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Assessment of Spring discharge Measurement Data for Priority Springs in the St. Johns River Water Management district

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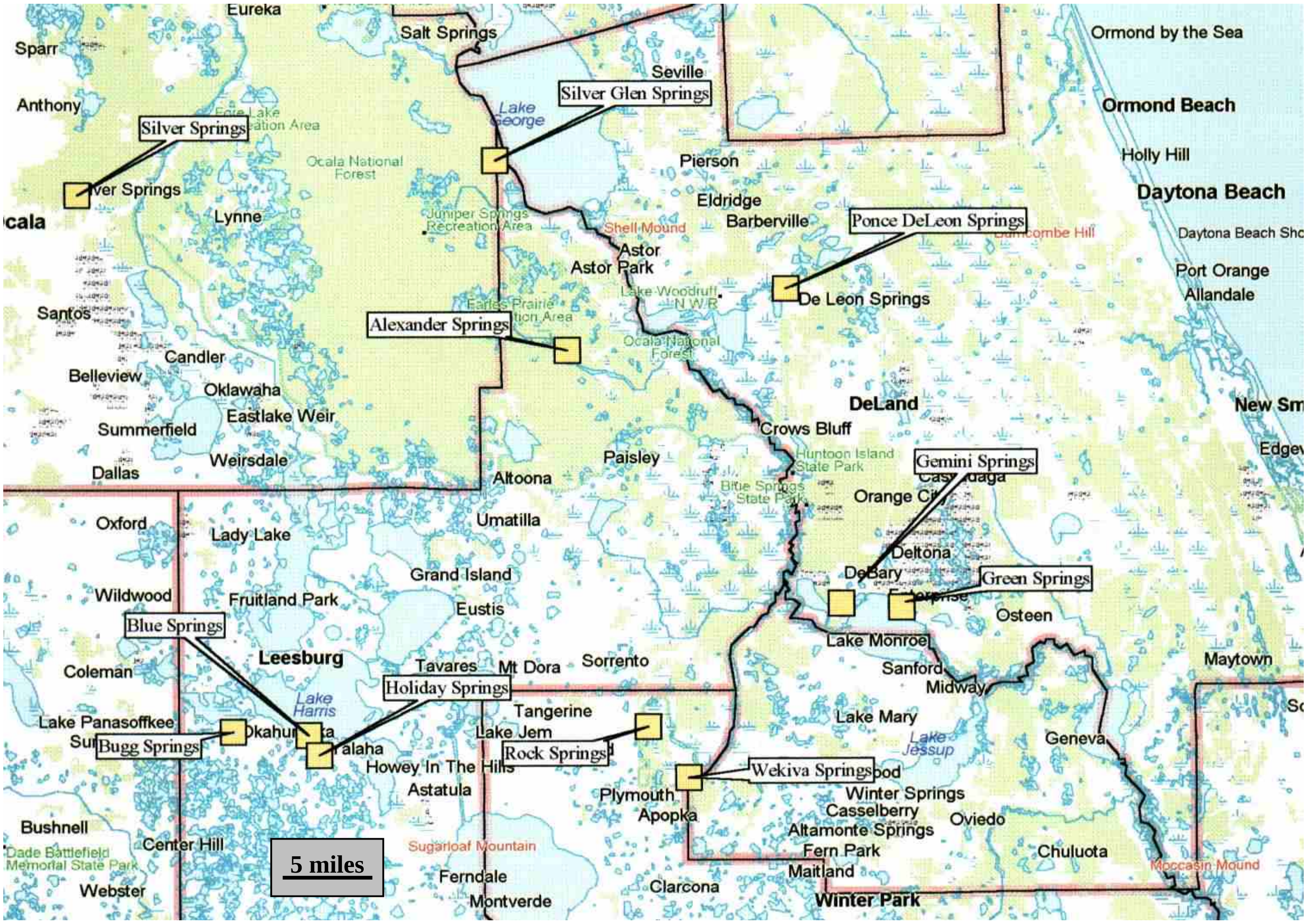

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Background

The St. Johns River Water Management District's (SJRWMD) Minimum Flows and Levels (MFLs) Program, implemented pursuant to Section 373.042, *Florida Statues*, establishes MFLs for lakes, streams and rivers, wetlands, and springs. MFLs define the frequency and duration of high, average, and low water events necessary to prevent significant ecological harm to aquatic habitats and wetlands from permitted water withdrawals. The MFLs Program is subject to the provisions of Chapter 40C-8, *Florida Administrative Code*, and provides technical support to SJRWMD's regional water supply planning process, and Consumptive Use and Environmental Resource permitting programs.

MFLs are represented by hydrologic statistics comprised of three components: a water level and/or flow, duration, and a return interval (frequency). MFLs designate hydrologic conditions below which significant harm is expected to occur and above which water is available for reasonable beneficial use. As it applies to wetland and aquatic communities, significant harm is a function of changes in the frequencies and durations of water level and/or flow events, causing impairment or destruction of ecological structures and functions. The determination of MFLs considers the protection of nonconsumptive uses of water, including navigation, recreation, fish and wildlife habitat, and other natural resources.

SJRWMD has initiated data collection and analysis to determine MFLs for a number of priority springs. Determination of these MFLs requires an extensive review and evaluation of the historical database of spring discharge measurements that will be used during development of hydrologic models for each priority spring.

Scope

This assessment involved completion of the following tasks:

- Preparation of a computer data base of measured discharge and related information
- Identification of locational bias in discharge measurements
- Identification of temporal trends in spring discharge
- Generation of an unbiased record of spring discharge, if possible
- Identification of additional data collection and evaluation needs
- Preparation of report

The computer database, including all known measurements of spring discharge for priority springs, was created in spreadsheet format. These measurements have been made by USGS, SJRWMD, or contractors employed by SJRWMD. In one case, most measurements were provided by the spring owner.

The database includes the following attributes from measurement notes:

- Date of measurement
- Water level in the spring pool or spring run
- Measurement location in relation to distance downstream from spring boil
- Measurement cross-section width
- Measurement cross-section area
- Mean streamflow velocity in cross-section
- Measured discharge
- Accuracy assessment of the measurement made by person making the measurement

Eleven priority MFLs springs were included in this study (Table 1).

Table 1. Priority springs included in this study

Priority	Spring	County	Latitude (deg-min-sec)	Longitude (deg-min-sec)	Period of record (Number of measurements)	Maximum discharge measured	Minimum discharge measured	Mean discharge measured
1	Gemini	Volusia	28 51 44	081 18 39	6-1966:8-2003 (61)	13	6.2	9.9
2	Ponce DeLeon	Volusia	29 08 02	081 21 47	2-1929:9-2003 (277)	12.2	41.8	26.8
3	Green	Volusia	28 51 45	081 14 55	3-1932:8-2003 (26)	2.78	0	1.16
4	Silver	Marion	29 12 57	082 03 11	5-1906:6-2004 (319)	1290	250	764
5	Bugg	Lake	28 45 07	081 54 06	3-1943:2-2001 (140)	19.8	3.8	9.8
6	Wekiva	Orange	28 42 43	081 27 36	3-1932:9-2003 (215)	91.7	29.4	67.4
7	Rock	Orange	28 45 20	081 29 58	2-1931:9-2003 (279)	83.2	34.1	58.3
8	Blue	Lake	28 44 55	081 49 41	3-1972:8-2003 (23)	3.6	.79	2.2
9	Holiday	Lake	28 43 54	081 49 05	6-1967:8-2003 (23)	4.9	0.88	2.6
10	Alexander	Lake	29 04 50	081 34 30	2-1931:9-2003 (178)	202	55.9	105
11	Silver Glen	Marion	29 14 43	081 38 37	2-1931:4-2004 (156)	245	58.5	105.7

Methods

Data used in these analyses were summarized and presented graphically using Microsoft Excel 2000 worksheets (Blattner, et al. 1999). Statistical hypothesis testing was done using the JMP statistical software package (SAS Institute, Inc. 2002).

Preparation of data base

The first step in this study was to retrieve measurements of spring discharge and related information from computer files of the USGS and SJRWMD and merge them to create a single data base. The computer-stored information generally did not include locational information and other data, so it was necessary to examine paper copies of all discharge measurement notes to obtain the desired information. In some cases it was not possible to determine measurement location, and these cases were not used in the analysis of locational effects on measured discharge.

Identification of locational bias in discharge measurements

Graphical and statistical techniques were used to determine if multiple spring vents, seeps, or tributaries could result in inflow of water in the spring run, with a resultant locational bias in the discharge measurement. The techniques used for this analysis are:

- Graphical analysis, using discharge hydrographs with measurement location (in distance downstream from the spring boil) indicated by color and/or symbol.
- Statistical analysis using the Kruskal-Wallis test, to determine if there are significant differences in discharge among groups of measurements classified according to measurement location.

The Kruskal-Wallis test (Conover 1971) is a non-parametric procedure for comparing groups of observations to determine if the groups are identical with respect to the population of the groups (the measured discharge). Each group represents a selected range of distance downstream from the spring boil. The null hypothesis is that all groups are identical with respect to the magnitude of the measured discharges. The alternate hypothesis is that one or more of the groups tends to have greater discharge quantities. The test is based on ranks of the discharge data within each group, rather than the “raw” discharge data. Thus the test is non-parametric and is not affected by the distribution of the data (i.e., normal or non-normal), and is not unduly affected by outliers. The sums of ranks of discharge data in each group are used to calculate a test statistic known as the chi-squared statistic. This test statistic has a distribution that can be approximated by the chi-squared distribution, and is used to test the null hypothesis.

Use of the test required selection of a significance level to accept or reject the null hypothesis. The significance level is compared with the probability that the procedure’s test statistic indicates non-identical groups. If this probability level exceeds the selected significance level, the null hypothesis is considered to be true, that is, there is no difference in discharges among the locational groups tested**.** In this study, a significance level of 0.05 was used to determine if the null hypothesis (discharge in all groups are from the same population) could be rejected. This significance level means that there is a 5 percent or less chance of incorrectly stating that a difference in discharge among groups exists when in fact there is no difference.

