TECHNICAL REPORT

MFL ESTABLISHMENT
FOR THE
LOWER SUWANNEE RIVER & ESTUARY,
LITTLE FANNING, FANNING,
&
MANATEE SPRINGS

OCTOBER 2005

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CERTIFICATION

This Technical Report was prepared for the use of the Suwannee River Water Management District for the establishment of Minimum Flows and Levels for the Lower Suwannee River and Estuary, Little Fanning, Fanning and Manatee Springs by the undersigned.

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Technical Report

MFL Establishement for the Lower Suwannee River & Estuary, Little Fanning, Fanning & Manatee Springs

SUWANNEE RIVER WATER MANAGEMENT DISTRICT

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1.0 Introduction

This Minimum Flows and Levels for the Lower Suwannee River and Estuary – Technical Report (Report) presents the data and analyses which provide technical support for the establishment and adoption of Minimum Flows and Levels (MFLs) for the Suwannee River Estuary ("Lower Suwannee River"), Manatee Springs, and Fanning Springs. The goals for these MFLs are:

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

1.1 State of Florida Law Pertaining to the Establishment of MFLs

Chapter 373.042, F.S:

(1) Within each section or the water management district as a whole, the Department (Florida Department of Environmental Protection) or the district Governing Board shall establish the following:

(a) Minimum flow for all surface watercourses in the area. The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.

(b) Minimum water level. The minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area.

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

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

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

These requirements constitute the statutory framework and the outline for the scope of work required to develop the MFLs for the Lower Suwannee River including Manatee Spring and Fanning Springs.

1.2 Project Scope

In September 1994, the Governing Board of the Suwannee River Water Management District (District) initiated the effort to develop MFLs for the Lower Suwannee River. The study area (Fig. 1.1) included the Lower Suwannee River from Fanning Springs to the river mouth, and including the estuary of the river (the region including Suwannee Sound, Horseshoe Cove, Cedar Key, and the nearshore waters of the Gulf of Mexico influenced by freshwater discharge from the river). Note that the study area, which is termed the Lower Suwannee River in this report, is the tidal portion of the Lower Suwannee hydrologic unit as identified by the U.S. Geological Survey (USGS; Kenner, et al., 1967).

As the Lower Suwannee River MFL was being developed, it became evident that the two major springs on the Lower Suwannee River (Fanning and Manatee Springs), which are also on the District's list for MFL development, would play a significant role in MFLs for the river. This is due to the fact that the Suwannee River has an integral relationship to the MFLs for each spring as a contributing flow back into the springs and as a dilution factor for thermal effects of the spring discharges which impacts manatee refuge. Therefore, it was decided that the three sets of MFLs would be established simultaneously.

1.3 Water Body Regulatory Designations

The Suwannee River is widely regarded as a river system with high conservation value. In a study using data from the National Rivers Inventory (NRI), Benke (1990) identified the Suwannee as one of 42 "large, intact" river drainages remaining in the U.S. He defined these as rivers with more than 124.2 miles (200 km) of length that are unaffected by any major dams, flow diversions, or navigation projects. These 42 river systems cumulatively represented only 2% of the total length of river reaches in the NRI database. Based largely on Benke's work, Noss et al. (1995) designated large intact streams and rivers in the U.S. as "Endangered Ecosystems", which they defined as those ecosystem types which have experienced an 85-98% decline in the existence of high-quality, intact examples. In similar fashion, a report on U.S. river ecosystems by The Nature Conservancy (Master et al., 1998) classified the Suwannee/Santa Fe drainages as "critical watersheds to protect freshwater biodiversity." Moreover, the federal government has designated portions of the Suwannee River as Critical Habitat for Gulf sturgeon, a federally threatened species. Existing state designations recognize the Suwannee as a river system of both regional and statewide importance. The Suwannee is recognized as a system having high conservation and recreational value, through designations such as Outstanding Florida Water (OFW) and Aquatic Preserve.

The Suwannee River, including the Lower Suwannee River MFL study area, is designated an Outstanding Florida Water (Chapter. 62-302.700[9][i][34], F.A.C.). This designation is conferred to waters of the state with "exceptional recreational or ecological significance" (Chapter 62-302.700[3], F.A.C.).

Figure 1-1 Map showing the Lower Suwannee River MFL study area.

A substantial portion of the MFL study area also lies within the Big Bend Seagrasses Aquatic Preserve. Aquatic Preserves are established by the State Legislature "…for the purpose of being preserved in an essentially natural or existing condition so that their aesthetic, biological and scientific values may endure for the enjoyment of future generations." (Chapter 18-20.001[2], F.A.C.). The Big Bend Seagrasses Aquatic Preserve was created in 1985 and includes the Lower Suwannee River from Fanning Springs to the mouth and all of the coastal waters of the Suwannee estuary.

The Lower Suwannee River study area also includes a number of important conservation areas, including two National Wildlife Refuges (Lower Suwannee and Cedar Keys NWRs), two State Parks (Fanning Springs and Manatee Springs), a state Wildlife Management Area (Andrews

WMA) and numerous parcels of Water Management District lands. These lands provide important ecological services as well as public recreation benefits (hiking, swimming, fishing, hunting, kayaking, etc.).

The springs play an integral role in the ecological and health and hydrology of the Lower Suwannee system. Manatees move freely from the river to the springs to find refuge if winter months and the river provides a carbon source to the spring biota for maintenance of the spring ecosystem.

Fanning Springs is a State Park. The spring is classified as a 1st magnitude spring but the flow no longer meets 1st magnitude flow requirements of 100 cfs median flow. Based on review of available discharge data, Fanning Springs has not ever met the criteria for 1st magnitude classification (mean or median discharge of 100 cfs or greater). The spring does experience intermitting discharge greater than 100 cfs. The spring is currently being renovated and is a popular swimming and picnicking area. Attendance at the spring for fiscal year 2003/2004 was recorded at 249,565.

Manatee Springs is a popular State Park that boasts a 1st magnitude scenic spring and spring run, swimming area, manatee viewing, and cave diving, among other activities. Attendance at the spring for fiscal year 2003/2004 was recorded at 129,661 (FDEP- 2004).

1.4 Relevant Water Resource Values

As noted in Section 1.1, Chapter 62-40.473, F.A.C. provides policy guidance regarding establishment of MFLs. In particular, this section of Florida's Water Policy lists 10, specific environmental and water resource values that should be considered in setting MFLs. As part of the MFL establishment process, Chapter 62-40.473, F.A.C. environmental and water resource values evaluation matrices are prepared to allow the MFL evaluators the opportunity to identify potential target values that may be the limiting factors for the proposed MFLs (Tables 1-1 thru 1-3). This process helps to focus the evaluation and shape the types of analyses needed to complete the MFL. This ranking process is initiated after compilation of all available data and review by the MFL evaluators. The rankings represent the professional opinion of the WRA team of experts based upon their collective experience in the development of MFLs after reviewing available data for each waterbody. Each ranking is based upon the collective experience of the evaluation team in establishing MFLs and review of the available data. Target values have the highest probability of limiting the amount of water available for the water body without causing significant harm. As an example, if the fish passage criterion requires the most water flow to avoid significant harm to the water body, then that value becomes the limiting factor for the proposed MFL since all other values would require less flow to avoid significant harm. This value ranking procedure is not inflexible and new target criteria can emerge in the evaluation process, but in most cases the initial determinations are accurate

The relevance of each, and how they were incorporated into the establishment of MFLs for the Lower Suwannee River, Fanning Springs and Manatee Springs, is discussed below:

a. Recreation in and on the water. This water resource value is considered relevant to the Lower Suwannee River and its springs. The Outstanding Florida Water designation of the river is in part based on the recreational significance of the Suwannee system. Uses include swimming, boating, water skiing, recreational fishing, kayaking and canoeing. The District and the Florida Department of Environmental Protection (FDEP) are currently engaged in creating the "Suwannee Wilderness Trail"; a 207-mile canoe trail on the Suwannee River, linked with a network of camping and cabin facilities located on State and District lands. In establishing MFLs for the Lower Suwannee River and

Estuary, general information was considered on the economic value of ecotourism, recreational fishing, and related activities.

Similarly, recreation is a major use of Fanning and Manatee springs. Both are popular and heavily utilized. Maintaining an acceptable spring discharge for recreation was considered for each.

b. Fish and wildlife habitats and the passage of fish. This water resource value is considered relevant for the Lower Suwannee River MFLs. Fish passage is not as much an issue in the river channel itself, due to the general lack of shallow shoal areas in the MFL study area, but it may be considered as a component of adequate water depths on the floodplain and tidal marshes. A major focus of the studies conducted to support the Lower Suwannee River MFLs was on the major wetland and aquatic habitats of the lower river and estuary (see Chapter 4 in this report), and how hydrologic conditions structure those habitats.

The springs are both secondary refuges for the West Indian Manatee (Warm Water Task Force, 2004). Consideration was given to providing acceptable refuge for manatees during cold months as well as for fish passage and wildlife habitat in general.

c. Estuarine resources. This water resource value is considered relevant for the Lower Suwannee River. The estuary of the river is the largest and most extensive river estuary in the Big Bend region of the Florida Gulf Coast (Mattson, 2002a); it is part of the Big Bend Seagrasses Aquatic Preserve, an OFW, and it supports extensive recreational and commercial fisheries. To support establishment of the Lower Suwannee River MFLs, relationships between stream flow and estuarine salinity dynamics were investigated, and studies of important estuarine habitats were conducted to evaluate the effects of freshwater inflow and salinity on those habitats. The results of these were incorporated into the Lower Suwannee River MFLs.

The spring flows did not in themselves merit consideration as having impacts on the estuarine resources but consideration was given to the contribution of spring discharge to overall discharge of the river below Wilcox (Fanning Springs).

d. Transfer of detrital material. It has been well-established that a principal food base in aquatic and wetland ecosystems is decaying plant material, collectively termed “plant detritus” or simply detritus. Transport of this material from the river floodplain wetlands to the river channel is an important source of food material for riverine invertebrates, and transport of material from the river to the estuary is similarly a vital component of maintenance of the food base for estuarine consumers. This water resource value is relevant to the Lower Suwannee River MFLs, and existing data in the scientific literature were used to assist in determination of MFLs for the Lower Suwannee River.

Transport of detrital material is not a consideration with respect to spring discharge. During periods of high discharge in the river, the springs perform as estevelles. That is, they backflow and transport humic substances and minor detritus from the river into the cavern systems that feed the springs. No data exist as to the importance of this process or how it specifically impacts these springs.

e. Maintenance of freshwater storage and supply. This water resource value is considered relevant to the Lower Suwannee River MFLs, and it is considered in more detail in

Chapters 3. Establishment of an MFL for a water body implicitly establishes potential availability of that water. This water resource value refers to the long-term maintenance (i.e., sustainability) of water storage and supply capability of the water body. The result of the protection of this value by MFL establishment is to ensure that, over time, the ability of the water body to serve as a supply source for existing and future legal permitted users is preserved without causing "significant harm" to the water resource or ecology of the area.

f. Aesthetic and scenic attributes. This water resource value is closely linked with the first one pertaining to recreation, in that part of the recreational value of the Lower Suwannee River is the aesthetic experience.

Aesthetic and scenic attributes are considered relevant to the establishment of MFLs for the Lower Suwannee River, and were incorporated as an important characteristic along with recreation.

Both springs are in state parks and are considered to have high aesthetic and scenic value. MFL consideration included acceptable maintenance of these attributes through provisions for a full spring bowl, minimization of black water reversal from the river and maintenance of stage in the spring runs.

g. Filtration and absorption of nutrients and other pollutants. This water resource value is considered relevant to the Lower Suwannee River MFL. The role of wetlands in maintenance of water quality is well-established (Mitsch and Gosselink, 1986). By allowing for settlement of suspended particulates, uptake of nutrients by plants, and sequestration of heavy metals and other contaminants in sediments, wetlands help protect water quality. Data from the scientific literature on nutrient cycling and other biochemical functions of wetland were taken into consideration in establishing MFLs, with the assumption that maintaining an acceptable level of ecological integrity for wetland ecosystems of the Lower Suwannee River would maintain this particular function.

Both spring systems have records of increasing nitrate concentrations. The spring systems, however, have little nutrient sorption capability. Submerged aquatic vegetation (SAV) provides minor sorption because of the short residence time of water in the spring systems.

h. Sediment loads. This water resource value is considered relevant to the Lower Suwannee River MFL. Available evidence indicates that the Suwannee River carries substantially lower sediment loads than similar-sized rivers along the northern Gulf Coast (USDA, 1977). This is primarily due to the physiography and soil types present in the basin. Despite this fact, the presence of alluvial features in the floodplain of the river and the existence of an estuarine delta indicates that the river does carry some sediment, which is important in the maintenance of these geomorphic features and their associated ecological communities. It is probable that most of the river's sediment load is carried at higher flows. General information from the literature on riverine fluvial dynamics was considered in setting the MFLs.

Transport of sediment loads is not considered to be an issue with respect to the springs. Both spring systems are sediment starved.

i. Water quality. This water resource value is considered relevant to setting MFLs on the Lower Suwannee River. The main water quality consideration was salinity variation in the estuary in relation to freshwater inflow and its effects on important estuarine habitats and fauna.

While increasing nitrate concentrations in the springs is a concern, the increases are not related to levels or flows. They are related to land use within the springsheds. Water quality was not considered in MFL development for the springs.

j. Navigation. This water resource value was considered not relevant to the Lower Suwannee River MFLs, in that the system is not a waterway which supports commercial shipping or barge traffic. Passage by recreational vessels, canoes, etc. was considered under the "Recreation in and on the water" value, above.

Neither spring has a navigable run. Canoeing and swimming were considered as recreational and scenic/aesthetic criteria.

SUWANNEE RIVER WATER MANAGEMENT DISTRICT

Table 1-1 MFL DECISION MATRIX: FANNING SPRINGS

Potential Criteria	Resource at Risk	Resource Value	Legal Factors	Rank	Available Data	Preliminary Data Analysis: Related to Flow/Level?	Limiting Criterion?
Notes	1	2	3	4	5	6	7
Recreation in and on the water	3	3	2	8	2	Y	N
Fish and wildlife habitats and the passage of fish	3	3	3	9	4	Y	Y
Estuarine resources	1	1	1	3	4	Y	N
Transfer of detrital material	1	1	1	3	1	N	N
Maintenance of freshwater storage and supply	2	3	1	6	6	Y	N
Aesthetic and scenic attributes	3	3	3	9	1	Y	N
nutrients and other pollutants	1	1	1	3	1	N	N
Sediment loads	1	1	1	3	1	N	N
Water quality	3	2	1	6	3	N	N
Navigation	1	1	1	3	1	N	N

Notes:

1. Evaluation of the level to which the resource is potentially at risk. 1 = low risk, 2 = medium risk, 3 = high risk
2. Evaluation of importance of the criterion with respect to resource. 1 = low importance, 2 = medium importance, 3 = highly important
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. 1 = low, 2 = medium, 3 = high
4. Sum of columns 1, 2, and 3. Indicates overall importance of criterion to MFL development.
5. Evaluation of available data for use in development of MFL based on the criterion. 0 = no data available, 8 = abundant and relevant data available
6. Evaluation as to whether criterion is related to flow or level in resource. (Yes or No)
7. Evaluation as to whether criterion is potentially limiting for MFL development. (Yes or No)

Table 1-2 MFL DECISION MATRIX: MANATEE SPRINGS

Potential Criteria	Resource at Risk	Resource Value	Legal Factors	Rank	Available Data	Preliminary Data Analysis: Related to Flow/Level?	Limiting Criterion?
Notes	1	2	3	4	5	6	7
Recreation in and on the water	3	3	2	8	2	Y	N
Fish and wildlife habitats and the passage of fish	3	3	3	9	4	Y	Y
Estuarine resources	1	1	1	3	4	Y	N
Transfer of detrital material	1	1	1	3	1	N	N
Maintenance of freshwater storage and supply	2	3	1	6	6	Y	N
Aesthetic and scenic attributes	3	3	3	9	1	Y	N
nutrients and other pollutants	1	1	1	3	1	N	N
Sediment loads	1	1	1	3	1	N	N
Water quality	3	2	1	6	4	N	N
Navigation	1	1	1	3	1	N	N

Notes:

1. Evaluation of the level to which the resource is potentially at risk. 1 = low risk, 2 = medium risk, 3 = high risk
2. Evaluation of importance of the criterion with respect to resource. 1 = low importance, 2 = medium importance, 3 = highly important
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. 1 = low, 2 = medium, 3 = high
4. Sum of columns 1, 2, and 3. Indicates overall importance of criterion to MFL development.
5. Evaluation of available data for use in development of MFL based on the criterion. 0 = no data available, 8 = abundant and relevant data available
6. Evaluation as to whether criterion is related to flow or level in resource. (Yes or No)
7. Evaluation as to whether criterion is potentially limiting for MFL development. (Yes or No)

SUWANNEE RIVER WATER MANAGEMENT DISTRICT

Table 1-3 MFL DECISION MATRIX: LOWER SUWANNEE RIVER

Potential Criteria	Resource at Risk	Resource Value	Legal Factors	Rank	Available Data	Preliminary Data Analysis: Related to Flow/Level?	Limiting Criterion?
Notes	1	2	3	4	5	6	7
Recreation in and on the water	3	3	1	7	1	Y	N
Fish and wildlife habitats and the passage of fish	3	3	3	9	8	Y	Y
Estuarine resources	3	3	3	9	8	Y	Y
Transfer of detrital material	2	2	1	5	1	Y	N
Maintenance of freshwater storage and supply	2	3	2	7	4	Y	N
Aesthetic and scenic attributes	2	2	3	7	1	Y	N
nutrients and other pollutants	3	2	1	6	1	N	N
Sediment loads	1	1	1	3	1	N	N
Water quality	3	3	3	9	8	N	Y
Navigation	2	1	1	4	1	N	N

Notes:

1. Evaluation of the level to which the resource is potentially at risk. 1 = low risk, 2 = medium risk, 3 = high risk
2. Evaluation of importance of the criterion with respect to resource. 1 = low importance, 2 = medium importance, 3 = highly important
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. 1 = low, 2 = medium, 3 = high
4. Sum of columns 1, 2, and 3. Indicates overall importance of criterion to MFL development.
5. Evaluation of available data for use in development of MFL based on the criterion. 0 = no data available, 8 = abundant and relevant data available
6. Evaluation as to whether criterion is related to flow or level in resource. (Yes or No)
7. Evaluation as to whether criterion is potentially limiting for MFL development. (Yes or No)

SECTION 2

2.0 Introduction to the Suwannee River Basin and Study Area

2.1 Suwannee River Basin

2.1.1 Physical Setting of the Suwannee Basin

The Suwannee River Basin encompasses 9,950 mi^2 (25,770 km^2) in Florida and Georgia (Figure 2-1; Franklin et al., 1995). It is the second largest river system in Florida by drainage area and mean annual flow (Table 2-1). Major tributaries of the river are the Withlacoochee and Alapaha Rivers, which are mostly located in Georgia, and the Santa Fe River in Florida. In total, approximately 57% of the basin is in Georgia. The Suwannee is a low-gradient stream, with an average gradient of 0.4 feet per mile. The following discusses general characteristics of this complex river system.

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

	Basin Area (mi^2)	Total Length (miles)	Florida Length (miles)	Gradient (ft/mile)	Average Flow (ft^3/sec)
Suwannee River**	9,950	235	206.7	0.42	10,540**
Withlacoochee River	2,360	120	30.0	2.32	1,714
Alapaha River	1,840	130	22.6	1.80	1,674
Santa Fe River	1,360	79.9	79.9	1.90	1,608

** - includes contributions of the Withlacoochee, Alapaha and Santa Fe sub-basins

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

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

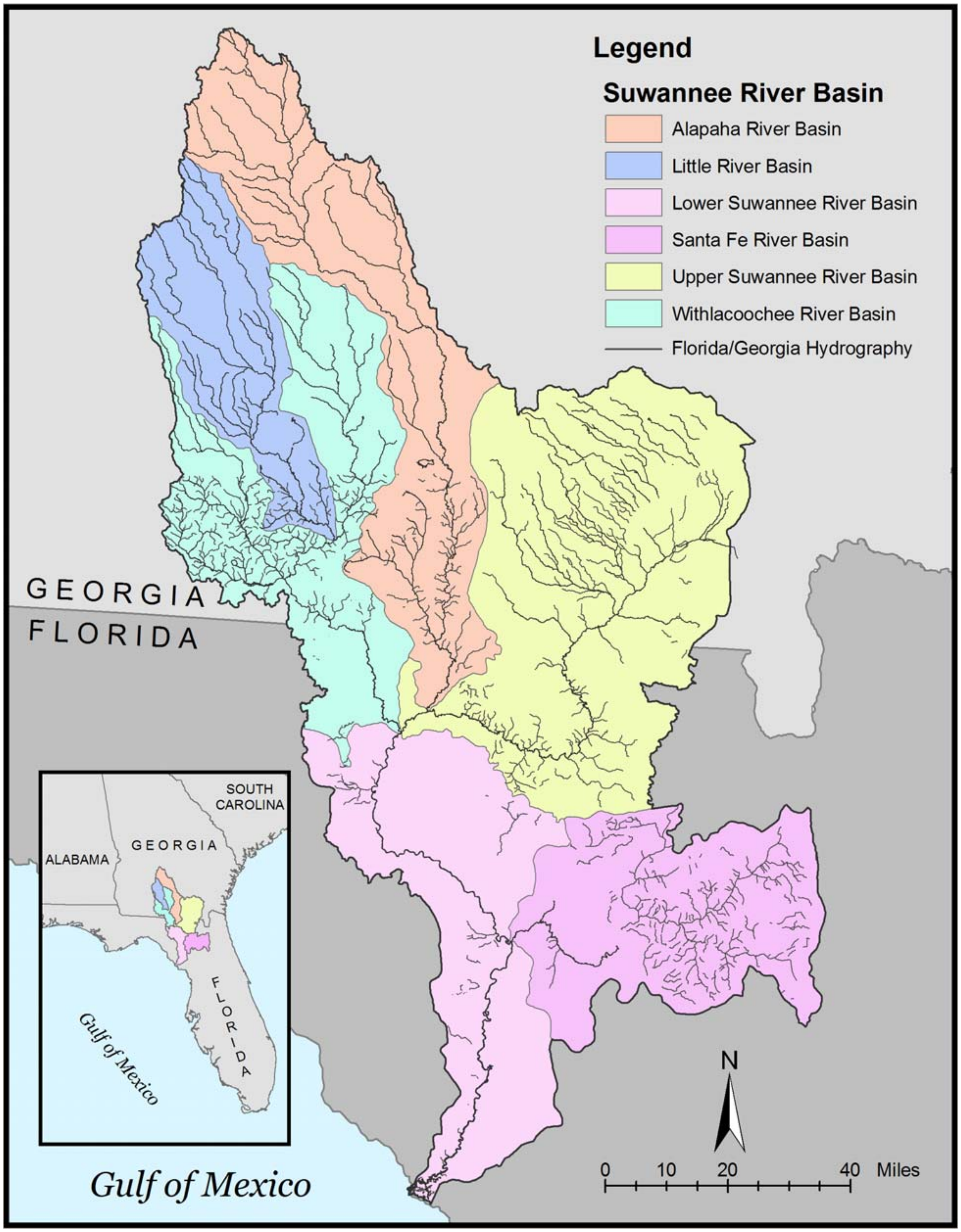

Figure 2-1. Suwannee River Basin in Florida and Georgia. Basins shown are USGS hydrologic units (Kenner et al., 1967).

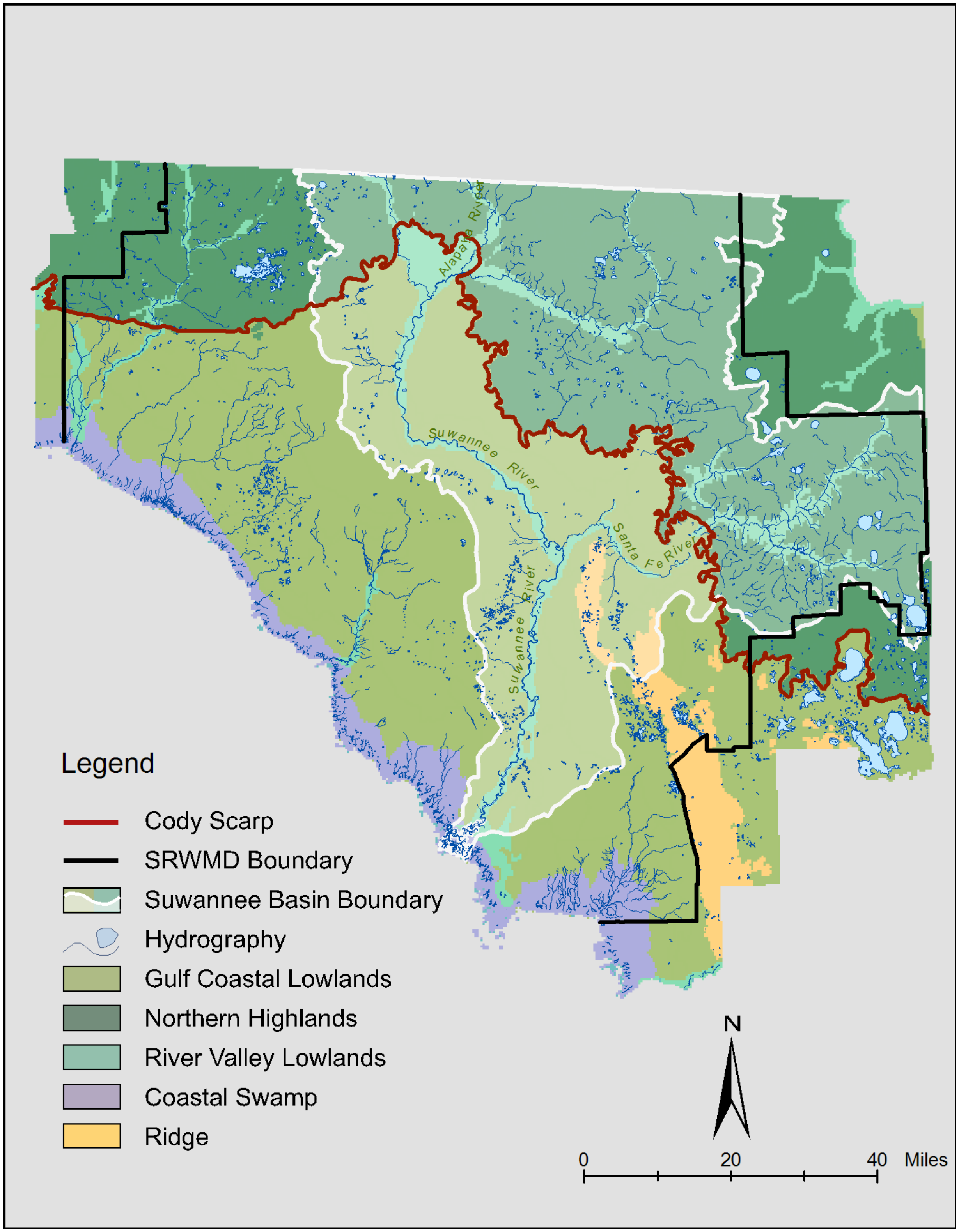

Figure 2-2. Physiographic regions in the SRWMD and regional hydrography in relation to the Suwannee River Basin in Florida. Data sources include White (1970); Ceryak et al. (1983); SRWMD data.

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

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

Ridges, such as Bell Ridge and the Brooksville Ridge, are prominent features in the southern part of the District (Figure 2-2). These ridges were formed by a combination of karst scarp retreat and marine terrace development.

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

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

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

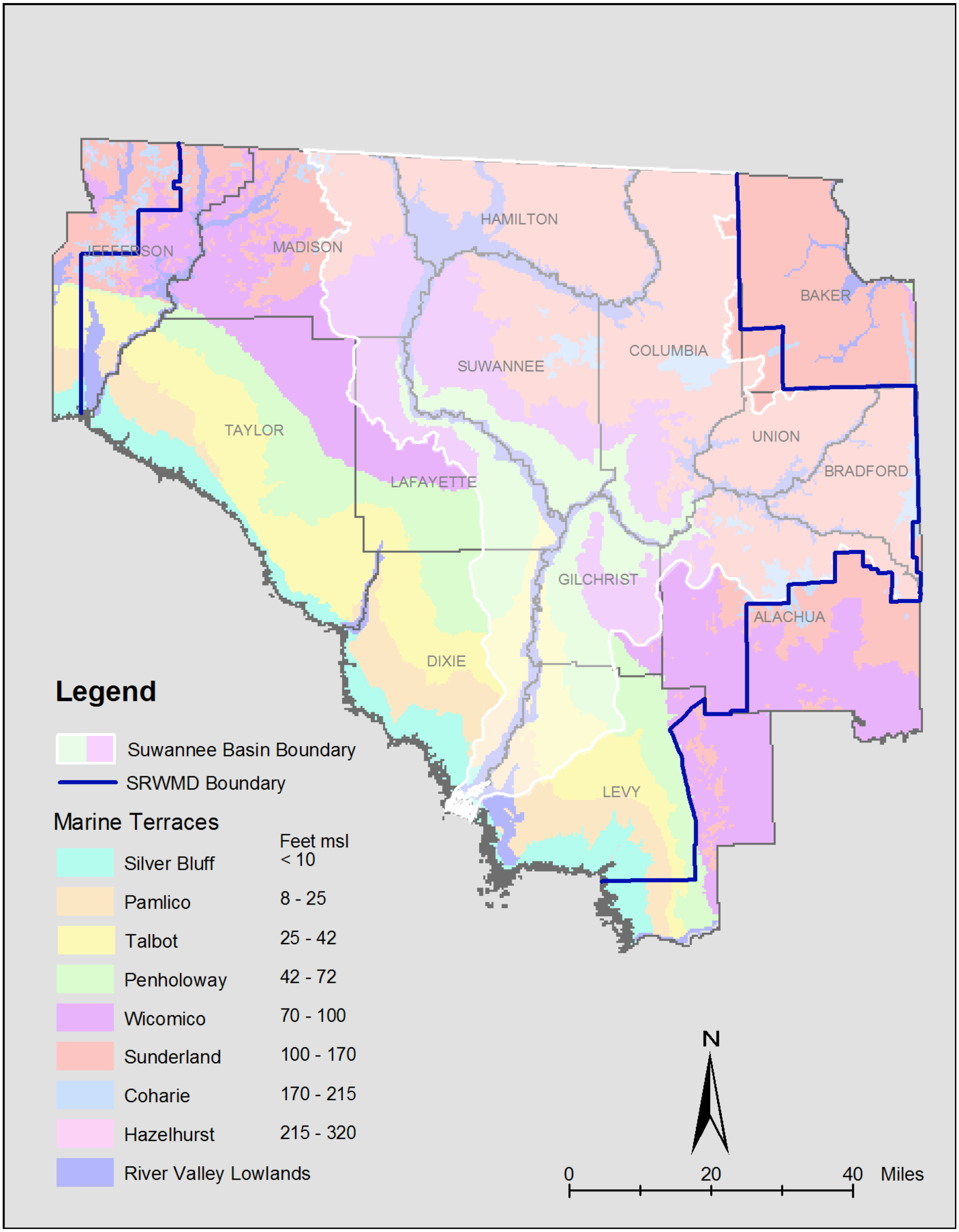

Figure 2-3. Marine terraces in the SRWMD in relation to the Suwannee River Basin. Data sources: USGS topographic GIS data and Healy, (1975).

2.1.2 Climate of the Suwannee River Basin

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

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

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

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

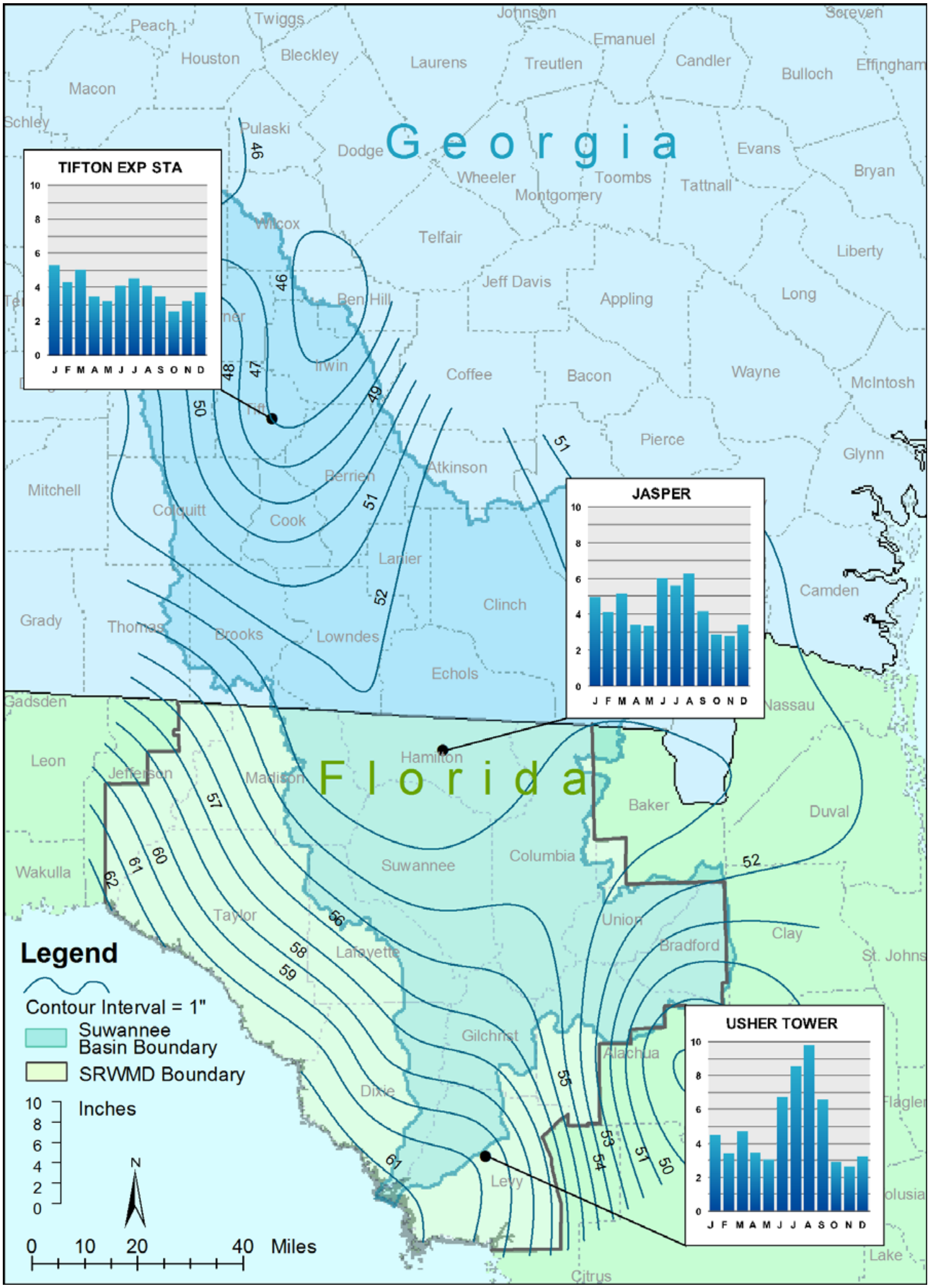

Figure 2-4. Average annual and monthly rainfall patterns in the Suwannee River Basin (Data: NOAA, 2002).

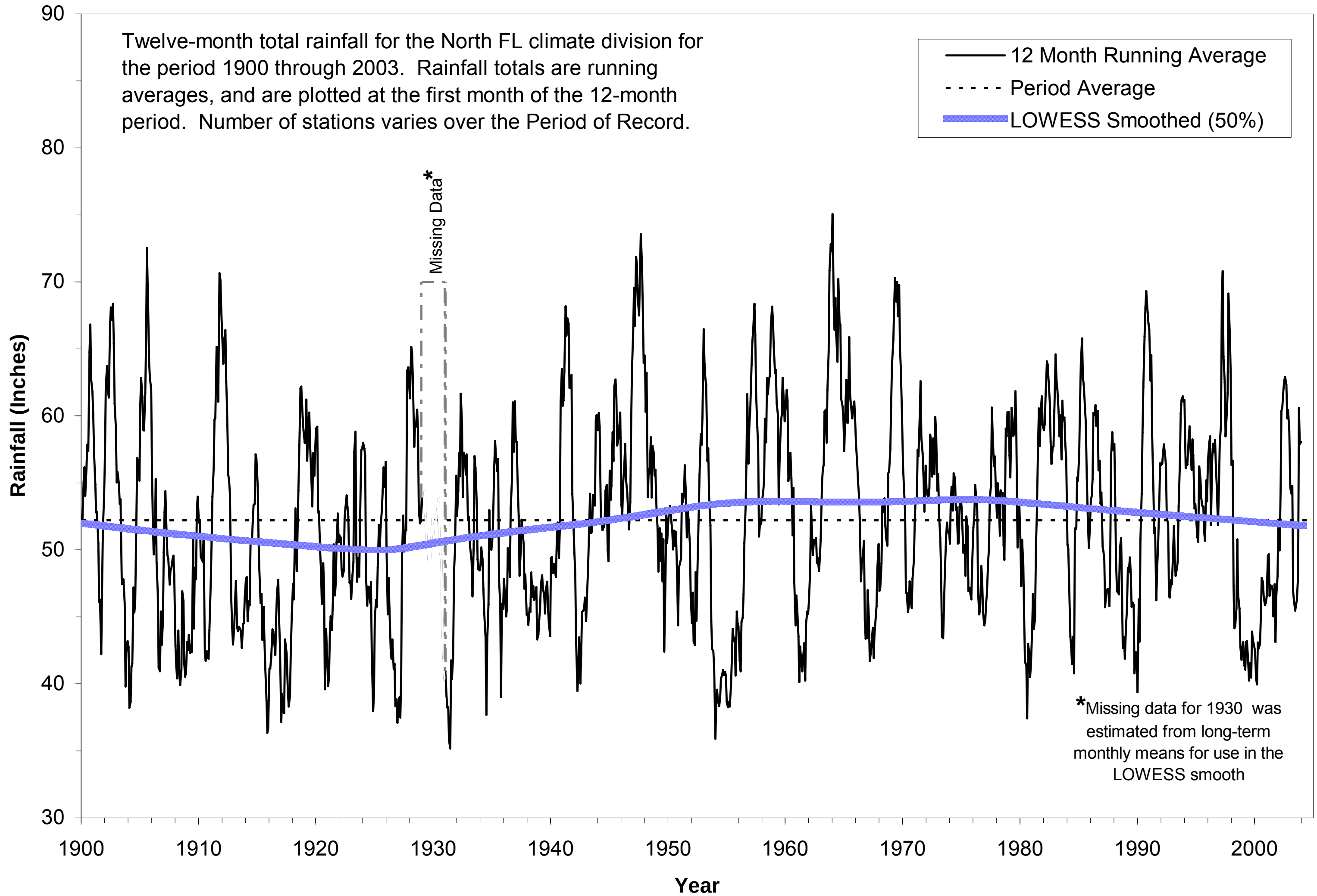

Figure 2-5. Twelve-month total rainfall for the North Florida climate division for the period 1900 to 2003. Rainfall totals are running averages, and are plotted at the first month of the 12-month period Data: NOAA (2005).

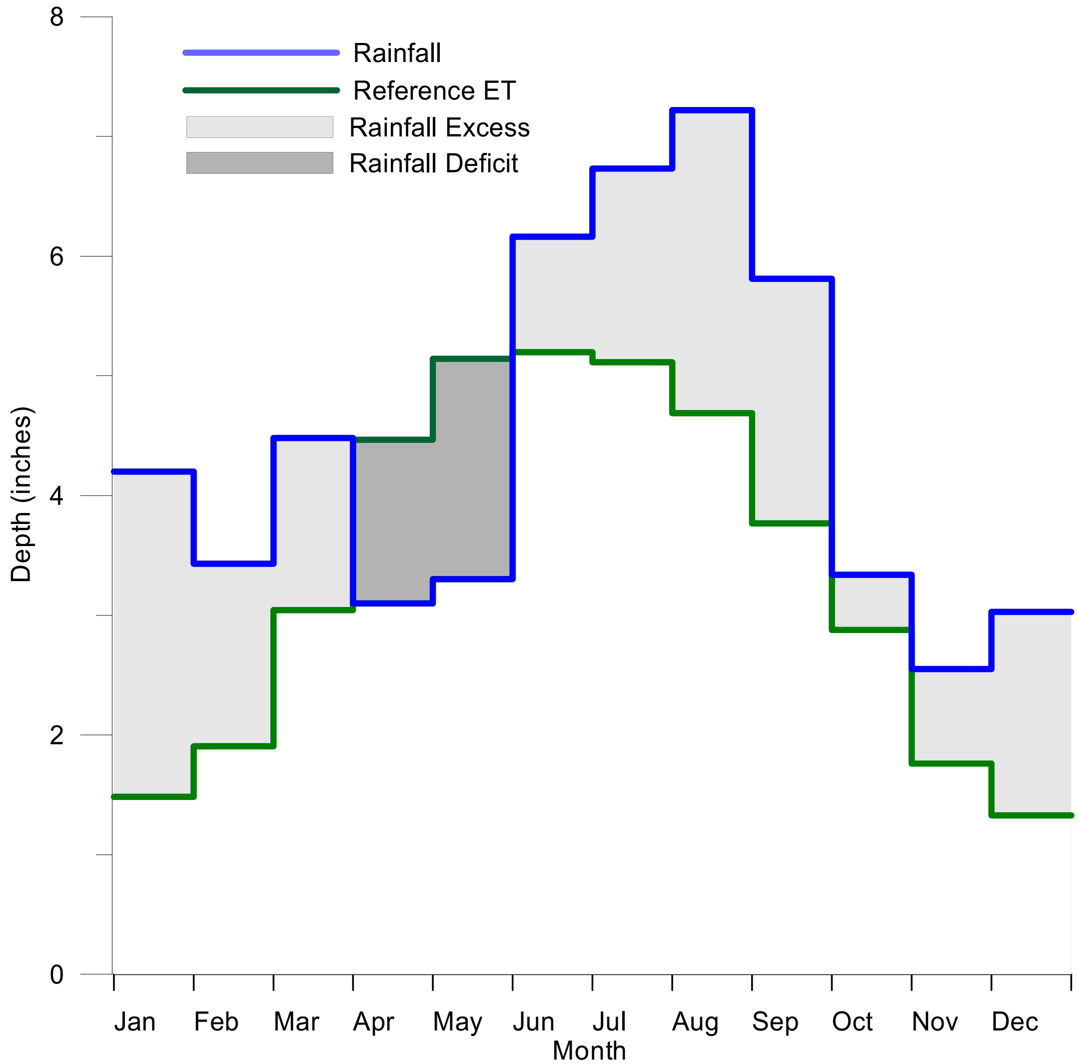

Figure 2-6. Mean monthly rainfall and reference evapotranspiration in the north Florida region. Data: NOAA (2002); Jacobs and Dukes (2004); Jacobs and Satti (2001).

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

Figure 2-6 indicates potential months of net rainfall surplus and/or deficit. During the cooler winter months, a water surplus can exist that serves to recharge the groundwater system. During late spring, a rainfall deficit can occur. Utilization of soil moisture (Fernald and Purdum, 1998) and late frontal systems can offset this effect. In the summer, the situation reverses, with rainfall typically exceeding ET. However, for climate-affected activities, such as agriculture, the scattered nature of summer convective rainfall events combined with excessive- to well-drained soils often result in site conditions that require supplemental irrigation.

2.1.3 Geology of the Suwannee Basin

The Suwannee River Basin lies in the Coastal Plain Physiographic Province of the United States (Hunt, 1974). The highly productive Floridan aquifer (Miller, 1997) underlies the region. It is capable of producing thousands of gallons of water per minute to wells. This section describes the geologic and groundwater systems of the Suwannee River Basin. Note that the lower Suwannee MFL study area is described in more detail in Section 2.3.

Carbonate rock (limestone and/or dolostone) as much as 5,000 feet thickness exists in the subsurface of the basin. These strata, which are primarily Tertiary in age, make up the Florida Platform. The Floridan aquifer is found within these strata and in similar strata in Georgia, the Carolinas, and portions of Alabama. The permeable portion of this carbonate-rock platform ranges from about 600 feet to 1700 feet in thickness (Miller, 1982).

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

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

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

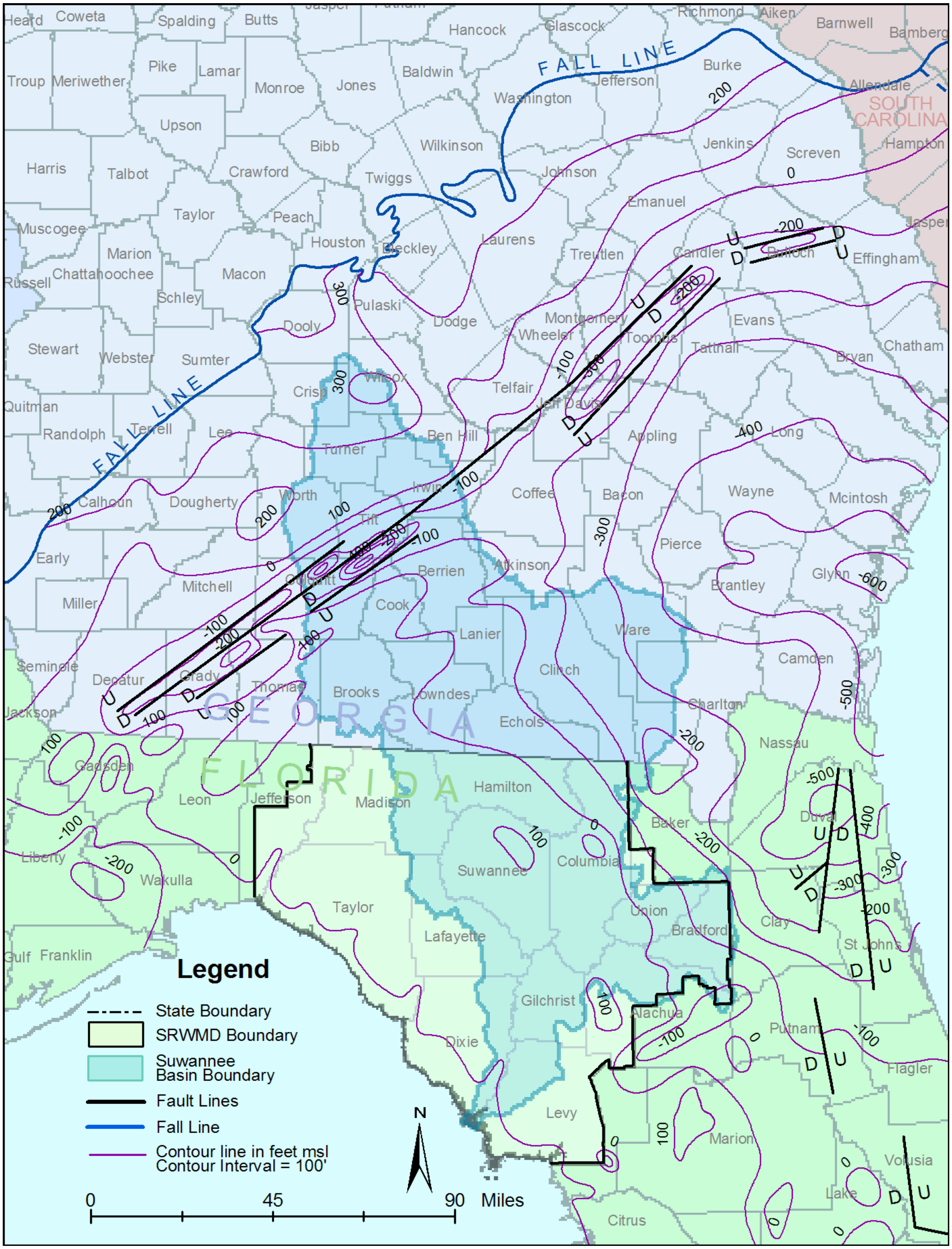

Figure 2-7. Extent of the limestone unit bearing the Floridan aquifer in the southeastern U.S. Fault line labels indicate: U = Uplift; D = Downlift. Adapted from Miller (1982).

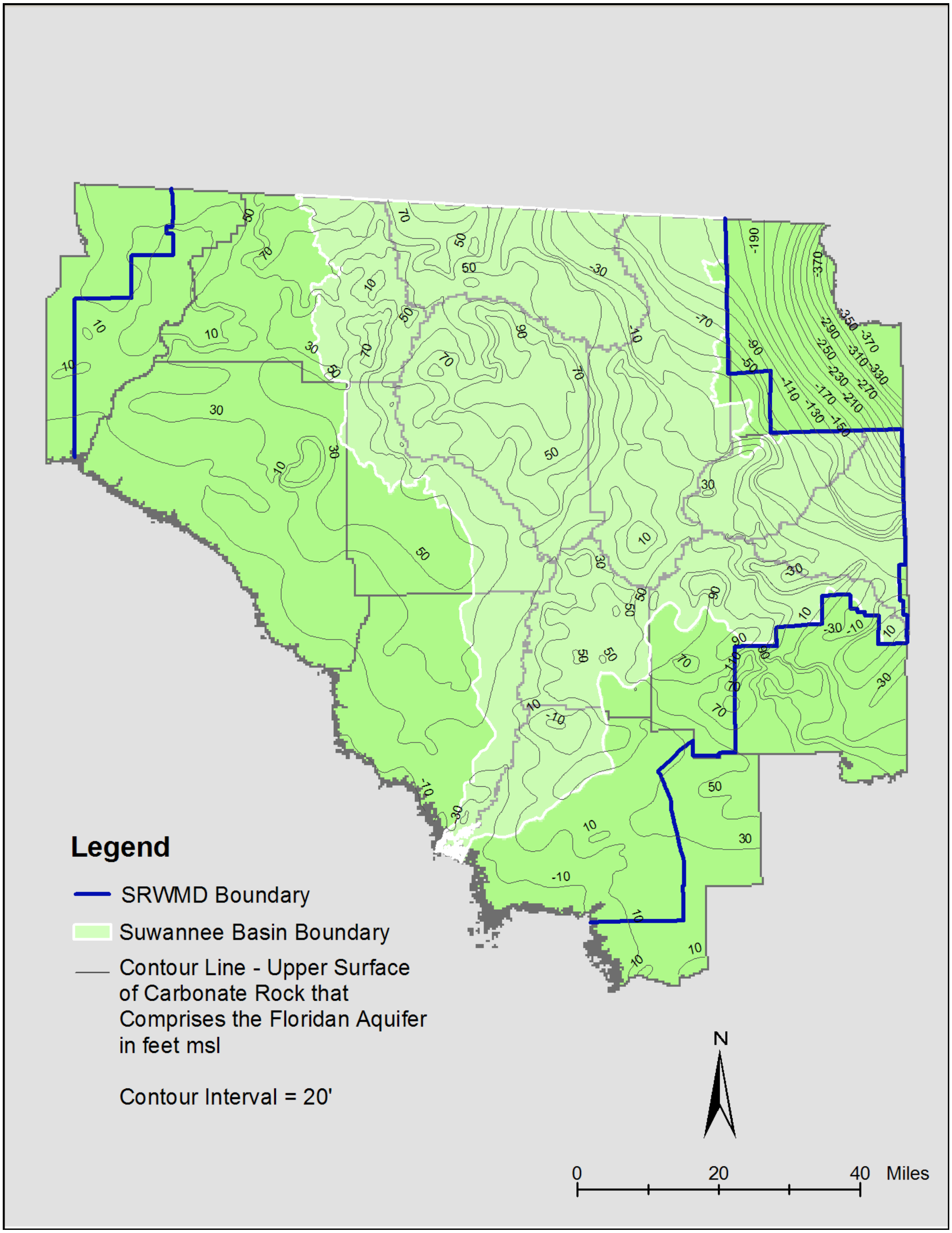

Figure 2-8. Elevation of the upper surface of the Tertiary limestone strata that constitute the Floridan aquifer within the District. Adapted from Allison et al. (1995).

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

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

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

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

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

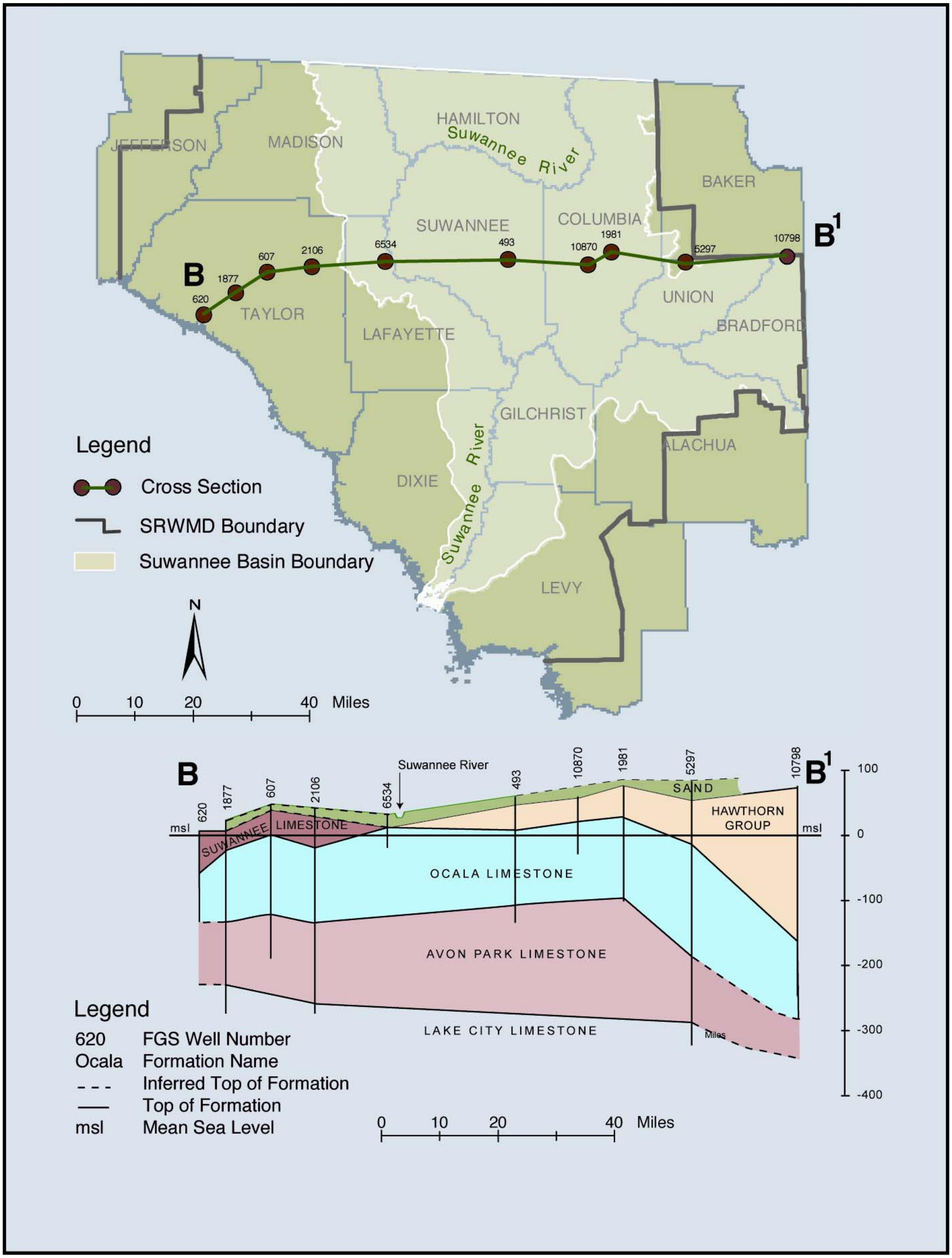

Figure 2-9. Generalized geologic cross section of the region. Adapted from Ceryak et al. (1983).

2.1.4 Regional Aquifer Systems

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

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

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

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

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

The saltwater/freshwater transition zone is the wedge-shaped groundwater zone where fresh ground water flows seaward, up and over saline water related to the

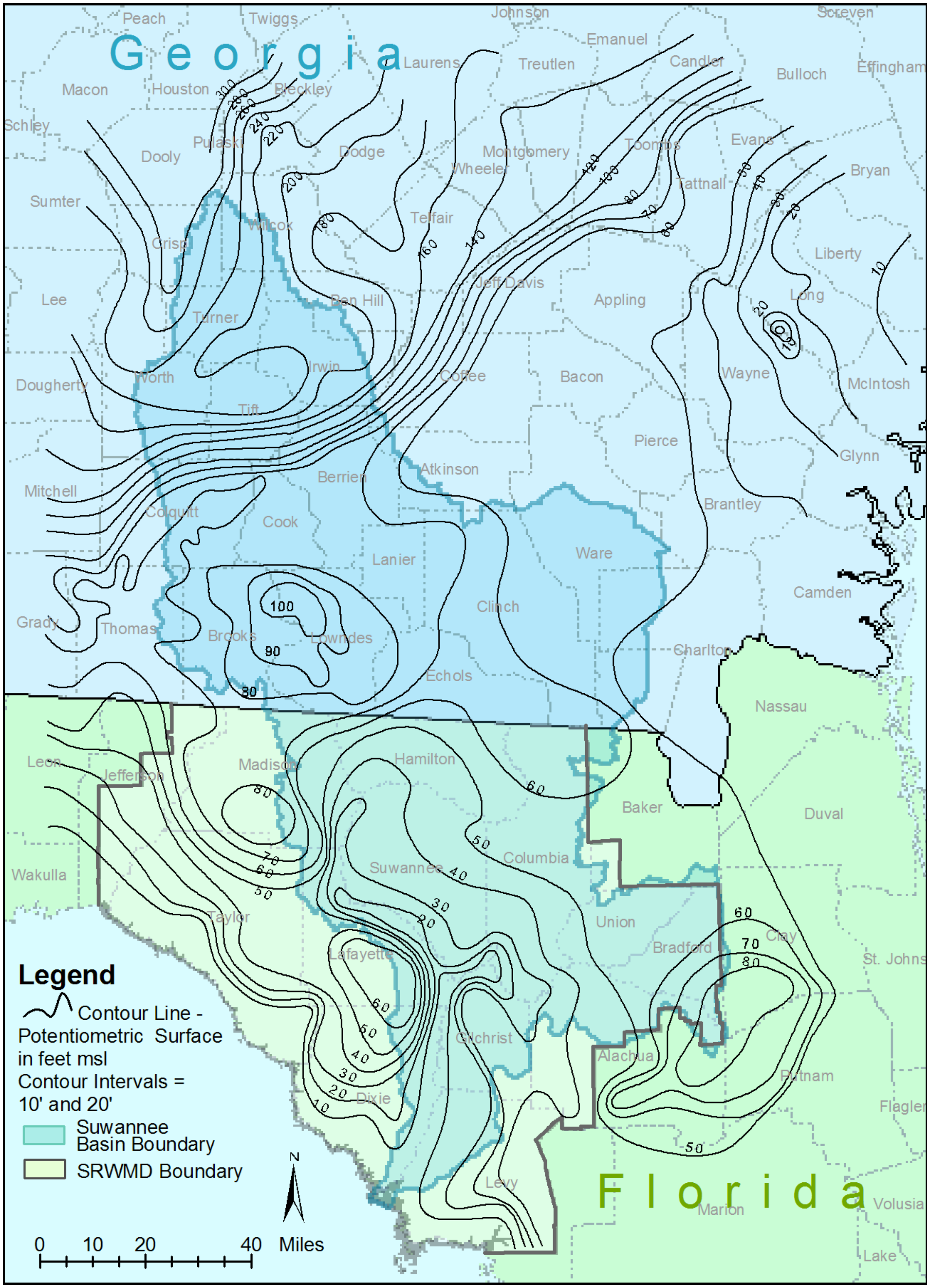

Figure 2-10. Potentiometric surface of the Floridan aquifer in May 1976. Adapted from Laughlin (1976); Rosenau and Meadows (1977); Fisk and Rosenau (1977).

Gulf of Mexico. The transition zone is characterized by upward movement and mixing of fresh water with saline water. The position of the transition has been roughly delineated by sodium and chloride data (Upchurch, 1990) along the Gulf of Mexico, and it has been defined by geophysics within a 20-kilometer radius around the mouth of the Suwannee River (Countryman and Stewart, 1997). Shallow aquifer water within about 5 miles of the Gulf coast tends to have relatively higher concentrations of sodium, chloride and potassium; however, chloride concentration does not exceed the 250 mg/L drinking water standard, (Copeland, 1987). Well depths in the larger coastal communities range from 85 feet to 170 feet without a significant increase in sodium, chloride or sulfate concentrations.

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

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

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

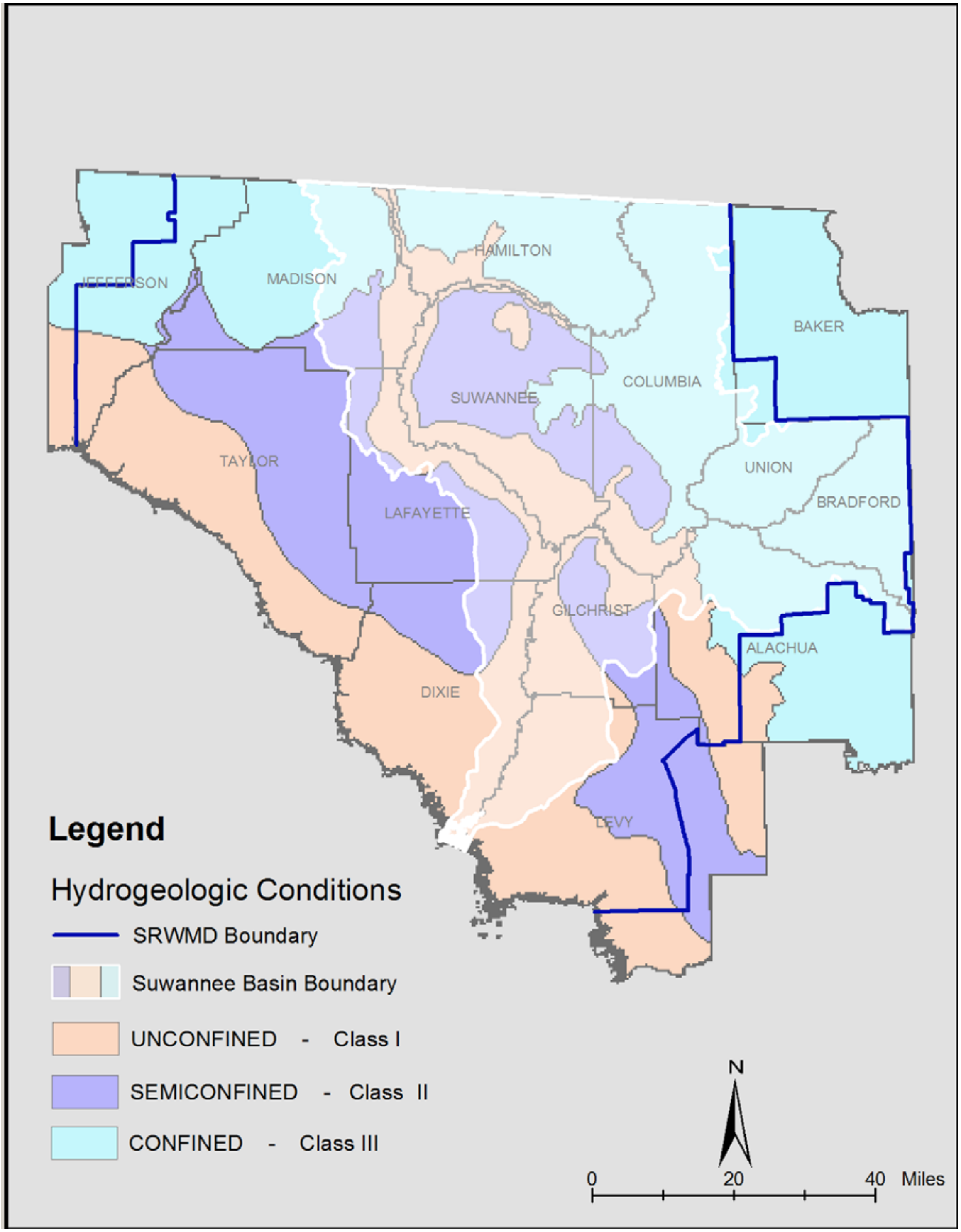

Figure 2-11. Confinement conditions of the Floridan aquifer in the region. Adapted from SRWMD (1982).

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

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

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

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

The lower Suwannee groundwater basin is characterized by flow toward the river (Figure 2-10) from the east and west. The groundwater basin boundary to the east is in central Levy and Gilchrist counties (Figure 2-10). There, a groundwater divide separates the Suwannee groundwater basin from the Waccasassa basin and the High Springs Gap groundwater flow system. The divide is located under the Waccasassa Flats and Bell and Brooksville Ridges. To the west, the groundwater basin is limited by the potentiometric surface high in Dixie and Lafayette counties (Figure 2-10).

The total fluctuation of the Floridan aquifer potentiometric surface in the basin ranges up to 40 feet in the Alapaha River Basin in the northern part of the Suwannee River Basin. There is less than 15 feet of total fluctuation in at least two-thirds of the District and there is less than 5 feet of total fluctuation along the coast. Average annual fluctuation is less than 4 feet for approximately two-thirds of the District.

2.1.5 Land and Water Use in the Basin

2.1.5.1 Land Use and Population Characteristics

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

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

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

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

2.1.5.2 Water Use

Estimated water use in the District in 2000 (Table 2-4) was 314 million gallons/day (mgd; WRA, 2005), which equates to about 486 cfs. Water use patterns in the District somewhat mirror land use. Agricultural irrigation accounts for a large fraction of the existing and projected water use, although commercial/ industrial is also a large overall use, principally due to phosphate mining and processing and once-through cooling water for power generation (Marella, 2004; WRA, 2005). By 2020 and 2050, agriculture and industrial water uses are predicted to continue being the largest uses in the District (WRA, 2005). Total water use in the District is projected to be approximately 547 mgd in 2020 (which equates to about 846 cfs), and 895 mgd in 2050 (1385 cfs).

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

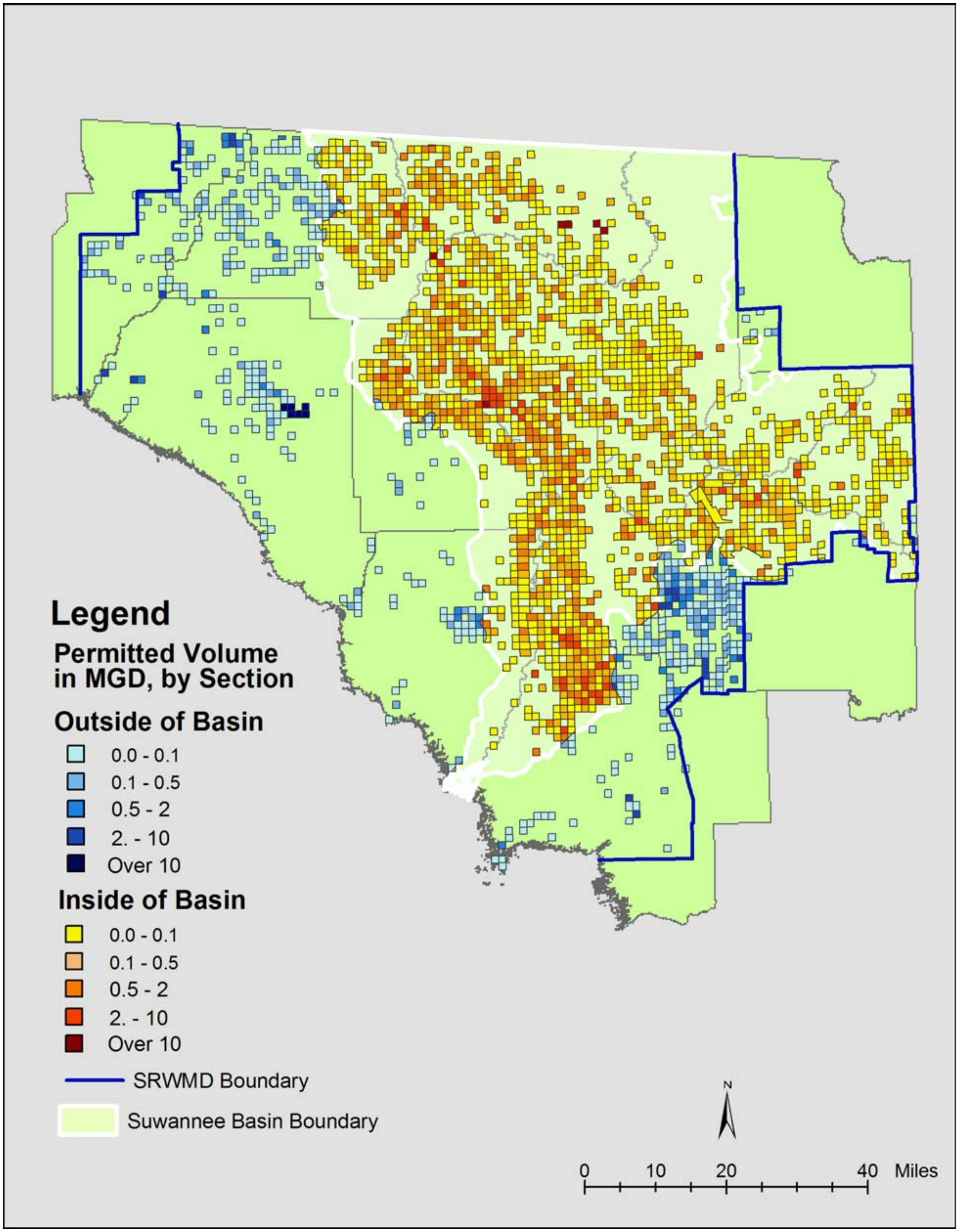

Figure 2-12. Map showing permitted water use patterns in the SRWMD. Each symbol represents the sum of the Average Daily Rate of Withdrawal (ADR) within each 1 mi.^{2} section.

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

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

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

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

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

2.2 Suwannee River

2.2.1 Surfacewater Hydrology

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

2.2.1.1 Annual Yield

The annual yield of the Suwannee River is the amount of water discharged to the Gulf of Mexico. Discharge for the Suwannee is determined by river flow as measured by the U.S. Geological Survey (USGS) streamflow gaging program at the most downstream, long-term river gage (Suwannee River near Wilcox – USGS Station Number 02323500). Approximately 97 percent of the basin drainage area is upstream of this gage. Mean daily discharge at Wilcox is 10,166 cfs (Table 2-5), which is equivalent to 14.8 inches of annual runoff from the basin area (Franklin et al., 1995). Since the average annual rainfall across the basin is 53.35 inches (Section 2.2), about 28 percent of the mean annual rainfall is discharged as runoff to the Gulf of Mexico. Generally, the response of discharge lags behind rainfall by approximately four months. The remainder, about 39 inches annually, is utilized either as ET or consumptive use. This estimate corresponds well with the ET estimate of 40.8 inches presented in Section 2.1.2.

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

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

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

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

The annual median discharge (nonexceedance probability of 50 percent; 2 year return period) is about 8,040 cfs. The 10-year drought condition (nonexceedance probability of 10 percent) specified in Chapter 373.0361(2)(a)(1) as a level-of-certainty planning goal for water supply needs is 4,390 cfs, or about 55 percent of the annual median discharge. Inter-annual variability in discharge is largely a function of annual rainfall (Figure 2-15).

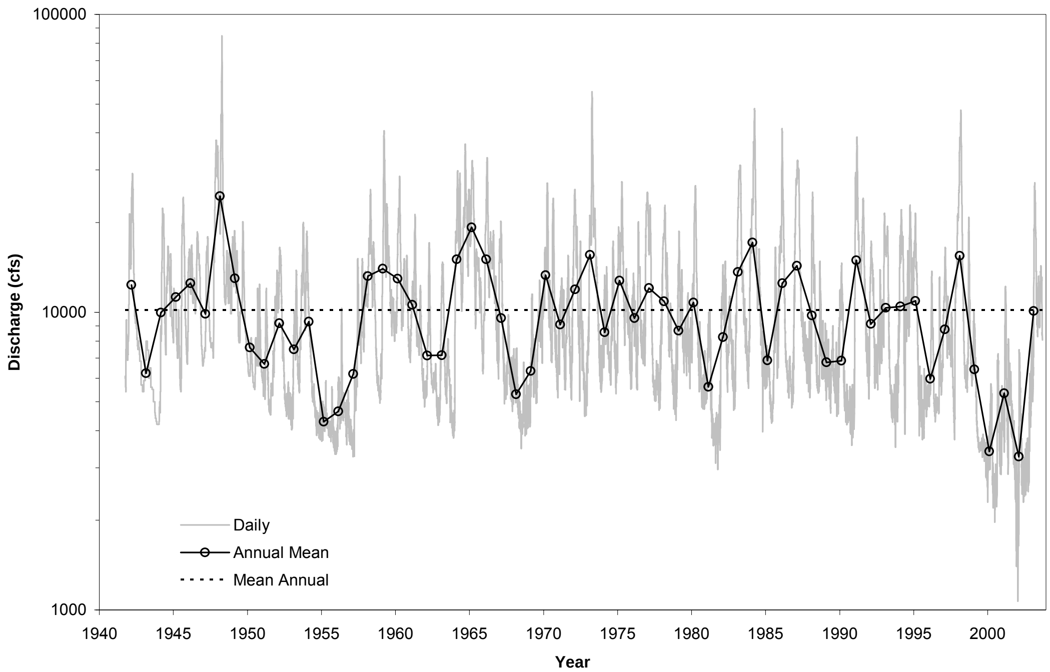

Figure 2-13. Daily and annual discharge (1942-2003) for the Suwannee River near Wilcox (USGS Station Number 02323500).

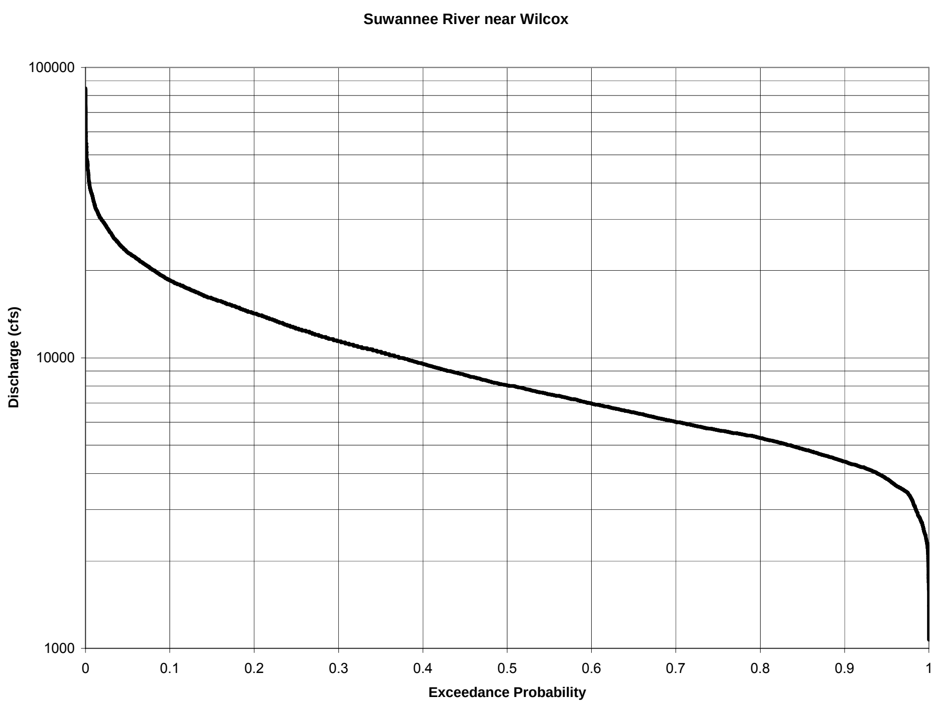

Figure 2-14. Discharge flow duration curve (1942-2003) for the Suwannee River near Wilcox (USGS Station Number 02323500).

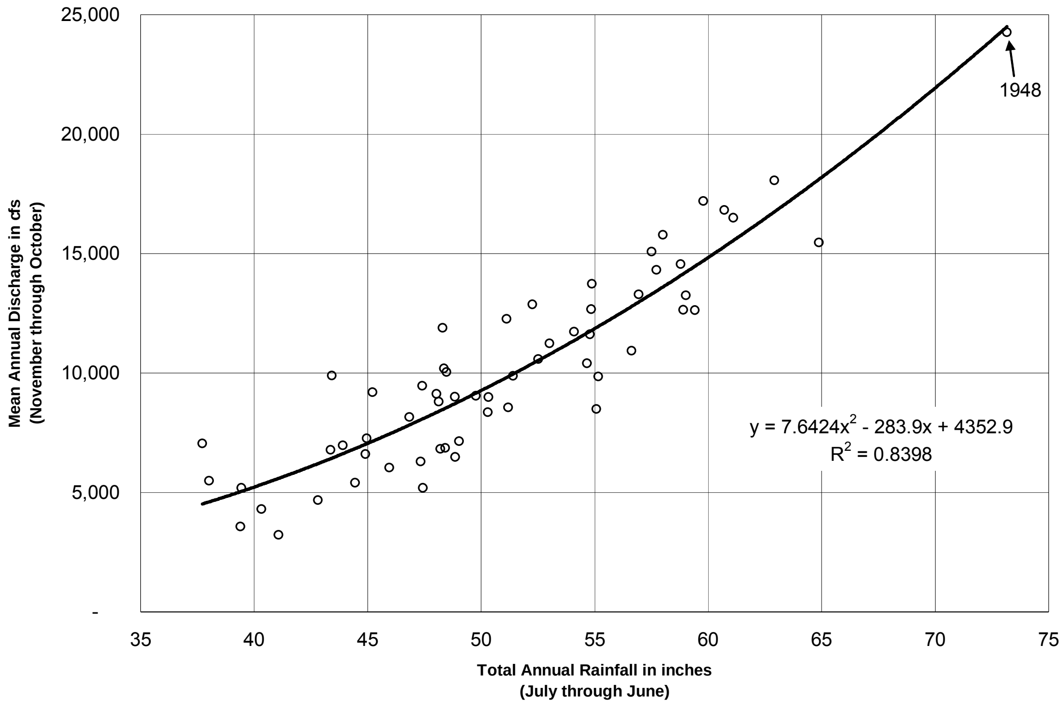

Figure 2-15. Relationship between annual rainfall and discharge for the Suwannee River near Wilcox (USGS Station Number 02323500).

2.2.1.2 Spatial Flow Patterns

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

Flow is more variable in the upper portions of the Suwannee and Santa Fe basins (Figure 2-17A). Flow may vary by 2-3 orders of magnitude in these areas, which are primarily fed by runoff. Flow is higher but less variable in the lower reaches of these rivers (Figure 2-17B), varying generally within one order of magnitude. Part of this is a function of increasing drainage area contributing to flows at the downstream gage sites. For the Suwannee system, however the reduced variability also results from the increased importance of groundwater inflow from the unconfined Floridan aquifer system adjoining the middle and lower river reaches.

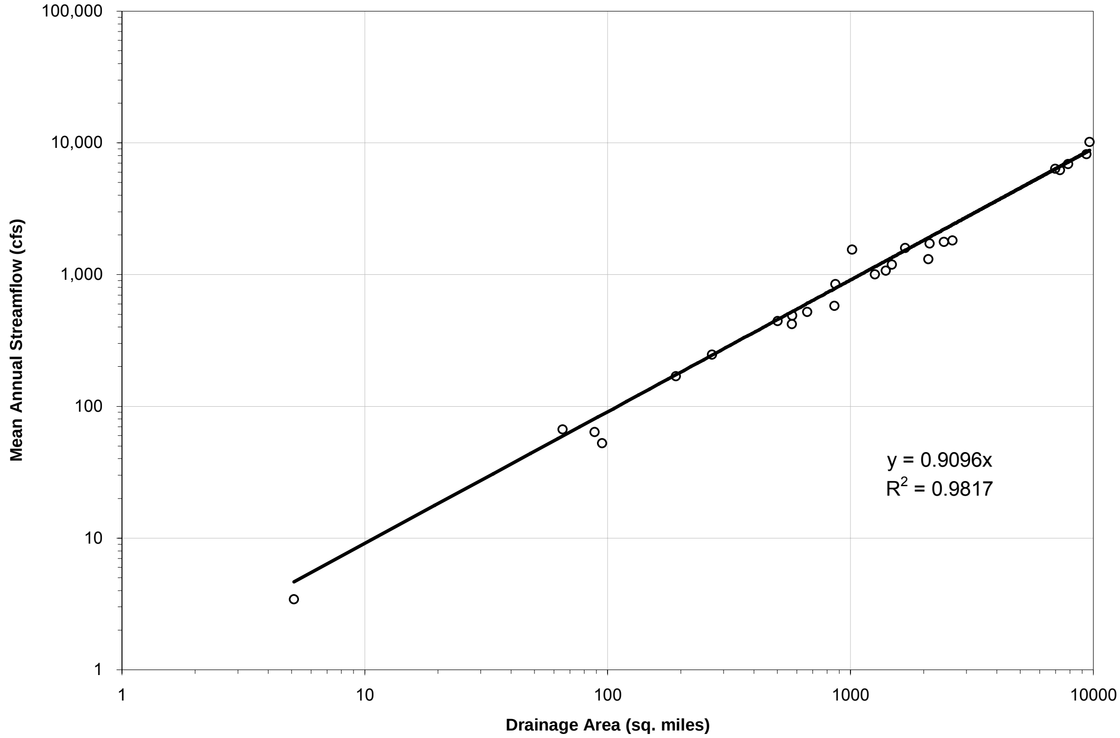

Figure 2-16. Relationship of drainage area and mean annual streamflow for the Suwannee Basin for gages with 10 or more years of systematic record. Data source: USGS.

Table2-6. Summary of hydrologic characteristics at flow gaging sites along the Suwannee River and its major tributaries (from Franklin et al., 1995 and Water Resources Data, GA, 1996). Data are annual summaries.

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

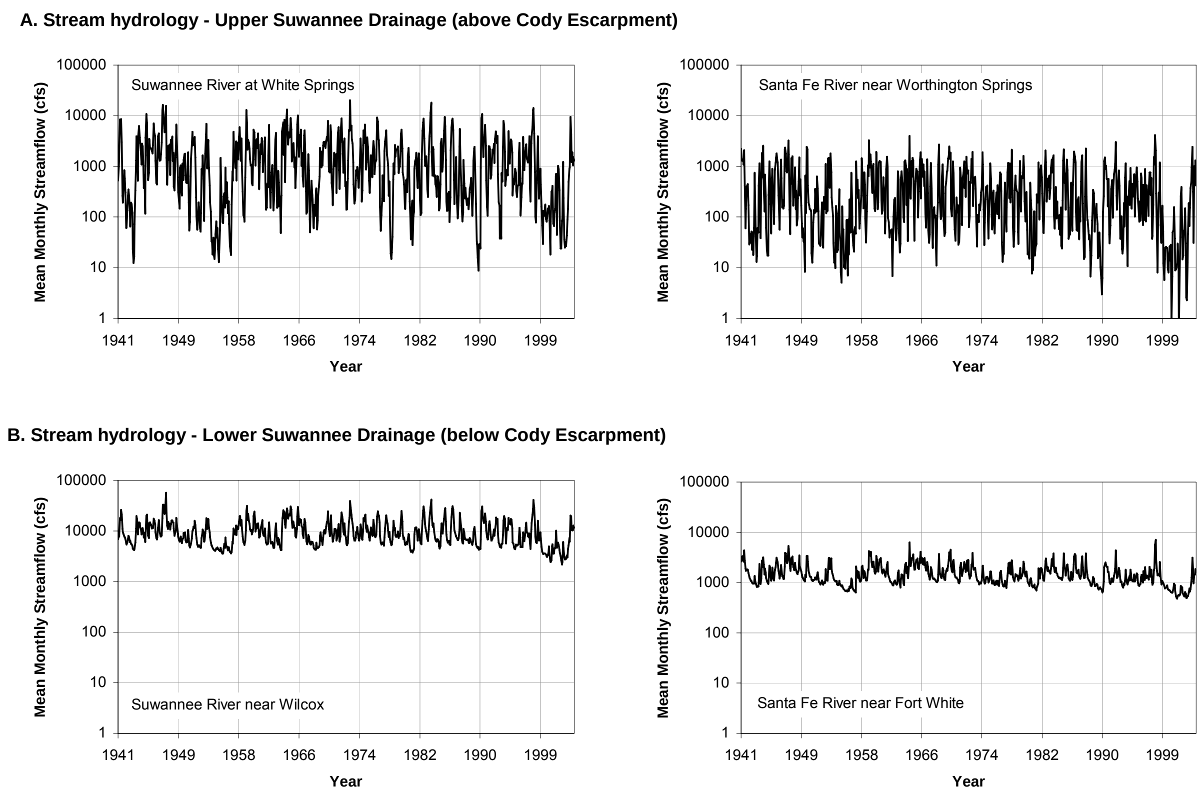

Figure 2-17. Mean monthly streamflow at four USGS gaging sites on the upper (A) and lower (B) Suwannee and Santa Fe Rivers, reflecting stream hydrology in the upper and lower portions of the drainage (after Mattson et al., 1995).

2.2.1.3 Seasonal Flow Patterns

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

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

Figure 2-19 shows mean monthly discharge for several long-term gages with at least 60 years of record in the Suwannee Basin. The data are expressed as a proportion of the mean total annual discharge. The distinct late winter/spring flood is evident, particularly at the sites in the northern portion of the basin. The two gauging sites in the Santa Fe River drainage basin (Worthington Springs and Ft. White) exhibit more of the “bimodal” pattern, as they lie along the climatic divide discussed above.

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

2.2.1.4 Tidal River and Estuary

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

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

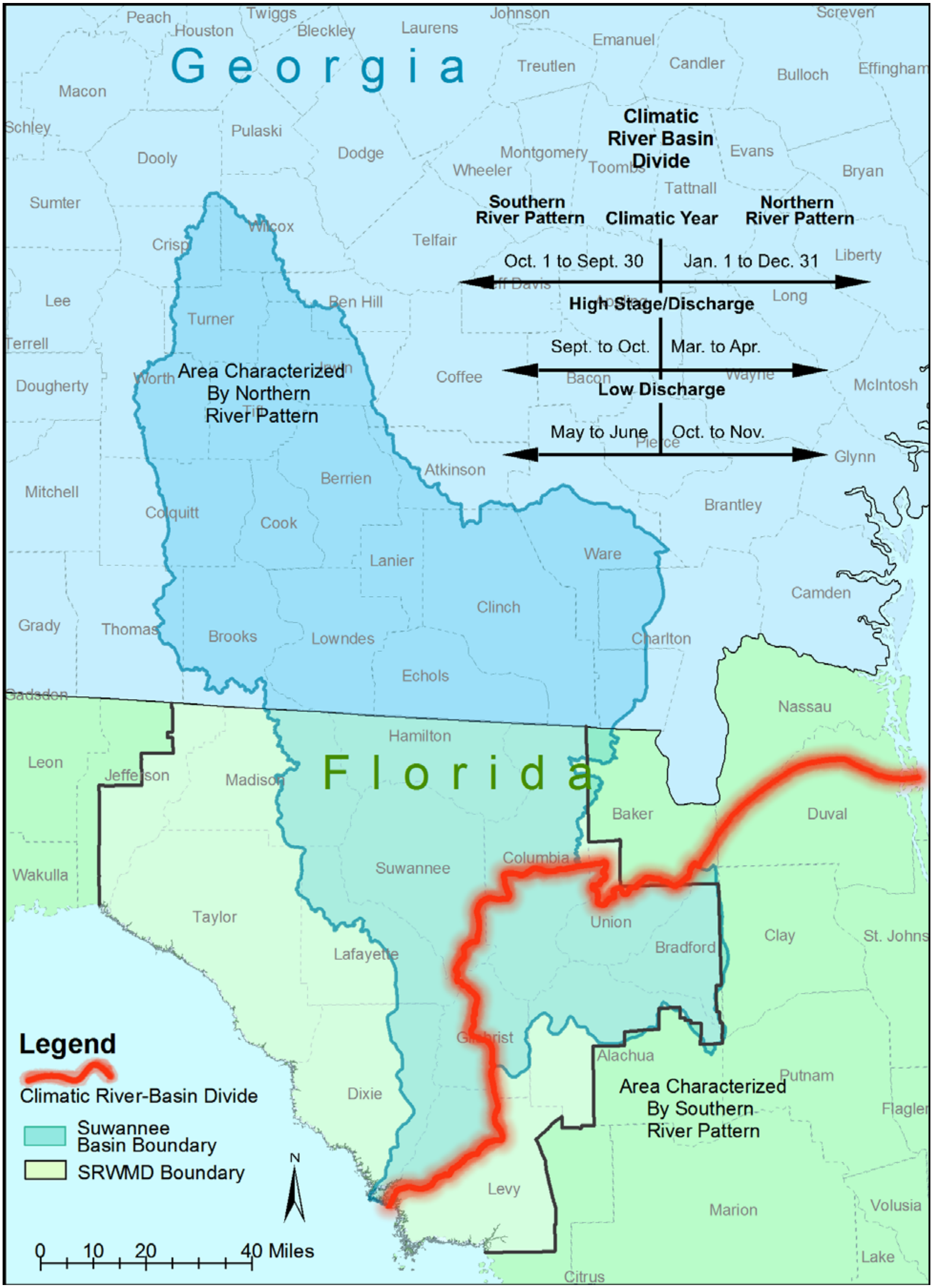

Figure 2-18. Climatic river-basin divide of Heath and Conover (1981). River pattern data from Kelly (2004).

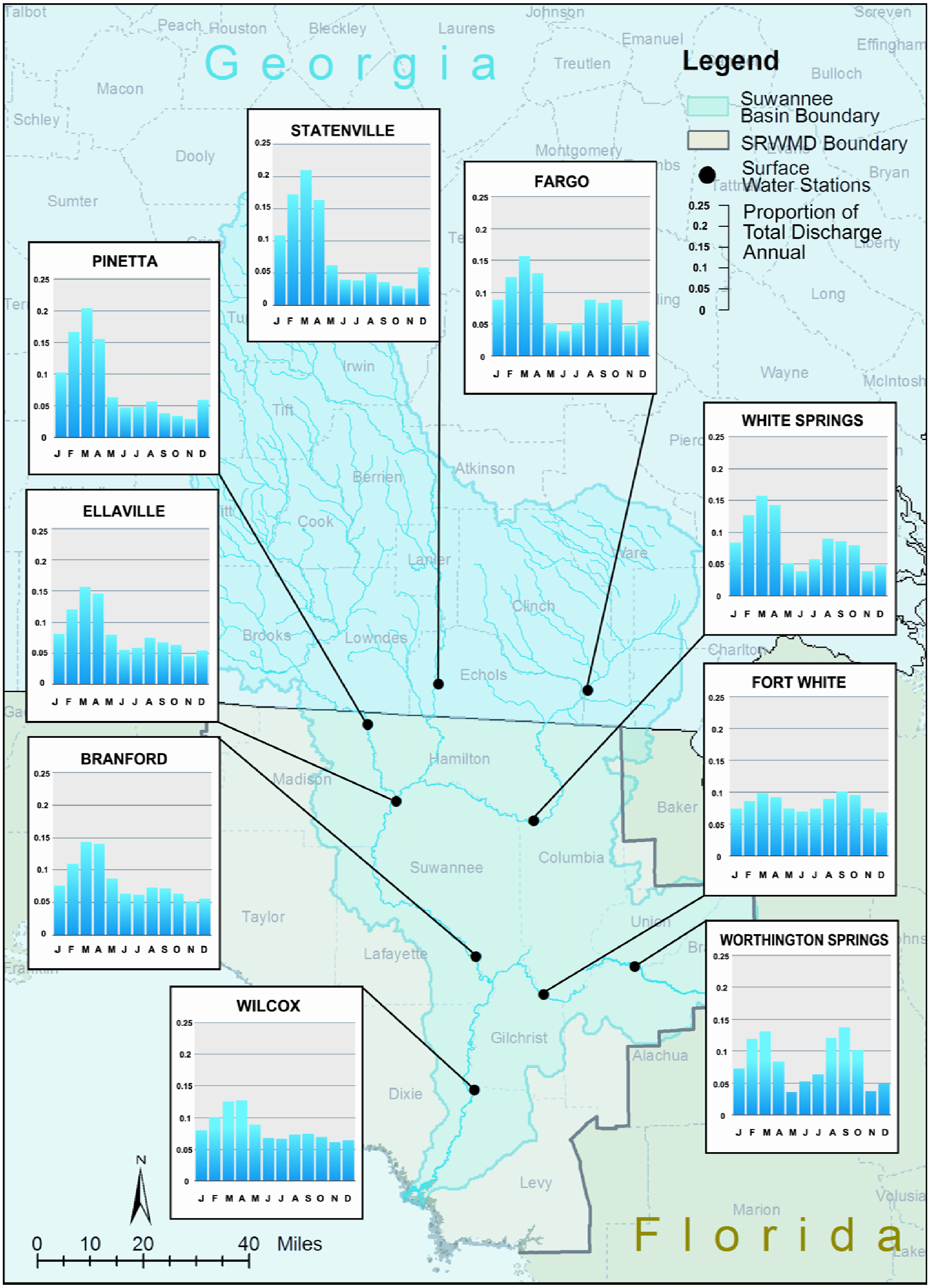

Figure 2-19. Gage locations and mean monthly discharge patterns at selected long-term surface water gages in the Suwannee River Basin. Discharge expressed as a proportion of mean annual discharge at each gage. Data source: USGS flow data.

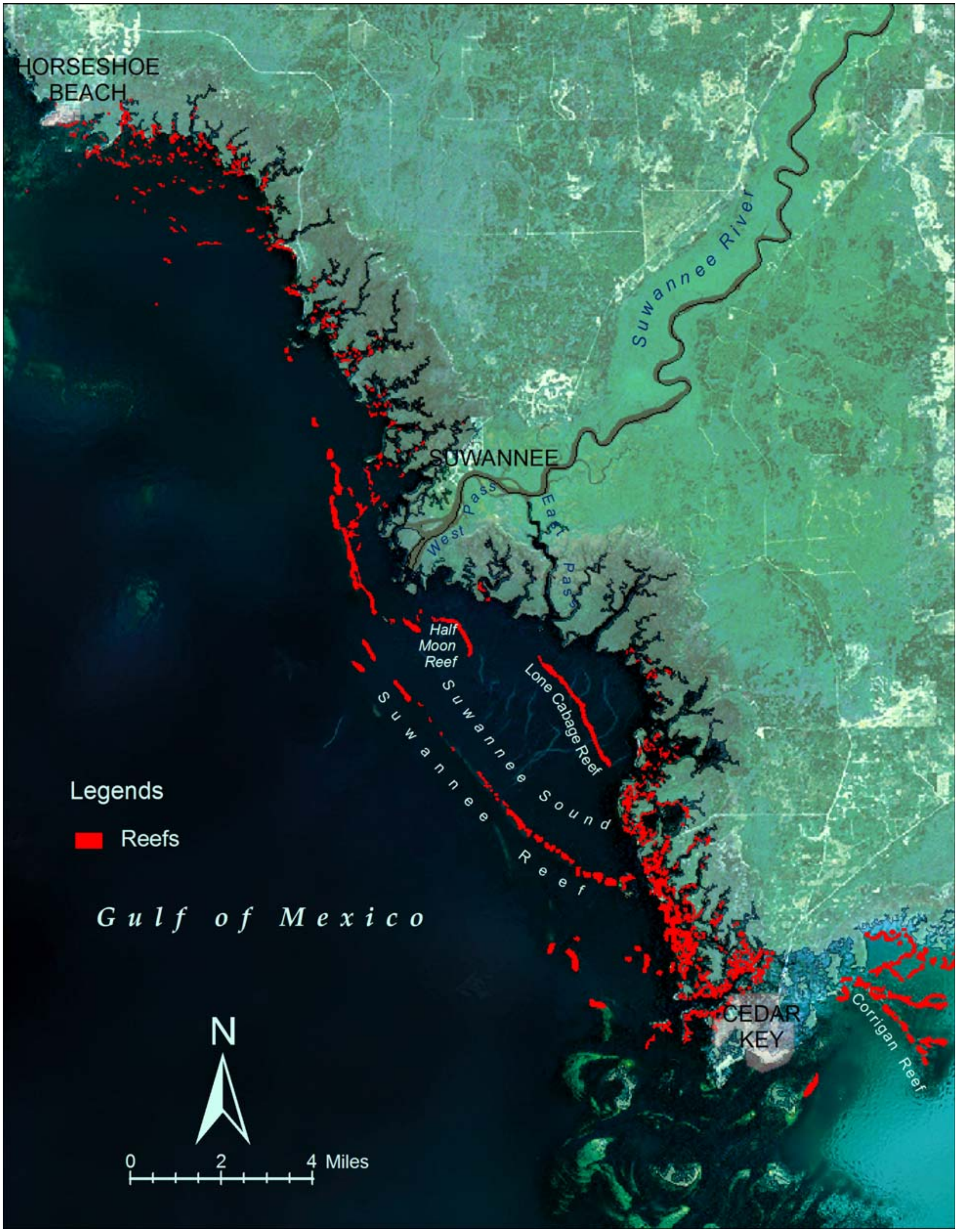

Figure 2-20. Major features of the Suwannee estuary. Data sources: USGS aerial imagery and SRWMD map data.

Depths in the Suwannee Sound average 6.6 feet, with depths to about 20 feet in the river channels of East and West passes (Figure 2-20).

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

2.2.1.5 Chemical Characteristics

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

Reach 1. Upper River Blackwater
Reach 2. Cody Scarp Transitional
Reach 3. Middle River Calcareous
Reach 4. Lower River Calcareous
Reach 5. Tidal Riverine

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

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

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

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

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

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

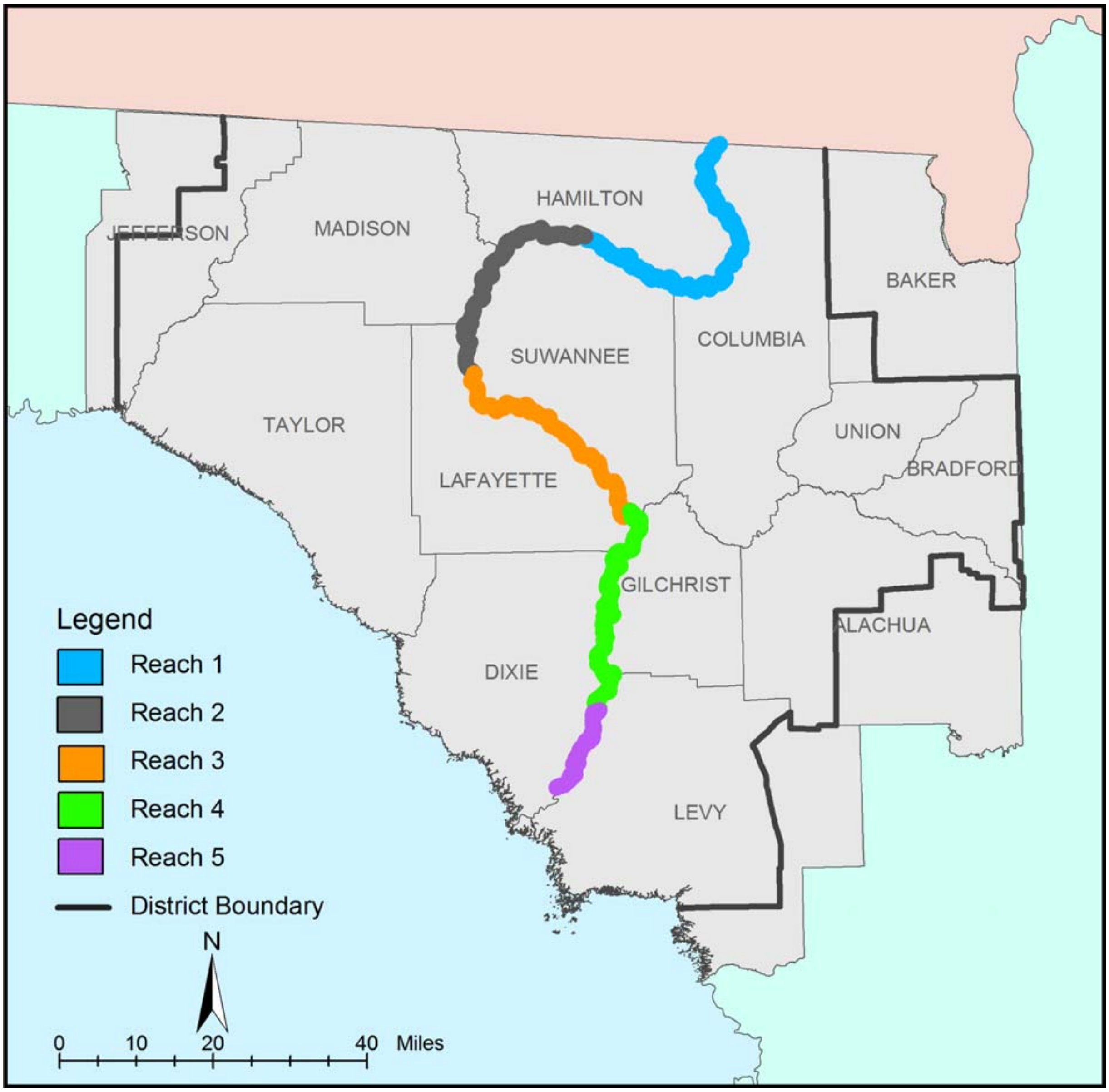

Figure 2-21. Map showing the "ecological reaches" of the Suwannee River in Florida. Source: SRWMD data and Hornsby et al. (2000).

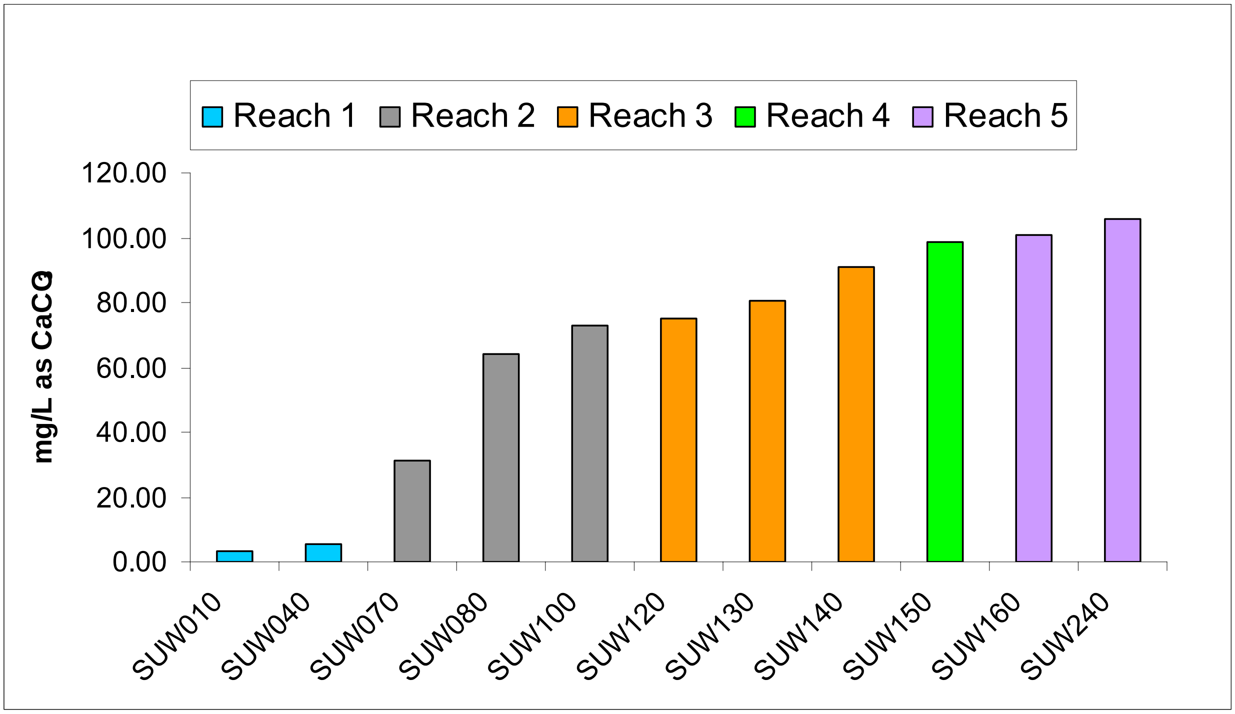

Figure 2-22. Plot of mean alkalinity (mg/L as $CaCO_3$) in the five reaches of the Suwannee River in Florida.

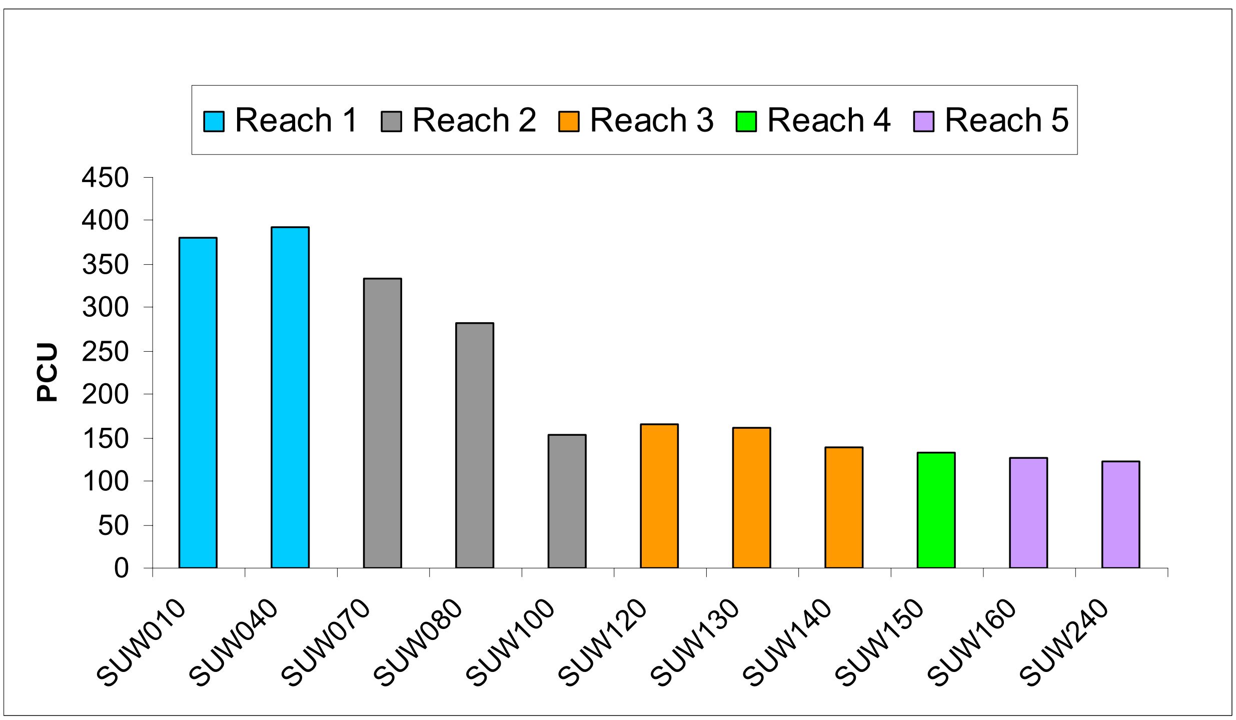

Figure 2-23. Plot of mean color (platinum cobalt units; PCU) in the five reaches of the Suwannee River in Florida.

2.2.2 Ecology

2.2.2.1 Aquatic and Wetland Communities

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

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

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

2.2.2.2 River Reach Ecology

2.2.2.2.1 Suwannee River Mainstem

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

Reach 2. Cody Scarp Transitional Reach. In this reach, the river is mostly within the Tifton Uplands/Tallahassee Hills subregion. The river channel is still incised into the landscape, and varies from 130-260 ft. in width (Figure 2-24). The channel bottom is still dominated by shallow water habitat, with depths 3-6 ft. or less and numerous areas of sandy or rocky shoals. Channel bottom substrates include medium to coarse sand, exposed clay, and rock (limestone, chert, dolostone). Some of these shoal areas in the region of the Alapaha Rise and confluence are critical spawning habitat for the Gulf sturgeon (Sulak et al., 2001). In this region, the river crosses the Cody Scarp (Ceryak et al., 1983). This is a region, with numerous sinkholes. Karst features are evident in the river floodplain, which produces high plant diversity due to the topographic variation. This reach includes the confluences of the Alapaha and Withlacoochee rivers with the Suwannee River mainstem. Limestone outcrops are prominent along the river channel throughout this reach, and springs discharge ground water to the river. Major springs include White Springs, Suwannee Springs, Holton Spring, Alapaha Rise, Ellaville Spring, and Lime Spring.

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

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

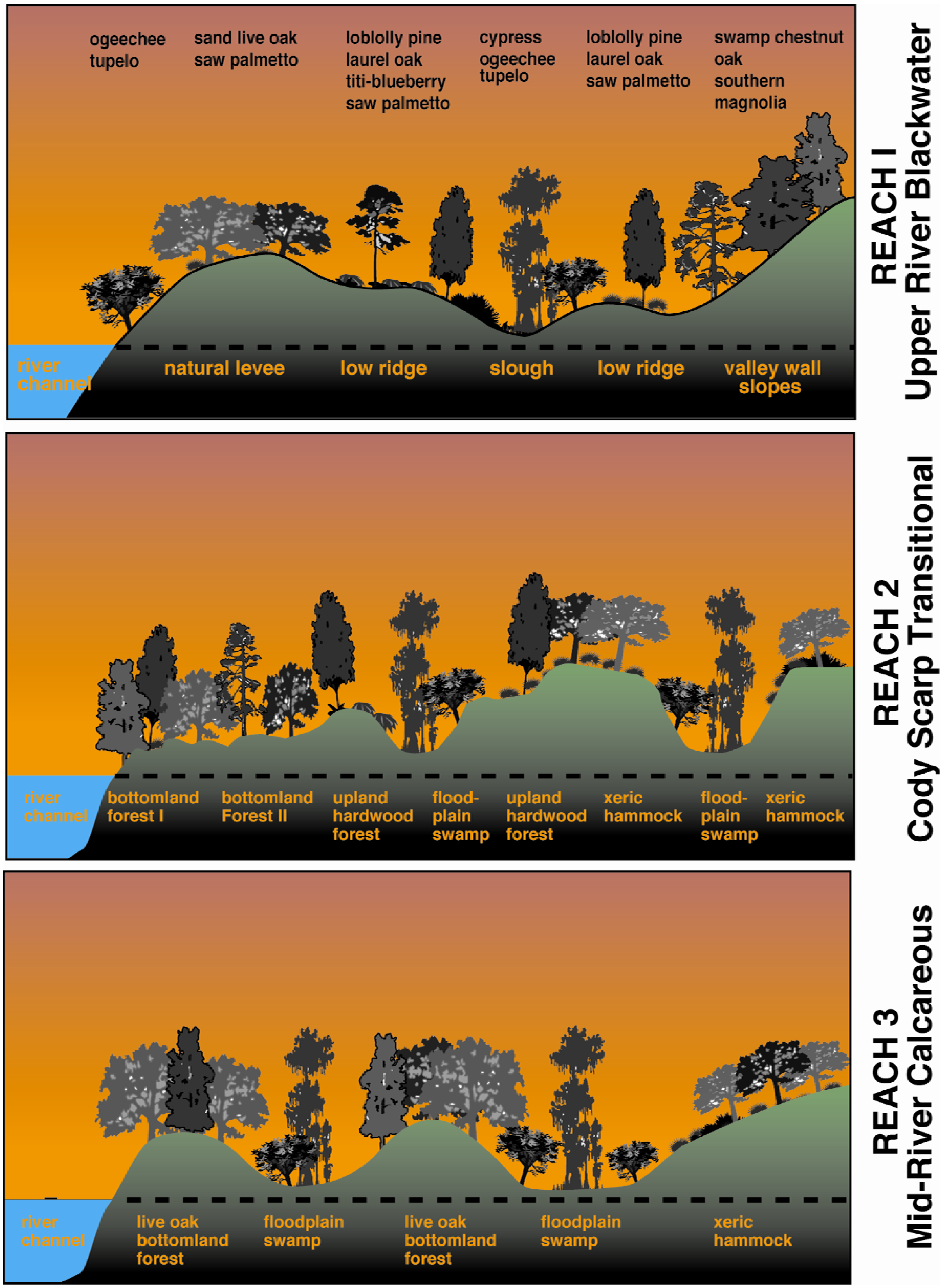

Figure 2-24. Basic geomorphology of the river channel and floodplain and typical plant communities in each of the five ecological reaches (Figure 2-20) of the Suwannee River. Adapted from Lynch, 1984.

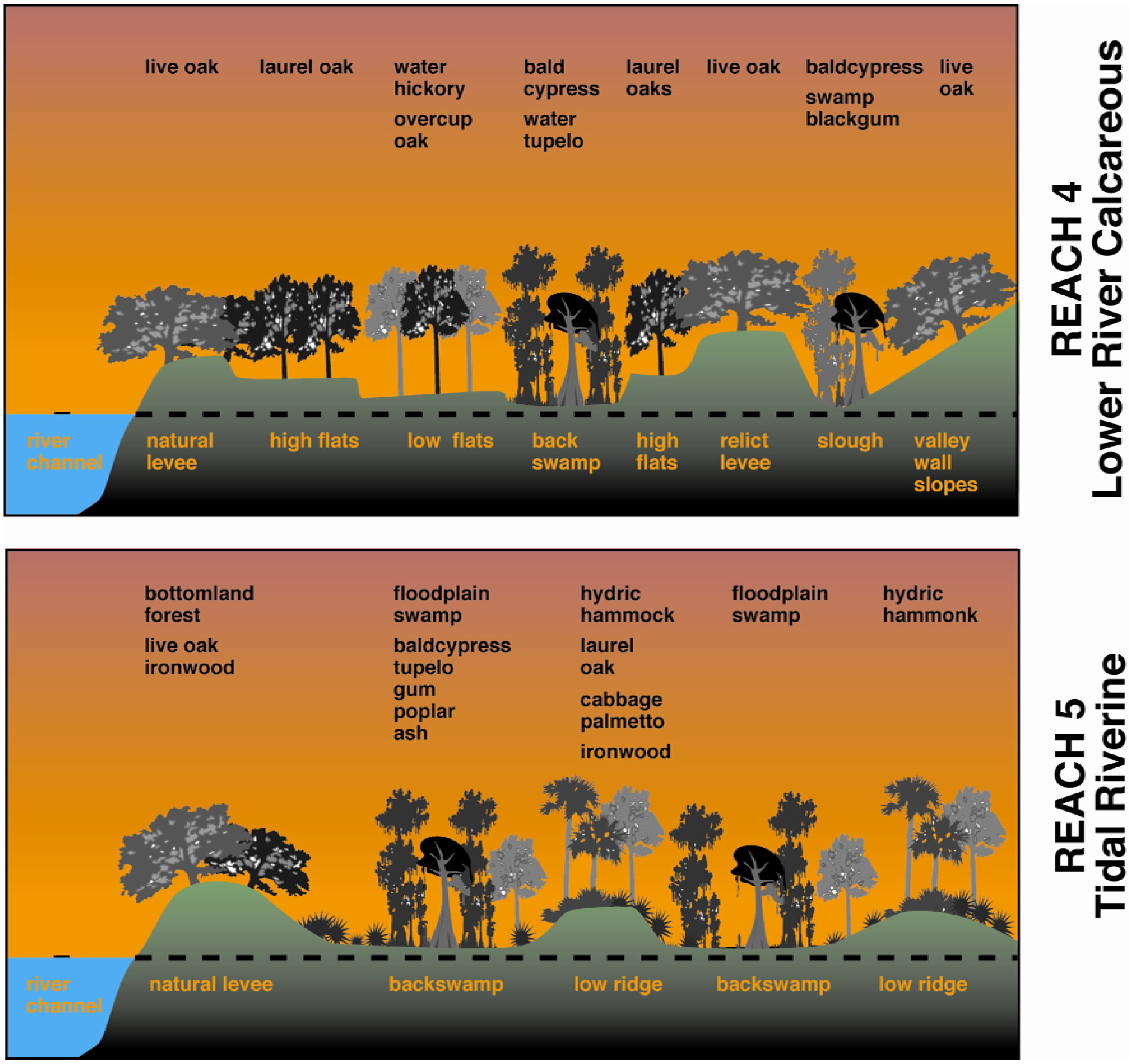

Figure 2-24. Continued.

Reach 5. Tidal River Reach. This reach, begins at the U.S. 19 bridge at the town of Fanning Springs. As indicated in the section on hydrology, tidal variation in river stage is evident here at low flows. This reach also lies entirely within the Gulf Coast Flatwoods subregion. The river channel approaches 800-1000 ft. in width. River channel substrata include exposed limestone, medium and coarse sand, and sandy mud in areas of reduced current velocity. The channel is fringed by tidal, freshwater marsh, which becomes more evident downstream. These marshes are dominated by wild rice, bulrushes, cattail, pickerelweed, spatterdock, and water hemlock. Along the outer edge of these marshes, where water depth and sediment conditions permit, beds of submerged vegetation dominated by eelgrass and spring tape may grow. The floodplain in the upper portions of this reach includes forest types similar to those seen in Reach 4. As the river nears the Gulf, tidal freshwater swamps (Wharton et al., 1982) and hydric hammock (Vince et al., 1989) become the dominant forest types. The tidal swamps are dominated by bald cypress, pumpkin ash, swamp and sweet bay, cabbage palm, red maple, and swamp tupelo. Hydric hammocks are a wetland forest type unique to Florida, with the greatest extent occurring in this region of the Florida coast (Vince et al., 1989). These forests are characterized by a diverse tree canopy. Characteristic species include cabbage palm, laurel and live oak, sweetgum, sweet bay, swamp bay, southern red cedar, red maple and blue beech. Two major springs, Fanning Springs and Manatee Springs, occur on this reach. Benthic invertebrate communities are similar to those in Reaches 3 and 4, although as the river nears the Gulf, estuarine species begin to appear (i.e., olive nerite snail, red-joint fiddler crab, wharf crab).

2.2.2.2.2 Santa Fe River

The Santa Fe River drainage encompasses more sub-ecoregions (6) than any other river basin in Florida. The river drainage lies within portions of the Tifton Uplands/Tallahassee Hills, Central Florida Ridges and Uplands, Okeefenokee Swamps and Plains, Sea Islands Flatwoods, Eastern Florida Flatwoods, and Gulf Coast Flatwoods subecoregions. This landscape diversity accounts for the high overall biological diversity exhibited in this river system. The upper portion of the river includes numerous shallow runs, with a sand-bottomed channel, which may become braided and diffuse in some reaches. Flow in the upper Santa Fe is dominated by surfacewater runoff. The river is captured by a sink at O'Leno State Park, and re-emerges about 3 miles downgradient as the Santa Fe Rise. The lower Santa Fe River is heavily influenced by spring inflow, and is typically clear and alkaline. The upper portions of this lower reach are mostly shallow and include numerous shoal areas of exposed limestone and beds of submerged aquatic vegetation (SAV). The lower portion is wider and deeper, with SAV beds confined to the channel margins. In terms of channel morphology, the lower Santa Fe somewhat resembles Reach 3 of the Suwannee, although with a narrower river channel. The channel bottom substrata are mostly coarse sand and exposed limestone. Major springs include the Ichetucknee Springs group, the Ginnie Springs group, Hornsby Spring, Gilchrist Blue Spring group, Poe Spring, and Rum Island Spring. Benthic invertebrate communities are characterized by mayflies, caddisflies, chironomids, amphipods and snails.

2.2.2.2.3 Withlacoochee River

The Withlacoochee River drainage lies mostly within Georgia, in the Southeastern Plains Ecoregion. The river's general morphology is that of a low gradient, eastern, coastal plain stream with a sand-bed channel (Brussock et al., 1985). Using Beck's (1965) classification, the Withlacoochee is a "sand-bottom stream". In Florida, the river channel is incised in the underlying Suwannee and Ocala limestones, and numerous limestone shoals are found in the channel. Other channel bottom substrata are medium and coarse sand. Water chemistry in the river is moderately to highly colored, somewhat alkaline, and highly turbid on occasion. Because of the somewhat higher relief and clay soils found primarily in the Georgia portion of the watershed, the Withlacoochee carries a higher sediment load than other streams in the Suwannee drainage (USDA, 1977). Consequently, the river is more of a "muddy" river than the Suwannee during higher flows. This sediment load is obvious when viewing the confluence of the Withlacoochee and Suwannee at higher flows (generally average flow and greater). At baseflow, the river water is substantially less turbid and more reflective of a southeastern coastal plain, blackwater stream. The inflow of hard, carbonate-rich ground water from the Floridan aquifer at baseflow (via springs and diffuse inflow) contributes to the higher pH and alkalinity of the water in Florida. Major springs include Blue, Pot, and Suwannacoochee. Benthic invertebrate communities are dominated by chironomids. Other dominants in the benthic community include crustaceans (the amphipod *Hyalella* and grass shrimp, *Palaemonetes paludosus*), blackflies (*Simulium* spp.), aquatic beetles (Coleoptera), caddisflies (Trichoptera) and mayflies (Ephemeroptera).

2.2.2.2.4 Alapaha River

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

2.2.2.2.5 Suwannee Estuary

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

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

2.2.2.2.6 Species and Habitats of Interest

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

Key species of interest (e.g., listed taxa, rare or endemic species) dependent upon aquatic and wetland habitats in the lower Suwannee are shown in Table 2-7. These are listed as either (1) endangered or threatened by the U.S. Fish and Wildlife Service (USFWS), (2) endangered, threatened, or a species of special concern by the Florida Fish and Wildlife Conservation Commission (FWCC), or (3) “Rare and Endangered Biota of Florida” published by the Florida Committee on Rare and Endangered Plants and Animals (FCREPA), or (4) as S1, S2, or S3 by the Florida Natural Areas Inventory (FNAI).

Additional species of interest that occur in the Suwannee estuary are shown in Table 2-8. These are listed by the National Oceanic and Atmospheric Administration as important “Estuarine Living Marine Resources” (ELMR), chosen based on four criteria (Nelson, 1992): 1 -

commercial value (harvested commercially), 2 - recreational value (sportfish), 3 - indicator of environmental stress, and 4 - ecological value (important forage or food base organisms). Many are also listed by the Florida Fish and Wildlife Research Institute (FWRI) as "Selected Taxa" because of their commercial, recreational or ecological value.

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

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

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

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

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

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

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

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

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

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

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

2.3 Lower Suwannee Drainage Basin and Springs

2.3.1 Introduction

The Lower Suwannee River watershed, including Manatee and Fanning Springs, is an important recreational and ecologic resource. Much like the river, the springs are important to the natural and scenic beauty of the area. The springs are also important thermal refuges for manatees, which frequent the springs throughout the year, especially during the cold, winter months of November through April.

That portion of the Suwannee River Basin downstream of the Wilcox Gage at Fanning Springs comprises the drainage basin associated with the study area. This portion of the basin includes, in part, the groundwater basins for Manatee and Fanning Springs. This section of the report describes the springs and their springsheds.

The Manatee-Fanning springshed lies to the east of the Suwannee River and encompasses approximately 450 square miles of northwestern Levy and southwestern Gilchrist counties (Figure 2-25). The groundwater basins were delineated by Upchurch and Champion (2003a), who used geostatistical analysis to define the basin boundaries. The District is currently monitoring the Manatee-Fanning springshed, which will greatly improve refinement of the basin delineations (Upchurch and others, 2001). Because of their close proximity and uncertainties as to the location of the divide between the individual spring basins for Manatee and Fanning Springs, these two basins are treated as one basin in this report.

Most of the surfacewater portion of the springshed appears to lie within the surface- and groundwater basins (Figure 2-25) of the Suwannee River.

