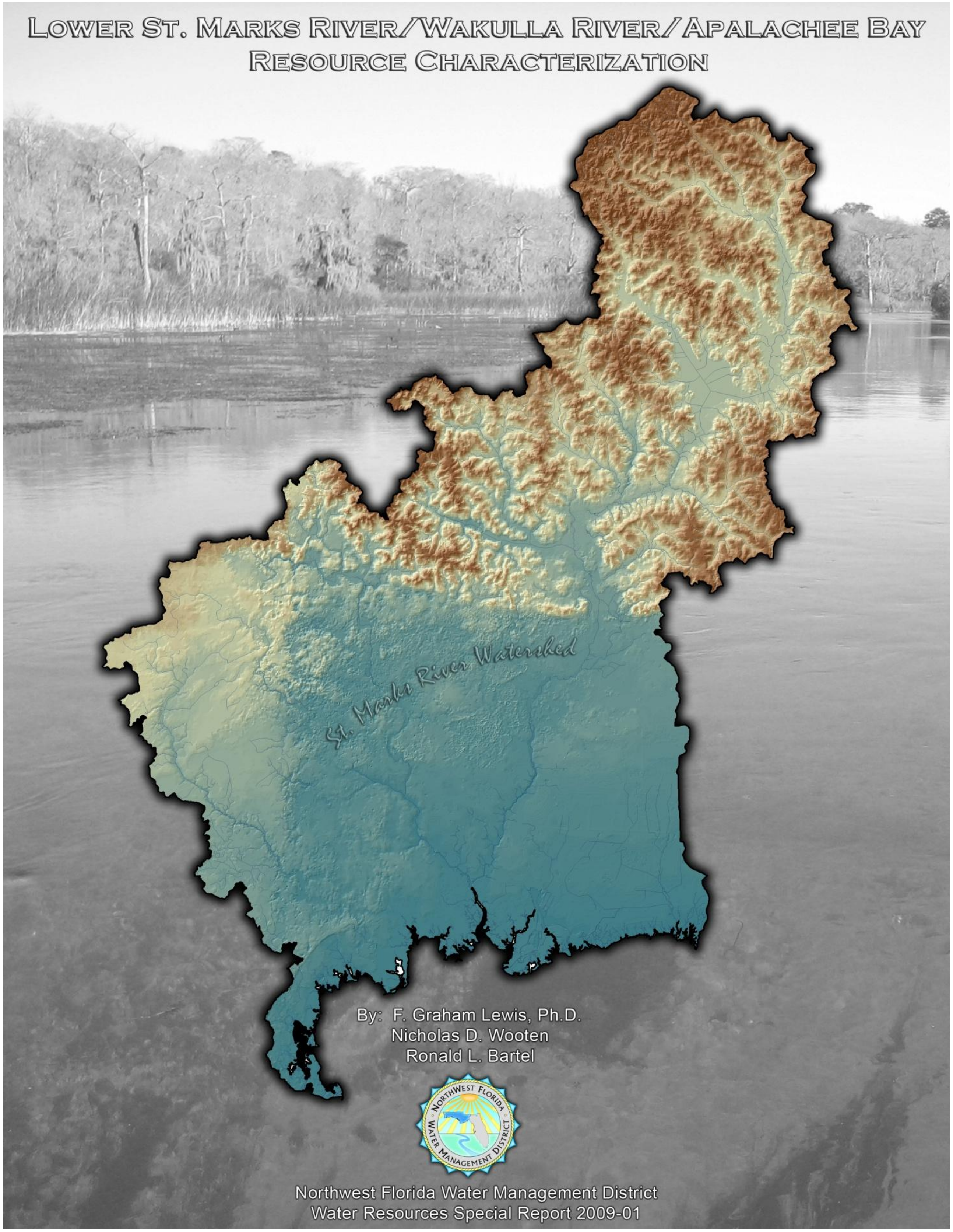
Lower St. Marks River/Wakulla River/Apalachee Bay Resource Characterization



By: F. Graham Lewis, Ph.D.
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Ronald L. Bartel

Northwest Florida Water Management District
Water Resources Special Report 2009-01

LOWER ST. MARKS RIVER/WAKULLA RIVER/APALACHEE BAY RESOURCE CHARACTERIZATION

With a Discussion of Freshwater-dependent Habitats and Species

By F. Graham Lewis, Ph.D.
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Cover and Geographical Information Systems: *John Crowe, NWFWMD*

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ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practice
cfs	Cubic feet per second.
CPUE	Catch Per Unit Effort
DACS	Florida Department of Agriculture and Consumer Services
DO	Dissolved oxygen in water
FAC	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FFWCC	Florida Fish and Wildlife Conservation Commission
FLMNH	Florida Museum of Natural History
FMRI	Florida Marine Research Institute
FNAI	Florida Natural Areas Inventory
LIDAR	Light Detection and Ranging
mgd	Million gallons per day
NFF	National Flood Frequency program
NPS	Non Point Source Pollution
NWFWMD	Northwest Florida Water Management District
NWI	National Wetlands Inventory
NWR	St. Marks National Wildlife Refuge
NWS	National Weather Service
OFW	Outstanding Florida Water
ppt	Parts per thousand
SAV	Submerged Aquatic Vegetation
SKA	Sensitive Karst Area Designation
SRWMD	Suwannee River Water Management District
STORET	U.S. EPA’s Storage and Retrieval water quality database
SCI	Stream Condition Index
SWIM	Surface Water Improvement and Management Program
TMDL	Total Maximum Daily Load
TKN	Total Kjeldahl Nitrogen in water
TN	Total Nitrogen in water
TP	Total Phosphorus in water
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WBID	Water body Identification Number

LOWER ST. MARKS RIVER/WAKULLA RIVER/APALACHEE BAY RESOURCE CHARACTERIZATION

1.0 INTRODUCTION

1.1 Purpose and Scope

The St. Marks River Watershed was included by the Northwest Florida Water Management District (NWFWMD) as one of its priority water bodies in the Surface Water Improvement and Management (SWIM) Program in an effort to preserve and protect this area from further degradation. The SWIM Program was initiated by the Florida legislature in 1987 to prioritize surface waters of the state and to develop and implement plans to improve the quality of these waters and their associated resources. The five water management districts were directed to carry out the SWIM Program under the aegis of the Florida Department of Environmental Regulation (now the Florida Department of Environmental Protection). The SWIM Plan for the St. Marks River Watershed was approved in 1997 and a draft revision of the plan (2009) was presented at a public workshop in August 2009 to incorporate input from the community and stakeholders prior to final adoption. The plan provides a framework to address strategic priorities of water quality, natural systems, and flood protection with the goal of long-term sustainability of the watershed ecosystem. The current programs and initiatives of the NWFWMD supportive of the SWIM Program are provided in the SWIM Update (2009) plan and include a broad range of activities to manage and protect ground water and surface water resources. The cumulative effect of these efforts results in significant protection and improvement in the watershed.

1.2 Watershed Research and Evaluations

Numerous studies and evaluations related to the St. Marks watershed provide a broad range of information including ground water quality (Madonia 1977; Clemens 1988; FDEP 2003; Barrios and DeFosset 2005, 2006), springs inventory (Scott et al. 2004; Barrios 2006), and karst/geological features (Johnston and Bush 1988; Davis 1996; Pratt et al. 1996; Benoit et al. 1992). Other studies have focused on urban stormwater management (Bartel et al. 1991) and nutrient loading to the watershed (Chelette et al. 2002; Davis and Katz 2007). The primary focus of this study is to provide a detailed characterization and description of the water resources and natural systems of the lower St. Marks River and Wakulla River. For the purpose of this resource characterization, operational boundaries of the study area are restricted to the Wakulla River, St. Marks River from the rise near the border between Leon and Wakulla Counties to the mouth near the St. Marks Lighthouse, and adjacent portions of Apalachee Bay.

1.3 Watershed Protection and Preservation

The NWFWMD uses a variety of management strategies and tactics that are identified in the SWIM Update (2009) plan to restore, protect and preserve the water resources in the watershed. The goal as provided in the plan: *"The St. Marks River watershed shall be managed to ensure the long-term sustainability of watershed resources, values, and functions. This shall encompass preservation and, where necessary, restoration of ecosystem health and integrity"*. Some of the ongoing activities undertaken by the NWFWMD include: hydrologic data collection and monitoring, freshwater needs assessment, local stormwater planning assistance, construction of stormwater retrofit facilities and implementation of BMPs, integration of the Flood Hazard Map Modernization Program, preservation of critical lands and habitats, ecological restoration, public education and outreach, and reuse of reclaimed water. The implementation of these activities is outlined in the SWIM plan.

In addition to these activities, the NWFWMD initiated a program of water quality protection in the watershed through less-than-fee land acquisition. In "less-than-fee" purchases, the NWFWMD acquires only those rights in the property (i.e., development and land use conversion rights) that are needed to accomplish specific resource and environmental protection goals. This method enables the protection of more land with limited funds and the property remains in private ownership and thus remains on the local property tax rolls. As of 2007, the NWFWMD had approximately 1,181 acres under less-than-fee acquisition. Nearly 45,650 acres have been identified for possible less-than-fee acquisition (NWFWMD 2009). In 2003, the NWFWMD and the City of Tallahassee-Leon County BluePrint 2000 Intergovernmental Agency developed a five-year Memorandum of Agreement (MOA) to work cooperatively to acquire property in the St. Marks basin in Leon County. The overall goal of the MOA is to protect and preserve water resources of the basin.

Public lands are prominent in the basin and consist of portions of the Apalachicola National Forest, the Wakulla State Forest, the Edward Ball Wakulla Springs State Park, the St. Marks River State Park and the St. Marks National Wildlife Refuge. The Tallahassee-St. Marks Historic Railroad State Trail (bicycle trail from Tallahassee to St. Marks), the San Marcos de Apalachee Historic State Park (old Spanish fort at St. Marks), Tall Timbers Nature Conservancy, The Nature Conservancy, the City of Tallahassee and Leon County also have conservation land in the basin. A significant portion of the lower St. Marks basin and adjacent lands lie within the St. Marks National Wildlife Refuge. This refuge was established in 1931 to provide wintering grounds for migratory bird species. The refuge occupies nearly 68,000 acres in Jefferson, Wakulla, and Taylor counties and includes 32,000 acres of aquatic habitat in Apalachee Bay.

Freshwater inflows are a dominant influence on habitat and biological resources within the St. Marks/Wakulla/Apalachee Bay system. The quantity, quality and timing of these discharges are important to maintaining the riverine and estuarine conditions found here. Activities in the drainage basin (e.g., the City of Tallahassee's wastewater treatment spray field in SE Leon County and future development in the watershed) have the potential to significantly affect aquatic resources in the watershed. The following report describes these natural resources within the system potentially at risk for impacts arising from modifications to the quality and quantity of freshwater inflow.

2.0 ST. MARKS RIVER WATERSHED

The St. Marks River watershed (Figure 1) covers an area of about 1,170 square miles (748,800 acres). The northern boundary of the watershed starts near Thomasville Georgia and extends approximately 52 miles to the south terminating at Apalachee Bay. The majority of the watershed (about 91 percent) is in three Florida counties, Leon (~ 40% of the watershed), Wakulla (~ 30% of the watershed) and Jefferson (~ 21% of the watershed). A watershed is the geographic area of land that drains to a common destination, in this case the St. Marks River and Apalachee Bay. The watershed has two rivers, the St. Marks River and Wakulla River (which is a tributary of the lower St. Marks River), that capture the majority of the surface drainage in the basin. Other major surface water features within the watershed are lakes Miccosukee, Lafayette, and Munson, and the coastal receiving waters of Apalachee Bay. In addition to surface water drainage in the watershed, ground water provides a significant amount of the flow into both rivers and Apalachee Bay. The regional ground water contribution zone is represented in Figure 1 and includes an area of approximately 1,963 square miles (1,256,061 acres) which is about 68% larger in area than the surface watershed. The estimated ground water contribution zone for the St. Marks River watershed was delineated using the potentiometric surface altitude of the Floridan Aquifer to develop ground water contours and contribution zone boundaries (Chelette et al. 2002; Barrios 2006). This contribution zone may change slightly depending on climatic variability that effects recharge, pumping and the potentiometric surface. The hydrogeology of the watershed is characterized by the complex interaction between surface water and ground water due to the limestone bedrock below the region.

2.1 Hydrogeology of Watershed

The Floridan Aquifer is a thick sequence of carbonate rocks and forms one of the most productive ground water supplies in the United States due to the its highly porous structure. The Floridan Aquifer underlies the entire St. Marks River Watershed. The watershed encompasses two main physiographic regions: the Tallahassee Hills subdivision of the Northern Highlands in the north, and the coastal lowlands in the southern portion of the watershed (Pratt et al. 1996). The watershed is described as a karst topography, which is a term commonly used to describe this type of carbonate geological formation and is characterized by dissolution features such as sinkholes, swallets, springs, disappearing streams, and underground drainage channels. These dissolution features provide pathways for pollutants from stormwater runoff and other anthropogenic sources to be rapidly transported into the ground water.

The topographic feature that separates the Tallahassee Hills and the coastal plain is an escarpment (Cody Scarp) that runs east-west across southern Leon County (Figure 1). The Cody Scarp marks the northern encroachment of the sea in the Pleistocene epoch and is identified by a significant drop in elevation between the Tallahassee Hills and coastal plain that removed Miocene and Pliocene sediments exposing carbonates of the St. Marks Formation and Suwannee limestone (Pratt et al. 1996). The Upper Floridan Aquifer in the Tallahassee Hills region of the watershed is considered to be semi-confined due to clay soils overlaying the aquifer that become thicker to the north. The layer of sediments overlaying the aquifer in the Tallahassee Hills slows recharge as it moves downward to the water table providing filtering in combination with biological and chemical

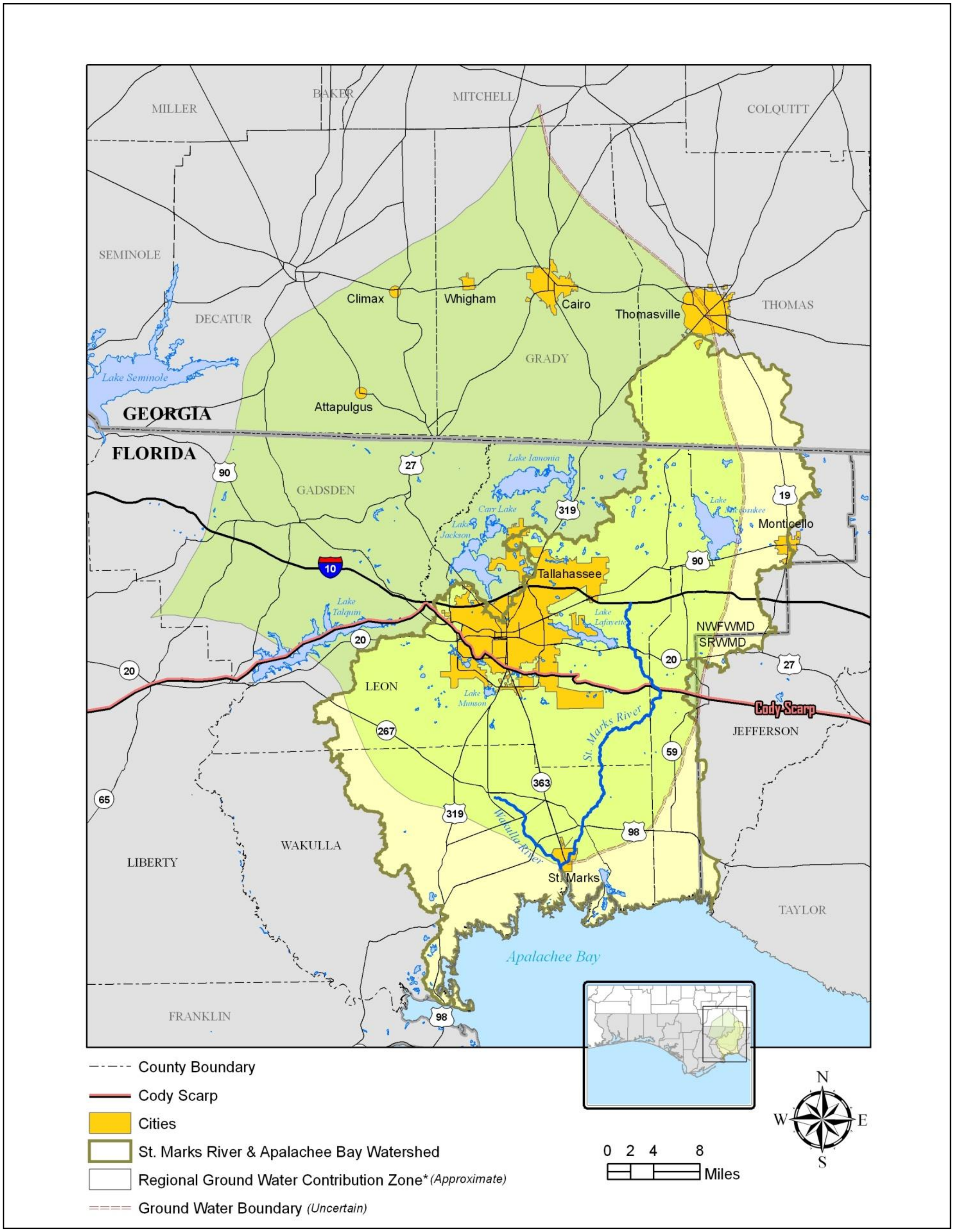


Figure 1 – St. Marks River & Apalachee Bay Watershed

processes that remove contaminants as it slowly migrates downward. Much of the surface drainage north of the Cody Scarp drains to lakes that have outlet channels that intermittently discharge downstream depending on rainfall. Most of the lakes have one or more sinkholes that breach the confining layer and discharge into the water table.

2.2 Woodville Karst Plain

The Woodville Karst Plain is an area that has been designated south of the Cody Scarp starting in southern Leon County and extending to the coast in Wakulla County and including a portion of southwest Jefferson County (Figure 2). This is an area where the top of the Floridan Aquifer is at or near land surface and is considered unconfined due to a thin or absent layer of soil that slows recharge to the aquifer (Pratt et al. 1996). The occurrence of karst features in the landscape increases dramatically below the Cody Scarp in the Woodville Karst Plain as shown in Figure 2. The proximity of the Floridan Aquifer to the surface increases the erosive processes on the limestone and accelerates the formation of dissolution features by slightly acidic surface water as it moves downward. Approximately 42 sinkholes north of the Cody Scarp have been identified and mapped by state and local agencies with about 232 sinkholes and 66 springs mapped below the scarp. There are likely many more sinkholes and springs that have yet to be mapped.

A digital elevation model of the watershed (Figure 3) was developed by the NWFWMD using Light Detection and Ranging (LIDAR) data to accurately measure bare earth elevations and map topographic features of landscape. Close examination of this map indicates that the landscape has many more sinkholes and karst features, particularly in the Woodville Karts Plain, than the karstic features currently identified. This new mapping technique provides a new tool to help locate and map karst features and identify areas that may require additional measures to protect the Floridan Aquifer and ground water resources from contamination.

An area in northern Wakulla County along U.S. Highway 319 that has a high concentration of sink holes and karst features is shown in the digital elevation map in Figure 4. This elevation map was created using 2008 LiDAR data with a resolution of about ± 0.5 feet; previous topographic maps of this area had 5 foot contours. The red circles on the map indicate sink holes that have previously been indentified and mapped in the Future Land Use Mapping (FLUM) database. LiDAR data provides a valuable tool to accurately map the landscape and locate karst features that have not previously been identified as shown in Figure 4. The small blue circular features in the figure indicate numerous sinkholes and dissolution karst features that have not been mapped and may have a hydraulic connection with the Upper Floridan Aquifer. Identification and protection of sink holes and karst features will be an increasingly important responsibility for state and local governments to protect the Floridan Aquifer from future contamination and degradation.

2.3 Sensitive Karst Areas

The NWFWMD and the Florida Department of Environmental Protection (FDEP) have recognized the potential for contamination to ground water resources in karst regions of the panhandle and have developed new rules to minimize contamination of the Floridan Aquifer by stormwater runoff from new development. The Environmental Resource Permitting Handbook (FDEP and NWFWMD 2007) designated several areas of the panhandle as Sensitive Karst Areas (SKAs) which include

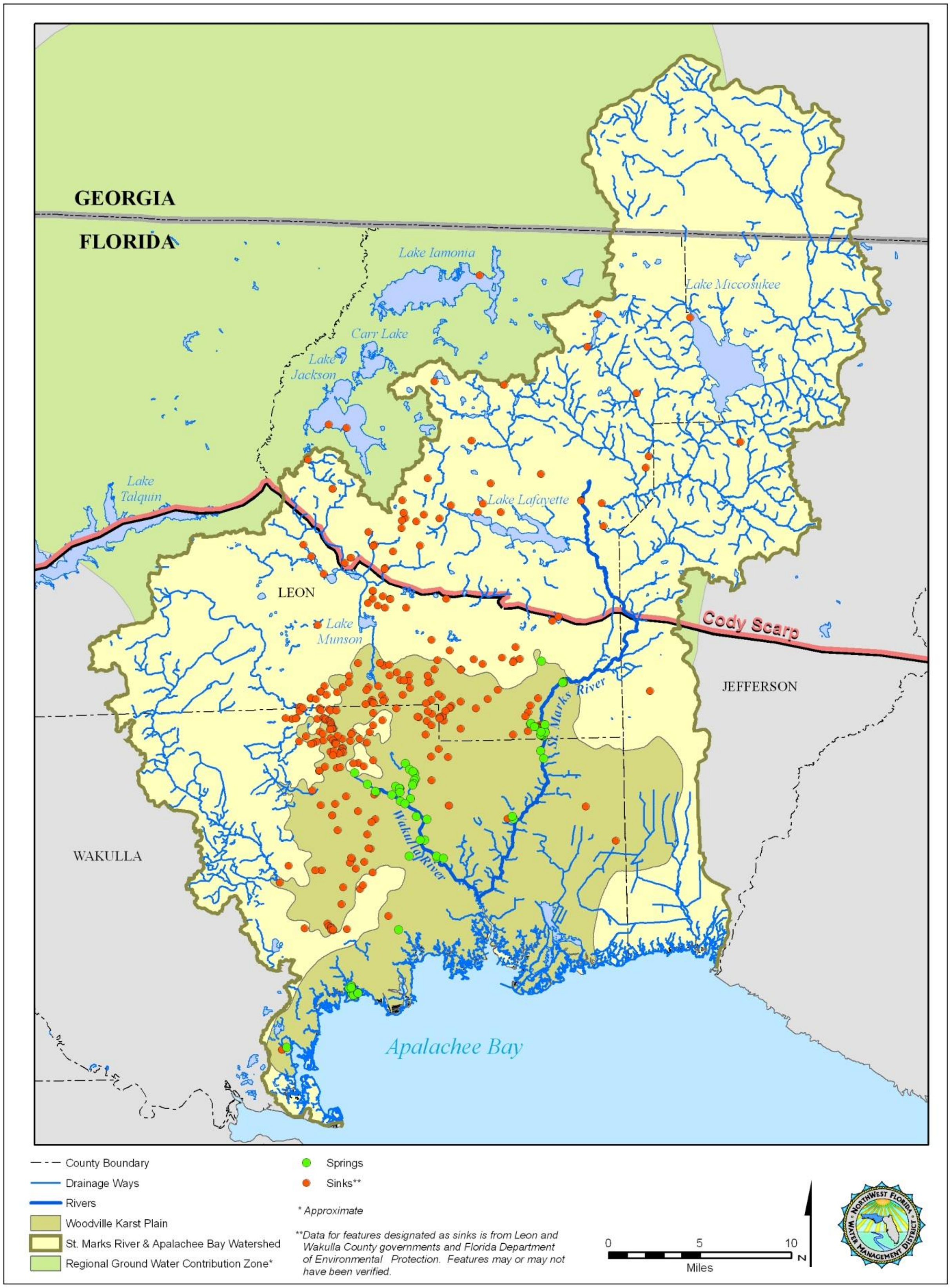


Figure 2 – Surface Water and Identified Karst Features of the St. Marks River Watershed

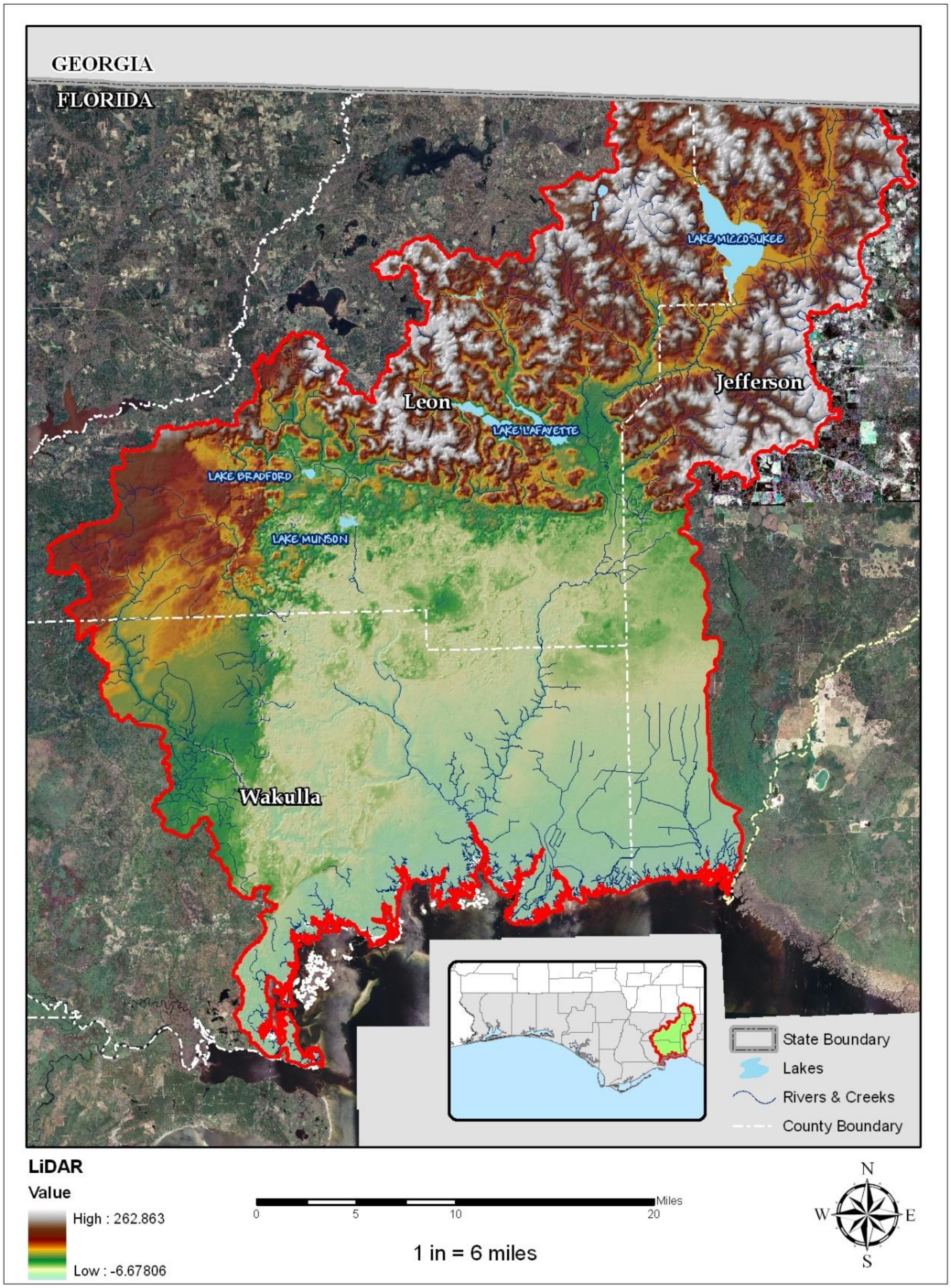


Figure 3 – Digital Elevation Map of the St. Marks River Watershed

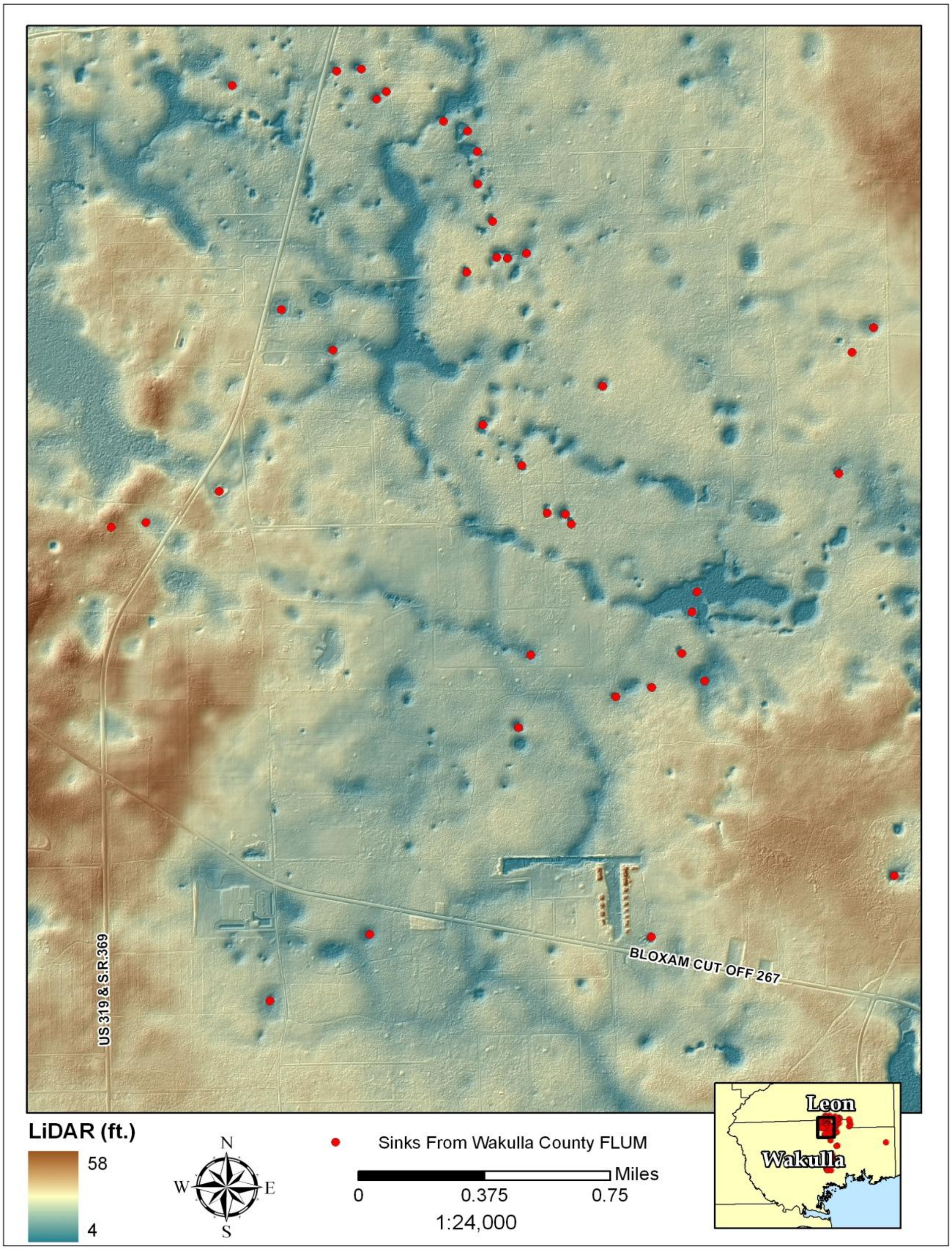


Figure 4 – Digital Elevation Map of River Sink Area in North Wakulla County
(Numerous Unmapped Karst Features Indicated On Map)

the St. Marks River Watershed (Figure 5). The requirements for new stormwater management systems in these sensitive areas include additional design criteria that are intended to prevent the direct discharge of stormwater runoff from new development into the Floridan Aquifer.

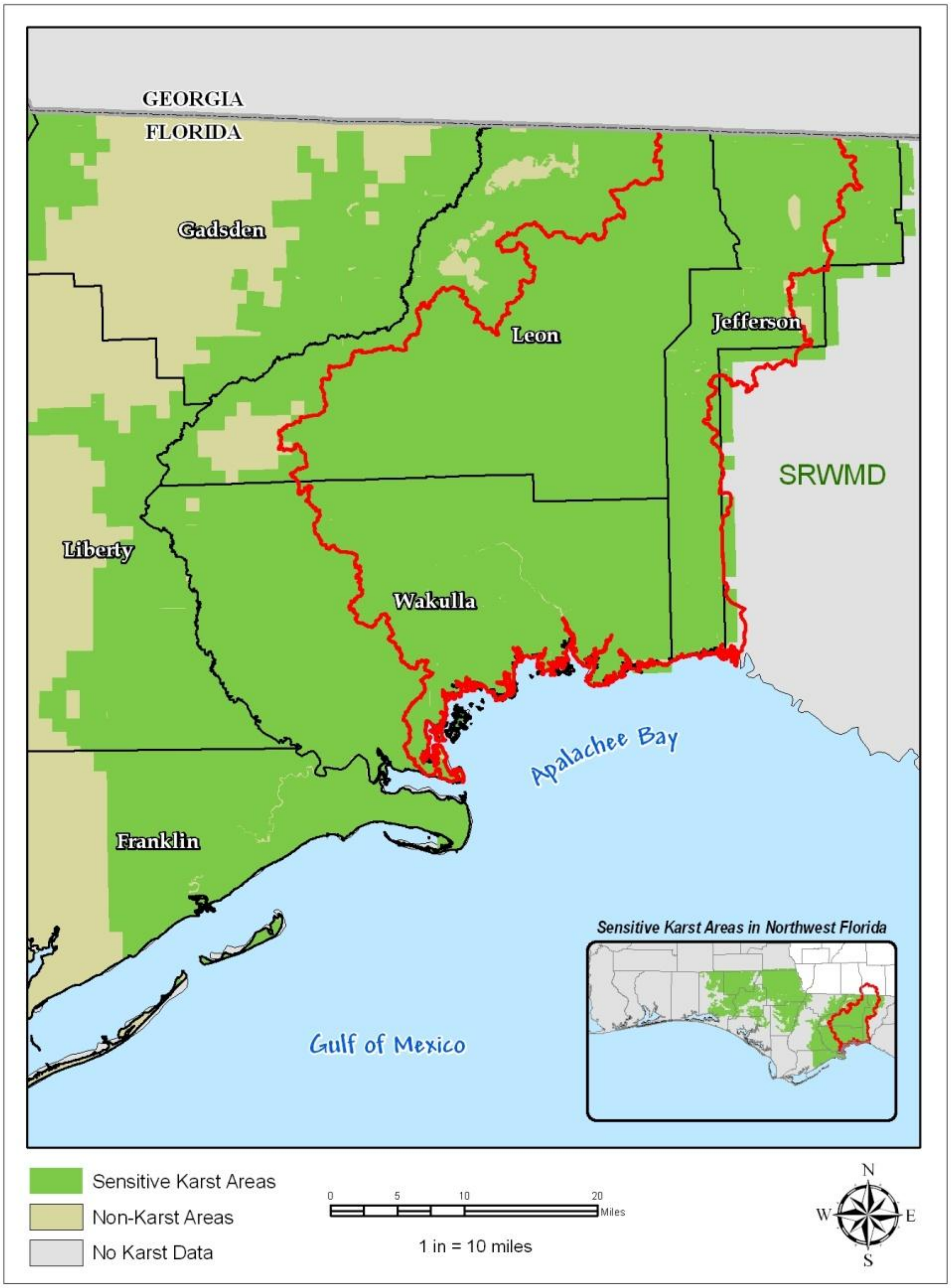


Figure 5 – Sensitive Karst Areas of St. Marks River Watershed

2.4 Non-Point Source Runoff

Non-point source (NPS) pollution originates from the general landscape with no single source and is transported in stormwater runoff. It is considered one of the most significant sources of contamination to surface and ground water resources in Florida. FDEP, water management districts and local governments regulate the discharge of stormwater in the state. Stormwater management and pollutant load reduction criteria are outlined in the Florida Administrative Code (FAC) 62-40. This rule establishes that stormwater design criteria provide at least 80 percent reduction of the average annual load of pollutants that cause or contribute to violations of State Water Quality Standards. When the stormwater system discharges to an Outstanding Florida Water (OFW), the design and performance criteria increase to 95 percent reduction (Harper and Baker 2007).

Urban land use has been shown to have the highest stormwater-generated NPS pollution per acre due to increased impervious surface area that increases runoff. Urban areas also typically have less vegetation and wetland areas that moderate flows and provide recharge, storage and treatment for runoff. In urban areas, lawns, roadways, buildings, commercial and institutional properties all contribute to NPS pollution. The pollutants include nutrients (primarily nitrogen and phosphorus), heavy metals, pesticides, petroleum products (oil, gas, grease, etc.), sediment and other contaminants that degrade water resources and natural systems. In the St. Marks River Watershed, a large percentage of the stormwater runoff that carries NPS pollution enters the Floridan Aquifer through sinks and swallets.

Many stormwater improvement projects are directed at correcting existing flooding problems. These projects typically also improve water quality by providing additional treatment, storage and reduction of nutrient loads by aquatic vegetation. The City of Tallahassee and Leon County have stormwater utility fees to help pay for stormwater improvements along with additional funding provided by NWFWMD, FDEP and federal grants. The City and County have jointly spent about $183,775,877 on completed or ongoing stormwater improvements in the Lake Lafayette and Lake Munson sub-basins that drain to the St. Marks River watershed (Tallahassee-Leon County Watershed Protection Initiative web site).

Agricultural land use, including silviculture, also contributes to NPS pollution. The use of best management practices (BMPs) including proper use of fertilizer and pesticides, erosion control measures, proper irrigation practices and providing buffers near wetlands and other water resources can minimize NPS pollution from agriculture.

The population of Leon County increased from 148,655 in 1980 to 272,497 in 2006 and almost tripled in Wakulla County from 10,887 in 1980 to 28,393 in 2006 (University of Florida, Bureau of Economic and Business Research). The additional wastewater generated from this population increase has been identified as a growing source of nutrients and other contaminants in the watershed. The City of Tallahassee southeast wastewater spray field has been identified as a source of pollution (primarily nutrients) in the basin. The City is completing a waste water reuse facility in southeast Tallahassee that will reduce nutrient loads into the ground water. Septic tanks have also been identified as an increasing source of nutrient pollution particularly in the watershed. Proper maintenance of existing septic systems and installation of performance-based systems to reduce nutrient loads to the ground water will be necessary to protect water resources.

3.0 LAND USE AND LAND COVER

Land use and land cover have a significant effect on the function and hydrologic characteristics of watersheds. Land use changes and urbanization affect peak flow characteristics, changes in total runoff and changes in the quality of water (Leopold 1968). In urban areas and medium to high density residential and commercial land use areas, impervious surfaces (primarily buildings and paved surfaces) allow stormwater to flow unimpeded downhill transporting pollutants such as sediment, oil, pesticides, fertilizers and other contaminants into streams, lakes and ground water. In the St. Marks Watershed a significant amount of the stormwater runoff is eventually transported into the ground water through sinkholes.

The major land use/land cover in the St. Marks River Watershed is upland forest which covers about 550 square miles (352,133 acres). The upland forests in the watershed primarily include natural forested land and silviculture (Figure 6). Wetlands are the next largest land cover and include about 302 square miles (192,988 acres). Agricultural land use and developed land use cover roughly equal areas of the basin, 147 square miles (94,369 acres) and 142 square miles (91,036 acres), respectively. The developed land use category includes a combination of residential, commercial and industrial land uses. Open water covers only about 16 square miles (10,017 acres) in the watershed and primarily includes lakes, rivers, streams and ponds. Institutional land use (educational, religious, health and military facilities) encompasses about 8 square miles (5,197 acres). Recreational and open land accounts for the remaining land use; these categories include about 3 square miles (1773 acres) and 2 square miles (1,286 acres), respectively.

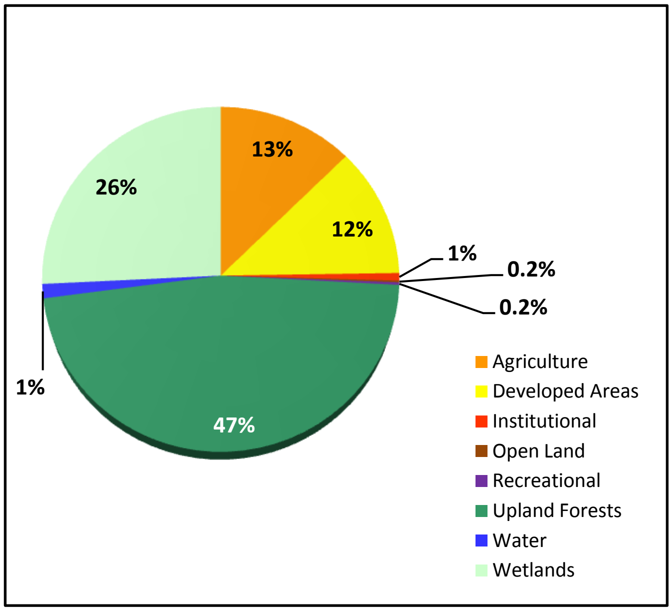


Figure 6 - St. Marks Watershed Land Use By Category

3.1 Hydrologic Impacts of Land Use

Land uses that have the greatest impact on the hydrology of the watershed are the developed and institutional uses due to the significant alteration of flow and diminished recharge created by landscape changes and impervious surfaces. Land cover and uses associated with forested land, wetlands and agriculture (that use best management practices) typically allow for more absorption of rainfall and runoff. Limited impervious surface allows greater recharge in these areas and the presence of vegetation results in increased transpiration, both of which contribute to a reduction in the quantity and rate at which water runs off the land.

The two most developed sub-basins in the St. Marks River Watershed are the Lake Lafayette and Lake Munson sub-basins. These two basins include a large proportion of the developed land use areas in Leon County. The Lake Lafayette sub-basin is about 53,956 acres with about 46 percent of the land use developed and institutional. The Lake Munson sub-basin is about 43,494 acres with about 55 percent of the land use developed and institutional. The land area of these two sub-basins combined (97,090 acres) is only about 13 percent of the entire St. Marks River Watershed (748,800 acres) yet it accounts for 51% of the developed and institutional acreage in the watershed (Figure 7).

The northern-most area of the watershed in Georgia is 108 square miles (69,308 acres) or about 9% of the watershed. The predominant land cover is upland forest (75%) with agriculture (12%), wetlands (7%), developed (5%) and water (1%) making up the remaining land use/land cover.

3.2 Conservation Lands

Conservation lands cover a significant portion (about 33%) of the basin and include federal, state, local government and private land (Figure 8). Conservation lands provide many benefits including protection of natural systems, recharge in the watershed, flood control, recreation and protection of historical and environmentally sensitive areas. Conservation lands also provide direct economic benefits for local communities by attracting visitors that spend money on goods and services. Forest and natural lands also provide the resource base for other economically beneficial activities such as timbering and recreational related businesses.

The Apalachicola National Forest is the largest national forest in Florida covering 571,088 acres, of which 106,944 acres are in the St. Marks River watershed. The management strategy for the national forest includes a sustainable multi-use concept that includes a diverse array of activities that provide economic value and manage and protect the natural environment. Recreational activities in the national forest and surrounding public lands include: camping, hiking, hunting, fishing, boating, bird and wildlife watching, swimming, horseback riding, mountain biking, off-road vehicle use and visiting natural and historic landmarks. Visitors to the national forest stimulate the local economy with the goods and services they purchase which include food, gas, lodging, supplies and services of guides and eco-tourism related businesses. The forest is also managed for timber production that provides additional economic benefits to local communities.

The St. Marks National Wildlife Refuge is the next largest conservation area in the watershed and encompasses the majority of the land along the coast in the lower St. Marks River Watershed. The wildlife refuge includes 50,184 acres in the lower St. Marks Watershed and provides valuable resource protection, wildlife habitat and recreational opportunities. Wakulla Springs State Park covers 2,860 acres and protects the area surrounding the main spring and the first three miles of the Wakulla River. An economic impact study was completed for four Florida spring state parks in 2003 by the Florida State University (Bonn and Bell 2003). The report concluded that 180,793 people visited Wakulla Springs in 2002 and about 70 % of these visitors were from outside Wakulla County. The report estimated that Wakulla Springs-related visitors spent about $22.19 million in Wakulla County on food, lodging, admission fees, entertainment, transportation, and associated expenditures in 2002 (Bonn and Bell 2003). This clearly demonstrates the positive economic impacts of conservation lands for local communities along with the resource protection provided by this type of land use.