Identification of temporal trends in spring discharge

Graphical and statistical techniques were used to determine if temporal trends in spring discharge have occurred. Simple plots of discharge as a function of time were examined for evidence of trends. The possibility of monotonic temporal trends (discharge either increasing or decreasing consistently during the period of record) was tested statistically using the Kendall's Tau procedure (Conover 1971), for annual means and seasonal means of the measured discharges. The Kendall's Tau procedure is based on the relative numbers of discharge measurement pairs that are concordant or discordant in time. A measurement pair (consisting of two measurements made on different days) is concordant if the later date corresponds with the greater discharge. Otherwise, the measurement pair is discordant. A test statistic is generated from comparison of all possible measurement pairs. If the number of concordant and discordant measurements is significantly different, then the null hypothesis of "no monotonic trend" is rejected and a trend is indicated. In this study, a significance level of 0.05 was used to determine if the null hypothesis (equal concordant and discordant pairs) could be rejected.

The Kendall's Tau test is effective only for monotonic trends, that is, trends that are consistently in one direction or the other for the period of record. A record with increasing discharge for a few years, followed by decreasing discharge, is an example of a set of data that might not show evidence of a trend by the Kendall's Tau test, yet would contain two separate trends within the record.

Trend tests in this study were done on a number of seasonal groups. Annual means and annual means of seasons were tested. Four seasons, as follows, were selected to represent the seasonal pattern of discharge observed at most springs:

- February – April, moderately low discharge
- May – July, low discharge
- August – October, high discharge
- November – January, moderately high discharge

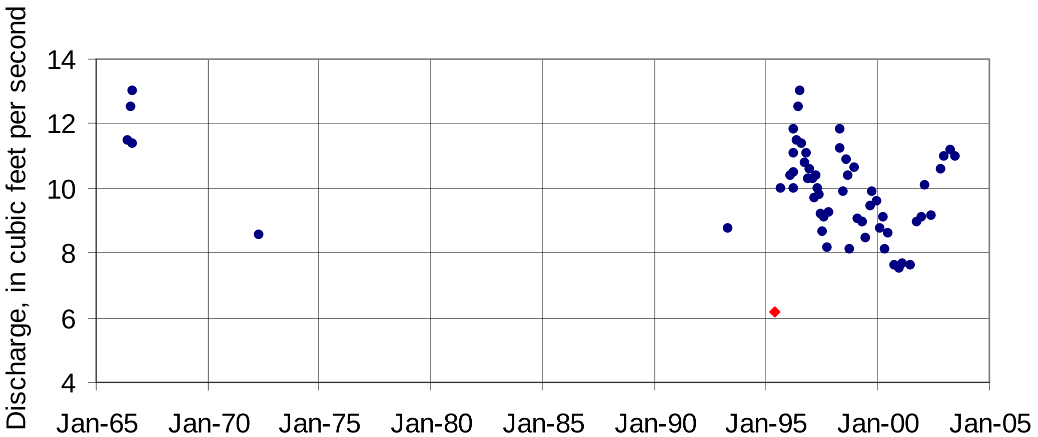
Because spring measurements were made at infrequent and irregular intervals for some springs, the annual means are probably not a good indication of spring discharge for some years. For example, a year might contain only a single measurement, made during low or high discharge conditions. Thus, different annual mean discharges might represent different seasonal conditions. Therefore, the seasonal grouping is probably more appropriate for the trend tests. In any case, trend tests by themselves may be misleading and are presented only to supplement the graphical presentations, and to indicate if there are seasonal patterns to trends. For example, it seems possible that discharge during dry seasons might be affected more by pumping of groundwater for irrigation than during wet seasons when such pumping is minimal.

Discussion

Gemini Springs

There have been 61 measurements of discharge from Gemini Springs from June 1966 to August 2003, by Hydrogage (seven measurements), SJRWMD (20 measurements), and USGS (34 measurements). All but six of the measurements were made since 1993. Most measurements were made at the weir outlet at the east end of a reservoir receiving inflow from a group of at least three springs. One discharge measurement may not include flow from all 3 springs, according to remarks on the measurement data sheet. This measurement, shown in red on Figure 1, was made June 23, 1995, by USGS. The measurement seems anomalously low, and was not used in trend testing. Location of discharge measurement sections is unlikely to be a factor in determining spring discharge because all measurements were made at or near the outflow weir. The plot of discharge measurements (Figure 1) does not indicate a definite monotonic trend in spring discharge.

Figure 1 Measured discharge of Gemini Springs
(Red designates possible anomalous measurement)



Seasonal and annual trend analyses (Table 2) also do not indicate that there are trends in spring discharge. However, the relatively short period of discharge records makes trend analyses inconclusive.

Table 2. Kendall's Tau test for temporal trends by season in spring discharge: Gemini Springs

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	12	9.9	0.00	1.00
February - April	8	9.8	0.071	0.80
May - July	11	9.9	-0.14	0.59
August - October	7	10.6	-0.24	0.45
November - January	7	9.5	-0.14	0.65

Ponce DeLeon Springs

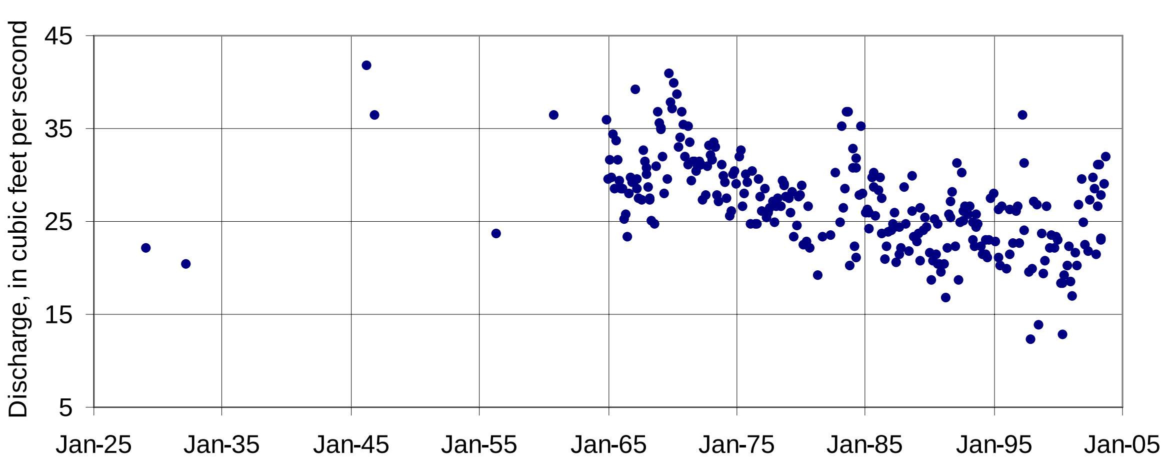
There have been 277 measurements of discharge from Ponce DeLeon Springs from February 1929 to September 2003, by Hydrogage (11 measurements), SJRWMD (98 measurements), and USGS (168 measurements). All but six of the measurements were made since 1964. Measurements were made at or in the vicinity of a weir outlet in the dam at the west end of the impounded spring pool and also at a flume used to supply water to a water wheel (no longer functional) on the southwest side of the pool. Location of discharge measurement sections is unlikely to be a factor in determining spring discharge because all measurements were made at or near the outflow weirs.

Changes and leaks in the bulkhead impounding the spring pool have affected discharge measurement accuracy. Prior to re-building the bulkhead in the spring of 2000, there was unmeasureable leakage through the bulkhead that would have caused measurements of spring discharge to be too low by an unknown amount. The new bulkhead contains a 4 ft by 6 ft submerged gated culvert that is left open, but is generally clogged to a varying degree with algae and grass that restrict discharge through the culvert. This discharge is not measurable, so measurements of spring discharge at the weir are lower than actual spring discharge by an unknown and probably variable amount. Because of this unmeasured discharge, the record of spring discharge both before and after bulkhead re-construction should be considered biased to the low side by an unknown and possibly variable amount. These changes in the bulkhead probably have not affected spring discharge. Rather, the changes may have affected the ability to accurately measure the discharge.

Concrete decking and weir height were raised about 0.5 ft in 1995. This change increased the head over the spring vents and probably caused a reduction in flow.

The plot of discharge measurements (Figure 2) indicates a definite monotonic downward trend in spring discharge, at least since the 1960s. This downward trend may be mostly a reflection of rainfall patterns. The 1960s and 1970s are generally considered to be relatively high in rainfall, and the 1990s and into the 2000s have had periods of drought.

Figure 2. Measured discharge of Ponce DeLeon Springs



Seasonal and annual trend analyses (Table 3) also indicate that there are significant trends in discharge from Ponce DeLeon Springs during all seasonal groupings. However, conclusions regarding trends in spring discharge should be regarded as tentative because of the possibility that bias associated with the measurement were not constant over time.

Table 3. Kendall's Tau test for temporal trends by season in spring discharge: Ponce DeLeon Springs

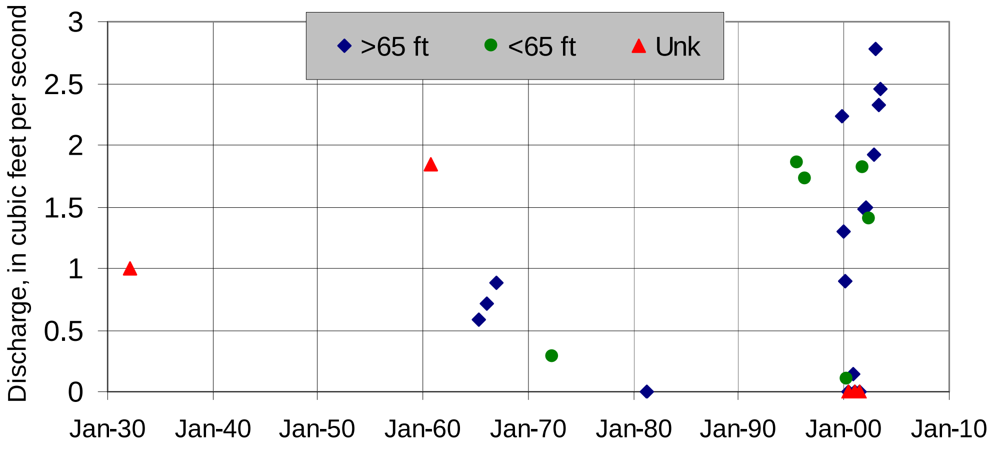
Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	41	27.9	-0.32	<0.01
February - April	39	25.1	-0.44	<0.01
May - July	39	27.6	-0.35	<0.01
August - October	38	27.2	-0.66	<0.01
November - January	45	26.8	-0.46	<0.01

Green Springs

There have been 26 measurements of discharge from Green Springs from March 1932 to August 2003, by Hydrogage (seven measurements), SJRWMD (12 measurements), and USGS (seven measurements). All but two of the measurements were made since 1965. All measurements appear to have been made within about 100 ft of the spring pool. There is no indication that measured discharge is related to measuring location, though data are too sparse for definite conclusions. The plot of discharge measurements (Figure 3) does not indicate a definite monotonic trend in spring discharge.

