Wekiva Area
Water Budget

University of Central Florida Stormwater Management Academy

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16. Abstract

Flow volume in the river and springs for the Wekiva Springs area of Florida is defined from historical data and related to the groundwater and rainfall in the area. The springshed is estimated at approximately twice the size of the surface watershed using WASH123D. A 10,000 square mile area is modeled.

The major questions to be answered are:
1) Is the springflow decreasing?
2) If so, how can the springflow be maintained, and
3) How do you build a road in the area that will maintain the spring flow?

There are fifteen findings of facts reported. Answers to the above question are that flow rates in the major springs are decreasing. Measured yearly spring flow correlates well with a yearly water budget using the local climatic data base. To prevent further decrease in spring flow, stormwater volume controls are recommended and a procedure to balance the water budget on a yearly basis is recommended. Regional irrigation ponds using FDOT right-of-way areas and operated by an irrigation or stormwater utility is one solution that maintains the water budget.

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ACKNOWLEDGEMENTS

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CHAPTER 1 - INTRODUCTION

This research is conducted to help understand the hydrologic balance of the Wekiva River area and includes analysis of precipitation, groundwater elevations, streamflow, and springflow data. The Wekiva River is located in the St. John's River Water Management District in Florida on the border between Seminole, Orange, and Lake Counties; it joins with the Little Wekiva River to discharge into the St. John's River. Figure 1 is an overview of the Wekiva River area and illustrates the relative locations of the gauging stations and Springs analyzed.

The surface watershed area for the Wekiva River is about 189 square miles and the total recharge zone for the Wekiva Springflow is estimated to be larger. The surface area reflecting the extent of the recharge zone is defined as a Springshed. The watershed surface features vary from dry, sandy upland soils in the South to the swampy lowlands in the North.

The Wekiva River water flows from South to North and is composed of direct precipitation, surface runoff, surficial aquifer flow, and the deeper groundwater aquifers through the many Springs discharging to the River. The Wekiva River has special legal designations designed to protect the Springflows and the wildlife of the area. The River is designated as an Outstanding Florida Water, and Aquatic Preserve, a National Wild and Scenic River, and it has its own Wekiva River Protection Act.

1.1 - OBJECTIVES

With the use of historical data, the information within this report will help define the Springshed area of the Wekiva River, and the effect that precipitation and changes in groundwater pressure and quantity have on Springflow and Streamflow in the Wekiva area. The Watershed surface conditions and Spring and River flow will be compared to other rivers around the Wekiva area. Any trends in River Streamflow and Springflow will also be explained. The feasibility of using a hydrologic or water budget to predict infiltration volume and control runoff will be examined.

1.2 - LIMITATIONS

The study area is defined within East Central Florida and assumed Springshed hydrologic region and it is limited by the potentiometric flow of groundwater in the upper Floridan aquifer to the Springs in the Wekiva Region. The precipitation data were from the Florida climate center and were from areas either in the assumed Springhed or adjacent to the Springshed. Both the precipitation and flow data did not usually extend to a time period before the decade of the 1960s.
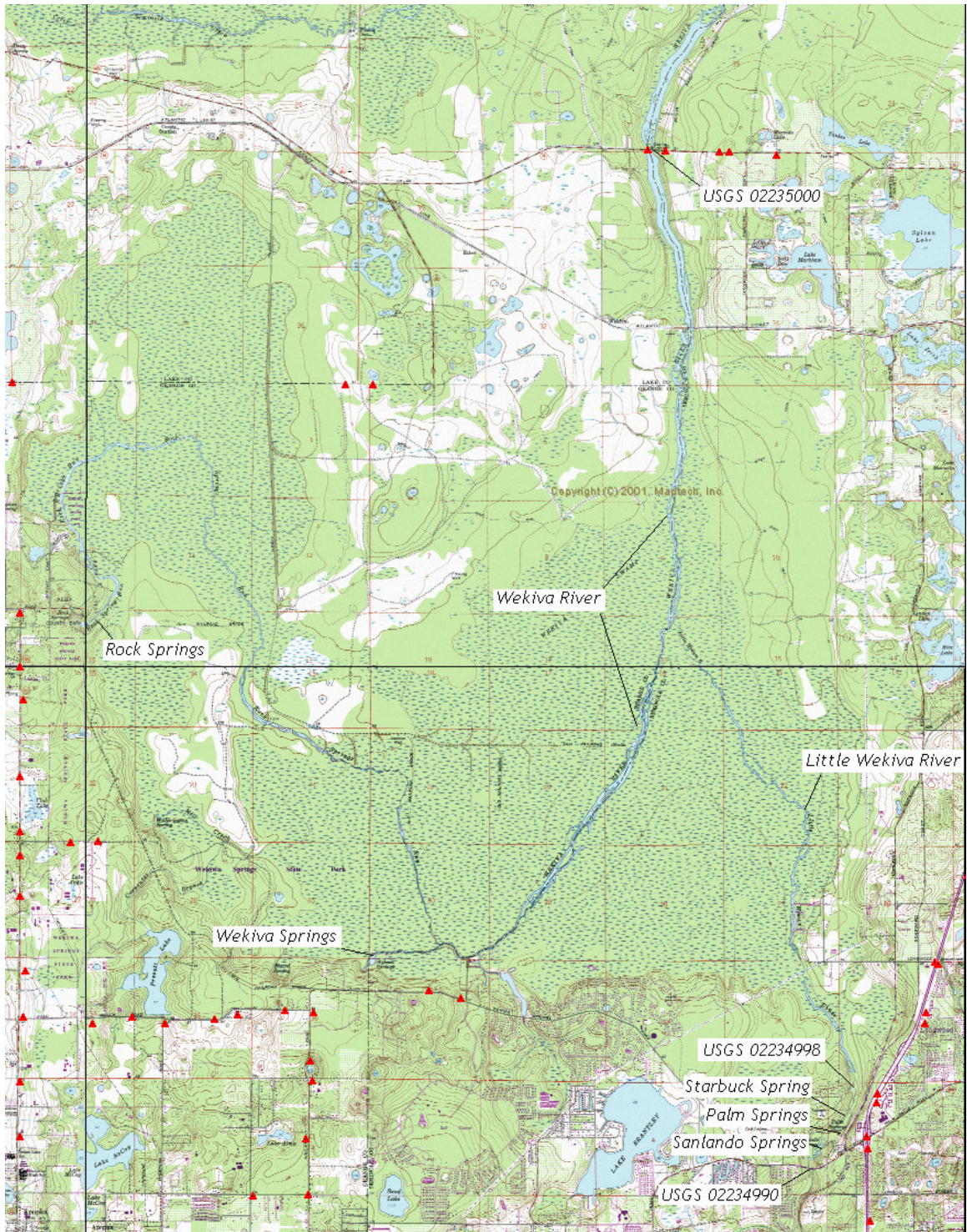
Figure 1 – Map of Wekiva River Area
[Appendix, Figure 8]
Source: USGS Sanford SW Quadrangle

CHAPTER 2 - METHODOLOGY

Rainfall over the Springshed can contribute to both the aquifer water storage and thus Springflow in addition to runoff directly into the River. Thus the historical rainfall data from the area will be evaluated.

The average annual streamflow will be plotted versus annual precipitation, then the average annual Springflow versus the annual precipitation. If either is related to precipitation, a trend line should result.

Average annual Springflow will be compared to the piezometric head (aquifer pressure) in seven wells located around the River. A strong relationship would indicate the Springflows are affected by the groundwater level and the Wekiva River flow is composed of water from the groundwater aquifer.

The Wekiva River and Little Wekiva River Streamflows will be compared to other streamflows in the region by plotting the unit streamflow (cfs/mi^2, or inches) versus time.

A computer-model, WASH123D, will be "built" and implemented for the Wekiva area. The results of this model will be compared with the conclusions from the analysis of historical data.

Finally, a water budget approach will be reviewed for possible application and description of the water resources of the Springshed.

The relationships are limited to historical data and the statistical analysis thereof. No new data were collected; however, the available data will be assumed to give accurate results since most records date back to around the 1960s.

From visual observation, it is believed that there are many Springs feeding into the River. Five of the Springs are commonly measured for discharge and will be used in this report: Wekiva, Starbuck, Sanlando, Rock, and Palm. Four rain gauging stations are located in the surrounding area and will also be used: Clermont (gauging station 14), Orlando Int. Airport (station 76), Sanford (station 92), and Lisbon (station 57). These are numbered in accordance with the Florida Climate Center data bases. The Little Wekiva and Wekiva River Streamflow data used are from USGS 02234990 and USGS 02235000, respectively. The Springflow data and well elevation data are from the United States Geological Survey. For the well analysis, geographic information for seven wells in the Wekiva area are analyzed and their data are summarized in Table 1. Twenty-six USGS gauging stations are used for the comparison to the Wekiva and Little Wekiva Rivers; geographic information and flow data for these are summarized in Table 2.

TABLE 1: USGS Well Locations

WELL	USGS Well number	County Code	Latitude	Longitude	Lat/Log Datum	Datum for Altitude Water Surface
1	283813081325701	95	283813	813257	NAD27	NGVD29
2	284453081284401	95	284453	812844	NAD27	NGVD29
3	284529081301001	95	284528	813011	NAD27	NGVD29
4	284541081265201	95	284541	812652	NAD27	NGVD29
5	284635081280601	95	284635	812806	NAD27	NGVD29
6	283849081273401	117	283849	812734	NAD27	NGVD29
7	284012081264601	117	284012	812646	NAD27	NGVD29

TABLE 2: USGS Stream Gauging Station Locations

Figure	Site	Average Unit Flow (cfs/mi^2)	Flow Trend (Δcfs/mi^2/yr)	Inches/yr	Location	Classification	Latitude	Longitude	County
13.1	USGS 02232500	0.842	-0.001	11.45	St. John's R. NR Christmas	Unaffected	28°32'34"	80°56'37"	Orange
13.2	USGS 02233001	0.829	0.018	11.27	Econ. R. at Magnolia Ranch	Unaffected	28°25'27"	81°07'10"	Orange
13.3	USGS 02233200	1.124	0.017	15.30	Little Econ. NR Union Park	Affected	28°31'29"	81°14'39"	Orange
13.4	USGS 02262900	0.677	0.010	9.20	Boggy Creek NR Taft	Affected	28°22'16"	81°18'39"	Orange
13.5	USGS 02264000	0.064	-0.001	0.87	Cypress Creek at Vineland	Controlled	28°23'25"	81°31'11"	Orange
13.6	USGS 02264051	3.297	0.077	44.80	Black Lake Outlet at S-101A	Controlled	28°22'28"	81°31'01"	Orange
13.7	USGS 02264060	0.378	0.003	5.14	Lateral 101 at S-101 NR B. Vista	Controlled	28°22'15"	81°31'45"	Orange
13.8	USGS 02266025	0.114	0.016	1.55	Reedy Creek NR Vineland	Affected	28°24'14"	81°36'42"	Orange
13.9	USGS 02266200	0.365	0.013	4.97	Whittenhorse Creek NR Vineland	Affected	28°23'05"	81°37'00"	Orange
13.10	USGS 02266291	0.288	0.015	3.92	Doctor Phillips	Affected	28°25'34"	81°36'23"	Orange
13.11	USGS 02266295	0.620	-0.060	8.43	Vineland	Unaffected	28°21'58"	81°35'55"	Orange
13.12	USGS 02233500	1.140	0.002	15.50	Econ. R. NR Chuluota	Affected	28°40'40"	81°06'51"	Seminole
13.13	USGS 02234000	0.970	0.013	13.20	St. John's R. NR Geneva	Unaffected	28°42'50"	81°02'08"	Seminole
13.14	USGS 02234324	0.963	-0.017	12.80	Howell Creek NR Slavia	Affected	28°38'51"	81°15'53"	Seminole
13.15	USGS 02234384	0.571	-0.001	1.80	Soldier Creek NR Longwood	Unaffected	28°43'07"	81°18'32"	Seminole
13.16	USGS 02234400	1.220	-0.008	16.60	Gee Creek NR Longwood	Affected	28°42'12"	81°17'25"	Seminole
13.17	**USGS 02234990**	**0.670**	**-0.012**	**9.10**	**Little Wekiva R.**	**Affected**	**28°41'13"**	**81°23'50"**	**Seminole**
13.18	**USGS 02235000**	**1.519**	**0.002**	**20.70**	**Wekiva R.**	**Affected**	**28°48'54"**	**81°25'10"**	**Seminole**
13.19	USGS 02235200	0.447	-0.010	6.10	Blackwater Creek NR Cassia	Unaffected	28°52'37"	81°29'21"	Lake
13.20	USGS 02236000	0.996	-0.002	13.54	St. John's R. NR Deland	Unaffected	29°00'29"	81°22'58"	Lake
13.21	USGS 02236500	0.259	-0.003	3.53	Big Creek NR Clermont	Unaffected	28°26'51"	81°44'25"	Lake
13.22	USGS 02236700	0.785	0.001	10.70	Little Creek NR Clermont	Unaffected	28°27'39"	81°45'26"	Lake
13.23	USGS 02236900	0.140	-0.009	1.85	Cherry LK Out NR Groveland	Unaffected	28°35'33"	81°49'21"	Lake
13.24	USGS 02237293	0.129	-0.001	1.75	Palatlakaha NR Okahumpka	Unaffected	28°44'39"	81°52'22"	Lake
13.25	USGS 02237700	0.400	-0.007	4.90	Apopka Beauclair Canal	Unaffected	28°43'20"	81°41'06"	Lake
13.26	USGS 02238000	0.324	-0.005	4.40	Haines Creek at Lisbon	Affected	28°52'14"	81°47'02"	Lake

The rainfall data were recorded on a daily basis; however, some rainfall data were missing. To correct this, a value of zero inches was substituted for each missing day, and then the average daily rainfall was calculated from the resulting data set, which usually dated back to 1900. To ensure the most accurate results, the previously obtained average daily precipitation was substituted for each missing data point and the annual precipitations were then calculated accordingly.

Along with each trend line, the coefficient of determination, R^2, is presented; it represents how well the trend line correlates to the data. R^2 ranges from zero (no correlation) to one (perfect correlation). In practical terms, R^2 shows the amount of variation in the data that can be explained by the trend line. For instance, if a trend line has an R^2 value of 0.55 then the trend line accounts for 55 percent of the variation in the data. Keep in mind that R^2 only describes how well the trend line represents the data; it is independent from the slope of the line.

$$R^2 = 1 - \frac{SSE}{SSyy}$$; where SSE is the sum of squares of deviations of each y value about the trend line $\hat{Y}$, and SSyy is the sum of squares of deviations of each y value about the mean Yave. $SSE = \Sigma(Yi - \hat{Y}i)^2$ and $SSyy = \Sigma(Yi - Yave)^2$. So if x contributes no information for predicting y, then the best prediction for y is Yave, SSE = SSyy and R^2 = 0. Also, if all points are located on the trend line, SSE = 0 and R^2 = 1 (if all points are located on the trend line there is no variation present, so naturally the trend line will account for 100% of the variation of the sample of y values). The coefficient of determination is independent from the slope of the line. The significance of the slope of the trend line is calculated by a two-tailed test of hypothesis; this test is two-tailed since

the slope could either be negative or positive. The test is as follows: $Ho : m = 0$,

$Ha : m \neq 0$, and the test statistic is

$$t = \frac{Ha - Ho}{s / \sqrt{SSxx}}$$

Where:
Ho = null hypothesis or slope equals zero
Ha = alternative hypothesis, or slope not equal to zero
m = slope of the trend line
s = standard deviation = $\sqrt{(SSE/(n-2))}$ =
$\sqrt{\{1/(n-2) [\Sigma(Yi - Yave)^2 - m \Sigma (Yi - Yave)(Xi - Xave)]\}}$
$SSxx = \Sigma(Xi - Xave)^2$

The absolute value of t is compared to the distribution obtained from standard

statistical tables: $|t| > t_{\alpha/2}$ is the rejection region where $t_{\alpha/2}$ is based on (n-2) degrees of

freedom (accounting for the slope and y-intercept of the trend line). For example, if a 95

percent confidence interval is used, $t_{0.025}$ will be compared with $|t|$. So if $|t| > t_{0.025}$, the *Ho*

is rejected and one can be 95 % certain that the slope is *not* equal to zero, meaning the

slope of the trend line is significant. Otherwise, if *Ho* is accepted, the slope is

insignificant, or equal to zero. (Mendenhall, 1995)

On the other hand if *Ho* is rejected the slope is statistically significant. However,

if the R^2 value is close to zero, the straight line relationship is more complex: x has an

effect on y but the trend line cannot be used to predict y.

CHAPTER 3 - PRECIPITATION ANALYSIS

To determine if there exists a relationship of Streamflow to precipitation, the average annual streamflow (cfs) was compared and graphed versus the annual precipitation (in/yr) measured at the Clermont, Orlando, Sanford, and Lisbon gauging stations, as well as the mean of these four. Also, average annual discharge for each Streamflow, Wekiva, Starbuck, Sanlando, Rock, and Palm were compared to annual precipitation.

Knowing the surface watershed, the drainage area average streamflow in cfs per year can be converted to inches of discharge per year and compared to inches of rainfall per year. The following formula is used for the calculation.

$$\text{Flow}\,(cfs)\left(\frac{acre}{43560\,ft^\wedge 2}\right)\left(\frac{1}{DrainageArea(acres)}\right)\left(\frac{86400*365\sec}{year}\right)\left(\frac{12in}{ft}\right)$$

This simplifies to: $\text{Flow}\,(cfs)\dfrac{8687.6}{DrainageArea(acres)}=in/\,year$

Streamflow is multiplied by a constant, thus the resulting graph would have a trend line with the same coefficient of determination. The average annual streamflow in cubic feet per second can thus be compared with the annual precipitation in inches per year.

Wekiva Streamflow and Wekiva Springflow also were compared with Clermont precipitation for both a calendar year and a water year. In Central Florida, streamflow is lowest during the end of a long "dry period" and the "dry period" for rainfall ends around the beginning of June. Thus a water year can be defined as June 1st to May 31st. The annual precipitation, average annual Wekiva Streamflow, and average annual Wekiva

Springflow were calculated for the water year; all showed similar results to the calendar year, as can be seen from Appendix, Figures 1.1A, 1.1B, 2.1A and 2.1B. The only noticeable difference is that the slope of Figure 2.1a is insignificant and the slope of Figure 2.1b is significant; however, the |t| values for Figures 2.1a and 2.1b are close to the $t_{0.025}$ value. Therefore, using a calendar year analysis versus a water year analysis will give similar results. Only calendar years are considered in this report. Table 3 illustrates the significance of the slopes for Figure 1.1 to 7.5. Depending on the calculated t-statistic, many of the slopes are statistically significant with confidence intervals ranging from 90 to 99.99 percent. For the slope analyses summarized in Table 3, a statistically significant slope indicates an influence of precipitation on the Springflow or Streamflow analyzed.

TABLE 3: Streamflow Statistical Analysis

over table: **Null Hypothesis Test for Slope of Figures 1.1 - 7.5**

FIG	n	Slope Δcfs/ Δin	|t|	$t_{0.025}$ at (n-2)	$t_{0.01}$ at (n-2)	$t_{0.005}$ at (n-2)	$t_{0.001}$ at (n-2)	$t_{0.0005}$ at (n-2)	Slope Significance	% Confi- dent
1.1a	63	3.190	4.872	2.000	2.39	2.66	3.232	3.46	**significant**	99.9
1.1b	63	3.040	4.694	2.000	2.39	2.66	3.232	3.46	**significant**	99.9
1.2	63	3.390	4.996	2.000	2.39	2.66	3.232	3.46	**significant**	99.9
1.3	43	3.140	4.219	2.021	2.423	2.704	3.307	3.551	**significant**	99.9
1.4	40	3.310	3.853	2.021	2.423	2.704	3.307	3.551	**significant**	99.9
1.5	40	4.420	5.047	2.021	2.423	2.704	3.307	3.551	**significant**	99.9
2.1a	36	0.123	0.991	2.042	2.457	2.75	3.385	3.646	insignificant	
2.1b	33	0.172	2.141	2.042	2.457	2.75	3.385	3.646	**significant**	95.00
2.2	36	0.155	1.158	2.042	2.457	2.75	3.385	3.646	insignificant	
2.3	36	0.080	0.707	2.042	2.457	2.75	3.385	3.646	insignificant	
2.4	36	0.017	0.133	2.042	2.457	2.75	3.385	3.646	insignificant	
2.5	36	0.120	0.844	2.042	2.457	2.75	3.385	3.646	insignificant	
3.1	29	0.020	0.587	2.052	2.473	2.771	3.421	3.69	insignificant	
3.2	29	0.022	0.623	2.052	2.473	2.771	3.421	3.69	insignificant	
3.3	29	0.054	1.991	2.052	2.473	2.771	3.421	3.69	insignificant	
3.4	29	0.052	1.575	2.052	2.473	2.771	3.421	3.69	insignificant	
3.5	29	0.052	1.402	2.052	2.473	2.771	3.421	3.69	insignificant	
4.1	29	0.100	1.421	2.052	2.473	2.771	3.421	3.69	insignificant	
4.2	29	0.169	2.449	2.052	2.473	2.771	3.421	3.69	**significant**	95
4.3	29	0.132	2.349	2.052	2.473	2.771	3.421	3.69	**significant**	95
4.4	29	0.147	2.151	2.052	2.473	2.771	3.421	3.69	**significant**	95
4.5	29	0.181	2.457	2.052	2.473	2.771	3.421	3.69	**significant**	95
5.1	41	0.321	3.028	2.021	2.423	2.704	3.307	3.551	**significant**	99
5.2	41	0.292	2.472	2.021	2.423	2.704	3.307	3.551	**significant**	98
5.3	41	0.208	2.070	2.021	2.423	2.704	3.307	3.551	**significant**	95
5.4	40	0.214	1.842	2.021	2.423	2.704	3.307	3.551	insignificant	
5.5	40	0.322	2.591	2.021	2.423	2.704	3.307	3.551	**significant**	98
6.1	29	-0.003	0.088	2.052	2.473	2.771	3.421	3.69	insignificant	
6.2	29	-0.025	0.631	2.052	2.473	2.771	3.421	3.69	insignificant	
6.3	29	0.006	0.180	2.052	2.473	2.771	3.421	3.69	insignificant	
6.4	29	0.070	1.798	2.052	2.473	2.771	3.421	3.69	insignificant	
6.5	29	0.020	0.378	2.052	2.473	2.771	3.421	3.69	insignificant	
7.1	24	0.781	3.042	2.074	2.508	2.819	3.505	3.792	**significant**	99
7.2	24	0.927	4.365	2.074	2.508	2.819	3.505	3.792	**significant**	99.9
7.3	24	0.928	6.050	2.074	2.508	2.819	3.505	3.792	**significant**	99.9
7.4	24	1.024	4.482	2.074	2.508	2.819	3.505	3.792	**significant**	99.9
7.5	24	1.159	5.573	2.074	2.508	2.819	3.505	3.792	**significant**	99.9
* Shading indicates statistical significance

3.1 - STREAMFLOW VERSUS PRECIPITATION

The Wekiva River average annual Streamflow data were obtained from gauging station USGS 02235000. The gauging station is located at the junction of Route 46 and the Wekiva River. So the Wekiva River Streamflow is measured after Rock and Wekiva Springflows, and after the Little Wekiva River have discharged into the Wekiva River, but the Streamflow is measured before the Seminole Spring System discharges into the Wekiva River.

Illustrated in Figure 2 is Average Annual Streamflow versus Annual Precipitation for the Wekiva River:
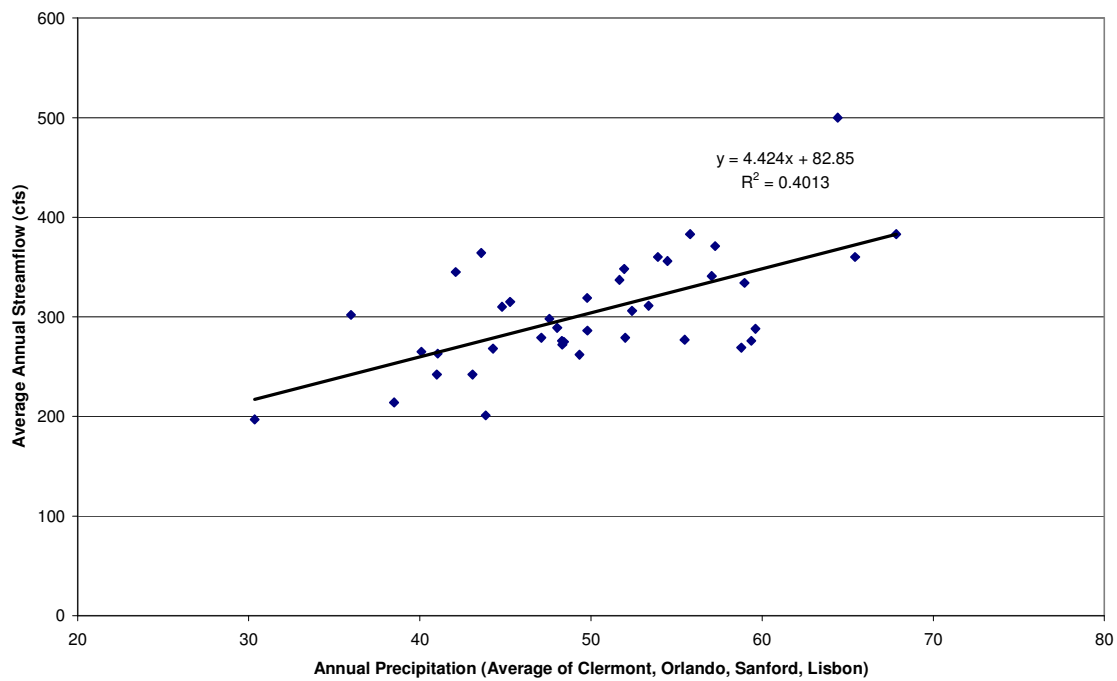

FIGURE 2 - Average Annual Streamflow Wekiva River Vs Average Precipitation
Appendix, Figure 1.5

The slope of the trend line is calculated to be significant and positive, which indicates that precipitation affects the Wekiva River Streamflow. Higher precipitation values result in higher Streamflow values, and vice versa. Since the R^2 is 0.4, the trend

line accounts for only 40 percent of the variation. Precipitation affects Streamflow in the Wekiva River, but since the correlation is weak there must be other factors besides precipitation that affect Streamflow. Storage of water before release to the River both in surface ponds and in the aquifer may account for an explanation of some of the remaining variation. Another indication of other sources affecting Streamflow is the y-intercept of the trend line of 82.85 cfs. For instance, if the y-intercept in Figure 2 were close to zero, the influence of any other factors besides precipitation would be minor. In other words, if rainfall were the only source, then a zero Streamflow value would be expected for a zero rainfall value. Thus, flow from the Springs help maintain a minimum Streamflow. Figures 1.1 to 1.5 in the Appendix all illustrate similar trend lines with statistically significant slopes for the Wekiva River: all indicate a Wekiva Streamflow which is affected by precipitation, but also indicate Streamflow is most likely affected by other sources as well as precipitation.

USGS 02234990, which is located just upstream of Starbuck, Palm, and Sanlando Springs, is used to measure the average annual Streamflow in the Little Wekiva River. Table 4 compares the average annual streamflows of USGS 02234990 and USGS 02234998, which are located just upstream and just downstream of Starbuck, Palm, and Sanlando Springs, respectively. There is a large increase in Little Wekiva Streamflow after Starbuck, Palm and Sanlando Springs discharge into the River: ranging from a 130 % increase in 1996 to a 310 % increase in 2000, and 57 to 76 percent of Little Wekiva Streamflow originates as Springflow (Table 4).

TABLE 4: Little Wekiva River Streamflow Influence (Based on Average Annual Flows) (cfs)

	USGS 2232990 [Upstream of Starbuck, Palm, Sanlando Streamflows] (cfs)	USGS 2234998 [Downstream of Starbuck, Palm, Sanlando Streamflows] (cfs)	Springflow percent of downstream Streamflow	% increase
1996	48.1	111	56.7	131
1997	31.5	80	60.6	154
1998	42.7	94.3	54.7	121
1999	35.1	76.1	53.9	117
2000	8.19	33.6	75.6	310

Besides Springflow, precipitation also has an effect on the Little Wekiva Streamflow. In Figure 3, illustrated is a statistically significant influence (99.9 % confident) of annual precipitation on average annual Little Wekiva Streamflow upstream of Palm, Sanlando, and Starbuck Springs.
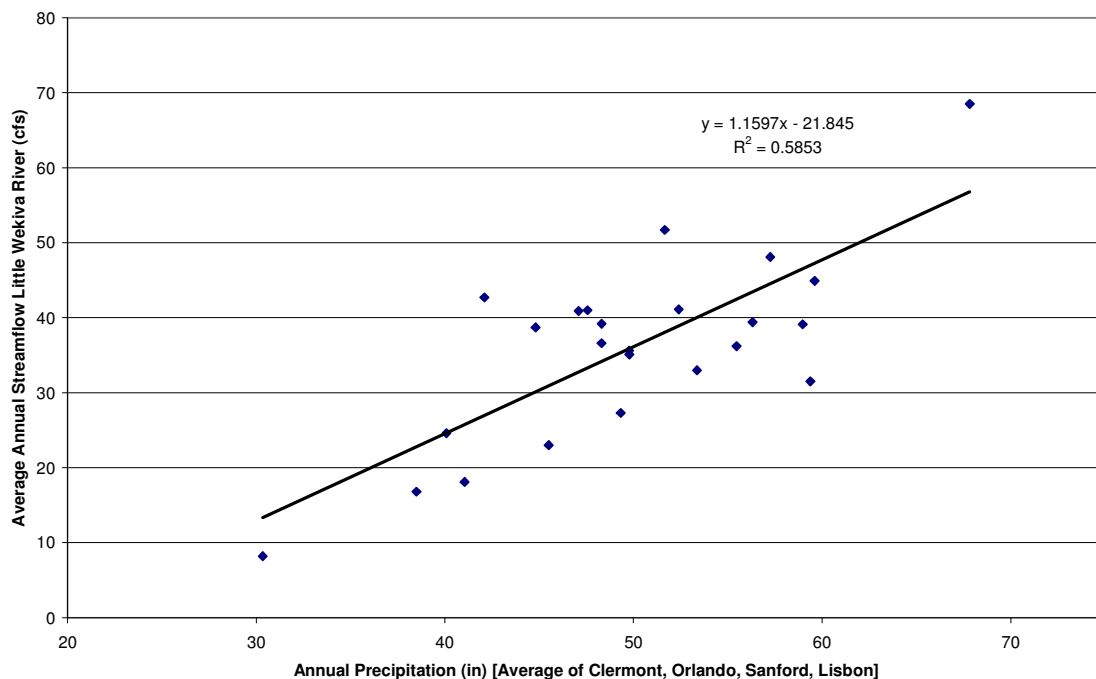

$y = 1.1597x - 21.845$
$R^2 = 0.5853$

FIGURE 3 - Average Annual Streamflow Little Wekiva River Vs Average Precipitation
Appendix, Figure 7.5

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Figure 3 and Appendix, Figures 7.1 to 7.4, illustrate the influence of precipitation on the Little Wekiva River: all have similar trend lines with significant slopes indicating the influence of precipitation on Little Wekiva Streamflow. Also, the y-intercept is closer to zero than for the Wekiva River, indicating a lower influence of other sources besides precipitation. The trend line's accounting for about 50 percent or more of the variability in the sample of Streamflow values as shown in Figures 7.1 to 7.5 in the Appendix. Precipitation has an influence on the Little Wekiva River Streamflow; however, other factors, such as groundwater storage levels as related to consumptive use of groundwater, and infiltration of rain, influence the Little Wekiva River Streamflow.

3.2 - SPRINGFLOW VERSUS PRECIPITATION

Annual Springflow relative to River flow is less influenced by annual precipitation (see Figure 4). This is expected since rainfall has to percolate through the soil and is stored in a vast underground reservoir. The reservoir acts to attenuate the impacts of percolated rainfall water releasing the stored water at a rate determined by the aquifer pressure, soil and rock channels, and the discharge characteristics of each Spring. Also note that annual precipitation has a minor predictive relationship to Wekiva (Appendix, Figure 2.1 – 2.5), Starbuck (Appendix, Figure 3.1 – 3.5), and Palm (Appendix, Figure 6.1 – 6.5) Springs yearly flow as each slope is insignificant and thus can be considered to have a numerical values of zero. Sanlando (Appendix, Figure 4.1 – 4.5) and Rock (Appendix, Figure 5.1 – 5.5) Springs annual discharge, however, are predictable by annual precipitation, and thus most likely receive a majority of their flow from aquifers that are in close proximity to the Springs.

When the annual precipitation values of the four rain gauging stations were compared to the Rock and Sanlando Springflows, three out of four comparisons resulted in a significant slope indicating precipitation's influence. Only the Clermont rain gauging station and the Lisbon rain gauging station comparisons with Sanlando and Rock Springs respectively resulted in insignificant slopes. Although rainfall is an influence for Sanlando and Rock Springs, the R^2 values are low and the y-intercepts are high. Therefore, rainfall is a minor influence for Sanlando and Rock Springs. Figure 4 illustrates the common trend that there is no correlation between average annual Springflow and annual precipitation.
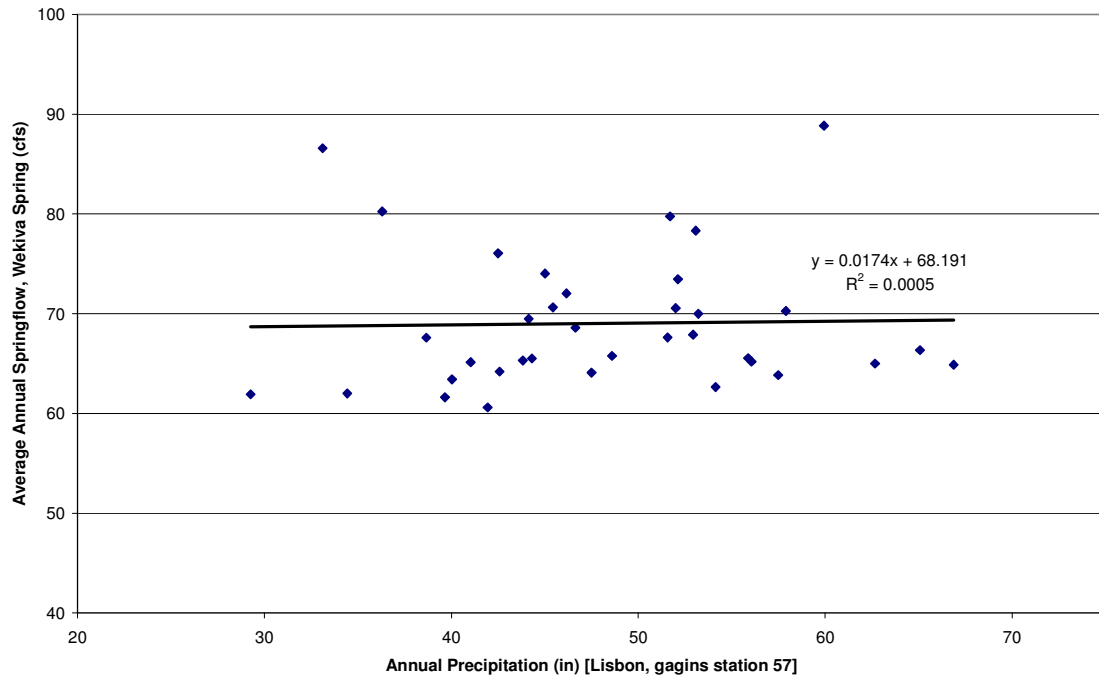
FIGURE 4 - Wekiva Springflow Vs Precipitation (Lisbon)
Appendix, Figure 2.4

Because the coefficient of determination is 0.0005 and the slope of the trend line is calculated to be insignificant, there is no relationship between average annual Wekiva Springflow and annual Lisbon precipitation. This is shown if Figure 4.

Figure 4 illustrates that there is no relationship between average annual Wekiva Springfow and annual Lisbon annual precipitation: the coefficient of determination is 0.0005 and the slope of trend line is calculated to be insignificant.

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3.3 - PRECIPITATION ANALYSIS CONCLUSION

The Wekiva River and Little Wekiva River average annual Streamflows are influenced by annual precipitation; however, there are other factors besides precipitation that influence the Streamflows of these Rivers. Also, the Little Wekiva River flow is more influenced by precipitation than the Wekiva River flow. Annual precipitation has no predictive value for Wekiva, Starbuck, and Palm Springs average annual discharge but has a predictive relationship for Sanlando and Rock Springs average annual discharge. The predictive relationship most likely indicates that a majority of the annual discharge in Sanlando and Rock Springs is influenced by the local recharge area, allowing the annual percolated water to reach the Springs within the year. However, the other measured Springs have a longer groundwater residence time and thus there is no predictive relationship of annual Springflow to annual rainfall.

CHAPTER 4 - UNIT FLOW ANALYSIS

Since each river has a different Streamflow with a different drainage area contributing to it, to accurately compare river flows the 'unit flow' of each river is calculated. The unit flow is the streamflow per square mile of drainage area, cfs/mi^2. One cfs/mi^2 translates to about 13.6 inches of water per year over the Watershed or surface drainage area:

$$\left(\frac{1\,ft\text{^}3}{\sec - mi\text{^}2}\right)\left(\frac{86400*365\sec}{year}\right)\left(\frac{mi\text{^}2}{5280\text{^}2\,ft\text{^}2}\right)\left(\frac{12in}{ft}\right) = 13.6 \text{ in.}$$

The unit flow analysis is used to compare annual flows for different rivers around the Wekiva River as well as different gauging stations on the same river.

A larger unit streamflow would be expected for rivers with springs, such as the Wekiva River. The surface condition of a river's drainage area also has an affect on unit streamflow. A developed drainage area, for instance, would generally allow for less infiltration and more precipitation runoff. See Chapter 6 "Springflow Decrease" of this report for more details. Some developments in Florida route the stormwater runoff into detention ponds; however, detention ponds mostly only "slow down" the runoff to control its outflow and do not in general infiltrate the stored waters, as done in retention ponds. Developed areas also contain more wells from which water is extracted. Thus, development in a river's drainage area is expected to increase the unit flow of rivers influenced by rainfall runoff, and development is expected to decrease the unit flow of rivers influenced mostly by the groundwater level or contributing Springs. Data were collected to ascertain if the unit flows of rivers around the Wekiva area match the expected unit flows in reference to the surface conditions of the drainage areas.

Twenty-six USGS river gauging stations located in Orange, Lake, and Seminole Counties were analyzed. There are numerous factors that affect the drainage area of each station and its unit streamflow, but primarily the human factors are of interest to this report. Each gauging station is therefore categorized as Affected, Unaffected, or Controlled. Controlled means much water is either prevented from entering the river, added to the river, or the streamflow is controlled. One example is Cypress Creek at Vineland. Affected refers to a contributing watershed area that has been affected by development, such as the Wekiva and Little Wekiva Rivers. Unaffected refers to a contributing watershed area that is rural and unaffected by development, such as the upper St. John's River near Christmas.

4.1 - WEKIVA UNIT FLOW COMPARISON

River flow in the Wekiva can be substantially influenced by Springflow and by urbanization. The Wekiva unit flow will be compared with the unit flow of other gauging stations around the Wekiva area.

An example of a changing unit streamflow in an 'affected' area is presented in Figure 5:
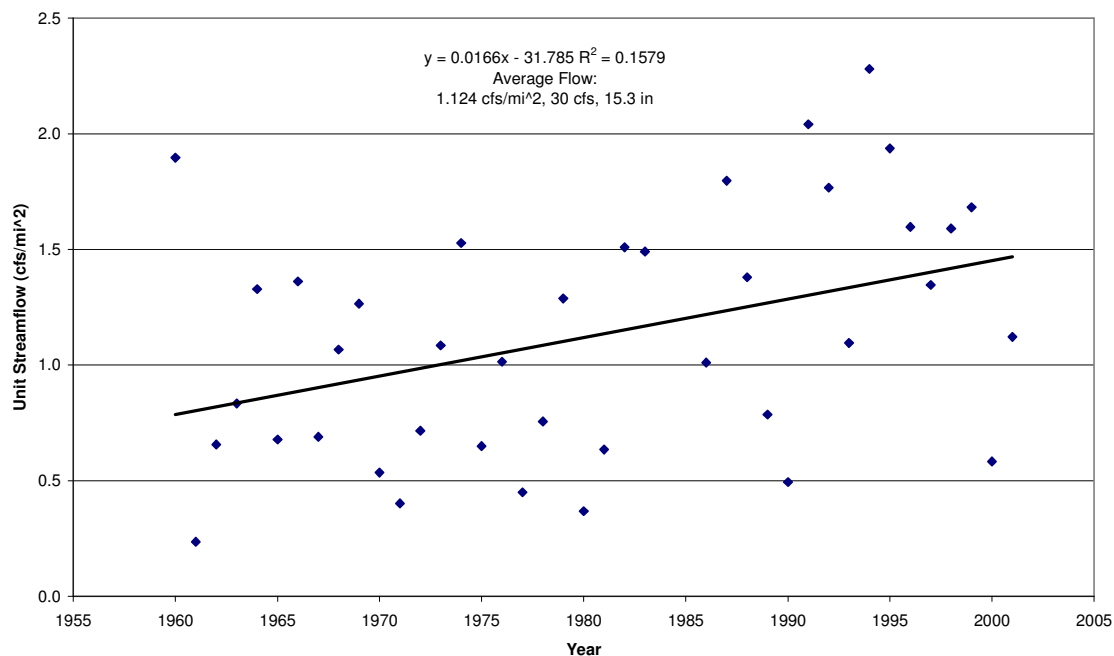

FIGURE 5 - 02233200 Unit Streamflow vs time
[LITTLE ECONLOCKHATCHEE R NR UNION PARK]
Appendix, Figure 13.3

The Little Econlockhatchee River shows an increase from about 0.73 to 1.46 cfs/mi^2 (10 to 20 inches) during the forty years of record, during which the area around the Little Econlockhatchee was developed. The slope of the trend line is significant and positive. There are other factors influencing the relationship as indicated by the coefficient of determination, R^2.

The Little Econlockhatchee discharges into the St. John's River; its affect is illustrated in Figure 6 and Figure 7. The St. John's River near Christmas has an average unit flow of 11.45 inches and The St. John's River above Lake Harney has an average unit flow of 13.2 inches. The Little Econlockhatchee River joins the Econlockhatchee River to discharge into the St. John's River between Christmas and Lake Harney; this is the only apparent contributing surface source of streamflow between the two St. John's River gauging stations. Both Christmas and Lake Harney gauging stations are classified as 'unaffected' and the only major source of streamflow being the Econlockhatchee River, the Little Econlockhatchee River's increase in unit streamflow is most likely the cause of the increase in unit streamflow in the St. John's River between Christmas and Lake Harney. Figure 6 and Figure 7 illustrate the increase in average unit streamflow from 11.45 inches in Christmas to 13.2 inches in Lake Harney.
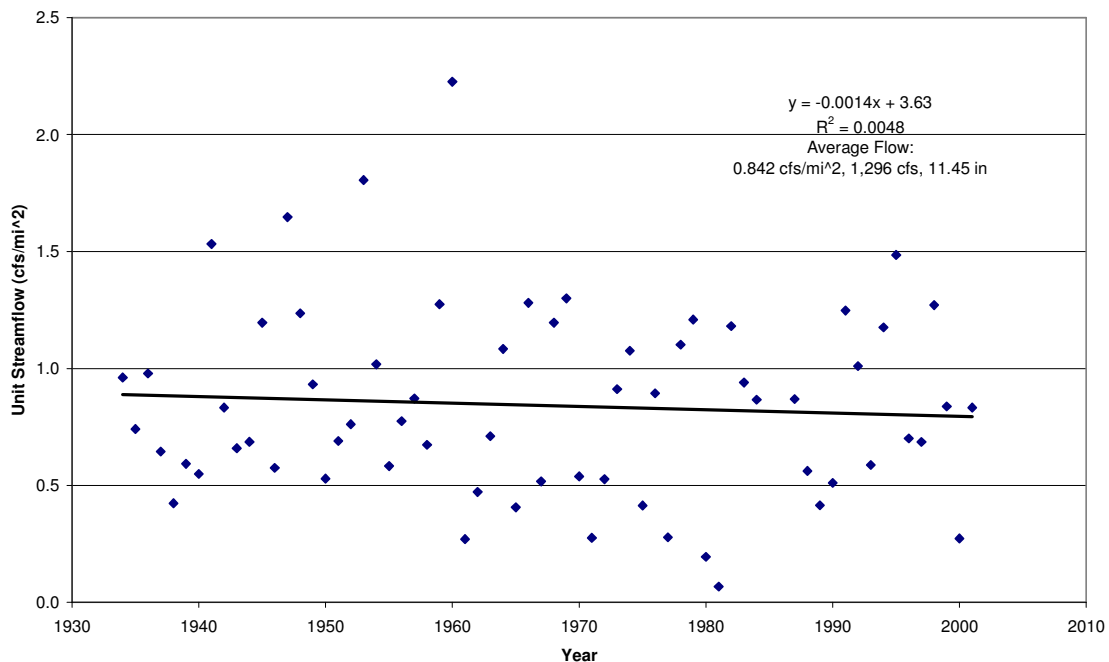
FIGURE 6 - 02232500 Unit Streamflow vs time
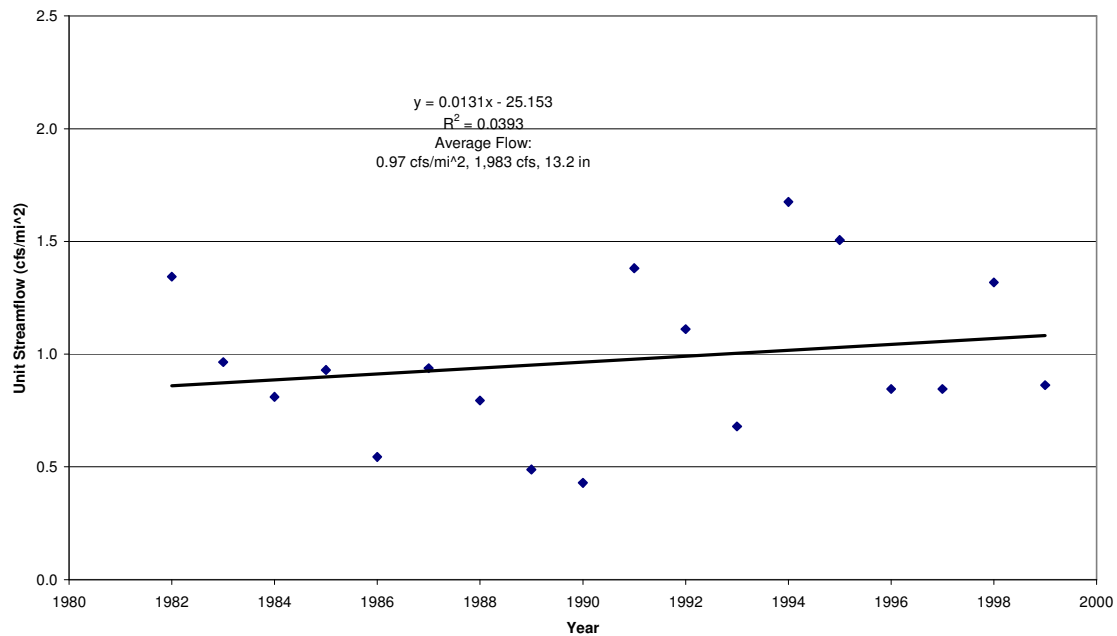**[ST. JOHNS RIVER NR CHRISTMAS]**
Appendix, Figure 13.1

FIGURE 7 - 02234000 Unit Streamflow versus Time
[ST. JOHNS RIVER ABOVE LAKE HARNEY NR GENEVA]
Appendix, Figure 13.13

Of particular interest to the Wekiva basin are the Wekiva and Little Wekiva River

unit flows. The Little Wekiva River unit flow, which is shown in Figure 8, indicates a

significant decrease in unit Streamflow while the Wekiva River unit Streamflow, which is

shown in Figure 9, experiences an insignificant change in unit Streamflow. Both Rivers

are affected by development in the Watershed areas. Due to the many Springs in the

area, the Wekiva and Little Wekiva Rivers are affected by the groundwater level (Please

refer to the "Groundwater Analysis" section in Chapter 5 of this report for more details).

