Water Resource Inventory and Assessment: Okefenokee National Wildlife Refuge

Ware, Charlton, and Clinch Counties, Georgia
Baker County, Florida

U.S. Department of the Interior
Fish and Wildlife Service
Southeast Region
Atlanta, Georgia

August 2015

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COVER PHOTO: Canoe trail near Minnie Lake at Okefenokee National Wildlife Refuge. August 26, 2014. Photo credit: Theresa Thom/USFWS. Used by permission.

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1 Executive Summary

The Water Resource Inventory and Assessment (WRIA) for Okefenokee National Wildlife Refuge (Okefenokee NWR or the refuge) summarizes available information relevant to refuge water resources, provides an assessment of water resource needs and issues of concern, and makes recommendations to address the identified needs and concerns. Major topics covered in this report include the natural setting of the refuge (topography, climate, geology, soils, hydrology), impacts of development and climate change, significant water resources and associated infrastructure within the refuge, past and current water monitoring activities on and near the refuge, water quality and quantity information, and state water use regulatory framework. Information was compiled from publicly available reports, databases, and geospatial datasets from federal, state, and local agencies; published research reports; websites maintained by government agencies, academic institutions, and non-governmental organizations; and from files and GIS data layers maintained by the refuge. For the purposes of this assessment, the Region of Hydrologic Influence (RHI) was defined as the Upper Suwannee and St. Marys River watersheds, and a portion of the Satilla watershed to the north. The RHI includes a total drainage area of 2,978,461 acres.

1.1 Findings

- Okefenokee NWR protects the headwaters of both the Suwannee River and the St. Marys River. The St. Marys and the Suwannee River Basins lie entirely within the Coastal Plain physiographic province. Both the St. Marys and the Suwannee Rivers are two of the best-preserved and most unique rivers in the United States. In 1986, the Okefenokee Swamp, one of the world's largest intact freshwater ecosystems, was designated by the Wetlands Convention as a Wetland of International Importance. The refuge contains the third largest National Wilderness Area (353,981 acres) east of the Mississippi River and has over 400,000 visitors annually. Universities and colleges across the country and from abroad, as well as federal, state, and local agencies have conducted research on the refuge.
- For the purposes of this assessment, the Region of Hydrologic Influence (RHI) was defined as the Upper Suwannee and St. Marys River watersheds, and a portion of the Satilla watershed to the north. The RHI includes a total drainage area of 2,978,461 acres [4,653.8 square miles (mi^2)] and generally corresponds with the geographic extent of several previous hydrologic analyses.
- The Okefenokee Swamp receives water via precipitation (70 %) and surface runoff (30 %). Measurement of the watershed draining directly into the swamp (30 X 60 minute Geological Survey Map; scale-100,000, 1980) shows a drainage area of 600 mi^2. Over 400 mi^2 of the watershed are located northwest of the swamp.
- In the lower coastal plain of Georgia, the principal water-bearing geologic units are the surficial aquifer system, the Brunswick aquifer system, and Floridan aquifer system. Low-permeability, clayey confining units separate these water-bearing units. The surficial aquifer is found where the Hawthorn Group serves as a confining unit and minimizes recharge to the underlying Floridan Aquifer. The regional hydrogeology, including recharge areas and aquifer hydraulic properties, is described in Clarke et al. (1990).
- Near the refuge, the surficial aquifer is used for domestic well water. The surficial aquifer water levels show a pronounced response to climate. The Floridan Aquifer underlies the Hawthorn Group, a confining unit; both the Floridan Aquifer and the Hawthorn Group are found throughout the Okefenokee Basin. The Upper Floridan Aquifer is the principal source of drinking water taken from groundwater within the Coastal Plain of Georgia.

- Based on several conservation plans, land use characteristics of the St. Marys River Basin are primarily agriculture/forested and parks/recreation/conservation. Collectively, these two land use categories account for roughly 90% of the total land area in the basin. Future land use, coupled with projected population growth in the basin indicates that residential development will occur within the basin - a mix of suburban residential growth and conservation land in the area immediately bordering the St. Marys River.

- While the majority of the basin remains mainly privately owned rural lands, management of those lands is changing. Rural forest cover types (primarily pine plantations) were prevalent in the early 1900s, but land cover has shifted towards open, unforested agricultural lands over the past century. Timber harvesting has been a consistent source of hydrologic alteration. Even when considering the mitigating effects of modern forestry best management practices, timber harvesting can have an impact on local hydrology.

- Combining Okefenokee NWR with Osceola National Forest, private timberlands, and state-owned forests, more than 1 million contiguous acres provide wildlife habitat and pervious cover. Approximately 23% of the RHI is in conservation lands. Developed areas occur along the outskirts of the RHI (e.g., Waycross, Georgia and Jacksonville, Florida). Between 2001 and 2011, less than 0.1% of the lands within the RHI were developed and less than 6% of lands within the RHI are currently considered developed. Growth and development along the RHI's rivers, especially the Suwannee River, has been limited, largely because of floodplain management ordinances, land use plans, and land acquisition programs at state, regional, and local levels.

- Fire has a pivotal role in the ecology of the Okefenokee Swamp. Uplands were historically dominated by fire-maintained pine forests, with longleaf nearer the coast and inland on sandy soils and a mixture of shortleaf, loblolly, and hardwoods elsewhere.

- An inventory of named rivers, streams, and creeks was compiled from the National Hydrography High-Resolution (1:24000) Dataset (NHD) for the RHI, using the flowline feature dataset. The RHI for Okefenokee NWR includes a total of 5,050 miles of named and unnamed streams. Within the refuge acquisition boundary, there are 31 named streams, totaling 120.5 miles, as well as 594.4 miles of unnamed streams.

- As required by the Wilderness Act, refuge staff maintains 120 miles of canoe trails within the peat, connecting areas of naturally occurring deeper water. The canoe trails are maintained to dimensions of approximately 8 feet wide by 3 feet deep in the prairies. There are 8.5 miles of surface trails and boardwalks near the Camp Cornelia entrance to the refuge.

- The USGS has collected water quality and/or water quantity data at 193 active and historic surface water sites and 423 active and historic groundwater sites within the RHI. Fifteen of these sites are within the NWR. Twenty six of these sites have at least a ten year period of record within the RHI.

- Based on GAEPD's 1998-1999 water quality assessment, nonpoint sources are the primary contributors to the failure of water bodies to meet their designated uses in all three basins. Nonpoint source pollution in all three basins includes stormwater runoff from urban, industrial, and residential sources and from agricultural and forestry land use practices. Surface water contamination by mercury due to atmospheric deposition and diffuse stormwater runoff, and the associated methylation by bacteria in wetland environments, contributes to the subsequent accumulation of mercury in aquatic animal tissue.

- A suite of land management ordinances are used by the local governments in the St. Marys watershed, including Camden County, the City of St. Marys and the City of Kingsland. A number of land management ordinances are model ordinances developed by the State of Georgia to directly or indirectly protect water quality.

1.2 Key Water Resources Issues of Concern

For many freshwater aquatic ecosystems like that protected by Okefenokee NWR, water quantity and water quality are the two most critical factors influencing the ability of managers to meet the primary purposes of refuge establishment. A primary concern of Okefenokee NWR is to maintain the quantity and quality of surface water flows and the rich biological diversity within the basin.

Related to water quantity, water withdrawals for municipal, industrial, and agricultural use are a primary concern. The effects of altered hydrology (increased drainage rate and decreased duration of seasonal flooding) related to forestry operations adjacent to and upstream of the refuge; potential decreased water availability in the future associated with climate change impacts; and increased water demand (primarily from groundwater) due to population growth and development, are all also a concern. Insufficient information about the current water budget for the Okefenokee Swamp, including the degree of connection between surface flows and groundwater, currently limits the ability to accurately assess these threats and develop management strategies to address them.

Key water quality issues of concern for Okefenokee NWR include low dissolved oxygen in surface water; elevated nitrate concentrations in surface and groundwater associated with agriculture, forestry (fertilizers, animal waste), and sewage effluents; excess sediment from agriculture and forestry; and mercury from atmospheric deposition and subsequent bacterial methylation. The Suwannee River, the primary outflow from the refuge, is listed as impaired due to elevated mercury levels along the entire length through the refuge, a distance of approximately thirty miles.

Additional threats to the refuge and the greater Okefenokee Ecosystem highlighted in the Comprehensive Conservation Planning (CCP) for the Okefenokee NWR included mining and oil and gas development, impacts to wetland habitat from changing land use, urbanization, climate change, and the influence of authorized recreational activities and air pollution.

Within the St. Marys Basin, several management plans have been developed to identify issues and recommend solutions to promote and protect the long-term viability of both the environmental and economic resources of the St. Marys River. Issues identified center on water quantity, water quality (point and nonpoint sources contributing to pollutant loading and decreased dissolved oxygen), and environmental stressors including stream channelization.

Water resources threats and issues of concern are discussed in greater detail in Section 6.1.

1.3 Needs and Recommendations

Highlights of the needs and recommendations for Okefenokee NWR are summarized below. A more in-depth discussion of needs and recommendations is provided in Section 6.2 of this document.

The CCP for Okefenokee NWR identified several needs, including: 1) maintaining the ability to work with refuge neighbors, private landowners and state forestry organizations to manage wildland fire; 2) evaluating the impacts of public use activities on Wilderness and other resources, and using these data to more adaptively manage public use activities within the refuge; and 3) the need for biological inventory and monitoring work documenting the use of the refuge by many endemic, sensitive, rare, threatened, and endangered species.

The “Pulse-Check” completed for Okefenokee NWR (USFWS 2009) identified a critical need for determining new water quality and quantity monitoring parameters that would serve to inform management and ensure the long-term ecological integrity of the Okefenokee Swamp. The need to assess the ecological and hydrological impacts of the Swamp Edge Break was also identified, as was the need to establish a systematic and statistically valid monitoring program to monitor ecosystem health in relation to climate change.

Katz and Raabe (2005) summarized issues and research needs in detail for the Suwannee River Basin; many of the issues and research needs identified in 2005 are still relevant ten years later. Perhaps of greatest need is renewed coordination between Federal and State agencies and other organizations. In 2004, the Suwannee Basin Interagency Alliance (SBIA) was formed, with a main goal to promote coordination among agencies in the basin and estuary. This alliance is no longer active despite a continued need. A primary recommendation of this report would be to reorganize the Suwannee Basin Interagency Alliance, and to seek funding to support the various needs and priorities identified by the alliance.

Additional research and monitoring needs and opportunities within the Suwannee and St. Marys Watersheds have been identified by multiple universities, State, and Federal agencies, including supporting efforts related to USFWS Region 4 Species-at-Risk. Data needs include basic flora and fauna inventories, life history work, as well as water availability and habitat requirements of species. Limerock mining is a current threat to the watershed; however, more research is needed to determine the degree of the associated threats. Detailed mapping of springsheds to facilitate prioritization of conservation actions in recharge areas and other sensitive areas is also needed.

Within the St. Marys Basin, several management plans have been developed to identify issues and recommend solutions to promote and protect the long-term viability of both the environmental and economic resources of the St. Marys River. Needs identified in these plans center on inter-agency coordination and data sharing, watershed assessment, and long-term watershed planning as well as addressing issues such as septic tanks and riparian buffer health, width, and zoning.

2 Introduction

This Water Resource Inventory and Assessment (WRIA) Summary Report for Okefenokee National Wildlife Refuge (NWR) inventories relevant hydrologic information, provides assessments, and makes recommendations to address identified water resource needs and concerns. The information compiled as part of the WRIA process will ultimately be housed in an online WRIA database maintained by the U.S. Fish and Wildlife Service (USFWS or Service) Natural Resources Program Center (NRPC), which is being implemented in phases, with the initial phase released in summer 2014. Together, the WRIA Summary Report and the accompanying information in the online WRIA database are intended to be a reference to help guide on-going and adaptive water resource management. This WRIA was developed in conjunction with the Refuge Manager and Assistant Refuge Manager, other refuge staff, and both internal and external partners with extensive knowledge about the Suwannee River and St. Marys River Basins. The document incorporates existing hydrologic information compiled between May 2014 and May 2015.

The WRIA database and summary reports provide a reconnaissance-level inventory and assessment of water resources on and adjacent to National Wildlife Refuges and National Fish Hatcheries. Achieving a greater understanding of existing refuge water resources will help identify potential concerns or threats to those resources and will provide a basis for wildlife habitat management and operational recommendations to refuge managers, wildlife biologists, field staff, Regional Office personnel, and Department of Interior managers. A national team comprised of Service Water Resource staff, Environmental Contaminants Biologists, and other Service employees developed the standardized content of the national interactive online WRIA database and summary reports.

The long term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date, accurate data on NWRS water quantity and quality in order to acquire, manage, and protect adequate supplies of clean and fresh water. An accurate water resources inventory is essential to prioritize issues and tasks, and to take prescriptive actions that are consistent with the established purposes of the refuge. Reconnaissance-level water resource assessments evaluate water rights, water quantity, known water quality issues, water management, potential water acquisitions, threats to water supplies, and other water resource issues for each field station.

WRIAs are recognized as an important part of the NWRS Inventory and Monitoring (I&M) initiative and are prioritized in the National I&M Operational Blueprint as Task 2a (USFWS 2010a). In addition, this WRIA work supports the Water Resources Inventory and Monitoring (WRIM) Operational Goal, as well as Objective WRIM 1.0, and Task WRIM 1.4 within the National I&M Seven Year Plan (USFWS 2013). The seven-year plan outlines a strategic, focused, measureable and prioritized plan directly tied to the I&M Operational Blueprint. Hydrologic and water resource information compiled during the WRIA process can facilitate the development of other key documents for each refuge including Hydrogeomorphic Analyses (HGMs), Comprehensive Conservation Plans (CCPs), Habitat Management Plans (HMPs) and Inventory and Monitoring Plans (IMPs). In addition, water quality and pollutant source information compiled as part of this WRIA will help inform the Contaminant Assessment Process (CAP) and vice-versa. The most recent CAP for Okefenokee NWR was completed in 1995 (USFWS 1995). FY2015 funding was authorized to re-evaluate contaminants on the refuge through CAP in April 2015, resulting in an updated contaminants summary by the end of FY2015.

A CCP for the refuge was completed in 2006 (USFWS 2006). Preliminary water resource assessments conducted within Region 4 by the USFWS beginning in 2007, as well as hydrologic and climate change vulnerability assessments conducted by the USFWS and U.S. Geological Survey (USGS) in 2009, identified Okefenokee National Wildlife Refuge as one of six top-priority sites within Region 4 recommended for detailed hydrologic characterization conducted by USGS (Buell et al. 2009). A final hydrologic and landscape database for Okefenokee NWR was received from USGS in August 2014, and a final summary report is anticipated in 2015 (Buell 2014). Key issues were outlined in the hydrologic assessment by Buell et al. (2009) for Lower Suwannee NWR, which included the portion of the Region of Hydrologic Influence (RHI; see Section 4.1) in the Upper Suwannee Basin but specifically addressed Lower Suwannee NWR and not Okefenokee NWR. The Lower Suwannee assessment highlighted water quantity and water quality factors, primarily related to the preservation of the Suwannee River delta and estuary and associated endangered and sensitive species. Groundwater quantity and minimum flows were prioritized as issues in relation to groundwater withdrawals affecting the refuge and surrounding landscape. Land use impacts in the watershed relate primarily to agriculture and timber operations that affect both water quantity and water quality. Predicted climate related impacts were specifically mentioned, including the conversion of freshwater wetlands and forested riverine wetlands to estuarine and saltwater marsh as a result of multiple factors including sea-level rise, altered hydrologic regimes, and increased water withdrawals affecting salinity (Buell et al. 2009).

Primary water resource threats to Okefenokee NWR identified in the CCP include water quality degradation due to activities on lands adjacent to the refuge; altered hydrologic functioning of the swamp and the upper Suwannee River due to the Suwannee River Sill; altered surface hydrology due to land management activities from silvicultural practices on adjacent lands; prescribed/wildland fire management; groundwater demand increases for commercial and industrial uses; increased urbanization of the areas directly adjacent to the refuge; and a proposed titanium strip mining operation near the refuge (USFWS 2006). In addition, invasive plants and animals pose a major threat to the biological integrity of the Greater Okefenokee ecosystem.

The WRIA process was initiated at the refuge in May 2014 with an initial site visit. A kick-off meeting was held on August 26, 2014 at refuge headquarters in Folkston, Georgia, with a field visit and deployment of water temperature data loggers the following day. The kick-off meeting sought to bring together scientists, managers, and others to collaborate and share information/data about the St. Marys and Suwannee Rivers, the refuge, management issues, on-going and future research and monitoring, and other efforts happening in the watershed including public education/outreach. The overall objectives were to achieve a greater understanding of existing refuge water resources; identify data needs, concerns, and threats to those resources at multiple spatial and temporal scales; and provide a basis for refuge management actions and operational recommendations. A summary of the meeting, attendees, and meeting products is provided in Appendix A.

3 Facility Information

Okefenokee National Wildlife Refuge is located in Ware, Charlton, and Clinch Counties in southeast Georgia, and Baker County in northeast Florida, all within the South Atlantic Landscape Conservation Cooperative (SALCC) boundary (Figure 1). The towns of Waycross, Folkston, St. George, Fargo, and Homerville, Georgia surround the refuge. Jacksonville, Florida is approximately 40 miles to the southeast of the refuge (Figure 2). The refuge was established on March 30, 1937 by Franklin D. Roosevelt under Executive Order 7593 to protect the ecological system of the Okefenokee Swamp. Specifically, the Executive Order states that all lands, including lands under water, acquired or to be acquired by the United States, lying within the following-described area, and comprising approximately 479,450 acres in Charlton, Clinch and Ware Counties, Georgia, be, and they are hereby, reserved and set apart, "as a refuge and breeding ground for migratory birds and other wildlife" (USFWS 2006; EO 7593).

The Okefenokee NWR includes 403,119[1] acres currently owned by the U.S. Fish and Wildlife Service within the approved acquisition boundary of 519,480 acres (USFWS 2006, USFWS 2010b). The current refuge boundary incorporates 371,000 acres, or approximately 85% of the 438,000-acre Okefenokee Swamp. The refuge is part of the over 1 million-acre Greater Okefenokee Ecosystem, which also includes Osceola National Forest, state-owned forests and privately-owned forestlands. In 1974, Congress designated 343,850 acres of the refuge as a National Wilderness Area by Public Law 93-429, which is managed to preserve existing habitats and resources in their natural condition. Today, the wilderness area is approximately 353,981 acres, making it the third largest wilderness area east of the Mississippi River (Figure 2; USFWS 2006). Six broad wetland habitats were described for the refuge from Loftin's (1998) vegetation mapping and classification system. These habitats include broadleaved hardwoods, cypress/hardwoods (mature), mixed wetland pine, scrub/shrub, prairie and open water (USFWS 2006). Upland vegetation communities are described by Phernetton (2001) and relate to the Society of American Foresters (SAF) standard forest types. The upland communities include upland hardwoods, longleaf pine, longleaf/mixed pine, and mixed pine (USFWS 2006). Additional information about vegetation types within Okefenokee NWR is summarized in the refuge CCP (USFWS 2006), and in multiple publications (e.g. Loftin 1998; Cohen et al. 1984; Hamilton 1982; Eyre 1980). More information on land cover and anthropogenic changes within the refuge can be found in Section 4.6.

The current Okefenokee NWR acquisition boundary encompasses the headwaters of both the St. Marys and Suwannee Rivers, and encompasses over 22 miles of the Suwannee River. Along with Lower Suwannee NWR in Florida, the two refuges protect the headwaters and the lower portions of the Suwannee River. The long-term ecosystem goal and primary focus of the Service in this ecosystem is to maintain the quality of large, undeveloped forested and wetland habitats in the upper and lower portions of the Suwannee River basin by linking them with a corridor of protected habitat along the river (USFWS 2001).

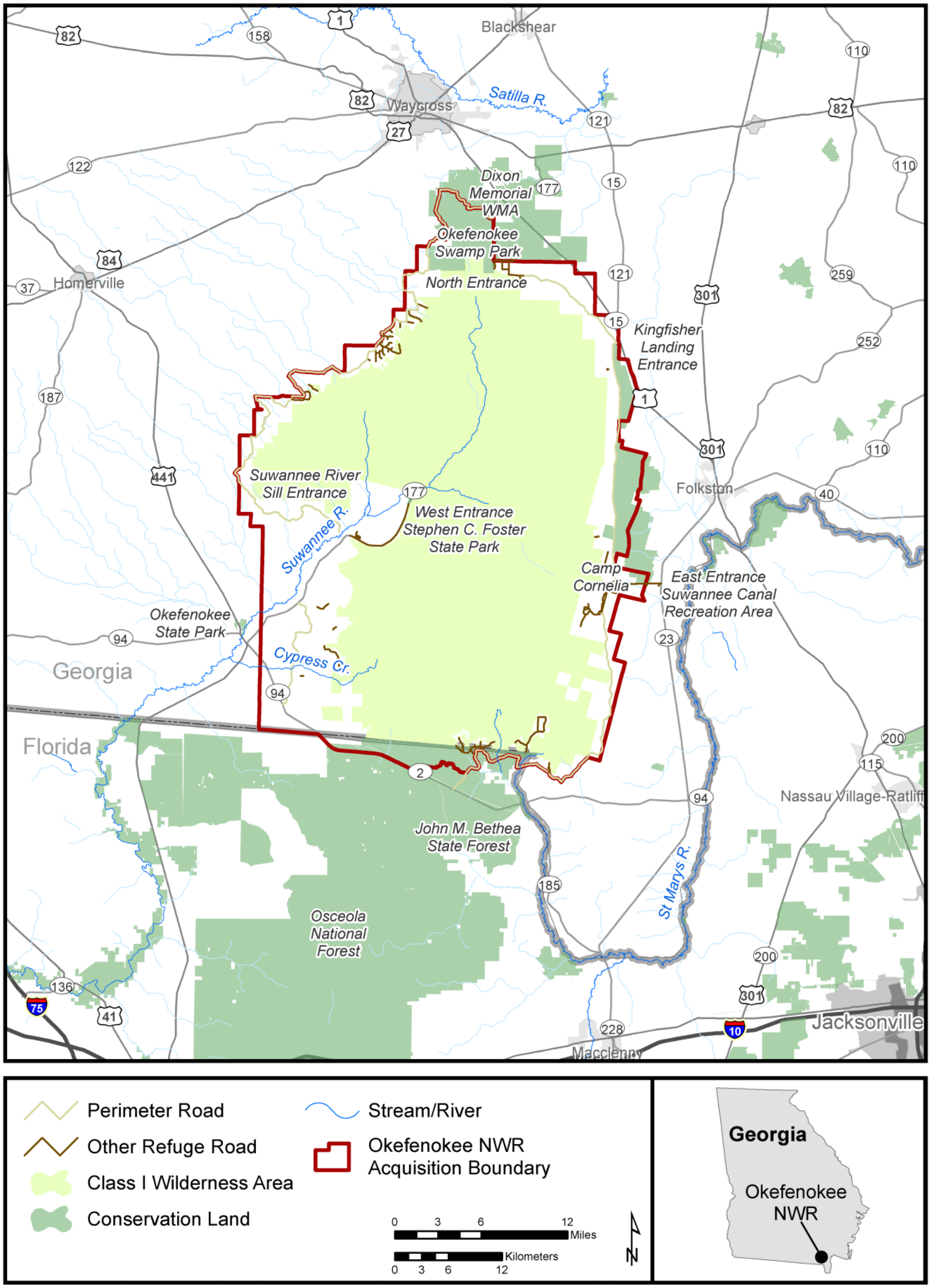
Refuge management activities within Okefenokee NWR are focused on managing wildlife species within the refuge's wetland and upland habitats. Wetland habitats are typically managed through the reliance upon natural fires rather than prescribed burning; surveying, removing, and monitoring invasive plant species; and removing non-native animals from refuge lands. The primary management tool used on refuge uplands is prescribed fire. Fire (both natural and prescribed) is used to manage the refuge's upland

[1] For the purposes of this report, all units are expressed in English measures, unless citing information from a primary source where the native data are presented in metric units. In those cases, the English unit conversions are also provided.

longleaf pine and wiregrass habitat, isolated wetlands found within upland habitats on the refuge, and the Okefenokee Swamp's biological species composition.

Map Date: 4/21/2015 File: R4_overview Data Source: USFWS Refuge Boundaries and LCC Boundaries; Natural Earth 10m River and Lake Centerlines.

Figure 1. Region 4 overview and Landscape Conservation Cooperative (LCC) boundaries.



Map Date: 7/6/2015 File: Refuge_Overview Data Source: NHD Flowlines, USFWS Special Designations , Transportation, and Cadastral Data, GA Conservation Lands, ESRI Topo Service.

Figure 2. Okefenokee National Wildlife Refuge Overview.

The Wilderness designation limits motorized vehicle access and management activities, such as timber harvests, in designated wilderness areas. One goal of the Okefenokee NWR CCP is to promote and provide high-quality habitat and protection for threatened and endangered species and conserve the natural diversity, abundance, and ecological function of native flora and fauna on and off refuge lands. This goal includes a primary objective to identify factors influencing declines in the refuge's fishery by examining water chemistry, groundwater withdrawals, water quality, pH levels, invertebrate populations and the physical environment.

Another goal of the Okefenokee NWR CCP is to restore, enhance, and promote the native upland communities and the associated wetlands to maintain the natural vegetation mosaic, diversity, and viability found historically within the Greater Okefenokee Ecosystem while improving opportunities for red-cockaded woodpecker habitation. This goal includes a primary objective to maintain, enhance, and promote the Greater Okefenokee Ecosystem's native wetland communities, their natural vegetation mosaic, diversity, viability, and dynamics, as found within the Okefenokee Swamp (USFWS 2006).

Okefenokee NWR is home to more than 600 species of plants, 49 species of mammals, 233 species of birds, 39 species of fish and 101 species of reptiles and amphibians (USFWS 2006; USFWS 2010b). Several federally listed species are found within Okefenokee NWR, including eastern indigo snake (*Drymarchon corais couperi*), red-cockaded woodpecker (*Picoides borealis*) and the wood stork (*Mycteria americana*) (USFWS 2006). Additionally, historical records indicate that the frosted flatwoods salamander (*Ambystoma cingulatum*) existed just off the refuge on Trail Ridge. Bald eagles (*Haliaeetus leucocephalus*), de-listed from the Federal Threatened and Endangered Species List, are found within the refuge, although no nesting sites have been recorded. No federally listed plants are known to occur within the refuge. However, the USFWS species database for Okefenokee NWR shows a record for the federally endangered *Baptisia arachnifera* (ECOS 2015; accessed May 6, 2015). However, this plant does not occur on the refuge despite its inclusion in the refuge's CCP (USFWS 2006). The range map for this plant appears wrong, and may have been included because the refuge was thought to be a site for establishment of this species as part of a restoration project, although this restoration has not yet occurred (M. Boyle, personal communication, May 6, 2015).

Several federal species of special concern on the refuge include: Sherman's fox squirrel (*Sciurus niger niger*), round-tailed muskrat (*Neofiber alleni exoristus*), Bachman's sparrow (*Aimophila aestivalis*), Florida sandhill crane (*Grus Canadensis pratensis*), blackbanded sunfish (*Enneacanthus chaetodon*), mud sunfish (*Acantharchus pomotis*), banded topminnow (*Fundulus cingulatus*), and many neotropical migratory birds (USFWS 2006). The gopher tortoise (*Gopherus polyphemus*) and Rafinesque's Big-eared bat (*Corynorhinus rafinesquii*), both federal candidates for listing, are also found in the refuge and in the surrounding area. The refuge is also valuable for species such as the black bear that have large home ranges. A healthy population of the Florida black bear (*Ursus americanus floridianus*) exists today, moving on and off the refuge depending on the resources available. The Florida panther (*Felis concolor coryi*) once roamed the area; however, there have been no recent confirmed sightings (USFWS 2006).

Numerous plant species listed as endangered, threatened or rare in both Georgia and Florida are known to occur within the refuge boundary (Table 1).

Table 1. Rare, Threatened and Endangered Plant species found within Okefenokee National Wildlife Refuge. [Source: USFWS 2006; M. Boyle personal communication, May 6, 2015.]

	Conservation Status[1]		
Name	**Georgia**	**Florida**	**Occurs on Refuge**
Drosera intermedia	-	T	Yes
Epidendrum magnolia	U	CE	Yes
Hartwrightia floridana	T	T	Yes
Lilium catesbaei	-	T	Yes
Pinckneya bracteata	-	T	Historic Record
Pinguicula caerulea	-	T	Yes
Pinguicula lutea	-	T	Yes
Platanthera cristata	-	T	Yes
Platanthera integra	-	E	Yes
Platanthera nivea	-	T	Yes
Pogonia ophioglossoides	-	T	Yes
Rhododendron austrinum	-	E	Yes
Sarracenia flava	U	-	Yes
Sarracenia minor	U	T	Yes
Sarracenia psittacina	T	T	Yes
Sideroxylon alachuense	-	E	Historic Record
Tillandsia recurvate	T	-	Yes
Zephyranthes atamasca	-	T	Yes

[1]The following abbreviations are used to indicate the status of state-protected plants and animals or those proposed for state-protection in Georgia and Florida:

E = Listed as endangered. A species which is in danger of extinction throughout all or part of its range

T = Listed as threatened. A species which is likely to become an endangered species in the foreseeable future throughout all or parts of its range.

R = Listed as rare. A species which may not be endangered or threatened but which should be protected because of its scarcity.

U = Listed as unusual (and thus deserving of special consideration). Plants subject to commercial exploitation would have this status.

CE = Plants that are on the Commercial Exploited list (Florida only).

Additional plant species are thought to occur, but have not yet been documented for the refuge (USFWS 2006):

Asclepias viridula FL (T) - known to occur in Baker County, FL; but herbarium record on Florida plant atlas not confirmed. A vouchered specimen is needed for confirmation.

Ctenium floridanum FL (E) - there are several GA EO records of this plant from sites adjacent to the refuge; but never been documented for the refuge. Similar to *C. aromaticum*, but with gland-less glumes.

Drosera filiformis FL (E) - unknown, probably a question mark for occurrence on Okefenokee

Litsea aestivalis FL (E); GA (T) - on the list b/c of a historical GA EO record from just outside refuge boundary on the NW-side of swamp and a new record (~1997) from also outside boundary on the SE-side. A vouchered specimen is needed to confirm occurrence on refuge.

Malaxis unifolia FL (E) –Does not occur in the refuge; not documented to occur.

Matelea pubiflora FL (E) GA (R) – Not documented in the refuge. In GA, it only occurs in sandhills along Altamaha River. There is no voucher for this plant in any of the counties that include the refuge.

Platanthera ciliaris FL (T) - unknown, probably a question mark for occurrence on Okefenokee NWR.

