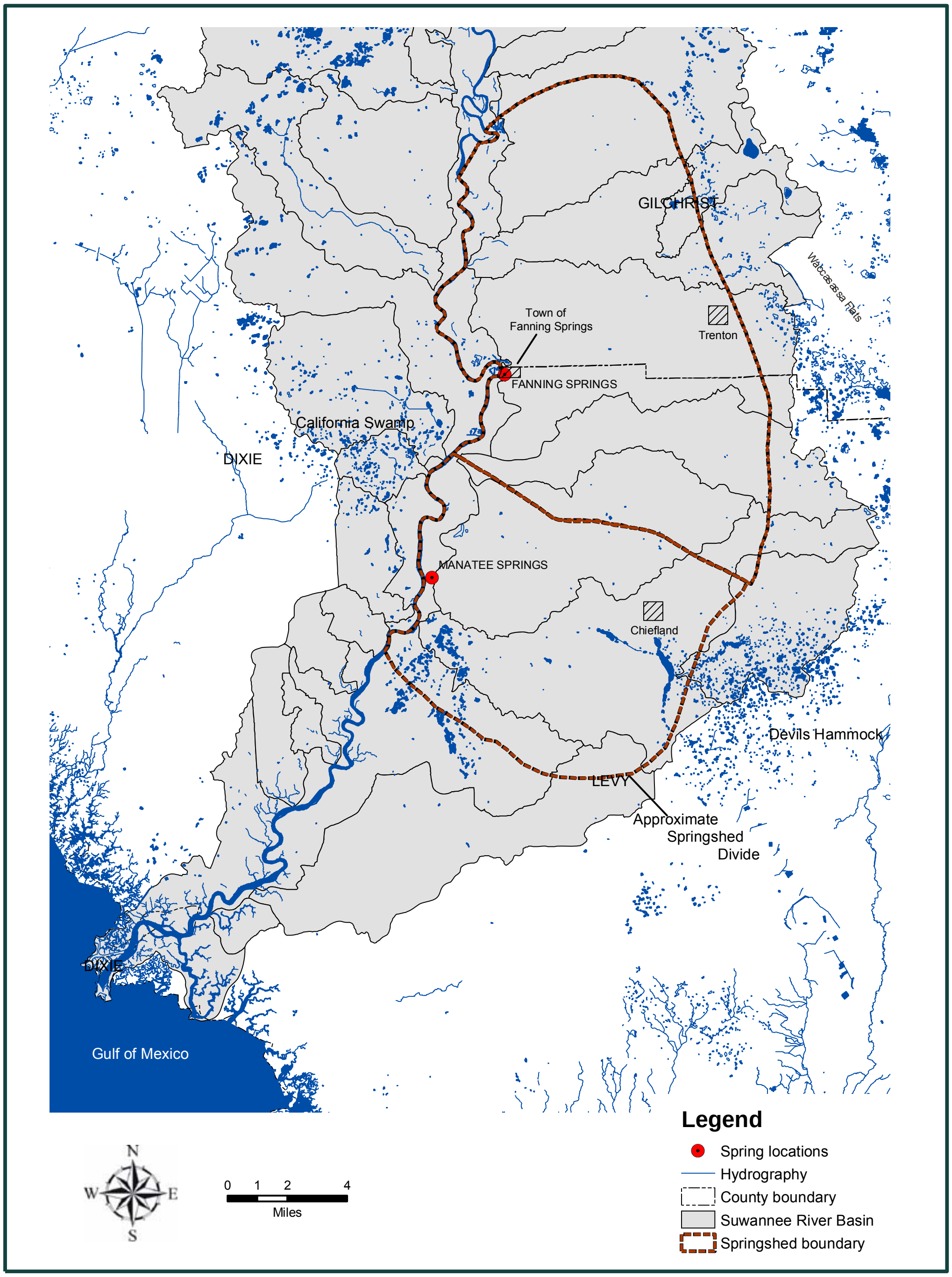

Figure 2-25. Study area showing the springsheds of Manatee and Fanning Springs. Data are from Upchurch and Champion (2003a).

2.3.2 Population and Water Use

2.3.2.1 Population Distribution

Two centers of population lie within the lower Suwannee study area and the Manatee-Fanning springshed (Figure 2.26). Chiefland, the largest population center in the study area, contains approximately 2,000 residents. Since 1960, the population of Levy County has increased 150 percent, from approximately 10,364 to 25,923 (U.S. Census Bureau, 2002). Even with this growth, the County retains a decidedly rural character, with a population density of approximately 31 persons per square mile.

The second center of population, Trenton, is a small community that contains approximately 1,617 residents. This town lies just north of the Gilchrist/Levy County line. Since 1960, the population of Gilchrist County has increased 237 percent, from approximately 2,868 to 9,667 (U.S. Census Bureau, 2002). Much like Levy County to the south, Gilchrist County is largely rural, with a population density of approximately 41 persons per square mile.

2.3.2.2 Land Use

Land use in the Lower Suwannee River/Manatee-Fanning springshed was identified using the 1996 USGS ARCView™ land-use coverage (Florida Geographic Data Library, 2004). Except for areas in and near Trenton and Chiefland, the study area is a sparsely populated region. The major land uses in the Lower Suwannee River/Manatee-Fanning springshed include pine plantations, improved pasture, hardwood conifer forests, wetland-mixed forests, temperate hardwood forests, and areas of forest regeneration (Figure 2-26). Together, these six land uses cover approximately 75 percent of the Lower Suwannee River/springshed.

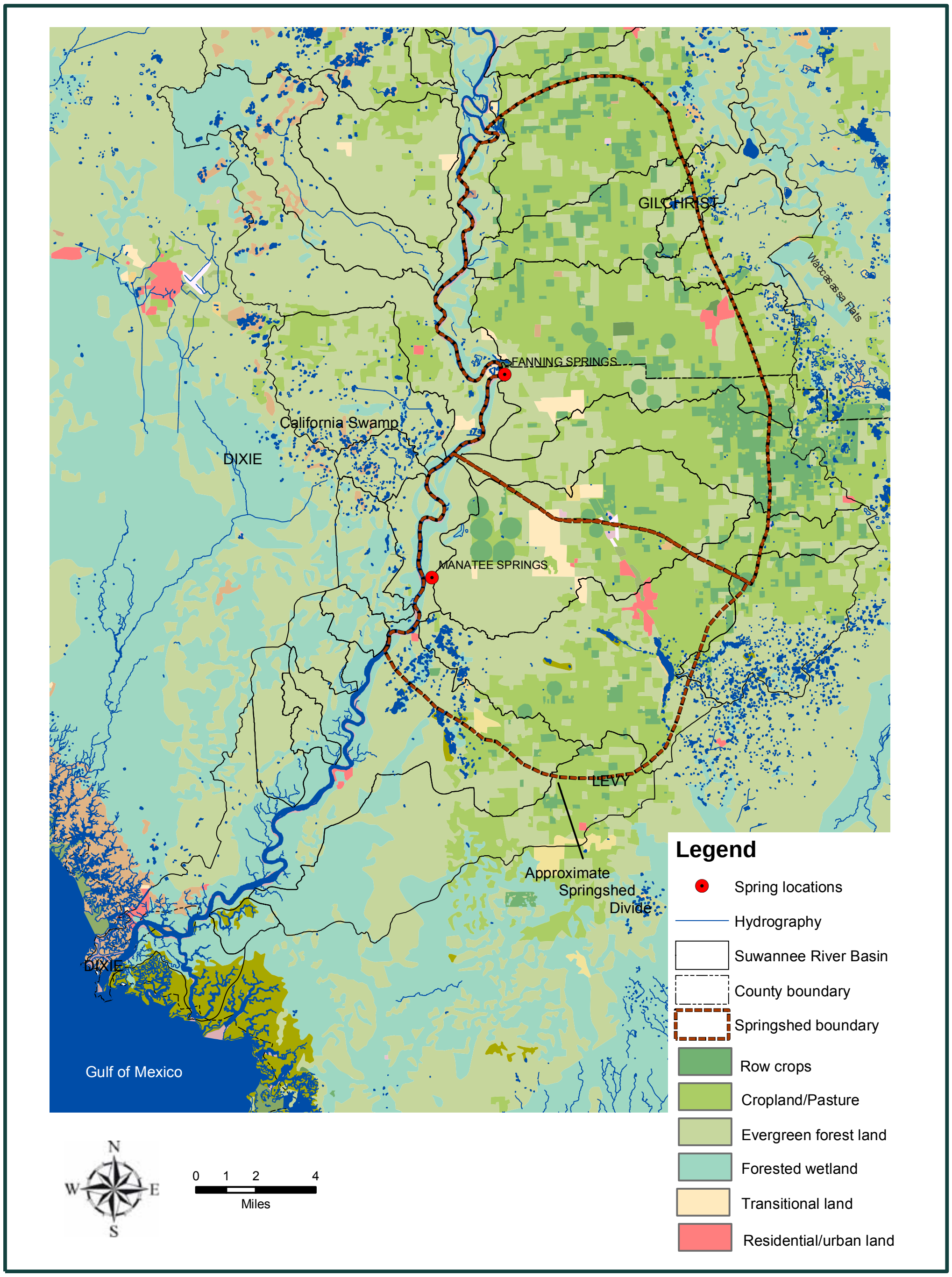

Figure 2-26. Major land uses in the Lower Suwannee River study area.

2.3.2.3 Water Use

According to estimates by WRA (2005), ground water was withdrawn from the Floridan aquifer in the District portion of Levy County at the rate of approximately 18.3 million gallons per day (mgd) in 2000. Agricultural withdrawals, commercial, industrial, mining and power, rural self-supplied, and public water-supply systems accounted for approximately 76 percent (13.9 mgd), 11 percent (2 mgd), 6 percent (1.1 mgd) and 6 percent (1.1 mgd), respectively, of the total withdrawals in the County (WRA, 2005). Total future water use in the District portion of Levy County is projected to be about 39.2 mgd in 2020, and 69 mgd in 2050, with agricultural withdrawals accounting for 80% of the total projected withdrawals (WRA, 2005).

Ground water was withdrawn from the Floridan aquifer in Gilchrist County at the rate of approximately 12.1 mgd in 2000 (WRA, 2005). Agricultural withdrawals, commercial, industrial, mining and power, rural self-supplied, and public water-supply systems accounted for approximately 90 percent (10.9 mgd), 2 percent (0.2 mgd), 6 percent (0.7 mgd) and 2 percent (0.2 mgd), respectively, of the total withdrawals in the County (WRA, 2005). Total future water use in Gilchrist County is projected to be about 11.5 mgd in 2020, and 14.5 mgd in 2050, with agricultural withdrawals accounting for only 66% of the total projected withdrawals by 2050 (WRA, 2005).

2.3.3 Topography, Physiography, and Drainage

The topography of the Lower Suwannee River/Manatee-Fanning springshed is somewhat subdued. Land-surface elevations range from sea level along the coastline to areas in excess of 75 feet above sea level in higher regions to the northeast of the springshed (Figure 2-27). In the immediate vicinity of the river and springs, however, elevations are typically less than 25 feet above sea level.

White (1970) divided Levy County and the Lower Suwannee River region into three physiographic regions: the Coastal Swamps, Gulf Coast Lowlands, and Bell Ridge. Bell Ridge is a broad upland area that lies to the west of the Waccasassa Flats (Figure 2-28). In contrast, the Gulf Coast Lowlands (typically less than 100 feet above sea level) is a mature, karst plain characterized by rapid infiltration of runoff, and few, if any, lakes or wetlands (Figure 2-28). Sinkholes in the Coastal Lowlands (Figure 2-29) are typically small in area, but they are numerous (Upchurch, 2002). The Coastal Swamps lie along the coastline and are generally less than 10 feet above sea level. The Coastal Swamps are lowlands containing an abundance of tidal creeks, forested wetlands, and marsh habitats. There are relatively few sinkholes in the Coastal Swamps due the thin veneer of sand and organic-rich sediments that overlie the limestone, to which prohibits the formation of large sink features.

Between the Waccasassa Flats and the Manatee-Fanning springshed is a transitional region characterized by an abundance of large sinkholes (Figure 2-29). Hydraulically, this transitional area behaves very similarly to the Cody Scarp (White, 1970), where sinkholes and sinkhole-related karst features tend to be large and recharge is relatively high (Upchurch, 2002; Upchurch and Champion, 2003b, 2004).

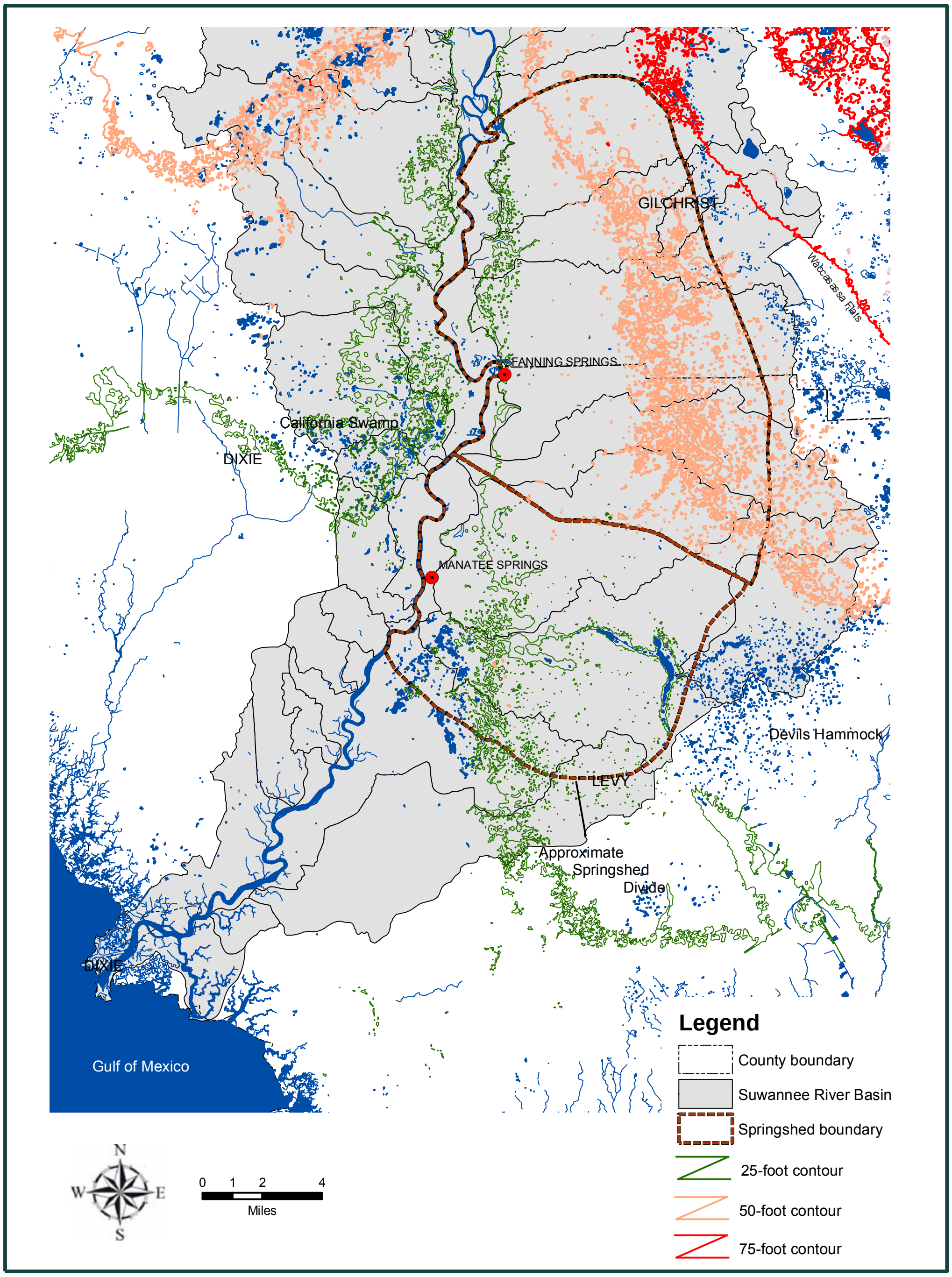

Figure 2-27. Topography of the Lower Suwannee River Study Area.

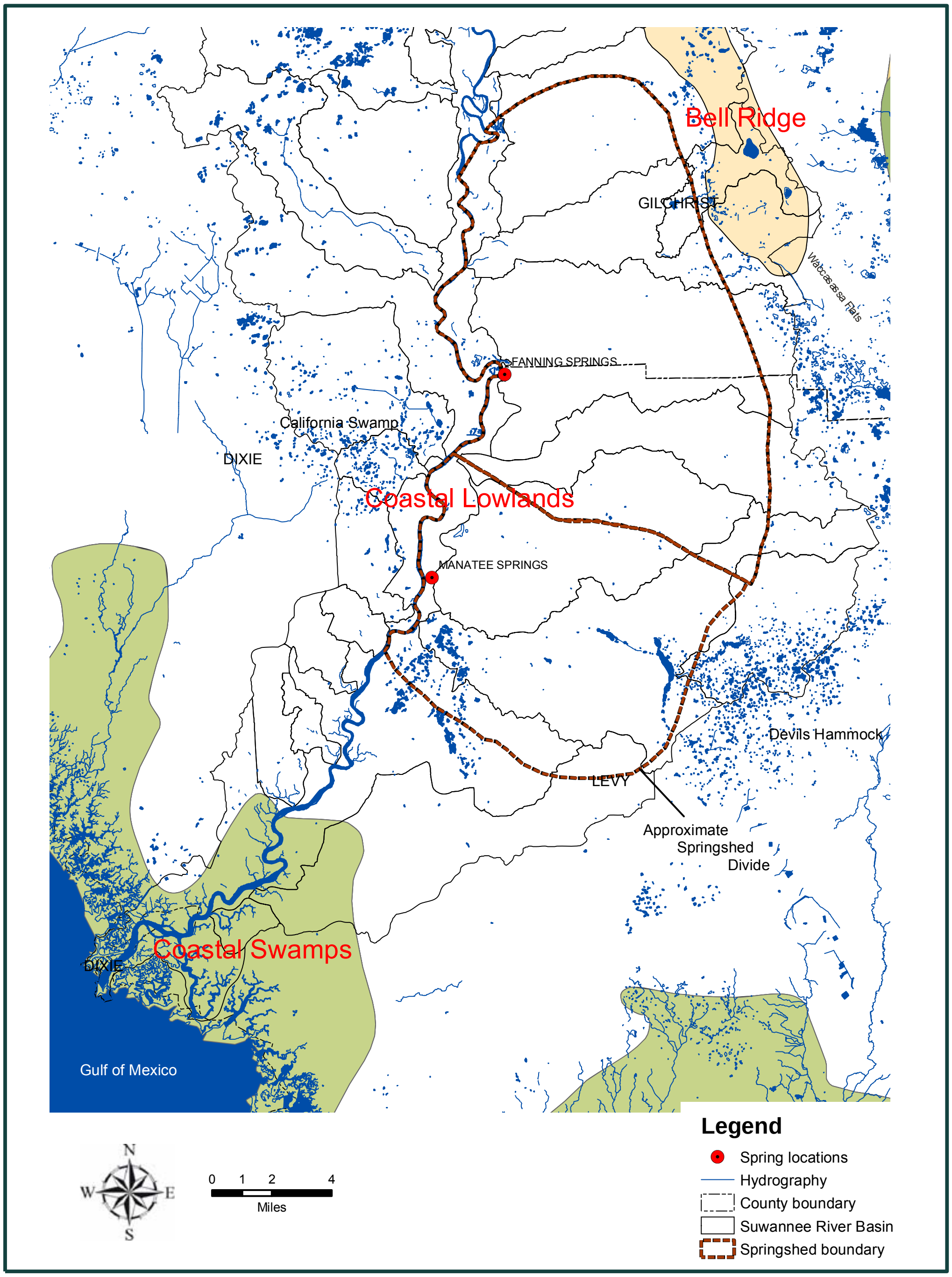

Figure 2-28. Physiographic regions in the Lower Suwannee River study area.

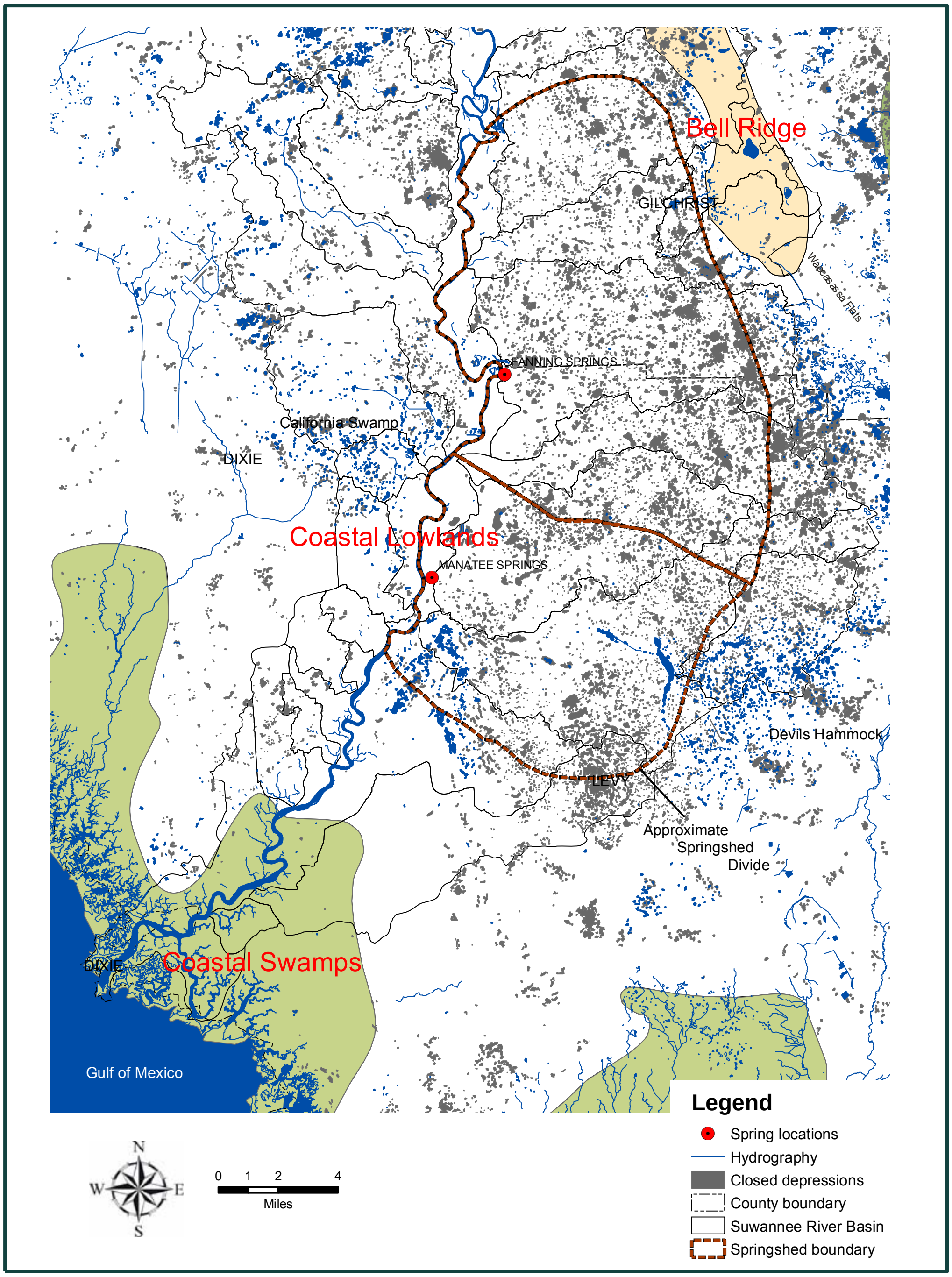

Figure 2-29. Closed depressions (sinkholes and other karst features) in the Lower Suwannee study area.