As mentioned previously, through limiting infiltration and well extraction, development

is expected to decrease the unit streamflow for rivers affected by groundwater. The unit

Streamflow for Wekiva River has remained constant, and unit Streamflow for the Little

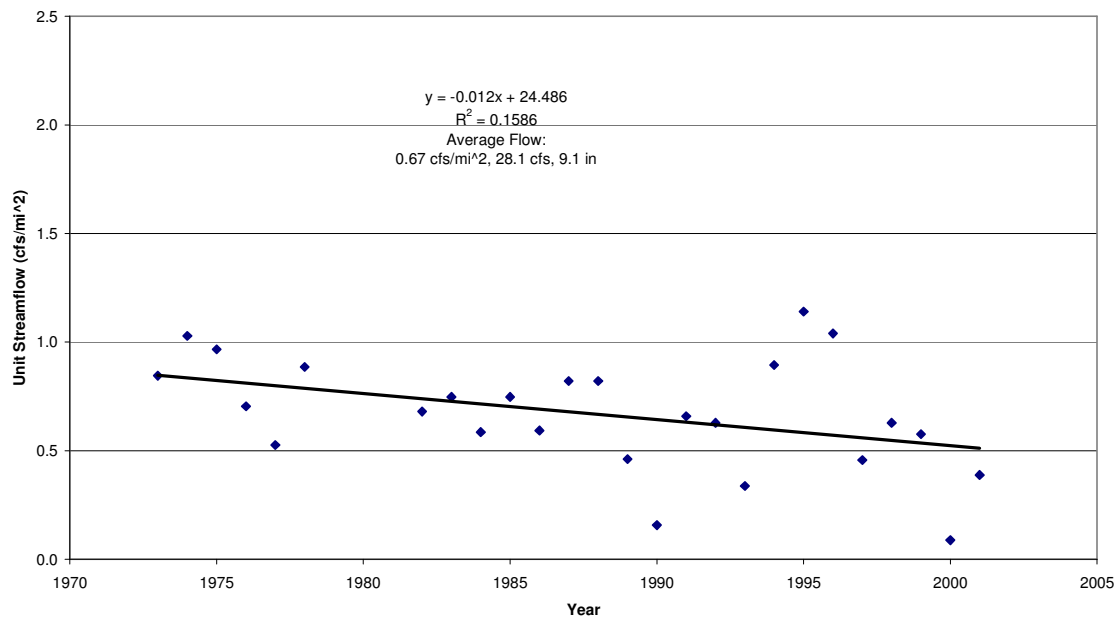Wekiva River has decreased by about five inches during the period of record of 25 years.

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FIGURE 8 - 02234990 Unit Streamflow versus Time
[LITTLE WEKIVA RIVER NR ALTAMONTE SPRINGS]
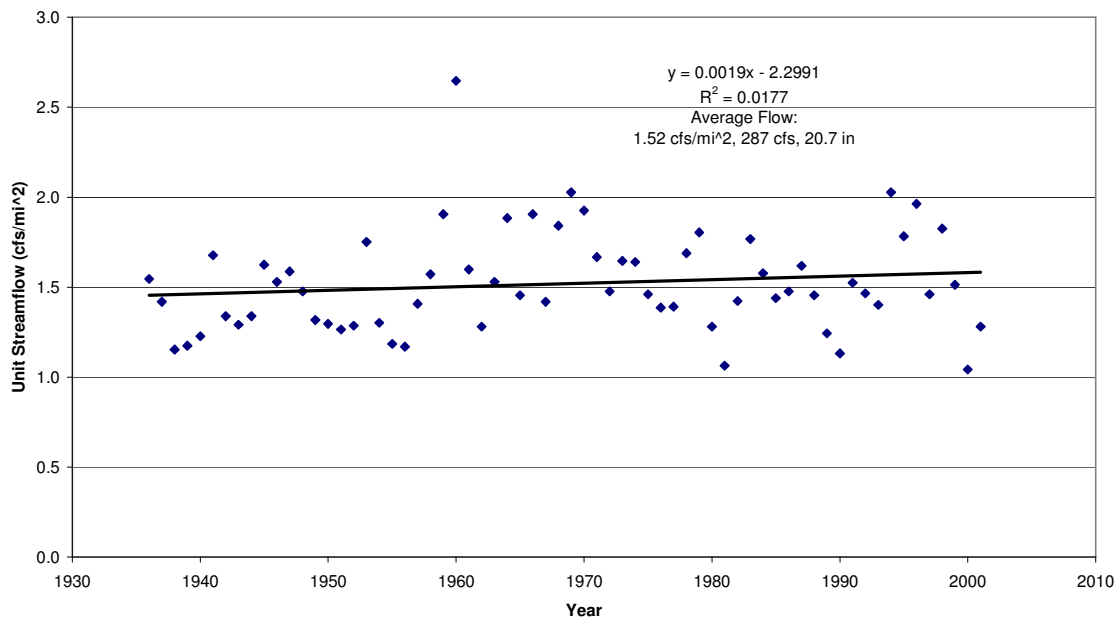**Appendix, Figure 13.17**

FIGURE 9 - 02235000 Unit Streamflow versus Time
[WEKIVA RIVER NR SANFORD]
Appendix, Figure 13.18

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Since Wekiva River flow is composed of Springflow and rainfall runoff, and the contributing Springflow has been decreasing (Appendix, Figure 9.1 to 9.5), other factors must have increased for the Streamflow in the Wekiva River to remain relatively constant. The increased runoff from the surrounding developed area has most likely increased the Streamflow while decreased Springflow has resulted in a Streamflow decrease. The Wekiva River unit Streamflow has remained relatively constant: the increase in rainfall runoff has most likely compensated for the decrease in contributing Springflow. For further discussion on the decreased Springflow refer to the section, "Springflow Decrease" in Chapter 6 of this report.

The Little Wekiva River has shown a decrease in unit Streamflow, which is mostly likely due to decreased Springflow and decreased seepage from the aquifer. The development around the River has most likely caused runoff to increase, but the increase has not been enough to produce a constant unit Streamflow in the Little Wekiva River as in the Wekiva River.

Appendix, Figures 13.1 to 13.26, contains the unit streamflow versus time graphs for all twenty-six gauging stations analyzed. Table 2 illustrates summary information on the twenty-six gauging stations, and most importantly, Table 5 illustrates the classifications for Figures 13.1 – 13.26 and whether the flow trend ($\Delta cfs/mi^2/yr$) of each Figure is significant or insignificant.

TABLE 5: Unit Flow Statistical Analysis

FFIG	n	Slope Δcfs/ mi^2/ year	|t|	$t_{0.025}$ at (n-2)	$t_{0.01}$ at (n-2)	$t_{0.005}$ at (n-2)	Slope Significance	Classifica- tion	% Con- fident
					Null Hypothesis Test for Figures 13.1 - 13.26				
13.1	66	-0.001	0.554	2.000	2.390	2.660	Insignificant	Unaffected	
13.2	28	0.018	1.962	2.056	2.479	2.779	Insignificant	Unaffected	
13.3	40	0.017	2.669	2.021	2.432	2.704	Significant	Affected	98
13.4	42	0.010	2.248	2.021	2.432	2.704	Significant	Affected	95
13.5	56	-0.001	0.927	2.021	2.432	2.704	Insignificant	Controlled	
13.6	15	0.077	1.449	2.160	2.650	3.012	Insignificant	Controlled	
13.7	13	0.003	0.193	2.201	2.432	2.704	Insignificant	Controlled	
13.8	15	0.016	1.516	2.160	2.650	3.012	Insignificant	Unaffected	
13.9	35	0.013	2.571	2.042	2.457	2.750	Significant	Affected	98
13.10	15	0.015	0.773	2.160	2.650	3.012	Insignificant	Unaffected	
13.11	15	-0.060	2.731	2.160	2.650	3.012	Significant	Controlled	98
13.12	66	0.002	0.702	2.000	2.390	2.660	Insignificant	Affected	
13.13	18	0.013	0.809	2.120	2.583	2.921	Insignificant	Unaffected	
13.14	26	-0.017	2.127	2.064	2.492	2.797	Significant	Affected	95
13.15	18	-0.001	0.107	2.120	2.583	2.921	Insignificant	Unaffected	
13.16	22	-0.008	0.565	2.086	2.528	2.845	Insignificant	Affected	
13.17	**26**	**-0.012**	**2.127**	**2.064**	**2.492**	**2.797**	**Significant**	**Affected**	**95**
13.18	**66**	**0.002**	**1.075**	**1.990**	**2.370**	**2.630**	**Insignificant**	**Affected**	
13.19	17	-0.010	1.252	2.110	2.567	2.898	Insignificant	Unaffected	
13.20	65	-0.002	0.905	2.000	2.390	2.660	Insignificant	Unaffected	
13.21	43	-0.003	1.007	2.021	2.432	2.704	Insignificant	Unaffected	
13.22	18	0.004	0.139	2.120	2.583	2.921	Insignificant	Unaffected	
13.23	41	-0.009	0.561	2.021	2.432	2.704	Insignificant	Unaffected	
13.24	29	-0.001	0.129	2.052	2.473	2.771	Insignificant	Unaffected	
13.25	41	-0.007	0.498	2.021	2.432	2.704	Insignificant	Unaffected	
13.26	49	-0.005	2.685	2.021	2.432	2.704	Significant	Affected	98
*Shading indicates statistical significance, Wekiva and Little Wekiva Rivers are in bold									

In Table 5, *all* unit streamflows classified as 'unaffected' have an insignificant slope, meaning the slopes are not different from zero and there has been no change in the rivers' unit streamflows. About half of the affected gauging stations have a significant slope: half increasing and half decreasing. Gauging stations which were classified as 'affected' had different stages of development. Generally, the affected gauging stations

that had a constant unit flow were less developed than the affected gauging stations which did have a changing unit flow. Although the drainage areas are very complex with many factors contributing, the constant unit flow of all unaffected stations and the changing unit flow of the most affected stations prove that development around a river has an effect on its streamflow. Any increase in unit streamflow in an 'affected' river is most likely caused by increased runoff from impervious areas.

4.2 - RECHARGE AREA

An area of low unit flow is located around Clermont in Lake County: gauging stations USGS 02236500 and USGS 02236900 are both classified as 'Unaffected', and both have very low average unit flows of 0.259 cfs/mi^2 and 0.14 cfs/mi^2 or 3.53 inches and 1.85 inches, respectively. The St. John's River, in comparison, is also 'Unaffected' but it has a much higher unit Streamflow of about 0.8 to 1.0 cfs/mi^2. Wekiva and Little Wekiva have unit flows of 20.7 in and 9.1 in, respectively. The stations around Clermont are located in a recognized recharge area; this becomes clear when observing the maps of the area as well as an aerial photo: Figure 10 and Figure 11.
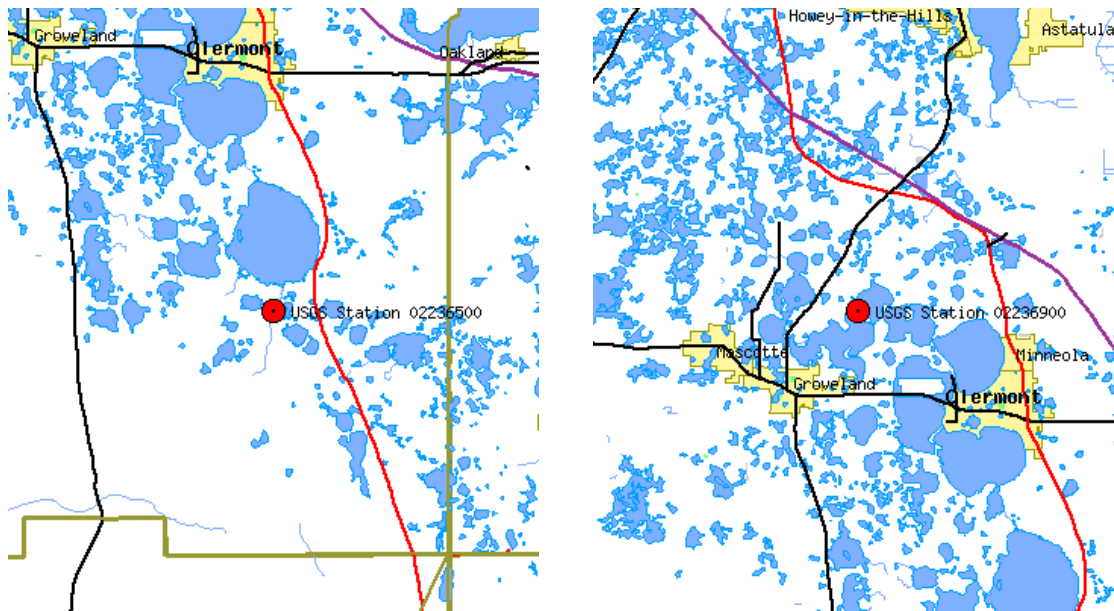
FIGURE 10 – CLERMONT AREA [USGS 02236500 and USGS 02236900]

FIGURE 11 – Aerial photograph of Clermont, Florida area [23 January, 1990].
(The many lakes and lack of streams give the indication of a recharge area)

There are few streams in this relatively high elevation area (around 90 feet above sea level), and the Clermont rainfall amount is similar to the amount in Sanford, Orlando, and Lisbon. Comparing the Clermont stream gauging stations to the St. John's River stream gauging stations in Christmas and Lake Harney, similar precipitation amounts result in less runoff in rivers in the Clermont area (i.e. low unit streamflow). More water must be infiltrated into the ground in order to balance the water budget, provided evapotranspiration is not significantly different.

4.3 - UNIT FLOW ANALYSIS CONCLUSION

A watershed has unique characteristics affecting streamflow. The overall trend of the twenty-six gauging stations analyzed is that development has an effect on a river's streamflow.

The Wekiva River has a relatively high unit Streamflow and is characteristic of a river with Springflow inputs. Runoff from the developed watershed most likely has increased and the contributing Springflow has decreased to result in a near constant unit flow over time for the Wekiva River. The Little Wekiva River has a decreasing Streamflow presumably due to a decrease in contributing Springflow and the cumulative decline in rainfall.

Through observation of the surrounding geography and the relatively low unit streamflows, the watershed around Clermont, Florida, has high infiltration and low precipitation runoff. The area around Clermont has been identified as a groundwater recharge area.

CHAPTER 5 - GROUNDWATER ANALYSIS

5.1 - INTRODUCTION

Springs have historically played an important role in Florida's history and the Wekiva River is a Spring-fed system associated with many, possibly 19 Springs connected to the Floridan aquifer. Maintaining groundwater recharge to the aquifer is a key factor of the viability of the regional water supply as well as Wekiva ecosystem. A first principle, physics-based watershed model WASH123D (A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in WAterSHed Systems of 1-D Stream/River Network, 2-D Overland Regime, and 3-D Subsurface Media, Yeh 1998) has been applied to conduct the study of Wekiva "Springshed", which is the recharge area and watershed contributing groundwater and surface water to the Spring.

Briefly introduced in this chapter are the basic hydrogeologic characteristics of the study area. The mathematical concepts of WASH123D are presented in succession. The hydrologic data input are then discussed followed by the development of the numerical model. The Wekiva WASH123D model was run to evaluate the average, steady state 1995 hydrological conditions. The distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows very good agreement with the field observations at corresponding locations. Also identified are the areas of recharge to and discharge from the Floridan aquifer system. Decreases in the discharge from the Springs due to the urbanization are discussed, and the relationship between distance and percentage of groundwater flow contribution for Rock Spring discharge is analyzed.

The region of study is essentially the same as the ECF model [1] developed by the SJRWMD (St. Johns River Water Management District). It is centered upon Seminole and Orange counties but includes most of Brevard, Lake, and Osceola counties plus parts of the Marion, Polk, and Volusia counties (Figure 12).

5.2 - TOPOGRAPHY AND SURFACE WATER FEATURES

Topographic relief and the nature of surface water features affect the distribution of recharge and discharge within the groundwater flow system. They are briefly described.

The area of the study is approximately 10,000 square miles. Land surface elevations range from sea level at the coast to greater than 200 ft above the National Geodetic Vertical Datum of 1929 (NGVD, formerly called mean sea level) at hilltops in Lake and Polk counties. In general, the topography increases in elevation in a step-wise fashion westward from the coast to highland areas in Lake, Polk, and western Orange counties (McGurk and Presley, 2002). Generally, the major topographic features are oriented in a coast-parallel or northwest to southeast direction (Figure 12).

The major surface water bodies within this area include rivers and their tributaries, canals, coastal lagoons, over 50 large lakes, numerous small storage ponds, 23 Floridan aquifer Springs and over 5,097 wells. Long term flow measurement records

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[1] Hydrologic data utilized in this preliminary study were obtained mainly from the input files for running the SJRWMD ECF (East-Central Florida) regional groundwater flow model. Documentation for the model can be found in the following report: McGurk, Brian, and Paula Presley, 2002, *"Simulation of the Effects of Groundwater Withdrawals on the Floridan Aquifer System in East-Central Florida: Model Expansion and Revision"*, SJRWMD Technical Report SJ2002-3, Palatka, FL, 196 p.

indicate that the St. Johns, Ocklawaha, and Kissimmee Rivers account for approximately 85% of the total surface water discharge within the region (USGS 1998).

Figure 12: Land surface elevations and Floridan aquifer springs in the modeling area
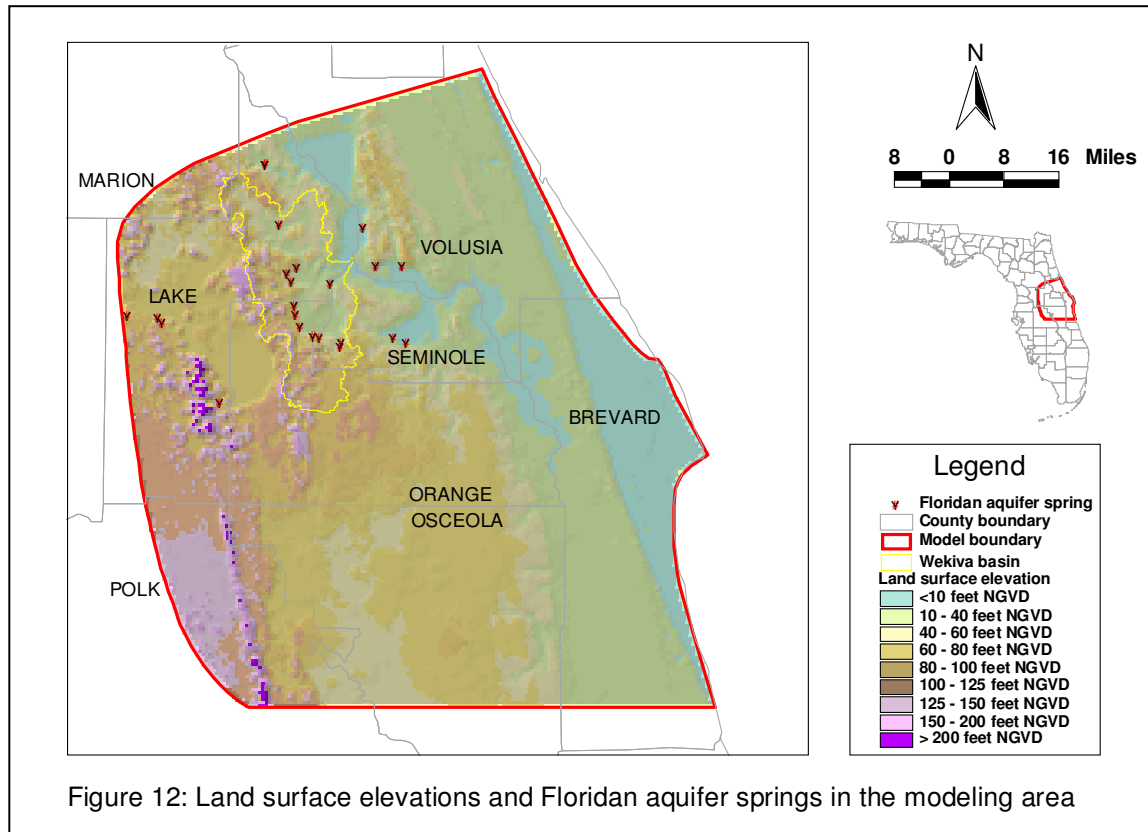
Rainfall represents the largest input of water to the hydrologic system. The average annual rainfall amount measured within the region is about 50 in/year. Evapotranspiration (ET) and evaporation (E) account for the largest water loss from the hydrologic system. The upper limit of ET rates ranges from 46 in/yr in the northeastern part within the region to 49 in/yr in the southwestern part; while the estimates of the minimum annual ET rate range from 25 in/yr to 35 in/yr (Tibbals, 1990).

5.3 - GROUNDWATER FLOW

The clastic and carbonate sediments beneath the area can be grouped into three aquifers (Surficial aquifer system, Upper Floridan aquifer, Lower Floridan aquifer) bounded by three confining layers (Intermediate confining unit, Middle semi confining unit, Lower confining unit). These hydrostratigraphic units apply throughout the domain and their characteristics are introduced as follows.

The uppermost unit is the surficial aquifer system with the thickness ranging from less than 20 ft to as much as 150 ft. The top of this unit (the water table) is located from within a few feet to several tens of feet below land surface. The surficial aquifer system receives recharge mainly from rainfall, irrigation water, and the Floridan aquifer while the discharge occurs mainly due to the evapotranspiration from the water table, seepage to surface water bodies and pumpage. Reported horizontal hydraulic conductivity of the surficial aquifer system sediments ranges from 0.03 ft/day to 200 ft/day and are highly variable.

The intermediate confining unit separates the surficial aquifer system from the underlying Floridan aquifer system. The generalized thickness of the intermediate confining unit is from less than 50 ft to over 200 ft, increasing from north to south. This unit is believed to receive recharge from the surficial layers and discharge to the Floridan aquifer where the water table is higher than Floridan aquifer potentiometric surface. The estimated leakance (ratio of vertical conductivity to thickness of the intermediate confining unit) derived from aquifer tests ranges from 10^{-6}/day to 0.8/day. Total thickness of the Upper Floridan aquifer ranges from less than 200 ft to more than 650 ft in the study area, generally increasing from the northwest to the southeast.

Reported transmissivities of Upper Floridan aquifer are between 1,200 ft^2/day and 530,000 ft^2/day. Total thickness of the Lower Floridan aquifer ranges from approximately 1,000 ft to greater than 2,000 ft and gradually increases in a southward direction. Reported transmissivities of Lower Floridan aquifer are between 200,000 ft^2/day and 670,000ft^2/day. Estimated rates of natural recharge range from less than 4 in/yr to greater than 12 in/yr through the Floridan aquifer system. Natural discharge occurs as diffuse upward leakage to the surficial aquifer system and as Springflow, approximate 42% of which comes from the Springs of Wekiva River Basin.

Total thickness of the revised middle semi confining unit ranges from approximately 150 ft to 650 ft and also generally increases in a southward direction. The leakances of the middle semi confining unit range from less than 0.00005/day to more than 0.001/day.

5.4 - POTENTIOMETRIC LEVELS

Figure 13 provides the average 1995 potentiometric surface of the Upper Floridan aquifer. The elevations of the estimated contours are from less than 10 ft NGVD to approximate 130 ft NGVD and this is consistent with the terrain features. Different from the ECF model, the boundary set for western, southwestern and northern was assumed as the zero-flux condition based on the measured potentiometric contours.

Figure 13: Estimated average 1995 potentiometric surface of the Upper Floridan aquifer (adapted from Knowles et al.1995 and O'Reilly et al.1996)
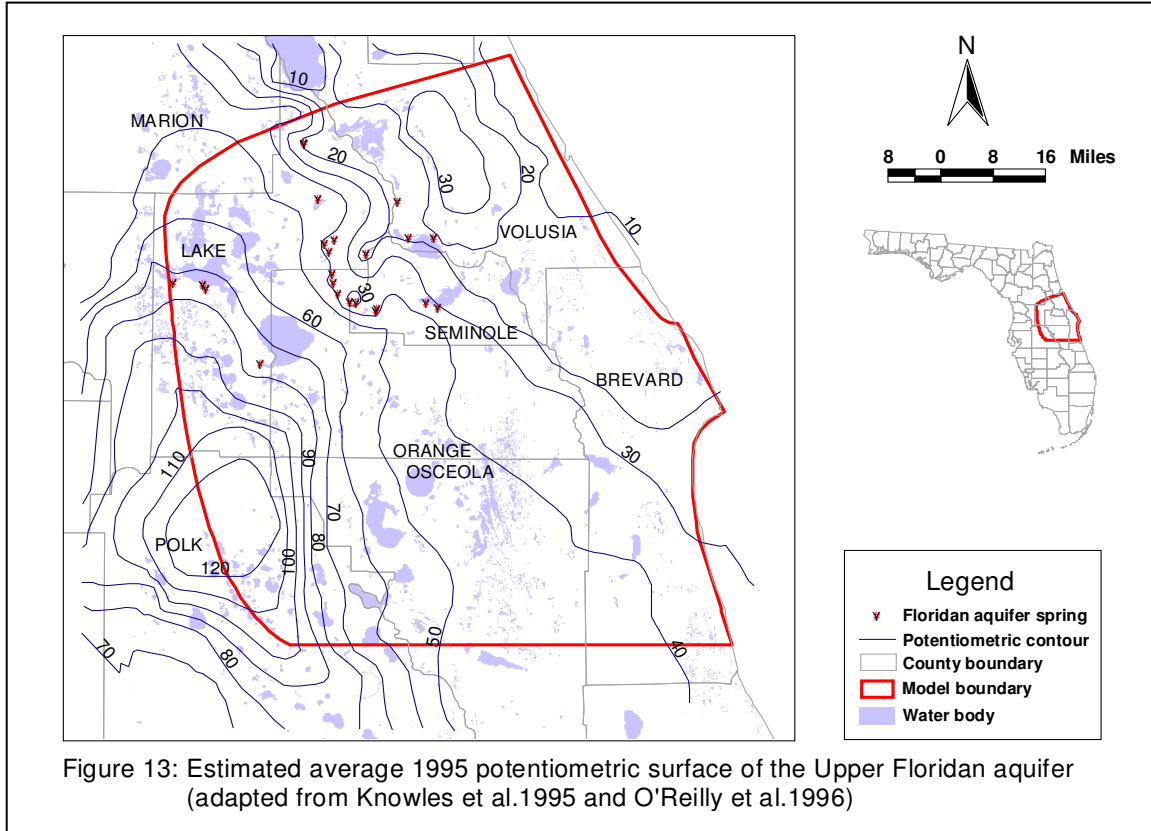
5.5 - MODELING WEKIVA SPRINGSHED

A first principle, physics-based watershed model WASH123D (A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in WAterSHed Systems of 1-D Stream/River Network, 2-D Overland Regime, and 3-D Subsurface Media, Yeh 1998) has been applied to conduct the preliminary Wekiva Springshed study. WASH123D was first developed by Gour-Tsyh (George) Yeh (University of Central Florida, Stormwater Management Academy) in 1994 for EPA (Athens) and U.S. Army Corps to study the groundwater, overland and river hydraulics. It was modified in 1998 to couple the contaminant, sediment, salinity, and thermal transport. The 3-D groundwater

module of WASH123D is employed in the Wekiva Springshed study and the mathematical basis is stated as follows.

The flow of groundwater is governed by the principles of conservation of mass and momentum. WASH123D applies Darcy's law as the general equation of the motion for groundwater so that the linear laminar flow is assumed during the investigation. The governing equation of subsurface flow through variably saturated media can be derived as (Yeh, 1987):

$$\frac{\partial \theta}{\partial t} + \nabla \cdot V = F \frac{\partial h}{\partial t} + \nabla \cdot \left[- K \cdot (\nabla h + \nabla z)\right] = q$$

where θ is the effective moisture content [L^3/L^3]; h is the pressure head [L]; t is time [T]; K is the hydraulic conductivity tensor [L/T]; z is the potential head [L]; q is the source and/or sink representing the artificial injection or withdraw of fluid [L^3/L^3]; and F is the water capacity [$L^3/L^3/T$] given by

$$F = \frac{d\theta}{dh}$$

And the Darcy's velocity (L/T) can be calculated as:

$$V = -K \cdot (\nabla h + \nabla z)$$

These equations are the constitutive relationships among the pressure head, degree of saturation, and hydraulic conductivity tensor, together with associated initial and boundary conditions, can be used to compute the temporal-spatial distributions of the hydrological variables, such as total head, pressure head, and Darcy's velocity. WASH123D has the following main features that make it flexible and versatile in modeling a wide range of real-world problems.

(a) "True" rather than "quasi" three-dimensional subsurface problems can be simulated;

(b) Irregular elements facilitate the representation of complex geometry;

(c) Both heterogeneous and anisotropic media, as many as desired, can be taken into account;

(d) On the ground surface, infiltration rates are determined by the WASH123D model rather than imposed as an input parameter by users of MODFLOW;

(e) Vadose zone can be incorporated to more realistically simulate the infiltration;

(f) Density dependent flow is available to more realistically model coastal aquifers;

(g) Many options are available to both compose and solve matrix equations.

The FORTRAN code WASH123D iteratively solves the three-dimensional groundwater flow equations. Input to the program includes the geometry of the system, the properties of the media, and the initial and boundary conditions. Output includes the spatial distribution of pressure head, total head, velocity fields, moisture contents, as a function of time.

The use of WASH123D requires the modeling domain divided into discrete elements. The numerical equations of groundwater flow are solved iteratively for each node to produce simulated water levels, or head values and Darcy's velocity field. As showed in Equation (1), the groundwater flow between elements depends on the head gradient as well as the conductivities assigned to the each element. The model domain was discretized as shown in Figure 14.

Figure 14: 3-D Finite Element Mesh of the Modeling Domain
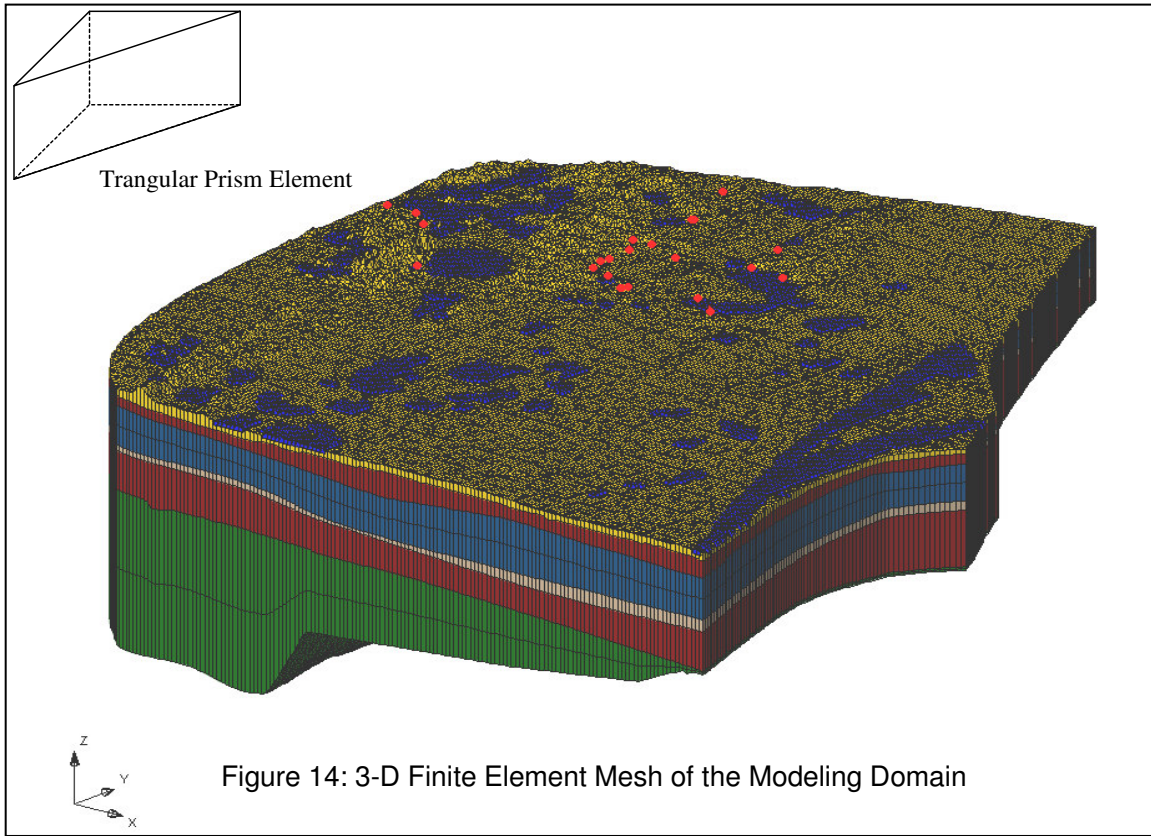
The domain profile was divided into six layers along the vertical direction (Figure 14). The discretization is coinciding with the ECF model except that the intermediate confining unit and the middle semi confining unit were incorporated in the simulation. The six layers are stated as following:

(1) ECF Layer 1, known as the surficial layer (indicated as yellow in Figure 14);

(2) The intermediate confining unit (indicated as upper red layer in Figure 14);

(3) ECF Layer 2, known as the upper zone of the Upper Floridan aquifer (indicated as blue in Figure 14);

(4) ECF Layer 3, known as the lower zone of the Upper Floridan aquifer (indicated as gray in Figure 14);

(5) The middle semi confining unit (indicated as lower red layer in Figure 14);

(6) ECF Layer 4, known as the Lower Floridan aquifer (indicated as green in Figure 14).

Numerically, the modeling domain was totally discretized into 437,576 Triangular Prism Elements (see upper left of Figure 14) connected at 249,057 nodes. The interior elements have the equal size 3,125,000 square feet while the boundary elements have the approximate size of one-eighth square mile due to the irregularity. Furthermore, considering the large depth of ECF Layer 2 and Layer 4, each was divided into two sub-layers of elements with the same media parameters. Therefore, eight numerical layers are included in the simulation.

Several types of input hydrologic data are required for the model. These include information needed to assign boundary conditions, applied stresses, and properties of each numerical layer.

Boundary conditions were estimated and applied at the sides of the model domain for the Floridan aquifer system layers and confining units, at Springs, at water bodies such as lakes, and at the air-media interface. Choices for boundary condition assignments can be classified into three types: (1) prescribed potentiometric levels (heads); (2) prescribed flow rates; and (3) head-dependent flux.

The base of the model is a zero-prescribed flux boundary. Since clearly defined hydrogeologic boundaries do not exist within the Floridan aquifer system in the modeling domain, realistic conditions should be set up and applied along the lateral sides of the domain to represent flow that occurs across these artificial boundaries. Potentiometric

surface map of the Upper Floridan aquifer (Figure 13) was used to locate the model boundaries and to help in defining these conditions. On a regional scale, flow directions within the Upper Floridan aquifer will be perpendicular to the potentiometric contours shown in Figure 13. Therefore, the northern, southwestern, and western sides of the domain are prescribed as zero-flux boundary conditions. While the head values are defined along the southern and the seaward boundary. Those head values are mainly from the input for general-head boundary (GHB) package of the ECF model. At Springs and lakes, the constant elevations were assumed and the boundaries conditions of them were assigned as prescribed levels (heads), which values are also defined in the ECF model input.

Because several stresses were applied to the model, including well withdrawals from different depths within the Floridan aquifer system, recharge to the Upper Floridan aquifer through drainage wells and recharge to the surficial aquifer system caused by rainfall and evapotranspiration, the air-media interface is usually a boundary on which the subsurface flow direction is not predetermined and needs to be set up so that consistent computational results can be obtained. WASH123D is such designed as: when a boundary is flux-type for the rainfall period, a complete adsorption of through fall water is assumed, while a potential evapotranspiration is simulated if it is for the evaporation period. The ponding-type boundary is to simulate the accumulation of water above ground surface while the minimum pressure-type boundary is to describe the allowed minimum pressure associated with the soil being considered. The ECF model input dataset for the evapotranspiration (EVT) package provides such parameters, such as ponding depth and minimum pressure.

The most important input stress to the model is the recharge applied to the surficial aquifer system, including precipitation, flow to rapid infiltration basins, septic tank effluent, the evapotranspiration from the unsaturated zone, applied irrigation as well as the overland runoff. The recharge rates were estimated by developing an algorithm that incorporates the appropriate portions of the steady state water budget for the surficial layer in the ECF model and these values are used as air-media boundary condition input as discussed above and can be found in the ECF model input for the recharge (RCH) package.

Totally 5,097 wells are applied to different depth of the modeling domain. These wells are classified as four types: (1) withdraw wells; (2) drainage wells; (3) self-supplied domestic wells; and (4) free-flowing wells. The withdraw wells introduces the majority of the water consumed. The ECF model provides much of the information used to prescribe well rates in the well (WEL) package input. During the simulation with WASH123D, these wells were treated as point sources or sinks as indicated by the q term in Equation (1). Withdraw wells, self-supplied domestic wells, and free-flowing wells have the negative rates and each of these kinds of well was treated as a point of sink while each of the drainage well as a point of source in WASH123D.

Input data representing the model geometry or hydrostratigraphy, such as aquifer layer and confining unit top and bottom elevations, were obtained from the calibration data of the ECF model.

Horizontal isotropy was assumed for all the eight numerical layers. That is, horizontal hydraulic conductivity was assumed to be equal along the x- and y- directions. The calibrated vertical conductivities and leakance of the intermediate confining unit of

ECF model were employed to estimate the hydraulic characteristics of the model layers represented by the material types input of WASH123D. Due to the scarcity of large-scale hydraulic conductivities estimates for the surficial layer, a homogeneous horizontal hydraulic conductivity equaled 20 ft/day is assumed throughout this system. While the other seven numerical layers have unique material type defined at each element. Moreover, the media within the vicinity of the Springs usually have large conductivities to drive the groundwater upward; each material type is defined for each element of the 23 Springs in the modeling domain. Totally 273,509 material types were used in the simulation.

5.6 - SIMULATION RESULTS

The Wekiva WASH123D model was run to evaluate the average, steady state 1995 hydrological conditions. As shown in Figures 15, 16, and 17, the distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows very good agreement with the field observations at corresponding locations. One can also investigate that the simulated 1995 water levels mimic the topography on a regional scale.

The simulated 1995 layer 2 potentiometric surface compares favorably with the average 1995 Upper Floridan aquifer potentiometric surface (Figure 16). The simulated layer 3 potentiometric surface is similar to the layer 2 surface, differing only along the St. Johns River valley and near where layer 3 is inactive due to the location of the saltwater interface (Figure 16). The simulated 1995 layer 4 (Lower Floridan aquifer)

potentiometric surface is a subdued reflection of the Upper Floridan aquifer

potentiometric surface. Layer 4 water levels are lower than layer 2 and layer 3 (Upper

Floridan aquifer) water levels in the southwestern corner of the model and in central

Volusia County. The simulated layer 4 water levels match the observed well data fairly

well. The simulated potentiometric contours also verify the zero-flux boundaries having

been set for the western, southwestern, and northern sides of the modeling domain.

Figure 15: Average 1995 Upper Floridan aquifer (UFA) potentiometric surface and simulated Layer 2 1995 potentiometric surface with WASH123D

Figure 16: Average 1995 Upper Floridan aquifer (UFA) potentiometric surface and simulated Layer 3 1995 potentiometric surface with WASH123D

Figure 17: Simulated Layer 4 potentiometric surface with WASH123D and observed Lower Floridan aquifer water levels, average 1995 conditions

One can observe the groundwater flow patterns based on the simulated velocity fields as well as the potentiometric surfaces. Three cross-sections along Rock Spring are selected as shown in Figure 18.

Figure 18: Three cross-sections along Rock Spring
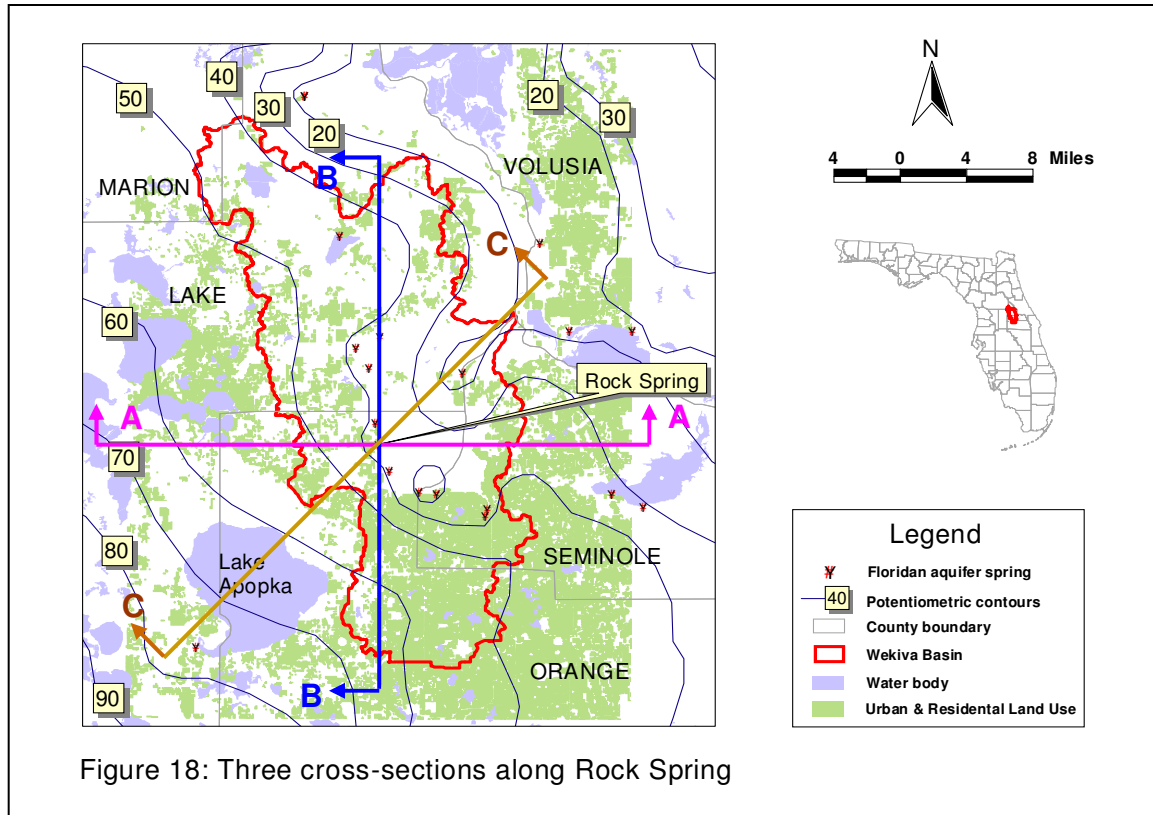
It is seen from Figure 19 that the potentiometric head difference drives the groundwater moving within the subsurface aquifer system. In a regional scale, the velocities are perpendicular to the head contours. Due to the large conductivity within the vicinity of the Spring, the Darcy's velocities are large upwards resulting in the Spring discharge. One can also see that the majority of groundwater recharge to Spring flow comes from the relatively shallow aquifer within the nearness of the Spring, where the velocities are relatively high thus less time needed for the groundwater moving to the Spring. Other part of recharge is from deeper aquifer as well as seepage from the surface.
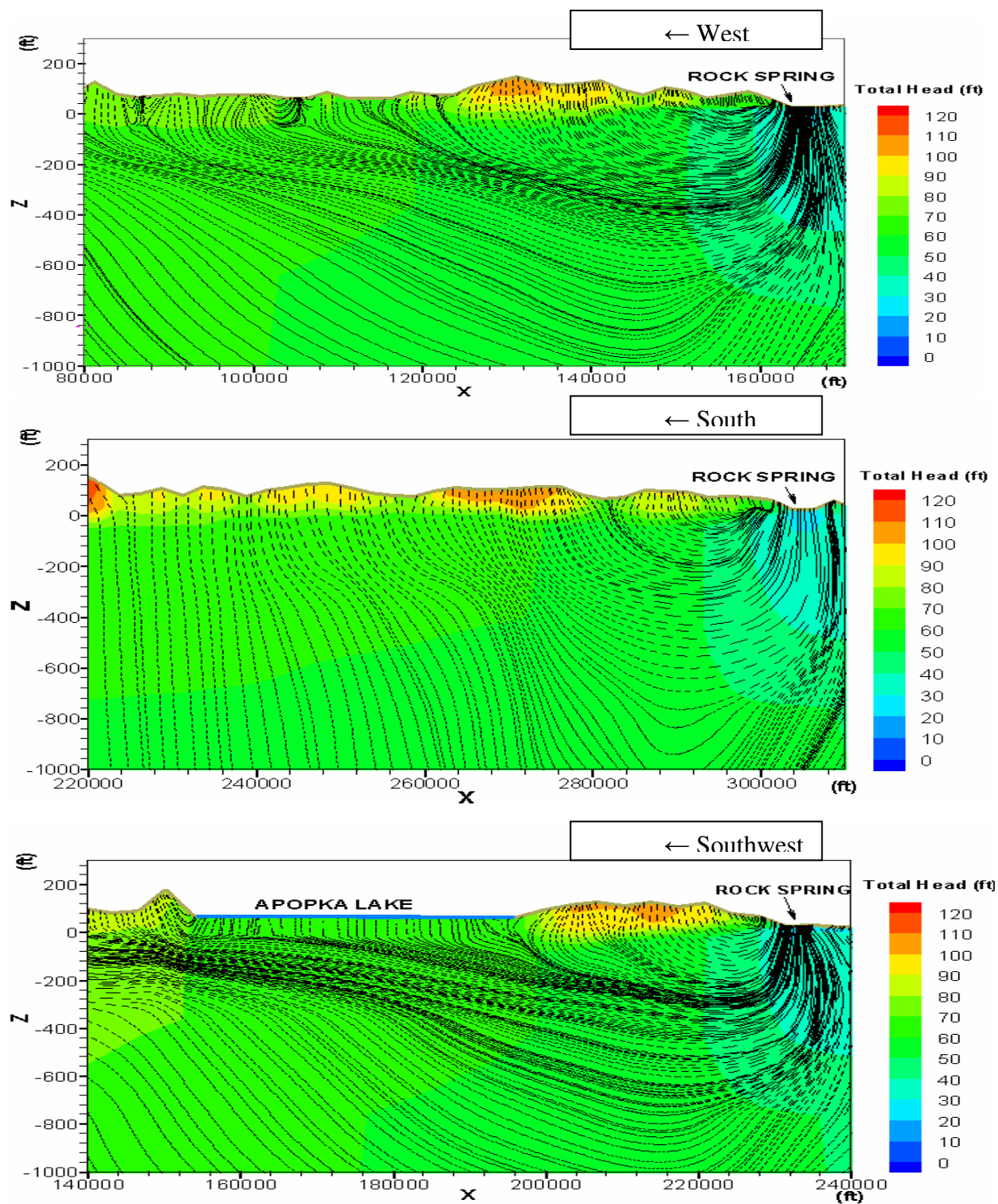
Figure 19: Groundwater flow along three cross-sections: upper (A-A); middle (B-B); lower (C-C)

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5.7 - AREAS OF RECHARGE AND DISCHARGE

Areas for recharge and discharge from the Floridan aquifer system are identified. This simulation result is consistent with that simulated with the ECF model very well. It also shows good agreement with the reported areas for recharge and discharge by Wekiva Basin Area Task Force [2] and by Boniol (et al. 1993).

Natural discharge from the Floridan aquifer system occurs as diffuse upward leakage to the surficial aquifer system and as Spring flow (McGurk and Presley, 2002). Simulated rates of natural recharge range from less than 4 in/yr to greater than 12 in/yr. Water leaks upward to the surficial aquifer system through the intermediate confining unit wherever the Floridan aquifer potentiometric level is higher than that of the surficial aquifer system, as delineated as discharge areas in Figure 20. While areas where the surficial aquifer potentiometric level is higher than that of the Floridan aquifer system are defined as the recharge areas in Figure 20.

High-rate recharge areas coincide with high lands characterized by sandy ridges with deep water table soils and karst topography and where there are few perennial streams to collect overland runoff (McGurk and Presley, 2002), within the areas where the head gradient between the surficial aquifer and Upper Floridan aquifer is large and where the intermediate confining layer is thin or more permeable. Adversely, low-rate recharge zone appears in the low or flat areas where the water table is near the land surface thus enhancing the ET from the saturated zone, where the head gradient is small, and where the intermediate confining layer is thick or having low permeability.

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[2] The documentation can be found in the final report: Wekiva Basin Area Task Force, 2003, *"Recommendations for planning and locating the Wekiva Parkway while Preserving the Wekiva River Basin Ecosystem"*.
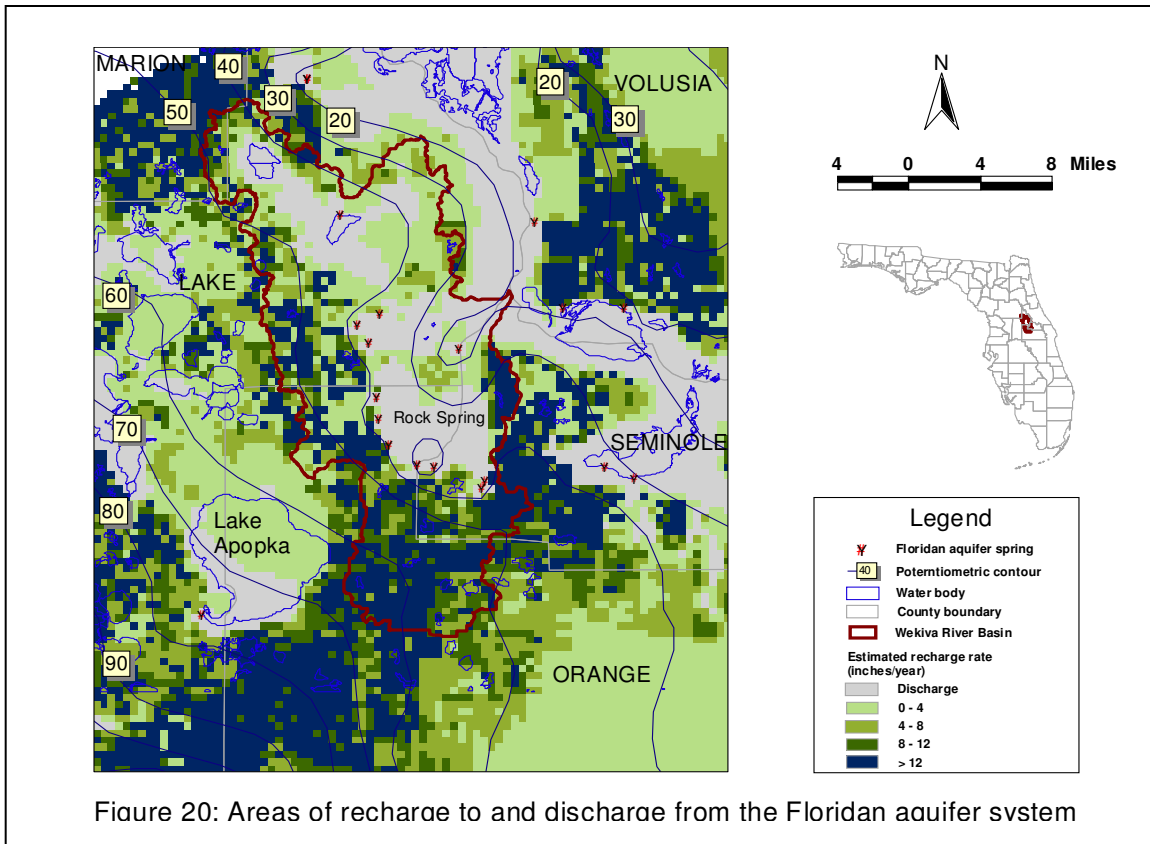
Figure 20: Areas of recharge to and discharge from the Floridan aquifer system

One can see that high-rate recharge areas are concentrated within the Wekiva River Basin, and over half of the Lake Apopka provides a source of recharge to the Wekiva Springs. There are also high and moderate areas that extend farther south and west and also to the east within Seminole County.

