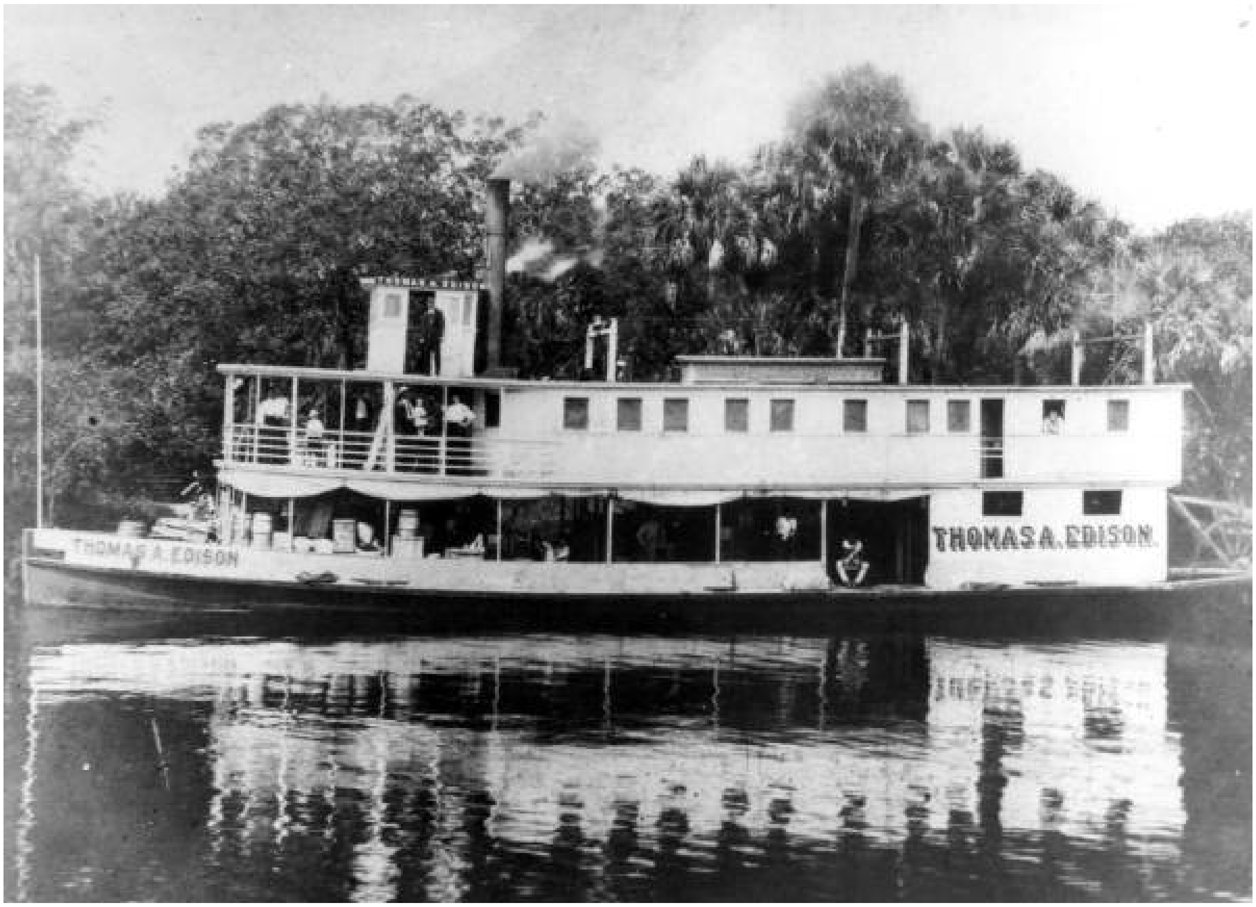
Florida River Flow Patterns and the Atlantic Multidecadal Oscillation



The Thomas A. Edison steamer on the Caloosahatchee River circa 1904.
From the Florida Photographic Collection

Draft Report
Ecologic Evaluation Section
Southwest Florida Water Management District
August 10, 2004

TABLE OF CONTENTS

Florida River Flow Patterns and the Atlantic Multidecadal Oscillation

Author: Martin Kelly, Manager
Ecologic Evaluation Section
Southwest Florida Water Management District
2379 Broad Street
Brooksville, Florida 34604-6899
E-mail: marty.kelly@swfwmd.state.fl.us

This document has been reviewed by:
David Moore, Executive Director
Bill Bilenky, SWFWMD General Counsel
Bruce Wirth, Deputy Executive Director
Gregg Jones, Director, Res. Cons. and Dept.
Mike Heyl, Doug Leeper -- Ecologic Evaluation Section
Mark Barcelo, Ron Basso – Hydrologic Evaluation Section
David Tomasko – Environmental Section
Harry Downing – Engineering Section

List of Figures

List of Tables

EXECUTIVE SUMMARY

This report contains essentially three parts. It begins with a discussion of river flow patterns throughout Florida, showing a south to north difference in the timing or seasonality of flows. It then discusses changes in stream flow due to differences in rainfall as influenced by the Atlantic Multidecadal Oscillation (AMO) showing how this causes a significant multidecadal south to north difference in river flow volumes across Florida. Finally significant differences in flows are discussed for a select number of sites in the Southwest Florida Water Management District with emphasis on how climate and anthropogenic factors have affected these river flows.

While much of Florida has a summer monsoon, the north to northwest portion of the state experiences higher flows in the spring similar to most of the southeast United States. Differences in flow have been highlighted by a graphical approach not routinely used. By constructing plots of median daily flows (in cubic feet per second), it was possible to develop hydrographs of river flow patterns that clearly reveal the seasonal flow pattern that can be expected. By dividing median daily flows by the upstream watershed area, flows could be directly compared between watersheds of varying size. One of the more interesting features evident from this presentation was the existence of a distinctly bimodal flow pattern which characterizes a number of streams in a rather narrow geographic transition band that extends from the Georgia-Florida border in the northeastern part of the state where the St. Mary's River discharges into the Atlantic Ocean and stretches in a generally southwest direction towards the mouth of the Suwannee River in the Big Bend area. Both the Wacasassa River to the south of the Suwannee River and the Steinhatchee River to the north display bimodal flow patterns. Rivers south of this line (most of peninsular Florida) exhibit highest flows in the summer, while those north of the line exhibit highest flows in the spring.

The discussion of flow patterns is followed by a consideration of the Atlantic Multidecadal Oscillation (AMO), a name applied to denote long-term oscillations in the sea surface temperature of the North Atlantic Ocean and how it affects river flow patterns temporally over multidecadal periods. Based on an emerging body of research, climatologists now believe that multidecadal periods of warming and cooling of the North Atlantic Ocean's surface waters ultimately affect precipitation patterns across much of the United States. Since river flows are largely rainfall dependent, variation in rainfall should result in variations in river flows as well. Multidecadal periods consistent with warming and cooling phases of the AMO were examined for numerous gage sites within the District, the state, and the southeastern United States to discern if increases and decreases in river flows were likewise consistent with these multidecadal periods. For those sites with an adequate period of record, plots of median daily flows were compared. Flow increases and decreases in the northern part of the state and flow decreases in peninsular Florida are consistent with the AMO and the

reported relationship with rainfall. When rivers in peninsular Florida were in a multidecadal period of higher flows (1940 to 1969), rivers in the north to northwestern part of the state were in a low flow period. Conversely rivers in peninsular Florida exhibited generally lower flows (1970 to 1999) when rivers in the northern portion of the state exhibited higher flows. Examination of streams with a bimodal flow pattern offered particularly strong supporting evidence for a distinct difference in flows between northern and southern rivers, since changes in the spring mode behaved similarly to changes in northern river flows while changes in the summer mode behaved similarly to flow changes in southern rivers.

The AMO suggests that a step trend rather than a monotonic trend should be expected in rainfall and river flows. While several authors have examined stream flow patterns in anticipation of monotonic trends, data were tested for a step change in flows as well. Statistical evidence is presented demonstrating a step change in both rainfall (for sites in south-central Florida) and river flows that is consistent with a step in warming and cooling phases of the AMO. It is demonstrated that many of the observed decreasing flow trends reported for rivers in the SWFWMD are consistent with a step trend. A Kendall's tau test of pre and post periods (1940 to 1969 and 1970 to 1999) suggests no trends in flow in either period for many cases, while a Mann-Whitney test of the two periods indicates a significant difference in flows between the two periods.

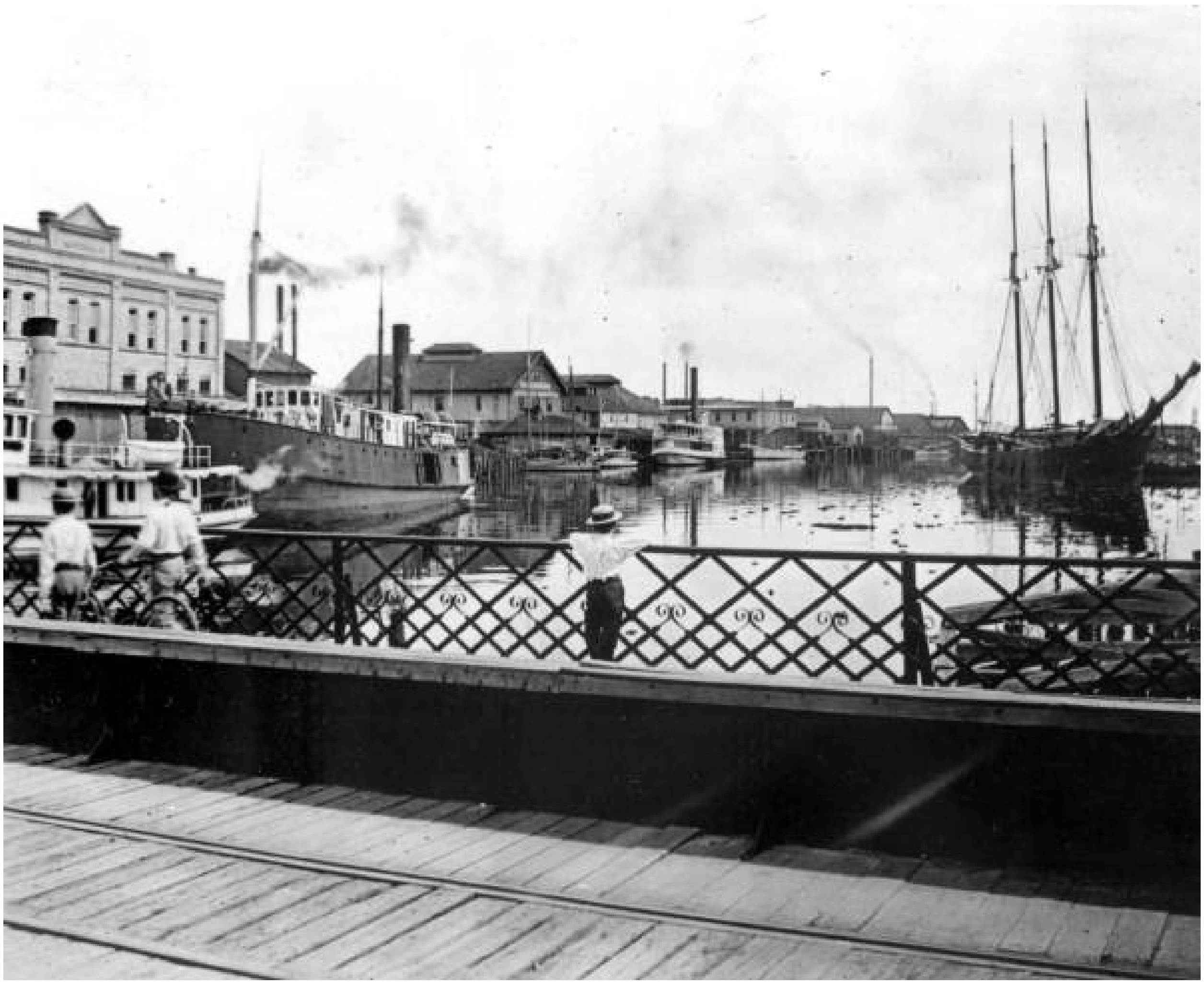
This work does not suggest that monotonic trends and human induced changes in flow have not occurred; several examples of such monotonic trends are discussed. However, it is demonstrated that several decreasing trends which have been assumed to be anthropogenic and monotonic are more easily explained as a natural step trend related to the AMO.

In the third part of this report, flows are examined for a number of SWFWMD rivers and their tributaries in some detail. The SWFWMD is currently working to develop Minimum Flows and Levels (MFLs) for these rivers. For the Peace River, flows at the Arcadia gage are compared to flows from two major sub-basins, Charlie and Horse Creeks. When normalized for watershed area (i.e., flows expressed as cfs/sq mile), Charlie Creek, Horse Creek and the Peace River at Arcadia show very similar flow patterns, both pre and post 1970. When percent decreases in median daily flows where compared between periods, both Charlie and Horse Creeks showed almost identical flow declines to that observed for the Peace River at Arcadia. This is important since some have attributed much of the flow decline in the Peace River to phosphate mining impacts. This assertion is unwarranted since there has been very little mining in the Horse Creek watershed and essentially none in the Charlie Creek watershed yet both demonstrate flow declines remarkably similar to flow declines observed in the middle Peace River. If phosphate mining is largely responsible for the flow reductions seen at the Arcadia gage, what other factors are responsible for the almost identical declines seen in Horse and Charlie Creeks? It is suggested that most of the flow decline observed between the two periods investigated must be attributable largely to climate. This is true for flow reductions at Charlie Creek, Horse Creek and the Peace River at Arcadia.

By contrast, an example of an anthropogenic alteration of flows can be found in the Myakka River. Flows for the Myakka River have been impacted by agriculturally related discharges, and overall flow declines in this river are small when compared to the nearby Peace River. However, it is demonstrated that there were appreciable flow declines in the Myakka River during the wet season that are comparable to most rivers in peninsular Florida. The rather small declines reported for the Myakka River are based on annual means and are attributable to the relatively large percent increase in flow that has occurred during the dry season. Anthropogenic dry season increases have tended to offset wet season decreases; however, inspection of seasonal flow patterns clearly show that even the Myakka River has experienced climate related flow declines. While climate driven flow declines reflect a step trend, agriculturally driven flow increases appear to reflect a monotonic trend. Based on a comparison of flow differences between the pre and post periods examined and an examination of percent exceedance flows of each gage site, it is believed that agriculturally related flow increases have also occurred in a number of other watersheds including those of the Little Manatee River, the Manatee River, Joshua Creek and Shell Creek.

Flows in the Alafia River and the North and South Prongs of the Alafia River have been affected by mining. Historically, phosphate mining related discharges acted to increase flows in the Alafia River. Despite assertions to the contrary, declines in Alafia River flows since about 1980 are in large part attributable to removal of or a substantial reduction in mining related discharges, not to increasing area of land mined. Because flows generated from off the South and North Prong watersheds are almost identical despite relatively large differences in the amount of mined area between the two watersheds, it is argued that increasing area of mined lands has not caused significant flow declines. Inspection of various percent exceedance flows for the North and South Prongs and the Alafia River demonstrate a rather sudden increase in low to median flows that began in the 1950s. Water quality data suggest that these increases are attributable to mining related activities. Documented flow declines are in part attributable to climate and to removal of anthropogenic discharges related to mining.

This report is important to the overall process of MFLs development since it demonstrates that relatively large decreases and increases in flow are attributable to rainfall differences between multidecadal periods. Although most appreciate that rainfall is the primary driving factor affecting river flows, it has been traditionally assumed with respect to hydrology that river flows are the consequence of a sequence or random independently and identically distributed random variables. To paraphase Olsen et al. (1999), these results challenge this generally held assumption and suggest that those involved in water management issues may need to rethink their paradigm with respect to river flow analysis and allow for multidecadal variations in river flow patterns.



Hillsborough Riverfront , Tampa, Florida – circa 1905
From Florida Photographic Collection

Florida River Flow Patterns and the Atlantic Multidecadal Oscillation

Overview

It is essential for the development of minimum flows and levels (MFLs) that temporal and spatial flow trends are understood in terms of natural and anthropogenic effects. Significant declining trends in flow have been documented or discussed for a number of streams in the Southwest Florida Water Management District (SWFWMD) including the Peace (Hammett 1990, Coastal Environmental 1996, Lewelling et al. 1998, Flannery and Barcelo 1998, Hickey 1998, Basso 2002, Garlanger 2002, SDI 2003) and Alafia Rivers (Stoker et al. 1995, Hickey 1998, SDI 2003). Increases in flow have also been documented for some watercoures (e.g., Little Manatee River, Joshua Creek; Flannery and Barcelo 1998). At issue in all of these discussions is the relative importance of climate (rainfall) and man (anthropogenic factors) on these trends.

The discussion that follows relies heavily on a graphical presentation of flow data to develop a general appreciation of the temporal and spatial variability in river flows not only in the SWFWMD but statewide. This perspective is necessary for developing a consistent and cohesive approach for setting MFLs, particularly as it relates to seasonal flow patterns and long-term cycles in rainfall. The position taken in this presentation is that climate, specifically multidecadal differences in rainfall, is a significant and yet relatively under appreciated factor that explains much of the variability in river flow, some of which has been assumed attributable to man. This should not be interpreted to mean that man has not, in some cases, substantially affected river flow volumes and patterns; however, relatively large flow declines or increases in many instances may be attributable to climate.

Trends in Flows

Considerable discussion related to flow trends has centered on an assessment of mean annual flows and attempts to relate changes in mean flow to changes in total annual rainfall. This approach can be refined by examining differences between wet and dry seasons and high and low flow periods. Inspection of monthly rainfall totals and mean monthly flows demonstrates a clear seasonality in rainfall and consequent flows. For peninsular Florida, the rainy season is often defined as the months of June through September. The highest flow months typically extend from July through October. The types of data analysis that have routinely been performed on flow data have been repeated here, but other, largely graphical approaches not normally used are used extensively in this report, since the nature of the presentation relies on a different perspective for examining the data. This graphic approach illustrates patterns that are not evident when the data are viewed in tabular form or when different, more traditional, graphical approaches (e.g., time series plots of mean annual flows) are used.

A fundamental premise of this discussion is that river flows are largely rainfall driven and that patterns and seasonality in flows reflect patterns and seasonality in rainfall. Most would readily agree with this interpretation; however, the tendency has been to quickly move on to flow changes that can be attributed to anthropogenic factors without closely examining the effect that climate may have on declining or inclining flow trends. This is done with the underlying bias that in most cases it is assumed that variation in flow results from a sequence of random independently and identically distributed random variable (see Olsen et al. 1999). Much work on stream flows has been based on analysis of mean annual flows; however, as explained elsewhere (SWFWMD 2002) the mean annual flow is, for most systems in peninsular Florida, a high flow statistic. As demonstrated on the upper Peace River, the mean annual flow is roughly equivalent to the annual 30% exceedance flow (the flow exceeded only 110 days of the year). In the SWFWMD, a large portion of high flows is concentrated in the rainy season (as would be expected) which generally lasts 120 to 135 days. Since anthropogenic withdrawals are typically reduced during the rainy season and greatest during the drier months (this is especially true for agriculturally related withdrawals and withdrawals for domestic water supply and consequent lawn irrigation), one would expect the effects of these withdrawals to be most pronounced during the drier months. Not only are flows greatly diminished due to reduced rainfall, but anthropogenic withdrawals would constitute a greater percentage of the available flow. Even for those withdrawals that remain relatively constant during the year, effects should be most pronounced during the drier (low flow) months.

There is an apparent long-term cycle in rainfall that leads to multi-decadal oscillations in stream flow. In general, rainfall data will not be examined directly (see discussion by Enfield et al. 2001 and Basso and Schultz 2003), but a series of flow plots for various rivers will be examined which exhibit similar patterns in flow. It is argued that the similarity of flows is reflective of similarity in rainfall patterns. Although it has generally been assumed that annual variation in rainfall is a more or less random event, the premise taken here is that a long-term oscillation in rainfall (approximately 60 to 80 years) is evident, although this pattern may be affected by other short-term (e.g., El Nino – 6 years) or long-term cycles (McCabe et al. 2004). Whether this oscillation does or does not exist has more than academic interest, since it should influence the way that MFLs are developed, particularly for mid to high flows.

Gage Sites and Periods of Record

Flow data from 122 USGS gage sites in Florida (Table 1) were used to characterize the temporal and spatial variation in stream flow that may be expected and to illustrate the difficulty that this variation poses when trying to develop MFLs. Data from a subset of these sites was examined to assess multidecadal differences in flow. The subset was restricted to those sites with at least 60 years of record. To examine multidecadal flow differences, it was desirable to have sites of sufficient record so that two relatively long time periods could be compared. A large number of sites outside of Florida were examined in support of this work, but will not be considered in great detail here. All flow data used in this report were retrieved from the USGS website.

Seasonal Flow Patterns

Plotting the Data

Although flow data have traditionally been presented in a number of different ways (see examples in Figure 1) for a number of different purposes, an accurate impression of the seasonality of flows can be obtained from a less traditional

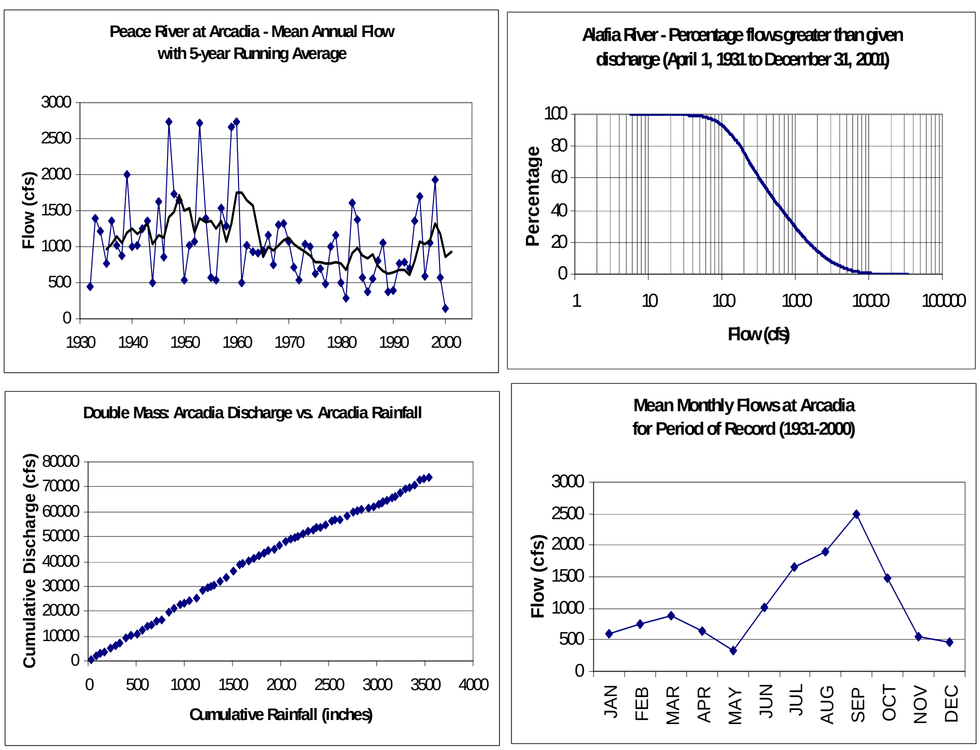


Figure 1. Examples of various ways to graphically present flow data.

approach. For lack of a better name, plots of Median Daily Flow (MDQ) were routinely developed for (1) the period of record, (2) for each decade in the period of record, and (3) two mutidecadal periods (1940-1969 and 1970-1999) for those sites with an adequate period of record (>60 years). As an example, for a site with 70 years of continuous daily flow record extending from 1932 to 2001 (e.g., Peace River at Arcadia), the median of 70 values for each day of the year was plotted. This produced a plot with 365 data points (one for each day of the year excluding the 366th day in leap years). The median flow (in cubic feet per second – cfs) for all 70 January 1 flows was obtained and plotted against Julian day one, the median flow of all 70 January 2's was plotted against Julian day two, the median flow of all 70 January 3s was plotted against Julian day three, etc. until all 365 Julian day median flows were plotted. Data points were joined by a line, resulting in a hydrograph representative of the median daily flow for the site for the period of record (see Figure 2). This was also done for mean daily flows (Figure 2); however, the median daily flow plot is the one that will most often be addressed in this report. This is because one can be assured that for the time period represented in the plot (either period of record, decade or multidecade) flows on any given day were below the plotted line half the time and above the plotted line half the time. The plot is not overly influenced by extreme events as is the case in the plot of daily means.

These MDQ plots are informative in that they provide an easily understood picture of the range of flow that can reasonably be expected at a site over the course of a year and a temporal impression of when those flows are most likely to occur throughout the year (seasonally). As an example refer to Figure 2, this figure shows that for the most part highest flows in the Peace River as measured at the Arcadia gage (1367 square mile watershed) occur during a four month period (July-October). Although flows vary considerably from year to year, it is reasonable to expect that flows should vary directly with rainfall. For the period of record, the lowest expected flow day for the Peace River at Arcadia based on an analysis of median daily flows is May 21, while the highest median daily flow is most likely to occur on or around September 22.

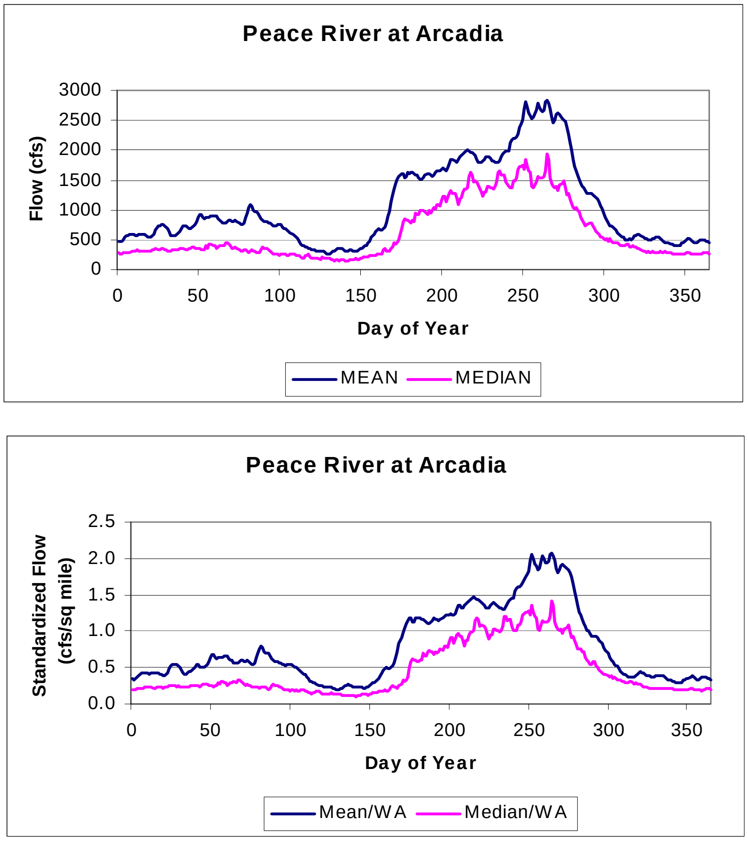


Figure 2. Hydrographs of mean and median daily flows for the Peace River gage at Arcadia.

Geographic Differences in River Flow Patterns

In total, flow data for 122 Florida gage sites were examined (refer to Table 1). This analysis suggested that there are two distinct seasonal patterns. For convenience, these two flow patterns are referred to as a Southern River Pattern (SRP) and a Northern River Pattern (NRP). A transitional pattern with a clear bimodal flow distribution, Bimodal River Pattern (BRP), was found in a band between those rivers with a SRP and NRP. Two other patterns, one characteristic of spring dominated systems and the other obviously affected by significant structural alteration, will not be considered in detail.

Table 1. Florida gage site data evaluated for flow patterns and trends.

