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OCKLAWAHA RIVER BASIN RAINFALL YIELD ANALYSIS

Water Supply Solutions, Inc.

Technical Memorandum

To: Barbara A. Vergara, P.G.
James T. Gross, P.G.

From: Ronald L. Wycoff, P.E., D.WRE

Date: March 11, 2008

Re: Lower Ocklawaha River Basin Rainfall –Yield Analysis

Purpose and Scope

The primary purpose of this technical memorandum (TM) is to report the results of an investigation of the relationship between total annual rainfall and total annual yield of the Ocklawaha River Basin. This investigation was performed to support discussions and decisions concerning the possible development of water supplies from the Lower Ocklawaha River. The Lower Ocklawaha River is described as the portion of the Ocklawaha River extending from its confluence with the Silver River downstream to the St. Johns River and is the focus of this investigation. The analysis is based on average annual water year discharge records published by the United States Geological Survey (USGS) and total annual water year rainfall depths derived from National Oceanic and Atmospheric Administration (NOAA) monthly rainfall records.

The Ocklawaha River Basin

The Ocklawaha River Basin is located in central Florida and is a major tributary to the St. Johns River (Figure 1). It is located primarily within the St. Johns River Water Management District (SJRWMD). However, the extreme southern portion, in Polk County, is located within the Southwest Florida Water Management District.

Like the St. Johns River, the Ocklawaha is a northward flowing river. Its headwaters begin in the Green Swamp in Polk County. From there it forms the Clermont Chain of Lakes in southern Lake County and becomes the Palatlakaha River where it discharges into Lake Harris in northern Lake County. Lake Apopka, located partially in Orange County and partially in Lake County is also a tributary. Following discharge from Lake Griffin the river enters southern Marion County and the river channel is called the Ocklawaha River.

A major water control structure, located at Moss Bluff, controls water levels in Lake Griffin. Further downstream, at its confluence with the Silver River, near SR-40, the river flow is greatly increased by the contribution of Silver Springs. From this point north the basin is often referred to as the Lower Ocklawaha River Basin.

The main river flow enters the southern end of Rodman Reservoir at Eureka, Florida, near SR 316. Rodman Reservoir, located in Marion and Putnam counties, was constructed in 1968, and also receives inflow from Orange Creek, the last major tributary before the Ocklawaha River's confluence with the St. Johns River. Orange Creek drains portions of Alachua, Marion, and Putnam counties.

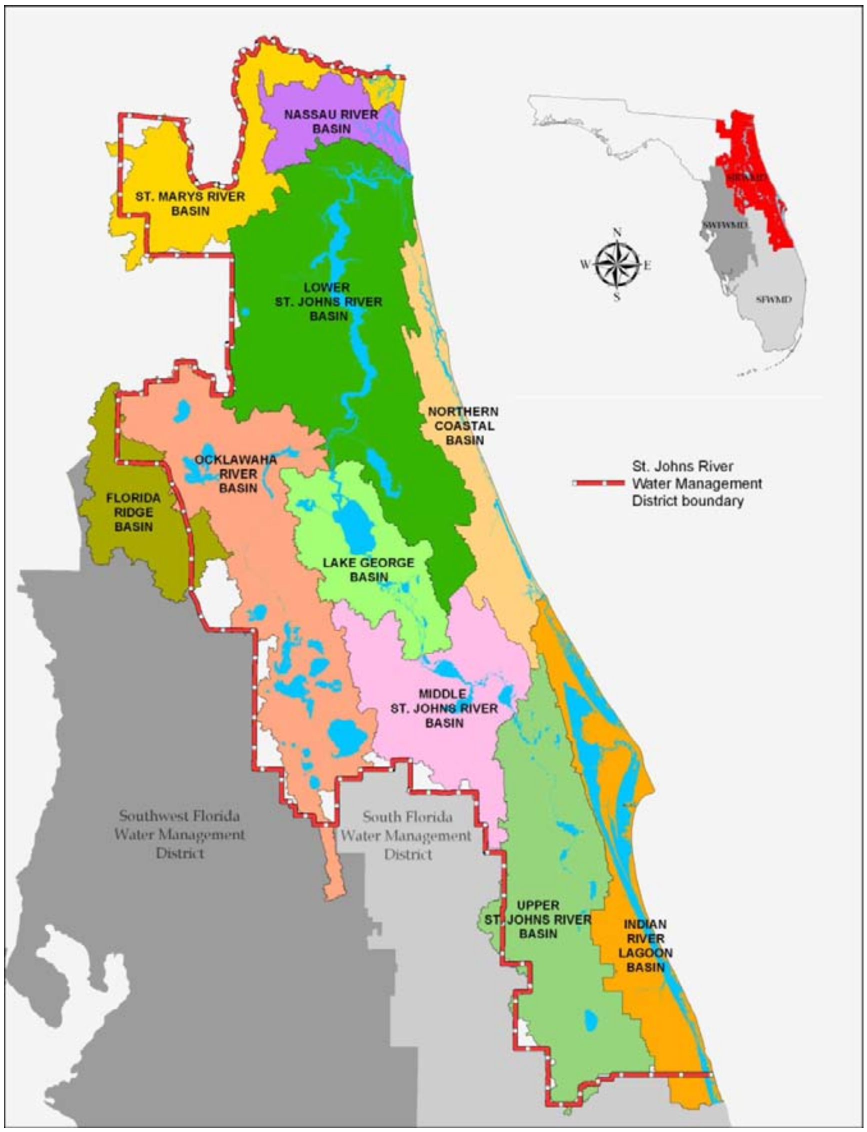

Figure 1 Major SJRWMD basins showing the location of the Ocklawaha River Basin

Ocklawaha River Basin Discharge Records

The USGS has been monitoring stream discharge at various locations within the Ocklawaha River Basin for many decades. The focus of this investigation is total basin yield and, therefore, discharge records at or near the basin outlet are of primary interest. There are five USGS gaging stations considered in this analysis. These include the Silver River gage and four downstream USGS gaging stations that collectively can be used to quantify total basin (outlet) yield for the period of record (POR). The gaging stations are listed in Table 1 and their locations are illustrated on Figure 2.

Table 1 USGS gaging stations for Lower Ocklawaha River

Map Index	Station Name	Station Number	Period of Record
1	Silver River	2239501	1933-2006
2	Orange Springs	2243000	1931-1952
3	Riverside	2244000	1944-1968
4	Rodman Dam	2243960	1968-2006
5	Buckman Lock	2244032	1971-2004

Note: Location map index refers to location numbers on Figure 2.

Basin Outlet Discharge Records

USGS stream discharge measurements at or near the Ocklawaha River Basin outlet began in water year 1931 at the *Ocklawaha River near Orange Springs Florida* gaging station (see location 2, Figure 2). This gage was operational through 1952. The total gaged tributary area is 2,657 square miles and includes the Orange Creek Basin. However, the Orange Creek Basin also includes the 650-square mile Paynes Prairie basin, a diked sinkhole area, which does not normally contribute surface runoff to Orange Creek. Therefore, the effective tributary area, defined as the watershed area actually contributing surface flow at the gage location, is about 2,007 square miles. It is the effective tributary area which is important to this evaluation of total Ocklawaha River Basin yield.

Annual discharge records for the downstream *Ocklawaha River at Riverside Landing near Orange Springs Florida* gaging station begin in 1944 (see location 3 on Figure 2). This gage was operational until construction of Rodman Reservoir in 1968. The total and effective tributary areas for this gaging station are 2,747 square miles and 2,097 square miles, respectively. The effective tributary area for this gage is 90 square miles (4.5%) greater than the effective tributary area of the Orange Springs gage. Therefore, in order to more accurately represent total basin yield, the discharge records from the upstream gage (*Ocklawaha River near Orange Springs Florida)* should be increased by 4.5% to account for total basin effective tributary area.