The identification of the recharge area is particularly important in preserving the ecosystem of the Wekiva River Basin. It is noted that the estimation agrees with the observations of Section 4.2 in this report. Clermont is located south of Lake Apopka and is indicated as a recharge area in Figure 20.

5.8 - URBANIZATION EFFECT

Since the early 1980s, the central Florida region has continued to experience tremendous growth that has resulted in increasing demands on the region's transportation system and rising development pressures on the land surrounding the Wekiva River Protection Area (Wekiva Basin Area Task Force, 2003). The intensive urbanization has been responsible for the increases of the impervious surface (such as streets and parking areas) thus increasing the runoff while decreasing the recharge to the Floridan aquifer system. It is possible that the volume of groundwater moving toward discharge from the Wekiva River Spring systems has diminished over time due to the loss of recharge as a consequence of land development.

During the preliminary study of the Wekiva Springshed, calculated were the discharges of the Springs based on the simulated velocity fields. Using the Rock Spring for example, the simulated discharge is approximately 68 cfs (cubic feet per second), which is compared to the measured 62 cfs, under the steady state condition of the year 1995. Using this simulation below ground set of conditions, the impervious area was increased by about 60 square miles, as indicted in Figure 21 within the dark-red lines. This impervious area is about 20% of the total Springshed area estimated to contribute water to Rock Springs. The simulation results on Rock Springs flow after the increase of impervious areas indicated a decrease of approximately 10-15 percent in Rock Spring flow. Most likely, other springflows will also be affected and decreased, but only Rock Springs discharge was estimated.

In Figure 22, the groundwater flow simulations are presented for the before and after the increase of the impervious areas. Used for the presentation was the cross-section

C-C as shown in Figure 21. It is noted that the areas between the Lake Apopka and the Rock Spring have the different potentiometric contours. The increase of the impervious area introduces the smaller head gradient thus lower Darcy's velocities are generated, resulting the decrease of the Springflow. The model conclusions agree with the analysis of historical data in Chapter 6 of this Report.

Figure 21: Wekiva River Basin and estimated impervious area
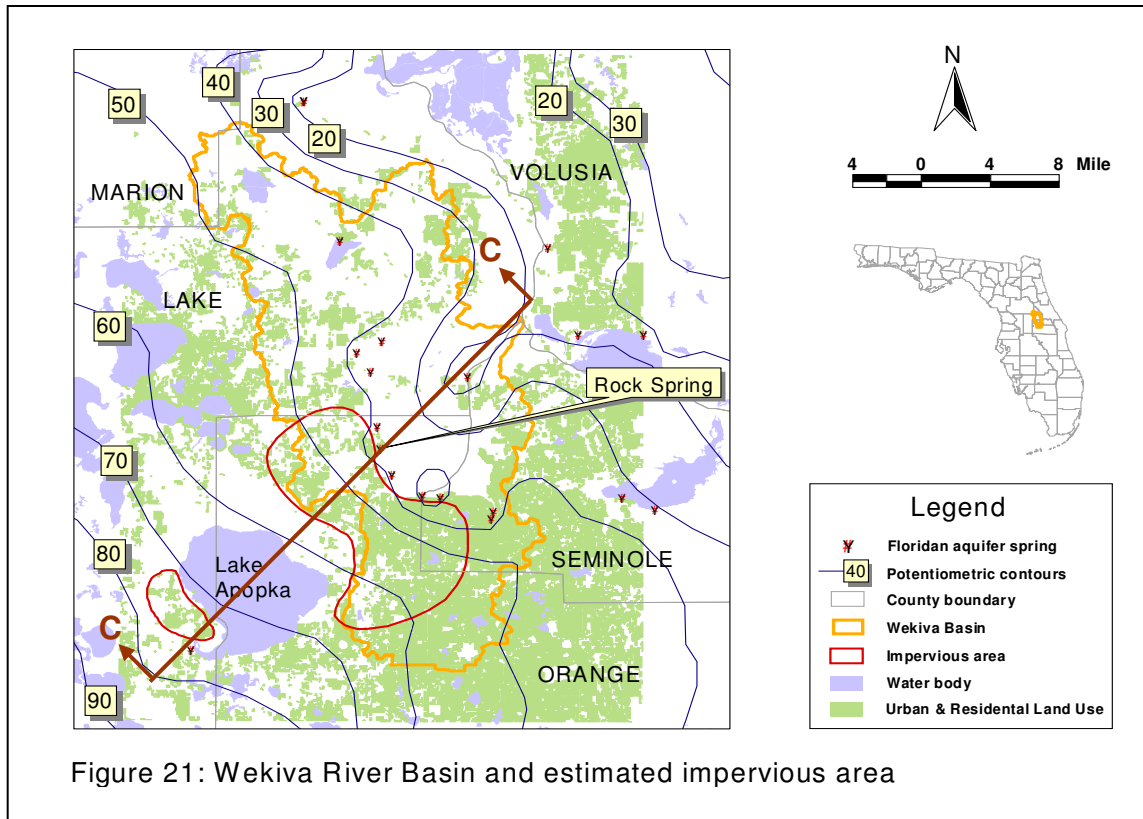
The U.S. Geological Survey has defined "Most Effective Recharge Areas" as areas having greater than 10 inches of recharge per year. As discussed before, high-rate recharge areas are concentrated within the Wekiva River Springshed area (Figure 20), protecting the high recharge areas that furnish water to the Springs is so critical. Therefore, high-impact land use such as mining, industrial, heavy commercial and urban area with extensive impervious surface should be of interest to protect the existing recharge potential within the Springshed.
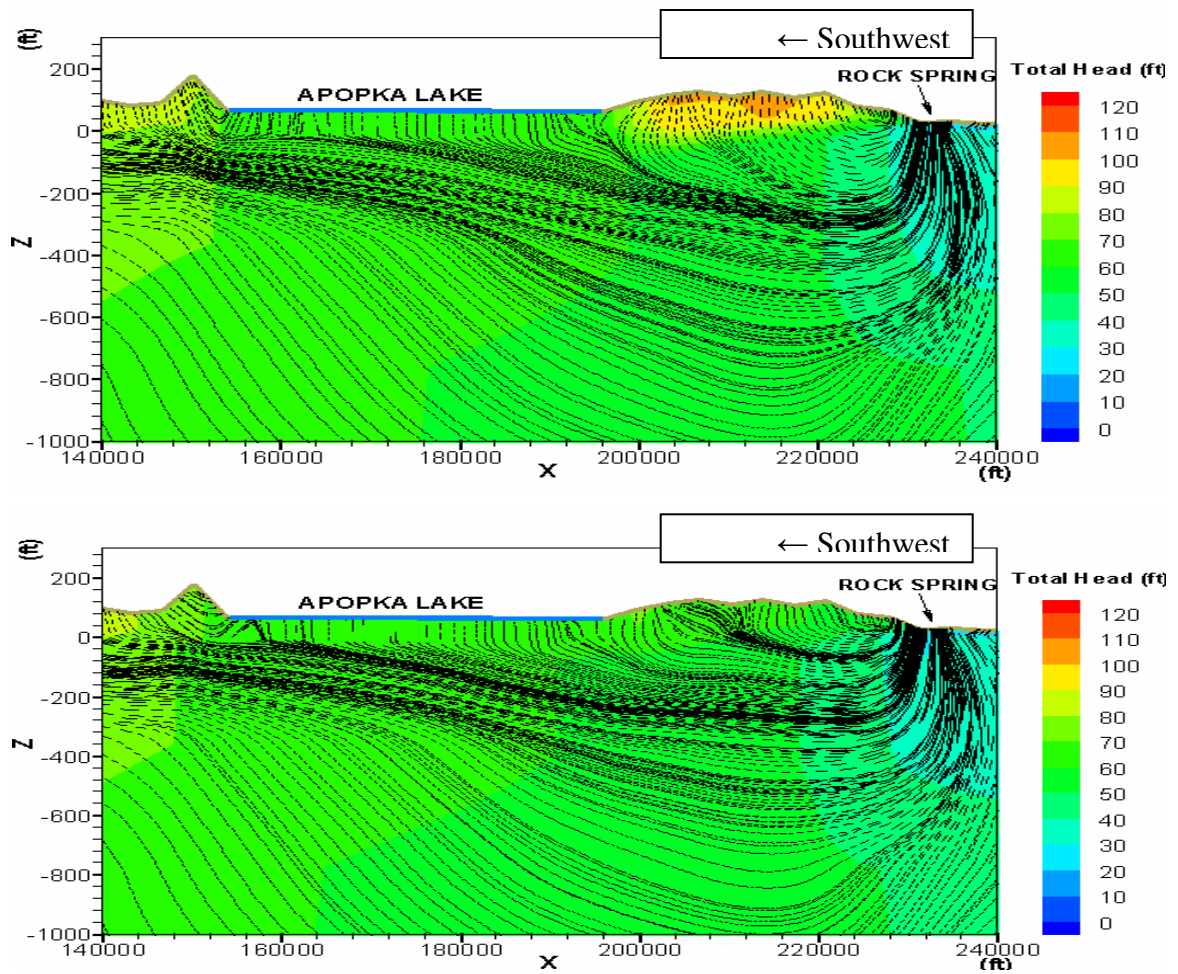
Figure 22: Groundwater flow along the cross-section C-C before (upper) and after (lower)
the increase of the impervious area

5.9 - SPRINGFLOW RELATIONSHIP TO DISTANCE

The relationship between distance and the percentage of groundwater contribution for Springs can be estimated using the reverse particle tracking method. The WASH 123D model does not assume the recharge area but calculates the rate and extent. As can be imagined from Figure 23, particles within the vicinity of Rock Springs travel faster than those faraway thus less time is need for them to appear as the Spring flow. For the Rock Springs as shown in Figure 23, it is estimated the around 70 percent of the Spring flow is contributed from within the 8 miles of the vicinity. Lake Apopka contains both recharge and discharge regions and contributes around 5 percent of the Rock S Springs discharge. And it is estimated that less than 5 percent of the Springflow is contributed from the area beyond 14 miles of Rock Spring.

Figure 23: Distance and percentage of groundwater contribution for Rock Spring
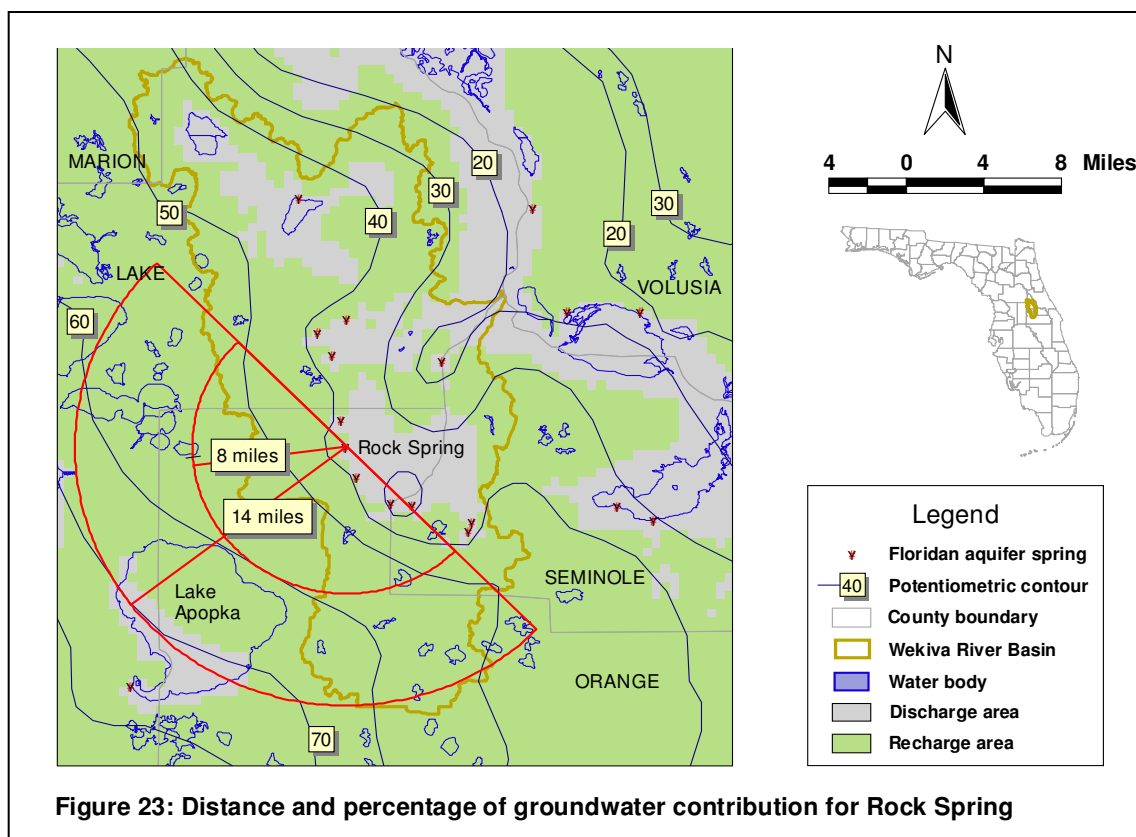
5.10 - SPRINGSHED AREA RELATIONSHIPS

An estimation of the Springshed area has been made using the WASH123D model. The recommend Wekiva study area is approximately 480 square miles. The estimated area contributing groundwater to Springs modeled by WASH123D of Wekiva is approximately 450 square miles, which is by the authors' calculation larger by only 20 square miles than the original assumed recharge area (Wekiva Basin Area Task Force, November 2003). In Figure 24, the recommended Wekiva study area and estimated Springshed are delineated.

It is estimated that 60 percent of the Springshed is located within the recommended Wekiva study area. Within the recommended Wekiva study area, there is about 40 percent high recharge zone (defined as the recharge rate larger than 8 inches/year). Also, approximated 60-65 percent of the estimated Springshed is in high recharge zone.
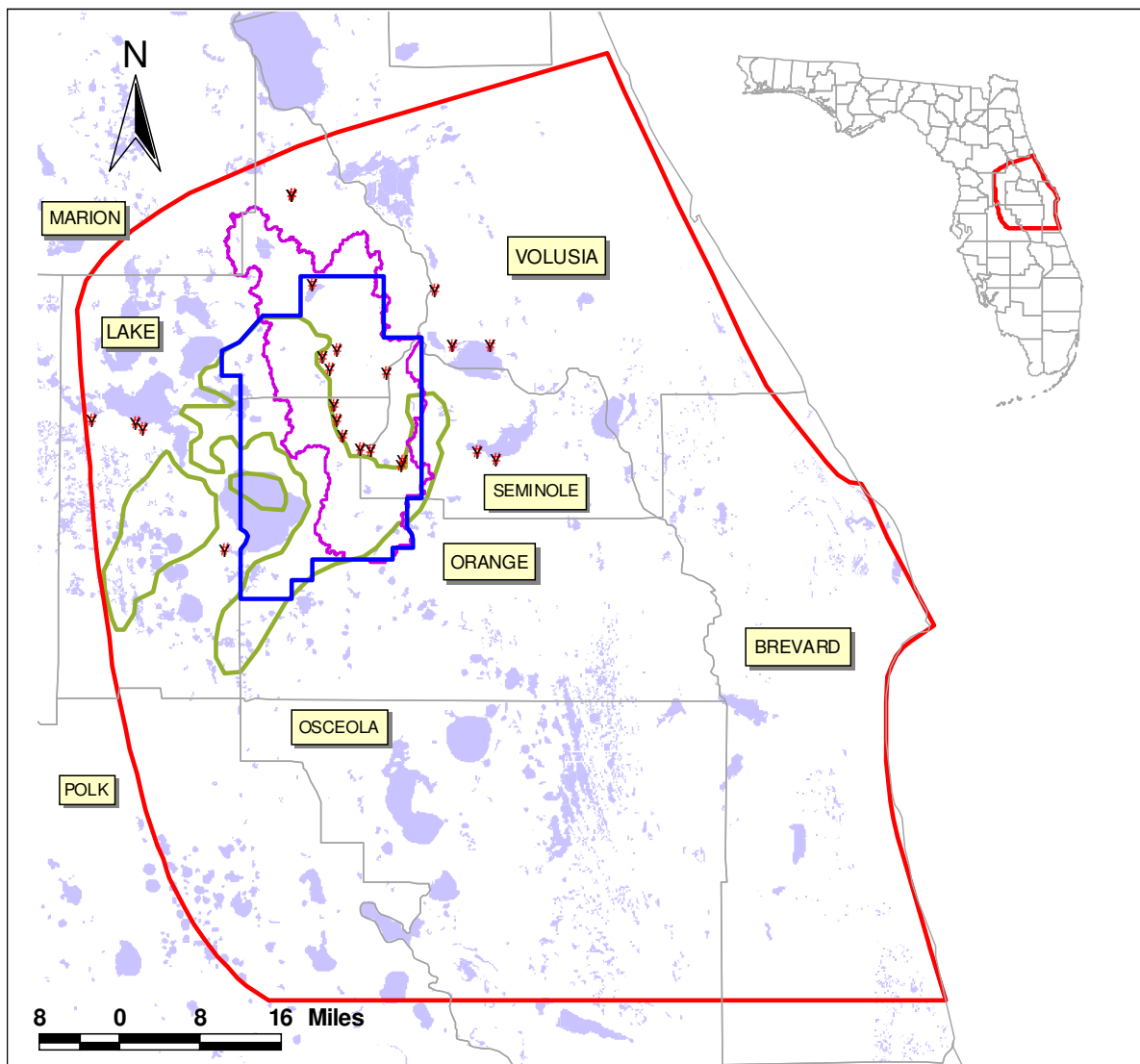
Figure 24: Recommended Wekiva study area and estimated springshed with WASH123D

Legend

- ⚡ Floridan aquifer spring
- ▭ Recommended Wekiva Study Area
- ▭ Wekiva Basin
- ▭ Model boundary
- ▨ Water body
- ▭ County boundary
- ▭ Estimated springshed with WASH123D model
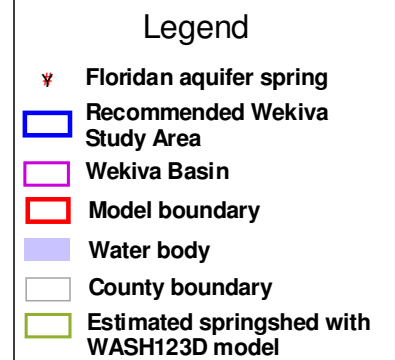
5.11 - PRESSURE HEAD AND STREAMFLOWFLOW

Based on Figure 18 in Technical Publication SJ2002-3 by the St. John's River

Water Management Districts (Appendix Figure 10), which depicts the estimated average

1995 level of the Upper Floridan Aquifer, the area of the aquifer that would have an

effect on the flow of the previously mentioned five Springs was estimated using the

contour lines in Appendix, Figure 10. The following latitude/longitude box roughly

corresponds to that area:

TABLE 6: LATITUDE LONGITUDE BOX FOR WELL LOCATIONS

	28°48'00"	
81°44'00"		81°24'00"
	28°28'00"	

Seven Wells that are located within the latitude/longitude box have been

identified; information for these wells' locations is available in Table 1. Data are

available for May and September for the years expanding 1990 to 1999. Each Springflow

was related to the pressure head in the seven wells versus time, using the Springflows for

May and September (Appendix Figures 11.1 to 11.5). Figure 25 illustrates a typical

comparison of Rock Spring s discharge with the surrounding groundwater level in the

seven wells.
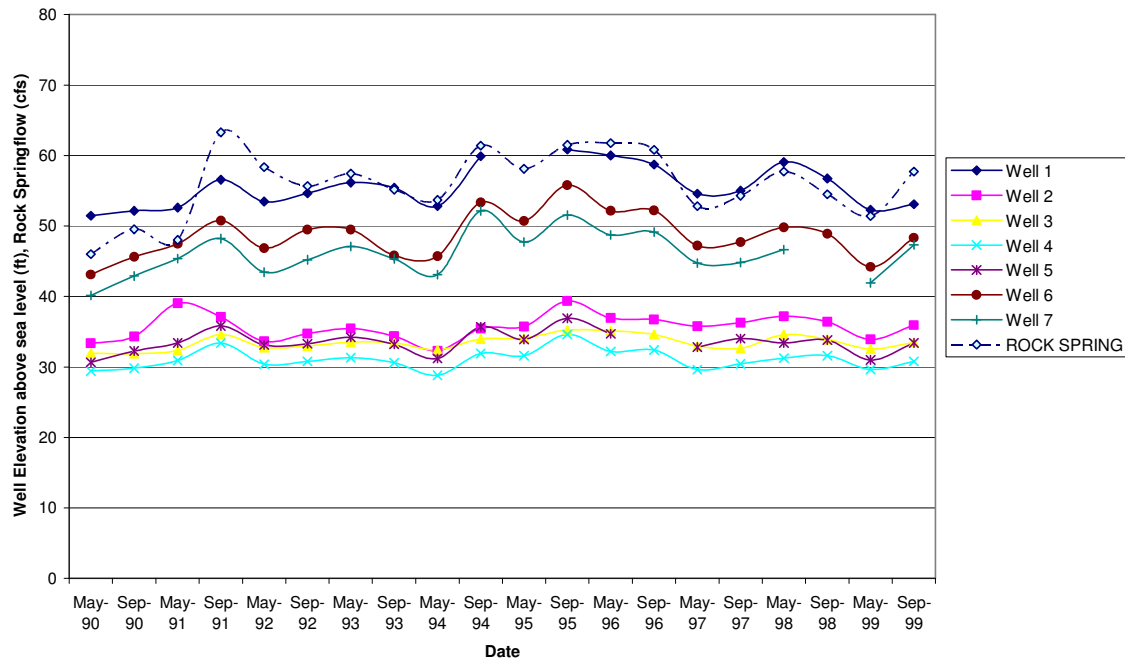
FIGURE 25 - Rock Springsflow and Well Elevations versus time
Appendix, Figure 11.4

Presented in Figure 25, is a strong relationship between Rock Springs discharge

and the well elevations in the area. Similarly, Figures 11.1 to 11.5 in the Appendix depict

relationships between Wekiva, Starbuck, Sanlando, and Palm Springflows and the

surrounding well elevations: the dashed blue line corresponding to Springflow displays

similar characteristics to the well elevations, or the groundwater levels. The Springflows

of the smaller three Springs; Palm, Sanlando, and Starbuck show a weaker relationship to

the groundwater level than the larger Springs Wekiva and Rock. In the case of Sanlando,

the weaker relationship to the groundwater level could be explained by the influence of

precipitation. For Palm and Starbuck Springs, reasons for the weaker relationship to the

well elevations could be that Palm and Starbuck Springs correspond to wells that are not

located in the assumed recharge area, rainfall runoff could be more influential, or the

Spring water could originate from a deeper aquifer. Another possibility is that since

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smaller Springs have a lower average Springflow, and thus have less variability in the Springflow amount, any change in groundwater level could result in a less noticeable change in these smaller Springflows. From Figures 11.1 to 11.5 in the Appendix it can be concluded that Springflow in the Wekiva area is closely related to the surrounding groundwater level.

Moreover, double mass diagrams of Springflow and average well elevation (Appendix, Figures 12.1 to 12.5) show a *consistent* relationship between the Springflows and the surrounding well elevations. Figure 26 is an example of the consistent relationship between Rock Springflow and the surrounding groundwater level: the cumulative Springflow is directly related to the cumulative pressure head in the surrounding wells.

The chart shows data with trendline:
$y = 1.3957x - 5.3735$
$R^2 = 1$

Y-axis: Cumulative Average Annual Rock Springflow (cfs)
X-axis: Cumulative Yearly Average Upper Floridian Pressure Head in Reference to Sea Level (ft)
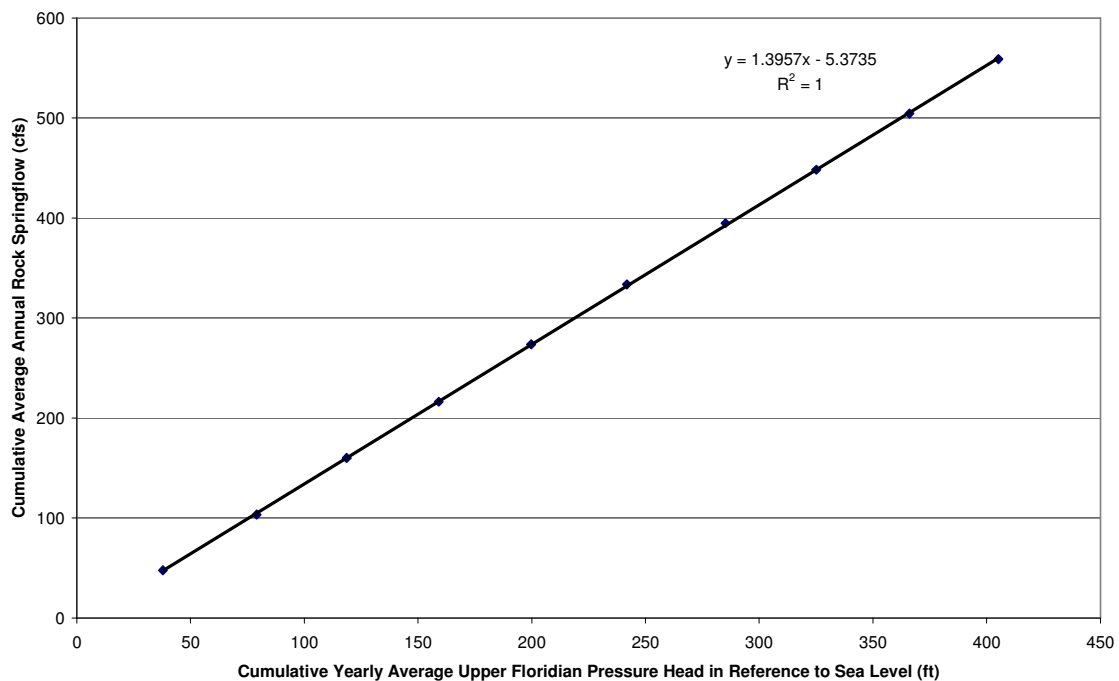
FIGURE 26 - Double Mass Diagram Rock Springflow vs Pressure Head
Appendix, Figure 12.4

Similar to Figure 26, in Appendix Figure 12.1 to 12.5, the double mass diagrams illustrate a perfect correlation ($R^2 = 1$) between groundwater level in the estimated area and the Springflows of Wekiva, Starbuck, Sanlando, Rock, and Palm Springs. Although the relationship between Springflow and the surrounding groundwater level is less obvious for the smaller Springs in, Appendix, Figure 11.1 to 11.5, the double mass diagrams (Appendix, Figure 12.1 - 12.5) illustrate a direct relationship between Springflow and groundwater level in the Wekiva area.

Furthermore, at least 58 percent of the Wekiva River Streamflow originates from Springflow as shown in Table 7. Since there are several other smaller Springs (Barrel Spring, Witherington Spring, Sulphur Spring, etc) besides Wekiva, Starbuck, Sanlando, Rock, and Palm that are not considered in this report, the actual percentage is probably between 60 and 70 percent. The remaining 30 to 40 percent most likely originates from precipitation, runoff, and nearby groundwater seepage into the River. Table 7 was constructed by dividing the sum of the five average annual Springflows by the average annual Streamflow in the Wekiva River for each year. The Streamflow was measured at a location after the Wekiva River has joined with the Little Wekiva River but before the Seminole Spring system discharges into the River (USGS 02235000, Latitude 28°48'54", Longitude 81°25'10" NAD27).

TABLE 7: Wekiva River Springflow Influence

YEAR	TOTAL YEARLY STREAMFLOW FLOW	AVERAGE ANNUAL STREAMFLOW	Springflow / Streamflow *
1972	177.24	279	0.635
1973	177.24	311	0.570
1974	174.22	310	0.562
1975	175.99	276	0.638
1976	167.83	262	0.641
1977	160.80	263	0.611
1978	171.00	319	0.536
1979	168.18	341	0.493
1980	167.30	242	0.691
1981	148.36	201	0.738
1982	170.44	269	0.634
1983	173.63	334	0.520
1984	167.46	298	0.562
1985	155.20	272	0.571
1986	161.96	279	0.581
1987	168.64	306	0.551
1990	138.37	214	0.647
1991	161.01	288	0.559
1992	166.38	277	0.601
1993	161.14	265	0.608
1994	155.74	383	0.407
1995	179.71	337	0.533
1996	178.93	371	0.482
1997	157.67	276	0.571
1998	163.50	345	0.474
1999	154.60	286	0.541
2000	139.19	197	0.707
		AVERAGE	**0.580**

* Fraction values

5.12 - GROUNDWATER ANALYSIS CONCLUSION:

A model is any device that represents an approximation of a field situation (Anderson and Woessner, 1992). The Wekiva WASH123D model shows comparable simulation results with the observation data even without calibration. However, the model results are limited by the simplification of the conceptual model upon which the numerical model is based, the element size, the inaccuracies of measurement data, and incomplete knowledge of the spatial variability of input parameters. For example, it is suspicious that the laminar flow is assumed throughout the subsurface, especially within the vicinity of the Springs. It is also suspicious that the elevations of the lakes are treated as not functions of time since interactions between such water bodies and the subsurface need to be considered to ensure the mass conservation. And more, element refinement around Springs, wells, and lakes is required to increase the simulation accuracy.

All input in this study represented average, steady state conditions. In the designation of WASH123D, both sources/sinks and all types of boundary conditions can be considered spatially- and/or temporally- dependent plus transient simulations can be processed based on the appropriate initial conditions. So, the Wekiva WASH123D model can be further applied to examine the potential long-term, transient impact due to changes of stresses.

There exists a strong relationship between the pressure in the aquifer system and discharge from the Springs in the Wekiva basin. Thus water extracted from or added to the aquifer system affects Springflow.

It is estimated that at least 60 to 70 percent of the Wekiva River Streamflow originates from Springflow. Wekiva, Starbuck, Sanlando, Rock, Palm Springs have a

consistent correlation with the nearby groundwater level and thus originate from the

groundwater aquifer.

CHAPTER 6 - SPRINGFLOW DECREASE

For Wekiva, Rock, and Palm Springs, it is calculated with over 99.9 percent confidence that the Springflow has decreased over the recent past period of record (35 to 70 years). Also with a 90 percent confidence Starbuck Springs discharge has decreased during the period of record of 35 years (Table 8, and Appendix, Figures 9.1 – 9.5). The decreasing trend in Springflow around the Wekiva area is also supported in detail by the research conclusions of the St. John's River Water Management District, which states in Technical Publication SJ2002-3 that the predicted 2020 Springflow in the Wekiva River Basin (Rock, Palm, Sanlando, and Starbuck) will be about 15% less than the 1995 Springflow.

The decrease in Wekiva Springflow could be caused by development over the Spring recharge area; the new impervious areas would allow less water to infiltrate into the ground to recharge the Springs. Another cause could be increased well extraction from the aquifer in and around the Spring recharge area. Because springflow is affected by the pressure from the groundwater, it will decrease when the groundwater level decreases. Even though it might take a particle of water over 100 years to travel 100 miles through the soil to discharge into a Spring, due to a decrease in pressure the Springflow would be affected before the particle would reach the Spring. Rather, as illustrated by Figure 11.1 to 11.5 in the Appendix, the pressure head in the groundwater has an immediate affect on Springflow.   Figure 27.1 and 27.2 illustrate a decreasing trend for Rock Springs discharge over thirty-five years of about 0.3 cfs/year.

TABLE 8: Springflow Statistical Analysis

				Null Hypothesis Test for Slope of Figures 9.1 - 9.5							
FIG	n	Slope Δcfs/year	|t|	$t_{0.05}$ at (n-2)	$t_{0.025}$ at (n-2)	$t_{0.01}$ at (n-2)	$t_{0.005}$ at (n-2)	$t_{0.001}$ at (n-2)	$t_{0.0005}$ at (n-2)	Slope Significance	% Confident
9.1	248	-0.326	7.844	1.654	1.960	2.326	2.576	3.09	3.291	significant	99.9
9.2	120	-0.034	1.921	1.658	1.980	2.358	2.617	3.16	3.373	significant	90
9.3	123	0.033	0.908	1.658	1.980	2.358	2.617	3.16	3.373	insignificant	
9.4	249	-0.402	11.569	1.654	1.960	2.326	2.576	3.09	3.291	significant	99.9
9.5	124	-0.146	14.496	1.654	1.980	2.326	2.576	3.09	3.291	significant	99.9

* Shading indicates statistical significance
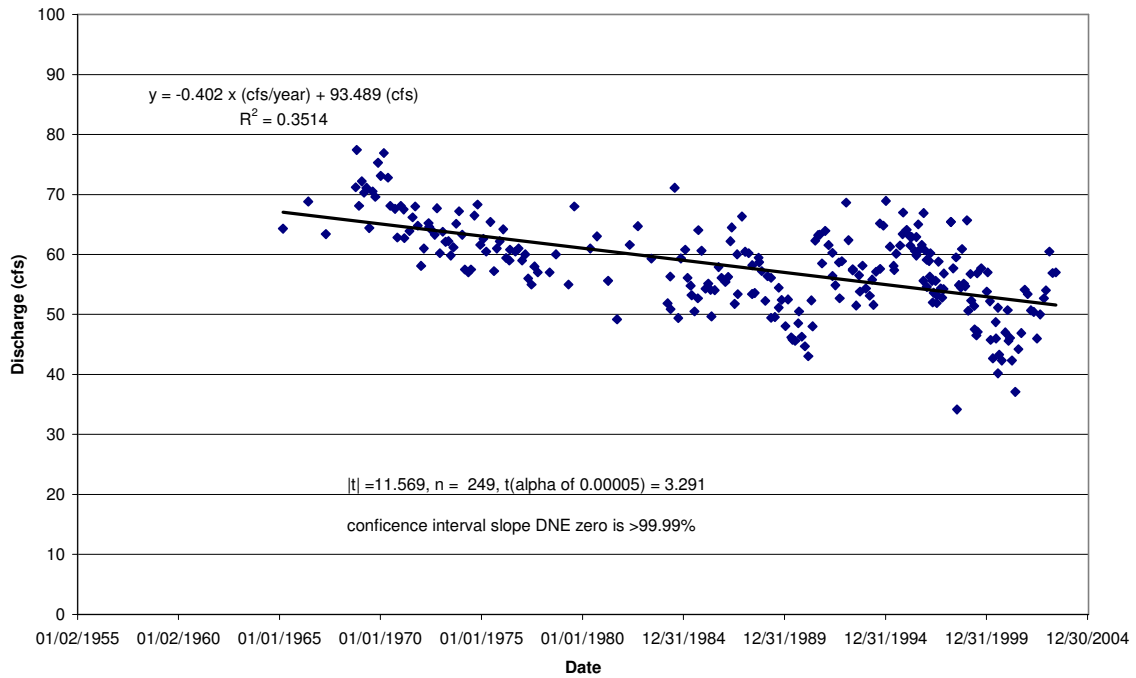
FIGURE 27.1 - Discharge versus Time for Rock Spring
Appendix, Figure 9.4 (Source of data: St. John's River Water Management District)
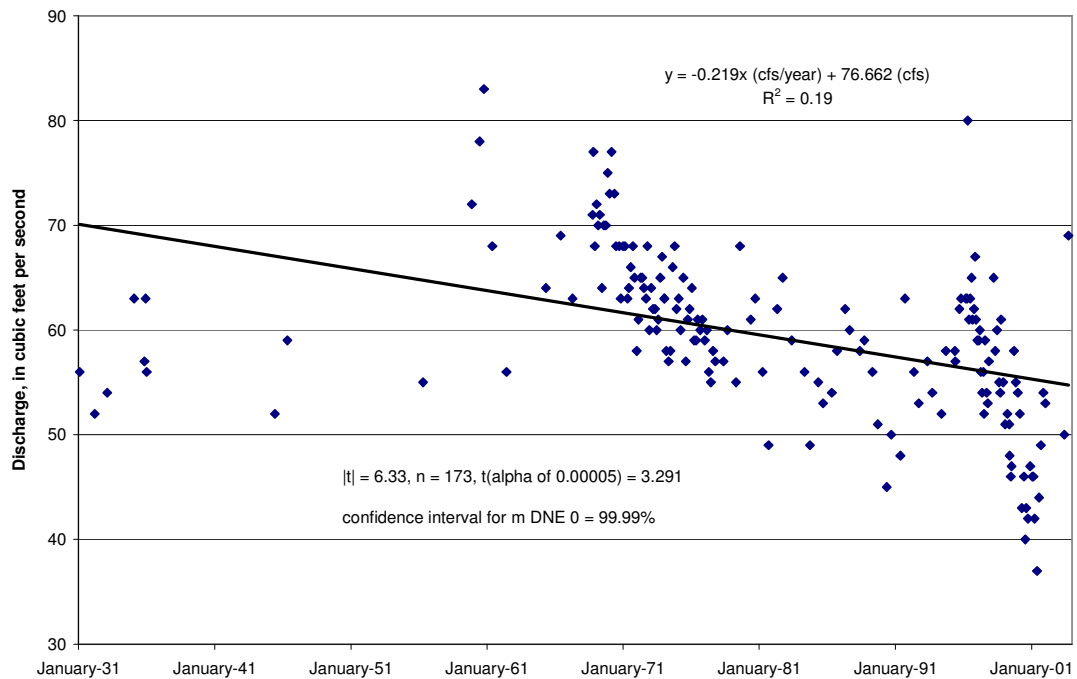
FIGURE 27.2 - Discharge versus Time for Rock Spring
(Source of Data: US Geologocal Survey)

Figure 27.1 and 27.2 were constructed with the use of data from the St. John's River Water Management District and the US Geological Survey, respectively. Although, the data for Figure 27.1 provides 76 more data points, the data for Figure 27.1 dates back to 1931. Both slopes are significant (99.99% confident) and both Figures indicate Rock Springs discharge is decreasing. Table 9 illustrates a comparison of two different data sources of Wekiva, Rock, and Sanlando Springflow.

TABLE 9: Comparison of Sources of Springflow Data

		n	Data Range	slope (cfs/year)	|t|	% confidence of slope
St. John's River WMD	Wekiva	248	1968-2003	-0.326	7.84	99.99
	Rock	249	1965-2003	-0.402	11.57	99.99
	Sanlando	123	1972-2003	0.033	0.91	insignificant slope
USGS	Wekiva	161	1932-2003	-0.265	6.89	99.99
	Rock	173	1931-2003	-0.219	6.33	99.99
	Sanlando	116	1941-2003	0.05	1.31	90.00

Both sources provide similar results with slopes varying by about 0.1 cfs/year. Sanlando Springs discharge is either constant or slightly increasing depending on the source.

The declining trend in Springflow could be caused by declining precipitation if precipitation has changed dramatically during the period of record for the annual Springflows and annual Streamflows, which is roughly from 1967 to 2001. Figure 14.1 to 14.5 in the Appendix illustrate the annual difference from the average precipitation for each of the four gauging stations. Figure 28 illustrates the difference from the average precipitation over time for Orlando International Airport gauging station.
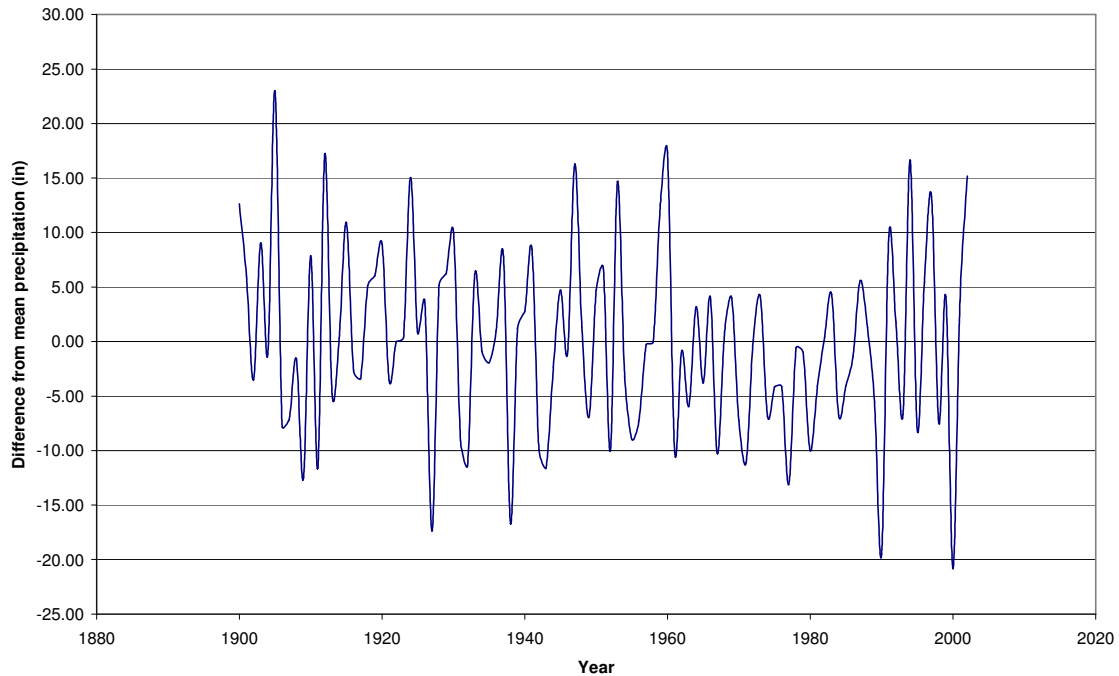
FIGURE 28 - Orlando Annual Precipitation Difference from average of 51.21 in with a standard deviation of 8.68.
Appendix, Figure 14.2

Naturally, there is 'noise' but over the period of record, the annual precipitation fluctuates around the average with a relatively consistent standard deviation among the four gauging stations. Because there have been no significant impacts on the Florida climate, annual precipitation can be considered an independent random event, so approximately 68% of the annual precipitations will fall within one standard deviation from the average and approximately 95% of the annual precipitations will fall within two standard deviations from the average. The standard deviations for Clermont, Orlando, Sanford, and Lisbon are 8.48, 8.68, 9.99, and 8.83 respectively. The standard deviation of around 9.0 inches is an indicator that the annual precipitation in the Wekiva area has fluctuated close to the average precipitation of 50.05 (Mendenhall, 1995).

Water travels through the soil; therefore the analogy can be made where the spring recharge area (springshed) is like a water tank in which water would flow over a

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period of time to travel from the surface to the bottom outlet, the spring. A springflow

decrease could be caused by a decrease in precipitation or a decrease in groundwater

level. Figures 29.1 to 29.3 depict three possible scenarios: one year with a precipitation

below the average, many years with precipitations below the average, and average

precipitation with impervious area and well extraction over the spring recharge area.

Less than average Precipitation for one year

Springflow

Less than average Precipitation for one year causes a relatively minor springflow decrease.

FIGURE 29.1 – Case 1

Less than average Precipitation for many years

Springflow

Less than average Precipitation for many years causes a springflow decrease.

FIGURE 29.2 – Case 2

Average Precipitation

Loss

Directly Connected Impervious Area

Well Extraction

Springflow

Impervious Areas and Well Extractions causes major Springflow decrease.