2.3.4 Geology and Hydrology

2.3.4.1 Local Stratigraphy and Geomorphology

Figure 2-30 is a geologic map showing the stratigraphic units at or near land surface in the Lower Suwannee River/Manatee-Fanning springshed. Thick sequences of limestone are exposed at or very near (10-20 ft.) the land surface in many parts of the study area, especially along the Suwannee River. Where limestone is near land surface, the thin veneer of sediment that covers the limestone consists of Quaternary-age, unconsolidated to poorly indurated, siliciclastic deposits dominated by quartz sand. These sands are primarily marine terrace deposits.

The uppermost limestone units in the study area include the Ocala Limestone and Avon Park Formation, both of Eocene age. The major carbonate unit in the study area is the Ocala Limestone, which lies at or near land surface throughout much of the region (Figure 2-30). Based on well cuttings, Crane (1986) described the Ocala Limestone in the study area 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 Florida. In the study area, the early Eocene age 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 the study area (Crane, 1986). The Ocala Limestone and the Avon Park Formation comprise the Floridan aquifer in the Manatee-Fanning springshed.

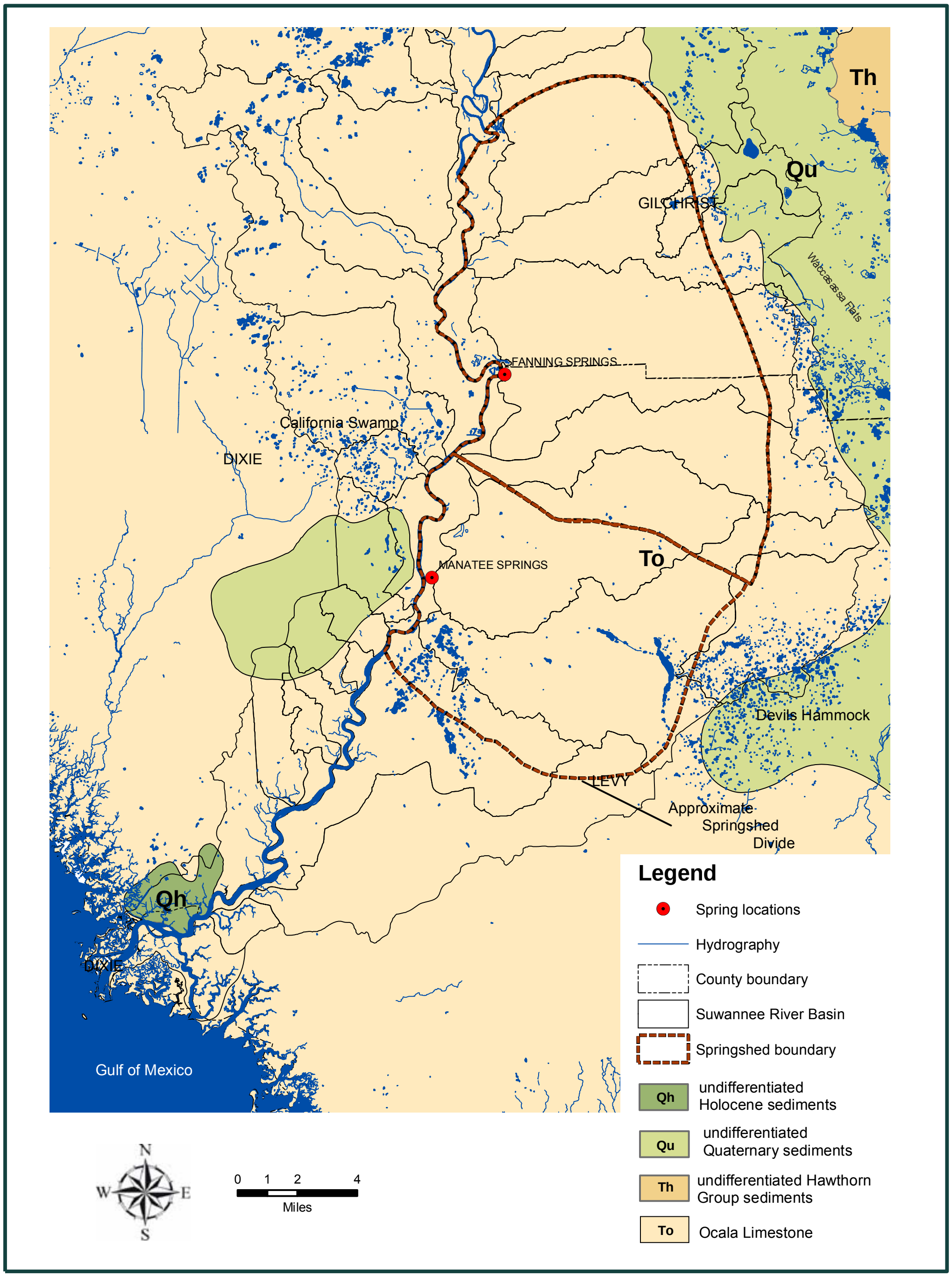

Figure 2-30. Geologic map of the Lower Suwannee River study area.

In Bell Ridge, the carbonate units of the Floridan aquifer are overlain by Pleistocene-Holocene, undifferentiated sand (Figure 2-31). This sand was apparently deposited as part of a barrier-island system during periods of higher sea level over the last several million years. Sand hills along the margin of the Bell Ridge originated as dune features (Puri and others, 1967).

2.3.4.2 Surfacewater Hydrology

Surfacewater features are abundant in the eastern and southwestern portions of the Manatee-Fanning springshed (Figure 2-31). These areas correspond to the Waccasassa Flats and Devils Hammock, respectively. As noted by Upchurch et al. (2005), these wetland areas are important hydrologic boundaries to the Manatee-Fanning springshed. To the west of the springshed in Dixie County lies the California Swamp. This wetland area covers a significant amount of eastern Dixie County and, as will be shown later in this report, has imparted subtle water-quality characteristics that differ from Floridan aquifer ground water in Levy-Gilchrist portions of the study area.

The lack of streams and rivers throughout much of the Lower Suwannee River/Manatee-Fanning springshed study area results from a well-developed underground drainage system in the Floridan aquifer. Recharge to the Floridan aquifer is relatively high in the Lower Suwannee River/Manatee-Fanning springshed because Hawthorn Group sediments are generally absent and the limestone is at or near land surface. In addition, the sandy soils that mantle the limestone are generally well drained and porous.

2.3.4.3 Karst and Groundwater Hydrology

The lower Suwannee River/Manatee-Fanning springshed study area is an area of intensive karst development, characterized by numerous sinkholes, lack of surface drainage, and undulating topography (Figures 2-27and 2-29). In karst areas, the dissolution of limestone has created enlarged cavities along fractures in the limestone, which eventually collapse or reach the 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 increasingly larger amounts of water to be transported through the groundwater system.

Ground water may flow rapidly through conduits and passages with the limestone, or slowly through minute pore spaces within the rock matrix. Dye-trace studies in Columbia County show that ground water near Ichetucknee Springs may travel approximately one mile per day in active conduits in the Floridan aquifer (Karst Environmental Services, 1997). Similar velocities were recorded near Sulphur Springs in Hillsborough County (Stewart and Mills, 1984). Studies such as these clearly indicate that ground water has the potential to flow rapidly and traverse great distances in a short amount of time in karst environments near major springs. 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.

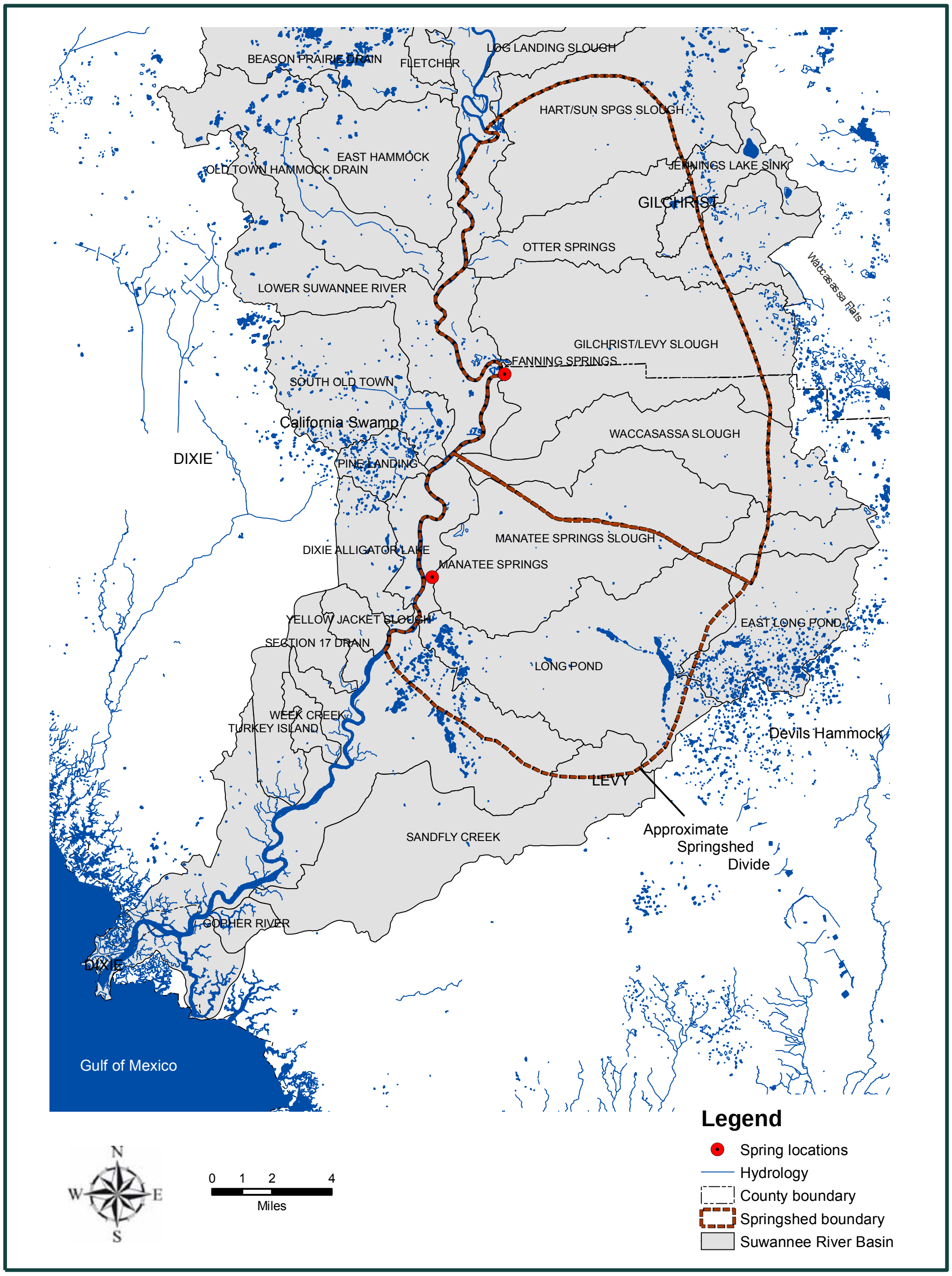

Figure 2-31. Hydrolographic features in the Lower Suwannee study area.

Recent studies by the USGS and SRWMD have demonstrated that much of the spring water in northern Florida (and the study area) has been in the Floridan aquifer for an average of 10-25 years (Katz et al., 1999). This estimate is based on age-dating techniques using chlorofluorocarbons (CFC's) derived from the use of aerosol propellants and refrigerants. These CFC compounds, released into the atmosphere over the last 50 years, have dissolved in precipitation that recharges ground water (Katz and Hornsby, 1998). The occurrence of CFC's in spring water in the study area indicates that, while a portion of the ground water moves quickly through conduits in the Floridan aquifer, much of the water percolates slowly through the soil and into the aquifer. Once the ground water recharges the aquifer, it begins moving through the smaller pores and openings in the limestone before reaching an active conduit or spring vent. The slower movement of ground water through the aquifer is known as diffuse flow. Because of the diffuse flow and ability of the limestone matrix to improve ground water quality, the springs are typically clear and free of most contaminants.

2.3.4.4 Groundwater Hydrology

2.3.4.4.1 Recharge

Recharge to the Floridan aquifer 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. Such conditions occur throughout the study area. Recharge may also be high in areas where the confining layers are breached by karst features, such as sinkholes (Figure 2-29). Other factors affecting recharge rates include the development of surfacewater drainage; variations in water-level gradients between surface water, 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 water-level gradient exists between the Floridan and surficial aquifers. Figure 2-32 shows the estimated recharge potential of the Floridan aquifer in the study area.

Katz et al. (1999) estimated the "average" dates of recharge at Fanning Springs to range from 1983-1984 based on CFC-113 concentrations. Manatee Springs recharge date estimates ranged from 1975 (CFC-11) to 1986 – 1988 (CFC-113). These dates do not suggest that all of the water discharging from these springs recharged the aquifer less than 20 years ago. It clearly indicates, however, that movement of water through the aquifer is dynamic and rapid. It also indicates the high vulnerability of the springs to activities in their watersheds.

2.3.4.4.2 Potentiometric Surface

The potentiometric surface of the Floridan aquifer in the Lower Suwannee River/Manatee-Fanning springshed study area is shown in Figure 2-33. Some distinctive features are visible on the potentiometric surface map. Most importantly, the areas where the contour lines are widely spaced reflect areas where the Floridan aquifer is highly permeable. The low potentiometric-surface relief area immediately east of the Suwannee River represents a region of well-developed karst. This karst region is several miles wide and extends from the Suwannee River eastward to Trenton and Chiefland. The slope of the potentiometric surface in this area is low and averages roughly 1 to 2 feet per mile (Upchurch and others, 2005). On the other hand, the closely-spaced isopleths in Dixie County and the Waccasassa Flats/Devils Hammock east of the river indicate regions where the Floridan aquifer has lower permeabilities and flow is less dynamic. In these regions, the slope of the potentiometric surface is much steeper and averages 5 to nearly 10 feet per mile (Upchurch and others, 2005). The close proximity of the steep potentiometric-surface contours west of the Suwannee River suggests that there is minimal contribution of ground water to the river or springs from west of the river.

The Manatee-Fanning springshed boundary is also shown on Figure 2-33. This springshed was delineated by geostatistically analyzing water levels from approximately 100 monitor wells within western Gilchrist and Levy counties. As may be noted, the springshed boundaries do not match well with the May 1995 potentiometric data. This is because the springshed boundaries change in response to water levels in the Floridan aquifer. In general, the eastern edge of the springshed could be approximated by the 20-foot isopleth on Figure 2-33. Given the elevation of the potentiometric surface in the study area, an "average" groundwater basin boundary between the two springsheds, was drawn by Upchurch and Champion (2004).

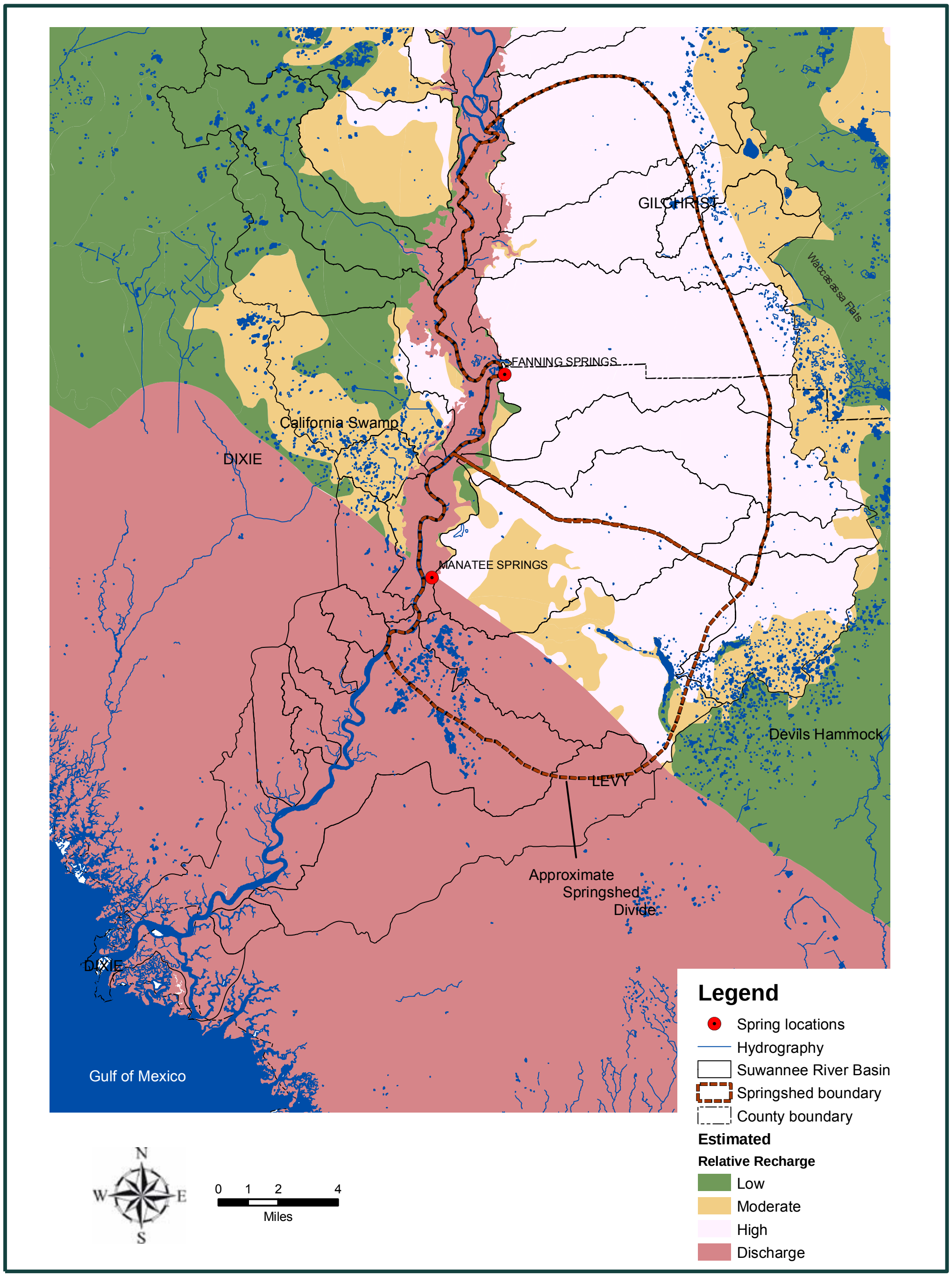

Figure 2-32. Relative groundwater recharge in the Lower Suwannee River study area.

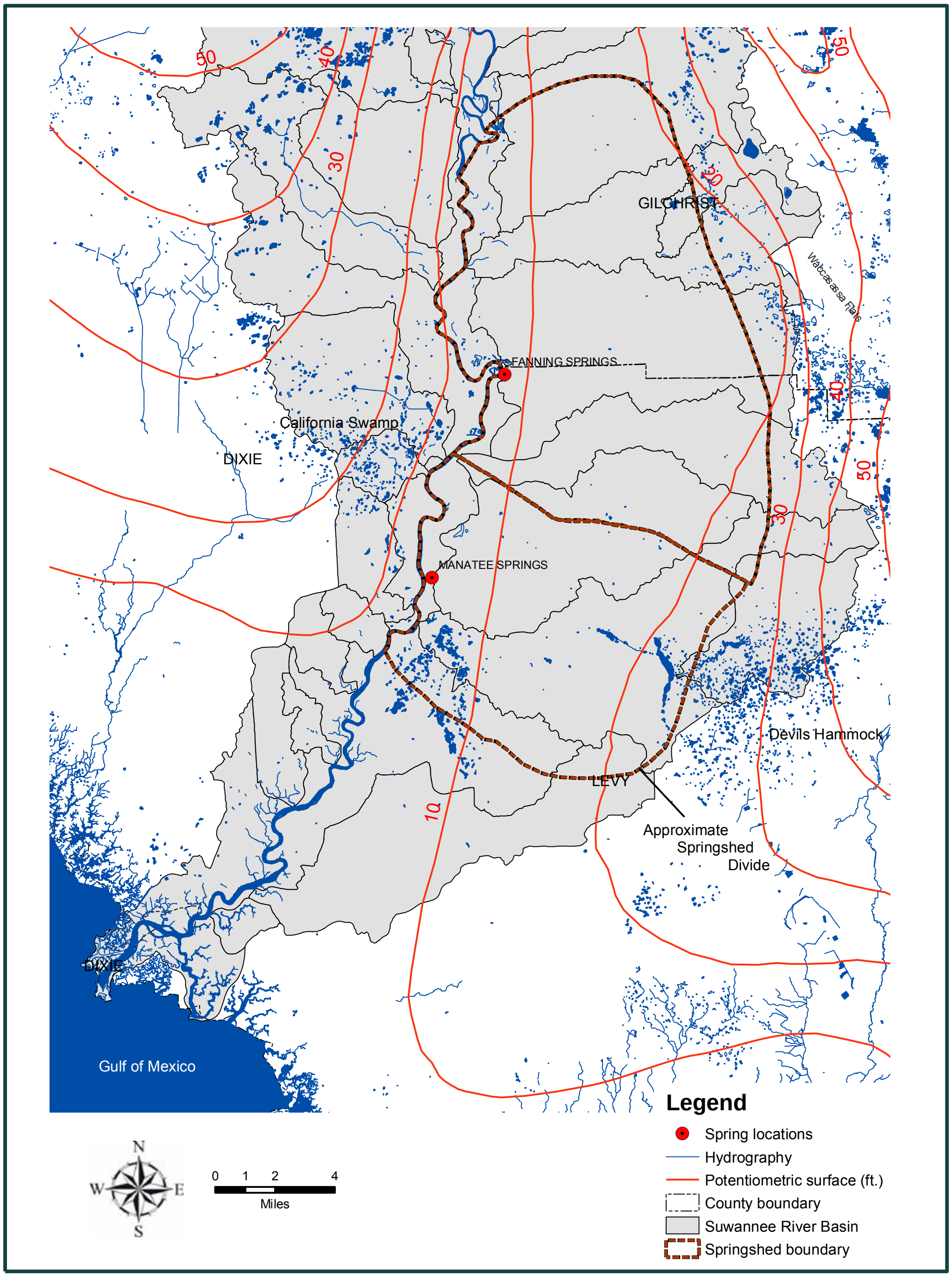

Figure 2-33. September 1995 potentiometric surface of the upper Floridan Aquifer in the study area.