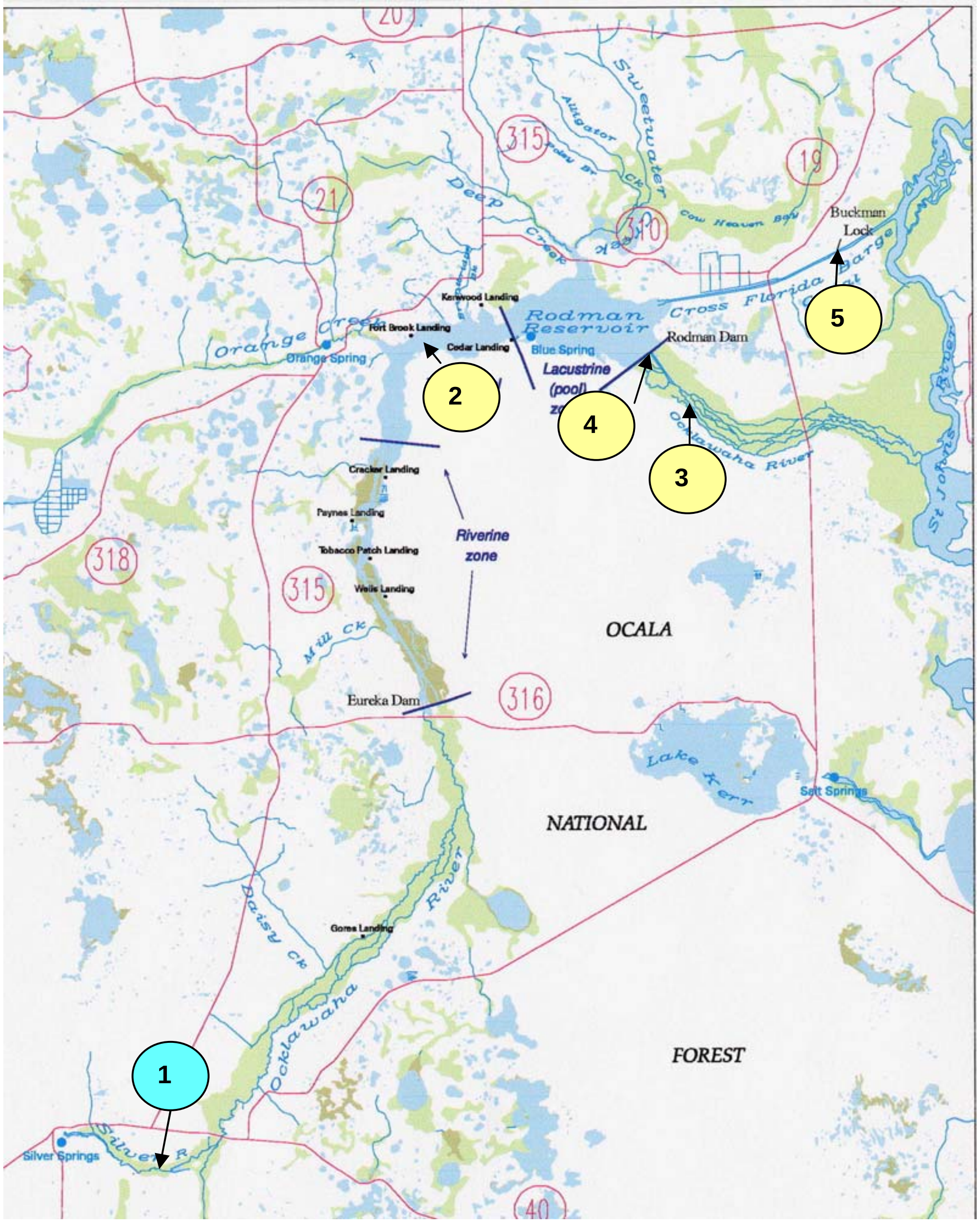

Figure 2. Lower Ocklawaha River USGS gaging station locations

Note: Location numbers refer to map index numbers on Table 1.

Since Rodman Reservoir was completed, discharge from the Ocklawaha River Basin has been controlled by Rodman Dam (see location 4 on Figure 2) and the Buckman Lock on the barge canal (see location 5 on Figure 2). Annual discharge records extend from 1969 through 2006 for Rodman Dam and from 1971 through 2004 for Buckman Lock. The total and effective tributary areas for these combined outlets are essentially the same as for the Riverside gaging station.

In aggregate, there are 76 years of annual discharge measurements available for evaluating the discharge of the Ocklawaha River Basin near its confluence with the St. Johns River. These records span the period from 1931 to 2006.

Lower Ocklawaha River Basin Total Yield for Period of Record

Development of a composite total basin yield record from these four individual gaging station data requires the consideration of the following four time periods (Figure 3).