FIGURE 29.3 – Case 3

FIGURE 29 – STREAMFLOWSHED SCHEMATICS

For a year with below average precipitation, the springflow is expected to decrease minimally. However, if there are many consecutive years with lower than average rainfalls, the springflow decreases. Third, less infiltration into the ground and more well extraction will also cause a decrease in springflow. Figure 30 is constructed by calculating the average precipitation of the four gauging stations and calculating the difference from the mean precipitation of the four stations, which turns out to be 50.05 inches/year. The *cumulative* difference about 50.05 inches is plotted: each year the difference is added to the running difference.
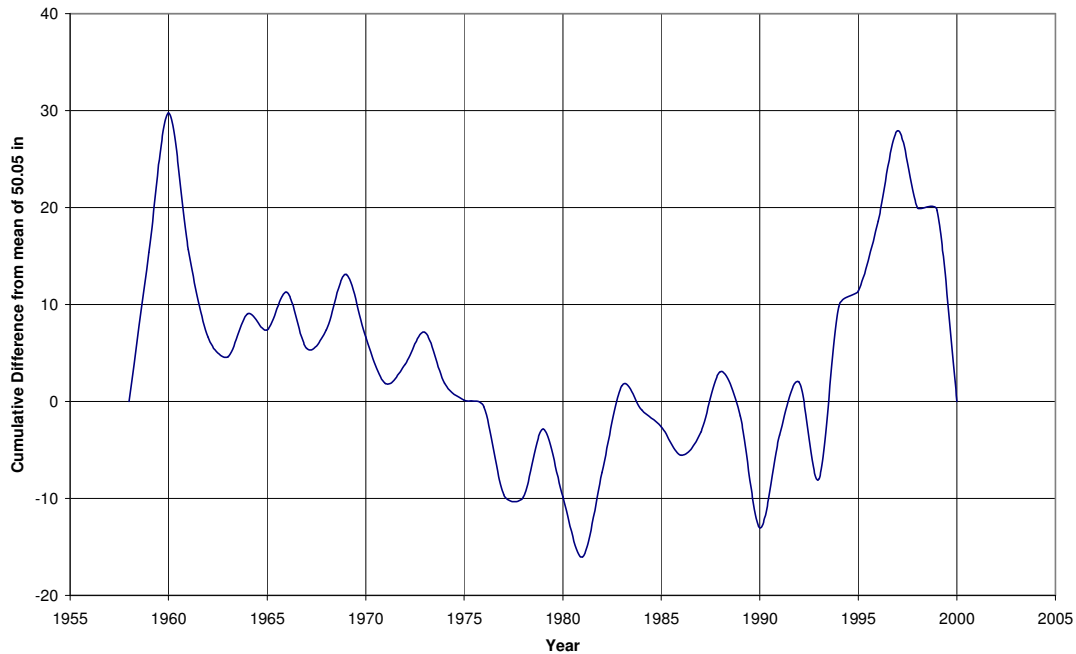
FIGURE 30 - Cumulative Annual Precipitation Difference about 50.05 in
(average of Clermont, Orlando, Sanford, Lisbon) with a standard deviation of 10.43.
Appendix, Figure 14.6

Basically Figure 30 is a depiction of the water level in the "tank" which is compared to the springshed. Figure 30 illustrates that the "tank" water elevation is mostly above average but there is a cumulative decrease in the "tank" water elevation (Case 2) from about 1968 to 1982; there is a cumulative increase in the "tank" water

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elevation from about 1982 to 1999. The following four Figures illustrate a comparison of

Figure 30 to the Springflow versus Time graphs for Wekiva and Rock Springs. The

Springflows during the 1970s and from 1990 to 1997 were sharply decreasing and

slightly increasing, respectively.
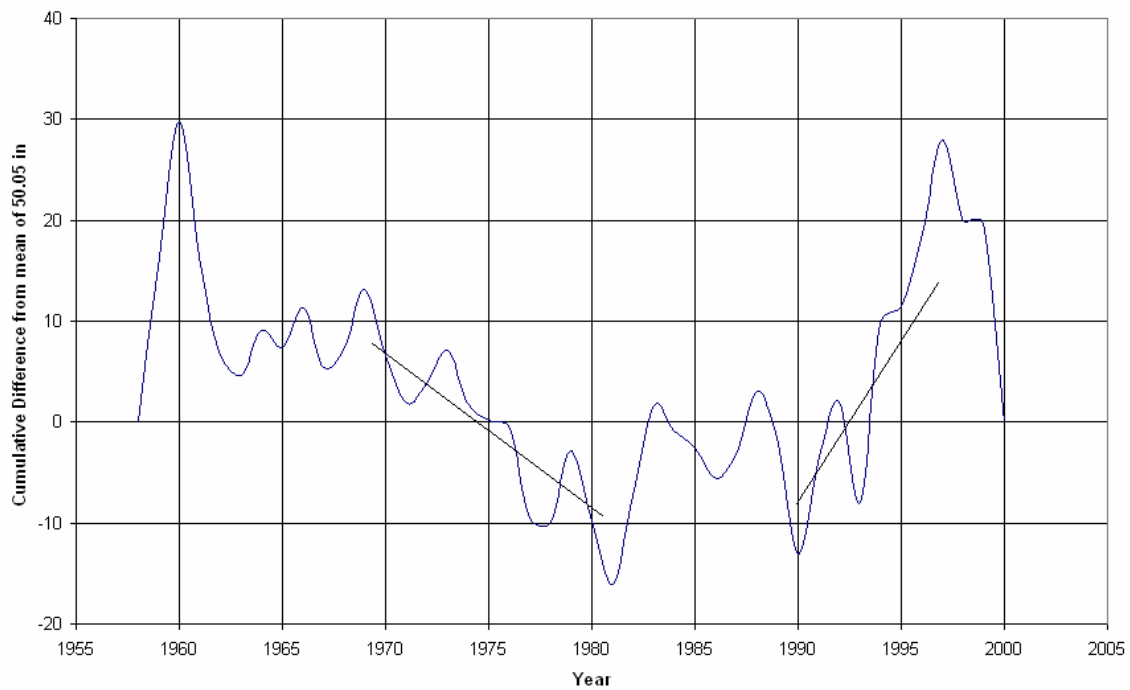
FIGURE 30 - Cumulative Annual Precipitation Difference about 50.05 in
(average of Clermont, Orlando, Sanford, Lisbon) with a standard deviation of 10.43.
Appendix, Figure 14.6
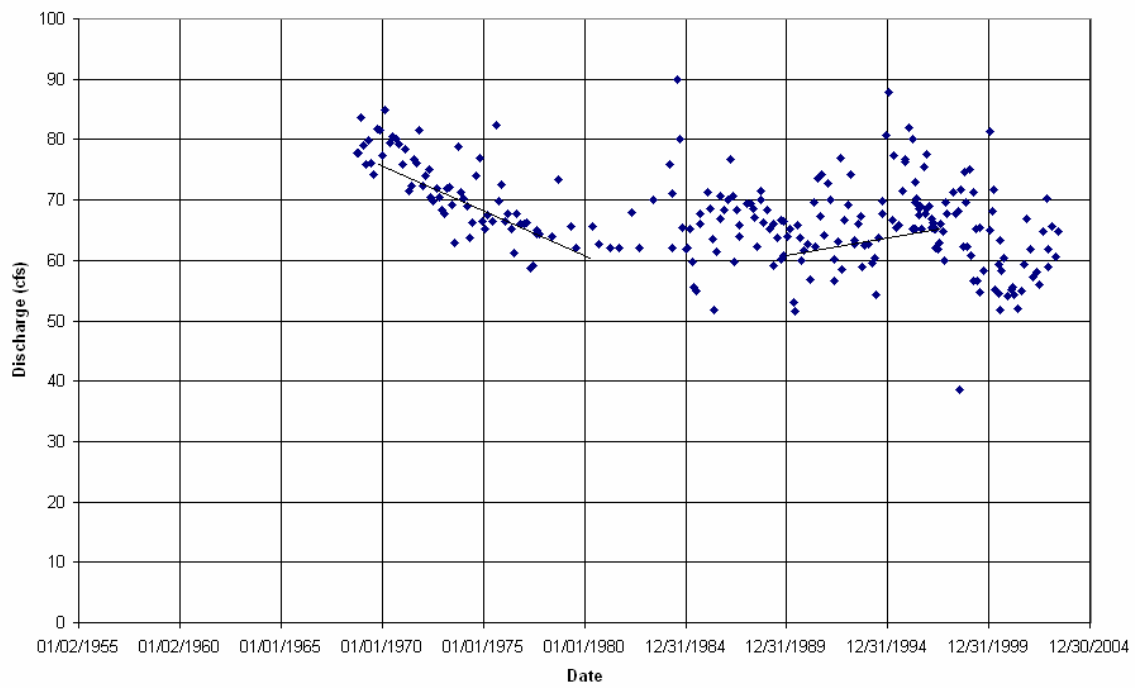
FIGURE 31 - Discharge versus Time for Wekiva Springs
Appendix, Figure 9.1
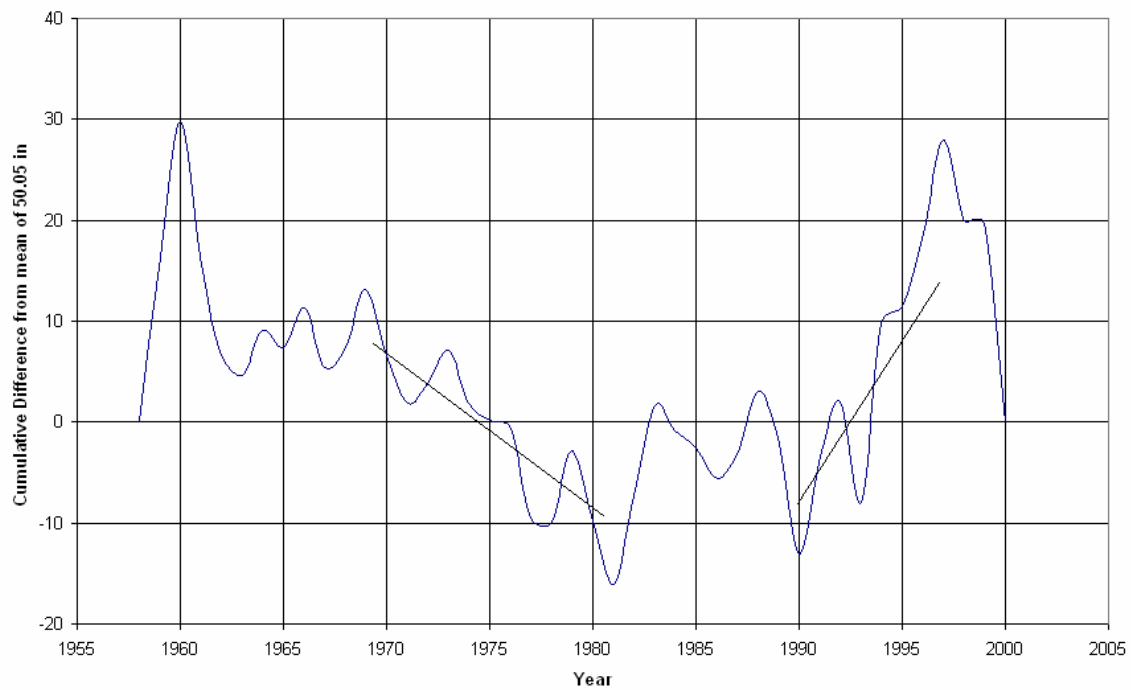
73

FIGURE 30 - Cumulative Annual Precipitation Difference about 50.05 in
(average of Clermont, Orlando, Sanford, Lisbon) with a standard deviation of 10.43.
Appendix, Figure 14.6
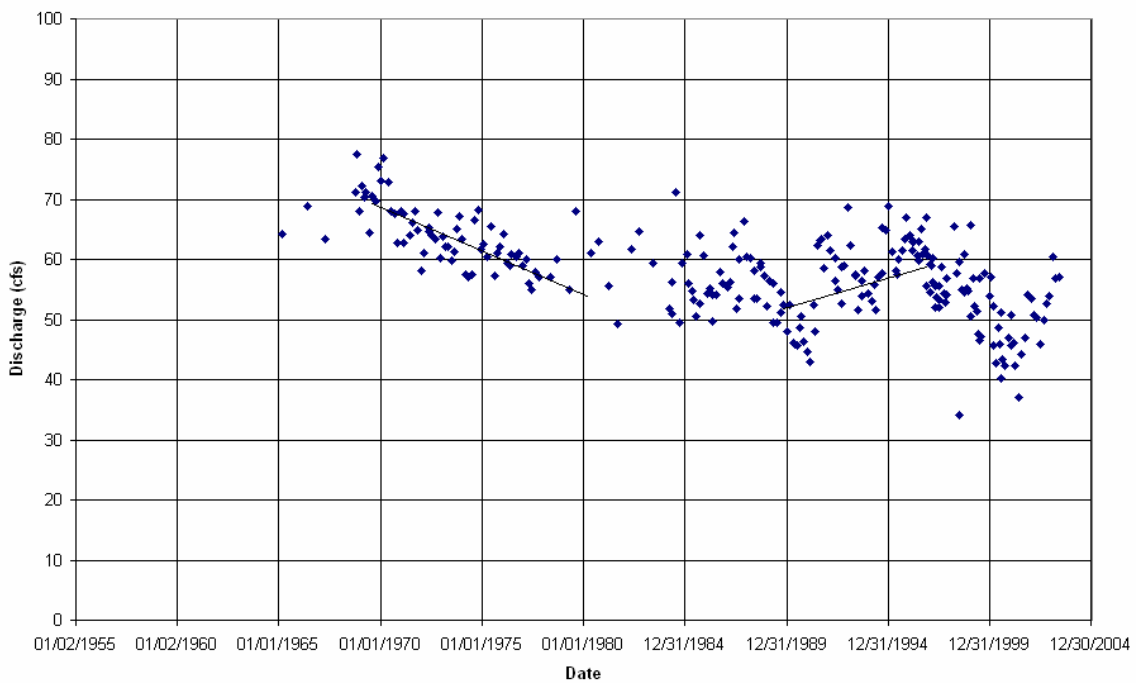
FIGURE 32 - Discharge versus Time for Rock Spring
Appendix, Figure 9.4

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From the comparisons between cumulative precipitation difference and the Wekiva and Rock Springflows it can be concluded that there is a relationship between cumulative precipitation in the Wekiva Springshed and Wekiva and Rock Springflow. From Figures 14.1 to 14.5 in the Appendix can be seen that the precipitations for all gauging stations vary around the average. From the comparisons of Figure 30 with Figures 31 and 32, it can be seen that there is a relationship between cumulative precipitation with Wekiva and Rock Springflow. The decrease in Springflow *cannot* be explained by only a change in precipitation or any change in cumulative precipitation. Rather, the decrease in Springflow is most likely due to a decrease of water in the aquifer and an increase in aquifer water extraction for municipal and agricultural use over the Spring recharge area as well as precipitation decreases. Thus, other factors influence Springflow.

6.1 - SPRINGSHED WATER BUDGETS

In February of 2003, the US EPA published *Protecting Water Quality from Urban Runoff*, which compares developed areas with non-developed areas. This comparison used a water budget approach and concluded that after a watershed is developed, evapotranspiration and infiltration decrease while runoff increases. This water budget approach supports the water budget approach of this report. However, the water budget for the Wekiva Florida Springshed is unique due to local flora and a subtropical climate.

First consider an annual water budget for a watershed which is 100 % impervious, as shown in schematic form in Figure 33. The precipitation is rounded to an average of 50 inches as calculated using data from the four gauging stations in the Wekiva area.
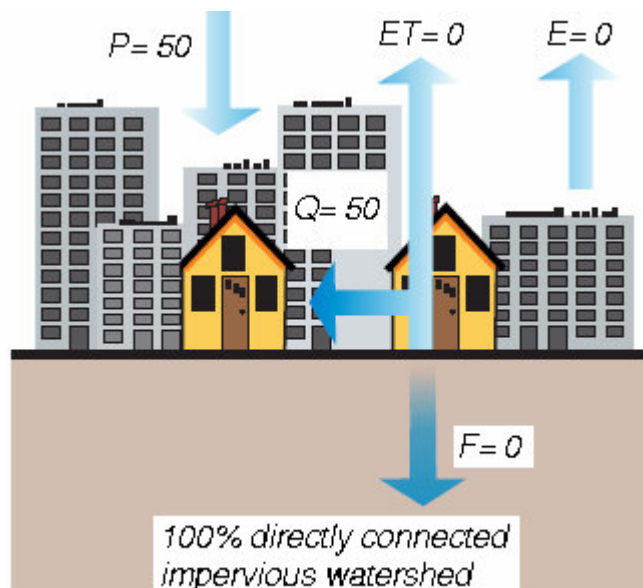
FIGURE 33 – Wekiva Springshed Schematic for 100% Impervious Cover.
Picture Source: from US EPA, 2003.

Where P is Precipitation, F is Infiltration, Q is Precipitation Runoff, ET is Evapotranspiration, and E is Evaporation. There will be some evaporation from

depressions on impervious areas (as much as 4 inches/year in the Wekiva area), but generally precipitation would result in Runoff. All the numbers in the mass balance in Figure 33 are in inches per year.

In Figure 34, an illustration for a typical yearly water budget for a closed basin in the Wekiva Springshed is shown with no impervious area and no water bodies. The evapotranspiration rate assumes a densely vegetated area with a high water table. For lower water table areas and less vegetation, an estimate of 36 inches per year is used. Pasture lands and some "cleared" areas also have less vegetation, which results in an evapotranspiration of less than 40 inches per year.
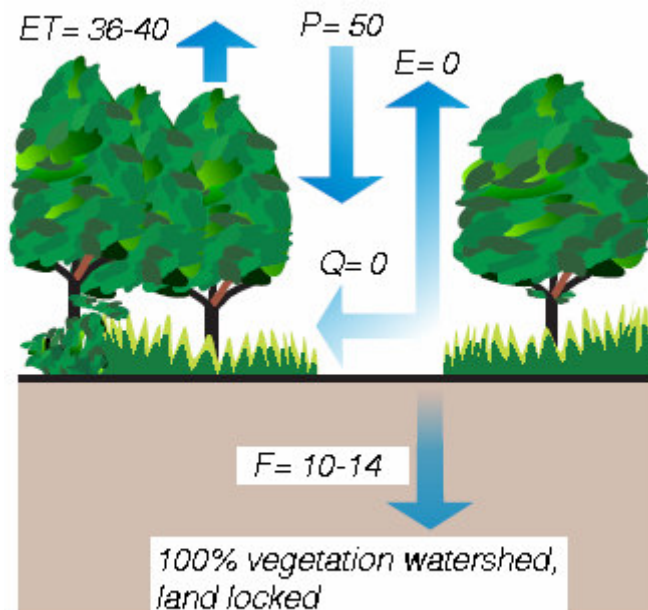
FIGURE 34 – Wekiva Springshed Schematic for a Land Locked Area of 100% Vegetation Cover. Picture Source: US EPA, 2003.

For a 100 % densely vegetative watershed, approximately 10 to 14 inches of rainfall will infiltrate into the ground during an average rainfall year (Figure 34).

An annual water budget for a land locked area with a lake in the Wekiva area results in an infiltration volume of 6 inches for the average year and this assumes 44 inches will evaporate from the lake (Figure 35).
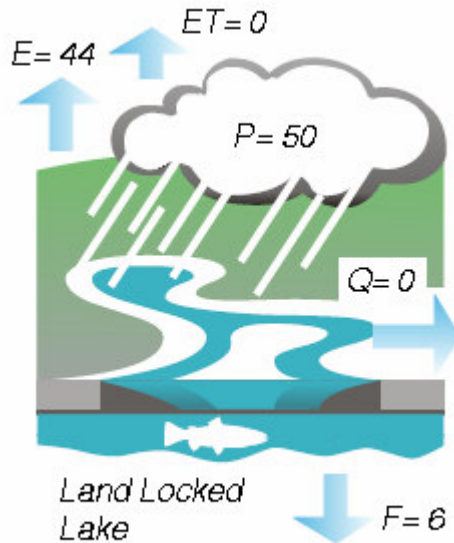
FIGURE 35 – Wekiva Springshed Schematic for Land Locked Lake
        Picture Source: US EPA, 2003.

Figures 34 and 35 illustrate that the infiltration rates (difference between rainfall and evapotranspiration) for water bodies and vegetative areas in the Wekiva Springshed are 6 to 10 inches per year, respectively. However, within the Springshed, there are areas which have no water bodies, and have less evapotranspiration because of a lower water table or sparsely vegetated areas. Thus the recharge rates for undeveloped areas in the Wekiva Springshed area most likely in excess of 10 inches per year.

FIGURE 36 – Aerial photograph of Wekiva Springs

As illustrated by Figure 36, some of the Wekiva Springshed is developed and can be represented as a combination of the water balances illustrated in Figures 33, 34, and 35. Figure 37 is a schematic for the developed areas in the Wekiva Springshed, assuming 20% directly connected impervious area, 60% dense vegetation, and 20% water surfaces. The hydrologic parameters assumed yearly rates are E_L = lake evaporation at 44 inches, ET = vegetation area at 40 inches, and E_D = Depression storage on impervious surfaces assumed as part of runoff. The mass balance calculation for a 100 acre area is:

Rainfall – Runoff – Evapotranspiration –Evaporation – Infiltration = 0

or: 50 (100) – 50 (20) – 40 (60) – 44 (20) – F(60) = 0

and: F = 12 inches from 60 acres, or 7.2 acres for the 100 acres.
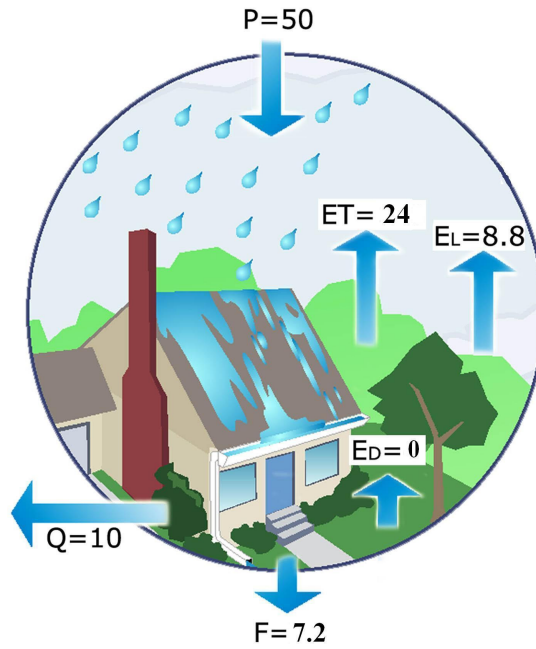
FIGURE 37 – Wekiva Springshed Schematic for 20% Directly Connected Impervious Area (DCIA), 60% Vegetation, and 20% Water Surfaces, and yearly rates based on total area. Picture Source: US EPA, 2003.

As illustrated in Figure 37, development of only 20% DCIA on the Wekiva Springshed without stormwater management will result in less infiltration into the ground (7.2 inches versus 10 inches), resulting in a decrease in Springflow in the Wekiva Springs Area. Some of the precipitation is lost due to runoff, or 10 inches. To balance the water budget, the post runoff volume must equal or be less than the pre runoff volume. It is possible to convert this post runoff into infiltration by stormwater management practices. Additionally, if the DCIA were 40% of the total area, the recharge would be only 5.2 inches, and the runoff volume would be 20 inches.

From aerial photos of the Springshed approximately 40% of the Springshed is developed.   Using the infiltration values of 7.2 in/yr for developed areas, 10 in/yr for the vegetative areas, and 6 in/yr for water bodies, and assuming 40% development, 15%

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water surfaces, and 45% vegetation, the Springflow for the present Springshed surface

conditions is calculated to be about 8.3 inches per year.

$$0.40 (7.2) + 0.45 (10) + 0.15 (6) = 8.3 \text{ inches/year}$$

Another estimate of the developed area is 50% with 15% water area, resulting in an

estimated recharge of 8.0 inches year and for a 20% DCIA, an uncontrolled discharge of

10 inches per year. These are water budget estimates for Springflow, taking into account

the present Wekiva Springshed surface conditions, including natural lake areas,

undeveloped vegetative areas, and developed areas.

Next, these watershed budget estimates are compared to actual Springflow. As

previously stated, the Springshed area identified by the WASH123D model is

approximately 450 square miles. The measured Springs discharge for the 450 square

mile Springshed area is shown in Table 10.   These estimates are for only those Springs

which are gauged. It is recognized that there exist other Springs that are not measured.

TABLE 10 – Mean Discharge for Major Springs in the WASH123D Estimated Springshed Area.

County	Spring	Mean Discharge (cfs)*	period
Orange	Barrel	0.26	1995-1997
	Rock	59.3	1932-2000
	Witherington	2.28	1972-1995
	Wekiva	68.51	1932-2000
Lake	Messant	14.7	1946-1995
	Seminole	35.3	1931-1995
Seminole	Island	6.4	1982-1997
	Miami	4.93	1945-2000
	Palm	7.17	1941-2000
	Sanlando	19.82	1941-2000
	Starbuck	14.5	1944-2000
Total		233.17	

*Source of Mean Discharge Data: St. John's River Water Management District

Thus an estimated depth of water over the Springshed for one year is calculated as

$$\left(\frac{233.17\,ft^\wedge 3}{\sec}\right)\left(\frac{1}{450mi^\wedge 2}\right)\left(\frac{mi^\wedge 2}{5280^\wedge 2\,ft^\wedge 2}\right)\left(\frac{86400*365\sec}{year}\right)\left(\frac{12in}{ft}\right)=7.0\ \text{in}$$

The volume of Springflow over the Springshed is *at least* 7 inches per year. Based on 7 inches of water released from the Springs, the volume of water in an average year is 54.6 billion gallons per year. One inch reduction in infiltration results in a decrease of 7.8 billion gallons per year.

$$(7in)(450mi^\wedge 2)\left(\frac{640acre}{mi^\wedge 2}\right)\left(\frac{ft}{12in}\right)\left(\frac{0.325MG}{acre-ft}\right)=54.6\ \text{Billion Gallons per year}$$

$$(1in)(450mi^\wedge 2)\left(\frac{640acre}{mi^\wedge 2}\right)\left(\frac{ft}{12in}\right)\left(\frac{0.325MG}{acre-ft}\right)=7.8\ \text{Billion Gallons per year}$$

The average annual precipitation in the Wekiva Springshed is estimated at 50 inches and as seen before from Figure 25, the Springs are recharged by the groundwater aquifer. The calculated 7.0 inches based on measured Springflow compares reasonably well with the estimated 8.3 inches based on water budgets and existing conditions. These facts emphasize the validity of the water budget assumptions for a developed Springshed as shown in Figure 37 as well as predict that the Springflow would decrease to below 7.0 inches per year over the Springshed area if the Springshed is further developed without consideration of groundwater recharge and surface discharge controls. Stormwater management for infiltration and reduction of runoff is an option to retain present Springflows.

6.2 - SPRINGFLOW DECREASE CONCLUSION

Based on the Springflow discharge data, there is more than a 99.9 percent confidence level that the Springflow of Wekiva, Rock, and Palm Springs are decreasing, and a 90 percent confidence level that the Springflow of Starbuck Spring is decreasing. Sanlando Spring has maintained a relatively constant Springflow.

The decrease in Springflow can be explained by a decrease in precipitation, less infiltration due to impervious areas in the Springshed, and increased well water extraction form the groundwater in and around the Wekiva Springshed. If the Springshed is further developed without consideration of recharge volume control, the measured Springflow will decrease below 7 inches per year. In addition, a water budget for the area indicates that increased impervious areas will decrease the volume of infiltration and increase the volume of runoff. Stormwater management to increase infiltration volume and decrease runoff volume will help maintain springflow and reduce runoff flow volume with the associated pollutants.

CHAPTER 7 - SUMMARY, FINDINGS OF FACT & RECOMMENDATIONS

7.1 - SUMMARY

Development pressure in the Wekiva Watershed and Springshed may cause changes in the water quantity and quality of both the Springs and the River. Presented in this report are the results from hydrologic data analysis that were used to document River flow, Springflow, groundwater, and Watershed conditions. Used for the analyses were five Spring discharge gauging stations, four rain gauging stations, twenty-six stream gauging stations, and seven wells located in the Wekiva Springshed.

Average annual discharge for Starbuck, Sanlando, Rock, Palm, and Wekiva Springs and average annual Streamflow for Wekiva and Little Wekiva Rivers were compared to annual precipitation data of Lisbon, Sanford, Orlando, and Clermont rain gauging stations as well as the average of the four rain gauging stations. Each comparison was plotted, thus allowing a trend line and coefficient of determination to illustrate any relationship between precipitation and Spring discharge or precipitation and Streamflow. A statistical analysis (null hypothesis test) using the data from each comparison was performed to test the hypothesis that each trend line slope was zero. Taking into account the amount of data available and the standard deviation, the percent confidence of each statistical test was calculated; any result with less than 90% confidence was considered to be insignificant or the trend line was equal to zero.

For each of the twenty-six gauging stations, the unit flow (cfs/mi^2 or inches) was calculated and plotted versus time. The area around each river was classified as either

'affected' or 'unaffected', referring to development in the Watershed. The unit flow of each river was compared to watershed development, recharge characteristics, and the presence of Springs. For each unit flow, a statistical analysis was performed indicating with a certain confidence interval of whether or not the slope of the trend line was zero.

Springflow was also compared to the piezometric head from seven wells in the Wekiva area. For each of the five Springs, Spring discharge versus time was plotted along with the seven well elevations versus time to illustrate any relationship. Moreover, the cumulative Spring discharge versus cumulative well elevation (average of the seven wells) was plotted to illustrate any consistent relationship between Spring discharge in the Wekiva area and the surrounding groundwater level.

The discharge of Sanlando, Starbuck, Rock, Palm, and Wekiva Springs was plotted versus time; a trend line was added to illustrate any trend in Springflow, which was concluded with a certain confidence interval from a statistical analysis. The cumulative precipitation difference around the average was plotted and compared to Wekiva and Rock Springs discharge. Water budgets were calculated for different Springshed surface conditions. Any trend in Springflow was analyzed and explained by the cumulative precipitation trends or the Springshed surface conditions. Furthermore, the percentage of Wekiva River flow that originates from Springflow was calculated

A first principle, physics-based watershed model WASH123D was applied to conduct the groundwater analysis for Wekiva Basin. The approximately 10,000 square mile region of study was centered upon Seminole and Orange counties but included most of Brevard, Lake, and Osceola counties plus parts of Marion, Polk, and Volusia counties. Numerically, the modeling domain was discretized into 437,576 Triangular Prism

Elements connected at 249,057 nodes and eight numerical layers were included in the simulation. There were 5,097 wells used in the simulation, other model inputs included assignation of boundary conditions, flow conditions, and geologic properties of each numerical layer.

The Wekiva WASH123D model was "built' and run to evaluate the average, steady state 1995 hydrological conditions. The distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows agreement with the field observations at corresponding locations. In addition, the simulated 1995 water levels mimic the topography on a regional scale. The Springshed area was estimated using this model as approximately 450 square miles.

From average annual Springflow data and the Springshed area, the cumulative flow from the measured Springs was estimated as at least 7.0 inches per year. Not all Spring flows were measured, thus the cumulative Spring flows may be higher. This was compared to an annual water budget method, which estimated around 8 inches per year infiltrating into the ground.

An annual water budget was used to illustrate calculations for land areas within the Springshed. There are sufficient data for the calculations. The water budget was shown to be useful as a method to quantify pre and post development water budgets that estimate the infiltration and rainfall excess (runoff). Stormwater management using regional irrigation ponds or infiltration areas (retention ponds, swales, bio-retention, green roofs and others) was suggested to maintain the balance.

7.2 - FINDINGS OF FACT

1.   Springflow to the Wekiva River is decreasing.

2.   Springflow is affected by the groundwater level in the Wekiva Springshed.

3.   The groundwater level is affected by precipitation, well extraction, and directly connected impervious areas of development.

4.   At least 58 percent of Wekiva River flow originates from the Springs.

5.   Wekiva River flow has remained relatively constant over the past sixty years and Little Wekiva River flow has decreased over the past thirty years.

6.   The Springshed area for the Springs is approximately 450 square miles.

7.   Over half of Lake Apopka provides a source of recharge to the Springs.

8.   The Wekiva study area is approximately 60 percent of the estimated Springshed area of 450 square miles.

9.   Approximately 60 to 65 percent of the estimated Springshed area of 450 square miles is estimated to have a recharge rate equal to or exceeding 8 in/year.

10.   The 450 square miles contributes at least 7 inches of Springflow during the average year.

11.   For Rock Springs, approximately 70 percent of the discharge comes from a springshed within an 8 mile radius of the Spring. In addition, 95 percent of the discharge comes from a springshed within a 14 mile radius of the Spring.

12.   The Volume of water percolating into the aquifer from rainfall affects the pressure head and storage volume which in turn affects Springflow.

13. Urbanization of 20 percent of the Rock Springs Springshed area with no replacement of infiltration (no stormwater management) causes approximately 10 to 15 percent decrease in the discharge at Rock Springs. Discharge at Springs adjacent to Rock Springs also decreases.

14. A post equal pre yearly volume water budget is an approach for maintaining post equal pre infiltration and discharge volumes.

15. Stormwater Management using regional irrigation ponds near the Parkway and operation by local utilities is an option to maintain the balance.

7.3 - RECOMMENDATIONS

Based on the data analysis and the modeling, it is recommended to maintain a water budget for the Wekiva Springshed which would result in matching pre conditions for infiltration and discharge of waters. This can be done efficiently and cost-effectively by using or controlling the runoff from precipitation through a stormwater management program. Such a program should as an objective maintain the water budget through irrigation and retention. There is an opportunity to use DOT right-of-way areas for regional irrigation ponds near the planned Parkway. The ponds can be operated as a revenue source to local interests, such as, stormwater or irrigation utilities.

The stormwater management practices can be classified as on-site and off-site practices. Some examples of on-site practices would be pervious drive-ways, pervious parking lots, parking lot bio-retention landscaping, depression areas for water storage, and cisterns for roof drains, more infiltrative soils (non-compaction building soil), green roofs, and general methods to minimize directly connected impervious areas. Some examples of off-site practices would be regional irrigation utilities, infiltration basins and

trenches, exfiltration (underground) pipes, land purchase for aquifer recharge, swales and swale blocks, and maintaining a zone of protection around sinks and Springs.

Stormwater management practices have been successfully used in the past within the Wekiva area. There exists the current practice for retention of the runoff from the first 3 inches of rainfall, and the use of "REV" curves for design of irrigation ponds have been useful to maintain pre equal post volumes of irrigation and discharge.

Also, in other areas, regional stormwater management programs were implemented. An example is the successful restoration of Staten Island's Riparian Ecology. "Through a system of 90 carefully placed BMP's, reduced flooding and improved water quality for a 12,000-ac region on the southern end of the island" (Vokral, 2003) was achieved. Another example is from construction in Springfield, Pennsylvania., where groundwater infiltration beds underneath a porous pavement parking lot allowed the capture of 100 percent of the water during a 100-year rainfall event while avoiding detentions basins and stormwater piping. (Merrill, 2003) And in the State of Florida, irrigation utilities are being operated to provide lawn and ornamental irrigation at a cost that saves money for homeowners and businesses, while protecting valuable potable water resources (Wanielista, 2003).

In conclusion, the quantity and quality of water entering the aquifer Springshed must be maintained in order to preserve Springflow quantity and quality in the Wekiva River area. Off-site and on-site stormwater management methods can be used throughout the Springshed area to maintain the pre-development water budget in post-development. Besides maintaining Wekiva Springflow, a stormwater management program which maintains a water budget also will preserve potable water sources.

APPENDIX

$y = 3.1869x + 129.76$
$R^2 = 0.2802$

Average Annual Streamflow (cfs)

Annual Precipitation (in) [Clermont, gaging station 14]
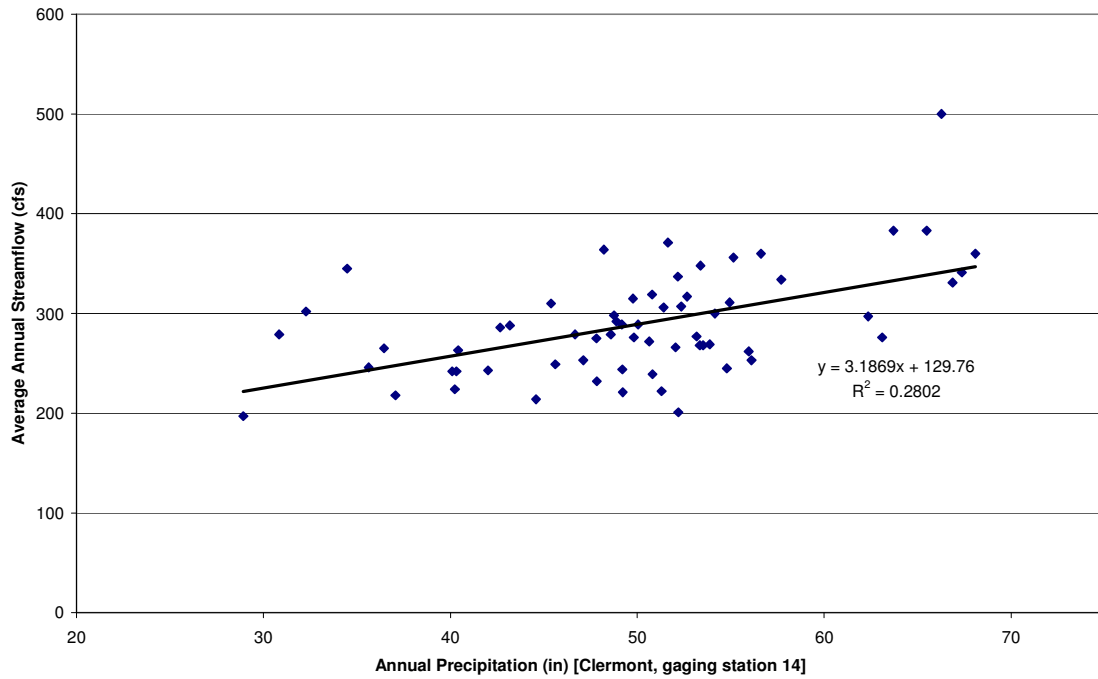
FIGURE 1.1A - Average Annual Streamflow Wekiva River Vs Precipitation [Clermont]

$y = 3.0366x + 135.98$
$R^2 = 0.2654$

Average Annual Streamflow [june 1st - june 1st] (cfs)

Water Year Precipitation, june1st - june 1st (in) [Clermont, gaging station 14]
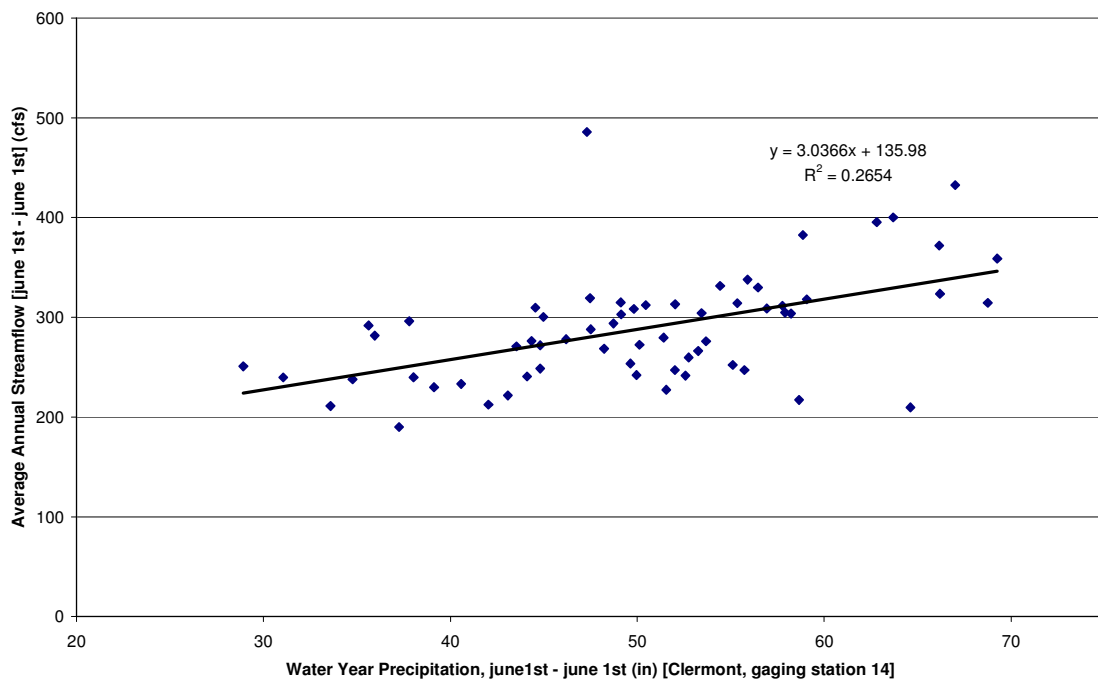
FIGURE 1.1B - Average Annual Streamflow Vs Precipitation [Clermont]

90
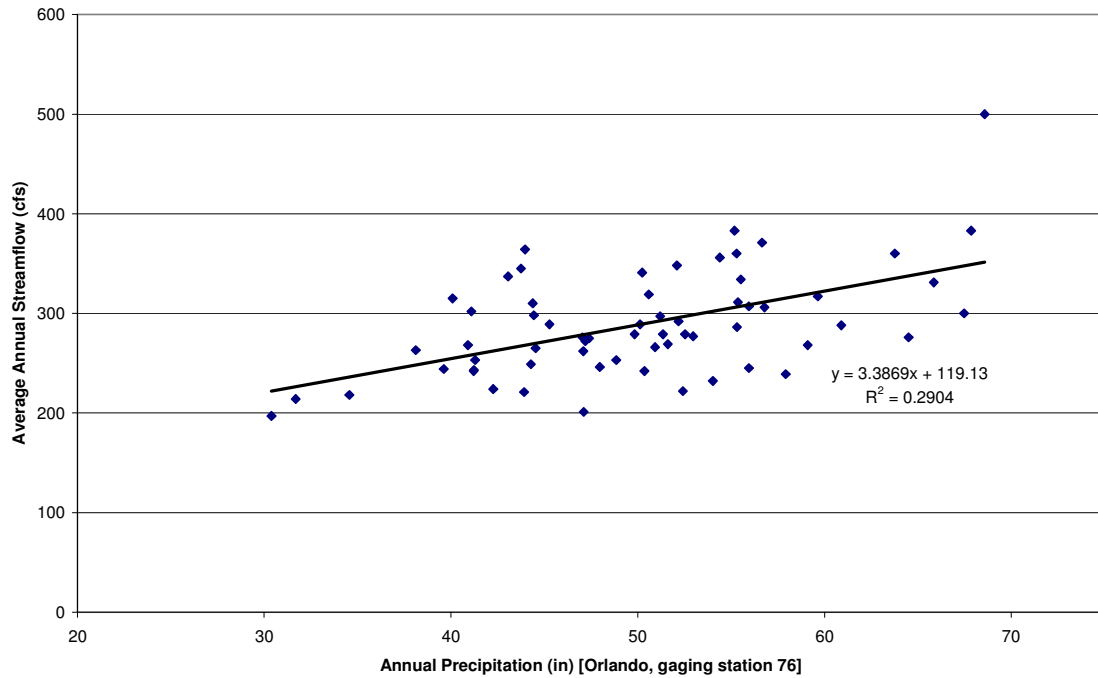
FIGURE 1.2 - Average Annual Streamflow Wekiva River Vs Precipitation [Orlando]
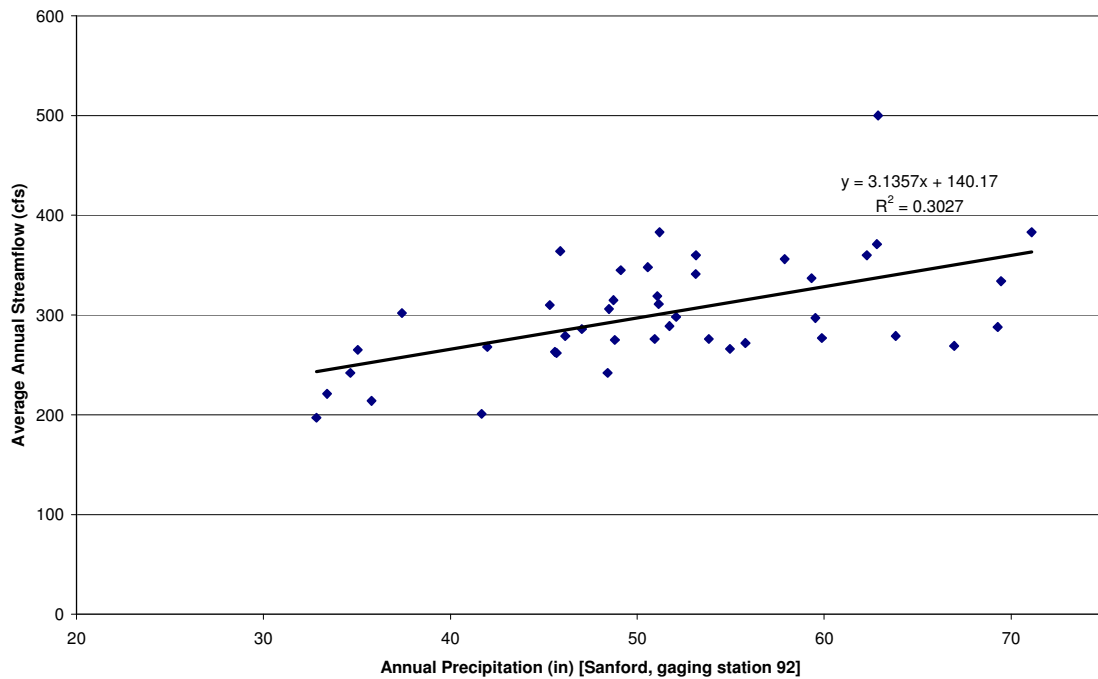
FIGURE 1.3 - Average Annual Streamflow Wekiva River Vs Precipitation (Sanford)

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$$y = 3.3075x + 143.77$$
$$R^2 = 0.2809$$
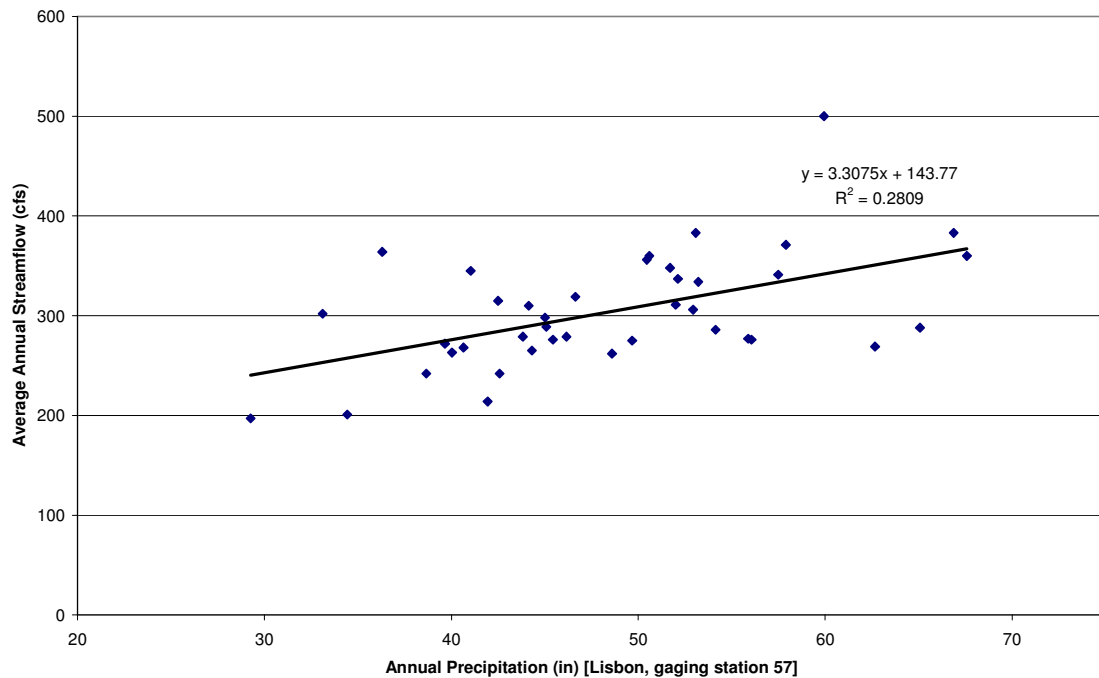
FIGURE 1.4 - Average Annual Streamflow Wekiva River Vs Precipitation (Lisbon)

$$y = 4.424x + 82.85$$
$$R^2 = 0.4013$$
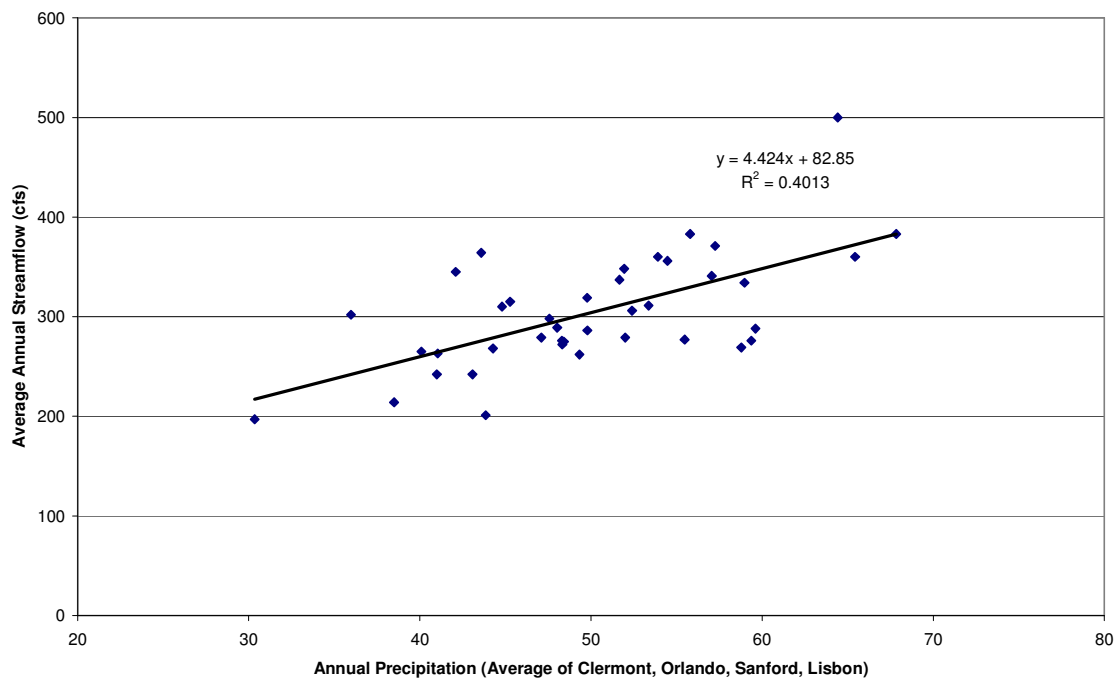
FIGURE 1.5 - Average Annual Streamflow Wekiva River Vs Average Precipitation
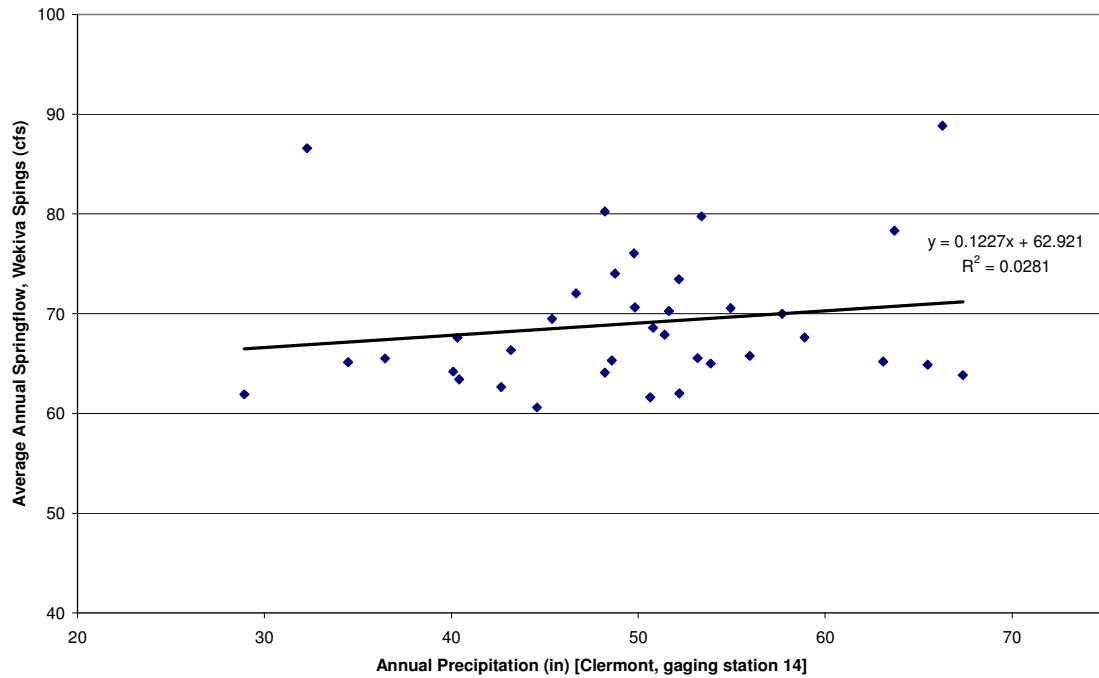
FIGURE 2.1A - Wekiva Springflow Vs. Precipitation [Clermont]
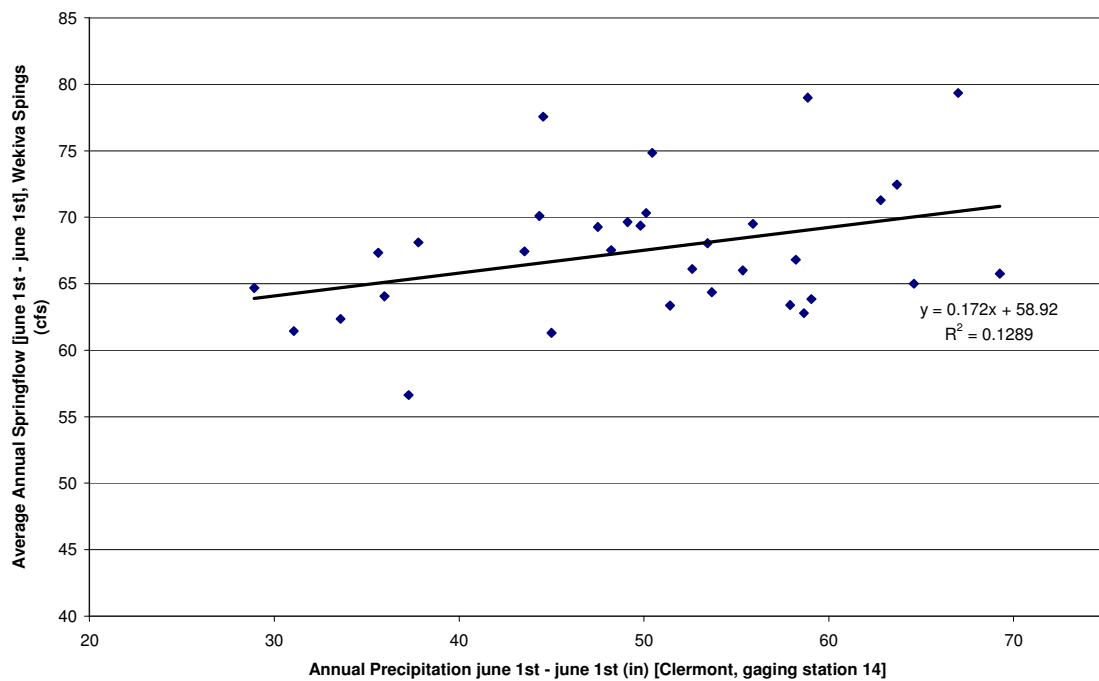
FIGURE 2.1B - Wekiva Springflow Vs. Precipitation [Clermont]
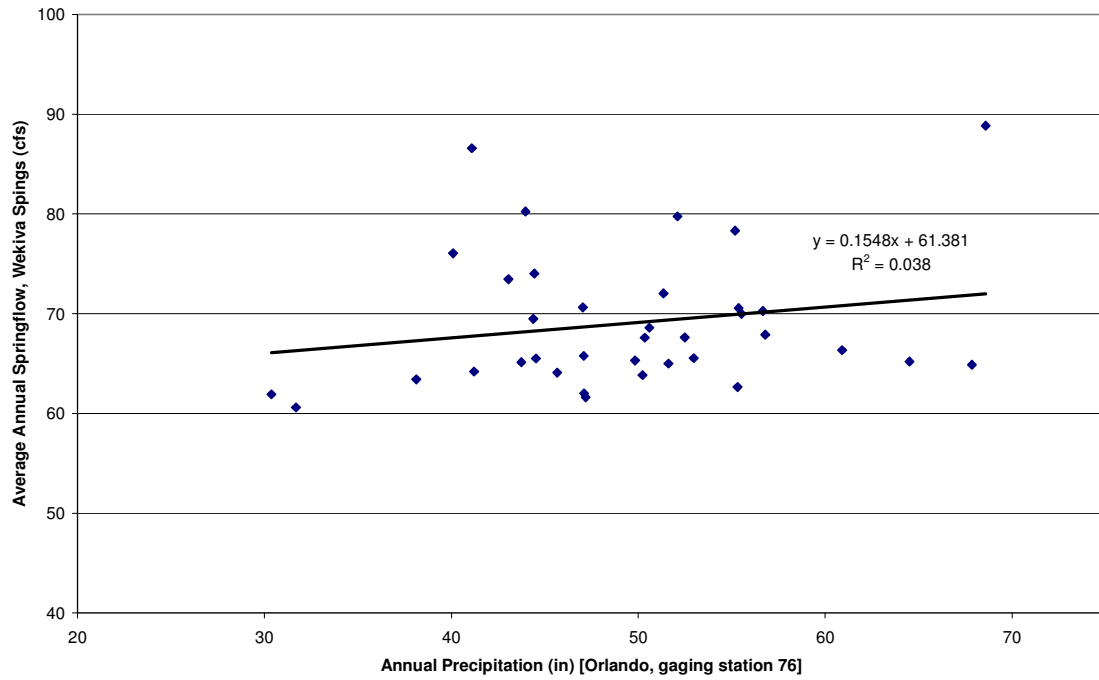
FIGURE 2.2 - Wekiva Springflow Vs. Precipitation [Orlando]
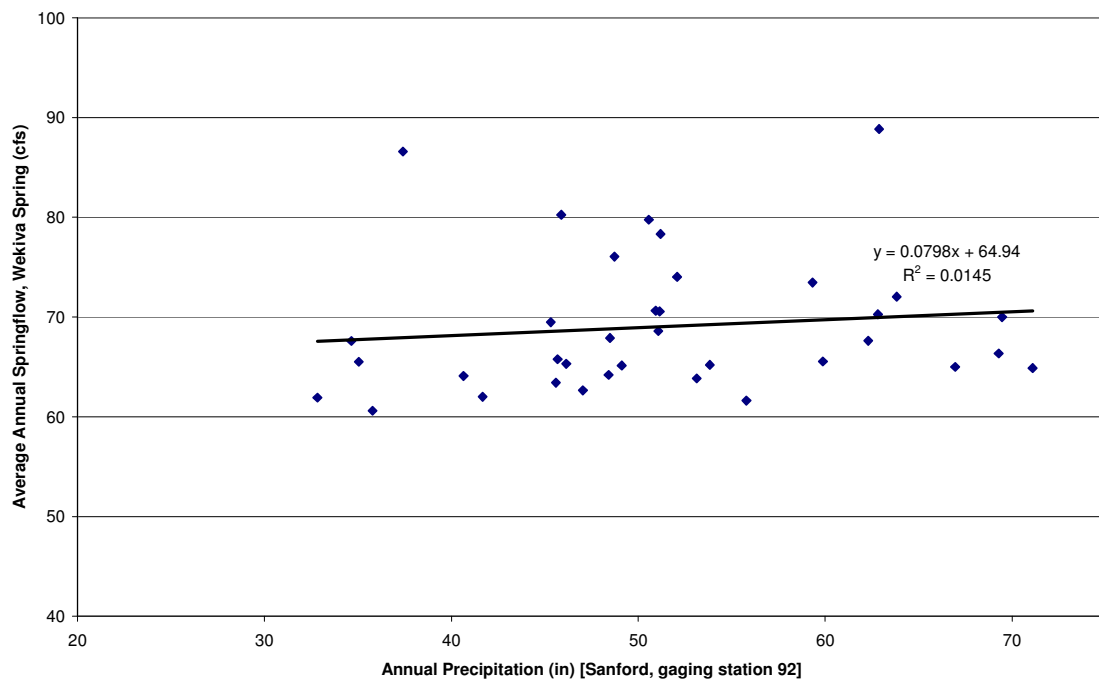
FIGURE 2.3 - Wekiva Springflow Vs Precipitation (Sanford)