Figure 3 Measured discharge of Green Springs

(Legend refers to distance downstream from spring pool. Unk indicates location unknown).



Seasonal and annual trend analyses (Table 4) do not indicate that there are significant trends in discharge from Green Springs. However, the small number of measurements makes trend analysis inconclusive.

Table 4. Kendall’s Tau test for temporal trends by season in spring discharge: Green Springs (-- indicates too few measurements (<5) for trend analysis)

Season	Number of groups	Mean discharge	Kendall’s Tau	Probability of no temporal trend
January - December	13	1.16	0.13	0.54
February - April	8	0.88	0.18	0.53
May - July	5	0.93	0.20	.062
August - October	3	2.05	--	--
November - January	6	1.31	.20	.57

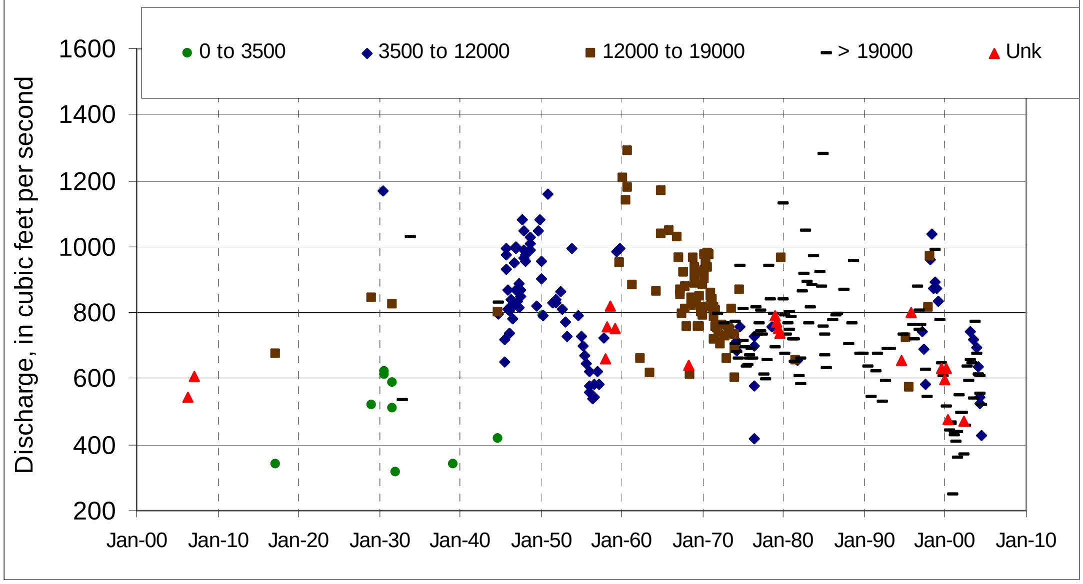
Silver Springs

There have been 319 measurements of discharge from Silver Springs from May 1906 to August 2004, by USGS. All but 16 of the measurements were made since 1944. The plot of discharge measurements (Figure 4) indicates an apparent downward trend in spring discharge, especially since about 1990. However, measurement locations have varied over considerable distances from the spring boil during the period of record, and measurement location affects measured discharge. In addition to several spring vents in the pool at the head of Silver River, there are several smaller springs in the bed or at the edges of Silver River within about 3500 ft of the main boil (Rosenau, et al. 1977).

Prior to 1945 many measurement were made within 3500 ft of the spring boil, some as close as about 300 ft below the boil. During the 1940s and 1950s measurements were generally made within 3500 ft to 12,000 ft below the boil. During the 1960s to the mid-1970s measurements were generally made within 12,000 ft to 19,000 ft from the boil. From the mid-1970s on, most measurements were made at locations greater than 19,000 ft below the boil. However, several measurements in the 1990s were made at distances from 3,500 ft to 12,000 ft below the boil.

This variation in measurement location needs to be considered in assessing temporal trends in spring discharge, because seepage and inflow from other spring vents may occur all along the course of the Silver River. However, the general tendency for the measurement locations to have been moved from upstream locations early in the period of record to downstream locations later in the period of record supports the observation that spring discharge has been decreasing with time, because the Silver River is probably gaining some inflow throughout the reach from the main boil to the Ocklawaha River. There may also be surface inflow along the reach, especially at about 4100 ft below the boil where a tributary enters Silver River from the north.

Figure 4 Measured discharge of Silver Springs
(Legend refers to distance downstream from boil. Unk indicates location is unknown.)



The Kruskal-Wallis test was used to determine if there is statistical evidence that discharge measurements from four selected river-run segments are different (Table 5). The test indicates that there is a significant difference among the 4 segments, with a small probability (<0.01) that the discharges observed in all segments are from the same population. However, the differences are likely not entirely location related.

Table 5. Kruskal-Wallis Test for differences in discharge among Silver River segments (River segments are defined by distance, in ft, downstream from the mail boil. Measurements made at unknown locations (18 measurements) are not included)

River segment	# of measurements	Mean Discharge	Mean rank score
0 to 3500	10	506	36.4
3500 to 12000	91	813	173.8
12000 to 19000	81	853	194.0
> 19000	119	702	114.0

Chi-square statistic: 64.8
Probability of no difference in discharge among the distance classes: <0.01

Some of the observed differences among the river segments are likely due to the non-uniformity of measurement locations in time. For example, the segment with the next-to-lowest mean discharge is located at the downstream end of Silver River (Table 5). This reach should contain flow from all seeps, vents and tributaries in the upstream segments, and thus should have a higher discharge than the upstream segments on any selected day. The relatively low mean discharge for the downstream-most reach is probably related to the measurement dates, which were generally later than the mid 1970s. Thus, discharge in this segment was generally not measured during higher-discharge periods in the 1950s and 1960s.

The best indication of the effect of measurement location on discharge is given by measurements made at different locations along Silver River on the same day (Figure 5 and Table 6). Two or more locations have been measured on the same day seven times since 1917. Although these measurements span a period off 88 years, the relative amounts of inflow along the river are fairly consistent from one set of measurements to another, and some general conclusions regarding inflow quantities probably can be made.

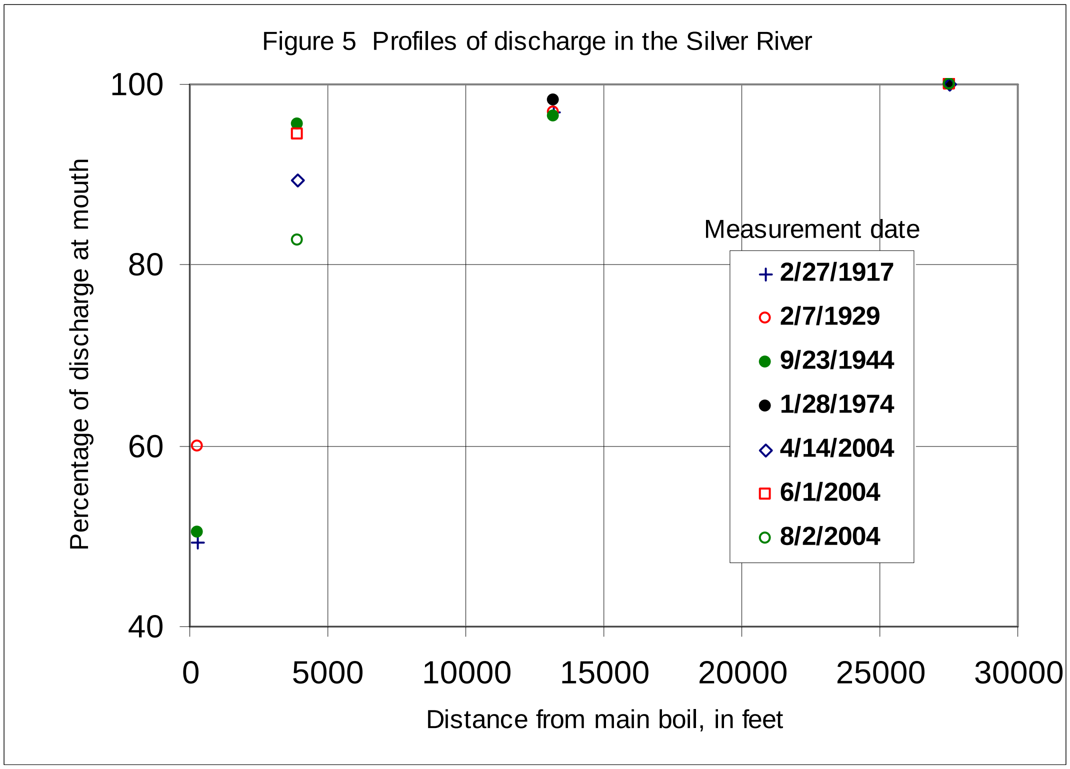


Figure 5 Profiles of discharge in the Silver River

Table 6. Profiles of discharge in the Silver River
(Discharge is in cubic feet per second. Location is distance from boil. The * indicates discharge is estimated based on average gain in reach on 9-23-1944 and 1-28-1974. Numbers in parenthesis are percent of flow measured or estimated at 27,500 ft below boil at mouth of Silver River)

	Discharge at indicated distance			
Date	**300 ft**	**3900 ft**	**13200**	**27500**
02-27-1917	342 (0.49)		674 (97)	695*
02-07-1929	521 (0.60)		843 (97)	869*
09-23-1944	419 (0.50)	795 (0.95)	802 (0.96)	832
01-28-1974			689 (0.98)	702
04-14-2004		542 (0.89)		606
06-01-2004		523 (0.95)		553
08-02-2004		429 (0.83)		519

Most inflow along the Silver River occurs between 300 and 3900 feet below the boil, and the discharge measured 300 ft below the boil is only about 50% to 60% of discharge at the mouth of Silver River (27,500 ft below the boil). Relatively small inflow occurs between 3900 feet and the mouth of the river. The discharge at 3900 feet below the boil is 83% to 95% (average 90%) of the discharge at the mouth. Some of this inflow could be surface runoff, especially from a tributary that enters Silver River about 4100 ft below the main boil.