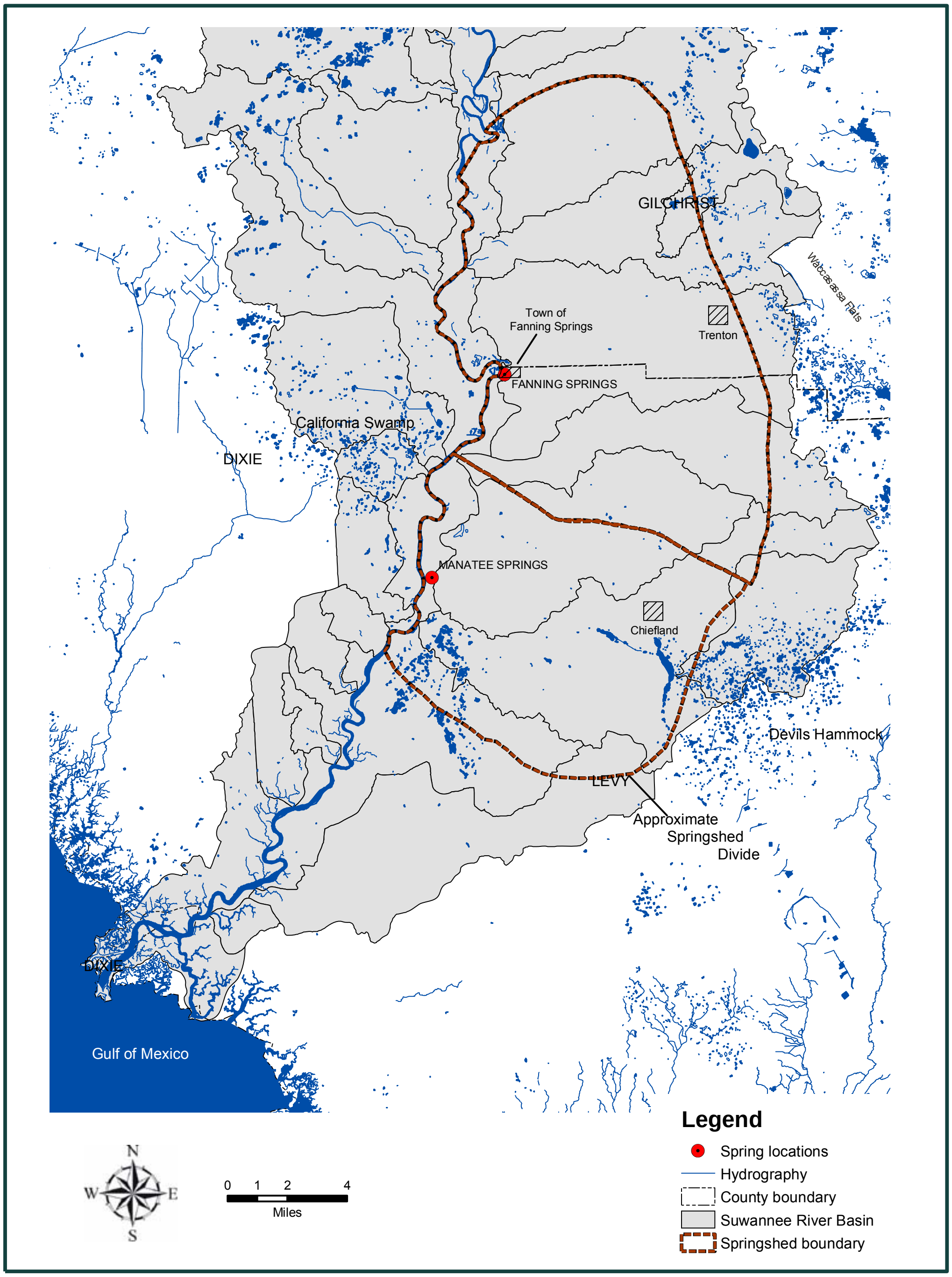

Figure 2-25. Study area showing the springsheds of Manatee and Fanning Springs. Data are from Upchurch and Champion (2003a).

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.

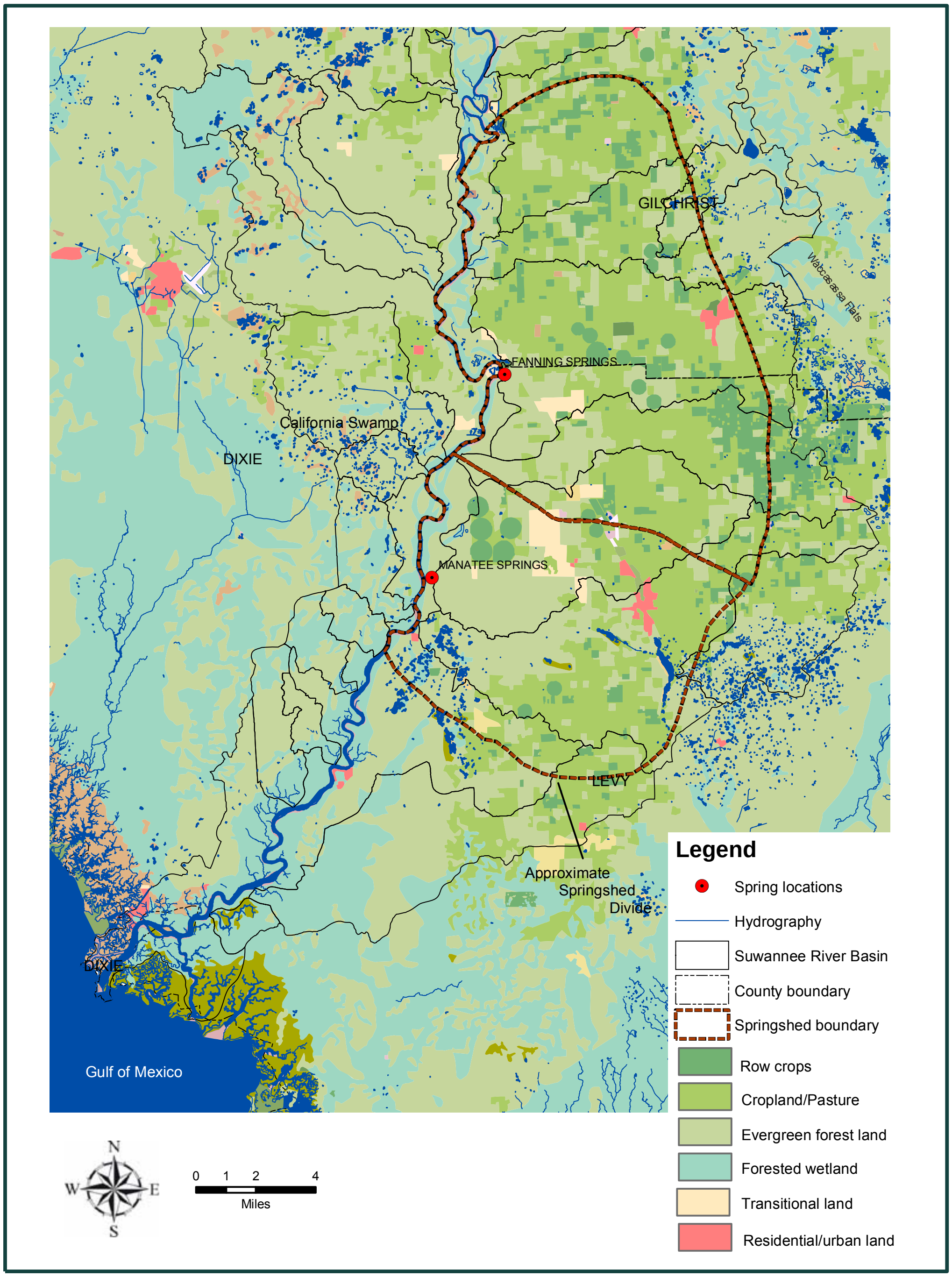

Figure 2-26. Major land uses in the Lower Suwannee River study area.

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).

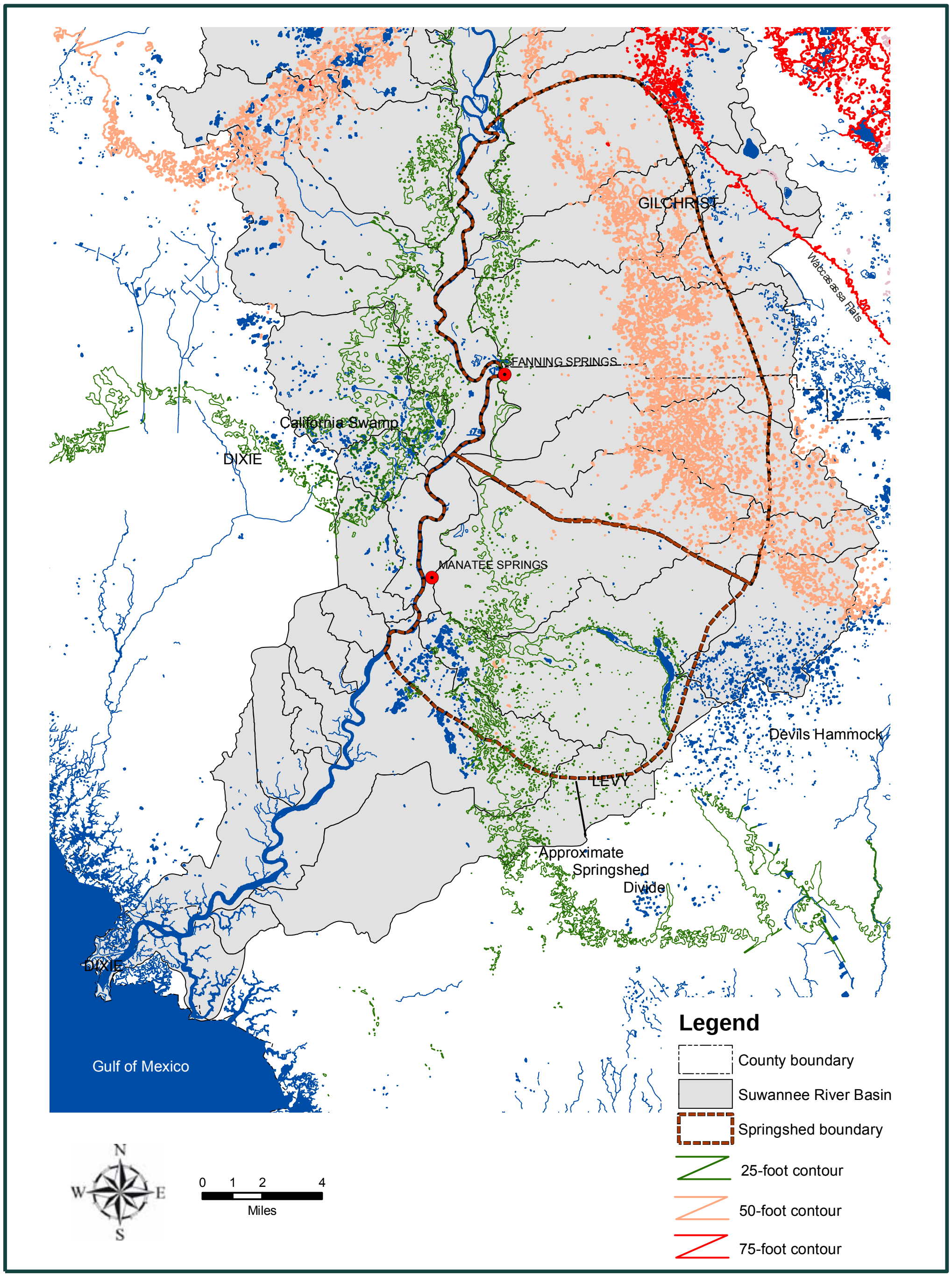

Figure 2-27. Topography of the Lower Suwannee River Study Area.

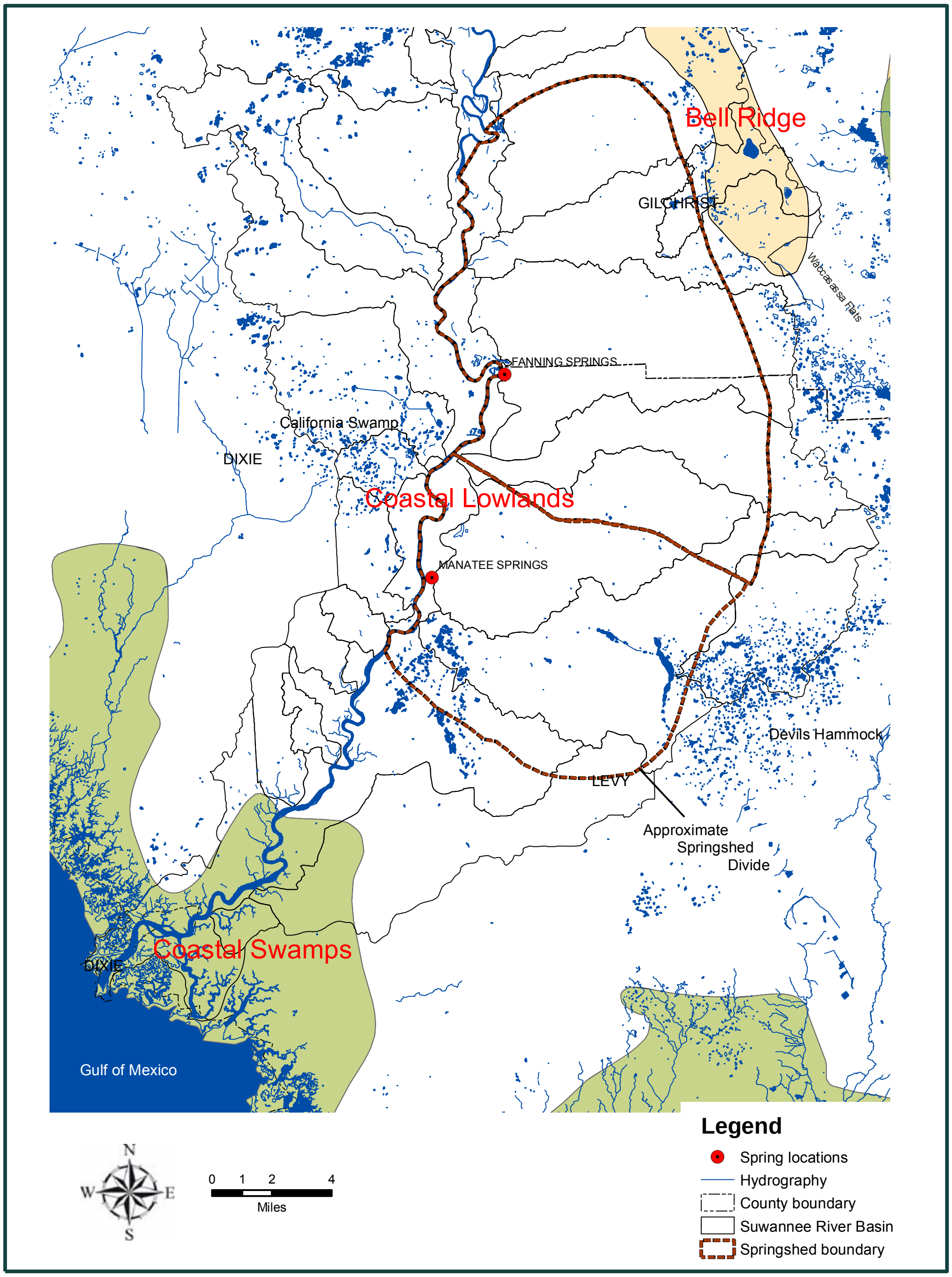

Figure 2-28. Physiographic regions in the Lower Suwannee River study area.

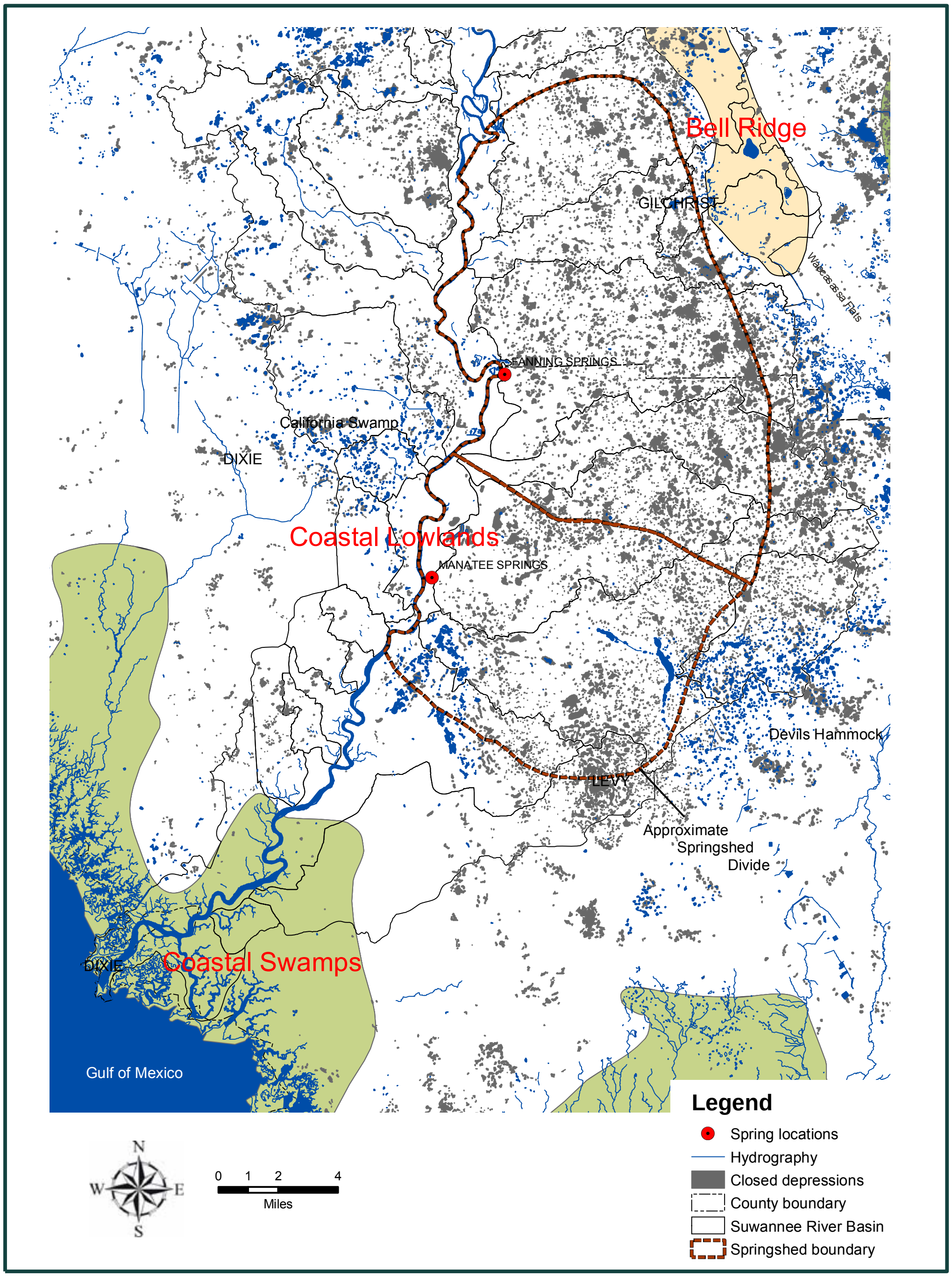

Figure 2-29. Closed depressions (sinkholes and other karst features) in the Lower Suwannee study area.

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.

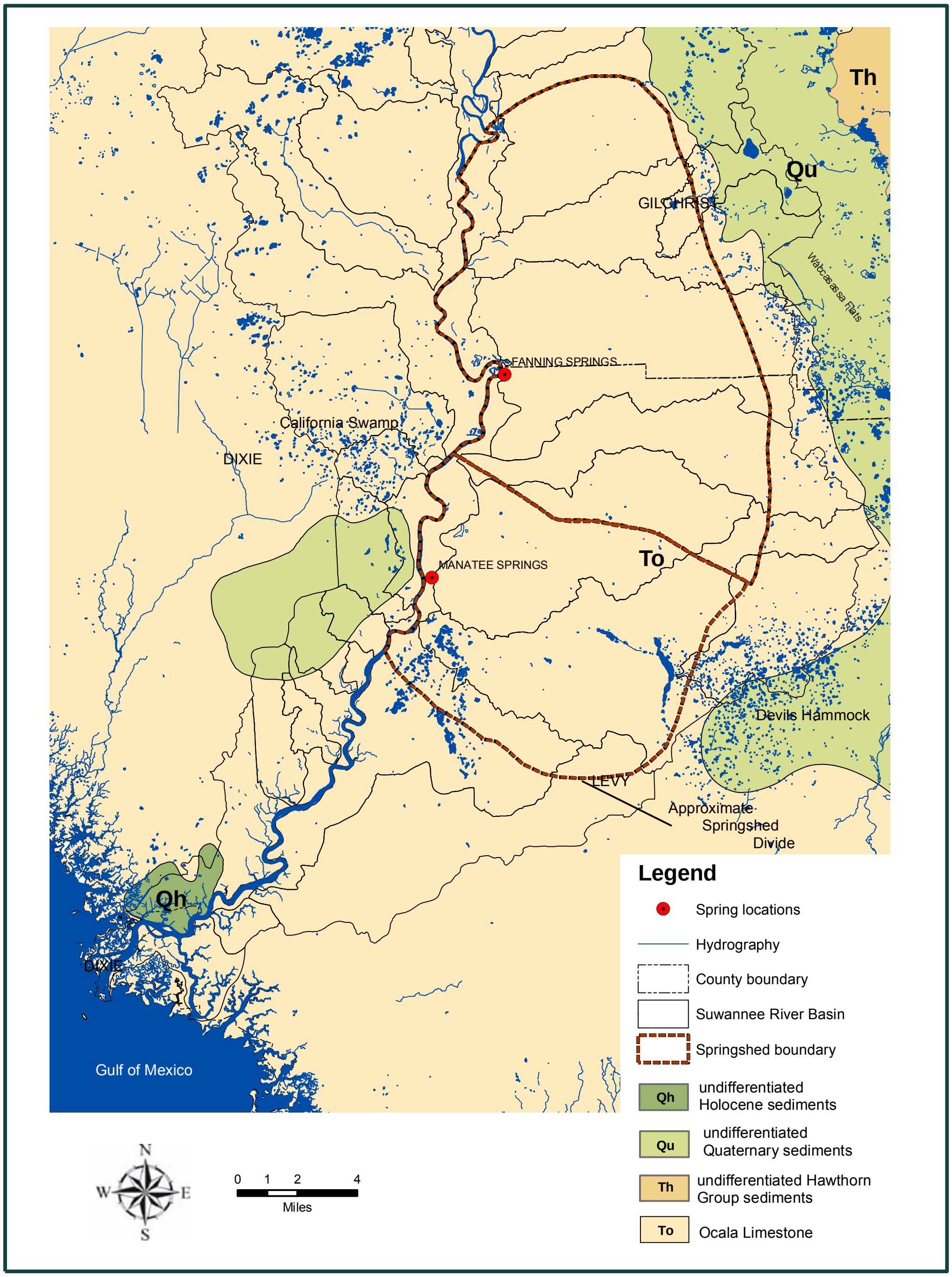

Figure 2-30. Geologic map of the Lower Suwannee River study area.

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.

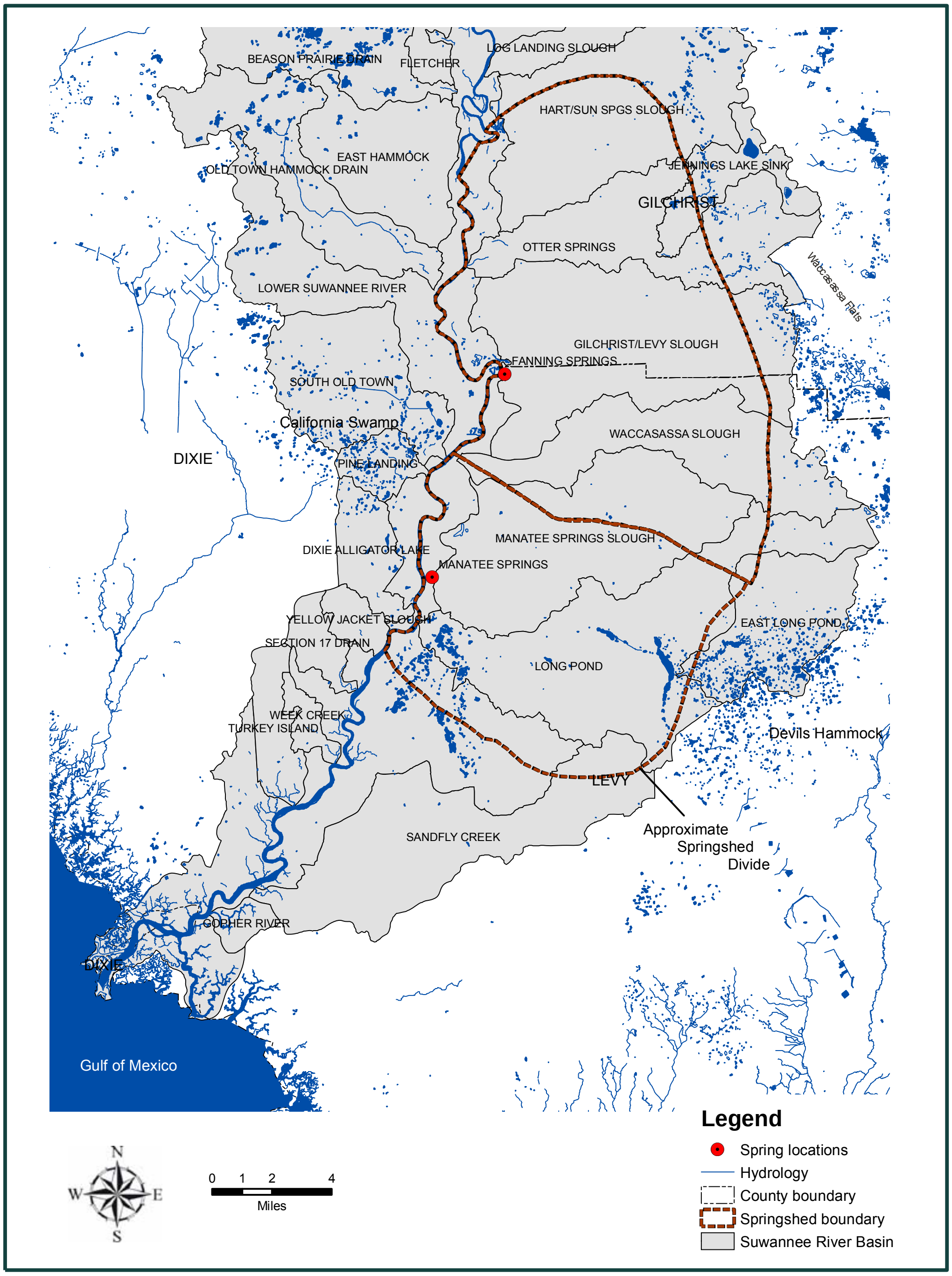

Figure 2-31. Hydrolographic features in the Lower Suwannee study area.

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).

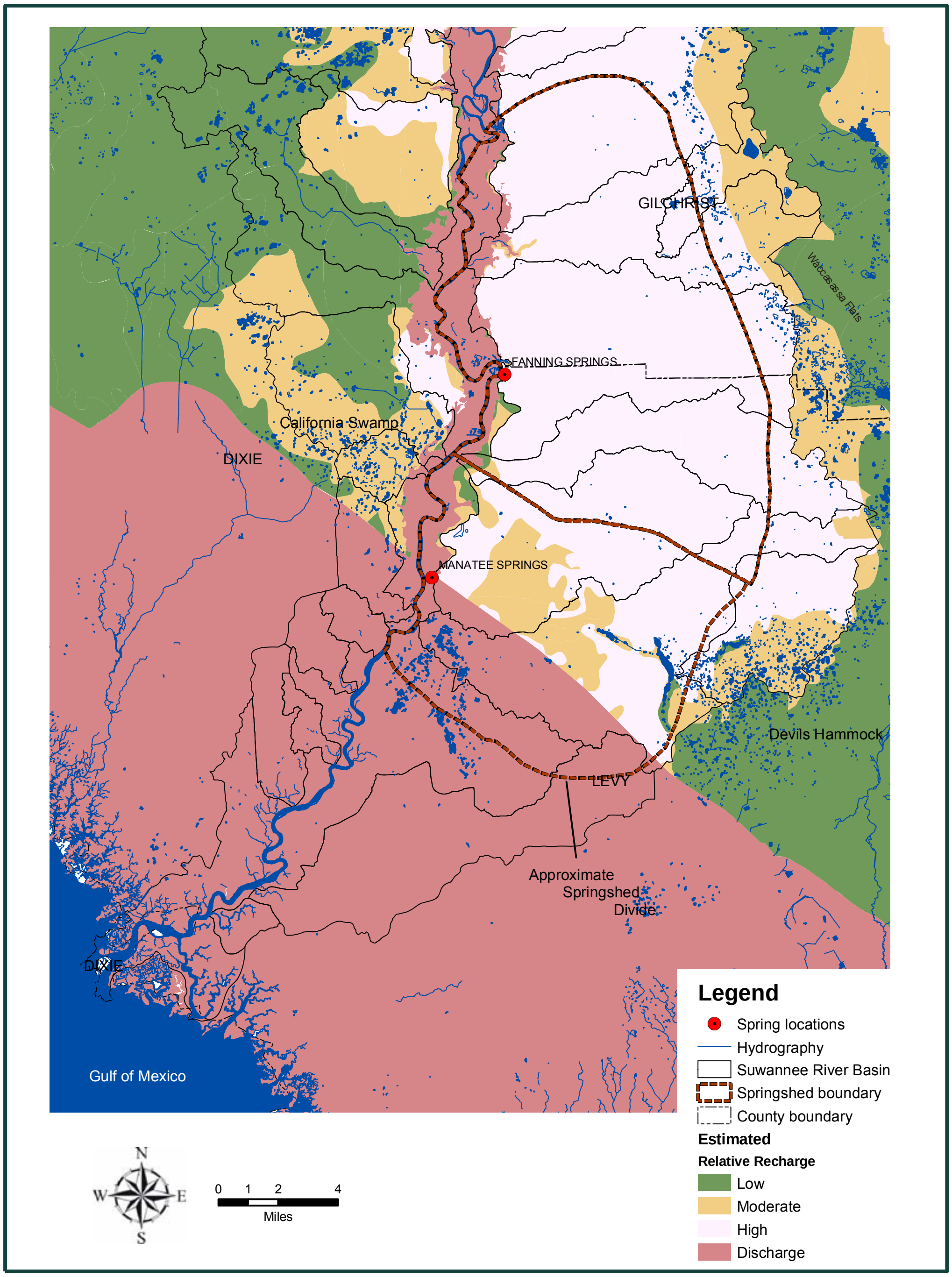

Figure 2-32. Relative groundwater recharge in the Lower Suwannee River study area.

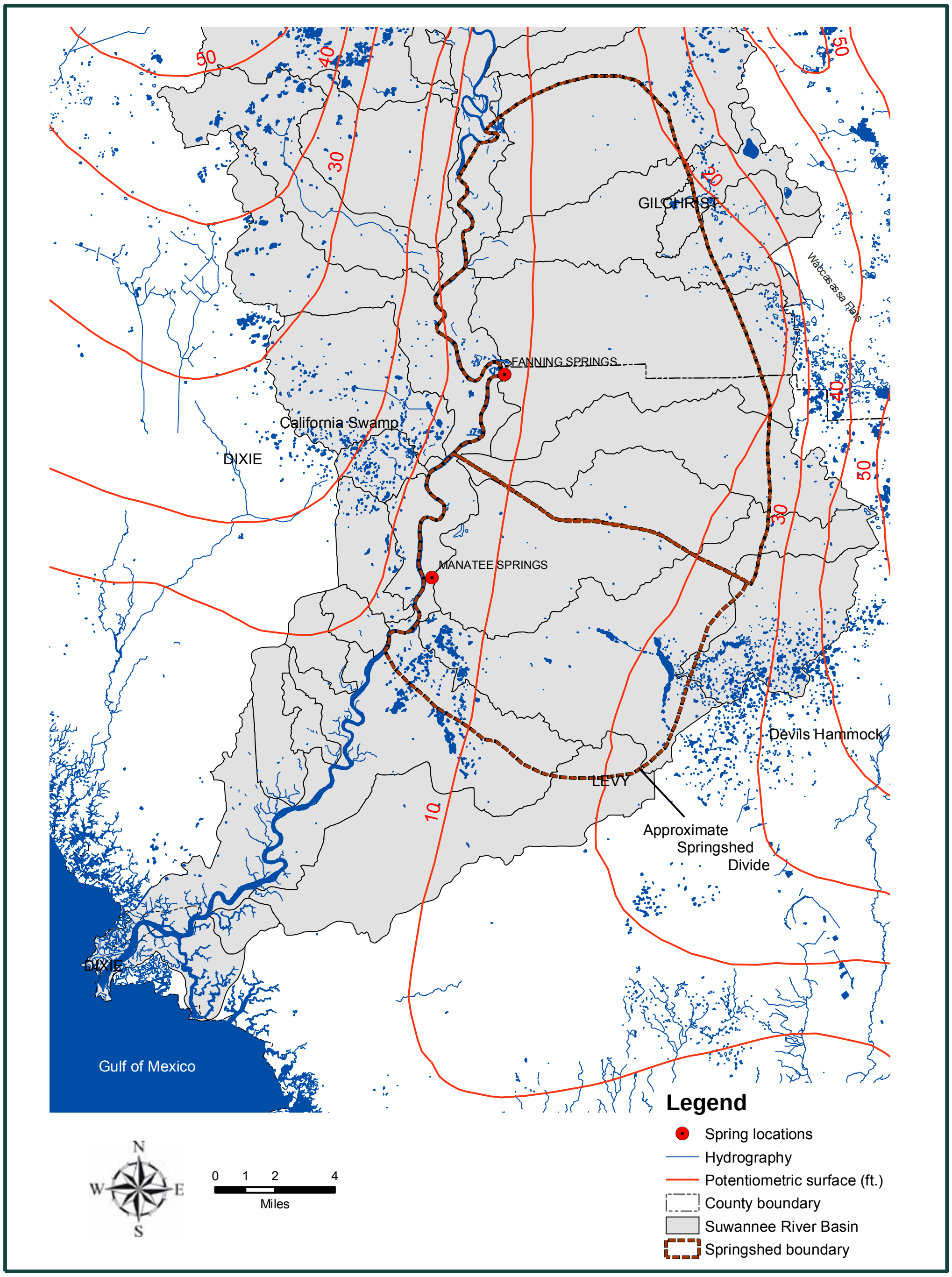

Figure 2-33. September 1995 potentiometric surface of the upper Floridan Aquifer in the study area.

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.

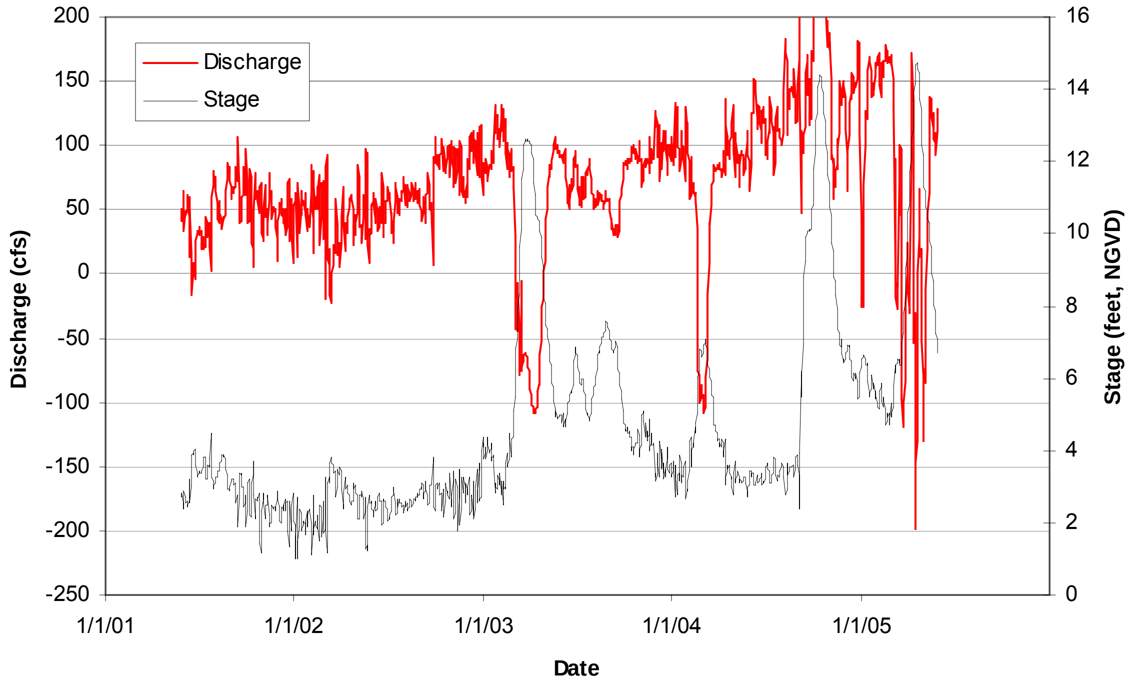

Figure 2-34 - Comparison of continuous stage at Wilcox with AVM discharge measurements at Fanning Spring.

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.

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

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.

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.

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.

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.

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.

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.

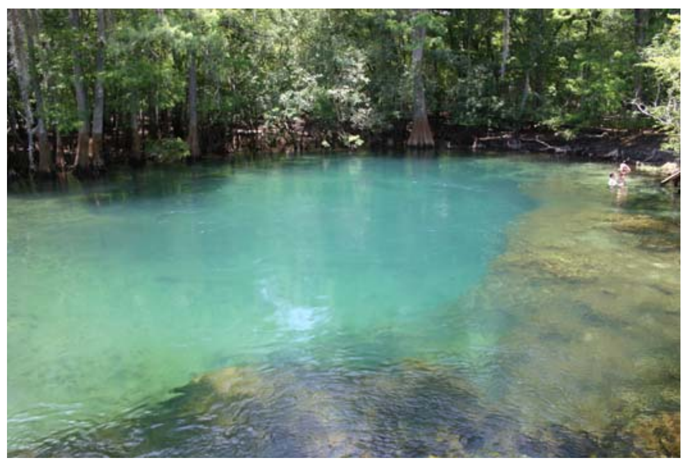

Figure 2-38a. View of Manatee Spring in June, 2005. Note the rock ledge surrounding the vent area.

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).

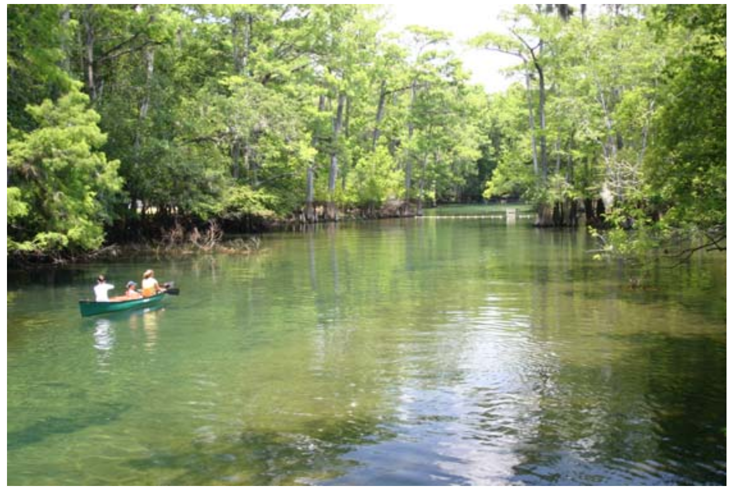

Figure 2-40a. View upstream of the Manatee Springs run in June, 2005. The sand shoal that constitutes a partial barrier to manatee passage is located in front of the canoe.

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.

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.

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.

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.

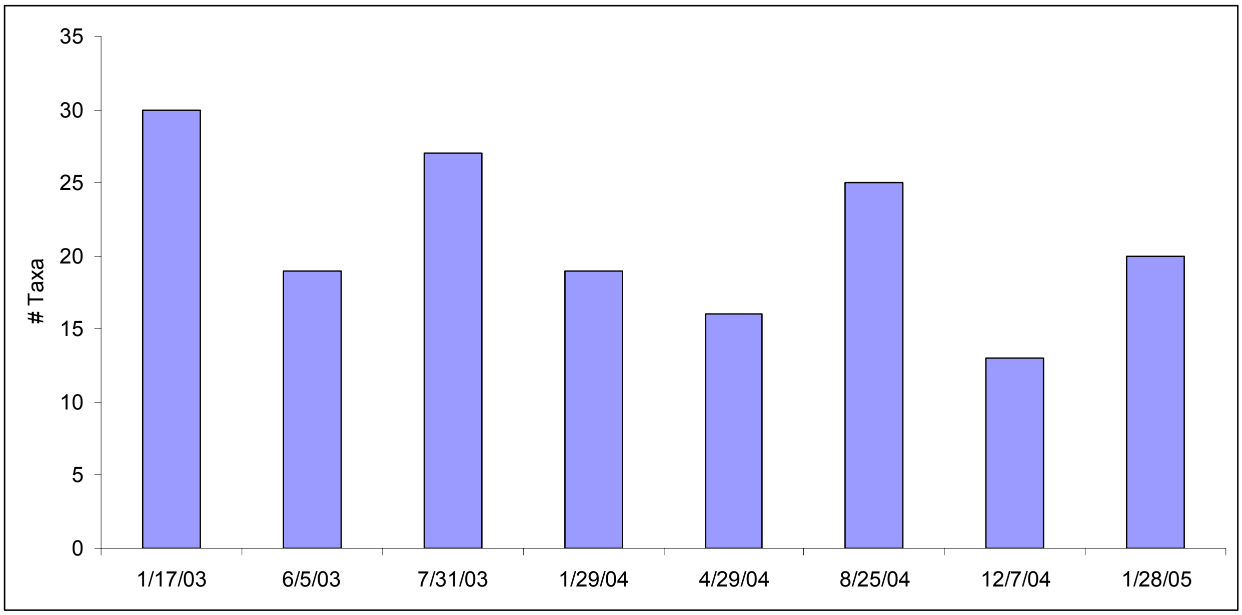

Figure 2-42. Taxa richness of benthic macroinvertebrates in Manatee Springs. Source: FDEP Bioassessment Program.

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).

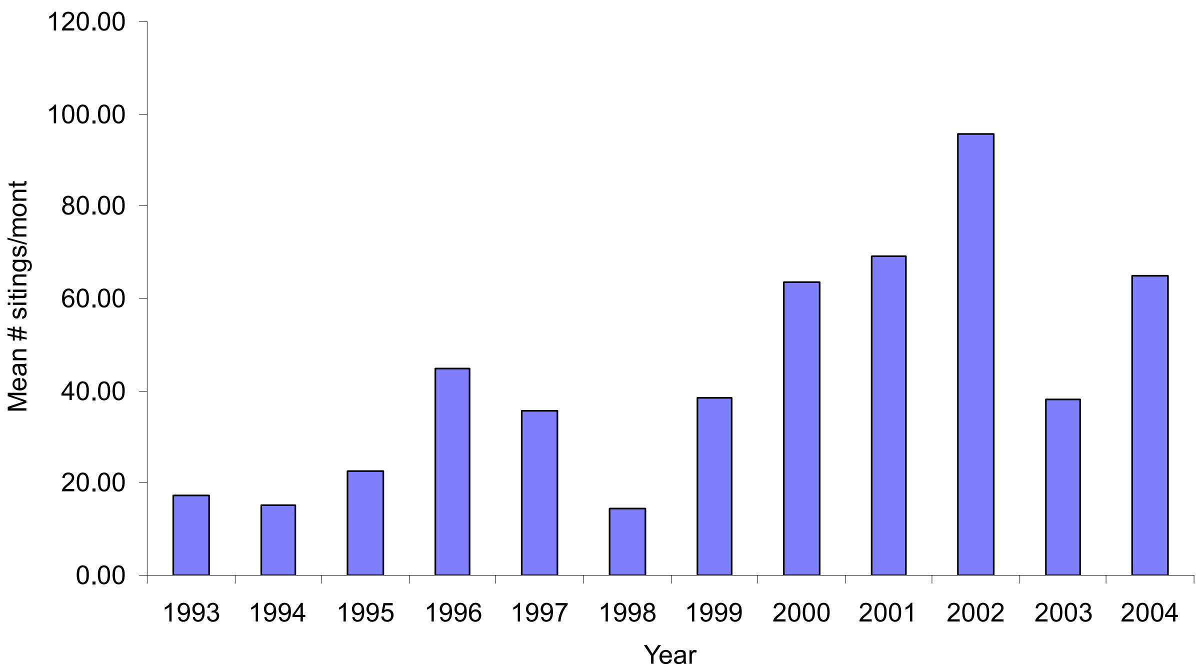

Figure 2-43. Mean number of manatee sightings /month from 1993 to 2004 at Manatee Springs. Source: Manatee Springs State Park.

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.

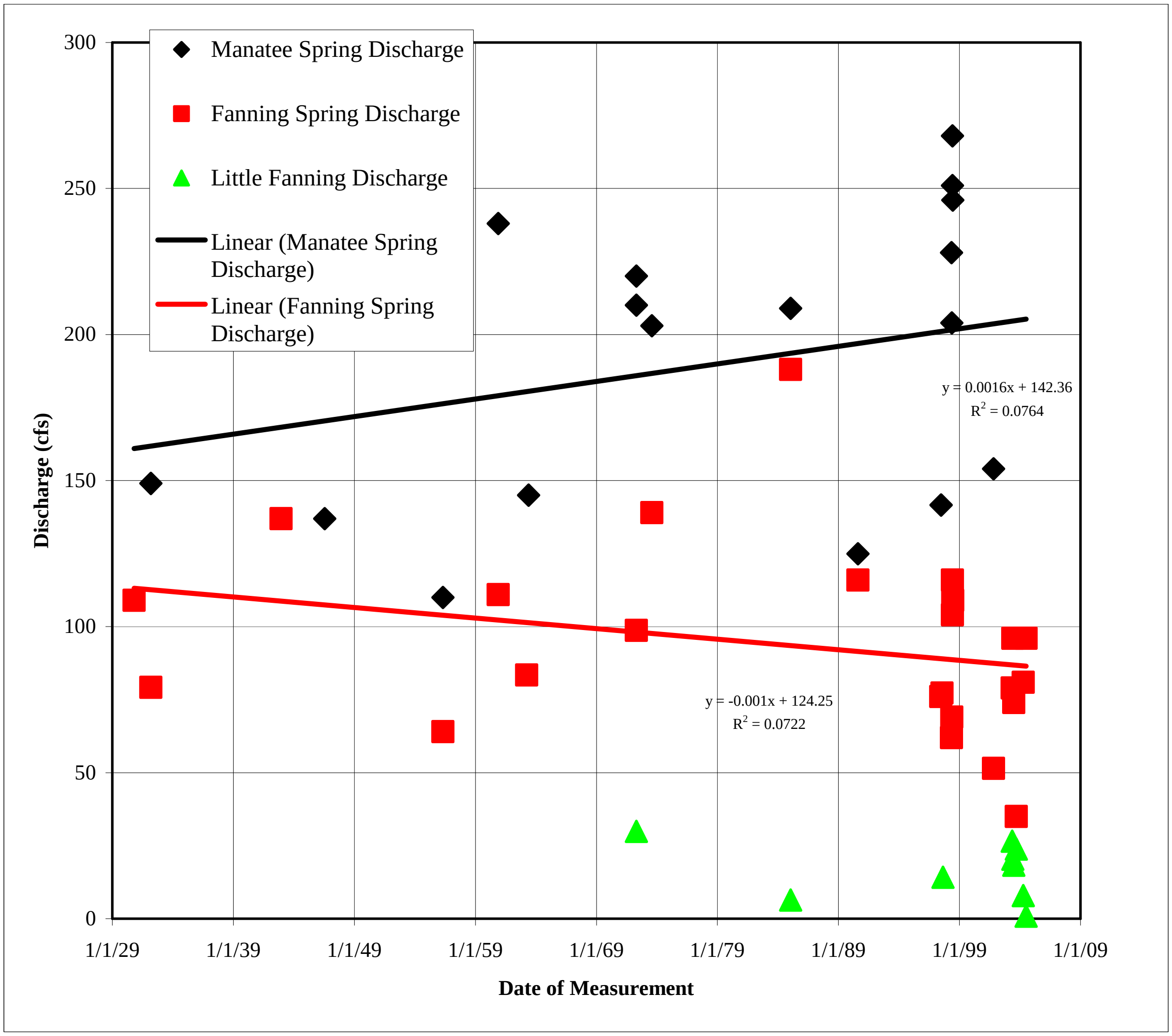

Figure 2-44. Linear estimations of discharge trends at Fanning and Manatee Springs. Neither trend line is statistically significant.

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

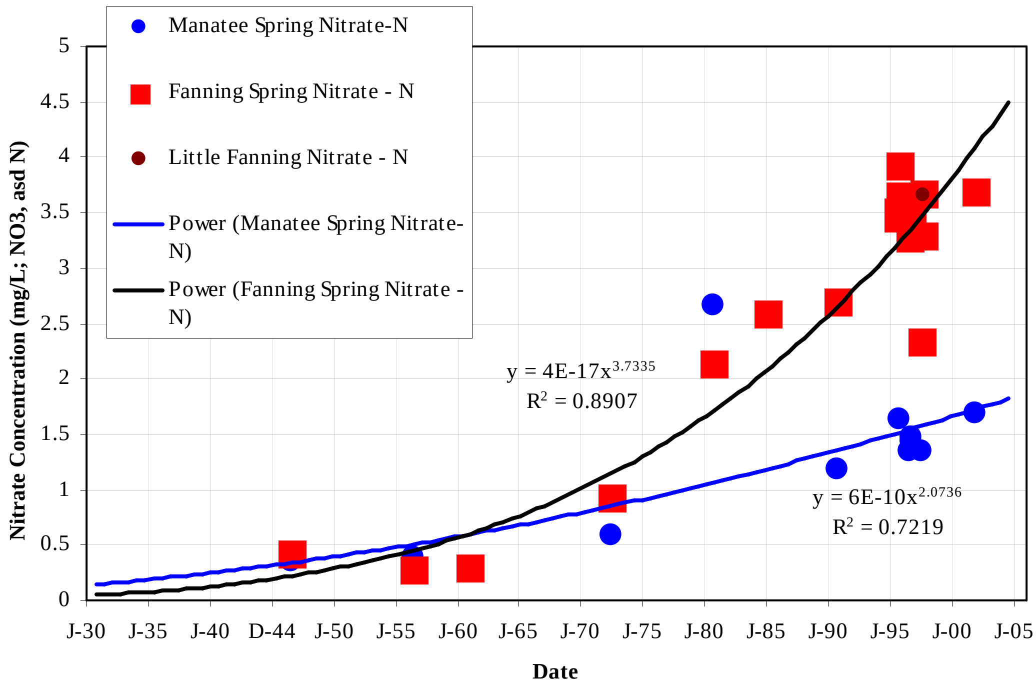

Figure 2-45. Increases in nitrate (NO_3, as N) in Fanning and Manatee Springs. Data are from Hornsby and Ceryak, 1998).

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.

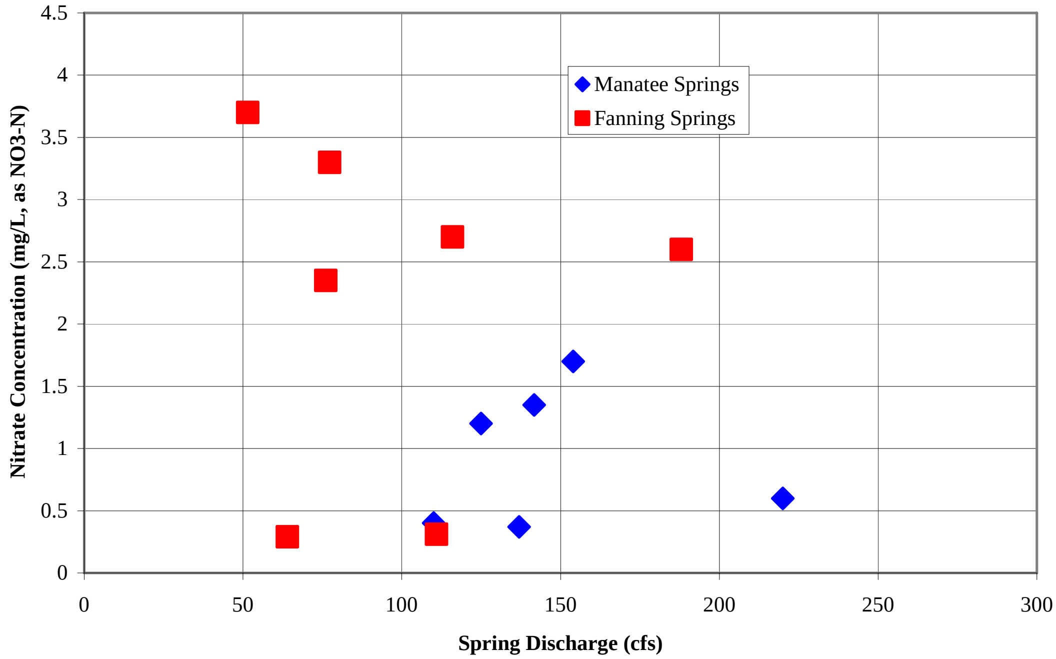

Figure 2-46. Comparison of nitrate concentrations (NO_3, as N) and spring discharge. Note the absence of any pattern of a process-response relationship.

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. <u>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.</u> 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).

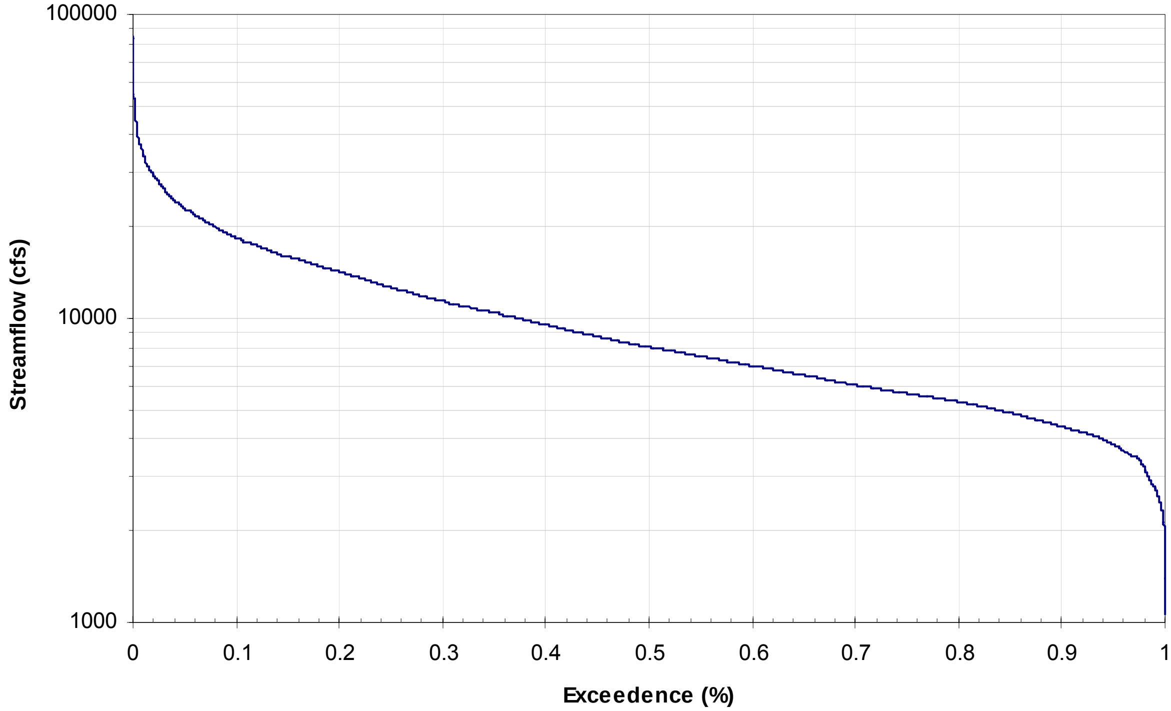

Figure 3-2. Flow-Duration Curve for the Lower Suwannee River near Wilcox gage.

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.

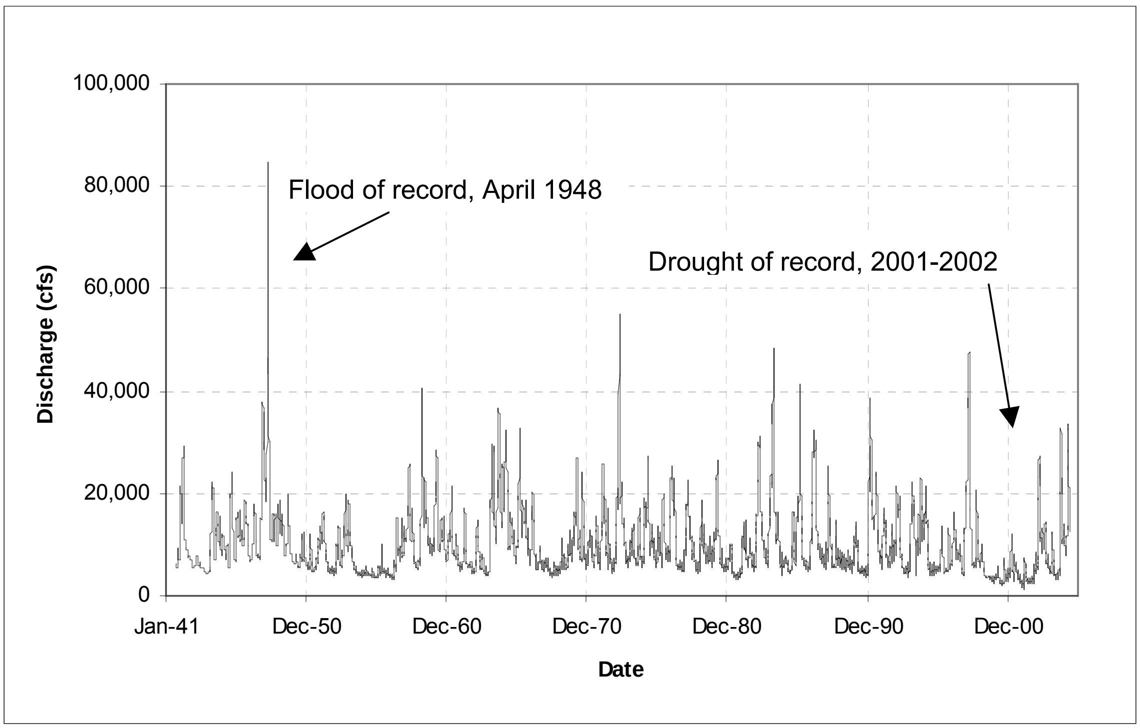

Figure 3-3. Pattern of discharge in cubic feet per second at Wilcox gage for the period of record.

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.

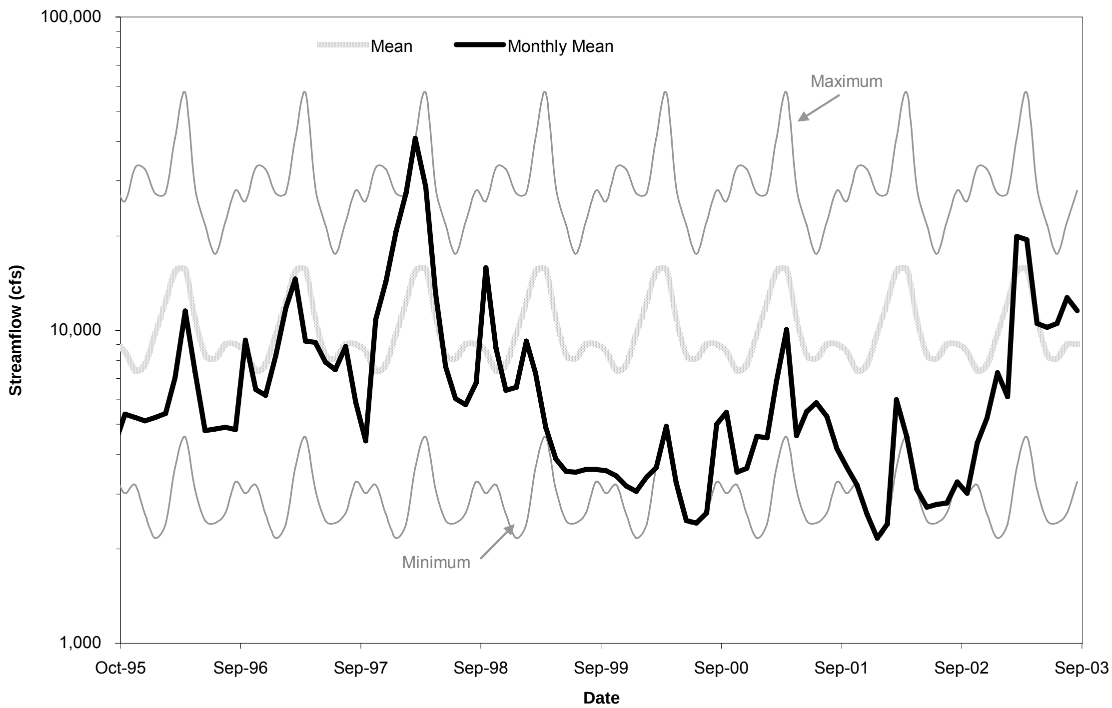

Figure 3-4. Monthly mean discharge of the Suwannee River near Wilcox for the period 1995-2003 compared to the maximum, minimum, and average monthly mean discharge for the period of record (1941-2005).

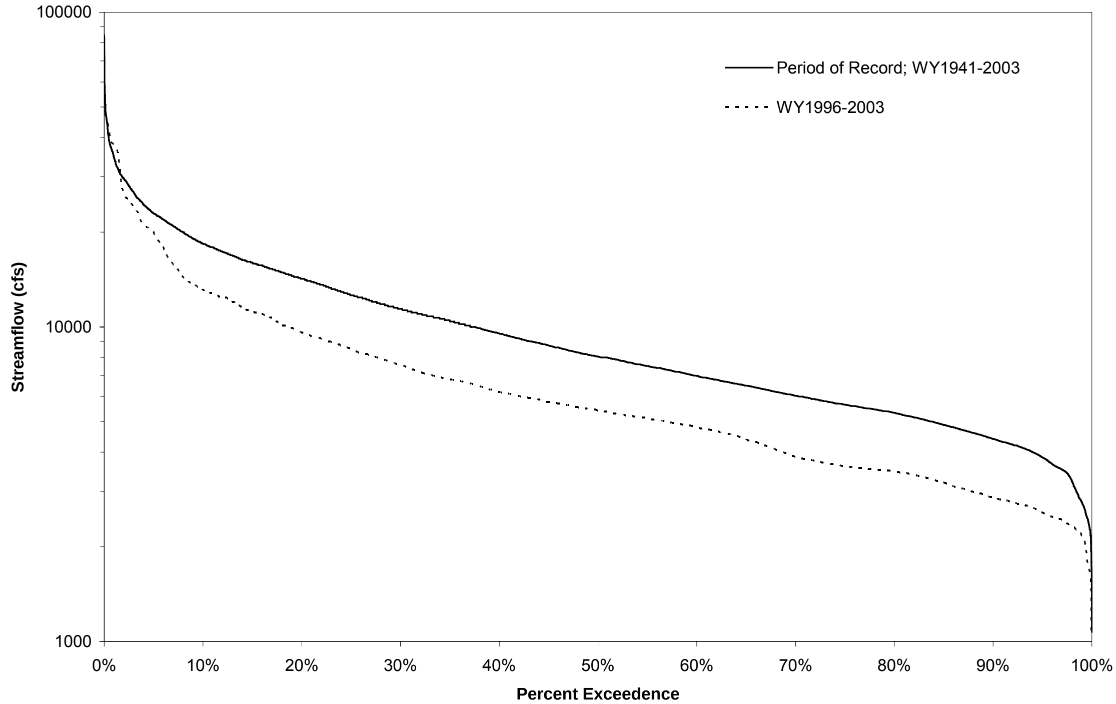

Figure 3-5. Suwannee River near Wilcox flow duration curve for the period 1996-2003 compared to the period of record flow duration curve.

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).

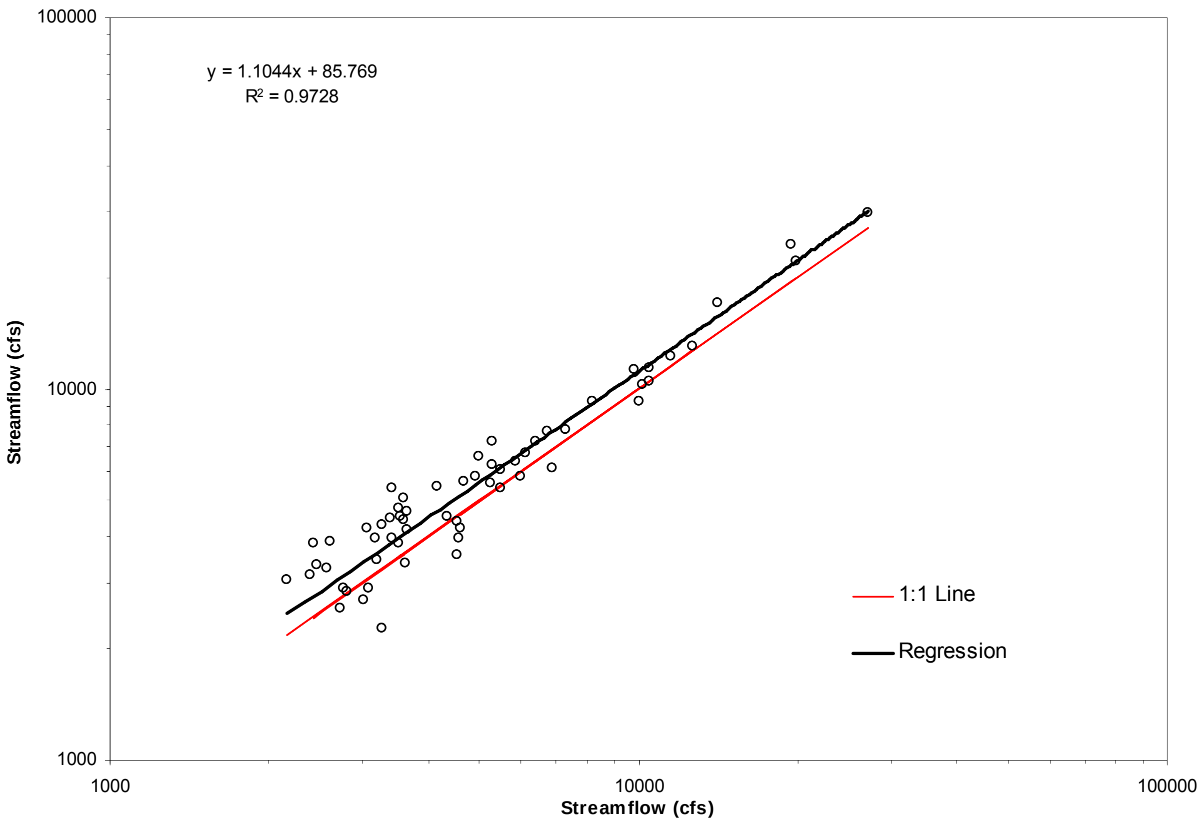

Figure 3-6. Relationship between mean monthly stream flow at the Above Gopher River (AGR) and Wilcox gages.

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,

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

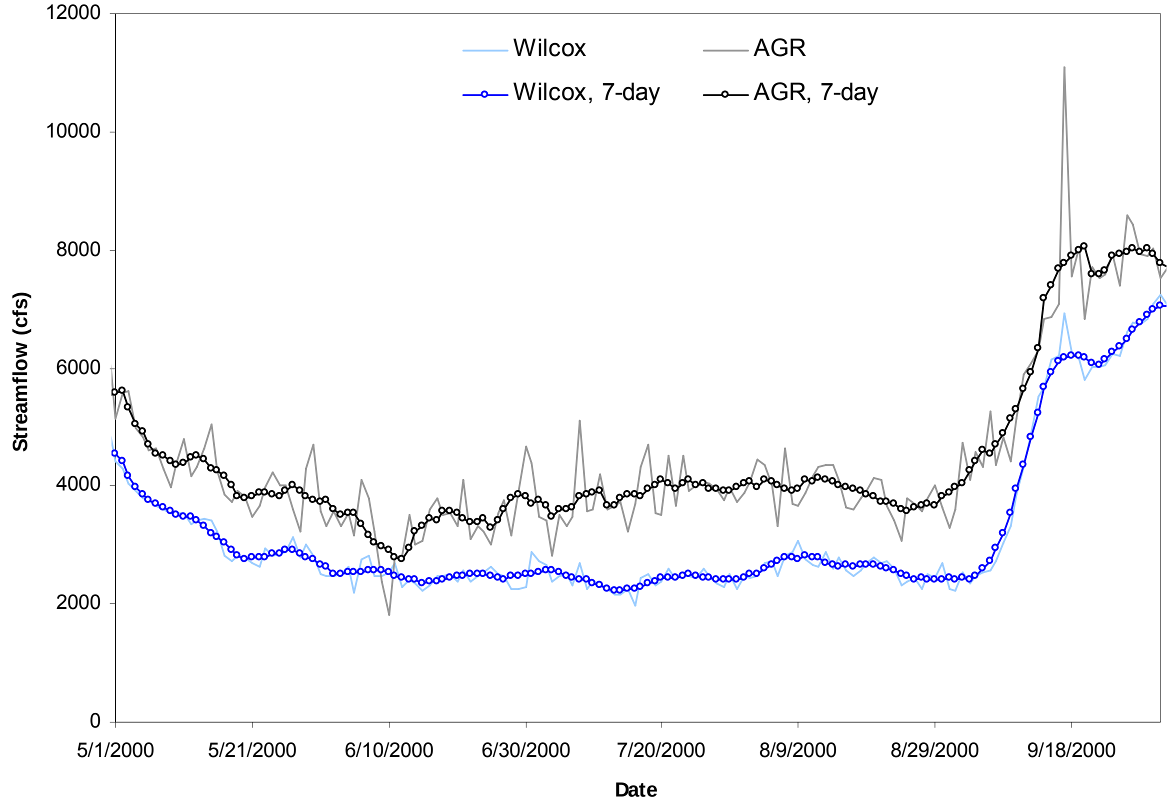

Figure 3-7. Comparison of raw and smoothed daily values at AGR and Wilcox gages.

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].

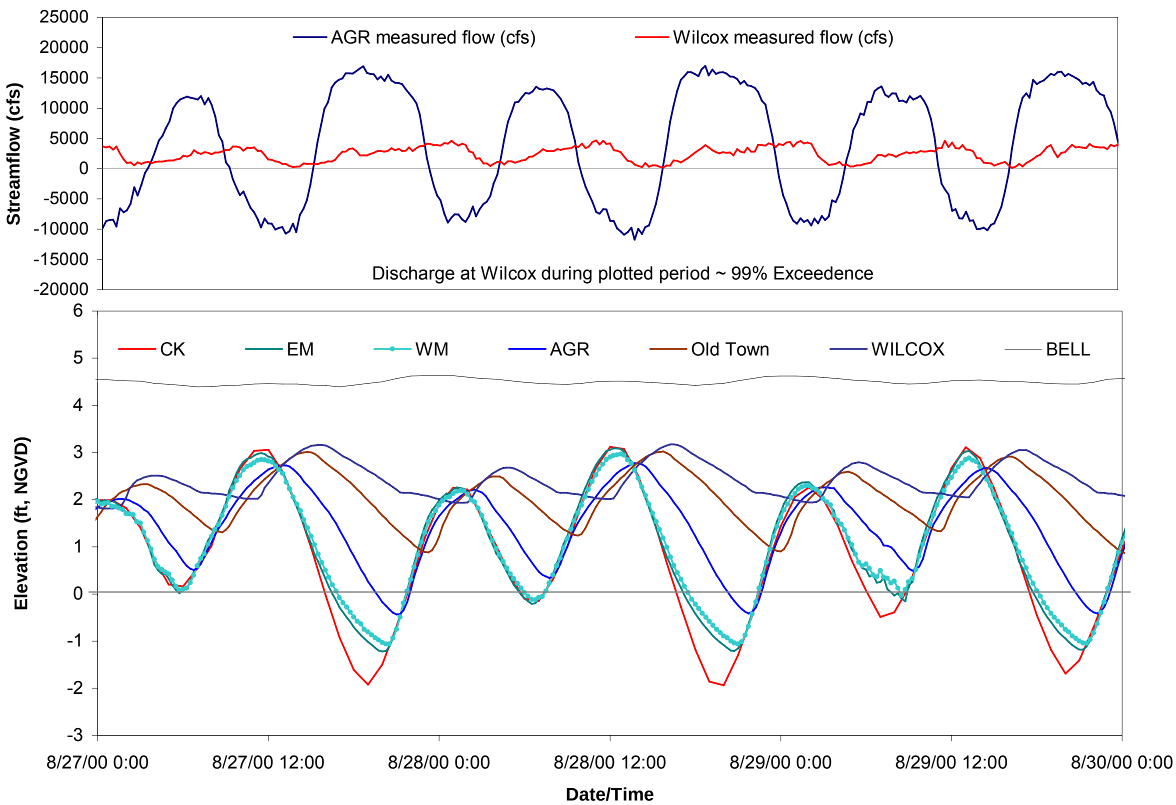

Figure 3-8. Typical tidal patterns associated with extremely low freshwater flow. The Suwannee River near Old Town (USGS No. 02323570) is the auxiliary level gage for the Wilcox slope-rating. Tables 3-1 and 3-4 give additional gage abbreviation meanings.

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.

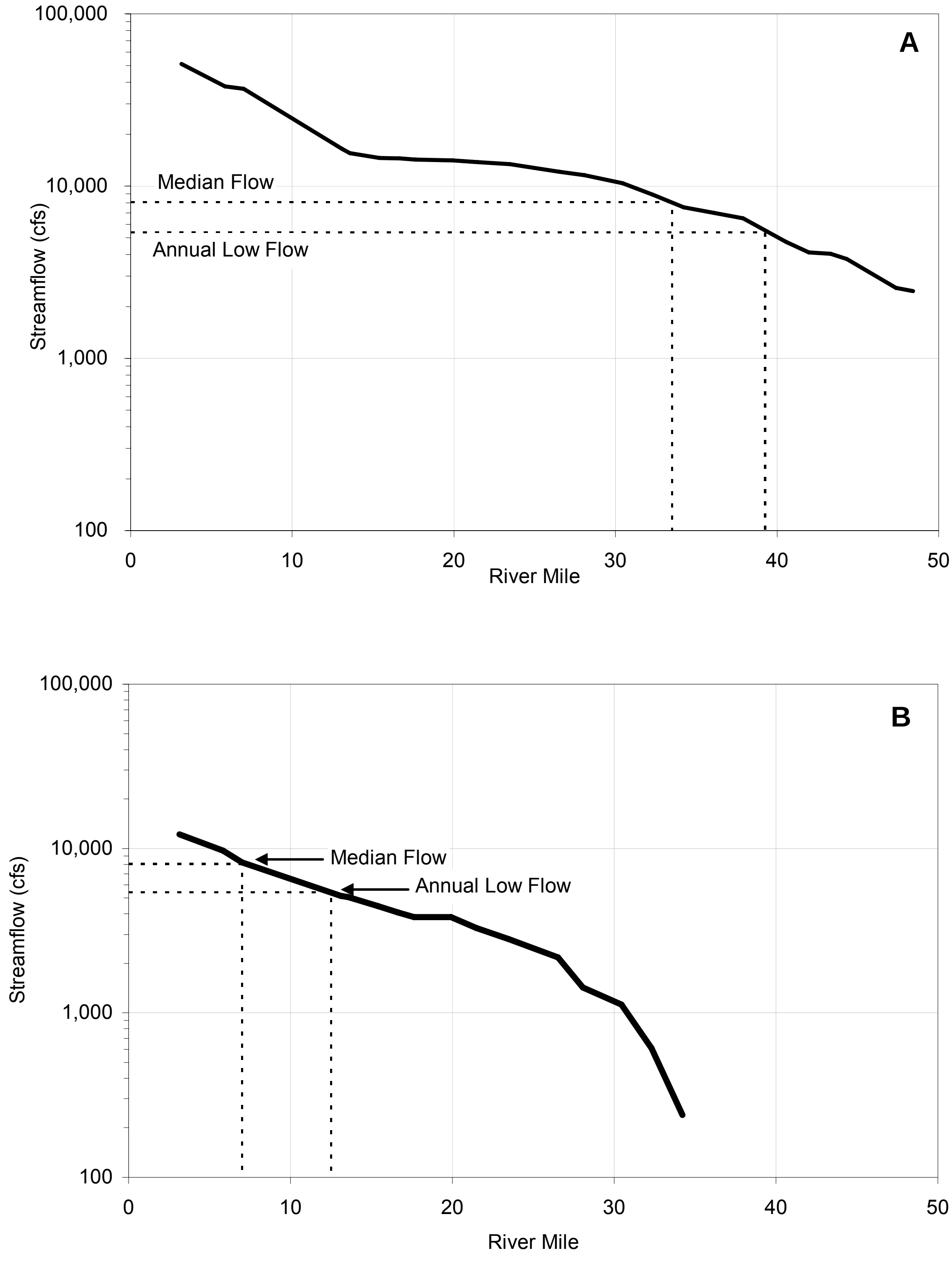

Figure 3-9. Average location of (A) head of tide with discharge at Wilcox and (B) flow reversal point with discharge at Wilcox.

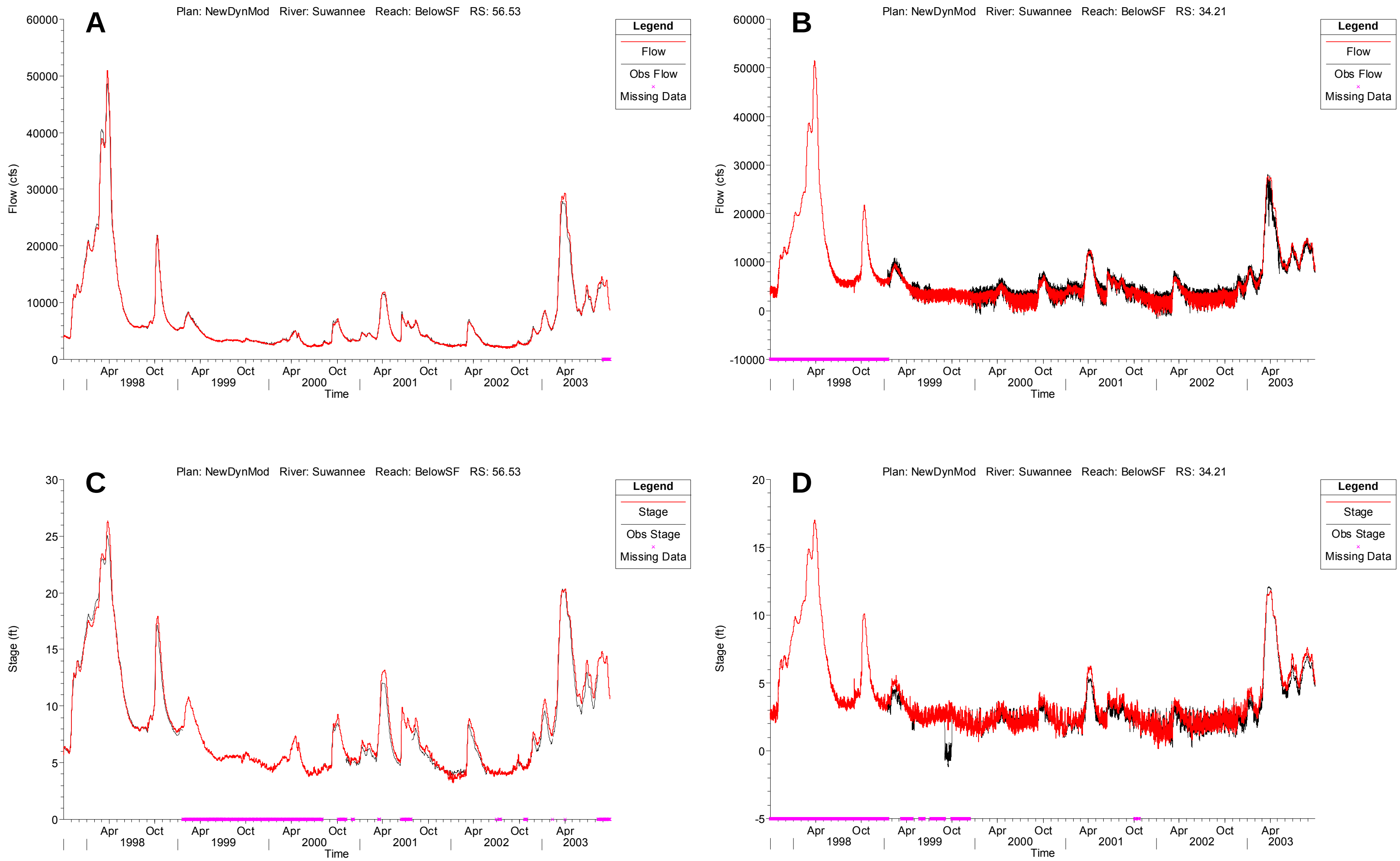

Figure 3-10. HEC-RAS simulated and observed hydrographs for discharge at (A) and stage (B) at Wilcox. Plotted time step is hourly.

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.

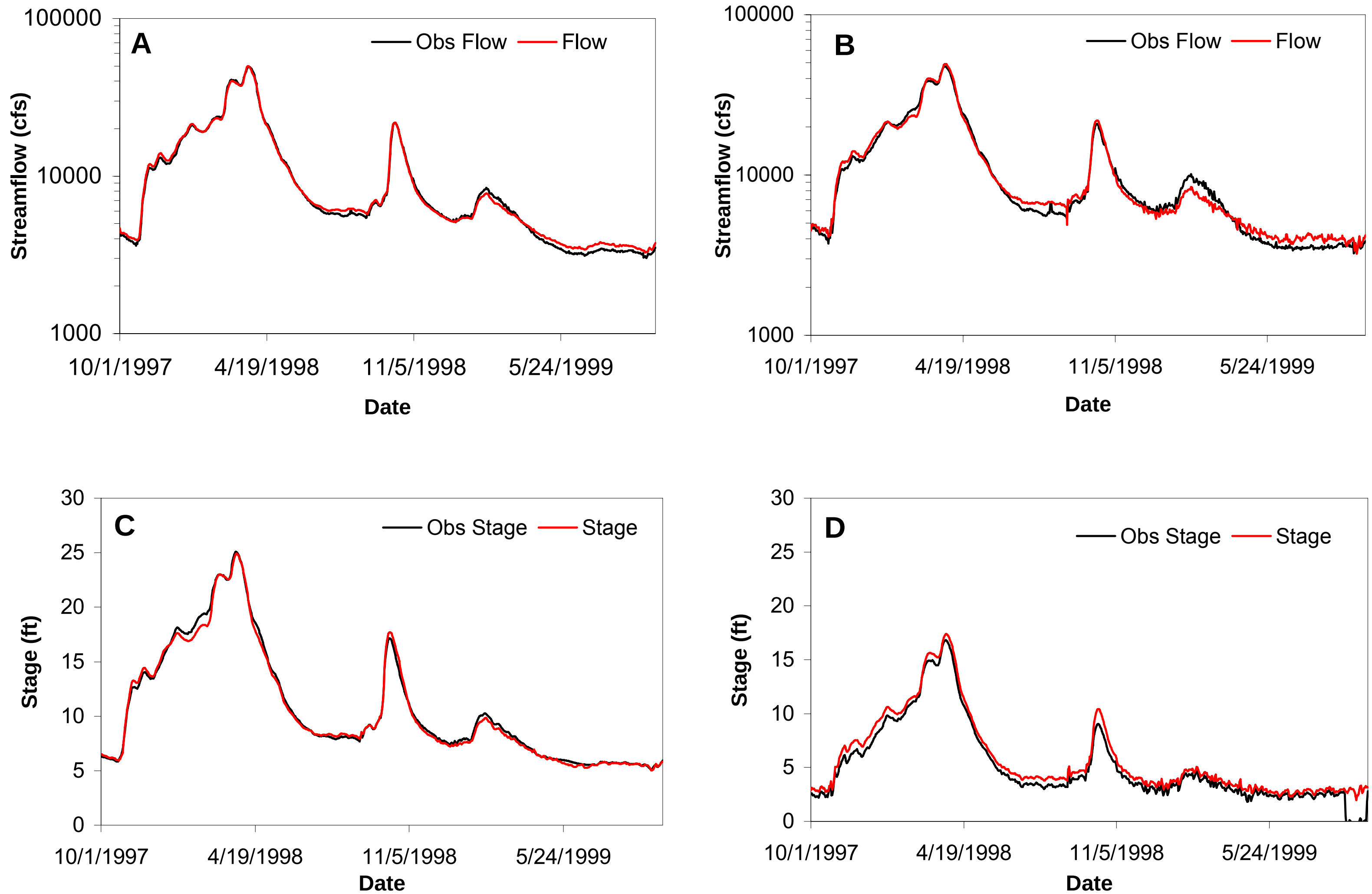

Figure 3-11. MODBRANCH simulated and observed hydrographs for stream flow at (A) Bell and stage (B) at Wilcox. Plotted time step is daily.

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.

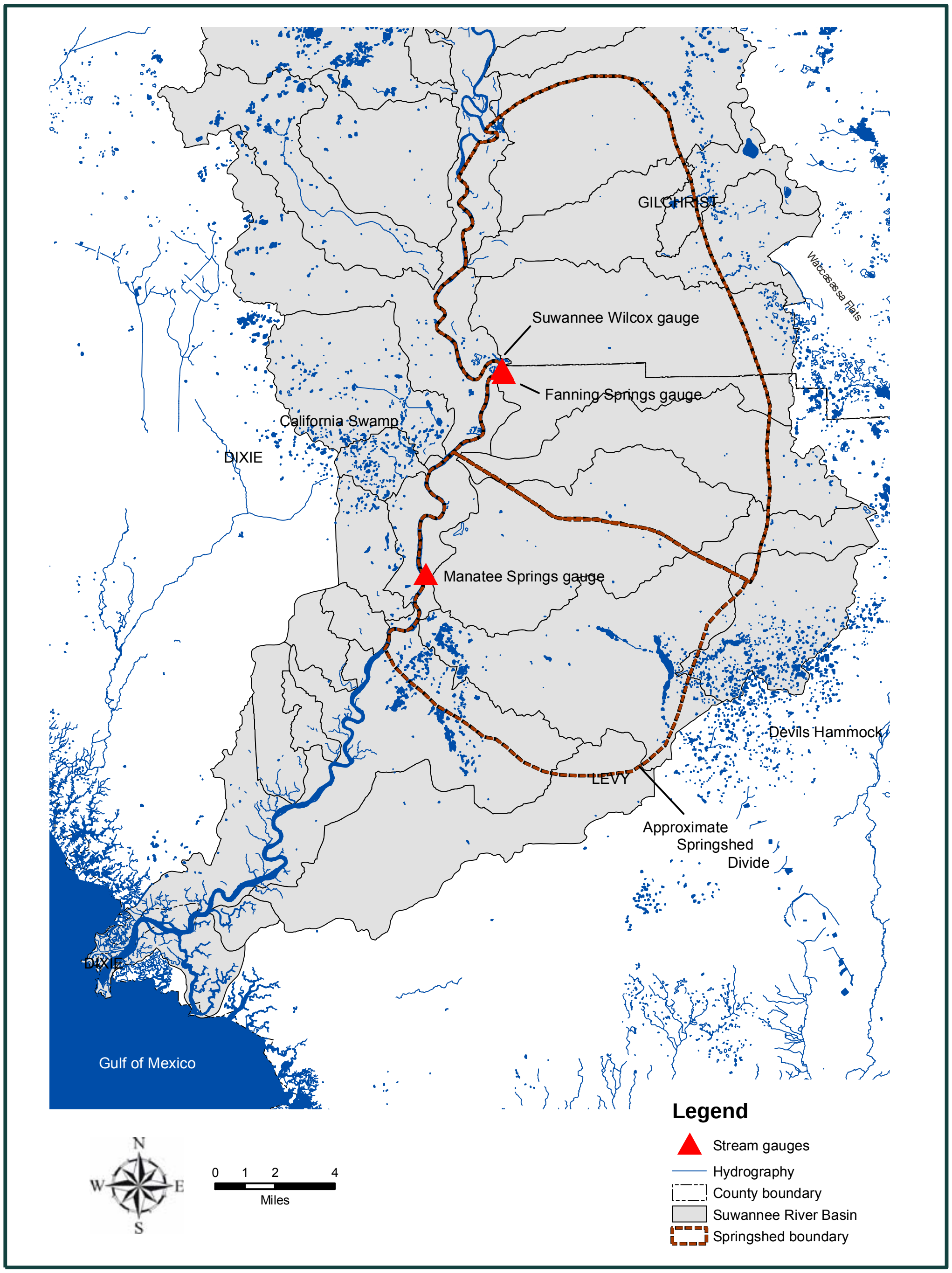

Figure 3-12. Location of stream gages within the Fanning and Manatee Springs springshed.

Stream Gaging Station			Period of Record	# of Daily Gage Values		# of Direct Measurements	
USGS Ref. #	SRWMD Site ID	Description		Stage	Discharge	Stage	Discharge
02323500	-101429002	Suwannee River near Wilcox	10/01/1941 – 05/31/2005	20801	23254	326*	293*
02323556	-111326002	Manatee Springs	01/19/2001 – 05/31/2005	1469	1486	54	66
02323502	-101429001	Fanning Springs	05/27/2001 – 05/31/2005	1455	1466	39	47

Table 3-10. Stage and discharge data available within the study area (data after 9/30/2004 are provisional).
*Measurements not available in digital format prior to 1983.

The most complete and extensive dataset is for the gage located on the Suwannee River near Wilcox. This gage is discussed in Section 3.1.

Temporary and then permanent staff gages have been located at Manatee and Fanning springs for many years. Early discharge measurements were based on temporary rating curves developed at the time of measurement. Historical discharge data (measurements made prior to 2001) for Fanning and Manatee Springs are summarized in Table 3-11. Note that these data were described as historic, “sporadic” discharge data in Section 2.3.5.1. The AVM gages at Fanning and Manatee Springs were installed in 2001, so a fairly short, though continuous, set of daily stage and discharge data has been collected there.

Manatee Spring			Fanning Spring			Little Fanning Spring	
Date	Discharge (cfs)		Date	Discharge (cfs)		Date	Discharge (cfs)
03/14/1932	149		10/25/1930	109		1/18/1985	6.38
12/17/1942	218		03/14/1932	79.2		05/8/2003	26.5
07/24/1946	137		12/17/1942	137		05/28/2003	20.4
04/27/1956	110		05/01/1956	64		06/25/2003	18.3
11/18/1960	238		11/18/1960	111		09/10/2003	23.8
05/28/1963	145		03/27/1963	83.4		04/07/2004	7.94
04/19/1972	220		04/25/1972	98.7		07/01/2004	0.89
04/25/1972	210		07/31/1973	139			
07/31/1973	203		01/18/1985	188			
01/18/1985	209		08/14/1990	116			
08/14/1990	125		06/16/1997	76.1			
06/25/1997	141.7		07/24/1997	77.3			
05/11/1998	228		05/11/1998	62			
05/18/1998	204		05/18/1998	69			
06/01/1998	251		06/01/1998	116			
06/08/1998	268		06/08/1998	104			
06/15/1998	246		06/15/1998	109			

Table 3-11. Historical discharge measurements, in cubic feet per second, for Fanning, Little Fanning, and Manatee Springs.

Little Fanning Springs has never been monitored on a regular basis. Discharge has been measured at Little Fanning Spring a total of seven times to date (Table 3-11). While one of these measurements might be considered “historical”, the remaining six measurements were all completed within a relatively short time frame in 2003 and 2004.

3.2.2.2 Spring Bathymetry Data

3.2.2.2.1 Manatee Spring Bathymetric Survey

In April of 2005, the Florida Geological Survey completed a bathymetric survey of the Manatee Spring run and the Suwannee River in the vicinity of the spring. The survey utilized a precision depth recorder and GPS navigation system. Depths were converted to elevations (NGVD) by correlating with stage observations at Manatee Springs State Park. The results of this survey are shown in Figure 3-13. Using these data, a series of cross-sectional profiles were constructed over the shoals within the spring run. The locations of these profiles are shown on the inset in Figure 3-13. Plots of these cross-sectional profiles are included in Appendix B.

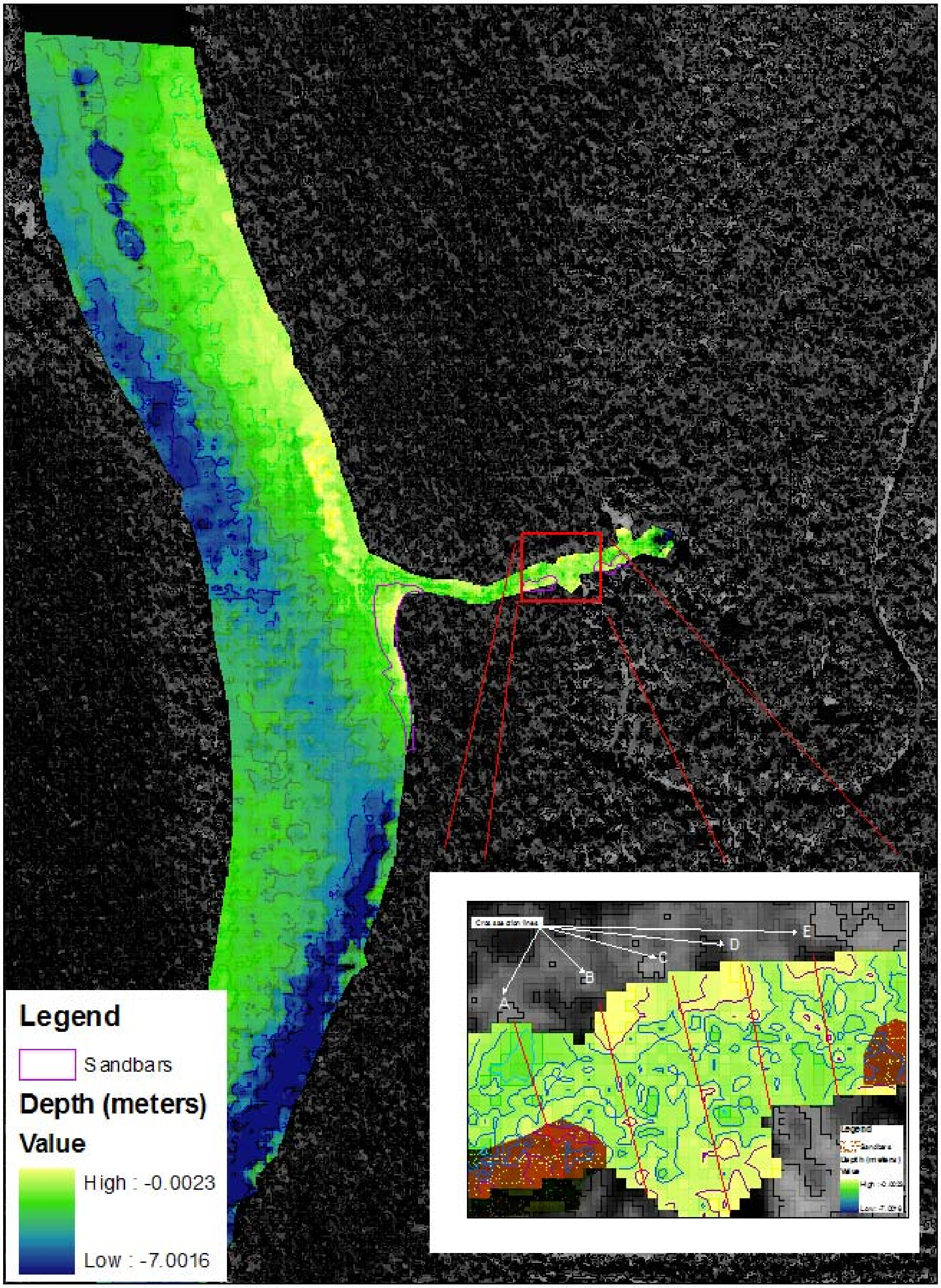

Figure 3-13. Bathymetry surface of Manatee Spring and the adjacent Suwannee River. Inset: Locations of cross-sectional profiles across the shoals in the Manatee Spring run. Data source: Florida Geological Survey, 2005.

These profiles were utilized to identify the highest elevation within the thalweg (the line defining the lowest points along the length of a channel). This “sill” within the spring run is important because it limits the passage of manatees up the spring run into the area of the spring pool. As shown in Figure 3-13, the shoals are located approximately two-thirds of the way up the run from the river. Manatees have relatively free access down stream from the shoal. Within the profiles shown on Figure 3-13, the elevation of the thalweg ranges from greater than 4 feet (Profile A) to just under 2 feet (Profile C) below the water surface.

3.2.2.2.2 Fanning Spring Bathymetric Profiles

On June 20, 2005, a land surveying company retained by Water Resource Associates collected five cross-sectional profiles across the shallowest part of the Fanning Spring run. The location of these profiles is shown in Figure 3-14. Plots of these cross-sectional profiles are included in Appendix C.

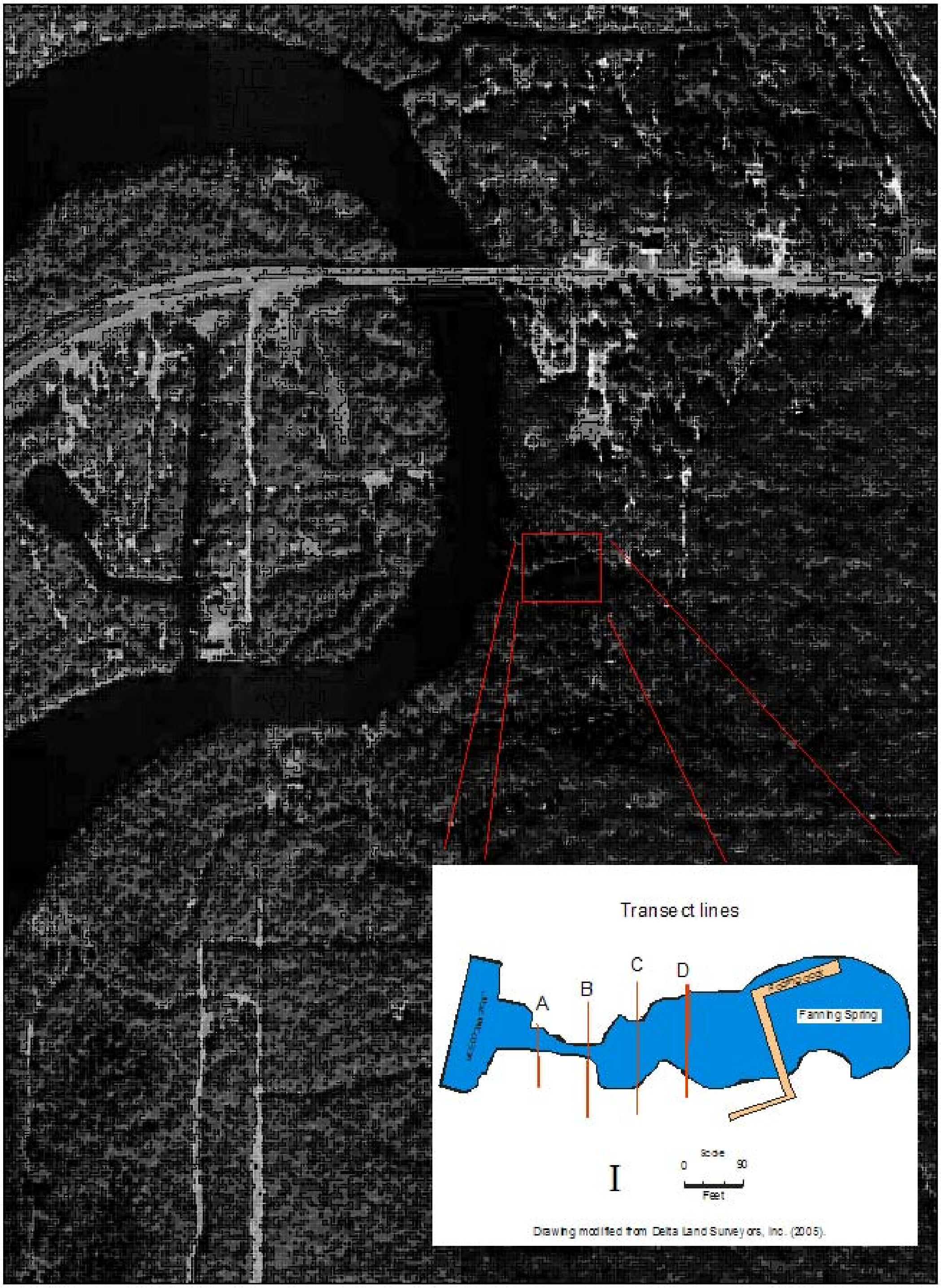

Figure 3-14. Locations of cross-sectional profiles across the Fanning Spring run.

As with the Manatee Spring profiles, this survey was utilized to identify the “sill” within the thalweg of the spring run in order to address manatee passage issues. The elevation of the thalweg within these profiles ranged from a low of –3.81 feet NGVD (Profile C) to as high as –2.29 feet NGVD (Profile B).

3.2.2.3 Groundwater Data

3.2.2.3.1 Groundwater Levels

The District has collected groundwater level data in Levy and Gilchrist County at 183 wells located within the Suwannee River drainage basin. Of these, a total of 109 wells are located within the Manatee and Fanning Springs springshed (Figure 3-15). Table 3-12 contains information on water-level data available for these wells, including the date first and last measured, the frequency measured, total number of measurements, and minimum and maximum groundwater levels within each well. Appendix E contains the complete data set for each of the wells in the study area. Only those wells with 10 or more measurements are depicted graphically in Appendix D; the data from the remaining wells (74% of the total wells) are presented in a table in the Appendix.

Of these 109 wells, only 12 have been monitored on a daily basis for some period, and only two have been continuously monitored on a daily basis for an extended period of time (e.g. longer than ten years). The remaining wells have been monitored on a monthly, quarterly, or yearly basis. Some wells have significant gaps within their monitoring records.

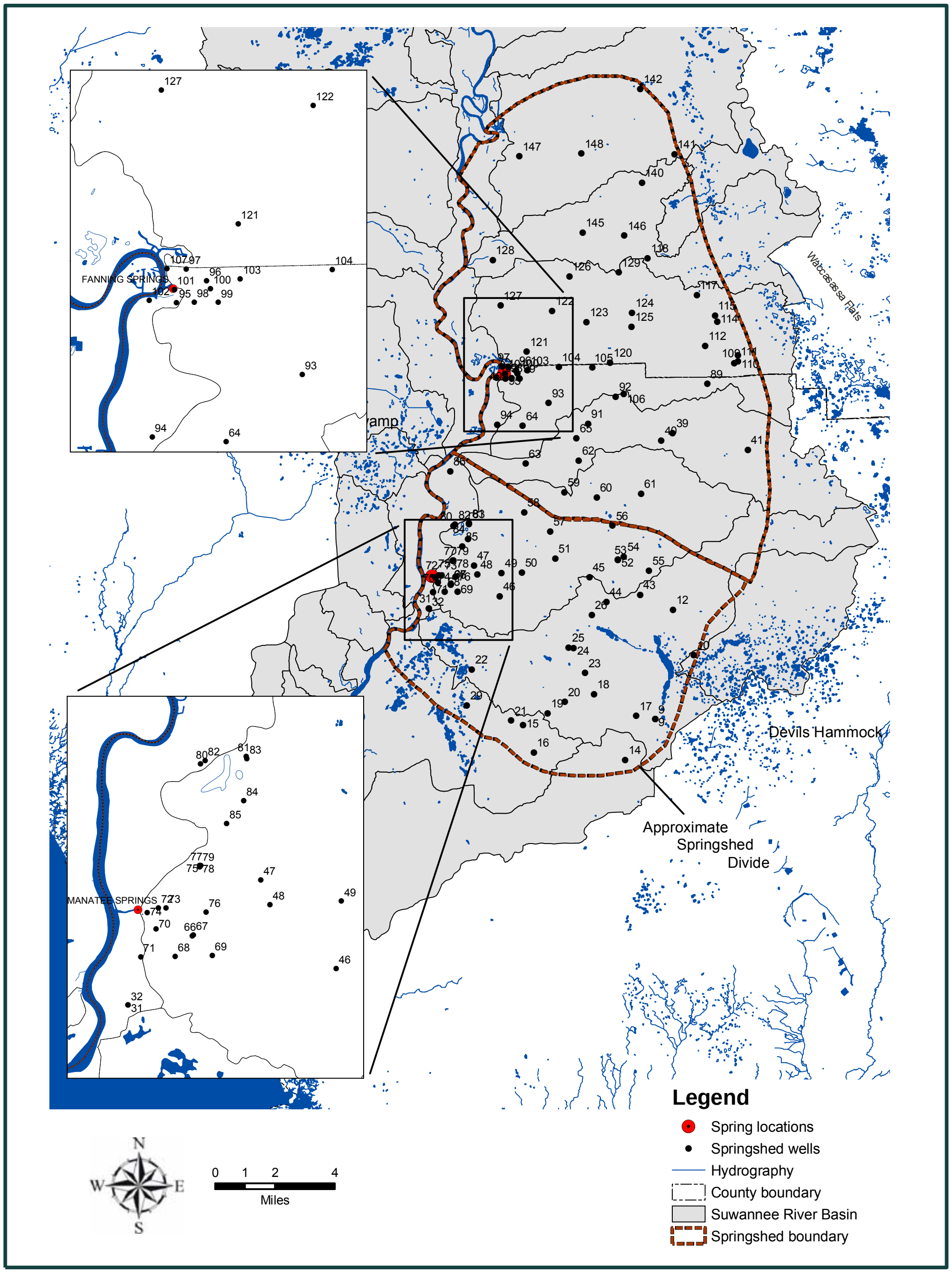

Figure 3-15. Location of water-level monitoring wells within the Fanning and Manatee Springs springshed.

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
9	-121519001	05/21/2002	01/28/2004	Quarterly	3	8.40	12.94
10	-121508005	09/07/2000	09/24/2004	Daily	1439	15.31	30.50
12	-121506002	12/12/2001	01/28/2004	Yearly	4	8.66	15.28
14	-121436002	09/30/2003	01/28/2004	Quarterly	2	9.94	13.65
15	-121429005	06/13/1989	09/09/2004	Monthly*	38	5.86	20.11
16	-121428004	12/17/2003	01/28/2004	Monthly	2	11.25	12.34
17	-121424006	03/05/2002	01/28/2004	Quarterly*	4	5.23	9.89
18	-121423007	03/05/2002	01/28/2004	Quarterly*	4	4.30	9.17
19	-121422002	03/06/2002	01/28/2004	Quarterly*	4	4.50	8.80
20	-121422001	03/06/2002	09/29/2004	Daily	808	5.03	20.03
21	-121420001	11/01/1976	01/28/2004	Monthly*	58	6.04	22.70
22	-121418002	06/22/1982	12/06/1982	Quarterly	3	9.89	12.23
23	-121415003	03/06/2002	01/28/2004	Quarterly*	4	5.72	10.56
24	-121410003	05/28/2002	01/28/2004	Yearly	4	5.17	11.09
25	-121410001	06/22/1982	03/27/2003	Quarterly*	6	4.88	13.47
26	-121402003	02/28/2002	01/28/2004	Quarterly*	4	6.32	11.45
29	-121324001	03/07/2002	01/28/2004	Quarterly*	4	7.85	12.01
31	-121302011	02/21/2003	03/11/2004	Yearly	3	3.49	6.23
32	-121302010	02/21/2003	03/11/2004	Yearly	3	4.49	6.23
39	-111506010	03/08/2002	01/29/2004	Quarterly*	4	5.20	11.44
40	-111506001	06/23/1981	12/08/1982	Quarterly	5	9.45	14.49
41	-111503011	03/06/2002	01/29/2004	Quarterly*	4	10.90	18.23
43	-111436001	01/06/1966	05/13/1998	Monthly*	65	12.17	27.17
44	-111435007	12/19/2001	01/29/2004	Quarterly*	5	7.03	12.59
45	-111434010	02/22/2002	01/29/2004	Quarterly*	4	6.90	12.67
46	-111431006	03/05/2002	10/03/2002	Quarterly	3	2.89	4.08
47	-111430015	05/31/2002	01/29/2004	Yearly	3	1.56	4.72
48	-111430014	01/19/2001	01/29/2004	Quarterly*	5	2.20	4.29
49	-111429006	12/19/2001	01/29/2004	Quarterly*	5	2.94	5.21
50	-111429005	02/21/2002	01/29/2004	Quarterly*	4	3.81	7.71

Table 3-12. Wells located within the Fanning and Manatee springshed. (* large gaps in data collection)

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
51	-111428007	02/21/2002	01/29/2004	Quarterly*	4	5.37	10.13
52	-111426010	12/11/2001	01/28/2004	Quarterly*	5	7.37	12.80
53	-111426001	07/24/1979	12/06/1982	Monthly	38	12.50	19.31
54	-111425012	04/25/2001	01/28/2004	Quarterly*	7	7.48	15.69
55	-111425001	07/24/1979	01/28/2004	Monthly*	44	7.31	19.76
56	-111423013	04/27/2001	04/07/2004	Quarterly*	8	5.51	14.04
57	-111421001	03/11/2002	01/29/2004	Quarterly*	4	5.05	9.93
58	-111417003	03/05/2002	01/29/2004	Quarterly*	4	4.91	9.62
59	-111415002	03/11/2002	01/29/2004	Quarterly*	4	5.60	10.27
60	-111414008	02/22/2002	01/29/2004	Quarterly*	4	5.65	11.32
61	-111413007	02/27/2002	01/29/2004	Quarterly*	4	5.76	12.84
62	-111410024	02/22/2002	01/29/2004	Quarterly*	4	3.17	9.49
63	-111408002	03/11/2002	01/29/2004	Quarterly*	4	4.77	8.56
64	-111405001	06/13/1989	1/29/2004	Monthly*	27	3.47	9.19
65	-111403008	03/06/2002	01/29/2004	Quarterly*	4	5.08	9.34
66	-111336005	01/28/2004	03/11/2004	Monthly	2	2.32	4.76
67	-111336004	01/28/2004	04/30/2004	Monthly	3	2.35	4.81
68	-111336003	04/29/2002	01/28/2004	Quarterly*	6	1.71	3.09
69	-111336002	04/29/2002	01/28/2004	Quarterly*	6	1.21	3.14
70	-111335006	01/28/2004	01/28/2004	----------	1	1.73	1.73
71	-111335005	04/29/2002	09/14/2004	Daily	756	1.14	8.42
72	-111335002	09/09/1981	05/06/1987	Bimonthly	30	-0.75	8.23
73	-111326008	02/15/2000	10/03/2002	Quarterly*	4	1.23	1.85
74	-111326004	10/01/1981	08/27/2004	Daily	7930	0.34	12.91
75	-111325018	04/29/2002	01/28/2004	Quarterly*	6	2.47	4.52
76	-111325017	04/29/2002	09/14/2004	Daily	755	2.08	9.45
77	-111325016	02/15/2001	05/29/2002	Quarterly*	4	2.61	3.29
78	-111325008	12/13/2000	01/28/2004	Yearly	5	2.52	4.48
79	-111325001	07/24/1979	12/11/2001	Monthly*	41	2.96	10.68
80	-111324033	05/15/2002	05/15/2002	----------	1	1.91	1.91

Table 3-12. (cont.). Wells located within the Fanning and Manatee springshed. (* large gaps in data collection)

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
81	-111324030	05/23/2002	06/26/2002	Monthly	2	2.74	3.00
82	-111324029	04/29/2002	01/28/2004	Quarterly*	8	3.94	6.70
83	-111324028	04/29/2002	09/26/2004	Daily	767	4.00	14.73
84	-111324027	04/29/2002	03/16/2004	Quarterly*	6	3.87	8.98
85	-111324026	04/29/2002	08/05/2004	Daily	716	3.65	12.05
86	-111312001	04/01/2003	04/07/2004	Quarterly*	3	6.70	10.25
89	-101528013	03/06/2002	01/29/2004	Quarterly*	4	6.04	12.11
91	-101435008	12/18/2001	01/29/2004	Quarterly*	5	5.02	9.54
92	-101435007	12/18/2001	01/29/2004	Quarterly*	5	5.41	9.90
93	-101433012	12/18/2001	01/29/2004	Quarterly*	4	2.77	5.35
94	-101432001	03/22/2002	04/30/2004	Quarterly*	6	3.13	6.53
95	-101429025	04/26/2002	09/14/2004	Daily	754	2.10	12.05
96	-101429024	04/26/2002	01/29/2004	Quarterly*	6	2.46	4.50
97	-101429023	04/29/2002	09/14/2004	Daily	754	1.97	11.81
98	-101429022	04/26/2002	01/29/2004	Quarterly*	6	2.15	4.43
99	-101429021	04/26/2002	01/29/2004	Quarterly*	6	2.01	4.48
100	-101429020	04/26/2002	09/14/2004	Daily	753	2.33	8.37
101	-101429016	11/03/2000	08/27/2004	Daily	1211	1.62	11.84
102	-101429011	10/14/1997	09/10/2004	Monthly	91	1.01	14.70
103	-101428001	09/09/1981	09/09/2004	Monthly*	129	2.40	16.03
104	-101427005	12/18/2001	01/29/2004	Quarterly*	5	3.13	5.94
105	-101426007	12/18/2001	10/04/2002	Quarterly*	4	3.87	4.76
106	-101425008	01/31/2001	04/01/2004	Quarterly*	7	3.35	10.63
107	-101420026	12/06/2001	01/29/2004	Quarterly*	4	3.57	4.19
109	-101528003	07/24/1979	10/21/1981	Monthly	22	12.60	19.67
110	-101522006	10/01/1981	01/28/2004	Quarterly*	8	39.71	55.21
111	-101522001	02/12/1982	12/07/1982	Monthly	10	17.00	24.37
112	-101520004	03/14/2002	01/28/2004	Quarterly*	4	7.09	13.15
114	-101516017	01/12/1993	09/29/2004	Daily	3421	5.66	25.15
115	-101516001	11/01/1976	10/04/1994	Monthly*	151	7.49	24.84

Table 3-12. (cont.). Wells located within the Fanning and Manatee springshed. (* large gaps in data collection)

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
117	-101508002	03/29/1982	01/28/2004	Quarterly*	8	6.00	24.56
118	-101506003	05/08/1998	09/29/2004	Daily	2075	3.80	21.41
120	-101423001	08/29/1979	12/06/1982	Monthly	39	9.59	16.37
121	-101421003	03/12/2002	01/28/2004	Quarterly*	4	2.83	4.35
122	-101416006	03/13/2002	01/28/2004	Quarterly*	4	3.28	7.04
123	-101414001	03/21/2002	01/28/2004	Quarterly*	4	3.76	7.84
124	-101413010	03/21/2002	01/28/2004	Quarterly*	4	4.78	10.07
125	-101413001	11/01/1976	05/15/1979	Quarterly	10	8.37	13.73
126	-101410005	03/13/2002	01/28/204	Quarterly*	4	3.61	7.68
127	-101408003	03/12/2002	01/28/2004	Quarterly*	4	2.89	5.21
128	-101406001	03/21/1982	01/29/2004	Quarterly*	7	3.58	6.06
129	-101401002	03/13/2002	01/28/2004	Quarterly*	4	4.31	9.19
140	-91530005	06/14/1989	07/01/2004	Monthly*	75	4.75	17.80
141	-91520001	09/08/1981	10/04/2002	Quarterly*	8	11.96	22.99
142	-91506002	09/21/1981	01/28/2004	Quarterly*	6	9.38	21.85
145	-91436008	03/25/2002	01/28/2004	Quarterly*	4	4.21	8.78
146	-91436002	03/22/1982	12/06/1982	Quarterly	4	15.41	19.32
147	-91420001	11/01/1976	09/09/2004	Monthly	299	3.71	19.77
148	-91415002	10/01/1981	10/04/2002	Quarterly*	8	4.58	18.22

Table 3-12. (cont.). Wells located within the Fanning and Manatee springshed. (* large gaps in data collection)

3.2.2.5 Precipitation Data

Precipitation data exist for several stations in the vicinity of Fanning and Manatee Springs. The first and last date measured, along with the largest rainfall total for a single month at that gage, are presented in Table 3-13 and locations of the gages are shown in Figure 3-16. The data are presented graphically in Appendix F. Only monthly rainfall totals are available for the three rainfall stations located within the Fanning and Manatee Springs basin. The total period of record for these gages ranges from about 7 to 30 years.

Station	First Measured	Last Measured	Maximum Event (Date)
Trenton Tower (71)	January 1976	Present	16.87 in. (Aug. 1985)
Fanning Spring (72)	May 1998	Present	11.6 in. (July 2001)
Manatee Spring (93)	March 1989	Present	17.66 in. (July 1994)

Table 3-13. Available precipitation data in the Fanning and Manatee Spring basins.

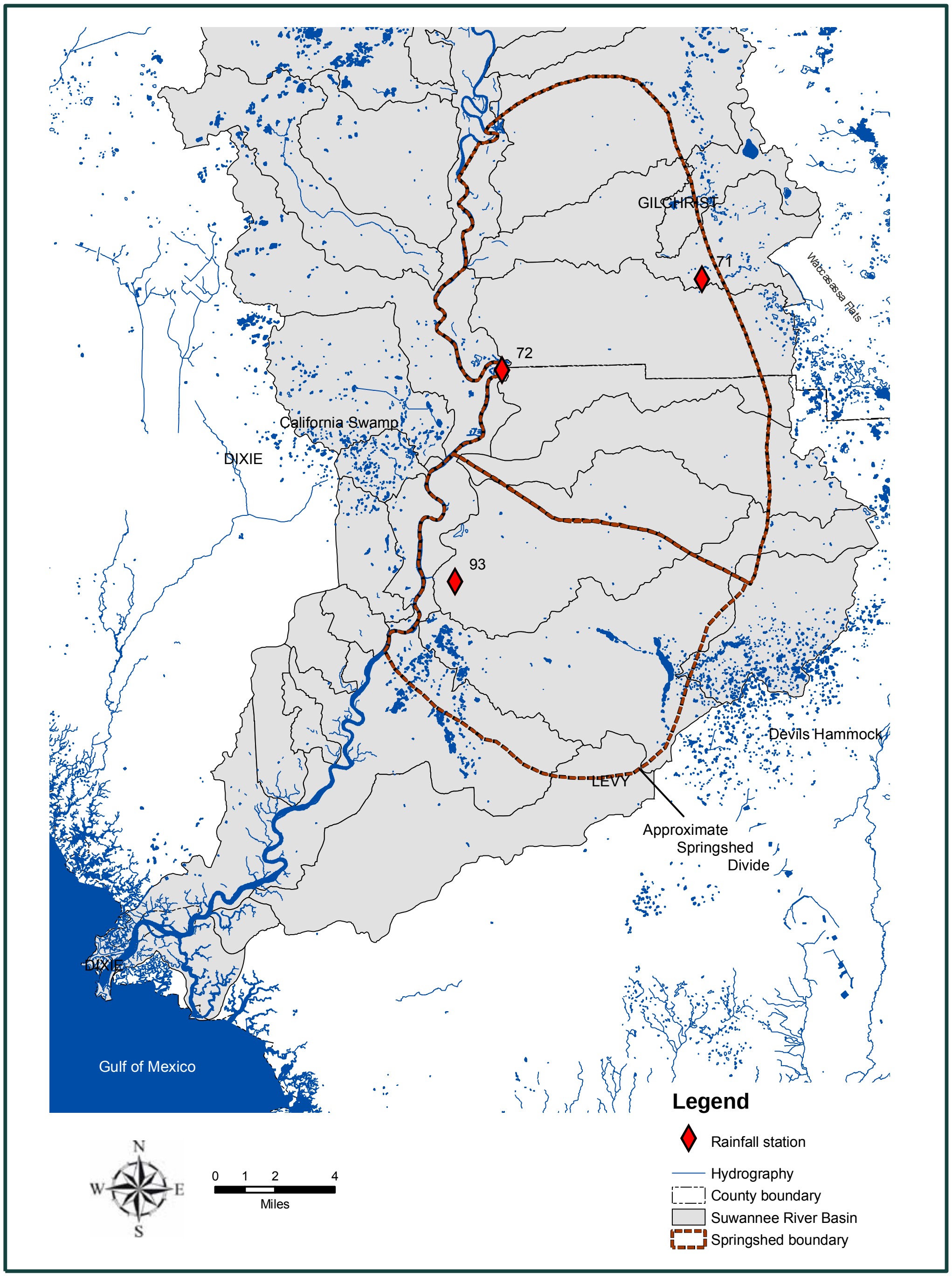

Figure 3-16. Location of rainfall gages within the Fanning and Manatee Springs springshed.

3.2.2.6 Summary

The hydrologic and geologic data available for the determination of minimum flows and levels for Manatee and Fanning Springs are:

- An excellent period of record for stage and discharge at the Suwannee River near Wilcox;
- Fairly short periods of record for the gages at Fanning and Manatee Springs;
- Monthly to yearly groundwater level data from 96 wells;
- A short daily record of groundwater levels from 11 wells;
- Significantly long daily records of groundwater levels from 2 wells;
- Groundwater permit information by county;
- Monthly rainfall data from three stations in the vicinity of study area;
- Bathymetric survey data for the Fanning and Manatee Spring runs; and
- Thermal data from the Suwannee River at Manatee Springs for approximately two months in March and April 2004.

3.2.3 Data Synthesis and Analyses

3.2.3.1 Introduction

As noted above, Fanning and Manatee Springs are part of a complex, interdependent hydrologic system. Discharge from the springs depends on both water levels within the springshed (groundwater potentials) and within the river. Water levels and discharge in the river are affected by the flux of water from the upstream portion of the Suwannee Basin as well as by tidal flux in the Suwannee River Estuary.

Unfortunately, the data available for use in characterizing the inter-relationships within this system are not extensive. Gages have only been present within the springs for a few years. Furthermore, due to the problems inherent in installing and calibrating these gages, there is uncertainty regarding the quality of the short dataset available. The Fanning Spring discharge record appears to be representative of actual discharge from this spring, while significant portions of the Manatee Spring discharge record appear to be flawed.

Although there are over 100 wells located within the Fanning and Manatee springsheds, groundwater elevations have not been measured in most of these wells with regularity. In addition, due to the hydraulic interactions between the Floridan aquifer and the Suwannee River, wells in close proximity to the river appear to better represent conditions within the river. One well (Well #114) with a fairly long period of daily measurements is located a sufficient distance from the river to reduce influences of the river. This dataset, combined with the data from the gage on the Suwannee River near Wilcox, was sufficient to characterize the driving forces behind discharge from Fanning and Manatee springs.

The results from the data synthesis presented below indicate that, while daily stage values in the springs can be simulated from river stage with a high degree of confidence, working with average monthly values to simulate discharge significantly increases confidence in the results. Equations for simulation of daily discharge have been developed and could be used; however, a MFL for either water body is likely to be based on longer-term average or median flows (i.e. monthly average) due to the significant short-term variability in discharge at both springs and in the river. Therefore, the simulated monthly discharge represents the statistically best values, as well as likely being the most useful.

The regression equations developed for simulating monthly discharge from Fanning and Manatee springs represent statistically significant relationships. However, these equations are only based on a period of record for Fanning Spring of approximately 40 months. In the case of Manatee Spring, this period of record is much shorter (about 16 months); much of the remaining data from this gage appear to be flawed and were not used. While the simulated monthly discharge for these two springs (Figure 3-17) appear to be reasonable, the numerous limitations in the available data result in a certain level of uncertainty. As such, hydrologic conditions not experienced during the period of record for the springs may result in spring conditions different from those predicted by the regression equations. Even though this analysis makes use of the "best available" data, the inherent limitations should be considered when applying these data to management decisions.