Yucca gloriosa FL (E) - unknown, probably a question mark for occurrence on Okefenokee NWR.

Three primary entrances (Suwannee Canal Recreation Area, Stephen C. Foster State Park, and Okefenokee Swamp Park) and two secondary entrances (Kingfisher Landing and Suwannee River Sill) exist on the refuge (Figure 2). The refuge headquarters, managed solely by the USFWS, is located at the east entrance (near Suwannee Canal Recreation Area) which is approximately 11 miles southwest of Folkston, Georgia. Camp Cornelia and Suwannee Canal Recreation Area are accessed by Spur 121. An administration building is located on Spur 121 and serves as offices for 16 employees. A shop area at Camp Cornelia is headquarters for 10 additional employees. The visitor center at the Suwannee Canal Recreation Area houses two additional employees. Volunteer Village, adjacent to the shop, provides out of town volunteers with housing and trailer/RV hookups to facilitate long-term volunteer opportunities at the refuge. The Suwannee Canal Recreation Area is open to the public and includes a Visitor's Center as well as a concessionaire offering guided swamp tours, boat rentals, food, and souvenirs. Other infrastructure found on the refuge at this entrance includes hiking trails, a wildlife drive, a boardwalk with a 40 foot tall observation platform, and a restored homestead site.

The western entrance leads to "The Pocket", an upland peninsula that extends into the swamp, via Spur 177. Stephen C. Foster State Park, at Jones Island at the end of Spur 177, operates on 82 acres of refuge land and was established in 1954. The land is operated under the provisions of a long-term agreement with the Georgia State Parks and Historic Sites until the year 2016. A renewal lease agreement is in progress (S. Aicher, written communication, May 8, 2015). The park offers boat and cabin rentals, boat tours, souvenirs, camping facilities, a picnic area, and the Suwannee River Visitor Center.

Okefenokee Swamp Park, 12 miles south of Waycross, Georgia, is located at the northern entrance to the refuge (Figure 2). The park was opened in 1946 and is administered by a nonprofit organization. The park is located on refuge and state-owned forestland.

Two secondary entrances, Kingfisher Landing and Suwannee River Sill, are found on the eastern and western sides of the refuge, respectively. Kingfisher Landing is located about 13 miles north of Folkston, GA along U.S. 1. The Suwannee River Sill is reached by the same road as Stephen C. Foster State Park. This entrance features the Suwannee River Sill, boat ramp, two parking lots, a kiosk, and a restroom. A paved 1.25 mile drive leads to the second parking lot, boat ramp, and the first of two water control structures (USFWS 2006).

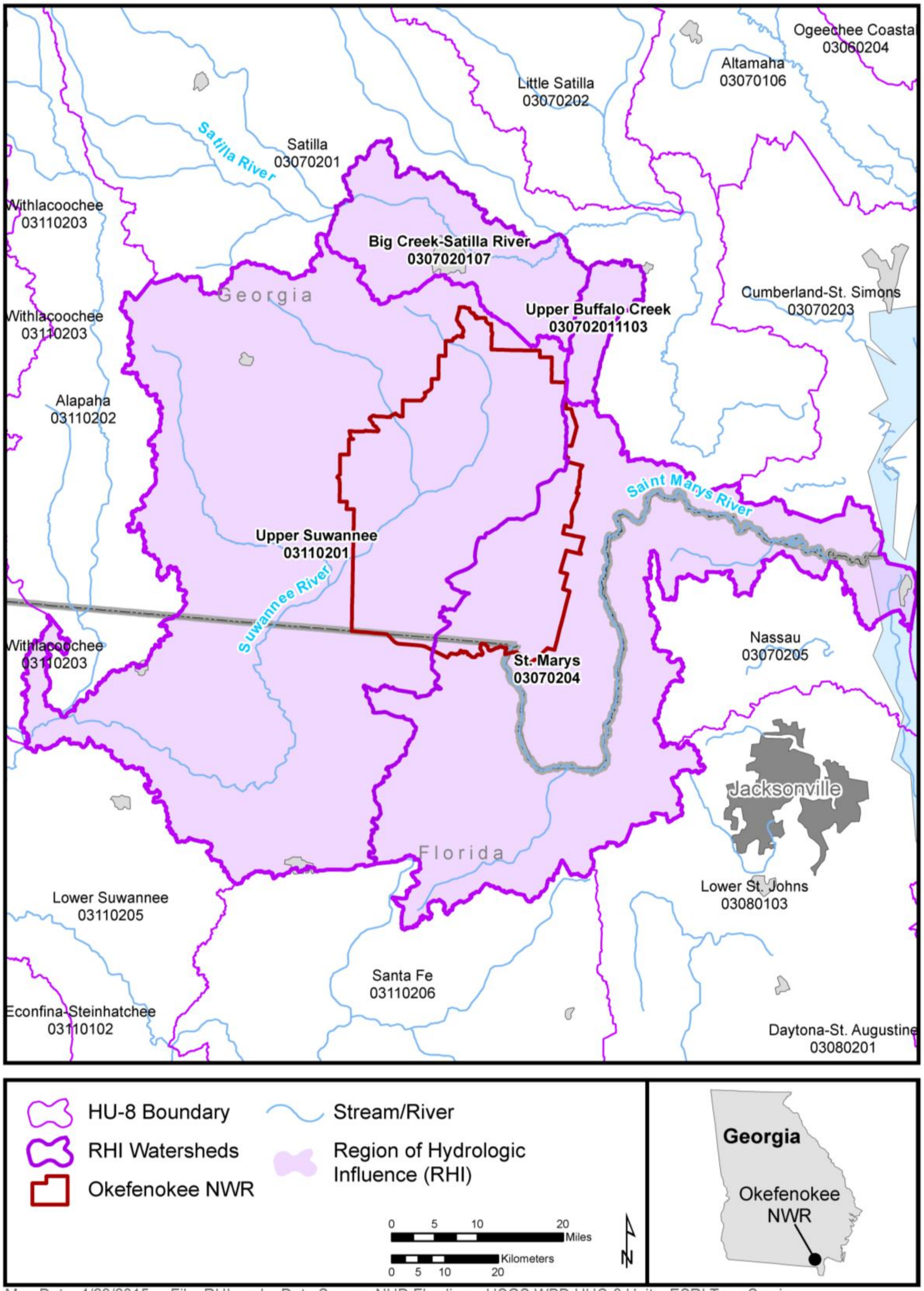
4 Natural Setting

4.1 Region of Hydrologic Influence (RHI)

This assessment focuses on water resources within the geographic extent of the refuge acquisition boundary, and more broadly on water resources within a Region of Hydrologic Influence (RHI) containing the refuge. The RHI delineates some portion of the watershed (or watersheds) that affects the condition of water resources on the refuge. This construct provides a reference for discussing the refuge within a watershed context. Because water travels down gradient, the activities occurring upstream of the refuge tend to have the greatest effect on water quantity (e.g., diversions, withdrawals, land cover changes) and water quality (e.g., pollution from agricultural, urban, or industrial land uses) on the refuge. Accordingly, the focus of the RHI is primarily on areas upstream of the refuge.

For the purposes of this assessment, the RHI was defined as the Upper Suwannee and St. Marys River watersheds, and a portion of the Satilla watershed to the north (Figure 3). The RHI includes a total drainage area of 2,978,461 acres.

Geographic delineations are drawn from the National Watershed Boundary Dataset [WBD], a hierarchical framework that divides the landscape into progressively smaller hydrologic units [HUs]. At the coarsest scale these HUs are called hydrologic regions and assigned unique 2-digit codes. At progressively finer scales, 4-, 6-, 8-, 10-, and 12-digit HUs are called subregions, basins, subbasins, watersheds, and subwatersheds, respectively (Laitta et al. 2004). For this assessment, the RHI consists of the two subbasins encompassing the refuge: the Upper Suwannee [03110201] and St. Marys [03070204], plus the Big Creek-Satilla River watershed [0307020107] and Upper Buffalo Creek subwatershed [030702011103]. Major surface water features within the RHI, including rivers and waterbodies, are described in Section 4.5.



Map Date: 4/23/2015 File: RHI.mxd Data Source: NHD Flowlines, USGS WBD HUC-8 Units, ESRI Topo Service

Figure 3. Okefenokee National Wildlife Refuge Region of Hydrologic Influence (RHI).

4.2 Topography, Landforms, and Geomorphology

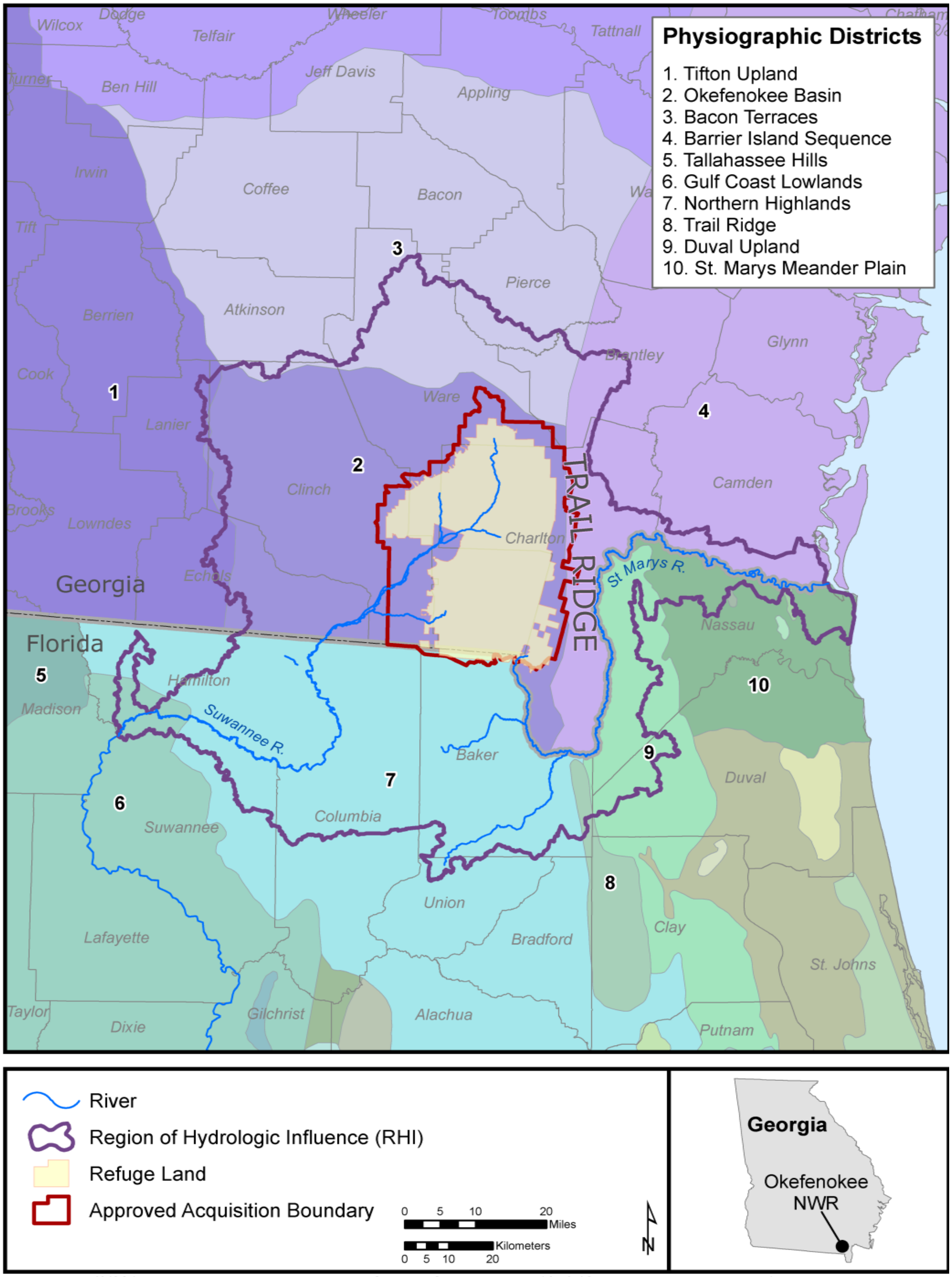
Okefenokee NWR is located within the Atlantic Coastal Plain physiographic region that covers the southern half of Georgia, northeast Florida, and the eastern halves of North and South Carolina (Fenneman and Johnson 1946). The Atlantic Coastal Plain is generally characterized as a low, flat region of well-drained, gently rolling hills and poorly drained flatwoods, ranging from mean sea level to 750 feet above mean sea level (AMSL) in elevation. The Fall Line is the inland boundary of this physiographic region, which marks the beginning of the Piedmont physiographic region.

Physiographic regions can be further subdivided into districts at the local level. In Georgia, the approved acquisition boundary of the Okefenokee NWR falls within the Okefenokee Basin district of the Atlantic Coastal Plain physiographic region (#2 on Figure 4; Clark and Zisa 1976). The Okefenokee basin district is characterized as having relief that varies from 50 to 5 feet decreasing to the southeast. Elevations in the district range from 240 feet AMSL in the northwest to 75 feet AMSL in the southeast. Swamps are common in lowland depressions in this area, and range in size from a few hundred square feet to the 660 square miles within the Okefenokee Swamp. The northern and western boundaries of the district coincide with the northern and western drainage divides of the Suwannee River. The eastern boundary is the western base of Trail Ridge, which separates the Okefenokee Basin District from the Barrier Island Sequence district to the east (Clark and Zisa 1976). Trail Ridge is a long narrow sandy ridge with peak elevations 35 to 50 meters (115 to 164 feet) AMSL. This unique natural ridge dramatically shapes the hydrology of this area and prevents drainage on the Atlantic side (Loftin 1997).

The topography of Okefenokee NWR includes variations between the Okefenokee Swamp and surrounding uplands. The swamp is a depression within the Okefenokee Basin district that ranges from about 130 feet AMSL on the northeast side to about 105 feet AMSL on the southwest side (Smedley 1968). Uplands adjoining the swamp are abandoned terraces related to historically changing sea levels, which can reach elevations of 160 feet AMSL outside of the refuge (Smedley 1968).

The Tifton Upland District (#1 on Figure 4) lies to the west of the refuge and is characterized by a well-developed, extended dendritic stream pattern where narrow, rounded interfluves (areas of higher ground between two rivers in the same drainage system) occur 50 to 200 feet above relatively narrow stream valley floors (Clark and Zisa 1976). To the north, the Bacon Terraces feature a southeast-trending dendritic drainage pattern (#3 on Figure 4). Marshy floodplains are found 50 to 100 feet below long and narrow interfluves with slightly round to flat summits. The district also contains moderately dissected terraces that are generally parallel to the coastline (Clark and Zisa 1976). These terraces serve as drainage divides and impact the direction of surface hydrology. To the east of the Okefenokee Basin is the Barrier Island Sequence District (#4 on Figure 4). This district contains step-like terraces of decreasing elevations that descend toward the Atlantic Ocean. Each terrace represents a former barrier island-salt marsh-shoreline depositional complex resulting from retreating sea levels. At the western border, Trail Ridge represents the most prominent terrace in the district, with an elevation of approximately 160 feet AMSL (Clark and Zisa 1976).

The Florida portion of Okefenokee NWR lies within the Northern Highlands physiographic district (#7 on Figure 4). The Northern Highlands are characterized by gently rolling topography, with average elevations ranging from 100 to 200 feet AMSL. Like the districts to the north in Georgia, the Northern Highlands feature step-like marine terraces resulting from changes in mean sea level associated with the repeated retreat and growth of continental glaciers during the Pleistocene and possibly Pliocene Epochs (Healy 1975). The highest terrace in this district reaches an elevation of 320 feet AMSL (Water Resources Associates, Inc. 2005).



Map Date: 7/6/2015 File: Physio_Districts Data Source: Clark and Zisa 1976 (GA Physiographic Districts), FDEP FL Physiographic Districts, NHD High Resolution Flowlines, ESRI Topo Service

Figure 4. Physiographic districts within the Gulf Coastal Plain in relation to the Region of Hydrologic Influence (RHI) and the Okefenokee National Wildlife Refuge acquisition boundary.

The 438,000-acre Okefenokee Swamp is a vast peat bog filling a saucer-shaped sandy depression (USFWS 2006). The entire floor of the swamp is covered by a bed of peat varying from a few inches thick at the swamp's edge to 3 to 15 feet thick in the swamp's interior (USFWS 2006). The Okefenokee Swamp has been an area of virtually continuous peat deposition for at least the last 7,000 years (Fearn and Cohen 1984). More information on peat development can be found in Section 4.4.

Geomorphology and topography within the swamp is subtle, influenced by the underlying geology; fluvial, climatic, and pedogenic processes; and fire. Most of the swamp is covered by water ranging from 1 to 5 feet deep, but there are several small lakes which are completely free of vegetation and have greater water depths (USFWS 2006). The areas of shallow open water are known as prairies. They exist where peat layers are thick over depressions in basement topography and represent roughly 8% of the swamp (Loftin et al. 2000). Generally, prairies and lakes have formed in areas where fire has burned holes in the peat (USFWS 2006). Smedley (1968) described areas of intermediate relief, known as "houses," which are floating islands of peat where the mat of decayed vegetation has become detached from lower layers and has risen to the surface. These "houses" are solid enough to support trees and underbrush. "Bays" are areas of true swamp where trees grow out of the water. The areas of highest relief within the swamp are sand bars referred to as islands. These are sandy areas of solid ground that may rise up to 5 feet above the surrounding water. Islands are remnants of Pleistocene sand dunes and sand bars that extended northeast across the extent of the swamp (Smedley 1968).

4.3 Geology and Hydrogeology

The coastal plain is a homocline (downward slope) of a peninsular arch dating to the late Cretaceous Period, the axis of which trends northwest from Florida (Smedley 1968). Strata under the refuge dip gently to the northeast, away from the arch and toward the coast (Herrick 1965). Surface formations in the area beneath the RHI consist of unconsolidated Pleistocene and Holocene sediments. Tertiary marine rocks are in the subsurface. Following Tertiary deposition, the general area of the arch was raised during the Ocala uplift (Smedley 1968; Scott 1988).

Coastal plain stratigraphy extends inland to the fall line, and consists of layers of sand, clay, limestone, and dolomite that range in age from Late Cretaceous through Holocene (Figure 5) (Clark and Zisa 1976). Sediment origins are fluvial, deltaic, marine, coastal, and shelf deposits (Prowell et al. 1985). The sedimentary sequence unconformably overlies Paleozoic to Mesozoic igneous, metamorphic and sedimentary rocks (Chowns and Williams 1983).

Parrish and Rykiel (1979) summarized two theories of the Okefenokee Swamp's origin. The Harper-Cooke Pleistocene marine origin theory postulates that the swamp originated as a salt water lagoon during the transition period from the Yarmouth Interglacial to the Illinois glaciations. The Harper-Cooke theory was based primarily on topographic and geologic studies, and was widely accepted through the 1950s and 1960s. The alternative Holocene freshwater origin theory, which originated in 1911 and was further supported by scientific evidence gathered in the 1970s, asserts that the geologic origins of the swamp date to 200,000 years before present (ybp), but that the actual swamp formed more recently (6,500 ybp). The basic premise of the Holocene freshwater origin theory postulates that impermeable lagoonal clay deposited during the Sangamon Interglacial Stage (approximately 114,000 - 130,000 years ago) was overlain with Pleistocene sands with organic sedimentation occurring in a freshwater setting (Cohen 1973; Fair-Page and Cohen 1990). As sea levels rose following the glacial period, coastal swamps formed, followed by swamps further inland at higher elevations. Swamp forests spread laterally away from stream courses and small lakes as peat accumulated. Climate and vegetation resulted in an accelerated cycle of peat development, which expanded the swamp. The Holocene freshwater origin theory evolved as evidence emerged concerning the rapid cycle of peat development in the Southeast, and was supported by paleoecological reconstruction of vegetation history based on pollen/macrofossil analyses, glacial and climatic history, radiocarbon dating, and sea level changes (see Fair-Page and Cohen 1990; Stack 1985; Fearn 1981; Rich 1979; Spackman et al. 1976; Bond 1970).

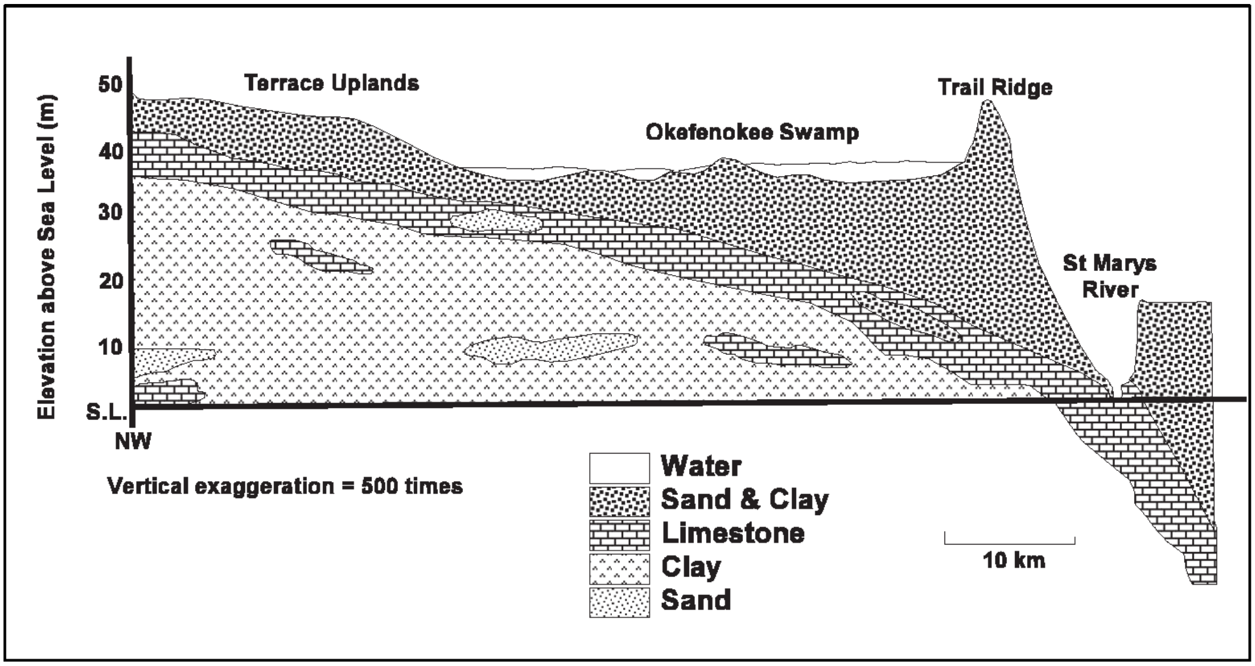


Figure 5. West to east profile of the sediments under the Okefenokee Swamp and surrounding Region of Hydrologic Influence (RHI). [Source: USFWS 2006, Figure 7].

The swamp is located on the marsh and lagoonal facies of the Wicomico Terrace, a marine feature left by a receding sea level, dating to the Pliocene or Pleistocene and extending 100 to 120 feet above sea level. Stratigraphy of the Wicomico Terrace includes surficial sand and clay deposits associated with marine terrace formation as well as erosion and chemical weathering of pre-existing strata. The barrier island facies at the eastern margin of the terrace is Trail Ridge (USFWS 2006). The Wicomico Terrace is underlain by a 200-foot thick impermeable layer of interbedded clay, sand and carbonate strata called the Hawthorn Group, which dates to the Miocene and acts as a confining unit which holds water in the basin (Thom et al. 2015 – see Figure 6; Water Resources Associates, Inc. 2005). The strata below the Hawthorn Group are composed of carbonate rock (limestone [calcium carbonate] and/or dolomite [calcium-magnesium carbonate]) up to 2,500 feet thick (Hornsby and Ceryak 1998; Weary and Doctor 2014). These strata include, in descending order: Oligocene-age Suwannee Limestone, Eocene-age Ocala Limestone, middle Eocene-age Avon Park and Lake City Limestone Formations, and Lower Eocene-age Oldsmar Limestone Formation (Stringfield 1966; SRWMD 2010).

In the lower coastal plain of Georgia, the principal water-bearing geologic units are the surficial aquifer system, the Intermediate (Brunswick) aquifer system, and Floridan aquifer system (Clarke et al. 1990; Water Resources Inc., 2005). Low-permeability, clayey confining units separate these water-bearing units (Clarke et al. 1990; Priest 2004). The surficial aquifer is found in some areas of Georgia and Florida where the Hawthorn Group serves as a confining unit and minimizes recharge to the underlying Floridan Aquifer. The surficial aquifer, which is found throughout the RHI, is up to 230 feet thick and consists of interlayered sand, clay and limestone. Near the refuge, the surficial aquifer is used for domestic well water (Water Resources Associates, Inc. 2005). Water levels in the surficial aquifer show a pronounced response to climate; effects of climate are greatly diminished in confined aquifers and any fluctuations are largely due to changes in ground-water pumping (Priest 2004).

The Hawthorn Group represents the Intermediate Aquifer and Confining Beds System, which consists of thin layers of gravel, sand and carbonate rock that produce small well-yields in the northern and northeastern portions of the basin (Water Resources Associates, Inc. 2005). These permeable units are able to transmit water on a limited basis for domestic or livestock supplies, but are not capable of supporting regional water needs (Stringfield 1966; SRWMD 2010).

The Floridan Aquifer, found throughout Florida, the Coastal Plain of Georgia and portions of the coastal plain in South Carolina, North Carolina and Alabama, underlies the Hawthorn Group which is found throughout the Okefenokee RHI. The Upper Floridan Aquifer is the principal source of drinking water taken from groundwater within the Coastal Plain of Georgia (Miller 1986). It is an extremely permeable, high-yielding aquifer that has been used extensively since the 1880s. Saltwater contamination due to groundwater pumping has been noted in the Upper Floridan aquifer at Brunswick, GA (Clarke et al. 1990; Krause and Clarke 2001).

Recharge to the confined groundwater-flow system is from precipitation in and near parts of the outcrop areas of the confined aquifers. The recharge areas for these aquifers and detailed descriptions of each of these aquifers, including hydraulic properties, are provided by Clarke et al. (1990). Natural discharge from the groundwater-flow system occurs as flow to streams and springs in the upgradient areas of confined aquifers, and as vertical leakage into adjacent units where head gradients are favorable. Groundwater also is discharged offshore and to wells in the coastal area. Water levels in each aquifer fluctuate as a result of recharge to and discharge from the aquifer (Clarke et al. 1990); Recharge varies in response to precipitation, evapotranspiration, and surface water infiltration into the aquifers. Discharge varies in response to changes in natural flow from the aquifers to streams and springs, evapotranspiration, leakage into adjacent aquifers, and withdrawal from wells.

Throughout the lower coastal plain of Georgia, surface and groundwater interaction in the surficial aquifer is linked to seasonal climate and anthropogenic withdrawals. When groundwater levels are high from natural recharge due to precipitation, groundwater contribution to streamflow is correspondingly high; conversely, when groundwater levels are low because of lack of recharge or pumping, groundwater contribution to streamflow is correspondingly low (Priest 2004).

4.4 Soils

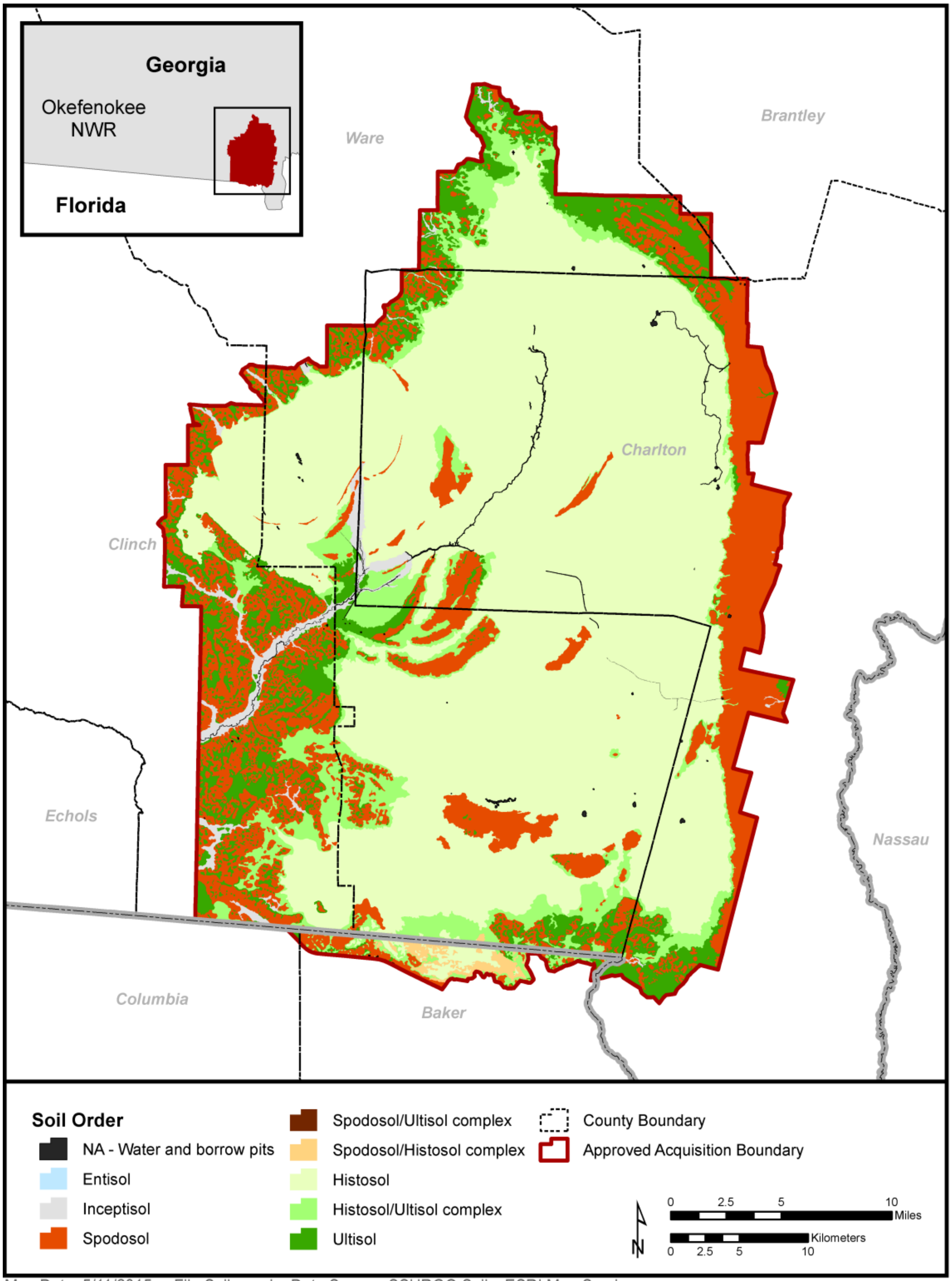
Soil properties are generally the product of parent material, climate, and position on the landscape. At the coarsest scale, soils can be grouped into major orders, which share general common properties such as base saturation, bulk density, and organic, mineral, or clay content (NSSH Undated). The most common soil orders found within the Okefenokee Swamp system are histosols, spodosols, and ultisols (Figure 6). Histosols are organic based soils that have developed in saturated environments. Spodosols are mineral soils that are characterized by the presence of a spodic horizon, which represents a subsurface accumulation of soil organic matter with aluminum and / or iron sesquioxides (UFL 2015). Ultisols are highly weathered soils with low base saturation status and clay-enriched subsoil (UFL 2015). All of these soil orders (Histosols, Spodosols and Ultisols) are highly acidic and dominate Okefenokee NWR. Generally, histosols are directly related to the swamp areas of the refuge. The non-swamp areas include floodplains, sand islands, and uplands, and are a mix of spodosols and ultisols (SSURGO undated-a).