The discharge data summarized in Table 6 were used to derive relations for making gross estimates of discharge at the mouth of the Silver River based on location of measurements made elsewhere in the river. The relations are based on the average relative gains between measuring points and the mouth of Silver River as follows: 300 ft, 50%; 3900ft, 90%; 13200 ft, 97%. By assuming that the inflow increases linearly between each measuring point and the next point downstream a set of interpolation equations were derived. The equations are:

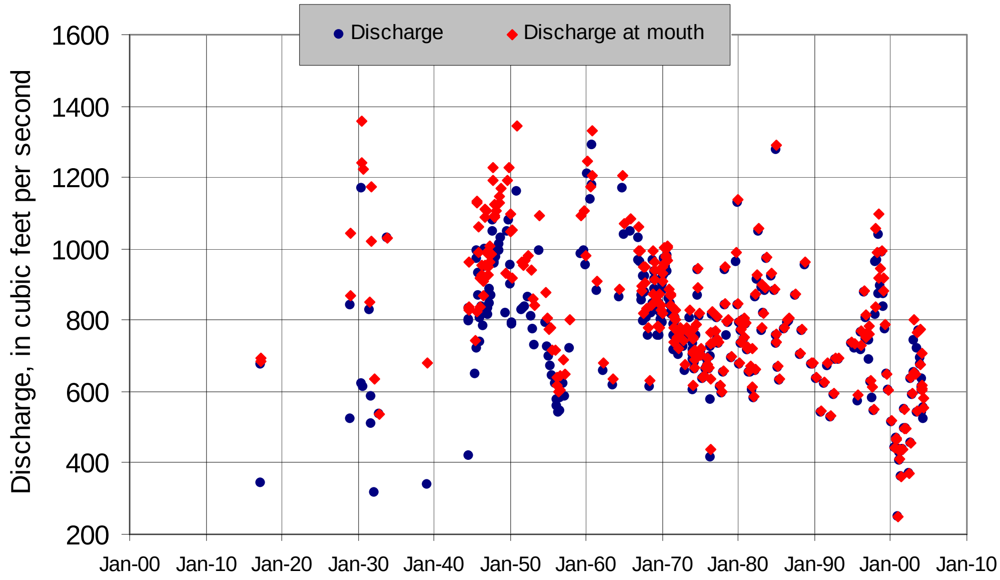
From 300 ft to 3900 ft: $Q_{mouth} = Q(2.074 - 2.469x10^{-4} D)$
From 3901 ft to 13200 ft: $Q_{mouth} = Q(1.145 - 8.613x10^{-6} D)$
From 13201 ft to mouth: $Q_{mouth} = Q(1.059 - 2.161x10^{-6} D)$

where Q_{mouth} is estimated discharge at the mouth of Silver River, Q is the measured discharge at distance D, and D is the distance downstream from the boil, in feet.

Estimates made using the above equations should be regarded as gross approximations because the equations were derived with a very limited amount of data. Also, surface runoff from tributaries, such as the one about 4100 ft below the boil, would likely be seasonally variable and would require more data to evaluate.

A comparison of measured discharge and the estimated discharge at the mouth of Silver River is shown in Figure 6. Both sets of discharge data indicate apparent downward temporal trends.

Figure 6 Measured discharge and estimated discharge at mouth of Silver River



Seasonal and annual trend analyses were done on the estimated discharge at the mouth of Silver River (Table 7). Downward temporal trends were significant for all seasonal groups tested. However, the trends are not monotonic and there are periods of increasing discharge and periods of decreasing discharge throughout the period of record. The 1960s and 1970s are generally considered to be relatively high in rainfall, and the 1990s and into the 2000s have had periods of drought. The effects of wet periods and dry periods are apparent in Figure 6, especially the high flows that occurred in the 1960s and 70s during relatively wet conditions, and the low flows that occurred in the 1990s and into the 2000s during relatively dry conditions.

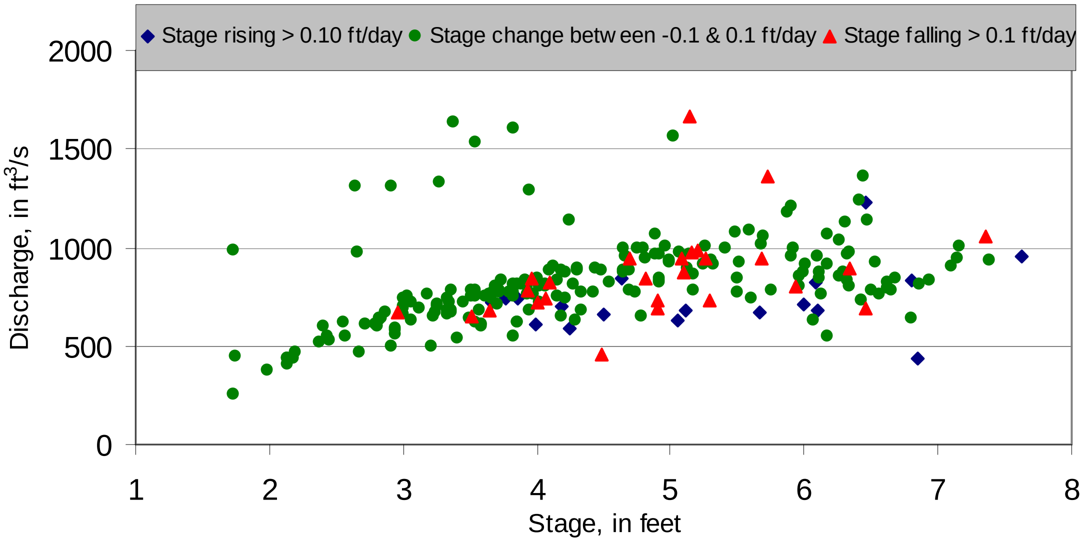
Table 7. Kendall's Tau test for temporal trends by season in spring discharge: Silver River at mouth (estimated discharges)

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	67	822	-0.39	<0.01
February - April	45	778	-0.24	0.02
May - July	43	776	-0.40	<0.01
August - October	44	878	-0.48	<0.01
November - January	46	853	-0.42	<0.01

Discharge in the Silver River could be affected by backflow of water from the Ocklawaha River into the Silver River during periods of increasing stage in the Ocklawaha River. Also, backwater from the Ocklawaha River may affect stage in the Silver River even as far upstream as the main Silver Spring boil. This increase in stage over the boils would result in a decrease in spring discharge if the head difference between the potentiometric level in the Upper Floridan aquifer and the spring pool were decreased. Because the Upper Floridan aquifer is largely unconfined in the Silver Springs basin the aquifer storage coefficient is relatively large and effects of river-level changes may be especially significant. Also, effects on spring discharge could persist even after the river recedes.

A plot of Silver River discharge and stage in the Ocklawaha River near Conner (Figure 7) indicates that the discharge versus stage relation is direct, rather than the inverse relation that might be expected from an increase in water level over the spring boils. This increase in discharge with stage indicates that potentiometric levels in the Upper Floridan aquifer are generally directly related to surface-water levels and that the head difference between ground water and surface water may actually be greater during times of higher river stage. This apparent direct relation between spring discharge and river water level is probably the result of seasonal patterns in water levels. The potentiometric level in the Upper Floridan aquifer, the river stage, and the head difference between aquifer and spring pool probably are all relatively high during the wet season.

Figure 7 Relation of Silver River estimated discharge (at mouth) to stage of Ocklawaha River (Stage of Ocklawaha River is daily mean for USGS station at Conner)



The rate of change of Ocklawaha River stage could affect Silver River discharge. Rates of river stage change were calculated by subtracting mean Ocklawaha River stage for the day before the Silver River discharge measurement from the mean stage on the day of the Silver River measurement. Figure 7 indicates that Silver River discharges tended to be relatively low when the Ocklawaha River water level was rising at rates greater than 0.1 ft/day. This lower discharge is likely the combined effects of backflow of water into the Silver River and storage of water in the Upper Floridan aquifer. However, little or no effect on Silver River discharge is apparent from falling stage rates in the Ocklawaha River greater than 0.1 ft/day. This could indicate that release of water from aquifer storage during falling stages is relatively slow compared to input of water into aquifer storage during rising stages.

Because some Silver River discharge measurements may have been affected by rapidly-changing stage of the Ocklawaha River, the statistical test for differences in discharge among Silver River segments was repeated using only measurements made on days when stage of the Ocklawaha River was changing at rates of less than ± 0.05 ft/day (Table 8). The test indicates that there is a significant difference among the 4 segments, with a small probability (<0.01) that the discharges observed in all segments are from the same population. This test result is in agreement with the test using all measurements. However, as noted previously, the differences in discharge among Silver River segment are likely not entirely location related. Some of the observed differences among the river segments are likely due to the non-uniformity of measurement locations in time.