	River/Stream	USGS Code	River Pattern	WA	POR Begins	Count
				sq miles		
1	Alafia River at Lithia	02301500	SRP	335	10/01/32	25567
2	Anclote River near Elfers	02310000	SRP	72.5	06/01/46	19023
3	Apalachicola River at Chattahoochee	02358000	NRP	17200	10/01/28	27028
4	Apalachicola River near Blountstown	02358700	NRP	17600	10/01/57	16430
5	Apopka-Beauclair Canal near Astatula	02237700	Altered	NOWAG	07/01/58	16163
6	Arbuckle Creek near De Soto City	02270500	SRP	379	07/01/39	23103
7	Aucilla River at Lamont	02326500	NRP	747	03/01/50	12052
8	Barron River near Everglades	02291000	SRP	NOWAG	02/01/52	18398
9	Big Coldwater Creek near Milton	02370500	NRP/Spring	237	12/01/38	20706
10	Big Creek near Clermont	02236500	Bimodal	68	08/01/58	16132
11	Blackwater Creek near Knights	02302500	SRP	110	01/01/51	18901
12	Blackwater River near Baker	02370000	NRP/Spring	205	04/01/50	17763
13	Boggy Creek near Taft	02262900	SRP	83.6	09/01/59	15736
14	Bonnet Creek near Vineland	02264100	SRP	44.7	05/06/66	13298
15	Braden River near Lorraine	02300032	SRP	25.8	07/01/88	5205
16	Brooker Creek near Tarpon Springs	02307359	SRP	30	09/01/50	19023
17	Bullfrog Creek near Wimauma	02300700	SRP	29.1	10/01/56	10047
18	Caloosahatchee Canal at Moore Haven	02292000	Altered	NOWAG	10/01/38	23371
19	Catfish Creek near Lake Wales	02267000	Spring?	58.9	10/01/47	20089
20	Charlie Creek near Gardner	02296500	SRP	330	05/01/50	19146
21	Chipola river near Altha	02359000	NRP	781	12/01/12	25142
22	Choctawatchee River at Bruce	02366500	NRP	4384	10/01/30	25871
23	Choctawhatchee River at Caryville	02365500	NRP	3499	08/01/29	26036
24	Cypress Creek at Vineland	02264000	SRP	29.3	08/01/45	20880
25	Cypress Creek near San Antonio	02303400	SRP	56	01/01/63	13889
26	Cypress Creek near Sulphur Springs	02303800	SRP	160	03/01/64	14093
27	Ecofina Creek near Bennett	02359500	Spring	122	10/01/35	23011
28	Econfina River near Perry	02326000	Bimodal NRP/SRP	198	02/01/50	19235
29	Econlockhatchee River near Chuluota	02233500	SRP	241	10/01/35	24472
30	Escambia River near Century	02375500	NRP	3817	10/01/34	24837
31	Fenholloway River at Foley	02324500	Altered	120	09/01/46	19652
32	Fisheating Creek at Palmdale	02256500	SRP	311	05/01/31	26086
33	Flint Creek near Thonotosassa	02303300	SRP	60	10/02/56	8492
34	Fox Branch near Socrum	02301900	SRP	9.5	01/01/64	14153
35	Haines Creek at Lisbon	02238000	Bimodal	648	07/01/42	19450
36	Hillsborough River at Morris Bridge	02303330	SRP	375	07/01/72	11049
37	Hillsborough River at Zephyrhills	02303000	SRP	220	10/01/39	23011
38	Hillsborough River near Tampa	02304500	SRP	650	10/01/38	23376
39	Horse Creek near Arcadia	02297310	SRP	218	05/01/50	19146
40	Horse Creek near Myakka Head	02297156	SRP	42	10/01/77	8766
41	Jane Green Creek near Deer Park	02231600	SRP	248	10/01/53	17897
42	Josephine Creek near De Soto City	02271500	SRP	109	10/01/46	19359
43	Joshua Creek at Nocatee	02297100	SRP	132	05/01/50	19146
44	Jumper Creek Canal near Bushnell	02312640	SRP to Spring	40	10/01/63	14245
45	Jumping Gully at Loyce	02310240	SRP	43	06/01/64	9869

Table 1. (Continued)

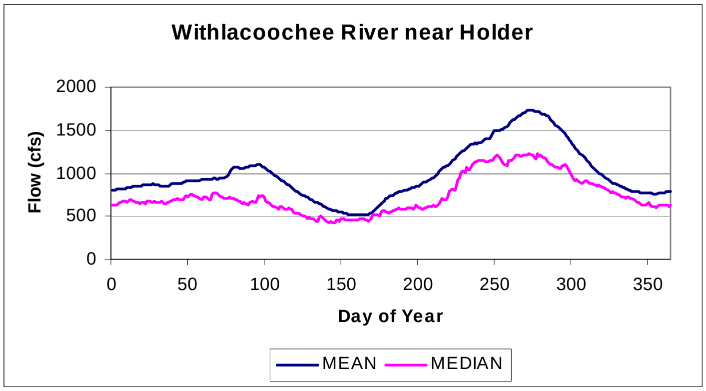
	River/Stream	USGS Code	River Pattern	WA	POR Begins	Count
				sq miles		
46	Kissimmee River at S-65E near Okeechobee	02273000	SRP/ALT	NOWAG	10/01/28	26297
47	Little Charley Bowlegs Creek near Sebring	02296223	SRP	41.9	02/01/52	11565
48	Little Econlockhatchee River near Union Park	02233473	SRP	27.1	10/01/59	15341
49	Little Haw Creek near Seville	02244420	Bimodal SRP/NRP	93	01/01/51	18901
50	Little Manatee River near Fort Lonesome	02300100	SRP	31.4	09/01/63	14275
51	Little Manatee River near Wimauma	02300500	SRP	149	04/01/39	23194
52	Little River near Quincy	02329500	NRP	237	04/01/50	14779
53	Little Withlacoochee River at Rerdell	02312200	SRP	145	08/01/58	16132
54	Little Withlacoochee River at Tarrytown	02312180	SRP	85	10/01/66	13149
55	Manatee River near Bradenton	02300000	SRP	87.1	04/01/39	9953
56	Manatee River near Myakka Head	02299950	SRP	65.3	04/01/66	13313
57	Middle Prong St. Marys River at Taylor	02229000	Bimodal NRP/SRP	125	10/01/55	13697
58	Myakka River at Myakka City	02298608	SRP	125	02/01/63	10465
59	Myakka River near Sarasota	02298830	SRP	229	08/01/36	24136
60	North Fork Black Creek near Middleburg	02246000	Bimodal SRP/NRP	177	10/31/03	25933
61	North Prong of Alafia River at Keysville	02301000	SRP	135	05/01/50	18143
62	North Prong St. Marys River at Moniac, GA	02228500	Bimodal NRP/SRP	160	02/01/21	21688
63	Ochlockonee River near Bloxham	02330000	NRP	1700	06/01/27	27806
64	Ochlockonee River near Havana	02329000	NRP	1140	10/01/26	27759
65	Orange Creek at Orange Springs	02243000	Bimodal	1119	08/01/42	19665
66	Oretega River at Jacksonville	02246300	Bimodal	30.9	01/01/65	13489
67	Outlet River at Panacoochee Retreat	02312700	Spring	420	10/01/62	14610
68	Palatlakaha River at Cherry Lake outlet near Gr	02236900	Altered	165	03/01/57	16650
69	Payne Creek near Bowling Green	02295420	SRP	121	10/01/63	10228
70	Peace River at Arcadia	02296750	SRP	1367	04/01/31	26116
71	Peace River at Bartow	02294650	SRP	390	10/01/39	23011
72	Peace River at Fort Meade	02294898	SRP	480	06/01/74	10349
73	Peace River at Zolfo Springs	02295637	SRP	826	09/01/33	25232
74	Pine Barren Creek near Barth	02376000	Spring	75.3	10/01/52	15340
75	Pithlachascotee near New Port Richey	02310300	SRP	180	04/01/63	14428
76	Pithlachascotee River near Fivay Junction	02310280	SRP	150	10/01/83	6940
77	Prairie Creek near Fort Ogden	02298123	SRP	233	10/01/63	10958
78	Rainbow Springs near Dunnellon	02313100	Spring	7.5	01/01/65	13787
79	Reedy Creek near Loughman	02266500	SRP	177	10/01/39	19806
80	Reedy Creek near Vineland	02266298	SRP	84.6	05/06/66	13306
81	Rocky Creek near Sulphur Springs	02307000	SRP	35	01/01/53	18170
82	Saddle Creek at Structure P-11 near Bartow	02294491	SRP/ALT	135	12/01/63	14184
83	Santa Fe River at Worthington Spgs	02321500	Bimodal SRP/NRP	575	10/01/31	25933
84	Santa Fe River near Ft. White	02322500	Spring	1017	06/01/32	26178
85	Santa Fe River near High Springs	02322000	Bimodal SRP/NRP	868	02/01/31	14852
86	Shell Creek near Punta Gorda	02298202	SRP	373	01/01/65	11555
87	Shingle Creek near Kissimmee	02263800	SRP	89.2	10/01/58	16071
88	Shoal River near Crestview	02369000	Spring (NRP)	474	08/01/38	23437
89	Silver Springs near Ocala	02239500	Spring	750	10/01/32	25567
90	Sixmile Creek at Tampa	02301800	SRP Altered	28	10/01/56	10343

Table 1. (Continued)

	River/Stream	USGS Code	River Pattern	WA	POR Begins	Count
				sq miles		
91	Sopchoppy River near Sopchoppy	02327100	Bimodal SRP/NRP	102	06/01/64	14001
92	South Fork Black Creek near Penney Farms	02245500	3imodal SRP/(NRP	134	10/01/39	23011
93	South Prong of Alafia River	02301300	SRP	107	01/01/63	14518
94	Spruce Creek near Samsula	02248000	SRP	33.4	05/01/51	18781
95	St. Johns River near Christmas	02232500	SRP	1539	10/01/33	24837
96	St. Johns River near Cocoa	02232400	SRP	1331	10/01/53	17532
97	St. Johns River near De Land	02236000	SRP	3070	10/01/33	24471
98	St. Johns River near Melbourne	02232000	SRP	968	10/01/39	23011
99	St. Marks River near Newport	02326900	Spring	535	10/01/56	16162
100	St. Marys River near Macclenny	02231000	Bimodal SRP/NRP	700	10/01/26	27759
101	Steinhatchee River near Cross City	02324000	Bimodal NRP/SRP	350	03/01/50	19207
102	Sulphur Springs at Sulphur	02306000	Spring	NOWAG	07/01/59	15798
103	Suwanee River at Branford	02320500	NRP	7880	07/01/31	26025
104	Suwanee River at Ellaville	02319500	NRP	6970	02/01/27	27636
105	Suwanee River at White Springs	02315500	Bimodal NRP/SRP	2430	02/01/27	28581
106	Suwanee River near Wilcox	02323500	NRP	9640	10/01/41	22645
107	Sweetwater Creek near Sulphur Springs	02306500	SRP	7.43	10/01/51	18628
108	Telogia Creek near Bristol	02330100	NRP	126	04/01/50	17742
109	Thomas Creek near Crawford	02231280	Bimodal	29	01/01/65	13640
110	Tomoka River near Holly Hill	02247510	SRP	76.8	10/01/64	13879
111	Trout Creek near Sulphur Springs	02303350	SRP	23	06/01/74	10349
112	Waccasassa River near Gulf Hammock	02313700	Bimodal NRP/SRP	480	04/01/63	10762
113	Wekiva River near Sanford	02235000	Spring	189	10/01/35	24472
114	Whittenhorse Creek near Vineland	02266200	SRP	12.4	05/04/66	13299
115	Withlacoochee River [northern] near Pinetta	02319000	NRP	2120	10/01/31	25933
116	Withlacoochee River at Croom	02312200	SRP	810	10/01/39	23011
117	Withlacoochee River at Trilby	02312000	SRP	570	08/01/28	26665
118	Withlacoochee River at Wysong Dam at Carlsoı	02312720	SRP	1520	08/10/65	13201
119	Withlacoochee River Bypass Channel near Ingli	02313000	Spring	1825	01/01/70	11960
120	Withlacoochee River near Cumpressco	02310947	SRP	280	01/01/67	13057
121	Withlacoochee River near Holder	02313000	SRP	1820	09/01/28	26116
122	Yellow River at Milligan	02368000	NRP	624	08/01/38	22358

*WA - watershed area
**NOWAG - no watershed area given
SRP - Southern River Pattern
NRP - Northern River Pattern
POR - Period of Record
Mean DQ/WA - Mean of daily flows per unit area (cfs/sq mile)
Median DQ/WA - Median of daily flows per unit area (cfs/ sq mile)

With the exception of spring dominated systems, the SRP is characteristic of all rivers in the SWFWMD as demonstrated in Figure 3a for the Withlacoochee River at Holder. Clearly evident is a seasonal pattern of higher flows that generally extends from July to October. This pattern is apparent on all unstructured river systems in the District (refer to appendix for plots of all sites examined). This pattern is also found on a number of rivers in the South Florida



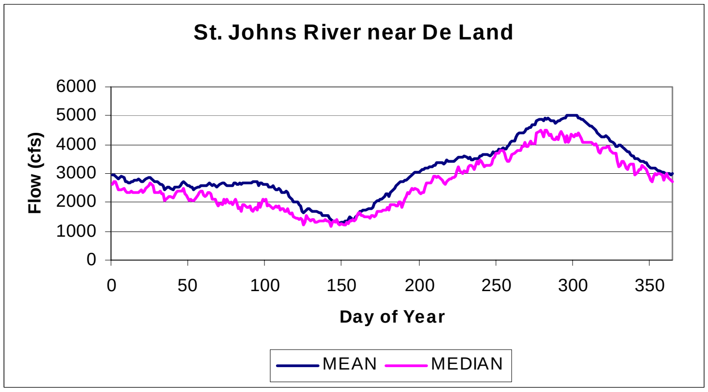
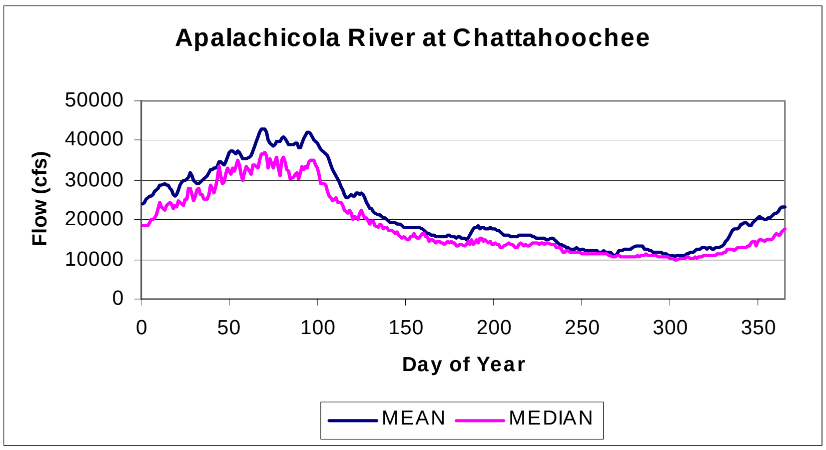


Figure 3. Hydrographs of mean and median daily flows for the (a) Withlacoochee River near Holder, FL and for the (b) St. Johns River near Deland, FL.

Water Management District (SFWMD) and the St. Johns River Water Management District (SJRWMD) as is evident from Figure 3b which shows mean and median daily flows for the St. Johns River at De Land. [One will notice, however, that the seasonal peak of high flows is shifted slightly to the right (i.e., occurs a little later in the year).]

The NRP is characteristic of unstructured rivers in the north to northwestern part of the state such as the Apalachicola and Escambia Rivers (see Figure 4). Peak flows consistently occur in the spring in NRP rivers, while lowest flows occur in the summer and fall. This pattern appears typical of many if not most rivers in the southeast United States based on reviewed flow data for numerous gage sites in Alabama, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Virginia and West Virginia (see Figure 5).



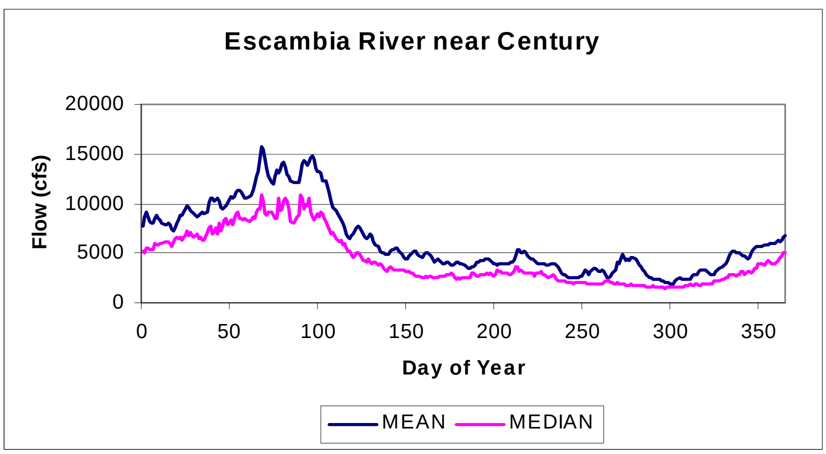
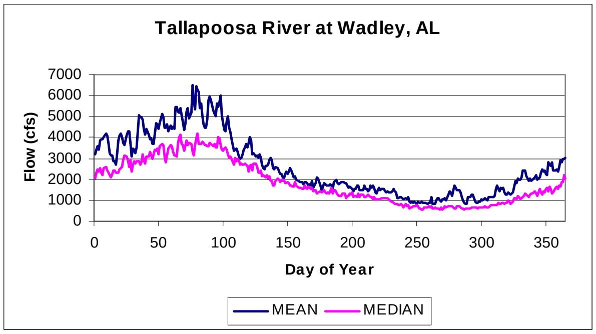
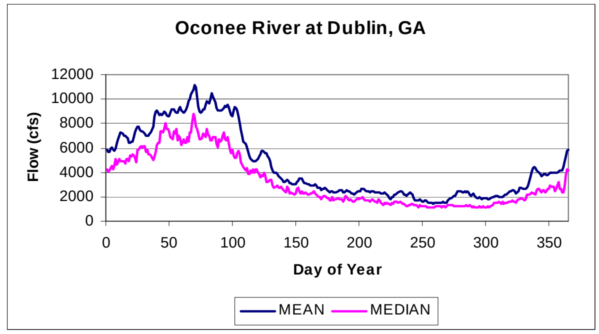
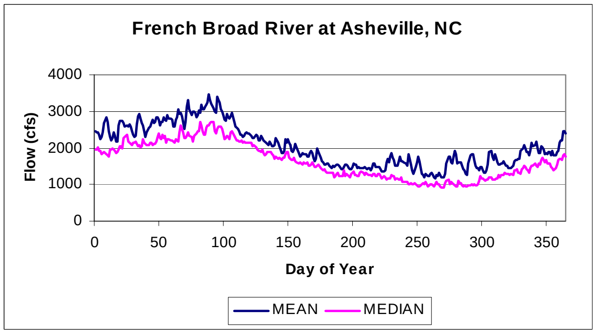


Figure 4. Hydrographs of mean and median daily flow for the (a) Apalachicola River at Chattahoochee, FL and the (b) Escambia River near Century, FL.







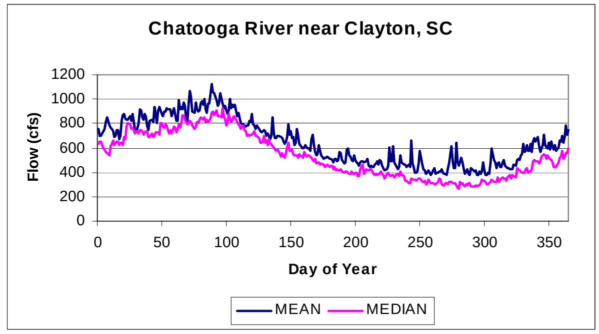


Figure 5. Examples of hydrographs of mean and median daily flows for rivers scattered throughout the southeastern United States.

The SRP and NRP rivers are roughly 180 degrees out of phase as shown in Figure 6 [note: the vertical scale in this figure is expressed as cfs/square mile; by dividing flow data by watershed area, the data are essentially standardized allowing direct comparison of gage sites regardless of watershed size]. When low flows are occurring in rivers that exhibit a NRP, high flows occur in SRP rivers.

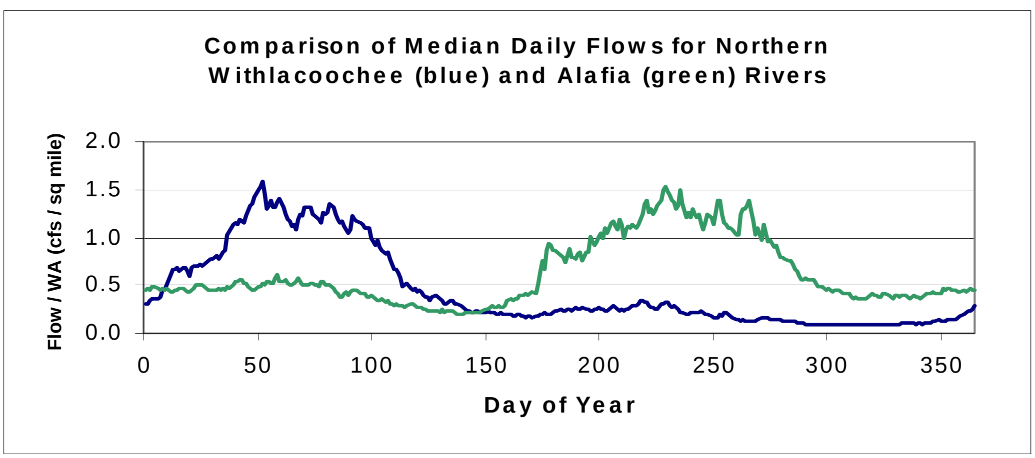
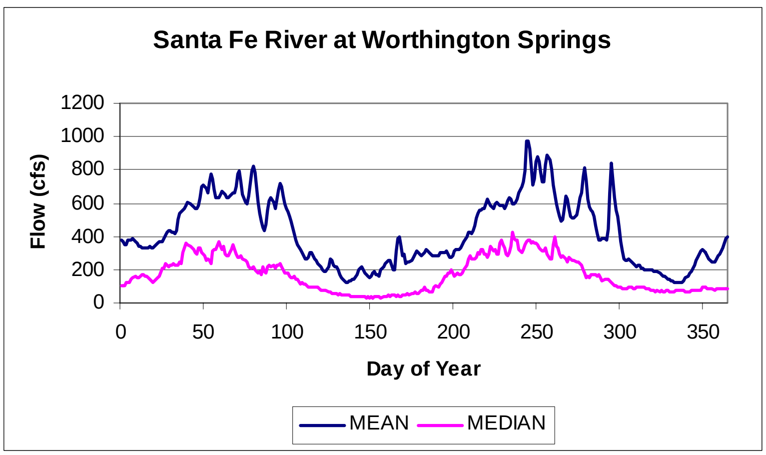


Figure 6. Comparison of two Florida river flow patterns. The Northern Withlacoochee River has a Northern River Pattern (NRP) and the Alafia River has a Southern River Pattern (SRP).

As one moves from south to north in Florida, it might be reasoned that a transition in flow patterns should occur. It was initially anticipated that hydrographs at transition sites would show a pattern intermediate between the SRP and NRP, and that peak flows would likely be flattened or peak somewhere between late spring and early summer. A transition flow pattern was found; however, rather than a melding of two patterns, a clear bimodal distribution in peak flows was found at a number of sites. This Bimodal River Pattern (BRP), for example, is evident in the flow records of the Santa Fe River in the Suwannee River Water Management District (SRWMD) and the St. Marys River which forms Florida's northeastern border with Georgia in the St. Johns River Water Management District (SJRWMD) (Figure 7).



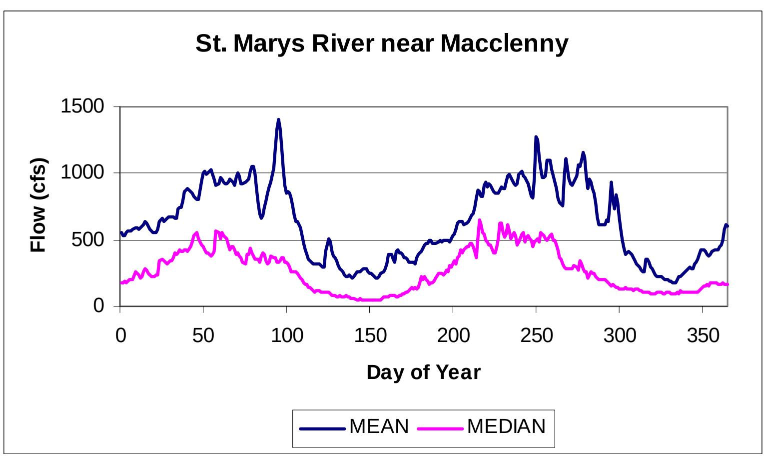


Figure 7. Hydrographs of mean and median daily flow for the (a) Santa Fe River gage at Worthington Springs, FL and for the (b) St. Marrys River near Macclenny, FL .

Inspection of flow plots for numerous gages indicates that there is a fairly clear band of tributaries and rivers that runs from the northeast corner of the state diagonally southwest to the Big Bend area that exhibit a more or less bimodal flow pattern (Figure 8). Some exhibit almost equivalent spring and summer peaks, while in others one pattern (the SRP or NRP) is more or less dominant. As will be discussed, there are interesting variations in the magnitude of the bimodal peaks when multidecadal periods are compared. We have not observed a similar bimodal pattern anywhere else across the United States with the possible exception of some sites in Arizona (Figure 9; Nichols et al. 2002), and we have thus far examined flow data from more than 1000 sites with period of record flows of 60 years or greater.

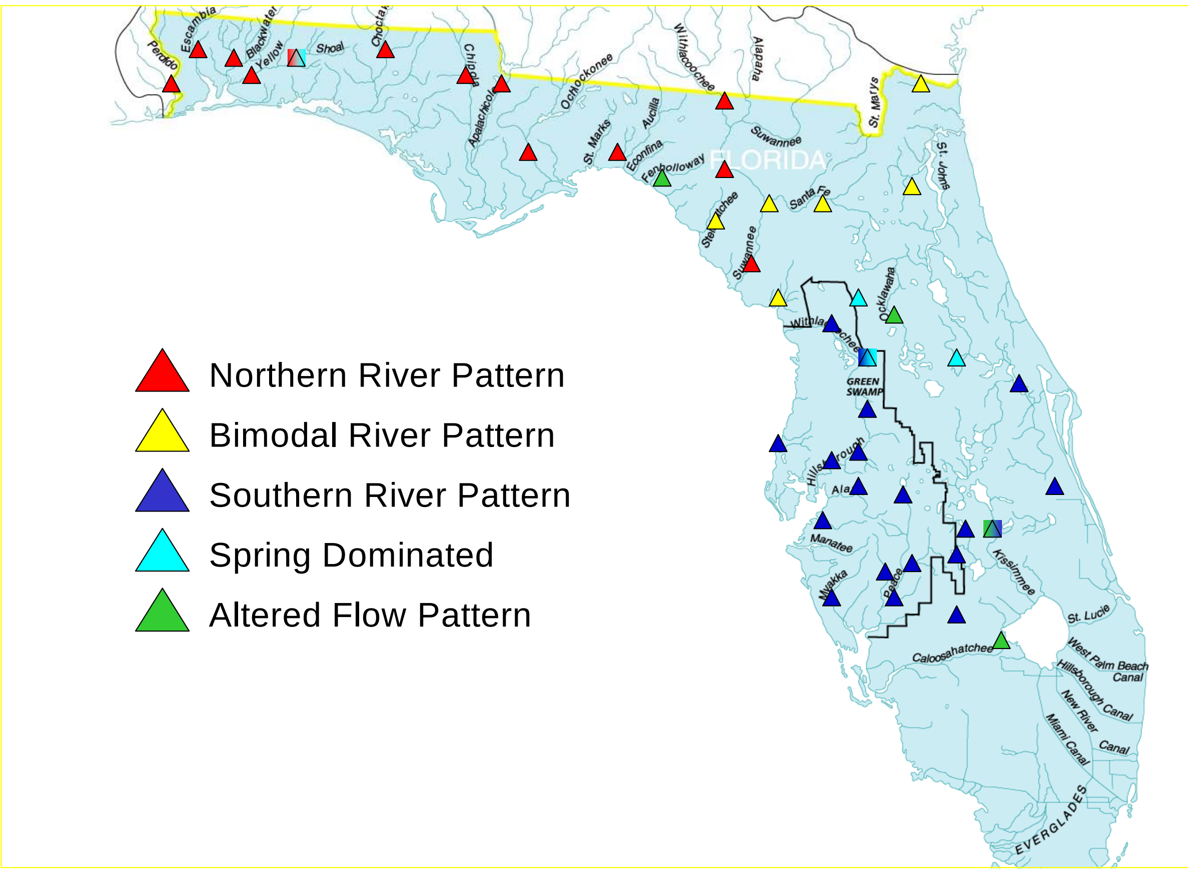
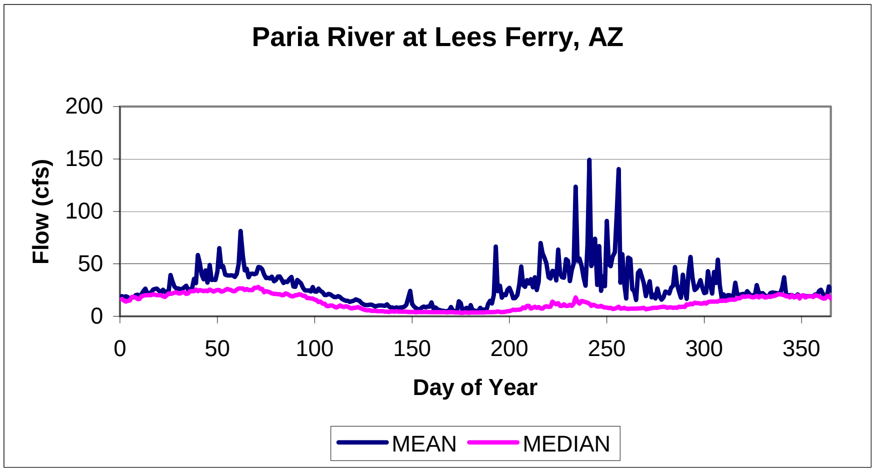


Figure 8. Map showing the geographic distribution of sites exhibiting various river flow patterns.



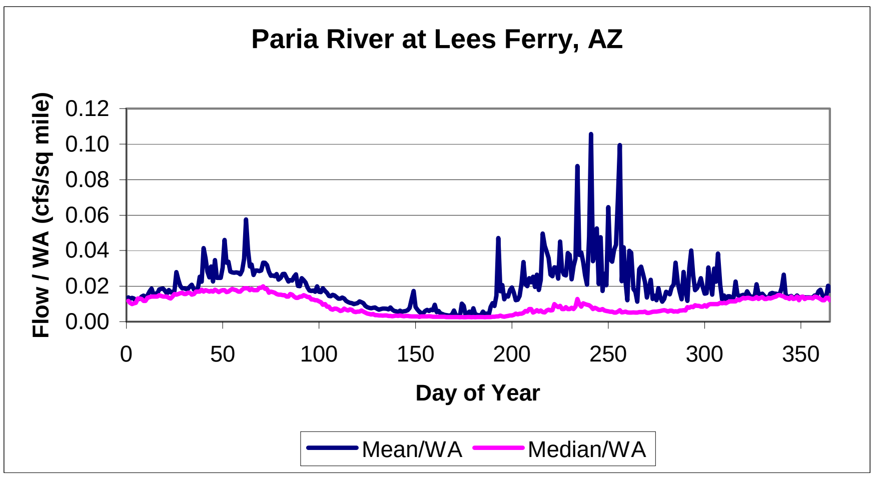
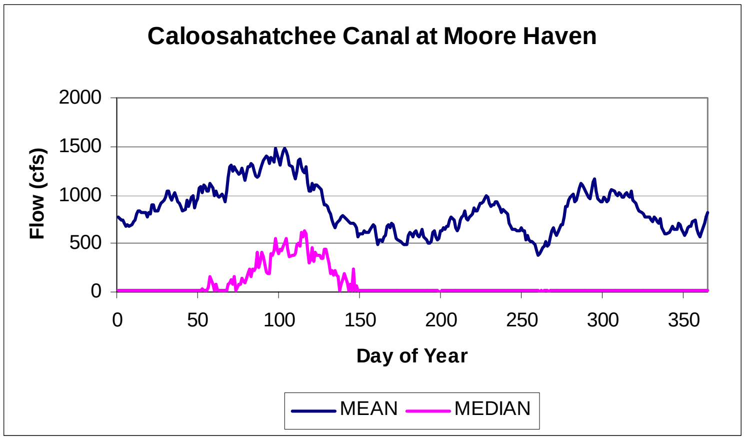


Figure 9. Example of a river in Arizona with a bimodal flow pattern.

Two other types of flow patterns were identified for Florida river systems. These are flow patterns that are (1) obviously affected by significant structural alteration or (2) dominated by spring flow. Examples of both these patterns are shown in Figure 10. Table 1 lists all gage sites examined and the type of flow pattern exhibited by each.



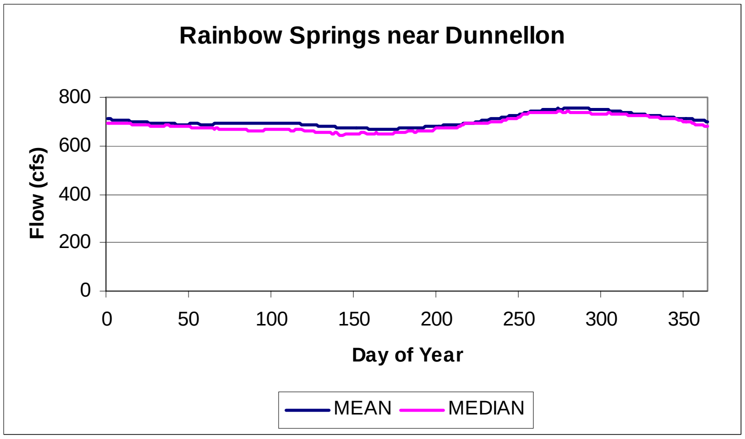


Figure 10. Examples of gage sites demonstrating (a) an "altered flow pattern" and (b) a "spring dominated" flow pattern.