The vast majority of the soils at Okefenokee NWR are histosols, which form in thick accumulations of organic matter from decaying plant material (Figure 6). They have a minimum of 12 to 18% organic carbon, by weight (depending on clay content), and most have significantly more organic content (SSM 1993). When histosols accumulate rapidly with little decomposition under wet conditions, they are described as "peat" deposits. Histosols do not exhibit the kinds of horizons common to mineral soils but rather have layers, or tiers, that vary in color, botanical origin of the organic material, amount of mixed-in mineral soil material, degree of decomposition, and other properties used to differentiate between species (e.g., the area exemplified by the profile in Figure 7). In describing histosols in general, "peat" is relatively undecomposed organic material in which the original fibers constitute almost all of the material; "muck" is well-decomposed organic soil material; and "mucky peat" is material intermediate between muck and peat (SSM 1993).

Soil orders can be further broken down into individual soil series, also called map units, which share more location-specific properties such as parent material, runoff potential, texture, and permeability. The purpose of the soil series category is closely allied to the interpretive uses of the system (NSSH Undated). Major soil series located within Okefenokee NWR are listed along with their soil orders and other distinguishing properties in Table 2.

The Natural Resources Conservation Service (NRCS), the principal agency responsible for soil mapping and characterization, assigns each map unit to a hydrologic soil group as an indicator of the runoff (and indirectly, recharge) potential for the soil unit when thoroughly wet. There are four groups, ranging from group A (high infiltration/low runoff) to group D (very slow infiltration/high runoff; Table 3). If a soil is assigned to a dual hydrologic group, the first letter is for drained areas and the second letter is for undrained areas. The distribution of hydrologic groups assigned to soils within the acquisition boundary of Okefenokee NWR indicates that infiltration and runoff in the area are closely linked with hydrologic alterations to soils units, in the form of drainage ditches and other historic alterations. Under natural conditions without drainage, the majority of soils (99%) within the refuge acquisition boundary would fall into hydrologic group D; however, due to anthropogenic modifications, 87% of soils fall within groups A and B, which exhibit high to moderate infiltration and low to moderate runoff (Table 3).

NRCS defines hydric soils as "soils that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part." The concept of hydric soils includes soils developed under sufficiently wet conditions to support the growth and regeneration of hydrophytic vegetation. Soils that are sufficiently wet because of artificial measures are included in the concept of hydric soils. Also, soils in which the hydrology has been artificially modified are hydric if the soil, in an unaltered state, was hydric. Some series, designated as hydric, have phases that are not hydric depending on water table, flooding, and ponding characteristics. NRCS maintains a national list of hydric soil components (NRCS 2014). Within the Soil Survey Geographic (SSURGO) Database, "hydric soils" include all map units in which the majority of soil components meet hydric criteria. "Partially hydric soils" may have some hydric components within a larger matrix of non-hydric components (SSURGO undated-b). A vast majority of the refuge is composed of partially hydric soils (97.9 %), with the remainder completely hydric (1.9 %) and non-hydric (0.2 %).



Map Date: 5/11/2015 File:Soils.mxd Data Source: SSURGO Soils, ESRI Map Service.

Figure 6. Soil orders within the Okefenokee National Wildlife Refuge acquisition boundary.

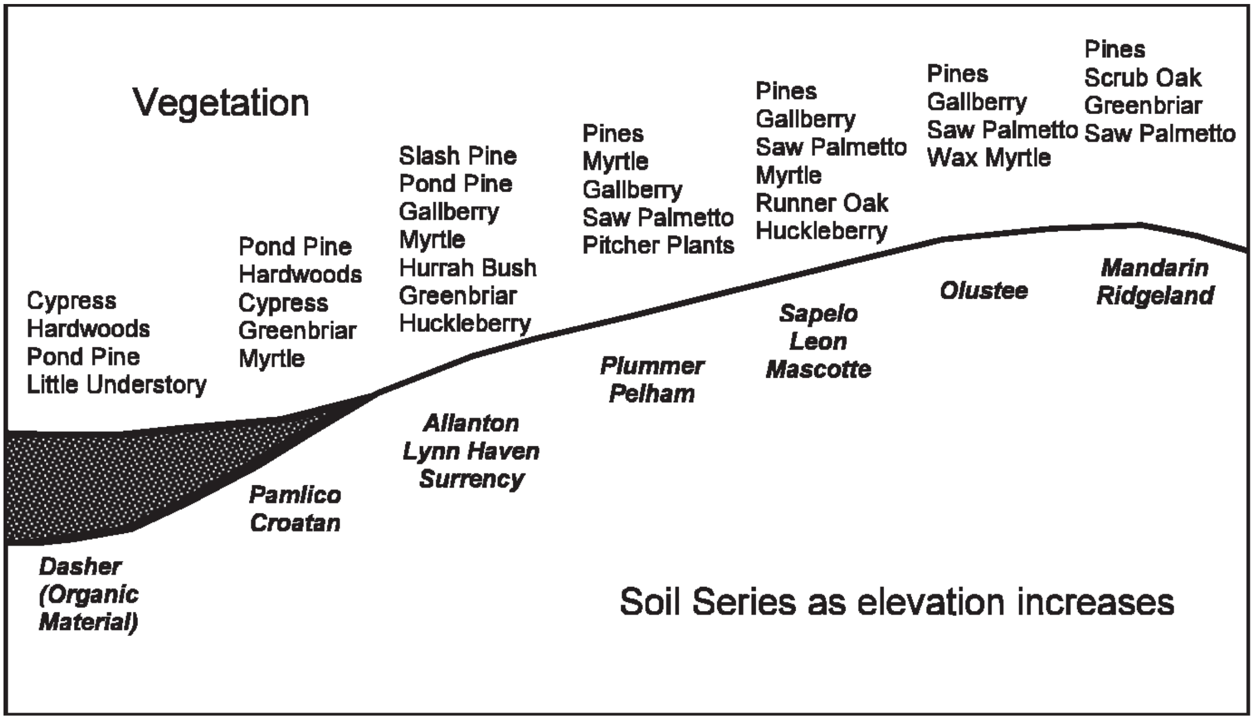


Figure 7. Typical histosol soils series according to elevation within the Okefenokee National Wildlife Refuge and the associated vegetation types. Distinctions between histosol series are made according to relative elevation position and dominant forming vegetation, rather than horizon development. [Source: USFWS 2006, Figure 8. Updated from USFWS 1987(Figure 1 p. 54).]

Table 2. Descriptions of the major soil series found within the Okefenokee National Wildlife Refuge acquisition boundary. [Sources: SSURGO Undated-a].

Series	Order	Depth	Slope	Drainage Class	Surface Texture	SubSoil Texture	Landform	Parent Material	Permeability
Allanton	Spodosol	very deep	0-2%	very poorly drained	sandy, loamy sand	sandy loam	flats, depressions, drainageways	sandy marine deposits	moderately rapid
Croatan	Histosol	very deep	0-2%	very poorly drained	Muck	mucky fine sand, sandy clay load	Depressions	decomposed organic material	slow to moderately rapid to moderately slow in the substratum
Dasher	Histosol	very deep	0-1%	very poorly drained	mucky peat	sand or fine sand	Swamps	decomposed organic material	moderately rapid
Dorovan	Histosol	very deep	0-1%	very poorly drained	mucky peat	sand, fine sand, sandy loam, loamy fine sand	depressions, floodplains	decomposed organic material over sandy deposits	moderate
Johnston	Inceptisol	deep	0-2%	very poorly drained	mucky sand	sand	Floodplains	loamy stratified alluvial deposits	Moderately rapid to rapid in the substratum
Kinston	Inceptisol	very deep	0-2%	poorly drained	fine sandy loam	sandy loam	Floodplains	loamy stratified alluvial deposits	moderate
Leon	Spodosol	very deep	0-2%	poorly drained	fine sand	sand	flats, depressions, drainageways	sandy marine deposits	moderate
Lynn Haven	Spodosol	very deep	0-5%	poorly drained, very poorly drained	mucky fine sand	fine sand	Depressions	sandy marine deposits	moderately rapid to moderate in the spodic horizon
Mascotte	Spodosol	very deep	0-2%	very poorly drained	fine sand	loamy sand	flats, depressions, low stream terraces	sandy, loamy marine sediments	moderately slow
Pamlico	Histosol		0-1%	very poorly drained	Muck	loamy sand	depressions, floodplains, bays	decomposed organic material underlain by sandy sediment	moderate to moderately rapid in organic layers and slow to very rapid in the mineral layers
Pantego	Ultisol	very deep	0-2%	very poorly drained	Loam	sandy clay loam	flatwood depressions	medium textured Coastal Plain deposits	moderate

Series	Order	Depth	Slope	Drainage Class	Surface Texture	SubSoil Texture	Landform	Parent Material	Permeability
Pelham	Ultisol	very deep	0-5%	poorly drained	loamy sand	sandy loam	flats, toe slopes, depressions, drainages	unconsolidated Coast Plain sediments	moderate
Sapelo	Spodosol	very deep	0-2%	somewhat poorly to poorly drained	fine sand	sandy clay loam	Flats	marine sediments	moderate
Surrency	Ultisol	very deep	0-1%	very poorly drained	decomposed organics	sandy clay loam	flats, depressions, swamps	marine and fluvial sediments	moderately slow to moderate

Table 3. Soils by NRCS Hydrologic Group found within the Okefenokee NWR acquisition boundary. [Source: SSURGO Undated-a].

Hydrologic Group	Description	Acres within Acquisition Boundary	Percent of Total Land Acreage
A	High Infiltration/Low Runoff	6,114	1
A/D	Modified Areas: High Infiltration/Low Runoff Natural Condition: Very Slow Infiltration/High Runoff	426,167	82
B/D	Modified Areas: Moderate Infiltration/Moderate Runoff Natural Condition: Very Slow Infiltration/High Runoff	27,490	5
C/D	Modified Areas: Slow Infiltration/Moderately High Runoff Natural Condition: Very Slow Infiltration/High Runoff	61,612	12
Total		***521,383***	

The majority of the refuge soils are representative of the poorly-drained Croatan, Pamlico, and Surrency histosols, and the ponded Dasher-Dorovan-Croatan histosol complexes (Table 2). The very deep, moderately slowly permeable Croatan, Pamlico, and Surrency complex is composed of all poorly-drained, highly-organic histosols found in areas of flats, depressions, and stream terraces of the Coastal Plain. This complex formed in sandy and loamy marine sediments. The Dasher Series is a poorly-drained series that is normally ponded for at least 10 months of the year as part of marshes and swamps. The Dorovan series is similarly found in floodplains and hardwood swamps of the Atlantic Coastal Plain flatwoods, while the Croatan series is found in the lower and middle Coastal Plain and composed of highly decomposed organic material underlain by fluvial sediment (USDA 2008).

The Mascotte fine-sand soil series is the third largest series on the refuge. Mascotte soils (very deep, poorly-and-very-poorly-drained, moderately slowly permeable) are found on areas of flats, depressions, and low stream terraces of the Coastal Plain. The Leon fine sand (very deep, poorly-and-very-poorly-drained, moderately rapid to moderately slowly permeable) is the fourth largest soil series on the refuge, and is found on upland flats, depressions, stream terraces, and tidal areas.

The most common non-hydric soil found within the approved acquisition boundary is Hurricane fine sand, a Spodosol. Hurricane soils (very deep, somewhat poorly drained, moderately to rapidly permeable) are found on uplands commonly associated on the landscape with Albany, Boulogne, Chipley, Foxworth, and Leon soils. Strictly upland soils are a very small percentage of the refuge.

The repeating pattern of Dasher, Dorovan, and Croatan histosols that dominates the swamp areas of the refuge (SSURGO Undated-a) differ in their extent of decomposition but are largely similar in most regards. The botanical origin of the peat in these series broadly reflect the vegetation communities along a soil catena as depicted in Figure 7 from open-marsh environments; glades and island fringes; to tree-island and swamp environments (Cohen et al. 1984). The botanical composition of deeper peats is likely somewhat different due to changing local and regional paleoecological trends in vegetation. When drained, the histosols' organic material is prone to oxidation and vulnerable to fires. Most or all of the lakes in the swamp occur where natural depressions in the topography exist or where the peat has burned as a result of wildfires (USFWS 2006). In-depth discussion about vegetation composition, distribution, and vegetation change can be found in Loftin (1998). Additional information about the role of fire and the ecology of the Okefenokee Swamp can be found in Cypert (1961), the Forest Habitat Management Plan for Okefenokee NWR (USFWS 1987), in the Comprehensive Conservation Management Plan for the refuge (USFWS 2006), and in Section 4.6 of this report.

4.5 Surface Hydrology

As summarized by Priest (2004): "Water in streams and aquifers interact through a dynamic hydrologic system including aquifers, streams, reservoirs and floodplains. These interconnected systems form a hydrologic environment that is stressed by natural hydrologic, climate, and anthropogenic factors."

The Okefenokee Swamp is considered to be the headwaters of both the Suwannee and St. Marys Rivers (USFWS 2006). The Suwannee River originates in the western central portion of the refuge and flows for over 248 miles before emptying into the Gulf of Mexico near the town of Suwannee, Florida (Katz and Raabe 2005). The St. Marys River originates in the southeast corner of the refuge and flows for over 125 miles to the Atlantic Ocean near St. Marys, Georgia and Fernandina Beach, Florida (Blair et al. 2009). The St. Marys River is the border between Florida and Georgia east of Okefenokee NWR. The relatively high topography of Trail Ridge influences the path of surface water tributaries within the refuge that flow into the St. Marys River; the river flows south along Trail Ridge from the southeastern corner of the refuge before turning east at the southern extent of this feature.

The major surface drainage of the northern portion of the RHI is the Satilla River (Figure 3), which drains an area of almost 4,000 mi^2 and flows into the Atlantic Ocean approximately 10 miles south of Brunswick, Georgia. The Satilla River is not hydrologically connected to the Okefenokee Swamp by surface water features, but was included in this hydrologic analysis following discussions during the WRIA kickoff meeting related to unknown groundwater connections and potential contamination sources (Appendix A). Major creeks draining into the swamp on the northwest side are Black River, Alligator Creek (north), Greasy Branch, Suwannee Creek, Cane Creek, Bear Branch, Surveyors Creek, Barnum Branch, Turkey Branch, and Big Branch (USFWS 2006).

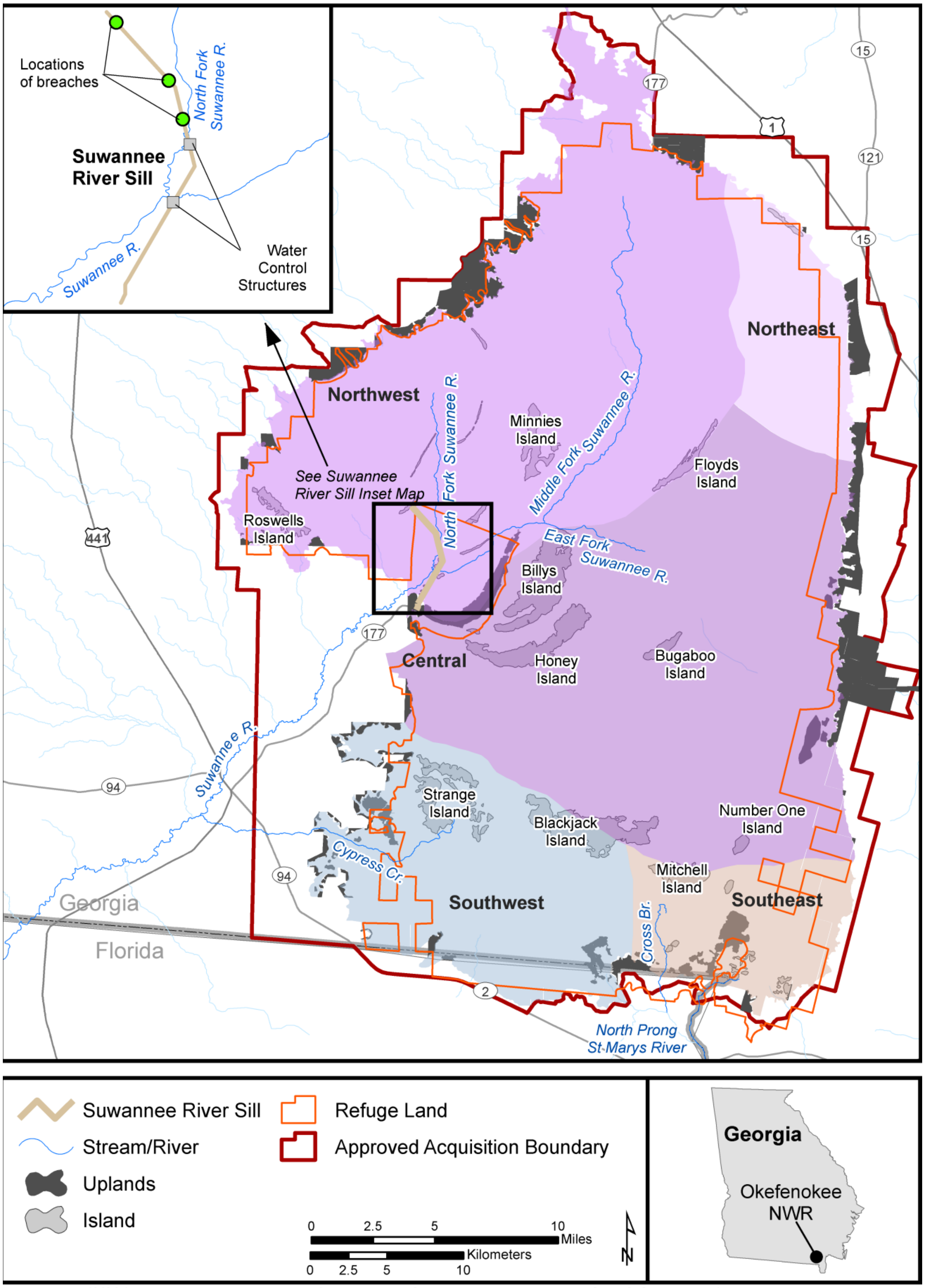
The refuge encompasses 85% of the Okefenokee Swamp (Loftin et al. 2000), a drainage area of roughly 600 mi^2 (Loftin 1998). Long-term hydrological budgets based on water balance estimates, and assuming no change in water storage, suggest that the swamp receives 72 to 78% of its water directly as precipitation (Brook and Sun 1987). Other estimates place the ratio of precipitation to surface runoff as 70/30 (Rykiel 1977; USFWS 2006). Changes in long-term precipitation rates would have a large impact on the refuge hydrology and ecology. Groundwater exchange in the area of the refuge is thought to be minimal (Brook and Hyatt 1985), although additional research examining surface water and groundwater connections in the swamp are needed, as significant connections between surface water and surficial groundwater exist within the Georgia Coastal Plain. Priest (2004) found that in the lower Coastal Plain of Georgia, groundwater contributions to streamflow are greatest during the winter when evapotranspiration (ET) is low and least during the summer when ET is high (Priest 2004). Some prairies may be influenced locally by groundwater (Rykiel 1977; Loftin 1988). There is a possibility of sinkholes in the bed of the swamp which may allow seepage through the Hawthorn formation to/from the aquifers below. However, most studies indicate that Hawthorn Group acts as a barrier between the swamp and the Floridan aquifer (Rykiel 1977). The interactions with the surficial aquifer and the Brunswick aquifers could be explored.

Rykiel (1977) estimated that 80% of water input to the swamp is taken up by ET and 20% exits through surface water flow. Within the refuge, there are three major surface drainage outlets. The Suwannee River carries 85% of surface water, the St. Marys River carries 11% and Cypress and Sweetwater Creeks carry the rest (4%) (Rykiel 1977). The northern 4/5 of the swamp drains to the Suwannee River. Areas to the east and south of Blackjack Island and south of Mitchell Island drain to the St. Marys River (Figure 8; USFWS 2006). Loftin (1998) analyzed water level data and further delineated five sub-basins within the swamp, based on areas exhibiting similar seasonal trends but different water level variability and magnitudes of those trends (Figure 8). The northwest region experiences the greatest seasonal and annual fluctuations in water elevations. Over a 3 to 4 week period, water elevations may fluctuate +/- 0.75 m, in correspondence with seasonal rainfall over the swamp and areas of the Suwannee River basin to the northwest of the swamp. The northeast region of the swamp has the smallest water level fluctuations. This may be due in part to a difference in dominant vegetation types between the basins that may affect ET (USFWS 2006); also, surface outflow is more limited from the northeast basin, due to a combination of water retention by peat and by natural berms in the topography of the swamp that hold water in the basin during drought conditions (S. Aicher, personal communication, May 6, 2015).

Surface flow leaving the majority of the swamp has had anthropogenic modification. From 1962 to 2001, the lone impoundment on the Suwannee River was an earthen dam known as the Suwannee River Sill, which was located across the main outflow channel of the Suwannee River from the Okefenokee Swamp, within the Okefenokee NWR boundary but outside the designated Wilderness Area. Following wildfires in 1954-1955 that burned 80% of the swamp during a severe drought, Congress authorized construction of the sill to protect the refuge's natural resources as well as forest resources on adjacent lands. The sill was constructed between 1960 and 1962 and consists of a berm spanning 7.2 km (4.5 mi) and averaging 35.5 m (116.5 ft) AMSL and 3-4 m (10-13 ft) above the surrounding floodplain (Loftin et al. 2000). Two spillway gates were also closed as part of sill construction; though maneuverable, they remained closed to maximize impoundment.

In 2001, the sill floodway gates were opened and the sill was breached in three places (Inset Map, Figure 8). This action was in response to an inspection that found the sill to be damaged and compromised, questions regarding the effectiveness of the sill for fire retardation, and a growing body of scientific evidence concerning the negative effects of the sill on swamp hydrology and ecology (Loftin et al. 2000; Cohen 1973).

In 1988, USGS undertook a study of the hydrology of the Suwannee River and areas surrounding the swamp, in anticipation of the restoration. The USGS stream gage at Fargo, Georgia, was found to account for 90% of the Suwannee River flow at the sill. Flow data from this gage was later analyzed for pre-sill (1937-1959), with-sill (1961-2001), and post-restoration (2001-2003) conditions. The most significant findings included a decrease in post-sill peak flows of up to 3,000 cfs on the Suwannee River at Fargo, Georgia, as well as an increase in baseflow following construction of the sill (Giese 2004). Gage data analysis revealed there were 73 days with zero flow prior to sill construction; post-sill, there have been none. The number of days with flows of less than 10 cubic feet per second (cfs) decreased from 30 days per year pre-sill to 7.1 days per year with-sill; however the number of days with flows of less than 10 cfs increased to 11.9 days per year in the 3 years following the sill restoration. No significant changes with regard to streamwater levels, water quality, or groundwater downstream of the sill were noted (Giese 2004). Downstream of the refuge, the Suwannee River is unimpounded and undiverted and has been referred to as one of the most pristine and undeveloped river systems in the United States (Katz and Raabe 2005; Master et al. 1998).



Map Date: 7/6/2015 File: hydrography_landforms Data Source: NHD Flowlines, USFWS Swampline/Hydrologic Basins and Cadastral Data, ESRI Topo Service.

Figure 8. Local hydrologic sub-basin delineation and surface hydrology within Okefenokee National Wildlife Refuge, based on hydrologic analysis from Loftin (1998).

4.6 Land Use and Anthropogenic Change

According to the most recent land use data available for the entire RHI, land cover is primarily native vegetation. Approximately 90% is classified as woody wetlands, evergreen forest, shrub/scrub, grassland/herbaceous, or emergent herbaceous wetland (Figure 9) (Homer et al 2015). However, the land cover is not undisturbed. As the majority of the RHI remains privately owned rural land, management of those lands is changing. Rural forest cover types (primarily pine plantations) were prevalent in the early 1900s, but over the last century pine plantations have been converted to open, nonforested agriculture lands (USFWS 2006; Loftin 1998). The cultural environment and human history of the swamp are detailed in the Okefenokee NWR Comprehensive Conservation Plan (USFWS 2006). Anthropogenic alterations and land use practices directly affecting swamp hydrology are highlighted below.

Anthropogenic change affects the landscape surrounding and including the refuge. Timber harvesting has been one constant source of hydrologic alteration. From attempts to drain the swamp in the late 1890s to current management of slash pine on lands adjacent to the refuge, silvicultural activities have impacted hydrology (water quantity and quality) and vegetation dynamics within the Okefenokee Swamp, and within the RHI (USFWS 2006; Loftin 1998). Even when considering the mitigating effects of modern forestry best management practices, timber harvesting can have an impact on local hydrology (Bosch and Hewlett 1982; Sun et al. 2001). Historically, timber harvest within Okefenokee Swamp was extensive; when logging operations were halted on what would become the refuge in 1927, more than 423 million board feet of timber, mostly cypress, had been removed from the swamp (USFWS 2006). Logging in the RHI resulted in a fragmented habitat as well as a change in species composition (Loftin 1998) and species distribution. The refuge boundary in most areas is within or adjacent to the swamp edge, leaving only fragments of uplands around the perimeter of the swamp. Virtually all old growth timber on adjacent lands has been harvested, eliminating available nesting and foraging habitat for the endangered red cockaded woodpecker outside the refuge. The value of refuge old-growth forests as nesting and foraging habitat is severely limited because of its location and size (USFWS 2006). Shifts from forested to agricultural land use and changes in silvicultural and agricultural practices increase the risk for water contamination and degradation of both surface and groundwater. For example, from national analyses, pesticides were found in all samples from major rivers with mixed agricultural and urban land use influences (Aktar et al. 2009; Gilliom et al. 2007; USGS 1999). Water quality impacts and changing land use are discussed in Section 5.

Peat and sphagnum moss harvesting occurred in the swamp between the 1930s and the 1960s, creating localized impacts to geomorphology and hydrology. In addition to the indirect hydrologic alteration resulting from timber and peat mining operations, there have been several direct hydrologic alterations. Construction of the Suwannee River Sill in the early 1960s and subsequent restoration efforts in 2001 are detailed in section 4.5. In 1891, construction of the Suwannee Canal was begun between the swamp and the St. Marys River. Sixteen miles were excavated into the swamp and through the upland before the project finally failed due to economic and engineering difficulties. The hydrology of the area was further altered through the creation of King's Canal, a 3 mile canal, which resulted from peat and sphagnum moss mining operations. This canal begins at the swamp's northeastern edge near the Kingfisher Landing entrance, enters Carters Prairie, and extends a short distance north and south (USFWS 2006). Section 5.2.6 provides more information on the location and extent of these canals.

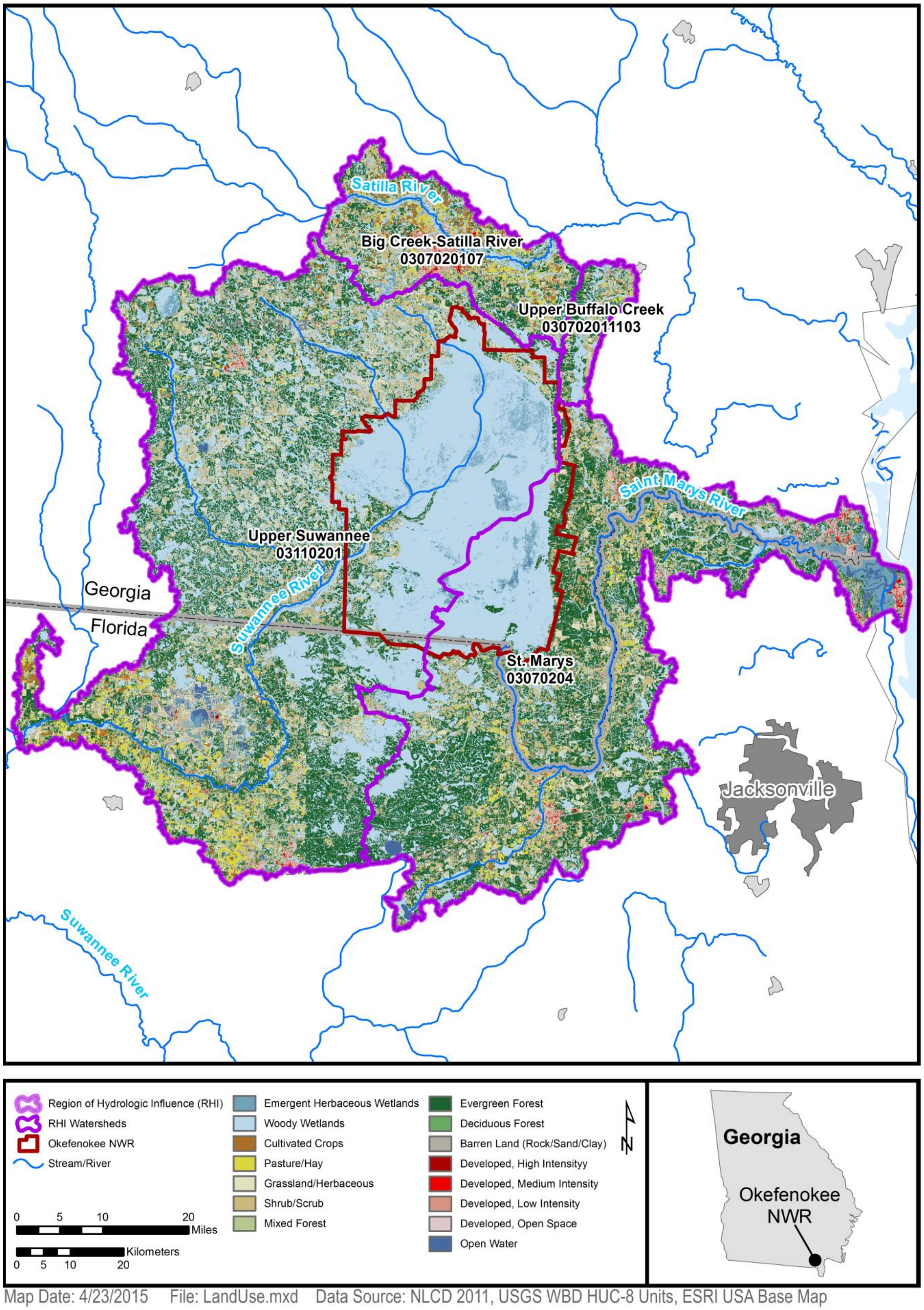


Figure 9. 2011 land use within the Region of Hydrologic Influence (RHI).