Table 8. Kruskal-Wallis Test for differences in discharge among Silver River segments, using only measurements made on days when rate of change of Ocklawaha River stage was less than $^{+}_{-}$ 0.05 ft/day

(River segments are defined by distance, in ft, downstream from the mail boil. Measurements made at unknown locations (18 measurements) are not included)

River segment	# of measurements	Mean Discharge	Mean rank score
0 to 3500	6	466	11.7
3500 to 12000	21	786	72.6
12000 to 19000	41	846	90.6
> 19000	60	686	49.1

Chi-square statistic: 43.8
Probability of no difference in discharge among the distance classes: <0.01

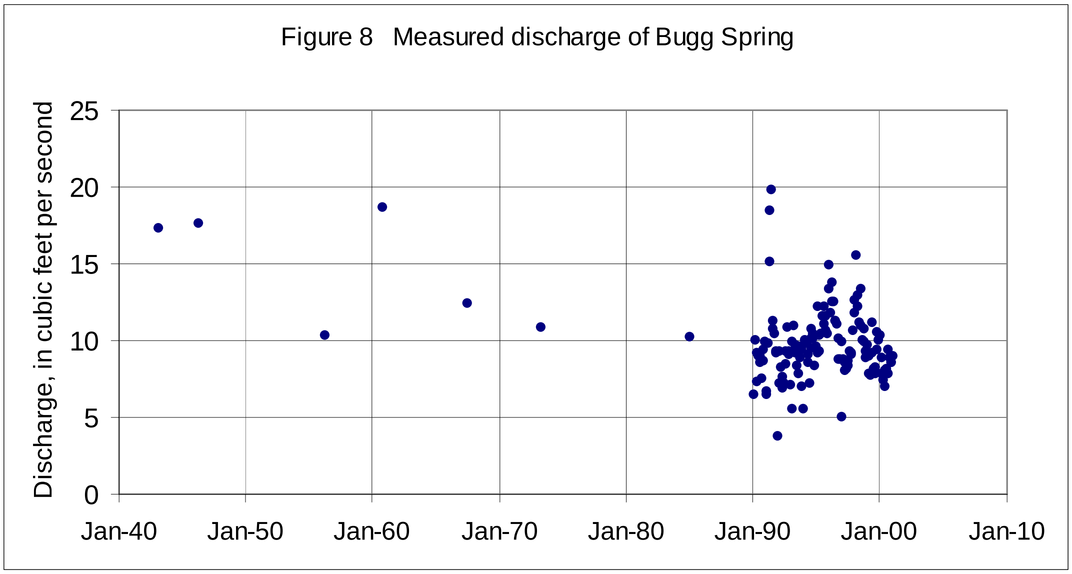
The seasonal and annual trend analyses were also repeated using only measurements made on days when stage of the Ocklawaha River was changing at rates of less than $^{+}_{-}$ 0.05 ft/day (Table 9). Downward temporal trends were significant for all seasonal groups tested except the February – April group. This test result is generally in agreement with the test using all measurements. However, the seasonal trend test for the February – April measurements was insignificant using all measurements.

Table 9. Kendall's Tau test for temporal trends by season in spring discharge: Silver River at mouth (estimated discharges), using only measurements made on days when rate of change of Ocklawaha River stage was less than $^{+}_{-}$ 0.05 ft/day

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	44	790	-0.45	<0.01
February - April	19	752	-0.21	0.20
May - July	20	729	-0.45	<0.01
August - October	18	880	-0.58	<0.01
November - January	26	796	-0.39	<0.01

Bugg Spring

There have been 139 measurements of discharge from Bugg Spring from March 1943 to February 2001, by the landowner (132 measurements), USGS (seven measurements), and SJRWMD (one measurement). Most measurements were made at approximately the same location, at a chain-link fence across the spring run just downstream from the pool. All but seven of the measurements were made since 1990. The plot of discharge measurements (Figure 8) does not indicate a definite monotonic trend in spring discharge, though the measurements made before 1965 generally indicate higher rates of discharge.



Seasonal and annual trend analyses (Table 10) indicate a significant trend in annual mean discharges from Bugg Spring. However, there is no indication of a trend in any of the seasonal groupings. The trend tests are probably inconclusive because of the sparse data before 1991. Trend testing of data from 1991 on indicates no significant trends in any seasonal grouping.

Table 10. Kendall's Tau test for temporal trends by season in spring discharge: Bugg Spring

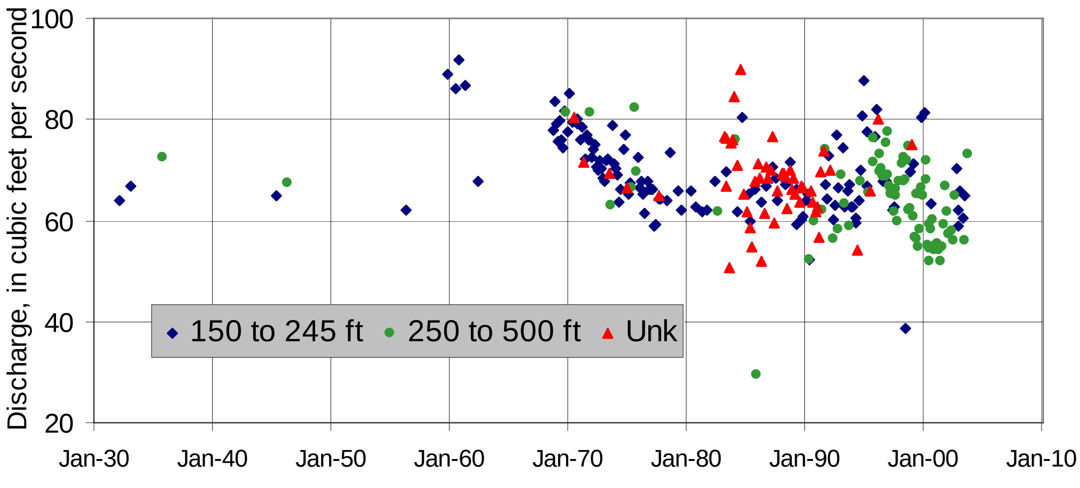
Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	19	9.8	-0.39	0.02
February - April	17	10.2	-0.19	0.28
May - July	12	10.1	-0.15	0.49
August - October	11	9.6	-0.11	0.64
November - January	12	9.3	0.06	0.78

Wekiva Springs

There have been 267 measurements of discharge from Wekiva Springs from March 1932 to September 2003, by Hydrogage (seven measurements), SJRWMD (92 measurements), and USGS (168 measurements). All but six of the measurements were made since 1959. Nearly all measurements were made within 200 to 300 ft downstream from the main boil. Several changes have been made over the years to the area surrounding the spring pool, none of which are likely to have affected discharge or ability to measure discharge of the springs. The rock wall surrounding the pool was present at least as early as the 1930s, according to photographs. In 1948, a boathouse and hotel were removed but the rock wall was retained. In 1970-71, a concrete bulkhead was built over and behind the rock wall. This construction did not change the shape of the basin or affect water levels in the spring pool.

The plot of discharge measurements (Figure 9) indicates periods of increasing spring discharge as well as periods of decreasing spring discharge during the period of record.

Figure 9 Measured discharge of Wekiva Springs
Legend refers to distance downstream from boil. Unk indicates location unknown).



The Kruskal-Wallis test was used to determine if there is statistical evidence that discharge measurements made at the two measurement-location groups is different. Using all data with known measurement locations, there is a significant difference in discharge between the two groups (Table 11).

Table 11. Kruskal-Wallis Test for differences in discharge among location groups: Wekiva Springs: Period of record

Distance downstream	Number of measurements	Mean Q	Mean rank score
150 to 245 ft	135	69.3	121.3
250 to 300 ft	79	64.0	84.0

Chi-square statistic: 18.0
Probability of no difference in discharge among the location groups: <0.01

The difference in discharge between the two groups may be an artifact of the distribution of measurement location in time. Most measurements in the 250 to 300 ft group have been made since 1990, when spring discharge has been lower than in previous years. The Kruskal-Wallis test was repeated using only measurements from the 1992 through 1998 period. During this period, the number of measurements made in both locational groups was similar. Results of this test indicate no significant difference in discharge between the 2 measurement location groups from 1992 through 1998 (Table 12).

Table 12. Kruskal-Wallis Test for differences in discharge among location groups: Wekiva Springs: 1992 through 1998

Distance downstream	Number of measurements	Mean Q	Mean rank score
150 to 245 ft	29	67.7	32.2
250 to 300 ft	35	67.5	32.7

Chi-square statistic: 0.013
Probability of no difference in discharge among the location groups: 0.91

Seasonal and annual trend analyses (Table 13) indicate that there are significant downward trends in spring discharge for all seasonal groupings. However, the trends are not monotonic, so the results of the trend tests are inconclusive. The 1960s and 1970s are generally considered to be relatively high in rainfall, and the 1990s and into the 2000s have had periods of drought. The effects of wet periods and dry periods are apparent in Figure 9, especially the high flows that occurred in the 1960s and 70s during relatively wet conditions, and the low flows that occurred in the 1990s and into the 2000s during relatively dry conditions.