Summarizing, simple inspection of daily median (or mean) flows for the period of record on numerous watercourses throughout the state suggests a south to north shift in the type of river flow pattern expected. In the central and southern part of the state that includes the SWFWMD, SFWMD and most of the SJRWMD, the pattern has been described as one where a summer rainy season predominates (SRP). In the north central to northwestern portion of the state, highest flows typically occur during the spring. This NRP characterizes most of the rivers in the Northwest Florida Water Management District and some in the SRWMD. The largest number of sites displaying a BRP is found in a band that extends from the northeast corner of the state to the Big Bend area. Many of these sites are located in the SRWMD, and this type of river flow pattern may be unique to Florida.

Multi-decadal Periods of High and Low Flows

Because of recent developments in the literature related to the Atlantic Multi-decal Oscillation (AMO) (see Enfield et al. 2001, Basso and Schultz 2003) and interest in changes in the rainfall-runoff relationship (see Hammett 1990, Hickey 1998) which seems to have occurred in the late 1960's, median daily flow plots for gage sites with at least 60 years of record were examined for two 30-year time periods, pre and post 1970 (i.e., 1940 to 1969 and 1970 to 1999).

Citing Enfield et al. (2001), Basso and Schultz (2003) realized that the AMO offered an apparent explanation for observed rainfall deficits throughout central Florida. Although the SWFWMD and others (Hammett 1990, Hickey 1998) have discussed the lack of tropical storm activity and deficit rainfall in recent decades, the mechanism or mechanisms that would account for such differences were unknown. What is particularly interesting in the paper by Enfield et al. (2001) is that unlike most of the continental United States, there is a positive (rather than negative) correlation between rainfall and prolonged periods of North Atlantic Ocean sea surface warming. While periods of warmer ocean temperature generally resulted in less rainfall over most of the United States, there are some areas, including peninsular Florida where rainfall was increased.

To be consistent with Enfield et al.'s (2001) conclusions regarding the AMO and rainfall and with Basso and Schultz (2003) who examined long-term variations in rainfall in west-central Florida, one would expect to find in Florida gage sites where flows are highest when sea surface temperatures in the North Atlantic are in a warm period (i.e., positively correlated). At the same time most of the continental United States would be expected to be in a period of lower flows during these warm periods (i.e., negatively correlated). Conversely the majority of continental gage sites would be expected to exhibit higher flows during AMO cool periods; at this time sites in much of peninsular Florida would be expected to be in a period of low flows.

Graphical Analysis of Flow Data for Two Time Periods

Referring to Figure 11, sea surface temperatures were in a warm phase from approximately 1930 to 1965. From about 1970 to at least 1995 sea surface temperatures reflected a cooler period, and rainfall and hence river flows in much of Florida should be in a low flow phase. In contrast, most sites in the continental US would be expected to exhibit higher flows. A number of sites in Florida (42) have flow records of 60 years or more (refer to Table 7). Because a sixty year flow record from 1940 to 1999 would coincide with a 30-year a warm phase followed by a 30-year period during a cool phase, flow data for sites with records extending from 1940 to 1999 were examined by comparing plots of median daily flows for the two periods.

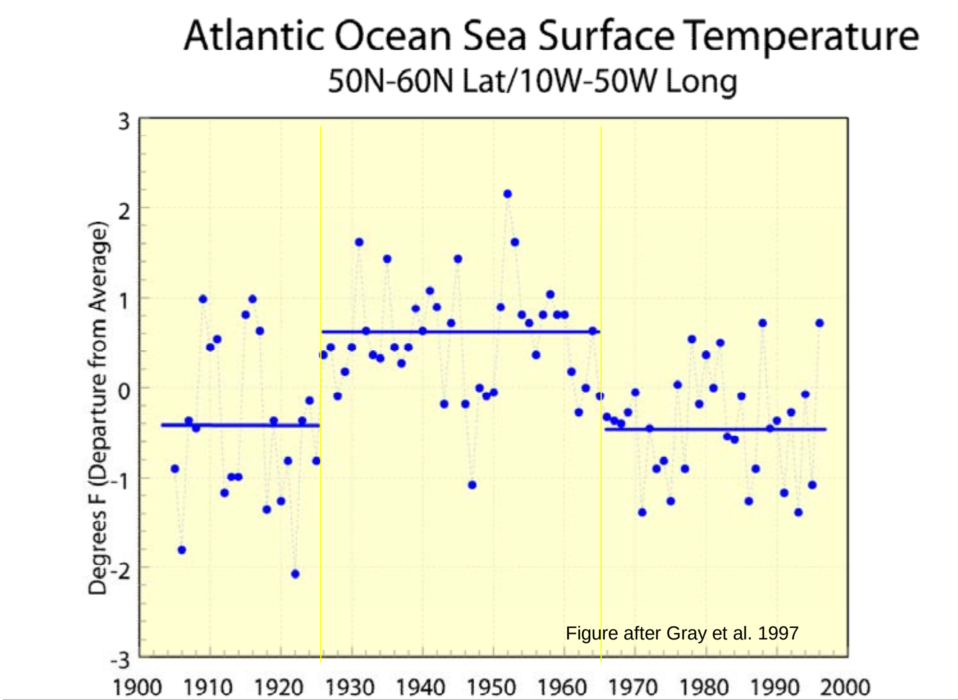


Figure 11. Departure of mean annual sea surface temperature of the Atlantic Ocean from the long-term mean.

The results of such plots were consistent with the observations of Enfield et al. (2001). Sites with a SRP generally exhibited higher flows in the 1940 to 1969 period compared with flows in the 1970 to 1999 period (Figure 12); this was also confirmed by examining decadal plots for a break between the decade of the 60s and 70s (see Figure 13 for an example of such decadal plots; decadal plots for all long-term Florida sites examined are included in the appendix).

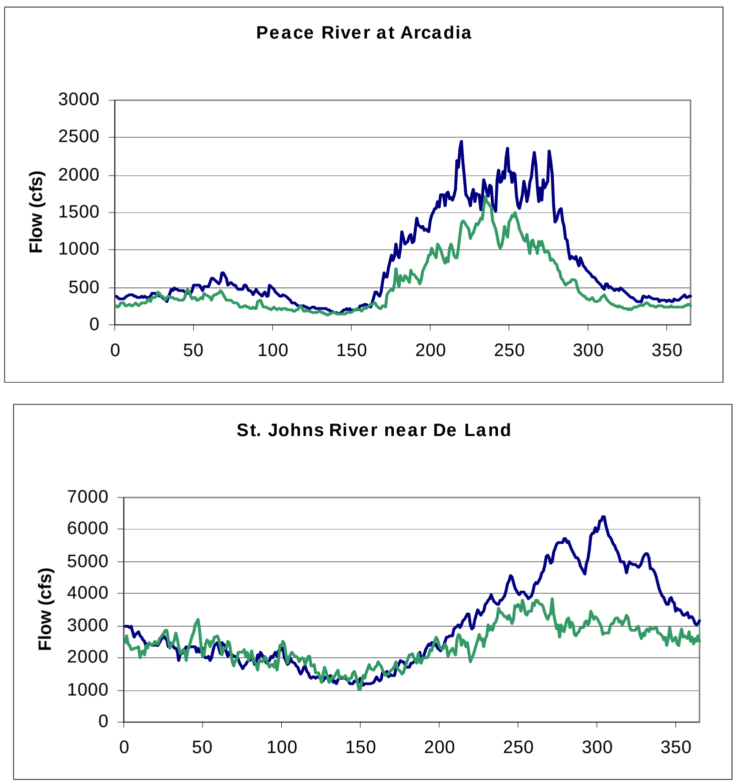


Figure 12. Example of two Southern River Pattern (SRP) sites comparing median daily flow plots for two time periods (1940-1969 and 1970-1999).

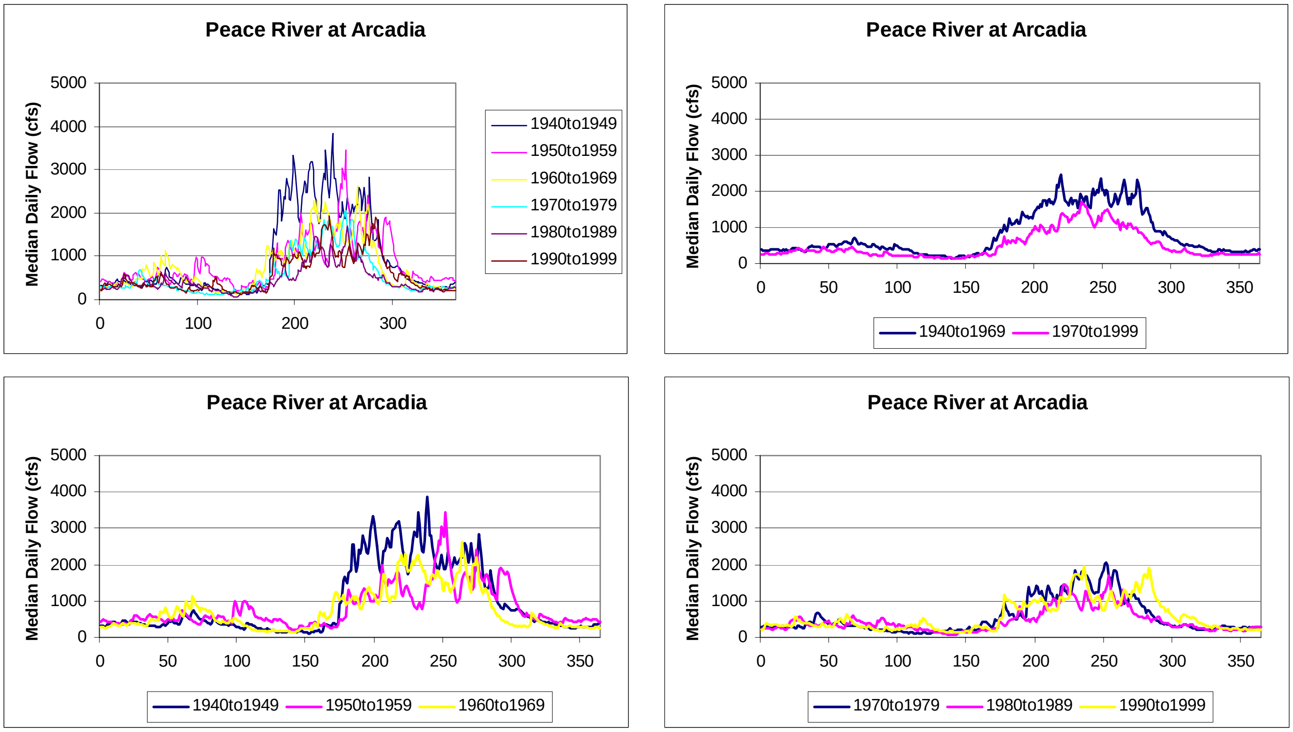
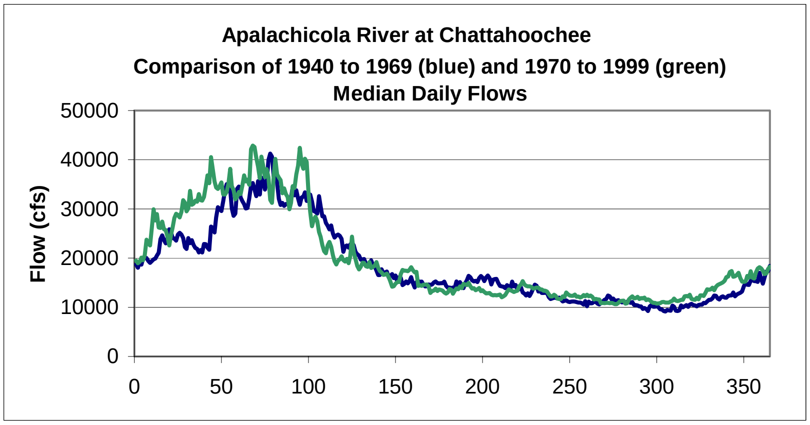


Figure 13. Example of a SRP gage site with at least a 60 year record of daily flows demonstrating the break between decadal plots. Plots for all long-term Florida gage sites are included in the Appendix.

Sites with a NRP showed the opposite pattern, exhibiting higher flows during the last 30 years (1970 to 1999) when compared with the preceding 30 years (1940 to 1969) (Figure 14). NRP sites in Florida closely resemble the flow pattern for the majority of gage sites examined in neighboring states. Changes in flow at Florida NRP sites and sites in neighboring states were consistent with Enfield et al.'s (2001) observation; flows in the most recent 30-year period typically exceeded flows in the preceding 30-year period (1940-1969). The BRP sites as discussed below are especially interesting, and multidecadal flow differences and the AMO offer the most plausible explanation for long-term flow variation at these sites.



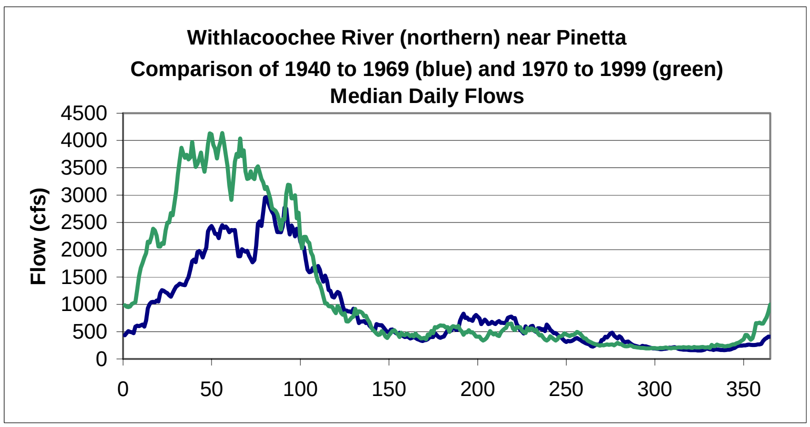


Figure 14. Example of two Northern River Pattern (NRP) sites comparing median daily flow plots for two time periods (1940-1969 and 1970 –1999).

Tables 2, 3 and 5 summarize the results for the 39 Florida gage sites with 60 or more years of record (three of the original 42 sites were deleted from consideration because they exhibited flow patterns characteristic of altered systems). Seventeen gage sites, representing ten river systems, displayed a SRP (Table 2). Sixteen of the seventeen gage sites showed a net decrease in flow between the two 30-year periods. While some of the decrease at any given site may be attributable to anthropogenic factors, a decrease in flows at SRP sites is consistent with Enfield et al. (2001) and is expected at sites with a SRP. Of sites with a SRP (see Table 2) and a period of record of at least 60 years, only the Econlockhatchee River (Figure 15) showed an overall increase in flows between the two periods. It is worth noting, however, that all SRP sites showed a decrease in flow between the two 30-year periods during the SRP wet season, defined as the period extending from June 14 to October 27 of each year. The average decrease in median daily flows for the SRP wet season was approximately 35%, and ranged from 12 to 68%. Based on a comparison of median daily flows, flows at SRP sites were on average approximately 30% lower in the more recent period (1970-1999) when compared to the preceding 30-year period (1940-1969).

All 12 of the 39 long-term Florida sites with a NRP showed an overall increase in flow between the two 30-year periods (see Table 3); the average percent increase was 14% and ranged from 5 to 35%. It is interesting to note that all 12 of the NRP sites showed a decrease in flows during that part of the year that represents the SRP wet season, but showed an average increase in median daily flow of 27% during the NRP wet season (defined as January 1 to May 15). Overall increases in flow for sites with the NRP are consistent with Enfield et al. (2001). Rivers in north Florida have a flow pattern similar to most sites in the southeast United States, and ninety-one percent (91%) of the 311 sites examined with a 60 year record spanning 1940 to 1999 showed an average increase in annual median daily flow of 15% between the two 30-year periods (see Table 4).

Table 2. Pecent decrease in flows between two multidecadal periods at long-term Florida gage sites with a Southern River Pattern.

Note: Positive values indicate a decrease in flow between the two multidecal periods (1940-1969 and 1970-1999) since the mean of the more recent period was subtracted from the earlier period.

River/Stream	USGS Code	WA	%Change for Year	%Change for SRP Wet Season	%Change for NRP Wet Season
Alafia River at Lithia	02301500	335	23.70	30.31	13.22
Arbuckle Creek near De Soto City	02270500	379	34.28	29.60	42.05
Econlockhatchee River near Chuluota	02233500	241	-2.69	12.04	-49.45
Fisheating Creek at Palmdale	02256500	311	18.59	17.60	21.72
Hillsborough River at Zephyrhills	02303000	220	29.18	38.91	13.81
Hillsborough River near Tampa	02304500	650	70.72	68.30	67.01
Little Manatee River near Wimauma	02300500	149	2.71	24.07	-54.37
Myakka River near Sarasota	02298830	229	6.17	22.51	-150.73
Peace River at Arcadia	02296750	1367	36.46	39.04	30.53
Peace River at Bartow	02294650	390	59.12	51.91	67.67
Peace River at Zolfo Springs	02295637	826	33.23	33.15	33.40
St. Johns River near Christmas	02232500	1539	23.78	28.01	-1.91
St. Johns River near DeLand	02236000	3070	19.52	24.72	-3.83
St. Johns River near Melbourne	02232000	968	17.02	13.81	-2.76
Withlacoochee River at Croom	02312500	810	46.28	55.53	21.78
Withlacoochee River at Trilby	02312000	570	48.75	55.44	24.00
Withlacoochee River near Holder	02313000	1820	38.26	46.63	24.53
Means		816.12	29.71	34.80	5.69
Median		570.00	29.18	30.31	21.72
Minimum		149.00	-2.69	12.04	-150.73
Maximum		3070	70.72	68.3	67.67

WA = watershed area in square miles

Table 3. Pecent decrease in flows between two multidecadal periods at long-term Florida gage sites with a Northern River Pattern.

Note: Positive values indicate a decrease in flow between the two multidecal periods (1940-1969 and 1970-1999) since the mean of the more recent period was subtracted from the earlier period.

River/Stream	USGS Code	WA	%Change for Year	%Change for SRP Wet Season	%Change for NRP Wet Season
Apalachicola River at Chattahoochee	02358000	17200	-6.67	1.38	-8.93
Chipola river near Altha	02359000	781	-7.6	3.21	-15.94
Choctawatchee River at Bruce	02366500	4384	-12.75	3.19	-19.44
Choctawhatchee River at Caryville	02365500	3499	-12.76	3.19	-19.44
Escambia River near Century	02375500	3817	-12.94	4.04	-17.33
Ochlockonee River near Bloxham	02330000	1700	-8.06	24.87	-22.66
Ochlockonee River near Havana	02329000	1140	-21.85	12	-33.48
Suwanee River at Branford	02320500	7880	-14.88	7.89	-43.35
Suwanee River at Ellaville	02319500	6970	-17.87	16.31	-49.69
Suwanee River near Wilcox	02323500	9640	-4.78	9.51	-23.96
Withlacoochee River [northern] near Pinetta	02319000	2120	-35.17	12.28	-50.49
Yellow River at Milligan	02368000	624	-12.45	6.58	-19.43
Means		4980	-13.98	8.70	-27.01
Median		3658	-12.76	7.24	-21.05
Minimum		624	-35.17	1.38	-50.49
Maximum		17200	-4.78	24.87	-8.93

WA =watershed area in square miles

Table 4. Differences in flow at long-term gage sites in the Southeastern United States (excluding Florida) between two multidecadal p

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
AL	Alabama River near Montgomery, AL	02420000	10/01/27	23011	15087	-9.67	1.59	1.24
AL	Black Warrior River at Northport, AL	02465000	01/01/85	29645	4820	-39.47	1.66	1.04
AL	Cahaba River at Centreville, AL	02424000	08/01/01	27678	1027	-14.76	1.55	0.9
AL	Choctawhatchee River near Newton, AL	02361000	12/01/21	26359	686	-7.64	1.39	0.98
AL	Coosa River at Childersburg, AL	02407000	10/01/13	23741	8392	-36.6	1.64	1.2
AL	Coosa River at Jordan Dam near Wetumpka, AL	02411000	10/01/12	28427	10102	-9	1.63	1.23
AL	Flint River near Chase, AL	03575000	05/01/30	23256	342	-16.57	1.67	0.92
AL	Locust Fork at Sayre, AL	02456500	10/01/28	23193	885	-12.17	1.65	0.92
AL	Mulberry Fork near Garden City, AL	02450000	10/01/28	26663	365	-21.83	1.87	0.98
AL	Murder Creek near Evergreen, AL	02374500	10/01/37	23376	176	-14.95	1.6	1.18
AL	Paint Rock River near Woodville, AL	03574500	01/01/36	24015	320	-18.69	2.14	1.01
AL	Perdido River at Barrineau Park, AL	02376500	06/09/41	22029	394	-10.38	1.98	1.34
AL	Sucarnoochee River at Livingston, AL	02467500	10/01/38	23011	607	-29.05	1.36	0.74
AL	Tallapoosa River at Wadley, AL	02414500	10/01/23	28490	1675	-18.4	1.55	1.1
AL	Tallapoosa River below Tallassee, AL	02418500	10/01/28	26663	3328	1.3	1.43	1.3
AL	Tennessee River at Florence, AL	03589500	10/01/1894	38351	30810	-19.65	1.7	1.43
AL	Tennessee River at Whitesburg, AL	03575500	10/01/24	27243	25610	-7.95	1.68	1.46
AL	Tombigbee River at Demopolis L&D near Coatopa, AL	02467000	08/01/28	26724	15385	-20.78	1.55	1.09
AR	Arkansas River at Murray Dam, AR	07263450	10/01/27	26664	158030	-38.8	0.28	0.18
AR	Arkansas River near Van Buren, AR	07250550	10/01/27	27029	NOWAG	-59.92		
AR	Bayou Bartholomew near McGehee, AR	07364133	10/01/38	22280	576	-6.85	1.2	0.79
AR	Black River at Black Rock, AR	07072500	10/01/29	23376	7369	-19.85	1.17	0.91
AR	Black River near Corning, AR	07064000	10/01/38	21915	1749	-36.37	1.05	0.74
AR	Buffalo River near St. Joe, AR	07056000	10/01/39	23011	829	-12.76	1.26	0.58
AR	Elevenpoint River near Ravenden Springs,AR	07072000	10/01/29	23376	1134	-20.48	1.01	0.79
AR	Little River near Horatio, AR	07340000	04/01/31	25386	2662	-59.24	1.5	0.7
AR	Ouachita River at Camden, AR	07359001	10/01/28	26298	5357	-25.16	1.45	0.87
AR	Ouachita River at Remmel Dam below Jones Mill, AR	07359002	10/01/28	25933	1550	-44.62	1.59	1.03
AR	Ouachita River near Malvern, AR	07359500	10/01/28	23010	1585	-43.41	1.57	0.99
AR	Ouachita River near Mount Ida, AR	07356000	10/01/41	21915	414	-20.37	1.77	0.77
AR	Petit Jean River at Danville, AR	07260500	06/01/16	31168	764	-42.54	1.12	0.53
AR	Poteau River at Cauthron, AR	07247000	03/01/39	22495	203	-59.6	1.14	0.31
AR	Red River at Index, AR	07337000	10/01/36	23741	42030	-42.06	0.31	0.18
AR	Saline River near Rye, AR	07363500	10/01/37	23376	2102	-12.65	1.24	0.75
AR	St. Francis at River at Parkin, AR	07047800	01/01/30	23634	NOWAG	24.28		
AR	White River at Calico, AR	07060500	10/01/39	22646	9978	-45.13	1.02	0.75
AR	White River at Newport, AR	07074500	10/01/27	24837	19860	-32.52	1.13	0.9
GA	Alapaha River at Statenville, GA	02317500	01/28/21	26017	1400	-37.11	0.77	0.46
GA	Altamaha River at Doctortown, GA	02226000	10/01/31	25933	13600	-1.62	1	0.78
GA	Brier Creek at Millhaven, GA	02198000	04/14/37	23911	646	6.26	0.97	0.77
GA	Broad River near Bell, GA	02192000	11/01/26	25902	1430	-10.09	1.23	0.84
GA	Canoochee River near Claxton, GA	02203000	05/26/37	23869	2650	-24.22	0.18	0.1
GA	Chattahoochee River at Atlanta, GA	02336000	08/01/28	25354	1450	-2.35	1.73	1.33
GA	Chattahoochee River at Buford Dam near Buford, GA	02334430	01/27/42	22162	1040	8.11	1.93	1.44
GA	Chattahoochee River at Columbus, GA	02341500	08/23/29	26446	4670	-13.41	1.45	1.16

Table 4. (Continued)

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
GA	Chattahoochee River at West Point, GA	02339500	08/01/1896	38776	3550	-21.85	1.52	1.2
GA	Chattahoochee River near Norcross, GA	02335000	01/01/03	32780	1170	0.87	1.9	1.46
GA	Chattooga River at Summerville, GA	02398000	03/11/37	23945	192	-10.9	1.84	1.16
GA	Chestatee River near Dahlonega, GA	02333500	07/08/29	23766	153	-5.41	2.38	1.89
GA	Conasauga River at Tilton, GA	02387000	06/05/37	23859	687	-15.58	1.76	1
GA	Coosa River near Rome, GA	02397000	10/01/1896	265113	4040	-13.68	1.62	1.22
GA	Coosawattee River near Pine Chapel, GA	02383500	11/11/38	22969	831	-16.07	1.8	1.37
GA	Etowah River at Allatoona Dam above Cartersville, GA	02394000	09/01/38	23406	1119	-10.88	1.67	1.27
GA	Etowah River at Canton, GA	02392000	10/01/1896	27392	613	-13.61	1.96	1.58
GA	Etowah River at Rome, GA	02396000	08/01/04	26632	1819	-21.23	1.57	1.25
GA	Etowah River near Kingston, GA	02395000	07/18/28	22834	1630	-15.3	1.58	1.24
GA	Flint River at Albany, GA	02352500	10/01/01	33876	5310	2.8	1.12	0.87
GA	Flint River at Montezuma, GA	02349500	10/01/04	29039	2900	8.28	1.21	0.92
GA	Flint River near Culloden, GA	02347500	07/01/11	29550	1850	4.6	1.21	0.81
GA	Flint River near Griffin, GA	02344500	03/01/37	23955	272	6.42	1.27	0.77
GA	Ichawaynochaway Creek at Milford, GA	02353500	09/01/05	23863	620	0.29	1.23	0.96
GA	Middle Oconee River near Athens, GA	02217500	10/01/01	25445	398	-9.56	1.29	0.91
GA	Ocmulgee River at Lumber City, GA	02215500	10/01/36	24106	5180	0.27	1.06	0.85
GA	Ocmulgee River at Macon, GA	02213000	02/01/1893	34148	2240	0.94	1.19	0.85
GA	Oconee River at Dublin, GA	02223500	10/01/1897	38350	4400	6.74	1.02	0.74
GA	Oconee River at Milledgeville, GA	02223000	09/01/03	36190	2950	5.02	1.06	0.72
GA	Oconee River near Greensboro, GA	02218500	08/01/03	25812	1090	Insufficient period of record		
GA	Ogeechee River near Eden, GA	02202500	04/27/37	23898	2650	2.3	0.88	0.62
GA	Ohoopee River near Reidsville, GA	02225500	06/24/03	25522	1110	-10.81	0.9	0.57
GA	Oostanaula River near Rome, GA	02388320	10/01/39	22645	2115	-17.41	1.71	1.15
GA	Satilla River at Atkinson, GA	02228000	03/21/30	26492	2790	-20.48	0.81	0.42
GA	Satilla River near Waycross, GA	02226500	03/29/37	23937	1200	-28.32	0.86	0.41
GA	Savannah River at Augusta, GA	02197000	10/01/1883	35063	7508	-6.35	1.26	0.99
GA	Savannah River near Clyo, GA	02198500	10/01/29	24837	9850	-4.28	1.19	0.99
GA	Suwannee River near Fargo, GA	02314500	04/26/37	25317	1260	-33.19	0.78	0.42
GA	Tobesofkee Creek near Macon, GA	02213500	04/01/37	23914	182	12.02	1.87	1.1
GA	Toccoa River near Blue Ridge, GA	03559000	110/01/1898	24075	233	Insufficient period of record		
GA	Toccoa River near Dial, GA	03558000	01/01/13	30589	177	-13.61	2.77	2.38
KY	Cumberland River at Barbourville, KY	03403500	10/1/1922	22373	960	-24.79	1.8	1.04
KY	Cumberland River near Harlan, KY	03401000	4/1/1940	22828	374	-26.07	1.83	1.11
KY	Elkhorn Creek near Frankfort, KY	03289500	5/1/1915	23025	473	-34.04	1.35	0.68
KY	Green River at Lock 2 at Calhoun, KY	03320000	4/1/1930	26481	7566	-34.44	1.48	1.05
KY	Green River at Lock 6 at Brownsville, KY	03311500	10/1/1924	22462	2762	-52.27	1.62	0.98
KY	Green River at Munfordville, KY	03308500	3/1/1915	27790	1673	-52.22	1.62	0.95
KY	Kentucky River at Lock 10 near Winchester, KY	03284000	10/1/1907	36699	3955	-23.5	1.34	0.75
KY	Kentucky River at Lock 13 at Heidelberg, KY	03282000	10/1/1925	25749	2657	-23.33	1.4	0.78
KY	Kentucky River at Lock 2 at Lockport, KY	03290500	10/1/1925	27173	6180	-24.78	1.34	0.79
KY	Kentucky River at Lock 4 at Frankfort, KY	03287580	10/1/1925	27575	5292	-22.19	1.34	0.79
KY	Kentucky River at Lock 6 near Salvisa, KY	03287000	10/1/1925	28124	5102	-22.07	1.32	0.77
KY	Levisa Fork at Paintsville, KY	03212500	10/1/1915	27394	2144	-28.62	1.15	0.68
KY	Levisa Fork at Pikeville, KY	03209500	10/1/1937	23741	1238	-32.79	1.17	0.68
KY	Licking River at Catawba, KY	03253500	8/1/1915	27902	3300	-44.96	1.25	0.66
KY	Licking River at McKinneysburg, KY	03251500	7/23/1924	22016	2326	-49.36	1.3	0.75
KY	Little River near Cadiz, KY	03438000	2/6/1940	22883	244	-20.68	1.45	0.84
KY	Little Sandy River at Grayson, KY	03216400	4/1/1938	23559	400	-26.95	1.18	0.55
KY	Middle Fork Kentucky River at Tallega, KY	03281000	10/1/1930	23559	537	-22.2	1.39	0.77

Table 4. (Continued)