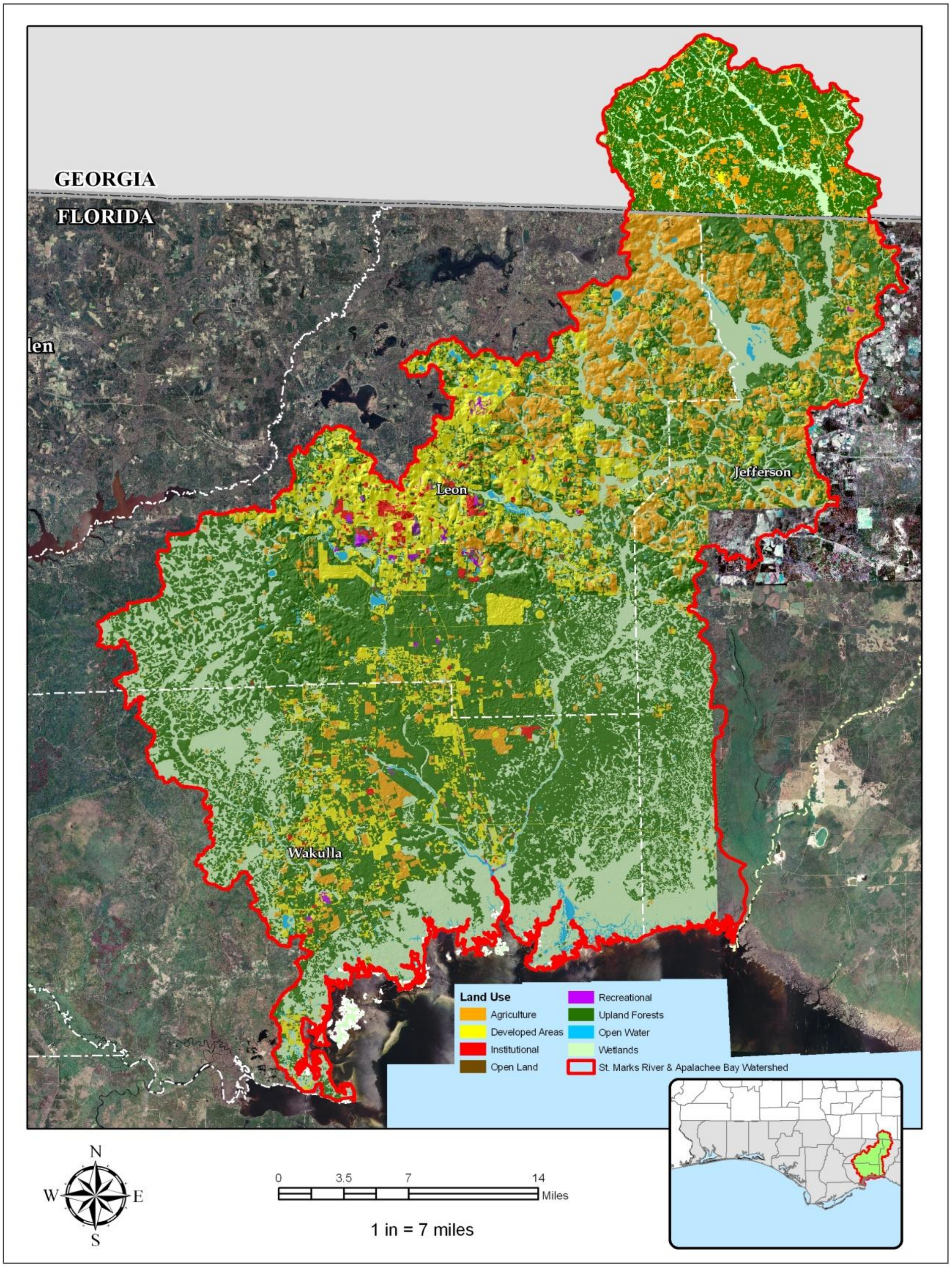


Figure 7 - Land Use and Land Cover in the St. Marks River Watershed

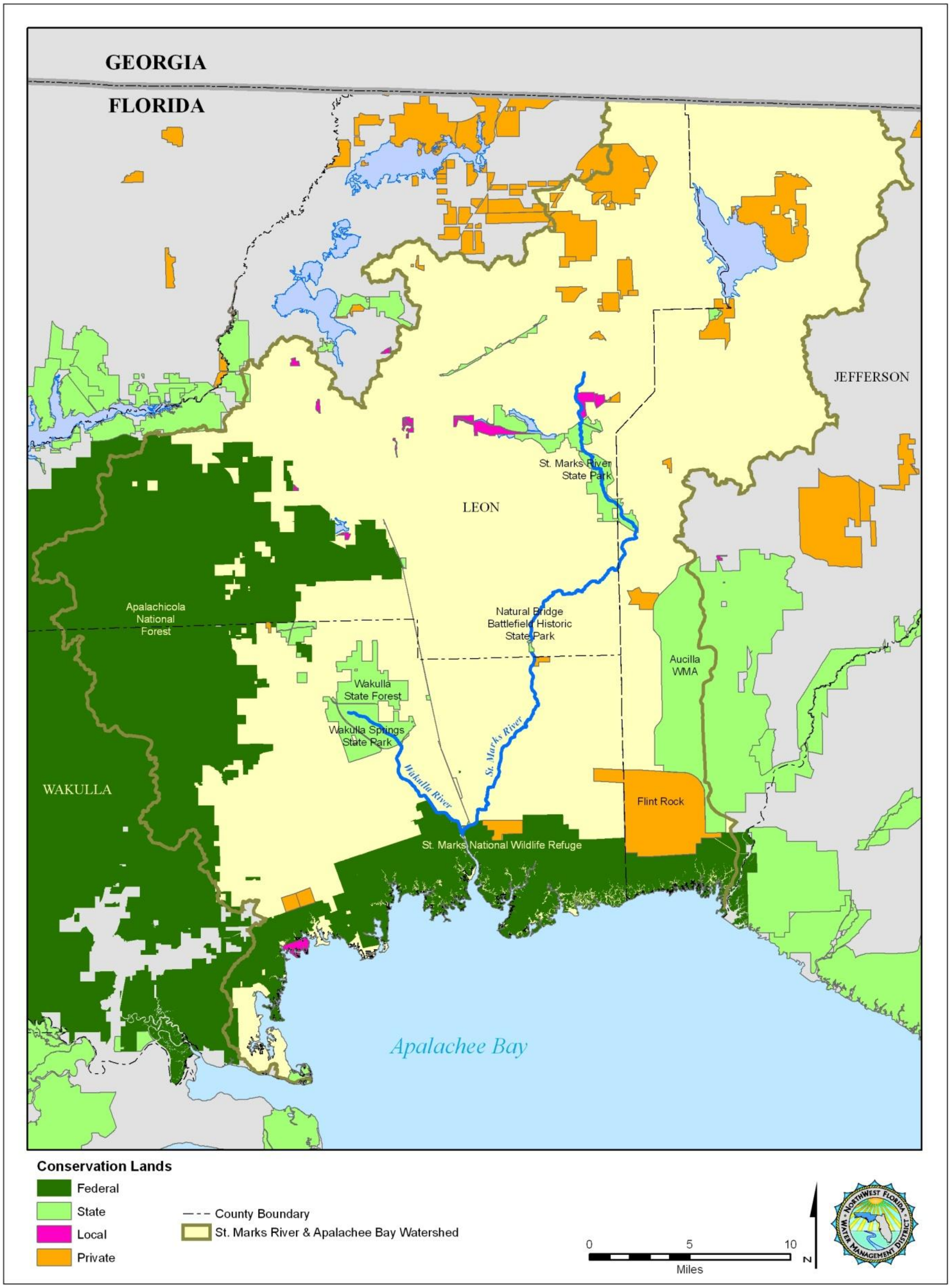


Figure 8 – Conservation Land in the St. Marks River Watershed

4.0 ST. MARKS RIVER HYDROLOGY

The St. Marks River originates in eastern Leon County near an area of connected wetlands and travels south about 35 miles to Apalachee Bay. The upper portion of the river is primarily comprised of a combination of wetlands, intermittent streams and sinking streams. The main defined portion of the river arises in the Tallahassee Hills of northeastern Leon County as little more than a collection of connected wetlands (Barrios and DeFosset 2006). The upper St. Marks River receives intermittent surface flow from four sub-basins in the upper watershed, Lake Miccosukee, Patty Sink Drain, Black Creek (upper) and Lake Lafayette sub-basins (Figure 9). These sub-basins function as closed basins much of the time and drain to sinkholes or wetlands without direct surface discharge to the St. Marks River. The surface topography shown in Figure 3 (Digital Elevation Map of the St. Marks River Watershed) indicates that these sub-basins discharged to the Upper St. Marks River in the past before sinkholes captured the stream flow diverting it underground. During wet periods, high stream flows exceed the drainage capacity of sinkholes and streams in the upper basin flow directly into the St. Marks River or into wetlands that contribute flow to the upper river.

4.1 Lake Lafayette Sub-Basin

During high flow periods the river can pick up significant flow from the Lake Lafayette sub-basin which has a high percentage of development and impervious surface area. Lake Lafayette is a shallow depressional lake typical of lakes in the area. It has three distinct sections: Upper Lake Lafayette, Piney Z Lake (created by impoundments and situated between the upper and lower lake) and Lower Lake Lafayette. A large sinkhole in the northwest corner of Upper Lake Lafayette typically swallows a significant amount of the runoff from the sub-basin during low to moderate flow periods. During higher flow periods surface drainage flows through Piney Z Lake into Lower Lake Lafayette and combines with runoff from the Alford Arm Tributary and flows east under Chaires Cross Road and into the St. Marks River.

There is a strong correlation between the river flow at the U.S. Geological Survey (USGS) station near Natural Bridge and the NWFWMD stage recorder on the Lake Lafayette Outfall channel (Figure 10). There is an 80 percent correlation between the outfall stage level (during periods of discharge to the river) and the river flow indicating a significant contribution of discharge from the Lake Lafayette sub-basin to the river during moderate to high flow periods. The flat periods on the bottom of the Lake Lafayette graph are periods when the outfall channel is dry and is not discharging to the river.

4.2 Lower St. Marks Basin

The river continues to pick up additional flow from wetland areas, intermittent streams and small seeps and springs as it crosses the Cody Scarp and flows south. Two second-order springs, Chicken Branch Spring and Horn Springs, contribute flow to the river above Natural Bridge in southeast Leon County. At Natural Bridge in southeast Leon County the entire river disappears underground into sinks and reemerges a half mile downstream at St. Marks Rise. A series of 17 synoptic discharge measurements were completed between 2003 and 2009 by NWFWMD above and below

Figure 9 – St. Marks River Watershed Sub-Basins

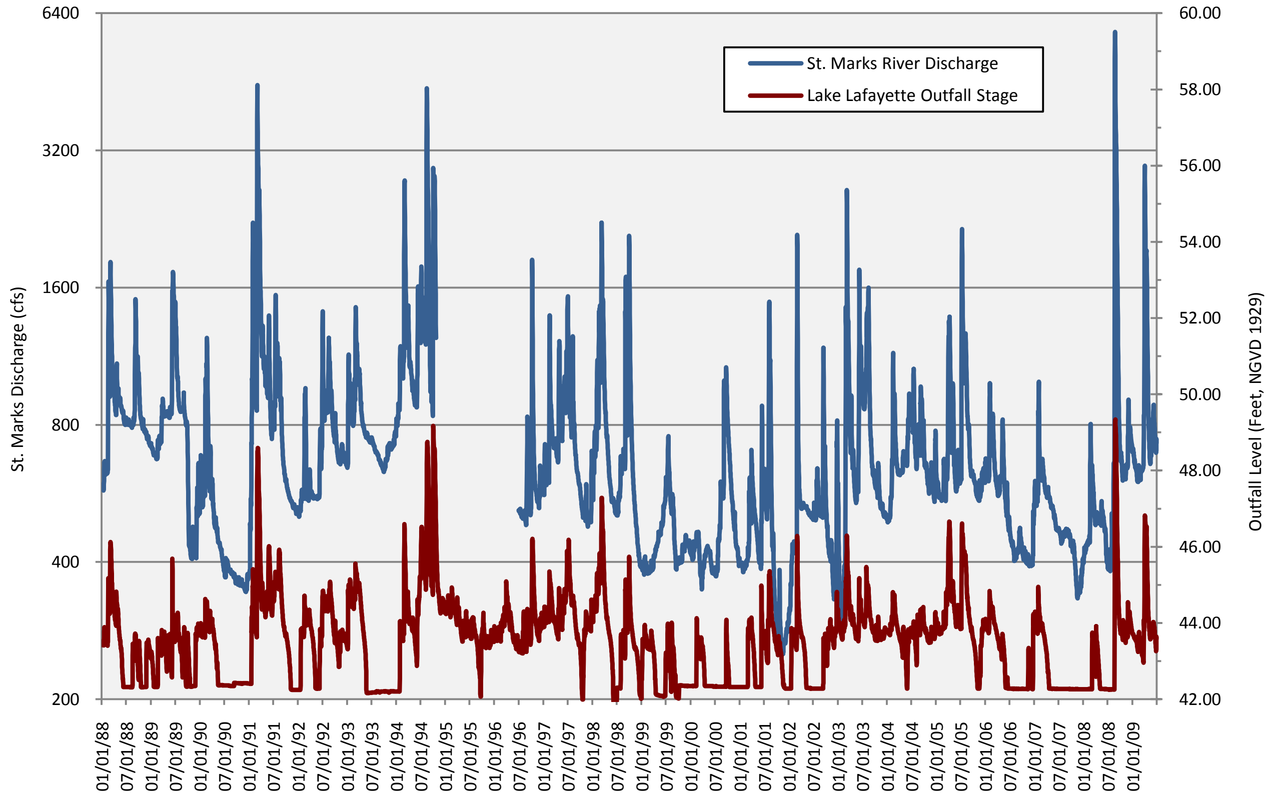


Figure 10 – St. Marks River and Lake Lafayette Outfall Flows

the St. Marks Rise to quantify the additional contribution of ground water to the river below the rise. The upstream and downstream measurements were completed within a few hours of each other to provide an accurate comparison of river flow above and below the rise. The river flow increased between 53 to 87 percent below the river rise (Figure 11) with an average increase of 80 percent for the 17 instantaneous measurements completed to date. These measurements indicate the majority of the river flow below the rise is additional ground water flow as it re-emerges, under the measured flow conditions. The measurements completed to date have all been during moderate to low flow periods, the percentage of ground and surface water contribution to the river below the rise likely has a different ground water/surface water ratio under high flow conditions.

A baseflow separation analysis was performed on the daily flow record for the St. Marks River below the rise to estimate the baseflow (ground water storage) component of the river flow. This analysis provides an estimate of the proportion of flow from direct surface runoff and baseflow derived from ground water storage. The results of three baseflow separation methods were analyzed and included Eckhardt, BFlow and local minimum methods (Lim et al. 2005). The final baseflow separation analysis was performed using a combination of the Eckhardt and local minimum (modified HYSEP) to develop a conservative result that does not over estimate the baseflow component. These results combined with discharge measurements completed above and below the rise confirm that the St. Marks River Rise is a first magnitude spring with average discharge above 100 cfs.

Figure 12 shows the river flow at the USGS station below the river rise and the estimated baseflow (ground water contribution) using the baseflow separation analysis. The differences in flow between the paired instantaneous measurements above and below the rise (Figure 12) indicate the amount of additional ground water contribution to the river from the spring at the rise. The instantaneous discharge measurements below the rise may be different than the mean daily river flow (represented by the solid blue line) due to tidal influence, backwater and other factors. The instantaneous measurements above the rise are represented by blue circles and during low flow periods include a significant amount of ground water from springs above the rise.

The estimated baseflow contribution to the St. Marks River below the rise is about 77 percent of the river flow on average for the 51-year mean daily flow period of record using the baseflow separation analysis. The cumulative ground water and surface water contribution to the river for period of record is provided in Figure 13. The cumulative flow distribution indicates the influence of the ground water storage component of the aquifer and the importance of ground water flow to the lower St. Marks River system.

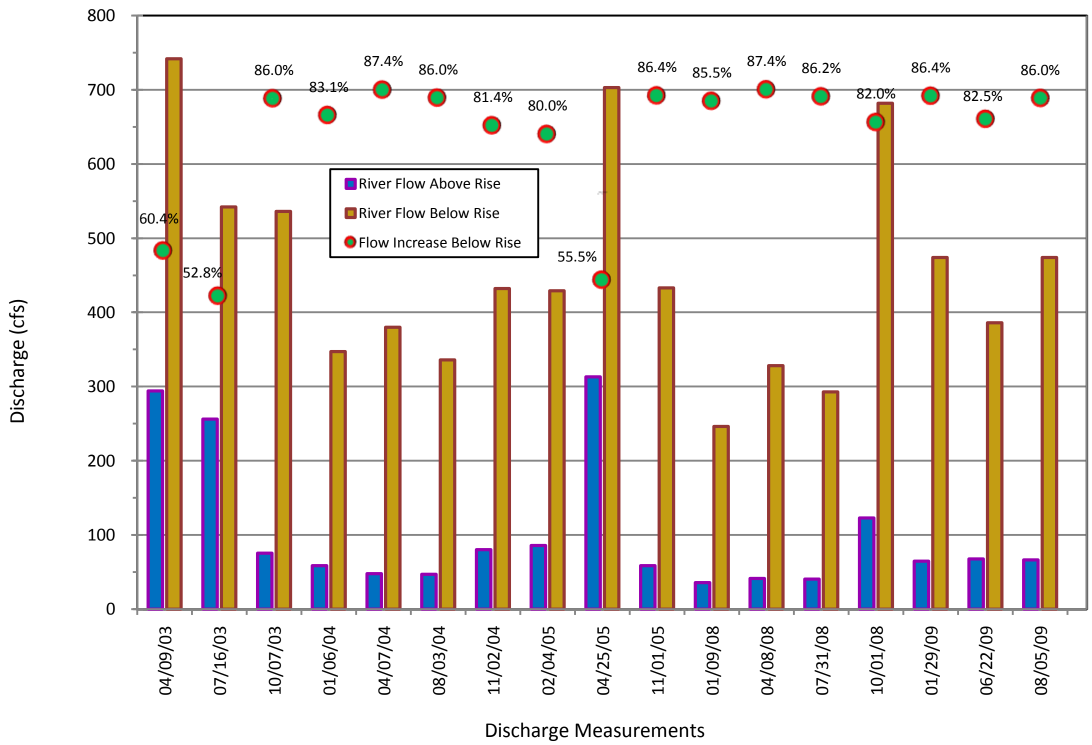


Figure 11 – Discharge Measurements at St. Marks River Rise

When the river re-emerges below Natural Bridge it flows south about 11.4 miles to the confluence with the Wakulla River at the town of St. Marks. The majority of the St. Marks River Watershed (93 percent of the watershed) lies above Natural Bridge Rise. While the river continues to pick up inflow in the lower reaches, the majority of the input to the river above the confluence with the Wakulla River is from the drainage area (both surface and ground water flow contribution) above the rise. After joining with the Wakulla River, the St. Marks River flows about 4 miles south through coastal estuarine habitat and empties into Apalachee Bay near the St. Marks Lighthouse.

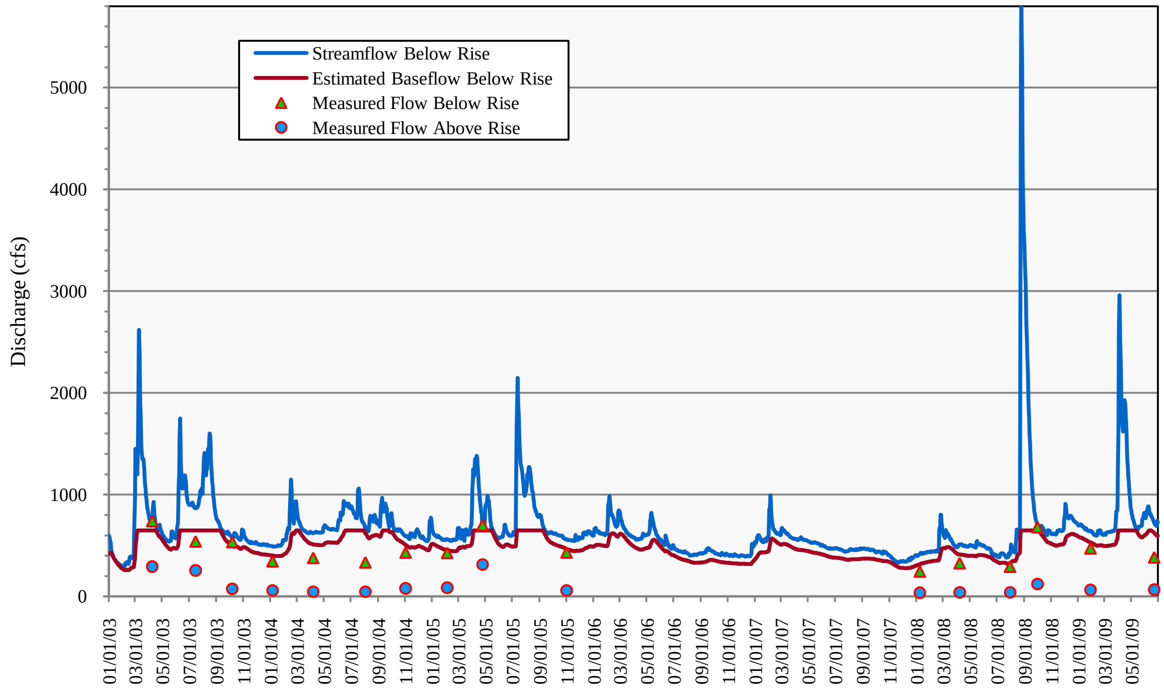


Figure 12 – Baseflow Estimation at St. Marks River Rise

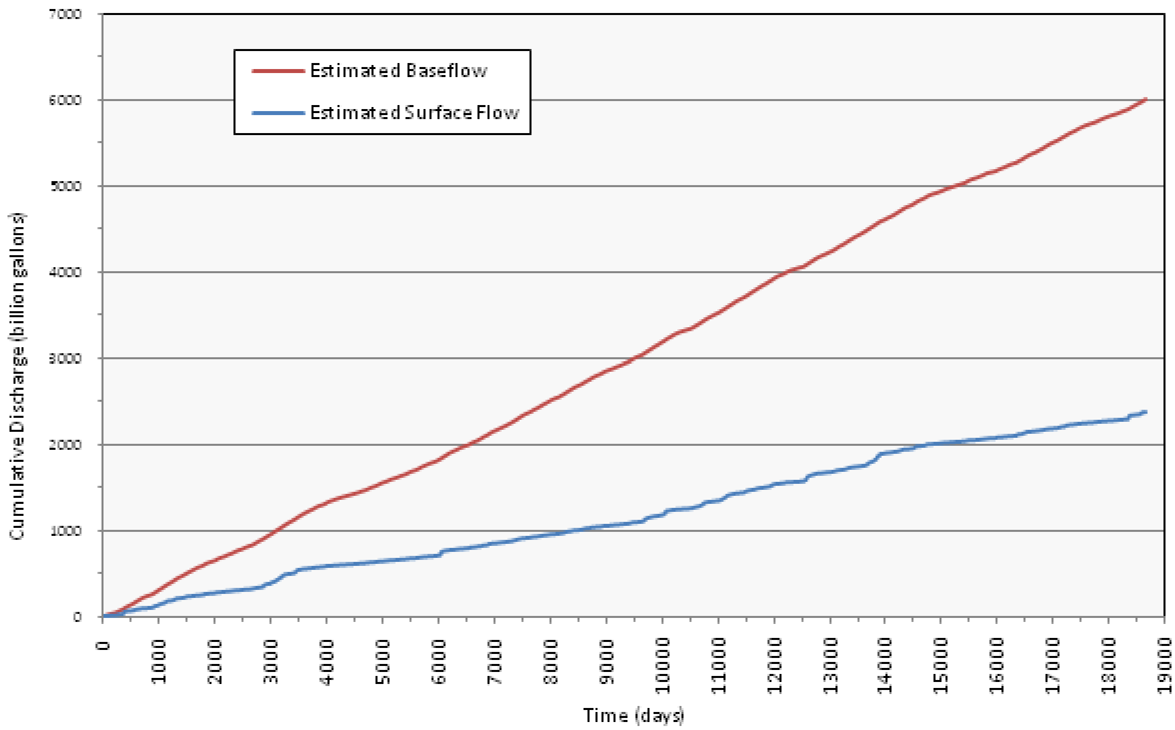


Figure 13 – Cumulative Baseflow (Ground Water Storage) and Surface Discharge at St. Marks Rise (1957 – June 2009)

5.0 WAKULLA RIVER HYDROLOGY

The main tributary of the St. Marks River is the Wakulla River, which originates in northern Wakulla County at Wakulla Springs and flows south approximately ten miles before joining the St. Marks River at the City of St. Marks. The Wakulla River is a classic spring run and receives most of the freshwater flow from springs or small spring runs that discharge into the river. The sub-basins that contribute flow to the Wakulla River include: Munson/McBride Slough, Bradford Brook, Fischer Creek, Black Creek and Wakulla River (Figure 9). The majority of the flow into the Wakulla River is discharged through the main spring vent at Edward Ball Wakulla Springs State Park.

In addition to the main spring vent that discharges on average about 450 cfs (about 291 mgd), 28 additional springs have been identified in close proximity to the river that discharge directly or through spring runs into the river (Barrios 2006). The combined discharge of these smaller springs represents a small percentage of the Wakulla River flow. Sally Ward Spring had the next highest flow after Wakulla Springs with a measured discharge of 12.5 cfs (Second Magnitude). Five additional springs had flows from 1 to 6 cfs (Third Magnitude) with the remaining springs discharging less than 1 cfs.

5.1 Sinking Streams

Excluding the Wakulla River, all major streams in the Wakulla River Watershed eventually drain to sinkholes and become sub-surface flow. Portions of the drainage from these sinking streams reappear throughout the Woodville Karst Plain contributing to the outflows of the numerous springs such as Wakulla Spring and vents at Spring Creek.

The Munson/McBride sub-basin of the Wakulla River Watershed collects the majority of stormwater from the west and south side of the City of Tallahassee. Much of this stormwater runoff flows through Lake Munson and continues flowing south about eight miles in Munson Slough to Ames Sink where it flows underground. Dye trace studies conducted in 2005 by Hazlett-Kincaid indicated that a portion of the runoff entering Ames Sink from Munson Slough emerges from Indian, Sally Ward and Wakulla Springs within 14-22 days (Kincaid et al. 2007a). Cave divers have also mapped underground tunnels that connect Fisher Creek and Black Creek (sinking streams near the Leon/Wakulla county line in the Leon Sinks Geological Area) to Indian Springs and Wakulla Springs.

The surface topography (Figure 14) indicates that sinking streams like Munson Slough, Fisher Creek and Black Creek were surface streams in the past and drained directly to the Wakulla River. The erosive processes on the limestone in the upper Floridan Aquifer, particularly in the Woodville Karst Plain with little or no confinement, created sinkholes and other dissolution features creating the numerous sinking streams and springs we see today in the watershed.

One of the challenges today is to recognize the highly interactive connection between surface and ground water resources and the direct impacts our activities in the watershed have on the water resources. Best management practices (including stormwater, wastewater treatment and disposal, agricultural activities and public education to reduce non-point pollution) will need to continue to be implemented to improve and protect both surface and ground water resources. The City of

Tallahassee and Leon County have completed numerous stormwater retrofit projects in the Munson/McBride sub-basin in recent years that provide flood attenuation and improve water quality. These ongoing efforts continue to improve water quality and reduce the impairment of downstream water resources that include streams, lakes, springs and the Wakulla and St. Marks Rivers.

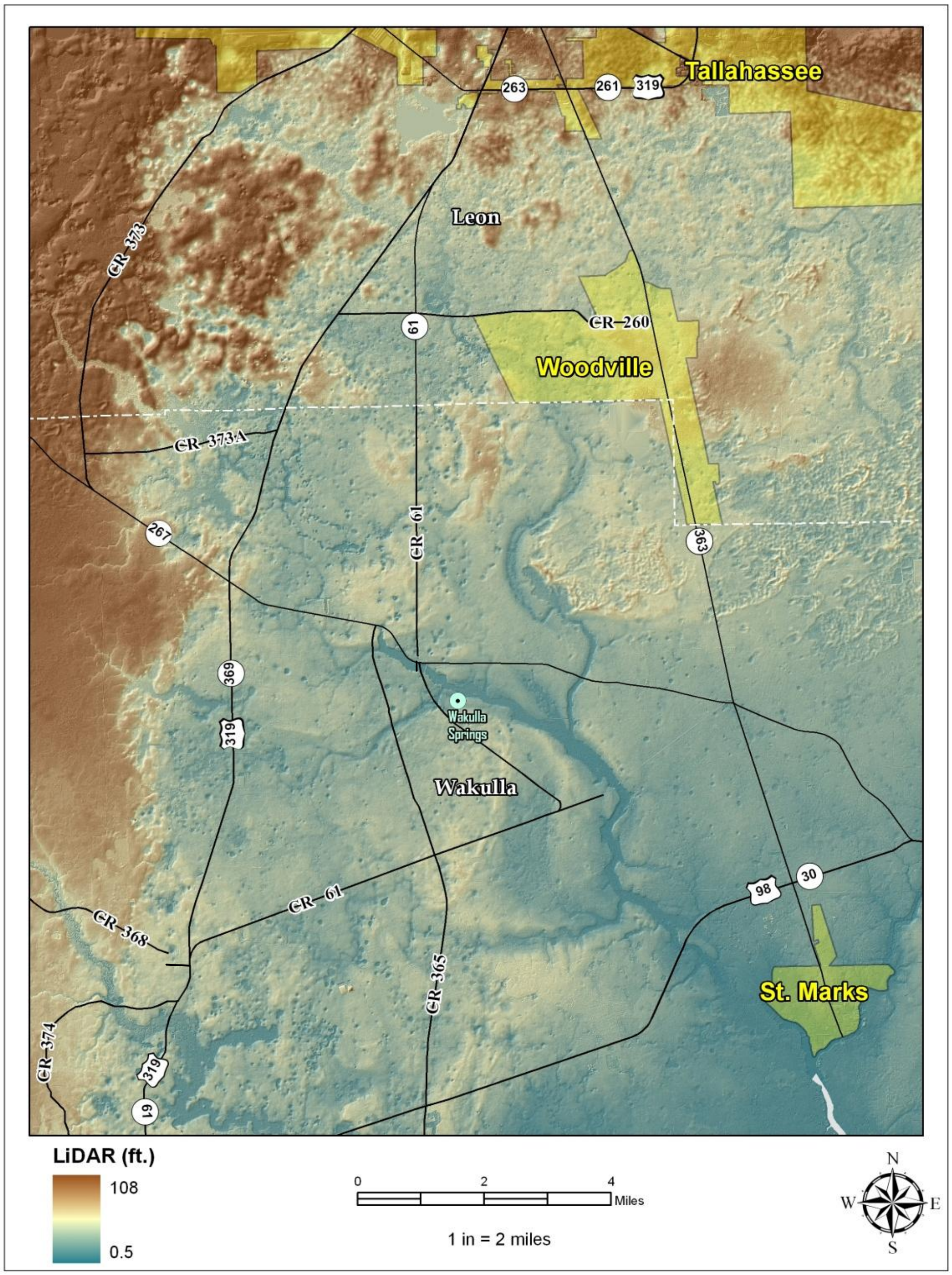


Figure 14 – Wakulla River Digital Elevation Map

6.0 ST. MARKS WATERSHED DISCHARGE

The primary freshwater inflows to the lower reaches of the St. Marks River Watershed are from the St. Marks River and its tributary the Wakulla River. As previously discussed, a significant portion the flow in both rivers is spring flow into the rivers. The St. Marks River flows directly into Apalachee Bay; freshwater also enters the bay from the Ochlocknee River on its western side as well as through a number of adjacent small tidal creeks and springs, particularly the Spring Creek Springs Group and several offshore vents (Scott et al. 2004). Further to the east, the Aucilla, Econfina and Fenholloway Rivers provide freshwater inflows to the bay. The comparative annual discharge for the rivers that flow into Apalachee Bay is shown in Figure 15. The St. Marks and Wakulla Rivers receive a large proportion of their flow from ground water and have less annual flow variability than the other major rivers discharging to the bay.

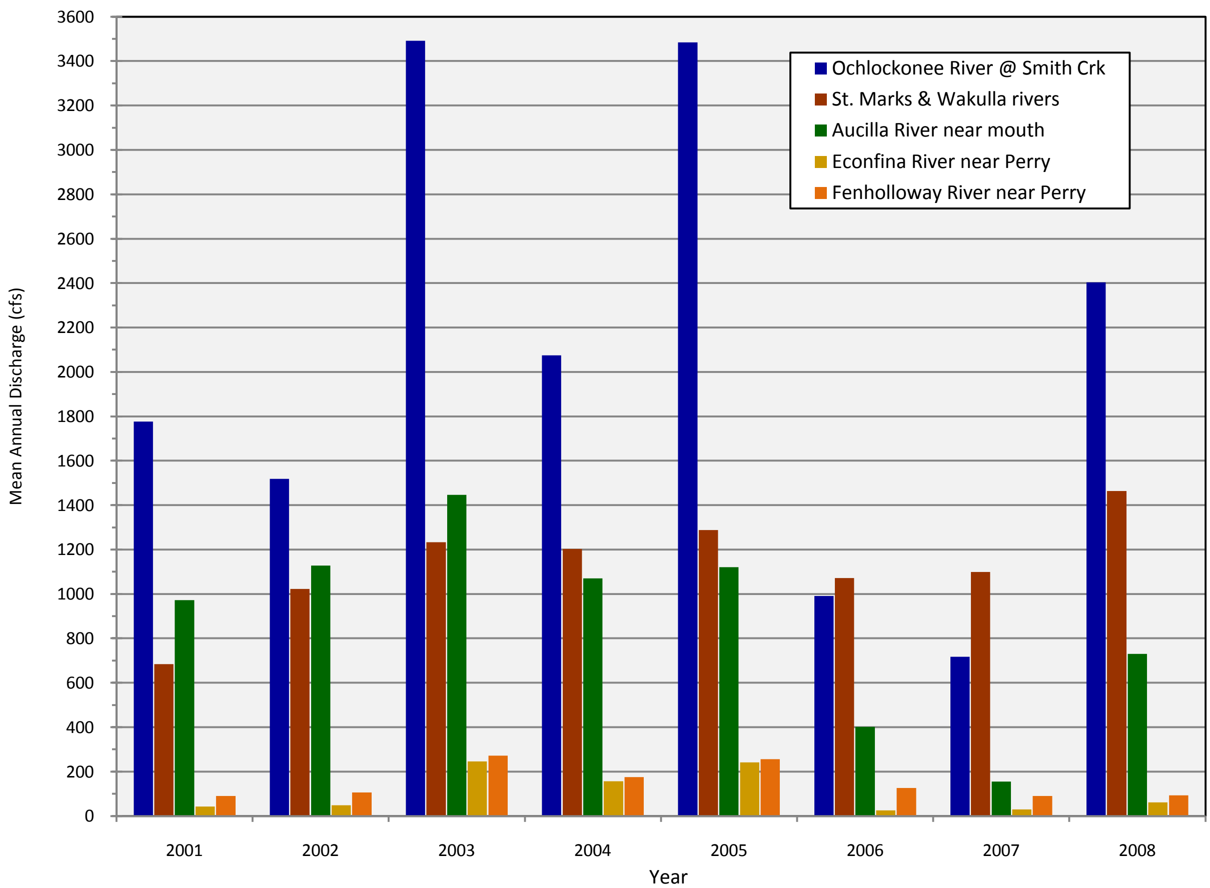


Figure 15 – Freshwater Inflows to Apalachee Bay

6.1 St. Marks River Flow

In the lower St. Marks River Watershed there are two continuous flow monitoring stations operated by the USGS on the St. Marks River, one located below the river rise (St. Marks River near Newport) and the other on the Wakulla River at CR 365 (Wakulla River near Crawfordville) at the south end of the Wakulla Springs State Park. In addition, there are continuous monitoring stations operated by the NWFWMD that collect discharge, river stage, rainfall, and other environmental data (Figure 16). The USGS also operates a monitoring station in the estuary at Spring Creek that collects discharge, tidal, and other environmental data.

Figure 16 - Monitoring Stations in the Lower St. Marks River Watershed

The St. Marks River (Newport) station is located about 0.6 miles south of the Natural Bridge Rise where the river re-emerges after flowing below ground. This station has been in operation since October 1956 with a 20-month break of record between October 1994 and June 1996. The surface drainage area for this station is about 561 square miles (359,308 acres) which is approximately 93 percent of the surface drainage for the river. The river picks up additional flow below the USGS station before it is joined by the Wakulla River; but this percentage is small relative to total river flow because the majority of the surface drainage and ground water contribution area is above the gauging station.

The mean daily discharge at the Newport station has a wide range of flows as shown in Figure 17. The daily mean flow for the period of record ranged from a high of 5,820 cfs in August 2008, when Tropical Storm Fay generated over 20 inches of rainfall in parts of the watershed over a 3-day period, to a low of 251cfs during a severe drought in October 2001. The mean discharge for the 51-year period of record is 695 cfs (449 mgd). Rainfall distribution and intensity in the watershed is the primary factor influencing the magnitude and timing of flows on the St. Marks and Wakulla rivers.

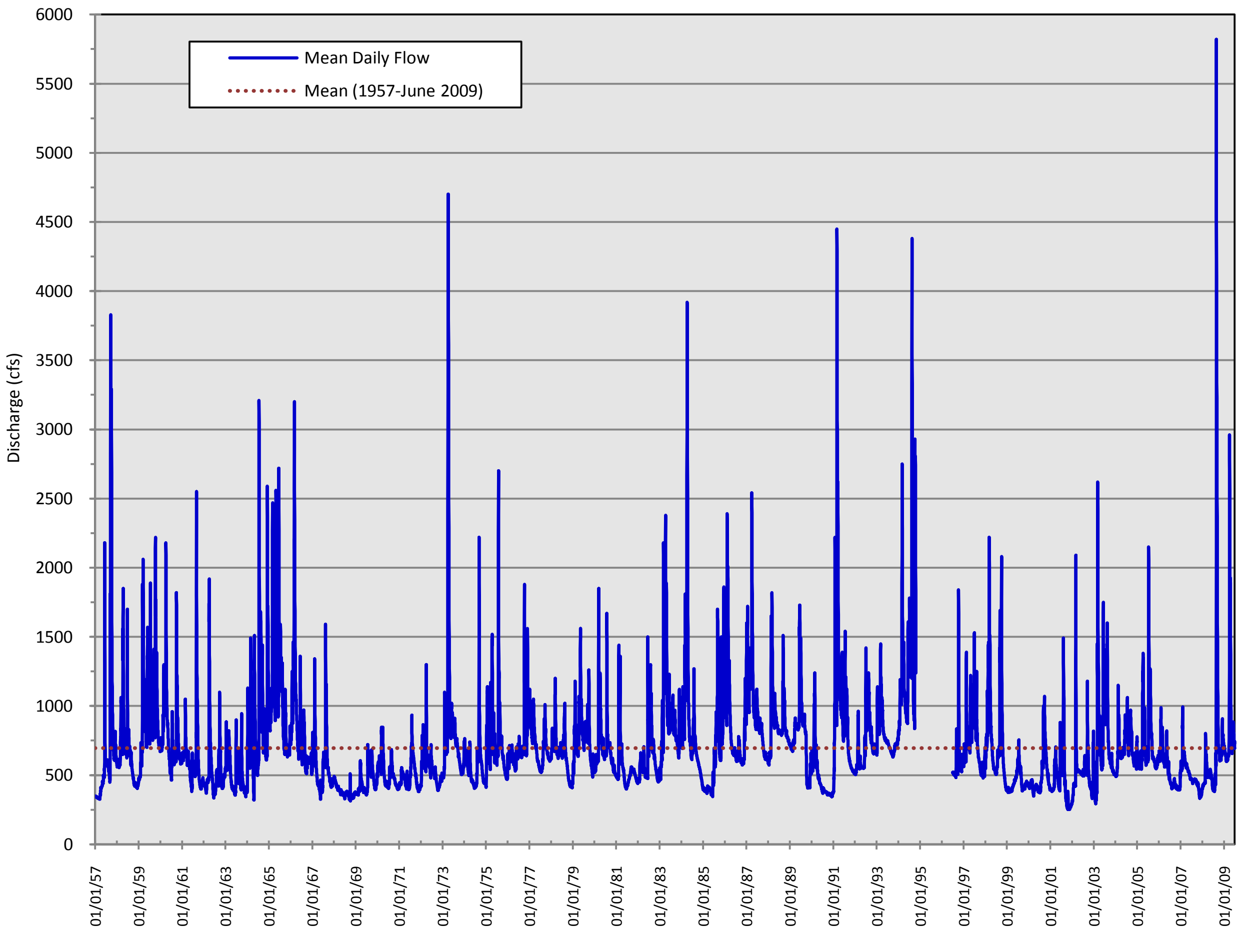


Figure 17 - Daily Mean Discharge – St. Marks River (1957-June 2009)
(Missing Record Period: 10/24/1994 - 06/30/1996)

6.2 Rainfall and Flow

The National Weather Service (NWS) operates a rainfall station in Tallahassee that reflects the long-term average precipitation in the St. Marks Watershed. Rainfall distribution can be highly variable for individual rainfall events across small geographic areas but long-term precipitation records are representative of rainfall in the watershed.

The St. Marks River Watershed typically receives abundant rainfall throughout the year. The current long-term average annual rainfall in Tallahassee for the years 1971 through 2000 (National Weather Service) is 63.21 inches (Figure 18). During the last 61 years the highest annual rainfall in Tallahassee was 104.18 inches in 1964 and the lowest annual amount was 30.98 inches in 1954; the next two lowest years were 2007 and 2000 (44.47 inches and 44.51 inches respectively).

Rainfall can be highly variable from year to year depending climatic conditions and storm systems affecting the region (Figure 19). The long-term rainfall record indicates summer months (June - August) are typically the wettest season of the year receiving on average about 22 inches of rainfall (Figure 20). This is due to tropical storm systems and convective thunderstorm activity which occur most frequently during the summer months. The fall months in the panhandle usually receive the lowest rainfall, with October normally receiving the least monthly precipitation during the year followed by April (Figure 18).

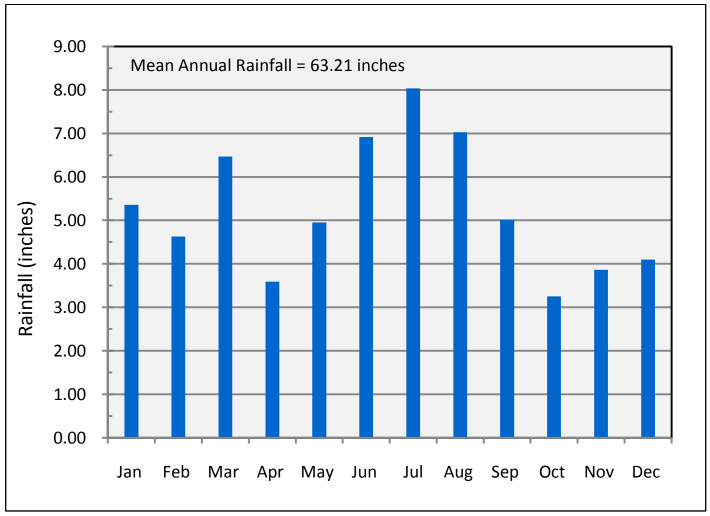


Figure 18 – Tallahassee Normal Monthly Rainfall

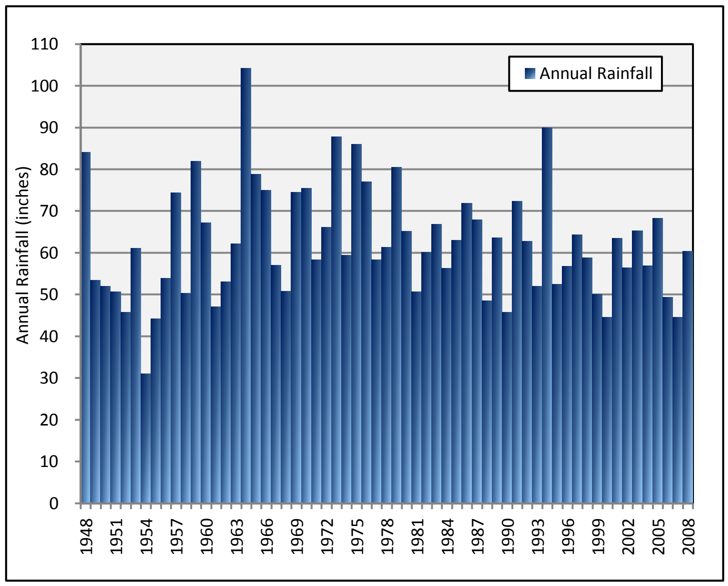


Figure 19 – Tallahassee Annual Rainfall (1948-2008)

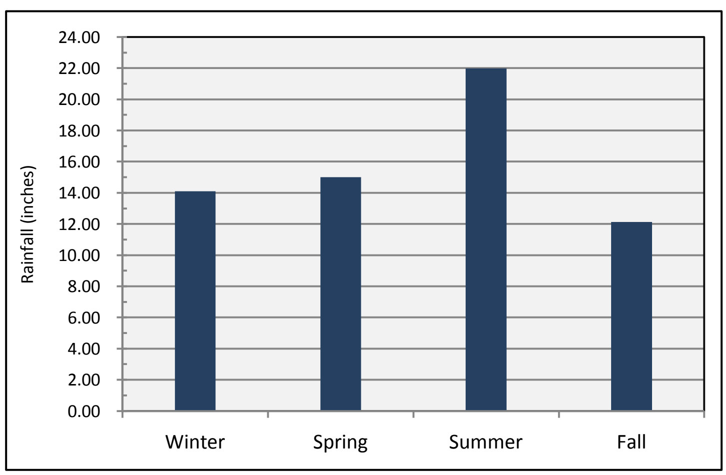


Figure 20 – Tallahassee Normal Seasonal Rainfall

Flow variability in the St. Marks River is significantly less than other Florida panhandle rivers that are primarily fed by surface runoff. In Figure 21 a comparison of the daily mean flows for the Ochlockonee River (Havana) and the St. Marks River (Newport) for the 2004 – 2008 illustrates the variability of daily flows for the two rivers. The surface drainage area for the Ochlockonee River at Havana (1,140 square miles) is about twice the size of the St. Marks at Newport (561 square miles). The peak flow in August 2008 (runoff from Tropical Storm Fay) on the Ochlockonee River was 34,300 cfs compared with a peak of discharge of 5,820 on the St. Mark River. The lowest flow on the Ochlockonee River for this record period was 26 cfs in October 2007 and the lowest flow on the St. Marks River was 333 cfs in November 2007. The St. Marks River has a significant baseflow contribution from ground water.

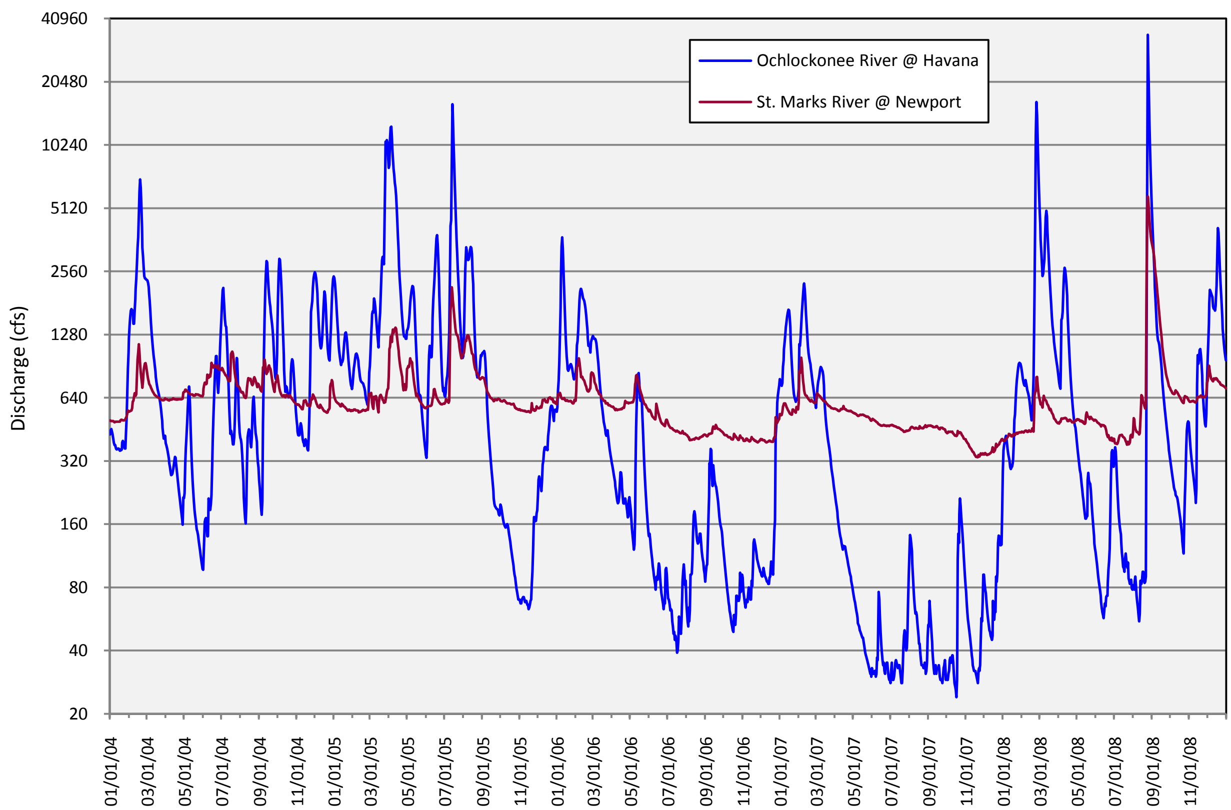


Figure 21 - Daily Mean Discharge – Ochlockonee and St. Marks Rivers (2004 - 2008)

The range of observed flows for each calendar day (maximum, mean and minimum for complete years) is provided in Figure 22 for the St. Marks River at Newport. The highest flows for the period of record were observed in the summer and spring months, the lowest flows occurred during the fall.