Table 13. Kendall's Tau test for temporal trends by season in spring discharge: Wekiva Springs

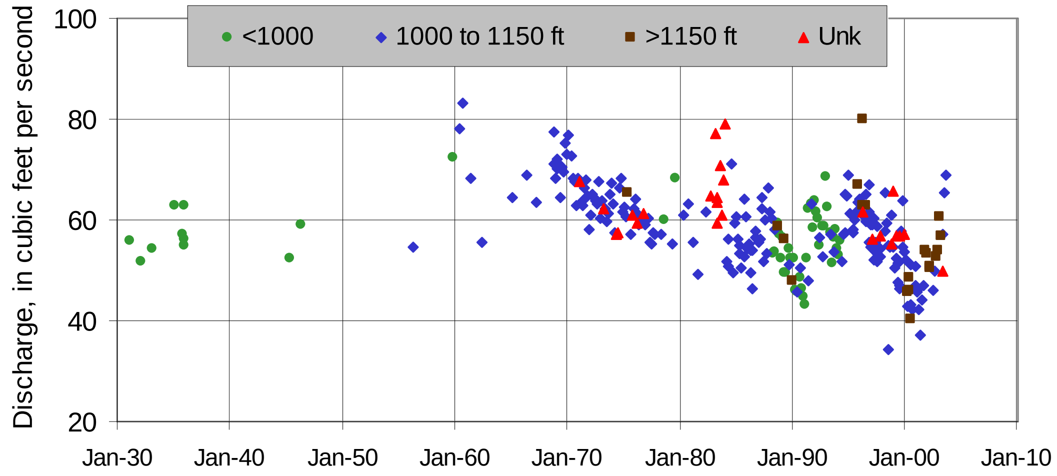
Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	46	67.5	-0.29	<0.01
February - April	35	68.0	-0.24	0.047
May - July	38	64.3	-0.49	<0.01
August - October	37	69.2	-0.37	<0.01
November - January	31	69.7	-0.34	<0.01

There are some reasons to believe that discharge from Wekiva Springs has actually increased since before 1960. The six discharge measurements made before 1960 are all lower than many measurements made after 1960, suggesting a long-term trend of increasing discharge. Also, an analysis by Tibbals (1990), using a double-mass analysis of discharge and rainfall at Orlando for the period 1936 – 1982, suggested that the average discharge in the Wekiva River increased after 1960. Tibbals attributed about half of this increase in river discharge to increased ground-water discharge into the river from springs, including Wekiva Springs. One explanation for the increased spring flow after 1960 is that the spring vents were flushed of silt and debris during the period of high spring discharge in the early 1960s. Another possible explanation is that construction of the Haines Creek and Moss Bluff control structures on the Ocklawaha Chain of Lakes in 1960 resulted in higher lake stages and thus increased ground-water recharge in the Wekiva and Rock Springs basins (Tibbals, Fulton, and Bradner 2004).

Rock Springs

There have been 280 measurements of discharge from Rock Springs from February 1931 to September 2003, by Hydrogage (six measurements), SJRWMD (82 measurements), and USGS (144 measurements). All but 11 of the measurements were made since 1959. Nearly all measurements were made within 500 to 1200 ft downstream from the main boil. The plot of discharge measurements (Figure 10) indicates periods of increasing spring discharge as well as periods of decreasing spring discharge during the period of record.

Figure 10 Measured discharge of Rock Springs, period of record
(Legend refers to distance downstream from boil. Ukn indicates location is unknown.)



The Kruskal-Wallis test was used to determine if there is statistical evidence that discharge measurements among the three measurement-location groups is different. Using all data with known measurement locations, there is a significant difference in discharge among the three groups (Table 14).

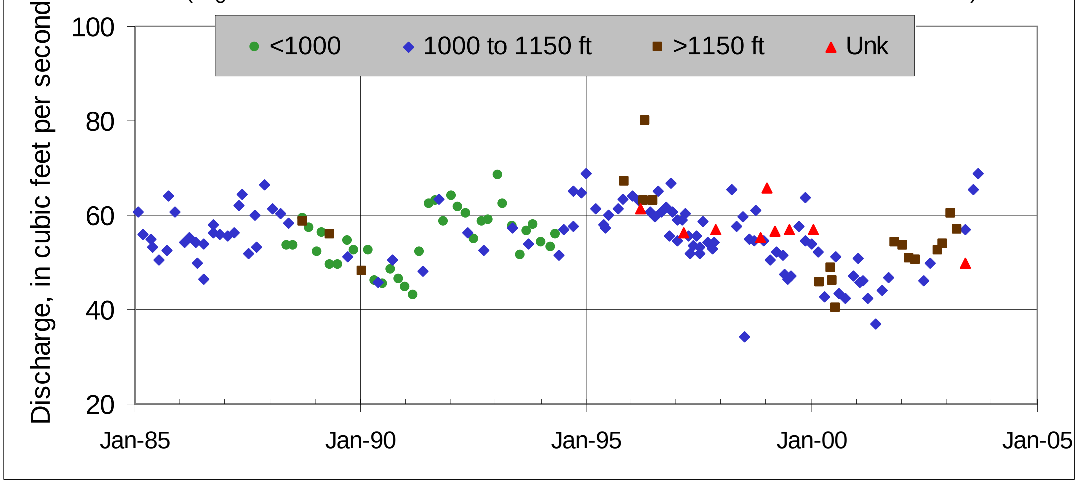
Table 14. Kruskal-Wallis Test for differences in discharge among location groups: Rock Springs: Period of record

Distance downstream	Number of measurements	Mean Q	Mean rank score
100 to 999 ft	49	56.0	107.0
1000 to 1150 ft	185	58.7	135.7
1151 to 1400	20	55.7	101.8
Chi-square statistic: 8.54 Probability of no difference in discharge among the location groups: 0.014			

The difference in discharge among the three groups may be an artifact of the distribution of measurement location in time. Most of the measurements from 1960 to 1980, when spring discharge was relatively high, were in the 1000 to 1150 ft group. An expanded plot of discharge for 1985 through 2003, when measurements were made within all three locational groups, does not seem to indicate shifts in discharge that relate to measurement location (Figure 11).

Figure 11 Measured discharge of Rock Springs, 1985 - 2003

(Legend refers to distance downstream from boil. Ukn indicates location is unknown.)



Seasonal and annual trend analyses (Table 15) indicate that there are significant downward trends in spring discharge for all seasonal groupings except the February – April group. However, the trends are not monotonic, so the results of the trend tests are inconclusive. The 1960s and 1970s are generally considered to be relatively high in rainfall, and the 1990s and into the 2000s have had periods of drought. The effects of wet periods and dry periods are apparent in Figure 10, especially the high flows that occurred in the 1960s and 70s during relatively wet conditions, and the low flows that occurred in the 1990s and into the 2000s during relatively dry conditions.

Table 15. Kendall’s Tau test for temporal trends by season in spring discharge: Rock Springs

Season	Number of groups	Mean discharge	Kendall’s Tau	Probability of no temporal trend
January - December	51	58.3	-0.26	<0.01
February - April	38	58.0	-0.21	0.07
May – July	39	56.1	-0.50	<0.01
August - October	37	59.9	-0.46	<0.01
November - January	32	60.0	-0.43	<0.01

As discussed for Wekiva Springs, there are reasons to believe that discharge from Rock Springs has actually increased since 1960. The twelve discharge measurements made before 1960 are all lower than many measurements made after 1960, suggesting a long-term trend of increasing discharge. And the double-mass analysis by Tibbals (1990) suggests that the discharge in the Wekiva River has increased since 1960. Tibbals attributed about half of this increase in river discharge to increased ground-water discharge into the river from springs, including Rock Springs. One explanation for the increased spring flow after 1960 is that the spring vents were flushed of silt and debris during the period of high spring discharge in the early 1960s. Another possible explanation is that construction of the Haines Creek and Moss Bluff control structures on the Ocklawaha Chain of Lakes in 1960 resulted in higher lake stages and thus increased ground-water recharge in the Wekiva and Rock Springs basins (Tibbals, Fulton, and Bradner 2004).

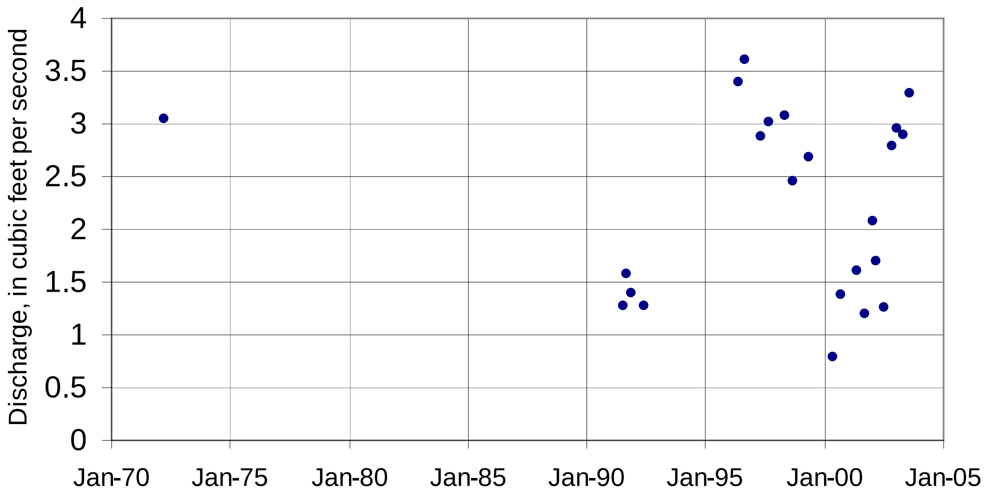
Blue Springs

There have been 23 measurements of discharge from Blue Springs from March 1972 to August 2003, by Hydrogage (seven measurements), SJRWMD (15 measurements), and USGS (one measurements). All but one of the measurements was made since 1991. Blue Springs includes several sand boils enclosed by a concrete retaining wall forming a swimming pool. Outflow from the swimming pool is through a weir in the retaining wall into a 300-ft long run. A culvert at the downstream end of the run transports the flow into a boat canal leading into Lake Harris. Several sand boils in the bottom of the run between the swimming pool and the culvert may contribute substantial inflow.

Most measurements were made in or near the culvert at the downstream end of the run. The four measurements in 1991-1992 were made on the weir at the upstream end of the spring run and thus do not include the discharge from the sand boils in the bottom of the spring run. Therefore, they do not represent the total discharge from the Blue Springs group.

The plot of discharge measurements (Figure 12) does not indicate a monotonic trend in spring discharge.

Figure 12 Measured discharge of Blue Springs



Seasonal and annual trend analyses (Table 16) were done using only the measurements made at the downstream end of the spring run. The analyses do not indicate any significant trends in discharge from Blue Springs. However, the small number of measurements makes trend analysis inconclusive.