2.3.4.4.3 Groundwater Chemistry

Previous groundwater investigations have indicated that the chemistry of ground water in north Florida is affected by a number of geologic, hydrologic, and anthropogenic (man-made) factors. These include 1) residence time in the aquifer, which affects the amount of dissolution of limestone, 2) the thickness and mineralogy of the Hawthorn Group sediments, 3) recharge rates (Lawrence and Upchurch, 1976; Crane, 1986; Upchurch, 1992), and 4) the presence of agricultural and other land uses in areas near the springs (Katz et al., 1999). In addition, data presented by Katz et al. (1999) suggest that much of the water discharging from the springs has moved through a relatively short, shallow flow system and has been in the Floridan aquifer for only a few decades, at most.

Regional groundwater quality outside and within the study area has been characterized by Upchurch (1990, 1992). The SRWMD updates the results of nitrate monitoring in its Groundwater Quality Monitoring Reports on an annual basis (Hornsby and Ceryak, 1999), as well.

Overall, ground water in the Floridan aquifer in the lower Suwannee River is fresh and is classified as a calcium-bicarbonate water type, reflecting the dissolution of limestone in the aquifer. A thin band of saline or brackish ground water may be found in the lower Suwannee River basin near the coastline. The temperature and chemical quality of ground water in the lower Suwannee River suggest rapid recharge to the Floridan aquifer over large areas and regional discharge along the course of the Suwannee River and in coastal areas (Upchurch, 1990).

Water quality discharging from springs in north Florida has been characterized in a number of studies, including Rosenau and others (1977), Hornsby (1998), Katz et al. (1999), Scott et al. (2002), and Upchurch and Champion (2003a, 2003b, 2004). In general, the water is of excellent quality, but there is concern for increasing nitrate-nitrogen concentrations in several of the springs within the District, including Manatee and Fanning Springs.

2.3.5 Fanning and Manatee Springs

2.3.5.1 Function of Springs as Estavelles

An estavelle is a spring that reverses flow when the receiving water (i.e., the Suwannee River) stage is higher than the potentials in the aquifer at the spring throat. Both Fanning and Manatee Springs act as estavelles when the Suwannee is in flood. The patterns of Fanning Spring discharge and stage (Fig. 2-34) illustrate this function of the springs.

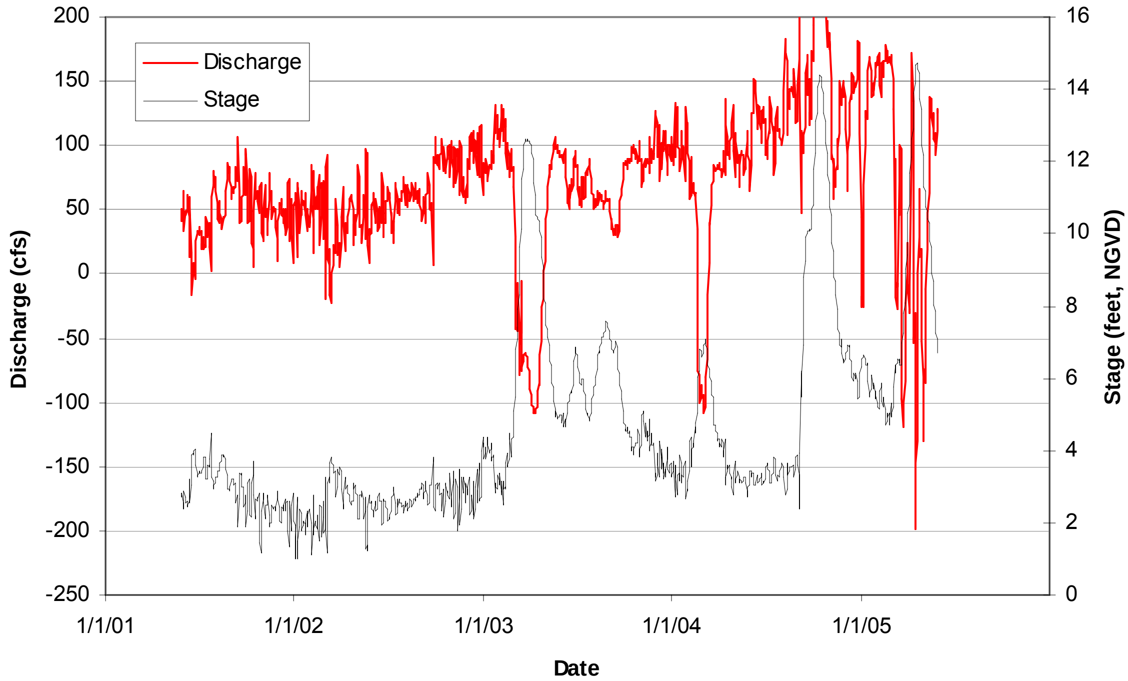

Figure 2-34 - Comparison of continuous stage at Wilcox with AVM discharge measurements at Fanning Spring.

As illustrated in Figure 2-34, when the stage of the river at Wilcox reaches approximately 9 feet NGVD, the flow from Fanning Spring ceases and then reverses. The reversal in flow in March, 2003, illustrates this phenomenon. Note that the pattern repeated in April, 2005. The coincident peaks in October, 2004, are unexplained and may reflect data acquisition problems.

The importance of estavelle action by springs is unclear. Colored river water enters the aquifer and temporarily reduces groundwater quality. Typically, the river water is discharged from the spring in a short time once the stage is lowered sufficiently. It is thought that introduction of river water into the cavern system may supply detritus to cave-dwelling aquatic organisms, but similar fauna exist in caves where estavelle springs are not present.

Also, it is clear that river stage forces estavelle processes. Increasing or decreasing spring discharge has little or no impact on the frequency or duration of flow reversals in the springs. Therefore, regulatory spring discharge to control backflow is ineffectual.

2.3.5.2 Fanning Springs

2.3.5.2.1 Introduction

Fanning Springs State Park is located in the city of Fanning Springs, Levy County, Florida. The park is a State Recreation Area, and its 204± acres (Division of Recreation and Parks, 2003) are being developed for multiple uses centered around the spring and adjacent Suwannee River. Two springs are found within the park. Fanning Springs consists of the main spring (Fanning Spring) and Little Fanning Spring.

Figure 2-35a. View of Fanning Spring in June, 2005. Note the diving area and "beach".

Fanning Spring - Fanning Spring is historically a first magnitude spring but flows as a second magnitude spring based upon modern, continuous data. Scott et al. (2002) provide some morphometric descriptive data: the main spring has an oval-shaped pool roughly 200 by 140 feet in area with depths to about 16-17 feet. The run to the Suwannee River is about 450 feet in length. Much of the bottom area of Fanning Spring and its run consists of course to medium sand with some areas of exposed limestone in the headspring basin (Figure 2-35a), which is approximately 20 feet in depth, depending on river stage. Discharge from the spring ranges from 32 cfs to 188 cfs. Median discharge for the period of record is 90 cfs and average discharge is 94 cfs.

Figure 2-35b. View of Fanning Spring in December, 2001 – a period of low flow. The USGS gage is located on the diving tower, which is located over the spring vent.

Figure 2-35a illustrates the spring bowl as seen from the southwest. The vent is to the right of the diving platform. Figure 2-35b illustrates the spring bowl during low discharge and stage. Note the location of the gage used by the USGS to measure spring discharge on the diving tower.

Figure 2-36a. View of Fanning Spring run during low river stage in December, 2001. Note the floodplain and small shoal near the mouth of the run.

Figure 2-36b. View of the Fanning Spring run in December, 2001 – a period of low flow. The floating dock separates the spring from its run and may provide a barrier to manatee entry during periods of low flow.

There is a spring run (Figure 2-36a) approximately 100 feet in width, depending on river stage, and 450 feet in length. Depth in the run is approximately 10 feet. The bottom is predominantly sand with algae. A floating dock/swimming platform (Figure 2-36b) separates the bowl from the run and boat traffic can enter the run to the dock. The boat traffic may be responsible for maintaining the depth and absence of submerged aquatic vegetation in the run.

Figures 2-36a and 2-36b show the run during low flow. A staff gage is located on the left (south) bank near the river.

Increased recreational use has resulted in bank erosion and sedimentation in the spring bowl. The spring is undergoing restoration and development as a recreation area. In addition to a terraced area for sunbathing, the banks of the spring are being protected and debris is being removed from the spring bowl. According to SRWMD personnel (Hornsby, 2005, pers. communication), the spring throat may have been dynamited sometime prior to 1970. The vent area was dredged in 2002, but large blocks of rock were not removed. Submerged aquatic vegetation was replanted on the slopes of the spring bowl at that time.

According to the Division of Recreation and Parks (2003), the most important designated species in the park is the manatee. Manatee visit the park at any time of the year, but it primarily is used as a thermal refuge during colder months (November through April). At other times, the manatee visit the spring while foraging in the river. A major goal of the Park Service is manatee access, especially as a thermal refuge (Division of Recreation and Parks, 2003).

Little Fanning Spring - Little Fanning Spring is a low, historic, second magnitude spring with discharge that has ranged from 1 to 30 cfs (based on 9 measurements from 1987 to 2004). According to District staff (Hornsby, 2005, pers. communication), the spring has been observed to not be flowing on numerous occasions. Median discharge is 18 cfs, and average is 16 cfs.

Figure 2-37a . View of Little Fanning Spring in June, 2005. Note the fissure from which the spring discharges.

Figure 2-37b. View of the Little Fanning Spring run in June, 2005. Cypress dominates the small valley that constitutes the run.

The spring emerges from a limestone exposure (Figure 2-37a) on the north side of a small valley, which is characterized by cypress and hardwoods (Figure 2-37b). Walsh and Williams (2003) provided some morphometric description of Little Fanning Spring. The headspring is a seep area that feeds a narrow spring run which extends about 1000 feet to the Suwannee River. The substrate of the run consists of exposed limestone and course to medium sand. The northern shore of the run is characterized by limestone exposures with numerous solution channels and other karst features. According to the Division of Recreation and Parks (2003), limestone exposures in the Little Fanning run are thought to have been mined in the past.

The park management plan (Division of Recreation and Parks, 2003) indicates that portions of the Little Fanning valley have been developed, and there is debris remaining. There was also apparently a small dam in the spring run, which was removed by the park service (Division of Recreation and Parks, 2003, Appendix A).

Relationship of Springs to the River - As will be explained in Section 3, discharge and stage in Fanning Spring and its run are controlled by stage of the Suwannee River. Discharge from Little Fanning Spring is a function of the stage of the Fanning Spring pool. Stage in the Little Fanning Spring run is controlled by river stage.

Park Management - According to the management plan for Fanning Springs State Park (Division of Recreation and Parks, 2003), the park will continue to be developed as a recreation area while protecting environmental values, especially manatee habitat. Uses such as water resource development and water supply, among others, are not considered compatible with the park management plan or purposes of the State. Restoration efforts (Division of Recreation and Parks, 2003) include protection of native aquatic vegetation in Fanning Springs and removal of rocks, sandbags, and other cultural debris from Little Fanning. With respect to manatee habitat, the park plans include:

Continuing monitoring of manatees within the spring (Fanning Spring);

Protection of the manatee from disturbance in Fanning Spring run and spring, particularly during winter months; and

Seasonal closure of the Fanning Spring run to boating with provision of an alternative mooring and park access in the river.

2.3.5.2.2 Flow Characteristics

Discharge from Fanning Spring is highly variable. Flow reverses when the stage in the Suwannee River at the Wilcox gage reaches approximately 9 feet msl. At 9 feet msl, the head in the Suwannee River is greater than the head in the Floridan aquifer; thus, the Spring becomes an estavelle. Also, discharge is highly sensitive to drought conditions.

Table 2-10 summarizes the annual discharge and stage distributions for Fanning Springs based on the continuous, AVM data. Maximum discharge during the period of record for the AVM data (May 27, 2001 – May 31, 2005) is reported to have been 400 cfs (note that this observation occurred during October, 2004, and is highly questionable). Minimum flow was –199 cfs, which reflects backflow of river water into the spring system. Median daily discharge was 73 cfs for the period of record.

Table 2-10. Annual flow and stage distribution data, Fanning and Manatee Springs.

	Manatee Stage (ft. NGVD)	Manatee Discharge (cfs)*	Fanning Stage (ft., NGVD)	Fanning Discharge (cfs)
Maximum	10.12	180.00	14.72	400.00
P75	2.78	140.00	5.94	99.00
Median	1.56	106.00	3.57	73.00
P25	1.14	98.00	2.81	46.00
Minimum	-0.39	78.00	0.99	-199.00
Number of Observations	1,469	1,486	1,445	1,446

The distribution of flow is not uniform throughout the year. Table 2-11 illustrates the monthly discharge statistics for Fanning Spring. Lowest median flow is in March and April, and maximum median discharge is in June, September, and October. The discharge of the spring is controlled to a large extent by river stage. When the river is low, discharge from the spring is initially high because of high relative gradients. As time passes, however, the discharge decreases as groundwater potentials equilibrate with river stage. When river stage is high (the rainy season), discharge is inhibited, and may reverse if the river is in flood stage.

Stages of the spring and spring run are directly controlled by river stage, and there is seldom more than a tenth of a foot difference in stages of the river at Wilcox and the spring. Table 2-10 summarizes the annual daily stage distribution based on the May 27, 2001 to May 32, 2005 data. Table 2-11 summarizes daily stage distributions by month.

Table 2-11 Monthly discharge and stage data for Fanning Spring
(Based on AVM data from 5/27/2001 – 5/31/2005)

Fanning Springs Discharge (cfs)

Month	Maximum	Q75	Median	Q25	Minimum
January	190.08	111.50	96.64	71.04	-27.48
February	152.33	87.51	63.37	29.63	-59.64
March	159.07	58.12	38.51	6.32	-86.00
April	161.69	76.28	49.23	33.00	-60.83
May	167.85	121.88	95.07	76.65	53.61
June	213.15	132.40	104.89	78.15	40.15
July	213.74	135.68	88.73	74.59	35.10
August	201.53	130.48	87.62	54.39	46.64
September	173.61	131.51	117.82	63.08	51.80
October	133.70	124.95	100.38	66.67	9.93
November	193.97	124.70	90.98	67.98	49.16
December	207.60	122.21	105.93	75.16	16.82

Fanning Springs Stage (ft., MSL)

Month	Maximum	Q75	Median	Q25	Minimum
January	10.26	5.38	3.63	2.85	1.71
February	11.74	7.74	5.09	3.53	1.85
March	15.34	9.13	7.11	4.09	2.06
April	15.04	9.66	6.38	4.34	2.43
May	12.09	7.25	4.49	3.30	2.26
June	10.05	5.29	3.72	3.06	2.32
July	8.29	5.17	3.82	3.08	2.32
August	10.22	5.80	4.13	3.29	2.33
September	11.90	5.49	4.13	3.30	2.48
October	13.03	5.01	3.59	2.87	2.16
November	8.38	4.16	3.19	2.66	2.10
December	9.55	4.02	3.06	2.50	1.70

2.3.5.2.3 Ecological Characteristics

An overall assessment of the ecological value of the main spring is “fair”. Heavy recreational use limits the value of the spring for wildlife and prevents the development of important spring/run habitats, such as dense beds of submerged plants. The ecological value of Little Fanning is better, since it is in a more natural condition and not used for recreation. However, the low discharge rate of this spring appears to result in frequent periods of no or very low flow, which limits the value of the spring run as aquatic habitat.

Plant Communities

The main spring and the headspring of Little Fanning are rimmed by steep, high banks vegetated with mixed upland forests of live oak, pignut hickory, and slash pine. The runs of both springs are flanked by floodplain swamp with bald cypress, pop ash, and swamp privet. Portions of the spring bank around the main spring are vegetated with marsh plants such as pickerelweed (*Pontederia cordata*), bog hemp (*Boehmeria cylindrica*), pennywort (*Hydrocotyle* sp.), and various sedges.

Scattered patches of submerged aquatic vegetation (SAV), primarily freshwater eelgrass (*Vallisneria americana*) are found around the rim of the main spring basin. SRWMD personnel conducted some supplemental planting of *Vallisneria* in September, 2002. Survival of these transplants was fair. Other SAV found in the spring include naiads (*Najas* sp.), red ludwigia (*Ludwigia repens*), and the exotic *Hydrilla verticillata*. Overall, SAV coverage in the spring and run is very low, with most of the bottom being unvegetated as described above.

Algal communities of the main spring and run were assessed by FDEP in 2000 (FDEP, 2000a). Twenty-seven taxa of periphytic algae were collected, with about 95% of these being diatoms. Species composition of the diatom community is dominated by taxa indicative of nutrient-enriched conditions. Filamentous green algae are occasionally abundant and may cover SAV to the point of being a detriment to the macrophytes. No quantitative estimates of filamentous algal cover or standing crop appear to have been made.

Animal Communities

FDEP conducted semi-quantitative sampling of macro invertebrates in the main spring basin. Habitat conditions were considered “sub-optimal” (FDEP, 2000a), mainly due to low water velocities, low habitat diversity, and lack of a healthy riparian buffer along portions of the spring bank. A total of 31 taxa of invertebrates were collected, 9 of which were chironomid midges. The EPT score was low (= 2), with one mayfly (Ephemeroptera) and one caddisfly (Trichoptera) collected. Based on their Stream Condition Index, the spring quality was rated as “fair to good”.

Franz (2002) conducted qualitative surveys for crustaceans in the main spring basin and in the “seeps” located around the main basin. Two common amphipods (*Hyalella azteca* and a *Gammarus* sp.), an isopod (*Caecidotea*), and two taxa of epigean crayfish (*Procambarus fallax* and *Cambarellus schmitti*) were found in the main spring basin and the seeps. No crayfish were found directly in the main basin; all were found only in the seeps. Franz notes that the *Cambarellus* is “rare” and that its presence in the South seep was “very interesting”. He also notes that *Procambarus spiculifer* has been reported previously from Fanning Spring, but they were not found in this survey. Walsh and Williams (2003) conducted sampling for unionid mussels in the main spring basin and run but found none.

Walsh and Williams (2003) listed 40 taxa of fishes in or adjacent to Fanning Spring, based on their own sampling and a search of the ichthyological collection at the Florida Museum of Natural History (FLMNH). Their electrofishing collections were dominated primarily by redeye chub (*Notropis harperi*) and redbreast sunfish (*Lepomis auritus*). Bluefin killifish (*Lucania* *goodei*), bluegill sunfish (*Lepomis macrochirus*) and spotted sunfish (*L. punctatus*) were also relatively common. Gulf sturgeon (*Acipenser oxyrinchus desotoi*) have been photographed in the spring basin (J. Moran, personal communication), indicating sturgeon use the spring on occasion. The spring is also used by marine taxa known to penetrate far upriver, such as striped mullet (*Mugil cephalus*) and grey snapper (*Lutjanus griseus*). These are commonly observed in the main spring and run, particularly during the colder months.

Conservation Issues

Two habitats listed by the Florida Natural Areas Inventory (FNAI) are present in Fanning Spring: spring-run stream and aquatic cave. Spring-runs are designed as GS/S2 by FNAI. This designation means they are "Imperiled….because of rarity" (http://www.fnai.org/ranks.cfm), both at a global (=G) and state (=S) level. Aquatic caves are listed as G3/S3 by FNAI, meaning they are "Either very rare and local throughout its range. . . or found locally in a restricted range. . .", both at a global and state level. Fanning Spring is also listed as a "Secondary Warm-Water Site" (Category 2) by the Manatee Warm-Water Task Force (2004).

The main species of "conservation interest" (i.e., listed as endangered, threatened, etc., rare, or endemic), which uses Fanning Spring, is the Florida manatee (*Trichechus manatus*). Manatee occasionally penetrate upriver during the winter and use Fanning Spring as a warm water refuge. Park staff have been recording "manatee sightings" since 1996. Note that these may include repeat sitings of the same animal and so do not reflect the actual manatee population size using the spring. An average of 11.4 sightings per month were observed between 1996-2004, ranging from 4.75-21.9 sightings per month for each year. Peak periods of manatee sightings are December-March in any given year, suggesting the primary purpose of the spring for manatee is warm-water refuge. The Manatee Warm-Water Task Force (2004) noted that manatee seek refuge from cold temperatures in the spring and spring run when caught in the river by decreasing water temperatures. Therefore, the spring is a "harbor of refuge," not a primary wintering site.

Other species of conservation interest observed using the spring or likely to use it are listed in Table 2-12. The Lower Suwannee River adjacent to Fanning Springs has been designated as critical habitat for Gulf sturgeon (50 CFR Parts 17 and 226), and as noted earlier, sturgeon have been informally observed using the spring basin. Suwannee bass have been collected in the adjacent Suwannee River (Walsh and Williams, 2003) and likely enter the spring run and main basin. Various listed wading birds (Table 2-12) forage along the shores of the spring run.

Table 2-12. Aquatic and wetland-dependent species of conservation interest in the Fanning and Manatee Springs study areas (including the immediately adjacent Suwannee River).