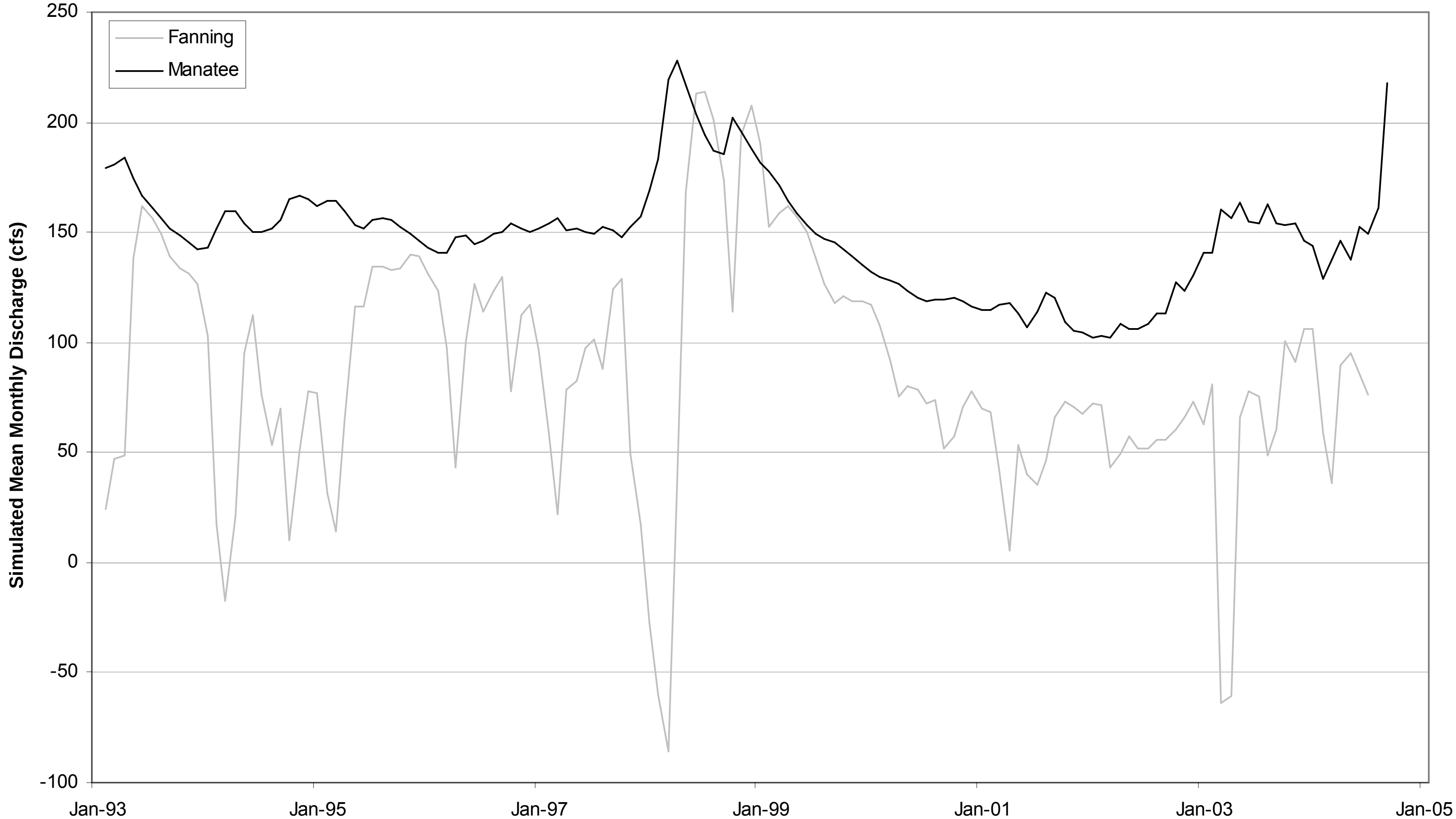

Figure 3-17. Simulated average monthly discharge for Manatee and Fanning Springs.

3.2.3.2 Methods

3.2.3.2.1 Simulating Stage Data

The spring runs for Fanning and Manatee springs are relatively short and do not contain significant sills that restrict interaction with the Suwannee River, such as holding the elevation of the spring pool above that of the adjacent Suwannee River. Therefore, spring stage is generally dependent on the stage within the river adjacent to the spring. In order to develop relationships between measured spring and river stage, cross-plots of the data were created. Generating trendlines for the data and evaluating various types of trends (e.g. linear, polynomial) and the quality of their fit produced simplified relationships between spring stage and river stage as measured at a nearby gage. This relationship, or equation, relating spring stage to river stage was used to generate more complete periods of record for spring stages at Fanning and Manatee springs.

3.2.3.2.2 Simulating Discharge Data

Discharge from Fanning and Manatee springs is dependent on several variables, as will be discussed further below. Due to this complexity, multiple linear regressions are necessary to define the relationships between spring discharge and the environmental factors that drive it. Stepwise multiple linear regressions performed to develop equations using the statistical software package SYSTAT®. The regression analysis was begun with all potentially important independent variables included. A backward, stepwise regression systematically removed each variable that exceeded the designated alpha value of 0.05. The result of each step-wise regression is a set of variables and associated coefficients for a equation that relates the statistically significant independent variables to the dependent one (spring discharge). The equation can then be applied for the entire period of record of the independent variables to generate a simulated period of record data set for the dependent variable.

3.2.3.2.3 Uncertainty Associated With Data Simulation

Fanning and Manatee Springs, the Suwannee River, and related portions of the Floridan aquifer form a complex, interactive hydrologic system. Due to this level of complexity, there is a level of uncertainty that goes along with simulating data for Fanning and Manatee springs. This uncertainty is additive at each step in the data simulation process. Even if the uncertainty associated with each step in the process of data simulation is kept to a minimum, the uncertainty can compound as simulated data are used to simulate additional data sets. Uncertainty is kept reasonably low during each phase of data simulation, but the inherent complexities of the system result in some uncertainty, particularly with the peak stage and discharge values. Primary control on uncertainty is through calibration or confirmation comparisons of calculated and observed stage or discharge.

3.2.3.3 Fanning Spring

The water level in Fanning Spring generally reflects the stage of the adjacent Suwannee River due to the lack of any significant sill within the spring run. Therefore, discharge from the spring is impeded or enhanced based upon the river stage. Figure 2-36 shows the Wilcox stage for corresponding measured discharge at Fanning Spring. As can be seen, spring discharge fluctuates on a daily basis due to the tidal nature of the Suwannee River in the vicinity of the spring. Flood events significantly reduce spring discharge, and extreme floods actually reverse the flow of the spring. Discharge from the spring reverses at a river stage of approximately 9 ft.

NGVD. These patterns are superimposed on the long-term discharge trends, which are primarily due to variability of water levels within the Floridan aquifer.

3.2.3.3.1 Simulating Spring Stage

Average daily stage measurements for Fanning Spring were compared to the average daily stage for the Suwannee River gage near Wilcox, located just upstream from Fanning Spring. As Figure 3-18 shows, the two data sets are highly correlated. This relationship was used to simulate a time series of average daily stage for Fanning Springs. Figure 3-19 shows the simulated historical time-series data, along with the measured stage for comparison.

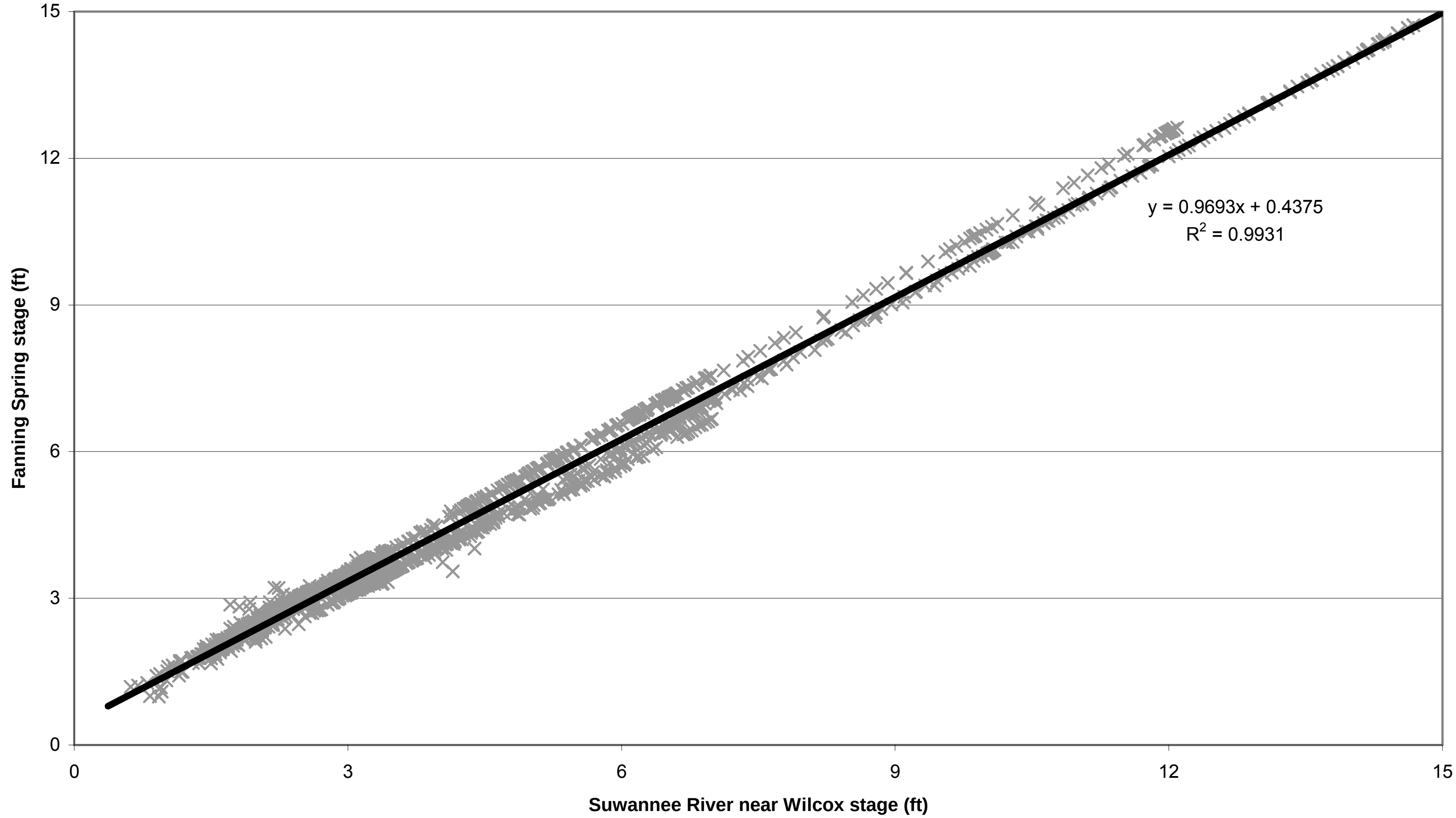

Figure 3-18. Cross-plot of stage data from the Suwannee River near Wilcox and the Fanning Spring gages.

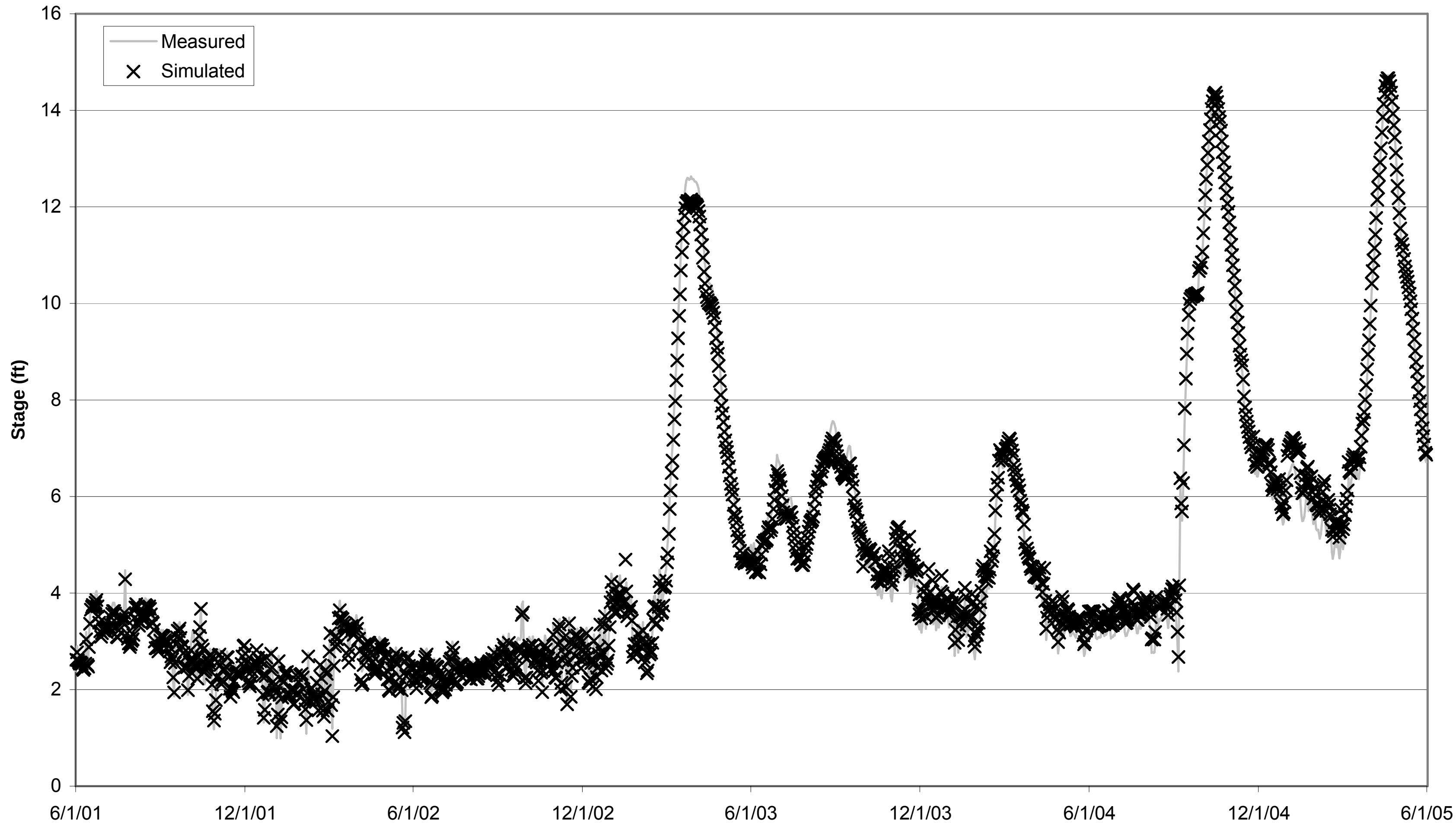

Figure 3-19. Comparison of measured and simulated stage at Fanning Spring.

3.2.3.3.2 Simulation of Fanning Spring Discharge

As discussed above, discharge from Fanning Spring is dependent on water levels in both the aquifer and the adjacent Suwannee River. A step-wise multiple linear regression was developed using average monthly well, rainfall, and river data from sources with the longest period of record. Average monthly values were utilized in an attempt to smooth the short-term, tidally induced variability in the data (also, the rainfall data were only available in monthly format).

Of the 109 wells located within the springshed, only two (#74 and #114) have been continuously monitored for some substantial period of time. Well #74 actually has a longer period of record, and this well is located within close proximity to Fanning Spring and the Suwannee River. Well #114 is located some distance from the river; and measured water levels in this well reflect only the long-term fluctuations in the aquifer, as opposed to the short-term fluctuations seen in Well #74 which result primarily from changes in river stage (Figure 3-20).

The rainfall gage located at Manatee Spring (#93) was used as a basis of simulation because it has a much longer period of record (i.e., it was installed in 1989) than the gage located at Fanning Spring (installed in 1998). The monthly average stage for the Wilcox gage was used; this data set extends back to the 1940's. The monthly average water level data for well #114 is most limiting; this dataset begins in 1993.

The stepwise multiple linear regression proceeded to remove the gage #93 rainfall data and retain the data for Well #114 (h_{114}) and the Wilcox gage (h_{Wilcox}). The resulting polynomial for the average monthly discharge at Fanning Spring is:

$Q_{Fanning} = 28.825 - 24.994(h_{Wilcox}) + 12.511(h_{114})$.

This equation reproduces the discharge at Fanning Spring with an R^2 of 0.78, a statistically significant fit. The maximum residual is approximately 40 cfs. As expected, higher water levels in the aquifer yield higher spring discharge, and greater water levels in the river reduce the spring discharge.

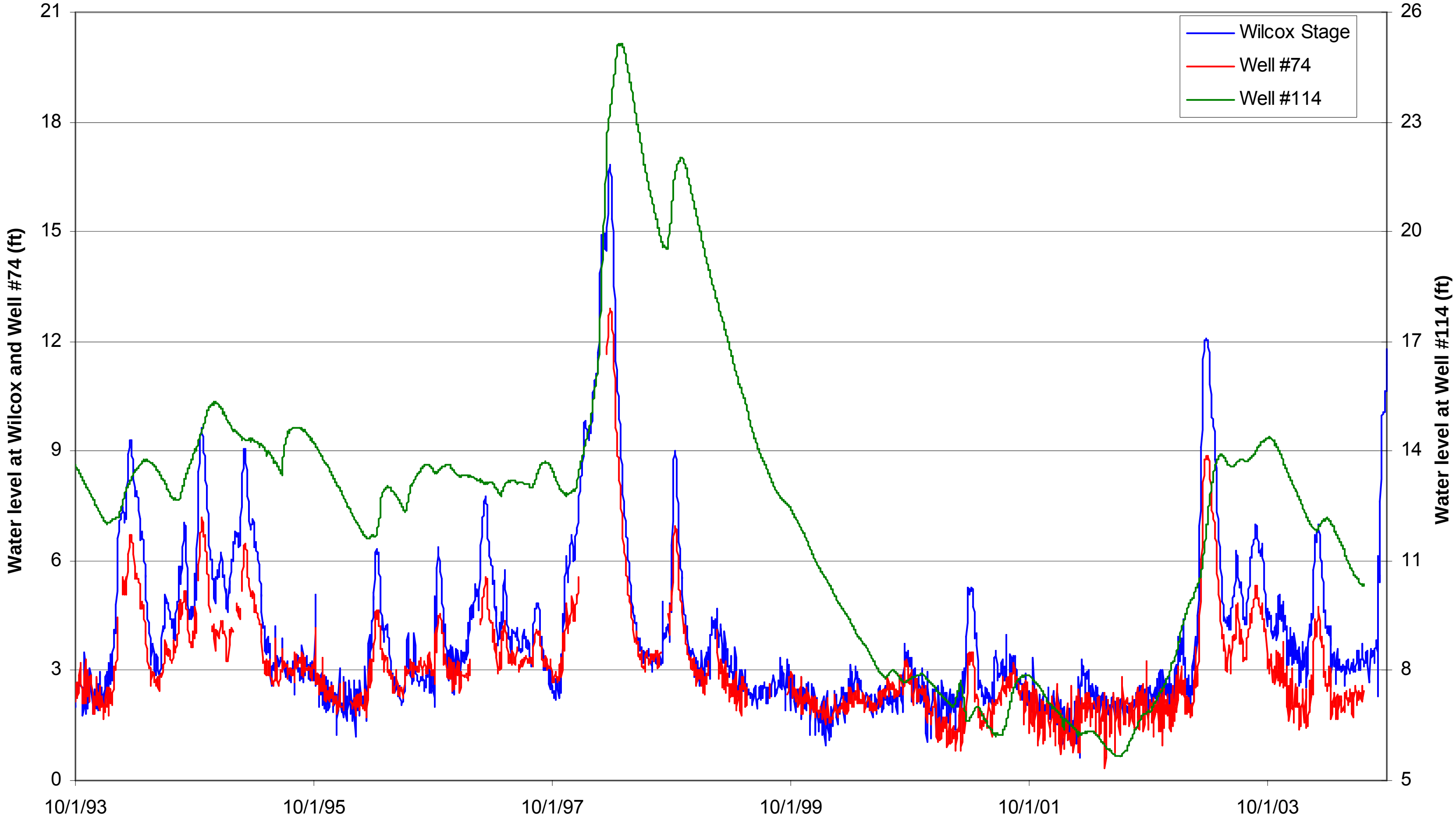

Figure 3-20. Comparison of Wilcox stage and water levels in nearby wells.

Figure 3-21 compares the predicted and measured mean monthly discharge for Fanning Spring. The magnitude of spring discharge is generally well reproduced, and the pattern of change in spring discharge with time is also well simulated.

A similar analysis was completed using the daily water level values, instead of monthly averages. The rainfall data are only available as a monthly total and could not be included. A similar result (the coefficients are nearly the same) was obtained using the daily river and aquifer water levels, though the uncertainty is greater. The resulting polynomial for daily discharge simulation at Fanning Spring is:

$Q_{Fanning} = 26.468 – 25.043(h_{Wilcox}) + 12.724(h_{114})$.

The equation reproduces the daily values with an R^2 of 0.71, and the maximum residual is approximately 100 cfs. Therefore, the error inherent in the synthesized monthly discharge is significantly less than that associated with simulated daily values.

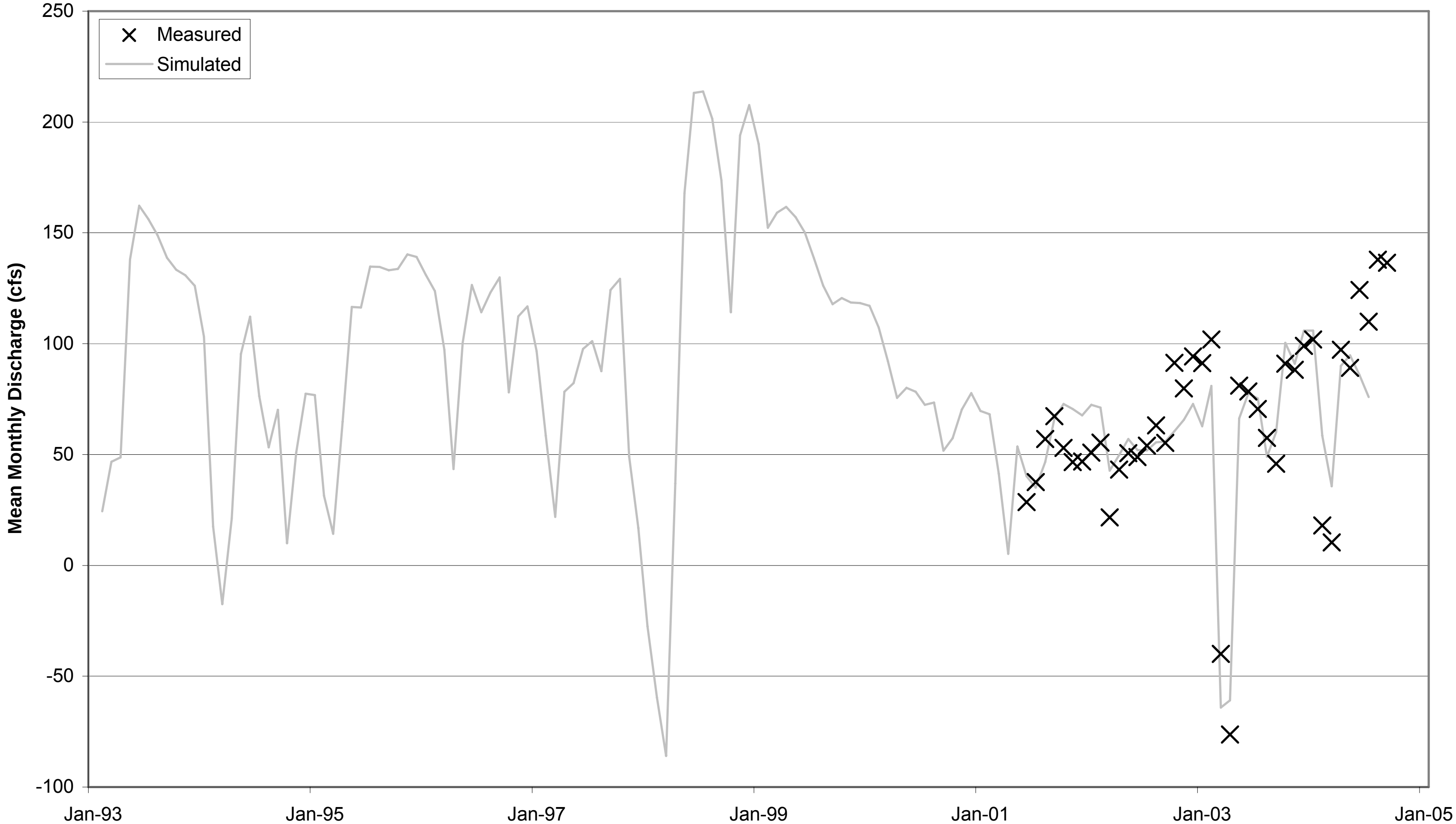

Figure 3-21. Comparison of measured and simulated average monthly discharge for Fanning Spring.

3.2.3.3.3 Data Characteristics

3.2.3.3.3.1 Population Descriptors

Summaries of the daily AVM data collected at Fanning Spring are presented in Tables 2-11 and 2-12. The simulated data, however, represent a longer period of record, resulting in a better data sample for descriptive statistics. Average daily stage data were synthesized for Fanning Spring based on the relationship between spring stage and stage at the Wilcox gage. The Wilcox gage has been in operation since 1941; however, the available stage data prior to 1951 do not contain values for times when stage was below approximately 5 feet. As these censored data tend to skew the simulated dataset, the period of record for the synthesized stage data at Fanning Spring begins in 1951.

Because of tidal and other transient discharge variability, the best results for synthesizing discharge data were obtained for the average monthly discharge at Fanning Spring (Section 3.2.3.2.2). The period of record for the simulated discharge data is limited by the sampling period for Well #114. Therefore, the simulated discharge data only extend back to 1993. Figures 3-22 and 3-23 present box-whisker graphs of the simulated daily stage data and the simulated monthly discharge data, respectively.

3.2.3.3.3.2 Flow and Stage Duration Curves

Flow- and stage-duration curves were constructed from the synthesized data for Fanning Spring. The flow-duration curve (Figure 3-24) represents the exceedance probabilities for average monthly spring discharges. Over the period of record for this dataset (February 1993 – July 2004) the median average monthly discharge was approximately 78 cfs. The resulting stage duration curve for this dataset is shown in Figure 3-25. The median average daily stage at Fanning Spring was approximately 4 feet.

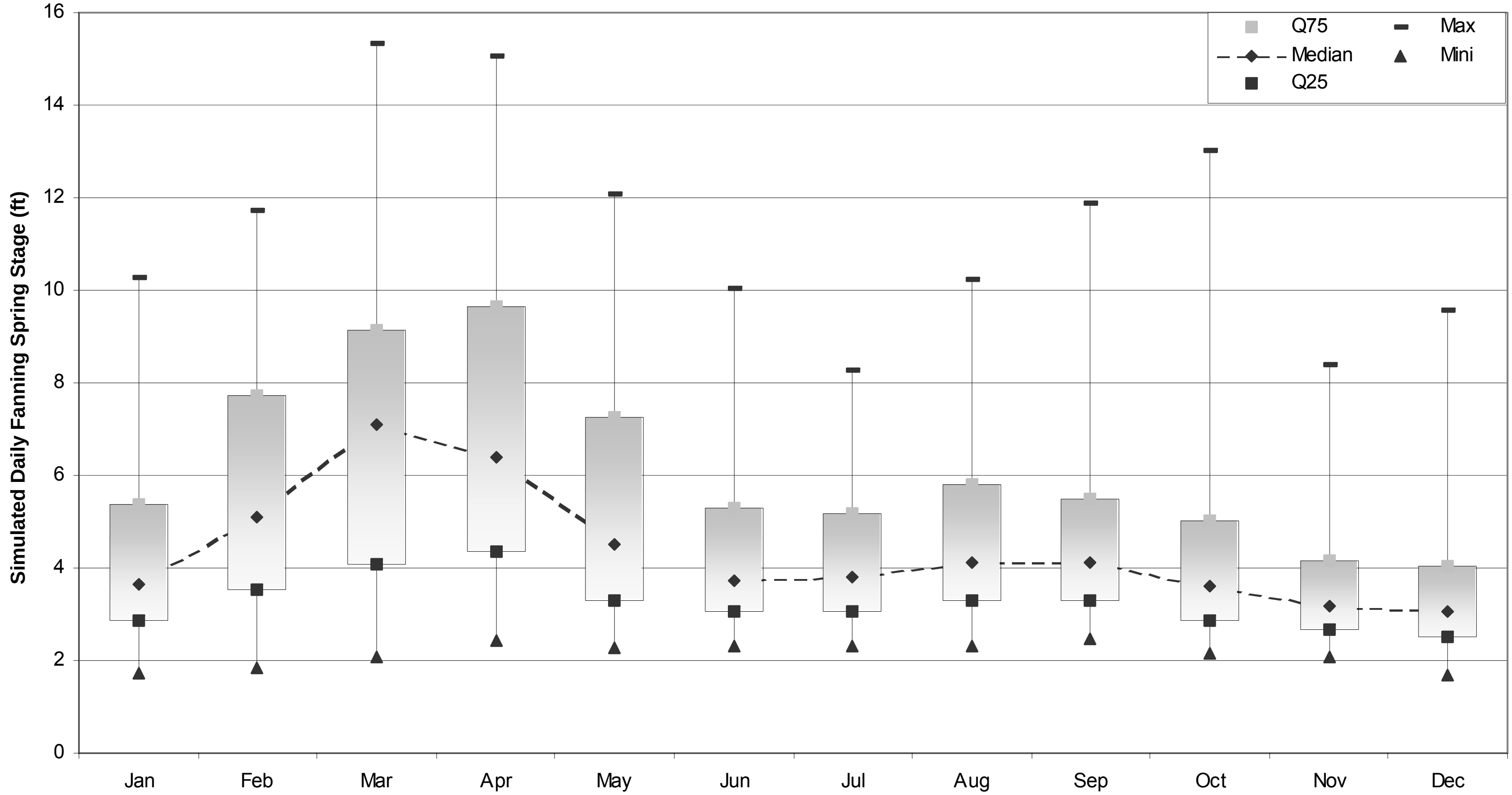

Figure 3-22. Box-whisker plot of simulated daily stage for Fanning Spring, by month.

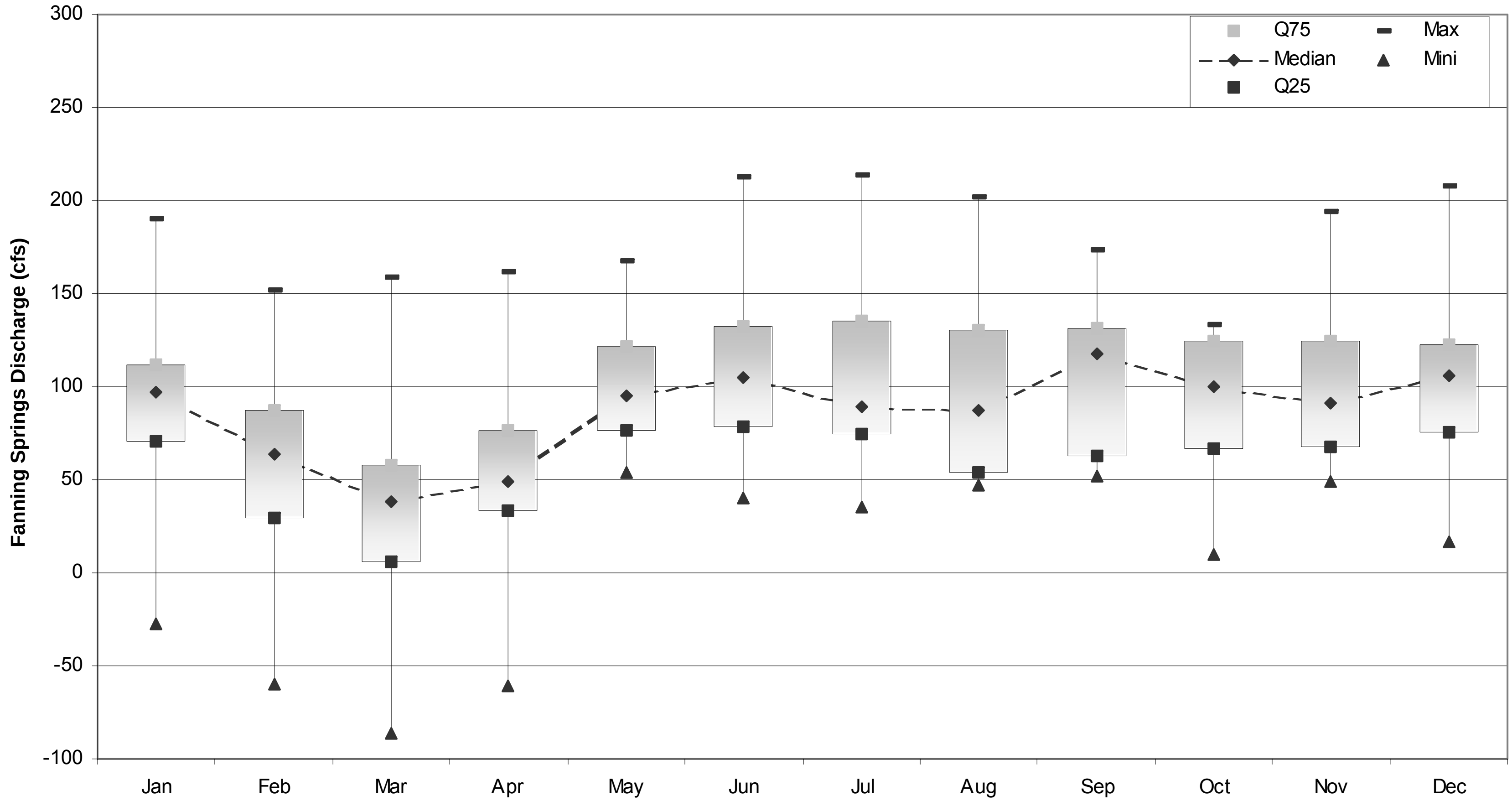

Figure 3-23. Box-whisker plot of simulated monthly discharge for Fanning Spring, by month.

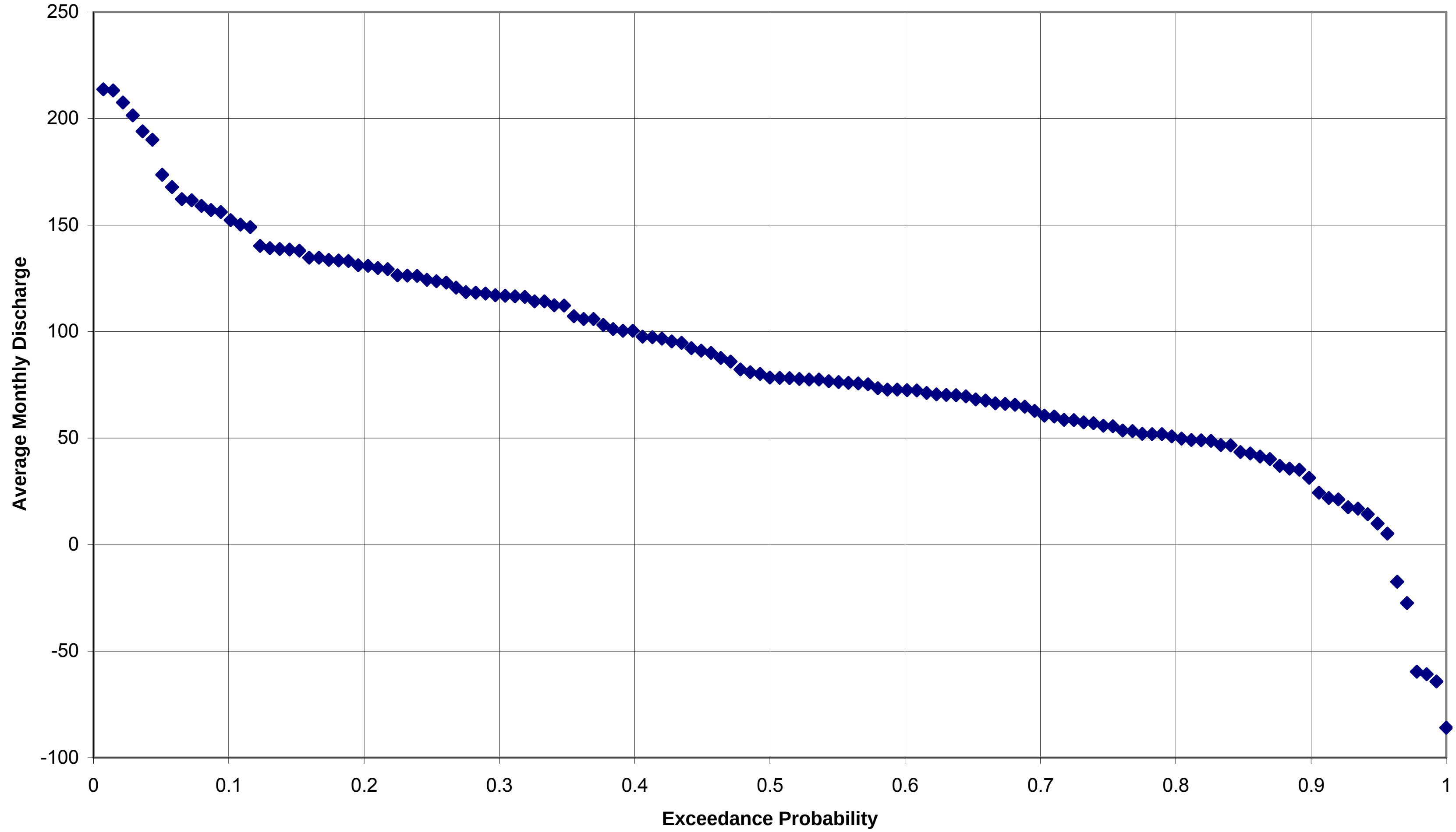

Figure 3-24. Flow-duration curve for simulated average monthly discharge at Fanning Spring.

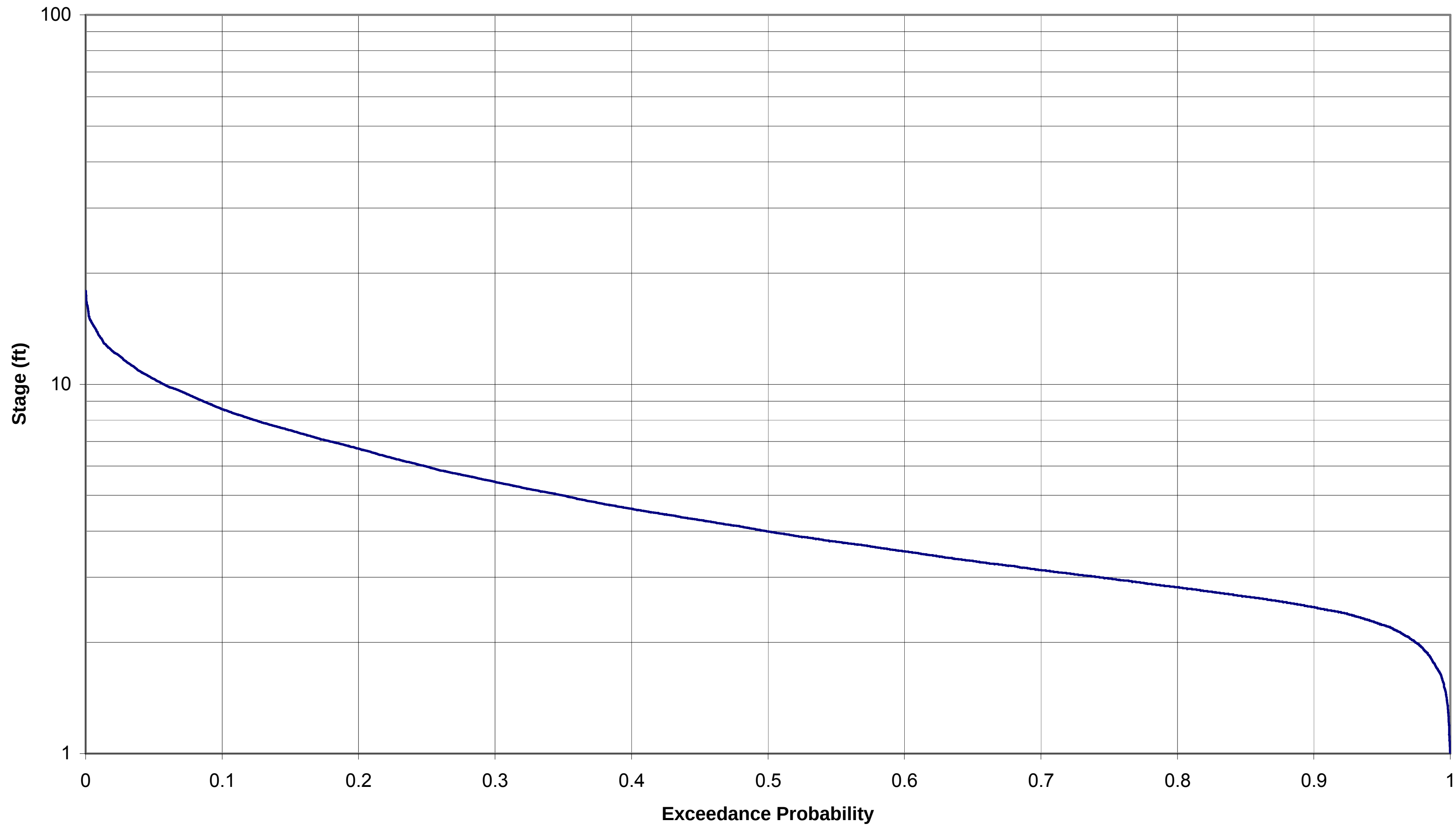

Figure 3-25. Stage-duration curve for synthesized average daily stage at Fanning Spring.

3.2.3.3.3.3 Relationship to Wilcox Stage and Flow

Over the simulated period of record, stage at Fanning Spring peaks in the spring (with a secondary peak in the late summer), and discharge is lowest in the spring (Figures 3-24 and 3-25). As seen in Section 3.2.3.3.1, stage at Fanning Spring is directly related to stage in the Suwannee River at Wilcox. So the pattern of stage at Wilcox through the year (Figure 3-26) is identical to that shown in Figure 3-24 for Fanning Spring. The pattern in discharge is also, but to a lesser extent, controlled by the stage at Wilcox. Times of peak stage in the river (February-April) correspond to times of lowest discharge from the spring. Moreover, aquifer levels within the springshed probably play a more significant role in determining spring discharge patterns the remainder of the year, when floods are infrequent.

Because there is significant tidal and other noise in the Wilcox stage and Fanning discharge data, the ability of the predictive equations to fit the daily Fanning Spring discharge data is weakened somewhat. Analysis of manatee passage issues and other factors discussed in subsequent sections of this report indicates that a seasonal MFL is appropriate. Therefore, it was determined that the equation to predict monthly discharge, which eliminated much of the high frequency noise and strengthened ability to estimate discharge, from Fanning Spring is the preferred approach. Because the MFLs to be proposed for Fanning Spring are seasonal and based on monthly stage estimates in the river, it was also reasoned that a predictive model using the same time frame was appropriate.

3.2.3.3.3.4 Discharge Trends

Trends in historic measurements of Fanning Spring discharge are discussed in Section 2.3.5.5. There are short- and mid-term, cyclic trends resulting from rainfall cycles. However, there is little evidence indicating the presence of long-term changes in discharge at Fanning Spring within the historic discharge measurements. The simulated discharge dataset is not of sufficient length (only about 12 years) to analyze for the presence of long-term trends.

3.2.3.3.4 Hydrologic Conditions During MFL Study

The majority of Fanning spring data for this study was collected within the last approximate four years. At the beginning of this period (May 2001), Florida was experiencing one of the worst droughts on record. As a consequence, even though conditions have since improved considerably, the MFL study period represents much drier conditions than normal.

As previously discussed, Fanning Spring discharge is dependent on conditions in the Suwannee River and the Floridan Aquifer within the springshed. Figure 3-27 depicts a flow-duration curve for the period of record at the Wilcox gauge, along with a curve representing the MFL study period. With the exception of peak flows (exceedance probability less than 10 %), flows in the Suwannee River were considerably less than for the period of record as a whole. Median discharge was approximately 5,600 cfs for the study period, compared to 8,040 cfs for the period of record.

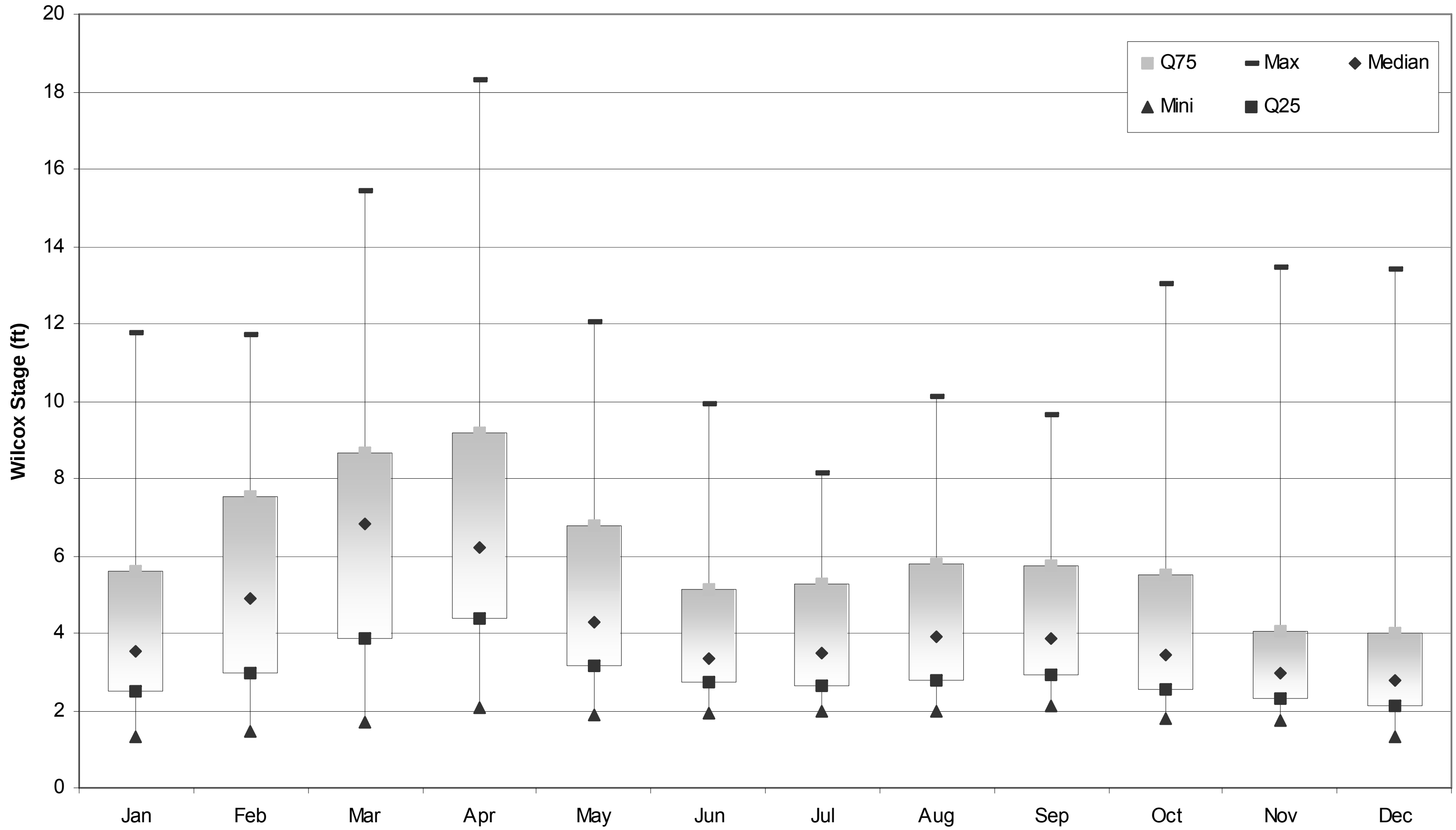

Figure 3-26. Box-whisker plot of measured stage at the Wilcox gauge, by month.

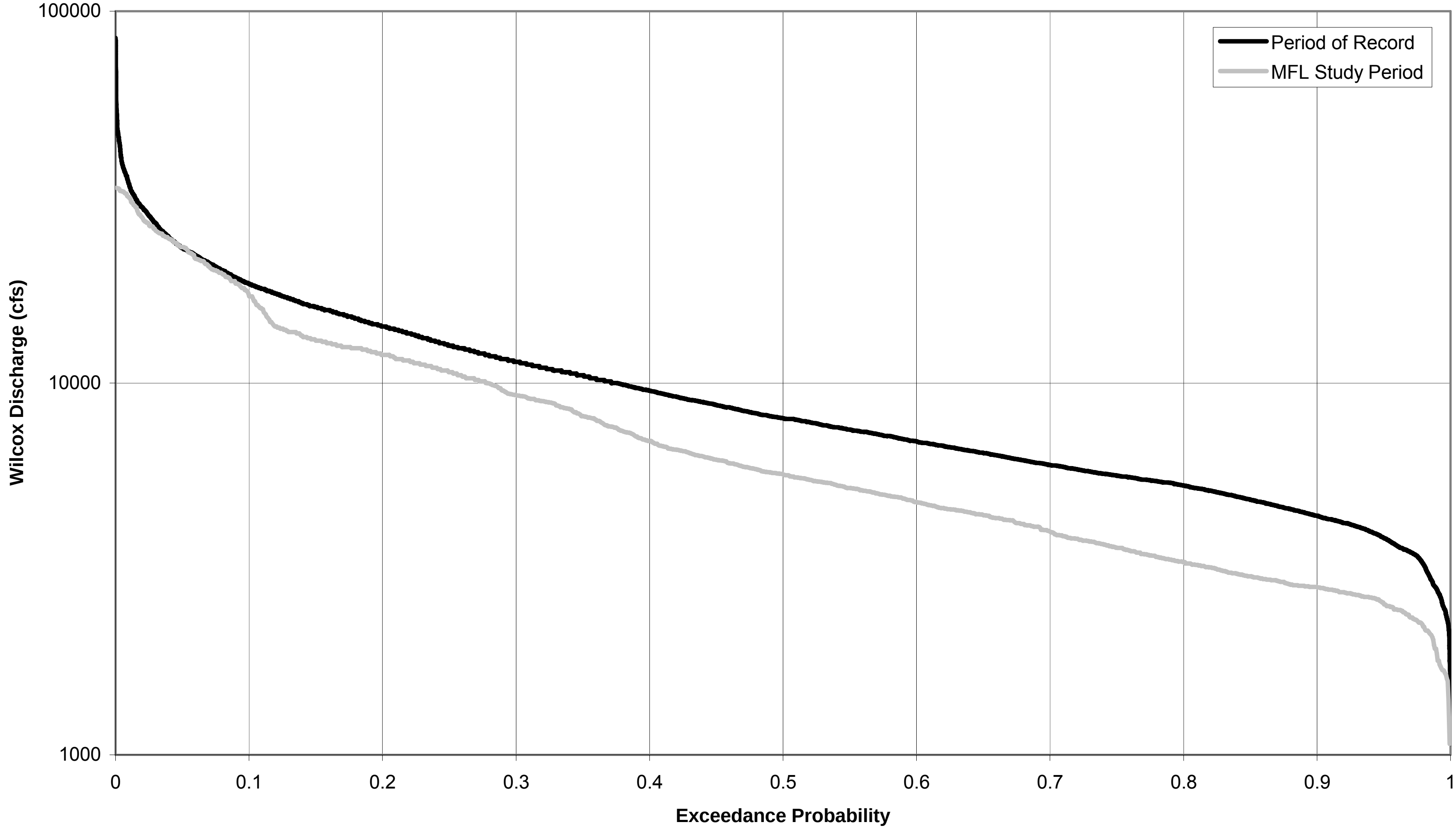

Figure 3-27. Comparison of Wilcox flow conditions during the MFL study period for the springs and the period of record.

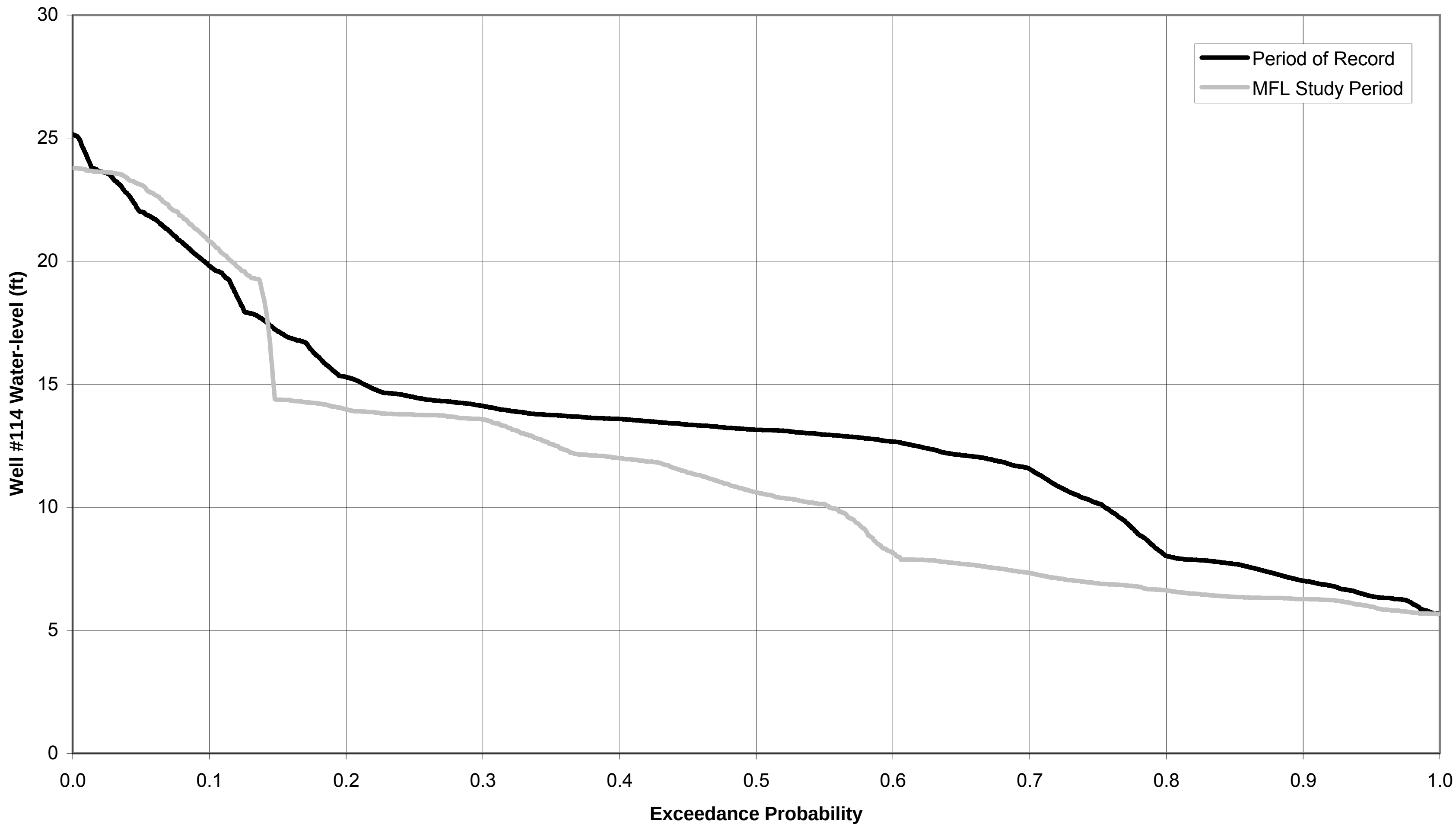

Figure 3-28. Analysis of aquifer levels during the MFL study period for the springs and the period of record.

Figure 3-28 contains duration curves for water levels in the Floridan Aquifer, as recorded at Well #114. The two curves compare the pattern of water levels during the study period (May 2001 – May 2005) to the entire period of record for this well (1993-2005). Water levels below an exceedance probability of about 15 % are actually greater during the study period than for the period of record as a whole. For the remainder of the time, water levels were much lower. The median water level during the study period is approximately 10.5 ft, compared with a median water level of about 13.1 for the period of record.

3.2.3.4 Manatee Spring

While Manatee Spring is an estavelle and the discharge pattern for all river events would show an inverse relationship between spring discharge and river stage, the historic data do not depict the rare events when flooding caused the spring to backflow. As will be shown below (see Figure 3-46), the majority of valid discharge data was collected during low to moderate flow conditions, which are of interest with respect to manatee refuge conditions. The monthly data, especially data taken during low flow to moderate flood in the river (the period of record for the spring), reflect fluctuations in rainfall and potentiometric head in the Fanning/Manatee spring system. Daily discharge data from Manatee Spring show an inverse relationship between river stage and spring discharge. When the river stage rises because of increased rainfall, discharge from the spring is inhibited. Conversely, when the river is low, Manatee Spring discharge is at a maximum. On a monthly time scale, the small scale variations in discharge, including tidally influenced variations, are masked and the diving forces for Manatee Spring discharge at low to moderate river stage are a result of regional groundwater flow and river stage.

The equation for predicting daily discharge indicates that there are short-term inverse relationships between river stage and discharge, which are discussed in Section 3.2.3.3. These data are affected by tidal variations as well as rainfall-discharge events, however.

Discharge at Fanning Spring was utilized as an independent variable in the Manatee discharge predictive equations because those data are of high quality and reflect the regional interplay between groundwater potentials in the Fanning/Manatee springshed and river. The springs essentially share a single springshed (Upchurch and Champion, 2003a), so discharge behavior in Fanning Spring reflects springshed interaction with the river and groundwater potential distributions in the springshed.

Only one well with a sufficiently long period of record is located in the vicinity of Manatee Spring. Water levels in this well are more representative of stage in the Suwannee River than the potentiometric head in the springshed (Figure 3-21). Therefore, it was decided that Fanning Spring discharge data provide a better variable for aquifer behavior prediction than the available well data. The monthly data provide ability to quantify seasonal conditions by use of monthly simulations while minimizing daily tidal interferences.

As with Fanning Spring, the water level in Manatee Spring generally reflects the stage of the adjacent Suwannee River due to the lack of any significant sill within the spring run. Therefore, discharge from the spring is impeded or enhanced based upon the river stage. Figure 3-29 shows the stage for corresponding measured discharge at Manatee Spring. While portions of the discharge data follow this expected pattern, a significant part of the discharge data do not.

Discharge from Fanning and Manatee springs is controlled by similar environmental conditions. The two springs essentially drain separate portions of a single springshed. The pattern and relative magnitude of river levels that impede springflow do not vary between the two springs. Therefore, while the magnitude of spring discharge from these springs may differ, the pattern of discharge variability through time should be similar.

Figure 3-30 shows smoothed (31-day running average) discharge data for both Fanning and Manatee springs. Shading of this figure indicates time intervals where the pattern of variability in spring discharge over time for the two springs are similar (not shaded), and where they are not (shaded). The discharge data from Fanning Spring follow a pattern that is expected from the variability of river stage (Figure 2-35). Therefore, it seems reasonable to "believe" the entire dataset for Fanning Spring, and to only "believe" those portions of the Manatee Spring discharge data that mirror the Fanning Spring data.

As a result, the available AVM-derived discharge data for Manatee Spring are much more limited than the Fanning Spring data. Similar to the Fanning Spring analysis, data simulation was carried out using average monthly values due to the significant short-term variability in spring stage and discharge. Only the average monthly discharge values for June 2001 through February 2002 and October 2003 through May 2004 were included in the analysis, as these data appear to reflect actual conditions at the spring while the remainder of the data does not.

The systematic offsets in discharge data from Manatee Springs (Figure 3-29) appear to have resulted from changes in calibration of the gage data

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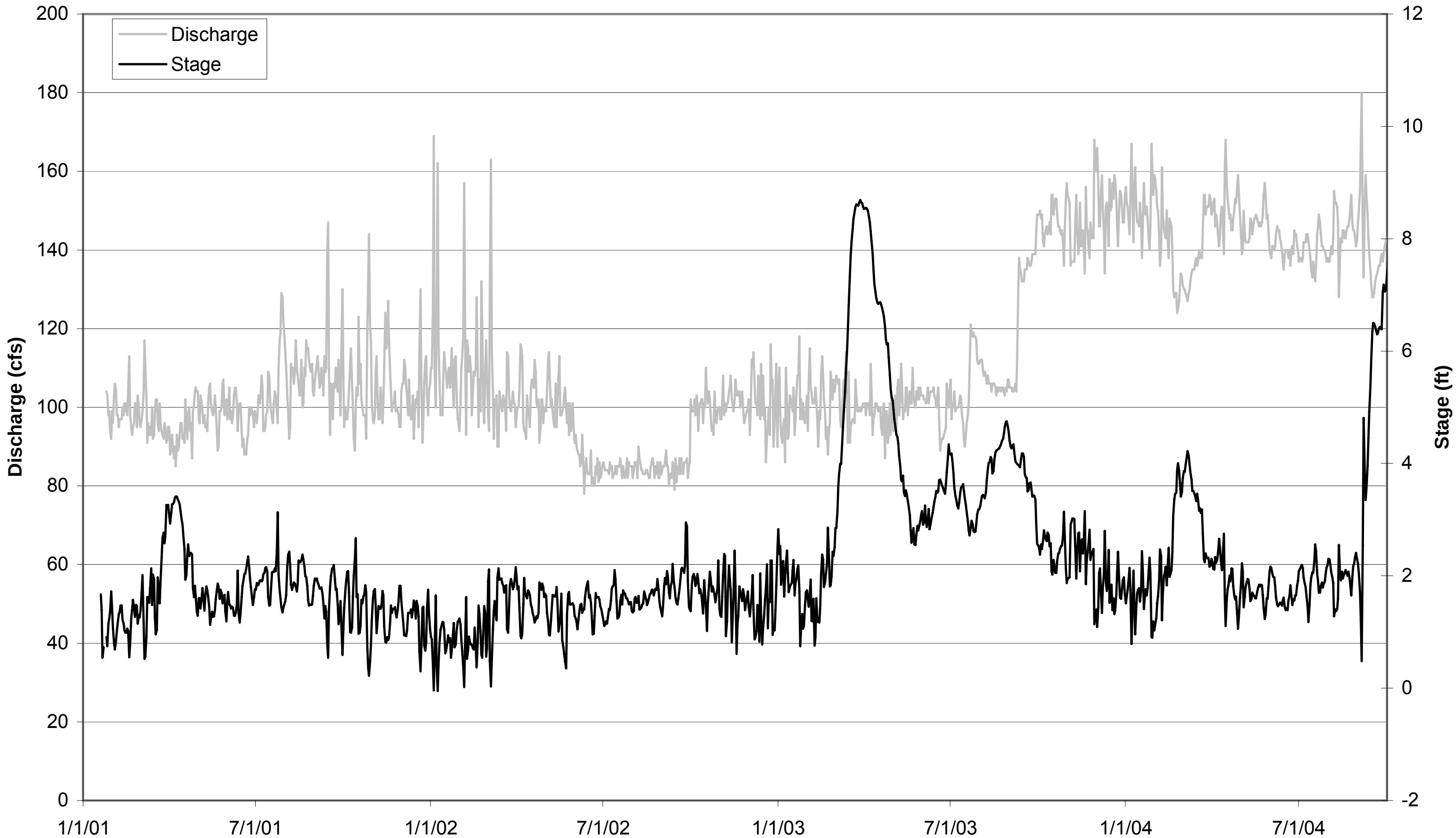


Figure 3-29. Average daily stage and discharge, Manatee Spring gage.

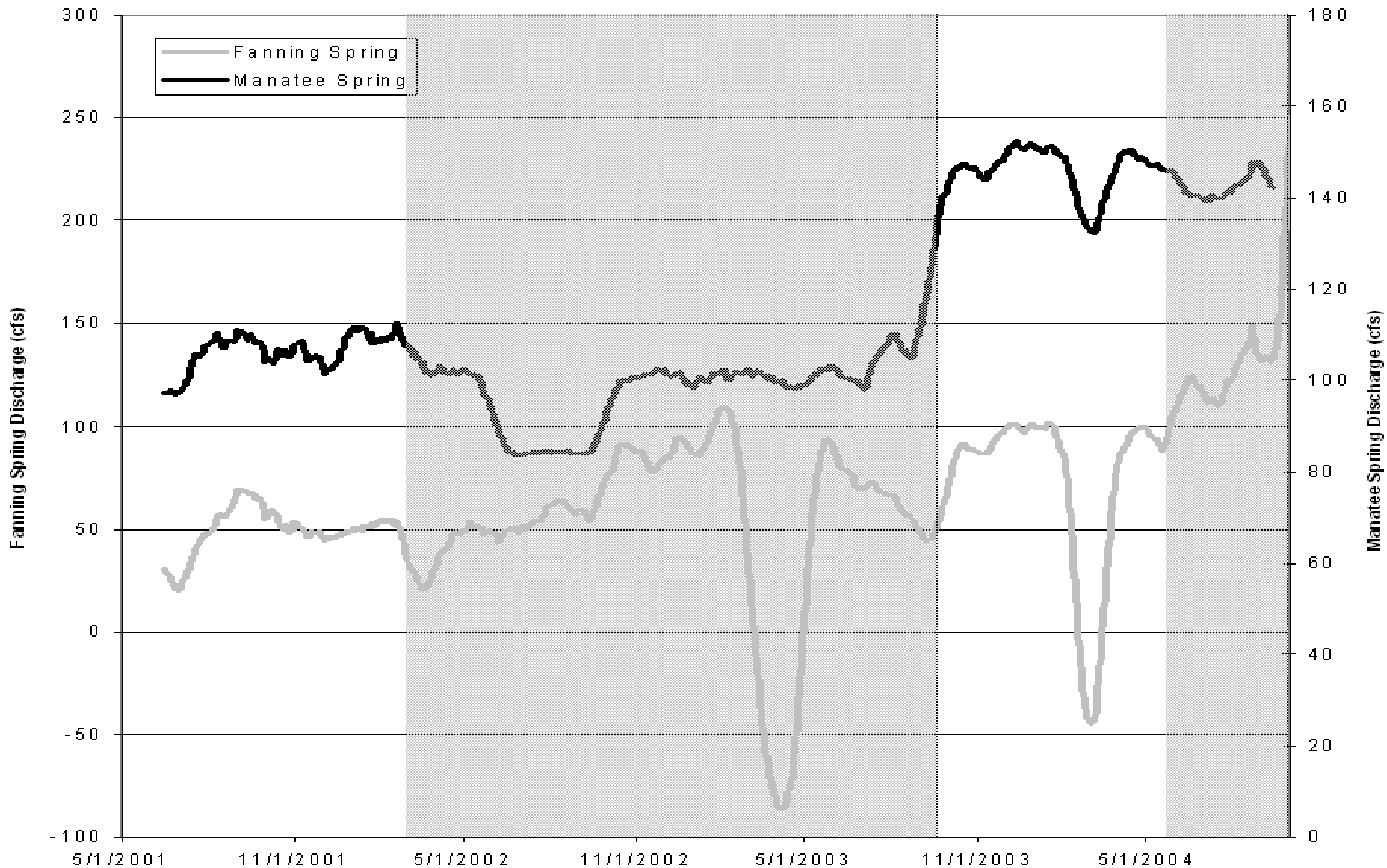


Figure 3-30. 31-day running average discharge for Manatee and Fanning Spring. Shading indicates time when discharge patterns do not agree.

3.2.3.4.1 Simulation of Manatee Spring Stage

Average daily stage measurements for Manatee Spring were compared to the average daily measured stage for the Suwannee River gage near Wilcox. As was the case for Fanning Spring, the stage at Manatee Spring is highly correlated to the Wilcox gage (Figure 3-31). In this case, an exponential trendline provided a better fit to the data than a linear one. This relationship was used to simulate a time series of average daily stage for Manatee Spring. Figure 3-32 shows the simulated data, along with the measured stage data for comparison.

3.2.3.4.2 Simulation of Manatee Spring Discharge

As discussed above, the pattern of discharge from Manatee Spring is similar to the pattern of discharge observed at Fanning Springs, though the magnitude of variability is not as great. According to the available data, flooding in the Suwannee River appears to easily reverse the flow at Fanning Springs, while discharge is only moderately impeded at Manatee Springs. For example, the flood event in March of 2004 reduced Fanning Spring discharge to –50 cfs from previous values of around 100 cfs, while Manatee Spring discharge was only reduced by approximately 20 cfs, from about 150 cfs to approximately 130 cfs (Figure 3-30). While the two datasets are clearly related, a simple linear regression between the two does not adequately reproduce Manatee Spring discharge.

A step-wise multiple linear regression was developed using monthly average values for Fanning Spring discharge, Wilcox stage, and rainfall at Manatee Spring (gage #93). The stepwise multiple linear regression proceeded to remove the gage #93 rainfall data and to retain the data for Fanning Spring discharge ($Q_{Fanning}$) and the Wilcox gage (h_{Wilcox}). The resulting polynomial for the discharge at Manatee Spring is:

$$Q_{Manatee} = 60.462 + 12.649(h_{Wilcox}) + 0.423(Q_{Fanning}).$$

This equation reproduces the discharge at Manatee Spring with a R^2 of 0.84, a statistically significant fit. The maximum residual is approximately 15 cfs.

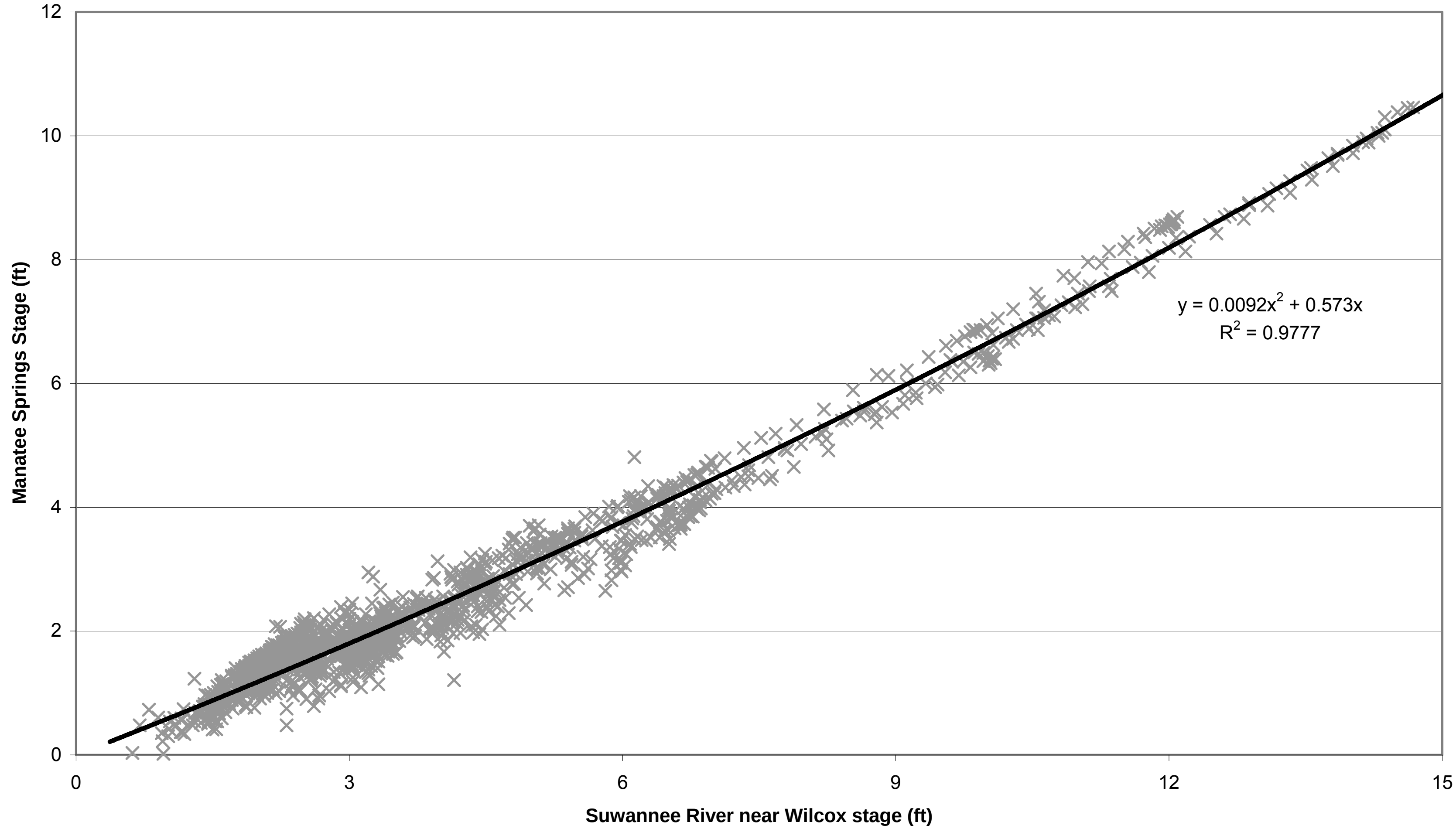


Figure 3-31. Cross-plot of Suwannee River near Wilcox stage and Manatee Springs stage.

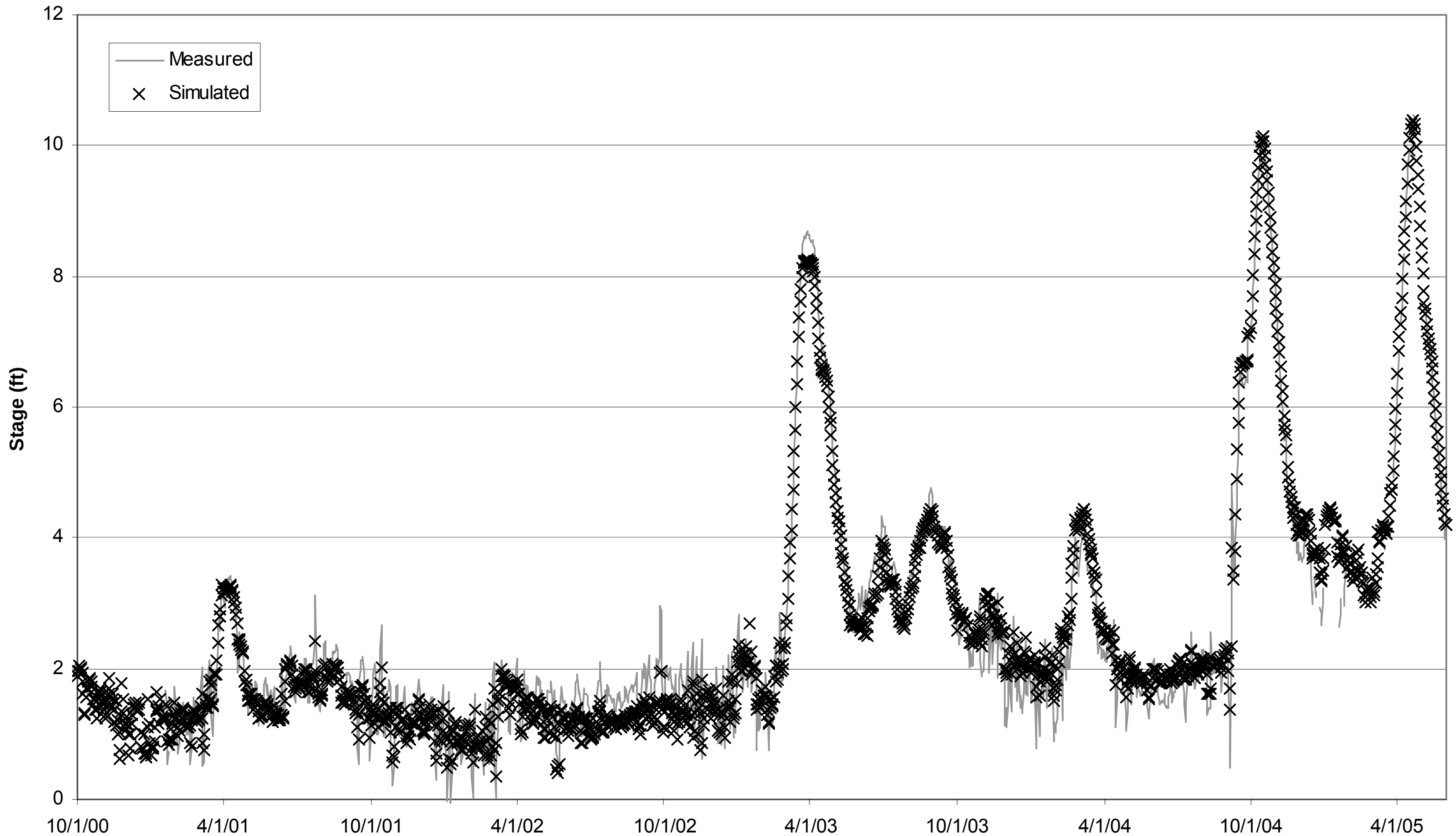


Figure 3-32. Comparison of measured and simulated Manatee Spring stage.

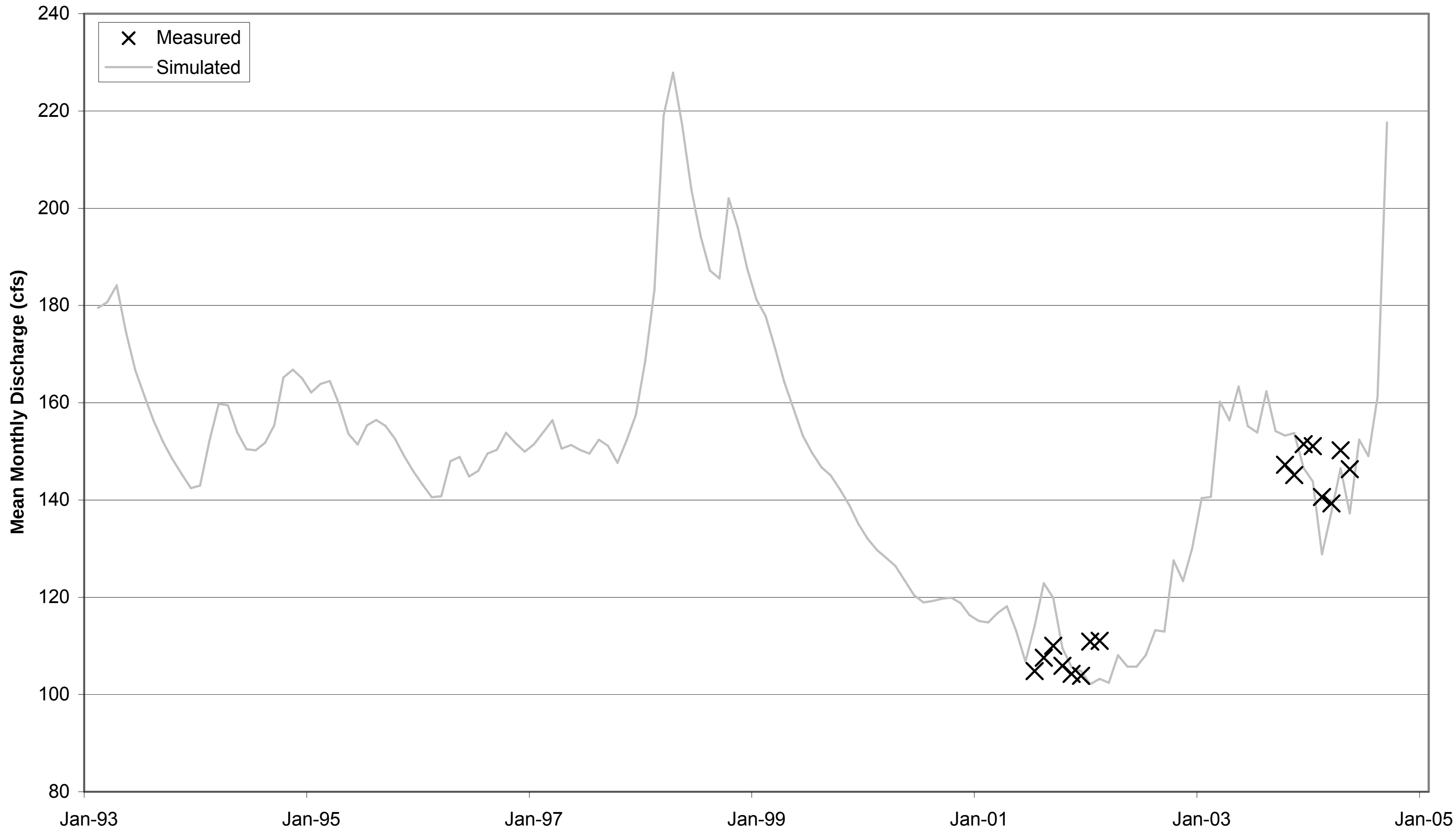


Figure 3-33. Comparison of measured and simulated average monthly discharge at Manatee Spring.

Figure 3-33 compares the predicted and measured mean monthly discharge for Manatee Spring. As shown in Figure 3-33, the magnitude of spring discharge is generally well reproduced. A similar analysis was completed using daily data, as opposed to monthly data. Similar to the results from Fanning Spring, the daily data yielded a poorer fit. The resulting polynomial for the daily discharge at Manatee Springs is:

$$Q_{Manatee} = 43.619 - 11.057(h_{Wilcox}) + 0.659(Q_{Fanning}).$$

The equation reproduces the daily values with a R^2 of 0.80, and the maximum residual is approximately 60 cfs. Therefore, the uncertainty inherent in the synthesized monthly discharge is significantly less than that associated with daily values.

3.2.3.4.3 Data Characteristics

3.2.3.4.3.1 Population Descriptors

Summaries of the daily AVM data collected at Manatee Spring are presented in Tables 2-11 and 2-13. The simulated data, however, represent a longer period of record, resulting in a better data sample for descriptive statistics. Furthermore, the simulated data attempt to correct data problems discussed in Section 3.2.3.4. As for Fanning Spring, average daily stage data were synthesized for Manatee Spring based on the relationship between spring stage and stage at the Wilcox gage. Therefore, simulated stage data for Manatee Spring extends back to 1951 (see Section 3.2.3.3.3.1)

The best results for synthesizing discharge data for Manatee Spring were obtained for the average monthly discharge (Section 3.2.3.4.2). The period of record for the simulated discharge data is limited by the simulated Fanning Spring dataset. Therefore, the simulated discharge data only extend back to 1993. Figures 3-34 and 3-35 are box-whisker plots of the simulated daily stage data and the simulated monthly discharge data, respectively.

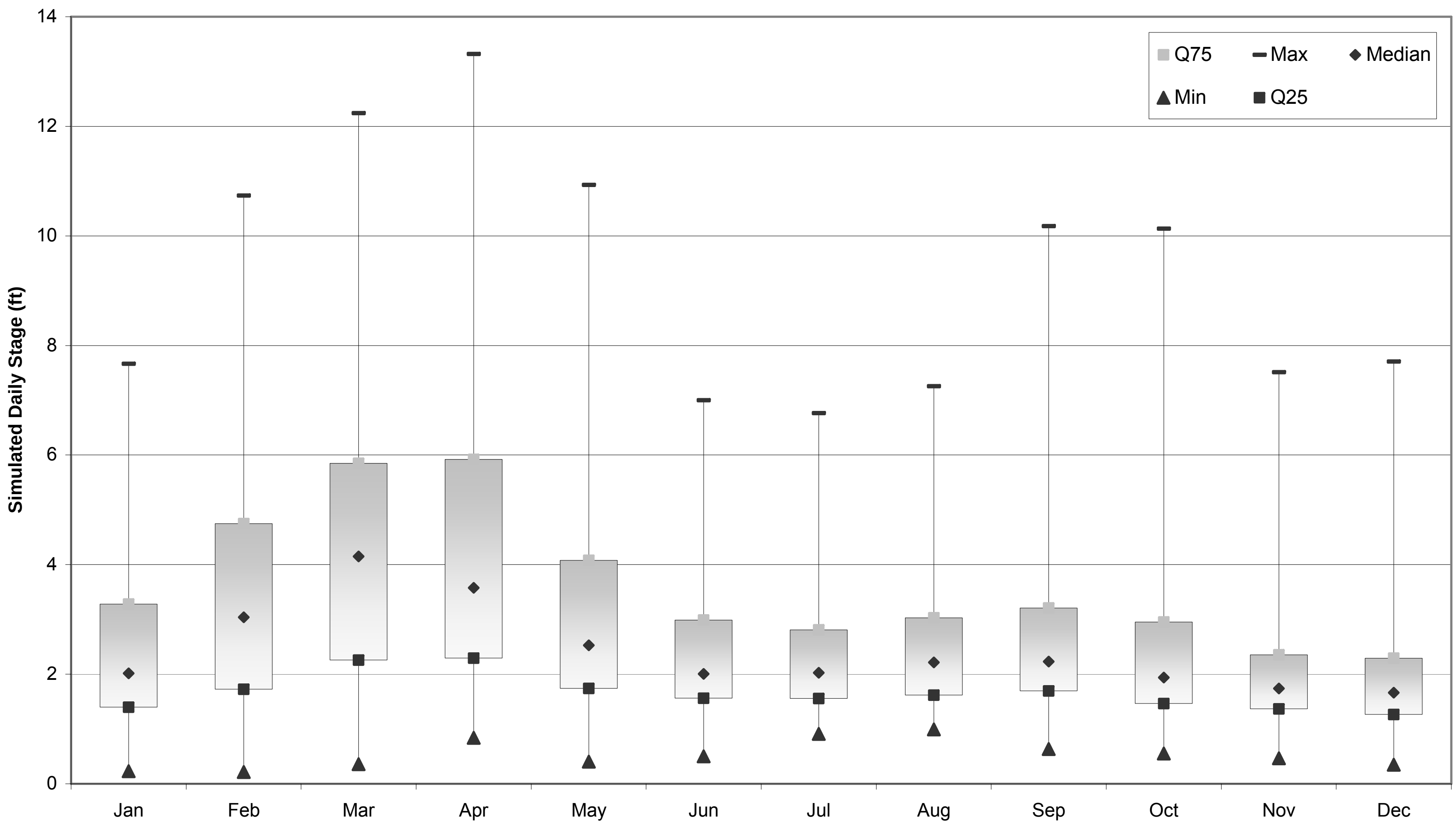


Figure 3-34. Box-whisker plot of simulated daily stage data for Manatee Spring, by month.

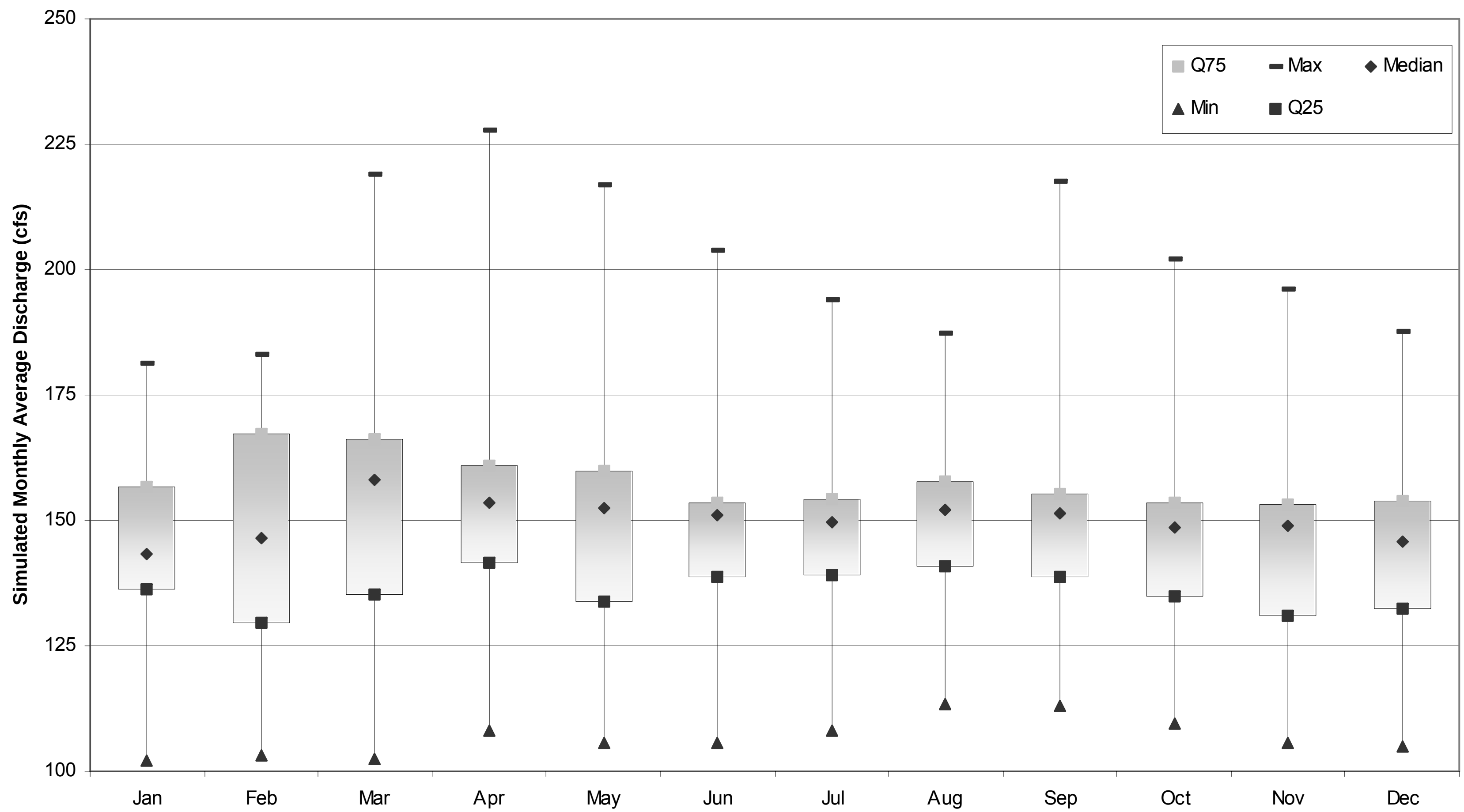


Figure 3-35. Box-whisker plot of simulated monthly average discharge for Manatee Spring, by month.

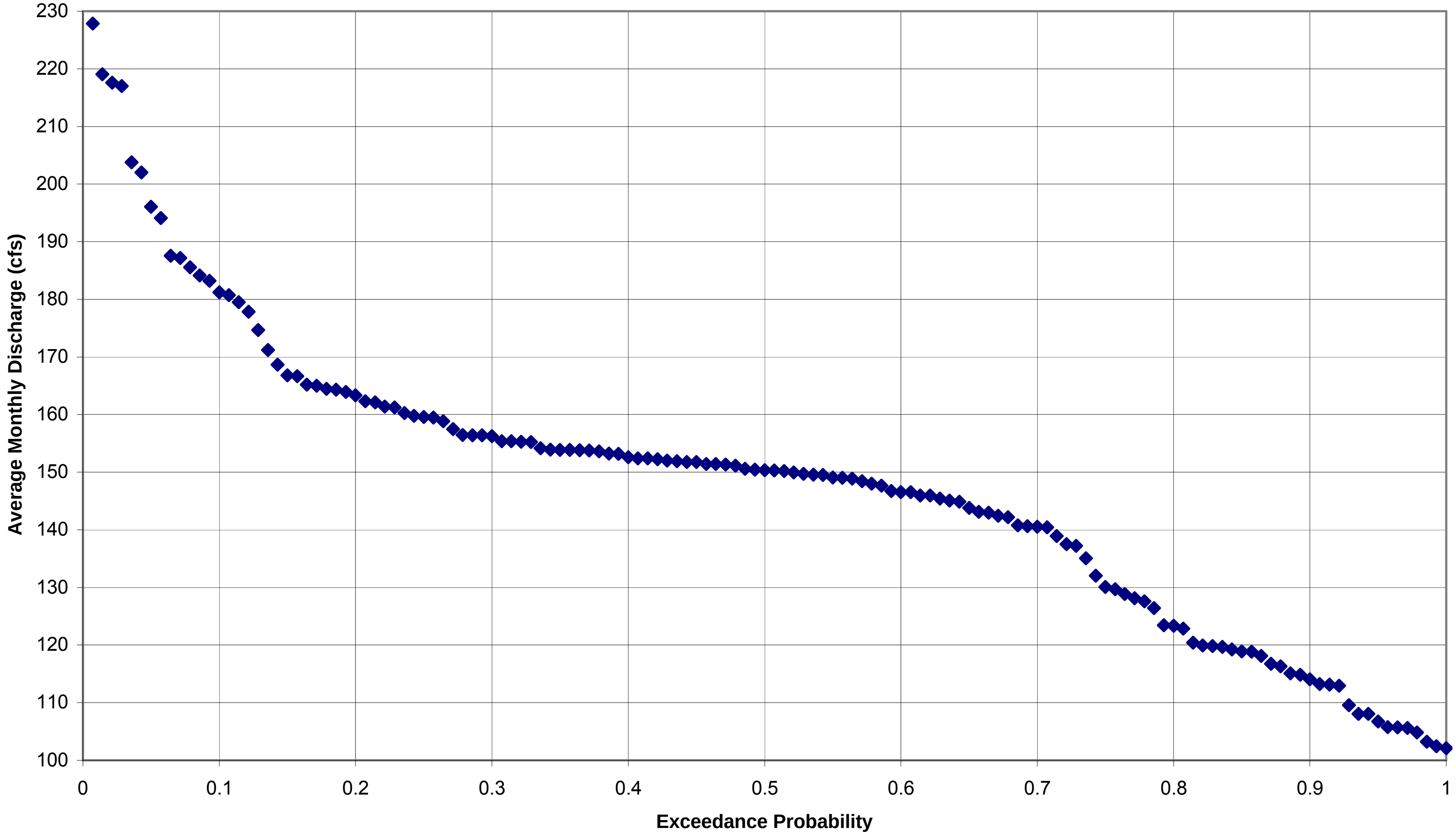


Figure 3-36. Flow-duration curve for simulated average monthly discharge at Manatee Spring.

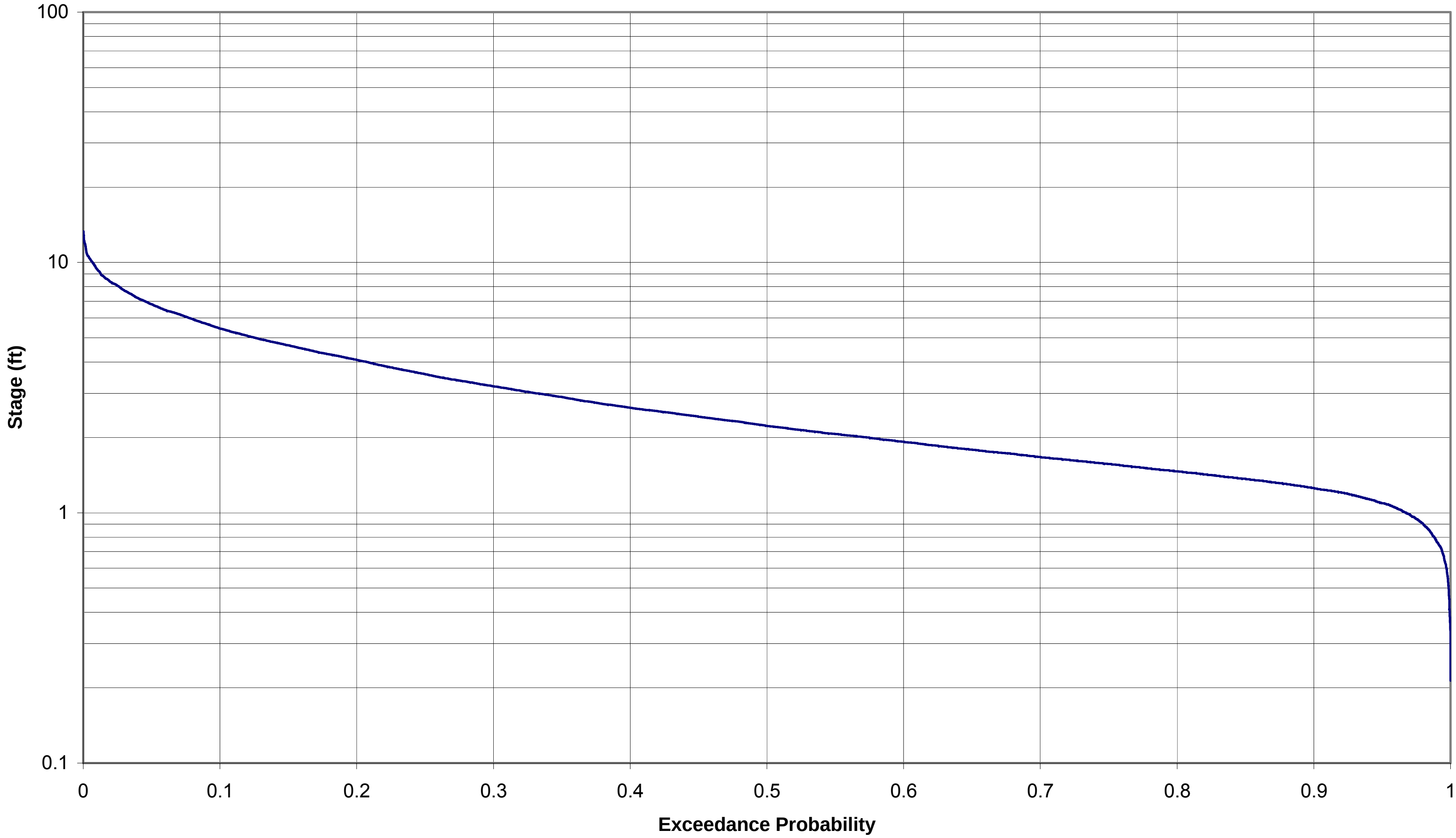


Figure 3-37. Stage-duration curve for synthesized average daily stage at Manatee Spring.

3.2.3.4.3.2 Flow and Stage Duration Curves

Flow- and stage-duration curves were constructed from the synthesized data for Manatee Spring. The flow-duration curve (Figure 3-36) represents the exceedance probabilities for average monthly spring discharges. Over the period of record for this dataset (February 1993 – July 2004), the median average monthly discharge was approximately 150 cfs. The resulting stage duration curve for this dataset is shown in Figure 3-37. The median average daily stage at Manatee Spring was approximately 2.2 feet.

3.2.3.4.3.3 Relationship to Wilcox Stage and Flow

Over the simulated period of record, stage at Manatee Spring peaks in the spring, with a secondary peak in the late summer (Figure 3-34). As seen in Section 3.2.3.3.1, stage at Manatee Spring is directly related to stage in the Suwannee River at Wilcox. So the pattern of stage at Wilcox through the year (Figure 3-26) is identical to that shown in Figure 3-34 for Fanning Spring.

Contrary to Fanning Spring discharge, the simulated discharge at Manatee Spring does not exhibit a low coinciding the peak in stage (Figure 3-35). Median monthly stage only varies by about 2 feet throughout the year at Manatee Spring, versus a range of about 4 feet in median stage at Fanning Spring. Apparently, the smaller range of stages experienced at Manatee Spring results in less variability in spring discharge.

None of the historic or AVM data indicate reversals in flow when the river is in flood. This appears to be a sampling problem, and at extreme high river stage, the spring should show an inverse relationship in discharge with river stage.

3.2.3.4.3.4 Discharge Trends

Trends in historic measurements of Manatee Spring discharge are discussed in Section 2.3.5.5. There are short- and mid-term, cyclic trends resulting from rainfall cycles. However, there is little evidence indicating the presence of long-term changes in discharge at Manatee Spring within the historic discharge measurements. The simulated discharge dataset is not of sufficient length (only about 12 years) to better analyze for the presence of long-term trends.

3.2.3.4.4 Hydrologic Conditions During MFL Study

The MFL study period for Manatee Spring was similar to Fanning Spring (the Manatee Spring's AVM gauge was installed several months before the gauge at Fanning Spring). Therefore the hydrologic conditions during the Manatee Spring study period were similar to conditions experienced during the Fanning Spring study period (Section 3.2.3.3.4).

3.2.3.5 Contribution of Springs to River Flow

While the combined discharge of Manatee and Fanning Springs constitutes a large flux to the river, the overall contribution from these springs to Suwannee River discharge is minimal. Average monthly combined discharge for the springs ranges from about 100 cfs to about 400 cfs, while average monthly discharge at the Wilcox gauge ranges from about 2,000 cfs to 40,000 cfs (Figure 3-38).

Figure 3-39 shows a graph of the combined Wilcox and spring discharge and percent of this combined discharge that comes from Fanning and Manatee springs. The percent contribution from the springs ranges from less than one to almost eight percent. The percent contribution is inversely proportional to the total combined discharge. This is attributed to two factors. First, the range in spring discharge is much less than that for river discharge. Therefore, as river discharge increases, spring discharge becomes a smaller proportion of the river discharge. Second, during very high river stage and discharge, spring discharge becomes impeded, and eventually reverses (particularly at Fanning Spring). So the proportion of total river discharge derived from the springs is largest when river discharge is low, and it becomes very small at high river discharge.

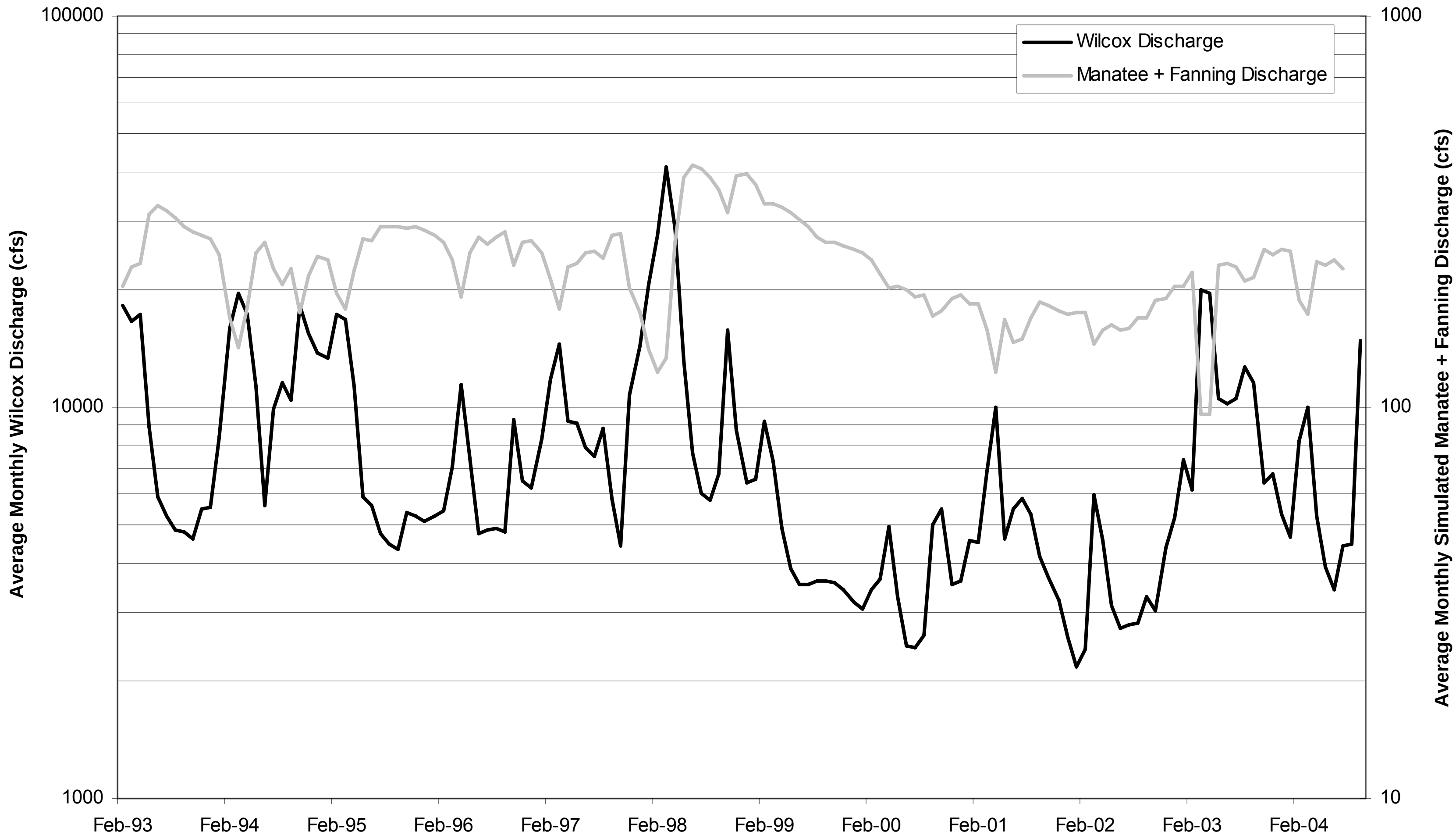


Figure 3-38. Comparison of average monthly Wilcox discharge and average monthly Fanning + Manatee discharge.

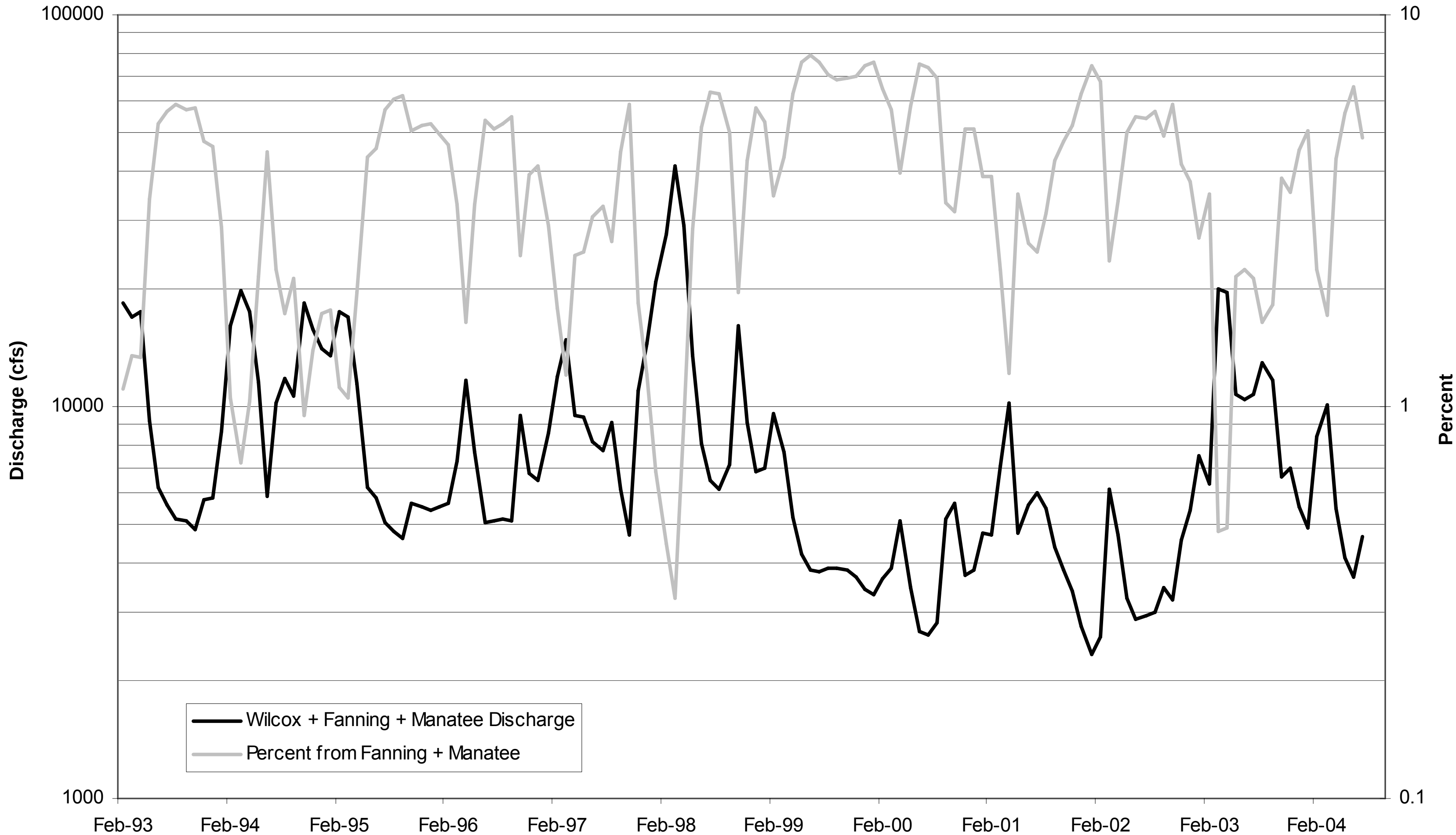


Figure 3-39. Comparison of Wilcox + Fanning + Manatee discharge with the percent of discharge from Fanning + Manatee.

3.2.3.6 Relationship of Spring Discharge and Stage to Discharge at Wilcox Gage

MFLs are developed in this report for the Suwannee River based in part on discharge in the Suwannee River at the Wilcox gage. The Lower Suwannee River and its springs constitute a linked system with discharge from the springs controlled by river stage and discharge. It is anticipated that river and correlated spring behavior will control the MFL regime for the Lower Suwannee. Therefore, this section of the Lower Suwannee River MFL report presents some additional details on the relationships between the river and its springs.

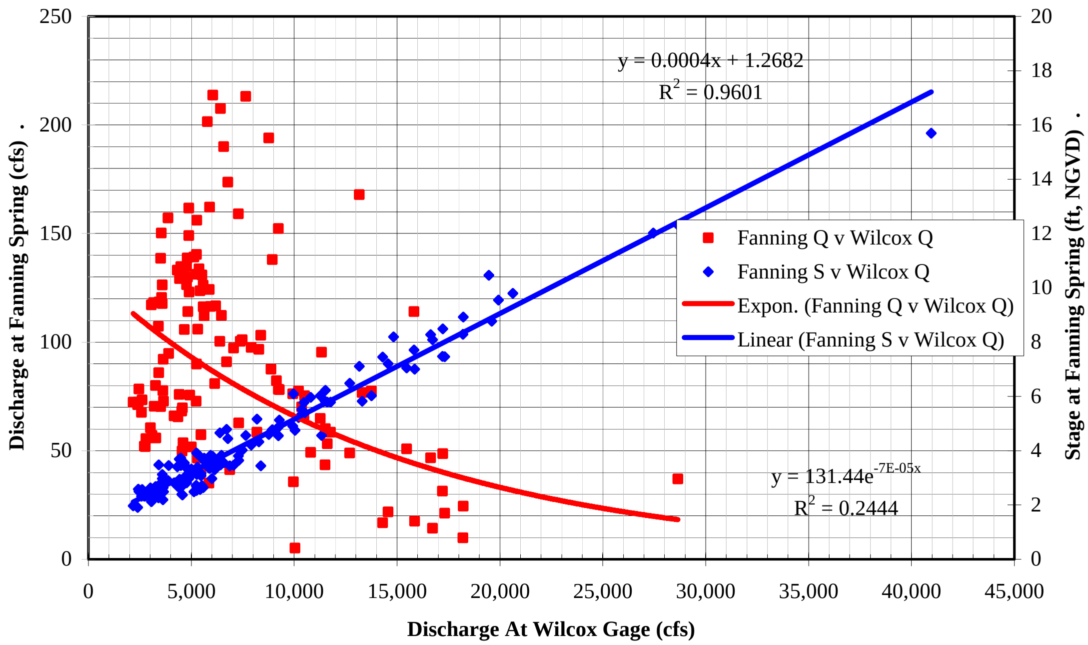


Figure 3-40. Relationships of discharge and stage at Fanning Spring to discharge at the Wilcox gage on the Suwannee River. Note that these are monthly averages in order to minimize tidal and other noise sources. Also, negative discharge as a result of backflow of river water has been eliminated from the Fanning discharge data.

Figures 3-40 and 3-41 depict the relationships of discharge and stage at Fanning and Manatee springs, respectively. The values plotted are monthly averages and negative discharge values at Fanning Spring have been removed to enhance data fitting. Note that there is a very nearly perfect linear relationship between discharge at the Wilcox gage and stage at both springs. The higher the discharge and therefore the higher the river stage, the higher the stage in the spring runs and springs. Notice also that discharge relationships are opposite with high discharge (and stage) in the river inhibiting discharge from the springs.

These relationships clearly demonstrate that the behavior of the springs can have an affect on MFL development in the river and vice versa. To assist in quantifying these relationships and understanding the consequences of MFL development in the river, best-fit equations were developed for each of the data sets shown in Figures 3-40 and 3-41. The equations are shown in the figures. These relationships and the contributions by the springs of water to the river at low flow are utilized in Section 6 of this report to develop MFLs for the rivers and springs.

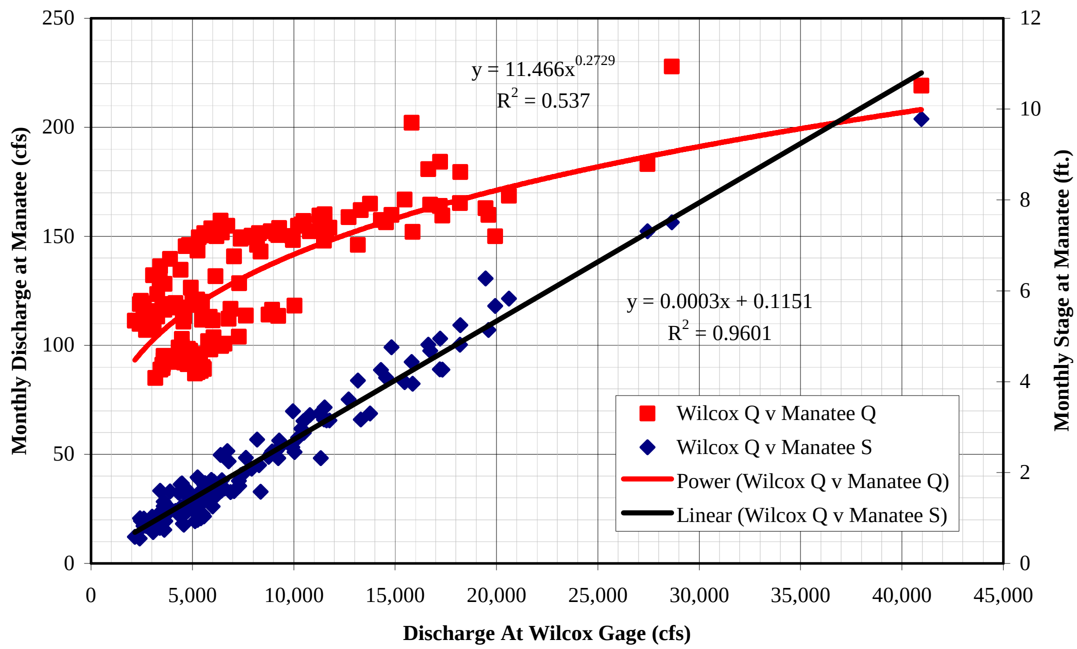


Figure 3-41. Relationships of discharge and stage at Manatee Springs to discharge at the Wilcox gage on the Suwannee River. Note that these are monthly averages in order to minimize tidal and other noise sources.

SECTION 4

4.0 Ecological Foundations

4.1 Hydrology-Habitat Linkages

Hydrologic conditions include the principal physical forces, which influence the structure and function of stream ecosystems (Poff et al., 1997; Poff and Ward, 1989). Flow influences ecological integrity directly (Poff and Allan, 1995), or indirectly via other factors such as water quality, physical habitats, etc. (Schlosser, 1991; Poff et al., 1997). The MFLs proposed in this document are initially oriented toward protection of estuarine habitats of the Lower Suwannee and thermal refuge for manatee in Fanning and Manatee springs. Furthermore, subsequent MFL criteria further upstream will focus on other portions of the flow regime in order to protect other target riverine habitats.

Priority Habitat Targets and Significant Harm Considerations

The approach for developing MFLs for the Lower Suwannee River is a resource-based approach, focusing on meeting the water needs of priority or target habitats in order to protect the resource values of the Lower Suwannee River ecosystem. USEPA (United States Environmental Protection Agency), National Marine Fisheries Service and others note that the primary emphasis for maintaining wildlife biodiversity in Florida (including protection of listed species) should be the conservation of the important habitats upon which indigenous wildlife depend. Thus, basing the development of MFLs for the lower Suwannee on sustaining target habitats is consistent with a variety of other conservation approaches at national, regional, and state levels.

Another justification for the habitat-based approach is that it is generally acknowledged that impacts to and changes in habitat are relatively straightforward to measure and quantify (Stalnaker, et al., 1995). This is in contrast to documenting impacts to or changes in fish and wildlife populations. Quantitative, repeatable measurement of many fish and wildlife populations remains subject to wide error. Thus, by focusing on target habitats, ecological changes due to hydrologic alteration may be detected or predicted at an earlier stage more reliably, and MFL criteria can be modified accordingly. This section identifies the priority target habitats used to develop MFLs for the lower Suwannee, the rationale for selecting those habitat targets, and criteria considered in developing an MFL for the Lower Suwannee system.

4.1.1 Manatee Thermal Refuge

Two major springs are found in the Lower Suwannee MFL study area: Fanning Springs and Manatee Springs. Many springs in Florida are known to provide important warm-water refuge during the winter for populations of Florida manatee (*Trichechus manatus latirostris*), when water temperatures drop below 68 °F (20 °C; Warm-Water Task Force, 2004). The manatees need these warm-water refuges, as they are unable to tolerate cold temperatures for an extended period of time.

Langtimm et al. (2003) discussed manatee population characteristics in the Big Bend region and the role of Manatee Springs for the manatee population in the region. Manatees in this region are recognized by the U.S. Fish and Wildlife Service as the “Northwest Region” manatee population. The primary winter warm-water refuges for this manatee population are the headspring areas of the Crystal River and Homosassa River (Langtimm et al., 2003).

Manatee Springs appears to provide important secondary warm-water refuge, most often during the late fall and late winter when manatees are more dispersed from the main wintering refuge areas (Langtimm et al., 2003). Tidal fluctuation and river stage combined with the shallow depths of the spring run at Manatee Springs limit the extent to which manatees can swim up the run. Thus, the main thermal refuge at Manatee Springs is the “plume” of spring outflow at the confluence of the spring run and the Suwannee River (Langtimm et al., 2003).

The role of Fanning Spring in providing warm-water refuge is less-established, but manatee use of this spring is commonly observed in the winter (FDEP, 2005). The Warm Water Task Force has classified Fanning Spring as a secondary refuge. Depths in the spring run, which depend on river stage, are often adequate to allow manatees to swim up the run and congregate about the main spring.

Evaluation of the potential for adverse environmental impacts to manatee thermal refuge includes considerations of maintaining spring flows and/or stages necessary to preserve adequate volumes of warm-water at the critical temperature of $\geq$68 °F (20 °C). Maintaining spring stage for manatee passage should allow for depths $\geq$5 feet (1.5 m) to allow for manatee passage. These recommendations were made by Langtimm et al. (2003) and are consistent with criteria used to develop proposed MFLs for Blue Spring in Volusia County (Newfields Inc., 2004).

4.1.2 Upper Estuary Submerged Aquatic Vegetation

Beds of fresh-water submerged aquatic vegetation (SAV), which are tolerant of modest levels of salinity (Figure 4-3) represent one of the major aquatic habitats in the upper Suwannee estuary. In their study of conservation priorities in the northern Gulf of Mexico, Beck et al. (2000) identified these tidal, fresh-water grasses as one of their highest-ranked “Priority Habitat Targets.” They are often under-represented in assessments of coastal habitats in the Gulf (M. Beck, pers. comm.), and few estimates of SAV acreage are available. Estevez and Sprinkel (1999) reported 19 species of SAV in these beds and found they were dominated by fresh-water eelgrass (*Vallisneria americana*), springtape (*Sagittaria kurziana*), and Eurasian watermilfoil (*Myriophyllum spicatum*). A later study (Golder Associates, 2000) delineated 27.1 acres (0.11 km^2) in the study area. The Golder study was made during a period of record low river flows. During this time, salinity in the upper estuary was much higher than normal, which considerably reduced SAV coverage. An additional 4.4 acres of “potential SAV acreage” were conservatively identified in by Golder. This acreage encompassed areas known to previously support SAV stands prior to the reduced flows of 1999-2000. Note that this spatial estimate includes only SAV beds present in the main channel of the Suwannee River and East and West passes. It does not include SAV, which may be found in the small tidal creeks branching off the main passes. SAV coverage in these creeks is substantial and could account for much of the total acreage of this community type in the upper estuary.

The habitat value of these low-salinity SAV beds for small fishes and benthic invertebrates has been documented (Rozas and Odum, 1987a; 1987b; Thorp et al., 1997). In conjunction with their location in the upper, lower salinity reaches, they are a major nursery habitat for early larval and juvenile fishery species, and important forage species such as shrimps of the genus *Palaemonetes*. Electro-shocking surveys conducted in East Pass by the FWCC in 1993-95 documented use of these beds by juvenile spotted seatrout and other recreational fishery species (Mattson and Krummrich, 1995). The abundance of SAV in tidal creeks in the estuary, which are also important fish and wildlife habitats (Montague and Wiegert, 1990), is another facet of their overall importance in the ecology of the Suwannee estuary.

Figure 4-1. A bed of *V. americana* (center and foreground) in upper West Pass in the Suwannee estuary. These beds are known to be important nursery habitat for the juveniles of spotted seatrout, an important recreational fishery species. Map shows generalized location of upper estuary SAV habitat in the lower Suwannee MFL study area.

The potential for significantly adverse environmental impacts to low salinity SAV beds can be assessed by evaluating changes in salinity, which might cause the following significant alterations in plant community diversity or composition in the beds,

- unacceptable changes in natural populations of benthic invertebrates characteristically found in low salinity SAV beds (including considering taxa richness, diversity, abundance, productivity, or species composition);
- unacceptable upstream movement of the downstream limit of SAV distribution in the estuary; or
- the potential for unacceptable overall loss of acreage of low salinity SAV habitat.

4.1.3 Tidal, Fresh-water Swamps

The intertidal areas of the uppermost Suwannee estuary are vegetated with tidal fresh-water swamps (Wharton et al., 1982; Clewell et al., 1999; Light et al., 2002). Tidal fresh-water swamps have been characterized as the least understood (in terms of quantitative study) coastal wetland ecosystems in the southeastern U.S. (Tiner, 1993; Clewell et al., 1999). Because of this lack of study, these forested wetlands are rarely identified as a distinct wetland community type in west-coast Florida rivers, so no data are available to compare the Suwannee to other river systems. However, it is probable that the lower Suwannee River supports the most extensive acreage of this wetland type on the Florida Gulf coast. Likewise, the habitat values of these swamps have not been studied or quantified. It is known that they provide important nesting habitat for Swallow-tailed kites in the Lower Suwannee Wildlife Refuge (Sykes et al., 1999). The abundance of fiddler and shore crabs in these swamps suggests that they may provide important forage habitat for crab-feeding birds, such as Yellow-crowned night heron and Little green heron, and mammals such as raccoon and mink. The leaf detritus produced in these swamps is likely an important allochthonous food base for the downstream estuarine aquatic communities.

Light et al. (2002) and Darst et al. (2003) mapped 6,652 acres (2,692 ha) of tidal, fresh-water swamps in the upper estuary. These areas correspond to their “Lower Tidal Swamp 1 and Swamp 2” forest types (Figure 4-2). Most of these are flooded daily by high tides. An additional 2,572 ac (1,041 ha) of Lower Tidal Mixed forest were also mapped. These are flooded during the higher spring tides each month. The “Lower Tidal” reach identified by Light et al. is regarded as the tidal, fresh-water portion of the Suwannee estuary (after Odum et al., 1984). In the estuary dominant trees include bald and/or pond cypress, pumpkin ash, swamp tupelo, cabbage palm, sweet and swamp bay, and red maple (Light et al., 2002; Clewell et al., 1999; Wharton et al., 1982).

Figure 4-2. Tidal, fresh-water swamp forest in the upper Suwannee estuary. Map shows generalized location of upper estuary tidal forest habitat in the lower Suwannee MFL study area.

The potential for significant harm to tidal, fresh-water swamps can be estimated by considering changes in salinity, which might cause undesirable shifts in species composition of canopy, subcanopy, or groundcover plant communities to those of a more saline community type;. In fact, the change can be responsible for not only the loss of canopy species from the swamps; encroachment of plants or animals indicative of higher salinity conditions into upstream areas where they have not previously been observed or recorded. Furthermore, the change can also lead to the following:

- the potential for unacceptable upstream movement of the tree line denoting the demarcation between tidal marsh and tidal freshwater swamp; or
- the loss of acreage of tidal swamps or changes in acreage of swamp forest types.

4.1.4 Tidal Creeks

Tidal Creeks fringing the East and West Passes and on the adjacent delta areas (Figure 4-3) represent the most important animal habitat in the tidal marshes (Montague and Odum, 1997). They note that "Tidal creeks are perhaps the key to some of the greatest values of intertidal marshland to estuarine animal life." (Montague and Odum, 1997; p. 19). The creeks provide access to the marshes for fish and natant invertebrates (e.g., shrimp, blue crabs), they include shallow water bank habitat and SAV which provides important nursery refuge for small fishes and invertebrates, and they are important feeding habitat for wading birds and waterfowl (Montague and Weigert, 1990).

Figure 4-3. Portion of the Suwannee estuary delta. Note the dense network of tidal creeks penetrating the delta area and branching off the two major passes. Map shows generalized location of tidal creek habitat in the lower Suwannee MFL study area.

Tsou and Matheson (2002) analyzed four years of juvenile fish data collected in the Florida Marine Research Institute's Fisheries Independent Monitoring Program in the Suwannee estuary and found that tidal creeks were an important explanatory variable accounting for the distribution and abundance of several important "FWRI selected taxa" (Table 2-7). These included important forage species such as spot (*Leiostomus xanthurus*), pinfish (*Lagodon rhomboides*), silversides (*Menidia* spp.) and mojarras (*Eucinostomus* spp.); juvenile sportfish including redfish (*Sciaenops ocellatus*) and spotted seatrout (*Cynoscion nebulosus*); and commercial taxa including blue crab (*Callinectes sapidus*), pink shrimp (*Farfantepenaeus duorarum*), and mullet (*Mugil cephalus*). They attributed one of the main habitat values of tidal creeks to be the associated areas of reduced salinity. Thus, a suitable regime of fresh-water inflows to the Suwannee estuary is necessary to maintain the fishery habitat values of tidal creeks.

In assessing the potential for significantly adverse environmental impacts to tidal creek habitat, consideration was given to alterations in natural populations of fauna or flora of tidal creeks (including consideration of taxa richness, diversity, abundance, productivity or species composition); and alterations in fisheries habitat value due to loss of critical habitat (e.g., SAV or oyster) or other changes due to exposure to unacceptably high salinities.