94
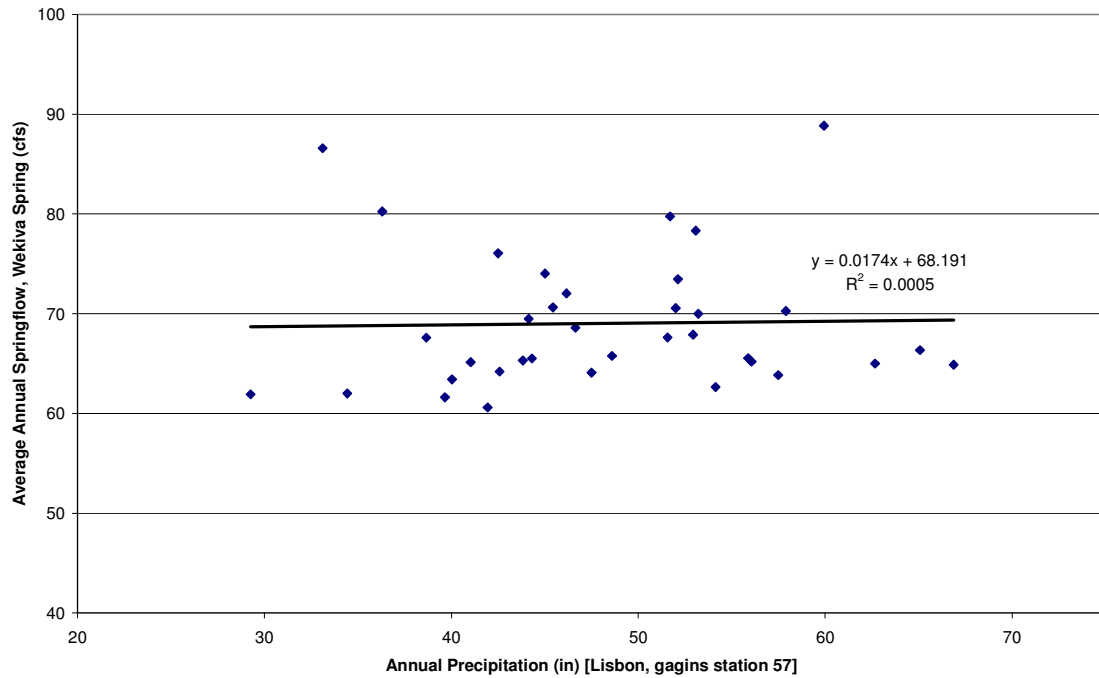
FIGURE 2.4 - Wekiva Springflow Vs Precipitation (Lisbon)
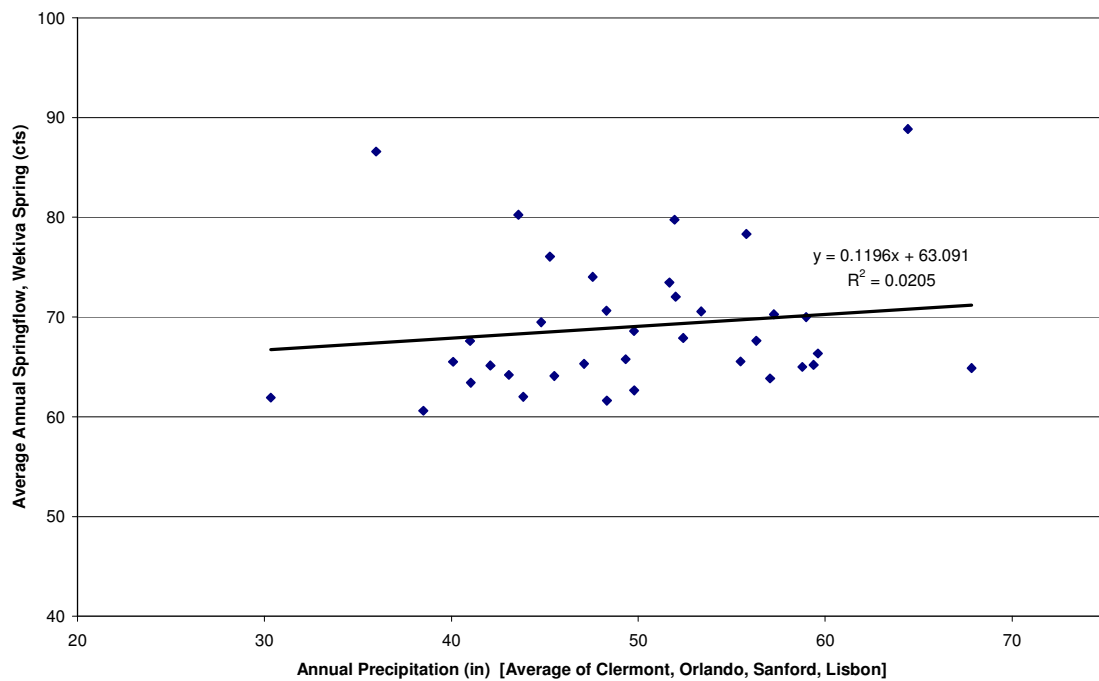
FIGURE 2.5 - Wekiva Springflow Vs. Average Precipitation

95
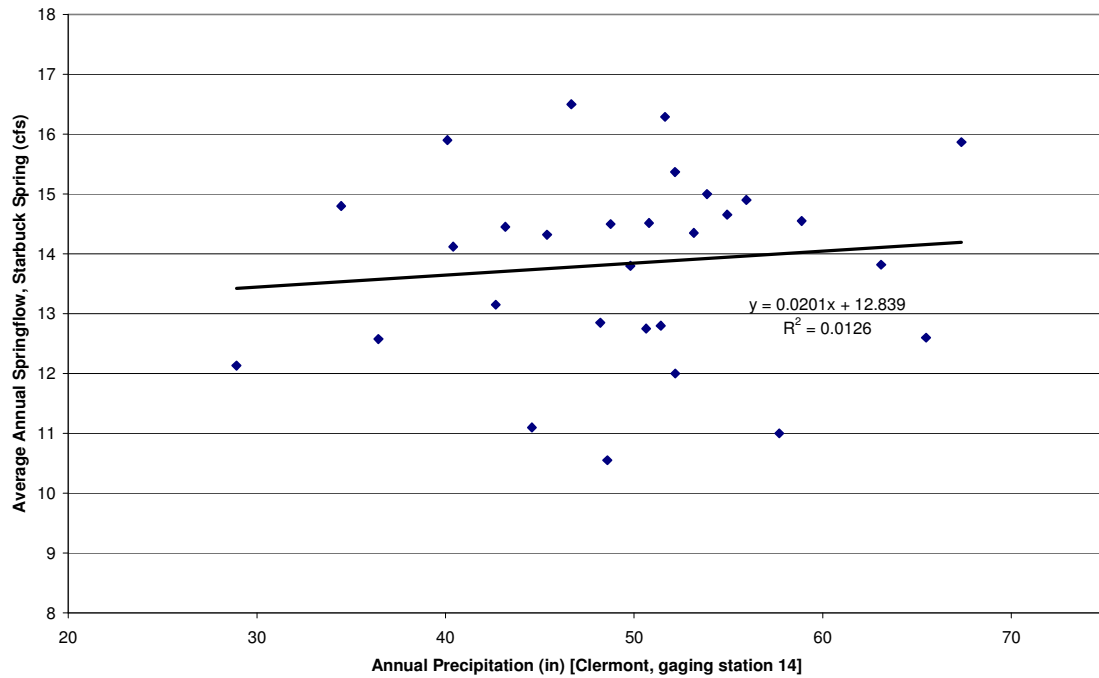
FIGURE 3.1 - Starbuck Springflow Vs. Precipitation [Clermont]

$y = 0.0201x + 12.839$
$R^2 = 0.0126$
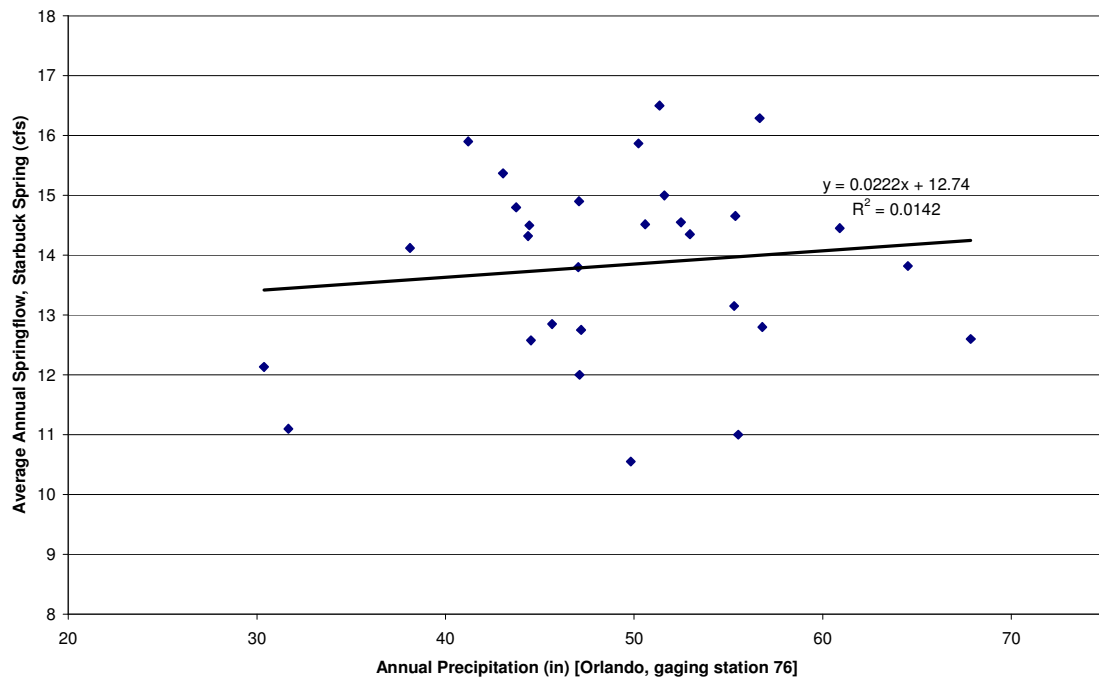
FIGURE 3.2 - Starbuck Springflow Vs. Precipitation [Orlando]

$y = 0.0222x + 12.74$
$R^2 = 0.0142$
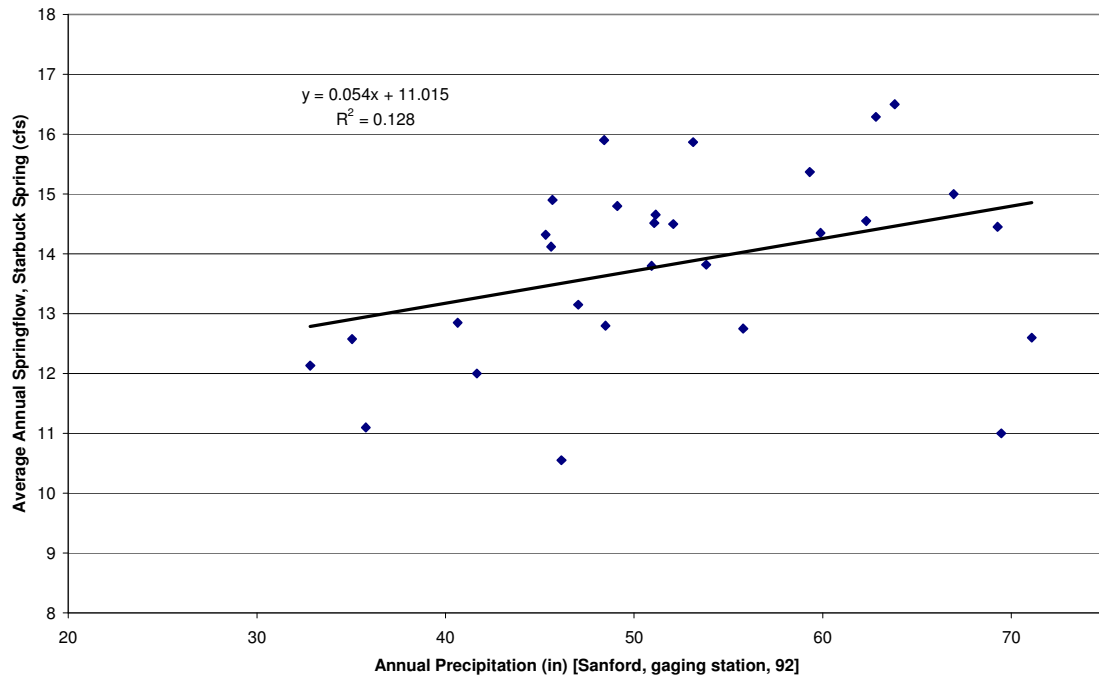
FIGURE 3.3 - Starbuck Springflow Vs. Precipitation (Sanford)
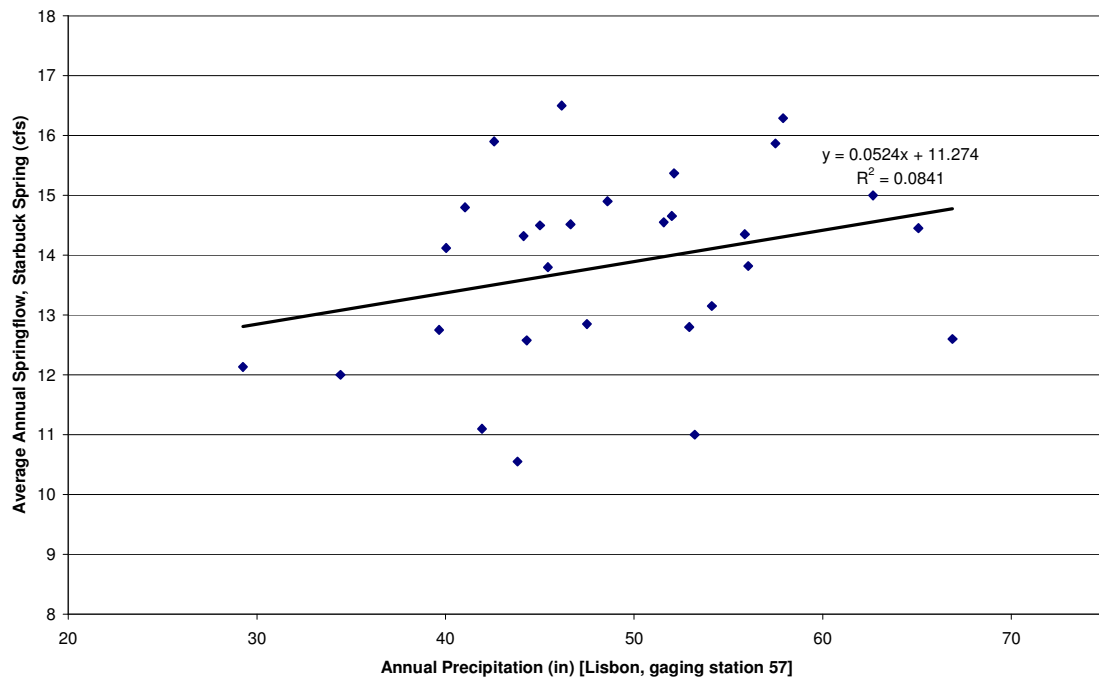
FIGURE 3.4 - Starbuck Springflow Vs. Precipitation (Lisbon)
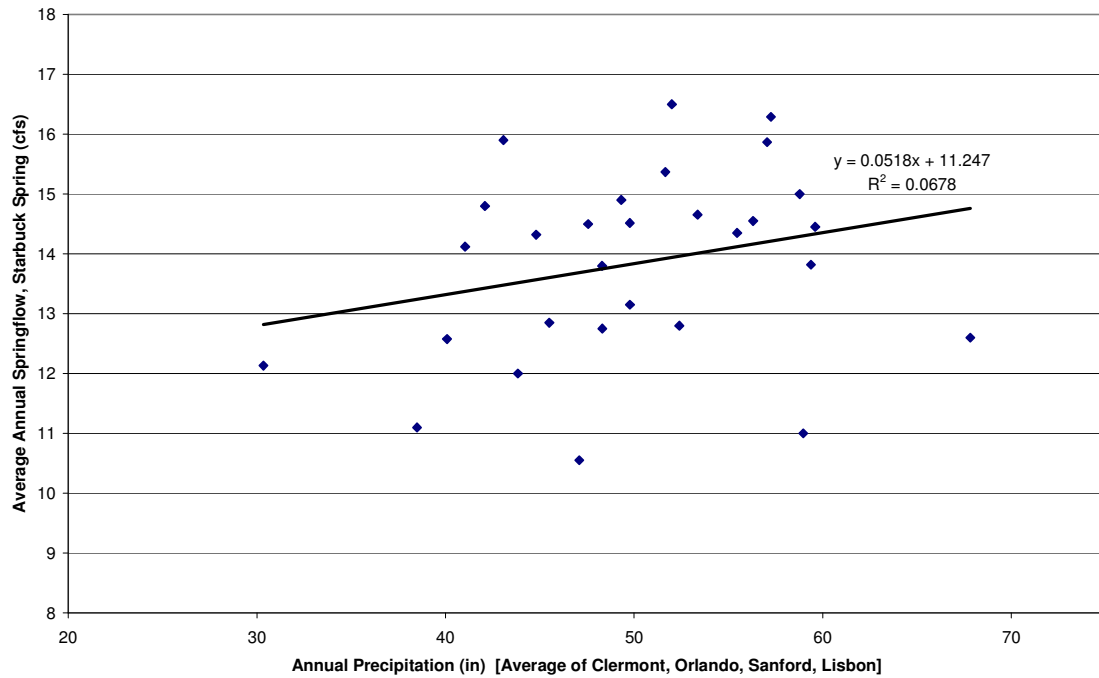
FIGURE 3.5 - Starbuck Springflow Vs Average Precipitation
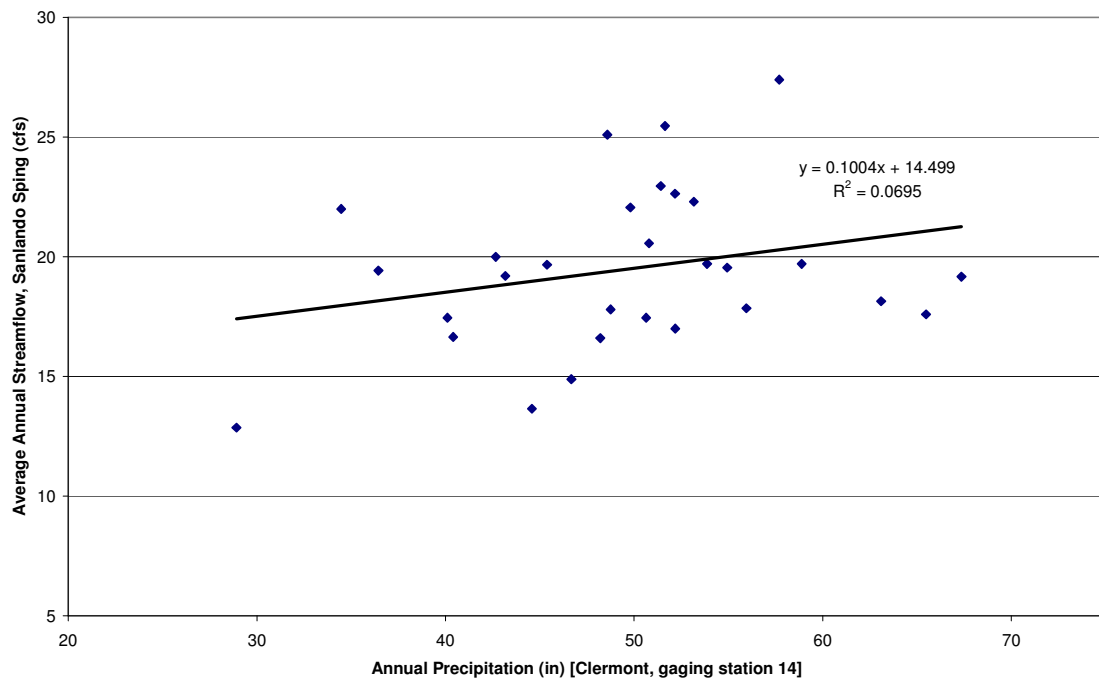
FIGURE 4.1 - Sanlando Springflow Vs. Precipitation [Clermont]
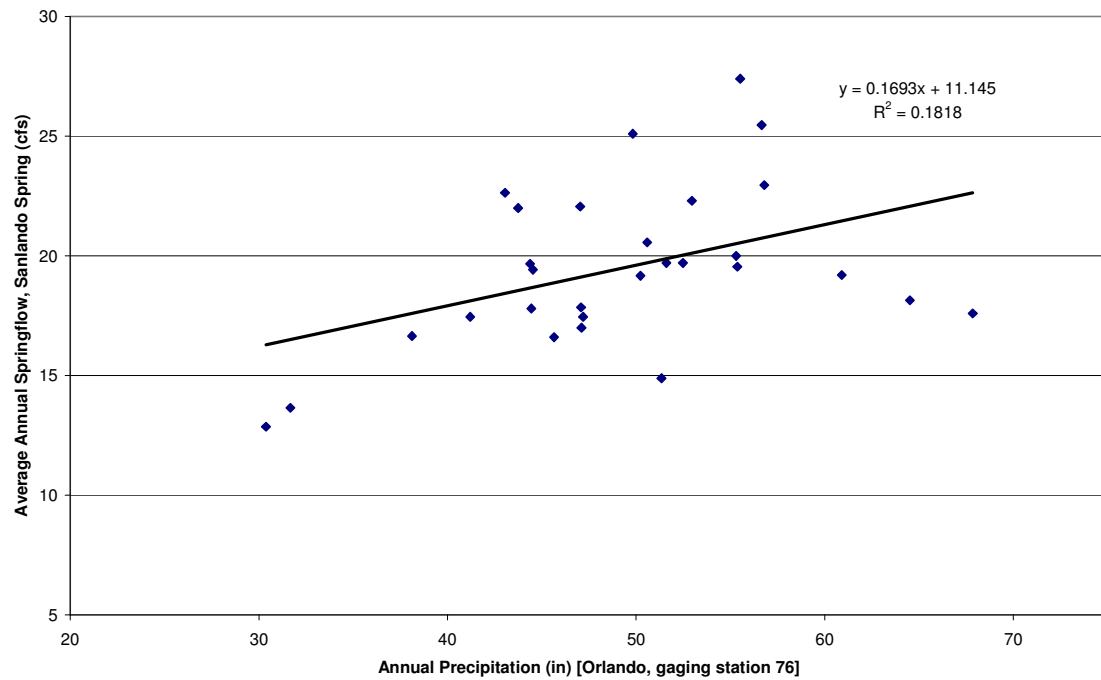
FIGURE 4.2 - Sanlando Springflow Vs. Precipitation [Orlando]
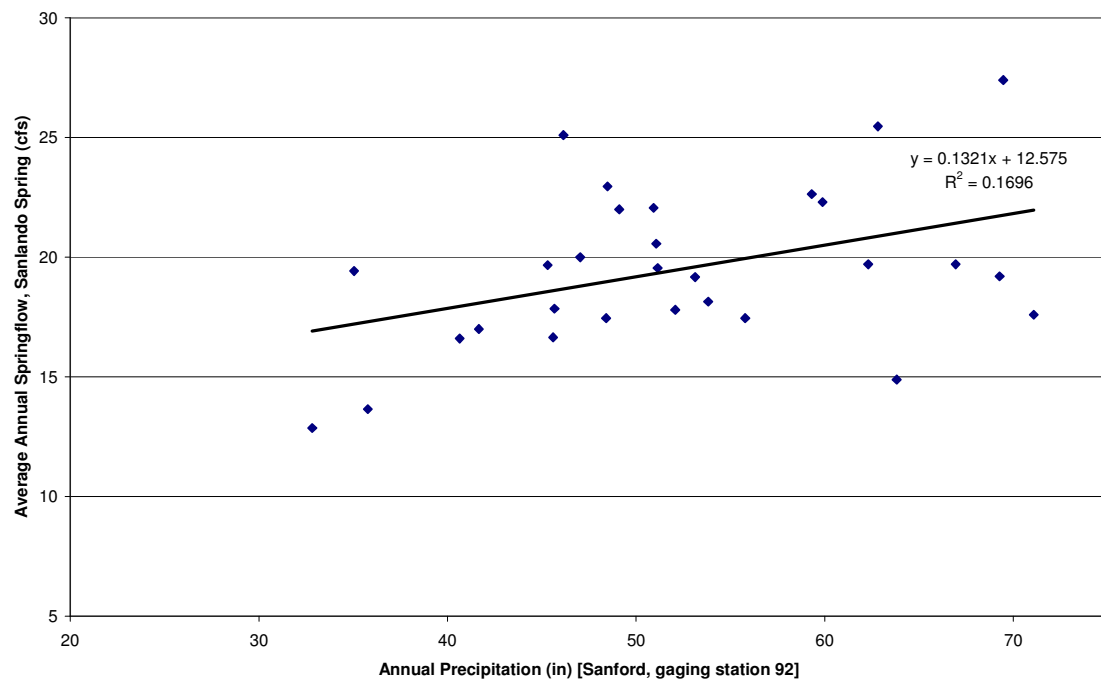
FIGURE 4.3 - Sanlando Springflow Vs. Precipitation (Sanford)
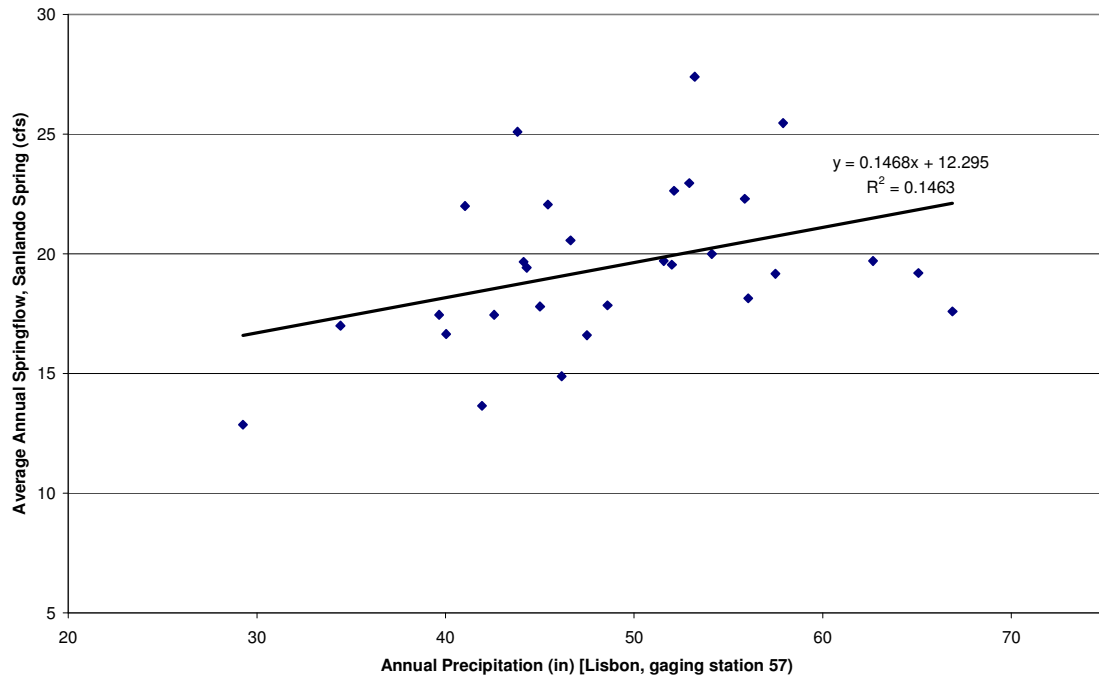
FIGURE 4.4 - Sanlando Springflow Vs. Precipitation (Lisbon)
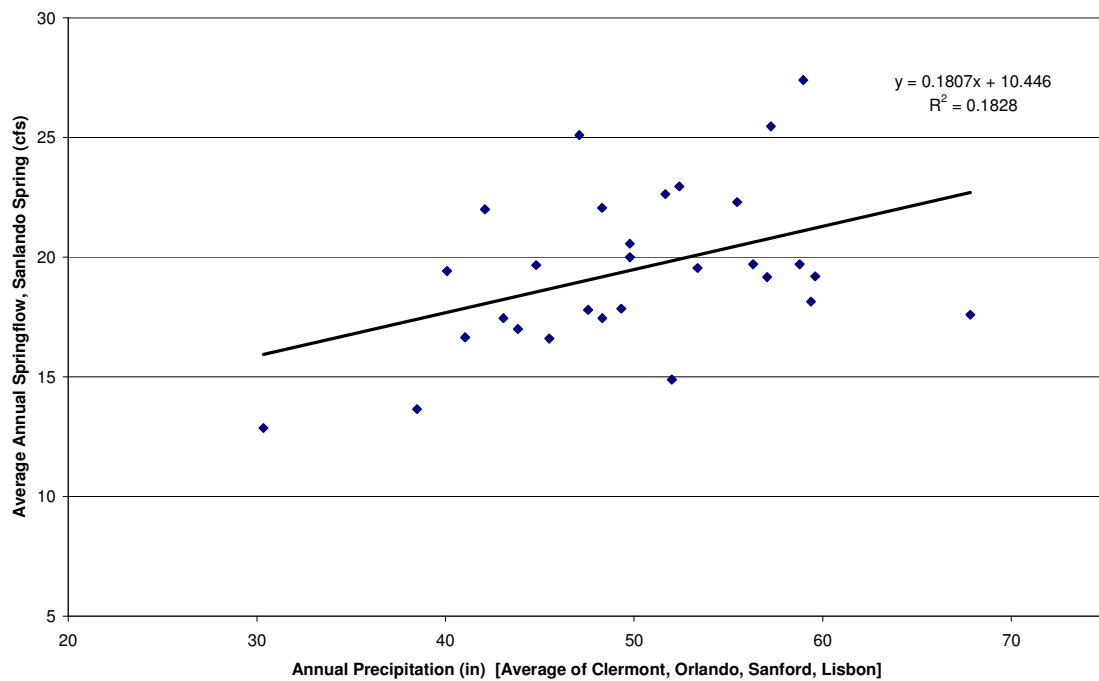
FIGURE 4.5 - Sanlando Springflow Vs Average Precipitation
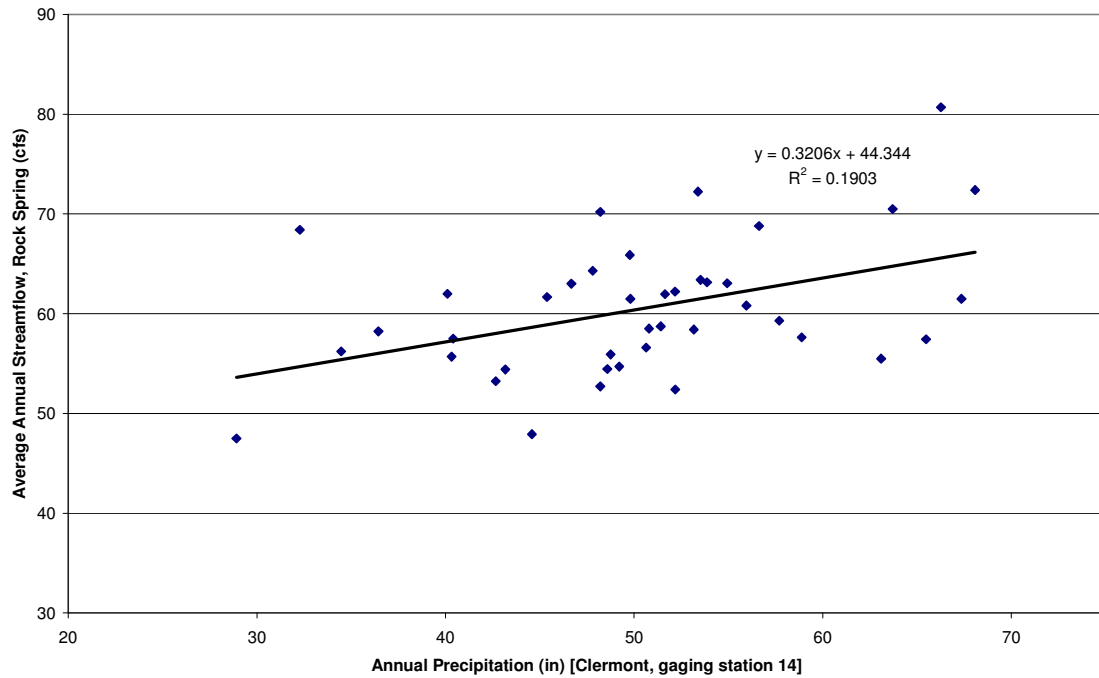
FIGURE 5.1 - Rock Springflow Vs. Precipitation [Clermont]
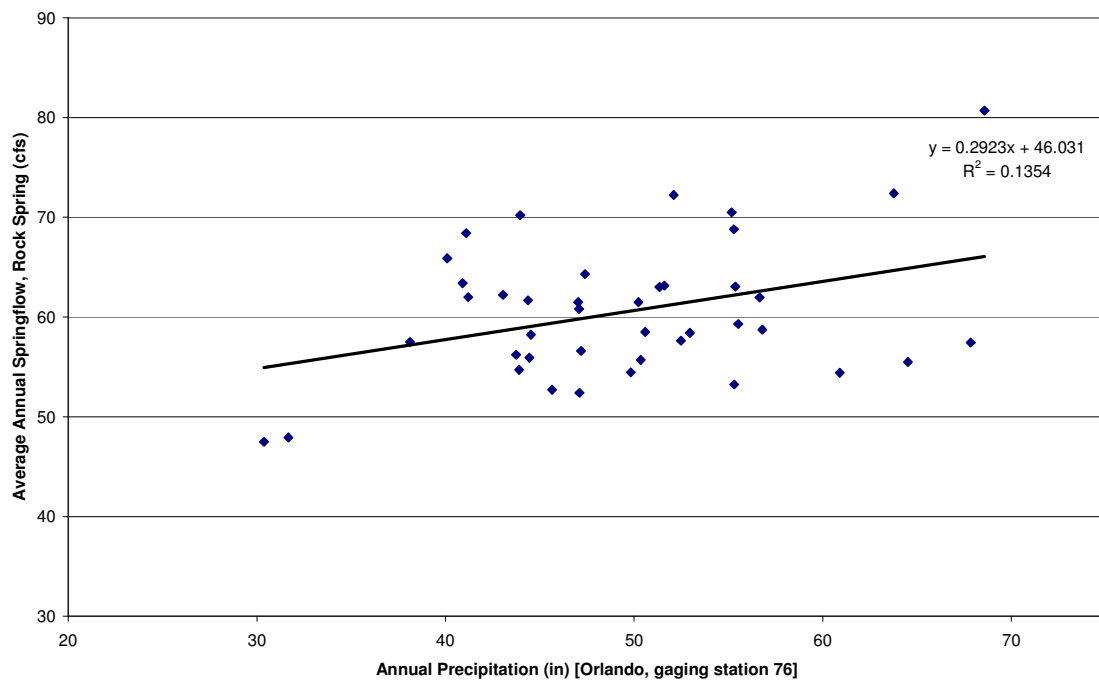
FIGURE 5.2 - Rock Springflow Vs. Precipitation [Orlando]
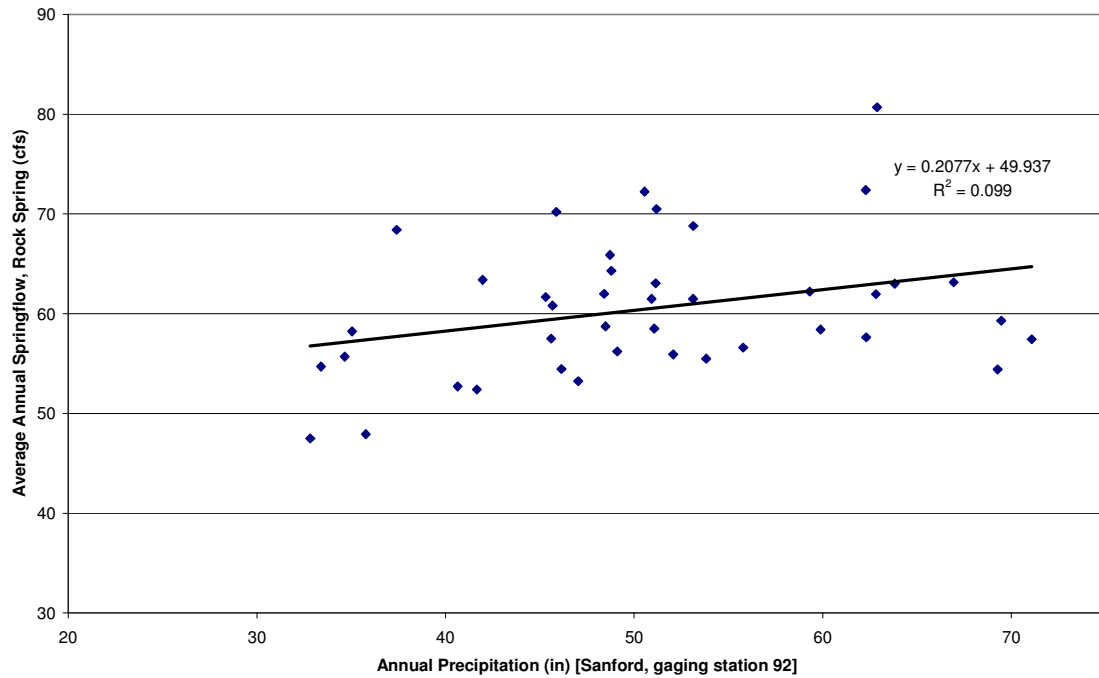
FIGURE 5.3 - Rock Springflow Vs. Precipitation (Sanford)
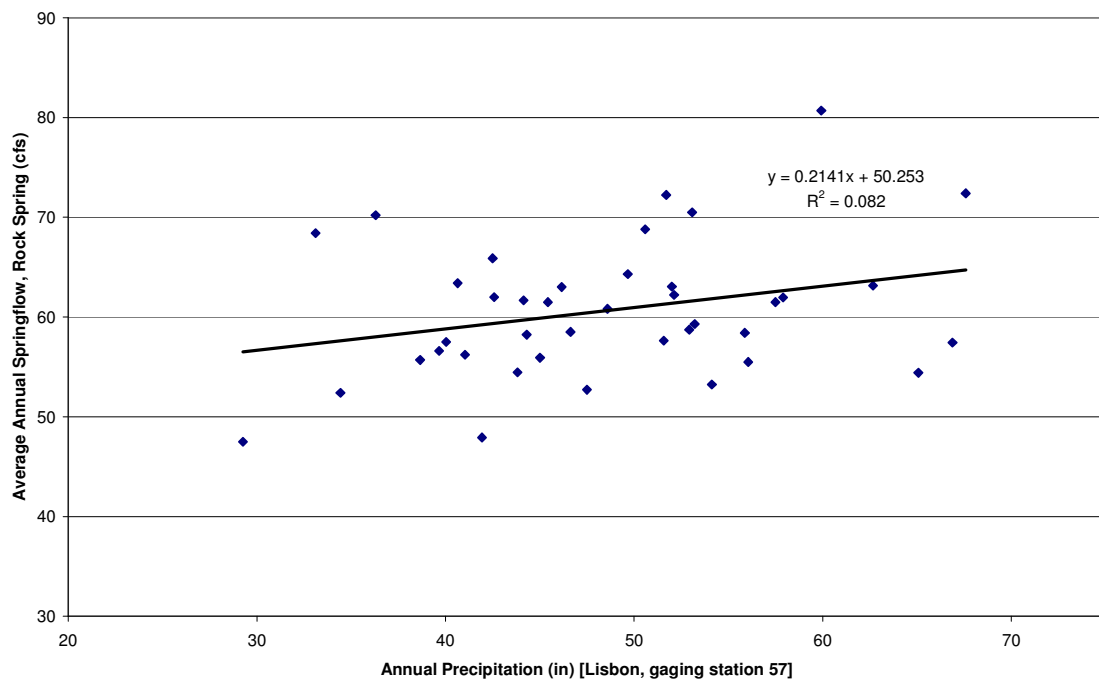
FIGURE 5.4 - Rock Springflow Vs. Precipitation (Lisbon)

y = 0.3219x + 44.56
$R^2 = 0.1502$
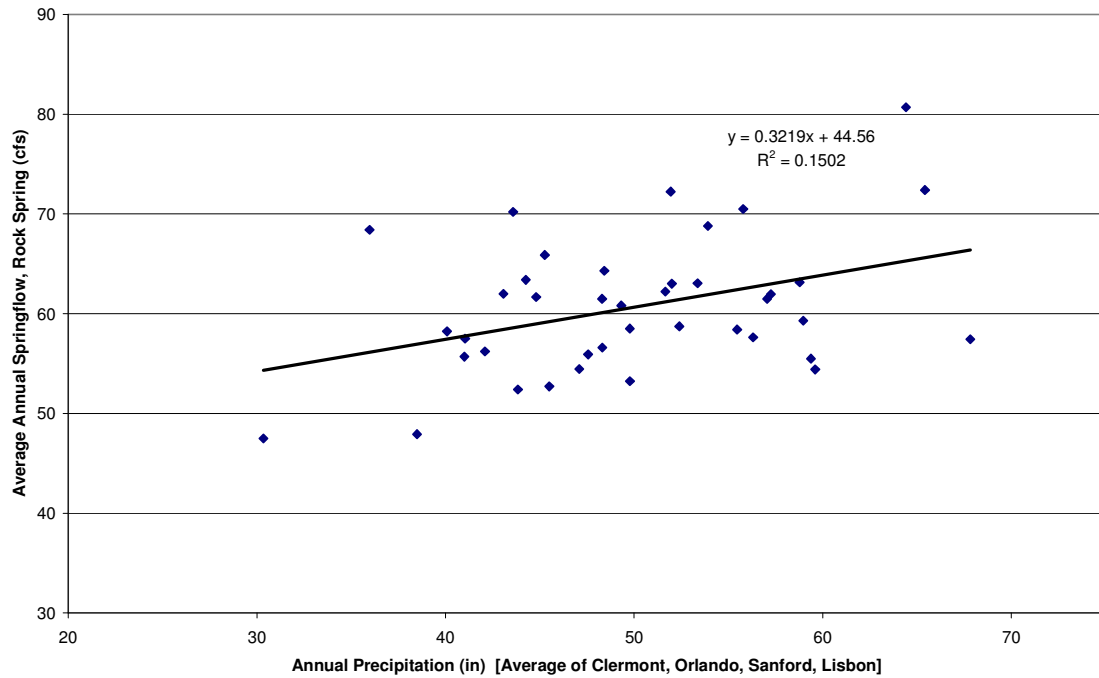
FIGURE 5.5 - Rock Springflow Vs. Average Precipitation