		Federal	State	FCREPA	FNAI
Fishes					
Acipenser oxyrinchus desotoi	Gulf sturgeon	T	SSC	T	S2
Micropterus notius	Suwannee bass		SSC		S2-S3
Notropis harperi**	Redeye chub				
Reptiles					
Alligator mississippiensis	American alligator	T	SSC		S4
Macroclemys temmincki	Alligator snapping turtle		SSC	SSC	S3
Pseudemys concinna suwanniensis	Suwannee cooter		SSC	SSC	S3
Birds					
Aramus guarauna	Limpkin		SSC	SSC	S3
Casmerodius albus	Great egret			SSC	S4
Egretta caerulea	Little blue heron		SSC	SSC	S4
Egretta rufescens	Reddish egret		SSC	R	S2
Egretta thula	Snowy egret		SSC	SSC	S4
Egretta tricolor	Tricolor heron		SSC	SSC	S4
Eudocimus albus	White ibis		SSC	SSC	S4
Elanoides forficatus	Swallow-tailed kite			T	S2-S3
Haliaeetus leucocephalus	American bald eagle	T	T	T	S3
Mammals					
Trichechus manatus latirostris	Florida Manatee	E	E	E	S2

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; FNAI=species listed by the Florida Natural Areas Inventory; 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 or uncommon in Florida; S4=apparently secure in Florida; ** - included due to restricted distribution in north central Florida or narrow habitat requirements.

2.3.5.3 Manatee Springs

2.3.5.3.1 Introduction

Manatee Springs State Park is located five miles west of the city of Chiefland, Levy County, Florida. The park consists of 2,443 acres (Division of Recreation and Parks, 2004). It is developed for multiple uses centered around the spring and adjacent Suwannee River. Manatee Springs is a popular area for bathing in the spring, canoeing in the spring run, cave diving, and manatee viewing.

Manatee Spring is an historic first magnitude spring and consists of a spring "bowl" and run approximately 1,200 feet in length. The main vent is at the head of the spring run (Figure 2-38a). The south side of the spring bowl and portions of the run have been developed with a concession building and paved terraces. The northern side (Figure 2-38b) has been left in a natural state, in part, and a small, grassy swimming area is present.

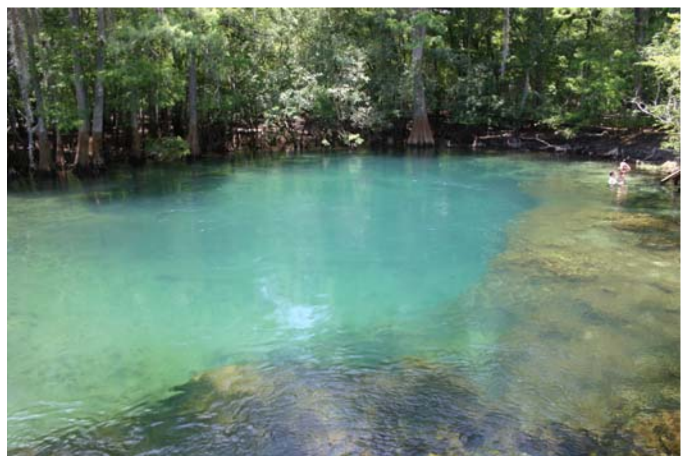

Figure 2-38a. View of Manatee Spring in June, 2005. Note the rock ledge surrounding the vent area.

Discharge from the spring has ranged from 110 cfs to 268 cfs, based on 19 observations from 1932 to 2004. Median discharge for the period of record is 204 cfs and average discharge is 189 cfs.

Cave diving is popular at Manatee Springs. The water current exiting the cave in the spring vent is too strong for entry, so Catfish Hotel, an adjacent karst window (Figure 2-39), has been developed by the Florida Park Service for entry into the cave system.

Figure 2-38b. View of the swimming area on the north side of the spring run, just downstream from the vent.

There is a spring run (Figure 2-40a) approximately 1,200 feet in length. The run and adjacent river have broad riverine swamp floodplains. Depth in the run is approximately 10 feet at the mouth of the river. There is a sand shoal (Figure 2-40b) that may restrict manatee entry into the spring bowl area. This shoal has depths less than 5 feet. The bottom is predominantly sand with algae. A floating rope separates the swimming area from the remainder of the run. Boat traffic is banned in the spring run, and canoe traffic is prohibited in the winter months in order to provide protection for manatee.

The USGS stream gage is located near the downstream portion of the swimming area, on the south side of the run. A staff gage and acoustic velocity meter (AVM) are used to monitor stage and discharge.

Figure 2-39. View of Catfish Hotel, a karst window utilized for cave-diver access to the Manatee Spring cavern system.

Manatee Spring is an estavelle, a spring that reverses flow when the adjacent river is in flood stage. Reversal of flow is a function of river stage. When the river, which contains humic substances that give it a brown coloration, flows into the cavern system that feeds the spring, detritus that serves as a food source for cave fauna is introduced.

Because of proximity to the Gulf of Mexico, the river seldom floods the spring, so reversals of flow are less common than at Fanning Spring.

Until recently, a boat launch area was available near the concession stand. This launch area resulted in bank erosion and sedimentation in the spring run (Division of Recreation and Parks, 2004). This sediment may be the cause of the shoal, just downstream from the former launch area. In addition to a terraced area for viewing and sunbathing, the banks of the spring are generally protected from erosion by riparian swamp.

According to the Division of Recreation and Parks (2003), the most important designated species in the park is the manatee. Manatee visit the park at any time of the year, but it is used as a thermal refuge during colder months (November through April). At other times, the manatee visit the spring while foraging in the river. As will be shown below, approximately 75% of the manatee sightings are downstream from the shoal in the western half of the spring run and in a thermal plume that develops at the mouth of the run. The Manatee Warm-Water Task Force (2004) noted that manatee seek refuge from cold temperatures in the spring and spring run when caught in the river by decreasing water temperatures. Therefore, the spring is a “harbor of refuge,” not a primary wintering site.

The spring run was formally carpeted by Submerged Aquatic Vegetation (SAV). Apparently, as a result of boat traffic, *Hydrilla* invaded the spring run. The *Hydrilla* was removed from the spring run manually and by mechanical harvester. The *Hydrilla* blocked flow in the run and made passage by manatees difficult (Division of Recreation and Parks, 2004).

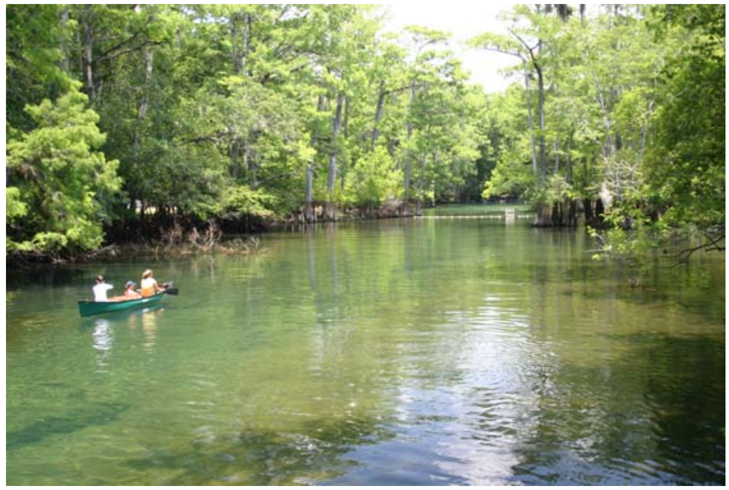

Figure 2-40a. View upstream of the Manatee Springs run in June, 2005. The sand shoal that constitutes a partial barrier to manatee passage is located in front of the canoe.

In 1991, the river remained at flood and river water limited light penetration. This greatly reduced *Hydrilla* biomass, and it has been controlled since that time.

During the winter of 2000-2001, a record number of manatees grazed on the SAV in the spring run and Suwannee River near shore. This removed much of the SAV and a bare sand bottom with algal mats is present today.

Figure 2-40b. View of water color in the Manatee Spring run in July, 2005. The brown color is the result of river entering the spring run from the left (west).

Discharge and stage in Manatee Spring and its run are controlled by stage of the Suwannee River. Most important to use of Manatee Springs as a thermal refuge, manatee must be able to find a plume of warm water in the mouth of the run and in the dock area within the river. The stability of this plume of warm water depends on both discharge from the spring and velocities in the river. The mouth of the run (Figure 2-41a) is located on the outer bank of a river meander, so river velocities are naturally high. A small island has developed upstream from the spring-run mouth, apparently as a result of interference in river flow by the spring discharge. This island shields the thermal plume area somewhat. Even so, if river velocities are high, the plume extent is limited in extent or disrupted. High flow in the spring run is ineffective in displacing river water and forcing a large thermal plume to develop.

Park Management - According to the management plan for Manatee Springs State Park (Division of Recreation and Parks, 2004), the park will continue to be managed as a recreation area while protecting environmental values, especially the manatee habitat. Uses such as water resource development and water supply, among others, are not considered compatible with the park management plan or purposes of the State.

Management goals include restoration of SAV in the Manatee Springs run and, potentially, removal of sand introduced near the former boat ramp. With respect to manatee habitat, the park plans on:

Continuing monitoring of manatees within the spring, run, and river;

Protecting the manatee from disturbance in the spring run and spring, particularly during winter months; and

Closing the spring run seasonally to boating with provision of an alternative mooring and park access in the river.

Figure 2-41a. View of the mouth of the Manatee Springs run taken from the floating dock in the Suwannee River in June, 2005. This is the principal thermal refuge area for manatee during cold months.

Figure 2-41b. View of the floating dock in the Suwannee River looking downstream (south). The thermal refuge does not extent significantly past the downstream end of the dock area because of mixing with river water.

2.3.5.3.2 Flow Characteristics

Historic discharge from Manatee Spring is somewhat variable. Flow reverses when the river is at high flood stage, but the discharge data are insufficient to quantify the threshold at which the spring flow reverses.

Table 2-10 summarizes the reported annual discharge and stage distributions for Manatee Springs based on the continuous, AVM data. Maximum discharge during the period of record for the AVM data (May 27, 2001 – May 31, 2005) is reported to have been 180 cfs. Minimum flow was 78 cfs. Median daily discharge was 106 cfs for the period of record. Note that these discharge data are highly questionable because of adjustments in rating the AVM at Manatee Springs. These questionable data were not used in developing the MFL for Manatee Springs. Synthesized data (Section 3) replaced the AVM data for MFL development.

The distribution of flow is not uniform throughout the year. Table 2-10 illustrates the reported monthly discharge statistics for Manatee Spring based on the AVM data. Lowest median flow is in March and April and maximum median discharge is in June, September, and October. Discharge from the spring is controlled to a large extent by river stage. When the river is low, discharge from the spring is initially high because of high relative gradients. As time passes, however, the discharge decreases as groundwater potentials equilibrate with river stage. When river stage is high (the rainy season), discharge is inhibited, and may reverse if the river is in flood stage.

Stage of the spring and spring run is directly controlled by river stage Table 2-10 summarizes the annual daily stage distribution based on the May 27, 2001 to May 32, 2005 data. Table 2-13 summarizes daily stage distributions by month.

Table 2-13. Monthly reported discharge and stage data for Manatee Spring.
(Based on AVM data from 5/27/2001 – 5/31/2005)

Manatee Springs Discharge (cfs)*

Month	Maximum	Q75	Median	Q25	Minimum
January	169	151	141	109.25	94
February	161	143	128	110	93
March	154	149	137	131.5	127
April	168	153	149.5	146.25	139
May	157	148	147	143.5	139
June	105	100	98	94	88
July	129	108.5	102	97.5	94
August	117	111	109	103.5	92
September	147	110.75	108.5	105	93
October	157	146	138.5	102.25	89
November	168	143.25	130.5	101	95
December	166`	151	132	104	91

Manatee Springs Stage (feet, NGVD)

Month	Maximum	Q75	Median	Q25	Minimum
January	2.10	1.35	0.84	0.53	-0.39
February	3.66	1.82	1.12	0.48	-0.32
March	3.88	3.45	3.02	2.02	1.82
April	2.41	1.92	1.71	1.29	0.72
May	1.88	1.50	1.37	1.26	0.89
June	2.00	1.59	1.27	1.10	0.83
July	2.79	1.73	1.57	1.34	1.01
August	2.09	1.88	1.52	1.35	1.13
September	1.85	1.57	1.42	1.03	0.2
October	2.80	2.19	1.72	1.24	-0.12
November	2.81	2.10	1.45	1.07	0.47
December	2.46	1.42	1.11	0.95	-0.04

*** Discharge data are highly suspect. See Section 3 for discussion of data quality and utilization.**

2.3.5.3.3 Ecological Characteristics

General Description

Manatee Spring consists of the main spring basin and a run of about 1200 feet to the Suwannee River. Scott et al. (2002) provided morphometric descriptive data: the main spring has roughly circular pool 60 by 75 feet in area with depths to about 25 feet. Much of the bottom area of Manatee Spring and its run consists of course to medium sand with some areas of exposed limestone in the headspring basin and along the run.

An overall assessment of the ecological value of the spring is “good”. Restrictions on boat traffic in the spring run, including closed seasons when no craft are allowed on the run, help maintain its value as wildlife habitat. Recent loss of historically dense beds of SAV has been attributed to a combination of herbivory (by manatee and/or grass carp) and overgrowth by filamentous algae. This loss diminishes somewhat the ecological value of the spring and run.

Plant Communities

The south side of the headspring basin is rimmed by mixed upland forests of live oak, pignut hickory, American holly and slash pine. The north side of the spring basin and the run is flanked by floodplain swamp with bald cypress, water tupelo, swamp tupelo, pop ash, swamp privet, and buttonbush.

PBS&J mapped 400 square feet of SAV in spring 2003, primarily spring tape (*Sagittaria kurziana*), in the headspring basin and part of the run. They conducted their mapping survey when the river was coming down from flood stage, and a portion of the run was inundated with highly colored water from the Suwannee River. They attributed low SAV coverage to be due, in part, to dieback as a result of shading from the dark river water. Other SAV taxa observed in the spring during the PBS&J survey were red ludwigia (*Ludwigia repens*) and an unidentified pond weed (*Potamogeton* sp.). Woodruff (1993) observed *S. kurziana*, *Hydrilla verticillata*, *L. repens*, *Cabomba caroliniana*, and *Sagittaria subulata* in the spring run. *Vallisneria* was formerly abundant in the spring and its run. Park staff attribute its decline to a combination of manatee foraging and overgrowth by filamentous algae. The Florida Fish and Wildlife Conservation Commission conducted caging studies of SAV in November and December 2002 to evaluate the impacts of manatee grazing. Statistically significant reductions in SAV shoot densities were documented in uncaged plots in December 2002 (when manatee were grazing in the spring) compared to November 2002 (prior to arrival of manatees).

FDEP (2000b; 2001) sampled periphytic algae in the spring and found 21 taxa in 2000 and 35 taxa in 2001. In both sampling efforts, diatoms comprised the bulk of the taxa richness. Most of these indicated enriched, eutrophic conditions. As noted above, large blooms of filamentous green algae have begun occurring in the spring over the last 5 years. The main taxa appears to be a species of *Vaucheria* (S. Hetrick, Florida Park Service, pers. communication).

Animal Communities

FDEP (2000b; 2001; 2005) sampled macroinvertebrates in the spring and run from 2000 to present, typically twice per year. Benthic taxa richness over the past two years is shown in Figure 2-42; ranging from 13 to 30 taxa of invertebrates collected. In 2000, the spring scored in the "good" range for the Stream Condition Index (SCI) score. In 2001 and 2005 the spring was rated as "poor" and "very poor", respectively. Metrics contributing to these ratings were not discussed. As seen in Figure 2-42, taxa richness has not changed appreciably (although there may be a slight declining trend), so the poor SCI scores are likely related to changes in the composition of the invertebrate community. Habitat assessment scores were in the "optimal" range in 2000 but were "sub-optimal" in 2001 and 2005, primarily due to reduced substrate diversity, "habitat smothering" (inferred here to be overgrowth with filamentous algae), and low riparian buffer scores.

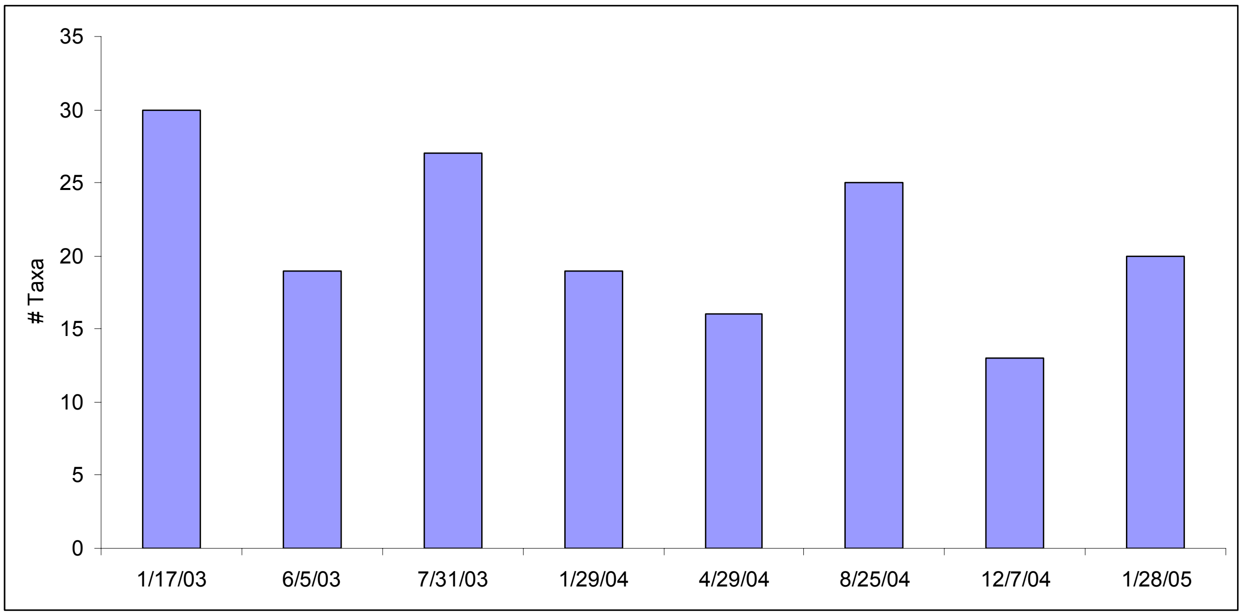

Figure 2-42. Taxa richness of benthic macroinvertebrates in Manatee Springs. Source: FDEP Bioassessment Program.

Woodruff (1993) sampled infaunal macroinvertebrate communities in the headspring with cores and identified invertebrates to major taxonomic group (order or above). The community was dominated by Oligochaetes (68%), with leeches (10%) and amphipods (12%) comprising most of the remainder of the relative abundance. He also collected gastropod molluscs and crustaceans and identified those to species. Five crustaceans were collected from the headspring and run: the amphipods *Crangonyx* sp. and *Hyalella azteca*; the isopod *Asellus* sp. (now *Caecidotea* sp.); a crayfish (*Procambarus* sp.); and the grass shrimp *Palaemonetes paludosus*. Nine species of snail were collected. The River horn snail (*Elimia floridensis*), a normally common inhabitant of the spring, disappeared during the drought of 1999-2002 (SRWMD biologist's observation R. Mattson pers. comm. 2005).

Walsh and Williams (2003) found no unionid mussels in the headspring or run but found three taxa in the river at the confluence with the spring run. They did note the occurrence of dead shells of the exotic bivalve *Corbicula fluminea* within the spring run. They attributed the lack of mussels in the spring run to poor substrate, which they described as "soft, flocculent organic detritus overlain by thick growths of filamentous algae". Franz (2002) found "amphipods" (no species identification) in the headspring and a crayfish (*Procambarus* sp.) and the amphipod *Hyalella azteca* in the spring run. He also notes "run mostly algae matted in a weedy aquatic macrophyte" and that since the late 1970's, there have been substantial changes in the vegetative cover in the headspring and run. As with Fanning Spring, he notes that *Procambarus spiculifer* has previously been collected from Manatee Springs but was not found in his 2002 survey.

Walsh and Williams (2003) list a total of 33 taxa of fishes collected from the headspring and run, the adjacent Suwannee River, and the "Catfish Hotel" sink based on their own collections and observations and records in the FLMNH. Dominant taxa include bluefin killifish, redbreast sunfish, spotted sunfish and redeye chub. The adjacent Suwannee River is designated as critical habitat for Gulf sturgeon, but it is unknown if sturgeon use the headspring or run. Like Fanning Spring, occasional marine species use the spring, including striped mullet, hogchoker, and possibly Atlantic croaker (one observation of croaker in the adjacent Suwannee River in the FLMNH records). The exotic triploid grass carp has been observed on several occasions in the spring run (J. Hinkle, Florida Dept. of Environmental Protection, pers. comm. and D. Canfield, University of Florida, pers. comm.) and may also be responsible for the loss of SAV in the run and headspring.

Conservation Issues

Similar to Fanning Springs, Manatee Springs contains two habitat types designated by the Florida Natural Areas Inventory: spring-run stream and aquatic cave. Their FNAI designation was described above. The spring run of Manatee Springs is longer and perhaps of greater conservation interest than that of Fanning due to its ability to support dense beds of native submerged aquatic vegetation. Like Fanning, Manatee is listed as a "Secondary Warm-Water Site" (Category 2) by the Manatee Warm-Water Task Force (2004).

The main species of "conservation interest" (i.e., listed as endangered, threatened, etc., rare, or endemic), which uses Manatee Springs, is the Florida manatee (*Trichechus manatus*). Park staff have been recording "manatee sitings" since 1993. Note that these may include repeat sightings of the same animal and so the observations do not represent the actual size of the manatee population using the spring. An average of 43.4 sightings per month was observed between 1993-2004, ranging from 14.5-95.8 sightings per month for each year. Peak periods of manatee sightings are December-March in any given year, suggesting that the primary purpose of the spring for manatee is warm-water refuge. Identification of individual manatees by unique features indicates that 21 individuals use the spring on a fairly regular basis from year-to-year (Langtimm et al., 2003). Most of these individuals also use the Crystal and/or Homosassa Rivers as well, traveling between the Suwannee and the Citrus county area. Park staff counted 32 animals using the spring and adjacent river in March 2001 (Langtimm et al., 2003), following a late-season cold front.