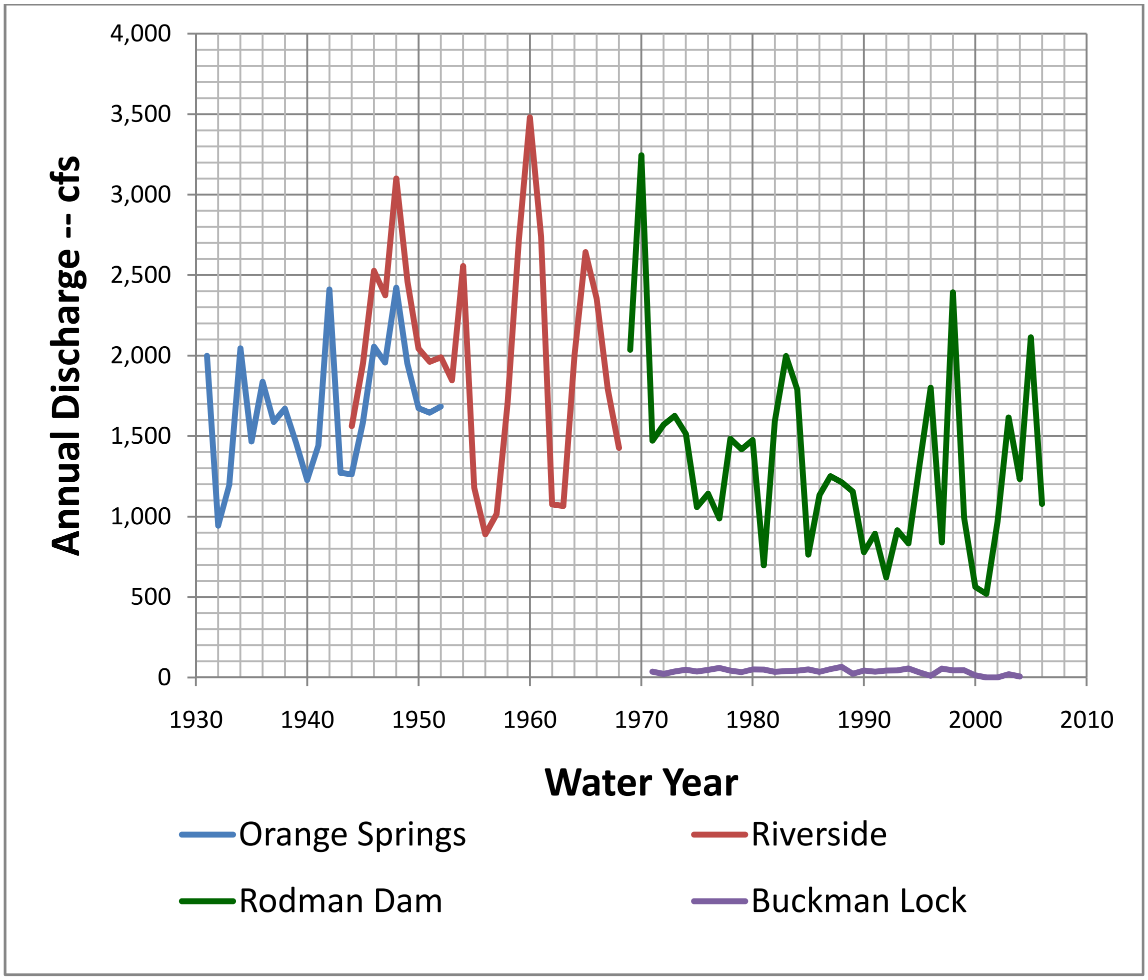

Figure 3 Ocklawaha River Basin average annual discharge data for four USGS stream gaging stations

- 1931 through 1943 – For this time period, only Orange Springs data are available. Annual yield is computed as the individual Orange Springs annual reported discharge increased by 4.5% to account for the slightly larger basin outlet tributary area.

- 1944 through 1952 – For this time period, both Orange Springs and Riverside data are available. Annual yield is computed as the average of the Orange Springs reported discharges (increased by 4.5%) and the Riverside reported discharges. In this manner data from both gaging stations are weighted equally.

- 1953 through 1968 – For this time period, only Riverside data are available and these reported discharges represent the total basin yield.

- 1969 through 2006 – For this time period, total basin yield is equal to the sum of the measured discharge from Rodman Dam and Buckman Lock.

As in most basins the annual yield is quite variable from year to year. Minimum annual discharge occurred during the drought years of 2000 and 2001. However, this minimum annual discharge still exceeded 500 cubic feet per second (cfs). Maximum annual discharge (3,480 cfs) occurred in 1960, a year influenced by Hurricane Donna.

A cyclic trend is evident in the 5-year moving average for the composite computed average annual total basin discharge (Figure 4). In the early years, 1930's through mid 1940's, both individual annual discharges and the 5-year moving average matched the long-term mean. The 1950's and 1960's are generally above average, while recent years, 1970's, 1980's and 1990's, are generally below average. The first 5-year average discharge (through 1935) equals 1,598 cfs and the most recent 5-year average, through 2006, equals a reasonably comparable 1,407 cfs.

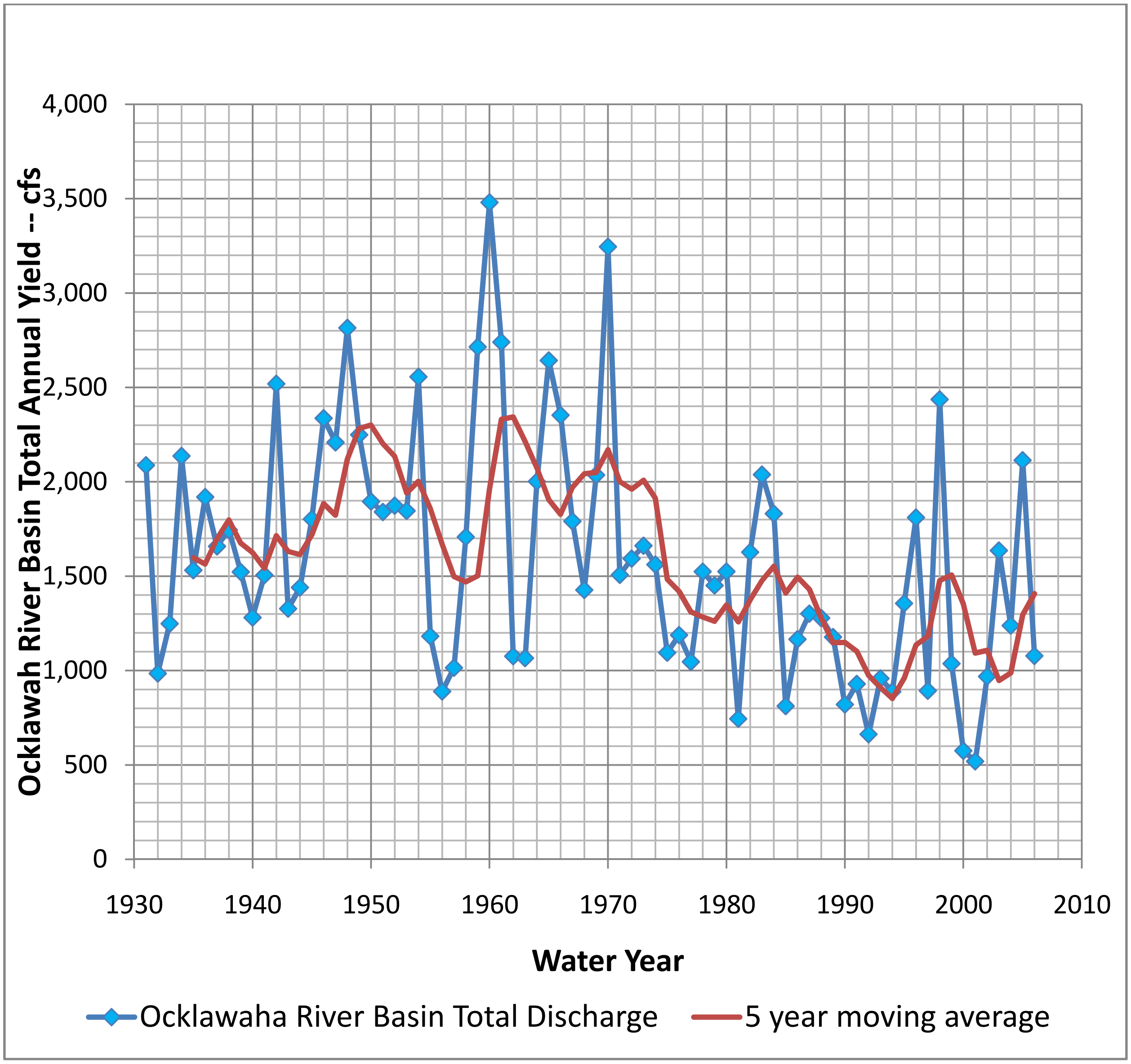

Figure 4 Ocklawaha River Basin computed annual basin yield including 5-year moving average

Influence of Silver River Discharge on Total Basin Yield

Annual discharge records for the *Silver River near Ocala Florida* gaging station begin in water year 1933 and extend through 2004 (with 2003 currently missing from the published record). Provisional daily Silver River discharge data were use to provide estimates of discharge for water years 2003, 2005 and 2006. Therefore, with provisional data included, a total of 74 years of annual discharge records are available. Silver Springs discharge via the Silver River provides base flow for the Lower Ocklawaha River.

Annual recorded discharges for the Silver River follow the same general pattern as the total basin yield except that variability is reduced (Figure 5). Like the total Ocklawaha Basin yield, the minimum annual Silver River discharge occurred in 2001 and the maximum occurred in 1960.

