Nonetheless, the biomass estimation methods used in this study were similar to Odum (1957) and Knight (1980), allowing a qualitative comparison among studies (Table 6-5). Estimates of total fish biomass were much lower in 2004 (42 kg/ha) than during the studies of Odum (1957) who found 527 kg/ha and Knight (1980) who estimated 115 kg/ha. However, the differences resulted from reductions in relatively few species. For example, Odum (1957) estimated high biomass for striped mullet and catfishes, whereas these species occupied relatively low biomass in this study (Table 6-5). Knight (1980) found that gizzard shad occupied the most biomass of any fish, whereas gizzard shad had low biomass in this survey. Biomass estimates for other species were generally similar among the three studies. Thus, although total fish biomass has declined in the system, the declines resulted from reductions in a few species rather than large changes in biomass across many species.

Table 6-5 Biomass estimates (kg/ha) of fishes in the spring run of Silver River, Florida based on results of visual surveys from Odum (1957), Knight (1980), and this study. Methods used for visual surveys were different among studies. *Anguilla rostrata* was listed as *A. bostoniensis* in Odum (1957). Biomass was derived from grams per meter ^{2} in Odum (1957) and in Knight (1980).

Family	Common Name	Scientific Name	Biomass (kg/ha)		
			Odum	Knight	This Study
Amiidae	Bowfin	*Amia calva*		0.58	2.79
Anguillidae	American eel	*Anguilla rostrata*			0.01
Belonidae	Atlantic needlefish	*Strongylura marina*		0.01	
Catostomidae	Lake chubsucker	*Erimyzon sucetta*		1.97	1.10
Centrarchidae	Redbreast sunfish	*Lepomis auritus*			0.26
Centrarchidae	Bluegill	*Lepomis macrochirus*			10.99
Centrarchidae	Redear sunfish	*Lepomis microlophus*			2.42
Centrarchidae	Spotted sunfish	*Lepomis punctatus*			0.04
Centrarchidae	Sunfish sp.	*Lepomis sp.*	47.62	15.56	
Centrarchidae	Largemouth bass	*Micropterus salmoides*	27.14	18.65	11.10
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*		0.02	0.01
Cichlidae	Blue tilapia	*Tilapia aurea*			0.23
Clupeidae	Gizzard shad	*Dorosoma cepedianum*		66.28	2.57
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*		6.32	0.59
Cyprinodontidae	Golden topminnow	*Fundulus chrysotus*			0.00007
Cyprinodontidae	Bluefin killifish	*Lucania goodei*	18.57		0.002
Esocidae	Chain pickerel	*Esox niger*		1.34	2.61
Ictaluridae	Channel catfish	*Ictalurus punctatus*			0.03
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	1.43		2.06
Lepisosteidae	Florida gar	*Lepisosteus platyrhincus*	44.29	1.33	3.52
Mugilidae	Striped mullet	*Mugil cephalus*	266.67	2.57	1.55
Percidae	Swamp darter	*Etheostoma fusiforme*			0.00007
Poeciliidae	Gambusia sp	*Gambusia sp.*	21.43		0.00003
Poeciliidae	Least killifish	*Heterandria formosa*	3.33		0.00003
	Catfish		95.24		
	Shiners		0.95		0.01
TOTAL FISH BIOMASS			526.7	114.6	41.90

However, the changes between studies represent some shifts in community structure. Odum (1957) and Knight (1980) found a higher proportion of omnivores relative to this study. For example, Odum (1957) reported a high biomass of striped mullet, and Knight (1980) found high biomass of gizzard shad (Table 6-5). Both of those studies resulted in a community structure with about a 1:1 ratio for biomass of omnivores to carnivores. Striped mullet and gizzard shad were observed in this study, but not in high abundance, resulting in an estimated omnivore to carnivore ratio of 1:2. Fish communities in degraded lotic systems tend to shift from carnivores to omnivores (Karr *et al*. 1986), whereas the current analysis revealed the opposite shift between studies at the Silver River due to reductions in omnivore biomass.

The lower biomass of gizzard shad observed in this study was not intuitive, given that the project also found higher nitrate concentrations. Gizzard shad abundance and biomass increases with nutrient levels in Florida lakes (Allen *et al*. 2000), and gizzard shad biomass is typically highest in eutrophic systems with large amounts of phytoplankton and zooplankton. Lower gizzard shad abundance in this study relative to Knight (1980) may have occurred due to temporal movement of gizzard shad into and out of the system rather than changes in the habitat or nutrient concentrations. If nutrients were influencing gizzard shad biomass in this system, one would expect to find higher gizzard shad biomass in this study than in previous estimates. In light of the fact that both Odum's and the present observations consisted of low gizzard shad biomasses, the higher biomass of gizzard shad in Knight's study likely relates to fish movement rather than changes in habitat quality for the species.

In contrast to the visual surveys in this study, spotted sunfish was the most abundant species collected with electrofishing techniques in the samples collected by this team in 2004 (Table 5-17) and in both 1990 samples collected by the Florida Fish and Wildlife Conservation Commission personnel (Table 6-6). Spotted sunfish comprised approximately 50% of the fish collected for each electrofishing sampling date (Table 6-6). Spotted sunfish were not observed on the first two visual survey sampling dates (Tables 5-13 and 5-14), and were the ninth and twelfth most abundant fish species observed on June 4th and 17th, 2004, respectively (Tables 5-15 and 5-16). The visual studies done in the late 1970s (Knight 1980) did not classify the sunfish to species level. Odum (1957) argued that spotted sunfish were not accurately quantified with visual surveys on this spring run because they reside in the *Sagittaria* beds, making them difficult or impossible to observe. His observations were followed up with analysis by Caldwell *et al*. (1957), with collections taken by seine, spear gun, and cast net, in which spotted sunfish as well as largemouth bass were reported to be "by far the most abundant fishes in their respective roles as carnivore and top carnivore." Similarly, despite a low abundance observed by Knight (1980) and during the current visual surveys, spotted sunfish was the most abundant taxon

Table 6-6 Number of fish collected using electrofishing from two historic dates (April 26th and April 27th of 1990) and a recent date (July 22nd of 2004) on the spring run of Silver Springs, Florida

Catch per unit effort (CPUE) is expressed as number of fish collected per minute, with each date having a total of 30 minutes of electrofishing time.

Species	Scientific Name	4/26/1990		4/27/1990		7/22/2004	
		Number	CPUE	Number	CPUE	Number	CPUE
Black crappie	*Pomoxis nigromaculatus*	0	0.00	0	0.00	1	0.03
Blackbanded darter	*Percina nigrofasciata*	3	0.10	6	0.20	0	0.00
Blue tilapia	*Tilapia aurea*	0	0.00	0	0.00	1	0.03
Bluefin killifish	*Lucania goodei*	36	1.20	16	0.53	0	0.00
Bluegill sunfish	*Lepomis macrochirus*	16	0.53	31	1.03	61	2.03
Bowfin	*Amia calva*	7	0.23	0	0.00	3	0.10
Brown bullhead	*Ameiurus nebulosus*	1	0.03	0	0.00	1	0.03
Chain pickerel	*Esox niger*	1	0.03	2	0.07	2	0.07
Coastal shiner	*Notropis petersoni*	9	0.30	0	0.00	0	0.00
Dollar sunfish	*Lepomis marginatus*	0	0.00	4	0.13	0	0.00
Florida gar	*Lepisosteus platyrhincus*	0	0.00	2	0.07	13	0.43
Gambusia	*Gambusia holbrooki*	13	0.43	20	0.67	0	0.00
Lake chubsucker	*Erimyzon sucetta*	0	0.00	3	0.10	11	0.37
Largemouth bass	*Micropterus salmoides*	28	0.93	24	0.80	41	1.37
Least killifish	*Heterandria formosa*	4	0.13	1	0.03	0	0.00
Pirate perch	*Aphredoderus sayanus*	5	0.17	4	0.13	0	0.00
Pygmy sunfish	*Elassoma sp.*	2	0.07	0	0.00	0	0.00
Rainwater killifish	*Lucania parva*	0	0.00	28	0.93	0	0.00
Redbreast sunfish	*Lepomis auritus*	5	0.17	15	0.50	3	0.10
Redear sunfish	*Lepomis microlophus*	11	0.37	5	0.17	19	0.63
Redfin pickerel	*Esox americanus*	1	0.03	0	0.00	0	0.00
Sailfin molly	*Poecilia vigil*	1	0.03	4	0.13	0	0.00
Spotted sunfish	*Lepomis punctatus*	139	0.10	203	6.77	164	5.47
Swamp darter	*Etheostoma fusiforme*	0	0.00	1	0.03	0	0.00
Tadpole madtom	*Noturus gyrinus*	0	0.00	1	0.03	0	0.00
Taillight shiner	*Notropis maculatus*	0	0.00	0	0.00	2	0.07
Warmouth	*Lepomis gulosus*	1	0.03	20	0.67	1	0.03
Yellow bullhead	*Ameiurus natalis*	1	0.03	1	0.03	2	0.07
Total		284	9.47	390	13.00	325	10.83

collected with electrofishing during this study. Visual surveys obviously underestimate spotted sunfish abundance in this system, requiring alternate sampling methods (e.g., electrofishing) to obtain estimates of relative fish community composition.

The total biomass collected with electrofishing was not comparable to the visual surveys due to the fact that the electrofishing transects did not cover the entire sample stretch and were done on a timed basis. However, the relative species composition found between visual surveys and electrofishing in this study was similar to results found by Odum (1957) for visual surveys and quadrat sampling.

The total number of fish caught (325) and the catch per unit effort (10.83 fish/minute) with electrofishing on the July 22nd, 2004 sampling date were between those values of the historic sampling dates of June 26th and 27th in 1990 (284 and 390 fish; 9.47 and 13.00 fish/minute, respectively), suggesting a similar abundance of total number of fish within the system between 1990 and 2004 (Table 6-6). Despite an absence of many of the species found in historical electrofishing data that were not documented in the current electrofishing data, all but two of the species, the coastal shiner (*N. petersoni*) and the dollar sunfish (*L. marginatus*) were present in the visual observations. Neither the coastal shiner nor the dollar sunfish were identified in the studies of Hubbs and Allen (1943), Odum (1957), or Knight (1980).