From the park observation data, there appears to be an upward trend in overall manatee use of the spring (Figure 2-43). This may be a result of the general expansion of the northwest Florida regional population of manatees as described by Langtimm et al. (2003) for the region. This report documented the use of the spring by manatee and identified the habitat values of the spring for manatee. The primary value of the spring is as a temporary, warm-water refuge for manatees as they travel to the main wintering areas in the Crystal and Homosassa Rivers, or if they are dispersing along the coast in the spring and must take refuge during passage of late-season cold fronts. The apparent increasing trend in use of Manatee Spring (Figure 2-45), presumably as a result of the increasing regional population, indicates that the spring's importance to manatees is increasing. The main warm-water refuge area is the "plume" of spring outflow at the confluence of the run and the Suwannee River (Langtimm et al., 2003). Manatee use of the spring run and headspring is less frequent, apparently due to a combination of shallow depths, lack of forage, and possibly current velocity. It is assumed that manatees that enter the headspring are either relatively small requiring 3 feet or less passage depth or enter and leave during high tide. This is due to the fact that a five foot manatee passage depth has not been consistently available to allow unfettered ingress and egress for the manatee into the headspring. Observations by park staff suggest that the run and headspring may be important for manatee calves; sightings of lone, sleeping calves in shallow areas in the run and headspring indicate they are left there by the mother while she forages in the river (S. Lieb email to D. Hornsby dated 13 June 2005).

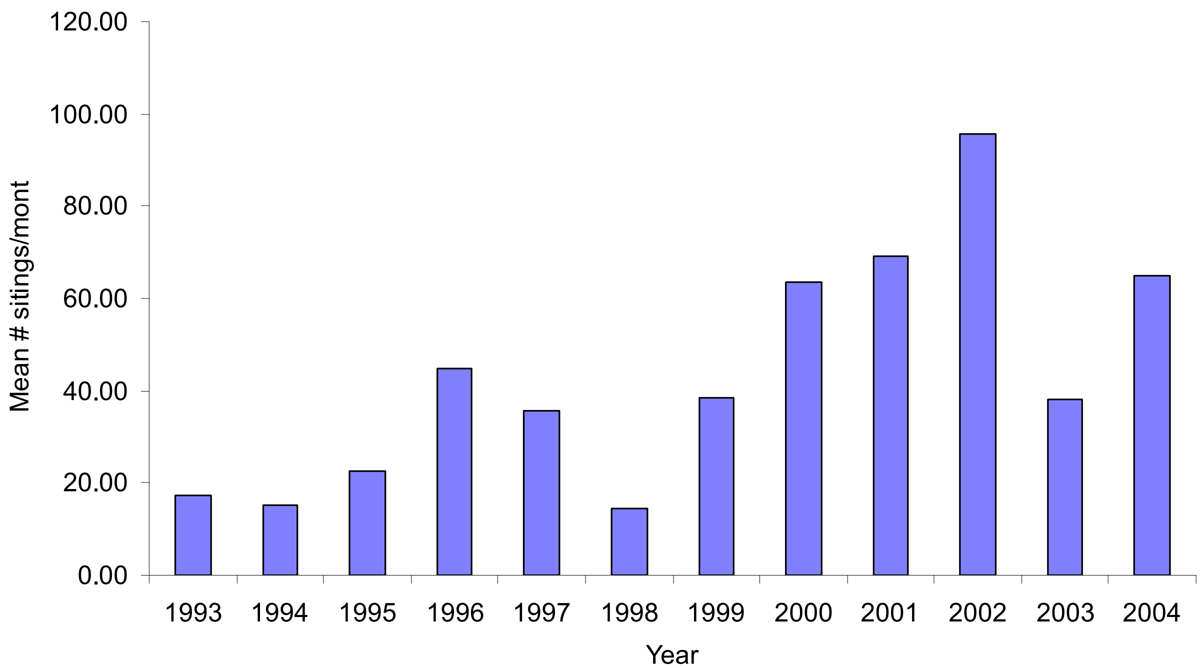

Figure 2-43. Mean number of manatee sightings /month from 1993 to 2004 at Manatee Springs. Source: Manatee Springs State Park.

Other species of conservation interest observed using the spring or likely to use it are listed in Table 2-12. The Lower Suwannee River adjacent to Fanning Springs has been designated as critical habitat for Gulf sturgeon (50 CFR Parts 17 and 226), but sturgeon use of the spring has not been documented. Suwannee bass have been collected in the adjacent Suwannee River (Walsh and Williams, 2003) and likely enter the spring run and main basin. Various listed wading birds (Table 2-12) forage along the shores of the spring run. Park staff have recorded alligator sightings in the spring and its run.

2.3.5.4 Temporal Trends in Spring Discharge

The historical discharge data from Fanning and Manatee springs do not indicate long-term changes in discharge. There are short- and mid-scale trends that result from rainfall cycles (Kelly, 2004), but these differences appear cyclic and, therefore, do not represent long-term trends.

Figure 2-44 illustrates the historical discharge data from Fanning, Little Fanning, and Manatee springs. Linear regression lines are superimposed over the data for Fanning and Manatee springs. These regression lines do not have statistically significant ($\alpha = 0.05$) slopes and R^2 values indicate that they account for less than 10 percent of the data variability.

While the trend for Fanning Springs is not statistically significant, the Division of Recreation and Parks (2003) has expressed the opinion that discharge has declined. The apparent decline in discharge at Fanning Spring appears to be a result of sampling. Until recently, the spring had been infrequently sampled during the traditional dry season. As a result, there is a bias in early samples. Therefore, there is little evidence for long-term, historic changes in discharge at Fanning Spring.

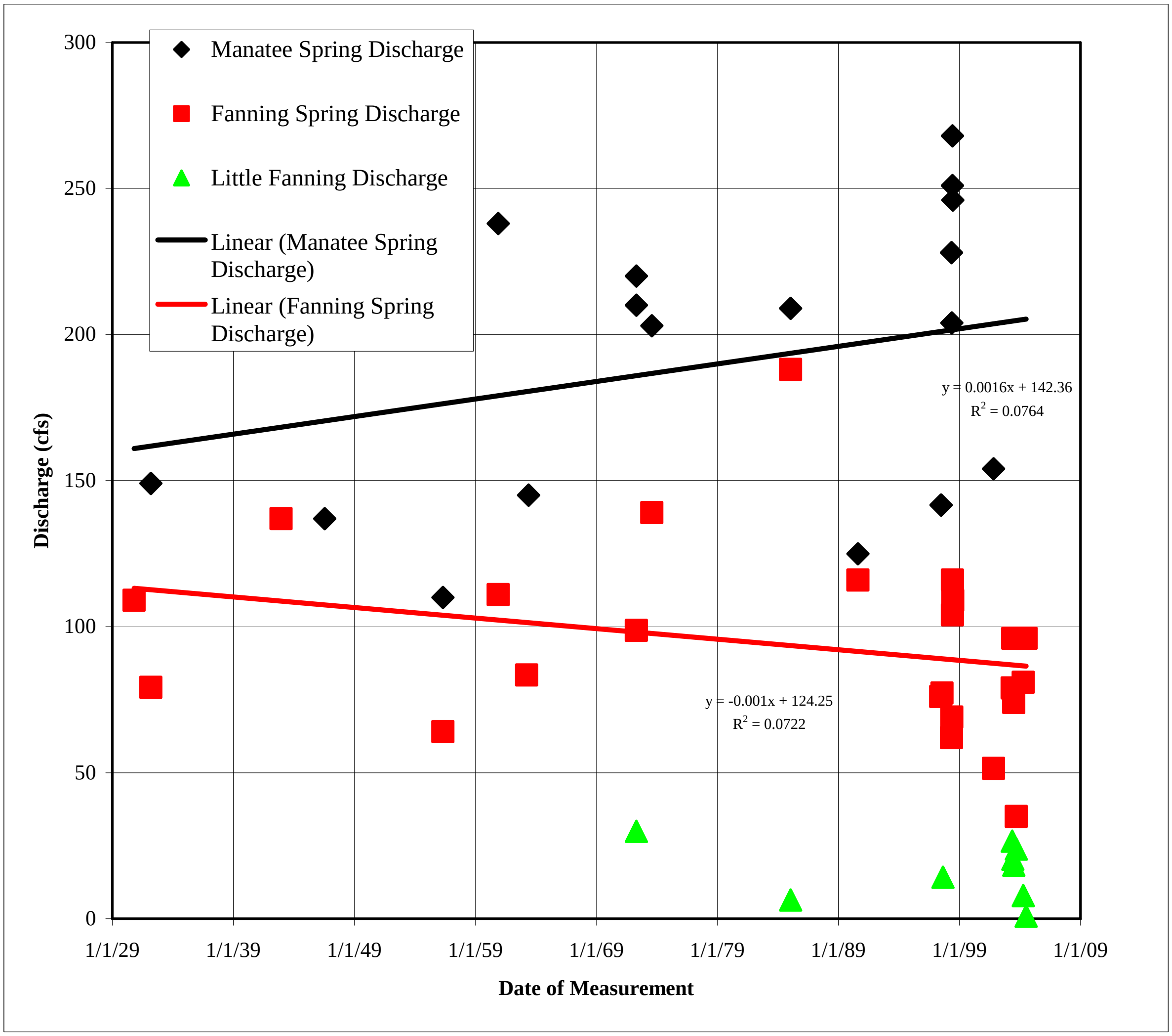

Figure 2-44. Linear estimations of discharge trends at Fanning and Manatee Springs. Neither trend line is statistically significant.

2.3.5.5 Nitrate Issues

Nitrate concentrations have increased from background (<0.5 mg/L) over the last 30 years and have reached an alarming level in many of Florida's springs.

The drinking water standard for nitrate is 10 mg/L as N based on the risk of methemoglobonemia, or "blue-baby syndrome" (Upchurch, 1992). While the nitrate maximum concentration level (MCL) is 10 mg/L, as N, concentrations of nitrate can cause unwanted and deleterious algal growth at concentrations well below the 10 mg/L standard. The increases in nitrate experienced by Florida's springs are a result of human activities within the spring drainage basins. These activities include waste disposal, fertilization, and other causes. The increasing nitrate concentrations are thought to be a cause of algal growth in many of the springs, including both Manatee and Fanning springs.

Figure 2-45 illustrates the increases in nitrate concentrations with time at Fanning and Manatee

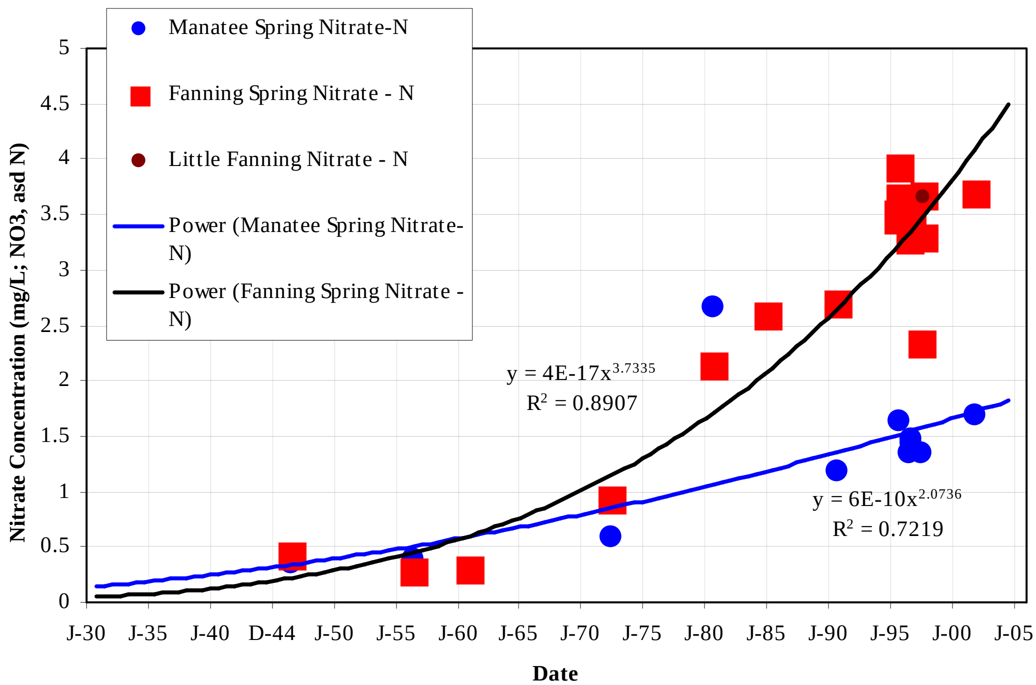

Figure 2-45. Increases in nitrate (NO_3, as N) in Fanning and Manatee Springs. Data are from Hornsby and Ceryak, 1998).

springs. Regression lines are based on power series and intended to suggest the nature of the increases, only. Note that Fanning Springs has experienced a much greater rise in nitrate concentrations, and that both upward trends began at about the same time (about 1965).

Figure 2-46 depicts nitrate concentrations from the two springs as a function of spring discharge. The wide scatter of data points clearly indicates that the increases in nitrate are not related to spring discharge. Therefore, MFL development cannot be utilized to control nitrate concentration, nor will MFL development have an impact on nitrate levels.

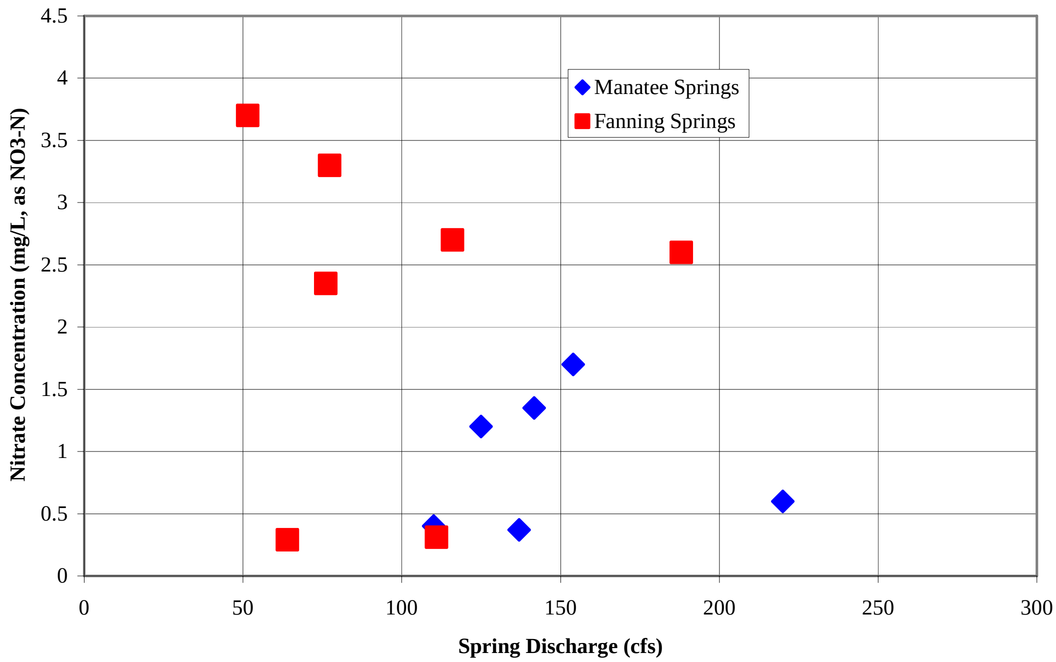

Figure 2-46. Comparison of nitrate concentrations (NO_3, as N) and spring discharge. Note the absence of any pattern of a process-response relationship.

SECTION 3

3.0 Hydrologic Approach

This chapter describes the available hydrologic data and methods used. This includes an examination of trends, and data synthesis methods and results that are specific for the MFL development of the Lower Suwannee River system. The models sections provide summaries of models developed for the Lower Suwannee River MFL project with brief examples of output compared to observed data. Hydrologic issues related to climatic cycles and trends are also discussed. Data (e.g., groundwater levels) used by others in supporting studies are incorporated by reference.

Section 3.1 presents surfacewater data utilized for development of MFLs for the Lower Suwannee River. Section 3.2 discusses hydrologic data utilized for MFL development at Manatee and Fanning springs.

3.1 Surfacewater Systems (Lower Suwannee River)

3.1.1 Overview

The USGS has collected continuous stage and stream flow data at locations in the Lower Suwannee River since 1932 (Fig. 3-1). The USGS and Suwannee River Water Management District (District) have funded the network cooperatively since 1975. The data collected at these sites vary by the parameters measured, collection frequency, instrumentation, and calculation methods, and each of these has varied over time at individual sites. The period of record differs among sites, as some sites were discontinued and then re-established at a later date.

In addition to the long-term monitoring sites, a number of continuous but short-term, project-specific sites were operated from 1994 to 2000. These included estuarine and tidal sites that monitored various combinations of water temperature, water level, salinity, velocity, and computed flow. The data available at these sites were reported in detail in Water Resources Data, Florida, Water Year 2000, in a special project data section (USGS, 2001).

Synoptic flow, velocity, and salinity data were obtained in and around the lower Suwannee River. During 1990, 1995, and 1996, synoptic, low-flow measurement surveys were conducted by the USGS throughout the District (Giese and Franklin, 1996b). Also, the USGS collected short-term (one or two tidal cycles) intensive synoptic flow data at multiple locations in the study area (focused in the main river channels and springs) in August 1996, August 1998, August 1999, and September 1999 (Grubbs and Crandal, in press). Additional synoptic monitoring flow efforts during December 1999 and May-June 2000 focused on East and West Passes and other channels in the river delta area (Bales, in press). Synoptic longitudinal salinity data were collected in the lower river by multiple agencies from 1993 through 2000 as described in more detail in following sections. The short-term, continuous data and synoptic data were used primarily to support modeling and the development of regression relationships by the USGS, the District and/or District contractors. Additional salinity data came from monitoring networks operated by the Florida Department of Agriculture and Consumer Services and the Florida Fish and Wildlife Conservation Commission.

3.1.2 Stream-Flow Data

3.1.2.1 Field Measurements

3.1.2.1.1 Gage Locations

Table 3-1 presents a summary of the stream flow sites selected for use in developing MFLs in the Lower Suwannee River. Locations of these sites are shown in Figure 3-1. Data from the gage at Wilcox (USGS Station Number 0232300) are the primary tools for MFL development in the Lower Suwannee. Note that data for Water Year 2004 and portions of 2005 were provisional at the time of report preparation. These sites provide the data required to characterize the lower river hydrology and the relevant hydro-biological relationships. Recommended MFLs are proposed at the Suwannee River near Wilcox (Wilcox) gage (Chapter 6).

Franklin et al. (1995) produced the most comprehensive, recent summary of long-term continuous stream-flow sites in the District. This report includes data through 1993, although auxiliary stage sites for slope-rated stations and other stage-only sites were not included. Giese and Franklin (1996a, 1996b) added an additional year of data and produced analyses of the magnitude and frequency of flood flows and low flows in the District. The USGS maintains a national database of stream flow data accessible from http://waterdata.usgs.gov/fl/nwis/. This web site includes access to both real time and historical data.

USGS Station Number	Station Name (Short Name)	Latitude	Longitude	Beginning Date	Period of Record (Years)	Percent (Complete)	Drainage Area (sq. mi.)	
02323000	Suwannee River near Bell, FL (Bell)	29.791	-82.924	06/01/32	71.4	100%[3]	9,390	
02323500	**Suwannee River near Wilcox, FL (Wilcox)**	**29.590**	**-82.937**	**10/01/30**	**73.0**	**86%**	**9,640**	
02323592	Suwannee River above Gopher River near Suwannee, FL (AGR)	29.791	-82.924	06/01/32	71.4	100%[3]	9,390	
USGS Station Number	**Station Name (Short Name)**	**Average (cfs)**	**Maximum (cfs)**	**Minimum (cfs)**	**10% Exceeds (cfs)**	**50% Exceeds (cfs)**	**90% Exceeds (cfs)**	**Runoff (inches)**
02323000	Suwannee River near Bell, FL (Bell)	9,167	82,300	2,053	17,200	7,120	3,799	13.25
02323500	**Suwannee River near Wilcox, FL (Wilcox)**	**10,159**	**84,700**	**1,065**	**18,400**	**8,040**	**4,400**	**14.31**
02323592	Suwannee River above Gopher River near Suwannee, FL (AGR)	30	-82.924	33,614	10,899	4,536	2,729	8.17

NOTES:
1. Beginning date is the earliest available systemic daily value.
2. Percent complete and descriptive statistics for the Suwannee River near Bell, FL gage include synthesized data. See Section 3.1.4.

Table 3-1. Stream flow gage sites used in lower Suwannee MFL study. The gage at Wilcox (shown in bold typeface) was the primary source of data used for MFLs.

3.1.2.1.2 Stage and Discharge Measurement Methods

Techniques for the measurement of stage and discharge in the Lower Suwannee River and springs vary among gages due to site-specific conditions. These conditions include tidally-induced variations in stage magnitude and flow direction, riverine backwater, relative groundwater and surfacewater levels, and site relief/slope.

Stage measurement techniques at the Lower Suwannee River sites have changed over time from simple periodic readings using a staff gage or other manual device to digitally recorded 15-minute measurements with automated equipment. The stage measurement methods currently used at sites in the lower Suwannee are summarized in Table 3-2.

Discharge measurement techniques have also changed over time, from simple stage-discharge relationships, to slope rating sites that incorporate backwater conditions, to water current (velocity) ratings that account for rapidly changing conditions and flow reversals, if necessary, due to tidal influences. Currently, all sites except Bell are equipped with water current meters; stage and current data are recorded digitally every 15 minutes. Table 3-2 summarizes the discharge methods currently used at sites in the Lower Suwannee River.

MFLs for the Lower Suwannee River will be based on data from the Wilcox gage because of the long period of record and data quality at the gage. The history of data collection at that location is presented in more detail below.

From March 26 to May 14, 1942, a weekly stage recorder was in operation at this site. For the period from May 15, 1942 to January 24, 1951, a staff gage was in use at Wilcox. The staff gage was read daily when gage heights were above 6 ft. Discharges above 11,000 cfs were computed using a normal discharge rating curve. Discharge values below 11,600 cfs (corresponding to the 6 ft gage height) for the Water-Year 1942 to 1951 period were not initially computed due to tidal effects. For periods with missing gage heights above 6 ft in this period, discharges were estimated based on records from the Bell gage.

On Feb 1, 1951 an hourly recorder was installed at Wilcox and a continuous stage gage was also deployed about 9 miles down stream. Both consisted of floats in stilling wells. The down-stream gage allowed the determination of the slope between the sites. This permitted development of a fall rating, which was used for lower flow periods when tide affected the gage. Although not explicit in the station records, it appears that at some point this new information was used to fill in the low-flow gaps in the 1942 to 1951 record. A fall rating method (with variations) was used from 1951 until December 9, 1999.