In 1986, the Okefenokee NWR was designated by the Wetlands Convention as a Wetland of International Importance. Combining Okefenokee NWR with the Osceola National Forest, private timberlands, and state-owned forests, accounts for more than 1 million contiguous acres of wildlife habitat and pervious cover (USFWS 2006). Developed areas occur along the outskirts of the RHI (e.g., Waycross, Georgia and Jacksonville, Florida), and less than 6% of the RHI is currently considered developed (Figure 9)(Homer et al 2015). Growth and development along the basin's rivers, especially the Suwannee, has been limited, largely because of floodplain management ordinances, land use plans, and land acquisition programs at state, regional, and local levels (FDEP 2003). To the west and north of the Suwannee River, the dominant land uses are tree plantations, forested wetlands, and agriculture. Agricultural land use also dominates the eastern portion of the RHI, although significant concentrations of urban and rural development are present along the northern and southeastern margins. The region maintains small farms that combine row crops with livestock, as well as large dairies and irrigated row crop and forage operations. Timber companies hold most of the coastal lowlands in large tracts of intensively managed, planted pine. Large tracts of timber are also found in the wet flatwoods to the east of the uppermost Suwannee River.

Between 2001 and 2011, by far the largest changes to land use in the RHI were reflected in transitioning undeveloped land from one type of native vegetation to another (over 15%). During this period, over 8% of the RHI changed from either grassland/herbaceous or shrub/scrub, to evergreen forests (Jin et al 2011). Approximately 3% of the RHI changed from evergreen to mixed forest and another 2% went from evergreen forest to shrub/scrub. A possible explanation for at least a portion of this change could be the planting of pine trees and activities related to timber harvesting.

Land use in the northeastern portions of the watershed draining directly into the swamp consists of more agriculture and low intensity development than in other areas of the RHI. Charlton County had a population of 10,282 in 2000 and a population of 12,171 in 2010, with an estimated 2014 population of 12,897 (USCB 2015). While development in areas upstream from the refuge could be a concern for the future, surface flow input represents a smaller percentage of the swamp's overall hydrologic budget when compared to the input of precipitation, and it is not likely that the current rates of development play a major role in the swamp's ecology.

Zirconium and titanium sands have been mined in southeast Georgia for almost 100 years and titanium has been mined in north Florida for at least the last 30 years. Humphrey Mining Company extracted titanium northeast of Folkston, 7 miles to the east of the refuge on Trail Ridge, from 1950 to 1981 (Smedley 1968; S. Aicher, personal communication, May 6, 2015). DuPont proposed a titanium mine on Trail Ridge adjacent to the refuge but backed out in 2003 due to public opposition to the proposed operations. In 2014, a titanium mine on 1,000 acres opened near Nahunta, 29 miles west of Brunswick, Georgia, just outside the RHI. Zircon is currently being mined in the area, but not adjacent to the refuge (S. Aicher, personal communication, May 6, 2015). No economically significant concentrations of heavy minerals are thought to exist under the refuge. The Pleistocene sands and Tertiary rocks under the refuge peat are likely to contain phosphate, which is present and mined in the surrounding region (Smedley 1968). Demands for groundwater from oil, gas, or titanium development, along with potential residential, industrial, and commercial, could alter the basic ecology of the Okefenokee Swamp.

Fire has long played a pivotal role in the ecology of the Okefenokee Swamp. Native uplands were historically dominated by fire-maintained pine forests, with longleaf nearer the coast and on sandy soils inland and a mixture of slash pine, pond pine, and hardwoods elsewhere (USFWS 2006). As mentioned in Section 4.4, the landscape of the swamp has been shaped and maintained by fire. Historically, fires in the Okefenokee Swamp most likely originated in the swamp as lightning strikes and were eventually extinguished by saturated peat or precipitation. Throughout the swamp there is evidence of a large fire 6,000-10,000 years ago and intensive fires roughly every few hundred years since (Loftin 1998). In 1954 and 1955, during an extended drought, severe fires occurred in the Okefenokee Swamp and surrounding uplands in southeast Georgia and northeast Florida (Cypert 1961). The severe fires have altered the substrate of the swamp and reinforced the dominant hydrologic patterns at the swamp by favoring fire tolerant species, maintaining openings in the vegetation, and creating scattered depressions. Private industrial forestland, refuge facilities, and the growing urban interface areas adjacent to the refuge create challenges to maintaining this fire regime (USFWS 2006).

Aggressive fire suppression and other silvicultural and land use changes within the southeastern coastal plain have altered the natural fire regime and vegetation distribution (USFWS 2006). Because of fire suppression, slash, loblolly and pond pines, once confined to wet areas due to frequent upland fires, are now able to encroach into the open longleaf pine communities. Hardwood understory species unable to survive the periodic growing season fires are replacing the open upland understory. Fires no longer approach the swamp on a several mile front due to the burning out of areas comprised of scrub/shrub and scrub forest within the swamp or the burning of depressions into the peat layer during drier periods. Without fire, open marsh areas and ponds within the swamp are no longer created or maintained (USFWS 2006). The fires of 2007 and 2011 indicate that large fires still occur naturally on the refuge. These large fires covered extensive areas of scrub/shrub forest, transforming burned areas into marsh habitat. The prescribed burning program at Okefenokee NWR has been very effective at maintaining pine-dominated upland habitat while reducing the hardwood understory (S. Aicher, personal communication, August 26, 2014).

4.7 Climate

4.7.1 Historical Climate

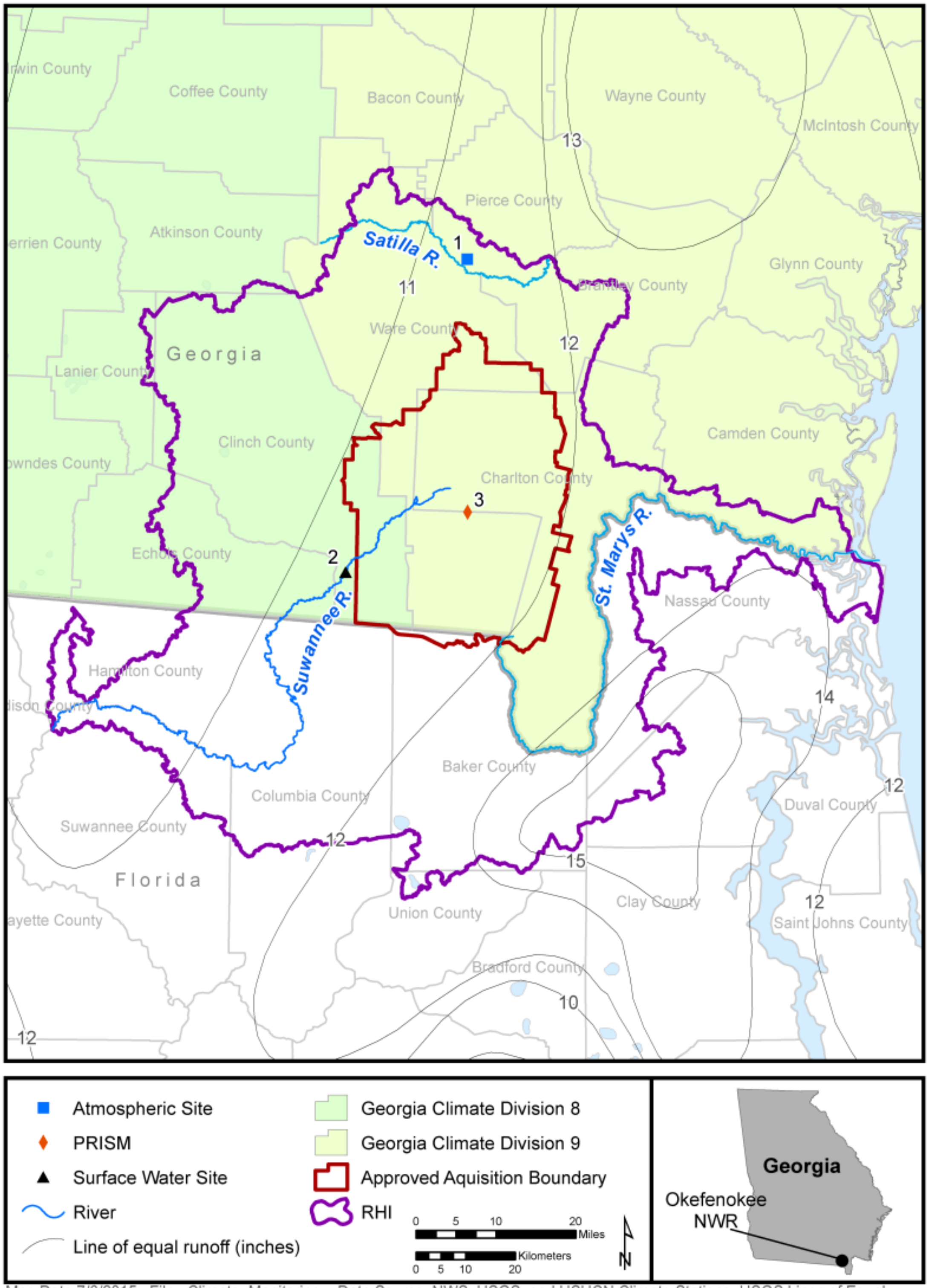
Climatic information presented in this WRIA comes from the U.S. Historical Climatology Network (USHCN) of monitoring sites maintained by the National Weather Service (NWS) (Menne et al. undated), the Hydro-Climatic Data Network, and the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping service, which is the U.S. Department of Agriculture's (USDA) official method of serving climatological data (PRISM 2010). The period of record for the USHCN precipitation data and temperature data is from 1893 to 2013, and from 1892 to 2013, respectively. The PRISM data represents 1971-2000 climatological normals. The closest USHCN station within the Suwannee River Basin is located in Waycross, Georgia, approximately 15 miles north of the refuge. For the PRISM location, a central point within the refuge was selected (latitude, longitude) and used to access the PRISM Data Explorer (PRISM 2011). Climate station information and locations are detailed in Table 4 and Figure 10. Gebert et al. (1987) collected soils and hydrologic data for over 12,000 gaging stations between 1951 and 1980 in order to estimate runoff for the coterminous United States. Figure 10 also shows the estimated annual runoff in inches for the Okefenokee NWR RHI.

Table 4. Climate monitoring stations located near the Okefenokee National Wildlife Refuge acquisition boundary [Sources: NACSE, USDOC, USGS].

Number on Figure 10	Station ID	Name	Type	Agency
1	099186	WAYCROSS, Georgia	USHCN	USDOC
2	02314500	Suwannee River at Fargo, Georgia	HCDN	USGS
3	N/A	PRISM Climate Normal	PRISM	NACSE

4.7.1.1 Temperature

The Okefenokee Swamp lies within the warm, temperate climate of the southeastern U.S. (Water Resources Associates, Inc. 2005). Mean monthly temperatures for Waycross, Georgia, range from approximately 52°F (11°C) in January to 82°F (28°C) in August (Figure 11). Mean monthly temperatures exhibit the greatest year-to-year variability in fall and winter (November to March) and the least variability in the summer (July and August) (Figure 11). Average maximum, mean and minimum temperatures at Waycross, Georgia, have remained relatively stable over the period of record (1892 - 2012), with the exception of some fluctuation among minimum and mean temperatures between the 1940s and 1980s (Figure 12). The PRISM dataset shows average monthly minimum temperatures in the vicinity of the refuge range from approximately 39.3°F (4.1°C) in January to 69.9°F (21.1°C) in July, while average monthly maximum temperatures range from approximately 63.9°F (17.7°C) in January to 93.2°F (34.0°C) in July (Table 5).



Map Date:7/6/2015 File: Climate_Monitoring Data Source: NWS, USGS, and USHCN Climate Stations, USGS Lines of Equal Runoff, NHD Flowlines, ESRI Topo Service

Figure 10. Climate monitoring stations, Georgia Climate Divisions, and lines of annual equal runoff for the Okefenokee National Wildlife Refuge Region of Hydrologic Influence (RHI). Numbered sites are listed in Table 4.

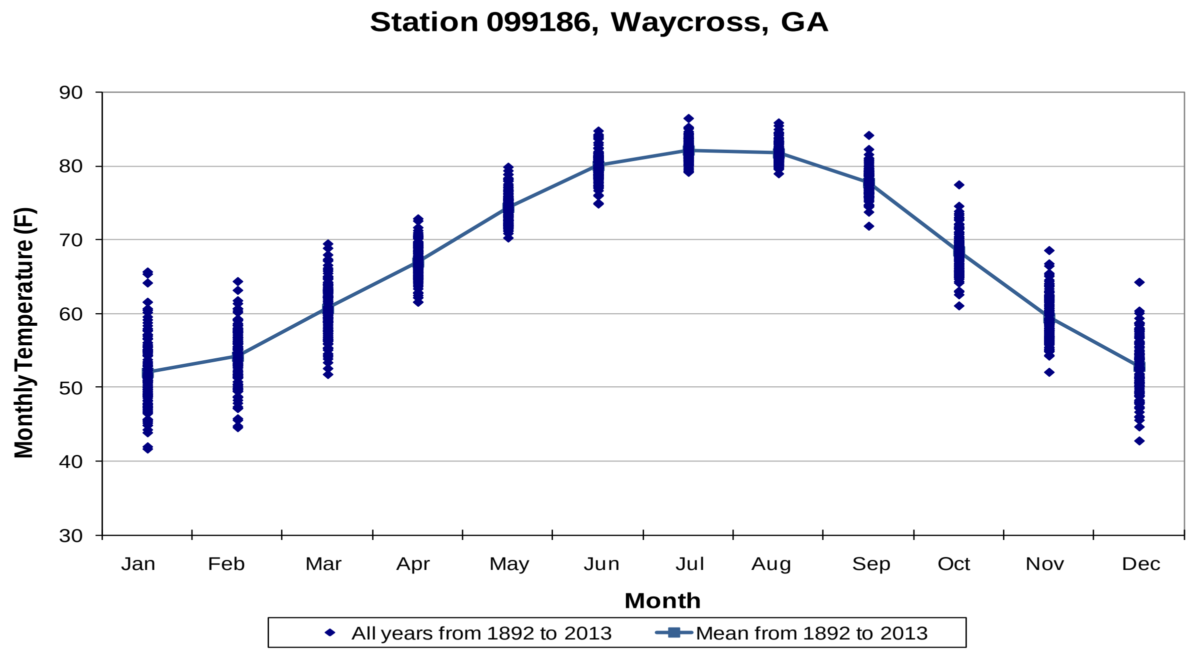


Figure 11. Mean and distribution of monthly temperature (1892 – 2013) at Waycross, GA (USHCN Station 099186). [Source: Menne et al. undated].

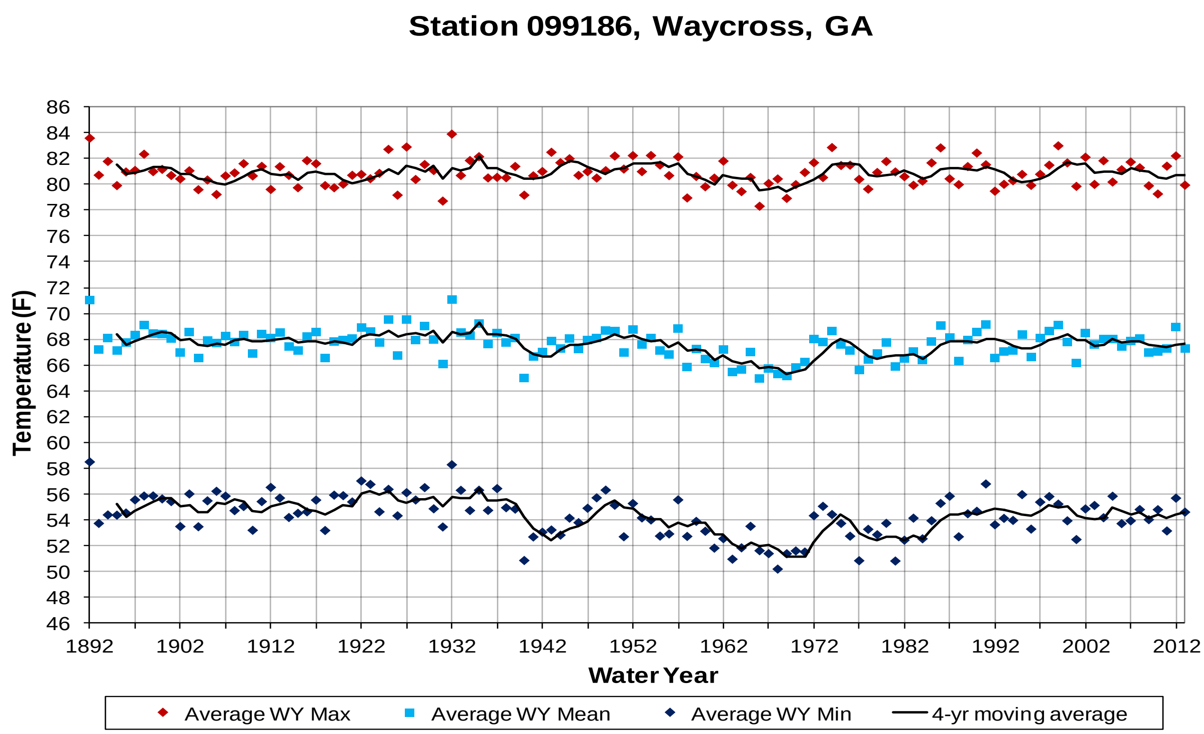


Figure 12. Average daily maximum, mean, and minimum temperature by water year (1892 – 2013) at Waycross, Georgia (USHCN Station 099186).

Table 5. PRISM monthly normals (1971-2000) for precipitation and maximum and minimum temperature at Okefenokee Swamp NWR. [Source: PRISM 2010].

Month	Precipitation (in)	Max Temperature (F)	Min Temperature (F)	Range of Temperatures (F)
January	4.17	63.93	39.29	24.64
February	3.58	67.62	41.72	25.90
March	4.50	74.62	47.98	26.64
April	3.09	80.42	52.57	27.85
May	3.36	87.03	60.01	27.02
June	5.79	91.60	66.79	24.81
July	6.84	93.15	69.89	23.26
August	6.28	92.44	69.40	23.04
September	4.26	88.68	66.25	22.43
October	2.86	80.96	55.78	25.18
November	2.62	73.20	47.97	25.23
December	3.07	65.64	41.22	24.42
Total Precipitation	**50.42**			
Average Temperature		**79.94**	**54.91**	**25.04**

1971-2000 Normals for 30.792, -82.306. Downloaded 4/01/2015 from http://prismmap.nacse.org/nn/. Copyright 2010. PRISM Climate Group, Oregon State University.

4.7.1.2 Precipitation

Based on average annual precipitation the Okefenokee NWR receives the most precipitation, approximately 6.8 inches (17.3 cm), in July and the least precipitation, approximately 2.6 inches (6.6 cm), in November. These maximum and minimum averages are reflected in the USHCN data collected at Waycross, Georgia, with greatest average monthly precipitation, approximately 6.5 inches (16.5 cm) occurring in July and the least, approximately 2.2 inches (5.6 cm), occurring in November. Average annual precipitation is approximately 50 inches (128 cm) (Table 5). Precipitation varies across the refuge from nearly 50 inches (127 cm) in the northern part of the refuge to over 56 inches (142.2 cm) near the Florida line (NOAA 2008). The greatest year-to-year variability in precipitation at the USHCN station in Waycross, Georgia, occurs in June through September (Figure 13). Total annual precipitation variation at the USHCN station in Waycross, Georgia, appears to be fairly consistent, ranging from 40 to 60 inches (102 to 152 cm) with various extreme lows and highs during certain years (Figure 14). However, it is notable that the two driest years on record occurred in 2011 and 2012.

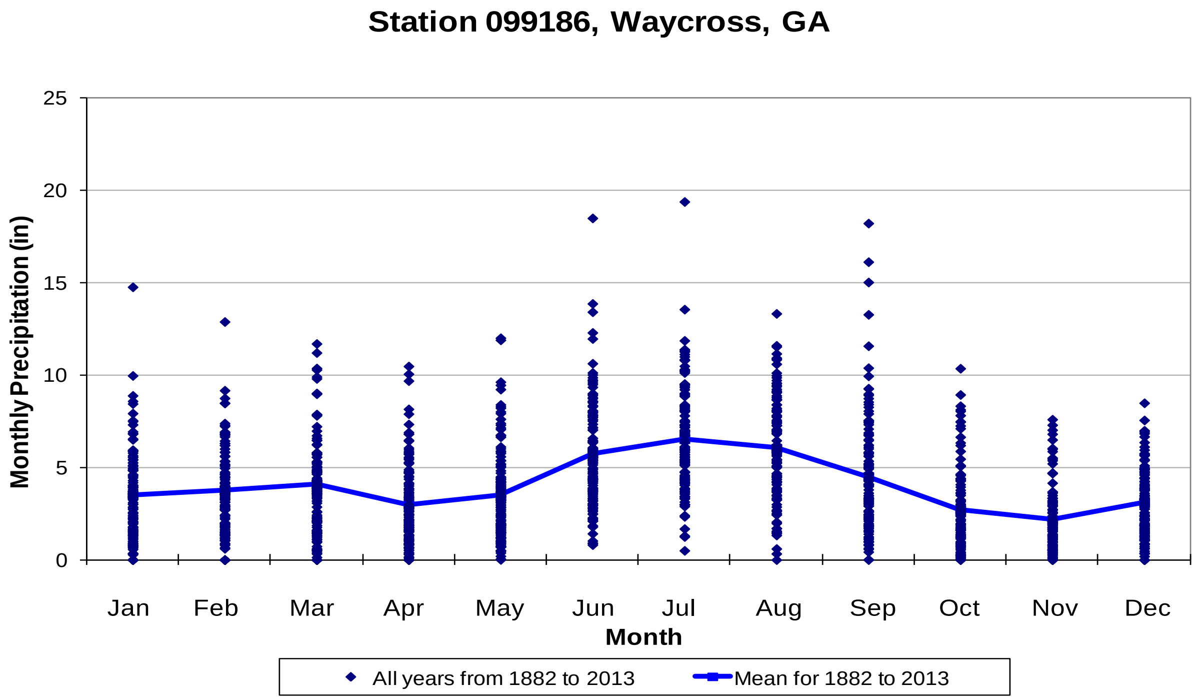


Figure 13. Mean and distribution of monthly precipitation (1882 – 2012) at Waycross, Georgia (USHCN Station 099186). [Source: Menne et al. undated].

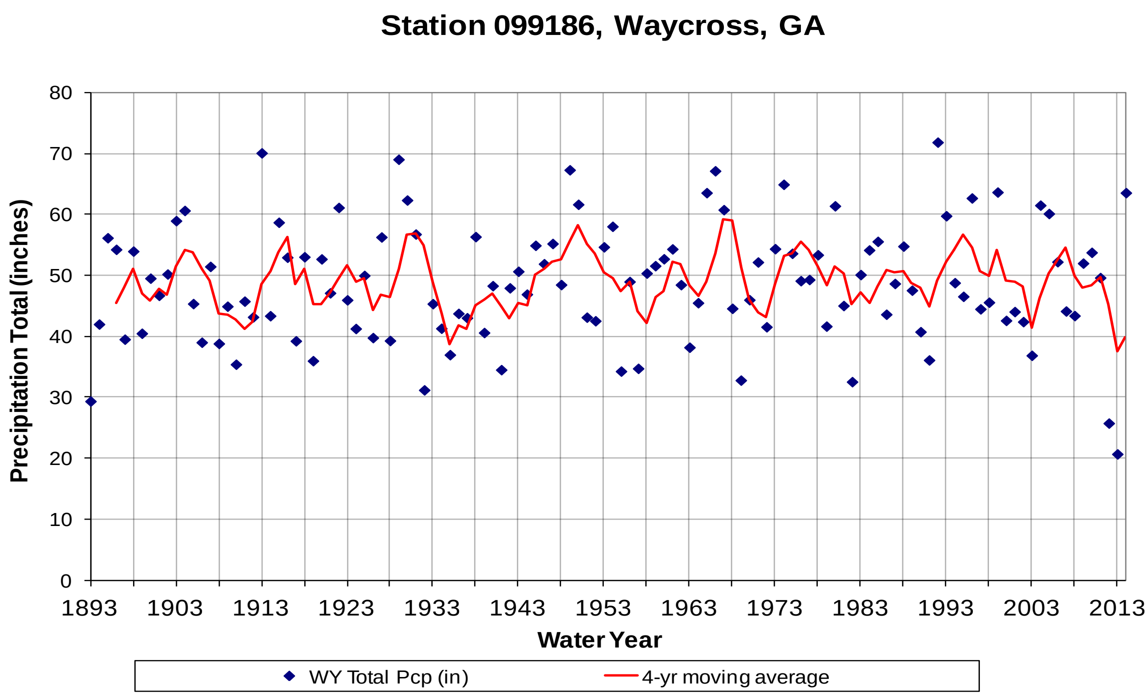


Figure 14. Total annual precipitation by water year (1892 – 2012) at Waycross, Georgia (USHCN Station 099186). [Source: Menne et al. undated].

4.7.1.3 Storm Frequency and Intensity

Rainfall on the Okefenokee NWR primarily results from frontal rainfall events in the spring and winter, and by tropical events in the summer, including localized thunderstorms, tropical storms and hurricanes (Cao 2000; Garza and Mirti 2003). During the summer months, the Bermuda High Pressure phenomena blocks fronts from progressing into South Georgia and ushers in warm moist air from the Atlantic Ocean and the Gulf of Mexico. As these moist coastal air masses pass over warm land surfaces their temperature increases, resulting in frequent and intense afternoon thunderstorms. During the winter, without the blocking effect of the Bermuda High, cold fronts will move through South Georgia, potentially precipitating and leaving behind cold, dry and relatively stable high pressure systems. The greatest average annual precipitation occurs on the Okefenokee NWR from May to October, during both the Bermuda High and Atlantic Coast Hurricane season. More information regarding the effects of the Bermuda High may be found in Section II of the Okenfenokee NWR CCP. Precipitation frequency and intensity in the Suwannee River Basin is also influenced by El Niño-Southern Oscillation (ENSO) events. El Niño years produce strong rainfall and flood events in winter. In contrast, during La Niña events there is less precipitation and conditions are dry in winter (Cao 2000; Tootle and Piechota 2004). The fall season is typically drier, but occasional tropical storms and hurricanes produce intense precipitation, which results in rapid but relatively short-lived increases in river discharge.

4.7.1.4 Streamflow

Within the Okefenokee Swamp region, stream flow is linked to precipitation, as well as to upstream surface water flows and, to a lesser extent, surficial groundwater contributions. The Hydro-Climatic Data Network (HCDN) is a network of USGS stream gaging stations that are considered well suited for evaluating trends in stream flow conditions (Slack et al. 1992). Sites in the network have periods of record that exceed 20 years and are located in watersheds that are relatively undisturbed by surface water diversions, urban development, or dams. The USGS HCDN gage (02314500) at Fargo, Georgia, is located on the Suwannee River at US 441, immediately downstream of the refuge (site no. 2 in Figure 10). The station has a period of record from 1927 to present. Monthly and annual discharge data are summarized in Figure 15 and Figure 16, respectively.

Mean daily discharge on the Suwannee River at Fargo, Georgia, is 964 cfs; maximum flows occur from November to January and low flows occur in spring (February through April) and late summer (August and September) (Figure 15). Elevated summer precipitation (Table 5, Figure 13) has little effect on river discharge because of high (relative to overall precipitation amounts) rates of ET, as evidenced through low to average summer flow rates (Figure 15). Periods of predominantly above-average streamflow occurred in the years 1945-1949, 1958-1961, 1964-1966, and 1970-1973. The highest annual flow was in 1948 (3,512 cfs or 364% of average annual flow). Periods of below average streamflow include 1938 to 1941, 1950 to 1957, 1999 to 2002, and 2006 to 2012. Besides USGS documented periods of zero flow prior to the construction of the sill, the lowest annual flow was in 2011 (14.5 cfs or 1.5% of average annual flow). Based on anecdotal information, it appears year-to-year variability in discharge is high (approximately 50%; Figure 16), and much greater than the annual variability in precipitation (approximately 20%; Figure 14).

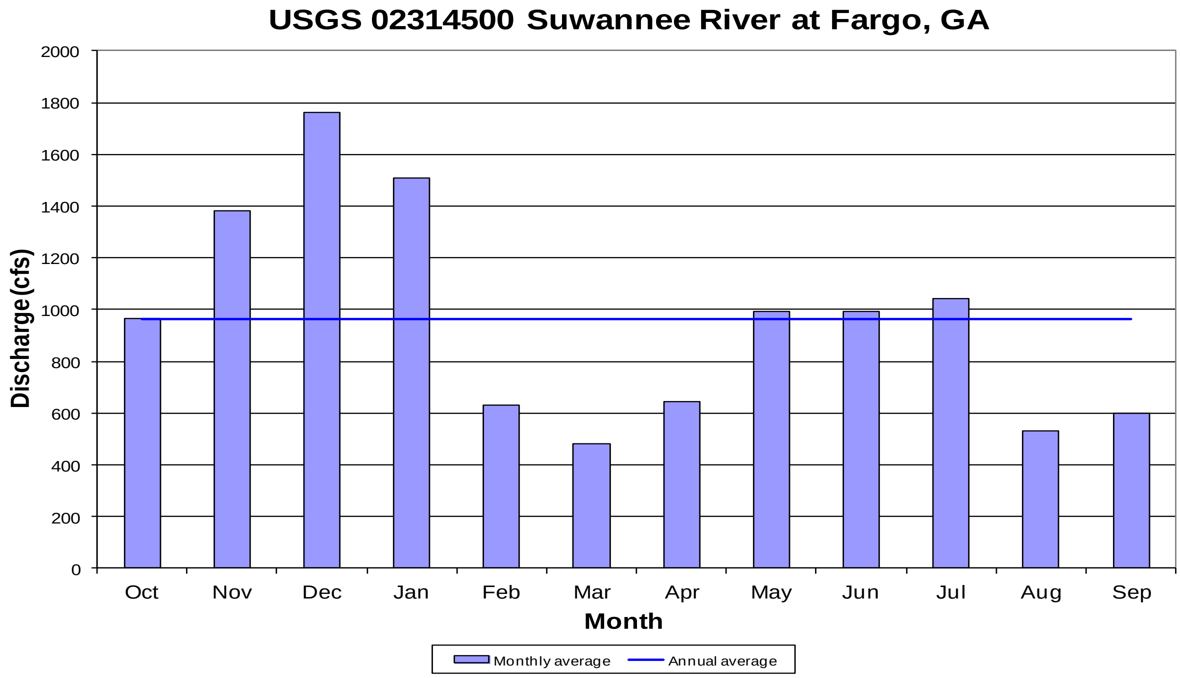


Figure 15. Average monthly discharge from the Suwannee River at Fargo, Georgia. From data collected between 1927 and 2014. [Source: USGS 2013].