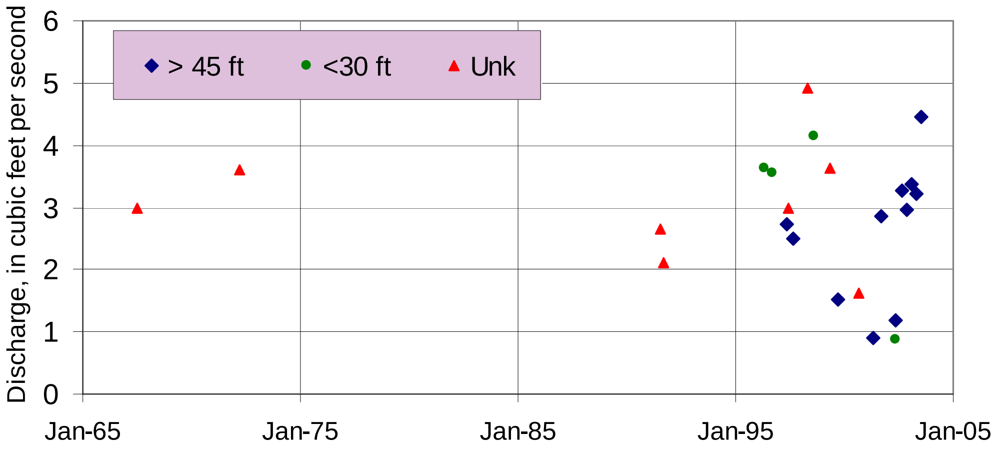
Table 16. Kendall's Tau test for temporal trends by season in spring discharge: Blue Springs (-- indicates too few measurements (<5) for trend analysis)

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	9	2.42	-0.39	0.14
February - April	3	2.56	--	--
May – July	8	2.32	-0.42	0.14
August - October	6	2.49	-0.47	0.19
November - January	3	2.09	--	--

Holiday Springs

There have been 23 measurements of discharge from Holiday Springs from June 1967 to August 2003, by Hydrogage (seven measurements), SJRWMD (13 measurements), and USGS (three measurements). All but two of the measurements were made since 1991. All measurements were made in the vicinity of the culvert under an abandoned railroad bed. The plot of discharge measurements (Figure 13) does not indicate a monotonic trend in spring discharge.

Figure 13 Measured discharge of Holiday Springs
(Legend refers to distance downstream from spring pool. Unk indicates location unknown).



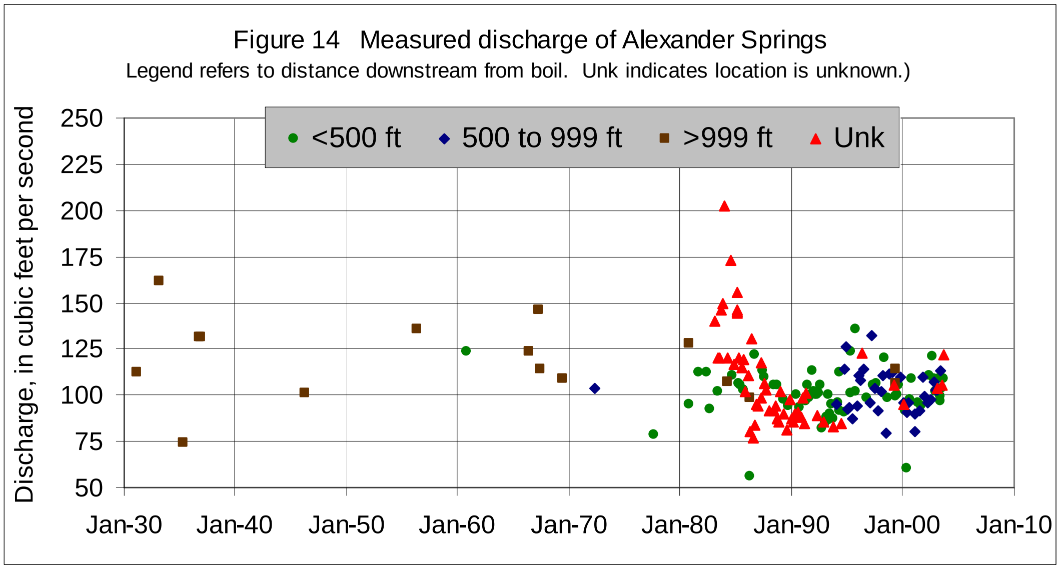
Seasonal and annual trend analyses (Table 17) do not indicate that there are significant trends in discharge from Holiday Springs. However, the small number of measurements makes trend analysis inconclusive.

Table 17. Kendall's Tau test for temporal trends by season in spring discharge: Holiday Springs (-- indicates too few measurements (<5) for trend analysis)

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	11	2.86	-0.18	0.43
February - April	2	--	--	--
May – July	9	2.70	-0.08	0.75
August - October	9	2.90	0.28	0.30
November - January	1	--	--	--

Alexander Springs

There have been 177 measurements of discharge from Alexander Springs from February 1931 to September 2003, by SJRWMD (111 measurements), and USGS (66 measurements). All but 8 of the measurements were made since 1966. Most measurements were made within 100 to 900 ft downstream from the main boil. The USGS made 14 measurements about 1.3 miles downstream from the boil at the State Highway 445 bridge. The plot of discharge measurements (Figure 14) does not seem to indicate a monotonic downward trend in spring discharge.



The Kruskal-Wallis test was used to determine if there is statistical evidence that discharge among the 3 measurement-location groups is different. Using all data with known measurement locations, there is a significant difference in discharge among the three groups (Table 10.1). The mean measured discharge in the two upper-most locational groups (<500 ft and 500 to 999 ft) is nearly identical, but the downstream-most group mean discharge is about 18 percent higher than the other 2 groups.

Table 18. Kruskal-Wallis Test for differences in discharge among location groups: Alexander Springs

Distance downstream	Number of measurements	Mean Q	Mean rank score
<500 ft	70	101.0	56.2
500 to 999 ft	35	101.7	56.5
> 999 ft	16	118.4	91.7

Chi-square statistic: 14.1
Probability of no difference in discharge among the location groups: <0.01

A set of discharge measurements along the Alexander Spring run was made on October 30, 1980 (Tibbals, 1990). The measured discharge was 95 ft^3/s just below the main boil, 128 ft^3/s at the HW445 bridge, 118 ft^3/s about 4 miles downstream from the HW445 bridge (near the mouth of Tracy Creek), and 128 ft^3/s about 6 miles below the HW445 bridge. These data indicate a substantial source of inflow between the main spring boil and the HW445 bridge. Because there is no significant difference in discharge in the <500 ft locational group and the 500 to 999 group (Table 18) the source of inflow is probably more that 1000 ft downstream from the mail boil.

A pair of measurements was made on May 8, 1986, one at the head of the spring run and the other at the HW445 bridge. These measurements indicate that discharge increased from 55.9 ft^3/s to 98.9 ft^3/s between these two locations.

There are two possible sources of inflow to Alexander Spring Run between the spring boil and the HW445 bridge. One source is surface inflow from Billies Bay Branch and Ninemile Creek, which discharge into the spring run upstream of the HW445 bridge. Another source is additional spring vents or areas of seepage into the spring run. The measurements made on October 30, 1980 were done during an extended drought period, and there was no surface inflow into the spring run (Tibbals, 1980). Thus, the inflow between the mail boil and the HW445 bridge must have been from spring vents or seeps in the spring run. During wet periods, however, surface runoff and discharge from Billies Bay Branch and Ninemile Creek could contribute additional flow.

Seasonal and annual trend analyses (Table 19) indicates that there are significant downward trends in spring discharge for only the annual and the May – July seasonal groupings. However, the apparent presence of trends may be an artifact of the locations of the discharge measurements. Most of the measurements before 1970 were made at the HW445 bridge, and thus included additional inflow along the spring run as discussed in the previous paragraph. This additional inflow, measured early in the period of record, could create the appearance of a trend in spring discharge.

Table 19. Kendall's Tau test for temporal trends by season in spring discharge: Alexander Springs: All measurements

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	36	105.0	-0.25	0.03
February - April	26	110.7	-0.25	0.07
May - July	25	102.5	-0.29	0.04
August - October	26	103.7	-0.02	0.86
November - January	22	105.8	-0.14	0.35

An additional set of trend tests was done using only measurements made at locations known to be within 1000 ft of the main boil (Table 20). These tests did not indicate significant trends in any seasonal group.

Table 20. Kendall’s Tau test for temporal trends by season in spring discharge: Alexander Springs: Only measurements made within 1000 ft of the mail boils

Season	Number of groups	Mean discharge	Kendall’s Tau	Probability of no temporal trend
January - December	27	101.3	-0.003	0.98
February - April	12	101.0	-0.06	0.78
May - July	21	99.3	-0.15	0.33
August - October	24	102.7	0.09	0.54
November - January	13	103.0	0.03	0.90

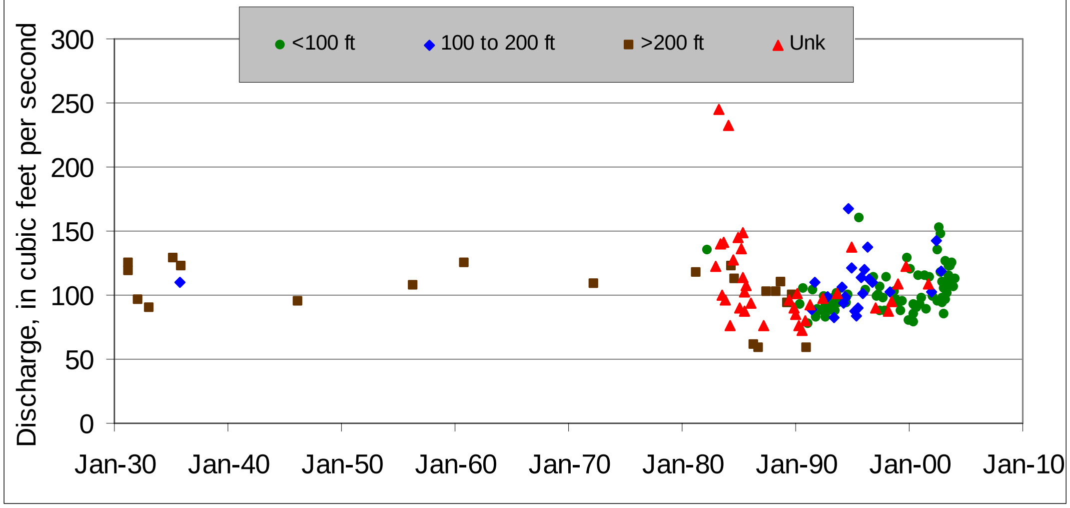
Silver Glen Springs

Most spring discharge probably occurs from two vents within and adjacent to the pool at the head of the spring run. Some inflow also occurs from numerous vents in the bottom of the spring run several hundred ft downstream from the pool (Rosenau, et al. 1977).