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
KY	North Fork Kentucky River at Jackson, KY	03280000	6/1/1928	25048	1101	-24.29	1.33	0.71
KY	Ohio River at Louisville, KY	03294500	1/1/1928	27302	97170	-14.59	1.28	1.03
KY	Pond River near Apex, KY	03320500	8/21/1940	22686	194	-31.39	1.4	0.47
KY	Red River at Clay City, KY	03283500	10/1/1930	24107	362	-19.19	1.39	0.69
KY	Rockcastle River at Billows, KY	03406500	7/15/1936	24184	604	-20.39	1.54	0.77
KY	Rolling Fork near Boston, KY	03301500	5/24/1938	23506	1299	-29.44	1.38	0.56
KY	Russell Creek near Columbia, KY	03307000	10/1/1939	22646	188	-17.61	1.52	0.7
KY	Salt River at Shepherdsville, KY	03298500	5/23/1938	23507	1197	-49.4	1.31	0.52
KY	South Fork Kentucky River at Booneville, KY	03281500	3/1/1925	25416	722	-17.86	1.46	0.7
KY	Tradewater River at Olney, KY	03383000	8/18/1940	22416	255	-25.6	1.31	0.52
KY	Tygarts Creek near Greenup, KY	03217000	8/5/1940	22702	242	-19.4	1.26	0.56
KY	Yellow Creek near Middlesboro, KY	03402000	8/9/1940	22698	60.6	-25.1	1.96	0.99
LA	Amite River near Denham Springs, LA	07378500	9/1/1938	22676	1280	-21.71	1.65	0.79
LA	Bayou Cocodrie near Clearwater, LA	07382000	6/1/1922	22513	240	-13.68	1.8	1.4
LA	Bayou Des Cannes near Eunice, LA	08010000	10/1/1938	22646	131	1.16	2.09	0.41
LA	Bayou Nezpique near Basile, LA	08012000	10/1/1938	22646	527	-23.65	1.58	0.55
LA	Bogue Chitto River near Bush, LA	02492000	10/1/1937	23011	1213	-17.72	1.65	1.07
LA	Calcasieu River near Oberlin, LA	08013500	9/1/1922	22595	753	-2.95	1.51	0.76
LA	Tangipahoa River at Robert, LA	07375500	10/1/1938	22646	646	-13.86	1.8	1.1
LA	Tensas River at Tendal, LA	07369500	4/1/1936	22827	309	-39.73	1.16	0.55
LA	Whiskey Chitto Creek near Oberlin, LA	08014500	2/1/1939	22158	510	-14.12	1.61	0.84
MS	Big Black River near Bovina, MS	07290000	2/1/1936	23953	2812	-39.88	1.34	0.81
MS	Boule Creek near Hattiesburg, MS	02472500	9/16/1938	23386	304	-11.92	1.48	0.86
MS	Chickasawhay River at Enterprise, MS	02477000	8/20/1938	23418	918	-48.49	1.37	0.76
MS	Chickasawhay River at Leakesville, MS	02478500	9/14/1938	23393	2690	-26.63	1.44	0.94
MS	Chunky River near Chunky, MS	02475500	8/20/1938	23418	369	-26.48	1.34	0.61
MS	Homochitto River at Eddiceton, MS	07291000	10/1/1938	23350	181	-22.87	1.47	0.58
MS	Leaf River at Hattiesburg, MS	02473000	8/15/1938	23392	1748	-15.39	1.54	0.93
MS	Leaf River near Collins, MS	02472000	9/12/1938	23395	743	-19.58	1.47	0.71
MS	Leaf River near Mclain, MS	02475000	10/1/1939	23011	3495	-15.64	1.55	0.97
MS	Little Tallahatchie River at Etta, MS	07268000	9/24/1938	22137	526	-33.62	1.66	0.49
MS	Mississippi River at Vicksburg, MS	07289000	10/1/1931	24469	1140500	-21.86	0.53	0.49
MS	Noxubee River at Macon, MS	02448000	8/8/1928	24860	768	-33.52	1.38	0.61
MS	Pascagoula River at Merrill, MS	02479000	10/1/1930	26298	6590	-17.52	1.52	1.02
MS	Pearl River at Edinburg, MS	02482000	8/15/1928	27060	904	-29.28	1.3	0.72
MS	Pearl River at Jackson, MS	02486000	10/1/1901	30551	3171	-22.41	1.31	0.78
MS	Pearl River at Monticello, MS	02488500	10/1/1938	23376	4993	-22.26	1.35	0.88
MS	Tallahala Creek at Laurel, MS	02473500	9/13/1938	23392	238	-24.03	1.45	0.69
MS	Tallahala Creek near Runnelstown, MS	02474500	10/1/1939	22565	612	-20.32	1.54	0.89
MS	Tombigbee River at Columbus, MS	02441500	10/1/1899	25547	4453	-13.334	1.48	0.87
MS	Tombigbee River at Stennis Lock and Dam, MS	02441390	10/1/1899	31411	4440	-21.24	1.57	0.91
MS	Tombigbee River near Fulton, MS	02431000	8/13/1928	27077	612	-7.25	1.56	0.83
MS	Town Creek near Nettleton, MS	02436500	10/1/1939	22949	620	-61.8	1.58	0.47
MS	Tuscolameta Creek at Walnut Grove, MS	02483000	10/1/1938	22668	411	-20.12	1.25	0.41
MS	Yockanookany River near Kosciusko, MS	02484000	8/17/1938	23394	303	-26.46	1.47	0.51
NC	Beetree Creek near Swannanoa, NC	03450000	3/1/1926	25094	5.46	-10.64	1.94	1.38
NC	Broad River near Boiling Springs, NC	02141500	7/1/1925	28216	875	-11.46	1.71	1.38
NC	Cape Fear River at Lillington, NC	02102500	1/1/1924	28763	3464	-20.53	0.97	0.51
NC	Cape Fear River at Wilm O Huske Lock nr Tarheel, NC	02105500	10/1/1937	23741	4852	-8.04	1.01	0.62
NC	Contentnea Creek at Hookertown, NC	02091500	12/1/1928	26965	733	-6	1.06	0.7
NC	Dan River near Wentworth, NC	02071000	12/1/1939	22950	1053	-11.25	1.14	0.81

Table 4. (Continued)

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
NC	Davidson River near Brevard, NC	03441000	10/1/1920	28918	40.4	-6.37	3.16	2.45
NC	Deep River at Moncure, NC	02102000	8/1/1930	26359	1434	-4.79	1.01	0.45
NC	Deep River at Ramseur, NC	02100500	4/1/1923	29038	349	-17.05	1.02	0.48
NC	Deep River near Randleman, NC	02099500	10/1/1928	27028	125	-21.35	1.02	0.48
NC	Drowning Creek near Hoffman, NC	02133500	10/1/1939	23011	183	2.66	1.37	1.11
NC	East Fork Deep River near High Point, NC	02099000	10/1/1928	25749	14.8	-21.81	1.17	0.51
NC	Eno River at Hillsborough, NC	02085000	10/1/1927	22286	66	10.43	0.92	0.45
NC	Fisher River near Copeland, NC	02113000	10/1/1931	25933	128	-6.24	1.41	1.06
NC	Fishing Creek near Enfield, NC	02083000	10/1/1926	27757	526	-2	0.94	0.56
NC	Flat River at Bahama, NC	02085500	8/1/1925	28185	149	-10.84	0.97	0.41
NC	French Broad River at Asheville, NC	03451500	10/1/1895	39081	945	-14.42	2.16	1.73
NC	French Broad River at Blantyre, NC	03443000	10/1/1920	29950	296	-10.04	3.4	2.73
NC	French Broad River at Marshall, NC	03453500	10/1/1942	21915	1332	-8.22	1.84	1.49
NC	French Broad River Rosman, NC	03439000	10/1/1907	25111	67.9	-8.03	3.49	2.8
NC	Haw River at Haw River, NC	02096500	10/1/1928	27028	606	-11.66	0.99	0.52
NC	Henry Fork near Henry River, NC	02143000	8/1/1925	24501	83.2	-14.69	1.62	1.19
NC	Hiwassee River above Murphy, NC	03548400	10/1/1897	38350	406	-17.25	2.18	1.87
NC	Linville River near Nebo, NC	02138500	7/1/1922	29312	66.7	-11.98	2.28	1.5
NC	Little River near Princeton, NC	02088500	3/1/1930	26511	232	3.59	1.1	0.62
NC	Lumber River at Boardman, NC	02134500	10/1/1929	26663	1228	-6.93	1.08	0.84
NC	Middle Creek nera Clayton, NC	02088000	10/1/1939	23011	83.5	10.32	1.09	0.6
NC	Mills River near Mills River, NC	03446000	10/1/1924	25750	66.7	-6.28	2.55	2.04
NC	Nantahala River near Rainbow Springs, NC	03504000	10/1/1940	22645	51.9	-7.7	3.92	3.21
NC	Neuse River at Kinston, NC	02089500	3/1/1930	26511	2692	-2.9	1.07	0.76
NC	Neuse River near Clayton, NC	02087500	8/1/1927	27455	1150	-0.53	1	0.57
NC	Neuse River near Goldsboro, NC	02089000	3/1/1930	25779	2399	-3.9	1.05	0.71
NC	North Fork Buffalo Creek near Greensboro, NC	02095500	9/1/1928	24228	37.1	-27.2	1.57	0.88
NC	Northeast Cape Fear River near Chinquapin, NC	02108000	8/1/1940	22706	599	-8.86	1.2	0.73
NC	Pee Dee River near Rockingham, NC	02129000	9/1/1906	29342	6863	-21.26	1.15	0.89
NC	Pigeon River near Hepco, NC	03459500	8/1/1927	27455	350	-9.75	1.92	1.51
NC	Reddies River at North Wilkesboro, NC	02111500	10/1/1939	23011	89.2	-16.13	1.58	1.27
NC	Reedy Fork near Gibsonville, NC	02094500	10/1/1928	27028	131	33.29	0.76	0.32
NC	Roanoke River at Roanoke Rapids, NC	02080500	1/1/1912	33144	8384	-20.31	0.97	0.73
NC	Rocky River near Norwood, NC	02126000	10/1/1929	26663	1372	-20.38	0.98	0.37
NC	Second Broad River at Cliffside, NC	02151000	7/1/1925	26117	220	-17.66	1.44	1.08
NC	Smith River at Eden, NC	02074000	10/1/1930	23011	538	-27.85	1.19	0.87
NC	South Fork New River near Jefferson, NC	03161000	10/1/1924	27757	205	-11.16	2.11	1.71
NC	South Yadkin River near Mocksville, NC	02118000	10/1/1938	23376	306	-13.35	1.11	0.81
NC	Swannanoa River at Biltmore, NC	03451000	10/1/1920	27150	130	-5.42	1.22	0.87
NC	Tar River at Tarboro, NC	02083500	8/1/1896	27543	2183	-0.75	1.03	0.65
NC	Tar River near Tar River, NC	02081500	10/1/1939	23011	169	-6.6	0.92	0.34
NC	Tuckasegee River at Bryson City, NC	03513000	10/1/1897	37287	655	-14.16	2.4	2.02
NC	Valley River at Tomotla, NC	03550000	7/1/1904	33845	104	-14.57	2.4	1.8
NC	Waccamaw River at Freeland, NC	02109500	8/1/1939	22707	680	-19.74	1.07	0.62
NC	Watauga River near Sugar Grove, NC	03479000	4/1/1940	22828	92.1	-13.19	1.93	1.29
NC	Yadkin River at Patterson, NC	02111000	10/1/1939	23011	28.8	-15.89	1.75	1.33
NC	Yadkin River at Wilkesboro, NC	02112000	4/1/1903	31868	504	-21.84	1.59	1.25
NC	Yadkin river at Yadkin College, NC	02116500	8/1/1928	27089	2280	-15.67	1.31	1.01
SC	Black River at Kingstree, SC	02136000	10/01/29	25933	1252	-38.43	0.78	0.48
SC	Broad River near Carlisle, SC	02156500	10/01/38	22646	2790	-3.343	1.41	1.07
SC	Catawba River near Rockhill, SC	02146000	10/01/1895	24289	3050	-11.5	1.35	1.14

Table 4. (Continued)

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
SC	Chattooga River near Clayton, SC	02177000	10/01/39	23011	207	-10.95	3.13	2.58
SC	Congaree River at Columbia, SC	02169500	10/01/39	22646	7850	0.9	1.15	0.89
SC	Edisto River near Givhans, SC	02175000	01/01/39	22919	2730	-4.34	0.95	0.71
SC	Lynches River at Effingham, SC	02132000	10/01/29	26298	1030	-15.72	1.01	0.76
SC	North Fork Edisto River at Orangeburg, SC	02173500	12/01/38	22585	1083	-4.29	0.72	0.63
SC	North Pacolet River at Fingerville, SC	02154500	04/01/30	26116	116	-6.51	1.77	1.37
SC	Pacolet River near Fingerville, SC	02155500	12/01/30	26116	212	2.83	1.57	1.18
SC	Pee Dee River at Peedee, SC	02131000	10/01/38	23011	8830	-22.82	1.11	0.9
SC	Reedy River near Ware Shoals, SC	02165000	04/01/39	22829	236	-22.25	1.5	1.13
SC	Saluda River at Chappells, SC	02167000	10/01/26	27394	1360	6.65	1.37	1.09
SC	Saluda River near Columbia, SC	02169000	08/14/25	27807	2520	12.39	1.11	0.8
SC	Saluda River near Ware Shoals, SC	02163500	03/24/39	22837	580	-2.36	1.7	1.35
SC	South Fork Edisto River near Denmark, SC	02173000	08/04/31	22310	720	4.03	1.32	1.13
SC	Wateree River near Camden, SC	02148000	10/01/29	26298	5070	-13.01	1.21	1.01
VA	Appomattox River at Farmville, VA	02039500	4/1/1926	27942	303	-20.06	0.97	0.6
VA	Appomattox River at Mattoax, VA	02040000	4/1/1926	27942	726	-15.98	0.99	0.58
VA	Banister River at Halifax, VA	02077000	10/1/1904	27423	547	-5.16	0.93	0.6
VA	Big Otter River near Evington, VA	02061500	4/1/1937	23924	3230	-11.33	0.1	0.07
VA	Big Reed Island Creek near Allisonia, VA	03167500	10/1/1908	23379	278	-12.75	1.44	1.14
VA	Calfpasture River above Mill Creek at Goshen, VA	02020500	10/1/1938	22646	144	-10.86	1.16	0.55
VA	Cedar Creek near Winchester, VA	01634500	10/1/1937	23741	103	-27.83	0.94	0.5
VA	Cickahominy River near Providence Forge, VA	02042500	1/1/1942	22188	252	-7.44	1.02	0.7
VA	Clinch River at Cleveland, VA	03524000	10/1/1920	39950	528	-16.71	1.32	0.85
VA	CowpastureRiver near Clifton Forge, VA	02016000	10/1/1925	28124	461	-11.31	1.17	0.67
VA	Craig Creek at Parr, VA	02018000	4/1/1925	28307	329	-16.09	1.19	0.69
VA	Dan River at Danville, VA	02075000	8/1/1934	22341	2105	-13.01	1.11	0.78
VA	Difficult Run near Great Falls,VA	01646000	4/1/1935	24655	57.9	-17.52	1.05	0.67
VA	Dunlap Creek near Covington, VA	02013000	10/1/1928	27028	164	-17.55	1.04	0.55
VA	Falling River near Naruna, VA	02064000	10/1/1929	24106	173	-13.86	0.91	0.59
VA	Goose Creek near Huddleston, VA	02059500	10/1/1930	26298	188	-13.66	0.97	0.62
VA	Goose Creek near Leesburg, VA	01644000	7/12/1909	27717	332	-26.01	0.97	0.56
VA	Hardware River below Briery Run near Scottsville, VA	02030000	10/1/1938	23020	116	-22.08	1.11	0.73
VA	James River and Kanawha Canal near Richmond, VA	02037000	10/1/1936	24106	NOWAG	74.31		
VA	James River at Bent Creek, VA	02026000	4/1/1925	27941	3683	-10.31	1.16	0.78
VA	James River at Buchanan, VA	02019500	10/1/1910	33603	2075	-15.11	1.2	0.74
VA	James River at Cartersville, VA	02035000	1/1/1899	37893	6257	-17.35	1.12	0.76
VA	James River at Holcomb Rock, VA	02025500	4/1/1927	27577	3259	-6.7	1.13	0.71
VA	James River at Lick Run, VA	02016500	4/1/1925	28307	1373	-13.46	1.19	0.74
VA	James River at Scottsville, VA	02029000	10/1/1924	28489	4584	-14.89	1.15	0.78
VA	James River near Richmond, VA	02037500	10/1/1934	24837	6758	-29.72	1.02	0.68
VA	Johns Creek at New Castle, VA	02017500	10/1/1926	27759	104	-22.2	1.24	0.73
VA	Kerrs Creek near Lexington, VA	02022500	4/1/1927	27394	35	-16.51	1.03	0.59
VA	Little River at Graysontown, VA	03170000	10/1/1928	27028	300	-10.42	1.2	0.92
VA	Maury River at Rockbridge, VA	02021500	10/1/1928	27028	329	-16.3	1.18	0.61
VA	Maury River near Buena Vista, VA	02024000	10/1/1938	23376	646	-15.31	1.04	0.63
VA	Meherrin River near Lawrenceville, VA	02051500	12/19/1928	26949	552	-12.72	0.91	0.5
VA	Middle River near Grottoes, VA	01625000	10/1/1927	27394	375	-20.55	0.86	0.57
VA	New River at Eggleston, VA	03171500	10/1/1914	22646	2941	Insufficient period of record		
VA	New River at Glen Lyn, VA	03176500	10/1/1927	27394	3768	-9.76	1.33	1.05
VA	New River at Radford, VA	03171000	10/1/1907	25933	2748	-18.03	1.4	1.12
VA	New River near Galax, VA	03164000	10/1/1929	26663	1131	-13.56	1.69	1.32

Table 4. (Continued)

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
VA	North Fork Holston River near Saltville, VA	03488000	6/1/1907	30530	222	-17.44	1.33	0.82
VA	North Fork Shenandoah River at Cootes Store, VA	01632000	4/1/1925	28307	210	-13.18	0.95	0.39
VA	North Fork Shenandoah River near Strasburg, VA	01634000	4/1/1925	28307	768	-16	0.8	0.48
VA	North Mayo River near Spencer, VA	02070000	10/1/1928	26663	108	-18.94	1.2	0.88
VA	North River near Burketown, VA	01622000	6/1/1926	26948	379	-14.16	1.02	0.6
VA	Nottoway River near Stony Creek, VA	02045500	10/1/1930	26298	579	-8.43	0.97	0.59
VA	Pamunkey River near Atlee, VA	01673000	10/1/1941	22280	1081	-10.99	0.93	0.55
VA	Passage Creek near Buckton, VA	01635500	4/1/1932	25750	87.8	-23.67	0.82	0.42
VA	Potts Creek near Covington, VA	02014000	10/1/1928	23741	153	-15.62	1.17	0.7
VA	Pound River below Flannagan Dam near Haysi, VA	03209000	10/1/1926	27394	221	-33.2	1.24	0.68
VA	Powell River near Jonesville, VA	03531500	10/1/1931	25933	319	-22.48	1.68	1
VA	Rappahannock River near Fredericksburg, VA	01668000	9/19/1907	34711	1596	-17.45	1.06	0.63
VA	Reed Creek at Grahams Forge, VA	03167000	10/1/1908	30499	247	-13.62	1.08	0.75
VA	Rivanna River at Palmyra, VA	02034500	10/1/1934	24837	664	-18.52	1.09	0.65
VA	Roanoke River at Altavista, VA	02060500	10/1/1930	26298	1784	8.08	1.01	0.7
VA	Roanoke River at Brookneal, VA	02062500	10/1/1923	28855	2415	-4.11	1.01	0.7
VA	Roanoke River at Niagara, VA	02056000	10/1/1926	27759	512	-8.69	1.01	0.67
VA	Roanoke River at Roanoke, VA	02055000	2/13/1899	37012	395	-8.29	0.91	0.57
VA	Russel Fork at Haysi, VA	03208500	7/17/1926	27835	286	-31.43	1.16	0.6
VA	Sandy River near Danville, VA	02074500	10/1/1929	26663	112	-14.81	0.99	0.66
VA	Slate River near Arvonia, VA	02030500	4/1/1926	25034	226	-13.97	1.01	0.59
VA	Smith River at Bassett, VA	02072500	4/1/1939	23194	259	-16	1.29	1
VA	Smith River at Martinsville, VA	02073000	10/1/1929	26663	380	-23.43	1.26	0.95
VA	South Anna River near Ashland, VA	01672500	10/1/1930	24473	394	-14.25	0.94	0.55
VA	South Fork Holston River at Riverside near Chilhowie, VA	03471500	10/1/1920	26024	76.1	-9.36	1.46	1.05
VA	South Fork Holston River near Damascus, VA	02473000	10/1/1931	25933	301	-15.6	1.57	1.15
VA	South Fork Shenandoah River at Front Royal, VA	01631000	10/1/1930	26298	1645	-14.31	0.97	0.64
VA	South Fork Shenandoah River near Lynnwood, VA	01628500	10/1/1930	26298	1084	-18.01	0.96	0.61
VA	South River at Harriston, VA	01627500	2/15/1925	22142	212	-12.6	1.26	0.8
VA	Tye River near Lovingston, VA	02027000	10/1/1938	23376	92.8	-15.25	1.69	1.11
VA	Walker Creek at Bane, VA	03173000	4/1/1938	23559	305	-11.27	1.06	0.99
VA	Wolf Creek near Narrows, VA	03175500	7/22/1908	26187	223	-14.75	1.33	0.87
WV	Big Coal River at Ashford, WV	03198500	7/1/1908	28729	391	-23.55	1.34	0.81
WV	Big Sandy Creek at Rockville, WV	03071000	5/7/1909	32262	200	-19.34	2.06	1.26
WV	Blackwater River at Davis, WV	03066000	5/1/1921	29008	85.5	-18.18	2.38	1.44
WV	Buckhannon River at Hall, WV	03053500	4/15/1915	31216	277	-17.42	2.17	1.32
WV	Buffalo Creek at Barrackville, WV	03061500	6/3/1907	28783	116	-28.49	1.46	0.67
WV	Cacapon River near Great Cacapon, WV	01611500	12/12/1922	28052	675	-15.97	0.88	0.47
WV	Cheat River at Rowlesburg, WV	03070000	1/10/1923	26664	939	-19.01	2.5	1.57
WV	Cheat River near Parsons, WV	03069500	1/1/1913	32050	722	-15.05	2.4	1.5
WV	Elk River at Queen Shoals, WV	03197000	10/1/1928	26298	1445	-30.1	1.45	0.92
WV	Gauley River above Belva, WV	03192000	10/20/1928	25908	1317	-20.55	2.1	1.35
WV	Greenbrier River at Alderson, WV	03183500	8/1/1895	38412	1364	-17.14	1.43	0.84
WV	Greenbrier River at Buckeye, WV	03182500	10/1/1929	25929	540	-12.73	1.66	0.96
WV	Greenbrier River at Hilldale, WV	03184000	6/12/1936	23487	1619	-14.31	1.4	0.84
WV	Guyandotte River at Branchland, WV	03204000	10/1/1915	25020	1224	-24.8	1.35	0.83
WV	Kanawha River at Charleston, WV	03198000	6/1/1939	22403	10448	-14.89	1.44	1.07
WV	Kanawha River at Kanawha Falls, WV	03193000	4/1/1877	45108	8371	-15.8	1.45	1.05
WV	Little Kanawha River at Glenville, WV	03152000	6/1/1915	27881	387	-22.79	1.61	0.8
WV	Little Kanawha River at Palestine, WV	03155000	10/1/1939	22281	1516	-24.22	1.42	0.72
WV	Middle Island Creek at Little, WV	03114500	10/1/1915	24837	458	-21.75	1.42	0.6

Table 4. (Continued)

State	Site Name	Site Number	From	Count	WA	%forYear	POR Daily Mean/WA	POR Daily Med/WA
WV	New River at Hinton, WV	03184500	6/15/1936	23484	6256	-10.05	1.26	0.92
WV	Patterson Creek near Headsville, WV	01604500	8/1/1938	22676	211	-46.63	0.82	0.41
WV	Potomac River at Shepherdstown, WV	01618000	8/1/1928	24897	5936	-26.77	1.03	0.67
WV	Shavers Fork at Parsons, WV	03069000	10/1/1910	25488	213	-10.29	2.54	1.63
WV	Shenandoah River at Millville, WV	01636500	4/1/1895	31473	3022	-22.15	0.91	0.59
WV	South Branch Potomac River near Petersburg, WV	01606500	6/25/1928	26395	676	-18.33	1.11	0.69
WV	South Branch Potomac River near Springfield, WV	01608500	7/1/1899	28305	1486	-17.54	0.92	0.54
WV	Tygart Valley River at Belington, WV	03051000	6/5/1907	34087	406	-18.02	2.03	1.18
WV	Tygart Valley River at Philippi, WV	03054500	4/1/1940	22098	914	-16.9	2.09	1.29
WV	Tygart Valley River near Dailey, WV	03050000	4/20/1915	26535	185	-28.68	1.89	1.06
WV	West Fork River at Butcherville, WV	03058500	4/8/1915	31131	181	-46.93	1.66	0.82
WV	West Fork River at Clarksburg, WV	03059000	3/3/1923	22127	384	Insufficient period of record		
WV	West Fork River at Enterprise, WV	03061000	6/2/1907	27858	759	-18.36	1.53	0.85
WV	Wheeling Creek at Elm Grove, WV	03112000	10/1/1940	21915	281	-24.59	1.19	0.65
WV	Williams River at Dyer, WV	03186500	9/16/1929	25948	128	-16.15	2.62	1.57

		Count	WA	%forYear	POR DailyMean/WA	POR Daily Med/WA
282 increased	Mean	26882	6495	-16.54	1.39	0.90
29 decreased	Median	25750	704	-15.97	1.33	0.80
4 insufficient record	Min	21915	5	-61.80	0.10	0.07
	Max	265113	1140500	74.31	3.92	3.21

WA = watershed area in square miles
POR Daily Mean/WA = Period of Record Mean Daily Flow divided by watershed area (cfs/sq mile)
POR Daily Med/WA = Period of Record Median Daily Flow divided by watershed area (cfs/sq mile)
1940 to 1969 Flow/WA = Median Daily Flow for the period 1940 to 1969 divided by watershed area (cfs/sq mile)
1970 to 1999 Flow/WA = Median Daily Flor for the period 1970 to 1999 divided by watershed area (cfs/sq mile)
insufficient period of record - generally refers to a large data gap in one of the periods of interest

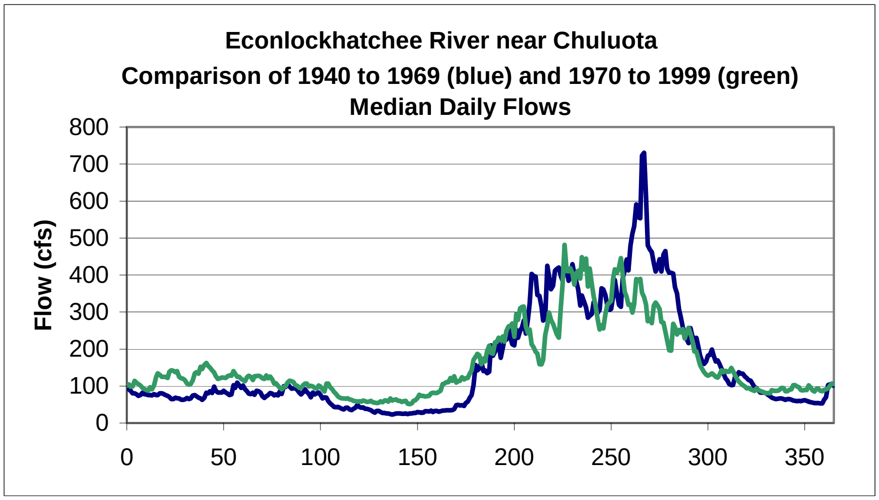


Figure 15. Plots of median daily flows for the Ecolockhatchee River near Chuluota, FL.

Particularly interesting, however, is the pattern of increases and decreases in flow seen at the five long-term flow sites with a BRP (see Table 5; Figure 16). In all cases the SRP mode (the peak in flow occurring in the June 14 to October 27 timeframe) decreased between the two 30-year periods; the average decrease in median daily flows was 23%. In contrast is the average increase in flows for the NRP mode (January 1 to May 15) of 53%. For gage sites with a BRP, one mode increased while the other decreased and vice versa consistent with Enfield et al. (2001). This is clear evidence of a significant climatic factor. While one might argue that different anthropogenic factors could lead to decreases at SRP gage sites and increases at NRP gage sites, it is difficult to postulate an anthropogenic factor that would cause one mode to increase and the other to decrease during one 30-year period with the reverse occurring in the other 30-year period.

Flows at most sites with a SRP decreased between the two 30-year periods examined. Anthropogenic factors are suspected of causing flow declines at some sites in the SWFWMD (e.g., see Hammett 1990, Flannery and Barcelo 1998); however, deficit rainfall consistent with observations of Enfield et al. (2001) should lead to appreciable declines at these sites as well. Apparent in these plots are relatively long periods (multiple decades) of high wet season flows and relatively long periods (multiple decades) of low wet season flows. The trend is evident not only in those rivers for which we are currently working to develop MFLs but in most rivers and streams in peninsular Florida.

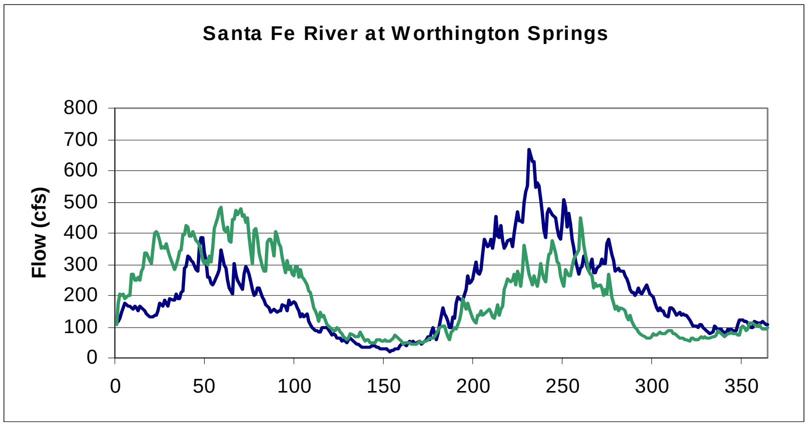
For each site examined with a sufficient period of record, three plots and one summary table were prepared as demonstrated in Figure 17. The plot in the upper left is a hydrograph showing the median daily flow for each day of the year for the two periods. The plot in the lower left is identical to the one above except that the 30-year median daily flow for each day has been divided by the gaged watershed area, and as a result, values are expressed as cubic feet per second per square mile of watershed. This is essentially an expression of runoff yield per unit area and allows direct comparisons between watercourses with differing watershed areas. The plot in the upper right of the example figure (Figure 17) was obtained by subtracting the 1970 to 1999 median daily flow for each day from the corresponding median daily flow for each day in the 1940 to 1969 period. As a result, if the median flow during one day in the recent period was lower than the corresponding median daily flow, the difference would be positive and representative of a decrease and thus plotted as a positive number (above the red line in the figure); if the result were negative, this would indicate an increase between the two periods and would be plotted below the red reference line. The average of all median daily flows for each 30-year period was determined and is given in the summary table (bottom right hand corner of the figure). The percent increase or decrease between periods was determined. A positive number is actually representative of the percent decrease between the two periods, while a negative number represents a net percent increase. Summary plots and tables for all 39 Florida sites with at least 60 years of record are presented in the Appendix**;** also included are some Florida sites with a period of record less than 60 years, but of particular interest to the SWFWMD.