4.1.5 Oyster Bars and Reefs

In Suwannee Sound, the bay into which the river drains, and in adjacent tidal creek areas north and south of the river, the principal habitat that provides “structure” is oyster reefs and bars (Figure 4-4). These are composed primarily of the eastern oyster (*Crassostrea virginica*), with two species of mussels (*Brachidontes* spp. and/or *Ischadium recurvum*) being secondary members of the reefs. The oysters themselves are a harvestable economic resource. Oyster landings from Dixie and Levy counties (which primarily reflect harvest in the Suwannee estuary) in 2001 were 78,000 lbs, and average 50,000-100,000 lbs annually (FWCC website; www.florida conservation.org), making the Suwannee estuary the second largest oyster-producing area in the state, after Apalachicola Bay.

In addition to their economic importance, perhaps even more important, is the value of oyster habitats for estuarine invertebrates and fishes (Bahr and Lanier, 1981). A recent study by Glancy (2000) found that oyster habitats in the Crystal River area supported significantly higher biomass and density of decapod crustaceans (primarily various crabs) than seagrass or marsh-edge habitats. He interpreted this result to indicate that “. . .oyster makes a potentially important contribution to estuarine systems by supporting large abundances of a distinct assemblage of decapod crustaceans.” (Glancy, 2000 - p. xi). This contribution constitutes an important food base for highly sought recreational species such as red drum, black drum, and sheepshead (Pattillo et al., 1997). Biodiversity of oyster-associated fauna is relatively high. Mote Marine Laboratory (1986) collected a total of 248 taxa of oyster reef-associated benthic invertebrates in estuaries in the southern Big Bend region of Florida (Levy to Pasco counties). Bass and Guillory (1979) documented a distinct assemblage of oyster reef-associated fish in the Withlacoochee River estuary. This assemblage is dominated by benthic species, such as gobies, toadfish and blennies.

Figure 4-4 . Lone Cabbage Reef; an oyster reef habitat in Suwannee Sound. Map shows generalized location of oyster reef and bar habitat in the lower Suwannee MFL study area.

Baymont (2002) mapped oyster habitats in the Suwannee estuary using natural color, 1:24,000 scale aerial photography taken in November, 2001. They identified 680 acres of oyster habitat in Suwannee Sound and the adjacent tidal creek areas north and south of the river mouth. Beck et al. (2000) designated oyster reefs a Primary Habitat Target for estuarine conservation in the northern Gulf of Mexico, and they specifically designated this habitat as being of direct importance in the Suwannee estuary.

Evaluation of the potential for significant harm to oyster habitats involved consideration of changes in salinity that would cause unacceptable alterations in natural populations of oyster-associated benthic invertebrates (including consideration of taxa richness, diversity, abundance, productivity or species composition); alterations in oyster reef characteristics (juvenile, subadult, or adult oyster density or cover) due to exposure to unacceptably high salinities; or the potential for loss of acreage of oyster habitat due to increases in salinity caused by fresh-water inflow reductions.

4.1.6 Other Important Habitats

Three other habitats, two riverine and one estuarine, were identified as being target habitats, which, while not "priority" habitats, were given consideration in setting of MFLs. The two river habitats were riverine upper tidal bottomland hardwood forests ('UTblh' forests of Light et al., 2002) and riverine woody snag habitat on the lower river below Wilcox. The estuarine habitat is tidal marsh.

Upper Tidal Bottomland Hardwood Forests. In their study of floodplain forests of the lower Suwannee River, Light et al. (2002) identified 13 distinct wetland forest community types in three major reaches in their lower Suwannee study area. Five of these forest types are associated with their 'Riverine Reach', which mostly occurs upstream of Wilcox, and development of MFLs to protect these forests will be considered as part of the middle

Suwannee MFL effort. The four forest types associated with their ‘Lower Tidal’ reach are considered part of the estuary, and were discussed above in Section 4.2.3. The remaining four forest types are found in the current MFL study area below Wilcox, in the ‘Upper Tidal Reach’ of Light et al. and consist of Upper Tidal Swamps 1 and 2 (Utsw1 and Utsw2), Upper Tidal Mixed forest (Utmix), and Upper Tidal Bottomland Hardwood forest (UTblh - Light et al., 2002). The Swamps are typically inundated a few days each month by the spring tides, which occur at spring high tides and during river floods. The Mixed and Bottomland Hardwood forests are inundated by river flooding.

Floodplain wetlands are known to be an integral part of the river ecosystem, with important roles in nutrient, organic matter, and sediment dynamics, fish and wildlife habitat, and flood-water storage (Wharton, et al., 1982; Mitsch and Gosselink, 1986; Schlosser, 1991; Kleiss, et al., 1989; Light, et al., 1998). Some of the organic production in these wetlands is transported to the adjacent river and downstream to the estuary, where it is used in aquatic food webs (Mattraw and Elder, 1984). Hynes (1975) elucidated the need to consider this important “lateral connectivity” in understanding and managing stream ecosystems. Subsequent conceptual paradigms in stream ecology have incorporated the importance of river-floodplain linkages (Ward, 1989; Schlosser, 1991).

Noss et al. (1995) designated riparian forests nationwide, including floodplain wetlands, as “threatened ecosystems”, meaning they experienced a 70-84% decline in the occurrence of high quality, intact examples. In the southeastern U.S., the acreage of intact bottomland hardwood wetlands has declined by 78% since pre-European settlement times (Harris, 1984). Within the MFL study area, floodplain wetland habitats remain largely intact and in good ecological condition, the only major impact being historical logging. Several large tracts of floodplain in the Lower Suwannee River study area were identified as being of exceptionally high ecological quality by Lynch (1984) in a survey of the river. These included forests located in the MFL study area near Yellow Jacket and Fowler’s Bluff. Many of these areas have been acquired by the District or by the Lower Suwannee National Wildlife Refuge for conservation, in part because of their high quality.

Of the Upper Tidal forest types identified by Light et al. (2002), three of the four forest types had >30 canopy and subcanopy taxa (Upper Tidal Swamp 2 - 33, Mixed - 31, and Bottomland Hardwood forests – 35). This species richness was among the highest compared to tree diversity in other southeastern U.S. floodplain forests (Light, et al., 2002). These results indicate that plant community diversity is exceptional in many of the Upper Tidal forests of the lower Suwannee floodplain. The Upper Tidal forests should be taken into account because some of this forest type may convert to upland if flood flows are changed too much. Light et al. (2002) identified flood depth as an important hydrologic variable influencing the canopy composition of these floodplain forests, as well as the location of the transition zone between the Riverine and Upper Tidal reaches.

In assessing the potential for significantly adverse environmental impacts, ecological considerations for floodplain wetlands should include preventing unacceptable shifts in canopy, subcanopy, and/or groundcover plant species composition in a particular wetland forest type to that of a “drier” forest type; potential alterations to natural populations of floodplain wetland-dependent fauna (which might include changes in biodiversity, productivity, species richness or composition); unacceptable upstream movement of the boundary between upper tidal and riverine forest types; unacceptable loss of acreage of floodplain wetlands; or the potential for unacceptable changes in acreage of forest types.

Riverine Woody Snag Habitat. Some of the most ecologically important aquatic habitats in the Lower Suwannee River, channel are associated with the river bank zone (Bass and Cox, 1985; Dolloff, 1994). In particular, areas of submerged, large woody debris bordering river channels have been shown to support high biological diversity and production (Dolloff, 1994; Maser and Sedell, 1994), especially in southeastern coastal plain streams (Benke et al., 1984; Benke et al., 1985). These have been referred to as “snag” habitats (Maser and Sedell, 1994; Benke et al., 1984). Although the distribution of this habitat may change following flood events (e.g., wood moved downstream by the current) or wood may degrade over time, the constant input of wood to the river from tree fall means that this is a “persistent” habitat which is always available in the river. Estevez and Sprinkel (2000) cite a South Carolina study, which indicated that the amount and distribution of wood at a river site was comparable among years over a 6 year period.

Much of the fish production in southeastern coastal plain streams is associated with snag habitat (Benke et al., 1985; Smock and Gilinsky, 1992). Benke et al. (1985) showed that 82% of the diet of redbreast sunfish in the Ogeeche River was composed of snag-associated invertebrates. They indicated that the snag invertebrate community was part of a “snag habitat – invertebrates – sunfish” food chain in the river. Redbreast are the dominant fish, by abundance, in the Lower Suwannee system (FDER, 1985; Bass, 1991), and snags are likely a key habitat supporting production of this important sportfish. For these reasons, riparian aquatic wood, such as snags, planters, etc., was identified as an important habitat in the river channel portion of the lower Suwannee.

Considerations for riverine snag habitat in assessing the potential for significantly adverse environmental impacts include evaluation of whether hydrologic changes would cause unacceptable alterations in natural populations of benthic invertebrates on snags (including possible changes in taxa richness, diversity, abundance, composition, or productivity); unacceptable reductions in frequency or duration of availability of aquatic snag habitat during the year (particularly at low flow conditions); or unacceptable losses of the surface area or volume of aquatic snag habitat at a given flow condition.

Tidal Marsh Habitat. The major intertidal wetland community in the Suwannee estuary is tidal marsh. Three broad types of tidal marsh communities occur in the estuary (Clewell et al., 1999). Tidal fresh-water marshes are found in the upstream, lowest salinity reaches of the upper estuary. Dominant plants include sawgrass, bulrushes, wild rice, cattail, arrowhead, water parsnip, pickerelweed, spatterdock, and other freshwater emergent marsh plants (Clewell et al., 1999). Overall they have the highest plant diversity of the various tidal marsh community types in the Suwannee estuary. The general structure and function of tidal fresh-water marsh communities were described by Odum et al. (1984). Their fisheries habitat value is likely equivalent to those of downstream, higher salinity marshes (Odum et al., 1984). Beck et al. (2000) identified “tidal fresh marshes” as a high priority habitat target for conservation in the northern Gulf of Mexico.

Intertidal marsh areas adjacent to the lower 4-5 miles (5-7 km) of the river passes are oligohaline or brackish tidal marsh. Dominant plants in these marshes include sawgrass, black rush, giant reed, bulrushes, cordgrasses, and lance- leaved arrowhead (Clewell et al., 1999). These low-salinity marshes, in association with their complex of tidal creeks, are known to provide critical nursery habitat for many fishes of commercial or recreational importance (Rozas and Hackney, 1983; Comp and Seaman, 1985), particularly during the earliest larval stages. “Oligohaline saltmarsh” was identified as a priority Habitat Target for conservation in the northern Gulf of Mexico by Beck et al. (2000).

Salt marshes are found in the intertidal wetland areas north and south of the river delta. Dominant plants include black rush, cordgrasses, sea lavender and seashore saltgrass. These higher-salinity tidal marsh communities have been well-studied in estuaries throughout the southeastern U.S. and Florida (Montague and Wiegert, 1990; Coultas and Hsieh, 1997). Concurrently, their ecological value as fishery and wildlife habitat has been well documented (Weinstein, 1979; Boesch and Turner, 1984; Durako et al., 1985). Beck et al. (2000) designated these higher-salinity intertidal marshes (which they termed “mesohaline saltmarsh” and “polyhaline saltmarsh”) as Priority Habitat Targets for conservation in the northern Gulf of Mexico.

In assessing the potential for significantly adverse environmental impacts to tidal marshes, consideration was given to changes in salinity that might cause the following:

- changes in the species composition of marsh plant communities to those of a more saline marsh type; cause unacceptable encroachment of tidal marsh plants or animals indicative of higher salinity conditions into upstream areas where they have not previously been observed or recorded;
- cause or increase the potential for unacceptable losses of acreage of low salinity tidal marsh habitat (those in the areas of <10 ppt average annual salinity); or
- cause unacceptable alterations in natural plant or animal populations in low salinity oligohaline and tidal freshwater marshes.

4.2 Target Species

Although the District’s approach to MFLs includes consideration of the water needs of target habitats, incorporation of the water requirements of certain key species within each of those habitats can provide additional information to set and evaluate the proposed MFL criteria. Working with PBS&J (2003), the District identified a suite of “target taxa” associated with each of the priority habitats (Table 4.1). Some are officially listed taxa, others are important because of commercial or recreational value, and others are sensitive environmental indicators. All are dominant (by abundance or occurrence) or characteristic taxa associated with each of the habitats. Some are characteristic of more than one habitat type. A literature search was conducted (PBS&J, 2003) to compile and evaluate the best available data to determine the water needs of these target taxa.

Additional taxa were examined by Janicki Environmental (2005a) and McMichael and Tsou (2003) using fish and salinity data from the FWCC Fisheries Independent Monitoring Program in the Suwannee estuary. McMichael and Tsou examined several taxa from the FWCC’s “Selected Taxa” list (Table 4.2) and their responses to salinity and river flow. Janicki Environmental also analyzed the species-specific responses of a number of fish taxa to salinity/flow, most of which were either FWCC Selected Taxa or ELMR taxa (Table 4.2). Janicki

Taxonomic grouping	Habitat			
	Low Salinity SAV	Tidal Creeks	Tidal Swamps	Oyster reefs/bars
Invertebrates	Pink shrimp, Grass shrimp, Blue crab, Olive nerite	Grass shrimp, Blue crab, Fiddler crab	Grass shrimp, Blue crab, Fiddler crab	Stone crab, Blue crab, Oysters
Fish	Bay anchovy, Red drum, Silversides, Mullet, Silver perch, Mojarras, Spotted seatrout	Bay anchovy, Silversides, Mullet, Red drum, Silver perch, Mojarras, Spotted seatrout		Spotted and Sand seatrout, Red drum, Mojarras, Black drum, Spot, Pinfish
Reptiles		Diamondback terrapin, *American alligator*		
Birds		*Limpkin*	Swallow-tailed kite, *Yellow-crowned night heron,* Little green heron	*American oystercatcher*
Mammals	*Florida manatee*	*Florida manatee*		
Plants	Tapegrass, Strapleaf Sagittaria		Cabbage palm, Tupelo, Ash, Cypress	

Table 4-1. List of targeted taxonomic groups/priority taxa and commensurate habitats for development of minimum flows and levels for the Suwannee River (taxa in italics are listed species). Filled cells were not assigned species. Table adapted from PBS&J (2003).

INVERTEBRATES	FWCC Selected Taxon	ELMR Taxon
Blue crab (*Callinectes sapidus*)[1,2]	√	√
Pink shrimp (*Farfantepenaeus duorarum*)[1,2]	√	√
Penaid shrimp (*Farfantepenaeus* spp.)[2]	√*	√ *
FISHES		
Diamond killifish (*Adinia xenica*)[2]		
Striped anchovy (*Anchoa hepsetus*)[1,2]		
Bay anchovy (*Anchoa mitchilli*)[1,2]		√
Menhaden (*Brevoortia* spp.)[1,2]		√ *
Spotted seatrout (*Cynoscion arenarius*)[2]	√	√
Sand seatrout (*Cynoscion nebulosus*)[1,2]	√*	√ *
Spotfin mojarra (*Eucinostomus harengulus*)[2]		
Mojarra (*Eucinostomus* spp.)[1,2]		
Gulf killifish (*Fundulus grandis*)[2]		√ *
Striped killifish (*Fundulus majalis*)[2]		
Scaled sardine (*Harengula jaguana*)[2]		
Pinfish (*Lagodon rhomboides*)[1,2]		√
Spot (*Leiostomus xanthurus*)[1,2]	√*	√ *
Redbreast sunfish (*Lepomis auritus*)[2]		
Spotted sunfish (*Lepomis punctatus*)[2]		
Rainwater killifish (*Lucania parva*)[2]		
Rough silverside (*Membras martinica*)[1,2]		
Silversides (*Menidia* spp.)[1,2]		
Gulf whiting (*Menticirrhus americanus*)[1,2]	√	
Clown goby (*Microgobius gulosus*)[2]		
Largemouth bass (*Micropterus salmoides*)[2]		
Striped mullet (*Mugil cephalus*)[1,2]	√	√
Gulf flounder (*Paralichthys albigutta*)[2]	√*	√ *
Red drum (*Sciaenops ocellatus*)[1,2]	√*	√ *

Table 4-2. Estuarine fish and invertebrate taxa examined by McMichael and Tsou (2003) and/or Janicki Environmental (2005a). * - listed as "moderate to high sensitivity" to salinity change by Christensen et al. (1997) for the Suwannee estuary.

Environmental (2005a) also examined species-specific and community-level responses to river flow and salinity using benthic invertebrate data collected in the FWCC Inshore Monitoring and Assessment Program (IMAP) in the Suwannee estuary (2000 and 2003 sampling) and invertebrate data collected with Hester-Dendy samplers by the SRWMD in their ambient river monitoring program from the river sites SUW150C1 and SUW240C1 (1989-2003 sampling period).

4.3 Habitat-Based Hydrologic Analyses

4.3.1 Riverine Studies and Data

Wetland communities

Data used to develop MFLs to protect floodplain wetlands and aquatic habitats came mostly from a study by Light et al. (2002). They collected data on topography, soils, and plant communities at 5 intensive study transects, located along the river from the Santa Fe confluence down to near Fowler's Bluff (Figure 4-5). They also conducted forest type mapping (Darst et al., 2003), and surveys at a number of sites to verify the classification accuracy of the maps (locations shown in Light et al., 2002 and Darst et al., 2003). A summary of groundcover data at transects and verification sites was presented in Darst et al. (2002). Other information on floodplain wetland and aquatic communities was derived from the scientific literature in a review by PBS&J (2003), which is cited. Other than the work reported above, there exist no detailed, quantitative studies of floodplain wetlands (or other floodplain habitats or biological communities) in the lower Suwannee.

Study	Investigator(s)	Description	Period of Record
Floodplain wetlands and aquatic habitats	U.S. Geological Survey	Specific study for lower Suwannee MFL effort	October 1996-September 1999
Riverine snag habitat	Mote Marine Laboratory	Specific study for lower Suwannee MFL effort	February 1998-November 1998
Riverine benthic invertebrates	Janicki Environmental	Analysis of SRWMD monitoring data	February 1989-December 2003
Tidal Marshes	A.F. Clewell, Inc.	Specific study for lower Suwannee MFL effort and follow-up study	July 1997- September 1998 and June 2000
	SRWMD	Follow-up study during drought	July 2002
Tidal Freshwater Swamps	U.S. Geological Survey	Specific study for lower Suwannee MFL effort	October 199 - September 1999
Low-salinity SAV – field studies	Mote Marine Laboratory	Specific study for lower Suwannee MFL effort and follow-up studies	January 1998-January 1999; June 2000 and July 2002
Low-salinity SAV - mapping	Golder Associates	Specific study for lower Suwannee MFL effort	May - October 2000
Oyster reefs – field studies	University of Florida	Specific study for lower Suwannee MFL effort	October 2002- March 2003
Oyster reefs - mapping	Agra-Baymont	Specific study for lower Suwannee MFL effort	Based on Nov. 2001 photography
Estuarine fisheries	FWCC Fish and Wildlife Research Institute	Analysis of Fisheries Independent Monitoring Program data	January 1997 - December 2000
	Janicki Environmental	Analysis of Fisheries Independent Monitoring Program data	January 1997 – December 2003
	FWCC Freshwater Fish Division	Fish populations in East Pass	February 1993-1995

Table 4-3. Summary of ecological studies and data networks conducted on the lower Suwannee, which provided data used in MFL development.

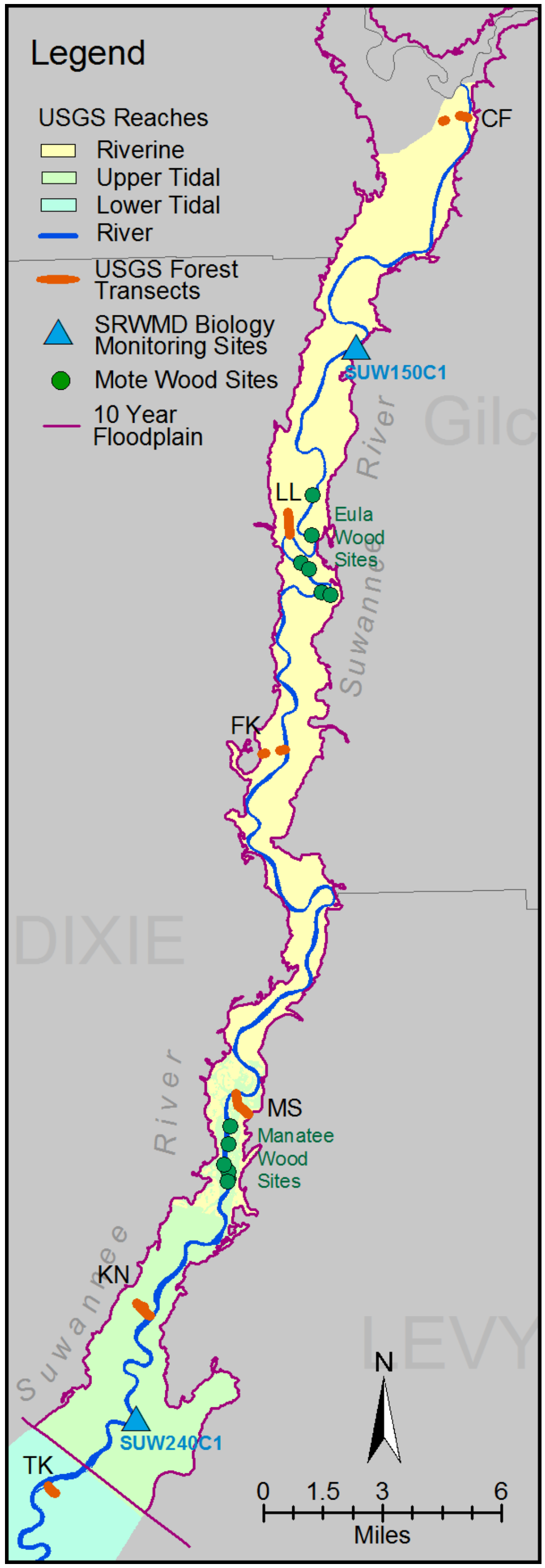


Figure 4-5. Map of the riverine portion of the Lower Suwannee River MFL study area and reaches upstream to the confluence with the Santa Fe. Locations of USGS floodplain transects, Mote wood study sites, and SRWMD long-term surfacewater quality/ biology sites are shown.

Wharton et al. (1982) and Lynch (1984) presented qualitative, descriptive summaries of floodplain plant communities and tree canopy species composition in the Suwannee River. Their data are useful as background information but could not be used directly for establishing MFLs. In like manner, Howell (1999) conducted detailed studies of soils and geomorphology in the Lower Suwannee River floodplain. Some of his data were reported and used in Light et al. (2002) and are incorporated into the Lower Suwannee study area MFLs via use of their work.

Aquatic communities. Studies on riparian snag habitat were conducted by Mote Marine Laboratory at six river bank sites located in each of two regions of the river: near Eula Landing and near Manatee Springs (Figure 4-5). Their methodology and results are reported in Estevez and Sprinkel (2000). Characteristics of benthic invertebrate communities existing on snags were estimated using Hester-Dendy sampler data collected in the SRWMD long-term river monitoring network at the sites SUW150C1 and SUW240C1 (Figure 4-5). These invertebrate analyses are reported in Janicki Environmental (2005a). Information from the scientific literature was also employed in evaluating snags and riverine SAV, summarized in PBS&J (2003).

Some historical studies of riverine aquatic habitats and their fauna have been conducted in the lower Suwannee. Bass and Cox (1985) and Bass and Hitt (1973) report on studies of fish populations and benthic invertebrates associated with different habitats in the lower Suwannee River. FDER (1985), Mason (1991), Mason et al. (1994) and Mattson et al. (1995) presented data on riverine benthic macroinvertebrate and periphytic algal communities in the Suwannee River, but all of these studies are primarily descriptive. They serve as useful background information but were not specifically incorporated into the Lower Suwannee MFLs. Fish population data at several locations in the Lower Suwannee have been collected for the past 25 years by the FWCC, in the form of electroshocking surveys conducted annually or for special investigations (Bass and Hitt, 1973; Bass, 1990; 1991). These data were collected to characterize the status and condition of fish populations in this reach of the river and were evaluated for use in MFL development but were found to be unusable for that purpose. The FWCC is currently collecting fish data more amenable to use in MFLs, but the data have not been collected over a long enough period of time yet. A number of studies of Gulf sturgeon in the Suwannee River have been conducted (summarized in Sulak et al., 2001). Their data either were focused more on the upper river, where the spawning locations are, or were too qualitative to use for MFL development. Langtimm et al. (2003) provided an overview of Florida manatee population dynamics in the lower river. Their study primarily focused on evaluating the importance of Manatee Spring as temporary warm-water refuge in the winter. This study is useful for development of MFLs for that spring, but is not as useful for the Lower Suwannee system as a whole.

4.3.2 Estuarine studies and data

Wetland communities. Data on tidal-marsh communities were collected by Clewell, et al. (1999). They collected topographic, soils, and plant community data at 7 intensive study transects located in the estuary (Figure 4-6). Supplemental qualitative observations were made at numerous other sites located throughout the estuary (Clewell et al., 1999). Marsh plant community data were also collected during this time by Clewell et al. (1999) along both river banks at the locations of 15 salinity sites sampled for two years by the FWCC in 1993-95 (Mattson and Krummrich, 1995) and by the USGS from 1997-1999 (Tillis, 2000). Follow-up plant community surveys at most of the intensive tidal marsh transects were conducted in 2000 (Clewell, 2000) and 2002 (Mattson, 2002b), Data used to develop MFLs to protect tidal freshwater swamps came from the floodplain wetland study by Light et al. (2002). The data they collected in this plant community came from 6 intensive study transects stretching from Turkey Island to near the treeline (Figure 4-6), and consisted of topography, soils, and plant communities. Maps of tidal freshwater swamp forest types were presented in Darst et al. (2003) and groundcover data from the tidal swamp study transects were summarized in Darst et al. (2002).

A few general studies have been conducted in tidal marshes of the Suwannee estuary. Coultas (1997) summarized marsh soils studies he conducted in tidal marshes in Dixie and Levy counties (including the Suwannee estuary). Wright (1995) studied the geologic history and sedimentation characteristics of the delta area at the mouth of the Suwannee. Additional data from Suwannee estuary marshes were reported in several presentations and posters at a Symposium held in 1997 (Lindberg, 1997). All of these studies provided descriptive data useful for generally characterizing the marshes and tidal creeks of the estuary, but they were determined to be not directly useful for MFL development.

Aquatic communities. Studies in low salinity SAV beds in the upper estuary were conducted by Mote Marine Laboratory at 16 sites (Figure 4-6). Non-destructive sampling of SAV was conducted at all of these, consisting of Braun-Blanquet measurement of vegetation. A subset of these sites was sampled more intensively for above- and below-ground vegetation standing crop and epiphytic invertebrate communities, as described in Estevez and Sprinkel (1999). Revisits of the Mote sites were conducted in 2000 and 2002 (Estevez, 2000b; 2002). Low salinity SAV was mapped in 2000 by Golder Associates (2000). Studies in oyster reef habitats were conducted by the University of Florida (Baker et al., 2003) at 36 sites, along with selected elements of the oyster-associated benthic invertebrate fauna (Figure 4-7). Salinity data collected by the FDACS shellfish monitoring program (SEAS) were employed in this oyster study (Figure 4-7) to characterize salinity conditions for comparison with the oyster data (as described in Baker et al., 2003). The SEAS data were also used to develop salinity/flow regression models (Janicki Environmental, 2005b) used in evaluating salinity dynamics for other estuarine target habitats. Other salinity data networks used were described in Section 3.1.9. Oyster reefs and bars were mapped in 2002 by Baymont (2002) using natural color, 1:24,000 scale natural color aerial photography flown by a contractor for SRWMD in 2001. Data on benthic invertebrate communities in the upper estuary were analyzed by Janicki Environmental (2005a) from the site SUW275C1 (Figure 4-6).

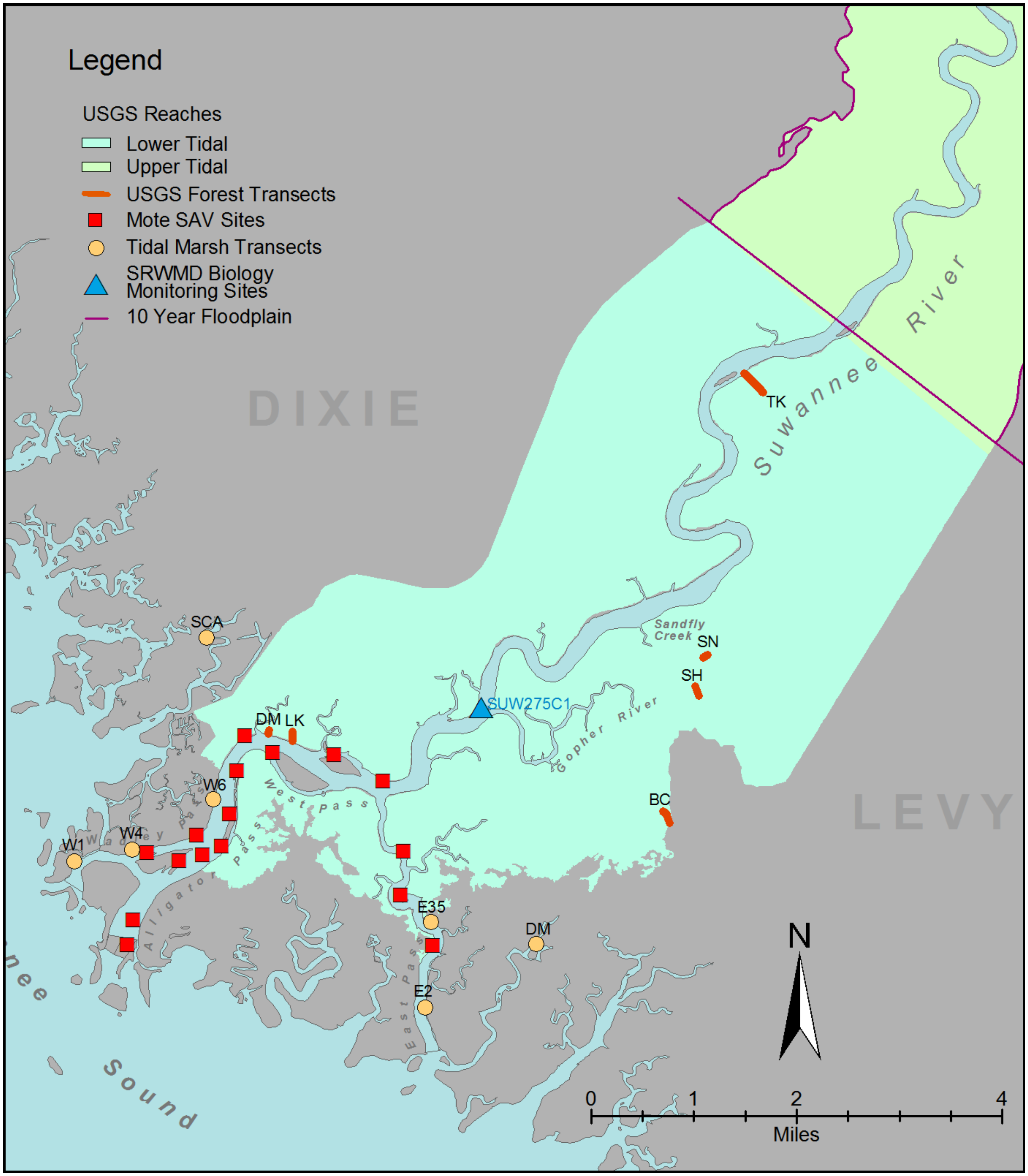


Figure 4-6. Map of the upper Suwannee estuary, showing locations of Clewell tidal marsh transects, USGS tidal freshwater swamp transects, Mote SAV study sites, and SRWMD long-term surfacewater/biology site.

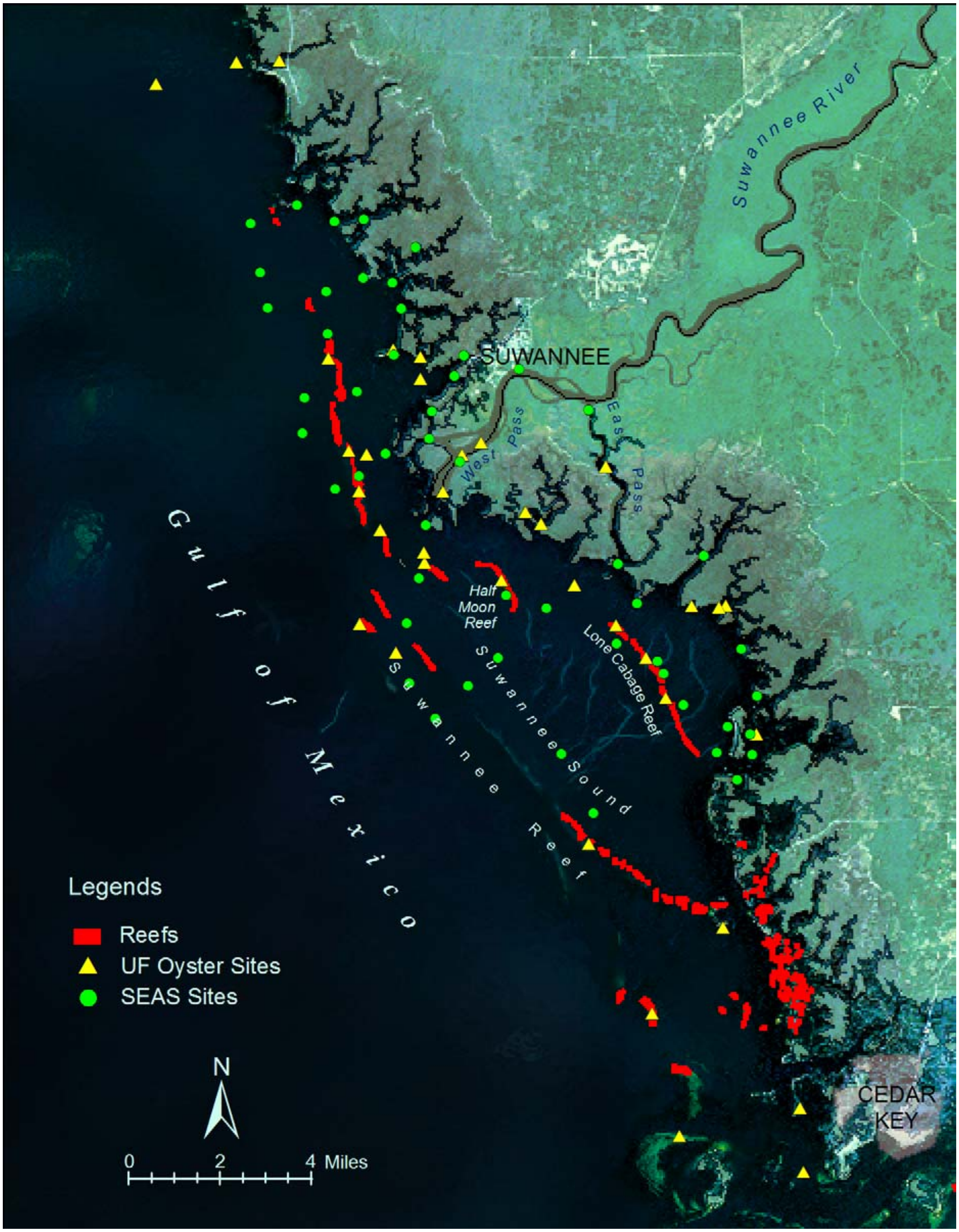


Figure 4-7. Satellite image of the Suwannee estuary showing locations of UF oyster study sites and SEAS salinity sites.

Information on tidal creeks and related fisheries data came from several sources. SRWMD developed a GIS coverage of tidal creeks on the Suwannee delta area. This was used in conjunction with a GIS coverage, created by SRWMD, segmenting the major passes (East, West, Alligator and Wadley) into 0.25 km sections to evaluate cumulative geographic characteristics of tidal creeks in the estuary. Additional data came from the FWRI Fisheries Independent Monitoring program. This program samples juvenile fishes and related physical and habitat characteristics in the Suwannee estuary using a stratified random sampling grid. Station locations used in analyses in this report are indicated in Figure 4-8. Data from the FIM program collected 1997-2000 were analyzed by McMichael and Tsou (2003) and Tsou and Matheson (2002). Janicki Environmental (2005a) conducted additional analyses using FIM data collected from 1997-2003. Some analysis of benthic invertebrate data from the FWRI Inshore Marine Monitoring and Assessment Program (IMAP) was also conducted by Janicki Environmental (2005a). Fish population data collected by electroshocking at six sites in East Pass were used to evaluate upper estuary fish populations (Mattson and Krummrich, 1995). Additional information on estuarine wetland and aquatic communities in the scientific literature was consulted to develop MFLs for the lower Suwannee. This is summarized in PBS&J (2003).

Bledsoe (1998; 2003), Bledsoe and Phlips (2000) and Bledsoe et al. (2004) studied phytoplankton communities and water quality in the Suwannee estuary. Their focus was on determination of water quality and physical factors most responsible for influencing the composition and standing crop of phytoplankton in the estuary. Even though their data are extensive, because their study design was not oriented towards examining specifically how freshwater inflow affects phytoplankton populations, the data are not entirely applicable towards developing MFLs for the lower Suwannee. Wolfe and Wolfe (1985) presented some phytoplankton community data from the estuary, but they were critical of the sampling design, and thus those data were not used in the lower Suwannee MFL effort. Information on estuarine benthic macroinvertebrates were reported in Wolfe and Wolfe (1985) and Mason, et al. (1994). These data are primarily descriptive and provide useful background information but were not suitable for use in MFL development. Data collected by Brooks and Sulak (2004) were more quantitative, but were not collected over a wide enough range of salinities or a long enough period of time to be useful for MFLs. Grinnel (1971) conducted surveys of the structure and development of oyster reefs in the Suwannee estuary, but again, his data are largely descriptive and cannot be used in MFL development. Adicks (1998) evaluated juvenile and small fish populations in Alligator Pass and tried to relate fish community characteristics to salinity variation but did not find clear relationships. Additional data from the Suwannee estuary were reported in several presentations and posters at a Symposium held in 1997 (Lindberg, 1997), but these are mostly descriptive.

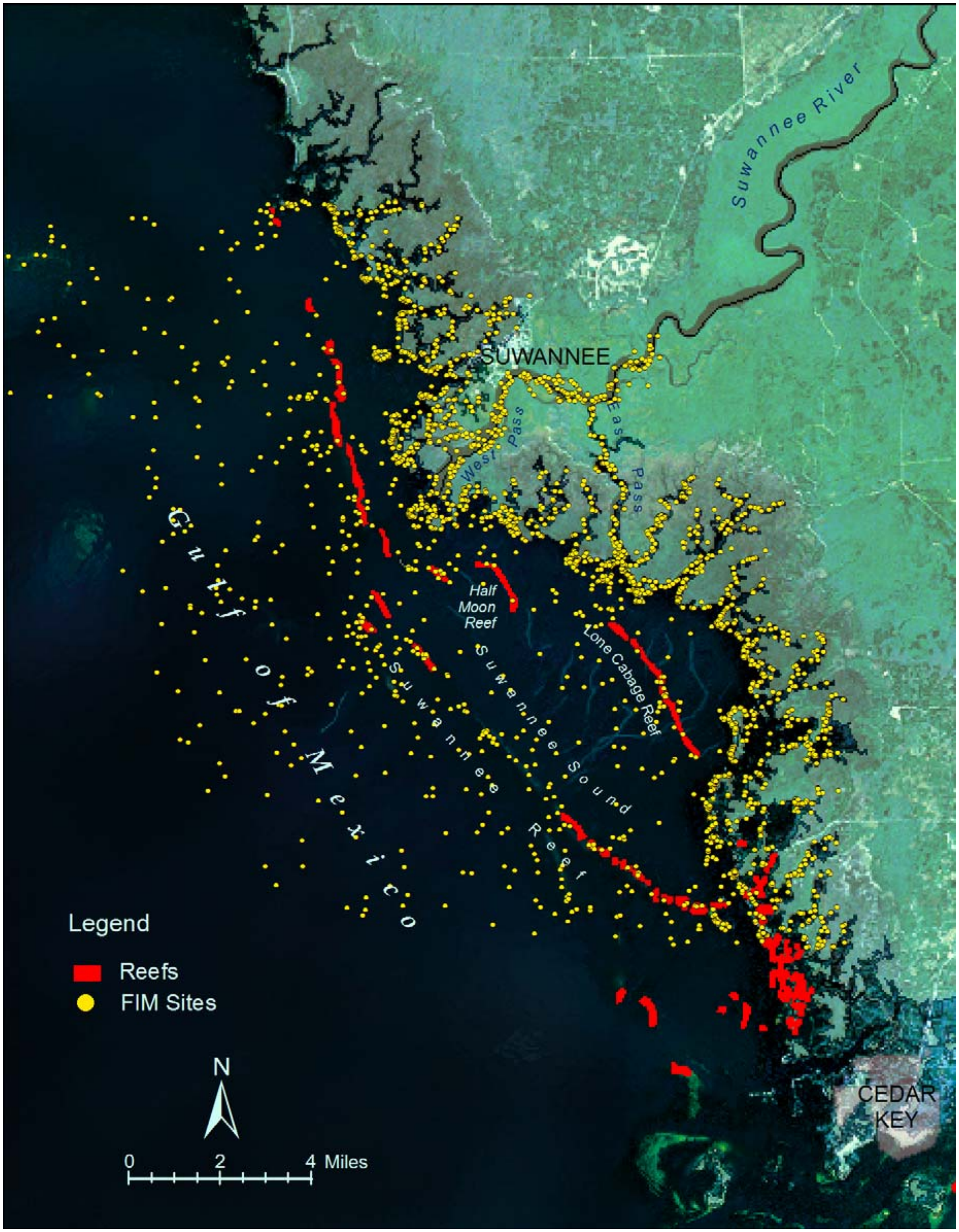


Figure 4-8. Satellite image of the Suwannee estuary showing locations of the FWCC Fisheries Independent Monitoring (FIM) sites used in analyses in this report.

SECTION 5

5.0 Flow-Habitat Relationships: Establishment of Hydrologic Shifts

5.1 Approach and Rationale

This section identifies the physical, physiological, and habitat-limiting criteria for each of the major habitats of interest in the Lower Suwannee River MFL study area and quantifies relationships between river flow and habitats to guide the establishment of Minimum Flows and Levels (MFLs) for the Lower Suwannee River including Manatee and Fanning springs based on the results of the analyses and previous studies described in Sections 3 and 4. Manatee and Fanning springs feed the Lower Suwannee River below Wilcox and either contribute to or receive water from the Lower Suwannee depending on flow conditions. Therefore, it is imperative when considering MFLs for the Lower Suwannee River to examine the relationships between flows and levels in the Lower Suwannee and stage and flows in Manatee and Fanning springs since the geographic and hydrographic characteristics are inextricably related.

An empirical data analysis approach was used to evaluate the relationships between flows at Wilcox and downstream habitat availability. The intent was to quantify the effects of upstream discharge including antecedent flow conditions on downstream habitat availability and estimate the associated risk of reductions in river flows for each habitat of interest due to any perturbation, natural or anthropogenic. In the case of Manatee and Fanning springs, which are considered Class II manatee refuge springs, it is important to preserve a thermal refuge during winter months and provide adequate water depth to allow access to the thermal refuge. Therefore, the amount of flow required to provide adequate access to the thermal refuge was assessed. For the other 4 major habitat types (i.e., tidal swamp, SAV, tidal creeks and oyster beds), all expressed some degree of sensitivity to changes in estuarine salinities so salinity during low flow conditions became the determinant criterion for the estuarine portion of the Lower Suwannee. Spring discharge is an important contributor to river flow at times of low flow. Therefore, spring discharge was included for MFL consideration in the warm, low-flow season (May to October).

The threshold criterion established for each habitat type of interest was based on the best available information including published literature and empirical evidence. A key underlying concept in establishing these criteria was the evaluation of risk. Risk was established for manatee habitat based on access to a thermal refuge. Risk was established for downstream estuarine habitat based on exposure to a threshold salinity value. It is important to note the conservative nature of our established estimates of risk. For each of the habitats, criteria were selected to minimize the potential risk to the biological organisms of interest. The conservative nature of the assessments was based on identifying conditions where the biological organism under consideration would begin to encounter conditions that were physiologically stressful. These conditions occur in the natural system periodically as a function of climatological variation. Further, two of the organisms, manatee and fishes, are motile and can relocate to areas that are more preferential. Only under chronic conditions would exceedance of these criteria pose a threat to actual loss of habitat.

Several important tools were developed to guide selection of MFLs for the Lower Suwannee River system.

A thermal model was developed to describe the extent of the thermal refuge under varying river flow and spring flow conditions for Manatee springs and river flow was related to stage and discharge at Manatee and Fanning springs to allow for adequate depth for manatee passage and to support river flows during the low-flow season.

Regression analysis was used to relate salinity isohaline locations in the river passes to flow using data collected on full moon high tides. By sampling on spring tides, these salinity profiles represented the maximal upstream incursion of salinity into the estuary under normal environmental conditions.

ArcGIS was used to quantify available habitat for several of the habitats of interest.

A river mile system was constructed to relate the location of various salinity isohalines to habitats in and along the Lower Suwannee River such that exceedances of a particular habitat salinity requirement would constitute potential risk for a certain proportion of the total available habitat in the Lower Suwannee River and estuary.

Attempts were made to validate the inference regarding isohaline location and subsequent potential risk for each habitat type of interest by comparing regression results with independent analysis of other datasets in a weight of evidence approach.

5.2 Springs Target Habitat Analysis

5.2.1 Introduction

Manatee and Fanning springs were given first consideration in establishing MFLs for the Lower Suwannee River system because, as described in Section 3, the flow of the springs is inextricably related to the flow of the river. These springs are located upstream from the portion of the Lower Suwannee usually susceptible to salinity influences so requirements pertaining to MFLs for the springs might directly impact the downstream assessment of the estuarine portion of the Lower Suwannee.

As discussed in Section 4, the Florida Manatee is an endangered species that must be protected by federal and state law. In providing adequate flow and passage for this species, other habitats are concurrently protected based upon the “best available data” criterion.

Manatee Habitat Requirements

It has been recommended that the most critical need for manatee survival in Florida is the availability of adequate amounts of warm-water habitat during the winter (Warm-Water Task Force, 2004). Manatee thermal refuge appears to be the primary factor of concern for development of MFLs for Manatee and Fanning springs.

The Warm-Water Task Force (2004) recommended that thermal refuges maintain a temperature of $\geq 68^{\circ}$ F (20 $^{\circ}$ C). This recommendation was also made by the USGS Sirenia Project for consideration at Manatee spring (Langtimm et al., 2003). This temperature criterion was also used by the St. Johns River Water Management District for the development of MFLs for Volusia Blue spring (Newfields Inc., 2004), with protection of manatee thermal refuge being a primary consideration for that spring system.

A second consideration for manatee thermal refuge, after temperature, is water depth. Langtimm et al. (2003) recommended minimum depths of 5 to 7 ft (1.5 to 2 m) for adequate manatee passage/thermal refuge volume. This was also the minimum recommended depth recommended for Volusia Blue Spring (Newfield, Inc., 2004).

As noted in Chapter 4, the main thermal refuge at Manatee Springs is the outflow plume of warm spring discharge at the confluence of the spring run and the river. Maintenance of adequate depths in this region is largely a function of the river flow. Maintenance of Manatee Spring flow is important to preserve the size of the plume in the river, and thus a minimum flow criterion is needed at Manatee.

Fanning Spring is different. The spring and spring run are the main thermal refuge, but water levels are primarily controlled by water levels in the adjacent Suwannee River (Section 3.2.3). Maintenance of manatee thermal refuge at Fanning Spring is a function of water depths in the spring run, which are a function of stage in the river (Section 3.2.3).

5.2.2 Thermal Refuge Analyses for Manatee and Fanning Springs

5.2.2.1 Data Sources

The data sources used for the thermal refuge analysis are as follows:

Manatee Spring

- Bathymetry: collected by Florida Geological Survey over April 4-5, 2005.
- Temperature: collected at six fixed sites (Figure 3-16) by USGS.
  1) Upstream of spring mouth on piling, 30 minute frequency, 12/19/03 - 06/17/04
  2) In spring run, 30 minute frequency, 12/19/03 - 06/17/04
  3) Buoy 1, ~180m downstream of spring mouth
1m, 15 minute frequency, 03/09/04 - 06/17/04
2m, 15 minute frequency, 12/18/03 - 06/17/04
  4) Buoy 2, ~105m downstream of Buoy 1
1m and 2m, 15 minute frequency, 03/10/04 - 06/17/04
  5) Buoy 3, ~95m downstream of Buoy 2
1m and 2m, 15 minute frequency, 12/18/03 - 06/17/04
  6) Buoy 4, ~50m downstream of Buoy 3
1m and 2m, 15 minute frequency, 12/18/03 - 06/17/04
- Water surface elevation, upstream and downstream, USGS
- New Clay Landing, upstream of Manatee Spring, 15 minute frequency, 02/19/04 - 06/25/04
- Fowlers Bluff, downstream of Manatee Spring, 15 minute frequency, 02/19/04 - 06/17/04
- Spring discharge, USGS, period of record
- Manatee sighting data, Florida Park Service (1993-present)
- Manatee sighting data, USGS (2003)

Fanning Spring

- Bathymetry: collected by WRA, June 2005
- Spring discharge, USGS, period of record
- Manatee sighting data, Florida Park Service (1996-present)
- Manatee sighting data, USGS (2003)

5.2.2.2 Water-Temperature Data

Water-temperature data were only available for Manatee Spring. Data to evaluate manatee winter thermal refuge came from several locations in relation to the Manatee Spring discharge into the river. Water-temperature data were collected by the USGS at Manatee Spring in the spring run and at several locations in the plume at the confluence of the spring run with the Suwannee River (Source: SRWMD). Data were collected mainly with continuous recording probes. Supplemental water-temperature data were collected during synoptic discharge runs with acoustic doppler instruments.

5.2.2.3 Spring Bathymetry Data

Spring bathymetry data at Manatee Spring were collected by the Florida Geological Survey under contract to the Florida Park Service. They used a GPS correlated acoustic depth finder and custom designed capture software to record position and depth information at one second sampling intervals. Additional bottom imaging was conducted using sidescan sonar to image the river bottom sediments. This data sidescan sonar product provides an aerial view of the river bottom in a wide swath looking sideways from the vessel centerline. Bathymetric soundings were simultaneously collected while sidescan operations were underway. Vertical control was achieved by correlating the depth of water below the transducer to river level data from nearby monitoring stations. Several river level gages are operated by the USGS within the vicinity of and at the vent of Manatee spring. River level data were downloaded at the end of survey operations from the USGS National Water Information System Web Site and used to calibrate the depth values for changes in river level caused by tides and spring discharge. This calibration ensures that data collected over the course of several days are vertically correlated to the same base plane, regardless of the river stage. Bathymetry data at Fanning Spring were collected in June 2005 by a licensed survey firm under contract to Water Resources Associates, using conventional rod and level techniques. The survey data were set to elevations in the National Geodetic Vertical Datum (1929) using a nearby benchmark.

5.2.2.4 Manatee Sighting Data

Manatee-sighting data were provided by the Florida Park Service for both Manatee and Fanning springs. Manatee sightings at Manatee spring have been taken by park personnel since 1993, and at Fanning spring since 1996. Note that these records may include repeated sightings of the same animal. They are based upon the single highest count of individuals seen on any given day, i.e. if a ranger sees 3 in the morning, and 5 in the afternoon, the total count on the day is 5. Therefore, these data do not reflect the actual manatee population size using the spring, rather they are a general index of manatee abundance.

Additional manatee data came from a study conducted for SRWMD by the USGS Sirenia Project (Langtimm et al., 2003). They summarized characteristics of the regional (Northwest Florida) manatee population and their main winter refuges (Crystal and Homosassa rivers). This population has been exhibiting a clear increasing trend in numbers over the last 30 years. As noted earlier, Manatee Spring was identified as an important secondary, winter-refuge area, primarily during the late fall and late winter, when manatees are either traveling to or dispersing from the main winter-refuge sites and must find a short-term thermal refuge when early- or late-season cold fronts affect the region. They also presented actual "hard counts" of manatee abundance in the Suwannee River and Manatee Spring, based on aerial surveys and identification of discrete individuals. Some of their data on individual manatees go back 30 years. One female manatee ('CR071') has returned to Manatee Spring repeatedly during the winter since 1976. A total of 21 distinct individual manatees have been recorded using Manatee Spring since the mid-1970's. This report (Langtimm et al., 2003) also presented recommendations for manatee habitat considerations with respect to developing MFLs for Manatee Spring.

Manatee sightings data indicate that peak use of Fanning and Manatee springs occurs between December and March (Figures 5-1 and 5-2), indicating the value of the springs as winter warm-water habitat. Manatee sightings data from Fanning Spring indicate that more sightings are made when the spring stage exceeds 2.71 feet msl (Figure 5-3). This equates to a depth of at least 5 feet (1.5 m) in the shallowest part of the Fanning spring run. Sightings probably decline at higher stages because more river water is intruding into the spring, lessening its value as thermal refuge.

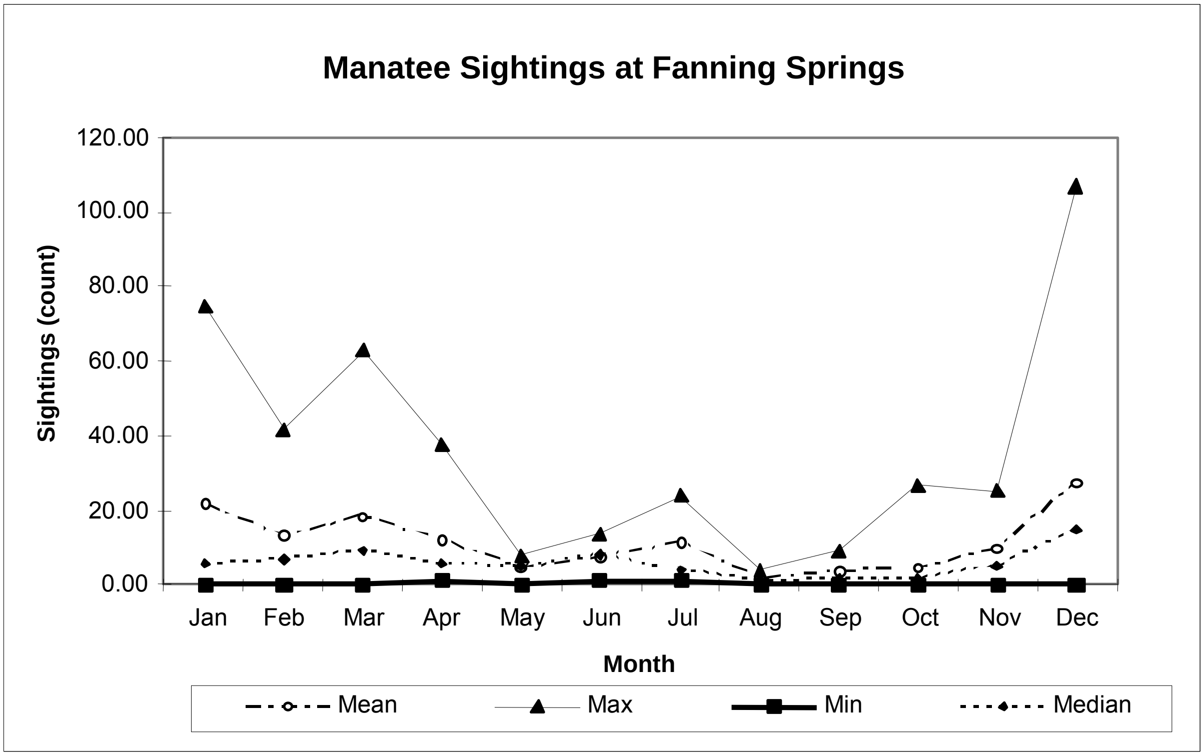


Figure 5-1. Plots of monthly manatee sightings at Fanning Springs. Source: Florida Park Service.

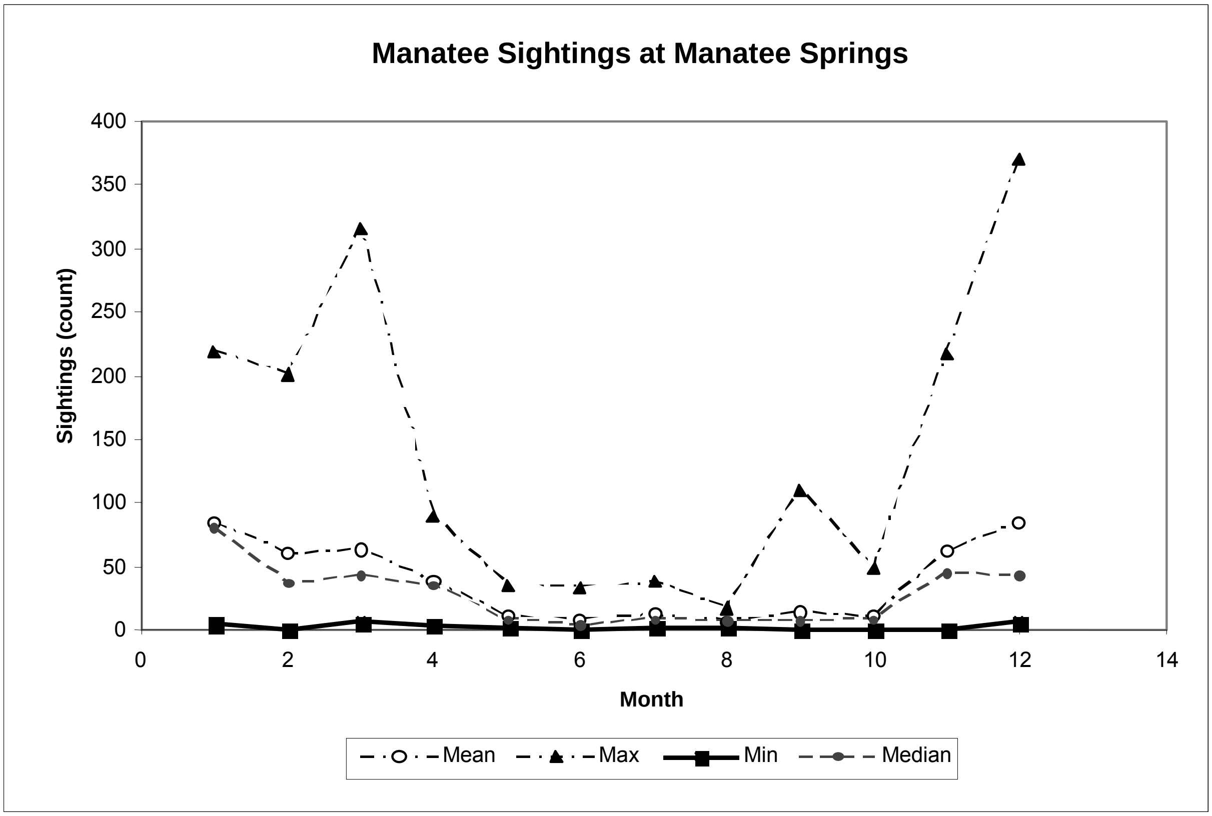


Figure 5-2. Plots of monthly manatee sightings at Manatee Springs. Source: Florida Park Service.

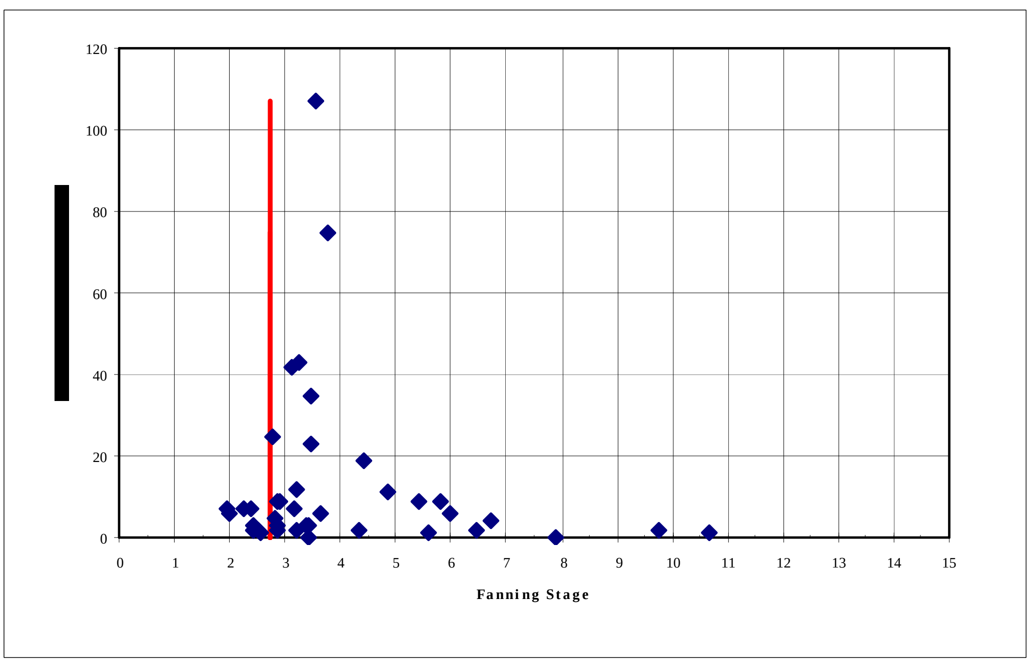


Figure 5-3. Plot showing manatee sightings in Fanning spring versus stage. Vertical line indicates depth of 5 feet in the spring run at a stage of 2.71 feet in the spring pool.

5.2.2.5 Thermal Model Description for Manatee Spring

To aid in MFL development, a temperature model was developed for that portion of the Suwannee River in which the temperature effects of the spring discharge are most likely discernable (Figure 5-4). The affects on temperatures in the river of various scenarios of river flow and spring flow were examined using CE-QUAL-W2. CE-QUAL-W2 is a two-dimensional, laterally averaged, hydrodynamic model developed and supported by the US Army Corps of Engineers, Waterways Experiment Station (Cole and Wells, 2000). The mechanistic model predicts water-surface elevations, velocities, salinity, and temperature.

The model provides predictions that are laterally averaged (across the entire water body perpendicular to the direction of horizontal flow), so that the model integrates any lateral differences in velocities, temperatures, or modeled constituent concentrations. The model accommodates multiple inflows and time-varying boundary conditions for surface elevation, temperature, and constituent concentrations.

5.2.5 Model Development

To identify the effects of the spring discharge on temperature in the river, the temporal domain of the model was limited to the February - April 2004 period, during which river temperatures ranged from 55°F (13°C) to 75°F (24°C). With the relatively constant spring-water temperature of 72°F (22°C), the effects on temperatures in the river were expected to be most evident during this period. However, temperature observations at the fixed buoys showed that water temperature was below 68°F (20°C) until the middle of March, so that the effects of the warmer spring water were not detected at the buoy locations.

The model spatial domain was limited to the nearshore region in the vicinity of the spring mouth, the most likely location of the spring plume (D. Hornsby, pers. com.). The length of the domain along the axis of the river is 2,195 ft., with the width of the domain approximately 82 ft. The model domain was divided into 11 grid cells, with the highest resolution grid cells from the mouth of the spring downstream for approximately 330 ft. This highly resolved region represents the area most likely affected by the plume (Figure 5-4). Cells 1-8 were each one layer deep. Cells 9-11 were two layers deep. The surface layer in each of the 11 cells was 5 ft. deep.

Note the distribution of the plume is flow sensitive. At high flows the plume is closer to the eastern shore and more extended downstream than at low river flows where it is more wider into the river.

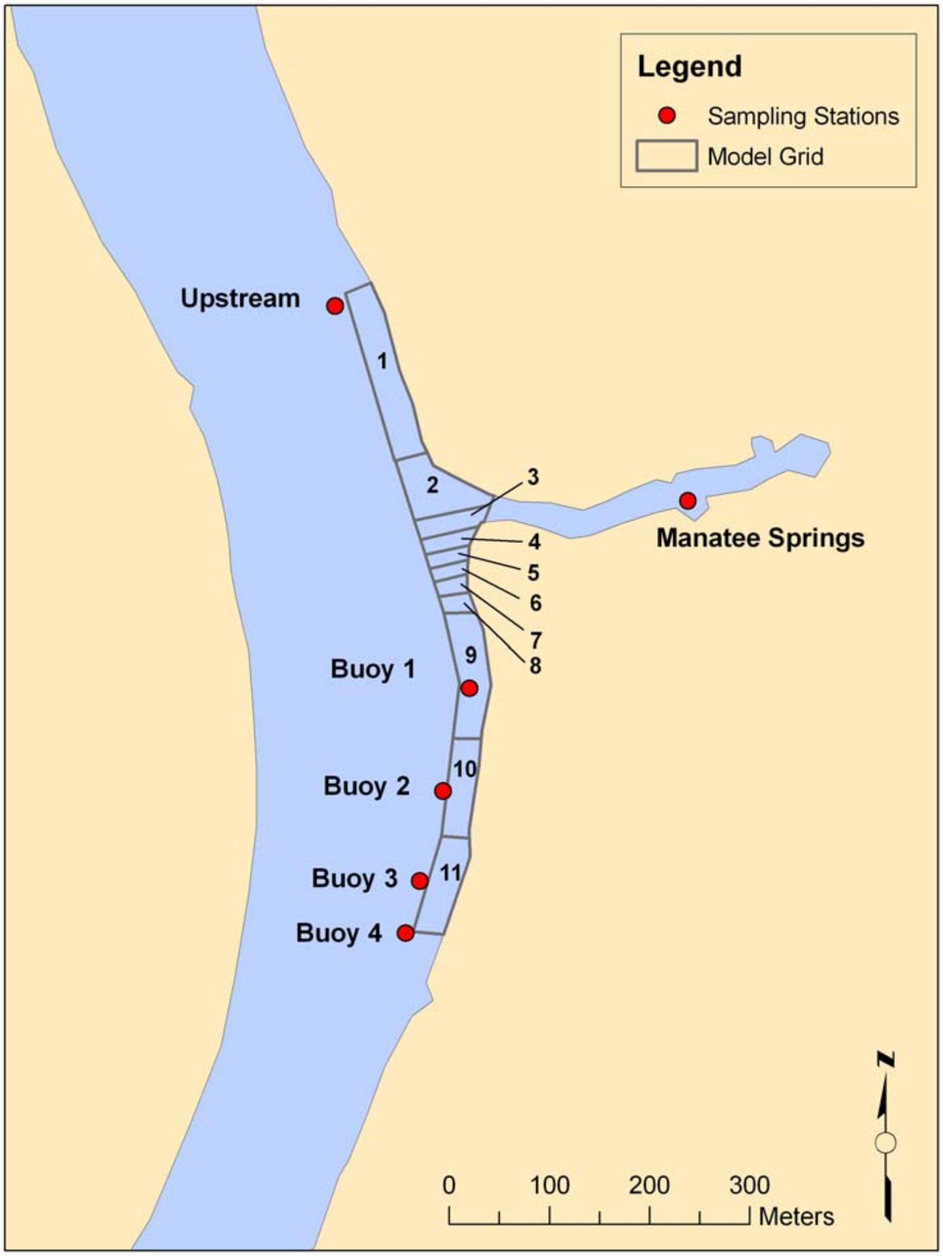


Figure 5-4. Temperature sampling sites and model grid for Suwannee River near Manatee Spring. Upper grid shows horizontal along-stream layout with numbered gridcells.

5.2.2.5.2 Model Calibration

The model was calibrated using data for the period February 20 – April 30, 2004. During this period, Manatee Spring flow ranged from 124 cfs to 168 cfs (Figure 5-5), while river flow ranged from 4,200 cfs to 12,500 cfs (Figure 5-6). As river flow declined and spring flow increased, the relative proportion of Manatee Spring flow as a fraction of the total river flow increased from 1% to 3.5% (Figure 5-7). From a mass-balance perspective, the effect of Manatee Spring on river water temperature increases as the proportion of the total river flow made up of spring discharge increases.

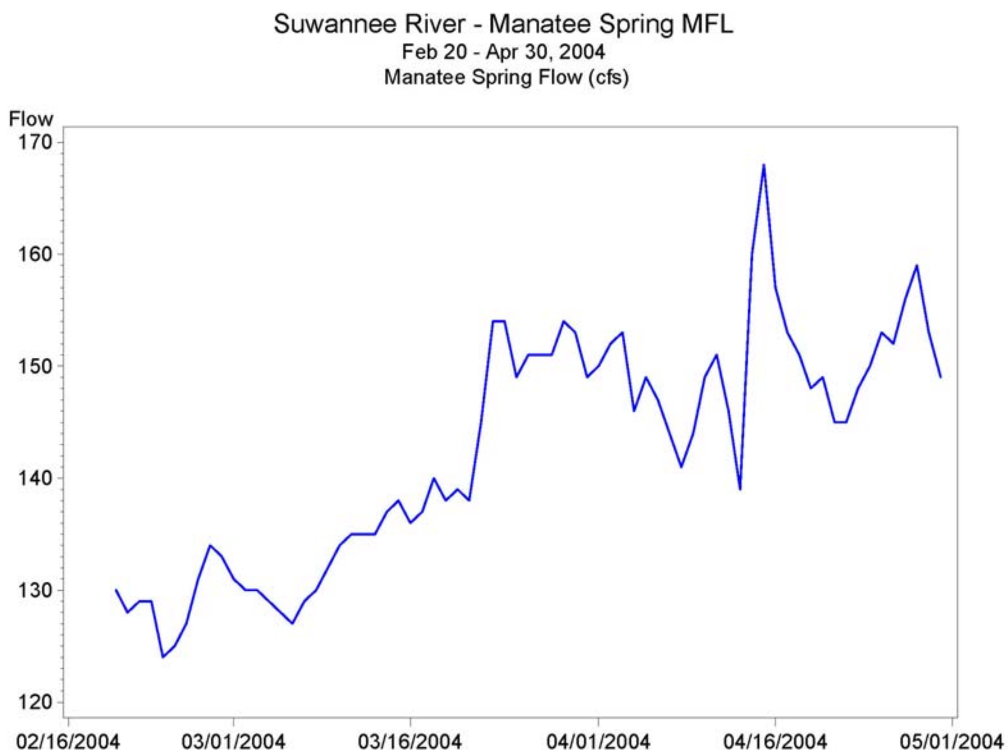


Figure 5-5. Manatee Spring flow, 2/20/04-4/30/04.

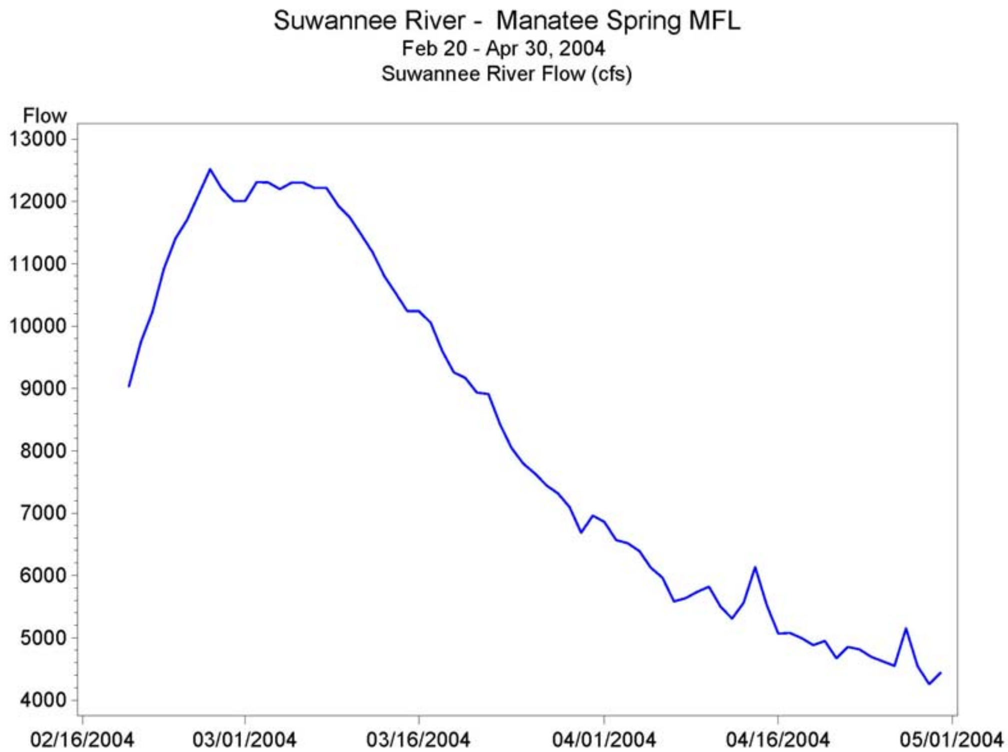


Figure 5-6. Total river flow (Suwannee River near Wilcox + Fanning Springs near Wilcox), 2/20/04-4/30/04.

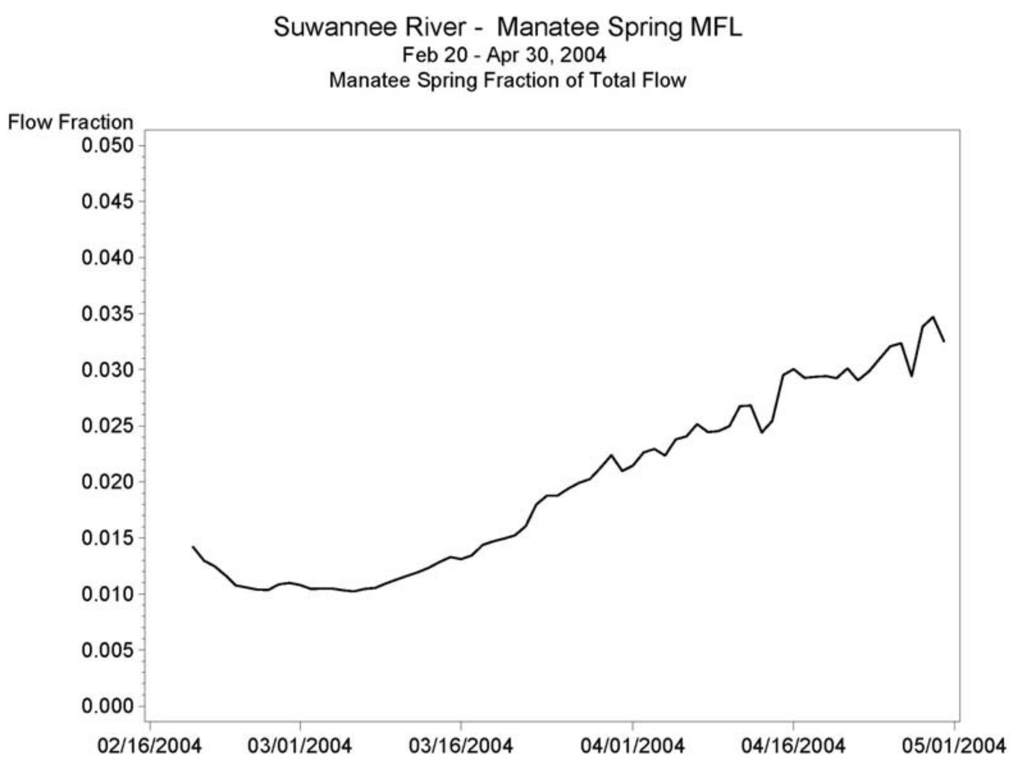


Figure 5-7 Fraction of total river flow made up of Manatee Spring flow, 2/20/04-4/30/04.

The river flow into the model was estimated using the total river flow and the bathymetry. The river-flow estimate into the northern model domain was derived by scaling the flow into the domain by the fraction of the river cross-sectional area represented by the northern face of the model domain. The portion of the river within the northern domain of the model is very shallow. This area was estimated at approximately 2% of the total river cross-sectional area, so that the flow into the northern model domain was set to 2% of the total river flow. The bathymetry shows increasing depths along the eastern shore south of the mouth of the spring, suggesting that the amount of flow through the model domain increases in the southern portion of the grid. Additional inflows into the southern cells of the domain (cells 9-11) were included to account for this increase in depth, based on the relationship of the total river volume across the river to the cell volume. This resulted in an additional 3.5% of the river flow going in to cell 9, an additional 6.5% of the river flow going in to cell 10, and another 6% of the river flow going in to cell 11.

The model output was compared to observed data collected at Buoy 1, Buoy 2, and Buoy 3. Appendix F shows the comparisons of daily mean temperatures at both 1m and 2m at each of the buoys. The model accurately predicts the observed temperatures during this period.

5.2.2.5.3 Model Scenarios

To examine the effects on temperature in the river as a function of river flow and spring flow, a baseline flow regime was selected, with variations on this regime selected for comparison. Monthly discharge estimates were developed for the springs based on river and local ground-water levels for the period February 1993 – September 2004 (Section 3.2.3.3). The baseline flow regime was selected as the median monthly flow for the river just upstream of Manatee Spring (Suwannee River near Wilcox + Fanning Springs near Wilcox) and the median monthly flow at the AVM gage at Manatee Spring. Variations included modifying the Manatee Spring flow to the 25th and 75th percentile while keeping the total river flow at the median, and modifying the river flow to the 25th and 75th percentile while keeping the Manatee Spring flow at the median. These scenario definitions are shown in Table 5-1.

Table 5-1. Thermal Modeling Scenario Definitions.

Scenario	River Flow	Manatee Spring Flow
Baseline (Scenario 1)	50th percentile	50th percentile
Scenario 2	50th percentile	25th percentile
Scenario 3	50th percentile	75th percentile
Scenario 4	25th percentile	50th percentile
Scenario 5	75th percentile	50th percentile

The monthly flow rates for February-April are shown in Table 5-2. Data for Fanning and Manatee Springs are for the period of record for those gages (see Tables 2-12 and 2-13). This period was drier then normal (see Section 3.2); long-term median discharge for these springs is greater than shown in Table 5-2.

Table 5-2. Suwannee River and Manatee Spring monthly flow rates.

Month	River Flow (cfs) (Suwannee+Fanning)			Manatee Spring Flow (cfs)		
	25th	50th	75th	25th	50th	75th
February	6915	11406	16645	110	128	143
March	8550	14412	19792	132	137	149
April	8398	13379	19854	146	150	153

Elevation and temperature boundary conditions were the same for all scenarios, and were set by observed conditions for February 20 – April 30, 2004.

5.2.2.6 Flow Analyses for Manatee Protection at Manatee Springs

As for the calibration, time-series graphs of daily mean predicted temperatures were plotted. The temperatures within each grid cell were examined. The temperature time series are shown in Appendix F. As expected, scenarios with a higher ratio of Manatee Spring flow to total river flow (Scenarios 3 and 4) show warmer temperatures than the baseline.

The effects of the Manatee Spring inflow on temperatures are not seen in the cells upstream of the mouth of the spring run, cells 1 and 2 (Appendix F; Figures F-7 and F-8). The effects are seen in all cells downstream of the mouth, especially at lower temperatures.

The metric of primary interest in evaluating the scenario results is the volume of water greater than 68°F (20°C). This defines the available volume for manatee refuge during colder periods. For each scenario, the proportion of the volume in cells 3-8 greater than 68°F was estimated on a daily basis. Appendix F illustrates a comparison for each scenario to the baseline (Figure F-21).

The greatest increase in volume of water greater than 68°F as compared to the baseline is found in Scenario 4, where the river flow is 25th percentile. This is as expected, as this scenario maximizes the ratio of spring flow to river flow.

The two scenarios with river flow at the median and Manatee Spring flow at the 25th and 75th percentiles do not differ greatly. This is the result of the relatively small change in the ratio of Manatee Spring flow to the total river flow, from approximately 0.9% to 1.1%, as spring flow goes from 25th to 75th percentile. However, comparison of these scenarios to the baseline does indicate that a decrease in Manatee Spring flow below the median results in a decrease in the volume of water with temperature of 68°F or more.

Given these results, a potential minimum flow for Manatee Spring during the cold season (November-March) would be the median monthly flow for the period from 2001 to present. For these months, the median monthly flows are as follows:

November	130.5 cfs
December	132.0 cfs
January	141.0 cfs
February	128.0 cfs
March	137.0 cfs

The seasonal median flow, based on AVM data from the Manatee Spring gage, is approximately 130 cfs.

5.2.3 Stage (Level) Analysis for Manatee Protection at Fanning Spring

The criteria for manatee refuge access at Fanning Spring was based on stage in the spring and spring run. On June 20, 2005, a land surveying company retained by WRA collected several cross-sectional profiles across the Fanning Spring run. This survey was utilized to identify the "sill" within the thalweg of the spring run, in order to address manatee passage issues. The elevation of the thalweg within these profiles ranged from a low of –3.81 feet NGVD to as high as –2.29 feet NGVD) (see Appendix C for cross-sections). Since the 5-foot passage criterion has been suggested for manatee passage, a 5-foot depth was added to -2.29 resulting in a stage of 2.71 feet NGVD. This stage provides adequate protection from significantly adverse impacts to manatee habitat for Fanning spring. Figure 5-8 compares the distribution of stage at Fanning Spring by month with the possible cold season MFL criterion of 2.71 feet NGVD.

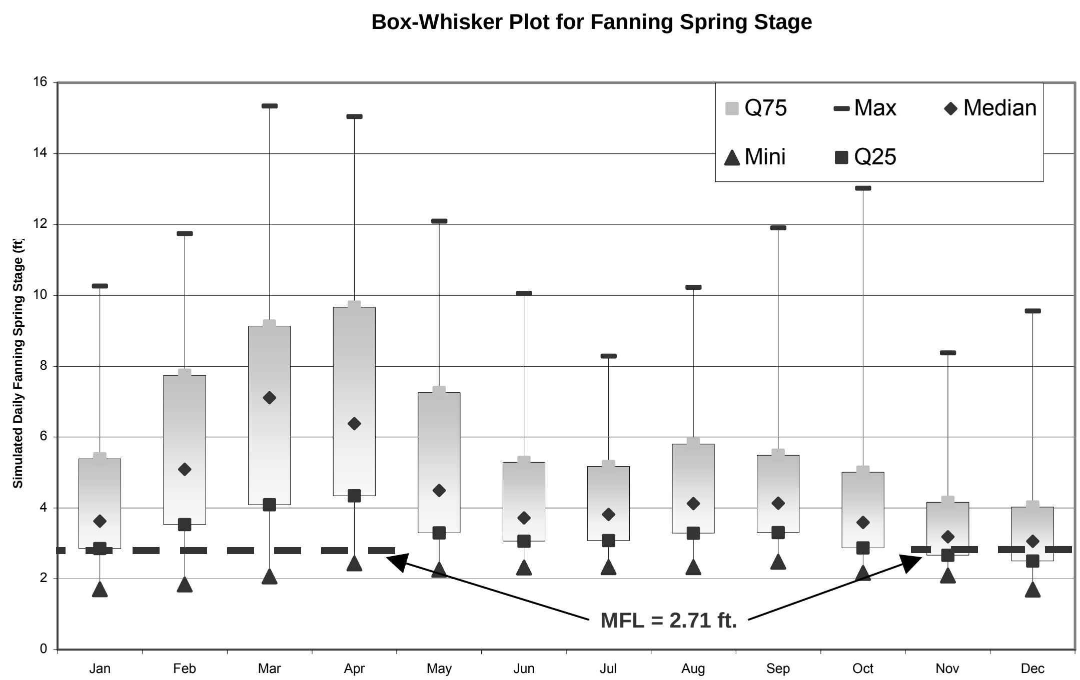


Figure 5-8 Distribution of Fanning spring Stage with cold-season reference line at 2.71 feet NVGD.

Stage at Fanning Springs is dependant on stage within the Suwannee River (see Section 3.2.3.3.1), which is not a simple function of flow, particularly at low river stage/discharge (Figure 5-9). At a stage of 2.34 ft (which equates to 2.71 feet NGVD at Fanning Spring), discharge at the Wilcox gage ranges from about 2000 cfs to about 9000 cfs. Therefore, it is not possible to state a unique discharge value for Wilcox that corresponds to an exact stage of 2.71 feet NGVD at Fanning Spring. However, it is possible to calculate a probability that stage will be 2.71 feet NGVD or greater at Fanning Spring for a given Wilcox discharge. As manatee passage is only of critical concern during the winter months, the probability of Fanning stage exceeding 2.71 feet NGVD for a range of Wilcox flows was determined for the cold months only (November – April).

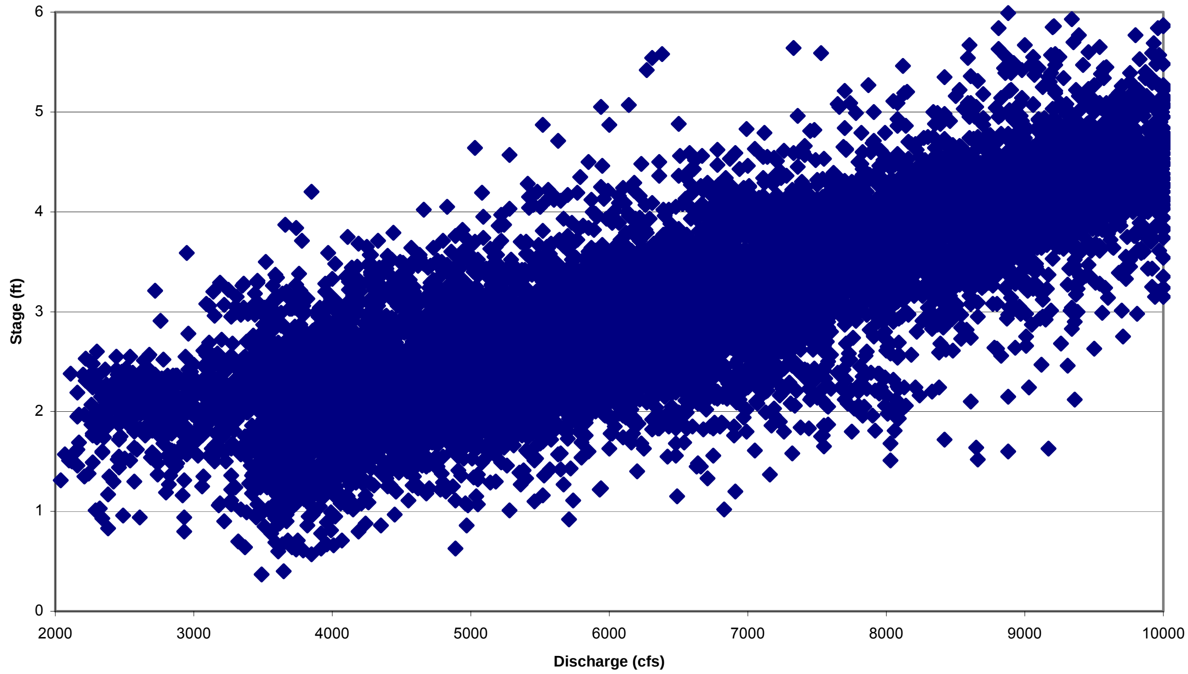


Figure 5-9. Stage-discharge graph for the Wilcox gage at low stage/discharge.

As discussed in Section 3, the historic dataset for the Wilcox gage does not contain stage data between 1941 and 1951 for days when the stage was below approximately 5 feet NGVD. To avoid skewing the results of the following analysis, only stage and discharge data for the Wilcox gage from after February 1951 were used. This stage and discharge data were first sorted from highest to lowest discharge, keeping the stage value for a given day with the corresponding discharge. The data pairs where then ranked from first to last by discharge and assigned an exceedance probability based on this ranking, in the same manner that the flow duration curve for Wilcox was developed (Figure 3.2).

Next, the range in stage was analyzed for a series of flow values with a set interval of exceedance probabilities (i.e. exceedance probability of 0.5, 0.55, 0.6, etc.). For example, the median discharge within this data set is 8,620 cfs. Within a 1 % range of the median discharge (exceedance probability of 0.495 to 0.505, discharge from 8,530 cfs to 8,710 cfs), the stage at Wilcox has varied between 1.52 and 5.67 feet NGVD. By sorting and ranking by the stage, it is determined that the stage at Fanning Spring is above 2.71 feet NGVD 97 % of the time for the median discharge at Wilcox during the cold season.

The resulting probability distribution for a range of flows at Wilcox is shown in Figure 5.10. This figure can be utilized to determine the reduction in the percent of time Fanning Spring run is passable by manatees for a given reduction in Suwannee River flow as measured at the Wilcox gage.

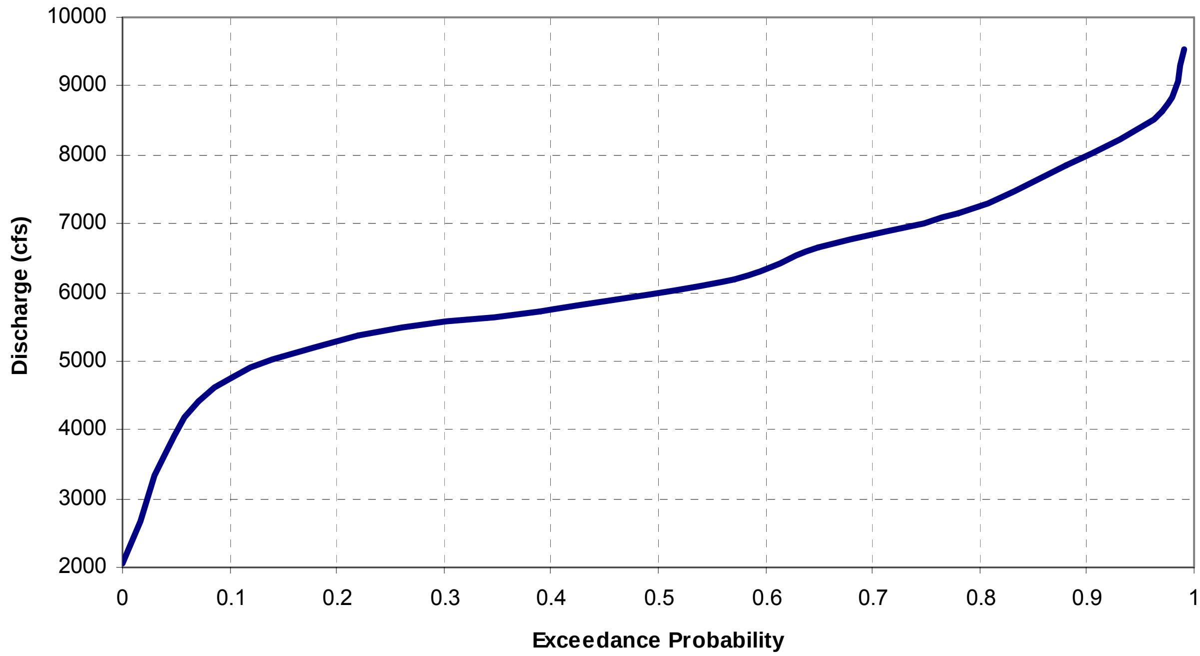


Figure 5-10. Probability that the stage at Fanning Spring will be greater than 2.71 ft. NGVD for a given discharge at the Wilcox gage (cold season only).

5.3 Lower Suwannee River Target Habitat Analyses

5.3.1 Quantifying Relationships between Flow and Salinity for Downstream Habitats

5.3.1.1 Data sources

Several data sources were used to develop salinity-flow regressions.

- Daily average discharge data were obtained for USGS gage number 02323500 (Suwannee near Wilcox) from 1984-2004.
- Salinity data from longitudinal surveys conducted at fixed station locations in the Lower Suwannee River by SRWMD in co-operation with the Florida Game and Fish Commission (GFC) at high slack tide 1993-1995 (Figure 5-11) were used to develop isohaline regressions.
- Four USGS fixed station gages located in East and West pass of the Suwannee River were also used to represent daily average or daily maximum salinity at the surface, mid-water, and bottom depths.
- In Suwannee Sound, the SEAS salinity collections throughout Suwannee Sound and in the Lower Suwannee River were used to assess monthly median salinities as a function of flows. Hourly tidal measurements taken at the NOAA Cedar Key Station from 1997-2003 were used to correct salinity for tidal state when possible.

5.3.1.2 Relating Flow and Isohaline Location

Regression relationships were developed between flow at Wilcox and isohaline location in the Lower Suwannee River. The flow at Wilcox was regressed on salinity by considering the flow rate in cubic feet per second (cfs) on the date when the salinity data were recorded as well as antecedent flows. Derived flow variables included:

- Daily flows as well as various transformations of flows (e.g. logarithmic, inverse, and power transformations such as flow^$^{1/2}$).
- Lag flows to 15 days: For example lag1 flow is the flow on the date prior to the salinity sample date.
- Cumulative flows to 8 lagged days: For example, cum4 is the sum of the flow on the sample date and the three previous days flow.
- Lag average flows in 15 day intervals to 90 days: for example lag average 7 is the sum of the flow on the sample date and 6 days prior to sampling divided by 7.

Salinities and salinity isohalines could then be related to various antecedent flows as well as the sample date flows at Wilcox. A hypothetical relationship between flow and the location of a given isohaline (e.g., 5 ppt surface isohaline) is shown in Figure 5-12.

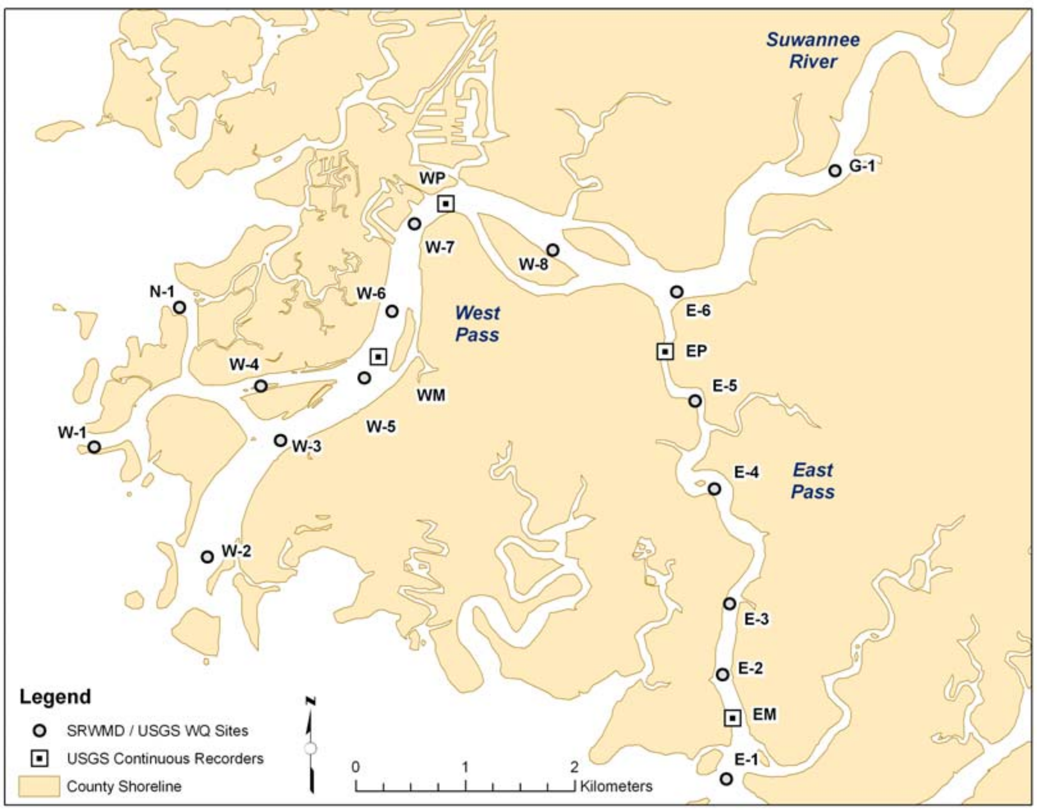


Figure 5-11. Salinity sampling stations used by the SRWMD and USGS to characterize salinity in the Lower Suwannee River.

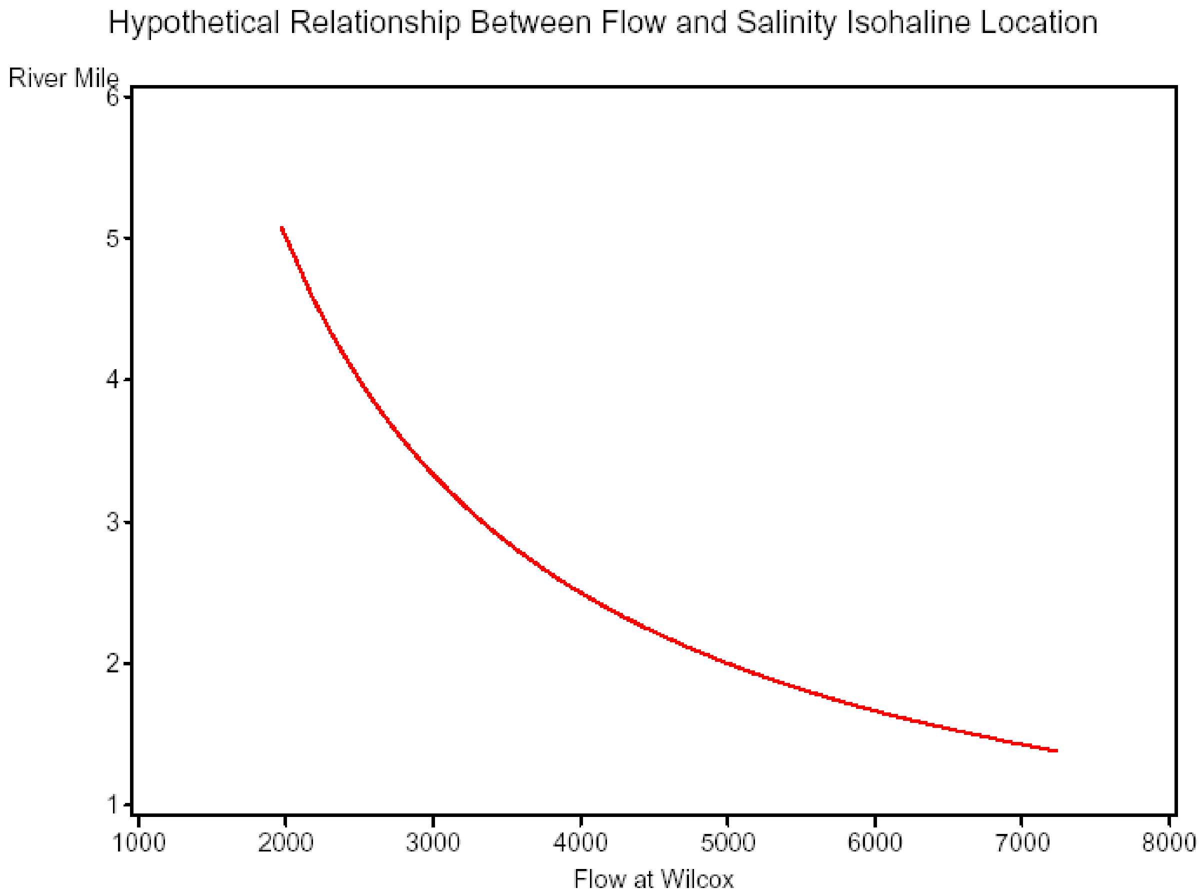


Figure 5-12. Conceptual relationship between flow at Wilcox and the location of an isohaline in the Lower Suwannee River.

5.3.1.3 Quantification of Habitat

Important habitats (as identified in Section 4.0) were quantified using geo-referenced habitat data when available. ArcGIS allows the user to calculate total areas for polygon or line coverages. Geo-referenced data were available for tidal swamp and SAV habitats. A river mile system was constructed for the Lower Suwannee based on District georeferencing (Figure 5-13: also see Appendix G for details). Quantification of each habitat type began at the downstream limit of that habitat. Cumulative percentages of the total acreage were calculated at ¼ mile intervals from the downstream limit. Linear interpolation was used to calculate percentages between ¼ mile intervals when necessary. This allowed for the cumulative percentages to be directly related to a location in the Lower Suwannee (Figure 5-14). Tidal creek habitat was evaluated by counting the total number of access points, defined as the mouth of each creek, and calculating cumulative percentages of the total number of creek access points for each ¼ mile interval starting at the downstream limit.

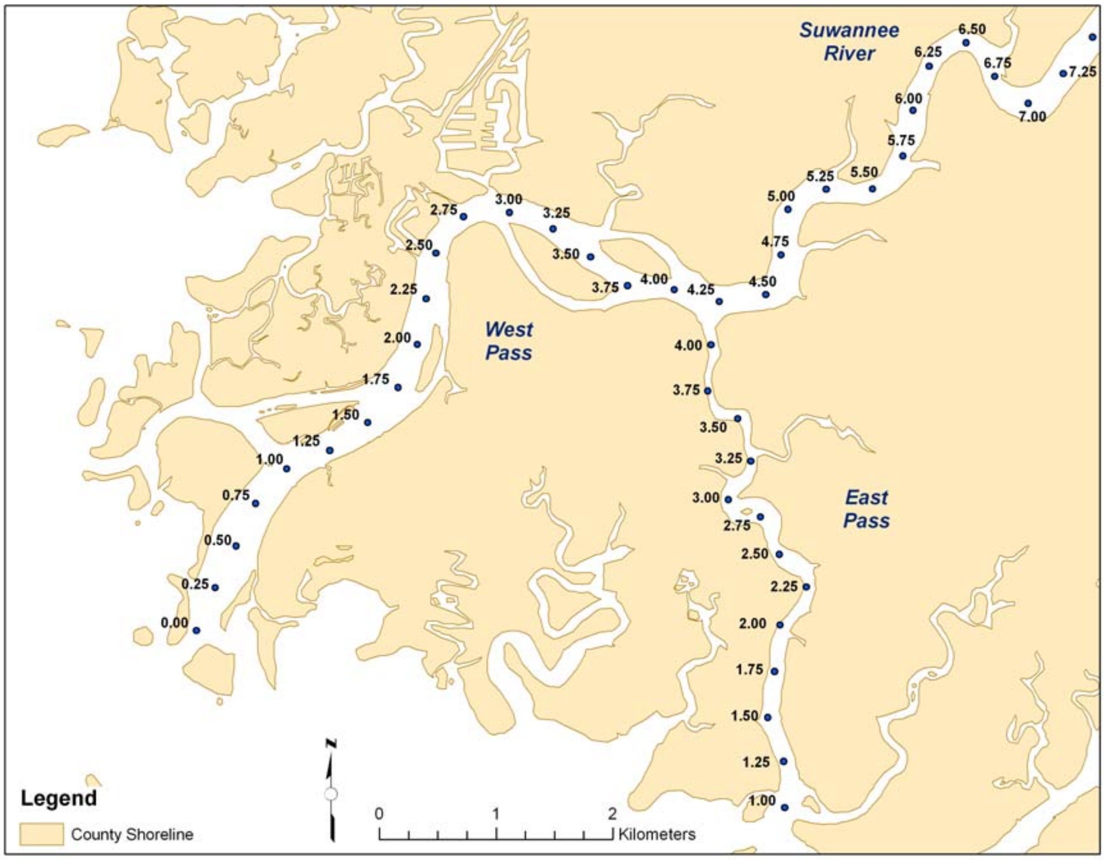


Figure 5-13. River mile system used to quantify habitat in the Lower Suwannee River.

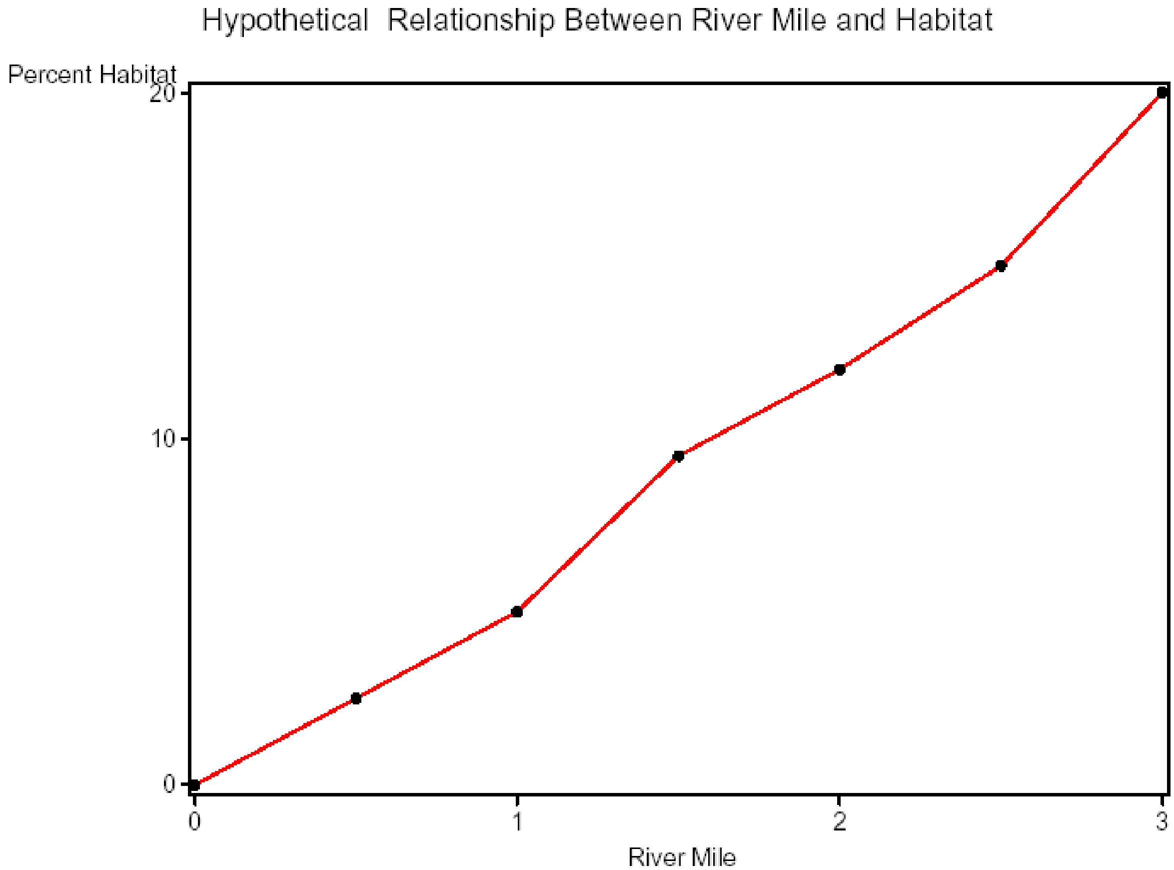


Figure 5-14. Conceptual relationship between river mile and cumulative habitat distribution.

5.3.1.4 Estimating Habitat at Risk with Changes in Flow

Estimations of flow-isohaline location relationships were used to identify the upstream incursion of a specific isohaline under varying flow conditions. River locations associated with 0 to 15 % of the total habitat were identified as risk points for each habitat type of interest. A regression equation could then be used to solve for the flow required to keep a particular isohaline below each of the risk points (Figure 5-15).

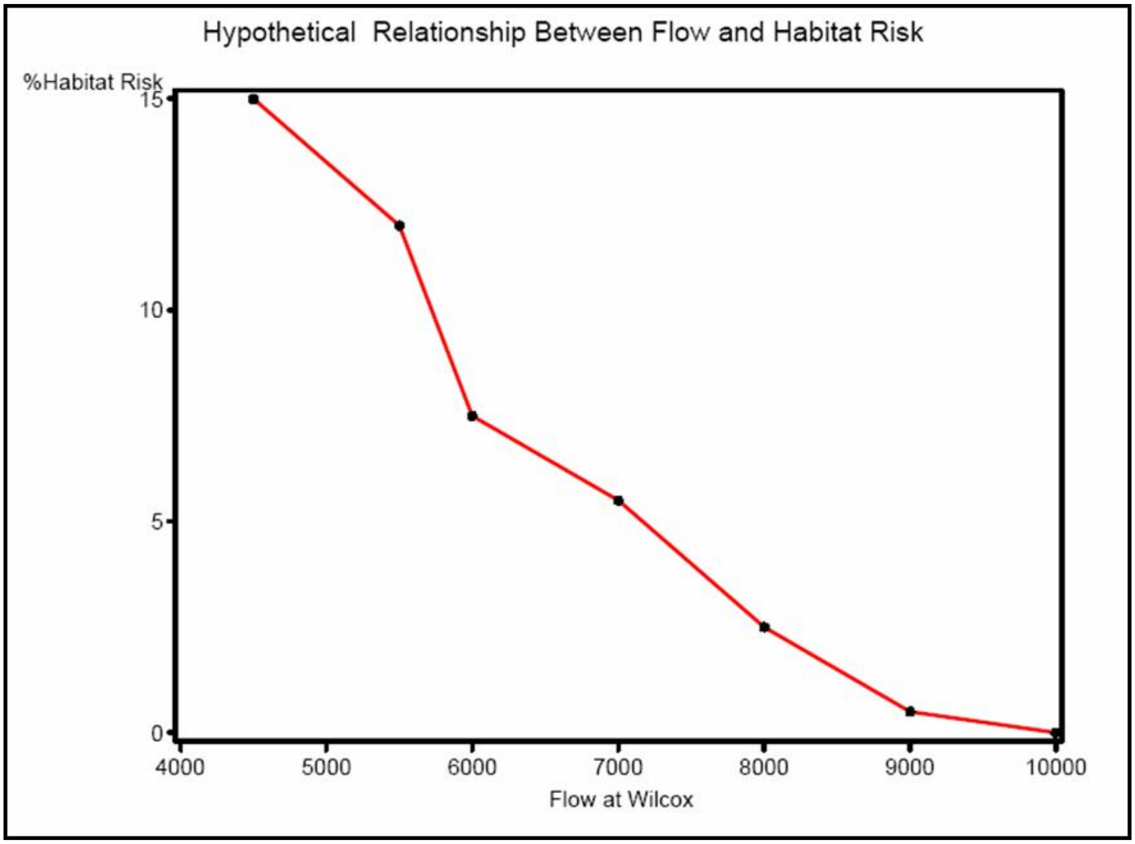


Figure 5-15. Conceptual relationship between flow and associated risk of habitat loss.

5.3.2 Upper Estuary Submerged Aquatic Vegetation

5.3.2.1 Data Sources

Studies on submerged aquatic vegetation (SAV) in the upper estuary were conducted for the SRWMD by Mote Marine Laboratory (Mote) (Estevez and Sprinkel, 1999; Estevez, 2000b; 2002) and by Golder Associates (2000). Mote sampling sites are shown in Figure 4-6 of Golder and Associates (2000). These 16 sites were selected jointly by Mote and District scientists during a pre-study reconnaissance. Placement of sites was systematic, extending from the downstream limit of SAV in East, Alligator, and Wadley passes up to the confluence with the Gopher River, where salinity never penetrates under ordinary climatic and river flow conditions. The overall goal of the Mote SAV study was to describe the characteristics of SAV where it occurred in the upper estuary and relate to salinity regimes, as opposed to making broader generalizations about SAV in the upper estuary, which would have required a probability based site selection procedure.

At all 16 sites, SAV characteristics of frequency, cover and abundance by species were measured using 0.25 m^2 quadrats and the non-destructive Braun-Blanquet method. This involves assigning a score to each species of SAV observed in the quadrats based on the following scale:

Braun-Blanquet Score	Estimated Cover
1	< 5%
2	5-25 %
3	25-50 %
4	50-75%
5	75-100%

Quadrats were deployed haphazardly about the grassbed at each site during sampling. Sampling was conducted 4 times on a quarterly schedule from March 1998 to January 1999. The 16 sites were re-visited in June 2000 and July 2002 during a severe drought.

Additional SAV data were collected at a subset of six of the 16 study sites. Six (6) quadrats of 0.0625 m^2 area were haphazardly deployed about the grassbed at each site, and all SAV within the quadrat was harvested for determination of dry weight standing crop. In the laboratory, collected plant material was separated by individual plant species and then divided into leaf (above ground) and root (below ground) components by species. This material was air-dried for 24 hours, and then further dried at 75-80^{o}C in ovens to obtain dry-weight standing crop.

SAV was mapped by Golder Associates (2000) in late spring and summer of 2000. Mapping was conducted using “in-the-field” technology. A Trimble® AgGPS 132 Global Positioning System unit was linked to a laptop computer with software which linked the GPS system to ESRI® GIS software. The edges of individual grass beds were delineated in the field by walking the perimeter of each bed with the GPS unit. The hardware and software recorded this polygon on the laptop computer. Various attributes of the grassbed (species composition, dominant species, salinity, etc.) could then be entered into the computer to build the GIS attribute database. Because the mapping effort was conducted during an extreme drought, there were areas known to historically support SAV which were now unvegetated. SRWMD staff located these for Golder Associates field personnel, and areas of unvegetated substrate in depths <3 ft (0.9 m) were delineated during dead low tide to conservatively estimate the amount of “potential” or “historic” SAV habitat. A river mile system was developed and used to help calculate the cumulative acreage of SAV in West Pass, moving from the downstream limit up to the confluence with East Pass.

5.3.2.2 Spatial Extent of SAV

Golder Associates (2000) delineated 27.1 acres (0.11 km^2) of SAV in the upper estuary during the drought of 2000 (Figure 5-16). An additional 4.4 acres of “potential/historical” SAV cover was conservatively identified in areas known to previously support SAV on a long-term basis. The majority of the SAV acreage is found in West Pass (Figure 5-16), from about river mile 1.5 (where Wadley and Alligator Passes split) up to the confluence with East Pass.

SAV generally grows in relatively shallow areas where depths are typically $\leq$3 ft at low tide. For purposes of MFL development, the downstream limit of SAV coverage in West Pass is regarded as river mile 1.0.

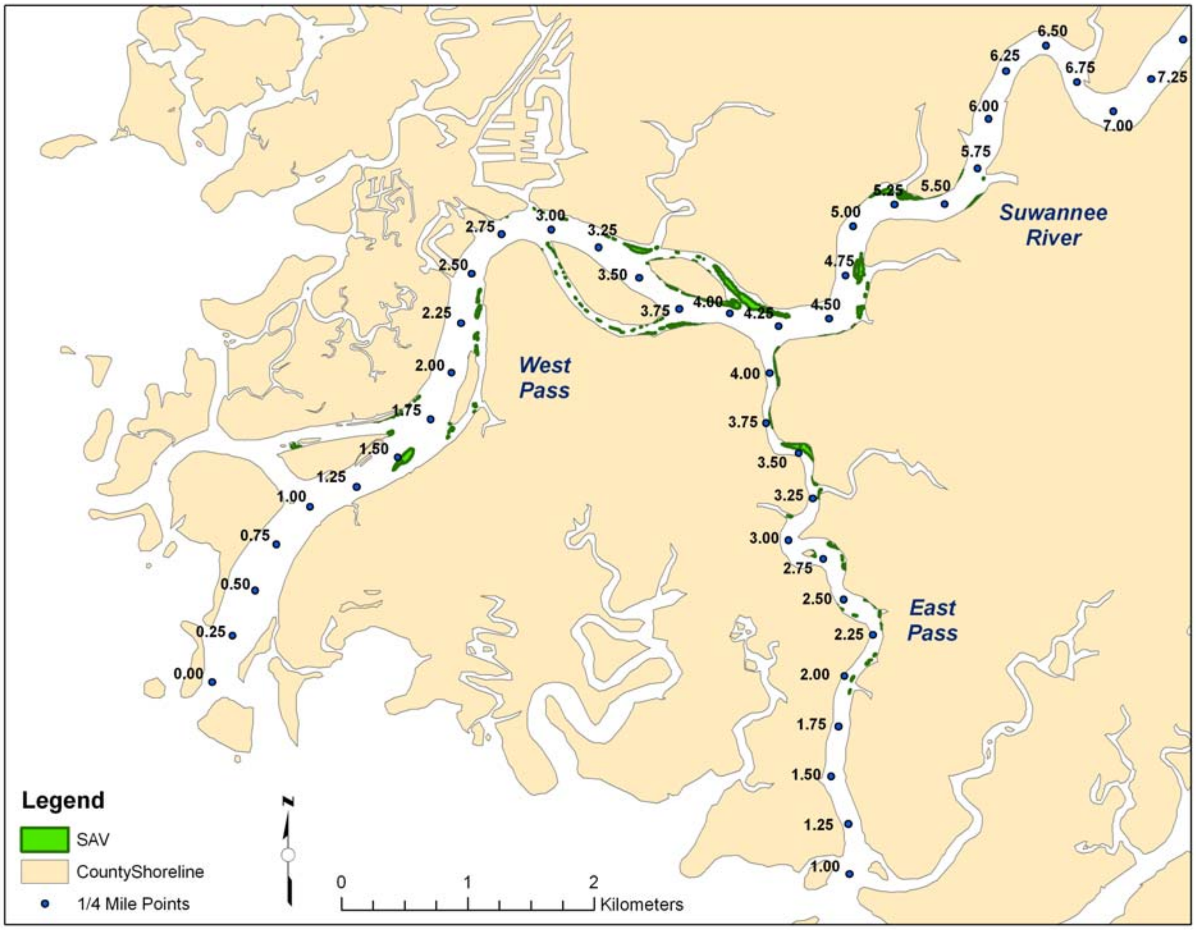


Figure 5-16. Map of the upper Suwannee estuary showing river mile system and SAV/potential SAV polygons mapped by Golder Associates in summer 2000.

5.3.2.3 SAV Habitat Requirements

The dominant species found in the upper estuary SAV beds are fresh-water plants, which are able to tolerate moderate levels of salinity. The dominant plant in these beds, *Vallisneria americana*, has been the subject of several studies. Haller et al. (1974) found that growth of *Vallisneria* ceased at 6.66 ppt salinity (i.e., ~7 ppt) in a greenhouse experiment. Twilley and Barko (1990), in an outdoor microcosm study, found that growth of *Vallisneria* was not significantly affected by salinities of up to 12 ppt. Doering et al. (1999) conducted laboratory studies of *Vallisneria* salinity tolerance and found that growth began to decline at salinities $\geq$9 ppt, and that growth ceased at salinities of 15 ppt.

As noted earlier, the downstream limit of *Vallisneria*-dominated beds in West Pass of the Suwannee estuary is approximately river mile 1.0. This area has a mean high-tide salinity of about 12 ppt (Mattson and Krummrich, 1995). During outgoing and low tides, salinity is lower (down to 0 ppt). Approximately 4 acres of SAV disappeared from the lower reaches of West Pass during the drought of 1999-2002. Figure 5-17 shows the Braun-Blanquet abundance data from the three surveys (1998-99; 2000 and 2002). Note how *Vallisneria* disappeared downstream of Station 7 in June 2000. A small amount of recovery occurred at selected downstream sites in July 2002, but other sites continued to be unvegetated (Figure 5-16).

This loss of SAV is presumed to be primarily due to increased salinity. Tidal currents in the passes are particularly strong, and the water column is generally well mixed, so dissolved oxygen was probably not a problem. Water clarity was much better than usual during the drought, and little periphyton growth was observed on the grasses, so light limitation can be largely ruled out.

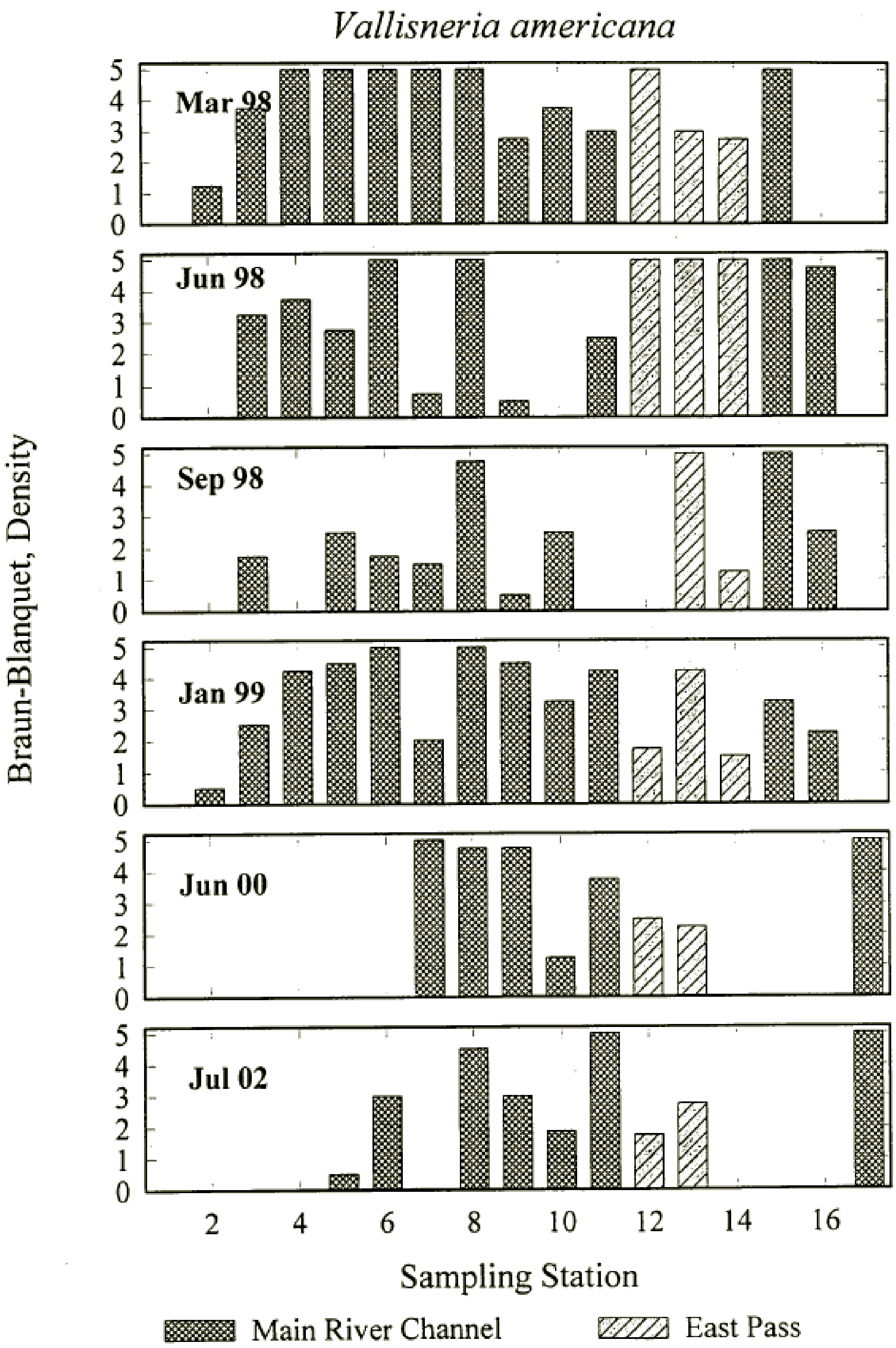


Figure 5-17. Braun-Blanquet abundance data of *Vallisneria americana* from surveys conducted by Mote Marine Laboratory in 1998-99; 2000; and 2002. Source: Estevez, 2002.

Based on the field observations in the Suwannee estuary, supplemented by the work of Doering et al. (1999), a critical salinity threshold of 9 ppt was chosen for analysis. In order to maintain the downstream limit of SAV at its present location, this salinity threshold was regarded as a conservative limit that would not stress *Vallisneria* beyond its normal tolerance.

5.3.2.4 Estimating Location of 9 ppt Isohaline

Salinity data collected by the SRWMD/FWCC in 1993-1995 were used to develop a regression model relating flow at Wilcox to the location of the 9 ppt isohaline (Figure 5-18). Analyses were restricted to Wadley and West Pass, since the majority of the SAV coverage in the upper estuary is found in West Pass. Salinities are uniformly lower in East Pass, compared to West Pass (Tillis, 2000; Mattson and Krummrich, 1995), so salinity criteria to protect SAV in West Pass should be equally protective in East Pass.