A qualitative comparison of fish species richness and biomass in this study to those done by Odum (1957), and Knight (1980) indicated similar fish community structure between time periods, with a slight shift toward carnivores due to lower abundance of striped mullet, gizzard shad, and channel catfish. Largemouth bass and sunfish were found in high relative abundance and weight during all studies, including this work. This study revealed evidence that the striped mullet and gizzard shad biomass in Silver Springs may have declined compared to historical values of Odum (1957) and Knight (1980), respectively. The only fish species observed by Knight (1980) that was not present in this study was the Atlantic needlefish (*Strongylura marina*), a fish more commonly found in coastal marine waters (Mettee *et al*. 1996). Like Knight (1980), this team also documented low relative abundance of striped mullet and catfish in the system compared to Odum (1957). The abundance of estuarine fishes such as striped mullet and Atlantic needlefish may have declined in the system following construction of the dam at Rodman Reservoir. However, an American eel, which is a catadromous fish that spawns in saltwater and returns to freshwater for its adult life, was observed during this study. Both the Atlantic needlefish and the American eel were observed by Hubbs and Allen (1943) and Odum (1957). Similarly, striped mullet and Atlantic needlefish have both been observed in the Ocklawaha River downstream of Silver Springs within Rodman Reservoir (authors, personal observation). Occurrence of American eel and other estuarine species in this system suggests that access to the St. Johns River may not be completely obstructed, although the abundance of striped mullet appears to have declined compared to Odum (1957).

Silver Springs is an open system that flows into the Ocklawaha River and is connected downstream to Rodman Reservoir and upstream to the Harris Chain of Lakes. Given the potential for fish to move freely across a large system, fish abundance and community composition likely varies seasonally and across years at the Silver River. The relatively few species shifts observed during this study compared to historical data from up to fifty years ago suggests that large changes in the fish community have not likely occurred.

In addition to the general similarities of the fish community at Silver Springs through time, the system was in the range of fish biomass to phosphorus compared to historical data at other Florida springs. The estimates of total fish standing crop from the four visual sampling dates in the 76,000 square meter sampling region of the Silver River ranged from 26.8 kg/ha to 51.7 kg/ha and averaged 41.9 kg/ha. The phosphorus levels were 55 µg/liter (Donelly and Phlips, personal communication) for this region of Silver Springs. Total fish biomass estimates were similar to values from Alexander Springs (70 µg/liter and 45 kg/ha) and Ichetucknee Springs (60 µg/liter and 48 kg/ha) (Hoyer and Canfield 1991) (Figure 6-8). The methods of estimating total fish standing crops differed between Silver Springs and the other two springs, because of the use of visual counts whereas Hoyer and Canfield (1991) used depletion electrofishing surveys. Nevertheless, comparisons of the total phosphorus and total fish standing crop at Silver Springs to those of Alexander Springs and Ichetucknee Springs indicate that fish biomass is similar among these three springs (Figure 6-8).

6.4.4.5 Summary of Faunal Discussion

These results suggest that the faunal components of the Silver River system have not changed drastically from those described in historical records. A comparison of turtle and bird populations of the 1970s (Florida Game and Freshwater Fish Commission, 1976) to Odum's (1957) work also indicates that major shifts had not occurred. Qualitative comparisons to historical records did not reveal major shifts in turtle, bird, alligator, or fish biomass, species richness, or community composition. Fish biomass estimates conducted by visuals surveys in the 1950s, 1979-80, and 2004-05 found that abundance of at least three dominant fish species (striped mullet, channel catfish, and gizzard shad) were reduced by about 92% over the fifty-year period of record in Silver Springs. Although the alligator counts in this study were lower than those documented by Knight (1980), the difference in sampling at night (his study) versus daytime (this study) likely contributed to this difference. Thus, no indication of large changes in the faunal community composition and abundance were found at the Silver River.

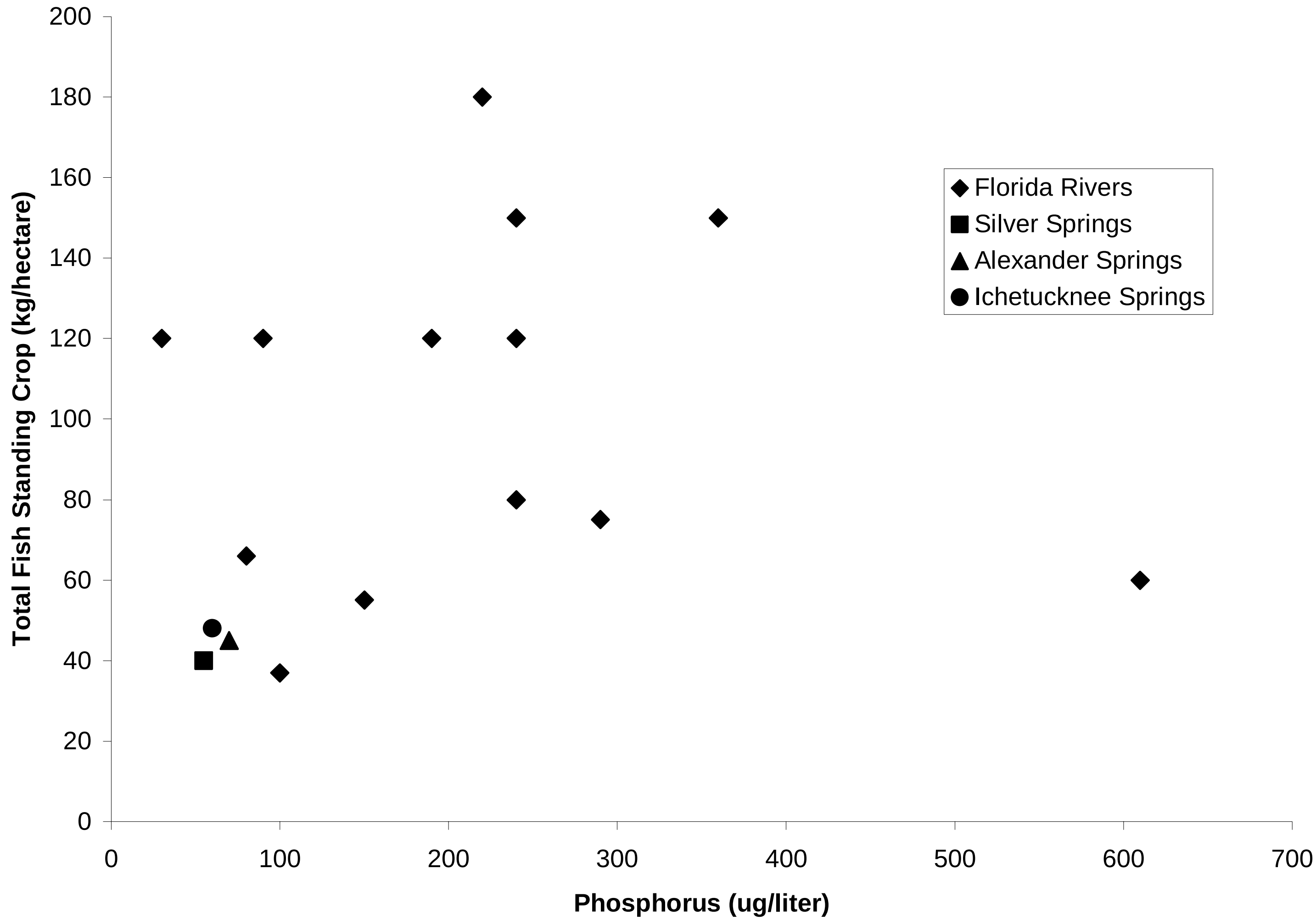


Figure 6-8 Relationship between total fish standing crop and total phosphorus concentrations in Florida rivers and springs

6.4.5 Community Metabolism

One comparison method between these three studies is to overlay the downstream DO measurements recorded by the three studies at the 1,200-m station as described previously in Figures 6-4 through 6-6. Figure 6-7 compares the average DO diurnal curves for 1952-55, 1978-79, and the current study (February 2004 – March, 2005). These curves show some interesting differences. The average maximum daily data reported by Knight (1980) were higher than those reported by Odum (1957) with a peak daily DO concentration of about 5.4 mg/L compared to his value of about 5.0 mg/L. The average maximum daily DO concentration during the current study was lower than both of the previous studies with a value of about 4.8 mg/L. Of more importance, the area under Knight's curve is about 21.6 ppm-hrs compared to Odum's value of 15.5 ppm-hrs, and the WSI value of 19.8 ppm-hrs. These areas provide a fair approximation of the overall ecosystem metabolism and gross primary productivity and can be converted to g $O_2/m^2/d$ by multiplying by the average flow rate and dividing by 24 times the average area. The Knight (1980) curve has an area in ppm-hrs that is about 40% higher than the earlier data reported by Odum. The WSI curve also has a larger area than Odum's (about 28% higher) and lower than Knight's (8% lower). However, the relative order of these estimates is rearranged when corrected for the significant change in the area of the upper 1,200-m section of the Silver River with the completion of the Back Channel in about 1979 (from about 89,200 m^2 in Odum's time to about 116,750 m^2 during Knight's and WSI's studies).

Table 6-7 summarizes all of the observed community metabolism differences in Silver Springs over the past fifty years. NPP24 and R24 followed a similar pattern to GPP. PAR efficiency was also reduced during this time period. There was no significant reduction in estimated P/R ratio observed over this time period.

Table 6-8 summarizes the Silver Springs GPP estimates by month for the current study using the original DO concentration data measured by Odum and Knight but with the updated spring run area and flow data. Figure 6-9 updates the seasonal comparison of GPP values published earlier by Knight (1980) applying the same assumptions and calculation algorithms to all three data sets.