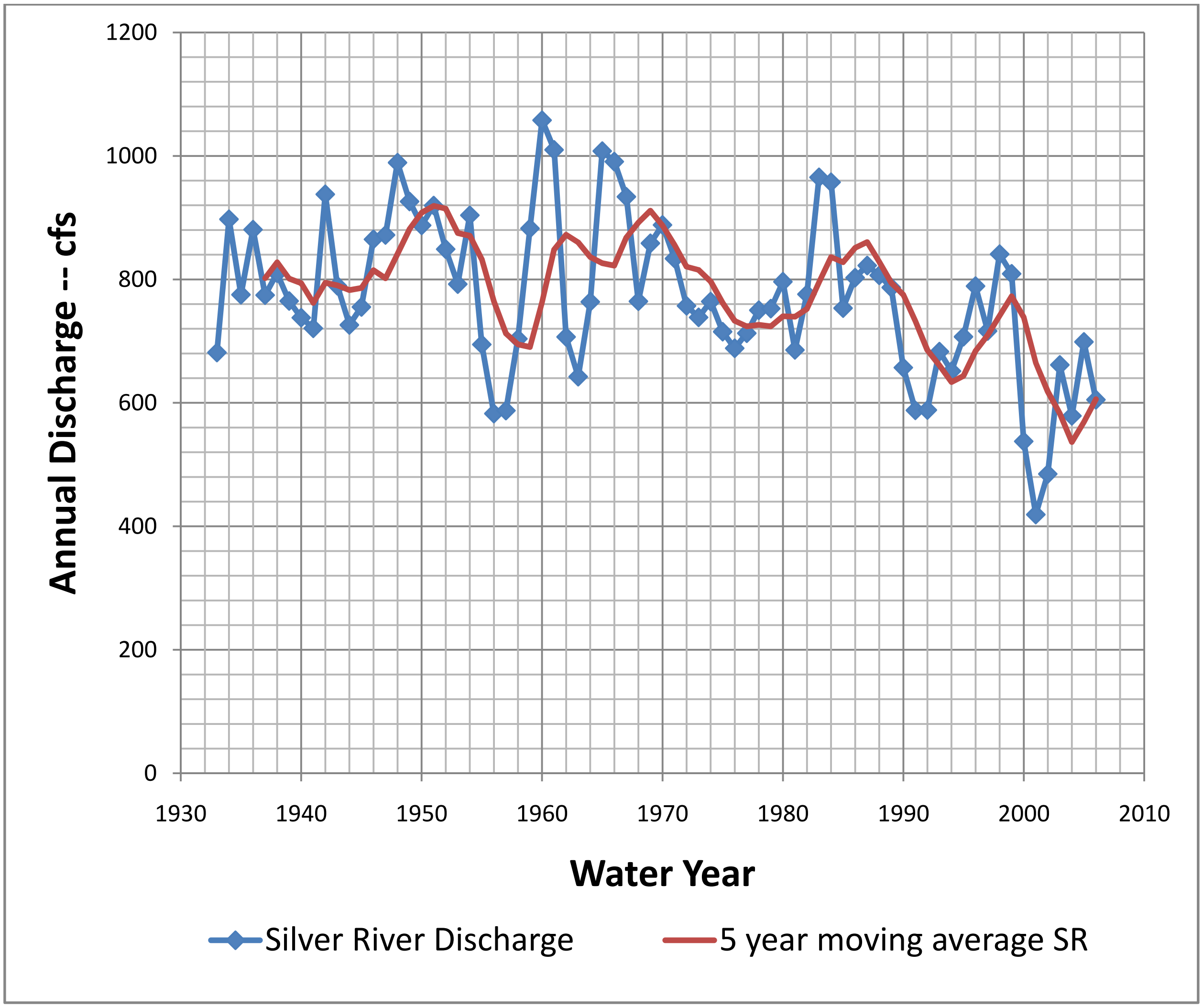

Figure 5 Recorded average annual discharges from the Silver River including 5-year moving average

When the Silver River and total basin discharge are plotted together the base flow contribution of the Silver River is apparent (Figure 6).

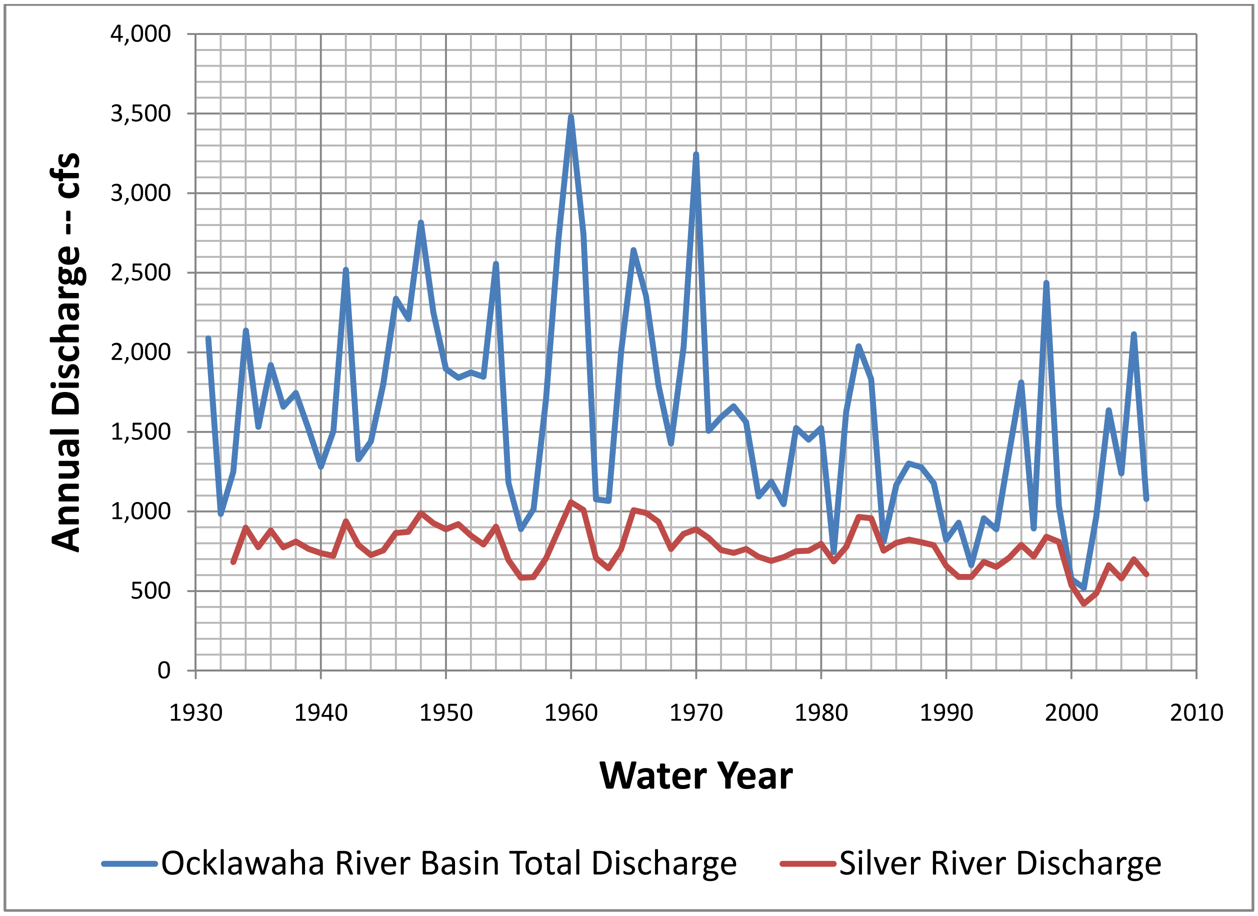

Figure 6 Period of record discharge hydrographs for the Ocklawaha River and the Silver River

The period of record mean discharge of 773 cfs for the Silver River accounts for nearly half of the period of record mean discharge of the Ocklawaha River Basin (1,602 cfs). During the 2001 drought of record Silver Springs discharge accounted for 81% of the total basin yield.