The high recharge rate and sinking streams in the Woodville Karst Plain contribute to the ground water inflow to the river and provide a significant proportion of the total flow. Travel time for precipitation to recharge the aquifer and re-emerge in the St. Marks watershed is highly variable and

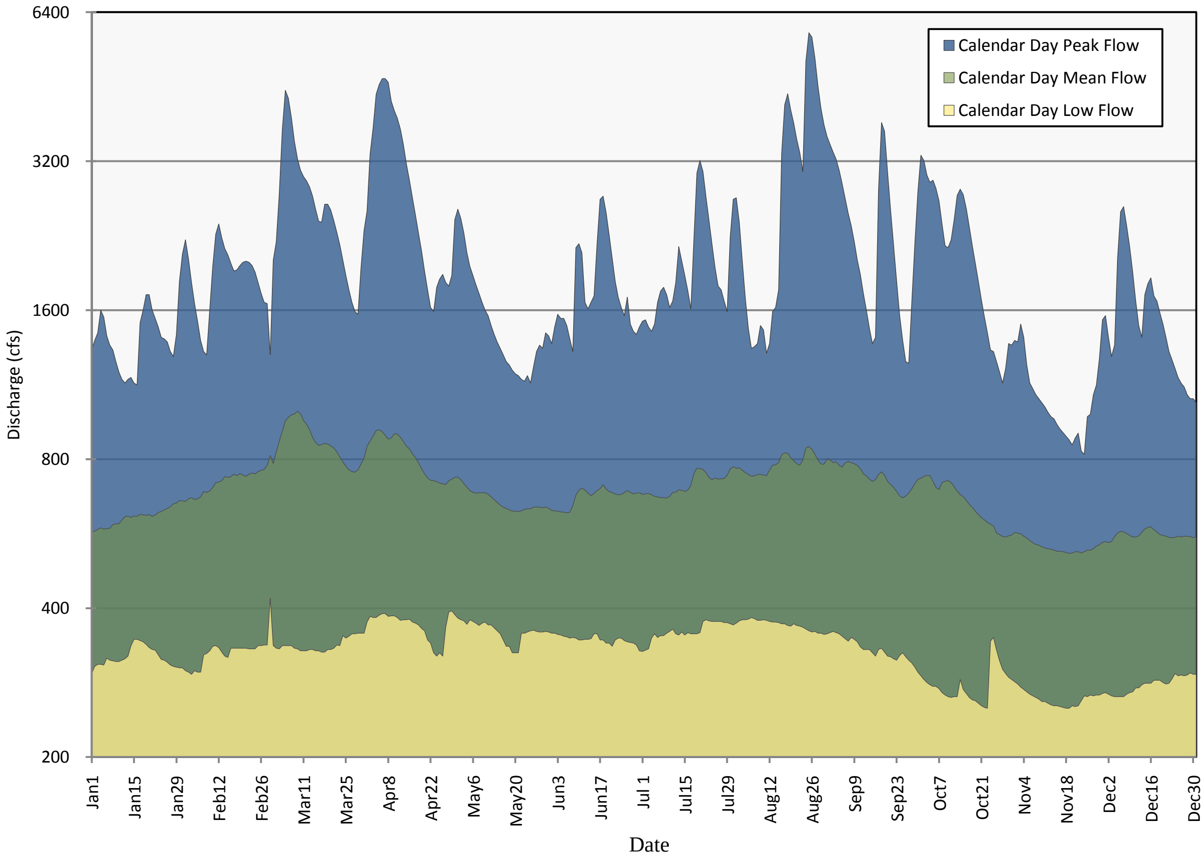


Figure 22 - Daily Flow Characteristics – St. Marks River (1957 - 2008)

can be days, weeks or years depending on where the recharge occurs in the watershed. The USGS analyzed the relative age or resident time for ground water from four City of Tallahassee public water supply wells (Davis and Katz 2007). These wells were drilled to depths of 200 feet in southern Leon County to 450 feet in northern Leon County. The estimate age of ground water ranged from 7 to 31 years for these Floridan wells. The results also showed a consistent trend indicating relative age decreases from north to south in the watershed. Dye trace studies completed in 2006 and 2007 by Hazlett-Kincaid demonstrated that it took 45 – 60 days for ground water to travel from the two wells in southern Leon County to Wakulla Springs (Kincaid et al. 2007b).

6.3 St. Marks River Low-Flow Analyses

Analysis of the mean daily flows for the St. Marks River at Newport was completed using a Log-Pearson Type III probability distribution. This type of analysis provides probabilistic estimates of low and high flow frequencies and is typically used for stations with at least ten years of continuous flow record. The Newport station has a 51-year period of record from 1957 – 2008 with a period of missing data from October 1994 – June 1996. The low-flow statistics for the Newport station are provided in Figure 23 and Table 1. The low-flow recurrence (Figure 23) shows a convergence of flows for the 50- and 100-year recurrence intervals. This indicates a significant ground water contribution during low-flow conditions.

The lowest observed mean daily flow for the 51-year Newport record was 251 cfs in October 2001. This flow is equal to the 1Q100 which is the lowest one-day flow expected to occur in 100 years. This record low flow occurred after two significant drought years in 1999 and 2000 when the cumulative rainfall for the two years was 31.84 below normal. This record low flow occurred in October 2001 despite two tropical storms (Allison and Barry) bringing very high rainfall and wide spread flooding to the watershed in June and August of 2001, respectively. This delayed low flow response on the St. Marks River demonstrates the slow recharge rate of the aquifer in comparison with the rapid surface water response after rainfall events.

A widely used low-flow statistic is the 7Q10 which is defined as the lowest stream flow for seven consecutive days expected to occur once in 10 years. The 7Q10 statistic is used for regulatory purposes for stormwater and wastewater allocation, Total Maximum Daily Loads (TMDLs) and biological assessments. The 7Q10 for the Newport station on the St. Marks is 321 cfs (Table 1). The 7Q10 for the Ochlockonee River at Havana is 31 cfs (Rumenik and Grubbs 1996) which is about one-tenth of the flow on the St. Marks. The Havana station has twice the contributing basin area as the Newport station which further illustrates the significant ground water influence on low flows on the St. Marks River.

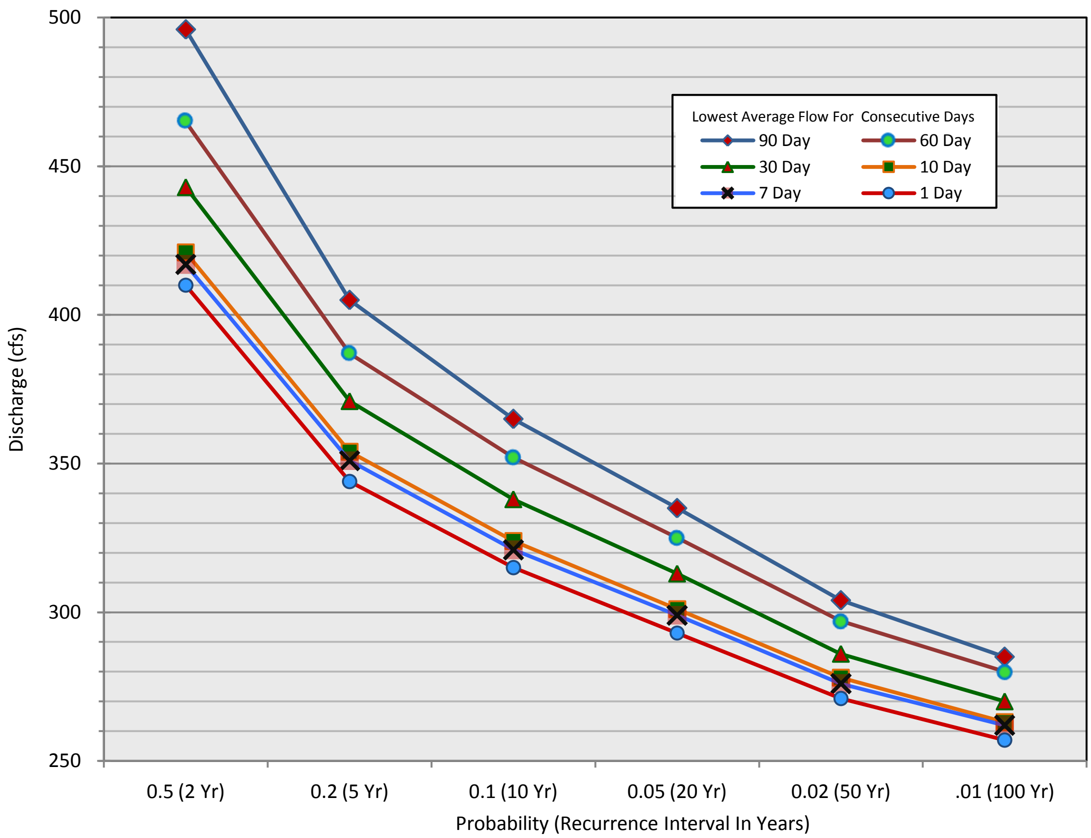


Figure 23 - Low Flow Recurrence – St. Marks River at Newport

Recurrence Interval	Lowest Average Flow for Indicated Consecutive Days (cubic feet per second)									
	1-day	2-day	3-day	7-day	10-day	30-day	60-day	90-day	183-day	365-day
100 Years	257	258	258	262	263	270	280	285	318	360
50 Years	271	272	272	276	278	286	297	304	342	388
20 Years	293	294	295	299	301	313	325	335	381	435
10 Years	315	316	317	321	324	338	352	365	418	480
5 Years	344	346	347	351	354	371	387	405	468	539
3 years	375	376	377	381	385	405	423	447	518	599
2 Years	410	412	413	417	421	443	465	496	577	668
1.01 Years	687	689	690	693	693	708	776	875	998	1157

Table 1 – St. Marks River at Newport - Low Flow Frequency Analysis

6.4 St. Marks River High-Flow Analyses

The high-flow probabilities for the St. Marks at Newport are provided in Figure 24 and Table 2. High-flow statistics are typically used to predict recurrence frequencies for stormwater design and flood frequency analyses. The range of high flow increases significantly with the increasing recurrence interval in years. A mean one-day peak flow of 5,927 cfs would only be expected to occur once every 100 years. The peak daily mean observed flow for the 51-year Newport record was 5,820 cfs in August 2008 after record rainfall in the basin from Tropical Storm Fay. The peak two-day mean flow was 5,760 cfs following T.S. Fay. The peak one-day and two-day mean flows were just below the 100-year recurrence high flow.

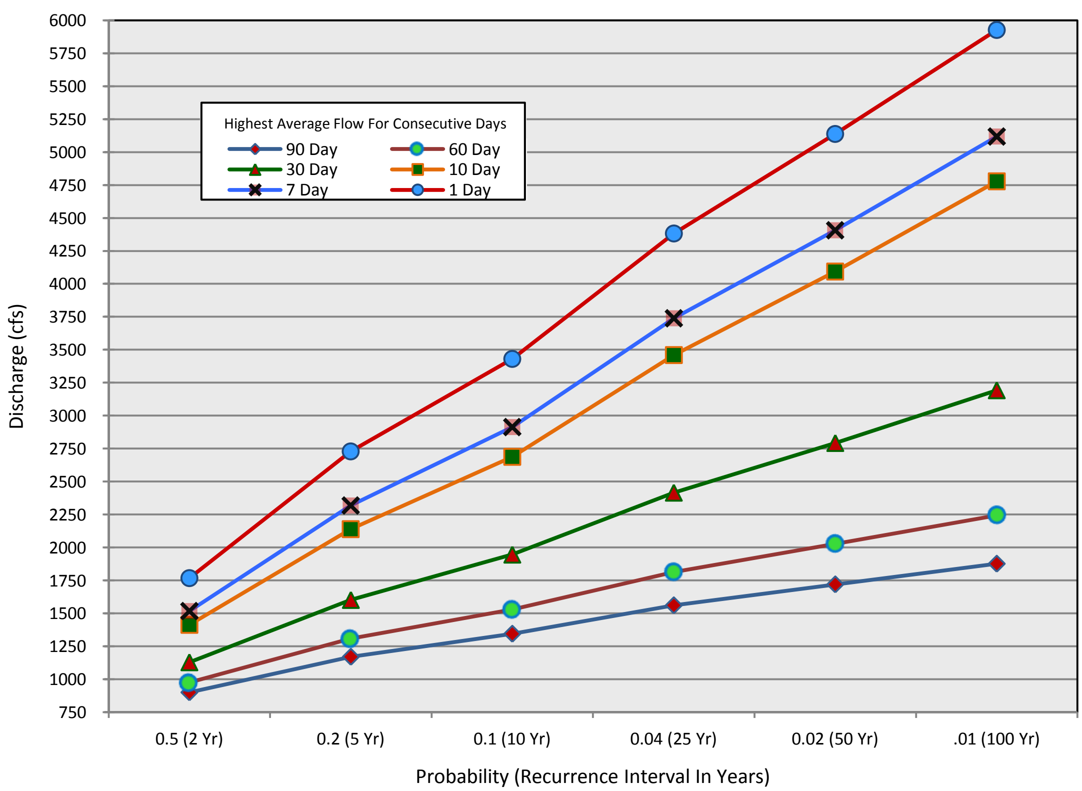


Figure 24 - High Flow Recurrence – St. Marks River at Newport

Recurrence Interval	Highest Average Flow for Indicated Consecutive Days (cubic feet per second)									
	1-day	2-day	3-day	7-day	10-day	30-day	60-day	90-day	183-day	365-day
100 Years	5927	5895	5742	5118	4777	3193	2242	1876	1498	1157
50 Years	5137	5095	4961	4407	4093	2793	2026	1719	1390	1089
25 Years	4383	4335	4219	3740	3460	2416	1813	1560	1279	1017
10 Years	3431	3379	3288	2914	2688	1946	1529	1344	1123	912
5 Years	2729	2677	2607	2318	2139	1602	1308	1169	991	822
3 years	2210	2161	2106	1884	1744	1348	1134	1029	882	744
2 Years	1766	1721	1680	1517	1412	1129	976	899	778	668
1.01 Years	539	518	513	514	518	498	457	442	386	360

Table 2 – St. Marks River at Newport - High Flow Frequency Analysis

6.5 St. Marks and Wakulla River Flood Model

A riverine flood analysis was completed for the lower St. Marks River below the rise and the Wakulla River to estimate flood inundation for 10-, 50- and 100-year flood events. A frequency analysis was performed using NWFWMD and USGS continuous gage records. Results of this analysis were fit to a log-Pearson Type III distribution to obtain the desired discharge frequency relationship to be used in the regression analysis. The analysis was performed using the National Flood Frequency (NFF) program and results were used in the hydraulic analysis.

The HEC-RAS 3.1.3 model (U.S. Army Corps of Engineers) was used to estimate flood elevations and floodplain boundaries. The analysis was a one-dimensional model run to calculate the steady flow water surface profiles. The model schematic was developed using HEC GeoRAS version 4.0, Wakulla County LiDAR data, ortho-aerial photography, USGS 7.5 minute quadrangles, field inspections and surveyed cross-sections of the river channel. Bridge data from Florida Department of Transportation (FDOT) plans were used in the model. The CR 365 Bridge was surveyed and referenced using LiDAR. Finally, the mean high tide measured at the Wakulla and St. Marks Rivers was used as the boundary condition of the model. The results of this model analysis were overlayed on a digital elevation map (Figure 25) to show the extent of flooding for the 10- and 100-year flood events. The flood zones depicted in the map represent flooding from river flow only and do not include coastal flooding from storm surge. The NWFWMD is currently in the process of restudying the 100-year flood boundary that would be caused by coastal flooding from hurricanes.

The flood plain area inundated by flood events on spring fed rivers like the St.Marks and Wakulla rivers is typically less extensive than for rivers primarily fed by surface runoff. In the Woodville Karst Plain the sinking streams provide an additional storage mechanism for runoff which reduces the peak flows discharging from the springs into the rivers. This is illustrated by comparing the peak flows from a flood event in August 2008 caused by intense rainfall in north Florida and south Georgia from Tropical Storm Fay. This storm generated over 20 inches of rainfall during a three-day period in parts of the St. Marks River watershed. The St. Marks River and the Ochlockonee River both experienced significant flooding from this event but the impacts on the St. Marks River were primarily confined to the flood plain in the immediate vicinity of the river. The drainage area contributing to the Ochlockonee River at Havana is about twice the size of the St. Marks River above the river rise. The peak flows resulting from the storm were over 6 times higher on the

Ochlockonee River at Havana than the St. Marks River. Mean daily flow on the Ochlockonee River at Havana preceding T.S. Fay was 85 cfs rising to 37,400 cfs on 08/25/09 after the storm. Mean daily flow on the St. Marks River was 569 cfs before the event increasing to 5,890 cfs after storm passage (Figure 21). Peak flow on the Wakulla River after T.S. Fay was about 2,510 cfs with no reports of riverine flooding.

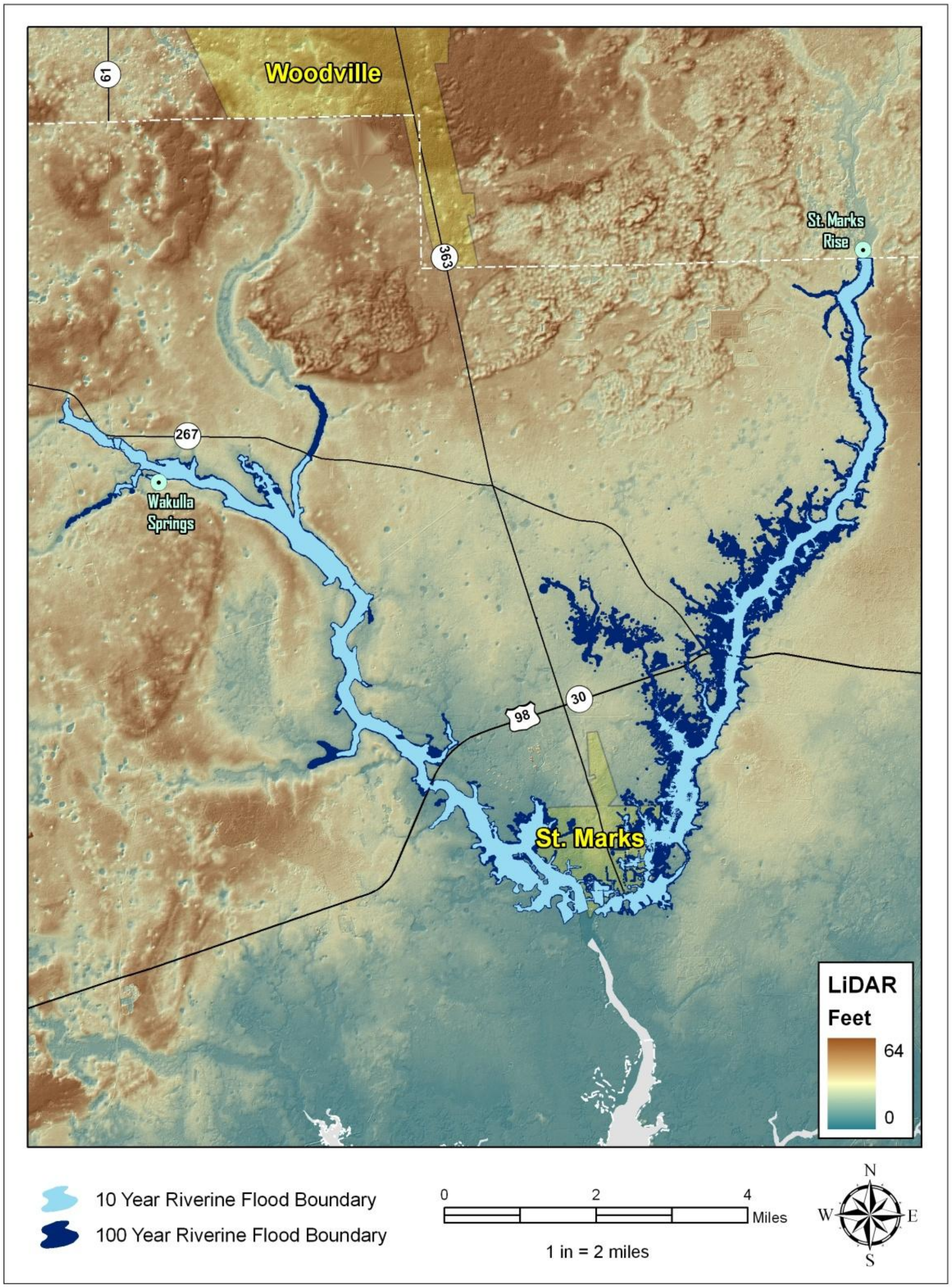


Figure 25 - St. Marks and Wakulla Riverine Flood Inundation

6.6 Wakulla Springs Flow

The Wakulla River is the main tributary to the St. Marks River and contributes a significant proportion of the flow to the lower St. Marks. The two rivers join near the City of St. Marks in Wakulla County about 9.3 miles south of the main spring vent that forms the Wakulla River which is located in the Edward Ball Wakulla Springs State Park. The Wakulla River receives most if its flow from the main spring vent with additional flow from spring runs and submerged springs in the river. Twenty-eight small springs have been identified in close proximity to the Wakulla River and contribute flow through spring runs or direct discharge into the river (Barrios 2006). Sixteen springs that contribute flow to the Wakulla River below the main spring vent were measured in 2005 and 2006; the combined flow from these springs was about 36 cfs. The average discharge from Wakulla Spring for the period from May 1997 – June 2009 was 450 cfs. The minor springs that were measured contribute about 8% in additional flow to the river compared with the average flow of the main spring vent. The flow from the main spring fluctuates significantly depending on recharge in the basin; a similar large fluctuation in flow is likely with the minor springs contributing flow to the river. The main spring vent is the dominant source of fresh water discharge to the Wakulla River.

The NWFWMD operated a continuous discharge meter in the main vent of Wakulla Springs from May 1997 to July 2006. In order to calibrate and verify the flow data in the main spring vent, 24 sets of discharge measurements were completed on the Wakulla River, Sally Ward Spring and the McBride Springs between 1997 and 2006. Sally Ward and McBride Springs provide the largest flow into the river between the main spring vent and the bridge at CR 365. The combined discharge of Sally Ward and McBride Springs was subtracted from the Wakulla River at CR 365 discharge to estimate the main spring vent discharge. River discharge was measured at the CR 365 Bridge rather than upstream due to heavy aquatic vegetation in the river downstream of the main spring vent that interferes with accurate measurements across the river.

In February 2004 the river was relatively clear of aquatic vegetation. Discharge measurements were completed below the main spring vent, the CR 365 Bridge, Sally Ward Spring and McBride Springs on the same morning. The main spring vent discharge and CR 365 discharge were 778 and 776 cfs, respectively, after subtracting Sally Ward and McBride Spring from the flow at the CR 365 site. This confirmed the procedure of estimating the main spring vent discharge.

The USGS installed a continuous flow station on the Wakulla River at the CR 365 Bridge over the Wakulla River that has been providing data since October 2004. The USGS station is located about three miles downstream of the main spring vent. The USGS record for the period from August 2006 to June 2009 was normalized using the mean combined discharge of Sally Ward Spring and the McBride Springs to estimate the main spring vent discharge. A continuous record was generated for the main spring discharge for the May 1997 to June 2009 period. The Wakulla Springs daily mean flow for the period of record ranged from a high of 2,195 cfs in August 2008 (rainfall from Tropical Storm Fay) to a low of 56 cfs during a severe drought period in May 2000 (Figure 26); mean discharge for the 11-year period of record was 450 cfs (291 mgd).

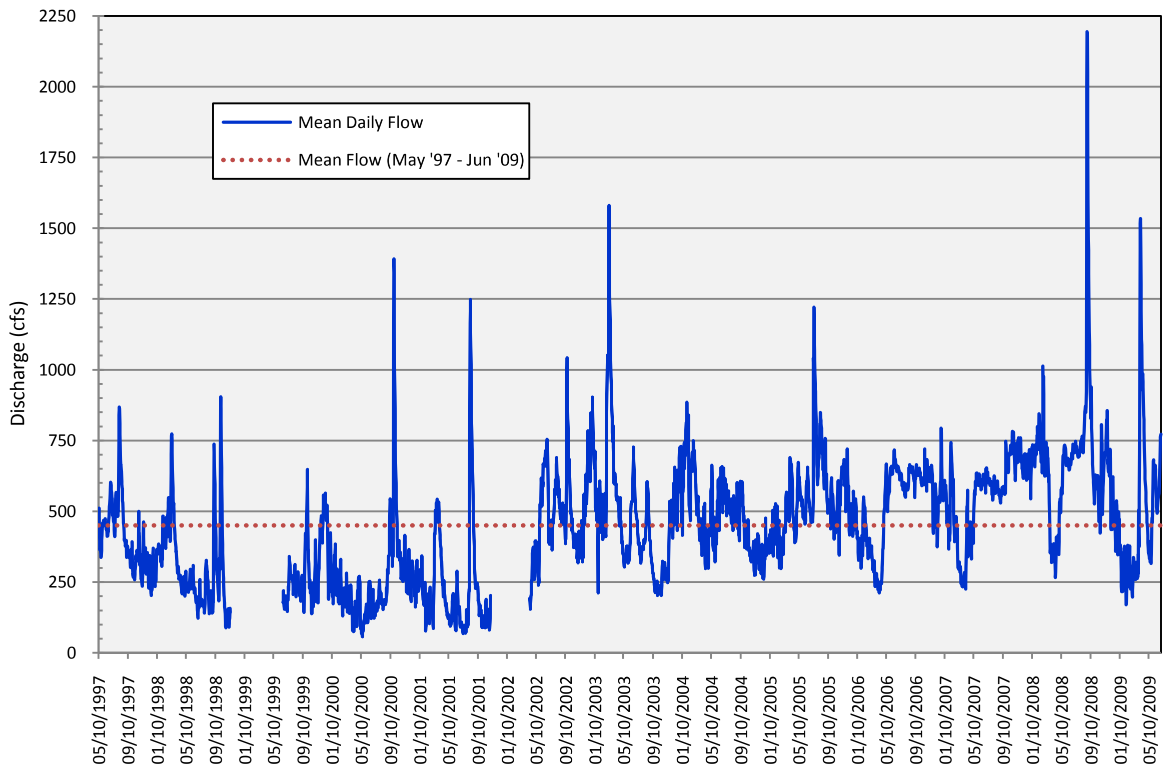


Figure 26 - Daily Mean Discharge – Wakulla Springs (May 1997 - June, 2009)
(Missing Record Periods: 11/12/98 - 06/18/99 and 11/03/01 - 04/13/02)

A series of 297 periodic discharge measurements were completed on the Wakulla River at CR 365 by the USGS from 1907 to 1987 (Figure 27). The measurements were too infrequent to provide a good flow record for this period but they do indicate the range of flows that were observed during this 80-year period. Highest flow measured during this period was 1,766 cfs in April 1973 and the lowest measurement was 23 cfs in June 1931. The annual rainfall in 1931 in Tallahassee was reported as 37.99 inches, the lowest annual rainfall on record (1886 to present). A series of 13 monthly or bi-monthly measurements were completed between February 1931 and June 1932. These measurements indicate that this was one of the lowest flow periods on record for the Wakulla River; lowest discharge measured during this period was 23 cfs and the highest was 237 cfs. Flows on the Wakulla River are affected by tides, wind and other factors that can influence discharge measurements particularly during low flow periods.

There were no measurements completed between the years 1933 to 1940. Measurements resumed in July 1941 and 268 measurements were made monthly or bi-monthly for over the next 36 years until April 1976. Periodic measurements with this frequency do not capture the peak flows and minimum flows on dynamic systems like the Wakulla River but they do provide a relative indication of the range and average flows during the period. The highest flow measured during this 36-year period (1941-1976) was 1,766 cfs (April 1973) and the lowest flow was 89 cfs (May 1955). The average flow for this series of measurements was 377 cfs.

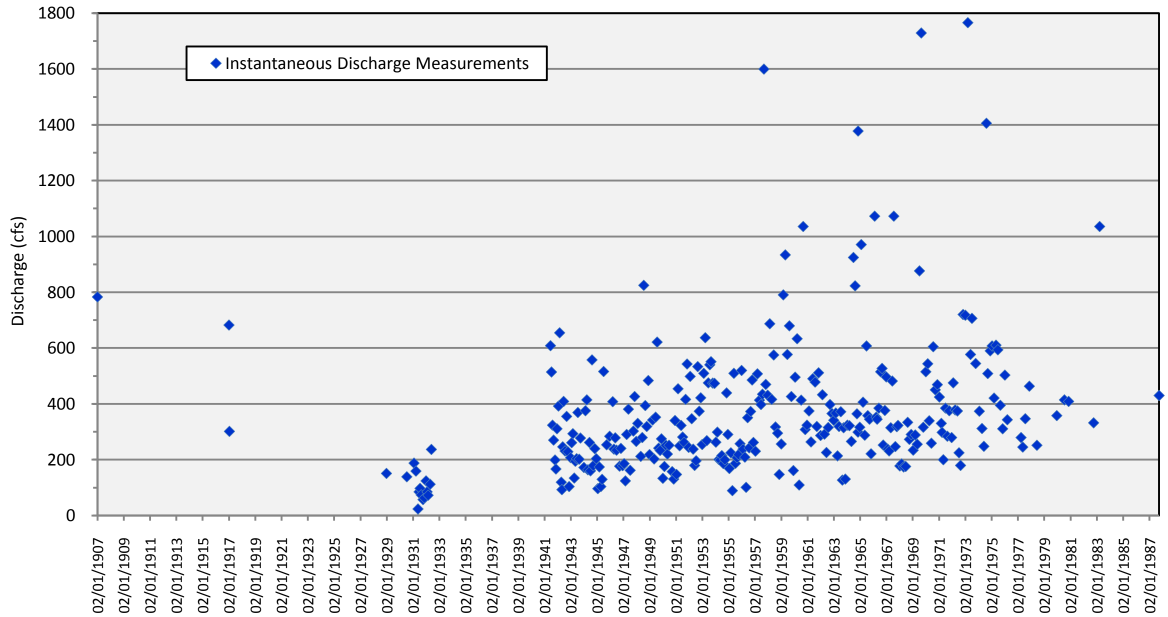


Figure 27 - Periodic Wakulla River Discharge Measurements (1907 to 1987)

The range of observed flows for each calendar day (maximum, mean and minimum) for the 11 years of continuous record for Wakulla Springs (May 1997 to June 2009) is provided in Figure 28. The highest flows for the period of record were observed in the summer and spring months. The calendar day mean and low flows exhibit little seasonal variability.

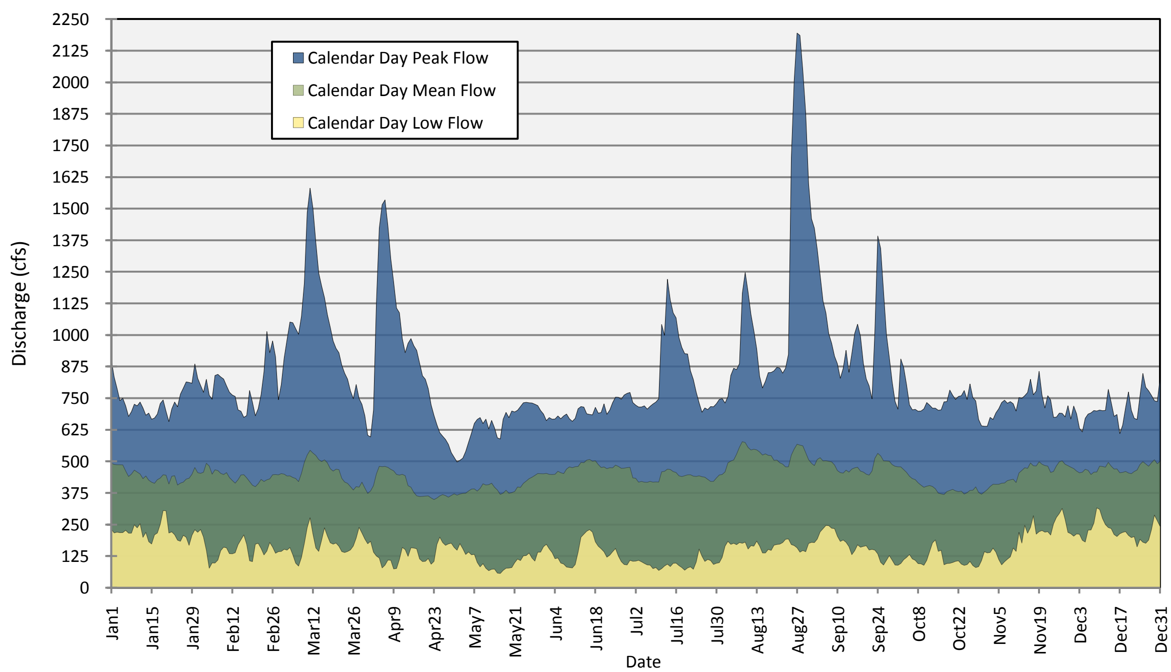


Figure 28 - Daily Flow Characteristics – Wakulla Springs (May 1997 to June 2009)

6.7 Wakulla Spring Low-Flow Analyses

The low flow statistics for Wakulla Springs (Log-Pearson Type III probability distribution) are provided in Figure 29 and Table 3. The eleven-year record period was used for the Wakulla Springs analysis. The lowest daily mean flow measured during the 11-year continuous record for Wakulla Springs was 56 cfs in May 2000. This flow is slightly lower than the estimated one-day 20-year (1Q20) low flow recurrence. A low flow measurement of 23 cfs was made by the USGS in June 1931 on the Wakulla River at the CR 365 bridge below the spring. This instantaneous measurement may not represent the mean daily flow for that day but a flow of 23 cfs is equivalent to the one-day 100-year daily mean low flow for Wakulla Springs (Table 3).

The observed and estimated low flows are lower for Wakulla Springs than the St. Marks River at Newport. The mean daily flow measured for Wakulla Springs was 56 cfs and the lowest St. Marks River flow was 251 cfs, about 4.5 times higher than the Wakulla Springs flow. The 100-year daily mean low flow is 23 cfs for Wakulla Springs and 257 cfs for the St. Marks River (Newport).The 7Q10 low flow (lowest stream flow for seven consecutive days expected to occur once in 10 years) for Wakulla Springs is 108 cfs and 321 cfs for the St. Marks River.

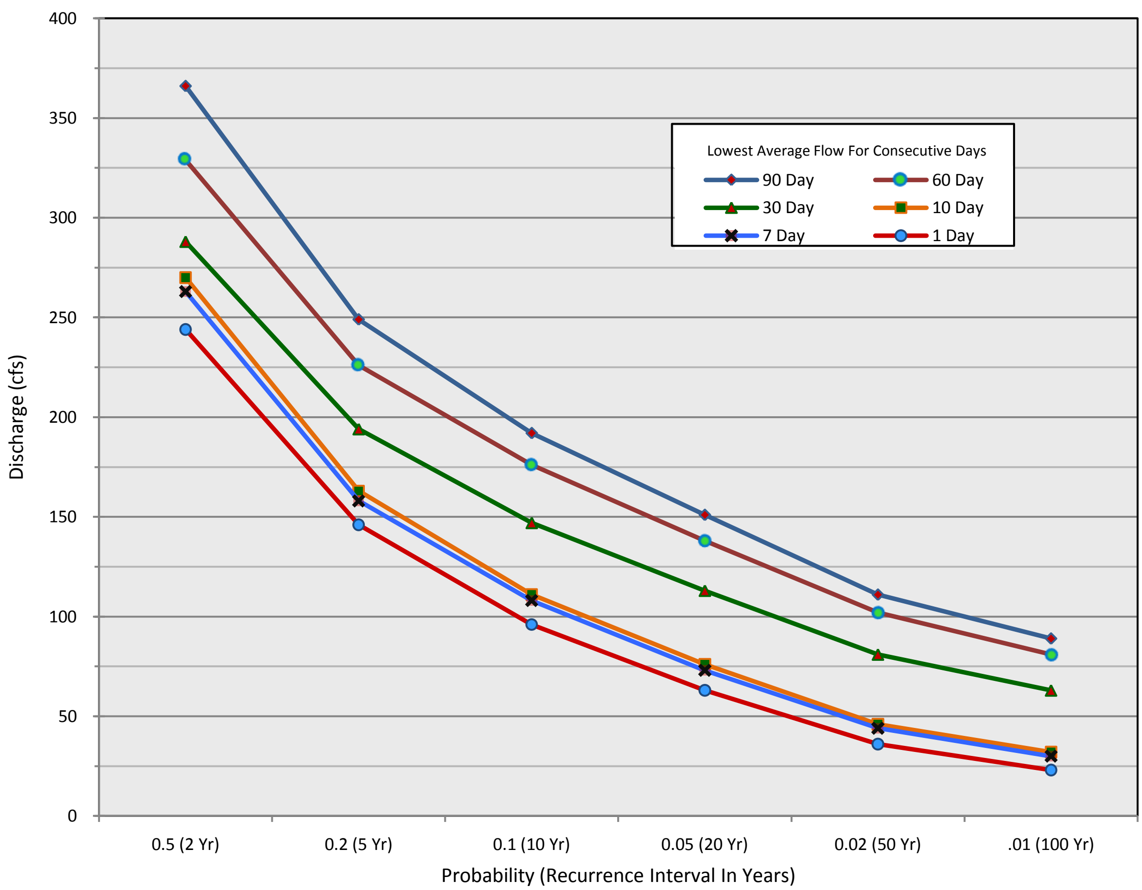


Figure 29 - Low Flow Recurrence – Wakulla Springs

Recurrence Interval	Lowest Average Flow for Indicated Consecutive Days (cubic feet per second)									
	1-day	2-day	3-day	7-day	10-day	30-day	60-day	90-day	183-day	365-day
100 Years	23	23	25	30	32	63	81	89	92	159
50 Years	36	36	39	44	46	81	102	111	120	195
20 Years	63	64	68	73	76	113	138	151	174	258
10 Years	96	98	102	108	111	147	176	192	230	320
5 Years	146	149	153	158	163	194	226	249	307	399
3 years	194	199	202	209	214	239	275	304	381	471
2 Years	244	251	253	263	270	288	329	366	460	543
1.01 Years	329	340	342	381	397	449	517	596	678	730

Table 3 – Wakulla Springs - Low Flow Frequency Analysis

6.8 Wakulla Springs High-Flow Analyses

The high flow probabilities for Wakulla Springs are provided in Figure 30 and Table 4. The range of high flows increases significantly with the increasing recurrence interval in years. The peak daily mean observed flow for the 11-year Wakulla Springs record was 2,195 cfs in August 2008 after record rainfall in the basin from Tropical Storm Fay. This peak observed flow exceeds the estimated mean one-day 10-year flow (2,039 cfs) but is less than the estimated mean one-day 25-year flow (2,606 cfs).

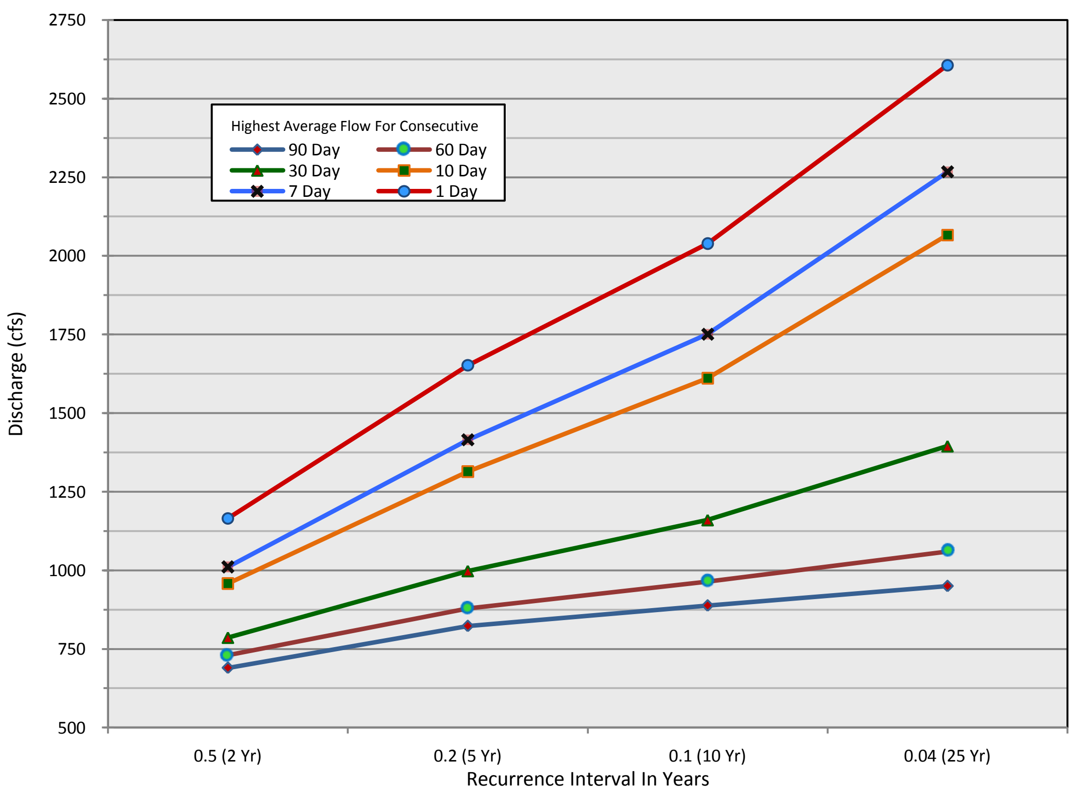


Figure 30 - High Flow Recurrence – Wakulla Springs

Recurrence Interval	Highest Average Flow for Indicated Consecutive Days (cubic feet per second)									
	1-day	2-day	3-day	7-day	10-day	30-day	60-day	90-day	183-day	365-day
25 Years	2607	2596	2540	2267	2066	1395	1060	950	817	714
10 Years	2039	2012	1963	1752	1612	1161	964	888	787	689
5 Years	1652	1621	1578	1415	1314	998	879	823	746	652
3 years	1385	1354	1317	1190	1116	882	804	760	694	604
2 Years	1165	1137	1106	1011	958	786	730	690	627	543
1.01 Years	612	609	599	607	609	548	407	326	206	159

Table 4 – Wakulla Springs - High Flow Frequency Analysis

6.9 St. Marks River and Wakulla River Discussion

The flows measured on the St. Marks River at the rise and Wakulla Springs comprise most of the freshwater flow to the lower St. Marks River. A graph of the mean daily flows for the St. Marks River and Wakulla Springs (Figure 31) illustrates the flow contribution from these two river systems. The continuous record for Wakulla Springs starts in May 1997. The St. Marks River has higher baseflow for the majority of the record and higher peak flows than Wakulla Springs. Rainfall distribution in the watershed can have a significant effect on the timing and magnitude of flows on the two rivers. The peak flows on the St. Marks River are consistently about 2 times higher than Wakulla Spring with a few exceptions that may be due to differences in rainfall distribution in the watershed.

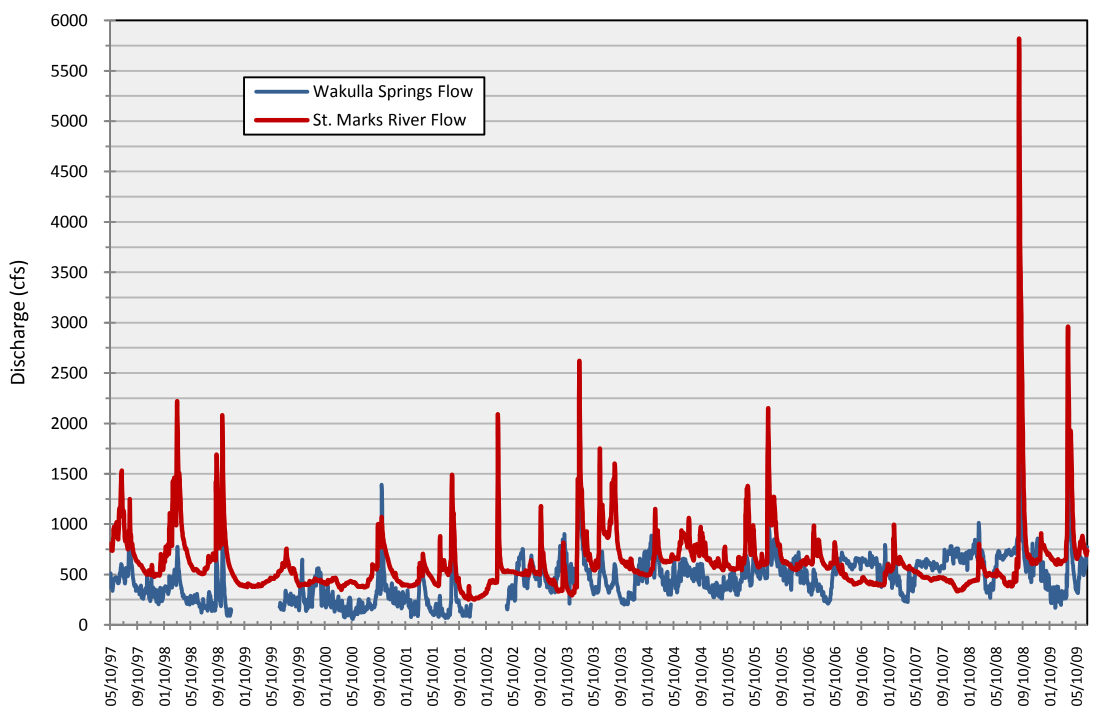


Figure 31 - Mean Daily Flows - St. Marks River and Wakulla Springs
(Missing Wakulla Record: 11/12/98 - 06/18/99 and 11/03/01 - 04/13/02)

The lowest mean daily flow for this record period for Wakulla Springs was 56 cfs in May 2000; flow in the St. Marks for that day was 420 cfs. The lowest mean daily flow for this record period on the St. Marks was 251 cfs in October 2001; flow for Wakulla Springs on that day was 117 cfs. The average daily flow in the St. Marks and Wakulla rivers was 618 cfs and 450 cfs, respectively, for this period (May 1997 to June 2009). The observed record indicates that the flow on the St. Marks River is consistently higher than Wakulla Springs for all ranges of flows. These latest measurements and the estimated ground water contribution to the discharge at the St Marks River Rise confirm the spring at the rise is a first-magnitude spring with a greater discharge than Wakulla Springs. This data indicates the St. Marks River Rise is the largest spring in the watershed.

The combined flow for the St. Marks River at Newport and Wakulla Springs approximates the fresh water flow discharging into Apalachee Bay from the lower St. Marks River (Figure 32). The combined mean daily discharge for the rivers for the 11 years of combined record was 1,097 cfs. The lowest flow was 354 cfs in October 2001 and the peak flow was 8,060 cfs following Tropical Storm Fay.

The St. Marks and Wakulla rivers pick up additional flow in the lower reaches of the rivers downstream of the monitoring stations but this addition is estimated to be a small percentage of the total flow. Numerous small springs flowing into the Wakulla River downstream of the main spring vent were measured in 2005 and 2006 and contributed only about 8% additional flow to the river compared with the average flow of the main spring vent (Barrios 2006). Only four springs have been indentified on the St. Marks River downstream of the Newport station; they contribute less than one percent of the average flow at Newport.

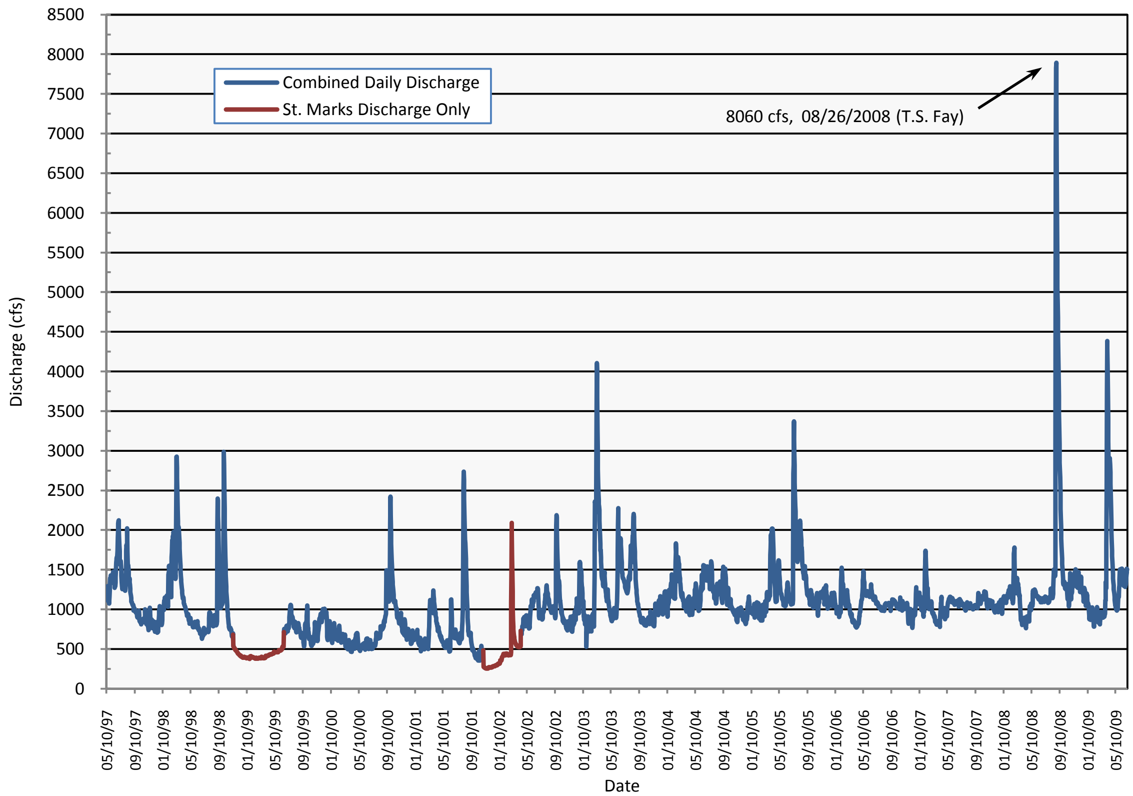


Figure 32 - Combined Daily Flows St. Marks River and Wakulla Springs (May 1997 to June 2009)

7.0 WATER AND SEDIMENT QUALITY IN THE ST. MARKS WATERSHED AND APALACHEE BAY

The St. Marks River estuarine complex is a relatively small shallow estuarine embayment located in the western portion of Apalachee Bay system. The bay system consists of a relatively shallow shelf gradually grading into deeper water (Figure 33); the slope of the bottom is so slight that depths are only 15 feet up to 6-8 miles offshore. Fresh water from the lower St. Marks River (downstream of the confluence with the Wakulla River) discharges through the estuarine complex into the Apalachee Bay system.