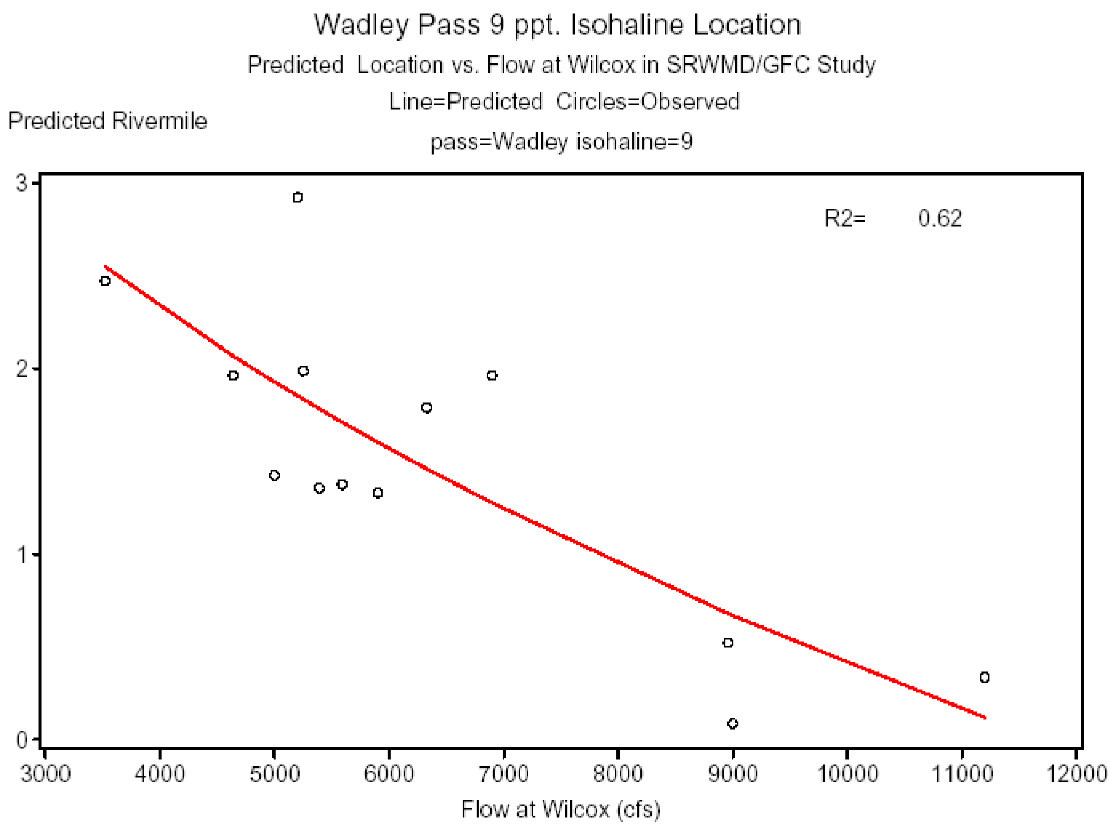


Figure 5-18. Plot of regression model relating flow at Wilcox to the location of the 9 ppt surface isohaline in Wadley Pass and West Pass.

The isohaline regression relationship developed for the 9 ppt isohaline in West Pass was validated against predicted and observed salinities at the WM continuous recorder (river mile 1.82). This validation exercise is described in more detail in Appendix H. The isohaline regressions predicted a 9 ppt isohaline at river mile 1.82 for a flow of 5,320 cfs at Wilcox. This compared well with the average flow (5,353 cfs) for predicted daily maximum mid-water salinities at WM between 8.5 and 9.5 ppt. Further validation was achieved by comparing regression results with salinity flow regressions from individual fixed station which all suggested that the 9 ppt isohaline predictions in West pass provided valid inference for establishing SAV habitat risk.

5.3.2.5 Estimating SAV Habitat at Risk

Flows below 6,200 cfs were associated with a rapid increase in the amount of SAV habitat at risk (Figure 5-19). This area corresponds to a shallow flat located at river mile 1.5 just below station W-5 (Figure 5-20). This is an area is known to be affected by the drought of 2000 which resulted in the area recorded as barren substrate in the Golder (2000) census (Figure 5-20).

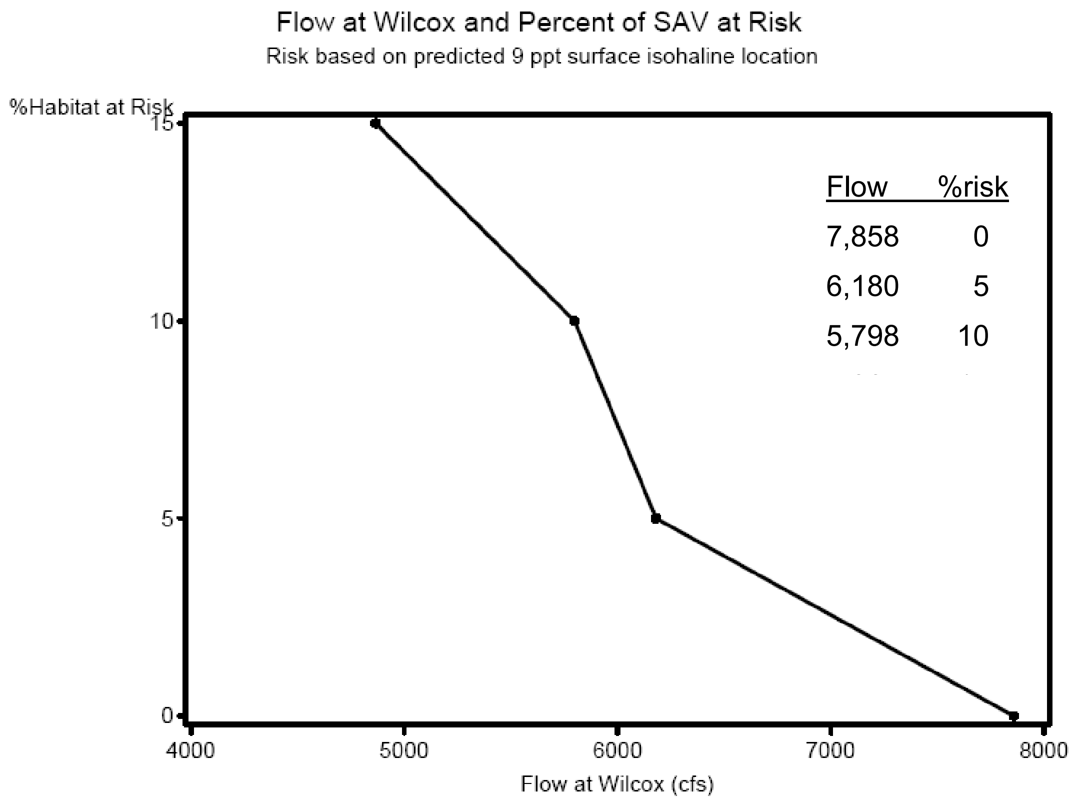


Figure 5-19. Relationship between flow at Wilcox and predicted percentage of SAV at risk.

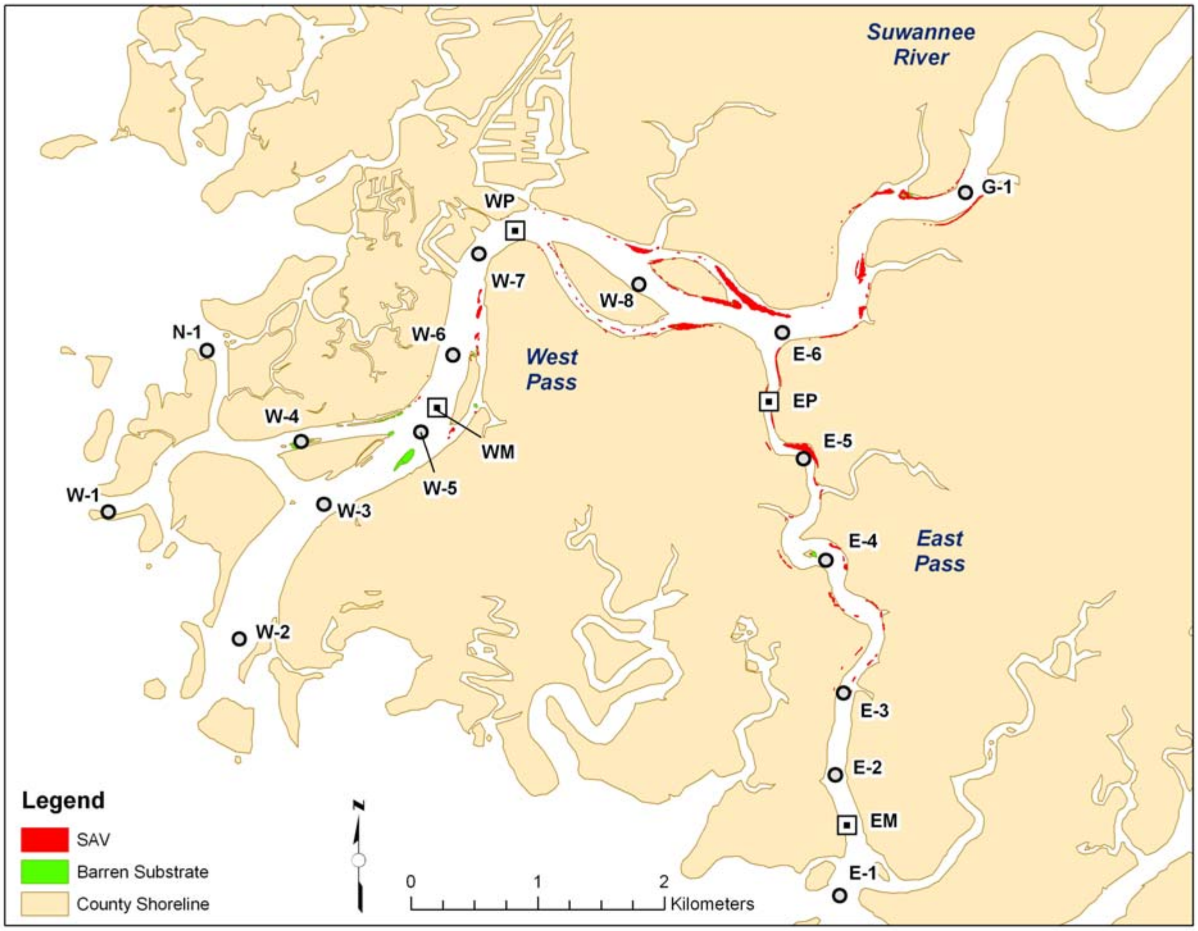


Figure 5-20. Map showing effects of drought on SAV habitat in the Lower Suwannee River as a result of drought of 2000.

5.3.3 Tidal Freshwater Swamps

5.3.3.1 Data Sources

Light et al. (2002) identified a "Lower Tidal" reach of the Lower Suwannee River study area, which for purposes of this report, is considered to be the tidal fresh-water zone of the upper Suwannee estuary. Six intensive study transects were established in forests of the Lower Tidal reach (Table 5-3). The transects were belt transects, with a width of 16.5 feet (5 meters) if over 1,320 feet (400 meters) in length and a width of 33 to 42.9 feet (10 to 13 meters) if less than 1,320 feet long. These judgments were made by the investigators based on their experience in forested wetland sampling in order to obtain a large enough sample of trees to census. Detailed descriptive data on the location of transects are provided in Lewis et al. (2002).

Table 5-3. Basic descriptive information on the six tidal freshwater swamp study transects in the upper Suwannee estuary (Light et al. 2000).

Reach	Transect Name	Abbreviation	Location (river km)	Length in feet (meters)
Lower Tidal	Turkey Island	TI	19.8	1359.3 (411.9)
	Sandfly North	SN	13	291.4 (88.3)
	Sandfly Hammock	SH	12.6	498.3 (151)
	Barnett Creek	BC	11.3	711.5 (215.6)
	Lock Creek	LK	5.1	480.2 (145.5)
	Demory Creek	DM	4.8	175.6 (53.2)

The locations of the intensive study transects were all on public land and were not made in a completely random fashion. Transects had to be located on public land for two main reasons:

- So that permanent transects could be established which could be visited reliably in the future (eliminating the possibility that a future landowner on private lands would bar access); and
- Public land typically had the best examples of reasonably intact, minimally impacted wetland forest, which would remain so in the future.

By distributing the transects at upstream, middle, and downstream ends of the Lower Tidal Reach, and by extending transects across a wide range of topographic and soils conditions (from the river bank to upland), a wide range of variability in the data was captured. The data from the intensive transects were supplemented with plant community and soils observations at 150 additional observation sites (some systematically selected, some randomly selected). The data from these supplemental sites verified the information derived from the transects, and thus the data from the transects is considered to reasonably describe the range of conditions and forest types found in the upper Suwannee estuary.

Land surface elevations along each transect was determined using a surveyor's level and rod. Elevation measurements were made approximately every 16.5 feet (5 meters) and also at locations of topographic breaks, at the edge of standing water, and other "points of interest". Elevations along each transect were tied to a temporary benchmark which was eventually referenced to the National Geodetic Vertical Datum (NGVD) by a licensed professional surveyor. All elevation data were then referred to this datum. Horizontal locations were measured using a portable Precise Lightweight Global Positioning System Receiver with a typical accuracy under tree cover of 19.8 to 49.5 feet (6 to 15 meters) and fiberglass measuring tapes.

Hydrologic data in the study area were derived from seven continuous record USGS surface water gage sites as shown in Table 3 in Light et al. (2002). Most of the flow data used in the floodplain wetland study came from the Branford and Fort White gages (Light et al., 2000). The other five gages were primarily used to supply stage data for construction of rating curves on each transect. Additional water-level measurements were made by tape-down from reference points ("RP's") established at the riverbank end of each transect and in selected surface water features (creeks, sloughs, floodplain ponds) on each transect. These were nails driven into trees and marked with a metal tag. Over the course of the study, about 400 separate water level measurements were made at the transects under a wide range of hydrologic conditions.

Soils data were collected on all intensive study transects to generally characterize soil types associated with the different forest types. The number of borings per transect ranged from 8 to 13 on longer transects and 3 to 6 on shorter transects. Soil profiles were described to a depth of 5 to 6.6 feet (1.5 to 2 meters), typically using a 3-inch bucket auger. Soil profiles were also examined in a few cases with a 1-inch coring tube sampler, or a 108-inch muck probe. Soil moisture was also evaluated at all transects and observation sites as dry, saturated, or inundated. Inundation meant the soil was covered with standing water. Saturation was evaluated by firmly squeezing a handful of soil. If free water was squeezed out, the soil was considered saturated. Approximately 600 soil moisture observations were made over a wide range of hydrologic conditions. Twenty-one surface soil samples and 11 subsurface soil samples were collected for salinity analyses, which were conducted by the National Soil Survey Center in Nebraska.

Vegetation sampling was divided into three strata; canopy, subcanopy, and shrub/groundcover. A canopy plant was defined as a woody plant with a stem diameter at breast height (dbh; 1.4 meters above ground surface) of ≥4 inches (10 cm) and a height of 10 feet (3 meters) or taller. Subcanopy plants were those woody plants with a dbh of 0.8 to < 4 inches (2 to 9.9 cm) and a height ≥10 feet (3 meters). Woody plants smaller than this and all herbaceous plants were considered part of the shrub/groundcover layer. The dbh of all canopy and subcanopy plants was measured on each belt transect using a pair of calipers. Trees with swollen bases or buttressing were measured above the swelling. Estimates of percent cover of groundcover were made as well. Tree species identifications were made in the field concurrent with each dbh measurement. Where necessary to confirm identification, leaves, seeds, branches, etc. were collected for subsequent examination in the laboratory.

In addition to the field studies, forested wetland communities were mapped using NAPP digital ortho-photo quadrangles taken in 1994. These were false-color infrared images at a scale of 1:40,000. Initially, photo signatures were related to plant communities on the intensive study transects. A decision matrix was developed based on canopy composition to make a determination of a particular forest type (Table 6 in Light et al., 2002). Once the specific signatures of all the forest community types on the photos were confirmed, the remainder of the floodplain was mapped. Classification accuracy of the mapping was determined by visiting 111 randomly-selected verification sites, in conjunction with the decision matrix.

Rating curves were developed for each intensive study transect, relating river stage at the transect to flows at Branford-Fort White. These formed the basis for understanding the hydrology associated with each forest type and for evaluating the impacts of potential flow reductions. First, rating curves were developed for selected long-term gages using continuous daily values of stage at the gage related to daily flow at Branford-Fort White (Figure 5-21). Appropriate time-lags were determined and a line fit to aggregated daily values of flow and stage (in increments from 1,000 to 90,000 cfs). Then, the transect ratings were developed by linear interpolation using river mile distances. Table 4 in Light et al. (2002) lists the detailed methods and data sources by transect.

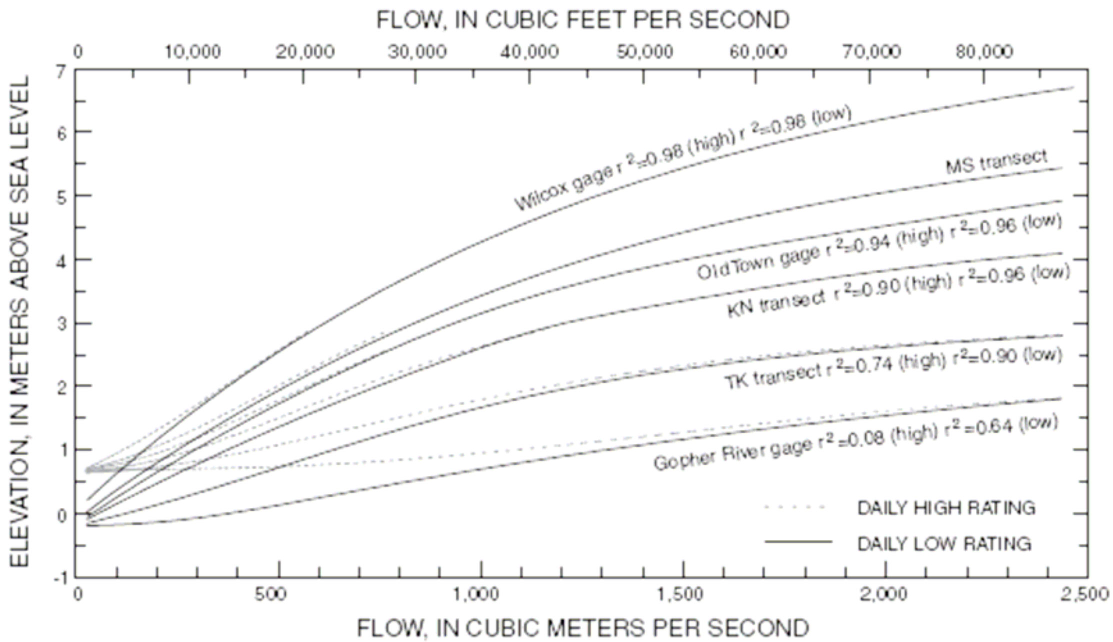


Figure 5-21. Daily high and low stage at gages and tidal transects in relation to flow in the lower Suwannee River, Florida. Flow is combined flow of Suwannee River at Branford and Santa Fe River near Fort White.

Light et al. (2002) identified four different forest types in the upper estuary (Table 5-4); Lower Tidal swamps 1 and 2 (LTsw1 and 2), Lower Tidal mixed forest (LTmix), and Lower Tidal hammock (LTham = hydric hammock). The swamps were flooded daily by high tides, with the mixed forests being flooded several times a month during the spring tides at the full and new moons. Hammocks were occasionally flooded by river flooding. Soils in all lower tidal forest types were primarily continuously saturated mucks, with some sand in the hammocks.

Table 5-4. Summary of plant community and soil characteristics in the Lower Tidal forest types. Adapted from Light et al. (2002).

Forest type	Dominant canopy species	Total no. canopy and subcanopy species	Total acreage unaltered forest acres (hectares)	Primary soil texture in root zone
LTsw1	Nyssa biflora; Fraxinus profunda; Taxodium distichum	25	3,343 (1,353)	Muck
LTsw2	Nyssa biflora; Fraxinus profunda; Taxodium distichum	23	3,309 (1,339)	Muck
LTmix	Fraxinus profunda; Nyssa biflora; Magnolia virginiana	28	2,572 (1,041)	Muck
LTham	Sabal palmetto; Pinus taeda	34	1,525 (617)	Muck, sand

Light et al. (2002) considered salinity the primary limiting factor influencing the community structure of the lower tidal forests and in setting the downstream limit of the “tree line”, where tidal forest grades into tidal marsh. Salinity came from several sources; intrusion of saline water via the river channel at low flows, marine aerosols, and deposition of salt water from storm surges during hurricanes and tropical storms. Maximum salinities in isolated standing water on the Barnett Creek transect ranged from approximately 2 to 5 ppt, but fell to zero during a flood event in 1998. Salinities of up to 2 ppt were measured in isolated standing water on the Sandhill Hammock transect. Subsurface soil conductivities were generally equivalent to or higher than surface soil conductivities (Figure 23 in Light et al., 2002).

5.3.3.2 Spatial Extent of Tidal Fresh-Water Swamps in the Upper Estuary

A total of 6,652 acres (2,692 ha) of swamps (LT Swamps 1 & 2) were mapped by Light et al. (2002) in the upper estuary. These were combined and termed “Tidal Swamps” in subsequent analyses. The focus was on swamps, since they are inundated daily by high tide floodwaters and would thus be most susceptible to impacts from changes in salinity. The other two forest types are inundated only by the higher spring tides, or during flood or storm events.

Figure 5-22 presents a map of the forest types in the lower half of the Lower Tidal Reach (up to the Gopher River confluence). This area was chosen since the forests in this area of the upper estuary would be most susceptible to salinity intrusion due to reduced river flows. Areas further upstream would only be affected during severe, infrequent droughts, or the amounts of flow reduction would be unrealistically high to cause salinity intrusion further upstream than the area shown in Figure 5-20.

5.3.3.3 Tidal Swamp Habitat Requirements

Important considerations for development of freshwater inflow criteria, which provide for the protection of tidal fresh-water swamps, included maintaining the tree canopy composition in the Lower Tidal Swamp and Mixed forest types. Some information is available on the salinity tolerances of some of the dominant trees in these swamps. Table 5-5 presents a summary of the literature reviewed to determine salinity tolerances of the dominant trees in the tidal swamps. Pezeshki et al. (1987) found that bald cypress seedlings exhibited reduced photosynthetic rates and stomatal conductance at salinities of 2 ppt and higher.

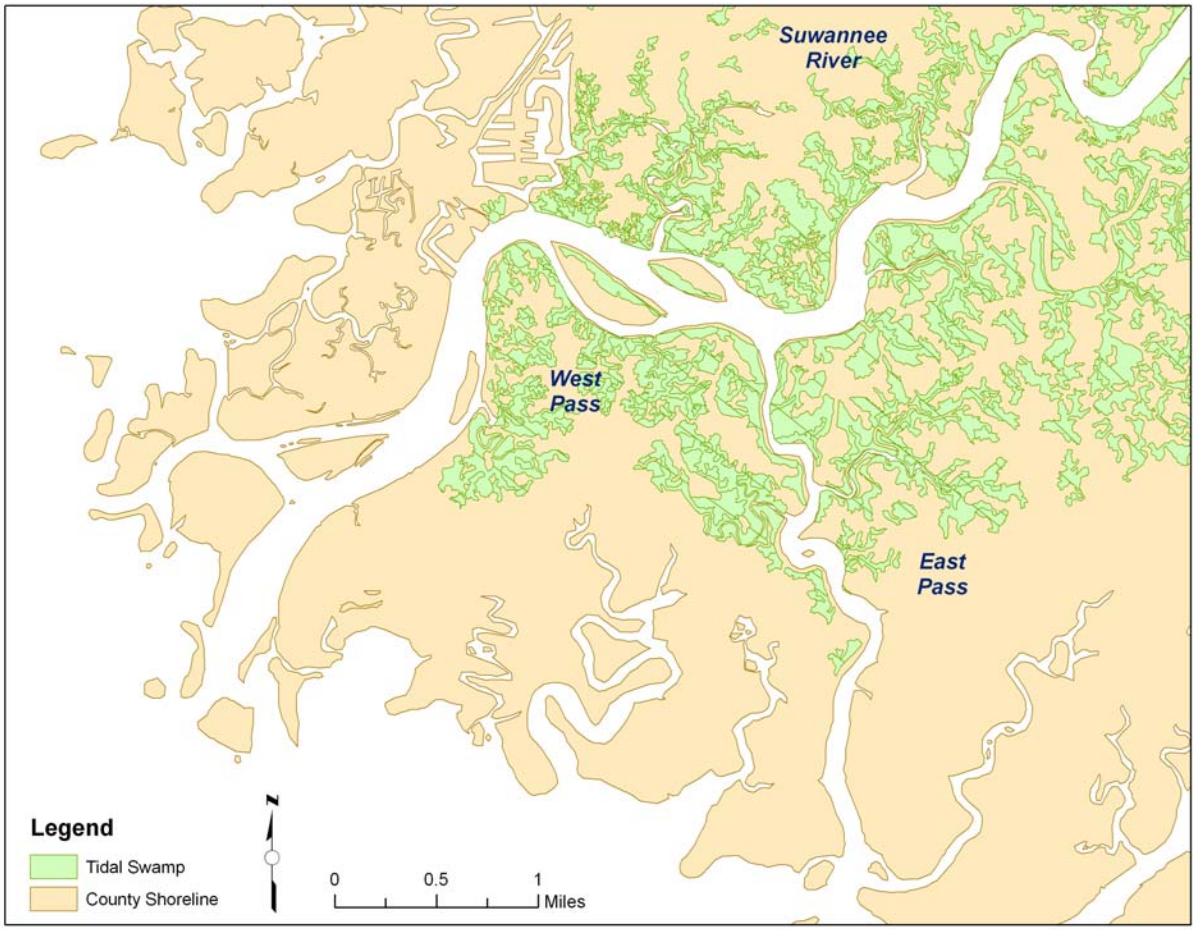


Figure 5-22. Map showing the extent of tidal swamp in the upper Suwannee estuary. Shown is the extent of combined "Lower Tidal Swamp 1 and Swamp 2" of Light et al. (2002).

Table 5-5. Summary of literature reviewed to determine salinity tolerance of the dominant trees (or similar species) found in tidal swamps of the upper Suwannee estuary.

Source	Tree Taxa	Salinity	Notes
Brinson et al. 1985	Green ash; Swamp tupelo; Water oak; Red maple; Slippery elm; Sweetgum; Red bay (adult, canopy trees)	Average soil pore water salinities of 0.75 ppt to 5.8 ppt	Monitored soil pore water salinity for 22 months at four sites in tidal freshwater swamps in the Pamlico River estuary, N. Carolina. Highest canopy species diversity and evenness were found at the two more upstream sites, with lower salinities (mean < 2 ppt). Swamps managed to persist in areas with mean salinities up to about 6 ppt. Higher density of dead snags was seen in downstream, higher salinity sites.
Allen et al., 1997	Baldcypress (seedlings)	Salinities from 0 to 8 ppt in increments of 2 (0, 2, 4, 6, 8)	Laboratory analyses of salinity tolerances of cypress from locations in Alabama and Louisiana. Highest mean leave, stem and root biomass at 0 and 2 ppt. Declines in net photosynthetic rate at salinities > 4 ppt. Strains from brackish locations had better salinity tolerance than those from freshwater locales.
Pezeshki et al., 1990	Mixed tidal wetland forests of Louisiana (adult trees and seedlings)	Approx. <1 to about 7-8 ppt	Review paper summarizing prior work. Water tupelo shows large reductions in photosynthesis and stomatal response at ~3 ppt. Green ash showed reductions at <1 ppt, with progressively larger reductions at increasing salinities up to about 7-8 ppt.
McCarron et al., 1998	Seedlings of: Swamp tupelo; Buttonbush	0, 2 and 10 ppt	Laboratory experiments on seedlings of tupelo and cypress. Swamp tupelo watered with 2 ppt exhibited reduced % survival. Watering with 10 ppt or flooding with 2 and 10 ppt resulted in death of all tupelo seedlings. Buttonbush survived watering and flooding with 2 ppt, exhibited reduced survival when watered with 10 ppt and total mortality when flooded with 10 ppt. Physiological changes associated with watering with 2 ppt were minimal for both species.

Table 5-5. Continued.

Williams et al., 1998	Seedlings of: Cabbage palm; Red cedar; Live oak; Sugar-berry; Elm (mixed spp.); Florida maple; Loblolly pine; Sweetgum	0, 2, 4, 8, 15, and 22 ppt	Six-month greenhouse experiment using plants from Florida coastal hammock forests. Maple and elm were stressed by 2 ppt and died at all higher salinities. Live oak, Sugarberry and Sweetgum slightly stressed at 2 ppt, moreso at 4 ppt. Sweetgum and Sugarberry died at 8 ppt and Live oak at 15 ppt. Cabbage palm and Cedar stressed at 8 and 15 ppt. Cedar dead at 22 ppt.
Pezeshki et al., 1987	Baldcypress (seedlings)	0, 2, 4, 6, and 7 ppt	Laboratory experiment on cypress seedlings. Plants flooded with 2 ppt exhibited reduced photosynthetic rates and stomatal conductance but recovered somewhat during the experiment. Seedlings exposed to 4 ppt and up exhibited significantly reduced physiologic responses and no recovery over the course of the study. All salinity treatments resulted in leaf injury (chlorosis, “burn”, etc.).
South Florida Water Management District, 2002	Seedlings of Baldcypress	30 ppt	Literature review from Loxahatchee River MFL Report. One study on cypress seedlings indicated those 6 months old were more sensitive than older seedlings (18 months or more), in that no 6 mo old seedlings survived flooding with 30 ppt for 2 days, while 90% of 18 mo old seedlings survived 2 days of flooding with 30 ppt.

Progressively greater reductions in these physiological responses were seen up to 7 ppt. Leaf yellowing (chlorosis) was observed in seedlings in all salinity treatments. Williams et al. (1998) demonstrated that seedlings of elm, Florida maple, and sweetgum exhibited reduced survival at 2 ppt and little or no survival at 4 ppt and higher. Cabbage palm, red cedar, and live oak exhibited reduced survival at 4 ppt and higher (Williams et al., 1998). Based on their work evaluating the effects of sea-level rise on coastal wetland forests, Williams et al. (1999) inferred that adult trees were more salt tolerant, based on the existence of "relict" stands in areas of higher salinity, and that dieback of the forests occurred first due to elimination of seedling recruitment. Based on the above, and the review in Table 5-5, average salinities of high tide waters flooding the swamps should be kept ≤2 ppt, with briefer periods of higher salinity tolerable.

Based on available electro-shocking data collected in East Pass by the FWCC, the fish communities in the river channel associated with the distribution of tidal freshwater swamp appear to be dominated by freshwater fish taxa (Figure 5-9). The tree line in East Pass is located near their Station E4 (Fig. 5-9). The proposed salinity target of 2 ppt appears to be adequate to maintain the structure and function of these fresh-water fish communities in the upper estuary. The fish data indicate that the proposed salinity target would allow for the persistence of a fish community still dominated by freshwater taxa, suggesting that the fauna associated with the swamps should be sustained (Figure 5-23).

5.3.3.4 Estimating Location of the 2 ppt Isohaline

The salinity data used for the SAV flow isohaline regressions was also used for assessment of risk to tidal swamp habitat as a function of flow. A regression relationship was developed to predict the 2 ppt isohaline location as a function of flow (Figure 5-24). No statistical difference was observed in the isohaline-pass relationship for the 2 ppt isohaline (Appendix I) so the model predicted the location in all passes.

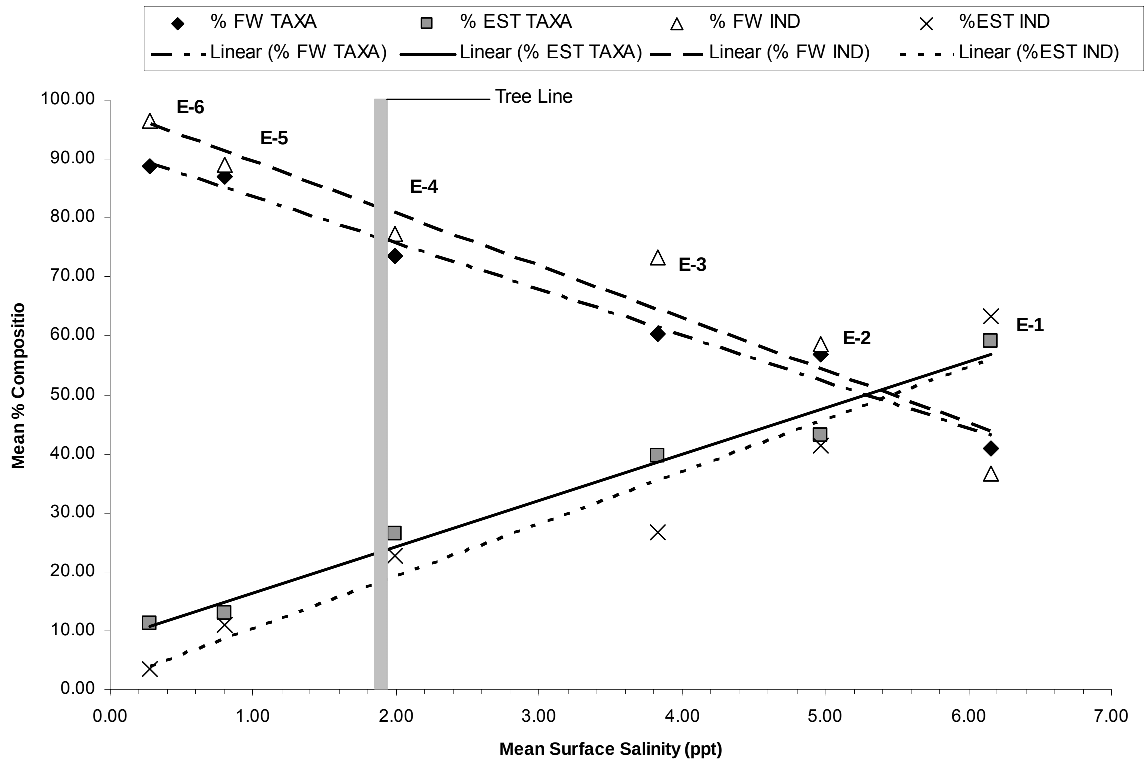


Figure 5-23. Composition of the fish community in East Pass (as %taxa and %individuals at six sites sampled in the Pass by the FWCC in 1993-95, shown in relation to the treeline. Source: Mattson and Krummrich, 1995.

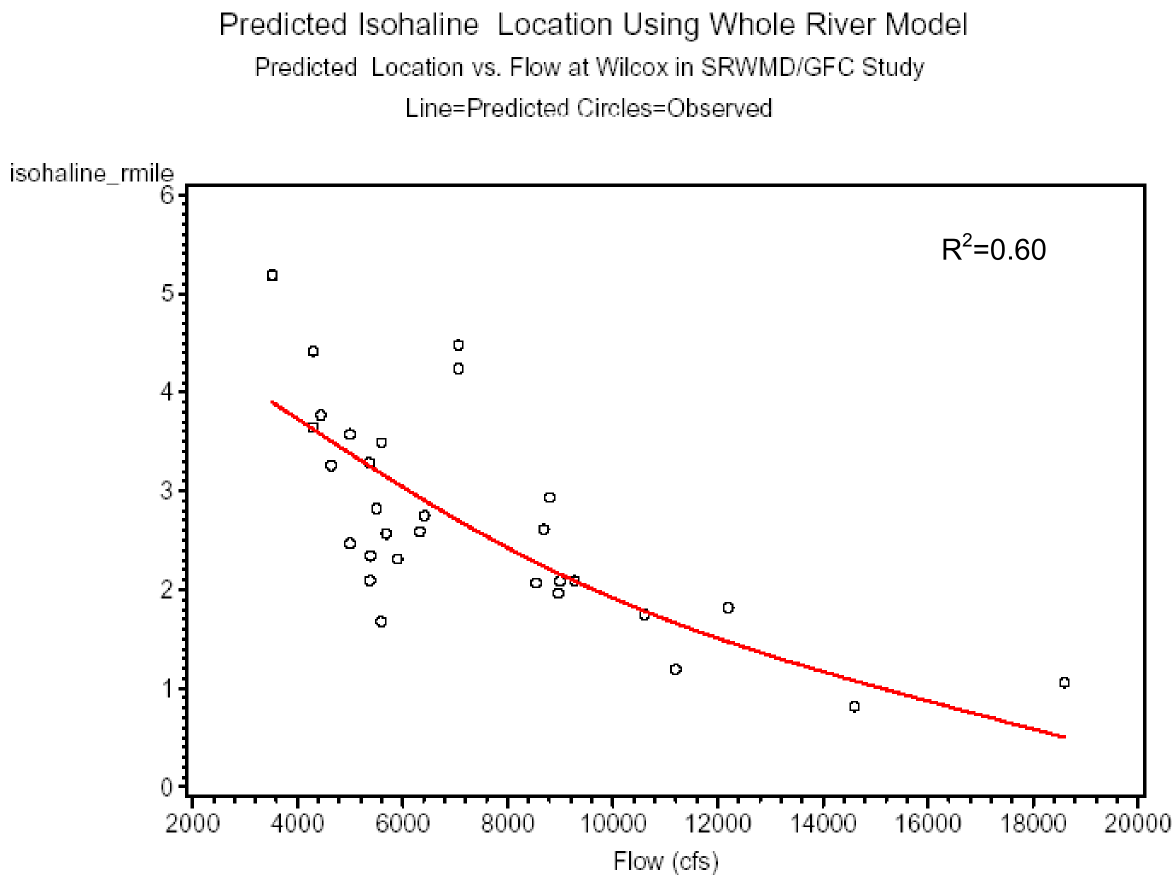


Figure 5-24. Regression relating the location of the 2 ppt isohaline to river flow at Wilcox in the upper Suwannee estuary.

5.3.3.5 Estimating Tidal-Swamp Habitat at Risk

The risk to tidal-swamp habitat with exposure to salinities above 2 ppt was evaluated based on calculations of the cumulative amount of shoreline lined by tidal swamp. Shoreline length was used instead of total area of tidal swamp coverage since these are the areas that would be impacted first. Further, much of the total area for tidal swamp occurred greater than one half mile from the shoreline so the uncertainty of risk also increased with distance from shore. Therefore, to reduce this uncertainty, we chose to use shoreline length instead of total area. The highest rate of change in tidal-swamp habitat loss was observed for flows less than 6,800 cfs (Figure 5.25).

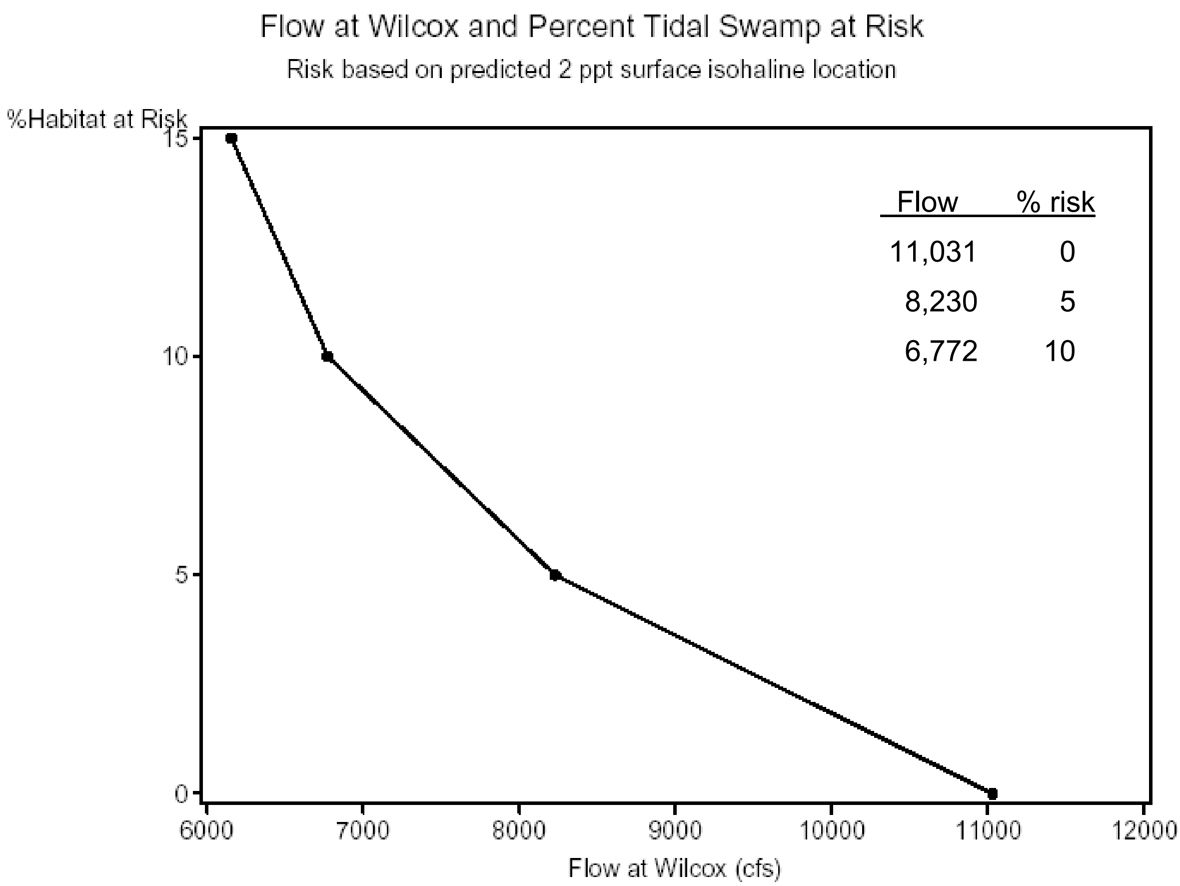


Figure 5-25. Estimates of flow associated risk for Tidal Swamp habitat.

5.3.4 Tidal Creeks

5.3.4.1 Data Sources

SRWMD created a detailed coverage of tidal creeks on the Hog Island delta and fringing East and West Passes up to the Gopher River. The centerline of all tidal creeks on Hog Island and fringing East and West Passes was delineated, using 1999 USGS digital ortho-photos (false color infra-red; scale 1: 24,000). The shorelines of the Passes were also delineated. This was overlain with another coverage, created by Janicki Environmental, segmenting the passes into 0.25-mile increments (see Appendix G).

Juvenile fish data from the FWCC Fisheries Independent Monitoring Program, collected between 2001 and 2003, were used to evaluate and determine a critical salinity for subsequent analysis. Data from tidal creek samples collected within east and west pass using 21m seines set along the river banks were used to identify biologically based salinity zones for the Lower Suwannee River using multivariate analysis described by Bulger et al. (1993) and Christensen et al. (1997). Briefly, Principal Components Analysis (PCAwas used to derive 5 PCA axes, which represent commonalities in salinity ranges among the species captured in the seine catch. Ontogenetic shifts in salinity requirements with increasing size was accounted for by delineating size classes for fish <40 mm in standard length from those equal or greater than 40 mm. If fewer than 30 total individuals of a particular species were collected over the survey period, then those species were removed prior to analysis. Individual salinity increments were plotted against factor loads derived using Varimax rotation (SAS, 1989) to identify salinity zones using a threshold correlation value of 0.60.

5.3.4.2 Habitat Requirements

Salinity tolerances have been described for many common fish and invertebrate taxa in the Lower Suwannee River (Table 5-6; Heard, 1982; Gosner, 1978). Based on Rogers et al. (1984), salinities of $\leq$10 ppt may be critical for recruitment of many fish taxa. Additionally, creeks in very low-salinity areas ($\leq$ 5 ppt) are important nursery habitat for commercial and recreational fishery species (Rozas and Hackney, 1983).

From the multivariate analysis described in Section 5.4.1, a critical salinity of $\leq$5 ppt was chosen as a group which may be most sensitive to changes in flow regime and salinity patterns (Figure 5-26). This category represented the classic "oligohaline" zone for estuarine environments and exhibited a fairly narrow range indicating potential for a high degree of sensitivity to habitat alterations.

Table 5-6. Common invertebrates found in Suwannee estuary tidal marshes and tidal creeks and their characteristic salinity ranges. Sources: Heard, 1982; Gosner, 1978; SRWMD data.

TAXON	SALINITY RANGE	TAXON	SALINITY RANGE
Polychaeta		**Crustacea**	
Neanthes succinea	5 - 30 ‰	*Chthamalus fragilis*	>15 ‰
Laeonereis culveri	0 - 35 ‰	*Balanus subalbidus*	"freshwater to oligohaline"
Namalycastis abiuma	0 - 20 ‰	*Taphromysis bowmani*	0 - 30 ‰
Stenoninereis martini	0 - 30 ‰	*Mysidopsis almyra*	0 - 25 ‰
Parandalia americana	"oligohaline to mesohaline"	*Hargeria rapax*	0 - >40 ‰
Scoloplos fragilis	> 10 ‰	*Halmyrapseudes bahamensis*	>10 ‰
Heteromastus filiformis	<15 - >30 ‰	*Almyracuma* sp.	"fresh to brackish"
Hobsonia florida	"oligohaline and mesohaline"	*Cyathura polita*	<1 - 20 ‰
Streblospio benedicti	<5 - >25 ‰	*Uromunna reynoldsi*	<1 - 15 ‰
Ficopomatus miamiensis	<2 - >25 ‰	*Asellus* spp.	"freshwater"
Mollusca		*Grandidierella bonnieroides*	<1 - >40 ‰
Neritinea usnea	<1 - > 40 ‰	*Corophium louisianum*	<1 - >25 ‰
Littoridinops palustris	0 - >25 ‰	*Hyalella azteca*	"freshwater"
Littoridinops monroensis	"fresh and brackish"	*Orchestia* spp.	"euryhaline"
Assiminea succinea	"moderate to high salinities"	*Palaemonetes pugio*	<1 - >30 ‰
Cerithidea spp.	"moderate to high salinities"	*Clibanarius vittatus*	10 - >35 ‰
Littorina irrorata	"mesohaline"	*Callinectes sapidus*	<1 - >35 ‰
Melongena corona	12 - >30 ‰	*Panopeus obesus*	<10 - >35 ‰
Sayella spp.	"mesohaline"	*Rhithropanopeus harrisii*	0 - 20 ‰
Melampus bidentatus	0 - 50 ‰	*Sesarma reticulatum*	"euryhaline"
Detracia floridana	"brackish marshes"	*Sesarma cinereum*	"euryhaline"
Polymesoda caroliniana	<15 ‰	*Uca longisignalis*	"mesohaline"
Geukensia demissa	"mesohaline"	*Uca minax*	"freshwater to low salinity"
Cyrenoida floridana	<1 - >25 ‰	*Uca speciosa*	"mesohaline to polyhaline"
Tagelus plebius	"mesohaline"		

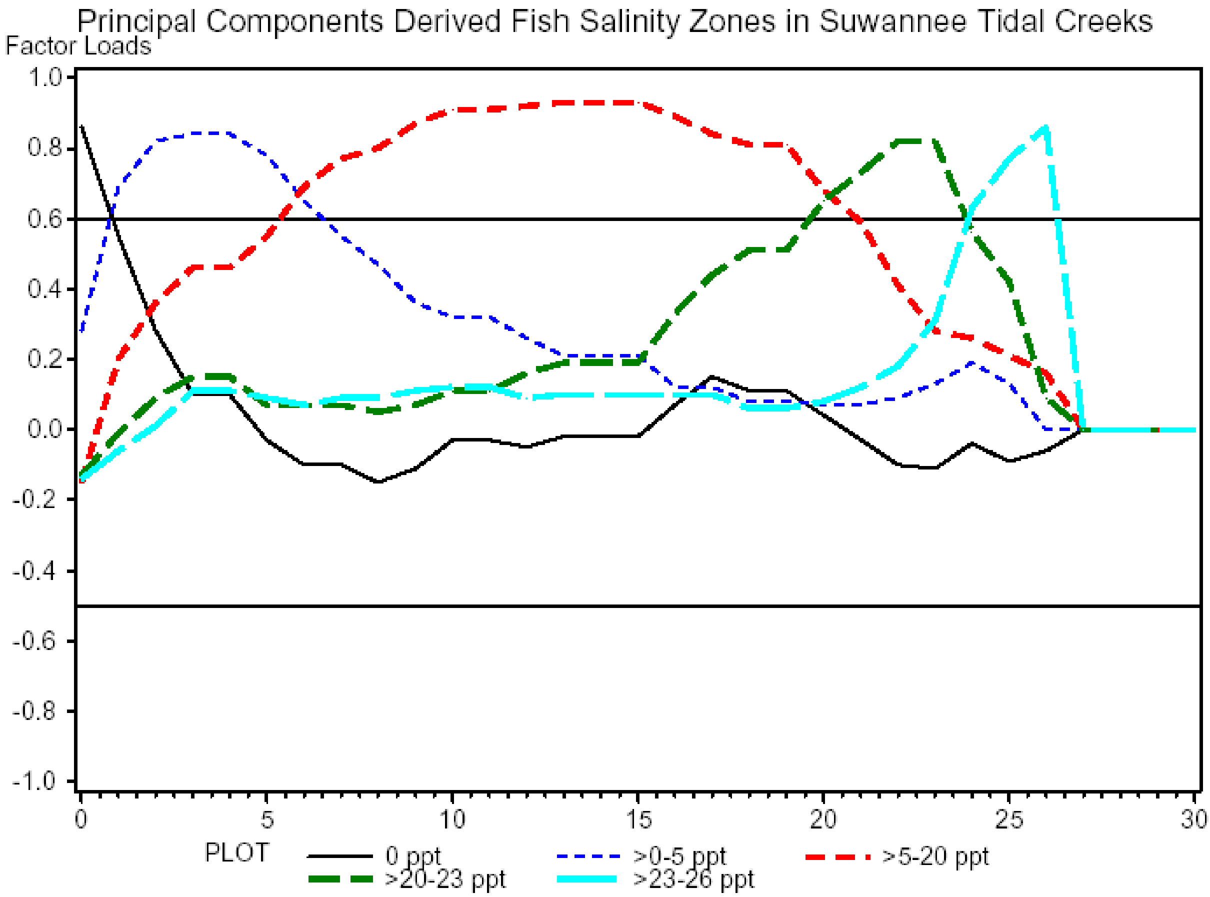


Figure 5-26. Biologically based salinity zone classifications using Principal Components Analysis on tidal creek fish data collected by the FIM program in the Lower Suwannee River 2001-2003.

5.3.4.3 Spatial Extent of Tidal Creeks

The cumulative number of tidal creek connections was counted starting at the downstream limit of the Lower Suwannee River. These tidal creek connections were assumed to represent access to the network of tidal creeks in the delta, for fish and invertebrates entering the river via the passes (Figure 5-27). Wadley Pass, a dredged channel, was excluded from regression analysis.

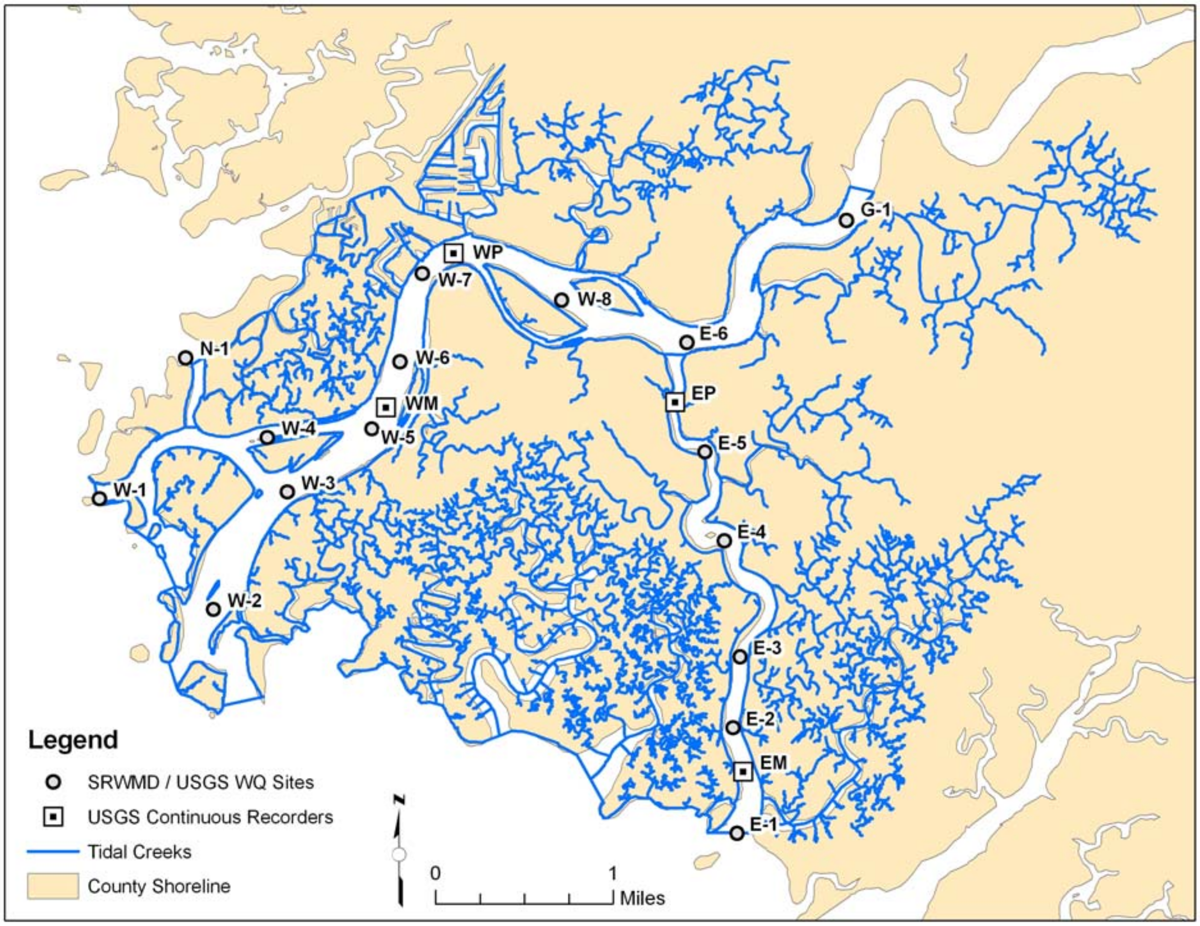


Figure 5-27. Map showing tidal creek coverage and related FWCC and USGS salinity stations used for the analysis of tidal creek habitat.

5.3.4.4 Estimating Location of 5 ppt Isohaline

Establishing the relationship between the 5 ppt isohaline as a function of flow was complicated by the dynamics of the estuarine system near the mouth of each pass. Large variability in location of the isohaline for a given flow condition also played a role in the limitations of the regressions. Antecedent flows, specifically the average flow of the week prior to the sample collection date was incorporated into the analysis to capture some of the variation associated with the effects of antecedent flows (Figure 5-28; see Appendix I for details). Tillis (2000) had similar problems in establishing isohaline relationships for the 5 ppt isohaline, especially in East Pass. When the 5 ppt isohaline was observed within the river, the maximal upstream incursion was generally above river mile 1 such that the valid range of the flow isohaline relationship was for isohaline locations above river mile 1. However, nearly 25% of the tidal creek connections occurred below river mile 1 in the Lower Suwannee River.

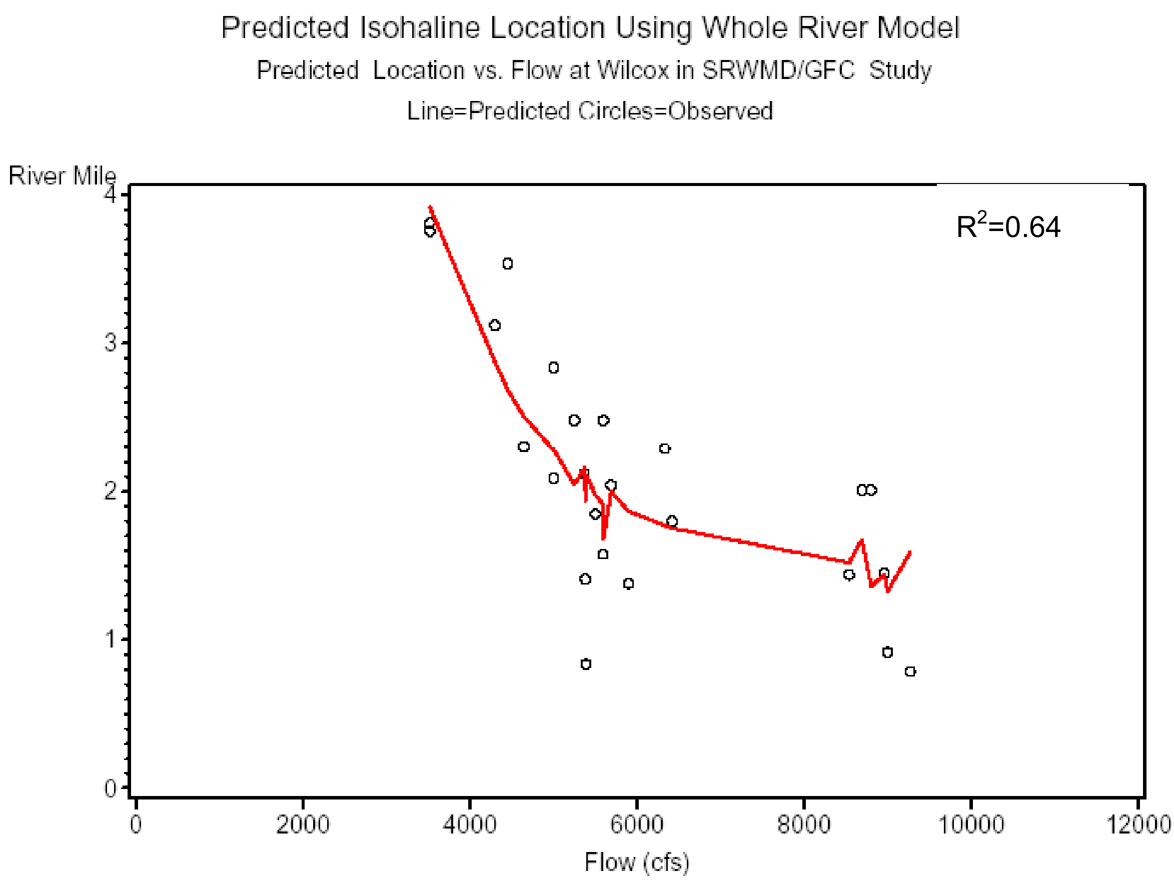


Figure 5-28. Predicted location of the 5 ppt isohaline as a function of flow at Wilcox.

5.3.4.5 Estimating Tidal Creek Habitat at Risk

Flows above the long-term median at Wilcox are required to keep the 5 ppt isohaline below the 15% risk point for tidal creeks (Figure 5-29). It is highly likely that the mouths of these creeks are regularly exposed to much greater salinities than the 5 ppt criterion established for risk assessment. Further, since these relationships are based on full moon incursions, the salinities will be much lower on average and especially on outgoing tides such that fish may access the tidal creeks at times when the salinity is more preferable.

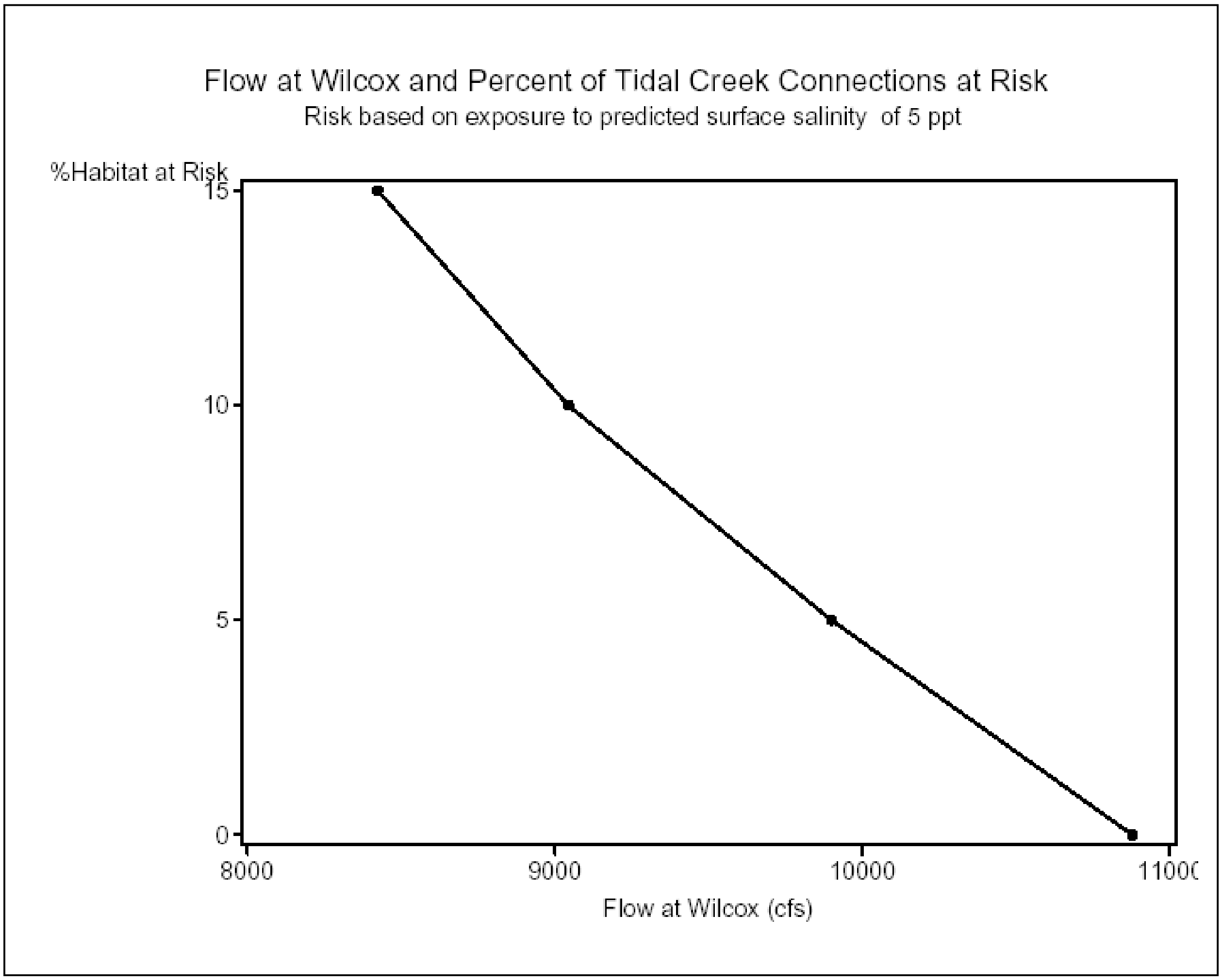


Figure 5-29. Flow associated risk for tidal creek access points in the Lower Suwannee River.

5.3.5 Oyster Bars and Reefs

5.3.5.1 Data Sources

Oyster data in the Suwannee estuary were collected in a study by Baker et al. (2003). Thirty-six oyster study sites were systematically selected. Similar to other habitat studies, the objective was to evaluate characteristics of oyster habitat where it occurred, and relate to salinity, rather than make broader generalizations about the distribution of oyster habitat in the Suwannee estuary. Considerations in site selection included distributing sites across a range of salinity regimes, from those near the river mouth exposed to fresh water a large portion of the time, to those located far from the freshwater discharge of the river. Sites were also distributed across three reef "strata", identified from preliminary surveys in the estuary: inshore bars at tidal creeks; middle reefs (Lone Cabbage and Half Moon), and outer reefs (Suwannee Reef).

Study sites were sampled during low tides. Several types of sampling were conducted at each study site. First, the site was divided into high intertidal and low intertidal strata. This was determined based on inspection in the field at each sampling site; the "break" typically occurring at the reef crest. Locations of sampling quadrats at each site were determined randomly by proceeding in a random direction (right or left) along the tidal stratum for a randomly determined distance from 1-10 meters. Live oyster cover was determined using a minimum of six replicate samples (more if cover was very sparse). Cover was determined using a 1 m^2 grid divided into 100 subsections 10 by 10 cm each in area. Cover was measured by counting the number of subsections lying over live oyster and expressing as a proportion of 100. Oyster density was measured using a 0.25 m^2 quadrat (1 m^2 where live cover/density was very sparse), from which all live oyster was harvested down to dead shell. Live oysters were counted as adult ($\geq$ 76 mm shell length), sub-adult (50 to <76 mm shell length), and juvenile ($\geq$25 to <50 mm shell length). Counts of four major oyster reef associate animals were also made in the oyster density quadrats: the mussels *Brachiodontes spp*. and *Ischadium recurvum*, and the crabs *Eurypanopeus depressus* and *Petrolisthes armatus.*

Oyster community parameters were related to salinity using data from the SEAS monitoring program collected 2000-2002 and data from Phlips and Bledsoe (2002) collected in the estuary in 1999-2001. Monthly surface salinity measurements from these studies were incorporated into a GIS coverage of the salinity sampling sites. Surface salinity was used since depths in much of Suwannee Sound are quite shallow and these data reflected the salinities that the oyster reefs were most exposed to (Baker et al., 2003). ArcGrid® was used to generate salinity contours using the field data, and salinity characteristics at each individual oyster study site were estimated from this coverage by interpolation using the inverse distance-weighted method. Mean salinity for the periods 12 months and 24 months prior to the oyster survey was determined for comparison with oyster reef community characteristics.

5.3.5.2 Spatial Extent of Sampling

Salinity data sources were described in Section 3. Salinity data to evaluate oyster habitat characteristics were provided by the Shellfish Environmental Assessment Section (SEAS) (Figure 5-30). Rather than identify salinity-flow relationships for each of the fixed stations, we decided to assess the covariance patterns of these stations using PCA (Janicki Environmental, 2005b). Principal Components Analysis allowed us to identify stations that react similarly to changes in Suwannee flows such that stations could be grouped for analysis. Three salinity zones were delineated using PCA (Figure 5-31):

The river zone; including sampling stations located in the river and in tidal creeks directly associated with riverine outflow;

An Inshore Reef zone; including stations located in the estuary in direct proximity to the outflow from Alligator and East Pass; and

An "Offshore" zone; including stations in the estuary located farther from and more indirectly related to the Suwannee effluent.

Orlando et al. (1993) identified a similar zone scheme in the Suwannee estuary based on their analysis of SEAS data.

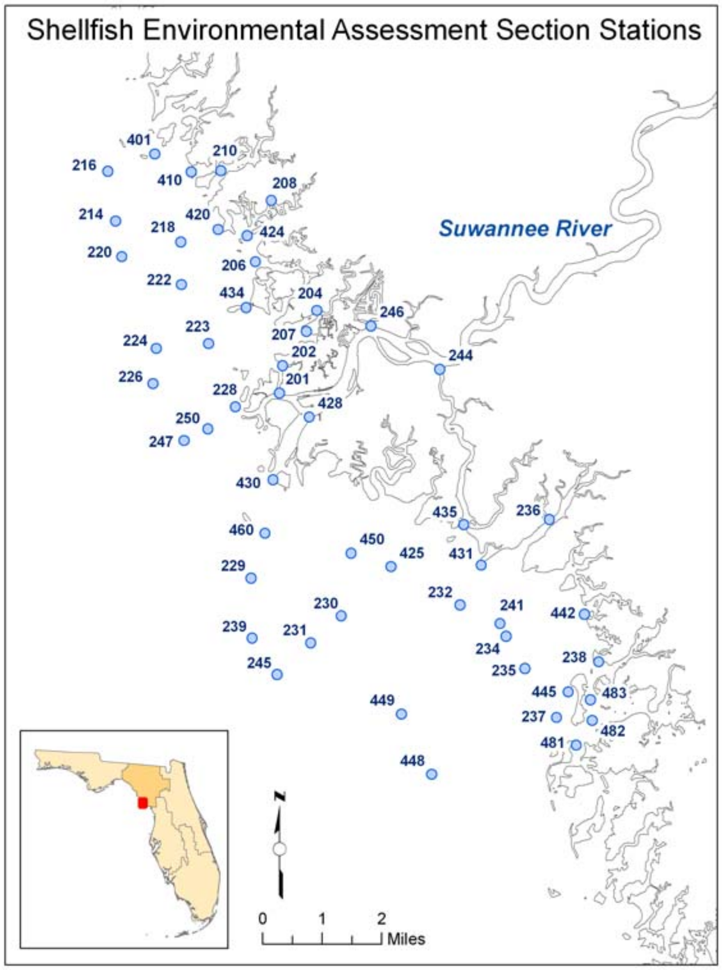


Figure 5-30. Sampling stations of the SEAS program used to assess Suwannee Sound salinities.

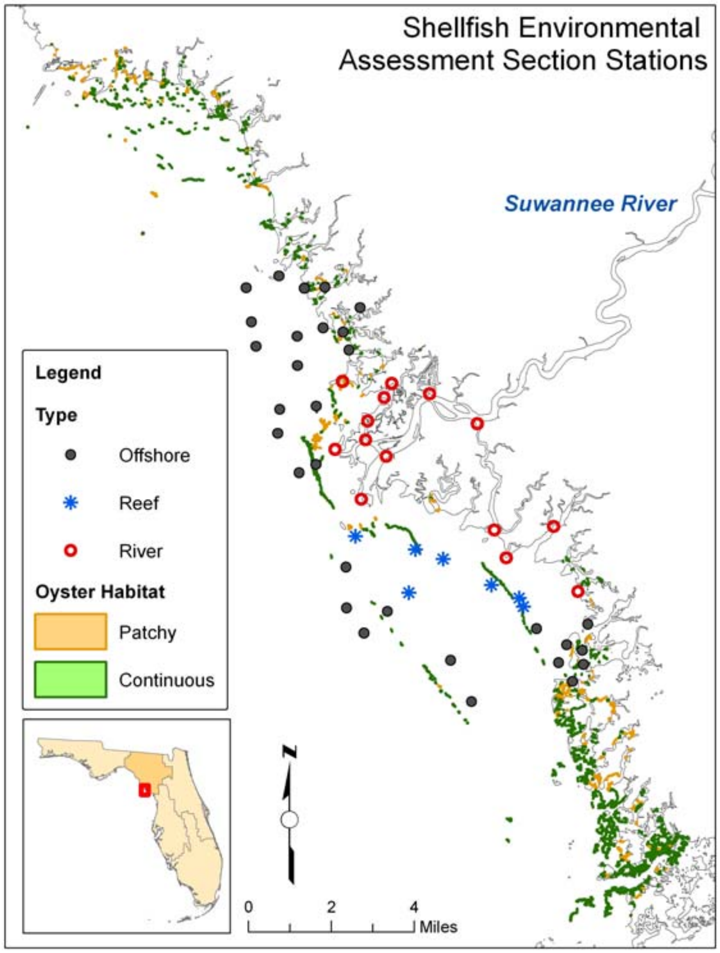


Figure 5-31. Grouping of SEAS stations used for estimating salinity flow relationships in Suwannee Sound.

5.3.5.3 Habitat Requirements

Baker et al. (2003) evaluated oyster-habitat characteristics in the Suwannee estuary in relation to salinity and relative tidal elevation. They found highest oyster- habitat characteristics (% cover, juvenile, sub-adult, and adult density) occurred at mean salinities <20 ppt, for periods 1 year and 2 years prior to their survey (Figure 5-31 adapted from Figures 4 and 5 in Baker et al., 2003). Based on the oyster- field data from the Suwannee estuary, it will be important to maintain an adequate area of habitat with mean annual salinities of $\leq$20 ppt in order to maintain the existing coverage and health of oyster reefs in the estuary.

Available information in the literature supports this proposed optimal salinity target of $\leq$20 ppt for oyster. Burrell (1986) recommended that "moderate salinities (those less than 15 ppt)" be maintained for "a significant period during the year" to exclude most oyster predators and diseases and maintain oyster reef community structure. Stanley and Sellers (1986) indicated that highest oyster abundance in Gulf of Mexico oyster populations occurred between 10-20 ppt. Oyster reefs with highest densities in Apalachicola Bay were found where mean salinities were 20-23 ppt (Livingston et al., 2000). This appeared largely due to the exclusion of dominant oyster predators (Livingston et al., 2000).

Dominant associated macroinvertebrates in the Suwannee oyster reefs were the crabs *Eurypanopeus depressus* and *Petrolisthes armatus* and the mussels *Brachiodontes spp.* and *Ischadium recurvum* (Baker et al. 2003). The abundances of *E. depressus* and *I. recurvum* were negatively associated with mean annual salinity at a statistically significant level in both the high and low intertidal strata sampled by Baker et al. (2003). Of additional significance is that these two taxa appear to be obligately associated with oyster habitat (Baker et al., 2003 – Table 10a & b; also Heard, 1982), indicating that they are key indicator taxa. The xanthid crab *E. depressus* is listed as occurring in salinities generally below 20 ppt (Ryan, 1956; Gosner, 1978).

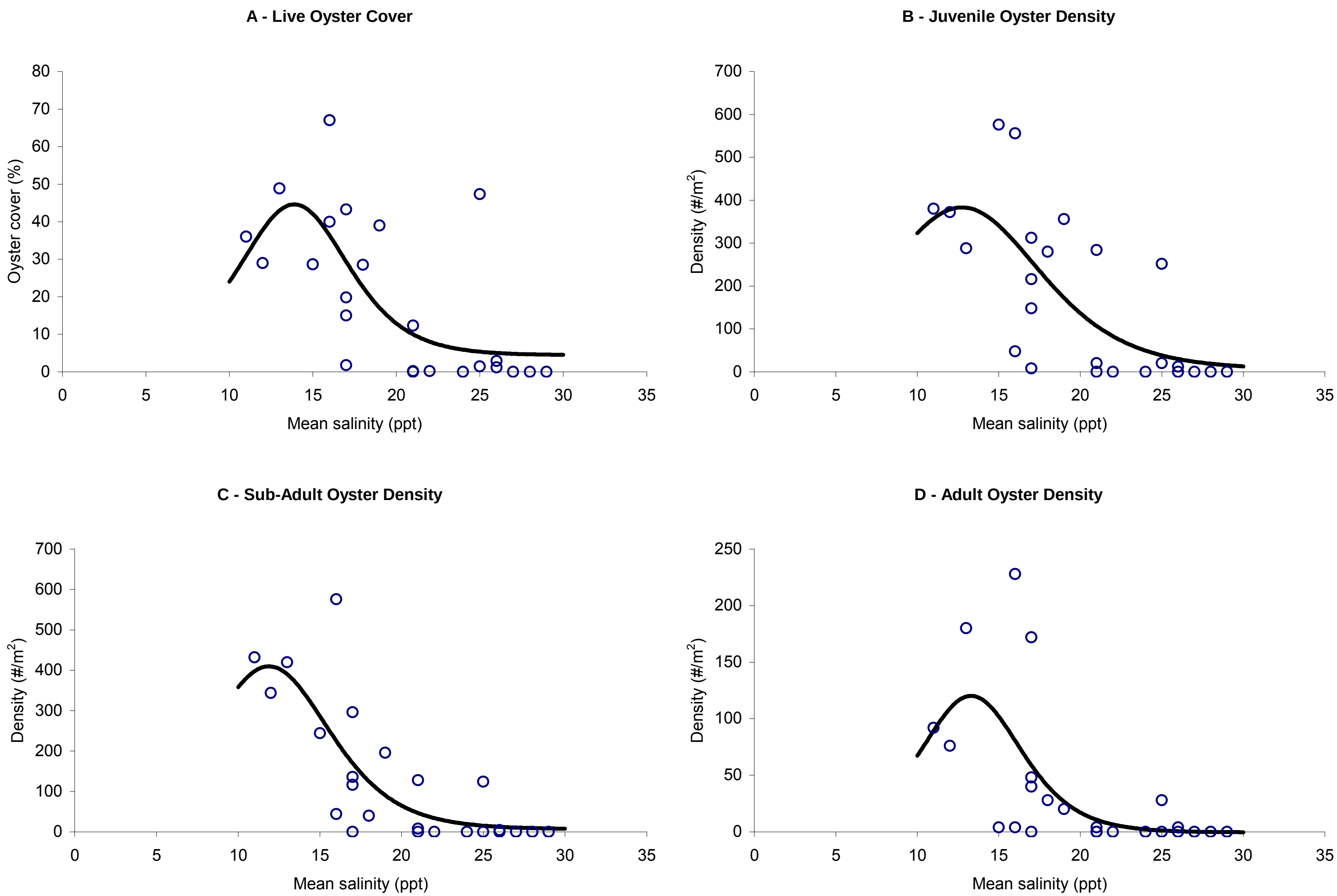


Figure 5-32. Plots relating oyster reef community characteristics to mean salinity one year prior to collection of the oyster data. Adapted from Baker et al., 2003.

5.3.5.4 Estimating Exceedance of 20 ppt Surface Salinity

Salinity-flow regressions were developed to predict the median surface salinities for each of the three regions identified by PCA as a function of flow at Wilcox. To account for tidal influence on the salinity-flow relationship, only samples collected after 1996 were used for the regression analysis since the period of record for the tidal data began in 1996. Once salinity-flow relationships were established for each of the groups, the long-term flow record was used to estimate the change in the probability of an annual average surface salinity of 20 ppt. The long-term average flow (10,166 cfs) was used as the baseline probability (see Appendix J for details). Risk was estimated as a change between 0 and 15 percent in the exceedance threshold of the 20 ppt criterion for surface salinity. Only the Inshore Reef and Offshore zones were evaluated since the River zone median

Table 5-7. Summary of PCA analysis of SEAS salinity data in the Suwannee estuary. From Janicki Environmental, 2005b.

Region	Median Salinity (ppt)	Minimum Salinity (ppt)	Maximum Salinity (ppt)
River	3.6	0	32.8
Inshore/Reef	14.3	0	32.2
Offshore	19.8	0	36.0

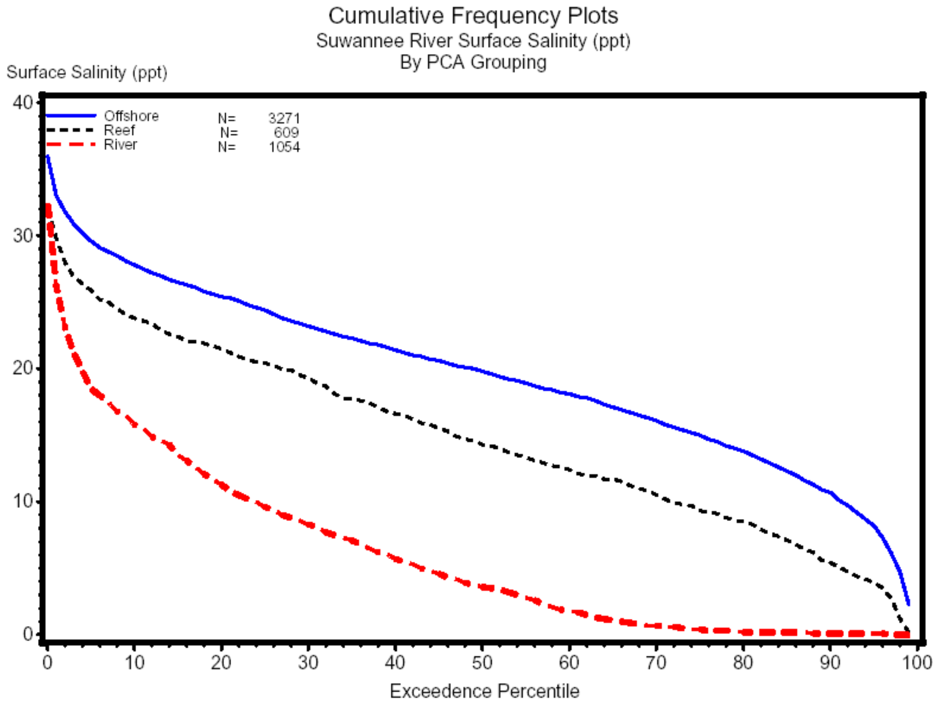


Figure 5-33. Exceedance frequency plots for each of the PCA groups for the Suwannee Estuary.

The Inshore Reef group displayed an inflection point in the risk estimates for flow less than 6,800 cfs coinciding with a 5% increase in the number of years the average annual salinity would exceed 20 ppt (Figure 5-34). The results of estimating risk for the Offshore group suggested that Offshore surface salinities were at the 20 ppt threshold approximately 50% of the time based on the study period of record (1997-2003). Therefore, a 15% change in the probability of annual average exceedance was associated with flows that were still above the long-term median flow for Wilcox (Figure 5-35). Thus, the use of the 20 ppt threshold for the assessment of risk for the Offshore group appears to be unrealistic.

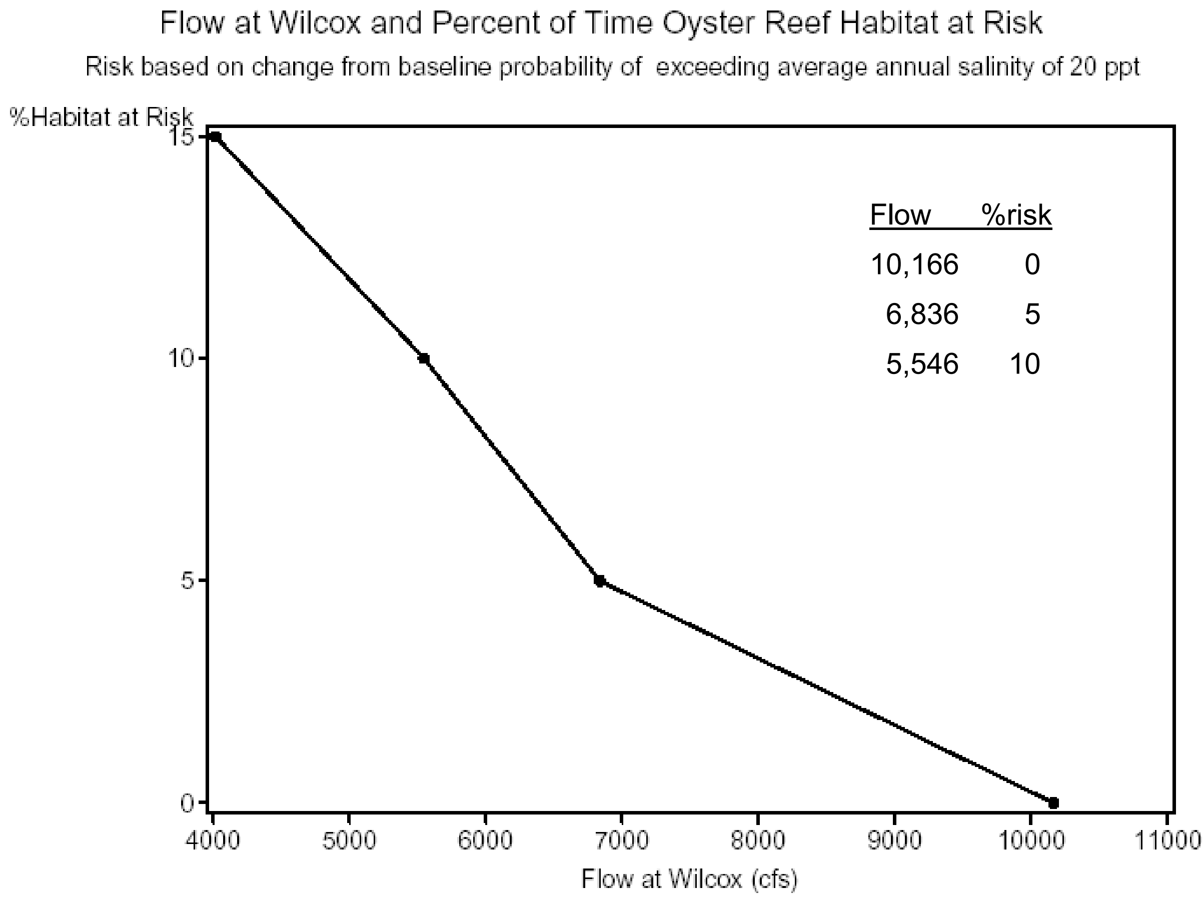


Figure 5-34. Flow associated risk of an annual average salinity of at least 20 ppt in the Inshore Reef group.

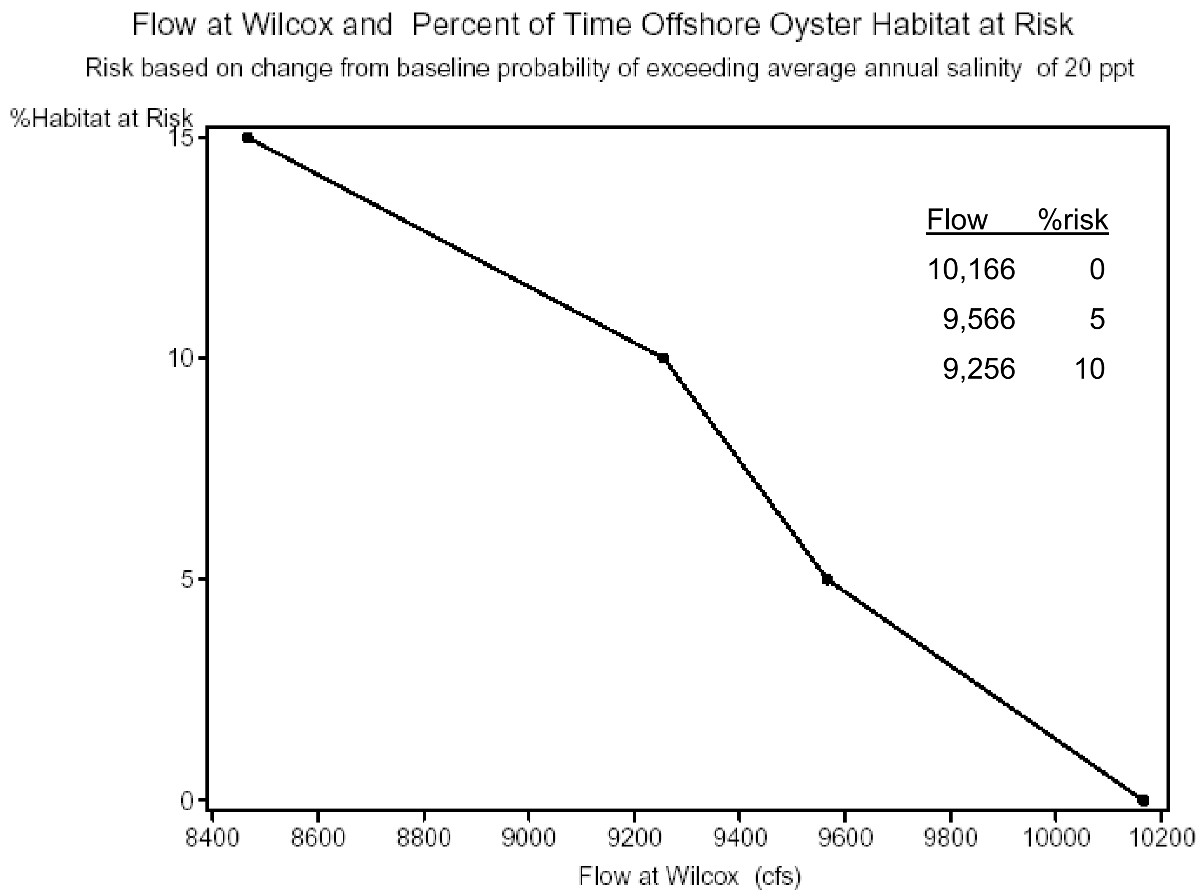


Figure 5-35. Flow associated risk of an annual average salinity of 20 ppt in the Offshore group.

5.3.6 Other Important Habitats

5.3.6.1 Riverine Upper Tidal Bottomland Hardwood Swamps

Light et al. (2002) studied relationships between hydrology, soils, and canopy/subcanopy vegetation in floodplain wetland forests of the 10-year floodplain of the lower Suwannee River. They confined their study to the 10-year floodplain because the vast majority, if not all, of the wetlands structured by riverine flooding are below the 10-year flood elevation. Land areas above this elevation are mostly developed (i.e., cleared for agriculture, managed pine plantation, or residential land use), or consist of upland ecosystems structured by other environmental forces, such as fire.

5.3.6.1.1 Methodology and Analysis

Two intensive study transects were established in the Upper Tidal portion of the system as shown in Figure 4-5. The most intensive data collection occurred on these, including land surface elevation, water-level measurements, soil conditions, and vegetation (canopy, subcanopy, and groundcover). Basic information on the transects is shown in Table 5-8. As described in Section 5.3.3, transects were belt transects, with a width of 16.5 feet (5 meters) if over 1,320 feet (400 meters) in length and a width of 33 to 42.9 feet (10 to 13 meters) if less than 1,320 feet long. These judgments were made by the investigators based on their experience in forested wetland sampling in order to obtain a large enough sample of trees to census. Detailed descriptive data on the locations of the transects is provided in Lewis et al. (2002). The rationale for selecting transect locations was discussed in Section 5.3.3.

Table 5-8. Basic descriptive information on the two forested wetland study transects in the Upper Tidal Reach of the lower Suwannee Study area.

Reach	Transect Name	Abbreviation	Location (river km)	Length in feet (meters)
Upper Tidal	Manatee springs	MS	42.5	3,329.7 (1,009)
	Keen/Keen Island	KN/KI	31.2	2,422.5/330 (734.1/100)

Land surface elevations, soils data, and canopy and subcanopy vegetation data were collected as described in Section 5.3.3, the only difference being that no soil salinity data were collected. Hydrology on the transects was related back to the combined flow of the Suwannee River at Branford and the Santa Fe River near Fort White ("Branford-Fort White flow"), using the rating curves in Figure 5-36.

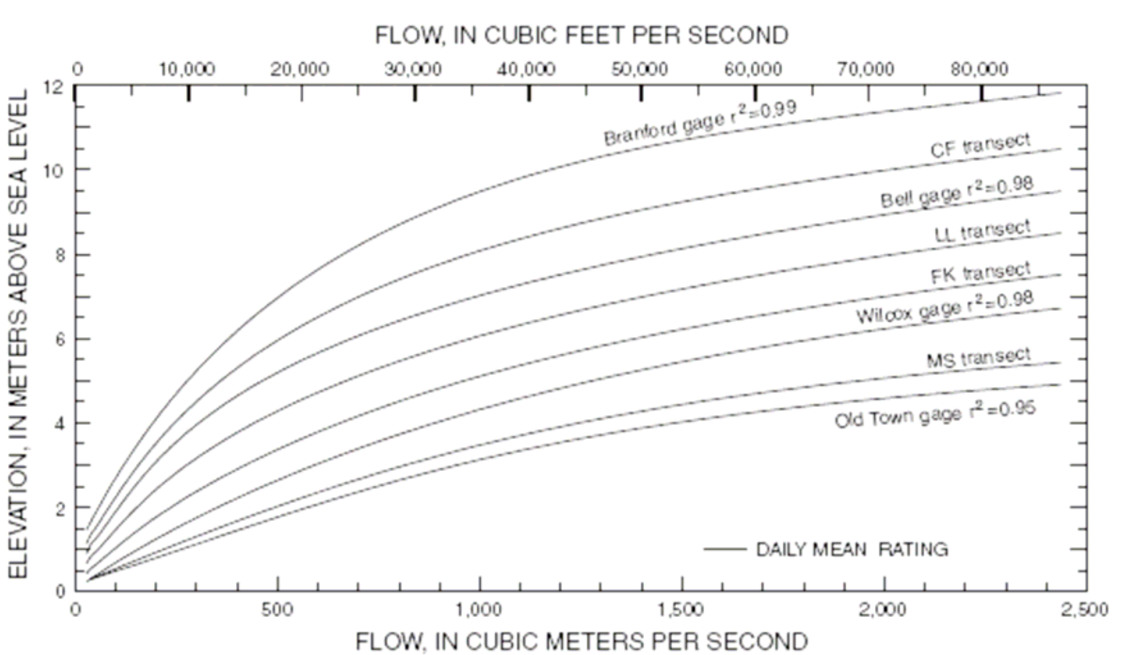


Figure 5-36. Daily mean stage at gages and riverine transects in relation to flow in the lower Suwannee River, Florida. Flow is combined flow of Suwannee River at Branford and Santa Fe River near Ft. White.

Light et al. (2002) identified four forest types in the Upper Tidal Reach, four forest types were identified: Upper Tidal Swamps 1 and 2 (Utsw1 and Utsw2), Upper Tidal Mixed Forest (Utmix) and Upper Tidal Bottomland Hardwood (UTblh). Description and summary of the soils data in the various forest types were provided in Howell (1999) and Light et al. (2002). Floodplain soils exhibited high variability, with 7 soil orders and 18 taxonomic subgroups. Histosols was most common soil type in the Upper Tidal Reach. Soil profiles in the swamps were dominated by clays and mucky clays. Profiles in bottomland hardwood communities were more dominated by sand or mucky sand.

A summary of general plant community and soil characteristics in each forest type is presented in Table 5-9. The extent to which a particular tree species dominates the composition of a forest is indicated by its "importance", based on relative basal area for canopy species and relative density for subcanopy species Bald cypress (*Taxodium distichum*) was an important tree in riverine and upper tidal swamps. Various oaks (*Quercus* spp.) were important in the riverine and upper tidal bottomland hardwood forest types. Pumpkin ash (*Fraxinus profunda*) and Water tupelo (*Nyssa aquatica*) were important trees in upper tidal swamp and mixed forests. In general, most of the wetland forest types were in a largely unaltered condition (not affected by logging or clearing as observable on the aerial photography). The proportion of altered forest was higher in the "higher drier" forest types; UTmix and UTblh (Figure 26 in Light et al., 2002).

Table 5-9. Summary of plant community and soil characteristics in the Upper Tidal forest types. Adapted from Light et al. (2002).

Forest type	Dominant canopy species	Total no. canopy and subcanopy species	Total acreage unaltered forest acres (hectares)	Primary soil texture in root zone
Utsw1	Nyssa aquatica; Taxodium distichum; Fraxinus profunda	22	2,217 (897)	Muck
Utsw2	Nyssa aquatica; Taxodium distichum; Fraxinus profunda	33	2,686 (1,087)	Muck
Utmix	Taxodium distichum; Fraxinus profunda; Quercus laurifolia	31	944 (382)	Loam, muck, & sand
UTblh	Quercus laurifolia; Sabal palmetto	35	1,196 (484)	Sand

5.3.6.2 Flood depths in Upper Tidal Forests.

Inundation and soil saturation appear to be less important in maintaining plant community composition in Upper Tidal forest types because soils tend to be almost constantly saturated in most types and inundation and saturation due to tides becomes increasingly more important than variation in these due to river flows (Light et al., 2002). Consequently criteria for Upper Tidal forests will focus on the 5-year/14 day threshold flood depth. This flood appears to be more important in maintaining plant community composition in the forest types; especially the Upper Tidal Bottomland Hardwood Swamps, at the highest, driest range of the riverine wetlands.

5.3.7 Riverine Snag (Wood) Habitat

The ecological importance of wood habitat in southeastern coastal plain streams was reviewed in Section 4. The Southwest Florida WMD (SWFWMD, 2002) identified riparian wood as an important habitat for development of MFLs for the upper Peace River. Estevez and Sprinkel (2000) conducted surveys of wood habitat at six study transects on the Lower Suwannee River (Figure 4-5) near Manatee Springs.

5.3.7.1 Methodology and Analysis

Wood was surveyed at six bank transects selected systematically by SRWMD scientists and the consultant's Principal Investigator. As noted in the Methods section of Estevez and Sprinkel (2000), the purpose of this wood study was to identify relationships between the vertical distribution of wood and river stage where accumulations of wood occurred, rather than to make general statements about the distribution/occurrence of wood in broad reaches of the lower river study area. The goal was to determine if a quantitative relationship between river stage and some wood metric could be developed which could be used to set MFL criteria. The six bank study sites are considered to be "index" sites, similar to a shoal or other key river cross section used to relate habitat conditions to flow. The results from the wood sites are related back to an upstream gage to serve as a general indicator of the relationship between river stage and a wood metric where wood occurs. The six bank transects were distributed over about 1.5 river miles.

At each bank transect, an adaptation of the line-intercept method was employed as used in forestry (Van Wagner, 1968 and references therein). A line of known length was extended perpendicular from the bank towards the river channel centerline, to the maximum extent of occurrence of wood in the river channel, or to a depth that could not be sampled. The line was kept level using a string level and/or measuring down to the water surface. Surveys at each bank transect began at the top of bank and progressed down-bank at 1.65 feet (0.5 meter) intervals. Within each 0.5 m increment, where a piece of wood intercepted the line transect (or the vertical plane formed by the line), its diameter was measured. Various rules must be followed (Van Wagner, 1968), and all were adhered to in this sampling effort:

1. The sample line must be of known length;
2. If the sample line crosses the end of a piece of wood, tally only if the central axis of the wood is crossed;
3. If the sample line passes exactly through the end of a piece's central axis, tally every second such piece;
4. Ignore any piece whose central axis is parallel with the sample line; and
5. If the sample line crosses a curved piece more than once, tally each crossing.

A piece of wood was counted where it was intercepted within a particular 0.5 m stratum; i.e., it was not counted multiple times. Diameter was measured using a forester's dbh tape for larger wood debris and estimated with a drafting template for smaller diameters (generally < 2 inches). From these data, the surface area and volume of wood intercepted by the sample line can be determined (after Wallace and Benke, 1984):

For wood surface area: $\hat{X}sa = (\pi^2 / 2L)\sum^{n} d_i$;

where '$\hat{X}_{sa}$' is mean surface area, L is the length of the sample line, d_i is the diameter of a piece of wood intercepted by the sample line and n is the number of pieces of wood intercepted by the sample line.

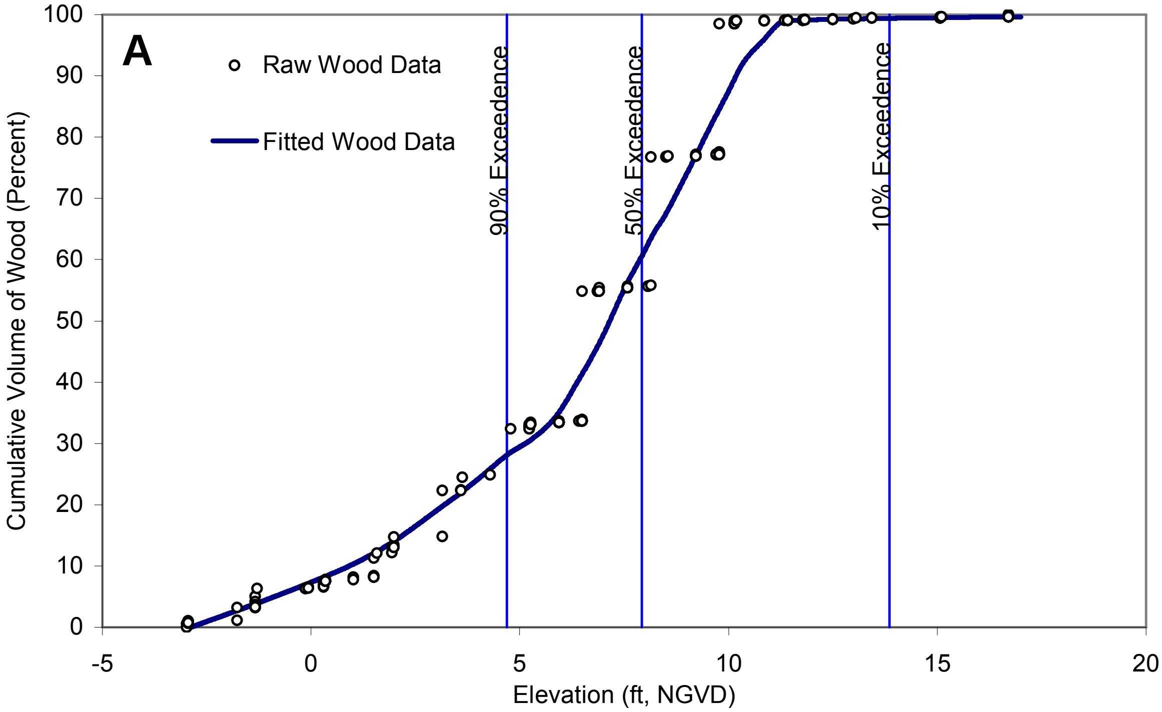
For wood volume: $\hat{X}v = (\pi^2 / 8L)\sum^{n} d_i^2$;

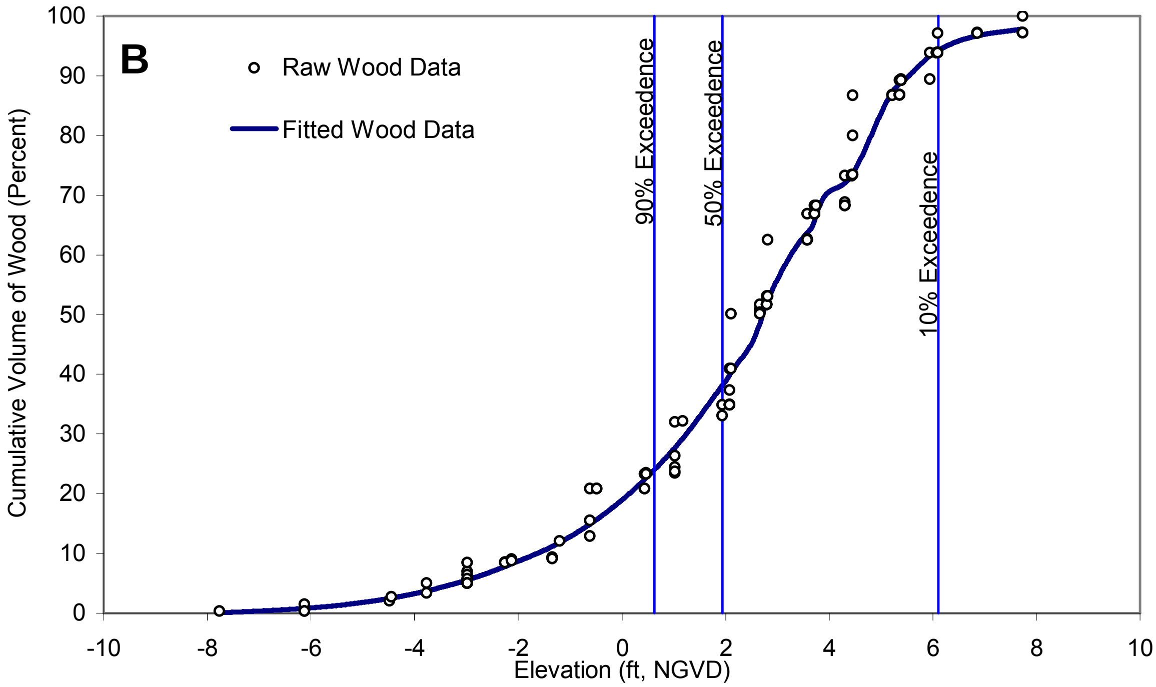
Where '$\hat{X}_v$' is mean volume, and L, n and d_i are as above.

Vertical locations at each bank transect were standardized to the top of bank at the transect, to water level on the day the bank transect was surveyed (based on water level at the closest gage related to a temporary staff gage placed at the wood transect site), and to NGVD using either the measured river stage or surveying from a known benchmark nearby.

5.3.7.2 River Stage and Wood Volume

A significant relationship was discovered between proportional surface area and volume of submerged wood and river stage (Figure 5-32). These relationships appear to be more than a coincidence. Estevez and Sprinkel (2000) compared the Suwannee wood data to a survey of wood, using a similar line-intercept technique, in the Ogeechee River, Georgia, about 100 miles north of the Suwannee River basin. There were differences in size and geomorphology of the river channel between these two studies; the Ogeechee is a smaller river system, and the Georgia study measured wood across the entire stream channel, whereas this study was confined to bank transects due to the size of the Suwannee River. Basic patterns of vertical wood dispersion were similar





Data fitted using a Loess-type (locally-weighted least-squares) procedure with B-spline smoothing as implemented in TableCurve 2D (v 5.0) by SPSS Inc

Figure 5-37. Relationships between river stage and volume of submerged wood habitat at locations on the Suwannee River (adapted from Estevez and Sprinkel, 2000). (A) Suwannee River near Eula Boat Ramp, and (B) Suwannee River near Manatee springs. Vertical lines indicate flow exceedance percentiles at Bell and Wilcox gages, respectively.

between the two streams, suggesting that the relationships seen in Figure 5-37 reflect some type of real pattern, not a sampling artifact. Estevez and Sprinkel used volume to relate to river stage because volume tended to exaggerate wood abundance, making the observation of a pattern easier to see.

Wood data were related to river stage using rating curves developed with HEC-RAS at a typical channel cross section selected in at each study location where the wood data were collected; half of the six transects located upstream and half downstream of the selected cross section. The rating curves related stage at the wood collection sites to streamflow at Wilcox (Figure 5-37). The Wilcox-Manatee rating curve was based on minimum daily stages at Wilcox.

The important consideration for wood habitat is to develop minimum flow criteria that allow for the persistence and availability of this habitat at average and low streamflows. MFLs to protect wood habitat must maintain inundation of adequate amounts of riparian wood habitat in order to make it available for fish and benthic invertebrate populations. Flows at which 50% of the wood is inundated may represent available wood during “average” flow conditions. Flows necessary to maintain the community composition and structure of the benthic invertebrate communities on snags must also be considered.

The flow reductions proposed to maintain adequate amounts of wood habitat should be adequate to maintain the structure and composition of attached benthic invertebrate communities. Data from the District’s long-term water quality monitoring program, using Hester-Dendy samplers (which imitate wood habitat) at the site SUW150C1 (Suwannee River at Rock Bluff), indicate that the proportion of “filtering collector” invertebrates in the benthic community in the Eula region is positively related to flow (Figure 5-39). These types of invertebrates include many aquatic insects such as *hydropsychid* caddisflies, *tanytarsid* midges, and blackflies, all of which are important as food base for riverine fishes, particularly sunfish such as Redbreast and Spotted sunfish (Benke et al., 1985).

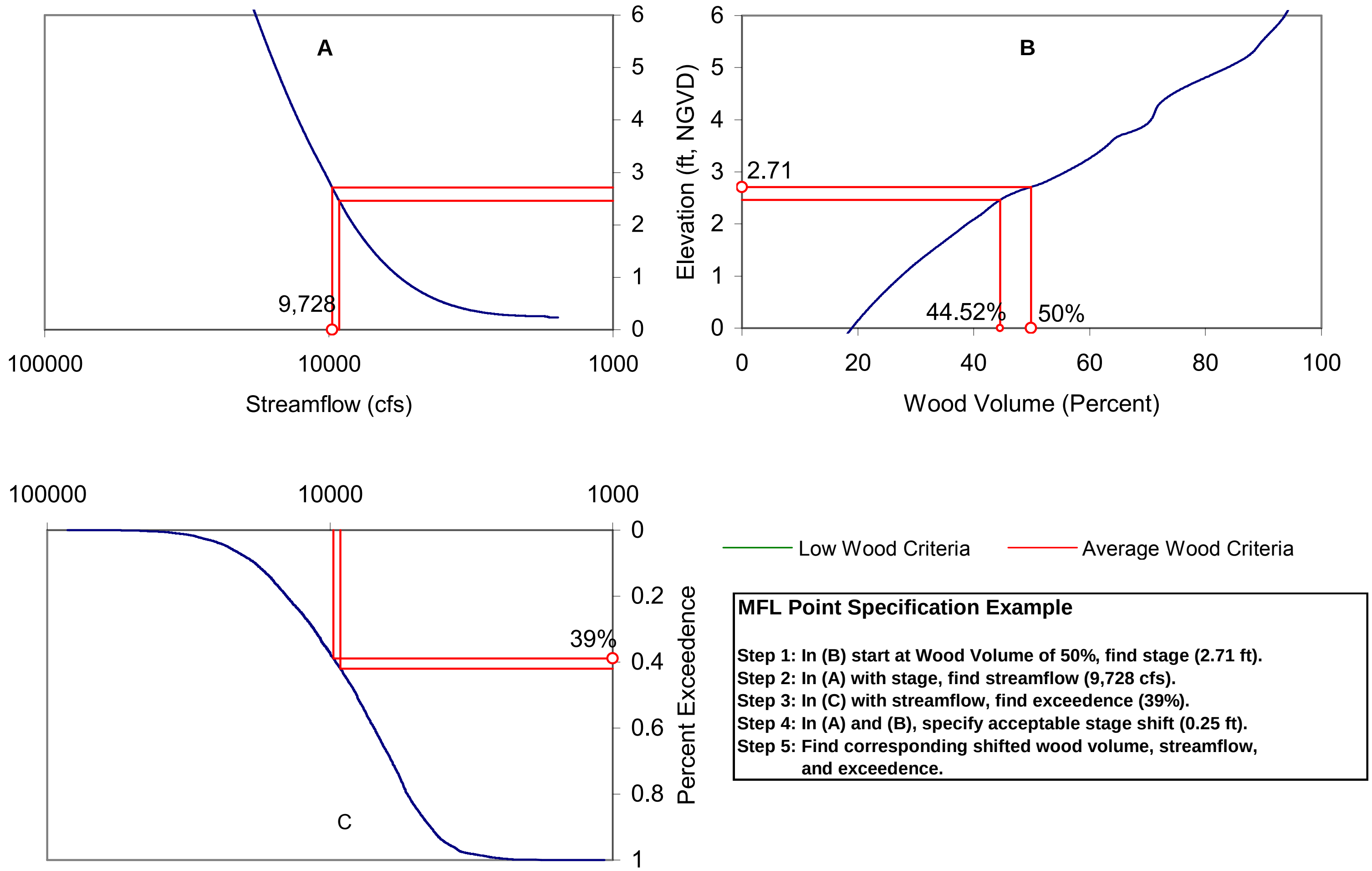


Figure 5-38. Estimated streamflow with a 0.25-foot shift in stage for submerged wood at Manatee study site. (A) The stage-discharge rating for stage at Manatee and flow at Wilcox from HEC-RAS model, (B) The relationship between wood volume and stage at Manatee, (C) The long-term FDC for Wilcox.

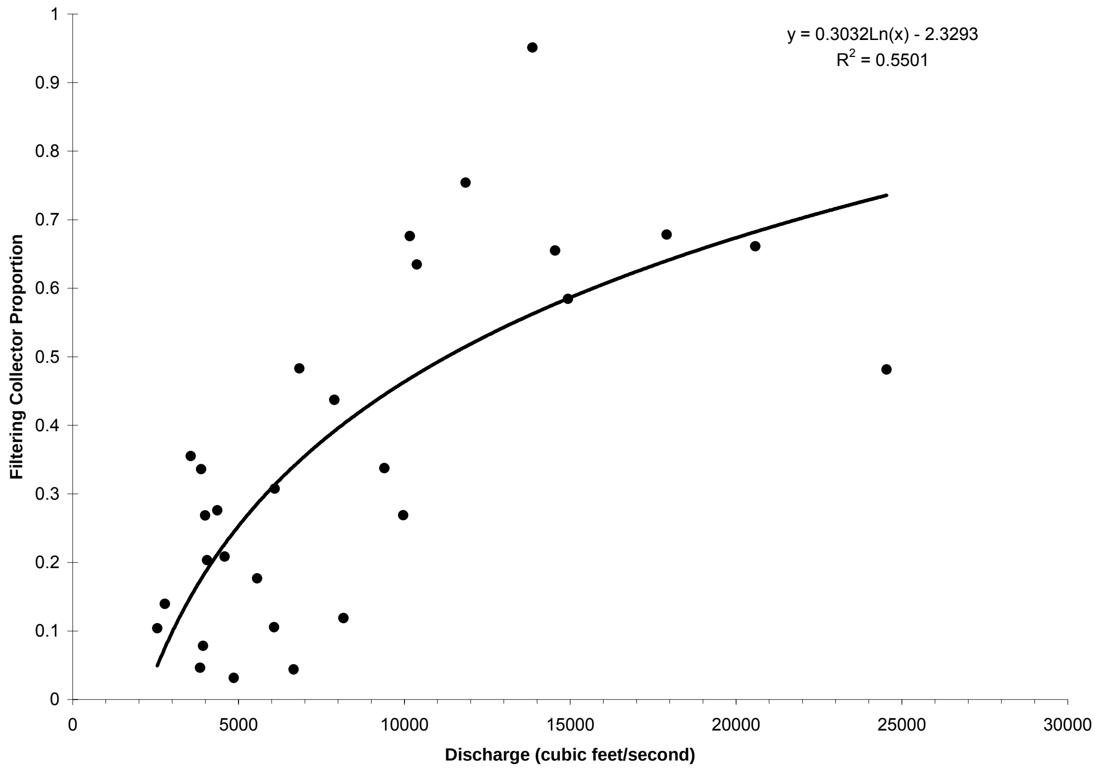


Figure 5-39. Relationship between river flow and proportion of filtering collector invertebrates on Hester-Dendy samplers at SRWMD long term site SUW150C1 – Suwannee River at Rock Bluff.

5.3.8 Tidal Marshes

Of the tidal- marsh habitats found in the Suwannee estuary, the lower salinity marsh types (oligohaline and tidal freshwater) will be most susceptible to changes caused by increased salinity due to water withdrawal. However, even the higher-salinity salt marshes could be impacted from elevated salinities caused by flow reductions. The “brown marsh” phenomenon in coastal Louisiana involves dieback of *Spartina alterniflora*, one of the most salt-tolerant tidal marsh plants. This dieback appears to be associated with stress induced during drought, with sustained periods of elevated salinity (www.LAcoast.gov/brownmarsh), thus, maintenance of adequate levels of freshwater inflow will be important for the conservation of all types of tidal marsh ecosystems in the Suwannee estuary. Important considerations for setting fresh-water flows which maintain the salinity fields needed to protect tidal marsh communities include the plant species composition in low-salinity marsh types (oligohaline and tidal fresh water) and the salinity tolerances of the dominant plants and animals in the marshes.

5.3.8.1 Methodology and Analysis

Clewell et al. (1999) conducted surveys of land surface elevation, soils, soil and water salinity and tidal marsh plant communities at seven intensive transects located across the delta area of the Suwannee estuary. The locations of the intensive transects were selected to span a range of marsh types, from brackish to mesohaline. These lower-salinity marsh systems will be most susceptible to adverse ecological impact from reductions in freshwater inflow. Tidal marshes north or south of the river mouth, along the coast, were not sampled because those are classic “salt” marshes, dominated by halophytes, which will be less sensitive to changes in salinity caused by reductions in fresh-water inflow.

Three intensive transects were located in West Pass and two in East Pass. Two other intensive transects, Salt Creek and Dan May Creek, were located in areas less influenced by the fresh-water flow of the Suwannee in order to separate out the effects of reductions in fresh-water inflow from other phenomenon, such as sea level rise. Transects ranged from 399 feet (121 meters) to 604 feet (183 meters) in length and extended from the shoreline of the river or creek into the interior marsh. Shoreline vegetation surveys were also conducted along transects 100 feet (30 m) in length (laid parallel to the shoreline) on both sides of the river channel at 15 sites sampled monthly for salinity by Mattson and Krummrich (1995) in 1993-95.

Land-surface elevation was measured on each intensive transect using a tripod-mounted level and survey rod. Additional readings were taken where the transect crossed features such as small tidal creeks. Horizontal distances were measured using a fiberglass tape and locations of all sampling sites were recorded with a differential GPS unit. Soils were sampled at 100 feet intervals on each of the intensive transects, and at the midway point (50 feet) on the shoreline vegetation transects. Soil samples were obtained using a 3-inch bucket auger. A standard posthole digger was occasionally used when larger samples were needed. Typically, soil profiles were sampled to a depth of 2 feet (1.2 meters). Soil parameters surveyed were pH, conductivity, moisture content, percent saturation, bulk density, organic matter, texture, and redox potential. Methods were described in detail in Clewell et al. (1999).

Tidal marsh plant community data were collected at the intensive transects and shoreline transects using a 0.5 m^2 circular quadrat. The occurrence of all plant species within the quadrats was recorded. On the intensive transects, plant community measurements were made in groups of 20 quadrats clustered in a rectangular area 100 feet long by 12 feet wide centered over the transect centerline. Six equally spaced groups of 20 quadrats were collected along each intensive transect. Plant data were expressed as frequency of occurrence, or number of observations of a plant species out of the 20 quadrats. On the shoreline vegetation transects, 20 quadrats equally spaced along the 100 feet length of the transect were collected, with plant data again expressed as frequency of occurrence (number of quadrats) of a plant species.

One hundred fifty-eight plant taxa in 75 families were identified in various plant communities on the Suwannee delta. Most of these were tidal marsh species, and others were found in tidal freshwater swamps, maritime hammocks, and submerged vegetation beds. Dominant groups were sedges and grasses in the monocots and composites (Asteraceae) and Apiaceae (=Umbelliferae; carrot family) in the dicots. Using the intensive transect data, regressions of occurrence of more common marsh plant taxa versus soil conductivity and various other soil parameters indicated that conductivity (= salinity) explained a considerable fraction of the variation in plant species occurrence. This result was confirmed with Canonical Correspondence Analysis, which indicated that conductivity was a major variable explaining the distribution of plant communities and plant taxa in this region of the Suwannee estuary (Figure 5-32 in Clewell et al., 1999). These results indicate the importance of salinity in structuring tidal marsh plant communities.

5.3.8.2 Cladium/Juncus ratios

Very little data exist on the actual salinity tolerances of the dominant plants growing in the oligohaline and tidal freshwater marshes. *Cladium*-dominated marshes in the Suwannee estuary appear to be exposed to higher salinities of up to 12-15 ppt during extreme droughts (Clewell, 2000). These result in loss of fresh-water plant taxa in oligohaline marshes intolerant of these salinities, but dominants such as *Cladium, Scirpus americanus*, and *Saururus cernuus* appear to persist (Clewell, 2000). A summary table in Odum et al. (1984 – their Table 5), indicates that a number of the plants found in the tidal fresh-water marshes (*Pontedaria cordata*, *Scirpus validus*, *Typha sp., Bohmeria cylindrica*, and other plants common in Suwannee estuary marshes) can occur in salinities ranging over 3-7 ppt, suggesting that they can tolerate some periods of elevated salinity. Other dominants in the Suwannee marshes, such as *Zizania aquatica* and *Cicuta mexicana*, appear to be much less tolerant of salinity (Odum et al., 1984; Clewell, 2000), but the proposed targets for tidal fresh marshes are within the ranges currently experienced in these regions of the Suwannee estuary. Overall, the data available appear to indicate that the proposed tidal marsh salinity targets will be adequate to sustain the various marsh types. Although the classic "Venice" system of salinity zonation in an estuary describes the oligohaline zone as areas with a mean annual salinity of < 5 ppt, more recent, biologically based salinity classifications place the oligohaline zone as lying between mean annual salinities of 2-14 ppt (Bulger et al., 1993) and 0-8 ppt (Christensen et al., 1997). The above targets for mean and maximum annual salinity lie within these zones.

Clewell et al. (1999) demonstrated a significant relationship between maximum salinity at a location and the ratio of occurrence of *Cladium jamaicense* (reflecting lower salinity marshes) and *Juncus roemerianus* (reflecting higher salinity marshes) in shoreline marshes fringing East and West passes in the Suwannee estuary (Figure 5-40). Between salinities of 6 and 12 ppt (seasonal maximum measured mid-river channel),

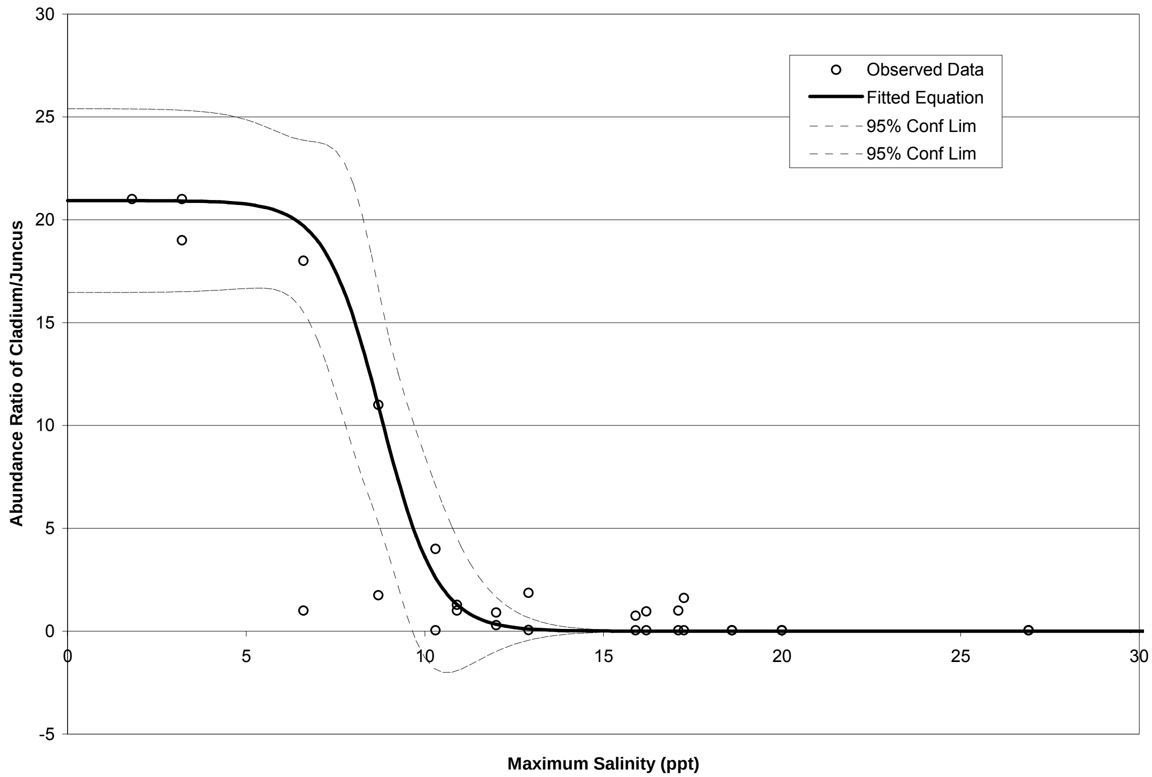


Figure 5-40. Relationship maximum salinity at sampling sites in East and West Passes and the ratio of occurrence of *Cladium* to *Juncus*. Adapted from Clewell et al. (1999).

shoreline communities shifted from a *Cladium*-dominated to a *Juncus* dominated marsh community. An increase of 10% in the maximum salinity is proposed as an allowable shift. This results in relatively small changes to the *Cladium/Juncus* ratio, suggesting minimal changes to plant community composition in the shoreline and adjacent marshes. The ratio shifts from <1 (indicating *Cladium* dominant) to >1 (*Juncus* dominant) at a maximum salinity of about 12 ppt (Clewell et al., 1999). The proposed maximum salinity targets are all ≤12 for oligohaline marshes.

Salinity tolerances of many of the dominant animal taxa found in the tidal marshes of the Suwannee estuary are generally quite broad (Table 5-6; Heard, 1982; PBS&J, 2003), and thus the marsh fauna should not be adversely affected by the proposed salinity targets. Two characteristic taxa are the olive nerite snail (*Neritina usnea*) and the freshwater fiddler crab (Uca minax). The olive nerite is reported to tolerate an exceptionally wide range of salinities of (Heard, 1982; PBS&J, 2003), indicating that the abundant populations of this snail should not be affected by the proposed salinity shifts. Similarly, the proposed shifts remain in the salinity ranges where abundance of *U. minax* is maximal; mostly <12 ppt (Figure 5-41).

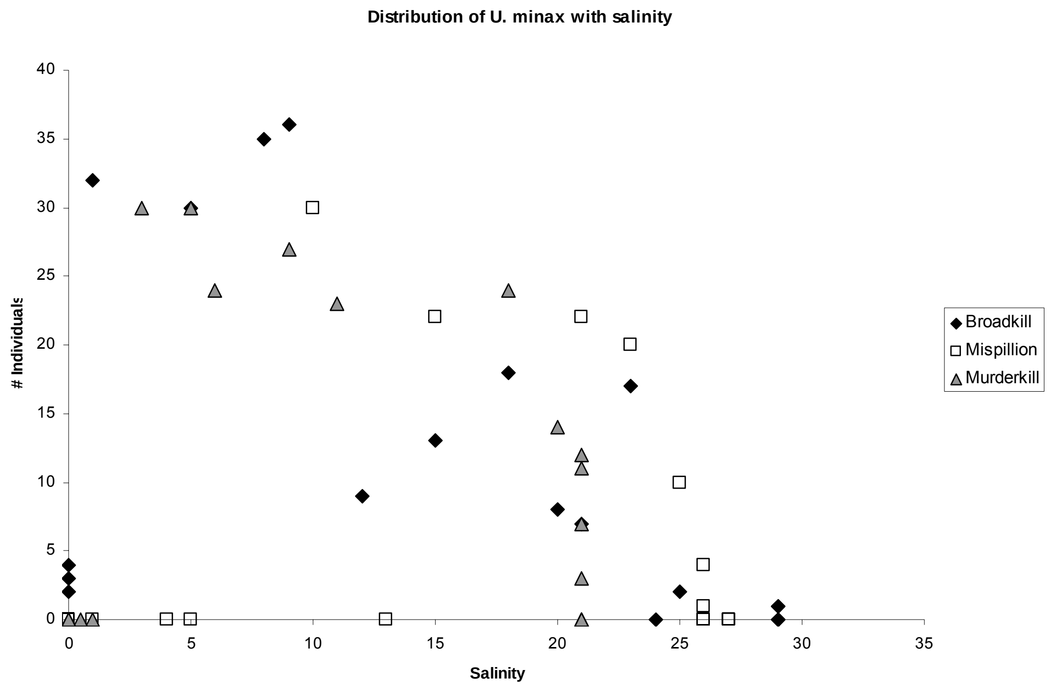


Figure 5-41. Distribution of *U. minax* with salinity in three river estuaries in Delaware. Data from Miller and Mauer, 1973.

Additionally, the benthic invertebrate communities commonly found in these tidal creeks appear to be characterized by species with broad salinity tolerance. Horlick and Subrahmanyam (1983) described a tidal creek benthic community in the St. Mark's estuary, and found many of the taxa listed in Table 5-7, including polychaetes such as *Streblospio benedicti*, various estuarine amphipods (*Ampelisca spp.*, *Grandidierella spp.*, *Gammarus spp.*), isopods (*Cyathura polita*), and snails (*Bittium varium*, *Cerithidea costata*). Based on this information, the proposed tidal creek salinity criteria appear to be adequate to maintain the composition and diversity of benthic fauna and fish communities of the tidal creeks.