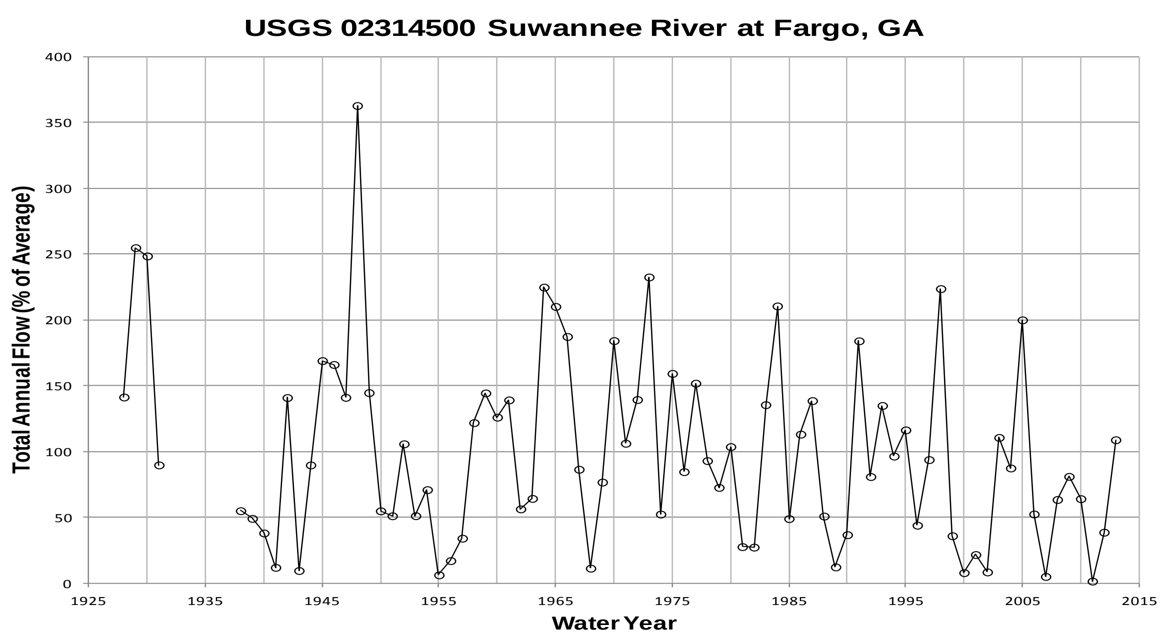


Figure 16. Percentage of average annual flow on the Suwannee River at Fargo, Georgia: 1927 – 2012. Average annual flow from the period of record is 958 cubic feet per second (cfs). 1 cfs = 448.8 gallons per minute. [Source: USGS 2013].

4.7.1.5 Drought Conditions and Wildfires

Wildfire is a natural, frequent, and desirable occurrence on the Okefenokee NWR. Wildfires are typically subject to drought conditions and are most common during the summer under Bermuda High conditions when evapotranspiration is elevated, the water table is low, and thunderstorms are more frequent. The last recorded wildfire with enough intensity to burn away the upper layer of the peat bed and create prairie habitat occurred in 1844. However, the droughts and subsequent fires of 1932 and 1954-1956 are notable events. More specifically, the 1954-1956 drought was correlated with a La Niña event and is documented as being one of the worst droughts on record (Cao 2000). This is illustrated in long-term precipitation trends recorded at Waycross, Georgia (Figure 14) and below average stream flows recorded at the USGS HCDN site at Fargo, Georgia, between 1954 and 1955 (Figure 16).The lowest flow ever recorded at the Fargo gage was in 2011 (1.5% of the annual average) (Figure 16). During the 2011 drought in the southeastern U.S., drought intensity in the upper basin was exceptional (1 in 50 years) and groundwater levels reached record lows (Gordon et al. 2012). A lightning strike in April 2011 during the prolonged drought caused the Honey Prairie Fire in the southwest portion of the refuge. The fire was officially declared out almost one year later, in April 2012. The fire burned a total of 309,200 acres, primarily within refuge boundaries (USFWS 2012). Wildfires also occurred under drought conditions in 2007.

Figure 17 and Figure 18 are graphical representations of two long-term drought indices for Climate Division 9, Georgia's southeastern climate division, as shown in Figure 10. Figure 17 illustrates the Palmer Drought Severity Index (PDSI), a meteorological drought index, which responds to weather conditions that have been either abnormally dry or wet (NOAA 2015). Palmer developed criteria to measure when a drought or wet spell begins and ends, which adjust the PDSI accordingly. The PDSI is calculated based on precipitation, temperature and local available water content in soil (NDMC 2015). The index is primarily used to verify long-term drought conditions and is considered most effective for unirrigated cropland (NIDIS 2015). Figure 18 depicts the Palmer Hydrological Drought Index (PHDI), a near real-time hydrological index based on moisture inflow (precipitation), outflow and storage (NOAA 2015). The PDHI does not take into account long-term meteorological trends. (NDMC 2015). Both indices reflect historical records of droughts on the refuge for the period of record from 1895 to 2014. Based on both indices, drought intensity and frequency between 1995 and 2014 appear to have increased as compared to any other 20 year span within the period of record. The last 20 years of data suggest a climatic shift in the region and a predisposition to drought conditions. The most extreme PDSI and PHDI negative values during the period of record occurred in 2011, coinciding with the second driest year in the precipitation record (followed by an even drier year in 2012; see Figure 14).

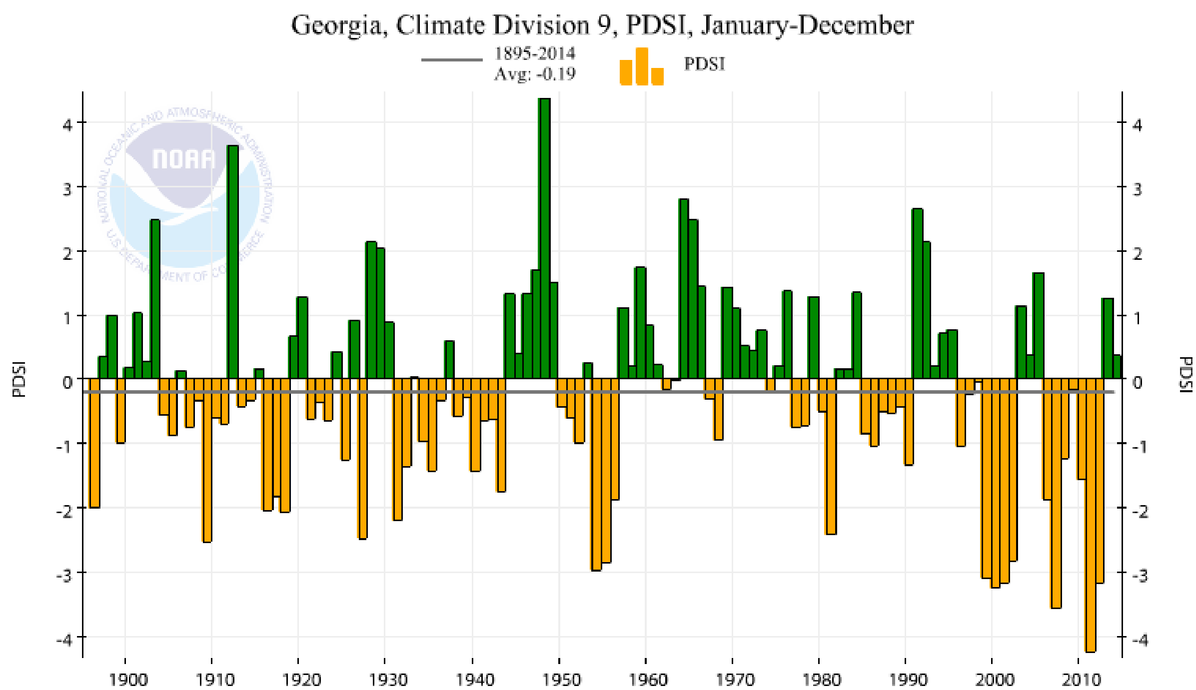


Figure 17. Palmer Drought Severity Index (PDSI) for Georgia's southeast climate division, Division 9, over a period of record form 1895 to 2014. [Source: NOAA 2015]

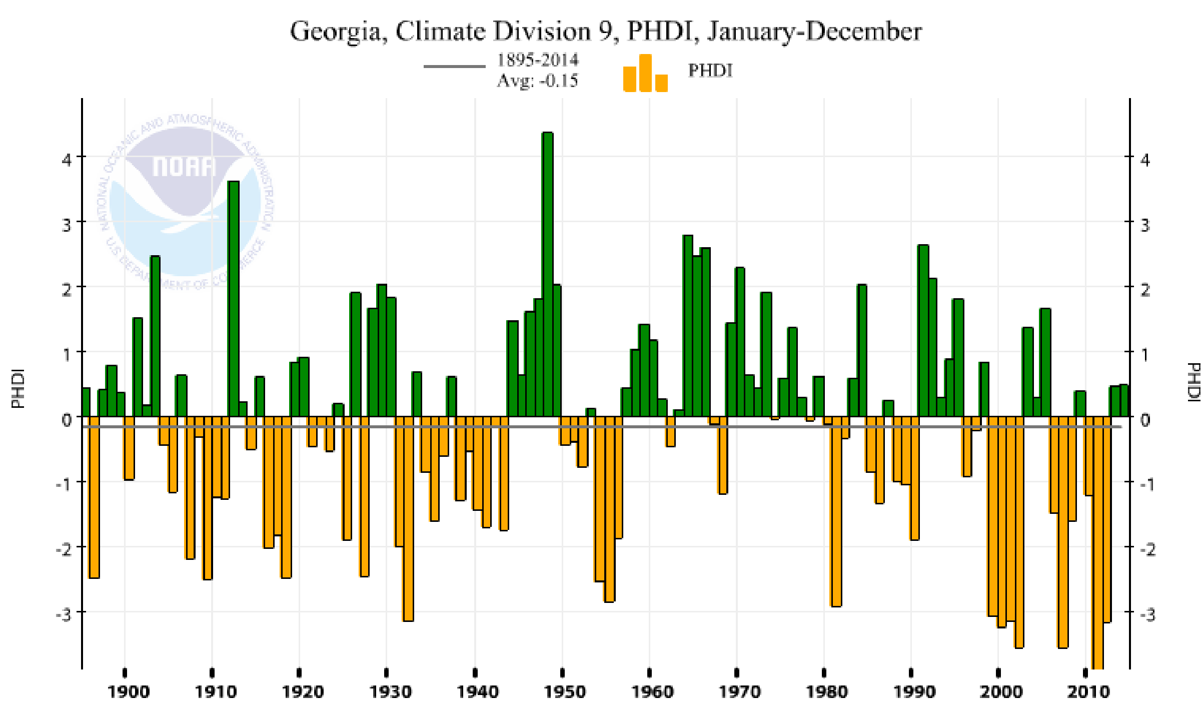


Figure 18. Palmer Hydrologic Drought Index (PHDI) for Georgia's southeast climate division, Division 9, over a period of record form 1895 to 2014. [Source: NOAA 2015]

4.7.2 Climate Change Projections

The U.S. Global Change Research Program's 2009 report Global Climate Change Impacts in the United States (Karl et al. 2009) synthesized a large body of scientific information composed of numerous peer-reviewed scientific assessments. Climate models project continued warming in the southeastern United States, and an increase in the rate of warming through 2100. The projected rates of warming are more than double those experienced since 1975, with the greatest temperature increases projected to occur in the summer. By the last decade of the 21st century, global average surface temperature is projected to rise by 2.8 C (5°F) under the A1B (moderate) emissions scenario and 3.4 C (6.1°F) under the A2 (high) emissions scenario relative to a 1980-1999 baseline (IPCC 2007). For the RHI area, the Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model mean simulation predicts an increase of about 1.5 to 2.5°F by 2050 for both the high (A2) and low (B1) emission scenarios. By 2085, there is a variance between the warming predictions of the models, with a simulated temperature warming range of 2.5 to 3.5°F under the B1 scenario, and 6.5 to 7.5°F under the A2 scenario. The CMIP3 models indicate that temperature changes across the Southeast US for all future time periods and both emissions scenarios are statistically significant (NOAA 2013). The North American Regional Climate Change Assessment Program (NARCCAP 2012) Regional Climate Model (RCM) Multi-Model Simulation indicates a projected mean increase of between 25 and 35 days per year with a maximum temperature of 95°F within the RHI (NOAA 2013).

Most global climate models (GCMs) predict that as the climate warms, the frequency of extreme precipitation will increase across the globe (O'Gorman and Schneider 2009). However, less than two-thirds of GCMs agree on the predicted change in direction of future precipitation events for the eastern USA (IPCC 2007). The Intergovernmental Panel on Climate Change (IPCC) AR4 model simulation of the A1B "middle-of-the-road" climate scenario projects a 7% increase in rainfall in eastern North America by the end of the 21st century (2080 – 2099); however, the same model predictions for the Caribbean are significantly different, indicating that projections for Southern Georgia and Northern Florida are complex and uncertain.

The NARCCAP RCM projects a slight overall increase in total annual precipitation (3 to 6%) within the RHI, based on the difference between projections for 2041-2070 and the baseline of 1971-2000 under the A2 scenario. Seasonally, precipitation amounts are projected to remain consistent with the exception of the fall months, which may see an increase of 10-15 % change (from Ingram et al. 2013, NOAA 2013).

Due to the uncertainty in projections for future precipitation in the southeast, there is also uncertainty regarding the effects of climate change on water resources. In the Coastal Plain regions, direct human impacts on streamflow have generally been larger than the impacts of recent climatic trends (Wang and Hejazi 2011). The RHI is predicted to have a slightly increasing (but not statistically significant) trend in mean annual water yield for 2010 to 2060, normalized by the 2001 to 2010 mean annual water yield (Marion and Sun 2012).

The 2009 National Climate Assessment suggests that droughts, floods, and water quality problems are likely to be amplified by climate change in the southeastern United States (Karl et al 2009). Climate models and theories project that climate change will cause the globally averaged *intensity* of tropical cyclones to increase by 2 to 11% by the year 2100 (Knutson et al. 2010), but the globally averaged *frequency* of tropical cyclones is projected to decrease by 28% (IPCC 2007; Bender et al. 2010). This is projected to result in more frequent and/or severe droughts, given the contribution of tropical cyclones to rainfall during the warm season (Misra et al. 2011).

Future climate warming likely will increase water loss through ET due to increased evaporative potential and plant species shift. Greater ET can decrease total streamflow, groundwater recharge, flow rate, and regional water supplies (Ingram et al. 2013). The combination of higher evapotranspiration with the expected increase in severity of storm events, will lead to less water absorbed, retained and available for use by natural systems, businesses and the public.

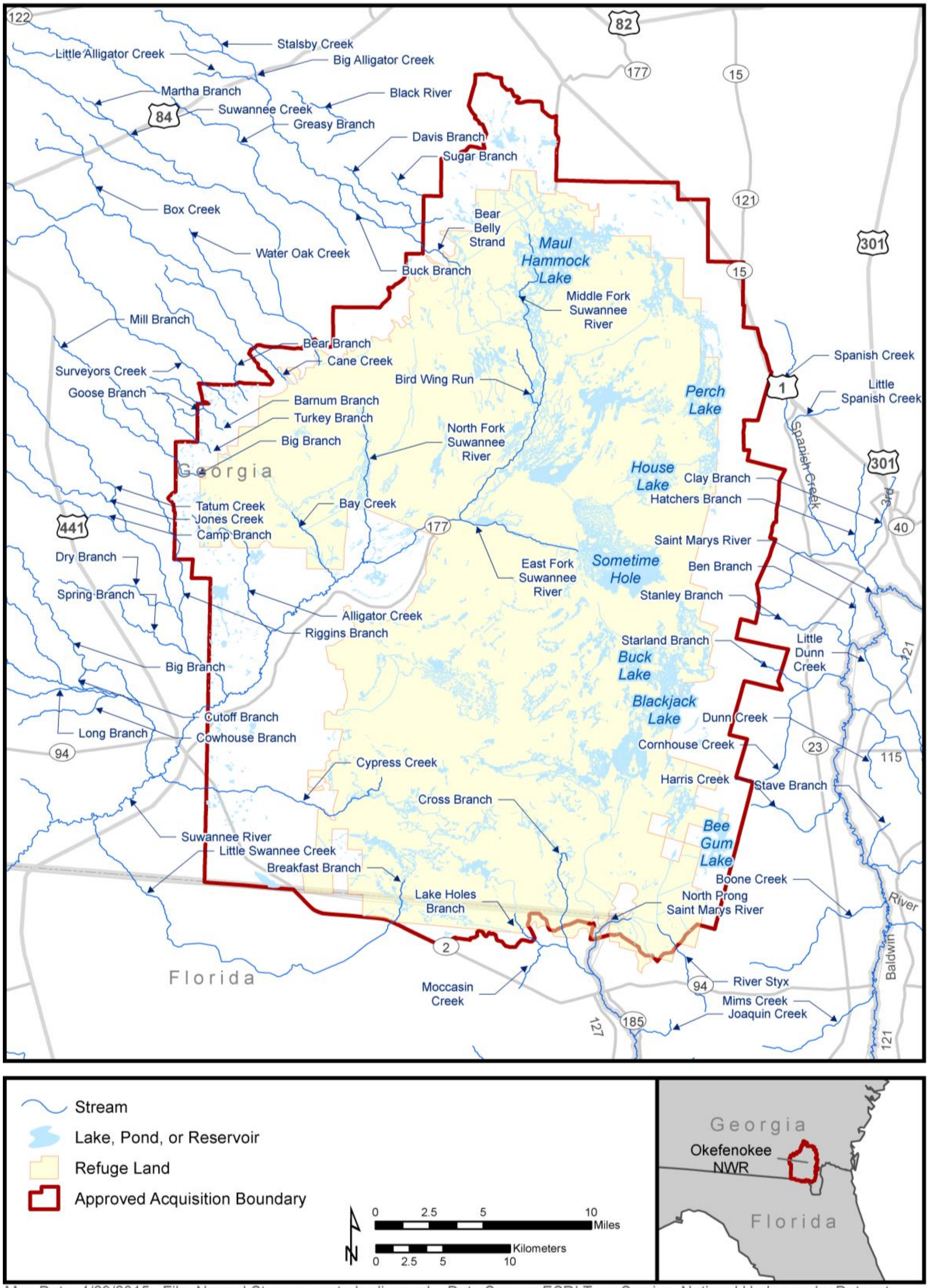
5 Inventory Summary and Discussion

5.1 Water Resources

This section briefly summarizes and discusses important aspects of the water resources inventory (both surface water and groundwater) for Okefenokee NWR, including important physical water resources, water resources related infrastructure and monitoring, water quantity, and water quality conditions. Water Resource links from the USGS, including links to streamflow and groundwater data and relevant water resource reports for the St. Marys and Upper Suwannee subbasins (HUCs 03070204, and 03110201, respectively) (and the other subbasins in the RHI) are available from the USGS website.

5.1.1 Rivers, Streams, and Creeks

An inventory of named rivers, streams, and creeks was compiled from the National Hydrography High-Resolution (1:24,000) Dataset (NHD) for the RHI, using the flowline feature dataset. The RHI for Okefenokee NWR includes a total of 5,050 miles of named and unnamed streams. Within the refuge acquisition boundary, there are 31 named streams, totaling 120.5 miles, as well as 594.4 miles of unnamed streams. On refuge land, there are 19 named streams, totaling 61.8 miles, as well as 335.5 miles of unnamed streams (Figure 19, Table 6). The Middle Fork of the Suwannee River is the longest stream on refuge land. The Suwannee River begins at the confluence of the Middle Fork and East Fork, flows for 2.1 miles within refuge land, continuing downstream for another 20 miles within the refuge acquisition boundary.



Map Date: 4/29/2015 File: Named Streams_waterbodiesmxd Data Source: ESRI Topo Service, National Hydrography Dataset.

Figure 19. National Hydrography Dataset (NHD) named streams and waterbodies near Okefenokee National Wildlife Refuge. See Table 6 for miles of streams on the refuge and Table 7 for acres of waterbodies.

Table 6. National Hydrography Dataset (NHD) named streams within Okefenokee National Wildlife Refuge. Locations are shown on Figure 19. [Source: USGS 2010]

Named Stream/River	**Miles Within Acquisition Boundary**	**Miles on the Refuge**
(unnamed)	*594.4*	335.5
Alligator Creek	9.4	2.9
Barbers Run	1.1	1.1
Barnum Branch	1.8	--
Bay Creek	4.3	3.5
Bear Belly Strand	2.3	0.7
Bear Branch	1.0	--
Big Branch	1.5	--
Bird Wing Run	3.3	3.3
Breakfast Branch	2.4	2.3
Cane Creek	2.2	0.3
Cross Branch	4.5	4.5
Cypress Creek	10.4	4.1
Double Branches	0.8	--
East Fork Suwannee River	4.7	4.7
Goose Branch	0.4	--
Gum Swamp	2.6	--
Lake Holes Branch	1.7	1.1
Middle Fork Suwannee River	17.1	17.1
North Fork Suwannee River	7.0	5.3
North Prong Saint Marys River	2.2	1.7
Riggins Branch	1.2	--
River Styx	1.5	1.5
Stanley Branch	0.4	--
Starland Branch	1.5	--
Surveyors Creek	2.3	--
Suwannee Canal	4.8	4.8
Suwannee Creek	1.3	0.6
Suwannee River	22.1	2.1
Suwannee River Sill	2.0	0.1
Tatum Creek	1.8	--
Turkey Branch	0.9	--
Total	***715.0***	***397.2***

5.1.2 Lakes, Ponds, and Reservoirs

According to the NHD, the RHI contains 103,203 acres of lakes, ponds, and reservoirs, of which, 30,583 acres consist of named waterbodies. Within the Okefenokee NWR acquisition boundary, there are 53,749.2 acres of lakes, ponds, and prairie habitat, including 24,201 acres comprising 22 named waterbodies (Figure 19, Table 7).

Table 7. Named lakes, ponds, and prairie habitat within the RHI for Okefenokee NWR. Lakes larger than 500 acres are labeled on Figure 19. [Source: USGS 2010]

Waterbody Name	**Acres within Acquisition Boundary**
(unnamed)	*29,488.2*
Bee Gum Lake	538.8
Big Water Lake	385.9
Billys Lake*	60.0
Blackjack Lake	7,369.6
Boone Lake	0.6
Buck Lake	604.1
Buzzards Roost Lake	17.0
Coward Lake	20.3
House Lake	936.8
Lake Holes	0.4
Long Pond	121.9
Lower Lake	0.8
Marys Lake	0.4
Maul Hammock Lake (Maul Hammock Prairie)	4,972.7
Monkey Lake	1.9
Perch Lake	3,777.8
Sand Lake	5.2
Skull Lake	6.1
Sometime Hole (Chase Prairie)	5,359.5
Suwannee Lake	6.8
The Pocket	1.7
Trout Lake	12.7
Total	***53,689.2***

*This is a local name for a waterbody that is not named in the NHD

5.1.3 Springs and Seeps

The NHD inventory of springs and seeps indicates that there are no known springs within the Okefenokee NWR approved acquisition boundary. There are 21 known springs in the St. Marys River portion of the RHI: six are located in Georgia and 15 are located in Florida. All are downstream from the refuge. The springs are listed as unnamed in the NHD, although they may be known by local names. South of the refuge, there are two springs that feed the North Prong St. Marys River, one in Georgia and one in Florida. There is one spring along the St. Marys River, south of the refuge in Florida.

5.1.4 Wetlands

The National Wetland Inventory (NWI) was established by the U.S. Fish and Wildlife Service in 1974 to provide information on the extent of the nation's wetlands (Tiner 1984). NWI produces maps of wetland habitat as well as reports on the status and trends of the nation's wetlands. Using the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979), wetlands have been inventoried and classified for approximately 90% of the conterminous United States and approximately 34% of Alaska. Cowardin's classification places all wetlands and deepwater habitats into 5 "systems": marine, estuarine, riverine, lacustrine, and palustrine. Most of the wetlands in the United States are either estuarine or palustrine (Tiner 1984). By far the dominant wetland system at Okefenokee NWR is palustrine, with lacustrine a distant second. These are defined in Cowardin et al. (1979) as follows:

> **Palustrine**: The Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean derived salts is below 0.5% (e.g., inland marshes, bogs, fens, and swamps).
>
> **Lacustrine:** The Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water. Lacustine waters may be tidal or nontidal, but ocean derived salinity always less than 0.5%.

The different systems can be broken down into subsystems, classes and hydrologic regimes based on the wetland's position in the landscape, dominant vegetation type, and hydrology.

Approximately 95% of the area within the Okefenokee NWR acquired land boundary and 83% of the area within the acquisition boundary is classified as wetlands according to the NWI (USFWS undated; Table 8, Figure 20). Approximately 98% of the wetlands are classified as palustrine, the majority of which is freshwater forested/shrub wetland, while the 2% is classified as lacustrine.

The NHD waterbodies feature class also contains a "SwampMarsh" feature type. Approximately 78% of the land within the Okefenokee NWR acquisition boundary (407,280 acres) is classified as SwampMarsh according to the NHD dataset, slightly lower than the 83% classified as wetlands in the NWI.

Table 8. National Wetlands Inventory wetland habitat types within Okefenokee National Wildlife Refuge acquired and acquisition boundaries. [Source: USFWS undated]

Habitat Type	**System**	**Acres on Refuge**	**Percent of Total**	**Acres within Acquisition Boundary**	**Percent of Total**
Freshwater Emergent Wetland	Palustrine	25409.9	7.1	28591.7	5.5
Freshwater Forested/Shrub Wetland	Palustrine	303760.1	84.9	392665.7	75.2
Freshwater Pond	Palustrine	1911.3	>1	2121.8	>1
Lake	Lacustrine	8856.8	2.5	8935.2	1.7
Riverine	Riverine	144.9	>1	318.7	>1
Upland/Unclassified		*17632*	*4.9*	*89547.5*	*17.1*
All Wetlands		*340083*	*95.1*	*432633.1*	*82.9*
Total		***357715***	***100.0***	***522180.6***	***100.0***

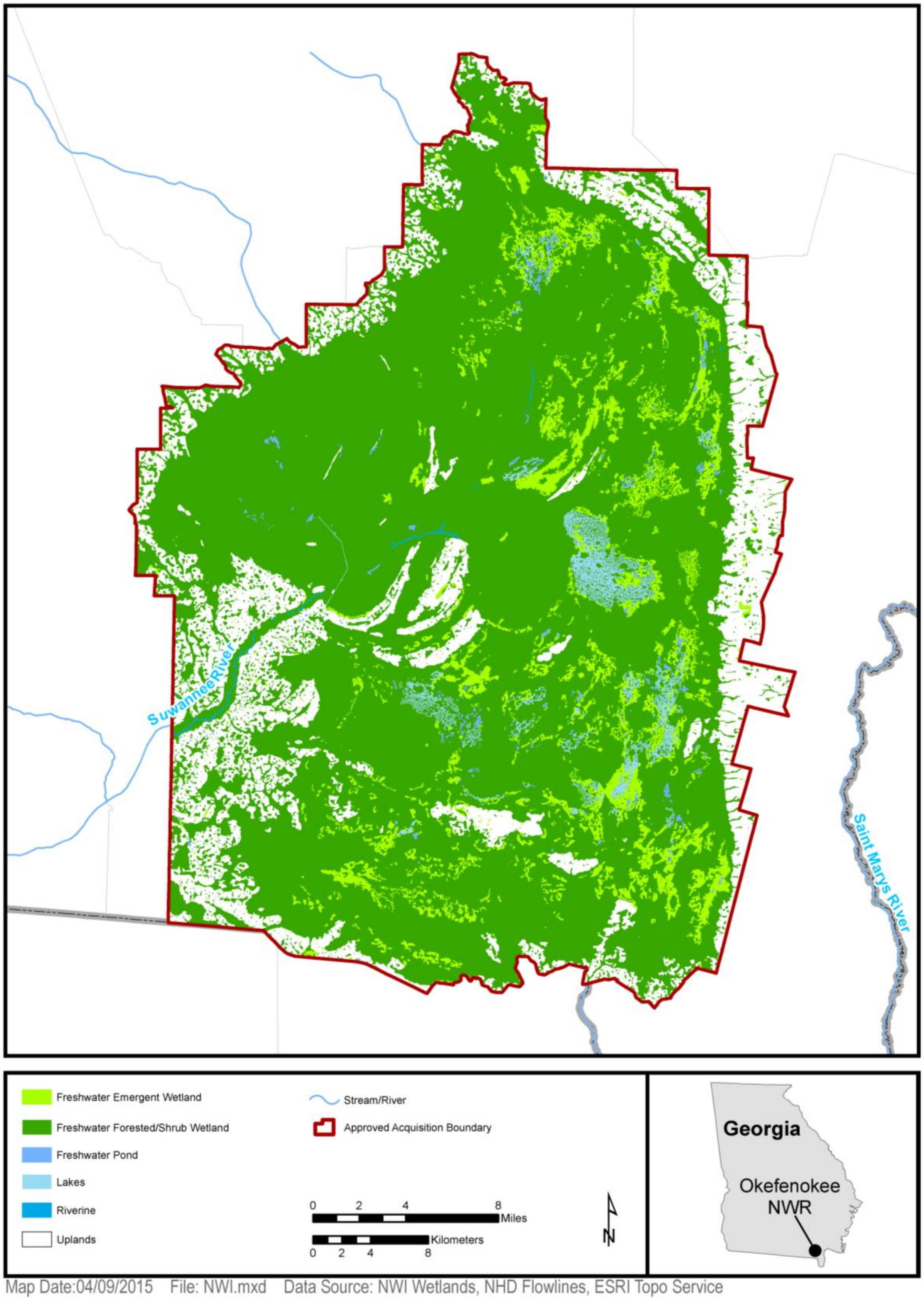


Figure 20. National Wetlands Inventory (NWI) land cover within the Okefenokee NWR acquisition boundary.

5.1.5 Groundwater

Groundwater resources are used for refuge maintenance and operations. Aquifers are discussed in greater detail in section 4.3. Infrastructure in place to obtain groundwater on the refuge is discussed in section 5.2.5.