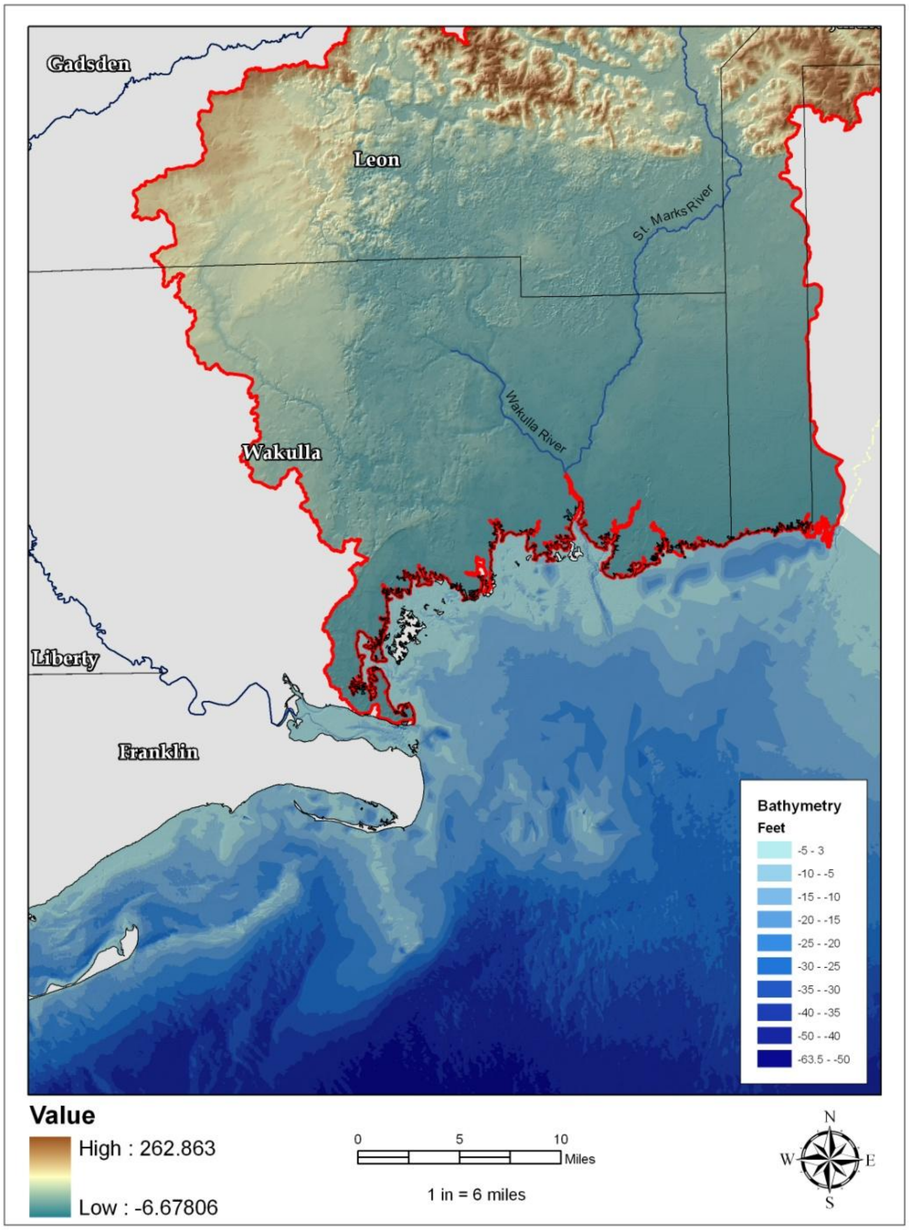


Figure 33 - Bathymetry of Apalachee Bay and Adjacent Waters

7.1 Water Quality Classifications

Surface waters within the St. Mark River/Apalachee Bay are classified by the State of Florida (Florida Department of Environmental Protection) as either Class II or III. These classifications are based on use, not by the actual quality of the water.

Class II waters are designated as Shellfish Propagation or Harvest areas. These areas have water quality standards focusing on particular components that affect the quality of the shellfish harvested to protect consumers from possible diseases associated with their consumption. Shellfish harvesting areas within the Wakulla County portion of Apalachee Bay (Area #22) are shown in Figure 34 for the winter months; spring harvesting areas are identical. Currently, commercial harvesting is

SHELLFISH HARVESTING AREA CLASSIFICATION MAP #22A (Effective: August 17, 2004)
Wakulla County (#22) Shellfish Harvesting Area in Wakulla County
Winter Months: October - March

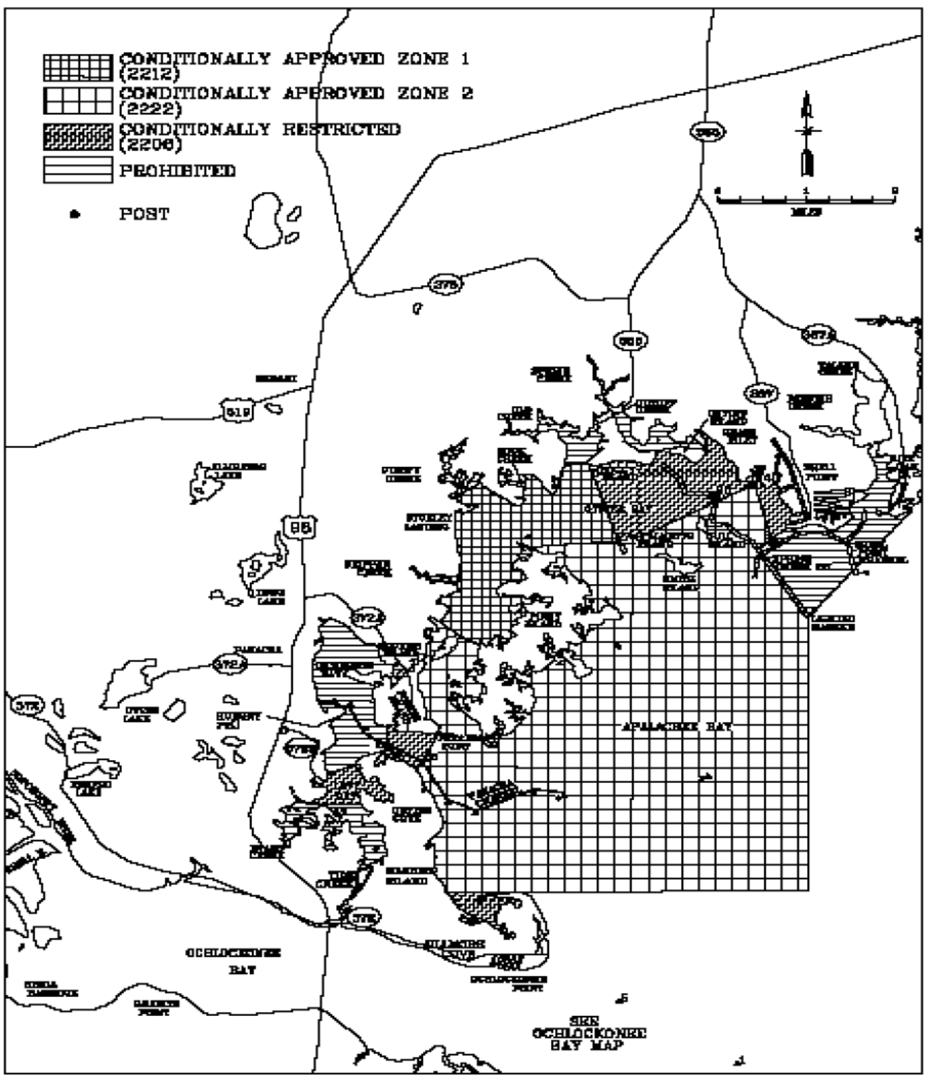


Figure 34 - Shellfish Harvesting Areas in Western Apalachee Bay for Winter Months (October-March, DACS 2004)

prohibited in areas east of Live Oak Island, including the mouth of the St. Marks River and adjacent offshore waters. No approved harvesting areas are found to the east until reaching Horseshoe Beach in Dixie County. This designation does not apply to scallop harvesting which is a major recreational activity in the seagrass beds in Apalachee Bay. Scallops may be taken in season (July 1 to September 10) from all bay areas (west bank of the Mexico Beach Canal in Bay County to the Pasco-Hernando County line) with a valid saltwater fishing license.

The majority of western Apalachee Bay is conditionally approved during both seasons with relatively small scattered portions of bottom conditionally restricted. Harvesting is prohibited in portions of Dickerson Bay, two areas near Spring Creek and an inshore triangle between Shell Point and Live Oak Island. Conditionally approved waters are open for harvest during the winter months (October to March) unless rainfall at the Ochlockonee River State Park exceeds 1.08 and 2.24 inches, respectively, for Zones 1 and 2. Conditionally approved waters are harvestable during the spring/fall months (April, May and September) unless rainfall, measured at the State Park, exceeds 2.35 and 3.78 inches for Zones 1 and 2, respectively. A portion of the waters are conditionally restricted when rainfall exceeds 4.02 inches (winter) and 4.75 inches (spring/fall). In all cases waters are temporary closed when the above conditions occur and are reopened when bacteriological levels meet the standards described in Rule 5L-1.003 (DACS) and fecal coliform levels in shellfish return to normal background levels. Closure and reopening is administered through the Division of Aquaculture, Department of Agriculture and Consumer Services.

All surface waters in St. Marks/Apalachee Bay not specifically listed as Class II are designated as Class III. Class III waters are designated to provide Recreation and Propagation of Healthy, Well-balanced Populations of Fish and Wildlife. Standards for these waters are not as stringent for most parameters as for Class II and are directed to maintaining biodiversity and water quality sufficient for human contact such as swimming (hence the name Fishable/Swimable waters). All waters in the St. Marks River (except those in the City of St. Marks), the Wakulla River and waters within the Big Bend Seagrasses Aquatic Preserve are Outstanding Florida Waters and receive additional protection to maintain ambient conditions with no degradation.

7.2 Water Quality Characteristics

Considerable water quality data have been collected in the St. Marks/Apalachee Bay System over the last 30 years; yet, most has been restricted to waters near the upstream extent of tidal influence, particular in and around the City of St. Marks and its docking terminals for offloading petroleum products and bulk chemicals (FDEP 2003). Numerous oil spills have been documented over the years, including a sizeable spill in 1978, that have contaminated bottom sediments in the river. Limited amounts of water quality data have been collected in the Wakulla Springs and River system, despite the present location of the State Park. This is likely because much of the upper river reach was in private ownership before it was purchased by the state in 1986. Some collections have been made in and around Big Boggy Branch, a tributary in the lower reach of the Wakulla River, associated with the discharge from Primex Technologies (formally Olin Corporation), a manufacturer of small and intermediate arms propellants. LakeWatch has sampled several locations in the river since the mid-1990s.

Existing water quality data for the estuarine portion of the St. Marks and adjacent Apalachee Bay is relatively sparse and generally restricted to short-term collections associated with larger sampling efforts focused on other portions of the system. Bacteriological collections are made routinely by the Division of Aquaculture (DACS) in association with shellfish harvesting areas and by the county health department to assess the status of local beaches (e.g., Shell Point Beach, Mashes Sands). While several nearby areas (near Panacea and offshore waters of the Econfina/Fenholloway rivers) have had greater sampling efforts over the past 25 years, no comprehensive, long-term, water quality monitoring program is being carried out currently in either the St. Marks estuary or adjacent Apalachee Bay.

As part of the FDEP's watershed management approach for protecting water resources and addressing Total Maximum Daily Load (TMDL) requirements, a water quality assessment was developed for the Ochlockonee and St. Marks system (FDEP 2003). Recent water quality data were obtained from FDEP's Florida Storage and Retrieval (STORET) databases, new data collected as necessary, and all information was assessed according to methodologies prescribed in the 1972 federal Clean Water Act and the 1999 Florida Watershed Restoration Act. From this assessment a verified list of water bodies not meeting state water quality standards (impaired waters) was developed; TMDLs are under development for these water bodies.

Several portions of the St. Marks estuary and adjacent Apalachee Bay were placed on the verified list as not meeting water quality standards (FDEP 2003). Three water body segments in western Apalachee Bay (Apalachee Bay-west, Marshes Island and Shell Point) were listed for bacteria in shellfish and beach advisories, as well as all Florida Gulf Coast segments for excessive mercury in fish tissue.

Two segments in the St. Marks River basin (low dissolved oxygen) and one segment of the Wakulla River (biological imbalance due to excessive nutrients) were included on the verified impaired list. St. Marks River sub-basins, Black Creek (WBID 628) and Lake Weeks (WBID 971B), were verified as impaired for dissolved oxygen (DO) resulting from high nutrients. The northern portion of the St. Marks River (WBID 793B) is potentially impaired for DO as are two springs (St. Marks Spring WBID 971 and Horn Spring WBID 793Z). DO is typically naturally low in spring waters. The Wakulla River (WBID 1006) was placed on the verified list because of a biological imbalance attributable to nutrients discharges from the springs. Some waters, including Sally Ward Spring and McBride Slough, are potentially impaired for DO; however, as in the St. Marks springs, the low DO appears to be naturally occurring. The report (FDEP 2003) cites trend data for Wakulla Springs (WBID 1006X) and Wakulla River (WBID 1006) indicating a decrease in total phosphorus since 1970, but an increase in total nitrogen (TN) and alkalinity. Big Boggy Branch (WBID 1124), a tributary of the river, has shown increasing trends for TN and fecal coliform.

Water quality data from a variety of sites representative of the St. Marks and Wakulla Rivers as well as adjacent areas of Apalachee Bay were retrieved from the Florida STORET database and are summarized here. Collections were taken by various agencies and organizations (e.g., FMRI, FDEP, LakeWatch) with varying characteristics, sampling procedures and analytical methods. These are combined and presented here only to provide an overview of environmental characteristics in the various reaches of the system.

Data were retrieved from 44 sites scattered throughout the Wakulla and St. Marks Rivers and the adjacent waters of Apalachee Bay. Twenty-nine sites were examined from the lower tidal reaches of both rivers along with sites in Apalachee Bay (Figure 35) to evaluate inputs to the estuarine portion of the system. Twenty-four sites were examined from the Wakulla River (Figure 36) to assess downstream water quality trends from the head springs to the confluence with the St. Marks. Nine sites were common to both analyses. Sites were chosen where collections spanned a range of sampling dates; single sample collections were avoided when possible. Information concerning the agencies responsible for sampling and dates of collection are given in Tables 5 and 6 for each site.

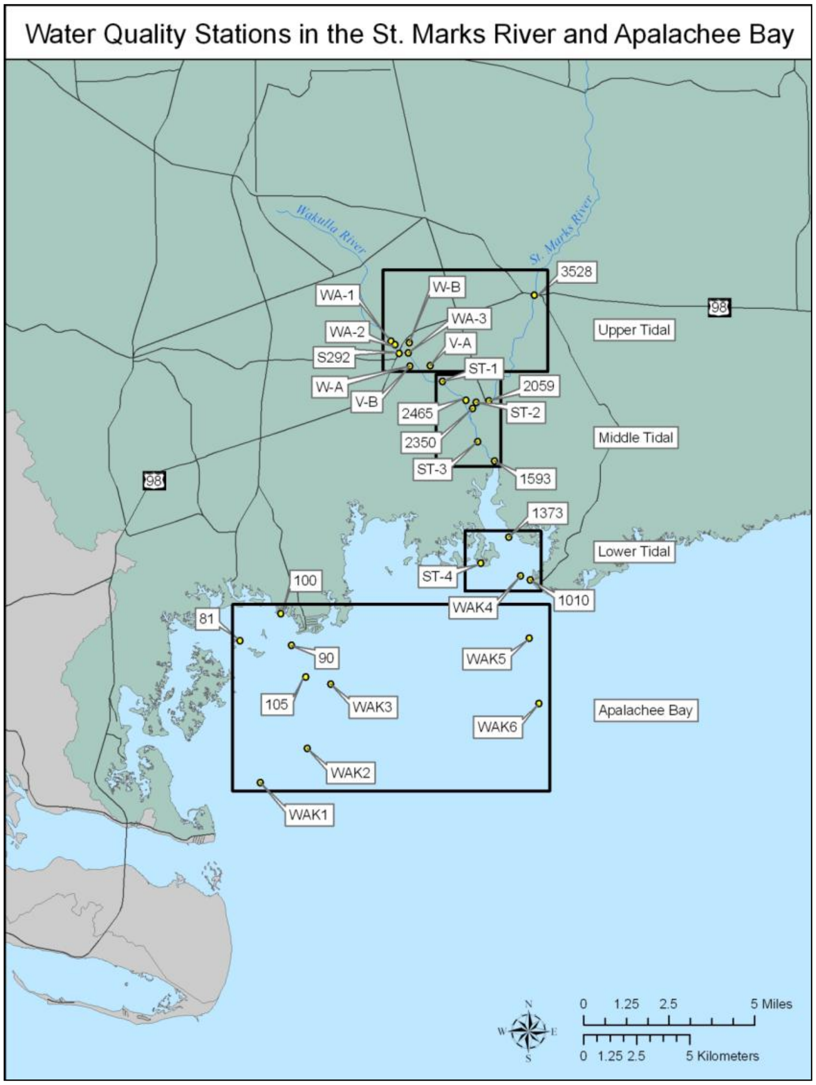


Figure 35 - Water Quality Stations in the Lower St. Marks Watershed and Apalachee Bay (Boxes indicate station groups)

For the estuarine comparison, stations were combined into four groups representing the upper reach of tidal influence, middle and lower reach of the estuary, and Apalachee Bay (including adjacent embayments such as Dickerson and Oyster Bays). Water quality characteristics varied spatially and temporally throughout the collection sites with specific conductance/salinity increasing and most of the other characteristics generally decreasing with movement downstream (Table 7).

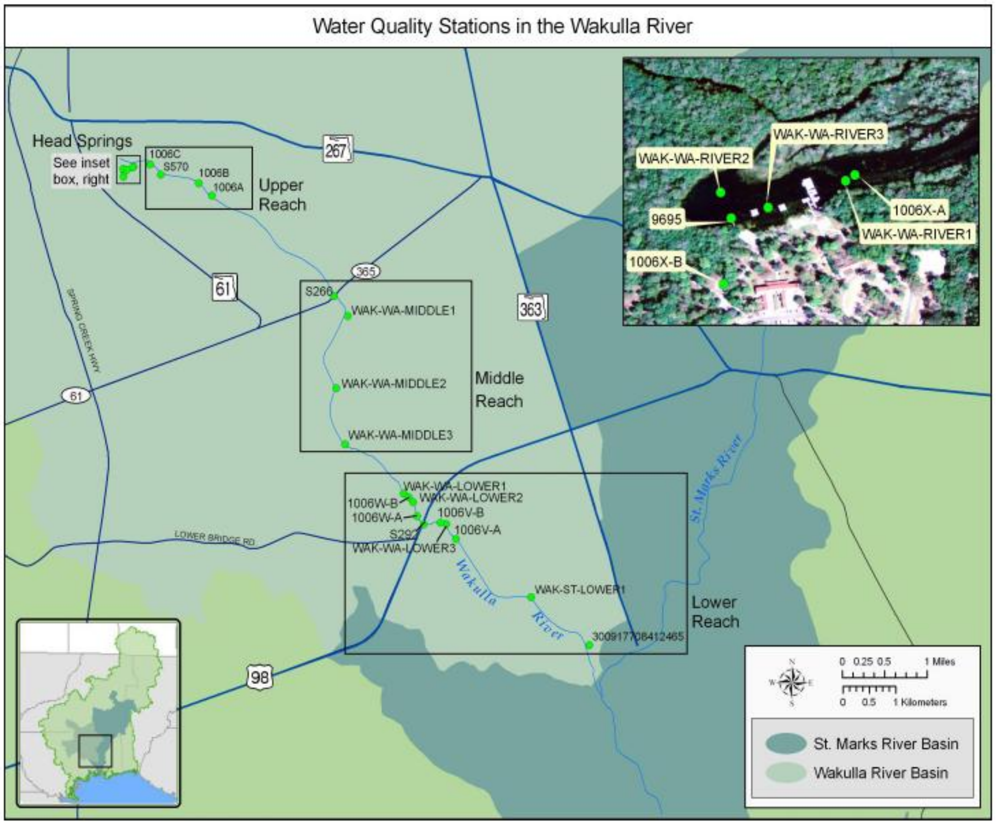


Figure 36 - Wakulla River Water Quality Stations (Boxes indicate station groups)

Specific conductance was low in the upper portions of both rivers with values in the Wakulla River (mean = 429 μmho/cm) higher than in the St. Marks (mean = 250 μmho/cm); salinities corresponding to these specific conductance are less than 0.2 ppt. Variation in conductance also appeared greater on the Wakulla (272-824 μmho/cm) compared to the St. Marks River (92-300 μmho/cm). No seasonal variation was noted at either site (Figure 37).

Mean salinity increased with distance from the upper reach of the St. Marks and Wakulla Rivers to Apalachee Bay (Table 7). Salinity averaged 3.5 ppt near the confluence of the St. Marks and Wakulla Rivers, 14.8 ppt near the mouth of the St. Marks River and over 25 ppt offshore in Apalachee Bay. Salinity offshore in Apalachee Bay (e.g., Station 105) was relatively stable with occasional precipitous declines (Figure 38), presumably associated with increased freshwater runoff from localized storm events. Generally, salinity returned fairly quickly to pre-event conditions. Salinity declined and variability increased significantly closer to shore (e.g., Station 100) in greater proximity to freshwater sources. No pronounced seasonality was noted in either inshore or offshore salinity at the sites selected.

Station ID	Agency Responsible For Collection	Collection Period
Upper Tidal Reach		
St. Marks @ Newport (3528)	NWFWMD/FDEP	10/12/98 - 08/09/06
Wakulla @ Highway 98 (S292)	NWFWMD/FDEP	02/28/00 - 01/31/02
1006V-A/B	FDEP	04/11/06 - 09/12/06
1006W-A/B	FDEP	04/11/06 - 09/12/06
WAK-WA-Lower-1/2/3	Florida LakeWatch	03/27/99 - 03/13/06
Middle Tidal Reach		
WAK-ST-Lower-1/2/3	Florida LakeWatch	04/22/01 - 06/30/02
2350	FDEP	10/03/01
2059	FDEP	10/03/01
2465	FDEP	10/03/01 & 02/28/06
1593	FDEP	1/26/06 - 09/27/06
Lower Tidal Reach		
WAK-ST-Lower-4	Florida LakeWatch	4/22/01-6/30/02
1373	FDEP	1/26/06-9/27/06
WAK-WAK4	Florida LakeWatch	01/10/01 - 05/17/01
Apalachee Bay		
WAK-WAK1-3	Florida LakeWatch	01/10/01 - 05/17/01
WAK-WAK5-6	Florida LakeWatch	01/10/01 - 05/17/01
S081	FDEP	08/30/89 - 05/25/05
S090	FDEP	07/19/79 - 05/25/05
S100	FDEP	07/19/79 - 05/25/05
S105	FDEP	01/12/95 - 05/25/05

Table 5 – Water Quality Site Summary for Tidal Reaches of the St. Marks River and Apalachee Bay

Station ID	Agency Responsible For Collection	Collection Period
Head Springs		
9695	FDEP	09/27/01 - 12/06/05
1006X-A/B	FDEP	04/10/06 - 11/28/06
WAK-WA-River-1/2/3	Florida LakeWatch	04/26/96 - 02/27/06
Upper Reach		
S570	NWFWMD/FDEP	02/28/00 - 01/31/02
1006-A/B/C	FDEP	04/10/06 - 12/06/06
Middle Reach		
S266 (Highway 365)	NWFWMD/FDEP	02/13/92 - 08/11/92
WAK-WA-Middle-1/2/3	Florida LakeWatch	01/03/96 - 01/11/06
Lower Reach		
S292 (Highway 98)	NWFWMD/FDEP	02/28/00 - 01/31/02
1006V-A/B	FDEP	04/11/06 - 09/12/06
1006W-A/B	FDEP	04/11/06 - 09/12/06
WAK-WA-Lower-1/2/3	Florida LakeWatch	03/27/99 - 03/13/06
WAK-ST-Lower-1	Florida LakeWatch	04/22/01 - 06/30/02
300917708412465	FDEP	10/3/01 - 02/28/06

Table 6 – Summary of Wakulla River Water Quality Sites

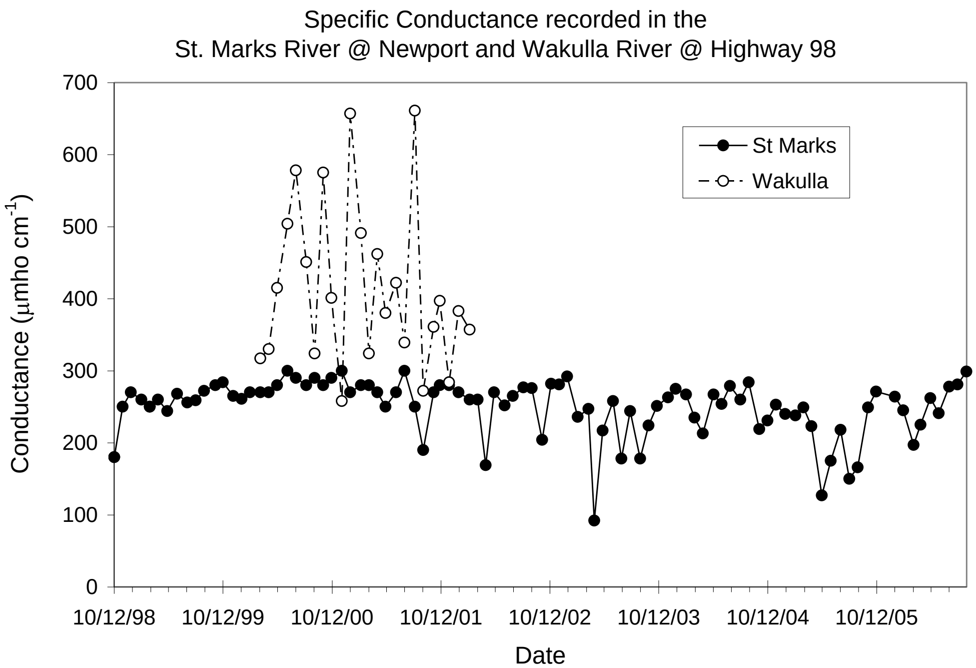


Figure 37 - Specific Conductance in the Wakulla and St. Marks Rivers (FL STORET 2007)

STATION	Specific Cond.	Salinity	Temp	DO	NH3	NO2+ NO3	TKN	TN	PO4	TP	CHL-A
Upper Tidal Reach											
St. Marks @ Newport (3528)	250		20.4	6.0	0.011	0.12	0.20	0.34	0.033	0.043	
Wakulla @ Highway 98 (S292)	414		21.0	8.1	0.013	0.38	0.16	0.55	0.018	0.031	
1006	451	0.2	22.3	7.7		0.35	0.16		0.014	0.025	2.0
WAK-WA-Lower-1/2/3								0.53		0.025	2.5
Middle Tidal Reach											
WAK-ST-Lower-1/2/3								0.39		0.031	5.1
2350/2059/2465/1593		3.5	21.2	7.6	0.027	0.13	0.38		0.020	0.037	0.85
Lower Tidal Reach											
WAK-ST-Lower-4								0.31		0.026	6.1
1373/1010		14.8	22.0	7.1	0.040	0.06	0.53		0.009	0.028	1.0
WAK-WAK4								0.28		0.015	2.9
Apalachee Bay											
WAK-WAK1-3								0.24		0.013	2.0
WAK-WAK5-6								0.24		0.012	1.4
S081		19.0	21.1	8.7							
S090		22.1	20.7	8.4							
S100		17.0	21.1	8.2							
S105		25.3	22.3	8.1							

Abbreviations/units of measure: Specific conductance (µmho/cm), Salinity (ppt), Temperature (ºC), DO-dissolved oxygen (mg/l), NH3-ammonia (mg/l), NO2+NO3-nitrate+nitrite (mg/l), TKN-total Kjeldahl nitrogen (mg/l), TN-total nitrogen (mg/l), PO4-ortho-phosphate (mg/l), TP-total phosphorus (mg/l), CHL-A, chlorophyll a (µg/l)

Table 7 – Summary of Selected Water Quality Characteristics in the St. Marks and Wakulla Rivers and Apalachee Bay (FL STORET 2007)

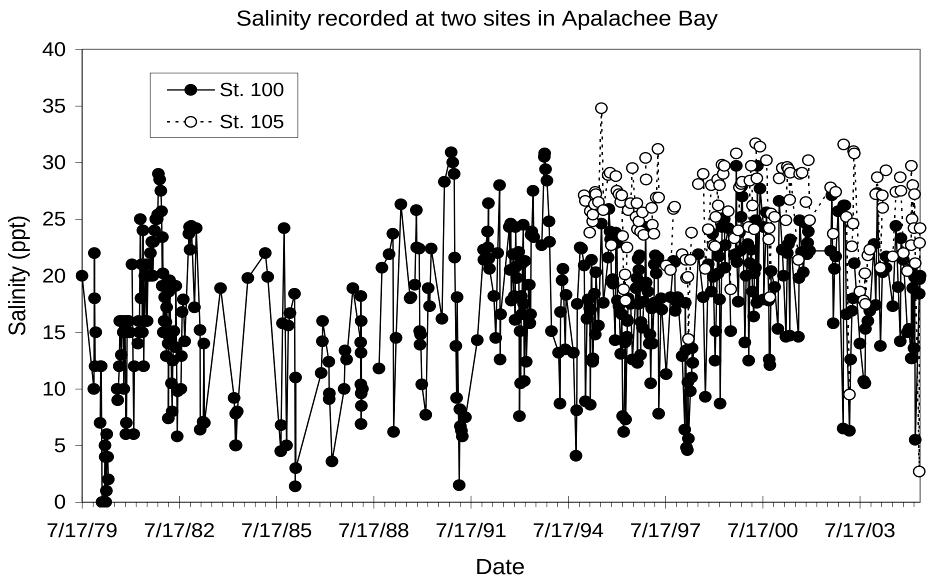


Figure 38 - Long-term Salinity at Inshore (Station 100) and Offshore (Station 105) Sites in Apalachee Bay (FL STORET 2007)

Temperature varied seasonally both in the rivers (Figure 39) and offshore in Apalachee Bay (Figure 40). The Wakulla River appeared significantly warmer in summer and cooler in winter than the St. Marks with slight differences in timing of seasonal peaks. Temperature varied from 11.8 to 26.7 ^{o}C on the Wakulla while only ranging between 14.5 and 24.3 ^{o}C on the St. Marks. This trend appears counterintuitive given the spring-fed origin of the Wakulla River. Water temperature in Apalachee Bay exhibited a wider range of values (8.2-35.3 ^{o}C) than those observed in the rivers. Winter lows tended to vary more among years than summer highs both in the rivers and offshore.

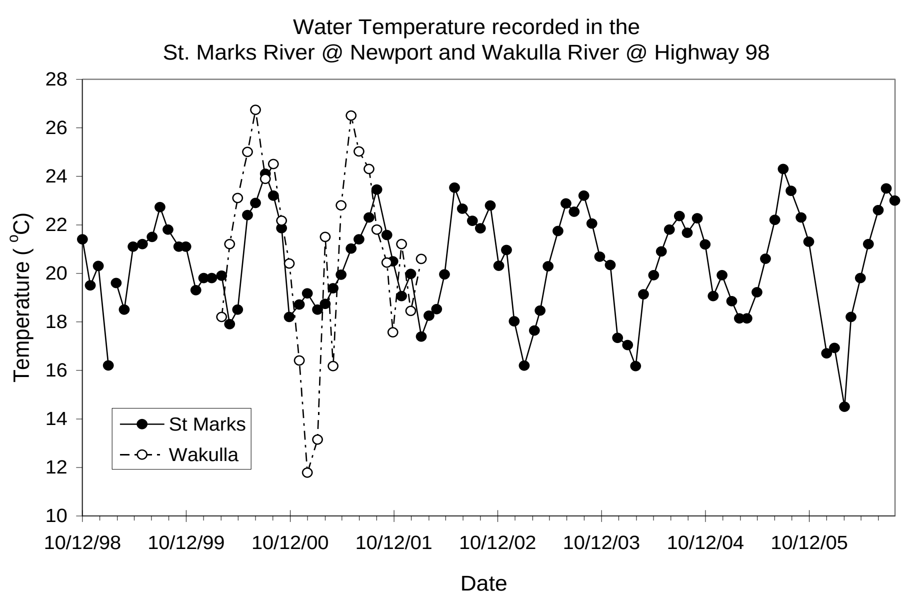


Figure 39 - Long-term Water Temperature in the Wakulla and St. Marks Rivers (FL STORET 2007)

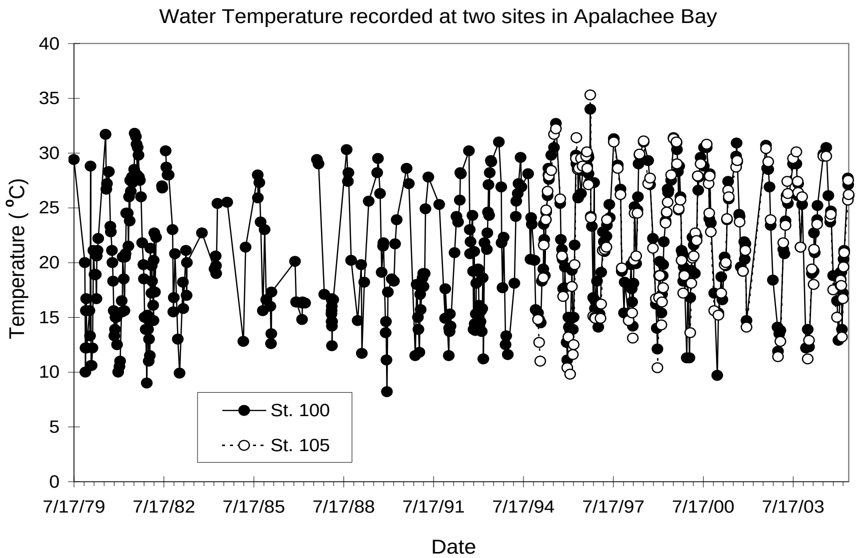


Figure 40 - Long-term Water Temperature at Inshore (Station 100) and Offshore (Station 105) Sites in Apalachee Bay (FL STORET 2007)

Dissolved oxygen (DO) was relatively high with surface values averaging greater than 7.0 mg/l at all water quality collection sites except the St. Marks at Newport site which had a mean value of only 6.0 mg/l (Table 7). Values ranged between 4.9 and 10.7 mg/l on the Wakulla River and between 3.4 and 9.4 mg/l on the St. Marks (Figure 41). In Apalachee Bay, DO was slightly higher than in the rivers with mean values greater than 8 mg/l (Table 7); however, variability was also greater with several observations below 5 mg/l (range at Stations 100 and 105 was 3.1-13.8 mg/l; see Figure 42). DO was generally related to water temperature with higher values in colder months, but differences were noted.

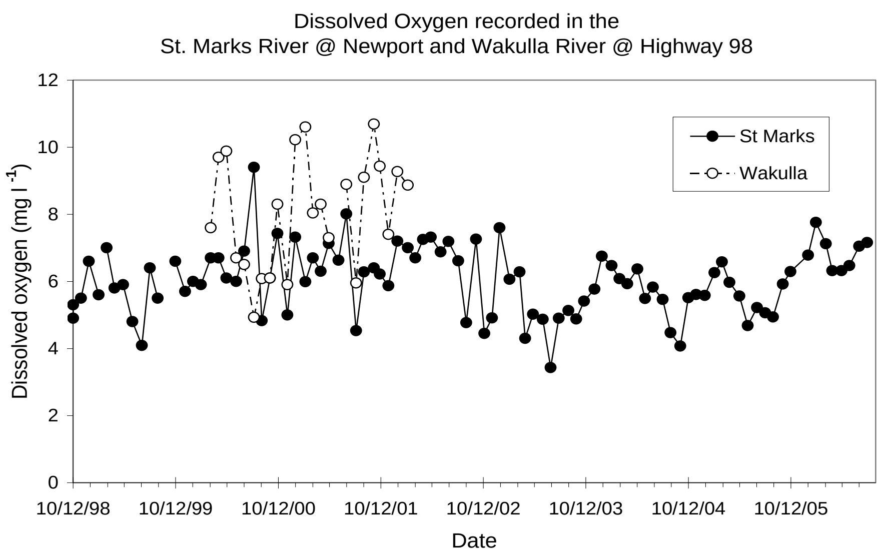


Figure 41 - Dissolved Oxygen in the Wakulla and St. Marks Rivers (FL STORET 2007)

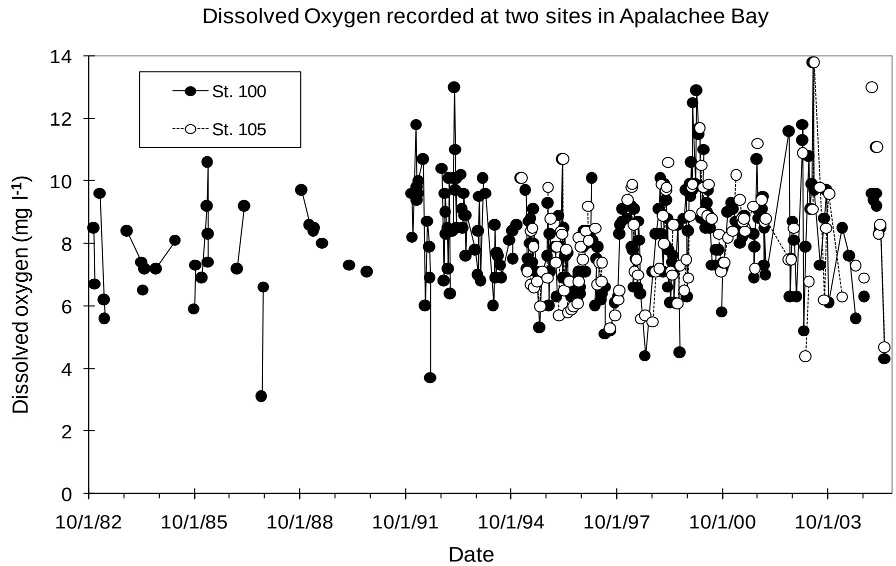


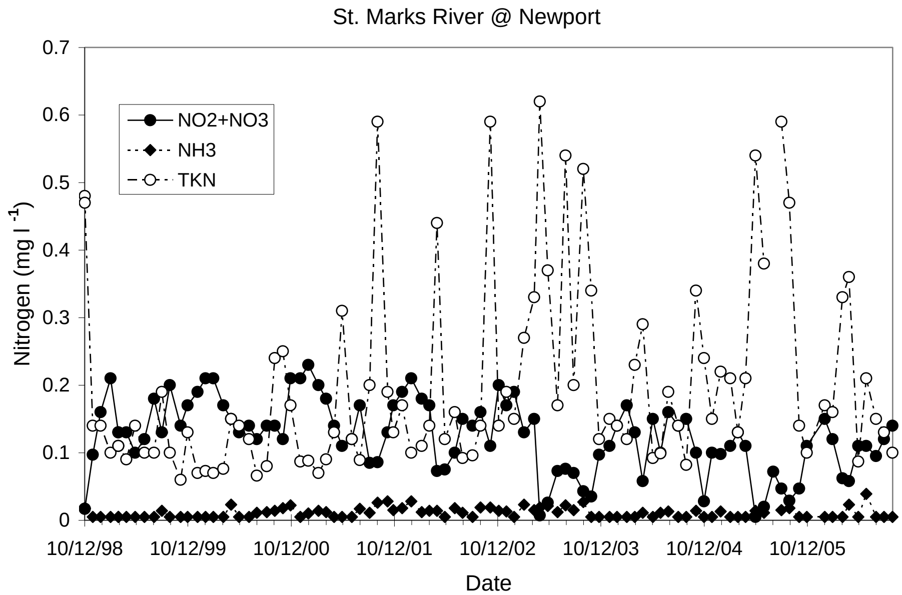
Figure 42 - Dissolved Oxygen at Inshore (Station 100) and Offshore (Station 105) Sites in Apalachee Bay (FL STORET 2007)

Nutrient concentrations (both nitrogen and phosphorus) were generally low throughout the St. Marks/Apalachee Bay system, except in the upper reach of the Wakulla River (i.e., Wakulla Spring where higher levels of nitrates have resulted in increased density of nuisance aquatic plants). Nitrate+nitrite concentrations in the upper tidal reach of the Wakulla River (US98 bridge) averaged three times greater than that observed on the St. Marks River at Newport (US98 bridge) (Table 7). Orthophosphate concentrations in the Wakulla, on the other hand, were only about one-half that noted for the St. Marks (Table 7). Ammonium values were low in the upper tidal reach of both rivers. Ammonium and total Kjeldahl nitrogen generally increased with distance downstream while nitrate+nitrite and orthophosphate generally decreased (Table 7). Total nitrogen and total phosphorus were lower in Apalachee Bay than in the rivers. Some seasonality was noted in levels of nitrate+nitrite in the upper tidal reaches of both rivers (Figures 43 and 44) but not in orthophosphate.

Chlorophyll concentrations were generally low throughout much of the system with sporadic peaks in the rivers, particularly in the middle and lower tidal reaches (Table 7) where levels averaged 5.1 and 6.1 μg/l, respectively. Values in these reaches were observed to exceed 10 μg/l on several occasions.

To examine downstream trends in water quality on the Wakulla River, stations were combined into four groups representing the head springs, the upper, middle, and lower reaches of the river as shown in Figure 36. Water quality characteristics varied spatially and temporally throughout the collection sites with specific conductance/salinity, dissolved oxygen and chlorophyll generally increasing and most of the other characteristics decreasing with movement downstream (Table 8).

Specific conductance was low in the upper reaches of the Wakulla with mean values ranging from 269 to 310 μmho/cm; salinities corresponding to these specific conductance are less than 0.1 ppt. Substantial variation in specific conductance was noted in the lower reach of the river with mean values increasing from 414-474 μmho/cm near the U.S. 98 bridge to over 8,600 μmho/cm near the confluence with the St. Marks. Conductance was seasonally stable (Figure 45) in the upper reach near the main spring (site S570) yet varied noticeably in the lower reach (site S292). Fluctuations at the lower site likely reflect inputs from tributaries and, more importantly, tidal influence.



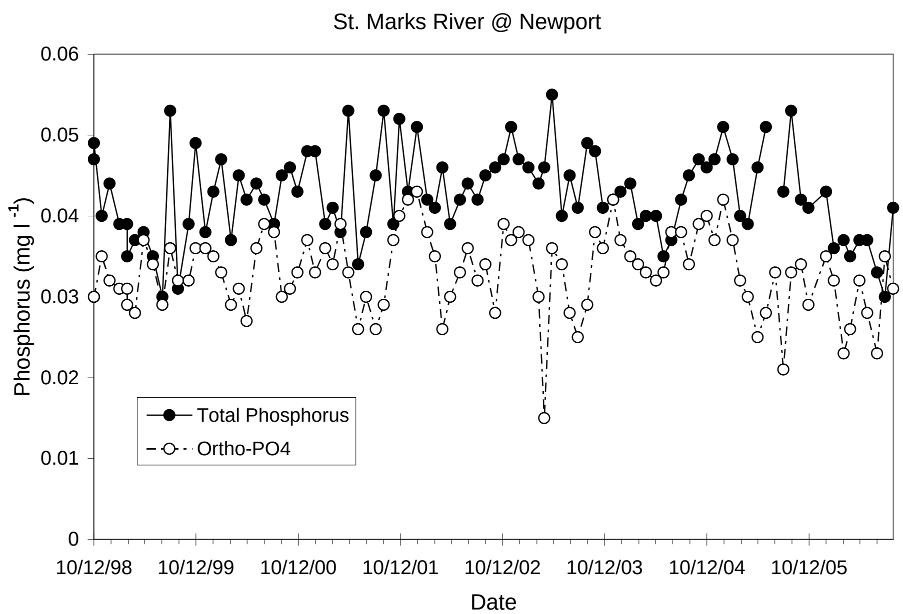


Figure 43 - Nitrogen (upper) and Phosphorus (lower) Concentrations in the St. Marks River (FL STORET 2007)

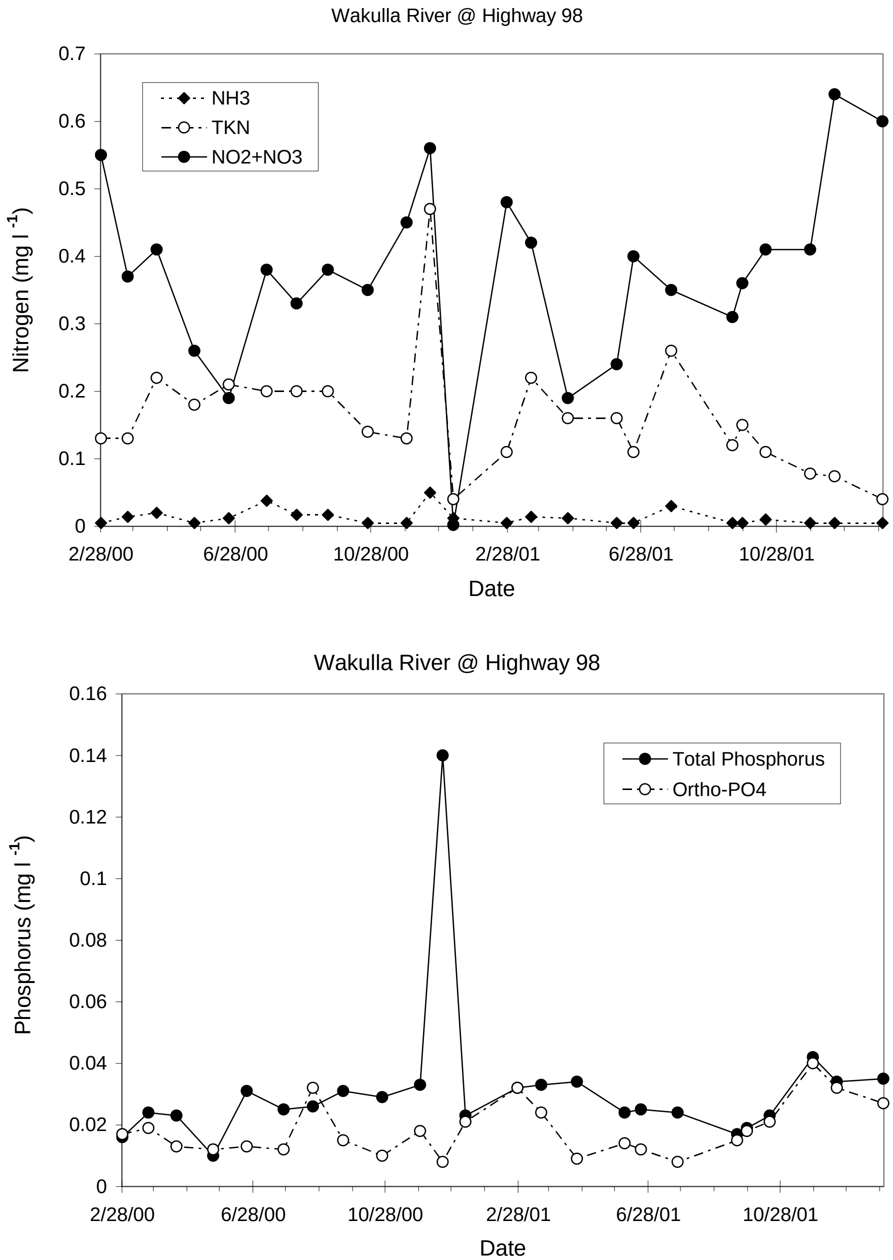


Figure 44 - Nitrogen (upper) and Phosphorus (lower) Concentrations in the Wakulla River (FL STORET 2007)

Mean salinity values were retrieved only from sites in the lower reach and ranged from 0.2 ppt near the U.S. 98 bridge to 4.9 ppt near the St. Marks confluence (Table 8). As noted previously, salinity increases with distance downstream in the St. Marks to Apalachee Bay (see Table 7). The lower reach of the Wakulla River appears to encompass the upper limit of salt intrusion under most conditions and as such is an area that is relatively sensitive to modifications in river flow and salinity distribution. Large changes in floral and faunal assemblages might be expected in this reach with changes in the salinity regime.