Estimated GPP was approximately the same during the studies by Odum (1957) and Knight (1980), and lower throughout the annual period based on the data collected during the current work. Corrected annual average estimates for the three time periods were: 1952-55 – 15.7 g $O_2/m^2/d$; 1978-79 – 15.6 g $O_2/m^2/d$; and 2004-05 – 11.4 g $O_2/m^2/d$.

Net ecosystem primary productivity was directly estimated from plant and particulate export rates measured at the 1,200-m station. These values were used to help adjust DO accrual rates which were not directly measured. This correction factor means that estimates of NPP24 and

Table 6-7 Silver Springs Run metabolism summary

Parameter	Odum 1952-1955	Knight 1979-1980	WSI 2004-2005
GPP (g O_2/m^2/d)			
Average	15.75	15.64	11.37
Maximum	24.41	23.43	17.63
Minimum	10.10	7.83	0.61
Std Error	1.90	1.72	0.168
N	7	9	373
NPP (g O_2/m^2/d)			
Average	1.02	0.80	0.42
Maximum	10.76	8.40	8.93
Minimum	-6.86	-6.71	-11.51
Std Error	2.35	1.80	0.183
N	7	9	373
R (g O_2/m^2/d)			
Average	14.73	14.84	10.95
Maximum	17.09	17.45	16.44
Minimum	10.26	13.37	-0.05
Std Error	0.91	0.47	0.08
N	7	9	373
P/R Ratio			
Average	1.11	1.06	1.06
Maximum	1.79	1.56	3.00
Minimum	0.60	0.54	0.05
Std Error	0.16	0.12	0.02
N	7	9	372
PAR Efficiency (%)			
Average	8.82	8.53	7.63
Maximum	12.32	12.11	21.86
Minimum	6.41	4.92	0.57
Std Error	0.85	0.75	0.16
N	7	9	373
GPP Efficiency (g O_2/mol)			
Average	1.09	1.06	0.95
Maximum	1.53	1.50	2.71
Minimum	0.79	0.61	0.07
Std Error	0.11	0.09	0.02
N	7	9	373

Table 6-8 Preliminary comparison of Silver Springs gross primary productivity estimates

Odum (1957)		Knight (1980)		WSI (this study)	
Date	GPP ($gO_2/m^2/d$)	Date	GPP ($gO_2/m^2/d$)	Date	GPP ($gO_2/m^2/d$)
2/19/1953	12.4	8/31/1978	19.3	Feb-04	8.2
3/7/1953	14.0	10/5/1978	13.6	Mar-04	11.4
3/25/1953	17.5	12/13/1978	7.8	Apr-04	13.2
1/7/1954	10.1	3/7/1979	10.7	May-04	13.9
5/23/1954	24.4	4/15/1979	16.8	Jun-04	12.7
7/12/1955	12.1	5/16/1979	23.4	Jul-04	13.6
8/11/1955	19.7	6/19/1979	20.7	Aug-04	12.3
		7/17/1979	11.2	Sep-04	10.9
		8/15/1979	17.1	Oct-04	11.7
				Nov-04	9.8
				Dec-04	8.5
				Jan-05	8.6
				Feb-05	11.1
				Mar-05	10.8
Average	**15.7**		**15.6**		**11.2**

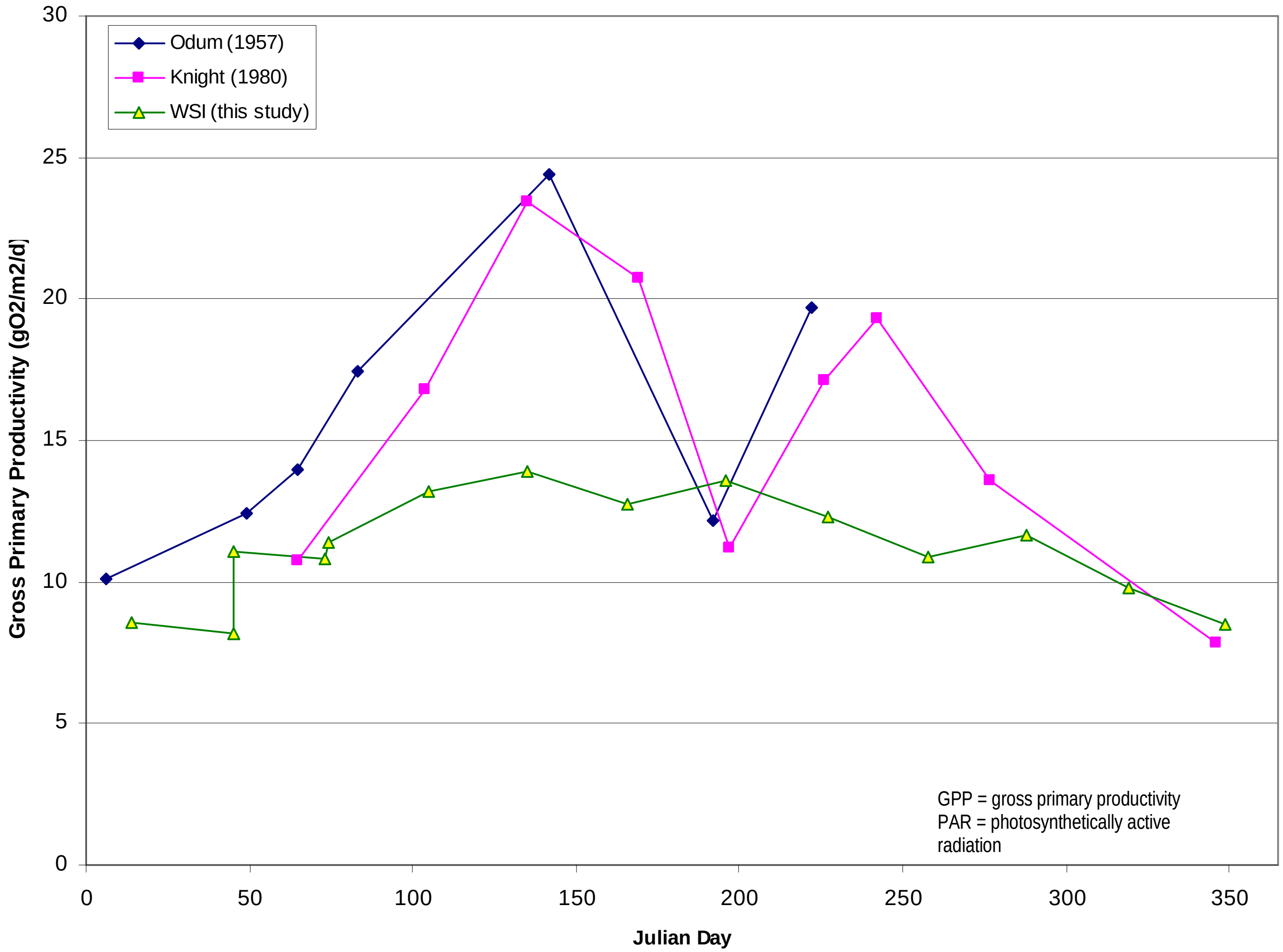


Figure 6-9 Comparison of Silver Springs ecosystem metabolism from the early 1950s (Odum, 1957), late 1970s (Knight, 1980), and this study

R24 are subject to more potential error than the GPP estimates and therefore must be used with some caution when developing conclusions about the ecological health of the Silver River.

Figure 6-10 compares the estimated relationships between GPP and PAR for the three study periods. This data comparison indicates that the overall shape of the GPP efficiency curve has changed in addition to the observed change in average efficiency values.

6.4.6 Downstream Floating Plant and Particulate Export

Odum (1957) measured the export of floating and drifting SAV from Silver Springs on three occasions in January and March 1953. He recorded a dry weight export of 5.18 kg dw/d at the 1,200-m station. The current study estimated macrophyte export as about 22.4 kg dw/d, which is more than four times greater than the export rates reported by Odum. Once again Odum's plant export rates were based on very limited sampling. It is possible that within the sample variability observed in this study that these estimates are not statistically different.

Odum (1957) reported an estimated particulate export rate at the 1,200-m station of about 2.40 g dw/m^2/d based on his main channel area of about 76,000 m^2. This average included only four data points with a coefficient of variation of about 34%. In this current study a much lower average particulate export rate was measured at this station, about 0.67 g dw/m^2/d based on the larger area that includes both the main channel and Back Channel of 116,750 m^2. This is about 27 to 42% of the average rate Odum reported based on whether or not an area correction is applied.

The average 2004-2005 combined plant and fine particulate matter export rate is about 0.86 g dw/m^2/d based on the full area of the main channel and Back Channel. Odum (1957) estimated downstream export as about 2.1 g dw/m^2/d based only on the main channel area.

6.5 Ecosystem Level Changes

In all of these comparisons of ecosystem metabolism changes at Silver Springs it must be remembered that the current study had many more diurnal curves than the previous studies and that those curves more fully document the full annual pattern of sunlight inputs, flows, and resulting dissolved oxygen concentrations. For this reason alone differences are expected. Year-to-year variability in light, rain, and flows will also cause variation in metabolism comparisons. Based on this perspective it is likely that some portion of the observed differences is more or less caused by annual and long-term climatic changes and normal environmental variability.