Ocklawaha River Basin Rainfall Records

Long term NOAA rainfall records considered in this analysis include recording stations located at Ocala, Lisbon and Clermont Florida. All stations have monthly data dating back to the 1880's. These monthly records were used to develop water year totals to compare to the USGS water year discharge records.

The Ocala station is located in the lower basin in close proximity to Silver Springs. Both Lisbon and Clermont are located much further upstream in the upper basin. The continuous record, beginning in water year 1931, is illustrated in Figure 7 and summary statistics for each rain gage are reported in Table 2.

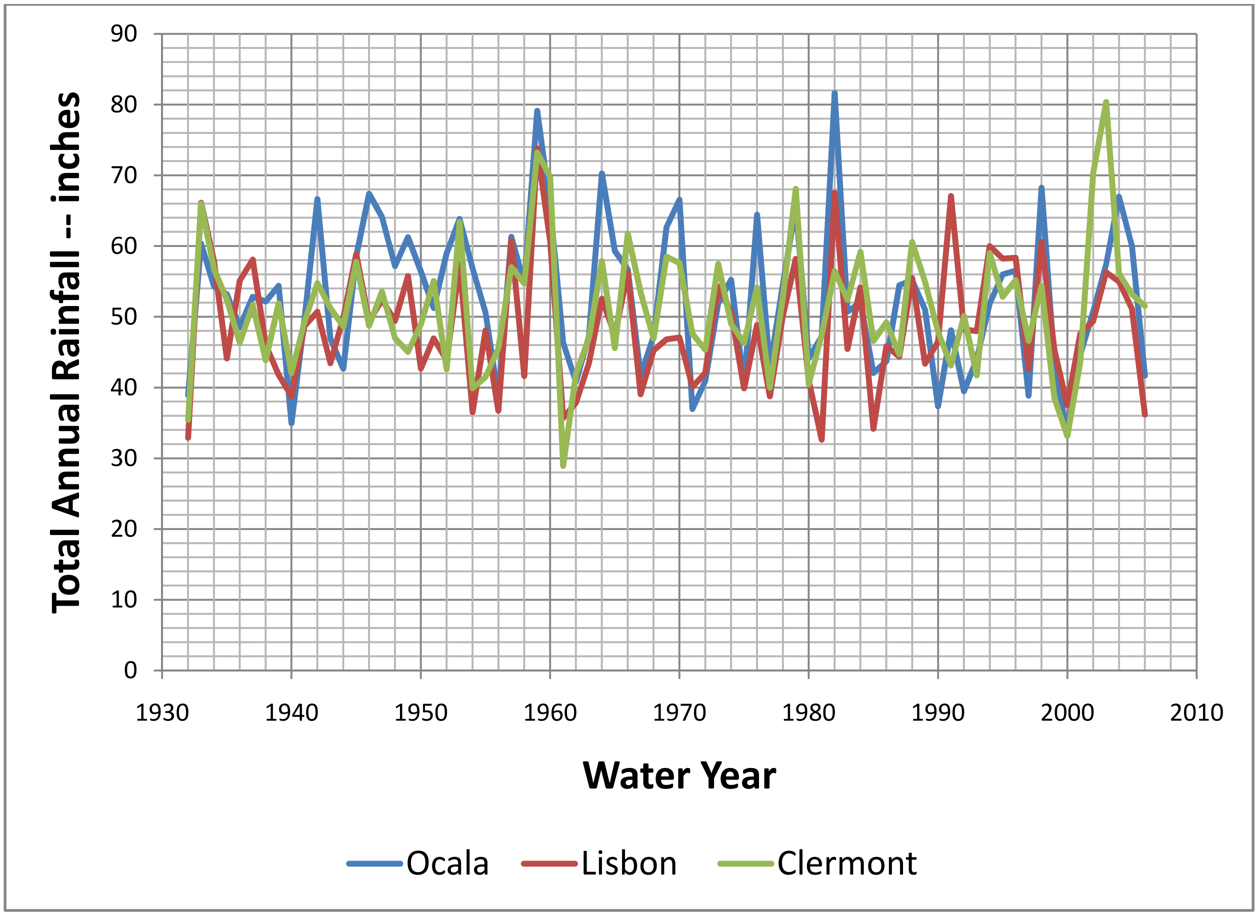

Figure 7 Water year rainfall for Ocala, Lisbon and Clermont, 1931 through 2006.

Table 2 Summary statistics for 3 rain gages - water years 1931 through 2006.

Annual Rainfall Statistic	Station		
	Ocala	Lisbon	Clermont
Mean	52.61	48.76	51.23
Std. Dev.	10.21	8.74	9.00
Maximum	81.64	73.82	80.37
Minimum	33.18	32.63	28.92
Range	48.46	41.19	51.45

Note: all rainfall values are expressed in inches.

Annual rainfall at Ocala averaged 52.61 inches and was highly variable with a range of over 48 inches. Slightly less rainfall was recorded for Lisbon. Clermont had characteristics very similar to Ocala. As can be seen from Figure 7, year-to-year and gage-to-gage variations are obvious. There is, however, considerable correlation between the gages. The correlation coefficient between Ocala and Lisbon is 0.665. Between Ocala and the more distance Clermont it is 0.590.

Double Mass Curve Analysis

As an initial indicator of overall correlation between rainfall and discharge, double mass curves were developed for Ocala rainfall and total Ocklawaha Basin Discharge (Figure 8) and Ocala rainfall and Silver River discharge (Figure 9).