STATION	Specific Cond.	Salinity	DO	NH3	NO2+ NO3	TKN	TN	PO4	TP	CHL-A
Head Spring										
9695	307		2.2	0.005	0.71	0.05	0.75	0.028	0.030	
1006X-A/B	310		2.4		1.28	0.14	1.42	0.023	0.026	0.9
WAK-WA-River 1/2/3							0.76		0.028	0.05
Upper Reach										
570	300		7.6	0.010	0.72	0.06	0.78	0.026	0.033	
1006 A/B/C	309		4.8		0.52	0.10	0.62	0.024	0.029	1.1
Middle Reach										
S266 (Hwy 365)	269		7.9	0.017	0.61	0.46	1.07		0.032	
WAK-WA-Middle-1/2/3							0.58		0.025	1.5
Lower Reach										
S292 (Hwy 98)	414		8.1	0.013	0.38	0.16	0.54	0.018	0.031	
1006 W/V	474	0.2	8.0		0.34	0.17	0.51	0.013	0.025	2.1
WAK-WA-Lower-1/2/3							0.50		0.024	2.5
WAK-ST-Lower-1							0.47		0.026	5.2
300917708412465	8666	4.9	8.1	0.013	0.17	0.53	0.70	0.020	0.024	

Abbreviations/units of measure: Specific conductance (µmho/cm), Salinity (ppt), Temperature (C), DO-dissolved oxygen (mg/l), NH3-ammonia (mg/l), NO2+NO3-nitrate+nitrite (mg/l), TKN-total Kjeldahl nitrogen (mg/l), TN-total nitrogen (mg/l), PO4-ortho-phosphate (mg/l), TP-total phosphorus (mg/l), CHL-A, chlorophyll a (µg/l)

Table 8 – Summary of Selected Water Quality Characteristics in the Wakulla River System (FL STORET 2007)

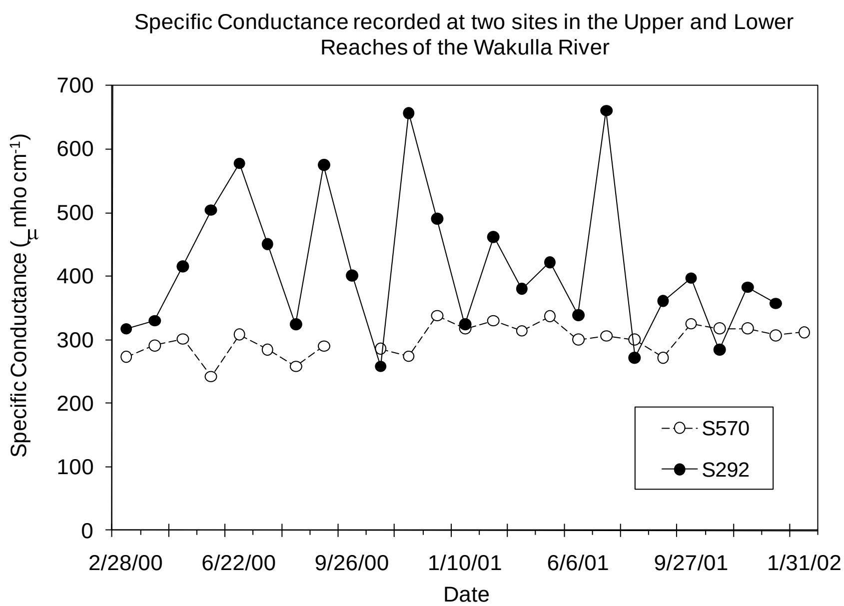


Figure 45 - Specific Conductance at Upper (S570) and Lower (S292) Sites in the Wakulla River (FL STORET 2007)

Temperature varied seasonally (Figure 46) in the Wakulla River with lowest values in November-December and highest values varying from April to July depending on location. Temperatures in the upper reach (14.2-23.6 ^{o}C) varied less than downstream (11.8-26.7 ^{o}C), indicating the buffer effect of the spring. Dissolved oxygen (DO) was relatively low near the head springs with increasing values downstream (Table 8). Mean DO at the springs was 2.3 mg/l while most locations downstream averaged over 7 mg/l. Some seasonality was observed, primarily at lower reach sites (Figure 47). DO was generally related to water temperature with higher values in colder months, but differences were noted (see site S570, Figure 47).

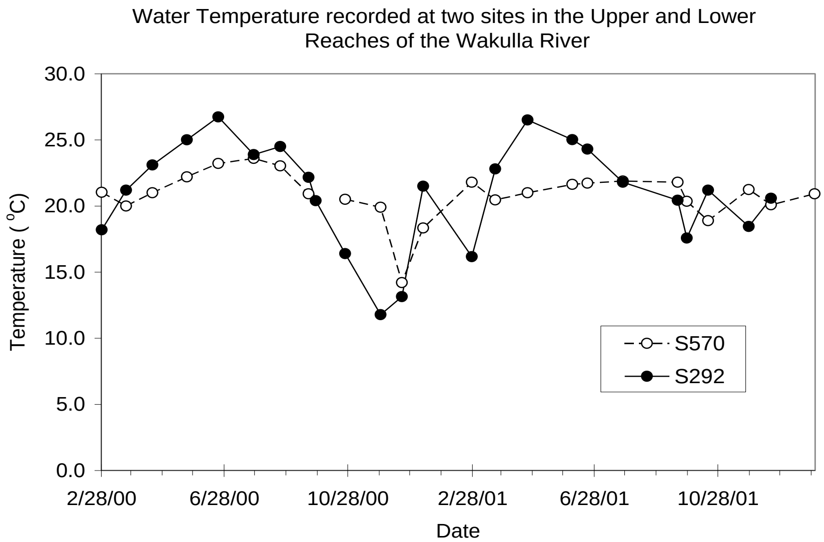


Figure 46 - Water Temperature at Upper (S570) and Lower (S292) Sites in the Wakulla River (FL STORET 2007)

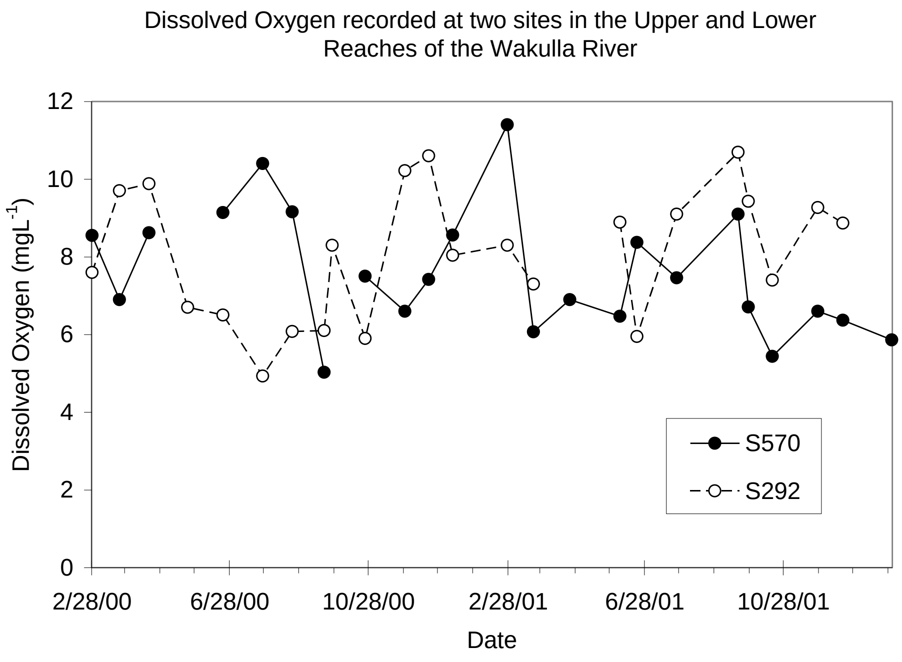


Figure 47 - Dissolved Oxygen at Upper (S570) and Lower (S292) Sites in the Wakulla River (FL STORET 2007)

Nutrient concentrations (both nitrogen and phosphorus) were moderately high throughout the Wakulla River system (Table 8). Ammonia and total Kjeldahl nitrogen (TKN) were low at the head springs and generally increased downstream, although several lower reach sites had low TKN. This generally low TKN was indicative of the spring-run character of the river which receives little organic inputs; the majority of the total nitrogen (TN) is in the dissolved inorganic form (i.e., nitrate+nitrite-N). Unlike the previous nutrient trends, nitrate+nitrite-N was relatively high at the head springs (e.g., 1.28 mg/l at sites 1006X) and decreased downstream; however, moderate levels were maintained through much of the lower reach (e.g., 0.38 mg/l at site S292). Concentrations fell to relatively low levels near the confluence with the St. Marks River (0.17 mg/l at site 300917708412465). No apparent seasonality was observed in nitrate+nitrite-N at either upper or lower reach sites (Figure 48) The concentration of nitrate+nitrite versus discharge at the main spring vent of Wakulla Springs for the period from July 1997 to July 2009 is shown in Figure 49. This data indicates nitrate + nitrite concentrations are higher during low flow periods when ground water provides the majority of the flow to the spring. Nitrate+nitrite concentration decreases as flow increases indicating surface water discharging to the spring has lower nitrate+nitrite than ground water.

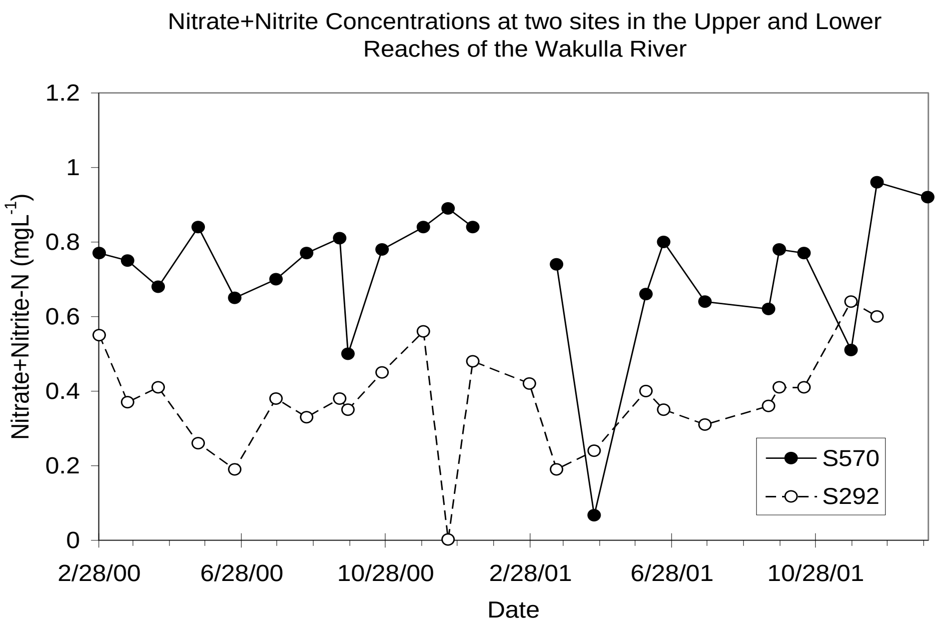


Figure 48 - Nitrate+Nitrate at Upper (S570) and Lower (S292) Sites in the Wakulla River (FL STORET 2007)

Soluble reactive phosphate (orthophosphate) concentrations were moderate to low throughout all reaches of the river; a slight decline in concentrations was observed with distance downstream (Table 8). No seasonality was noted in levels at either upper or lower reach sites (Figure 50).

As with nitrogen, the bulk of the total phosphorus (TP) was in the dissolved inorganic form indicating little organic input (Table 8). Some long-term nutrient trends were observed at LakeWatch stations, monitored for the last 10 years. TN appears to have declined slightly at upper reach stations (Figure 51), while TP has increased at middle and lower reach sites (Figure 52). Since TN and TP in this system primarily consist of inorganic forms of nitrogen and phosphate, it is likely that similar trends occur in nitrate+nitrite and soluble reactive phosphate as well. Nitrate+nitrite concentrations in the lower reach of the Wakulla River (U.S. 98 bridge) averaged three times greater (0.38 mg/l) than that observed on the St. Marks River at Newport-U.S. 98 bridge

(0.12 mg/l). Orthophosphate concentrations in the Wakulla River (0.018 mg/l), on the other hand, were only about one-half that noted for the St. Marks (0.033 mg/l). Chlorophyll concentrations were generally low throughout much of the system (Table 8) with occasional peaks at lower reach sites where levels averaged 5.2 μg/l at one station (WAK-ST-Lower-1).

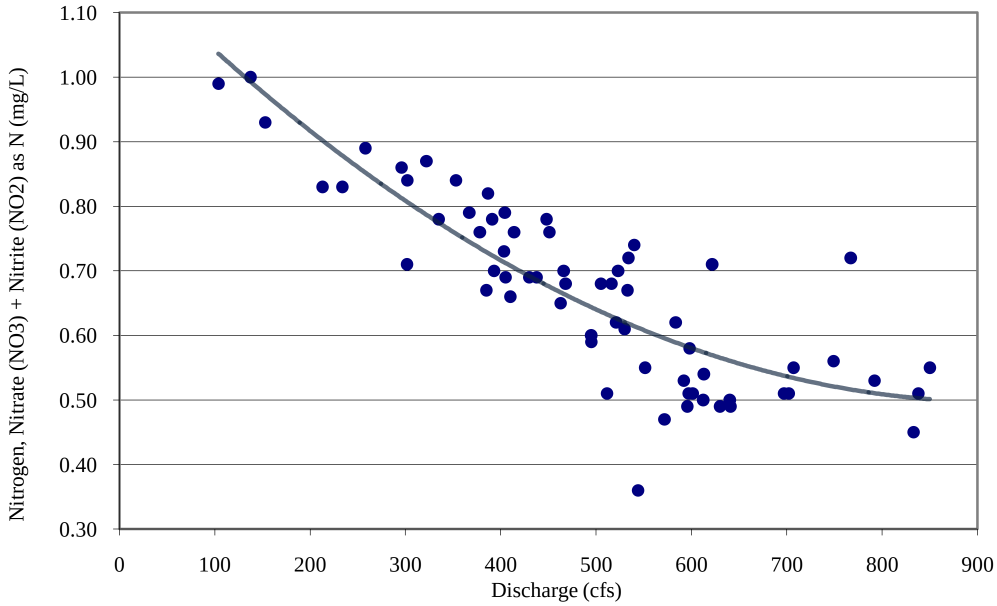


Figure 49 - Nitrate+Nitrite vs. Discharge at Wakulla Springs (Main Vent) (July 1997 - July 2009, NWFWMD)

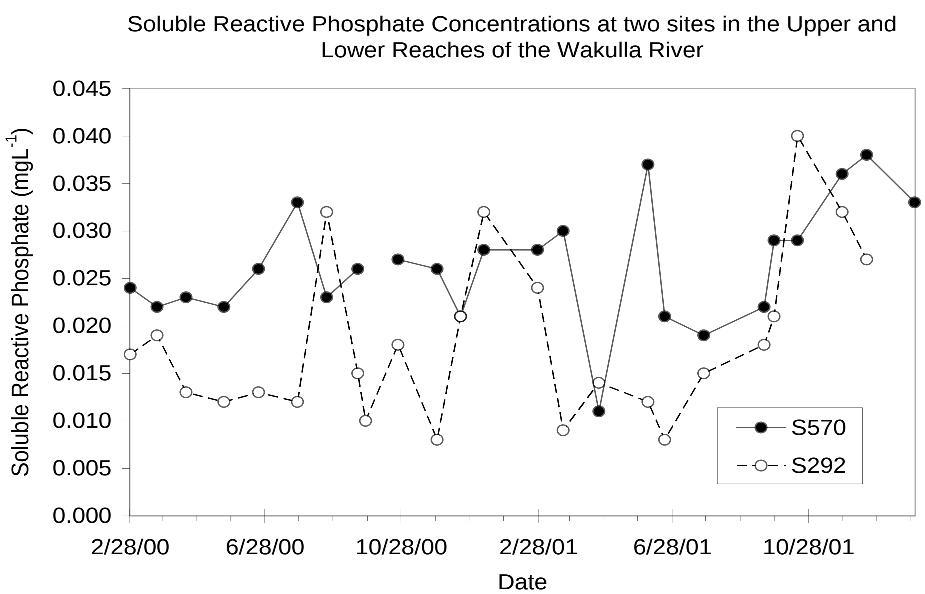


Figure 50 - Soluble Reactive Phosphate (Ortho-phosphate) at Upper (S570 and Lower (S292) Sites in the Wakulla River (FL STORET 2007)

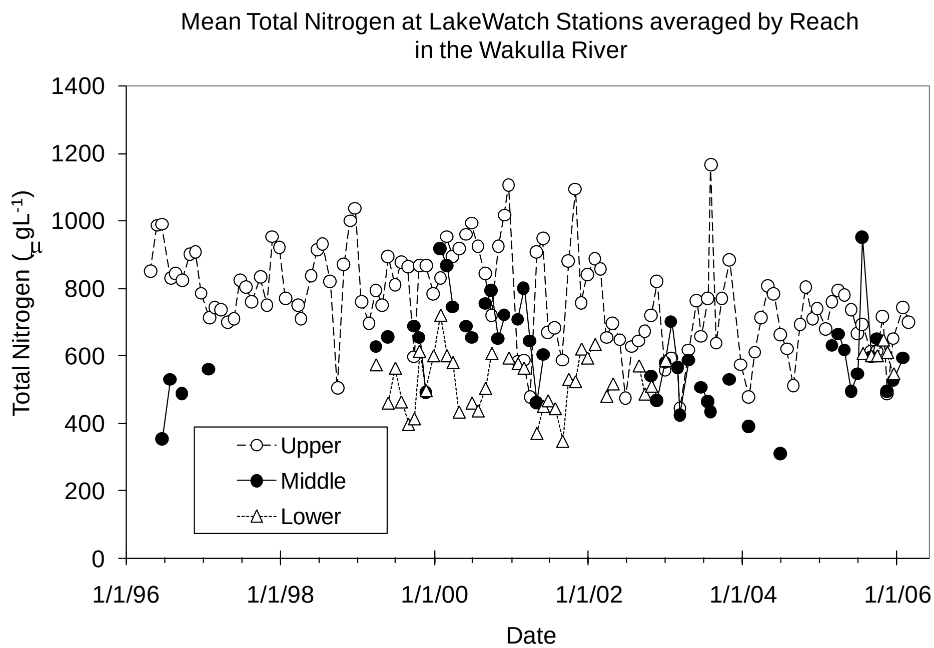


Figure 51 - Mean Total Nitrogen in the Wakulla River by Reach (LakeWatch Stations, FL STORET 2007)

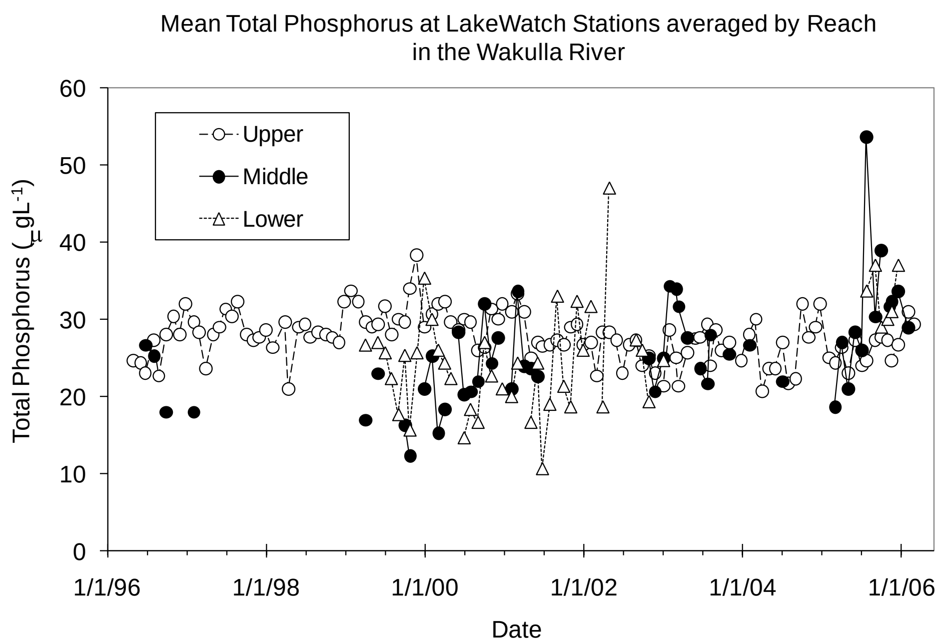


Figure 52- Mean Total Phosphorus in the Wakulla River by Reach (LakeWatch Stations, FL STORET 2007)

In addition to the above analysis, FDEP Environmental Assessment Section, in conjunction with NWFWMD, has collected water quality and biological data at a site on the upper Wakulla River just below the turning basin in the State Park. These data, while included in the above discussion, are reported separately in the EcoSummary section on the FDEP website. Information on water quality and Stream Condition Index (SCI) has been provided from quarterly sampling since February 2000. According to these summaries, stream health has ranged from healthy to impaired. High nitrate-nitrite concentrations have been consistently observed along with a highly variable SCI. SCI values ranged from very poor to excellent (most in the poor and very poor categories) and were in part influenced by the presence of the exotic weed hydrilla (see latter section on submerged aquatic vegetation).

7.3 Sediment Characteristics

A sediment survey was conducted by the U.S. Fish and Wildlife Service in 1988 (Hemming and Brim 2002) to examine sediment quality in and around the St. Marks National Wildlife Refuge (NWR). Thirty-two sites (14 within and 18 north of the NWR) were sampled for grain size, metals, polycyclic aromatic hydrocarbons (PAH), aliphatic hydrocarbons, and organochlorine pesticides. Analytical results were compared to sediment quality guidelines (Long et al. 1995) and risks were assigned based on these numeric recommendations.

Sediments were generally sandy throughout the survey area with localized patches of finer material. Sand ranged from 12.3 to 94.6%, silt from 2.3 to 49.6% and clay from 2.9 to 51.9%. Areas with greater percentages of silts and clays were associated with human activity such as the lighthouse boat basin, and the fuel docks, power plant intake and marinas in the City of St. Marks. Total organic carbon was generally low ranging from 0.2 to 4.9% dry weight.

Sediment contamination was relatively low throughout the NWR but was noted occasionally at sites outside the refuge. Metals (copper and mercury) exceeded the Effects Range Low (ERL; Long et al. 1995) at several sites outside the NWR but were not found in the NWR. PAHs and organochlorine pesticide concentrations in the NWR did not exceed guidelines; however, PAH contamination was noted in the industrial area of the St. Marks associated with fuel docks and marinas. Aliphatic hydrocarbons and oils and grease residues were the only contaminants observed in sediments within the NWR; these were thought to be associated with motor vessel traffic in the refuge.

8.0 ST. MARKS/APALACHEE BAY HABITATS

The lower St. Marks and Wakulla Rivers/Apalachee Bay system supports a variety of wetland habitats and biotic communities, and maintains a high level of biodiversity. Those habitats directly associated with surface waters of the springs, rivers and nearshore areas include: palustrine forests, fresh and brackish wetlands, tidal salt marshes, submerged aquatic vegetation, seagrasses, soft and hard bottom.

8.1 Palustrine Forest

Few investigations have focused on the wetland forests of the Wakulla and lower St. Marks basins. Based on forest community studies in the Ochlockonee, Wakulla/St. Marks and Suwannee rivers (Clewell 1986; Leitman et al. 1991; Light et al. 1993; Light et al. 2002), palustrine forests in this area are composed of at least three major vegetation types: bottomland hardwoods, cypress swamps and coastal tidal swamps. The distribution of these forests types are heavily influenced by elevation, the degree and type of inundation, and proximity to the coast (i.e., salt water).

Bottomland hardwood forests occupy wet-mesic to nearly hydric habitats that are usually associated with stream and river floodplains (Clewell 1986). Habitats in these forests are generally inundated, sometimes briefly but occasionally for prolonged periods annually. During the dry season, the root zone is usually well aerated. In areas where flooding is more pronounced, cypress-tupelo swamps dominate. These swamps are characterized by prolonged hydroperiods in which the soils are inundated at least several weeks every year and often for as long as six months (Clewell 1986). Clewell (1986) described a variant of the cypress-tupelo swamp from the Wakulla River in which tupelos were generally absent leaving bald cypress as the dominant vegetation. Coastal swamps occur along river floodplains within the zone of tidal influence and along the inland margins of tidal marshes (Clewell 1986). While freshwater conditions generally prevail, coastal swamps are subject to tidal fluctuations and can tolerate some salt water inundation. Proximity to the coast results in rapid dissipation of flood waters precluding lengthy or prolonged inundation during seasonal flooding. Generally uniform hydrological conditions and occasional salinity shock likely limit the species present.

The vegetation community along the Wakulla River was divided into three zones roughly parallel to the river (Clewell 1986). A cypress swamp consisting primarily of bald cypress (*Taxodium distichum*), pop and pumpkin ash (*Fraxinus carolina* and *F. profunda*), and red maple (*Acer rubrum*) was noted along the river bank. Bottomland hardwoods comprised the adjacent terrace and slope leading to the uplands. Terrace trees were dominated by pumpkin ash, red maple, swamp laurel oak (*Quercus laurifolia*), planer-tree (*Planera aquatica*), and swamp red bay (*Persea palustris*), while the drier slope was inhabited by swamp laurel oak, sweetbay (*Magnolia virginiana*) and ironwood (*Carpinus caroliniana*). A bottomland hardwood site along the St. Marks River south of Natural Bridge (Clewell 1986) was dominated by ironwood (*Carpinus carolina*), green ash (*Fraxinus pennsylvanica*), sweet gum (*Liquidambar styraciflua*) and hackberry (*Celtis laevigata*). Other relatively abundant trees included loblolly pine (*Pinus taeda*), red maple and bald cypress. Another site about 1 km below Natural Bridge was examined by Light et al. (1993); they described three relatively distinct floodplain vegetation zones, similar to Clewell (1986), that included the low plain and the lower and upper slopes. Ironwood and sweet gum dominated all zones with sweetbay, swamp dogwood (*Cornus foemina*) and bald cypress common in the lower regions. Loblolly pine was the most abundant tree on the upper slope.

Although not examined in detail in the Wakulla/St. Marks area by Clewell (1986), coastal swamps have been described by Light et al. (2002) for the lower Suwannee River and are expected to be similar to those in the St. Marks. Canopy composition in these lower tidal swamps was dominated by pumpkin ash, bald cypress, swamp tupelo (*Nyssa biflora*), with pumpkin ash, swamp tupelo, sweet bay, cabbage palm (*Sabal palmetto*) and loblolly pine (*Pinus taeda*) dominating in the lower tidal mixed bottomland and hammocks. Cabbage palms were found in all tidal communities as both canopy and subcanopy trees. Lower tidal hammocks, as described by Light et al. (2002), vary in elevation and in distance from the Gulf, thus in exposure to river flooding, tidal surge, and salinity. Hammocks closest to the Gulf tended to have the largest proportion of cabbage palms.

Light et al. (2002) defined three major and 14 specific forest types in the ten-year floodplain of the lower Suwannee River. General forest types were divided into riverine, upper tidal and lower tidal components. These forest types are similar to those described by Clewell (1986) from limited sampling in the Wakulla/St. Marks vicinity. Dominant canopy species, primary soil texture in the root zone, and typical hydrological conditions are summarized for the specific wetland forest types (Light et al. 2002). Riverine bottomland hardwoods and riverine swamps comprise the riverine habitats. These forest types vary in inundation levels ranging from durations of 1-2 months every 3 years to 4-7 months annually. Dominant trees included live oak (*Quercus virginiana*), sweet gum (*Liquidambar styraciflua*), swamp laurel oak, river birch (*Betula nigra*), bald cypress, overcup oak (*Quercus lyrata*) and planer-trees. Upper tidal habitats were dominated by swamp laurel oak, cabbage palm, bald cypress, pumpkin ash and water tupelo (*Nyssa aquatica*). Flooding in upper tidal habitats ranged from once every 2 years, with rapid soil drying after flood recession, to monthly by high tides or high river flow with continuously saturated soils. Lower tidal hammocks and swamps ranged in inundation from every 1-2 years to daily or several times monthly. In most cases, soils are saturated continuously, at least in the lowest areas. Lower tidal forests consist of cabbage palm and loblolly pine on the higher sites and pumpkin ash, swamp tupelo, sweetbay and bald cypress in the wetter sites.

Approximately 39,500 acres of palustrine forests (both forested and scrub-shrub wetlands) are found in the St. Marks and Wakulla basins (Figure 53; NWI coverage) with the majority (78%) found in the St. Marks. The bulk of the St. Marks palustrine forest is found in the upper portion of the basin. Of the nearly 8,800 acres of wetland forests in the Wakulla basin, most are located in the lower, tidal portion just upstream of its confluence with the St. Marks River. A relatively narrow fringe of forested habitat extends upriver and includes the areas around the main and secondary springs (e.g., Sally Ward and McBride).

8.2 Freshwater and Brackish Wetlands

The fresh and brackish wetlands include both emergent and submergent plant forms and result in a floral continuum from the headwaters/springs to the estuary. A riparian marsh habitat is found in the freshwater portion of the system with the brackish marsh extending downstream through the oligohaline region of the estuary where salinities range from 0 to 15 ppt. Marsh species composition is likely influenced by a combination of salinity tolerance and differences in soil type, elevations and competitive interactions.

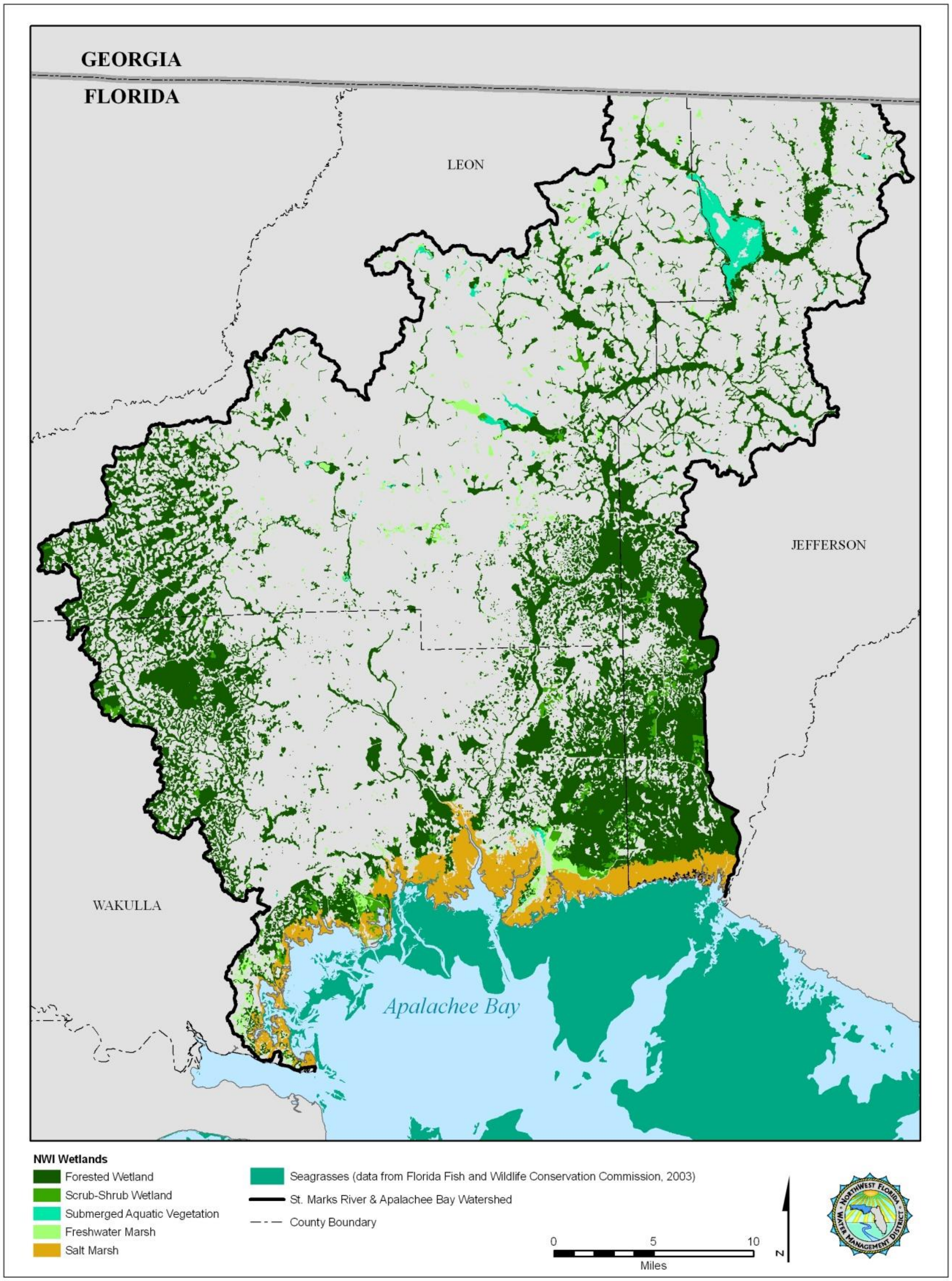


Figure 53- Wetland and Aquatic Habitats in the St. Marks/Apalachee Bay Watershed (NWI 1994)

Often the emergent portions of these fresh/brackish marshes are dominated by sawgrass (*Cladium jamaicense*), maidencane (*Panicum hemitomon*), giant cutgrass (*Zizaniopsis miliacea*) and cattails (*Typha* spp.), but may contain large interspersed patches of black needlerush (*Juncus roemerianus*). In the underwater areas, various species of submerged aquatic vegetation often proliferate. While numerous freshwater marshes are evident scattered throughout the coastal region, none were noted in the National Wetlands Inventory (NWI) coverage along either of the river corridors (Figure 53).

Riparian freshwater and brackish marshes were examined in the Wakulla River by Thompson (1977). Five locations were studied from the U.S. 98 bridge (transect I) to a point about halfway between the lighthouse and the confluence of the Wakulla and St. Marks rivers (transect V) with three sites upstream of the confluence and two downstream. Ninety-four species of plants were identified consisting of 74 emergent marsh species, 10 permanently submerged aquatics, 8 intertidal aquatics and 2 floating species. Overall, clearly defined communities were not observed at each site rather an intergrading of species between locations; gradual changes in dominance of individual species were noted between adjacent locations (Table 9).

A riparian freshwater marsh exists at the upper site (transect I) and is dominated by dwarf arrowhead (*Sagittaria subulata*), needle rush (*Juncus polycephalus*), pickerelweed (*Pontederia cordata*), and obedient plant (*Dracocephalum purpureum*). No appreciable salinity was measured at this site (salinity range: 0.0-0.3 ppt). Sites along the middle and lower river were brackish in nature with mean salinities ranging from 1 ppt (transect II) to 8 ppt (transect V). Middle river stations (transects II and III) were dominated by black needle rush (*Juncus roemerianus*), sawgrass (*Cladium jamaicense*), dwarf arrowhead, spiked loosestrife (*Lythrum lineare*), and climbing hempweed (*Mikania scandens*). These sites had higher mean salinities (1-2 ppt) with significantly greater salinity ranges (11-13 ppt). Lower river locations (transects IV and V) were inhabited by black needlerush, sawgrass, dwarf arrowhead, false loosestrife (*Ludwigia repens*), marsh fimbry (*Lilaeopsis chinensis*), and eastern grasswort (*Fimbristylis castanea*). Salinitiy ranged up to nearly 25 ppt at these lower sites even though mean values were only 3 and 8 ppt, respectively. Upper site (I) vegetation was more distinctly limnetic and displayed differences between east and west river banks, probably a result of differences in bank slope and degree of inundation. Lower sites (IV and V) had some salt marsh characteristics (see tidal salt marsh section) but were more heterogenous in species composition. In contrast with more coastal salt marshes, these sites lack the extensive salt flats of salt grass (*Distichlis spicata*) and glasswort (*Salicornia* spp.) and salt barrens. Thompson (1977) suggested that their absence resulted from low tidal inundation that was either too fresh (not sufficient salt) or too infrequent to allow the development of these flats and barrens.

Limited information is available on the extent of fresh and brackish marsh in the system. Freshwater wetlands were found in the NWI coverage of the watershed (Figure 53), but were not mapped along the river corridor proper, possibly because of the small amount of habitat existing or their intergrading with the narrow fringing palustrine forest. Freshwater and brackish wetlands were not differentiated for mapping purposes in the NWI coverages, but were readily distinguished from the tidal salt marshes (see below).

	Transects				
	I	**II**	**III**	**IV**	**V**
River Mile (from Mouth)	**15**	**12**	**10**	**8**	**5**
Species					
Sagittaria subulata (dwarf arrowhead)	32	16	1	13	1
Juncus polycephalus (needle rush)	34				
Cladium jamaicense (sawgrass)		9	13	8	<1
Pontederia cordata (pickerelweed)	6	2			
Dracocephalum purpureum (obedient plant)	7				
Juncus roemerianus (black needlerush)		55	79	63	82
Lythrum lineare (spiked loosestrife)		5			
Mikania scanden s (climbing hempweed)		4			
Saurus cernuus (lizard's tail)		1			
Scirpus americanus (bull rush)				1	
Ludwigia repens (false loosestrife)			1	4	
Fimbristylis castanea (marsh fimbry)				2	1
Lilaeopsis chinensis (eastern grasswort)				2	12
Other species	21	8	6	7	3
Mean salinity (top/bottom)	**0/0**	**0/1**	**1/2**	**2/3**	**4/8**
Max. salinity (top/bottom)	**0/0**	**2/12**	**4/13**	**7/24**	**13/25**

Table 9 – Mean Relative Abundance of Marsh Macrophytes in the Wakulla and Lower St. Marks Rivers (Thompson 1977)

8.3 Tidal Salt Marsh

Salt marshes are similar to brackish marshes in that they serve as a transition between terrestrial and marine systems. Generally, salt marshes are intertidal and develop along relatively low energy shorelines. Unlike brackish marshes, they may be found under significantly more saline conditions.

Salt marshes in the Florida panhandle are usually characterized by large, fairly homogeneous expanses of dense black needlerush (*Juncus roemerianus*). Often they are accompanied on the water ward side by smooth cord grass (*Spartina alterniflora*). The *Juncus* and *Spartina* zones are very distinctive and can be separated easily by elevation, with *Spartina* inhabiting the lower, regularly flooded zone, and *Juncus* found in higher, less flooded area. Frequently, additional species of cord grass (*Spartina* spp.), salt grass (*Distichlis spicata*), glasswort (*Salicornia virginica*), various sedges (*Scirpus* spp.) and the common cane (*Phragmites australis*) occur.

Generally, tidal salt marshes can be divided into four ecological zones governed by elevation and extent of inundation: *Spartina alterniflora* zone, *Juncus* marsh, salt flats, and barrens (Wolfe et al. 1988). The *Spartina* zone typically fringes tidal creeks and channels. A small landward increase in elevation permits development of lush *Juncus* stands that are by far the most extensive and conspicuous feature of the tidal marsh. *Juncus* plants may grow to 6-7 feet in height throughout the majority of the marsh declining to about one-half this height at the landward edge of the marsh near the flatwoods where they merge with the salt flats. Stunted plants of several genera typify the flats, especially *Salicornia*, *Batis*, *Borrichia* and *Aster*. The barrens are landward of the flats and consist of bare ground flooded by high tides for only brief periods. This infrequent tidal inundation coupled with long exposure to sunlight results in such high salt content of the soil that excludes most plants. True salt marshes appear limited to the higher salinity regions of the St. Marks/Apalachee Bay complex with an expansive area noted all along the coastal region.

Salt marsh production and zonation were examined in the vicinity of the East River, a small tidal creek along the eastern side of the St. Marks River mouth (Kruczynski et al. 1978). The study site was dominated by black needlerush, followed by smooth cord grass and salt grass. Productivity was greatest in the low marsh (i.e., closest zone to the water) and decreased landward for both needlerush and cord grass; salt grass was found primarily in the high marsh. Needlerush production was significantly greater than cord grass in all zones examined; salt grass production, however, exceeded both needlerush and cord grass in the high marsh (the only zone in which it was noted in appreciable abundance).

Early estimates of salt marsh habitat in the vicinity of the St. Marks River were provided for a larger section of Apalachee Bay (McNulty et al. 1972) and included the area from Alligator Harbor eastward to the Econfina River (shown in Figure 18 of the above cited report). Within this larger area, approximately 137,600 acres of tidal marsh were mapped. More recent information, available from the NWI mapping, indicated about 22,300 acres of tidal marsh and 5,350 acres of salt flats within the basin adjacent to the mouth of the St. Marks River (Figure 54). This acreage represents only a small fraction of the tidal marsh habitat located along the shoreline of Apalachee Bay, as indicated in both Figure 54 and McNulty et al. (1972). Approximately 3,200 acres of salt marsh/salt flats were noted in the lower St. Marks basin proper with only 218 acres of marsh and flats in the lower portion of the Wakulla basin just upstream of the confluence of the Wakulla and the St. Marks Rivers.

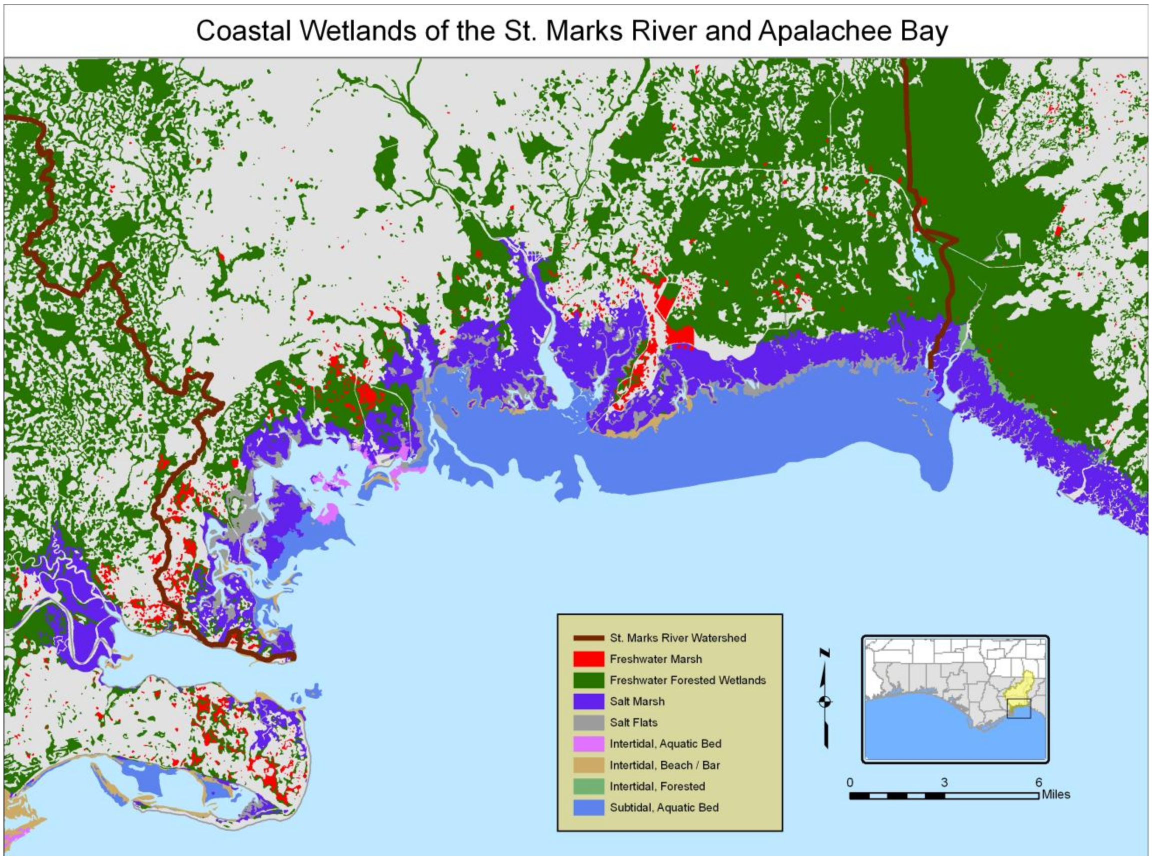


Figure 54- Coastal Wetlands in the St. Marks/Apalachee Bay Area (1995 NWI data)

8.4 Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV), including seagrass, represents one of the most important and productive habitats in freshwater, estuarine and nearshore environments. SAV beds support highly diverse and abundant floral and faunal communities and provide spawning, feeding, nursery and protective refugia for a wide array of aquatic organisms including many of recreational and commercial value.

Submerged and intertidal vegetation has been characterized in the Wakulla River by Thompson (1977) at the same transect locations described previously for riparian and brackish marshes. Nine species were collected with SAV biomass varying noticeably between locations from 63 to 759 g per m^2 (Table 10). Upper, less saline sites (I and II) were dominated by tape grass (*Vallisneria americana*), strap-leaf sag (*Sagittaria kurziana*), dwarf arrowhead (*S. subulata*), southern naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), and Illinois pondweed (*Potamogeton illinoensis*). Strap-leaf sag, Illinois pondweed and small pondweed (*Potamogeton pusillus*) were found only at these upper sites. Although not shown in Table 10, dwarf arrowhead made up nearly 65% of the intertidal marsh vegetation on the west bank of site I. Total plant biomass was greatest at upper sites and least at the lower site. Eight of the nine species decreased in biomass with distance downstream and increasing salinity. Widgeon grass (*Ruppia maritima*) was the only species to increase in biomass from sites I to IV and was the only SAV collected at the downstream, most saline station (V). Despite its presence at this lower site, biomass declined from the values noted at the two adjacent upstream locations. This suggests that while widgeon grass is the most salt tolerant of the riverine SAV it cannot tolerate the wide salinity range at the lower site. Red pondweed (*Potamogeton perfoliatus*) was noted only at site IV and showed no distribution trends. Thompson (1977) suggested that salinity is a major influence on SAV distribution throughout these sections of the river. Thompson cited anecdotal claims by local residents that Hurricane Agnes in 1972 virtually eliminated all aquatic vegetation from at least the brackish portions of the Wakulla River; Clewell (1986) questioned whether this defoliation resulted from salinity intrusion or uprooting.

	Transects				
	I	**II**	**III**	**IV**	**V**
River Mile (from Mouth)	**15**	**12**	**10**	**8**	**5**
Species					
Ceratophyllum demersum (coontail)	0	189	1	0	0
Najas guadalupensis (southern naiad)	44	154	2	0	0
Potamogeton illinoensis (Illinois pondweed)	79	0	0	0	0
Potamogeton perfoliatus (red pondweed)	0	0	0	68	0
Potamogeton pusillus (small pondweed)	2	1	0	0	0
Ruppia maritima (widgeon grass)	0	52	92	144	63
Sagittaria kurziana (strap-leaf sag)	204	1	0	0	0
Sagittaria subulata (dwarf arrowhead)	0	154	29	1	0
Vallisneria americana (tape grass)	242	209	143	111	0
TOTAL	**571**	**759**	**267**	**324**	**63**
Mean salinity (top/bottom)	**0/0**	**0/1**	**1/2**	**2/3**	**4/8**
Max. salinity (top/bottom)	**0/0**	**2/12**	**4/13**	**7/24**	**13/25**

Table 10 – Mean Dry Weight Biomass (g/m^2) of Submerged and Intertidal Macrophytes in the Wakulla and Lower St. Marks Rivers (Thompson 1977)

Birkitt (1981) reported considerably higher SAV biomass from three vegetation transects taken near the U.S. 98 bridge (near Thompson's (1977) transect I). Four macrophyte species were noted yielding a total biomass of about 1545 g per m^2. Strap-leaf sag dominated the sites making up 88.6% of the total plant biomass; tapegrass and Illinois pondweed contributed 8.5% and 2.9%, respectively. Trace amounts of southern naiad were observed. Birkitt reported significant heterogeneity (i.e., patchiness) in vegetation distribution that was particularly noticeable with dense patches of tapegrass interspersed within dense areas of strap-leaf sag yielding a mosaic pattern. Strap-leaf sag biomass increased upstream while tapegrass biomass increased downstream within the river reach examined. Birkitt suggested this pattern was related in part to the distribution of chlorinity/salinity within the river with tapegrass having the greater tolerance. Plant biomass was uncorrelated with most of the sediment characteristics collected (i.e., grain size, skewness, or percent silt/clay); total biomass was correlated with the degree of sediment sorting and as such was likely related to current velocity.