Since nitrate nitrogen is the only chemical nutrient that has significantly changed (increased) in concentration at Silver Springs over this time period (approximately doubled from about 0.46

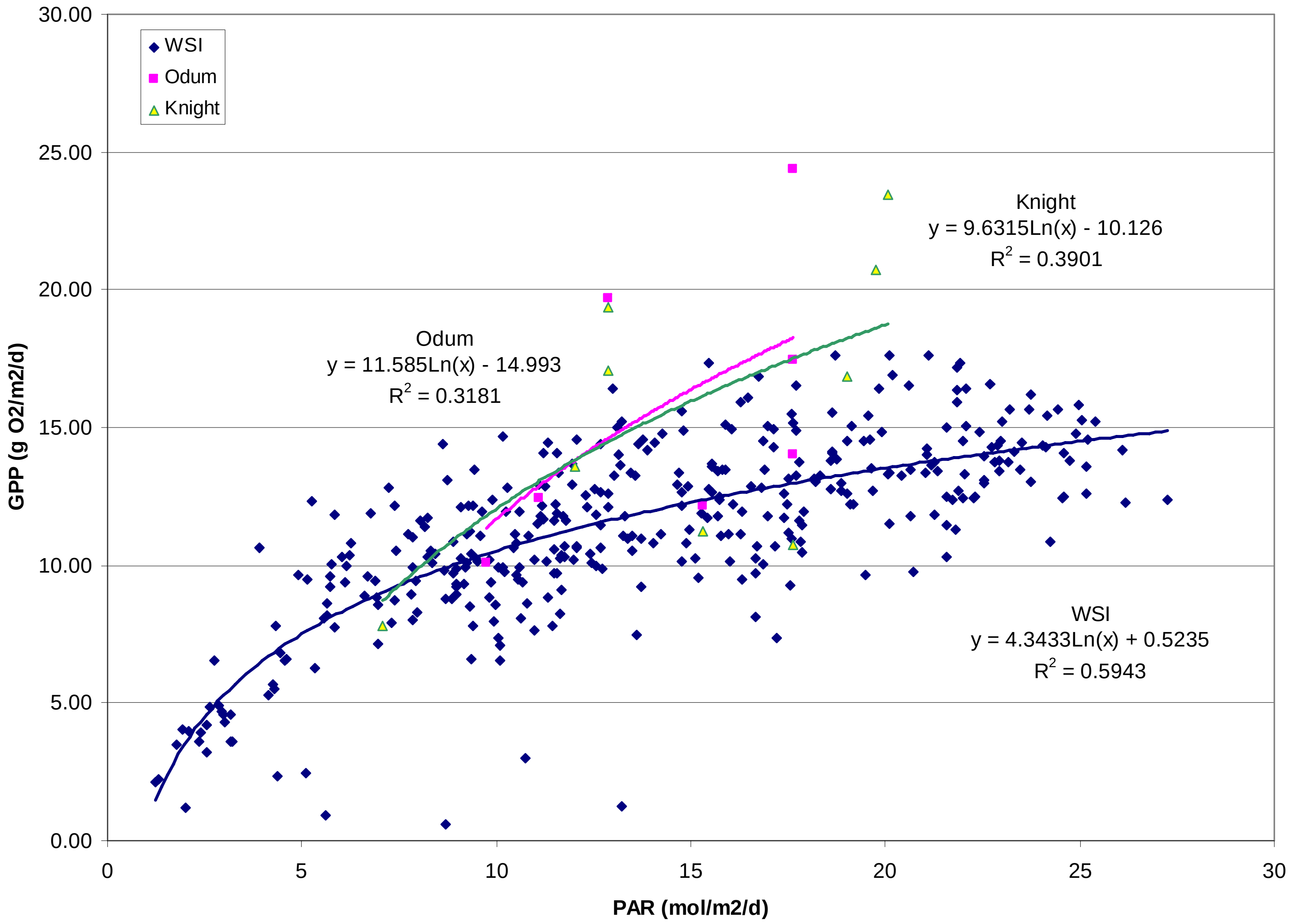


Figure 6-10 Silver Springs PAR/GPP relationship as estimated based on GPP from Odum (1957), Knight (1980), and WSI and based on WSI PAR data

mg/L in the early 1950s to greater than 1.1 mg/L in 2004), it is hypothesized that the increasing concentration of that form of nitrogen is the principal causative factor for any observed changes in ecosystem metabolism. The declining flow rate during the past fifty years at Silver Springs may also be a contributing factor to the detected ecological changes.

Both the direct measurements and the estimated system metabolism analyses indicate that the Silver Springs ecosystem may be producing considerably less fixed organic matter than it was fifty years ago. This does not appear to be a consequence of higher community respiration but rather a result of lowered gross primary productivity and efficiency of light utilization. This result appears to be counter-intuitive to the observation that plant growth nutrient levels (nitrate nitrogen) have increased in Silver Springs. It is generally thought that an increase in nutrients will stimulate both gross and net primary productivity in aquatic ecosystems (Wetzel 2001). However in a balanced aquatic ecosystem previously supplied with adequate nutrients to maximize community metabolism, an increase of nutrients may result in a stress rather than a subsidy (Odum *et al.* 1979).

Another factor long recognized as having an important impact on the Silver River fish populations and therefore the entire aquatic ecosystem is the Rodman Dam on the Ocklawaha River downstream. Both Knight (1980) and Odum (1976) implicated the dam in changing populations of seagoing fish species through physical blockage of their migrations and breeding success. Odum suggested that the U.S. Army Corps of Engineers construct a fish ladder around the dam while Knight proposed testing his theories about consumer control by removing the dam entirely.

The apparent decline in ecosystem metabolism and efficiency observed in Silver Springs over the past fifty years could be the result of a number of ecosystem-level factors working in concert or at odds. Four preliminary hypotheses are offered to explain these observations:

- Decreased usable solar radiation is reaching the level of submerged aquatic plants in Silver Springs due to increased shading by a growing tree canopy (natural wetland forest succession) along the river and this reduced input of solar energy may have lowered GPP and PAR efficiency
- GPP may have declined as areas of optimal submerged aquatic vegetation growth (*Sagittaria* beds with adapted periphytic algae) have been replaced with benthic algal mats, possibly due to increasing nitrate nitrogen concentrations, flow decreases, or physical factors related to human uses

- Decreases in flow rate and water velocities due to natural climatic conditions or consumptive groundwater uses may have reduced the previous subsidy needed for maximum plant/periphyton growth and higher GPP and PAR efficiency
- Decreased consumer control of the primary producers and lowered GPP is resulting from lower fish/consumer populations below optimal grazing densities, possibly due to obstruction of fish migration by the Rodman Dam, lower minimum daily dissolved oxygen concentrations, or due to indirect effects of nitrate on consumers

Decreased light transmittance due to increased turbidity (lower secchi distance and higher light attenuation coefficients) is not considered to be a reasonable hypothesis to explain the observed ecosystem changes during the past fifty years because available data for particulate export rates measured by Odum (1957) were considerably higher than those documented during this study.

Future studies will be needed to determine the most important processes at work at Silver Springs and to better understand the actual effects of nutrient enrichment and climatic variability. Continued monitoring of the plant communities and ecosystem-level parameters would appear to be the most cost-effective approach to establishing trends in the health of the Silver Springs ecosystem.

6.6 Summary of Observed Changes

A summary of the apparent changes that have occurred at Silver Springs during the past fifty years includes the following:

- Average discharge rates were about 13% lower during the current study compared to flows fifty years ago when Odum and other University of Florida researchers conducted their studies.
- Horizontal secchi distance has decreased and vertical light attenuation coefficients have increased during the past fifty years.
- Nitrate nitrogen concentration has increased from an average of about 0.38 to 1.05 mg/L during this same time interval.
- Although Sagittaria kurziana is still the dominant submerged aquatic macrophyte found in this portion of the Silver River, measured average annual biomass was about 21% lower in the current study compared to the 1952-55 period.
- Average annual epiphytic (attached) algal biomass increased by about 171% over this period.

- Benthic algal mass was considered to be too low to estimate by Odum in the early 1950s, but was noted later by Odum to be much higher in the Main Spring Boil during a 1976 class field trip to Silver Springs. The present study found benthic algal biomass to be comparable to macrophyte and epiphytic biomass estimates.
- Average annual plant and algal biomass increased 88% over the past fifty years, from 809 g DW/m2 in 1952-55 to 1,518 g DW/m2 in 2004-05.
- Although Sagittaria kurziana was still found to be the dominant species in floating downstream macrophyte export, estimated export rates were found to be 179% higher during the current study compared to Odum's measurements during the 1952-55 period.
- Average particulate export rates were found to be 72% lower during the current study compared to data published by Odum (1957).
- Although daily emergence of aquatic insects still occurs at Silver Springs year-around as previously observed by Odum (1957) and Knight (1980), measured rates of emergence were less during the current study with an apparent decrease of about 72% since the early 1950s.
- Visual observations of turtles present in Silver Springs found that dominant populations of cooters observed during the early 1950s were still present as were smaller populations of soft shelled turtles. Musk turtles were observed during the Odum study; although they were not observed in the present study they are likely to still be present in the spring (K. Bjorndal, UF Zoology, personal communication).
- Alligator populations were not estimated by Odum in the 1950s but were estimated at a nighttime density of about 3.4/ha by Knight (1980) and at a daylight density of 0.91/ha during the current study.
- Populations of fish-eating birds such as the double-crested cormorant have apparently increased at Silver Springs since the 1950s study period.
- Largemouth bass and bluegill sunfish continue to be among the most dominant larger fish present in Silver Springs based on data during the past fifty years.
- Catfish and mullet populations were very high in Silver Springs fifty years ago and had largely disappeared during Knight's 1978-79 study and were observed at low abundance in the current study.
- Knight found gizzard shad to be the most abundant fish species twenty-five years ago, while the current study found much lower populations of this species.

- Overall estimated annual average fish live-weight biomass has declined in Silver Springs since Odum's study in the early 1950s. Knight's 1978-1979 study found a 78% decline in total fish biomass, and this study revealed a 92% decline compared to Odum's work. These reductions were due to large declines in a few species (i.e., catfish, mullet), and most species were of similar total biomass between the three time periods.
- Annual average gross primary productivity declined from about 15.6 g O2/m2/d in the 1950s and late 1970s to about 11.4 g O2/m2/d during the current study, a decline of about 27%.
- Community respiration also declined from about 14.8 g O2/m2/d during the earlier studies to about 10.9 g O2/m2/d during the current study, a 26% reduction.
- Resulting net community primary productivity declined from about 1.0 g O2/m2/d in the 1950s, to 0.80 g O2/m2/d in the late 1970s, to about 0.42 g O2/m2/d during the current study, a decline of about 59% over the past fifty years.
- P/R ratio remained relatively consistent between the three studies, ranging from about 1.11 during Odum's 1950s' study to about 1.06 during Knight's study in the late 1970s, and 1.06 in the current study.
- Ecological efficiency declined from about 1.09 g O2/mol of Photosynthetically Active Radiation (PAR) during Odum's study to about 0.94 g O2/mol of PAR during the current study, a decline of about 13%.