5.2 Infrastructure

Since the refuge was established in 1936, infrastructure on the refuge has been constructed and maintained for multiple purposes, including recreation, fire management, and research. For example, wooden platforms have been constructed along the canoe trails for overnight camping, the Suwannee Sill was constructed for fire management, and water monitoring stations have been installed for baseline research purposes. Within Wilderness areas on the refuge, there are special provisions that allow certain infrastructure. For information on the legal obligations related to wilderness designation, see section 5.7.

5.2.1 Water Control Structures

Prior to restoration activities in 2001, there were two concrete water control structures located along the Suwannee River Sill. During its operational lifetime (1962-2001), the sill was operated as a fixed entity with no attempt at regulation by the gates or stop logs (Loftin et al. 2000, Giese 2004). The south water control structure collapsed in 1979 and was replaced (Loftin et al. 2000). The gates at the spillways were permanently opened in 2001 as a part of the Suwannee River Sill restoration in an attempt to restore more of the natural hydrology to Okefenokee Swamp.

5.2.2 Impoundments

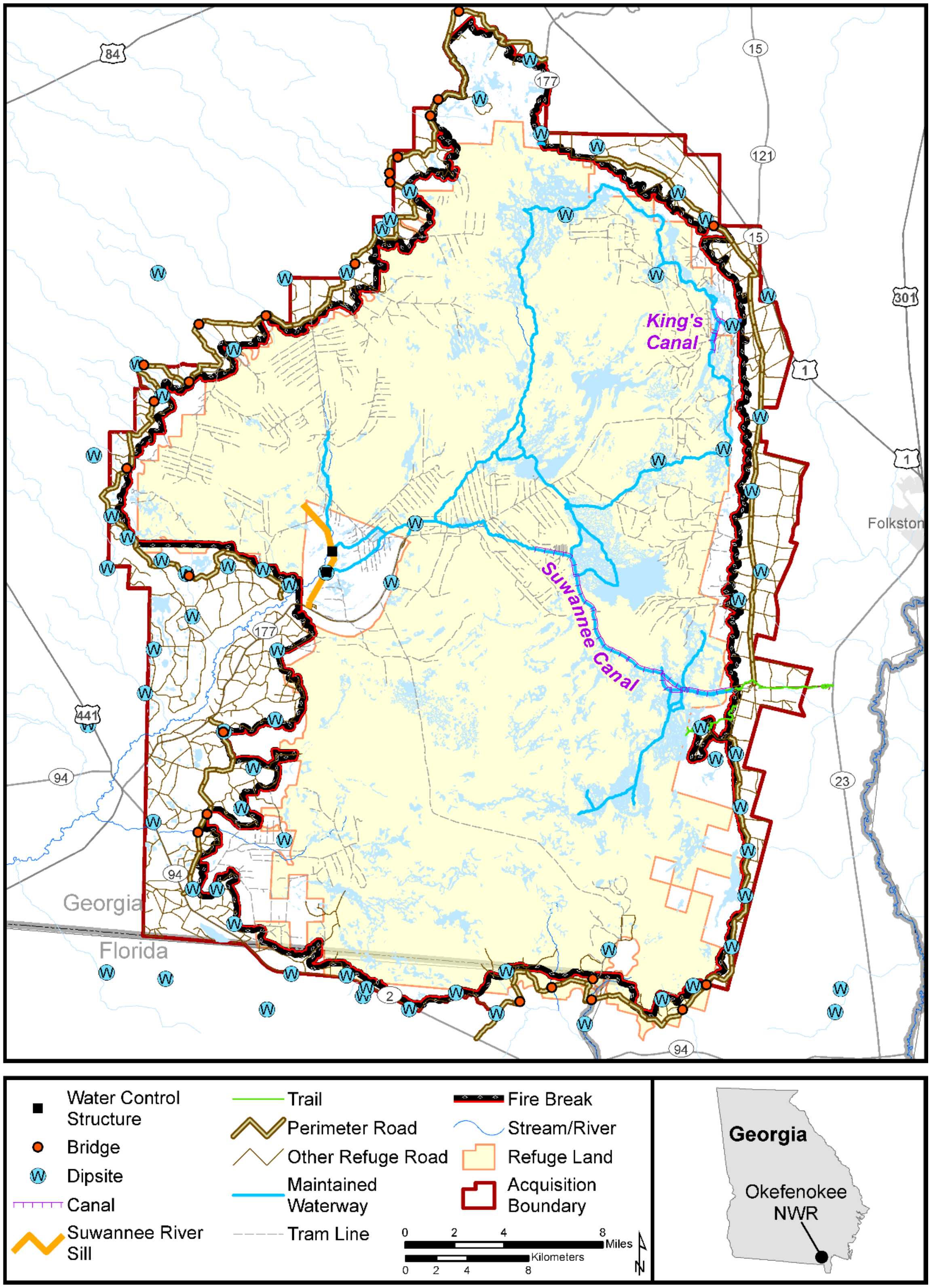
Various impoundments to stabilize swamp water levels for maintenance of waterfowl habitat in the swamp have been proposed since the inception of the refuge. The Suwannee River Sill was the first structure constructed on refuge land for the purpose of retaining water. Completed in 1962, the Sill was intended to impound water during periods of drought for the purpose of fire suppression. Due to a combination of factors, including high evapotranspiration rates occurring simultaneously with seasonally high precipitation, the Sill never fulfilled its original impoundment goals. During low water periods, the Sill affected water levels only in a 10,000- to 15,000-acre area, or 1% of the swamp (Loftin 1998). At higher water levels, the Sill affected water levels in 18% of the swamp (Loftin et al. 2000). The Sill was modified in 2001 when the water control structures were opened and the structure was breached in three places (in 2010) in an attempt to restore hydrology within this portion of the swamp (S. Aicher, written communication, May 6, 2015). Section 4.5 contains additional information on the history of the Suwannee River Sill and its hydrologic effects.

5.2.3 Roads and Bridges

The Swamp Perimeter Road was established after the fires of 1954-1955 to provide access around the swamp. Along with numerous forest industry roads, it also provides access from public roads to the upland management compartments. Within the refuge boundary, approximately 70 miles of roads provide access through the 16 compartments (USFWS 2006). Geographic Information Systems (GIS) spatial data of roads on the refuge indicate that the refuge contains a total of 175 miles of mapped and maintained roads (Figure 21).

The refuge is responsible for the maintenance of the portions of the Swamp Perimeter Road that falls on refuge lands and all of the 26 bridges on the Swamp Perimeter Road (Figure 21) (USFWS 2006). At times, the Perimeter Road and other roads on the refuge can impound water. In 2007, fire suppression activities created large berms along the Perimeter Road that altered water flows. Many of these berms were never re-structured. Culverts along the roads are often in need of repair and may also contribute to altered hydrology (S. Aicher, written communication, May 6, 2015).

A network of tram roads were constructed deep into the major timbered areas of the swamp prior to cessation of logging in 1927 (USFWS 2006). Known locations of tram roads have been mapped by USFWS staff and are shown on Figure 21. The total length of historic tram roads mapped on the refuge is 563 miles.



Map Date: 7/15/2015 File: Infrastructure_v2 Data Source: NHD Flowlines, USFWS Swampline/Hydrologic Basins and Cadastral Data, ESRI Topo Service.

Figure 21. Infrastructure affecting water on and near Okefenokee National Wildlife Refuge.

5.2.4 Dams, Dikes, and Levees

The Suwannee River Sill is located near the west entrance to the refuge at Stephen Jackson State Park, within the acquisition boundary but outside the designated Class I Wilderness Area. It spans 7.2 km (5 miles) at an average elevation of 35.5 m (116.5 feet) AMSL. It stands approximately 3 to 4 m (10 to 13 feet) above the surrounding Suwannee River floodplain. A ditch borders the entire length of the structure to the east. The original structure contained two spillway gates, which were left closed for most of their existence (Loftin et al. 2000). The Suwannee River Sill is discussed in detail in Sections 4.5 and 5.2.2.

Within the Upper Suwannee subbasin, the National Inventory of Dams (NID) lists one privately owned dam, the Lake Verne Dam, on Sweetwater Creek in Clinch County (NID ID: GA03529). Sweetwater Creek is a tributary of Suwannoochee Creek, which is a tributary to the Suwannee River; however, the confluence is downstream from the refuge. Completed in 1915, the dam is 7 feet high and 740 feet long, with a maximum discharge of 2,800 cfs and maximum storage of 2,131 acre-feet.

5.2.5 Water Supply Wells

There are several wells located on the refuge, mainly related to the east side office, maintenance and visitor services complex, the west side maintenance shop and residences, and Stephen C Foster State Park facilities on Jones Island. There is a well that was placed near the Mill Road dip site outside USFWS property that was used to fill the dip site during the 2007 fires. The refuge recently installed a well to supply water to a sprinkler system along the newly constructed boardwalk at the east entrance. This will be used during wildfires to protect the boardwalk (S. Aicher, written communication, May 6, 2015).

5.2.6 Trails, Canals, and Maintained Waterways

Refuge staff maintains 120 miles of canoe trails within the peat, connecting areas of naturally occurring deeper water. The canoe trails are maintained to dimensions of approximately 8 feet wide and 3 feet deep in the prairies (S. Aicher, written communication, May 6, 2015). There are 8.5 miles of surface trails and boardwalks near the Camp Cornelia entrance to the refuge (Figure 21).

The NHD lists 123.8 miles of canals within the Okefenokee NWR RHI, and 20.7 miles of canals within the Acquisition Boundary. On the refuge, there is only one inventoried named canal, the Suwannee Canal, which is listed at 1.4 miles. The entirety of the original length of the canal is not captured by the NHD. The Suwannee Canal originated at Camp Cornelia. Sixteen miles were originally excavated. The current canal extends west 11.5 miles toward the Upper Suwannee River subbasin (Figure 21; USFWS 2006). King's Canal, a 3 mile long canal related to 1930s peat mining, begins at the swamp's edge, enters Carters Prairie, and extends a short distance north and south near the Kingfisher Landing entrance (Figure 21; USFWS 2006). King's Canal is not represented in the NHD. Both canals are a part of the maintained canoe trails network, and are approximately 20 to 40 feet wide and 4 to 6 feet deep (S. Aicher, written communication, May 6, 2015).

5.2.7 Fire Management Infrastructure

Infrastructure related to fire fighting and fire management has altered the hydrology, geomorphology, and vegetative communities of the refuge. As mentioned in Section 5.2.3, the Swamp Perimeter Road that surrounds the swamp was created for the purpose of access for fighting fires, and at times alters swamp hydrology. There are 54 dip sites for firefighting water withdrawal within the Okefenokee NWR acquisition boundary; eleven of these sites are on refuge land, and five are within the designated Class I Wilderness Area (Figure 21).

In 1993, the Swamps Edge Break (SEB) was created to provide a fuels management zone to allow indirect suppression actions during wildfires (USFWS 2006). GIS layers from the refuge indicate that 200 miles of firebreaks are maintained around the refuge. The SEB was originally only 25 feet wide and was to be maintained by mowing and disking. The purpose was to allow the area between the SEB and the Swamp Perimeter Road to be burned out more regularly so there would be a low fuel zone surrounding the swamp where wildfires may be able to be stopped from coming out of the swamp and burning commercial timber. In 2007, the SEB was expanded to 60 to 100 feet wide in many places, especially along the east side of the refuge, in an attempt to enhance and further establish a fire break. It passes through the small creeks and drains that enter the swamp, where it channelizes the water in these localized areas. Refuge staff plan to discontinue maintenance of the SEB on refuge lands and create a line of defense within the uplands rather than in the transition zone. Maintenance of the SEB outside of refuge lands is at the responsibility and discretion of the individual landowner (S. Aicher, written communication, May 6, 2015).

A helibase with 18 helispots is located near the east entrance at Camp Cornelia. The helibase provides a safe environment for takeoff and landing of land management flights over the refuge. The helibase consists of a cement pad surrounded by an area that is mowed periodically. The helispots on the islands are cleared of trees and a small area is kept free of shrubs. A square cement brick marks the landing location (S. Aicher, written communication, May 6, 2015).

5.3 Water Monitoring

This section presents current information on federal and state surface water and groundwater quantity and quality monitoring locations in the RHI containing the Okefenokee NWR and associated acquisition boundary. The USGS maintains a nationwide network of surface and groundwater water monitoring stations and makes monitoring data available through the National Water Information System (NWIS) database. Water monitoring can be broadly categorized as either water quality or water quantity focused. Water quality monitoring typically consists of collecting surface water or groundwater samples for chemical analyses in a laboratory or with sensors deployed in the field. Alternative protocols may use techniques such as aquatic invertebrate sampling as a proxy for water quality. Water quantity monitoring typically includes stage (water levels relative to a local reference point) and/or discharge (flow rate) in streams as well as water levels in other surface waterbodies or groundwater aquifers and typically is recorded at fifteen minute intervals. Continuous data for temperature and precipitation also is often available at these sites. WRIAs also consider weather stations and tide gages as other types of water-related monitoring. Due to the influence of atmospheric deposition of contaminants on surface water quality within the RHI, this section will also present monitoring locations from several national atmospheric monitoring networks. Sections 5.4 and 5.5 address trends for water quantity and quality at the RHI scale.

5.3.1 Surface Water Monitoring

5.3.1.1 Water Level and Discharge Monitoring

There are 213 USGS surface water monitoring sites within the RHI and 193 of these monitor surface water quantity (USGS 2015). In 2013, the USGS began construction of a hydrologic database containing detailed streamflow information and analysis for 26 gage sites in the Upper Suwannee and St. Marys subbasins (Table 9, Figure 22; Buell 2014). The USGS hydrologic database does not consider surface water sites in the Satilla River portion of the RHI due to a lack of surface water connection with the swamp. As of this writing, preparation of a final report was still in progress. A detailed final report is anticipated by the end of 2015.

Two sites featured in the USGS hydrologic database are within the Okefenokee NWR acquisition boundary: Site 02314274, Suwannee River at Sill near Fargo, Georgia (#15 in Table 9 and on Figure 22,) and site 023142741, North Fork Suwannee River at Sill near Fargo, Georgia (#16 in Table 9 and on Figure 22). Both sites have very short periods of record that start in the late 1990s and end in the early 2000s. These gages were established at the water control structures on the Sill to measure flow for a USGS study measuring pre- and post-restoration conditions (Giese 2004). The gage with the longest period of record is site 02314500, Suwannee River at US 441 near Fargo, Georgia (#19 in Table 9 and on Figure 22).

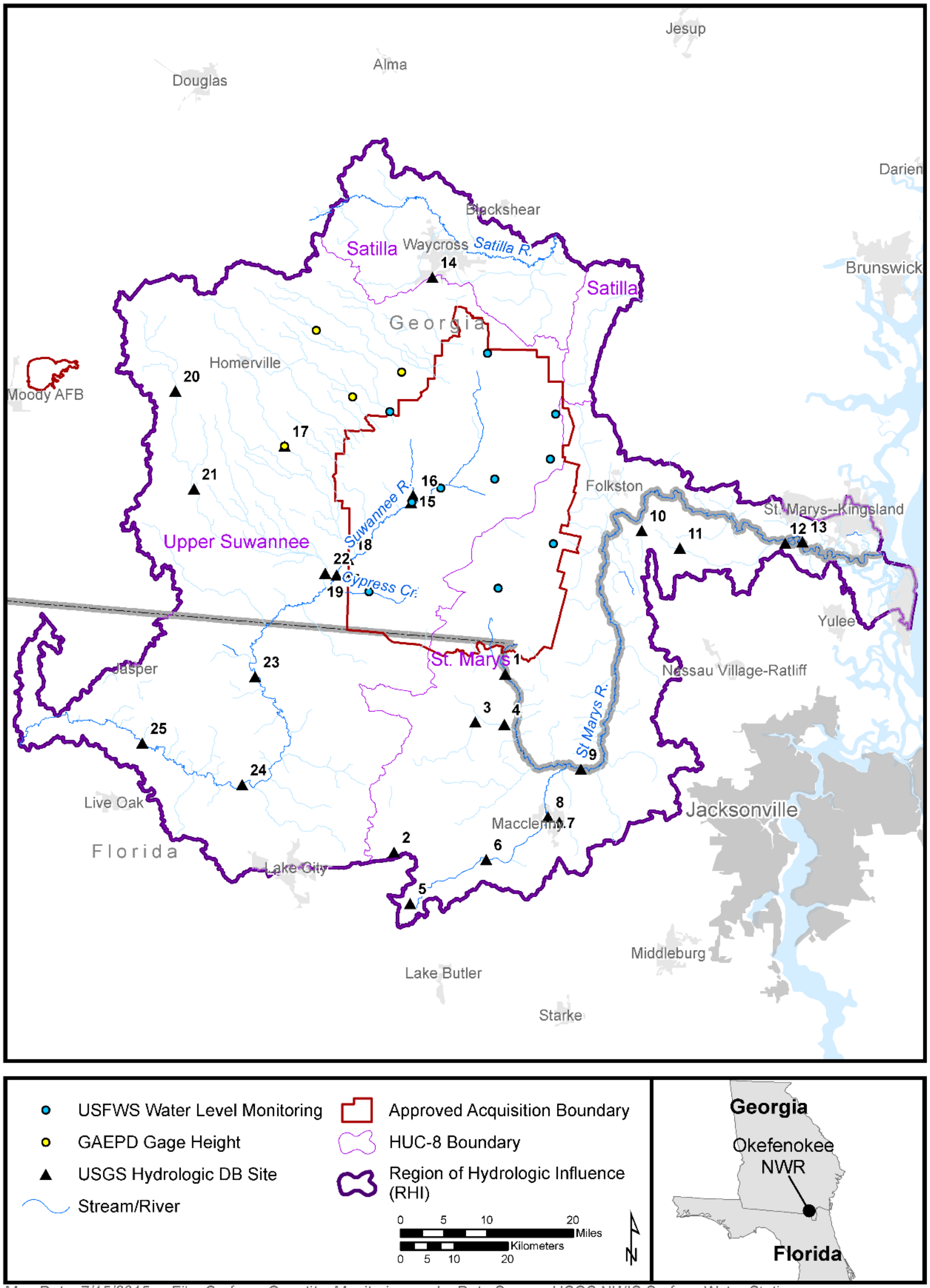
The Environmental Protection Division of the Georgia Department of Natural Resources (GAEPD) maintains a network of monitoring stations that are sampled periodically, primarily as a part of the state's water quality program. Some of the sites in this network also have monthly stage or discharge measurements that were collected during the period of monitoring. There are 57 GAEPD monitoring sites within the RHI. Thirteen of these sites are upstream from the refuge. Of these 13 sites, 4 have stage or discharge measurement data (shown on Figure 22).

Refuge staff collects water level information at nine sites using Forest Technology Systems dataloggers located throughout the refuge (shown on Figure 22).

Table 9. U.S. Geological Survey (USGS) gaging stations used in hydrologic database for Okefenokee NWR; see Figure 22 for locations. [Source: Buell 2014; USGS 2015].

# on Figure 22	Site Number	Name	Type	Agency / Type	Period of Record
1	02228500	NORTH PRONG ST. MARYS RIVER AT MONIAC GA	Daily Discharge	USGS Stream	1921 - current
2	02228700	OCEAN POND AT OLUSTEE FLA.	Daily Elevation above NGVD 1929	USGS Lake	1975 - 1993
3	02229000	MIDDLE PRONG ST. MARYS RIVER AT TAYLOR FL	Daily Discharge	USGS Stream	1955 - 2001
4	02229250	MIDDLE PRONG ST. MARYS RIVER NEAR TAYLOR FL	Daily Discharge	USGS Stream	1997 - 2002
5	02229400	PALESTINE LAKE NR OLUSTEE FL	Daily Elevation above NGVD 1929	USGS Lake	1975 - 1993
6	02229500	SOUTH PRONG ST. MARYS RIVER NR SANDERSON FLA.	Daily Discharge	USGS Stream	1955 - 1960
7	02230000	TURKEY CREEK AT MACCLENNY FLA.	Daily Discharge	USGS Stream	1955 - 1977
8	02230500	SOUTH PRONG ST. MARYS RIVER AT GLEN ST. MARY FL	Daily Discharge	USGS Stream	1950 - 1971
9	02231000	ST. MARYS RIVER NEAR MACCLENNY FL	Daily Discharge	USGS Stream	1926 - current
10	02231230	PIGEON CREEK AT BOULOGNE FLA.	Peak Streamflow	USGS Stream	1964 - 1976
11	02231250	LITTLE ST. MARYS RIVER NR HILLIARD FLA.	Daily Discharge	USGS Stream	1965 - 1967
12	02231253	ST. MARYS RIVER NEAR GROSS FLA.	Daily Discharge	USGS Stream	1966 - 1990
13	02231254	ST. MARYS RIVER AT I-95 NEAR KINGSLAND GA	Daily Discharge	USGS Tidal Stream	2010 - current
14	02314261	BOGGY BAY TRIB AT FOURTH AVE NR WAYCROSS GA	Peak Streamflow	USGS Stream	1967 - 1969
15	02314274	SUWANNEE RIVER AT SILL NEAR FARGO GA	Daily Discharge	USGS Stream	1999 - 2002
16	023142741	NORTH FORK SUWANNEE RIVER AT SILL NEAR FARGO GA	Daily Discharge	USGS Stream	1998 - 2003

# on Figure 22	Site Number	Name	Type	Agency / Type	Period of Record
17	02314300	TATUM CREEK AT US 441 NEAR HOMERVILLE GA	Gage Height, Discharge	USGS Stream	1951 - 2006
18	02314495	SUWANNEE RIVER ABOVE FARGO GA	Daily Gage Height	USGS Stream	1999 - current
19	02314500	SUWANNEE RIVER AT US 441 AT FARGO GA	Daily Discharge	USGS Stream	1927 - current
20	02314600	SUWANNOOCHEE CREEK AT US 84 AT DUPONT GA	Stream Flow, Gage Height	USGS Stream	1949 - 2006
21	02314700	SUWANNOOCHEE CREEK AT GA 187 NEAR THELMA GA	Peak Streamflow	USGS Stream	1929 - 1991
22	02314780	SUWANNOOCHEE CREEK AT GA 94 NEAR FARGO GA	Stream Flow, Gage Height	USGS Stream	1943 - 2006
23	02315000	SUWANNEE R NR BENTON FLA	Daily Discharge	USGS Stream	1932 - current
24	02315500	SUWANNEE RIVER AT WHITE SPRINGS FLA.	Daily Discharge	USGS Stream	1906 - current
25	02315550	SUWANNEE RIVER AT SUWANNEE SPRINGS FLA	Daily Gage Height, Daily Discharge	USGS Stream	1969 - current



Map Date: 7/15/2015 File: Surface_Quantity_Monitoring.mxd Data Source: USGS NWIS Surface Water Stations, NHD Named Flowlines, WBD HUC-8 Units.

Figure 22. U.S. Geological Survey (USGS) gaging stations used in the hydrologic database for Okefenokee National Wildlife Refuge (numbered sites), as well as GAEPD and USFWS gage height and water level monitoring sites.

5.3.1.2 Water Quality Monitoring

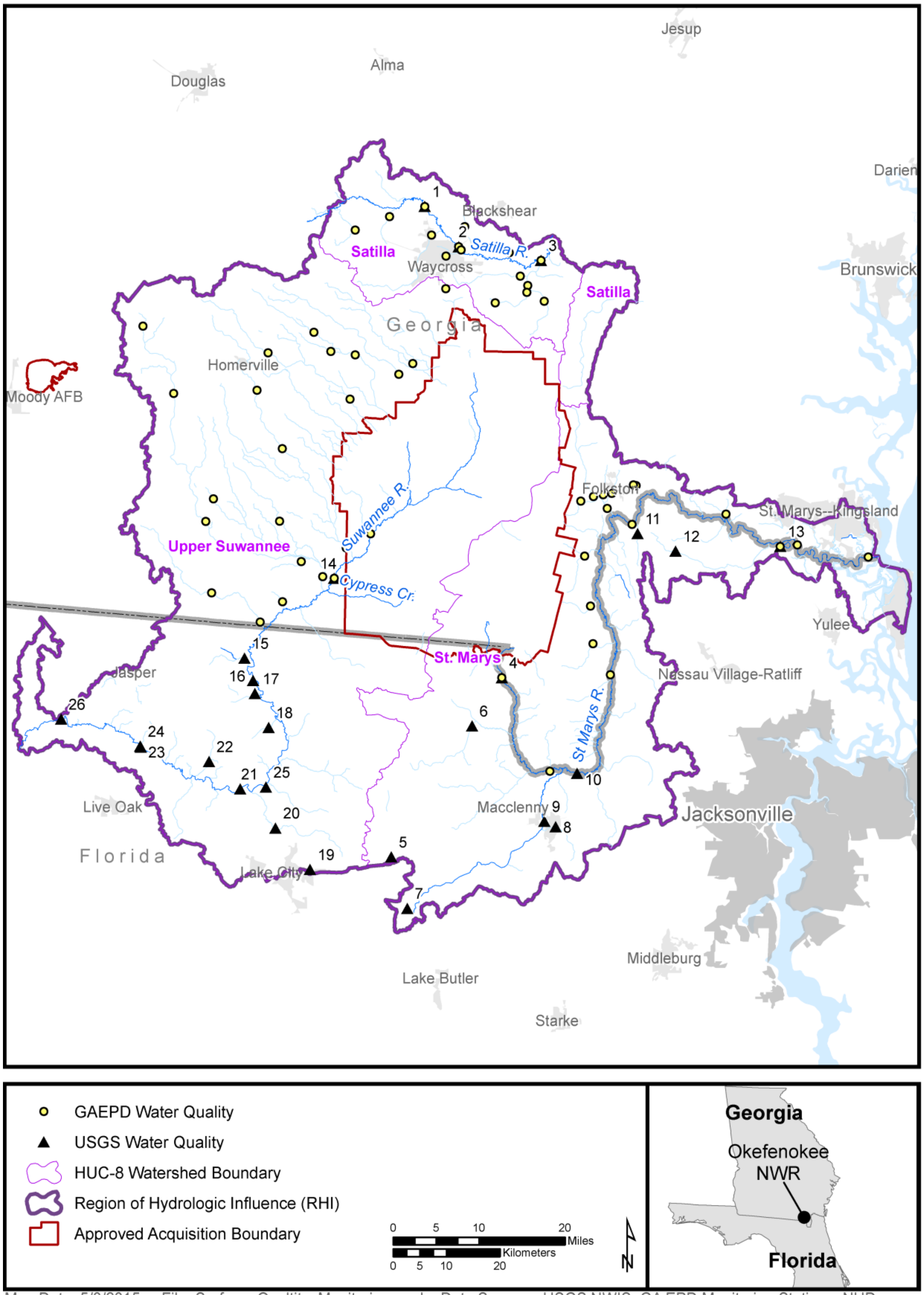
USGS conducts water quality monitoring within the RHI. The USGS has collected water quality data at 193 active and historic surface water sites within the RHI (USGS 2015). Two of these sites are within the NWR. Twenty six of these sites have at least a ten year period of record (Table 10, Figure 23.). These sites have been monitored for a variety of water quality parameters, including mercury, lead, temperature, specific conductance, dissolved oxygen, pH, phosphorous, and dissolved solids.

GAEPD maintains a network of monitoring stations that are sampled periodically as a part of the state's water quality program. There are 57 GAEPD monitoring sites within the RHI. Thirteen of these sites are upstream from the refuge. All upstream sites are within the Upper Suwannee subbasin.

Table 10. U.S. Geological Survey (USGS) surface water quality and monitoring sites within the Okefenokee RHI boundary. [Source: USGS 2015].

# on Figure 23	Site Number	Name	Type	Agency	Period of Record
1	02226475	SATILLA RIVER AT WALTERTOWN GA	Stream	USGS	8/15/1974 - 8/25/1999
2	02226500	SATILLA RIVER NEAR WAYCROSS GA	Stream	USGS	5/1/1937 - 8/9/1974
3	02226582	SATILLA RIVER AT GA 15&121 NEAR HOBOKEN GA	Stream	USGS	8/20/1974 - 3/26/2015
4	02228500	NORTH PRONG ST. MARYS RIVER AT MONIAC GA	Stream	USGS	5/19/1958 - 8/26/1999
5	02228700	OCEAN POND AT OLUSTEE FLA.	Lake, Reservoir, Impoundment	USGS	8/15/1966 - 9/30/1982
6	02229000	MIDDLE PRONG ST. MARYS RIVER AT TAYLOR FL	Stream	USGS	6/1/1966 - 6/11/1996
7	02229400	PALESTINE LAKE NR OLUSTEEFL	Lake, Reservoir, Impoundment	USGS	8/13/1965 - 9/7/1982
8	02230000	TURKEY CREEK AT MACCLENNY FLA.	Stream	USGS	5/31/1966 - 8/31/1977
9	02230500	SOUTH PRONG ST. MARYS RIVER AT GLEN ST. MARY FL	Stream	USGS	5/31/1966 - 10/6/1979
10	02231000	ST. MARYS RIVER NEAR MACCLENNY FL	Stream	USGS	2/25/1958 - 3/22/2006

# on Figure 23	Site Number	Name	Type	Agency	Period of Record
11	02231230	PIGEON CREEK AT BOULOGNE FLA.	Stream	USGS	3/1/1965 - 9/24/1974
12	02231250	LITTLE ST. MARYS RIVER NR HILLIARD FLA.	Stream	USGS	5/1/1965 - 9/24/1974
13	02231253	ST. MARYS RIVER NEAR GROSS FLA.	Stream	USGS	3/12/1965 - 4/11/1974
14	02314500	SUWANNEE RIVER AT US 441 AT FARGO GA	Stream	USGS	4/21/1937 - 3/26/2015
15	02314986	ROCKY CREEK NR BELMONTFLA.	Stream	USGS	10/6/1970 - 10/4/1983
16	02315000	SUWANNEE R NR BENTON FLA	Stream	USGS	4/24/1956 - 8/17/1988
17	02315005	HUNTER CREEK NEAR BELMONT FLA	Stream	USGS	11/21/1967 - 8/17/1988
18	02315090	ROARING CREEK NEAR BELMONT FLA	Stream	USGS	11/21/1967 - 8/17/1988
19	02315450	WATERTOWN LAKE AT WATERTOWN FLA	Lake, Reservoir, Impoundment	USGS	8/15/1966 - 3/15/1977
20	02315470	FALLING CREEK NR WINFIELD FLA	Stream	USGS	3/15/1977 - 8/5/1981
21	02315500	SUWANNEE RIVER AT WHITE SPRINGS FLA.	Stream	USGS	5/10/1966 - 8/17/1988
22	02315520	SWIFT CREEK AT FACIL FLA	Stream	USGS	8/16/1967 - 8/16/1988
23	02315550	SUWANNEE RIVER AT SUWANNEE SPRINGS FLA	Stream	USGS	4/25/1956 - 8/16/1988
24	02315600	SUWANNEE SPRINGS NR LIVE OAK FLA	Spring	USGS	4/25/1956 - 10/24/2013
25	30194508 2411800	BELL SPRINGS NEAR WHITE SPRINGS FL	Spring	USGS	11/8/1977 - 11/29/2012
26	30261408 3052300	ALAPAHA RISE	Spring	USGS	11/25/1975 - 8/13/1990



Map Date: 5/8/2015 File: Surface_Qualtity_Monitoring.mxd Data Sources: USGS NWIS, GA EPD Monitoring Stations, NHD Named Flowlines, WBD HUC-8 Boundaries, ESRI Map Service.