Additional qualitative investigations of SAV have been made in the upper portion of the river, from the head springs (within the State Park) to the U.S. 98 bridge, primarily to examine results of an exotic weed eradication program initiated there. The accidental introduction of hydrilla (*Hydrilla verticillata*) in 1997 to the Wakulla Springs system, fueled by high nutrient concentrations, led to explosive nuisance plant growth and prompted the State of Florida to begin herbicide application in 2002. Excessive hydrilla growth degrades the river by physical smothering of native habitats and water quality degradation (e.g., low dissolved oxygen levels and extensive organic silt buildup resulting from decomposition of dead plant tissue). An herbicide overdose in April 2002 damaged native vegetation and lead to sediment scouring in portions of the river; partial recovery followed relatively quickly over the next growing season. A tapegrass transplanting program was initiated by State Park staff in 2004 to aid in the re-vegetation of native species (S. Savery, FDEP, personal communication).

Limited information exists on the acreages of submerged and intertidal vegetation in the system; the areas of SAV mapped in the NWI wetlands coverage (Figure 53) are found scattered in the upper reaches of the basins and are not related to the river corridors.

8.5 Seagrass

Seagrasses represent one of the most important and productive habitats in estuarine and nearshore environments. Seagrass beds support highly diverse and abundant floral and faunal communities and provide spawning, feeding, nursery and protective refugia for a wide array of aquatic organisms including many of recreational and commercial value. Seagrass beds in the St. Marks/Apalachee Bay system are dominated by turtle grass (*Thalassia testudinum*) and shoal grass (*Halodule wrightii*). Other species include manatee grass (*Syringodium filiforme*), star grass (*Halophila engelmanni*) and widgeon grass (*Ruppia maritima*).

Vertical zonation of seagrasses generally correlates with tidal level in most shallow estuarine waters (Zieman 1987). *Halodule wrightii* and *Ruppia maritima* are abundant intertidally, with *Ruppia* preferring a somewhat lower level than *Halodule*; *Thalassia*, *Syringodium* and *Halophila* are found only below low water levels. Low or unusually high salinity may restrict or eliminate *Thalassia* and *Syringodium*. *Thalassia* and *Syringodium* are usually associated with stable, near-marine salinities (20-36 ppt), open coastal water, and subtropical to tropical temperatures. *Halodule* is generally found in more estuarine conditions (10-25 ppt), but also forms dense stands in open coastal, high-salinity regions, in areas of high water movement or in tidal flats where it is subject to exposure. *Ruppia* is most common in very brackish water (1-5 ppt), with meadows extending into the mouths of rivers (Dawes 1987).

Grass beds in Apalachee Bay are comprised of a variety of rooted seagrasses and attached and drifting macroalgae. In an adjacent area of Apalachee Bay (off the Econfina and Fenholloway Rivers), Zimmerman and Livingston (1976a, b, 1979) collected a total of 39 species of benthic macrophytes; red algae dominated the list with 17 species. These studies focused on a comparison of plant assemblages in the relatively unpolluted Econfina River and the heavily polluted Fenholloway River (receiving effluent from a pulp mill). Grass beds in the unpolluted Econfina area are likely very similar to those off the mouth of the St. Marks River, about 15 miles to the west. Examining only those stations directly off the mouth of the Econfina River (seven sites), 30 species were observed (Table 11); the calcareous green alga *Halimeda incrassata* was the most prevalent macrophyte in the area in terms of biomass, followed by turtle grass and manatee grass. Widgeon grass and shoal grass were present but in less abundance. Overall biomass of macrophytes was highly seasonal with maximum standing stock noted during the warm summer months.

Seagrass in Apalachee Bay was estimated to occupy about 58,100 acres in the early 1970s (McNulty et al. 1972). These acreages were mapped in the above cited report and included the area from Alligator Harbor eastward to the Econfina River. Later mapping by the NWI (Figure 53) indicated approximately 29,630 acres (classified as estuarine algal beds) along the Apalachee Bay coastline (see discussion of Wakulla County beds in Sargent et al. 1995). These mapped beds appear limited in size and spatial extent and likely do not depict total seagrass coverage in the area. More recent surveys, including one by FDEP in 1992 (statewide) and one by SRWMD in 2001 (Big Bend only), were carried out in the area but are not directly comparable because of differences in photography and mapping techniques. Despite these differences, the recent maps can be evaluated by examining overlapping mapped portions of the coverages and estimating seagrass acreages for each survey within the overlap zone. In this way we can estimate possible differences over the time period between surveys. Given the above caveats, seagrasses were estimated to cover about 89,350 acres (Figure 55) and 68,300 acres (Figure 56), respectively, during the 1992 and 2001 surveys. While this difference may reflect artifacts of the sampling, if real, this would be a loss of almost 25% of the seagrass in the compared area.

On a larger scale, seagrass declines have been observed for the Big Bend area, defined as the five counties from the Apalachicola to the Withlacoochee Rivers (Handley et al. 2007). Investigators cited total seagrass acreage (continuous and patchy cover) to have been 817,528 acres in 1984, 267,639 acres in 1992 and 447,251 acres in 1995. While it is unclear if the 1995 estimate is a reversal of a downward trend or if the 1992 values were low, seagrass habitat covers less acreage now than historically.

8.6 Soft-Bottom Habitat

Unvegetated sand and mud make up sizeable portion of both rivers, adjacent tributary and tidal creek channels, and bay bottom in the St. Marks/Apalachee Bay system. These bottom areas, although devoid of most structure, can be quite productive in terms of infaunal organisms and the communities they support. While the most conspicuous habitats are tidal marsh, oyster reef and SAV/seagrass, soft bottom areas can serve as significant feeding grounds for a variety of fin and shellfish of recreational and commercial value. The extent of the soft-bottom habitat is unclear having not been mapped to date in the area.

Species	Plant Phylum	Total Dry Weight (g)
Halimeda incrassata	Chlorophyta	20648
Thalassia testudinum	Spermatophyta	18335
Syringodium filiforme	Spermatophyta	3969
Digenia simplex	Rhodophyta	2330
Ruppia maritima	Spermatophyta	687
Laurencia poitei	Rhodophyta	466
Penicillus capitatus	Chlorophyta	365
Halodule wrightii	Spermatophyta	337
Polysiphonia harveyi	Rhodophyta	278
Caulerpa prolifera	Chlorophyta	125
Halophila engelmanni	Spermatophyta	100
Anadyomene stellata	Chlorophyta	82
Gracilaria verrucosa	Rhodophyta	59
Padina vickersiae	Phaeophyta	51
Spyridia filamentosa	Rhodophyta	35
Sargassum pteropleuron	Phaeophyta	26
Udotea flabellum	Chlorophyta	25
Gracilaria cervicornis	Rhodophyta	24
Laurencia intricata	Rhodophyta	15
Sargassum filipendula	Phaeophyta	7
Gracilaria foliifera	Rhodophyta	6
Udotea conglutinata	Chlorophyta	4
Caulerpa paspaloides	Chlorophyta	4
Codium isthmocladum	Chlorophyta	4
Cladophoropsis membranacea	Chlorophyta	<1
Laurencia papillosa	Rhodophyta	<1
Cladophora sp.	Chlorophyta	<1
Chondria tenuissima	Rhodophyta	<1
Polysiphonia subtilissima	Rhodophyta	<1
Chaetomorpha linum	Chlorophyta	<1

Table 11 – Biomass of Macrophytes in Apalachee Bay Offshore of Econfina River (Zimmerman and Livingston 1976)

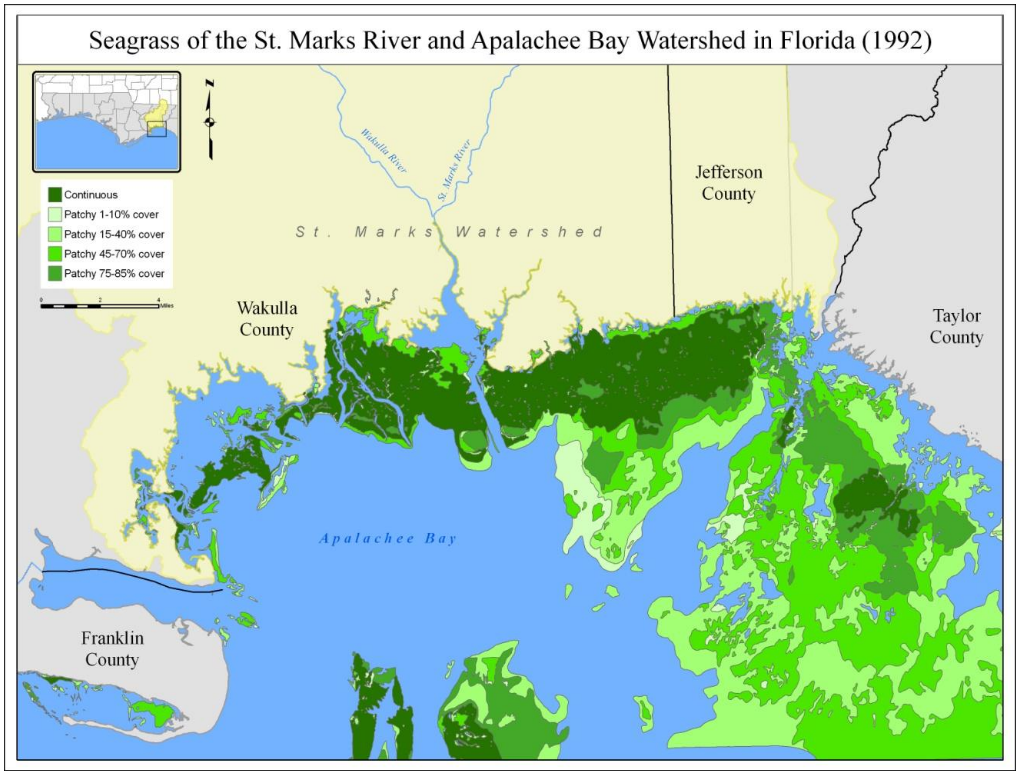


Figure 55- Seagrass Coverage (1992) in the Nearshore Area of Apalachee Bay

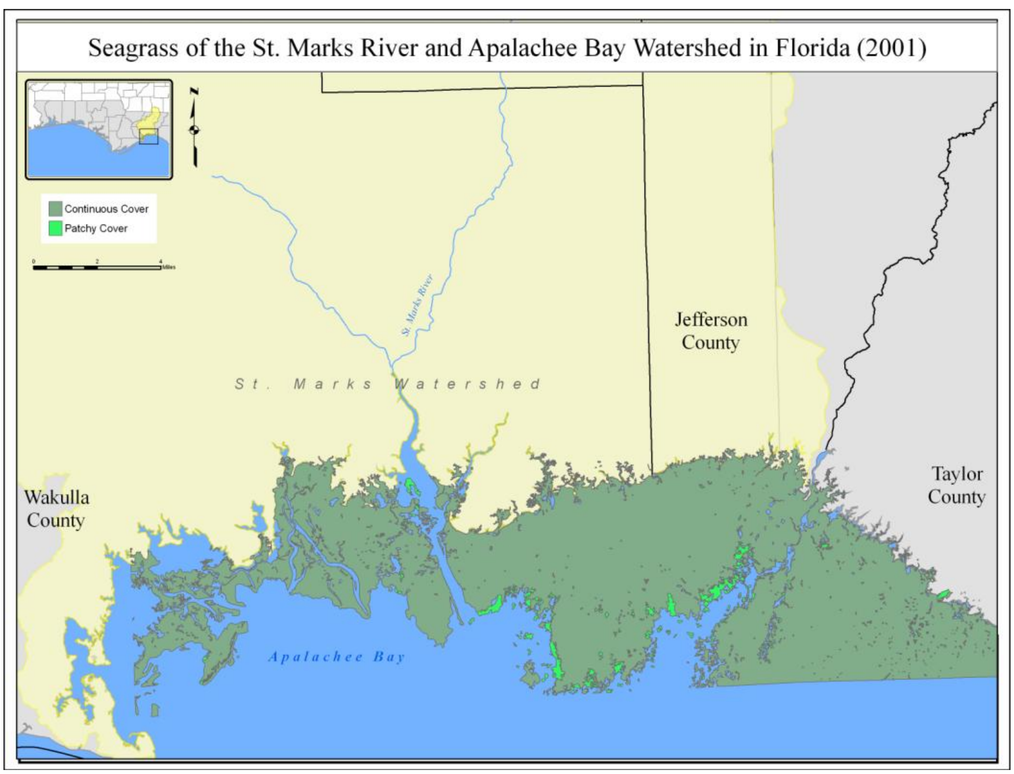


Figure 56- Seagrass Coverage (2001) in the Nearshore Area of Apalachee Bay

8.7 Hard-Bottom Habitat

Much of the hard substrate habitat in panhandle estuaries is artificial, comprised of structures such as jetties, bridges, and pier pilings. Of the naturally occurring hard substrate habitats in this area, oyster reefs are the most abundant as well as being ecologically and economically important. Natural oyster reefs are extensive in the lower St. Marks River and adjacent tidal marshes, but are restricted in the lower Wakulla River because of low salinity.

The biology of the oyster has been extensively studied worldwide because of its economic value (see summaries by Galtsoff 1964; Kennedy et al. 1996). Oysters are typically reef building organisms, growing on the shell substrate accumulated from generations of oysters. They may occur in both intertidal and sub-tidal environments. The primary reef-building commercial oyster in the panhandle is the Eastern or American oyster (*Crassostrea virginica*). This species grows in a wide salinity range (10-30 ppt) with optimal growth occurring at water temperature of about 25^{o}C. Frequently reefs also contain large numbers of other bivalve mollusks such as horse oysters (*Ostrea equestris*) and hooked mussels (*Ischadium recurvum*).

The location and distribution of oyster reefs depend on many interacting factors which include complex combinations of geological, physical, chemical and biological processes. Reef oysters, although tolerant of broad ranges of important habitat variables such as temperature and salinity, are susceptible to various forms of physical disturbance that can adversely affect or destroy reef structures. Success of the eastern oyster depends on factors that influence spawning, planktonic larval development, metamorphosis of the spat stage, and longevity of the sexually mature adult. Commercial harvesting, predation, disease and physical processes such as sedimentation (burial) are major causes of mortality in the developing oyster reefs. Water circulation is important for larval transport and settlement, delivery of food (phytoplankton), and removal of waste. Salinity is a key factor in the incidence of predation and disease, both increasing with increasing salinity.

McNulty et al. (1972) attempted to estimate oyster habitat in Apalachee Bay from Alligator Harbor to Econfina River (see Figure 18 in above cited report) but likely underestimated the coverage. They noted approximately 2,700 acres of beds, of which nearly 90% were closed to shell fishing. Currently shellfish harvesting is allowed in some western parts of Apalachee Bay but not in the immediate vicinity of the St. Marks (see previous section on water quality classifications). No recent oyster bar location mapping is available for the area.

In addition to living hard bottom, limestone outcroppings appear throughout the river and nearshore area and undoubtedly provide habitat and shelter for a variety of aquatic organisms. These structures, however, have not been mapped and little is known about their influence on floral and faunal assemblages.

9.0 FAUNAL COMMUNITIES OF THE LOWER ST. MARKS/WAKULLA RIVERS AND APALACHEE BAY SYSTEM

The St. Marks watershed and nearshore Apalachee Bay provide a diversity of habitats supporting a wide range of riverine and estuarine biological communities. Interestingly, considerably more information has been gathered over the years on the less accessible estuarine assemblages than on the relatively easily observed freshwater plant and animal communities. This noted difference is probably more a function of specific interests of nearby university researchers than accessibility to sampling sites.

9.1 Riverine Communities

Much of the information available concerning riverine animal communities in the watershed are derived from studies in the Wakulla River. The Wakulla Springs and River system supports a variety of biotic communities and maintains a relatively high level of biodiversity. As a spring-fed stream, the Wakulla River differs from other types of panhandle streams in several important ways (Wolf et al. 1988), all of which influence the floral and faunal assemblages present. Spring waters are generally clear and as such can support lush plant growth. These waters also have a relatively constant temperature that persists to a certain extent downstream, making them thermally buffered. Because they travel through subterranean limestone sediments/caverns, spring waters have relatively high concentrations of calcium, magnesium, iron and other minerals and are notably less acidic than non-spring streams. These characteristics influence the types and abundances of animals present.

9.1.1 Benthic and Epifaunal Invertebrates

Studies examining the invertebrate communities in the river are few, including those of Birkitt (1981), Walsh and Williams (2003) and ongoing investigations by FDEP and NWFWMD of environmental conditions at Edward Ball Wakulla Springs State Park. Additionally, long-term monitoring has occurred in the vicinity of Big Boggy Branch, a tributary to the lower Wakulla River that receives treated industrial discharge from Primex Technologies, Inc. (aka. Olin Corporation).

Birkitt (1981) examined benthic and epifaunal communities associated with submerged aquatic macrophytes at three transects in the lower reach of the Wakulla River near the U.S. 98 bridge. The study site was co-located with that of Thompson (1977) and near the upper limit of salinity in the system under all but extreme conditions (e.g., above normal tides, hurricanes). Twenty-six epifaunal and 29 benthic taxa were collected from a seasonally limited sampling program. Density of epifaunal invertebrates was three times greater at the upstream transect relative to the two downstream ones, ranging from 296 to 845 individuals per $0.25m^2$ over the three locations. Number of individuals per gram of plant was also greatest upstream. Number of taxa was similar among the sampling sites, ranging from 16 to 18. The upstream transect was dominated by the caddisflies *Orthotricha* sp. and *Agraylea* sp., and the oligochaete *Nais* sp.; downstream transects had high numbers of *Nais* sp. and the chironomid midge *Orthocladius* sp. Epifaunal abundance was significantly correlated with the biomass of strap-leaf sag (*Sagittaria kurziana*), the dominant SAV in the river at this location. Density and number of taxa of benthic invertebrates was also greatest at the upstream transect. All three locations were dominated by unidentified oligochaete worms and gammarid amphipods; chironomid midges represented a sizable fraction of the individuals collected at the upper two sites. Benthic abundance was correlated with percent silt/clay in the sediments; number of benthic taxa was associated with total SAV biomass, decreased sorting of sediments and greater percent silt/clay. Overall, Birkitt noted that salinity, macrophyte biomass and species, and various sediment characteristics (i.e., degree of sorting and percent silt/clay) appeared to influence aquatic community structure.

Freshwater mussels were surveyed in a brief investigation within the boundaries of the State Park (Walsh and Williams 2003). Only four species of native unionids were collected: variable spike (*Elliptio icterina*, 86.6%), peninsular floater (*Utterbackia peggyae*, 7.3%), Florida pondhorn (*Uniomerus carolinianus*, 3.7%), and southern rainbow (*Villosa vibex*, 2.4%). Several specimens of the nonindigenous Asian clam (*Corbicula fluminea*) were also found. The authors suggested that the Wakulla River likely supports a native mussel fauna relatively depauperate in species richness, but that may have moderately large populations, especially of the variable spike, a species widely occurring in springs and spring-fed rivers throughout north central Florida.

The apple snail (*Pomacea paludosa*) was a common inhabitant of the springs and upper river historically; however, its abundance has dwindled in recent years (S. Savery FDEP, personal communication). Apple snails are a primary food of the limpkin (*Aramus guarauna*) (Bryan 1981), a protected wading bird once common on the Wakulla River but now rarely seen. Apple snails generally live in slow flowing, relatively shallow water, and require SAV for grazing and egg laying. They prefer broad-leafed emergent plants that grow more than 10 cm above the water surface. Because of the dramatic declines in numbers of apple snails (and limpkins) in the Wakulla River, the State Park initiated a snail release program in 2003 to restore population levels. To date over 3,000 snails have been released, averaging about 600 per year (S. Savery FDEP, personal communication); nearly 2,000 snails were released in 2005. In addition, an egg cluster survey was begun in the upper reach of the river within the park. Numbers of egg clusters have increased from 86 in 2005, 753 in 2006, to 1826 in 2007 (S. Savery FDEP, personal communication), perhaps indicating the success of the snail release program. Recent reports cite the presence of the exotic island apple snail (*P. insularum*) within park boundaries yet little is known about its current distribution. This species has invaded a number of panhandle water bodies with devastating effects on native vegetation.

9.1.2 Fishes

Fish assemblages in the river and springs have been sampled for a number of years primarily through collections by Yerger and students at Florida State University; considerable material from these collections resides in the Florida Museum of Natural History (FLMNH) but was only recently summarized along with results of new collections (Walsh and Williams 2003). In addition, sport fishes have been compared from several Big Bend coastal streams by the Florida Fish and Wildlife Conservation Commission (Cailteux et al. 2004, 2005).

A total of 43 species representing 20 families and 31 genera were located in FLMNH collections; these represented collections made in the head springs, downstream sections of the river and McBride Slough (a tributary entering the river downstream of the head springs). Twenty-three species from 13 families and 21 genera were recently collected, restricted to areas from the main spring pool downstream to the mouth of McBride Slough, and results were compared with museum specimens (Walsh and Williams 2003). Both sets of collections were combined and are shown in

Table 12; forty-seven species have been recorded from these studies. Recent collections were dominated by redeye chub (*Notropis harperi*), coastal shiner (*Notropis petersoni*) and spotted

Family	Species	USGS		FLMNH		
		Number	**Percent**	**Spring**	**Adjacent**	**Percent**
Lepisosteidae	*Lepisosteus osseus*	9	0.9	3		0.05
	Lepisosteus platyrhincus	4	0.4			
Amiidae	*Amia calva*	6	0.6			
Anguillidae	*Anguilla rostrata*	8	0.8	9		0.15
Cyprinidae	*Notropis cummingsae*			355		5.84
	Notropis harperi	273	28.1	841	72	15.01
	Notropis petersoni	154	15.9	436	36	7.76
	Opsopoeodus emiliae			82		1.35
	Pteronotropis hypselopterus	1	0.1	252	51	4.98
Catostomidae	*Erimyzon sucetta*	39	4.0	17	1	0.3
	Minytrema melanops	3	0.3	6		0.1
Ictaluridae	*Ameiurus catus*			1		0.02
	Noturus gyrinus			24	2	0.43
	Noturus leptacanthus			10		0.16
Esocidae	*Esox americanus*			11	4	0.25
	Esox niger			2		0.03
Aphredoderidae	*Aphredoderus sayanus*	18	1.9	69	3	1.18
Mugilidae	*Mugil cephalus*	3	0.3			
Atherinopsidae	*Labidesthes sicculus*	4	0.4	195		3.21
Belondiae	*Strongylura timucu*			1		0.02
Fundulidae	*Fundulus confluentus*			28		0.46
	Fundulus escambiae				1	0.02
	Fundulus grandis			1		0.02
	Fundulus seminolis	43	4.4	426		7.0
	Lucania goodei	78	8.0	734	27	12.5
	Lucania parva			67		1.10
Poeciliidae	*Gambusia holbrooki*	61	6.3	524	22	8.98
	Heterandria formosa	43	4.4	142	32	2.86
	Poecilia latipinna	7	0.7	145		2.38
Syngnathidae	*Syngnathus scovelli*			1		0.02
Centrarchidae	*Lepomis auritus*	2	0.2	143		2.35
	Lepomis gulosus			3		0.05
	Lepomis marginatus			5		0.08
	Lepomis microlophus			4		0.07
	Lepomis punctatus	167	17.2	188		3.09
	Micropterus notius	5	0.5			
	Micropterus salmoides	35	3.6	44	1	0.74
Percidae	*Percina nigrofasciata*			47		0.77
Gerreidae	*Eucinostomus argenteus*			72		1.18
Sparidae	*Lagodon rhomboides*			21		0.35
Sciaenidae	*Bairdiella chrysoura*			8		0.13
	Leiostomus xanthurus			6		0.10
Elassomatidae	*Elassoma okefenokee*	5	0.5	500	9	8.37
	Elassoma zonatum			5	4	0.15
Gobiidae	*Gobiosoma bosc*			4		0.07
	Microgobius gulosus			1		0.02
Achiridae	*Trinectes maculatus*	3	0.3	384		6.31
	Total number of species	**23**		**42**	**14**	
	Total number of individuals	**971**		**5817**	**265**	

Table 12 – Fishes Collected in Edward Ball Wakulla Springs State Park and Adjacent Reaches (Walsh and Williams 2003)

sunfish (*Lepomis punctatus*). Museum collections were dominated by redeye chub, coastal shiner, Seminole killifish (*Fundulus seminolis*), bluefin killifish (*Lucania goodei*), eastern mosquitofish (*Gambusia holbrooki*), and Okefenokee pygmy sunfish (*Elassoma okefenokee*). Differences in sampling effort, locations and methods between the various collections preclude discussion of population or species trends over time. However, the combined data set results in a good representation of the fish fauna in the springs and upper river. An interesting observation drawn from these comparisons is the current presence of Suwannee bass (*Micropterus notius*); Suwannee bass were absent from earlier collections. This species is not native to the St. Marks/Wakulla drainage and was likely introduced from an adjacent or nearby system (Walsh and Williams 2003). The Suwannee bass is a State of Florida recognized Species of Special Concern (FFWCC 2007). Recent collections by the FFWCC (Table 13; T. Hoehn, unpublished data) suggest that Suwannee

Species	Common Name	Number	Percent Composition
Micropterus notius	Suwannee bass	162	11.7
Micropterus salmoides	Largemouth bass	99	7.2
Lepomis auritus	Redbreast sunfish	23	1.7
Lepomis microlophus	Redear sunfish	5	0.4
Lepomis punctatus	Spotted sunfish	266	19.2
Lepomis macrochirus	Bluegill	1	0.1
Lepomis gulosus	Warmouth	2	0.1
Erimyzon sucetta	Lake chubsucker	35	2.5
Minetrema melanops	Spotted sucker	14	1.0
Lepisosteus oculatus	Spotted gar	4	0.3
Lepisosteus osseus	Longnose gar	9	0.7
Mugil cephalus	Striped mullet	2	0.1
Fundulus seminolis	Seminole killifish	9	0.7
Lucania goodei	Bluefin killifish	10	0.7
Gambusia holbrooki	Gambusia	11	0.8
Labidesthes sicculus	Brook silverside	32	2.3
Notropis petersoni	Coastal shiner	486	35.1
Notemigonus crysoleucas	Golden shiner	2	0.1
Notropis cummingsae	Dusky shiner	202	14.6
Pteronotropic hypselopterus	Sailfin shiner	1	0.1
Anguilla rostrata	American eel	2	0.1
Esox niger	Chain pickerel	1	0.1
Aphredoderus sayanus	Pirate perch	1	0.1
Noturus gyrinus	Tadpole madtom	1	0.1
Percins nigrofasciata	Blackbanded darter	3	0.2
Total (24 species)		**1383**	

Table 13 – Fishes Collected from Six Sites in the Wakulla River
(T. Hoehn – FFWCC, unpublished data)

bass are now one of the dominant species throughout much of the river, comprising nearly 12% of samples. As with previous samples, FFWCC collections also contained relatively high numbers of spotted sunfish, and coastal and dusky (*Notropis cummingsae*) shiners.

Sportfish populations have been examined in several Big Bend coastal rivers (Cailtreux et al. 2004, 2005). The Wakulla River had the highest overall catch per unit effort (CPUE) of the four rivers examined (Table 14) with collections in the St. Marks a close second. Sportfish catch, like that observed in general collections (e.g., Walsh and Williams 2003), were dominated by spotted sunfish; Suwannee and largemouth (*M. salmoides*) bass made up a sizeable percentage of the catch.

Overall, the fish assemblage in the Wakulla River appears relatively depauperate in species number, as is typical of spring runs, with dominance by common riverine species. The downstream extent that many of these species travel is likely determined in large part by the upstream movement of salinity in the river; many of these freshwater species are salinity intolerant. Several species, on the other hand, are typical inhabitants of the estuary and are frequently found upstream in oligohaline and fresh areas. These estuarine species include striped mullet (*Mugil cephalus*), timucu (*Strongylura timucu*), Gulf pipefish (*Syngnathus scovelli*), pinfish (*Lagodon rhomboides*), silver perch (*Bairdiella chrysoura*), spot (*Leiostomus xanthurus*) and hogchoker (*Trinectes maculatus*) (Walsh and Williams 2003). Relatively high concentrations of calcium ions in the upper reaches of the river likely influence these species ability to live in this region.

Species	Wakulla (N=16)	St. Marks (N=10)	Wacissa (N=12)	Aucilla (N=12)
Largemouth bass	1.55	0.94	1.38	0.54
Suwannee bass	2.25	2.65	2.46	0.01
Redbreast sunfish	0.72	0.90	0.22	2.45
Bluegill	0.01	0.09	0.02	0.07
Redear sunfish	0.38	0.43	0.03	0.13
Black crappie	NC	0.10	NC	0.02
Spotted sunfish	4.31	3.67	2.92	1.08
Warmouth	0.13	0.36	0.01	0.11
Flier	NC	NC	NC	0.18
Total Sport fish	**9.35**	**9.14**	**7.04**	**4.59**

Table 14 – Mean Catch per Unit Effort (CPUE) of Sportfish in the Wakulla, St. Marks, Aucilla and Wacissa Rivers (Cailtreux et al. 2004, 2005)

9.1.3 Amphibians and Reptiles

Limited information is available on the distribution of herptofauna in the St. Marks/Wakulla River system. Fifteen species of amphibians and 39 species of reptiles have been recorded within the Edward Ball Wakulla Springs State Park (S. Savery, FDEP, personal communication). Of these, nine amphibians and 21 reptiles (Appendix A) are thought to use habitats directly associated with the river (e.g., floodplain marshes).

Amphibians are unable to reproduce under strictly terrestrial conditions and most species must return to water to lay their eggs. Eggs usually develop into aquatic larvae with external gills, muscular tails and a free-living lifestyle. Varying amounts of time are necessary before metamorphosis into adults occurs, thus requiring specific minimum periods of inundation. Metamorphosis will not occur in habitats inundated for less than the required period. Reptiles, on the other hand, do not require water for reproduction; most lay eggs with protective coverings on land. As such, they depend on water levels only as sources of drinking water.

9.1.4 Birds

Over 190 species of birds (Appendix B) have been observed within the Edward Ball Wakulla Springs State Park (S. Savery, FDEP, personal communication). While many of these species are found strictly in terrestrial habitats, an abundance of water fowl, wading birds and other species use the river, the fringing marshes and swamps, and are dependent indirectly on water level maintenance. At least 75 species use habitats directly associated with the river (e.g., floodplain marshes).

Numerous species, including a variety of waterfowl and wading birds, rely on inundated habitats for food, either submerged aquatic vegetation or the abundant benthic invertebrates and fishes associated with it. Food limitation can lead to local extinctions, as has been noted in Wakulla Springs with the limpkin (*Aramus guarauna*). Limpkins are limited in geographic range by their diet of large aquatic snails (Bryan 1981), chiefly the apple snail (*Pomacea paludosa*). While smaller snails and bivalves may be consumed, an abundance of *Pomacea* is usually required. Bryan (1981) cites varying numbers of limpkins on the Wakulla River from fewer than 20 in 1949 to 65 on average between 1968 and 1972 declining back to 17-19 over the 1976-1980 period. A resident population has not been present since the late 1990s. Surveys in recent years by State Park personnel documented few if any birds observed; sporadic sightings have been made, the most recent in April 2007. Their decline was coincident with the near extirpation of apple snails from the area.

Waterfowl are common in the Wakulla and lower St. Marks rivers and the St. Marks National Wildlife Refuge, a federally operated sanctuary set up to provide habitat for over-wintering waterfowl. Annual mid-winter inventories of waterfowl have been conducted throughout this area as part of a nationwide effort to survey waterfowl in major concentration areas (D. Eggeman, FFWCC, personal communication). The survey is useful in documenting the distribution of waterfowl on their wintering grounds and in assessing habitat use. Surveys are conducted primarily by fixed-wing aircraft with specific sampling procedures undefined. Instead, an aerial crew determines the best and most practical means to count all waterfowl seen within a predefined unit area. The exact means of coverage may vary from year to year; however, the objective is to count all waterfowl within the survey unit. The survey is conducted annually beginning in early January. Two flight tracks (#105 St. Marks; #120 Wakulla) are surveyed in this area.

Annual abundances of waterfowl observed in the Wakulla River during the mid-winter inventory are shown in Figure 57; number of birds varied from year to year with peak observances in 1974, 1982 and 1986. Except for these peaks, numbers have remained relatively stable throughout the period of observation. Fewer birds, however, were seen in the most recent year of the compilation (2003). American widgeon and scaup made up 75% of the waterfowl observed over the 30-year period (Figure 58); ring-necked ducks (14%), American coot (9%) and ten other species (2%)

comprised the remainder of the inventory. Similar abundances of waterfowl observed in the lower St. Marks River during the mid-winter inventory are shown in Figure 59. Number of birds varied significantly from year to year with peak observances in 1972, 1973, 1984, 1992 and 1996; greater

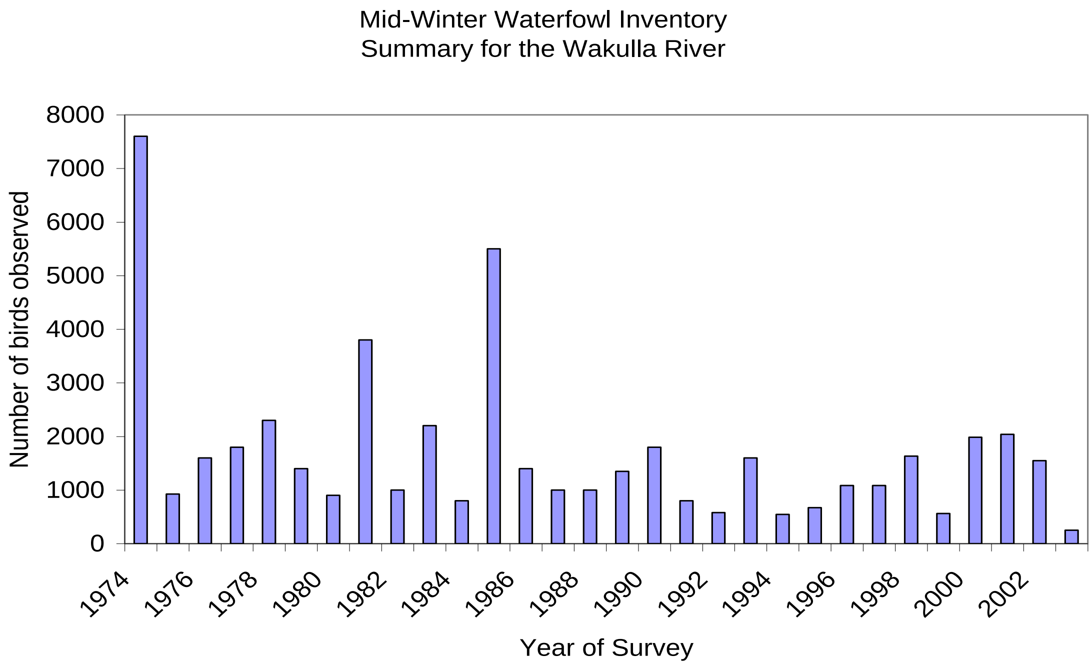


Figure 57- Annual Mid-winter Waterfowl Inventory on the Wakulla River from the Headwaters to U.S. 98 (FFWCC 2007)

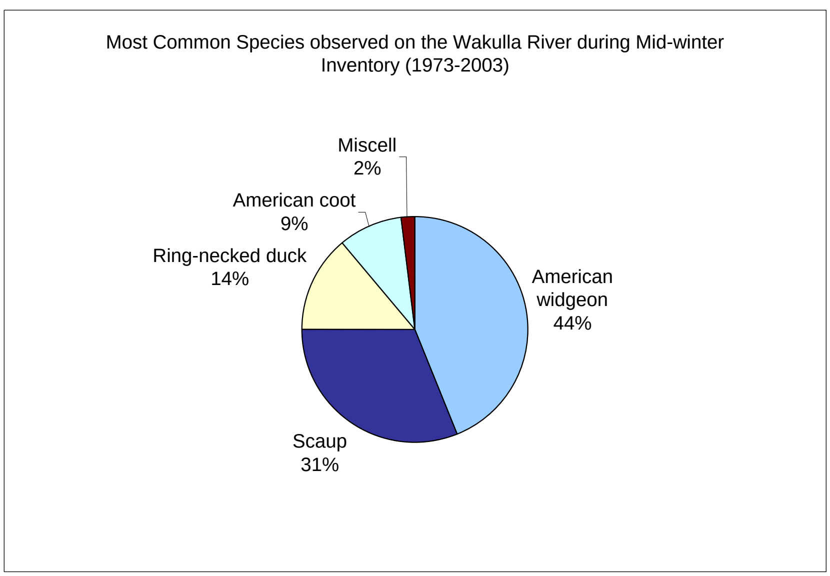


Figure 58 - Dominant Waterfowl Observed During Annual Mid-winter Waterfowl Inventory on the Wakulla River (FFWCC 2007)

than 35,000 birds per survey were estimated for these peak years. Few birds were seen during the period from 1974 to 1982. Redhead ducks made up 45% of the waterfowl observed over the 30-year period (Figure 60); American coots (13%), scaups (12%), American green-winged teal (6%), northern pintail (6%) and 16 other species (18%) comprised the remainder of the inventory.

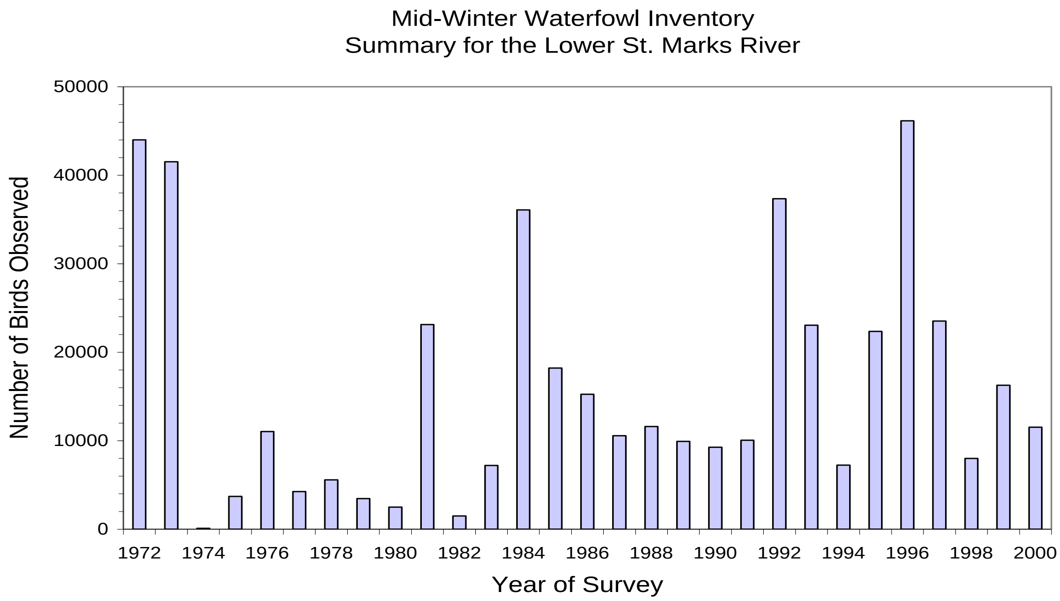


Figure 59 – Annual Mid-winter Waterfowl Inventory on the lower St. Marks River (FFWCC 2007)

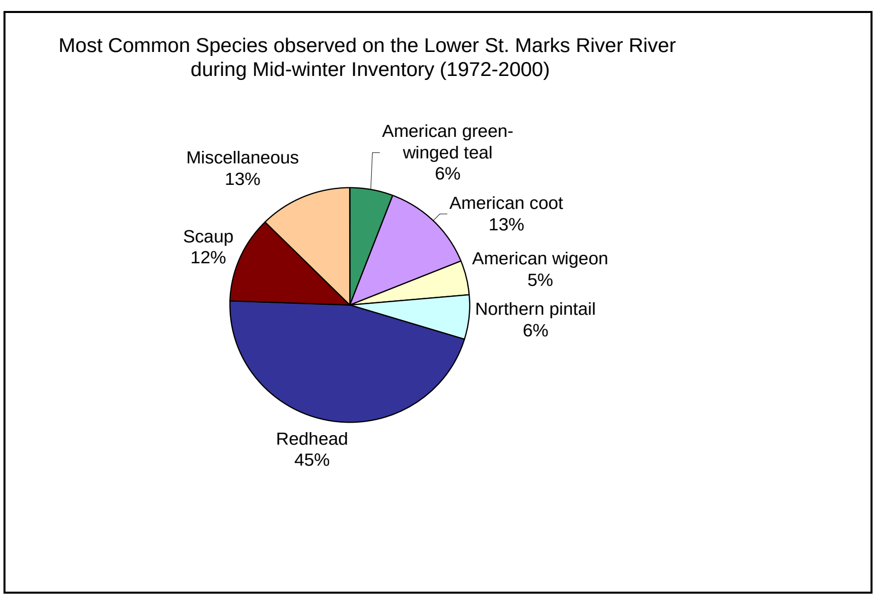


Figure 60 - Dominant Waterfowl Observed During Annual Mid-winter Waterfowl Inventory on the lower St. Marks River (FFWCC 2007)

Differences in abundance and species composition between birds observed in the Wakulla and St. Marks areas are likely due to size and habitat differences between the two systems, especially the extensive marshes along the lower St. Marks River and the adjacent, shallow diked ponds maintained in the St. Marks Wildlife Refuge. These areas provide significantly more aquatic habitat for overwintering waterfowl than that found along the riverine corridor of the Wakulla.

9.1.5 Mammals

Twenty-two species of mammals (Appendix C) have been recorded from the Edward Ball Wakulla Springs State Park (S. Savery, FDEP, personal communication). While most of these species rely on aquatic habitats to only a limited extent, others like the West Indian manatee (*Trichechus manatus latirostris*) live in and depend heavily on maintenance of river flows and levels. Manatees are a protected species both at the federal and state level (i.e., listed as endangered by both, although the state is considering downgrading their listing to threatened) and have been observed with increasing frequency in panhandle estuaries (T. Calleson, FFWCC, personal communication).

Florida manatees are habitat generalists living in a wide variety of environments, from urban canal systems to pristine mangroves (Haubold et al. 2006). They can tolerate a wide range of salinities from freshwater to marine conditions. Manatees are herbivores requiring relatively large expanses of submerged aquatic vegetation for feeding. Manatees are particularly susceptible to cold-related stress, generally seeking warmer waters when temperatures drop below 20^{o}C; they cannot withstand prolonged exposure to temperatures below 16^{o}C. In the northern portion of their distributional range, winter aggregations are observed in springs, spring-run rivers and in warm-water outfalls from power plants and other industrial facilities.

Few documented sightings of manatees had been made in Wakulla County (either the Wakulla or St. Marks River) prior to the early-1980s (Powell and Rathbun 1984); the Suwannee River appeared to be the northern limit to their year-round range on the Gulf coast. By the mid-1980s, however, the number of manatee sightings had increased during the warm months. Sightings west of the Suwannee River were considered outside the normal range and were likely animals moving from their winter aggregations in Crystal and Homosassa rivers. The Big Bend and panhandle coasts contain highly suitable habitat with abundant submerged aquatic vegetation (SAV) and less boat traffic than peninsular Florida (Morris 2007). Increasing numbers of sightings and increasing human usage during the mid-1990s prompted the FFWCC to conduct an aerial survey of the area to document habitat usage (Morris 2007). Two hundred sixty-six manatees were observed on 46 monthly flights between 1994 and 1996, averaging about six individuals per survey. Twenty-eight of these individuals were calves. A high count of 24 animals was sighted in June 1996. Distinct seasonal usage was noted with higher numbers found during the warm season (April-October); June had the highest number of observations. During summer, most individuals were sighted on the Wakulla River between the U.S. 98 bridge and just downstream of the confluence with the St. Marks. All of these sites had abundant SAV. During winter, most manatees were seen in the St. Marks River within or near the discharge canal of the Purdom power plant. Little evidence to date supports over-wintering west of the Suwannee River. Despite more sightings within the basin at Wakulla Springs, no individuals had been observed to over-winter in either the Wakulla or St. Marks system (Morris 2007) until 2008 when at least ten individuals were noted in and around Wakulla Spring.

Recent counts by State Park personnel in and around the spring basin indicated 39 manatee sightings in 2003, 8 in 2004, 104 in 2005, 225 in 2006, and 38 as of August 2007 (S. Savery, FDEP, personal communication). Most observances were single individuals or pairs; however, on two occasions in 2005 as many as nine animals were noted together.

9.2 Estuarine Communities

Ecological information on invertebrate and fish communities in the immediate vicinity of the St. Marks estuary appears limited to a handful of studies carried out in the St. Marks National Wildlife Refuge to examine zonation patterns in salt marsh communities (Subrahmanyam and coworkers) and the influence of food web structure on overwintering migratory waterfowl in nearshore seagrass beds (Baird et al. 1998; Christian and Luczkovich 1999). However, Livingston and coworkers have amassed considerable information on the ecology of seagrass beds in adjacent areas of Apalachee Bay (i.e., offshore of the Econfina and Fenholloway Rivers to the east of St. Marks). The areas examined by the Livingston group are very similar to those in the nearshore regions of the St. Marks with comparable floral and faunal assemblages and dynamics. The majority of this work (in both salt marsh and seagrass communities) was conducted during the 1970's and 1980's, with little follow up investigations. Despite the lack of recent data, these works provide an excellent characterization of the area. Information gleaned from these studies is summarized in the following sections.

9.2.1 Salt Marshes

Tidal salt marshes are the most visible habitat along the shoreline of the lower St. Marks River and adjacent coastline of Apalachee Bay. These marshes are drained by a series of small tidal creeks, usually with very limited watersheds, and provide refuge for a variety of macroinvertebrates and fishes. The following sections summarize a series of studies conducted in the marshes of the lower St. Marks (Subrahmanyam and coworkers).

9.2.1.1 Benthic Infauna

Horlick and Subrahmanyam (1983) examined the macroinvertebrate infauna in a small tidal creek near the St. Marks Lighthouse. Four sampling sites were established along the length of creek beginning at the mouth and ending at the origin. A total of 111 species was collected with the number of species at each site positively related to the distance from the creek mouth; greatest number of species was noted near the mouth with least number at the creek origin. Densities of organisms varied spatially and temporally ranging from 979 to 43,343 individuals per m^2. Generally, densities followed the gradient described for species with greatest densities usually observed near the creek mouth. Dominant species varied with creek location and included *Ampelisca abdita* (amphipod), *Hargeria rapax* (tanaid), unidentified oligochaetes, *Xenathura brevitelson* (isopod), unidentified hydrobid snail, and the polychaetes *Aricidea* sp., *Laeonereis culveri*, and *Haploscoloplos foliosus*. As expected, species composition at the creek mouth more closely resembled open estuarine assemblages while faunal composition at the upper creek site was more similar to adjacent salt marsh assemblages. Distinct seasonal patterns of abundance were seen with peaks in spring and fall thought to be related to breeding and recruitment, while midsummer declines were related to increased numbers of predatory fish.

9.2.1.2 Macroinvertebrate Community

Species composition, abundance and spatial distribution of macroinvertebrates were examined in two tidal marshes near the mouth of the St. Marks River, one located on the western side of the river along Goose Creek Bay and the other adjacent to the East River just north of the lighthouse (Subrahmanyam et al. 1976; Kruczynski and Subrahmanyam 1978; Subrahmanyam and Coultas 1980). A total of 22,814 organisms representing 51 species were collected from the two sites with mollusks accounting for 31%, annelids 24%, crustaceans 44% and insect larvae 1% of the total numbers. Overall mean density from the sites was 475 individuals per m^2 with significantly higher density in the low marsh (540 individuals per m^2) relative to the high marsh (381 individuals per m^2). Seasonal mean density tended to be greater in winter (578 individuals per m^2) than summer (375 individuals per m^2); similarly, greater number of species was noted in winter. In contrast, biomass was highest in summer; the gastropod *Littorina irrorata* accounted for 81% of summer biomass.

