



TECHNICAL REPORT

MFL Establishment for the Upper Santa Fe River

MAY 2007



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CERTIFICATION

This Technical Report was prepared for the use of the Suwannee River Water Management District for the establishment of Minimum Flows and Levels for the Upper Santa Fe River by the undersigned.

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EXECUTIVE SUMMARY

In September 2002, the Governing Board of the Suwannee River Water Management District (District) initiated the effort to develop MFLs for the Upper Santa Fe River.

This technical report presents the data and analyses that provide technical support for the establishment and adoption of Minimum Flows and Levels (MFLs) for the Upper Santa Fe River, a tributary of the Suwannee River. The goals for these MFLs are:

- To implement the intent and policy of the Governing Board of the Suwannee River Water Management District;
- To satisfy the requirement of state water law and policy.

Chapter 373.042, Florida Statutes (F.S.) specifies that:

- (1) Within each section or the water management district as a whole, the Department (Florida Department of Environmental Protection) or the district Governing Board shall establish the following:
 - (a) Minimum flow for all surface watercourses in the area. The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.
 - (b) Minimum water level. The minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area.

Subsequent language in the statute (Chapter 373.042(1), F.S.) provides guidance that the Governing Board shall use the “best information available”, and that the Board may consider “seasonal variations” and the “protection of nonconsumptive uses” in establishing MFLs.

The Santa Fe River is one of three major tributaries of the Suwannee River system. The Santa Fe is the only major tributary wholly located within Florida and the District. The Upper Santa Fe River, for which this document is the technical basis report and for which MFLs are recommended herein, includes those portions of the Santa Fe River that are upstream and immediately downstream from the USGS stream gage located at Worthington Springs. The Santa Fe River goes under ground in a large swallet at O’Leno State Park (the River Sink), downstream from Worthington Springs and re-emerges a few miles southeast of the River Sink at the River Rise within the River Rise State Preserve. From the River Rise, the river flows south and west to its confluence with the Suwannee River. The portion of the Santa Fe downstream from the River Rise is termed the Lower Santa Fe River, for which the District will set separate MFLs in 2008.

The Upper Santa Fe River is recognized on its own merits as a system having high conservation and recreational value, and has been designated an Outstanding Florida Water (OFW). At present, there are no federal or state designations of protection areas concerning wildlife in the Upper Santa Fe. There is concern for the Oval pigtoe (*Pleurobema pyriforme*), a freshwater mussel known to occur in portions of the Upper Santa Fe. A recovery plan for this species is being implemented (U.S. Fish and Wildlife Service, 2003).

Three distinct types of ecological analyses were performed to determine the most protective method of defining ecological risk to the target biota. These were the wetted perimeter method, the minimum fish passage method and the Ecosystem Functions Model (EFM) method. It was determined that the wetted perimeter method was the most protective of the target biota for the proposed MFL stations at Graham and Worthington Springs.

Proposed MFL for the Upper Santa Fe River at Graham

Flow equivalent to, or less than, the 2.3 cfs threshold occurs 25 percent of the time according to the Baseline Flow Duration Curve (FDC). In order to protect the water resources or ecology of the river system, it was determined that up to a 15 percent shift in the FDC could occur at flows in excess of 2.3 cfs, limited by the flows not being less than the 2.3 cfs control point. The MFL FDC was, therefore, scaled so that up to a 15% flow reduction could occur at flows greater than 2.3 cfs and the available water would decrease to 0 cfs beginning at a recurrence probability of 75%, or 2.3 cfs.

Proposed MFL for the Upper Santa Fe River at Worthington Springs

Flow equivalent to, or less than, the 42 cfs threshold occurs 25 percent of the time according to the Baseline FDC. In order to protect the water resources or ecology of the river system, it was determined that up to a 15 percent shift in the FDC could occur at flows in excess of 42 cfs, limited by the flows not being less than the 42 cfs control point. The MFL FDC was, therefore, scaled so that up to a 15% flow reduction could occur at flows greater than 42 cfs and the available water would decrease to 0 cfs beginning at a recurrence probability of 75%, or 42 cfs.

Additional policy guidance is provided in the State Water Resources Implementation Rule regarding MFLs (Chapter 62-40.473, Florida Administrative Code [F.A.C.]), indicating that “. . . consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic, and wetlands ecology. . . .” These environmental and water resource values may include:

- a) Recreation in and on the water;
- b) Fish and wildlife habitats and the passage of fish;
- c) Estuarine resources;
- d) Transfer of detrital material;
- e) Maintenance of freshwater storage and supply;
- f) Aesthetic and scenic attributes;
- g) Filtration and absorption of nutrients and other pollutants;
- h) Sediment loads;
- i) Water quality; and
- j) Navigation.

It was determined in the evaluation of the “best available information” that the water resource value that provided the best opportunity to establish a MFL protective of all the identified applicable water resource values was “fish and wildlife habitats and the passage of fish”. Hence, even though there was not quantitative information available to discretely evaluate all the applicable water resource values, the MFL recommended for the protection of significant harm to “fish and wildlife habitats and the passage of fish” will be protective of the less conservative water resource values by a qualitative comparison.

TAB 1

1.0 Introduction

The technical report (Report) presents the data and analyses which provide technical support for the establishment and adoption of Minimum Flows and Levels (MFLs) for the Upper Santa Fe River, a tributary of the Suwannee River. The goals for these MFLs are:

- To implement the intent and policy of the Governing Board of the Suwannee River Water Management District
- To satisfy the requirement of state water law and policy.

1.1 Florida Law Concerning the Establishment of MFLs

Chapter 373.042, Florida Statutes (F.S.) specifies that:

- (1) Within each section of the water management district as a whole, the Department (Florida Department of Environmental Protection) or the district Governing Board shall establish the following:
 - (a) Minimum flow for all surface watercourses in the area. The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.
 - (b) Minimum water level. The minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area.

Subsequent language in the statute (Chapter 373.042(1), F.S.) provides guidance that the Governing Board shall use the “best information available”, and that the Board may consider “seasonal variations” and the “protection of nonconsumptive uses” in establishing MFLs.

Additional policy guidance is provided in the State Water Resources Implementation Rule regarding MFLs (Chapter 62-40.473, Florida Administrative Code [F.A.C.]), indicating that “. . . consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic, and wetlands ecology. . . .” These environmental values may include:

- a) Recreation in and on the water;
- b) Fish and wildlife habitats and the passage of fish;
- c) Estuarine resources;
- d) Transfer of detrital material;
- e) Maintenance of freshwater storage and supply;
- f) Aesthetic and scenic attributes;
- g) Filtration and absorption of nutrients and other pollutants;
- h) Sediment loads;
- i) Water quality; and
- j) Navigation.

These requirements constitute the statutory framework and the outline for the scope of work to establish MFLs for the Upper Santa Fe River.

1.2 Project Scope and Study Area Delineation

In September 2002, the Governing Board of the Suwannee River Water Management District (District) initiated the effort to develop MFLs for the Upper Santa Fe River.

The Santa Fe River (Figure 1-1) is one of three major tributaries of the Suwannee River system. The Santa Fe is the only major tributary completely located within Florida and the District. The Upper Santa Fe River, which this document is the technical basis report of and for which MFLs are recommended herein, includes those portions of the Santa Fe River that are upstream and immediately downstream from the stream gage located at Worthington Springs (Figure 1-1). The drainage basin of the Upper Santa Fe (Figure 1-1) constitutes the study area for this report.

The Santa Fe River goes under ground in a large swallet at O'Leno State Park (the River Sink), downstream from Worthington Springs and then re-emerges a few miles southeast of the River Sink at the River Rise within the River Rise State Preserve. From the River Rise, the river flows south and west to its confluence with the Suwannee River. The portion of the Santa Fe downstream from the River Rise is termed the Lower Santa Fe River which the District will set separate MFLs.

The River Sink and Rise represent a complex hydrologic system where streams sink and rise multiple times. As such, MFLs for the reach of the Upper Santa Fe River from the Sink and O'Leno State Park upstream to, and including, Olustee Creek will be set concurrently with the Lower Santa Fe MFLs.

1.3 Importance and Regulatory Designations

The Upper Santa Fe River is a scenic and relatively undeveloped river. It has several interesting hydrologic and geologic characteristics that add to its importance. Upstream of the Santa Fe Spring (COL61981), an historic first magnitude spring that is tributary to the Upper Santa Fe, and the confluence of Olustee Creek with the Santa Fe River (Figure 1-1), the river is perennial and has a well-developed, dendritic drainage. The river has a small floodplain, and several portions of the river are braided. Normally, the river and its tributaries are slow-moving and relatively undisturbed.

COL61981 or Santa Fe Spring (Figure 1-1), an historic first-magnitude spring (Hornsby and Ceryak, 1998), is located on the northern bank of the river. During times of drought, this spring appears to contribute much of the flow to the river downstream of the spring and upstream of the River Sink (Hornsby, 2005, pers. comm.).

There are several siphons (in-stream swallets) that capture portions of the river flow in this reach of the river (Hornsby and Ceryak, 1998; Hornsby, 2005, pers. comm.). River Sink is a large swallet where remaining flow of the Upper Santa Fe is normally totally captured. There is an overflow flood chute that begins at the River Sink and extends southwest approximately 2.8 miles to the River Rise, where the Santa Fe emerges and the Lower Santa Fe River begins (Figure 1-1).

The Suwannee River system is widely regarded as a river system with high conservation value. In a study using data from the National Rivers Inventory (NRI), Benke (1990) identified the Suwannee as one of 42 "large, intact" river drainages remaining in the U.S. He defined these as rivers with more than 124.2 miles (200 km) of length that are unaffected by any major dams, flow diversions, or navigation projects. These 42 river systems cumulatively represented only

2% of the total length of river reaches in the NRI database. Based largely on Benke's work, Noss et al. (1995) designated large intact streams and rivers in the U.S. as "Endangered Ecosystems", which they defined as those ecosystem types which have experienced an 85-98% decline in the existence of high-quality, intact examples. In similar fashion, a report on U.S. river ecosystems by The Nature Conservancy (Master et al., 1998) classified the Suwannee/Santa Fe drainage systems as "critical watersheds to protect freshwater biodiversity."

The Santa Fe River is recognized on its own merits as a system having high conservation and recreational value, and it is designated an Outstanding Florida Water (OFW). The OFW designation (Chapter. 62-302.700[9][i][28], F.A.C.) is conferred to waters of the state with "exceptional recreational or ecological significance" (Chapter 62-302.700[3], F.A.C.).

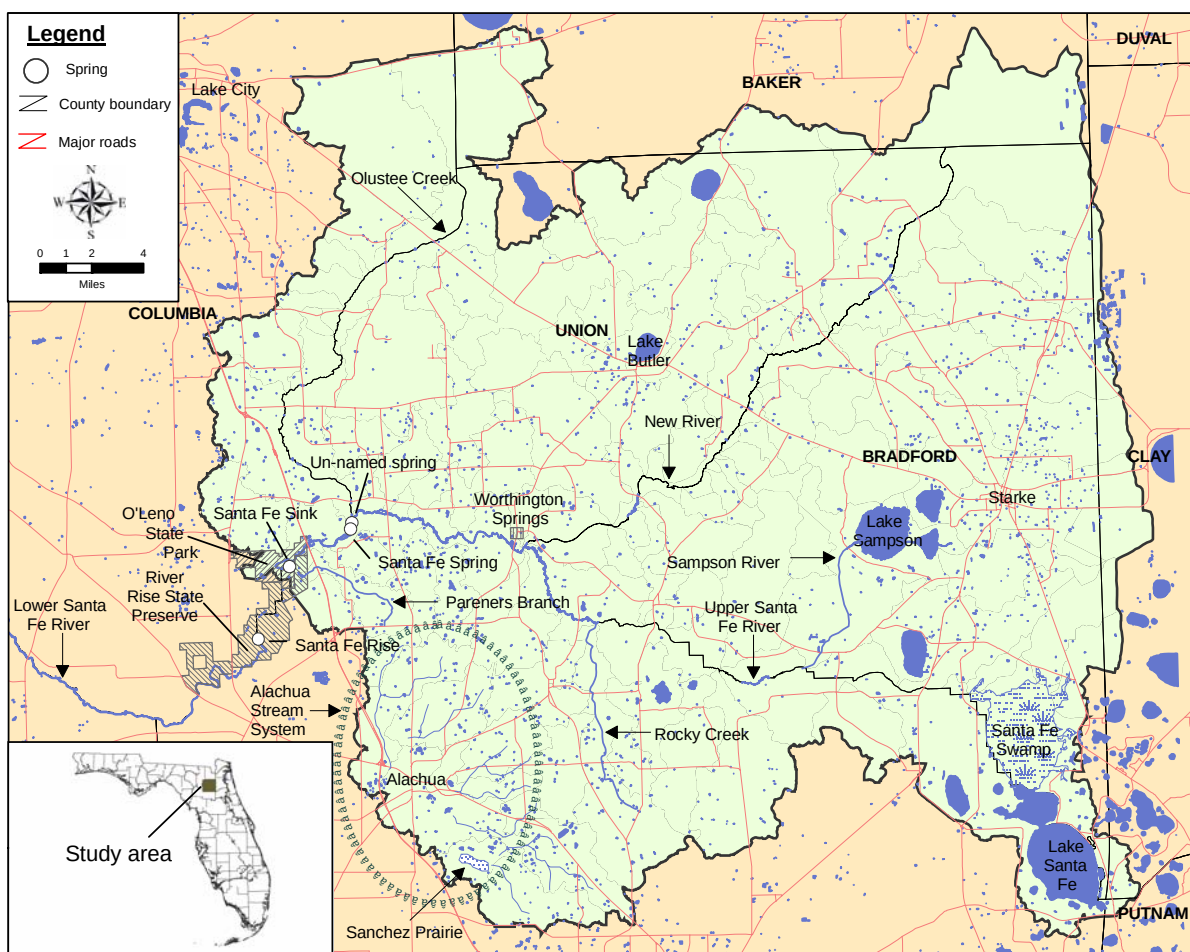


Figure 1-1. Upper Santa Fe River MFL study area and total extent of the Upper Santa Fe drainage basin.

Specifically, the OFW designation applies to the Santa Fe River, Lake Santa Fe, Little Lake Santa Fe, Santa Fe Swamp, Olustee Creek, and the Ichetucknee River below SR 27 (the Ichetucknee is in the Lower Santa Fe basin and outside of the study area). All other tributaries of the Upper Santa Fe are exempted from the OFW designation. Waters of O'Leno State Park,

River Rise State Preserve, and Ocean Pond, the headwaters of Olustee Creek, are also designated as OFW water bodies.

At present, there are no federal or state designations of protection areas concerning wildlife in the Upper Santa Fe. There is concern for the Oval pigtoe (*Pleurobema pyriforme*), a freshwater mussel known to occur in portions of the Upper Santa Fe. A recovery plan for this species is being implemented (U.S. Fish and Wildlife Service, 2003).

While the District has not designated the Upper Santa Fe River as a resource of concern, its scenic and recreational values and importance as a tributary to the Suwannee River warrant MFL protection.

1.4 Relevant Water-Resource Values

As noted in Section 1.1, Chapter 62-40.473 F.A.C. provides policy guidance regarding establishment of MFLs. In particular, this section of Florida's Water Policy lists 10 specific environmental and water-resource values that should be considered in setting MFLs. Some are more relevant to the study area than others. As part of the District's MFL-establishment process, these environmental and water-resource values are evaluated through a matrix approach designed to identify potential target values that may be the limiting factors for the proposed MFLs (Table 1-1). This process serves to focus the evaluation and to shape the types of analyses needed to complete the MFL process. This ranking process is initiated after compilation and review of all available data. Each ranking is based upon the collective experience of the evaluation team in establishing MFLs. Target values are those that potentially have the highest probability of limiting the amount of water available for the water body without causing significant harm. As an example, if the fish passage criterion requires the most water flow to avoid significant harm to the water body, then that value becomes the limiting factor for the proposed MFL since all other values would require less flow to avoid significant harm. This value ranking procedure is flexible, and new target criteria can emerge during the evaluation process. In most cases, the initial determinations have proven to be accurate.

The relevance of each resource value and how it was incorporated into the establishment of MFLs for the Upper Santa Fe River is discussed below:

- a. Recreation in and on the water. This water-resource value is considered relevant to the Upper Santa Fe River. The upper, perennial reaches of the river are utilized for canoeing and kayaking. Public lands adjacent to the river provide access for hiking and other outdoor activities, and two state parks (O'Leno State Park and River Rise State Preserve) are utilized for hiking and other activities. In establishing MFLs for the Upper Santa Fe River, general information was considered regarding value of ecotourism, recreational fishing, and related activities, more specifically to ensure that these activities would not be significantly adversely impacted.
- b. Fish and wildlife habitats and the passage of fish. This water-resource value is considered relevant for the Upper Santa Fe River MFLs. Because of shoals and intermittent portions of the river, fish passage is of concern. Major emphases of studies conducted to support the Upper Santa Fe River MFLs were on the major habitats of the Upper Santa Fe, the opportunities for fish populations to interact during periods of low discharge (see Chapter 4 in this report), and how the hydrologic conditions structure habitats within the river system. To the extent possible with limited data, the habitats for the Oval pigtoe mussel were given emphasis.

- c. Estuarine resources. This water-resource value is not considered relevant for the Upper Santa Fe River. The Suwannee River estuary is far downstream from the Upper Santa Fe. Therefore, while discharge from the river contributes to the Suwannee River flow, the Upper Santa Fe plays a minimal direct role in Suwannee River estuary function.
- d. Transfer of detrital material. It is well established that a principal food base in aquatic and wetland ecosystems is decaying plant material, collectively termed “plant detritus” or simply detritus. Transport of this material from the river floodplain wetlands to the river channel is an important source of food material for riverine invertebrates. This water-resource value is relevant to the Upper Santa Fe River MFLs, and existing data in the scientific literature were used to assist in the determination of MFLs for the Upper Santa Fe River.
- e. Maintenance of freshwater storage and supply. This water-resource value refers to the long-term maintenance (i.e., sustainability) of water storage and supply capability of the water body. The result of the protection of this value by MFL establishment is to ensure that, over time, the ability of the water body to serve as a supply source for existing and future legal permitted users is available without causing “significant harm” to the water resource or ecology of the area. This water-resource value is considered relevant to Upper Santa Fe River MFLs and is considered in more detail in Chapter 3. Establishment of an MFL for a water body implicitly establishes potential availability of that water.
- f. Aesthetic and scenic attributes. This water-resource value is closely linked with the first one pertaining to recreation in that part of the recreational value of the Upper Santa Fe River is the aesthetic experience. Aesthetic and scenic attributes are considered relevant to the establishment of MFLs for the Upper Santa Fe River and were incorporated as an important characteristic along with recreation.
- g. Filtration and absorption of nutrients and other pollutants. This water-resource value is considered relevant to the Upper Santa Fe River MFL. The role of wetlands in maintenance of water quality is well established (Mitsch and Gosselink, 1986). By allowing for settlement of suspended particulates, uptake of nutrients by plants, and sequestration of heavy metals and other contaminants in sediments, wetlands help protect water quality. Data from the scientific literature on nutrient cycling and other biochemical functions of wetlands were taken into consideration in establishing MFLs, with the assumption that maintaining an acceptable level of ecological integrity for wetland ecosystems of the Upper Santa Fe River would maintain this particular function.
- h. Sediment loads. This water-resource value is considered minimally relevant to the Upper Santa Fe River MFL. Sediment transport is important in the maintenance of geomorphic features (bed forms and the floodplain) and their associated ecological communities in the river. General information from the literature on riverine fluvial dynamics was considered in setting the MFLs.
- i. Water quality. This water-resource value is considered relevant to setting MFLs on the Upper Santa Fe River. Surface-water quality effects on important aquatic habitats and fauna were considered. Because of the capture of stream flow by the swallets near O’Leno State Park (Figure 1-1), ground-water quality is also influenced by river-water quality. The main in-stream water-quality considerations were dissolved oxygen, color, and turbidity in relation to surface-water quality and flow into the aquifer system.

- j. Navigation. This water-resource value was not considered to be relevant to the Upper Santa Fe River MFLs, in that the system is not a waterway that supports commercial shipping or barge traffic. Passage by recreational vessels, canoes, etc. was considered under the “Recreation in and on the water” value, above.

Based on the preliminary screening (Table 1-1), the following resources were investigated to identify the limiting conditions for MFL development:

- Recreation on and in the water,
- Fish and wildlife habitats and the passage of fish,
- Maintenance of freshwater storage and supply,
- Aesthetic and scenic attributes, and
- Water quality.

Table 1-1
MFL DECISION MATRIX: UPPER SANTA FE RIVERS

Potential Criteria	Resource at Risk	Resource Value	Legal Factors	Rank	Available Data	Preliminary Data Analysis: Related to Flow?	Limiting Criterion?
<i>Notes</i>	1	2	3	4	5	6	7
Recreation in and on the water	2	2	3	5	1	Y	N
Fish and wildlife habitats and the passage of fish	3	3	3	9	2	Y	Y
Estuarine resources	NA	NA	NA	NA	NA	NA	NA
Transfer of detrital material	1	1	1	3	0	Y	N
Maintenance of freshwater storage and supply	2	2	1	5	2	Y	N
Aesthetic and scenic attributes	2	3	3	6	1	Y	N
Filtration and adsorption of nutrients and other pollutants	1	2	1	4	1	Y	N
Sediment loads	1	2	1	4	1	Y	N
Water quality	2	2	3	7	2	Y	N
Navigation	NA	NA	NA	NA	NA	NA	NA

Notes:

1. Evaluation of the level to which the resource is at risk. 1 = low risk, 2 = medium risk, 3 = high risk
2. Evaluation of importance of the criterion with respect to resource. 1 = low importance, 2 = medium importance, 3 = highly important
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. 1 = low, 2 = medium, 3 = high
4. Sum of columns 1, 2, and 3. Indicates overall importance of criterion to MFL development.
5. Evaluation of available data for use in development of MFL based on the criterion. 0 = no data available, 3 = abundant and relevant data available
6. Evaluation as to whether criterion is related to flow or level in resource. (Yes or No)
7. Evaluation as to whether criterion is potentially limiting for MFL development. (Yes or No)

TAB 2

2.0 Introduction to the Suwannee River Basin and Study Area

The Upper Santa Fe River is one of three major tributaries of the Suwannee River in Florida. As such, the following discussions begin with an overview of the Suwannee River Basin. The discussion then focuses on that part of the Suwannee Basin relevant to the establishment of the Upper Santa Fe River minimum flows and levels (MFLs).

2.1 Suwannee River Basin

2.1.1 Physical Setting of the Suwannee Basin

The Suwannee River Basin encompasses 9,950 mi² (25,770 km²) in Florida and Georgia (Figure 2-1; Franklin et al., 1995). It is the second largest river system in Florida by drainage area and mean annual flow (Table 2- 1). Major tributaries of the Suwannee River are the Withlacoochee and Alapaha Rivers, which are primarily located in Georgia, and the Santa Fe River in Florida. In total, approximately 57% of the Suwannee River Basin is in Georgia.

The Suwannee is a low-gradient stream, with an average gradient of 0.4 feet per mile. Table 2- 1 presents general characteristics of this complex river system.

Table 2- 1 Descriptive data on the Suwannee River and its major sub-basins (Franklin et al., 1995, and Berndt et al., 1996).

	Basin Area (mi²)	Total Length (miles)	Florida Length (miles)	Gradient (ft/mile)	Average Flow (ft³/sec)
Suwannee River**	9,950	235	206.7	0.42	10,540**
Withlacoochee River	2,360	120	30.0	2.32	1,714
Alapaha River	1,840	130	22.6	1.80	1,674
Santa Fe River	1,360	79.9	79.9	1.90	1,608
** - Includes the contributions of the Withlacoochee, Upper Santa Fe and Santa Fe sub-basins					

The physiographic setting of the Suwannee River Basin (Allan, 1995; Berndt et al, 1996), acting in conjunction with regional climatic characteristics, controls water chemistry and hydrologic characteristics of the river system. The river basin lies entirely within the Southeastern Coastal Plain (Berndt et al., 1996). Major physiographic provinces in Florida include the Northern Highlands and Gulf Coastal Lowlands physiographic regions (White, 1970; Ceryak et al., 1983; Figure 2-2).

Characteristics of the Northern Highlands include gently rolling topography, generally from 100-200 feet above mean sea level (msl). Soils typically range from sand to clayey sand. Clayey sediments in the subsurface serve as a base for a surficial aquifer and retard infiltration of rainwater into the underlying upper Floridan Aquifer System. The result is abundant surface-water features (streams, lakes and ponds) throughout the Highlands. Most of the Upper Santa Fe River Basin is located within the Northern Highlands Province.

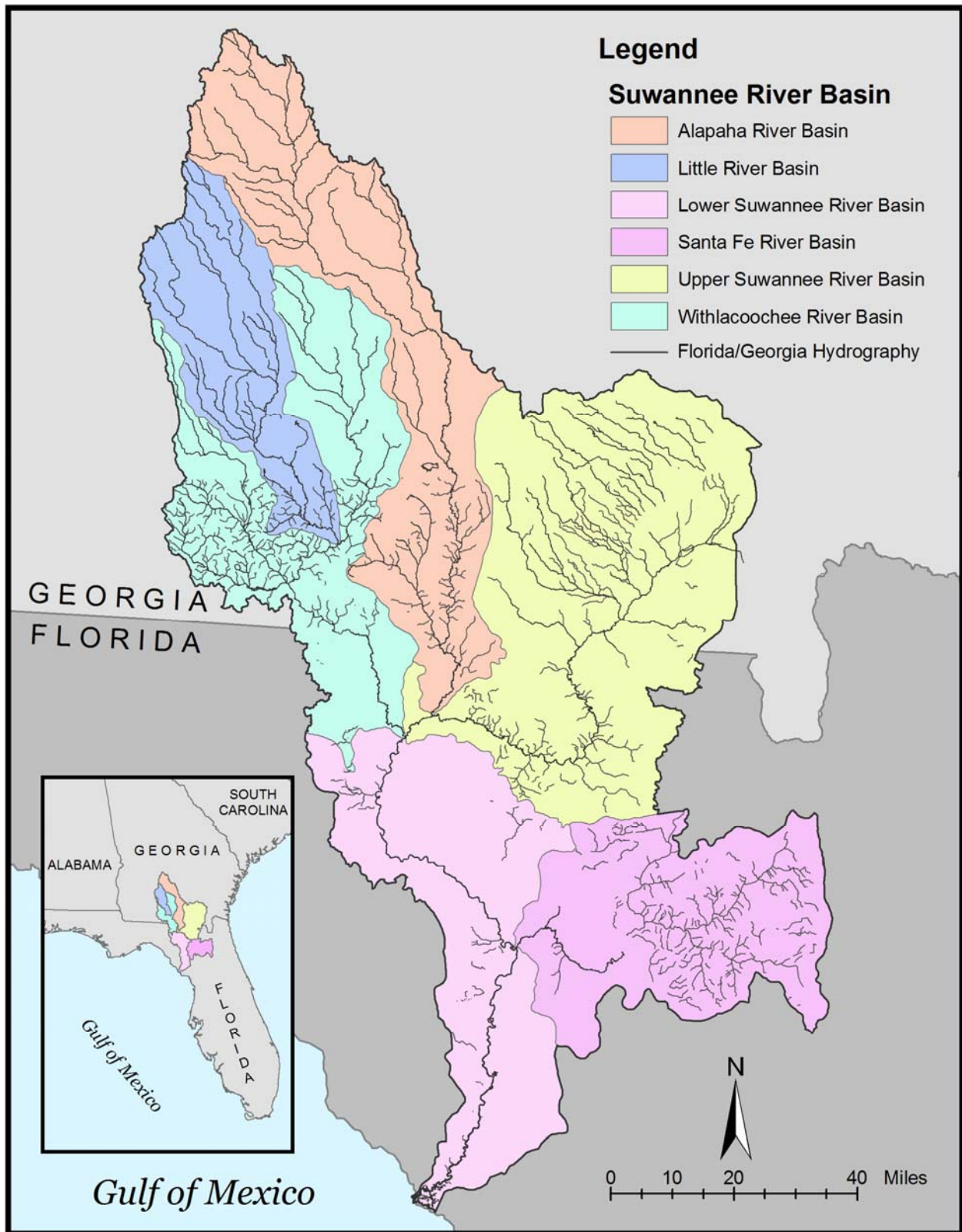


Figure 2-1 Suwannee River Basin in Florida and Georgia. Basins shown are USGS hydrologic units (Kenner et al., 1967).

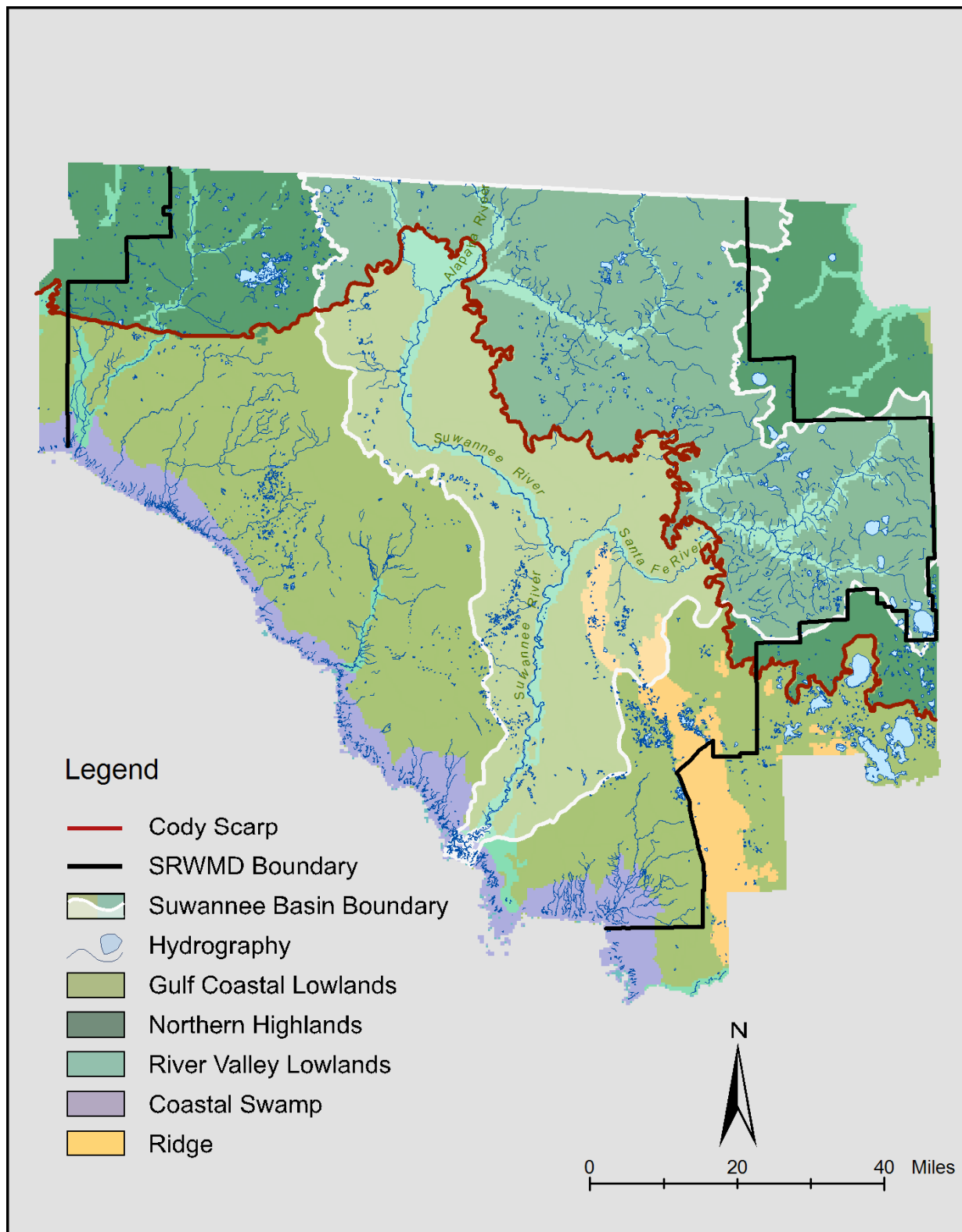


Figure 2-2 Physiographic regions in the SRWMD and regional hydrography in relation to the Suwannee River Basin in Florida. Data sources include White (1970); Ceryak et al. (1983); SRWMD data.

The Gulf Coastal Lowlands are characterized by elevations from sea level to about 100 feet above mean sea level (msl), relatively flat, karstic topography, and shallow sandy soils with muck in many wetland areas. Karst landforms are widespread in the lowlands, with abundant features such as sinkholes, sinking streams and springs, and a high degree of interconnection between surface-water and ground-water systems. Carbonate rock (limestone, dolostone) is at or near land surface throughout the Gulf Coastal Lowlands. Whereas, the surface-water features in the Northern Highlands reflect the water table of the surficial aquifer, those in the Gulf Coastal Lowlands represent the water table in the Upper Floridan Aquifer system.

A significant geologic region separating the two major provinces is the Cody "Scarp" or Escarpment (Figure 2-2; depicted as a line for illustrative purposes), the most persistent topographic break in Florida (Puri and Vernon, 1964). There can be as much as 80 feet of relief along the Scarp. It is a karst escarpment that has been highly modified by marine shoreline processes. The Scarp region is characterized by active sinkhole formation, large uvalas, poljes and lakes, springs, sinking streams, and river rises (Ceryak et al., 1983). During average and lower flows, the Santa Fe and Alapaha Rivers are completely captured by sinkholes as they cross the Scarp and re-emerge down gradient as river rises. The Withlacoochee River is partly captured as it crosses the Scarp near Valdosta, Georgia. Due to its size, the Suwannee River is the only stream that is not significantly captured by a sink feature as it crosses the Scarp. Upgradient of the Scarp, dendritic drainage networks have developed, with numerous small creeks branching off the upper Suwannee River and its tributaries (Figure 2-2). Below the Scarp, drainage is predominantly internal and streams that are tributary to the Suwannee River are rare.

Relict marine terraces are important features of the Suwannee River Basin in Florida. These terraces were established by different stands of sea level during the Pleistocene (and possibly Pliocene) Epoch. The terraces stair-step from the Gulf to the Northern Highlands, and the marine and coastal processes that created the terraces were responsible for deposition of the surficial sands that mantle the region (Healy, 1975; Schmidt, 1997). Inland and upward from the coast (Figure 2-3), these terraces include:

<u>Terrace</u>	<u>Approximate Elevation Range</u>
Silver Bluff Terrace	1-10 feet above mean sea level (msl)
Pamlico Terrace	8-25 feet msl
Talbot Terrace	25-42 feet msl
Penholoway Terrace	42-72 feet msl
Wicomico Terrace	70-100 feet msl
Sunderland Terrace	100-170 feet msl
Coharie Terrace	170-215 feet msl
Hazlehurst Terrace	215-320 feet msl

The terraces from Silver Bluff to Wicomico occur primarily in the Gulf Coastal Lowlands physiographic region, while the Sunderland, Coharie, and Hazlehurst terraces are found in the Northern Highlands.

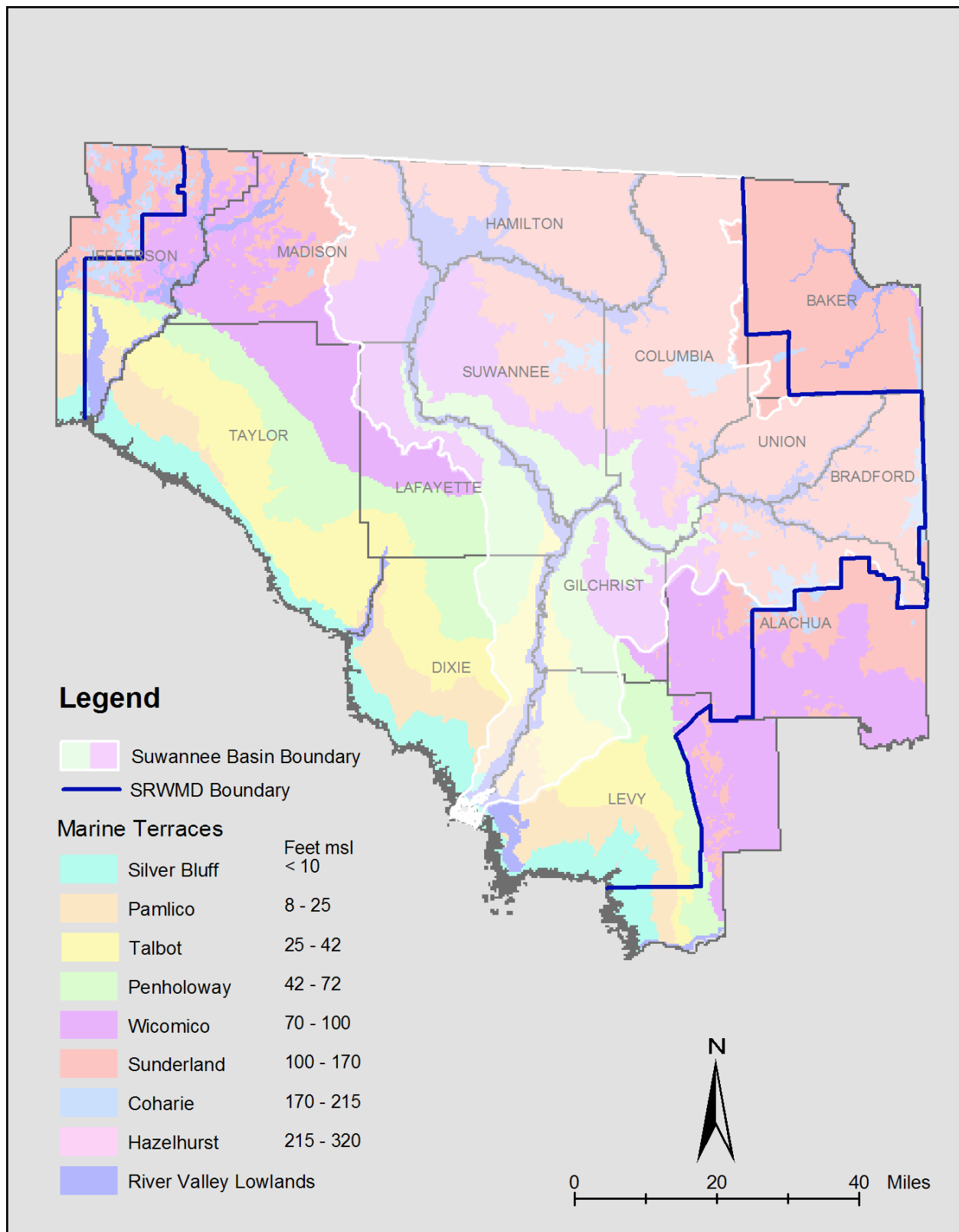


Figure 2-3 Marine terraces in the SRWMD in relation to the Suwannee River Basin. Data sources: USGS topographic GIS data and Healy, (1975).

2.1.2 Climate of the Suwannee River Basin

Climate is a description of aggregate weather conditions, including all statistical weather information for a region (Lutgens and Tarbuck, 1989). The climate of the Suwannee River Basin can be described as a mixture of warm temperate and subtropical conditions. Mean annual temperature in the Florida portion of the basin is 68.6 °F (NOAA, 2002). The maximum and minimum average monthly temperatures are 81.3 °F (in July) and 54.2 °F (January), respectively.

Precipitation and evapotranspiration (ET) are the climatic features most significant to long-term hydrologic conditions in the Suwannee Basin. Average annual rainfall in the basin is approximately 53.4 inches (NOAA, 2002), but this amount varies spatially from 46 inches in the upper basin to over 60 inches near the Gulf Coast (Figure 2-4). This precipitation gradient is largely controlled by the range in latitude of the basin (equivalent to approximately 200 miles) and the proximity of the lower third of the basin to the Gulf of Mexico (NOAA, 1972).

Year-to-year rainfall is rarely comparable to the average annual spatial differences. In the area covered by the NOAA North Florida Climatic Division, annual (calendar year) rainfall has varied from a low of 35.5 inches (1955) to a high of 77.9 inches (1964). Figure 2-5 shows the long-term (104 year) rainfall conditions for the north Florida region. The data were smoothed with a LOESS-type smoothing algorithm, as implemented in TableCurve 2D (AISN Software, 2000). As shown, the smoothed curve suggests that a drier period existed in the first half of the 20th Century, with wetter conditions subsequently prevailing through the 1990's.

The month-to-month variation in rainfall is as important to understanding the Suwannee's hydrology as annual rainfall. Figure 2-4 shows the typical monthly rainfall pattern at three locations in the Suwannee River Basin. As with annual rainfall, there is a gradient in seasonal climatic conditions from the northern to southern regions of the basin. The seasonal pattern is strongest in the south where a pronounced wet season occurs in the summer months (June through September). In this area, summer rainfall is associated with localized, convective thunderstorms or periodic tropical weather systems (hurricanes, tropical storms). The pattern weakens in the middle and northern parts of the basin (compare Usher Tower to the Jasper and Tifton insets, Figure 2-4). More northerly portions of the basin are characterized by lower average annual rainfall and a weakened seasonal pattern with precipitation that is more evenly distributed between the warmer and cooler months. Winter rainfall to the north is somewhat higher than to the south. Winter precipitation events are due to mid-latitude frontal weather systems with individual rainfall events that are usually more widespread.

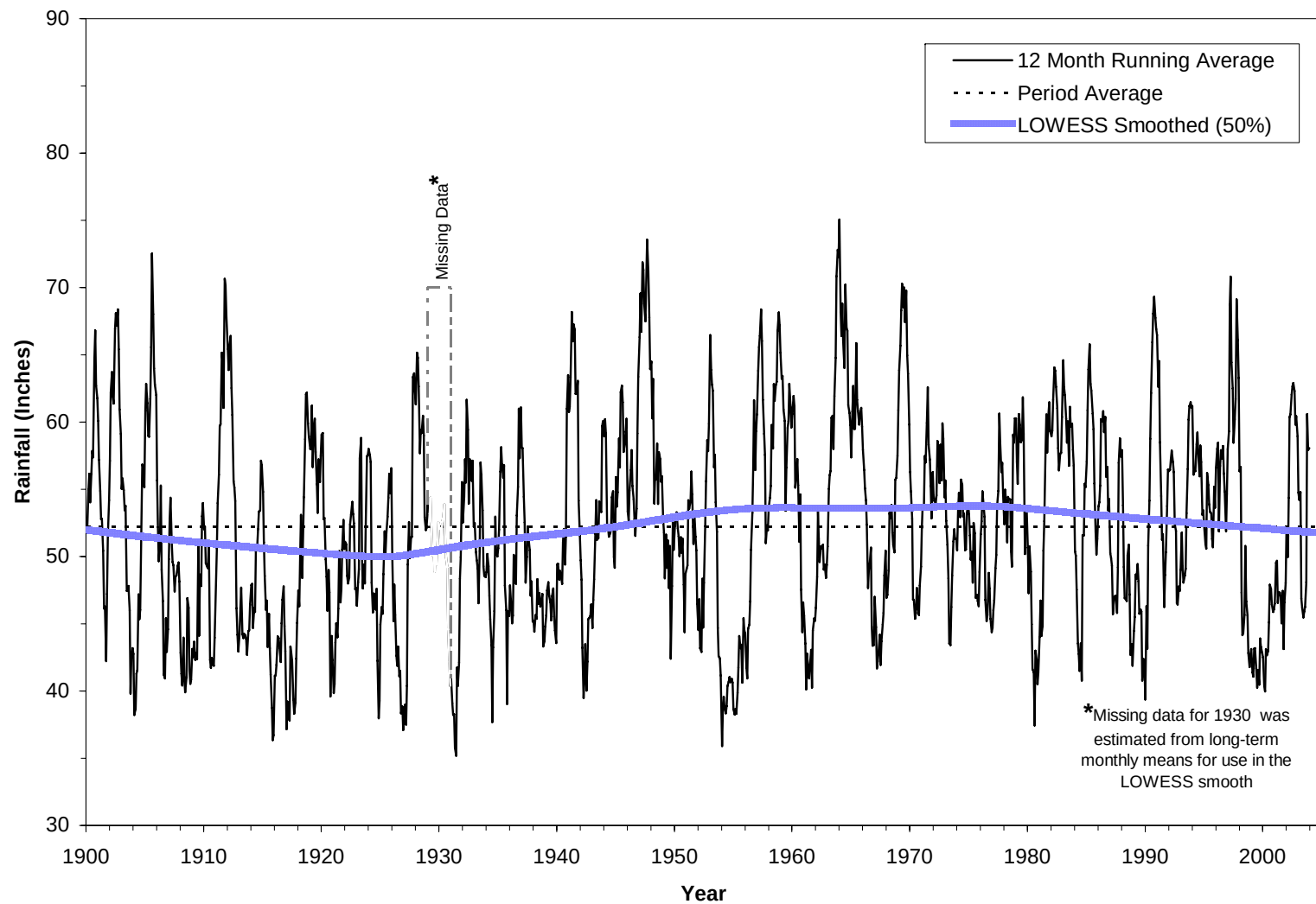


Figure 2-5 Twelve-month total rainfall for the north Florida Climatic Division for the period 1900 to 2003. Rainfall totals are running averages and are plotted at the first month of the 12-month period. Data: NOAA (2005).

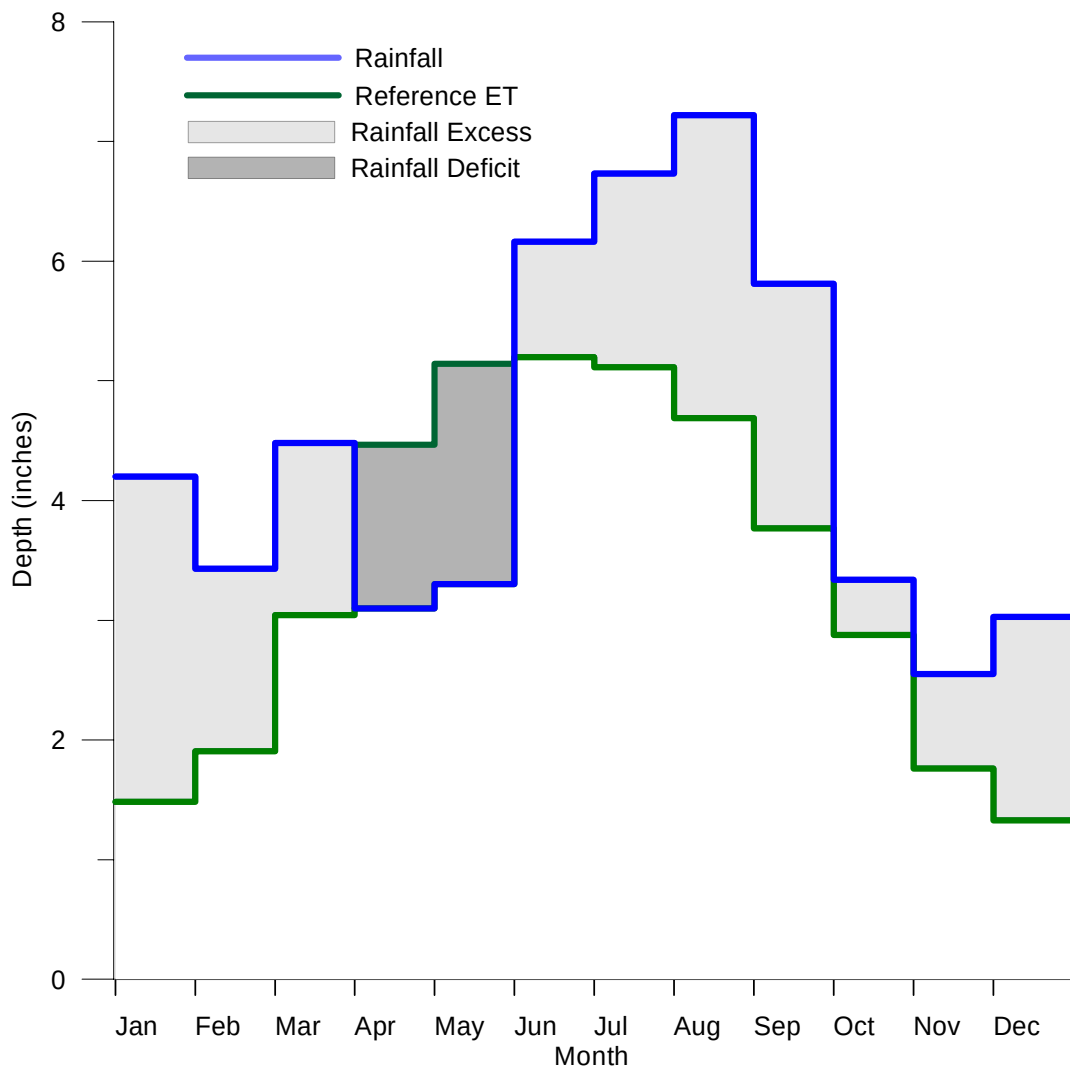


Figure 2-6 Mean monthly rainfall and reference evapotranspiration in the north Florida region. Data: NOAA (2002); Jacobs and Dukes (2004); Jacobs and Satti (2001).

Rates of evapotranspiration (ET) in the region have been estimated with a variety of direct measurements and/or computational methods. The average annual ET pattern shown in Figure 2-6 is estimated from computed reference ET for Gainesville (Jacobs and Dukes, 2004) multiplied by monthly crop coefficients for pasture (Jacobs and Satti, 2001). Reference ET is the potential ET from a short, well-watered grass crop. The resulting mean annual ET is 40.8 inches, with the largest mean monthly value of 5.20 inches in June and a minimum of 1.3 inches in December. The monthly rainfall values in Figure 2-6 are the North Florida Climatic Division means (NOAA, 2002).

Figure 2-6 indicates potential months of net rainfall surplus and/or deficit. During the cooler winter months, a water surplus can exist that serves to recharge the ground-water system. During late spring, a rainfall deficit can occur. Utilization of soil moisture (Fernald and Purdum, 1998) and late frontal systems can offset this effect. In the summer, the situation reverses with rainfall typically exceeding ET. However, for climate-affected activities, such as agriculture, the

scattered nature of summer convective rainfall events combined with excessive to well-drained soils often result in site conditions that require supplemental irrigation.

2.1.3 Geology of the Suwannee River Basin

This section describes the geologic and groundwater systems of the Suwannee River Basin.

Carbonate rock (limestone and/or dolostone), as much as 5,000 in feet thickness, exists in the subsurface of the Suwannee River Basin. These strata, which are primarily Tertiary in age, make up the Florida Platform. The Floridan Aquifer system is found within these strata and in similar strata in Georgia, the Carolinas, and portions of Alabama. The permeable portion of this carbonate-rock platform ranges from about 600 feet to 1,700 feet in thickness (Miller, 1982).

The extent and elevation of the upper surface of the limestone are depicted in Figure 2-7. The upper surface of the Tertiary limestone ranges from sea level to 90 feet msl throughout most of the basin. The limestone begins dipping to the northeast in the northeastern corner of the District. This dip is about 20 feet per mile and the top of the limestone reaches a depth of about 300 feet below sea level in the eastern corner of the District (Figure 2-7 and Figure 2-8). Figure 2-8 illustrates details of the elevation of the top of the Tertiary limestone within the District and the Suwannee River Basin.

Table 2- 2 presents the lithostratigraphic (geologic formation) as well as the hydrostratigraphic (aquifer system) nomenclature used to characterize the shallow geologic and hydrogeologic units in the District.

The uppermost geologic unit consists of the Pliocene- and Quaternary-aged (Pleistocene/Holocene) surficial sand deposits. These deposits are undifferentiated and may include shell and clay horizons. They were primarily formed by deposition associated with marine terraces and by erosion and chemical weathering of pre-existing strata.

Table 2- 2 Generalized lithostratigraphic column and aquifer systems in the Suwannee River Basin.

LITHOSTRATIGRAPHIC (ROCK) NOMENCLATURE			AQUIFER SYSTEM
SYSTEM	SERIES	FORMATION	
Quaternary	Holocene/Pleistocene	Undifferentiated Sand	Surficial
	Pliocene	Undifferentiated Sand	
Tertiary	Miocene	Hawthorn Group St. Mark's Formation	Intermediate
	Oligocene	Suwannee Limestone	Upper Floridan
	Eocene	Ocala Limestone Avon Park Limestone Oldsmar Limestone	
	Paleocene	Cedar Keys Formation	Mid-Floridan Confining Unit

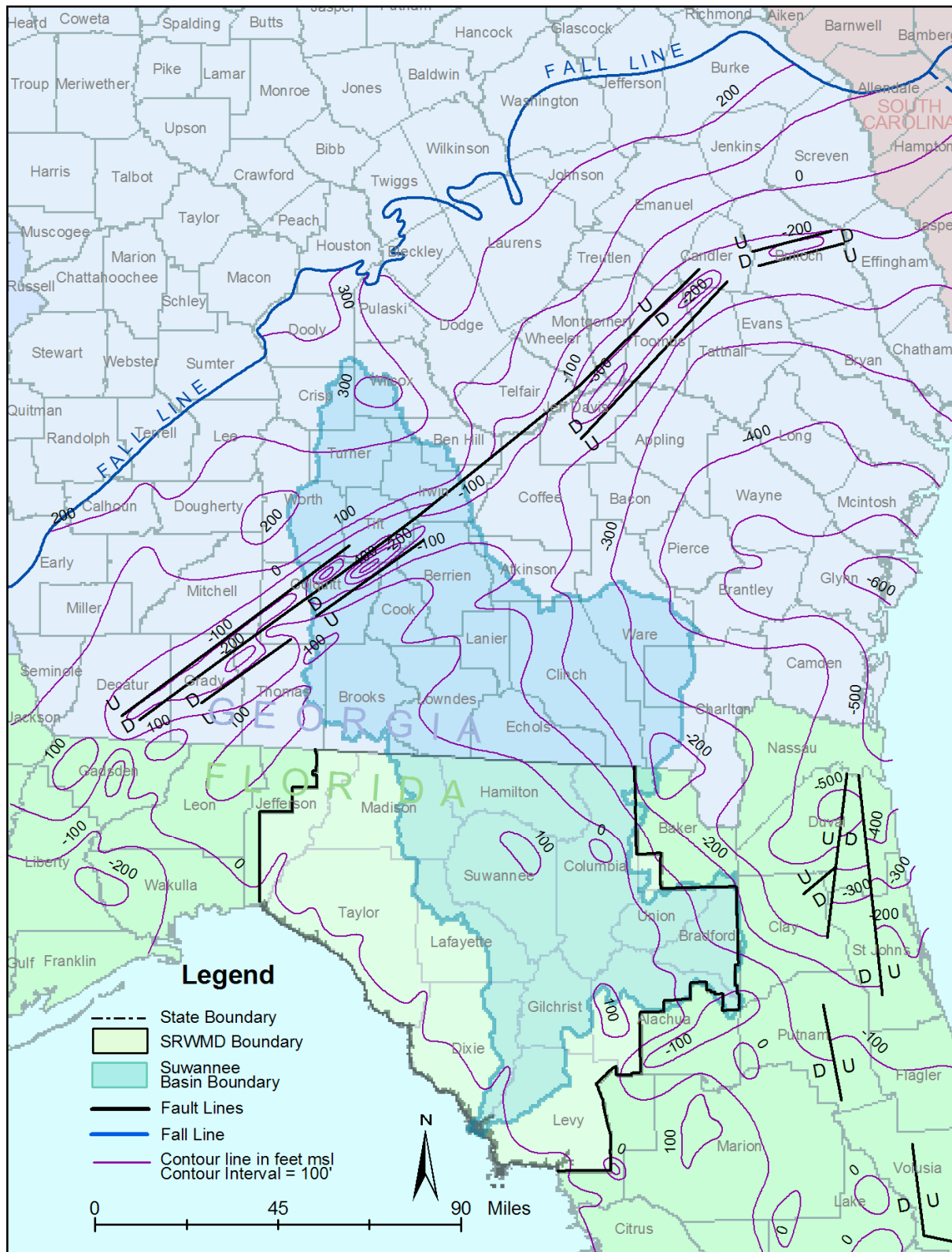


Figure 2-7 Extent of the limestone unit bearing the Floridan Aquifer system in the southeastern U.S. Fault line labels indicate uplift (U) and down throw (D). Adapted from Miller (1982).

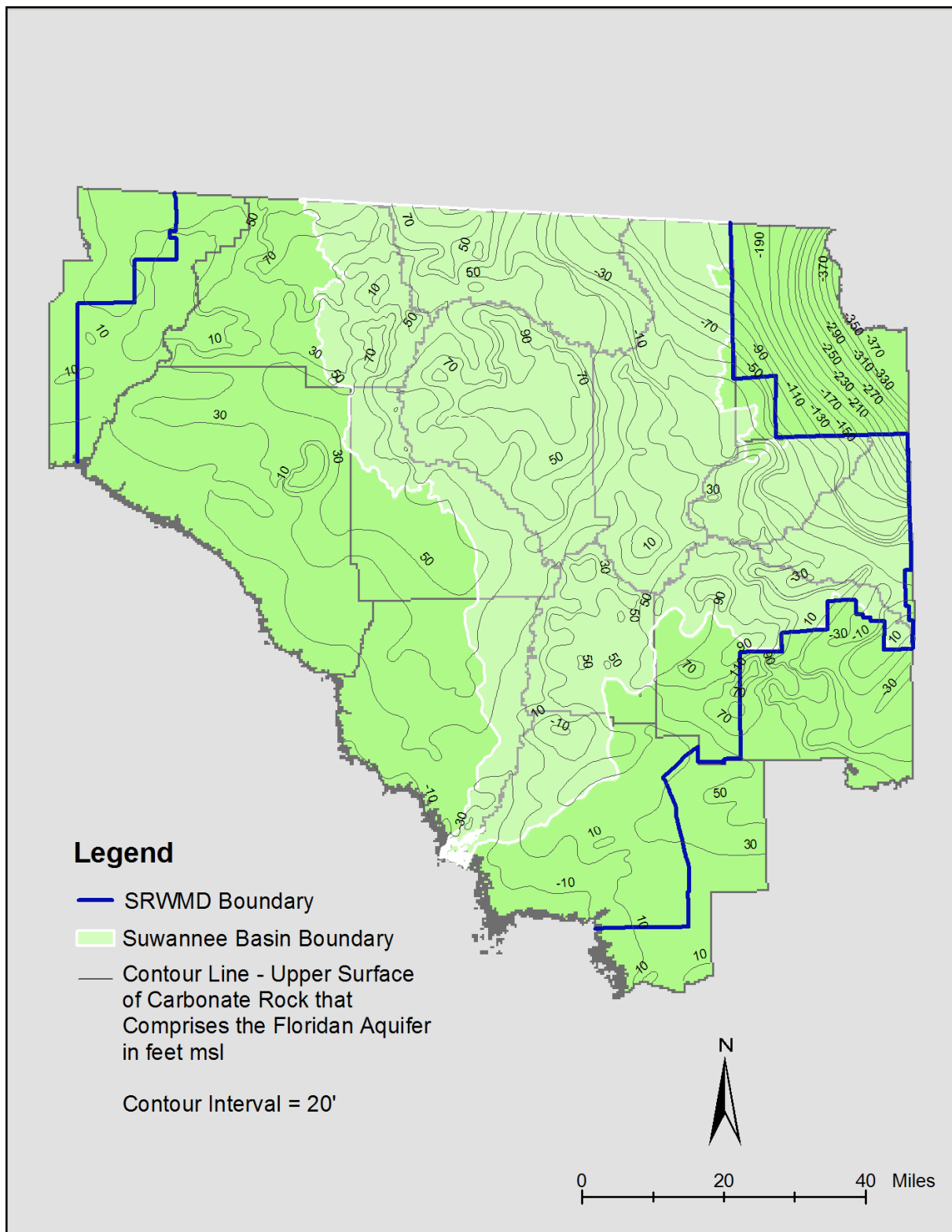


Figure 2-8 Elevation of the upper surface of the Tertiary limestone strata that constitute the Floridan Aquifer system within the District. Adapted from Allison et al. (1995).

The Miocene Hawthorn Group is present in the northern and northeastern portions of the District. It consists of interbedded clay, sand, and carbonate strata (Scott, 1988).

While the Miocene and Plio-Pleistocene strata are predominantly composed of siliciclastic materials (sand, clay, silt) interbedded with carbonate-rich strata, the underlying strata are predominantly composed of limestone and/or dolostone. These formations include (from top, or youngest, to bottom, or oldest) the Oligocene Suwannee Limestone, Eocene Ocala, Avon Park, and Oldsmar formations, and the Paleocene Cedar Keys Formation (Miller, 1997). These strata comprise the Upper Floridan Aquifer system and, where present, the Mid-Floridan Confining Unit. The Ocala Limestone, the uppermost section of the Floridan in the majority of the basin, is also the source of the majority of ground-water pumpage. The Suwannee Limestone overlies the Ocala in places and ranks second in water production.

Figure 2-9 is a geologic east-west cross section that depicts the relationships of these formations. From the cross section, it is evident that, in the west, the Suwannee Limestone overlies the Ocala Limestone from the Gulf to the Suwannee River. The Suwannee Limestone is more dolomitic than the Ocala Limestone within the District. East of the Suwannee River, the Suwannee Limestone is generally missing. Note that the Hawthorn Group overlies the Ocala and thickens as the Ocala dips to the east.

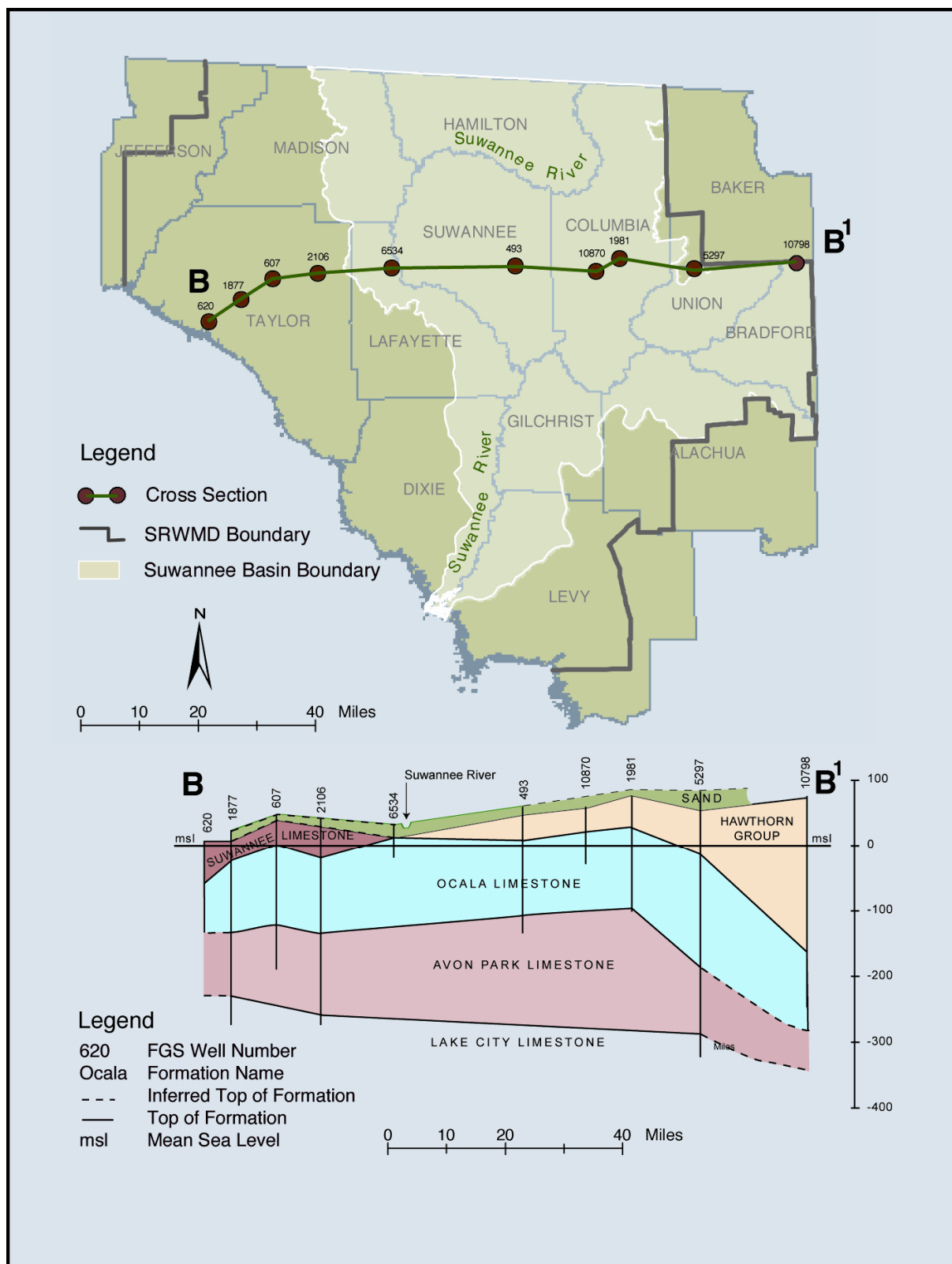


Figure 2-9 Generalized geologic cross section of the region. Adapted from Ceryak et al. (1983).

2.1.4 Regional Aquifer Systems

The uppermost aquifer within the District is the Surficial Aquifer System (Table 2- 2). The Surficial Aquifer occurs within the undifferentiated, Plio-Pleistocene, marine-terrace sands. This aquifer is only present in the northern and eastern parts of the District, where the underlying Hawthorn Group provides an effective aquitard, which minimizes recharge to the underlying aquifer. The Surficial Aquifer is found locally in the Northern Highlands (Tallahassee Hills west of the Withlacoochee River) Province and where water is perched over clays within the San Pedro/Mallory Swamp complex. The surficial aquifer is locally utilized for domestic well water. However because of dissolved organics, color, odor, and iron problems, water quality is generally poor and undesirable.

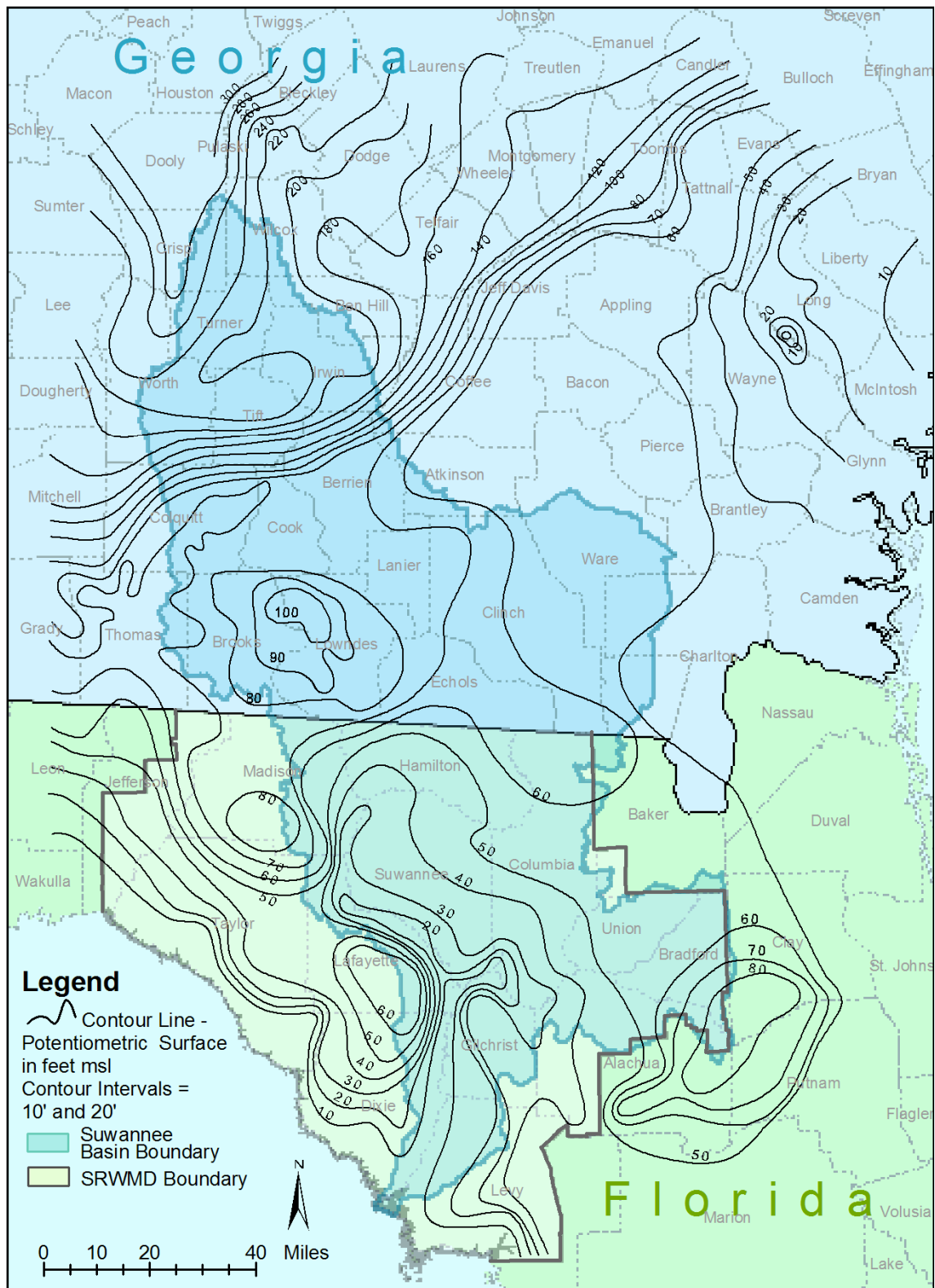
The Hawthorn Group (Table 2- 2) includes the Intermediate Aquifer and Confining Beds System (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Definition, 1986). The strata act primarily as aquitards within the District, but thin layers of gravel, sand, and carbonate rock form localized aquifers that are capable of producing water to small-yield wells.

The Upper Floridan Aquifer system extends throughout Florida, coastal plain Georgia and portions of the coastal plain in Alabama, North Carolina and South Carolina (Figure 2-7). The limestone unit begins along the Fall Line, where Coastal Plain sedimentary rocks lap against the metamorphic rocks of the Piedmont Province in central Georgia. The upper surface of the limestone dips easterly and southerly from the Fall Line in central Georgia. The rock surface elevation is about 300 feet above msl, along the Fall Line, and dips to elevations lower than 600 feet below msl in southeastern Georgia (Miller, 1982). Within the District, the top of the Upper Floridan Aquifer ranges from approximately -100 to +100 feet msl (Figure 2-8).

Figure 2-10 depicts the regional potentiometric surface for the Upper Floridan Aquifer system in the District in May 1976. The contour lines depict the elevation of the water table where the Floridan is unconfined and correspond to the elevation to which water would rise in wells where the aquifer is confined. The general direction of flow can be estimated by drawing flow lines that are perpendicular to the lines of equal potential from high to low potentials. The head pressure caused by elevation differences in the potentials drives movement of water in the aquifer. The average flow rate through the aquifer is estimated to be a few feet per day.

The Floridan Aquifer system is primarily composed of limestone and dolostone, and the movement of water through the aquifer is via both “conduit flow” (flow through fractures, caverns, etc.) and “diffuse flow” (flow through intergranular pore spaces in the rock). As such, water quality is generally excellent because of extensive dilution, chemical interactions with the rock matrix, and mechanical filtration.

The saltwater/freshwater transition zone is the wedge-shaped ground-water zone where fresh ground water flows seaward, up and over saline water related to the Gulf of Mexico. The transition zone is characterized by upward movement and mixing of fresh water with saline water. The position of the transition has been roughly delineated by sodium and chloride data along the Gulf of Mexico (Upchurch, 1990), and it has been defined by geophysics within a 20-kilometer radius around the mouth of the Suwannee River (Countryman and Stewart, 1997). Shallow aquifer water within about 5 miles of the Gulf Coast tends to have relatively higher concentrations of sodium, chloride and potassium; however, the chloride concentration does not exceed 25 mg/L, (Copeland, 1987). Well depths in the larger coastal communities range from 85 feet to 170 feet without a significant increase in sodium, chloride or sulfate concentrations.



The degree of confinement of the Upper Floridan Aquifer system is a critical factor in aquifer dynamics. Poorly confined areas tend to be rapidly recharged while highly confined areas may receive minimal recharge on an annual basis. The District has compiled a hydrogeologic classification based on the degree of confinement of the Floridan Aquifer (Figure 2-11) by combining and evaluating the physiography, geology, and hydrogeology (SRWMD, 1982). The classes of confinement are as follows.

Class 1 – Unconfined. Class I conditions exist where the Floridan is unconfined, is the only aquifer present, and the carbonate rock is at or near land surface. Where the limestone is not exposed, the Floridan is usually covered by porous sand. The limestone is porous and permeable and exhibits a high degree of secondary porosity that has been enhanced by a fluctuating water table. Due to the porous nature of the rock and sand, rainwater recharges the aquifer directly. Recharge rates in this region range from 16 to 31 inches annually (Grubbs, 1998). Surface-water features usually represent exposures of the water table in the unconfined Floridan Aquifer.

Class II - Semi-confined. Class II conditions exist where the Floridan Aquifer is semi-confined on top by discontinuous, leaky, clay beds. The Class II area in Gilchrist, Alachua and Levy counties coincides with the Waccasassa Flats, and the Class II area in Madison, Taylor, Dixie and Lafayette counties coincides with the San Pedro Bay/Mallory Swamp region. Because of reduced recharge, there are streams that drain the Waccasassa Flats and the San Pedro Bay, and there are lakes on the edges of these features. The Class II area that extends southeast from Suwannee County to Columbia County is the transition zone that parallels the Cody Scarp. This area is characterized by sinking streams and sinkhole lakes that periodically drain into the Floridan, and numerous steep-sided sinkholes. Recharge rates to the Floridan in this region are variable (Grubbs, 1998) and highly focused in location.

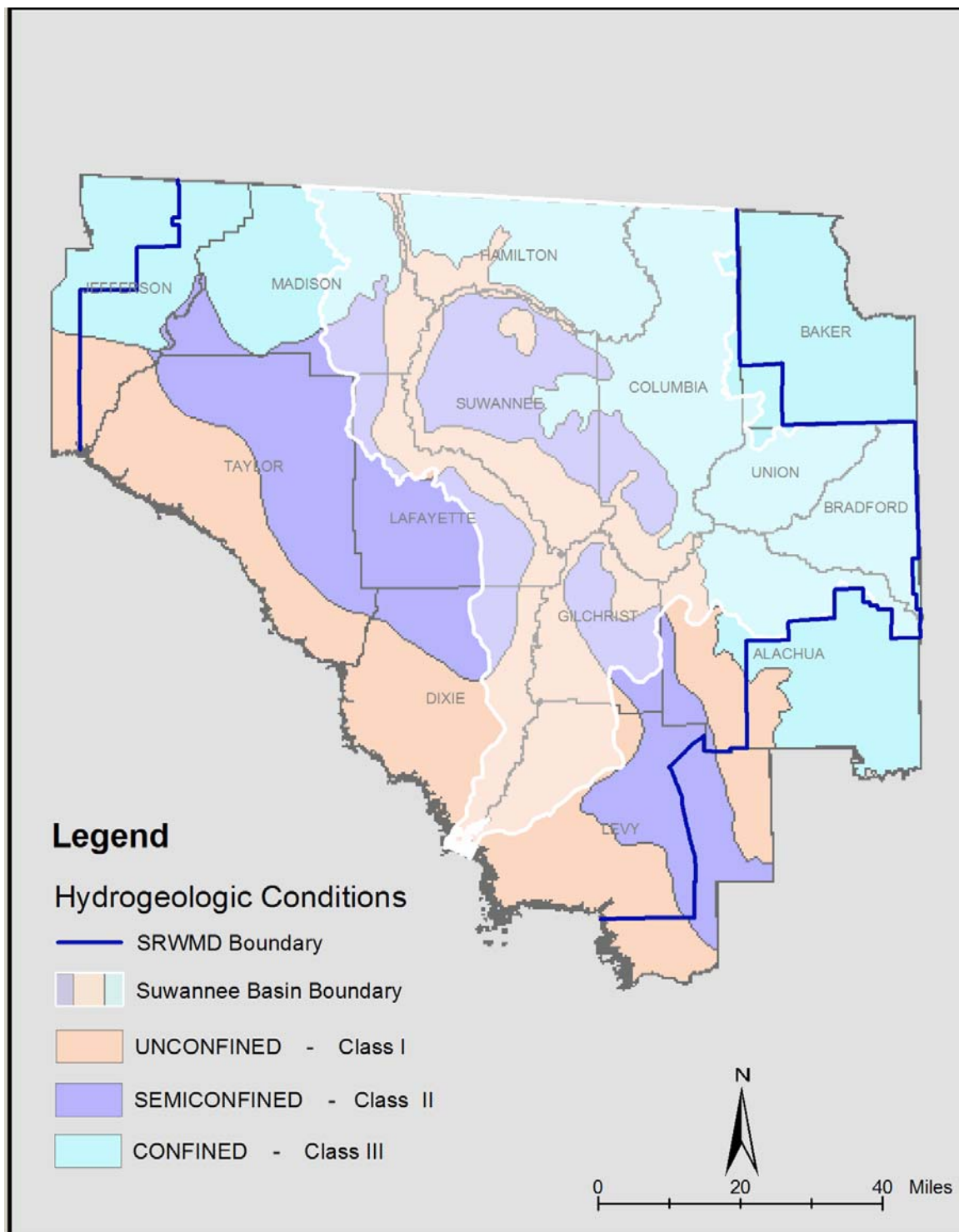


Figure 2-11 Confinement conditions of the Floridan Aquifer in the region. Adapted from SRWMD (1982).

Class III – Confined. The Class III area is characterized by deeper and confined portions of the Floridan Aquifer. Confinement is a result of at least 80 feet of Hawthorn Group clay overlying the Floridan. Recharge rates to the Floridan in this region average 12 inches or less annually (Grubbs, 1998). Confinement creates artesian conditions and water levels in wells that penetrate these aquifers usually rise to within 15 feet of land surface.

The Surficial Aquifer locally overlies the Floridan in the Class II and most of the Class III areas (Figure 2-11). The Surficial Aquifer consists of unconfined, saturated sand and ranges up to 55 feet in thickness. The water table is a subdued replica of the topography and is at, or near, land surface. It coincides with surface-water levels observed in the swamps, lakes, and ponds. Streams in these areas drain the surficial aquifer in addition to removing surface runoff. The Surficial Aquifer is recharged directly by rainfall and water level fluctuations are directly related to the amount of rainfall.

As suggested by Figure 2-11, recharge to the Floridan is highly variable. In Class III areas recharge is limited. The Cody Scarp is an area of generally moderate to high recharge owing to the presence of sinking streams that flow off the confined, Class III areas (i.e., the Northern Highlands) of the District and the presence of large sinkholes. A similar pattern exists in the transition from Class II to Class I regions west of the Suwannee River and in eastern Levy County (Figure 2-11). Recharge is generally high in the Class I area (Coastal Lowlands, etc.) because of the thin deposits that overlie the limestone of the Floridan and the presence of many sinkholes.

Areas defined by their high potentiometric surface elevations (Figure 2-10) vary in origin. In general, they reflect locations within the District where the hydraulic conductivity (permeability) of the Floridan is relatively low, and ground-water flow is, therefore, slow. The reduction in the ability to effectively drain water from the aquifer, results in the potentiometric highs in spite of the low relative recharge. Because of focused recharge on the Cody Scarp and the margins of other areas where recharge is limited, the margins of the potentiometric highs are supported by high recharge.

The total fluctuation of the Floridan Aquifer potentiometric surface in the basin ranges from zero to 40 feet in the Upper Santa Fe River Basin in the northern part of the Suwannee River Basin. Less than 15 feet of total fluctuation exists in at least two-thirds of the District, and less than 5 feet of total fluctuation occurs along the coast. Average annual fluctuation is less than 4 feet for approximately two-thirds of the District.

2.1.5 Land and Water Use in the Basin

2.1.5.1 Land Use and Population Characteristics

A summary of land cover/land use conditions (based on 1994 aerial photography) in the Florida portion of the Suwannee River Basin is shown in Table 2- 3. Major human land uses in the basin in Florida include managed pine forests and agriculture. Available information indicates that these two uses also dominate land cover in the Georgia portion of the basin (Berndt et al., 1996). Residential, commercial and industrial land uses collectively comprise less than 6% of the total land use in Florida. The other dominant land cover types in Florida are upland and wetland forests in a largely natural or relatively less-disturbed condition.

Population density in the basin averages 29.8 persons per square mile, which is well below the statewide average of 239 persons per square mile. The two largest private employment sectors are the forest products industry (pulp manufacturing, lumber milling, and related silvicultural activities) and phosphate mining and processing. The largest single source of employment in the region is government, with slightly over half of the total workforce in the region working for local, state, or federal governments. Major government employers include local school systems and county governments, the Florida Departments of Corrections and Transportation, and the federal Veterans Administration.

Most of the point-source discharges to the river are located in Georgia. These point sources are mostly municipal wastewater discharges. The three major point-source discharges in Florida are phosphate processing facilities, which discharge indirectly via Hunter and Swift Creeks on the upper Suwannee River; a pulp mill located in Clyattville, Georgia, which discharges to the Withlacoochee River in Florida via a pipeline which discharges at the mouth of Jumping Gully Creek; and a poultry processing plant, which discharges directly to the Suwannee River below the confluence with the Withlacoochee River.

Relative to other areas of Florida, urban non-point sources of water pollution are fairly low intensity and dispersed. The largest urban area in the drainage basin is Valdosta, Georgia, which lies adjacent to the Withlacoochee and Alapaha Rivers. In Florida, relatively urbanized areas along or adjacent to the river or its tributaries include the towns of White Springs, Dowling Park, Branford, Fanning Springs, Ft. White, and High Springs.

2.1.5.2 Water Use

Estimated water use in the District in 2000 was 314 million gallons/day (mgd; WRA, 2005), which equates to about 486 cubic feet per second (cfs). Water use patterns in the District somewhat mirror land use. Agricultural irrigation accounts for a large fraction of the existing and projected water use; although commercial/industrial is also a large overall use, principally due to phosphate mining and processing and once-through cooling water for power generation (Marella, 2004; WRA, 2005). By 2020 and 2050, agriculture and industrial water uses are predicted to continue being the largest uses in the District (WRA, 2005). Total water use in the District is projected to be approximately 547 mgd in 2020 (which equates to about 846 cfs), and 895 mgd in 2050 (1,385 cfs).

Spatial patterns in existing permitted water use are shown in Figure 2-12. This indicates that a large proportion of the permitted water use in the District is within the Suwannee River Basin. Total 2000 water use for counties entirely or partly within the Suwannee River Basin in Florida was approximately 259 mgd, which is 82% of the 314 mgd total District water use.

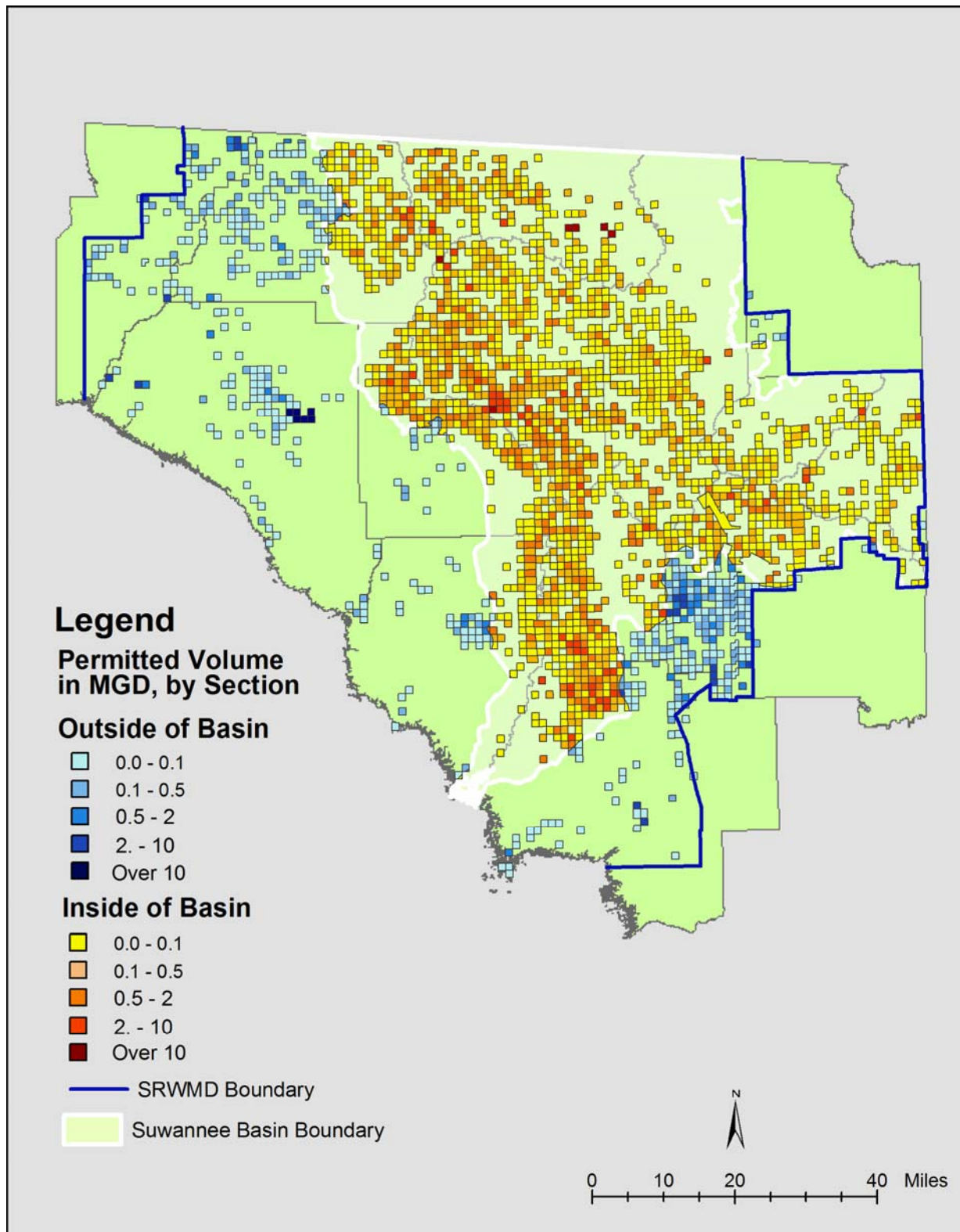


Figure 2-12 Map showing permitted water use patterns in the SRWMD. Each symbol represents the sum of the Average Daily Rate of Withdrawal (ADR) within each 1 mi.² section. Unpublished data from the District.

Table 2- 3 Land use/land cover conditions in the Florida portion of the Suwannee River Basin, based on 1994 NAPP aerial photography (Source: SRWMD data).

CATEGORY	ACRES	%
Residential (all types)	153,324	5.5
Commercial (shopping, office parks, malls, motels, campgrounds, etc.)	6,186	0.2
Industrial	3,296	0.1
Mining	39,278	1.4
Institutional (prisons, military facilities, schools, churches, hospitals, etc.)	4,031	0.1
Recreational (golf courses, race tracks, marinas, parks, etc.)	2,409	0.1
Other developed uses (land being developed, cleared land in urban areas)	22,992	0.8
Agriculture (pasture and row crops)	584,754	20.9
Agriculture (groves)	4,751	0.2
Agriculture-other (dairy, poultry, hogs, nurseries, aquaculture, etc.)	21,408	0.8
Non-forested uplands (shrubland, coastal scrub, etc.)	32,106	1.1
Forested uplands	426,120	15.2
Managed pine forests	1,001,541	35.8
Streams and lakes	33,017	1.2
Artificial water bodies (dug ponds, flooded rock pits, etc.)	5,822	0.2
Forested wetlands	420,265	15.0
Herbaceous wetlands	16,870	0.6
Disturbed lands	670	<0.1
Infrastructure (airports, power line corridors,	21,267	0.8

Table 2- 4 Summary of current and projected water use in SRWMD (Sources: SRWMD data; WRA 2005).

Water Use Category	Existing (2000)	Projected (2020)	Projected (2050)
Public supply (utilities)	15.8 mgd	25.2 mgd	40.5 mgd
Domestic (self-supplied)	15.4	25.4	41.2
Commercial/Industrial**	190.1	311.7	505
Agriculture	91.1	182.2	305
Recreation	1.5	2.3	3.6
TOTAL	314 mgd	546.8 mgd	895.2 mgd

** - Includes commercial, industrial, mining, and power generation

2.2 Suwannee River

2.2.1 Surfacewater Hydrology

The hydrology of the Suwannee River Basin is driven by climate, and it is modified by the topography, physiography, geology, and land cover characteristics of the drainage area. This section of the report describes rainfall/runoff relationships and spatial and temporal patterns in river flow. These patterns are the primary driving forces that shape the ecological characteristics of the river and estuary (Poff et al., 1997).

2.2.1.1 Annual Yield

The annual yield of the Suwannee River is the amount of water discharged to the Gulf of Mexico. Discharge for the Suwannee River is determined by river flow as measured by the U.S. Geological Survey (USGS) stream gaging program at the most downstream, long-term river gage (Suwannee River near Wilcox – USGS Station Number 02323500). Approximately, 97 percent of the basin drainage area is upstream of this gage. Mean daily discharge at Wilcox is 10,166 cfs (Table 2- 1), which is equivalent to 14.8 inches of annual runoff from the basin area (Franklin et al., 1995). Since the average annual rainfall across the basin is 53.35 inches (Section 2.2), about 28 percent of the mean annual rainfall is discharged as runoff to the Gulf of Mexico. The remainder of the rainfall, about 39 inches annually, is utilized either as ET or consumptive use. This estimate corresponds well with the ET estimate of 40.8 inches presented in Section 2.1.2.

Table 2- 5 Discharge Statistics of the Suwannee River at Wilcox (USGS Station Number 02323500), Levy County, Florida.

Metric	Annual (cfs)	Warm Season (cfs, May – October)	Cold Season (cfs, November – April)
Average	10,166	8,993	11,325
Standard Deviation	6,678	4,968	7,858
Maximum	84,700	40,400	84,700
75 th Percentile (P ₇₅)	12,600	11,300	14,600
Median	8,040	7,620	8,620
25 th Percentile (P ₂₅)	5,640	5,470	5,920
Minimum	1,070	1,970	1,070

Basin discharge varies over time as shown in Figure 2-13, which shows annual mean flows superimposed over daily flows at the Wilcox gage. Year-to-year variability in the annual means is quite evident. During the wettest year on record (1948), discharge was about two to three times the long-term average. Conversely, the driest recorded year (2002) was about 3 times less than the long-term average.

The frequency or return period of annual flow (also called the recurrence interval) is also of interest. The return period is defined as the average number of years between events for magnitudes equal to or greater than that specified. Figure 2-14 illustrates the flow duration curve from which exceedance probabilities were defined.

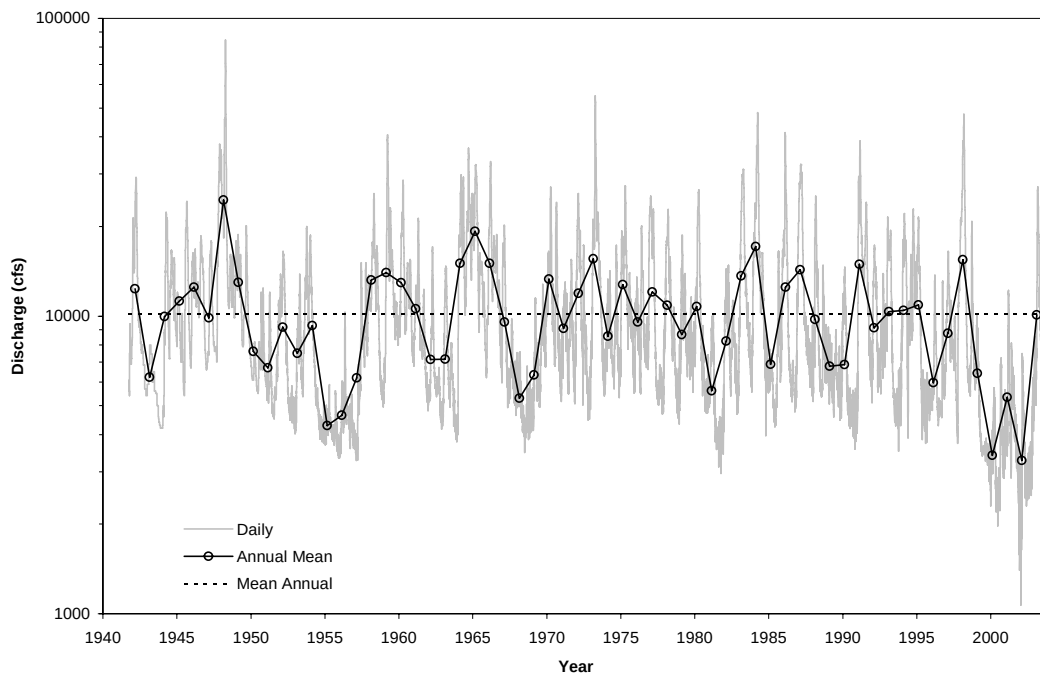


Figure 2-13 Daily and annual discharge (1942-2003) for the Suwannee River near Wilcox (USGS Station Number 02323500).

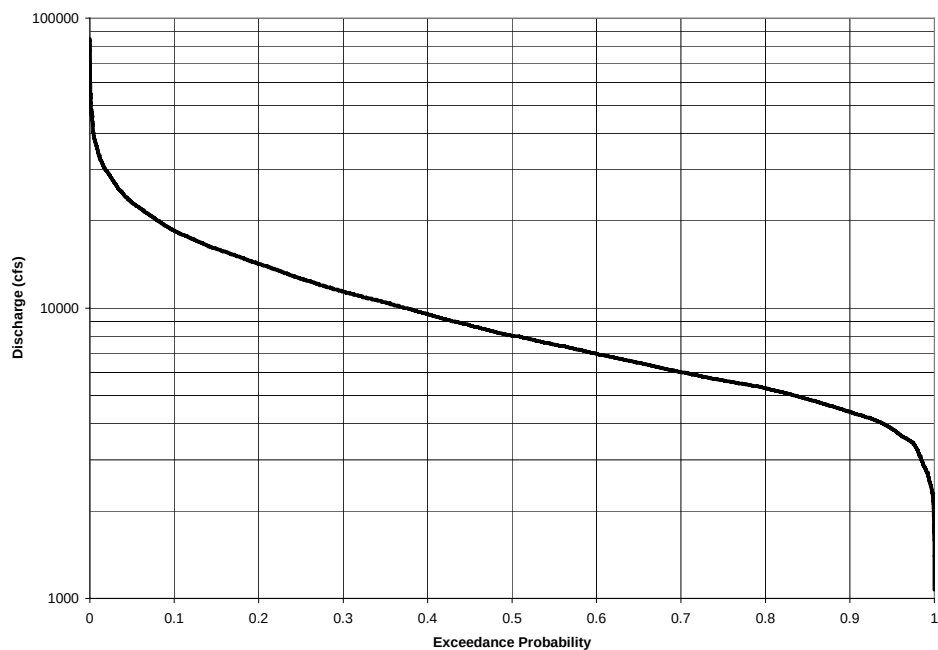


Figure 2-14 Discharge flow duration curve (1942-2003) for the Suwannee River near Wilcox (USGS Station Number 02323500).

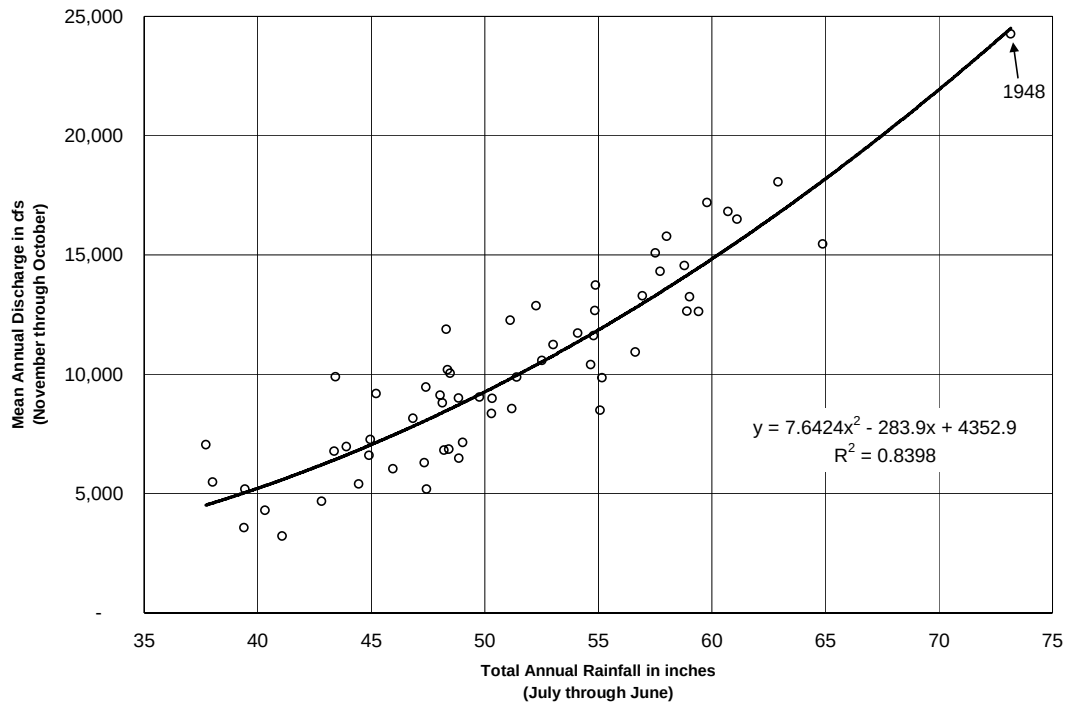


Figure 2-15 Relationship between annual rainfall and discharge for the Suwannee River near Wilcox (USGS Station Number 02323500).

The annual median discharge (exceedance probability of 50 percent; 2 year return period) is about 8,040 cfs. The 10 year drought condition (exceedance probability of 90 percent) specified in Chapter 373.0361(2)(a)(1) as a level-of-certainty planning goal for water supply needs is 4,390 cfs, or about 55 percent of the annual median discharge. Inter-annual variability in discharge is largely a function of annual rainfall (Figure 2-15). As shown in Figure 2-15, the best fit of annual relationship of discharge and rainfall is obtained when annualized discharge is lagged behind rainfall by approximately four months (annual rainfall determined from July through June and annual discharge from November through October data).

2.2.1.2 Spatial Flow Patterns

Annual discharge from a basin is related to drainage area (Linsley et al., 1982). The relationship between drainage basin area and unit discharge assists in understanding spatial patterns in stream flow. Figure 2-16 shows data from gages on the Suwannee River and tributaries with 10 or more years of record and illustrates that long-term annual stream flow throughout the basin varies linearly with drainage area. For main-stem river sites, annual discharge per unit area (unit discharge) varies from 0.76 to 1.58 cubic feet per second per square mile (cfs/mi), with an average of 1.09 cfs/mi for the entire basin as represented by the Wilcox gage (Table 2-6).

Flow is more variable in the upper portions of the Suwannee and Santa Fe River Basins (Figure 2-17A). Flow may vary by 2-3 orders of magnitude in these areas, where streams are primarily fed by runoff. Flow is higher but less variable in the lower reaches of these rivers (Figure 2-17B), varying generally within one order of magnitude. Part of this is a function of increasing drainage area contributing to flows at the downstream gage sites. For the Suwannee River

system, however, the reduced variability also results from the increased importance of ground-water inflow from the unconfined Floridan Aquifer System adjoining the middle and lower river reaches.

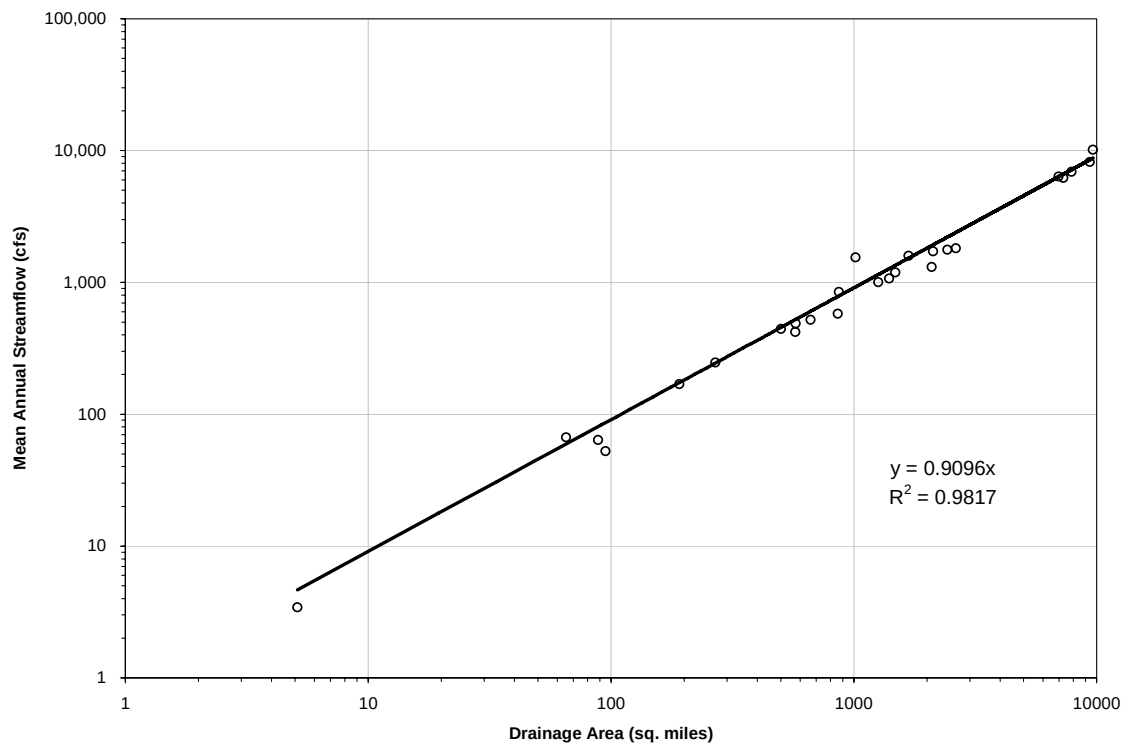
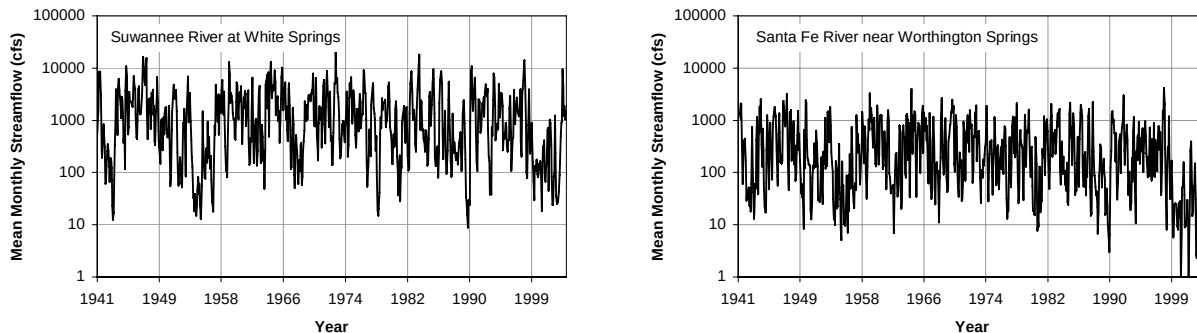


Figure 2-16 Relationship of drainage area and mean annual discharge for the Suwannee River Basin for gages with 10 or more years of systematic record. Data source: USGS.

Table 2- 6 Summary of hydrologic characteristics at flow gaging sites along the Suwannee River and its major tributaries (from Franklin et al., 1995 and Water Resources Data, GA, 1996). Data are annual summaries.

Station Name	Mean (cfs)	Median (cfs)	Max. (cfs)	Min. (cfs)	Unit Discharge (cfs/m)
Suwannee River at Fargo, GA	1,041	450	3,512	60	0.83
Suwannee River at White Springs, FL	1,840	727	6,810	155	0.76
Upper Santa Fe River at Statenville, GA	1,082	392	3,280	127	0.77
Withlacoochee River near Pinetta, FL	1,720	620	5,360	236	0.81
Suwannee River at Ellaville, FL	6,530	3,950	19,700	1,300	0.94
Suwannee River at Branford, FL	7,050	5,010	19,300	1,950	0.89
Santa Fe River at Worthington Springs, FL	437	143	1,160	55	0.76
Santa Fe River near Ft. White, FL	1,600	1,330	3,110	724	1.58
Suwannee River near Wilcox, FL	10,540	8,430	24,600	4,290	1.09

A. Stream hydrology - Upper Suwannee Drainage (above Cody Escarpment)



B. Stream hydrology - Lower Suwannee Drainage (below Cody Escarpment)

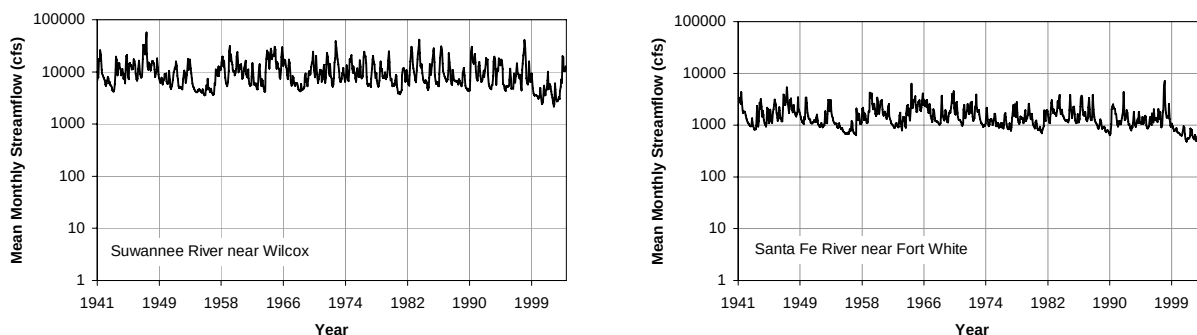


Figure 2-17 Mean monthly discharge at four USGS gaging sites on the upper (A) and lower (B) Suwannee and Santa Fe Rivers, reflecting stream hydrology in the upper and lower portions of the drainage (after Mattson et al., 1995).