Figure 23. U.S. Geological Survey (USGS) and Georgia Environmental Protection Division (GAEPD) surface water quality monitoring locations within the Okefenokee National Wildlife Refuge Region of Hydrologic Influence (RHI).

5.3.1.3 Aquatic Habitat and Biota Monitoring

The Executive Order (# 7593) establishing Okefenokee NWR (EO 1937) stated the purpose of the refuge as "a refuge and breeding ground for migratory birds and other wildlife." It is one of more than 560 national wildlife refuges administered by the USFWS. This refuge system is a network of U.S. lands and waters managed specifically for wildlife. The National Wildlife Refuge System Improvement Act of 1997 states the Refuge System mission is to "administer a national network of lands and waters for the conservation, management and, where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans."

Okefenokee NWR preserves the unique qualities of the Okefenokee Swamp, one of the world's largest intact freshwater ecosystems designated as Wetland of International Importance under the Ramsar Convention of 1971, and is the third largest National Wilderness Area (353,981 acres) east of the Mississippi River (USFWS 2006). The swamp is the headwaters of the Suwannee and the St. Marys Rivers, and is used as a benchmark for wetlands research worldwide. It provides habitats for rare, sensitive, endangered, and threatened species, native and endemic species, and a wide variety of other terrestrial, aquatic, and wetland plants and animals. It is world renowned for its amphibian populations, which are bio-indicators of global health. There is a long history of biological surveys and monitoring being conducted in Okefenokee Swamp, Okefenokee NWR, and within the St. Marys and Suwannee River Basins. Within Okefenokee NWR, there are five Research Natural Areas which were established in 1967 and 1973.

Paleoecology investigations have been completed within Okefenokee NWR and the swamp over the course of several studies and summarized in Cohen et al. 1984. More, specific studies include Fair-Page and Cohen (1990); Stack (1985); Fearn (1981); Parrish and Rykiel (1979); Rich (1979); Spackman et al. (1976); Bond (1970).

Plant surveys, inventories, and monitoring at Okefenokee Swamp have relative long history, with written surveys and summaries of botanical information dating back to the 1800s and early 1900s (primarily work by R.M. Harper). More recent research includes the role of disturbance on plant diversity and succession (Hamilton 1984, Cohen 1973).

Fishes have been inventoried within the Okefenokee Swamp and in the refuge (Palmer and Wright 1920; Fowler 1945; Laerm and Freeman 1986, Hoehn 1998; Tate and Walsh 2005), and sport fish inventory work completed in the Suwannee basin in the 1970s (Bass and Hitt 1971, 1973). The most recent and extensive fish survey within the Swamp was conducted over a ten year period (1992-2001) and summarized by Herrington et al. (2004). Additionally, survey monitoring efforts have been conducted within the Okefenokee Swamp and refuge which specifically focused on species of concern (e.g., blackbanded sunfish *Ennaecanthus chaetodon*; Bechler and Salter 2014). Benthic macroinvertebrates within Okefenokee NWR have also been investigated; primarily in relation to inventory work and also contaminants studies (Cox 1970; Batzer and George 2008; Kratzer and Batzer 2007; Bilger et al. 2001, Porter et al. 1999).

Cultural resources within Okefenokee NWR have also been surveyed. Newell Wright reported results in several volumes (Wright 1978) with other surveys including information on mapping and Native American use (Wright 1945; Braley 1995).

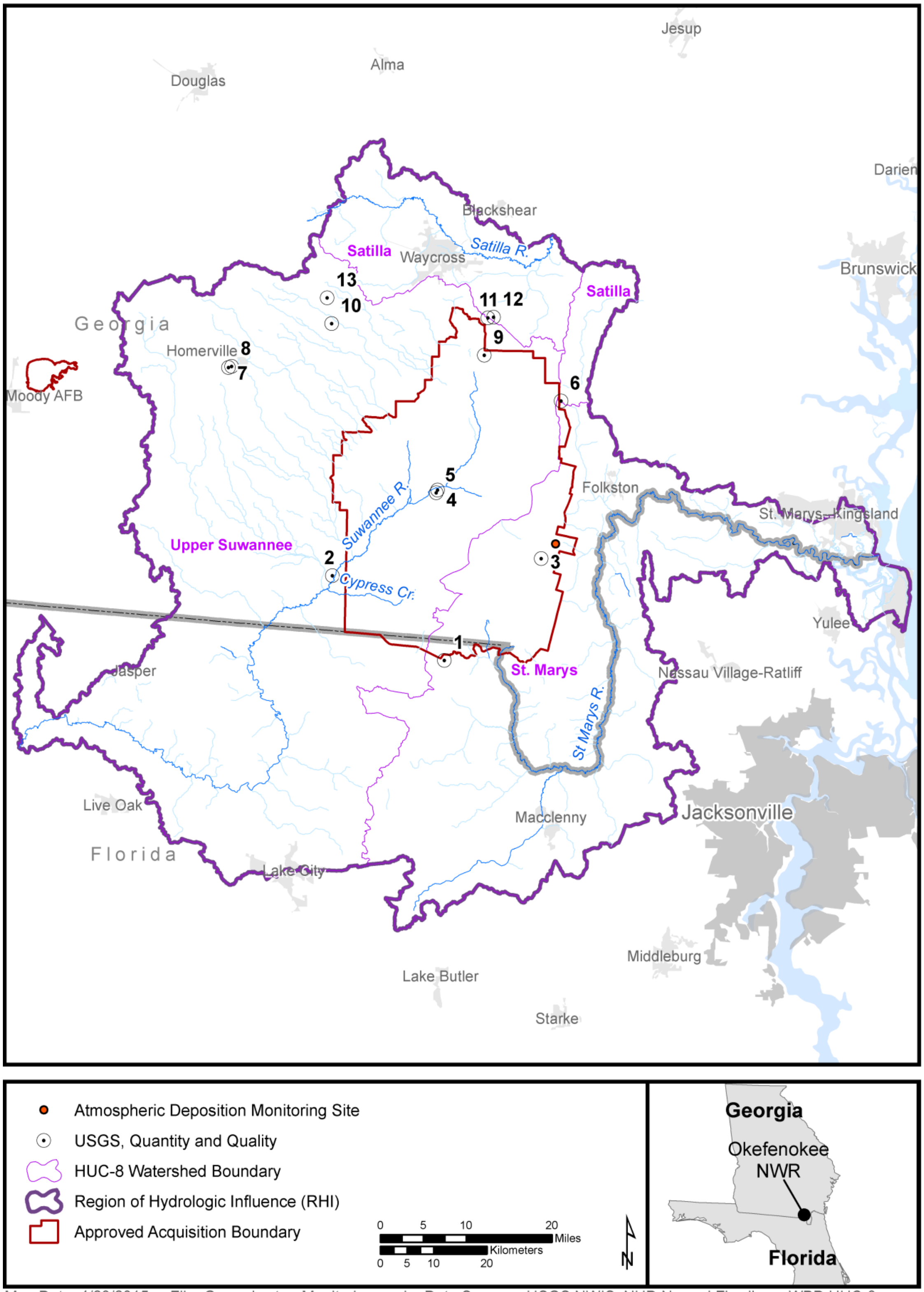
5.3.2 Groundwater Monitoring

This section presents federal and state groundwater monitoring (quantity and quality) locations in the hydrologic units closest to and containing the Okefenokee NWR acquisition boundary.

USGS conducts groundwater monitoring within the RHI. The USGS has collected data at 423 active and historic groundwater sites within the RHI (USGS 2015). Thirteen of these sites are within the NWR. There are 13 sites in the RHI with at least a ten year period of record (Table 11, Figure 24). Measurement frequency and the number of water quality samples vary among sites, and are not evenly distributed over the period of record.

Table 11. U.S. Geological Survey (USGS) groundwater quality and water level monitoring sites within the Okefenokee Region of Hydrologic Influence (RHI) acquisition boundary with a 10-year or longer period of record. All wells are completed in the Floridan Aquifer system. [Source: USGS 2015].

# on Figure 24	Site Number	Name	Water Quality or Level	Period of Record
1	303235082203501	BA-0057 EDDY FIRETOWER FLORIDAN	Level	5/18/1992 - 9/13/2010
2	304052082335201	25D001	Both	5/10/1966 - 9/26/2006
3	304256082092101	28D001	Both	11/7/1977 - 5/26/2010
4	304942082213801	27E004	Daily Level	5/25/1978 - 3/11/2015
5	304943082214701	27E003	Both	1/12/1976 - 9/22/2006
6	305907082070101	29F001	Both	1/17/1976 - 9/25/2006
7	310145082463501	23G001	Level	October 1962 - 5/20/1980
8	310152082460401	23G002	Both	December 1966 - 9/26/2006
9	310320082161801	27G006	Both	5/15/1980 - 5/26/2010
10	310620082342201	25G001	Both	11/27/1973 - 9/25/2006
11	310706082155101	27G003	Both (Daily Level)	11/10/1980 - 3/11/2015
12	310710082151501	27G005	Both	5/21/1980 - 9/25/2006
13	310854082345501	25H001	Level	9/10/1992 - 9/25/2006



Map Date: 4/28/2015 File: Groundwater_Monitoring.mxd Data Sources: USGS NWIS, NHD Named Flowlines, WBD HUC-8 Boundaries, ESRI Map service.

Figure 24. U.S. Geological Survey (USGS) groundwater monitoring locations and air quality monitoring site within the Okefenokee National Wildlife Refuge Region of Hydrologic Influence (RHI).

5.3.3 Air Quality Monitoring

Deposition of contaminants from precipitation and the atmosphere plays an important role in water chemistry and water quality on the refuge. Date for three air quality monitoring networks is collected at a location on the Okefenokee NWR (Figure 24, Table 12). Two of the monitoring networks, the Mercury Deposition Network (MDN) and National Trends Network (NTN) are part of the larger monitoring network, the National Atmospheric Deposition Program (NADP). The MDN only measures wet-deposition mercury concentrations. Samples are collected weekly and only during precipitation events (NADP 2014a). Like the MDN, the NTN collects weekly samples during precipitation events but measures the concentrations of a variety of the chemical constituents in precipitation (NADP 2014b). The third monitoring station, the Interagency Monitoring of Protected Visual Environments (IMPROVE), consists of aerosol, light scatter, light extinction and scene samplers used to measure a broad spectrum of air pollutants that are more related to visibility than deposition. The IMPROVE sampler collects four simultaneous samples every three days (IMPROVE 2013).

Table 12. Air quality monitoring data collected on Okefenokee National Wildlife Refuge. All measures are collected at the same location, which is shown on Figure 24.

Station ID	Network	Parameters[4]	Period of Record
GA09	MDN[1]	Hg	7/29/1997 – Present
GA09	NTN[2]	Ca, Mg, K, Na, NH_4, NO_3, Cl, SO_4, pH, Conductivity	6/03/1997 – Present
13-049-9000	IMPROVE[3]	Al, As, Br, Ca, Cl^-, Cl, Cu, Fe, Pb, Mg, Mn, Ni, P, K, Se, Si, Na, Sr, S, Ti, V, Zn, Zr, NO_2, NH_4NO_3, $(NH_4)_2SO_4$, SO_4, Organic C, Organic P, Particulate matter	9/28/1991 – Present

[1] Mercury Deposition Network (MDN).

[2] National Trends Network (NTN).

[3] Interagency Monitoring of Protected Visual Environments (IMPROVE); IMPROVE agencies and organizations: Air Resource Specialist, Bureau of Land Management, Desert Research Institute, US Fish and Wildlife Service (USFWS), US Forest Service, Mid-Atlantic Regional Air Management Association, National Oceanic and Atmospheric Association, National Park Service Air Resource Division (NPS ARD), Northeast States for Coordinated Air Use Management (NESCAUM), Research Triangle Institute, State and Territorial Air Pollution Program Administrators, US Environmental Protection Agency, University of California at Davis, University of California at Davis Crocker Nuclear Laboratory, Western States Air Resources Council.

[4] Aluminum (Al), Arsenic (As), Bromine (Br), Calcium (Ca), Carbon (C), Chloride (Cl^-), Copper (Cu), Iron (Fe), Lead (Pb), Magnesium (Mg), Manganese (Mn), Nickel (Ni), Phosphorous (P), Potassium (K), Selenium (Se), Silicon (Si), Sodium (Na), Strontium (Sr), Sulfur (S), Titanium (Ti), Vanadium (V), Zinc (Zn), Zirconium (Zr), Nitrite (NO_2), Ammonium Nitrate(NH_4NO_3), Ammonium Sulfate ($(NH_4)_2SO_4$), Sulfate (SO_4).

5.4 Water Quantity and Timing

5.4.1 Surface Water Quantity

Over the next 40 years, the population in the Suwannee-Satilla Region, a regional planning unit consisting of Atkinson, Bacon, Ben Hill, Berrien, Brantley, Brooks, Charlton, Clinch, Coffee, Cook, Echols, Irwin, Lanier, Lowndes, Pierce, Tift, Turner, and Ware Counties, GA, is projected to grow by 61%. This population growth will increase the demands for surface water and groundwater and increase the quantity of wastewater generated. Total water withdrawals by municipal, industrial, and agricultural sectors are forecasted to increase by 24% (62 MGD) from 2010 to 2050. Total wastewater flows are projected to increase by 46% (27 MGD) over the same period (SSWMP 2011).

The GAEPD's 2010 Surface Water Availability Resource Assessment estimates the availability of surface water to meet current and future municipal, industrial, agricultural, and thermal power water needs as well as the needs of instream and downstream users. Instream uses include fish, wildlife habitat, recreation, and dilution of wastewater, among others. The assessment used specific minimum flow levels as indicators of the ability to support instream uses. Minimum instream flows were based on State Policy, existing Federal Policy, or existing Federal Energy Regulatory Commission (FERC) license requirements. The results of the assessment are provided in terms of both severity (i.e., the amount by which the stream flow would drop below minimum instream flow requirements) and frequency (i.e., number of days below minimum instream flow requirements) (SSWMP 2011).

The term "surface water gap" is used when the computer modeling results indicate that off-stream uses of water increase the severity and/or frequency of critical low flow periods. When a surface water gap exists, management practices are needed to help address potential impacts. Significant surface water gaps were identified in the 2010 assessment at several locations in southern Georgia near the refuge, on the Alapaha, Satilla, and Withlacoochee Rivers. Modeling results indicate a potential surface water gap on the Suwannee River at Fargo; however, it is not considered significant based on the predicted length of shortfall and average shortfall. The estimated shortfall is less than 1 cfs; under current conditions, it is estimated to have a 3% duration, and, under future conditions, a 1% duration (SSWMP 2011).

5.4.2 Groundwater Quantity

The GAEPD's 2010 Groundwater Availability Resource Assessment (GAEPD 2010) estimates the sustainable yield for prioritized groundwater resources based on existing data. GAEPD prioritized the aquifers based on the characteristics of the aquifer, evidence of negative effects, anticipated negative impacts, and other considerations. This assessment identified the sustainable yield, or the volume of groundwater that can be used without negative impacts. Negative impacts include limiting use of neighboring wells (drawdown), significantly reducing flow in nearby streams (baseflow), and the permanent reduction of groundwater levels. If negative impacts occur or are expected to occur, then a groundwater "gap" exists. The Suwannee-Satilla Region will coordinate usage with other water planning regions to meet the sustainable yield for each groundwater source. Regionally, there is sufficient groundwater to meet forecasted needs over the next 40 years (SSWMP 2011).

5.5 Water Quality

The RHI for the Okefenokee NWR encompasses portions of the Upper Suwannee, St. Marys and the Satilla River Basins. Within the RHI, pollutants originate from point sources such as municipal and industrial wastewater discharge, and from nonpoint sources such as rural and urban runoff. Point sources, regulated under the National Pollutant Discharge Elimination System (NPDES), are permitted discharges of stormwater and treated wastewater into rivers and their tributaries from discrete conveyances. Nonpoint source pollution is the result of diffuse surface runoff and subsurface flow, and is associated with a variety of pollutants. Nonpoint sources are not regulated under NPDES. Based on GAEPD's 1998-1999 water quality assessment, nonpoint sources are the primary contributors to the failure of water bodies to meet their designated uses in all three basins. (GAEPD 2002a,b,c)

Nonpoint source pollution in all three basins includes stormwater runoff from urban, industrial, and residential sources and from agricultural and forestry land use practices. Constituents of this runoff contain oxygen-demanding waste, oil and grease, nutrients, metals, bacteria and pathogens from animal waste, fertilizers, herbicides, pesticides, and sediment. Nonpoint sources are the major contributors to the dissolved oxygen and fecal coliform impairments in the three river basins (GAEPD 2002a,b,c). To combat these and other nonpoint pollution sources, GAEPD revised its Statewide Nonpoint Source Management Program (NSMP) in 2014. The NSMP identifies individual land use practices that are contributing to nonpoint source pollution and provides both the associated State and Federal agencies with strategic plans tailored to address each issue. The most notable modification to the 2014 NSMP is the incorporation of the watershed prioritization tool, which enables a targeted approach to watershed protection by identifying waters with a high likelihood of localized restoration success, and water quality tracking tables which facilitate monitoring efforts and establish milestones for meeting nonpoint pollution reduction goals (GAEPD 2014). Silvicultural practices on lands surrounding the refuge are the primary source of nonpoint source pollution entering the refuge (USFWS 2006).

Surface water contamination by mercury and the subsequent accumulation of mercury in aquatic animal tissue occur due to atmospheric deposition and diffuse stormwater runoff. Significant potential sources of airborne mercury include coal-fired power plants, waste incinerators, cement and limekilns, smelters, pulp and paper mills, and chlor-alkali factories (EPA 1997). Mercury released into the atmosphere deposits predominantly as oxidized mercury (Hg(II)) via precipitation and dry deposition. In forested landscapes, deposition is accelerated by the assimilation of gaseous mercury into leaf tissue. Once deposited, Hg(II) forms complexes with soil organic matter and is transported to surface water via dissolved organic carbon (DOC) in diffuse runoff and in groundwater (EPA 1997). Typically, total mercury and methylmercury concentrations are positively correlated with DOC concentrations in lakes (Driscoll et al. 1995). Methymercury is produced by the addition of a methyl group to Hg(II) in the soil, in lake sediments and in the water column through microbial processes (EPA 1997).This transformation, known as methylation, is the key pathway by which mercury enters the food chain. Methylation is accelerated under anaerobic conditions, high temperature and low pH. Plants also have some ability to methylate mercury and may serve as another mechanism for the introduction of mercury into the food chain (Fortmann et al. 1977). Nearly 100% of the mercury found in fish muscle tissue is methylated (Bloom 1992). Methylmercury appears to be passed initially to the primary consumers in the aquatic food chain, planktivorous and piscivorous fish, and eventually to the longer lived fish species at the higher end of the food chain. While the NSMP does not directly address the contamination of surface water by mercury or provide for an action plan to reduce its emission into the atmosphere, the management practices in place to mitigate for fecal coliform and low dissolved oxygen may also be effective in mitigating the accumulation of mercury in fish tissue. (GAEPD 2014).

The primary surface water quality concerns on the refuge are low pH, low dissolved oxygen, and elevated levels of mercury (USFWS 2006). The Suwannee River, the primary outflow from the refuge, is listed as impaired due to elevated mercury levels along the entire length through the refuge, a distance of approximately thirty miles (GAEPD 2012). Other water quality impairments within the RHI for Okefenokee NWR are largely due to non-point sources and include low levels of dissolved oxygen, fecal coliform, and mercury. Additionally, one of tributaries to the St. Marys River is failing to meet its usage requirements due to high levels of residual Arsenic (GAEPD 2012). There are 12 NPDES permitted facilities within the RHI of Okefenokee NRW, several of which are upstream of the refuge (see Section 5.5.2.2).

5.5.1 Federal and State Water Quality Regulations

5.5.1.1 Designated Uses

Within the RHI, GAEPD and the Florida Department of Environmental Protection (FDEP) are responsible for water quality regulation. Georgia classifies waters of the state with the following six usage groups: (1) Drinking water; (2) Recreation; (3) Fishing, Propagation of Fish, Shellfish, Game and Other Aquatic Life; (4) Wild River; (5) Scenic River; and (6) Coastal Fishing (EPA 2012). Some waters may be assigned multiple classifications. Georgia State waters in the Satilla and St. Marys River basins are designated as fishing, propagation of fish, shellfish, game and other aquatic life; recreation; drinking water; and wild or scenic rivers (GAEPD 2002a,b). All littoral waters in the St. Marys basin on the ocean side of Cumberland Island, and all littoral waters in the Satilla Basin on the ocean side of Cumberland and Jekyll Islands are classified as strictly for recreation (EPA 2012). In Georgia the designated use for the Suwannee River and its tributaries is fishing, propagation of fish, shellfish, game and other aquatic life (GAEPD 2002c). Similarly, in Florida, the Suwannee River and its tributaries are Class III waterbodies, which are designated for recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. Tidal creeks and coastal waters in the RHI are designated as Class II waterbodies for shellfish propagation or harvesting (FDEP 2003). The Suwannee River is also designated as an Outstanding Florida Water by the FDEP (Florida Administrative Code Rule 62-302.700), which is a waterbody designated worthy of special protection because of its natural attributes. In general, FDEP cannot issue permits for direct discharges that would lower existing water quality or indirect discharges that would significantly degrade a nearby waterway designated as an OFW (FDEP 2012a).

5.5.1.2 Water Quality Standards

The GAEPD and FDEP administer the two states' water quality standards for surface water quality, including designated uses, numeric and narrative water quality criteria intended to protect those uses, and antidegradation policies that define the procedures to be followed when evaluating activities that may impact water quality. Georgia's water quality standards are found in Chapter 391-3-6-.03 of the Rules and Regulations for Water Quality Control (GAEPD 2005). Florida surface water quality standards and criteria are described in Chapter 62-302 of the Florida Administrative Register and Administrative Code (FACFAR 2010).

In 1998, the United States Environmental Protection Agency (EPA) issued a strategy requesting each state to develop a plan for adopting numeric nutrient water quality criteria, in addition to already established numeric criteria for other parameters (e.g., dissolved oxygen, pH, temperature, bacteria, metals, pesticides and other organic chemicals). Georgia has adopted numeric phosphorus criteria for some rivers and streams, as well as numeric nitrogen criteria for some lakes and reservoirs. Florida has adopted statewide numeric nitrogen and phosphorus criteria for river/streams and lakes/reservoirs, as well as site-specific phosphorus criteria for wetlands and nitrogen and phosphorus criteria for estuaries (F.A.C. Rules 62-302.531 and 62-302.532) (FACFAR 2010). In addition to numeric criteria, there are also narrative criteria such as the prohibition of discharging toxic materials in toxic amounts.

Under §303(d) of the Clean Water Act, states are required to compile a list of impaired waters and submit that list to EPA for approval. Impaired waters are those which do not meet applicable state water quality standards, i.e., do not support their designated use(s). The list of impaired waters is also required by the Georgia River Basin Management Plan (GRBMP) as defined in State law (O.C.G.A 12-5-520) and the Florida Watershed Restoration Act (FWRA; Subsection 403.067[4] Florida Statutes [F.S.]). These waters are then scheduled for development of a Total Maximum Daily Load (TMDL), which provides a plan that can be implemented to restore the designated use of the water. Federal regulations require that states consider all existing and readily available information when compiling a §303(d) list. EPA considers the formal listing process under the Endangered Species Act to be readily available information, and the loss of use of a water by a listed aquatic species due to degradation of water quality and/or aquatic habitat to be evidence of impairment. Consequently, such waters must be included on state §303(d) lists and addressed by TMDLs designed to restore conditions suitable for the endangered species. States have responsibility for the development of TMDLs, which are subject to EPA approval. Sections 403.067(6) and (7) of the Florida Statutes state that FDEP may develop a basin management plan (BMAP) that addresses some of all of the watersheds and basins tributary to a TMDL waterbody. The purpose of the BMAP is to implement load reductions to achieve TMDLs, including specific projects, monitoring approaches and best management practices (BMPs) (FDEP 2012b). BMPs were cited by the FWRA of 1999 as the best way to reduce pollution to Florida's waters. BMP Manuals contain a combination of practices designed to reduce loading from particular activities, such as nutrient management, pesticide usage and water management. As required by Section 403.067(7)(b)2(g) of Florida law, agricultural producers in basins with TMDLs must implement a BMP plan or conduct water quality monitoring to prove discharges meet state water quality standards. The FWRA also requires that when BMPs are adopted, FDEP must verify their effectiveness in achieving pollutant reductions (Migliaccio and Boman 2013).

5.5.1.3 NPDES

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program regulates point sources that discharge pollutants into waters of the United States. NPDES permits are required for operation and sometimes construction associated with domestic or industrial wastewater facilities or activities (e.g., wastewater treatment facilities, mines, etc.). In Georgia and Florida, the EPA has delegated administration of the NPDES permit program to GAEPD and FDEP, respectively.

5.5.1.4 Groundwater Regulations

Groundwater is protected by laws at both the federal and state levels. The EPA is responsible for groundwater protection through the Safe Drinking Water Act, which requires maximum contaminant level standards for drinking water. The Safe Drinking Water Act established the Underground Injection Control, Wellhead Protection, and Source Water Protection Programs, which are administered by GAEPD (Drinking Water Program) in Georgia and FDEP (Aquifer Protection Program) in Florida. The Resource Conservation and Recovery Act (RCRA) was initiated to regulate the disposal of solid and hazardous wastes and establish a national program for the regulation of underground storage tanks. The Comprehensive Environmental Resource Compensation and Liability Act (CERCLA) created a tax on chemical and petroleum industries and provided authority to the federal government to respond directly to clean up efforts for chemical spills or hazardous substance sites that threaten the environment. The CERCLA is commonly referred to as a Superfund. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), allows EPA to control the availability of potentially harmful pesticides. The Toxic Substances Control Act (TSCA) authorizes EPA to control toxic chemicals that could pose a threat to the public and contaminate ground water. The Surface Mining Control and Reclamation Act (SMCRA), regulates mining activities, some of which can negatively impact groundwater.

In addition to the Aquifer Protection Program, FDEP has a Ground Water Management Program that is responsible for evaluating and addressing groundwater resources that adversely affect surface water quality as part of Florida's Watershed Restoration Program. This program conducts groundwater and surface water interaction assessments, restoration of springs, and implementation of best management practices for agrichemical effects on water quality.

Specific laws passed by the Georgia Legislature that address protection of groundwater include the Groundwater Use Act, several acts pertaining to safe drinking water, the Water Quality Act and the Underground Storage Act. In Florida, rules pertaining to groundwater quality include Groundwater Classes, Standards and Exemptions, Wellhead Protection and Underground Injection Control.

5.5.2 Impaired Waters, TMDLs and NPDES Permits

Because the majority of the Okefenokee NWR is contained within Georgia, the following section will only discuss impaired waters in Georgia. Florida statewide final TMDL documents may be found through the Florida Department of Environmental Protection (FDEP 2015) and are discussed in the WRIA for Lower Suwannee NWR (Thom et al. 2015).

5.5.2.1 Georgia Impaired Waters and TMDLs

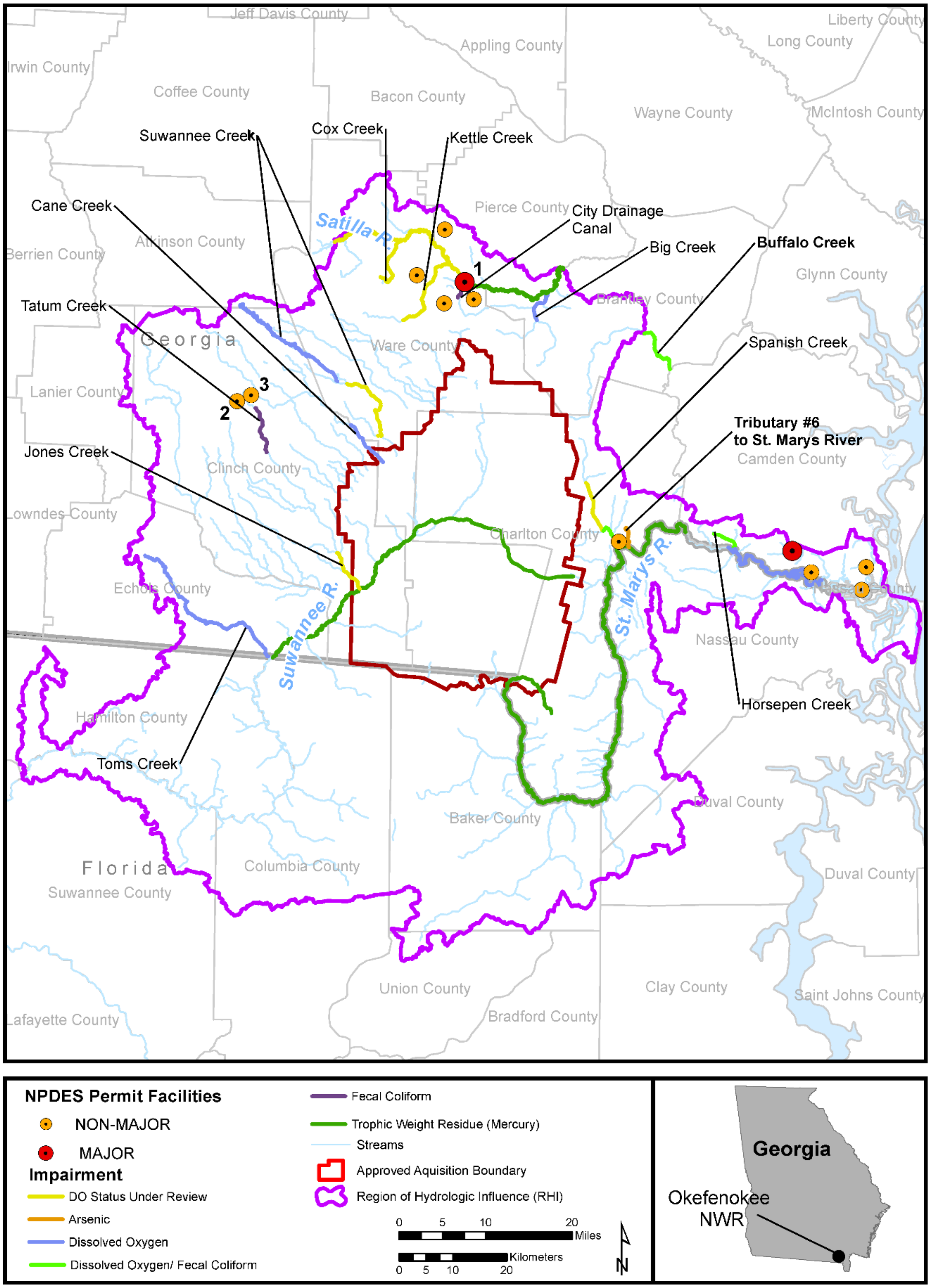
In order to meet Clean Water Act requirements, the GAEPD typically adheres to the Georgia River Basin Management Plan (GRBMP) as defined in State law (O.C.G.A 12-5-520). The GRBMP utilizes a five-year rotating basin approach for drafting TMDLs. In some cases GAEPD may draft a TMDL outside of the basin rotation schedule depending on pollutant severity and issues surrounding additional data collection and complex analysis. Georgia consists of fourteen river basins which are lumped into five major basin groups. Each group undergoes a GRBMP cycle of five phases on the five-year rotating schedule. Phases 1 and 2 consist of a review of basin planning goals and objectives, and respective data collection. Phase 3 assesses and prioritizes the data collected in Phase 2. In Phases 4 and 5, a basin plan is developed and implemented in order to achieve the TMDL. Each phase is scheduled to take about a year to complete (GAEPD 2004)

The RHI for Okefenokee NWR falls within the Ochlockonee-Suwannee-Satilla-St. Marys major basin group. The GRBMP began for this major basin group in 1997 with an implementation period initiating in 2001 and concluding in 2002. The most recent GRBMP was completed in 2012. TMDL information has been spatially assigned by GAEPD to stream reaches (Figure 25). Common causes for impairments requiring TMDLs within the Okefenokee NWR RHI are low dissolved oxygen, fecal coliform bacteria, and elevated levels of mercury in fish tissue. Impairment status regarding dissolved oxygen is still pending for six water bodies within the Okefenokee NWR RHI. Naturally low levels of dissolved oxygen are present in slow-moving water and where decomposition of plant material is high, as in the Okefenokee Swamp. The GAEPD is in the process of determining natural dissolved oxygen levels for the refuge and surrounding RHI before the assessment on the six aforementioned waterbodies is made. Table 13 lists the waterbodies within the RHI with verified impairments requiring TMDLs.