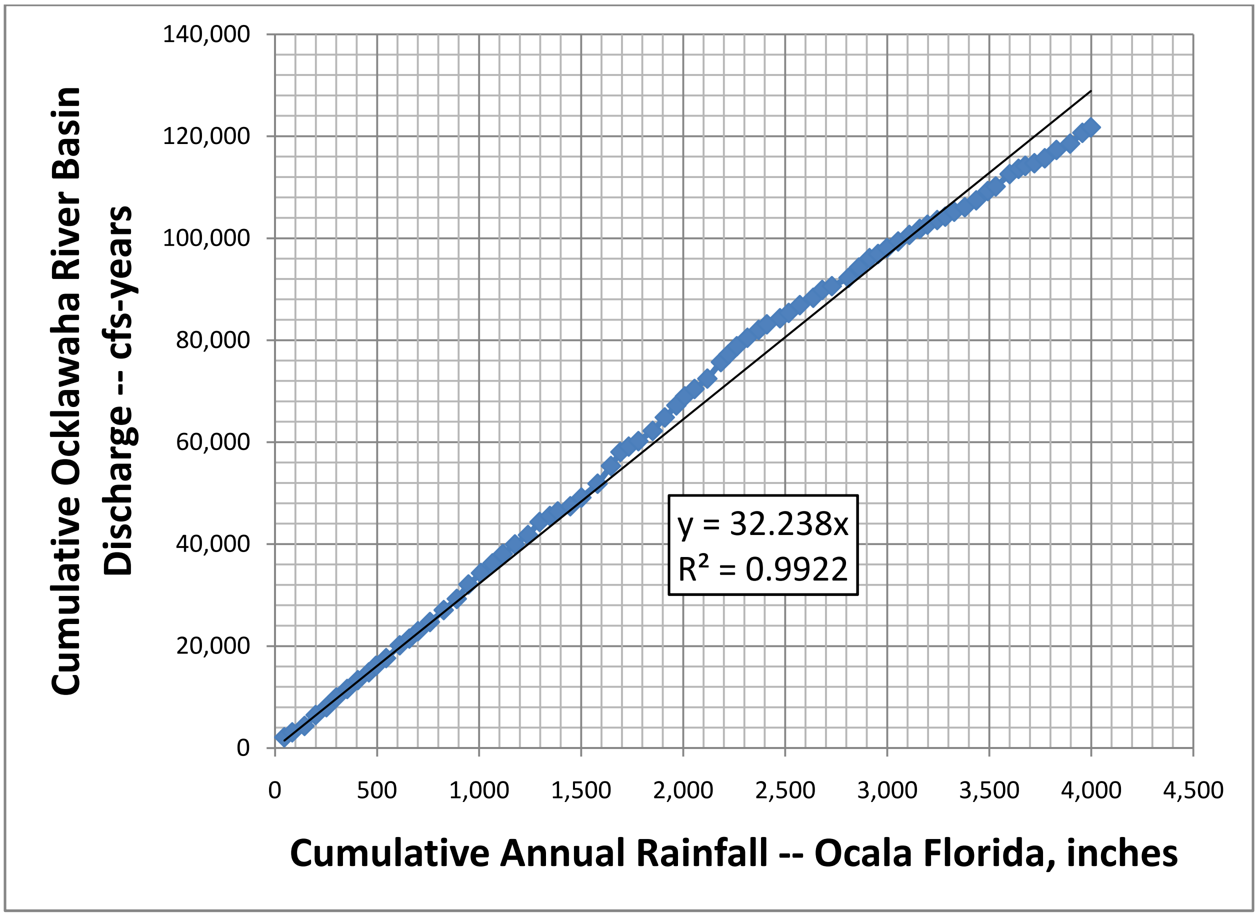

Figure 8 Double mass curve for Ocala rainfall and Ocklawaha River Basin discharge -- 1931 through 2006.

Overall the double mass curve indicates an average Ocklawaha River basin yield equal to about 32.2 cfs-years for each inch of Ocala rainfall. However, two periods vary somewhat from this long term average. From about 1958 through 1975 (cumulative rainfall from 1,500 to 2,500 inches) the unit yield is about 13% greater than the long term average and beginning in 1975 the unit yield is about 15% less than the long term average.   This could indicate variations in the overall basin rainfall yield relationship (first increasing, then decreasing) or it could be an artifact of the several gages and measurements techniques included in the period of record.

The double mass curve for the Silver River discharge is more uniform as illustrated on Figure 9.

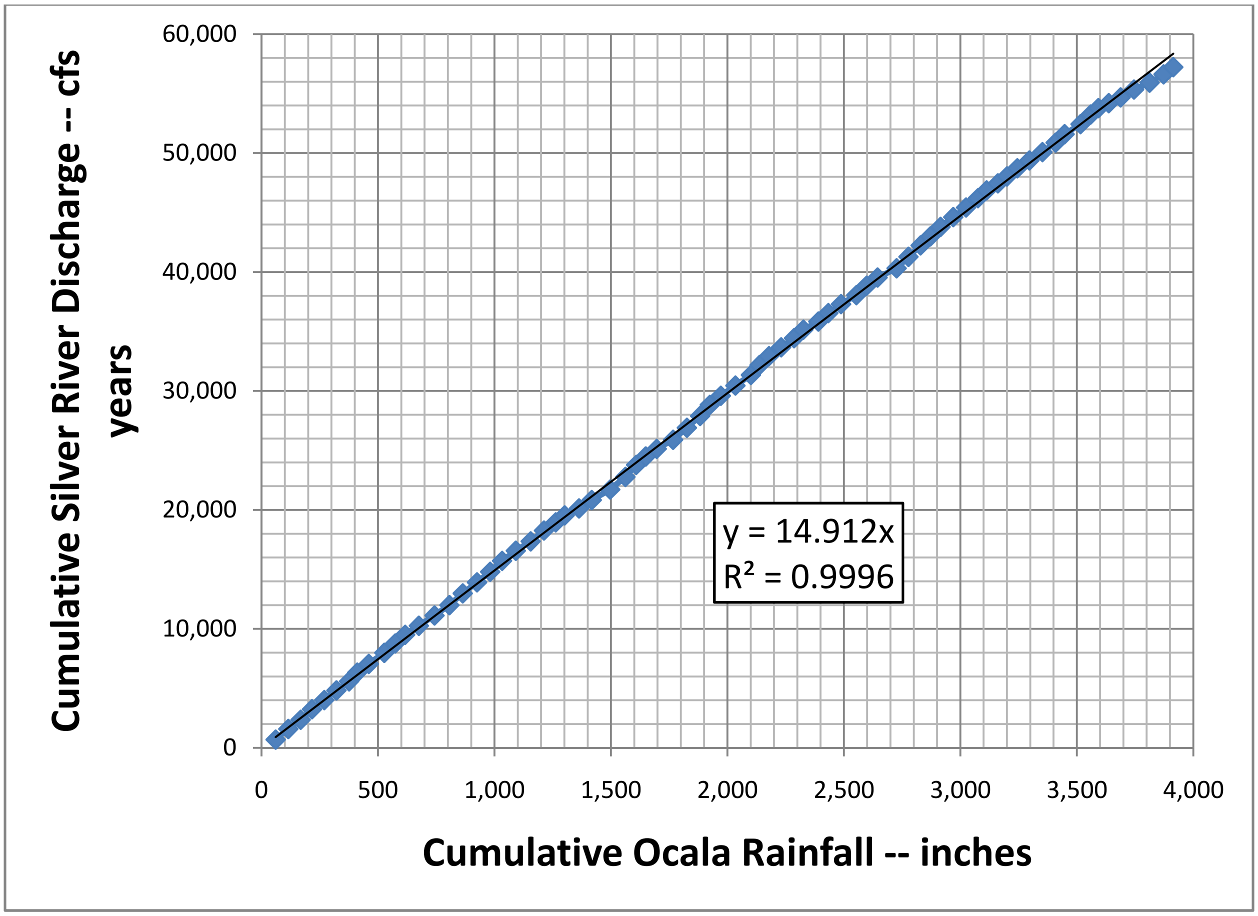

Figure 9   Double mass curve for Ocala rainfall and Silver River Basin discharge--1933 through 2006.

This curve illustrates a relatively constant relationship between Ocala rainfall and Silver River discharge. Silver River discharge averages about 14.9 cfs-years for each inch of rainfall.

Rainfall-Discharge Linear Correlation Analysis

A correlation analysis was conducted to investigate the linear correlation between observed annual Ocklawaha River basin discharge and rainfall measured at each of the 3 rainfall stations. In addition, correlations between current year discharge and prior year(s) rainfall were also considered (Figure 10).