7.0 Future Conditions

7.1 Introduction

Results from this study indicate that Silver Springs has undergone some significant changes since it was previously studied by Odum (1957) and Knight (1980). Based on this conclusion it can be safely surmised that this important spring ecosystem is not in a true steady state and will continue to change as an indirect result of surrounding land use changes and in light of variable environmental forcing functions. This section attempts to foresee some of the future changes that may occur at Silver Springs and to assess the possible magnitude of those changes based on projected land use changes in the springshed.

7.2 Spatial Land Use Model

Performance of the spatial land use model was assessed against observed nutrient loading rates (Table 7-1). These comparisons show that the model predictions fared well against the observed values. The large discrepancies seen in 1957 may be attributed to measuring differences. At the time of the 1957 observations, the samples were extracted near the Main Spring Boil. It has since been documented that there are several discharge areas along the run. Since 1957, samples have been collected at the 1,200-m station.

A projected Land Use/Land Cover (LULC) feature class for the year 2055 was provided to the SJRWMD by GIS Associates. The feature class was created as part of a population and water use projection for Marion County. This class can be more precisely defined as a population density map. It was, however, the only data available with any indication of future land use. The loading rates were applied to the features in the 2055 dataset (Table 7-2).

The results produced by the spatial land use model are presented in Table 7-3. The model predicts an 84% increase in the nitrogen levels in the spring. The actual values in 2055 are not likely to match those predicted by the model for several reasons. To begin, future land use designations and county future land use plans are continually being modified. Further, any actions taken by local governments to control nitrogen discharges will alter the loading rate. Currently there is a growing movement toward “Best Management Practices” (BMPs) by Marion County (the source for the nitrogen loading estimates used in the model). Further, there is also a growing concern over the abundance and continuing use of septic tanks as the primary sanitary sewer disposal method within the springshed. Any change to BMPs or decrease in the use of septic tanks will cause a divergence from the current nitrogen loading trend at the Silver Springs Complex.

Table 7-1 Performance assessment of the Spatial Land Use Model against observed nutrient loading rates in the Silver Springs two-year groundwater capture zone

Year	Observed Spring Flow	MODFLOW Simulated Spring Flow	Observed Nitrogen Load (lbs/yr)	Land Use / Land Cover Model Est N Load (lbs/yr)	Observed Spring Nitrogen Concentration (mg/L)	Land Use / Land Cover Model Estimated N Concentration (mg/l)
1957	640.0	716.5	94,416.0	399,054.10	0.10	0.38
1979	778.0	710.8	814,898.6	802,633.06	0.71	0.76
1995	720.0	708.3	955,962.0	1,036,198.93	0.90	0.99
2005	680.0	687.6	1,057,606.7	1,120,813.63	1.07	1.10

Year	Percent Differences (lbs/yr)	Percent Differences Mg/L Concentration
1957	322.7	2.8
1979	1.5	0.1
1995	8.4	0.1
2005	5.6	0.0

Note: Observations were made in Nitrogen Concentration. Model Predictions were in lbs/yr.
Calculations were used to return values for both values.
Calculations
mg/L = N Lbs Per Year / (1968.74 * (0.75 * Spring Flow))
As noted, Modeling showed that the capture zone represented 75% of the Flow at the Complex

Table 7-2 Observed Nitrogen Loading Rates Applied to Projected Land Use Sectors in the Silver Springs two-year Capture Zone for the Year 2055

2055 Land Use	Nitrogen Loading Rate (lbs/Acre)
AGRICULTURE	48.25
COMMERCIAL	
CONSERVATION	
COUNTY	
FORESTED & VEGETATED	0.57
GOVERNMENT	
GOLF COURSES	260.00
HIGH DENSITY RESIDENTIAL	29.60
HIGH IMPACT URBAN	
INDUSTRIAL	
LOW DENSITY RESIDENTIAL	14.80
LOW IMPACT URBAN	
MED DENSITY RESIDENTIAL	66.00
MEDIUM DENSITY RESIDENTIA	66.00
MULTI-FAMILY HIGH	29.60
MULTI-FAMILY MEDIUM	66.00
PROFESSIONAL OFFICE	
PUBLIC	
RECREATION	
RURAL RESIDENTIAL	14.80
URBAN COMMERCE DISTRICT	
URBAN NEIGHBORHOOD DISTRICT	

Table 7-3 Spatial Land Use Model Results for the Silver Springs Two-Year Capture Zone

Year	Observed Spring Flow (cfs)	MODFLOW Simulated Spring Flow (cfs)	Observed Nitrogen Load (lbs/yr)	Land Use / Land Lover Model Est N Load (lbs/yr)	Observed Spring Nitrogen Concentration (mg/L)	Land Use / Land Cover Model Estimated N Concentration (mg/l)
1957	640.0	716.5	94,416.0	399,054.10	0.10	0.38
1979	778.0	710.8	814,898.6	802,633.06	0.71	0.76
1995	720.0	708.3	955,962.0	1,036,198.93	0.90	0.99
2005	680.0	687.6	1,057,606.7	1,120,813.63	1.07	1.10
2055	NA	589.1		1,760,000.00	N/A	2.02

N Concentration Change (Model Predictions)	
1957 -1979	102.75%
1979 - 1995	29.56%
1995 - 2005	11.42%
2005 - 2055	83.64%

It should also be noted that the observed values were not known to the individual who created the model, in order to minimize bias. These predictions represent the only set of predictions done for this study. Future analysis and refinement of the expected loading rates and methodologies for determining land use in years prior to 1992 may show the correlation between model predictions and observations were due wholly to chance. Only time will tell.

7.3 Linked Landscape/Ecosystem Model

A number of parameters estimated through the fifty-year time span at the Silver River were correlated with changes in nitrates and discharge (Table 7-4). A series of correlations were constructed using the key data collected by Odum (1957), Knight (1980), and the current study. The resulting correlation coefficients are summarized in Table 7-5. Nitrate concentrations have risen steadily as percent developed land in the springshed has increased (R = 0.98). Nitrate concentration is inversely correlated with spring discharge, with lower concentrations associated with higher spring flows (R = -0.80).

General biological metrics measured in Silver Springs during the past fifty years that were negatively correlated with nitrate nitrogen concentrations were:

- insect emergence
- particulate export
- total fish density and biomass

Table 7-4 Silver Springs annual nitrate-nitrogen loading rate data comparison with other system level metrics

Parameter	Units	1949-1957	1964	1972	1978-1979	1989	1995	2004-2005	2055
MODFLOW Simulated Spring Flow	m^3/d	1,752,972			1,739,026		1,732,910	1,682,266	1,441,278
Measured Discharge	m^3/d	1,895,331	2,135,152	1,802,311	1,888,140	1,787,690	1,731,023	1,643,377	
Land Use / Land Cover Model Estimated NO3-N Concentration	mg/L	0.349			0.765		0.991	1.10	2.02
Measured NOx-N Concentration	mg/L	*0.384*	0.410	0.547	0.667	0.935	*0.905*	1.05	
Land Use / Land Cover Model Est NO3-N Load	kg/yr	167,295	216,410	260,677	364,068	430,263	470,012	508,393	798,336
% Developed	%	23.10	30.56	36.5	46.8	54.0	57.0	61.4	84.10
Insect Emergence	#/m^2/d	236						66.9	***0.00***
	g/m^2/d	0.010							
Macrophyte Export	dry g/m^2/d	0.068						0.190	***0.367***
Particulate Export	dry g/m^2/d	2.41						0.666	***0.00***
	AFDW g/m^2/d							0.292	
Fish Density	#/m^2	12.2			0.026			0.064	
Fish Biomass	wet g/m^2	52.7			10.8			4.19	***0.750***
	dry g/m^2	10.5			*2.16*			0.838	***0.150***
Epiphytic Algal Mass	dry g/m^2	188						509	***974***
	AFDW g/m^2							193	
Macrophyte Biomass	dry g/m^2	621						492	***304***
	AFDW g/m^2							363	
Benthic Algal Mat Biomass	dry g/m^2							517	
	AFDW g/m^2							225	
GPP	g O_2/m^2/d	15.7			15.6			11.4	***5.25***
NPP	g O_2/m^2/d	1.02			0.804			0.421	***-0.438***
R	g O_2/m^2/d	14.7			14.8			10.9	***5.69***
P/R Ratio	ratio	1.11			1.06			1.06	***1.02***
PAR Efficiency	%	8.82			8.53			7.63	***5.94***
GPP Efficiency	g O_2/mol	1.09			1.06			0.945	***0.735***

1949-1957 & 1995 NO3-N Concentration values estimated
*2055 estimates are calculated from NOx-N regressions (**bold, italics**)*
1978-1979 & 2004-2005 estimated Fish Biomass dry weight = 0.2 x Fish Biomass wet weight

Table 7-5 Silver Springs annual nitrate-nitrogen concentration and discharge regressions with other system level metrics