A water current meter was installed at Wilcox and used from December 10, 1999 to the present. For this period, 15-minute data were recorded and processed to produce daily values of stage and flow.

3.1.2.1.3 Data Quality and USGS Gage Rating of Data

The USGS characterizes the accuracy of measured and computed data with the following rating system:

If 95 percent of daily discharges are within:	The rating is:
5 percent of the true value	Excellent
10 percent of the true value	Good
15 percent of the true value	Fair
If accuracy is less than "fair"	Poor

Water Year 2003 ratings are given in Table 3-2. The accuracy of the data may vary over a year and between years. During the past 20 years, the long-term gage at Wilcox was primarily rated “Fair” by the USGS. For the period from 1999 through 2002, the Wilcox data were rated “Poor” due to the large percentage of each year with low, tidally affected flows. Data from both Manatee and Fanning Springs have been rated “Poor” for all years of record.

USGS Station Number	Station Name	Latitude	Longitude	Beginning Date (1)	Ending Date (2)	Period of Record (Years)	Gaging	Stage Measurement Methodology	Datum
02323000	Suwannee River near Bell, FL	29.791	-82.924	06/01/32	09/30/03	28	Water-stage recorder.	Bubbler system	N.G.V.D. of 1929
02323500	Suwannee River near Wilcox, FL	29.590	-82.937	10/01/30	09/30/03	62	Water-stage and water-current meter recorders.	Float in Stilling Well	0.53 ft below N.G.V.D. of 1929
02323592	Suwannee River above Gopher River near Suwannee, FL	29.339	-83.087	06/24/99	09/30/03	4.3	Water-stage and water-current meter recorders.	Pressure Transducer	2.10 ft below N.G.V.D. of 1929
02323502	Fanning Spring near Wilcox, FL	29.589	-82.933	05/27/01	09/30/03	2.3	Water-stage and water-current meter recorders.	Pressure Transducer	N.G.V.D. of 1929
02323566	Manatee Spring near Chiefland, FL	29.490	-82.977	10/01/01	09/30/03	2.0	Water-stage and water-current meter recorders.	Pressure Transducer	N.G.V.D. of 1929

USGS Station Number	Station Name	Discharge Measurement Methodology	Quality Rating	Remarks
02323000	Suwannee River near Bell, FL	Stage-Discharge Rating	Fair	Data record discontinuous from 1/1/57 to 8/3/2000
02323500	Suwannee River near Wilcox, FL	Velocity-Discharge Rating	Fair	Flow generally affected by tide when discharge is less than 17,500 cfs; (1)
02323592	Suwannee River above Gopher River near Suwannee, FL	Velocity-Discharge Rating	Fair	(2)
02323502	Fanning Spring near Wilcox, FL	Velocity-Discharge Rating	Poor	(1); (2); The Suwannee River flow can back up into the spring run during periods of high flow producing negative velocities and discharges. Flows recorded during these periods could contain a mixture of river and spring flow, or be totally river flow.
02323566	Manatee Spring near Chiefland, FL	Velocity-Discharge Rating	Poor	(1); (2)
DATE NOTES: (1) Beginning date is the earliest available systematic daily value. (2) Ending date is the selected cutoff point for establishment of the lower Suwannee MFL.				
REMARKS NOTES: (1) Discharge computed from continuous velocity record obtained from water-current meter. (2) Flow affected by tide.				

Table 3-2. Summary of stage measurement information in Lower Suwannee River. Gaging, measurement methods, and remarks are for Water Year 2003.

3.1.2.1.4 Tidal Signal

As mentioned in the previous section, tidal variations in stage and discharge are a problem with respect to monitoring and analysis of hydrologic data in the Lower Suwannee River study area. All gage data within the study area reflect the influence of tidal action. The USGS daily observations attempt to deal with short-term variations, but tidally generated, high frequency “noise” remains in the hydrographs derived from gage data.

3.1.2.1.5 Stream-Flow Data Trends

The development of hydrologic statistics to establish the Lower Suwannee MFLs is based on the conclusion that the data are without significant, long-term trends. This section provides support for that conclusion, summarizing two studies that included the Wilcox gage and others upstream of this gage. Rumenik and Grubbs (1996) examined flows in the Lower Suwannee River for trends in low flows as part of a state-wide study. They utilized a nonparametric test, Kendal’s Tau (Hirsh, 1982). They used data through 1987 and included the Bell gage (Figure 3-1), which was discontinued in 1956. None of the long-term, Lower Suwannee study gages listed in Table 3.1 exhibited trends (the above Gopher River gage was established subsequent to the Rumenik and Grubbs study).

More recently, Jacobs and Ripo (2002) looked for trends at the Wilcox gage, as well as upstream gages, utilizing data through 2000. They did not include the Bell gage (it had just been re-established in mid-2000) or the recently established Suwannee River above Gopher River near Suwannee gage (AGR; see Figure 3-1). They used exploratory and confirmatory methods. The exploratory tools were the double mass analysis, cumulative sum charts, autocorrelation and cross-correlation. None of these methods suggested a long-term trend at the gages. The confirmatory methods were parametric linear regression and the nonparametric Mann-Kendall test. These were applied to multiple exceedance probability statistics including the annual 10 percent, 50 percent, and 90 percent statistics and the annual minimum flows. The regression and Mann-Kendall tests indicated decreasing trends at the Wilcox gage for the annual minimum and 90 percent exceedance low-flow statistics. The linear regression technique found a statistically significant ($\alpha = 0.05$) trend for all exceedance probabilities greater than 70 percent. Similarly, the Mann-Kendall analysis found statistically significant trends at all exceedance probabilities above 76 percent.

Having found a low flow trend at Wilcox, Jacobs and Ripo examined possible causes, including gage period of record, precipitation, and water use. First, they noted that the lack of a trend at two upstream gages (Branford and Fort White) made it very unlikely that the magnitude of trend found in the Wilcox flow series is a result of upstream conditions.

They also noted the disparity between the period-of-record tested among the three gages. Wilcox was discontinued from 1932 through 1941 and thus has approximately 10 years of early period data missing, compared to the other two gages. To examine the impact of the period-of-record, a sliding Mann-Kendall analysis was performed, both forward and backward in time, starting with a 5-year window. The window size was increased in one year increments and the analysis repeated. The results suggested that the period of record plays an important role in the identification of trends. The beginning few years of the continuous Wilcox gage period of record (1942 through 1949) were wetter than average with the flood of record occurring in April 1948. Records at the Branford and Fort White gages were initiated during more moderate flow

Figure 3-1. Location of primary stream flow gage sites used in development of MFLs for the Lower Suwannee River.

conditions. Conversely, the end of the record used occurred during a drought. Jacobs and Ripo concluded, therefore, that the decreasing low flow trend at Wilcox is, in part, influenced by the period-of-record analyzed.

Precipitation records exhibited a similar pattern to the stream flow. Jacobs and Ripo (2002) concluded that the low flow trend at Wilcox is also, in part, climatic in origin.

Jacobs and Ripo (2002) concluded that historical water use intensifies the magnitude of decreasing trends in the low flow regime. In the final analysis, they noted that use of a longer period of record and actual water use would be advisable and that, given the uncertainties in an estimated un-impacted flow record, the Wilcox stream flow record could be accepted as observed. Therefore, the stream flow records at Wilcox and upstream in the Lower Suwannee River are assumed to be stationary and constitute the best available data for the purpose of establishing MFLs.

Kelly (2004) investigated the effects of the Atlantic Multidecadal Oscillation (AMO; Enfield et al., 2001) on stream discharge in Florida. He found that discharge of the Suwannee River at Wilcox was 4.8% higher in the 1970 – 1999 period than in the 1940 – 1969 period. This pattern is in agreement with the expected pattern caused by the AMO and the position of the river in the "transition zone" between the Northern and Southern River Pattern areas (Fig. 2-18). Seasonally, Kelly observed a decrease in discharge for the summer months (the "wet season" in the Southern River Pattern areas; Fig. 2-18). This observation appears to be consistent with the findings of Jacobs and Ripo (2002).

3.1.3 Summary and Characterization of Stream-Flow Data

A database was developed containing the stream-flow data for the Lower Suwannee River project. The data period is 10/01/1941 through 05/31/2005. Table 3-3 summarizes selected data characteristics for this period at the Wilcox gage. This 62-year period encompasses multiple high and low flow periods including the record flood of 1948 and the record, multi-year drought of 2000-2002.

Metric	Discharge (cfs)
Average	10,159
Maximum	84,700
Minimum	1,070
10% Exceeds	18,400
50% Exceeds	8,040
90% Exceeds	4,400

Table 3-3. Descriptive discharge statistics for the Suwannee River at Wilcox gage for 10/01/1941 – 05/31/2005.

A visual summary of these data is provided in Figure 3-2 using the flow duration curve. Flow duration curves (FDCs) have proven to be useful tools to describe water supply reliability (Maidment, 1993). A flow duration curve is constructed by ranking all stream flows for the period of record at a site from the largest to the smallest (Vogel and Fennessey, 1994). In the present case these are daily records. An exceedance probability is assigned to each flow point as $p_i = i/(N+1)$, where N is the total number of stream flow points in the series. This is the Weibull plotting position. For a period-of-record flow duration curve the exceedance is the probability or reliability of stream flow exceeding some level over the period of record. Flow duration curves represent the long-term exceedance probabilities for a gage and, assuming no trends, are useful for long planning horizons (Vogel and Fennessey, 1995).

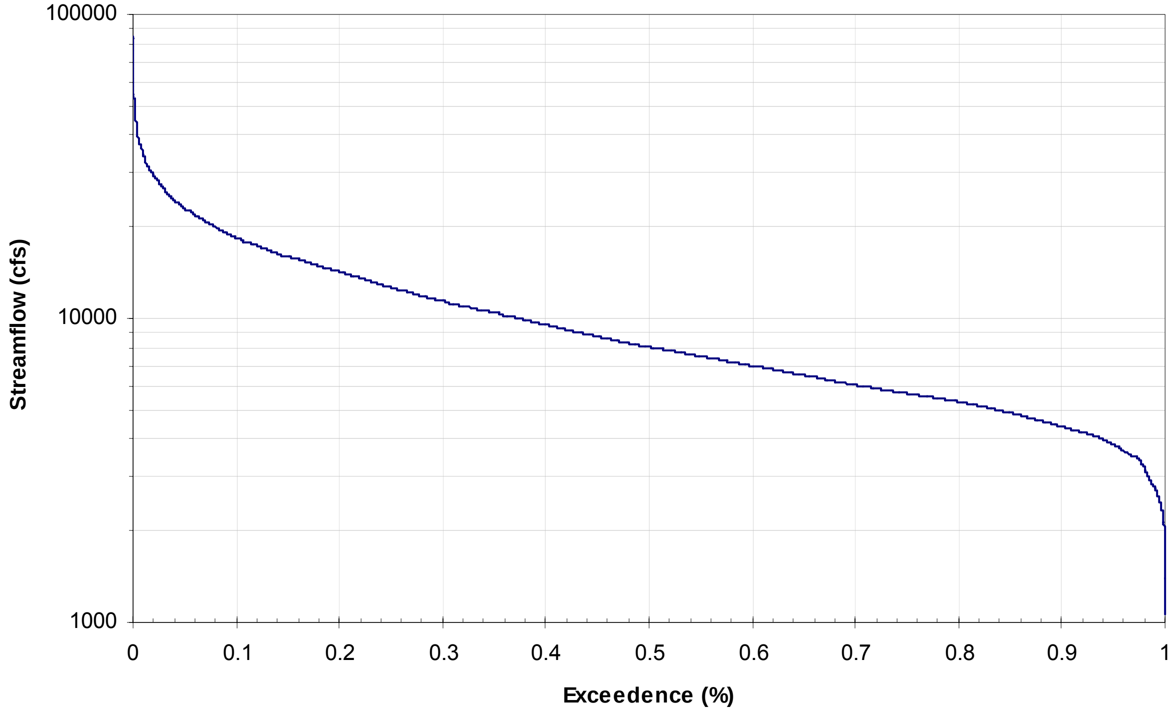

Figure 3-2. Flow-Duration Curve for the Lower Suwannee River near Wilcox gage.

3.1.4 Summary and Characterization of Wilcox Data

Table 3-4 summarizes the discharge and stage data from the Wilcox gage for the period of record (October 1, 1941 – May 31, 2005) and Figures 3-3 and 3-4 illustrate the patterns of discharge and stage, respectively, for the same period. Note the high-frequency tidal signals in the figures. Note also, the absence of stage data below 5 feet in the years prior to 1950. This reflects the period when low-flow discharge measurements were not being made (Section 3.1.2.1.2).

As will become evident in the discussion of flow and stage data, monthly data were of benefit to MFL development because they reduced the tidal effects associated with use of daily stage and discharge. As evidenced in Table 3-5 presents the population metrics for monthly discharge at Wilcox, and Table 3-6 includes similar metrics for stage.

	Discharge (cfs)	Stage (ft., NGVD)
Maximum	84,700	21.79
75th Quartile	12,600	6.19
Median	8,040	3.85
25th Quartile	5,640	2.67
Minimum	1,070	0.37
Mean	10,167	4.77

Table 3-4. Distribution statistics for discharge and stage at the Wilcox gage. Period of record is 10/1/1941 – 5/31/2005 for discharge data and 4/1/1942 – 5/31/2005 for stage.

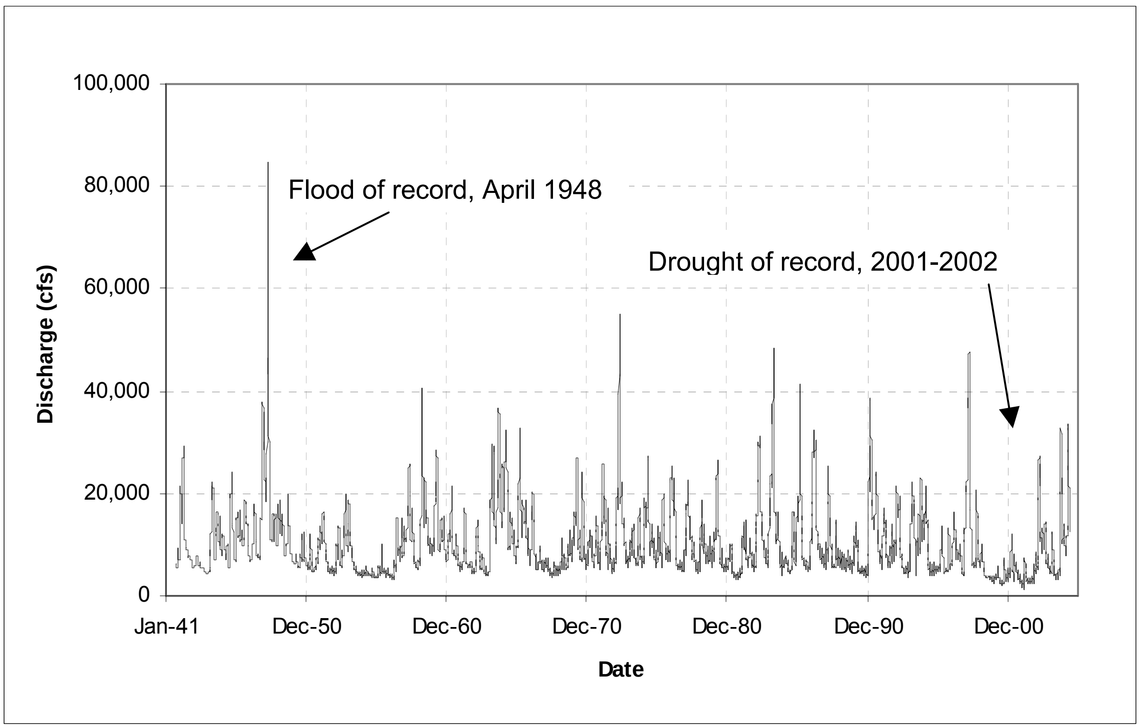

Figure 3-3. Pattern of discharge in cubic feet per second at Wilcox gage for the period of record.

Month	Maximum	75th Quartile	Median	25th Quartile	Minimum
January	36,100	12,000	7,715	5,800	1,400
February	41,300	16,900	11,000	6,728	1,070
March	47,600	19,825	13,600	8,290	2,670
April	84,700	19,400	13,000	7,918	3,560
May	40,400	13,700	9,525	6,098	2,450
June	23,100	10,175	7,000	5,440	2,200
July	22,100	10,200	7,190	5,330	1,970
August	24,100	11,200	7,740	5,420	2,260
September	36,700	11,600	775	5,490	2,220
October	32,900	10,900	7,135	5,240	2,500
November	37,800	8,600	6,620	5,070	2,680
December	36,900	8,600	6,480	5,160	1,580

Table 3-5. Distribution statistics for monthly discharge in cubic feet per second at the Wilcox gage. Period of record is 10/1/1941 – 5/31/2005.

Month	Maximum	75^{th} Percentile	Median	25^{th} Percentile	Minimum
January	14.27	5.78	3.48	2.39	0.40
February	15.08	7.63	5.07	3.00	0.37
March	16.82	8.94	6.67	3.89	0.62
April	21.79	9.36	6.05	3.98	1.43
May	15.31	6.76	4.26	2.94	0.70
June	10.46	4.95	3.36	2.65	0.86
July	10.15	4.74	3.39	2.61	1.55
August	10.79	5.78	3.81	2.75	1.69
September	14.42	5.64	3.84	2.88	1.09
October	14.37	5.31	3.43	2.51	0.95
November	14.62	4.00	2.93	2.32	0.80
December	14.52	4.03	2.84	2.15	0.60

Table 3-6. Distribution statistics for stage in feet NGVD at the Wilcox gage. Period of record is 4/1/1942 – 5/31/2005.

3.1.5 Antecedent Hydrologic Conditions During MFL Study

Data collection specific to establishment of Lower Suwannee MFLs began in late 1995. From that time, through 2003, hydrologic conditions have ranged from a record multi-year drought to a fifteen-plus year flood (Figure 3-4). The Lower Suwannee River was out-of-bank at least 5 of the last 8 years (defined as flow at Wilcox of approximately 14,000 cfs or more). In these 8 years there was an average of one flood event each year of occurrence. Each event lasted an average of 52 days. Conversely, the flow at Wilcox reached or exceeded (was dryer than) the 1-in-10 year, 7-day low flow (4,020 cfs) 6 of the last 8 years with an average of 5 events each year of occurrence. During the 1999-2002 drought, the monthly mean flow fell below the 90th percentile flow for 17 months, rebounded briefly in the fall of 2000 - spring of 2001 (only reaching the long-term mean), and fell below the 90th percentile flow again for another 14 months. Overall, the Lower Suwannee MFL study period was substantially dryer than long-term conditions (Figure 3-5). Comparing the median flow for the 1995-2003 period with the period-of-record median, the river was about 2,610 cfs 'drier' than the long-term record.

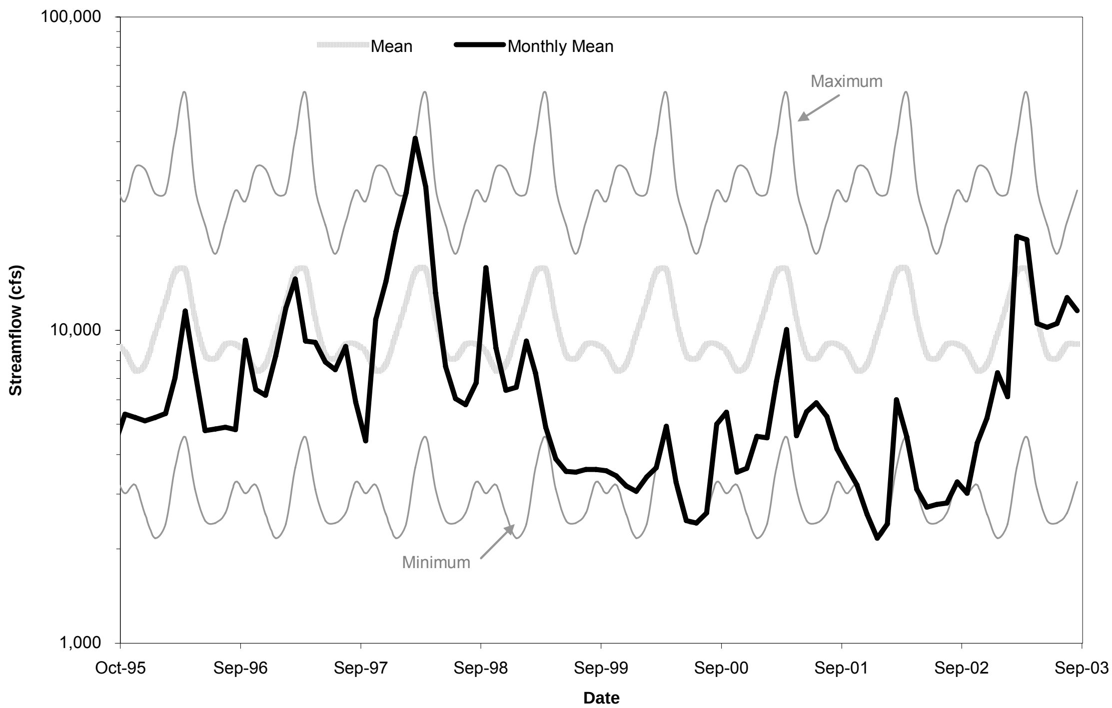

Figure 3-4. Monthly mean discharge of the Suwannee River near Wilcox for the period 1995-2003 compared to the maximum, minimum, and average monthly mean discharge for the period of record (1941-2005).