Table 5. Pecent decrease in flows between two multidecadal periods at long-term Florida gage sites with a Bimodal River Pattern.

Note: Positive values indicate a decrease in flow between the two multidecal periods (1940-1969 and 1970-1999) since the mean of the more recent period was subtracted from the earlier period.

River/Stream	USGS Code	WA	%Change for Year	%Change for SRP Wet Season	%Change for NRP Wet Season
Suwanee River at White Springs	02315500	2430	-23.25	33.50	-79.20
South Fork Black Creek near Penney Farms	02245500	134	9.86	22.56	-11.11
North Fork Black Creek near Middleburg	02246000	177	-5.65	11.02	-28.42
Santa Fe River at Worthington Spgs	02321500	575	2.93	38.26	-62.09
St. Marys River near Macclenny	02231000	700	-26.89	11.50	-85.67
Means		803	-8.60	23.37	-53.30
Median		575	-5.65	22.56	-62.09
Minimum		134	-26.89	11.02	-85.67
Maximum		2430	9.86	38.26	-11.11

WA =watershed area in square miles



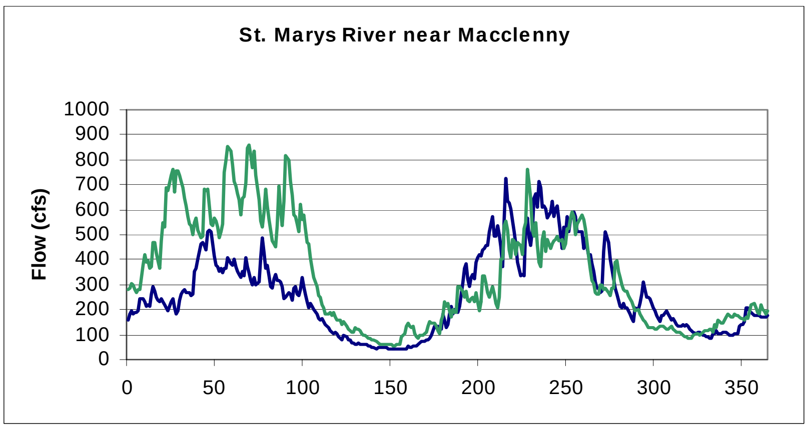
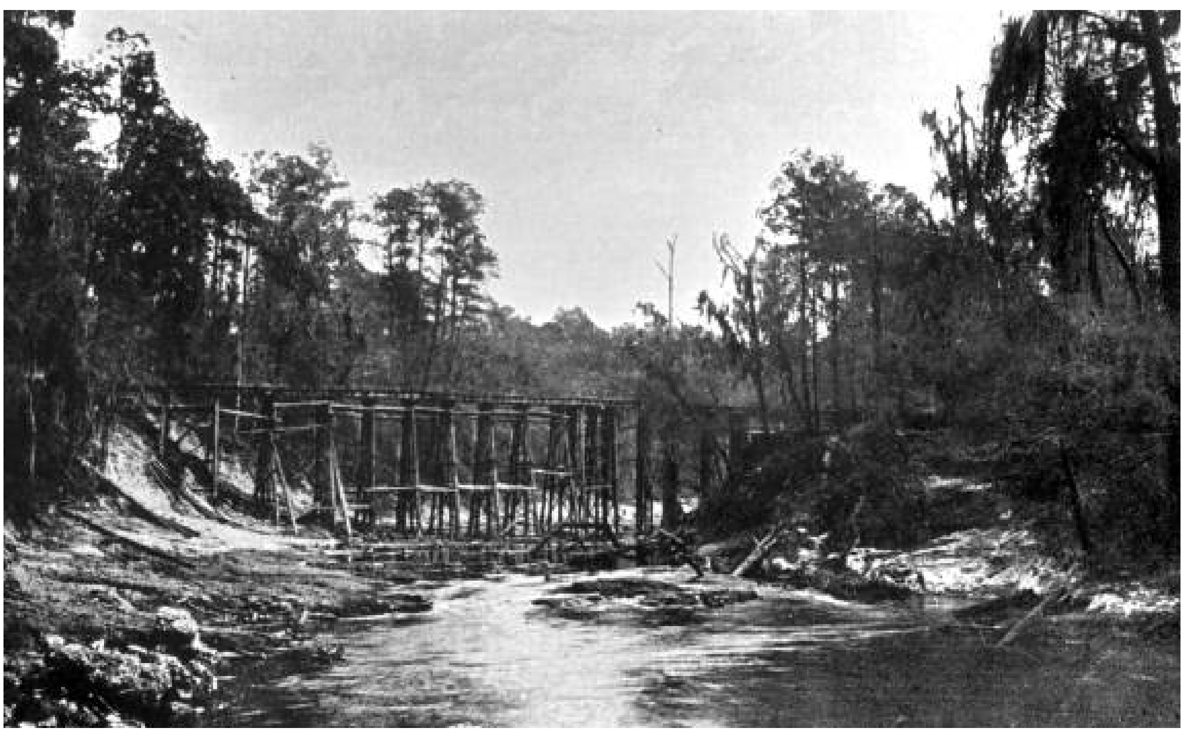
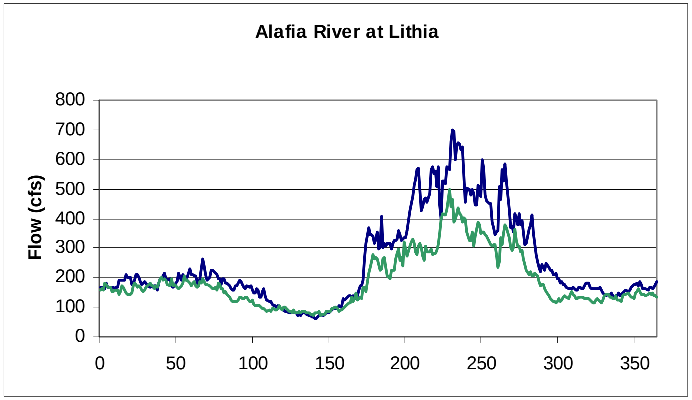


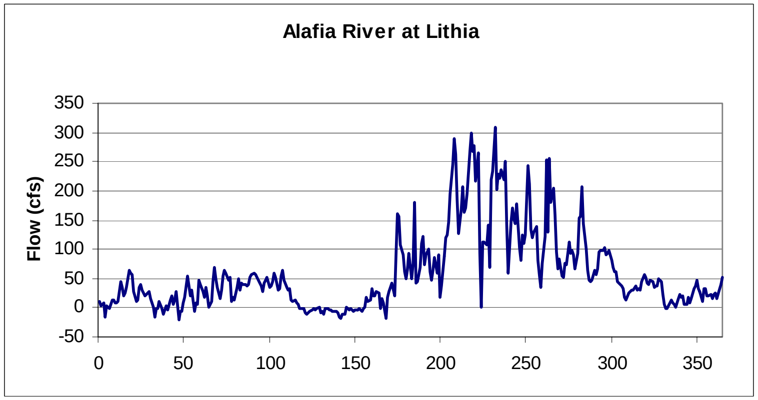
Figure 16. Example of two Bimodal River Pattern (BRP) sites comparing median daily

To be consistent with the AMO as described by Enfield et al. (2001), one would expect to find higher flows during AMO warmings in peninsular Florida (positive correlations between AMO warmings and rainfall) while at the same time lower flows at most sites across the United States (negative correlations between AMO warmings and rainfall). The reverse should be true during AMO cool periods in the absence of significant anthropogenic effects. Sites in most of peninsular Florida exhibit a SRP while those in the north central to northwest part of the state exhibit a NRP similar to that found in neighboring states. It was generally anticipated that to be consistent with Enfield et al. (2001) sites with a SRP would exhibit higher flows in the multidecadal period extending from 1940 to 1969 and lower flows in the multidecadal period extending from 1970 to 1999. It was likewise anticipated that streams with a NRP would exhibit lower flows in the multidecadal period extending from 1940 to 1969 and higher flows in the multidecadal period extending from 1970 to 1999. This was the case based on a comparison of the two multidecadal plots of median daily flows. Unfortunately Florida's continued growth and development during the last several decades means that all things have not remained equal. Although consistent with Enfield et al. (2001), human factors during the last three decades have likely affected flows to some degree; it is noted, however, that in the northern part of the state growth has also occurred, yet flows have apparently increased at those sites. Sites with a BRP actually demonstrate both an increasing and decreasing trend in flow depending on which mode is examined. The mode that is characteristic of the NRP has increased between the two multidecadal periods examined, while the mode that is characteristic of the SRP has decreased between the two mutidecadal periods. Although flow trends at NRP and SRP sites are consistent with Enfield et al. (2001), those sites with a BRP offer especially strong support, since they exhibit characteristics of NRP and SRP with each mode responding consistent with Enfield et al. (2001). After reviewing hundreds of multidecadal plot comparisons, we conclude that a strong argument can be made in favor of a multidecadal oscillation in flow as described by Enfield et al. (2001). This oscillation has only recently been appreciated and has important implications for many water resource related issues ranging from direct ecological affects to water supply planning to flood management.

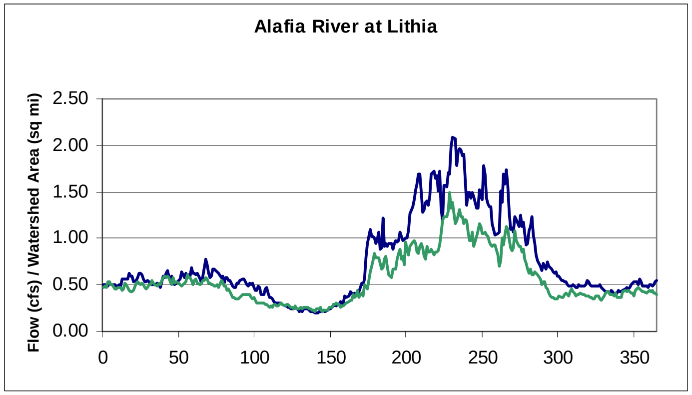


Suwannee River at Lover's Leap 1905
From the Florida Photographic Collection





Period	Average of the Median Daily Flows (cfs)	
1940 to 1969	247.37	
1970 to 1999	188.74	
Difference for year	58.62	37.87 MGD
% Change for year	23.70%	
Difference for SRP Wet Season	121.36	78.40 MGD for 135 days 29.01 MGD for ye
% Change for SRP Wet Season	30.31%	
Difference for NRP Wet Season	22.11	14.29 MGD for 135 days 5.29 MGD for ye
% Change for NRP Wet Season	13.21%	



Mean 40 to 69 Daily Median Flow (inches)	10.03
Change in inches between periods	2.38
Mean of 40 to 69 Mean Daily Flow in inches	15.74
Mean of 70 to 99 Mean Daily Flow in inches	11.50
Change in inches	4.24
Percent Change between periods	26.93%

SRP Wet Season is June 14 to Oct 27 - total of 135 consecutive days
NRP Wet Season is Jan 1 to May 15 - total of 135 consecutive days
Wet seasons differences are the average daily difference for the respective 135 day periods
to extrapolate to a daily value per year multiply by 0.37 (i.e., 135 days / 365 days)

Watershed area (WA) upstream of the gage in square miles is:		335
Mean of POR Daily Mean Flow/WA:	1.00	
Mean of POR Daily Median Flow/WA:	0.62	
Mean of 40 to 69 Daily Median Flow/WA:	0.74	
Mean of 70 to 99 Daily Median Flow/WA:	0.56	
% Change in DFF/WA	23.70%	

Figure 17. Example of plots and summary table generated for each Florida sites with a sufficient flow record. Plots and table for all sites are included in the appendix.

Statistical Analysis

Flow Trends – testing for a monotonic trend and a step trend

The analysis of flow patterns presented thus far has relied primarily on flow plots and a more or less visual comparison and interpretation of plots between periods that correspond closely with a warm and cool phase of the AMO. A typically applied statistical approach for assessing flow trends in southwest Florida has been the application of the Kendall's tau test to mean annual flows for various time periods (e.g., Hammett 1990, Flannery and Barcelo 1998, Stoker et al. 1996). This type of analysis was repeated here, although it is argued that this analysis is best suited for determining if a significant monotonic trend has occurred. Analysis was conducted on mean annual flows for several time periods. The period of record was tested for all sites examined, although it should be noted that there is considerable variation in the period of record between sites. For those sites with a sufficient period of record, it was desirable to do a trend analysis for the two time periods discussed above. As a result, for those Florida sites with sixty years of record extending from 1940 to 1999, three time periods were evaluated; 1940 to 1999, 1940 to 1969, and 1970 to 1999. The results of Kendall's tau for all Florida sites with sixty years of data from 1940 to 1999 are included in Table 6; also included in this table are an additional number of sites with less than 60 years of data. Those sites with 60 years of data will have statistics shown for the period 1940 to 1999. Those sites with less than 60 years of data do not have statistics displayed for this time period. For those sites with less than sixty years of data between 1940 and 1999, the time that the period of record began (after 1940) is highlighted in bold in the table as a reminder to the reader that the actual period analyzed begins after 1940. As an example, in Table 6 the Anlcote River is the second entry in the table. Its period of record did not begin until June 1, 1946, so there is no annual mean for each year in the period 1940 to 1946, and the Kendall's tau for the period 1940 to 1969 was actually run for the period 1947 to 1969 (23 years instead of 30 years). Based on 23 years of data, there is no significant monotonic trend in flow during the period 1947 to 1969, although the slope of the trend line is negative (slope = -0.1569 cfs; $p = 0.9159$). As an aside, it should be noted that for the period 1970 to 1999 (for which there is 30 years of data on the Anclote River), no significant monotonic trend in the mean annual flow is indicated, although the slope is negative (slope = -0.2417 cfs; $p = 0.6686$). Neither p value indicates a statistically significant trend, and both p values are relatively high; however, when the Kendall's tau is run on mean annual flows for the period 1947 to 1999, a highly significant statistical trend is found (slope = -0.9572 cfs, $p = 0.0029$). How should this be interpreted?

Since it is believed that much of the change in river flow pre and post 1970 can best be described as a step trend as suggested by a fairly abrupt change in North Atlantic Ocean sea surface temperature (see Figure 11), the Mann-Whitney trend test (also referred to as the Rank Sum test) was used to determine if flows were different between the two periods (1940 to 1969 and 1970 to 1999). Mann-Whitney test results for all Florida gage sites for which the Kendall's tau were run are presented in Table 7.

All SRP sites were tested with the expectation that the period from 1940 to 1969 (pre) should exhibit higher flows than the period from1970 to 1999 (post). Note that the Mann-Whitney test was statistically significant ($p = 0.0079$) for the Anclote River suggesting that pre period mean annual flows were higher than the post. It is possible that there has been both a step and monotonic trend in Anclote River mean annual flows; however, a comparison of pre and post Kendall's tau trends suggests that a step trend has occurred since pre and post Kendall's taus were not significant. It should be noted that prior to any consideration of the AMO as a causal mechanism for a step change in rainfall and consequently river flows, several authors (see especially Hickey 1998) suggested that a rather abrupt change in rainfall patterns had occurred. The occurrence of a step trend does not imply that anthropogenic factors have not lead to significant flow declines; in fact, anthropogenic changes can lead to rather abrupt changes in flow as will be discussed later. It is suggested, however, that the AMO as described by various workers would lead to rather abrupt changes in rainfall and consequently river flows.

In Table 7, p values less than 0.1 are highlighted in bold. Those p values less than 0.1 and where an increase in flows occurred between periods (pre<post) are shaded blue. Those p values less than 0.1 and where a decrease in flows occurred between periods (pre>post) are shaded yellow. It was generally expected that rivers with a SRP should show increased flow between periods since this was visually apparent when plots of median daily flows were compared as discussed above; this was likewise confirmed in most cases by a statistically significant ($p < 0.1$) Mann-Whitney test. Only one Florida site with a SRP and 60 years of data exhibited a step trend opposite that expected. As shown in Table 2**,** flows increased between periods for the Econlockhatchee River near Chuluota. The increase was small and amounted to only a 2.7% increase between periods based on a comparison of median daily flows; however, based on other sites with a SRP an approximate 30 to 35% decline might be anticipated. Close inspection of flow plots and Table 2 suggests that summer flows had decreased as expected (although by only 12%), but typical dry season flows (January through May) increased by almost 50%; it is unlikely that these increases can be attributed to increased dry season rainfall thus these data suggest that some anthropogenic flow increases have offset much of the expected decline (a monotonic increasing trend is clearly evident in a plot of the annual minimum flow of the Econlockhatchee River; see Figure 18). Only three others of the 45 sites examined with an SRP or SRP spring dominated pattern showed post-1970 flows greater than pre-1970 flows; these were Bullfrog Creek (near Wimauma), Sweetwater Creek (near Sulphur Springs) and the Wekiva River (near Sanford). It is speculated that increases in Bullfrog Creek may be attributable to agriculturally related discharges (see discussion of Myakka River

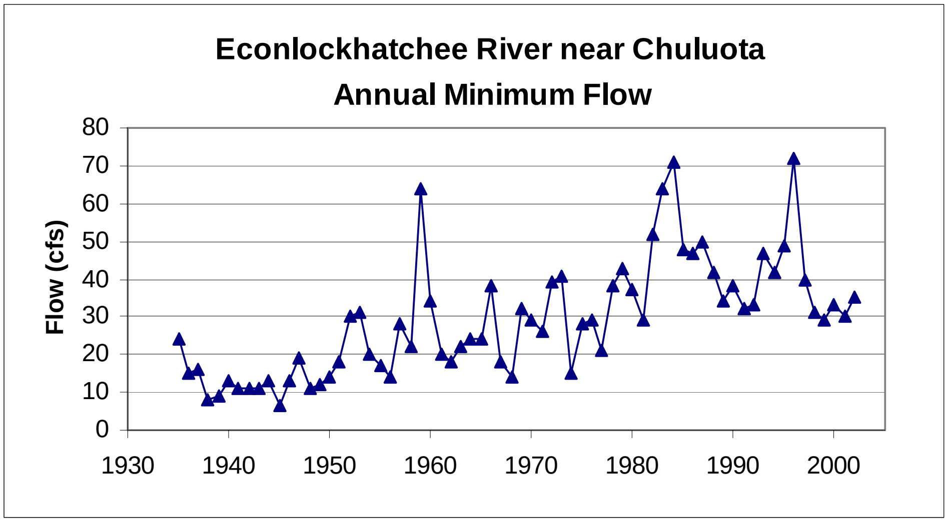


Figure 18. Annual minimum flow for the Econlockhatchee River showing apparent monotonic increasing flow trend.

below). Sweetwater Creek is located in a heavily urbanized area, and it is possible that increased runoff may be related to increasing impervious area and drainage improvements. With respect to the Wekiva River, the SJRWMD has attributed much of the flow increase there to treatment plant discharges (see Hupalo et al. 1994). Of the 45 sites with an SRP pattern, 30 showed a significant decrease ($p < 0.1$) in flow between the two periods based on results of the Mann-Whitney test; for eleven of the sites the test was not significant; however, several of the sites that fell into this category have experienced agriculturally related monotonic increases in flow (e.g., Little Manatee River, Myakka River, and Joshua Creek) that have partially offset expected natural flow declines.

Of the 18 NRP or NRP spring dominated sites tested for a positive step increase in flow between the two periods, none showed an opposite trend (decrease in flow). Ten of the 18 sites tested were statistically significant based on a $p < 0.1$. Those sites that exhibited a bimodal flow pattern as described above were tested assuming that flows between periods were different; however, there was no *a prioir* expectation that these flows should be either positive or negative. Of the ten biomodal sites tested, only one showed a significant change in flow between the two periods. The single exception was Big Creek (near Clermont), where there was a statistically significant decline in flow based on a p-value of 0.0165. Overall bimodal sites behaved as might be expected due to compensating increases and decreases in the two flow modes which is generally reflected in the relatively high p values obtained (considerably greater than 0.1) which indicated no trend in any one particular direction.

It is concluded, based on an analysis of those Florida sites with 60 years of flow data spanning the two periods of interest and analysis of an additional 32 sites with shorter flow periods, that there has been a step trend change in flow that occurred around 1970. The Mann-Whitney test confirmed that for SRP sites there was a rather abrupt (step) decrease in flows between the two periods tested, while there was a step increase in flows at most NRP sites. Bimodal flow sites essentially showed no step change in flow between the two periods examined; however, inspection of individual flow plots for each waterbody indicated that in general the SRP mode decreased between periods while the NRP mode increased. These increases and decreases in flow were essentially off-setting, and resulted in little net change in mean or median annual flows. It should be noted, however, that there was considerable seasonal variation in the magnitude of flows between the two modes between the two periods, and this could be ecologically significant.

Wekiva River Shingle Mill
From the Florida Photographic Collection

Table 6. Results of Kendall's Tau test on mean annual flows for selected gage sites and selected time periods. All p values < 0.1 are highlighted in bold.
XAnnQ = mean annual flow (cfs) for period analyzed; p values that represent an decrease in flow are shaded yellow, those that represent an increase are shaded bl

Site Name	POR	Period of Record			1940 to 1999				1940 to 1969				1970 to 1999		
	Year to 2002	XAnnQ	Slope	p	XAnnQ	Slope	p	n	XAnnQ	Slope	p	n	XAnnQ	Slope	p
Alafia River at Lithia	10/1/1932	329.8	-2.314	**0.0060**	336	-2.122	**0.0653**		388	3.796	0.3353		284	0.1081	1.0000
Anclote River near Elfers	06/01/46	63.11	-0.920	**0.0050**				23	83.7	-0.1569	0.9159		50.2	-0.2417	0.6686
Apalachicola River at Chattahoochee	10/1/1928	21766	-2.846	0.9108	22371	27.34	0.6599		21722	26.897	0.8865		23021	-77.22	0.3008
Arbuckle Creek near De Soto City	7/1/1939	313	-1.809	**0.0751**	310	-2.111	**0.0565**		373	-3.493	0.4755		247	3.642	0.1868
Big Coldwater Creek near Milton	12/01/38	551	1.621	0.1934	568	3.101	**0.0208**		513	-4.655	0.1640		631	5.418	0.1457
Big Creek near Clermont	08/01/58	22.4	-0.268	0.1123				11	43.7	-0.5518	0.7555		16.5	0.3527	0.2251
Blackwater Creek near Knights	01/01/51	78.3	-0.434	0.2051				18	103	0.9249	0.8796		68.4	1.183	0.1164
Brooker Creek near Tarpon Springs	09/01/50	18.7	-0.196	**0.0325**				20	25.9	-0.0672	0.7703		13.3	-0.0095	0.9715
Bullfrog Creek near Wimauma	10/01/56	42	0.406	0.2772				2	33.4			23	44.29	0.6286	0.2452
Caloosahatchee Canal at Moore Haven	10/01/38	839	-4.606	0.3162	880	-4.182	0.4328		1079	-3.269	0.8038		681	7.369	0.1339
Catfish Creek near Lake Wales	10/01/47	41.1	-0.485	**0.0003**				22	51.1	-0.8068	0.2839		33.7	0.0032	1.0000
Charlie Creek near Gardner	05/01/50	255	-1.802	0.2213				19	324	1.004	1.0000		221	1.961	0.2687
Chipola River near Altha	12/01/12	1457	-0.043	0.9596				25	1450	-14.43	0.4691		1538	3.5113	0.6427
Choctawhatchee River at Caryville	08/01/29	5513	4.530	0.6997	5683	12.94	0.4402		5306	-46.5	0.2250		6060	-6.918	0.8584
Choctawatchee River at Bruce	10/01/30	7085	0.907	0.9729	7283	11.74	0.4031		6922	-50.03	0.2535		7644	-13.88	0.7753
Cypress Creek near Sulphur Springs	03/01/64	80.1	-2.070	**0.0089**				5	121	-18.66	0.4624		74.6	-1.25	0.2251
Ecofina Creek near Bennett	10/01/35	535	0.430	0.5741	547	1.037	0.1623		532	-1.817	0.3353	27	564	2.986	0.1039
Econlockhatchee River near Chuluota	10/01/35	277	1.258	0.1761	282	1.192	0.3166		295	2.046	0.4324		269	7.704	**0.0021**
Escambia River near Century	10/01/34	6198	2.106	0.9367	6343	15.16	0.4253		5821	-72.8	0.1989		6865	-29.82	0.4324
Fenholloway River at Foley	09/01/46	130	0.097	0.7827				23	126	2.414	0.2673	29	140	-0.3694	0.3986
Fisheating Creek at Palmdale	05/01/31	251	0.290	0.7810	263	-0.206	0.8433		284	-1.004	0.7753		241	3.185	0.2251
Hillsborough River near Tampa	10/01/38	443	-6.863	**0.0000**	454	-6.3982	**0.0003**		632	3.149	0.6947		276	0.1813	0.9147
Hillsborough River at Zephyrhills	10/01/39	240	-1.453	**0.0091**	248	-1.223	**0.0419**		292	1.189	0.6427		202	1.703	0.4754
Horse Creek near Arcadia	05/01/50	191	-0.533	0.6643				19	230	2.036	0.7796		165	2.928	0.1989
Josephine Creek near De Soto City	10/01/46	71.8	-0.614	**0.0524**				23	97.3	-3.039	0.1696	28	52.6	0.3168	0.3330
Joshua Creek at Nocatee	05/01/50	106	0.034	0.9559				19	120	-1.246	0.7796		99.5	1.872	**0.0804**
Jumper Creek Canal near Bushnell	10/01/63	22.2	-0.591	**0.0005**				6	28.7	-1.211	1.0000		23	-0.5514	**0.0185**
Kissimmee River at S-65E near Okeechobee	10/01/28	1773	-10.474	**0.0166**	1731	-13.58	**0.0468**		2144	-13.77	0.6391		1332	22.13	0.1989
Little Econlockhatchee River near Union Par	10/01/59	30.7	0.508	**0.0074**				10	20	1.249	0.4743		31.9	1.034	**0.0009**
Little Haw Creek near Seville	01/01/51	81.1	-0.085	0.9224				18	93.4	3.194	0.2889		73	0.1281	0.8028
Little Manatee River near Ft. Lonesome	9/1/1963	30.7	0.101	0.5615				6	33.5	2.236	0.2597		30.7	0.5564	0.1007
Little Manatee River near Wimauma	04/01/39	171	-0.486	0.3997	171	-0.331	0.6324		184	0.3341	0.9431		158	2.318	**0.0867**
Myakka River near Sarasota	08/01/36	253	0.013	0.9911	251	0.4538	0.5966		261	1.721	0.5680		241	4.405	0.1435
North Fork Black Creek near Middleburg	10/31/03	187	0.320	0.5252	201	-0.1759	0.9847		212	3.462	0.1535		191	-0.1544	0.9715
North Prong of Alafia River at Keysville	05/01/50	150	-1.470	**0.0309**				19	187	5.296	0.1417	28	134	0.0851	0.8900
North Prong St. Marys River at Moniac, GA	02/01/21	146	-1.065	**0.0937**				19	130	6.379	**0.0688**		147	-3.6490	**0.0353**

Table 6. (Continued)

Site Name	POR Year to 2002	Period of Record XAnnQ	Slope	p	1940 to 1999 XAnnQ	Slope	p	n	1940 to 1969 XAnnQ	Slope	p	n	1970 to 1999 XAnnQ	Slope	p
Ochlockonee River near Bloxham	06/01/27	1695	1.594	0.7434	1781	4.55	0.4105		1707	4.687	0.8865		1855	-5.0127	0.6427
Ochlockonee River near Havana	10/01/26	1028	0.860	0.7638	1084	4.791	0.3167		1004	-0.7014	0.9715		1163	-5.593	0.6174
Ocklawaha at Moss Bluff	10/1/1943	239	-5.242	**0.0001**				15	363	-3.662	0.7665		197	-0.7777	0.6685
Outlet River at Panacoochee Retreat	10/01/62	173	-2.881	**0.0094**				7	202	-5.903	0.7639		177	-2.357	0.1751
Peace River at Arcadia	04/01/31	1061	-7.019	**0.0213**	1073	-8.825	**0.0268**		1289	-1.947	0.8028		856	3.759	0.5680
Peace River at Bartow	10/01/39	219	-2.715	**0.0010**	228	-2.425	**0.0075**		295	-1.367	0.6427		161	3.335	0.2251
Peace River at Zolfo Springs	09/01/33	635	-5.132	**0.0016**	614	-6.376	**0.0031**		751	-3.084	0.4754		477	1.231	0.8305
Pithlachascotee near New Port Richey	04/01/63	26.4	-0.554	**0.0136**				6	38.7	-8.036	0.4523		25.6	-0.3096	0.3435
Rainbow Springs near Dunnellon	01/01/65	700	-3.844	**0.0086**				4	784	-30.49	0.7341		697	-0.8021	0.7212
Rocky Creek near Sulphur Springs	01/01/53	37.4	0.027	0.8699	38.5	0.1415	0.5821	16	39.8	-0.1148	1.0000		37.3	0.7598	0.1083
Santa Fe River at Worthington Spgs	10/01/31	412	-1.126	0.4747	449	-1.4367	0.4711		478	1.901	0.7212		420	-3.335	0.5207
Santa Fe River near Ft. White	06/01/32	1525	-6.053	**0.0311**	1576	-5.745	0.1477		1683	3.763	0.8305		1469	-13.16	0.2389
South Fork Black Creek near Penney Farms	10/01/39	147	-0.843	**0.0854**	152	-0.5595	0.3045		163	0.6173	0.8304		141	-0.7443	0.6685
Shoal River near Crestview	08/01/38	1098	1.238	0.6472	1132	3.7318	0.1212		1062	-6.04	0.4537		1203	5.532	0.4536
Silver Springs near Ocala	10/01/32	779	-2.425	**0.0029**	794	-2.244	**0.0306**		829	1.428	0.7212		758	-2.8825	0.2535
Sopchoppy River near Sopchoppy	06/01/64	195	-0.446	0.7248				5	184	-27.37	0.2207		192	-0.8393	0.6427
South Prong of Alafia River	01/01/63	98	-1.445	**0.0277**				6	140	16.41	**0.0242**		93.7	-0.1917	0.8027
Steinhatchee River near Cross City	03/01/50	306	-0.956	0.5753				19	318	0.6287	0.7796		322	-1.813	0.6174
St. Johns River near Melbourne	10/01/39	684	-0.494	0.7397	685	-0.4909	0.7546		762	-2.548	0.7212		608	17.53	**0.0185**
St. Johns River near Cocoa	10/01/53	1102	2.947	0.5292				16	1145	4.989	0.8926		912	22.84	**0.0224**
St. Johns River near De Land	10/01/33	3092	-3.697	0.5929	3128	-9.6635	0.3139		3432	-7.408	0.7753	29	2813	37	0.1595
St. Johns River near Christmas	10/01/33	1306	-1.150	0.7363	1314	-2.195	0.5789		1451	1.928	0.8865		1176	20.57	0.1007
St. Marks River near Newport	10/01/56	695	0.108	0.9765								29	728	7.137	0.1595
St. Marys River near Macclenny	10/01/26	636	-2.081	0.3394	665	-0.7979	0.7741		688	2.921	0.8584		643	-6.608	0.2687
Sulphur Springs at Sulphur	07/01/59	38.1	-0.455	**0.0000**				10	47.5	-1.326	0.2831		35.4	0.2168	0.6174
Suwanee River at Branford	07/01/31	6811	4.870	0.7810	7273	11.028	0.6233		7068	43.28	0.6427		7478	-77.77	0.3177
Suwanee River at Ellaville	02/01/27	6293	-7.718	0.6020	6538	8.164	0.7839		6373	36.39	0.6947		6702	-68.02	0.2389
Suwanee River at White Springs	02/01/27	1778	-3.224	0.5986	1875	0.2439	0.9644		1868	11.47	0.7481		1882	-28.39	0.2535
Suwanee River near Wilcox	10/01/41	10048	-30.542	0.2965	10410	-3.885	0.9167		10298	-12.92	0.9252		10519	-98.26	0.1534
Sweetwater Creek near Sulphur Springs	10/01/51	6.09	-0.002	0.9352				18	7.71	0.0079	1.0000		5.72	0.0665	0.2389
Telogia Creek near Bristol	04/01/50	212	-0.314	0.7004				19	211	6.813	0.1617	28	225	-1.159	0.3956
Tomoka River near Holly Hill	10/01/64	51.7	-0.419	0.3145				5	73.2	14.03	0.4624		47.6	-0.2169	0.7212
Wekiva River near Sanford	10/01/35	286	0.487	0.1626	292	0.4943	0.1625		291	2.239	**0.0635**		293	0.1092	0.9148
Withlacoochee River at Croom	10/01/39	415	-4.458	**0.0045**	428	-0.5033	**0.0228**		531	1	0.7752		325	-0.3577	0.9147
Withlacoochee River near Holder	09/01/28	1019	-8.319	**0.0007**	1008	-8.9686	**0.0055**		1206	1.153	0.9147		810	-9.271	0.3008
Withlacoochee River at Trilby	08/01/28	334	-2.522	**0.0117**	322	-2.5065	**0.0672**		401	2.069	0.4537		244	1.301	0.8027
Withlacoochee River [northern] near Pinetta	10/01/31	1683	4.848	0.3716	1808	8.884	0.2280		1661	3.486	0.9148		1956	-7.768	0.7481
Yellow River at Milligan	08/01/38	1130	-2.872	0.3559	1166	0.5027	0.8933		1106	-8.312	0.2251	28	1230	-5.11	0.3956

Table 7. Mann-Whitney test for flow differences between mean annual flows for two multidecadal time periods (1940 to 1969 and 1970 to 1999). p values of 0.1 or less are highlighted in bold; p values that represent a decrease between periods are colored yellow, and those that represent an increase are colored blue.