Parameter	Units	Equation	R^2	N	Range	
NOx-N						
% Developed	**%**	y = 0.0181x - 0.1002	0.957	7	23.10	61.4
Avg Annual Discharge	**cfs**	y = -0.0034x + 3.2363	0.650	7	672	873
Insect Emergence	**#/m²/d**	y = -253.06x + 333.25	1.00	2	66.9	236
Macrophyte Export	**dry g/m²/d**	y = 0.1826x - 0.0022	1.00	2	0.068	0.190
Particulate Export	**dry g/m²/d**	y = -2.6024x + 3.4051	1.00	2	0.666	2.41
Fish Biomass	**wet g/m²**	$y = 4.4308x^{-2.5255}$	0.992	3	4.19	52.7
Epiphytic Algal Mass	**dry g/m²**	y = 480.38x + 3.3911	1.00	2	188	509
Macrophyte Biomass	**dry g/m²**	y = -193.8x + 695.48	1.00	2	492	621
GPP	**g O_2/m²/d**	y = -6.8245x + 19.038	0.839	3	11.4	15.7
NPP	**g O_2/m²/d**	y = -0.8988x + 1.3774	0.995	3	0.421	1.02
R	**g O_2/m²/d**	y = -5.9257x + 17.661	0.804	3	10.9	14.8
P/R Ratio	**ratio**	y = -0.0522Ln(x) + 1.0541	0.840	3	1.06	1.11
PAR Efficiency	**%**	y = -1.8143x + 9.6006	0.962	3	7.63	8.82
GPP Efficiency	**g O_2/mol**	y = -0.2247x + 1.1892	0.962	3	0.945	1.09
Discharge						
% Developed	**%**	y = -3.282x + 897.29	0.550	7	23.10	61.4
Insect Emergence	**#/m²/d**	y = 1.642x - 1036.1	1.00	2	66.9	236
Macrophyte Export	**dry g/m²/d**	y = -0.0012x + 0.9857	1.00	2	0.068	0.190
Particulate Export	**dry g/m²/d**	y = 0.0169x - 10.677	1.00	2	0.666	2.41
Fish Biomass	**wet g/m²**	$y = 3E\text{-}05e^{0.0175x}$	0.640	3	4.19	52.7
Epiphytic Algal Mass	**dry g/m²**	y = -3.117x + 2602.7	1.00	2	188	509
Macrophyte Biomass	**dry g/m²**	y = 1.2575x - 353.17	1.00	2	492	621
GPP	**g O_2/m²/d**	y = 0.0426x - 17.277	1.00	3	11.4	15.7
NPP	**g O_2/m²/d**	y = 0.0049x - 2.8527	0.891	3	0.421	1.02
R	**g O_2/m²/d**	y = 0.0378x - 14.424	0.998	3	10.9	14.8
P/R Ratio	**ratio**	$y = 0.8896e^{0.0003x}$	0.326	3	1.06	1.11
PAR Efficiency	**%**	y = 0.0103x + 0.6793	0.955	3	7.63	8.82
GPP Efficiency	**g O_2/mol**	y = 0.0013x + 0.0841	0.955	3	0.945	1.09

NOx-N Range: 0.38 - 1.05 mg/L
Discharge Range: 672 - 873 cfs

- macrophyte biomass, and
- all estimates of ecosystem metabolism (GPP, NPP24, R24, P/R ratio, and ecological efficiency)

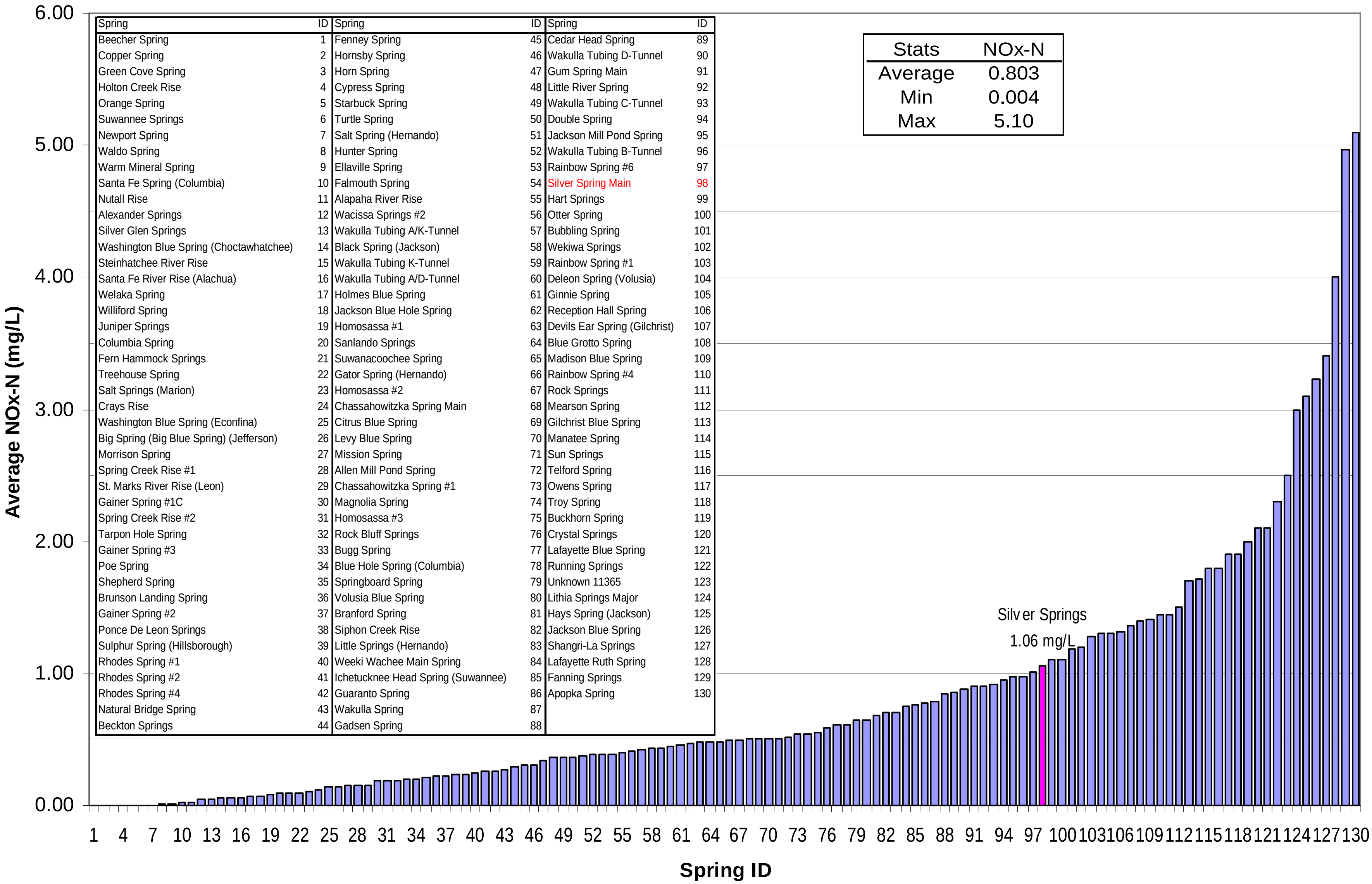
Ecological metrics that were positively correlated with nitrate nitrogen concentrations included only macrophyte export and epiphytic algal biomass. Due to the inverse correlation between discharge and nitrate, the relationship of the dependent variables listed above demonstrated reversed trends when correlated with discharge. These relationships do not infer cause-and-effect, as this research team is unable to conclude whether nitrate and discharge changes at the Silver River caused the observed changes. Nevertheless, the association of flora and fauna communities to nitrate and discharge changes is noteworthy and could mean that more changes are likely in the future. These estimates should provide concern for environmentalists and resource managers about the future ecosystem health of this important natural attraction.

7.4 Comparison to Florida Reference Springs

There are an estimated seven hundred named springs in Florida (Scott *et al.* 2004) and thirty-three of those are first magnitude springs in the same class as Silver Springs (Rosenau *et al.* 1977). Many of those springs have increasing nitrate concentrations, decreasing discharge rates, and various signs of ecological stress. In this section we compare the observations described in Section 6 for ecological changes at Silver Springs to changes documented at other Florida springs with a variety of water qualities and environmental stressors. The purpose of this comparison is to see if it is possible to substantiate any of the observations reported for Silver Springs over the past fifty years and to provide validation for the 2055 model predictions summarized in Section 7.3.

Figure 7-1 illustrates the observed range of nitrate nitrogen concentration data for a large number of the studied springs in Florida. This figure illustrates the fact that while Silver Springs is nowhere near the most polluted spring in Florida with respect to nitrate concentrations, it is well above the average concentrations and in the 75th percentile of the springs listed in this analysis. The median nitrate nitrogen concentration in this select group of Florida springs is about 0.5 mg/L, while the lowest recorded nitrate concentrations, in Florida springs located in isolated areas, are typically less than 0.05 mg/L.

The land use analysis described previously indicates that based on expected urban development rates in the Silver Springs springshed, the average nitrate nitrogen concentration can be expected to be about 2.02 mg/L by 2055. This concentration is in the 88th percentile on Figure 7-1. Other named springs that are in this nitrate concentration range or higher include: Gilchrist Blue, Manatee, Sun, Telford, Owens, Troy, Buckhorn, Crystal, Lafayette Blue, Running, Lithia, Hays, Jackson Blue, Shangri-La, Lafayette Ruth, Fanning, and Apopka. Unfortunately, none of these springs have been subjected to detailed ecological studies such as those described in this report for Silver Springs. However some measurements have been made and reported for several of them and for other springs with nitrate concentrations lower than observed in Silver Springs.