2.2.1.3 Seasonal Flow Patterns

Heath and Conover (1981) recognized the existence of a “climatic river basin divide” in Florida that approximates the sub-basin boundaries of the lower Suwannee and Santa Fe Rivers (Figure 2-18). Streams that are north and west of the climatic divide, exhibit high flows in the late winter/early spring in regards to late spring and fall low flows with streams south of the climatic divide exhibiting high flows in the late summer/fall, with spring low flows. Streams lying along the climatic divide tend to exhibit a mixture of both of these patterns (a “bimodal” pattern of floods in the spring and fall). More recently, Kelly (2004) reconfirmed these hydrologic patterns in streams in Florida, which he termed the “northern river” pattern (spring flooding), the “southern river” pattern (fall flooding), and the “bimodal” pattern (both spring and fall flooding).

These temporal flow patterns are driven in part by climatic characteristics. The Suwannee River drainage falls in the transitional climatic area between the warm, temperate climate of the southeastern U.S. and the subtropical climate of the Florida peninsula. Higher, late winter/early spring rainfall and lower ET in the northern part of the basin (Section 2.1) drives the spring flooding; correspondingly, high summer rainfall in combination with tropical weather events creates the southern river flooding pattern in peninsular Florida.

Figure 2-19 shows mean monthly discharge for several long-term gages with at least 60 years of record in the Suwannee River Basin. The data are expressed as a proportion of the mean

total annual discharge. The distinct late winter/spring flood is evident, particularly at the sites in the northern portion of the basin. Data from the two gages located on the Santa Fe River drainage basin (Worthington Springs and Ft. White) exhibit more of the “bimodal” pattern, as they lie along the climatic divide discussed above.

Temporal patterns in discharge are also affected by geologic characteristics. Down gradient of the Cody Escarpment (Figure 2-2), the Suwannee River and its tributaries receive increasing amounts of ground-water discharge from the Floridan Aquifer system. This ground-water inflow results in substantially higher base flow, which proportionally “dampens” the more pronounced spring flood peak seen in the upper basin. This dampening effect results in a more uniform hydrograph (Figure 2-19 the Santa Fe River near Ft. White and Suwannee River near Wilcox gages).

2.2.1.4 Tidal River and Estuary

The Suwannee estuary consists of the lower reach of the river, two major branches (East and West Passes), Suwannee Sound, and the adjacent coastal waters stretching from Horseshoe Beach to the Cedar Keys (Figure 2-20). The approximate upstream boundary of the estuary extends about 10 miles upstream from the river mouth. Moreover, the tidally influenced reach of the river (the “tidal river”) extends further upstream. During 2002, when record low discharges occurred in the lower river, daily stage at the Suwannee River near Bell (USGS Station Number 02323000) at River Mile 55 varied by as much as one foot, depending on tidal phase and wind. More typically, the tidal range at Bell is 0.25 to 0.5 feet. McPherson and Hammett (1991) indicated that the normal tidal reach of the Suwannee extended upstream 26.7 miles (43 km) from the river mouth, or about 12% of the total length of the river.

Mean tidal range in the estuary is about 3.4 feet (McNulty et al., 1972; Tiner, 1993). Tides are mixed semi-diurnal, typically with two unequal high and two unequal low tides occurring each day, separated in time by approximately 6.2 hours (Leadon, 1985). Low tide in the estuary occurs first near Cedar Key, with the result that typical Suwannee fresh-water plumes flow southward along the coast (Leadon, 1985).

East and West passes divide the flow from the basin with about 64 percent discharging through West Pass and 36 percent through East Pass. In fact, flow in the passes is dominated by tidal effects, superimposed on net fresh-water discharge.

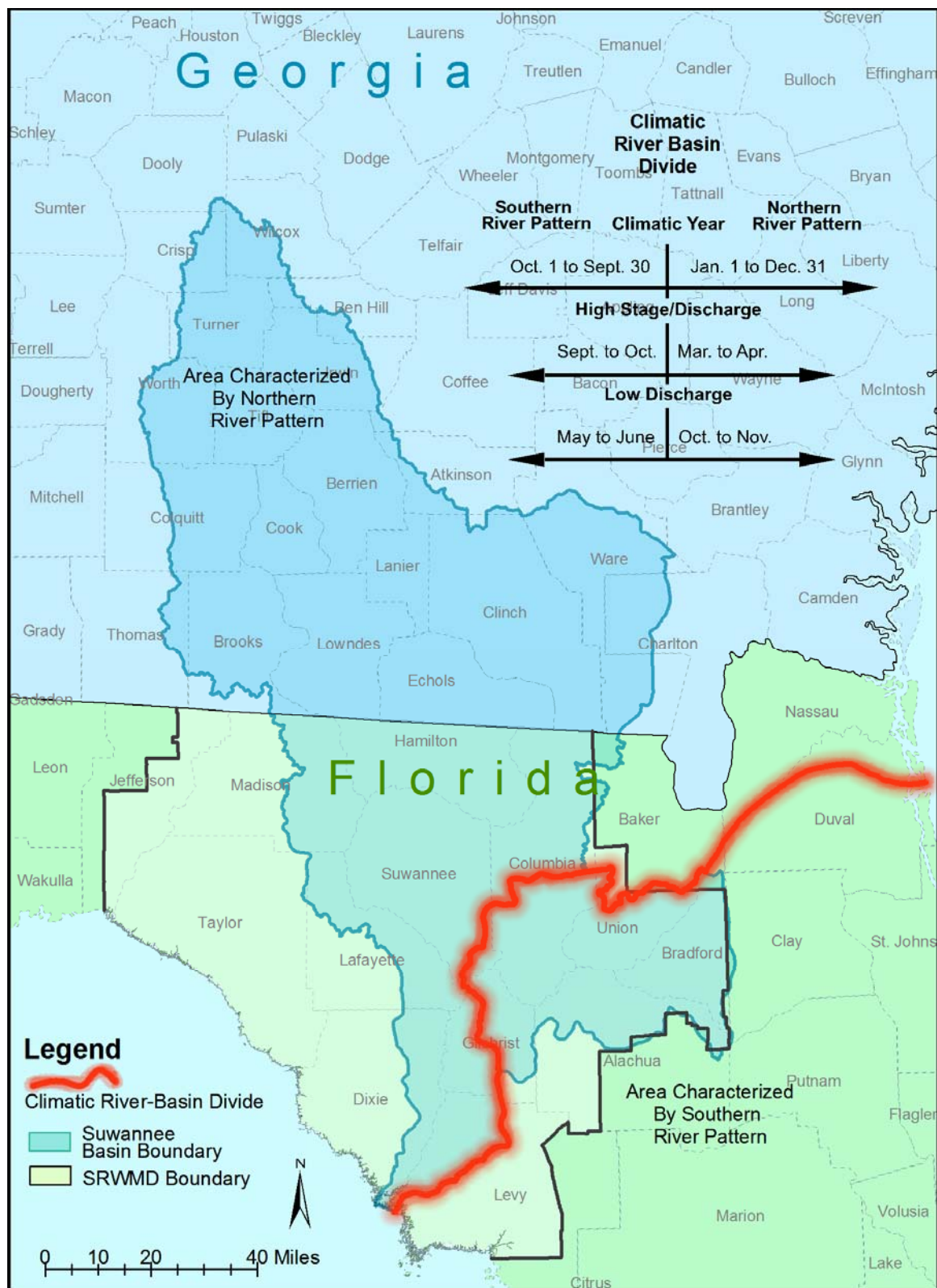


Figure 2-18 Locations of the climatic river-basin divide of Heath and Conover (1981) and the areas exhibiting different river discharge patterns from Kelly (2004).

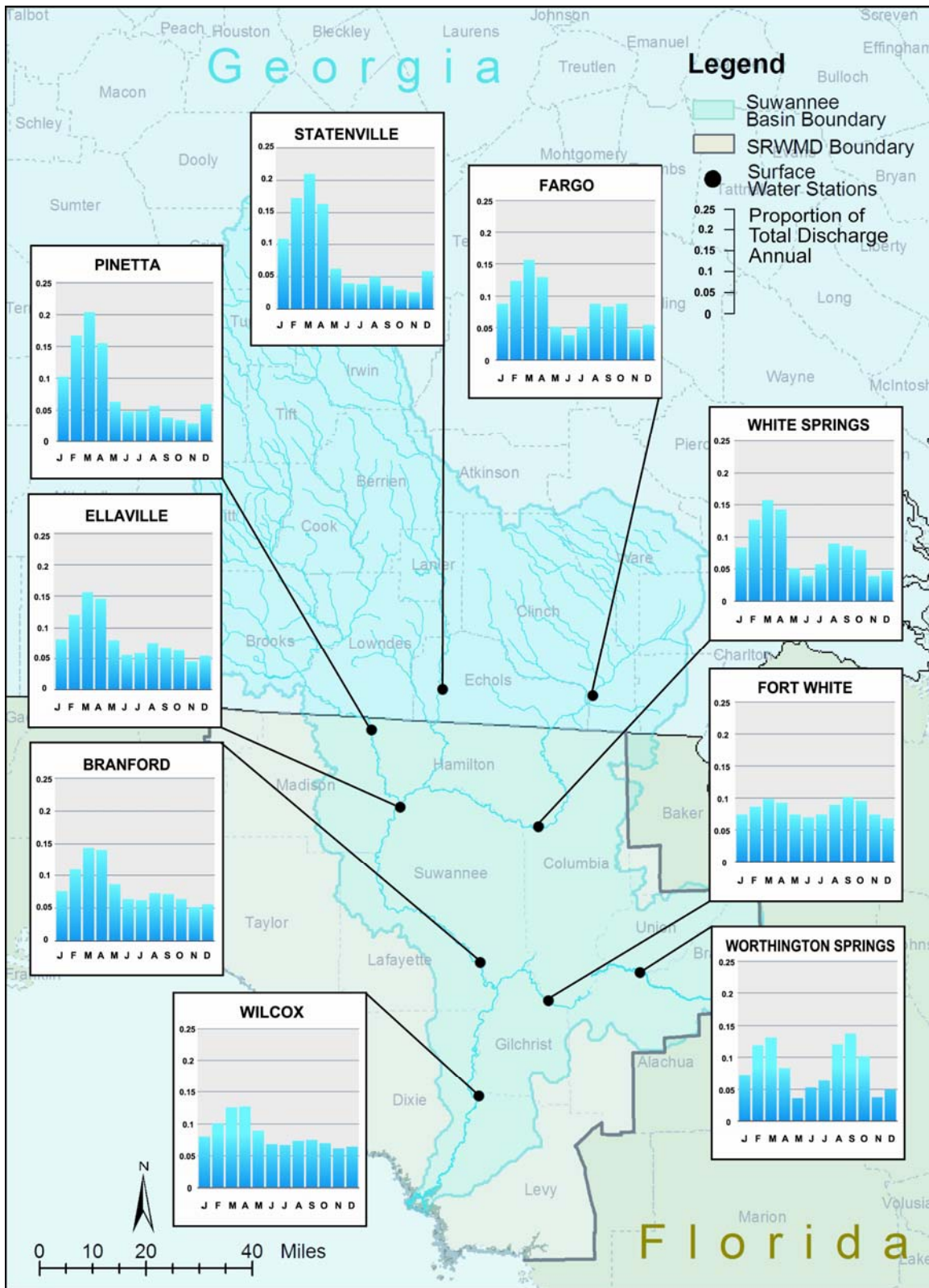


Figure 2-19 Gage locations and mean monthly discharge patterns at selected long-term surface water gages in the Suwannee River Basin. Discharge expressed as a proportion of mean annual discharge at each gage. Data source: USGS flow data.



Figure 2-20 Major features of the Suwannee estuary. Data sources: USGS aerial imagery and SRWMD map data.

2.2.1.5 Chemical Characteristics

Physiographic characteristics exert a strong influence on river hydrology and water chemistry in Florida. Because of the geologic and physiographic changes the Suwannee River experiences in its course through north central Florida, the river exhibits important longitudinal changes in water chemistry (Ceryak et al., 1983; FDER, 1985). The changes in these characteristics may best be described by recognizing five regions or “ecological reaches” of the Suwannee in Florida (Figure 2-21):

Reach 1. Upper River Blackwater
Reach 2. Cody Scarp Transitional
Reach 3. Middle River Calcareous

Reach 4. Lower River Calcareous
Reach 5. Tidal Riverine

Water chemistry in the Suwannee River changes in a unique way from upstream to downstream (Bass and Cox, 1985). The upper river (Reaches 1 and 2) is an acidic, blackwater stream, with waters of low mineral content (low hardness) and high color (Figure 2-22 and Figure 2-23). As the river progresses downstream (Reaches 3, 4, and 5), it receives increasing amounts of water from the Floridan Aquifer system, which changes river water quality to a clear, slightly colored, alkaline stream (Figure 2-22 and Figure 2-23).

These natural chemical gradients influence the ecology of the river in many ways. In terms of overall biological production, the upper river tends to be more oligotrophic, while the lower river is more productive.

Total organic carbon concentrations are higher in the upper reaches of the river (Hornsby et al., 2000), largely due to the dissolved and total organic carbon associated with the high water color. Nutrient concentrations (dissolved nitrogen and phosphorus) are low, generally near detection limits (Hornsby et al., 2000 and SRWMD data) in the uppermost reach (Reach 1). The low levels of nutrients in the upper reach contribute to its low biological productivity.

Dissolved nitrogen and phosphorus levels generally increase going downstream. Peak phosphorus levels are seen in Reach 2, partly as a result of the river crossing the phosphatic Hawthorn Group exposures and partly due to wastewater discharges from phosphate mining and processing.

Highest nitrate nitrogen levels are seen in the middle and lower reaches (Reaches 3, 4, and 5). A historical trend of increasing nitrate nitrogen has been identified in the middle and lower Suwannee River (Ham and Hatzell, 1996; SRWMD data). Much of this increase comes from ground water discharging via springs along the river corridor (Pittman et al., 1997; Katz et al., 1999). Areas of elevated nitrate nitrogen have been identified in the Upper Floridan Aquifer system in these regions (Hornsby and Ceryak, 2004). Sources of this nitrate nitrogen are diverse and include agricultural operations, wastewater sprayfields, areas with dense concentrations of septic tanks, and storm-water runoff to sinkholes.

The 2004 Florida Water Quality Assessment 305(b) Report (FDEP, 2004) revealed generally “good” water quality in the Suwannee River Basin. Portions of the lower river and most of the estuary were designated as “impaired” as they are candidates for total maximum daily load (TMDL) establishment. Portions of the upper Suwannee and Santa Fe sub-basins were indicated to be “potentially impaired.” These assessments appear to have been based on low dissolved oxygen (which is partly natural due to ground-water discharge), nutrients (discussed above), or elevated fecal coliform levels.

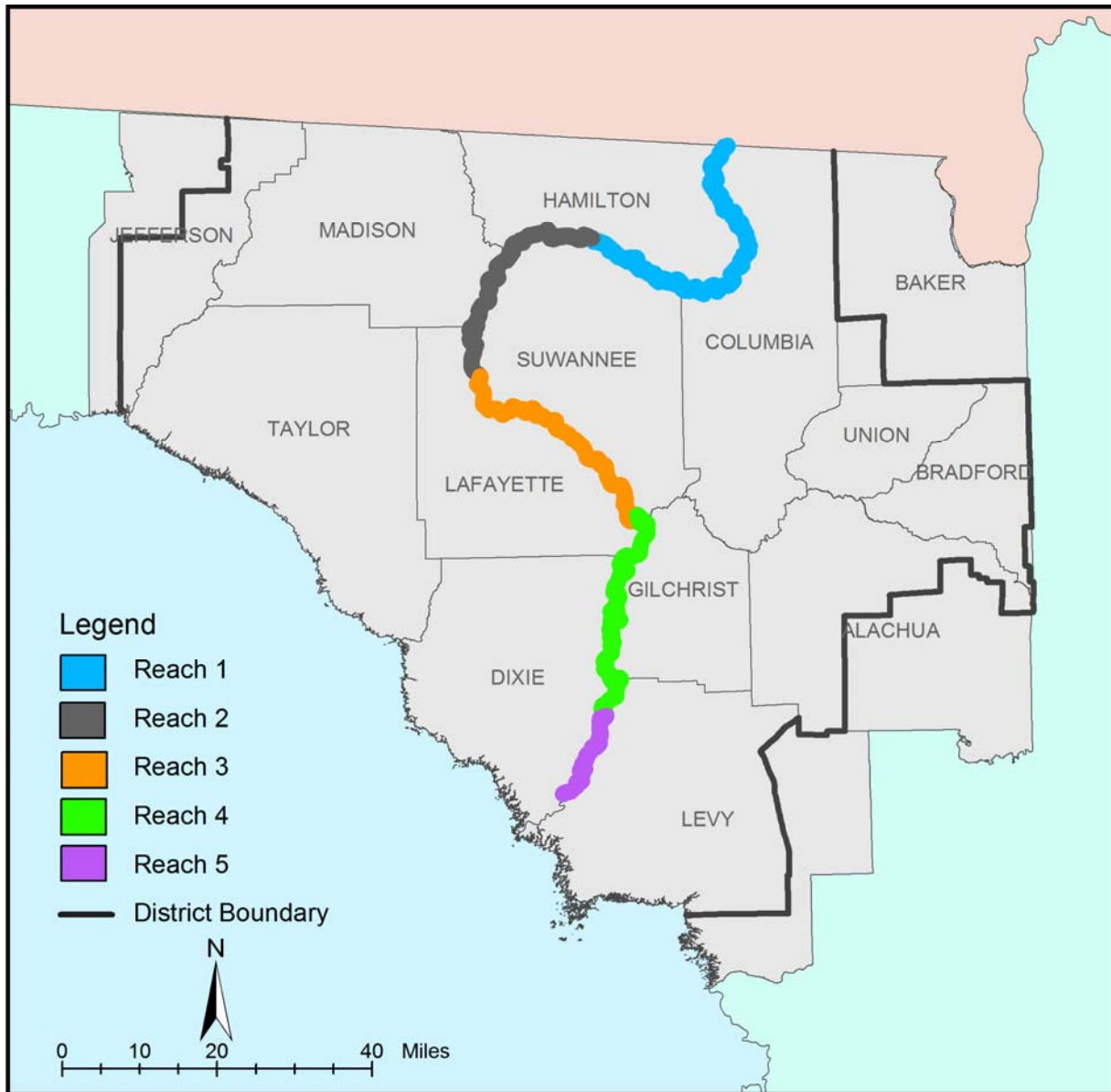


Figure 2-21 Map showing the “ecological reaches” of the Suwannee River in Florida. Source: SRWMD data and Hornsby et al. (2000).

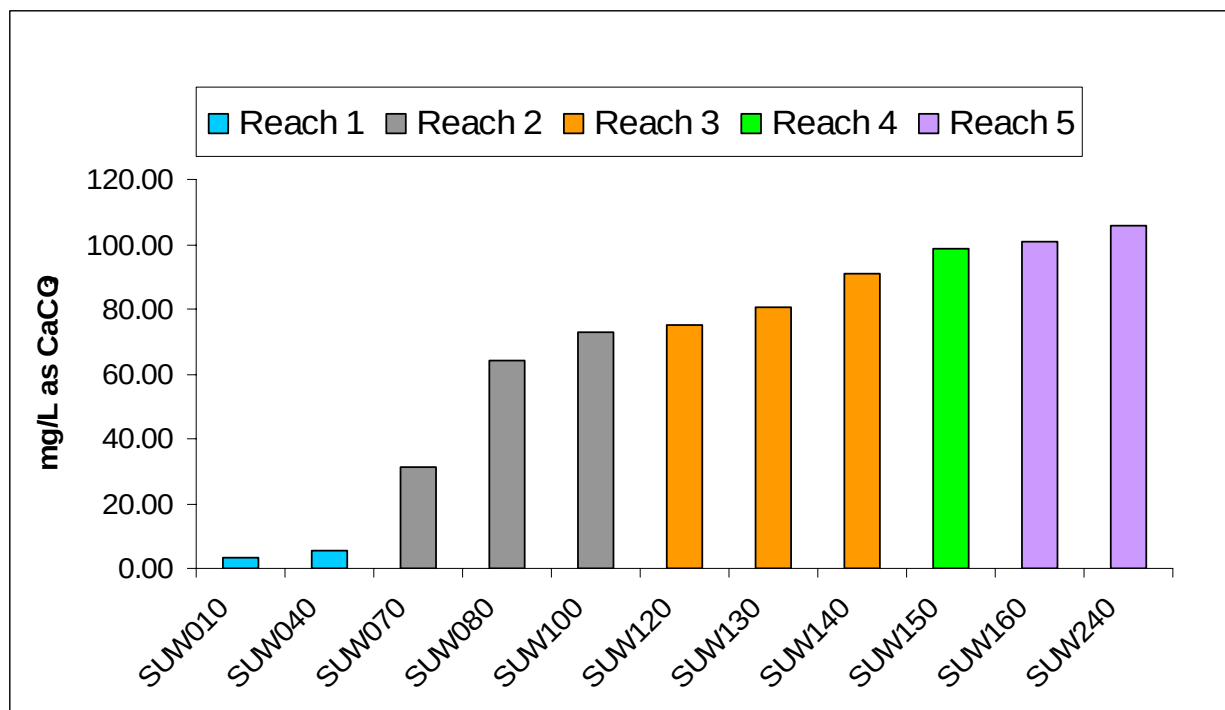


Figure 2-22 Plot of mean alkalinity (mg/L as CaCO₃) in the five reaches of the Suwannee River in Florida.

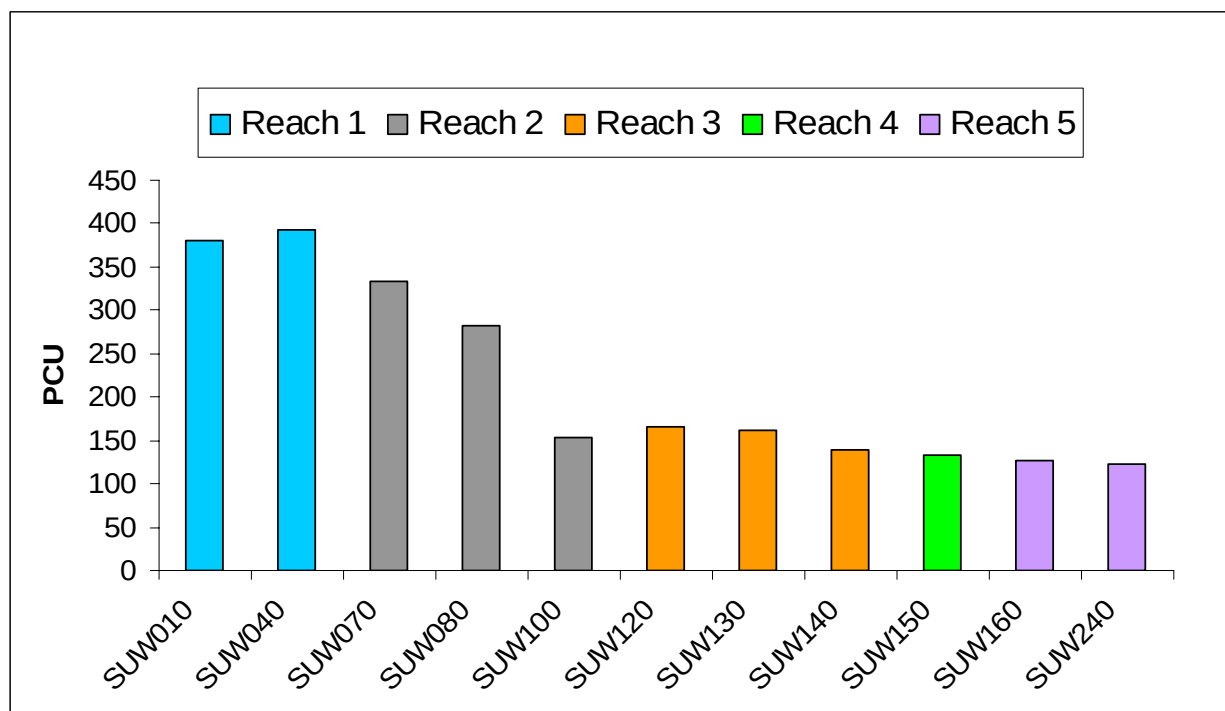


Figure 2-23 Plot of mean color (platinum cobalt units; PCU) in the five reaches of the Suwannee River in Florida.

2.2.2 Ecology

2.2.2.1 Aquatic and Wetland Communities

The physical setting described in the previous section is the framework that structures the ecological communities of the river ecosystem, including those communities in the river channel and on the adjacent floodplain. On a landscape scale, this linkage is recognized by delineating stream “ecoregions” (Griffith et al., 1994), which are regions within which lotic ecosystems exhibit generally similar morphology, hydrology, and water chemistry and thus support similar biological communities. The Suwannee River Basin in Florida lies within the following Florida ecoregions (Griffith et al., 1994):

- Southeastern Plains Ecoregion
 - Tifton Upland/Tallahassee Hills subregion
- Southern Coastal Plain Ecoregion
 - Okeefenokee Swamps and Plains subregion
 - Central Florida Ridges and Uplands subregion
 - Gulf Coast Flatwoods subregion
 - Eastern Florida Flatwoods subregion
 - Sea Island Flatwoods subregion

These ecoregions and subregions influence, and are influenced by, the hydrology, water chemistry, and biota of the major ecological reaches of the Suwannee River and its tributaries (as shown in Figure 2-21). An overview of each of these follows.

2.2.2.2 River Reach Ecology

2.2.2.2.1 Suwannee River Mainstem

Reach 1. Upper River Blackwater Reach. This reach lies within the Okeefenokee Swamps and Plains sub-region. The river channel in this reach (Figure 2-24) is more deeply incised into the landscape, as compared to downstream reaches, and this varies from 100-160 ft. in width. At base flows, depths in the channel are mostly < 3 ft. Shoals of exposed clay and shallow sandy runs are a prominent habitat feature in the river channel along this reach, and the river channel bottom is generally coarse sand or exposed clay. Well-developed surficial drainage in this part of the basin results in numerous small tributary creeks branch off the river channel. The river floodplain is inundated only by larger floods (i.e., floods with 5-10 year recurrence intervals), and flooding duration is often less than 30 continuous days. Plant communities in the floodplain are mostly upland forests, dominated by natural or planted pine, oaks, magnolia and hickory. Wetlands in the floodplain are mainly associated with the tributary creeks branching off the main channel, and these consist of cypress and deciduous hardwoods (swamp tupelo, river birch, ogeeche tupelo, and others). The Suwannee River in this reach is a classic, southeastern “blackwater” stream (see prior section). Benthic invertebrate communities are dominated by caddisflies and chironomids. Highest invertebrate densities are found in the shoal habitats (Bass and Cox, 1985). Fish communities include minnows, killifish, darters, sunfish and centrarchids such as the Suwannee bass and the largemouth bass.

Reach 2. Cody Scarp Transitional Reach. In this reach, the river is mostly within the Tifton Uplands/Tallahassee Hills subregion. The river channel is still incised into the landscape and varies from 130-260 ft. in width (Figure 2-24). The channel bottom is still dominated by shallow water habitat, with depths 3-6 ft. or less, and numerous areas of sandy or rocky shoals. Channel bottom substrates include medium to coarse sand, exposed clay, and rock (limestone,

chert, dolostone). Some of these shoal areas, in the region of the Upper Suwannee River, are critical spawning habitats for the Gulf sturgeon (Sulak et al., 2001). In this region, the river crosses the Cody Scarp (Ceryak et al., 1983). This is a region with numerous sinkholes. Karst features are evident in the river floodplain, which produces high plant diversity due to the topographic variation. This reach includes the confluences of the Alapaha and Withlacoochee rivers with the Suwannee River mainstem. Limestone outcrops are prominent along the river channel throughout this reach and springs discharge ground water to the river. Major springs include White, Suwannee, Holton Creek Rise, Alapaha Rise, Ellaville, SUW923973 (Steveson) and Lime. Benthic invertebrate communities are dominated by caddisflies, chironomids, and mayflies. Fish communities include minnows, killifish, darters, sunfish and centrarchids such as the Suwannee bass and the largemouth bass.

Reach 3. Middle River Calcareous Reach. The third reach of the river exhibits a number of changes reflecting greater flows and a larger drainage area. This reach crosses the Central Florida Ridges and Uplands subregion and the Gulf Coast Flatwoods subregion. The river channel is wider (260-330 ft. or more), with alternating deeper pool areas interspersed with rocky shoals. Some limestone crops out along the river channel. The floodplain is inundated more frequently, and, in some areas, alluvial features indicating this are seen (e.g., berm and swale topography; Fig. 2-27). Floodplain plant communities are largely high-terrace bottomland hardwood communities, with live oak, laurel oak, blue beech, American elm, swamp chestnut oak, and bald cypress. Benthic invertebrate communities are dominated by chironomids, mayflies, caddisflies and snails. Major springs include Troy, Charles, Telford, Peacock, Lafayette Blue, Royal, and Little River.

Reach 4. Lower River Calcareous Reach. Reach 4 of the Suwannee River begins at the Santa Fe River confluence and lies entirely within the Gulf Coast Flatwoods subregion. In this reach, the river channel is wide (400-500 ft.), with a deep-water channel. Little to no shoals occur in this reach. The river channel substratum includes coarse sand and exposed limestone. The floodplain has numerous topographic features caused by fluvial action, including relict levees, oxbow lakes, and high and low terraces (Figure 2-24). Floodplain plant communities include a diversity of types, ranging from swamps to bottomland hardwoods. Swamps are dominated by bald cypress, water tupelo, planer elm, swamp privet, and pop ash. Bottomland hardwood forests include some of the above, plus live oak, laurel oak, American elm, water hickory, overcup oak, blue beech, and other broadleaf deciduous hardwoods. Major springs include Rock Bluff, Hart, Guaranto, and Otter. Benthic invertebrate communities are similar to those in Reach 3. Fish communities include minnows, killifish, darters, sunfish and centrarchids such as the Suwannee bass and the largemouth bass.

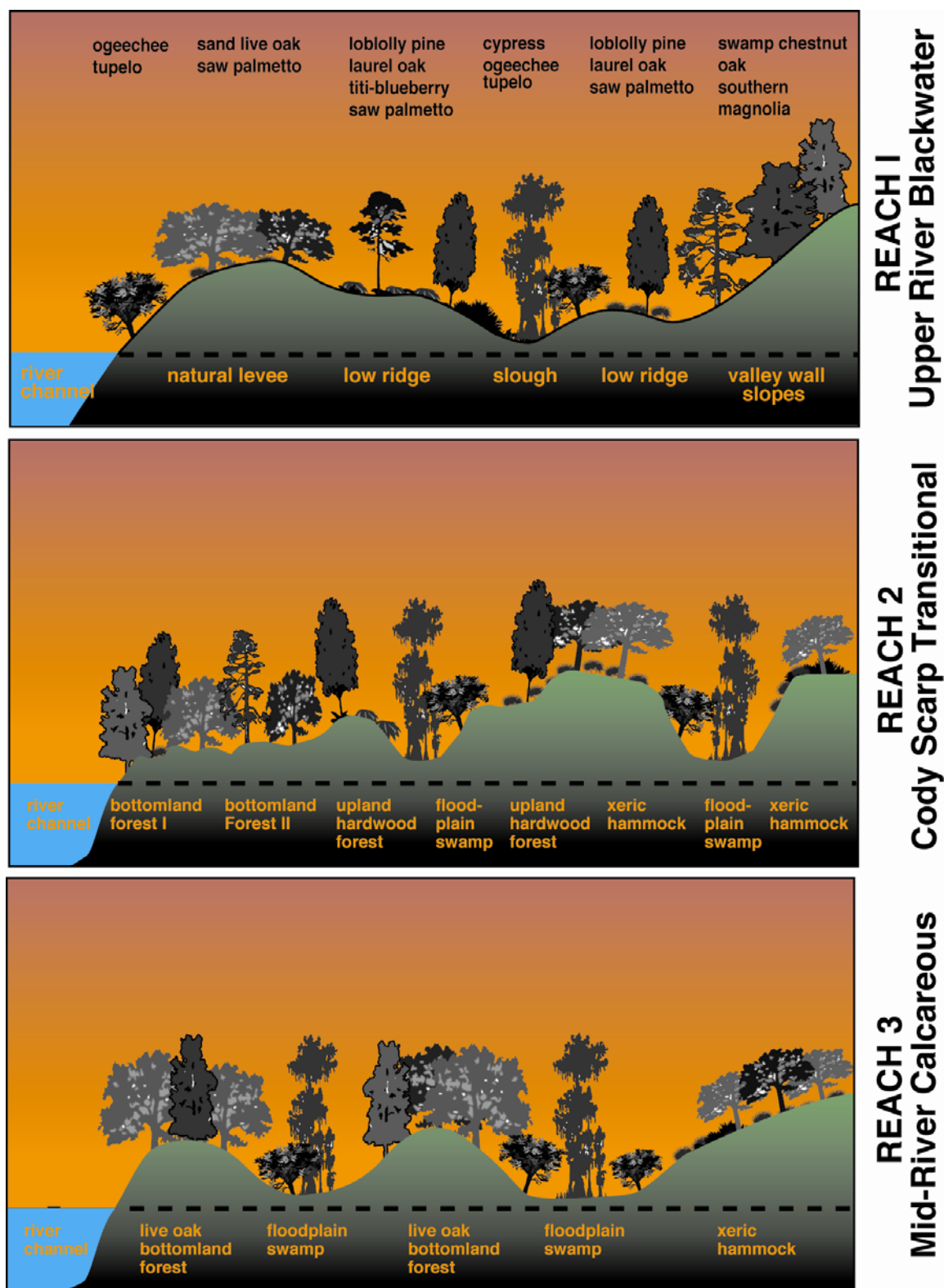


Figure 2-24 Basic geomorphology of the river channel and floodplain and typical plant communities in each of the five ecological reaches (Figure 2-20) of the Suwannee River. Adapted from Lynch, 1984.

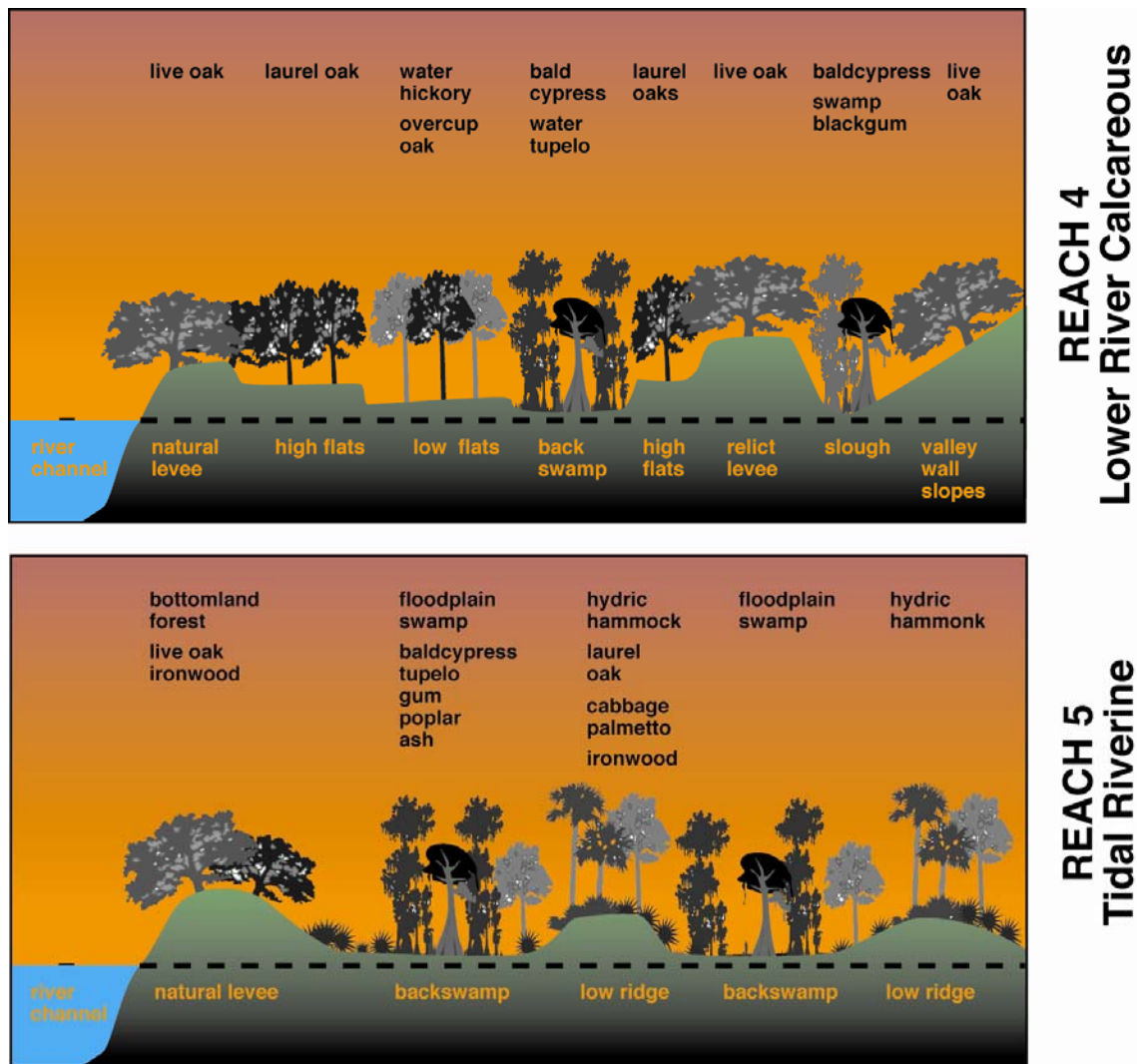


Figure 2-24. Continued.

Reach 5. Tidal River Reach. This reach, begins at the U.S. 19 bridge at the town of Fanning Springs. As indicated in the section on hydrology, tidal variation in river stage is evident here at low flows. This reach also lies entirely within the Gulf Coast Flatwoods subregion. The river channel approaches 800-1,000 ft. in width. River channel substrata include exposed limestone, medium and coarse sand, and sandy mud in areas of reduced current velocity. The channel is fringed by tidal, freshwater marsh, which becomes more evident downstream. These marshes are dominated by wild rice, bulrushes, cattail, pickerelweed, spatterdock, and water hemlock. Along the outer edge of these marshes, where water depth and sediment conditions permit, beds of submerged vegetation dominated by eelgrass and spring tape may grow. The floodplain in the upper portions of this reach includes forest types similar to those seen in Reach 4. As the river nears the Gulf, tidal freshwater swamps (Wharton et al., 1982) and hydric hammock (Vince et al., 1989) become the dominant forest types. The tidal swamps are dominated by bald cypress, pumpkin ash, swamp and sweet bay, cabbage palm, red maple, and swamp tupelo. Hydric hammocks are a wetland forest type unique to Florida with the greatest extent occurring in this region of the Florida coast (Vince et al., 1989). These forests are characterized by a diverse tree canopy. Characteristic species include cabbage palm, laurel

and live oak, sweetgum, sweet bay, swamp bay, southern red cedar, red maple and blue beech. Two major springs, Fanning and Manatee springs, occur on this reach. Benthic invertebrate communities are similar to those in Reaches 3 and 4, although as the river nears the Gulf, estuarine species begin to appear (i.e., olive nerite snail, red-joint fiddler crab, wharf crab). Fish communities include minnow, killifish, darters, sunfish and centrarchids such as the Suwannee bass and the largemouth bass. Additionally, estuarine fish species, such as those listed in Table 2-8, begin to appear.

2.2.2.2.2 Santa Fe River

The Santa Fe River drainage encompasses more sub-ecoregions (6) than any other river basin in Florida. The river drainage lies within portions of the Tifton Uplands/Tallahassee Hills, Central Florida Ridges and Uplands, Okefenokee Swamps and Plains, Sea Islands Flatwoods, Eastern Florida Flatwoods, and Gulf Coast Flatwoods subecoregions. This landscape diversity accounts for the high overall biological diversity exhibited in this river system.

The upper portion of the river includes numerous shallow runs, with a sand-bottomed channel, which may become braided and diffuse in some reaches. Flow in the Upper Santa Fe River Basin is dominated by surface-water runoff. The river is captured by sinks at O'Leno State Park and re-emerges about 3 miles downgradient at the Santa Fe Rise (River Rise). Only one major spring, COL61981 (Santa Fe Spring), occurs in the Upper Santa Fe River Basin.

The Lower Santa Fe River Basin is heavily influenced by spring inflow and is typically clear and alkaline. The upper portions of this lower reach are mostly shallow and include numerous shoal areas of exposed limestone and beds of submerged aquatic vegetation (SAV). The lower portion is wider and deeper, with SAV beds confined to the channel margins. In terms of channel morphology, the Lower Santa Fe River somewhat resembles Reach 3 of the Suwannee River, although with a narrower river channel. The channel bottom substrata are mostly coarse sand and exposed limestone. Major springs include the Ichetucknee group, the Ginnie group, Hornsby, Gilchrist Blue group, Poe, and Rum Island.

Benthic invertebrate communities in the Santa Fe River system are characterized by mayflies, caddisflies, chironomids, amphipods and snails.

2.2.2.2.3 Withlacoochee River

The Withlacoochee River drainage lies mostly within Georgia, in the Southeastern Plains Ecoregion. The river's general morphology is that of a low gradient, eastern, coastal plain stream with a sand-bed channel (Brussock et al., 1985). Using Beck's (1965) classification, the Withlacoochee is a "sand-bottom stream". In Florida, the river channel is incised in the underlying Suwannee and Ocala limestones and numerous limestone shoals are found in the channel. Other channel bottom substrata are medium and coarse sand. Water chemistry in the river is moderately to highly colored, somewhat alkaline, and highly turbid on occasion. Because of the somewhat higher relief and clay soils found primarily in the Georgia portion of the watershed, the Withlacoochee River carries a higher sediment load than other streams in the Suwannee drainage (USDA, 1977). Consequently, the river is more of a "muddy" river than the Suwannee during higher flows. This sediment load is obvious when viewing the confluence of the Withlacoochee and Suwannee rivers at higher flows (generally average flow and greater). At baseflow, the river water is substantially less turbid and more reflective of a southeastern coastal plain, blackwater stream. The inflow of hard, carbonate-rich ground water from the Floridan Aquifer at base flow (via springs and diffuse inflow) contributes to the higher pH and

alkalinity of the water in Florida. Major springs include Blue, Pot, and Suwannacoochee. Benthic invertebrate communities are dominated by chironomids. Other dominants in the benthic community include crustaceans (the amphipod *Hyaella* and grass shrimp, *Palaemonetes paludosus*), blackflies (*Simulium* spp.), aquatic beetles (Coleoptera), caddisflies (Trichoptera) and mayflies (Ephemeroptera).

2.2.2.2.4 Alapaha River

The third major tributary of the Suwannee is the Alapaha River. Its drainage, like the Withlacoochee River, lies mostly within Georgia. The physiography and soils of the drainage are more like those of the upper Suwannee and it lies almost entirely within the Southern Coastal Plain Ecoregion. Consequently, the river may be characterized as a southeastern coastal plain, blackwater stream. When river flows are below average, much of the river flow is captured by sinkholes about 4 miles south of the Florida-Georgia state line and the remainder of the river channel in Florida is dry for a substantial portion of a typical year (Ceryak, 1977). The river re-emerges at the Alapaha Rise (Ceryak, 1977) and possibly at Holton Creek Rise; both are characterized as blackwater springs. Benthic invertebrate communities in the upper, perennial reach of the river in Florida (above the sinks) are dominated by chironomids, mayflies, stoneflies, and caddisflies.

2.2.2.2.5 Suwannee Estuary

The estuary of the Suwannee River is deltaic (Day et al., 1989) with extensive intertidal areas ranging from tidal fresh water to polyhaline portions of the estuary. About 6 miles before it reaches the Gulf, the Suwannee branches into West Pass and East Pass (Figure 2-20). These distributaries flow through a broad delta area that includes Hog Island, Bradford Island, Little Bradford Island, and the area around Dan May Creek at the mouth of East Pass. The river empties into a shallow embayment called Suwannee Sound, which is partially enclosed by Suwannee Reef; a complex of oyster reefs and sand bars extending from north of Wadley Pass south to near Cedar Key.

The Suwannee River accounts for 60% of the total fresh-water inflow into the Big Bend region of the Florida coast (Montague and Odum, 1997), which makes it the largest estuary in the Big Bend. The intertidal wetlands and submerged habitats found throughout this area provide primary production and habitat for a great many animal species with ecological and economic value (i.e., those caught commercially or for sport). Spatial and temporal variation in salinity due to river flow variation is a major environmental influence that structures the plant and animal community composition of the wetlands on the river delta and the submerged habitats in the estuary.

2.2.2.2.6 Species and Habitats of Interest

Because the Suwannee River Basin coincides, in part, with a climatic transition zone, it is a significant biogeographic transition zone in Florida. Many species of flora and fauna reach their southernmost limits of distribution in the U.S. in the Suwannee region. Over half of the native fresh-water fishes found in Florida river systems, occur only in, or west of the Suwannee River (Bass and Cox, 1985; Bass, 1991). A number of plant species reach the southern limits of their distribution in the southeastern U.S. in the Suwannee region (Clewel, 1985).

Key species of interest (e.g., listed taxa, rare or endemic species) dependant upon aquatic and wetland habitats in the lower Suwannee are shown in Table 2-7. These are listed as either (1) endangered or threatened by the U.S. Fish and Wildlife Service (USFWS), (2) endangered, threatened, or a species of special concern by the Florida Fish and Wildlife Conservation

Commission (FWCC), or (3) "Rare and Endangered Biota of Florida" published by the Florida Committee on Rare and Endangered Plants and Animals (FCREPA), or (4) as S1, S2, or S3 by the Florida Natural Areas Inventory (FNAI).

Additional species of interest, which occur in the Suwannee estuary, are shown in Table 2- 8. These are listed by the National Oceanic and Atmospheric Administration as important "Estuarine Living Marine Resources" (ELMR), chosen based on four criteria (Nelson, 1992): 1 - commercial value (harvested commercially), 2 - recreational value (sport fish), 3 - indicator of environmental stress, and 4 - ecological value (important forage or food base organisms). Many are also listed by the Florida Fish and Wildlife Research Institute (FWRI) as "Selected Taxa" because of their commercial, recreational or ecological value.

Table 2-7 Aquatic and wetland-dependent species of interest in the lower Suwannee River study area.

Scientific Name	Common Name	Federal	State	FCREPA	FNAI	TNC
<u>Plants</u>						
<i>Lobelia cardinalis</i>	Cardinal flower		T			
<i>Matelea gonocarpa</i>	Angle pod		T			
<i>Peltandra sagittifolia</i>	Spoonflower			R		
<i>Ulmus crassifolia</i>	Cedar elm			R	S1	
<i>Zephyranthes atamasco</i> **	Zephyr lily					
<u>Invertebrates</u>						
<i>Caecidotea hobbsi</i>	Florida cave isopod				S2	
<i>Chimarra florida</i>	Florida finger-net caddisfly				S1	
<i>Cincinnatia mica</i>	Ichetucknee silt snail			SSC	S1	
<i>Crangonyx hobbsi</i>	Hobb's cave amphipod			SSC	S2-S3	
<i>Dolania americana</i>	Sand-burrowing mayfly			T	S1-S2	
<i>Medionidus walkeri</i>	Suwannee moccasinshell			T	S?	
<i>Poanes viator zizaniae</i>	Rice skipper			R		
<i>Polygonia comma</i>	(skipper)			R		
<i>Pleurobema reclusum</i>	Florida pigtoe			T		
<i>Procambarus erythrops</i>	Red-eye cave crayfish		SSC	R	S1	
<i>Procambarus lucifugus alachua</i>	Alachua light-fleeing cave crayfish			R	S2-S3	
<i>Procambarus pallidus</i>	Pallid cave crayfish			R	S2-S3	
<i>Satyrodes appalachia</i>	(butterfly)			R		
<i>Troglocambarus maclanei</i>	MacLane's cave crayfish			R	S2	
<u>Fishes</u>						
<i>Acipenser oxyrhynchus desotoi</i>	Gulf sturgeon	T	SSC	T	S2	Im
<i>Agonostomus monticola</i>	Mountain mullet			R	S3	
<i>Ameiurus serracanthus</i>	Spotted bullhead				S3	

Scientific Name	Common Name	Federal	State	FCREPA	FNAI	TNC
<i>Ameiurus serracanthus</i>	Spotted bullhead				S3	
<i>Cyprinella leedsi</i>	Bannerfin shiner				S3	
<i>Micropterus notius</i>	Suwannee bass		SSC		S2-S3	
<i>Notropis harperi</i> **	Redeye chub					
<u>Reptiles</u>						
<i>Alligator mississippiensis</i>	American alligator	T	SSC		S4	
<i>Caretta caretta</i>	Loggerhead sea turtle	T	T	T	S3	
<i>Chelonia mydas</i>	Green sea turtle	E	E	E	S2	
<i>Lepidochelys kempi</i>	Kemp's Ridley sea turtle	E	E	E	S1	Im
<i>Macrolemys temmincki</i>	Alligator snapping turtle		SSC	SSC	S3	
<i>Malaclemys terrapin</i>	Diamondback terrapin					Im
<i>Clemmys guttata</i>	Spotted turtle			R		
<i>Pseudemys concinna suwanniensis</i>	Suwannee cooter		SSC	SSC	S3	
<i>Drymarchon corais couperi</i>	Eastern indigo snake	T	T	SSC		
<i>Nerodia clarkii clarkii</i>	Gulf salt marsh snake			R	S3?	
<i>Eumeces egregius insularis</i>	Cedar Key mole skink			R		
<u>Birds</u>						
<i>Ajaia ajaja</i>	Roseate spoonbill		SSC	R	S2-S3	
<i>Aramus guarauna</i>	Limpkin		SSC	SSC	S3	
<i>Casmerodius albus</i>	Great egret			SSC	S4	
<i>Egretta caerulea</i>	Little blue heron		SSC	SSC	S4	
<i>Egretta rufescens</i>	Reddish egret		SSC	R	S2	
<i>Egretta thula</i>	Snowy egret		SSC	SSC	S4	
<i>Egretta tricolor</i>	Tricolor heron		SSC	SSC	S4	
<i>Nycticorax nycticorax</i>	Black-crowned night heron			SSC	S3?	
<i>Nycticorax violacea</i>	Yellow-crowned night heron			SSC	S3?	

Scientific Name	Common Name	Federal	State	FCREPA	FNAI	TNC
<i>Ixobrychus exilis</i>	Least bittern			SSC	S4	
<i>Eudocimus albus</i>	White ibis		SSC	SSC	S4	
<i>Mycteria americana</i>	Wood stork	E	E	E	S2	
<i>Grus canadensis pratensis</i>	Florida sandhill crane		T	T	S2-S3	
<i>Haliaeetus leucocephalus</i>	American bald eagle	T	T	T	S3	
<i>Elanoides forficatus</i>	Swallow-tailed kite			T	S2-S3	
<i>Pandion haliaetus</i>	Osprey			SSC	S3-S4	
<i>Pelecanus occidentalis</i>	Eastern brown pelican		SSC	T	S3	
<i>Haematopus palliatus</i>	American oystercatcher		SSC	T	S3	
<i>Recurvirostrata americana</i>	American avocet			SSC	S1-S2	
<i>Rynchops niger</i>	Black skimmer		SSC	SSC	S3	
<i>Sterna antillarum</i>	Least tern		T	T	S3	
<i>Sterna caspia</i>	Caspian tern			SSC	S2?	
<i>Sterna maxima</i>	Royal tern			SSC	S3	
<u>Mammals</u>						
<i>Trichechus manatus latirostris</i>	Florida manatee	E	E	E	S2	Im
<i>Ursus americanus floridanus</i>	Florida black bear		T	T	S2	
<i>Microtus pennsylvanicus dukecampbelli</i>	Florida saltmarsh vole	E	E	E	S1	

Federal and State are species officially listed by the U.S. or State of Florida (respectively); FCREPA=species listed by the Florida Committee on Rare and Endangered Plants and Animals; FNA I=species listed by the Florida Natural Areas Inventory; TNC=species listed in Beck, et al. (2000). E=endangered; T=threatened; SSC=species of special concern; R=rare; S1=critically Imperiled in Florida because of extreme rarity; S2=imperiled in Florida because of rarity; S3=rare, restricted, or otherwise vulnerable to extinction in Florida; S4=apparently secure in Florida; S?=status unknown; Im=imperiled. ** - included due to restricted distribution in north central Florida or narrow habitat requirements.

Table 2- 8 FWRI "Selected Taxa" and NOAA "Estuarine Living Marine Resources" (ELMR) taxa found in the Suwannee estuary.

	FWRI taxa	ELMR taxa
American oyster		XX
Common Rangia		XX
Bay squid		XX
Penaid shrimp (<i>Farfantepenaeus</i> spp.)	XX	XX
Grass shrimp		XX
Blue crab	XX	XX
Stone crabs (<i>Menippe</i> spp.)	XX	XX
Bull shark		XX
Tarpon	XX	XX
Ladyfish	XX	
Alabama shad		XX
Gulf menhaden		XX
Gizzard shad		XX
Bay anchovy		XX
Hardhead catfish		XX
Sheepshead minnow		XX
Gulf killifish		XX
Silversides		XX
Bluefish	XX	XX
Crevalle jack		XX
Grey snapper	XX	XX
Red snapper	XX	XX
Red grouper	XX	
Gag	XX	
Sheepshead	XX	XX
Pinfish		XX
Silver perch		XX
Sand seatrout	XX	XX
Spotted seatrout	XX	XX
Spot	XX	XX
Atlantic croaker		XX
Black drum	XX	XX
Red drum	XX	XX
Mulletts (<i>Mugil</i> spp.)	XX	XX
Code goby		XX
Pompano	XX	
Spanish mackerel	XX	XX
King mackerel	XX	
Cobia	XX	
Gulf flounder	XX	XX
Southern flounder		XX
Whiting/kingfish (<i>Menticirrhus</i> spp.)	XX	

Communities or habitats of conservation interest in the Suwannee River Basin are listed in Table 2- 9. These are listed as endangered or threatened by Noss et al. (1995), as imperiled or rare by the Florida Natural Areas Inventory (FNAI and FDNR, 1990), as a “Primary Habitat Target” for the northern Gulf of Mexico by Beck, et al. (2000), or as Essential Fish Habitat by the National Marine Fisheries Service (NMFS, 1999).

Table 2- 9 Aquatic and wetland habitats of conservation interest in the lower Suwannee River study area.

	USGS	FNAI	TNC	NMFS
Large, intact river systems	E			
Spring-run stream*		S2		
Aquatic cave		S2		
Intact floodplain wetlands*	T	S3-S4		
Tidal freshwater swamp*		S3	PT	
Tidal freshwater SAV beds*			PT	efh
Seagrass beds		S2	PT	efh
Tidal marshes*		S4	PT	efh
Oyster reefs & bars*		S3	PT	efh

USGS=ecosystems listed in Noss, et al. (1995); FNAI=Florida Natural Areas Inventory listed habitats; TNC=habitats listed in Beck, et al. (2000); NMFS=National Marine Fisheries Service designated Essential Fish Habitat (efh). E=endangered; T=threatened; S2=imperiled in Florida because of rarity; S3=rare or uncommon in Florida; S4=apparently secure in Florida; PT=listed as “Primary Habitat Target” for biodiversity conservation; *=target habitat identified for development of MFL in this report.

2.3 Upper Santa Fe River Watershed and Related Springs

2.3.1 Introduction

As noted in Section 1, the Upper Santa Fe River watershed is an important recreational and ecologic resource. The river and its swallet (sinkhole through which the river goes underground) are important to the natural and scenic beauty of the area.

The Upper Santa Fe River watershed encompasses roughly 1,000 square miles and includes portions of seven counties: Columbia, Union, Baker, Bradford, Clay, Putnam, and Alachua counties (Figure 1-1). However, Bradford, Union, Alachua, and Columbia Counties contain a majority of the watershed.

The surfacewater drainage basins (Figure 2-25) are based on surfacewater basins delineated by the U.S. Geological Survey (Foote, 1981). Approximately 88 sub-basins are contained within the Upper Santa Fe River watershed (Foote, 1981). Some of these sub-basins do not contribute direct runoff to the Upper Santa Fe River; they are internally drained, and with the exception of periods of very heavy rainfall and flooding, surface water does not flow out of the sub-basins. The Alachua stream system (Figure 1-1) is a good example of one of these internally drained sub-basins (Williams et al., 1977) which will be discussed in more detail in subsequent sections of this report. Note that while the Alachua stream system is placed within the Upper Santa Fe River drainage basin, it is apparent that the streams discharge to a portion of the Santa Fe River groundwater basin that drains to the Lower Santa Fe River.

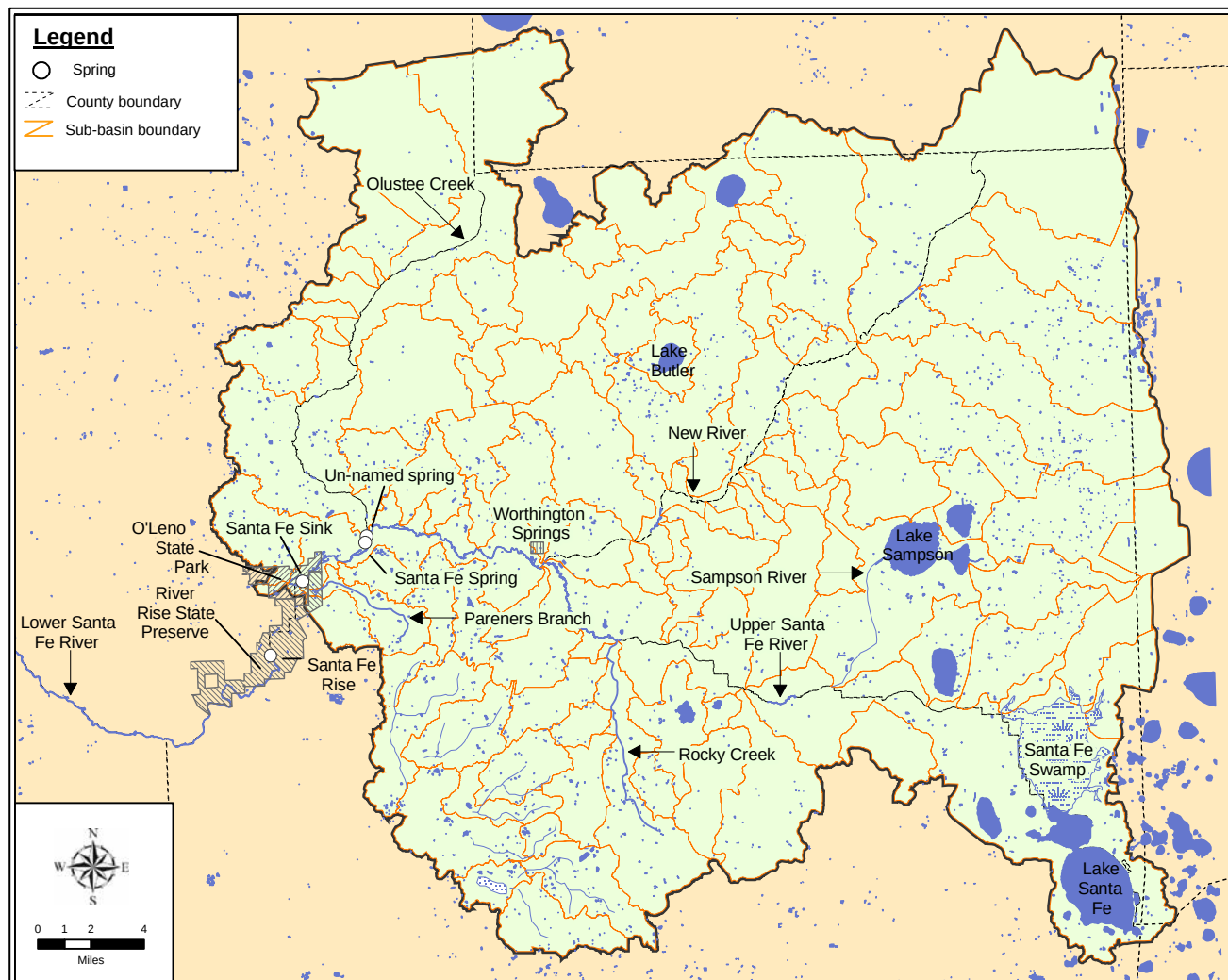


Figure 2-25 Surfacewater basins delineated by the U.S. Geological Survey (Foose, 1981)

The Santa Fe River begins in Lake Santa Fe and the Santa Fe Swamp in eastern Alachua County (Figures 1-1, 2-26). From its headwaters, the river generally flows west-northwest, forming the county boundaries between Alachua and Columbia, Union, and Bradford Counties. As it flows downstream, the river gains water from a number of tributary streams, notably Sampson River, which drains Lake Sampson in Bradford County, New River, which forms the boundary between Bradford and Union Counties, and Olustee Creek, the boundary between Union and Columbia County.



Figure 2-26 Headwaters of the Upper Santa Fe near Hampton and the Santa Fe Swamp. Note the swamp and braided stream channel.



Figure 2-27. Upper Santa Fe River near Graham. The river has a small channel and floodplain.

As the sequence of images shown in Figures 2-26 through 2-29 illustrates, the river typically has shallow, sandy banks and the channel can be simple or braided depending on sediment supply. The floodplain begins as a wide swamp, the Santa Fe Swamp, but then it narrows and the river emerges from the swamp. Downstream, the floodplain width increases, and levees and flood chutes can be observed.



Figure 2-28. Upper Santa Fe River near Brooker. Here, the river has a well-developed channel and floodplain, which is flooded in this image.



Figure 2-29. Upper Santa Fe River at Worthington Springs. The river has a well-developed floodplain with levees (right side of image) and flood chutes.

The river enters the Cody Scarp about 6 miles upstream from Brooker. Here, the river enters a V-shaped valley that terminates at Mud Swamp (the downstream end of the swamp is shown in Figure 2-28). The V-shaped valley reflects the reach over which the river is cutting through upper, clay-rich strata of the Hawthorn Group. Downstream from Brooker, the river floodplain increases in width (Figures 2-30) and the river takes on a pattern of alternating, broad swamps and upland floodplains. In this reach of the river, the main channel meanders extensively.



Figure 2-30. Typical Santa Fe River floodplain downstream of Brooker. Note the flood chute. Image taken at O'Leno State Park upstream of the River Sink.

When the river cuts into limestone or dolostone of the lower Hawthorn Group, it begins to lose water to siphons or temporary swallets in the



Figure 2-31. Santa Fe Spring (COL61981). Note the short spring run. Photo from Hornsby and Ceryak (1998).

streambed. Hornsby (2004, pers. com.) documented some of these siphons, and the flows identified in Section 3 support their presence. Water also discharges into the river by way of small seeps and springs.

Two springs, COL61981 (Santa Fe Spring) and COL61982, were documented by Hornsby and Ceryak (1998). Measurement of discharge from Santa Fe Spring (Figure 2-31) suggested that it was an historic first magnitude spring with discharge of about 150 cfs (6/1/1998). Subsequent measurements have indicated that the spring has lower discharge and should be considered a second magnitude spring.

COL61982 was estimated to have a discharge of 1 cfs in 1998. A fourth spring, Worthington Spring, had been developed as a small spa early in the last century. In 1972, the spring had been abandoned, and structures were deteriorating. Discharge was estimated to be less than 1 cfs in 1972 (Rosenau et al., 1977). A site visit in 2004 revealed that it had been bulldozed, thus blocking flow (Figure 2-32). No discharge was noted at the time of the site visit.



Figure 2-32. Worthington Springs, a former spa that is currently within a small park. The spring bowl has recently been modified and discharge from the spring appears interrupted.

The river passes over a series of shoals (Figure 2-33) before it sinks underground at O'Leno State Park, several miles downstream from the confluence with Olustee Creek (Figure 1-1). O'Leno is the site of a former mill, and some of the shoals have apparently been modified to form a millpond and race (Hoenstine and Weissinger, 1982).



Figure 2-33. Upper Santa Fe River at O'Leno State Park. As it crosses over the Cody Scarp, the river develops shoals and a small, incised channel. These shoals were once part of a small dam and mill at O'Leno.



Figure 2-34. The River Sink at O'Leno State Park. The Upper Santa Fe normally goes underground by way of this large swallet. It re-emerges approximately 3 miles southwest of the River Sink at the River Rise.

The River Sink (Figure 2-34) is a large gyre. Normally, the sink takes all of the water in the river. During extreme high flows, water overtops the sink and follows a trace to the southwest where it joins the Santa Fe River near its resurgence in River Rise State Preserve. Clark et al. (1964) estimated that an average flow of approximately 650 cfs, or 416 mgd, flows underground at the River Sink. This flow, according to Clark et al. (1964), is derived from four major streams: 130 cfs (84 mgd) from Olustee Creek, 240 cfs (155 mgd) from New River, 100 cfs (65 mgd) from Sampson River, and 180 cfs (116 mgd) from the main stem and smaller tributaries.

The O'Leno State Park maintains a swimming area just upstream of a suspension bridge constructed by the Civilian Conservation Corps in the 1930s (Figure 2-35). This swimming area is unsupervised, but the Park staff closes the swimming area from time to time as a result of flow-related conditions. Specifically, the swimming area has been closed during high flows because of risks of swimmers being swept downstream. Also, the area has been closed when extreme low flows create stagnant conditions based on visual observations and Park staff judgments. There are no data as to when the swimming area has been closed, and there are no flow-based criteria for closure (Dale Kendrick, Park Manager, 2006, pers. communication).



Figure 2-35. Swimming area at O'Leno State Park. Photograph courtesy of the Florida Department of Environmental Protection, Division of Recreation and Parks.

2.3.2 Population and Water Use

2.3.2.1 Population Distribution

From a regional perspective, the Upper Santa Fe River watershed is not heavily populated. According to the 2000 census, approximately 6,098 residents lived in Alachua (Figure 1-1), the largest center of population in the watershed, and approximately 5,593 residents lived in Starke (U.S. Census Bureau, 2002). The remaining area is largely rural and consists of agricultural land, forests, tree plantations, and undeveloped land. Population statistics indicate that, since 1960, the populations of Alachua, Bradford, Columbia, and Union counties have on average more than doubled. The median population density of these four counties is approximately 80 persons per square mile (U.S. Census Bureau, 2002), which if evenly distributed throughout the watershed, translates into a total population of approximately 80,000 people in the Upper Santa Fe Basin.

2.3.2.2 Water Use

According to estimates by Marella (1999), groundwater was withdrawn from Alachua, Bradford, Columbia, and Union counties at the rate of approximately 73.9 mgd in 1995. Agricultural withdrawals, rural self-supplied, and public water-supply systems accounted for approximately 27.7 percent (20.5 mgd), 19.6 percent (14.5 mgd) and 38.8 percent (28.7 mgd), respectively, of the total withdrawals in the counties (Marella, 1999). Cumulatively, these withdrawals accounted for approximately 86.1 percent of the water use in the watershed in 1995. In addition, approximately 6.1 mgd was withdrawn from the Floridan Aquifer System for industrial purposes, with a remainder of 4.1 mgd withdrawn from either surfacewater sources or the Surficial Aquifer (Marella, 1999).

Table 2-10 Projected water use in counties within the Upper Santa Fe River watershed for 2000 and 2025. From Water Resource Associates, Inc. (2004)

County and Year	Use (mgd)					Total (mgd)
	Agriculture	Commercial, Industrial, Mining, Power	Domestic Self Supply	Public Supply	Recreation	
Alachua						
2000	9.3	3.0	2.6	2.4	0.2	17.7
2025	23.7	5.2	4.9	4.2	0.2	38.2
Bradford						
2000	0.6	1.3	1.5	1.3	0.1	4.8
2025	0.9	2.0	2.3	2.0	0.1	7.4
Columbia						
2000	3.1	0.3	2.9	3.7	0.5	10.5
2025	4.6	0.6	5.4	6.8	0.8	18.3
Union						
2000	1.4	0.4	0.6	0.4	0.0	2.7
2025	6.7	0.7	1.0	0.6	0.0	8.9

Water Resource Associates, Inc. (2004) projected water use, by county, in 5-year increments from 2000 through 2050. Table 2-10 depicts the projected uses for 2000 and 2025 for the four counties that include most of the Upper Santa Fe Basin. Projected total use is 35.7 mgd for 2000. Most of this water use (50%) is in Alachua County and Columbia County (29%). Sizeable proportions of the water use in both counties are outside of the Upper Santa Fe Basin and are associated with the Gainesville and Lake City areas. By 2025, the projected total use is estimated to be approximately 72.8 mgd, a ~100% increase in water use. Again, much of this growth in water use will be outside of the Upper Santa Fe River Basin, but growth in communities along U.S. 301 and near the larger cities will utilize water from the basin.

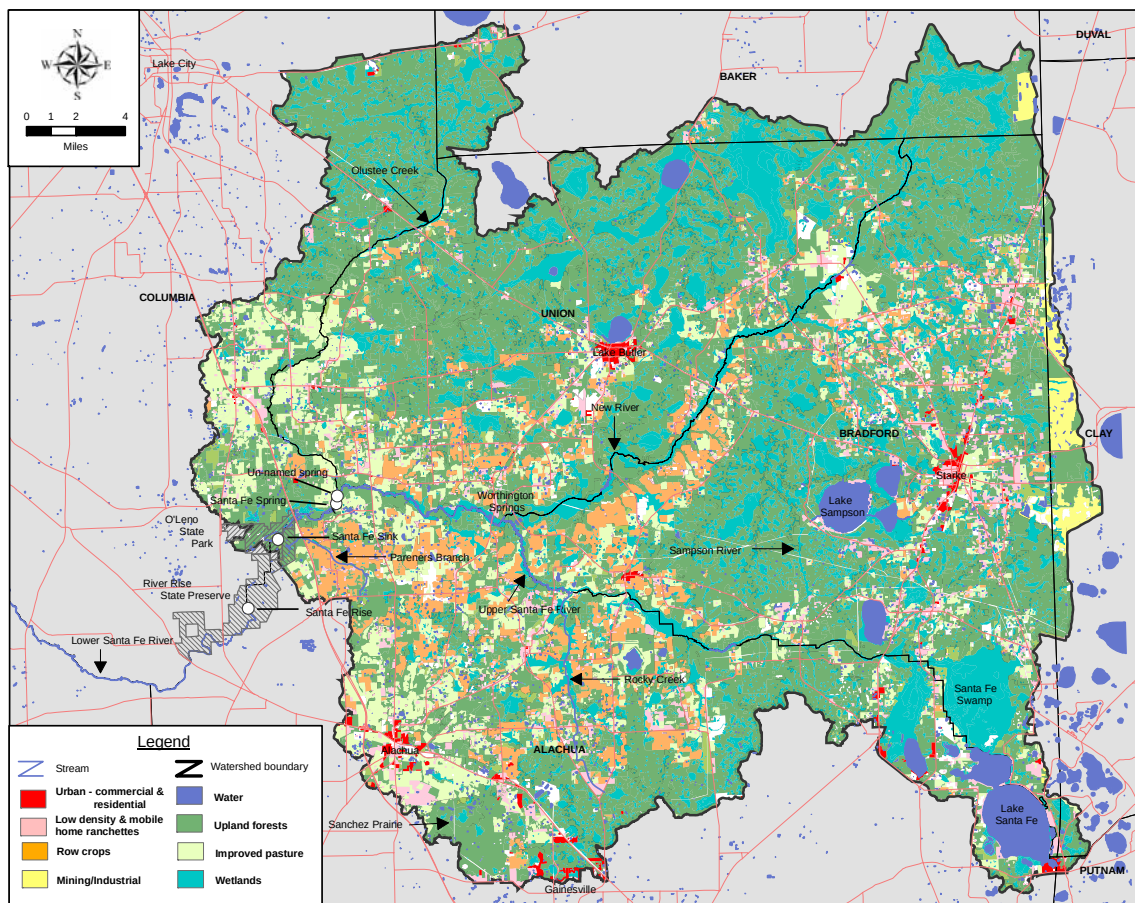


Figure 2-36. Major land uses in the Upper Santa Fe River Basin of Florida.

2.3.2.3 Land Use

Land use in the Upper Santa Fe River watershed was identified using the 1996 USGS Arcview™ land-use coverage (Florida Geographic Data Library, 2004). Forested wetlands, pine plantations, upland forests, improved pasture, and row crops cover much of the watershed. Residential land uses are scattered throughout the watershed and consist mainly of low-density, single-family units and mobile home ranchettes. Commercial and urban development is localized to small communities such as the towns of Alachua, Starke, and Lake Butler (Figure 2-36). Crops typically grown in the region include watermelons, peppers, cucumbers, corn, and soybeans (Soil Conservation Service, 1985, 1991a, 1991b).

2.3.3 Topography, Physiography, and Drainage

The topography of the Upper Santa Fe River watershed varies considerably (Figure 2-37), with land-surface elevations that range from less than 50 feet above msl along the confluence with Olustee Creek to heights in excess of 200 feet above msl in upland areas along the Trail Ridge in Clay County (Figure 2-38). In the immediate vicinity of the Upper Santa Fe River, however, elevations generally range from 50 to 150 feet above msl. As a result, the river has a low gradient along much of its course.

As shown in Figure 2-38, the Upper Santa Fe River Basin lies predominately within the Northern Highlands Physiographic Province (White, 1970). The Northern Highlands is an upland area (typically greater than 75 feet above msl) capped by relatively impermeable, clay-rich sediments of the Hawthorn Group. The low permeability of the Hawthorn Group inhibits recharge to the underlying aquifer systems and results in local surfacewater runoff. The abundance of sinkholes and closed depressions (Figure 2-39) along the margins of the Northern Highlands (i.e., the Cody Scarp (Puri and Vernon, 1964)) has created a landscape that favors large, internally drained basins, which greatly increase the relative amount of recharge to the Floridan Aquifer. The drainage basin of the Upper Santa Fe River terminates at the edge of the Northern Highlands. The Lower Santa Fe River originates at the base of the Scarp at the River Rise State Preserve.

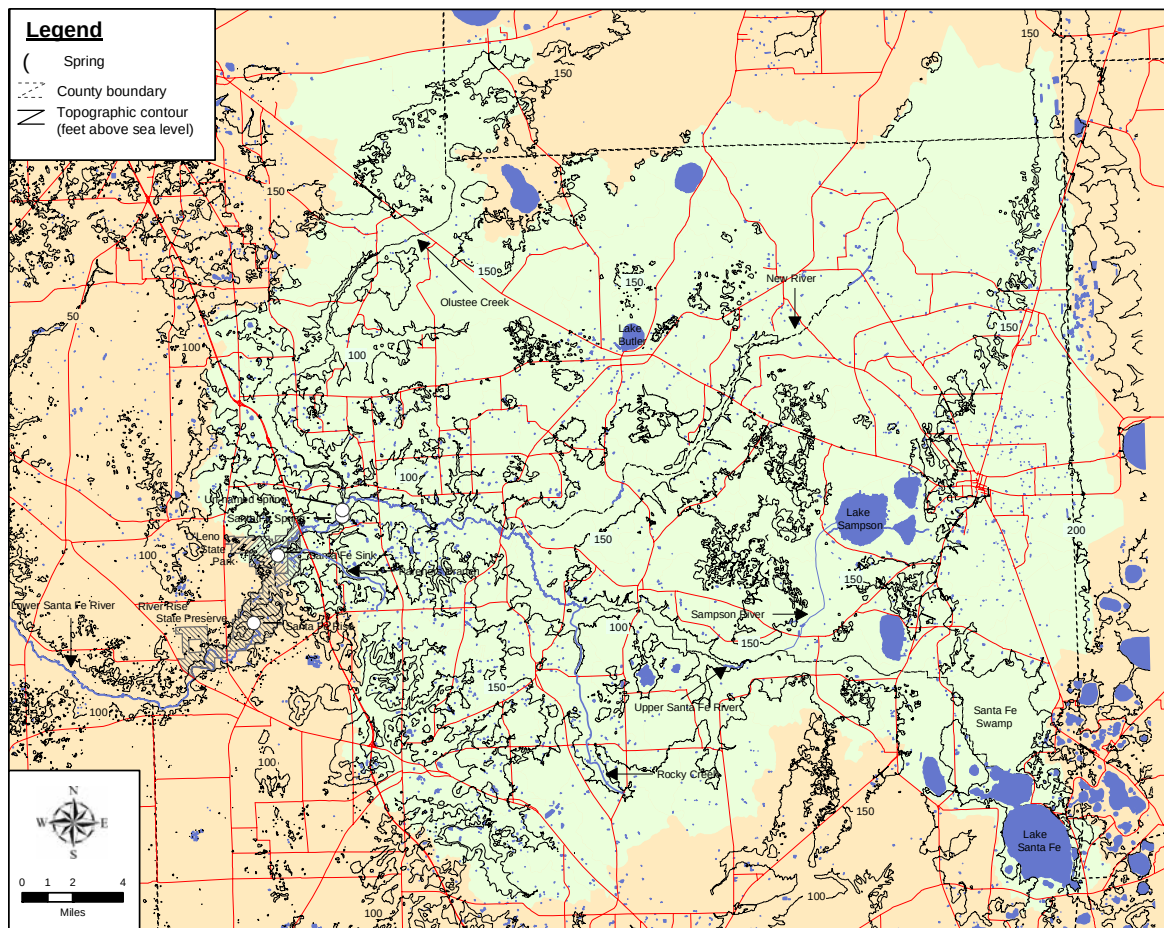


Figure 2-37. Topography of the Upper Santa Fe River Basin.

The internally drained basins that lie along the western side of the watershed contribute very little, if any, surfacewater runoff to the upper Santa Fe River. A good example of these internally drained basins is the Alachua stream system (Figure 1-1) which was described in detail by Williams et al. (1977). The Alachua stream system is a group of roughly half a dozen streams that have their headwaters near the western edge of the Northern Highlands. These streams typically flow short distances down the western edge of the Northern Highlands into sinkholes that lie at the base of the Cody Scarp. Essentially, the Upper Santa Fe River functions in the same way (a stream system that flows into a sinkhole, the River Sink at O'Leno State Park, near the base of the Cody Scarp).

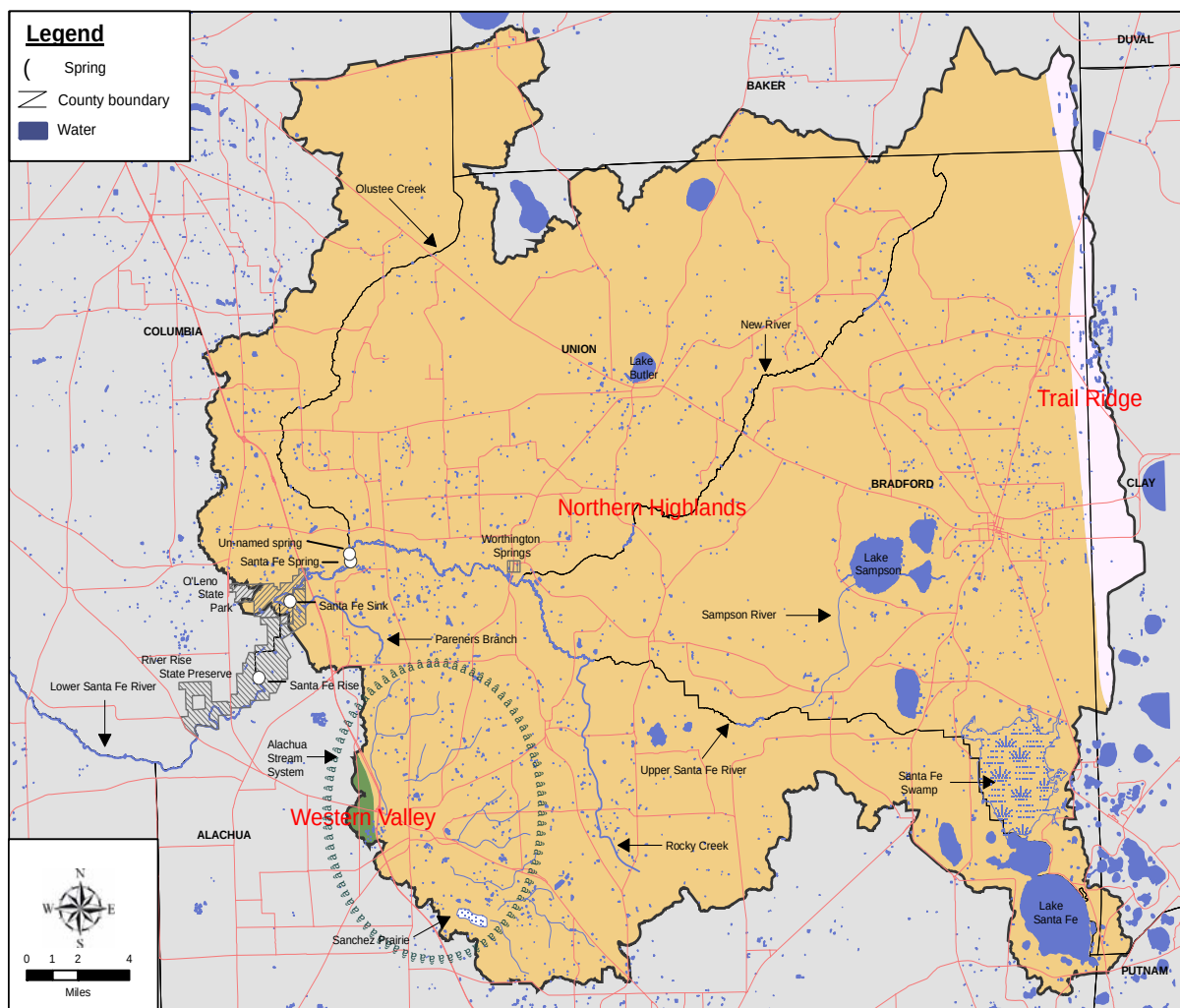


Figure 2-38. Physiographic provinces in the Upper Santa Fe River study area (White, 1970).

Two small areas, each representing a different physiographic province, lie on the western and eastern sides of the Upper watershed. The Western Valley (White, 1970) lies adjacent to the Northern Highlands on the western side of the Upper Santa Fe River Basin (Figure 2-38). This region is an area of subdued topography, underlain by a thin veneer of sandy cover over karstic limestone of the Floridan Aquifer System. The Western Valley (typically between 25 and 75 feet above msl) is a mature karst plain characterized by rapid recharge and numerous sinkholes.

Sinkholes in the regions along the Cody Scarp and edge of the Northern Highlands are typically small in area (Figure 2-39), but they are numerous (Upchurch, 2002).

Trail Ridge (White, 1970) lies on the eastern side of the watershed (Figure 2-38). This ridge is composed of thick deposits of sand, including commercial deposits of heavy minerals, such as zircon and ilmenite. Trail Ridge is thought to have formed as a beach ridge during higher sea levels in the Pleistocene Epoch. The Trail Ridge sands and ore deposits are generally less than 50 feet in thickness and overlie clay-rich sediments of the Miocene Hawthorn Group (Pirkle et al., 1977).

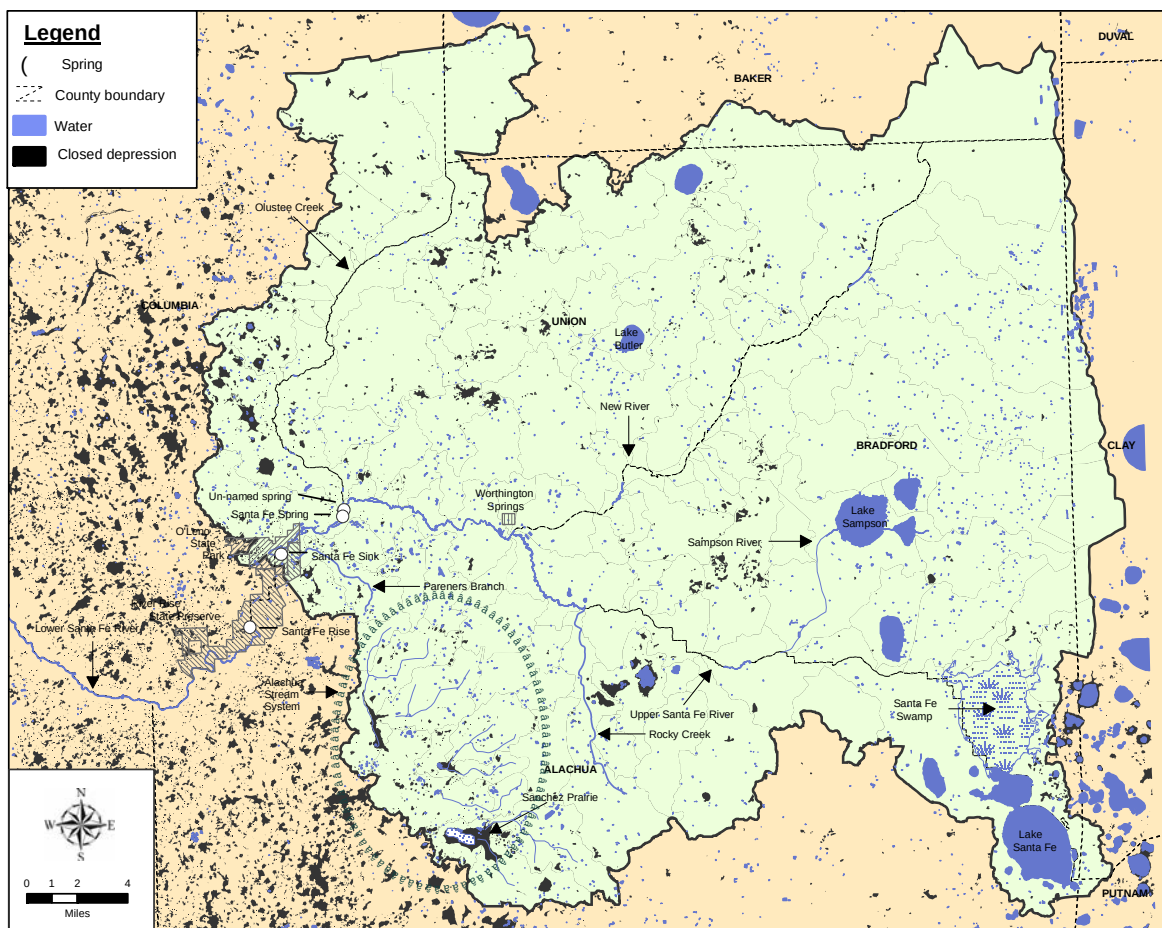


Figure 2-39. Locations of closed depressions, which are presumed to reflect karst features (i.e., sinkholes), in the Upper Santa Fe River study area.

2.3.4 Geology and Hydrology

2.3.4.1 Local Stratigraphy and Geomorphology

Figure 2-40 is a geologic map showing the stratigraphic units at or near land surface in the Upper Santa Fe watershed. The shallow strata typically consist of thick sequences of interbedded phosphatic sands, clays, and dolostones of the Hawthorn Group and undifferentiated Plio-Pleistocene terrace deposits (Scott et al., 2001). However in the western-most section of the watershed, the surface cover consists of undifferentiated Quaternary sand.

In the vicinity of Lake Santa Fe, the uppermost named formation is the Pliocene Cypresshead Formation. The Cypresshead Formation generally consists of reddish brown to reddish orange, unconsolidated to poorly consolidated, fine to very coarse grained sand and clayey sand. Quartz pebbles and discontinuous clay beds are also present in the formation. The Cypresshead Formation is moderately to highly permeable and supports a surficial aquifer in many areas (Scott et al., 2001).

Along the eastern margin of the watershed, the Pleistocene Trail Ridge sand overlies the Plio-Pleistocene terrace deposits. These sands are typically represented by thick accumulations of medium to fine-grained, light gray to grayish brown, tan, brown to black, clean to clayey or silty sand, and olive green to blue green, poorly to moderately consolidated sandy, silty clays. Gravel is occasionally present in the terrace sand. Plant debris, roots and disseminated organic-rich material or peat may also be found in the terrace sands. As noted earlier, the Trail Ridge terrace sands have been historically known for their heavy mineral deposits, some of which continue to be mined in Bradford, Clay, and Putnam counties (FDEP, 2005).

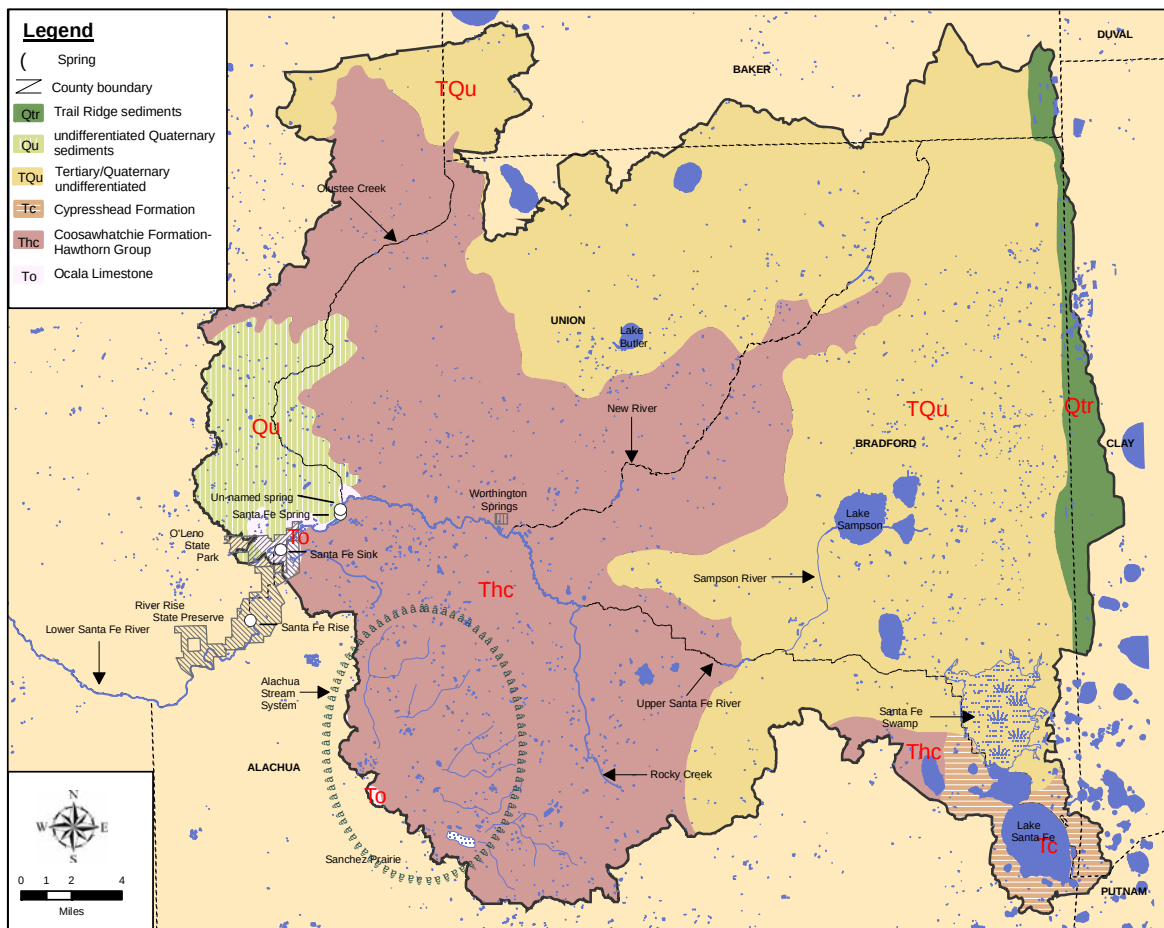


Figure 2-40 Geologic map of the Upper Santa Fe River study area.

Where Plio-Pleistocene or Pliocene deposits are thin or absent, the Miocene Hawthorn Group lies at or near the land surface. Due to its clayey composition, the relative permeability of the Hawthorn Group is generally low, so it tends to form an intermediate confining unit above the Floridan Aquifer System and below the Surficial Aquifer System. The Hawthorn Group includes clay-rich strata interbedded with sand and/or gravel horizons and dolostone and/or limestone strata. Sand, gravel, and carbonate beds can serve as local aquifers.

The uppermost persistent limestone units in the study area include the Suwannee and Ocala Limestones of Oligocene and Eocene age (Table 2-2), respectively. Below the Ocala Limestone is the Eocene Avon Park Formation. These units comprise the Upper Floridan Aquifer System in the Upper Santa Fe River watershed.

The Suwannee Limestone has been largely removed from the subsurface in the study area through erosion, though it does occur as scattered outliers in parts of the Upper Santa Fe watershed (Clark et al., 1964). Based on well cuttings, Crane (1986) described the Suwannee Limestone in the study region as consisting of several lithologies of marine origin: a dark yellowish-brown, moderately to well-indurated, sucrosic dolomite; a white-to-pale orange, poorly to moderately indurated, fossiliferous calcilutite; a yellow-gray, moderately to well-indurated, fossiliferous calcilutite; and a white, moderately to well-indurated, highly porous, and fossiliferous calcarenite. The upper surface of the Suwannee Limestone is marked by karst features (Crane, 1986).

The Ocala Limestone lies below the Suwannee Limestone, where present and is generally covered by tens to hundreds of feet of Miocene to Pleistocene sand and clay in the watershed. However, outcrops of the Ocala Limestone do occur along the lower reaches of the Upper Santa Fe at and below its confluence with Olustee Creek (Figure 2-40). Based on well cuttings, Crane (1986) described the Ocala Limestone in the region as consisting of several lithologies of marine origin. The deepest of these lithologies is a medium to well-indurated calcarenite composed almost entirely of Miliolid foraminifera. Above this unit lies a medium to well-indurated calcarenite composed of the foraminifera *Operculinoides* sp. and Miliolids. Capping these two lower lithologies is a unit that is described as a poorly to moderately indurated calcarenite composed of the foraminifera *Lepidocyclina* sp. Much like the underlying Avon Park Formation, the upper surface of the Ocala Limestone is highly variable and karstic (Crane, 1986).

The Avon Park Formation is the oldest rock unit that crops out in the State of Florida. While it is not exposed within the Upper Santa Fe Basin, it is present in the subsurface. The early Eocene Avon Park Formation consists of moderate to well-indurated, sugary dolostone, and moderately to well-indurated calcilutite, calcarenite and calcirudite. Thin seams of peat are often associated with the more dolomitized sections of the Avon Park Formation. In deeper, more calcitic sections of the Avon Park, Miliolids and foraminifers, especially *Dictyoconus americanus*, are often present (Crane, 1986). Gypsum is also present in small amounts in the Avon Park Formation, though it typically occurs several hundred feet below sea level in regions outside the study area (Crane, 1986).

2.3.4.2 Surfacewater Hydrology

Surfacewater features are widespread throughout the Upper Santa Fe River watershed (Figures 1-1, 2-39). The abundance of streams, lakes, and wetlands throughout most of the watershed reflects the low substrate permeability, high water table, and tendency for Surficial Aquifer water to discharge to area surfacewater bodies.

The Northern Highlands is a remnant of a much larger plateau that is being dissected by headward erosion of streams and where carbonate rocks are at shallow depths, dissolution (White, 1970). Relatively un-dissected portions of the plateau are characterized by broad wetlands and lakes that serve as headwaters of the Santa Fe River and its tributaries.

The Upper Santa Fe River is an excellent example of this process. Near its headwaters, the Upper Santa Fe River has not developed a well-integrated surfacewater drainage system. Instead, the uppermost reaches of the river and its tributaries are characterized by broad, shallow lakes and swamps. For example, Santa Fe Lake, the headwater lake for the Upper Santa Fe River (Figure 1-1), is approximately 5,900 acres in area and has a maximum depth of just over 26 feet. The lake is acidic and has a low total dissolved solids content, so it is not in direct contact with limestone or dolostone in the Intermediate or Floridan Aquifers system. It is, therefore, a shallow depression in the Cypresshead Formation (Figure 2-40). The outlet area of the lake is through a broad swamp (the Santa Fe Swamp).

Headward erosion is extending the dendritic Santa Fe drainage system into these areas. Within the upper, central portions of the Highlands, the streams are not well incised (Figure 2-37). As one progresses down stream, the stream channels become better incised, drainage becomes better integrated, and true floodplains develop. Figures 2-26 through 2-29 depict examples of this process. The head of accelerated erosion associated with the Cody Scarp is approximately 6 miles upstream from Brooker. Here, the stream begins to exhibit a V-shaped valley with an incised stream channel. Analysis of the base level at the Santa Fe River near Graham gage shows a gradual decline over the past 50 years by ~1.5 feet, reflecting the process of headward erosion (see Section 3.2.2.1).

Near the River Sink, the floodplain is broad and well developed. White (1970) believed that portions of this floodplain are relict and that they represented an earlier cycle of erosion. Near the toe of the Cody Scarp, flow is captured by sinkhole drainage. Surface flow in the Upper Santa Fe River is finally directed into the subsurface at O'Leno State Park to the north of High Springs. The river then flows approximately 3 miles underground before resurging at Santa Fe Rise near High Springs. As it flows through the subsurface, the surface flow is augmented by groundwater flow in the Floridan Aquifer System (Martin and Screaton, 2001).

2.3.4.3 Karst and Groundwater Hydrology

Karst - Karst processes play a dominant role in moving surface and groundwater through the lower part of the watershed and the Floridan Aquifer System, respectively. The Cody Scarp is an area of intensive karst development, characterized by numerous sinkholes, lack of surface drainage, stream capture through swallets, and undulating topography (Figure 2-39). In karst areas, the dissolution of limestone has created and enlarged cavities along fractures in the limestone which eventually reach the land surface and form sinkholes. Sinkholes capture surfacewater runoff and funnel it underground, which promotes further dissolution of limestone. This leads to progressive integration of voids beneath the surface over time and allows larger and larger amounts of water to be transported through the groundwater system.

Dissolution is most active at or immediately below the water table, typically within the zone of water-table fluctuation. In this zone, carbonic acid contained in atmospheric precipitation and generated by reaction with soil carbon dioxide reacts with limestone and dolostone (Carroll, 1970). Because the elevation of the water table has shifted in response to changes in sea level over the last 30 million years, many vertical and lateral paths have developed in the underlying carbonate strata in the study area. Many of these paths or conduits lie below the present water table and greatly facilitate groundwater flow.

Groundwater may flow rapidly through conduits and passages with the limestone, or slowly through minute pore spaces within the rock matrix. For example, dye-trace studies in Columbia County northwest of the lower Santa Fe River watershed show that groundwater near Ichetucknee Springs may travel approximately one mile per day in active conduits in the Floridan Aquifer System (Karst Environmental Services, 1997). Because the flow in these karst conduits is rapid and direct, dispersion, dilution, and retardation of contaminants is likely to be minimal, and the springs are vulnerable to contamination. For example, when Lawrence and Upchurch (1976) sampled the Floridan Aquifer System in the vicinity of Lake City (Columbia County), they found a plume of surfacewater under Alligator Lake that extended to the southwest for several miles. Shortly after completion of the study, the lake drained and residents down gradient reported colored water, organic debris, and other indicators of lake water. We now know that Alligator Lake is part of the headwaters of the Ichetucknee Springs and that the plume of surfacewater was migrating in a karst conduit system to the springs.

It is important to understand that rapid conduit flow and slower diffuse flow are, in fact, very useful in deciphering the hydrology of groundwater and springs in karst regions like the Upper Santa Fe River watershed. Older groundwater, which appears to dominate much of the aquifer system, mixes with younger groundwater traveling through active conduits. Two recent studies by the St. Johns River Water Management District (Toth, 1999) and the SRWMD (Katz and Hornsby, 1998) demonstrate and support this mixing model of groundwater at springs. As will be discussed below, the Santa Fe Sink/Rise is one of the best examples of the importance of mixing of diffuse and conduit flow. Therefore, the mixing of groundwaters must not be overlooked when assessing the origin, health and history of spring and groundwaters in karst environments, such as are found in the Upper Santa Fe River watershed.

Recharge - Recharge to the Upper Floridan Aquifer System is directly related to the confinement of the aquifer system. The highest recharge rates occur where the Floridan is unconfined or poorly confined, as in those areas where the aquifer is at or near land surface. Recharge may also be high in areas where the confining layers are breached by karst features, such as sinkholes in the Cody Scarp (Figure 2-38) and at River Sink.

Other factors affecting recharge rates include the development of surfacewater drainage, variations in water-level gradients between surfacewater, the Surficial Aquifer and the Floridan Aquifer, and aquifer permeability. Low recharge rates occur where confining materials overlying the aquifer retard downward vertical movement of water or where an upward gradient exists between the Floridan and Surficial Aquifers. Figure 2-41 shows the estimated recharge potential of the Floridan Aquifer System in the Upper Santa Fe River watershed (SRWMD, 2001).

The Santa Fe Sink/Rise System - Scientists at the University of Florida have investigated the processes that affect recharge water that enters the Santa Fe River Sink. Special focus has been on the mixing of river water with aquifer water underground. Some of the important findings of these investigations are discussed below.

A dye tracer test found that the River Sink is connected with Sweetwater Lake (a small lake between the Sink and Rise) and several karst windows. The tracer was not, however, detected at the Rise (Hisert, 1994). A second dye trace beginning at Sweetwater Lake was detected at the River Rise (Hisert, 1994) thus establishing the connection and demonstrating that dilution and/or dispersion may be important processes for reducing concentrations of the dye to less than detection limits. The Hisert investigation was undertaken when the river stage was

moderately high (44.3 ft. above msl). Hisert (1994) also estimated that the rate of travel from Sink to Rise was 2.7 miles per day.

Dean (1999) and Martin and Dean (1999, 2001) utilized temperature measurements to show that flow rates vary with river stage. At high stage (44.3 ft. above sea level), travel time was estimated to be less than 6 hours. During low stage (34.3 ft.), the travel time was over 7 hours. At “exceptionally low stage” in 2001, the entire flow of the river was captured by a small sink upstream from the River Sink (Smith et al., 2002). After several precipitation events, during which stage rose, discharge pulses moved through the Sink/Rise system. The data obtained indicated the possibility of a complex “plumbing” system controlled by differing elevations of conduits.

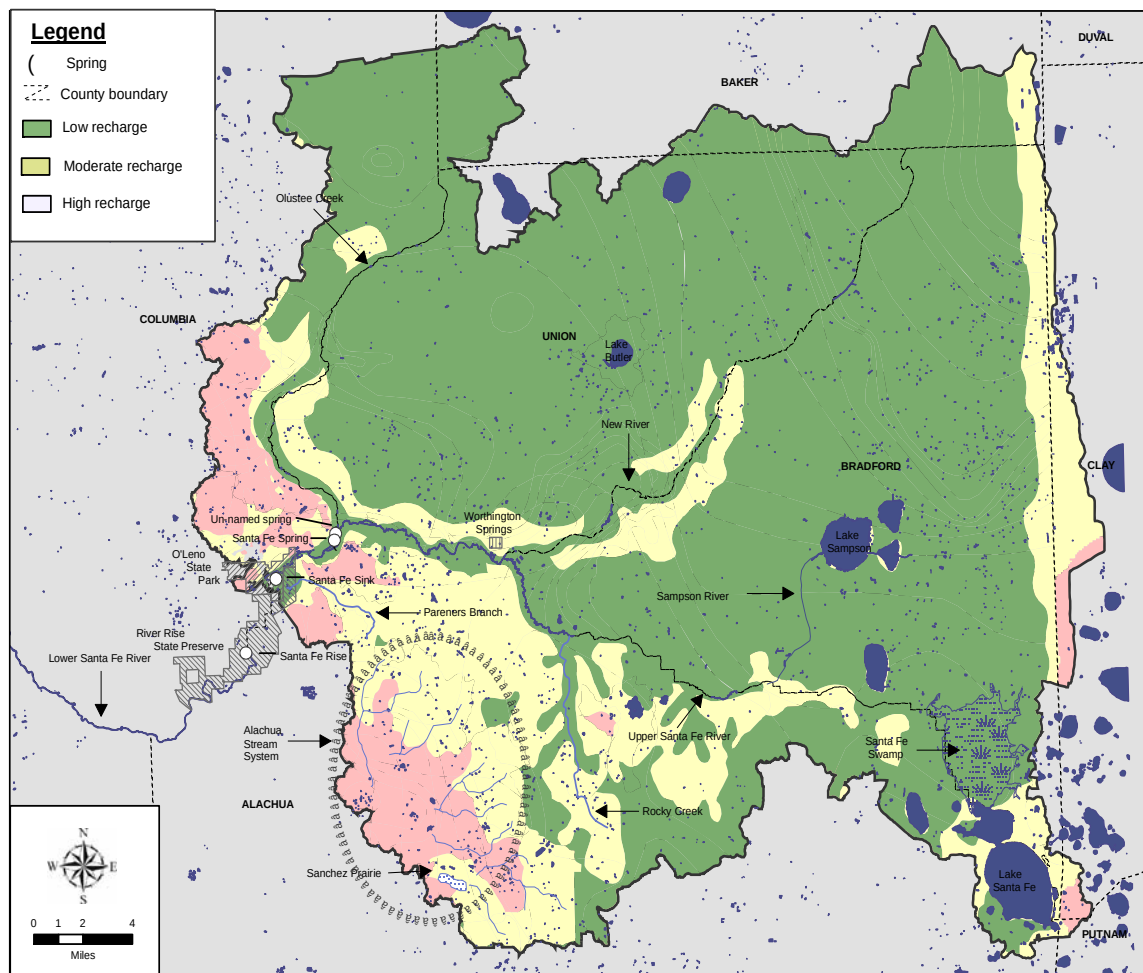


Figure 2-41. Recharge potential in the Upper Santa Fe River Basin.

Martin and Scream (2001) used the Sink/Rise system to characterize exchange and mixing of diffuse and conduit flow water. They concluded that only 4% of the water discharging from the River Rise was contributed at the River Sink at low river flow while, 96% of the water discharging from the sink was thought to be derived from other sources. The largest source of discharging water was thought to be a conduit system that had been mapped by cave divers to extend to the east. They further concluded that this eastern conduit system received little surfacewater, so most of the discharge was from diffuse flow. At intermediate discharge from the Rise, about 73% of the discharge was from the Sink and the remaining 27% was from other sources.