Stream / location	USGS Code	River Pattern	1940 to 1969 median	n	1970 to 1999 median	n	Test	p
North Prong St. Marys River at Moniac, GA	02228500	Bimodal NRP/SRP	103	13	140	30	Not equal	0.3001
Steinhatchee River near Cross City	02324000	Bimodal NRP/SRP	261	19	343	30	Not equal	0.5180
Suwanee River at White Springs	02315500	Bimodal NRP/SRP	1736	30	1685	30	Not equal	0.6952
Big Creek near Clermont	02236500	Bimodal SRP/NRP	29.19	11	16.4	30	Not equal	**0.0165**
Little Haw Creek near Seville	02244420	Bimodal SRP/NRP	73	18	79	30	Not equal	0.4123
North Fork Black Creek near Middleburg	02246000	Bimodal SRP/NRP	208	30	202	30	Not equal	0.5493
Santa Fe River at Worthington Spgs	02321500	Bimodal SRP/NRP	431	30	414	30	Not equal	0.2367
Sopchoppy River near Sopchoppy	02327100	Bimodal SRP/NRP	201	5	171	30	Not equal	0.9812
South Fork Black Creek near Penney Farms	02245500	Bimodal SRP/NRP	155	30	138	30	Not equal	0.2707
St. Marys River near Macclenny	02231000	Bimodal SRP/NRP	610	30	631	30	Not equal	0.9705
Apalachicola River at Chattahoochee	02358000	NRP	21455	30	23340	30	Pre<Post	0.1895
Chipola river near Altha	02359000	NRP	1286	25	1456	30	Pre<Post	**0.0868**
Choctawatchee River at Bruce	02366500	NRP	6460	30	7474	30	Pre<Post	**0.0834**
Choctawhatchee River at Caryville	02365500	NRP	4968	30	5791	30	Pre<Post	**0.0687**
Escambia River near Century	02375500	NRP	5381	30	6645	30	Pre<Post	**0.0362**
Ochlockonee River near Bloxham	02330000	NRP	1503	30	1588	30	Pre<Post	0.1386
Ochlockonee River near Havana	02329000	NRP	857	30	1053	30	Pre<Post	**0.0812**
Suwanee River at Branford	02320500	NRP	6085	30	7163	30	Pre<Post	0.2145
Suwanee River at Ellaville	02319500	NRP	5412	30	6405	30	Pre<Post	0.2601
Suwanee River near Wilcox	02323500	NRP	9546	29	10009	30	Pre<Post	0.3005
Telogia Creek near Bristol	02330100	NRP	189	19	223	28	Pre<Post	0.2613
Withlacoochee River [northern] near Pinetta	02319000	NRP	1474	30	1822	30	Pre<Post	**0.0687**
Yellow River at Milligan	02368000	NRP	1003	30	1084	28	Pre<Post	0.1504
Fenholloway River at Foley	02324500	NRP - Altered	107	23	134	29	Pre<Post	**0.0893**
Big Coldwater Creek near Milton	02370500	NRP - Spring	489.9	30	632.4	26	Pre<Post	**0.0027**
Ecofina Creek near Bennett	02359500	NRP - Spring	513	30	572	27	Pre<Post	**0.0763**
Shoal River near Crestview	02369000	NRP - Spring	974	30	1105	30	Pre<Post	**0.0724**
St. Marks River near Newport	02326900	NRP - Spring	654	13	707	29	Pre<Post	0.2839
Alafia River at Lithia	02301500	SRP	374.9	30	268.1	30	Pre>Post	**0.0054**
Anclote River near Elfers	02310000	SRP	70.91	23	45.24	30	Pre>Post	**0.0079**
Arbuckle Creek near De Soto City	02270500	SRP	313.2	30	215.3	30	Pre>Post	**0.0069**
Blackwater Creek near Knights	02302500	SRP	85.66	18	59.01	30	Pre>Post	**0.0312**
Brooker Creek near Tarpon Springs	02307359	SRP	16		11	30	Pre>Post	**0.0166**
Bullfrog Creek near Wimauma	02300700	SRP	33	22	46	30	Pre>Post	Post>Pre
Catfish Creek near Lake Wales	02267000	SRP	45	22	34	30	Pre>Post	**0.0007**
Charlie Creek near Gardner	02296500	SRP	292	19	195	30	Pre>Post	**0.0222**
Cypress Creek near Sulphur Springs	02303800	SRP	147	5	72	30	Pre>Post	**0.0752**
Econlockhatchee River near Chuluota	02233500	SRP	262	30	278	30	Pre>Post	Post>Pre
Fisheating Creek at Palmdale	02256500	SRP	278	30	218	30	Pre>Post	0.2698
Hillsborough River at Zephyrhills	02303000	SRP	247	30	187	30	Pre>Post	**0.0021**
Hillsborough River near Tampa	02304500	SRP	516	30	264	30	Pre>Post	**0.0000**
Horse Creek near Arcadia	02297310	SRP	207	19	161	30	Pre>Post	**0.0452**
Josephine Creek near De Soto City	02271500	SRP	72	23	47	28	Pre>Post	**0.0088**
Joshua Creek at Nocatee	02297100	SRP	122	19	99	30	Pre>Post	0.1806
Little Econlockhatchee River near Union Park	02233473	SRP	25.7	10	32.3	30	Pre>Post	0.1952
Little Manatee River near Fort Lonesome	02300100	SRP	33.8	6	28	30	Pre>Post	0.2833
Little Manatee River near Wimauma	02300500	SRP	178	30	139	30	Pre>Post	**0.0954**
Myakka River near Sarasota	02298830	SRP	215	30	228	30	Pre>Post	0.4094
North Prong of Alafia River at Keysville	02301000	SRP	181	19	129	28	Pre>Post	**0.0065**
Peace River at Arcadia	02296750	SRP	1113	30	738	30	Pre>Post	**0.0035**
Peace River at Bartow	02294650	SRP	241	30	145	30	Pre>Post	**0.0003**
Peace River at Zolfo Springs	02295637	SRP	636	30	422	30	Pre>Post	**0.0007**
Pithlachascotee near New Port Richey	02310300	SRP	39.6	6	23.7	30	Pre>Post	**0.0557**
Rocky Creek near Sulphur Springs	02307000	SRP	31.15	16	29.15	30	Pre>Post	0.4862
South Prong of Alafia River	02301300	SRP	123	6	87	30	Pre>Post	**0.0356**
St. Johns River near Christmas	02232500	SRP	1237	30	1184	30	Pre>Post	**0.0812**
St. Johns River near Cocoa	02232400	SRP	1051	16	971	30	Pre>Post	0.1418
St. Johns River near De Land	02236000	SRP	3067	30	2843	29	Pre>Post	**0.0532**
St. Johns River near Melbourne	02232000	SRP	639	30	632	30	Pre>Post	0.1170
Sweetwater Creek near Sulphur Springs	02306500	SRP	4.06	18	3.72	30	Pre>Post	Post>Pre
Tomoka River near Holly Hill	02247510	SRP	89.6	5	45	30	Pre>Post	**0.0348**
Withlacoochee River at Croom	02312200	SRP	431	30	330	30	Pre>Post	**0.0033**
Withlacoochee River at Trilby	02312000	SRP	339	30	244	30	Pre>Post	**0.0054**
Withlacoochee River near Holder	02313000	SRP	1038	30	742	30	Pre>Post	**0.0023**
Caloosahatchee Canal at Moore Haven	02292000	SRP - Altered	753	30	254	30	Pre>Post	**0.0768**
Kissimmee River at S-65E near Okeechobee	02273000	SRP - Altered	2010	29	1305	30	Pre>Post	**0.0039**
Ocklawaha at Moss Bluff	02238500	SRP - Altered	409	15	181	30	Pre>Post	**0.0004**

Rainfall Trends in Southwest Florida

Although Basso and Schultz (2003) provided a strong argument in support of a significant decreasing trend in rainfall at many rainfall sites in southwest Florida, their analysis was expanded upon by segregating annual rainfall totals into a wet and a dry period. Wet season rainfall for a given year was defined as the total rainfall falling during the months of June, July, August and September. The total rainfall falling during the remaining eight months was defined as the dry period.

Since the change between multidecadal periods was considered a step trend, the Mann-Whitney trend test was run on total annual, wet and dry season rainfall with the hypothesis that rainfall was higher for the 1940 to 1969 period than for the period 1970 to 1999 at southwest Florida sites. Results of this analysis for 20 rainfall sites are shown in Table 8. Using an alpha of 0.1, 14 of 20 sites showed a significant decrease in rainfall between the two periods examined. While it is interesting to note that one site, the Lakeland site, actually showed an increase in rainfall between the two periods, the vast majority of sites showed a statistically significant decrease in rainfall between the two periods. This analysis was performed for the wet season in addition to total annual rainfall because comparison of period flows on SRP sites suggested that the largest difference in flows occurred during the rainy season (June-September). These results only serve to strengthen the argument of Basso and Schultz (2003) and should satisfy those who insist on a statistically significant result based on a more traditional statistical approach. These results are consistent with the observation of Hickey (1998) that an abrupt change in rainfall occurred, and also confirm the results of Enfield et al. (2001) who found a significant positive correlation between rainfall and the AMO for south Florida.

The above findings are important to the overall process of MFL development since they demonstrate that significant decreases and increases in flow are attributable to rainfall differences between multidecadal periods. Although most appreciate that rainfall is the primary driving factor affecting river flows, it has been traditionally assumed with respect to hydrology that river flows are the consequence of a sequence or random independently and identically distributed random variables. To paraphase Olsen et al. (1999), results such as ours challenge generally held assumptions and suggest that those involved in water management issues may need to rethink their paradigm with respect to river flow analysis and allow for multidecadal variations in river flow patterns.

Table 8. Mann-Whitney Test for difference in rainfall between two multidecadal periods (1940 to 1969 and 1970 to 1999). All p-values given; tan shading indicates an alpha of 0.1 or less.

Rainfall Site		1940-1969 Median	1940-1969 n	1970-1999 Median	1970-1999 n	Test Comparison	p-value
Arcadia	Total	55.1	30	46.3	28	Pre > Post	0.0128
	Wet	33.4	30	27.3	28	Pre > Post	0.0264
	Dry	20.3	30	18.9	28	Pre > Post	0.2668
Archibold	Total	55.7	30	50.3	28	Pre > Post	0.0472
	Wet	34.1	30	29.4	28	Pre > Post	0.0204
	Dry	19.7	30	22.8	28	Pre > Post	Post > Pre
Avon	Total	54.9	30	47.6	27	Pre > Post	0.0178
	Wet	33.4	30	29.0	27	Pre > Post	0.0092
	Dry	23.0	30	20.5	27	Pre > Post	0.2075
Bartow	Total	53.3	30	49.9	30	Pre > Post	0.0594
	Wet	31.2	30	28.5	30	Pre > Post	0.0467
	Dry	23.1	30	23.2	30	Pre > Post	0.2796
Bradenton	Total	53.6	30	51.9	30	Pre > Post	0.2846
	Wet	34.9	30	32.9	30	Pre > Post	0.1486
	Dry	18.5	30	20.7	30	Pre > Post	Post > Pre
Brooksville	Total	57.1	30	51.1	30	Pre > Post	0.0527
	Wet	34.0	30	27.2	30	Pre > Post	0.0268
	Dry	22.9	30	24.5	30	Pre > Post	Post > Pre
Bushnell	Total	54.6	30	47.0	30	Pre > Post	0.0141
	Wet	29.6	30	24.9	30	Pre > Post	0.0050
	Dry	23.8	30	22.5	30	Pre > Post	Post > Pre
Clermont	Total	51.4	30	50.7	30	Pre > Post	0.5493
	Wet	29.8	30	28.2	30	Pre > Post	0.1538
	Dry	21.8	30	22.2	30	Pre > Post	Post > Pre
Inverness	Total	53.9	30	51.9	30	Pre > Post	0.1113
	Wet	32.1	30	27.3	30	Pre > Post	0.0027
	Dry	20.6	30	24.9	30	Pre > Post	Post > Pre
Lake Alfred	Total	54.0	30	48.3	30	Pre > Post	0.1452
	Wet	30.8	30	27.5	30	Pre > Post	0.1935
	Dry	22.1	30	21.9	30	Pre > Post	Post > Pre
Lakeland	Total	47.3	30	50.2	30	Pre > Post	Post > Pre
	Wet	27.3	30	27.5	30	Pre > Post	Post > Pre
	Dry	19.4	30	21.3	30	Pre > Post	Post > Pre
Ocala	Total	57.2	30	49.1	30	Pre > Post	0.0135
	Wet	31.5	30	23.6	30	Pre > Post	0.0001
	Dry	23.0	30	25.6	30	Pre > Post	Post > Pre
Plant City	Total	53.3	30	51.2	30	Pre > Post	0.0954
	Wet	31.2	30	27.1	30	Pre > Post	0.0182
	Dry	20.3	30	22.6	30	Pre > Post	Post > Pre
Punta Gorda	Total	51.5	30	49.5	30	Pre > Post	0.1895
	Wet	30.6	30	28.2	30	Pre > Post	0.1170
	Dry	19.4	30	20.3	30	Pre > Post	0.4912
St. Leo	Total	56.7	30	51.5	30	Pre > Post	0.2601
	Wet	30.9	30	27.8	30	Pre > Post	0.0399
	Dry	22.2	30	24.0	30	Pre > Post	Post > Pre
St. Petersburg	Total	53.4	30	47.5	30	Pre > Post	0.0577
	Wet	31.8	30	26.4	30	Pre > Post	0.0238
	Dry	20.2	30	21.2	30	Pre > Post	0.4383
Tampa International Airport	Total	46.0	30	43.3	30	Pre > Post	0.0594
	Wet	27.2	30	24.7	30	Pre > Post	0.0603
	Dry	18.3	30	18.9	30	Pre > Post	0.3531
Tarpon Springs	Total	53.6	30	50.3	30	Pre > Post	0.2601
	Wet	30.9	30	27.4	30	Pre > Post	0.0312
	Dry	19.1	30	24.9	30	Pre > Post	Post > Pre
Wauchula	Total	54.0	30	50.4	28	Pre > Post	0.1024
	Wet	32.6	30	28.9	28	Pre > Post	0.0956
	Dry	21.1	30	20.3	28	Pre > Post	0.3808
Winter Haven	Total	50.0	29	48.9	30	Pre > Post	0.2130
	Wet	28.1	29	28.2	30	Pre > Post	0.4607
	Dry	20.5	29	21.7	30	Pre > Post	Post > Pre

Flow Trends in Selected River Systems in SWFWMD

This section discusses river flows for selected river systems within the SWFWMD. The major purpose of this discussion is to demonstrate that there is a large climatic signature in observed flow declines throughout the District while also considering flow changes related to apparent anthropogenic effects (e.g., withdrawals, mining, agriculture). Flow data are presented in several different ways, because some analyses offer stronger support in implicating a particular causative factor. Mean annual flows are typically plotted and non-parametric statistical tests run to evaluate flow trends. In some cases these data and outputs are evaluated along with supporting water quality data. Time series plots of percent exceedance flows have been routinely examined to aid in determining how and when components of the flow regime have changed. In many cases there are interesting parallels and differences that can be recognized in flow patterns when comparisons are made between gages within and between watersheds.

Alafia River Flows

Annual percent exceedance flows were determined for each year in the period of record at gage sites located on the mainstem near Lithia, on the South Prong of the Alafia near Lithia, and on the North Prong of the Alafia at Keysville. The South Prong gage measures discharge from a 107 square mile watershed; and the North Prong gage measures discharge from a 135 square mile watershed. The Lithia gage measures discharge from an area of 335 square miles. Because the Lithia gage is located downstream of the confluence of the North and South Prongs, its watershed encompasses the combined area of the gaged North and South Prongs (i.e., 242 square miles) plus an additional 93 square miles. Based on relative watershed size, the gaged area of the South Prong should contribute approximately 32% of the flow as measured at the Lithia gage, and the gaged area of the North Prong should contribute 40% of the flow as measured at the Lithia gage.

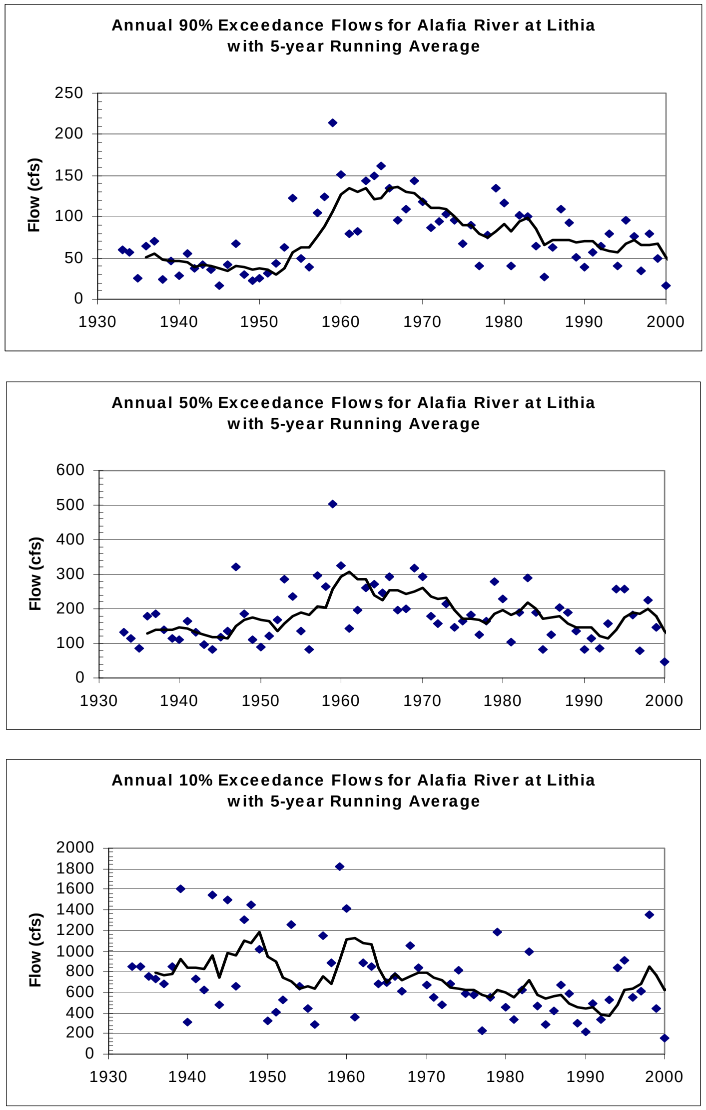


Figure 19. Annual percent exceedance flows for the Alafia River at Lithia gage displayed with a 5-yr running average.

Selected percent exceedance flows for the period of record at the Alafia, North Prong and South Prong gages are shown in Figures 19-21. Apparent at the Alafia gage at Lithia is a substantial increase in low flows to at least median flows beginning around 1960. Both Stoker et al. (1995) and Hickey (1998) noted this increase in flow; Hickey (1998) postulated that the increases could be attributed to phosphate mining related discharges. Inspection of USGS water quality data collected at the Lithia gage on an approximate quarterly basis validates this supposition (see Figure 22). Exceptionally high phosphorus concentrations and elevated fluoride concentrations are obviously mine related, since fluoride is found in association with apatite, the phosphate ore that is mined. What is evident from water quality data is a substantial decrease in both phosphorus and fluoride concentrations in the late 1970's. Although low flows decreased considerably since the 1960s and 1970s, they have not decreased below the levels seen in the earlier part of the record (1940s). Since rainfall was generally higher in this earlier period, one would expect flows during this earlier period to exceed or at least match those of the 1960-1970's, but this is not the case. While Stoker et al (1995) attributed the flow decline to a lowering of the potentiometric surface, Hickey (1998) was correct in attributing this decline to climate and curtailment of mining related discharges. This is also confirmed by decreases in parameter concentrations that are associated with groundwater inputs (e.g., calcium and sulfate).

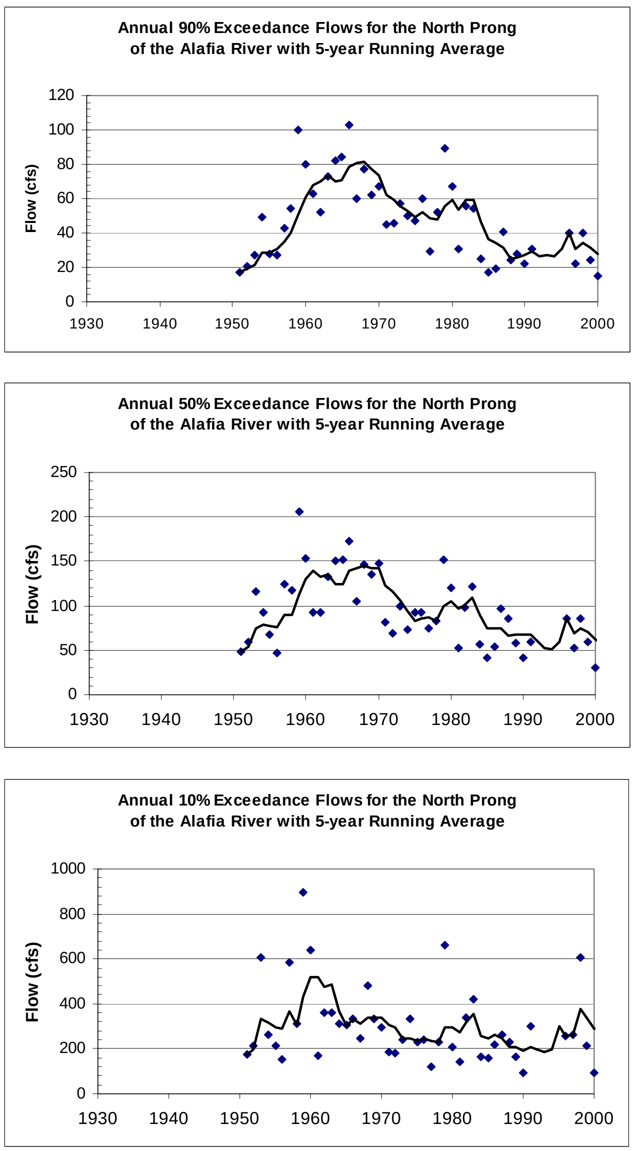


Figure 20. Annual percent exceedance flows for the North Prong of the Alafia River gage displayed with 5-yr running average.

Although Hickey (1998) concluded that climate was largely responsible for the decreasing trend, he did note that at the Alafia River at Lithia stream flow decreased about 44 cfs in the period between January 1962 to December 1981. He speculated that these flow declines were the result of mining, but were related to a substantial decrease in water being discharged rather than a hydrologic alteration which lead to decreases. Decreases in discharge were accomplished

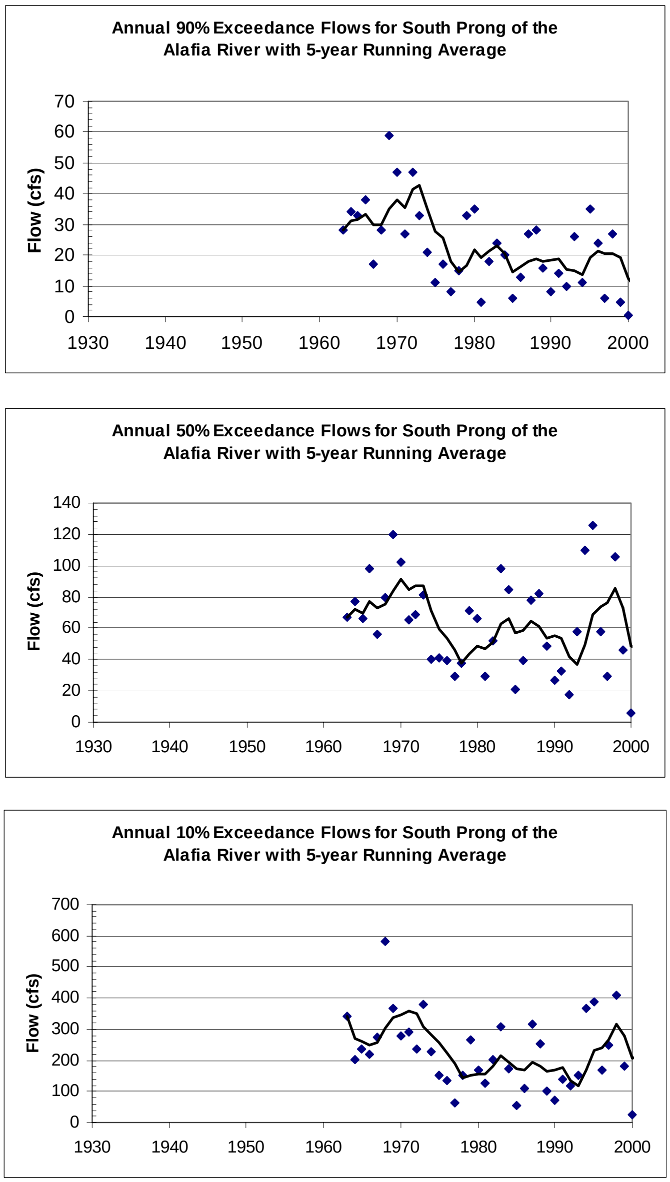


Figure 21. Annual percent exceedance flows for the South Prong of the Alafia River gage displayed with a 5-yr running average.

through increased water use efficiency and a decrease in ground water usage. Inspection of water quality data for the river suggests that Hickey (1998) is correct, and flow declines are related to improved efficiency rather than a diminishment of flows resulting from landscape alterations due to mining.

In developing a relationship for the expressed purpose of predicting the impact of increasing area of phosphate mined land on stream flow, SDI (2003) assumed that the trend of decreasing stream flow in the South Prong of the Alafia River was related to increasing area of land mined. This assumption was made because mining was essentially the only land use that changed during the time interval investigated.

While SDI (2003) assumed that the flow decline was attributable to increases in land area mined for phosphate, this is not the case. Using logic similar to SDI (2003), there should be a steady monotonic decreasing trend in flow with increasing mined area. While mined area in the South Prong increased substantially between 1972 and 1999 (from 10 to 72%) based on land use maps for this time period (see Figure 24), flow remained fairly stable. Kendall's 's tau was run on mean annual flows for the period 1970 to 1999, and the slope of the thiel line was –0.1918 with a p value of 0.8028; indicating no trend (see Figure 25).

Comparisons of land use changes and flows in the North and South Prongs of the Alafia River provides an additional means for evaluating the impact of mining on flow in the Alafia River. Although not as extensive as in the South Prong, phosphate mining has also occurred in this sub-basin (see Table 9). Between 1972 and 1999, nineteen percent (19%) of the North Prong watershed was mined; during this same time period, 62% of the South Prong watershed was mined. Using the logic applied by SDI (2003), one would expect to see a substantially greater reduction in flow in the South Prong due to mining than the reduction that would have occurred in the North Prong, since the percent of watershed mined was more than three times greater (19% versus 62%).