5.3.9 Integrating Relationships between Habitat Availability and River Flow

5.3.9.1 Assumptions and Considerations

In evaluating the relationships established between the flow at Wilcox and downstream habitat availability, it is important to recognize the assumptions under which the consideration of MFLs were based. Our approach was to assume that the habitat requirements to provide adequate thermal refuge for manatee was the priority factor in selecting MFLs for the Lower Suwannee River. Since the manatee habitats were located upstream from the portion of the Lower Suwannee River usually exposed to the influence of salinity, we assessed the springs requirements first. We then *a priori* assess the downstream habitats in relation to the springs requirements, assuming all these downstream habitats had equal ecological value. A weight of evidence approach was considered in assessing the relative applicability of each of the downstream habitat assessments. The criterion established for each of the habitats was assessed relative to what we observed in the long-term data record for the Suwannee River. For example, the data for SAV showed empirical evidence of the effects of drought conditions on the downstream limit of SAV in the West Pass of the Lower Suwannee River. Further, we were able to validate salinity-flow predictions based on the synoptic surveys to independent data collected at continuous recorders over a different period of record. This gave us more confidence in our assessment of the effects of flow on the location of the 9 ppt isohaline. Therefore, we were able to give more weight to estimates associated with risk to SAV habitats than to other estuarine habitats considered. The fact that SAV is a static habitat located within the river gives further credence to the validity and reliability of estimates of risk compared to tidal swamp habitats which include vegetation located up to a mile away from the river bank.

The conservative nature of our assessments minimized the possibility that acute exposures to threshold conditions would not result in a loss of habitat for the organism of interest. While there remains uncertainty in the precise location of an isohaline at any given time in the Lower Suwannee River, we can predict the average location of the maximal extent of salinity incursion into the Lower Suwannee with confidence. This approach allowed us to estimate the risk based on a change in the average condition representing a chronic exposure and is consistent with the empirical evidence of measured biological response to habitat perturbations.

Tidal Creek habitats were considered for assessment but relationships between flow and the 5 ppt isohaline location were more difficult to quantify over the range of locations of tidal creek access points. Further, little data were available on the salinities and fish collections in the backwater tidal creek areas within the Lower Suwannee River since these areas are difficult to access. The fact that fishes are motile and can to some extent choose the habitat they wish to utilize and avoid conditions that stress their osmoregulatory capacity resulted in giving less weight to the 5 ppt threshold when assessing the impacts of flow on risk of habitat degradation.

While no dedicated sampling program existed to relate salinity in Suwannee Sound to flows from the Lower Suwannee River, we were able to relate flows to median salinities for groups of stations sampled by a long-term water quality monitoring program in the sound. The groups we delineated using objective techniques corresponded well with knowledge of the dynamics of interaction between the Lower Suwannee and the Suwannee sound. An Inshore Reef zone resulted from the PCA analysis that corresponds to the location of several major oyster bars in Suwannee sound. This zone extended to the south, which is the dominant flow pattern of fresh water entering the sound from the river. The criterion for oyster habitat established based on published literature was a threshold annual average surface salinity of 20 ppt. Median salinities for the Inshore Reef group were well below 20 ppt and predictions suggested that the average annual salinities would only be above 20 ppt during drought conditions. The offshore group approach 20 ppt under normal conditions and therefore represents a zone relatively insensitive to changes in the frequency of exceedance of the 20 ppt threshold.

Given these considerations, protection of manatee habitat, the limiting target habitat criteria for establishing MFLs for Manatee and Fanning Springs, should be used to establish an MFL for the Lower Suwannee River during the high flow, winter months period (i.e., November through April) and risk to SAV habitat should considered as the limiting target habitat criteria to establish a MFL that covered the remaining months of the year (i.e., May through October). This approach is in reflection of the river-spring flow relationship discussed in this section and in Section 3. In both cases, the recommended flow or level that should avoid significant adverse environmental impact to the manatee habitat in the springs are also protective of the river habitat during the high flow, winter period. Conversely, the high flow, warmer months MFL in the river should avoid a significantly adverse environmental impact in the springs.

5.4 Critical Flows to Maintain Thermal Refuge and Passage and Lower Suwannee River Habitats

5.4.1 Manatee Spring

To avoid a significantly adverse impact to the thermal refuge for manatee at Manatee spring a minimum spring flow of 130 cfs was identified. This flow is based on modeling of the relationships of river and spring discharge during the winter months. While spring flows drop below the 130 cfs during other months of the year, the critical condition is access to the thermal refuge during the winter months.

5.4.2 Fanning Spring

Manatee passage at Fanning spring requires a minimum 2.71 ft. (NGVD) spring stage equivalent to provide enough depth for the 5.0 foot fully grown manatee passage requirement into the spring pool The probability that stage at Fanning Spring will be greater than 2.71 feet NGVD for a given discharge can be determined from Figure 5.10.

5.4.3 Lower Suwannee River

Downstream habitat considerations in the Lower Suwannee resulted in flow associated risk estimates for each habitat type of interest (Table 5.10). Inflection points were noted for three of the habitat types (i.e., SAV, Tidal Swamps, and Inshore Reef oyster habitats). These inflection points correspond to flows at Wilcox between 6,000 and 7,000 cfs. By averaging the flows associated with each inflection point, a critical flow of 6,596 cfs would be derived. Given that the weight of evidence for SAV appears to be more robust for SAV and since SAV is known to be important habitat for macroinvertebrates and fishes and is a food source for manatee, protecting this habitat is recommended to be the prime consideration for MFL establishment. Figure 5-42 presents a fine scale estimate of flow associated risk for SAV for risk points between 0 and 5%. With flows of 6,515 cfs it is estimated that 3.5 % of the SAV would be at risk. Averaging estimates of the average inflection point and the 3.5% risk estimate would equate to an estimate of 6,555 cfs. As stated previously, the conservative nature of the risk assessments was based on identifying conditions where the biological organism under consideration would begin to encounter conditions that were physiologically stressful and meet the conditions of a potentially significant adverse environmental impact. Therefore, these habitats are periodically exposed to conditions above the threshold values established for risk. In this way, we assume that some degree of risk is allowable but attempt to minimize this risk for the target habitats. Again, chronic exceedance conditions would be required to pose a threat to actual loss of habitat.

Table 5-10. Flow associated risk estimates for 0 to 15 % of each habitat type.

	Percent Habitat at Risk			
Habitat Types	**0%**	**5%**	**10%**	**15%**
	Flow (cfs)			
SAV	7,858	6,180	5,798	4,867
Tidal Swamp	11,031	8,230	6,772	6,157
Tidal Creeks*	10,878	9,899	9,043	8,424
Oyster Reef	10,166	6,836	5,549	4,016
Oyster Offshore*	10,166	9,566	9,256	8,466

Shaded cells indicate location of inflection points in risk estimates

* Indicates habitats given less weight in application to MFL

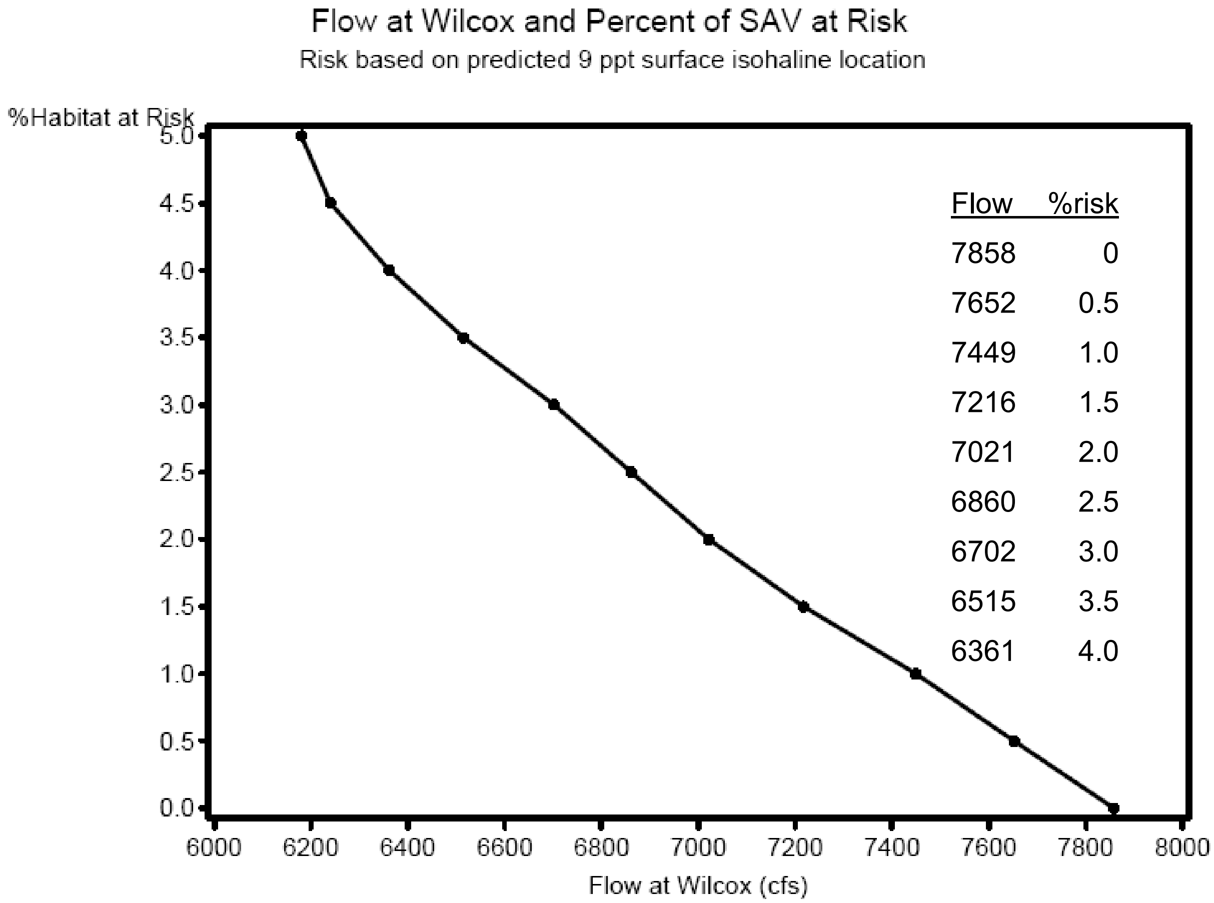


Figure 5-42. Flow associated risk for SAV in 0.5 % increments form 0 to 5%.

5.4.4 Sustaining River Low Flow Conditions During the Dry Season

As noted in Section 3.3.2.4.4, Manatee and Fanning springs contribute as much as 8 percent of the total discharge during low-flow periods in the Lower Suwannee River below Wilcox (Figure 3-44). The proposed MFLs for the Lower Suwannee River and estuary during the warm, low-flow season are supported, in part, by spring discharge. Figures 3-45 and 3-46 present monthly spring flow and stage relationships with discharge at the Wilcox gage. Based on the equations developed to characterize these relationships (Figures 3-45, 3-46), a series of potential MFLs can be considered for the warm season. Table 5-11 presents possible MFLs for warm season (May – October) conditions at the springs. Note that the R^2 values for discharge estimations are weak.

Table 5-11. Warm season calculated stage and discharge conditions at Fanning and Manatee springs. Stage and discharge values for each river discharge value are based on the equations presented in Figures 3-45 and 3-46.

Suwannee River Discharge at Wilcox (cfs)	Approximated Stage at Fanning Spring (ft., NGVD)	Approximated Discharge at Fanning Spring (cfs)	Approximated Stage at Manatee Springs (ft., NGVD)	Approximated Discharge at Manatee Springs (cfs)
6,000	3.7	86	1.9	144
6,200	3.7	85	2.0	144
6,400	3.8	84	2.0	145
6,600	3.9	83	2.1	146
6,800	4.0	82	2.2	147
7,000	4.1	81	2.2	148
7,200	4.1	79	2.3	149
7,400	4.2	78	2.3	149
7,600	4.3	77	2.4	150
Goodness of regression data fit (R^2)	0.960	0.244	0.960	0.537

Shaded values equate to LSR flow that reflects a 3.5% loss of SAV as discussed in Section 5.4.2.3

SECTION 6

6.0 Summary and MFL Recommendations

6.1 Summary

The Suwannee River is widely regarded as a natural river system with high conservation and recreational value. The Nature Conservancy (Master et al., 1998) classified the Suwannee/Santa Fe drainages as "critical watersheds to protect freshwater biodiversity" and has been designated by the state as an Outstanding Florida Water (OFW) and the Lower Suwannee River is part of the Big Bend Aquatic Preserve.

The Lower Suwannee River is the second largest river system in Florida by drainage area and mean annual flow. Major tributaries of the river are the Withlacoochee and Alapaha Rivers, which are located mostly in Georgia, and the Santa Fe River in Florida. In total, approximately 57% of the basin is located in Georgia.

6.1.1 Lower Suwannee River Study Area

That portion of the Suwannee River Basin downstream of the Wilcox Gage at Fanning Springs comprises the drainage basin associated with the MFL study area. For purposes of establishing MFLs for the Lower Suwannee River system, all river flow measurements are made from the long term USGS Wilcox gage. This portion of the basin includes, in part, the ground-water basins for Manatee and Fanning Springs. As discussed in Section 3.0, the flows of the river and springs systems are inextricably linked (Figure 6-1). The river flow controls the springs flow throughout the year allowing discharge from the springs during the low flow periods and the river flows back into the springs during high flow periods. Establishing the MFLs for the river and springs simultaneously was required to provide effective and coordinated regulation of each waterbody's MFL.

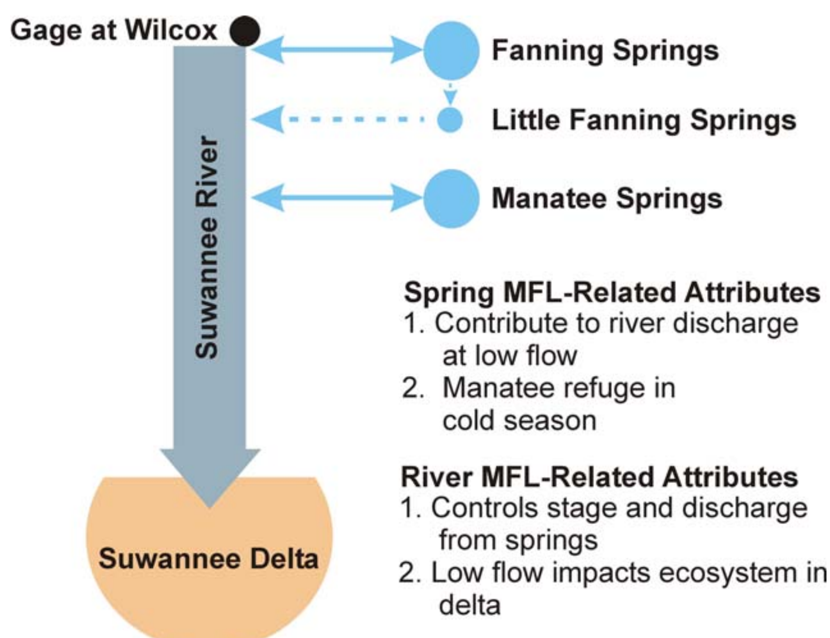


Figure 6-1. Lower Suwannee System Flow Relationships.

6.1.2 Fanning Spring

Fanning Springs State Park is located in the city of Fanning Springs, Levy County, Florida. The park is a State Recreation Area with two springs (Fanning and Little Fanning) located within the park. Much like the river, the springs are important to the natural and scenic beauty of the area. The Fanning Spring is also an important thermal refuge for manatees, which frequent the spring throughout the year, especially during the cold, winter months of November through April. The spring is classified as a Category 2 manatee refuge.

Median discharge for the period of record is 90 cfs and average discharge is 94 cfs. According to the Division of Recreation and Parks (2003), the most important designated species in the park is the Florida manatee. Discharge and stage in Fanning Spring and its run are controlled by stage of the Suwannee River. 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).

6.1.3 Little Fanning Spring

Little Fanning Spring is a 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, personal communication), the spring has been observed to not be flowing on numerous occasions. Median discharge is 18 cfs, and average is 16 cfs. 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. Little Fanning spring flow will be controlled by the flow from Fanning spring and therefore an MFL will be established in conjunction with the Fanning Spring MFL.

6.1.4 Manatee Spring

Manatee Spring State Park is located near the city of Chiefland, Levy County, Florida. Manatee Spring consists of a spring “bowl” and run approximately 1,200 feet in length. Median discharge for the period of record is 204 cfs and average discharge is 189 cfs. The spring is classified as a Category 2 manatee refuge.

6.2 MFL Evaluation Procedure

The evaluation performed for the establishment of MFLs for the three priority water bodies (Lower Suwannee River and Estuary, Fanning Spring and Manatee Spring) were conducted with the following approach:

1. Compile all “best available information” relative to the water bodies;
2. Evaluate information to determine flow and/or level relationships for each waterbody to adverse impacts to the water resource or related ecology;
3. Identify the limiting target criteria that, if protected from a significant adverse impact, will protect all other applicable criteria;
4. Recommend an MFL that will protect the waterbody and related ecology from “significant harm”.

6.3 MFL Ecologic Evaluation

After careful compilation of all "best available information" to evaluate the three water bodies, the analyses to determine the most limiting habitat to be protected from a significant adverse impact were conducted using the following eight habitats of interest:

1. Manatee Thermal Refuge
2. Upper Estuary Submerged Aquatic Vegetation
3. Tidal, Fresh-water Swamps
4. Tidal Creeks
5. Oyster Bars and Reefs
6. Upper Tidal Bottomland Hardwood Forests
7. Riverine Woody Snag Habitat
8. Tidal Marsh Habitat

6.3.1 MFL Water Resource Value Conclusions (Tables 6-1 thru 6-3)

1. Recreation and aesthetic values were the limiting water resource values for the Manatee and Fanning springs MFLs in addition to the wildlife habitat value in the form of manatee thermal refuge for the cold season (Nov-Apr).
2. Estuarine resources in the form of submerged aquatic vegetation was the limiting water resource value for the Lower Suwannee River in addition to the wildlife habitat value in the form of manatee thermal refuge for the cold season (Nov-Apr).

6.4 Recommended MFLs

6.4.1 Manatee Spring – Recommended MFL

To avoid a significantly adverse impact to the thermal refuge for manatee at Manatee Spring a minimum spring flow of 130 cfs during cold season (November–April) is recommended. This flow is based on modeling of the relationships of river and spring discharge during the cold season (November–April). In addition, throughout the year, the historic flow regime will not reduced by more than 10% (Figure 6-2). This is based on evaluation of the relationship of spring discharge to river stage, avoidance of significant adverse impact to the recreation and aesthetic values of the spring, manatee thermal refuge in the cold season (Nov-Apr) and available water in the springshed. (Table 6-1).

Table 6-1. Recommended MFL for Manatee Spring

	NOVEMBER 1- APRIL 30	ANNUAL
Minimum Flow	130 cfs	Flow regime that will maintain 90% of historic flow regime

In order to test if the recommended MFL avoids significant adverse impacts to each of the water resource values found in Chapter 62-40.473 F.A.C. Each recommended MFL was evaluated with respect to the ecological and human use value for each water body as discussed in Section 1-4 and summarized in Table 6-2.

Table 6-2. Manatee Spring Recommended MFL.
Summary considerations for each water resource value

ECOLOGIC & HUMAN USE VALUE	IS VALUE APPLICABLE TO WATER BODY?	REQUIREMENTS TO AVOID SIGNIFICANTLY ADVERSE IMPACT	DOES RECOMMENDED MFL ADDRESS VALUE?
Recreation in and on the water	Yes	Full pool that minimizes "dark water" intrusion from river	Yes
Fish and wildlife habitats and the passage of fish	Yes	130 cfs during cold season to maintain thermal refuge	Yes
Estuarine resources	Yes	Maintain acceptable flows to river in dry period to avoid significant adverse impacts	Yes
Transfer of detrital material	No	NA	NA
Maintenance of freshwater storage and supply	Yes	Availability of water for future use	Yes
Aesthetic and scenic attributes	Yes	Full pool that minimizes "dark water" intrusion from river	Yes
Filtration and absorption of nutrients and other pollutants	No	NA	NA
Sediment loads	No	NA	NA
Water quality	No	NA	NA
Navigation	No	NA	NA

Blue shading indicates limiting (most sensitive to flow reduction) value

6.4.2 Fanning Spring/Little Fanning– Recommended MFL

Manatee passage at Fanning Spring requires a minimum 2.71 ft. (NGVD) spring stage equivalent to provide enough depth for the 5.0 foot passage requirement during the cold season (November–April) for fully grown manatee to enter the spring pool. The recommended Lower Suwannee River median flow of 7,600 cfs in the cold season will control the spring run elevation and allow the 2.71 feet (NGVD) level to be met 85% of the time (7,600 cfs equates to average monthly stage of 4.3 ft). In addition, throughout the year, the historic flow regime for Fanning Spring will not reduced by more than 10% (Figure 6-3). This is based on evaluation of the relationship of spring discharge to river stage, avoidance of significant adverse impact to the recreation and aesthetic values of the spring, manatee thermal refuge in the cold season (Nov-Apr) and available water in the springshed. (Table 6-3).

Table 6-3. Recommended MFL for Fanning/Little Fanning Spring.

	NOVEMBER 1 – APRIL 30	ANNUAL
Minimum Level	2.71 ft. NGVD in Fanning spring run to be met 85% of the time	Flow regime that will maintain 90% of historic flow regime

Table 6-4. Fanning/Little Fanning Spring Recommended MFL.
Summary considerations for each water resource value

ECOLOGIC & HUMAN USE VALUE	IS VALUE APPLICABLE TO WATER BODY?	REQUIREMENTS TO AVOID SIGNIFICANTLY ADVERSE IMPACT	DOES RECOMMENDED MFL ADDRESS VALUE?
Recreation in and on the water	Yes	Full pool that minimizes “dark water” intrusion from river	Yes
Fish and wildlife habitats and the passage of fish	Yes	Minimum 5.0 ft. depth in Fanning spring run for manatee passage during cold season	Yes
Estuarine resources	Yes	Maintain acceptable flows to river in dry period to avoid significant adverse impacts	Yes
Transfer of detrital material	No	NA	NA
Maintenance of freshwater storage and supply	Yes	Availability of water for future use	Yes
Aesthetic and scenic attributes	Yes	Full Fanning spring pool that minimizes “dark water” intrusion from river	Yes
Filtration and absorption of nutrients and other pollutants	No	NA	NA
Sediment loads	No	NA	NA
Water quality	No	NA	NA
Navigation	No	NA	NA

Blue shading indicates limiting (most sensitive to flow reduction) value

6.4.3 Lower Suwannee River– Recommended MFL

Downstream habitat considerations in the Lower Suwannee River resulted in flow-associated risk estimates for each habitat type of interest. Given that the weight of evidence for SAV appears to be more robust and since SAV is known to be important habitat for macroinvertebrates and fishes and is a food source for manatee, protecting this habitat is recommended to be the prime consideration for MFL establishment. With flows of 6,515 cfs it is estimated that 3.5 % of the SAV would be at risk. Averaging estimates of the average inflection point and the 3.5% risk estimate would equate to an estimate of 6,555 cfs (6,600 cfs rounded). Therefore, the recommended Minimum Flow is 6,600 cfs for the warm period (May-October). The cold season (November to April) MFL is recommended at 7,600 cfs which will maintain the Fanning Spring 2.71 feet NGVD elevation approximately 85 % of the time, a reduction of 12% over current conditions. (Figure 6-5)

Table 6-5. MFL for Lower Suwannee River at Wilcox Gage.

	NOVEMBER 1 – APRIL 30	MAY 1 – OCT 31
Minimum Flow	7,600 cfs	6,600 cfs

Table 6-6. Warm season calculated stage and discharge conditions at Fanning and Manatee springs. Stage and discharge values for each MFL value are based on the equations presented in Figures 3-45 and 3-46.

LSR WARM SEASON MINIMUM FLOW (cfs)	APPROXIMATED MONTHLY AVERAGE STAGE @ FANNING SPRING (ft., NGVD)	APPROXIMATED MONTHLY AVERAGE DISCHARGE @ MANATEE SPRINGS (cfs)
6,600	3.9	146

Figure 6-2. Percent of time stage at Fanning spring is greater than 2.71 ft for selected monthly median cold season Wilcox discharges

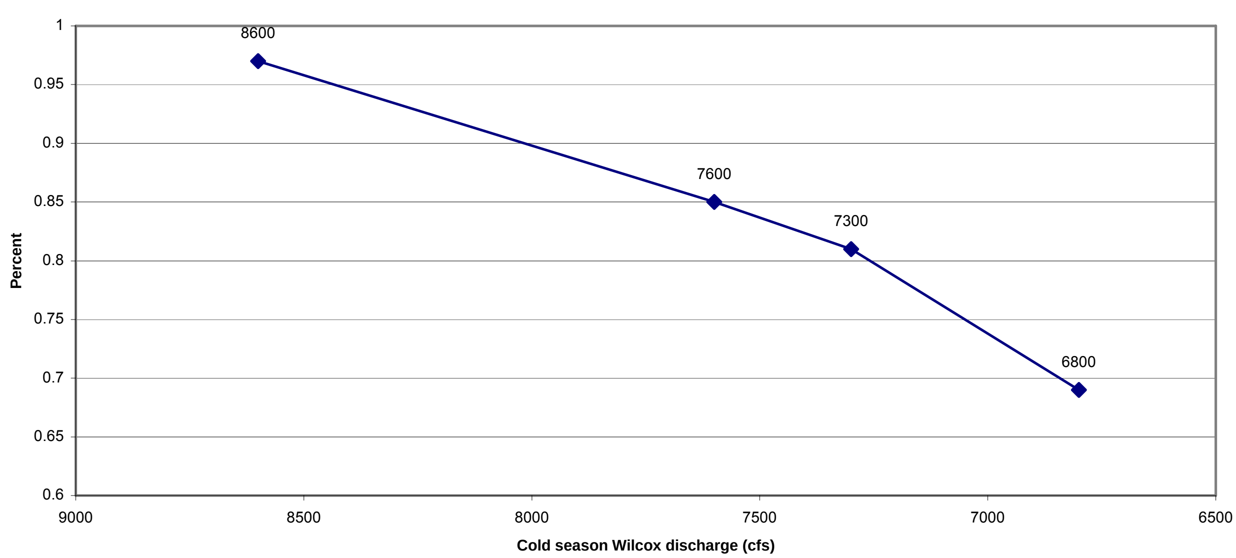


Table 6-7. Lower Suwannee River Recommended MFL.
Summary considerations for each water resource value

ECOLOGIC & HUMAN USE VALUE	IS VALUE APPLICABLE TO WATER BODY?	REQUIREMENTS TO AVOID SIGNIFICANTLY ADVERSE IMPACT	DOES RECOMMENDED MFL ADDRESS VALUE?
Recreation in and on the water	Yes	Sufficient flow for swimming, boating, fishing, kayaking and canoeing.	Yes
Fish and wildlife habitats and the passage of fish	Yes	Maintain manatee thermal refuge areas in springs	Yes
Estuarine resources	Yes	Avoid significant adverse impacts to limiting target resource SAV	Yes
Transfer of detrital material	Yes	Adequate flow to transport material from floodplain to river	Yes
Maintenance of freshwater storage and supply	Yes	Availability of water for future use	Yes
Aesthetic and scenic attributes	Yes	Flowing river	Yes
Filtration and absorption of nutrients and other pollutants	Yes	Flood flows moving into wetlands	Yes
Sediment loads	Yes	Transport sediment loads at higher flows	Yes
Water quality	Yes	Salinity movement limited to avoid significant adverse impacts to ecosystem	Yes
Navigation	NA	NA	NA

Blue shading indicates limiting (most sensitive to flow reduction) value

6.5 RECOMMENDATIONS

Based upon the scientific investigations performed for the Lower Suwannee River, Manatee and Fanning/Little Fanning springs in accordance with applicable Florida Statutes, the following recommendations are made for MFL establishment by the District:

1. A seasonal MFL regime be established for the Lower Suwannee River system that includes Manatee and Fanning Spring/Little Fanning Springs.
2. A Minimum Flow of 130 cfs be established for Manatee Spring for the period of November 1 – April 30. In addition, throughout the year, the historic flow regime will not reduced by more than 10%.
3. A Minimum Level of 2.71 feet (NGVD) in the Fanning spring run be established for Fanning Spring/Little Fanning Spring for the period of November 1 – April 30, to be met 85% of the time. In addition, throughout the year, the historic flow regime for Fanning Spring will not reduced by more than 10%.
4. A Minimum Flow of 7600 cfs median flow be established for the Lower Suwannee River for the period of November 1 – April 30.
5. A Minimum Flow of 6600 cfs median flow be established for the Lower Suwannee River for the period of May 1 – October 31.
6. The District 40B-2 water use permitting Basis of Review should be modified to include additional information required from the applicant to address issues for withdrawals that may impact the medium and higher flows for the Lower Suwannee River including Manatee and Fanning/Little Fanning Springs.

APPENDICES

Appendix A - Stream Measurements

Figure A-1 Stage at the Suwannee River Gage Near Wilcox (#02323500)

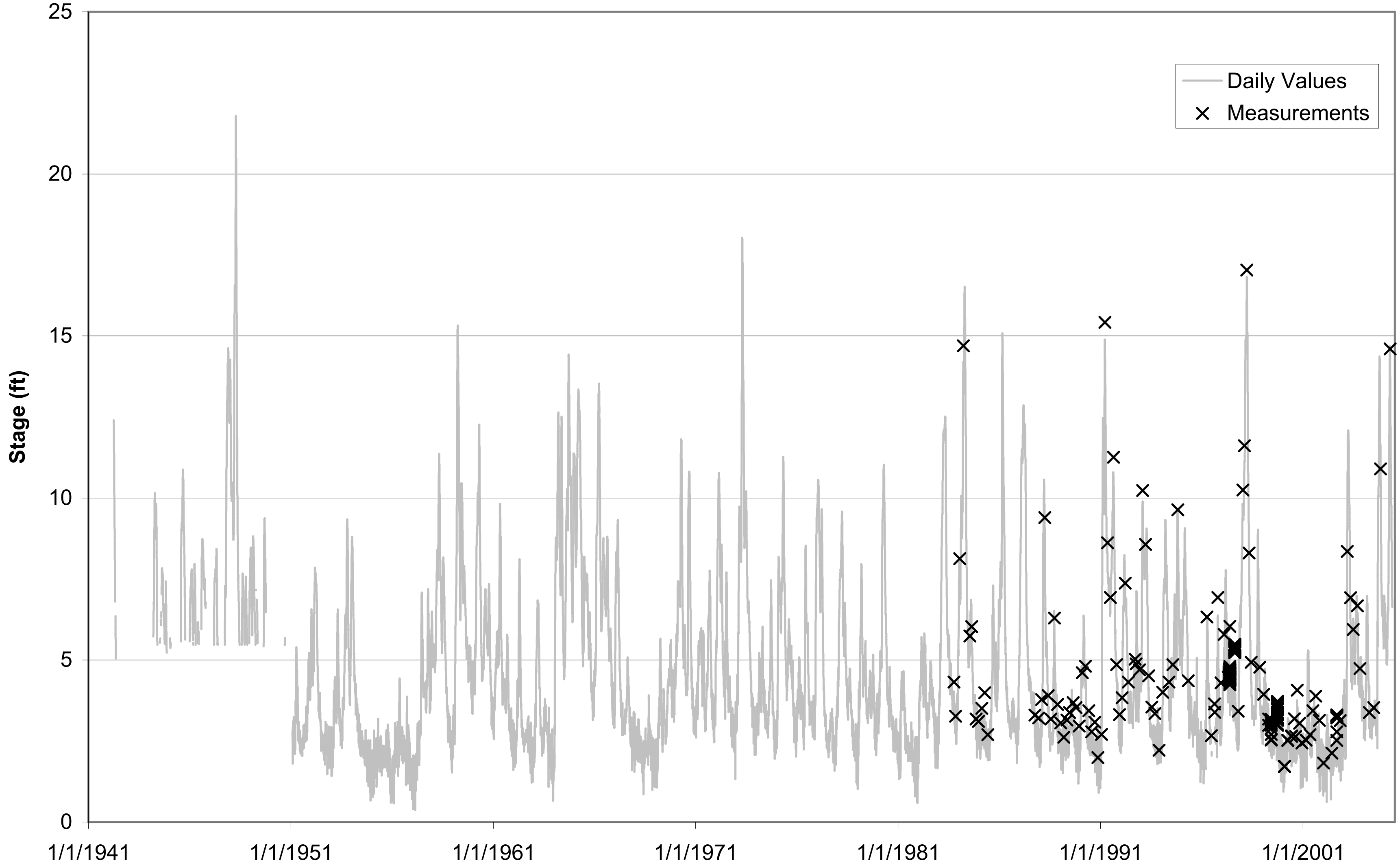


Figure A-2 Discharge at the Suwannee River Gage Near Wilcox (#02323500)

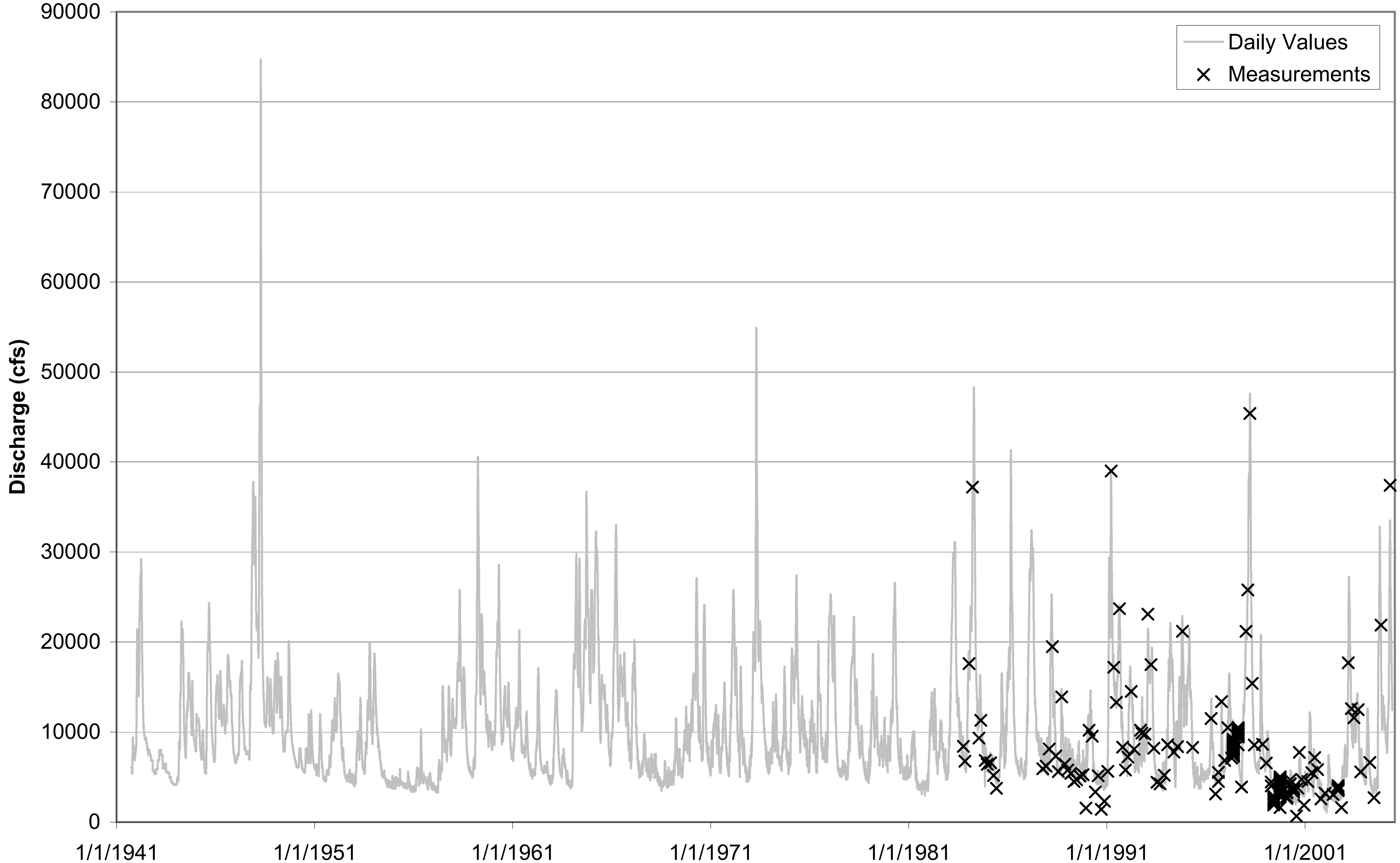


Figure A-3 Stage at the Fanning Spring gage (#02323502)

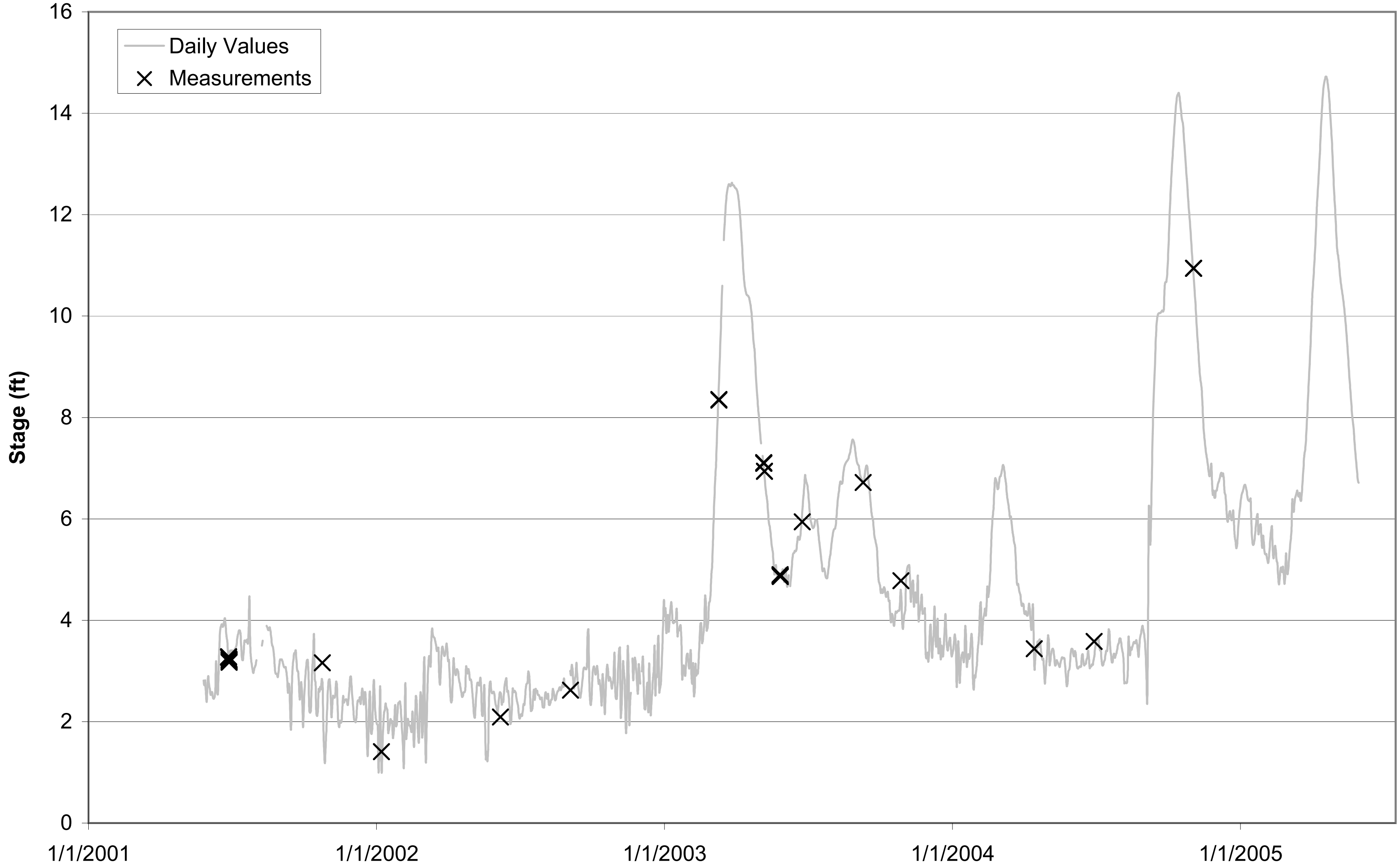


Figure A-4 Discharge at the Fanning Spring gage (#02323502)

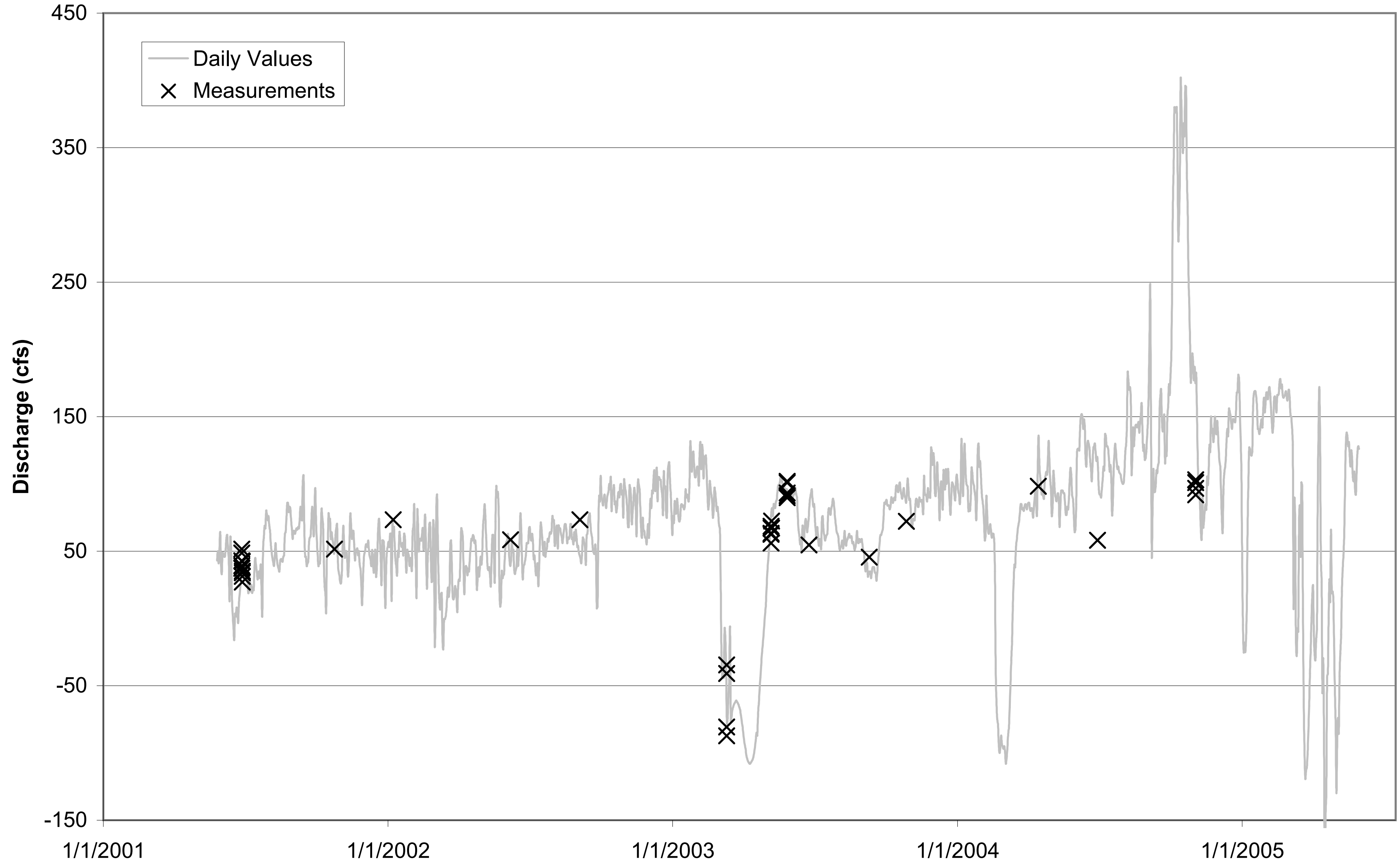


Figure A-5 Stage at the Manatee Springs Gage (#02323556)

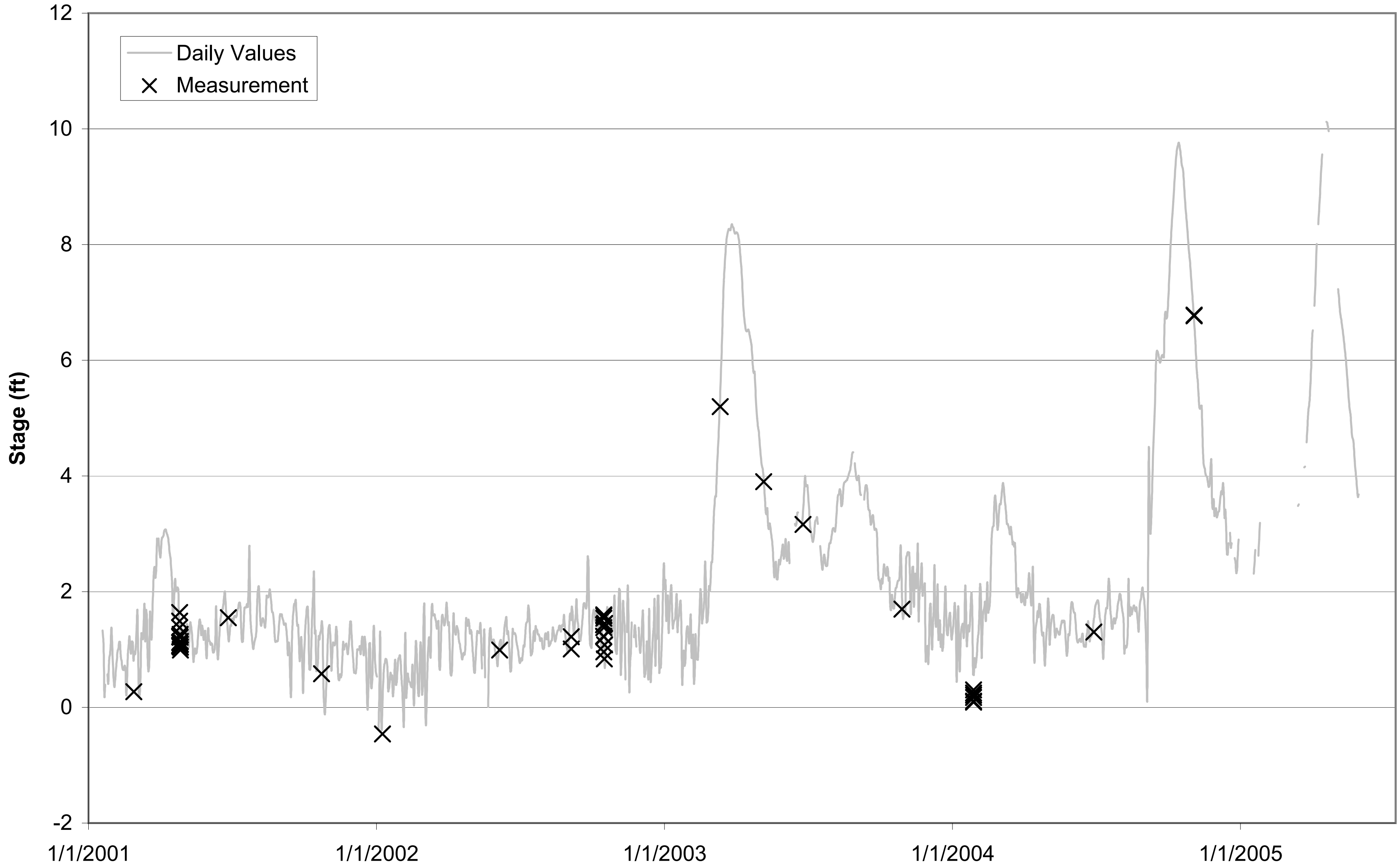
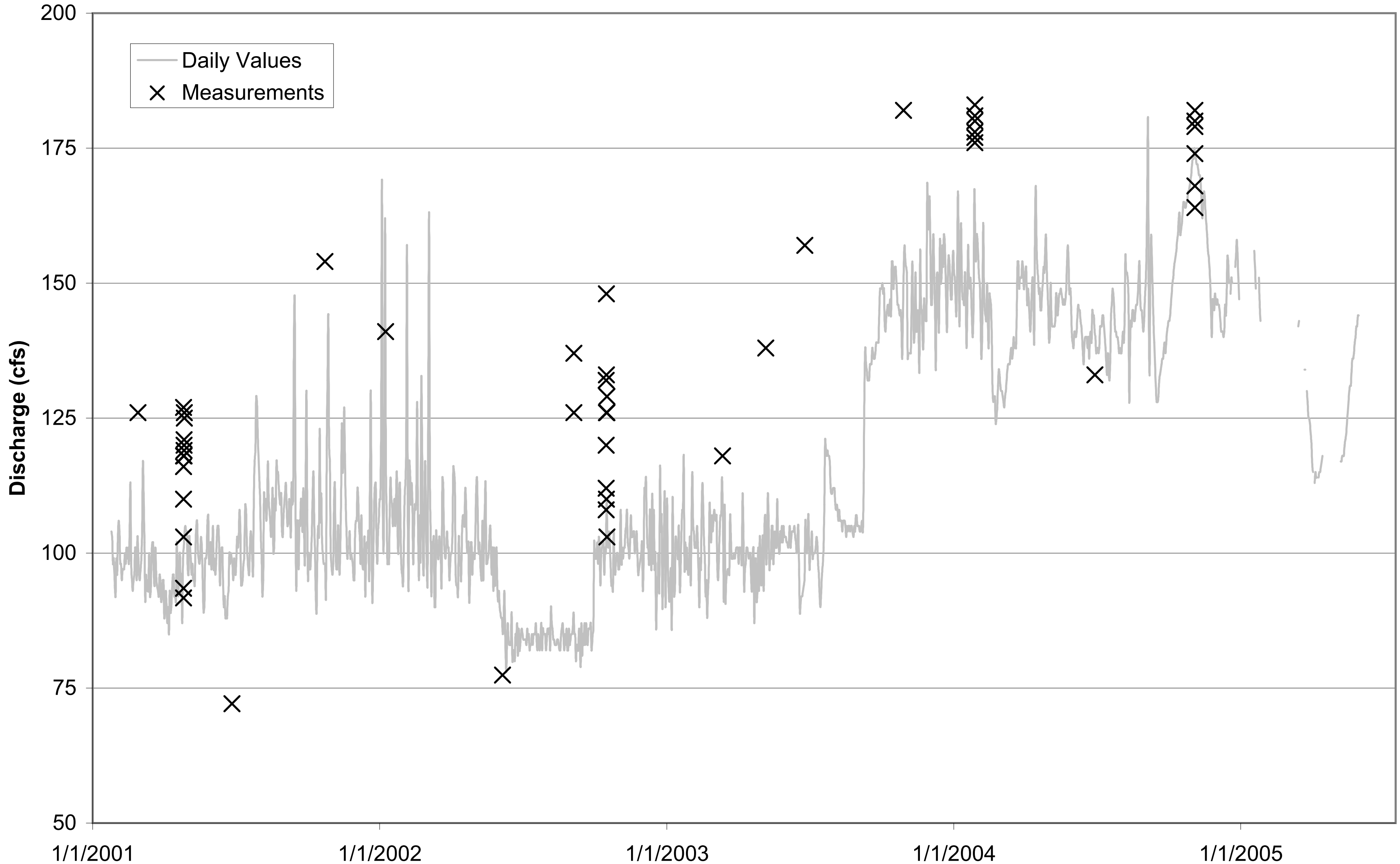
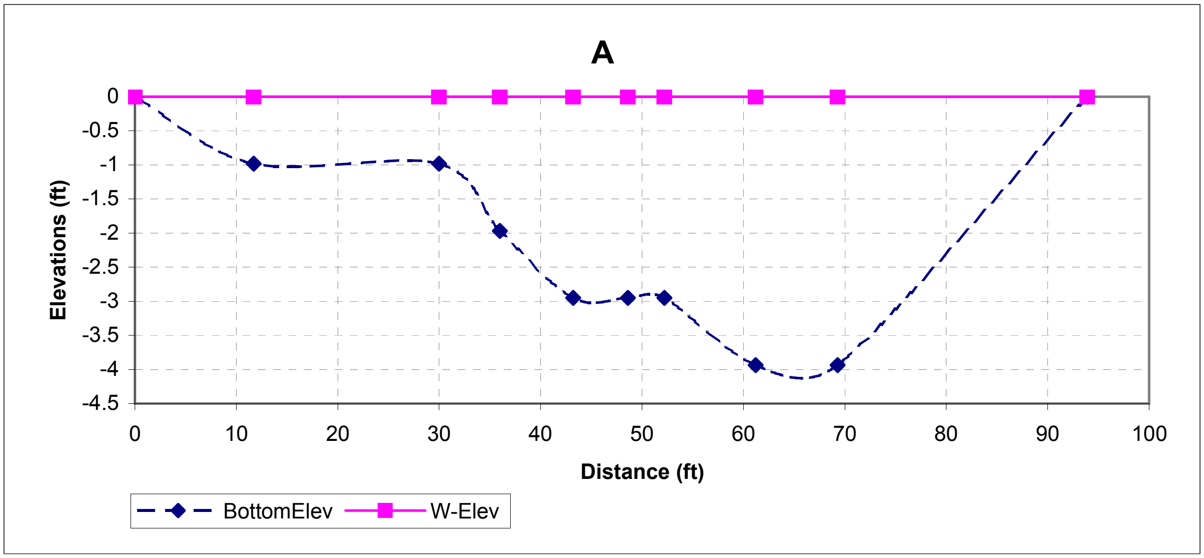
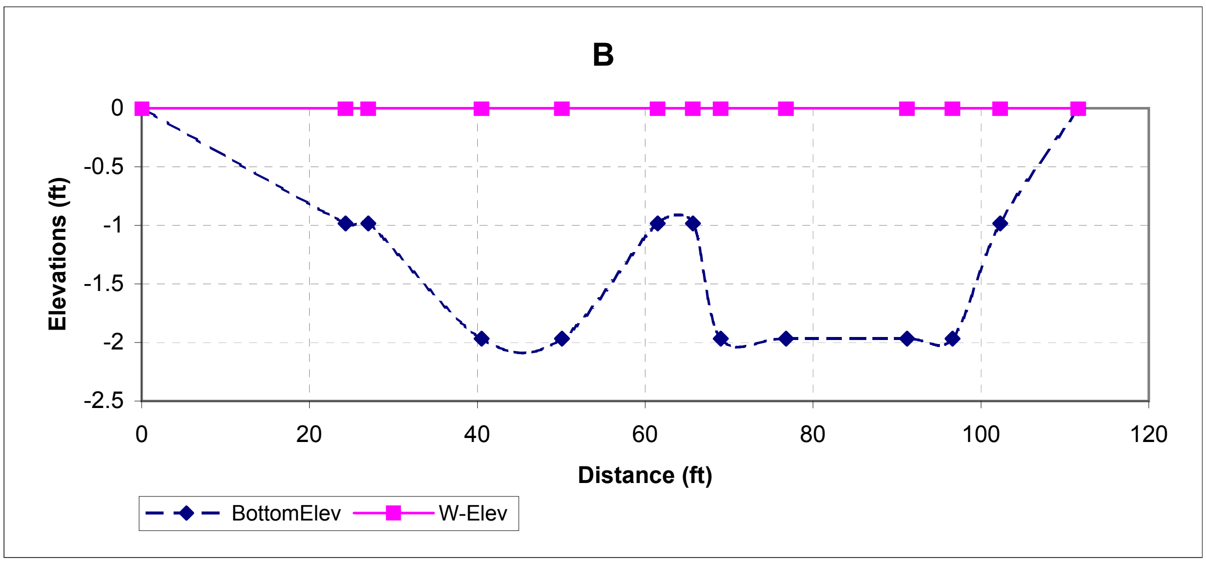


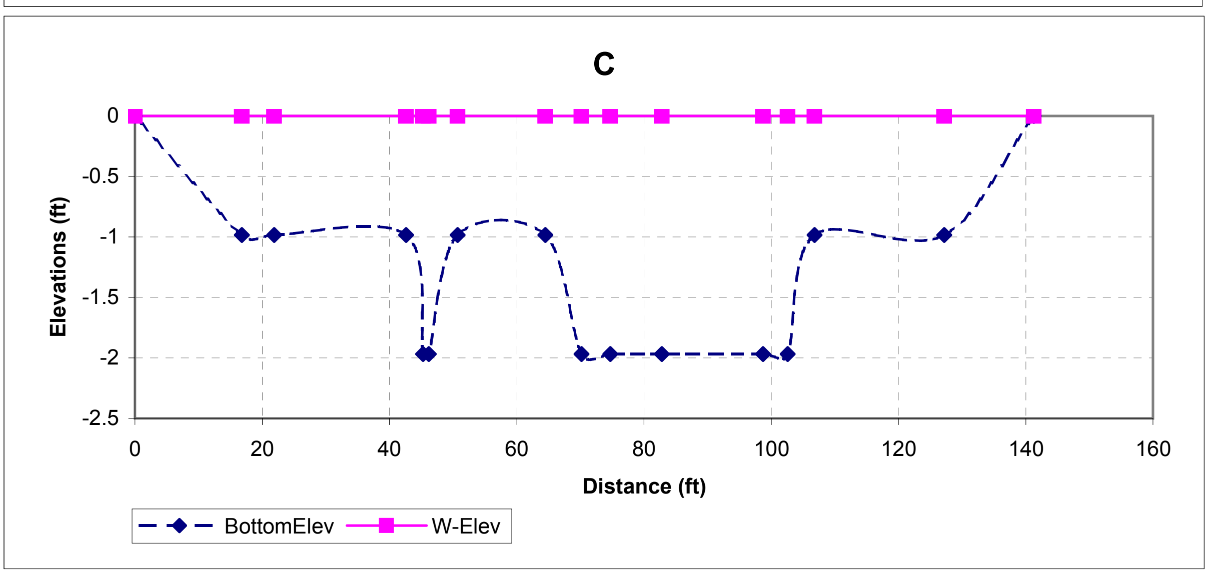
Figure A-6 Discharge at the Manatee Springs gage (#02323556)

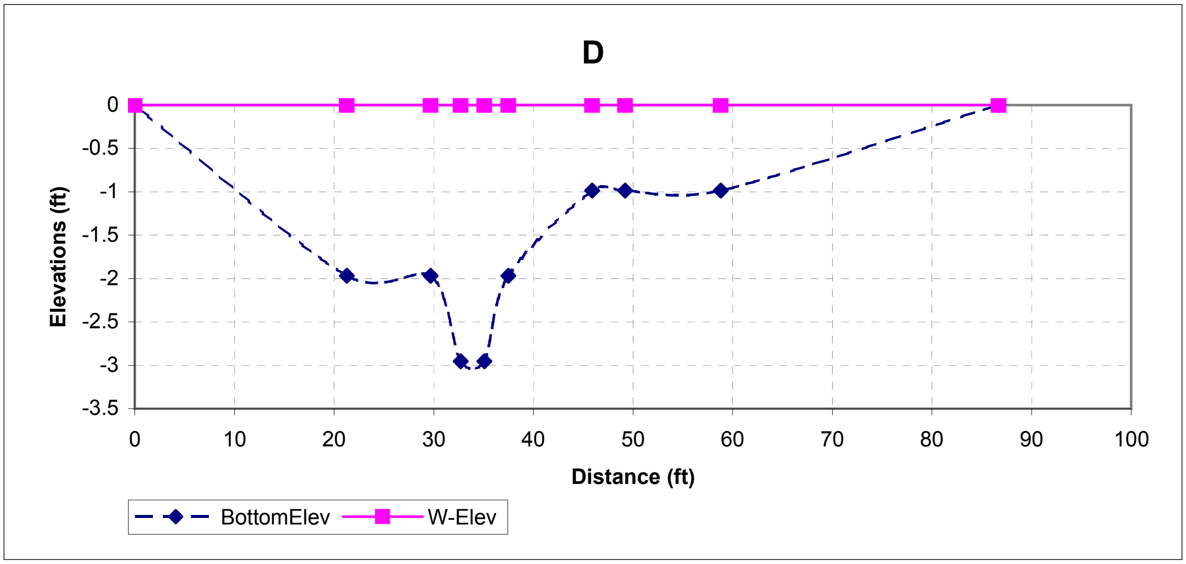


Appendix B - Manatee Spring Run Topographic Profiles


A
Elevations (ft)
Distance (ft)
BottomElev
W-Elev


B
Elevations (ft)
Distance (ft)
BottomElev
W-Elev


C
Elevations (ft)
Distance (ft)
BottomElev
W-Elev


D
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-1
-1.5
-2
-2.5
-3
-3.5
Elevations (ft)
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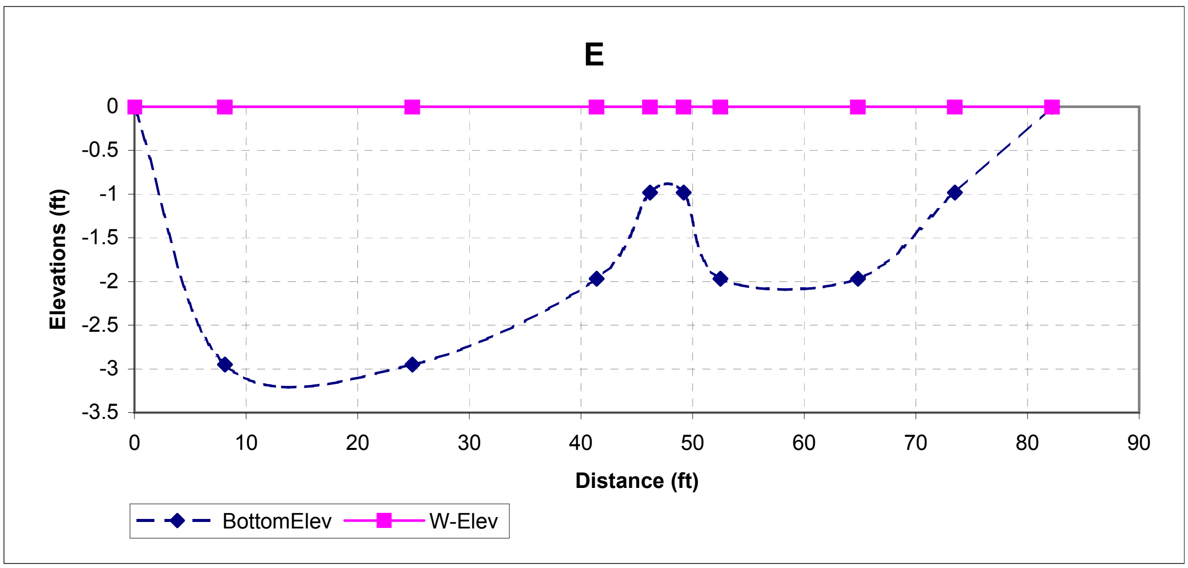
40
50
60
70
80
90
100
Distance (ft)
BottomElev
W-Elev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-1.5
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-3.5
Elevations (ft)
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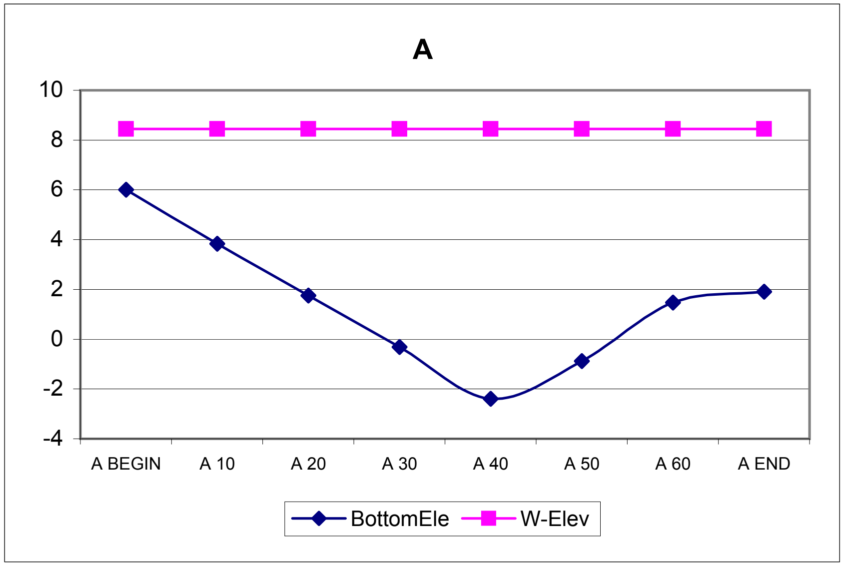
70
80
90
Distance (ft)
BottomElev
W-Elev

Appendix C - Fanning Spring Run Topographic Profiles


A
10
8
6
4
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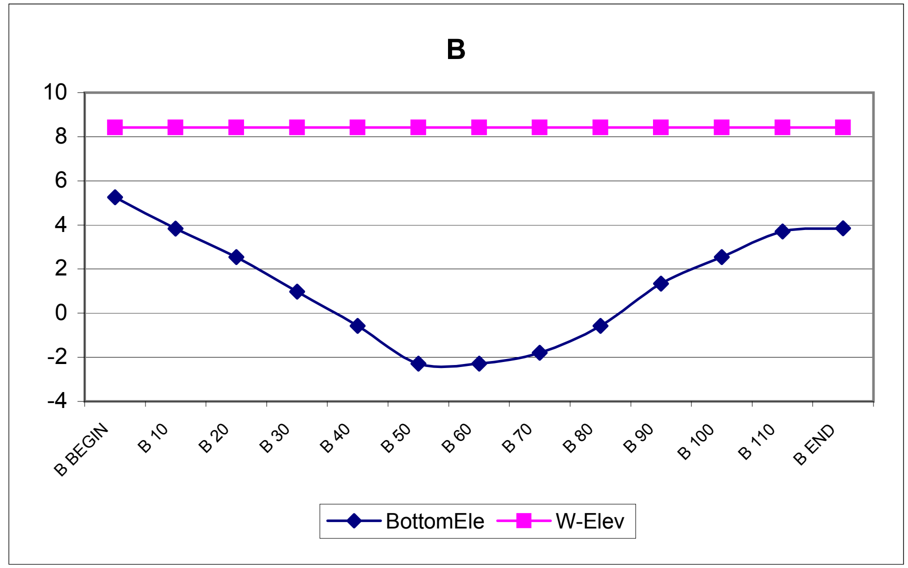
-2
-4
A BEGIN
A 10
A 20
A 30
A 40
A 50
A 60
A END
BottomEle
W-Elev


B
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B BEGIN
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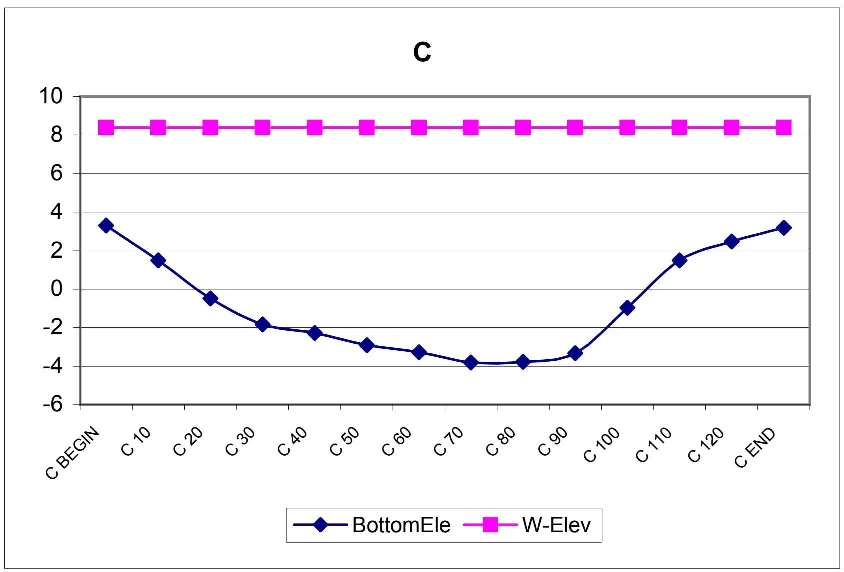
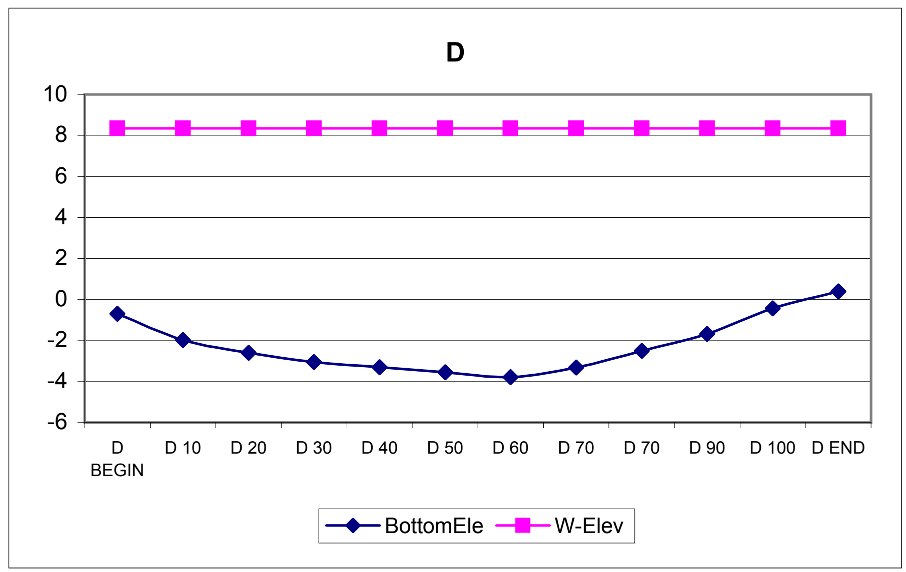
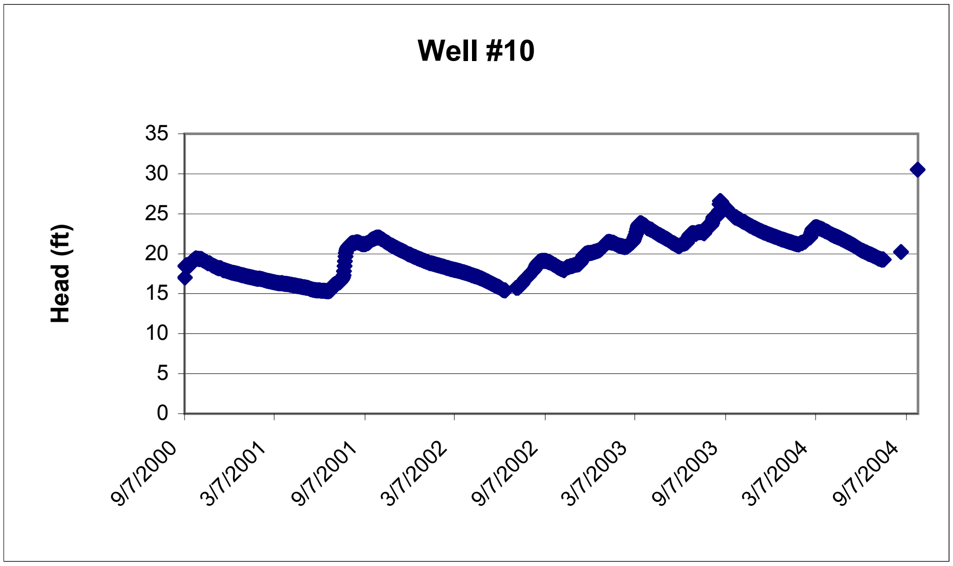
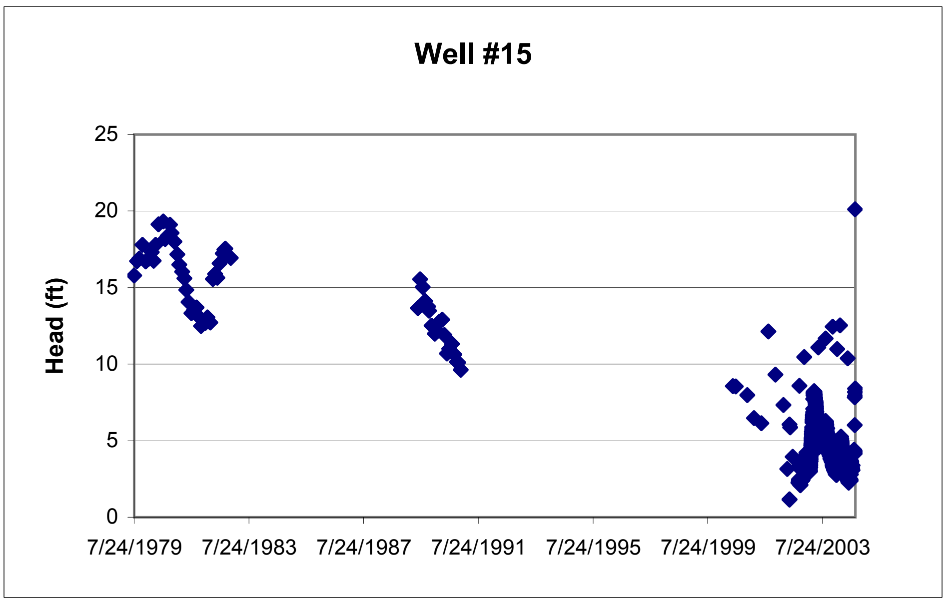
B 30
B 40
B 50
B 60
B 70
B 80
B 90
B 100
B 110
B END
BottomEle
W-Elev

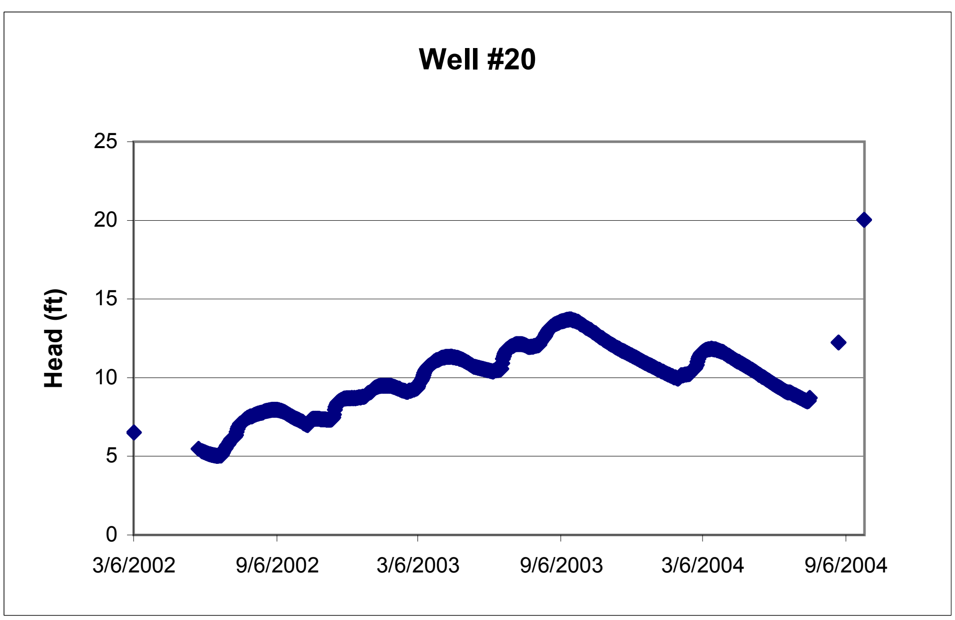

C
10
8
6
4
2
0
-2
-4
-6
C BEGIN
C 10
C 20
C 30
C 40
C 50
C 60
C 70
C 80
C 90
C 100
C 110
C 120
C END
BottomEle
W-Elev

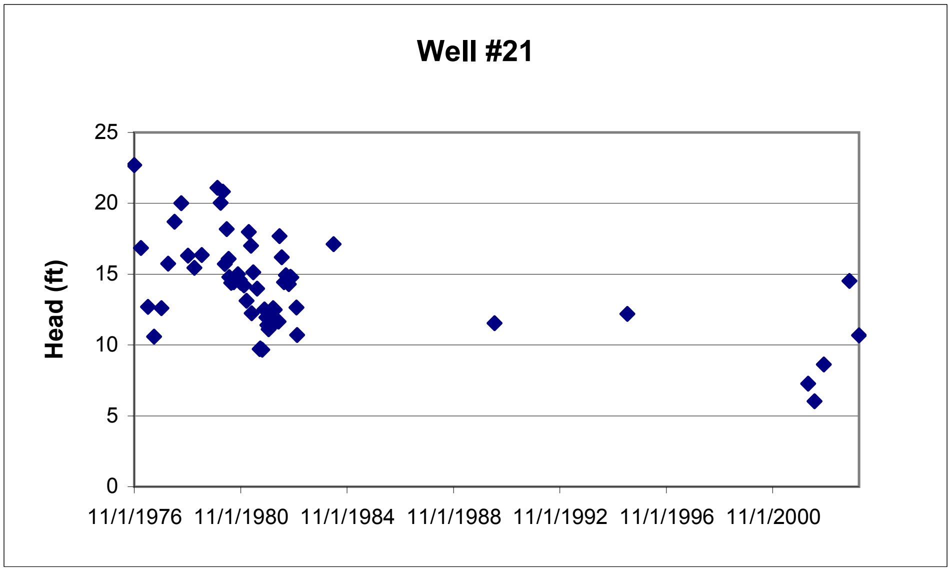

D
10
8
6
4
2
0
-2
-4
-6
D BEGIN
D 10
D 20
D 30
D 40
D 50
D 60
D 70
D 70
D 90
D 100
D END
BottomEle
W-Elev

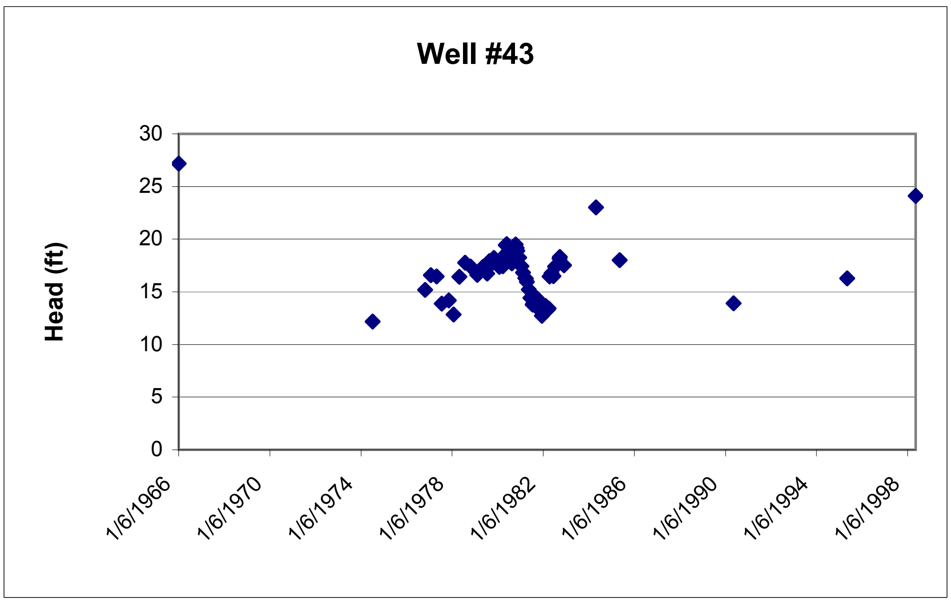
Appendix D - Ground Water Data

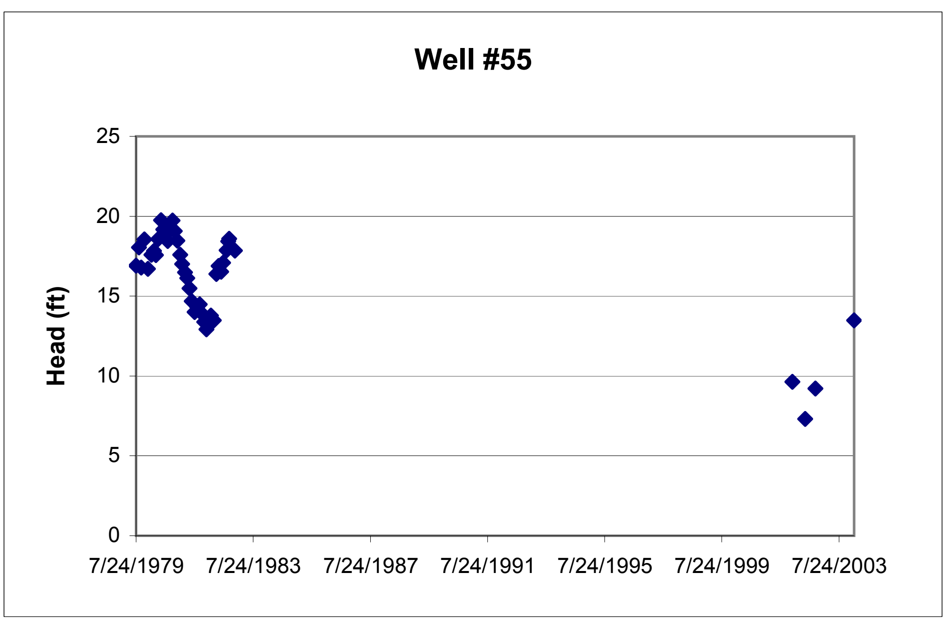

Well #10
Head (ft)
35
30
25
20
15
10
5
0
9/7/2000
3/7/2001
9/7/2001
3/7/2002
9/7/2002
3/7/2003
9/7/2003
3/7/2004
9/7/2004

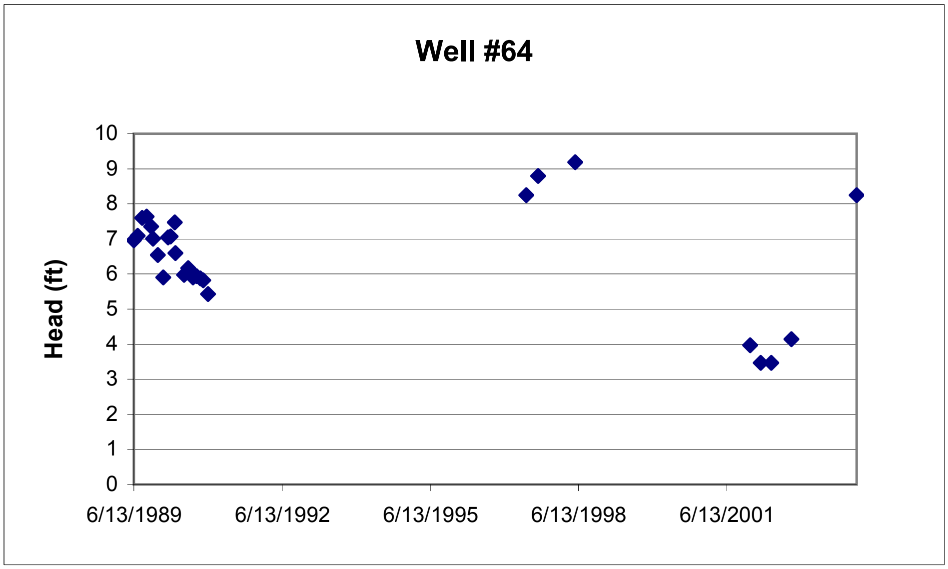

Well #15
Head (ft)
25
20
15
10
5
0
7/24/1979
7/24/1983
7/24/1987
7/24/1991
7/24/1995
7/24/1999
7/24/2003

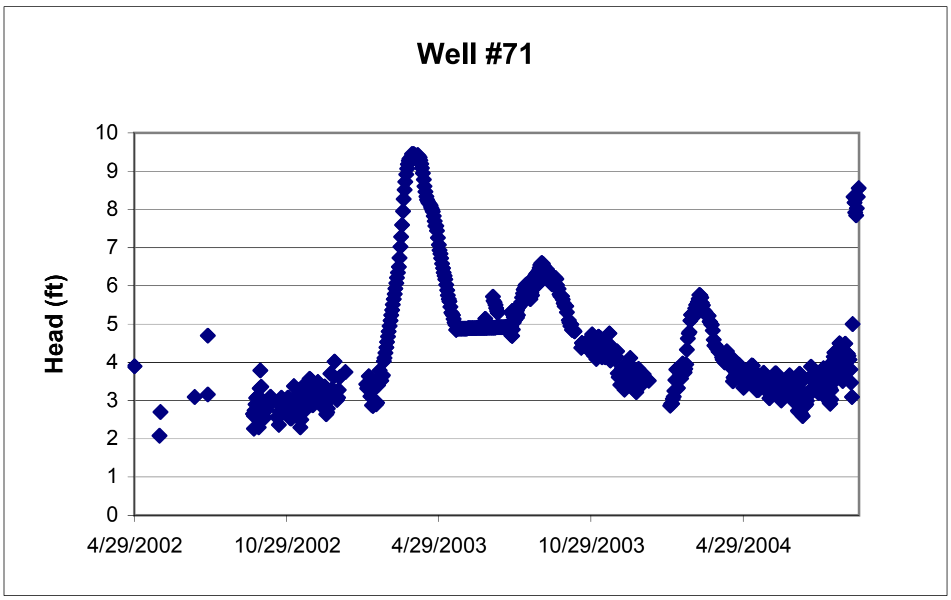

Well #20
Head (ft)
25
20
15
10
5
0
3/6/2002
9/6/2002
3/6/2003
9/6/2003
3/6/2004
9/6/2004

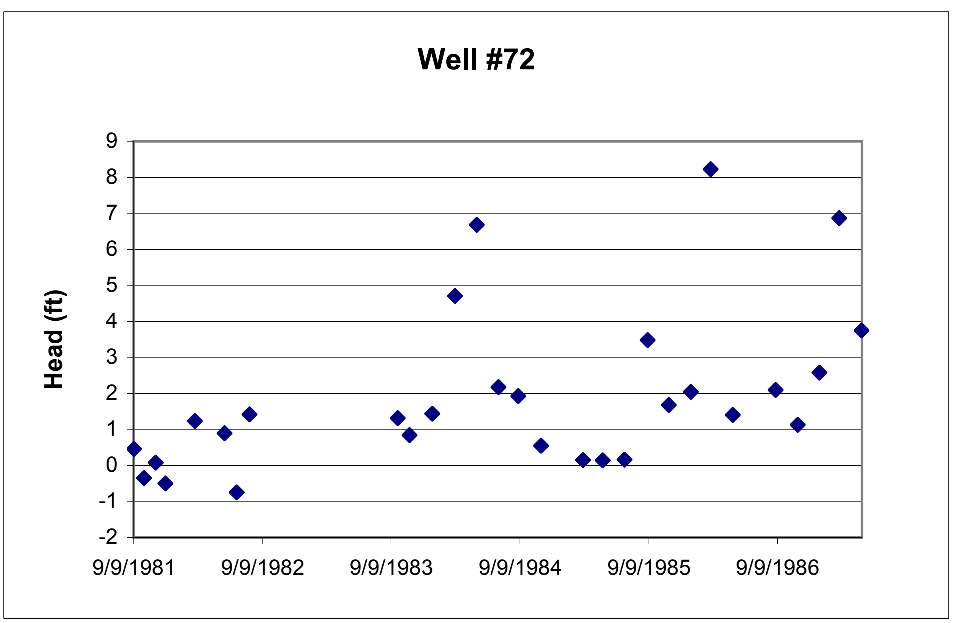

Well #21
25
20
15
10
5
0
Head (ft)
11/1/1976
11/1/1980
11/1/1984
11/1/1988
11/1/1992
11/1/1996
11/1/2000

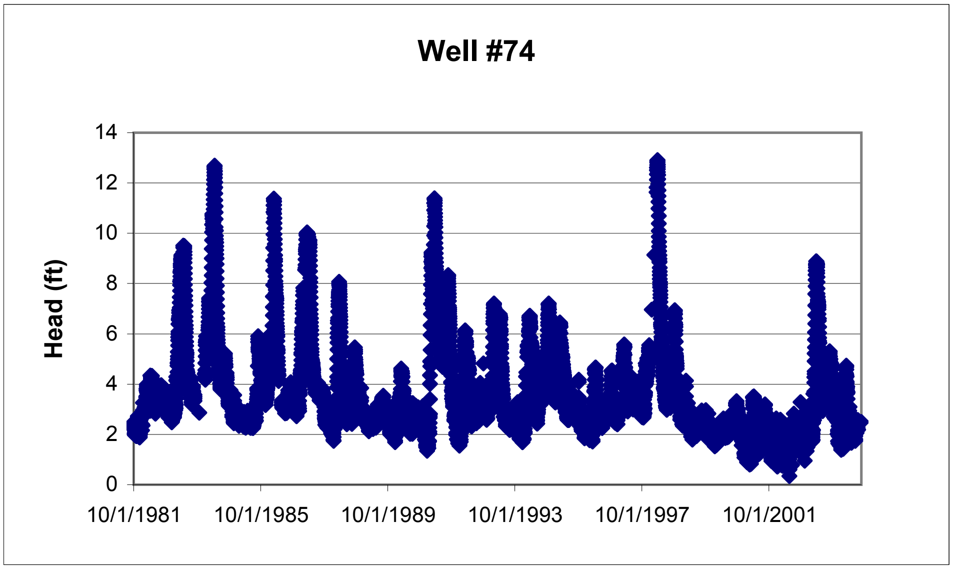

Well #43
30
25
20
15
10
5
0
Head (ft)
1/6/1966
1/6/1970
1/6/1974
1/6/1978
1/6/1982
1/6/1986
1/6/1990
1/6/1994
1/6/1998

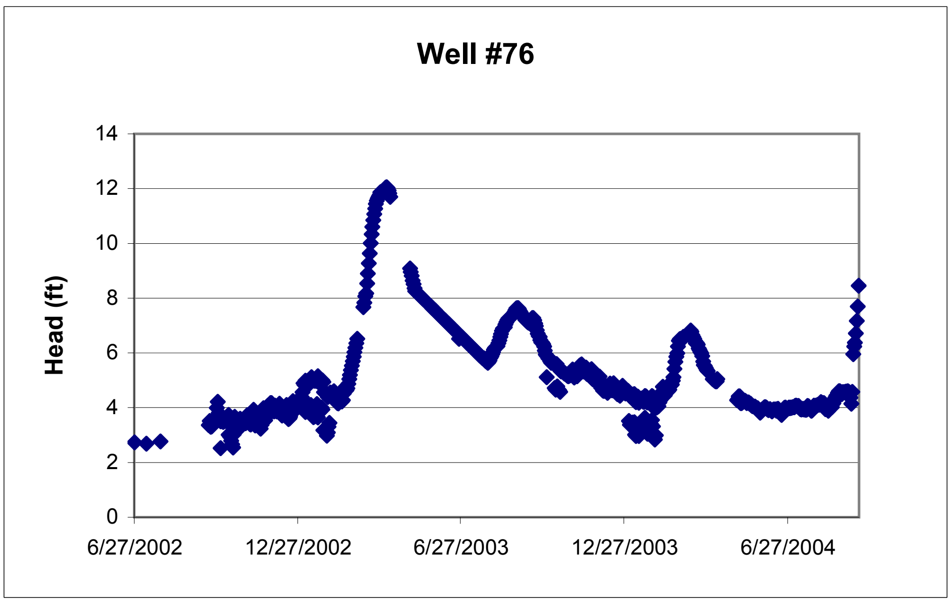

Well #55
25
20
15
10
5
0
Head (ft)
7/24/1979
7/24/1983
7/24/1987
7/24/1991
7/24/1995
7/24/1999
7/24/2003

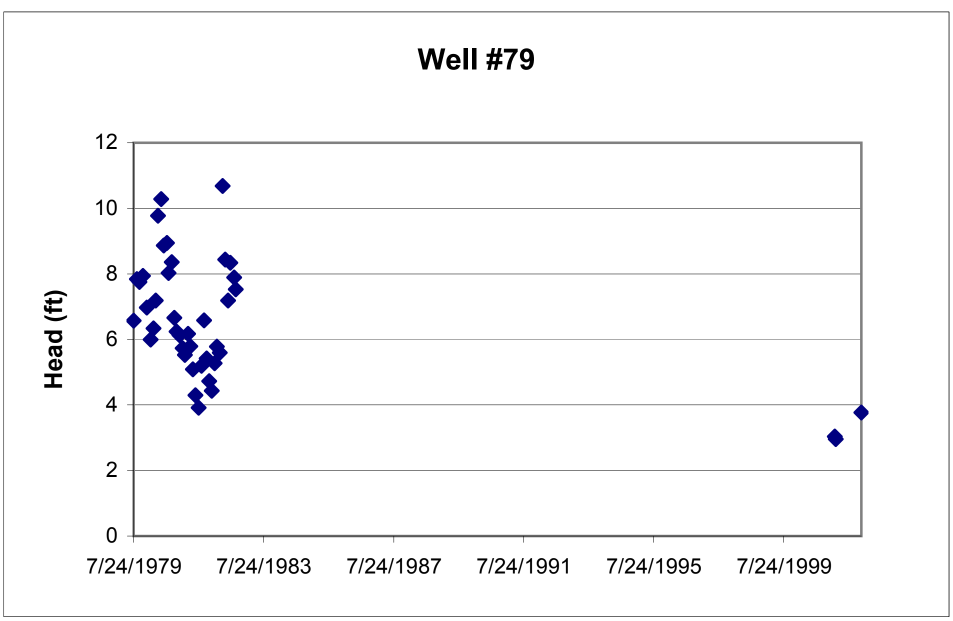

Well #64
Head (ft)
10
9
8
7
6
5
4
3
2
1
0
6/13/1989
6/13/1992
6/13/1995
6/13/1998
6/13/2001

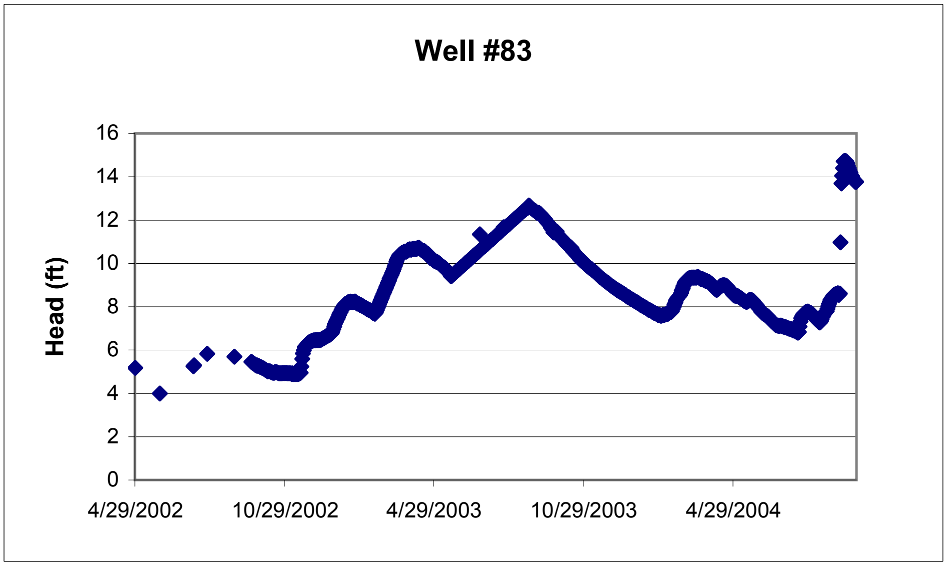

Well #71
Head (ft)
10
9
8
7
6
5
4
3
2
1
0
4/29/2002
10/29/2002
4/29/2003
10/29/2003
4/29/2004

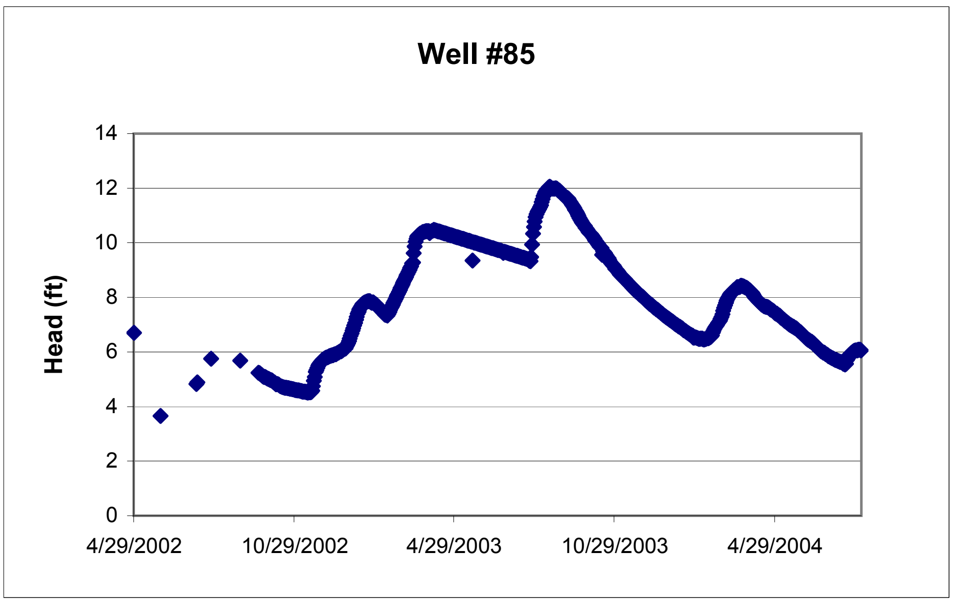

Well #72
Head (ft)
9
8
7
6
5
4
3
2
1
0
-1
-2
9/9/1981
9/9/1982
9/9/1983
9/9/1984
9/9/1985
9/9/1986

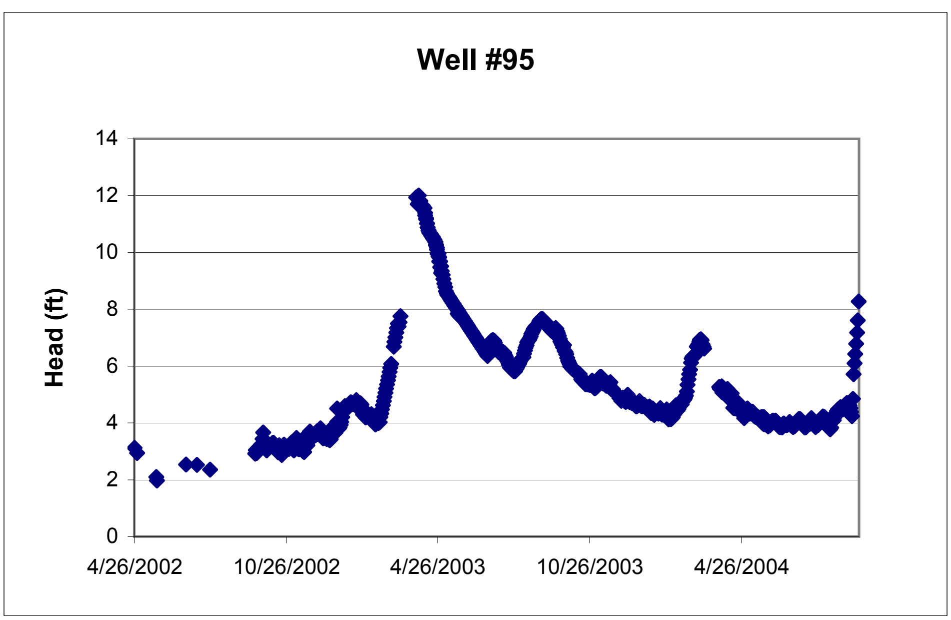

Well #74
Head (ft)
14
12
10
8
6
4
2
0
10/1/1981
10/1/1985
10/1/1989
10/1/1993
10/1/1997
10/1/2001

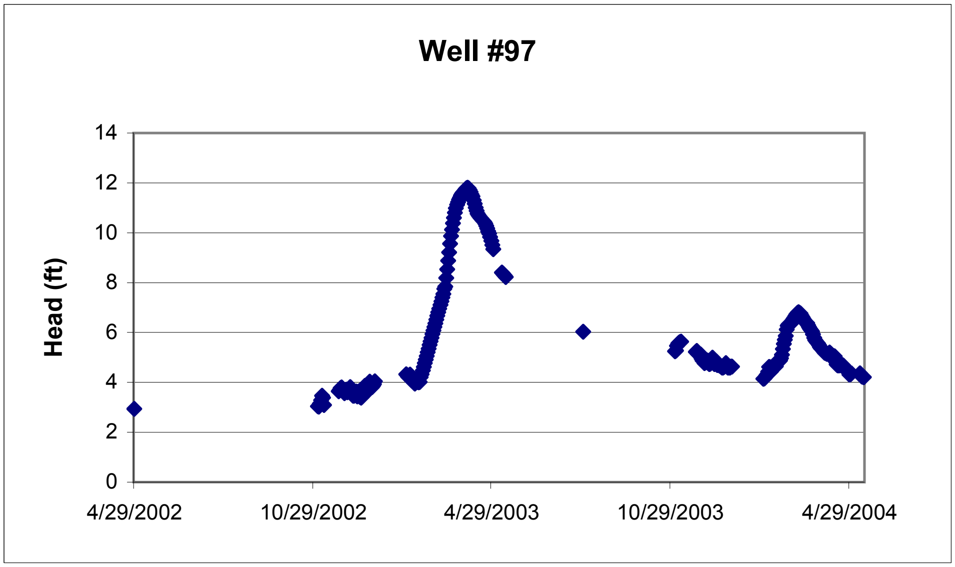

Well #76
Head (ft)
14
12
10
8
6
4
2
0
6/27/2002
12/27/2002
6/27/2003
12/27/2003
6/27/2004

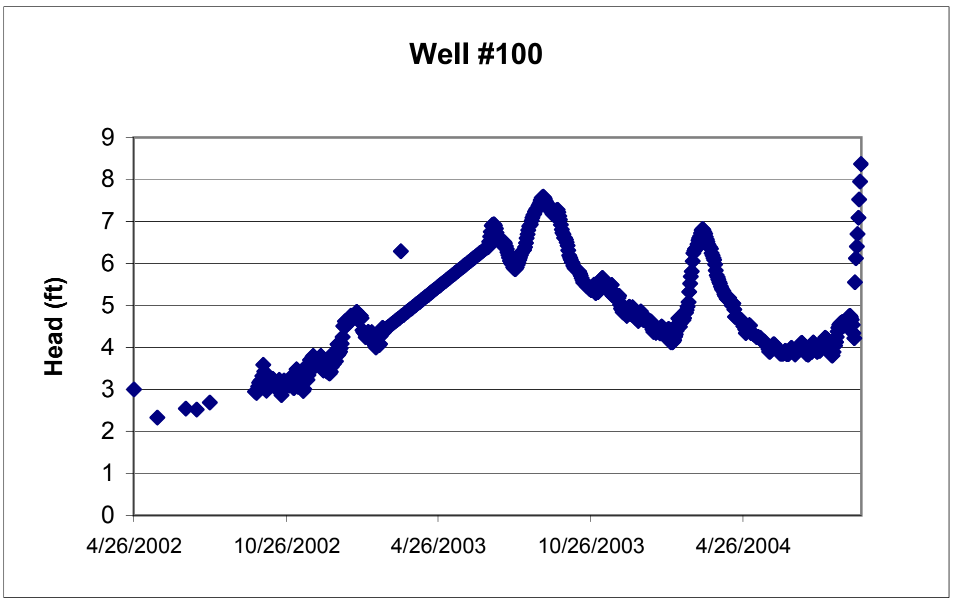

Well #79
Head (ft)
12
10
8
6
4
2
0
7/24/1979
7/24/1983
7/24/1987
7/24/1991
7/24/1995
7/24/1999

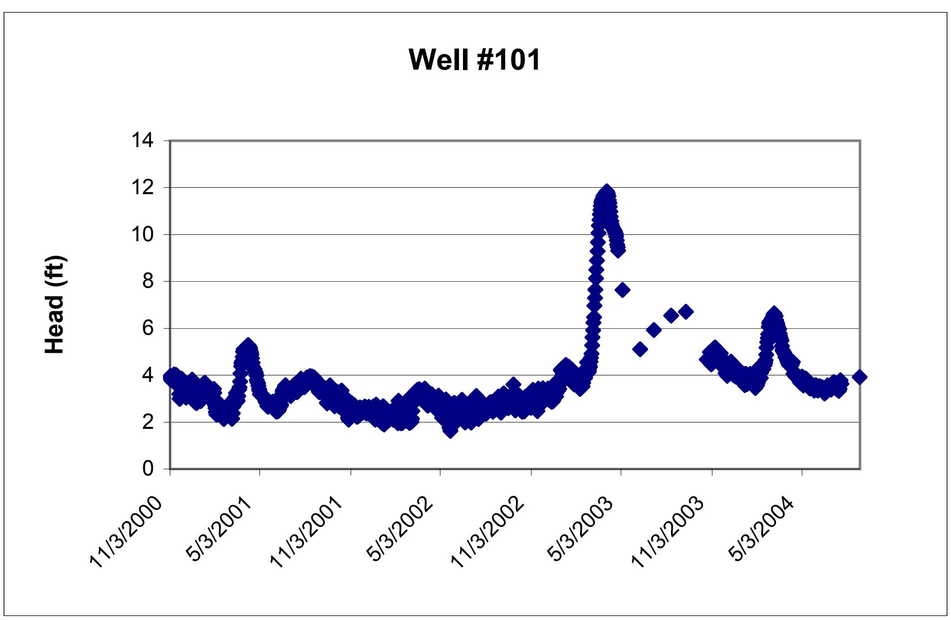

Well #83
Head (ft)
16
14
12
10
8
6
4
2
0
4/29/2002
10/29/2002
4/29/2003
10/29/2003
4/29/2004

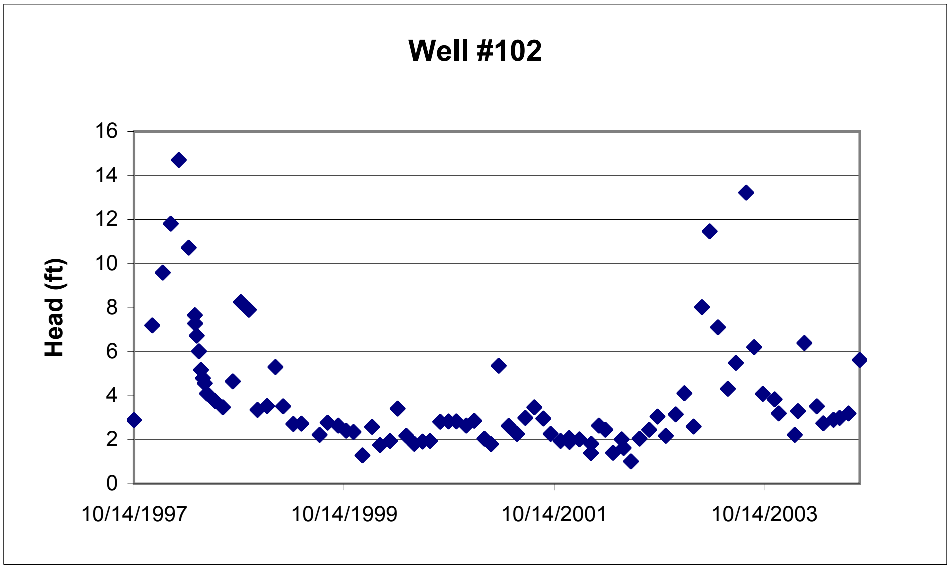

Well #85
Head (ft)
14
12
10
8
6
4
2
0
4/29/2002
10/29/2002
4/29/2003
10/29/2003
4/29/2004

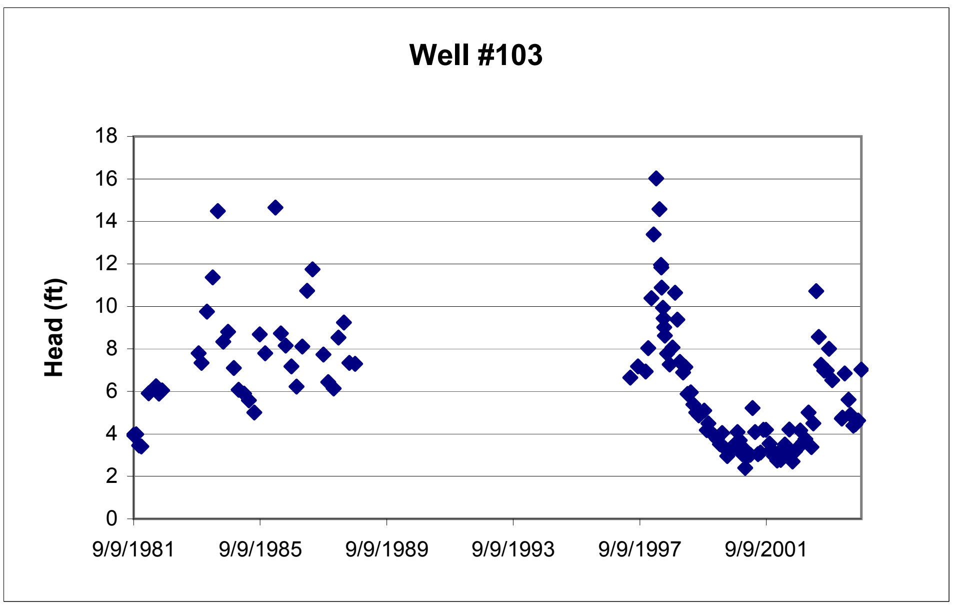

Well #95
Head (ft)
14
12
10
8
6
4
2
0
4/26/2002
10/26/2002
4/26/2003
10/26/2003
4/26/2004

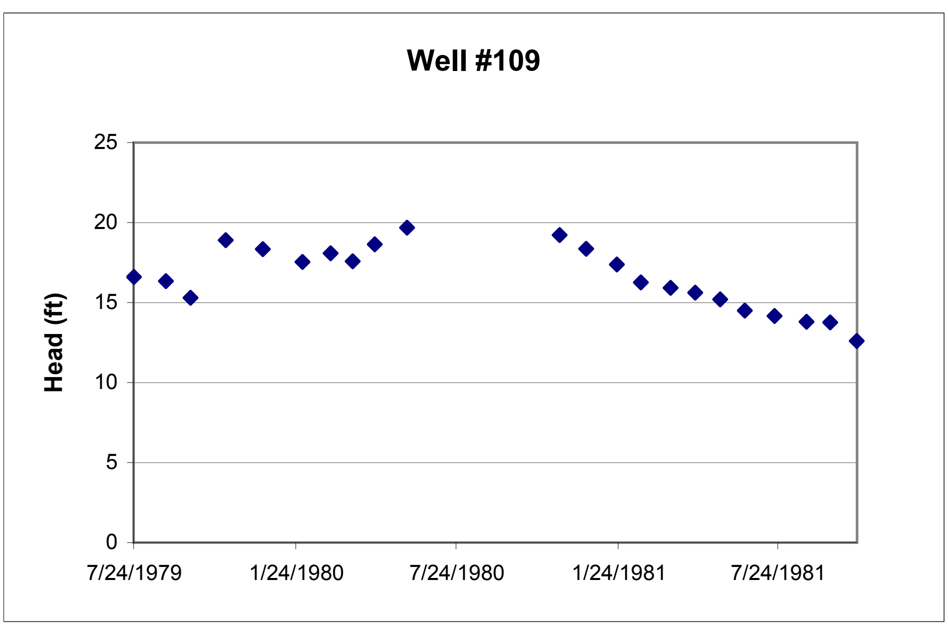

Well #97
Head (ft)
14
12
10
8
6
4
2
0
4/29/2002
10/29/2002
4/29/2003
10/29/2003
4/29/2004

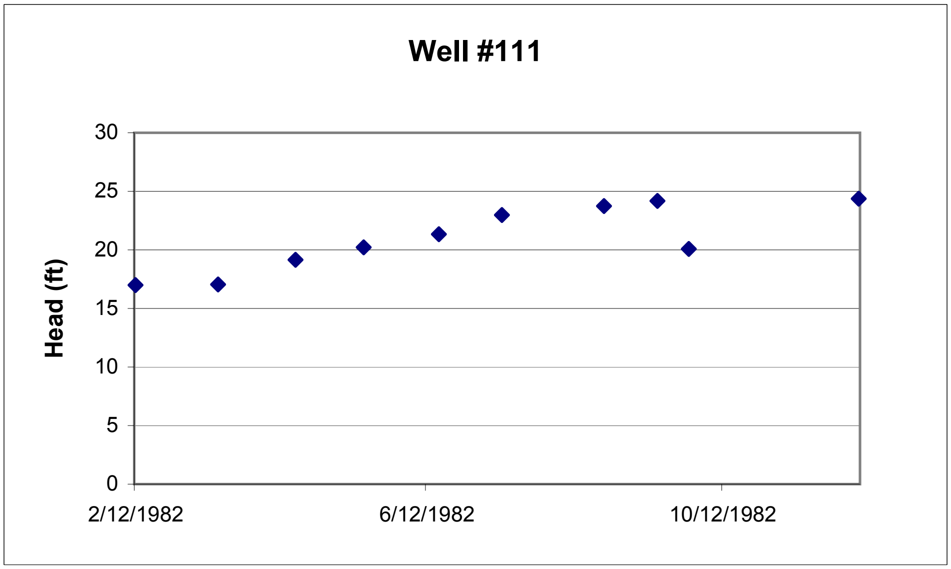

Well #100
Head (ft)
9
8
7
6
5
4
3
2
1
0
4/26/2002
10/26/2002
4/26/2003
10/26/2003
4/26/2004

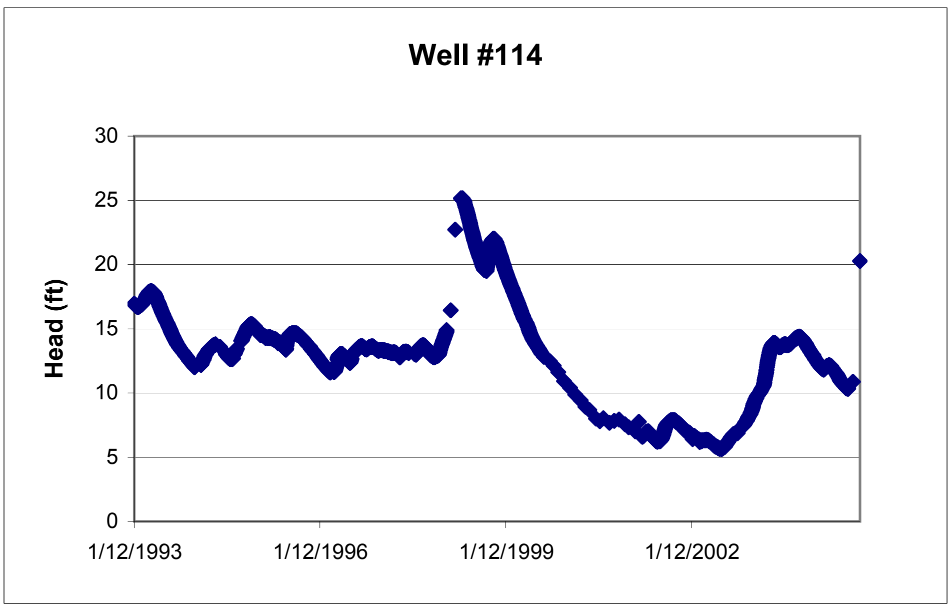

Well #101
Head (ft)
14
12
10
8
6
4
2
0
11/3/2000
5/3/2001
11/3/2001
5/3/2002
11/3/2002
5/3/2003
11/3/2003
5/3/2004

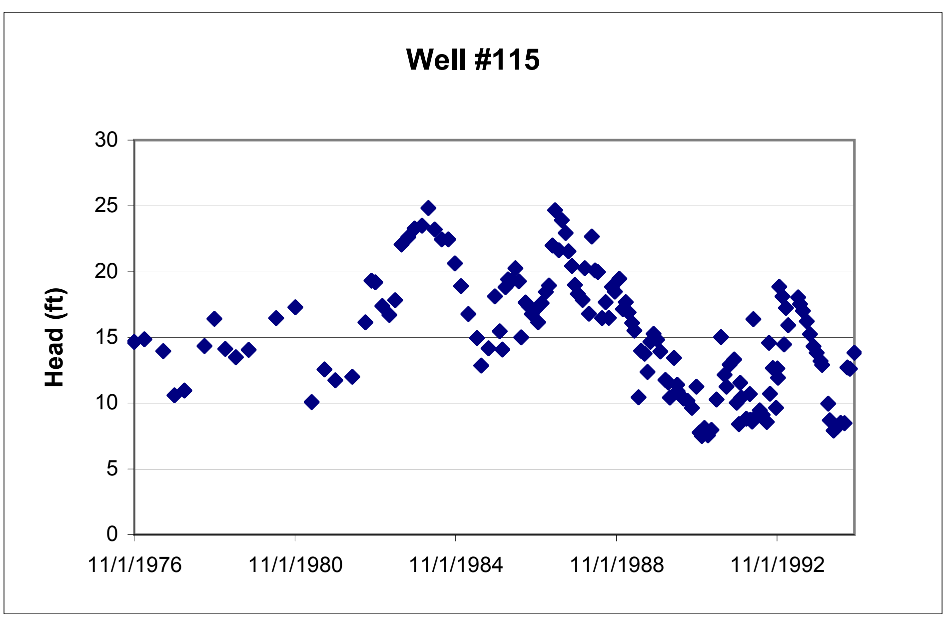

Well #102
Head (ft)
16
14
12
10
8
6
4
2
0
10/14/1997
10/14/1999
10/14/2001
10/14/2003

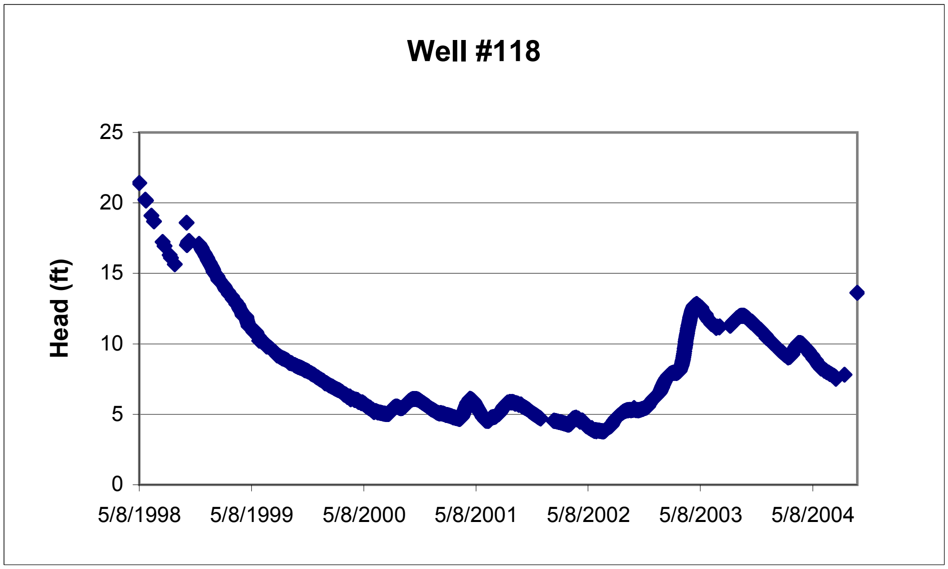

Well #103
Head (ft)
18
16
14
12
10
8
6
4
2
0
9/9/1981
9/9/1985
9/9/1989
9/9/1993
9/9/1997
9/9/2001

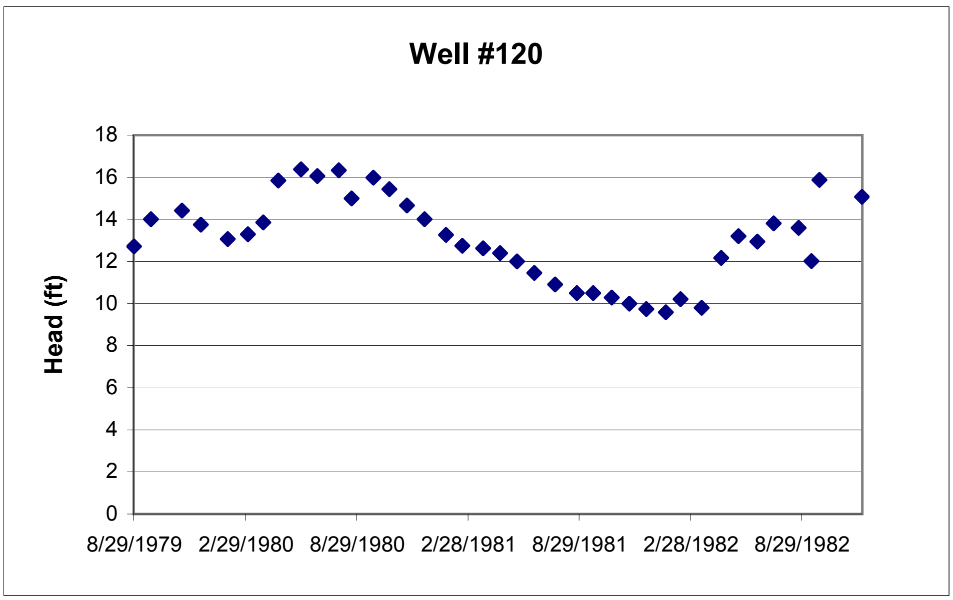

Well #109
Head (ft)
25
20
15
10
5
0
7/24/1979
1/24/1980
7/24/1980
1/24/1981
7/24/1981

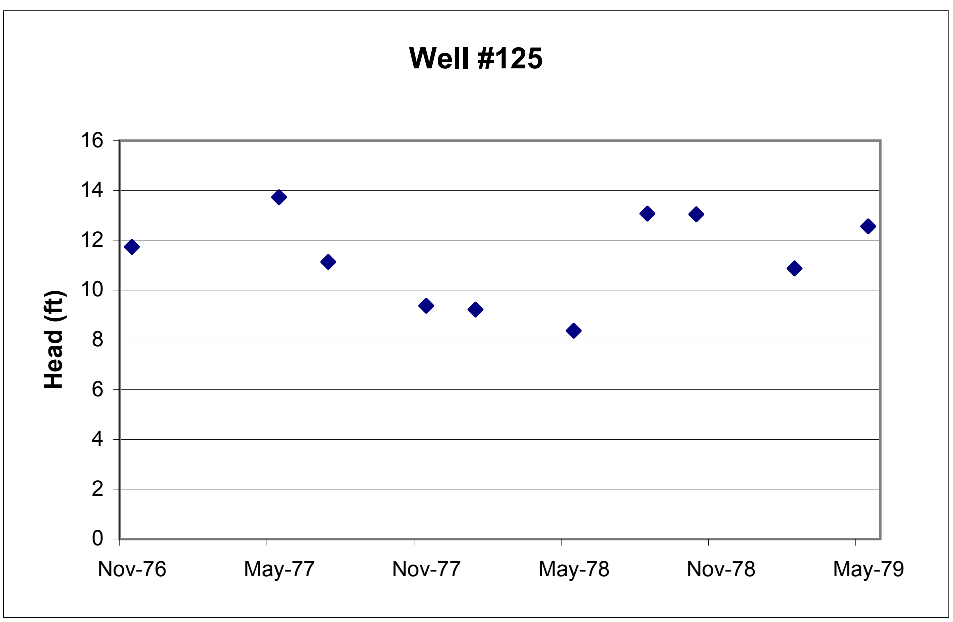

Well #111
Head (ft)
30
25
20
15
10
5
0
2/12/1982
6/12/1982
10/12/1982

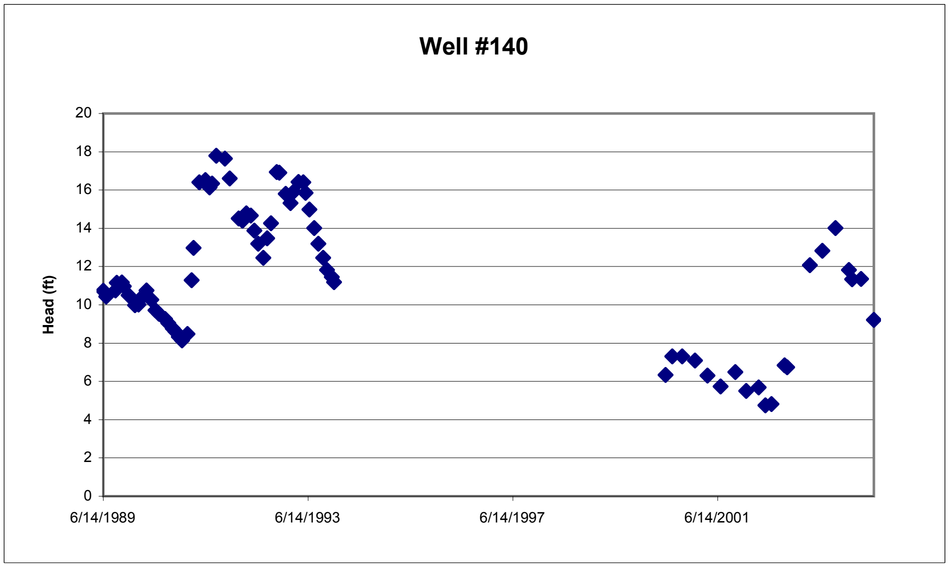

Well #114
Head (ft)
30
25
20
15
10
5
0
1/12/1993
1/12/1996
1/12/1999
1/12/2002

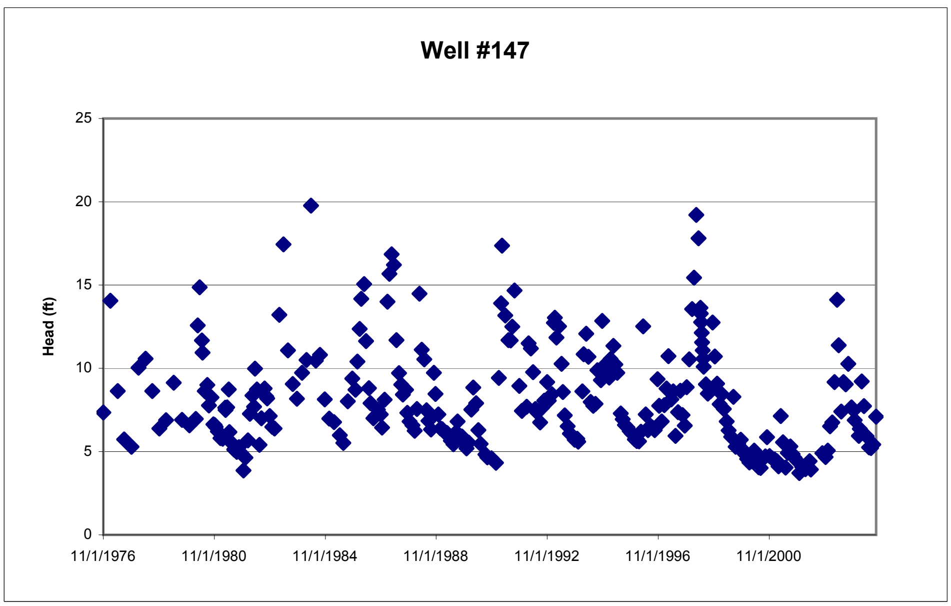

Well #115
Head (ft)
30
25
20
15
10
5
0
11/1/1976
11/1/1980
11/1/1984
11/1/1988
11/1/1992