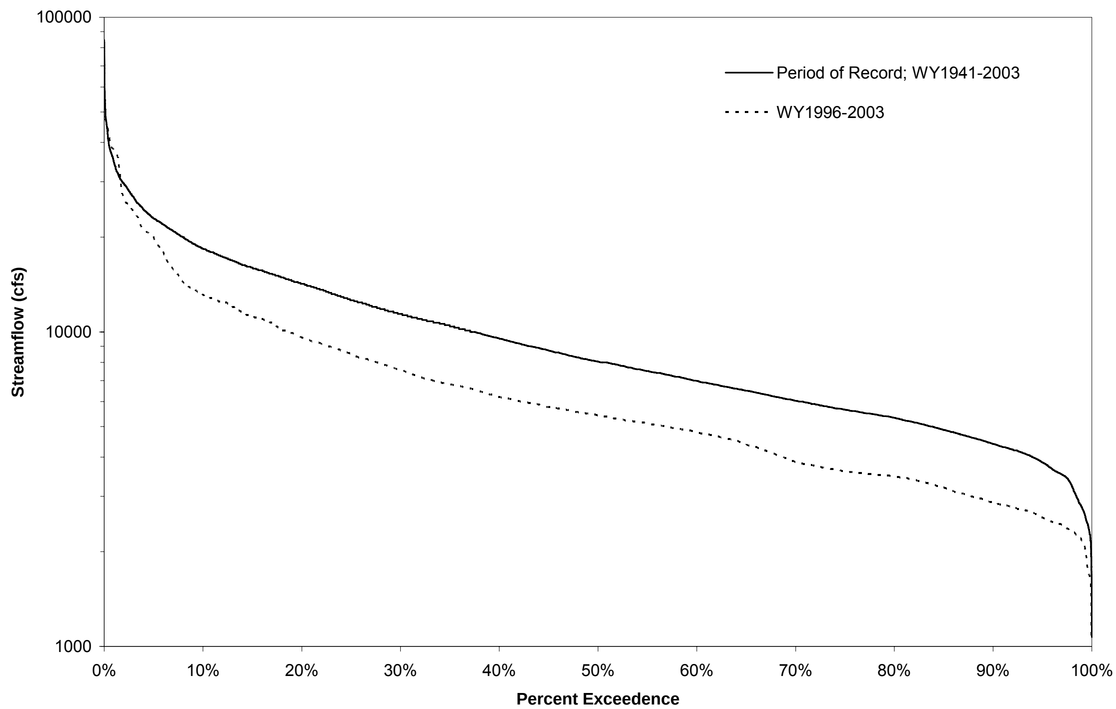

Figure 3-5. Suwannee River near Wilcox flow duration curve for the period 1996-2003 compared to the period of record flow duration curve.

3.1.6 Reach Pickup

Stream flow at a gage can be divided into surfacewater and groundwater (base-flow) components. Quantification of 'pickup', defined herein as groundwater flow into a reach between two gages, is an important part of subsequent calculations used in establishing MFLs for the Lower Suwannee River. The importance of the springs to maintenance of low-flow conditions is discussed in Section 3.3.2.3.5.

Pickup is defined, in this case, as the difference between daily estimates of base flow between two gages. This section describes the method used to estimate pickup in the Lower Suwannee River from Wilcox to the Above the Gopher River (AGR) gage.

Furthermore, a digital filter base-flow separation technique, an automated technique to estimate pickup, has been shown to give reasonable results for natural channels (Nathan and McMahon, 1990; Arnold et al., 1995; and Allen and Arnold 1999). The equation of the digital filter is

$$q_t = \beta q_{t-1} + (1+\beta)/2 \cdot (Q_t - Q_{t-1}) ,$$

where q_t is the filtered surface runoff for a gage on a daily time step (t), β is the filter parameter, and Q is the original stream flow. Nathan and McMahon (1990) determined a filter parameter value of 0.925 to be suitable from previous research. Base flow, b_t, is calculated as,

$$b_t = Q_t - q_t \,.$$

This filter may be passed over the data up to three separate times: forward, backward, then forward again. The filter parameter affects the attenuation, and the number of passes performed determines the degree of smoothing (Nathan and McMahon, 1990). After estimating base flow at the bounding gages of a reach, an estimate of pickup in the reach, PU_t, is calculated as,

$$PU_t = b_{Dt} - b_{Ut},$$

where b_{Dt} is the downstream base-flow estimate and b_{Ut} is the upstream base-flow estimate.

The method was applied for a six-year period (Water Years 1998 to 2003), for subsequent use in modeling (Section 3.2.1), as follows:

1. To Estimate missing data at AGR gage,
2. To Pre-process flow data from the tidally-affected gages,
3. To Estimate base flow with the digital filter technique,
4. To Subtract base flow at gages to estimate pickup between gages, and
5. To compare results to that from other methods.

Missing data for the AGR gage were estimated for the period October 1998 to June 1999. AGR is located in the Lower Suwannee River, upstream from the East Pass/West Pass split (Figure 3-1). The missing daily data were synthesized as a function of available Wilcox and AGR monthly mean flows as,

$$Q_{AGR} = 1.1044 \cdot Q_W + 85.769$$

with an R^2 of 0.9728 and a standard error for the estimate of 877 cfs (see Figure 3-7).

Both the Wilcox and AGR sites are tidally affected. The variability in mean daily values at these sites reduced the estimates of base flow produced by the digital filter by as much as 60 percent. The mean daily values at these sites were pre-processed with an equally weighted moving average smoothing algorithm. The smoothing window was varied from 3 days up to 13 days. The 7-day smoothing algorithm was selected as providing an appropriate balance between reduction in variability and retaining the significant magnitudes and patterns of flow. In a 90 day test period where flows ranged from 1,970 cfs to 3,080 cfs at Wilcox, a smoothing over a 7-day interval reduced the mean day-to-day variability by over 80 percent without significant changes to the underlying flow patterns or magnitude (Figure 3-7).

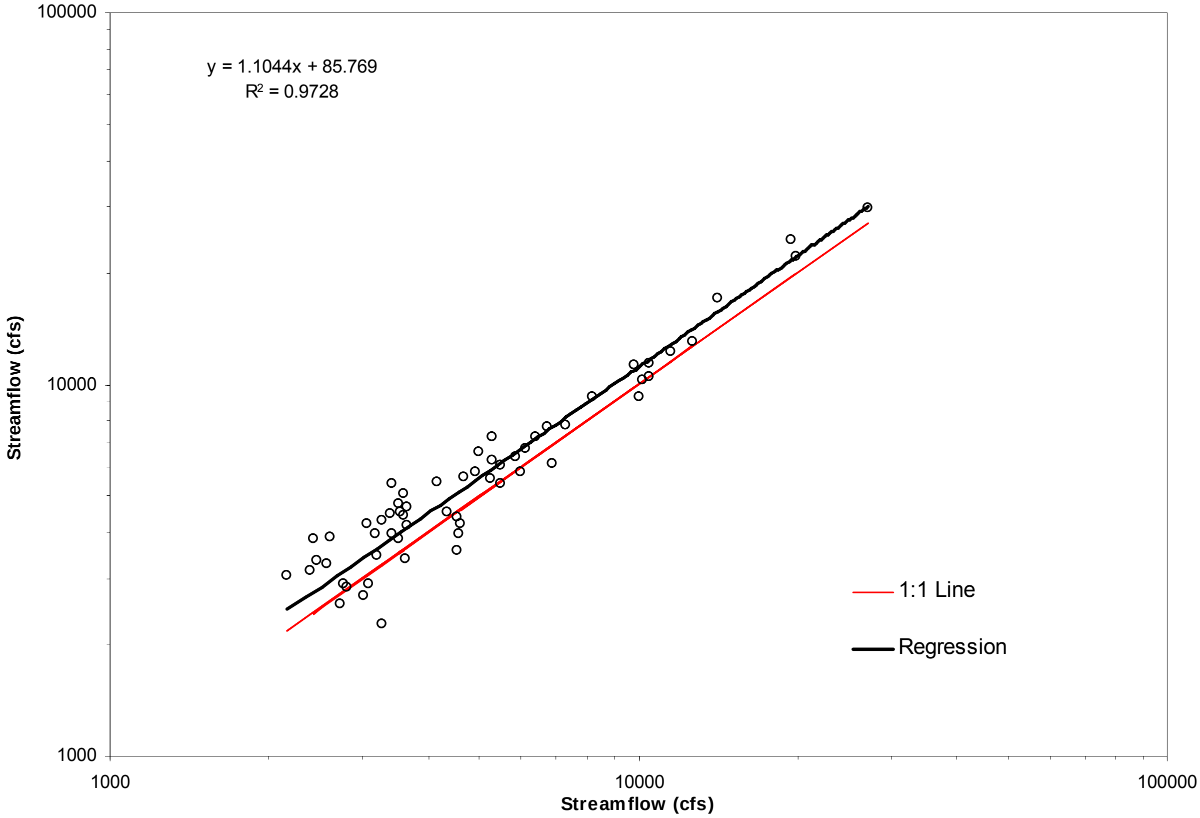

Figure 3-6. Relationship between mean monthly stream flow at the Above Gopher River (AGR) and Wilcox gages.

To determine the appropriate number of passes, the digital filter results were compared to both a chemical mass balance method and a simple difference between total flow at the gages. The chemical mass balance method was presented by Grubbs (1998) as,

$$Q_{GW} = \left[(Q_{DS} - Q_{US}) \cdot C_D - (Q_{DS} \cdot C_{DS} - Q_{US} \cdot C_{US})\right] / (C_D - C_{GW}),$$

where Q_{GW} is the groundwater flow into the reach (pickup); Q_{DS} is the stream flow out of the downstream end of the reach; Q_{US} is the stream flow into the upstream end of the reach; C_D is the concentration of direct runoff; C_{DS} is the concentration of flow out of the downstream end of the reach; C_{US} is the concentration at the upstream boundary of the reach; and C_{GW} is the concentration of the groundwater flow into the reach. Since there is minimal direct runoff into the reach under consideration, setting C_D equal to zero results in the following simplification,

$$Q_{GW} = (Q_{DS} \cdot C_{DS} - Q_{US} \cdot C_{US}) / C_{GW}.$$

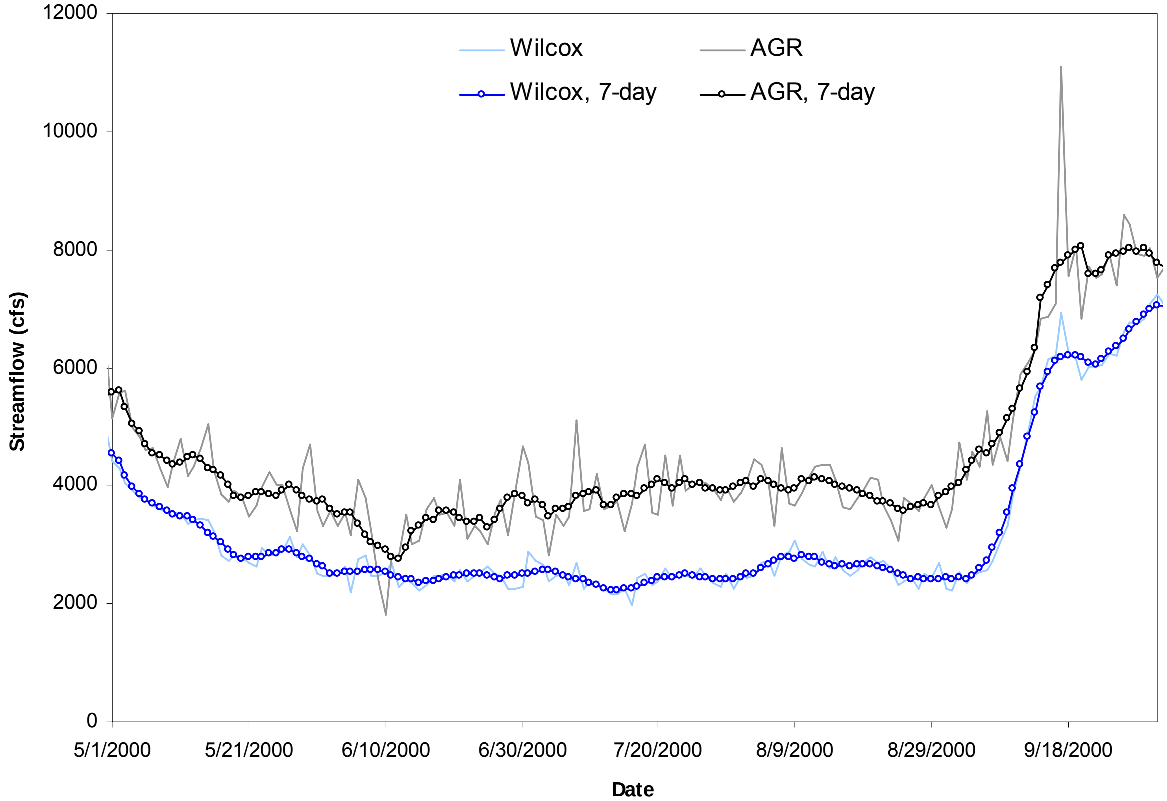

Figure 3-7. Comparison of raw and smoothed daily values at AGR and Wilcox gages.

For river terms in the equation, monthly specific conductivity data collected by the District (as grab samples), and stream flow on the day of sample collection were used. The groundwater conductivity was estimated, as the area weighted mean of average conductivity in wells adjoining the river.

Two passes of the filter were used to produce the final pickup estimates. The results are summarized in Table 3-7. The variability in the results between the mass balance and the other two methods is due, in part, to the variability inherent in attempting to estimate a continuous process with grab samples (Hornsby, 2005).

Method	Mean Pickup (cfs)
Digital Filter	739
Daily Difference	734
Chemical Mass Balance	625

Table 3-7. Comparison of results for base-flow estimation for the reach between the Wilcox and Above the Gopher River gages, Lower Suwannee River. Digital filter (2 passes) compared to daily difference and chemical mass balance.

The method was further checked by comparison to published results of a chemical mass balance for the Santa Fe River (Grubbs, 1998) that spanned the Cody Escarpment using the Worthington Springs and the Fort White gages (see Figure 2-19 for locations). In that effort, specific conductivity was continuously measured at both gages for a period of over six months. The digital filter was used to estimate the period of record pickup between the two gages. The resulting estimate and that reported by Grubbs agreed within 3 percent, which is considered excellent corroboration.

Note that the simulated monthly discharge estimate for Fanning and Manatee springs (see Section 3.2.3.5) combined averages 234 cfs (median combined discharge is 228 cfs) for the same period. This suggests that discharge from the two springs constitutes about 32 – 37% of the total average estimated pickup downstream of the Wilcox gage and above the AGR gage. Great Section!

3.1.7 Tides and Salinity

The primary long-term tide gage used in this study is located at Cedar Key, FL and operated by NOAA. Collection of hourly tide heights at this location began in 1997 and continues to present (http://co-ops.nos.noaa.gov/data_inv.html). As noted previously, tide data were also collected at six, short-term, continuous, project specific data sites during the 1994-2000 period. Table 3-8 lists these sites. In like manner, Figure 3-8 presents a short-term graph of the water levels from the estuary, as represented by Cedar Key (CK), up the river to Bell during late August 2000. The graph shows the relative height and timing of the tidal signal as it propagates up river.

Station Name (Abbreviation)	USGS Station Number	Latitude	Longitude	River Distance (mi)	Characteristics
Suwannee River above Gopher River near Suwannee, FL (AGR)	02323592	29º20'19"N	83º03'13"W	7.6	discharge, salinity, stage
West Pass Suwannee River at Suwannee, FL (WP)	291930083082800	29º19'30"N	83º08'28"W	2.8	discharge, salinity, stage
West Pass Suwannee River near Mouth, near Suwannee, FL (WM)	291842083085100	29º18'42"N	83º08'51"W	1.9	salinity, stage
East Pass Suwannee River at Mouth near Suwannee, FL (EM)	291652083064100	29º18'41"N	83º07'08"W	3.8	salinity, stage
East Pass Suwannee River near Suwannee, FL (EP)	291841083070800	29º16'52"N	83º06'41"W	1.2	discharge, salinity, stage
Gulf of Mexico at Red Bank Reef (RB)	291912083154800	29º19'12"N	83º15'48"W	off-shore	salinity, stage

Table 3-8. Continuous, MFL project-specific gaging sites in the Lower Suwannee River and Estuary.

Data used to characterize and model salinity in the estuary came from several sampling programs (Table 3-9). The USGS collected data specifically for the Lower Suwannee MFL effort. The other programs were conducted to generally characterize salinity in the estuary (e.g., Mattson and Krummrich, 1995) or were part of on-going monitoring conducted by other management programs (the FWCC fisheries monitoring data and the FDACS shellfish monitoring program).

Fresh-water inflow from the Suwannee is the dominant influence on salinity patterns in the estuary (Siegel et al, 1996; Orlando et al., 1993), with tide and wind having secondary roles. The general behavior of salinity in the lower river and estuary can be summarized as follows (Tillis, 2000; Janicki Environmental, 2005b):

- The salinity in East and West Passes ranges from freshwater to open Gulf salinity (i.e. ~32 parts per thousand (ppt)), depending on flow;
- The "head" of East pass is fresh over 50 percent of the time and the "mouth" of East pass has a salinity of 11.5 ppt or less, over 50 percent of the time;
- West Pass (near the Wadley cut-off) has a salinity of 8.53 ppt or less, 50 percent of the time;
- The river discharge is proportioned between the East and West Passes about 40 and 60 percent, respectively; and
- Salinity in Suwannee Sound varies widely, from 0 to 36 ppt, but Principal Components Analysis of the SEAS salinity data indicated three distinct areas based on salinity regime: a) riverine sites, b) inshore sites within/near Suwannee Reef, and c) "offshore" sites [located outside the reef or north or south of the river].

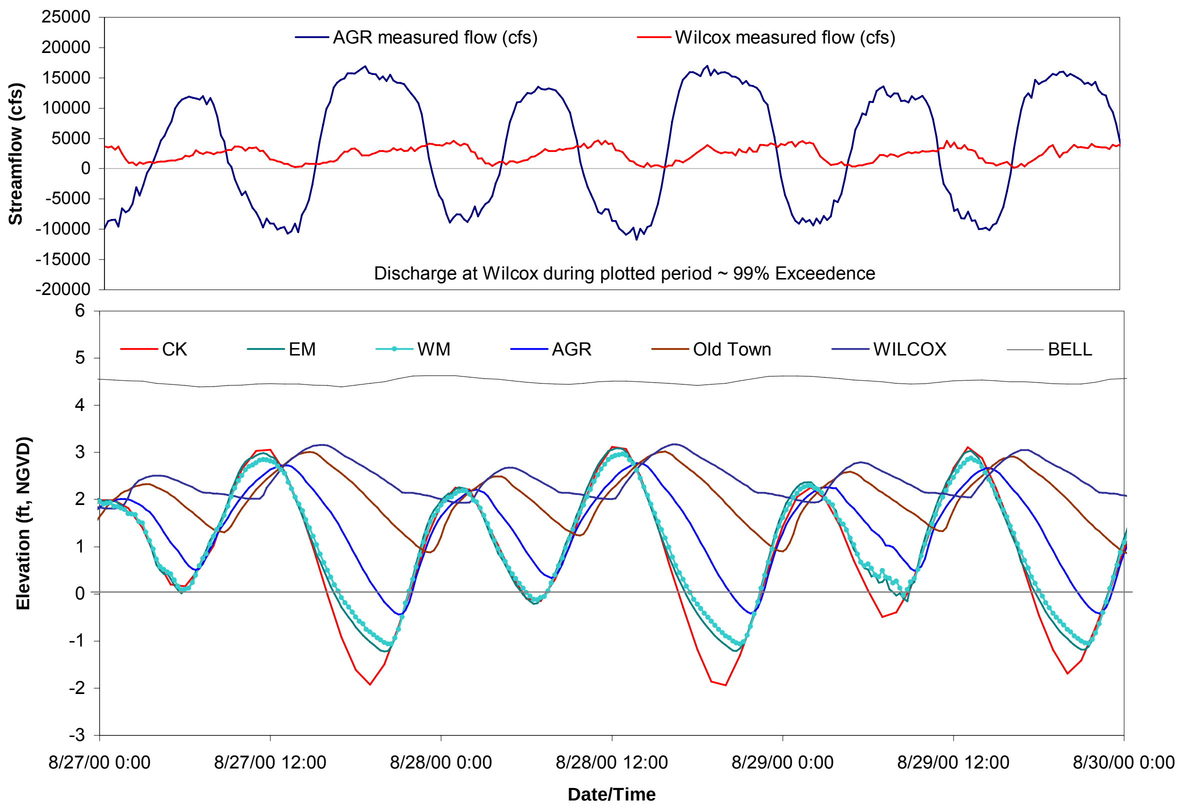

Figure 3-8. Typical tidal patterns associated with extremely low freshwater flow. The Suwannee River near Old Town (USGS No. 02323570) is the auxiliary level gage for the Wilcox slope-rating. Tables 3-1 and 3-4 give additional gage abbreviation meanings.

3.1.8 Numerical and Statistical Models of the Lower Suwannee Study Area

The purpose of this section is to describe modeling efforts developed specifically for the Lower Suwannee MFL project. Brief summaries are provided along with representative results. Two numerical models of surfacewater or groundwater systems used in development of the Lower Suwannee MFLs are described. Also, a set of statistical models that describe the interaction of fresh-water discharge from the river with salinity conditions in the lower river and estuary are presented.

Agency	# Sites/ Frequency	Period of Record	Reference	Notes
FWCC/SRWMD	16 fixed synoptic sites/monthly	1993-1995	Mattson and Krummrich, 1995	Sampled monthly during full moon high tide
USGS	4 cont. recorder sites/15 min intervals; 16 fixed synoptic sites/ monthly	1995-2000 (continuous); 1998-2000 (synoptic)	USGS, 2001; Tillis, 2000; Bales, in press	Fixed sites sampled independent of tide
FWCC Fisheries Independent Monitoring Program	Varies (suite of sites randomly selected on an annual basis)	1997 - current	Janicki Environmental, 2005b	Salinity data collected in conjunction with juvenile fish monitoring program
FDACS Shellfish Environmental Assessment Section (SEAS)	137 fixed sites/ monthly (not all were used for analysis)	1989 - current	Janicki Environmental, 2005b	Salinity data collected in conjunction with bacteriological monitoring in shellfish harvesting areas

Table 3-9. Summary of salinity monitoring programs in the Suwannee River Estuary that provided data used in the development of Minimum Flows and Levels.

3.1.8.1 HEC-RAS River Model

The U.S. Army Corps of Engineers (USCOE) developed a step back-water model of the Suwannee River and major tributaries in 1989. HEC-2, developed by the Army Hydrologic Engineering Center (HEC), was used to perform the step backwater calculations. The District was the local sponsor of the work. The USCOE's study focused on the reach of the Suwannee downstream from the confluence with the Santa Fe River and included 45 cross-sections covering approximately 66 river miles.

HEC-RAS (River Analysis System, USCOE, 1995), the revised HEC-2 model, is an integrated package of hydraulic analysis programs and is capable of performing steady and unsteady flow and water surface profile calculations. The original HEC-2 files for the Suwannee River system were converted to HEC-RAS steady-state format (Taylor Engineering, 2002). Furthermore, an unsteady flow version of the lower Suwannee portion of the model was also developed for use in Lower Suwannee MFL establishment (Good and Tara, 2005).