The Santa Fe Sink/Rise complex is, therefore, a complex system with significant recharge at the Sink and other conduits within the mainstem of the Santa Fe River during moderate to high flow conditions. During droughts, when the river is low, the discharge from the Rise is sustained by movement of water out of the aquifer matrix into the conduit system.

Potentiometric Surface - Potentiometric surfaces of the Floridan Aquifer in the Upper Santa Fe River watershed are shown in Figures 2-10 and 2-42. Some distinctive features are visible on the potentiometric surface map. Most importantly, the spacing between the isopotential lines suggests a well-developed karst with high hydraulic conductivity in the Upper Floridan Aquifer System. Given this potentiometric surface, it would appear that groundwater flow in the Upper Santa Fe River watershed generally flows northwestward in the upper basin from a potentiometric high in the Keystone Heights area of Clay and Bradford counties. Groundwater flow is southwestward in the central and lower portions of the watershed. The localized potentiometric high in the southwestern portion of the watershed between Alachua and the City of Gainesville (Figure 2-42) reflects recharge to the Floridan Aquifer in the vicinity of Sanchez Prairie (Figure 1-1) and the Cody Scarp. Finally, the potentiometric low along the southern boundary of the study area was interpreted by Clark et al. (1964) to reflect pumpage and groundwater withdrawals associated with the City of Gainesville.

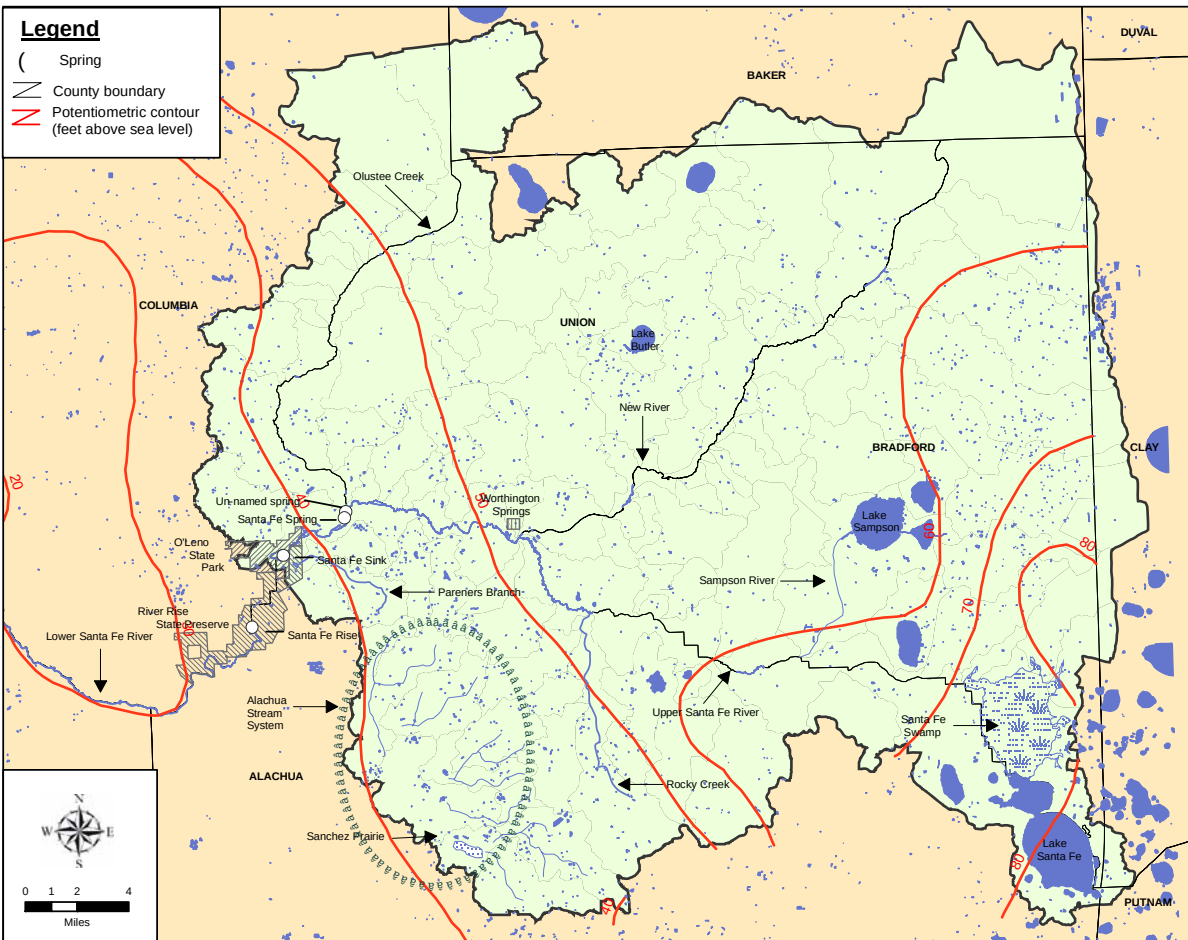


Figure 2-42 Potentiometric surface of the Floridan aquifer and approximate location of the Upper Santa Fe groundwater basin in the vicinity of the Upper Santa Fe River in Florida. Data modified from SRWMD (1995).

TAB 3

3.0 HYDROLOGIC ANALYSES

3.1 Overview

The USGS has collected continuous stage and stream flow data at locations on the Upper Santa Fe River since as early as 1932. The USGS and District have funded the network cooperatively since 1975. Beginning in 1997, the District assumed full responsibility for monitoring at some of the gages on the Upper Santa Fe River. The period of record for each of these sites varies by starting date and data collection frequency, and some sites were discontinued and then re-established at a later date. This section presents a summary and analysis of the hydrologic data that are available for determining MFLs for the Upper Santa Fe River.

3.2 Data

Unless otherwise noted, the District provided all data. The data set includes information on:

- Groundwater levels and use,
- Stream gage data for the Santa Fe River, its tributaries, and springs, and
- Precipitation.

3.2.1 Groundwater Data

3.2.1.1 Groundwater Levels

The complete record for all monitored wells was provided for all counties within the basin. Data exist for 61 wells located within the Upper Santa Fe River Basin (Figure 3-1). Table 3-1 contains information on water-level data available for these wells, including the first and last date measured, the frequency measured, total number of measurements, and minimum and maximum groundwater levels within each well. Appendix A contains graphs of the complete data set for each of the wells in the study area.

Of these 61 wells, only nine have been monitored on a daily basis (Table 3-1). The remaining wells have been monitored on a monthly, quarterly, or yearly basis. Some wells have significant gaps within their monitoring records.

3.2.1.2 Groundwater Quality

Many of the wells listed in Table 3-1 are also routinely sampled for geochemical indicators as part of the District's Water Assessment Regional Network (WARN). These data can be utilized, if appropriate, for source water identification and may provide some use for MFL development.

3.2.1.3 Groundwater Use

Information was provided on the existing groundwater withdrawal permits for the counties within the Upper Santa Fe River Basin. Note that many of the counties only include small portions of the Santa Fe River Basin (Figure 3-1); therefore, water use within these counties is not representative of use within the Upper Santa Fe River Basin portion of each county. Available data on these permits includes permit holder's name and address and the average and

maximum daily rates of pumping allowed for the well. Water use, by county, is available in Marella (1999).

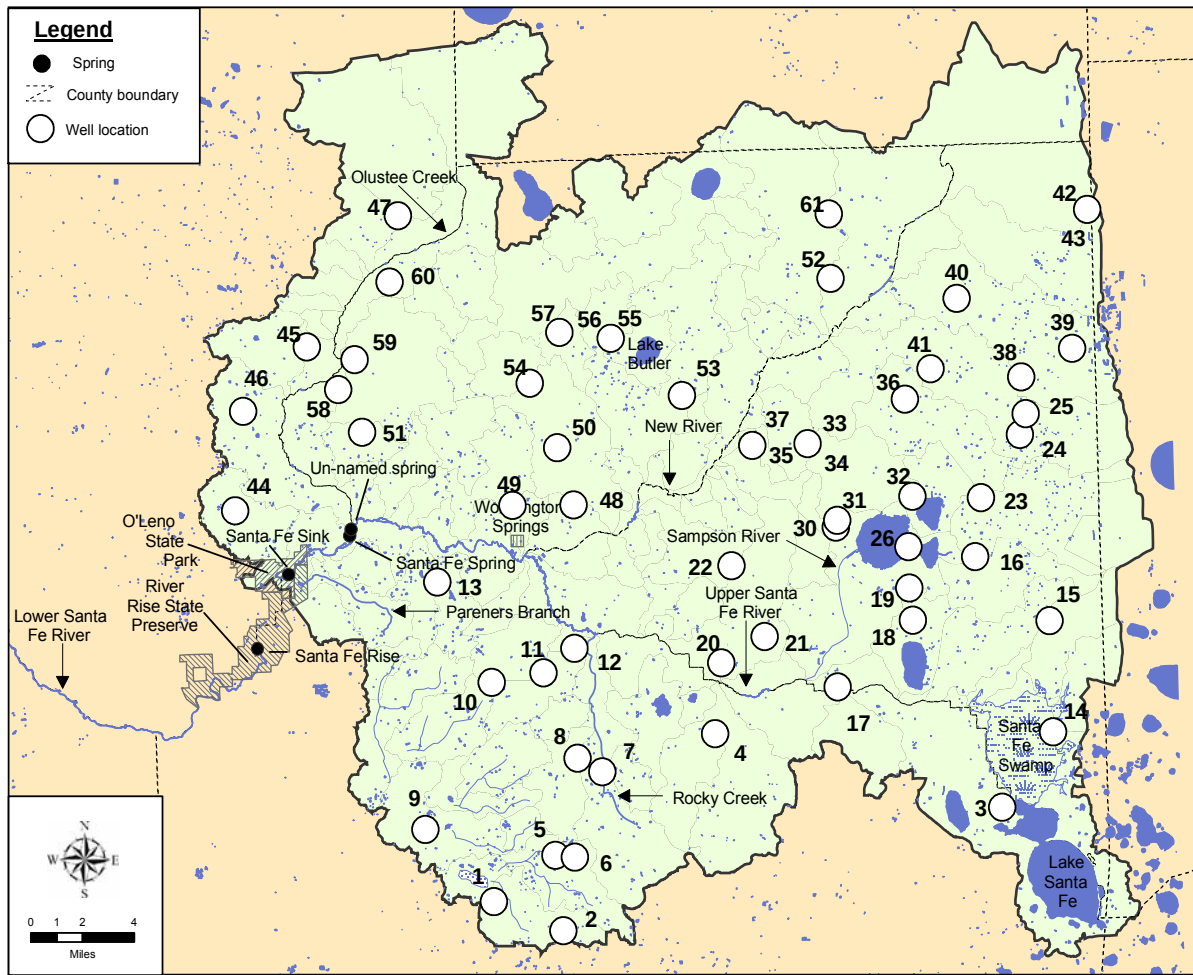


Figure 3-1. Locations of wells in the Upper Santa Fe River Basin.

3.2.2 Surfacewater Data

3.2.2.1 Stream Data

Stage and/or discharge data exist for 17 gaging stations in the Upper Santa Fe River Basin (Table 3-2; Figure 3-2). Table 3-2 presents the time ranges of data collection, the number of direct stage and discharge measurements, and the number of daily measurements of stage and discharge for each station. The data are presented graphically in Appendix B.

The most complete and extensive data sets are from several of the gages on the Santa Fe and New rivers. Other gage data typically reflect shorter time intervals.

Discharge data from springs near the lower reach of the upper Santa Fe River are limited. Worthington Spring has been dry in recent years, and Santa Fe Spring (COL61981) has limited discharge measurements.

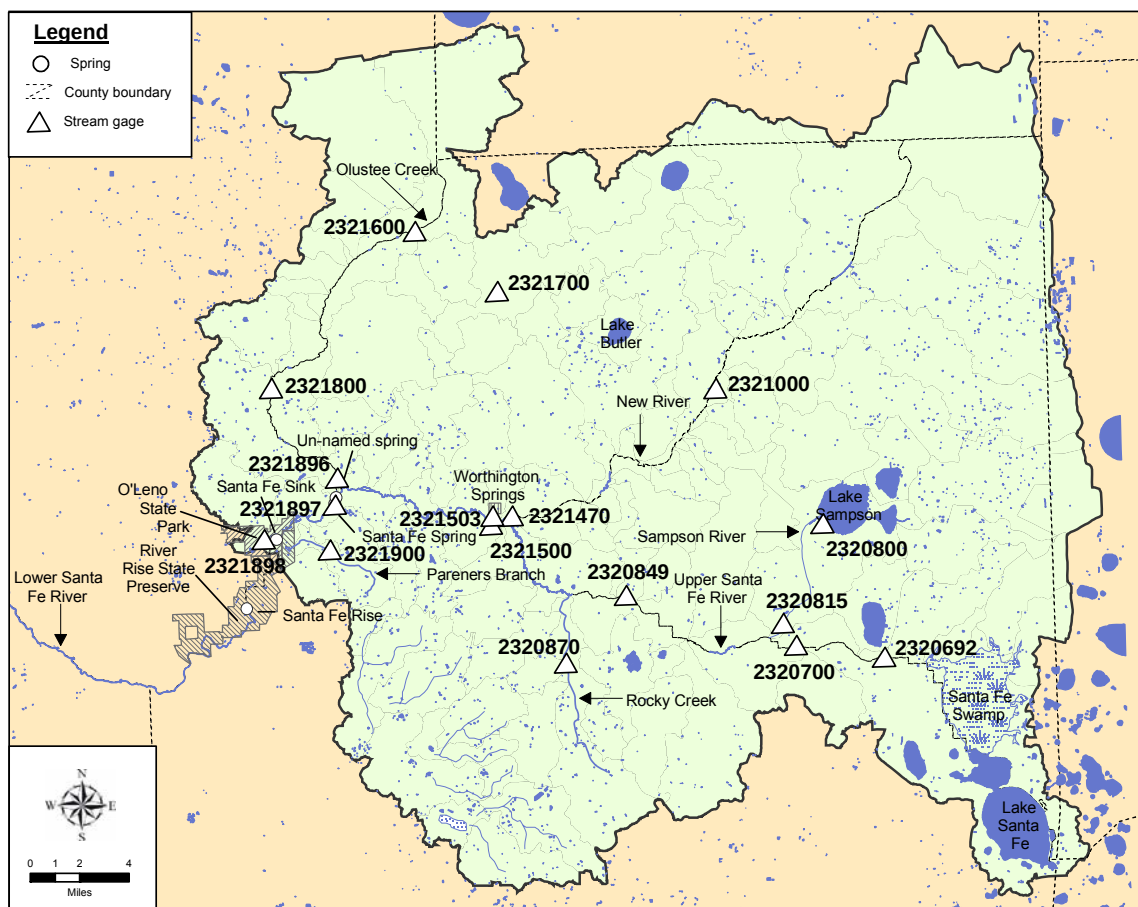


Figure 3-2. Stream gages in the Upper Santa Fe River Basin.

Table 3-1. Wells located within the Upper Santa Fe River Basin. (* Large gaps in data collection; shading indicates that daily water-level measurements have been obtained from the well)

Well	Site ID	Aquifer	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min. (ft msl)	Max. (ft msl)
1	-091938002	Floridan	08/13/1980	08/06/2004	Daily	7306	43.74	74.95
2	-091910002	Floridan	11/04/1977	04/06/1982	Quarterly	13	38.25	44.68
3	-082221001	Floridan	11/01/1976	05/14/2002	Quarterly*	27	72.00	81.73
4	-082003001	Floridan	11/01/1976	05/22/2002	Quarterly*	26	55.36	65.33
5	-081927001	Floridan	02/02/1977	05/15/1985	Quarterly*	11	35.50	46.93
6	-081926001	Floridan	02/14/1978	09/24/2004	Daily	8489	36.72	47.46
7	-081912004	Floridan	11/13/2000	08/12/2004	Quarterly	15	42.50	46.80
8	-081911001	Floridan	11/01/1976	05/22/2002	Quarterly*	24	39.10	48.48
9	-081823001	Floridan	11/01/1976	06/22/1985	Quarterly*	19	35.06	41.87
10	-071929003	Floridan	05/15/2001	03/25/2002	Yearly	2	41.30	41.72
11	-071927008	Floridan	06/05/1989	09/16/2004	Monthly*	70	39.15	46.83
12	-071923003	Floridan	11/13/2000	11/24/2003	Quarterly	12	40.46	46.16
13	-071801001	Floridan	05/22/2003	03/31/2004	Yearly	2	36.50	36.61
14	-082202001	Floridan	02/11/1988	09/15/2004	Daily	5734	70.75	83.53
15	-072215001	Floridan	11/01/1976	09/15/2004	Daily	7692	76.37	88.50
16	-072205001	Floridan	03/29/1988	08/10/2004	Monthly*	96	56.14	63.80
17	-072132001	Floridan	11/01/1976	09/17/2004	Daily	7929	55.80	69.15
18	-072114003	Intermediate	10/24/1995	09/14/2004	Monthly	102	133.69	143.79
19	-072111001	Floridan	11/01/1976	05/14/2002	Quarterly*	25	56.11	66.94
20	-072022001	Floridan	03/02/2001	04/20/2004	Yearly	3	54.10	58.00
21	-072013001	Intermediate	06/05/1989	09/14/2004	Monthly	180	133.34	141.11
22	-072002001	Floridan	02/12/1988	09/14/2004	Daily*	2025	52.50	65.50
23	-062229005	Intermediate	10/24/1995	09/14/2004	Monthly	109	134.75	140.95
24	-062210008	Intermediate	02/22/1996	02/23/1999	Monthly	33	137.06	144.29
25	-062210002	Floridan	05/17/2001	04/21/2004	Yearly	4	68.48	73.81
26	-062135004	Floridan	05/17/2001	04/23/2003	Yearly	3	57.81	61.30
27	-062129009	Intermediate	09/06/1995	08/26/1996	Monthly	13	134.42	136.24
28	-062129008	Intermediate	09/12/1995	08/26/1996	Monthly	12	134.42	135.83
29	-062129007	Intermediate	09/06/1995	09/14/2004	Monthly	115	127.90	138.76
30	-062129006	Intermediate	08/29/1995	02/29/1996	Monthly	10	134.81	136.77

Table 3-1 (cont.). Wells located within the Upper Santa Fe River Basin. (* large gaps in data collection; shading indicates that daily water-level measurements have been obtained from the well)

Well	Site ID	Aquifer	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min. (ft msl)	Max. (ft msl)
31	-062129002	Intermediate	08/29/1995	08/26/1996	Monthly	15	134.43	136.79
32	-062126007	Intermediate	09/27/1995	09/14/2004	Monthly	110	128.70	139.14
33	-062118005	Floridan	02/26/2001	04/28/2004	Yearly	3	60.02	64.67
34	-062118004	Surficial	10/25/1989	04/03/1998	Monthly*	16	135.21	144.85
35	-062118003	Floridan	10/25/1989	12/21/1990	Monthly	15	51.01	54.06
36	-062102001	Floridan	11/01/1976	09/16/2004	Daily	7946	52.63	66.09
37	-062014001	Intermediate	02/22/1996	09/14/2004	Monthly	107	119.46	130.12
38	-052234002	Intermediate	10/31/1995	09/14/2004	Monthly	106	135.59	144.31
39	-052225007	Intermediate	12/28/1995	09/14/2004	Monthly	102	152.46	160.70
40	-052218005	Intermediate	11/03/1995	09/14/2004	Monthly	105	125.10	134.70
41	-052136003	Intermediate	12/28/1995	09/14/2004	Monthly	106	126.30	135.12
42	-042236002	Surficial	06/05/1989	09/14/2004	Monthly	183	196.44	206.26
43	-042236001	Floridan	07/16/1987	09/14/2004	Daily*	494	50.16	62.83
44	-061722002	Floridan	09/26/2001	09/09/2003	Quarterly	6	31.54	35.96
45	-051819001	Floridan	11/01/1976	09/16/2004	Monthly	262	37.26	48.32
46	-051734001	Floridan	05/05/1977	09/09/2003	Quarterly*	27	29.81	39.32
47	-041827002	Floridan	08/19/1988	09/15/2004	Daily	5590	45.08	58.84
48	-061923002	Floridan	05/21/2003	04/26/2004	Yearly	2	53.41	54.45
49	-061920001	Floridan	11/01/1976	09/15/2004	Quarterly*	28	46.33	55.96
50	-061910004	Intermediate	02/22/1996	09/15/2004	Monthly	105	98.36	109.49
51	-061804001	Floridan	11/01/1976	05/19/1998	Quarterly*	23	39.39	47.04
52	-052108003	Surficial	06/05/1989	05/04/2004	Monthly*	24	120.80	129.65
53	-052033002	Intermediate	08/29/1995	09/15/2004	Monthly	111	117.14	127.06
54	-051933001	Floridan	11/01/1976	09/15/2004	Daily*	7525	48.77	62.19
55	-051924001	Intermediate	02/22/1996	09/23/2004	Monthly	102	123.28	133.73
56	-051922002	Surficial	06/05/1989	09/03/2004	Monthly	182	132.68	141.17
57	-051922001	Floridan	06/05/1989	09/01/2004	Monthly*	52	50.53	59.18
58	-051832002	Floridan	03/25/2002	03/25/2002	Yearly	1	42.37	42.37
59	-051828004	Floridan	05/05/2004	05/05/2004	Yearly	1	41.17	41.17
60	-051810004	Floridan	05/17/2001	04/26/2004	Quarterly*	9	38.09	43.44
61	-042132001	Floridan	11/01/1976	09/09/2003	Quarterly*	31	50.80	63.57

3.2.2.2 Precipitation Data

Precipitation data exist for numerous stations in the vicinity of the Upper Santa Fe River Basin. The date first and last measured, along with the largest rainfall total for a single month (or day) at that gage are presented in Table 3-3, and locations of the gages are shown in Figure 3-3. Note that gages outside of the basin, such as at Gainesville, are not included in this assessment. Where available, the data are presented graphically in Appendix C. Monthly precipitation data for seven gages located in the basin were included in the analysis. Daily records are available from the National Oceanic and Atmospheric Administration (NOAA) for the gages at Starke.

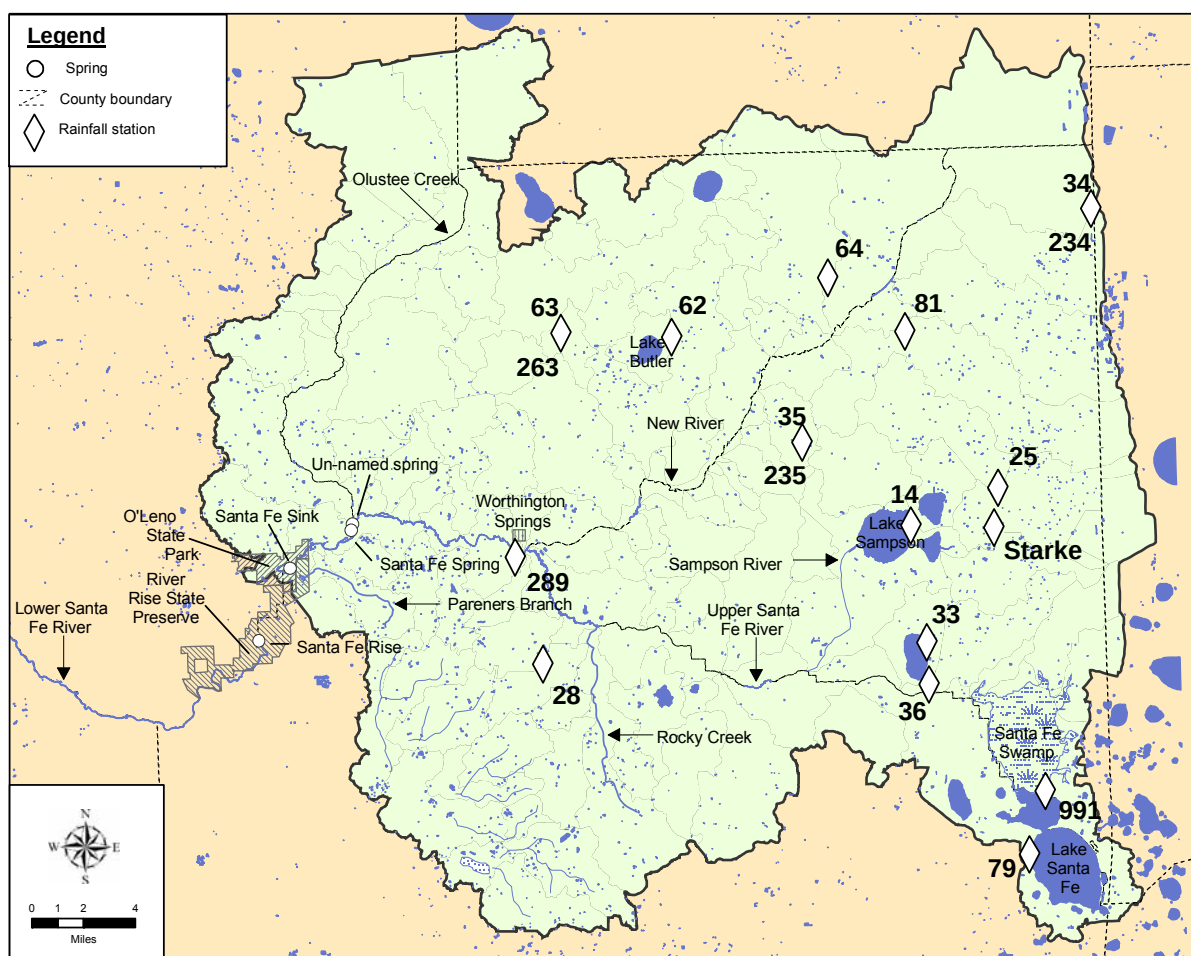


Figure 3-3 Rainfall stations in the Upper Santa Fe River Basin

3.2.3 Summary

The data available for the determination of minimum flows and levels for the Upper Santa Fe River Basin include:

- Excellent flow and level records for the Santa Fe River and somewhat more limited data for its tributaries;
- Very limited discharge data from springs within the basin;
- Predominately quarterly, monthly, or bi-monthly groundwater level data;
- Daily measurements at 9 monitoring wells which may provide the ability to correlate ground- and surfacewater levels;
- Groundwater permit information, by county;
- Monthly rainfall data from several stations; and
- Daily rainfall data from Starke.

Significant shortcomings of the available data include:

- The small amount of available stage and discharge data for springs;
- The gaps in long-term, stage and discharge data in some data sets from the tributaries of the Upper Santa Fe River; and
- Although water use estimates are available, by county, there are no data on actual water use and its distribution within the counties.

Table 3-2. Stage and discharge measurements available for the Upper Santa Fe River, its tributaries, and springs.

Stream Gauging Station			Period of Record	# of Measurements		# of Daily Values	
USGS Ref. #	SRWMD Site ID	Description		Stage	Discharge	Stage	Discharge
02320692	-072135001	Santa Fe River near Hampton	Data are infrequent and unusable for MFL development.				
02320700	-072132002	Santa Fe River near Graham	08/07/1957-12/03/2004	414	352	15430	16831
02320800	-072104008	Sampson River at Sampson City	07/09/1998-12/03/2004	159	35	1853	1709
02320815	-072129003	Sampson River at Graham	04/17/1997-07/04/2000	16	16	None	None
02320849	-072017001	Santa Fe River near Brooker	05/22/1996-12/18/2001	46	13	None	None
02320870	-071935002	Rocky Creek near Lacrosse	Data are infrequent and unusable for MFL development.				
02321000	-062002001	New River near Lake Butler	01/01/1950-09/30/2004	125	125	11615	12763
02321470	-061933004	New River at Worthington Springs	01/09/1998-09/22/1998	4	5	None	None
02321500	-061932001	Santa Fe River at Worthington Springs	10/01/1931-09/30/2004	474	129	24924	26664
02321503	-061932027	Worthington Springs at Worthington Springs	Spring is normally dry and limited data are unusable for MFL development.				
02321600	-041836001	Olustee Creek near Lulu	04/29/1997-09/29/2004	67	19	670	730

Table 3-2 (cont.). Stage and discharge measurements available for the Upper Santa Fe River, its tributaries, and springs.

Stream Gauging Station			Period of Record	# of Measurements		# of Daily Values	
USGS Ref. #	SRWMD Site ID	Description		Stage	Discharge	Stage	Discharge
02321700	-051916004	Swift Creek near Lake Butler	09/01/1957-06/04/1996	46	54	1070	1125
02321800	-061701001	Olustee Creek near Providence	10/01/1957-06/04/1996	28	34	1063	1095
02321896	-061820003	Olustee Creek near Mikesville	05/08/1996-10/15/2001	63	26	None	None
02321897	-061829002	Santa Fe Spring (COL61981)	08/23/1999-03/11/2003	None	9	None	None
02321898	-071702003	Santa Fe River at O'Leno State Park	03/12/1980-09/30/2004	6632	104	None	2084
02321900	-071805004	Pareners Branch near Bland	09/30/1992-10/17/1996	28	28	1428	1476

Table 3-3. Available precipitation data in the Upper Santa Fe River Basin

Station	Type	First Measured	Last Measured	Maximum Event (Date)
Lake Sampson (14)	Monthly	October 1996	May 2004	12.29 in. (Feb. 1998)
Starke (25)	Monthly	January 1958	April 2004	17.21 in. (Aug. 1967)
Hampton Lake (33)	Monthly	November 2000	May 2004	9.58 in. (June 2001)
Louis Hill Tower (34)	Monthly	January 1976	May 2004	20.9 in. (Sept. 1979)
New River Tower (35)	Monthly	January 1976	May 2004	17.65 in. (June 1983)
Lake Butler (62)	Monthly	January 2001	April 2004	12.1 in. (June 2001)
Heilbronn (81)	Monthly	August 1997	May 2004	14.23 in. (June 2003)
Starke (NOAA)	Daily	February 1, 1958	December 31, 2004	5.90 in. (May 4, 1978)

3.3 Data Simulation and Analysis

3.3.1 Methods

3.3.1.1 Simulating River Data

The datasets from the gages on the Upper Santa Fe River consist of continuous records within the monitoring period for discharge, while the record for stage is typically somewhat discontinuous due to gage recorder malfunctions. The USGS computes an estimated discharge to fill in these data gaps in the discharge record, though stage data is not estimated. Therefore, the first step in constructing complete, continuous data sets for the gages on the Upper Santa Fe River was to construct rating curves relating the stage to the discharge. To accomplish this, the stage-discharge curves were broken into several portions based on apparent breakpoints between trends. For example, a linear trend may best describe the relationship between stage and discharge at low flows, whereas a polynomial may be required to characterize the relationship between the data at higher flows. This allowed for the calculation of estimated stages from the USGS estimated discharges.

The most complete data set on the Upper Santa Fe River is for the gage at Worthington Springs, which has been operating continuously since 1932. Monitoring at all other gages was begun at a later date, discontinued for some period, or both. Data were simulated for these gages by developing regression equations that relate the measured stage or discharge (whichever exhibits a more significant relationship) to data from the Worthington Springs gage. The first step in this process was cross-correlation (Davis, 1988) of the data from the two gages to determine the appropriate lag time between the data. The data were then cross-plotted incorporating this lag, and the equation which best describes the relationship between the data was determined (e.g., linear, polynomial, logarithmic). Once the stage or discharge had been estimated from a regression equation, the missing value (i.e. discharge if stage were estimated via regression) was determined by a rating curve, as described above.

It is important to understand that these regression equations were not intended for statistical inference or direct trend detection. They were used to fill data gaps. As such, autocorrelation between data points is an advantage, not a liability. Highly correlated data sets were preferred whenever possible in order to synthesize data to fill data gaps.

Statistical significance of regressions was determined by the coefficient of determination (R^2). R^2 values ≥ 0.90 were considered significant in that at least 90 percent of the variability in the stage or discharge data had been accounted for. In addition, residuals analyses were conducted to identify systematic trends and other sources of error. Where there are residual trends, such as systematic under estimation of flood peaks in a regression, the amount of uncertainty introduced to the analysis was evaluated and the results rated as “moderately good.” The source of the uncertainty and its effects are then discussed.

3.3.1.2 Predicting Spring Discharge

There is one spring, COL61981 also known as Santa Fe Spring, on the MFL 2005 priority list for the Upper Santa Fe River. This spring is an estavelle, meaning that it discharges to the river during periods of low river stage and discharge and the river backflows into the aquifer through the spring during river flood.

Discharge from the spring is related to both river and aquifer water levels and requires the use of a multiple linear regression for data simulation. Discharge from Santa Fe Spring was simulated through the use of a step-wise, multiple linear regression (Davis, 1988). The regression was begun with all potential “independent” variables included. A backward, stepwise regression systematically removed each variable that exceeded the designated alpha value of

0.05. The result of the step-wise regression is a set of variables and associated coefficients for a polynomial equation that relates the statistically significant independent variables to the dependent one (spring discharge). The polynomial can then be applied for the entire period of record of the independent variables in order to generate a simulated period of record for Santa Fe Spring discharge.

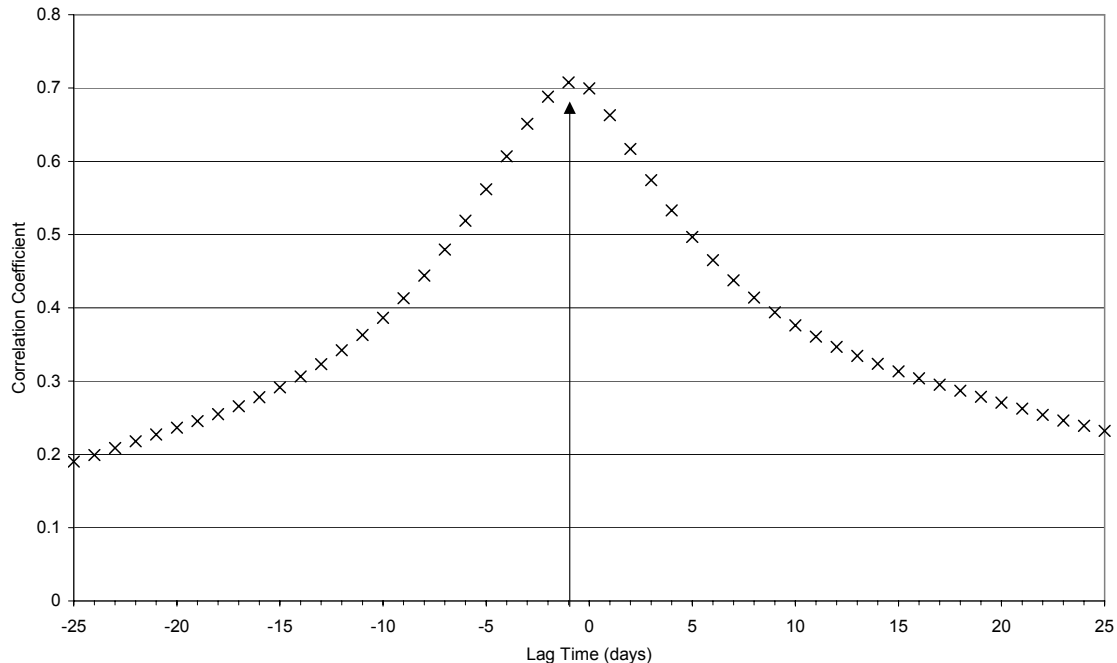


Figure 3-4. Cross-correlation between stage data from the Graham and Worthington Springs gage. A peak at –1 days indicates stage at Worthington Springs is most correlated to stage at Graham one day earlier.

3.3.1.3 Uncertainty Associated With Data Simulation

The Santa Fe River and related portions of the Surficial and Floridan Aquifer form a complex hydrologic system. Due to this level of complexity, there is a level of uncertainty that goes along with simulating data for the Upper Santa Fe River. This uncertainty is additive at each step in the data simulation process. Even if the uncertainty associated with each step in the process of data simulation is kept to a minimum, by the time the last step is reached, the uncertainty can compound. As will be seen in the results (Section 3.3), uncertainty is minimized during each phase of data simulation, but the string of simulations and the inherent complexities of the system result in some uncertainty, particularly with the peak stage and discharge values.

3.3.1.4 Use of Simulated Gage Data

The simulated data are used to fill in the period of record dataset for the gage of interest so that the period of record utilized in consideration of MFL development includes observed data, where available, with simulated data filling in any gaps back to the beginning of monitoring at the gage(s) used as a source of independent variables for data simulation.

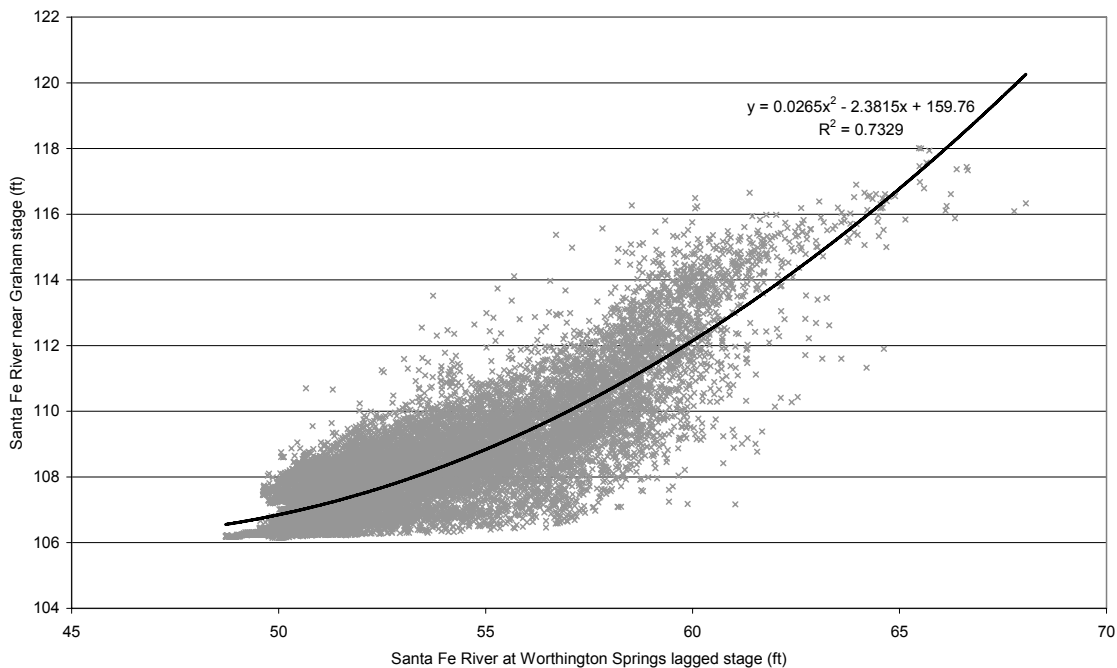


Figure 3-5. Cross-plot of stage at Graham versus stage at Worthington Springs for entire period of record.

3.3.2 Santa Fe River

3.3.2.1 Santa Fe River near Graham

The stream gage located on the Santa Fe River near Graham was originally installed in 1957 and has been continuously monitored since. Cross-correlation of stage data indicates that the stage recorded at Graham is most correlated to stage at Worthington Springs recorded one day later (Figure 3-4).

A cross-plot of the stage at Graham and the Worthington Springs stage data lagged one day reveals a relatively poor, though statistically significant, relationship (Figure 3-5). A polynomial trend line resulted in the best fit to the data, with an R^2 value of 0.7296.

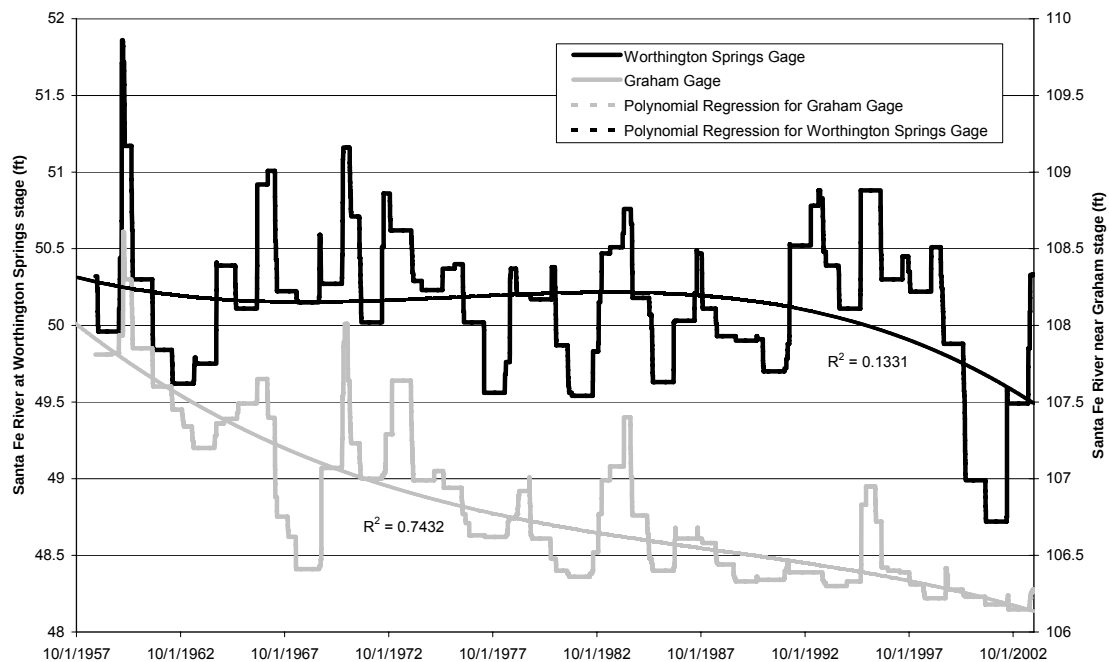


Figure 3-6. 365-day running minimum stage at the Graham and Worthington Springs gages.

A trend analysis was performed in an attempt to determine why data from these two gages are not more closely related. Figure 3-6 shows the 365-day running minimum stage for the two gages, along with cubic, polynomial trend lines fit to these data. As this graph shows, the minimum stage at the Graham gage has experienced an apparent, systematic downward trend over the period of record. This is likely due to a combination of factors including long-term ditching and drainage in the headwaters of the river basin, consumptive groundwater use, and, possibly, recovery of the forests after logging and partial denudation of the drainage basin or headward erosion in the upper parts of the basin. With the exception of the low minimums in the early 2000s, minimum stage at the Worthington Springs gage has remained relatively constant and variations appear to have been caused by droughts. The downturn in the 2000s is a result of the record drought during that period.

Figure 3-6 suggests that the stage at the Graham and Worthington Springs gages was more closely related during the period of 1957-1962, which is before the gradual reduction of the minimum stage at Graham began. A cross-plot of the Graham stage and the lagged Worthington Springs stage during this time period (Figure 3-7) confirms that the data exhibit a significantly better relationship (R^2 of 0.8615) than for the entire period of record as a whole.

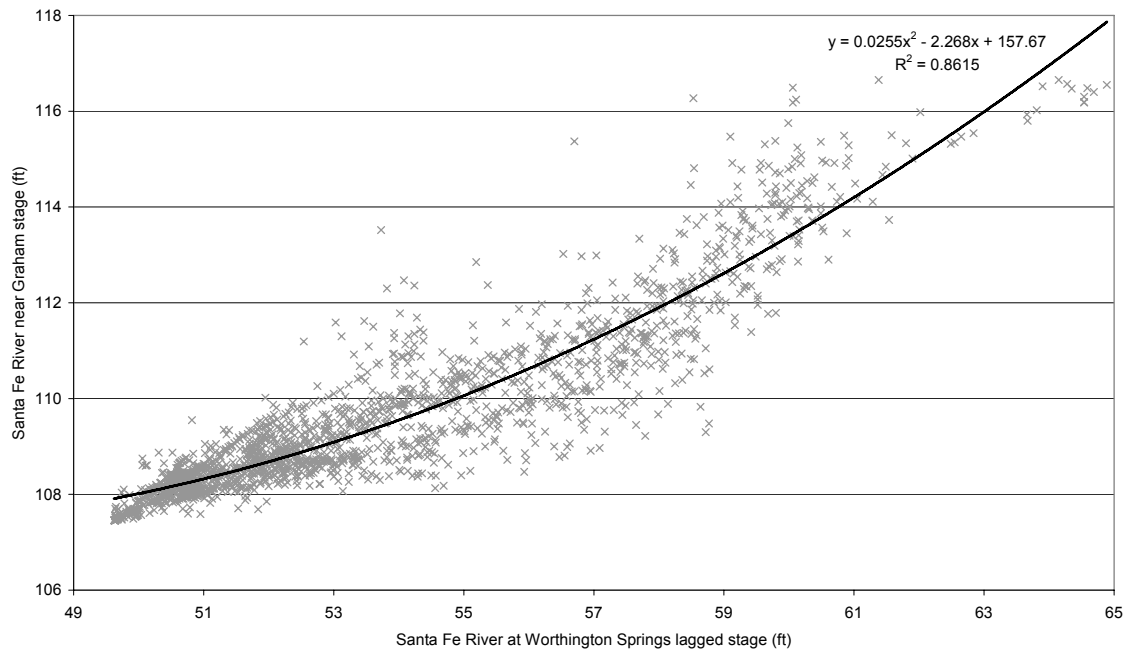


Figure 3-7. Cross-plot of stage at Graham versus stage at Worthington Springs for water years 1958 through 1962.

The Graham gage has been continuously monitored since the 1958 water year, so data only need to be simulated for the time prior to the advent of monitoring. The polynomial relationship shown in Figure 3-7 was used to simulate data for the Graham gage from the beginning of data collection at the Worthington Springs gage in 1932 to 1962. This process assumes that there was no significant trend in the stage at the location of the Graham gage prior to 1957, even though a significant trend was found after 1957. As a check on the ability to simulate stage at Graham from Worthington Springs historic data, a comparison of the daily value stage data to the simulated data for the water years 1958 through 1962 is shown in Figure 3-8. The match is generally excellent, particularly at low stages, with some of the flood peaks being moderately over- or underestimated.

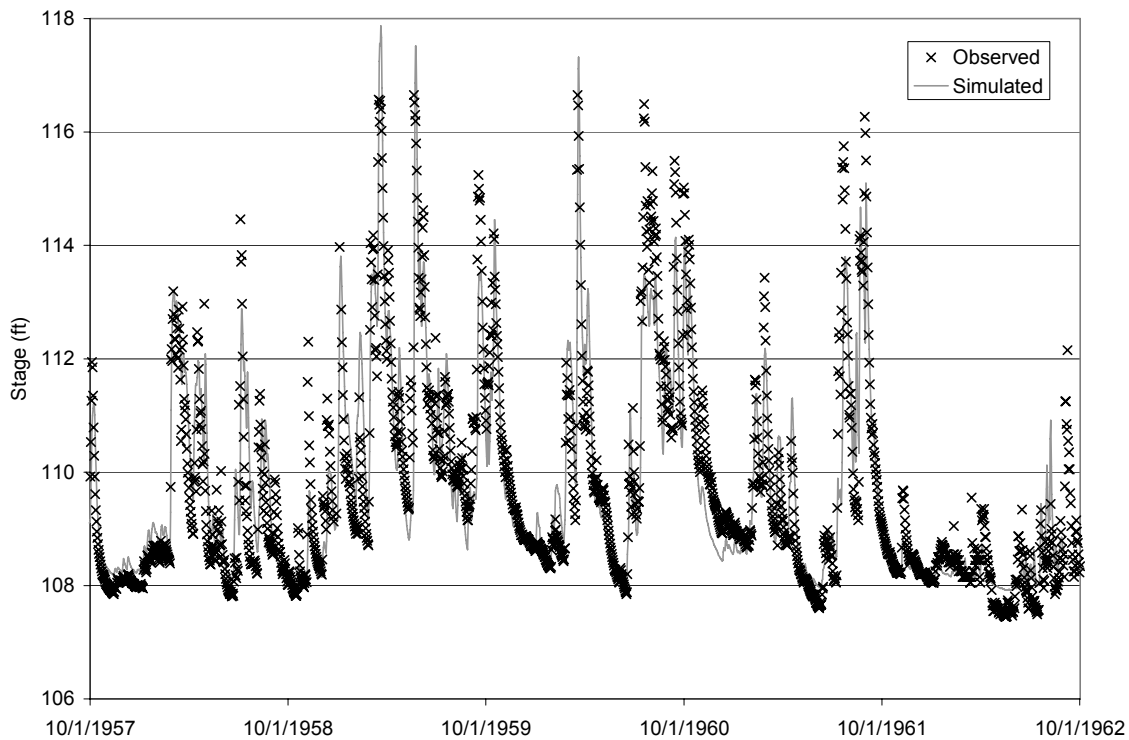


Figure 3-8. Comparison of observed and simulated stage for the Graham gage during water years 1958-1962.

A rating curve was developed for the Graham gage from the stage and discharge data collected during water years 1958-1962 in order to simulate discharge from the simulated stage data. A comparison of the daily value discharge data to the simulated data for the water years 1958 through 1962 is shown in Figure 3-9. Again the match is generally excellent, particularly at low stages, with some of the flood peaks being moderately over- or underestimated. This process allowed for extension of the period of record for the Graham gage back to 1932 or an increase in the period of record from 47 years to 72 years.

3.3.2.2 Santa Fe River near Brooker

The stream gage located on the Santa Fe River near Brooker has never been continuously monitored. As a result, cross-correlation of the Brooker data with the Worthington Springs data is not possible. This gage is located between the Graham and Worthington Springs gages (Figure 3-2), which exhibit a lag time in flow of one day. Therefore, it is assumed that the lag between the hydrologic events at the Brooker gage and the Worthington Springs or Graham gages is less than one day, and, therefore, responses at Brooker are essentially contemporaneous with events at the Graham and Worthington Springs gages.

Measured stage at the Brooker gage (h_{0849}) was related to stage at the Worthington Springs gage (h_{1500}) and stage at the Graham gage (h_{0700}) through a multiple linear regression. The final equation used to simulate a period of record of stage for the Brooker gage is:

$$h_{0849} = 18.9 + 0.4162(h_{1500}) + 0.3297(h_{0700}), R^2 = 0.853.$$

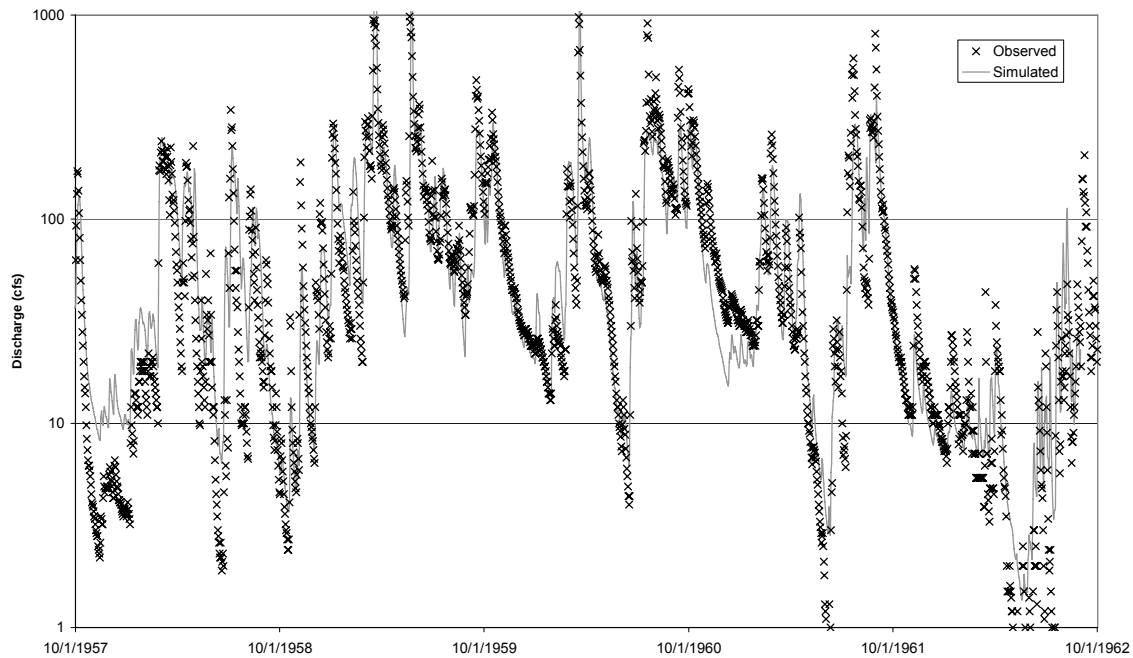


Figure 3-9 Comparison of observed and simulated discharge for the Graham gage during water years 1958-1962.

A comparison of the measured stage data to the simulated data is shown in Figure 3-10. The match is generally good, with some of the measurements being moderately over- or underestimated.

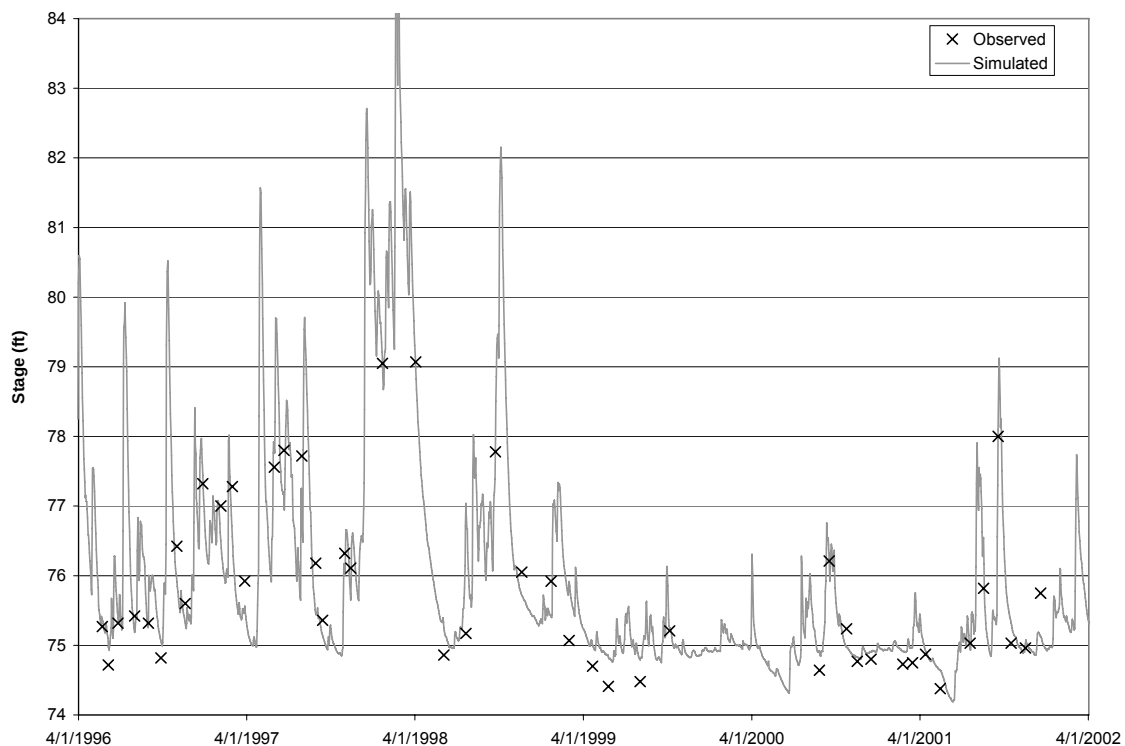


Figure 3-10 Comparison of observed and simulated stage for the Brooker gage.

Relative to stage data, significantly fewer discharge measurements were available for the Brooker gage (Table 3-2). In order to maximize the available data, a rating curve was developed (Figure 3-11), and used to generate discharge data from the measured stage data for times when no discharge measurements were available.

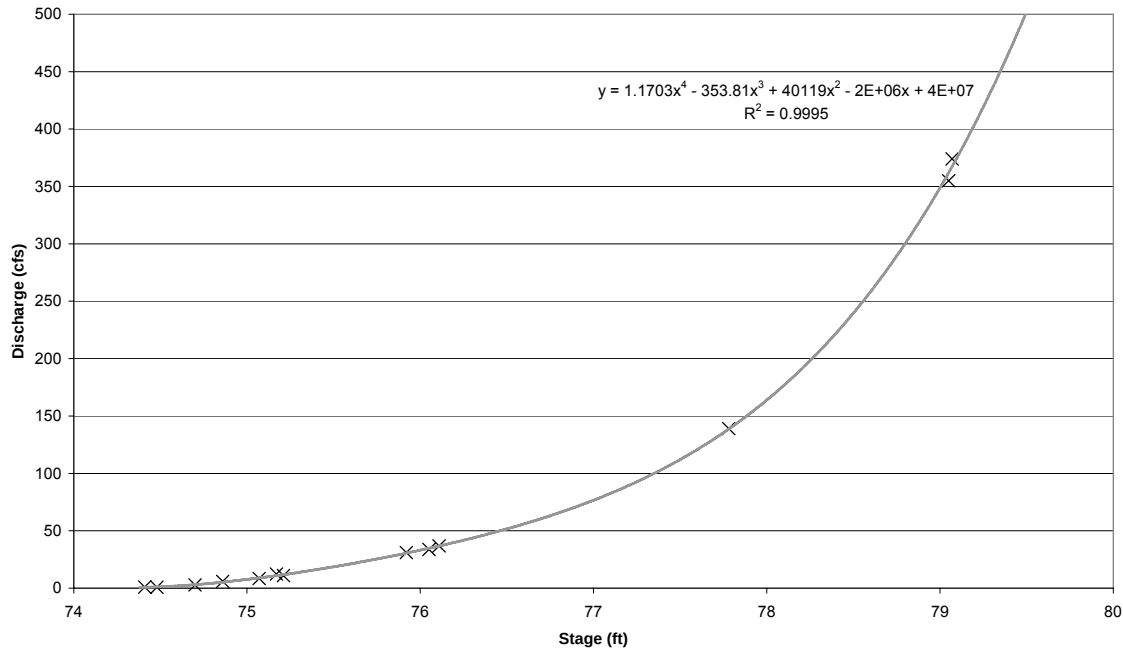


Figure 3-11. Relationship between measured stage and discharge for the Brooker gage.

The combined discharge measurements and discharge simulated from stage measurements at the Brooker gage (Q_{0849}) were related to discharge at the Worthington Springs (Q_{1500}) and Graham (Q_{0700}) gages through a multiple linear regression. The final equation used to simulate a period of record of discharge for the Brooker gage is:

$$Q_{0849} = 0.2432(Q_{1500}) + 1.017(Q_{0700}) \quad (R^2 = 0.912).$$

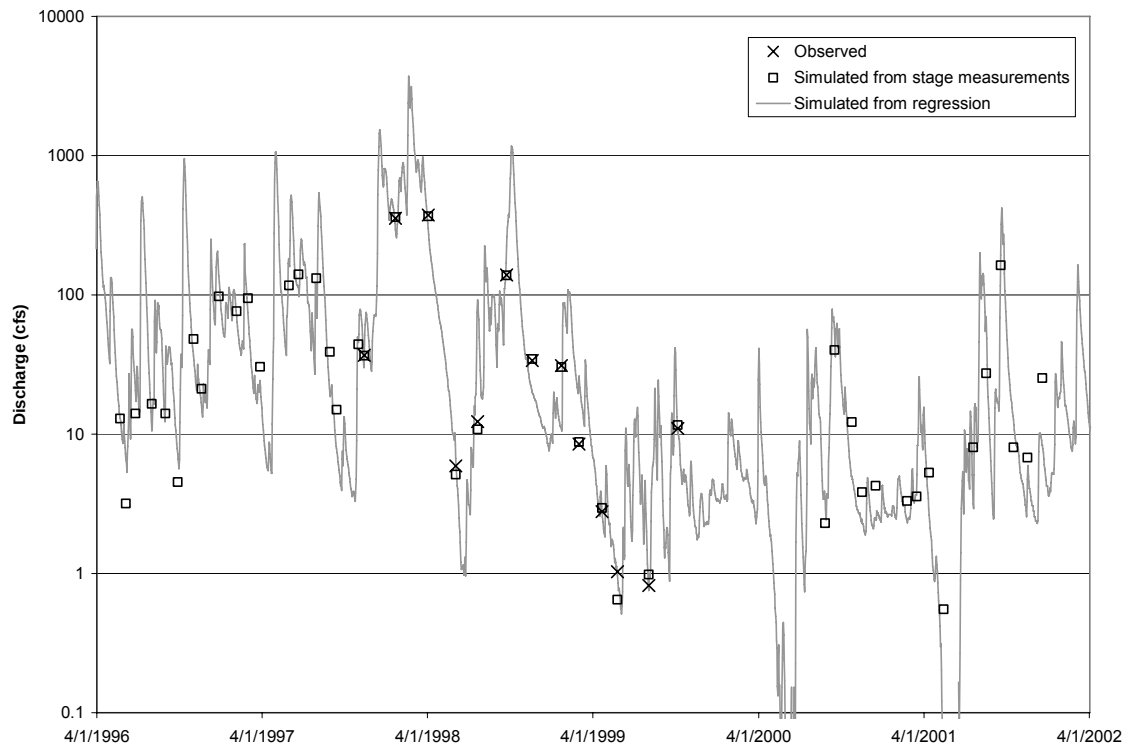


Figure 3-12. Comparison of observed and simulated discharge for the Brooker gage.

A comparison of the measured discharge data to the simulated data is shown in Figure 3-12. Again, the match is generally good, particularly at low discharge. This process allowed for simulation of a full period of record for the Brooker gage back to 1932.

3.3.2.3 Santa Fe River at O'Leno State Park

The stream gage located on the Santa Fe River at O'Leno State Park has been continuously monitored since 1997 when the District installed a continuously recording gage. Park employees have been sporadically recording the river stage, measured at a staff gage and the footbridge over the river, since the 1980's.

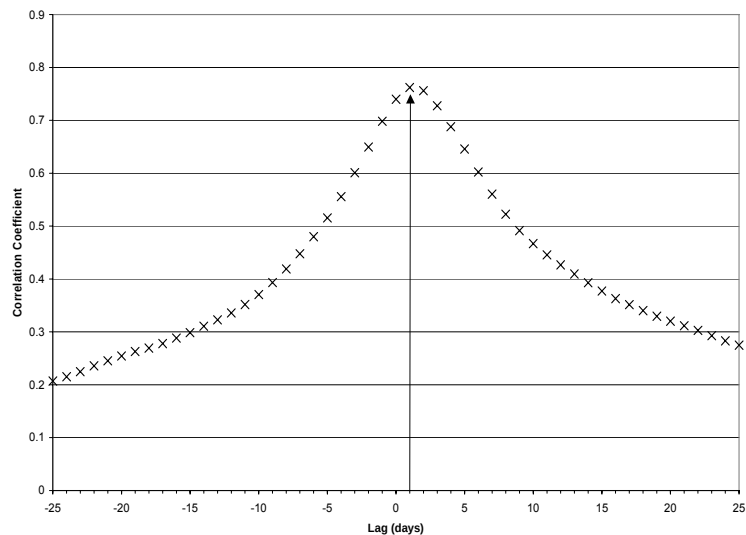


Figure 3-13. Cross-correlation between O'Leno and Worthington Springs gage. Peak at +1 days indicates stage at Worthington Springs is most correlated to stage at O'Leno one day later.

Cross-correlation of stage data indicates stage recorded at O'Leno State Park is best correlated to stage at Worthington Springs recorded one day earlier (Figure 3-13).

A cross-plot of the O'Leno stage data and the lagged Worthington Springs stage data reveals a complex, though statistically significant ($R^2=0.896$), relationship (Figure 3-14). A fourth-order polynomial trend line resulted in the best fit to the data, with an R^2 value of 0.896. The polynomial relationship shown in Figure 3-14 was used to simulate stage data for the O'Leno gage for the period of record of the Worthington Springs gage. A comparison of the daily stage data to the simulated data for the water years 1985 through 2004 is shown in Figure 3-15. The match is generally excellent, particularly at low stages, with some of the flood peaks being moderately over- or underestimated.

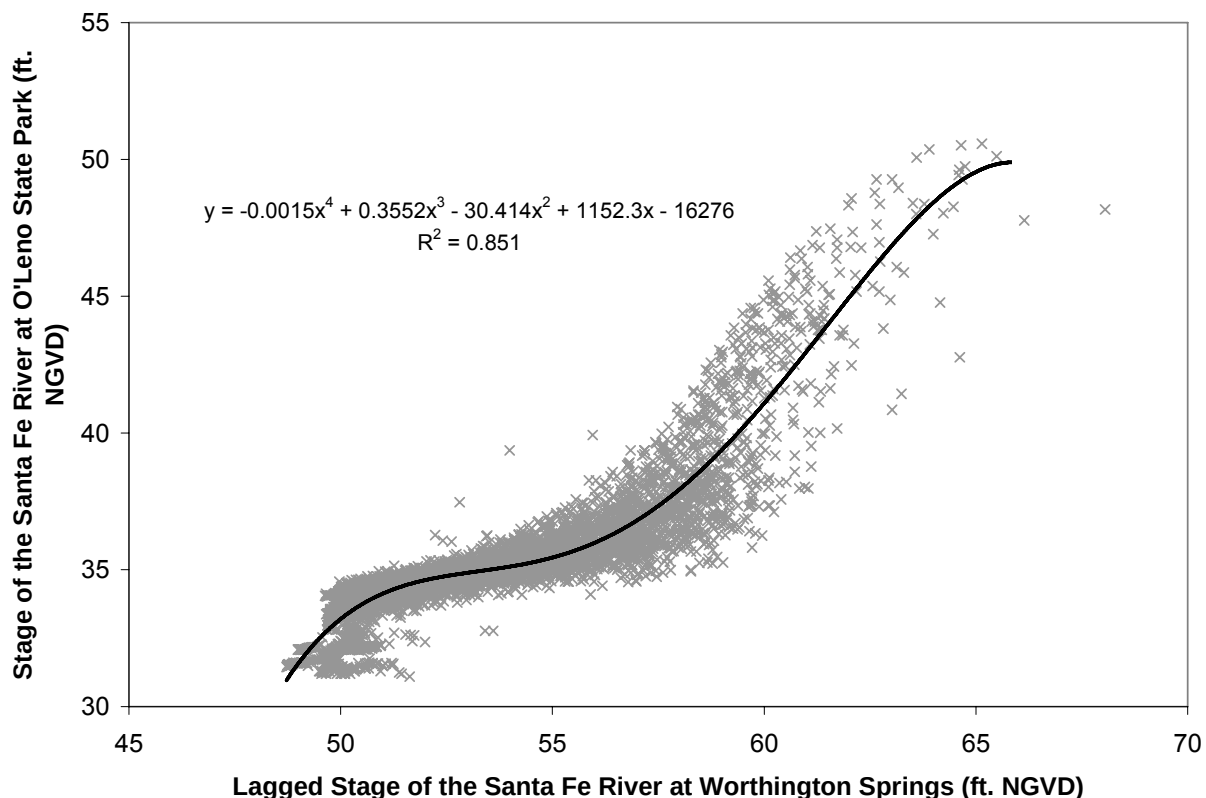


Figure 3-14. Comparison of stage at the O'Leno gage with lagged stage at the Worthington Springs gage.

A rating curve was developed for the O'Leno gage using the stage and discharge data collected since the automatic recording gage was installed in 1997. However, the best data fit to this curve that could be obtained was only marginally good (Figure 3-16). Apparently, the interaction of the Santa Fe River with the Upper Floridan Aquifer System at the River Sink downstream from the O'Leno gage creates a more complex discharge patterns (i.e., patterns resulting from backwater effects and overland flow during extreme floods) than the simple stage-discharge relationships observed at upstream gages.

In order to better represent the pattern of discharge at the O'Leno gage, data from gages in the Lower Santa Fe River were obtained and analyzed for potential relationships with the O'Leno gage data. Discharge at the Santa Fe River at River Rise gage (USGS Site # 02321910) has only been measured about 50 times. The nearest downstream gage with a long-term, continuous period of record is the gage on the Santa Fe River near Fort White (USGS Site # 02322500), located ~12.5 miles downstream from the River Rise. A significantly shorter, though continuous, record is also available for the gage on the Santa Fe River at US 441 near High Springs (USGS Site # 02321975), located approximately 2.5 miles downstream from the River Rise.

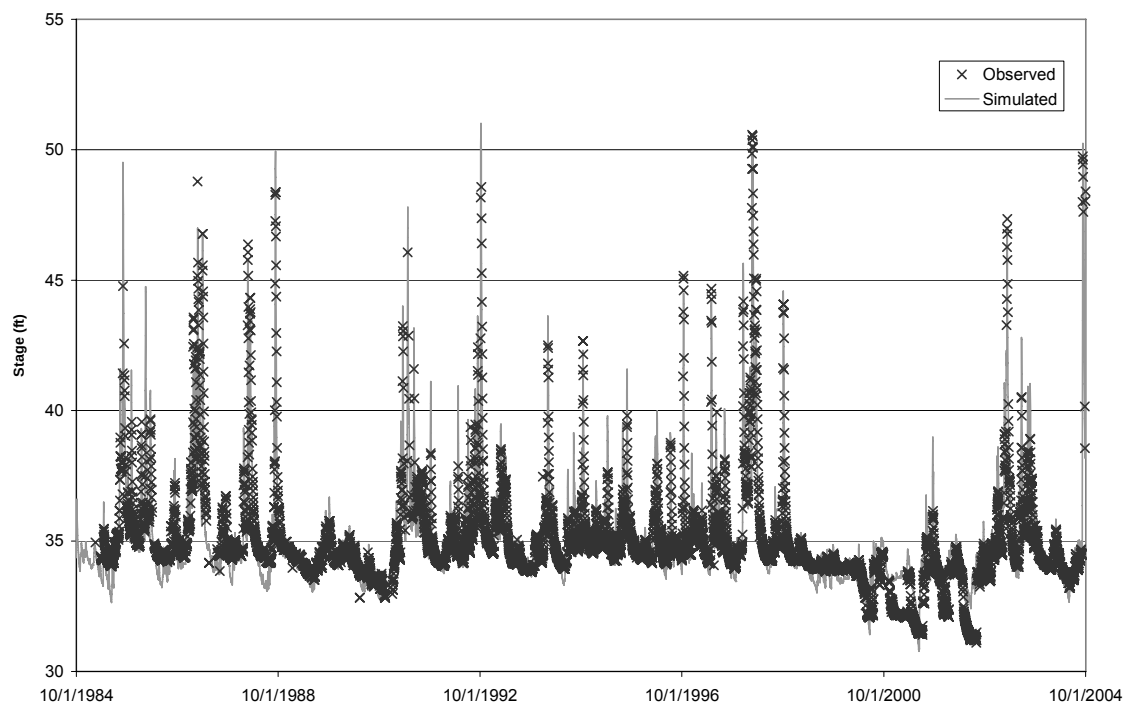


Figure 3-15. Comparison of observed and simulated stage data for the O'Leno gage.

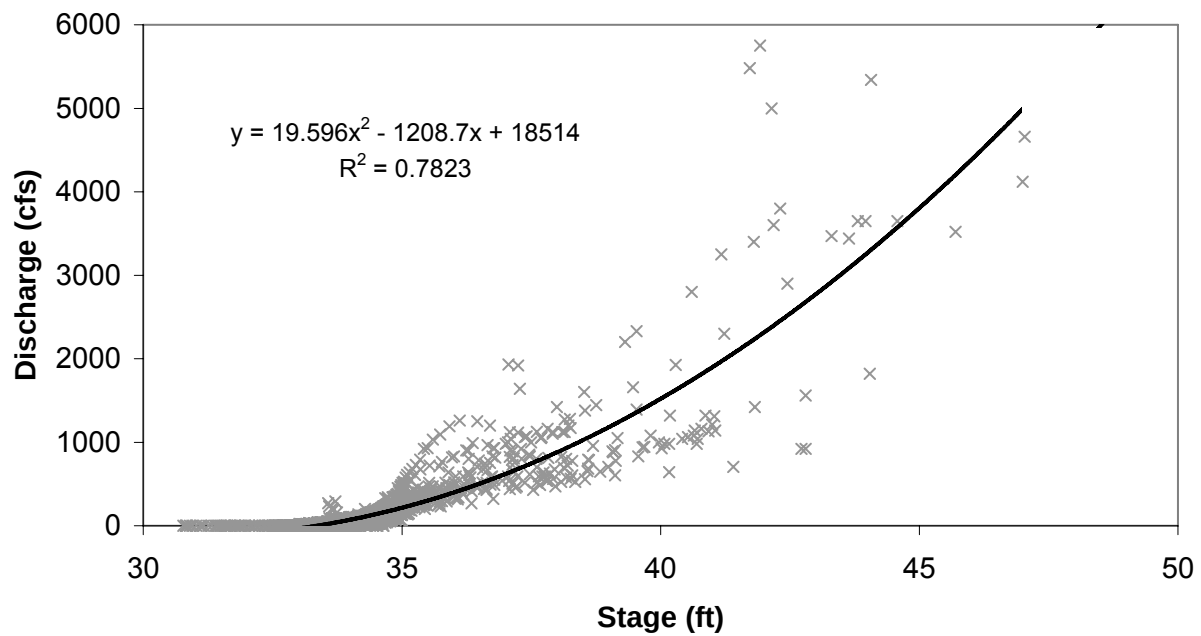


Figure 3-16. Rating curve for the gage on the Santa Fe River at O'Leno State Park

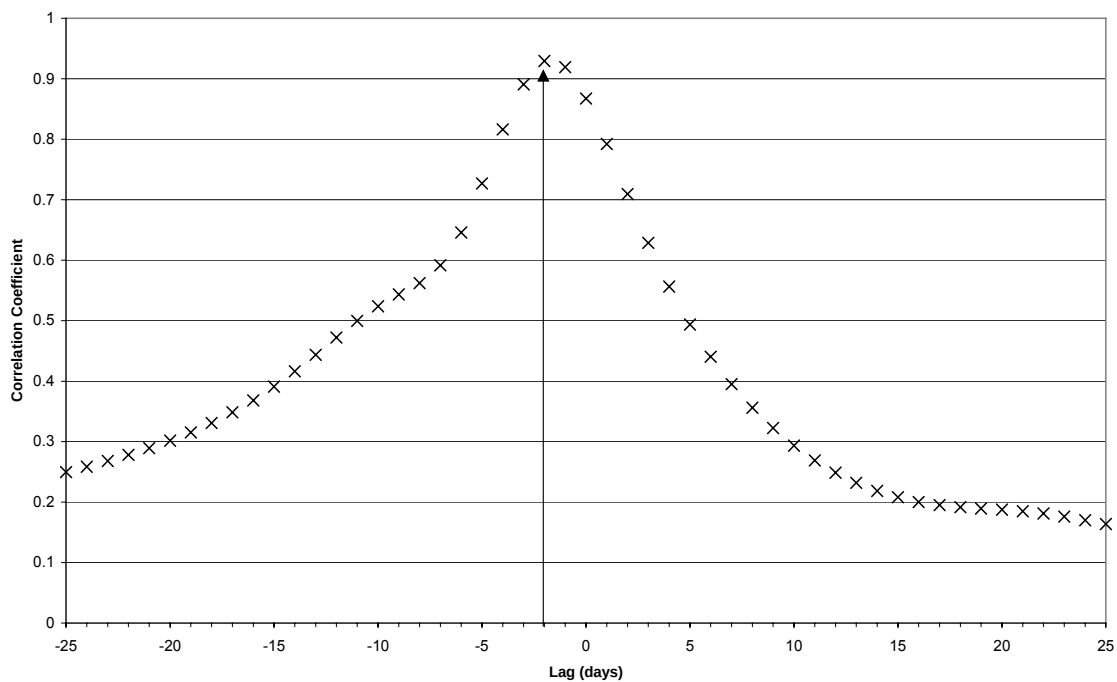


Figure 3-17. Cross-correlation between Fort White and Hwy 441 gages. The peak at -2 days means that Fort White discharge is most correlated to US 441 discharge measured 2 days earlier.

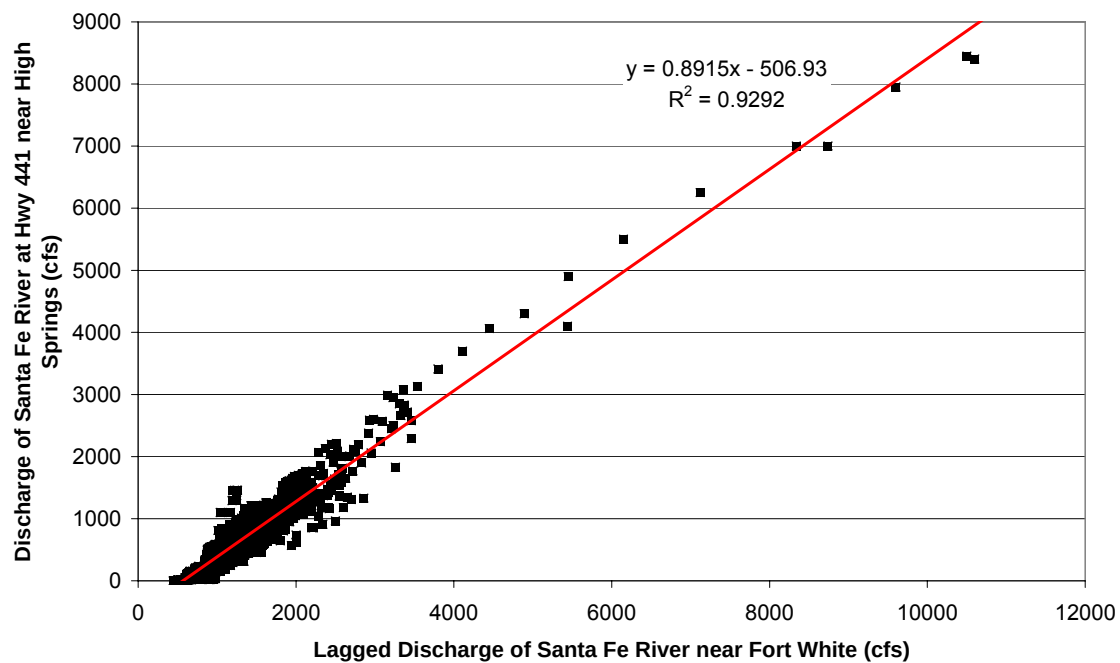


Figure 3-18. Comparison of discharge at the Hwy 441 gage with lagged discharge at the Fort White gage.

Cross-correlation of discharge data from the Fort White and US 441 gages indicates that the best correlation occurs at a lag of two days (Figure 3-17). Cross-plotting the US 441 and the lagged Fort White discharge data reveals an excellent linear relationship between the data

(Figure 3-18). This relationship was used to extend the US 441 gage discharge record back to 1932, matching the period of record for the Fort White gage.

Cross-correlation of the discharge data for the River Rise gage is not possible because of the sporadic data record. However, the close proximity between the Hwy 441 and River Rise gages suggests that any lag between them would be considerably less than one day.

Figure 3-19 shows a cross-plot of the contemporaneous US 441 and River Rise discharge data. An excellent fit to these data was obtained with a polynomial trend line. However, this polynomial equation predicted unreasonably large discharges at the River Rise during times of peak discharge in the river. For this reason, a linear relationship was developed for the higher measured discharge values, and this was used to simulate discharge at the River Rise for times when discharge at the US 441 gage was greater than 3,000 cfs. The polynomial equation was used to simulate discharge at the River Rise when US 441 discharge was less than 3,000 cfs. The result is a continuous period of record for the River Rise gage back to 1932.

Cross-correlation of the simulated River Rise discharge and the measured O'Leno discharge indicates a lag of three days between hydrologic events at the two gages (Figure 3-20). A multiple linear regression was developed for simulating O'Leno discharge (Q_{1898}) from lagged River Rise discharge ($Q_{1910Lag}$), discharge at the Santa Fe River at Worthington Springs (Q_{1500}), and Olustee Creek near Providence (Q_{1800}) discharge. The resulting equation is:

$$Q_{1898} = 0.455(Q_{1910Lag}) + 0.448(Q_{1500} + Q_{1800}), \quad R^2 = 0.8957.$$

The predictive ability of this equation is significantly better than the rating curve developed for this gage ($R^2 = 0.7823$).

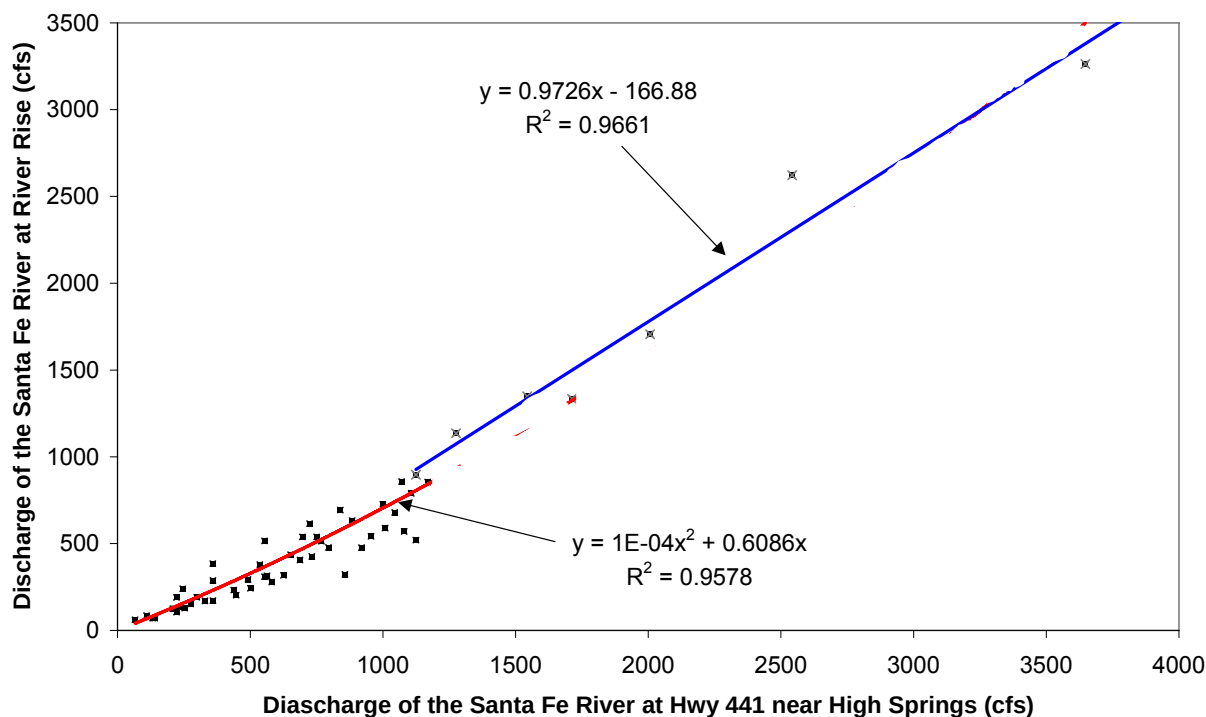


Figure 3-19. Cross-plot of discharge at the River Rise gage versus discharge at the Hwy 441 gage.

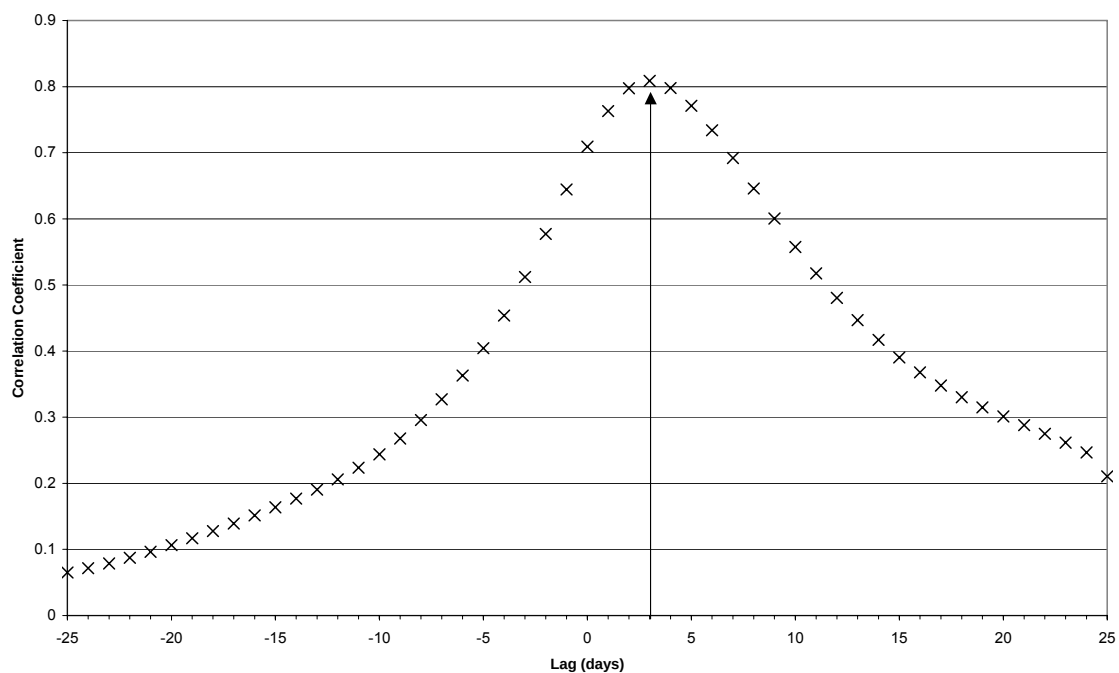


Figure 3-20. Cross-correlation between River Rise and O'Leno gages. Peak at +3 days indicates the discharge at O'Leno is most correlated to discharge at the River Rise 3 days later.

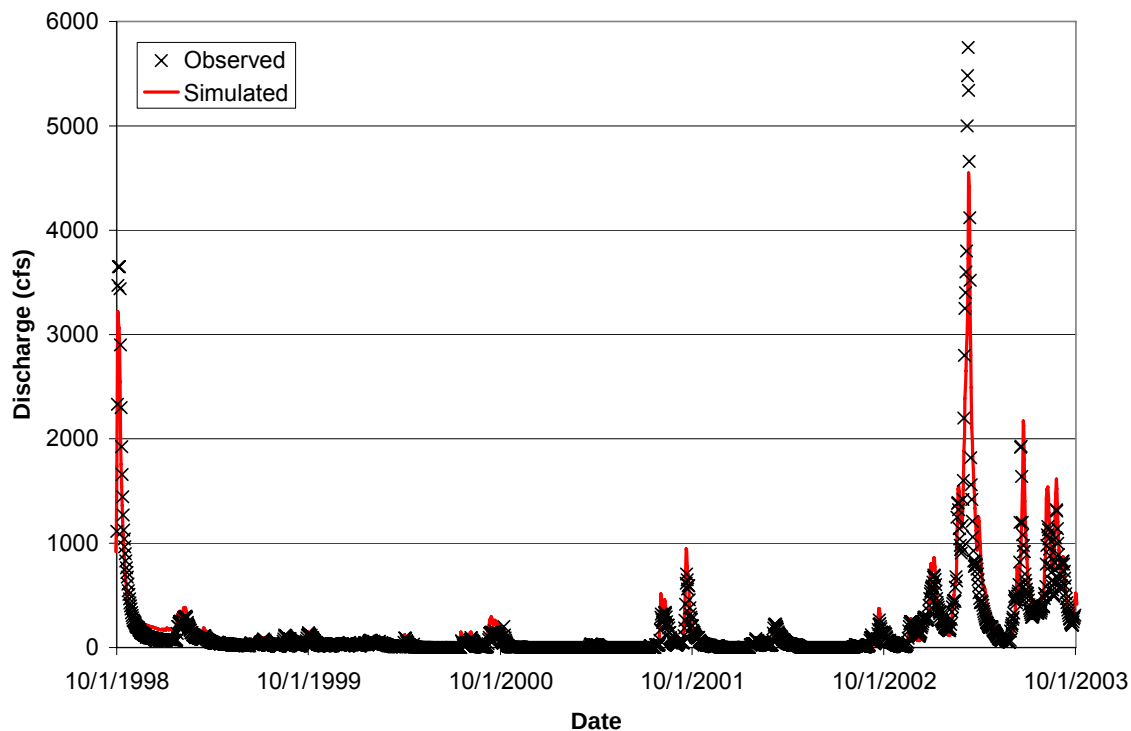


Figure 3-21. Comparison of observed and simulated discharge data for the O'Leno gage.

This regression equation was used to generate discharge data at O'Leno from the discharge data at the upstream and downstream gages. A comparison of the daily O'Leno discharge data to the simulated data for the water years 1998 through 2003 is shown in Figure 3-21. Again, the match is generally excellent, particularly at low stages, with some of the flood peaks being moderately over- or underestimated. This process allowed for simulation of a full period of record for the O'Leno gage back to 1932.

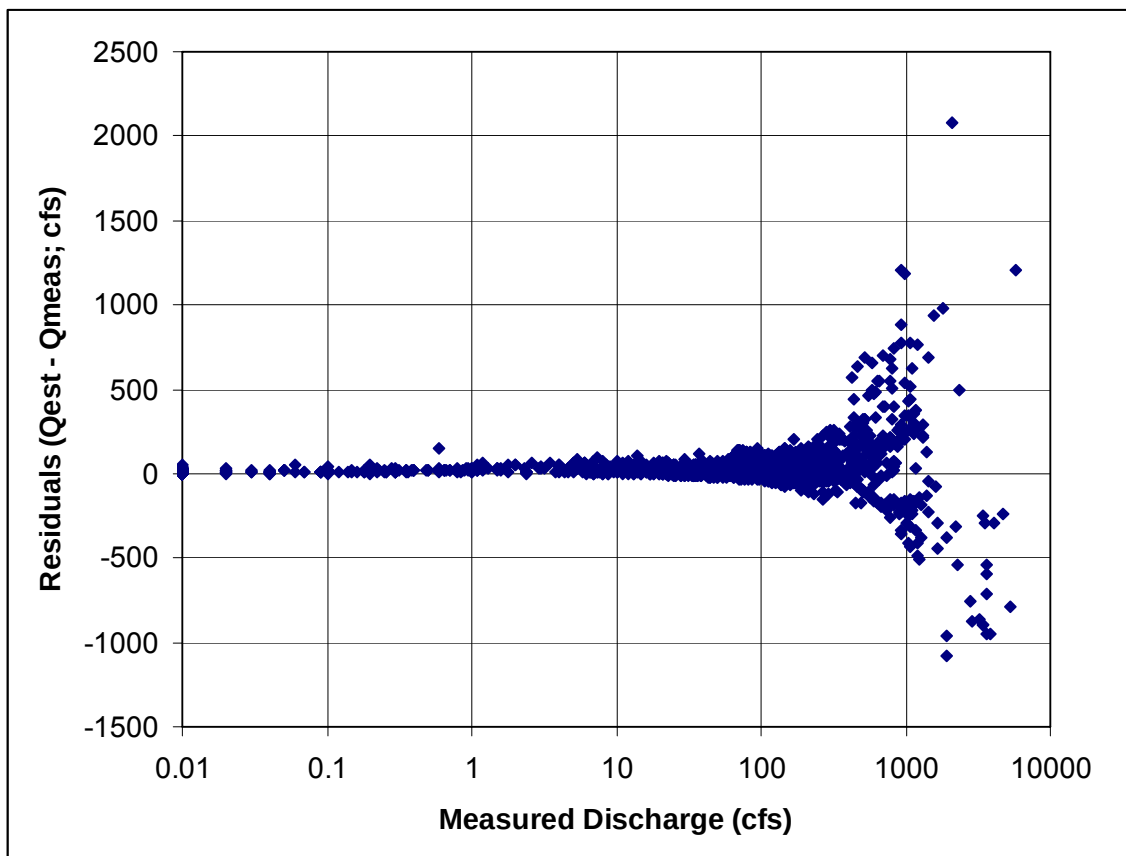


Figure 3-22. Comparison of residuals calculated by subtracting the measured discharge values from simulated values as a function of measured discharge.

As indicated by Figure 3-21, the fit of the simulated data to measured discharge data is reasonable at low to moderate flows. Figure 3-22 illustrates the goodness of fit of these data by plotting the residuals obtained by subtracting the measured discharge (Q_{meas}) from the simulated discharge (Q_{est}) as a function of measured discharge. The simulations clearly replicate the measured values up to a measured discharge of approximately 250 cfs. Above this threshold, the simulated data are unreliable because of backwater and other effects that could not be simulated.

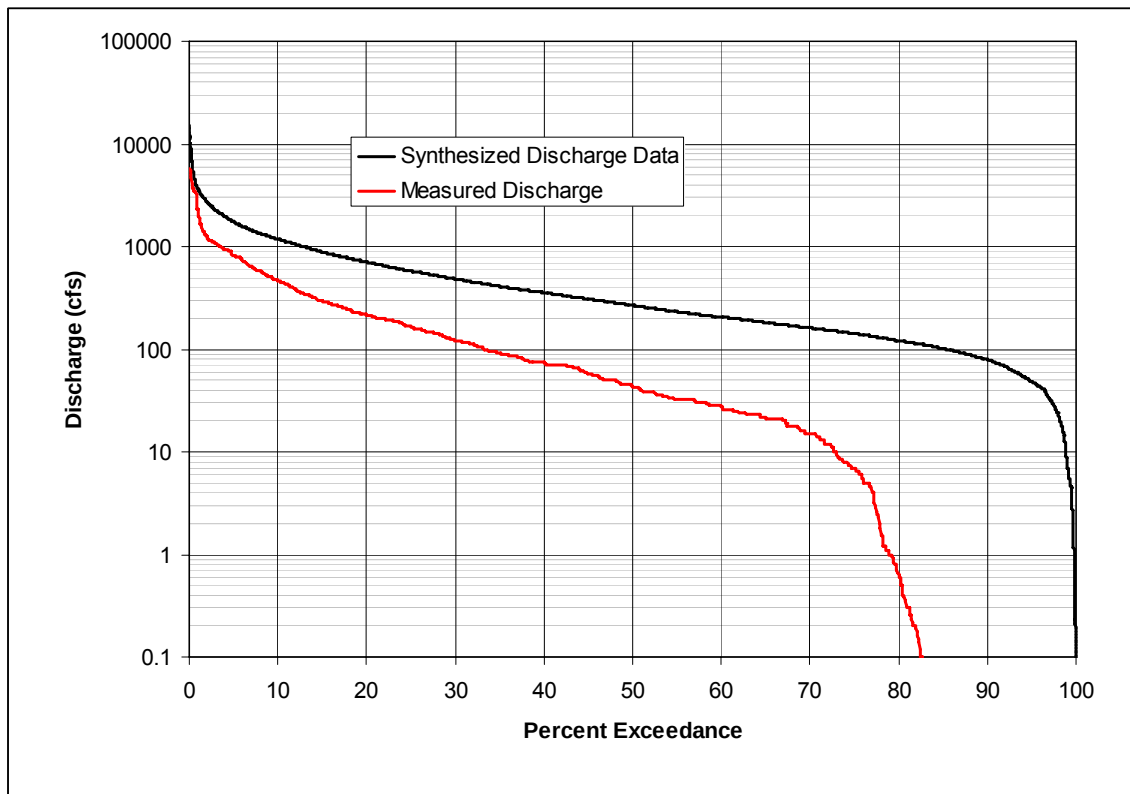


Figure 3-23. Flow duration curves for the measured and simulated discharge values at the O'Leno gage.

Table 3-4. Population characteristics for the measured and simulated discharge data from the O'Leno gage.

	Measured Discharge	Simulated Discharge
Minimum	0.0	0.1
P25	7.0	142.3
Median	43.5	267.1
P75	165.8	578.2
Maximum	5,750.0	15,141.2
Average	182.9	514.0
Count	2,084	26,418

Based on the observed and simulated discharge data for the gage at O'Leno State Park, an historic flow duration curve can be created (Figure 3-23). Note that there is a limited number of measurements (2084) as compared to the simulated data (26,418 discharge estimates), and the discharge measurements are biased because of the timing of the measurements (September 1997 – September 2003), which included the record drought of the early 2000s. The estimated data span the period from May 1932 through September 2004, so record droughts and rainfall events should be in proportion to the period of record. Table 3-4 compares the properties of the measured and simulated data sets.

Based on the apparent bias in the timing of measured discharge at the O'Leno gage, it is recommended that the simulated data be utilized for the historic flow duration curve.

3.3.3 Sampson River

3.3.3.1 Sampson River near Graham

The stream gage located on the Sampson River at Graham has never been continuously monitored. As a result, cross-correlation with the Santa Fe near Brooker gage is not possible. However, the Sampson River at Graham gage is located very near the Santa Fe River near Graham gage (Figure 3-2), which has a hydrologic-event lag time of less than one day with the Brooker gage. Therefore, it is assumed that the lag between the Sampson River near Graham gage and the Brooker gage is less than one day, so contemporaneous data were used.

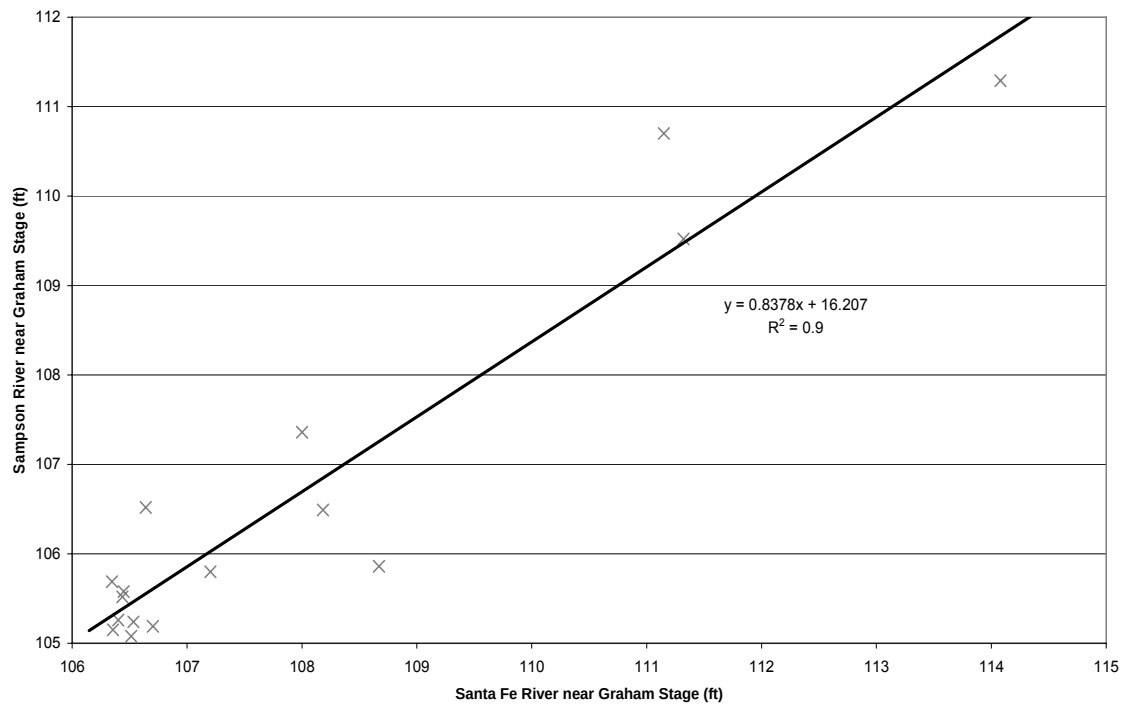


Figure 3-24. Cross-plot of stage at the Sampson River near Graham and the Santa Fe River near Graham.

A comparison of stage data from the Sampson River near Graham stage and the Santa Fe River near Graham stage data reveals a statistically significant relationship (Figure 3-24). A linear trend line resulted in the best fit to the data, with an R^2 value of 0.9. A comparison of the measured stage data to the simulated data for Sampson River near Graham is shown in Figure 3-25. The match is moderately good with some of the measurements being moderately over- or underestimated.

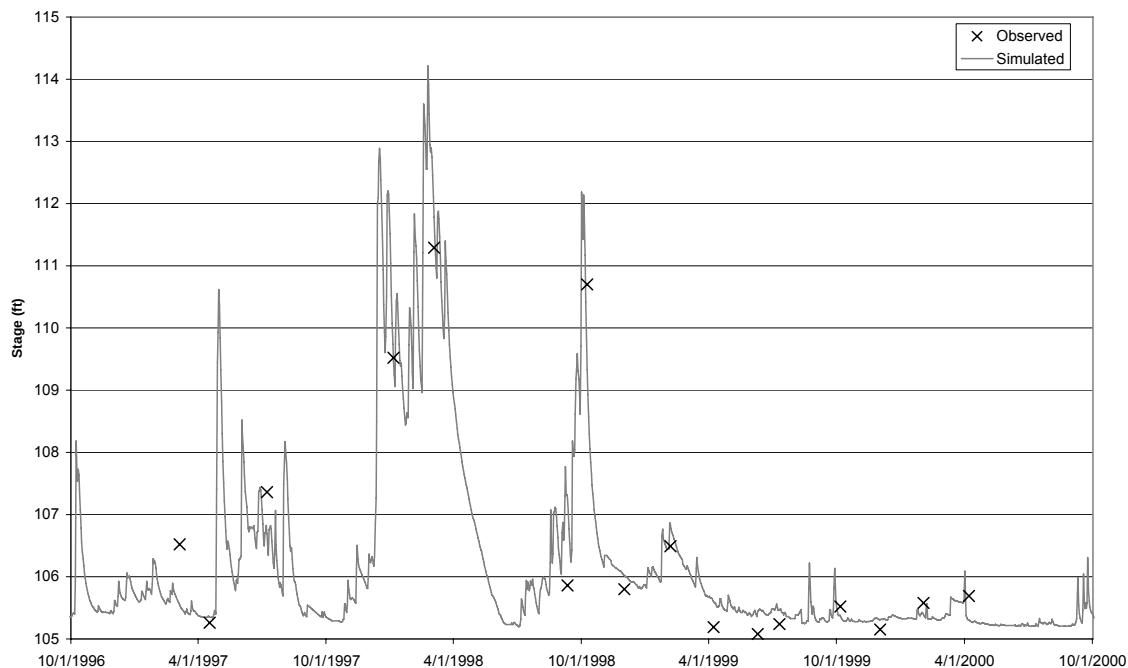


Figure 3-25. Comparison of measured and simulated stage data for the Sampson River near Graham.

A rating curve was developed for the Sampson River near Graham gage from the stage and discharge measurements. However, a better relationship was found between the measured discharge at the Sampson River at Graham gage and the simulated discharge at the Brooker gage. The linear relationship shown in Figure 3-26 was used to simulate discharge data for the Sampson River near Graham gage. A comparison of the measured discharge data to the simulated data is shown in Figure 3-27. The match is good, particularly at low stages. This process allowed for extension of the period of record for the Samson River at Graham gage back to 1932, or an increase in the period of record from 47 years to 72 years.

3.3.3.2 Sampson River at Sampson City

The gage on the Sampson River at Sampson City is located upstream from a control structure, which is used to maintain the level of Lake Sampson. The District has monitored this gage continuously since 1998 through the use of a water-level recorder and a rating curve for calculating discharge. In 2001, the control structure was refurbished and began to be operated by Bradford County (T. Mirti, pers. comm., 2005). In 2003, the District stopped calculating discharge from the previously defined rating curve, discharge data between July 2001 and 2003 are suspect (Figure 3-28).

Figure 3-28 shows the period of record of stage measurements for this gage. The dashed line indicates when the control structure was refurbished. Average water levels are clearly higher following this event. Due to the presence of this control structure, no effort was made to simulate stage data for this gage.

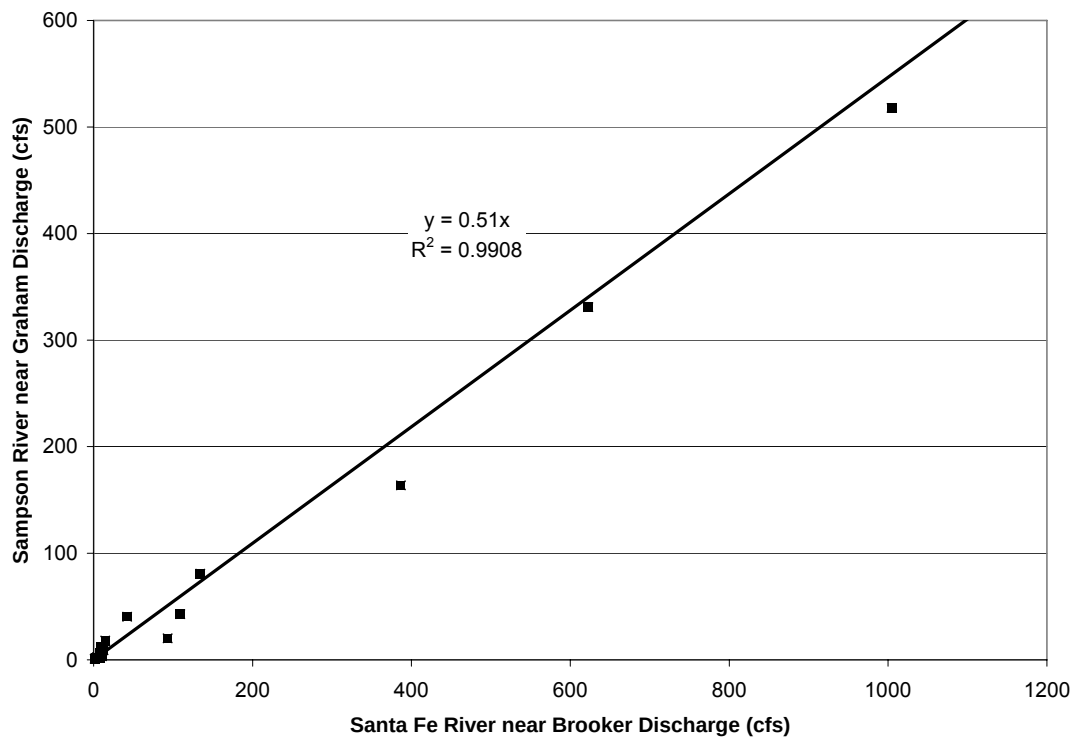


Figure 3-26. Cross-plot of measured discharge at the Sampson River near Graham and simulated discharge at the Santa Fe River near Brooker.