There have been 156 measurements of discharge from Silver Glenn Springs from March 1931 to April 2004, by Hydrogage (14 measurements), SJRWMD (78 measurements), and USGS (64 measurements). All but 11 of the measurements were made since 1981. Most measurements were made within 100 ft of the main boil. However, the USGS made eight measurements more than 1000 ft downstream from the boil. Two measurements by SJRWMD indicated discharges greater than 200 ft^3/s and are substantially higher than any other measurements. Field notes for these two measurements could not be located, so the measurements cannot be checked and should be considered as possibly in error. The plot of discharge measurements (Figure 15) does not seem to indicate a monotonic downward trend in spring discharge.

Figure 15 Measured discharge of Silver Glen Springs

(Legend refers to distance downstream from boil. Ukn indicates location is unknown.)



The Kruskal-Wallis test was used for all measurements with known measurement locations to determine if there is statistical evidence that discharge among the three measurement-location groups is different. The test indicates no significant difference in discharge among the three locational groups, even though the measurements made several hundred ft downstream from the pool would include discharge from vents in the spring run (table 21).

Table 21. Kruskal-Wallis Test for differences in discharge among location groups: Silver Glen Springs: Period of record

Distance downstream	Number of measurements	Mean Q	Mean rank score
<100 ft	75	102.7	56.8
100 to 200 ft	24	108.1	66.9
> 200 ft	21	102.7	66.3

Chi-square statistic: 2.24
Probability of no difference in discharge among the location groups: 0.33

All but one of the measurements made before 1980 were in the >200 ft location group. To eliminate any effects of changing discharge conditions over time that may have affected the >200 ft group more than other groups, the test was repeated using only measurements from 1980 on. The test indicates no significant difference in discharge from 1980 on among the 3 locational groups (Table 22).

Table 22. Kruskal-Wallis Test for differences in discharge among location groups: Silver Glen Springs: 1980 on

Distance downstream	Number of measurements	Mean Q	Mean rank score
<100 ft	75	102.7	53.4
100 to 200 ft	23	108.1	62.0
> 200 ft	11	102.7	51.4

Chi-square statistic: 1.49
Probability of no difference in discharge among the location groups: 0.48

Seasonal and annual trend analyses (Table 23) do not indicate that there are significant trends in discharge from Silver Glen Springs.

Table 23. Kendall's Tau test for temporal trends by season in spring discharge: Silver Glen Springs

Season	Number of groups	Mean discharge	Kendall's Tau	Probability of no temporal trend
January - December	32	105.7	-0.12	0.37
February - April	28	105.9	-0.04	0.77
May - July	22	100.0	-0.16	0.31
August - October	21	111.6	0.05	0.74
November - January	20	108.1	-0.03	0.85

There is no obvious relation between Lake George water level and spring discharge (Figure 16). The length of the spring run, from the spring pool to Lake George, is about 3500 ft. The water level in Lake George varies over a range of at least 2.5 ft. This variation in lake water level should affect the spring pool water level. The lack of a noticeable relation between spring discharge and river water level probably is the result of seasonal patterns in water levels. The potentiometric level in the Upper Floridan aquifer and the lake stage are both likely to be relatively high during the wet season, and relatively low during the dry season. The head difference between aquifer and spring pool may be relatively constant throughout most years.

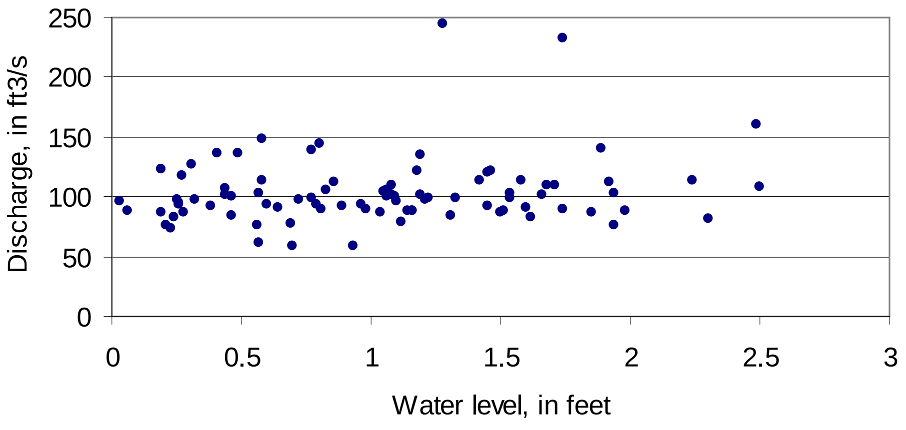


Figure 16 Relation of discharge from Silver Glen Springs to Lake George water level

Major Conclusions

Only two of the 11 springs appear to have locational effects on discharge measurements (Table 24). Inflow from spring vents and tributaries along the Silver River cause significant increases in discharge with distance downstream, especially in the first 3500 ft below the main boil. Smaller amounts of inflow occur between about 13,200 ft below the main boil to the mouth of the Silver River.

Table 24. Summary of locational effects on spring discharge measurements and temporal trends in spring discharge.

Spring	Locational effects	Temporal trends
Gemini	No	No
Ponce DeLeon	No	Yes
Green	No	No
Silver	Yes	Yes
Bugg	No	No
Wekiva	No	Inconclusive
Rock	No	Inconclusive
Blue	No	No
Holiday	No	No
Alexander	Yes	No
Silver Glen	No	No

Discharge in the Alexander Spring run may increase with distance downstream from the main boil (Table 24). Measurements made > 999 ft below the boil averaged about 18% higher than measurements in other segments.

There are two possible sources of inflow to Alexander Spring Run between the spring boil and the HW445 bridge. One source is surface inflow from Billies Bay Branch and Ninemile Creek, which discharge into the spring run upstream of the HW445 bridge. Another source is additional spring vents or areas of seepage into the spring run. Measurements made in October 1980 during an extended drought period indicated the presence of substantial inflow between the main boils and the HW445 bridge. No tributary inflow was observed between the two measurement locations, so the inflow must have been from spring vents or seeps in the spring run. A pair of measurements made on May 8, 1986, one at the head of the spring run and the other at the HW445 bridge, also indicates a substantial increase in discharge between these two locations. During wet periods, surface runoff and discharge from Billies Bay Branch and Ninemile Creek could contribute additional flow.

It is perhaps surprising that no locational effects on discharge were noted for Silver Glen Springs. Some inflow would be expected from reported sand boils in the run channel several hundred ft downstream from the main boil. Apparently the quantity of this inflow is insignificant compared to discharge from the main spring group.

There were temporal trends in discharge indicated for two springs (Table 22). These trends were for decreasing spring flow over time. At two other springs (Wekiva and Rock), trend testing indicated a downward trend in spring discharge. However, the tests at these two springs are inclusive because the trends were not monotonic, and because other studies have suggested spring flow has actually increased since 1960 in relation to rainfall. The indication of significant trends at some springs is probably the result of rainfall patterns. The 1960s and 1970s are generally considered to be relatively high in rainfall, and the 1990s and into the 2000s have had periods of drought. Thus, this change from wet conditions early in the period of record to dry conditions late in the period of record could be the principal reason for trend detections. The period of record at some springs (Gemini, Green, Blue, and Holiday) is not long enough to give definite information regarding trends.

Recommendations

The following data-collection needs are indicated by this study:

- More simultaneous discharge measurements are needed along the Silver River to verify the gross interpolation equations for estimating discharge at the mouth of the Silver River. Also, inflow from tributaries, such as the tributary entering Silver River about 4100 ft below the main boil, should be measured to determine if this inflow is a significant part of discharge in the Silver River. Suggested measuring locations along Silver River for the purpose of determining longitudinal profiles of discharge in the river are: a) within 300 ft of the main boil; b) about 3900 ft below the boil which is probably below all known spring vents in the Silver River and was at or near the site of longitudinal profile discharge measurements made in 1944 and 2004; c) tributary inflow at about 4100 ft below the boil; d) about 13200 ft below the boil, near where longitudinal profile discharge measurements were made in 1917, 1929, 1944, and 1974; and e) at or near the mouth of Silver River. These measurements should all be done on the same day if possible, and should be repeated to represent periods of low flow, intermediate flow, and high flow.

- An effort should be made to locate the sand boils reported in the Silver Glen spring run (Rosenau, et al. 1977). Measurements above and below these boils should be made to determine if they are a significant source of inflow.

- For all spring runs, measurements should be made (simultaneously if possible) at the customary measuring section and at the spring run mouth, to determine if there are additional spring vents that may be contributing inflow to the spring runs. These sets of measurements should be made during the dry season and also during the wet season to provide information on amount of surface runoff to the spring runs.

- It was difficult to determine measurement location with respect to the spring boil in many cases. Measurement locations are commonly with respect to gages, reference points, or local landmarks (such as the “Tarzan Tree”). It is highly recommended that all measurements be referenced to distance downstream from the spring head, pool, or main boil. Alternately, position of measurement section could be given each time by latitude and longitude readout from a GPS unit. The GPS position would probably provide the best method because it would eliminate the need for those making the measurement to estimate distance from the spring. Estimating such distance can be difficult, especially if the measuring section is downstream a considerable distance along a sinuous spring run.

- A follow-up analysis should be completed within five years to assess new data collection efforts.

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