Well #118
Head (ft)
25
20
15
10
5
0
5/8/1998
5/8/1999
5/8/2000
5/8/2001
5/8/2002
5/8/2003
5/8/2004


Well #120
Head (ft)
18
16
14
12
10
8
6
4
2
0
8/29/1979
2/29/1980
8/29/1980
2/28/1981
8/29/1981
2/28/1982
8/29/1982


Well #125
Head (ft)
16
14
12
10
8
6
4
2
0
Nov-76
May-77
Nov-77
May-78
Nov-78
May-79


Well #140
Head (ft)
0
2
4
6
8
10
12
14
16
18
20
6/14/1989
6/14/1993
6/14/1997
6/14/2001


Well #147
Head (ft)
0
5
10
15
20
25
11/1/1976
11/1/1980
11/1/1984
11/1/1988
11/1/1992
11/1/1996
11/1/2000

Appendix E - Ground \

Well #	Site ID	Date	Head (ft)
9	-121519001	5/21/2002	8.4
		10/3/2002	9.93
		1/28/2004	12.94
12	-121506002	12/12/2001	12.23
		5/25/2002	8.66
		10/3/2002	10.95
		1/28/2004	15.28
14	-121436002	9/30/2003	13.65
		1/28/2004	9.94
16	-121428004	12/17/2003	12.34
		1/28/2004	11.25
17	-121424006	3/5/2002	6.28
		5/28/2002	5.23
		10/3/2002	7.15
		1/28/2004	9.89
18	-121423007	3/5/2002	5.55
		6/5/2002	4.3
		10/3/2002	6.35
		1/28/2004	9.17
19	-121422002	3/6/2002	5.34
		5/21/2002	4.5
		10/3/2002	6.29
		1/28/2004	8.8
22	-121418002	6/22/1982	11.77
		9/27/1982	12.23
		12/6/1982	9.89
23	-121415003	3/6/2002	6.95
		5/21/2002	5.72
		10/3/2002	7.51
		1/28/2004	10.56
24	-121410003	5/28/2002	5.17
		10/3/2002	6.66
		3/27/2003	11.09
		1/28/2004	9.64
25	-121410001	6/22/1982	13.47
		9/27/1982	13.35
		12/6/1982	11.82
		2/28/2002	5.94
		5/28/2002	4.88
		3/27/2003	10.96
26	-121402003	2/28/2002	7.27
		5/21/2002	6.32
		10/3/2002	7.75
		1/28/2004	11.45
29	-121324001	3/7/2002	9.08
		5/16/2002	7.85
		10/3/2002	11.26
		1/28/2004	12.01

Well #	Site ID	Date	Head (ft)
31	-121302011	2/21/2003	3.49
		1/28/2004	4.47
		3/11/2004	6.23
32	-121302010	2/21/2003	5.52
		1/28/2004	4.49
		3/11/2004	6.23
39	-111506010	3/8/2002	5.87
		5/28/2002	5.2
		10/4/2002	6.56
		1/29/2004	11.44
40	-111506001	6/23/1981	10.83
		3/30/1982	9.45
		6/25/1982	13.55
		9/29/1982	14.22
		12/8/1982	14.49
41	-111503011	3/6/2002	11.93
		5/16/2002	10.9
		10/4/2002	12.45
		1/29/2004	18.23
44	-111435007	12/19/2001	9.02
		2/15/2002	8.09
		5/16/2002	7.03
		10/3/2002	8.61
		1/29/2004	12.59
45	-111434010	2/22/2002	8.03
		5/24/2002	6.9
		10/3/2002	8.48
		1/29/2004	12.67
46	-111431006	3/5/2002	3.59
		5/31/2002	2.89
		10/3/2002	4.08
47	-111430015	5/31/2002	1.56
		10/3/2002	2.77
		1/29/2004	4.72
48	-111430014	1/19/2001	3.29
		2/12/2002	2.75
		5/24/2002	2.2
		10/3/2002	3.63
		1/29/2004	4.29
49	-111429006	12/19/2001	3.88
		2/12/2002	3.3
		5/15/2002	2.94
		10/3/2002	4.09
		1/29/2004	5.21
50	-111429005	2/21/2002	4.76
		5/23/2002	3.81
		10/3/2002	5.52
		1/29/2004	7.71

Well #	Site ID	Date	Head (ft)
51	-111428007	2/21/2002	6.11
		5/15/2002	5.37
		10/3/2002	6.81
		1/29/2004	10.13
52	-111426010	12/11/2001	9.4
		2/13/2002	8.31
		5/16/2002	7.37
		10/3/2002	8.6
		1/28/2004	12.8
54	-111425012	4/25/2001	15.69
		12/4/2001	9.78
		3/19/2002	8.26
		5/15/2002	7.48
		10/3/2002	9.07
		5/20/2003	13.3
		1/28/2004	13.41
56	-111423013	4/27/2001	5.51
		12/4/2001	9.23
		3/19/2002	5.84
		5/15/2002	7.14
		10/3/2002	7.78
		5/20/2003	14.04
		1/29/2004	12.82
		4/7/2004	12.87
57	-111421001	3/11/2002	5.88
		5/21/2002	5.05
		10/3/2002	6.64
		1/29/2004	9.93
58	-111417003	3/5/2002	5.54
		5/21/2002	4.91
		10/3/2002	6.36
		1/29/2004	9.62
59	-111415002	3/11/2002	6.01
		5/13/2002	5.6
		10/3/2002	6.7
		1/29/2004	10.27
60	-111414008	2/22/2002	6.6
		5/7/2002	5.65
		10/3/2002	7.34
		1/29/2004	11.32
61	-111413007	2/27/2002	7.56
		5/7/2002	5.76
		10/3/2002	8.38
		1/29/2004	12.84
62	-111410024	2/22/2002	5.43
		5/7/2002	3.17
		10/3/2002	5.76
		1/29/2004	9.49

Well #	Site ID	Date	Head (ft)
63	-111408002	3/11/2002	5.08
		5/7/2002	4.77
		10/3/2002	5.65
		1/29/2004	8.56
65	-111403008	3/6/2002	5.29
		5/7/2002	5.08
		10/4/2002	5.94
		1/29/2004	9.34
66	-111336005	1/28/2004	2.32
		3/11/2004	4.76
67	-111336004	1/28/2004	2.35
		3/11/2004	4.81
		4/30/2004	2.53
68	-111336003	4/29/2002	3.09
		5/29/2002	1.71
		5/30/2002	1.75
		10/3/2002	2.45
		1/28/2004	2.53
69	-111336002	4/29/2002	2.16
		5/29/2002	1.95
		5/30/2002	2.01
		10/3/2002	2.76
		1/28/2004	2.17
70	-111335006	1/28/2004	1.73
73	-111326008	2/15/2000	1.23
		2/27/2002	1.46
		5/29/2002	1.33
		10/3/2002	1.85
75	-111325018	4/29/2002	3.57
		5/29/2002	2.5
		8/28/2002	4.52
		10/3/2002	3.91
		1/28/2004	4.49
77	-111325016	2/15/2001	3.04
		2/27/2001	2.86
		2/12/2002	3.29
		5/29/2002	2.61
78	-111325008	12/13/2000	3.67
		2/15/2001	2.96
		5/29/2002	2.52
		10/3/2002	3.84
		1/28/2004	4.48
80	-111324033	5/15/2002	1.91
81	-111324030	5/23/2002	3
		6/26/2002	2.74

Well #	Site ID	Date	Head (ft)
82	-111324029	4/29/2002	5.61
		5/24/2002	5.65
		7/9/2002	3.94
		8/28/2002	5.03
		10/3/2002	4.54
		1/27/2004	5.78
		1/28/2004	6.7
84	-111324027	4/29/2002	5.73
		5/29/2002	3.87
		8/28/2002	5.95
		10/3/2002	5.17
		1/28/2004	6.09
		3/16/2004	8.98
86	-111312001	4/1/2003	10.25
		1/29/2004	6.93
		4/7/2004	6.7
89	-101528013	3/6/2002	6.44
		5/16/2002	6.04
		10/4/2002	7.17
		1/29/2004	12.11
91	-101435008	12/18/2001	5.87
		2/13/2002	5.33
		5/7/2002	5.02
		10/4/2002	5.77
		1/29/2004	9.54
92	-101435007	12/18/2001	5.83
		2/6/2002	5.41
		5/7/2002	5.6
		10/4/2002	5.94
		1/29/2004	9.9
93	-101433012	12/18/2001	3.32
		5/20/2002	2.77
		10/4/2002	3.68
		1/29/2004	5.35
94	-101432001	3/22/2002	3.88
		4/16/2002	3.7
		5/15/2002	3.13
		10/4/2002	3.83
		1/29/2004	6.53
		4/30/2004	5.99
96	-101429024	4/26/2002	3.04
		5/23/2002	2.46
		6/27/2002	2.58
		10/4/2002	3.27
		1/22/2004	4.5
		1/29/2004	4.32

Well #	Site ID	Date	Head (ft)
98	-101429022	4/26/2002	3.21
		5/22/2002	2.15
		6/27/2002	2.83
		10/4/2002	3.4
		1/22/2004	4.43
		1/29/2004	4.15
99	-101429021	4/26/2002	2.95
		5/22/2002	2.01
		6/27/2002	2.57
		10/4/2002	3.21
		1/26/2004	4.48
		1/29/2004	4.17
104	-101427005	12/18/2001	3.52
		2/13/2002	3.14
		5/14/2002	3.13
		10/4/2002	3.94
		1/29/2004	5.94
105	-101426007	12/18/2001	4.4
		2/13/2002	4.04
		5/6/2002	3.87
		10/4/2002	4.76
106	-101425008	1/31/2001	5.98
		3/19/2002	4.06
		5/7/2002	3.35
		10/4/2002	6.13
		12/10/2002	6.37
		1/29/2004	10.63
		4/1/2004	10.63
107	-101420026	12/6/2001	3.57
		8/2/2002	3.96
		10/14/2002	4.08
		1/29/2004	4.19
110	-101522006	3/14/2002	7.94
		5/17/2002	7.67
		10/4/2002	8.31
		1/28/2004	14.43
112	-101520004	3/14/2002	7.37
		5/17/2002	7.09
		10/4/2002	8.01
		1/28/2004	13.15
117	-101508002	3/29/1982	16.21
		6/30/1982	16.8
		9/29/1982	24.56
		12/7/1982	20.89
		3/14/2002	6.87
		5/17/2002	6
		10/3/2002	7.23
		1/28/2004	14.52

Well #	Site ID	Date	Head (ft)
121	-101421003	3/12/2002	4.26
		5/15/2002	3.21
		10/4/2002	2.83
		1/28/2004	4.35
122	-101416006	3/13/2002	3.99
		5/31/2002	3.28
		10/4/2002	4.55
		1/28/2004	7.04
123	-101414001	3/21/2002	4.47
		5/20/2002	3.76
		10/4/2002	4.93
		1/28/2004	7.84
124	-101413010	3/21/2002	5.34
		5/20/2002	4.78
		10/4/2002	6.02
		1/28/2004	10.07
126	-101410005	3/13/2002	4.28
		5/20/2002	3.61
		10/4/2002	4.93
		1/28/2004	7.68
127	-101408003	3/12/2002	3.73
		5/17/2002	2.89
		10/4/2002	3.73
		1/28/2004	5.21
128	-101406001	3/21/1982	6.06
		6/24/1982	4.57
		9/27/1982	5.22
		12/6/1982	4.33
		7/23/2002	3.58
		10/4/2002	5.08
		1/29/2004	4.14
129	-101401002	3/13/2002	4.76
		5/17/2002	4.31
		10/4/2002	5.55
		1/28/2004	9.19
141	-91520001	9/8/1981	17.69
		3/22/1982	16.42
		6/24/1982	21.15
		9/27/1982	22.66
		12/6/1982	22.99
		3/25/2002	12.85
		5/20/2002	11.96
		10/4/2002	14.14

Well #	Site ID	Date	Head (ft)
142	-91506002	9/21/1981	21.85
		3/22/1982	19.72
		3/21/2002	9.94
		5/28/2002	9.38
		10/4/2002	12.18
		1/28/2004	16.71
145	-91436008	3/25/2002	4.88
		5/20/2002	4.21
		10/4/2002	5.38
		1/28/2004	8.78
146	-91436002	3/22/1982	15.41
		6/30/1982	16.44
		9/27/1982	19.32
		12/6/1982	18.37
148	-91415002	10/1/1981	14.39
		3/22/1982	15.14
		6/24/1982	18.22
		9/27/1982	17.43
		12/6/1982	18.06
		3/21/2002	5.45
		6/5/2002	4.58
		10/4/2002	6.23

Appendix E - Rainfall Data

Figure E-1 Trenton Tower Monthly Rainfall Totals

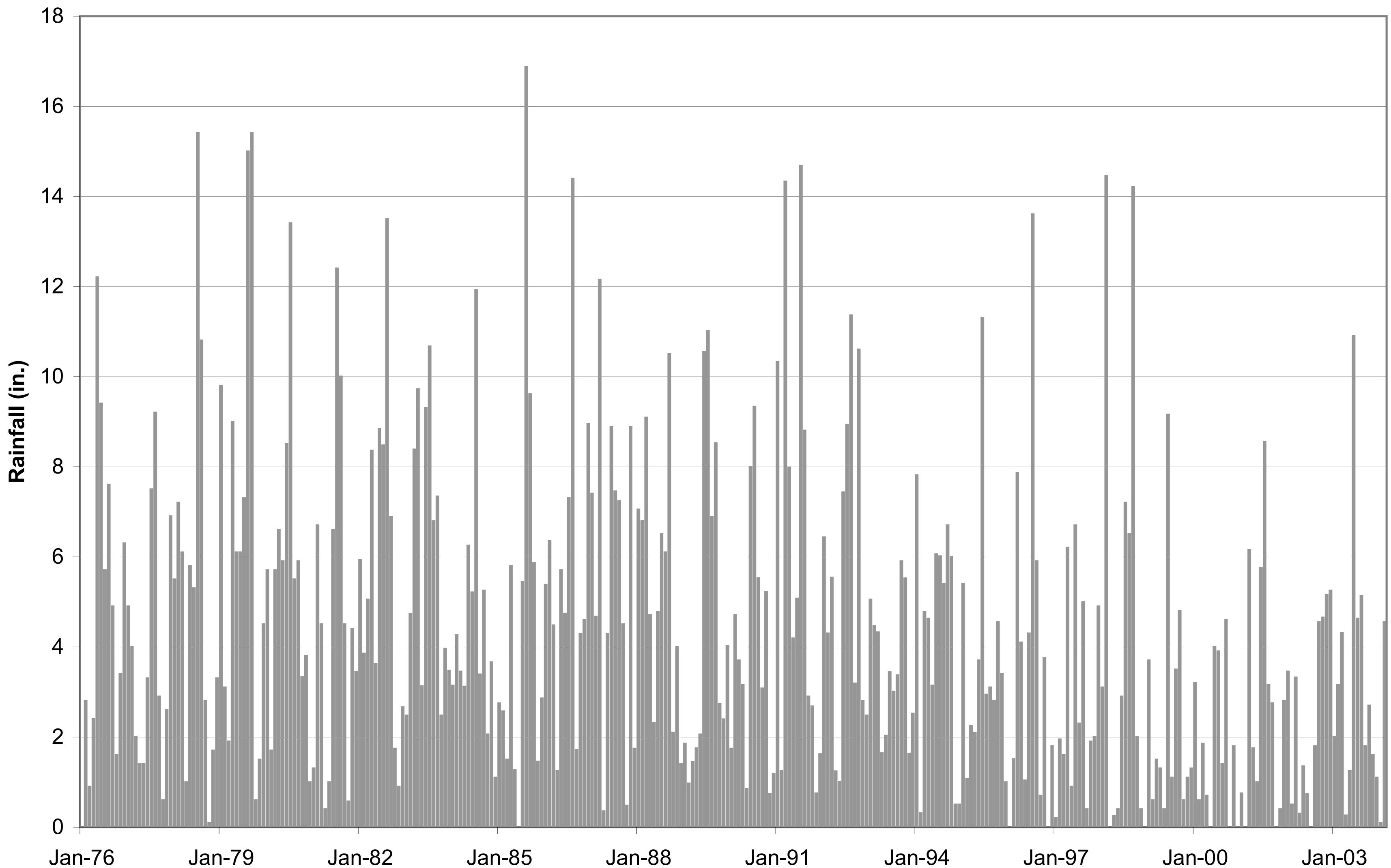


Figure E-2 Fanning Spring Monthly Rainfall Totals

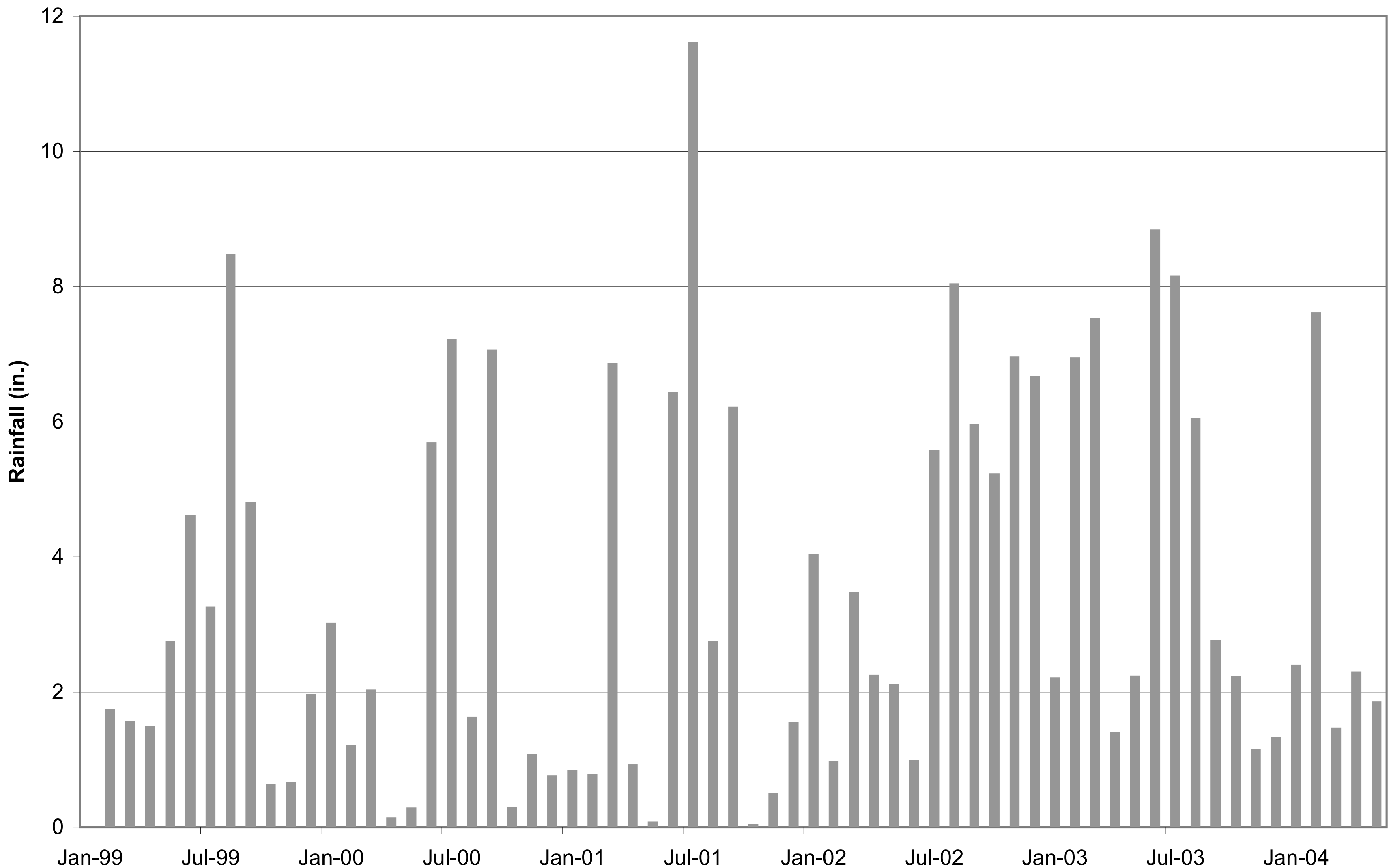
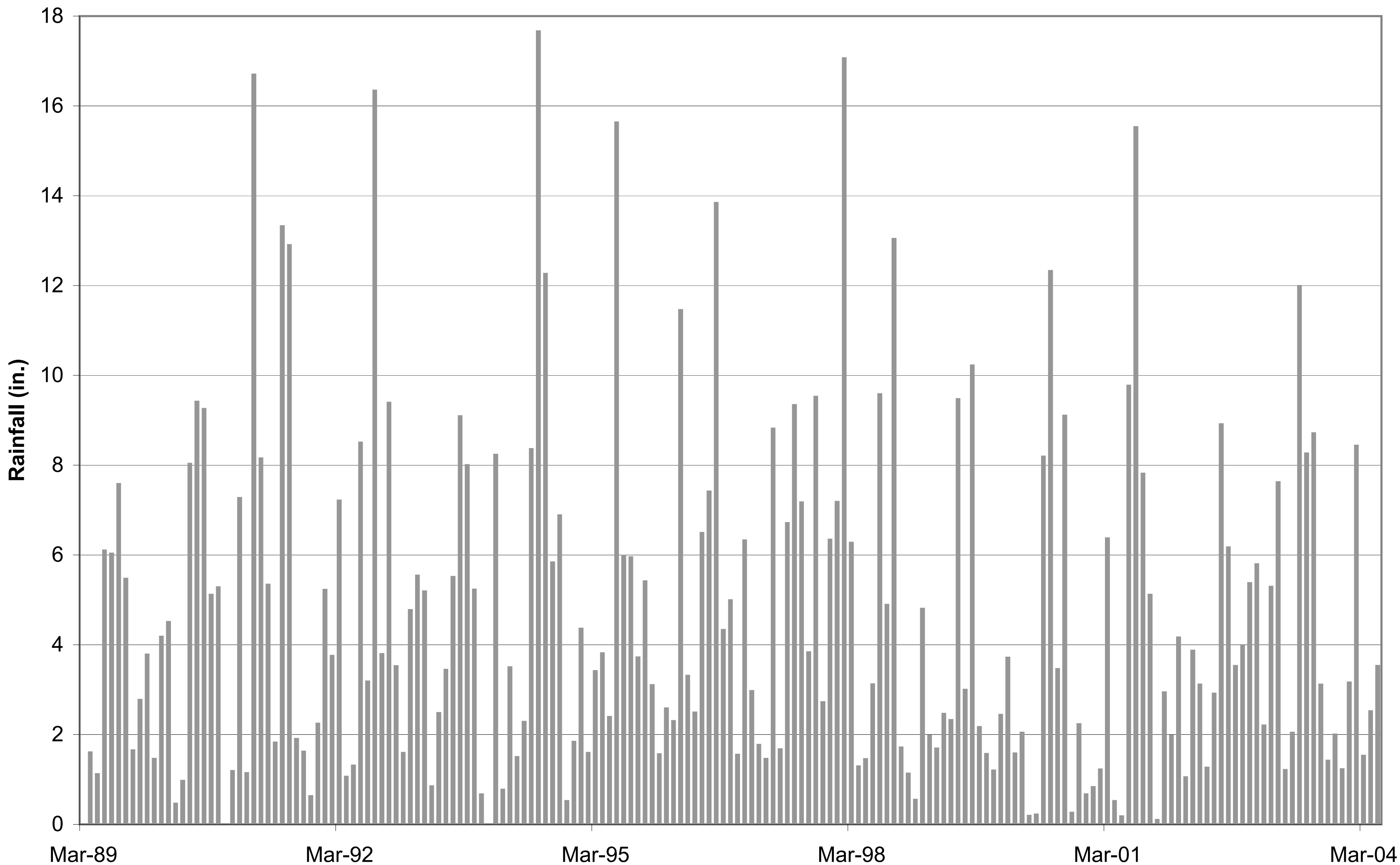


Figure E-3 Manatee Spring Monthly Rainfall Totals



Appendix F – Manatee Springs Thermal Plume Modeling Results

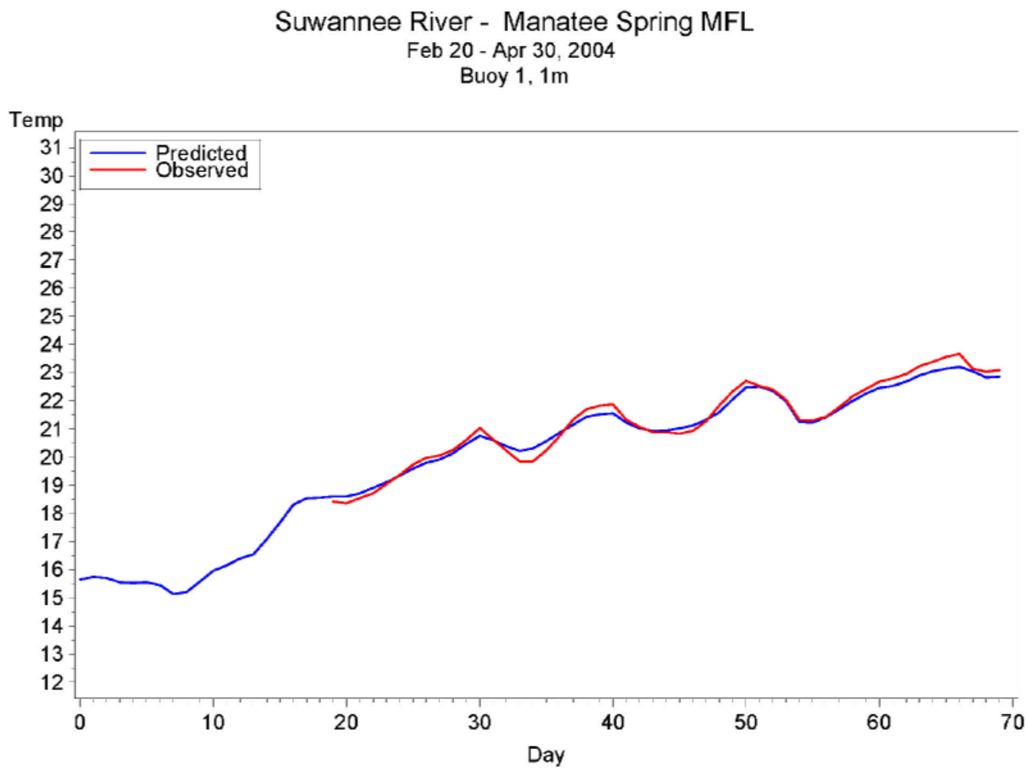


Figure F-1 Daily temperatures, predicted and observed, at Buoy 1, 1m, 2/20/04-4/30/04.

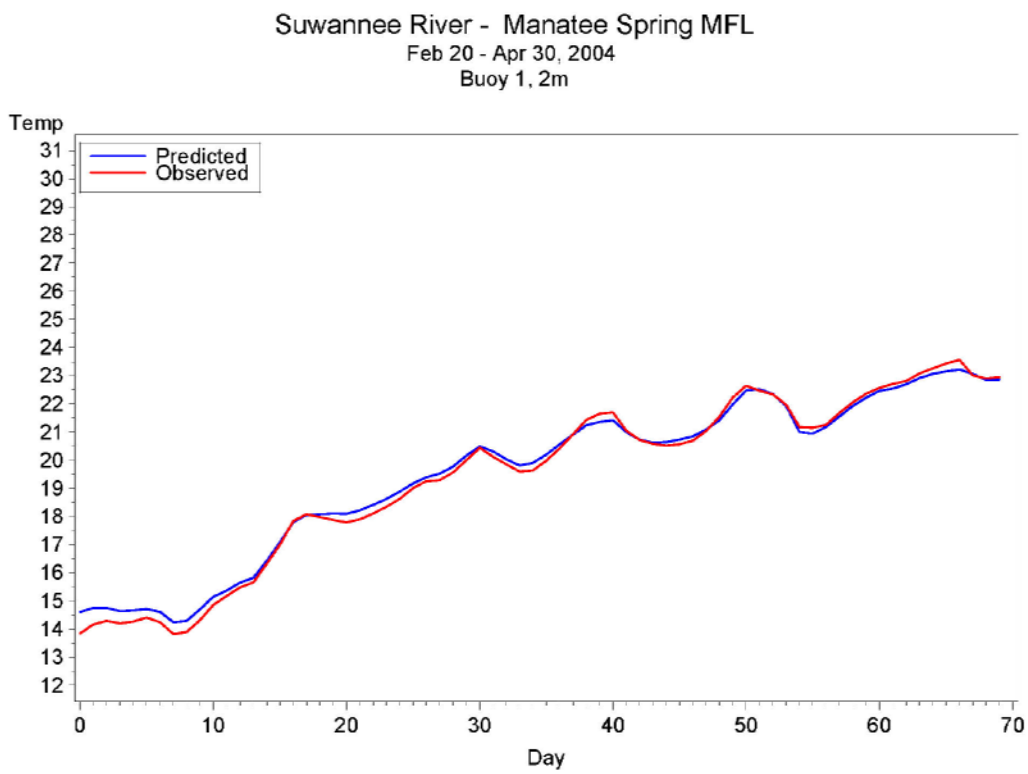


Figure F-2 Daily temperatures, predicted and observed, at Buoy 1, 2 m, 2/20/04-4/30/04.

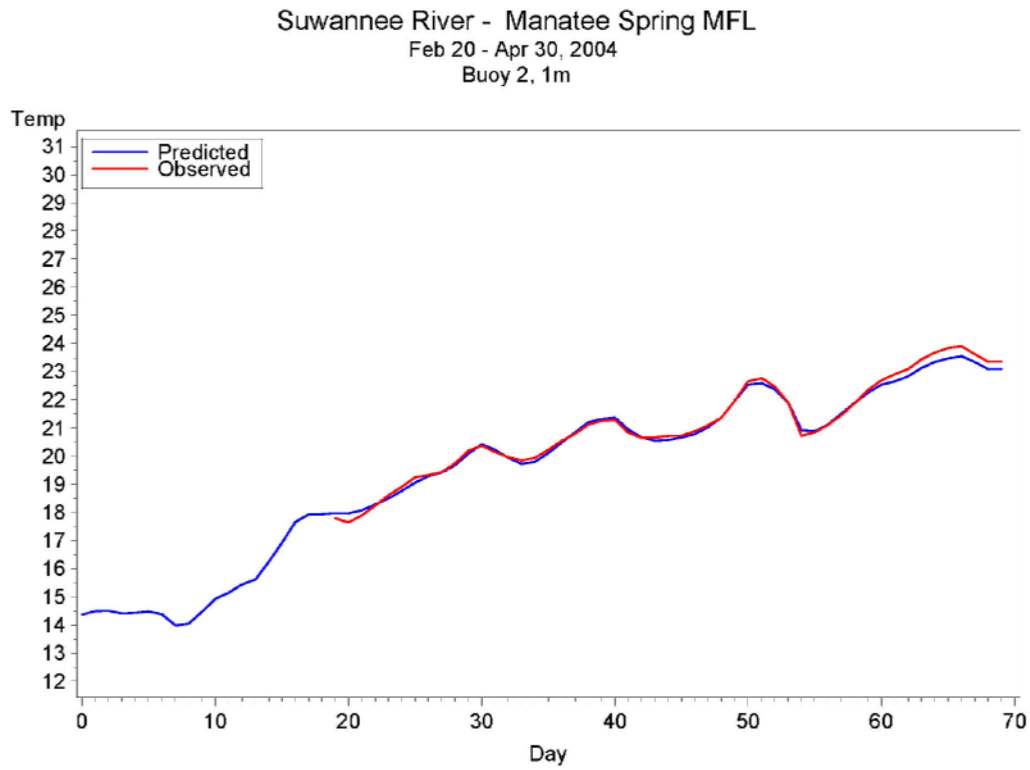


Figure F-3 Daily temperatures, predicted and observed, at Buoy 2, 1 m, 2/20/04-4/30/04.

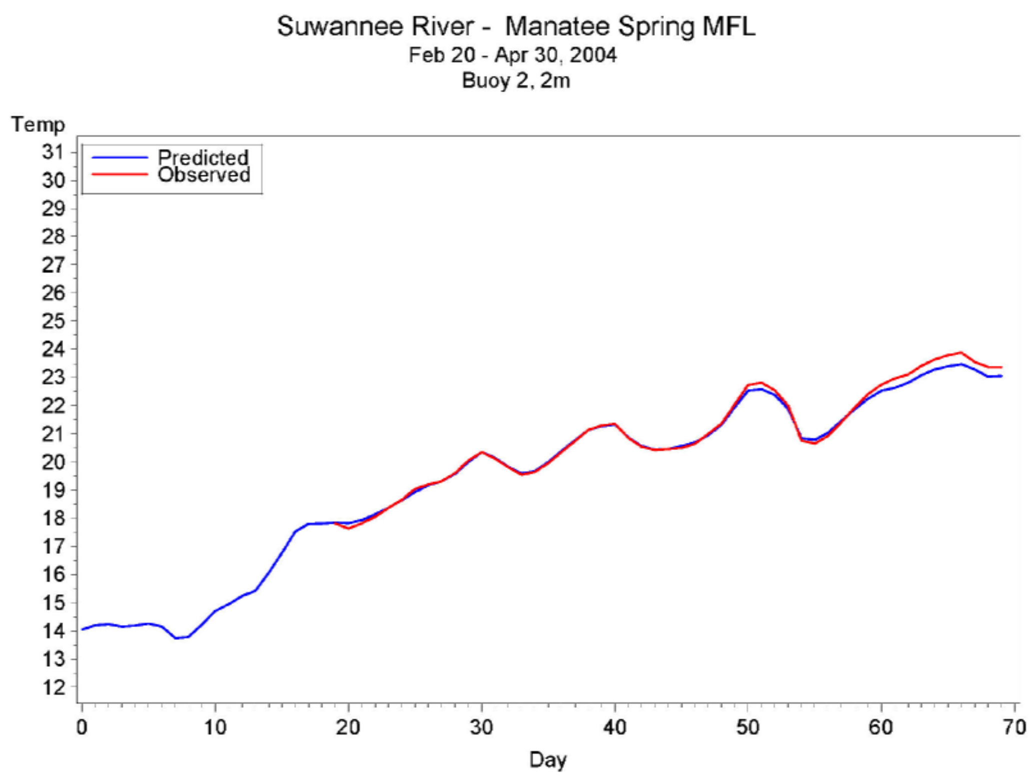


Figure F-4 Daily temperatures, predicted and observed, at Buoy 2, 2 m, 2/20/04-4/30/04.

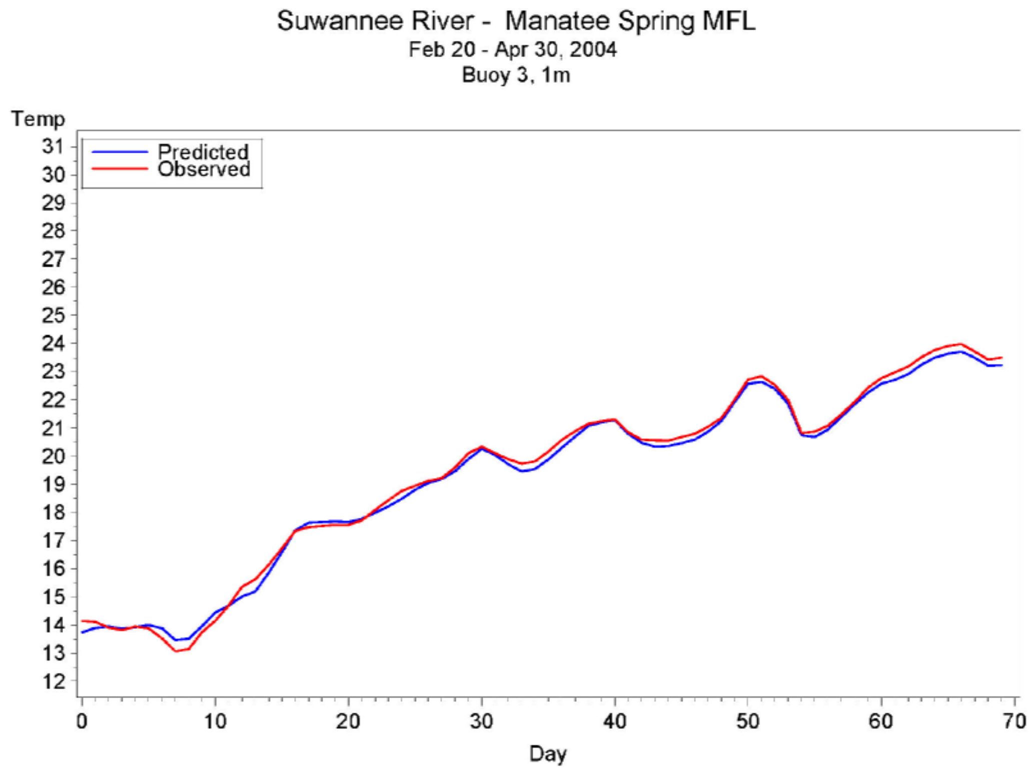


Figure F-5 Daily temperatures, predicted and observed, at Buoy 3, 1 m, 2/20/04-4/30/04.

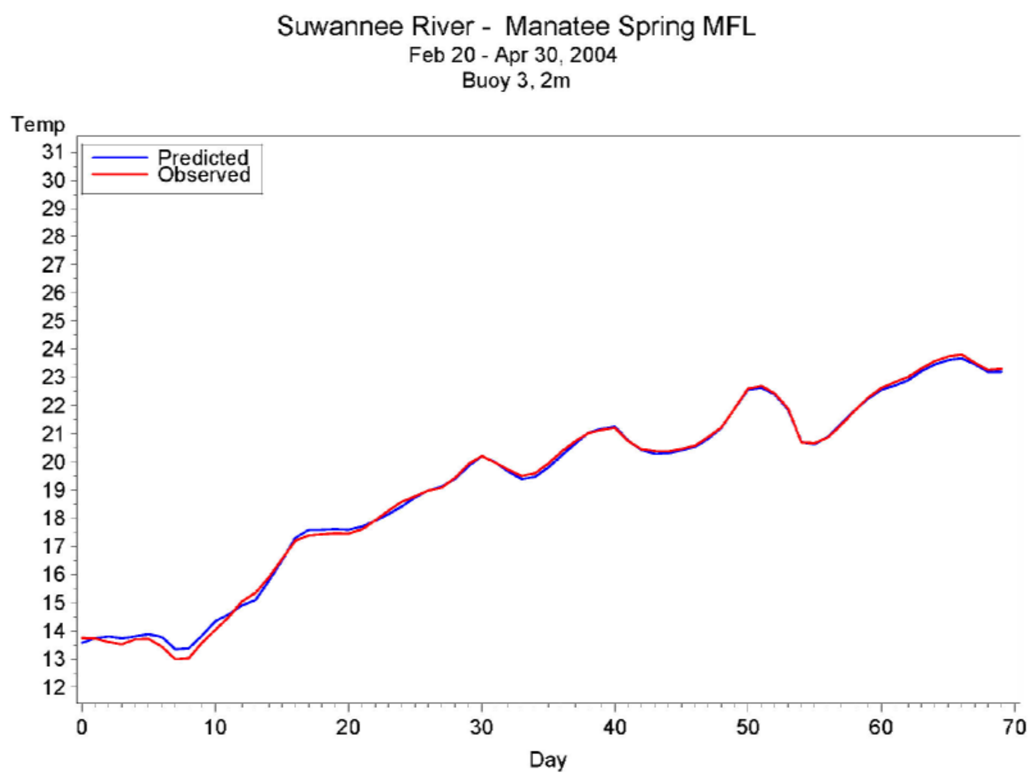


Figure F-6 Daily temperatures, predicted and observed, at Buoy 3, 2 m, 2/20/04-4/30/04.

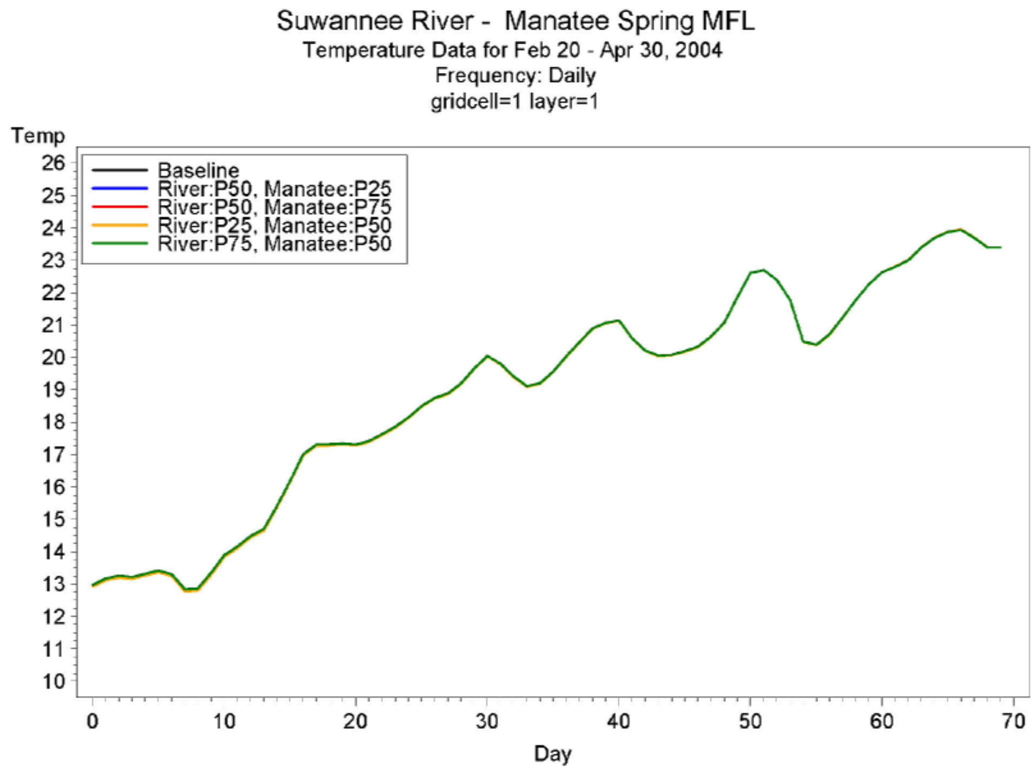


Figure F-7 Predicted daily temperatures, surface grid 1.

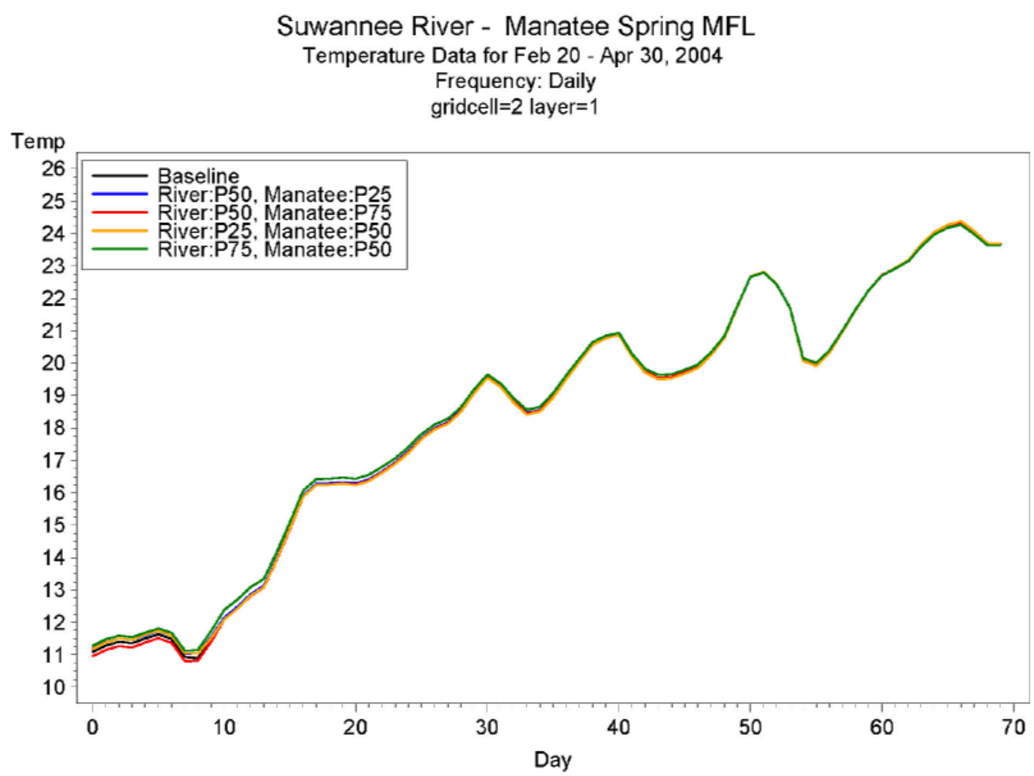


Figure F-8 Predicted daily temperatures, surface grid 2.

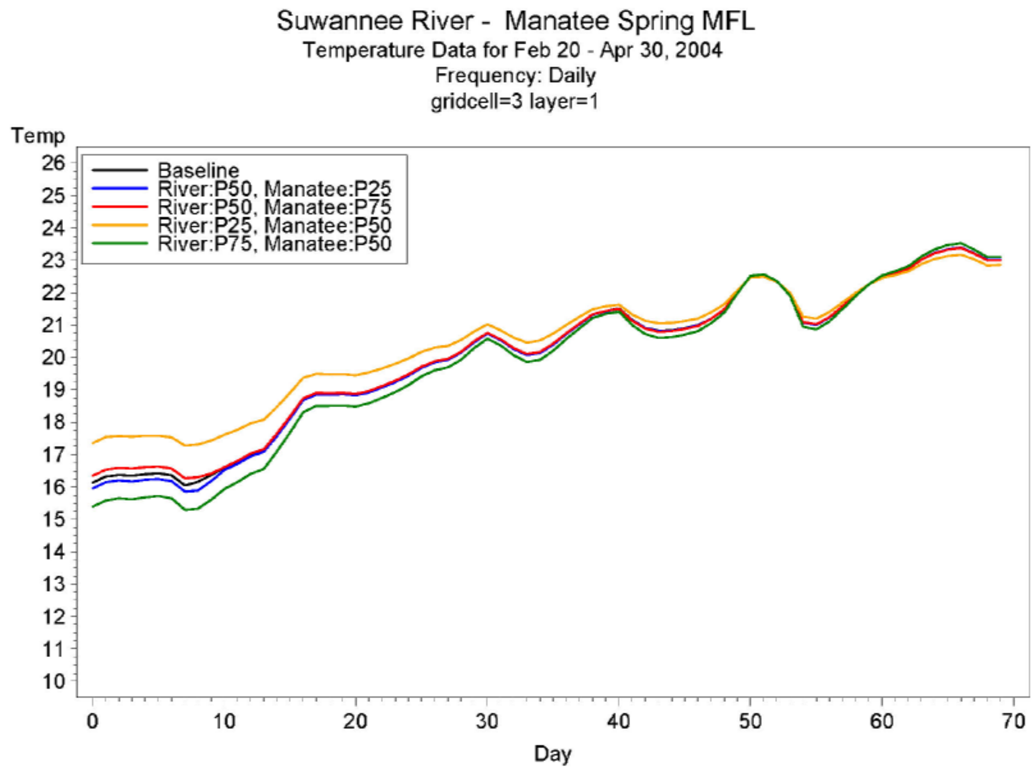


Figure F-9 Predicted daily temperatures, surface grid 3.

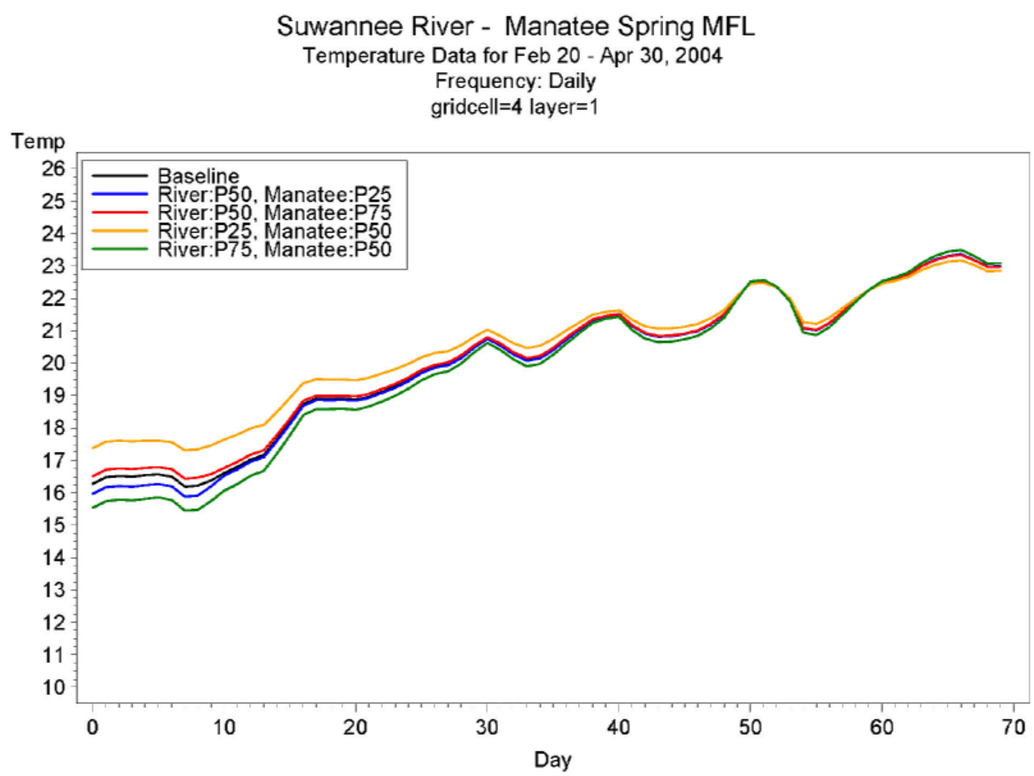


Figure F-10 Predicted daily temperatures, surface grid 4.

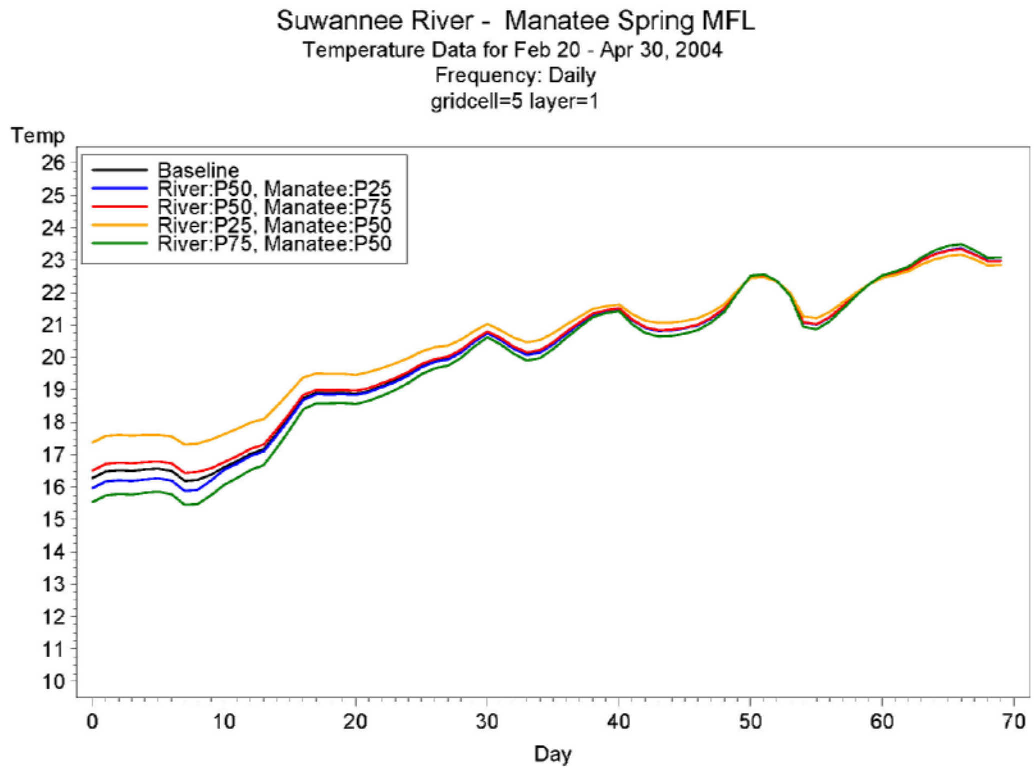


Figure F-11 Predicted daily temperatures, surface grid 5.

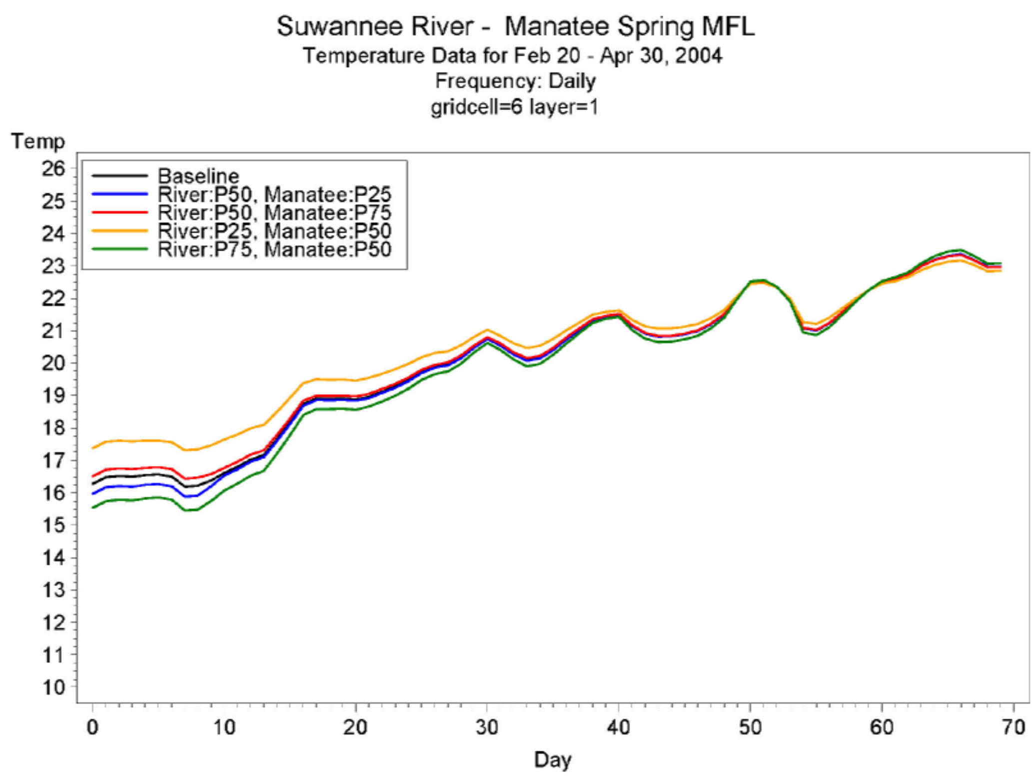


Figure F-12 Predicted daily temperatures, surface grid 6.

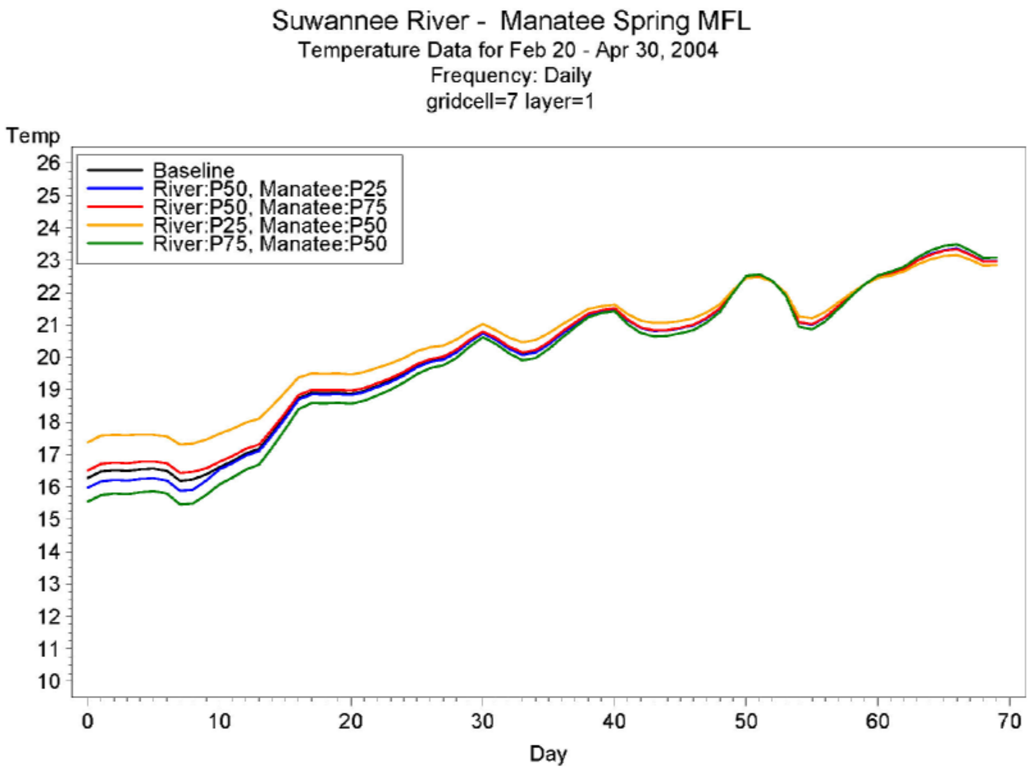


Figure F-13 Predicted daily temperatures, surface grid 7.

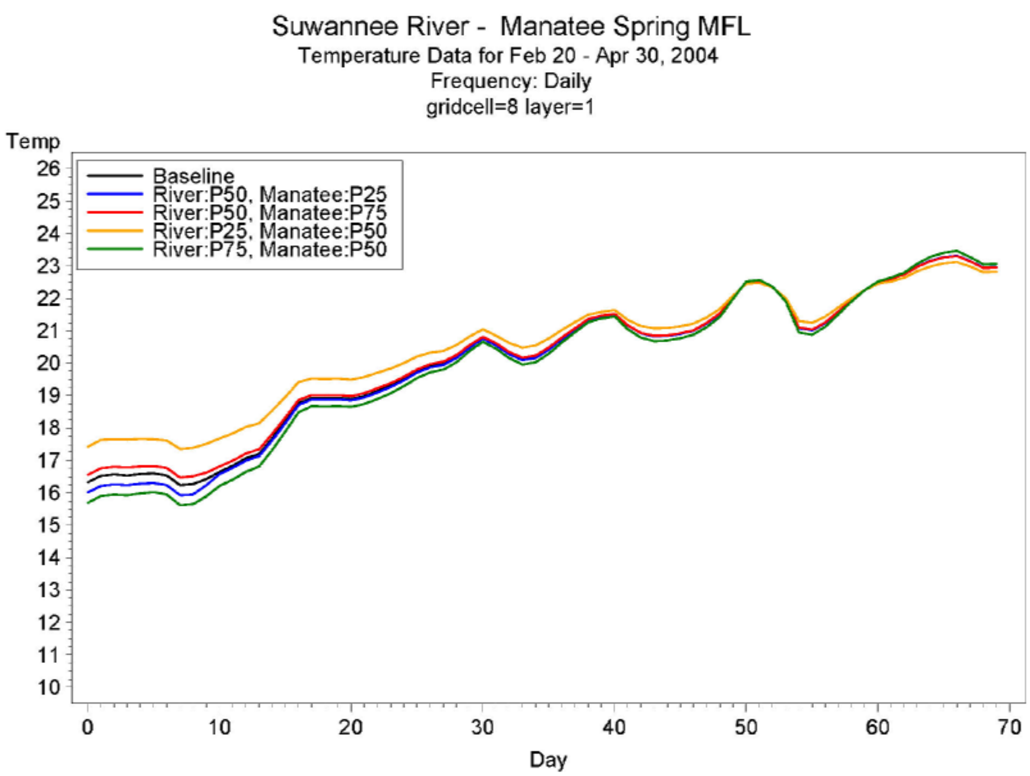


Figure F-14 Predicted daily temperatures, surface grid 8.

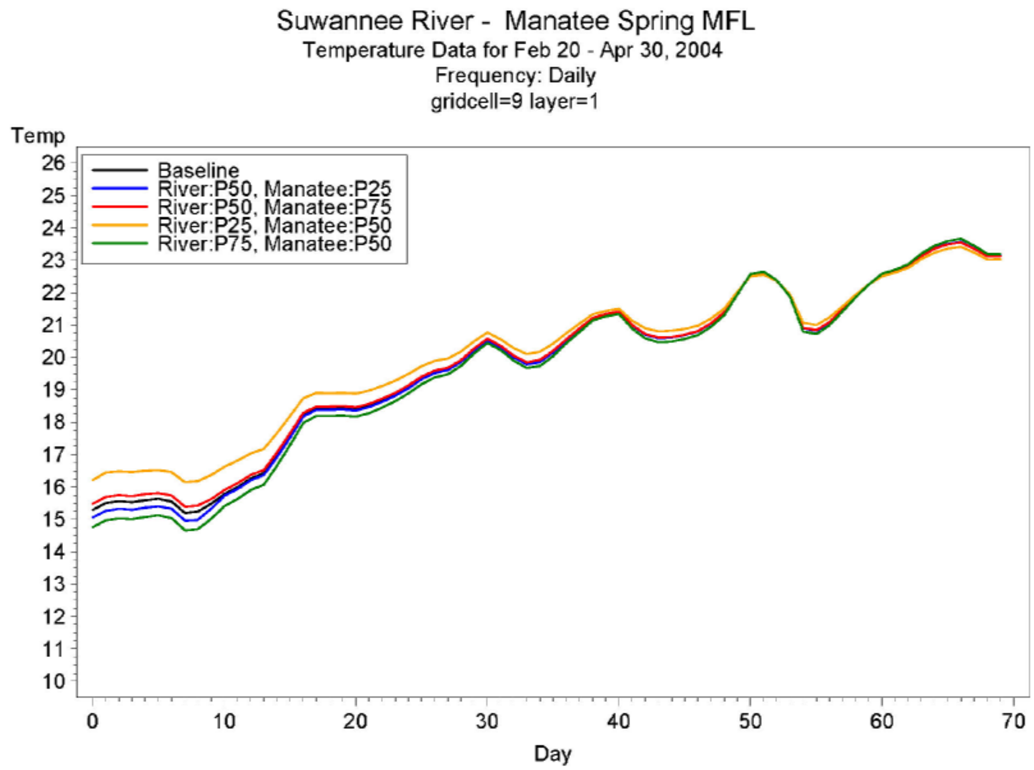


Figure F-15 Predicted daily temperatures, surface grid 9.

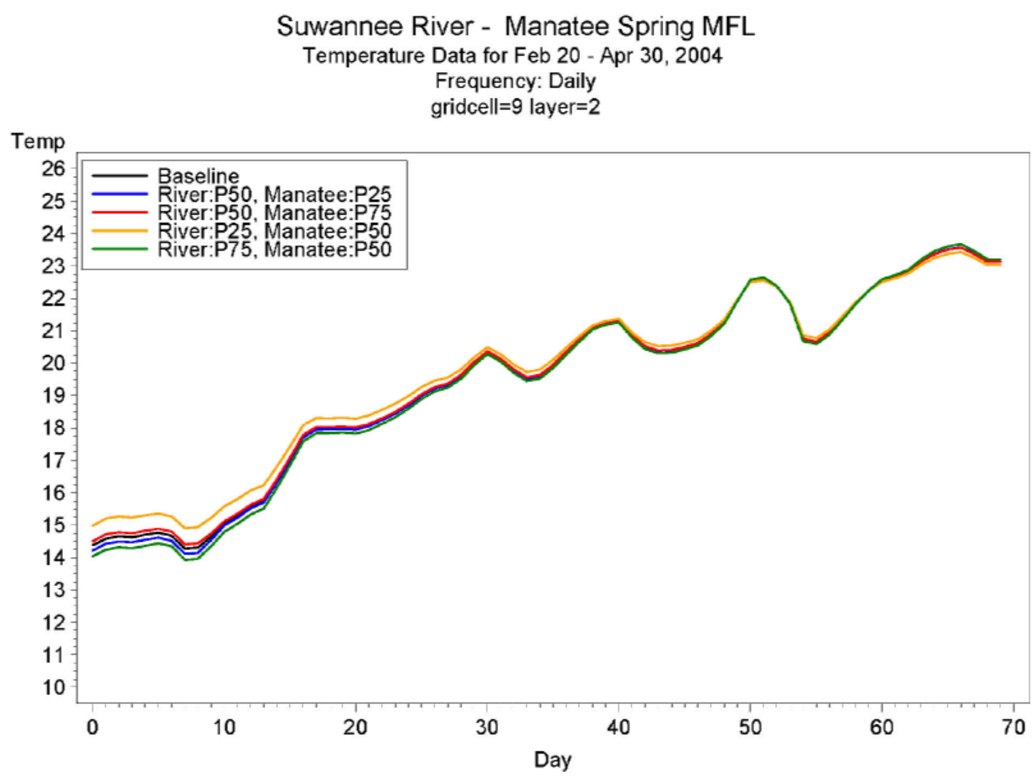


Figure F-16 Predicted daily temperatures, bottom grid 9.

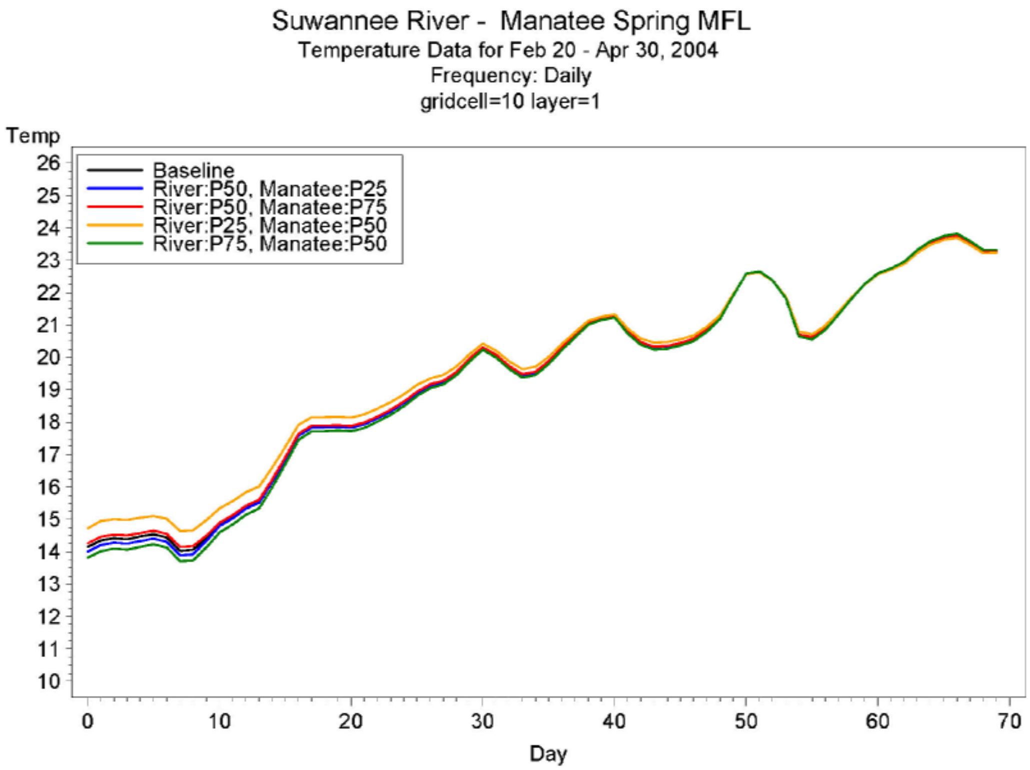


Figure F-17 Predicted daily temperatures, surface grid 10.

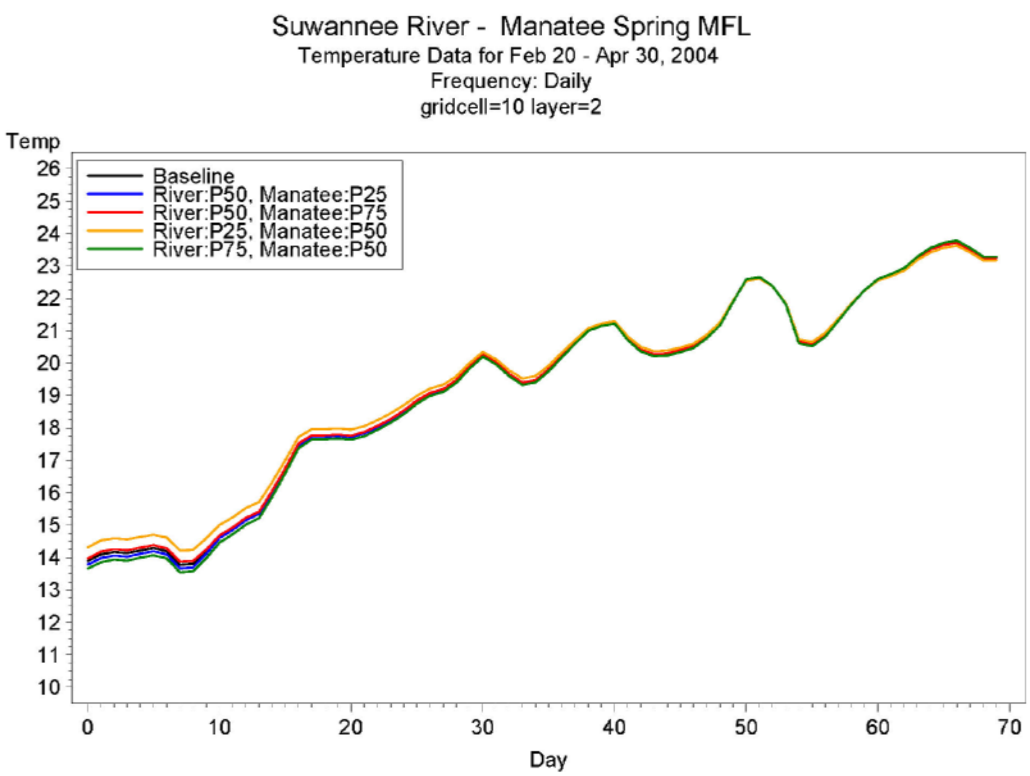


Figure F-18 Predicted daily temperatures, bottom grid 10.

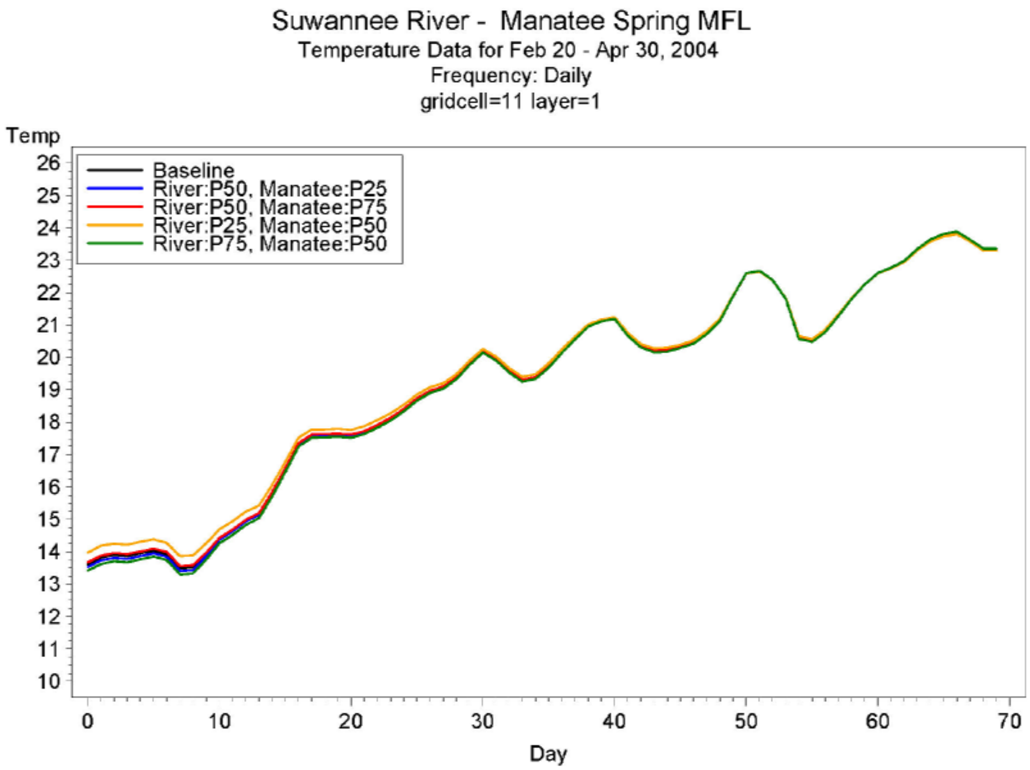


Figure F-19 Predicted daily temperatures, surface grid 11.

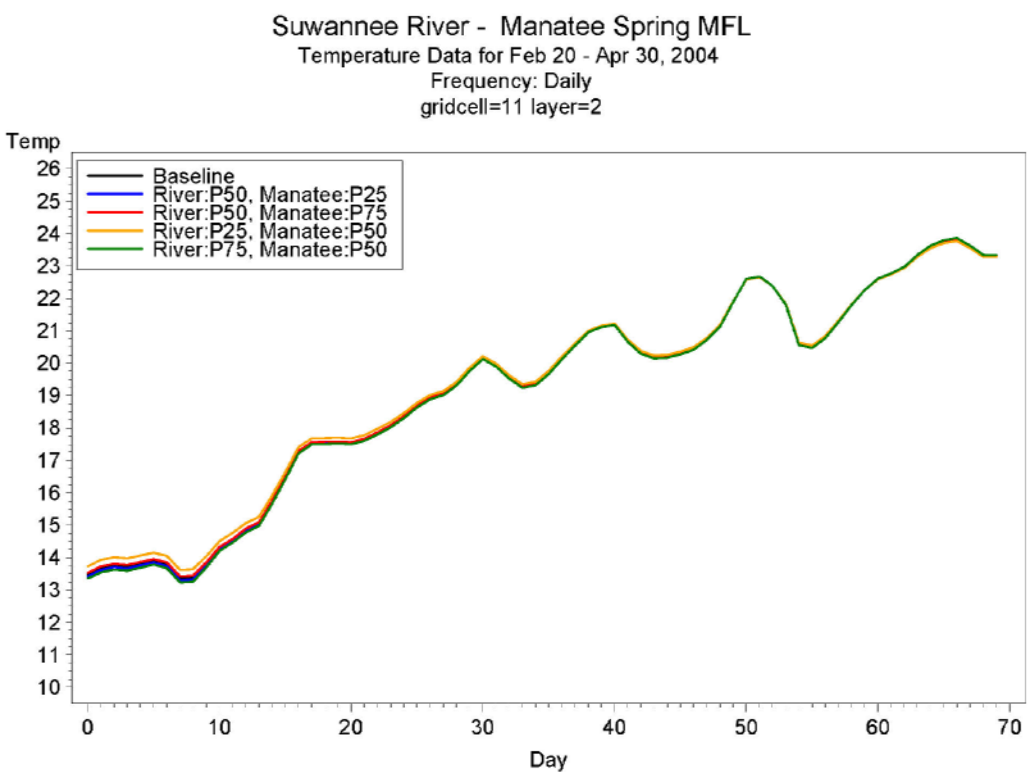


Figure F-20 Predicted daily temperatures, bottom grid 11.

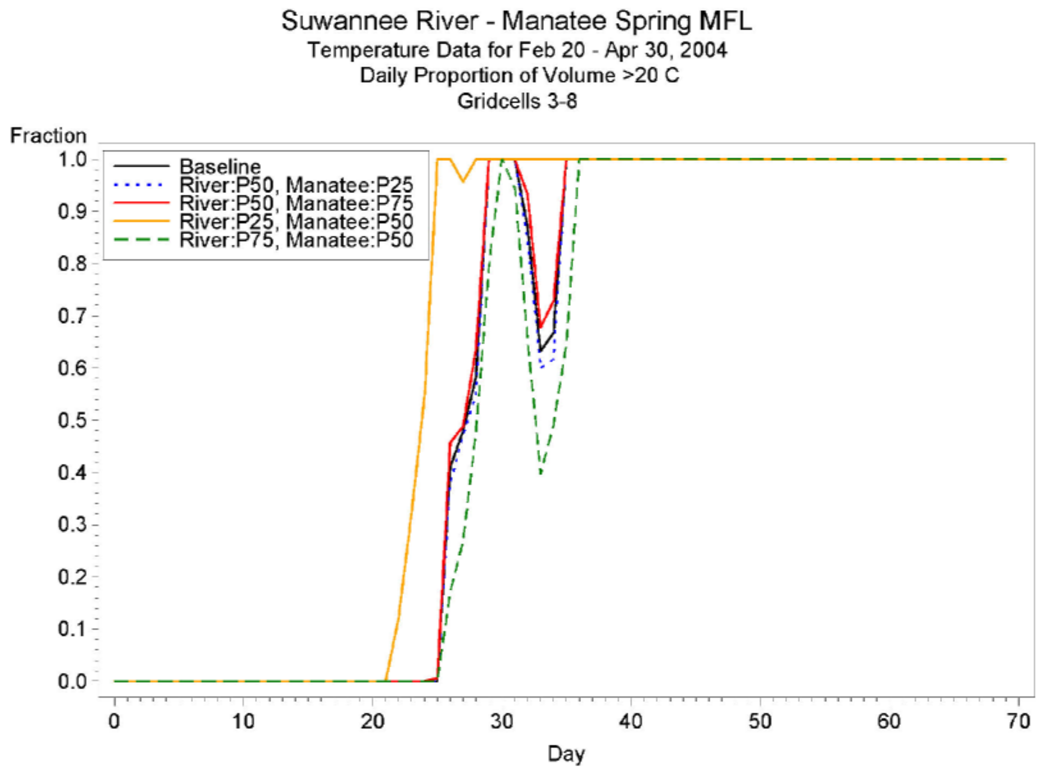
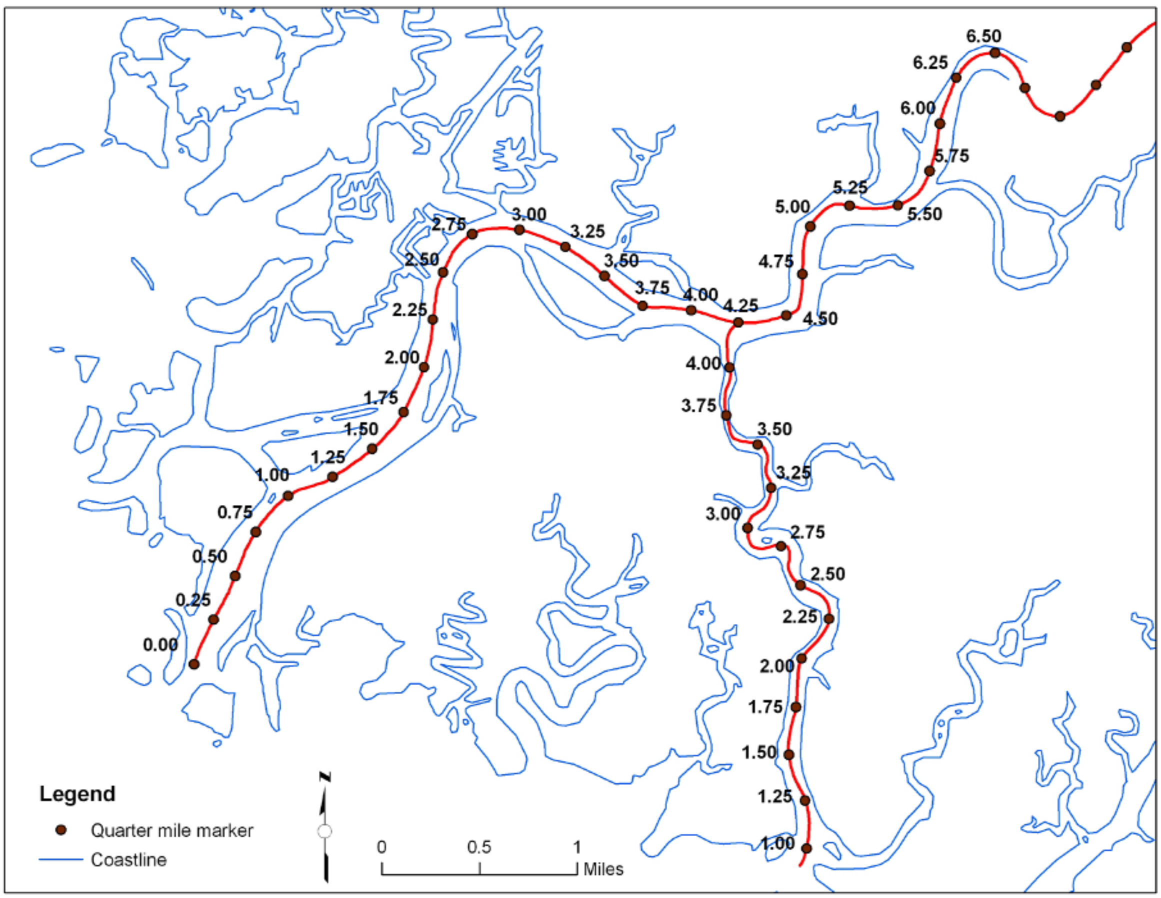


Figure F-21 Predicted daily fraction of volume greater than 20°C for cells 3-8.

Appendix G – Construction of the Lower Suwannee River Mile System



Background

- In studying flow-habitat and flow-salinity relationships, it is crucial to understand the spatial distribution of different riverine habitats. Such a study requires a common river distance system to link current habitat locations with isohaline locations.

Objectives

- To design a river mile system for analyzing the spatial distribution of the lower Suwannee River habitats.

Data Sources

- Centerline coverage as an ARC/INFO export (e00) file from John Good. The original source of this coverage is Jack Grubbs at the USGS and it was created by Augustine Alejandro Sepulveda (personal communication with John Good, 4/11/05).

Methods

- All GIS procedures were performed using ArcMap 9.0, ArcToolbox 9.0, and ArcCatalog 9.0 (packaged as ArcGIS).
- The ARC/INFO export files were converted to coverages using the ArcView Import from Interchange File function under Conversion Tools in ArcCatalog.
- The resulting ARC/INFO coverages were then converted to polyline shapefiles using the Data Export function in ArcMap.
- The splitPLine script was downloaded (http://arcscripts.esri.com/) and modified to split the polyline shapefiles into quarter mile segments. The modification involved setting the cutting distance to quarter mile sections (Figure G-1).
- The East Pass River mile section was constructed such that it had a common river mile marker at the connection point with West Pass (mile 4.25). As a result, the mouth of East Pass has a river mile marker around mile 1.
- Cross lines were constructed by digitizing line sections perpendicular to the centerline at the quarter mile locations (Figure G-2). These sections were used for analyzing the spatial distribution of the different habitats of concern.

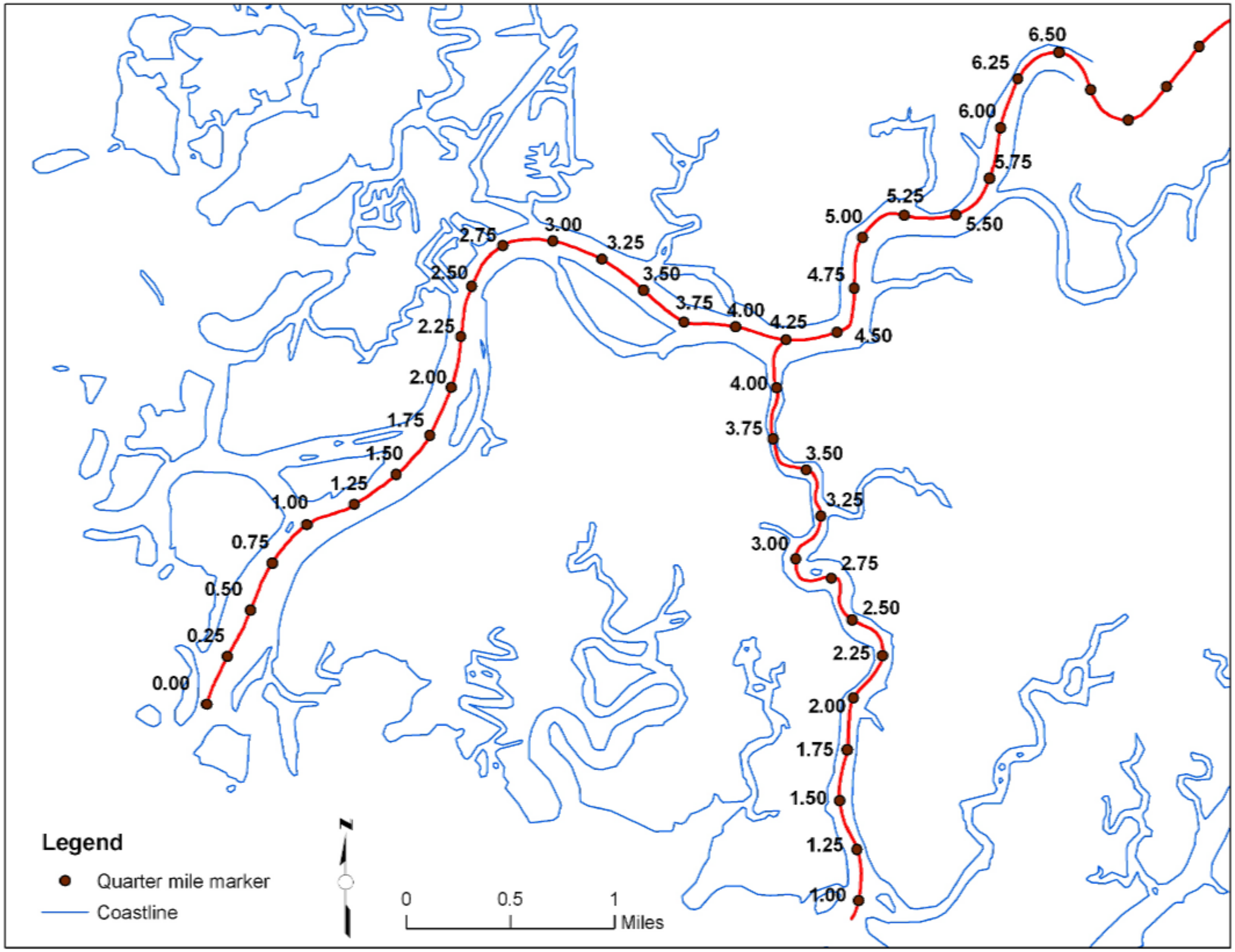


Figure G-1. Centerline and quartermile markers in West Pass, Suwannee River, and East Pass.

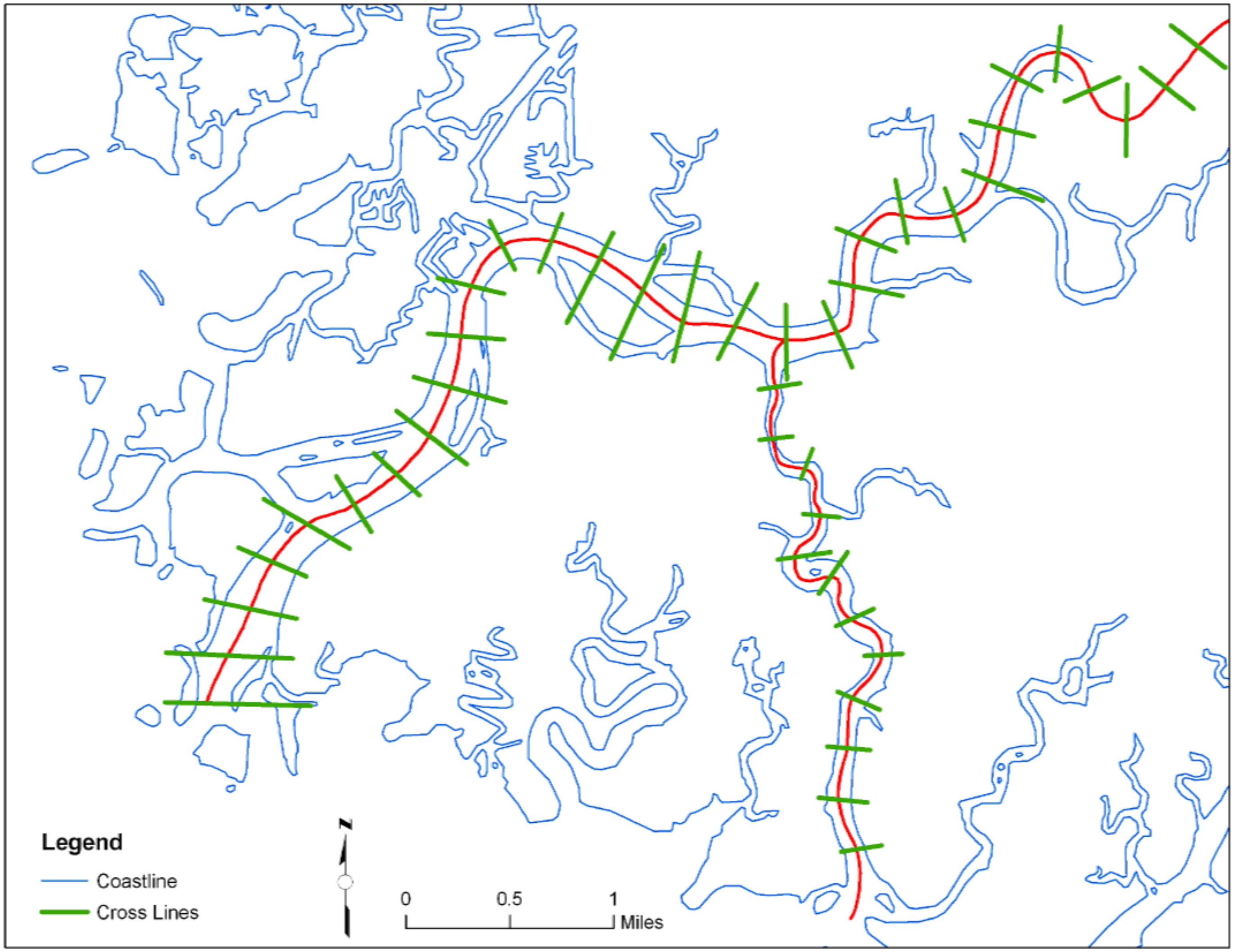
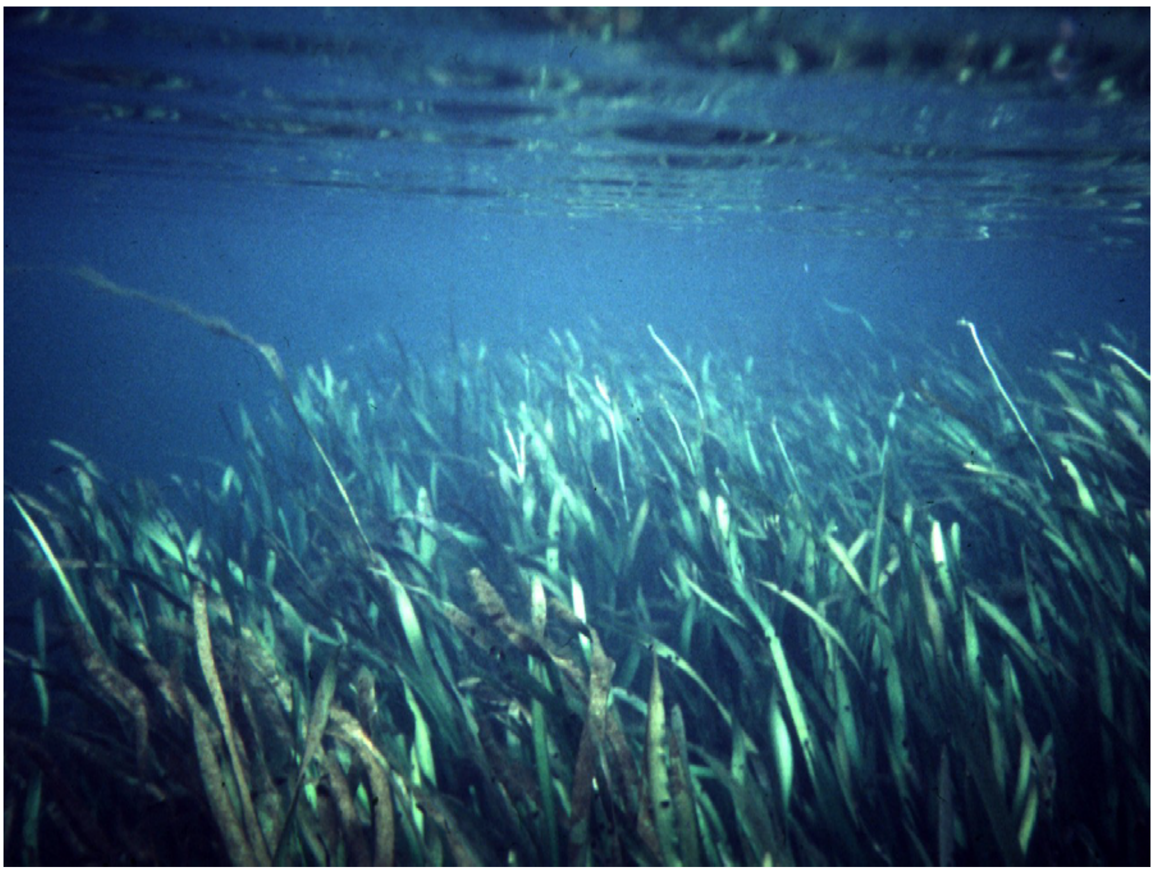


Figure G-2. Cross line sections at quarter mile markers in West Pass, Suwannee River, and East Pass.

Appendix H - Submerged Aquatic Vegetation



Background

- One of the major aquatic habitats in the Lower Suwannee River is beds of low salinity or freshwater submerged aquatic vegetation (SAV) (Figure H-1).
- SAV plays a critical role in terms of providing habitat for invertebrate and fish species, in addition to helping to stabilize sediments and contributing to the total primary productivity in the food web (Rozas and Odum, 1987a;1987b; Mattson and Krummrich, 1995;Thorp et al. 1997).
- The potential for significant harm to SAV habitat is related to changes in salinity, which is a function of flow. Changes in salinity could result in an unacceptable upstream movement of the downstream limit of SAV distribution in the estuary, or the potential for an overall loss of acreage of low salinity SAV habitat.

Objectives

- To evaluate how the relationship between flow and salinity affects the habitat suitability of SAV in the Lower Suwannee River.
- To estimate the risk to SAV habitat based on alterations to the flow regime (flow reductions).

Data Sources

- Daily average discharge data was obtained for the United States Geological Survey (USGS) gage number 02323500 (Suwannee near Wilcox) from 1984-2004.
- Daily lags were created to 15 days, lag averages to 90 days, cumulative flows to 8 days and transformations of flows (e.g. logarithmic, inverse, square root).
- Hydrologic data was also available from the USGS Continuous Recorder Gage WM (Figure H-1) located at river mile 1.82 (Figure H-2).
- Salinity data collected by the FWCC in 1993-1995 was used to develop regression models relating flow at Wilcox to the location of the 9 ppt isohaline.
- SAV habitat data were collected for the SRWMD by Mote Marine Laboratory (Estevez and Sprinkle, 1999; Estevez, 2000; 2002) and by Golder and Associates (2000).

    - The Mote Marine SAV study:
        - Sampling was conducted on a quarterly schedule (4 times) from March 1998 to January 1999. The 16 sites were re-visited in June 2000 and July 2002 during a severe drought.
        - Consisted of 16 sampling sites jointly selected by Mote and SRWMD during a pre-study reconassaince. Placement of sites was systematic, extending from the downstream limit of SAV in East, Alligator, and Wadley Passes up to the confluence with the Gopher River, where salinity never penetrates under ordinary climatic and river flow conditions.
        - The overall goal of the Mote SAV study was to describe the characteristics of SAV where it occurred in the upper estuary and relate to salinity regimes, as opposed to making broader generalizations about SAV in the upper estuary, which would have required a more randomized station distribution.
        - At all 16 sites, SAV characteristics of frequency, cover and abundance by species were measured using 0.25 m^2 quadrats and the non-destructive Braun-Blanquet method. Quadrats were

deployed haphazardly about the grassbed at each site during sampling.
    - Additional SAV data were collected at a subset of six of the 16 study sites. Six (6) quadrats of 0.0625 m^2 area were haphazardly deployed about the grassbed at each site, and all SAV within the quadrat was harvested for determination of dry weight standing crop. In the laboratory, collected plant material was separated by individual plant species and then divided into leaf (above ground) and root (below ground) components by species. This material was air-dried for 24 hours, then further dried at 75-80 degrees C in ovens to obtain dry weight standing crop.

- The Golder SAV study:
    - SAV was mapped by Golder Associates (2000) in late spring and summer of 2000.
    - Mapping was conducted using "in-the-field" technology. A Trimble® AgGPS 132 Global Positioning System unit was linked to a lap-top computer with software which linked the GPS system to ESRI® GIS software.
    - The edges of individual grass beds were delineated in the field by walking the perimeter of each bed with the GPS unit. The hardware and software recorded this polygon on the laptop computer. Various attributes of the grassbed (species composition, dominant species, salinity, etc.) could then be entered into the computer to build the GIS attribute database.
    - Because the mapping effort was conducted during an extreme drought, there were areas known to historically support SAV which were now unvegetated. SRWMD staff located these for Golder Associates field personnel, and areas of unvegetated substrate in depths <3 ft (0.9 m) were delineated during dead low tide to conservatively estimate the amount of "potential" or "historic" SAV habitat.
    - A river mile system was developed and used to help calculate the cumulative acreage of SAV in West Pass, moving from the downstream limit up to the confluence with East Pass.

Isohaline Selection

- Literature supports 9 parts per thousand (ppt) as the threshold value for suitable low salinity SAV habitat in Lower Suwannee River (LSR).
- Salinity data collected by the SRWMD/FWCC in 1993-1995 were used to develop a regression model relating flow at Wilcox to the location of the 9 ppt isohaline.
    - Analyses were restricted to Wadley and West Passes, since the majority of the SAV coverage in the upper estuary is found in West Pass. Salinities are uniformly lower in East Pass, compared to West Pass (Tillis, 2000; Mattson and Krummrich, 1995), so salinity criteria to protect SAV in West Pass should be equally protective in East Pass.
    - Wadley Pass is a historically more saline environment than Alligator Pass; a dynamic area of mixing is created at the confluence as tidally driven and saline water from Wadley Pass mixes with the Suwannee

discharge. Nine ppt is infrequently found in Alligator and East Passes.

Analytical Steps

- A prediction equation was developed for the location of the 9 ppt isohaline in the LSR as a function of flow using regression. The estimation of flow-isohaline location relationships were used to identify the upstream incursion of the 9 ppt isohaline under varying flow conditions (Figures H-3 through H-5).
- River locations associated with 0 to 15 % of the total SAV habitat were identified as risk points (Figure H-6).
- A regression equation was then applied to determine the flow required to keep the 9 ppt isohaline below each of the risk points (Figure H-6).
- Salinity-flow regressions were also developed for the WM continuous recorder in order to provide an independent assessment of the flow required to sustain suitable habitat for SAV.

Validation Using the WM Continuous Recorder

- The USGS Continuous Recorder Gage WM is located at river mile 1.82
- Surface isohaline regression results suggest that 5320 cfs would be required to keep the surface isohaline at the WM continous recorder.
- To validate the isohaline regressions, the flow predicted to keep the 9 ppt isohaline at river mile 1.82 (the location of the WM continuous recorder) was compared using the isohaline regressions to the observed and predicted salinity at the WM continuous recorder (WM salinity /flow regressions).

Validation Analytical Steps

- Hurricane dates were removed from the WM dataset.
- Daily maximum salinity was calculated using the mid-water measurements, which were the most frequent and had the longest period of record (POR) (Figure H-7).
- The salinity-flow relationship was estimated using the WM continuous recorder salinity (Figure H-8).

Inferences Made from Continuous Recorder Regressions

- Daily maximum salinities at the WM continuous recorded gage were highly variable for a given flow. However, despite the large variability, the regression equation predicted the average salinity well with little bias (Figures H-9 through H-11).
- The observed flow for predicted mid-water salinities between 8.5 and 9.5 ppt was averaged, resulting in a flow at Wilcox of 5,353 cfs.
- For observed flows between 5000 cfs and 6000 cfs, the average observed mid-water salinity was 9.18 ppt.
- These values correspond well with isohaline regression estimates of the flow corresponding to a surface isohaline location at the WM on a full moon (5320 cfs).

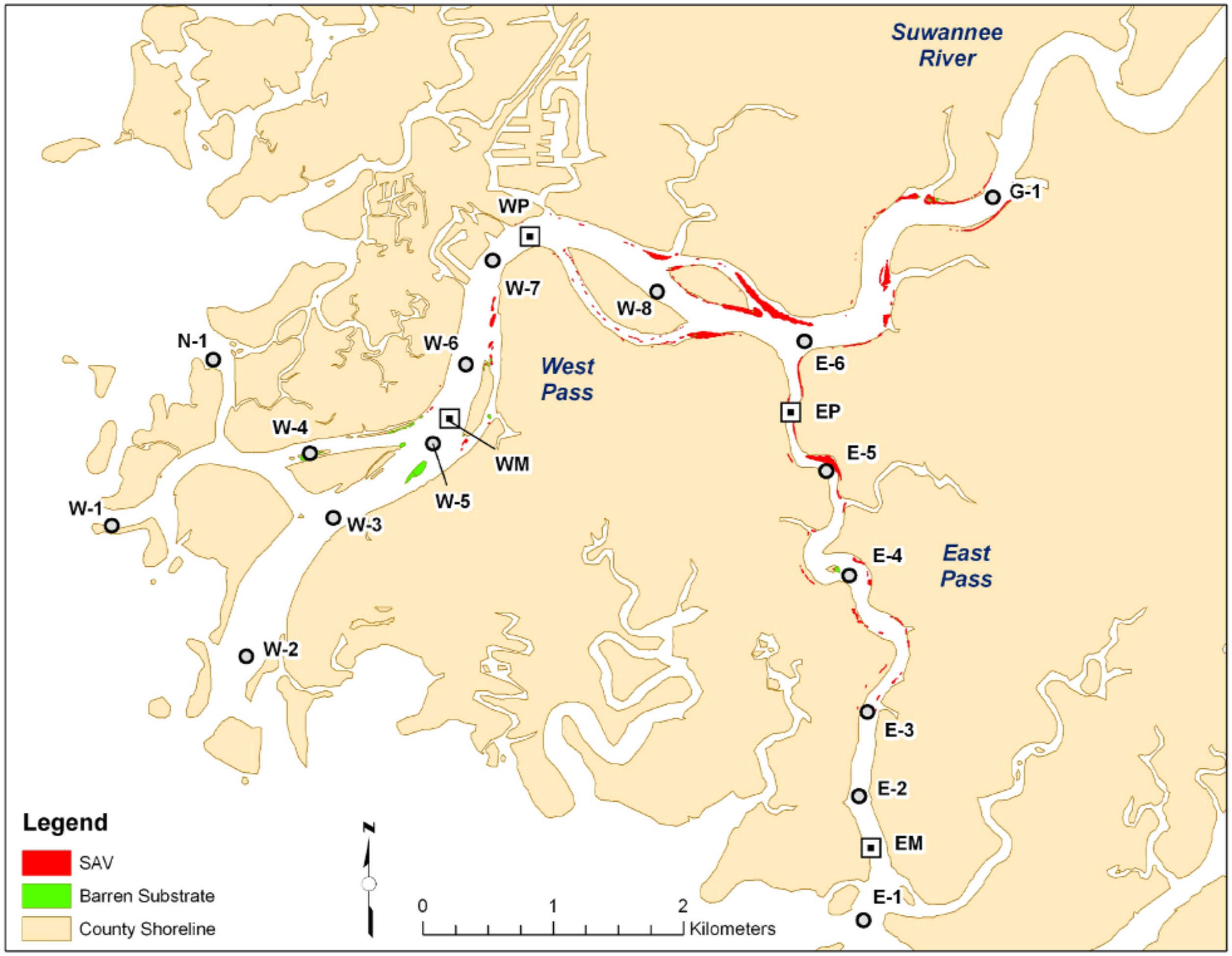


Figure H-1. Distribution of low salinity submerged aquatic vegetation (SAV) and location of continuous recorders in the Lower Suwannee River.

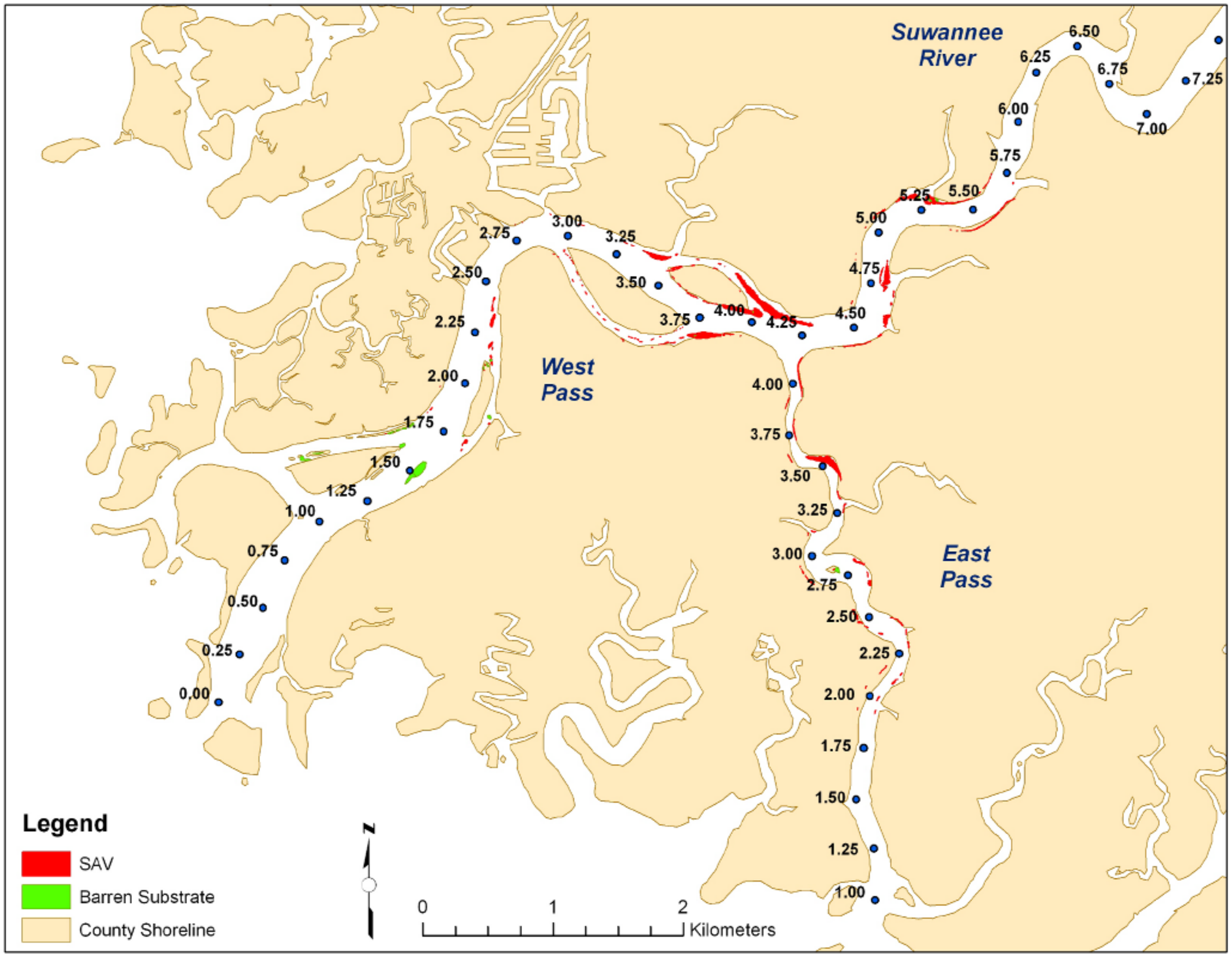


Figure H-2. River mile (rm) system overlaid on the distribution of SAV in the Lower Suwannee River.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	5.29858	5.29858	20.82	0.0008
Error	11	2.79973	0.25452		
Corrected Total	12	8.09831			

Root MSE	0.50450	R-Square	0.6543
Dependent Mean	1.50295	Adj R-Sq	0.6229
Coeff Var	33.56731		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	6.67722	1.14265	5.84	0.0001
Flow**0.4	1	- 0.15740	0.03450	-4.56	0.0008

Figure H-3. Regression details for the 9 ppt surface isohaline developed for Wadley Pass

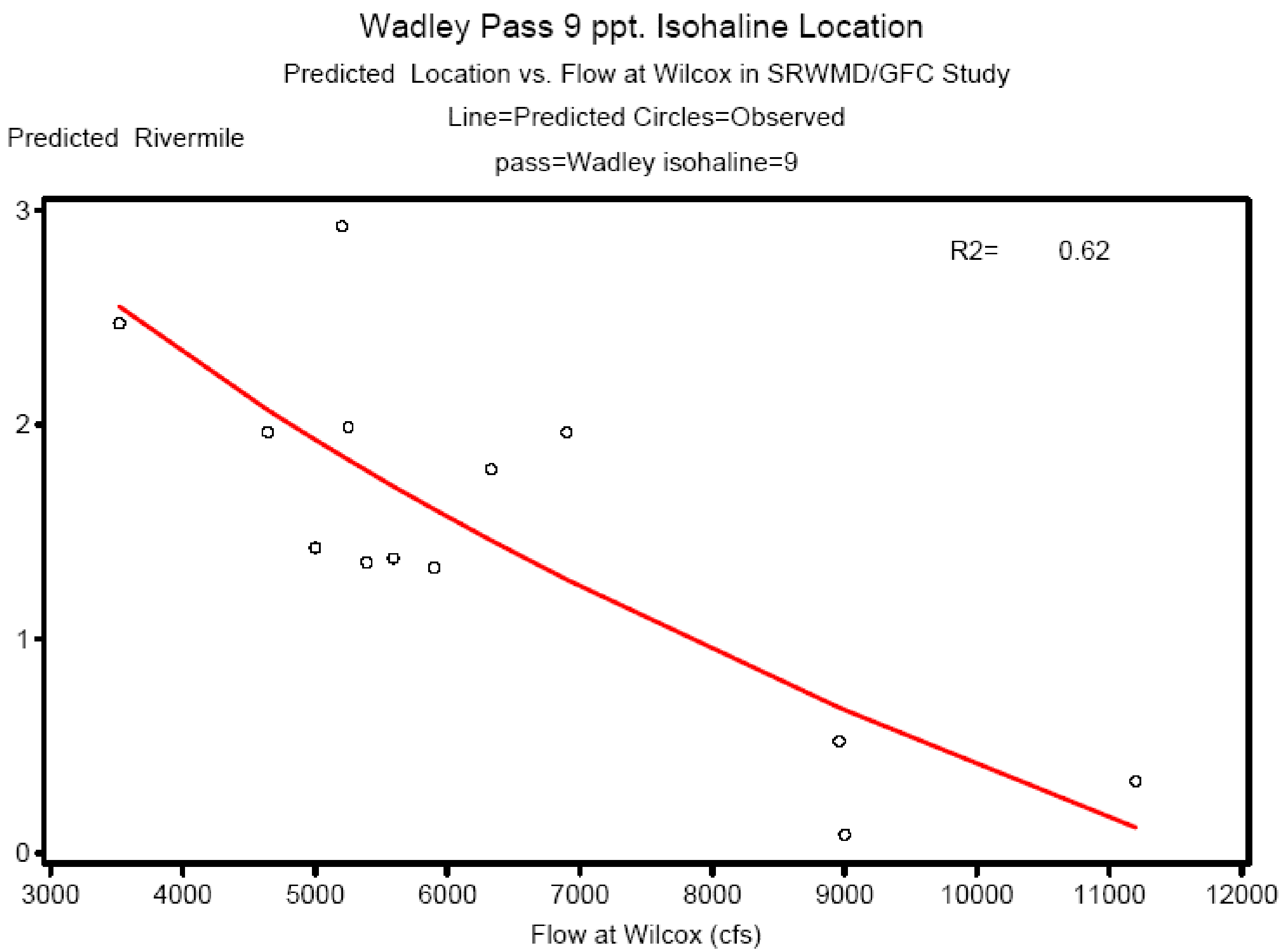


Figure H-4. Regression plots showing the location in river mile of the 9 ppt isohaline as a function of flow.

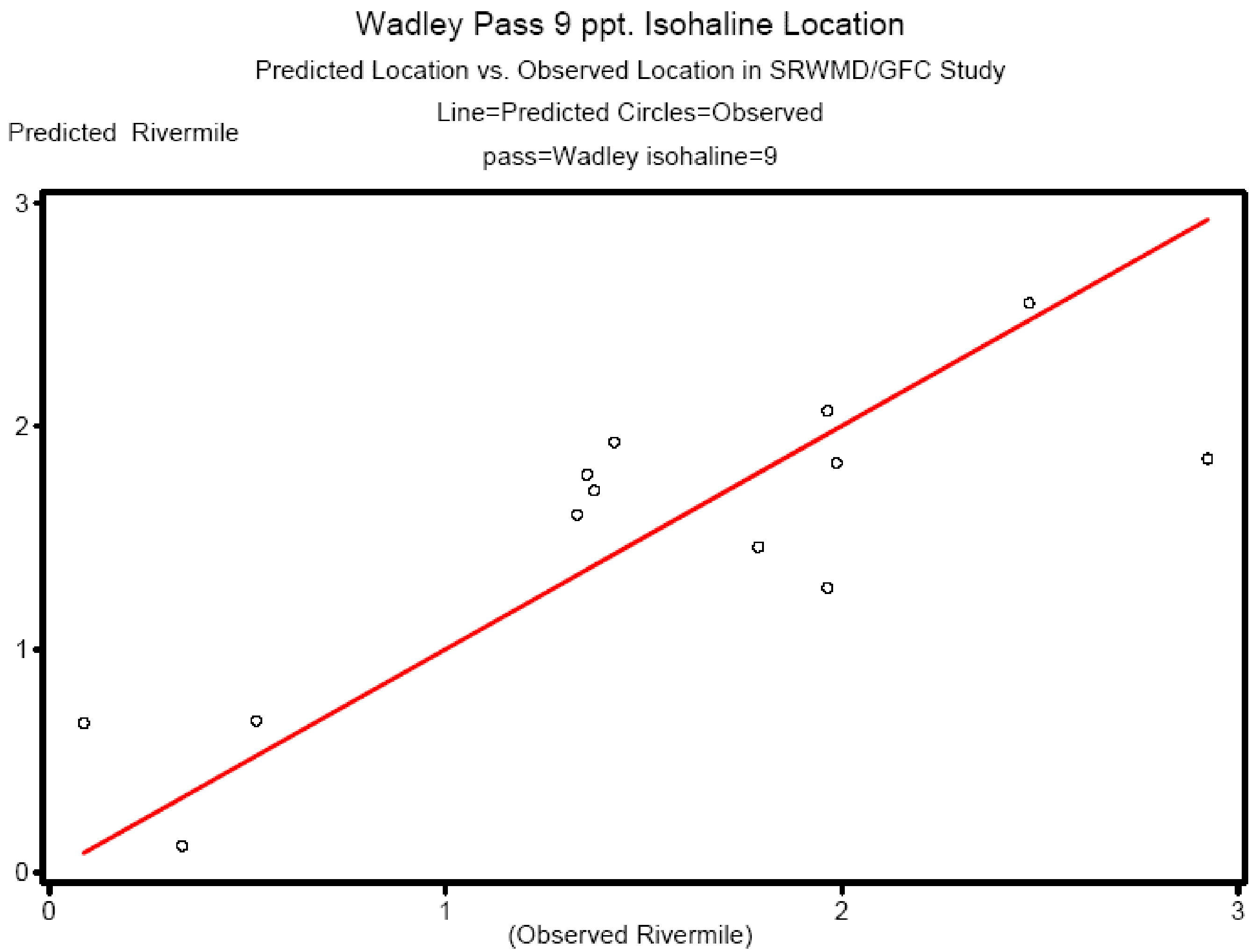


Figure H-5. Relationship between predicted and observed river mile for the 9 ppt isohaline location.

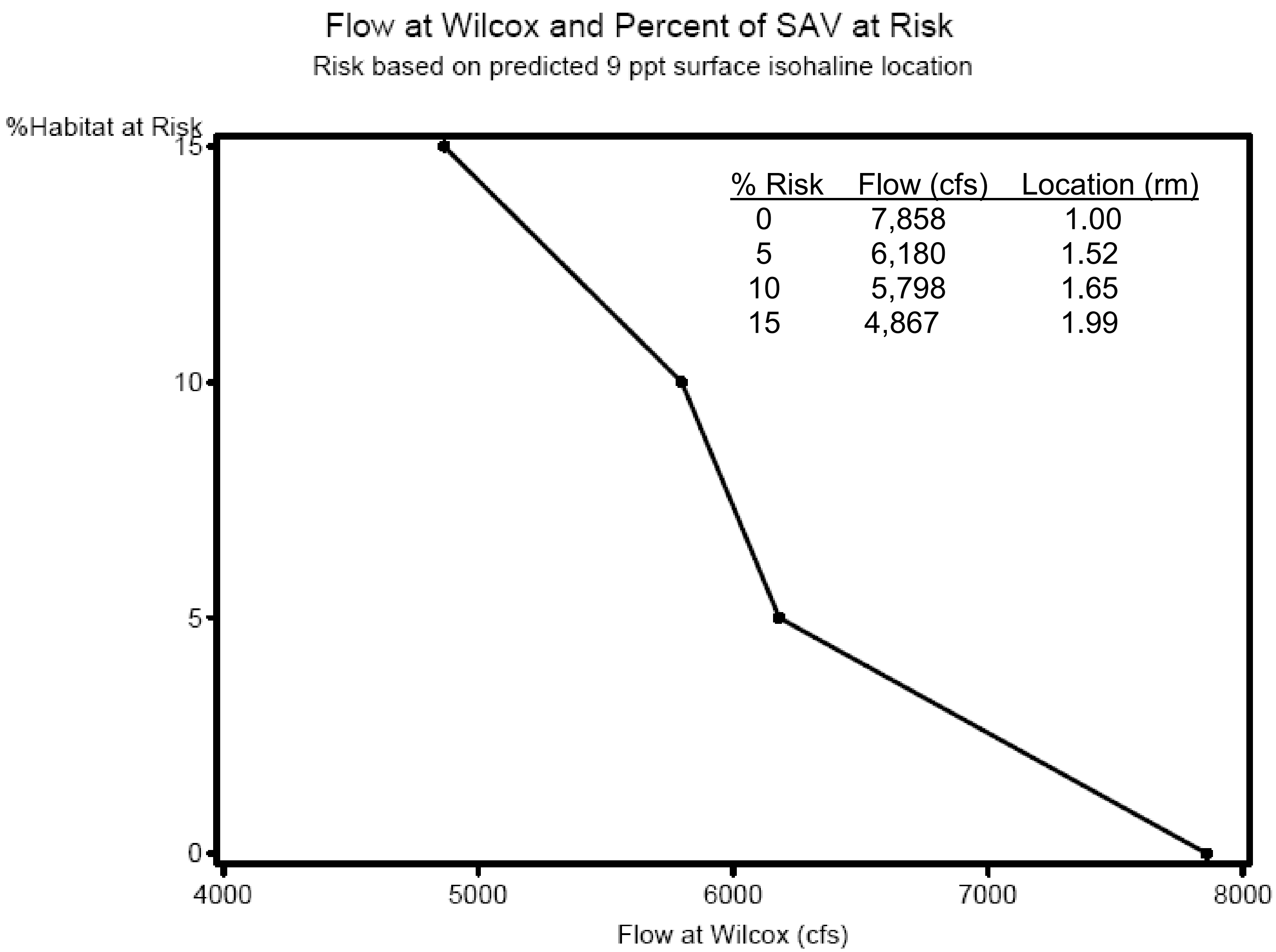


Figure H-6. Relationship between percent of habitat risk for SAV and flow, based on the predicted location of the 9 ppt isohaline.

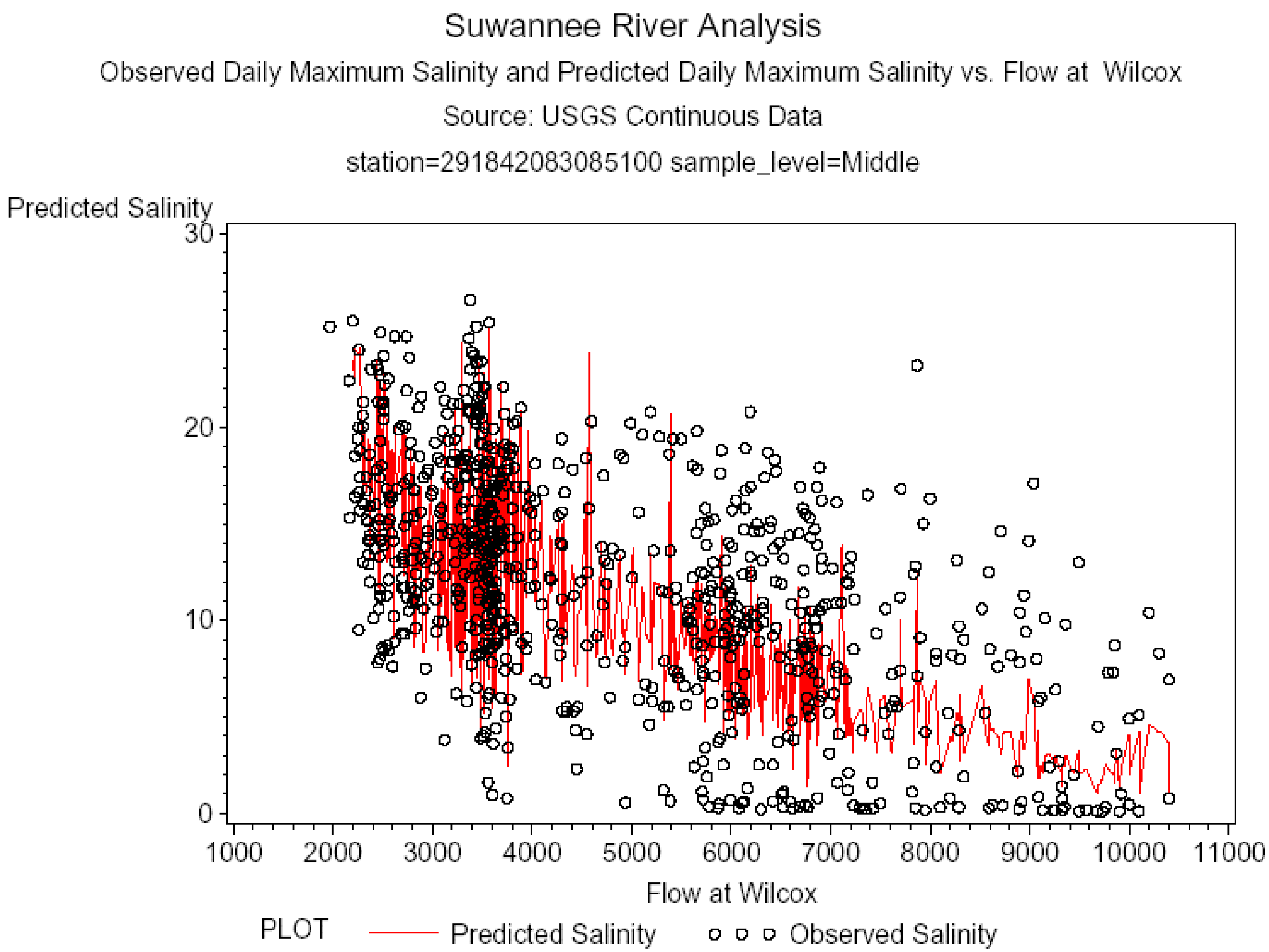


Figure H-7. Predicted and observed daily maximum salinity as a function of flow, based on mid-water column samples.