Inspection of percent exceedance flows and comparison of decadal flow plots for these two sub-basins suggest that mining related discharges were greater in the North Prong than the South Prong; however, water quality and flow data suggest that low flows were increased in both systems. Percent exceedance flow plots indicate similar temporal declines in mine related discharges in both systems; flow data indicate that mine related discharges were essentially eliminated from both the North and South Prongs by the late 1970s or early 1980s. Decadal by decadal comparisons of flow between the two sub-basins (Figure 26) verifies that both sub-basins have discharged remarkably similar flows (cfs / square mile) over the last several decades. These flows are essentially identical despite the fact that much more land area has been mined in the South Prong than has been mined in the North Prong. If flows decline as percent of mined area increases, one would expect to see monotonic flow declines in both sub-basin watersheds, and one would also expect to see a much greater rate of decline in South Prong flows relative to North Prong flows. The logic in selecting the South Prong as a good candidate for demonstrating mining impacts related to increased area of mined land was sound, in that, given the relatively larger increase in mined area since 1963 and the relative lack of other land use changes, one should expect to see a flow impact if increasing area of lands mined does in fact lead to decreases in stream flow. However, this was not the case. The remarkably similar discharges evident between the two watersheds despite relatively large differences in percent of land disturbed by mining suggests that these watersheds have tolerated considerable land disturbance without appreciable changes in flow. Inspection of decadal plots further suggests that the timing and seasonality of flows was not appreciably affected either. As a final check various annual percent exceedance flows per unit area (cfs/square mile) are compared in Figure 26. With the possible exception of the lowest flows plotted (annual 90% exceedance flows), examination of these plots suggests that mining may have lead to slightly increased flow. Again, if SDI (2003) was correct, one should expect to see a substantially greater reduction in flow when the South Prong is compared to the North Prong, this is obviously not the case.

Table 9. Percent of area mined above three USGS gages in the Alafia River watershed.

Percent of Watershed Mined			
	North Prong	***South Prong***	***Lithia minus NP&SP***
1972	**16**	**10**	**10**
1990	**34**	**63**	**16**
1999	**35**	**72**	**18**
Increase (1972 to 1999)	**19**	**62**	**8**
Area (sq miles)	**135**	**107**	**93**

Note: USGS lists area above South Prong gage as 107 sq miles;
SWFWMD determined the area based on 1999 landuse map to be 112 sq miles

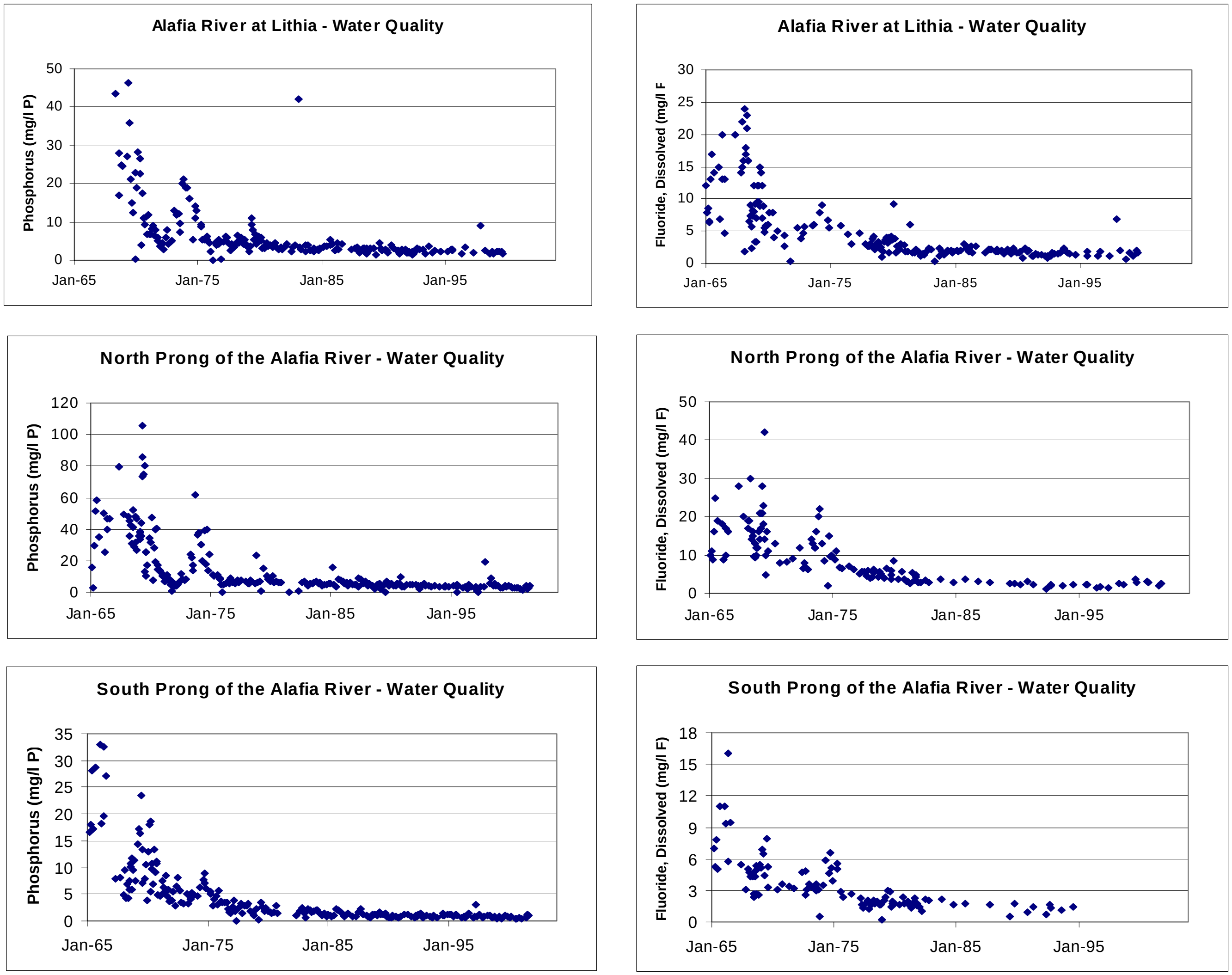


Figure 22. Phosphorus and fluoride concentrations in water quality samples taken from the Alafia River and the North and South Prongs. Water quality data from USGS.

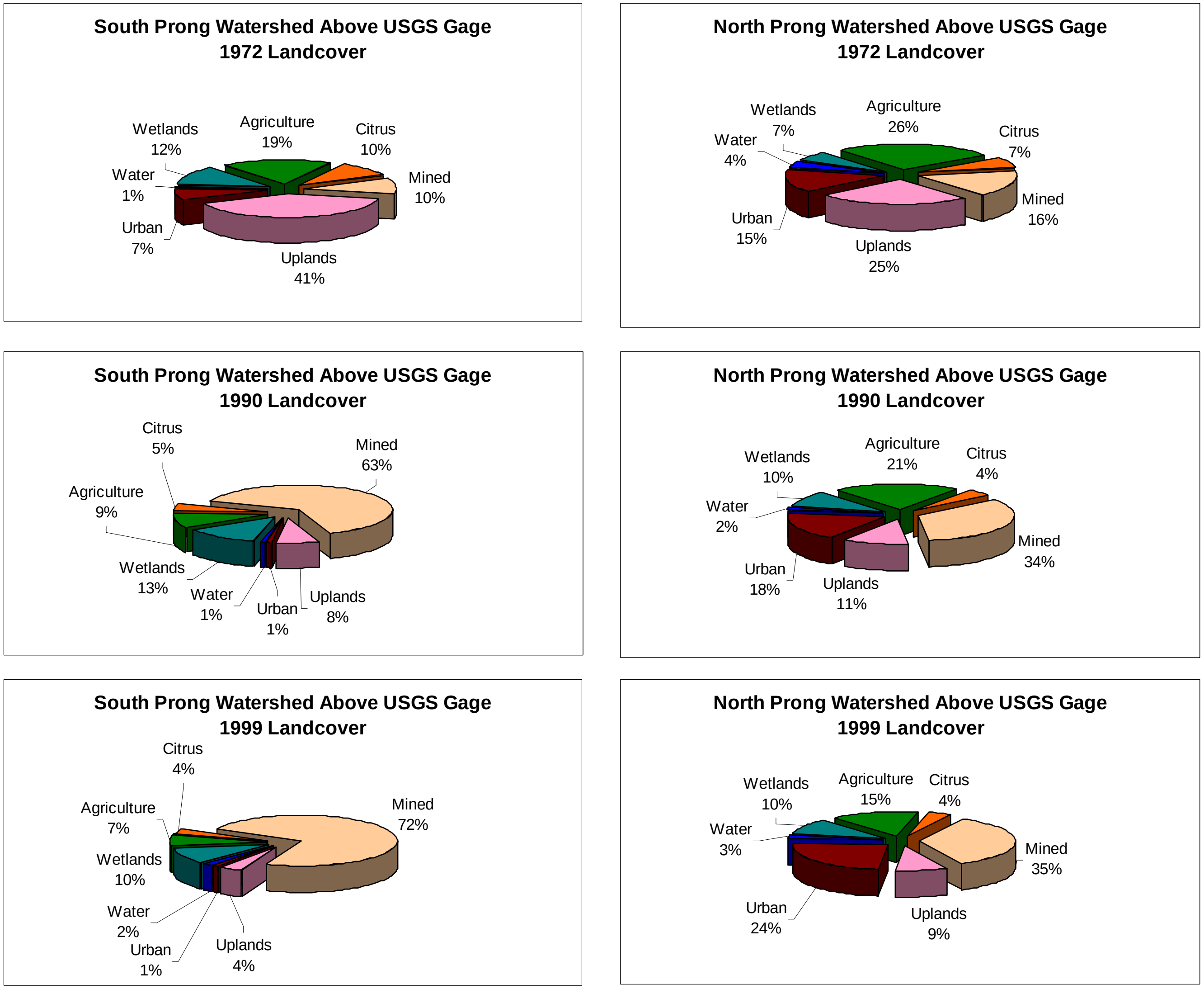


Figure 23. Land use in the watershed upstream of USGS gage sites on the South and North Prongs of the Alafia River based on mapping conducted in 1972, 1990 and 1999.

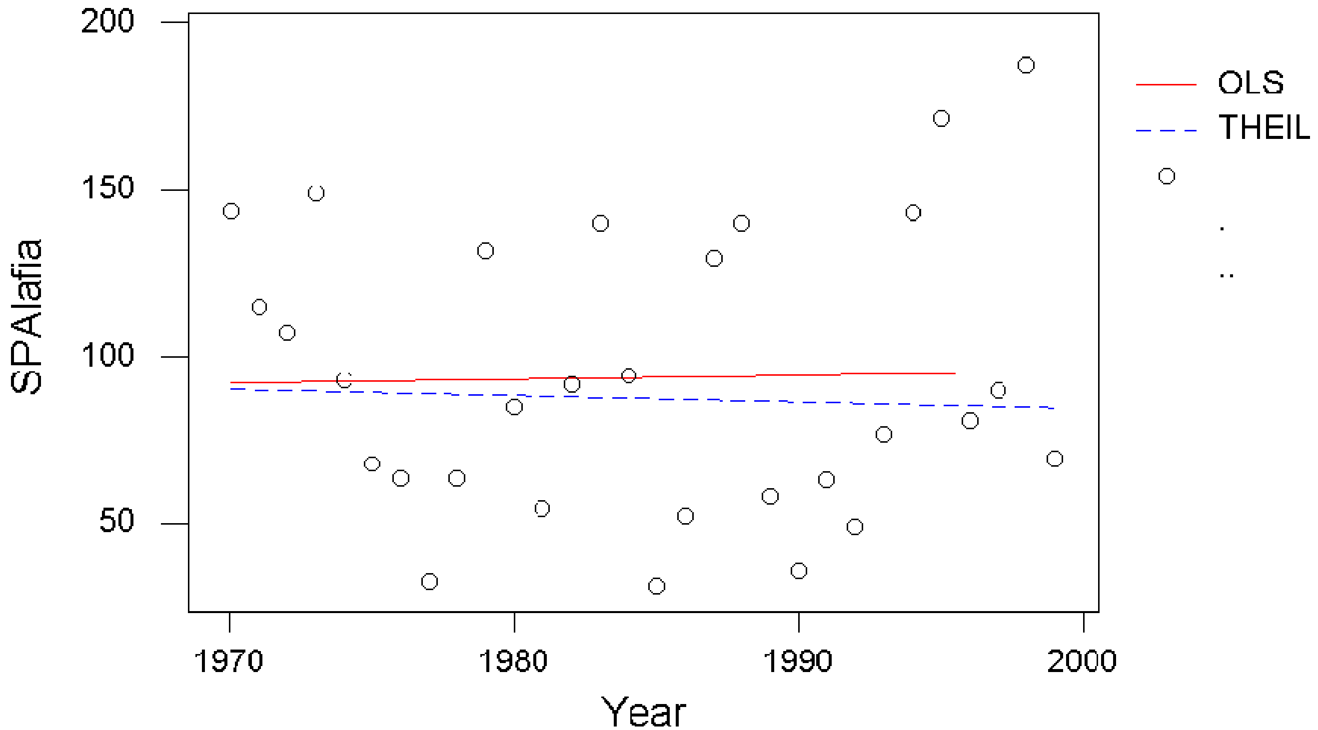


Figure 24. Graphical results of Kendall's tau test for trend in mean annual flows for the South Prong of the Alafia River for the period 1970 to 1999. Both the Ordinary Least Squares and Thiel best fit lines are shown. The slope of the Thiel line is -0.1918 with a p value of 0.8028.

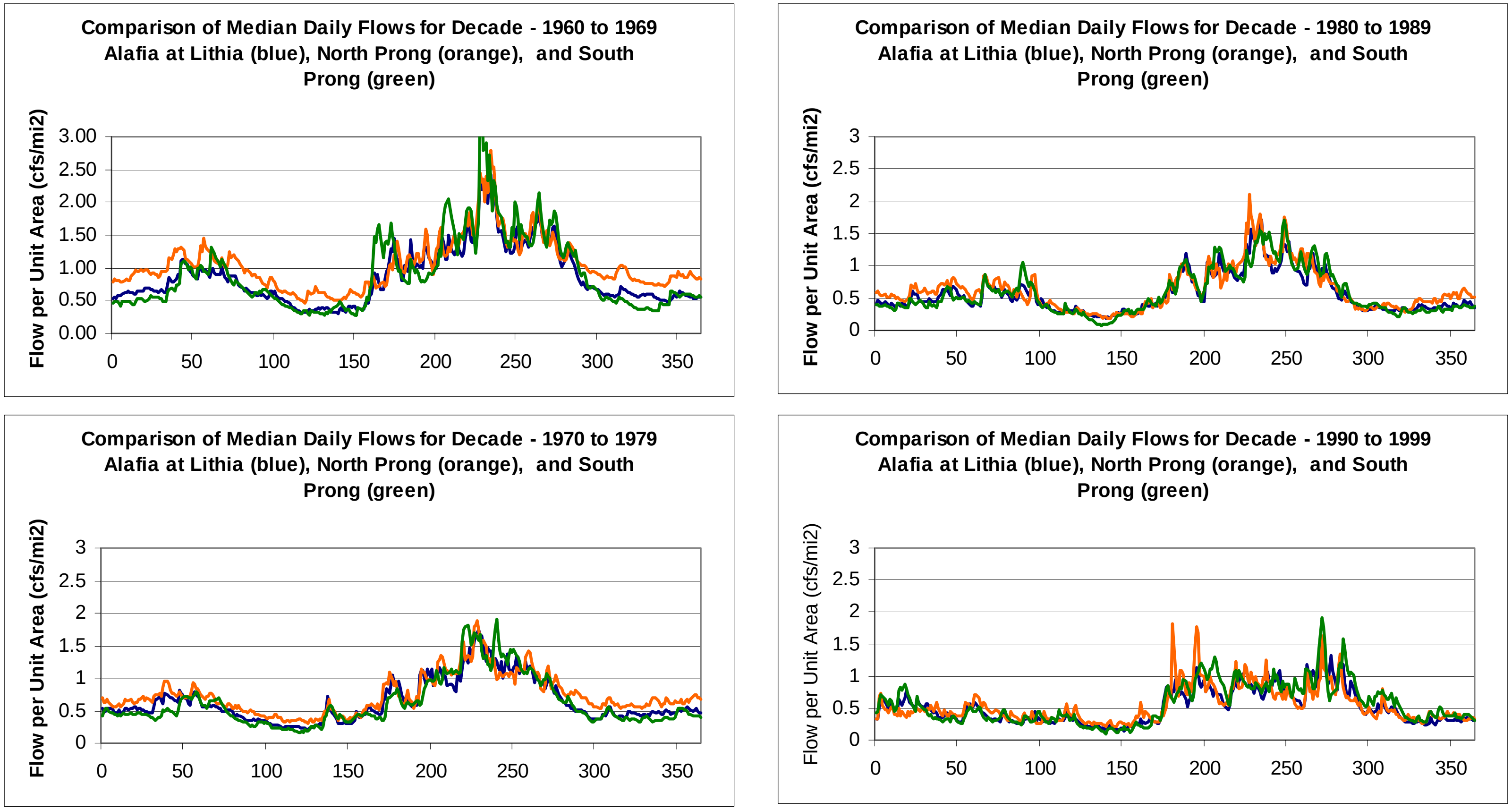
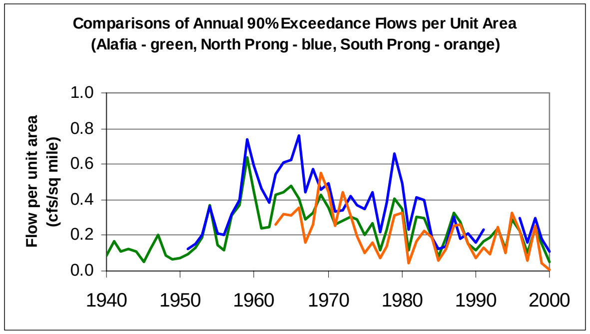
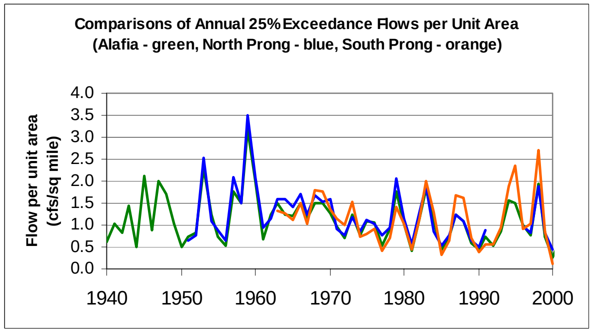
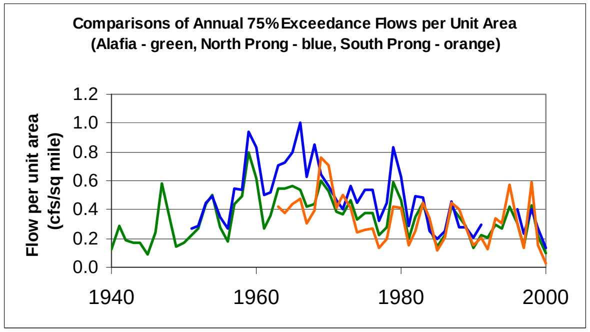
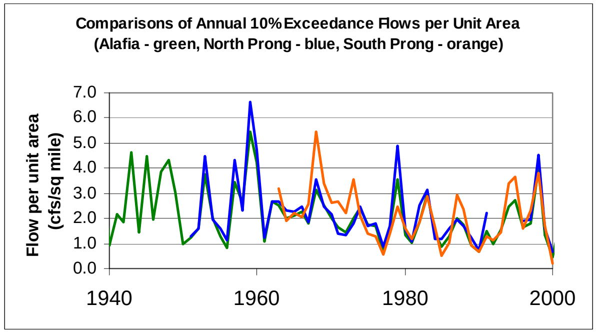


Figure 25. Plots comparing decadal median daily flows normalized by watershed area for the Alafia River at Lithia and the North and South Prongs.









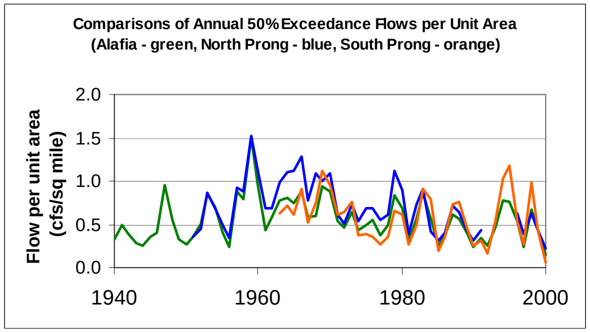


Figure 26. Comparison of selected annual percent exceedance flows normalized by watershed area for the Alafia River at Lithia and the North and South Prongs of the Alafia River.

The Myakka River

Low flows in the Myakka River as measured at two freshwater gaging sites have increased substantially during recent years. These increases in low flows are attributable to Floridan aquifer water used to irrigate agricultural fields (Coastal Environmental 1998, Ford and Brooks 2002). This increase in flow is of sufficient quantity that it has increased the median and mean flows as well. Inspection of percent exceedance flow plots (Figure 27) shows that the Myakka River which now appears to be a perennially flowing river (as measured at two USGS gages, one above and one below Upper Myakka Lake) probably ceased flowing in some years before augmentation with agriculturally related releases. Similar trends in flows have also been reported (Flannery and Barcelo 1998) for the Manatee and Little Manatee River, and Joshua Creek in the Peace River watershed. Increasing low flow trends for the Myakka River are readily apparent from inspection of annual percent exceedance flow plots or when comparing mutidecadal time periods (Figures 28).

With respect to the Myakka River, the amount of flow increase attributable to agriculturally related discharges can be approximated if it is assumed that there are no other significant anthropogenic increases simply by inspection of flow plots during typical low flow periods (e.g., less than median flows). Comparison of flows for the period 1940 to 1950 with the period 1980 to 1990 suggests that during parts of the year the amount of water discharged from agricultural lands upstream of the Myakka River near Sarasota gage could be in the range of 25 to 50 cfs (16 to 32 mgd). Percent exceedance flow plots also suggest that prior to receiving agriculturally related discharges of water, flows typically approached zero for approximately 30 to 60 days each year.

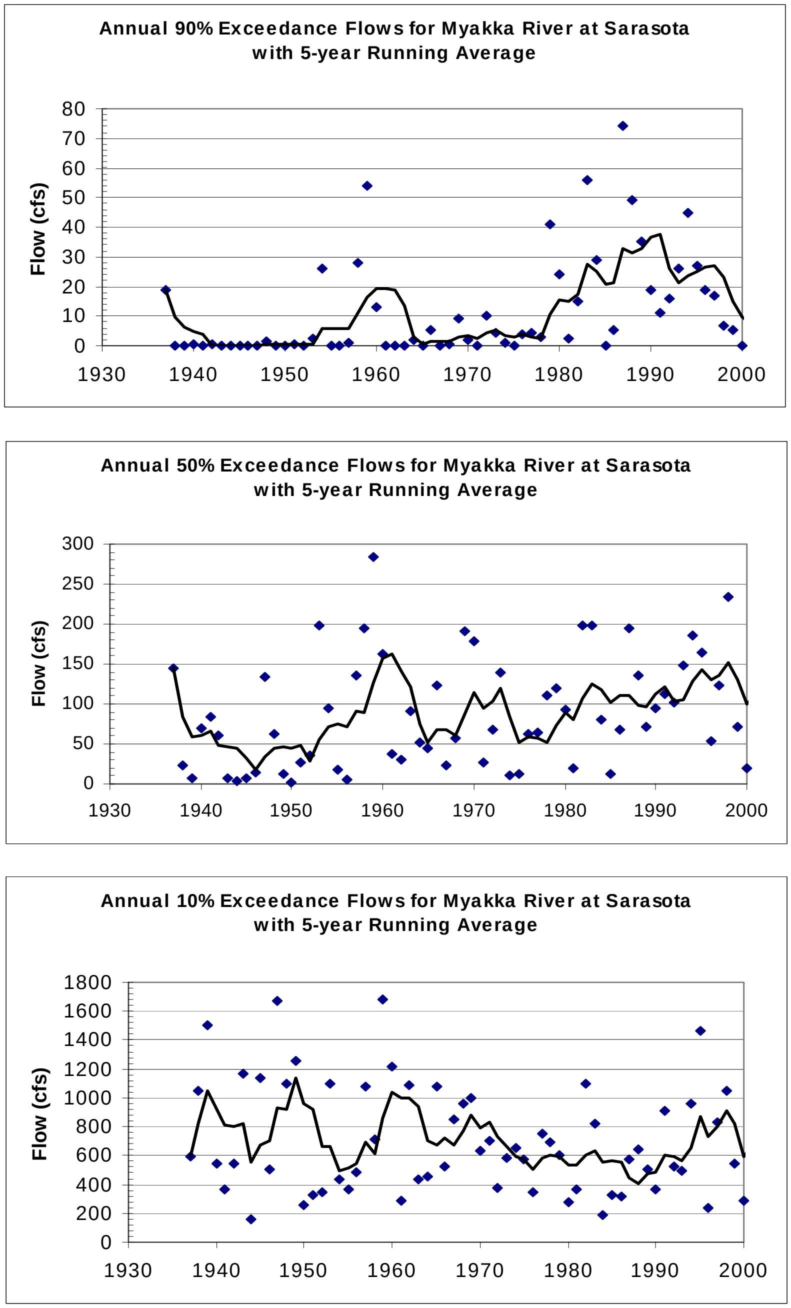
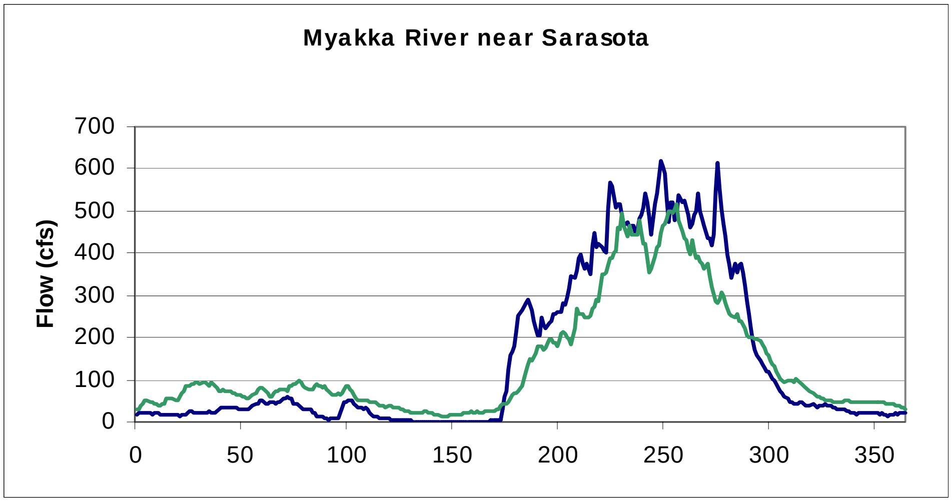


Figure 27. Selected annual percent exceedance flows for the Myakka River at Sarasota gage displayed with a 5-yr running average.



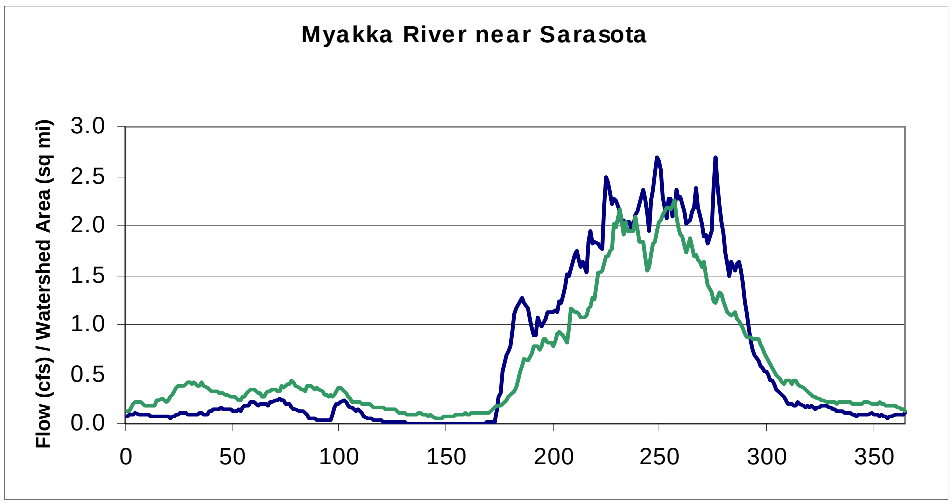


Figure 28. Comparison of Median Daily Flows for the Myakka River near Sarasota for two time periods - 1940 to 1969 and 1970 to 1999.

Flows in the Upper and Middle Peace River

It has been demonstrated that low flows in the upper Peace River (defined as the river segment above the Zolfo Springs gage) have been severely impacted due to the regional lowering of the potentiometric surface as a result of significant groundwater withdrawals (Hammett 1990, SWFWMD 2002, Basso 2002). While high flows have declined as well and some of this decline is no doubt attributable to loss of the Floridan aquifer baseflow component, uncertainty remains as to the factor(s) most responsible for medium and high flow declines. Because of this uncertainty, the SWFWMD refrained from proposing minimum mid and high flows on the upper Peace River (SWFWMD 2002).

Natural low flows to the middle Peace River (from Zolfo Springs to Arcadia) have also certainly declined because Floridan aquifer water was historically discharged to the upper portion of the river. These declines, however, have not been as great as in the upper river segment simply because of the increasing contributing area as one proceeds downstream and because the Payne Creek watershed apparently discharges more water during low flows than would be anticipated for a watershed of its size based on a comparison with other Peace River subbasins. Nevertheless, a disproportionately greater amount of the baseflow in low flow months historically originated upstream of Zolfo Springs (i.e., from the upper Peace) due to the greater degree of connectivity of this part of the watershed with the underlying Floridan and intermediate aquifers.

Based on a comparison of flows in the Peace River at Arcadia with flows from Charlie and Horse Creeks, it is concluded that most of the perceived decline in mid to high flows of the Peace River at Arcadia must be attributable to natural climatic variation. The similarity in flow trends between Charlie Creek and the Peace River at Arcadia in the median and high ranges suggests a similar causative factor is operative in both watersheds (granted that the Charlie Creek watershed is part of the larger Peace River at Arcadia watershed). Since there is no phosphate mining, little urbanization, and little surface water storage (few lakes) in the Charlie Creek watershed, it is suggested that the similar causative factor is climatic (i.e., rainfall).