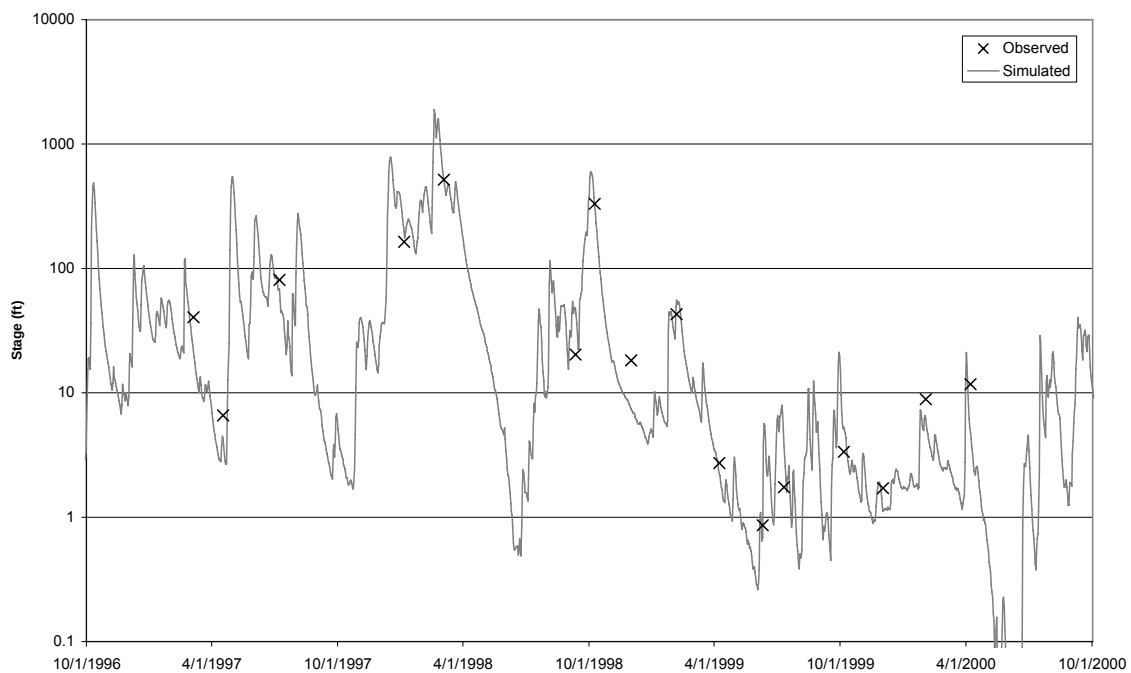


Figure 3-27. Comparison of measured and simulated discharge data for the Sampson River near Graham.

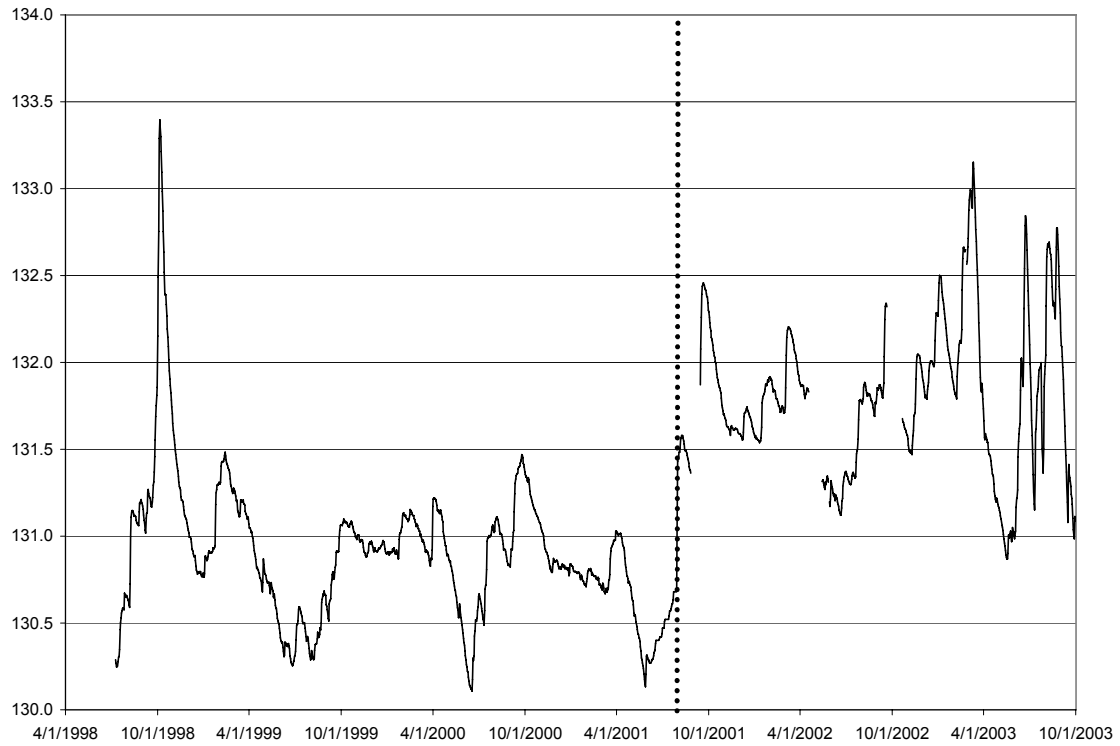


Figure 3-28. Stage data for the Sampson River at Sampson City gage. The dashed line indicates the approximate time the control structure was refurbished.

In order to quantify the relationship between discharge from Lake Sampson and discharge from the Sampson River into the Upper Santa Fe River, the discharge data for the Sampson River at Sampson City from before June 2001 were compared to simulated discharge at downstream gages.

Cross-correlation of discharge data for the Sampson City and Sampson River near Graham gages indicates that the best correlation is observed at a lag of one day (Figure 3-29). Cross-plotting the discharge at Sampson City and the lagged Sampson River near Graham discharge reveals an excellent

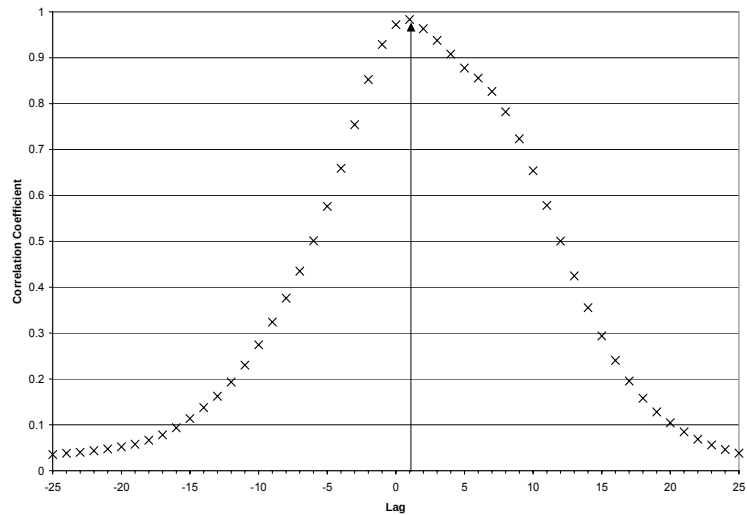


Figure 3-29. Cross-correlation between data from the Sampson City gage and from the Sampson River near Graham gage. The peak at +1 day indicates that upstream discharge is most correlated with downstream discharge 1 day later

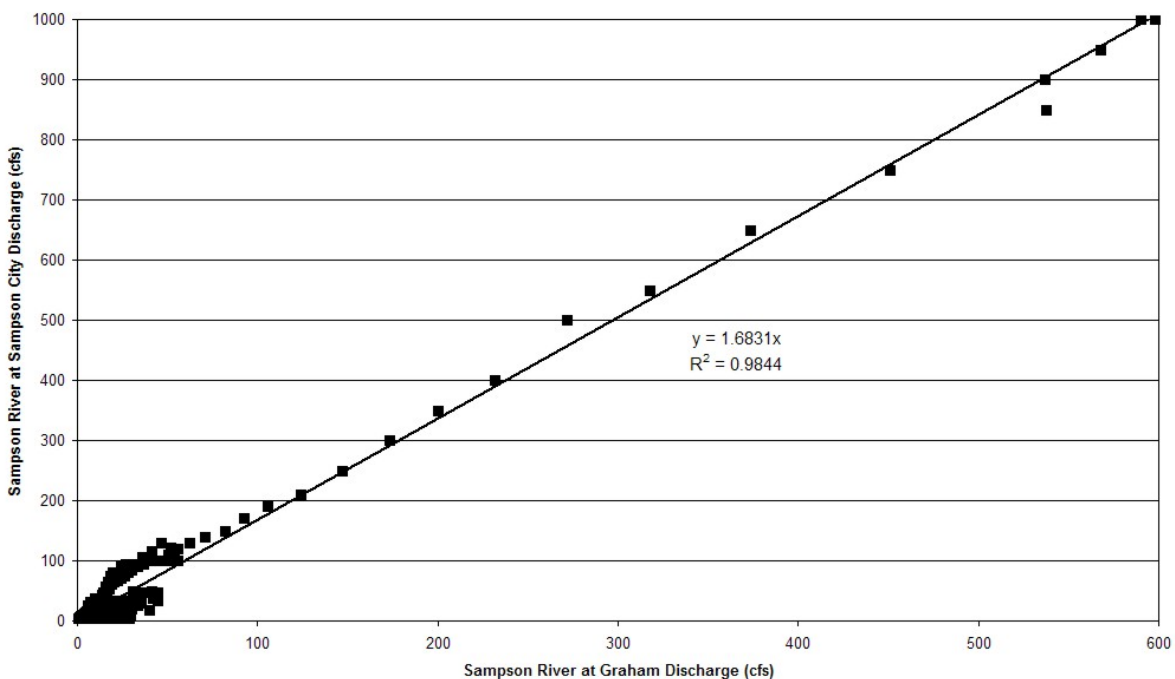


Figure 3-30. Comparison of discharge at Sampson City with lagged Sampson River near Graham discharge.

linear relationship between the data (Figure 3-30). The slope of the regression line (Figure 3-30) indicates that the discharge from Lake Sampson is approximately 60% greater than discharge from the Sampson River into the Santa Fe River.

Notice, however, that the linear fit is primarily through the high flow data, while the low flow data are farther from the line indicating greater error. Figure 3-31 compares the observed discharge to simulated discharge using this linear relationship. While the simulated data tend to generally follow the observed data, the fit is not very good at lower flows. The simulated data also tend to have more peaks than the observed data. Therefore, the apparent relationship between upstream and downstream flow on the Sampson River is not appropriate for simulation of a period of record of discharge at the Sampson River at Sampson City gage.

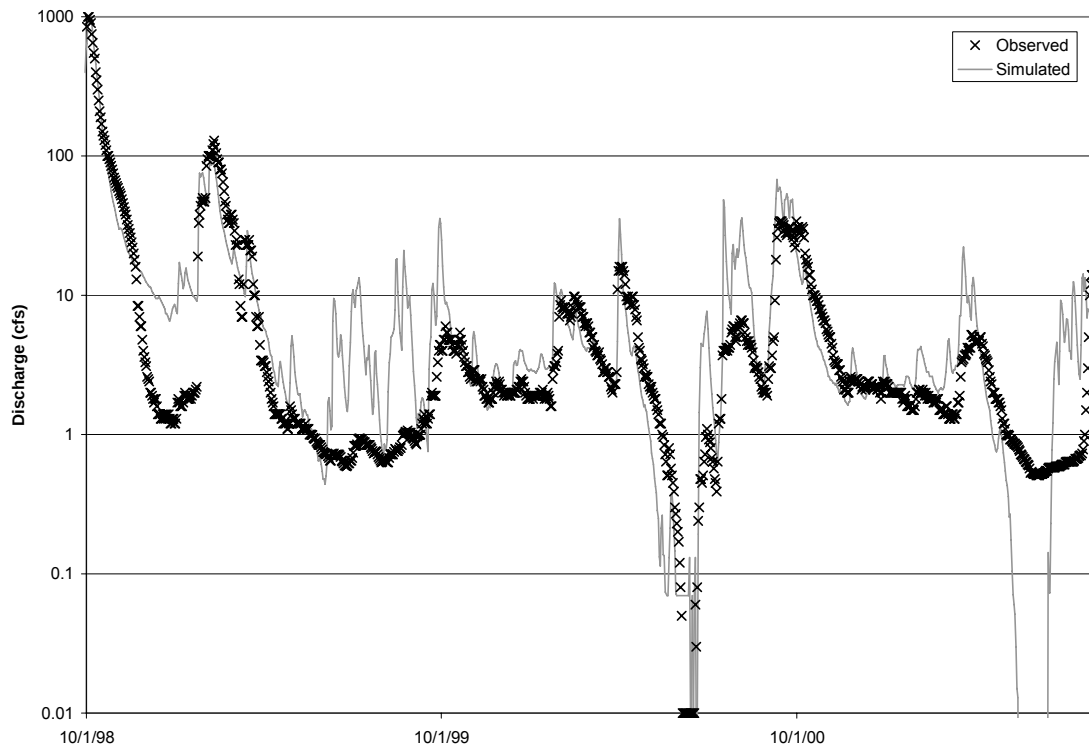


Figure 3-31. Comparison between observed and simulated discharge for the Sampson River near Sampson City.

3.3.4 New River

3.3.4.1 New River near Lake Butler

The stream gage located on the New River near Lake Butler was originally installed in 1950 and was continuously operated until 1971, when it was discontinued. Continuous monitoring began again in 1990 and has continued until the present with minor interruptions.

Cross-correlation of stage data indicates that stage recorded at the New River near Lake Butler is best correlated to stage data from Worthington Springs recorded one day later (Figure 3-32).

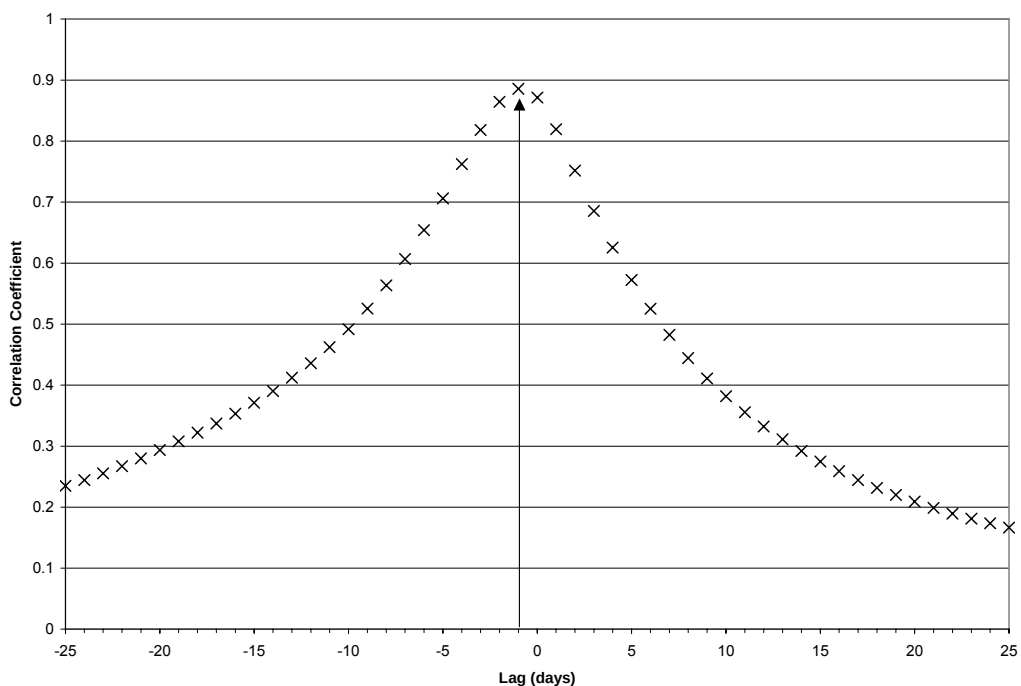


Figure 3-32. Cross-correlation between stage at the New River near Lake Butler gage and the Worthington Springs gage. The peak at -1 days indicates that water levels at the Worthington Springs gage are most correlated to water levels measured at the New River near Lake Butler one day earlier.

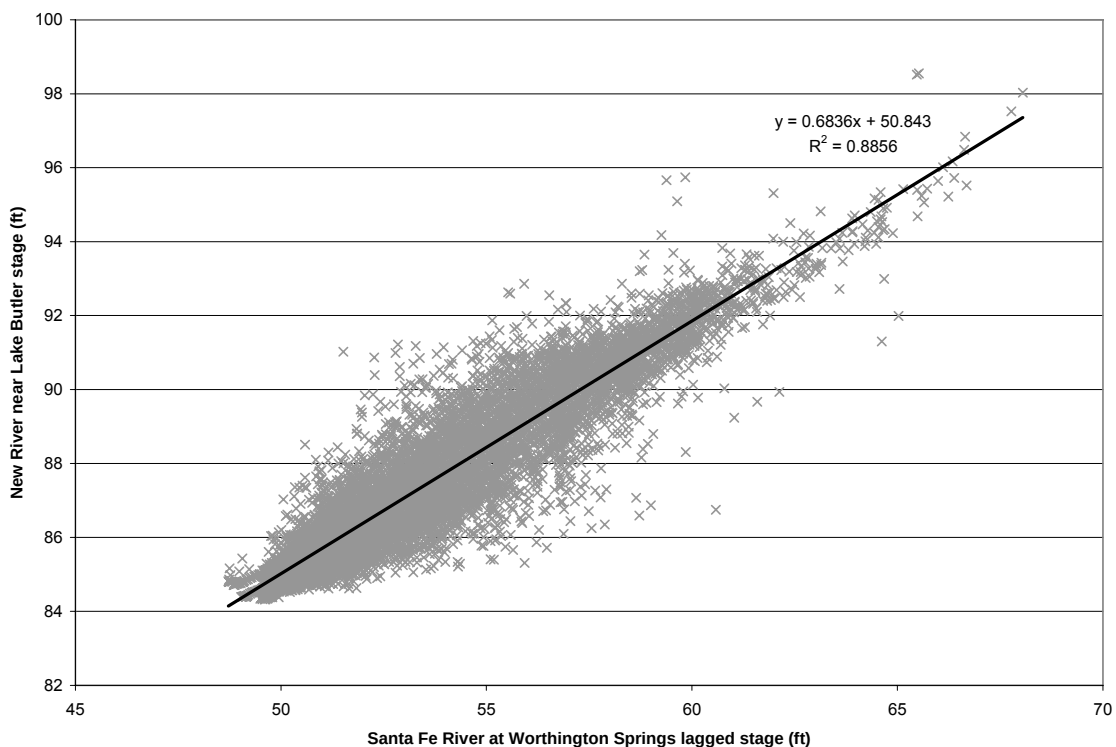


Figure 3-33. Comparison of stage of the New River near Lake Butler with lagged stage at the gage at Worthington Springs.

A cross-plot of stage data from the New River near Lake Butler gage and the lagged Worthington Springs stage data reveals a significant relationship (Figure 3-33). A linear trend line resulted in the best fit to the data, with an R^2 value of 0.8856. The linear relationship shown in Figure 3-33 was used to simulate data for the Graham gage for the period of record data from the Worthington Springs gage. A comparison of the daily value stage data to the simulated data for the New River near Lake Butler is shown in Figure 3-34. The match is generally excellent, particularly at low stages, with some of the flood peaks being moderately over- or underestimated.

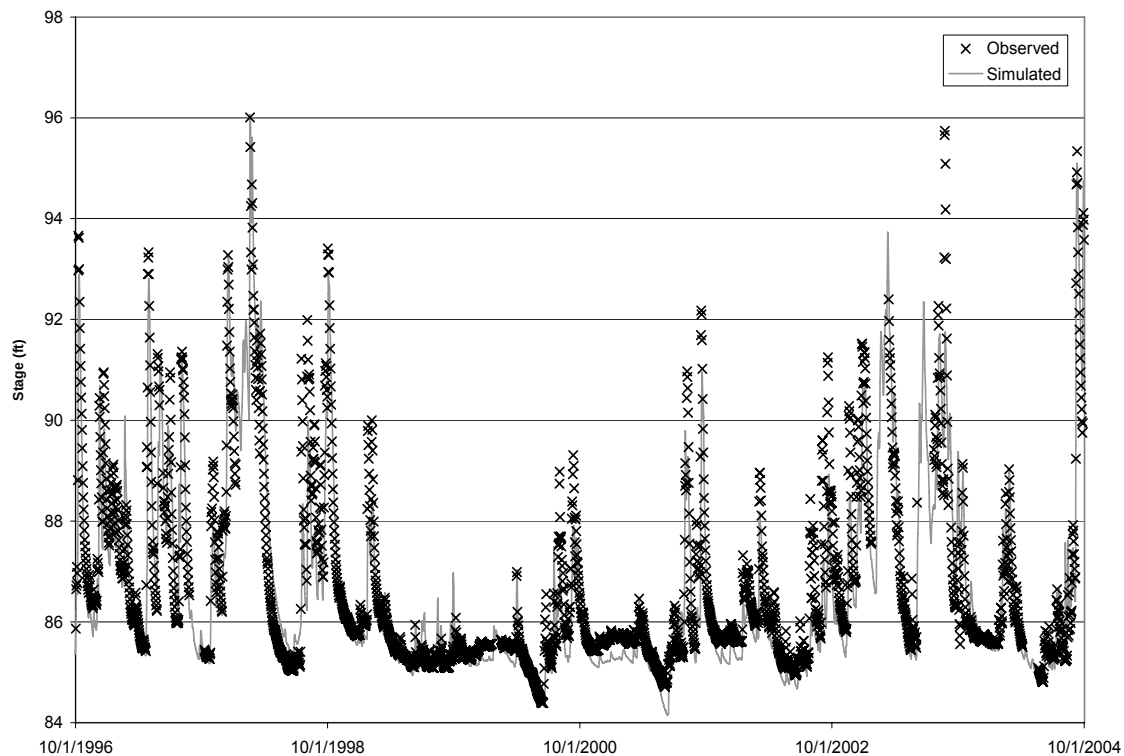


Figure 3-34. Comparison of observed and simulated stage for the New River near Lake Butler.

A rating curve was developed for the New River near Lake Butler gage from the full period of record in order to simulate discharge from the simulated stage data. A comparison of the daily value discharge data to the simulated data is shown in Figure 3-35. Again, the match is generally excellent, particularly at low stages, with some of the flood peaks being moderately over- or underestimated. The simulated data were used to fill in the period of record for the New River near Lake Butler, such that the period of record utilized in MFL development included observed data where available, with simulated data filling in any gaps back to the start of monitoring at the Worthington Springs gage in 1932.

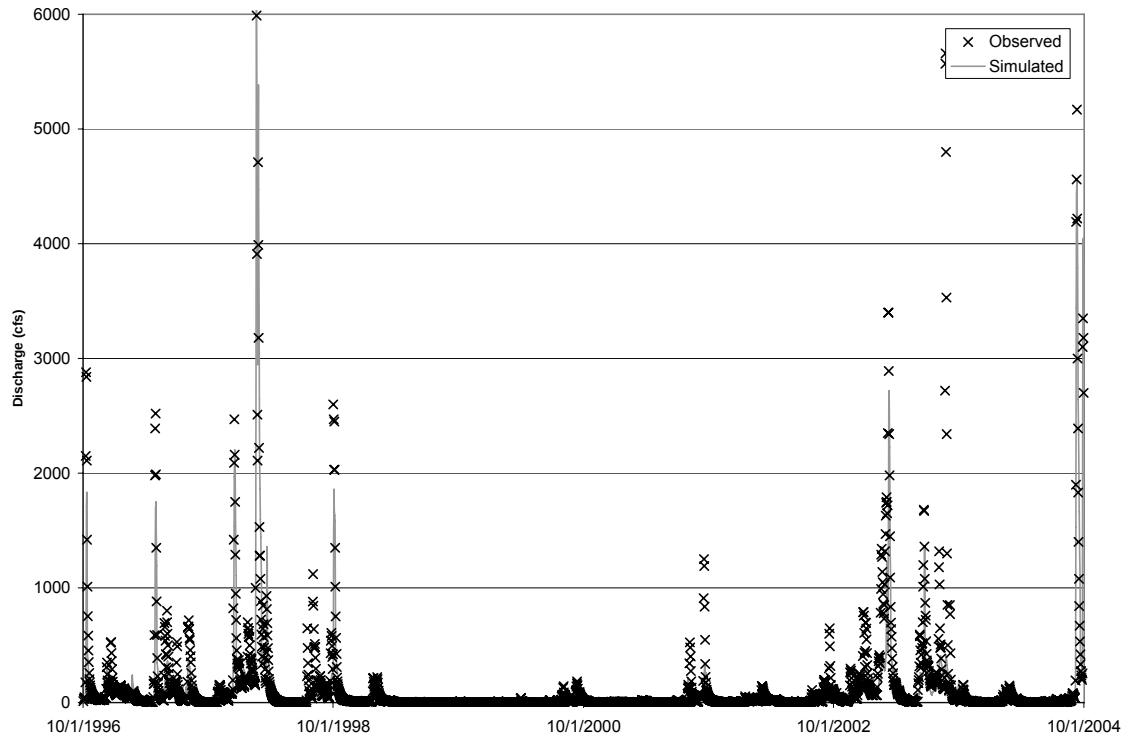


Figure 3-35. Comparison of observed and simulated discharge for the New River near Lake Butler

3.3.4.2 New River at Worthington Springs

Discharge has only been measured five times at the New River near Worthington Springs gage. While this data set is insufficient to simulate a period of record for this gage, the discharge data were compared with the discharge data from the New River near Lake Butler gage to determine the relationship between upstream flow and discharge from the New River to the Santa Fe River.

Cross-correlation of the discharge data from the Lake Butler gage with the discharge from the New River at Worthington Springs gage is not possible due to the limited number of measurements. However, the lag between the Lake Butler gage and the gage on the Santa Fe River at Worthington Springs is one day. Therefore, the lag between the Lake Butler gage and the intermediate New River at Worthington Springs gage is likely between 0 and 1 day.

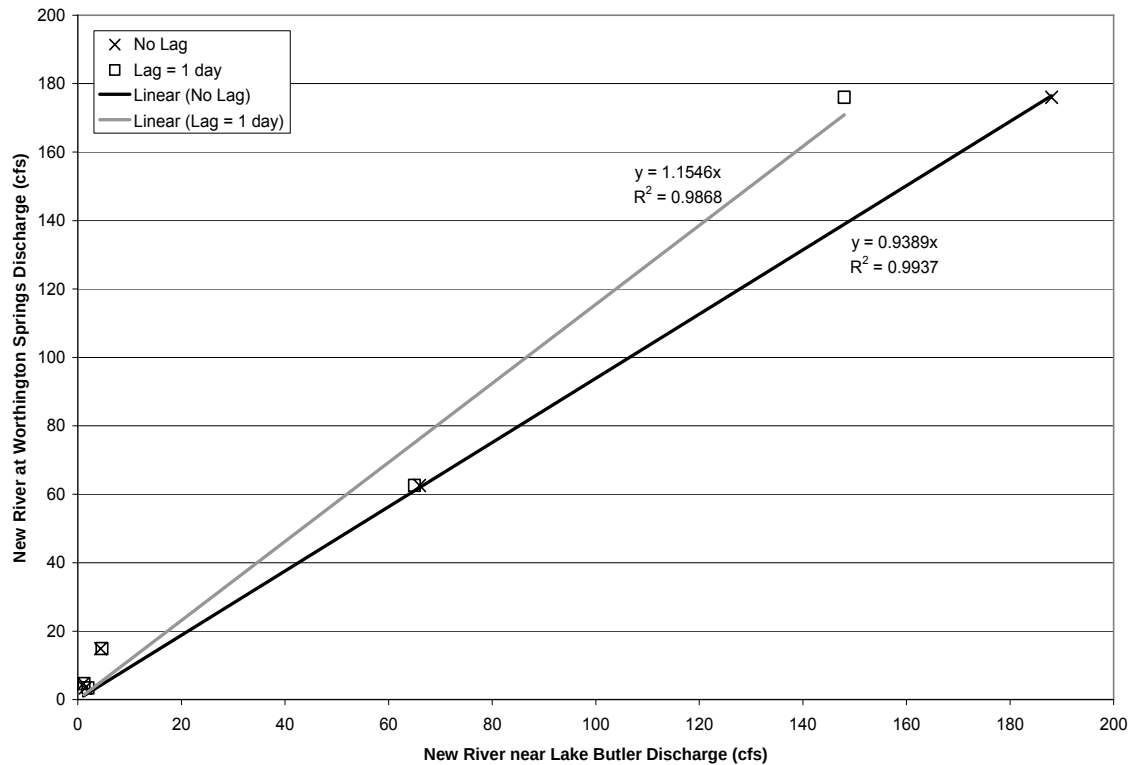


Figure 3-36. Comparison of discharge at the New River near Lake Butler gage with discharge at the New River at Worthington Springs gage for lags of 0 and 1 day.

Figure 3-36 shows a comparison of the measured discharge for the New River near Worthington Springs and Lake Butler for lag times of 0 and 1 day. Depending on the lag used, the discharge from the New River into the Santa Fe River appears to be between 94 and 115% of the discharge at the New River near Lake Butler. Note that these relationships only apply to relatively low flows, as high flow measurements at the New River at Worthington Springs are not available.

3.3.5 Olustee Creek and Swift Creek

3.3.5.1 Olustee Creek near Providence

The stream gage located on Olustee Creek near Providence was continuously monitored from 1957 through 1960, when its use was discontinued. Cross-correlation of the gage height data to contemporaneous stage data at Worthington Springs indicates that water levels recorded at the Olustee Creek near Providence gage are most correlated when there is no time lag (Figure 3-37).

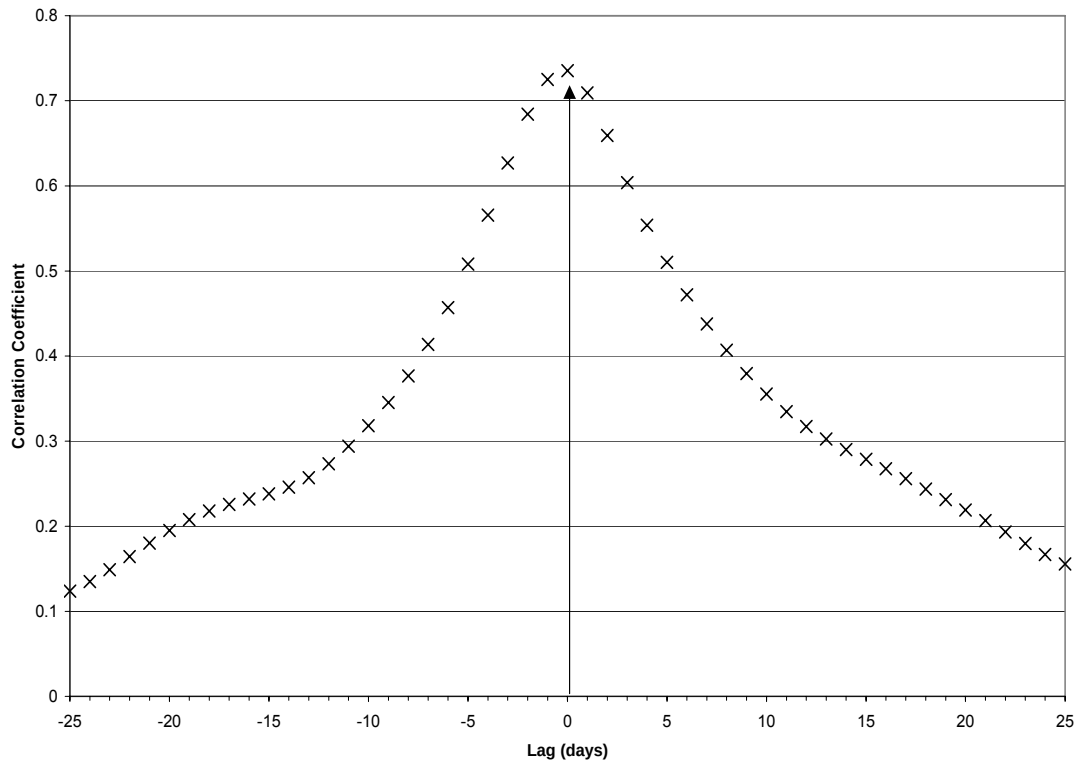


Figure 3-37. Cross-correlation between stage at the Olustee Creek near Providence gage and at the Worthington Springs gage indicating no significant lag between the data.

A cross-plot of the Olustee Creek near Providence gage height and the Worthington Springs stage reveal a significant, but complex, relationship (Figure 3-38). A polynomial trend line resulted in the best fit to the data, with an R^2 value of 0.787. The relationship shown in Figure 3-38 was used to simulate data for the Providence gage for the period of record at the Worthington Springs gage. A comparison of the daily value data to the simulated data for Olustee Creek near Providence is shown in Figure 3-39. The match is generally good, particularly at low stages, with some of the flood peaks being moderately over- or underestimated.

A rating curve was developed for the Olustee Creek near Providence gage from the full period of record in order to simulate discharge from the simulated gage height data. A comparison of the daily value discharge data to the simulated data is shown in Figure 3-40. Again, the match is generally good, particularly at low stages, with some of the flood peaks being moderately over- or underestimated. The simulated data were used to simulate a complete period of record for Olustee Creek near Providence back to the start of the Worthington Springs gage in 1932.

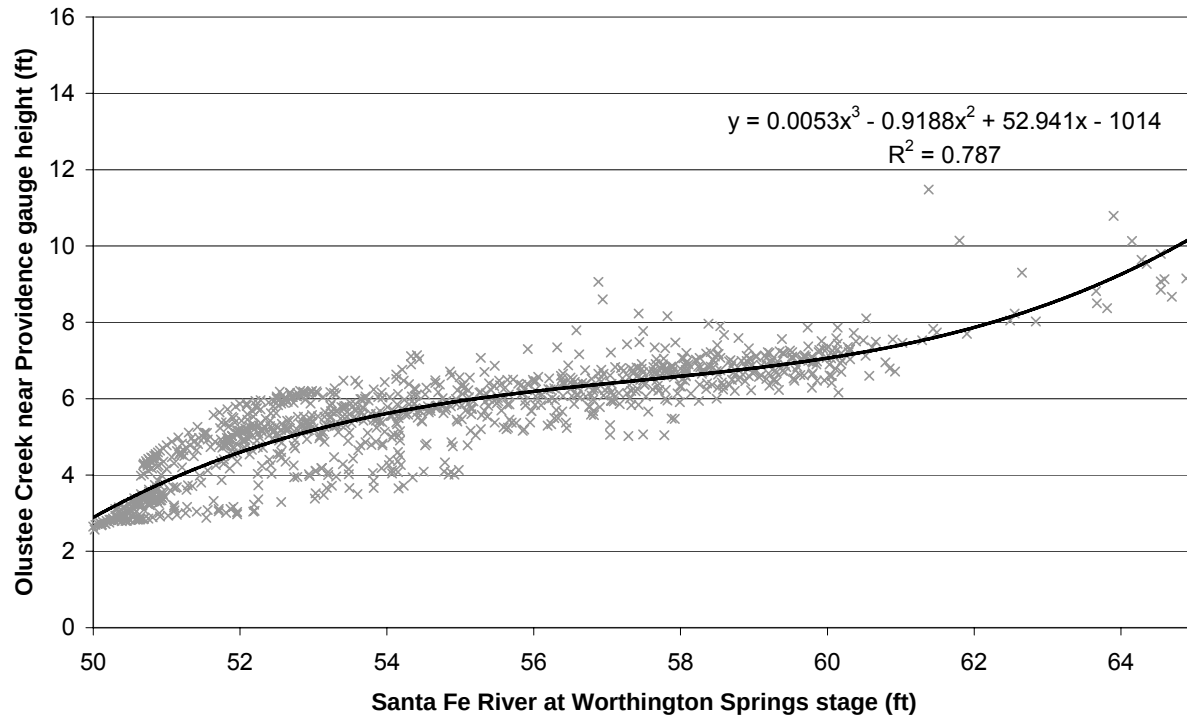


Figure 3-38. Comparison of gage height at Olustee Creek near Providence with the stage at Worthington Springs.

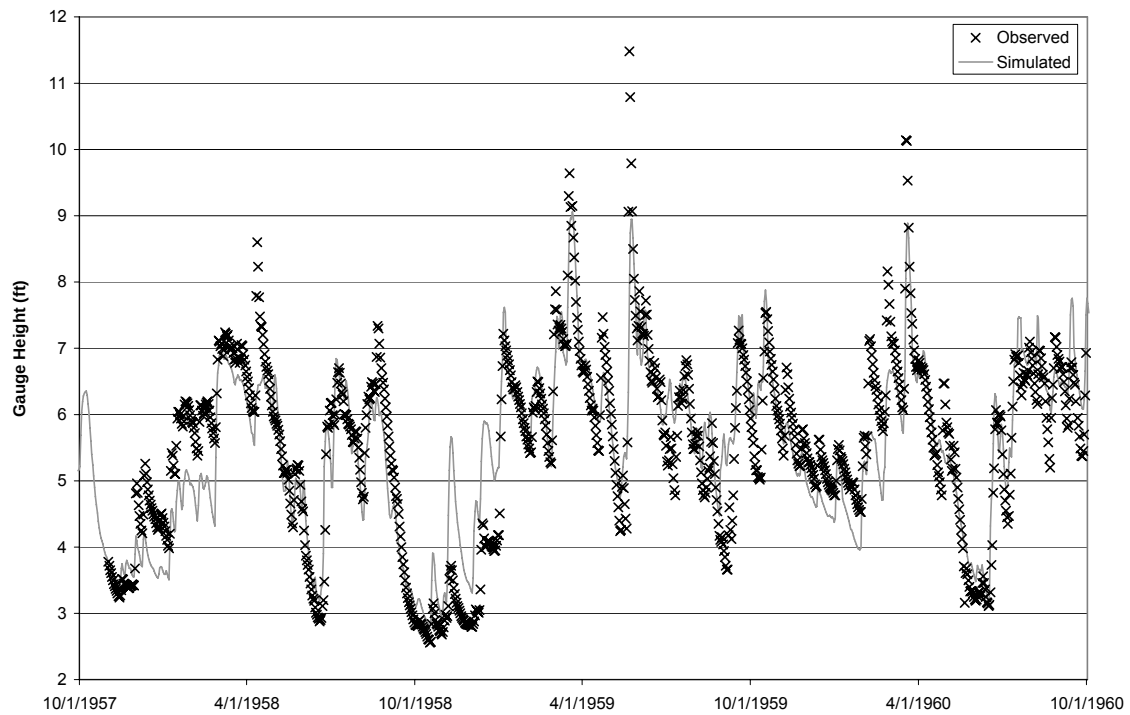


Figure 3-39. Comparison of observed and simulated gage height for Olustee Creek near Providence.

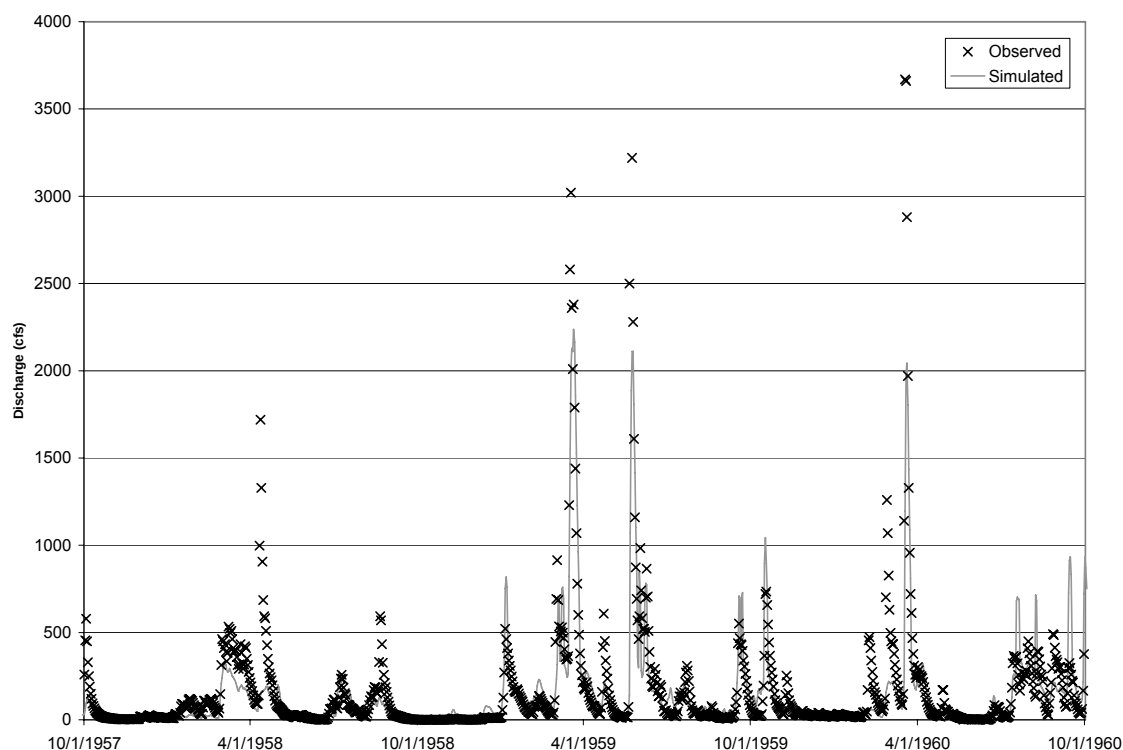


Figure 3-40. Comparison of observed and simulated discharge data for Olustee Creek near Providence.

3.3.5.2 Olustee Creek near Lulu

The stream gage located on Olustee Creek near Lulu was continuously monitored from 1957 through 1960, when it was discontinued. Cross-correlation of the gage height data indicates that water levels recorded at the Olustee Creek near Lulu gage are most correlated to stage at Worthington Springs recorded two days earlier (Figure 3-41). A comparison of the stage at the Olustee Creek near Lulu gage and the lagged Worthington Springs stage data reveals a significant relationship (Figure 3-42). An exponential trend line resulted in the best fit to the data, with an R^2 value of 0.825. The relationship shown in Figure 3-42 was used to simulate data for the Lulu gage for the period of record at the Worthington Springs gage. A comparison of the daily value data to the simulated data for Olustee Creek near Lulu is shown in Figure 3-43. The match is generally good, particularly at low stages, with some of the flood peaks being moderately over- or underestimated.

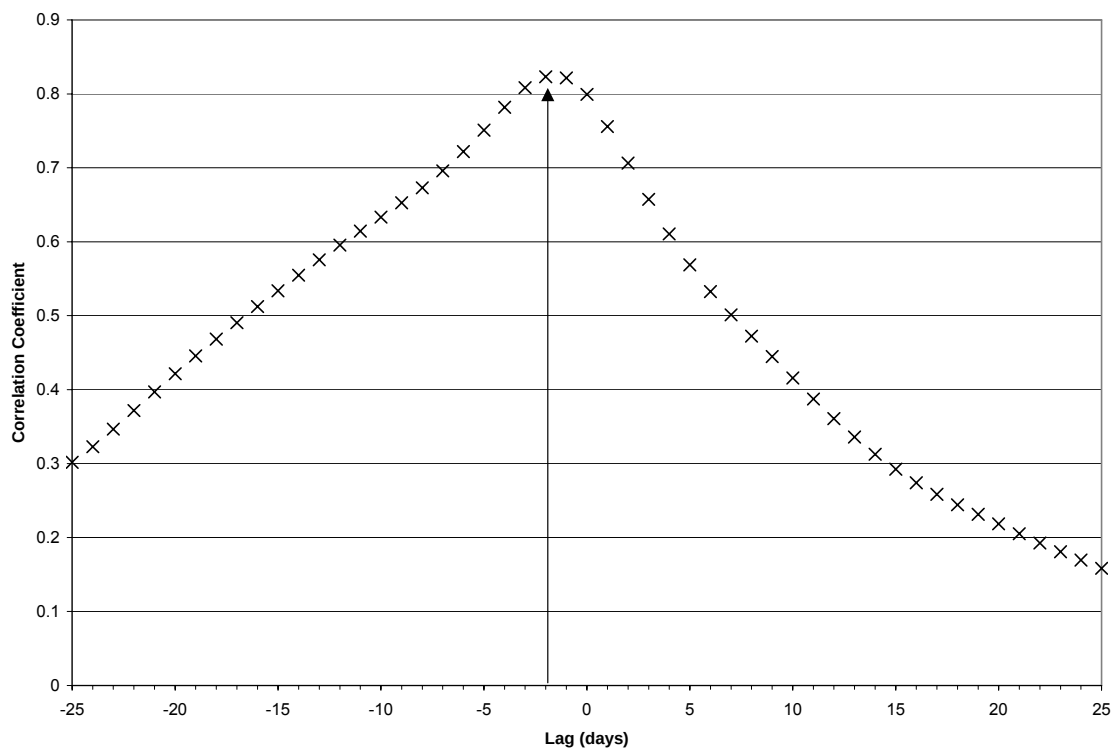


Figure 3-41. Cross-correlation of Olustee Creek near Lulu and Worthington Springs stage, indicating a maximum correlation at -2 days.

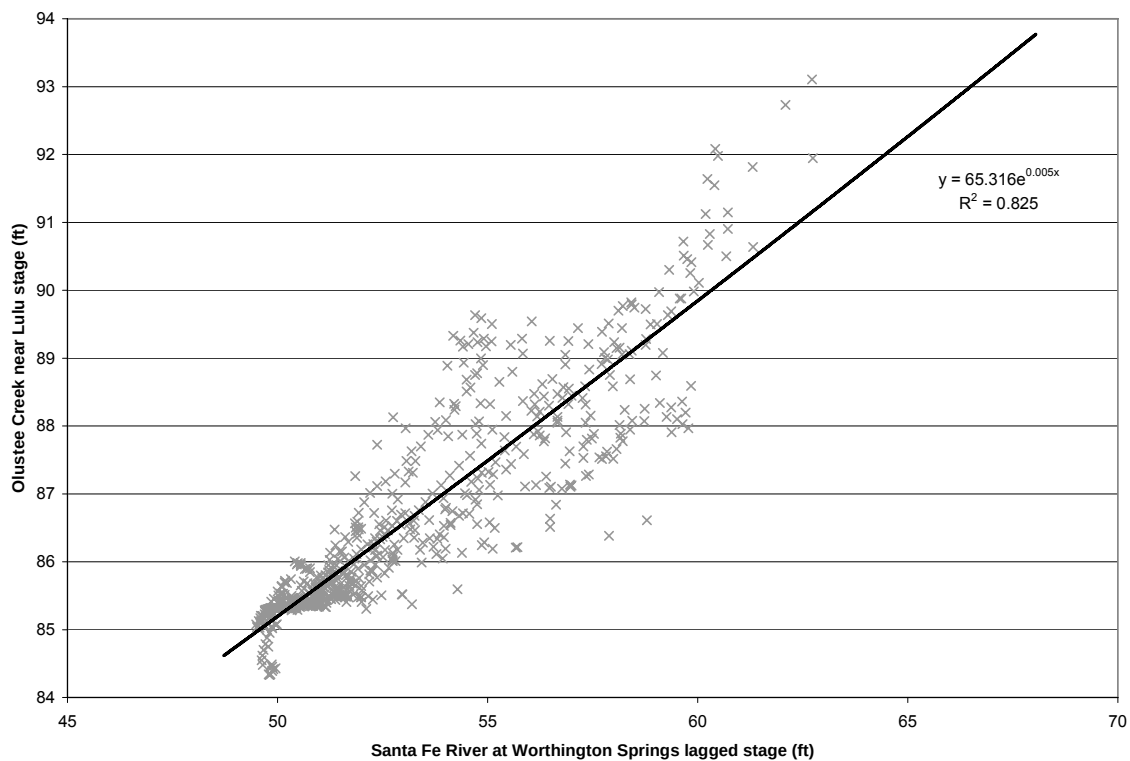


Figure 3-42. Cross-plot between Olustee Creek near Lulu stage and Worthington Springs lagged stage.

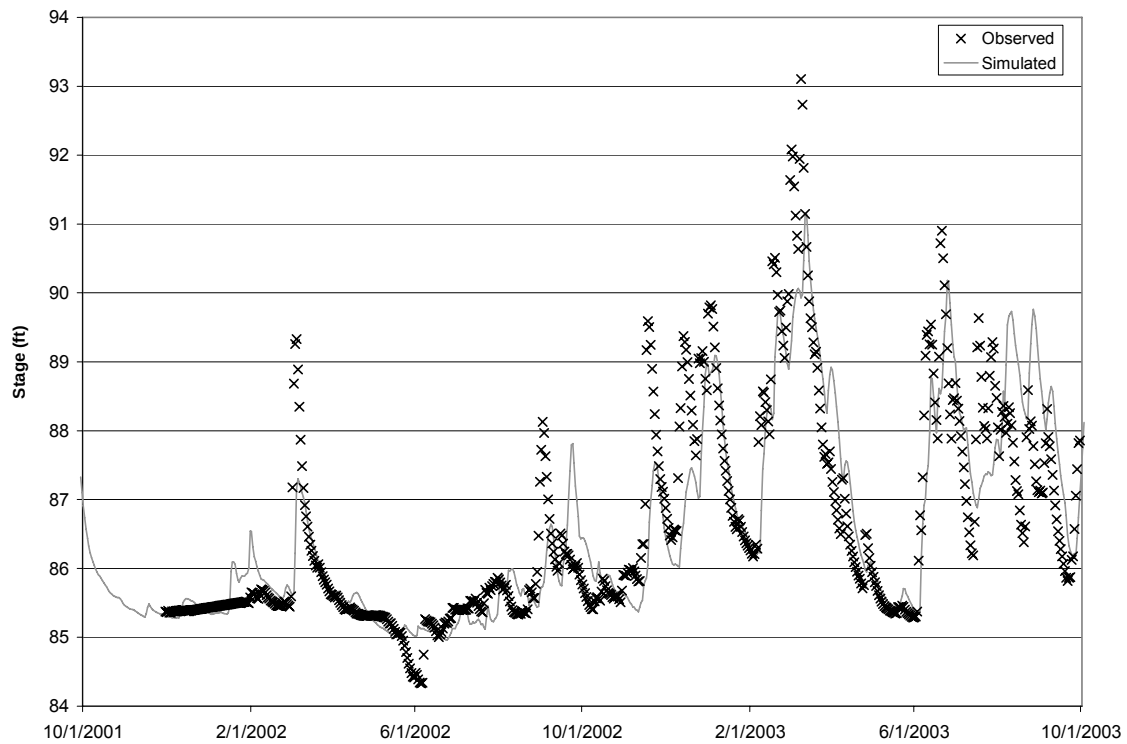


Figure 3-43. Comparison of observed and simulated stage at Olustee Creek near Lulu.

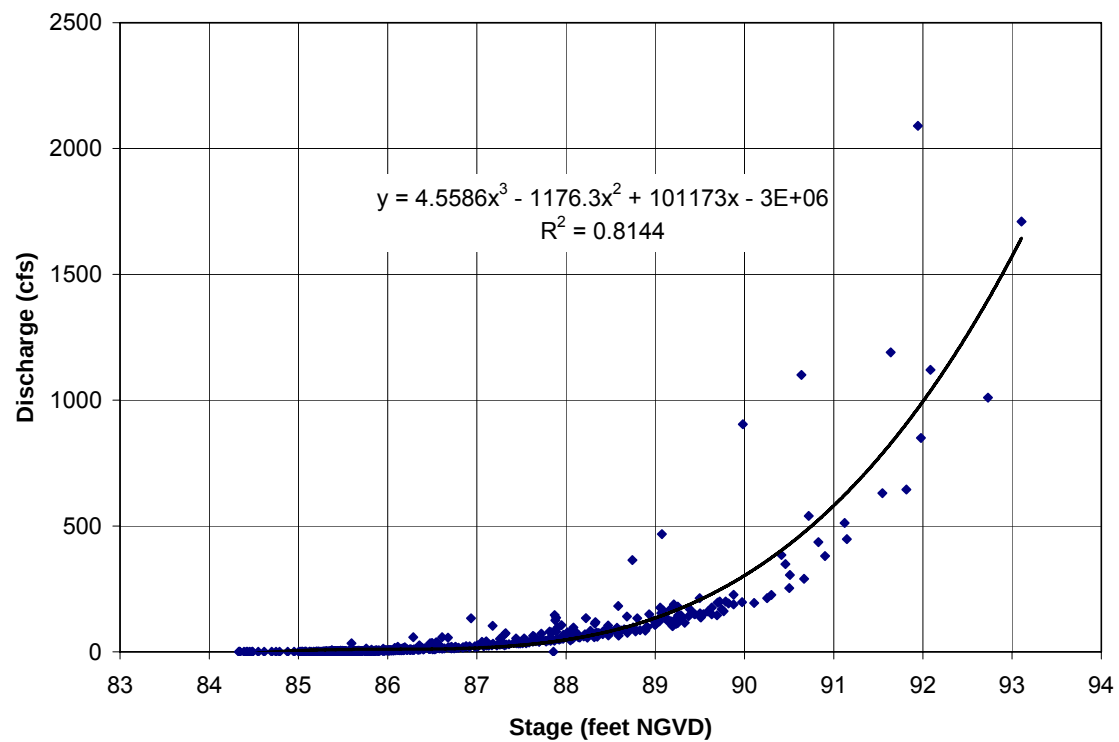


Figure 3-44 Rating curve for flow and stage at the Olustee Creek near Lulu gage (Gage 02321600)

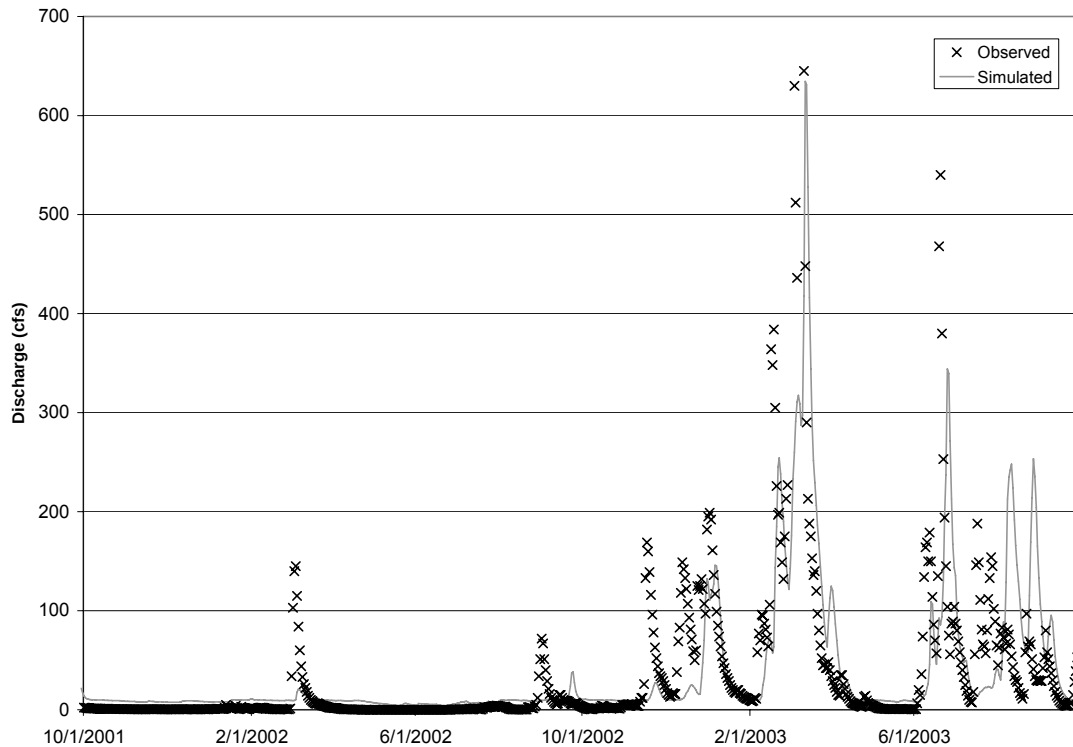


Figure 3-45. Comparison of observed and simulated discharge at Olustee Creek near Lulu.

A rating curve (Figure 3-44) was developed for the Olustee Creek near Lulu gage from the full period of record in order to simulate discharge from the simulated stage data. A comparison of the daily value discharge data to the simulated data is shown in Figure 3-45. Again, the match is generally good, with discharge being moderately over- or underestimated at some times. This relationship was used to simulate a complete period of record for Olustee Creek near Lulu back to the start of the Worthington Springs gage in 1932.

3.3.5.3 Swift Creek near Lake Butler

The stream gage located on Swift Creek near Lake Butler was continuously monitored from 1957 through 1960, when it was discontinued. A comparison of stage at the Swift Creek near Lake Butler stage with stage recorded downstream at the Olustee Creek near Providence gage and with the Worthington Springs gage revealed no statistically significant relationships.

A comparison of the Swift Creek near Lake Butler discharge data with contemporaneous Olustee Creek near Providence discharge reveals a significant relationship (Figure 3-46). A polynomial trend line resulted in the best fit to the data, with an R^2 value of 0.89. The relationship shown in Figure 3-46 was used to simulate data for the Swift Creek near Lake Butler gage from for the simulated period of record at the Olustee Creek near Providence gage. A comparison of the daily value data to the simulated data for Swift Creek near Lake Butler is shown in Figure 3-47. The match is generally good, particularly at low stages, with some of the flood peaks being moderately over- or underestimated.

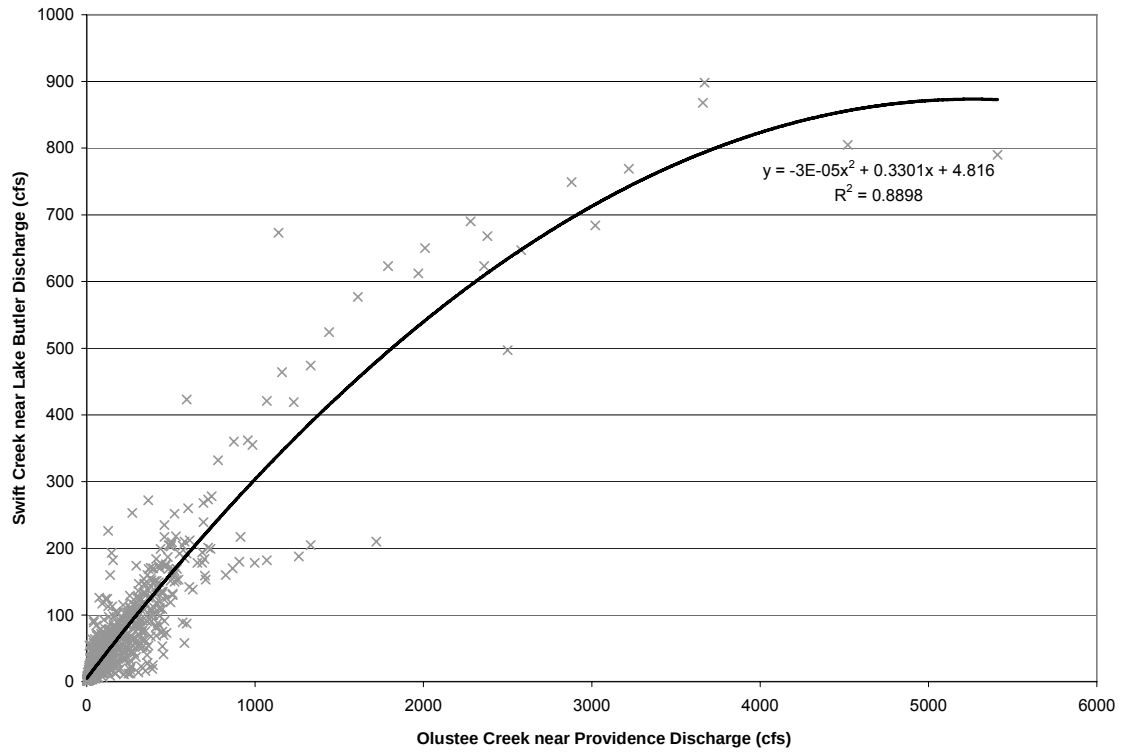


Figure 3-46. Comparison of discharge at Swift Creek near Lake Butler and Olustee Creek near Providence.

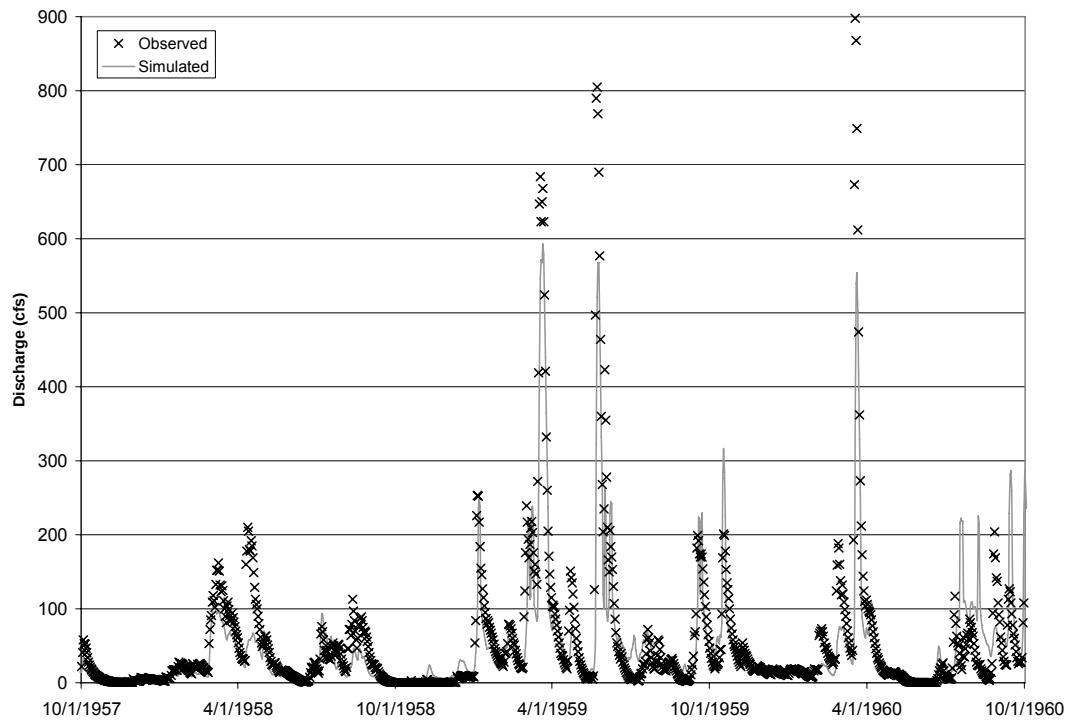


Figure 3-47. Comparison of simulated and observed discharge for the gage on Swift Creek near Lake Butler.

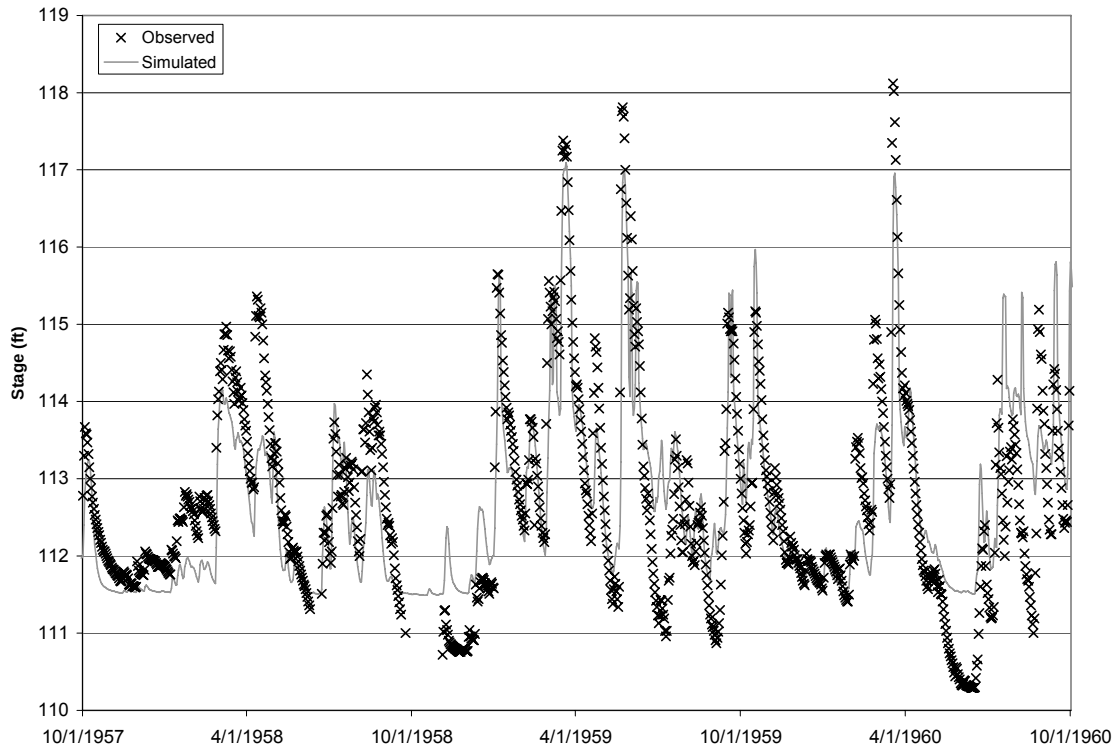


Figure 3-48. Comparison of simulated and observed stage for the Swift Creek near Lake Butler.

3.3.6 Santa Fe Spring (COL61981)

Discharge has only been measured about 15 times at the Santa Fe Spring (COL61981). In order to simulate a period of record for the spring, step-wise multiple linear regression was utilized that included all potential independent variables as a starting point. The regression removed all independent variables except the water level in Well #6 ($h_{\text{Well } 6}$), the stage at Worthington Springs (h_{1500}), and the stage at the O'Leno gage (h_{1898}). The resulting equation used to simulate a period of record of discharge for the spring was

$$Q_{\text{COL61981}} = 10.981h_{\text{Well } 6} + 29.316h_{1500} - 54.993h_{1898}.$$

This equation resulted in an $R^2 = 0.84$.

A comparison of the observed discharge to the simulated discharge is shown in Figure 3-49.

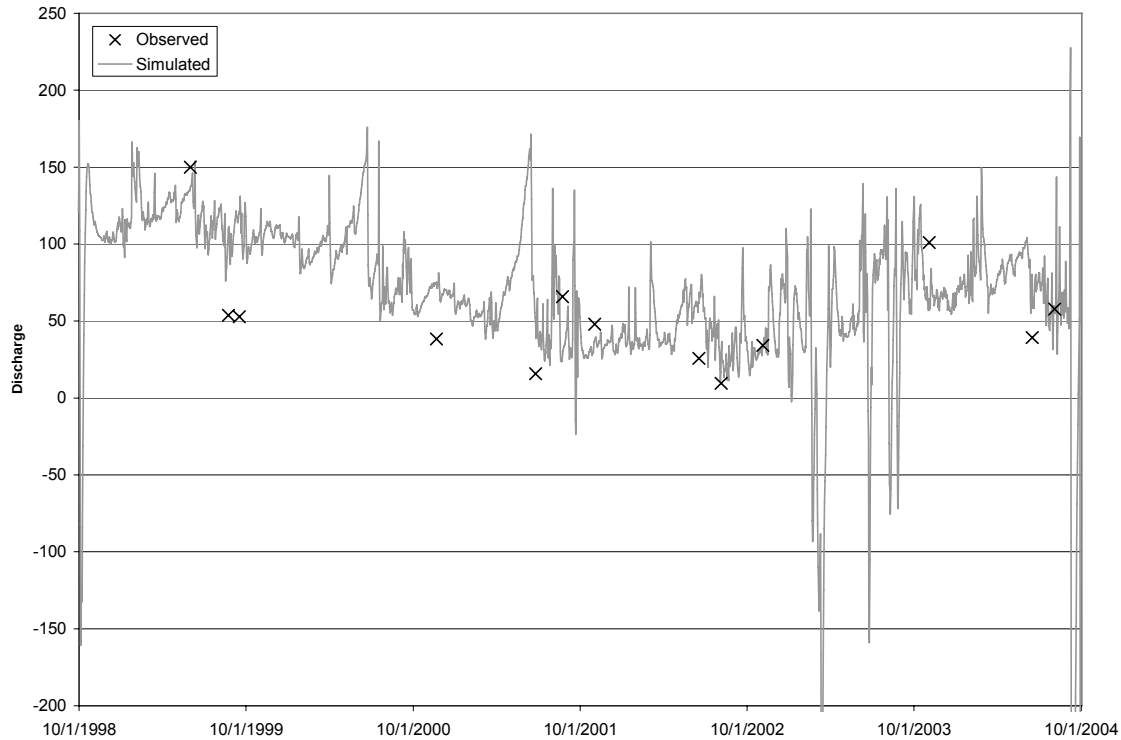


Figure 3-49. Comparison of observed and simulated discharge for spring COL61981

3.3.7 Discussion of Simulated Stream and Spring Behavior

3.3.7.1 Data Use and Quality Issues

As noted above, the purpose of simulating stage and discharge data from the stream gages on the upper Santa Fe is simply to fill in data gaps. Once the data gaps are filled, the data (actual data with synthesized data filling gaps) are used to

- Understand discharge-stage relationships within the watershed,
- Characterize flow-duration curves for relevant stations,
- Approximate seasonal and annual discharge and/or stage population parameters, and
- Provide input into the flow-routing model (HEC-RAS, see Section 3.5) for evaluation of the relationships of discharge to environmental and ecological MFL criteria.

The discussions of data synthesis in Sections 3.3.1 through 3.3.6 concluded that the simulations fit the data at low flow or stage and that there were problems with either under or overestimation of stage or discharge at higher flow. In order to understand these concerns, residual analyses¹

¹ Residuals are calculated by

$$X_{\text{res}} = X_{\text{calc}} - X_{\text{obs}},$$

were completed for each gage. The following is a discussion of the results of the residuals analysis for the data from the O'Leno gage. The results are similar to those obtained from the other gages.

Figure 3-50 presents the residual analysis results for simulation of stage data at the O'Leno gage, near River Sink. Note that the residuals are relatively uniformly distributed relative to stage value. The regression line suggests that there is little systematic variation of calculated stage relative to observed stage. The median residual is -0.03 feet and the average is 0.01 feet, so the residuals are not skewed. The 25th and 75th percentiles are -0.33 and 0.25 feet, respectively. In other words, 50 percent of the residuals are within 0.3 feet of the observed value. Minimum and maximum residuals are -4.82 and 4.19 feet, respectively. It is apparent that stage simulation at the O'Leno gage fits the data reasonably well, but occasional large values (± 5 feet or less) are possible.

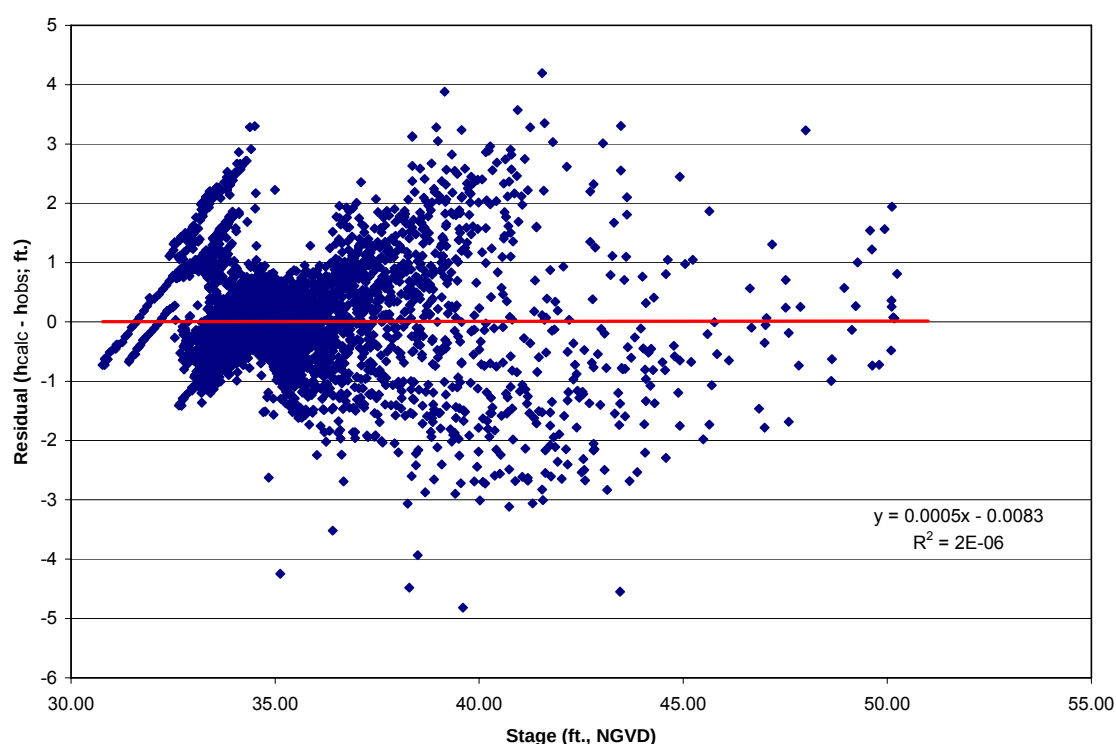


Figure 3-50. Stage residuals as a function of stage for simulated data from the O'Leno gage.

Figure 3-51 depicts similar data for discharge at O'Leno. Here, there is a systematic change in residuals with magnitude of discharge. Flood discharge is systematically underestimated. This is a result of the inability of the regression method to capture inflows and interactions with the floodplain during peak-flow events. Median and mean residuals are 20.3 and 29.4 cfs, respectively. This indicates that the majority of the flow events are relatively well characterized by the data simulations. The 25th and 75th residual percentiles are 3.23 and 51.9 cfs, respectively.

where X_{res} = residual for measured and calculated values of the variable X , X_{cal} = the calculated value of variable X , and X_{obs} is the observed value of variable X .

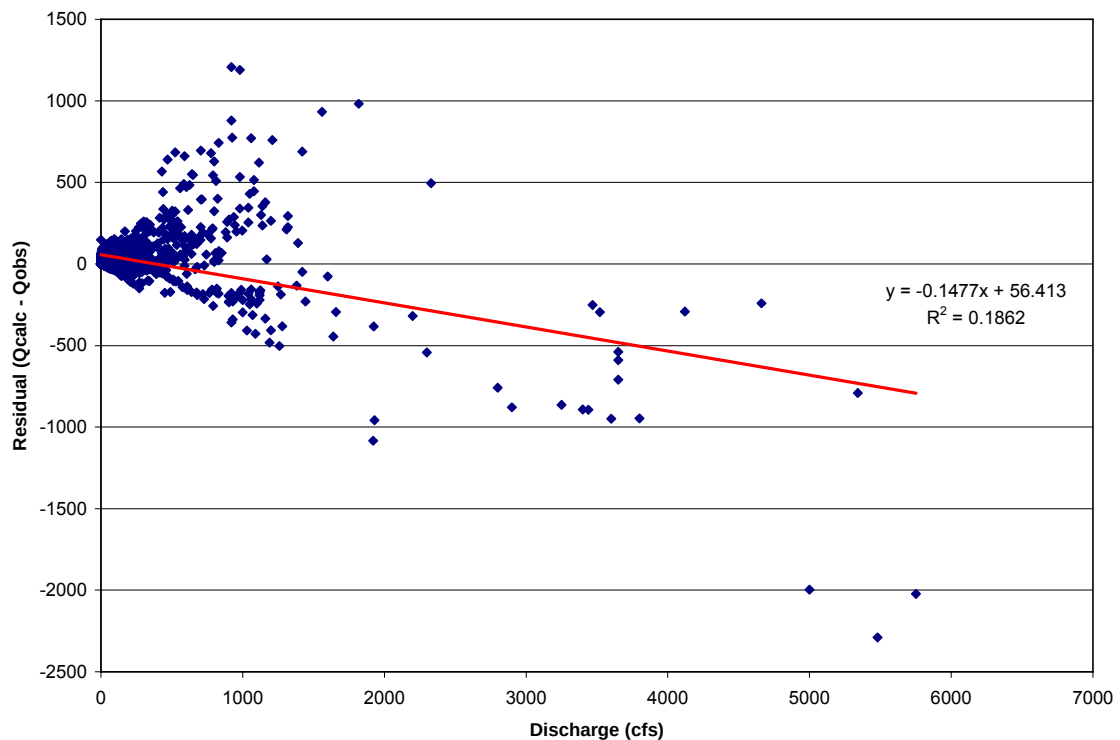


Figure 3-51. Distribution of discharge residuals as a function of measured discharge at the gage at O'Leno State Park.

Clearly, the simulated stage data appear marginally useable at all stages with the understanding that there are potentials for over or underestimating stage. The discharge data are also useable, but with limitations. Because there is a tendency to underestimate high flow events, care should be utilized when using synthesized, flood-event data. Synthesized discharge data are excellent for identification of low-flow MFLs. Setting high-flow regimes will predict that there is less water available than direct measurement may indicate.

3.3.7.2 Stream Flow Characteristics

The graphs depicting stage versus discharge (rating curves) provide important hydrologic behavior information. This section discusses selected rating curve graphs and the information they contain.

The rating curve for the Santa Fe River at Graham (Figure 3-52) is an excellent example. Note that there is a sharp break in slope at a stage of about 115 feet above sea level. Below this elevation, discharge is relatively insensitive to stage. This suggests that changes in stage at low flow reflect in-channel flow and discharge events that remain within the stream channel. At about 115 feet above sea level and about 500 cfs, the river overtops its banks and floodplains begin to be inundated. Once the floodplains begin to flood, cross-sectional area is controlled by the width of the floodplain. Discharge can increase dramatically by expanding the wetted perimeter of the stream with little increase in stage.

The rating curve for the Santa Fe River at Worthington Springs (Figure 3-53) illustrates a pattern similar to the Santa Fe River at Graham gage (Figure 3-52). The in-channel flow dominates up to a stage of about 60 feet above sea level and 2,000 cfs. Above these thresholds, the floodplain begins to be inundated.

Similar responses can be seen at the Brooker gage (Figure 3-12). Here, as in the data from the Graham and Worthington Springs gages, there is little data dispersion and the rating curve is well defined.

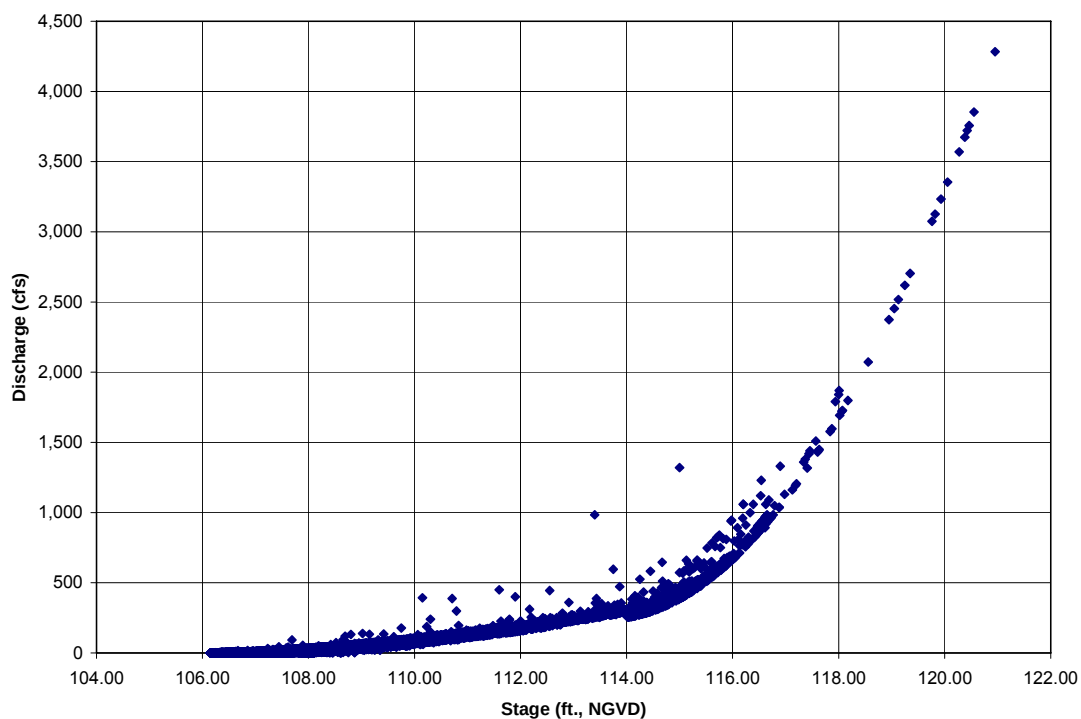


Figure 3-52. Rating curve for the gage on the Santa Fe River at Graham.

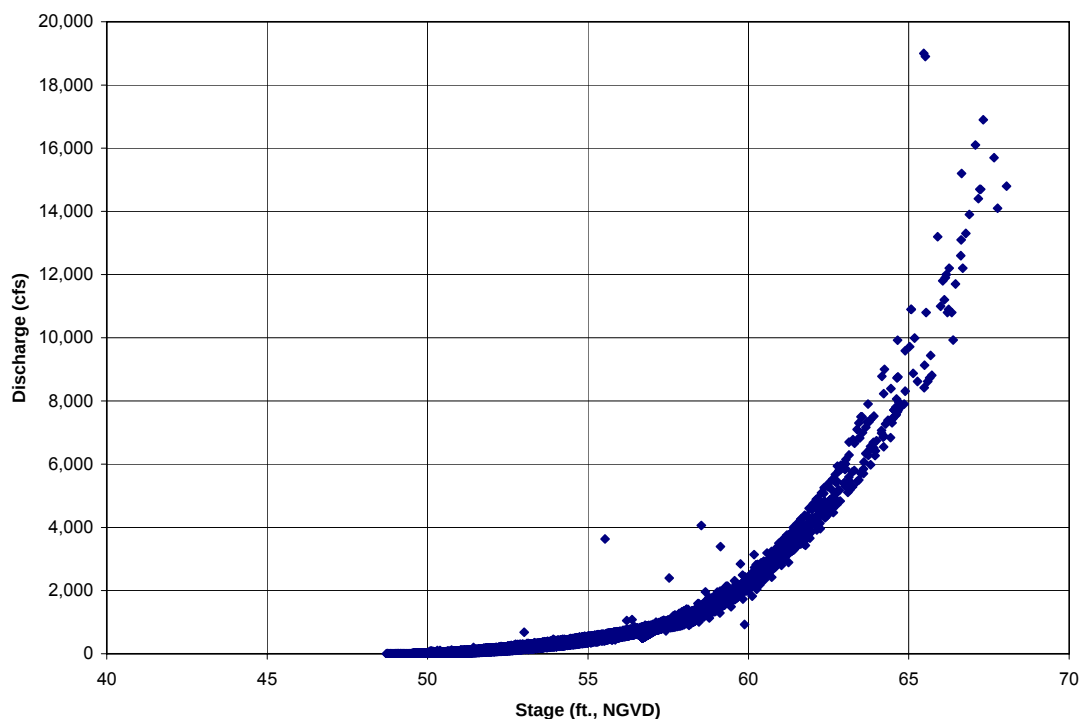


Figure 3-53. Rating curve for the Santa Fe River at Worthington Springs gage.

Note that the rating curve for the Santa Fe River at O'Leno (Figure 3-16) reveals considerable data dispersion above a stage of about 34 feet and discharge above about 170 cfs. Below this threshold, in-channel flow dominates. The data dispersion above this threshold is a result of complex interactions. At high river flow, Santa Fe Springs appears to act as an estavelle. At this time, river discharge is captured thus lowering discharge relative to stage at O'Leno. The floodplain at and above O'Leno (Figure 2-30) has well-developed flood chutes that apparently affect the rating curve, as well. Finally, White (1970) postulated that portions of the floodplain near O'Leno are relict, perhaps predating capture of the river at the River Sink. The routing of flood waters through the active floodplain and, perhaps, portions of the relict floodplain appear to contribute to this data dispersion.

3.3.7.3 Spring Flow Characteristics

Santa Fe Springs (COL61981) is clearly an estavelle, with flow reversals at high river stage. The simulated negative discharge events at the spring occur when the river stage is at its highest (Figure 3-54). Note also in Figure 3-54 that the episode of low, positive spring discharge coincided with a low river stage during the severe drought of the early 2000s.

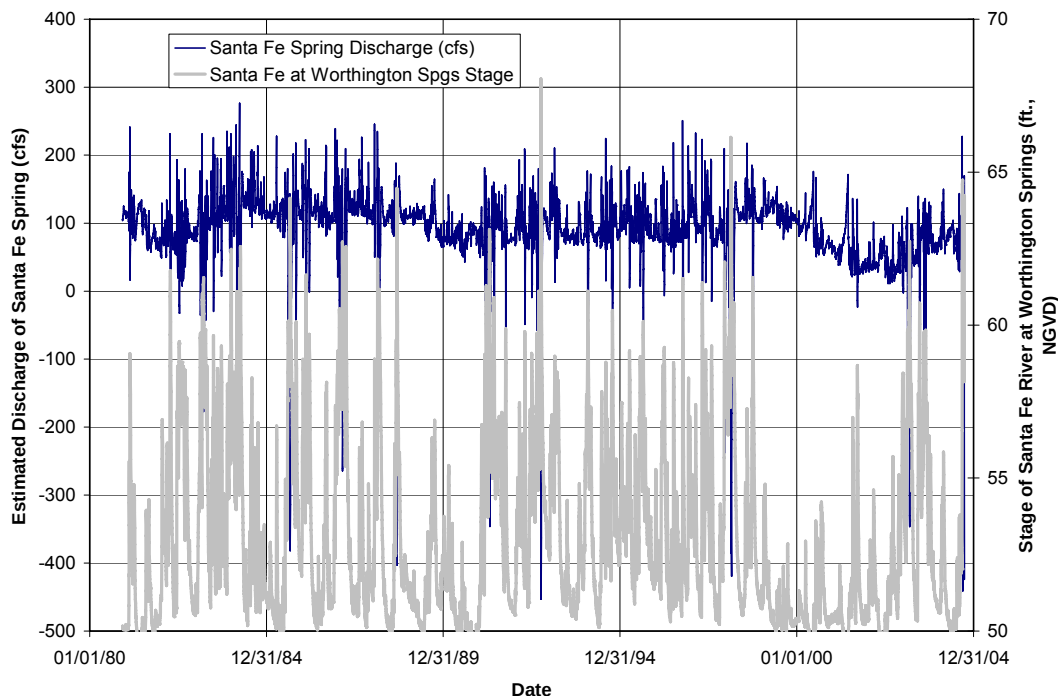


Figure 3-54 Comparison of the stage of the Santa Fe River at Worthington Springs with simulated discharge from the Santa Fe Spring (COL61981).

A comparison of river stage with spring discharge (Figure 5-55) suggests that the reversal in spring discharge occurs at a river stage of 59-60 feet NGVD at the Worthington Springs gage. Note that this is the stage elevation at which over-bank flow begins (Section 3.3.7.2). Below this stage, the spring supplies water to the river. When the river approaches an over-bank flood stage, reversal of flow from the spring begins.

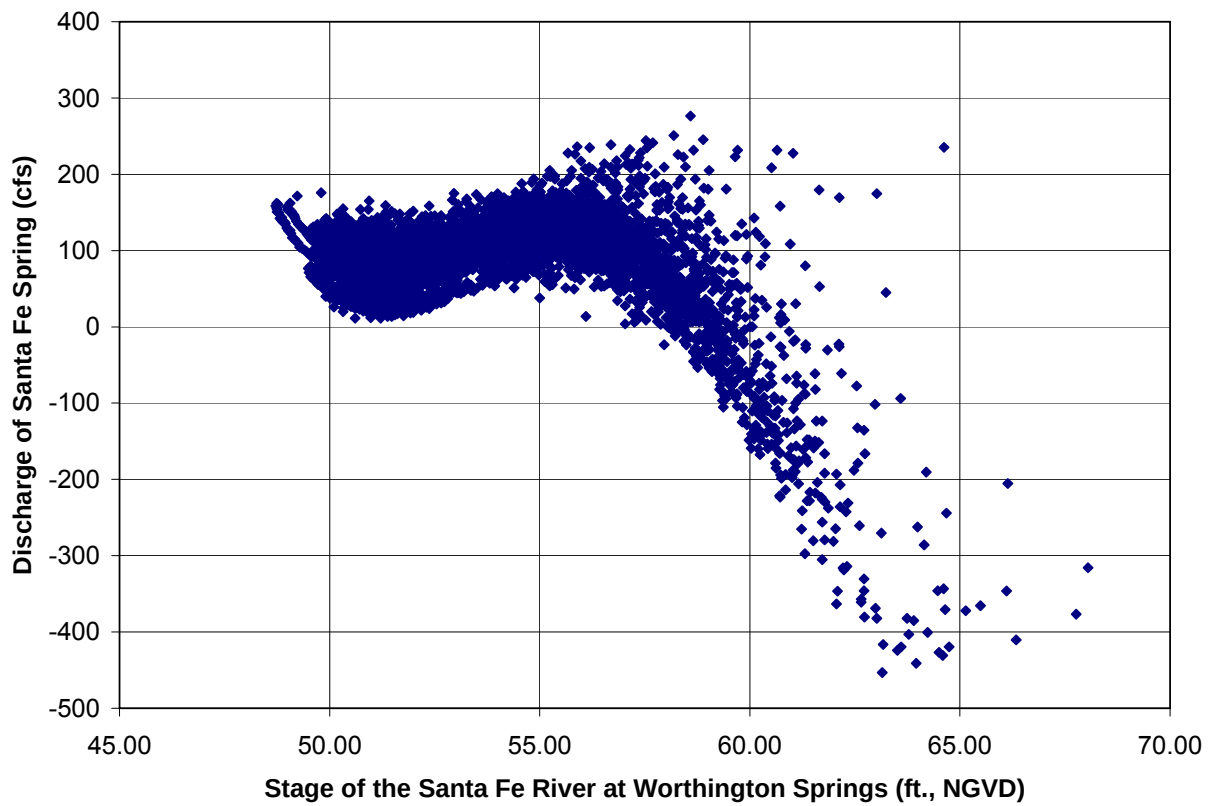


Figure 3-55 The effects of Santa Fe River stage on spring discharge.

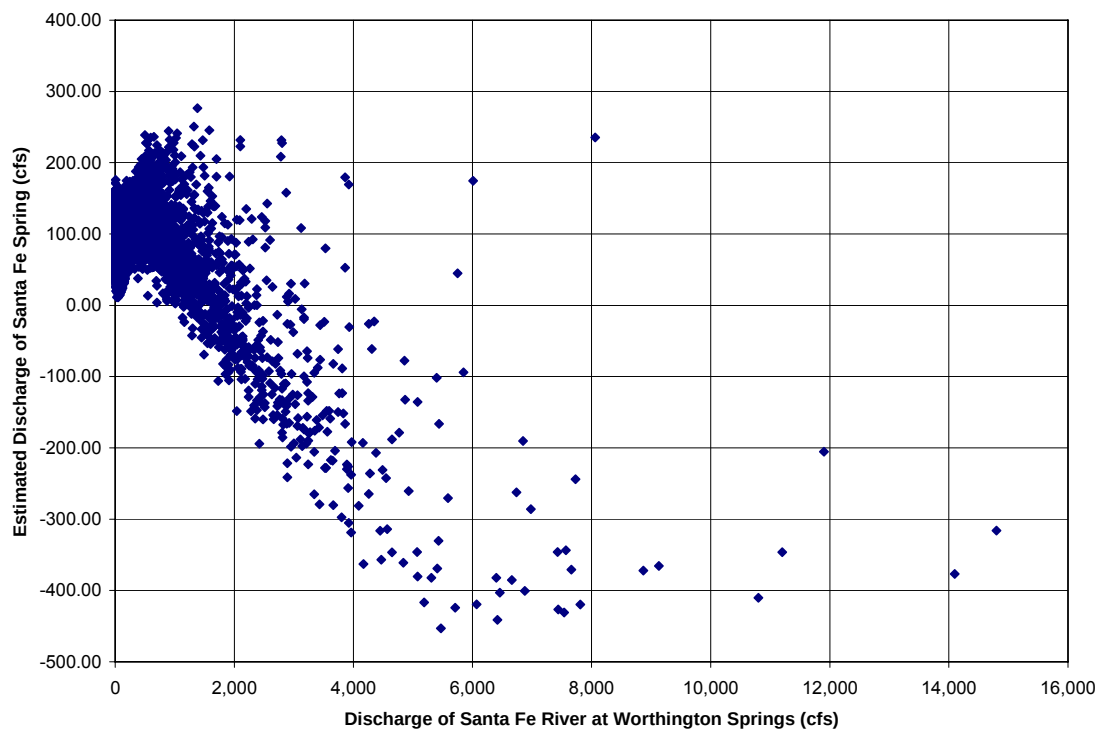


Figure 3-56 Relationship of Santa Fe River and spring discharge.

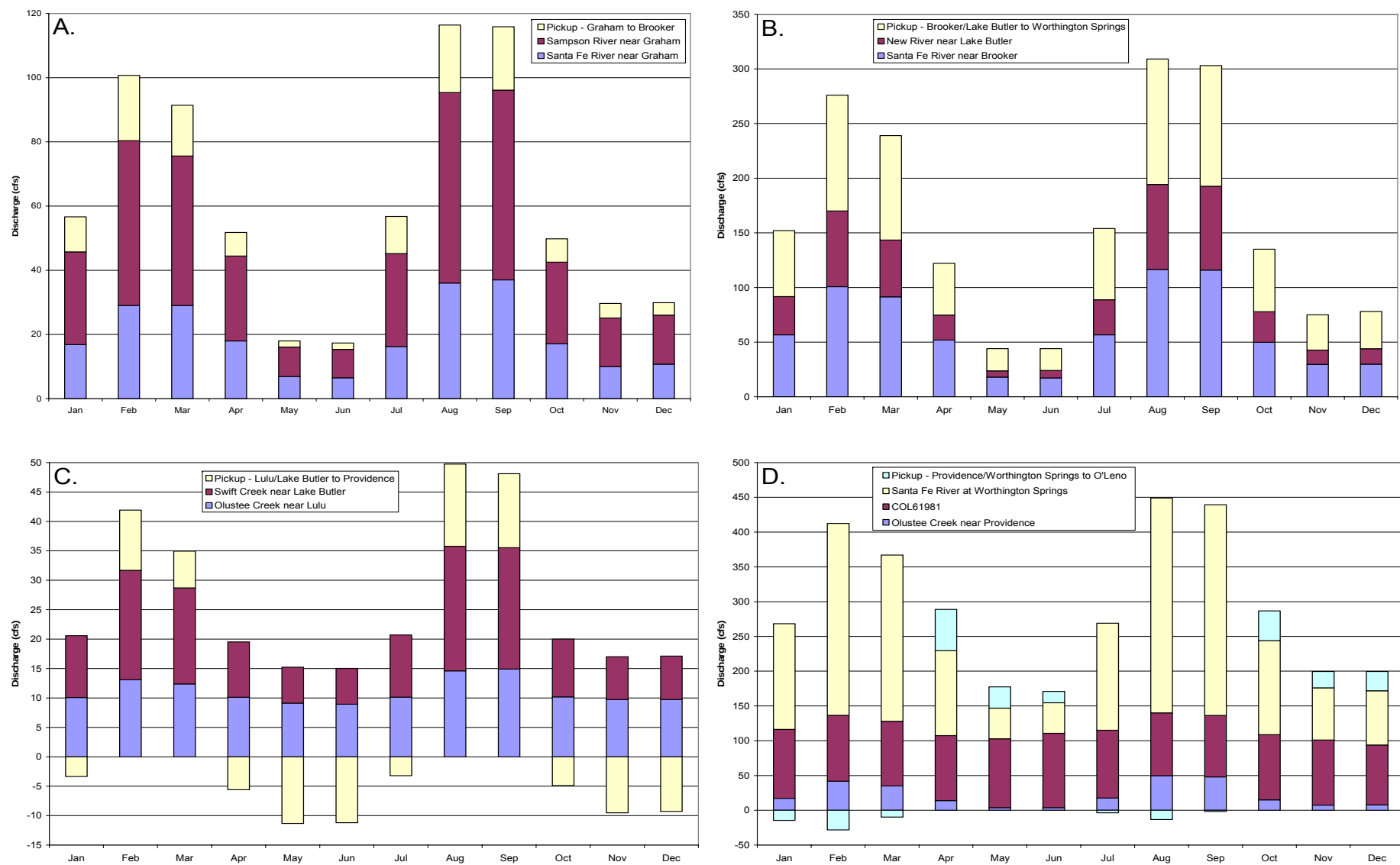


Figure 3-57 Contribution to discharge at select gages in the Upper Santa Fe Basin from discharge recorded at upstream gages and pickup between the upstream and downstream gage. A. Santa Fe River near Brooker, B. Santa Fe River at Worthington Springs, C. Olustee Creek near Providence, D. Santa Fe River at O'Leno State Park. All values are median monthly discharges for the period of record.

The relationship of spring discharge with river discharge is also important. Figure 3-56 compares the discharge of the Santa Fe River at Worthington Springs with estimated spring discharge. Based on the Worthington Springs gage-rating curve (Figure 3-53) over-bank flooding of the river begins at about 2,000 cfs. The reversal of spring flow also appears to begin at this point. Also, note that, while spring discharge reaches a maximum when river discharge at Worthington Springs is at about 1,000 cfs, spring discharge remains near 100 cfs when river flow is 100 cfs or less. In other words, spring discharge clearly sustains downstream river flow during extreme low river discharge events.

3.4 Relative Contributions of Tributaries to the Upper Santa Fe River

Several major tributaries contribute discharge to the Upper Santa Fe River, as well as numerous minor streams and springs. Figure 3-57 summarizes the mean monthly discharge for four gages within the Upper Santa Fe River Basin. Each bar is subdivided into the component contributions recorded at upstream gages, as well as the pickup between the upstream and downstream gage. The sum of all components within the bar represents the median monthly discharge for that gage. If all discharge components are positive, the total height of the bar represents the median monthly flow for that gage. If some of the components are negative, however, the median monthly flow at the gage is equal to the length of the positive portion(s) of the bar minus the negative portion(s).

Discharge at the Santa Fe River near Brooker (Figure 3-57A) is composed of water flowing down from Lake Santa Fe and the Santa Fe Swamp (represented by discharge measured at the Santa Fe near Graham), water flowing from Lake Sampson down the Sampson River, and additional pickup between Graham and Brooker. The most significant of these components is water derived from the Sampson River, which accounts for about half of the discharge measured at the Brooker gage on average. Water from upstream of the Santa Fe River near Graham contributes approximately one third of the median discharge at Brooker, while the pickup between Graham and Brooker represents about one-sixth of the median discharge at Brooker.

Discharge recorded at the Santa Fe River at Worthington Springs can also be divided into three components: discharge from upstream on the Santa Fe (as recorded at the Brooker gage), discharge recorded at the New River near Lake Butler, and pickup between Lake Butler/Brooker and Worthington Springs (Figure 3-57B). The water derived from upstream of the Brooker gage, as well as pickup between the upstream and downstream gages, each represent about 40% of the median monthly discharge at Worthington Springs, while water derived from upstream of the Lake Butler gage accounts for about 20% (Figure 3-58).

Under median flow conditions on Olustee Creek (as recorded at the Providence gage, Figure 3-57C) water is primarily derived from two sources: discharge from upstream of the Lulu gage on Olustee Creek and discharge from Swift Creek (as recorded at the Swift Creek near Lake Butler gage). On average, the contribution from these two sources is roughly equal, though Swift Creek appears to be more significant during wet months and Olustee Creek appears to be more significant during dry months. Pickup between upstream and downstream gages is also a significant source during wet months (Feb-Mar, Aug-Sept). During all other months, however, Olustee Creek is a losing stream during median flow conditions. During the driest months, as much as two-thirds of water contributed from upstream is lost before reaching the Providence gage.

Discharge at the O'Leno can be divided in four components (Figure 3-57D): discharge from upstream of the Worthington Springs gage, discharge from Olustee Creek (upstream of the

Providence gage), discharge from Santa Fe Spring (COL61981), and other pickup between Worthington Springs/Providence and O'Leno. On average, the largest contribution (about 56%) comes from upstream of Worthington Springs (Figure 3-59). The Santa Fe Spring contributes another ~33% on average, although during the dry months the spring contributes over half of the flow during median flow conditions. Contributions from Olustee Creek and additional pickup on the Santa Fe River downstream of Worthington Springs only account for about 11% of the discharge at O'Leno during median flow conditions, on average. In contrast to Olustee Creek, the pickup between upstream gages and downstream gages is negative during wet months and positive during dry months.

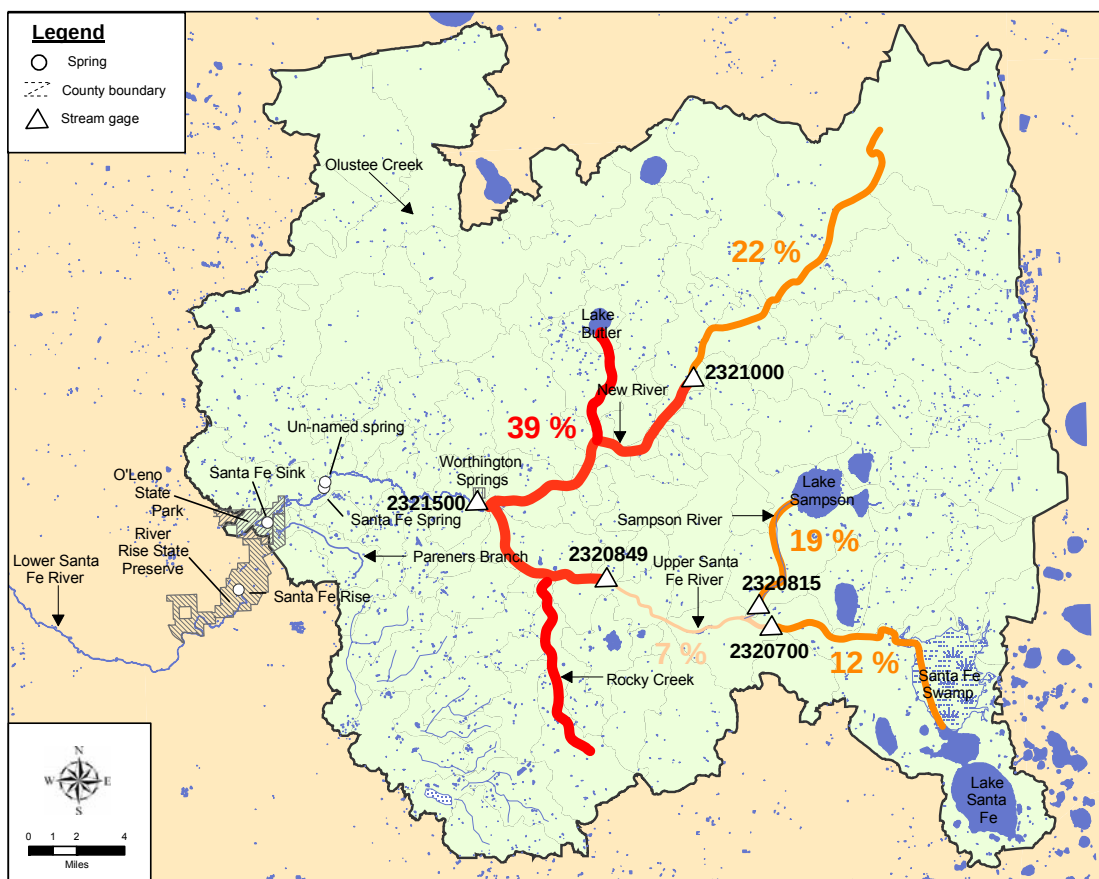


Figure 3-58 Average relative contribution to discharge on the Santa Fe River at Worthington Springs during median flow conditions.

The approximate extent of the Santa Fe Spring springshed was identified in order to account for the losses of water from Olustee Creek and Santa Fe River downstream of the Worthington Springs gage. Figure 3-59 illustrates the rough extent of the springshed and the 1961 potentiometric surface from which it was delineated. The springshed is approximately 90 mi.², which should result in a median flow of about 90 cfs.² This is approximately the median discharge of the spring, so it appears a reasonable approximation of the springshed. The

² Experience has shown that there is a very general relationship in the Suwannee River Water Management District of approximately 1 cfs of median spring discharge occurs for every square mile of drainage basin area. This approximation is utilized as a “reality check” when delineating springsheds utilizing low-resolution potentiometric-surface data.

conclusion drawn from this approximation is that much of the water lost to the subsurface upstream and to the north and northeast of the spring is discharged from the spring.

Initial considerations of the source(s) of water discharging from Santa Fe Spring focused on the sinking streams and swallets south of the spring. These streams drain the Northern Highlands and Cody Scarp. Based on the data presented above and the work of Martin and Screaton (2001) (Section 2.3.4.3), it now appears that the surfacewater that drains the Highlands to the south may enter the system as part of the gain in groundwater flow at the Santa Fe Sink and Rise complex.