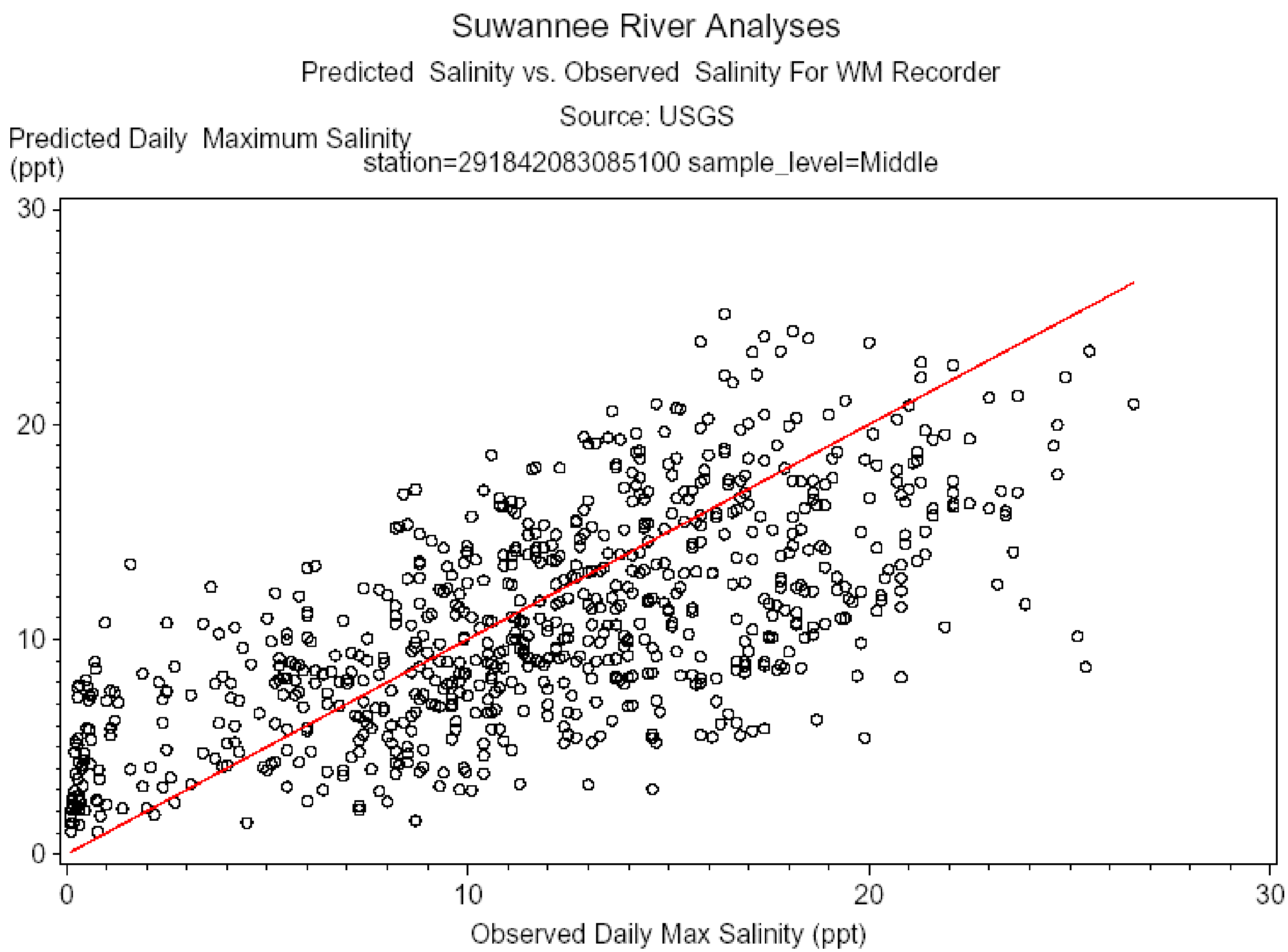


Figure H-8. Relationship between predicted and observed daily maximum salinity from continuous recorder data (WM recorder).

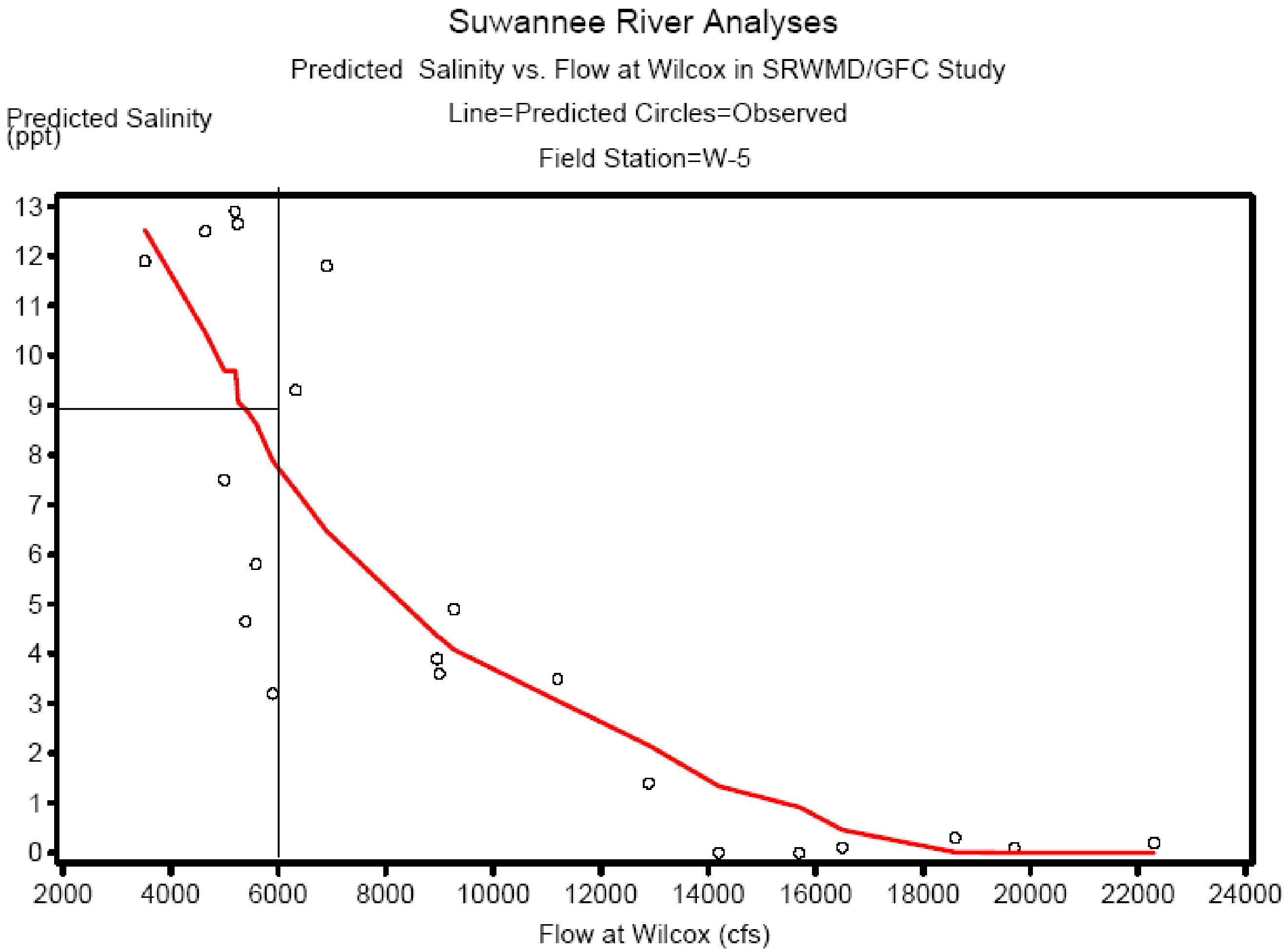


Figure H-9. Regression relationship between predicted salinity and flow for West Pass (fixed station W-5).

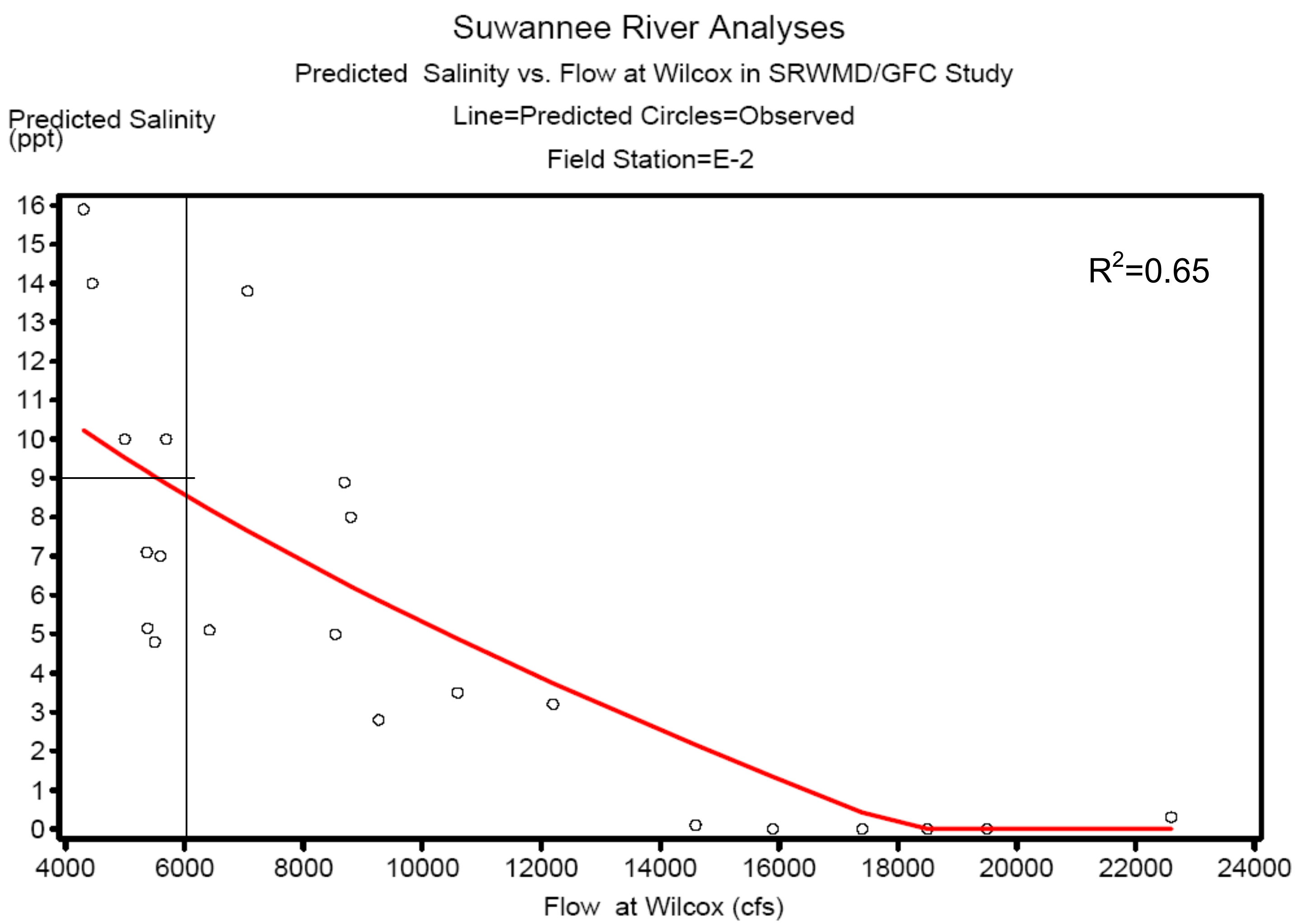


Figure H-10. Regression relationship between predicted salinity and flow for East Pass (fixed station E-2).

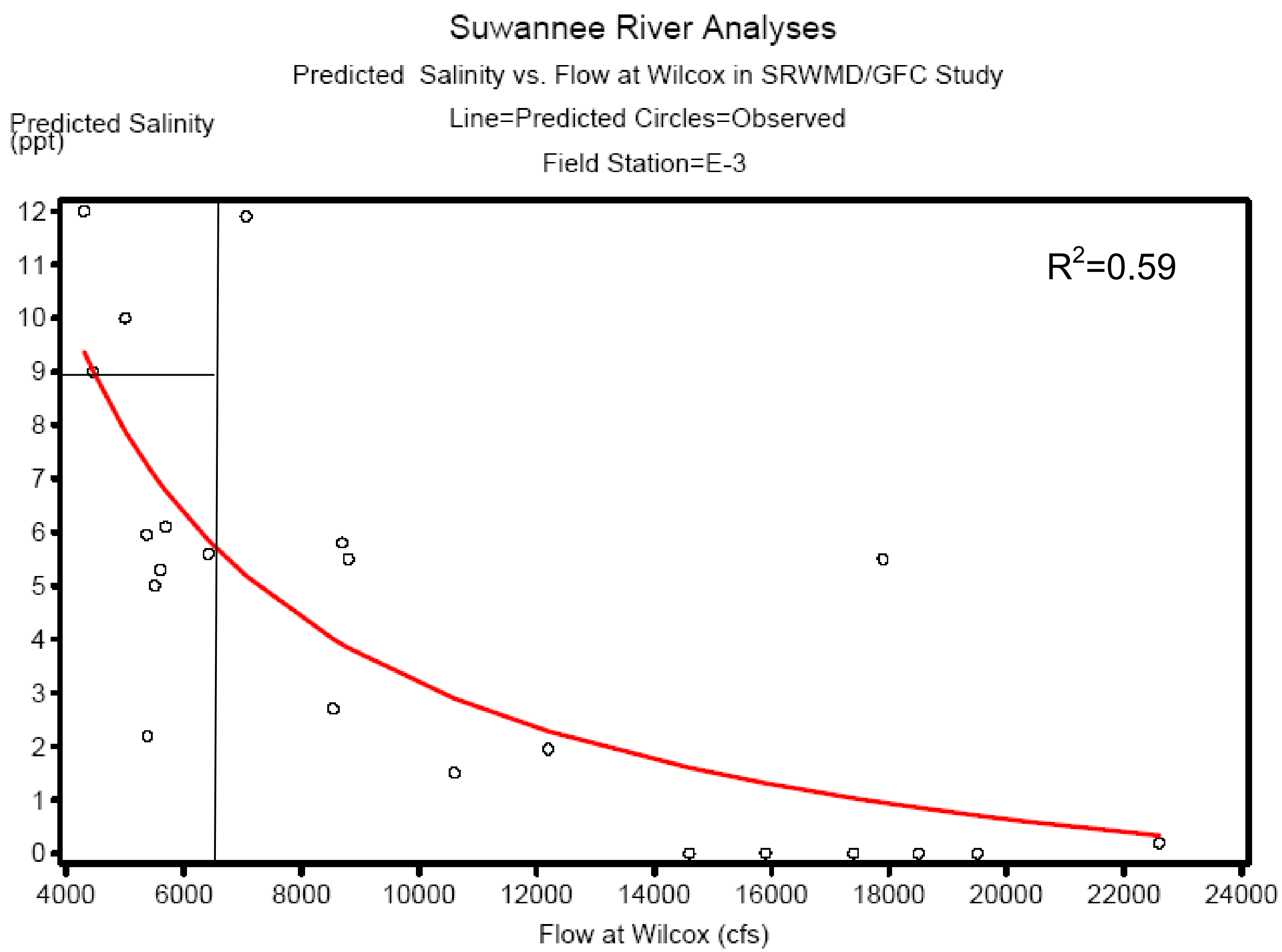


Figure H-11. Regression relationship between predicted salinity and flow for East Pass (fixed station E-3).

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Appendix I - Tidal Swamps

Background

- The intertidal areas of the uppermost Suwannee estuary are vegetated with tidal freshwater swamps (Wharton et al., 1982; Clewell et al., 1999; Light et al., 2002) (Figure I-1).
- Tidal freshwater swamps have been identified as the least understood (in terms of quantitative study) coastal wetland ecosystem in the southeastern U.S. (Tiner, 1993; Clewell et al., 1999). Because of this lack of study, these forested wetlands are rarely identified as a distinct wetland community type in Florida west coast rivers, so no data are available to compare the Suwannee to other river systems.
- However, it is probable that the lower Suwannee River supports the most extensive acreage of this wetland type on the Florida gulf coast. Likewise, the habitat values of these swamps have not been studied or quantified. It is known that they provide important nesting habitat for Swallow-tailed kites in the Lower Suwannee Refuge (Sykes et al., 1999). The abundance of fiddler and shore crabs in these swamps suggests they may provide important forage habitat for crab-feeding birds, such as Yellow-crowned night heron and Little green heron, and mammals such as raccoon and mink. The leaf detritus produced in these swamps is likely an important allochthonous food base for the downstream estuarine aquatic communities.
- Light et al. (2002) and Darst et al. (2003) mapped 6,652 acres (2,692 ha) of tidal freshwater swamps in the upper estuary, corresponding to their "Lower Tidal Swamp 1 and Swamp 2" forest types. Most of these are flooded daily by high tides. An additional 2,572 ac (1,041 ha) of Lower Tidal Mixed forest was also mapped. These are flooded during the higher spring tides each month. The "Lower Tidal" reach identified by Light et al. is regarded as the tidal freshwater portion of the Suwannee estuary (after Odum et al., 1984). Dominant trees include bald and/or pond cypress, pumpkin ash, swamp tupelo, cabbage palm, sweet and swamp bay, and red maple (Light et al., 2002; Clewell et al., 1999; Wharton et al., 1982).
- The potential for significant harm to tidal freshwater swamps should be assessed by considering changes in salinity which might cause undesirable shifts in species composition of canopy, sub-canopy, or groundcover plant communities to those of a more saline community type; loss of canopy species from the swamps; encroachment of plants or animals indicative of higher salinity conditions into upstream areas where they have not previously been observed or recorded; the potential for unacceptable upstream movement of the tree line denoting the demarcation between tidal marsh and tidal freshwater swamp; or loss of acreage of tidal swamps or changes in acreage of swamp forest types.

Objectives

- To evaluate how the relationship between flow and salinity affects the habitat suitability of tidal swamps in the Lower Suwannee River.
- To estimate risk to suitable tidal swamp habitat based on alterations to the flow regime (flow reductions).

Data Sources

- Daily average discharge data was obtained for the United States Geological Survey (USGS) gage number 02323500 (Suwannee near Wilcox) from 1984-2004. Daily lags were calculated to 15 days, lag averages to 90 days, cumulative flows to 8 days and transformations of flows (e.g. logarithmic, inverse, square root). Salinities could then be related to various antecedent flows as well as the sample date flows at Wilcox.

- Salinity data collected by the FWCC in 1993-1994 were used to develop regression models relating flow at Wilcox to the location of the 2 ppt isohaline.
- Tidal swamp habitat data were collected by Light et al. (2002).
    - Light et al. (2002) identified a "Lower Tidal" reach of the lower Suwannee study area which for purposes of this report is considered to be the tidal freshwater zone of the upper Suwannee estuary. Six intensive study transects were established in forests of the Lower Tidal reach. The transects were belt transects, with a width of 16.5 feet (5 meters) if over 1,320 feet (400 meters) in length and a width of 33 to 42.9 feet (10 to 13 meters) if less than 1,320 feet long. These judgments were made by the investigators based on their experience in forested wetland sampling in order to obtain a large enough sample of trees to census. Detailed descriptive data on the locations of the transects is provided in Lewis et al. (2002). The locations of the intensive study transects were all on public land and were not made in a completely random fashion. Transects had to be located on public land for two main reasons: so that permanent transects could be established which could be visited reliably in the future (eliminating the possibility that a future landowner on private lands would bar access); public land typically had the best examples of reasonably intact, minimally impacted wetland forest, which would remain so in the future.
    - By distributing the transects at upstream, middle and downstream ends of the Lower Tidal Reach, and by extending transects across a wide range of topographic and soils conditions (from the river bank to upland), as much range of variability as possible was captured. The data from the intensive transects were supplemented with plant community and soils observations at 150 additional observation sites (some systematically selected, some randomly selected). The data from these supplemental sites verified the information derived from the transects, and thus the data from the transects is considered to reasonably describe the range of conditions and forest types found in the upper Suwannee estuary.
    - Land surface elevations along each transect were determined using a surveyor's level and rod. Elevation measurements were made approximately every 16.5 feet (5 meters) and also at locations of topographic breaks, at the edge of standing water, and other "points of interest". Elevations along each transect were tied to a temporary benchmark which was eventually referenced to the National Geodetic Vertical Datum (NGVD) by a licensed professional surveyor. All elevation data were then referred to this datum. Horizontal locations were measured using a portable Precise Lightweight Global Positioning System Receiver with a typical accuracy under tree cover of 19.8 to 49.5 feet (6 to 15 meters) and fiberglass measuring tapes.
    - Hydrologic data in the study area were derived from seven continuous record USGS surface water gage sites as shown in Table 3 in Light et al. (2002). As indicated in Section 3.1.4, most of the flow data used in the floodplain wetland study came from the Branford and Fort White gages. The other five gages were primarily used to supply stage data for construction of rating curves on each transect. Additional water level

measurements were made by tape-down from reference points ("RP's") established at the river bank end of each transect and in selected surface water features (creeks, sloughs, floodplain ponds) on each transect. These were nails driven into trees and marked with a metal tag. Over the course of the study, about 400 separate water level measurements were made at the transects under a wide range of hydrologic conditions.

- Soils data were collected on all intensive study transects to generally characterize soil types associated with the different forest types. The number of borings per transect ranged from 8 to 13 on longer transects and 3 to 6 on shorter transects. Soil profiles were described to a depth of 5 to 6.6 feet (1.5 to 2 meters), typically using a 3 inch bucket auger. Soil profiles were also examined in a few cases with a 1 inch coring tube sampler or a 108 inch muck probe. Soil moisture was also evaluated at all transects and observation sites as dry, saturated, or inundated. Inundation meant the soil was covered with standing water. Saturation was evaluated by firmly squeezing a handful of soil. If free water was squeezed out, the soil was considered saturated. Approximately 600 soil moisture observations were made over a wide range of hydrologic conditions. 21 surface soil samples and 11 subsurface soil samples were collected for salinity analyses, which were conducted by the National Soil Survey Center in Nebraska.
- Vegetation sampling was divided into three strata; canopy, subcanopy, and shrub/groundcover. A canopy plant was defined as a woody plant with a stem diameter at breast height (dbh; 1.4 meters above ground surface) of $\geq$4 inches (10 cm) and a height of 10 feet (3 meters) or taller. Sub-canopy plants were those woody plants with a dbh of 0.8 to < 4 inches (2 to 9.9 cm) and a height $\geq$10 feet (3 meters). Woody plants smaller than this and all herbaceous plants were considered part of the shrub/groundcover layer. The dbh of all canopy and sub-canopy plants was measured on each belt transect using a pair of calipers. Trees with swollen bases or buttressing were measured above the swelling. Estimates of percent cover of groundcover were made as well. Tree species identifications were made in the field concurrent with each dbh measurement. Where necessary to confirm identification, leaves, seeds, branches, etc. were collected for subsequent examination in the laboratory.
- In addition to the field studies, forested wetland communities were mapped using NAPP digital ortho-photo quadrangles taken in 1994. These were false-color infrared images at a scale of 1:40,000. Initially, photo signatures were related to plant communities on the intensive study transects. A decision matrix was developed based on canopy composition to make a determination of a particular forest type (Table 6 in Light et al., 2002). Once the specific signatures of all the forest community types on the photos was confirmed, the remainder of the floodplain was mapped. Classification accuracy of the mapping was determined by visiting 111 randomly-selected verification sites, in conjunction with the decision matrix.
- *Results*. Rating curves were developed for each intensive study transect, relating river stage at the transect to flows at Branford-Fort White. These formed the basis for understanding the hydrology associated with each forest type and for evaluating the impacts of potential flow reductions.

First, rating curves were developed for selected long-term gages using continuous daily values of stage at the gage related to daily flow at Branford-Fort White. Appropriate time-lags were determined and a line fit to aggregated daily values of flow and stage (in increments from 1,000 to 90,000 cfs). Then, the transect ratings were developed by linear interpolation using river mile distances.

- Light et al. (2002) identified four different forest types in the upper estuary; Lower Tidal swamps 1 and 2 (LTsw1 and 2), Lower Tidal mixed forest (LTmix), and Lower Tidal hammock (LTham = hydric hammock). The swamps were flooded daily by high tides, with the mixed forests being flooded several times a month during the spring tides at the full and new moons. Hammocks were occasionally flooded by river flooding. Soils in all lower tidal forest types were primarily continuously saturated mucks, with some sand in the hammocks.
- Light et al. (2002) considered salinity the primary limiting factor influencing the community structure of the lower tidal forests and in setting the downstream limit of the "tree line", where tidal forest grades into tidal marsh. Salinity came from several sources; intrusion of saline water via the river channel at low flows, marine aerosols, and deposition of salt water from storm surges during hurricanes and tropical storms. Maximum salinities in isolated standing water on the Barnett Creek transect ranged from approximately 2 to 5 ppt, but fell to zero during a flood event in 1998. Salinities of up to 2 ppt were measured in isolated standing water on the Sandhill Hammock transect. Subsurface soil conductivities were generally equivalent to or higher than surface soil conductivities (Light et al., 2002).

Isohaline Selection

- Important considerations for development of freshwater inflow criteria which provide for the protection of tidal freshwater swamps included maintaining the tree canopy composition in the Lower Tidal Swamp and Mixed forest types. Some information is available on the salinity tolerances of some of the dominant trees in these swamps.
    - Pezeshki et al. (1987) found that bald cypress seedlings exhibited reduced photosynthetic rates and stomatal conductance at salinities of 2 ppt and higher. Progressively greater reductions in these physiological responses were seen up to 7 ppt. Leaf yellowing (chlorosis) was observed in seedlings in all salinity treatments.
    - Williams et al. (1998) demonstrated that seedlings of elm, Florida maple, and sweetgum exhibited reduced survival at 2 ppt and little or no survival at 4 ppt and higher. Cabbage palm, red cedar, and live oak exhibited reduced survival at 4 ppt and higher (Williams et al., 1998). Based on their work evaluating the effects of sea level rise on coastal wetland forests, Williams et al. (1999) inferred that adult trees were more salt tolerant, based on the existence of "relict" stands in areas of higher salinity, and that dieback of the forests occurred first due to elimination of seedling recruitment.
    - Based on the above, average salinities of high tide waters flooding the swamps should be kept $\leq$2 ppt, with briefer periods of higher salinity tolerable.

- Based on available electroshocking data collected in East Pass by the FWCC, the fish communities in the river channel associated with the distribution of tidal freshwater swamp appear to be dominated by freshwater fish taxa.
- The tree line in East Pass is located near their Station E4. The proposed salinity target of 2 ppt appears to be adequate to maintain the structure and function of these freshwater fish communities in the upper estuary. The fish data indicate that the proposed salinity target would allow for the persistence of a fish community still dominated by freshwater taxa, suggesting that the fauna associated with the swamps should be sustained.

Analytical Steps

- A prediction equation was developed for the location of the 2 ppt isohaline in the LSR as a function of flow using regression. The prediction equation was used to estimate the isohaline location under various flow conditions.
- River locations associated with 0 to 15% of the total cumulative tidal swamp habitat were identified as risk points using GIS.
- The regression equation was applied to solve for the flow required to keep the 2 ppt isohaline at specified risk point locations.

Regression Results

- Regressions were developed by pass in the LSR and relationships tested for differences in intercept and slopes (Figures I-2 through I-4).
- The inverse of flow was the best predictor of isohaline location for the 2 ppt regression (Figures I-2 through I-4).
- No statistical differences were observed in the flow isohaline relationships by pass, allowing a model to be developed for the whole river, irrespective of the different passes of the river.
- The risk to tidal swamp habitat with exposure to salinities above 2 ppt was evaluated based on calculations of the cumulative amount of shoreline lined by tidal swamp. Shoreline length was used instead of total area of tidal swamp coverage due to the large area of swamp located up to 1 mile away from the shore (Figure I-5).
- The highest rate of change in tidal swamp habitat loss was observed for flows less than 6,500 cfs (Figure I-5).

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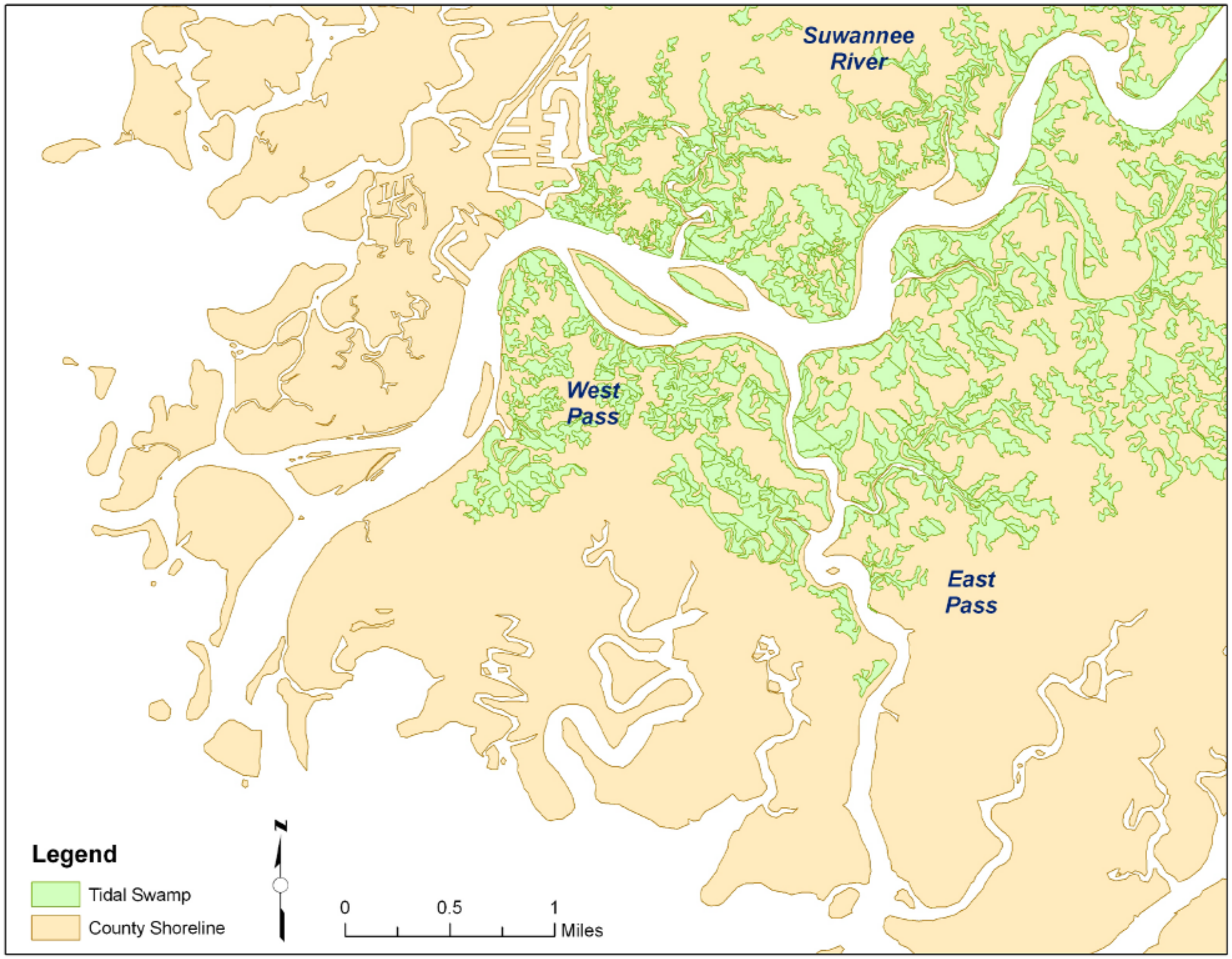


Figure I-1. Distribution of tidal swamp habitat in the Lower Suwannee River.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	23.24038629	23.24038629	44.43	<.0001
Error	29	15.16782692	0.52302851		
Corrected Total	30	38.40821321			

R-Square	Coeff Var	Root MSE	Mean isohaline_rmile
0.605089	25.90111	0.723207	2.792185

Source	DF	Type III SS	Mean Square	F Value	Pr > F
InvFlow	1	23.24038629	23.24038629	44.43	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	0.39823	0.381903	1.04	0.3057
InvFlow	14911.54424	2236.987892	6.67	<.0001

Figure I-2. Regression results for the 2 ppt surface isohaline regression developed for the whole river.

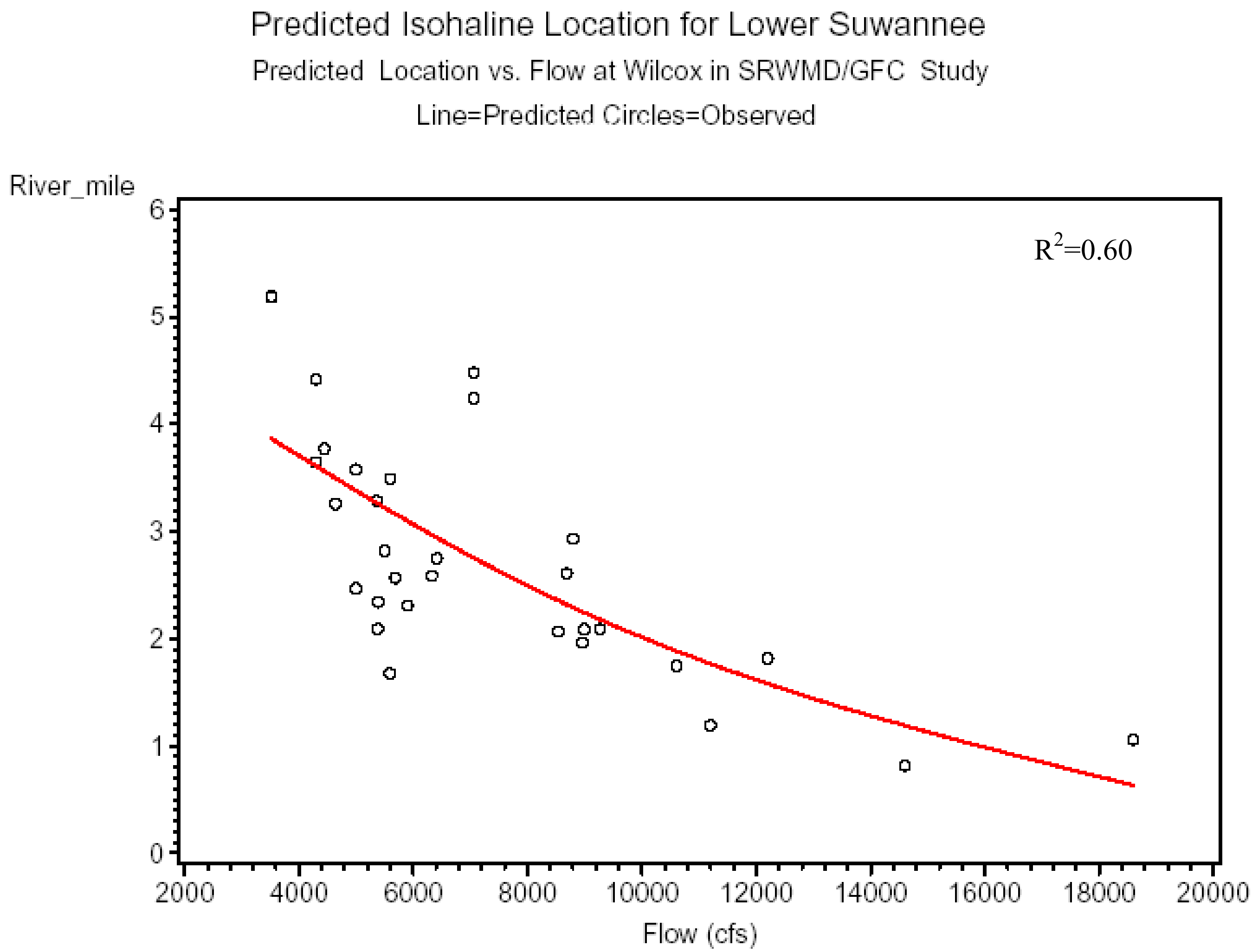


Figure I-3. Regression plot showing the location in river mile of the 2 ppt isohaline as a function of flow.

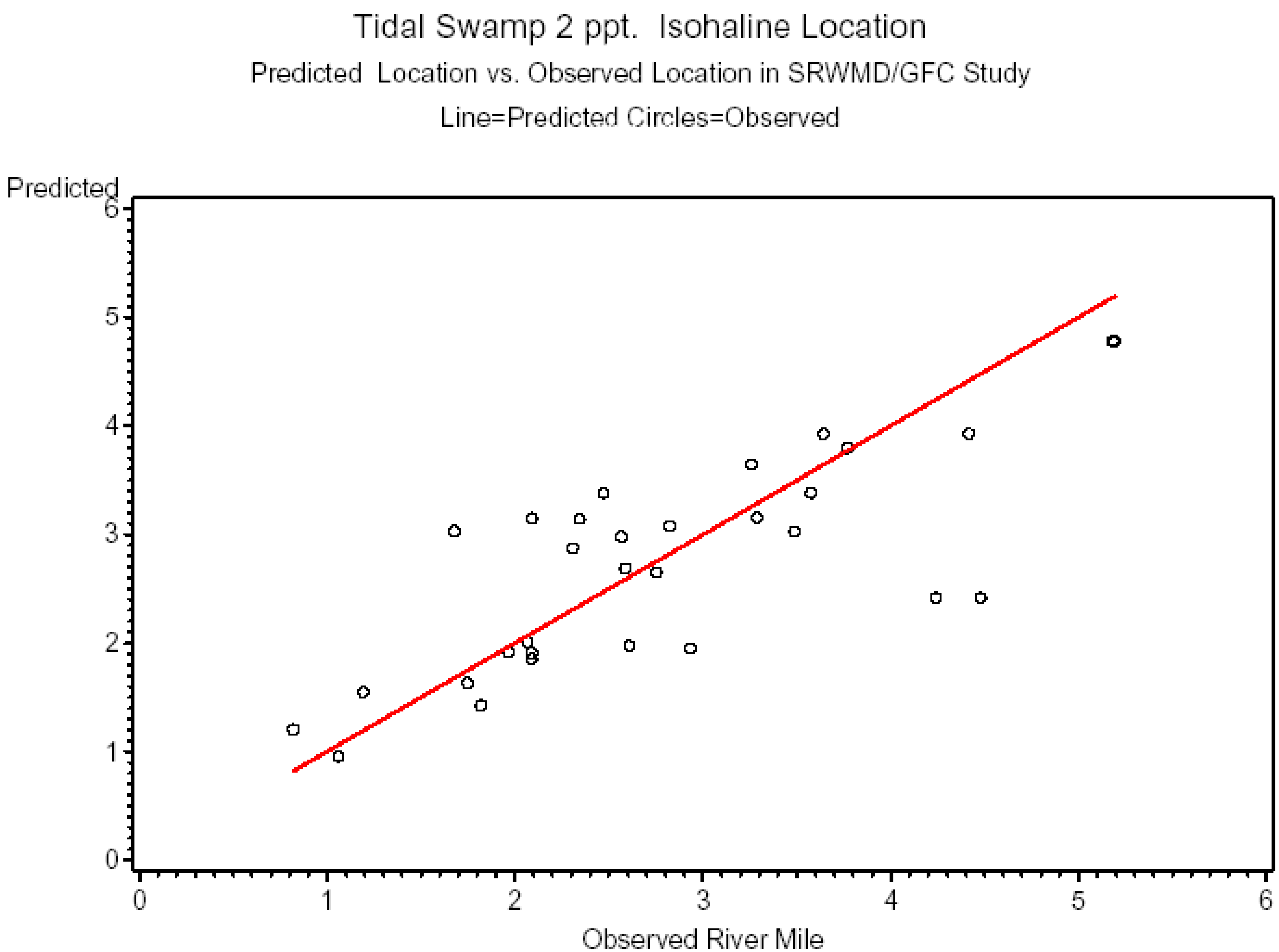


Figure I-4. Relationship between predicted and observed river mile for the 2 ppt isohaline regression

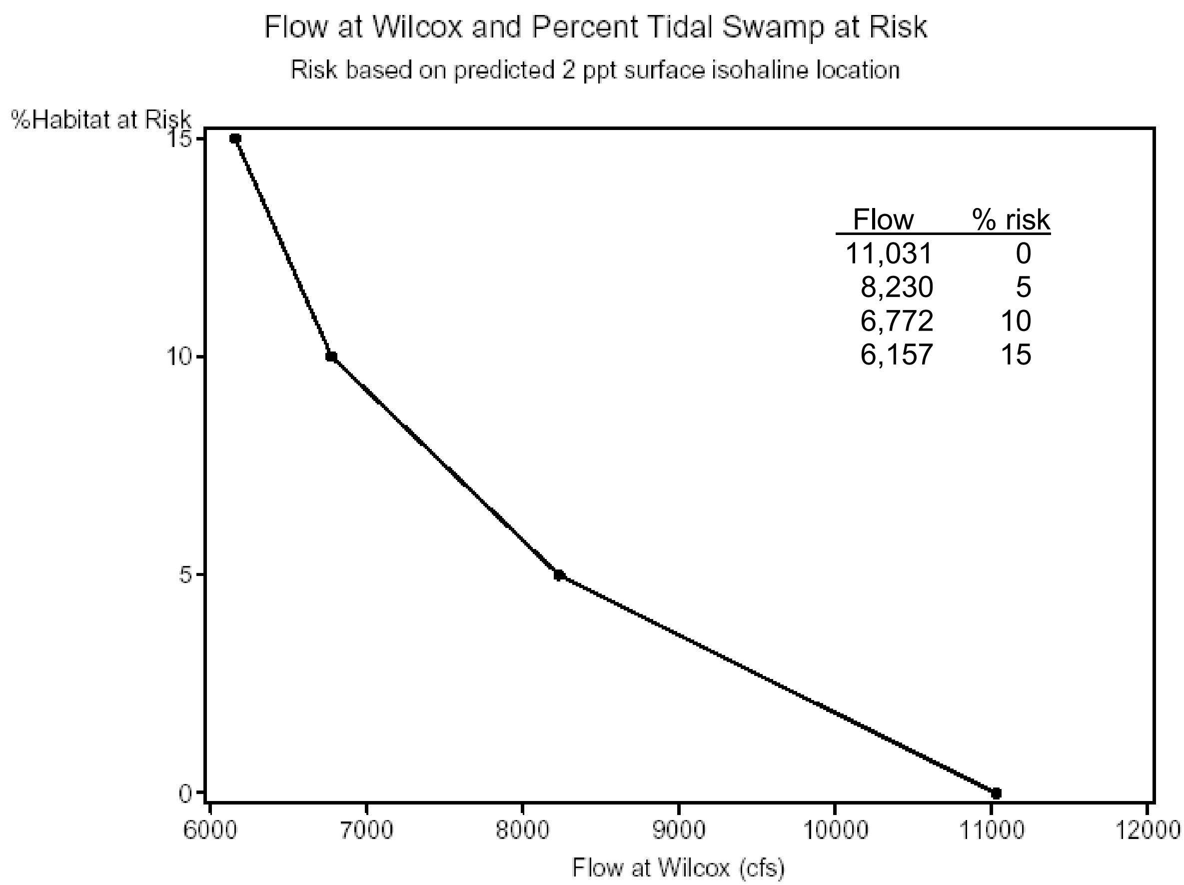
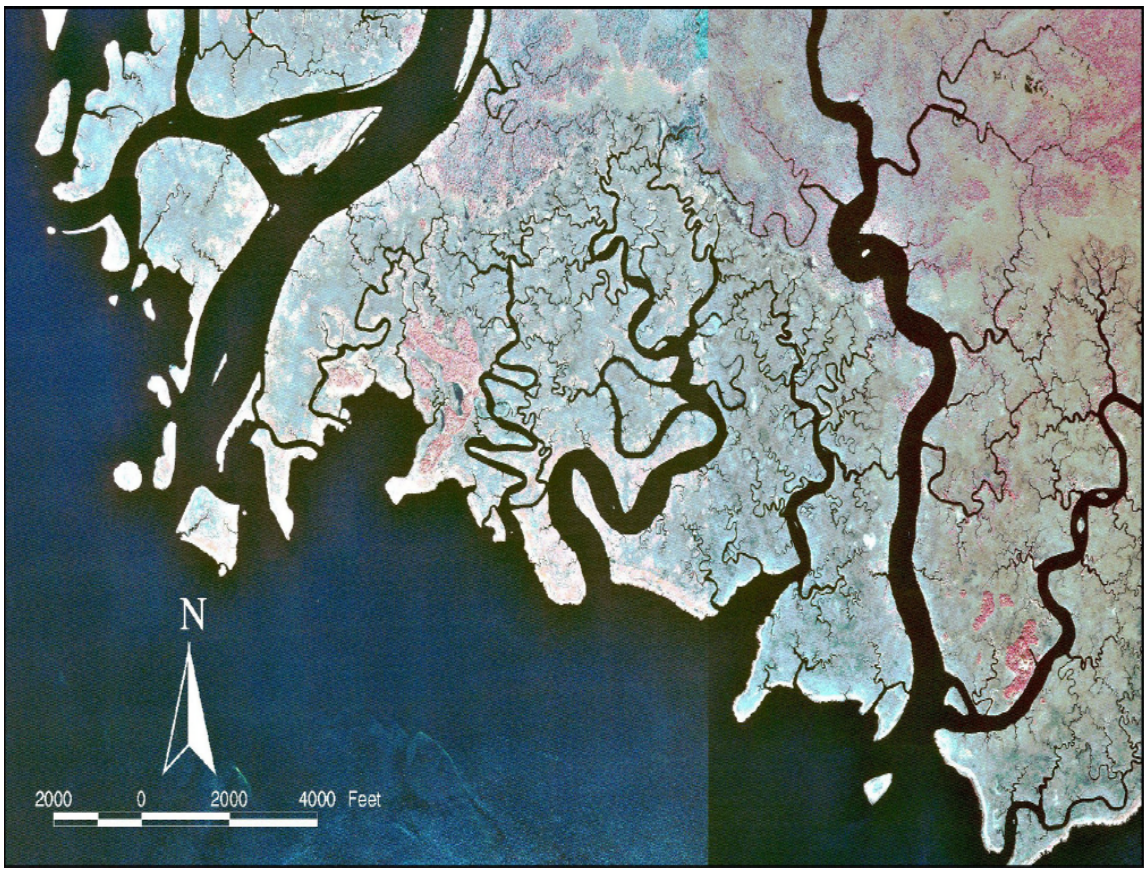


Figure I-5. Relationship between percent of habitat risk for tidal creeks and flow, based on the predicted location of the 2 ppt isohaline.

Appendix J - Tidal Creek



Background

- In addition to the main stem of the river, tidal creeks (Figure J-1) and adjacent marshes provide important habitat for estuarine organisms, including resident and estuarine-dependent fish and invertebrate species (i.e. shrimp, blue crab) (Tsou and Matheson, 2002). Additionally, tidal creeks and marshes provide feeding grounds for wading birds (Montague and Odum, 1997; Montague and Weigert, 1990).
- The potential for significant harm to tidal creek habitat is related to changes in salinity, which is based on the flow and resultant salinity in the river, as well as freshwater run off from the watershed. Changes in salinity could result in alterations to the natural populations of fauna or flora, including changes to diversity, species richness, abundance and productivity. Additionally, harm would occur if exposure occurred which would involved loss of habitat of previously submerged habitats (e.g., SAV or oyster beds).

Objectives

- To evaluate how the relationship between flow and salinity affects tidal creek habitat suitability in the Lower Suwannee River.
- To estimate risk to tidal creek habitat based on alterations to the flow regime (flow reductions).

Data Sources

- Daily average discharge data were obtained for the United States Geological Survey (USGS) gage number 02323500 (Suwannee near Wilcox) from 1984-2004. Daily lag flows were calculated to 15 days, lag averages to 90 days, cumulative flows to 8 days and transformations of flows (e.g., logarithmic, inverse, square root).
- Salinity data collected by the FWCC in 1993-1995 were used to develop regression models relating flow at Wilcox to the location of the 5 ppt isohaline.
- SRWMD created a detailed coverage of tidal creeks on the Hog Island delta and fringing East and West passes up to the Gopher River. The centerline of all tidal creeks on Hog Island and fringing East and West passes was delineated, using 1999 USGS digital ortho-photos. The shorelines of the passes were also delineated and this was overlain with another coverage, segmenting the passes into 0.25 mile increments.
- Juvenile fish data from the FWCC Fisheries Independent Monitoring Program, collected between 1997 and 2003, were used to evaluate and determine a critical salinity for subsequent analysis.

Biologically-Based Salinity Zone Classification

- Tidal creeks are abundant in the Lower Suwannee River (Figure J-1) and many estuarine and estuarine-dependent species (e.g., red drum, mullet, pinfish) are known to recruit to low salinity tidal creek habitats as juveniles.
- Different groups of fish have different salinity tolerances and/or preferences. Within an individual fish species, size classes representing different life history stages may have different salinity requirements.
- Biologically-based salinity zones were established for the Lower Suwannee River using catch data from the Fisheries Independent Monitoring Program and PCA analysis (Figure J-2). Emphasis was placed on identifying the lower salinity

ranges and fish that may have preferences for low salinity habitat (Bulger et al. 1993) .

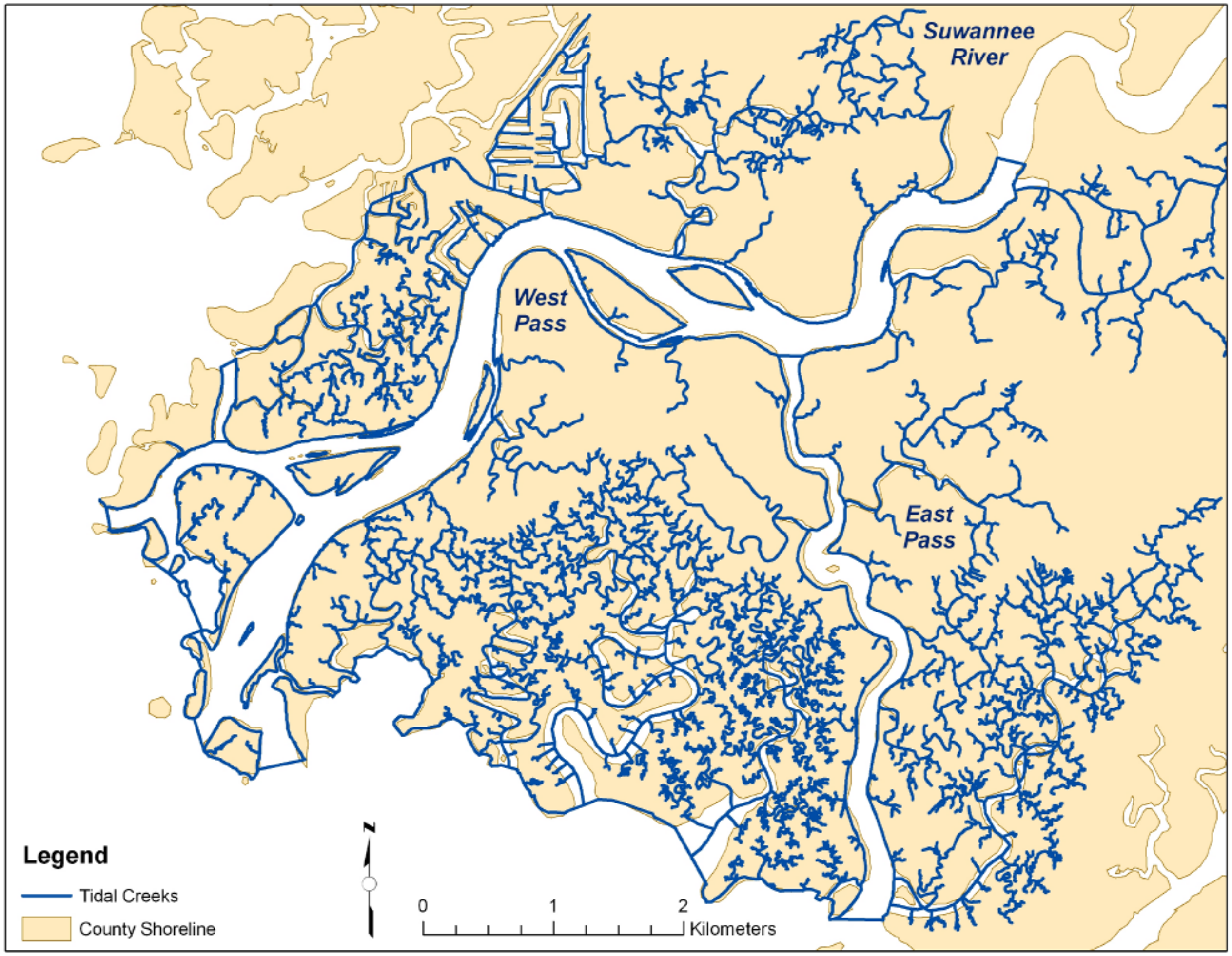
  - A zone consisting of species only captured in fresh water was identified.
  - A second zone with salinities from 1 to 5 ppt was also identified. This zone represents an oligohaline group of species that is of special interest with regard to MFL establishment.
  - The other groups are representative of more euryhaline and marine species that would likely be highly adaptable to salinity changes in the tidal creeks.
  - Analysis of similarity was used to identify fish species contributing to the dissimilarity between the fresh and oligohaline groups.
  - These species represented important recreational and commercial species as well as key forage fishes for the top level piscivores; species include spotted seatrout, mullet, blue crab, red drum, flounder, spot, pinfish, largemouth bass, redear sunfish ,and bluegill among others.

Analytical Steps

- A prediction equation was developed for the 5 ppt isohaline regression to represent the tolerance threshold for the oligohaline group of fish (Figures J-3 through J-5)..
- Cumulative tidal creek connections were calculated, based on SRWMD mapping, and converted from a kilometer to a river mile system.
- The river mile associated with various percentages of habitat risk, ranging from 0 to 15 by 5% increments, were applied to the inverted regression equation (Figure J-6). This was done to determine the flows required to keep the 5 ppt surface isohaline at the river mile associated with each increment of habitat risk.

Regression Results

- The 5 ppt surface isohaline regression can be used to predict isohaline location in LSR and can relate the location of the spring tide intrusion of the isohaline to flow in the Suwannee River (Figures J-3 through J-5).
- Establishing the relationship between the 5 ppt isohaline as a function of flow was complicated by the dynamics of the estuarine system near the mouth of each pass. Limited sample size and large variability in location of the isohaline for a given flow condition also played a role in the limitations of the regressions.
- Antecedent flows, specifically the average flow of the week prior to the sample collection date, was incorporated into the analysis to capture some of the variation associated with the effects of previous days flow



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• **Figure J-1. Network of tidal creek habitat located in the Lower Suwannee River.**

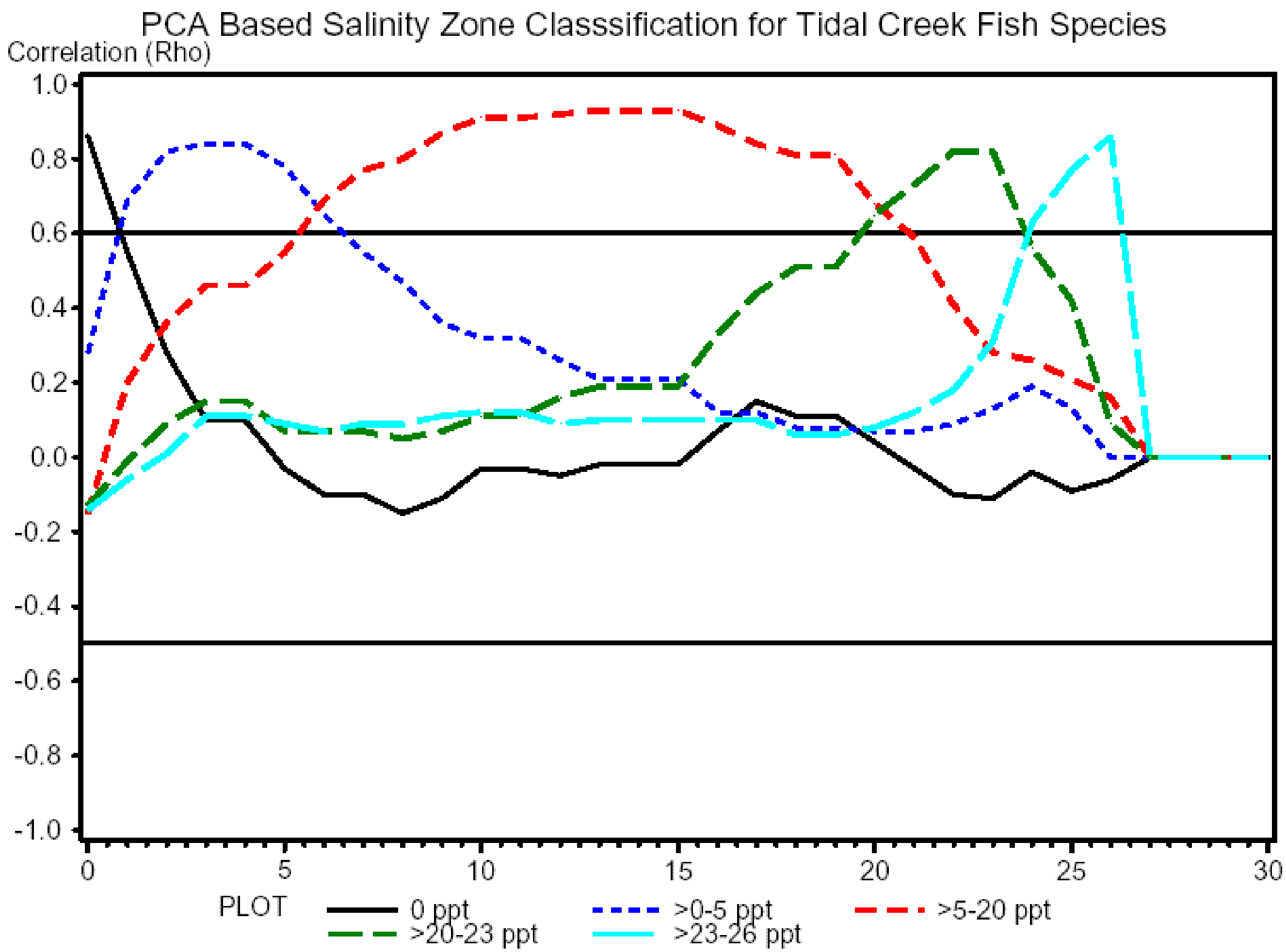


Figure J-2. Salinity zone classification for tidal creek fish species based on results of Principal Components Analysis (PCA).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	10.74516429	5.37258215	20.63	<.0001
Error	23	5.98850982	0.26036999		
Corrected Total	25	16.73367411			

R-Square	Coeff Var	Root MSE	isohaline_rmile Mean
0.642128	24.37049	0.510265	2.093781

Source	DF	Type III SS	Mean Square	F Value	Pr > F
InvFlow	1	8.72666554	8.72666554	33.52	<.0001
Average 8 days flow	1	3.57460303	3.57460303	13.73	0.0012

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-3.08548	1.027787	-3.00	0.0064
InvFlow	20910.06801	3611.825374	5.79	<.0001
Average 8 days flow	0.00023	0.000062	3.71	0.0012

Figure J-3. Regression results for the 5 ppt surface isohaline regression developed for the whole river.

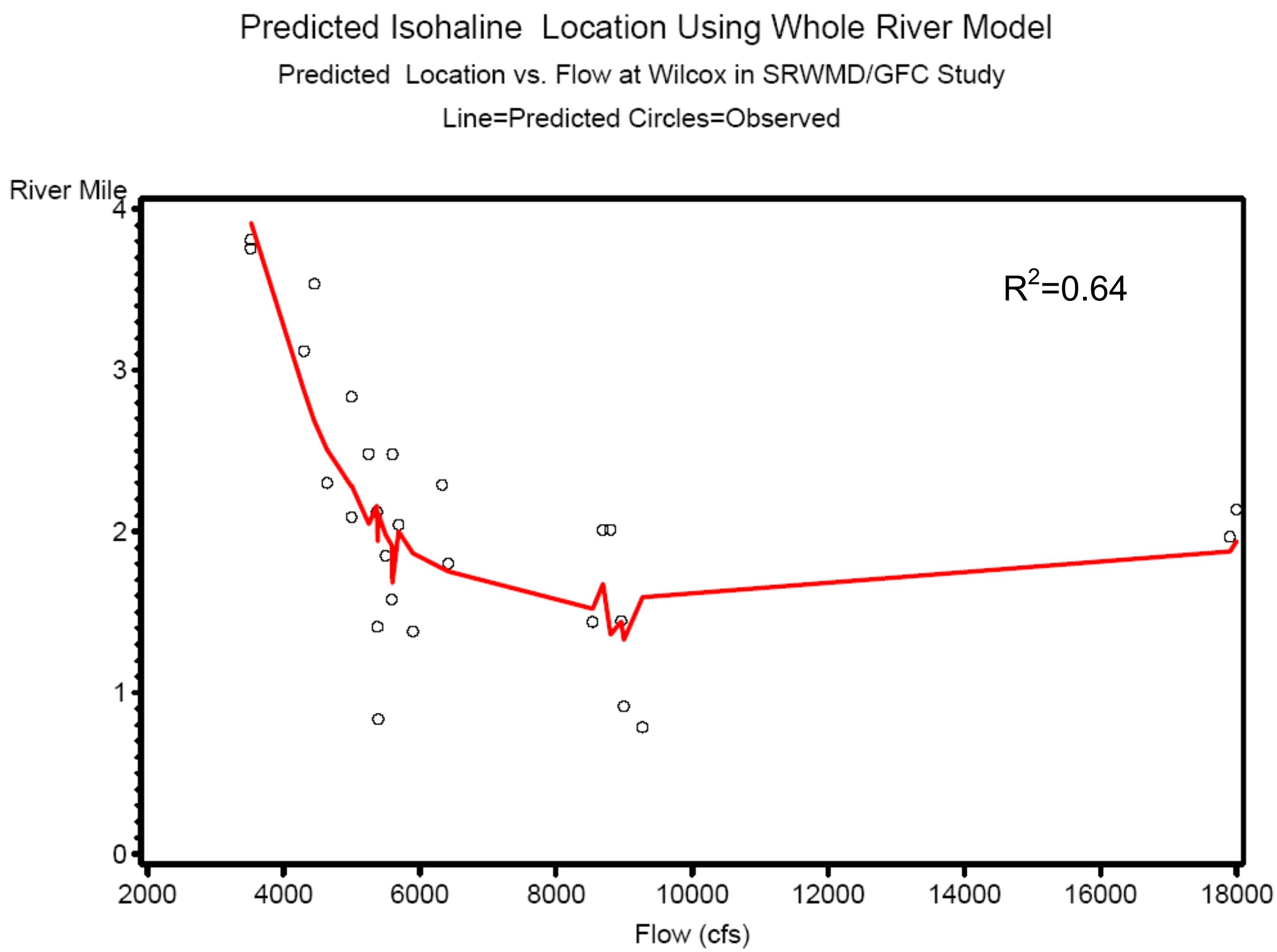


Figure J-4. Regression plot showing the location in river mile of the 5 ppt isohaline as a function of flow.

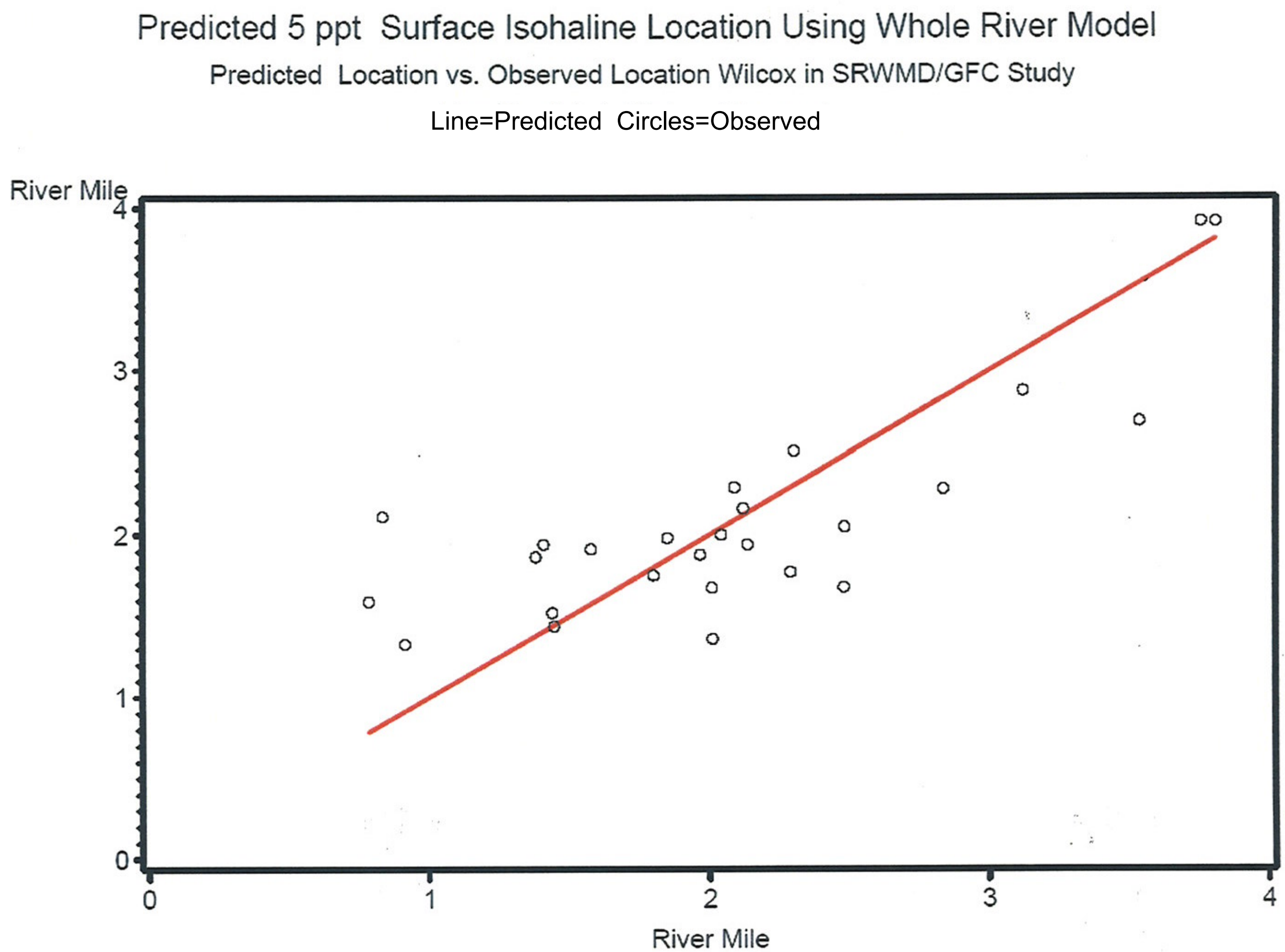


Figure J-5. Relationship between predicted and observed river mile for the 5 ppt isohaline regression.

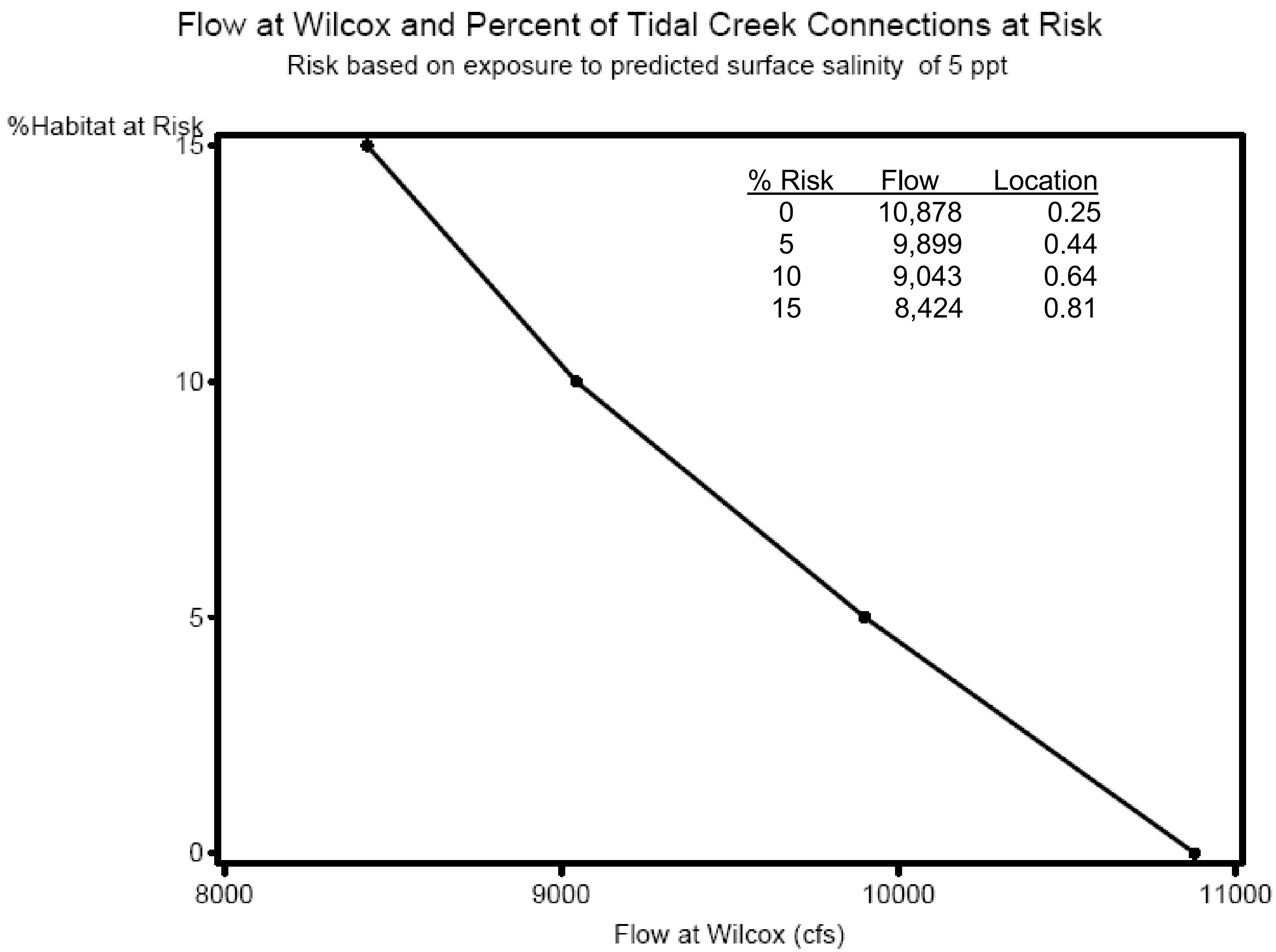


Figure J-6. Relationship between percent of habitat risk for tidal creeks and flow, based on the predicted location of the 5 ppt surface isohaline.

Appendix K - Oysters

Background

- In the Suwannee Sound and in tidal creek areas in the lower river, the principal habitat which provides structure is oyster bars and reefs. These are composed primarily of the eastern oyster (*Crassostrea virginica*), with two species of mussels (*Brachidontes sp.* and/or *Ischadium recurvum*) as secondary member of the reefs.
- Oysters are a harvestable economic resource and based on statistics reported for 2001, the Suwannee River estuary was the second largest oyster producing area in Florida, with Apalachicola Bay being the first most productive (FWC website www.floridaconservation.org).
- In addition to, and perhaps exceeding the economic importance of oysters, is the value of oyster habitat for estuarine invertebrates and fishes (Bahr and Lanier, 1981). Biomass and diversity of crustaceans has been reported to be higher in oyster reef habitat (Glancy 2000) and oyster reefs provide an important food base for recreationally important fish species (Pattillo et al. 1997).
- The potential for significant harm to oyster habitat is related to flow induced changes in salinity which would cause alterations to the natural populations of invertebrates associated with oyster habitat (i.e. species richness, diversity, abundance, productivity, etc.) alterations in oyster reef characteristics (juvenile, subadult, or adult oyster density or cover) due to exposure to high salinities, or the potential loss of acreage of oyster habitat.

Objectives

- To evaluate how the relationship between flow and salinity affects oyster habitat in the Lower Suwannee River.
- To estimate risk to suitable oyster habitat based on alterations to the flow regime (flow reductions).

Data Sources

- Daily average discharge data was obtained for the United States Geological Survey (USGS) gage number 02323500 (Suwannee near Wilcox) from 1984-2004. Daily lags were calculated to 15 days, lag averages to 90 days, cumulative flows to 8 days and transformations of flows (e.g. logarithmic, inverse, square root).
- Salinity data to evaluate oyster habitat characteristics were provided by the FDACS Shellfish Environmental Assessment Section (SEAS).
    - SEAS data consisted of 137 fixed sites (not all sites were used in analysis) throughout the Suwannee Sound that were established in 1989 and data collection efforts are still ongoing (Figure K-1).
    - Salinity data were collected in conjunction with bacteriological monitoring in shellfish harvesting areas.
- Oyster data in the Suwannee River estuary were collected by Baker et al. (2003) with the objective to evaluate characteristics of oyster habitat where it occurred and relate it to salinity.
    - Consideration in sample site selection included distributing sites across a range of salinity regimes, from those near the river mouth exposed to freshwater part of the time to those located far from the freshwater discharge from the river. The 36 sample sites were also distributed across three reef 'strata': inshore bars at tidal creeks, middle reefs (Lone Cabbage and Half Moon), and outer reefs (Suwannee Reef).
    - Study sites were sampled during low tides. Several types of sampling were conducted at each study site. First, the site was divided into high intertidal and

low intertidal strata. This was determined based by inspection in the field at each sampling site; the "break" typically occurring at the reef crest. Locations of sampling quadrats at each site were determined randomly by proceeding in a random direction (right or left) along the tidal stratum for a randomly determined distance from 1-10 meters. Live oyster cover was determined using a minimum of six replicate samples (more if cover was very sparse). Cover was determined using a 1 m^2 grid divided into 100 subsections 10 by 10 cm each in area. Cover was measured by counting the number of subsections lying over live oyster and expressing as a proportion of 100. Oyster density was measured using a 0.25 m^2 quadrat (1 m^2 where live cover/density was very sparse), from which all live oyster was harvested down to dead shell. Live oysters were counted as adult (≥ 76 mm shell length), sub-adult (50 to <76 mm shell length), and juvenile (≥25 to <50 mm shell length). Counts of four major oyster reef associate animals were also made in the oyster density quadrats: the mussels *Brachiodontes* spp. and *Ischadium recurvum*, and the crabs *Eurypanopeus depressus* and *Petrolisthes armatus*.

- Oyster community parameters were related to salinity using data from the SEAS monitoring program collected 2000-2002 and data from Phlips and Bledsoe (2002) collected in the estuary in 1999-2001. Monthly surface salinity measurements from these studies were incorporated into a GIS coverage of the salinity sampling sites. Surface salinity was used since depths in much of Suwannee Sound are quite shallow and these data reflected the salinities that the oyster reefs were most exposed to (Baker et al., 2003). ArcGrid® was used to generate salinity contours using the field data, and salinity characteristics at each individual oyster study site were estimated from this coverage by interpolation using the inverse distance-weighted method. Mean salinity for the periods 12 months and 24 months prior to the oyster survey was determined for comparison with oyster reef community characteristics.

Isohaline Selection

- Based on the oyster field data from the Suwannee estuary, it will be important to maintain an adequate area of habitat with mean annual salinities of ≤20 ppt in order to maintain the existing coverage and health of oyster reefs in the estuary.
- Additionally, literature values support 20 ppt as a threshold value for salinity.
  - Baker et al. (2003) evaluated oyster habitat characteristics in the Suwannee estuary in relation to salinity and relative tidal elevation. They found highest oyster habitat characteristics (% cover, juvenile, sub-adult, and adult density) occurred at mean salinities <20 ppt, for periods 1 year and 2 years prior to their survey (Baker et al., 2003).
  - Burrell (1986) recommended that "moderate salinities (those less than 15 ppt)" be maintained for "a significant period during the year" to exclude most oyster predators and diseases and maintain oyster reef community structure.
  - Stanley and Sellers (1986) indicated that highest oyster abundance in Gulf of Mexico oyster populations occurred between 10-20 ppt.
  - Oyster reefs with highest densities in Apalachicola Bay were found where mean salinities were 20-23 ppt (Livingston et al., 2000). This appeared largely due to exclusion of dominant oyster predators (Livingston et al., 2000).

Analytical steps

- Salinity zones for Suwannee sound were identified by analyzing covariance patterns for stations using Principal Components Analysis (PCA).
- Principal Components Analysis led to the establishment of three salinity zones; River, Inshore Reef and Offshore.
- Salinity-flow regressions were developed to predict the median surface salinities for each of the three regions (offshore, reef, river groups) identified by PCA as a function of flow at Wilcox (Figures K-2 through K-5). To account for tidal influence on the salinity-flow relationship, only samples collected after 1996 were used for the regression analysis.
- Once salinity-flow relationships were established for each of the groups, the long term flow record was used to estimate the change in the probability of an annual average surface salinity of 20 ppt. The long term average flow (10,166 cfs) was used as the baseline probability.
- Risk was estimated as a change between 0 and 15 percent in the exceedance threshold of the 20 ppt criterion for surface salinity (Figures K-6 and K-7). Only the Inshore reef and Offshore zones were evaluated since the River zone median salinities were over 20 ppt less than 10% of the time (Figures K-8 through K-10). The distribution percentiles (e.g., 10%, 50%, 90%) of surface and bottom salinities within each PCA group were identified (Figure K-11, K-12).

Results

- The Inshore Reef group displayed an inflection point in the risk estimates for flow less than 6800 cfs coinciding with a 5% increase in the number of years the average annual salinity would exceed 20 ppt.
- The results of estimating risk for the Offshore group suggested that Offshore salinities were at the 20 ppt threshold approximately 50% of the time based on the study period of record (1997-2003). A 15% change in the probability of annual average exceedance was associated with flows that were still above the long term median flow for Wilcox. Therefore, the use of the 20 ppt threshold for the assessment of risk for the Offshore group appears to be unrealistic.

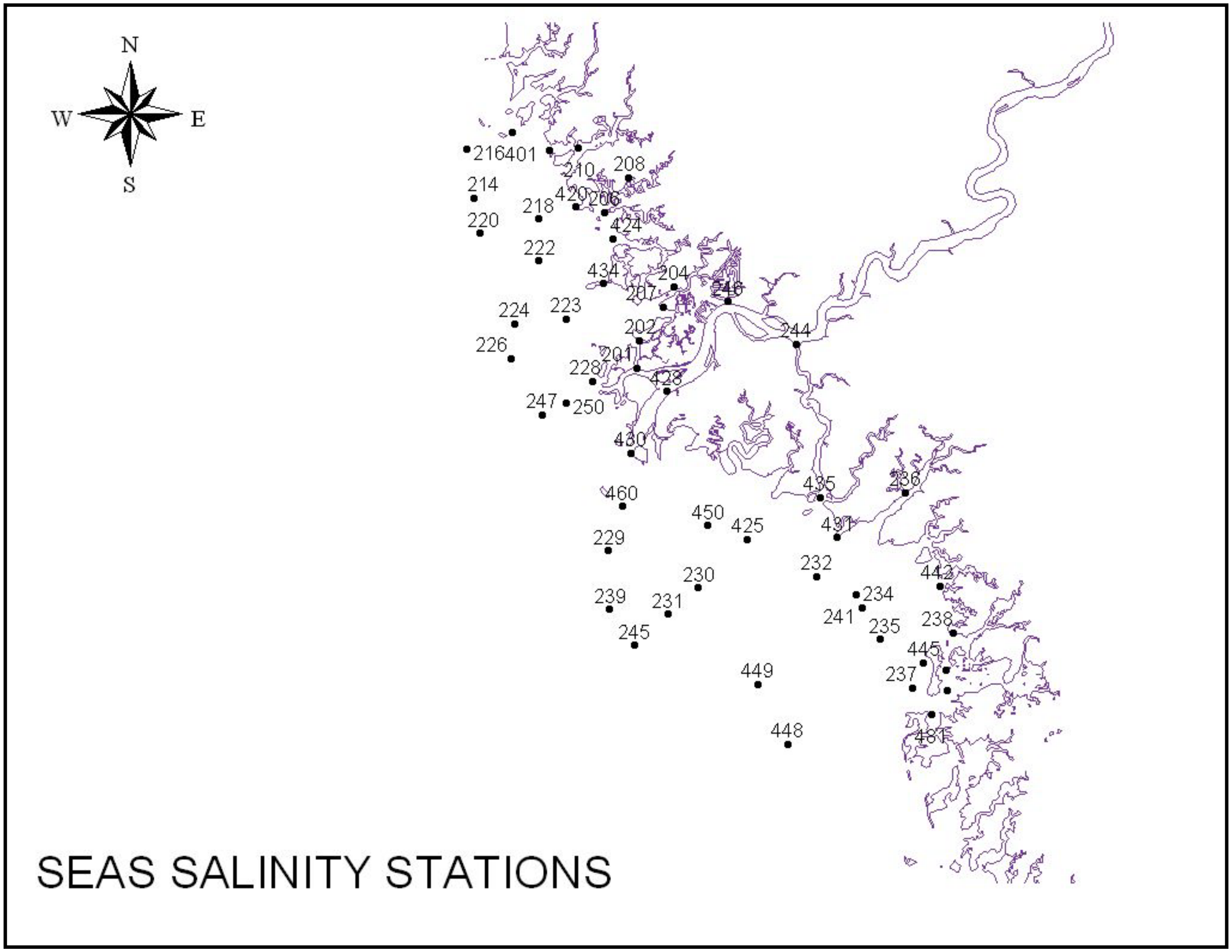


Figure K-1. Distribution of SEAS water quality stations in the Suwannee River Estuary.

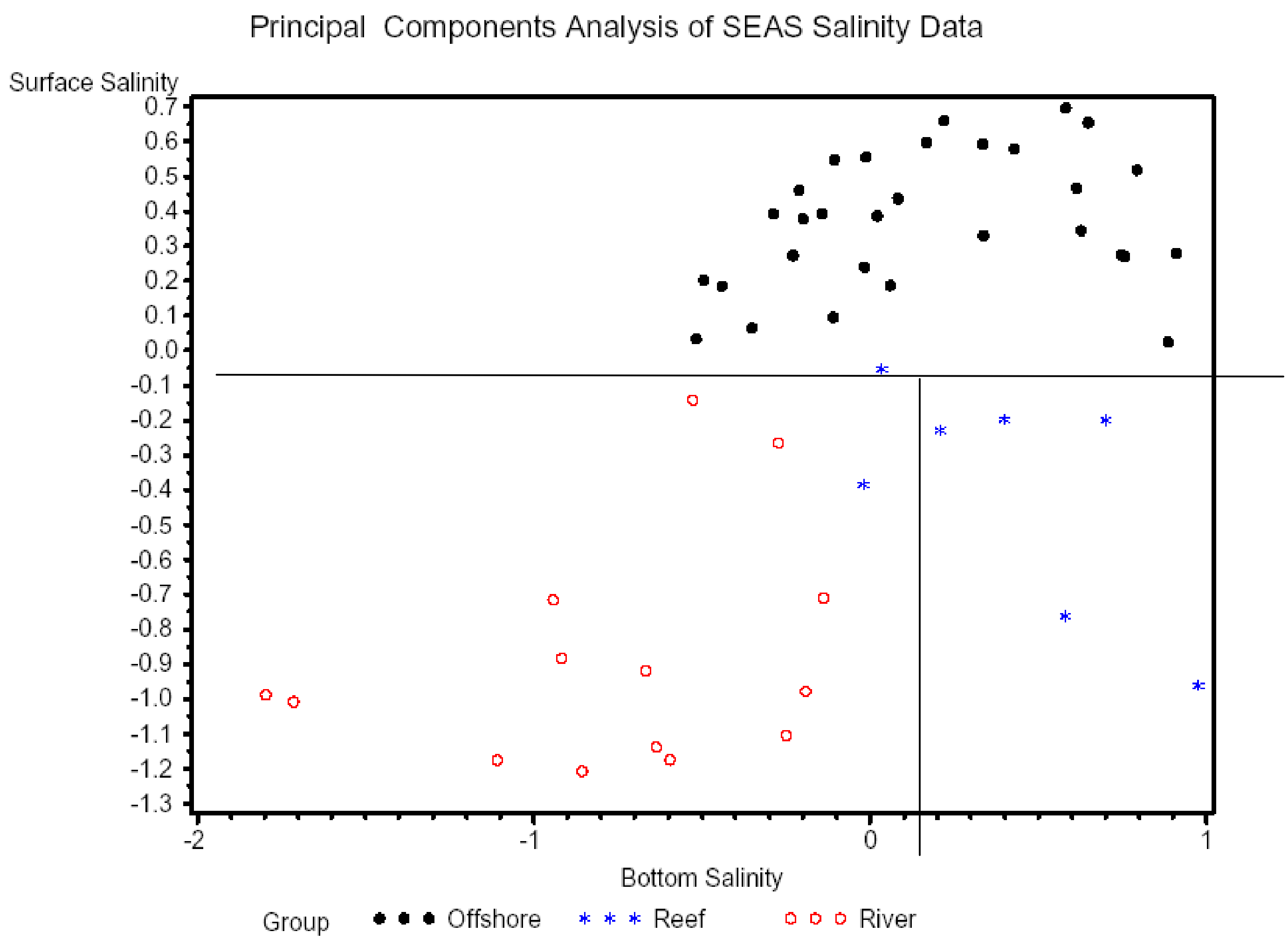


Figure K-2. Results of Principal Components Analysis, showing the separation of offshore, reef and river salinities.

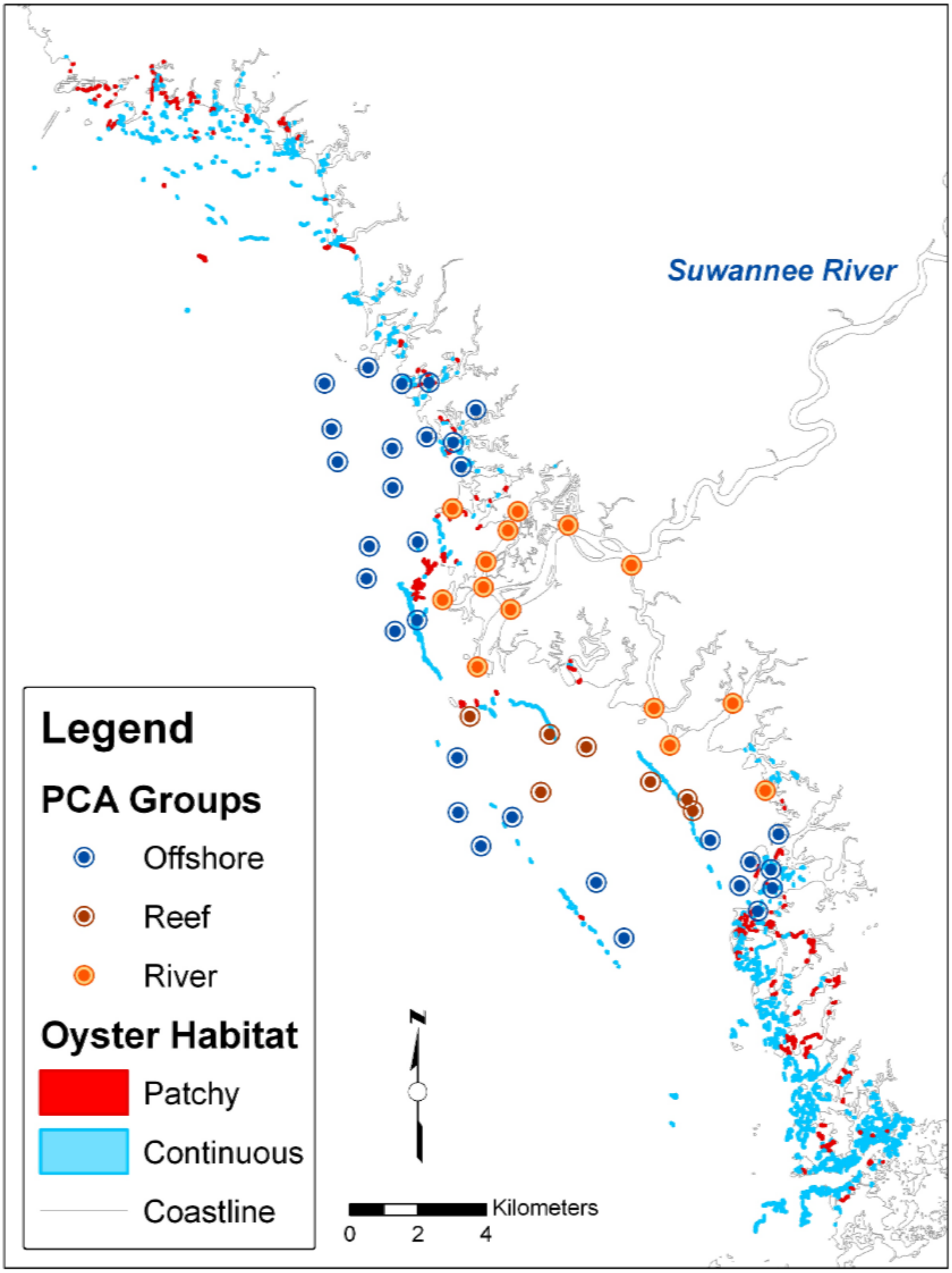
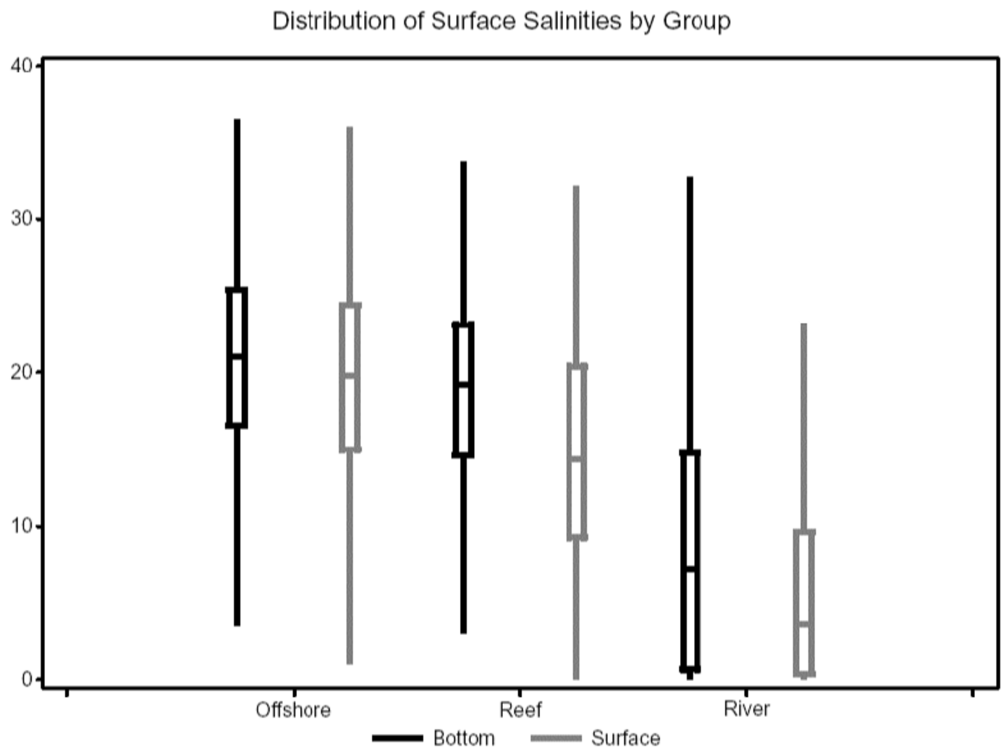


Figure K-3. Distribution of SEAS Water Quality stations, partitioned into offshore, reef and river groups and the distribution of oyster habitat, classified as patchy and continuous.



Distribution statistics for variables used in salinity flow regressions

	Offshore			Reef			River		
Distribution Percentile	Min	Median	Max	Min	Median	Max	Min	Median	Max
Surface Salinity	0	19.8	36.0	0	14.3	32.2	0	3.6	32.8
Bottom Salinity	0	21	36.5	0	19.2	33.8	0	7.25	32.8
Flow at Wilcox	1,970	6,070	43,200	1,970	6,040	43,200	1,970	6,510	43,200
Sample Hour	7	11	16	7	12	15	7	11	15
Tidal Stage (wl/feet mllw)	-1.02	2.32	4.73	-1.02	2.32	4.73	-1.29	2.30	4.52

Figure K-4. Distribution of surface salinities by group.

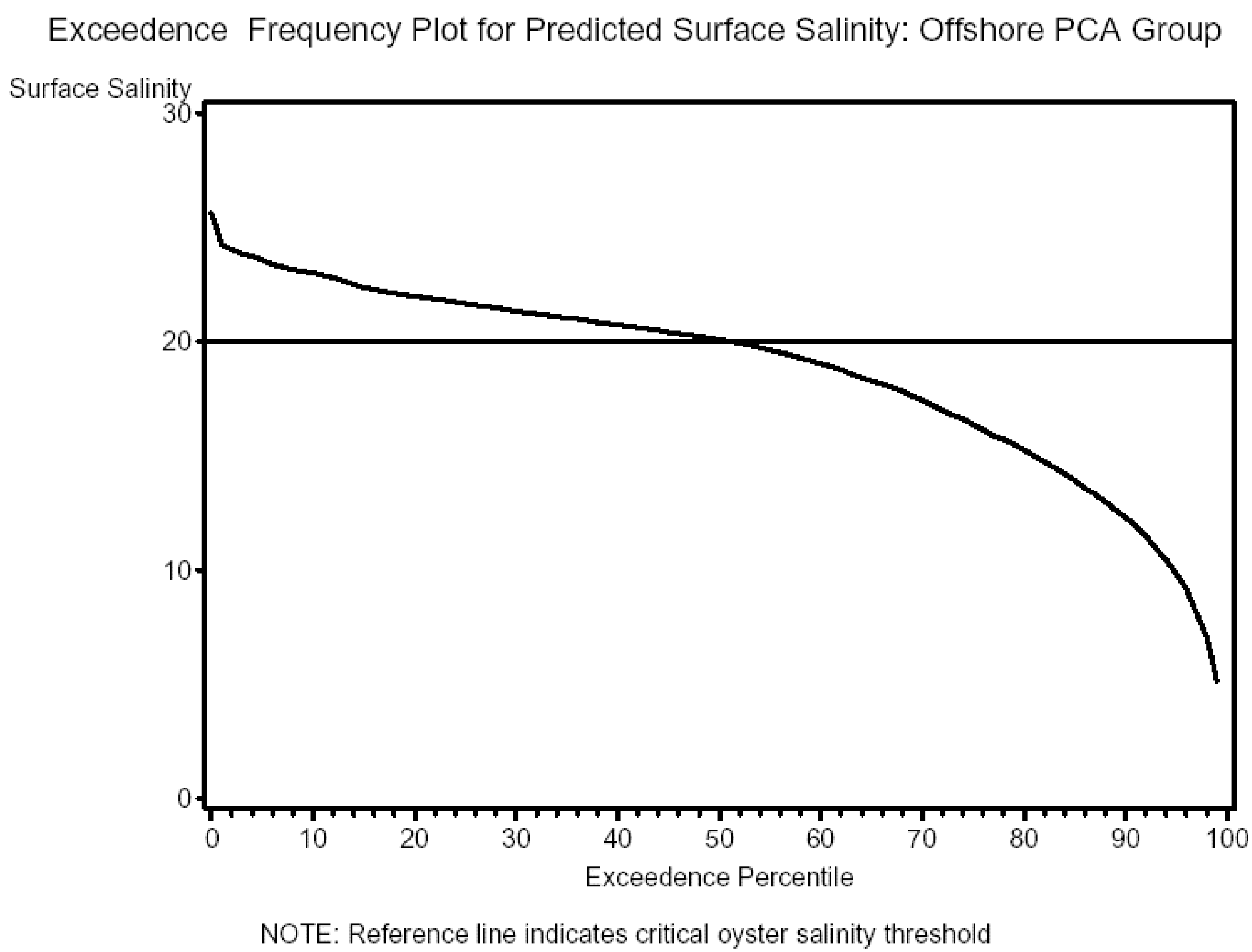


Figure K-5. Exceedance frequency plot for predicted salinity of the offshore group. The reference line at 20 ppt represents the critical salinity threshold for oysters.

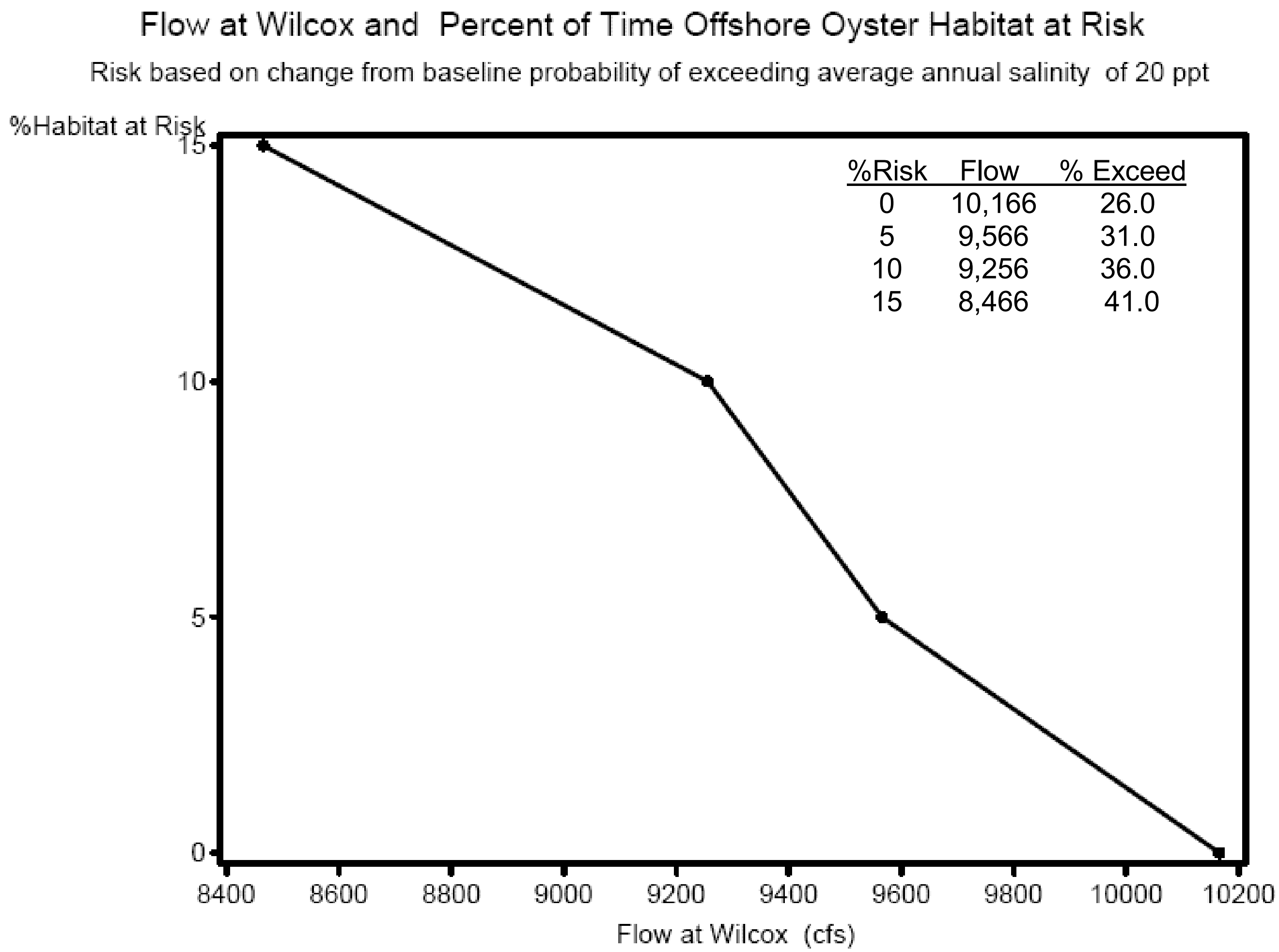


Figure K-6. Relationship between percent of habitat risk for oyster habitat and flow, based on the probability of exceeding the average annual salinity of 20 ppt.

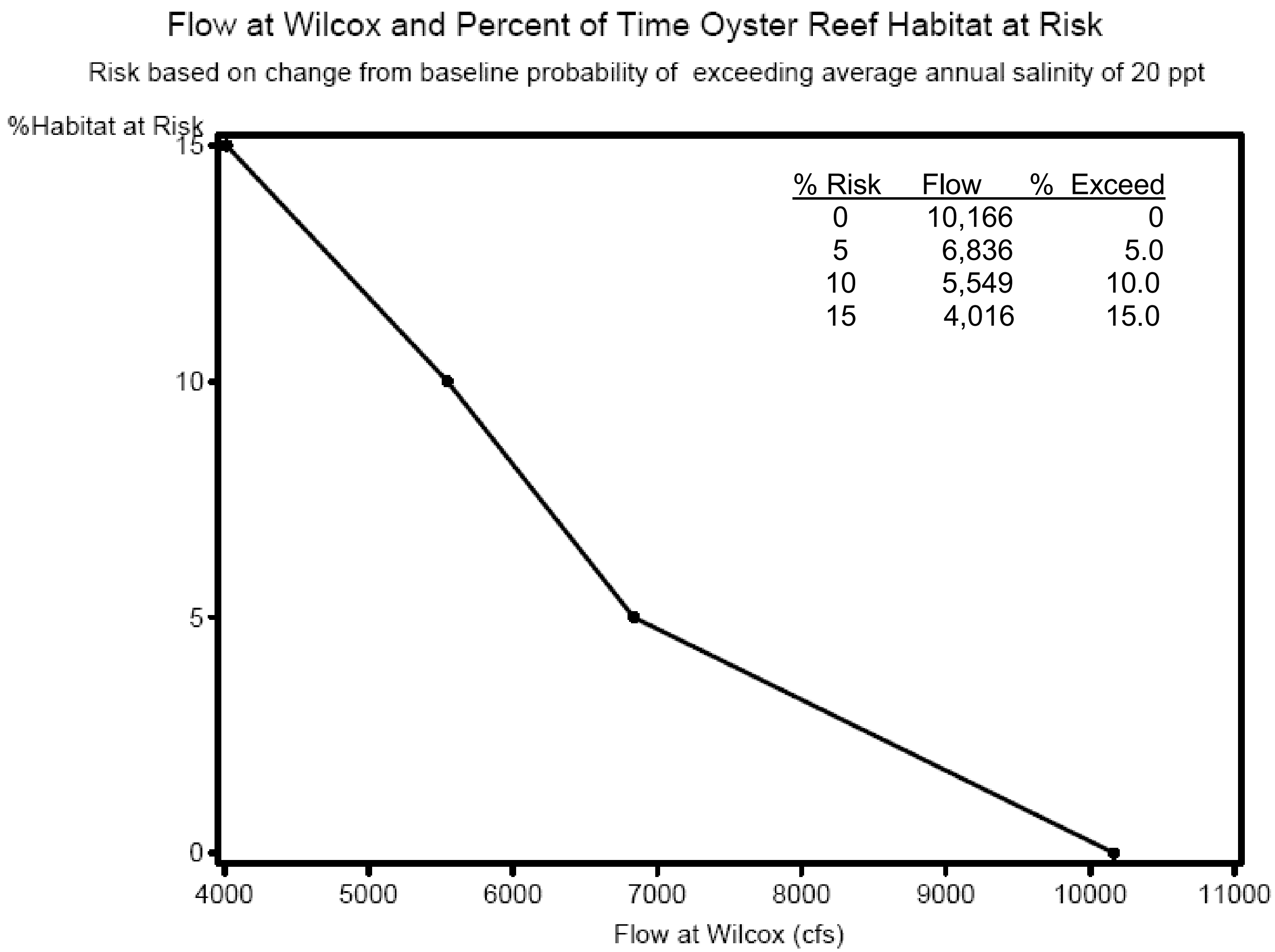


Figure K-7. Relationship between percent of habitat risk for oyster habitat and flow, based on the probability of exceeding the average annual salinity of 20 ppt.

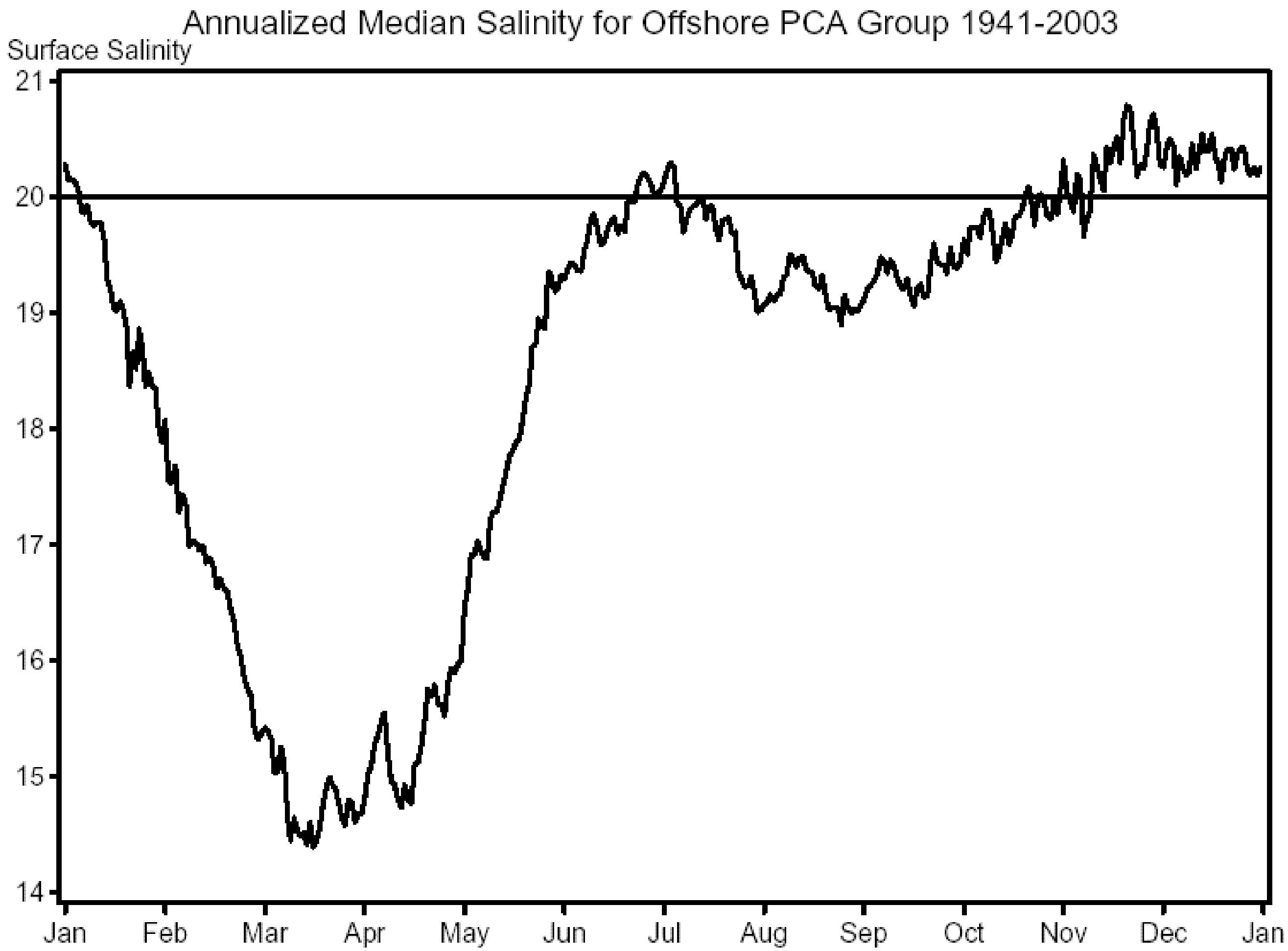


Figure K-8. Annualized median surface salinity for the offshore group.

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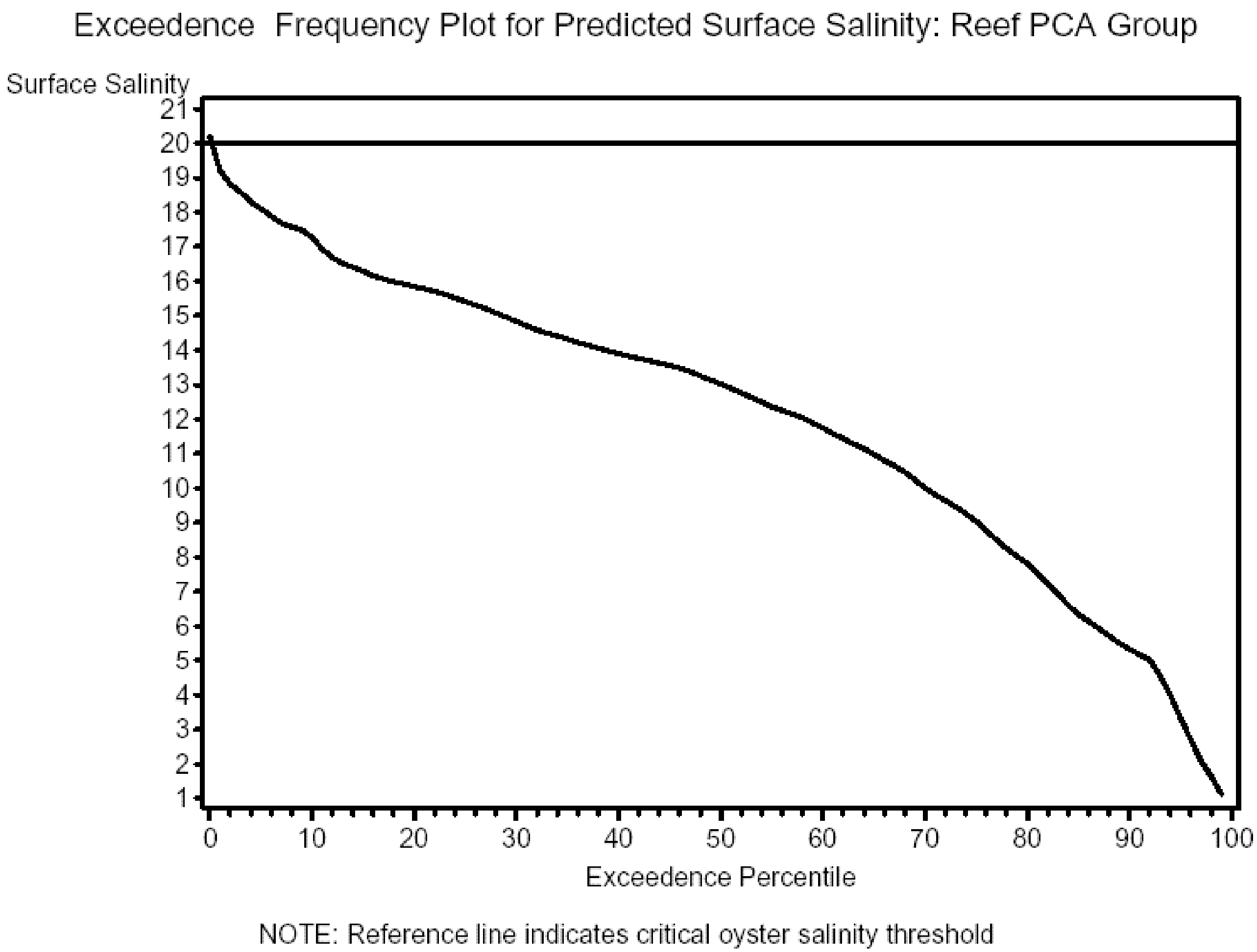

Figure K-9. Exceedance frequency plot for predicted salinity of the Inshore Reef group. The reference line at 20 ppt represents the critical salinity threshold for oysters.

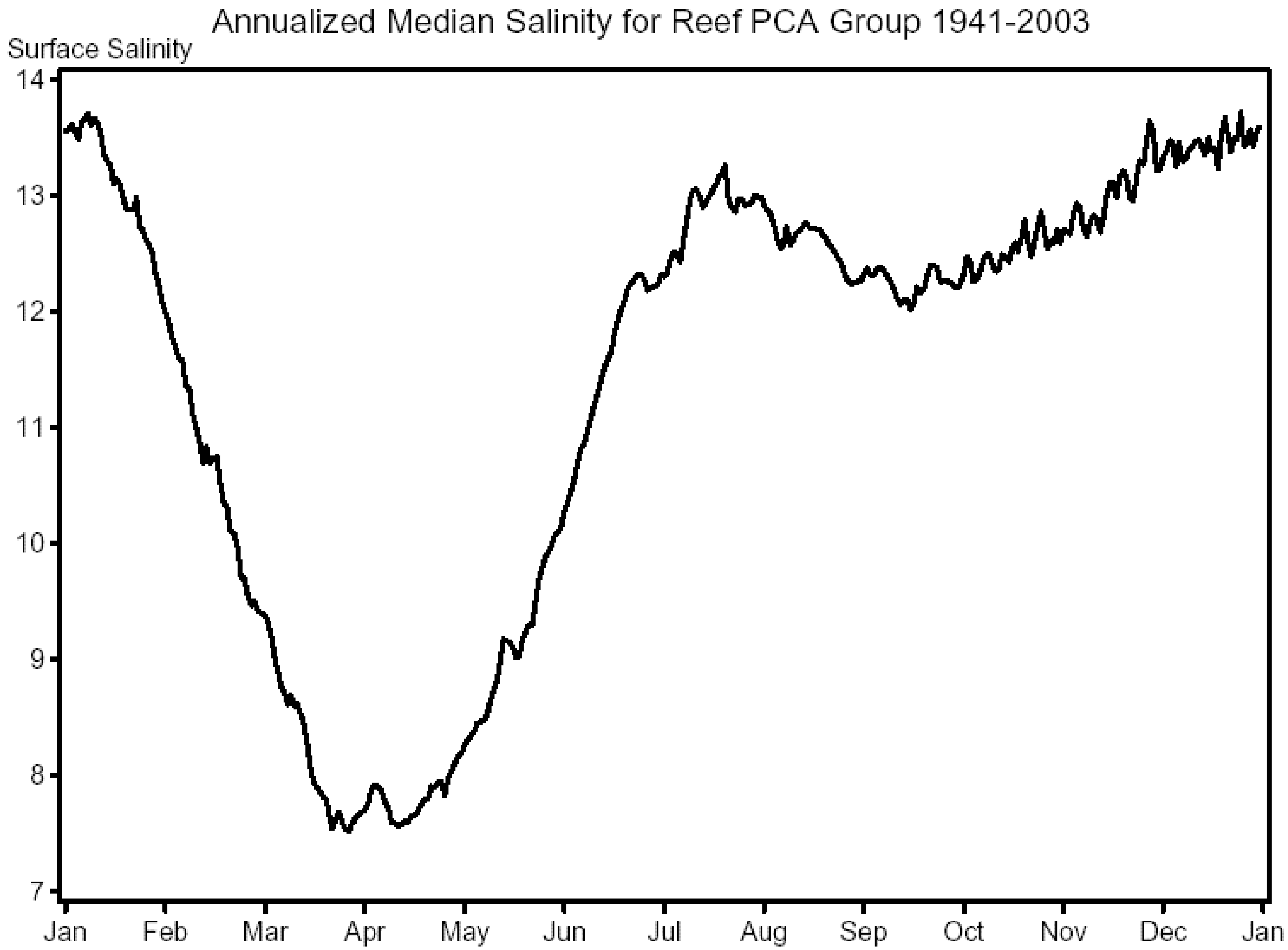

Figure K-10. Annualized median surface salinity for the reef group

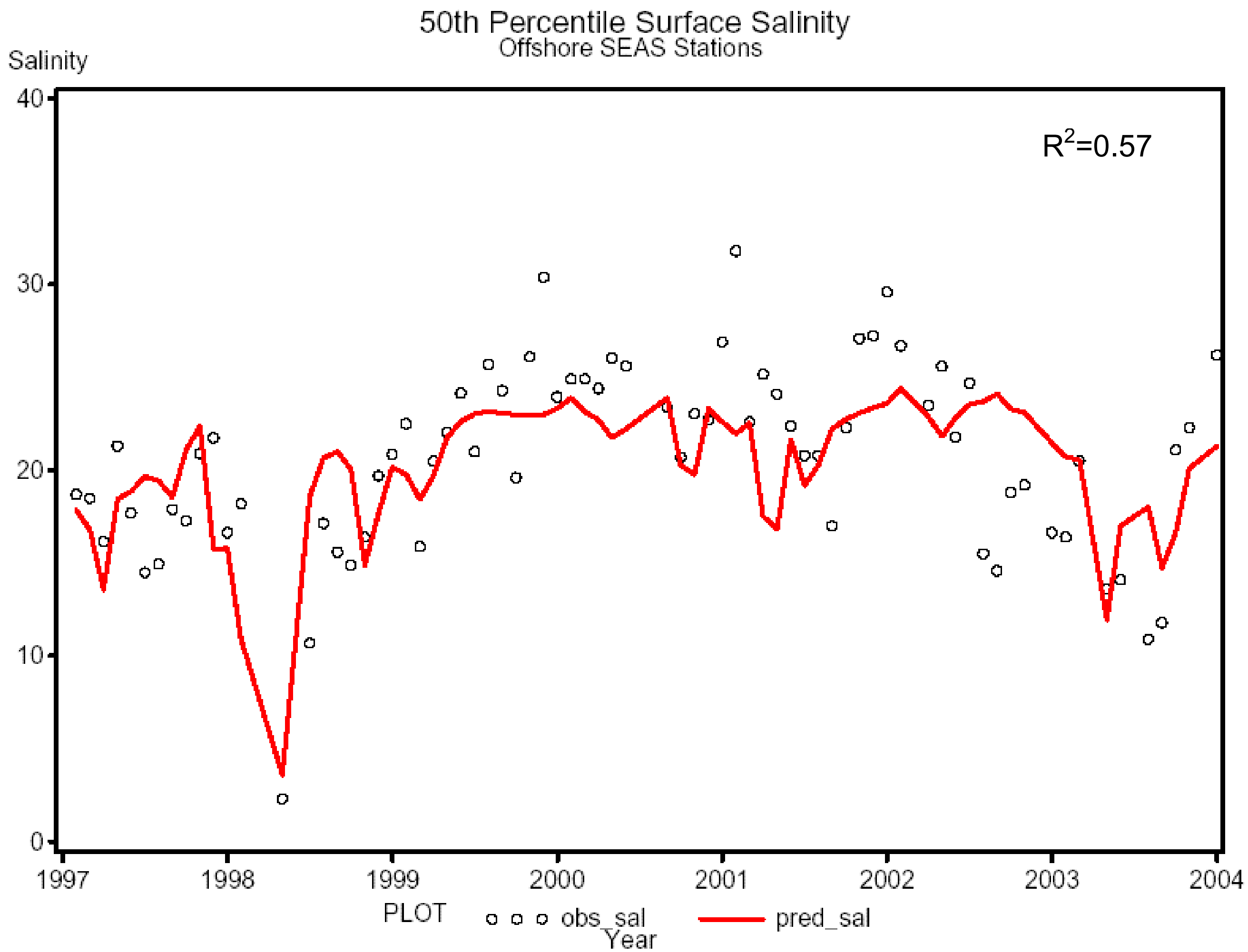

Figure K-11.. Plot showing the 50th percentile of surface salinity in the offshore SEAS stations. Predicted and observed salinity is shown.

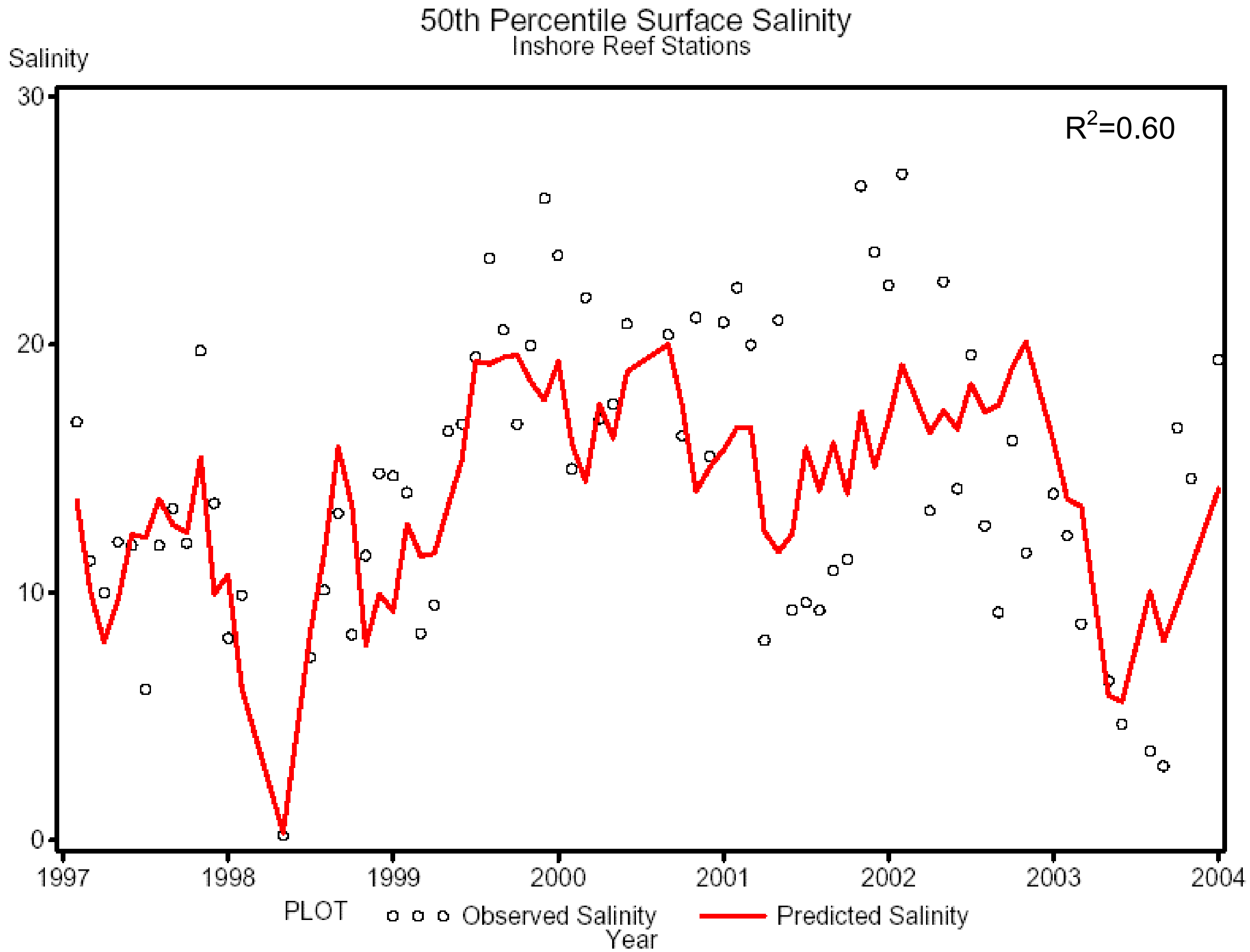

Figure K-12. Plot showing the 50th percentile of surface salinity in the inshore SEAS stations. Predicted and observed salinity is shown

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