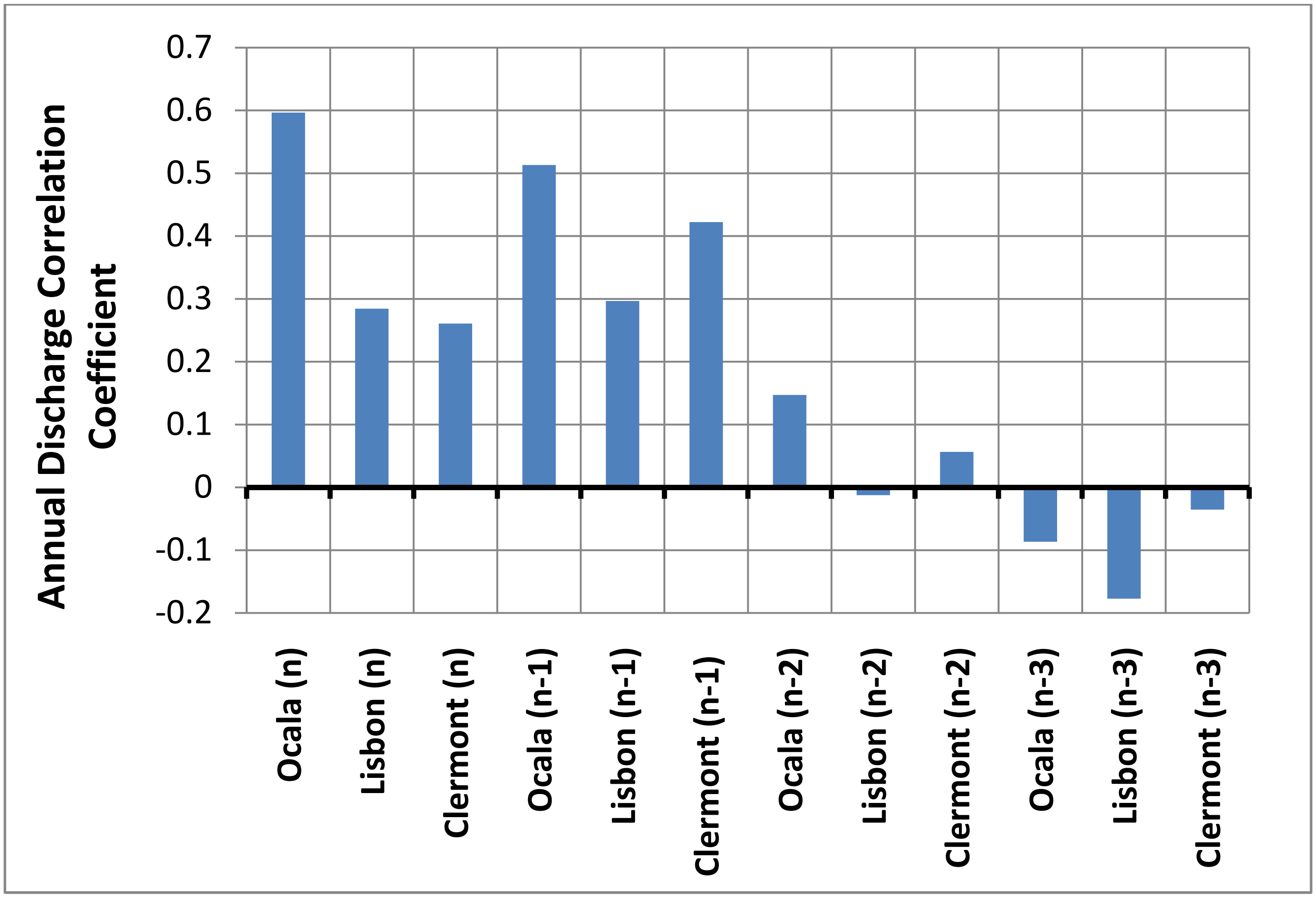

Figure 10 Rainfall-discharge correlation matrix

The rainfall station subscripts (n, n-1, n-2 & n-3) indicate years. For year n correlations, the current year discharge is compared to the current year rainfall. For year n-1 correlations, the current year discharge is compared to the prior year rainfall. For n-2 and n-3 correlations, the lag is increase to two and three years respectively.

The results indicate that the Ocala rainfall station is most highly correlated to total basin discharge and that there is a memory process involved. The highest correlation coefficient (0.597) is between current year discharge and current year Ocala rainfall and the next highest (0.513) is between current year rainfall and prior year Ocala rainfall. Prior year

Clermont rainfall also exhibits reasonable high correlation (0.422). All others have correlation coefficients below 0.3 and the two and three year lags exhibit very weak correlations.

These results suggest that storage plays a major role in the hydrologic response of the Ocklawaha River basin. This is intuitively logical given the influence of Silver Springs, an outlet of the Floridan Aquifer, and the extensive array of lakes and wetlands located in the upper basin.

Rainfall-Discharge Linear Regression Model

Several linear regression models relating Ocklawaha River total annual discharge to annual rainfall were considered. However a simple model including Ocala current year (n) and prior year (n-1) rainfall is considered to be most practical. The rainfall-discharge regression model is as follows:

ORB Q(n) = 26.45*Ocala rain(n) + 31.47*Ocala rain(n-1) +173.8*Trend – 1451.4 (1)

Where:

ORB Q(n) = Ocklawaha River Basin total annual discharge, for year n, in cfs.

Ocala rain(n) = Total annual rainfall, in inches, measured at Ocala Florida, for year n.

Ocala rain(n-1) = Total annual rainfall, in inches, measured at Ocala Florida, for year n-1.

Trend = a term to account for year-to-year trend, increasing or decreasing, in discharge.
(Trend equals +1 when current year discharge is greater than prior year discharge and -1 when current year discharge is less than prior year discharge.)

The goodness of fit characteristics of this linear regression model include a correlation coefficient of 0.796, a coefficient of determination (R^2) equal to 0.633 and a standard error of 387 cfs, or about 24% of the observed mean annual discharge.

Application of equation 1 to the Ocala annual rainfall record provides estimates of the expected value of total Ocklawaha River discharge which are compared to the observed discharge values (Figure 11).