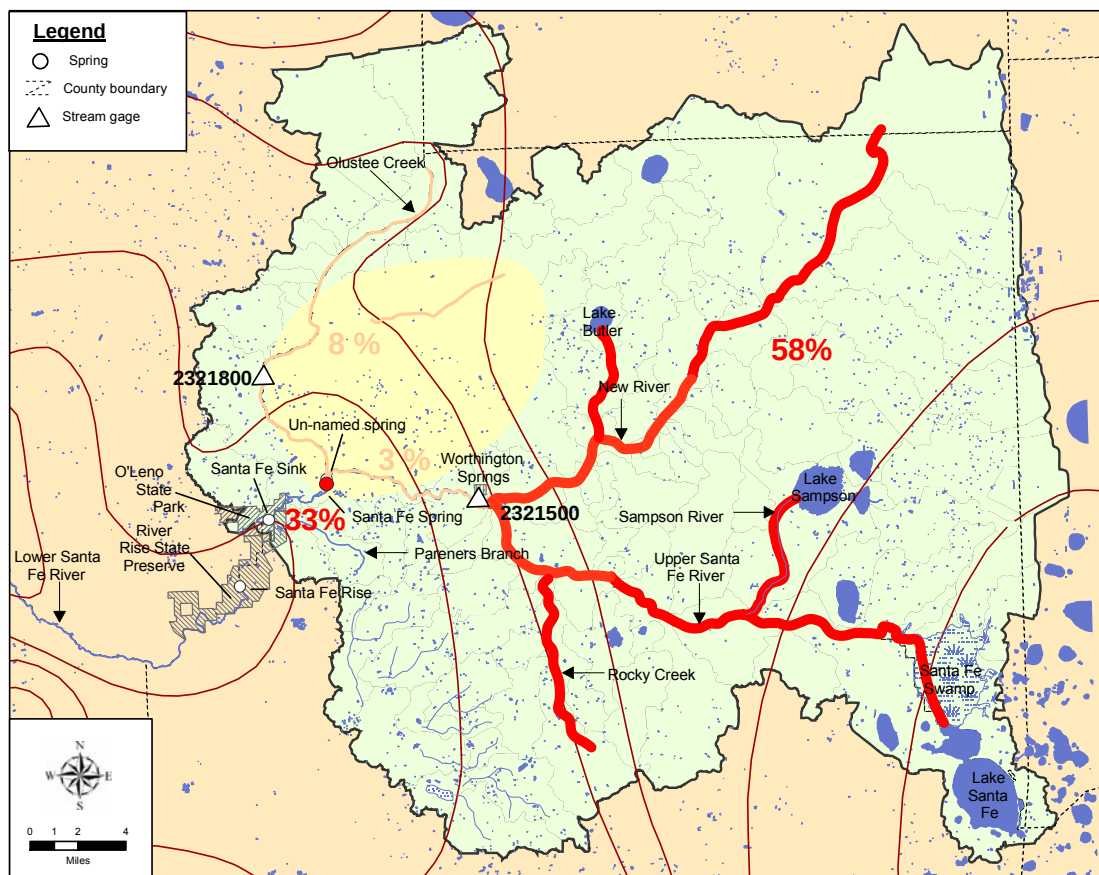


Figure 3-59. Average relative contribution to discharge on the Santa Fe River at O'Leno State Park during median flow conditions. The 1961 Floridan Aquifer potentiometric surface and approximate springshed for the Santa Fe Spring (COL61981) are discussed below.

3.5 HEC-RAS Model for the Upper Santa Fe River

A transient and steady state HEC-RAS model was developed for the Santa Fe River in order to support ecological modeling of the river and MFL development. An existing steady state HEC-2 model of the Santa Fe was developed for flood plain mapping by the Army Corps of Engineers. The HEC-2 model was converted to HEC-RAS by Taylor Engineering. This converted model was again modified as described below adding the transient simulation as well as better

representing the low flow conditions. The text below describes the tasks performed on the model simulating the Upper Santa Fe River. Figure 3-60 shows the model domain, simulated river cross sections, and observed gage locations. The final HEC-RAS model was developed using observed flows and estimated pickup as input to drive the simulation. The model was calibrated to match observed stages.

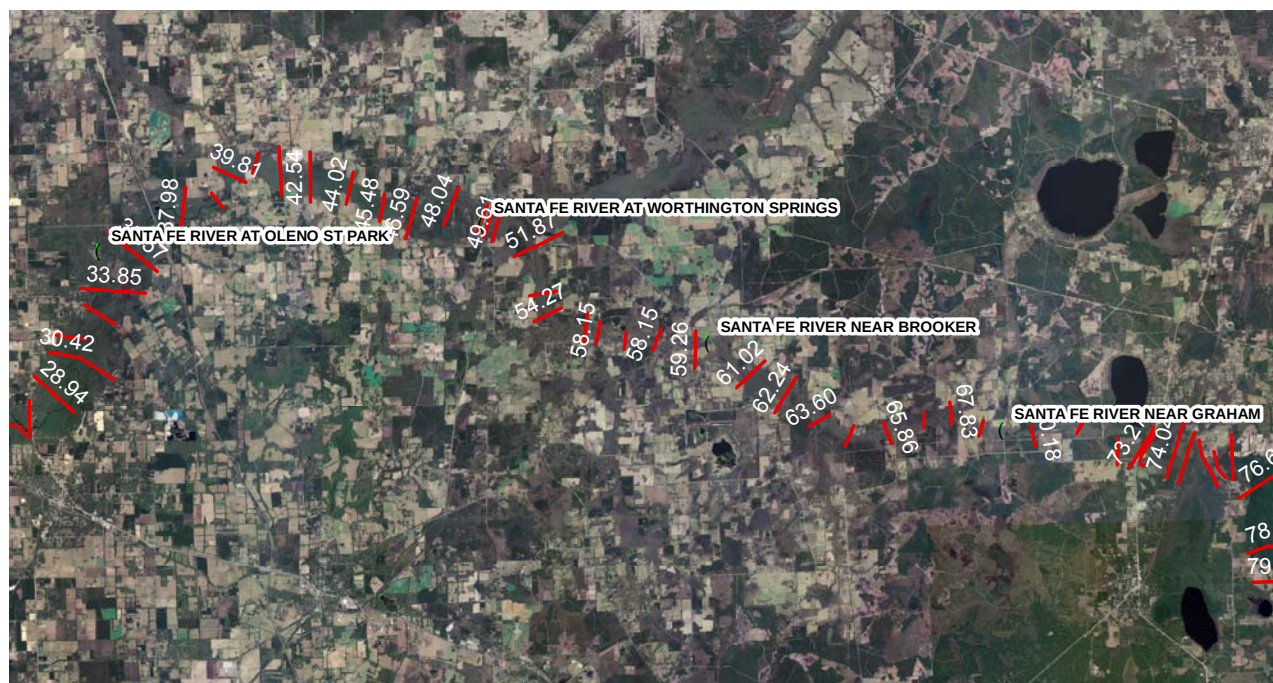


Figure 3-60 HEC-RAS model domain, simulated river cross sections, and observed gage locations.

3.5.1 Model Data Development

A database was developed to store the observed flow and stage data for the Upper Santa Fe River. The database was used to process the model input or boundary conditions as well as the model calibration targets. Various tools were programmed into the database to assist in the data management. All time series data were then exported to the DSS format for use in the HEC-RAS model. The observed flow data will serve to drive the HEC-RAS model as upstream and lateral boundary conditions. The observed stages will serve as a calibration target. Only the most downstream section will be driven with an observed stage boundary. The stations used to develop the observed flow and stage time series are shown in Figure 3-60.

3.5.2 Model Boundary Conditions

The model input time series or boundary conditions were stored and processed in an Access[®] database. The processing included regressions to fill missing data (as described above) and calculations to develop the lateral inflows or pickup. The time series data were then transferred to the DSS format using DSSUTIL. Two types of boundary conditions were used: stage boundary at the lower end of the model domain and flow boundaries both at the most upstream point as well as various lateral inflows.

Boundary data are required to be continuous and complete for successful application into HEC-RAS. Any missing periods in the observed data needs to be filled prior to use in pickup calculation and/or direct application in HEC-RAS. The Santa Fe near Graham station was missing necessary data. The Graham time series was filled with data developed from a regression with the Santa Fe at Worthington gage ($R^2=0.7191$). The observed flow for the two tributaries of Olustee Creek and New River were scaled later in the HEC-RAS model (see HEC-RAS Model Development section below). The scaling was required to account for the un-gaged portion of the respective basins. The up scaling was determined by the ratio of basin areas; total basin area/gaged basin area.

The lateral inflows or pickup were calculated by implementing a digital filtering method by Arnold and Allen (1999) and Arnold et al. (1995). The filtering smoothed the time series and allowed the generation of a smoothed difference between gages. The difference is the pickup or the change in flow from the upstream gage to the downstream gage. The pickup would then be applied in the HEC-RAS model as a uniform lateral inflow. VBA code was developed for fast computation of pickup. For the Olustee Creek and New River tributaries the flow was defined as a lateral inflow into the Santa Fe River at a point defined as the closest cross section available in the model.

All boundary condition time series were stored as separate paths in the "Boundary.DSS" file. All boundary data were recorded in the native daily time step. The DSS files contains six time series stage at O'Leno, Flow at Graham, Derived pickup between Graham and Worthington, derived pickup between Worthington and O'Leno, flows in New River, and flows in Olustee Creek.

3.5.3 Model Calibration Data

Calibration data consist of all stage and flow data available within the model domain. Comparisons of flow data with the model results are used to calculate and verify the pickup calculation and additional lateral inflows and ensure that the model adequately represents the hydrologic inflows to the physical system. The stage comparisons are used to calibrate and verify the simulated frictions factors within the model domain. Calibration data were available for Santa Fe River near Graham at RM 69.38, Santa Fe River near Brooker at RM 59.66, and Santa Fe River near Worthington at RM 49.28. The stage and flow data for the calibration stations were stored in an Access database. The data were then exported into HEC-RAS DSS files.

3.5.4 HEC-RAS Model Development

As stated earlier, a HEC-RAS model was available for the Santa Fe River. The original model was developed for flood mapping. Models developed for flood mapping purposes are not calibrated for low flow conditions. For this reason significant work is necessary to re-calibrate this existing model to better represent the low flow conditions. Additional survey data were collected to help improve the low flow calibration. Model stability at extreme low flow, especially when the river naturally runs dry, is also an issue for numerical modeling. Additional model stability issues were addressed by adding interpolated cross sections. The interpolated sections were added using the HEC-RAS interpolate cross section option within the interface. Lastly for the ecological modeling of the river, it was necessary to produce a transient model.

Several cross-sections were surveyed to support the model development for low flow calibration. The most significant model calibration improvement occurred with the addition of the shoal just downstream of the Worthington gage. There were other cross-sections added to the HEC-RAS model. Figure 3-61 depicts the river profile with the added cross-sections

highlighted. The profile displays the bridges present in the model with a vertical line. The profile represents the lowest point on the cross section within the HEC-RAS data set. The additional survey data were only available for the channel portion of the cross section. Since the model extends into the flood plane the surveyed cross sections were extended. Extending the cross sections was accomplished by copying the closest available cross section to the location of the surveyed section. The channel data were then replaced with the new survey data gathered as part of this investigation. A table listing the final cross-sections and the channel lengths is shown in Appendix 3-1. The interpolated sections are labeled with asterisks following the river mile. The table also shows the channel, left over bank, and right over bank lengths.

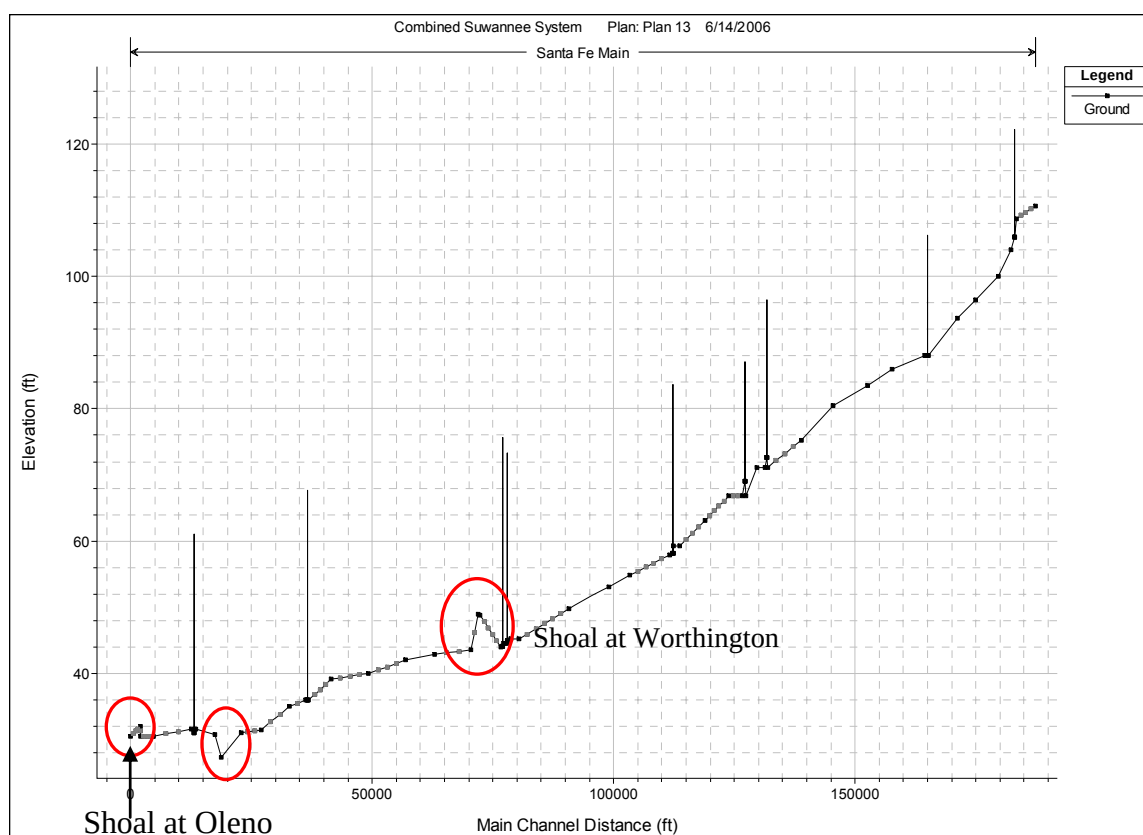


Figure 3-61 River profile with the added cross-sections

Since the Upper Santa Fe River historically has gone dry, a pilot channel was necessary. A pilot channel is merely a channel cross section modification for all cross sections. The modification is typically a narrow notch that extends below the bed. The pilot channel is only active when the model runs dry and does not dramatically impact the model results. Pilot channels are specified using a pilot channel width, pilot channel Manning's n , the pilot channel depth and pilot channel slope. HEC-RAS interpolates these data across all the cross sections between the specified end point cross sections. For the Upper Santa Fe River, a pilot channel was added between RM 70.18 to RM 30.31 for model stability. Additional model stability issues were addressed by adding interpolated cross sections and adding ineffective flow areas at bridges and other appropriate cross-sections

The model boundaries were specified for the Upper Santa Fe River domain. The tributaries, New River and Olustee Creek, were added at the nearest cross section available. These inflows were also scaled based on the ratio of contributing area. The lateral inflows representing these tributaries were added to the model using; 1.223 x New River near Lake Butler flows at RM 49.9 and 1.3821 x Olustee Creek near Providence flows at RM 39.81.

The pickup calculated (described in the paragraphs above) was added to the model domain as a uniform lateral inflow. The uniform lateral inflow was used because defined inflow points and associated ratios can not be determined. The pickup between Santa Fe River near Graham and the Santa Fe River near Worthington was added to the model as a uniform lateral inflow between RM 69.38 to RM 49.28. The pickup between Santa Fe River near Worthington and the Santa Fe River near O'Leno was added in two separate sections. The pickup calculations between these gages resulted in large negative pickup flows or losses of water from the river and entering the groundwater system. These losses caused numerical stability issues when distributed uniformly between the gage locations. The location of the Cody Escarpment places most of the losses below the Olustee Creek tributary. A simple mass balance analysis placed most of the loss below the Olustee Creek tributary. The presence of Santa Fe Spring (COL61981) and associated un-named sink within the Santa Fe River also places a large component of the computed pickup below the Olustee Creek tributary. For these reasons, a small ratio of the computed pickup was placed upstream of the Olustee Creek tributary. The remaining pickup was located below the Olustee Creek tributary. Therefore, 0.2 of the computed pickup between Worthington and O'Leno was placed as a uniform lateral inflow between RM 49.28 and RM 40.91 and 0.8 of the computed pickup between Worthington and O'Leno was placed as a uniform lateral inflow between RM 39.02 and RM 35.07. The schematic below (Figure 3-62) describes the defined model boundary conditions.

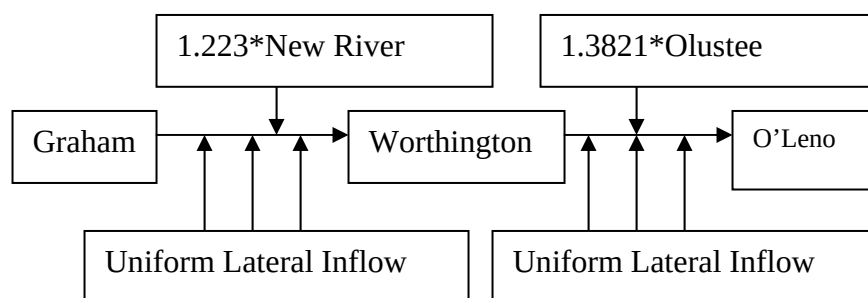


Figure 3-62 Schematic showing the defined model boundary conditions.

The processed model boundary conditions are listed below:

- Upstream Boundary at RM 70.18 Santa Fe near Graham Flow
- Downstream Boundary at RM 35.01 Santa Fe at O'Leno Stage
- Uniform Lateral Inflow between RM 69.38 and 49.28 (Graham to Worthington)
- Uniform Lateral Inflow between RM 49.28 and 35.07 (Worthington to O'Leno)
- Lateral Inflow for New River Near Lake Butler at RM 49.9
- Lateral Inflow for Olustee Creek near Providence at RM 39.81

The model was constructed to simulate the six-year period between 10/1/1997 to 9/29/2003. This period included two significant wet periods and included a severe drought. Confidence in

the model and its predictive capability is gained especially over the full range of flows included in the simulation period.

3.5.5 HEC-RAS Model Calibration

The HEC-RAS model of the Upper Santa Fe River was calibrated by adjusting the channel Manning's n friction factor. Consistency in the friction factors was maintained avoiding point calibration and increasing the model's predictive capability. The calibration comparisons occur at only a few cross sections (at gage locations) and maintaining consistency in the friction factors improves the prediction of river stages between the calibration points (Figures 3-63 – 3-66).

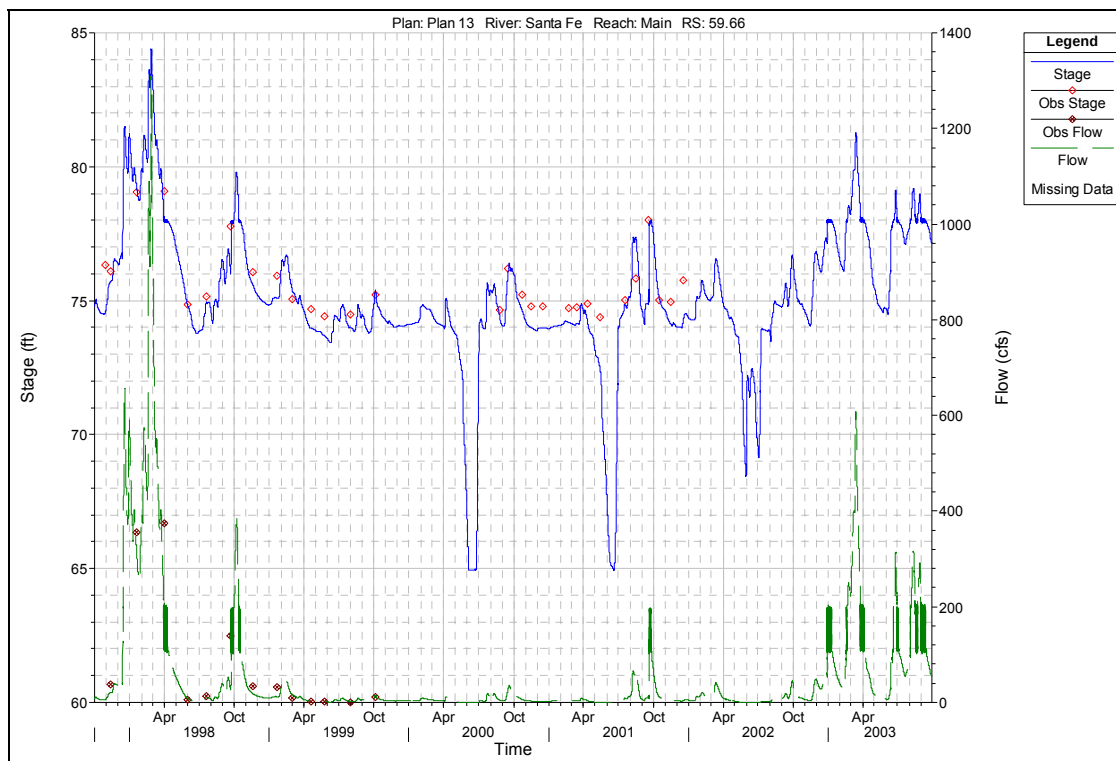


Figure 3-63 Calibration at Brooker.

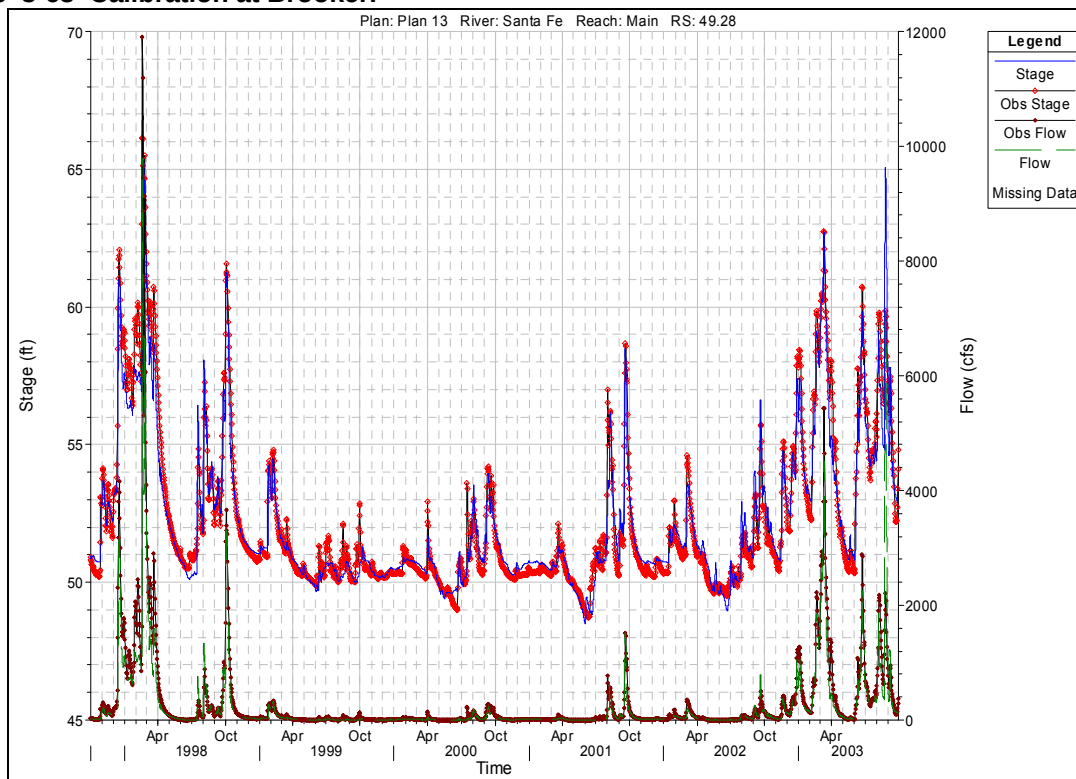


Figure 3-64 Calibration at Worthington

The roughness coefficients were factored for varying flow conditions. The roughness factoring allows the model to simulate high friction factors for low flow conditions while using lower friction factors for high flows. The low flow friction factors should be increased due to the increase in tortuosity and small scale friction elements. The roughness coefficients between RM 70.18 and RM 53.44 were set to vary from 2 to 0.85 times the defined Manning's coefficient for flows from 0 to 190 cfs. The roughness coefficients between RM 41.67 to RM 34.67 were scaled from 1.5 to 0.8 the defined Manning's 'n' for flows from 0 to 90.

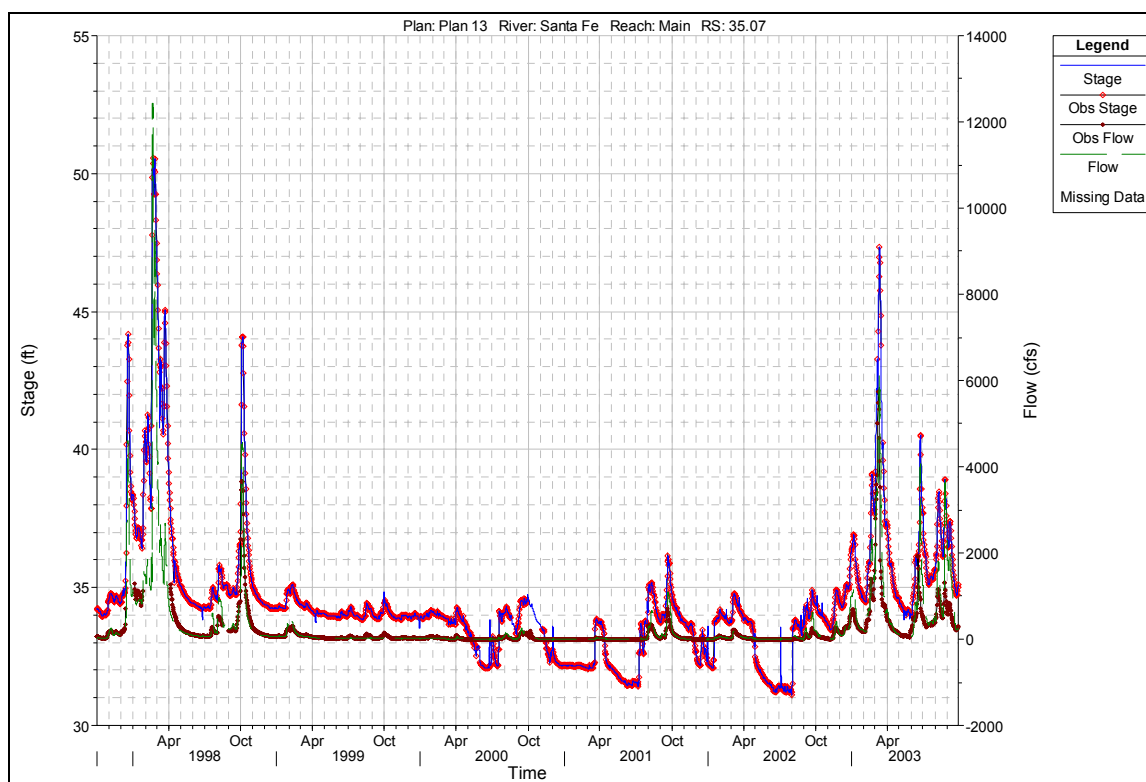


Figure 3-65 O'Leno as stage boundary condition

3.5.6 Exported HEC-RAS Data for EFM

Detailed output from HEC-RAS was exported to an ASCII file for use in the ecological modeling of the Upper Santa Fe River. The detailed output defines the velocities, depths, wetted perimeter, and other hydraulic properties for each cross-section. The observed flow and estimated pickup data (the data used for the model development and calibration) was compressed into 20 values representing a value at every 5% from the flow durations curves. The flow values and the calibrated model parameters were utilized to produce a steady state simulation for each flow and downstream stage condition. The detail output for each steady state run was again exported to an ASCII output file. The steady state output was exported to define the horizontal velocity distribution. The detailed output is sufficient enough to map the area of preferred habitat for various species.

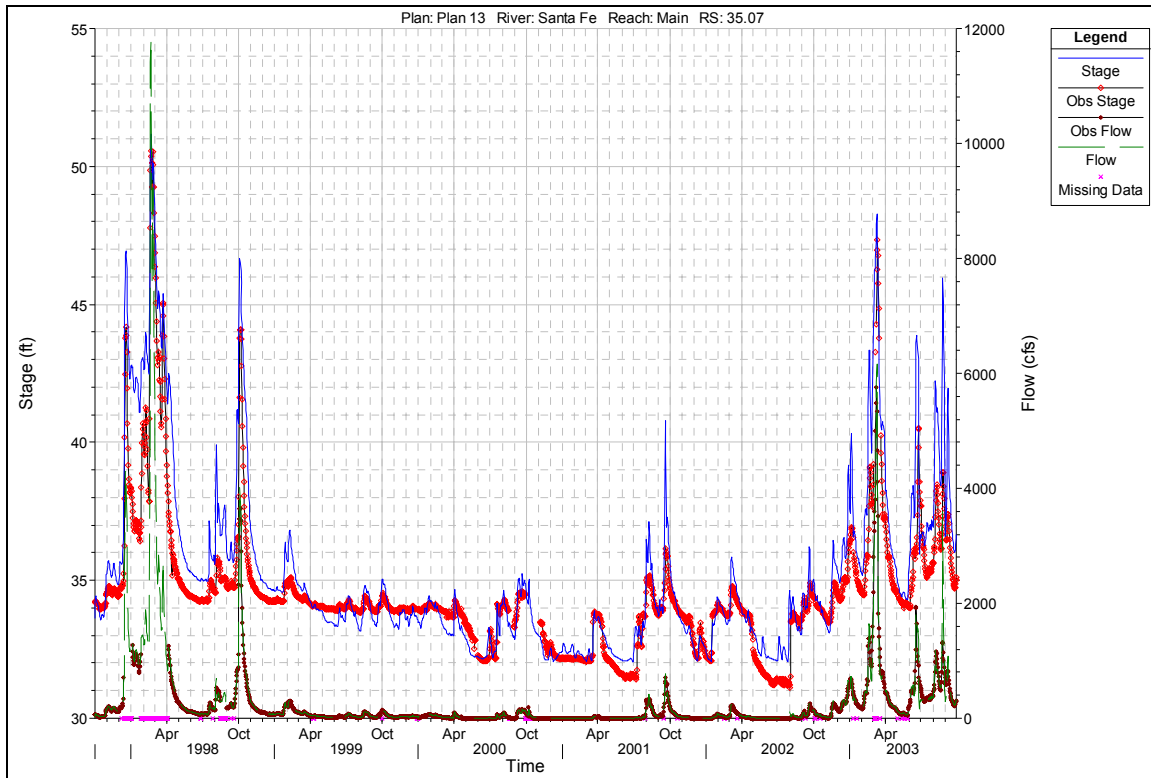


Figure 3-66 Santa Fe model: Graham to Suwannee confluence O'Leno calibration

3.6 Use of the Discharge Data for MFL Development

3.6.1 Introduction

This subsection includes long-term flow duration curves (FDCs) and monthly box and whisker graphs for discharge at the Upper Santa Fe River at Graham, Worthington Springs, and O'Leno gages. The purpose of the FDCs is to set baseline flow conditions, against which the MFL FDC will be set. Therefore, the Baseline FDC is the historic FDC based on the period of record of measured and simulated discharge data.

It is proposed that the MFLs for the Upper Santa Fe River be set at two locations: the Graham and Worthington Springs gages. Consequently, data from the Graham and Worthington Springs gages should be used to set the "Baseline" FDCs for the Upper Santa Fe River, excluding Olustee Creek and the river near O'Leno State Park. Section 3.6.4 discusses the basis for setting the MFL for Olustee Creek and the O'Leno reach of the Upper Santa Fe at a location downstream from the River Rise. In every case, raw data are utilized for creation of these data presentations where available. Where there were data gaps, synthesized data, as described in Section 3.3, were included.

The data from the Worthington Springs gage are entirely gage measurements. There are no synthesized data in the record. Discharge data collection at the Graham gage began in 1958. In order to extend the Graham data set back to 1932 to correspond with the Worthington Springs dataset, the 1932-1958 data were simulated as described in Section 3.3.2.1. Data from the O'Leno gage, which is located approximately 0.5 miles upstream from River Sink, and downstream of all major tributaries to the Upper Santa Fe, include a large proportion of

synthesized data points. Therefore, while the location of the gage is optimal, the data used for establishment of the MFL are, in part, synthesized.

3.6.2 Summary of Discharge at the Graham Gage

Figure 3-67 depicts the historic FDC for the Upper Santa Fe River at the Graham gage. The FDC is based partly on gage data and partly on synthesized data as described in Section 3.3.2.1. Table 3-5 summarizes the properties of this FDC. The Graham gage is downstream from Santa Fe Lake and the Santa Fe Swamp, so a MFL set at Graham assists in monitoring water availability in the headwaters of the river.

Table 3-5. Summary of Distribution Descriptors for Period of Record and Monthly Discharge at the Graham Gage, Upper Santa Fe River

Period	Minimum (cfs)	25 Percent Exceedance (cfs)	50 Percent Exceedance (cfs)	75 Percent Exceedance (cfs)	Maximum (cfs)
Period of Record	0.0	2	15	53	1,870
January	0.2	5	17	57	601
February	0.2	8	29	85	1,790
March	0.2	9	43	116	1,510
April	0.1	2	22	63	765
May	0.0	1	5	23	984
June	0.0	0.4	3	24	564
July	0.0	1	12	46	910
August	0.0	2	34	89	1,060
September	0.1	7	34	85	1,870
October	0.1	2	16	43	1,000
November	0.1	1	7	24	253
December	0.1	3	8	25	660

Table 3-5 also presents the monthly discharge summary statistics and Figure 3-68 depicts a box and whisker diagram of the monthly data. The pattern of monthly discharge has a distinct minimum in May and June, and two nearly equal episodes of high flow in February/March and August/September. This pattern is consistent with the mixed river discharge pattern described by Kelly (2004) (Figure 2.18).

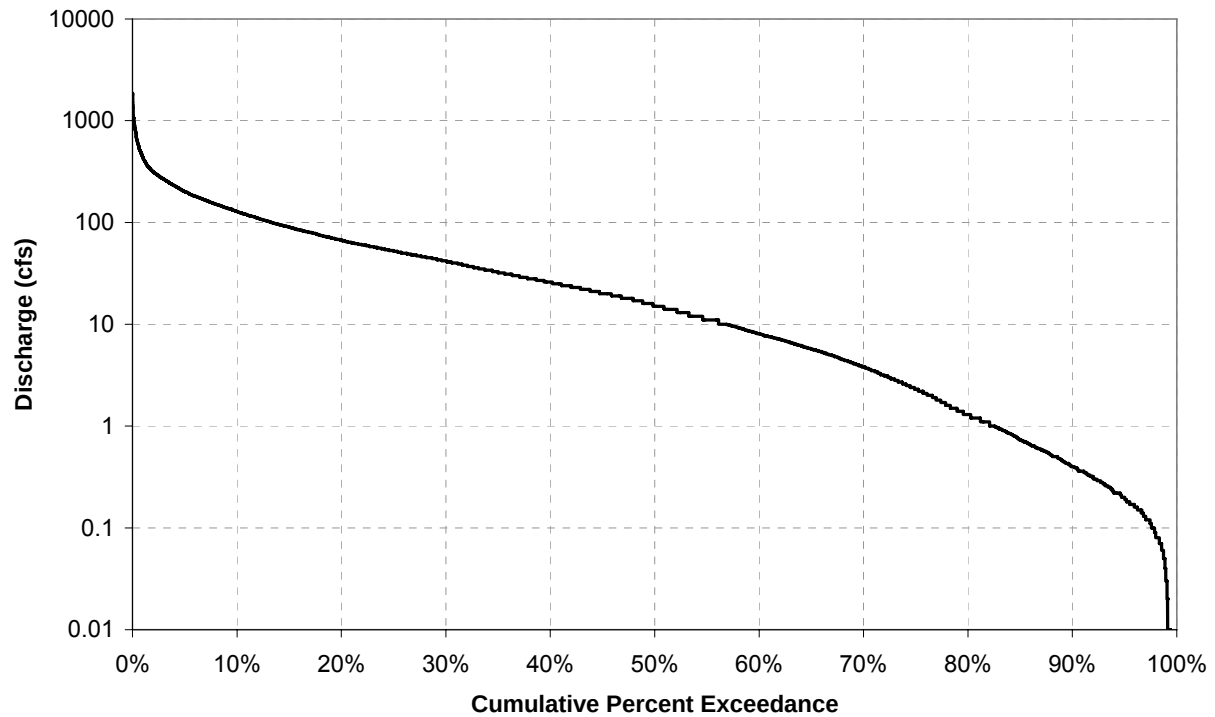


Figure 3-67. 1957-2004 period of record flow duration curve for discharge at the Upper Santa Fe River gage at Graham. Data were partly synthesized as described in Section 3.3.2.3.

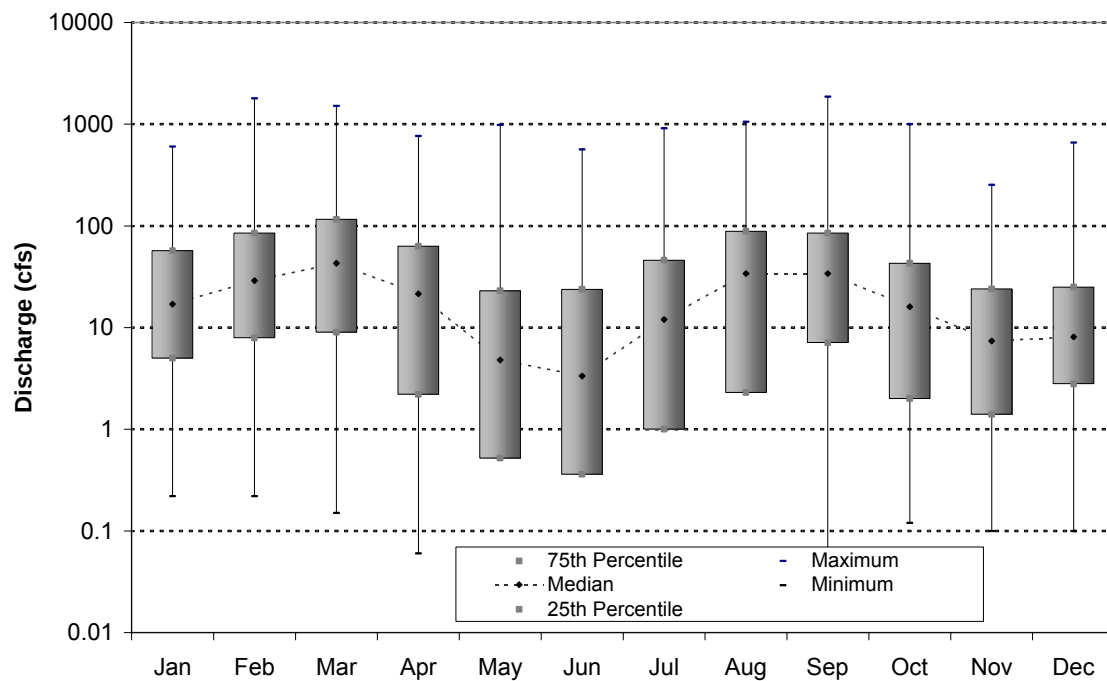


Figure 3.68. Box and whisker diagram depicting the monthly variations in flow at the Graham gage, Upper Santa Fe River.

3.6.3 Summary of Discharge at the Worthington Springs Gage

Figure 3-69 depicts the historic flow duration curve (FDC) for the Upper Santa Fe River at Worthington Springs. The FDC is based entirely on gage data. Table 3-6 summarizes the properties of this FDC.

Table 3-6. Summary of Distribution Descriptors for Period of Record and Monthly Discharge at the Worthington Springs Gage, Upper Santa Fe River

Period	Minimum (cfs)	25 Percent Exceedance (cfs)	50 Percent Exceedance (cfs)	75 Percent Exceedance Percentile (cfs)	Maximum (cfs)
Period of Record	0	42	131	432	19,900
January	4	57	152	413	4,680
February	4	96	276	756	11,900
March	5	73	239	754	14,700
April	0	34	122	446	8,620
May	0	15	44	127	7,710
June	0	15	44	163	16,900
July	3	41	154	422	3,700
August	3	108	309	828	9,440
September	2	116	303	681	19,000
October	2	50	135	429	15,700
November	2	32	75	190	4,000
December	3	34	75	191	5,450

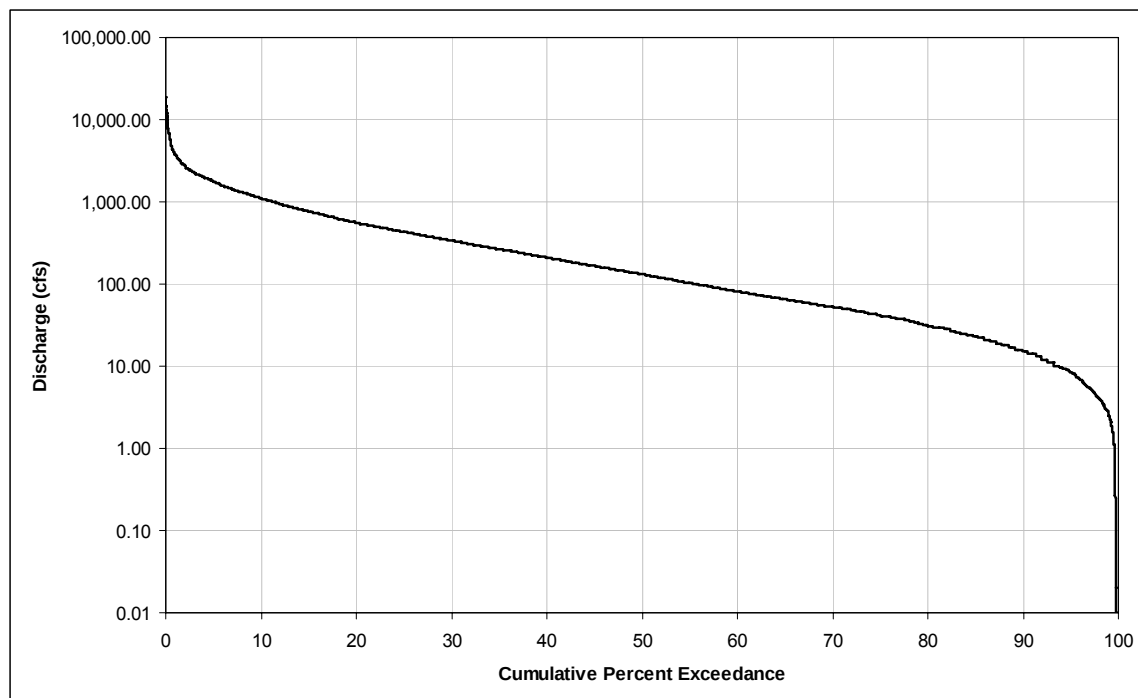


Figure 3-69. Baseline Flow Duration Curve for discharge at the Worthington Springs gage on the Upper Santa Fe River.

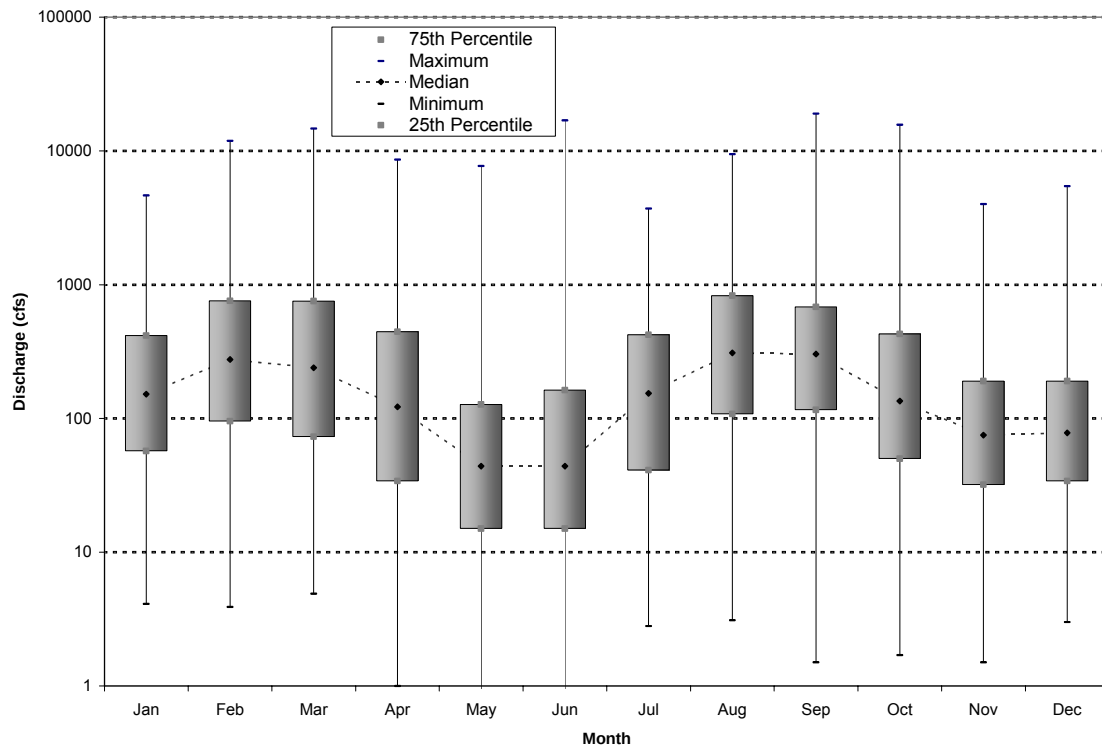


Figure 3-70. Box and whisker diagram illustrating monthly variability in discharge of the Upper Santa Fe River at the Worthington Springs Gage.

Month-by-month variation in flow at Worthington Springs is summarized in Table 3-6 and depicted in Figure 3-70. Note that minimum median discharge occurs in May and June, the end of the dry season in areas characterized by the southern river pattern of Kelly (2004). There are two intervals of maximum discharge – August/September and February/March. These episodes coincide with the rainy seasons in the southern river pattern and northern river pattern areas of Kelly (2004).

3.6.4 Flow Summary for Discharge at the O'Leno Gage

3.6.4.1 Flow Summary

Figure 3-71 depicts the historic flow duration curve (FDC) for the Upper Santa Fe River at the O'Leno gage. The FDC is based partly on gage data and partly on synthesized data as described in Section 3.3.2.3. Table 3-7 summarizes the properties of this FDC. The O'Leno gage is downstream from Olustee Creek and the Santa Fe Spring, so all major tributaries of the river are accounted for in the gage data.

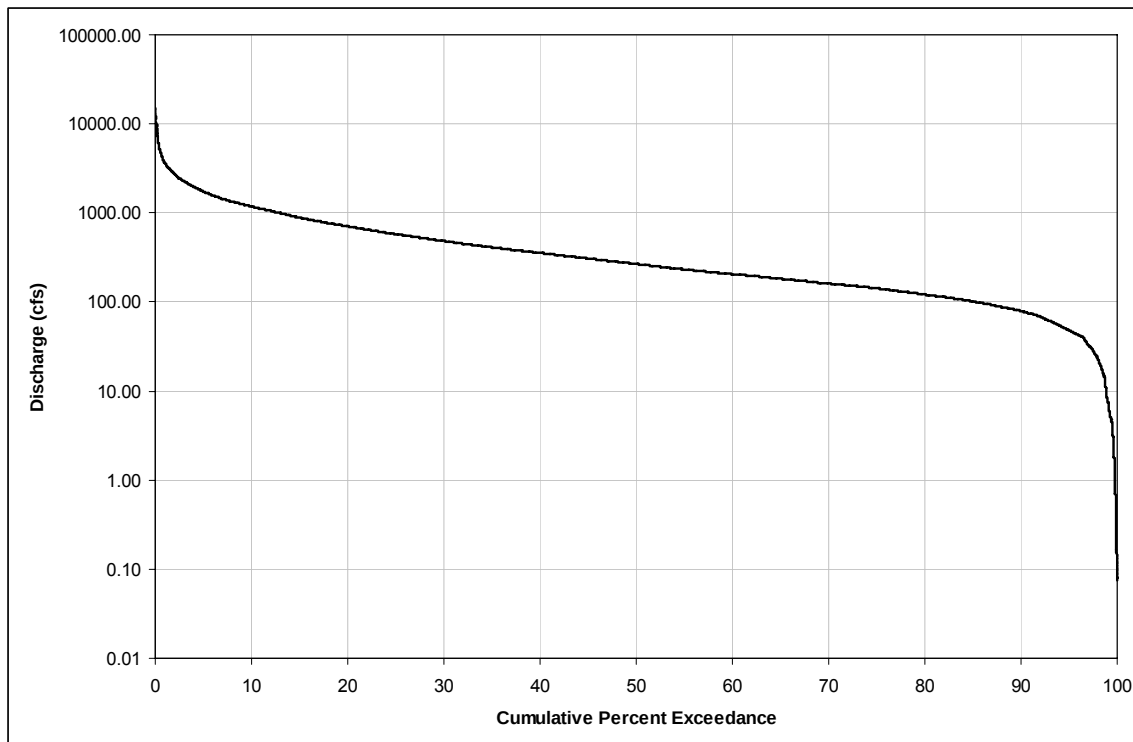


Figure 3-71. Period of record flow duration curve for discharge at the Upper Santa Fe River gage at O'Leno. Data were partly synthesized as described in Section 3.3.2.3.

Note that the median discharge at the O'Leno gage is approximately double the median at Worthington Springs. This increase reflects discharge from Santa Fe Spring, Olustee Creek and other, minor, tributaries.

Table 3-7 presents the monthly discharge summary statistics and Figure 3-72 depicts a box and whisker diagram of the monthly data. The pattern of monthly discharge is similar to Worthington Springs with a distinct minimum in May and June, and two nearly equal episodes of high flow in February/March and August/September. Discharge at O'Leno during the dry season (May and June) is nearly four times the May and June monthly medians, however (Figure 3-72).

The reduced proportion of discharge at O'Leno that is contributed by the Upper Santa Fe River above Worthington Springs (see Section 3.4) emphasizes the importance of Santa Fe Spring and, to a much lesser extent, Olustee Creek for maintaining flow in O'Leno State Park. Hornsby (2005, pers. comm.) explored the Upper Santa Fe during the extreme drought of the early 2000s. He observed that "most" of the water flowing through the park came from Santa Fe Spring during this drought. Olustee Creek and the river above Worthington Springs depend on runoff, so it is clear that the flow in the park during baseflow conditions is essentially a result of spring discharge as opposed to surfacewater drainage.

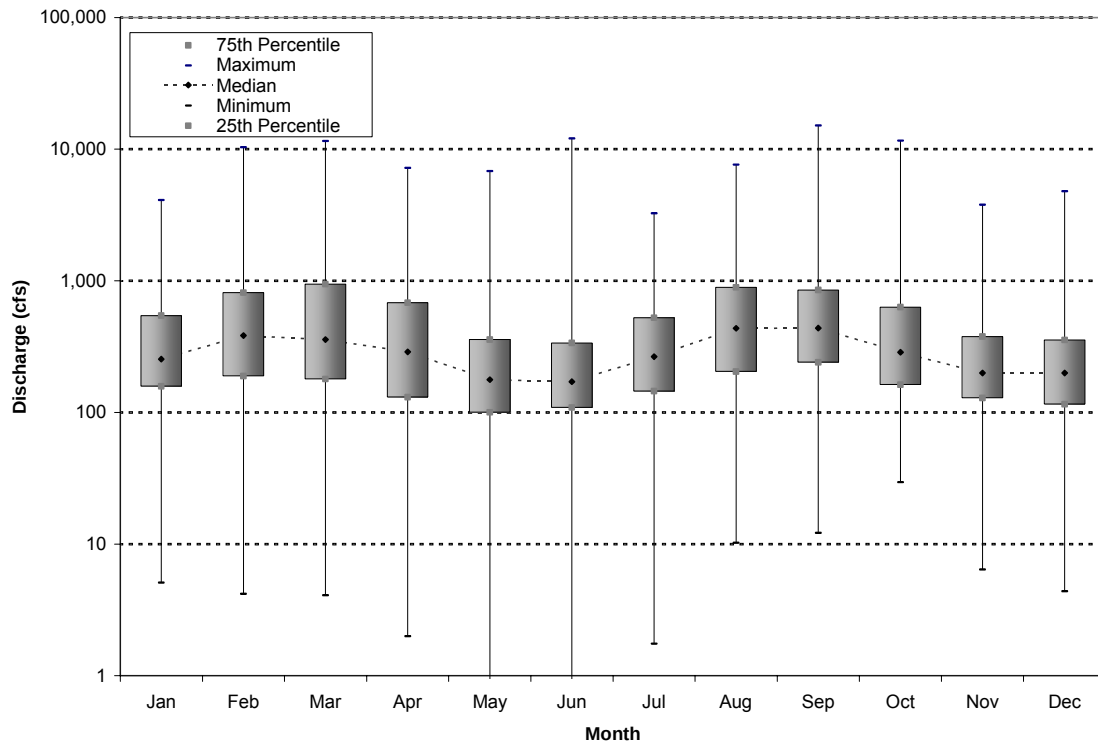


Figure 3-72. Box and whisker diagram summarizing the monthly characteristics of discharge at the O'Leno gage on the Upper Santa Fe River.

Table 3-7. Summary of Distribution Descriptors for Period of Record and Monthly Discharge at the O'Leno Gage, Upper Santa Fe River

Period	Minimum (cfs)	25 Percent Exceedance (cfs)	50 Percent Exceedance (cfs)	75 Percent Exceedance (cfs)	Maximum (cfs)
Period of Record	0.1	142	267	579	15,141
January	5	158	254	544	4,102
February	4	189	384	813	10,320
March	4	179	357	942	11,538
April	2	130	289	681	7,211
May	0.1	100	177	358	6,818
June	0.1	109	171	336	12,047
July	2	145	265	523	3,253
August	10	204	436	890	7,621
September	12	241	438	851	15,141
October	29	162	287	630	11,615
November	6	129	200	377	3,782
December	4	116	200	355	4,786

3.6.4.2 Effects of Swimming Use at O'Leno State Park on MFL Development

Carrying capacities for the picnicking and swimming (combined) have been promulgated for the swimming area at O'Leno State Park. The existing and estimated optimum carrying capacities for picnicking and swimming together is 184 individuals at one time and 368 persons on a daily basis (Florida Division of Recreation and Parks, 2003, Table 1).

Chapter 64E-9.013 F.A.C. sets minimum standards for public bathing based public health criteria. Specifically, the Rule requires that a survey for sources of contamination (specifically bacterial contamination) that could affect public bathing be made and that the flow-through of the bathing area be at least 500 gallons per anticipated bather per 24 hours unless the bathing area is 2 acres or more. At O'Leno, the 500 gallons per bather per 24 hours criterion is met by flows of 0.3 cfs or greater. The 0.3 cfs criterion has an exceedance probability of 99.89 percent using the synthesized data (Figure 3-71) and 81.2 percent using the historical measurements. Note that bather health is a minimum flow criterion. As noted in Section 2.3.1, the Park staff closes the swimming area when the water appears "stagnant" – a condition that probably occurs at flows near or above 0.3 cfs. As noted in Section 2.3.1, the Park staff also closes the swimming area when the water velocity appears unsafe. There is no benchmark velocity or discharge for closure as a result of high river velocities.

3.6.5 Suggested MFL Establishment Sequencing

It is suggested that MFLs be developed at the present time for the Upper Santa Fe River at Graham and at Worthington Springs. MFLs for the river at these locations will protect the Upper Santa Fe River from Worthington Springs upstream to the river headwaters. Santa Fe Swamp and, to some degree, Santa Fe Lake will be protected, as will the New River and other upstream tributaries.

As discussed in Sections 3.3.2.3 and 3.4, interactions of the river and groundwater system are complex in lower Olustee Creek and downstream of the confluence of Olustee Creek with the Santa Fe River. Portions of flow in both reaches go underground via in-stream swallets and there are small resurgences within the Santa Fe River. The Santa Fe Spring appears to be one of these resurgences that discharges water derived from Olustee Creek and elsewhere. Swallets in the Santa Fe above O'Leno and the River Sink capture portions of the river water, some of which rejoins the river prior to reaching River Sink. The plumbing of this system of swallets and resurgences, springs, and streams is unclear and some of the lost water appears to be gained by the river/groundwater system as water passes from the River Sink to the River Rise. In addition, a number of first and second-magnitude springs immediately downstream from the River Rise may be discharging some water derived from upstream of the Sink.

It is important that discharge from Olustee Creek and at O'Leno State Park be subjected to MFL development in order to prevent significant harm to these resources. However, it is suggested that setting a MFL downstream of the Rise and after the complex river/groundwater flow system becomes better defined be considered. The relationships of flow at O'Leno and the Santa Fe River at the U.S. 441 gage on the Lower Santa Fe have been explored as part of this report (Section 3.3.2.2.3). These relationships clearly indicate that setting a MFL at this gage will protect river discharge at O'Leno and Olustee Creek.

APPENDIX 3-1

APPENDIX 3-1

Cross-section IDs and Channel Lengths

River Mile	LOB (feet)	Channel (feet)	ROB (feet)
70.18	850	963.5	800
69.9975*	850	963.5	800
69.815*	850	963.5	800
69.6325*	850	963.5	800
69.45	370	370	370
69.38	32	32	32
69.375	Bridge		
69.37	791	791	791
69.22	2000	2640	2200
68.72	4150	4699	4300
67.83	3600	3802	3550
67.11	4500	5914	4800
65.99	130	130	130
65.97	27	27	27
65.965	Bridge		
65.96	369	369	369
65.89	100	158	90
65.86	5500	6811	4600
64.57	4400	5122	3900
63.6	5500	7180	5900
62.24	5400	6442	5000
61.02	1500	1768.75	1675
60.685*	1500	1768.75	1675
60.35*	1500	1768.75	1675
60.015*	1500	1768.75	1675
59.68	100	100	100
59.66	52	52	52
59.655	Bridge		
59.65	399.2	399.2	399.2
59.57	1500	1637.01	1400.01
59.26	2100	2376	2000.01
58.81	106	106	106
58.79	52	52	52
58.785	Bridge		
58.78	421	421	421
58.7	833.33	968	866.67
58.5166*	833.33	968	866.67
58.3333*	833.33	968	866.67
58.15	820	992.6	840
57.962*	820	992.6	840
57.774*	820	992.6	840
57.586*	820	992.6	840
57.398*	820	992.6	840

57.21	900	1306.75	887.5
56.9625*	900	1306.75	887.5
56.715*	900	1306.75	887.5
56.4675*	900	1306.75	887.5
56.22	800	1214	890
55.99	100	150	110
55.96	52	52	52
55.955	Bridge		
55.95	649	633	599
55.83	1160	1647.4	920
55.518*	1160	1647.4	920
55.206*	1160	1647.4	920
54.894*	1160	1647.4	920
54.582*	1160	1647.4	920
54.27	2900	4382	2700
53.44	5900	8290	6200
51.87	710.17	1698.99	893.51
51.5416*	710.17	1698.99	893.51
51.2133*	710.17	1698.99	893.51
50.885*	710.17	1698.99	893.51
50.5566*	710.17	1698.99	893.51
50.2283*	710.17	1698.99	893.51
49.9	1739	1739	1739
49.61	725	745	525
49.48	100	100	100
49.46	27	27	27
49.455	Bridge		
49.45	249	349	449
49.38	325	375	425
49.31	100	100	100
49.29	27	27	27
49.285	Bridge		
49.28	499	449	349
49.19	610.8	833.6	439
49.032*	610.8	833.6	439
48.874*	610.8	833.6	439
48.716*	610.8	833.6	439
48.558*	610.8	833.6	439
48.4	388	388	388
48.33	504	758	833.5
48.185*	504	758	833.5
48.04	1933.33	2552	2066.67
47.5566*	1933.33	2552	2066.67
47.0733*	1933.33	2552	2066.67
46.59	4200	5861	4550
45.48	1287.5	1927.25	1275
45.115*	1287.5	1927.25	1275
44.75*	1287.5	1927.25	1275

44.385*	1287.5	1927.25	1275
44.02	1325	1953.5	1400
43.65*	1325	1953.5	1400
43.28*	1325	1953.5	1400
42.91*	1325	1953.5	1400
42.54	850	1148.5	850
42.3225*	850	1148.5	850
42.105*	850	1148.5	850
41.8875*	850	1148.5	850
41.67	200	242	200
41.63	50	50	50
41.62	27	27	27
41.615	Bridge		
41.61	249	263.01	249
41.56	1625.01	1716.02	1500
41.235*	1625.01	1716.02	1500
40.91	1166.67	1936	1666.67
40.5433*	1166.67	1936	1666.67
40.1766*	1166.67	1936	1666.67
39.81	1300	1390.33	1166.67
39.5466*	1300	1390.33	1166.67
39.2833*	1300	1390.33	1166.67
39.02	4226	4117	2826
38.24	1374	1374	1374
37.98	3174.99	3854.01	3900
37.25	300	300	300
37.19	105	105	105
37.17	72	72	72
37.165	Bridge		
37.16	449	474	449
37.07	1566.66	2622.34	1800
36.5733*	1566.66	2622.34	1800
36.0766*	1566.66	2622.34	1800
35.58	20	20	20
35.57	2600	2600	2600
35.07	0	0	0

TAB 4

4.0 ECOLOGICAL ANALYSES

Hydrologic conditions include the principal physical forces, which influence stream ecosystems (Poff et al., 1997; Poff and Ward, 1989). Flow influences ecological integrity directly (Poff and Alan, 1995) or indirectly via other factors such as water quality, physical habitat availability, fish passage, etc. (Schlosser, 1991; Poff et al. 1997). The hydrologic description provided in Section 3.0 serves as the framework, which structures the ecological communities of the river, including those in the river channel and adjacent floodplains.

This section characterizes the ecology of the Upper Santa Fe River. As stated in previous sections, the Suwannee basin (which includes the Santa Fe) is a significant bio-geographic transition zone in Florida, with many species of flora and fauna reaching their southernmost limits of distribution in the U.S. in the Suwannee region. A number of plant species reach the southern or northern limits of their distribution in the southeastern U.S. in the Suwannee region (Clewell, 1985; Abbott and Judd, 1998) and over half of the native freshwater fishes found in Florida river systems occur only in or west of the Suwannee (Bass and Cox, 1985; Bass, 1991).

4.1 General Description

4.1.1 Physical Setting

The Santa Fe River originates in Santa Fe and Little Santa Fe lakes in the northeast corner of Alachua County, Florida. It flows westward along the Alachua County line and eventually goes completely underground at a large sinkhole known as the Santa Fe Sink (or River Sink), near O'Leno State Park (Hunn and Slack, 1983; SRWMD, 1977) (Figure 4-1). Total length of the river is approximately 70 miles (Nordlie, 1990), while the length of the portion above the sink is approximately 31 miles. The Santa Fe travels underground for over 2 miles before it resurfaces several miles north of High Springs at River Rise. While other rivers in limestone regions of Florida travel underground as they cross the Cody Scarp (the only exception being the Suwannee River, which remains surficial), they typically resurface within a few hundred feet, or do not resurface at all as the same stream (Hellier, 1967). Because the Santa Fe travels underground for such length, the natural land bridge acts as a divider forming two distinct reaches of the river: the Upper Santa Fe and the Lower Santa Fe.

The Upper and Lower Santa Fe are divided by a natural land bridge, which occurs as the Santa Fe crosses the Cody Scarp. The Cody Scarp is a significant geologic feature, which forms the most notable topographic break in Florida, generally corresponding to the 100-110 feet MSL contour elevation (Mattson 1992a,b). The river above the scarp flows through layers of Pleistocene sands, overlying layers of clay from the Miocene Hawthorne formation (Hellier, 1967; Mattson 1992a,b). In the Upper Santa Fe, the river and tributaries are fed mainly by surface runoff and seepage from the surficial aquifer. Flood peaks are more "flashy" in nature, owing to surface runoff during times of high rainfall. The shallow surficial aquifer provides low baseflow and groundwater input from the intermediate and Floridan aquifers are minimal (Mattson 1992 a,b). Generally, the river is sandy bottomed and clear with some input of tannins from blackwater streams draining rainwater from surrounding flatwoods. River depth varies according to rainfall in this section of the Santa Fe, and during very dry periods several miles of riverbed below Lake Santa Fe can dry up (Hellier, 1967). Just above the landbridge, near the mouth of Olustee Creek, the characteristics of the Santa Fe begin to change (Figure 4-1). Outcroppings become evident along the banks and the river becomes wider, slightly deeper, and more backwater reaches are evident (Hellier, 1967). Hellier (1967) reported the vegetation along this portion of the river as mixed river swamp and low hammock with bald cypress.

Below the land bridge, the river flows through a thin layer of surficial sands over limestone. The river receives large amounts of subterranean drainage via limestone springs and little amounts of surface flow (Hellier 1967). A substantial portion of baseflow in this reach of the river is received from groundwater, which is why the lower river has greater baseflow than the upper river (Mattson, 1992a,b). Peak flows in the lower river are not characterized as “flashy”, as they are somewhat stabilized by steady baseflow and more expansive floodplains (Mattson, 1992a,b). River bottom is generally sand or bear rock, and the current is swift and clear, except for periodic turbidity caused by heavy rains (Hellier. 1967).

The remainder of this document describes the portion above the land bridge: the Upper Santa Fe River. The Upper Santa Fe receives inflow from two main tributaries: the New River and Olustee Creek (Figure 4-1). It also receives inflow from smaller tributaries, such as the Sampson River, and intermittent input at times of high water from Palestine Lake and Ocean Pond (SRWMD, 1995) (Figure 4-1). Overall, the watershed for the Upper Santa Fe includes the northern portion of Alachua, all of Bradford and Union, portions of southwestern Baker, and southeastern Columbia Counties.

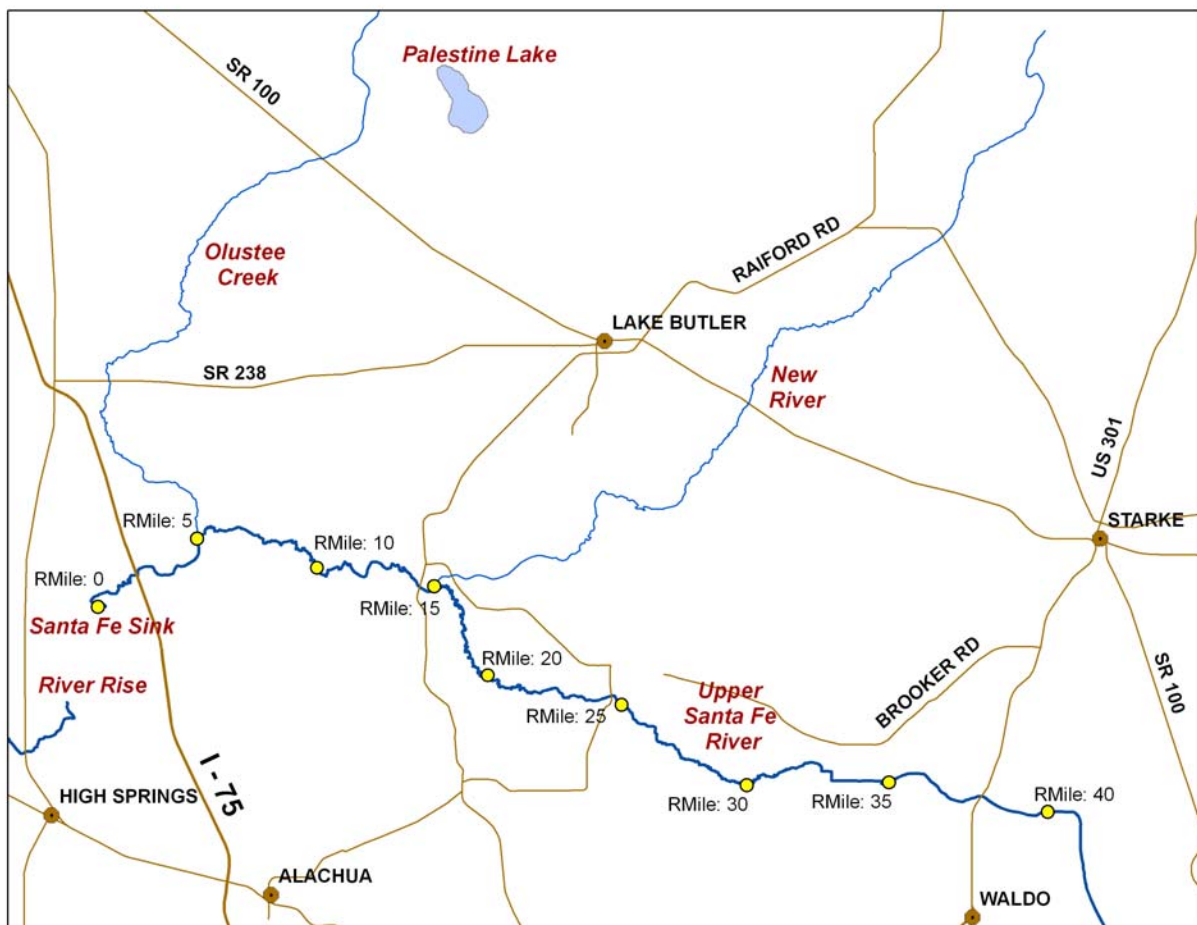


Figure 4-1 Locator map of the Upper Santa Fe River, showing major tributaries, sinks, resurgences, roadways, and the river mile system.

4.2 Water Quality

Water quality in the Upper Santa Fe is an issue in terms of both the impact of surface water entering the groundwater system, and the impact of surface water quality on aquatic habitat and associated fauna. Available water quality data were discussed in a previous report prepared for SRWMD (Water Research Associates, 2005). Long term (1989-2003) water quality data were available for SFR020, SFR030, and SFR040 (Figure 4-2). Parameters sampled include the following: alkalinity, chlorophyll, color, conductivity, dissolved oxygen (DO), nitrate+nitrite (NO_x) species, orthophosphate, pH, temperature, total Kjeldahl nitrogen (TKN), total nitrogen (TN), total organic solids (TOS), total phosphorous (TP), total suspended solids (TSS), and turbidity.

Mean annual dissolved oxygen (DO) was similar at SFR020 and SFR030, ranging from just above 5.0 - 7.5 mg/l, and between 6 - 7.5 mg/l, respectively (Figures 4-3 and 4-4). DO at the downstream station, SFR040, was slightly lower, ranging from 4.75 - 6.0 mg/l (Figure 4-5). Data were plotted in a timeseries for each station (Figures 4-6 through 4-8) and DO does not appear to be related to flow in this system.



Figure 4-2 Locator map of the Upper Santa Fe River, showing the main river stations (SFR020, SFR030, SFR040) as well as supplemental and tributary stations (New River (NEW), Alligator Creek (ALC), and Sampson River (SMR)). The blue area represents the District boundaries and the Santa Fe is the District's eastern most river.

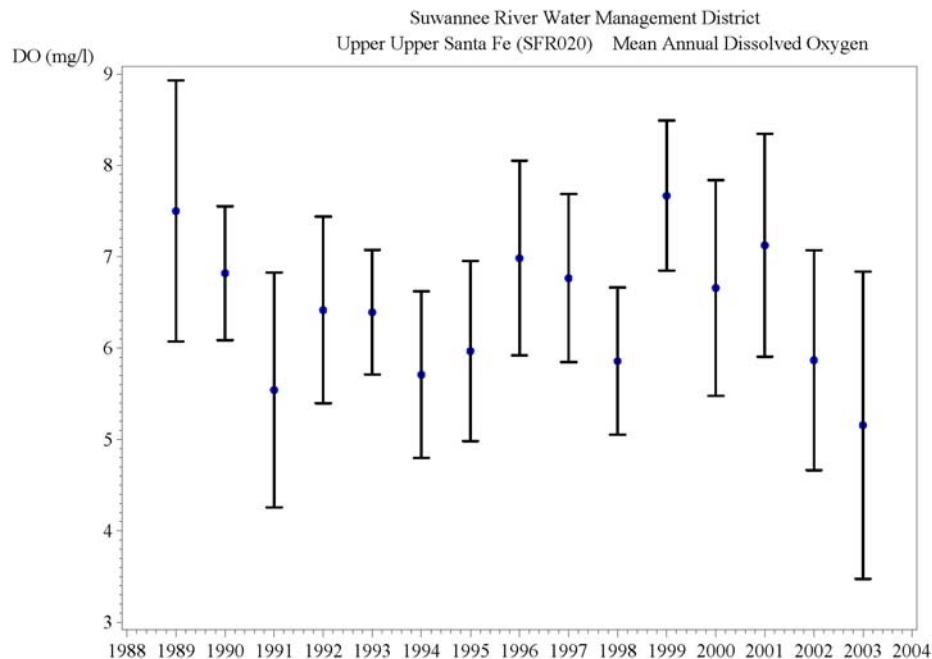


Figure 4-3 Mean annual dissolved oxygen (mg/l), with 95% confidence limits, for the Upper Santa Fe River (station SFR020) in the Suwannee River Water Management District (Source: Janicki Environmental, Inc., 2004)

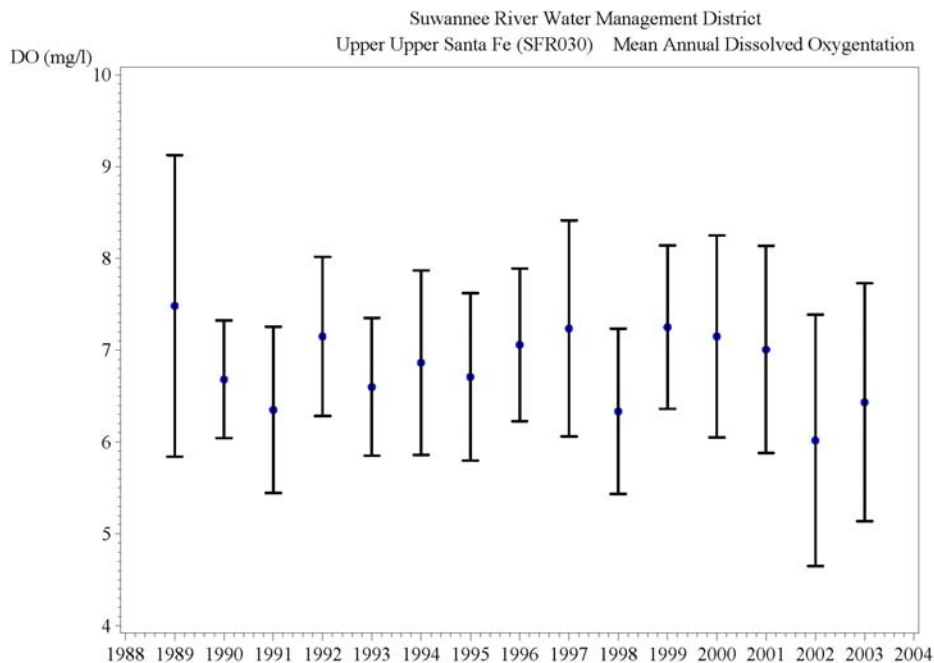


Figure 4-4 Mean annual dissolved oxygen (mg/l), with 95% confidence limits, for the Upper Santa Fe River (station SFR030) in the Suwannee River Water Management District (Source: Janicki Environmental, Inc., 2004)

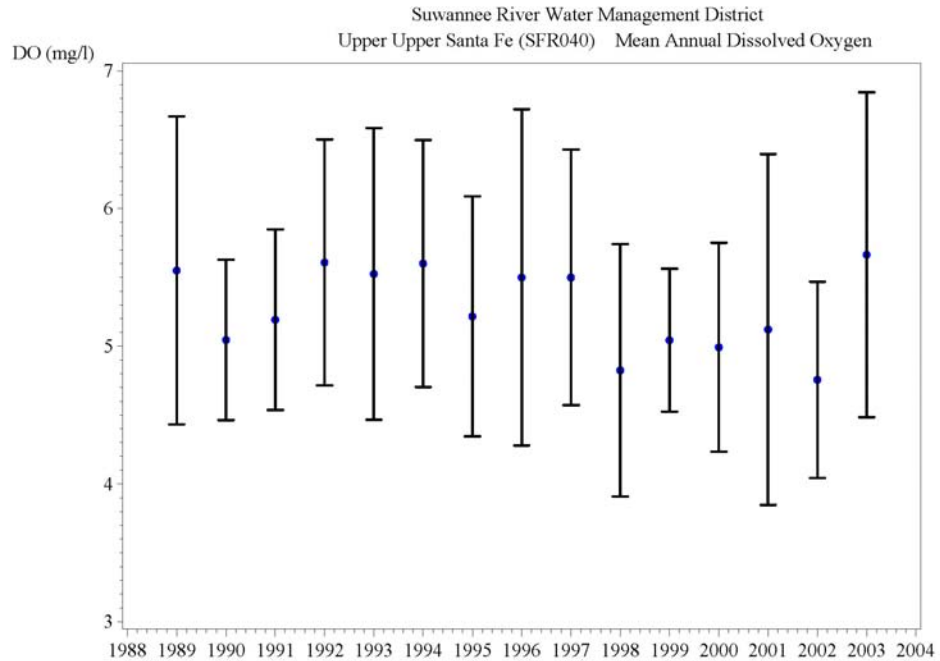


Figure 4-5 Mean annual dissolved oxygen (mg/l), with 95% confidence limits, for the Upper Santa Fe River (station SFR040) in the Suwannee River Water Management District (Source: Janicki Environmental, Inc., 2004)

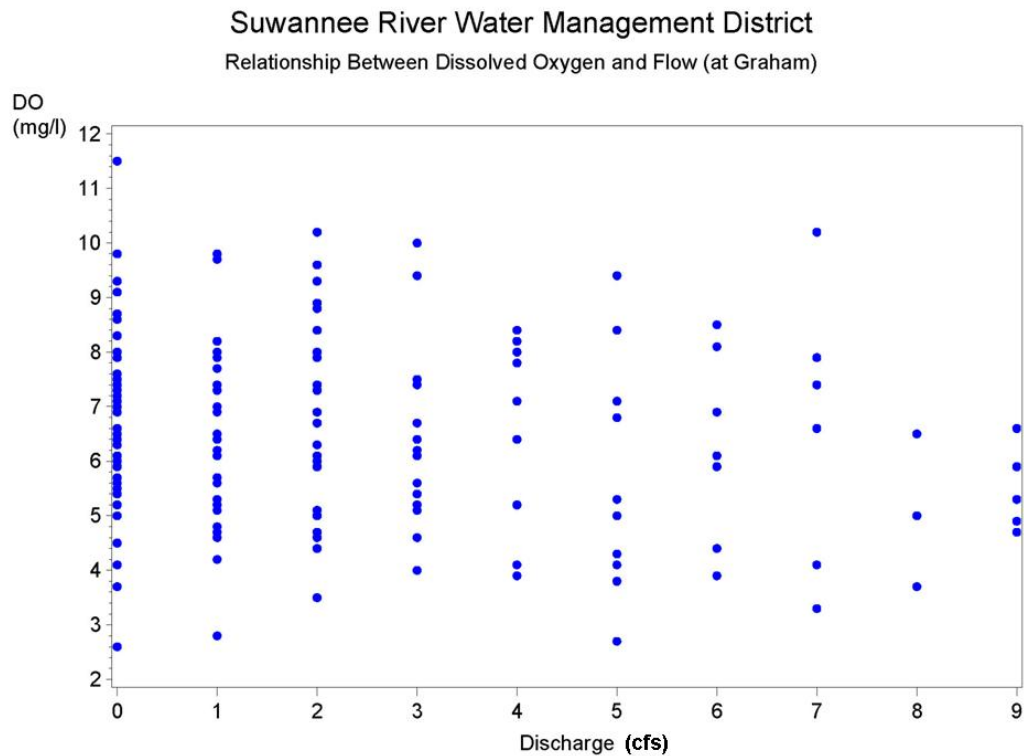


Figure 4-6 The relationship between dissolved oxygen at Suwannee River Water Management District station SFR020 and flow at Graham for the period of record (1989-2003).

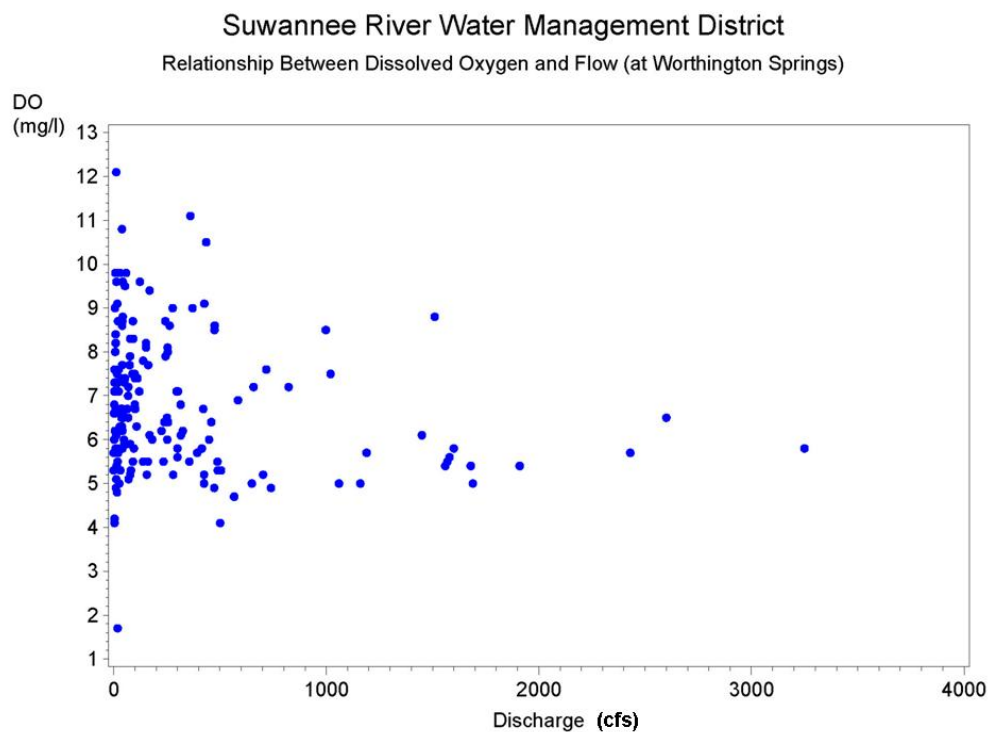


Figure 4-7 The relationship between dissolved oxygen at Suwannee River Water Management District station SFR030 and flow at Worthington Springs for the period of record (1989-2003).

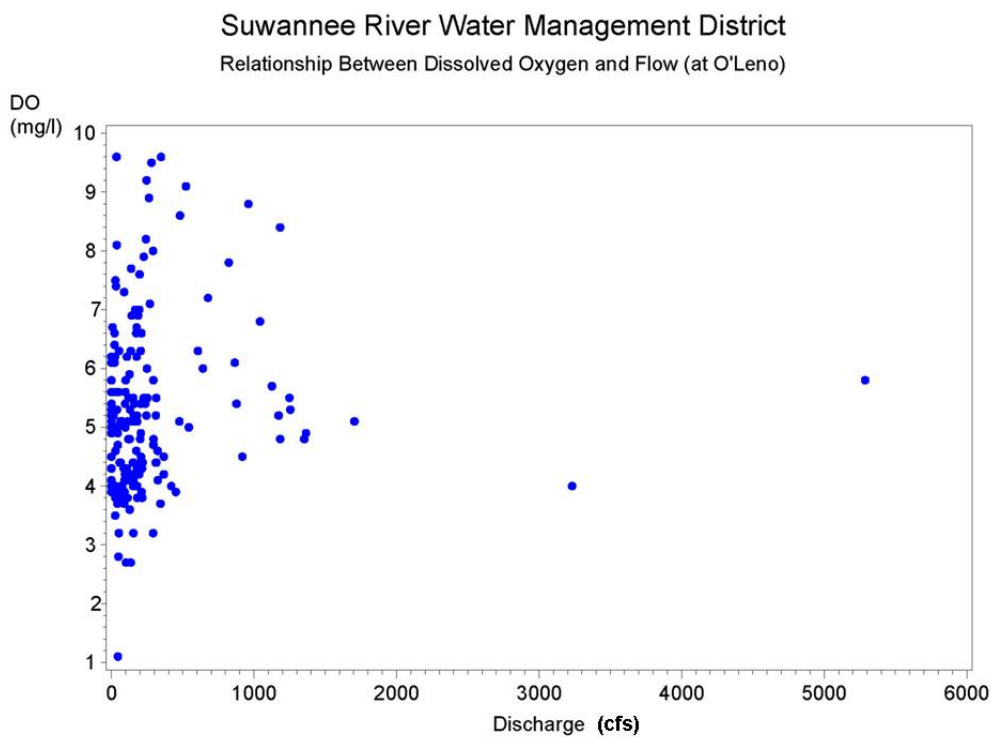


Figure 4-8 The relationship between dissolved oxygen at Suwannee River Water Management District station SFR040 and flow at O'Leno for the period of record (1989-2003).

4.3 Riparian Vegetation

The riparian wetland vegetation have been characterized and classified by the SRWMD 1994-1995 Land Use and Cover Project and from the National Wetlands Inventory (NWI).

The Land Use and Cover Project was funded as part of the SRWMD's Surface Water Improvement and Management (SWIM) program, in efforts to better understand the water resources and to monitor changes in land use and cover over time within the SWIM waterbodies (SRWMD, 1998). The land use and cover data was photo-interpreted from 1994-1995 National Aerial Photography Program (NAPP) 1:40,000 color infrared photography. Photo interpretation was done using United States Geological Survey 7.5' quadrangle basis (SRWMD, 1998). Data were classified based on a modified Florida Land Use Cover and Forms Classification System (FLUCFCS), originally established by the Florida Department of Transportation. Similar cover types were grouped into polygons using mylar overlay and then digitized into ARC/INFO. Ground truthing was performed and overall accuracy was determined to be 85% (SRWMD, 1998).

The National Wetlands Inventory (NWI) is a program established under the United States Fish and Wildlife Service with the purpose of characterizing the extent and status of the Nation's wetland, deepwater, and other wildlife habitats. The goals of the NWI are to classify and to map the nation's wetlands and to periodically assess status and trends (USFWS, 2002). NWI maps contain information on location and type (classification) of wetlands and deepwater habitats (stream, lakes, and estuaries). NWI information is based on the interpretation of high-altitude aerial photographs, with a minimum required mapping resolution of 2 acres. Additionally, it should be noted that the mapped area is the approximate location and size of the wetland, relative to geographic features (e.g., roads) and annual and seasonal variation (e.g. in dry years wetland extent will be limited compared to wetter years; same for dry vs. wet seasons within a year) at the time the aerial photos were taken. Accuracy is limited to 30-50 feet (USFWS, 2002).

National Wetland Inventory data shows much of the riverine habitat as palustrine forested, particularly near the headwaters and around rm 25.0 and between rms 5-15 (Figure 4-9). Areas of palustrine shrub-scrub occur between rms 5-10, 15-20, as well as in the headwaters (Figure 4-9). Landuse data shows adjacent vegetation in the headwaters as wetland mixed forest and wet flatwoods (Figure 4-10). In the middle segment of the reach, mixed wetlands forests and lesser areas of oak-pine-hickory are reported. In the lowest reach of the segment, between rm 0-7, hardwood-conifer mixed forest dominates (Figure 4-10). Based on the 10-year floodplain, the floodplain adjacent to the Upper Santa Fe River is categorized as saturated and semi-permanently flooded in the headwaters region, and a mix of semi-permanently, seasonally and temporarily in other regions (Figure 4-11).

Based on the landuse vegetation categories, characteristic species assemblages were determined and information on hydroperiod was extrapolated from the associated NWI water regime categories (Table 4-1).

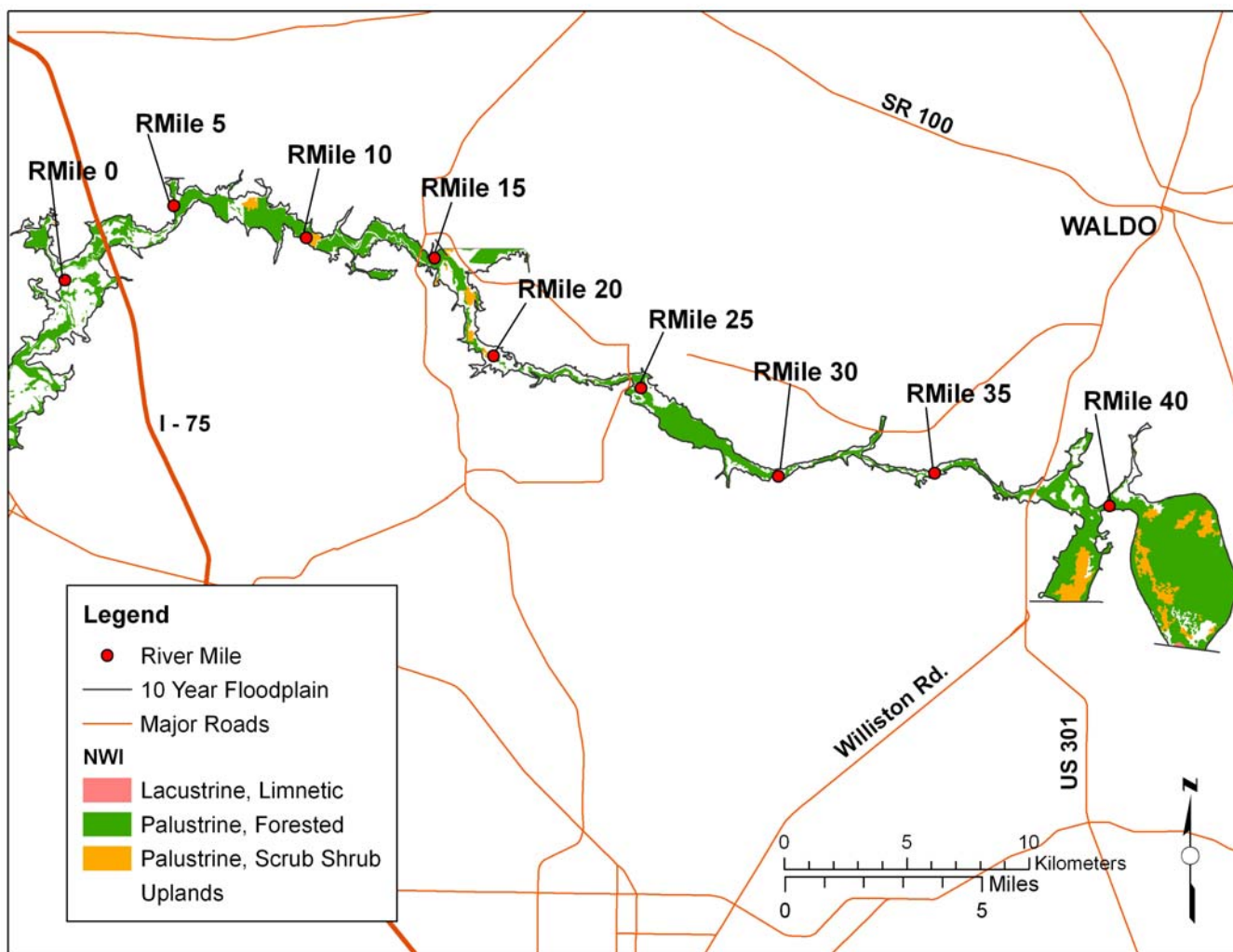


Figure 4-9 Map showing the National Wetlands Inventory habitat categories within the 10-year floodplain on the Upper Santa Fe River.

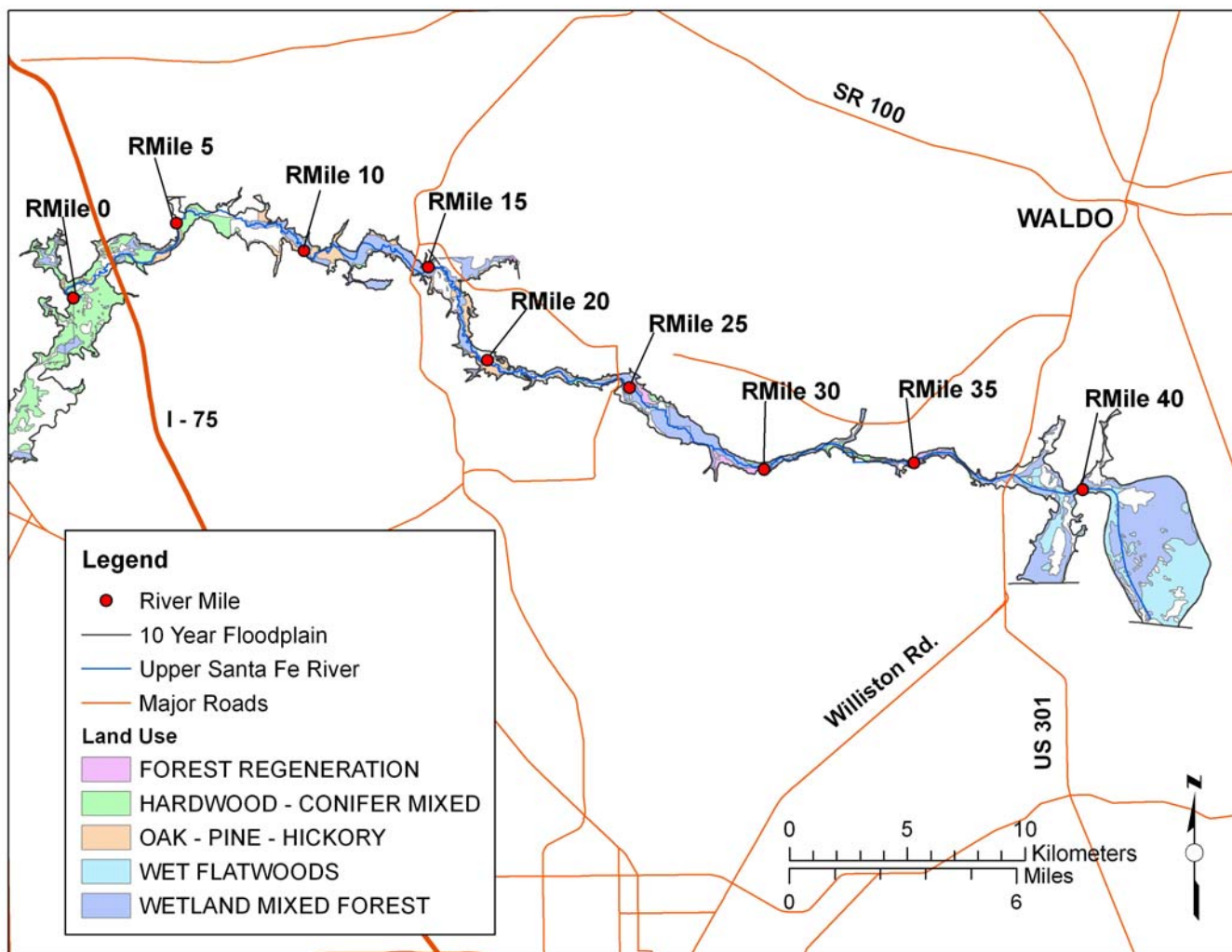


Figure 4-10 Map showing relevant vegetation categories as provided by the Suwannee River Water Management District's landuse coverage within the 10-year floodplain on the Upper Santa Fe River.

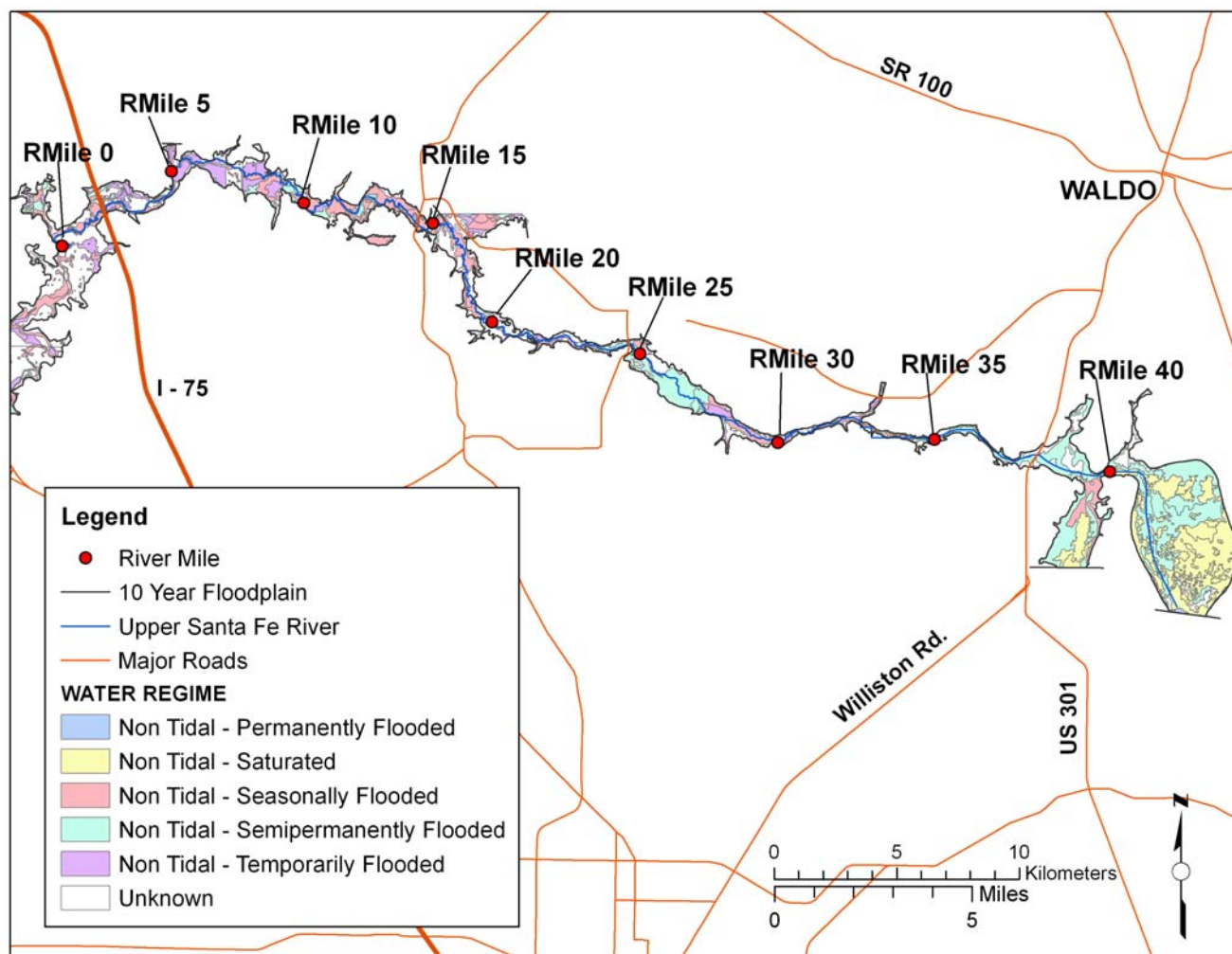


Figure 4-11 Map showing the National Wetlands Inventory water regime categories within the 10-year floodplain on the Upper Santa Fe River.

Table 4-1 Vegetation types found along the Upper Santa Fe River, including characteristic species assemblages and general hydrologic information.

SRWMD Land Use Category	Characteristic Species (SRWMD, 1998)	Associated NWI Water Regime (Cowardin et al., 1979; Larson et al., 1981 as cited in Mitsch and Gosselink, 1993)	Hydrologic Summary
Wet Flatwoods	Shrubby understory with invading bays and hardwoods. Understory characterized by fetterbush (<i>Lyonia lucida</i>), ferns and other herbaceous species, while the pines may be either pond pine (<i>Pinus serotina</i>) or slash pine (<i>Pinus ellioti</i>) (Figure 4-12). The bays may be comprised of the following species: sweetbay (<i>Magnolia virginiana</i>), loblolly bay (<i>Gordonia lasianthus</i>), red bay (<i>Persea borbonia</i>) and swamp tupelo (<i>Nyssa biflora</i>)	Overlaps with two categories: <i>saturated or intermittently exposed and semi-permanently flooded</i>	Soil saturation or surface water persists from >25-100% of the growing season; probability of annual flooding ranges from 51-100%.
Wetland Mixed Forest	Mixed wetland forest communities where neither hardwoods nor conifers dominate; includes hardwoods (<i>Quercus sp.</i>) pine (<i>Pinus sp.</i>), and/or cypress (<i>Taxodium sp.</i>) (Figure 4-13).	Overlaps with two categories: <i>semi-permanently flooded and seasonally flooded</i>	Soil saturation or surface water persists for between 12.5 to over 25% of the growing season; probability of annual flooding ranges from 51-100%
Oak-Pine-Hickory Association	Mixed wetland forest community in which no single species is consistently dominant, but tends to be a hardwood forest type in which southern pines are the major species. The following species may be found in this association: southern red oak (<i>Quercus falcata</i>), longleaf pine (<i>Pinus palustris</i>), mockernut hickory (<i>Carya tomentosa</i>), laurel oak (<i>Quercus laurifolia</i>), live oak (<i>Quercus virginiana</i>), water oak (<i>Quercus nigra</i>), sweet gum (<i>Liquidamber styraciflua</i>), loblolly pine (<i>Pinus taeda</i>), southern magnolia (<i>Magnolia grandiflora</i>) and pignut hickory (<i>Carya glabra</i>) (Figure 4-14).	<i>Seasonally flooded</i>	Soil saturation or surface water persists for between 12.5 to 25% of the growing season; probability of annual flooding ranges from 51-100%
Hardwood-Conifer Mixed Forest	Upland forest type that contains an even mix of pines and hardwoods, and therefore can not be placed in another category based on dominance.	Overlaps with two NWI categories :seasonally flooded and temporarily flooded	Soil saturation of surface water persists for 2-25% of the growing season; probability of annual flooding ranges from 11-100%



A



B



C

Figure 4-12 Species present in a wet flatwoods community: A) slash pine (*Pinus ellioti*) and understory taxa B) fetterbush (*Lyonia lucida*), and C) ferns.



A



B



C

Figure 4-13 Representative photographs of a mixed forest community: A) bald cypress (*Taxodium distichum*), B) laurel oak (*Quercus laurifolia*), and C) forested wetland swamp.



A



B



C

Figure 4-14 Species present in an Oak-Pine-Hickory association: A) long leaf pine (*Pinus palustris*), B) mockernut hickory (*Carya tomentosa*), and C) mix of oaks and hickory.

4.4 Periphyton

Periphytic algal communities in the Upper Santa Fe River were sampled at two stations on the Upper Santa Fe (i.e., SFR020 and SFR040, see Figure 4-2) by the SRWMD from 1990-2003. Samples were conducted on a quarterly basis, using glass slide periphytometers. These data were previously summarized (Water Research Associates, 2005) and reviewed (Janicki Environmental, Inc., 2004). These algal communities consisted of Cyanobacteria, Chlorophyta and Bacillariophyceae. Periphyton density was highest at the most downstream station and was dominated by Bacillariophyceae (Figure 4-15) (Janicki Environmental, 2004). Total species richness over the period of record was between 200-300 species, with a greater number of species recorded at the upstream station (Figure 4-16). Annually, for station SFR020 and SFR040 combined, species richness was greatest in 1990 (34 species) and was higher than range of richness observed in subsequent years (14-22 species) (Figure 4-17).

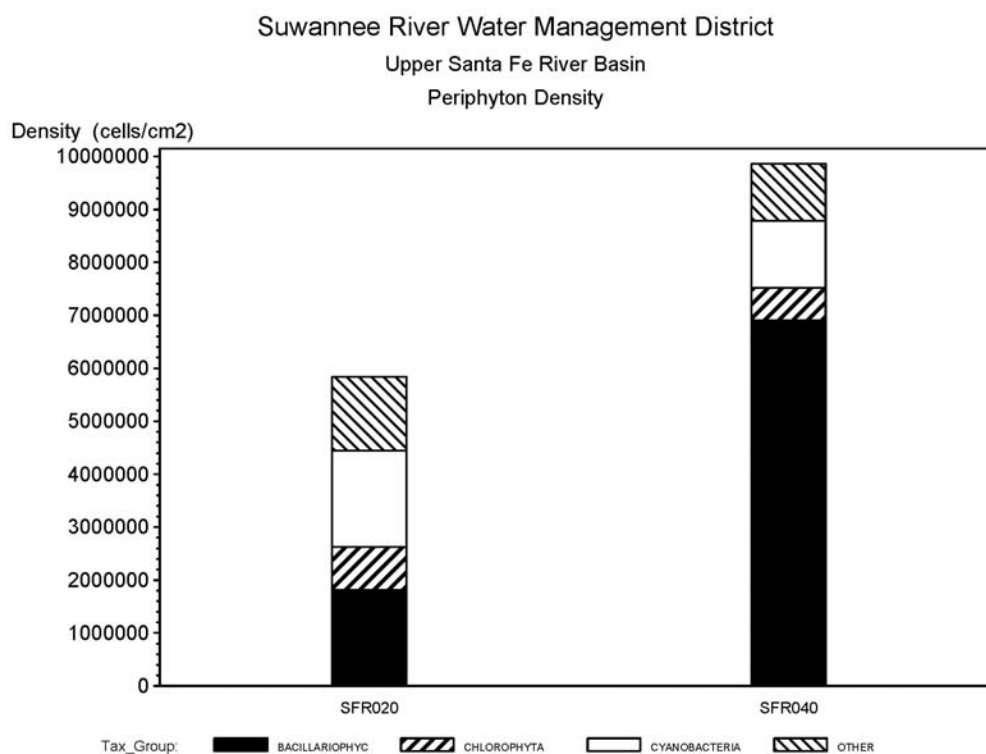


Figure 4-15 Stacked bar chart showing periphyton density in the Upper Santa Fe River as distributed by major taxonomic groups (Janicki Environmental, Inc., 2004).

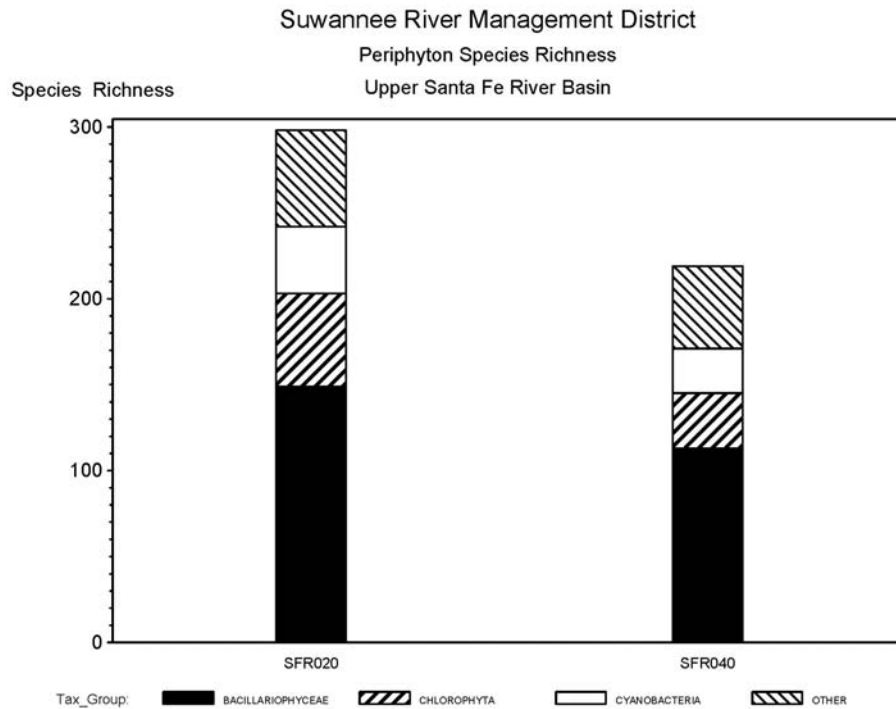


Figure 4-16 Stacked bar chart showing total periphyton species richness, as recorded over the period of record in the Upper Santa Fe River, and as distributed by major taxonomic groups (Janicki Environmental, Inc., 2004).