Species composition varied with distance from the creeks (Table 15), with certain species found in greater abundance in specific zones. The lower marsh zone was dominated by the gastropod *Littorina irrorata*, the isopod *Cyathura polita*, and the tanaid *Apseudes* sp., while the upper zone had high numbers of *Littorina*, *Cyathura* and unidentified fiddler crabs (*Uca* spp.). The high marsh zone, located above the salt flats, was characterized by the fiddler crab *Uca pugilator* and the mollusks *Melampus bidentatus* and *Cyrenoidea floridana*.

Species	Phylum	Marsh Zones		
		Lower	Upper	High Marsh
Littorina irrorata	M	1	1	7
Cyathura polita	C	2	2	10
Apseudes sp.	C	3		10
Scoloplos fragilis	A	4	5	
Leptochelia sp.	C	5	4	
Uca longsignalis	C	6	10	
Sesarma reticulatum	C	7		9
Eurytium limnosum	C	8		
Laeonereis culveri	A	9		
Lycastopsis pontica	A	10		
Uca spp.	C		3	8
Polymesoda caroliniana	M		6	6
Modiolus demissus	M		7	
Oligochaetes (unidentified)	A		8	5
Uca pugilator	C		9	1
Cyrenoidea floridana	M		10	3
Melampus bidentatus	M			2
Cerithidea scalariformis	M			4

Table 15 – Ranking of Most Important Salt Marsh Macroinvertebrate Species in Three Marsh Zones in the lower St. Marks (Subrahmanyam et al. 1976)
(Phylum ID: A = Annelida, C = Crustacea, M = Mollusca)

9.2.1.3 Fish Abundance

Subrahmanyam and Drake (1975) and Subrahmanyam and Coultas (1980) examined the fish community inhabiting tidal creeks in two marshes near the mouth of the St. Marks River (same locations as described above under Macroinvertebrate Community). Fifty-five species were collected during the year of the study. The community was dominated by five species of killifish (*Fundulus similis*, *F. grandis*, *F. confluentes*, *Adinia xenica*, and *Lucania parva*), sheepshead minnow (*Cyprinodon variegatus*), sailfin molly (*Poecilia latipinna*), tidewater silverside (*Menidia beryllina*), spot (*Leiostomus xanthurus*), spotfin mojarra (*Eucinostomus argenteus*), and pinfish (*Lagodon rhomboides*). Although distinct seasonal patterns were not evident, higher numbers of fish were generally collected during the cooler months at high tide, and in warmer months at low tide. Overall, average numerical abundance and biomass were greater during low tides when fish were concentrated in the tidal creeks; at high tide individuals could move out of the creeks into the salt marsh and forage with the tidal flooding. Abundance rankings of the numerically dominant species are shown for the two marshes over high and low tides (Table 16).

Species	St. Marks Marsh		Wakulla Marsh	
	Low Tide	High Tide	Low Tide	High Tide
Fundulus similis	1		1	12
Menidia beryllina	2	1	5	2
Fundulus grandis	3	10	3	5
Cyprinodon variegates	4		4	
Leiostomus xanthurus	5	2	2	1
Adenia xenica	6		6	
Eucinostomus argenteus	7	6	9	4
Poecillia latipinna	8		10	
Lagodon rhomboides	9	3	7	6
Anchoa mitchelli	10	5	8	3
Fundulus confluentes	11		11	
Paralichthys albigutta	12			
Lucania parva	13	11		
Strongylura notata				11
Strongylura marina		7		7
Polydactylus octonemus		4	12	8
Anchoa hepsetus		8		
Oligoplites saurus		9		9
Mugil cephalus		12		10
Cynoscion arenarius		13		
Dorosoma petenense			13	
Harengula jaguana				13

Table 16 – Ranking of Most Abundant Tidal Creek Fish Species at High and Low Tides (Subrahmanyam and Drake 1975)

Fish species were placed into four categories according to gut content, occurrence at low or high tides, and monthly length frequencies; groups included permanent residents, species using the marshes as nursery grounds, foraging species, and sporadic visitors. Those fishes collected as both young and adults on high and low tides were considered permanent residents. In this group, *Fundulus similis*, *F. grandis* and *Cyprinodon variegatus* were the most common, *Adenia xenica* and *Poecillia latipinna* less common, and *Lucania parva* and *F. confluentes* were least common. While juveniles of these species predominated, adults were relatively common. The second category contained primarily juveniles caught on both tides; adults were either not collected or were collected only on high tides. Included in this group were *Menidia beryllina*, *Leiostomus xanthurus*, *Eucinostomus argenteus*, *Mugil cephalus*, *Lagodon rhomboides*, *Oligoplites saurus*, *Anchoa mitchelli* and *A. hepsetus*, *Syngnathus scovelli*, *Synodus foetens*, *Gobiosoma bosci*, *Gobionellus boleosoma* and others. These species were considered to utilize the marsh as nurseries. A third category included those species caught only on high tides and included numerous adults; these species were considered to be foraging species using the marshes as feeding grounds on the flooding tide. This group contained such species as *Bairdiella chrysoura*, *Brevoortia patronus*, *Cynoscion arenarius*, *Harengula jaguana*, *Hyporhamphus unifasciatus*, *Orthopristis chrysoptera* and *Scianops ocellata*. These species are common inhabitants of the nearby offshore grass beds and move inshore to feed. The fourth category is the sporadic visitor and includes such species as *Polydactylus octenemus*, a relatively uncommon species along the northern Gulf that appears occasionally in high numbers. Its movements are erratic and it inhabits a variety of habitats.

Livingston (1975) recorded 36 species of fishes inhabiting a marsh tidal creek in the Econfina River about 12 miles east of the St. Marks River. His collections were dominated by *Brevoortia patronus*, *Menidia beryllina*, *Leiostomus xanthurus*, *Fundulus grandis*, *Anchoa mitchelli* and *Poecilia latipinna*. The overall species list was similar to that observed in the St. Marks marsh by Subrahmanyam and Drake (1975) and Subrahmanyam and Coultas (1980).

The marsh fish community is highly dynamic with various species entering the marshes in different seasons. Feeding migrations, recruitment of juveniles and movement of resident species generally account for the temporal variations in abundance, biomass and species composition in the marshes.

9.2.2 Seagrass Beds

Seagrass meadows are the most conspicuous habitat in the nearshore waters of Apalachee Bay. These beds are highly productive areas and provide food and habitat for a diverse array of species. While limited data are available for the portions of Apalachee Bay directly influenced by the St. Marks River, the following sections summarize information gathered from a variety of studies (Livingston and coworkers) in the shallow grass beds in the eastern sections of the bay (i.e., the areas offshore of the Econfina and Fenholloway rivers).

9.2.2.1 Benthic Macrofauna (infauna and epifauna)

A variety of small organisms are found associated with seagrass and macroalgae in Apalachee Bay, including a diverse array of polychaetes, mollusks and crustaceans (e.g., amphipods, isopods, tanaids, decapods). Stoner (1980) noted 170 species of macrofauna associated with seagrass beds in Apalachee Bay, including 75 polychaetes, 31 amphipods, 21 mollusks, 10 shrimp, 6 crabs and 5 isopods; the fauna were dominated by amphipods (37%) and polychaetes (45%). Mean macrofaunal density was 2,827 individuals per m^2 with values ranging from 833 to 8,301 per m^2. Density of animals generally peaked between April and May with declines in the late summer and fall. Numbers began to increase in November associated with a sharp decline in fish populations. This observation was attributed to a decrease in predation pressure with fewer fish predators on the beds in late fall and winter. Overall, macrofaunal abundance was positively correlated with plant biomass; the greater the plant biomass at a site, the greater the macrofaunal density (Stoner 1980).

Within the seagrass beds, animals are not distributed randomly, rather preferences have been noted among microhabitats/seagrass species (Lewis 1984, 1987). Eighty-two crustacean species were collected from a variety of microhabitats within the grass beds (Lewis 1982). Vegetated habitats consistently supported greater numbers of individuals and species that did unvegetated zones, either large bare patches or small sandy areas among the grass shoots (Lewis 1984). Distribution of crustaceans among seagrass microhabitats was thought to be a complex function involving faunal habitat choice and predation pressure, both of which are affected by the amount and kind of seagrass present.

Comparing the crustacean epifauna of turtle grass with that on the dominant macroalgae in the grass beds, a similar suite of species was noted despite significant differences in shape or architecture among plant species; however, relative abundances of many species varied among plant hosts (Lewis 1987). Species richness was generally higher on turtle grass than on any of the macroalgae. Abundances of crustaceans per plant biomass or per plant surface area, on the other hand, were greater on all macroalgal species compared to seagrass. Although abundances per plant biomass and plant surface area were greater on macroalgae relative to turtle grass, densities (individuals per meter square of bottom) of animals associated with turtle grass were significantly greater than those associated with macroalgae, primarily because of the greater abundance of turtle grass in the grass bed. These observed abundance differences can be influenced by several factors, including: (1) morphological constraints of individual species based on body size and shape, (2) differences in food availability, especially epiphytes and detritus, (3) competitive interactions and territorial behavior, and (4) differential susceptibility to predation.

The picture of crustacean abundance (as well as other organisms) that emerges from these and other studies is one of a spatial and temporal mosaic within the grass beds. First, greater abundance and species richness are associated with vegetated than with unvegetated areas in the beds. Second, animals do not occur in equal numbers on all macrophytes. The most common plant, *Thalassia testudinum*, had the lowest number of associated individuals of any of the macrophytes examined. Crustaceans are, in fact, concentrated on small, isolated "islands" of macroalgae scattered throughout the grass bed. As seagrass and macroalgal biomass change diurnally and seasonally, densities of associated animals are affected (Lewis 1987).

9.2.2.2 Macroinvertebrate Abundance

A variety of larger organisms are also found associated with seagrass and macroalgae in Apalachee Bay, including an assortment of mollusks, crustaceans (e.g., shrimp, crabs) and echinoderms (Hooks 1973; Heck 1976; Hooks et al. 1976; Dugan and Livingston 1982; Greening and Livingston 1982). Dugan and Livingston (1982) recorded 112 epibenthic macroinvertebrate species from trawl samples collected in Apalachee Bay from 1972 to 1979; 85 species were collected in the Econfina estuary, 95 in the Fenholloway. Decapod crustaceans accounted for 95% of the total number of individuals, followed by mollusks (4%) and echinoderms (1%). Nearly twice as many animals were collected from Econfina relative to Fenholloway stations; abundances were related to the amount of vegetation present (which was related to the presence of pulp mill pollution in the Fenholloway). The 10 dominant species for each estuary are shown in Table 17; these species made up over 92% and 80% of the fauna in the Econfina and Fenholloway, respectively, and consisted of small shrimp and crabs. Arrow shrimp (*Tozeuma carolinense*) and hermit crabs (*Pagurus maclaughlinae*) dominated the fauna in the Econfina while the hippolytid shrimp (*Hippolyte pleuracanthus*) and hermit crabs (*P. maclaughlinae*) were most abundant in the Fenholloway. Seven of the top ten species in each area were found in common. Dugan and Livingston (1982) categorized the dominant species by habitat associations (Table 18). They noted that despite high seasonal variability, macrofaunal abundance and species numbers were relatively constant from year to year. Reduced numbers of species tended to coincide with periods of climatological stress (e.g., low winter temperature, reduced salinities).

Econfina Species	Abundance	Percent	**Fenholloway Species**	Abundance	Percent
Tozeuma carolinense	13974	22.6	*Hippolyte zostericola*	4925	16.3
Pagurus maclaughlinae	11712	18.9	*Pagurus maclaughlinae*	3925	13.0
Palaemonetes intermedius	7133	11.5	*Periclimenes longicaudatus*	3338	11.0
Palaemon floridanus	7011	11.3	*Palaemon floridanus*	3064	10.1
Hippolyte zostericola	5180	8.4	*Tozeuma carolinense*	2983	9.9
Neopanope texana	4634	7.5	*Neopanope texana*	2894	9.6
Periclimenes longicaudatus	3435	5.6	*Neopanope packardii*	1163	3.8
Thor dobkini	1634	2.6	*Farfantepenaeus duorarum*	842	2.6
Neopanope packardii	1264	2.0	*Palaemonetes intermedius*	686	2.3
Farfantepenaeus duorarum	1046	1.7	*Callinectes sapidus*	514	1.6

Table 17 – Ten Dominant Species Collected from Pooled Econfina and Fenholloway Estuarine Sites from 1972 to 1979 (Dugan and Livingston 1982)

Low Salinity	**Oyster Bar**	**Red Algae**	**Seagrass**
Palaemonetes intermedius	*Ophiothrix angulata*	*Hippolyte zostericola*	*Echinaster sentus*
P. pugio	*Ophioderma brevispinum*	*Periclimenes longicaudatus*	*Argopectin irradians*
Callinectes sapidus	*Ophiolepis elegans*	*P. americanus*	*Columbella rusticoides*
Farfantepenaeus duorarum	*Brachiodontes exustus*	*Lysmata wurdemanni*	*Modulus modulus*
Rhithropanopeus harrisii	*Menippe mercenaria*	*Thor dobkini*	*Podochela riisei*
Panopeus herbstii	*Portunus gibbesii*	*Anachis avara*	*Tozeuma carolinense*
Eurypanopeus depressus	*Rhithropanopeus harrisii*	*Urosalpinx perrugata*	
	Panopeus herbstii		
	Eurypanopeus depressus		

Table 18 – Macroinvertebrate-habitat Associations in Apalachee Bay (Dugan and Livingston 1982)

In addition to seasonal and inter-annual variability, Greening and Livingston (1982) observed a significant amount of diurnal (day/night) variation in macroinvertebrate distributions (Table 19). Of the 34 species comprising greater than 0.1% of their catch, eight were more abundant during the day and 11 were more prevalent at night; 15 showed no preference. Habitat differences in the grass bed (e.g., presence of red algae clumps) appeared to influence the degree of variation between the sampled day and night communities.

Species	Phylum	D/N	Abundance	Percent of Total
Hippolyte zostericola	C	D	20526	14.0
Pagurus maclaughlinae	C	D	18558	12.7
Anachis avara	M	D	15200	10.4
Farfantepenaeus duorarum	C	N	11636	7.9
Periclimenes longicaudatus	C	D	11548	7.9
Tozeuma carolinense	C	D	10007	6.8
Palaemon floridanus	C	O	8472	5.8
Thor dobkini	C	O	6981	4.8
Neopanope texana	C	N	6951	4.7
Argopectin irradians	M	O	3721	2.5
Ambidexter symmetricus	C	N	3706	2.5
Turbo castanea	M	N	3467	2.4
Urosalpinx perrugata	M	D	2873	1.9
Modulus modulus	M	O	2710	1.8
Alpheus normanni	C	N	2096	1.4
Columbella rusticoides	M	D	2095	1.4
Neopanope packardii	C	N	2049	1.4
Echinaster sp.	E	O	1793	1.2
Libinia dubia	C	O	1583	1.1
Nassarius vibex	M	O	1554	1.1
Ophioderma brevispinum	E	D	1464	1.0
Cerithium muscarum	M	O	1083	0.7
Latreutes fucorum	C	O	785	0.5
Epialtus dilatatus	C	O	637	0.4
Palaemonetes intermedius	C	O	627	0.4
Prunum apicinum	M	O	496	0.3
Ophiothrix angulata	E	O	415	0.3
Metaporhapsis calcerata	C	N	395	0.3
Podochela riisei	C	O	383	0.3
Callinectes sapidus	C	N	366	0.2
Bulla striata	M	N	190	0.1
Portunus gibbesii	C	N	188	0.1
Sicyonia laevigata	C	N	166	0.1
Pagurus pollicaris	C	O	149	0.1

Table 19 – Total and Relative Abundance of Dominant Macroinvertebrate Species from Pooled Apalachee Bay Estuarine Stations (Greening and Livingston 1982)

(Only those organisms comprising $\geq$0.1% of total catch are included. Phylum id: C=Crustacea, E= Echinodermata, M=Mollusca. D/N: D=day catch greater, N=night catch greater, O=no difference between day and night catch)

9.2.2.3 Fish Abundance

Over one hundred species of fishes were collected from the seagrass beds of Apalachee Bay offshore of the Econfina and Fenholloway Rivers between 1971 and 1979 (Livingston 1984a, b). Total and relative abundance of dominant fishes collected are summarized for the multiyear sampling effort (Table 20). Both areas were dominated by pinfish (*Lagodon rhomboides*), probably the most common grassbed species in the northern Gulf of Mexico. Other abundant species included spot (*Leiostomus xanthurus*), filefish (*Monocanthus ciliatus* and *Stephanolepis hispidus*), silver perch (*Bairiedella chrysoura*), black sea bass (*Centropristis striata*), spottail pinfish (*Diplodus holbrooki*), dusky pipefish (*Syngnathus floridae*), pigfish (*Orthopristis chrysopterus*) and silver jenny (*Eucinostomus gula*). These ten species comprised 85% of the fishes caught in the Econfina estuary, and along with the bay anchovy (*Anchoa mitchelli*) made up 78% of the Fenholloway estuarine fish catch. Bay anchovies, not typically a grassbed species, were found in abundance in the Fenholloway estuary at sites relatively devoid of vegetation. Fish collections taken near the mouth of the Econfina River (Station 7), a site with conditions very similar to the lower St. Marks estuary, were dominated by spot, pinfish, silver perch, threadfin (*Polydactylus octonemus*), and silver jenny.

	Econfina			Fenholloway		
Species	Rank	Abundance	Percent	Rank	Abundance	Percent
Lagodon rhomboids (pinfish)	1	44463	54.1	1	8661	23.1
Leiostomus xanthurus (spot)	2	7747	9.4	2	5997	16.0
Bairidella chrysoura (silver perch)	3	5084	6.2	4	3694	9.8
Monocanthus ciliates (fringed filefish)	4	3435	4.2	6	1246	3.3
Diplodus holbrooki (spottail pinfish)	5	3164	3.9	11	650	1.7
Syngnathus floridae (dusky pipefish)	6	1982	2.4	12	521	1.4
Orthopristis chrysoptera (pigfish)	7	1965	2.4	5	2044	5.4
Eucinostomus gula (silver jenny)	8	1530	1.9	10	765	2.0
Centropristis striata (black sea bass)	10	1356	1.7	8	903	2.4
Stephanolepis hispidus (planehead filefish)	11	1218	1.5	7	928	2.5
Opsanus beta (Gulf toadfish)	12	1015	1.2	22	209	0.6
Eucinostomus argenteus (spotfin mojarra)	14	833	1.0	14	499	1.3
Paraclinus fasciatus (banded blenny)	15	605	0.7	16	379	1.0
Syngnathus scovelli (Gulf pipefish)	17	497	0.6	19	288	0.9
Chilomycterus schoepfi (striped burrfish)	18	467	0.6	13	510	1.4
Cynoscion nebulosus (spotted seatrout)	21	372	0.5	21	231	0.6
Anchoa mitchelli (bay anchovy)	26	184	0.2	3	5337	14.2
Synodus foetens (inshore lizardfish)	29	136	0.2	28	120	0.3
Total number of individuals		**82241**			**37582**	
Total number of species		**94**			**99**	

Table 20 – Rank and Relative Abundance of Dominant Fishes Collected in Apalachee Bay Offshore of the Econfina and Fenholloway Rivers (Livingston 1984)
(Collections were taken monthly at seven sites in each system between 1971 and 1979. Abundances were pooled for the collection period over all stations in each area.)

Total number of fishes was lowest in winter months (December to February) and highest between May and August; number of fish species was highest in July and August, concurrent with peaks in abundance. Both total fish number and number of the dominant species, *Lagodon rhomboides*, were highly correlated with the abundance of seagrass (Stoner 1983). These significant relationships likely result from increased food and shelter provided by seagrass.

9.2.2.4 Trophic Structure

Several studies focused on the feeding ecology of invertebrates (Leber 1983, 1985) and fishes (Stoner 1980; Stoner and Livingston 1980; Ryan 1981; Livingston 1982; Livingston 1984a, b; Clements and Livingston 1984) associated with Apalachee Bay seagrass beds. Decapod crustaceans and fish are among the principal macrofaunal predators in the Apalachee Bay grass beds; both groups have been found to be important links between primary production and higher consumers.

Leber (1983) examined feeding patterns of the dominant decapods, noting that they fell into two major subgroups: herbivores (largely brachyuran crabs) and carnivores (penaeid and caridean shrimps). Both subgroups included some strongly omnivorous trophic groups; however, within the carnivorous subgroup, plant material was limited and consumption may have been primarily incidental. Seagrasses were a major food item only in diets of brachyuran crabs (*Neopanope packardii, N. texana, Epialtus dilatatus, Pitho anisodon, Podochela riisei and Libinia dubia*) and an alpheid shrimp (*Alpheus normanni*). Considerable overlap in diet was noted among the feeding groups with nine dominant food categories observed: (1) crabs, (2) shrimp-amphipods, (3) polychaetes-amphipods, (4) amphipods, (5) amphipods-copepods-filamentous epiphytes, (6) *Thalassia*-detritus-encrusting algae-crustaceans, (7) encrusting algae-*Thalassia*, (8) filamentous epiphytes-*Thalassia*, and (9) *Thalassia*. The pink shrimp, *Farfantepenaeus duorarum*, was the dominant invertebrate predator on most animal prey types, feeding heavily on copepods, amphipods, bivalves, gastropods, and shrimp. The caridean shrimps, *Processa bermudensis* and *Ambidexter symmetricus*, were the dominant polychaete predators. *Callinectes sapidus*, *Palaemon floridanus, Metaporhaphis calcerata* were also highly predatory on grassbed epifauna. Previously thought to be predominantly opportunistic feeders, Leber (1983) found these decapods to be differentially restrictive in feeding mode with consumer selectivity of food types likely a function of prey accessibility, predator preferences and morphological constraints on consumers.

In addition to documenting dietary patterns of dominant decapods, Leber (1983, 1985) noted their influence in grassbed community dynamics. In a series of predator inclusion/exclusion experiments, he found predaceous pink shrimp (*F. duorarum*) were an important organizing force in faunal distribution and abundance patterns. Predation by pink shrimp strongly affected abundances of prey groups known to be important in its diet. The intense predation effects in his "simple" experimental habitat (clipped seagrass treatment) demonstrated the potential for shrimp to significantly depress prey population densities in sparsely vegetated microhabitats. As microhabitat structural complexity increased (intermediate and high plant biomass treatments) predation effects on prey densities were reduced for some prey species. For other prey species, however, predation effects remained relatively constant across the vegetation gradient. Amphipods and larger mollusks were most affected, with predation on these taxa significantly reduced in more complex habitats. Plant biomass appeared less important in reducing predation on decapods and polychaetes. Leber concluded that strong natural associations of epifauna with seagrass and macroalgae appear to be the net result of predation, refuge and habitat selection/preference.

Trophic relationships of fishes have been extensively examined in the Apalachee Bay grass beds by Livingston and coworkers. These beds serve as nursery areas for juvenile stages of many fishes migrating from offshore during varying seasons of the year. These species undergo seasonal progressions of feeding habits that follow specific size-related patterns including various trophic levels from herbivory to carnivory (Livingston 1982; 1984a, b). Using a nine-year data base of stomach analysis and food preferences, Livingston (1982) identified size-specific feeding classes within the dominant grassbed fishes according to similar dietary habits. Similar "ontogenetic trophic units" could be grouped together resulting in three major categories of trophic organization: planktivorous feeders, benthic omnivores and carnivores, and crustacean specialists. The planktivorous group fed primarily on copepods, amphipods and some plant remains, with polychaetes constituting a significant portion for some species; this group included bay anchovy (*Anchoa mitchelli*), spot (*Leiostomus xanthurus*) and the mojarras (*Eucinostomus gula* and *E. argenteus*). Benthic omnivores and carnivores fed on harpacticoid copepods, invertebrate eggs, benthic crustaceans and plant remains during the early stages, followed by increasing dependence on plant material and hydroids in more mature fish. Some members of this group fed on combinations of plant remains and small invertebrates such as amphipods, copepods, polychaetes and bivalves mollusks. The benthic omnivore/carnivore group included: pinfish (*Lagodon rhomboides*), spottail pinfish (*Diplodus holbrooki*), fringed and planehead filefish (*Monacanthus ciliatus* and *Stephanolepis hispidus*), striped burrfish (*Chilomycterus schoepfi*), Gulf toadfish (*Opsanus beta*), sea catfish (*Arius felis*), inshore lizardfish (*Synodus foetens*) and cownose rays (*Rhinoptera bonasus*). The final group specialized on crustaceans such as crabs, shrimp and amphipods and included dusky and Gulf pipefish (*Syngnathus floridae* and *S. scovelli*), pigfish (*Orthopristis chrysoptera*), silver perch (*Bairdiella chrysoura*), black sea bass (*Centropristis striata*), and banded blenny (*Paraclinus fasciatus*). Overall trophic organization of seagrass fishes appeared largely dependent on interactions of individual feeding aggregations with seasonal progressions of key habitat features and productivity cycles (Livingston 1982). Despite considerable seasonal and annual variability in physical conditions, general ontogenetic feeding patterns remained relatively stable over the period of observation (Livingston 1984b).

Additionally, the food web structure of inshore *Halodule wrightii* beds in the St. Marks National Wildlife Refuge was examined with particular emphasis on the role of overwintering migratory waterfowl (Baird et al. 1998; Christian and Luczkovitch 1999). Based on productivity, several taxa were noted to be potentially important to energy flow relative to their trophic position. These included protozoans in the water column and sediments, spot, predatory polychaetes, Gulf flounder and needlefish, and fish-eating birds. Through their analysis, detritus and benthic microalgae were important sources of food in the extended diets of many consumers. Energy flow through the winter *Halodule* community was dominated by detritus and benthic microalgae at the bottom and by waterfowl and piscivorous fish at the top. This pattern changed seasonally as seagrass productivity increased and many of the birds emigrated in summer.

9.3 Commercial Landings

Commercial harvests of several estuarine species have been reported for the Apalachee Bay area. Landings are reported by the county in which they are sold to a wholesale seafood establishment and do not necessarily reflect the actual location of capture. Landings shown here are those reported for Wakulla County and are expected to account for those harvests in the immediate vicinity of the St. Marks River as well as adjacent waters. While overall county landings include such offshore finfish as grouper, many commercial species are caught entirely or in part in the estuarine portions of the system. Blue crabs, oysters and mullet fall into the inshore group, having been harvested in more estuarine waters; shrimp, stone crab, grouper and sea bass are more marine.

Of the inshore species, blue crabs and mullet clearly dominated the Wakulla County harvest over the last six years (Table 21 and 22); relatively small catches were reported for oysters. Blue crabs made up over 85% of the invertebrate catch with mullet comprising nearly half of the finfish catch.

Invertebrates	Year 2000	Trips	2001	Trips	2002	Trips
Blue crab	939,535	2160	67,6191	2145	838,472	2215
Stone crab	76,619	767	69,810	508	107,244	610
Shrimp (Total)	34,445	63	48,102	99	38,588	59
Oysters	24,567	211	71,155	599	55,465	436
All Invertebrates	**1,081,256**	**3096**	**878,760**	**3262**	**1,046,751**	**3287**
Fish						
Mullet (Total)	320,223	961	395,528	939	365,679	826
Grouper						
Gag	142,978	537	179,185	643	151,872	602
Red	138,823	402	186,763	572	163,498	569
Sea bass	32,462	88	77,623	176	74,712	205
All Finfish	**765,032**	**1708**	**963,714**	**1791**	**888,212**	**1812**

Table 21 – Recent Commercial Harvests (in pounds) of Selected Fish and Shellfish Landed in Wakulla County (Fish and Wildlife Research Institute 2007)

Invertebrates	Year 2003	Trips	2004	Trips	2005	Trips
Blue crab	1,377,151	2494	1,591,136	2388	1,621,968	2520
Stone crab	73,949	551	74,845	422	75,317	489
Shrimp (Total)	42,177	66	24,483	44	18,523	28
Oysters	33,742	187	19,931	112	27,473	260
All Invertebrates	**1,534,153**	**3286**	**1,714,619**	**2828**	**1,750,129**	**3065**
Fish						
Mullet (Total)	382,300	862	358,354	836	295,834	862
Grouper						
Gag	96,645	408	114,790	365	103,495	324
Red	64,802	352	84,062	351	82,648	303
Sea bass	96,966	223	5610	56	24,842	105
All Finfish	**763,463**	**1601**	**659,965**	**1411**	**594,569**	**1392**

Table 22 – Recent Commercial Harvests (in pounds) of Selected Fish and Shellfish Landed in Wakulla County (Fish and Wildlife Research Institute 2007)

Overall, commercial landings appear to have increased slightly during the latter three years with a noticeable portion of that increase due to blue crabs. Grouper made up the majority of the offshore species, comprising about a third of the finfish catch. Stone crab and shrimp harvests, although an order-of-magnitude smaller than blue crab, contribute significantly to the area's commercial fisheries.

9.4 Threatened and Endangered Species

The St. Marks watershed supports about 32 species of plants and 74 species of animals designated by the federal government or the State of Florida as either threatened, endangered, species of special concern or rare (see Appendix A in NWFWMD 1997). Florida Natural Areas Inventory (FNAI 2008) includes 92 element occurrences of rare and endangered plants (31) and animals (61) within the basin. From these combined lists, only a limited number have been sighted or have the potential for inhabiting the submerged portions of St. Marks estuary and adjacent Apalachee Bay; these include gulf sturgeon (*Acipenser oxyrinchus desotoi*), West Indian manatee (*Trichechus manatus latirostris*) and three species of sea turtles (Atlantic loggerhead, *Caretta caretta*; Atlantic green turtle, *Chelonia guttata*; Kemp's ridley, *Lepidochelys kempii*).

Of these, West Indian manatees are one of the most frequent inhabitants of the area. Manatees are a protected species both at the federal and state level (i.e., listed as endangered by both, although the state is considering downgrading their listing to threatened) and have been observed with increasing frequency in panhandle estuaries (T. Calleson, FFWCC, personal communication). A detailed description of manatee sightings in the area is given in the previous section on Riverine Communities-Mammals.

Hoehn (1998) cited no references to rare and imperiled fishes in the St. Marks and Wakulla Rivers. He stated that Alabama shad (*Alosa alabamae*), gulf sturgeon, and Suwannee bass (*Micropterus notius*) have been observed in the Ochlockonee River and the blackbanded sunfish (*Enneacanthus chaetodon*) were found in the Aucilla and Econfina; however, none had been collected in the St. Marks system. Recent collections, however, have noted relatively large numbers of Suwannee bass in both the Wakulla and St. Marks Rivers (Walsh and Williams 2003; Cailteux 2004, 2005; T. Hoehn, FFWCC, pers. comm.). The western portion of Apalachee Bay was not included in the recent gulf sturgeon critical habitat designation (USFWS 2003) despite having collections from the Apalachicola, Ochlockonee and Suwannee Rivers (Wakeford 2001). Any gulf sturgeon found in the St. Marks River and adjacent waters are likely transients.

Beck et al. (2000) listed occurrence records of five "imperiled" species in the northeastern Apalachee Bay region (Ochlockonee Bay to Econfina River). These included one record of gulf sturgeon, one of manatee, three occurrences of Kemp's ridley, four observations of dwarf seahorse (*Hippocampus zosterae*) and six of fringed pipefish (*Anarchopterus criniger*). These latter two species were considered imperiled, primarily because of their declining habitat (high salinity seagrass beds), but are neither state nor federally listed.

10.0 IMPORTANCE OF FRESHWATER TO THE LOWER ST. MARKS AND WAKULLA RIVERS AND APALACHEE BAY SYSTEM

Freshwater inflow is thought to be one of the most important variables influencing riverine ecosystem components (e.g., fish populations, floodplain forest composition, nutrient cycling) both directly and indirectly (Poff et al. 1997; Richter et al. 1997; Richter et al. 2003). A river's flow regime has been described as the "master variable" governing many other parts of the riverine system (Richter et al. 2003) and includes characteristics of magnitude, frequency, duration, timing and rate of change (Poff et al. 1997). Increased natural variability of these characteristics generally results in greater diversity and complexity of riverine habitats and is essential to successful life-cycle completion for many aquatic, riparian and wetland species (Richter et al. 1996). Variation in hydrologic conditions frequently influences population dynamics of these species by affecting reproductive success, natural disturbance, biotic competition and predator-prey relationships (Poff and Ward 1989). Modifications to the hydrologic regime can result in alterations to the species composition, structure and function of these systems primarily through changes in the physical habitat (Richter et al. 1996).

The role of freshwater input in determining the productivity of river-dominated estuaries has been extensively discussed (Snedaker et al. 1977; Schroeder 1978; Cross and Williams 1981; Longley 1994; Livingston et al. 1997; Estuarine Research Federation 2002). Under natural river inflow conditions, the combination of generally high levels of primary production together with reduced predator activities by marine organisms have established conditions favoring rapid growth and enhanced productivity of estuarine populations that are adapted to rapidly changing environmental conditions (Livingston 1984c, 1991). This is particularly noticeable in systems with moderate to large riverine input and near the head of estuaries with relatively small freshwater inflow.

A key component of the estuarine environment is its dynamic nature, which in part is a function of an ever-changing, non-uniform freshwater input. This freshwater input is modified by basin morphology, winds and tides to produce highly variable conditions both spatially and temporally. The seasonal timing and magnitude of inflows are important, particularly during the critical periods of reproduction and growth. Relatively few organisms have evolved the physiological and behavioral adaptations to tolerate these widely fluctuating conditions; yet, those that have may be found in high numbers. These organisms have evolved life history strategies to maximize the benefits provided by the estuary. Despite the seasonal and inter-annual variation, inflows to panhandle estuaries display a recurrent pattern of winter peaks and summer-fall lows. This pattern is reflected in the seasonality of individual estuarine organisms that display species-specific phase-lagged relationships to flow (Livingston 1991).

10.1 Species and Habitats with Freshwater Dependence

Several species and habitats identified in this resource characterization appear dependent on freshwater flow to varying extents. While little long-term quantitative data exist on the abundance of species and habitats in the Wakulla and lower St. Marks Rivers and Apalachee Bay relative to river discharge, inferences can be made based on studies in nearby water bodies and the comparative amounts of freshwater entering the system. Based on the similarity of species composition between the St. Marks/Wakulla fauna and that collected in these neighboring areas, it seems reasonable to assume similar general relationships exist here with environmental characteristics.

Studies carried out recently in Apalachicola Bay (summarized in Lewis et al. 1997) indicated that the abundance and distribution of dominant estuarine organisms were associated with various environmental factors such as river flow, rainfall, salinity and temperature. These associations, however, were highly variable and differed for each species (or taxonomic group) and for each bay region. While some consistency across bay regions was noted for some species (or taxonomic groups), no single large-scale pattern was observed across the range of organisms examined. Flow and salinity were significant contributors to infaunal variance while salinity (and occasionally flow) was influential for catch of some shrimp. Temperature was the most frequently noted characteristic influencing the dominant fishes. Similar findings were noted for the dominant fishes and invertebrates in the Suwannee River estuary (Tsou and Matheson 2002). Salinity was an important covariate, along with bottom vegetation, affecting recruitment in nine of 13 species; water temperature was associated with abundances of six species. The lower St. Marks and inshore Apalachee Bay share many of the same dominant species with Apalachicola Bay and the Suwannee River estuary; presumably similar relationships with environmental variables exist.

In addition, significant correlations were found between annual fisheries catch and Apalachicola River flow (Wilber 1992, 1994). As with fisheries-independent data, commercial harvests of blue crabs and oysters were related to flow in different ways. Annual blue crab landings from both Franklin and Wakulla counties (Wilber 1994) were positively related to river flows during the previous years grow out period (September to May). Annual commercial oyster landings were related positively to flows two years before (Wilber 1992). Both relationships suggest mechanisms related to the physical conditions in the bay during the early life history stages of the organisms which may be coupled to either increased food or decreased predation (both of which are provided by increased river flows). Increased oyster mortality (from both predation and disease) was associated with increased salinity in Apalachicola Bay (Livingston et al. 1999, 2000). Blue crabs, and to a lesser degree oysters, make up a significant fraction of the commercial landings in the Wakulla County area and may be affected by changes in freshwater discharges.

Overall ecological system function in estuaries may also depend on freshwater inflows. Primary productivity is intimately linked to riverine input of dissolved inorganic nutrients. This relationship, however, is mediated by the residence time of freshwater in the estuary, which is clearly a function of freshwater inflow (primarily) and winds and tides (secondarily). In Apalachicola Bay about 75% of the estuarine phytoplankton production occurs during the warm, low-flow months of May to November (Mortazavi et al. 2000). Phytoplankton standing stock during this time, as estimated by chlorophyll concentrations, is relatively low and a function of phytoplankton growth rate, zooplankton grazing, nutrient limitation (primarily nitrogen), sedimentation, and export from the bay. The latter three factors are significantly affected by freshwater discharge.

Recent studies (Chanton and Lewis 1999, 2002) provide evidence that the bulk of the secondary production in large alluvial river estuaries (i.e., Apalachicola Bay) is fueled from *in situ* phytoplankton productivity. Zooplankton grazing can clearly result in substantial reductions in plankton biomass and provide a primary trophic transfer for phytoplankton primary production to upper level consumers in the estuary (Putland and Iverson 2007a, b). In addition, phytoplankton production can enter the food web through deposition to bottom sediments and subsequent incorporation into higher trophic levels through deposit-feeding infauna and epifauna. Organisms inhabiting areas closest to the mouth of the river and its distributaries appear more reliant on river-borne detritus than those living in areas more distant. However, even for these organisms, phytoplankton productivity plays a major role in faunal diets, making up at least half of the carbon transferred on average. Mid- and outer-bay organisms rely heavily on plankton production for subsistence (Chanton and Lewis 2002).

The lower St. Marks River and inshore Apalachee Bay estuary differ significantly from Apalachicola Bay in several important ways that influence primary production: significantly lower freshwater inflows, low nutrient loading (despite relatively high concentrations from Wakulla Spring) resulting in lower overall phytoplankton productivity, and the presence of large tidal marshes and seagrass beds in close proximity. Without more information on nutrient loading and primary productivity in this system, it is difficult to predict production dynamics. It is likely, however, that phytoplankton productivity provides at least a portion of the base of the food web in the St. Marks system and it is reasonable to expect similar trophic organization and transfers given a similar suite of organisms present. Seagrass and, more importantly, epiphytic algae growing on seagrass blades, are also important links to higher trophic levels in these seagrass-dominated systems (Moncrieff and Sullivan 2001), but at present their contribution is unknown. Direct feeding on seagrass blades, however, is limited to only a few species (Livingston 1982, 1984a; Leber 1983; Stoner and Livingston 1984).

The emerging picture of the structure and function of faunal assemblages in estuaries is one of overall stability amid and dependent upon a high level of variability and productivity in the system. Relatively few species inhabit estuaries, but those that do are physiologically and behaviorally adapted to the highly fluctuating conditions. These species are found in high numbers and biomass in response to high levels of primary production (both autochthonous and allochthonous). While individual species respond in different ways to changes in flow and its associated characteristics, the overall function (e.g., trophic organization) of the system is relatively constant within normal flow ranges. Deviations in river discharge, at both low- and high-flow ends of the flow spectrum, may be reflected in faunal changes that last several years (Livingston et al. 1997). Permanent flow modifications could be accompanied by important changes in estuarine productivity, related changes in faunal representation within the food web, and the potential reduction and loss of specific estuarine populations.

This discussion points to the complexity of estuarine systems and supports an adherence to the natural flow paradigm (Richter et al. 1997) which states: *the full range of natural intra- and inter-annual variation of hydrological regimes, and associated characteristics of timing, duration, frequency and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems*. Modifications in flow characteristics may be accompanied by subtle changes in estuarine faunal assemblages. Some populations will benefit while others will be negatively affected. Maintenance of overall system integrity requires minimizing departures from historical flows.

10.2 Flow Dependence and Salinity Tolerance

Habitats potentially vulnerable to changes in freshwater inflow in the Wakulla and lower St. Marks Rivers and Apalachee Bay include palustrine forests, fresh, brackish and salt marshes, submerged aquatic vegetation and seagrass beds, and oyster reefs. Species living in these habitats have varying abilities to tolerate salt and could be impacted adversely by long-term declines in freshwater inputs with subsequent intrusion of saline water. To assess this potential vulnerability, salinity tolerance ranges were compiled from the literature for the dominant organisms observed in both riverine and estuarine portions of the system (Appendix Tables D-1 for flora and D-2 for fauna). Ranges are provided for different life history stages, where available. In general, estuarine species have wide salinity tolerances to cope with the dynamic, highly variable environment; food is often the limiting factor. Freshwater species, on the other hand, are less tolerant (often intolerant) of saline conditions and the amount of inundation is more influential in determining habitat and species distributions; salinity may determine the downstream limit of their distribution.

10.2.1 Palustrine Forests

Floodplain and coastal hammock forests of the Wakulla River are composed of a variety of species with varying tolerances to salinity (Appendix Table D-1). The two dominant species in the lower reaches of the Wakulla, bald cypress and cabbage palm, display moderate salinity tolerance. Bald cypress exhibited significant reductions in photosynthesis and gas conductance at salinities between 2 and 8 ppt (Pezeshki et al. 1990; McLeod et al. 1996; Allen et al. 1997) with reduction in growth at salinities as low as 2 ppt (Conner et al. 1997). Mortality of 100% was noted at 10 ppt (Conner and Askew 1992). Cabbage palms exhibited significant declines in photosynthesis at salinities between 8 and 15 ppt (Perry and Williams 1996) with only 35% survival of seedlings at 8 ppt (Williams et al. 1998). Other less common species appear less tolerant and may be impacted more severely with reduction in freshwater inflow (see tolerances in Appendix Table D-1).

Light et al. (2002) examined the structure of the floodplain vegetation community in the lower Suwannee River basin and projected changes with varying amounts of freshwater depletions. Fourteen specific forest types were described within the riverine, upper tidal and lower tidal reaches of the river. They suggested that floodplain forest composition was primarily determined by duration of inundation and saturation, depth and frequency of floods, and salinity. Each forest type is associated with a specific range of durations of inundation and saturation and characteristic flood depths. Permanent long-term reductions in flow would result in decreases in duration of flooding and soil saturation which in turn lead to changes toward drier forest types and a movement upstream of forest species restricted by flood depths. Additionally, the boundary between forest and marsh (i.e., tree line) will shift upstream as salinity intrudes further upriver. Salt-intolerant species will retreat upstream as tidal movement extends further from the Gulf and forest species composition will be altered to include a greater percentage of salt-tolerant forms. Flow reductions will also result in decreases in the amount of inundated floodplain area affecting not only forest composition but also reducing habitat for a variety of floodplain animals, including fishes, reptiles and amphibians, birds and mammals. Similar findings were noted for the floodplain ground-cover vegetation (Darst et al. 2002). They suggested lower flows will result in changes in the understory species composition as some plants retreat upstream, decline in abundance or disappear altogether due to inundation requirements (i.e., flood depth and duration) and/or salt intolerance.

A variety of ecological consequences may result from these floodplain vegetation changes (Light et al. 2002). As changes occur in forest composition (i.e., movement toward drier forest types) there is an increased possibility of exotic invasion, an increased risk of human disturbance, a decrease in concomitant biological diversity because of vertical structure and microhabitat loss as forests are converted to marsh, a decrease in area of the wettest swamps and important swamp species such as cypress, and a decrease in canopy basal area, species richness and associated wildlife. A loss of saturated soils may result in a decrease in soil water retention and subsequent soil oxidation, decrease in soil denitrification, and an increased vulnerability to fire. Finally, a loss of inundated areas will be accompanied by decreases in aquatic habitat used by a variety of both floodplain dependent and main channel species that use the floodplain for feeding, shelter and reproduction.

Examining sea-level rise and the retreat of coastal forests, Williams et al. (1999) observed that zonation among tree species along the Florida Gulf coast was related to tidal-flooding frequency. Tree species number correlated negatively with frequency of flooding. Only cabbage palm (*Sabal palmetto*) and southern red cedar (*Juniperus virginiana*) were present on the most frequently flooded plots with cabbage palms the only living tree on the wettest sites. Live oaks (*Quercus virginiana*) occurred in areas with intermittent tidal flooding. Loss of tree species with inundation appeared the result of cessation of regeneration caused by exposure to salt. Forest understory replacement by salt marsh species appeared to follow, rather than cause, failure of regeneration. Field zonation patterns appeared consistent with greenhouse studies examining the relative salt tolerance of seedlings (Williams et al. 1998). Of the species examined, cabbage palm and southern red cedar were best able to maintain green leaves under experimental salt exposure; live oak survived high salt concentrations by dying back and re-sprouting. While their study focused on the effects of sea-level rise, the authors noted that coastal forest retreat as described could be accelerated by drought or upstream consumptive water use by humans (Williams et al. 1999).

Other authors have similarly addressed this retreat, discussing transitions in forested wetlands along gradients of salinity (Brinson et al. 1985; Brinson et al. 1995). With upstream movement of saline waters, forest changes are more pronounced at the transitions between wetland types. Freshwater forested wetlands tend to give way to brackish herbaceous wetlands. Two phases of transition are described in which the first appears to be the death of trees dominating the upper canopy and their replacement by mixed shrubs and herbaceous plants which are in turn replaced by herbaceous brackish marsh during the second phase (Brinson et al. 1985). The intrusion of salt water not only results in osmotic stress (and reduced water availability) to the trees but also is accompanied by abundant sulfate and the increased potential for anaerobic respiration. Toxicity to a variety of tree species often results under these conditions with sulfide accumulation in the surrounding sediments (Brinson et al. 1995). If high salinities are wide spread and persistent, swamp forests may be replaced by brackish marsh as was observed at the mouth of the Santee River, South Carolina (Kjerfve 1979). Some movement of the tree line with subsequent encroachment by marsh may occur in the lower Wakulla River floodplain depending on the magnitude of upstream flow reductions.

10.2.2 Freshwater/Brackish Marshes

Freshwater and brackish marshes are found through much of the Wakulla River and may be subjected to some impacts from salt intrusion in the lower reach of the basin. Marshes in the Wakulla are dominated by needlerush, sawgrass, pickerelweed, bull rush and a variety of other emergent and submergent species with varying degrees of salt tolerance (Appendix Table D-1). Some species like duck potato and pickerelweed have been observed in salinities up to nearly 9 ppt, while bull rush was recorded up to nearly 17 ppt (Penfound and Hathaway 1939). On the other hand, needlerush has a wide range of tolerance (see salt marsh section). Most other species found in the area displayed either significant declines in germination, growth, and photosynthesis or increases in mortality at salinities in the range of 2-6 ppt (Appendix Table D-1). These species may be affected by reductions in freshwater inflows and salinity increases.

Tidal marshes and their response to external variables were examined in the Suwannee River delta (Clewell et al. 1999). They found no relationships between individual marsh species abundance from shoreline transect sites and any of the environmental variables measured, particularly salinity or salinity maximum. There was a strong negative relationship, however, between the *Cladium-Juncus* (i.e., sawgrass-needlerush) abundance ratio and several variables, particularly mean salinity (R^2=0.85) and salinity maximum (R^2=0.91). *Cladium* is more prominent in freshwater areas while *Juncus* is more salt tolerant. For vegetation in the marsh interior, electrical conductivity/salinity was the single most important variable influencing plant abundance and species composition. Marsh vegetation was very heterogeneous with species composition and dominance highly variable spatially. Patchiness was likely caused in part by storm-related disturbances like erosion, knocked over plants, salt-kill and storm wrack deposition. These disturbances kill or destroy sizeable areas of live vegetation (particularly the dominant sawgrass and needlerush) and open up bare space for colonizing species. Over time sawgrass and needlerush grow into these areas and regain dominance.

Clewell et al. (1999) suggested that long-term low flows may be accompanied by several changes in the tidal marshes. It is likely that no change will occur in the hydroperiod because of the proximity to the Gulf and the influence of tides; however, marsh inundation is likely to be more saline. Higher salinity may cause no harm to salt tolerant species such as *Juncus* (needlerush), *Phragmites* (giant cane), *Spartina* (cord grass), *Scirpus* (bull rush) and *Typha* (cattail) but less tolerant species will likely not persist. Less tolerant species will retreat upstream ahead of the migration of more salt tolerant species. Significant ecological harm may be visible upstream in riverbank marshes where mesohaline (mid-salinity range) marshes may replace oligohaline (low-salinity range) marshes which in turn may expand into the freshwater zone. Some tidal river swamps may become salt stressed and be replaced by tidal salt marsh. Some upstream retreat and conversion of these fresh/brackish marshes may be expected in the Wakulla River depending upon the magnitude of flow and salinity change experienced.