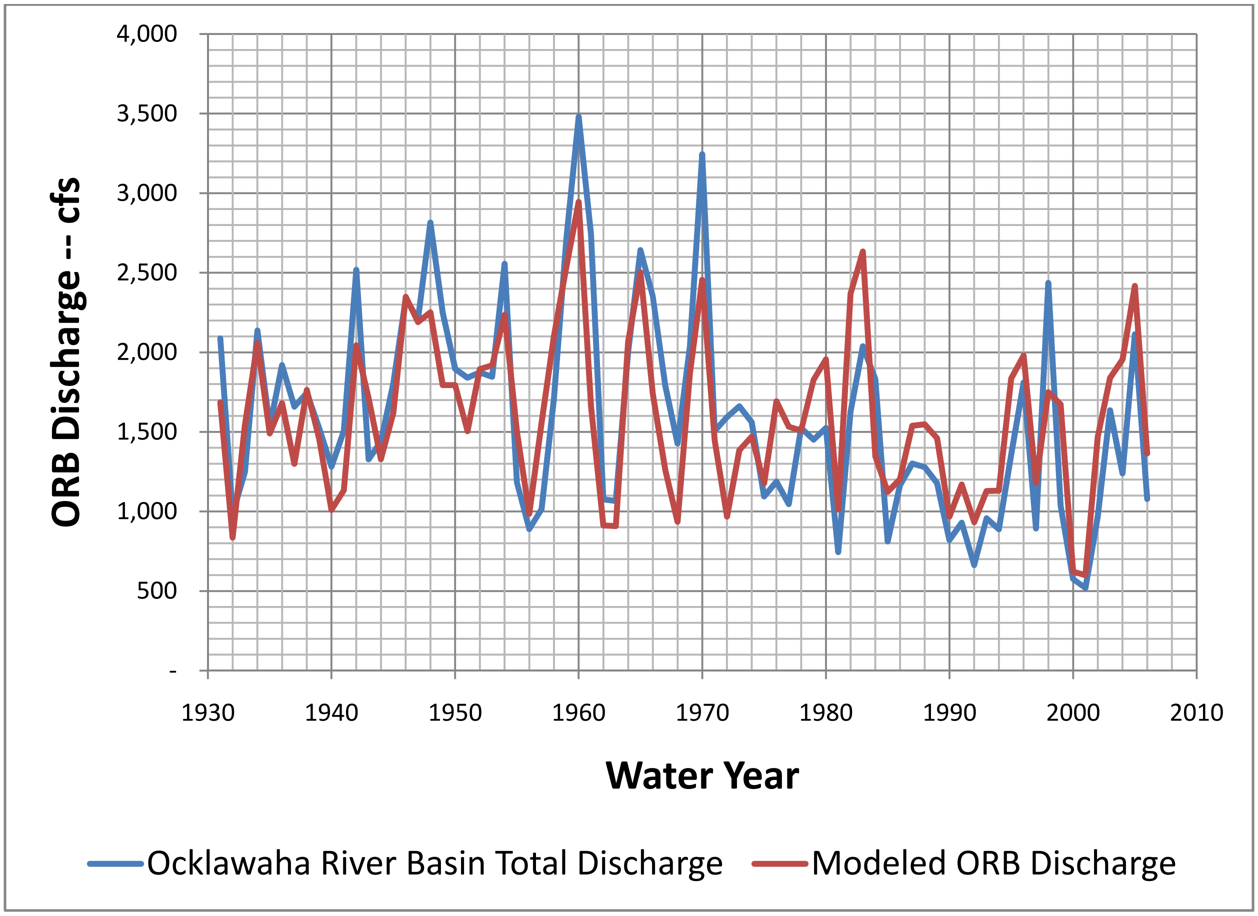

Figure 11 Ocklawaha River basin total annual discharge – historic record and regression model expected values.

The linear regression model clearly captures the overall year to year variations in annual discharge. However individual predicted values can differ significantly from the observed. Statistical regression models will always perform best near the center of the distribution (i.e. near the annual mean) and errors will be at their greatest at either end of the distribution. That is, errors are expected to be greatest for both the highest and lowest discharge years.

The residual model error, defined as the difference between individual observations and predicted (modeled) values, is often informative. The time series of annual residual error is illustrated in Figure 12.

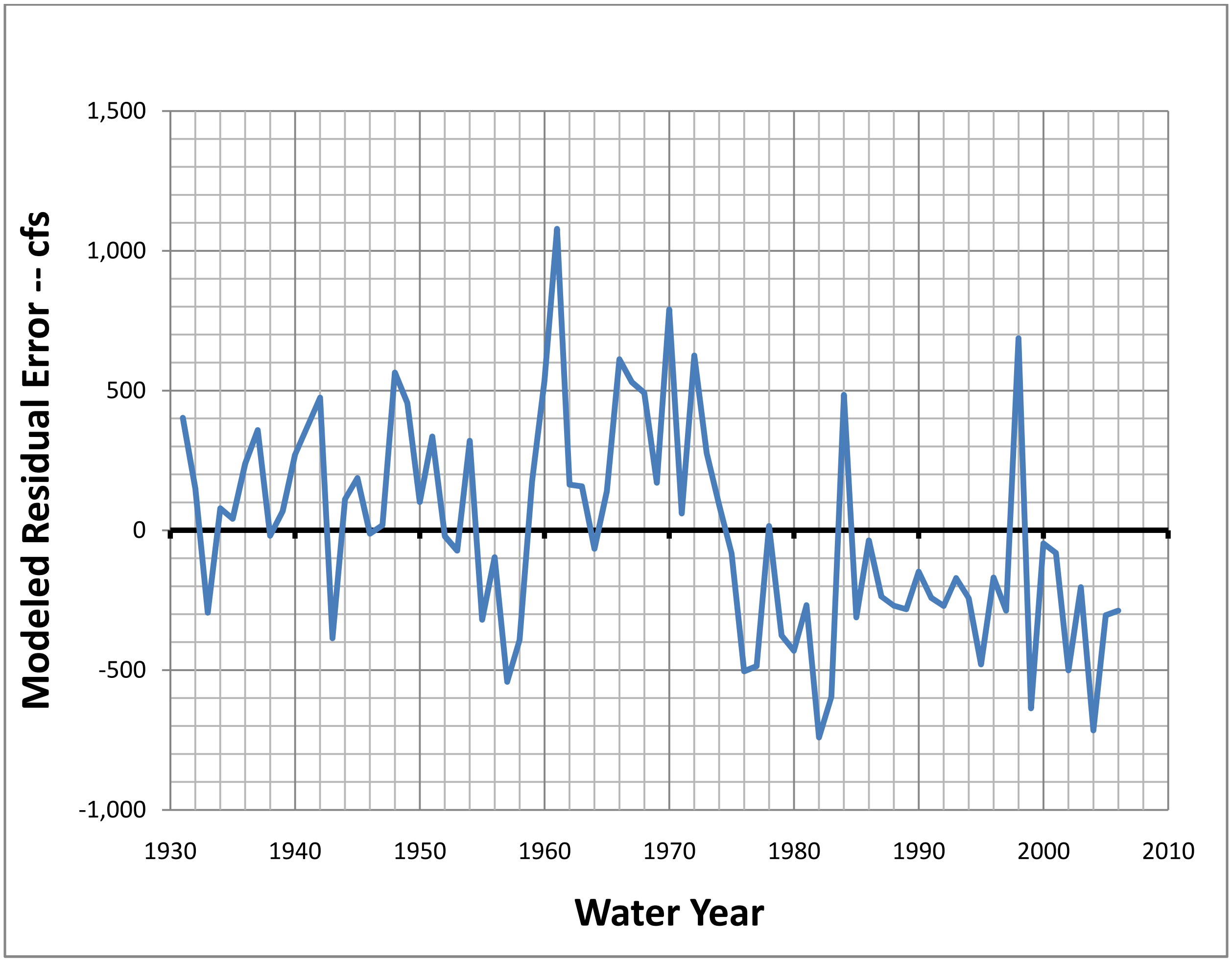

Figure 12 Linear regression model residual error

As with all linear regression models the estimated or predicted values are both greater than and less than the observed values. A positive residual error means that the observed value was greater than the predicted and a negative residual error means that the observed value was less than predicted. Approximately 2/3 of the values will be within one standard error (+/- 387 cfs) of the observed value. Positive and negative residual error are scattered within the period of record.

Strong trends in the residual error are not apparent. However, the error does appear to follow a pattern similar to the one exhibited by the double mass curve (Figure 8) where observed discharge is often greater than predicted from the late 1950's through the mid 1970's and is often somewhat less than predicted from the mid 1970's to the present.

Conclusions

- Total average annual yield for the Ocklawaha River Basin is 1,602 cfs (1.035 billion gallons per day) for the 76-year period of record.

- A cyclic trend in total basin yield is evident. In the early years, 1930's through mid 1940's, the 5-year moving average yield matched the long-term mean. The 5-year moving average yields in the1950's and 1960's are generally above average, while in recent years, 1970's, 1980's and 1990's, the 5-year moving average yields are generally below average.

- Silver River discharge has averaged 773 cfs (500 million gallon per day) over the 74-year period of record (including provisional data) and therefore accounts for nearly half of the long-term Ocklawaha River Basin total yield.

- Correlation analysis indicates that annual Ocklawaha River basin discharge is highly correlated to current year and prior year total annual rainfall recorded at Ocala Florida.

- A simple linear regression model, relating Ocklawaha River basin annual discharge to current and prior year Ocala rainfall, explains approximately 63% of the observed variance in annual discharge and, in general, reproduces the overall year-to-year variations in observed annual discharge.