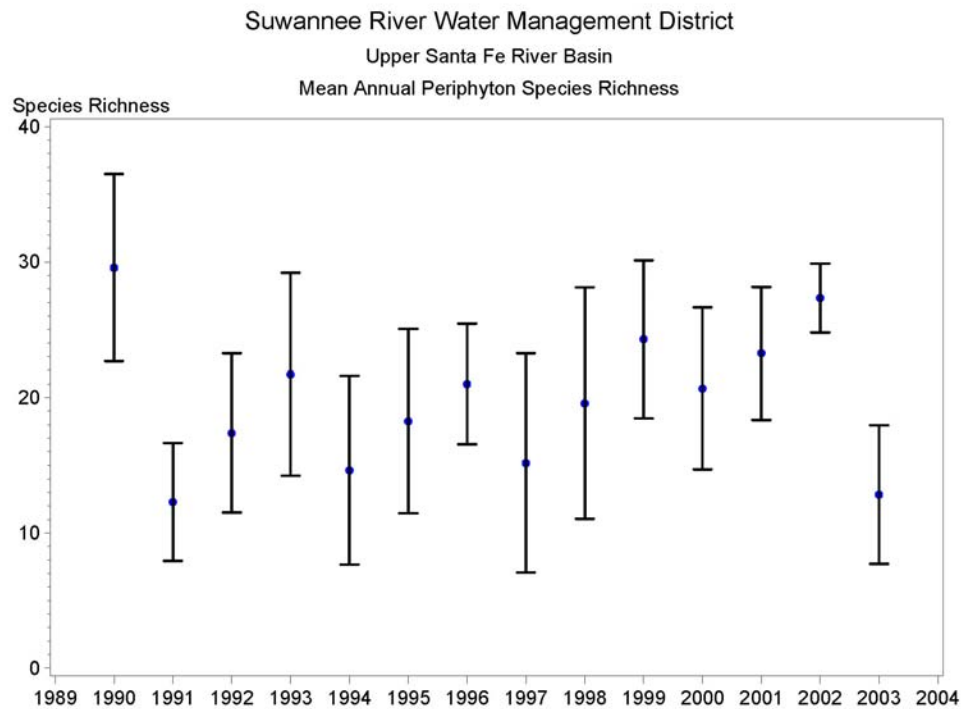


Figure 4-17 Mean annual periphyton species richness, with 95 % confidence limits, for the Upper Santa Fe River stations SFR020 and SFR040 (Janicki Environmental, Inc., 2004).

4.5 Benthos

Benthic biological data were previously summarized (Water Research Associates, 2005) and reviewed (Janicki Environmental, Inc., 2004). The SRWMD, as part of their water quality monitoring program, have collected benthic invertebrate data at three long-term stations (i.e., SFR020, SFR030, and SFR040; see Figure 4-2) on the Upper Santa Fe using the Hester-Dendy samplers, and at a fourth station (SFR010) using dip net sampling methods. The period of record available for the Upper Santa Fe was from 1989-2003.

Mean annual species richness in the Upper Santa Fe, as observed from Hester-Dendy samples, ranged from 21-32, with the lowest richness reported in 1990 and the highest in 2002 (Figure 4-18) (Janicki Environmental, Inc., 2004). Mean annual species richness, as observed from dip net samples, ranged from 25-44 (Figure 4-19). This was reportedly a higher number of species than was observed in the Suwannee River for the same period of record (Janicki Environmental, Inc., 2004). Composition by major taxonomic group, as reported from Hester-Dendy data, showed Chironomidae accounting for 60-70% of composition (Figure 4-20). Ephemeroptera, Trichoptera and Oligochaeta also contributed to overall composition in descending order (Janicki Environmental, Inc., 2004). Composition by major taxonomic group, as observed in dip net data, showed Chironomidae representing between 18-37% of the composition based on multiple stations (Figure 4-21). Coleoptera, Crustacea, and to a lesser extent, Ephemeroptera also contributed to relative composition (Janicki Environmental, Inc., 2004). The total number of species recorded over the period of record ranged for Hester-Dendy samplers was 150-350 (Figure 4-22). A similar number of species were recorded using the dip nets, 130-390 (Figure 4-23).

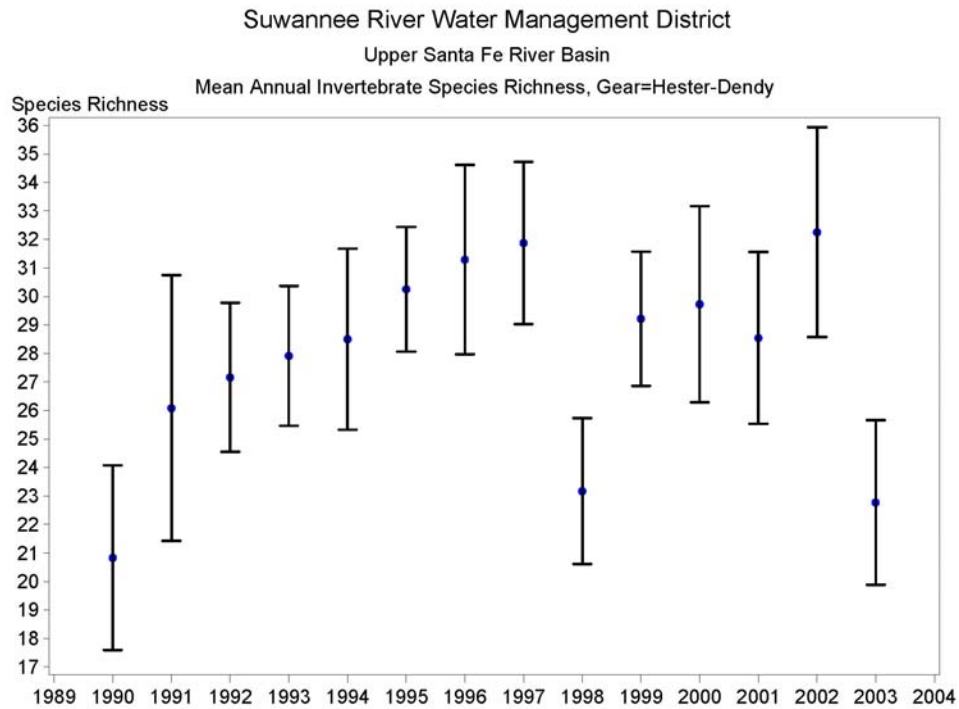


Figure 4-18 Mean annual benthic invertebrate species richness from Hester-Dendy samplers, with 95% confidence limits, for the Upper Santa Fe River (Janicki Environmental, Inc., 2004).

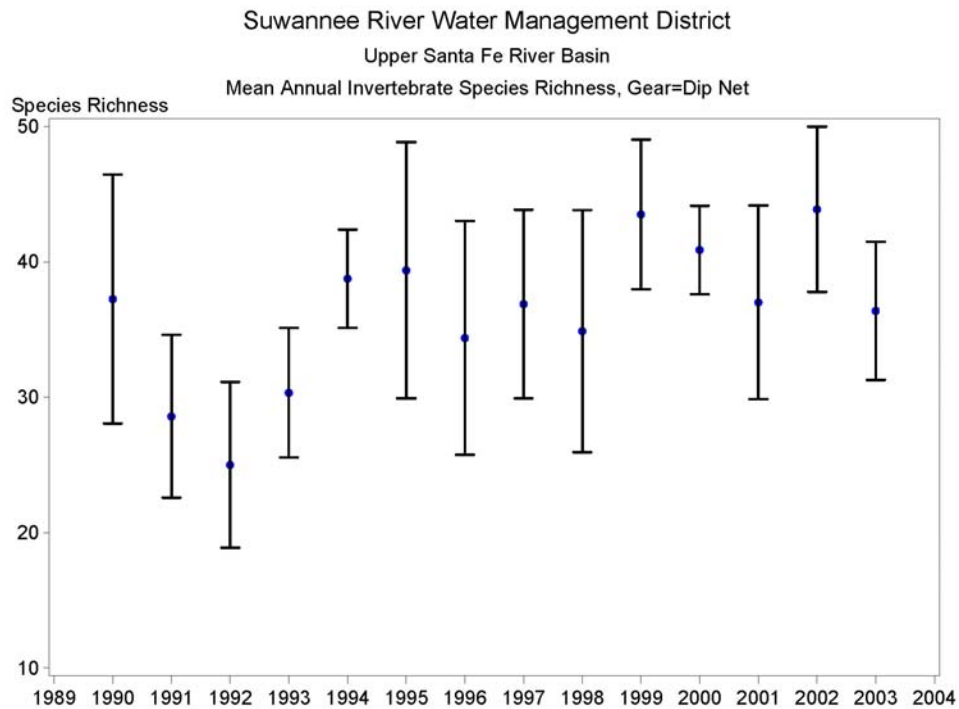


Figure 4-19 Mean annual benthic invertebrate species richness dip net collections, with 95% confidence limits, for the Upper Santa Fe River (Janicki Environmental, Inc., 2004).

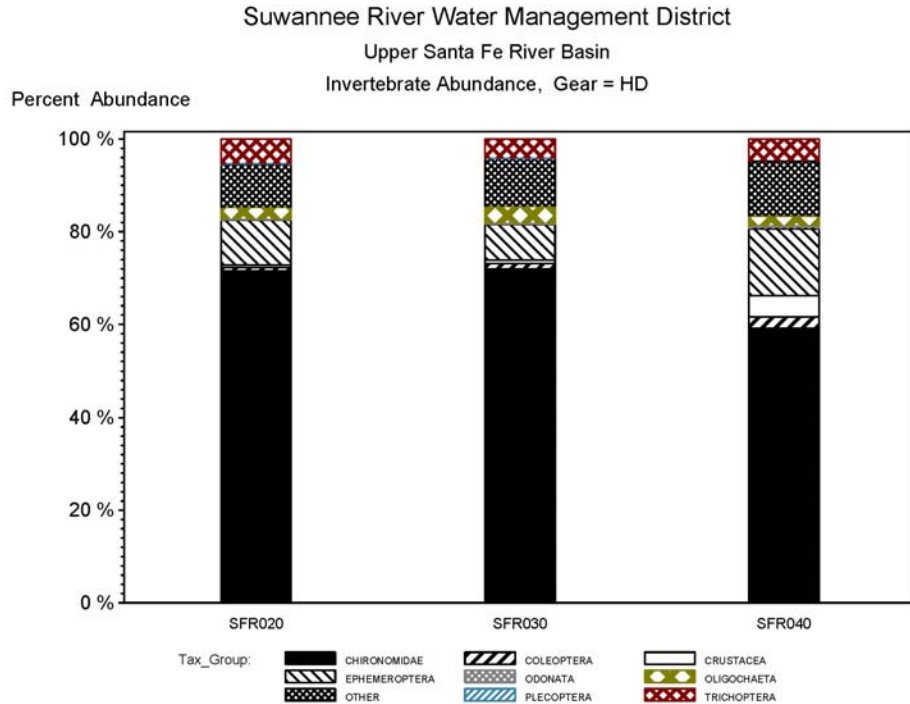


Figure 4-20 Stacked bar chart showing invertebrate percent abundance from the Hester-Dendy samplers (gear=HD), by major taxonomic group, in the Upper Santa Fe River (Janicki Environmental, Inc., 2004).

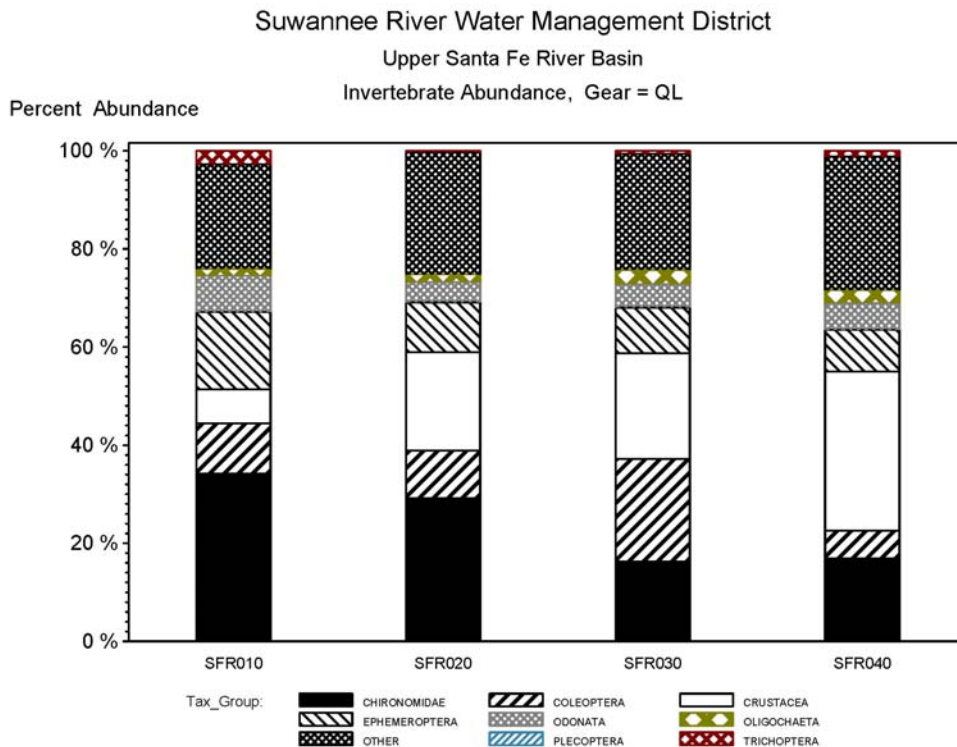


Figure 4-21 Stacked bar chart showing invertebrate percent abundance from dip net collections (gear=QL), by major taxonomic group, in the Upper Santa Fe River (Janicki Environmental, Inc., 2004).

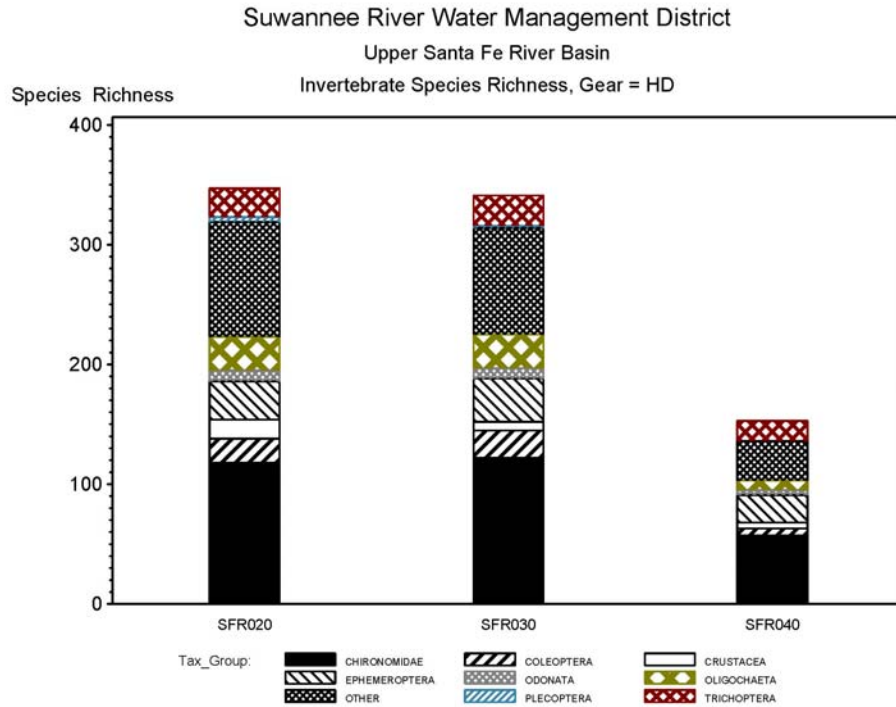


Figure 4-22 Stacked bar chart showing invertebrate species richness from Hester-Dendy samplers (gear=HD), as distributed throughout the major taxonomic groups (Janicki Environmental, Inc., 2004).

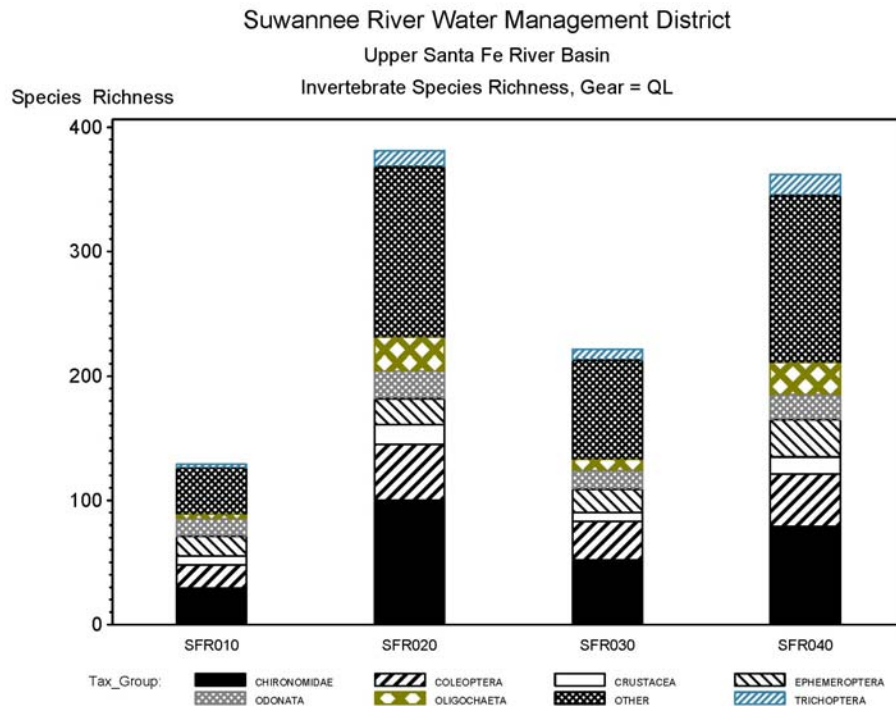


Figure 4-23 Stacked bar chart showing invertebrate species richness from dip net collections (Gear=QL), as distributed throughout the major taxonomic groups (Janicki Environmental, Inc., 2004).

The available data was used to analyze community composition of the macroinvertebrate fauna colonizing artificial substrate samplers. First the data was serially post-stratified (i.e., stations, years, and quarters) to facilitate the understanding of general patterns. Then, the relationships between regional meteorological conditions (i.e., El Niño-Southern Oscillation) and a series of cumulative river flows (based upon data collected or simulated from the gages closest to the macroinvertebrate sampling location) on the biota was examined (Figure 4-24 map). Finally, direct associations between different flow regimes and macroinvertebrate community structure were examined. SDII provided the flow records, including the simulated flows for the USGS Brooker Gage (USGS 02320849) for each of the three macroinvertebrate stations for the period 1989-2003. The effects of location (station), year (inter-annual differences), seasonality (quarter), and flow-related variables on univariate and multivariate community structure metrics were examined.

Pearson correlation coefficients were calculated (untransformed data) for the associations between numbers of taxa, Shannon-Wiener diversity, and total numbers of organisms versus a suite of water quality and flow-related variables. Community structure was defined as Bray-Curtis similarity (Boesch 1977) using fourth root transformed $n+0.1$ counts. PRIMER's (PRIMER-E Ltd. 2001) ANOSIM (analysis of similarities) program (Clarke and Warwick 2001) was used to determine whether community structure differed between selected factors (station, year, quarter, flow regime, etc.). The SIMPER (similarity percentage) program was then used to rank the various taxa's contribution to the dissimilarity between categories of factors (Clarke and Warwick 2001). Non-metric multidimensional scaling (MDS) was used to graphically highlight these patterns. "Bubble" plots representing the abundances of selected "key" species were superimposed over the MDS plots of benthic community structure to aid in explaining biotic variables contributing to the observed patterns (Clarke and Warwick 2001). PRIMER's RELATE and BIO-ENV procedures (Clarke and Warwick 2001) were used to explore the extent to which benthic community structure was associated with Upper Santa Fe River flows (as cumulative flows over time periods ranging from 7-days to 112-days preceding sample collection from the USGS gauge proximal to the sampling location) and the Oceanic Niño Index as a measure of El Niño-Southern Oscillation (ENSO) state during the three and six months preceding sample collection (National Weather Service, 2004). Flows for USF Station 20 at Brooker were simulated by SDII.

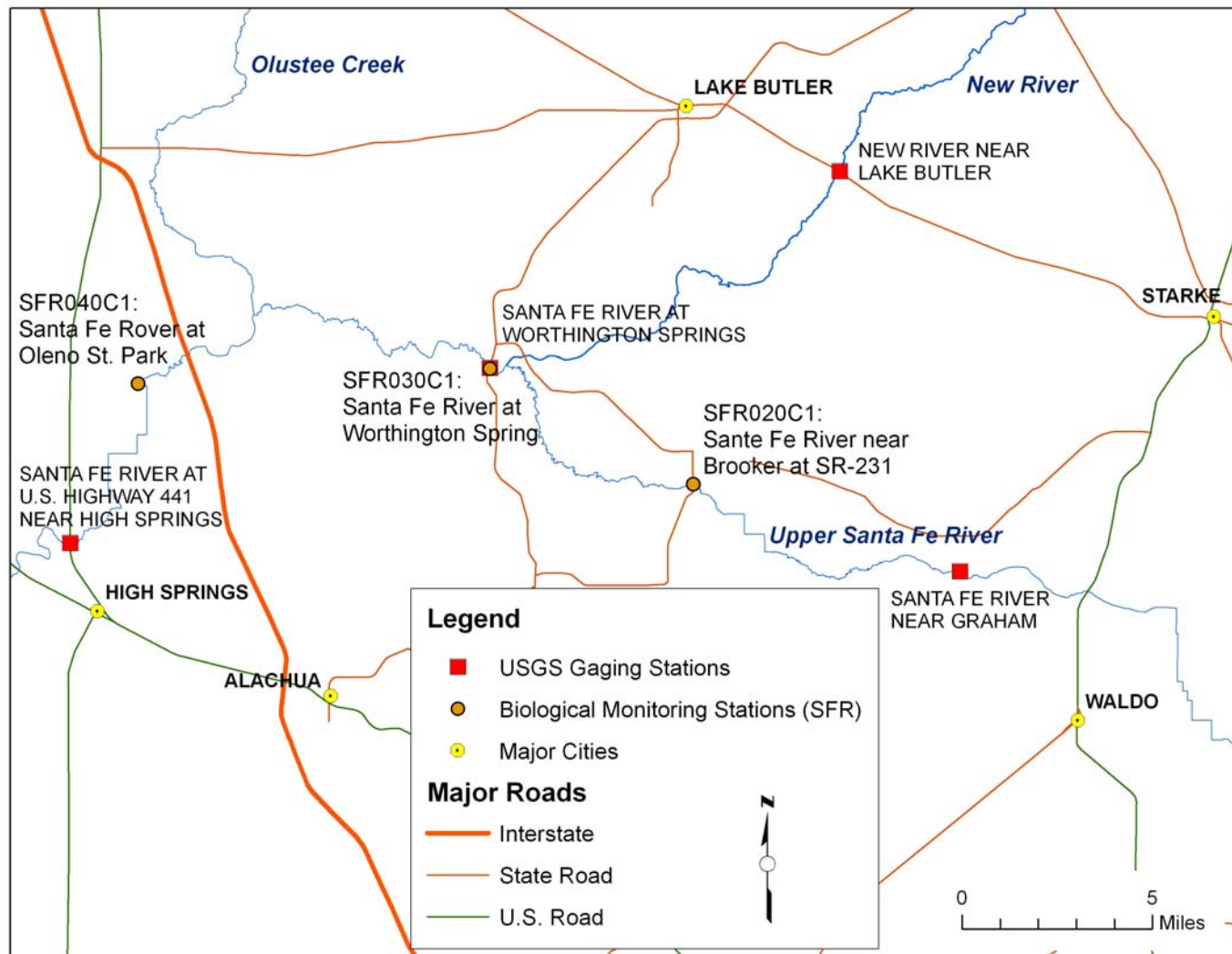


Figure 4-24 Locations of SRWMD biological and water quality stations and USGS flow gages on the Upper Santa Fe River.

The associations (Spearman rank correlations, R_s ; Clarke and Ainsworth 1993) between the macroinvertebrate community similarity matrix and the normalized flows were calculated for the 1990-2003 Upper Santa Fe River macroinvertebrate data collected by the District.

Pearson correlation coefficients between numbers of taxa, Shannon-Wiener diversity, and total counts of organisms showed that the highest correlations were with cumulative flow variables. Correlation coefficients for numbers of taxa ranged from -0.47 (cumulative flow over 7 days; $p < 0.05$) to -0.38 (cumulative flow over 112 days; NS $p > 0.05$); for Shannon diversity the range was -0.53 (cumulative flows over seven and 84 days) to -0.43 (112 day cumulative flow; p values were < 0.05); for total organism counts the correlations ranged from 0.24 (84 day cumulative flows) to 0.33 (28 day cumulative flows; $p < 0.001$). Correlations between the various water quality variables (e.g., conductivity, anions, cations, dissolved oxygen, pH, etc.) and the biotic variables were much lower, and not statistically significant.

Mean numbers of taxa and Shannon diversity were generally similar between the three stations (Figure 4-25); mean numbers of organisms were somewhat higher at the Worthington Springs station (SFR030). Each of the three stations included *Tanytarsus* sp. larvae and the heptageniid mayfly *Stenacron* sp. among their characteristic taxa (Table 4-2). Two species of *Polypedilum* (Chironomidae) larvae were characteristic of the Brooker and Worthington Spring locations. The MDS plot (Figure 4-26) shows that there is considerable overlap in community structure among the three stations. The Brooker and Worthington Spring stations, which had the longest data stream, differed in structure (Table 4-2). The Brooker and Worthington Spring stations differed because the chironomids *Tribelos fusicorne*, *Polypedilum scalaneum*, and *Tanytarsus* sp. S (Figure 4-27) were more abundant at Worthington Springs and *Tribelos jucundum* was more abundant at the Brooker site (Table 4-2). Mean numbers of taxa generally increased from 1990-1997 (Figure 4-28), decreased in 1998, and then increased again through 2002. Diversity did not show any linear inter-annual trend. Numbers of organisms were relatively low during 1990-1993 (Figure 4-28).

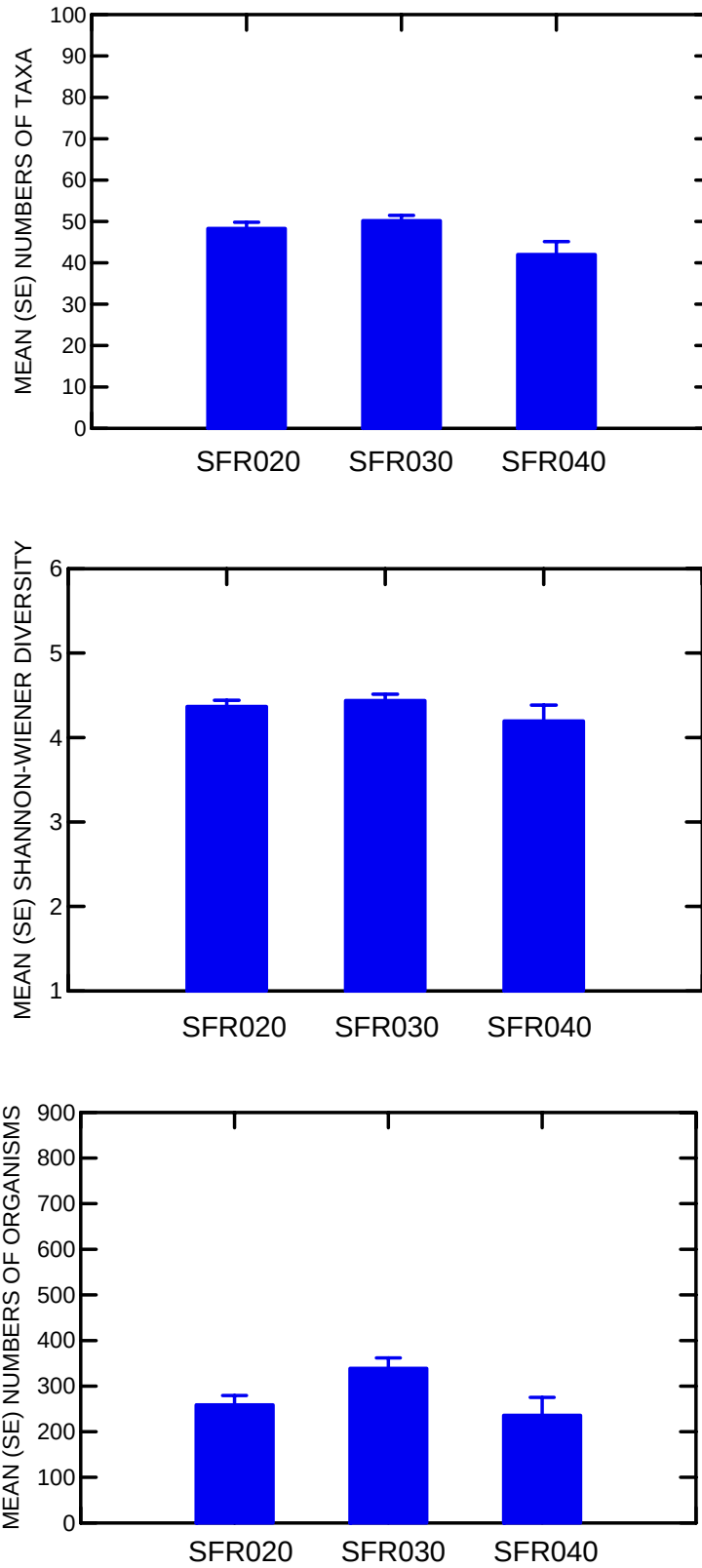


Figure 4-25 Mean numbers of macroinvertebrate taxa , Shannon-Wiener diversity, and numbers of organisms by station, Upper Santa Fe River, 1990-2003.

Table 4-2 ANOSIM and SIMPER analyses comparing (>25% of within and between station) macroinvertebrate community structure within and between stations, Upper Santa Fe River, 1990-2003 (Hester-Dendy samplers; 4th root n+0.1 transformed counts; Bray-Curtis similarity). ANOSIM table shows the R statistic for comparison of macroinvertebrate community structure between stations SFR020 and SFR030; the sample size was too small to evaluate SFR040. SIMPER tables are shown for the inter-year comparisons that are significantly different at the 5% level. Station counts are the 4th root transformed means; Percent Contribution = percent of overall between-group similarity attributed to each species; Cumulative Percent = cumulative percentage of between-group similarity contributed by the ranked species.

SIMPER TEST: WITHIN STATION SIMILARITY

A) SFR020 (Brooker)

Species	Average Abundance	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp.</i>	1.50	5.99	5.99
<i>Polypedilum fallax</i>	1.49	5.82	11.81
<i>Stenacron sp.</i>	1.33	4.64	16.45
<i>Ablabesmyia rhamphe</i>	1.13	3.73	20.18
<i>Tanytarsus sp. M</i>	1.20	3.55	23.73
<i>Polypedilum scalaneum</i>	1.24	3.43	27.16

B) SFR030 (Worthington Spring)

Species	Average Abundance	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp.</i>	1.80	6.03	6.03
<i>Polypedilum scalaneum</i>	1.71	4.81	10.84
<i>Polypedilum fallax</i>	1.53	4.51	15.35
<i>Stenacron sp.</i>	1.42	4.17	19.52
<i>Tanytarsus sp S</i>	1.51	4.00	23.51
<i>Ablabesmyia mallochi</i>	1.30	3.79	27.31

C) SFR040 (O'Leno Park)

Species	Average Abundance	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp C</i>	1.62	7.16	7.16
<i>Tanytarsus sp.</i>	1.40	6.26	13.42
<i>Tribelos fusicorne</i>	1.52	5.55	18.98
<i>Stenacron sp.</i>	1.24	4.84	23.82

ANOSIM TEST

STATIONS	R Statistic	Significance Level %
SFR020 vs.SFR030	0.076	0.1
SFR020 vs.SFR040	0.291	0.4
SFR030 vs.SFR040	0.385	0.1

SIMPER ANALYSIS: COMPARISON OF SFR020 (BROOKER) AND SFR030 (WORTHINGTON SPRINGS) Average dissimilarity = 66.30

Species	SFR020 (BROOKER)	SFR030 (WORTHINGTON SPRINGS)	Percent Contribution	Cumulative Percent
<i>Tribelos fusicorne</i>	1.03	1.19	1.35	1.35
<i>Polypedilum scalaneum</i>	1.24	1.71	1.32	2.68
<i>Tribelos jucundum</i>	1.15	0.82	1.30	3.98
<i>Tanytarsus sp S</i>	1.12	1.51	1.25	5.22
<i>Parakiefferiella sp B</i>	0.41	0.99	1.23	6.46
<i>Cyrnellus fraternus</i>	0.29	1.12	1.19	7.64
<i>Tanytarsus sp C</i>	0.68	1.21	1.18	8.82
<i>Tanytarsus sp T</i>	0.62	1.03	1.17	9.99
<i>Acerpenna pygmaea</i>	0.89	0.78	1.15	11.14
<i>Corynoneura sp.</i>	0.94	1.18	1.14	12.28
<i>Rheocricotopus robacki</i>	0.83	0.67	1.13	13.41
<i>Polypedilum convictum</i>	0.71	0.64	1.11	14.51
<i>Tanytarsus sp M</i>	1.20	1.17	1.08	15.60
<i>Thienemanniella sp</i>	0.79	0.75	1.06	16.65
<i>Tanytarsus sp L</i>	0.92	0.88	1.04	17.69
<i>Ablabesmyia rhamphe</i>	1.13	1.37	1.01	18.71
<i>Rheotanytarsus sp.</i>	0.63	0.56	0.99	19.70
<i>Tanytarsus sp A</i>	0.72	1.05	0.98	20.68
<i>Cheumatopsyche sp.</i>	0.60	0.48	0.96	21.63
<i>Ablabesmyia sp.</i>	0.90	1.23	0.96	22.59
<i>Nilothauma sp</i>	0.76	0.86	0.95	23.54
<i>Thienemanniella sp A</i>	0.54	0.60	0.94	24.48
<i>Cryptotendipes sp.</i>	0.44	0.68	0.93	25.41

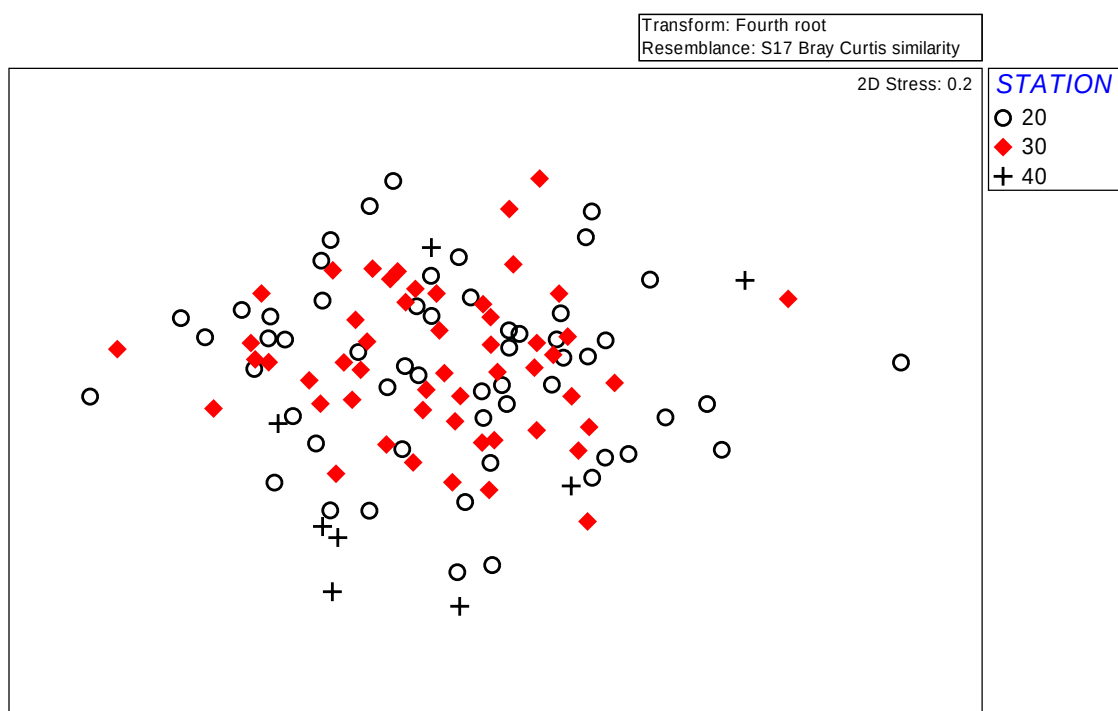


Figure 4-26. MDS plot depicting the similarity of Upper Santa Fe River macroinvertebrate assemblages by station, 1990-2003.



A



B



C

Figure 4-27 Various species of the benthic invertebrate *Tanytarsus*.

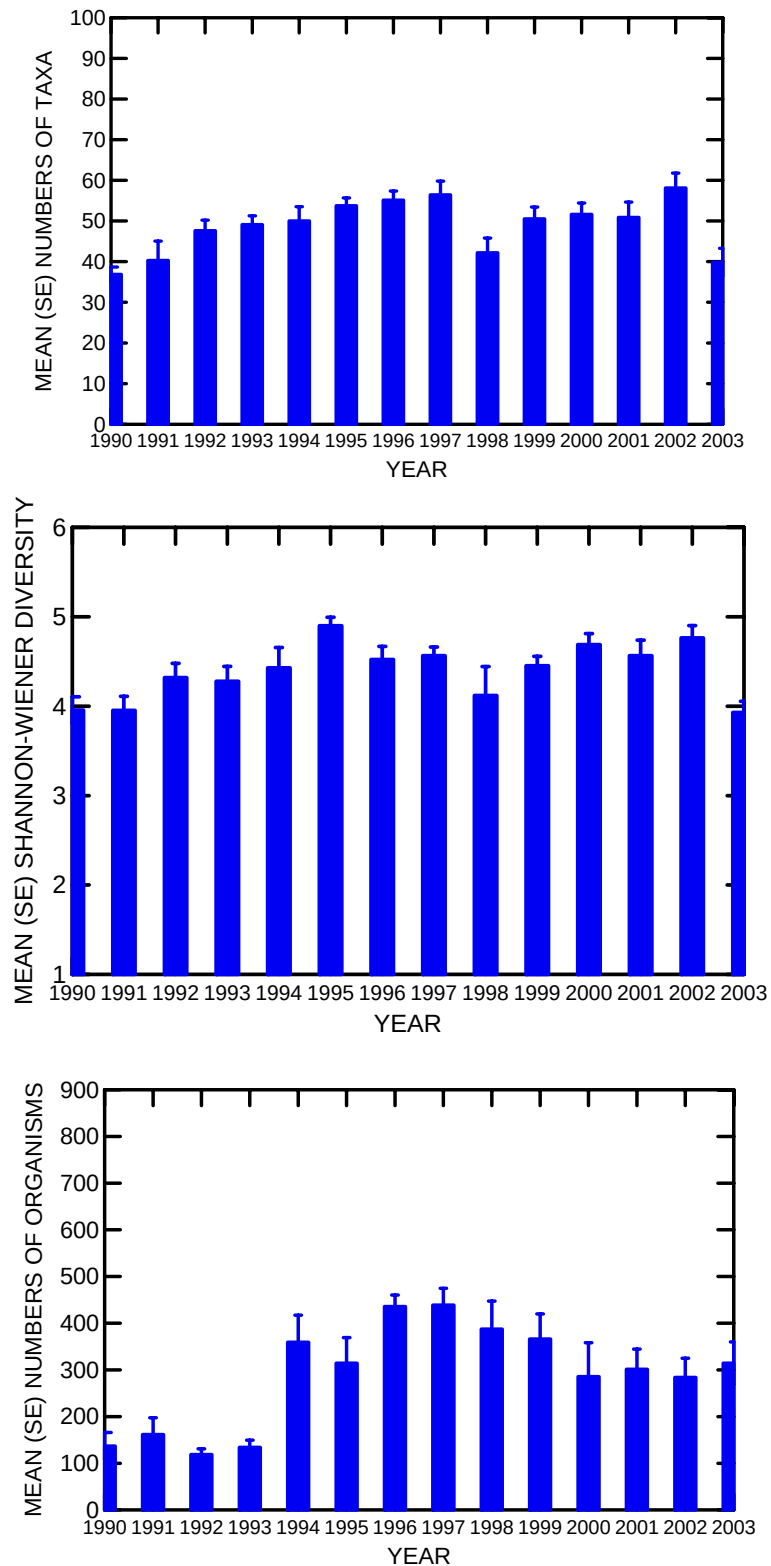


Figure 4-28 Mean (standard error) numbers of macroinvertebrate taxa , Shannon-Wiener diversity, and numbers of organisms by year, Upper Santa Fe River, all stations, 1990-2003.

SIMPER analyses were used to identify the macroinvertebrate species (collected on Hester-Dendy multiple plate samplers) that explained the largest fraction of within-year similarity and dissimilarity between consecutive years. Macroinvertebrate assemblages were generally similar between consecutive years (Table 4-3). Exceptions included:

- 1990 vs 1991: *Tribelos fusicorne* was more abundant in 1990; *Polypedilum convictum* and *Cheumatopsyche* sp. were more abundant during 1991; annual streamflow underwent more than a magnitude increase from 1990 (51 cfs) to 1991 (587 cfs; USGS Gage 02321470 at Worthington Springs, 2005);
- 1994 vs. 1995: *Corynoneura lobata* and *Thienemanniella* sp were more abundant during 1995 and *Corynoneura* sp. was more abundant during 1994; annual streamflow differed little between years (391 cfs in 1994 and 384 cfs in 1995)
- 1995 vs. 1996: both *Rheocricotopus robacki* and *Polypedilum convictum* were more abundant during 1995 and *Polypedilum scalaneum* was more abundant during 1996; annual streamflow differed little between years (384 cfs in 1995 and 326 cfs in 1996)
- 1996 vs. 1997: *Tribelos fusicorne* was more abundant during 1996 and *Acerpenna pygmaea* was more abundant during 1997 (Table 4-3); annual streamflow differed little between years (326 cfs in 1996 and 437 cfs in 1997).
- 2002 vs. 2003: The mean annual streamflow differed more than 700% between years (95 cfs in 2002 and 699 cfs in 2003). During the low flow year of 2002, *Tribelos jucundum* and *Tanytarsus* sp. S were much more abundant than during the high flow year of 2003. Taxa that were more abundant during 2003 than 2002 included *Rheotanytarsus exiguus*, *Polypedilum flavum*, and *Rheotanytarsus pellucidus*.

Both numbers of taxa and Shannon diversity were somewhat higher during the third quarter (Figure 4-29). Mean number of organisms seemed to decline slightly from quarter one through quarter four (Figure 4-29).

ANOSIM showed that the macroinvertebrate assemblages in consecutive quarters differed significantly (Table 4-4) although the MDS plot showed that there was considerable variability and overlap in community structure between calendar quarters (Figure 4-29). Quarters 1 and 2 were least similar (28%) because of the differences in the distributions of *Tribelos fusicorne* and *Tribelos jucundum* (more abundant during Quarter 2) and *Parakiefferiella* sp. B (more abundant during Quarter 1 (Table 4-4).

Table 4-3 ANOSIM and SIMPER analyses comparing (>25% of between-year similarity) macroinvertebrate community structure within years, Upper Santa Fe River, 1990-2003 (Hester-Dendy samplers; 4th root n+0.1 transformed counts; Bray-Curtis similarity). ANOSIM table shows the R statistic for comparison of macroinvertebrate community structure between consecutive years and the significance level of the comparison. SIMPER tables are shown for the inter-year comparisons that are significantly different at the 5% level. Year counts are the 4th root transformed means; Percent Contribution = percentage of overall between-group similarity attributed to each species; Cumulative percent = cumulative percentage of between-group similarity contributed by the ranked species.

ANOSIM TABLE

Years	R Statistic	Significance Level %
90 vs. 91	0.238	3
92 vs. 91	0.102	12.7
92 vs. 93	-0.019	49.6
93 vs. 94	0.138	9.7
94 vs.95	0.184	1.6
95 vs.96	0.264	0.5
96 vs. 97	0.28	0.6
97 vs. 98	0.127	6.4
98 vs. 99	0.131	6.1
00 vs. 99	0.002	42.2
00 vs. 01	0.033	30
01 vs. 02	0.012	39.4
02 vs. 03	0.263	1.7

SIMPER TABLE

A) 1990 VS. 1991 (Average dissimilarity = 63.38)

Species	Mean Count (1990)	Mean Count (1991)	Percent Contribution	Cumulative Percent
<i>Tribelos fusicorne</i>	1.57	0.38	2.43	2.43
<i>Polypedilum convictum</i>	0.64	1.56	2.30	4.73
<i>Cheumatopsyche sp.</i>	0.65	1.39	2.00	6.73
<i>Tanytarsus sp. C</i>	1.43	0.88	1.92	8.65
<i>Tanytarsus sp. L</i>	0.26	1.07	1.72	10.37
<i>Rheotanytarsus sp.</i>	0.63	0.91	1.71	12.07
<i>Dicrotendipes neomodestus</i>	0.93	0.20	1.62	13.70
<i>Rheocricotopus robacki</i>	0.41	0.97	1.59	15.29
<i>Corynoneura sp.</i>	0.47	1.16	1.57	16.87
<i>Tricorythodes albilineatus</i>	1.04	0.60	1.57	18.43
<i>Ablabomyia rhamphe</i>	0.54	0.84	1.57	20.00
<i>Stenacron sp.</i>	0.65	1.12	1.56	21.55
<i>Thienemanniella sp.</i>	0.61	1.42	1.55	23.11
<i>Tanytarsus sp. A</i>	0.84	0.92	1.53	24.64

B) 1994 VS. 1995 (Average dissimilarity = 57.24)

Species	Mean Count (1994)	Mean Count (1995)	Percent Contribution	Cumulative Percent
<i>Thienemanniella</i> sp. A	0.46	1.73	1.75	1.75
<i>Corynoneura</i> sp.	1.80	0.94	1.57	3.31
<i>Corynoneura lobata</i>	0.00	1.22	1.50	4.81
<i>Tribelos fusicorne</i>	1.09	1.28	1.46	6.27
<i>Polypedilum illinoense</i>	1.40	0.42	1.39	7.66
<i>Tribelos jucundum</i>	0.47	1.07	1.31	8.97
<i>Thienemanniella</i> sp.	1.42	0.96	1.31	10.28
<i>Tanytarsus</i> sp. L	1.03	1.74	1.31	11.59
<i>Polypedilum scalaneum</i>	1.26	1.61	1.30	12.89
<i>Pentineura inconspicua</i>	0.73	1.39	1.24	14.12
<i>Ablabesmyia mallochi</i>	1.37	0.60	1.23	15.36
<i>Corynoneura</i> sp. B	0.75	1.31	1.22	16.58
<i>Ablabesmyia rhamphe</i>	1.12	1.51	1.21	17.79
<i>Cynellus fraternus</i>	1.01	1.13	1.16	18.95
<i>Polypedilum convictum</i>	1.18	1.83	1.15	20.10
<i>Stenonema exiguum</i>	0.62	1.22	1.14	21.24
<i>Cheumatopsyche</i> sp.	0.81	1.09	1.11	22.35
<i>Tanytarsus</i> sp. C	1.33	0.73	1.08	23.43
<i>Rheocricotopus robacki</i>	1.32	1.85	1.07	24.50
<i>Rheotanytarsus</i> sp.	1.58	1.67	1.07	25.56

C) 1995 VS. 1996 (Average dissimilarity = 57.73)

Species	Mean Count (1995)	Mean Count (1996)	Percent Contribution	Cumulative Percent
<i>Rheocricotopus robacki</i>	1.85	0.79	1.54	1.54
<i>Polypedilum convictum</i>	1.83	0.63	1.50	3.04
<i>Polypedilum scalaneum</i>	1.61	2.76	1.47	4.51
<i>Tribelos fusicorne</i>	1.28	1.49	1.39	5.91
<i>Acerpenna pygmaea</i>	1.74	0.70	1.36	7.27
<i>Ablabesmyia mallochi</i>	0.60	1.39	1.23	8.50
<i>Tribelos jucundum</i>	1.07	1.07	1.23	9.73
<i>Tanytarsus</i> sp. T	0.29	1.08	1.20	10.92
<i>Parakiefferiella</i> sp. B	0.48	0.93	1.17	12.09
<i>Pentineura inconspicua</i>	1.39	0.61	1.16	13.25
<i>Corynoneura lobata</i>	1.22	0.80	1.14	14.39
<i>Cheumatopsyche</i> sp.	1.09	0.38	1.13	15.52
<i>Cynellus fraternus</i>	1.13	0.76	1.13	16.66
<i>Nilothauma</i> sp.	0.74	1.35	1.13	17.79
<i>Corynoneura</i> sp.	0.94	1.18	1.09	18.88
<i>Rheotanytarsus</i> sp.	1.67	1.15	1.07	19.95
<i>Polypedilum illinoense</i>	0.42	1.05	1.06	21.01
<i>Cernotina</i> sp.	0.53	1.05	1.06	22.08
<i>Tanytarsus</i> sp. C	0.73	1.02	1.06	23.14
<i>Nasis elinguis</i>	0.73	0.66	1.05	24.19
<i>Tanytarsus</i> sp. L	1.74	0.95	1.04	25.23

D) 1996 VS. 1997 (Average dissimilarity = 59.64)

Species	Mean Count (1996)	Mean Count (1997)	Percent Contribution	Cumulative Percent
<i>Polypedilum convictum</i>	0.63	1.75	1.67	1.67
<i>Acerpenna pygmaea</i>	0.70	1.90	1.51	3.18
<i>Tribelos fusicorne</i>	1.49	0.52	1.43	4.62
<i>Tanytarsus sp. C</i>	1.02	2.03	1.43	6.05
<i>Polypedilum scalaneum</i>	2.76	1.62	1.42	7.46
<i>Parakiefferiella sp. B</i>	0.93	1.22	1.40	8.86
<i>Cheumatopsyche sp.</i>	0.38	1.31	1.28	10.14
<i>Rheocricotopus robacki</i>	0.79	1.29	1.26	11.39
<i>Rheotanytarsus sp.</i>	1.15	0.92	1.21	12.60
<i>Tribelos jucundum</i>	1.07	0.17	1.18	13.78
<i>Ablabesmyia rhamphe</i>	2.20	1.21	1.18	14.95
<i>Bezzia/Palpomyia sp.</i>	1.39	0.74	1.15	16.10
<i>Corynoneura lobata</i>	0.80	1.51	1.13	17.23
<i>Tanytarsus sp. M</i>	1.88	1.28	1.10	18.33
<i>Nilothauma sp.</i>	1.35	0.63	1.04	19.37
<i>Pentineura inconspicua</i>	0.61	1.12	1.03	20.40
<i>Thienemanniella sp.</i>	0.69	1.44	1.03	21.43
<i>Tanytarsus sp. A</i>	1.04	0.61	1.00	22.43
<i>Cernotina sp.</i>	1.05	0.43	0.97	23.40
<i>Rheotanytarsus exiguus</i>	0.00	0.91	0.96	24.36
<i>Stenonema exiguum</i>	0.90	1.52	0.96	25.32

E) 2002 VS. 2003 (Average dissimilarity = 67.85)

Species	Mean Count (2002)	Mean Count (2003)	Percent Contribution	Cumulative Percent
<i>Rheotanytarsus exiguus</i>	0.27	1.69	1.74	1.74
<i>Tribelos jucundum</i>	1.94	0.73	1.64	3.39
<i>Polypedilum flavum</i>	0.27	1.33	1.41	4.80
<i>Tanytarsus spp</i>	1.16	0.00	1.31	6.11
<i>Tribelos fusicorne</i>	1.24	1.07	1.25	7.36
<i>Tanytarsus sp. S</i>	1.79	1.02	1.21	8.57
<i>Rheotanytarsus pellucidus</i>	0.22	1.11	1.19	9.76
<i>Corynoneura sp.</i>	0.73	1.00	1.18	10.94
<i>Parakiefferiella sp. B</i>	0.78	0.72	1.17	12.12
<i>Laevapex sp.</i>	1.19	0.35	1.17	13.28
<i>Tanytarsus sp. L</i>	1.21	0.82	1.17	14.45
<i>Tanytarsus sp. M</i>	0.79	1.49	1.15	15.60
<i>Polypedilum scalaneum</i>	1.06	1.53	1.15	16.75
<i>Dicrotendipes simpsoni</i>	0.86	0.73	1.13	17.88
<i>Dicrotendipes sp.</i>	0.87	0.30	1.10	18.97
<i>Tanytarsus sp. C</i>	0.97	0.96	1.05	20.02
<i>Polypedilum halterale</i>	0.88	0.00	1.03	21.06
<i>Polypedilum illinoense</i>	1.13	0.42	1.02	22.08
<i>Ablabesmyia rhamphe</i>	1.46	0.78	1.02	23.09
<i>Ablabesmyia sp.</i>	1.00	0.28	1.01	24.11
<i>Corynoneura sp. B</i>	0.58	0.94	0.99	25.09

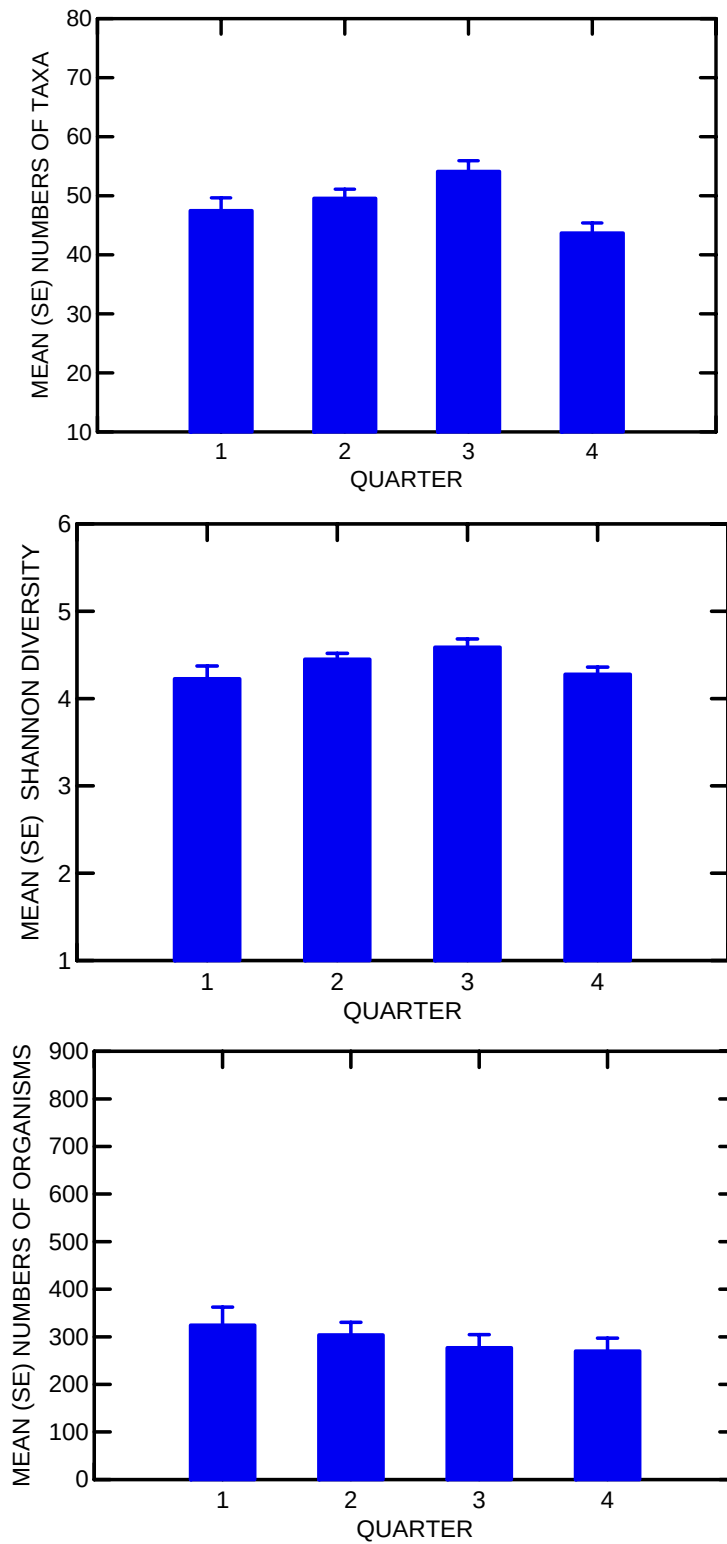


Figure 4-29 Mean numbers of macroinvertebrate taxa , Shannon-Wiener diversity, and numbers of organisms by quarter, Upper Santa Fe River, all stations, 1990-2003.

Table 4-4 ANOSIM and SIMPER analyses comparing macroinvertebrate community structure within and between calendar quarters, Upper Santa Fe River, all stations, 1990-2003 (Hester-Dendy samplers; 4th root $n+0.1$ transformed counts; Bray-Curtis similarity). ANOSIM table shows the R statistic for comparison of macroinvertebrate community structure between quarters and the significance level of the comparison. SIMPER tables are shown for each quarter. Quarter counts are the 4th root transformed means; Percent Contribution = percent of overall within-group similarity attributed to each species; Cumulative Percent = cumulative percentage of within-group similarity contributed by the ranked species.

ANOSIM TABLE

Quarters	R Statistic	Significance Level %
Q1 vs Q2	0.365	0.1
Q2 vs. Q3	0.057	1.8
Q3 vs. Q4	0.285	0.1

SIMPER TABLES

A) Quarter 1

Species	Mean Count	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp.</i>	1.77	5.82	5.82
<i>Corynoneura sp.</i>	1.54	4.78	10.60
<i>Parakiefferiella sp. B</i>	1.63	4.50	15.10
<i>Stenacron sp.</i>	1.34	4.12	19.22
<i>Thienemanniella sp.</i>	1.33	4.10	23.32
<i>Rheocricotopus robacki</i>	1.25	3.53	26.85
<i>Tanytarsus sp. S</i>	1.42	3.32	30.17
<i>Tanytarsus sp. C</i>	1.25	3.23	33.39
<i>Tanytarsus sp. M</i>	1.22	3.07	36.46
<i>Polypedilum fallax</i>	1.14	2.86	39.31
<i>Ablabesmyia mallochi</i>	1.05	2.62	41.94
<i>Polypedilum illinoense</i>	0.95	2.48	44.42
<i>Tanytarsus sp. A</i>	0.97	2.33	46.74
<i>Acerpenna pygmaea</i>	1.02	2.33	49.07
<i>Polypedilum convictum</i>	0.95	2.31	51.39

B) Quarter 2

Species	Mean Count	Percent Contribution	Cumulative Percent
<i>Tribelos fusicorne</i>	1.92	6.10	6.10
<i>Polypedilum scalaneum</i>	1.77	5.43	11.53
<i>Polypedilum fallax</i>	1.52	5.32	16.84
<i>Tanytarsus sp.</i>	1.30	4.37	21.22
<i>Bezzia/Palpomyia sp.</i>	1.34	4.37	25.59
<i>Ablabesmyia rhamphe</i>	1.33	3.89	29.48
<i>Stenacron sp.</i>	1.14	3.46	32.94
<i>Tribelos jucundum</i>	1.38	3.42	36.36
<i>Ablabesmyia mallochi</i>	1.18	3.37	39.73
<i>Tanytarsus sp. M</i>	1.10	3.08	42.80
<i>Nilothauma sp.</i>	1.06	2.82	45.62
<i>Ablabesmyia sp.</i>	1.06	2.74	48.37
<i>Laevapex sp.</i>	1.00	2.40	50.76

C) Quarter 3

Species	Mean Count	Percent Contribution	Cumulative Percent
<i>Tribelos fusicorne</i>	1.81	2.20	6.10
<i>Polypedilum scalaneum</i>	1.88	2.10	11.95
<i>Tanytarsus sp.</i>	1.49	1.80	16.96
<i>Bezzia/Palpomyia sp.</i>	1.36	1.66	21.58
<i>Stenacron sp.</i>	1.51	1.59	25.99
<i>Polypedilum fallax</i>	1.19	1.32	29.67
<i>Ablabesmyia rhamphe</i>	1.29	1.17	32.92
<i>Ablabesmyia mallochi</i>	1.06	0.98	35.65
<i>Ablabesmyia sp.</i>	1.04	0.93	38.23
<i>Nilothauma sp.</i>	0.94	0.87	40.66
<i>Tanytarsus sp. C</i>	0.96	0.81	42.91
<i>Tanytarsus sp. M</i>	0.94	0.81	45.15
<i>Tanytarsus sp. S</i>	1.03	0.73	47.19
<i>Cynellus fraternus</i>	0.92	0.72	49.18
<i>Tanytarsus sp. A</i>	0.85	0.69	51.10

D) Quarter 4

Species	Mean Count	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp.</i>	1.96	7.73	7.73
<i>Polypedilum fallax</i>	1.99	7.21	14.94
<i>Corynoneura sp.</i>	1.59	5.92	20.86
<i>Tanytarsus sp. S</i>	1.70	5.19	26.06
<i>Ablabesmyia mallochi</i>	1.34	4.75	30.81
<i>Stenacron sp.</i>	1.42	4.50	35.31
<i>Tanytarsus sp. M</i>	1.43	3.98	39.29
<i>Tanytarsus sp. L</i>	1.34	3.73	43.02
<i>Ablabesmyia sp.</i>	1.21	3.61	46.63
<i>Tanytarsus sp. A</i>	1.17	3.29	49.92
<i>Ablabesmyia rhamphe</i>	1.08	3.07	52.99

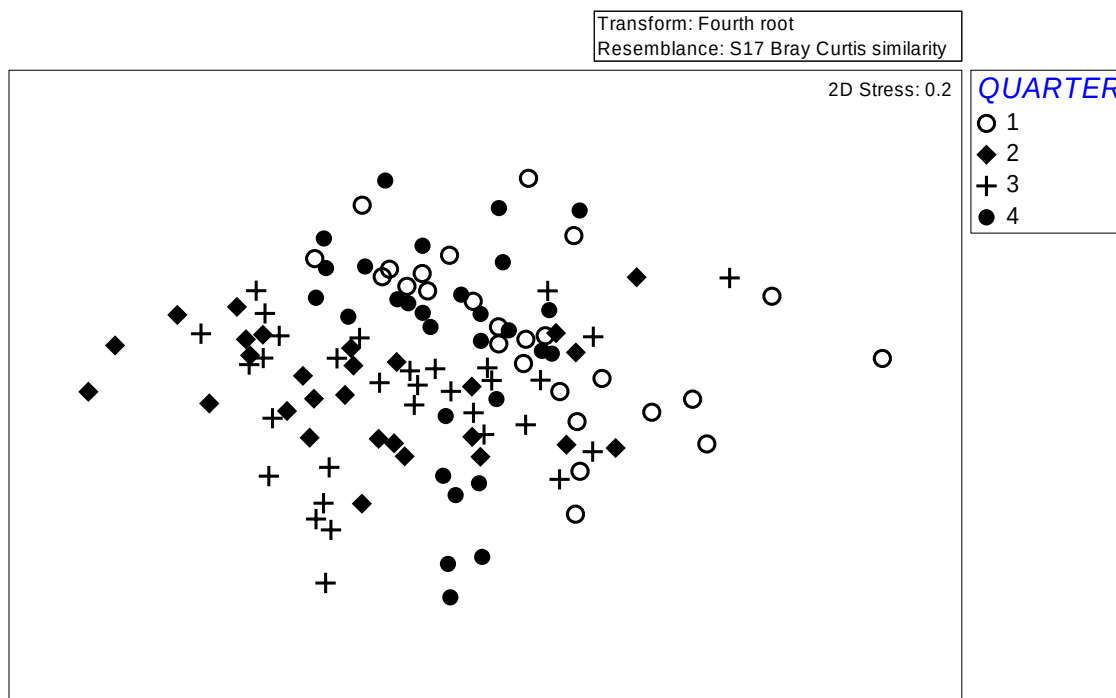


Figure 4-30 MDS plot depicting the similarity of Upper Santa Fe River macroinvertebrate assemblages by sampling quarter, all stations combined, 1990-2003.

The relationship between macroinvertebrate community structure and the antecedent flow regime as well as Oceanic Niño Index alluded to above, was examined more rigorously. First, the resemblance matrices for standardized cumulative flows and the standardized Oceanic Niño Index (Euclidean distance) and the biota were compared using the RELATE test. This showed that the two matrices were comparable. This was done first, for all data and then separately for stations SFR020 (near Brooker) and SFR030 (Worthington Springs).

The second step was to determine the combination of abiotic variables that gave the “best fit” with the biotic similarity matrix (BIO-ENV test). The variables giving the “best” fit over all data ($R_s=0.22$) were:

- 42-day,
- 14-day,
- 7--day, and
- 21-day cumulative flows.

When analyzed separately by station, the best fit at Brooker (SFR020) was also with the 42-day cumulative flows ($R_s=0.40$) whereas at Worthington Spring (SFR030), the best fit was over 56 days ($R_s=0.343$) and the combination of seven and 56-days ($R_s=0.343$). The relationships between the univariate community metrics and the 42-day cumulative flows were explored using scatterplots. Examination of the plots showed that there was little relationship to flow for each of the biotic metrics (Figure 4-31).

The macroinvertebrate community structure was then compared between four different flow scenarios, based upon the 42-day cumulative flows for all stations. Flow data were stratified by quartiles:

- Quartile 1: ≤ 714 cfs;
- Quartile 2: > 714 to $\leq 3,116$ cfs;
- Quartile 3: $> 3,116$ to $\leq 8,969$;
- Quartile 4: $> 8,969$ cfs)

The ANOSIM test (Table 4-5) showed that the structure of the macroinvertebrate assemblage shifted as the 42-day cumulative flows increased from the third quartile range (3,116 to 8,969 cfs) to the fourth quartile ($> 8,969$ cfs) (Table 4-5). The MDS plot also showed that there was some segregation of samples by quartiles of the 42-day cumulative flows (Figure 4-32). SIMPER analysis showed that the higher numbers of *Polypedilum convictum* and *Penteneura inconspicua* at fourth quartile flows and the higher numbers of *Tribelos fusicorne* and *Parakieffierella* sp. B at third quartile flows explained some of the differences in structure (Table 4-5).

The macroinvertebrates colonizing artificial substrate samplers in the Upper Santa Fe River differed by location, year, and season. There was also compelling evidence that the cumulative flow regime over intermediate time periods (e.g., 42 days) affected community structure.

The ENSO, with its concomitant effects on streamflow, was less important in these analyses. For example, inter-annual differences in community structure did not appear to be related to mean annual flows but analysis by calendar quarter did seem to be related. When samples were analyzed over time (by consecutive quarters) the periods during which there was greater variability in the macroinvertebrate assemblages generally did not correspond with large differences in streamflow. The lowest flows were most likely to occur during the second quarter of sampling (11 of 28 samples). The second and third quartiles of flow were more likely to occur during the second and fourth quarters (20 of 31 samples) and first, third, and fourth quarters (25 of 27) respectively. Highest flows were observed during the first and third quarter (23 of 30).

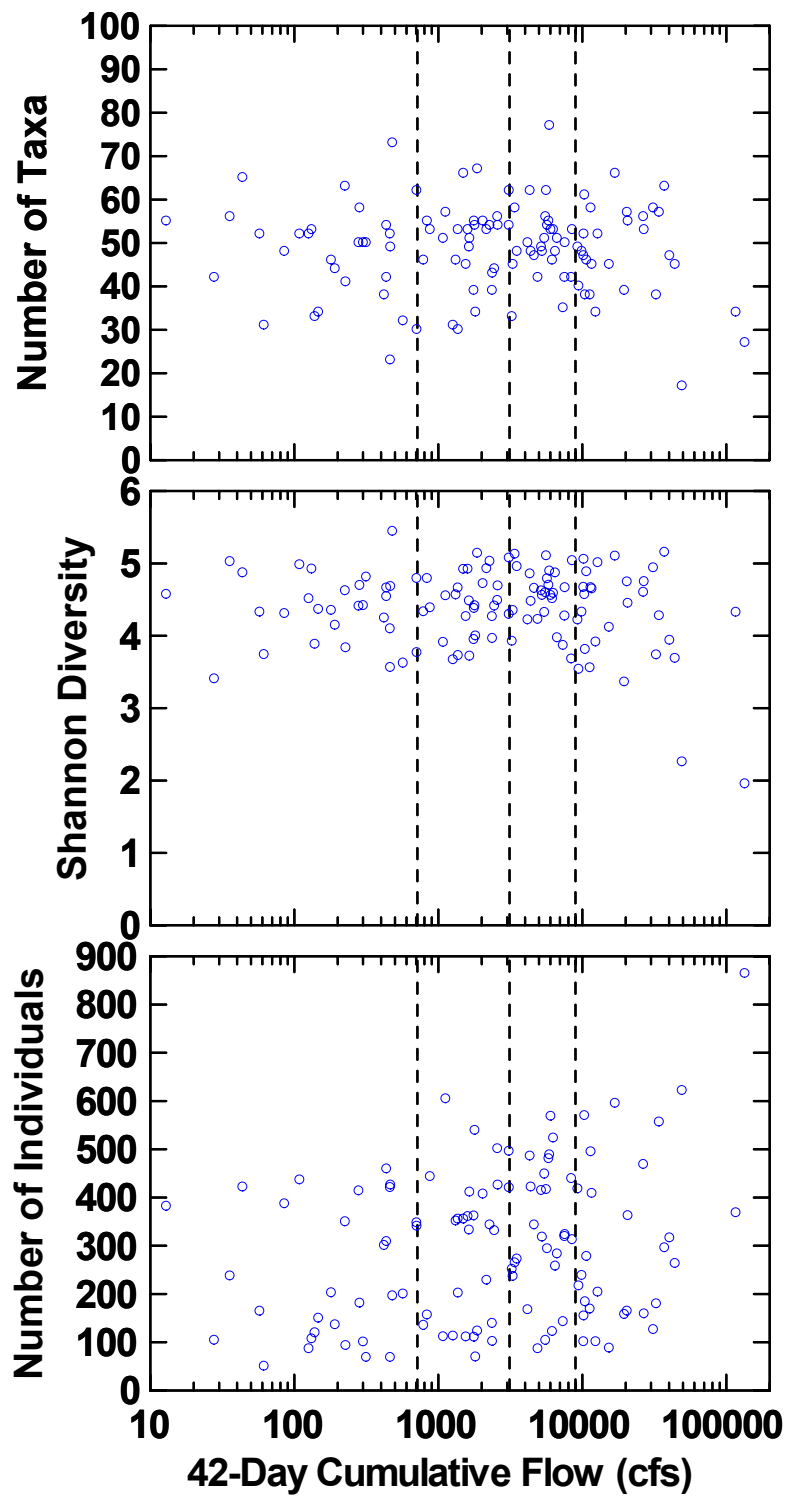


Figure 4-31 Relationships between numbers of taxa, Shannon-Wiener diversity, and numbers of organisms and $\log_{10}$ transformed 42-day cumulative flows. Vertical lines demarcate the flow quartiles. Upper Santa Fe River, 1990-2003.

Table 4-5. ANOSIM and SIMPER analyses comparing macroinvertebrate community structure between 42-day cumulative flow quartiles, Upper Santa Fe River, all stations, 1990-2003 (Hester-Dendy samplers; 4th root n+0.1 transformed counts; Bray-Curtis similarity). ANOSIM table shows the R statistic for comparison of macroinvertebrate community structure between quartiles based upon standardized 42-day cumulative flows and the significance level of the comparison. SIMPER tables are shown for the inter-quartile comparisons. Counts are the 4th root transformed means; Percent Contribution = percent of overall within-group similarity attributed to each species; Cumulative Percent = cumulative percent of within-group similarity contributed by the ranked species.

ANOSIM TABLE

Quartile Comparisons	R Statistic	Significance Level %
Q2 vs Q1	-0.088	83.8
Q2 vs. Q3	0.087	13.1
Q4 vs. Q3	0.164	0.1

SIMPER TABLES

A) Flow Quartile 1 (≤ 714)

Species	Quantile 1 Mean Count	Percent Contribution	Cumulative Percent
<i>Polypedilum fallax</i>	1.57	6.12	6.12
<i>Tanytarsus sp</i>	1.37	5.57	11.70
<i>Tribelos fusicorne</i>	1.68	5.16	16.86
<i>Ablabesmyia mallochi</i>	1.31	4.93	21.78
<i>Bezzia/Palpomyia sp.</i>	1.18	4.33	26.12

B) Flow Quartile 2 (>714 to $\leq 3,116$ cfs)

Species	Quantile 2 Mean Count	Percent Contribution	Cumulative Percent
<i>Polypedilum scalaneum</i>	1.90	6.03	6.03
<i>Tanytarsus sp</i>	1.48	5.42	11.45
<i>Tribelos fusicorne</i>	1.57	5.00	16.45
<i>Stenacron sp.</i>	1.32	4.67	21.11
<i>Polypedilum fallax</i>	1.50	4.41	25.53

C) Flow Quartile 3 ($>3,116$ to $\leq 8,969$ cfs)

Species	Quantile 3 Mean Count	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp</i>	1.95	6.58	6.58
<i>Polypedilum fallax</i>	1.84	6.27	12.85
<i>Polypedilum scalaneum</i>	1.84	5.83	18.69
<i>Ablabesmyia mallochi</i>	1.55	5.27	23.95
<i>Tanytarsus sp S</i>	1.56	3.92	27.87

D) Flow Quartile 4 (>8,969 cfs)

Species	Quantile 4 Mean Count	Percent Contribution	Cumulative Percent
<i>Tanytarsus sp</i>	1.71	4.80	4.80
<i>Stenacron sp</i>	1.72	4.80	9.61
<i>Polypedilum scalaneum</i>	1.71	3.78	13.38
<i>Pentineura inconspicua</i>	1.35	3.34	16.72
<i>Thienemanniella sp.</i>	1.40	3.32	20.05
<i>Tanytarsus sp C</i>	1.39	3.29	23.34
<i>Acerpenna pygmaea</i>	1.34	3.18	26.51

**SIMPER: Comparison of macroinvertebrate community structure under Quartile 4 vs. Quartile 3
Flows (Average dissimilarity =62.9)**

Species	Q4 Mean	Q3 Mean	Percent Contribution	Cumulative Percent
<i>Polypedilum convictum</i>	1.26	0.61	1.39	1.39
<i>Pentineura inconspicua</i>	1.35	0.33	1.33	2.72
<i>Tribelos fusicorne</i>	1.12	1.20	1.32	4.04
<i>Tanytarsus sp. S</i>	1.44	1.56	1.31	5.35
<i>Parakiefferiella sp. B</i>	0.60	1.04	1.30	6.65
<i>Thienemanniella sp. A</i>	1.03	0.79	1.25	7.90
<i>Thienemanniella sp</i>	1.40	0.57	1.24	9.14
<i>Rheocricotopus robacki</i>	1.15	0.49	1.22	10.36
<i>Ablabesmyia rhamphe</i>	1.26	1.31	1.21	11.57
<i>Simulium sp</i>	0.85	0.15	1.18	12.75
<i>Acerpenna pygmaea</i>	1.34	0.95	1.13	13.88
<i>Tanytarsus sp. T</i>	0.75	1.13	1.13	15.00
<i>Cheumatopsyche sp</i>	1.00	0.38	1.12	16.12
<i>Ablabesmyia mallochi</i>	0.78	1.55	1.10	17.21
<i>Polypedilum fallax</i>	1.19	1.84	1.09	18.31
<i>Polypedilum scalaneum</i>	1.71	1.84	1.09	19.40
<i>Rheotanytarsus sp.</i>	0.81	0.52	1.07	20.47
<i>Corynoneura sp</i>	1.15	1.31	1.06	21.53
<i>Stenonema exigua</i>	1.15	0.54	1.06	22.59
<i>Tanytarsus sp. C</i>	1.39	1.40	1.05	23.64
<i>Tricorythodes albilineatus</i>	0.97	0.44	1.03	24.67
<i>Ceratomyia sp.</i>	0.41	1.01	1.03	25.69

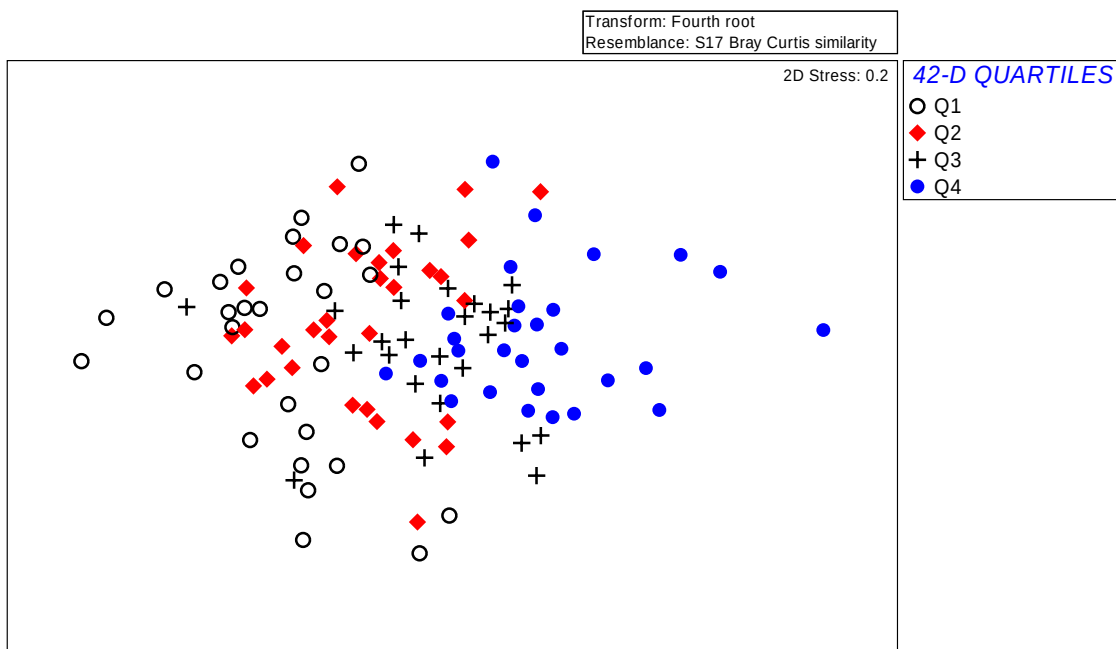


Figure 4-32. MDS plot depicting the similarity of Upper Santa Fe River (all stations) macroinvertebrate assemblages by quartiles of 42-day cumulative flows, 1990-2003. Quartile 1: ≤ 714 cfs; Quartile 2: >714 to $\leq 3,116$ cfs; Quartile 3: $>3,116$ to $\leq 8,969$ cfs; Quartile 4: $>8,969$ cfs:

The Upper Santa Fe River database, which extended over 14 years, permitted the 42-day cumulative flow regime to be stratified into quartiles and examined in more detail. Macroinvertebrate community structure shifted insignificantly as the flow regime changed from the first through third quartiles. This was also evident to some extent in regression plots of numbers of taxa, diversity, and numbers of organisms versus log transformed 42-day cumulative flows.

As the 42-day cumulative flows increased above 8,969 cfs the macroinvertebrate assemblage shifted. Numbers of taxa and diversity declined and numbers of organisms continued to increase. Two species of chironomids, one of which (*Tribelos fusicorne*) was characteristic of lower flows, declined as flows increased and two other chironomids, *Polypedilum convictum* and *Penteneura inconspicua*, increased in abundance.

In the Upper Santa Fe River then, there are demonstrable shifts in the assemblage of organisms colonizing artificial substrates only at the uppermost quartile of flows. The macroinvertebrate assemblage is similar in structure at the lowest and intermediate flows. There is a slight decline in numbers of taxa and diversity as flows increase from the first to the second quartile but they remain relatively constant through the third quartile flows.

4.6 Unionid Mussels

Ecologically, unionid mussels can be an important food resource for other aquatic animals including avifauna, mammals, and fishes. Since mussels are filter feeders, they remove microalgae, detritus, and zooplankton from the water column (Churchill and Lewis 1924; Yeager *et al.* 1994). There are at least 15 indigenous species of unionid mussels in the Suwannee River and its tributaries, including the Santa Fe River (Williams 2004; Williams and Butler 1994; Williams *et al.* 1993) (Table 4-6). Three of the species are endemic to this basin:

- *Medionidus walkeri* (Suwannee moccasinshell)
- *Quadrula kleiniana* (Suwannee pigtoe) and
- *Pleurobema reclusum* (= *Pleurobema pyriforme*; oval pigtoe).

Populations of unionids are diminishing as the quality and quantity of their habitat is altered (Neves 1993; Lydeard and Mayden 1995; Howard 1997; Neves *et al.* 1997; Hardison and Layzer 2001). Factors specific to the Suwannee River basin, including the Upper Santa Fe and New rivers are:

- increased use of nearby lands for agriculture and forestry; fertilizers and livestock feces are major sources of nitrogen to waters in this basin (Crandall 1996); Berndt *et al.* (1998) reported that groundwater contamination by nitrates is a specific concern in the Suwannee river basin;
- development in these basins that contributes to the general degradation of water quality via both increased point and non-point source pollution (Blalock-Herod and Williams 2001);

Table 4-6 Freshwater mussels from the Suwannee River Basin, Florida, including species known to have occurred historically in the Suwannee River Basin but not collected during Williams's 2001-2002 survey (Source: Williams 2004).

Scientific Name	Common Name
<i>Elliptio buckleyi</i>	Florida Shiny Spike
<i>Elliptio icterina</i>	Variable Spike
<i>Elliptio waltoni</i>	Florida Lance
<i>Lampsilis straminea</i>	Southern Fatmucket
<i>Lampsilis teres</i>	Yellow Lampmussel
<i>Medionidus walkeri</i>	Suwannee Moccasinshell
<i>Pleurobema reclusum</i> (= <i>Pleurobema pyriforme</i> ?)	Oval Pigtoe
<i>Quadrula kleiniana</i>	Suwannee Pigtoe
<i>Toxolasma paulus</i>	Iridescent Lilliput
<i>Unio merus carolinianus</i>	Florida Pondhorn
<i>Utterbackia imbecillis</i>	Paper Pondshell
<i>Utterbackia peninsularis</i>	Peninsular Floater
<i>Villosa lienosa</i>	Little Spectaclecase
<i>Villosa vibex</i>	Southern Rainbow
<i>Villosa villosa</i>	Downy Rainbow

- the invasive bivalve *Corbicula fluminea* (Asian clam) is able to out-compete native mussels for physical habitat and food (Heard 1977, Kraemer 1979, Clarke 1986; Blalock and Herod, 1999; Blalock-Herod 2000).

The current status of each of these unionid species in the Santa Fe River drainage warrants concern. *Medionidus walkeri* was not found during a recent survey of locations, including the Santa Fe and New Rivers (Blalock-Herod and Williams 2001). Blalock-Herod and Williams (2001) also found that the distribution of *Quadrula kleiniana* was diminished from the historical records and concluded that it should be identified as an endangered species. *Pleurobema reclusum* is recognized as Endangered (USFWS 1998) with the New River watershed constituting its last refuge. The USFWS (2003) has developed a recovery plan for this species.

The USFWS (2003) produced a Recovery Plan for seven species of threatened and endangered unionid mussels, including *Pleurobema pyriforme*, in rivers and streams ranging from the Alabama to Florida draining watersheds from the Escambia River eastwards to the Suwannee River. The objective of the Plan, with respect to the Santa Fe River basin, is to increase the numbers of this sub-population (of the Suwannee River drainage population) to the extent that it is self-sustaining. USFWS (2003) has joined with Florida's Fish and Wildlife Conservation Commission to support habitat assessments and surveys that are necessary to ascertain and track the status of *Pleurobema pyriforme* in the Santa Fe River watershed.

This Recovery Plan also recognizes the importance of host species (e.g., darters) for the glochidial stage. Without the host species, *Pleurobema pyriforme* will be unable to complete its life cycle and viable populations will not be established. With respect to setting a minimum flow for the Upper Santa Fe River, Gore *et al.* (2001) addressed the strategy of protecting habitat required to sustain the host species, given the paucity of quantitative habitat requirements, by life stage, for mussels in general.

4.6.1 Mussel Species Present in the Santa Fe Basin

Three species are reported in the Santa Fe Basin and species accounts for each follow. It should be noted that all three species have similar habitat requirements and protection of *Pleurobema pyriforme* habitat would also protect *Quadrula kleiniana* and *Medionidus walkeri*.

***Medionidus walkeri* (Suwannee Moccasinshell)**

Williams (2004) considers *Medionidus walkeri* to be endemic to the Suwannee River Basin, which includes the Upper Santa Fe River and New River (Figure 4-32). USFWS has listed this species listed as a Category 2 Candidate Species, meaning the available data are insufficient for a determination to be made as to whether it can be classified as a Threatened and Endangered Species (Williams 2004).

Williams (2004) conducted a survey for mussels in both the Upper Santa Fe River and New River in 2001. Museum collections (Appendix 4-1) showed that *Medionidus walkeri* had been present in the Upper Santa Fe River as recently as 1974 and present in the New River as recently as 1988. Records are listed from three counties in this watershed (Alachua, Bradford, and Union). However, the 2001 survey failed to find any specimens in either river (Williams 2004).

Medionidus walkeri has been found in waterways ranging in size from "medium-sized creeks" up to rivers (Williams and Butler 1994). Preferred stream bottoms are those characterized by sand-gravel or muddy-sand sized sediments. Currents may range from "slow to moderate" (Williams and Butler 1994). Museum records of *Medionidus walkeri* show an association with springs and their groundwater contributions (Mattson *et al.* 1995).

Williams (2004) conjectured that these reports could either reflect physiological requirements for specific anion-cation composition, thermal preferences or the records could be unduly influenced by the ease of collecting near springs.

Other habitat-related variables reflect the needs of the fish host (e.g., darters) for the glochidial larval stage. Although the host for *Medionidus walkeri* is unknown, the piscine hosts for a related species, *Medionidus penicillatus* (Gulf moccasinshell) are *Etheostoma edwini* (brown darter) and *Etheostoma nigrofasciata* (blackbanded darter) (USFWS, 1998). Both darters are found in the Santa Fe basin and habitat alterations that affect the distribution of the host fish species would also impact *Medionidus walkeri* (reference on fish list).

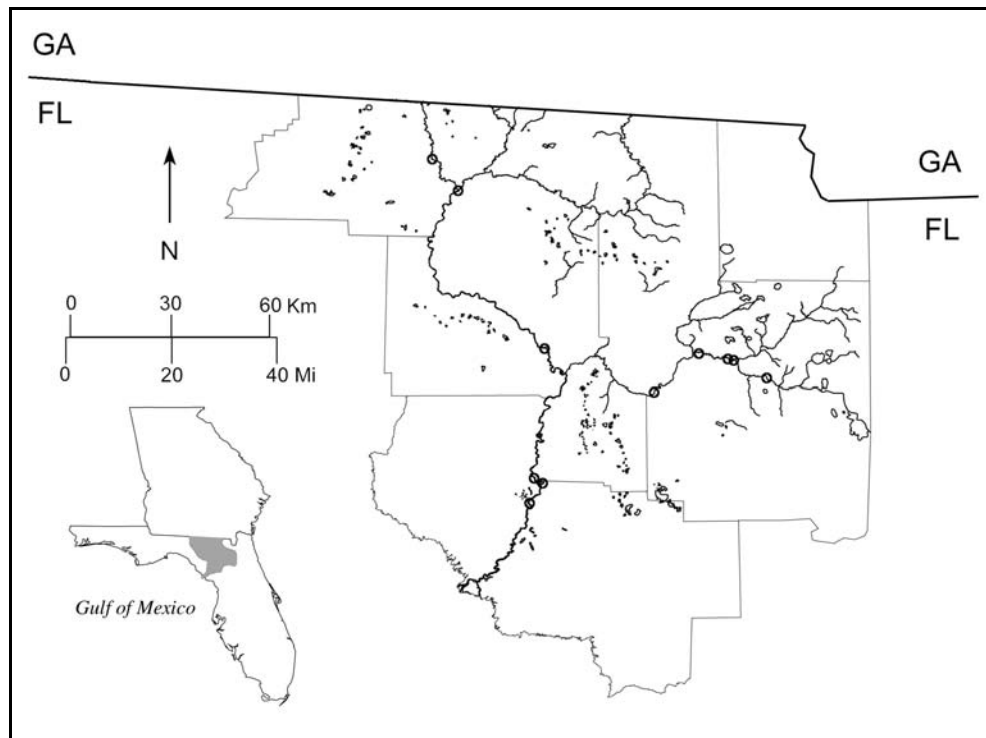


Figure 4-33. Historical distribution of *Medionidus walkeri* within the Suwannee River drainage, Florida. ○ = historical site only (Source: Blalock-Herod and Williams 2004).

***Quadrula kleiniana* (Suwannee Pigtoe)**

Quadrula kleiniana (Suwannee Pigtoe) is also believed to be a Suwannee River Basin endemic, occurring in southern Georgia and northern Florida, including the Santa Fe and New rivers (Lydeard *et al.* 2000) (Figure 4-34). Blalock-Herod and Williams (2001) and Williams (2004) in their 2001 survey, found its distribution reduced from the historical records (Appendix 4-1). They concluded that *Quadrula kleiniana* should be identified as an endangered species.

Quadrula kleiniana is found to co-occur with *Medionidus walkeri* and *Pleurobema pyriforme* (see below) in lotic waters ranging in size from “medium...creeks” to rivers. It occurs in sediments that are characterized as muddy sands, and “mixed sand and gravel”. Current velocities range from “slow to moderate” (Williams and Butler 1994).

The host of the glochidia is unknown. The related species *Quadrula cylindrica* parasitizes *Cyprinella spiloptera* (spotfin shiner), *Cyprinella galactura* (whitetail shiner), and *Notropis anabrops* (bigeye chub) (Louisiana Department of Wildlife and Fisheries Natural Heritage Program 2006). Another related species, *Quadrula asperata*, parasitizes *Ictalurus punctatus* (channel catfish) (Haig and Warren 2003).

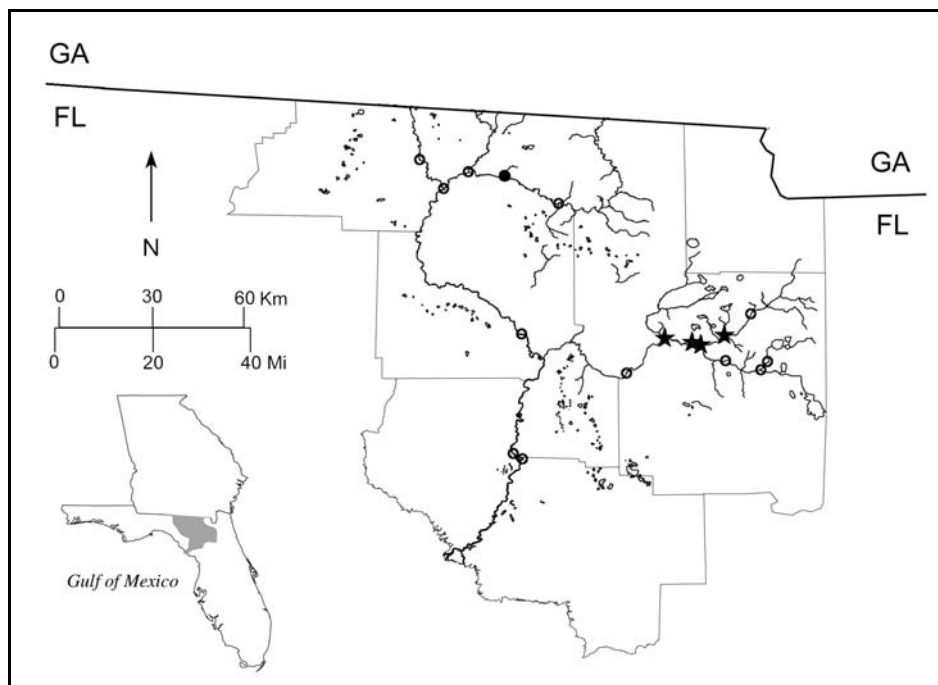


Figure 4-34. Historical and current distribution of *Quincuncina* (= *Quadrula*) *kleiniana* within the Suwannee River drainage, Florida. ○ = historical site only; ★ = both historical and recent sites; ● = recent site only. (Source: Blaylock-Herod and Williams 2004).

***Pleurobema pyriforme* (Oval Pigtoe)**

Pleurobema pyriforme has been considered to be an endemic of the Suwannee, Apalachicola, and Ochlockonee river basins (Figure 4-35) (Williams 2004). Both the Santa Fe and New rivers supported *Pleurobema pyriforme* populations in the past (Clench and Turner 1956, Butler 1993) (Figure 4-36; Appendix 4-1). Kandl *et al.* (2001) used DNA analysis to show that the Suwannee population is genetically different from the populations in the other drainages. The populations in the Suwannee River basin were considered by Williams and Butler (1994) to be *Pleurobema reclusum*. Williams (2004) observed that the determination of whether this species is, in fact, *Pleurobema reclusum* or another undescribed species will require additional DNA analysis. If this is, in fact, endemic to only the Suwannee River basin, then it has apparently disappeared from many of the locations at which it had been collected from in the past. In the most recent survey, this species was only collected at three locations-- two in the New River and one in the Santa Fe River (Blalock-Herod and Williams 2001). The USFWS (2003) considers both *Pleurobema pyriforme* and *Pleurobema reclusum* in their Recovery Plan.

In 1998, the USFS identified *Pleurobema pyriforme* as an Endangered Species (USFWS 1998). USFWS then developed a recovery plan that was approved in 2003 (USFWS 2003). Williams (2004) posited that whichever species of *Pleurobema* is present in the Suwannee River basin should also be protected as an Endangered Species.

Pleurobema pyriforme, as noted above, is found in “medium-sized creeks and rivers”; preferred current velocities are “low to moderate”; and, in the Suwannee River basin, it prefers clean, sandy muds and coarse sand-sized sediments (Williams and Butler, 1994; Blalock-Herod, 2000). Blalock-Herod, (2000) reported that dense populations of *Corbicula fluminea* effectively exclude populations of *Pleurobema pyriforme* from becoming established.

The preferred host for the glochidia is *Pteronotrophis hypselopterus* (sailfin shiner), although this species is not reported from the Santa Fe River. Laboratory studies showed that both *Gambusia holbrooki* (eastern mosquitofish) and *Poecilia reticulata* (guppy) were potential hosts (O'Brian 1997; O'Brien and Williams 2002). *Gambusia affinis* is the only species related to these reported from the Santa Fe drainage.



Figure 4-35. Photograph of *Quadrula kleiniana* (Source: Williams, 2004).

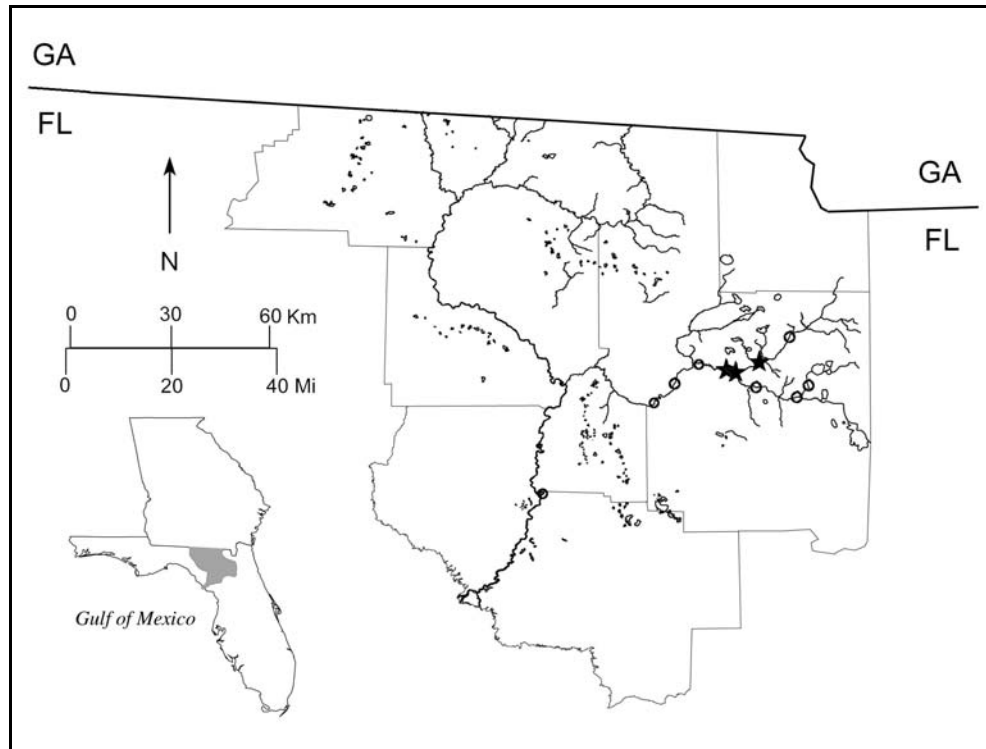


Figure 4-36. Historical and current distribution of *Pleurobema pyriforme* within the Suwannee River drainage, Florida. ○ = historical site only; ★ = both historical and recent sites. (Source: Blaylock-Herod and Williams 2004).

***Medionidus penicillatus* (Gulf Moccasinshell)**

Another species of mussel, *Medionidus penicillatus* (Gulf Moccasinshell), has been historically reported throughout Alabama, Georgia and Florida in the Apalachicola-Chattahoochee-Flint (ACF) basin and the Econfina River (USFWS, 1998; USFWS, 2003). It is generally accepted that sub-populations have been in decline, and extirpated in certain areas, so current distribution may not be as extensive as the historical records indicate. *Medionidus penicillatus* is listed as endangered in the Georgia and State Protected in Alabama. However, the species has been reported to be present in Florida in the Withlacoochee and New Rivers (pers. comm., Jim Williams, USGS, Feb. 2006). Additionally, the main host species for the glochidia in the ACF basin were reported to be *Etheostoma edwini* (Brown darter) and *Percina nigrofasciata* (Black banded darter). Both species of darters have been reported in rivers within the Suwannee basin (Hellier, 1967; Bass in Livingston, 1991).

4.6.2 Mussels and MFLs

Stream velocity and water depth preferences of these species are of particular interest with respect to MFLs. Concern was expressed over how MFLs in the Upper Santa Fe might affect mussels. Every effort was made to uncover relevant literature regarding specific requirements for mussels. However, Layzer and Madison (1995) and Gore *et al.* (2001) make the point that relating the success of mussels in establishing viable beds to flow related variables is a fairly new area of research. Layzer and Madison (1995) cautioned that any recommendations would only be applicable for the short-term success of mussel populations. The available information

has been summarized in this section, although there is not enough data to permit the use of mussel requirements as a criteria for MFL development.

The minimal velocities necessary for mussel species to survive appear to be $>10 \text{ cm sec}^{-1}$. Anderson (1998) found that the larger mussel beds in the Allegheny River (PA) at velocities of $>100 \text{ cm sec}^{-1}$ (Table 4-7). Johnson et al. (2001) found that mussel mortality was markedly higher as velocities declined to $<10 \text{ cm sec}^{-1}$ (Figure 4-37). Therefore, a conservative approach would require that stream velocities be maintained at $>100 \text{ cm sec}^{-1}$. Confounding even these criteria are the observations that the recruitment of some species may be greater at somewhat lower streamflows (Gore et al. 2001). Additionally, Hardison and Layzer (2001) found that mussel densities were more consistently correlated with hydraulic variables (e.g., shear velocities, roughness variables) rather than hydrologic.

It may be more valid to apply flow criteria to the fish species that are required for the completion of the mussels' life cycle (Gore et al. 2001). Freshwater mussels produce a larval stage (glochidia) which is parasitic on gill structures in particular fishes. When the glochidia mature, they are released from the host fish and the juveniles are planktonic until they reach a depositional area characterized by low flow velocity where they settle out. If streamflows are high during the settlement period, the juveniles may not be able settle in habitats that under lower flows would be satisfactory.

Table 4-7. Habitat characteristics of mussel beds in the Allegheny River, Foxburg, PA, 1998 (from: Anderson 1998).

Zone	Distance from bridge (m, - is downstream)	Width (m)	Mean depth (m)	Median 20 percent of depth velocity (m/s)	Median 80 percent of depth velocity (m/s)	Estimated area of mussel bed in zone (m ²)
A	41	145	2.74	0.15	0.09	4,550
B	-51	161	5.98	.13	.14	7,245
B/C ¹	-182	161	2.78	.14	.12	N/A
C	-258	171	2.66	.15	.10	15,000

¹ At the transition from zone B to zone C.

The majority of available information on fish distribution within the Suwannee Basin was for the Suwannee and Santa Fe Rivers and derived from Hellier (1967), Bass (1991), Swift et al. (1986), and the UF museum collection (accessed online Feb.-Mar, 2005). Most zoogeographic accounts and distribution studies were completed on a larger scale and do not provide enough resolution to differentiate between the Suwannee and its other tributary streams, however some information specific to the Santa Fe River is available.

Data on fish communities in the Santa Fe River was limited to electroshock data provided by the FWC (pers. comm., D. Dorosheff) for 1989 – 2001 at Route 441, near High Springs. Data for the following years were not available: 1994, 1999 and 2000. Forty seven species were reported and their abundance and distribution across the 10 sampling dates are shown in Table 4-8. Species richness and diversity were calculated on an annual (i.e., per sample) basis and are shown in Table 4-9.

Table 4-8. Total abundance of fish species caught across the period of record during the FWC electroshock efforts on the Upper Santa Fe (near Route 441, High Springs). Species are ranked by total abundance and listed in descending order.

Rank by Abundance	Common Name	Total Abundance Across All Samples	Total Number of Samples Where Present
1	Spotted Sunfish	1410	10
2	Redbreast Sunfish	1232	10
3	Coastal Shiner	536	10
4	Bluegill	456	10
5	Spotted Sucker	343	10
6	Pirate Perch	326	10
7	Largemouth Bass	266	10
8	Suwannee Bass	231	10
9	Redear Sunfish	194	10
10	Brook Silverside	172	10
11	Warmouth	124	10
12	Hogchoker	58	10
13	Black Crappie	52	8
14	Lake Chubsucker	42	7
15	Bowfin	33	8
16	Redfin Pickerel	30	5
17	Golden Shiner	26	8
18	Blackbanded Darter	25	8
19	Sailfin Shiner	20	3
20	Mosquitofish	19	7
21	Pigmy Sunfish	15	3
22	White Catfish	15	6
23	Pugnose Shiner	14	5
24	Mullet	13	4
25	Speckled Madtom	13	5
26	Swamp Darter	12	4
27	Florida Gar	11	3
28	Bluefin Killifish	10	4
29	Tadpole Madtom	5	2
30	Threadfin Shad	5	1
31	Longnose Gar	5	5
32	Gizzard Shad	4	1
33	American Eel	4	3
34	Channel Catfish	3	3
35	Chain Pickerel	3	3
36	Banded Pigmy Sunfish	3	1
37	Lined Topminnow	3	2
38	Bluespot Sunfish	2	1
39	Dollar Sunfish	2	2
40	Yellow Bullhead	2	1
41	Alabama Shad	1	1
42	Weed Shiner	1	1
43	Golden Topminnow	1	1
44	Flier	1	1
45	Starhead Topminnow	1	1
46	Taillight Shiner	1	1
47	Spotted Bullhead	1	1

Table 4-9. Fish species richness and Shannon-Wiener Diversity values for each year of electroshock sampling by the FWC in the Upper Santa Fe River (near Route 441, High Springs).

Year	Species Richness	Shannon-Wiener Diversity
1989	25	3.41
1990	22	2.94
1991	22	2.81
1992	22	3.14
1993	28	3.55
1995	21	3.24
1996	23	3.20
1997	31	3.30
1998	26	3.42
2001	21	3.15

4.7.1 Groups of Fish Present in the Suwannee Drainage

Family Cyprinidae

Cyprinids represent the largest family of fish in North America and most notably include the “minnows” (Figure 4-38). In addition to minnows, shiners, dace and chubs belong to this family. The largest genus of Cyprinids is *Notropis*, which are typically small, mid-water fishes that consume small crustaceans and insects.

In general, Cyprinids can occupy a variety of habitats ranging from headwater bogs, swamps, springs, rivers, ponds and lakes. Often times, many different species of minnows can occupy a single stretch of a moderately sized stream. Because of their small size, a large number of minnows can occupy a relatively small space and still find adequate food and shelter.

Family Fundulidae

Fundulids include killifish and topminnows (Figure 4-39). These fish are generally small and swim mainly at the top of the water column, near the surface (hence the name “topminnow”). Like Cyprinids, Fundulids can occupy a range of habitats including streams, rivers, lakes, ponds, and marshes. Terrestrial insects and insect larvae make up a large portion of the diet for a number of species belonging to this family, along with crustaceans and small water plants.