y = -0.0034x + 6.7993
$R^2 = 0.0003$
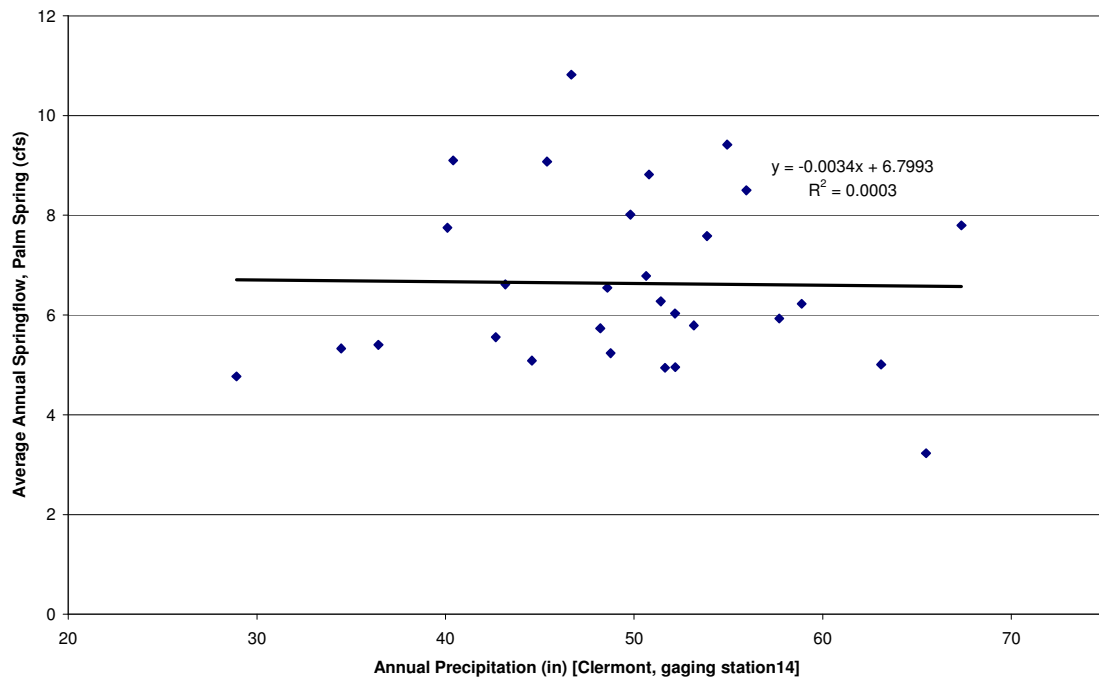
FIGURE 6.1 - Palm Springflow Vs Precipitation (Clermont)
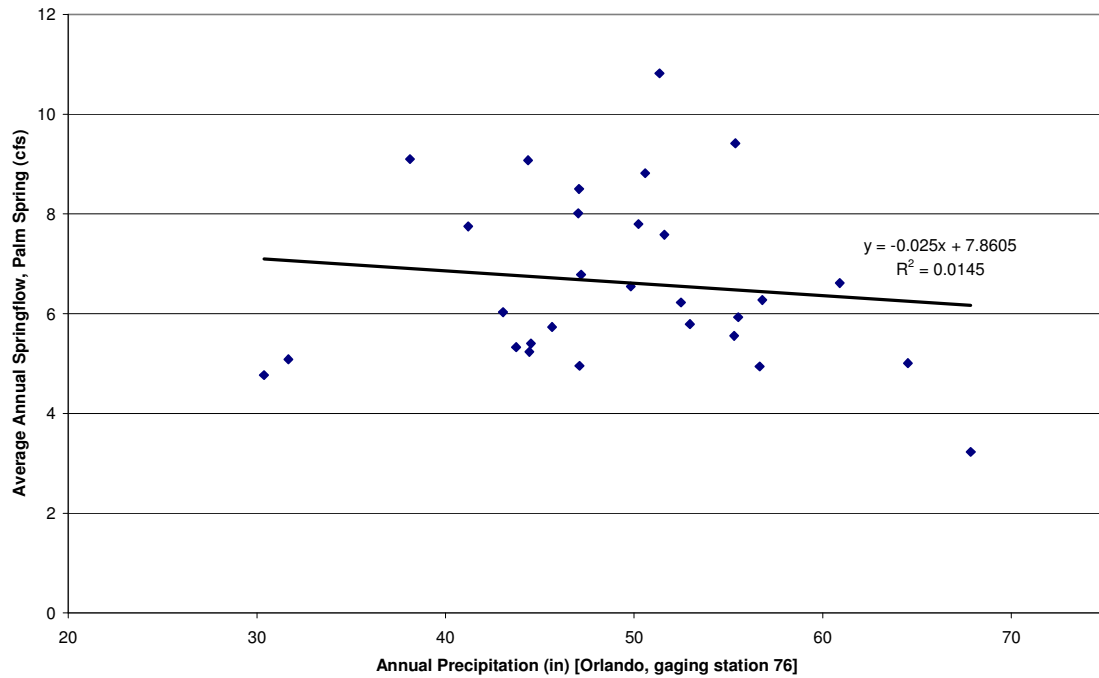
FIGURE 6.2 - Palm Springflow Vs. Precipitation (Orlando)
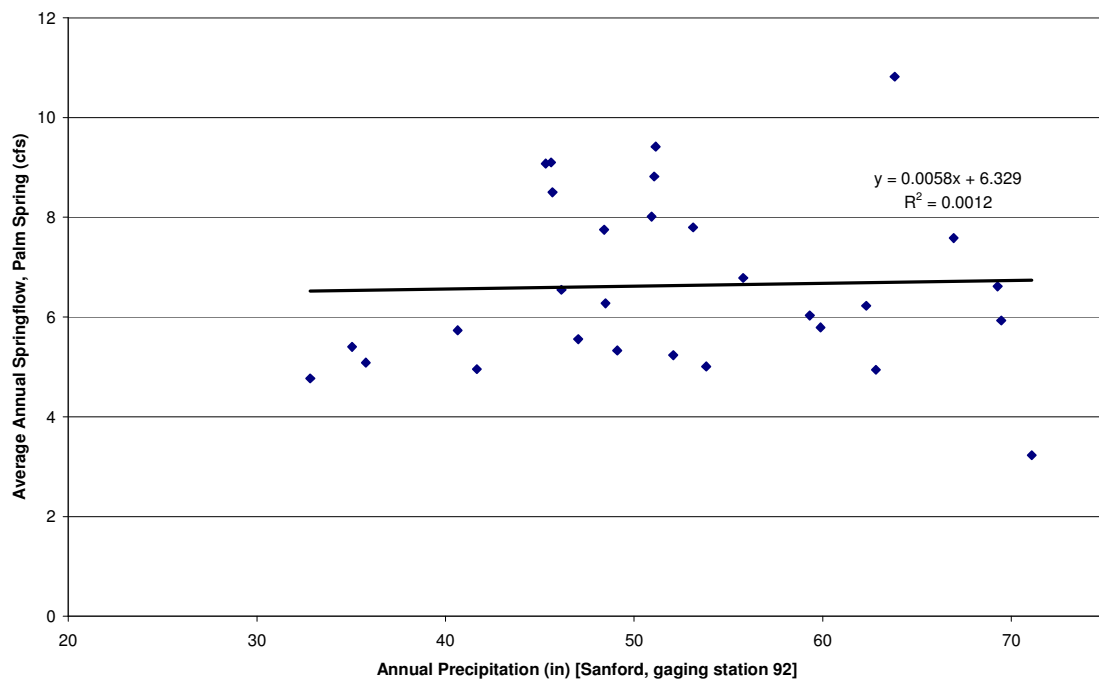
FIGURE 6.3 - Palm Springflow Vs. Precipitation (Sanford)
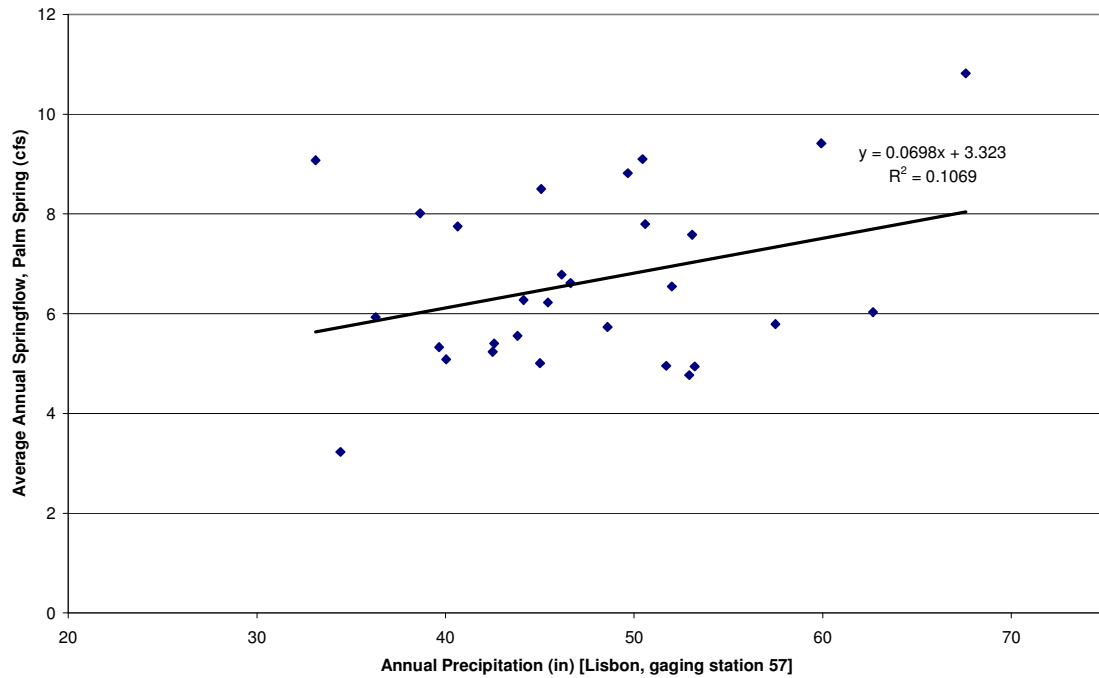
FIGURE 6.4 - Palm Springflow Vs Precipitation (Lisbon)
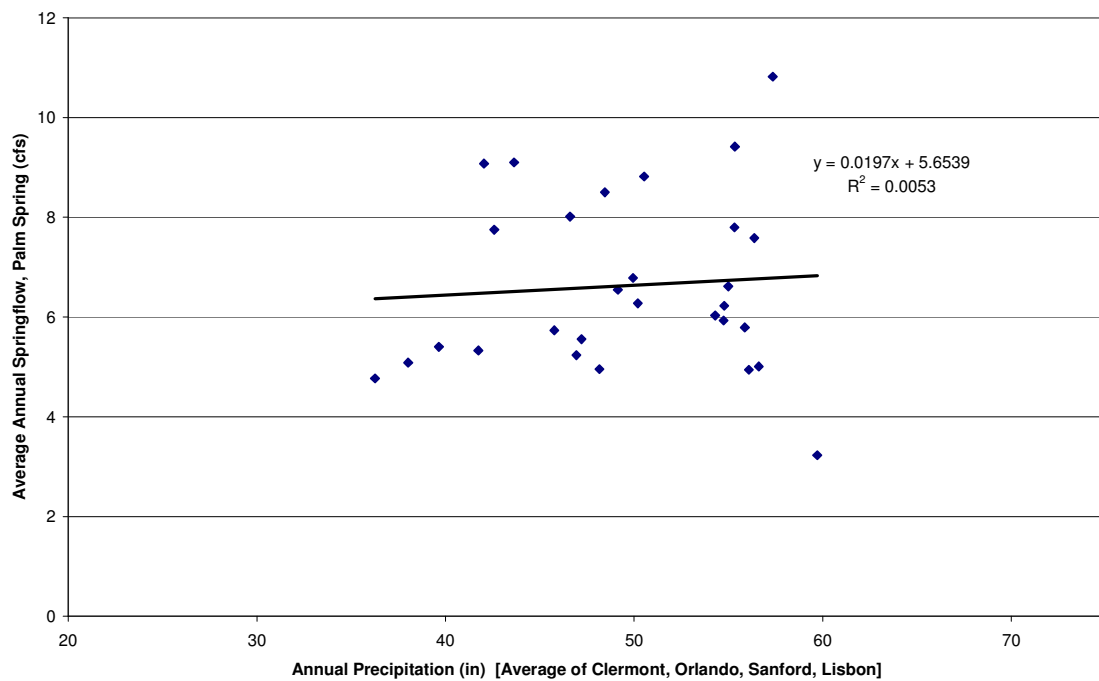
FIGURE 6.5 - Palm Springflow Vs Average Precipitation

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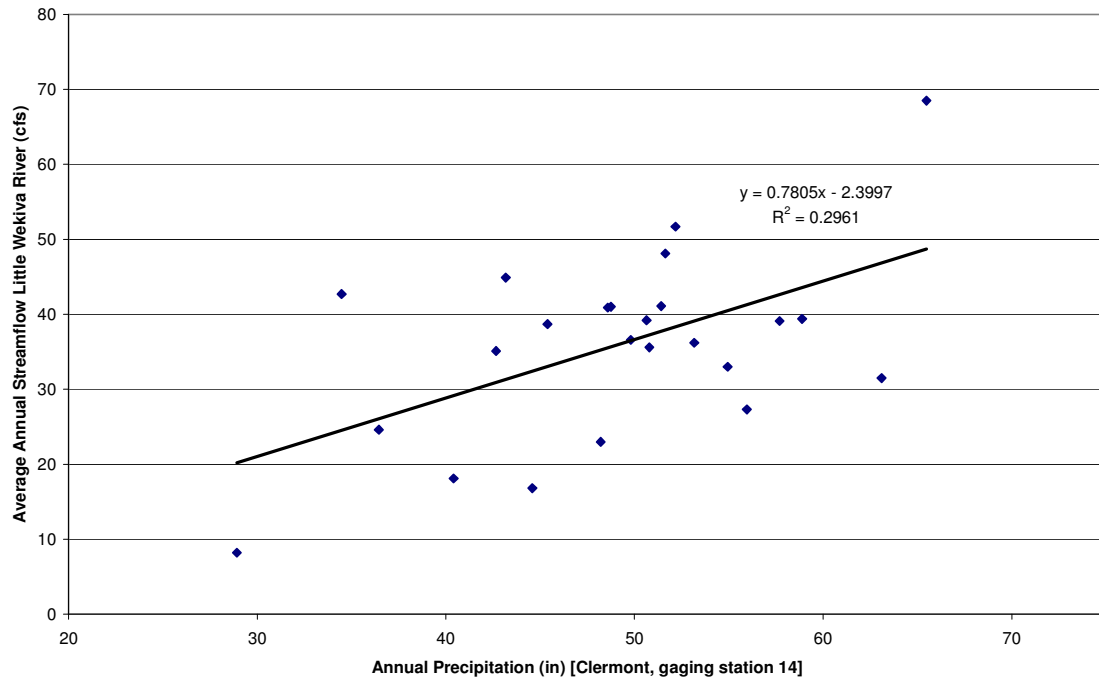
FIGURE 7.1 - Little Wekiva Streamflow Vs Precipitation (Clermont)

$y = 0.7805x - 2.3997$
$R^2 = 0.2961$

Annual Precipitation (in) [Clermont, gaging station 14]

Average Annual Streamflow Little Wekiva River (cfs)
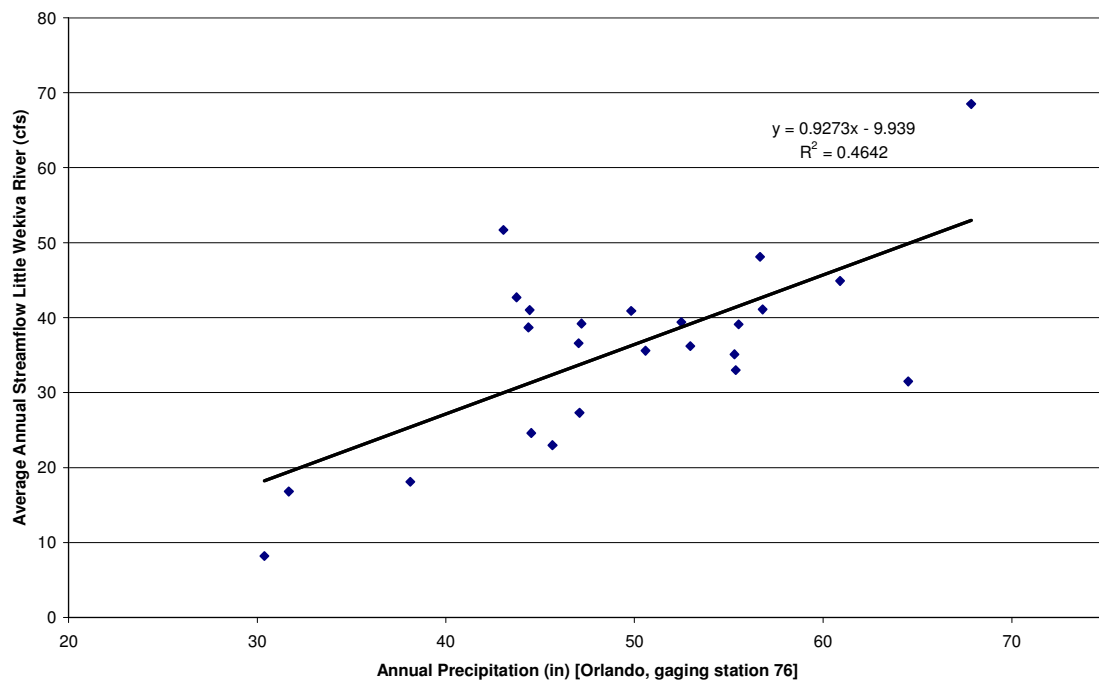
FIGURE 7.2 - Average Annual Streamflow Little Wekiva Vs Precipitation (Orlando)

$y = 0.9273x - 9.939$
$R^2 = 0.4642$

Annual Precipitation (in) [Orlando, gaging station 76]

Average Annual Streamflow Little Wekiva River (cfs)
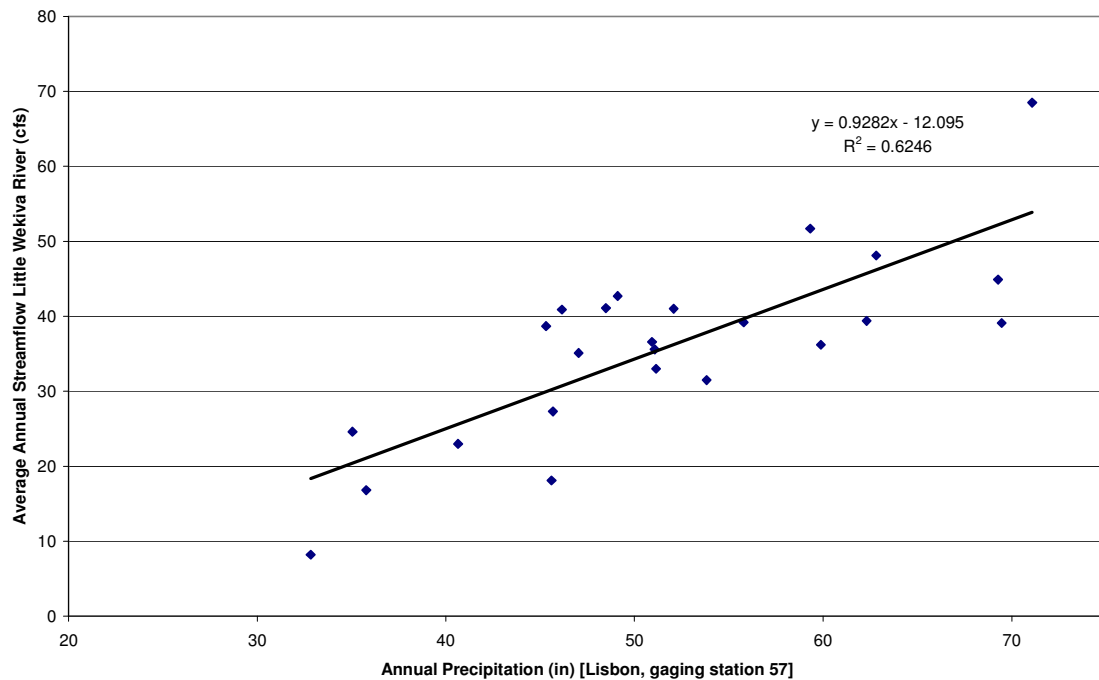
FIGURE 7.3 - Average Annual Streamflow Little Wekiva River Vs Precipitation (Sanford)
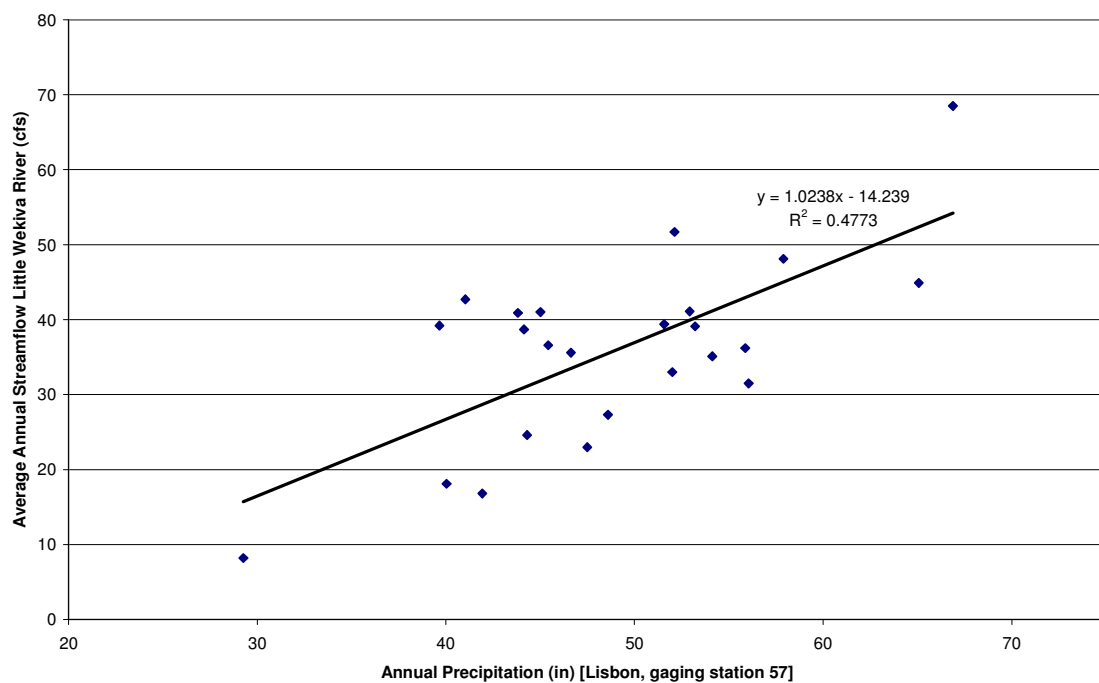
FIGURE 7.4 - Average Annual Streamflow Little Wekiva River Vs Precipitation (Lisbon)

$y = 1.1597x - 21.845$
$R^2 = 0.5853$
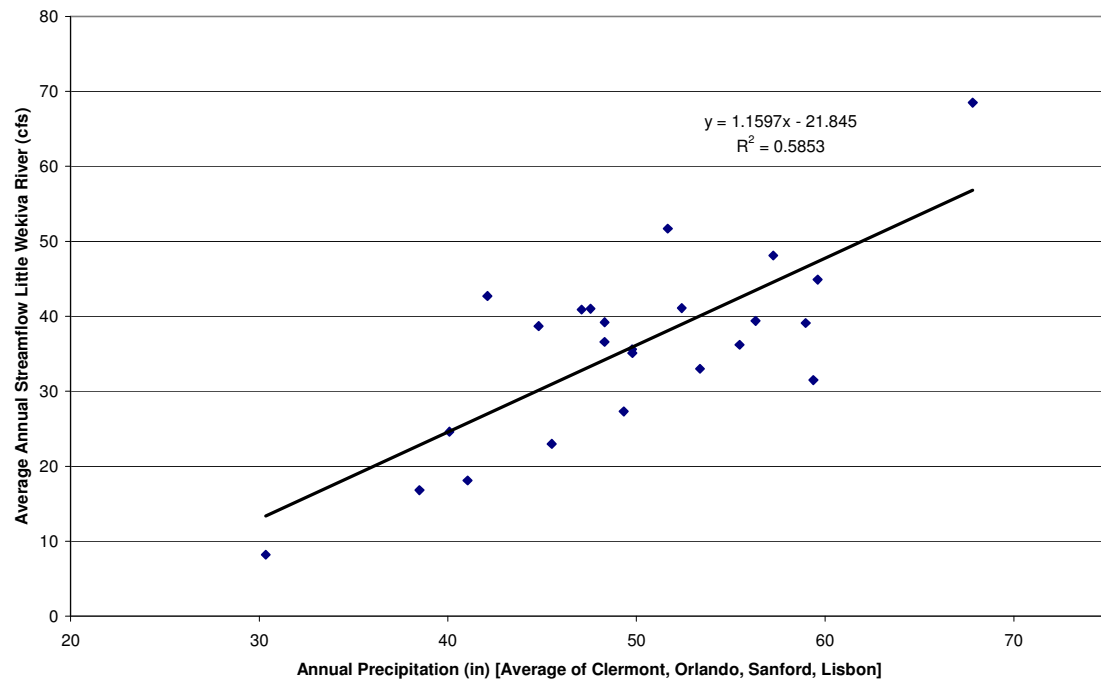
FIGURE 7.5 - Average Annual Streamflow Little Wekiva River Vs Average Precipitation
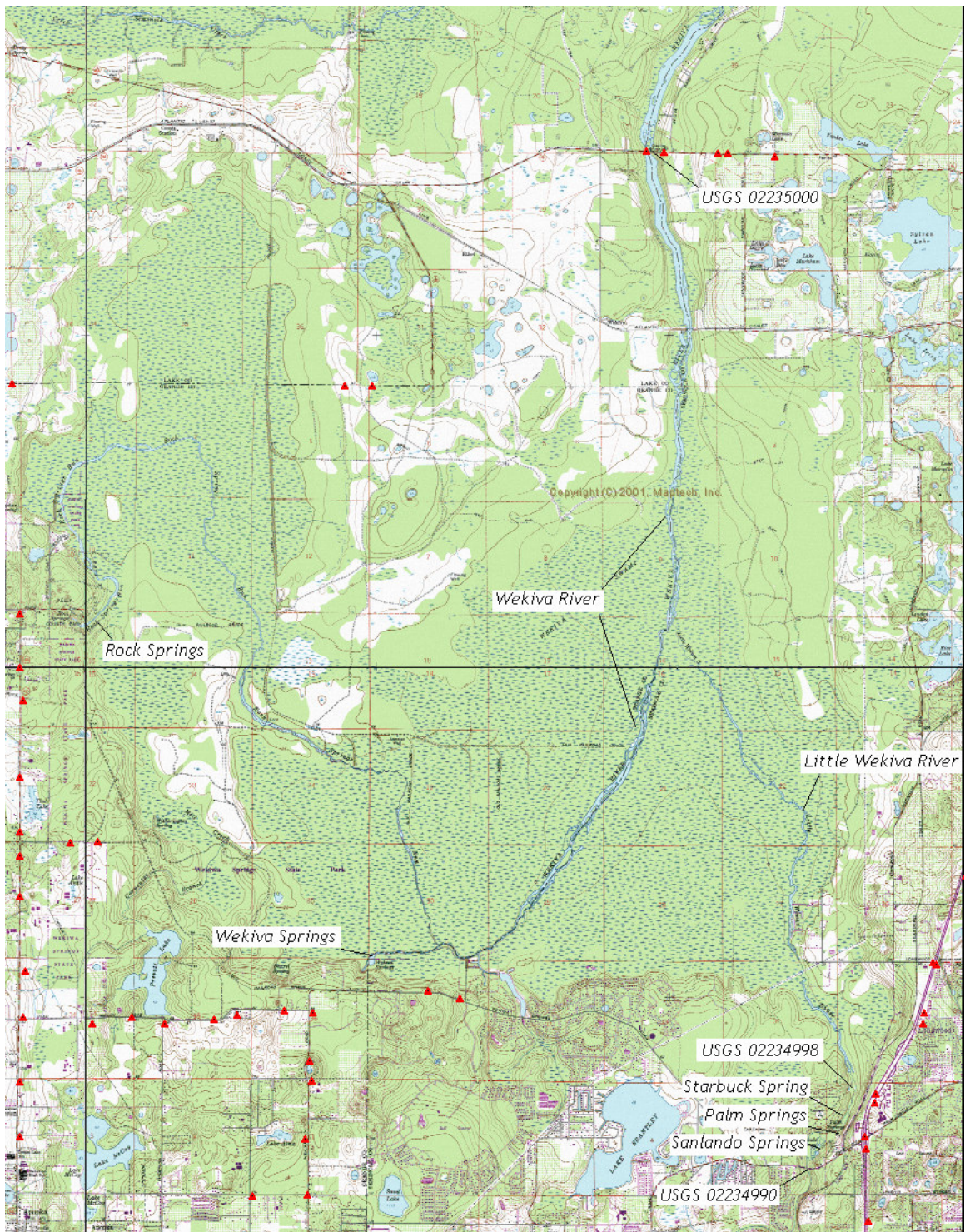
FIGURE 8 – Map of the Wekiva River Area
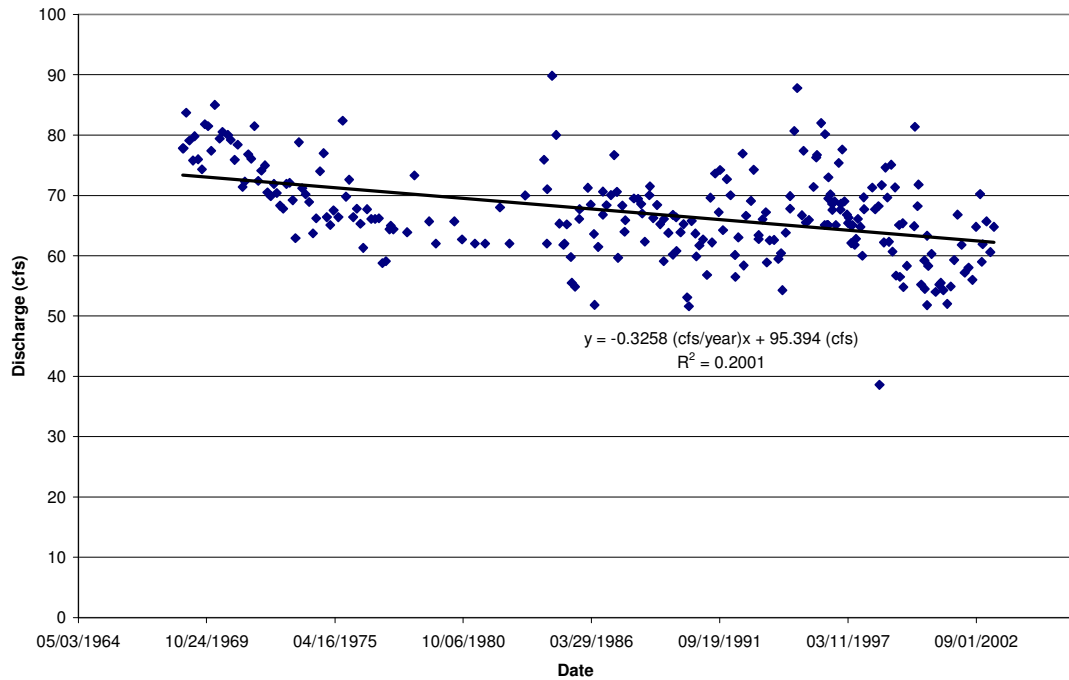
FIGURE 9.1 - Discharge versus Time for Wekiva Springs

In Figure 9.1:
$$y = -0.3258 \text{ (cfs/year)}x + 95.394 \text{ (cfs)}$$
$$R^2 = 0.2001$$
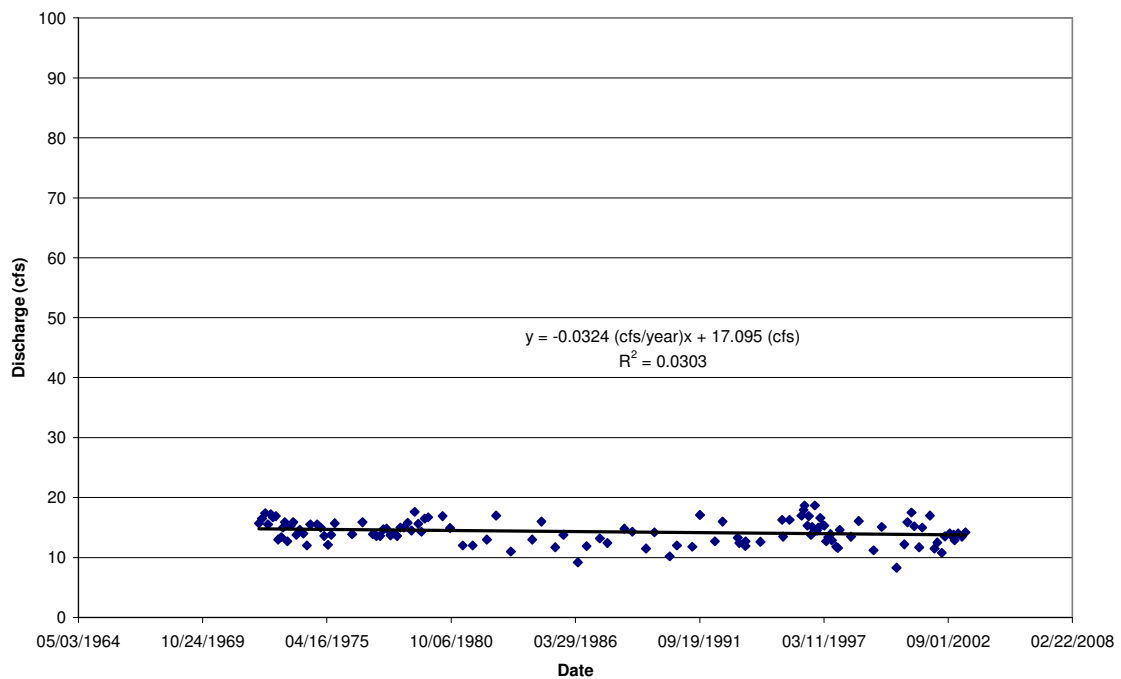
FIGURE 9.2 - Discharge versus Time for Starbuck Spring

In Figure 9.2:
$$y = -0.0324 \text{ (cfs/year)}x + 17.095 \text{ (cfs)}$$
$$R^2 = 0.0303$$

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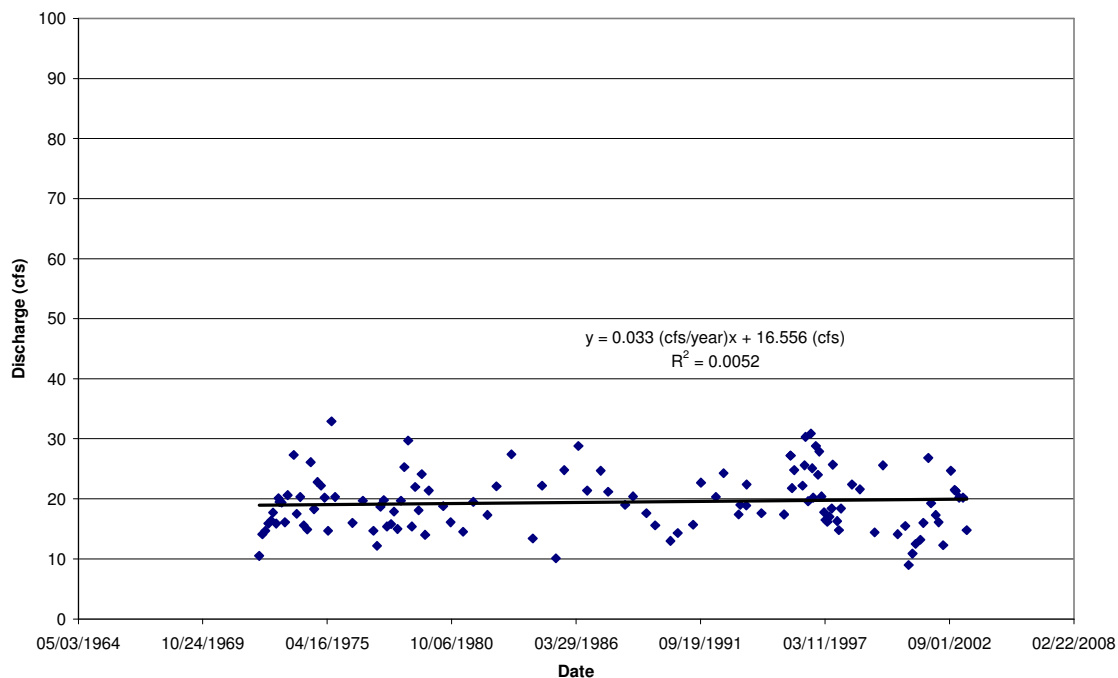
FIGURE 9.3 - Discharge versus Time for Sanlando Spring
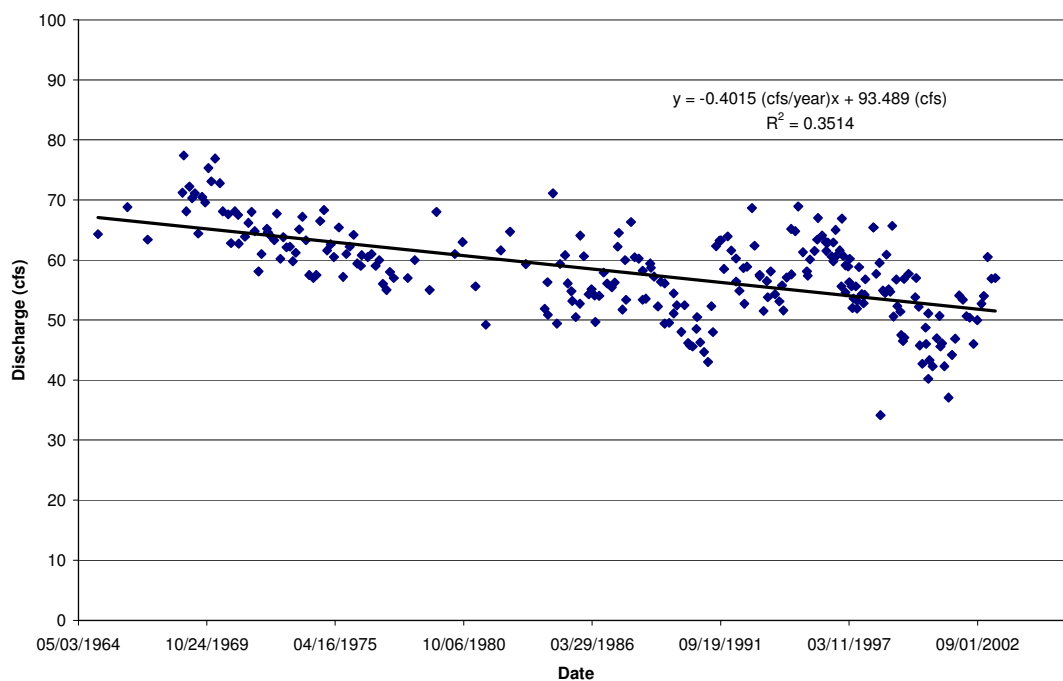
FIGURE 9.4 - Discharge versus Time for Rock Spring

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$$y = -0.146 \text{ (cfs/year)}x + 20.08 \text{ (cfs)}$$
$$R^2 = 0.6327$$
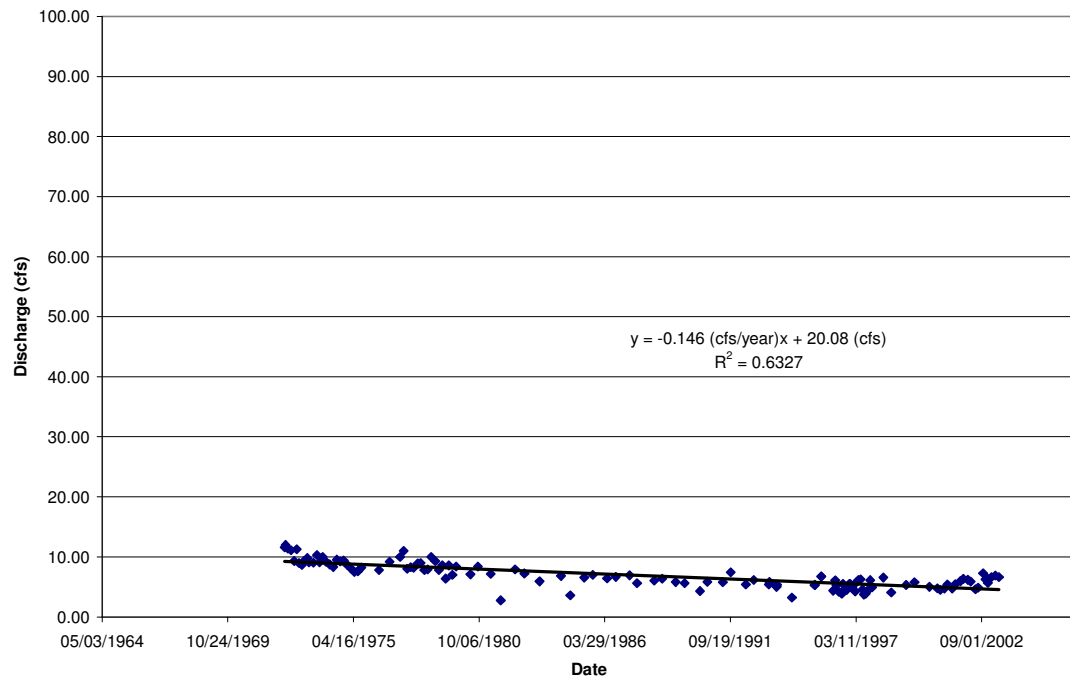
FIGURE 9.5 - Discharge versus Time for Palm Spring
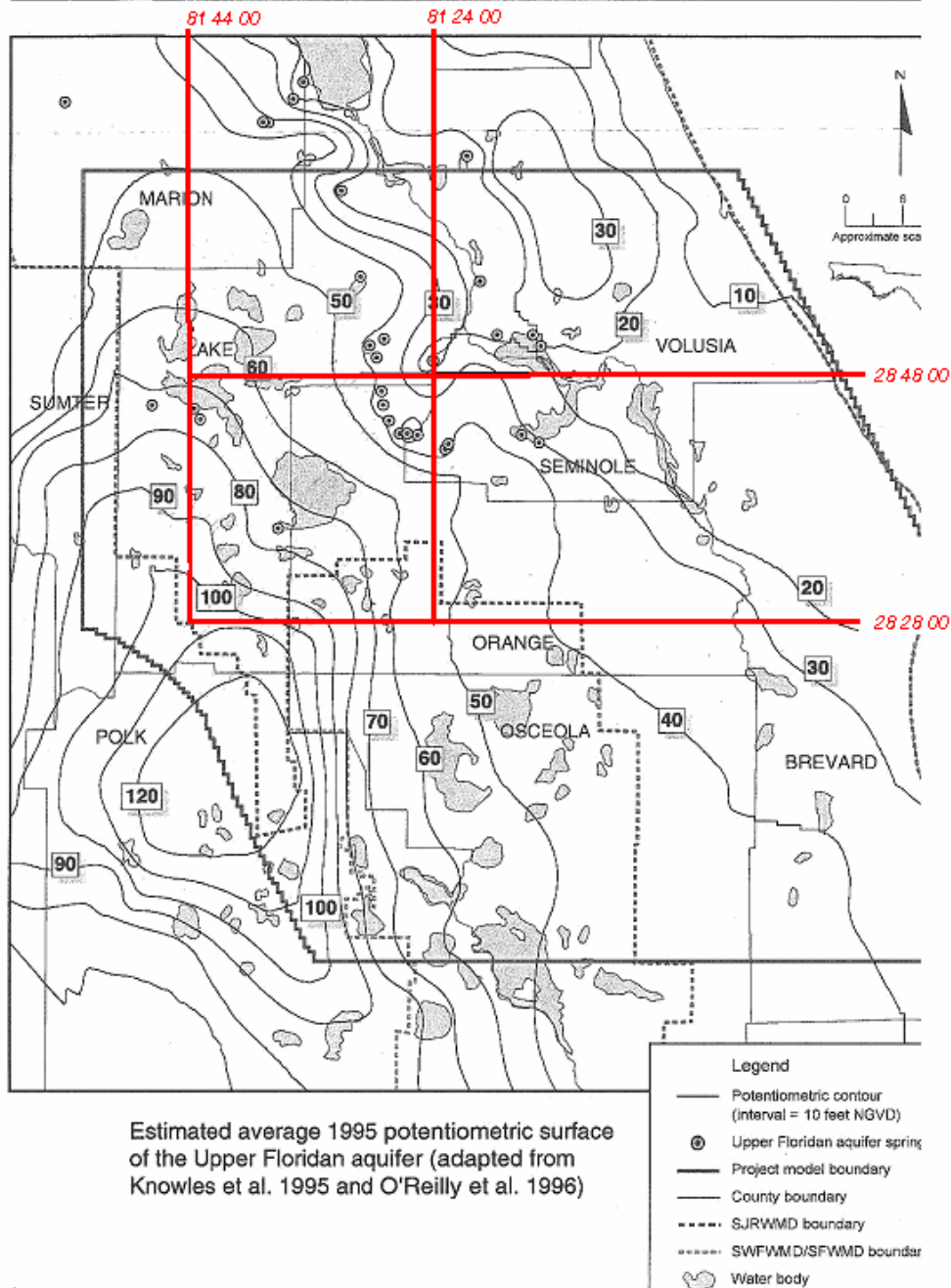
FIGURE 10 – Longitude/Latitude Box for Estimated Area of Groundwater Influence for Choice of Groundwater Wells
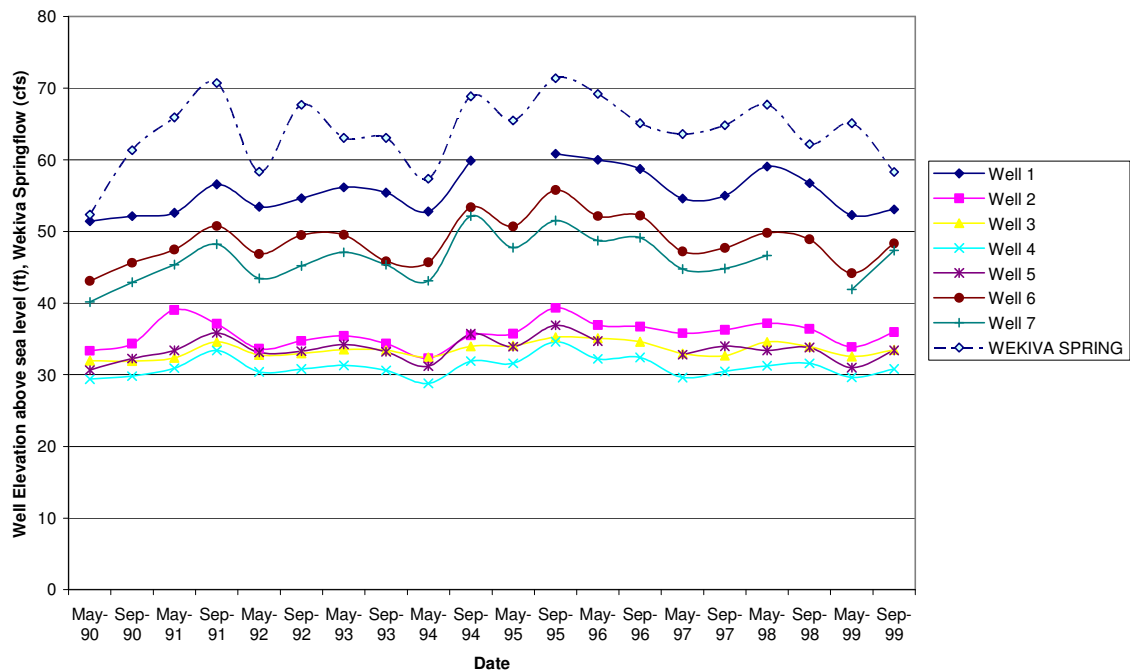
FIGURE 11.1 - Wekiva Springsflow and Well Elevations versus time
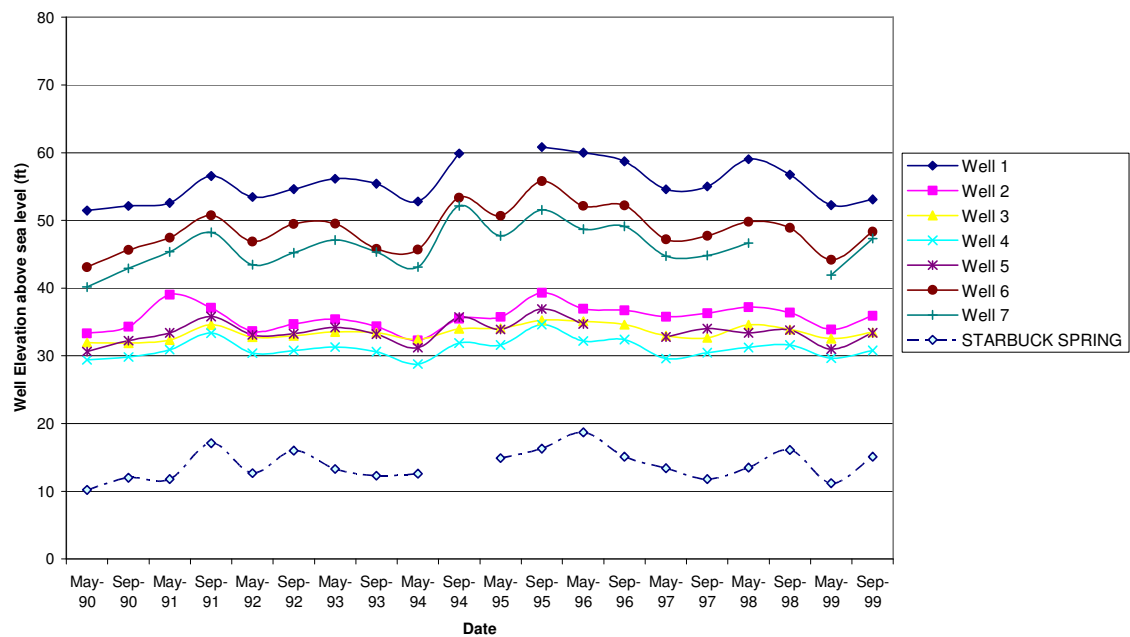
FIGURE 11.2 - Starbuck Springsflow and Well Elevations versus time
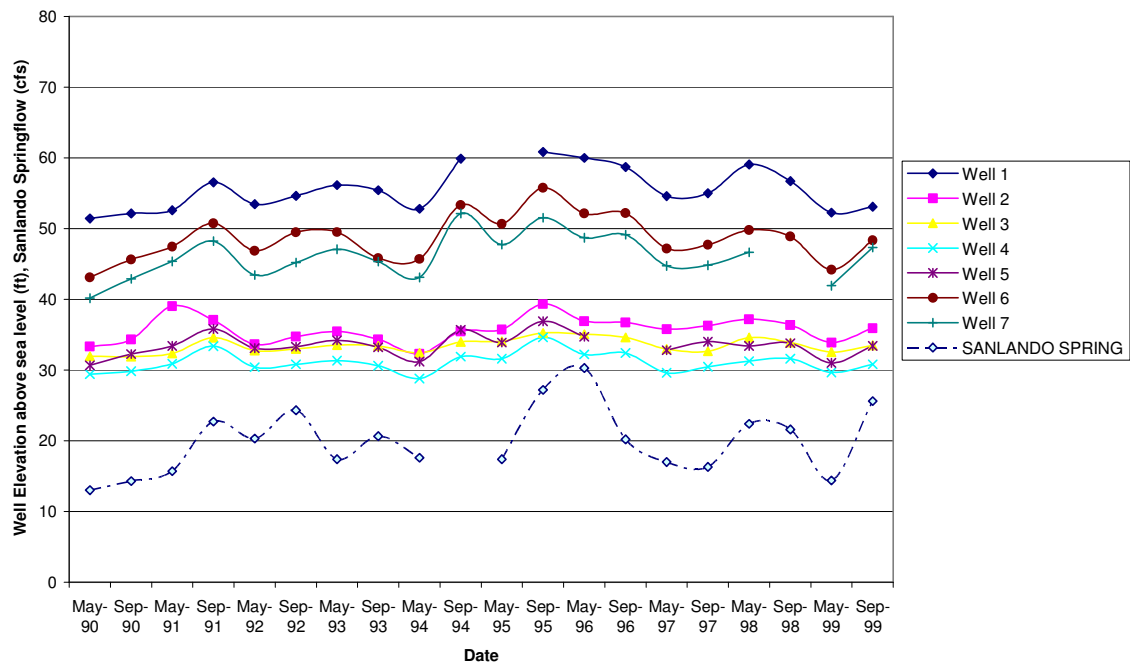
FIGURE 11.3 - Sanlando Springsflow and Well Elevations versus time
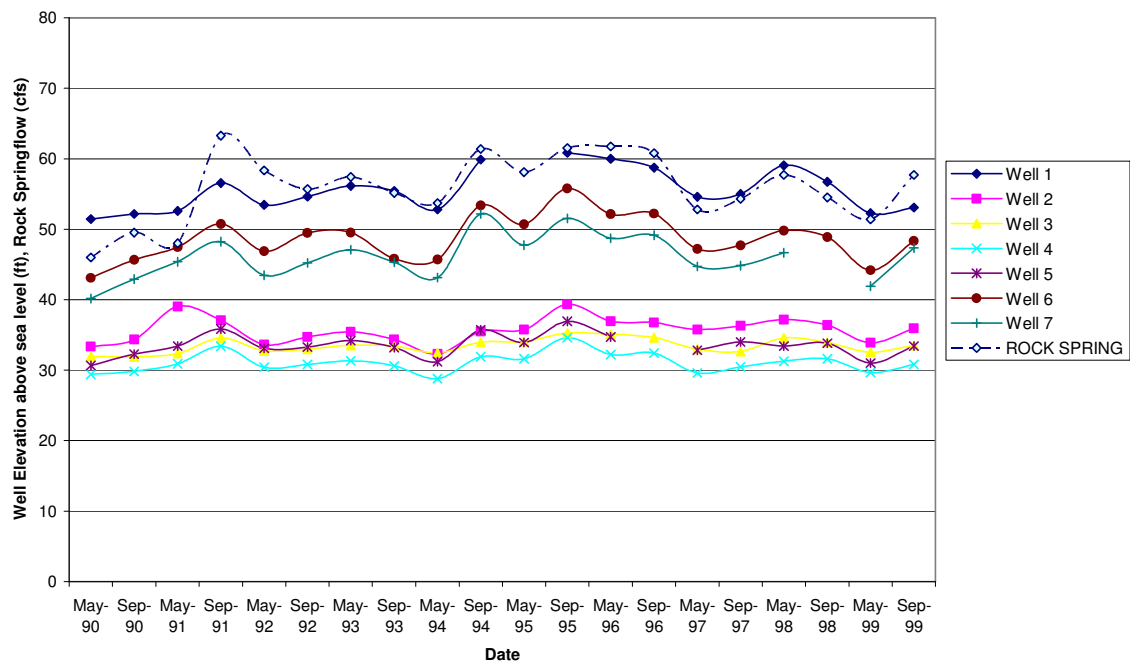
FIGURE 11.4 - Rock Springsflow and Well Elevations versus time