10.2.3 Tidal Salt Marsh

Salt marsh contributes only a small fraction of the overall wetlands acreage in the lower Wakulla basin being restricted to the downstream-most portion near the confluence with the St. Marks River. Its expanse is significantly greater in the lower St. Marks River where salt marsh is the predominant habitat bordering most of the lower river and estuary. These marshes are dominated by black needlerush (*Juncus roemerianus*) and smooth cord grass (*Spartina alterniflora*), both of which display wide tolerance to salt (Appendix Table D-1). Needlerush has been observed growing in salinities up to 60 ppt (Eleuterius 1984). Growth was noted, however, to be inversely related to salinity with greatest production actually observed in freshwater. Similarly, cord grass is found in environments with salinities ranging from near fresh to almost full sea water (Mendelssohn and Marcellus 1976; Pulich 1990); greatest production, again, was noted at salinities less than 19 ppt (Mendelssohn and Marcellus 1976). Needlerush and cord grass, because of their salt tolerance, are able to compete favorably and dominate in areas where less salt tolerant vegetation cannot survive. Some upstream expansion of these marshes into the lower Wakulla River may be expected depending upon the magnitude of flow and salinity change. No effects are anticipated in the more broadly distributed salt marshes throughout the lower St. Marks River with their high tolerance for moderate to high salinities.

10.2.4 Submerged Aquatic Vegetation (SAV)

Salinity intrusion will likely affect SAV negatively in the lower reaches of the Wakulla and St. Marks Rivers. Tapegrass (*Vallisneria americana*), for example, is a salt-tolerant freshwater angiosperm that occurs in fresh, oligohaline, and mesohaline reaches of estuaries in the eastern United States and Gulf of Mexico; it is one of several species found in SAV beds throughout the Wakulla River. Published salt tolerances (Appendix Table D-1) vary with growth cessation reported to occur from 6.6 (Haller et al. 1974) to 15 ppt (Doering et al. 1999); other work suggested mortality at salinities greater than 15 ppt (Kraemer et al. 1999). Doering et al. (2001) noted that while significant mortality occurred at 18 ppt, the degree of mortality was proportional to the duration of exposure. Recovery could be achieved with return to low salinity. They suggested that a 70-day intrusion of 18 ppt is near the upper limit of what might be tolerated without a net population reduction. This degree of intrusion would result in an approximate 80% reduction in shoot density, but with return to low salinity, recovery to pre-intrusion density was estimated in about 115 days. Multiple, repeated salinity intrusions, however, were not examined and could be expected to have more serious and perhaps unrecoverable consequences. Tapegrass has been observed in the lower St. Marks in areas with mean bottom salinity of 3 ppt and maximum values of 24 pp; some impacts may be sustained depending on the magnitude of flow reduction. Other species such as dwarf arrowhead, southern naiad, coontail and false loosestrife are primarily freshwater species with slight salt tolerances (Appendix Table D-1); these species are generally found at salinities below 3 to 6 ppt. Some impacts are likely even with moderate freshwater reductions. Exotic species such as Eurasian watermilfoil and hydrilla have relatively low salinity tolerances (exception: Twilley and Barko (1990) observed highest biomass of watermilfoil at 12 ppt) and may be affected in the lower reaches of the system.

Examining SAV beds in the lower tidal portion of the Suwannee River, Estevez and Sprinkel (1999) suggested that reduced flows will increase salinity in the lower river and cause an up-stream retreat and overall reduction of SAV beds. These consequences likely result from specific river-bed morphology (i.e., narrow to nonexistent shorelines upstream in the Suwannee) and lack of potential colonizing estuarine or marine grasses at the river mouth and in Suwannee Sound. They further suggested that as the SAV beds retreat upstream the overall community assemblage will be simplified by loss of sensitive species. Total bed area, cover or biomass might not be reduced, but habitat diversity would be negatively affected by species loss. Further down the Gulf coast in the Chassahowitzka, Homosassa and Crystal rivers, SAV biomass approached zero at sites where annual average salinity was greater than 3.5 ppt (Hoyer et al. 2004). While similar upstream movement of SAV beds might occur in the Wakulla system it is unlikely that the lower portion of the river would be left devoid of grasses because of the presence of potentially colonizing estuarine species in the lower St. Marks. Both widgeon grass (*Ruppia maritima*) and shoal grass (*Halodule wrightii*) are present in the lower reach of the system, have wide salinity tolerances (Appendix Table D-1) and will likely expand upstream with salt water intrusion. The replacement of the diverse and abundant SAV with fewer estuarine-tolerant species would likely result in a decrease in habitat structure with subsequent declines in associated fauna.

10.2.5 Seagrasses

Near and offshore grass beds in Apalachee Bay are unlikely to experience any change caused by minor modifications in freshwater flow. These beds are dominated by widgeon and shoal grasses inshore with shoal, manatee and turtle grass offshore. Widgeon and shoal grass have broad salinity tolerances (Appendix Table D-1) ranging from near fresh to hypersaline conditions while turtle grass is most abundant at intermediate to high salinities (Appendix Table D-1). Based on a series of stress indicators such as shoot decline, growth rate and photosynthetic efficiency, these species were able to tolerate salinities up to 55 ppt, with turtle grass (60 ppt) and shoal grass (65 ppt) having slightly higher thresholds than widgeon grass (55 ppt) when salinities were gradually increased (Koch et al. 2007). Stress threshold levels dropped noticeably for turtle grass (45 ppt) when salinity was pulsed without a slow osmotic adjustment period; no pulsed tests were run for the other species. In addition, turtle grass seedlings were observed to survive 50 ppt when exposed to slow increases in salinity, yet all died at this level in pulsed experiments (Kahn and Durako 2006). It is interesting to note that while widgeon grass is highly tolerant of high salinity (up to 390 ppt in review by Kantrud 1991) and is able to produce reproductive shoots across a wide salinity range, it is often found dominating the low salinity freshwater-marine interface community (Koch et al. 2007). At the other end of the salinity range, widgeon grass is the only species capable of surviving extended periods in freshwater (McMillan 1974). Shoal grass does not survive salinity less than about 3.5 ppt for six weeks (McMahan 1968) and turtle grass dies between 5 and 10 ppt (McMillan 1974). Interestingly, while widgeon grass survives well in low salinity waters, maximum photosynthetic efficiency has been observed between 10 and 20 ppt (Murphy et al. 2003). Because of the wide salinity tolerances of widgeon and shoal grass, and the preference of turtle grass for moderate to high salinity, little change in seagrass bed distribution and dynamics is likely in Apalachee Bay with small declines in freshwater inflows.

10.2.6 Oyster Reefs

Oyster reefs occur throughout the lower reach of the St. Marks River where they become a conspicuous feature, especially during low tides. While these reefs do not support a commercial fishery (an existing fishery is located in the western sections of Apalachee Bay in Dickerson and Oyster bays), they provide important habitat for organisms seeking food and shelter. The large reef expanse is located in the areas of significant tidal mixing and is likely limited to a certain degree by the amount of freshwater inflow. Salinities average 3.5 and 14.8 at middle and lower tidal reaches, respectively, with significant variation (see Water Quality section Table 3). Changing freshwater inflows may modify the salinity structure somewhat in this reach with subsequent effects on oysters.

The eastern oyster (*Crassostrea virginica*) is an estuarine resident and as such tolerates the dynamic conditions found there; salinity tolerances for various life history stages are shown in Appendix Table D-2. Adult oysters can survive in salinities from freshwater to 45 ppt with optimal conditions for growth between 10 and 30 ppt (Longley 1994; Pattillo et al. 1997). While capable of surviving at low salinities for short periods of time, oysters generally close their shells and do not feed below about 3 ppt (Loosanoff 1953). Eggs and larvae prefer moderate salinities (10-29 ppt) with optimal growth of spat occurring from 13 to 30 ppt (Pattillo et al. 1997). Predation and disease, as contributors to mortality, affect oyster population dynamics and are directly related to salinity; both are higher in high salinity waters. A variety of predators feed on oysters including gastropod mollusks (*Thais haemastoma* and *Melongena corona*), crabs (*Callinectes sapidus* and *Mennippe mercenaria*) and fishes (*Pogonias cromis* and *Archosargus probatocephalus*). The southern oyster drill (*T. haemastoma*) is thought to be one of the major predators along the Gulf coast and is limited by average salinity below 15 ppt (Butler 1953). Crown conch (*M. corona*), while preferring salinities between 20 and 29 ppt, have been found in waters as low as 8.5 ppt (Hathaway and Woodburn 1961). High levels of mortality on some reefs have been attributed to the sporozoan parasite *Perkinsus marinus*, also called “dermo”. Incidence of *Perkinsus* infection is correlated with temperature and salinity (Soniat 1996) with mortality suppressed at low salinity. Infection intensity increases as salinity increases with 9 to 12 ppt as a minimum threshold (Ragone and Burreson 1993). Little is known concerning the occurrence of predators and disease on lower St. Marks/Apalachee Bay reefs. Declining freshwater inflows may increase the incidence of both on the reefs with subsequent influence on oyster population dynamics dependent on the amount of change. Bergquist et al. (2006) found oyster percent cover and density in the Suwannee River estuary to be negatively related to salinity.

10.2.7 Faunal Abundance and Distribution

Information on the epibenthic invertebrate and fish assemblages in the Wakulla River is limited to the studies of Birkett (1981), Walsh and Williams (2003), and continuing collections by FDEP, FFWCC and NWFWMD. Other efforts, by both the academic and governmental community, have involved primarily terrestrial assemblages and are beyond the scope of this characterization. Epifaunal and benthic invertebrate communities were dominated by caddisfly and chironomid larvae and oligochaete worms (Birkett 1981). In addition, variable spikes and other unionid mollusks were most abundant in the upper reach of the river (Walsh and Williams 2003). These species are typical of freshwater systems and generally exhibit intolerance to salt. Similarly, apple snails once abundant in the upper river but now with declining numbers, are also salt intolerant; adequate water levels, however, are required for egg laying on emergent vegetation. Birkett (1981) noted a significant correlation between epifaunal invertebrate abundance and diversity and plant biomass. Thus many of these species not only are directly susceptible to salinity intrusion from a physiological perspective but also indirectly influenced by a loss of habitat as many of the freshwater macrophytes on which they live have limited tolerance to salt.

Many of the fishes documented from the collections of Walsh and Williams (2003) and the FFWCC (Cailteux et al. 2004, 2005) are freshwater species with limited range of salinity. These species will retreat upstream with salinity encroachment. Some of these species, however, have the ability to invade the oligohaline (low salinity) and mesohaline (moderate salinity) zones and have been collected at salinities as high as 15 to 20 ppt. Swingle and Bland (1974) recorded several of these latter species in Alabama water which are listed here along with the maximum salinity recorded: longnose gar (*Lepisosteus osseus*) 21.7, chain pickerel (*Esox niger*) 7.5, coastal shiner (*Notropis petersoni*) 7.4, lake chubsucker (*Erimyzon sucetta*) 14.4, spotted sunfish (*Lepomis punctatus*) 17.5, and largemouth bass (*Micropterus salmoides*) 17.5. No salinity information was found for the listed Suwannee bass (*M. notius*).

Little impact will be felt from slight salinity intrusions by most of the remaining fauna, including amphibians, reptiles, birds and mammals. Some loss of submerged aquatic vegetation may limit feeding by some water fowl and manatees from the downstream-most portions of the river, but this limitation should be relatively small given the abundance of SAV throughout the system.

Invertebrates and fishes inhabiting the downstream salt marshes will be little affected by salinity intrusion; these species, in fact, may expand their habitat if the fresh-salt marsh line retreats upstream. Common marsh invertebrates include marsh periwinkle (*Littorina irrorata*) and fiddler crabs (*Uca* spp.); blue crabs are frequent migrants into the tidal creeks. The marsh fish community is dominated by a number of resident (longnose killifish *Fundulus similis*, Gulf killifish *F. grandis*, sheepshead minnow *Cyprinodon variegatus*, sailfin molly *Poecilia latipinna* and tidewater silverside *Menidia beryllina*) and migrant species (bay anchovy *Anchoa mitchelli*, Gulf menhaden

Brevoortia patronus, pinfish *Lagodon rhomboides*, spot *Leiostomus xanthurus*). These species dominate many Gulf coastal marshes and estuaries and display wide tolerances for environmental conditions, including salinity. Salinity ranges for dominant salt marsh organisms, where available, are shown in Appendix Table D-2.

Seagrass invertebrates consist predominantly of small cryptic species including palaemonetid (*Palaemonetes* spp.) and hippolytid shrimp (*Tozeuma carolinense*, *Thor* spp., *Latreutes* spp.) and xanthid (*Neopanope* spp., *Panopeus* spp.) and hermit crabs (*Pagurus maclaughlinae*). Pink shrimp (*Farfantepenaeus duorarum*) and blue crab (*Callinectes sapidus*) are the most abundant larger seagrass invertebrates. Common seagrass fishes include pinfish (*Lagodon rhomboides*), spot (*Leiostomus xanthurus*), filefish (*Monocanthus ciliatus* and *Stephanolepis hispidus*), silver perch (*Bairiedella chrysoura*), black sea bass (*Centropristis striata*), spottail pinfish (*Diplodus holbrooki*), dusky pipefish (*Syngnathus floridae*), pigfish (*Orthopristis chrysopterus*) and silver jenny (*Eucinostomus gula*). Many of these species, while having broad tolerances, prefer moderate to high salinities (Appendix Table D-2).

In general, these species are typical estuarine inhabitants with broad environmental tolerances (Appendix Table D-2). Marsh and inshore resident are adapted for highly fluctuating and variable conditions. Many of the migrant species spawn in nearshore Gulf waters (penaeid shrimp spawn offshore) such that their eggs and larvae are found predominantly in high salinity. Larvae move into marshes and estuaries where they reside as juveniles and grow before emigration again to the Gulf. As adults most have been recorded in salinities from near freshwater to >35 ppt; some are frequent inhabitants of hypersaline lagoons with salinities >45 ppt. Despite their high tolerance, greatest abundance is often found in mesohaline conditions (5-18 ppt); pink shrimp and many of the seagrass fishes (especially those preferring turtle grass) have generally higher abundance in waters >18 ppt. Because of these wide salinity tolerances, little change in distribution and population dynamics of these species is likely with small declines in freshwater inflows.

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12.0 APPENDICES

Appendix A - Herptofauna of Edward Ball Wakulla Springs State Park with Primary Habitats Designated

Common Name	Scientific Name	Upland Hardwood Forest	Upland Pine Forest	Depression Marsh	Dome	Floodplain Marsh	Seepage Stream
AMPHIBIANS							
Slimy Salamander	*Plethodon glutinosus*			X	X	X	
Central Newt	*Notophthalmus viridescens*						
Eastern Narrow-mouthed Toad	*Gastrophryne carolinensis*	X	X				
Eastern Spadefoot Toad	*Scaphiopus holbrookii*	X	X				
Fowlers Toad	*Bufo woodhousei fowleri*	X	X				
Gray Teefrog	*Hyla chrysoscelis*			X	X	X	
Green Treefrog	*Hyla cinerea*			X	X	X	
Spring Peeper	*Hyla crucifer*			X	X	X	
Pinewoods Treefrog	*Hyla femoralis*	X	X				
Squirrel Treefrog	*Hyla squirella*	X	X				
Bull Frog	*Rana catesbeiana*			X	X	X	
Pig Frog	*Rana grylio*			X	X	X	
Southern Leopard Frog	*Rana utricularia*			X	X	X	
Southern Toad	*Bufo terrestris*	X	X				
Siren	*Siren* sp.			X	X	X	
REPTILES							
Florida Snapping Turtle	*Chelydra serpentina*					X	X
Suwannee Cooter	*Chrysemys concinna suwanniensis*					X	X
Gopher Tortoise	*Gopherus polyphemus*		X				
Eastern Mud Turtle	*Kinosternon subrubrum*					X	X
Alligator Snapping Turtle	*Macroclemys temminckii*					X	X
River Cooter	*Pseudemys concinna*					X	X
Florida Cooter	*Pseudemys floridana*					X	X
Stinkpot	*Sternotherus odoratus*					X	X
Gulf Coast Box Turtle	*Terrapene carolina major*	X	X		X		
Yellow-bellied Slider	*Trachemys scripta*					X	X
Florida Softshell Turtle	*Trionyx ferox*					X	X
American Alligator	*Alligator mississippiensis*					X	X
Green Anole	*Anolis carolinensis*	X	X	X	X	X	X
Fence Lizard	*Sceloporus undulatus hyacinthinus*	X	X				
Six-lined Racerunner	*Cnemidophorus sexlineatus*	X	X				
Eastern Glass Lizard	*Ophisaurus ventalis*	X	X				
Broad-headed Skink	*Eumeces laticeps*	X			X		
Southeastern Five-lined Skink	*Eumeces inexpectatus*	X	X		X		
Ground Skink	*Scincella laterale*	X	X				
Eastern Cottonmouth	*Agkistrodon piscivorus*			X	X	X	
Black Racer	*Coluber constrictor*	X	X				
Eastern Diamondback Rattlesnake	*Crotalus adamanteus*	X	X				
Dusky Pigmy Rattlesnake	*Sistrurus miliarius barbouri*	X	X				
Ring-necked Snake	*Diadophis punctatus*	X	X		X		
Scarlet Snake	*Cemophora coccinea*	X	X		X		
Scarlet King Snake	*Lampropeltis triangulum*	X	X		X		
Red Rat Snake	*Elaphe guttata*	X			X	X	
Gray Rat Snake	*Elaphe obsoleta spiloides*	X			X	X	
Eastern Hognose	*Heterodon platyrhinos*	X	X				
Eastern Kingsnake	*Lampropeltis getulus*	X	X		X	X	
Coachwhip	*Masticophis flagellum*	X	X				
Coral Snake	*Micrurus fulvius*	X	X		X		
Southern Watersnake	*Nerodia fasciata*			X		X	X
Brown Watersnake	*Nerodia taxispilota*			X		X	X
Red-bellied Watersnake	*Natrix erythrogaster*			X		X	X
Banded Watersnake	*Natrix fasciata*			X		X	X
Rough Green Snake	*Opheodrys aestivus*				X	X	
Pine Snake	*Pituophis melanoleucus*	X	X				
Eastern Garter Snake	*Thamnophis sirtalis*	X		X	X	X	

Appendix B - Birds of Edward Ball Wakulla Springs State Park with Primary Habitats Designated

Common Name	Scientific Name	Upland Hardwood Forest	Upland Pine Forest	Depression Marsh	Dome	Floodplain Marsh	Seepage Stream
BIRDS							
Common Loon	*Gavia immer*						X
Pied-billed Grebe	*Podilymbus podiceps*						X
Horned Grebe	*Podiceps auritus*						X
Great Cormorant	*Phalacrocorax carbo*						X
Double-crested Cormorant	*Phalacrocorax auritus*						X
Anhinga	*Anhinga anhinga*						X
Great Blue Heron	*Ardea herodias*						X
Great Egret	*Ardea alba*						X
Snowy Egret	*Egretta thula*						X
Little Blue Heron	*Egretta caerulea*						X
Tricolored Heron	*Egretta tricolor*						X
Green Heron	*Butorides virescens*						X
Black-crowned Night-Heron	*Nycticorax nycticorax*						X
Yellow-crowned Night-Heron	*Nycticorax violaceus*						X
American Bittern	*Botaurus lentiginosus*						X
Least Bittern	*Ixobrychus exilis*						X
White Ibis	*Eudocimus albus*						X
Roseate Spoonbill	*Ajaia ajaja*						X
Wood Stork	*Mycteria americana*						X
Canada Goose	*Branta canadensis*						X
Snow Goose	*Chen caerulescens*						X
Black Vulture	*Coragyps atratus*	X	X	X	X	X	X
Turkey Vulture	*Cathartes aura*	X	X	X	X	X	X
Wood Duck	*Aix sponsa*					X	X
Green-winged Teal	*Anas crecca*						X
Black-bellied Whistling Duck	*Dendrocygna autumnalis*						X
American Black Duck	*Anas rubripes*						X
Mallard	*Anas platyrhynchos*						X
Blue-winged Teal	*Anas discors*						X
Northern Shoveler	*Anas clypeata*						X
Gadwall	*Anas strepera*						X
Eurasian Wigeon	*Anas penelope*						X
American Wigeon	*Anas americana*						X
Canvasback	*Aythya valisineria*						X
Redhead	*Aythya americana*						X
Ring-necked Duck	*Aythya collaris*						X
Greater Scaup	*Aythya marila*						X
Lesser Scaup	*Aythya affinis*						X
Bufflehead	*Bucephala albeola*						X
Common Goldeneye	*Bucephala clangula*						X
Hooded Merganser	*Lophodytes cucullatus*						X
Red-breasted Merganser	*Mergus serrator*						X
Osprey	*Pandion haliaetus*					X	X
Swallow-tailed Kite	*Elanoides forficatus*	X	X	X	X	X	X
Snail Kite	*Rostrhamus sociabilis*						X
Mississippi Kite	*Ictinia mississippiensis*	X	X	X	X	X	X
Bald Eagle	*Haliaeetus leucocephalus*	X	X	X	X	X	X
Northern Harrier	*Circus cyaneus*						X

Common Name	Scientific Name	Upland Hardwood Forest	Upland Pine Forest	Depression Marsh	Dome	Floodplain Marsh	Seepage Stream
Sharp-shinned Hawk	*Accipiter striatus*	X	X	X	X	X	X
Copper's Hawk	*Accipiter cooperii*	X	X		X	X	
Red-shouldered Hawk	*Buteo lineatus*	X	X		X	X	
Broad-winged Hawk	*Buteo platypterus*	X	X		X	X	
Red-tailed Hawk	*Buteo jamaicensis*	X	X		X	X	
Golden Eagle	*Aquila chrysaetos*	X					
American Kestrel	*Falco sparverius*	X	X				
Merlin	*Falco columbarius*		X				
Peregrine Falcon	*Falco peregrinus*	X	X				
Wild Turkey	*Meleagris gallopavo*	X	X		X	X	
Northern Bobwhite	*Colinus virginianus*	X	X				
Sora	*Porzana carolina*				X	X	X
Purple Gallinule	*Porphyrula martinica*						X
Common Moorhen	*Gallinula chloropus*						X
American Coot	*Fulica americana*						X
American Oystercather	*Haematopus palliatus*						X
Limpkin	*Aramus guarauna*					X	X
Sandhill Crane	*Grus canadensis*	X	X				
Killdeer	*Charadrius vociferus*					X	X
Solitary Sandpiper	*Tringa solitaria*					X	X
Spotted Sandpiper	*Actitis macularia*					X	X
Common Snipe	*Gallinago gallinago*					X	X
American Woodcock	*Scolopax minor*	X			X	X	
Magnificent Frigatebird	*Fregata magnificens*						X
Laughing Gull	*Larus atricilla*						X
Bonaparte's Gull	*Larus philadelphia*						X
Ring-billed Gull	*Larus delawarensis*						X
Black Tern	*Chlidonias niger*						X
Foreter's Tern	*Sterna forsteri*						X
Sooty Tern	*Sterna fuscata*						X
Ground Dove	*Columbina passerine*	X	X		X		
Mourning Dove	*Zenaida macroura*	X	X		X		
Yellow-billed Cuckoo	*Coccyzus americanus*	X			X	X	
Common Barn Owl	*Tyto alba*	X			X	X	
Eastern Screech Owl	*Otus asio*	X			X	X	
Great Horned Owl	*Bubo virginianus*	X			X	X	
Barred Owl	*Strix varia*	X	X		X	X	
Common Nighthawk	*Chordeiles minor*	X	X				
Chuck-will's-widow	*Caprimulgus carolinensis*	X			X	X	
Whip-poor-will	*Caprimulgus vociferus*	X			X	X	
Chimney Swift	*Chaetura pelagica*	X	X		X	X	
Ruby-throated Hummingbird	*Archilochus colubris*	X			X	X	
Belted Kingfisher	*Ceryle alcyon*						X
Red-headed Woodpecker	*Melanerpes erythrocephalus*	X	X				
Red-bellied Woodpecker	*Melanerpes carolinus*	X	X				
Yellow-bellied Sapsucker	*Sphyrapicus varius*	X	X		X	X	
Downy Woodpecker	*Picoides pubescens*	X	X				
Hairy Woodpecker	*Picoides villosus*	X	X				
Northern Flicker	*Colaptes auratus*	X	X				

Common Name	Scientific Name	Upland Hardwood Forest	Upland Pine Forest	Depression Marsh	Dome	Floodplain Marsh	Seepage Stream
Pileated Woodpecker	*Dryocopus pileatus*	X	X		X	X	
Eastern Wood-Pewee	*Contopus virens*	X	X				
Eastern Phoebe	*Sayornis phoebe*	X	X				
Acadian Flycatcher	*Empidonax virescens*	X	X				
Great Crested Flycatcher	*Myiarchus crinitus*	X	X				
Eastern Kingbird	*Tyrannus tyrannus*	X	X				
Purple Martin	*Progne subis*	X	X		X	X	
Tree Swallow	*Tachycineta bicolor*				X	X	
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*				X	X	
Bank Swallow	*Riparia riparia*				X	X	
Barn Swallow	*Hirundo rustica*				X	X	
Blue Jay	*Cyanocitta cristata*	X	X		X		
American Crow	*Corvus brachyrhynchos*	X	X	X	X	X	X
Fish Crow	*Corvus ossifragus*	X	X			X	X
Carolina Chickadee	*Parus carolinensis*	X	X		X	X	
Tufted Titmouse	*Parus bicolor*	X	X				
Red-breasted Nuthatch	*Sitta canadensis*	X	X		X		
White-breasted Nuthatch	*Sitta carolinensis*	X	X		X		
Brown-headed Nuthatch	*Sitta pusilla*	X	X				
Brown Creeper	*Certhia americana*	X	X		X		
Carolina Wren	*Thryothorus ludovicianus*	X	X		X	X	
House Wren	*Troglodytes aedon*	X	X				
Winter Wren	*Troglodytes troglodytes*	X	X				
Marsh Wren	*Cistothorus palustris*				X	X	X
Sedge Wren	*Cistothorus platensis*					X	X
Golden-crowned Kinglet	*Regulus satrapa*	X			X	X	
Ruby-crowned Kinglet	*Regulus calendula*	X	X				
Blue-gray Gnatcatcher	*Polioptila caerulea*	X	X				
Eastern Bluebird	*Sialia sialis*	X	X				
Veery	*Catharus fuscescens*	X	X				
Gray-cheeked Thrush	*Catharus minimus*	X	X				
Swainson's Thrush	*Catharus ustulatus*	X	X				
Hermit Thrush	*Catharus guttatus*	X	X				
Wood Thrush	*Hylocichla mustelina*	X	X				
American Robin	*Turdus migratorius*	X	X		X	X	
Gray Catbird	*Dumetella carolinensis*	X	X			X	
Northern Mockingbird	*Mimus polyglottos*	X	X		X	X	
Brown Thrasher	*Toxostoma rufum*	X	X				
Cedar Waxwing	*Bombycilla cedrorum*	X	X		X	X	
Loggerhead Shrike	*Lanius ludovicianus*		X				
White-eyed Vireo	*Vireo griseus*	X	X				
Solitary Vireo	*Vireo solitarius*	X	X		X	X	
Yellow-throated Vireo	*Vireo flavifrons*	X	X				
Red-eyed Vireo	*Vireo olivaceus*	X	X				
Golden-winged Warbler	*Vermivora chrysoptera*	X	X				
Tennessee Warbler	*Vermivora peregrina*	X	X				
Orange-crowned Warbler	*Vermivora celata*	X	X		X		
Northern Parula	*Parula americana*	X	X		X		
Black-throated Blue Warbler	*Dendroica caerulescens*	X	X				
Chestnut-sided Warbler	*Dendroica pensylvanica*	X	X				
Magnolia Warbler	*Dendroica magnolia*	X	X				

Common Name	Scientific Name	*Upland Hardwood Forest*	*Upland Pine Forest*	*Depression Marsh*	*Dome*	*Floodplain Marsh*	*Seepage Stream*
Yellow-rumped Warbler	*Dendroica coronata*	X	X				
Yellow-throated Warbler	*Dendroica dominica*	X	X				
Pine Warbler	*Dendroica pinus*	X	X				
Palm Warbler	*Dendroica palmarum*	X	X		X	X	
Cerulean Warbler	*Dendroica cerulea1*	X	X		X		
Blackpoll Warbler	*Dendroica striata*	X	X				
Black-and-white Warbler	*Mniotilta varia*	X	X			X	
American Redstart	*Setophaga ruticilla*	X	X			X	
Prothonotary Warbler	*Protonotaria citrea*	X	X		X	X	
Worm-eating Warbler	*Helmitheros vermivorus*	X			X	X	
Ovenbird	*Seiurus aurocapillus*	X			X	X	
Northern Waterthrush	*Seiurus noveboracensis*				X	X	X
Louisiana Waterthrush	*Seiurus motacilla*				X	X	X
Kentucky Warbler	*Oporornis formosus*	X	X		X		
Common Yellowthroat	*Geothlypis trichas*	X					X
Hooded Warbler	*Wilsonia citrina*	X	X				
Wilson's Warbler	*Wilsonia pusilla*	X	X				
Blue-winged Warbler	*Vermivora pinus*	X	X				
Summer Tanager	*Piranga rubra*	X	X				
Scarlet Tanager	*Piranga olivacea*	X	X		X		
Northern Cardinal	*Cardinalis cardinalis*	X	X		X	X	
Blue Grosbeak	*Guiraca caerulea*	X			X	X	
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	X	X				
Indigo Bunting	*Passerina cyanea*	X	X				
Rufous-sided Towhee	*Pipilo erythrophthalmus*	X	X				
Chipping Sparrow	*Spizella passerina*	X	X				

Appendix C - Mammals of Edward Ball Wakulla Springs State Park with Primary Habitats Designated

Common Name	Scientific Name	Upland Hardwood Forest	Upland Pine Forest	Depression Marsh	Dome	Floodplain Marsh	Seepage Stream
MAMMALS							
Nine-banded armadillo	*Dasypus novemcinctus*	X	X		X	X	
Opossum	*Didelphis marsupialis*	X	X		X		
Eastern mole	*Scalopus aquaticus*	X	X		X		
Marsh rabbit	*Sylvilagus palustria*				X	X	
Eastern cottontail	*Sylvilagus floridanus*	X	X				
Gray squirrel	*Sciurus carolinensis*	X	X		X		
Fox squirrel	*Sciurus niger*	X					
Southern flying squirrel	*Glaucomys volans*	X	X		X		
Cotton mouse	*Peromyscus gossypinus*	X	X				
Golden mouse	*Ochrotomys nuttalli*	X	X				
Gray fox	*Urocyon cinereoargenteus*	X	X		X		
Florida black bear	*Ursus americanus floridanus*	X	X		X	X	
Raccoon	*Procyon lotor*	X			X	X	
River otter	*Lutra canadensis*					X	X
Bobcat	*Felis rufus*	X	X		X		
West Indian manatee	*Trichechus manatus latirostris*						X
White-tailed deer	*Odocoileus virginianus*	X	X		X	X	
Southeastern bat	*Myotis austroriparious*	X			X	X	
Eastern pipistrel	*Pipistrellus subflavus*	X			X	X	
Seminole bat	*Lasiurus seminolus*	X			X	X	X
Red bat	*Lasiurus borealis*	X			X	X	
Eastern yellow bat	*Lasiurus intermedius*	X			X	X	

Appendix D – Salinity Tolerances for Selected Organisms

Table D-1. Representative salinity tolerance ranges for the dominant plants (riverine forest, emergent marsh - fresh and salt, submerged aquatic vegetation and seagrasses) found in portions of Wakulla and lower St. Marks rivers and Apalachee Bay, Florida. Tolerances are given along with the source of information. Table entries are salinity values given in parts per thousand.

Species	Salinity Range	References
Riverine Forest		
Bald cypress (*Taxodium distichum)*	0-8.9	Penfound and Hathaway (1938)
	2-7 (58-84% reduction in photosynthesis)	Pezeshki et al. (1990)
	100% mortality of seedlings at 30 for ≥2 days (flooded)	Conner and Askew (1992)
	73% mortality at 8; leaf area reduction at >4	Allen et al. (1994)
	100% mortality of seedlings at 10 (flooded); decreased photosynthesis at 2 (flooded), unaffected at 2 (watered)	McLeod et al. (1996)
	2-8 (significant reductions in photosynthesis and stomatal conductance in seedlings)	Allen et al. (1997)
	Seedling growth (height) reduced at 2, no reduction in diameter or biomass	Conner et al. (1997
Cabbage palm (*Sabal palmetto*)	8-15 photosynthesis declined nearly 65%; none observed at 15; seed and seedlings survival greater at low (avg 3) vs. high (avg 23) salinity sites in field	Perry and Williams (1996)
	<5% survival of seedlings at 22, 25% at 15, 35% at 8, 65% at 4, >80% at 2; 25% green leaves at 15, 65% at 4	Williams et al. (1998)
Green ash (*Fraxinus pennsylvanica*)	0.8-8 (48-88% reduction in photosynthesis)	Pezeshki et al. (1990)
	100% mortality of seedlings at 10 (flooded); severly decreased photosynthesis at 2 (flooded), unaffected at 2 (watered)	McLeod et al. (1996)
	Seedling growth (height, diameter, biomass) reduced at 2	Conner et al. (1997)
Loblolly pine (*Pinus taeda*)	100% mortality of seedlings at 30 for ≥2 days (flooded)	Conner and Askew (1992)
Live oak (*Quercus virginiana*)	<10% survival of seedlings at 22, 50% at 15, 75% at 8, >75% at 4; <25% green leaves at 8, 25% at 4	Williams et al. (1998)
Sweet gum (*Liquidambar styraciflua*)	No survival of seedlings at >8, <5% at 4, 50% at 2; no green leaves at >8, <5% at 4, 50% at 2	Williams et al. (1998)
Red maple (*Acer rubrum*)	80% mortality of seedlings after 1-day exposure to 27, 100% >2 days; greatly reduced growth after 1-day exposure	Conner and Askew (1993)

Species	Salinity Range	References
Emergent Marsh (Fresh)		
Duck potato (*Sagittaria lancifolia*)	0.0-8.9 2.9 (37-45% decrease in photosynthesis; 34-67% decrease in stomatal conductance) 4.8 (tissue damage); 15 100% mortality $\geq$2 significantly reduced germination 4.6 (increased biomass relative to control at 2.3, in field) $\geq$6 (tissue damage); 12 (low mortality) >6 (reduced growth)	Penfound and Hathaway (1938) Pezeshki et al. (1987) McKee and Mendelssohn (1989) Baldwin et al. (1996) Webb and Mendelssohn (1996) Howard and Mendelssohn (1999) Spalding and Hester (2007)
Common arrowhead (*Sagittaria latifolia*)	2 (decreased survival, growth and time to emergence); 4 (reduced germination)	Delesalle and Blum (1994)
Pickerelweed (*Pontederia cordata*)	0-8.9 2.5 (highest recorded)	Penfound and Hathaway (1938) Clewell et al. (1999)
Maidencane (*Panicum hemitomon*)	0.0 9.4 (growth reduction); 15 100% mortality 7.6-10 lethal limits in lab experiments $\geq$6 (growth reduction); 12 (significant mortality) $\geq$4 (reduced growth, increased mortality)	Penfound and Hathaway (1938) McKee and Mendelssohn (1989) Hester et al. (1998) Howard and Mendelssohn (1999) Spalding and Hester (2007)
Bullrush (*Scirpus americanus*)	5.5-16.8 6 (highest recorded) $\geq$6 (some growth reduction); 12 (no mortality)	Penfound and Hathaway (1938) Clewell et al. (1999) Howard and Mendelssohn (1999)
Sawgrass (*Cladium jamaicense*)	0-2 4$\pm$3 (LA statewide) 8 (highest recorded)	Penfound and Hathaway (1938) Chabreck (1972) cited in Clewell et al. (1999) Clewell et al. (1999)
Emergent Marsh (Salt)		
Smooth cordgrass (*Spartina alterniflora*)	5.5-49.7 15.2$\pm$7.8 mean (LA statewide) 0.6-33.0 (<19 higher production) 6-34 (20$\pm$8 mean) 2-28 (12$\pm$7 mean) 83-115 lethal limits in lab experiments	Penfound and Hathaway (1938) Chabreck (1972) cited in Longley (1994) Mendelssohn and Marcellus (1976) Pulich (1990) cited in Longley (1994) Hester et al. (1998)
Black needlerush (*Juncus roemerianus*)	1.2-44.3 13.9$\pm$8.3 mean (LA statewide) 0-60 growth decreasing with salinity (max in freshwater) 0-20 0.5-38 (mean 17.3$\pm$9.3) 0->40	Penfound and Hathaway (1938) Chabreck (1972) cited in Longley (1994) Eleuterius (1984) Clewell (1986) Woerner and Hackney (1997) Touchette (2006)

Species	Salinity Range	References
Submerged Aquatic Vegetation (SAV)		
Tapegrass (*Vallisneria americana*)	<10 survived (0.2-3.3 growth; 6.7 no growth) 0-12.8 present (5.3 mean); 2.2-13.9 absent (7.6 mean) <12 growth unaffected <15 survival (higher growth <3 in dry, <9 in wet season) >ca. 15 upper limit to survival 18 upper limit with mortality proportional to exposure time up to 70 days >15 increased mortality	Haller et al. (1974) Davis and Brinson (1976) Twilley and Barko (1990) Doering et al. (1999) Kraemer et al. (1999) Doering et al. (2001) Frazer et al. (2006)
Dwarf arrowhead (*Sagittaria subulata*)	6 (highest recorded)	Clewell et al. (1999)
Southern naiad (*Najas guadalupensis*)	>10 no survival (0.2-6.7 highest growth; 6.7-10 growth very low) 1.73 (mean) observed in field	Haller et al. (1974) Hoyer et al. (2004)
Coontail (*Ceratophyllum demersum*)	1.92 (mean) observed in field	Hoyer et al. (2004)
Claspingleaf pondweed (*Potamogeton perfoliatus*)	>4 biomass and flower production decline	Twilley and Barko (1990)
False loosestrife (*Ludwigia repens*)	3 (highest recorded)	Clewell et al. (1999)
Eurasian watermilfoil (*Myriophyllum spicatum*)	4 highest net photosynthesis, declines at >16; >16 P:R ratio declines >13.3 no survival (0.2-6.7 highest growth; 6.7-13.3 growth decline) 12 highest biomass 2.04 (mean) observed in field >15 increased mortality, decreased growth	McGahee and Davis (1971) Haller et al. (1974) Twilley and Barko (1990) Hoyer et al. (2004) Frazer et al. (2006)
Hydrilla (*Hydrilla verticillata*)	>6.7 no survival (0.2-3.3 highest growth; 3.3-6.7 growth decline) >4 biomass decline; >6 stem density and length decline 1.48 (mean) observed in field >15 no survival	Haller et al. (1974) Twilley and Barko (1990) Hoyer et al. (2004) Frazer et al. (2006)

Species	Salinity Range	References
Seagrasses		
Widgeon grass (*Ruppia maritima*)	<28 to set seed 0-33.2 (<25 ma) <74 lab survival (>46 no growth) 16-24 in field 0->60 (up to 390) in field 0-40 (10-20 optimal) 0-30 (growth lower in pulsed salinity) 36-70 (>55 stress threshold)	Bourn (1935) cited in Longley (1994) Phillips (1960) McMillan and Moseley (1967) Zimmerman and Livingston (1976) Kantrud (1991) summary table Murphy et al. (2003) La Peyre and Rowe (2003) Koch et al. (2007)
Shoal grass (*Halodule wrightii*)	1-60 (dwarfing at high salinity); 25-34 abundant <74 lab growth 3.5-52.5 lab survival 23-37 lab survival 17(6 min)-36 in field May-55 5-45 blade growth (10-35 max) 35-62 in field 36-70 (>65 stress threshold)	Phillips (1960) McMillan and Moseley (1967) McMahan (1968) McMillan (1974) Zimmerman and Livingston (1976) Dunton (1996) Lirman and Cropper (2003) Cotner et al. (2004) Koch et al. (2007)
Turtle grass (*Thalassia testudinum*)	10-48 (25-38.5 optimal) <74 lab survival (>60 no growth) 10-50 lab survival 15-40 in field (24-35 optimal) 17(6 min)-36 in field 6-35 lab survival (growth least at 6); 22-36 field optimal 5-45 blade growth (15-40 max) 10-50 (30-40 optimal for photosynthetic efficiency) 36-70 (>60 stress threshold)	Phillips (1960) McMillan and Moseley (1967) McMillan (1974) Zieman (1975) Zimmerman and Livingston (1976) Doering and Chamberlain (2000) Lirman and Cropper (2003) Kahn and Durako (2006) Koch et al. (2007)

Table D-2. Representative salinity ranges for the dominant animals (invertebrates and fishes) found in portions of lower St. Marks River and Apalachee Bay, Florida. Salinity ranges are given for different life history stages, where available, along with the source of information. Table entries are salinity values given in parts per thousand; ma = most abundant in stated range.

Species	Eggs and Larvae	Juveniles	Adults	References
Invertebrates				
Eastern oyster			<3 no feeding	Loosanoff (1953)
(*Crassostrea virginica*)			5-30	Galtsoff (1964)
		3-44		Copeland and Hoese (1966)
	16-22 setting abundant			Chatry et al. (1983)
	17-24 optimal-spat		0-45 (10-30 best survival; 10-24 ma)	after Longley (1994)
	7.5-34 (10-22 optimal)-eggs 5-39 (25-29 optimal)-larvae	5.6-35 (13-30 optimal)-spat	2-43.5 (14-30 optimal for growth)	after Pattillo et al. (1997)
			2-35	Livingston et al. (2000)
			11-29 (means per site; 4-24 mean lows)	Bergquist et al. (2006)
Blue crab			0-30+ (2.0-4.9 ma)	Swingle (1971)
(Callinectes sapidus)			0-28.5	Swingle and Bland (1974)
		0-40 (<13 optimal)	0.1-60.0 (lit review)	Copeland & Bechtel (1974)
	23-30 for hatching	6-25 ma	0-60	after Longley (1994)
	10-33 (23-28 optimal)-eggs >5 (16-36 highest survival)-larvae	2-21 ma	<10 ma (males) 23-33 ma (egg-bearing females)	after Pattillo et al. (1997)
Grass shrimp			0-21.3 (10-15 ma)	Swingle (1971)
(*Palaemonetes pugio*)			0-25.4 (15-20 ma)	Swingle and Bland (1974)
	20-25 optimal-larvae		0-55 (2-36 ma)	after Pattillo et al. (1997)

Species	Eggs and Larvae	Juveniles	Adults	References
White shrimp (*Litopenaeus setiferus*)		<10 ma		Gunter et al. (1964)
		8-34		Perez Farfante (1969)
			1.3-30+ (5-10 & 25-30 ma)	Swingle (1971)
			2.7-35.0 ma	Stokes (1974)
		0-38 (no optimal)	0.2-45.3 (lit review)	Copeland & Bechtel (1974)
			1.1-28.5	Swingle and Bland (1974)
	5-15 (optimal)-postlarvae	1-20 ma	0-48	after Longley (1994)
	0.4-37 postlarvae	0.3-41 (<10 ma)	>27 offshore-usually	after Pattillo et al. (1997)
Pink shrimp (*Farfantepenaeus duorarum*)		>20		Hildebrand (1955)
	12-43	5-47	25-45	Tabb et al. (1962)
		>18 ma		Gunter et al. (1964)
			15.5-37.7 ma	Stokes (1974)
		8-36 (20-35 optimal)	0.6-65 (lit review)	Copeland & Bechtel (1974)
	12-43 postlarvae	<1-47 (>20 preferred)	1-69 (25-45 ma)	after Pattillo et al. (1997)
Fishes				
Bay anchovy (*Anchoa mitchelli*)			2.3-36.9 (<15 ma)	Gunter (1945)
			5-35	Springer and Woodburn (1960)
			0-30	Tabb and Manning (1961)
			0-34 (20-30 ma)	Swingle (1971)
			0-34 (25-30 ma)	Swingle and Bland (1974)
	0.5-1, 20-25	0-40	1-32	after Pattillo et al. (1997)
	0-30 (10-20 ma): means	0-30 (<15 ma): means	0-30 (<15 ma): means	Peebles et al. (2007)
Gulf menhaden (*Brevoortia patronus*)			2-33.7	Gunter (1945)
			6.6-34.2	Springer and Woodburn (1960)
	6.6-33.2 larvae	0.1-31.6 (10-15 & >30 ma)		Swingle (1971)
		0-26 (<12 optimal)	0.0-54.3 (lit review)	Copeland & Bechtel (1974)
		0-40+ (<12 ma)		Longley (1994)
	>29 eggs & early larvae		0-67 (20-25 ma)	after Pattillo et al. (1997)
	5-30 postlarvae			

Species	Eggs and Larvae	Juveniles	Adults	References
Gulf killifish (*Fundulus grandis*)	5-40 (5-18.3 optimal)-larvae		2-37.1 (5-15 ma) 0.8-35.6 (15-30 ma) 0.8-16.2 (<15 ma) 3.7-29.8 (13-20 ma) 0-5 & 20-25 0-25 0-76.1	Gunter (1945) Kilby (1955) Springer and Woodburn (1960) Swingle (1971) Swingle and Bland (1974) after Pattillo et al. (1997)
Longnose killifish (*Fundulus similis*)			2-37.1 (20-30 ma) 0.8-37.6 (15-30 ma) 3.2-32.3 5-30 (10-25 ma) 4.7-30 (>10 ma)	Gunter (1945) Kilby (1955) Springer and Woodburn (1960) Swingle (1971) Swingle and Bland (1974)
Sheepshead minnow (*Cyprinodon variegatus*)			2-35.7 (10-25 ma), one collection at 71.5 0.8-35.6 (15-30 ma) 0-26.1 (<15 ma) 0-35 10-25 (20-25 ma) 0.9-25 0-142 (10-30 ma)	Gunter (1945) Kilby (1955) Tabb and Manning (1961) Swingle (1971) Swingle and Bland (1974) after Pattillo et al. (1997)
Tidewater silverside (*Menidia beryllina*)	0-30 (2-8 optimal)-larvae	0-34.5 (2-28 optimal)	0-34.9 (15-20 ma), one collection at 71.3 3.5-37.6 (15-30 ma) 0-26.1 (<15 ma) 17-26 0-5 & 15-20 ma 0-23.8 0-120 (<45 ma)	Gunter (1945) Kilby (1955) Tabb and Manning (1961) Swingle (1971) Swingle and Bland (1974) after Pattillo et al. (1997)
Pinfish (*Lagodon rhomboides*)		2-30+ (>20 ma)	2.1-37.2 3.7-35.1 8-37 0-43.8	Gunter (1945) Springer and Woodburn (1960) Tabb and Manning (1961) Swingle (1971) Pattillo et al. (1997)

Species	Eggs and Larvae	Juveniles	Adults	References
Atlantic croaker (*Micropogonias undulatus*)			2-36.7 (<15 ma)	Gunter (1945)
			5-29.8	Springer and Woodburn (1960)
			19-32	Tabb and Manning (1961)
		0-30+ (5-15 ma)		Swingle (1971)
			0-29.1	Swingle and Bland (1974)
	25-35 (optimal)-eggs 15-35 (optimal)-larvae	0-37 (6-15 optimal)	0->60	after Longley (1994)
	15-36 larvae	0-36.7 (10-20 ma)	0-70 (15-20 ma)	after Pattillo et al. (1997)
Spot (*Leiostomus xanthurus*)			2-36.7 (>15 ma)	Gunter (1945)
			5-34.2	Springer and Woodburn (1960)
			9-48	Tabb and Manning (1961)
		0.1-30+ (5-20 & >30 ma)		Swingle (1971)
			0-28.5	Swingle and Bland (1974)
	30-35 eggs 6-36 larvae	0-36.2 (>10 ma)	0-60 (15-30 ma)	after Pattillo et al. (1997)
Silver perch (*Bairdiella chrysoura*)			2.1-33.7 (<25 ma)	Gunter (1945)
			3.7-35 (>20 ma)	Springer and Woodburn (1960)
			9-48	Tabb and Manning (1961)
			0.2-30 (>10 ma)	Swingle (1971)
			3.5-28.5 (>15 ma)	Swingle and Bland (1974)
	14.3-26 eggs <1-37.4 (>10 ma) larvae	0-35.5 (>20 ma)	0-48	after Pattillo et al. (1997)