Model conditions are discussed below. The model simulates the six-year period from 10/01/1997 to 09/30/2003. The upstream boundary conditions (stream flow) were established at the Branford and Fort White gages. The downstream boundary (stage) was based on tide at Cedar Key. The lateral boundary condition (i.e., along the river) is groundwater pickup as defined in Section 3.1.6.

One use of the model is to calculate the location of head of tide with flow (Figure 3-9A) and flow reversal (stagnation) points (Figure 3-9B). Head of tide is defined here as “the inland or upstream point where the mean range becomes less than 0.2 foot” (Hicks, 1984). Selected results of the model are shown in Figure 3-10 for flow and stage at the Wilcox gage

The model output was useful for characterizing the influences of tides on river flow.

3.1.8.2 Linked Groundwater/Surfacewater Model

A linked groundwater/surfacewater flow model was developed by the USGS, cooperatively with the District, for the Lower Suwannee MFL establishment. The model (Grubbs and Crandall, in press) uses MODFLOW linked to the BRANCH surface water model in a transient simulation (MODBRANCH). A regional, MODFLOW model (Planert, in press) provided the initial estimates of boundary conditions for the Lower Suwannee River. Field surveys were conducted in August 1996, May and August 1997, August 1998, and September 1999 to collect river flows and groundwater levels for calibration of the Lower Suwannee River Model.

The Lower Suwannee River Model simulates a two year period from 10/01/1997 to 09/30/1999. The MODFLOW domain is a one-layer representation, discritized into a rectangular grid with 163 rows and 148 columns and a uniform cell size of 5,000 feet for both rows and columns. Lateral boundaries include a specified head condition along the Gulf coast, no-flow boundaries that follow groundwater flow lines, and head-dependent flux boundaries. The BRANCH portion of the model is based upon cross-sections from the USCOE HEC-2 project cited above, with upstream boundary conditions (stream flow) established at the Suwannee River at Branford gage and the Santa Fe River near High Springs gage (USGS Station 02322000). The downstream boundary (stage) was based on levels at a gaging station near Old Town (USGS Station 02323570) which is the historical slope-rating gage for the Wilcox station. Below Old Town the MODFLOW River Package was used to represent the river.

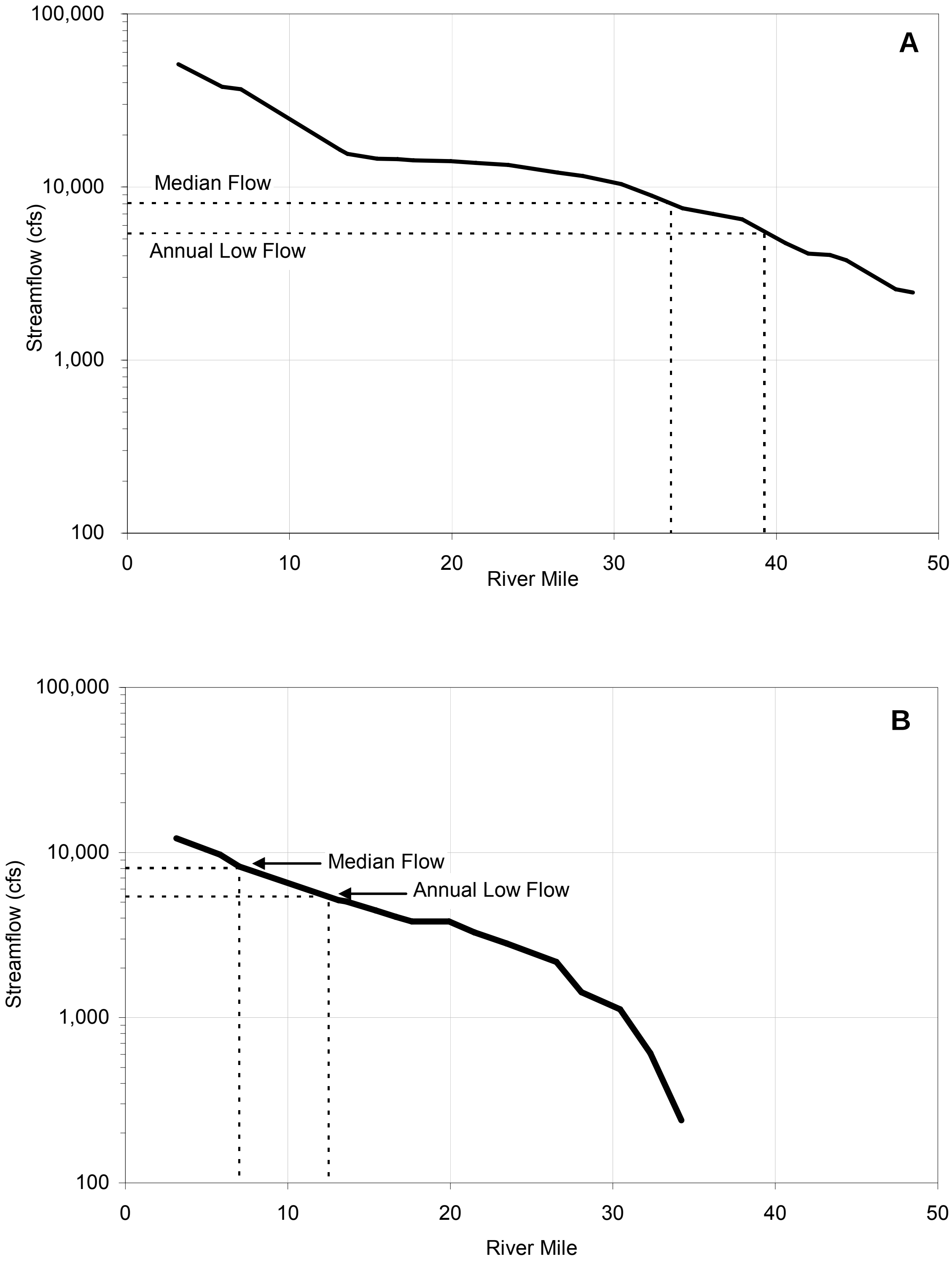

Figure 3-9. Average location of (A) head of tide with discharge at Wilcox and (B) flow reversal point with discharge at Wilcox.

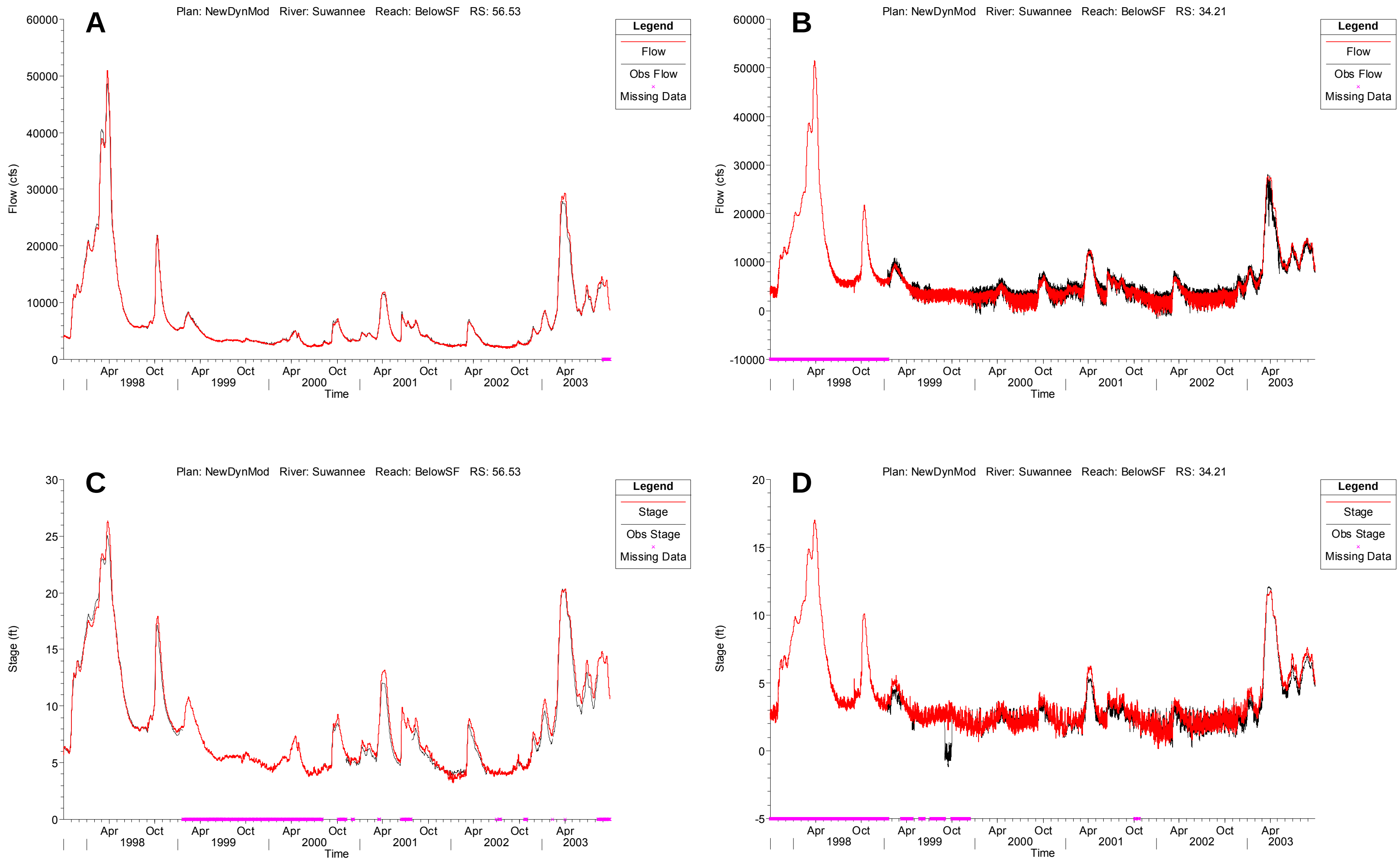

Figure 3-10. HEC-RAS simulated and observed hydrographs for discharge at (A) and stage (B) at Wilcox. Plotted time step is hourly.

The Lower Suwannee River Model was used to assess the impact of current levels of water use, as well as the cumulative impact of future uses, on river flows. Selected results of the model are shown in Figure 3-11 for flow and stage at the Wilcox gages.

3.1.9 Relationships between Flow and Salinity in the Lower Suwannee River and Estuary

Two additional projects were conducted to develop flow and salinity relationships in the Lower Suwannee River and estuary. Tillis (2000) described salinity dynamics in the riverine portion of the estuary from the mouths of East and West Passes upstream to about Gopher River based on 2½ years of data collection by the USGS. Tillis developed multiple-linear-regression models of how salinity shifts with changes in fresh-water discharge. Janicki Environmental (2005b) provided additional analyses using the USGS data; data collected in 1993-95 by the Florida Fish and Wildlife Conservation Commission (FWCC) and the District (Mattson and Krummrich, 1995); salinity data from the shellfish monitoring program in Suwannee Sound (SEAS), currently maintained by Division of Aquaculture, Florida Dept. of Agriculture and Consumer Services (FDACS); and salinity data collected by the FWCC Fisheries Independent Monitoring Program (FIM).

Tillis (2000) found that, under a 10 percent withdrawal scenario, the salt-water/fresh-water interface (0.5 ppt isohaline) would move 0.55 miles upstream under "typical" annual low flow conditions (2 year – 1 day low flow at Wilcox gage); would move upstream 0.74 miles under a dry low flow event, such as a 10 year low flow; and would move upstream approximately 0.85 miles under an extreme low flow event (a 50 year low flow). Using a different set of regression analyses, Janicki Environmental (2005b) found that the USGS synoptic data indicated that flow reductions from 5500 to 4500 cfs at Wilcox result in considerable upstream movement (1-2 miles) of isohalines in both East and West Passes (Janicki Environmental, 2005b).

The analysis of Janicki Environmental (2005b) incorporated data collected subsequent to the work of Tillis (2000). Therefore the Janicki Environmental analyses were used for all flow-salinity analyses for the lower Suwannee MFL project. These results and conclusions from this study are included in Section 5 of this report.

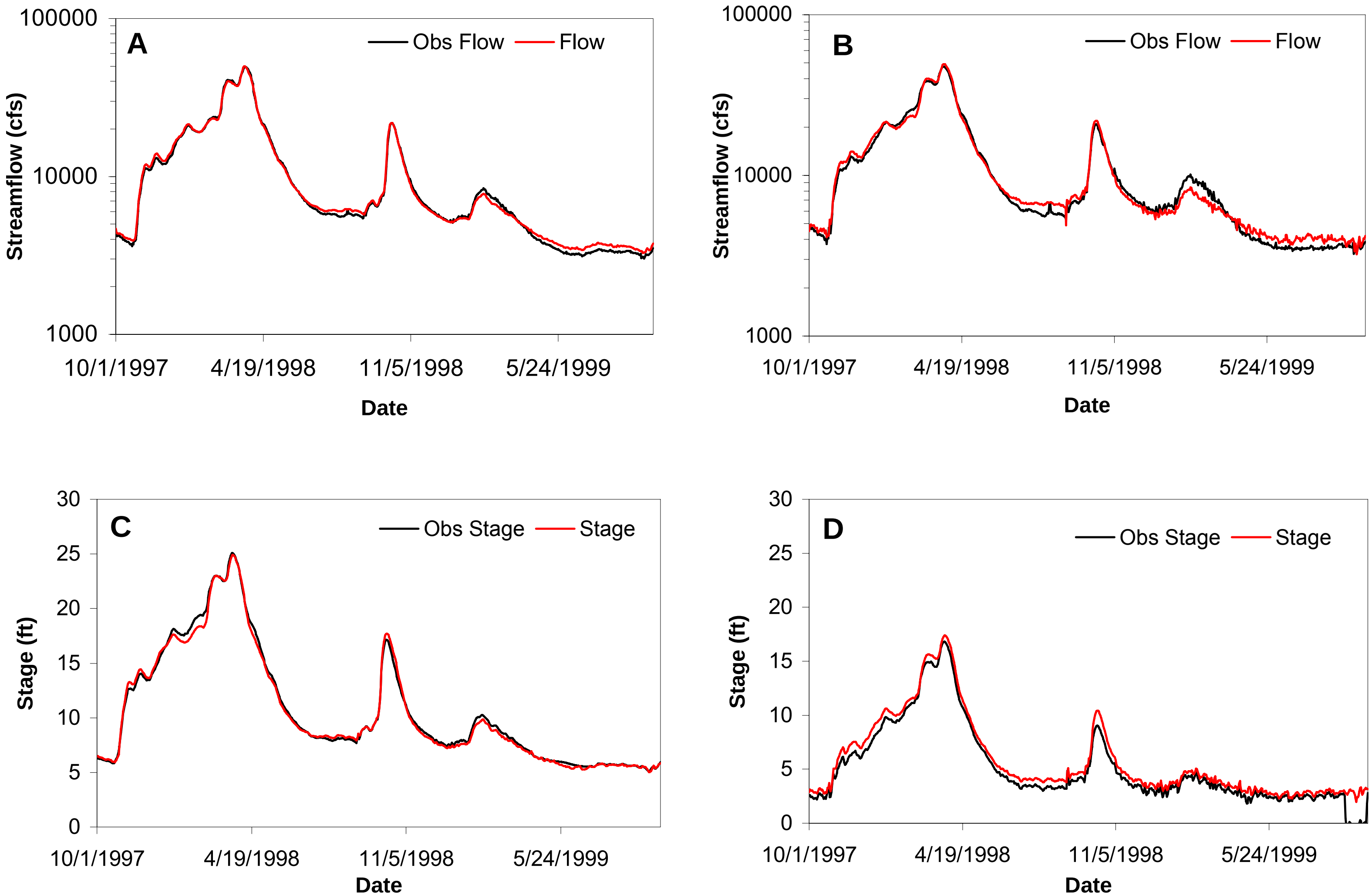

Figure 3-11. MODBRANCH simulated and observed hydrographs for stream flow at (A) Bell and stage (B) at Wilcox. Plotted time step is daily.

3.1.10 Hydrologic Issues

This section addresses issues that could affect the selection of the best available data for use in setting MFLs for the Lower Suwannee River. In all cases, SRWMD has determined that these issues are not directly relevant to establishment of the MFLs. The purpose of this section is to explain the rationale behind these decisions and why explicit analysis of these issues was not incorporated into the Lower Suwannee MFL process.

3.1.10.1 Long-term Climatic Cycles

In addition to the basic spatial and temporal effects of climate on hydrology, described in Section 2.0, two other large-scale climatic phenomena have a long-term influence on the hydrology of the Suwannee River. These are the El Niño Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation (AMO).

The ENSO phenomenon is associated with water temperatures and atmospheric pressure in the eastern equatorial Pacific Ocean (Tootle and Piechota, 2004). During the El Niño phase, warmer than average sea-surface temperature in the Pacific is associated with higher rainfall in Florida, due to shifts in the jet stream over the state. Especially strong effects are felt when the event is “moderate to strong” and lasts for >2 years (Fernald and Purdum, 1998). In fact, the larger floods occurring on the Suwannee (e.g., 1998, 1984, and 1973) were associated with strong El Niño events (Tootle and Piechota, 2004). In contrast, when sea surface temperatures in this region of the Pacific are colder than average (La Niña event), drought conditions prevail across the state. A strong La Niña during the period 1999-2002 resulted in mean annual flows at Wilcox exceeding a 60 year drought event, which surpassed the drought of 1954-56.

The AMO is connected with a cyclic pattern of sea surface temperatures in the northern Atlantic Ocean (Kelly, 2004). Periods of warmer surface temperatures appear to alternate with cooler periods on a roughly 30 year cycle (30 years warm/30 years cool). These AMO-influenced warmer periods appear to be associated with less rainfall over most of the U.S., but these warmer periods create greater amounts of rainfall over Florida, with the opposite occurring during cooler periods. Correspondingly, river flows respond to these climatic changes, with higher flows occurring during the wetter periods and lower overall flows during the drier intervals.

Kelly (2004) discussed the influence of the AMO on the hydrology of rivers in Florida. The “northern river” and “southern river” patterns (Section 2.2.1.3) exhibit opposite responses to the AMO, primarily because northern Florida rivers mirror climatic events of the continental U.S., while the southern rivers are influenced by the maritime climate of the Florida peninsula.

In developing MFLs for the Lower Suwannee River and estuary, ENSO and AMO effects were accounted for within the data utilized. Data collected during the La Niña event in 1999-2002 gave an indication of the consequences of droughts and low flows. This event included cessation or significant reduction of flow in many springs, declines in tidal marsh plant taxa richness of 25- 50 percent, extensive canopy defoliation in tidal fresh-water swamps (Clewell, 2000; Mattson, 2002b), upstream retreat of low-salinity SAV and substantial declines in SAV cover and standing crop in the upper estuary (Estevez, 2000b; 2002), and extensive loss of aquatic habitat in the floodplain (Light et al., 2002).

3.1.10.2 Sea-Level Rise

Sea-level rise in the Gulf of Mexico is a documented phenomenon that is currently having and will continue to have an effect on coastal ecosystems in the region. Locally, Williams et al. (1999) demonstrated that mean higher high water has increased by 0.89 ft. at the Cedar Key tide gage over the past century, and that this increase was a contributor to coastal forest dieback in Waccasassa Bay. Raabe and Stumpf (1996) also demonstrated an upward trend in sea level at Cedar Key over the last 60 years, yet they found no net change in tidal marsh acreage on the Suwannee delta using GIS analysis of LANDSAT thematic mapper data and comparing with historic estimates. However, they determined that changes which did occur were concentrated along the seaward edge of the delta marsh (principally erosion), and in the interior coastal forests and tidal swamps (conversion to marsh).

The main effects of sea-level rise will be increased water levels (intertidal areas will be flooded more frequently and for longer periods) and increased salinity in upstream areas (saline water will be forced further inland). These changes will influence the distribution of tidal swamp and marsh vegetation throughout the estuary, will affect oyster reef development, fish distribution, behavior, and recruitment, and other ecological effects. The fresh-water/salt-water transition zone will also move inland, which will reduce the thickness of the fresh-water lens and change groundwater and spring flow dynamics.

3.1.10.3 Tidally-Forced Extreme Events

Tropical weather events (hurricanes and tropical storms) occasionally impact the Suwannee basin. These events can be damaging to the natural ecosystems of the basin. Damage inland may result from high winds, which uproot trees and defoliate the tree canopy, and floods in low-lying areas. Along the coast, damage from storm surges results from deposition of large rafts of wrack (Clewell et al., 1999), inland intrusion of salt water, or shoreline erosion. Tillis (2000) recorded salinities of 26-27 ppt well upriver (at the WP and EP gages) as a result of Hurricane Opal in 1995. These are waters that are normally fresh most of the time. Even rarer, but just as destructive, are extra-tropical storm events during the winter, when strong cold fronts push southeast across the northern Gulf of Mexico. One such event (the “No Name Storm”) occurred in March, 1993. Despite the destruction caused by these events, the natural communities of the Suwannee River and Estuary have withstood them for thousands of years, and the ecosystems are adapted to deal with them.

3.2 Springs

3.2.1 Overview

There is a long history of spring discharge measurement at Manatee and Fanning Springs (Ferguson et al., 1947; Rosenau et al., 1977; Hornsby and Ceryak, 1998; Scott et al., 2002). Over the past several decades, limited groundwater monitoring and regular monthly monitoring of rainfall at several sites has occurred within the Manatee and Fanning Springs springsheds. In 2001, the District began a comprehensive monitoring and analysis program of five first-magnitude springs, including Manatee and Fanning Springs. This program (Upchurch et al., 2001) included monitoring of spring discharge and stage, spring basin delineation, and intensive ground water monitoring in each springshed. However, only a handful of discharge measurements exist for Little Fanning Spring. Monitoring history and physical descriptions of the springs are included in Section 2.3. This section presents a summary and analysis of the hydrologic data that are available for determining minimum flows and levels (MFL's) for Fanning and Manatee Springs.

3.2.2 Data

Unless otherwise noted, the District provided all data for this analysis. The data set includes information on groundwater levels and use, stream gage measurements, spring run, bathymetry, thermal data for the Suwannee River and Manatee Springs, and precipitation.

3.2.2.1 Gage Locations and Periods of Record

Stage and discharge data exist for three gages in the Fanning and Manatee springshed (Figure 3-12). Table 3-19 contains the periods of data collection, the number of direct stage and discharge measurements, and the number of daily gage measurements of stage and discharge for each station. The data are presented graphically in Appendix A.