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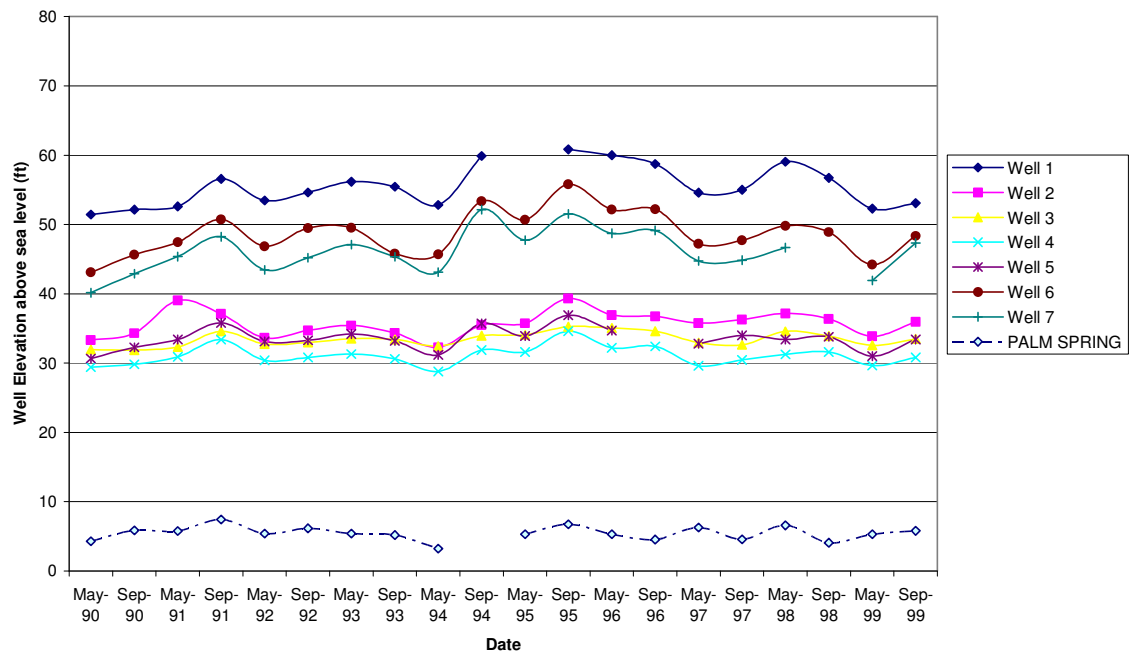
FIGURE 11.5 - Palm Springsflow and Well Elevations versus time

$$y = 1.5849x - 1.1945$$
$$R^2 = 1$$
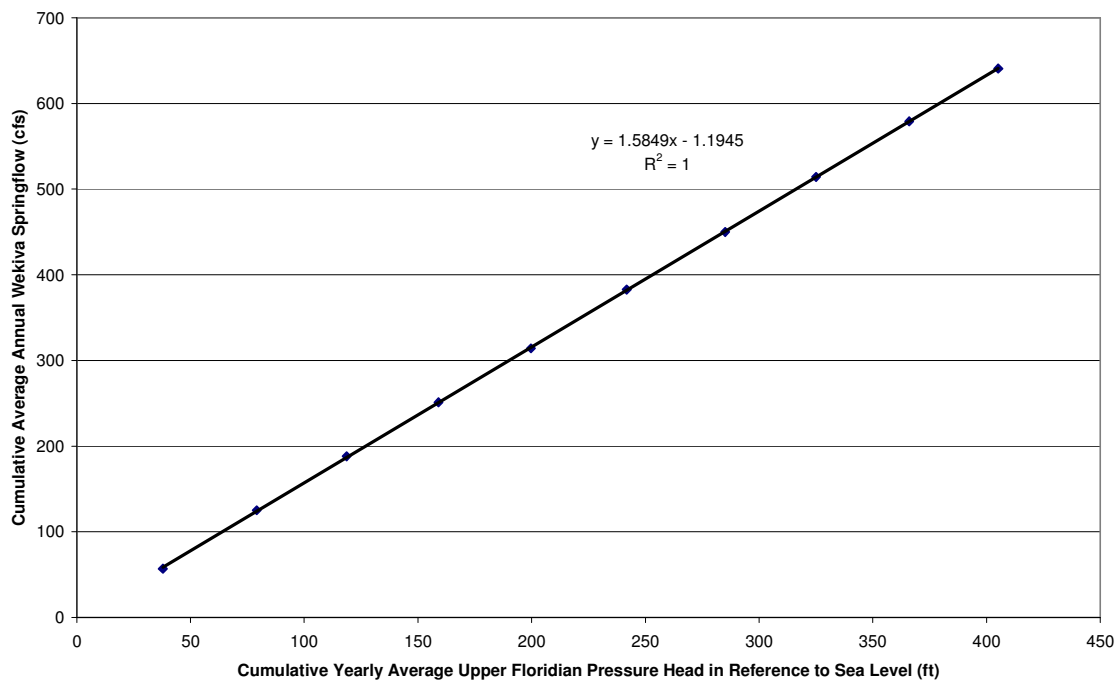
FIGURE 12.1 - Double Mass Diagram Wekiva Spring vs Pressure Head
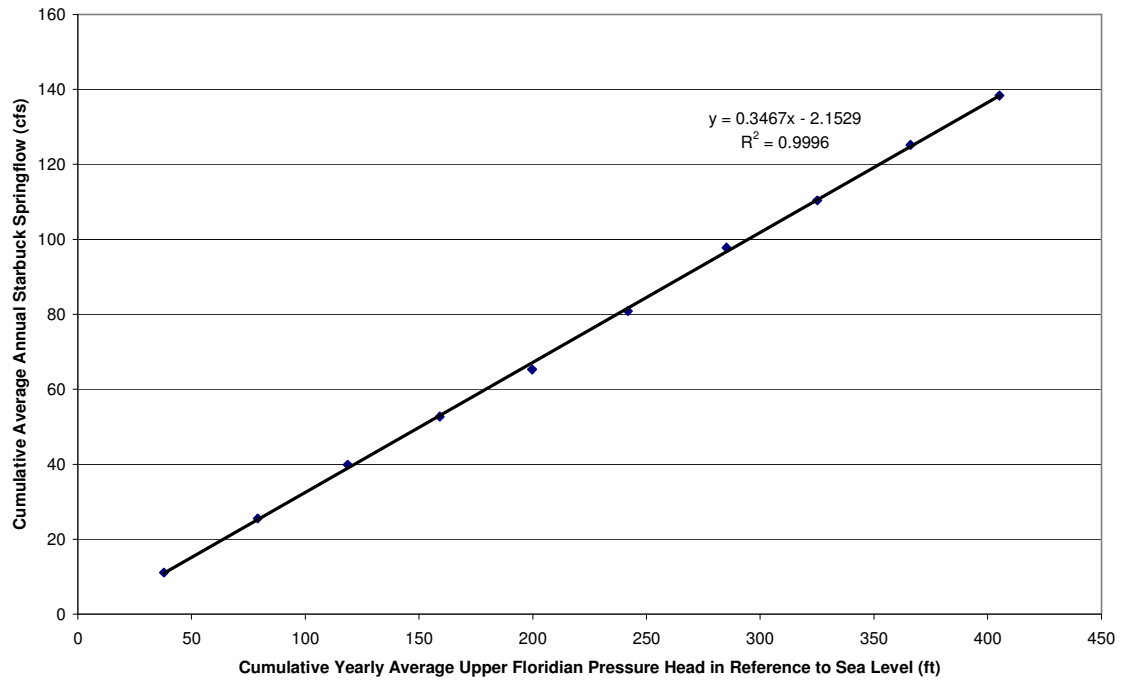
FIGURE 12.2 - Double Mass Diagram Starbuck Spring vs Pressure Head
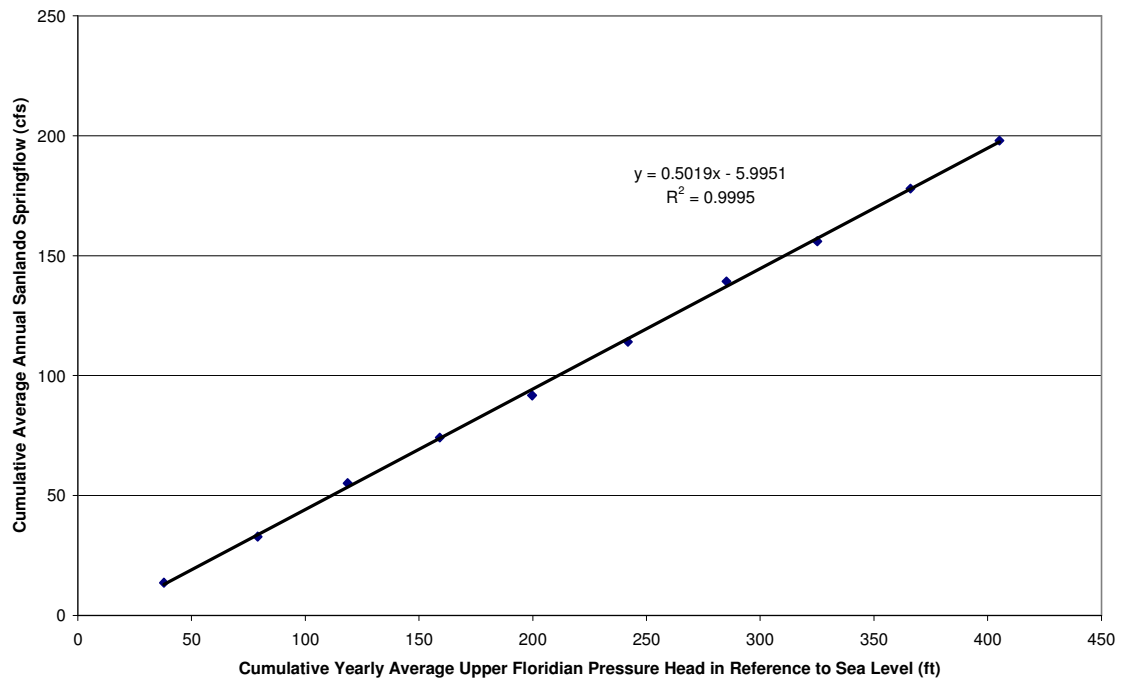
FIGURE 12.3 - Double Mass Diagram Sanlando Springflow vs Pressure Head

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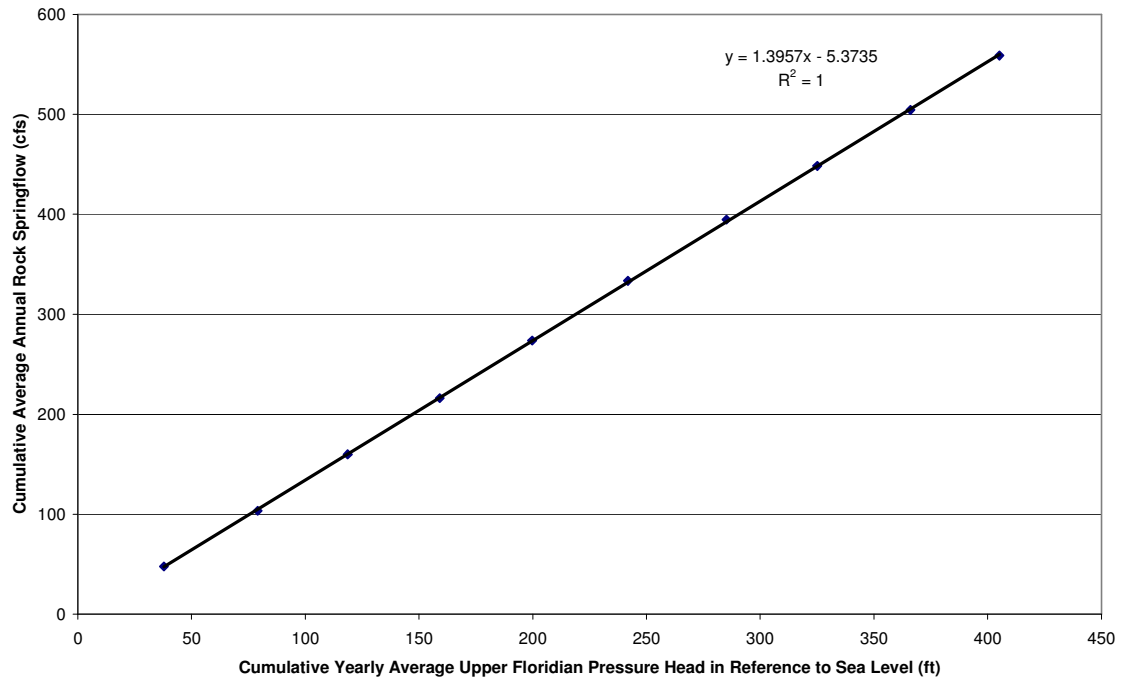
FIGURE 12.4 - Double Mass Diagram Rock Springflow vs Pressure Head
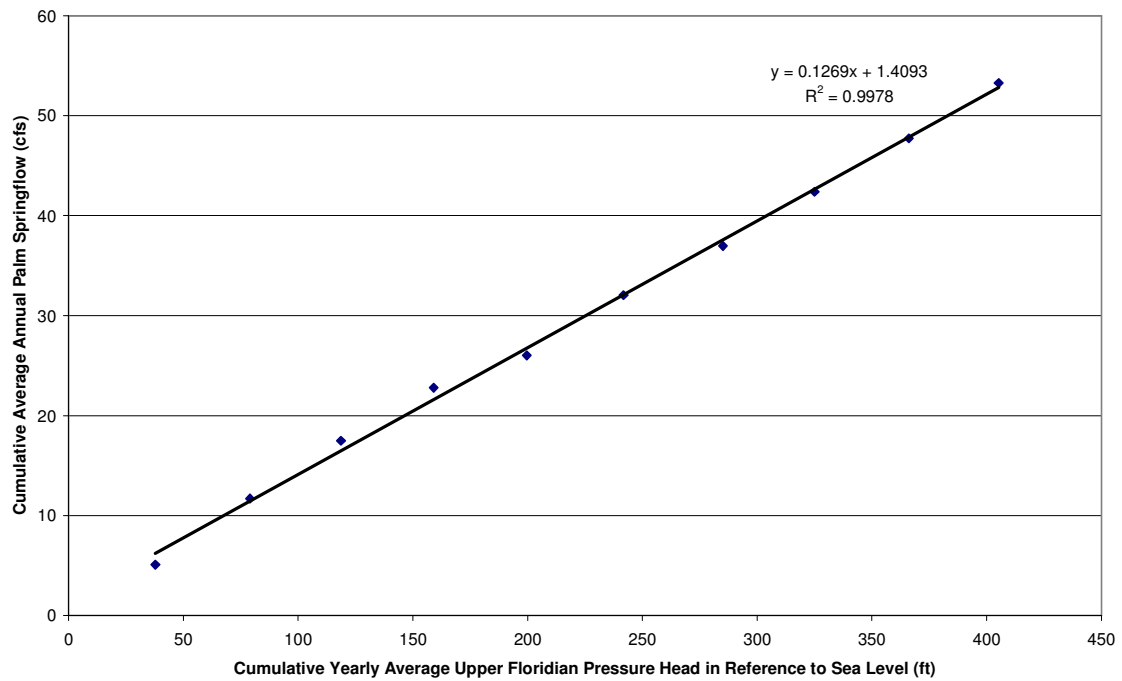
FIGURE 12.5 - Double Mass Diagram Palm Springflow vs Pressure Head
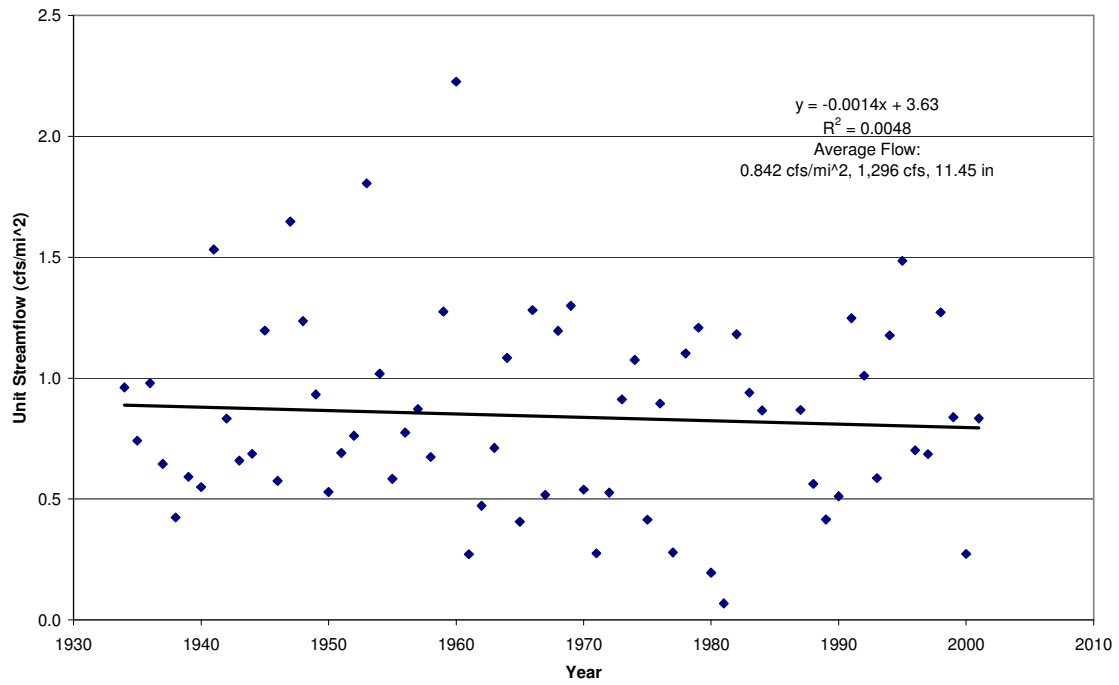
FIGURE 13.1 - 02232500 Unit Streamflow vs time
[ST. JOHNS RIVER NR CHRISTMAS]
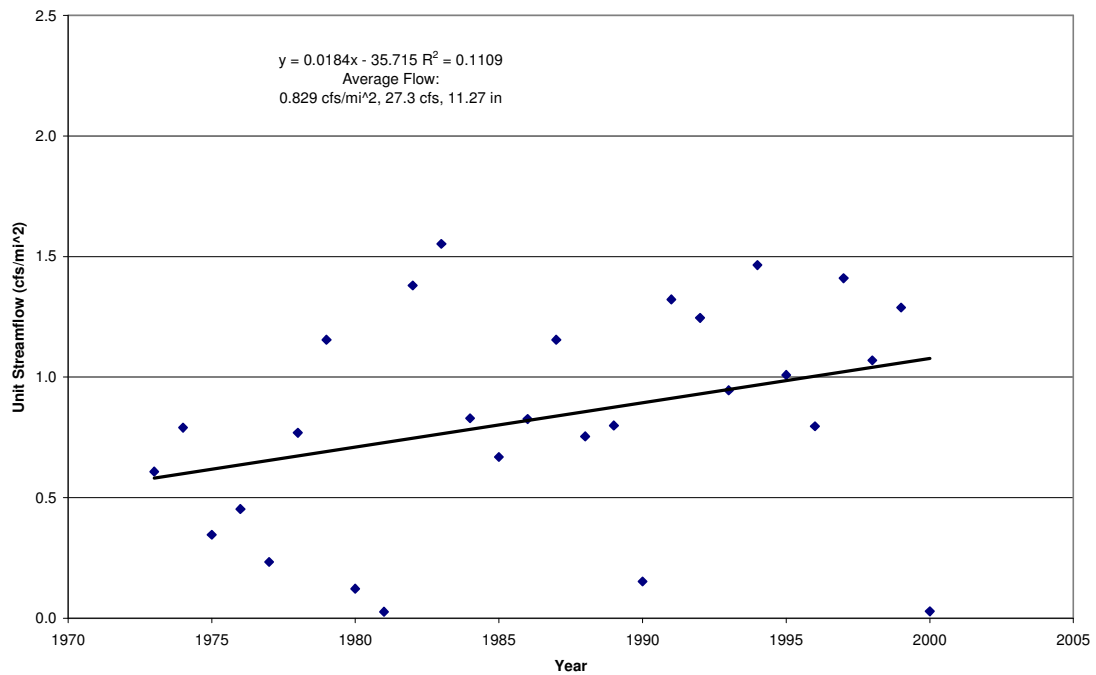
FIGURE 13.2 - 02233001 Unit Streamflow vs time
[ECONLOCKHATCHEE R AT MAGNOLIA RANCH NR BITHLO]

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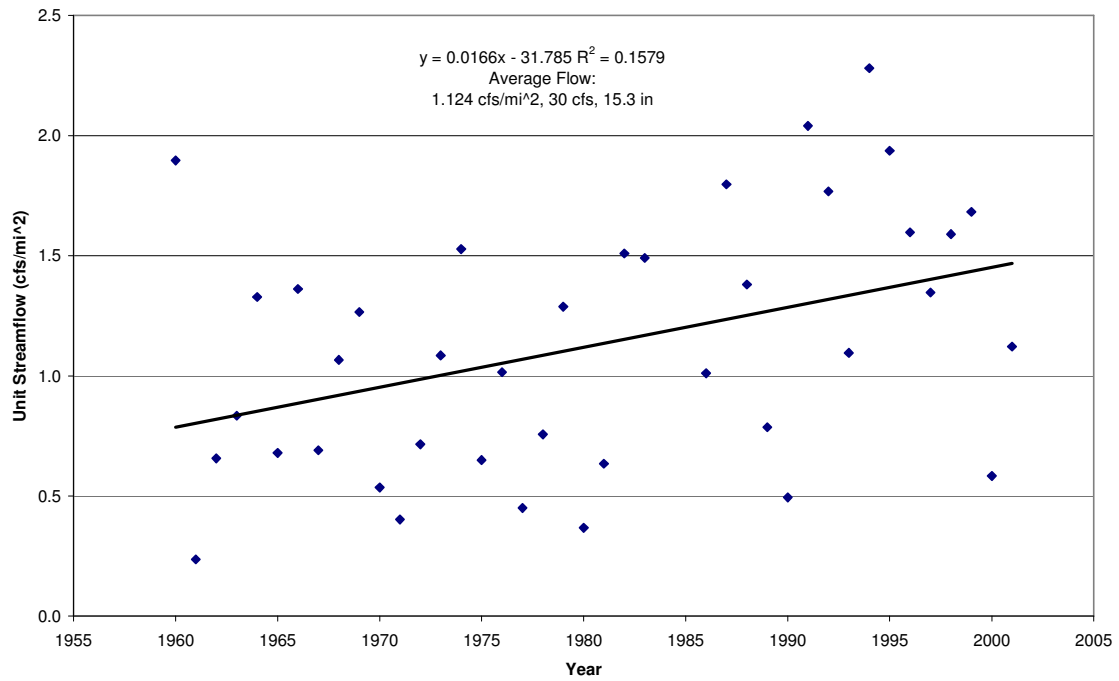
**FIGURE 13.3 - 02233200 Unit Streamflow vs time
[LITTLE ECONLOCKHATCHEE R NR UNION PARK]**
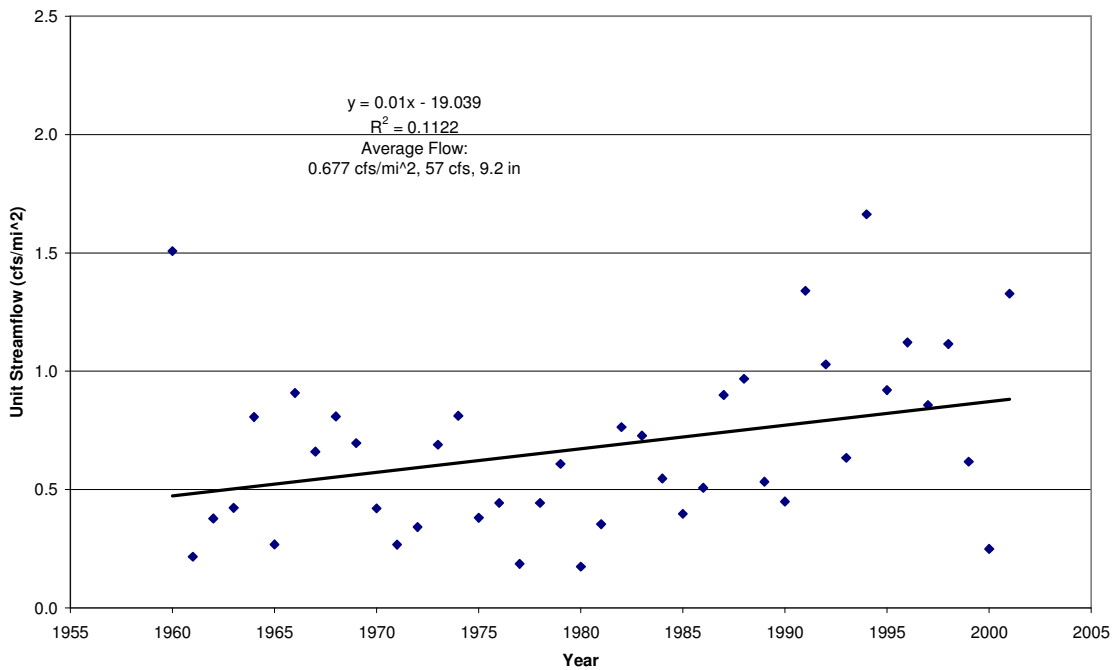
**FIGURE 13.4 - 02262900 Unit Streamflow vs time
[BOGGY CREEK NR TAFT]**

120
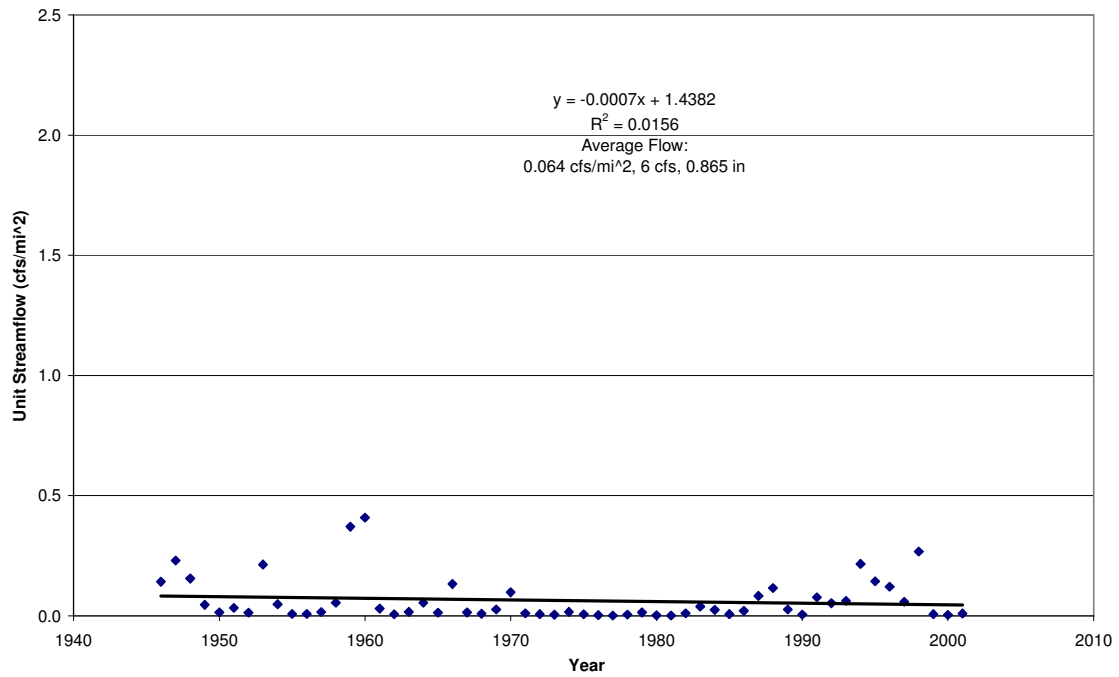
FIGURE 13.5 - 02264000 Unit Streamflow vs time
[CYPRESS CREEK AT VINELAND]
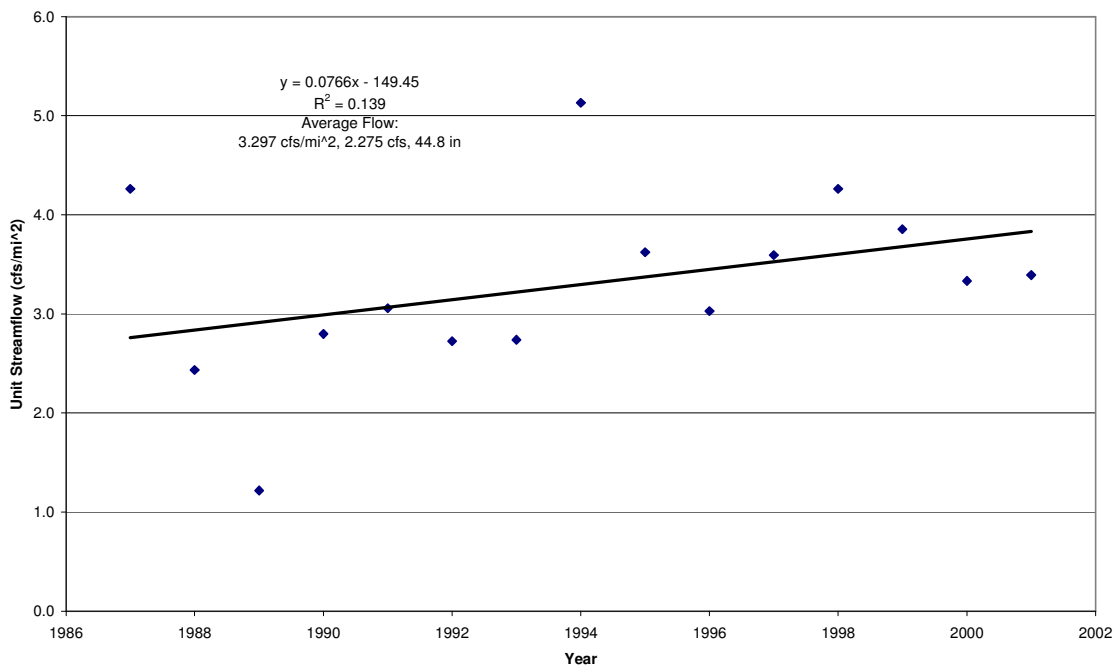
FIGURE 13.6 - 02264051 Unit Streamflow vs time
[BLACK LAKE OUTLET AT S-101A AT BUENA VISTA]

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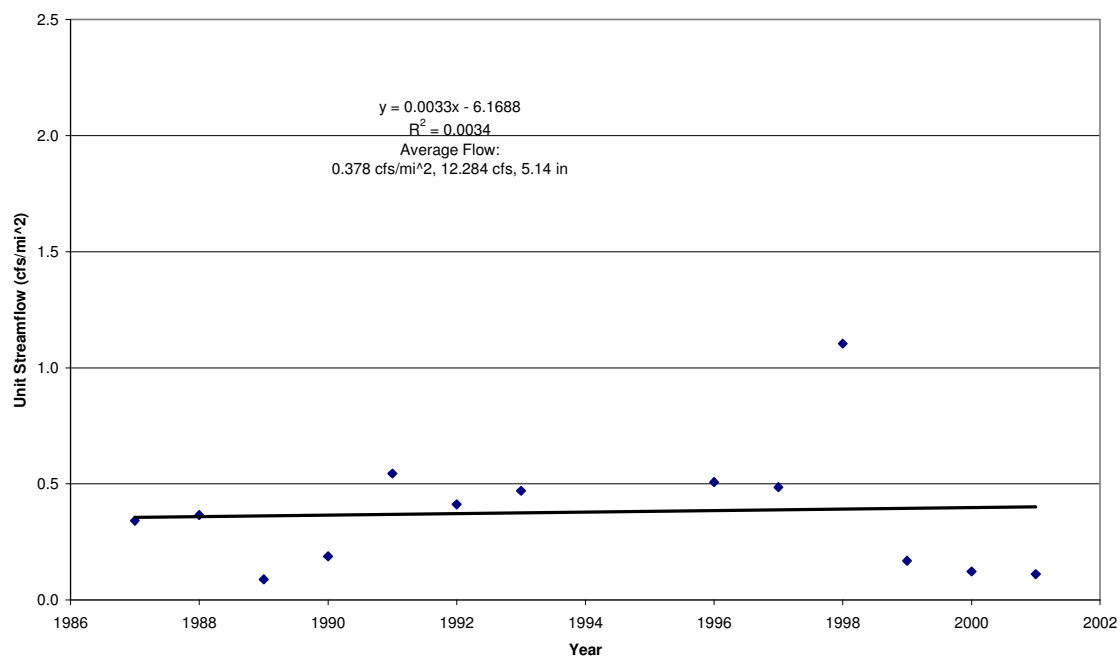
FIGURE 13.7 - 02264060 Unit Streamflow vs time
[LATERAL 101 AT S-101 NR BUENA VISTA]

$y = 0.0033x - 6.1688$
$R^2 = 0.0034$
Average Flow:
0.378 cfs/mi^2, 12.284 cfs, 5.14 in
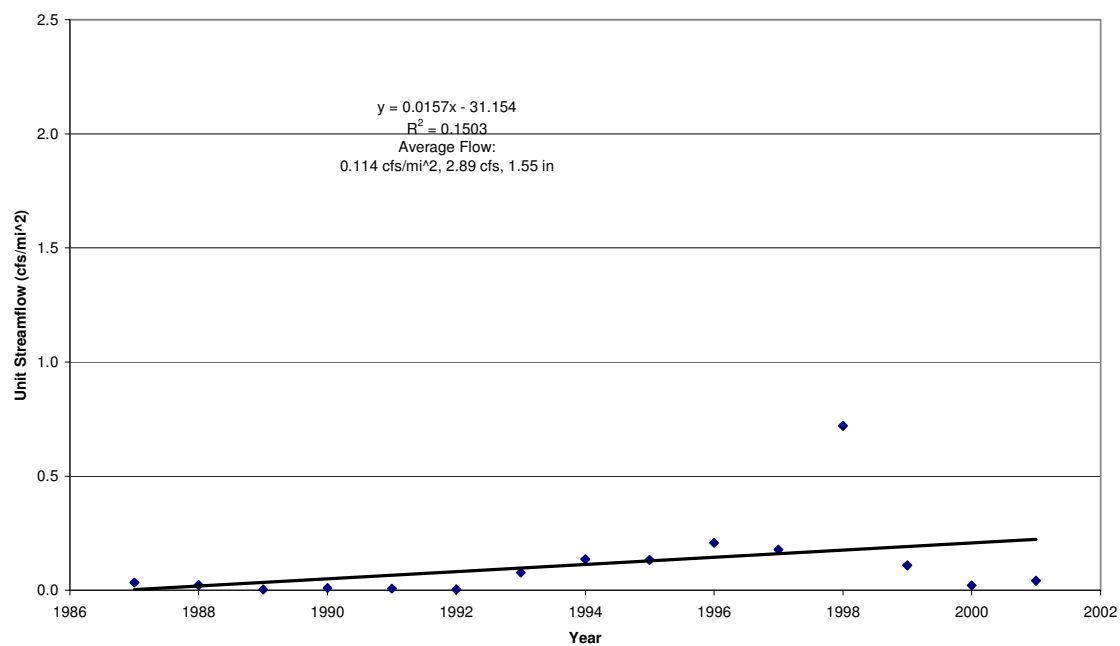
FIGURE 13.8 - 02266025 Unit Streamflow vs time
[REEDY CREEK AB S-46, NR VINELAND]

$y = 0.0157x - 31.154$
$R^2 = 0.1503$
Average Flow:
0.114 cfs/mi^2, 2.89 cfs, 1.55 in

122
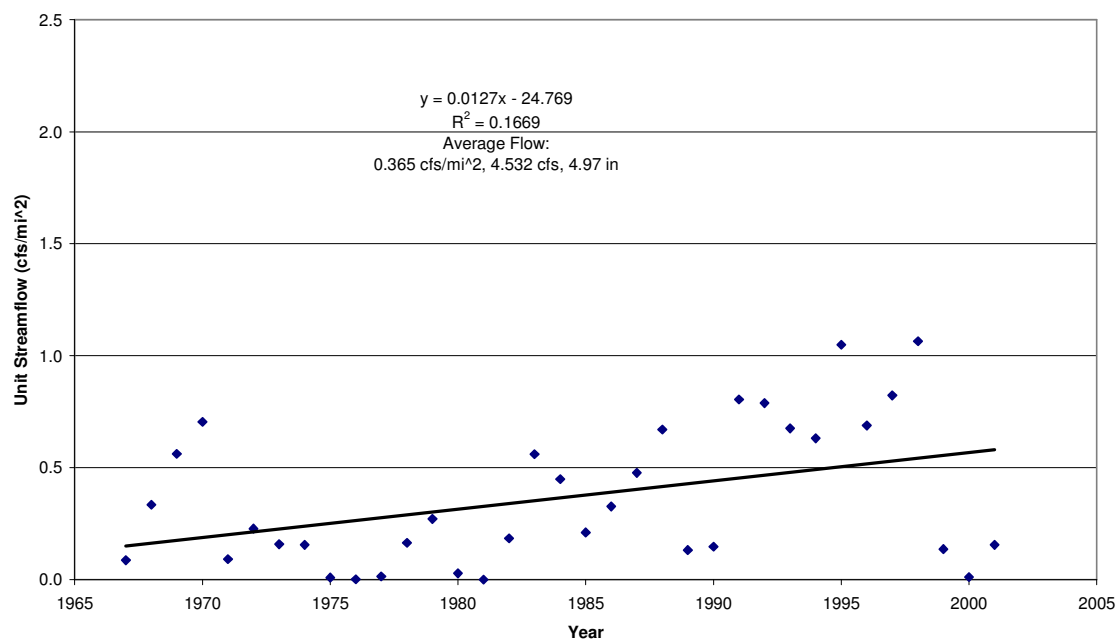
FIGURE 13.9 - 02266200 Unit Streamflow vs time
[WHITTENHORSE CREEK NR VINELAND]
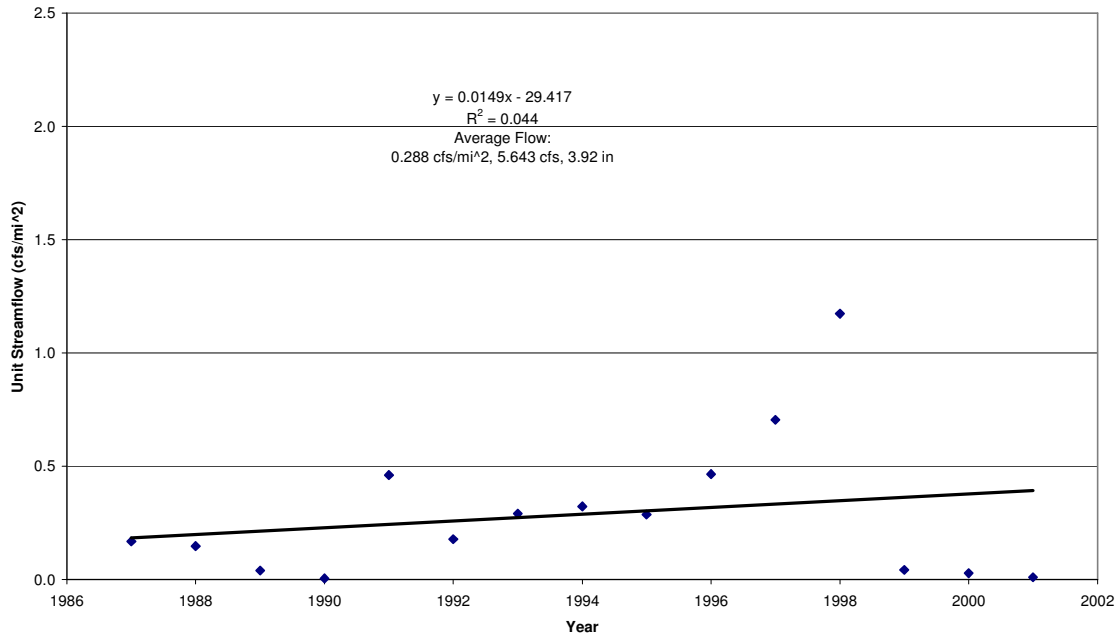
FIGURE 13.10 - 02266291 Unit Streamflow vs time
[LATERAL-405 AB S-405A, NR DOCTOR PHILLIPS]

123
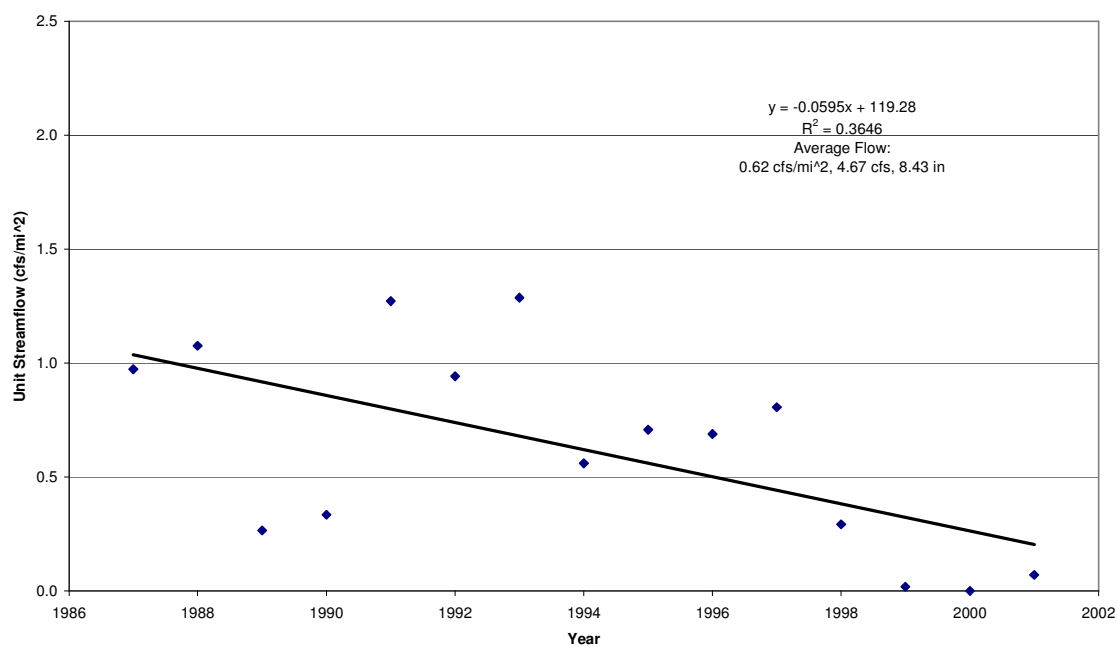
FIGURE 13.11 - 02266295 Unit Streamflow vs time
[10B LATERAL 410 AT S-410 NR VINELAND]
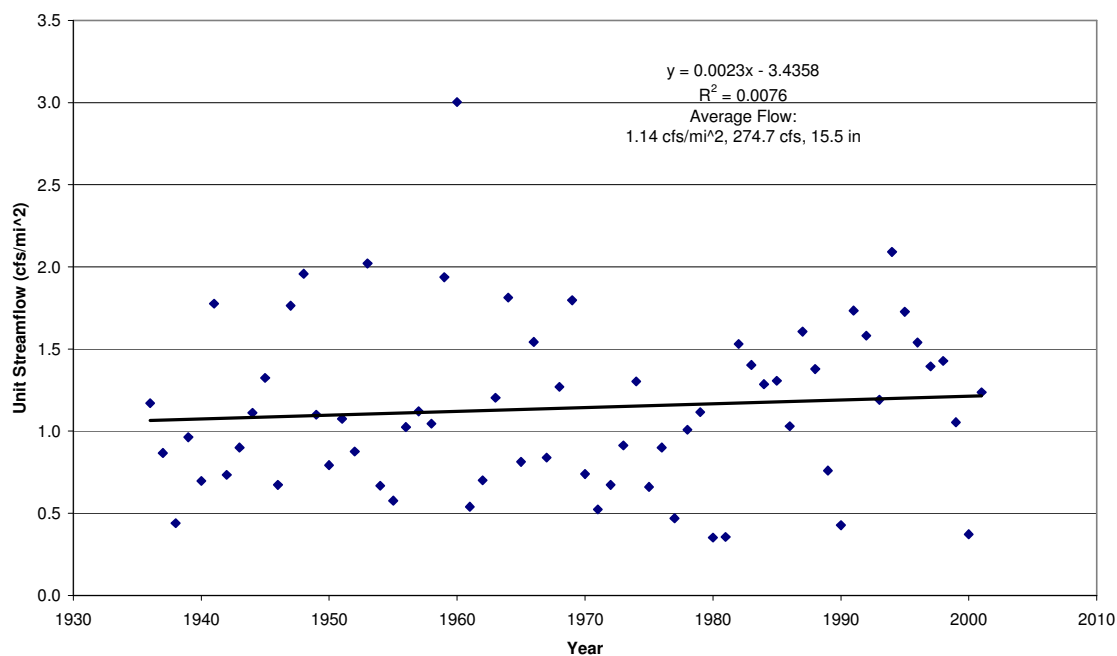
FIGURE 13.12 - 02233500 Unit Streamflow versus Time
[ECONLOCKHATCHEE RIVER NR. CHULUOTA]