Family Percidae

Darters are the 2nd most diverse family of fish after Cyprinidae. The genus *Percina* and *Etheostoma* represent darters in the Suwannee drainage. They typically inhabit fast flowing streams, or riffle areas where depth is shallow and velocity picks up. Through a combination of behavior and morphology, darters avoid being carried downstream with the current. Darters are a benthic group of fishes that completely lack, or have greatly reduced, swim bladders (gas bladders). These fish are also typically strong swimmers which can “dart” about from one point of cover to the next. They spend most of their time darting about on the bottom of streams and lakes eating small crustaceans and insects. *Percina* includes the most primitive darters, and they have retained a small swim bladder and generally swim above the stream bottom more so than other darters. The genus *Etheostoma* is the largest genus of North American fishes. In the Alapaha, the brown darter (*Percina*) and the blackbanded darter (*Etheostoma*) are likely inhabitants that would be associated with certain flow/velocity preferences (Figure 4-40).



Notemigonus crysoleucas

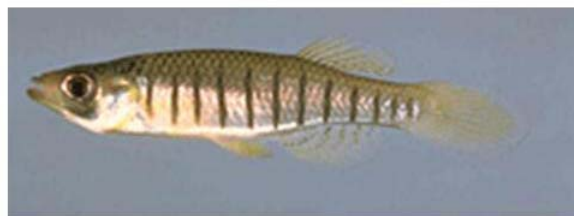


Notropis hypselopterus

Figure 4-38. Photographs of two species of Cyprinids, *Notemigonus crysoleucas* (Golden shiner) and *Notropis hypselopterus* (Sailfin shiner).



Fundulus seminolis



Fundulus lineolatus

Figure 4-39. Photographs of two representative species of Fundulids, *Fundulus seminolis* (Seminole killifish) and *Fundulus lineolatus* (line topminnow).

Being able to occupy a riffle habitat has certain advantages for darters, including affording some protection against terrestrial predators, as well as having access to an often under-exploited food supply. Riffles provide a degree of camouflage from the surface, making the fish less visible to predators. Additionally, insects often lay eggs near rocks or logs which are often associated with riffles. Darters are able to inhabit and feed on these eggs, whereas other fish may not be able to maintain position in the riffle long enough to feed.



Etheostoma edwini



Percina nigrofasciata

Figure 4-40. Photographs of two darter species in the Suwannee drainage, *Etheostoma edwini* (brown darter) and *Percina nigrofasciata* (blackbanded darter).

Family Centrarchidae

Centrarchids, which include sunfish and basses, generally prefer slow moving or sluggish waters and are common inhabitants of lakes and reservoirs. In riverine environments, centrarchids can often be found near pools or areas with aquatic vegetation, stumps, logs, etc. Changes in water level can affect spawning, specifically rapid drops in water level can cause spawning failure. Habitat suitability curves were initially developed for a number of sunfish species to address concerns over river impoundments and the possible rapid change in water level associated with the establishment of dams and water releases from the dams. However, because these species prefer slow moving waters, they are not considered to be the best taxa for use in the development of MFLs in this system.

One exception is the Suwannee Bass (*Micropetus notius*), which is listed by the State of Florida as a Species of Special Concern (Bass et al., 2004) (Figure 4-41). The main prey item of the Suwannee Bass is the crayfish *Procambrus spiculifer*, which has specific velocity requirements. The Suwannee bass is confined to flowing water environments and is native to the Suwannee and Ochlockonee River drainages (Gilbert, 1978; Hurst et al. 1975, Stevenson, 1976). The species has historically been uncommon on the Ochlockonee system, while the largest populations are reported in the Santa Fe River (Bass, 1974; Bass and Hitt, 1973). The Suwannee bass was also introduced, presumably by anglers, to the St. Marks River System where it appears they have successfully colonized the area and are abundant. The species was collected from the Suwannee, Santa Fe, St. Marks and Ochlockonee River systems by the Florida Imperiled Fish Species Investigation (Bass et al., 2004). The summation provided by the Imperiled Fish Species Investigation stated that although the Suwannee bass do not appear to be presently threatened, they should remain a Species of Special Concern on the Florida Fish and Wildlife Conservation Commission Register. Water quality conditions in the Santa Fe and Suwannee Rivers was cited as a cause for continued monitoring of the Suwannee bass population stability in the area (Bass et al., 2004).



Micropterus notius



Procambrus spiculifer

Figure 4-41. Drawing of *Micropterus notius* (Suwannee Bass) and it's prey species, the crayfish *Procambrus spiculifer*.

Family Ictaluridae

The catfish family is the largest family of freshwater fish endemic to North America. Catfishes are generally warmwater fish that are more tolerant of low dissolved oxygen conditions than most other groups of fish. They have sensory barbels which enable them to feed on insects, crustaceans and other fish at night or during the day in turbid waters. Because of their tolerance for low oxygen and low light conditions, catfish are generally bottomfeeders. While bullhead catfish and other larger species of catfish are commonly caught by anglers, other members of the family, smaller in size are seldom observed (i.e., madtoms). Channel catfish are very common and the species most typically farm raised. They prefer cooler, deeper, cleaner water than bullhead catfish (Figure 4-42).



Ictalurus punctatus

Figure 4-42. Photograph of *Ictalurus punctatus* (channel catfish).

APPENDIX 4-1

APPENDIX 4-1

SANTA FE RIVER SURVEYS: Observations of Blalock-Herod and Williams 2001

“Santa Fe River at Co. Rt. 1475, Alachua Co., Florida (SF 1475), was a run site with a shallow, narrow channel. Sediments consisted of claypan with gravel, sand, and silt and large deposits of shredded detritus. Land use was dominated by rural development. This was a historical site for *Pleurobema pyriforme* and *Quincuncina kleiniana*, however, these species were not detected during this survey. Two other unionid species, *Elliptio icterina* complex and *Uniomerus carolinianus*, were detected.

Santa Fe River at Co. Rt. 235, Alachua Co., Florida (SF 235), was a run site with a pool area. Sediments consisted of sand and some silt with areas of emergent aquatic vegetation. Land use was rural development and recreation. This was a historical site for *Medionidus walkeri*, *Pleurobema pyriforme*, and *Quincuncina kleiniana*. No *M. walkeri*, *P. pyriforme*, and *Q. kleiniana* were detected at this site; however, three other species, *Elliptio icterina* complex, *Toxolasma paulus*, and *Villosa vibex*, were located.

Santa Fe River at FL Hwy 121, Alachua Co., Florida (SF 121), was a run site that was too deep and swift to sample when we visited the site. Land use was dominated by rural development with extensive harvesting of trees for road/bridge/recreation improvements. This site was a historical site for *Medionidus walkeri*, *Pleurobema pyriforme*, and *Quincuncina kleiniana*. This site was visited 11 June 2001 during low water to demonstrate unionid collection techniques to state and federal government employees. Indiscriminate searches (not timed) were conducted. *Elliptio icterina* complex, *P. pyriforme*, *Q. kleiniana*, and *Villosa vibex*, were detected. This site should be revisited during low water conditions to determine relative species abundance, CPUE, or densities of the unionid species.

Santa Fe River at FL Hwy 241, Alachua Co., Florida (SF 241), was a run reduced to a series of isolated pools with long stretches of sandy river bottom exposed due to early spring 2001 droughts. The stream substrate was mostly coarse sand. However, the pools consisted of layers of detritus and silt over coarse sand. Land use was rural homes and silviculture. This was a historical site for *Medionidus walkeri*, *Pleurobema pyriforme*, and *Quincuncina kleiniana*. Live freshwater mussels of six species, *Elliptio icterina* complex, *Lampsilis straminea*, *Q. kleiniana*, *Toxolasma paulus*, *Villosa lienosa*, and *V. vibex*, were collected from isolated pools. Recent dry shell material was located along the banks of the exposed sandy reaches and in the pools.

Santa Fe River at O'Leno State Park, Columbia Co., Florida (SF OSP), was a riffle/run area with land use dominated by recreation in O'Leno State Park. This site was sampled 7 July 1999 (Blalock-Herod *et al.*, 1999). Sampling was limited to the shallow, sandy areas between the boulders and rubble, below the swim area and upstream only on the banks and the shallow areas around the aquatic vegetation. This was a historical site for *Medionidus walkeri* and *Pleurobema pyriforme*, however, these species were not located in 1999. Three unionid species were detected: *Elliptio icterina* complex, *Toxolasma paulus*, and *Villosa vibex*.

New River on Co. Rt. 229, Union Co., Florida (NR 229), was a new site characterized by a narrow stream area, which had very little habitat available. Substrate was mostly coarse, unconsolidated sand. Land use was natural and the riparian zone was intact.

Downstream of the bridge, one *Villosa vibex* was located in a mix of sand and sandy mud in a backwater eddy. One shell of *Elliptio icterina* was located upstream of the bridge. The majority of the site was run, with some riffle (due to logs) and a couple of backwater areas.

New River on Co. Rt. 100, Union Co., Florida (NR 100), was a historical site for *Pleurobema pyriforme* and *Quincuncina kleiniana*. Sampling was conducted in the relatively shallow area upstream of the bridge. Sediments were coarse sand with sandy mud near the banks. Land use was rural homes and silviculture, with some riparian zone intact. Three *Q. kleiniana* and one *P. pyriforme* were detected on the sampling date. Three other species, *Elliptio icterina* complex, *Lampsilis straminea*, and *Toxolasma paulus*, were located at this site.

New River on Co. Rt. 18, Union Co., Florida (NR 18), was a historical site for *Medionidus walkeri*, *Pleurobema pyriforme*, and *Quincuncina kleiniana*. This site consisted of mostly run with some pool areas in the river bends. At low water the run was reduced to a series of isolated pools. In October of this study, the water was too high to effectively sample for unionids. However, in May 2001, *P. pyriforme* and *Q. kleiniana* (approximately 5 and 10 individuals, respectively) were detected after about 30–60 minutes of search time, in an area located just downstream of the Co. Rt. 18 bridge. In an area just upstream of the bridge, densities of *P. pyriforme* and *Q. kleiniana* were reported as 0.03/m² and 0.09/m², respectively (Blalock-Herod, 2000). Other species located at this site included: *Elliptio icterina* complex, *Lampsilis straminea*, *Toxolasma paulus*, *Unio merus carolinianus*, *Villosa lienosa*, and *V. vibex*."

Table 1. Modified from Blaylock-Herod and Williams (2001): Catch per unit effort (CPUE) of unionid species by site within the Upper Santa Fe River, 1999-2001.

Species	SF 1475	SF 235	SF 121*	SF 241	SF OSP	SF 441	SF 27	SF 02	NR 229	NR 100	NR 18*	SR SC
<i>Elliptio icterina complex</i>	11.0	4.0	X	5.0	X	145.5	6.3	35.5	---	9.0	X	3.0
<i>Lampsilis straminea</i>	--	---	---	0.5	---	---	---	---	---	1.5	X	---
<i>Lampsilis teres</i>	---	---	---	---	---	---	---	---	---	---	---	---
<i>Medionidus walkeri</i>	---	---	---	---	---	---	---	---	---	---	---	---
<i>Pleurobema pyriforme</i>	---	---	X	---	---	---	---	---	---	0.5	X	---
<i>Quincuncina kleiniana</i>	---	---	X	0.3	---	---	---	---	---	1.5	X	---
<i>Toxolasma paulus</i>	---	8.0	---	0.5	X	3.8	8.5	0.9	---	0.5	X	---
<i>Unio merus carolinianus</i>	2.0	---	---	---	---	2.5	---	0.9	---	---	X	---
<i>Utterbackia imbecillis</i>	---	---	---	---	---	---	---	---	---	---	---	---
<i>Utterbackia peninsularis</i>	---	---	---	---	---	---	---	---	---	---	---	---
<i>Villosa lienosa</i>	---	---	---	0.8	---	---	---	0.9	---	---	X	---
<i>Villosa vibex</i>	---	1.8	X	1.0	X	16.0	1.4	18.2	0.5	---	X	---
<i>Villosa villosa</i>	---	---	---	---	---	---	---	0.9	---	---	---	---

Key: SF 1475 = Santa Fe River at Co. Rt. 1475; SF 235 = Santa Fe River at FL Hwy 235; SF 121 = Santa Fe River at FL Hwy 121; SF 241 = Santa Fe River at FL Hwy 241; SF OSP = Santa Fe River at O'Leno State Park.

Summary of Historical Museum Records of *Medionidus walkeri*, *Pleurobema pyriforme*, and *Quadrula kleiniana* in the Santa Fe River Drainage Basin (Source: Williams 2004)

Menidioides walkeri

New River

EPK 389-14 (6) New River, FL Rt. 18 bridge, 6 mi. NW of Brooker, 1 mi. SE of Worthington, Bradford/Union counties, Florida. 30 August 1983.
FLMNH 28659 () New River, at Rt. 18 bridge, Bradford County, Florida. 22 March 1974.
FLMNH 135331 () New River, 1.2 km ESE of Worthington Springs, FL18 crossing, Union/Bradford counties, Florida. 7 August 1987.
RSB87-015 (2) New River at FL18 crossing, 1.2 km ESE of Worthington Springs, Bradford/Union counties, Florida. 7 August 1987.
RSB87-071 (1) New River, FL18 crossing, 1.2 km ESE of Worthington Springs, 4.4 km S of Dukes, Bradford/Union counties, Florida. 12 December 1987.

Santa Fe River

FLMNH 4152 () Santa Fe River, at bridge, NW of High Springs, Alachua County, Florida. 25 August 1933.
FLMNH 4133 () Santa Fe River, at sink, Alachua County, Florida. 29 April 1934.
FLMNH 4159 () Santa Fe River, sink, E of High Springs, Alachua County, Florida. 12 May 1934.
FLMNH 4160 () Santa Fe River, sink, E of High Springs, Alachua County, Florida. 29 April 1934.
FLMNH 8397 () Santa Fe River, sink, E of High Springs, Alachua County, Florida. 29 April 1934.
FLMNH 4140 () Santa Fe River, at bridge, N of Bland, [north of Alachua on highway 241,] Alachua County, Florida. 28 April 1934.
FLMNH 66219 () Santa Fe River, East Fork, Worthington Springs, Union[/Alachua] County [counties], Florida. 8 October 1916.
FLMNH 133933 () Santa Fe River, Worthington Springs, Alachua[/Union] County [counties], Florida. 8 May 1948.
FMNH 89898 (2), Santa Fe River at Worthington Springs, Alachua[/Union] County [counties], Florida.
FLMNH 229356 () [Santa Fe River,] Worthington Springs, Union[/Alachua] County [counties], Florida. No date.
FLMNH 4137 () Santa Fe River, Worthington Spring, Union[/Alachua] County [counties], Florida. 26 May 1932.
FLMNH 4155 () Santa Fe River, Worthington Springs, Alachua[/Union] County [counties], Florida. 5 April 1934.
MCZ 104028 (2), Santa Fe River, Worthington Springs, [Alachua/Union counties], Florida. 8 October 1916.
UMMZ 59249 (1) Santa Fe River, Worthington Springs, [Alachua/Union counties], Florida. No date.
FLMNH 38488 () Santa Fe River, at Rt. 235, Brooker, Bradford[/Union] County [counties], Florida. 4 May 1974.

Quadrula kleiniana

New River

EPK 389-15 (2) New River, FL Rt. 18 bridge, 6 mi. NW of Brooker, 1 mi. SE of Worthington, Bradford County, Florida. 30 August 1983.
FLMNH 3998 (3) New River, bridge SE of Lake Butler, Union County, Florida. 25 December 1931.
FLMNH 4002 (13) New River, 5 mi. NE of Worthington Springs, Union County, Florida. 29 May 1932.
FLMNH 47116 (1) New River, Rt. 100, 4 mi. ESE of Lake Butler, Union County, Florida. 1 April 1974.
FLMNH 28665 (25) New River, Rt. 18 bridge, Bradford County, Florida. 22 March 1974.
FLMNH 244001 (9) New River, N of Rt. 100 bridge, 15 mi. W of Starke, Bradford County, Florida. 3 June 1989.
INHS 17820 (2) New River, 1 mi. SE of Worthington Springs below Rt. 18 bridge, Bradford County, Florida. 23 November 1988.
RSB87-071 (7) New River, FL18 crossing, 1.2 km ESE of Worthington Springs, 4.4 km S of Dukes, Bradford County, Florida. 12 December 1987.
RSB88-066 (1) New River, FL231 crossing, 7.6 km ENE of Worthington Springs, 6.5 km N of Brooker, Bradford County, Florida. 28 June 1988.
RSB87-014 (1 valve) New River at FL231 crossing, 7.6 km ENE of Worthington Springs, Bradford County, Florida. 7 August 1987.
RSB87-015 (4) New River at FL18 crossing, 1.2 km ESE of Worthington Springs, Bradford County, Florida. 7 August 1987.
UMMZ 172511 (3) New River, 0.6 mi. SE of Worthington Springs, Union County, Florida. No date.

Sampson Creek

FLMNH 38496 (11) Sampson Creek, Rt. 227 near Graham, Bradford County, Florida. 22 March 1974.

Santa Fe River

FLMNH 1556 (18) Santa Fe River, Worthington Springs, Alachua County, Florida. 8 October 1916.
ANSP 48101 (4), East Fork Santa Fe River, Washington [Worthington] Springs, [Union County,] Florida. No date.
FLMNH 3999 (34) Santa Fe River, Worthington Springs, Union County, Florida. 8 October 1916.
FLMNH 4001 (13) Santa Fe River, bridge N of Bland, Alachua County, Florida. 28 April 1934.
FLMNH 4003 (1) Santa Fe River, ford NW of Louise, Alachua County, Florida. 6 April 1934.
FLMNH 4006 (7) Santa Fe River, Worthington Springs, Union County, Florida. 26 May 1932.
FLMNH 4008 (11) Santa Fe River, Worthington Springs, Union County, Florida. 5 April 1934.
FLMNH 4010 (2) Santa Fe River, bridge near New Hope Church, Alachua County, Florida. 7 April 1934.
FLMNH 4011 (1) Santa Fe River, Sampson Creek junction NW of Louise, Alachua County, Florida. 6 April 1934.

FLMNH 4012 (3) Santa Fe River, sink E of High Springs, Alachua County, Florida. 12 May 1934.

FLMNH 4014 (1) Santa Fe River, Alachua County, Florida. 1 June 1927.

FLMNH 4013 (2) Santa Fe River, sink E of High Springs, Alachua County, Florida. 29 April 1934.

FLMNH 20741 (8) Santa Fe River, Worthington Springs, Alachua County, Florida. 27 November 1948.

FLMNH 27820 (1) Santa Fe River, ca. 0.7-1.0 mi. upstream of confluence of Olustee Creek, Alachua County, Florida. 22 July 1980.

FLMNH 27826 (8) Santa Fe River, ca. 0.4-0.5 mi. upstream of confluence of Olustee Creek, Alachua County, Florida. 22 July 1980.

FLMNH 38484 (8) Santa Fe River, Rt. 235, Brooker, Bradford County, Florida. 4 May 1974.

FLMNH 47085 (6) Santa Fe River, Rt. 18, 1 mi. S of Worthington Springs, Alachua County, Florida. 22 March 1974.

FLMNH 67942 (18) Santa Fe River, Worthington Springs, [Alachua County,] Florida. 10 October 1916.

FLMNH 127512 (7) Santa Fe River, Worthington Springs, Alachua County, Florida. 29 July 1988.

FLMNH 134944 (1) Santa Fe River, Worthington Springs, Alachua County, Florida. 8 October 1916.

FLMNH uncat. (2) Santa Fe River, Vinzant Landing, O'Leno State Park, Columbia County, Florida. 17 January 2000.

FMNH 68308 (4) Santa Fe River, Worthington Springs, [Alachua County,] Florida. No date.

FMNH 89912 (2) Santa Fe River at Worthington Springs, Alachua County, Florida. No date.

INHS 23121 (1) Santa Fe River, Worthington Springs, Union County, Florida. No date.

MCZ 93364 (3) Santa Fe River, Worthington Springs, [Alachua County,] Florida. No date.

MCZ 104081 (2) Santa Fe River, Worthington Springs, [Alachua County,] Florida. 1 October 1916.

MCZ 189629 (11 + 1 valve) Santa Fe River, Worthington Springs, [Alachua County,] Florida. 8 October 1916.

RSB87-007 (1) Santa Fe River, FL241 crossing, 7.7 km W of Worthington Springs, Alachua County, Florida. 24 June 1987.

UMMZ 54129 (12) Santa Fe River, Washington [Worthington] Springs, [Alachua County,] Florida. No date.

UMMZ 59251 (1) Santa Fe River, Worthington Springs, [Alachua County,] Florida. No date.

UMMZ 77042 (9) East Fork of Santa Fe River, Washington [Worthington] Springs, Union County, Florida. 8 October 1916.

UMMZ 183817 (9) Santa Fe River, Worthington Springs, Alachua County, Florida. 8 May 1948.

UMMZ 183818 (4) Santa Fe River, Worthington Springs, Alachua County, Florida. 26 August 1948.

UMMZ 246868 (3) Santa Fe River at Worthington Springs, Alachua County, Florida. 13 November 1948.

TAB 5

5.0 Ecological Basis for a Minimum Flow for the Upper Santa Fe River

A minimum flow that protects essential habitats of the Upper Santa Fe River system from significant risk should be based upon the following criteria:

- The maintenance and protection of essential fish foraging habitat, including snag habitat and habitat suitable for the crayfish *Procambarus spiculfer*; and
- The maintenance and protection of suitable habitat for freshwater mussels, including the threatened and endangered species that occur or have occurred in the New River basin (Blalock-Herod 2000) and the putative host species for their parasitic developmental stages (cf. Bigham 2002).

The available physical habitat for biological organisms in streams generally consists of the interaction of stream depth and velocity (Bovee *et al.* 1998), each of which is related to flow. Substrate and cover characteristics are additional parameters that affect habitat suitability, although depth and velocity are the primary determinants (Bovee *et al.* 1998). The focus on physical habitat characteristics is based on the lack of a direct relationship between factors such as water quality (e.g., dissolved oxygen) and stream flow (Figure 4-6 through 4-8). While water quality is an important water resource value, in this portion of the Upper Santa Fe, there is no significant relationship between dissolved oxygen and flows under the low flow regime.

With respect to establishing an MFL for the Upper Santa Fe River system, a 15% increased risk of reduced habitat availability was defined *a priori* as significant harm to the River. This criterion is consistent with guidelines applied elsewhere in Florida (cf. Gore *et al.* 2002; SWFWMD, 2002 and 2004) and previous peer reviewed MFLs established elsewhere in the State.

5.1 Methods

The establishment of MFLs for the Upper Santa Fe River relies on the “weight-of-evidence” approach based on using the following three methods:

- Wetted Perimeter;
- Ecosystem Functions Model (EFM); and
- Fish Passage.

Additionally, due to the available hydrologic data on the Upper Santa Fe River, the river was divided into two segments and a separate MFL recommendation will be made for each segment. The upstream segment extends from the headwaters to just above the Worthington Springs gage, and is driven by flow at the Graham gage (Figure 5-1). The downstream segment begins at Worthington Springs and extends to just upstream of the confluence with Olustee Creek, and relies on flow data from the Worthington Springs gage. Each segment will be analyzed separately, using identical methods, and receive a separate MFL recommendation. This was done because the confluence of the New River, a significant contributor to flow, with the Santa Fe naturally forms a dividing point (near the Worthington Springs gage) making it undesirable to use any one gage for the whole length of the Upper Santa Fe River (Figure 5-1).

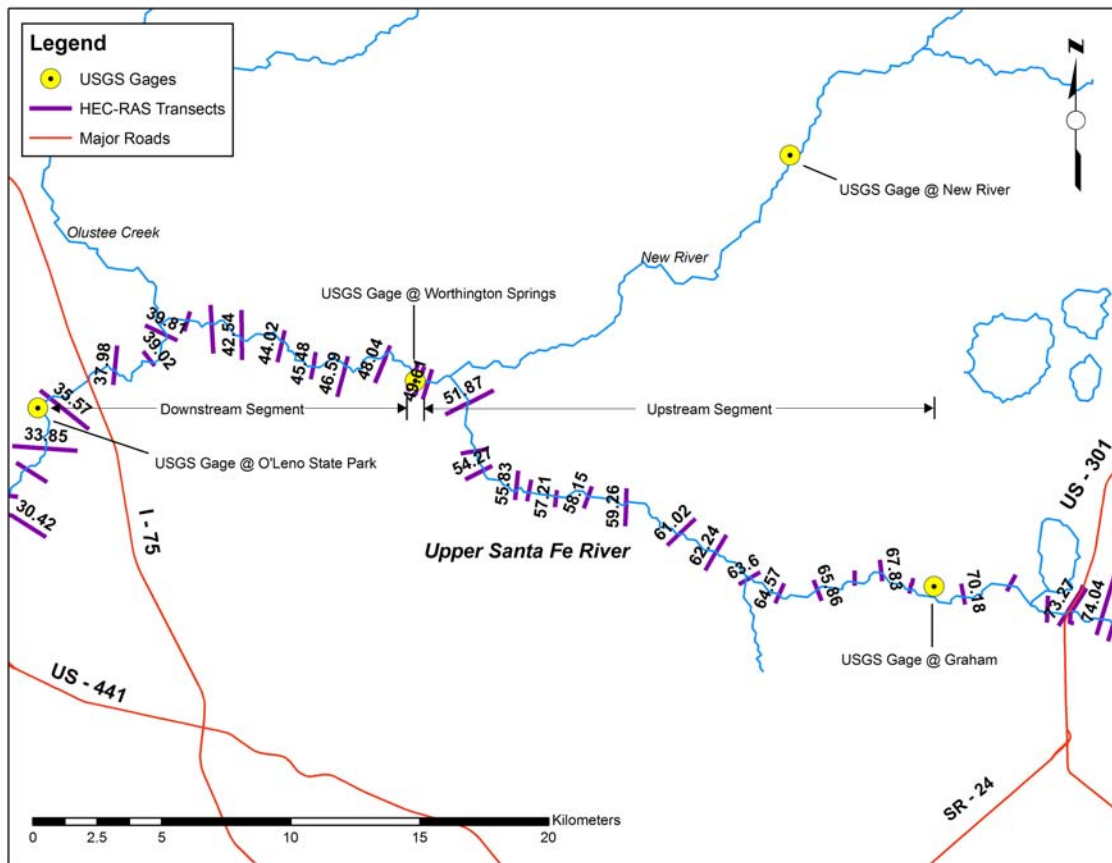


Figure 5-1. Location of HEC-RAS transects in the Upper Santa Fe River.

5.1.1 Wetted Perimeter

Wetted perimeter is used as an estimate of the amount of habitat available to aquatic organisms under different flow conditions. Generally, greater extents of wetted perimeter in a stream or river are associated with increased habitat availability for fish and macroinvertebrates. The wetted perimeter of a stream transect is the linear extent to which water in the stream is in contact with its channel bed (Parker and Armstrong. 2002). As such, changes in wetted perimeter represent how alterations in stream flow affect the morphometry of the stream (Parker and Armstrong, 2002). For example, given two reaches of a stream of equal depth but different channel widths, the wetted perimeter in the reach with the narrower channel will be more responsive to changes in flow than the reach with the wider channel (Parker and Armstrong. 2002; Water and Rivers Commission 2003).

In theory, as the flow regime changes there should be a stream flow at which wetted perimeter increases dramatically (i.e., an inflection point) (Parker and Armstrong. 2002; Water and Rivers Commission 2003; cf. Figure 5-2). This inflection point or threshold demarcates a “critical” minimum flow, for in-channel flow regimes (Gippel and Stewardson 1998; Parker and Armstrong. 2002). In practice, such inflection points are not always clearly defined or there can be multiple inflection points (Parker and Armstrong. 2002). The identification of the critical flow can be subjective, although there are more rigorous mathematical solutions to identify the inflection point (Gippel and Stewardson 1998). Expert knowledge of the system is often used to identify the most meaningful inflection point.

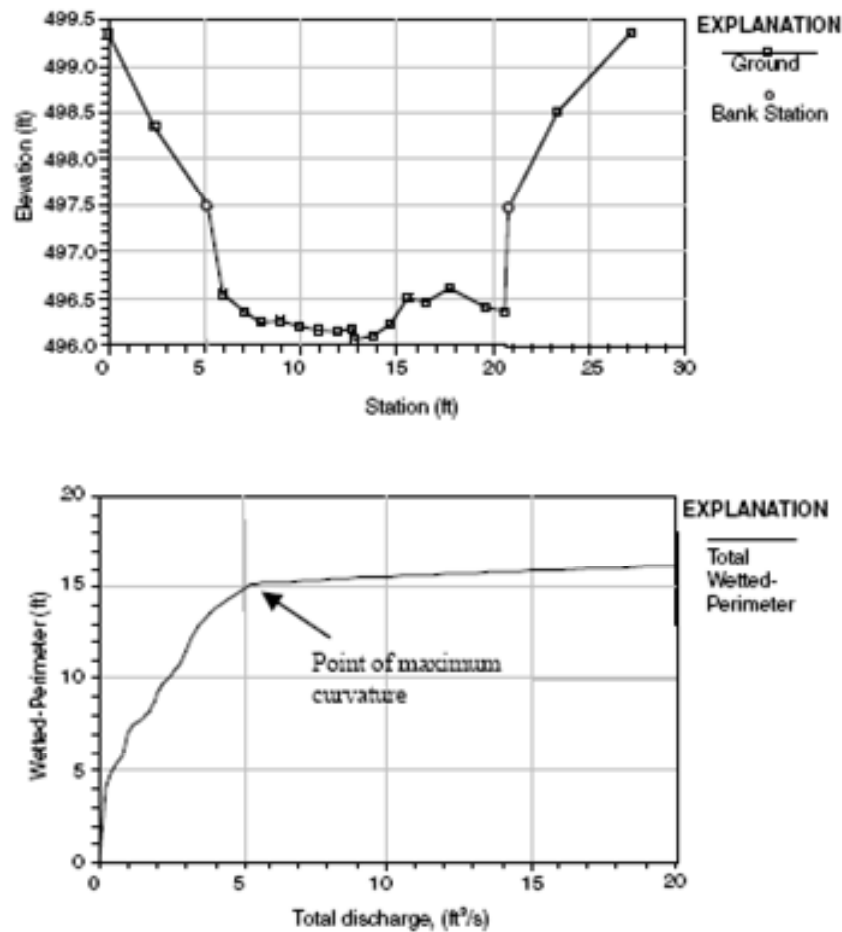


Figure 5-2. Examples of a stream cross-section (top) and the relationship between stream flow and wetted perimeter (Source: Parker and Armstrong 2002).

The wetted perimeter technique has been used, in conjunction with other methods, to establish MFLs in rivers of the Southwest Florida Water Management District (SWFWMD) including the Alafia (SWFWMD, 2004), Myakka (Kelly *et al.* 2005) and Peace Rivers (SWFWMD, 2002). Wetted perimeter has also been used to evaluate fisheries habitat in the western United States (Swift 1976; Moratz and Staley 1986; Leath 1989) and has been applied in concert with other methods to estimate available habitat in Australian rivers (Tunbridge, 1988; Tunbridge and Glenane, 1988; Anderson and Morison, 1989). The application of this technique requires the assumption that wetted perimeter is a valid measure of available habitat for fish and macroinvertebrates (Annear and Conder 1984; Arthington and Zalucki 1998). For the establishment of a MFL, wetted perimeter was calculated with data produced by the HEC-RAS model of the Santa Fe River as discussed in Section 3.5 (Figure 5-1).

5.1.2 Instream Flow Methods

There are two primary methods for addressing instream habitat conditions and flow requirements. These methods, Physical Habitat Simulation (PHABSIM) and Ecosystem Functions Model (EFM), are equally applicable to the Upper Santa Fe, but each has strengths and weaknesses. PHABSIM has been widely utilized in Florida, but it requires specific knowledge of flow and habitat relationships. EFM is an emerging method that relies on the HEC-RAS flow model and, therefore, requires less transect specific flow data.

5.1.2.1 Instream Flow Method Selection

Bovee *et al.* (1998) describe an incremental, multi-faceted process for evaluating the instream flow requirements of lotic organisms, particularly fishes. This approach, titled Instream Flow Incremental Methodology (IFIM) considers hydraulic conditions, water quality, temperature regime, morphology and morphometry of the channel, as well as the physical microhabitat requirements of the biota in terms of depth, velocity, substrate and cover (Bovee *et al.* 1998). The microhabitat requirements for the biota are considered in the Physical Habitat Simulation (PHABSIM) module of IFIM (Bovee *et al.* 1998). This method was contrasted with the HEC-EFM in order to determine which of the two approaches was most appropriate for evaluation of the Upper Santa Fe MFL.

PHABSIM assumptions and limitations:

- Selected cross sections for analysis are representative of the entire stretch of the reach
- The surveyed range of flows are representative and captures the range in ecosystem functions and can be safely extrapolated to the entire range of observed flows
- PHABSIM hydraulic model assumes the flow is uniform (not true for pool and riffle ecosystem)
- PHABSIM can not evaluate fish passage
- PHABSIM is limited by the amount of transects which are evaluated; thus, a small number of transects drive the hydraulic portion of the model

PHABSIM (Bovee *et al.* 1998) was the method initially selected to provide the ecological component of the “weight-of-evidence” approach adopted for establishing MFLs in the District, due to its previous application in Florida rivers. However, for much of the spring and summer of 2005, the Upper Santa Fe River experienced above-average stream flows. Consequently, the Upper Santa Fe River never experienced a sufficient drop in stage after the high flow survey period to allow a mid-flow survey.

Consequently, it was determined by the WRA team, in conjunction with the District staff, that the PHABSIM method would be compromised if applied to the Upper Santa Fe River MFL methodology. In the case of the Upper Santa Fe River MFL, the Ecosystem Functions Model (EFM) was determined to be the best methodology available in consideration of the river characteristics and available information used to evaluate the flow regime of the river system.

5.1.2.2 Ecosystem Functions Model

The Ecosystem Functions Model (EFM) estimates how the river would respond when presented a given flow scenario and the system was or was not modified. This method was developed by the California Department of Water Resources, the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC (State of California Reclamation Board and US Army Corps of Engineers 2002; Hickey and Dunn 2004), and Jones and Stokes (1999 and 2000). EFM was originally conceived of as a tool to address flood control issues in the Sacramento and San Joaquin River Basins in California. Flood damage under high flows could be evaluated and the effects of structural modifications (e.g., levee construction) and restoration of affected riverine and riparian ecosystems could be modeled. EFM has also been applied to the Sustainable Rivers Project, a collaboration of the U.S. Army Corps of Engineers and The Nature Conservancy on the Savannah River system (Hickey and Warner, 2005).

EFM requires the following types of data to estimate ecological responses to flow alterations:

- A record of historical flows,
- Establishment of HEC-RAS transects (see Section 3),
- HEC-RAS calibration for the stream reach, and
- Water depth and velocity requirements of key biota for that river system.

The EFM approach differs from PHABSIM in that:

- Data from the many HEC-RAS transects are employed to represent the entire river reach rather than relying on data collected from just a few albeit specific mesohabitats;
- The historical flow regime is incorporated into the EFM, this includes historical high flows and low flows where as the PHABSIM approach is only calibrated for the flows collected during the field surveys, likely missing significant high and low flows;
- HEC-RAS is the hydraulic model employed in the EFM which is superior to the hydraulic component of PHABSIM, HEC-RAS is well accepted and well documented and capable withstanding litigation scrutiny;
- A greater number of transects are available for incorporation into the EFM through use of the HEC-RAS model;
- HEC-RAS can be calibrated to fully dynamic simulations capturing the full range of flows allowing sufficient comparisons between simulated and observed data; long term comparisons allow added confidence in the model's ability in reproducing hydraulic response; and
- The HEC-RAS hydraulic component simulates the entire stream reach allowing the EFM to represent the 'pool and riffle' habitat pervasively found in the Santa Fe River.

There are several steps in the Ecosystem Functions Model:

- 1) Ecological Analysis:** The ecological analysis identifies relationships between river hydrologic and hydraulic conditions and the river's ecosystem and geomorphic system. These relationships reflect requirements of different biota or habitat types in terms of flow conditions, based on frequency, season, and duration.

Ecological attributes of the river that can be modeled for their inter-relationships with the hydrologic and hydraulic characteristics include:

- Estimates of spawning habitat for fish; and

- Suitability of habitat (defined by depth and current velocity) for aquatic macroinvertebrate production.

Ecological relationships relevant to setting a MFL in the Upper Santa Fe River were identified after an extensive review of the available literature. Species or taxonomic groups that were considered to be sensitive to alterations in stream velocity and depth were of particular interest. These taxa included (Table 5-1):

- Aquatic insect larvae that prefer higher flows. Gore *et al.* (2001) developed Habitat Suitability Indices for three such taxonomic groups, the Ephemeroptera, Trichoptera, and Plecoptera;
- The crayfish, *Procambarus spiculifer*, has been identified as the primary prey for the Suwannee Bass (*Micropterus notius*) and as a secondary prey for Largemouth Bass (*Micropterus salmoides*) (Schramm and Maceina, 1986). Both fish species are recreationally important and the Suwannee Bass is a state listed Species of Special Concern;
- Many darters (Family Percidae) have a preference for riffle habitats (Lee *et al.* 1980; Etnier *et al.* 1993. Marcinek *et al.* 2003), including two species known to occur in the Suwannee River drainage: the brown darter (*Etheostoma edwini*) and the blackbanded darter (*Percina nigrofasciata*); and
- Additionally darters are host species for the parasitic lifestage of certain unionid mussels (Bigham 2002). Many unionids are threatened or endangered, including species known to occur or have occurred in the New River basin, a tributary to the Santa Fe River (Blalock-Herod 2000). By establishing a flow regime protective of darters it is possible that protection is also provided for habitat that can be colonized by unionids (Gore *et al.* 2001).

Table 5-1. Summary of velocity and depth preferences for taxa chosen for the Ecologic Analysis step of the Ecosystem Functions Model.

Taxa	Velocity (ft/sec)	Depth (feet)	Reference
Brown darter (<i>Etheostoma edwini</i>) and Blackbanded darter (<i>Percina nigrofasciata</i>)	0.98-2.34	0.33-4.27	Prime: Williams, 1981. Supplemental: Hughey, 2003; Page, 1983.
Crayfish (<i>Procambarus spiculifer</i>)	1.47-2.93	1-4	Schramm and Maceina, 1986
Ephemeroptera	0.33-1.08	1.64-2.33	Gore et al., 2001
Plecoptera	0.33-1.08	1.64-2.62	Gore et al., 2001
Trichoptera	0.33-1.08	1.64-3.12	Gore et al., 2001
Redear Sunfish (<i>Lepomis microlophus</i>)	0.03-0.33	0.33-3.94	Twomey, 1984

- 2) Statistical Hydrology Analysis:** This analysis translates the ecosystem relationships developed in the Ecological Analysis into discharges with specified frequencies, seasons, and durations. The statistical analysis uses historical and existing flow records as the basis for determining the critical flows that satisfy the habitat-defined requirements developed in the Ecological Analysis.

Upper Santa Fe River flows ranging from 0.5 to 10 cfs, in 0.5 cfs increments, were considered for the EFM. These flows represented the historical range of flows up to the 45th percentile, based upon the flow-duration curve at the USGS gage at Graham (USGS 02320700), and were used as HEC-RAS steady-state model inputs (Figure 5-3). These flows are not intended to represent an annual flow statistic, such as a one-day minimum flow, but rather a range of flows below the median to evaluate a low flow MFL.

Each of the target taxa (Table 5-1) for the EFM have a year-long requirement for the critical velocities and depths. Therefore, there was no seasonal adjustment for the determination of critical low flows. An annual frequency for each low flow event was an assumption for the application of EFM to the Upper Santa Fe River. The annual frequency for low flow events was dictated by the relatively short life-spans for species in the selected taxonomic groups, especially the macroinvertebrates. The selection of an annual frequency for low flow events ensures viable populations over the short-run as well as the survival of every year-class.

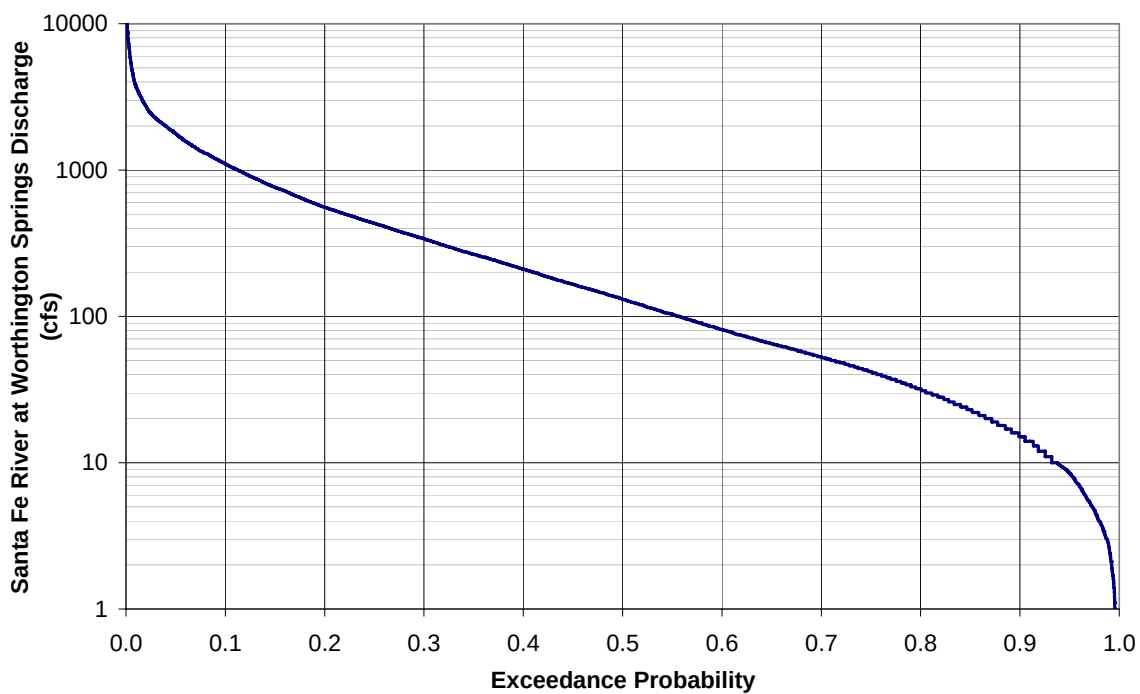
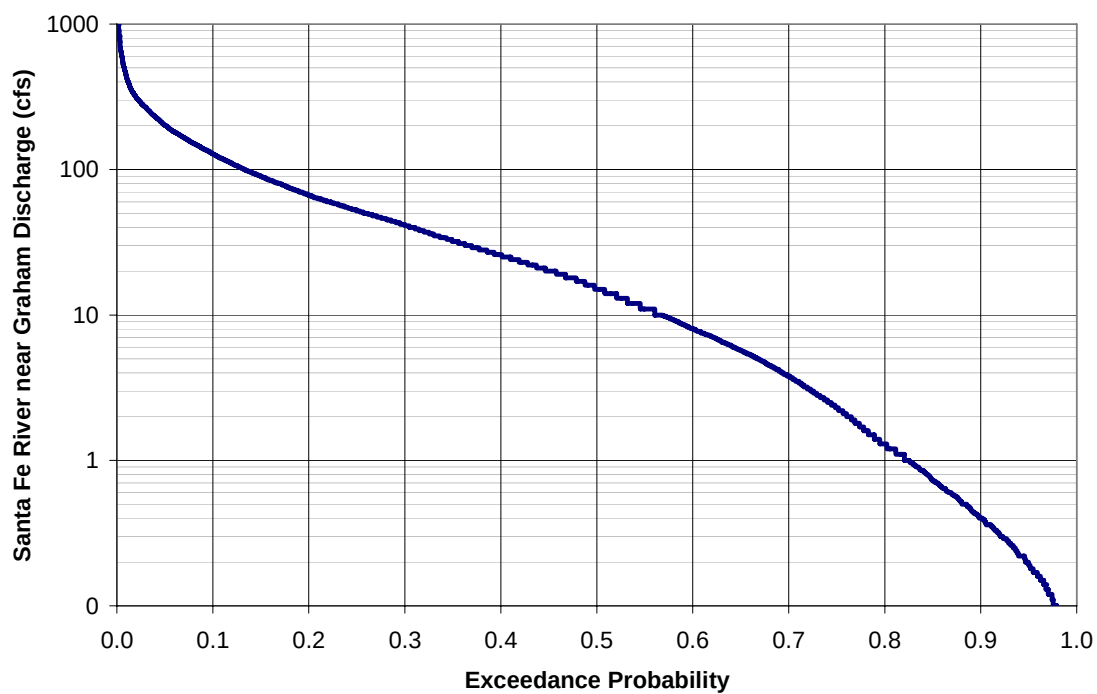


Figure 5-3. Flow-duration curve for the USGS Gage (02320700) at Graham (top) and the USGS Gage (02321500) at Worthington Springs (bottom).

3) Hydraulic Analysis: This analysis determines the hydraulic responses of discharges estimated in the previous step (i.e., Statistical Hydrology Analysis). The statistically determined discharges form the input to a hydraulic model for the calculation of corresponding stages and flood inundation areas. HEC-RAS, a hydraulic model developed by the Corps of Engineers (see Section 3.0), is used in its steady-state format to perform the hydraulic analyses at all transects (Figure 5-1) throughout the system.

Output from the model, at points along each of the transects, includes:

- Water surface elevation;
- Bed elevation;
- Velocity; and
- Wetted perimeter.

4) Ecological Interpretation: A conservative estimate of suitable habitat, as a function of flow, was determined through an analysis of depth and velocity at intervals along each transect. Depths were estimated from HEC-RAS model predictions of the difference between water surface elevations and bed elevations. Combinations of depth and velocity that satisfy both requirements for each species are deemed suitable habitats. Graphs are produced that depict the proportion of suitable habitat (vs. total available habitat) as a function of flow (0.5 to 10 cfs range). Graphical summaries were produced for flows up to the 45th percentile at a water depth of 2.0 feet, at each of four velocities (0.5, 1.0, 1.5, and 2.0 feet sec⁻¹). An example of the plots produced for the ecological interpretation is seen below in Figure 5-4.

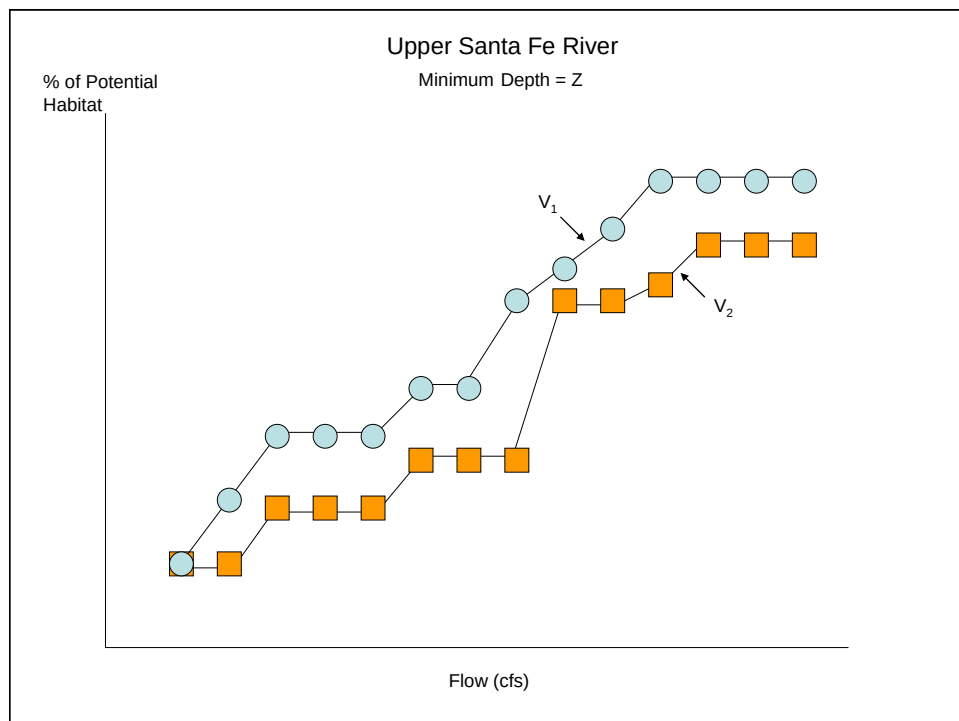


Figure 5-4. Ecosystem Functions Model sample output, for depth requirement, Z, and velocity requirements, V_1 and V_2 , where $V_1 < V_2$. Potential available habitat generally increases as a function of flow, with more potential habitat available when less conservative velocity criteria are used in the model.

The HEC-RAS model outputs depth and velocity at regular intervals along each transect. These estimates were organized into cells, which were then assessed for classification within the critical depth and velocity requirements for the key biota. Cells in which both depth and velocity are higher than the specified criteria become suitable habitat. Total available habitat is defined as the total number of cells in the transect at a given flow. The number of suitable habitat cells and the total number of cells for all transects within the reach are summed and a proportion of suitable cells is calculated.

5) Limits of Significant Risk

The MFL will be the flow that corresponds to a 15% reduction in available habitat at a depth of 2.0 feet. The adoption of a 15% reduction in habitat is consistent with the peer reviewed approach used by the Southwest Florida and St. Johns River Water Management Districts to determine the limit of significant risk to the available habitat (Gore *et al.* 2002; Southwest Florida Water Management District 2002 and 2004); Lower Suwannee River MFL, WRA 2005. The depth of the water column (2.0 feet) is protective of the requirements of the taxa of concern for the Upper Santa Fe River (Table 5-1). The minimum velocity adopted for the MFL was 0.5 feet sec⁻¹. This velocity is protective of the macroinvertebrate taxonomic groups of concern (Table 5-1). For the brown darter, a minimum velocity of 1.0 feet sec⁻¹ is required while for the crayfish, the 1.5 feet sec⁻¹ velocity criterion was employed.

5.1.3 Fish Passage

The term “fish passage” refers to the minimum water depth an organism requires to successfully navigate a stream channel. Guidelines for fish passage are typically based on body dimension measurements of several species of adult fish (Hupalo *et al.*, 1994). Few studies have actually documented minimum water depths required to maintain fish passage and it is unknown how many shallow obstructions can be navigated by fish before health and vitality are compromised (Hupalo *et al.*, 1994). Most studies on fish passage involve adult salmonoid fishes in cold water streams. Passage depths of between 0.6 and 0.8 feet were calculated for Chinook salmon and large trout, respectively (Thompson, 1972 as cited by Hupalo *et al.*, 1994). Minimum water depths of at least 0.6 feet have been applied previously in Florida (SWFWMD, 2002 and 2005).

Fish passage throughout the Upper Santa Fe River was assumed to require water depths of at least 0.6 feet at some point within the cross-section. The longitudinal connectivity that this minimum depth permits should be maintained throughout the river at a level that is consistent with its historical occurrence. The 0.6 foot criterion for fish passage was used for corroboration of the Ecosystem Functions Model-based MFL.

Each of the 0.5 cfs incremental flows from the USGS gage at Graham was used as inputs to the HEC-RAS steady-state channel model (see Section 3.5). Depths at each cross-section in the river were then modeled and a proportion of the two-dimensional river bed where depths were less than 0.6 feet were calculated.

5.2 Results

The establishment of an MFL for the Upper Santa Fe River was predicated on the need to:

- Maintain adequate physical habitat for production of macroinvertebrates with particular interest in the following taxa: Ephemeroptera, Trichoptera, Plecoptera, and the crayfish, *Procambarus spiculifer*, which is a preferred prey species of the Suwannee Bass and a secondary prey item for largemouth bass (Schramm and Maceina, 1986) in the Lower Santa Fe River;

- Maintain adequate physical habitat for those fish species that require higher velocities. Fish anticipated to require higher velocities were represented by the darters (Family Percidae). The protection of habitat for darters is also important because, as possible hosts for the glochidial larval stage, they may represent a critical path in the life stage of rare, threatened or endangered species of unionid mussels. Gore *et al.* (2001) have suggested that, because so little is known about the specific habitat requirements of all life stages of these mussels, that the protection of habitat needed to support the larval hosts may be more appropriate; and
- Ensure and maintain sufficient depth in the river to permit fish passage.

Three approaches were employed to determine the MFL:

- Wetted Perimeter
- Ecosystem Functions Model (EFM)
- Minimum Depth for Fish Passage

The results for the upper segment of the Upper Santa Fe River (Graham USGS gage to Worthington Springs) and the lower segment of the Upper Santa Fe River (Worthington to O'Leno State Park) are presented separately under the wetted perimeter and EFM methods. Results of the fish passage analyses are presented together.

5.2.1 Wetted Perimeter Results

5.2.1.1 Upper Segment (Graham to Worthington Springs)

Estimates of wetted perimeter were calculated for the HEC-RAS transects throughout the river (*cf.* Figure 5-1). At flows less than 2 cfs there is a distinct drop-off in wetted perimeter, as observed at the transects at river miles 49.48 and 51.87 (Figure 5-5). At flows above approximately 2 to 3 cfs there are less appreciable gains in wetted perimeter as flow increases, although wetted perimeter does still increase as a function of flow above the critical inflection point (Figure 5-5). The assumption is that it is of maximum benefit to the biota (*e.g.*, fish and their macroinvertebrate prey) to have a larger, rather than a smaller wetted perimeter. In order to determine with greater accuracy the prospective MFL for the Graham gage, an inflection point for each transect was estimated from visual inspection (Appendix 5-1). A simple median was then calculated from all of the transects' inflection points, which was determined to be 2.3 cfs. Therefore, flows of at least 2.3 cfs at the Graham gage are protective of the biota with respect to maximizing wetted perimeter.

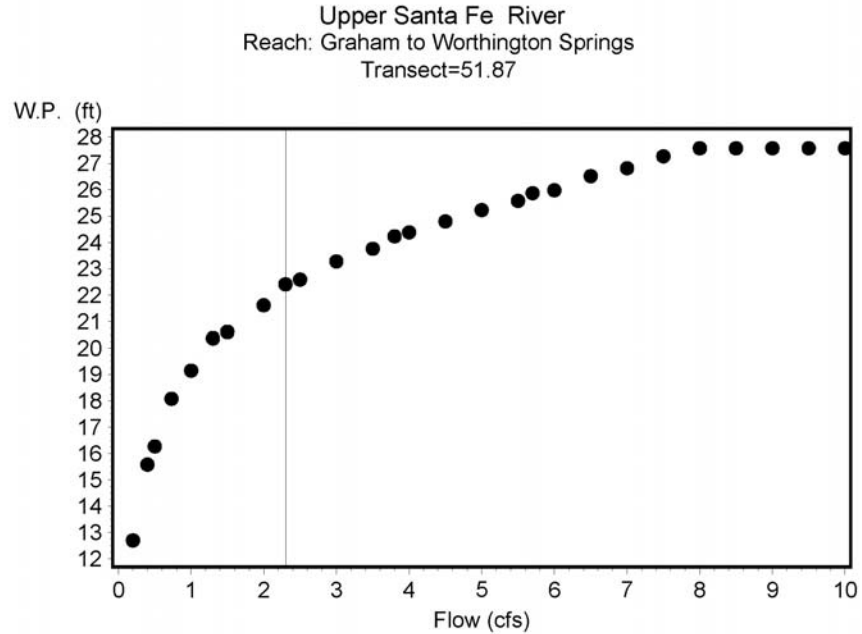
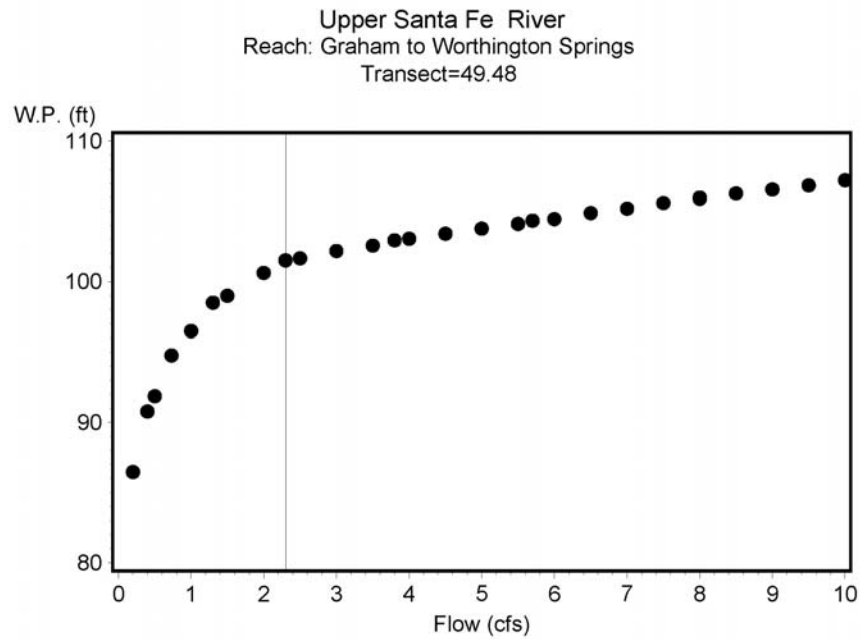


Figure 5-5. Plots of wetted perimeter vs. flow at river miles 49.48 and 51.87 in the upstream segment of the Upper Santa Fe River.

5.2.1.2 Lower Segment (Worthington Springs to Olustee Creek)

Estimates of wetted perimeter as a function of flow were calculated for the HEC-RAS transects throughout the river below the Worthington Springs gage. An analysis of each transect below Worthington Springs yields a variety of inflection points. In order to determine with greater accuracy the prospective MFL for the Worthington gage, an inflection point for each transect was estimated from visual inspection (Appendix 5-1). A simple median was then calculated from all of the transects' inflection points, which was determined to be 42 cfs. Note that the inflection points observed at the transects at river miles 42.54 and 45.48 demonstrate that at flows less than 42 cfs there is a distinct drop-off in wetted perimeter (Figure 5-6). For flows greater than 42 cfs, wetted perimeter does still increase as a function of flow, albeit at a lesser rate than for those flows below the critical inflection point. Therefore, flows of at least 42 cfs at the Worthington gage are protective of the biota with respect to maximizing wetted perimeter. Each of the wetted perimeter plots of the transects from the HEC-RAS model, in both reaches, are shown in Appendix A.

5.2.2 EFM Results

5.2.2.1 Upper Segment (Graham to Worthington Springs)

The Ecosystem Functions Model results indicated that the MFL for the upstream segment of the Upper Santa Fe River ranges between 2 and 3 cfs (Figure 5-7). Figure 5-7 shows that there is a marked downwards inflection in available habitat at a depth of 2 feet as flows decline from 3 cfs to 2 cfs. At flows above 3 cfs, and below 2 cfs, there is a plateau in available habitat. At flows ranging from 3 to 2 cfs, there is an increased risk of losing up to 15% of available habitat.

The results from the Ecosystem Functions Model indicate that a flow in the 2 to 3 cfs range is protective of habitats preferred by the target biota for the Upper Santa Fe River. This includes macroinvertebrates that are primary prey for riverine fishes, as well as fishes that may serve as hosts for mussel larvae (i.e., velocities >0.5 feet second⁻¹ and depths of at least two feet (cf. Table 5-2)). For these specified depths and velocities, a flow of 3 cfs is protective of ~48% of the total available habitat, while a flow of 2 cfs is protective of ~41% of the total available habitat. This potential decrease represents an approximate 15% loss of total available habitat. This range also brackets, and thus agrees with, the wetted perimeter results.

5.2.2.2 Lower Segment (Worthington Springs to Olustee Creek)

The Ecosystem Functions Model results indicated that the MFL for this segment of the Upper Santa Fe River ranges between 42 and 50 cfs (Figure 5-8). Consistently, and regardless of the minimum depth used to determine potential habitat, a clearly delineated inflection point is observed at this flow range. Figure 5-8 shows that there is a marked downwards inflection in available habitat at all depths as flows decline from 50 cfs to 42 cfs. At flows above 50 cfs, available habitat remains relatively static, even as flows continue to increase. Note that at flows below 42 cfs, the downward trend in available habitat continues. However, the wetted perimeter results were used to define the lower bound for potential EFM results. Thus, at flows ranging from 50 to 42 cfs, there is an increased risk of losing up to 7% of available habitat.

The results from the Ecosystem Functions Model indicate that a flow of at least 42 cfs is protective of habitats preferred by the target biota for the Upper Santa Fe River. This includes macroinvertebrates that are primary prey for riverine fishes, as well as fishes that may serve as hosts for mussel larvae (i.e., velocities >0.5 feet second⁻¹ and depths of at least two feet (cf. Table 5-2)). For these specified depths and velocities, a flow of 50 cfs is protective of ~76% of the total available habitat, while a flow of 42 cfs is protective of ~71% of the total available habitat. This potential decrease represents an approximate 7% loss of total available habitat.

5.2.3 Minimum Fish Passage Results

With respect to fish passage, transects 69.22 and 69.45 are shown in Figure 5-9. These transects were chosen because they are hydraulic control points and they represent the most restrictive transects, with respect to depth, in the system. Each transect maintains a depth greater than or equal to 0.6 ft at some portion of the river channel along the cross section when flows are greater than 2 cfs. The 0.6 ft passage criteria has been used previously by the Suwannee River Water Management District and other districts and it represents a peer reviewed value for acceptable fresh water fish passage in the determination of MFLs. At transect 69.22, only 12-32% of the cross section exhibits depths below 0.6 ft when flows between 2.5-6 cfs are maintained (i.e. between 68-88% of the cross section maintains adequate depths when flows between 2.5-6 cfs are maintained). When flows drop below 2 cfs, 100% of the cross section exhibits inadequate depth for fish passage. When flows are above 6 cfs, approximately 10% of the cross section exhibits inadequate depths (i.e., meaning 90% of the cross section has adequate depth for fish passage). At transect 69.45, when flows are between 2-4 cfs, between 22-30% of the cross section has inadequate depths (i.e., meaning between 70-78% of the cross section maintains adequate depths at flows between 2-4 cfs). When flows drop below 2 cfs at this transect, 100% of the cross section experiences depths inadequate for fish passage.

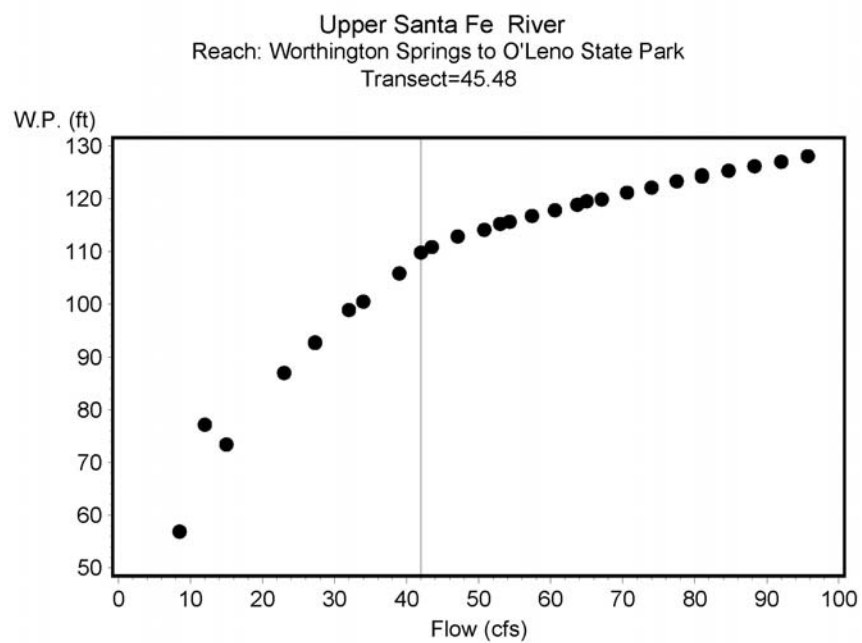
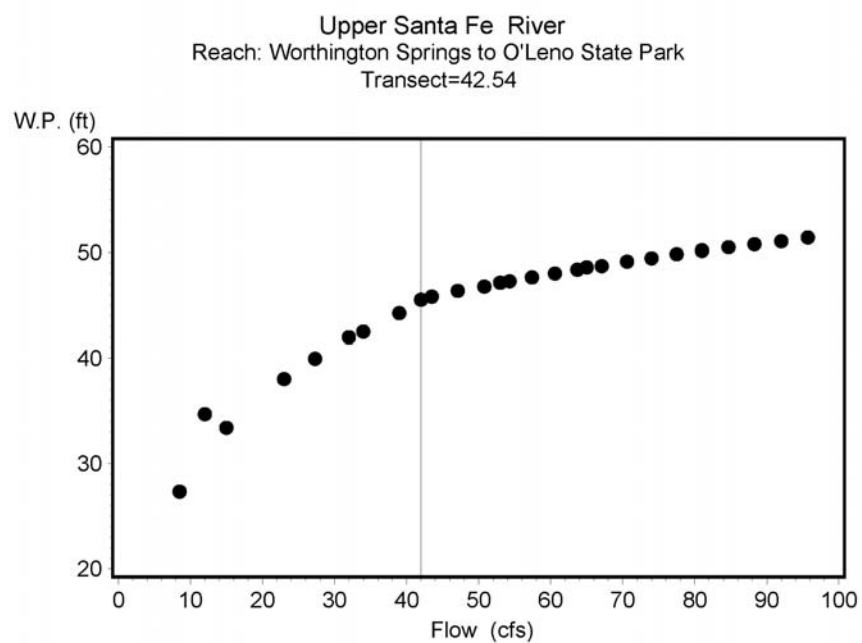


Figure 5-6. Plots of wetted perimeter vs. flow at river miles 42.54 and 45.48 in the downstream segment of the Upper Santa Fe River.

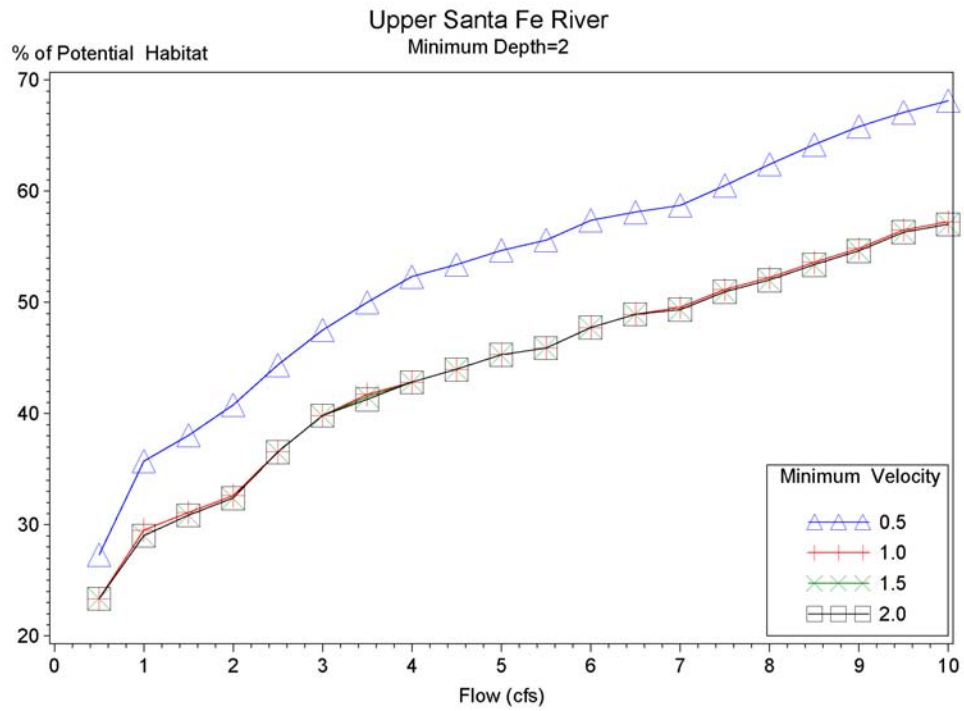


Figure 5-7. Summary of Ecosystem Functions Model results for the upstream segment of the Upper Santa Fe River protective of a 2.0 foot water depth and stream velocities of 0.5 to 2.0 feet sec^{-1} at the flows up to the 45th percentile of the USGS gage at Graham.

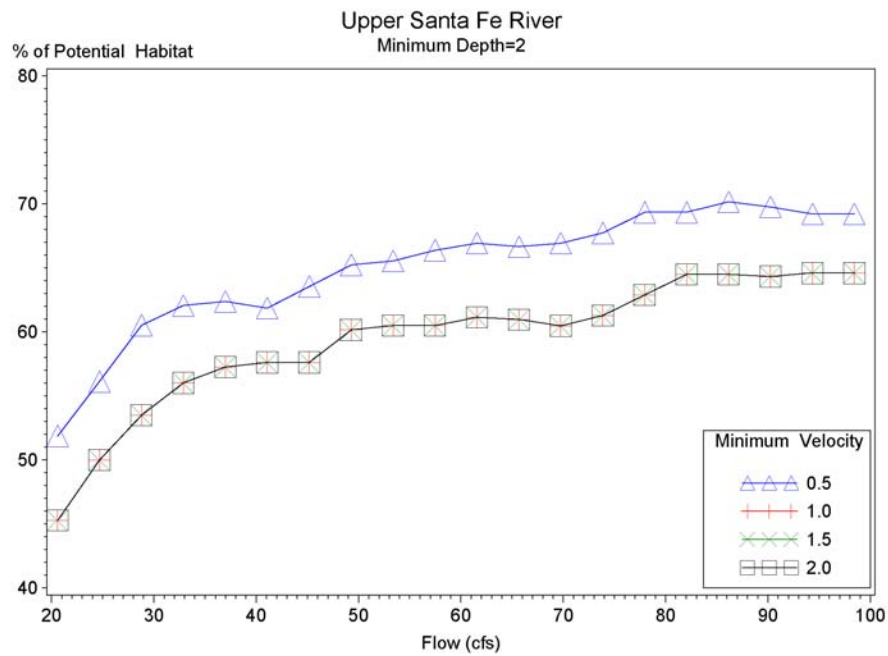
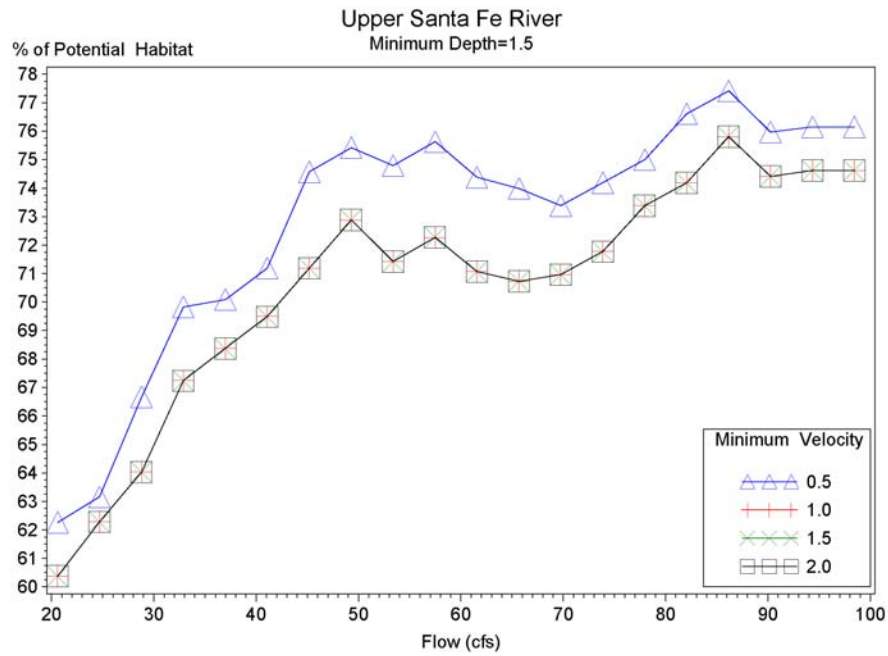


Figure 5-8. Summary of Ecosystem Functions Model results for the downstream segment of the Upper Santa Fe River protective of a 1.5 and 2.0 foot water depth and stream velocities of 0.5 to 2.0 feet sec⁻¹ at the flows up to the 45th percentile of the USGS gage at Worthington Springs.

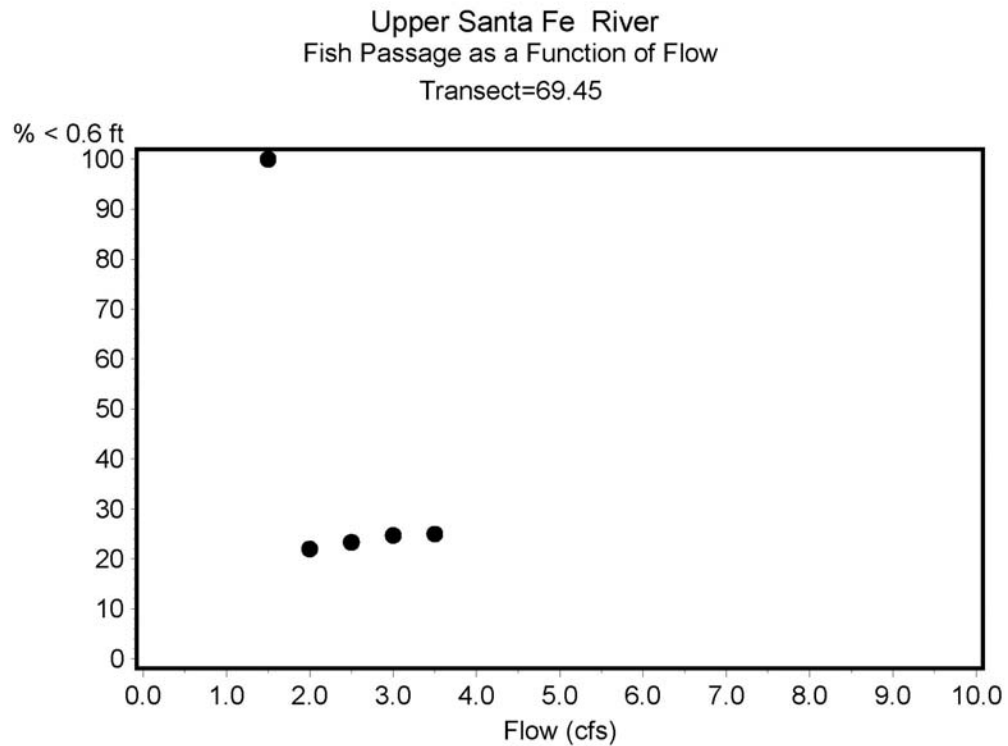
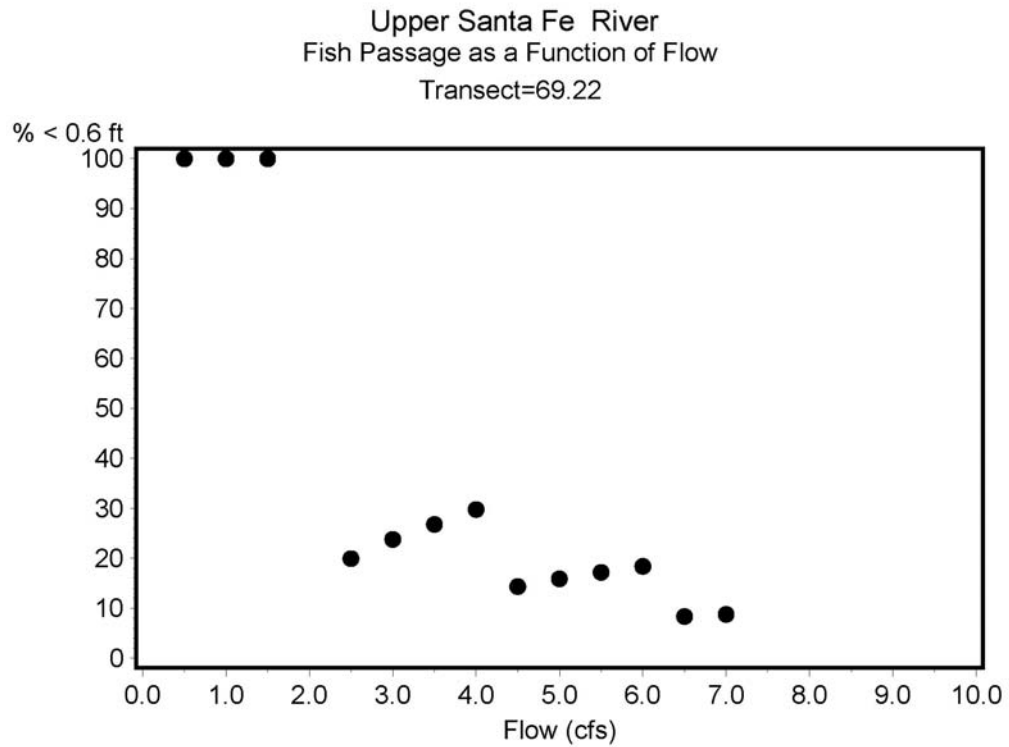


Figure 5-9. Percent of habitat with inadequate depth (less than 0.6 feet of water) for fish passage in the Upper Santa Fe River.

Water depths of at least 0.6 ft are considered adequate to permit upstream and downstream movement of fish populations. Based on this criterion, flow as low as 2.5 cfs maintains adequate fish passage along at least 68-70% of these transects.

5.3 Conclusions

Three separate approaches produced similar low flow recommendations for the Upper Santa Fe River. The result from the wetted perimeter analysis was more protective than the results from either the minimum fish passage analysis or the EFM analysis.

1. Based on the weight of evidence, the recommended minimum flow to avoid significant ecological risk to the Upper Santa Fe River, at the Graham USGS gage, is defined as 2.3 cfs at the 75th flow percentile. Reduction in flows below this point would result in significant ecological risk to the Upper Santa Fe River.
2. Based on the weight of evidence, the recommended minimum flow to avoid significant ecological risk to the Upper Santa Fe River, at the Worthington Springs USGS gage, is defined as 42 cfs at the 75th flow percentile. Reduction in flows below this point would result in significant ecological risk to the Upper Santa Fe River.

The minimum flows identified for each gage on the Upper Santa Fe River are defined by a point at which an increase in the frequency of flows equal to or less than the historic, or baseline 75th percentile flow represents significant risk to the overall ecological health of the Upper Santa Fe River.

5.4 Recommended MFL Regimes

Based on the recommendations in Section 5.3, changes in the baseline FDCs can be related to available water. The recommended minimum flows and associated exceedance can be used as points to control the shift of the historic, or baseline flow regime (i.e., control points). There appears to be sufficient water in the Upper Santa Fe River at the Graham and Worthington Springs gages to allow for a further reduction in the high flow regime without causing significant harm. The two constraints in available flow without significant harm are:

- The control point on the FDC at the Graham gage should be 2.3 cfs at the 75th percentile; and
- The control point on the FDC at the Worthington Springs gage should be 42 cfs at the 75th percentile.

Based on the baseline FDCs, flow at both gages falls below these minima without apparent significant harm, so the primary concern with additional reductions in flow is to prevent an increase in the frequency of occurrence of the minimum flows and to preserve the flood regime. Therefore, the effects of flow reductions at each gage were compared to the suggested minima and the amount of water available for future use.

In order to be conservative, a flow reduction of up to 15 percent of the baseline FDC at flows that are greater than the control points (limited by not reducing the control point values) was determined to be both protective of the ecological values of the river reaches and human use. The following sections present the MFL FDCs and comparisons of baseline and MFL water availability.

5.4.1 Proposed MFL for the Upper Santa Fe River at Graham

Figure 5-10 presents the baseline and proposed MFL FDCs for the Santa Fe River at Graham. Flow equivalent to, or less than, the 2.3 cfs threshold occurs 25 percent of the time according to

the Baseline FDC. In order to protect the flow regime, it was determined that up to a 15 percent shift in the FDC could occur at flows in excess of the 2.3 cfs minimum limited by the flows not being less than the 2.3 cfs control point. The MFL FDC was, therefore, scaled so that up to a 15% flow reduction could occur at flows greater than 2.3 cfs and the available water would decrease to 0 cfs beginning at a recurrence probability of 75%, or 2.3 cfs. Table 5-2 presents the Baseline and MFL FDCs and amounts of water available under different flows according to the proposed MFL FDC.

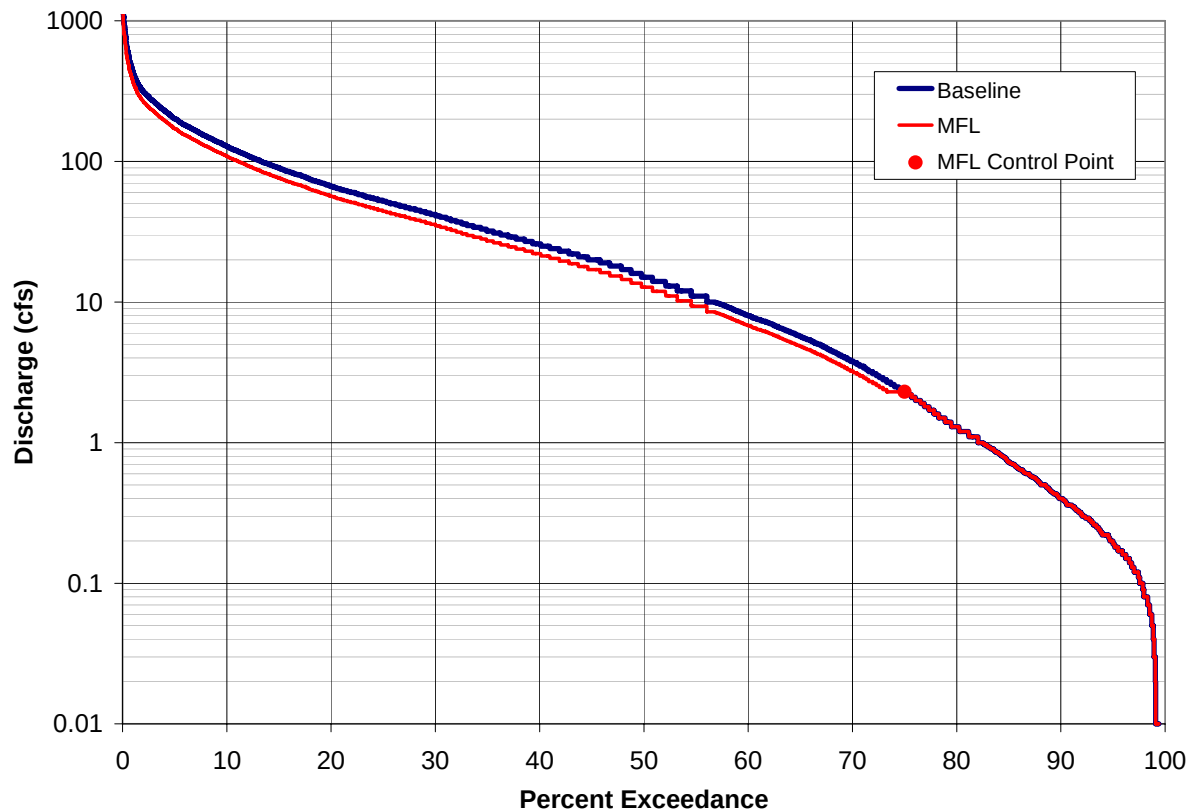


Figure 5-10. Comparison of Baseline and proposed MFL flow duration curves for Santa Fe River flow at the Graham gage.

Table 5-2. Comparison of Proposed Baseline and MFL FDCs for the Upper Santa Fe River at Graham.

FDC	Discharge Exceedance Amounts (cfs)						
	5%	10%	25%	50% (Median)	75%	90%	95%
Baseline	201	128	52	15	2.3	0.4	0.2
MFL	171	109	44	13	2.3	0.4	0.2
Difference	30	19	8	2	0.0	0.0	0.0

5.4.2 Proposed MFL for the Upper Santa Fe River at Worthington Springs

Figure 5-11 presents the baseline and proposed MFL FDCs for the Santa Fe River at Worthington Springs. Flow equivalent to, or less than, the 42 cfs threshold occurs 25 percent of the time according to the Baseline FDC. In order to protect the flow regime, it was determined that up to a 15 percent shift in the FDC could occur at flows in excess of the 42 cfs minimum limited by the flows not being less than the 42 cfs control point. The MFL FDC was, therefore, scaled so that up to a 15% flow reduction could occur at flows greater than 42 cfs and the available water would decrease to 0 cfs beginning at a recurrence probability of 75%, or 42 cfs. Table 5-3 presents the Baseline and MFL FDCs and amounts of water available under different flows according to the proposed MFL FDC.

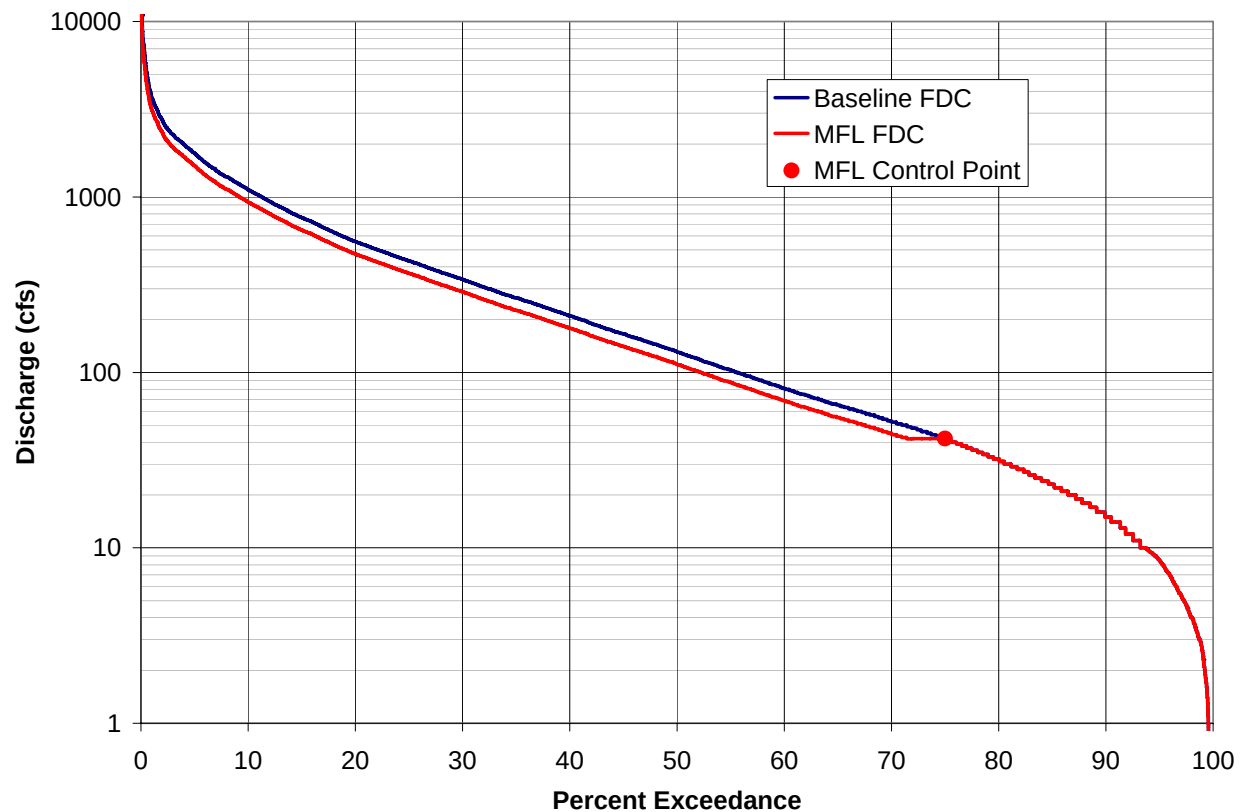


Figure 5-11. Comparison of the Baseline and proposed MFL FDCs for flow of the Upper Santa Fe River at Worthington Springs.

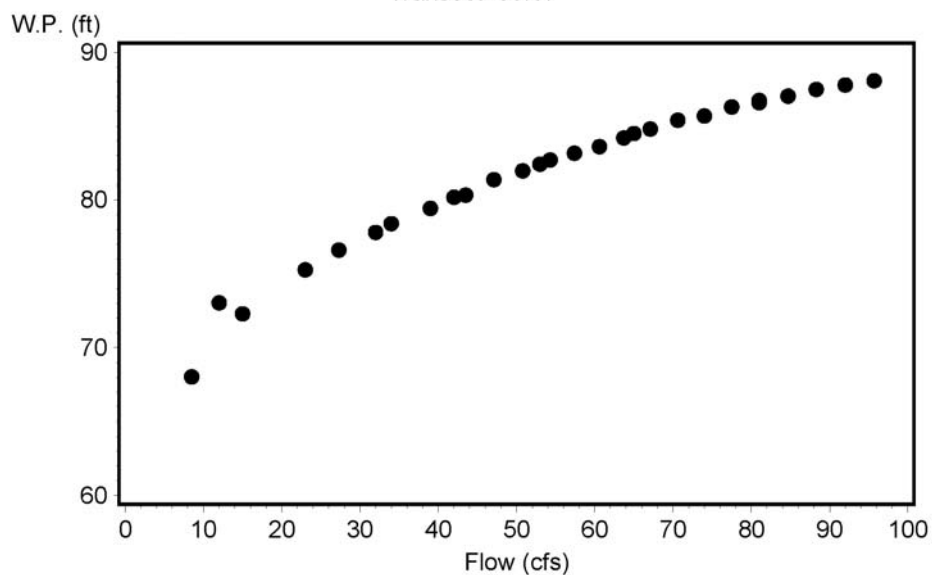
Table 5-3. Comparison of Proposed Baseline and MFL FDCs for the Upper Santa Fe River at Worthington Springs.

FDC	Discharge Exceedance Amounts (cfs)						
	5%	10%	25%	50% (Median)	75%	90%	95%
Baseline	1,780	1,100	432	131	42	15	8.5
MFL	1,513	935	367	111	42	15	8.5
Difference	267	165	65	20	0	0	0

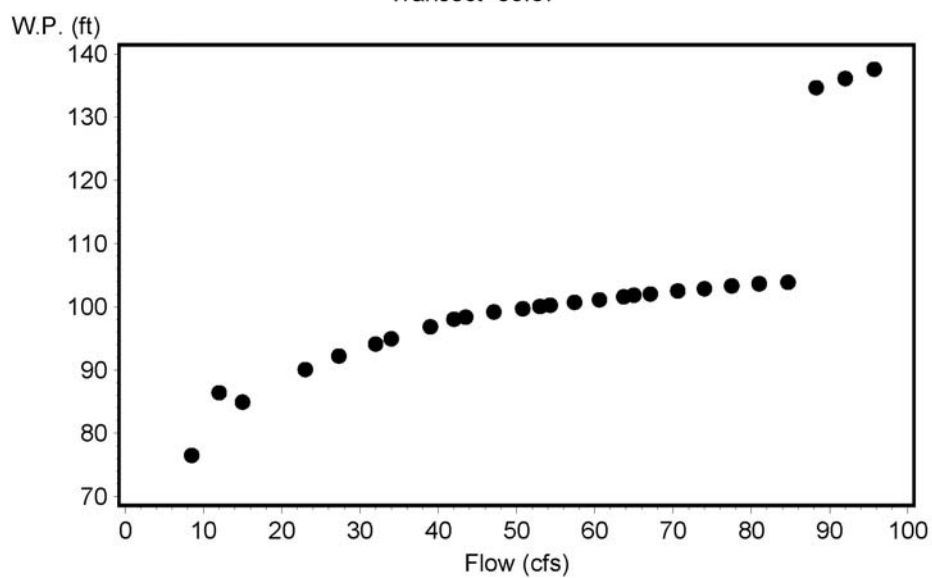
APPENDIX 5-1

APPENDIX 5-1 – Wetted Perimeter

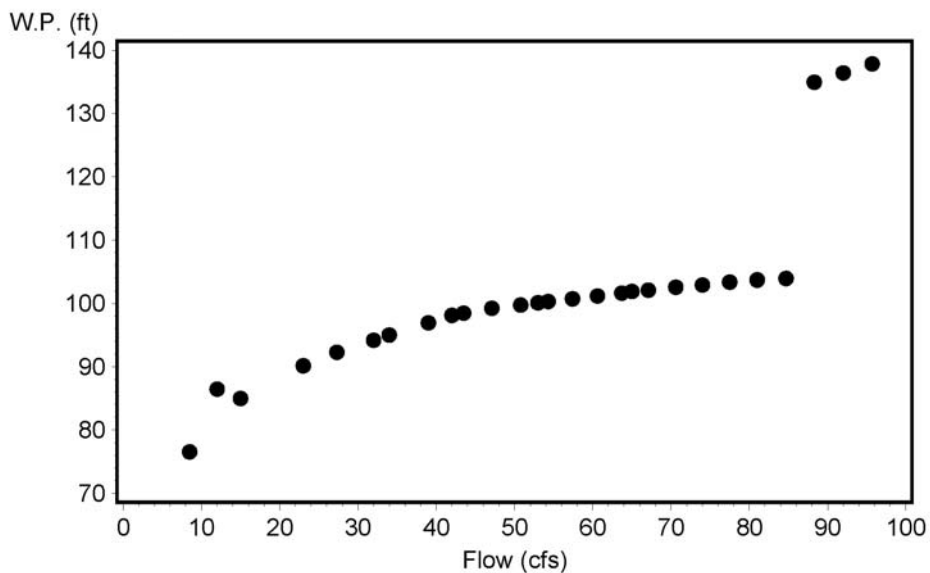
Upper Santa Fe River
 Reach: Worthington Springs to O'Leno State Park
 Wetted Perimeter - River Flow Relationship
 Transect=35.07



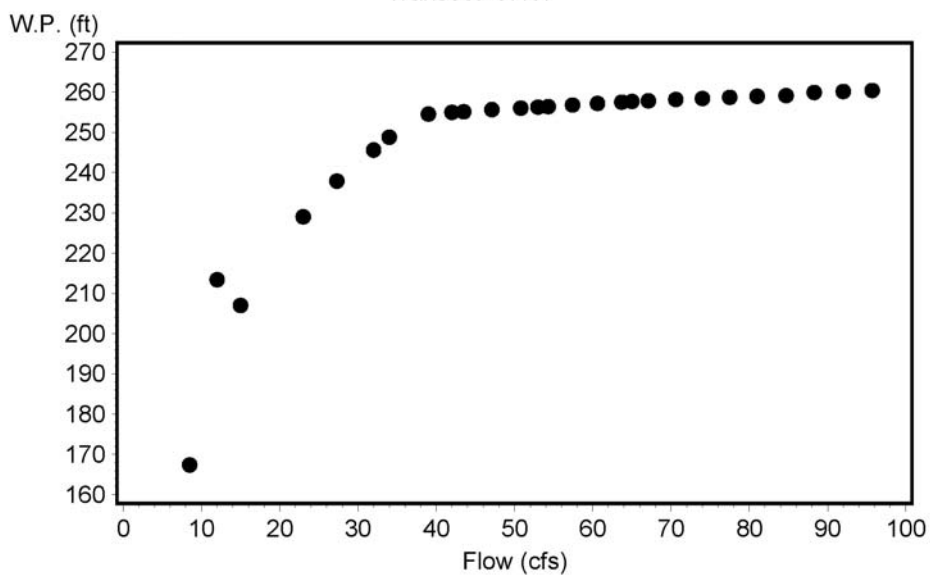
Upper Santa Fe River
 Reach: Worthington Springs to O'Leno State Park
 Wetted Perimeter - River Flow Relationship
 Transect=35.57



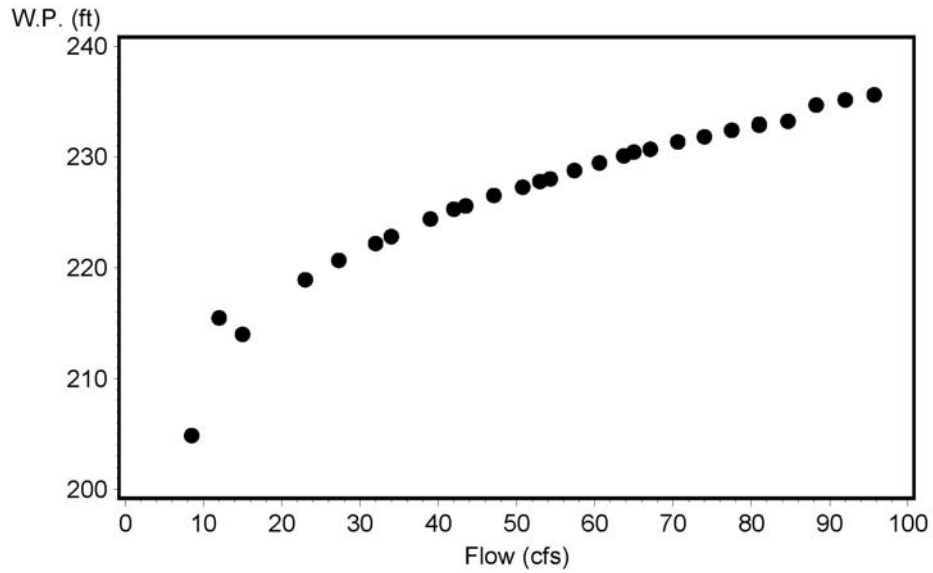
Upper Santa Fe River
 Reach: Worthington Springs to O'Leno State Park
 Wetted Perimeter - River Flow Relationship
 Transect=35.58



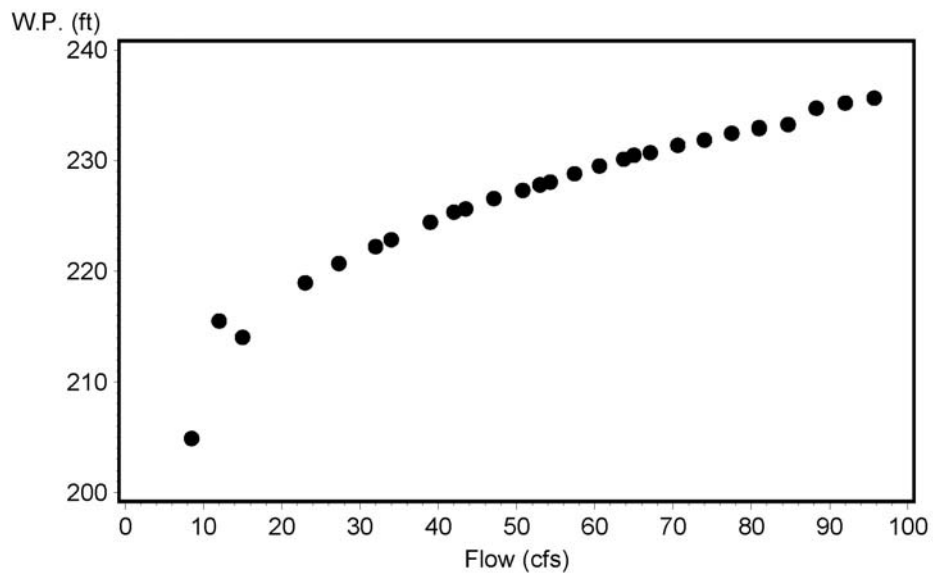
Upper Santa Fe River
 Reach: Worthington Springs to O'Leno State Park
 Wetted Perimeter - River Flow Relationship
 Transect=37.07



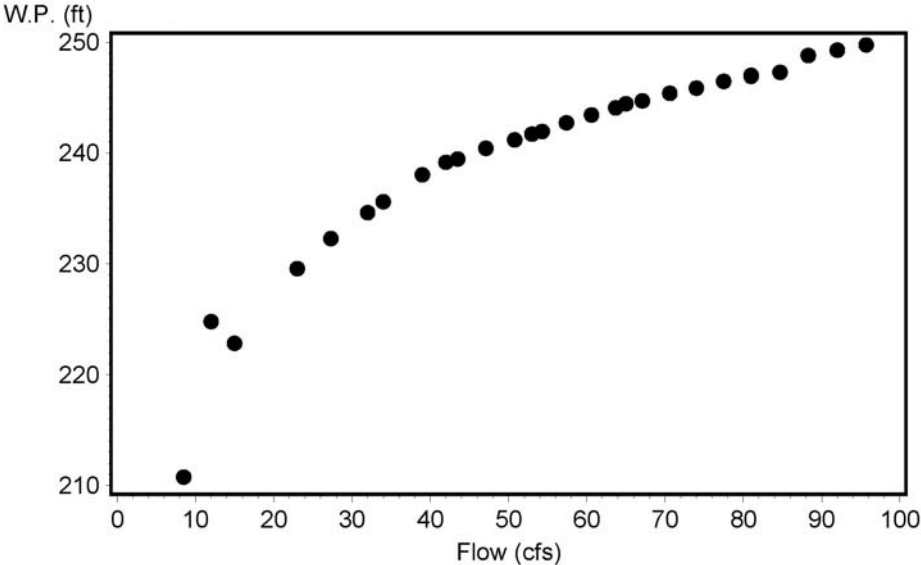
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Reach: Worthington Springs to O'Leno State Park
Wetted Perimeter - River Flow Relationship
Transect=37.16



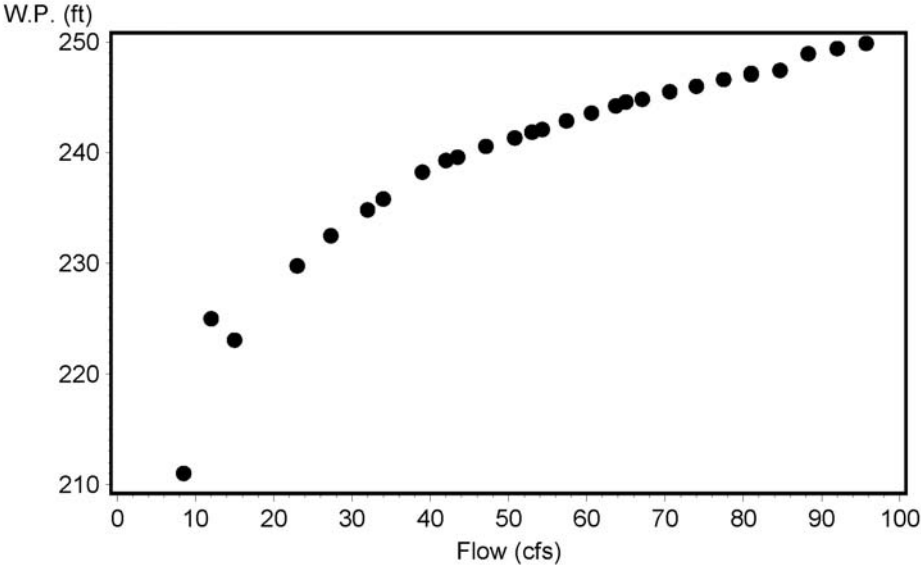
Upper Santa Fe River
Reach: Worthington Springs to O'Leno State Park
Wetted Perimeter - River Flow Relationship
Transect=37.17



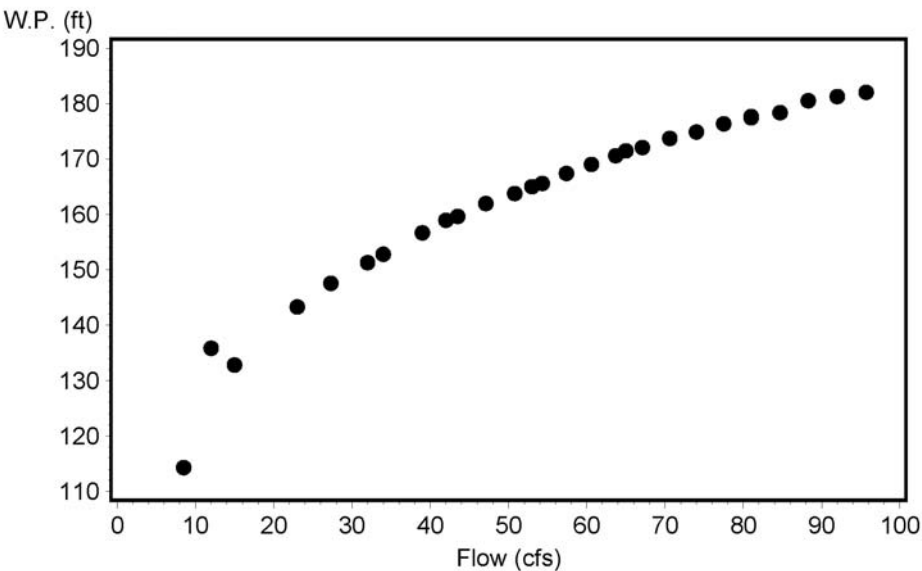
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Reach: Worthington Springs to O'Leno State Park
Wetted Perimeter - River Flow Relationship
Transect=37.19



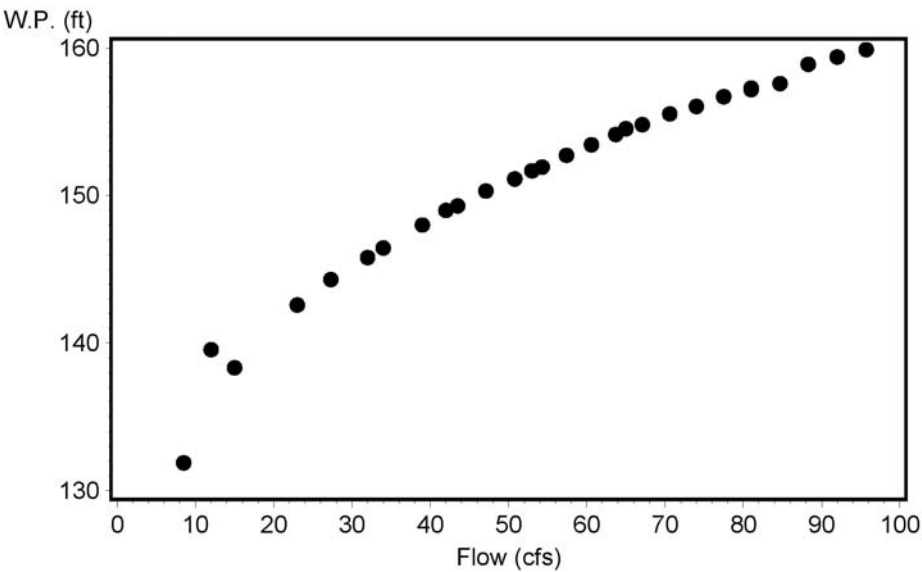
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Reach: Worthington Springs to O'Leno State Park
Wetted Perimeter - River Flow Relationship
Transect=37.25