A report by Hammett (1990) and its implications with respect to anthropogenic impacts on stream flow particularly as measured at the Arcadia gage has lead to considerable debate over man's impact on Peace River flows (see Garlanger 2002, SWFWMD 2002, SDI 2003). Keeping in mind that Hammett (1990) was examining flow data only through 1985, she stated and then concluded, "If rainfall were the controlling factor, then all streamflow stations in the area would show similar trends, which is not the case." While we concur with the opening phrase of this sentence, we cannot agree with the resulting conclusion. Hammett used the Kendall's tau test to evaluate whether or not a site demonstrated a significant declining trend, and applied an alpha level of 0.1 to her analysis. Simply stated if the alpha level at a site exceeded 0.1, then no trend was assumed. Since the

Peace River at Arcadia gage met the criterion for significance (its alpha level was exactly 0.1 –see Table 16 in Hammett (1990)), a significant trend was indicated. Both Charlie Creek and Horse Creek exhibited relatively low alphas, 0.17 and 0.11, respectively; however, neither site met the criterion for statistical significance, and it was apparently assumed that they did not exhibit similar flow trends. No flow plots similar to the Arcadia plot in Hammett's report were generated for either of these sub-basins, if this had been done a different conclusion may have been reached (see Figure 29 which shows a plot similar to Hammett's but also includes overlays for Charlie and Horse Creeks). Hammett (1990) also included in her analysis such sites as the Caloosahatchee Canal at Moore Haven, but should never have expected nor would one want the flows of the Peace River to compare favorably to this highly altered system (refer to Figure 10a). While one might anticipate flows in the Myakka River or Joshua Creek to exhibit flow trends similar to the Peace River at Arcadia, the fact that they do not compare as favorably as might be expected is attributable more to anthropogenic flow increases in the Myakka River (as discussed above) and Joshua Creek rather than to anthropogenic flow decreases in the Peace River. All in all, the lack of agreement with some sites is the result of anthropogenic factors acting on those sites which do not correspond well to the pattern seen at the Arcadia gage.

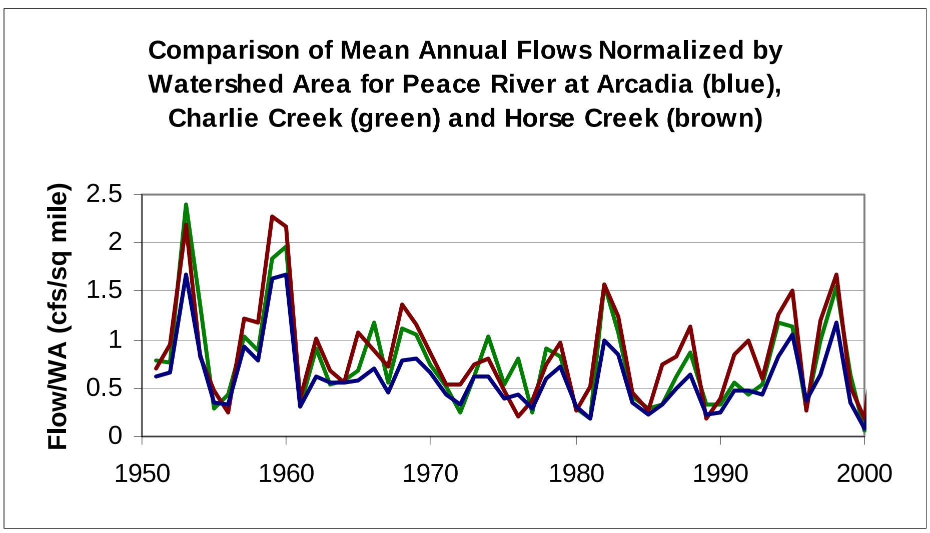
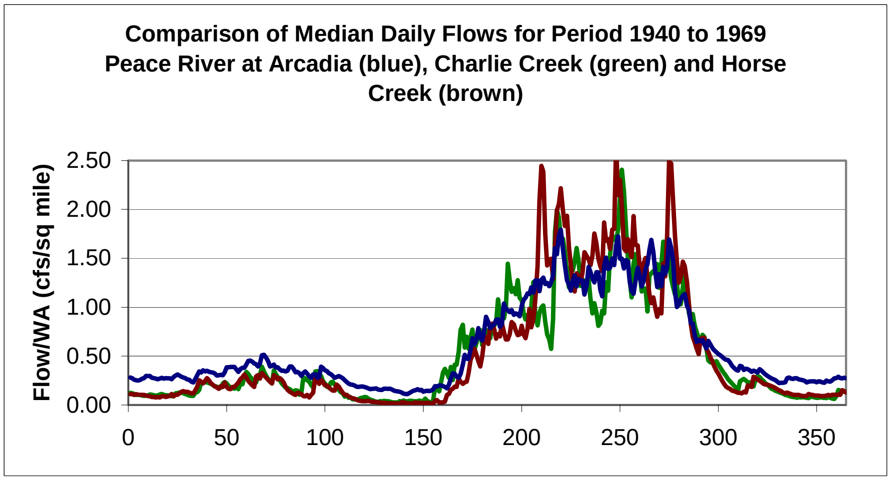


Figure 29. Comparison of Mean Annual Flows for Peace River at Arcadia, Charlie Creek and Horse Creek.

Flow variation was also examined for a number of major tributaries to the Peace River. Flow patterns for Horse and Charlie Creeks and the Peace River at Arcadia are remarkably similar when the two periods examined earlier in connection with the AMO are compared (see Figure 30). Please note that in order to make these comparisons, the earlier record for the Arcadia gage has been shortened to 1951 to 1969, since this is when flow records began on both Charlie and Horse Creeks. This simple visual comparison suggests that



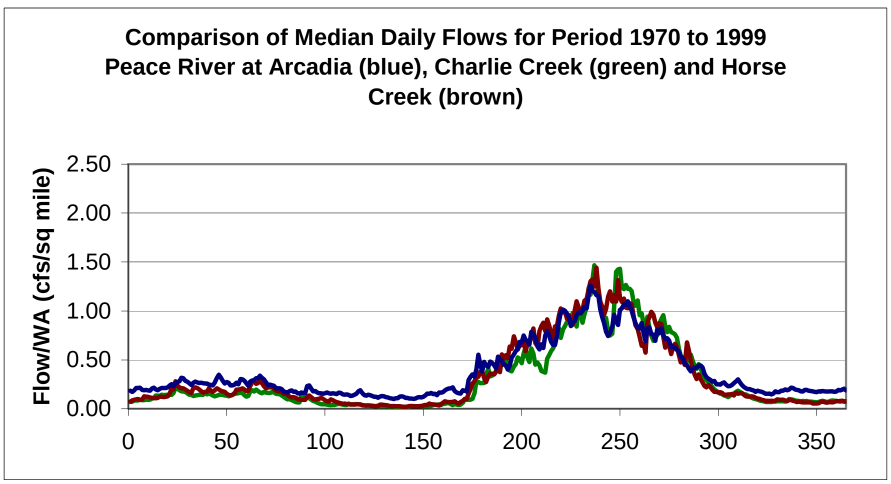


Figure 30. Comparison of median daily flows for two time periods for Peace River at Arcadia, Charlie Creek and Horse Creek.

variations in flow are largely the result of similar causative factors; no elaborate or complex analysis is needed, one only needs to examine the empirical data to come to this conclusion. Using median daily flows rather than means, all three sites showed a 35% decrease in flows when the 1951 to 1969 period is compared to the 1970 to 1999 period (Figure 30).

On its publicized listing of endangered rivers for 2004, American Rivers Inc. listed the Peace River as the eighth most endangered river in America. In a statement released by them and reported in the media, the organization concluded "that most of the flow decline of the middle Peace River is attributable to phosphate mining." Unfortunately this statement was not substantiated. Most of the flow decline in the Peace River at Arcadia (which is the gage obviously referenced) must be attributed to the same factor(s) that contributed to flow declines in Charlie and Horse Creek. We suggest that the obvious conclusion is climate. SDI (2003), representing one of the entities nominating the Peace River for this endangered status, reported that most of the flow decline of the Peace River as measured at the Arcadia gage is attributable to climate (55%) and that mining was responsible for 17% of the decline. While we agree that climate is the major controlling factor and while we cannot attribute a percentage figure to this decline, we conclude that the percent attributable to mining must be similar to the percentage attributable to mining in either the Charlie Creek or Horse Creeks sub-basins, a very low percentage at worst and considerably lower than the 17% referenced by SDI (2003).

There has been considerable discussion relative to anthropogenic effects on flows of the Peace River. The clear implication of a report published by the USGS (Hammett 1990) is that much of the flow decline seen in the Peace River as measured by flow at the Arcadia gage is attributable to factors other than rainfall. It should be appreciated that the conclusions in this report are based largely on an analysis of mean annual flows. Further it was stated that if rainfall were the major controlling factor behind flow declines then one should see similar flow patterns in neighboring watersheds, and it was concluded that this was not the case. A re-analysis of flows using the graphical approach presented above; however, strongly suggests that there are very similar flow patterns in neighboring watersheds leading us to conclude that rainfall does in fact explain most of the long-term variation in streamflow measured at the Arcadia gage. Consideration of differences in land use and anthropogenic factors that may affect stream flow in neighboring watersheds helps to explain in some cases why stream flows patterns do not appear similar. In fact, anthropogenic factors can explain why some of the neighboring river segments examined by Hammett (1990) did not show similar patterns to the Arcadia gage.

In recent years, there has been a dramatic increase in dry season flow in Joshua Creek, one of the sites to which Hammett compared the Arcadia gage flows. The Joshua site (located near Nocatee, FL) shows a true monotonic increasing trend in flow beginning in the late 1970s (Figure 31). As with the Myakka River discussed above, it is believed that this increasing flow trend is due largely to agriculturally related runoff of irrigation water. Consistent with the AMO discussion presented earlier, we should not expect to see increasing flow trends during the 1980s and midway into the 1990s; however, rather dramatic increases are apparent, and these increases are of sufficient magnitude to noticeably affect median and mean flows. As discussed earlier, this "SRP" river should show a declining flow trend when pre and post 1970 periods are compared. Although this site only has a flow record beginning in 1950 with the first complete year of record being 1951, there is a sufficient record to develop the type of period comparisons made earlier for the Florida sites with a 60 year period of record and for Charlie and Horse Creek as presented above (Figure 30). This increase, which is particularly evident in the normal dry period, is believed attributable to agricultural releases of groundwater, and based on changes in land use may be associated with the increasing amount of land in citrus production.

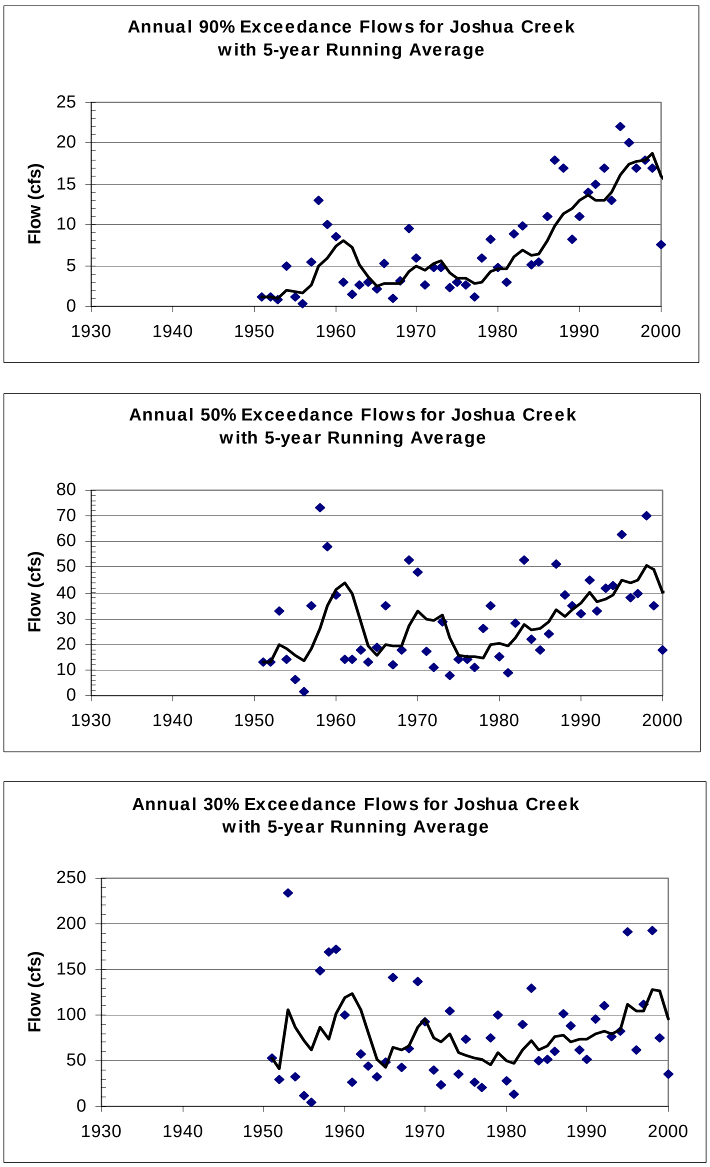
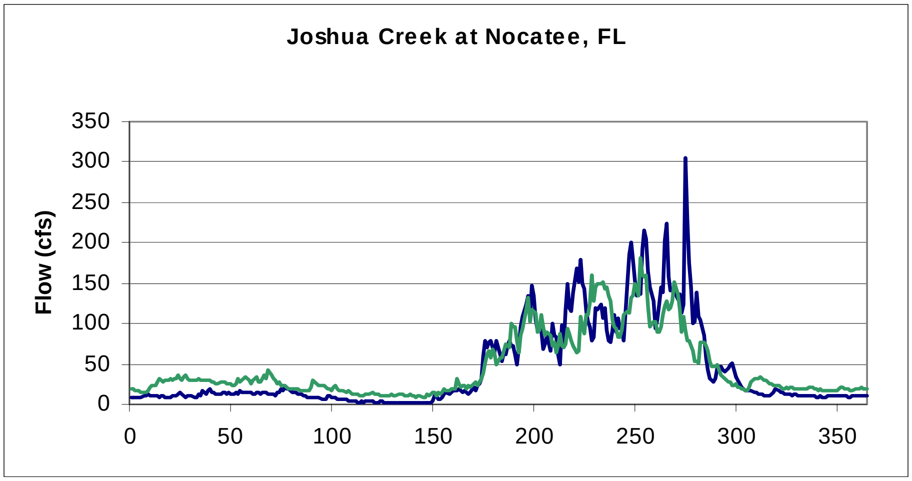


Figure 31. Annual percent exceedance flows for the Joshua Creek gage displayed with a 5-yr running average.



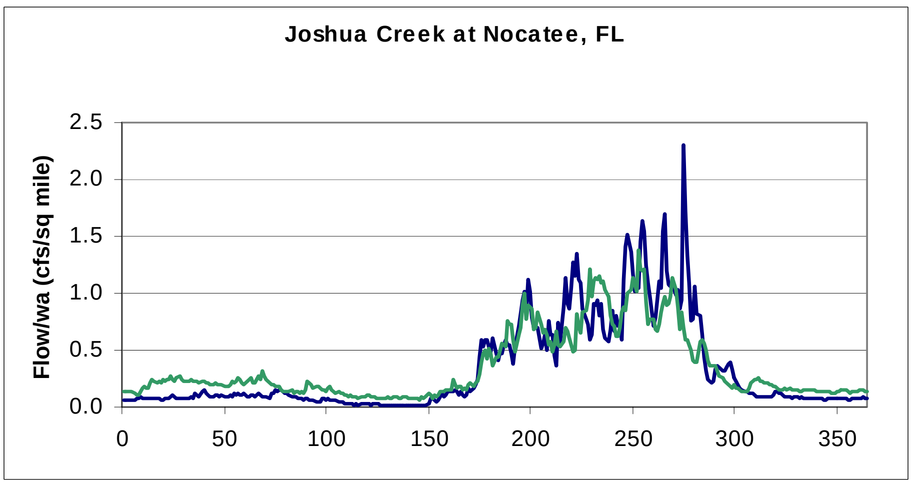


Figure 32. Comparison of Median Daily Flows for Joshua Creek at Nocatee for two time periods - 1940 to 1969 and 1970 to 1999.

Are Flow Declines a Monotonic or a Step Trend?

Figure 33 is an example of something that can be clearly described as a "monotonic" trend, which is defined as an incremental increase or decrease over time. This figure shows that potassium loading has increased in the Peace River watershed over time (refer to SWFWMD 2002). Interestingly, a number of workers have examined the relationship of flow and rainfall by constructing cumulative discharge plots (see Figure 1 for an example of such a plot). An inflection or abrupt change in the slope of the line between cumulative discharge versus time is interpreted as a change in the rainfall to runoff characteristics of the watershed. It seems reasonable that an inflection or abrupt change in this

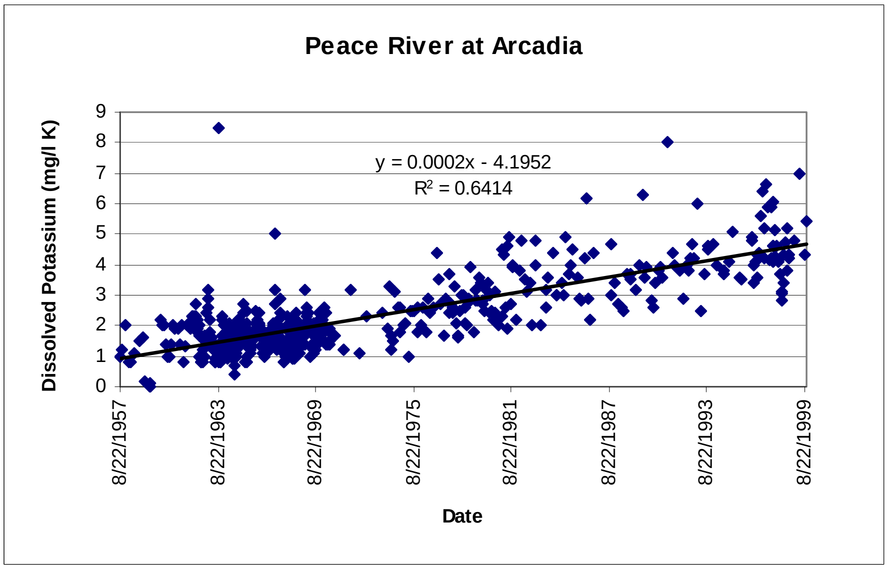


Figure 33. Potassium concentrations in water quality samples taken by USGS at Peace River at Arcadia gage.

relationship should be interpreted as a "step" trend and not a monotonic trend. A monotonic trend, an incremental increase or decrease over time, should cause the slope of the line to gradually curve upward or downward.

SDI (2003) attempted to relate increasing mined area to decreasing flow in the South Prong of the Alafia River and assumed that as mined area incrementally increased, flow would incrementally decrease. They essentially postulated a "monotonic trend" in flow such that there was an incremental decrease in flow with increasing area of land mined for phosphate. Hickey (1998), however, using a cumulative mass approach, observed a distinct inflection point in his cumulative discharge plot around 1970. He also constructed cumulative mass plots of discharge against time for a number of other rivers in the SWFWMD (Withlacoochee River near Trilby, Peace River at Bartow, Hillsborough River near Zephyrhills, Little Manatee near Wimauma and Anclote River near Elfers), and concluded that, "there was an abrupt regional decline in the average discharge in the post-1970 period relative to the pre-1970 period." This abrupt change is better described as a step trend rather than a montonic trend. This interpretation is consistent with a climatic change such as the one attributed to the Atlantic Multidecadal Oscillation (AMO; see Enfield et al. 2001). This conclusion is further supported by work done by McCabe and Wolock (2002) who examined flow trends in much of the continental United States. While they were examining river flow increases (rather than decreases), they concluded that a step change rather than a monotonic change in rainfall had occurred in 1970, and this resulted in a step change in river flows as well. There work is also consistent with Enfield et al. (2001).

The occurrence of a true monotonic trend is not precluded by the occurrence of a step trend (i.e., oscillation); however, a step change should not be confused with a monotonic trend. A statistically significant Kendall's tau test has been interpreted as strong evidence of a monotonic trend; however, a step function can yield a statistically significant result as well. This is demonstrated by results shown in Figure 34. The first plot (Figure 34a) shows the results of Kendall's tau test on Alafia River flows for the period 1940 to 1999. The Kendall's tau was significant at the p=0.0653 level with a slope of –2.122 (see Table 6). However, the Kendall's tau test was performed on two 30-year periods, pre and post 1970. As is seen in Figure 34b, Kendall's tau was not significant for the period 1940 to 1969 (p=0.3353, slope = 3.796), nor was it significant for the period 1970 to 1999 (p = 1.000, slope = 0.1081). It is suggested that relationships assumed to be monotonic trends over time may actually be step changes (refer to McCabe and Wolock 2002). Some of this confusion could be overcome by simple evaluation of flow plots in conjunction with trend test analysis. While it is possible that a trend could occur over part of a period and then stabilize (no trend) for part of a period, this could also be discerned from inspection of plots as well as consideration of Kendall's tau statistics (slope and p value). Joshua Creek is an example of a true monotonic trend in flow as demonstrated by the Kendall's tau statistics and plots (Figure 34 a-c); it is believed that this increasing trend in flow is attributable to agricultural use and subsequent discharge of groundwater.

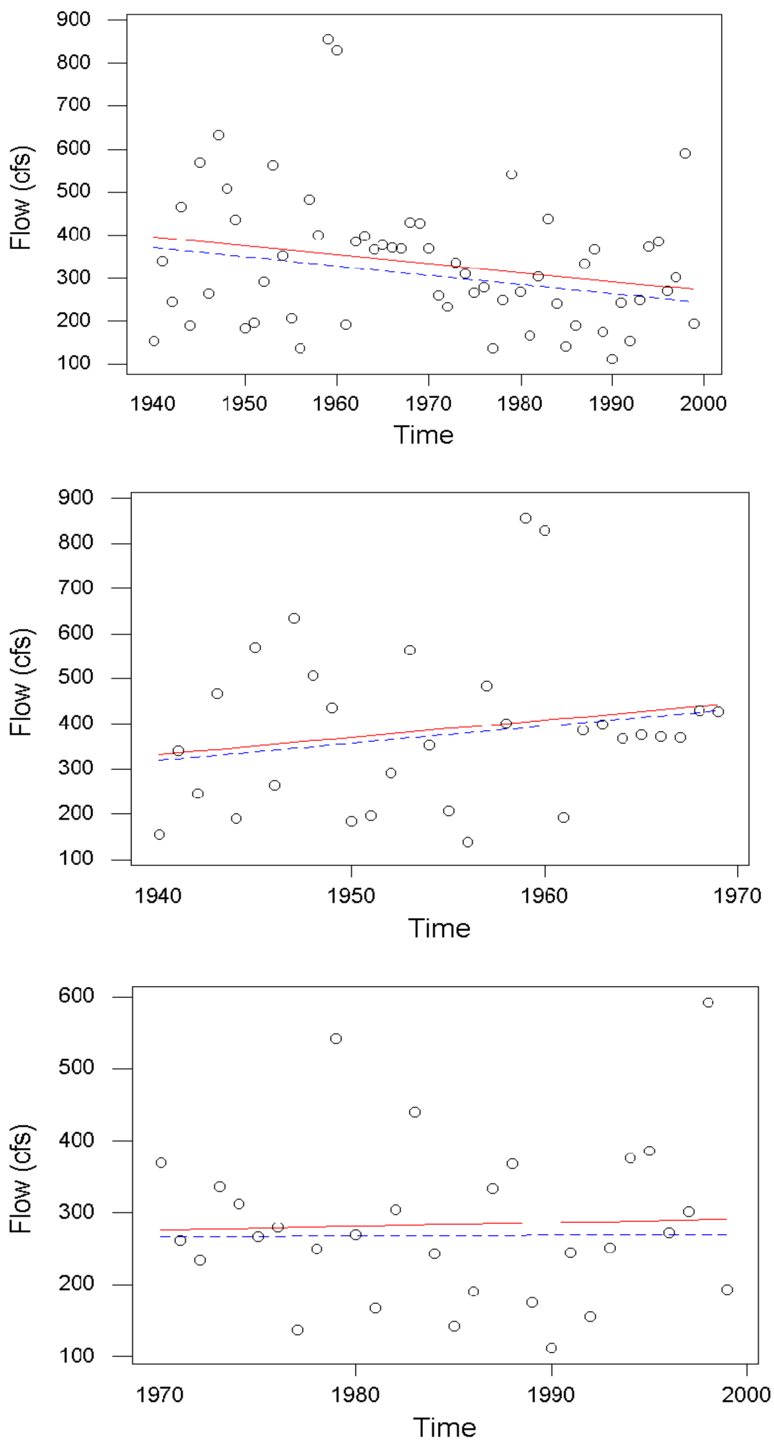


Figure 34. Graphical results of Kendall's tau test of mean annual flows for the Alafia River for the period 1940 to 1999, the period 1940 to 1969, and the period 1970 to 1999. The red line is the Ordinary Least Squares line, and the blue line is the Kendall's tau Thiel line.

Factors Affecting / Controlling River Flows

The main premise of this document has been that climatic factors can explain much of the relatively large flow declines that have been observed on watercourses in Florida with a SRP. While this does not mean that additional flow declines have not resulted as a consequence of anthropogenic impacts, it may be difficult to quantify or in some cases even identify these impacts. While most workers realize that there can be extreme annual variation in flow, most also believe that this variation is more or less random. As a result when flow declines occur, the tendency has been to look for an anthropogenic explanation for these flow trends. Olsen et al. (1999) in examining flood frequency estimation for the upper Mississippi and lower Missouri Rivers observed that, "the annual maximum peak floods are considered to be a sample of random, independent and identically distributed (iid) events. Thus one implicitly assumes that climatic trends or cycles are not affecting the distribution of flood flows in a significant way." Olsen et al. (1999) eventually conclude that "current interest in climate change and its potential impacts on hydrology in general and on floods in particular calls into question the iid assumption." Although Olsen et al. (1999) were interested in flood flows, their comments are applicable to flow variation in general. Further, in the words of McCabe and Wolock (2002), "The identification of an abrupt increase [a decrease in peninsular Florida] in streamflow rather than a gradual increasing [decreasing] trend is important because the implications of a step change are different from those of a gradual trend. The interpretation of a gradual trend is that the trend is likely to continue into the future, whereas the interpretation of a step change is that the climate system has shifted to a new regime that will likely remain relatively constant until a new shift or step change occurs."

This report is important to the overall process of MFL development since it demonstrates that relatively large decreases and increases in flow are attributable to rainfall differences between multidecadal periods (Enfield et al. 2001, Basso and Schultz 2003). Although most appreciate that rainfall is the primary driving factor affecting river flows, it has been traditionally assumed with respect to hydrology that river flows are the consequence of a sequence or random independently and identically distributed random variables. To paraphase Olsen et al. (1999), these results challenge this generally held assumption and suggest that those involved in water management issues may need to rethink their paradigm with respect to river flow analysis and allow for multidecadal variations in river flow patterns.

Literature Cited

Basso, R. and R. Schultz. 2003. Long-term variation in rainfall and its effect on Peace River flow in West-Central Florida. Hydrologic Evaluation Section. Southwest Florida Water Management District. 33 pp.

Coastal Environmental, Inc. 1996. Living resource-based freshwater inflow and salinity targets for the tidal Peace River. Final Report. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Coastal Environmental, Inc. 1998. Tree mortality assessment of the Upper Myakka River watershed. Prepared for Southwest Florida Water Management District. Brooksville, Florida.

Enfield, D., A. Mestas-Nunez, and P. Trimble. 2001. The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S. Geophysical Research Letters 28(10): 2077-2080.

Flannery, M. and M. Barcelo. 1998. Spatial and temporal patterns of streamflow trends in the upper Charlotte Harbor watershed. In Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor National Estuary Program. Technical Rept. No. 98-02.

Ford, C.R. and J.R. Brooks. 2002. Detecting forest stress and decline in response to increasing river flow in Southwest Florida. Forest Ecology and Management 160(1-3): 45-64.

Garlanger, J. 2002. Effects of phosphate mining and other land uses on Peace River flows. Prepared by Ardaman & Associates, Inc. for Florida Phosphate Council. Tallahassee, Florida. 19 pp.

Gray, W, J. Sheaffer and C. Landsea. 1997. Climate trends associated with multidecadal variability of Atlantic hurricane activity. In (Diaz and Pulwarty, eds.) Hurricanes: Climate and Socioeconomic Impacts. Springer-Verlag. New York. pp. 15-53.

Hammett, K. 1990. Land use, water use, streamflow characteristics, and water-quality characteristics of the Charlotte Harbor inflow area, Florida. United States Geological Survey Water-Supply Paper 2359. Prepared in cooperation with the Florida Department of Environmental Regulation. 64 pp.

Hickey, J. 1998. Analysis of stream flow and rainfall at selected sites in west-central Florida. SDI Environmental Services. Tampa, Florida. 53 pp.

Hupalo, R., C. Neubauer, L. Keenan, D. Clapp and E. Lowe. 1994. Establishment of minimum flows and levels for the Wekiva River system. Technical Publication SJ94-1. St. Johns River Water Management District, Palatka, Florida.

Lewelling, B., A. Tihansky, and J. Kindinger. 1998. Assessment of the hydraulic connections between ground water and the Peace River, West-Central Florida. U.S. Geological Survey Water Resources Investigations Report 97-4211. Prepared in cooperation with the Southwest Florida Water Management District. 96 pp.

McCabe, G., M. Palecki, and J. Betancourt. 2004. Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. PNAS 101 (12): 4136-4141.

McCabe, G., and D. Wolock. 2002. A step increase in streamflow in the conterminous United States. Geophysical Research Letters 29(24): 2185-2188.

Nichols, M., K. Renard, and H. Osborn. 2002. Precipitation changes from 1956 to 1996 on the Walnut Gulch Experimental Watershed. JAWRA 38 (1): 161-172.

Olsen, J., J. Stedinger, N. Matalas and E. Stakhiv. 1999. Climate variability and flood frequency estimation for the upper Mississippi and lower Missouri Rivers. AWRA 35 (6): 1509-1523.

Palmer, C. and H. Nguyen. 1986. Long-term rainfall deficits in Central Florida: implications for water management. Water Resources Department, Environmental Services Division. Polk County. Bartow, Florida.

SDI Environmental Services, Inc. 2003. Cumulative risk of decreasing streamflows in the Peace River Basin. Prepared for Charlotte County, Lee County and the Peace River / Manasota Regional Water Supply Authority. 15 pp + figures. Tampa, Florida.

Stoker, Y., V. Levesque and W. Woodham. 1996. The effect of discharge and water quality of the Alafia River, Hillsborough River, and the Tampa Bypass Canal on nutrient loading to Hillsborough Bay, Florida. U. S. Geological Survey. Water Resources Investigations Report 95-4107. Prepared in cooperation with the Southwest Florida Water Management District. Tallahassee, Florida. 69 pp.

SWFWMD. 2002. Upper Peace River: an analysis of minimum flows and levels. Draft. Ecologic Evaluation Section. Resource Conservation and Development Department. Brooksville, Florida

Florida River Flow Patterns and the Atlantic Multidecadal Oscillation

Appendix

The Appendix is available as a separate document and includes plots for 73 Florida gage sites as referenced in the text.

Peace River near Zolfo Springs – 1918
J.K. Small Collection
from Florida Photographic Collection

Draft Appendix
Ecologic Evaluation Section
Southwest Florida Water Management District
August 10, 2004