Spring	ID	Spring	ID	Spring	ID
Beecher Spring	1	Fenney Spring	45	Cedar Head Spring	89
Copper Spring	2	Hornsby Spring	46	Wakulla Tubing D-Tunnel	90
Green Cove Spring	3	Horn Spring	47	Gum Spring Main	91
Holton Creek Rise	4	Cypress Spring	48	Little River Spring	92
Orange Spring	5	Starbuck Spring	49	Wakulla Tubing C-Tunnel	93
Suwannee Springs	6	Turtle Spring	50	Double Spring	94
Newport Spring	7	Salt Spring (Hernando)	51	Jackson Mill Pond Spring	95
Waldo Spring	8	Hunter Spring	52	Wakulla Tubing B-Tunnel	96
Warm Mineral Spring	9	Ellaville Spring	53	Rainbow Spring #6	97
Santa Fe Spring (Columbia)	10	Falmouth Spring	54	Silver Spring Main	98
Nutall Rise	11	Alapaha River Rise	55	Hart Springs	99
Alexander Springs	12	Wacissa Springs #2	56	Otter Spring	100
Silver Glen Springs	13	Wakulla Tubing A/K-Tunnel	57	Bubbling Spring	101
Washington Blue Spring (Choctawhatchee)	14	Black Spring (Jackson)	58	Wekiwa Springs	102
Steinhatchee River Rise	15	Wakulla Tubing K-Tunnel	59	Rainbow Spring #1	103
Santa Fe River Rise (Alachua)	16	Wakulla Tubing A/D-Tunnel	60	Deleon Spring (Volusia)	104
Welaka Spring	17	Holmes Blue Spring	61	Ginnie Spring	105
Williford Spring	18	Jackson Blue Hole Spring	62	Reception Hall Spring	106
Juniper Springs	19	Homosassa #1	63	Devils Ear Spring (Gilchrist)	107
Columbia Spring	20	Sanlando Springs	64	Blue Grotto Spring	108
Fern Hammock Springs	21	Suwanacoochee Spring	65	Madison Blue Spring	109
Treehouse Spring	22	Gator Spring (Hernando)	66	Rainbow Spring #4	110
Salt Springs (Marion)	23	Homosassa #2	67	Rock Springs	111
Crays Rise	24	Chassahowitzka Spring Main	68	Mearson Spring	112
Washington Blue Spring (Econfina)	25	Citrus Blue Spring	69	Gilchrist Blue Spring	113
Big Spring (Big Blue Spring) (Jefferson)	26	Levy Blue Spring	70	Manatee Spring	114
Morrison Spring	27	Mission Spring	71	Sun Springs	115
Spring Creek Rise #1	28	Allen Mill Pond Spring	72	Telford Spring	116
St. Marks River Rise (Leon)	29	Chassahowitzka Spring #1	73	Owens Spring	117
Gainer Spring #1C	30	Magnolia Spring	74	Troy Spring	118
Spring Creek Rise #2	31	Homosassa #3	75	Buckhorn Spring	119
Tarpon Hole Spring	32	Rock Bluff Springs	76	Crystal Springs	120
Gainer Spring #3	33	Bugg Spring	77	Lafayette Blue Spring	121
Poe Spring	34	Blue Hole Spring (Columbia)	78	Running Springs	122
Shepherd Spring	35	Springboard Spring	79	Unknown 11365	123
Brunson Landing Spring	36	Volusia Blue Spring	80	Lithia Springs Major	124
Gainer Spring #2	37	Branford Spring	81	Hays Spring (Jackson)	125
Ponce De Leon Springs	38	Siphon Creek Rise	82	Jackson Blue Spring	126
Sulphur Spring (Hillsborough)	39	Little Springs (Hernando)	83	Shangri-La Springs	127
Rhodes Spring #1	40	Weeki Wachee Main Spring	84	Lafayette Ruth Spring	128
Rhodes Spring #2	41	Ichetucknee Head Spring (Suwannee)	85	Fanning Springs	129
Rhodes Spring #4	42	Guaranto Spring	86	Apopka Spring	130
Natural Bridge Spring	43	Wakulla Spring	87		
Beckton Springs	44	Gadsen Spring	88		

Figure 7-1 Average NOx-N Concentrations for Florida Springs With a Comparison to Silver Springs In Marion County

Strong (2004) examined temporal trends in water quality characteristics in 109 Florida springs. Parameters that were generally found to be increasing were specific conductance, alkalinity, hardness, and nitrate nitrogen. Only pH concentrations were observed to be declining. There were no apparent trends in phosphorus concentrations. Mean nitrate concentrations in his spring samples generally increased from about 0.43 mg/l before 1977 to about 1.13 since 1990. This study indicates that water quality changes documented at Silver Springs are typical of state-wide trends.

Odum (1957) made nitrate and gross primary productivity (GPP) measurements in eleven Florida springs in 1955. He found a weak but negative relationship between nitrate concentration and GPP ($R^2 = 0.14$). One of the eleven Florida springs studied by Odum was Manatee Springs in Levy County. He did not report a nitrate concentration for the spring but Rosenau *et al.* (1977) reported a nitrate concentration of 0.40 mg/L in 1956. Odum (1957) reported a single GPP estimate of 19.4 g $O_2/m^2/d$, a rate similar to those measured in Silver Springs at the same time and at the same nitrate concentration. Odum also estimated community metabolism at Rainbow Springs in Marion County during the same study. Data published by Rosenau *et al.* (1977) indicate a nitrate concentration of 0.80 mg/L while Odum (1957) reported 0.08 mg/L in 1955. The estimated GPP during Odum's study was 23.9 g $O_2/m^2/d$, considerably higher than Silver or Manatee Springs. These limited data indicate that the current findings of lower GPP in Silver Springs at higher nitrate nitrogen concentrations are consistent with Odum's earlier research.

Community metabolism results recently reported from the Wekiva River Pollutant Load Reduction Goal study were compared to results published from other spring ecosystems in Florida (WSI 2005). The Wekiva River and Rock Springs Run were found to have higher nitrate nitrogen concentrations (0.71 and 0.63 mg/L) compared to the reference streams located in the Ocala National Forest (Juniper Creek – 0.04 mg/L and Alexander Springs Creek – 0.02 mg/L). Upstream nitrate concentrations in the Wekiva River and in Rock Springs Run were significantly higher than downstream concentrations (Wekiva – 1.17 vs. 0.32 mg/L; Rock Springs Run – 1.09 vs. 0.16 mg/L). Gross primary productivity and PAR efficiency were found to be significantly lower in all of these spring-fed streams at higher nitrate nitrogen concentrations. This is the same trend documented at Silver Springs during this fifty-year retrospective study. Community respiration was also observed to increase downstream in the Wekiva River and in Rock Springs Run as nitrate concentrations decreased. Community respiration also declined at Silver Springs at the same time nitrate nitrogen concentrations were increasing.

Mulholland *et al*. (2001) reported stream metabolism results from a variety of autotrophic and heterotrophic streams. GPP estimates ranged from <0.1 to 15 g $O_2/m^2/d$. CR estimates ranged from about 2.0 to 11.1 g $O_2/m^2/d$. PAR efficiencies ranged from 0.042 to 0.45 g O_2/mol. GPP and NPP were not found to be correlated with either dissolved inorganic nitrogen or soluble reactive phosphorus concentrations but were significantly correlated with PAR. CR was correlated with soluble reactive phosphorus concentrations. These results are not directly applicable to Silver Springs due to the fact that only one of Mulholland's streams was spring fed.

Duarte and Canfield (1990) published plant community and productivity data for thirty-one Florida springs. Productivity data were not directly comparable to data collected by Odum (1957), Knight (1980), WSI (2005), or during the current study since they were based on a short-term, rapid assessment technique rather than on a full diurnal cycle. No correlation was found between total nitrogen (mostly in the form of nitrate) and total phosphorus as independent variables and the biomass or productivity of submerged aquatic vegetation (SAV) in the spring runs. SAV standing crop and maximum daily productivity were correlated with degree of shading by shoreline vegetation. These results indicate that an alternative hypothesis related to stream shading can be proposed for the observed community metabolism observations at Silver Springs during the past fifty years.

Water quality and biological conditions at the Kings Bay Spring Group, headwaters of the Crystal River in Citrus County, were summarized by the Southwest Florida Water Management District (2005). In their evaluation they reported average nitrate nitrogen concentrations of about 0.165 mg/L in Tarpon Hole and 0.291 mg/L in Hunters Spring. Numerous ecological impairments have been identified in Kings Bay, apparently partially in response to elevated concentrations of nitrogen. These observations include loss of water clarity, increased populations of benthic algae and especially *Lyngbya* (also see Cowell and Botts 1994), increases in occurrence of unconsolidated sediments, and loss of desirable rooted submerged aquatic plants (particularly *Vallisneria*). Increasing salinities in Kings Bay may be a result of declining spring flow due to increasing groundwater withdrawals. In turn these increased salinities may have resulted in reduced SAV biomass, triggering a self-reinforcing cycle of increased growth of phytoplanktonic algae, decreased water clarity, and reduced light needed by SAV. Decreased water clarity and increased benthic algal dominance were observed at Silver Springs during the past fifty years. The Kings Bay research offers a possible clue to the effects of declining submerged macrophyte plant communities on these changes.

Cowell and Dawes (2004) determined that increased populations of *Lyngbya* in the Rainbow River (nitrate > 1.0 mg/L) may be due to increased nitrate concentrations. *Lyngbya wollei* growth was stimulated by nitrate additions in the laboratory although no biomass increase was observed above about 1 mg/L of nitrate nitrogen. They concluded that based on their lab studies nitrate nitrogen concentrations would need to be reduced to below 0.3 mg/L in order to significantly reduce *Lyngbya* biomass. This research confirms that increased nitrate levels can increase benthic algal biomass, at least in the short term.

Stevenson (2004) found that percent cover and mat thickness for *Lyngbya* and other macroalgae were not correlated with total nitrogen and total phosphorus in a study of twenty-eight Florida springs and spring runs. Epiphytic diatom abundance was found to be responsive to spring nitrogen concentrations. Nitrate was found to stimulate growth of *Lyngbya* in laboratory cultures with an apparent threshold for stimulated growth at 0.1 mg/L nitrate nitrogen. Notestein *et al.* (2003) measured growth rates of periphyton on glass slides in the Chassahowitzka River in Citrus County, Florida in response to additions of nitrate and phosphate. Ambient nitrate nitrogen concentration was about 0.4 mg/L at the time of the experiments. The authors found that periphyton was most limited by phosphorus availability but that nitrogen alone also contributed to increased periphyton biomass. These research efforts generally duplicate Cowell and Dawes's research and indicate that when nitrate becomes abundant, phosphorus may become the more limiting macro-nutrient for epiphytic and benthic algal growth.

Frazer *et al.* (2001), Hoyer *et al.* (2004), and Hoyer *et al.* (no date) report on detailed studies conducted in five spring-fed rivers in southwest Florida: Weeki Wachee, Chassahowitzka, Homosassa, Crystal, and Withlacoochee. Water quality, hydrology, plant communities (algae and macrophytes), and bird populations were studied over a two-year period and compared between these five systems. Nitrate was found to be measurably assimilated in some of the spring-fed rivers (Chassahowitzka and Homosassa) but not in others (Frazer *et al.* 2001). Light and nitrate were found to be most highly correlated with the biomass of both macroalgae and submerged macrophytes (Hoyer *et al.* 2004). Hoyer *et al.* (no date) reported that wetland-dependent bird abundance and biomass were positively correlated with total nitrogen concentrations in these rivers, while bird diversity was inversely correlated with total nitrogen. Bird abundance, biomass, and species numbers were all found to be highly correlated with macroalgae and macrophyte biomass. These results provide additional validation of higher benthic algae populations with increasing nitrate. They may also provide an alternative explanation for the observed decrease in macrophyte biomass estimates for Silver Springs compared to Odum's research in the 1950s.