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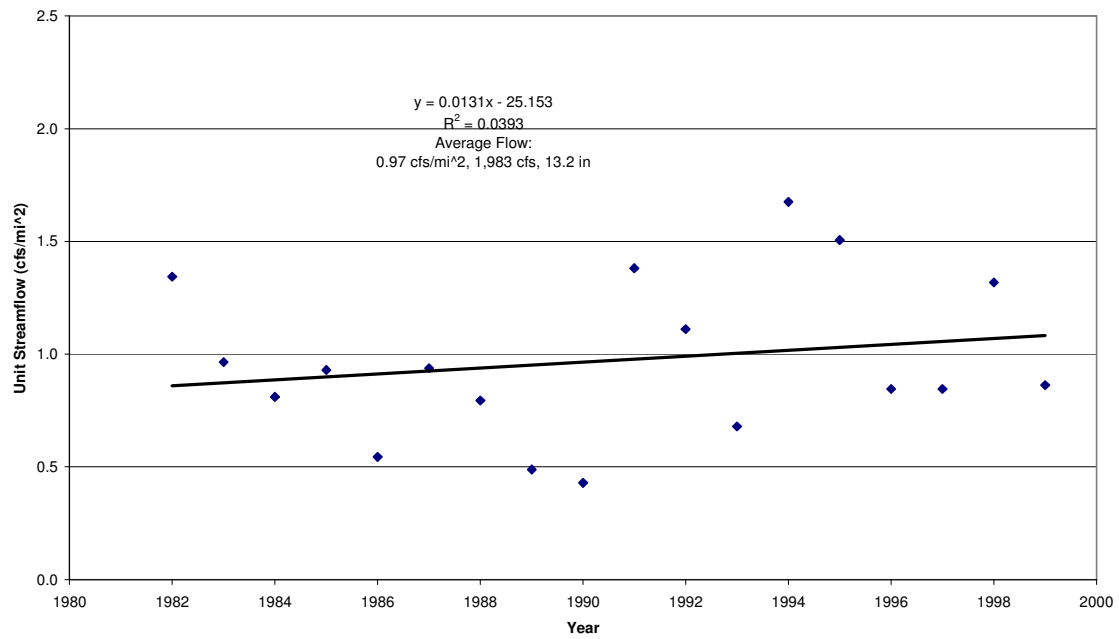
FIGURE 13.13 - 02234000 Unit Streamflow versus Time
[ST. JOHNS RIVER ABOVE LAKE HARNEY NR GENEVA]

$y = 0.0131x - 25.153$
$R^2 = 0.0393$
Average Flow:
0.97 cfs/mi^2, 1,983 cfs, 13.2 in
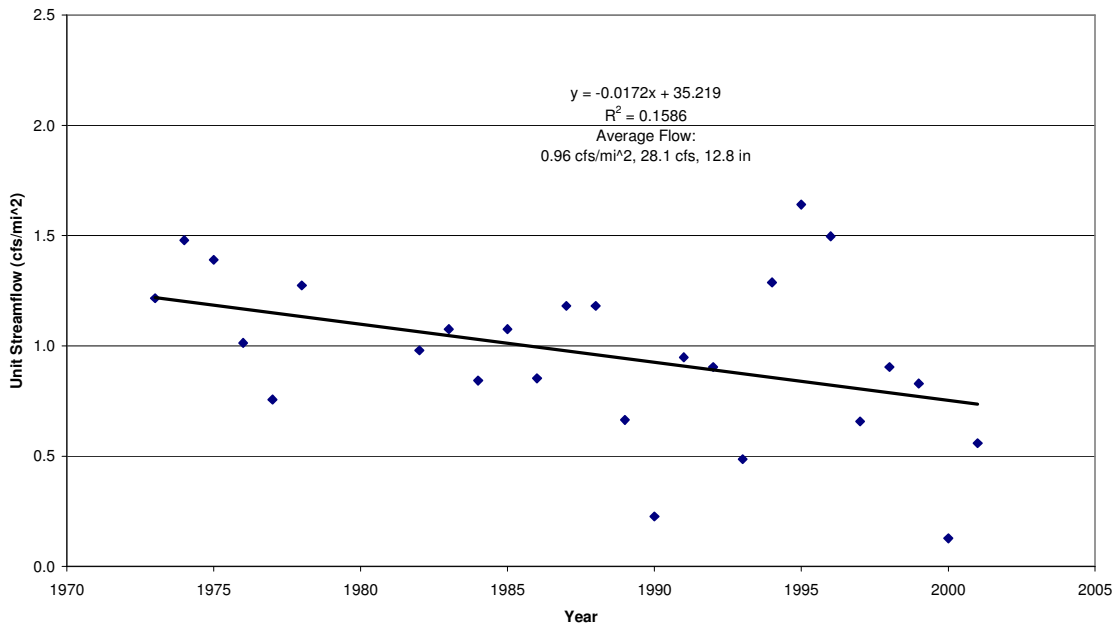
FIGURE 13.14 - 02234324 Unit Streamflow versus Time
[HOWELL CREEK NR SLAVIA]

$y = -0.0172x + 35.219$
$R^2 = 0.1586$
Average Flow:
0.96 cfs/mi^2, 28.1 cfs, 12.8 in

125
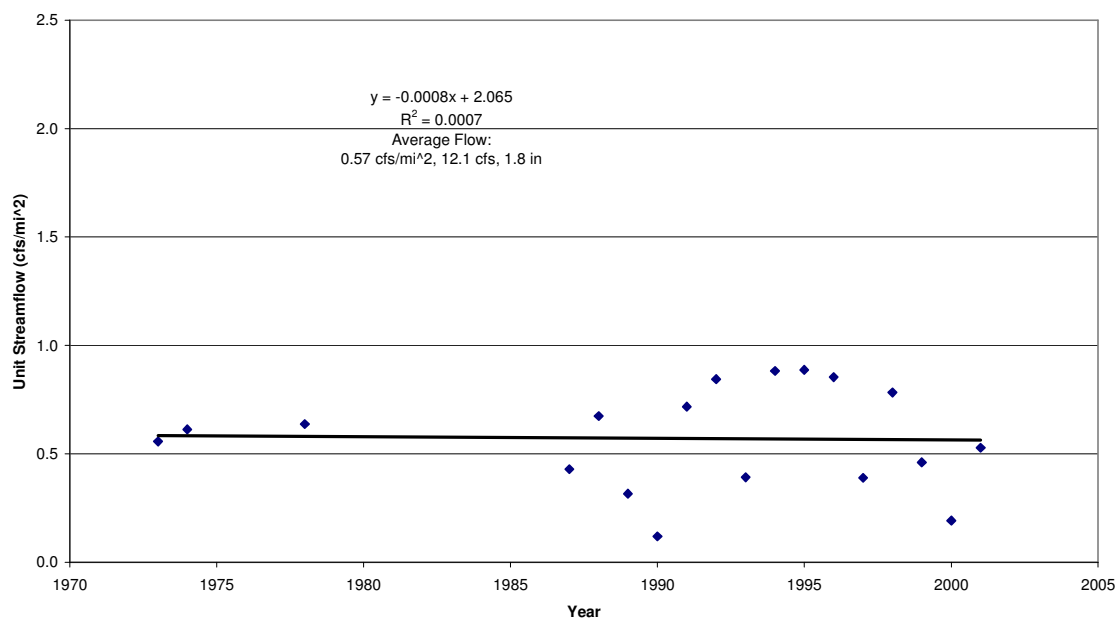
FIGURE 13.15 - 02234384 Unit Streamflow versus Time
[SOLDIER CREEK NR LONGWOOD]
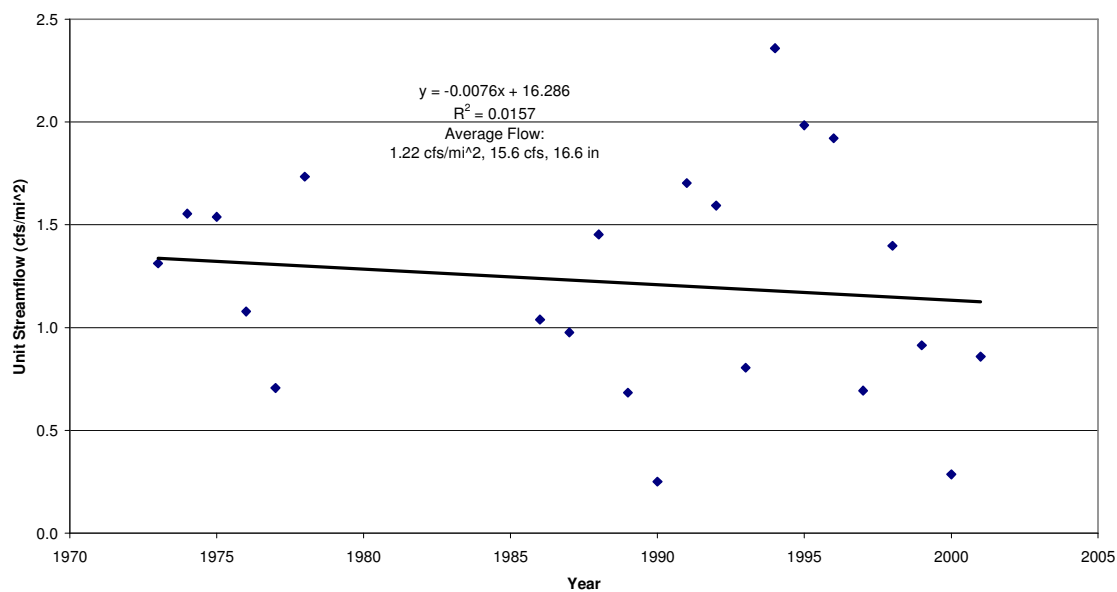
FIGURE 13.16 - 02234400 Unit Streamflow versus Time
[GEE CREEK NR LONGWOOD]

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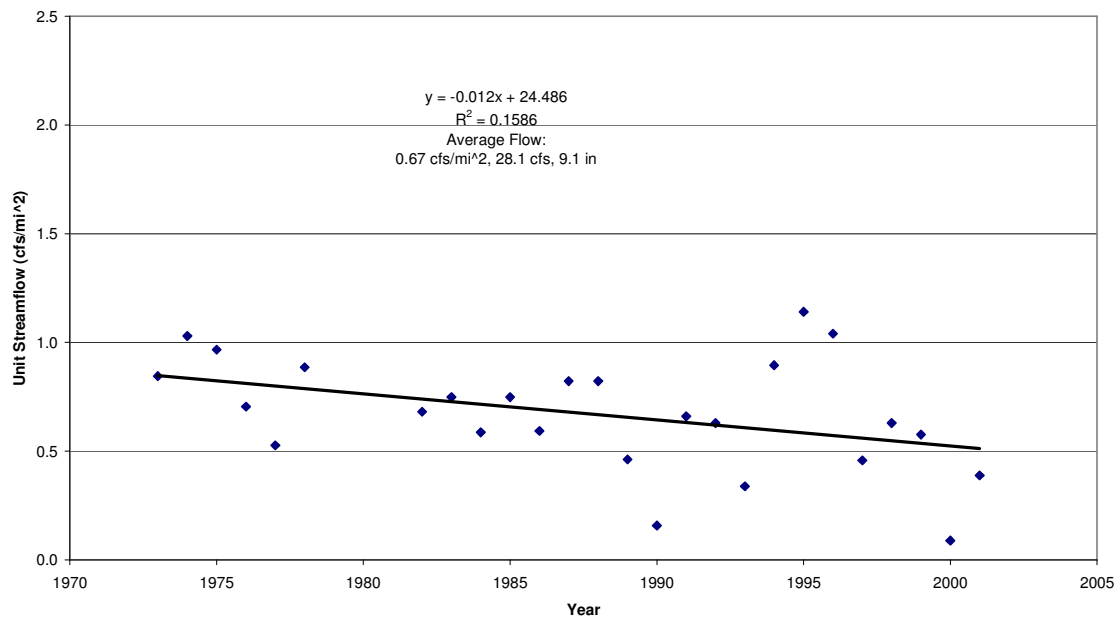
**FIGURE 13.17 - 02234990 Unit Streamflow versus Time
[LITTLE WEKIVA RIVER NR ALTAMONTE SPRINGS]**
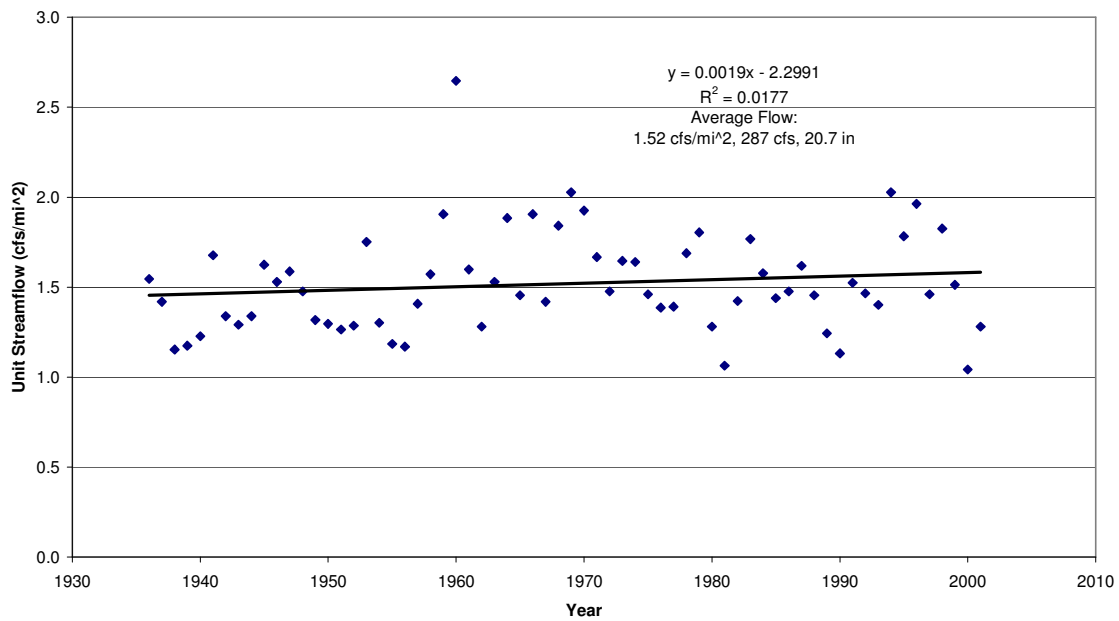
**FIGURE 13.18 - 02235000 Unit Streamflow versus Time
[WEKIVA RIVER NR SANFORD]**

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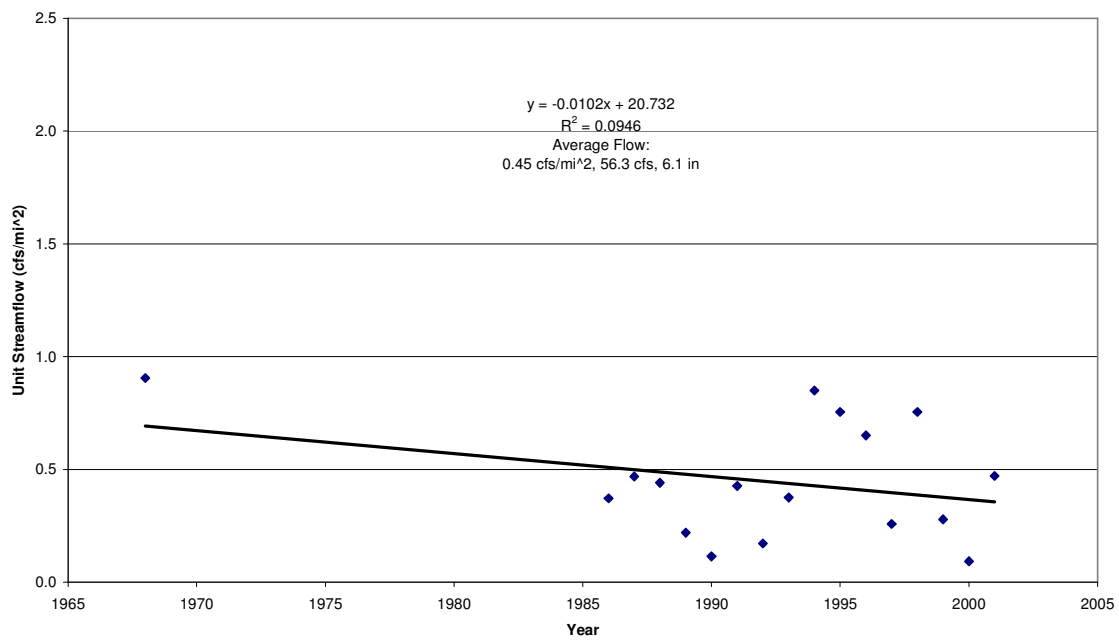
FIGURE 13.19 - 02235200 Unit Streamflow vs Time
[BLACKWATER CREEK NEAR CASSIA]
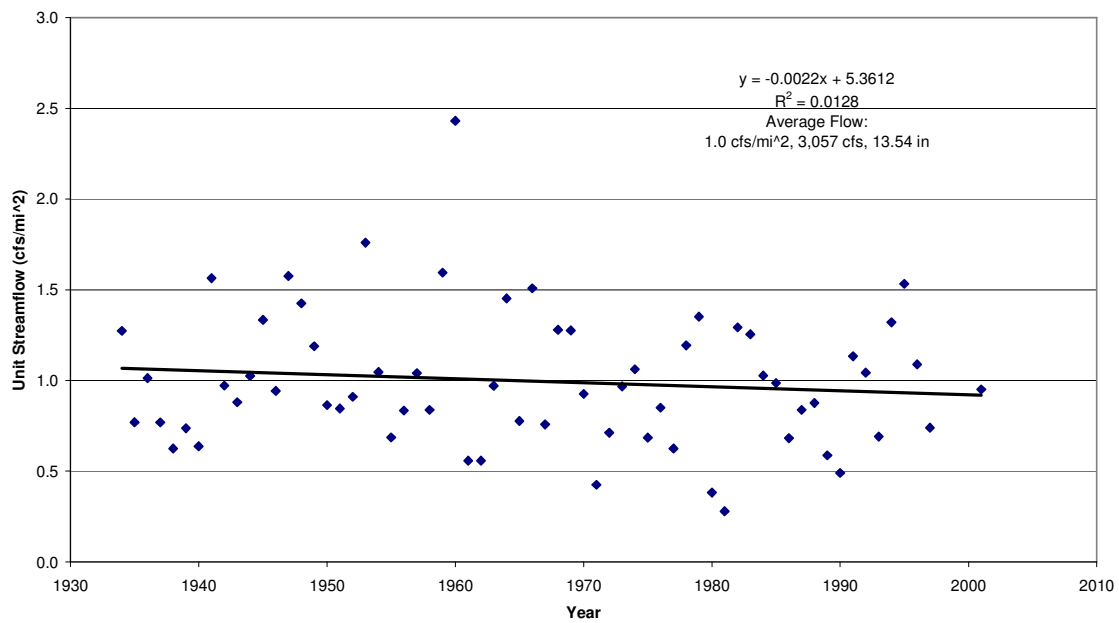
FIGURE 13.20 - 02236000 Unit Streamflow vs Time
[ST. JOHNS RIVER NR DELAND]

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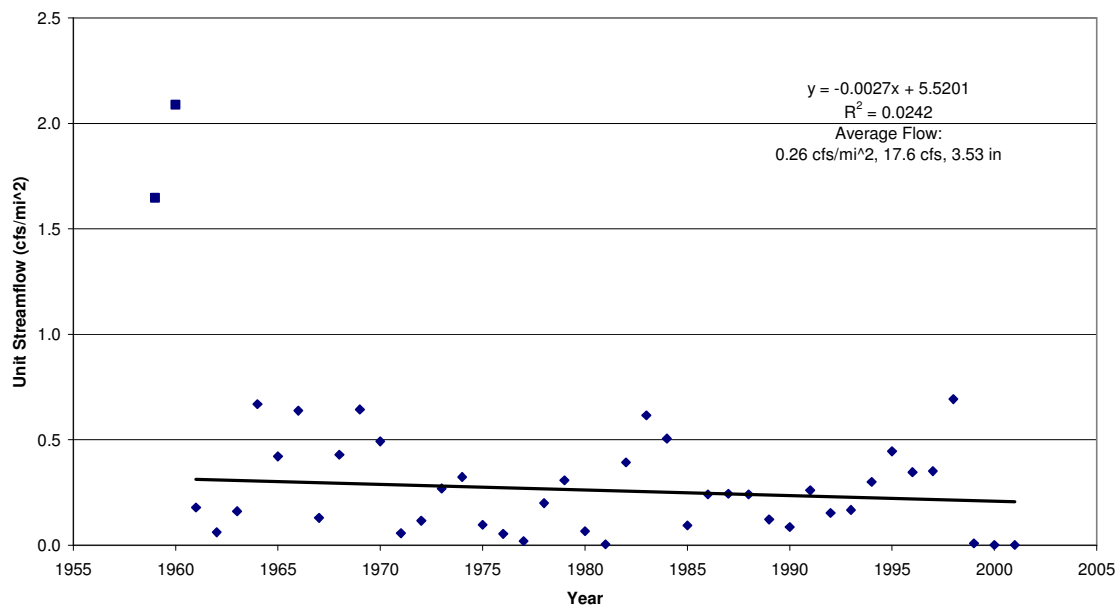
FIGURE 13.21 - 02236500 Unit Streamflow vs Time
[BIG CREEK NR CLERMONT]
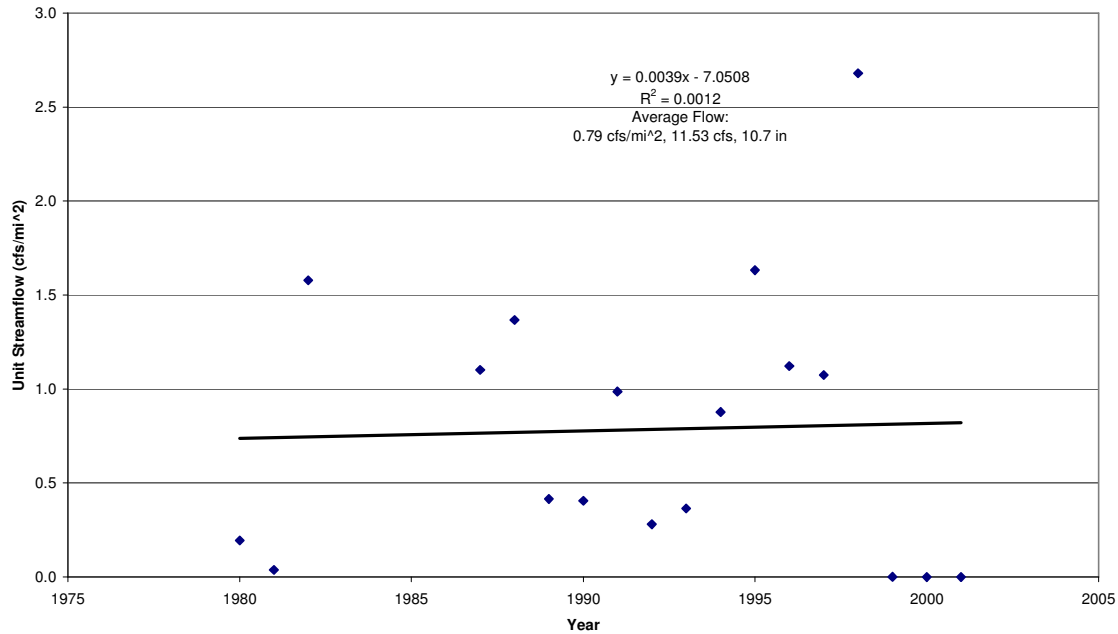
FIGURE 13.22 - 02236700 Unit Streamflow vs Time
[LITTLE CREEK NR CLERMONT]

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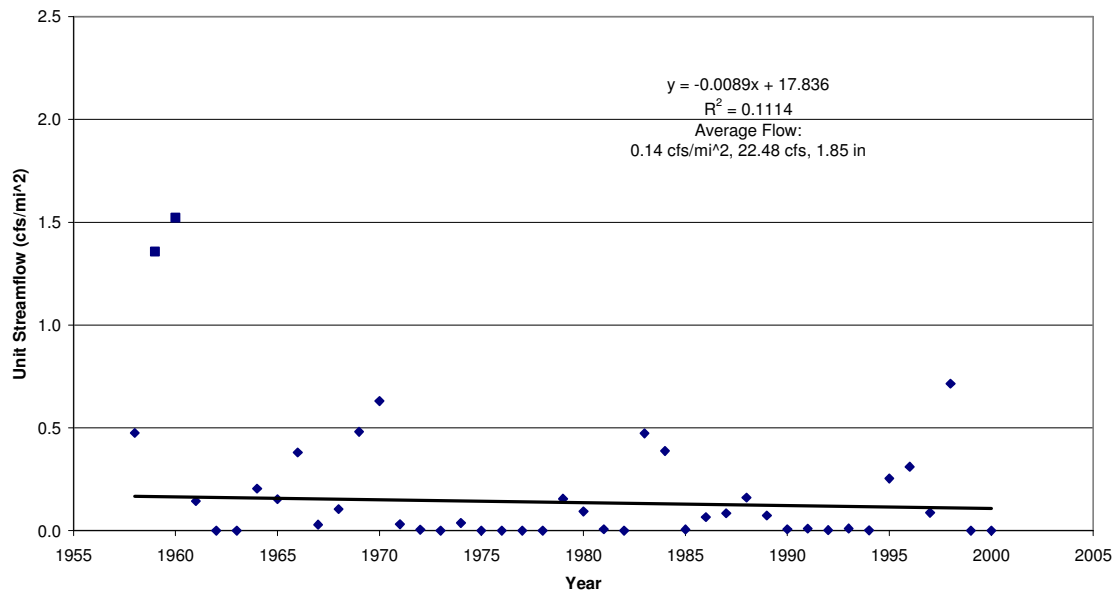
FIGURE 13.23 - 02236900 Unit Streamflow vs Time
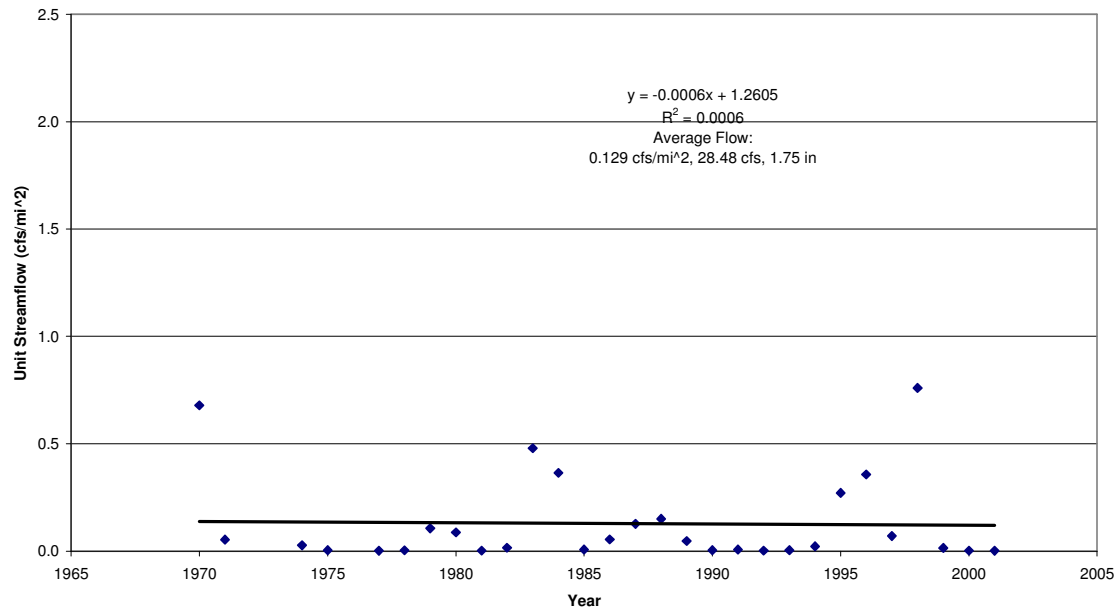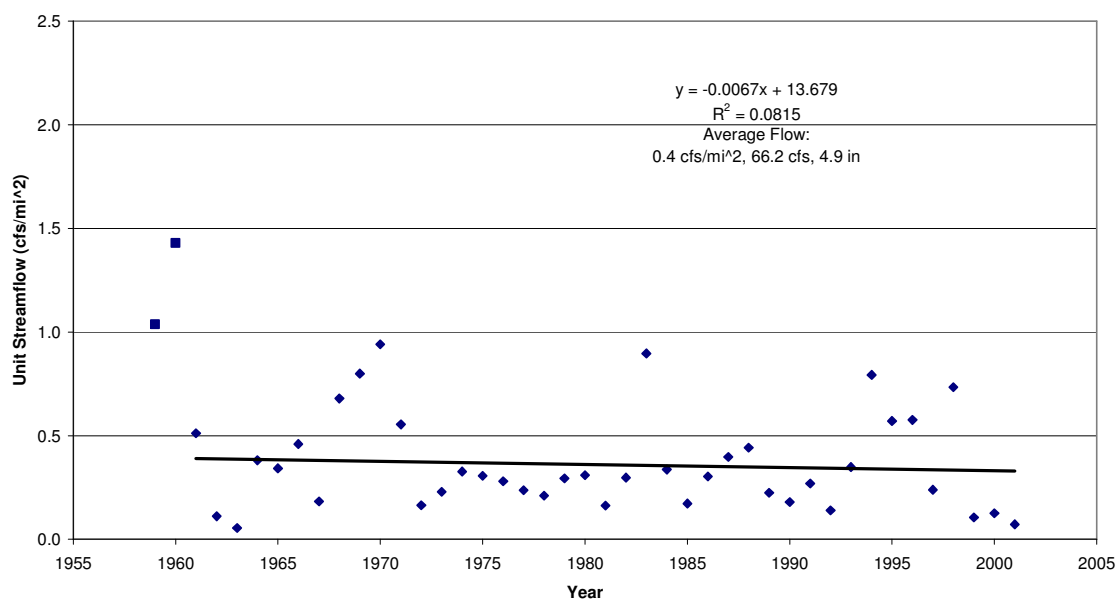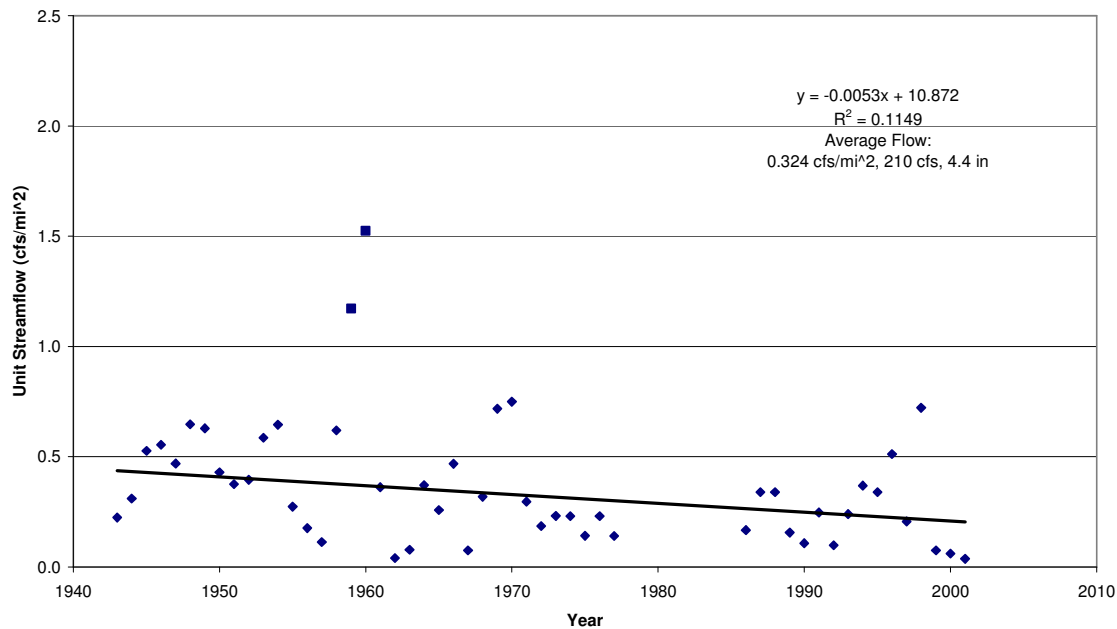**[PALATLAKAHA R AT CHERRY LK OUT NR GROVELAND]**

FIGURE 13.24 - 02237293 Unit Streamflow vs Time
[PALATLAKAHA R AT STRUCT M-1, NR OKAHUMPKA]

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FIGURE 13.25 - 02237700 Unit Streamflow vs Time
[APOPKA-BEAUCLAIR CANAL NR ASTATULA]

FIGURE 13.26 - 02238000 Unit Streamflow vs Time
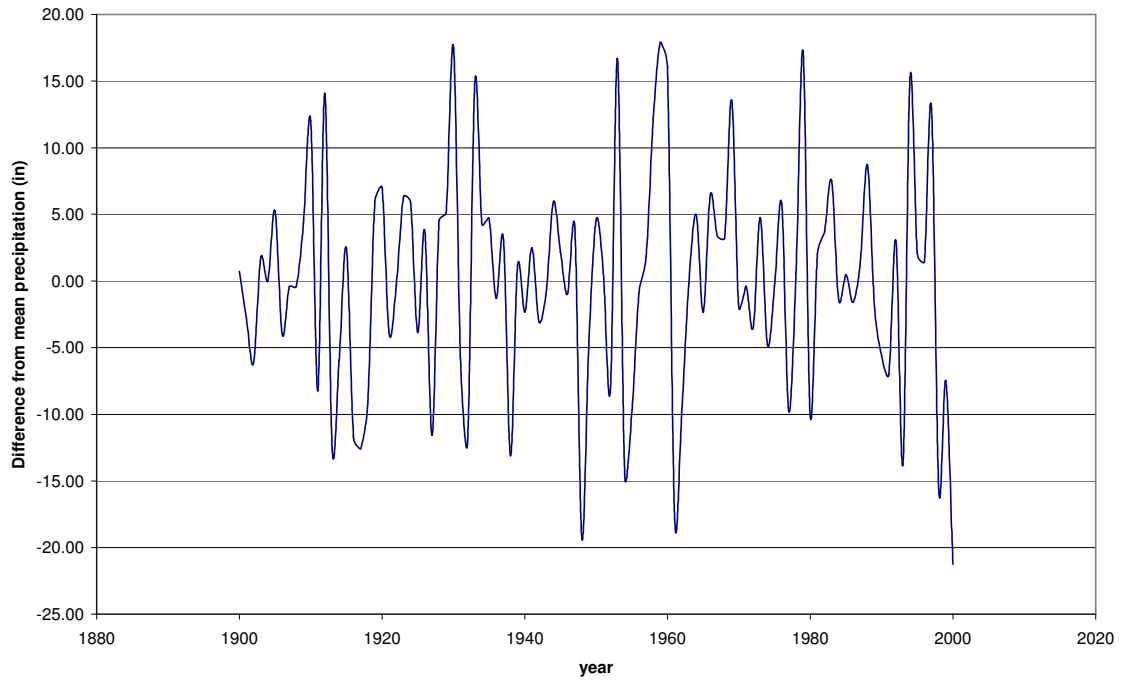**[HAINES CREEK AT LISBON]**

FIGURE 14.1 - Clermont Annual Precipitation Difference from average of 50.17 in with a standard deviation of 8.48.
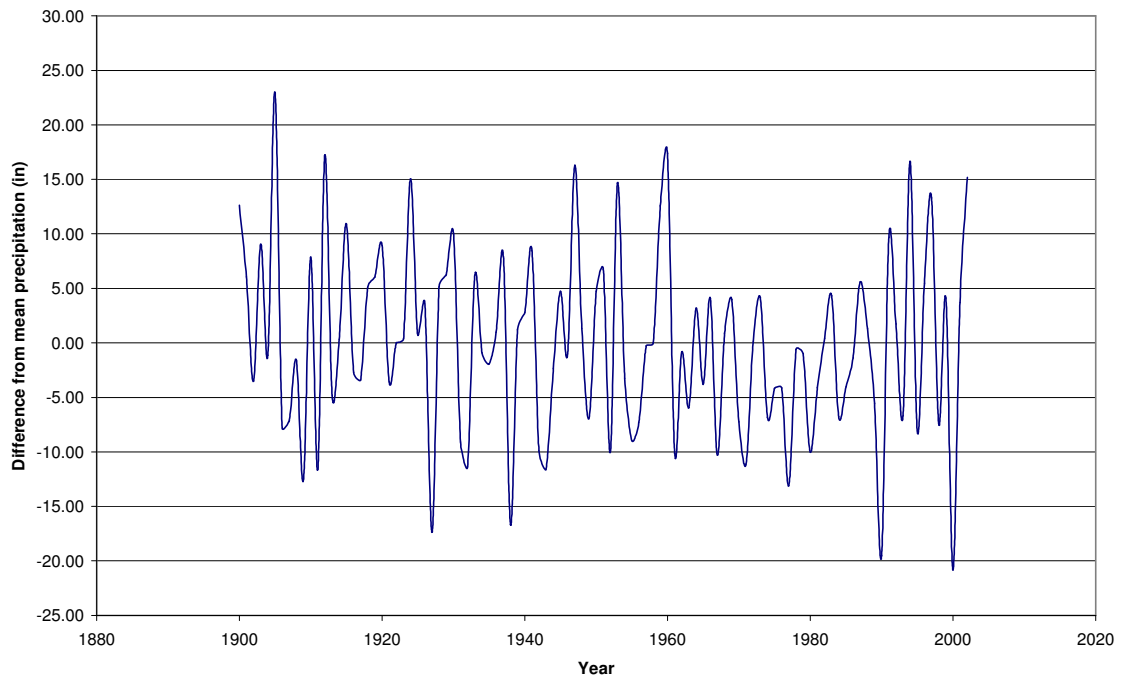

FIGURE 14.2 - Orlando Annual Precipitation Difference from average of 51.21 in with a standard deviation of 8.68.
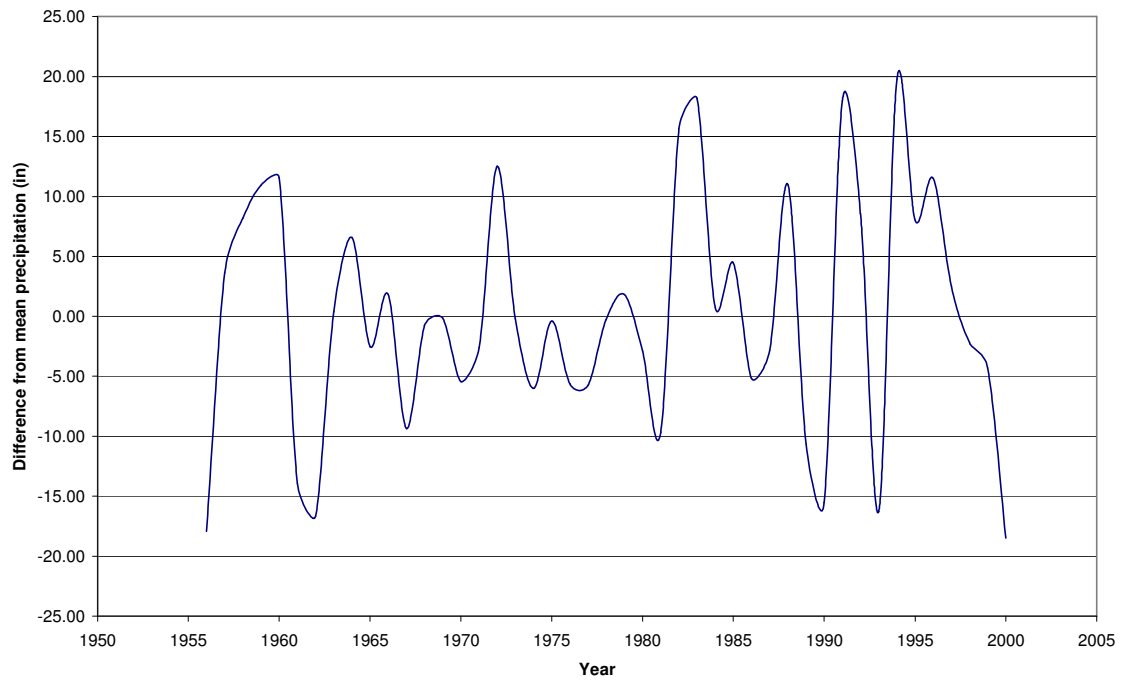
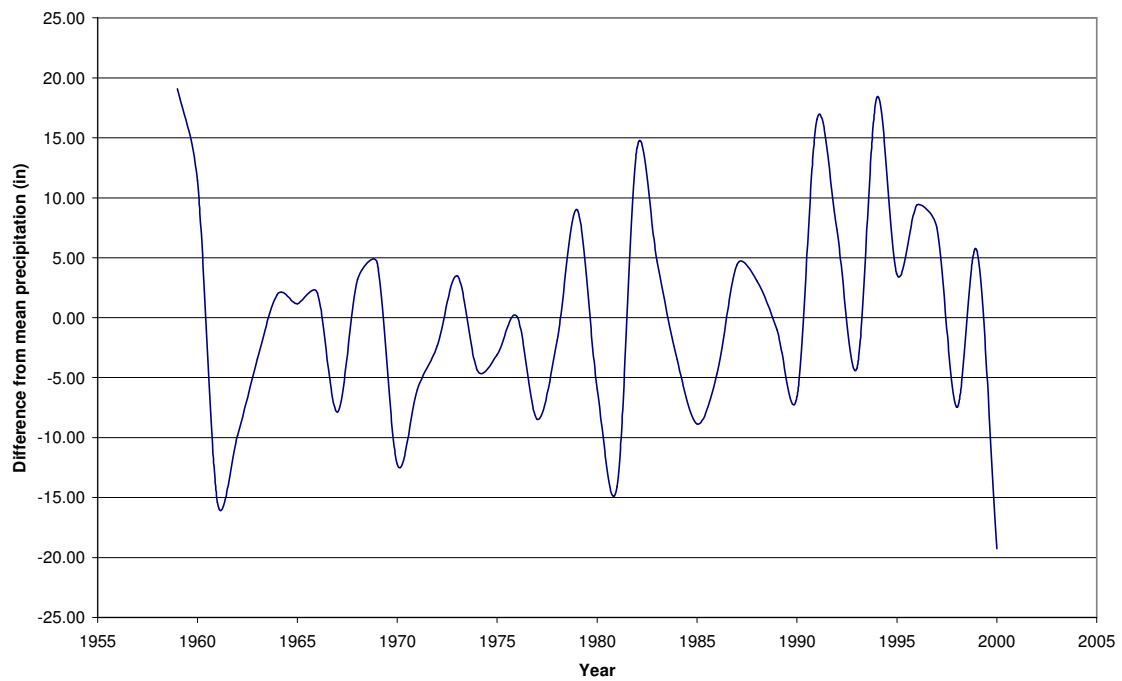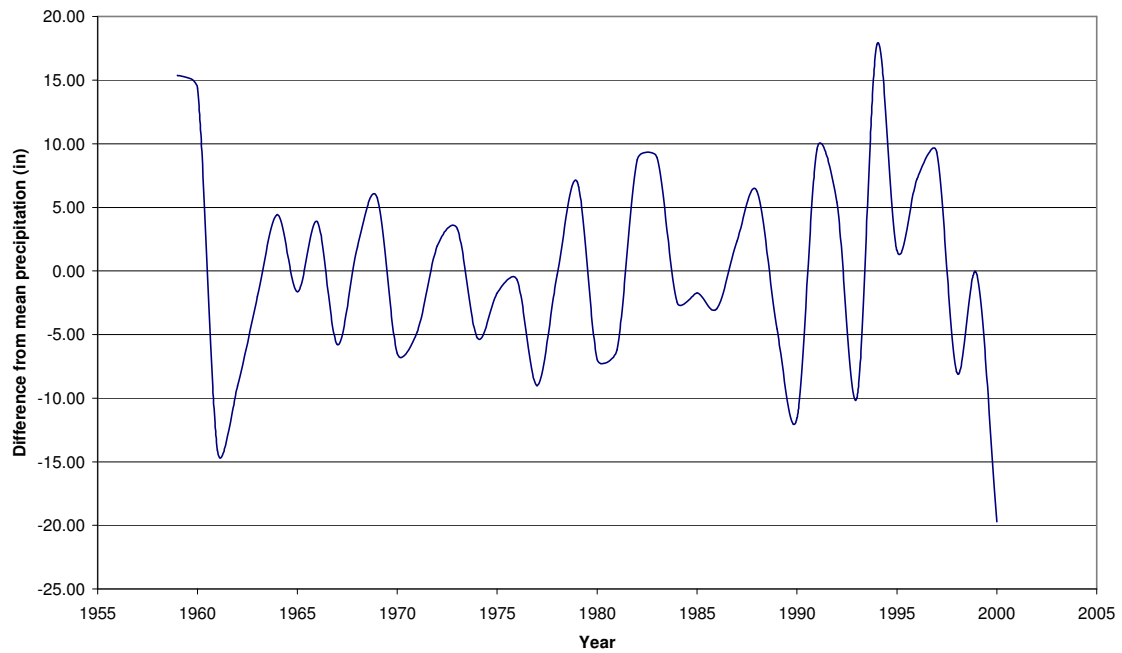**FIGURE 14.3 - Sanford Annual Precipitation Difference from average of 51.33 in with a standard deviation of 9.99.**
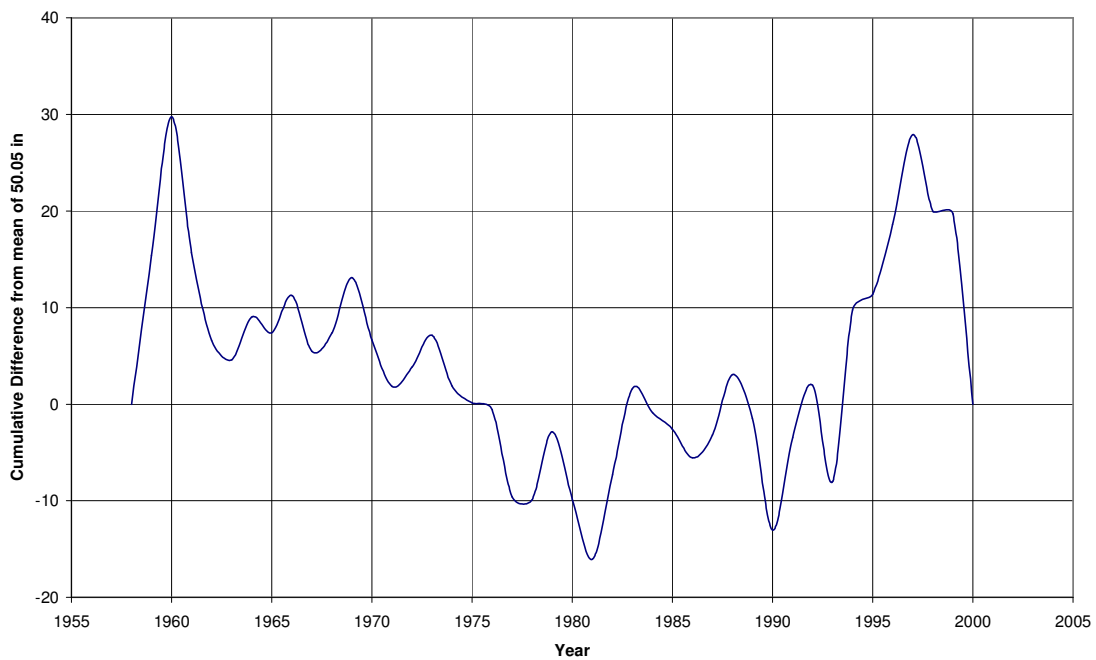

FIGURE 14.4 - Lisbon Annual Precipitatoin Difference from average of 48.52 in with a standard deviation of 8.93.

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**FIGURE 14.5 - Annual Precipitation Difference about 50.05 in
(average of Clermont, Orlando, Sanford, Lisbon) with a standard deviation of 8.06.**

**FIGURE 14.6 - Cumulative Annual Precipitation Difference about 50.05 in
(average of Clermont, Orlando, Sanford, Lisbon) with a standard deviation of 10.43.**

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