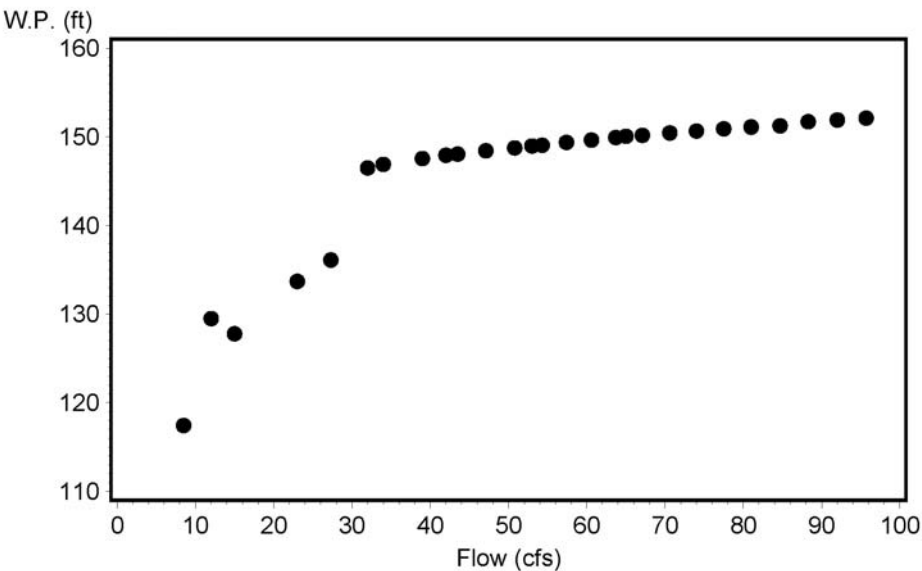
Upper Santa Fe River
Reach: Worthington Springs to O'Leno State Park
Wetted Perimeter - River Flow Relationship
Transect=37.98



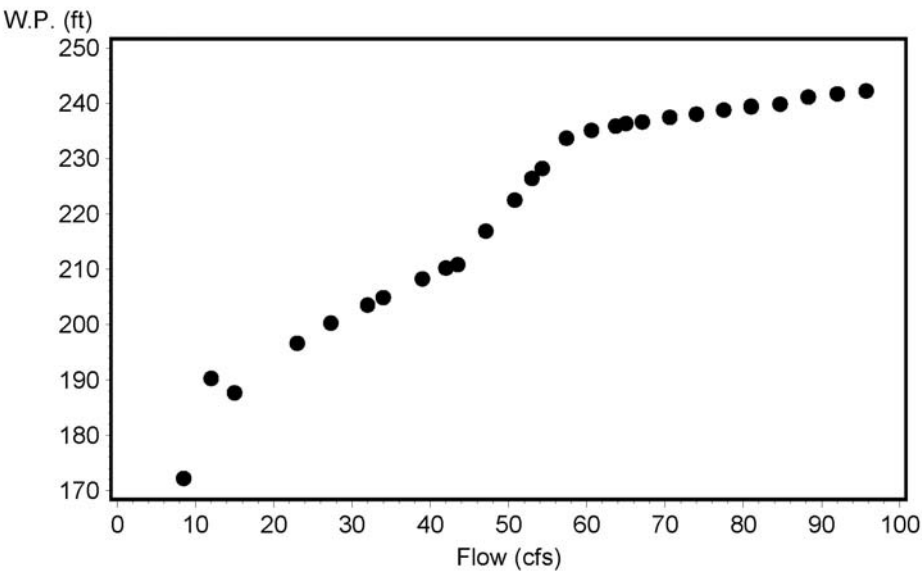
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Wetted Perimeter - River Flow Relationship
Transect=38.24



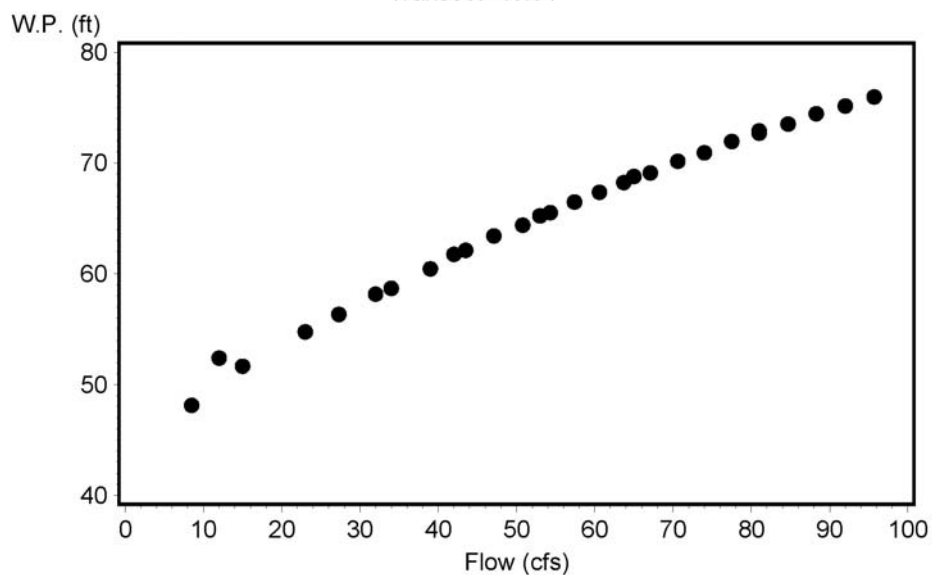
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Wetted Perimeter - River Flow Relationship
Transect=39.02



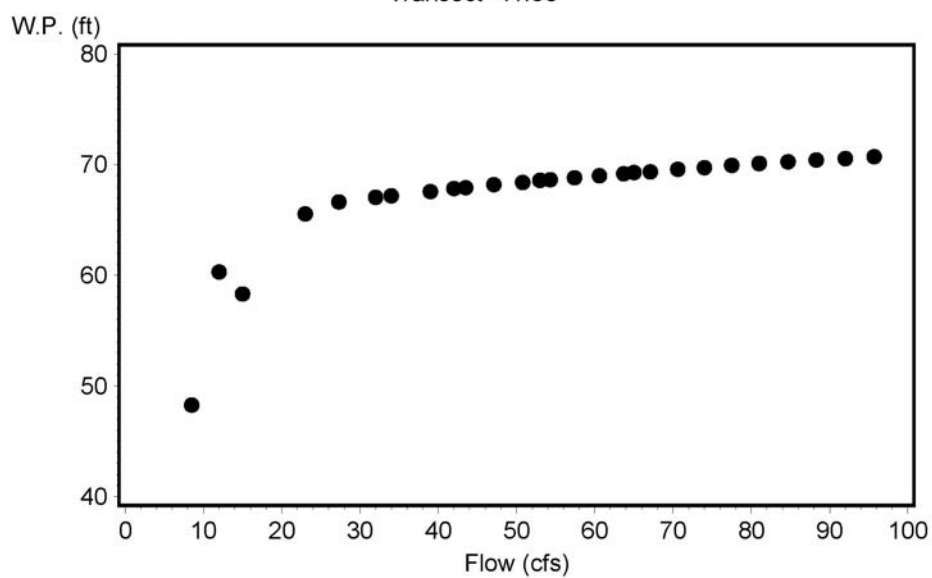
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Reach: Worthington Springs to O'Leno State Park
Wetted Perimeter - River Flow Relationship
Transect=39.81



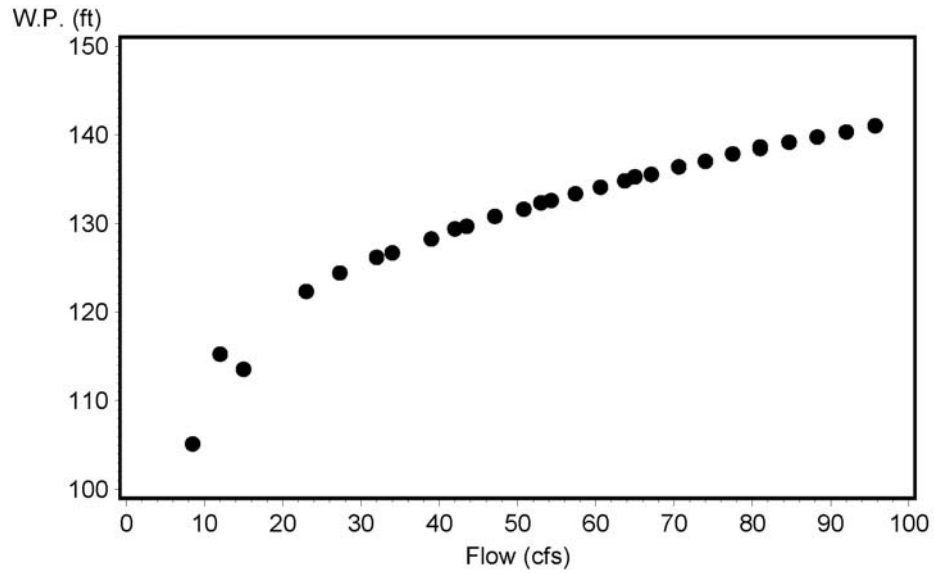
Upper Santa Fe River
 Reach: Worthington Springs to O'Leno State Park
 Wetted Perimeter - River Flow Relationship
 Transect=40.91



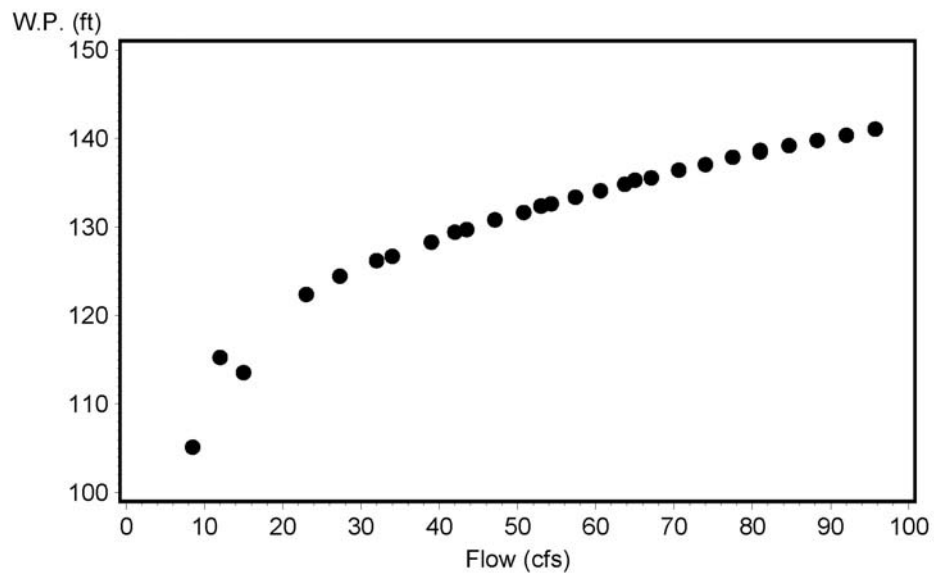
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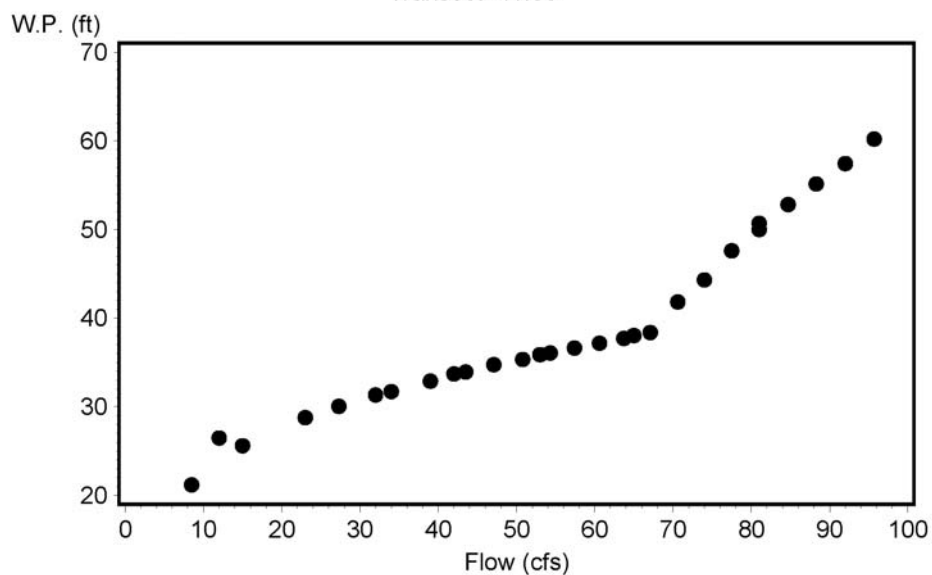
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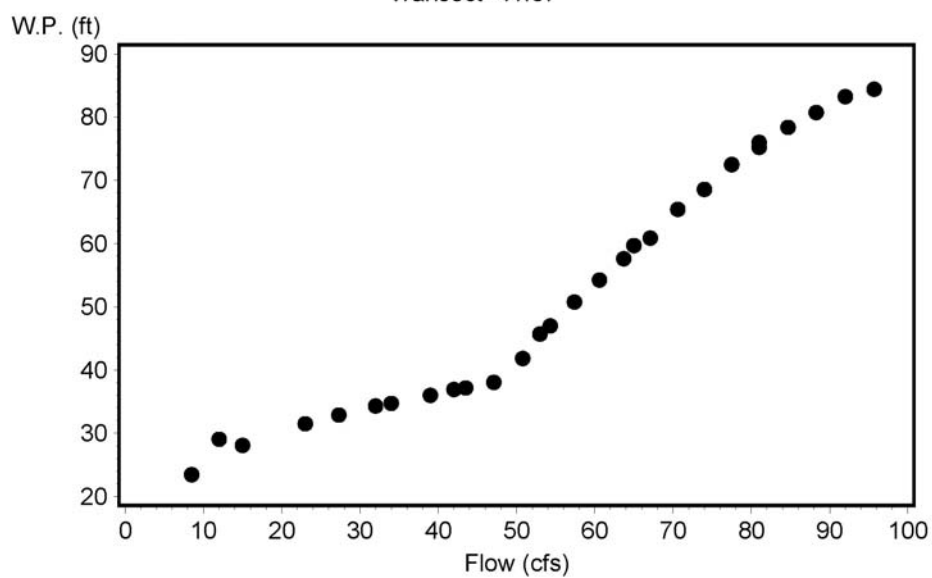
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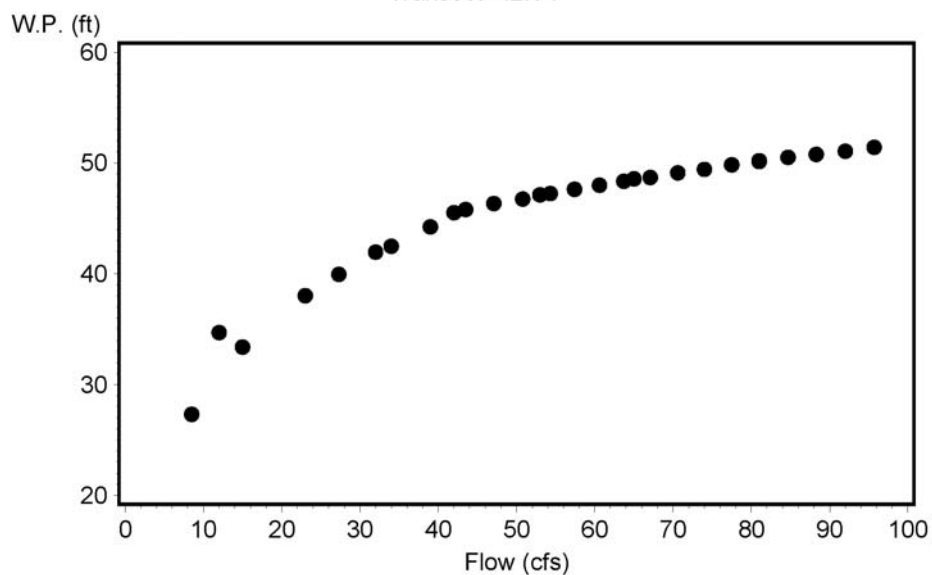
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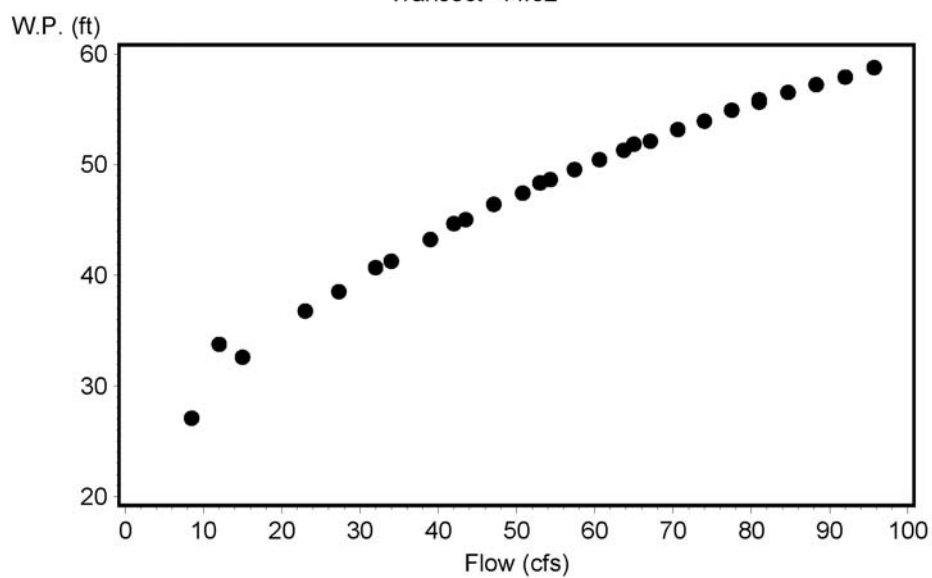
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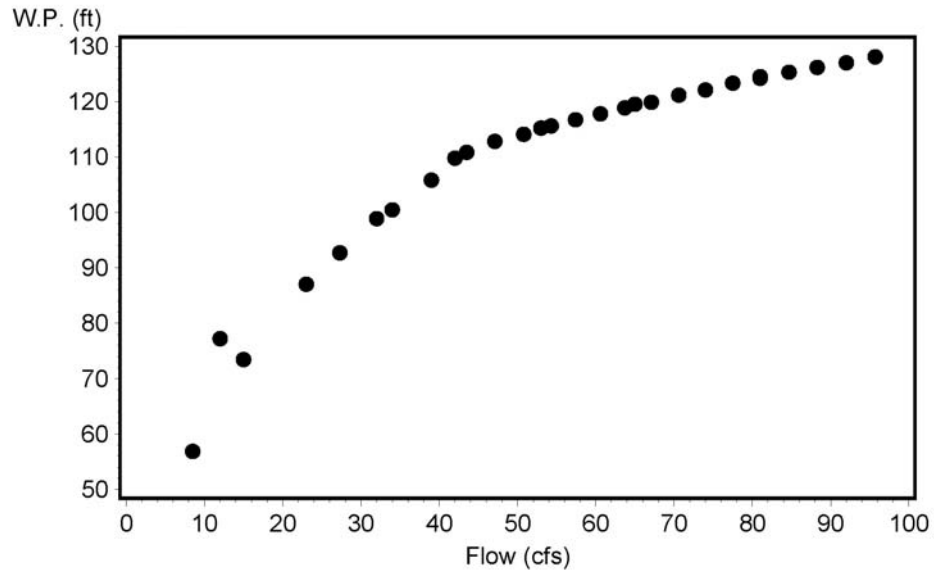
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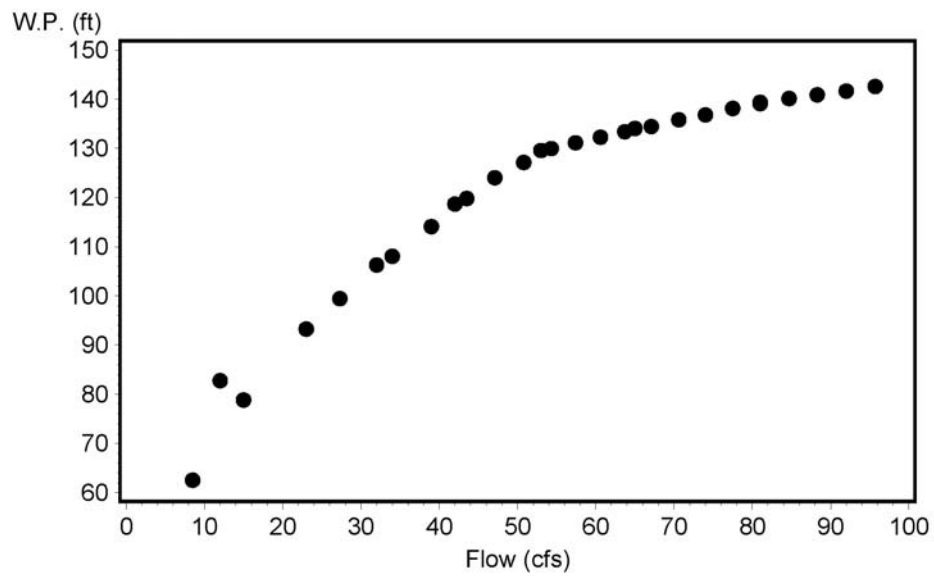
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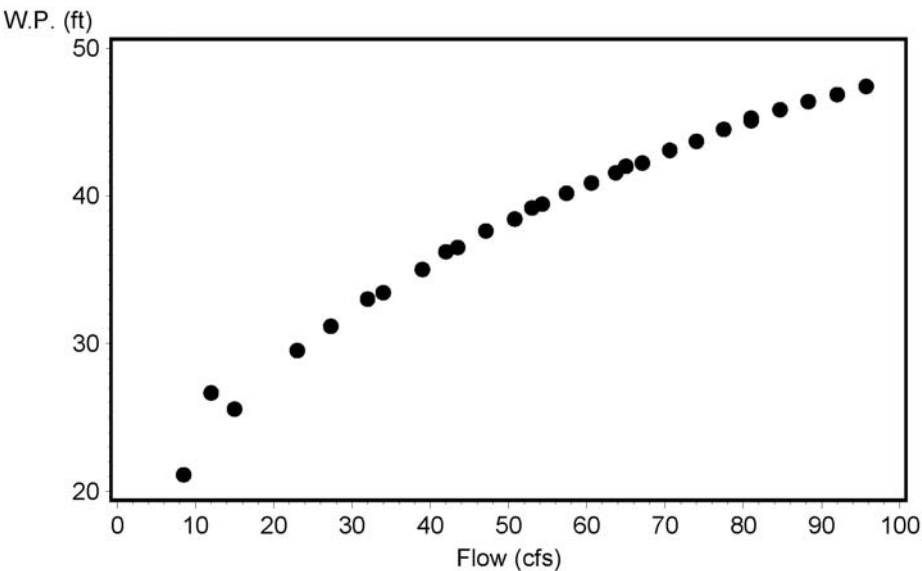
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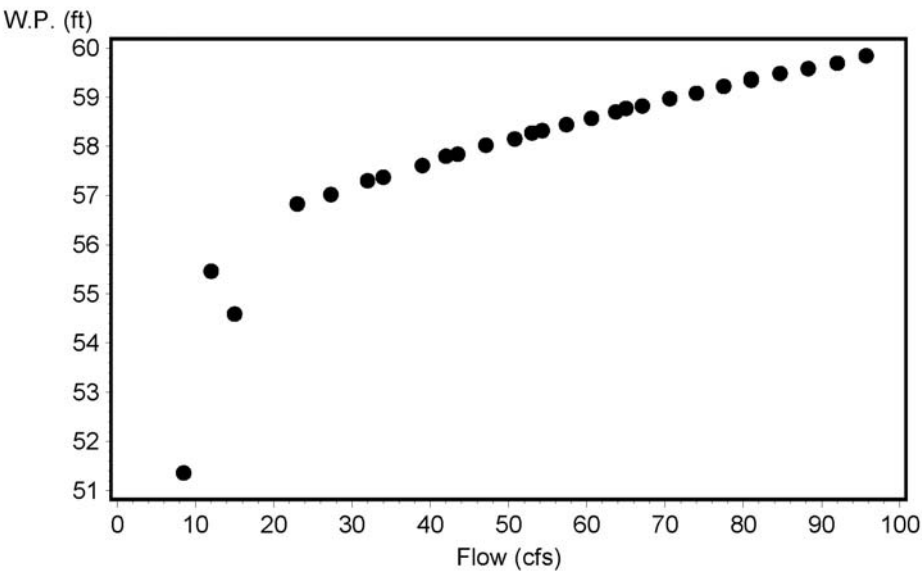
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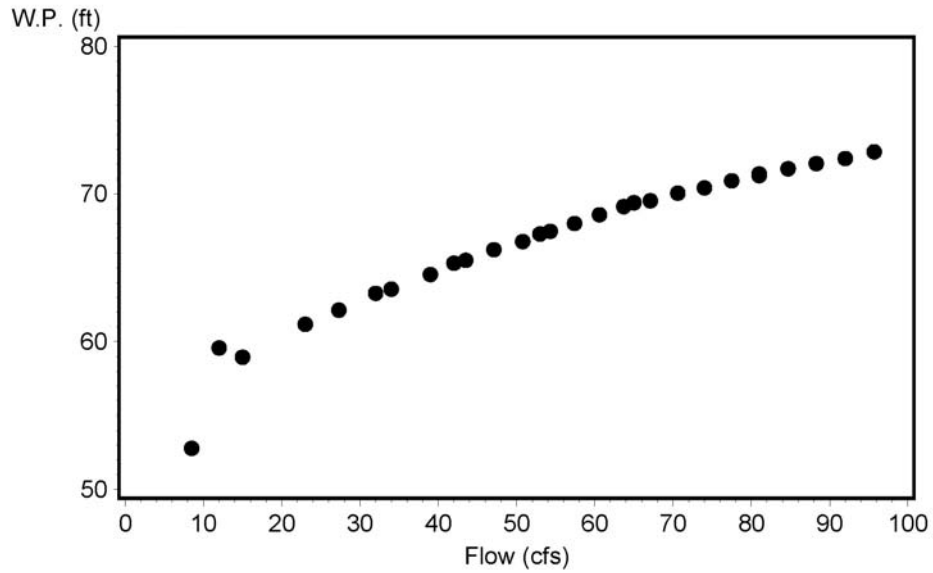
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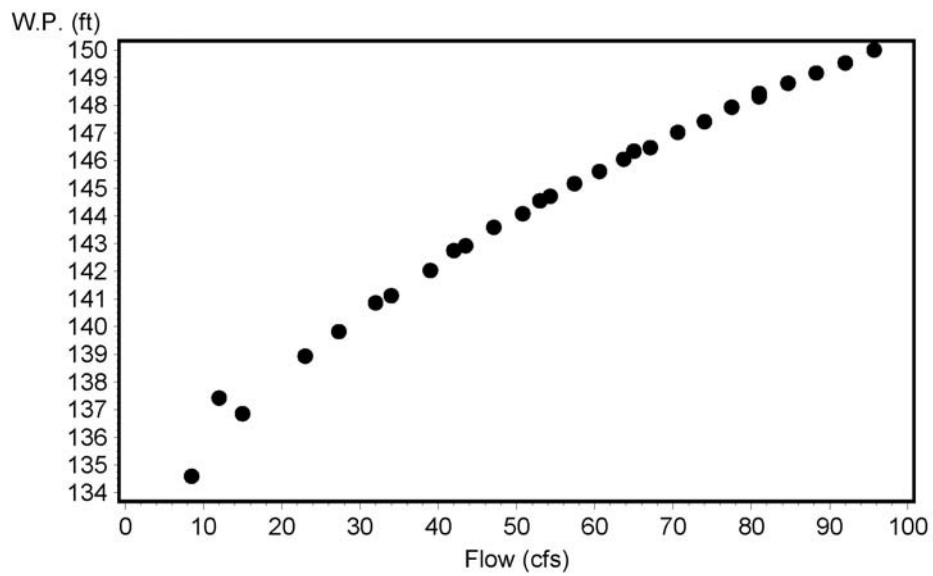
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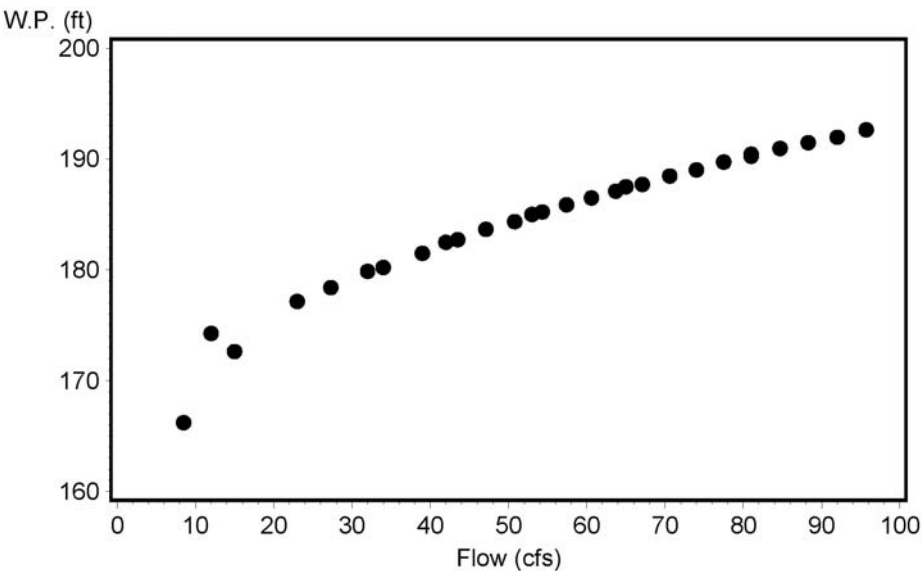
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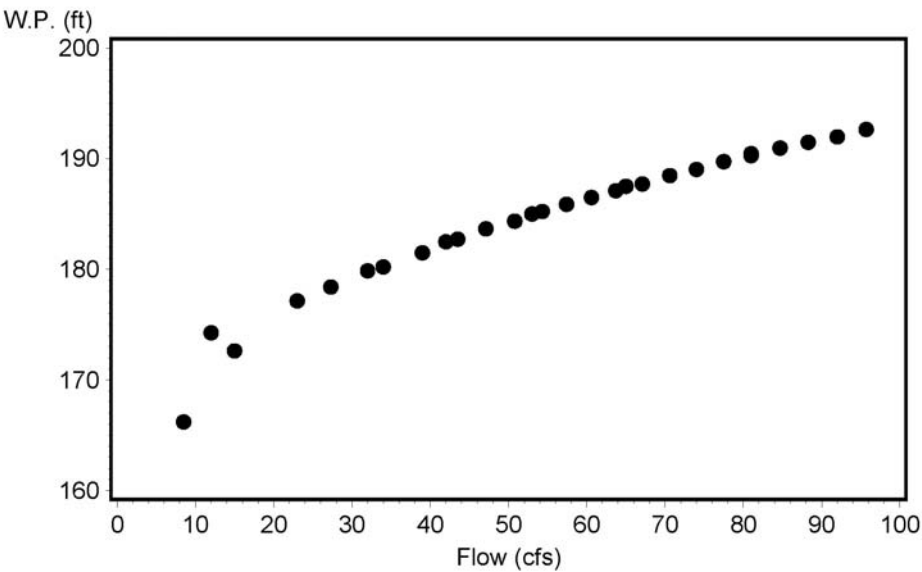
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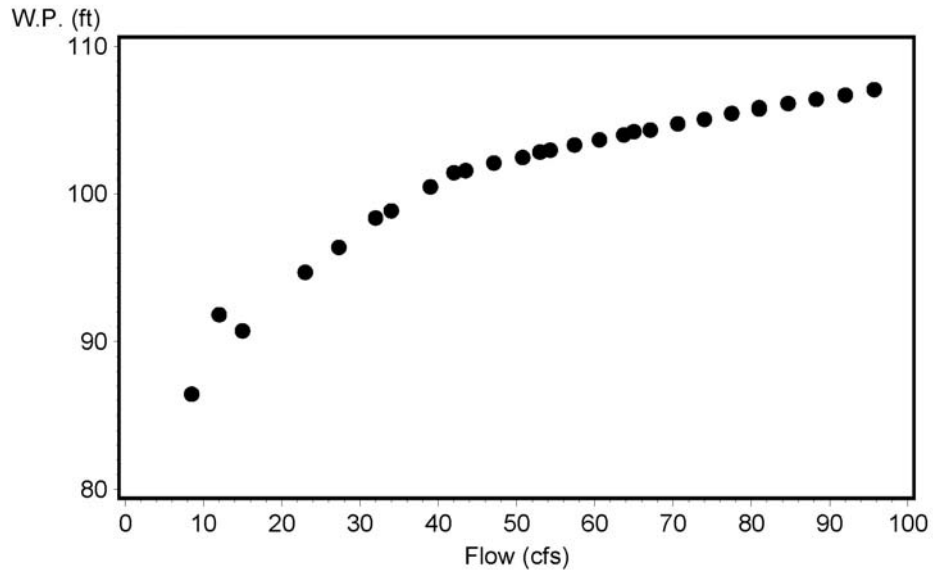
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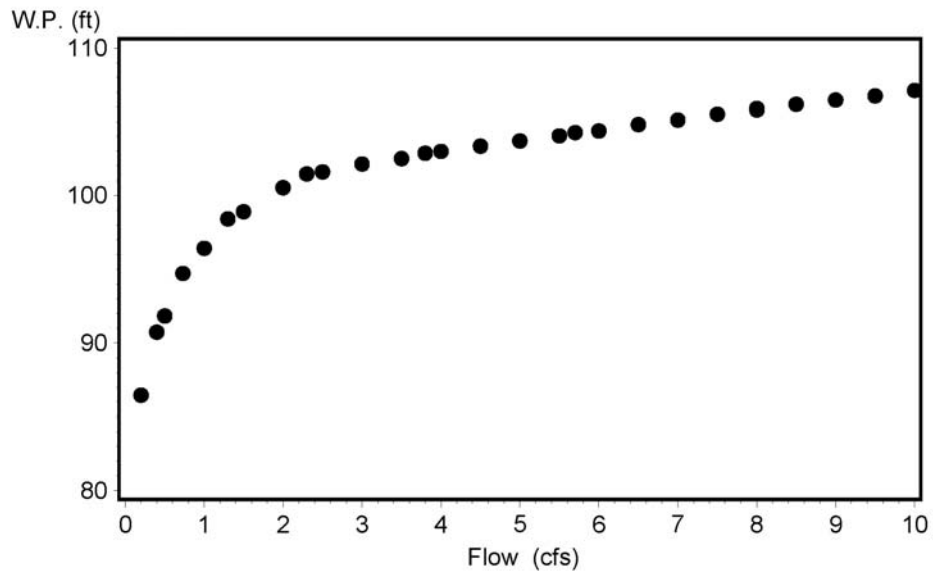
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Wetted Perimeter - River Flow Relationship
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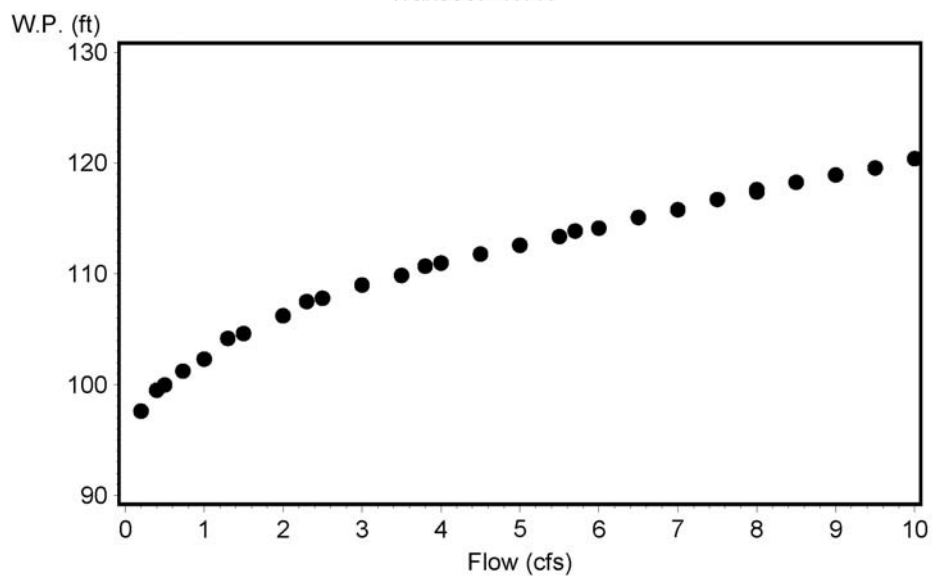
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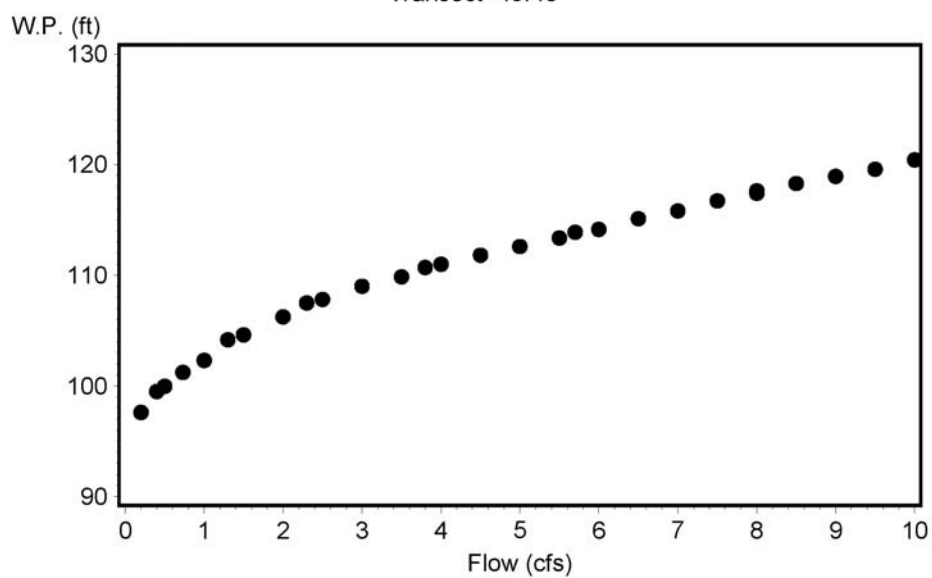
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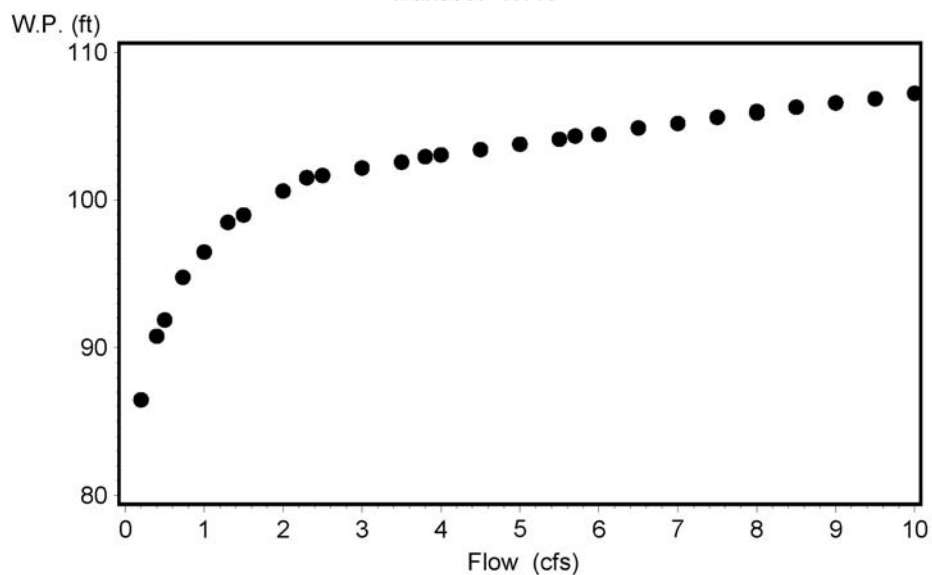
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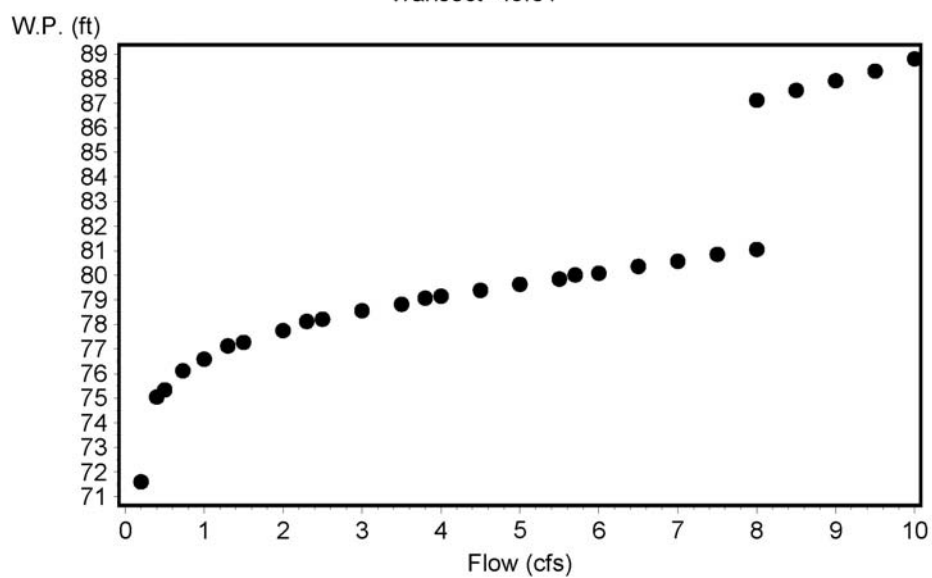
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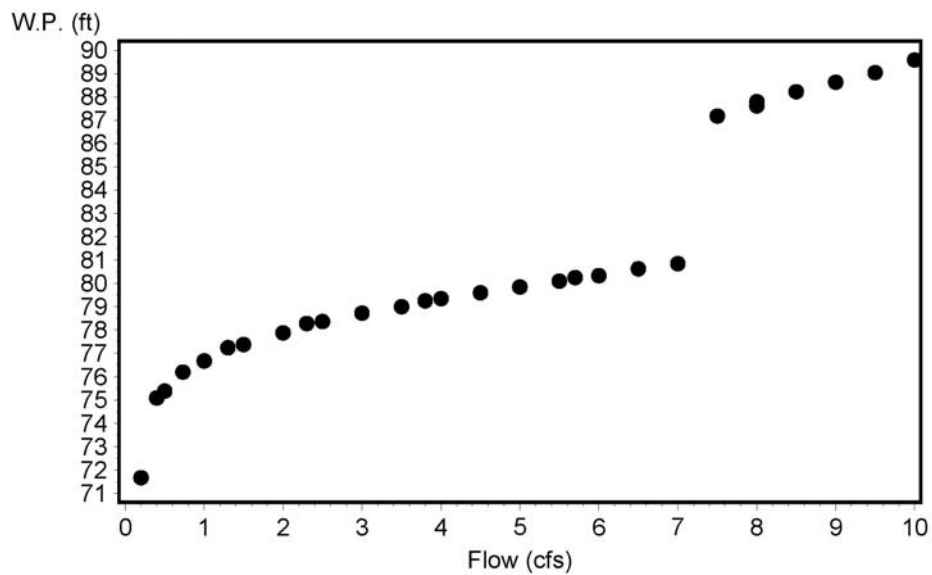
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 Wetted Perimeter - River Flow Relationship
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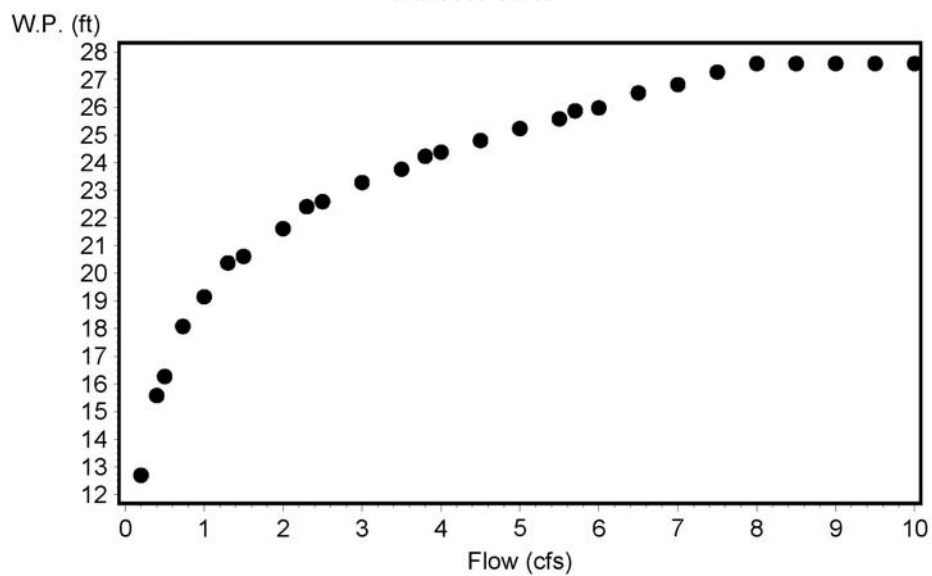
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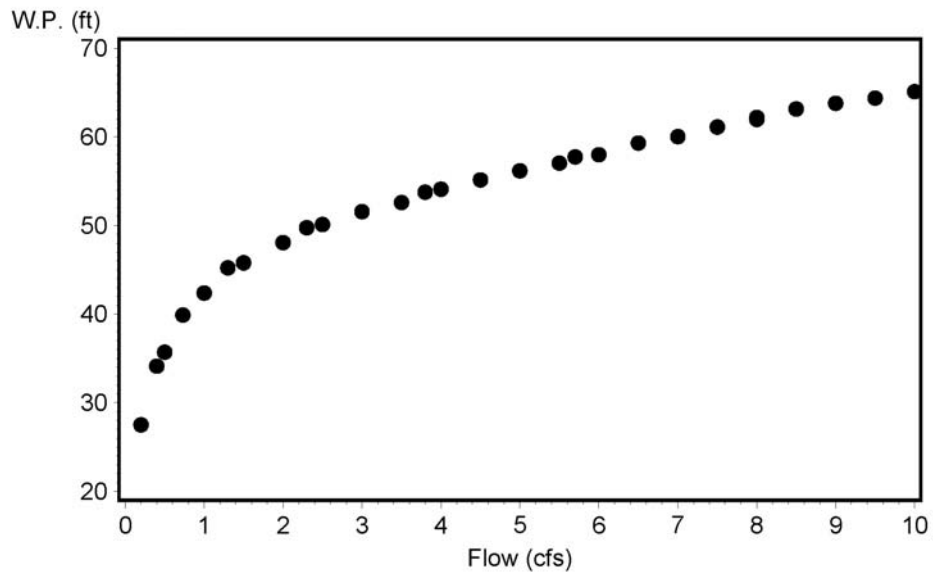
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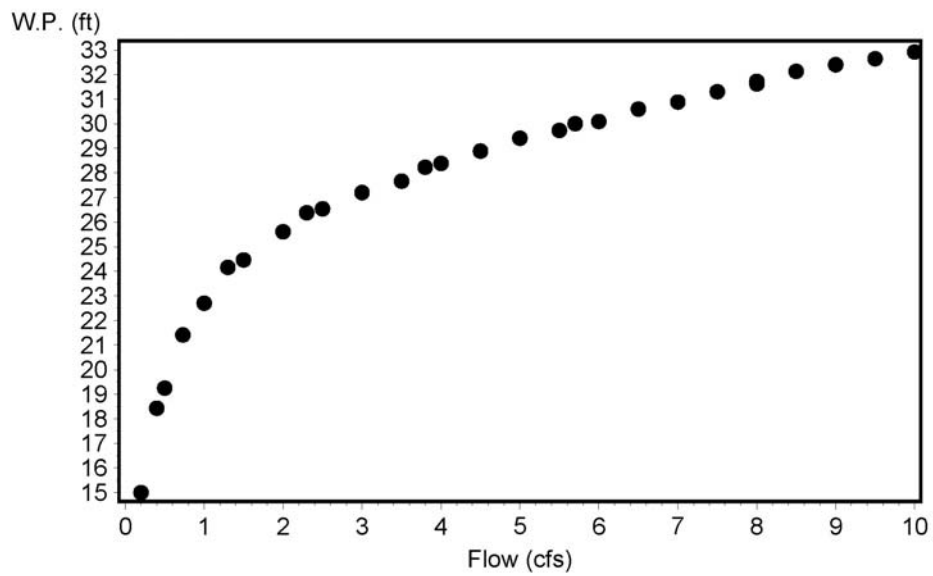
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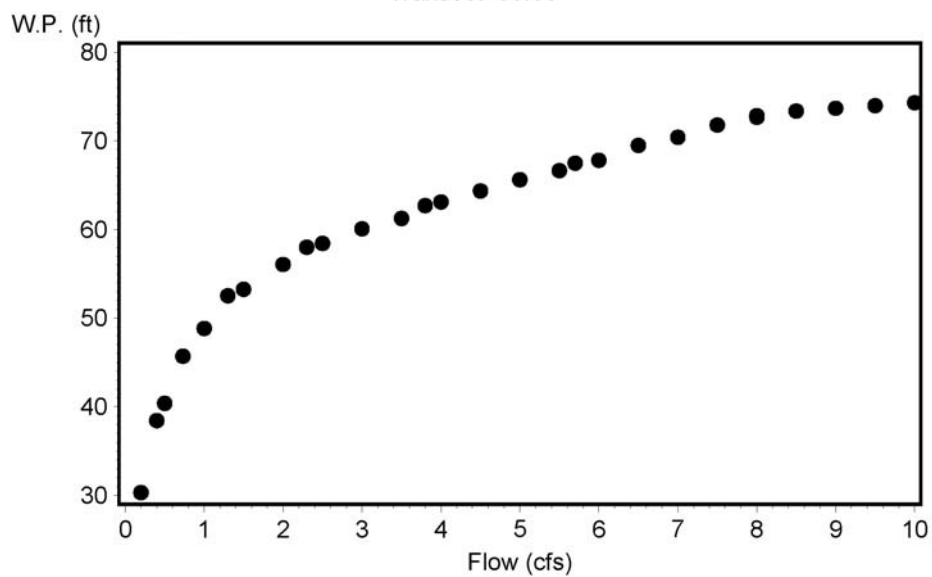
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 Wetted Perimeter - River Flow Relationship
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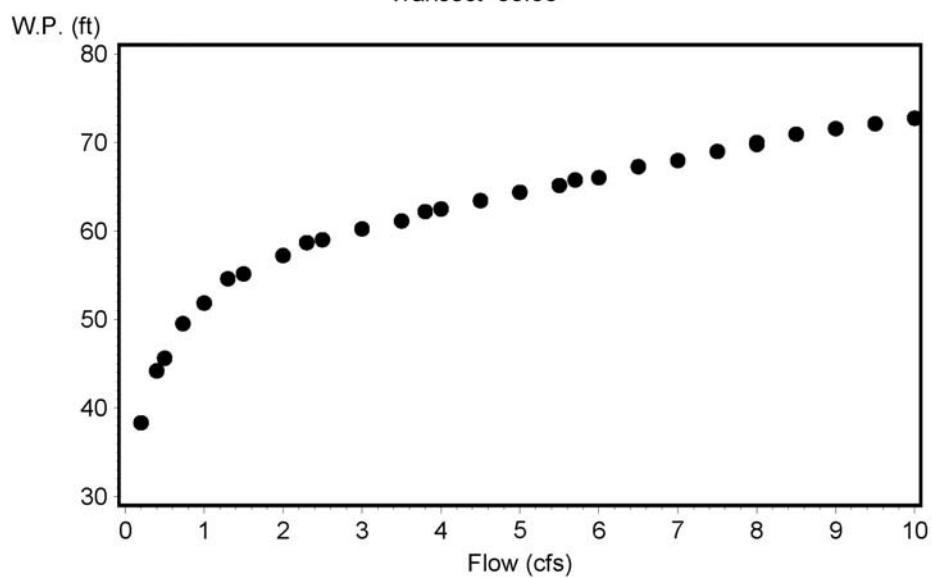
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 Wetted Perimeter - River Flow Relationship
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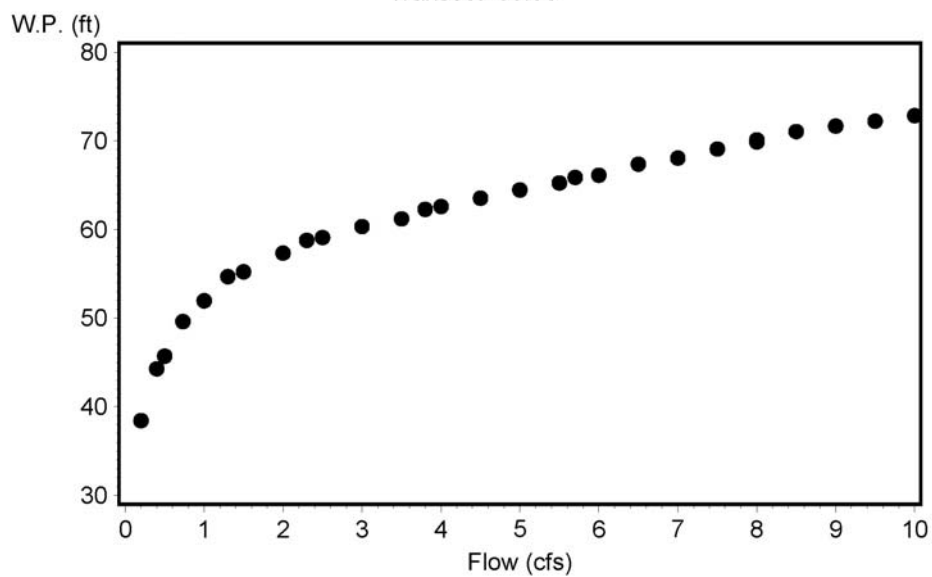
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 Wetted Perimeter - River Flow Relationship
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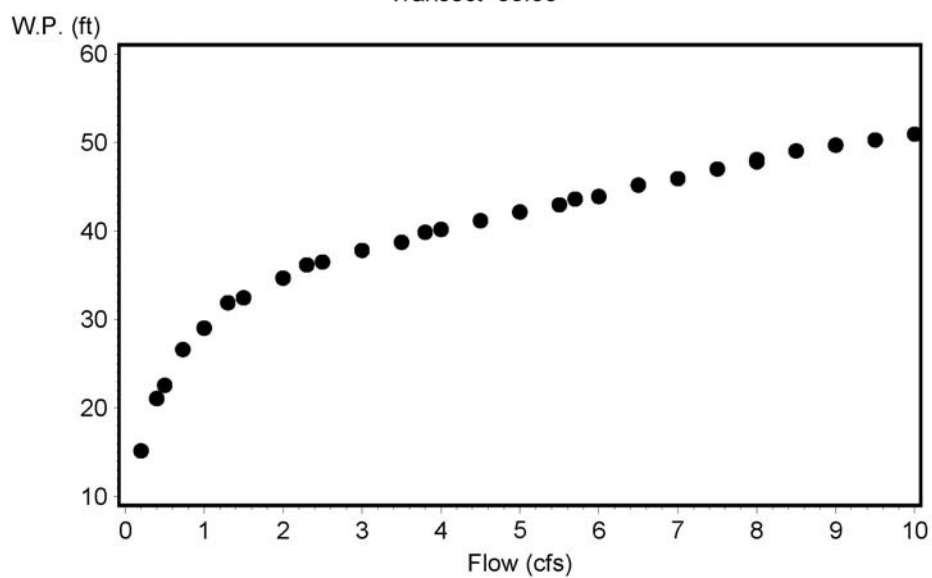
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 Wetted Perimeter - River Flow Relationship
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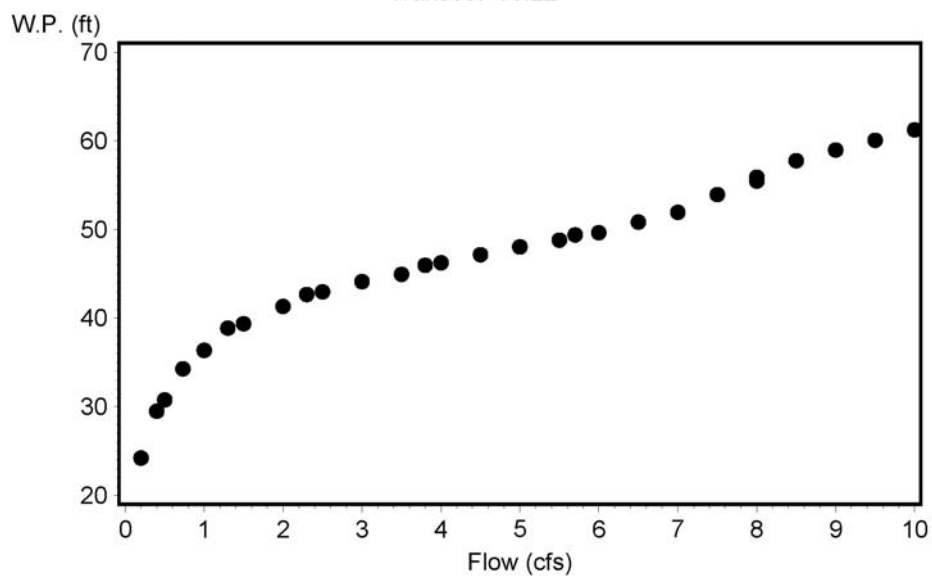
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Reach: Graham to Worthington Springs
Wetted Perimeter - River Flow Relationship
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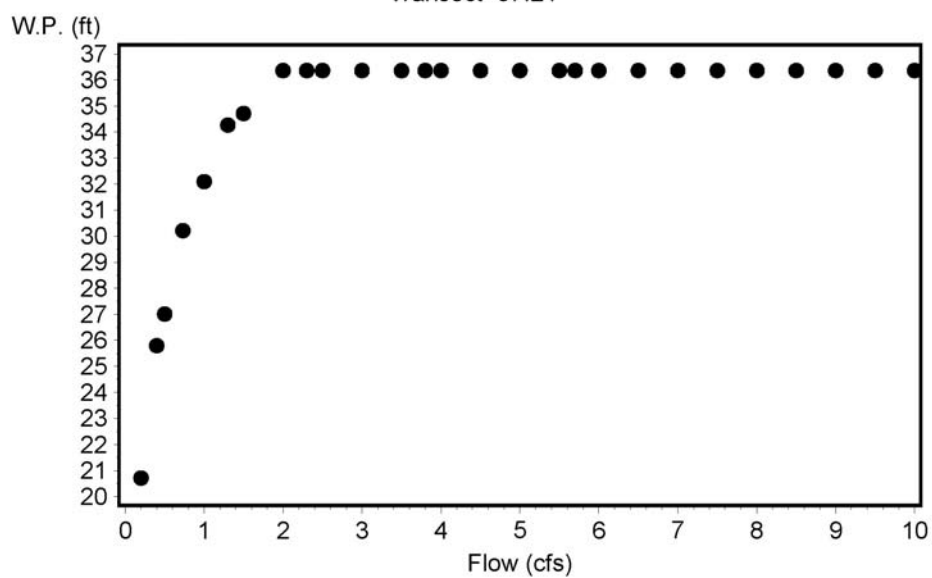
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Wetted Perimeter - River Flow Relationship
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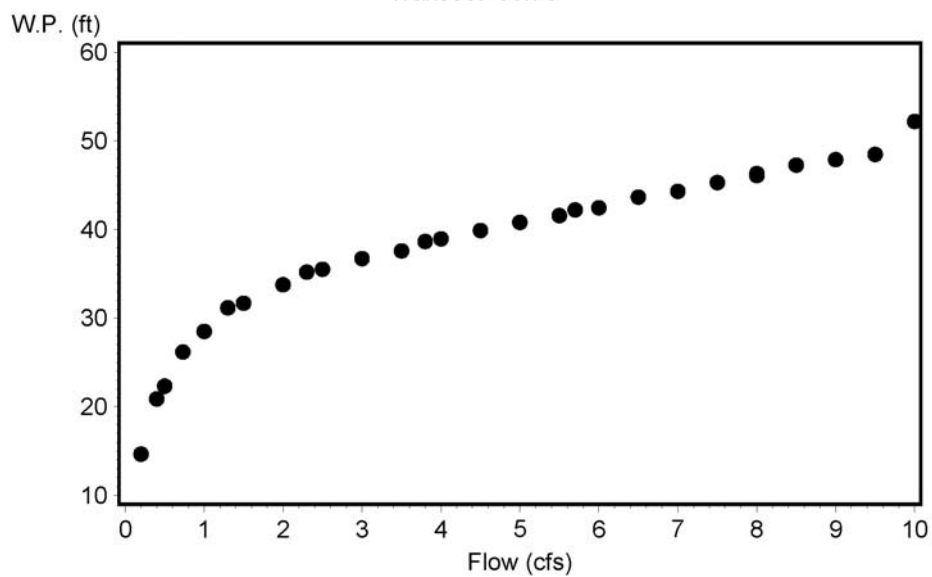
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 Wetted Perimeter - River Flow Relationship
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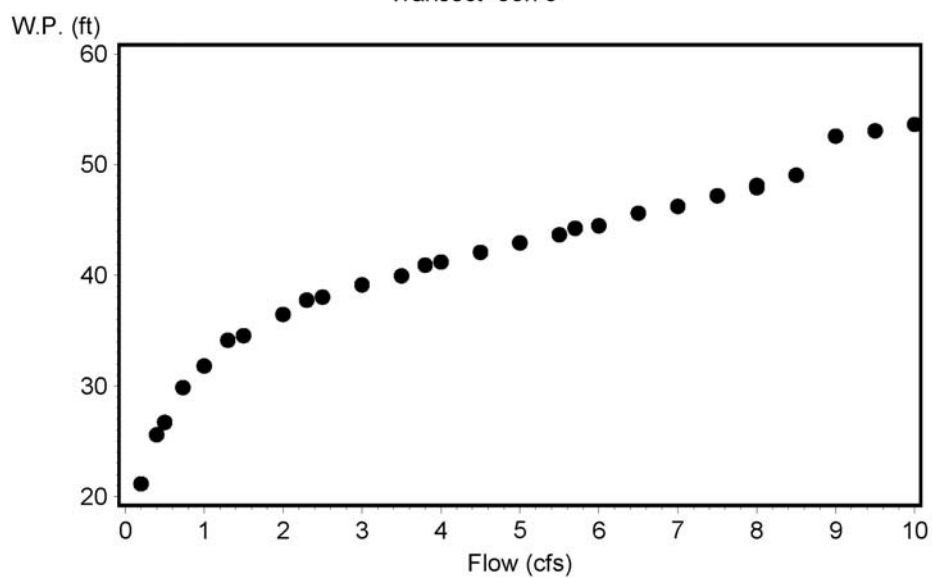
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 Reach: Graham to Worthington Springs
 Wetted Perimeter - River Flow Relationship
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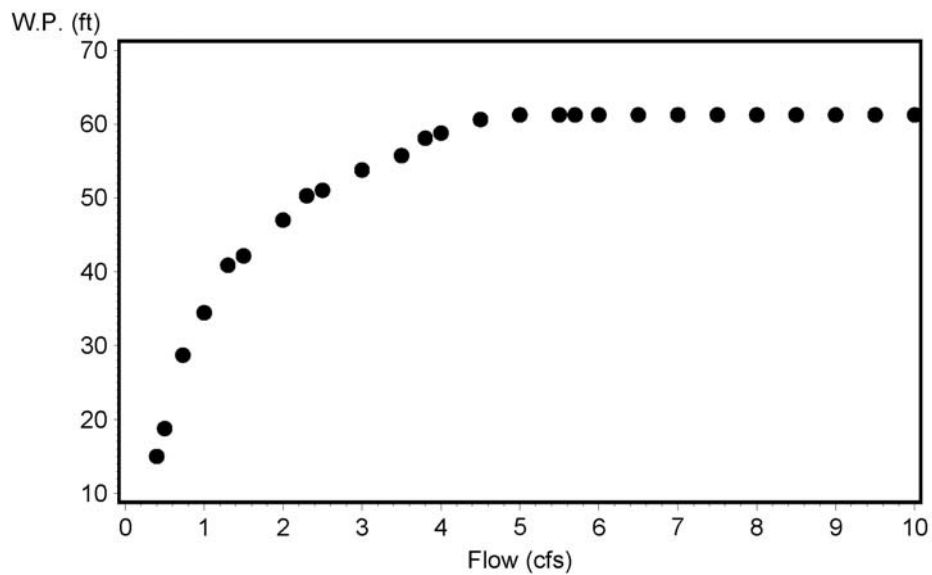
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Wetted Perimeter - River Flow Relationship
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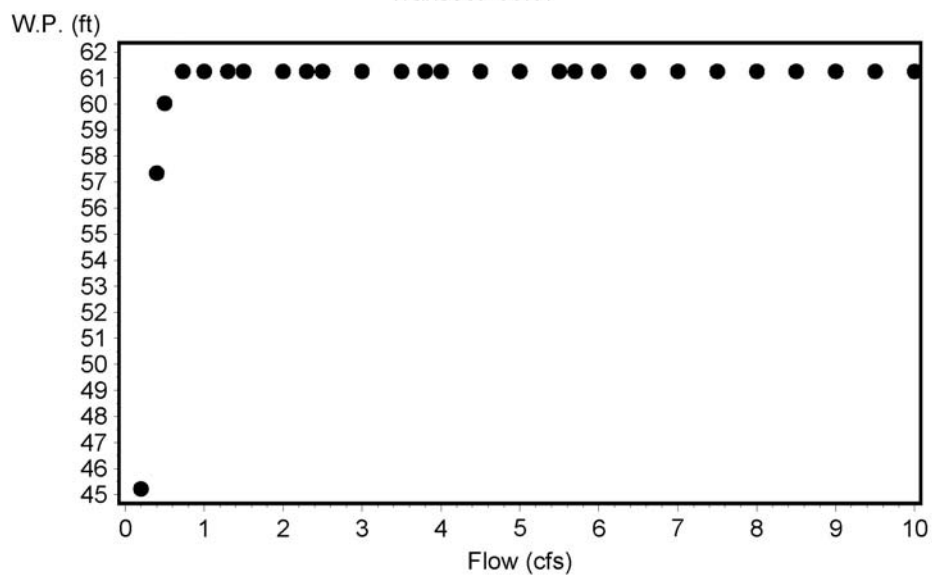
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Wetted Perimeter - River Flow Relationship
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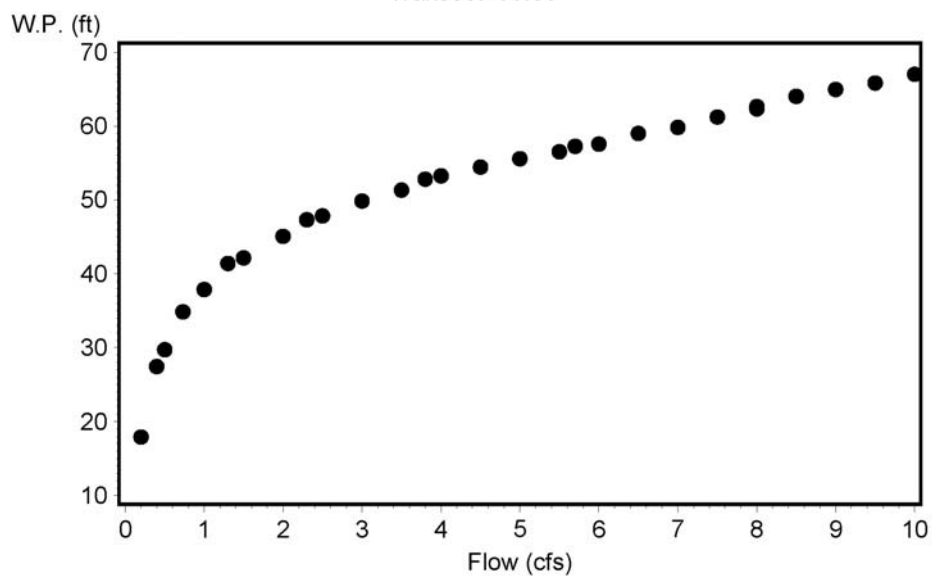
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 Wetted Perimeter - River Flow Relationship
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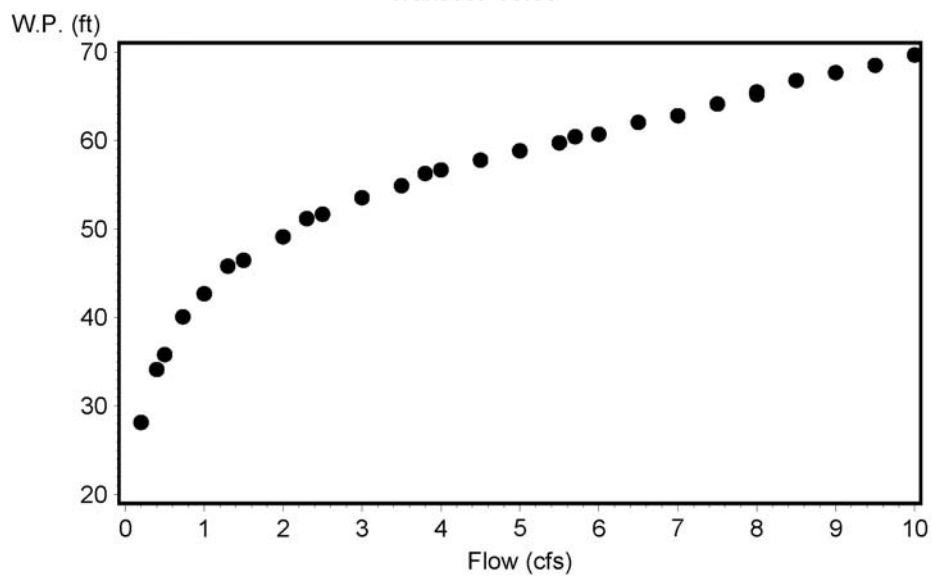
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 Wetted Perimeter - River Flow Relationship
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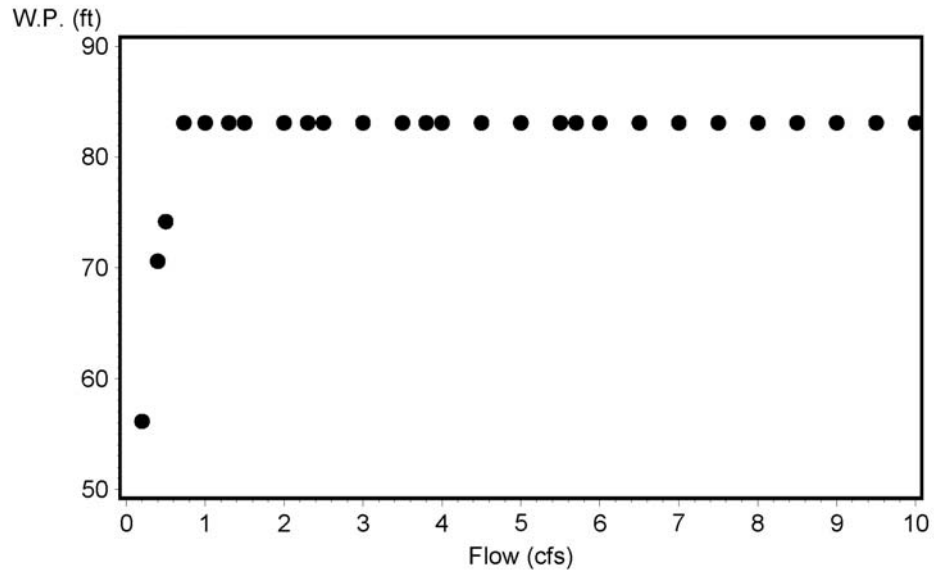
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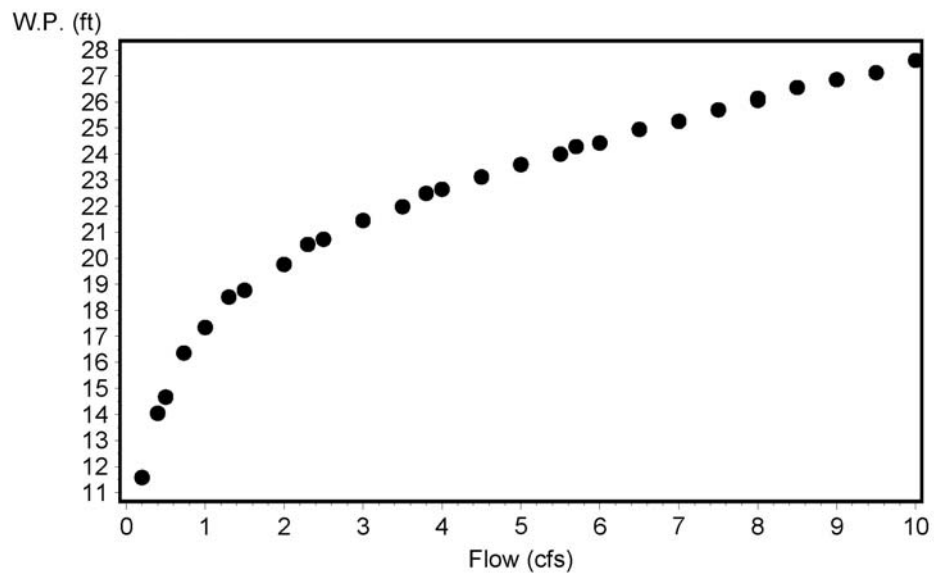
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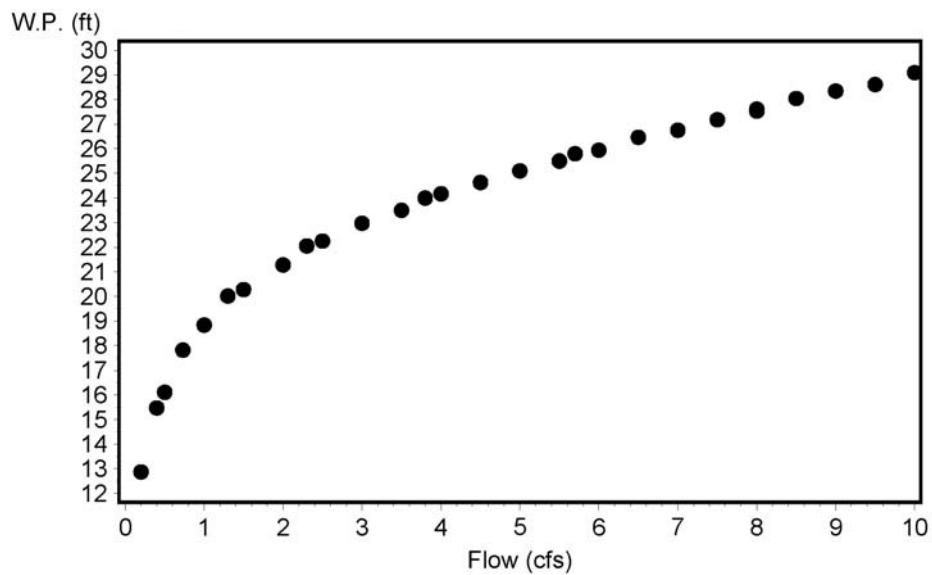
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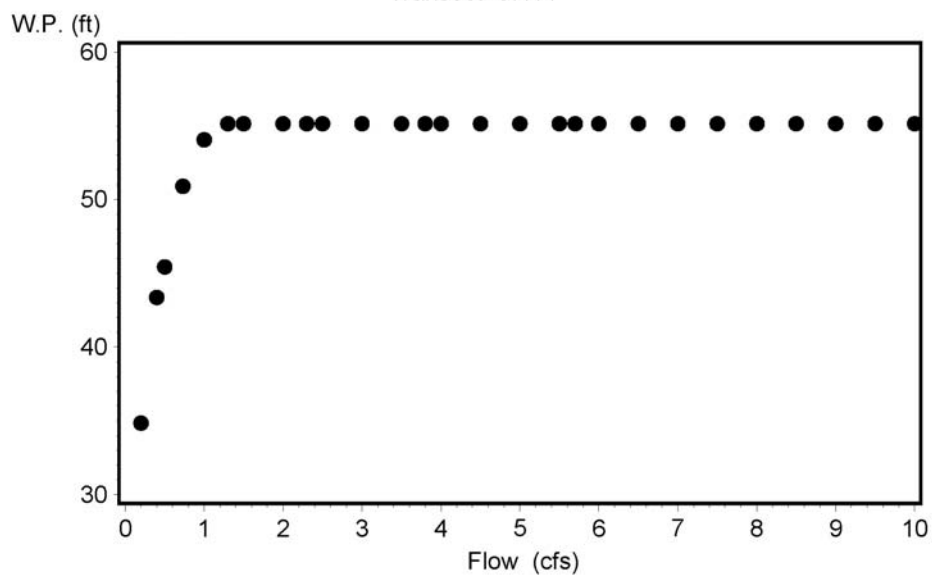
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Wetted Perimeter - River Flow Relationship
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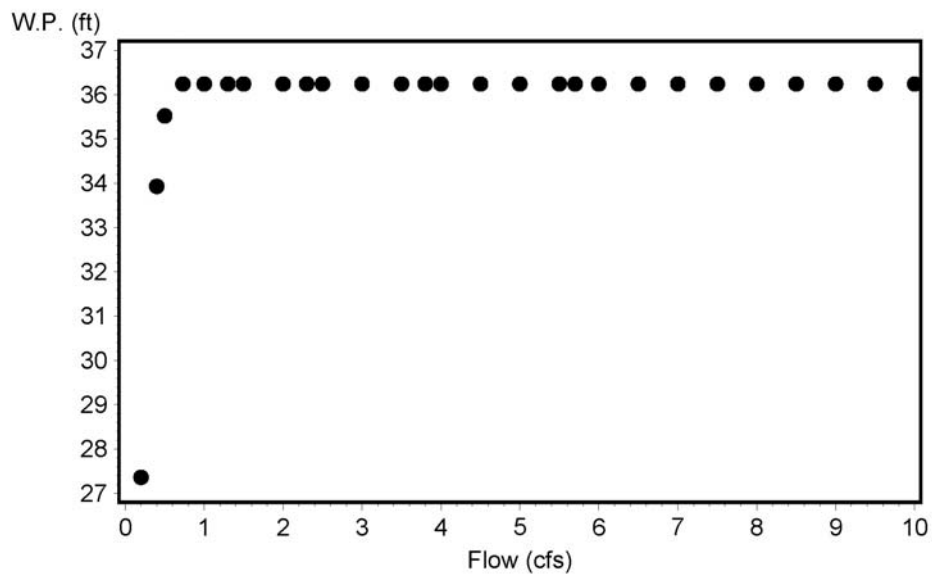
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 Wetted Perimeter - River Flow Relationship
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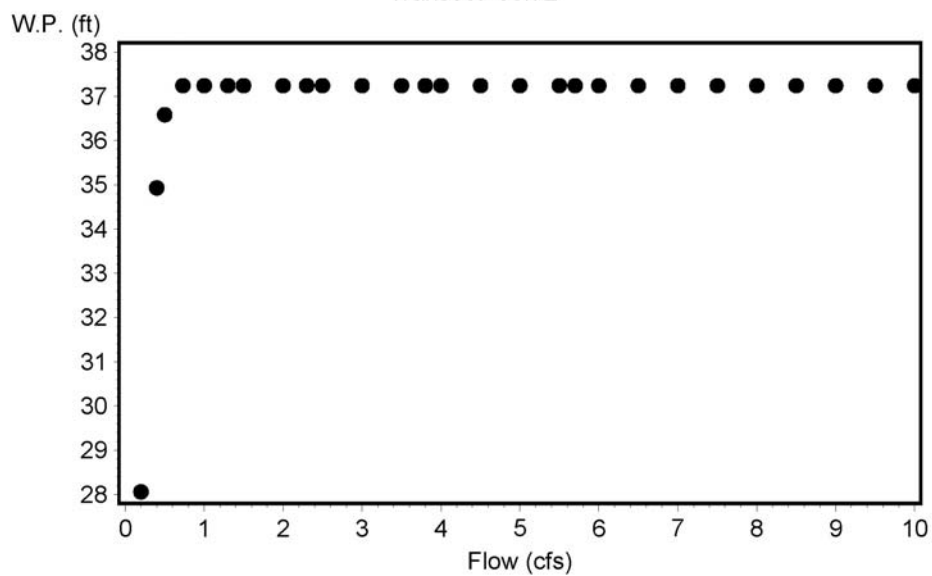
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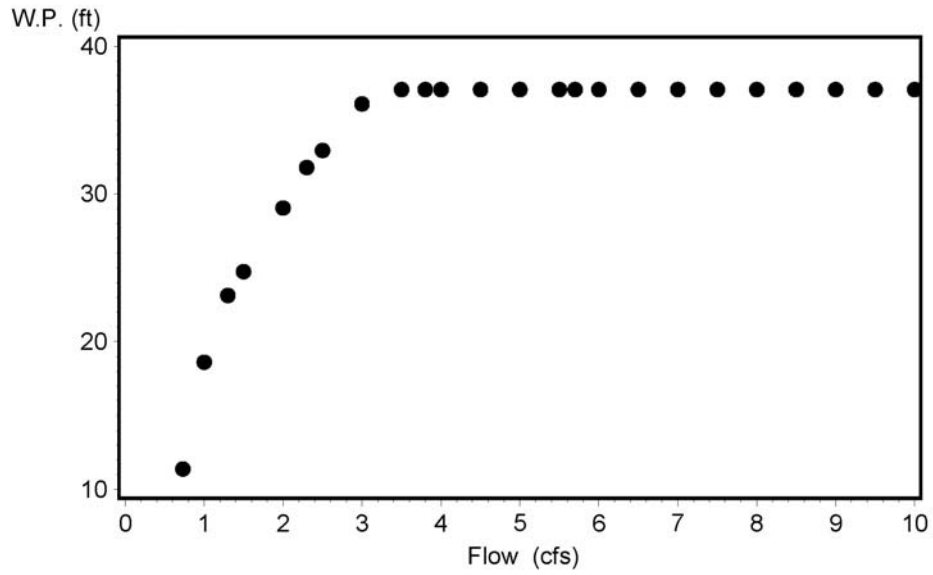
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Reach: Graham to Worthington Springs
Wetted Perimeter - River Flow Relationship
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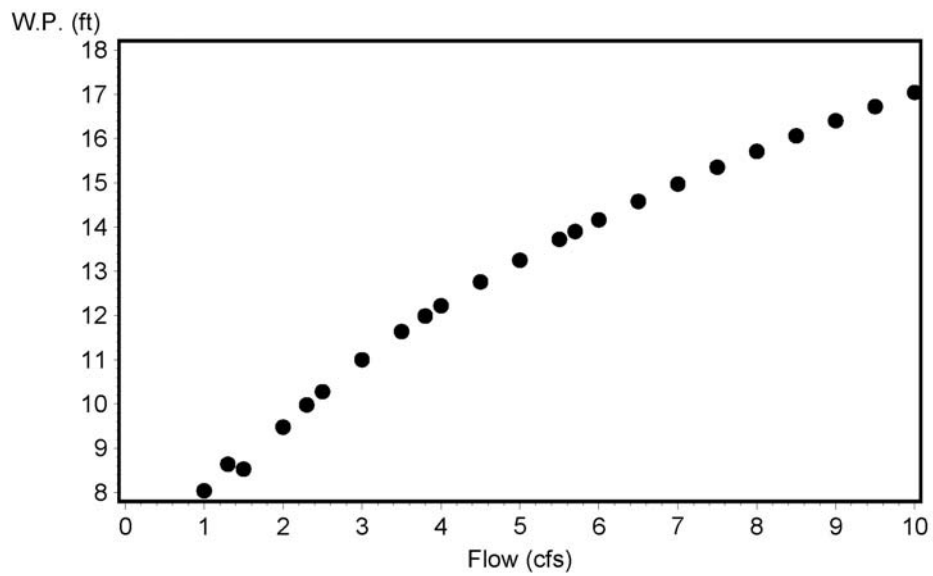
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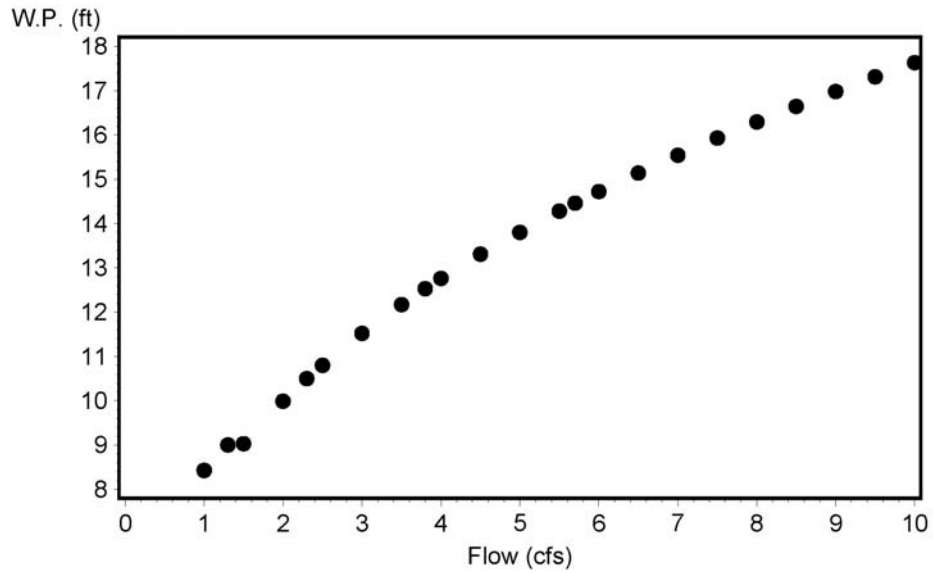
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 Reach: Graham to Worthington Springs
 Wetted Perimeter - River Flow Relationship
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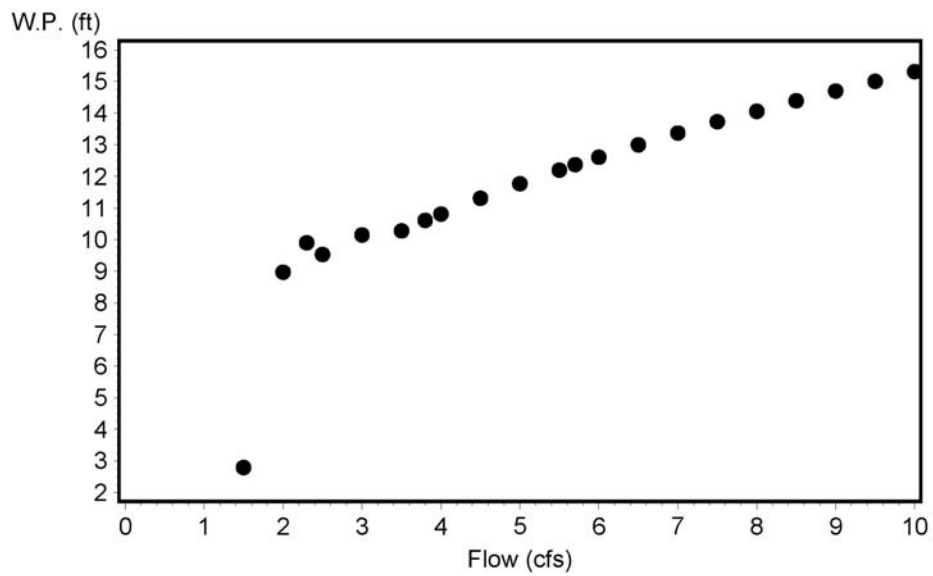
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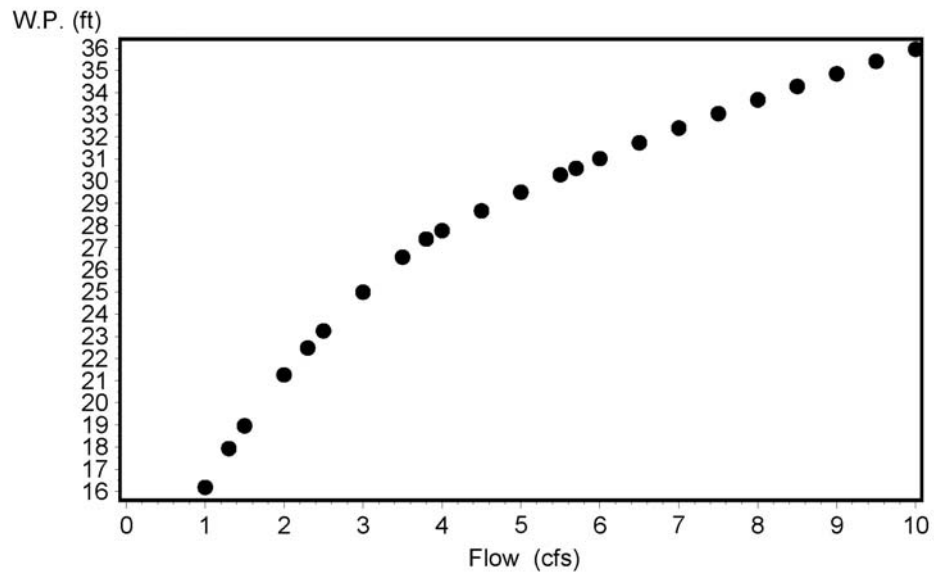
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Reach: Graham to Worthington Springs
Wetted Perimeter - River Flow Relationship
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Upper Santa Fe River
Reach: Graham to Worthington Springs
Wetted Perimeter - River Flow Relationship
Transect=69.45



Upper Santa Fe River
Reach: Graham to Worthington Springs
Wetted Perimeter - River Flow Relationship
Transect=70.18



TAB 6

6.0 Summary and MFL Recommendations

6.1 Upper Santa Fe River Study Area

The Santa Fe River originates in the Santa Fe and Little Santa Fe lakes in the northeast corner of Alachua County, Florida. It flows westward along the Alachua County line and eventually goes completely underground at a large sinkhole known as the Santa Fe Sink (or River Sink), near O'Leno State Park (Hunn and Slack, 1983; SRWMD, 1977). The total length of the river is approximately 70 miles (Nordlie, 1990), while the length of the portion above the sink is approximately 31 miles. The Santa Fe travels underground for approximately 3 miles before it resurfaces several miles north of High Springs at the Santa Fe Rise (River Rise). Because the Santa Fe travels underground for such length, the natural land bridge acts as a divider forming two distinct reaches of the river: the Upper Santa Fe and the Lower Santa Fe. The Santa Fe River drainage encompasses more sub-ecoregions (6) than any other river basin in Florida. The river drainage lies within portions of the Tifton Uplands/Tallahassee Hills, Central Florida Ridges and Uplands, Okefenokee Swamps and Plains, Sea Islands Flatwoods, Eastern Florida Flatwoods, and Gulf Coast Flatwoods subcoregions. This landscape diversity accounts for the high overall biological diversity exhibited in this river system. Only one major spring, COL61981 (Santa Fe Spring), occurs in the Upper Santa Fe River Basin.

In the Upper Santa Fe, the river and tributaries are fed mainly by surface runoff and seepage from the surficial aquifer. Flood peaks are more “flashy” in nature, owing to surface runoff during times of high rainfall. The shallow surficial aquifer provides low baseflow and groundwater input from the intermediate and Floridan aquifers are minimal (Mattson 1992 a, b).

6.2 MFL Evaluation Procedure

The evaluations performed for the establishment of MFLs for the Upper Santa Fe River were conducted with the following approach:

1. Compile all “best available information” relative to the water bodies;
2. Evaluate the ten specific water resource values (62-40, F.A.C.) for applicability to the water body in light of the potential for impact and the available data;
3. Evaluate the available information to determine the relationships between flow and/or level and the water resource or related ecology;
4. Identify the limiting target value(s) that, if protected from significant adverse impact, will protect all other potentially applicable criteria;
5. Recommend an MFL that will protect the water resource and related ecology from significant impact; and
6. Re-evaluate the ten specific water resource values to ensure potentially applicable values are sufficiently protected from significant risk.

6.3 MFL Evaluation Summary

As presented in Section 1, the following seven values were identified as potentially limiting conditions including recreation in and on the water; fish and wildlife habitats and the passage of fish; maintenance of freshwater storage and supply; aesthetic and scenic attributes; filtration and absorption of nutrients and other pollutants; sediment loads; and transfer of detrital material. Based on a relative impact ranking, data availability, and professional judgment, fish and wildlife habitats and the passage of fish was selected as the critical value that, if protected, would be most likely to protect the other potentially applicable criteria. As discussed in Sections 3 and 5, the Baseline FDC was developed using the period of record data (measured and

synthesized) and represent conditions upon which the MFL FDC was established. Unless the historic data upon which the MFLs were based change, the Baseline FDC remains unchanged as permitting proceeds. The MFL FDC is developed to represent the MFL, or significant impact, for the water body.

The development of an MFL for the Upper Santa Fe River based on the value of habitat was predicated on the need to:

- Maintain adequate physical habitat for production of macroinvertebrates with particular interest in the following taxa: Ephemeroptera, Trichoptera, Plecoptera, and the crayfish, *Procambarus spiculifer*, which is a preferred prey species of the Suwannee Bass and a secondary prey item for largemouth bass (Schramm and Maceina, 1986) in the Lower Santa Fe River;
- Maintain adequate physical habitat for those fish species that require higher velocities. Fish anticipated to require higher velocities were represented by the darters (Family Percidae). The protection of habitat for darters is also important because, as possible hosts for the glochidial larval stage, they may represent a critical path in the life stage of rare, threatened or endangered species of unionid mussels. Gore *et al.* (2001) have suggested that, because so little is known about the specific habitat requirements of all life stages of these mussels, that the protection of habitat needed to support the larval hosts may be more appropriate; and
- Ensure and maintain sufficient depth in the river to permit fish passage.

Three types of analyses were performed to determine which would be the most conservative protector of the water resource values. Analysis was performed using the wetted perimeter approach as an estimate of the amount of habitat available to aquatic organisms under different flow conditions. Fish passage analysis was used to determine the minimum flow necessary to allow 0.60 feet for fish passage through the most restrictive cross sections of the river. The Ecological Functions Model (EFM) was utilized to evaluate the minimum flow necessary to protect instream habitat conditions.

Upper Santa Fe River – Upper Segment (Graham to Worthington Springs)

1. The wetted perimeter analysis was more protective from risk due to additional withdrawals than either the EFM or minimum fish passage analyses.
2. The wetted perimeter results suggest a minimum flow represented by a control point of 2.3 cfs at the 75th percentile on a flow duration curve as measured at the Graham USGS gage as being protective of habitats preferred by the target biota.

Upper Santa Fe River – Lower Segment (Worthington Springs to Olustee Creek)

1. The wetted perimeter analysis was more protective from risk due to additional withdrawals than either the EFM or minimum fish passage analyses.
2. The wetted perimeter results suggest a minimum flow represented by a control point of 42 cfs at the 75th percentile on a flow duration curve as measured at the Worthington Springs USGS gage as being protective of habitats preferred by the target biota.

6.4 Recommended MFL Regimes

6.4.1 Proposed MFL for the Upper Santa Fe River at Graham

Figure 6-1 presents the baseline and proposed MFL FDCs for the Santa Fe River at Graham. Flow equivalent to, or less than, the 2.3 cfs threshold occurs 25 percent of the time according to the Baseline FDC. In order to protect the flow regime, it was determined that up to a 15 percent shift in the FDC could occur at flows in excess of the 2.3 cfs minimum limited by the flows not being less than the 2.3 cfs control point. The MFL FDC was, therefore, scaled so that up to a 15% flow reduction could occur at flows greater than 2.3 cfs and the available water would decrease to 0 cfs beginning at a recurrence probability of 75%, or 2.3 cfs. Table 6-1 and Figure 6-1 presents the Baseline and MFL FDCs and amounts of water available under different flows according to the proposed MFL FDC.

Table 6-1. Comparison of Proposed Baseline and MFL FDCs for the Upper Santa Fe River at Graham.

FDC	Discharge Exceedance Amounts (cfs)						
	5%	10%	25%	50% (Median)	75%	90%	95%
Baseline	201	128	52	15	2.3	0.4	0.2
MFL	171	109	44	13	2.3	0.4	0.2
Difference	30	19	8	2	0.0	0.0	0.0

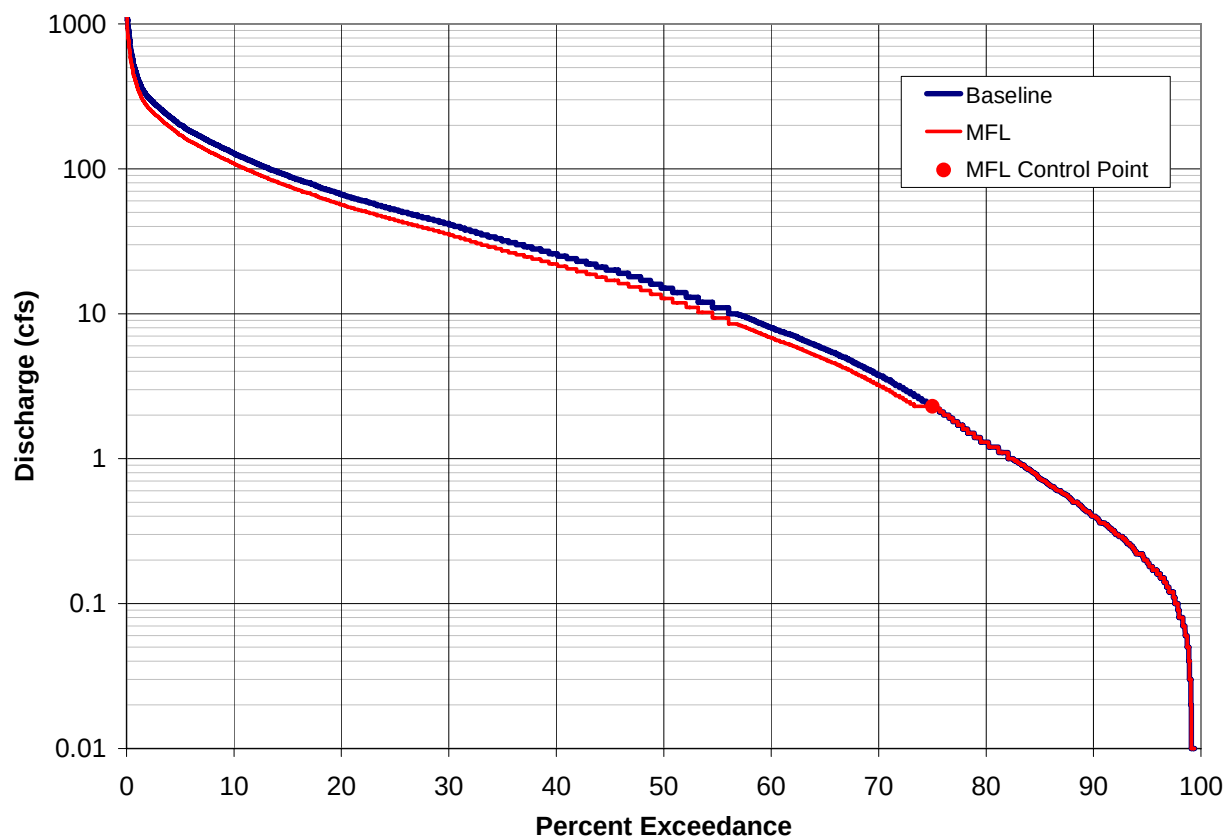


Figure 6-1. Comparison of Baseline and proposed MFL flow duration curves for Santa Fe River flow at the Graham gage.

6.4.2 Proposed MFL for the Upper Santa Fe River at Worthington Springs

The proposed MFL for the Santa Fe River at Worthington Springs is also designed to protect low flow conditions that could cause significant ecological risk to the ecosystem if their frequency changes. Flow equivalent to, or less than, the 42 cfs threshold occurs 25 percent of the time according to the Baseline FDC. In order to protect the flow regime, it was determined that up to a 15 percent shift in the FDC could occur at flows in excess of the 42 cfs minimum limited by the flows not being less than the 42 cfs control point. The MFL FDC was, therefore, scaled so that up to a 15% flow reduction could occur at flows greater than 42 cfs and the available water would decrease to 0 cfs beginning at a recurrence probability of 75%, or 42 cfs. Table 6-2 and Figure 6-2 presents the Baseline and MFL FDCs and amounts of water available under different flows according to the proposed MFL FDC.

Table 6-2. Comparison of Proposed Baseline and MFL FDCs for the Upper Santa Fe River at Worthington Springs.

FDC	Discharge Exceedance Amounts (cfs)						
	5%	10%	25%	50% (Median)	75%	90%	95%
Baseline	1,780	1,100	432	131	42	15	8.5
MFL	1,513	935	367	111	42	15	8.5
Difference	267	165	65	20	0	0	0

6.4.3 Final Qualitative Review of Water Resource Values

In order to determine if the recommended MFL avoids significant adverse impacts to each of the water resource values found in Chapter 62-40.473 F.A.C., the recommended MFL was evaluated with respect to the ecological and human use values for the Upper Santa Fe River, as discussed in Section 1.1 and summarized in Table 6-3.

It was determined in the evaluation of the “best available information” that the water resource value that provided the best opportunity to establish a MFL protective of all the identified applicable water resource values was “fish and wildlife habitats and the passage of fish”. Hence, even though there was not quantitative information available to discretely evaluate all the applicable water resource values identified in Section 1 of the Report, the MFL recommended for the protection of significant harm to “fish and wildlife habitats and the passage of fish” should be protective of the less conservative water resource values by a qualitative comparison.

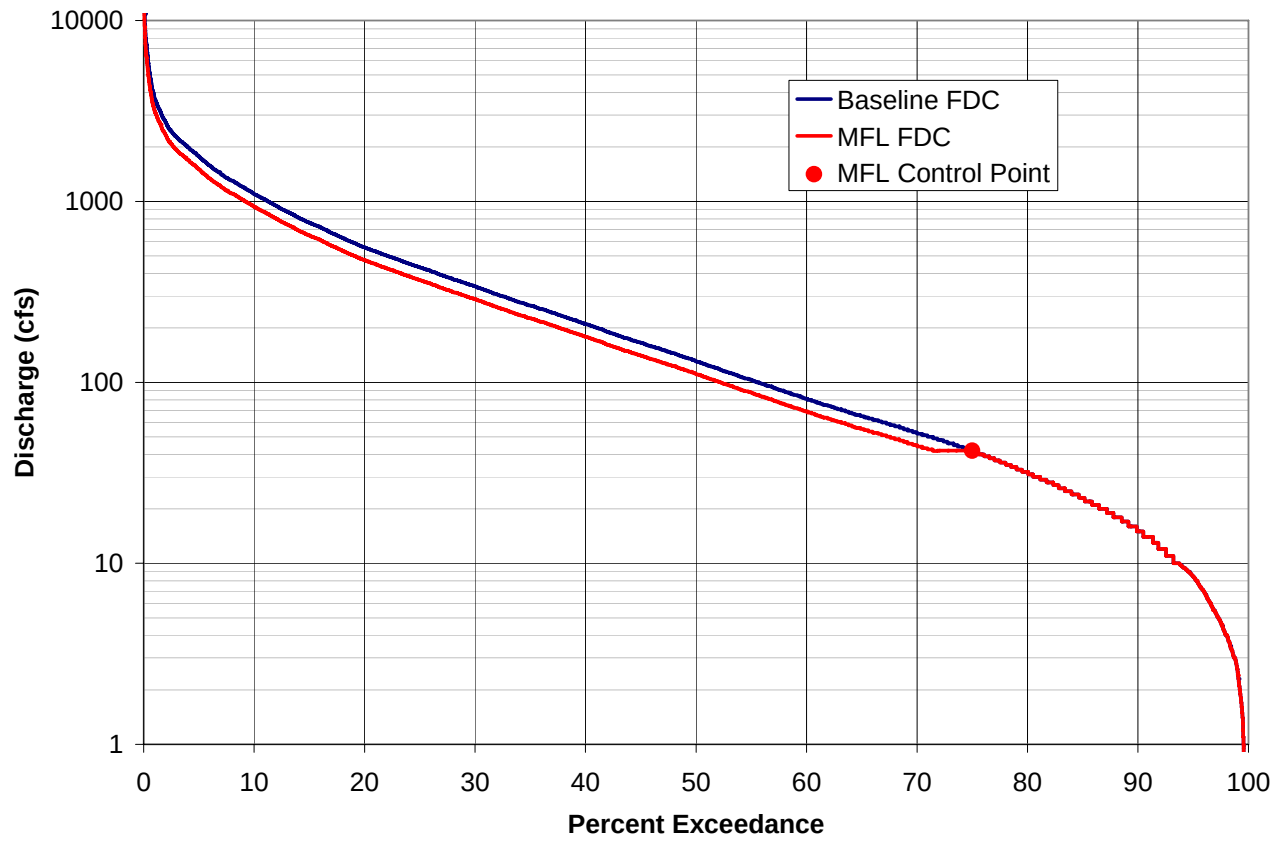


Figure 6-2. Comparison of the Baseline and proposed MFL FDCs for flow of the Upper Santa Fe River at Worthington Springs.

Table 6-3. Summary consideration for each water resource value for the Upper Santa Fe River Recommended MFLs.

ECOLOGIC & HUMAN USE VALUE	RECOMMENDED MFL IMPACT ON VALUE	DOES RECOMMENDED MFL ADEQUATELY ADDRESS VALUE?
Recreation in and on the water	Maintains fishing and boating opportunities by virtue of having at least 0.60 ft passage at all times	Yes
Fish and wildlife habitats and the passage of fish	Fish and wildlife habitats are maintained by virtue of fish passage, wetted perimeter and EFM analyses	Yes
Estuarine resources	NA	NA
Transfer of detrital material	Mid and high flow conditions are not significantly altered to affect the movement of detrital material I	Yes
Maintenance of freshwater storage and supply	Available water for future	Yes
Aesthetic and scenic attributes	River continues to flow at historically acceptable visual levels	Yes
Filtration and absorption of nutrients and other pollutants	Flow conditions are not significantly altered to affect vegetation for nutrient removal	Yes
Sediment loads	NA	NA
Water quality	Water quality is not impacted by flow	Yes
Navigation	NA	NA

Blue shading indicates applicable water resource value

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