Mattson *et al.* (1995) reported that spring run periphyton communities are typically dominated by epiphytic diatoms and that macroinvertebrate communities are typically dominated by chironomids, mayflies, and trichopterans. Chironomids, trichopterans, and lepidopterans dominated the Silver Springs collections. Observations made during this study indicate that daily chironomid emergence continues to be strong as long as *Sagittaria kurziana* dominates the submerged macrophyte plant community.

Walsh and Williams (2003) examined fish and mussel species diversity in sixteen Florida springs and spring runs. For the purposes of this review, their data were plotted against ambient nitrate nitrogen concentrations reported from fifteen of those springs. Although there were trends for lower fish and mussel species numbers with higher nitrate levels, they were not significant. Fish species diversity appears to be relatively constant at Silver Springs, as evidenced by the following: Walsh and Williams collected twenty-nine species in 2002, the current research observed thirty-three species in 2004-05, and Hubbs and Allen (1943) reported thirty-five species in the 1940s.

8.0 Recommendations and Research Priorities

8.1 Introduction

Silver Springs and the Silver River stand out as the most visited natural attraction in Florida, the largest freshwater spring in the state and country (by discharge), the most studied in terms of scientific research, the best known internationally, and perhaps one of the most finely adapted, productive, and visible inland aquatic habitats in Florida. In Florida's array of natural wonders, it is truly one of the most unique when one considers its ecological, environmental, and hydrological qualities.

The authors of this collaborative study have made every effort to provide documentation related to scientific methodologies and to present data to aid future hydrological and ecological evaluations. The contributors present the following research priorities and recommendations based upon their interpretation of historical and current data relating to Silver Springs.

8.2 Proposed Research Priorities

The contributors to this fifty-year retrospective project suggest the following future research priorities for Silver Springs:

- Collect additional hydrological and hydraulic data to support a finer-grid model design to improve simulation performance.
- Collect samples from all sites where thermal anomalies have been detected and analyze them for strontium isotopes. The results may help in the identification of areas of diffuse flow and in confirming that the discharge is from the Floridan Aquifer.
- When groundwater flow modeling is performed, incorporate the information from the newly-discovered discharge sites within the Silver River, as they affect the configuration of the potentiometric surface and flow paths.
- Collect and analyze water quality samples, particularly for dissolved oxygen and nitrates, on a limited periodic schedule, from all the vent groups in the upper 1,200 m of the Silver River.
- Compare water quality results from each vent group with wells in the Silver Springs springshed. The results may aid in the process of identifying areas that contribute nitrates to the springs.
- Perform discharge measurements at each vent group in the upper 1,200 m of the Silver River so that a more detailed evaluation of loading estimates can be performed.

- Use divers to perform field investigations of thermal anomalies in order to ground truth the location and physical characteristics of discharge points downstream of the 1,200-m station.
- Perform flow measurements to assess the volume of water being contributed to the Silver River from the thermal anomalies downstream of the 1,200-m station.
- Collect and analyze water quality samples both upstream and downstream of the thermal anomalies. This will help in assessing the impact of the additional flow.
- Apply the estimated spring discharge rates from 1957, 1979, 1995 and 2025 with the estimated nutrient loading rates to calculate nutrient concentrations in spring discharge. This will allow researchers to assess the impact of springshed land use changes on the nutrient concentration of the discharge at Silver Springs.
- With regard to future use of the LULC datasets, restrict the development of the LULC dataset by utilizing contemporary data, beginning with the development of parcel databases around 1990. This data, combined with improved infrared and color imagery, will greatly increase the relative accuracy in the LULC classification and the associated loading rates.
- Determine the most accurate estimates of nitrogen loading per LULC category.
- Install permanent *in situ* data loggers (minimum of three to five) at multiple locations within the Silver River to provide a continuous record of changing water quality conditions, including temperature, dissolved oxygen (concentration and percent saturation), pH, and specific conductance; estimate and tabulate ecosystem metabolism daily and release the results in an annual report.
- Routinely quantify insect emergence rates and diversity.
- Conduct comprehensive plant community studies in the Silver River on a three-to-five-year schedule.
- Quantify floating plant and particulate export over daily and seasonal time frames.
- Determine the role nutrient limitation plays in the growth of epiphytes and benthic algae at Silver Springs. The central question to be answered is whether future increases or decreases of nutrient levels will result in responses by the primary producer community.
- Determine the impact of changes in light availability on the structure and function of the Silver Springs ecosystem. Light availability can be affected by seasonal patterns of

incident irradiance, canopy cover and floating plant communities, and may have a role in the changes noted at Silver Springs.

- Conduct a comprehensive study on the Back Channel (added to the spring run in the late 1970s) in order to determine its impact on estimates of gross primary production (GPP), community respiration (CR) and net primary production (NPP).
- Determine the respiratory and photosynthetic potentials of epiphyte and benthic mat communities of different thicknesses. Current estimates of biomass for these two components may not be good indicators of their contributions to GPP, CR and NPP.
- Continue to monitor fish, birds, and reptiles in Silver Springs on a monthly basis (twelve events per year) for at least one year during each five-year period for the foreseeable future.
- Schedule monitoring events throughout the year to elucidate seasonal trends within the year.
- Monitor alligators at night during warm months (April-September) and in the day during cold months (October-March) for a twelve-month period during one year of each five-year period.
- Conduct a study for channel catfish. Channel catfish should be experimentally radio-tagged and placed in the Silver River to monitor habitat use and movement. Such a study would reveal factors influencing the decline in channel catfish in the system.
- Inventory human use activities on a routine basis (including number of glass-bottom and jungle boat trips per day, wildlife feeding activities, pleasure boating use of the river, etc.).
- Evaluate and document stormwater effects on the Silver River by conducting a watershed evaluation and focused storm sampling of flows and loads.

8.3 Recommendations

Project participants propose the following recommendations for Silver Springs:

- It is recommended that the State of Florida establish a permanent funding source for the establishment of a “Florida Springs Aquatic Ecology Research Center” (FSAERC, see Appendix S) at Silver Springs within the Silver River State Park in order to develop a consistent base of scientific knowledge for this and other Florida first magnitude spring ecosystems. Many of the research priorities listed in section 8.2 could be conducted under the direction of the FSAERC.

- It is recommended that Marion County explore the development of a springs protection plan that addresses such components as land development regulations and land acquisition, along with other groundwater and spring protection measures in order to halt and, if possible, reverse the observed increases in nitrate nitrogen concentrations in Silver Springs.
- It is recommended that the FDEP direct SJRWMD to undertake a project to develop Pollutant Load Reduction Goals (PLRGs) for nitrogen in Silver Springs and the Silver River. These PLRGs should then form the basis for a Total Maximum Daily Load (TMDL) nitrogen limit for the spring and spring run to be developed by the FDEP. TMDLs will provide a basis for the State and Marion County to enforce stringent nitrogen mass loading limits on all existing and future point and non-point sources in the Silver Springs springshed.

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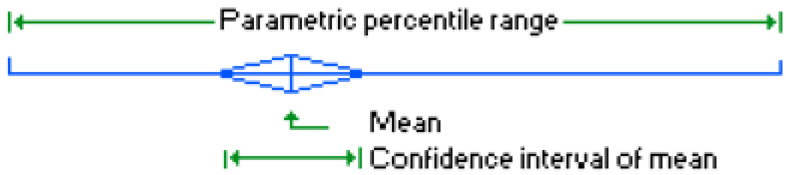
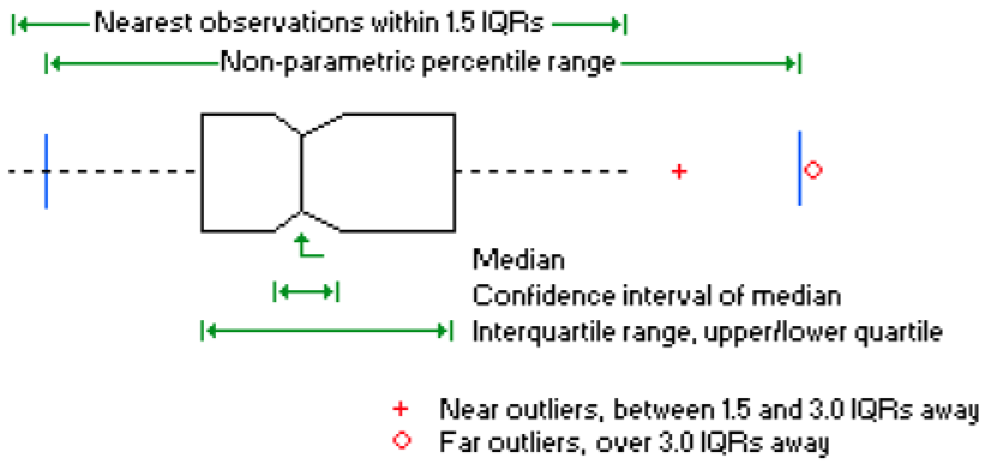
Legend for Figure 2-24
Source: Analyze-It for Microsoft Excel

The blue line series shows parametric statistics:



- the blue diamond shows the mean and the requested confidence interval around the mean.
- the blue notched lines show the requested parametric percentile range.

The notched box and whiskers show non-parametric statistics:



- the notched box shows the median, lower and upper quartiles, and confidence interval around the median.
- the dotted-line connects the nearest observations within 1.5 IQRs (inter-quartile ranges) of the lower and upper quartiles.
- red crosses (+) and circles (o) indicate possible outliers - observations more than 1.5 IQRs (near outliers) and 3.0 IQRs (far outliers) from the quartiles.
- the blue vertical lines show the requested non-parametric percentile range.