Table 13. Waterbodies in the Georgia portion of the RHI for Okefenokee NWR with approved or pending TMDLs, organized by county. Waterbodies are shown on Figure 25. [Source: GAEPD 2012].

County	Waterbody	TMDL Parameter and Pollutant(s)	Date Adopted
Brantley	Big Creek	Dissolved oxygen	2001
	Buffalo Creek	Dissolved oxygen	2001
	Buffalo Creek	Fecal coliform	2011
	Satilla River	Trophic-weighted residue	2002
Camden	Horsepen Creek	Dissolved oxygen	2001
	Horsepen Creek	Fecal coliform	2006
	St. Marys River	Dissolved oxygen	2006
	St. Marys River	Trophic-weighted residue	2002
Charlton	Boone Creek	Dissolved oxygen	2001
	North Prong St. Marys River	Dissolved oxygen	2001
	North Prong St. Marys River	Trophic-weighted residue[1]	2002
	Spanish Creek	Dissolved oxygen	2001
	Spanish Creek	Fecal coliform	2006
	Spanish Creek	Dissolved oxygen assessment pending[2]	-
	St. Marys River	Trophic-weighted residue	2002
	Tributary #6 to St. Marys River	Arsenic[3]	-
	Suwannee Canal	Trophic-weighted residue	2002
	Suwannee River	Trophic-weighted residue	2002
Clinch	Cane Creek	Dissolved oxygen	2001
	Jones Creek	Dissolved oxygen assessment pending	-
	Tatum Creek	Fecal Coliform	2011
	Suwannee Creek	Dissolved oxygen	2001
	Suwannee River	Trophic-weighted residue	2001
Echols	Suwannee River	Trophic-weighted residue	2002
	Toms Creek	Dissolved oxygen	2001
Pierce	Satilla River	Trophic-weighted residue	2002
Ware	City Drainage Canal	Fecal coliform	1998/2006
	Cox Creek	Dissolved oxygen assessment pending	-
	Kettle Creek	Dissolved oxygen assessment pending	-
	Satilla River	Trophic-weighted residue	2002
	Satilla River	Dissolved oxygen assessment pending	-
	Suwannee Canal	Trophic-weighted residue	2002
	Suwannee Creek	Dissolved oxygen	2001
	Suwannee Creek	Dissolved oxygen assessment pending	-
	Suwannee River	Trophic-weighted residue	2002

[1] Refers to a value of mercury in fish tissue that is in excess of the GAEPD human health standard of 0.3 mg/kg.
[2] Refers to the GAEPDs effort to determine the natural DO concentrations for the region before a use assessment is made. It is the GAEPD's goal to determine the natural DO concentrations before the 2014 list is drafted.
[3] The Arsenic impairment in Tributary #6 has been classified by GAEPD and approved by the EPA as a category 4b impairment, and thereby identifies the stream as a waterbody failing to meet one or more of its designated uses but a pollution control requirement other than a TMDL is in place.



Map Date: 8/10/2015 File: Document Name: Impaired waters, TMDLs and NPDES permits.mxd Data Source: GAEDP Stormwater and Wastewater NPDES Permits, NHD Flowlines, ESRI Topo Service

Figure 25. Impaired waterbodies with and without TMDLs and NPDES permitted facilities within the Georgia portion of the RHI for Okefenokee National Wildlife Refuge.

Impairments due to mercury are the most relevant to the Okefenokee NWR (Figure 25). The refuge is home to a diverse native fish assemblage (USFWS 2006) and boasts renowned recreational and sport fishing. Both the Suwannee and St. Marys Rivers are failing to meet the usage classification for fishing, propagation of fish, shellfish, game and other aquatic life due to the trophic weight residue of mercury exceeding the human health standard of 0.3 mg/kg of fish muscle tissue. The TMDLs for trophic weight residue were implemented in both the St. Marys and the Suwannee Rivers in 2002. Fish consumption guidance with respect to mercury contamination is available through the EPA (EPA 2014).

5.5.2.2 NPDES Permits

NPDES permit locations within Okefenokee RHI were identified using the EPA-State combined Facility Registry System (FRS). A query of the FRS was performed to isolate facilities with any NPEDS related classifications. Twelve NPDES permitted facilities were identified within the Okefenokee RHI (2 NPDES Major Facilities, and 10 NPDES Non-Major Facilities). However, nine of the facilities are considered to have no impact on the refuge due their position downstream of the refuge. Of the three facilities with the potential to impact the refuge, only one is considered “Major,” and is categorized as either:

- Publicly Owned Treatment Works (POTWs) facility with design flows ≥1 MGD or that serve a population ≥10,000 or cause significant water quality impacts, or
- Non-POTW facility that discharges surpass a point threshold based on criteria such as toxic pollutant potential, flow volume and water quality factors such as impairment of receiving water or proximity of discharge to coastal waters (EPA 2013a).

The “Major” NPDES facility (Site 1, Table 14, Figure 25), the Waycross Water Pollution Control Plant (WPCP), discharges into the Satilla River. Located outside Upper Suwannee River watershed, there is no natural surface water connection that exists between the facility and the refuge. Two facilities (Site 2 and 3, Table 14, Figure 25) considered “Non-Major,” the Homerville Industrial Park and the Homerville WPCP, discharge into Tatum Creek and Woodyard Creek, respectively. Both of these “Non-Major” facilities are located upstream of the refuge.

Table 14. NPDES facilities with potential impact on the Refuge. [Source: EPA 2013b].

Figure 25 Site ID	EPA Registry ID	Primary Facility Name	NPDES Permit Type
1	110000529456	Waycross WPCP	Major
2	110006777522	Homerville Industrial Park	Non-Major
3	110010040516	Homerville WPCP	Non-Major

5.5.3 *Other surface water quality information*

Other surface water quality information relating to the Suwannee-Satilla Water Planning Region is available through the Georgia Water Plan: Water Resources Information and Data (SSWMP 2011; USGS 2014a).

5.5.4 *Groundwater Quality*

According to the Suwannee-Satilla Watershed Management Plan (2011), there are 24 counties in southeast Georgia which are subject to the Coastal Georgia Water and Wastewater Permitting Plan for Managing Saltwater Intrusion (Coastal Permitting Plan). There are five counties (Bacon, Brantley, Charlton, Pierce, and Ware counties) in the Suwannee-Satilla Region that are located within the "Green Zone," an area with no pumping restrictions from the Upper Floridan aquifer according to the Coastal Permitting Plan; however, there are water conservation requirements related to groundwater withdrawals (SSWMP 2011).

5.6 Water Law/Water Rights (Georgia)

For a comprehensive summary of water law and water rights in the Florida portion of the RHI, see the Lower Suwannee National Wildlife Refuge WRIA.

5.6.1 *Georgia Water Law Overview*

The 2004 Comprehensive State-wide Water Management Planning Act mandates the development of a state-wide water plan that supports a far-reaching vision for water resource management: "Georgia manages water resources in a sustainable manner to support the state's economy, to protect public health and natural systems, and to enhance the quality of life for all citizens" (Official Code of Georgia [O.C.G.A.] 12-5-522(a)). The Georgia Comprehensive State-wide Water Management Plan, adopted by the General Assembly in 2008, promotes water planning in Georgia by assessing the State's water resources and by forecasting future water demands and use (SSWMP 2011). In accordance with O.C.G.A. §12-5-522(b)(5), water quality and quantity and surface and groundwater are interrelated and require integrated planning (GAWMP 2008).

Ten regional Water Councils have been appointed to prepare water-development and conservation plans. The Okefenokee NWR RHI lies within the Suwannee-Satilla water-planning region. The Suwannee-Satilla Regional Water Planning Council was established in February 2009. The vision statement, as established September 23, 2009, is to "…manage water resources in a sustainable manner under Georgia's regulated riparian and regulated reasonable use laws to support the state's and region's economy, to protect public health and natural resources, and to enhance the quality of life for all citizens; while preserving the private property rights of Georgia's landowners, and in consideration of the need to enhance resource augmentation and efficiency opportunities." Public and stakeholder involvement is a key component of the Georgia water planning process. A Public Involvement Plan was adopted by the Suwannee-Satilla Council on November 11, 2010. An initial Recommended Regional Water Plan was issued in May 2011 (SSWMP 2011).

Additionally, there are 12 Regional Commissions in Georgia. Regional Commissions are agencies of local governments and representatives from the private sector that facilitate coordinated and comprehensive planning at the local and regional levels. The Southern Georgia Regional Commission covers the same counties as the Suwannee-Satilla Council. In July 2009, the Georgia Department of Community Affairs required the Regional Commissions to adopt, maintain, and implement a Regional Plan (DCA Rule 110-12-6). A key component is the establishment of "performance standards", which are actions, activities, or programs a local government can implement or participate in that will advance their efforts to meet the vision of the Regional Plan. The Southern Georgia Regional Commission's Regional Plan defines two achievement thresholds (Minimum and Excellence), which are attained by implementing the performance standards. Local governments are required to achieve the Minimum Standard to maintain their Qualified Local Government status, which qualifies them for certain state funding. By achieving the Excellence Standard, a local government may be eligible for special incentives.

5.6.1.1 Antidegradation Policy

On March 15, 2012 the EPA approved Georgia's Water Use Classifications and Water Quality Standards (Chapter 391-3-6-.03), which include the state's Anti-degradation Policy. Implementation procedures for this policy have not yet been established.

5.6.1.2 Public Trust Doctrine

"Public trust doctrine" is a common law concept that stipulates that navigable waters are publicly owned or held in trust for all people. Georgia jurisprudence has not expressly recognized public trust doctrine (Bowmar Date unknown).

5.6.1.3 Minimum Flows and Levels and Permitting

There is no specific State statute regarding minimum flows in Georgia. However, O.C.G.A. 12-5-31(g) states that the granting of a withdrawal permit shall not have unreasonably adverse effects upon other water uses in the area; also O.C.G.A. 12-5-23 authorizes the Georgia Department of Natural Resources (GADNR) to manage water uses in the State. GADNR Rule 391-3-6-.07(4) requires persons withdrawing surface water to allow specified flows to remain in the river or to release specified flows from reservoirs (GADNR 2001).

Following the 1977 water allocation amendment to the Georgia Water Quality Control Act, GAEPD implemented its instream flow protection policy through provisions inserted in surface water withdrawal permits and coordinated with water quality loading limits established for wastewater dischargers under the National Pollutant Discharge Elimination System (NPDES). With some limited exceptions, applications for post-1977 withdrawals (whether new applications or modifications of permits already in-place) were required by GADNR Rule to allow a minimum instream flow, typically based on the seven-day, ten-year ("7Q10") low flow, after permitted withdrawals (GADNR 2001).

Although GADNR's 7Q10 rule was designed to protect water quality, it was not based on the science of how much water should remain in a stream to maintain a healthy aquatic community. An interim minimum stream flow protection policy became effective April 1, 2001. This policy stipulated that if recommended in-state site-specific studies have not been funded and conducted before June 30, 2006, then the interim modified policy would continue to be employed (GADNR 2001).

Effective April 1, 2001 all new applications for non-farm water withdrawals from new sources, or expanded use of existing surface water sources, are required to meet new interim minimum flow protection requirements that allow the applicants the flexibility to select from one of the ensuing three (3) minimum stream flow options:

Monthly 7Q10 Minimum Flow Option:

> For a water supply reservoir, the applicant is at all times required to release (at the reservoir's release point) the lesser of the monthly 7Q10 or the current inflow to the reservoir. For off stream reservoirs, the flows must be protected at the intake location as well as at the reservoir

outlet. For an instream withdrawal, the applicant is at all times required to pass the lesser of the monthly 7Q10 or the inflow at the withdrawal point.

Site-Specific Instream Flow Study Option:

The applicant may perform a site-specific instream flow study to determine what minimum flow conditions must be maintained for protection of aquatic habitat. Prior to commencing such an instream flow study, the applicant must receive prior approval of the study design from GADNR. Upon the applicant's completion of the instream flow study, the GADNR will evaluate the study results and recommendations for the minimum flows that must be preserved by the applicant. The GADNR acting through the GAEPD Director must concur or recommend an acceptable minimum flow.

Mean Annual Flow Options:

A. 30% Mean Annual Average Flow (Direct Withdrawal)

For direct water withdrawals (no on-stream impoundment) the applicant is at all times required to allow the lesser of 30% of the mean annual flow of the stream, or the inflow, to pass the instream withdrawal point.

B. 30/60/40% Mean Annual Flow (Water Supply Reservoir)

For applicants proposing a reservoir, the applicant is at all times required to release from the reservoir, the lesser of 30% of the mean annual flow or inflow during the months of July through November; 60% of the mean annual flow or inflow during the months of January through April; and 40% of the mean annual flow or inflow during the months of May, June, and December.

5.6.1.4 Riparian Water Rights

Georgia's surface water allocation policy is that of Regulated Riparian Doctrine. Rather than consider water a common resource (Riparian Doctrine) or as a private resource (Appropriative Rights Doctrine), regulated riparian considers water a public resource (a resource that can be used by all citizens, but public/industrial use is subject to regulation, usually in the form of permits). Regulated Riparian Rights have come about as states recognize the need for water management as the needs of large volume of water usage increases and those users begin to compete for water resources. A 1977 amendment to the Georgia Water Quality Control Act requires the GAEPD to permit water diversions and withdrawals of more than 100,000 gallons per day on a monthly average (Bowmar Date unknown). Regulated Riparian Rights do not take ownership of the right to use water away from riparian landowners (Dellapenna and Draper 2002; Blount et al. 2002).

Georgia's Riparian Rights doctrine is codified in O.C.G.A. §§ 44-8-1 and 51-9-7. Section 44-8-1 provides, to wit:

> Running water, while on land, belongs to the owner of the land, but he has no right to divert it from the usual channel, nor may he so use or adulterate it as to interfere with the enjoyment of it by the next owner.

Section 51-9-7 provides, to wit:

> The owner of land through which non-navigable watercourses may flow is entitled to have the water in such streams come to his land in its natural and usual flow, subject only to such detention or diminution as may be caused by a reasonable use of it by other riparian proprietors; and the diverting of the stream, wholly or in part, from the same, or the

> obstruction thereof so as to impede its course or cause it to overflow or injure his land, or any right appurtenant thereto, or the pollution thereof so as to lessen its value to him, shall be a trespass upon his property.

There is a “regulated reasonable use” statute for groundwater allocation.

5.6.1.5 Georgia Water Withdrawals as summarized by Brown-Kobil (2014)

The National Wildlife Refuge System Administration Act requires the USFWS to secure its water rights through state law. See 16 U.S.C. § 668dd(a)(4)(G). Below is an updated summary of the water laws of Georgia as of December 2013.

Georgia law treats groundwater and surface water separately, which is typical of state water laws. The GAEPD administers the Ground-water Use Act of 1972, Ga. Code Ann. § 12-5-90 through 107, and the Surface Water Act, Ga. Code Ann. § 12-5-31. Any person who withdraws or impounds more than 100,000 gallons per day on a monthly average is required to first obtain a permit from the GAEPD. “Person” is defined as “any and all persons, including individuals, firms, partnerships, associations, public or private institutions, municipalities or political subdivisions, governmental agencies, or private or public corporations organized under the laws of this state or any other state or country.” Ga. Code Ann. § 12-5-92(8) (emphasis added). Thus, if USFWS is withdrawing, obtaining, or using groundwater in excess of 100,000 gallons, it must first obtain a permit. Ga. Code Ann. § 12-5-96. However, a permit is not required for the withdrawal, diversion, or impoundment of surface water where:

1. *Any such withdrawal which does not involve more than 100,000 gallons per day on a monthly average;*
2. *Any such diversion which does not reduce the flow of the surface waters at the point where the watercourse, prior to diversion, leaves the person’s or persons’ property or properties on which the diversion occurred, by more than 100,000 per day of a monthly average;*
3. *Any such diversion accomplished as part of construction for transportation purposes which does not reduce the flow of surface waters in the diverted watercourse by more than 150,000 gallons per day on a monthly average; or*
4. *Any such impoundment which does not reduce the flow of the surface waters immediately downstream of the impoundment by more than 100,000 gallons per day on a monthly average. Ga. Code Ann. § 12-5-31.*

Ga. Code Ann. § 12-5-31(b)(1). Furthermore, no permit shall be required for a reduction of flow of surface waters during the period of construction of an impoundment, including the initial filling of the impoundment, or for farm ponds or farm impoundments constructed and managed for the sole purpose of fish, wildlife, recreation, or other farm uses. Id. at (b)(2)(emphasis added).

A reasonableness standard is used to determine whether to issue a permit to use surface or groundwater. The GAEPD takes into consideration the applicant’s needs for the water and ensures that the permit will not have an unreasonably adverse effect upon other water users in the area, including, but not limited to public use, farm use, and potential as well as present use. Id. at (g)(surface water); Id. at § 12-5-96(d)(groundwater). Non-farm surface permits may be revoked for, inter alia, the quantity of the water allowed under the permit would prevent other applicants from reasonable use of the surface water, including farm use. “Farm use” is defined as irrigation of any land used for general farming, forage, aquaculture, pasture, turf farming, or any other activity conducted in the course of a farming operation production, orchards, or tree and ornamental nurseries; provisions of water supply for farm animals, poultry farming, or any other activity conducted in the course of a farming operation (GA. CODE ANN. §

12-5-31(a)(3)). As a general rule, farm use is exempt from the reasonableness standard, including revocation based on unreasonable effects upon other non-farm users. Id. Groundwater permits likewise exempt farm use except revocation may be based on adverse effects upon other farm users of groundwater beneath their property. Id. at § 12-5-105(b)(3).

During emergency periods of water shortage which places "in jeopardy the health or safety of citizens of such area or to threaten serious harm to the water resources of the area," the Division may by emergency order impose restrictions on water permits after written notice to the holder. Any restrictions, except upon farm use, are effective immediately. Id. at § 12-5-102(a) (groundwater); § 12-5-31(l)(1) (surface water). The holder is then given five days from receipt of the notice to object to the proposed action. Id. During these shortages, the Division must give first priority to water for human consumption and second priority to farm use but water for industrial purposes is in no way affected or diminished. Id. at § 12-5-102(c) & (d) (groundwater); § 12-5-31(l)(3) & (4) (surface water). Although there is no formal procedure for protesting a water permit, nothing in the code prohibits it. See Id. at § 12-5-46.

5.7 Wilderness Area Law That May Affect Hydrologic Modifications and Water Use

The Okefenokee Wilderness Area established under public law 93-429 on October 1, 1974 and is administered by Secretary of the Interior in accordance with the provisions of the Wilderness Act of 1964 (P.L. 88-577; 16 USC 1131-1136). Under Section 2(c) of the Wilderness Act: "A wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this Act an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value" (TWS 2004).

Since its inception, the Wilderness Act has been interpreted and clarified through a number of subsequent Federal and State Wilderness laws. Notable Federal laws include the Eastern Wilderness Areas Act of 1974 (P.L. 93-622) and accompanying Senate Report 93-803, as well as the Endangered American Wilderness Act of 1977 (P.L. 95-220) and accompanying House Report 95-540. P.L. 98-514 of 1984 and P.L. 99-555 of 1986 refer to the Georgia Wilderness Act, which designated additional wilderness areas within Georgia. These laws do not provide additional local guidance regarding the Federal Wilderness Act.

5.7.1 Water Rights and Water Laws

A longstanding legal doctrine (the Winters doctrine) provides that, unless Congress says otherwise, water rights are created under federal law when the United States sets aside land for things like national parks, forests, and wildlife refuges. The Supreme Court has never decided whether this doctrine creates federal water rights when federal land is set aside as wilderness. Lower court decisions have pointed in both directions. This leaves unclear whether wilderness areas designated before the mid-1980s have federal law-based water rights, or whether such rights are created when Congress remains silent on water in designating new wilderness areas (TWS 2004).

P.L. 88-577 Section 4(d)(4)(1) states: "Within wilderness areas in the national forests designated by this Act… the President may, within a specific area and in accordance with such regulations as he may deem desirable, authorize prospecting for water resources, the establishment and maintenance of reservoirs, water conservation works, power projects, transmission lines, and other facilities needed in the public interest, including the road construction and maintenance essential to development and use thereof, upon his determination that such use or uses in the specific area will better serve the interests of the United States and the people thereof than will its denial"

Section 4(d)(6) of the Wilderness Act states: "Nothing in this Act shall constitute an express or implied claim or denial on the part of the Federal Government as to exemption from State water laws.

5.7.2 Managing Fish and Wildlife Habitat

Section 4 (b) of the Wilderness Act states: "Except as otherwise provided in this Act, each agency administering any area designated as wilderness shall be responsible for preserving the wilderness character of the area and shall so administer such area for such other purposes for which it may have been established as also to preserve its wilderness character. Except as otherwise provided in this Act, wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use."

Habitat modification in wilderness areas is inappropriate "except as necessary to meet minimum requirements for the administration of the area for the purpose of [the Wilderness] Act[.]" (Section 4(c)). The Wilderness Act specifically prohibits modifications to the wilderness landscape in its definition of wilderness: "An area of wilderness is further defined to mean in this chapter an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements…" (Section 2(c)). A large part of the value of wilderness is in the absence of human control over the land.

P.L. 95-237, House Report 95-540 adds: "Fisheries enhancement activities and facilities are permissible and often highly desirable in wilderness areas to aid in achieving the goal of 'preserving the wilderness character of the area' as stated in Section 4(b) of the Wilderness Act. Such activities and facilities include fish traps, stream barriers, aerial stocking, and the protection and propagation of rare species."

Fire management within Wilderness Areas is allowed under P.L. 88-577 Section 4(d)(1): "In addition, such measure may be taken as may be necessary in the control of fire, insects, and diseases, subject to such conditions as the Secretary deems desirable." The "permissible" measures allowed under Section 4(d)(1) were specified in HR 95-540 to include "the use of mechanized equipment, the building of fire roads, fire towers, fire breaks or fire pre-suppression facilities where necessary and other techniques for fire control… anything necessary for the protection of public health or safety is clearly permissible." However, when fire suppression is undertaken, it should be guided by the "minimum tool" principle and make use of the least damaging equipment and methods consistent with the safety of the public and firefighters. When heavy equipment must be used, the areas affected must be made a top priority for rehabilitation following suppression activities (TWS 2004).

P.L. 88-577 Section 4(d)(7) states: "Nothing in this Act shall be construed as affecting the jurisdiction or responsibilities of the several States with respect to wildlife and fish in the national forests."

5.7.3 Recreation

Recreation is an important component of Wilderness designation; however, facilities for recreation should be kept minimal. P.L. 88-577 Section 4(c) outlines: "Except as specifically provided for in this Act, and subject to existing private rights, there shall be…no permanent road within any wilderness area designated by this Act and except as necessary to meet minimum requirements for the administration of the area for the purpose of this Act (including measures required in emergencies involving the health and safety of persons within the area), there shall be no temporary road, no use of motor vehicles, motorized equipment or motorboats, no landing of aircraft, no other form of mechanical transport, and no structure or installation within any such area." Trails, bridges, and trail signs are permitted under H.R. 95-540, but they should be limited to meet safety objectives while minimizing intrusions in keeping with the wilderness environment concept. Trailside shelters or lean-tos should not be provided in wilderness areas except where necessary under Section 4(b) or (c) of the Wilderness Act for the protection of the wilderness, or for the health and safety of the user. In general, fire rings, hitching posts, non-permanent tent platforms or pads, and other temporary structures used by outfitters may be allowed at the discretion of the Secretary (TWS 2004).

P.L. 88-577 Section 4(d)(1) permits the use of aircraft or motorboats within Wilderness Areas where uses had already become established. Section 2 of P.L. 93-429 restricts the use of powered watercraft to motors of ten or less horsepower and authorizes the maintenance of 120 miles of watercraft trails, with access from the Suwannee River Sill, Steven Foster State Park, Kings Landing, and Suwannee Recreation Area (Camp Cornelia).

Sec 3 of P.L. 93-429 permits fishing within the Okefenokee Class I Wilderness Area, but allows the Secretary of the Interior to designate zones and establish periods when fishing is prohibited, for reasons of public safety, administration, fish and wildlife management, or public use and enjoyment.

5.7.4 Commercial Enterprise and Development

Section 4(c) of the Wilderness Act states: "Except as specifically provided for in this Act, and subject to existing private rights, there shall be no commercial enterprise and no permanent road within any wilderness area designated by this Act and except as necessary to meet minimum requirements for the administration of the area for the purpose of this Act (including measures required in emergencies involving the health and safety of persons within the area)."

P.L. 88-577 Section 4(d)(3) sanctioned the staking of mining claims and the operation of mineral laws in national forest wilderness areas until January 1, 1984, although Congress later blocked leasing of minerals in wilderness areas during 1982 and 1983. Congress and the courts have recognized that activities associated with mineral development are incompatible with the concept of wilderness (TWS 2004). The National Wildlife Refuge System Improvement Act of 1997 established clear standards for determining which activities to allow on refuge lands. While this law was intended to result in fewer commercial activities being allowed on refuges, wilderness designation precludes many of these activities outright (TWS 2004).

P.L. 88-577 Section 4(d)(4)(2) states: Within wilderness areas in the national forests designated by this Act…the grazing of livestock, where established prior to the effective date of this Act, shall be permitted to continue subject to such reasonable regulations as are deemed necessary by the Secretary of Agriculture."

P.L. 88-577 Section 4(d)(5) states: "Commercial services may be performed within the wilderness areas designated by this Act to the extent necessary for activities which are proper for realizing the recreational or other wilderness purposes of the areas."

6 Assessment

This section highlights major water resources threats or issues of concern pertaining to the refuge. To provide context, issues and needs identified in previous studies/plans and the kick-off meetings for the WRIA process for Lower Suwannee and Okefenokee NWRs is briefly summarized below. Then in Section 6.1 the primary drivers of threats to the refuge's aquatic resource base are briefly discussed first, followed by a discussion of specific threats or issues of concern in two categories: urgent or immediate issues (those for which impacts are already strongly manifest), and longer term issues. Some recommendations to address these threats are presented in Section 6.2.

Okefenokee NWR protects the headwaters of both the St. Marys River and the Suwannee River. Several conservation plans (GAEPD 2002b; SMRMC 2003; CRC 2014) describe the watershed condition of the St. Marys Basin; identify water pollutant sources; and discuss future issues and data needs, including long-term monitoring needs, water quality data gaps, and the need to work with the public. The dominant land use categories in St. Marys River Basin are primarily agriculture/forested and parks/recreation/ conservation. Collectively, these two land use categories account for roughly 90% of the total land area in the basin. Projected future land use, coupled with projected population growth in the basin, suggests that residential development will occur within the basin, primarily consisting of a mix of suburban residential growth and conservation land in the area immediately bordering the St. Marys River (GAEPD 2002b; CRC 2014).

Katz and Raabe (2005) summarized issues and research needs in detail for the Suwannee River Basin; many of the issues and research needs identified in 2005 are still relevant ten years later. Perhaps of greatest need is renewed coordination between Federal and State agencies and other organizations. Beginning in 1995, in response to concerns for the Suwannee River Basin broader watershed management initiatives, organizations with vested interests in the region held the first meeting of the Suwannee Basin Interagency Alliance (SBIA) to formally coordinate efforts and resources (Webster and Winn 1997). The SBIA helped align river basin management planning for Georgia and Florida. The goals of the SBIA were to promote coordination in the identification, management, and scientific knowledge of the natural resources in the basin and estuary. Timing was fortuitous as both Florida and Georgia had adopted river basin management planning approaches, and the USGS National Water Quality Assessment (NAWQA) was getting underway, with the Suwannee Basin as one of several focal points. SBIA and NAWQA were closely aligned (G. Mahon, personal communication, September 5, 2014). This alliance is no longer active despite the critical need for cooperation with Federal, State, and local agencies to address the most compelling conservation issues and to conduct fundamental environmental research and monitoring, primarily due to reductions in funding (A. Dausman, personal communication, July 29, 2013).

More recently, the WRIA process was initiated for Lower Suwannee NWR in May 2013, with an initial site visit, and in May 2014 for Okefenokee NWR. A large kick-off meeting was held on June 12, 2013 in Gainesville, Florida, for the Lower Suwannee NWR WRIA Process, and a similar kick-off meeting was held on August 26, 2014, at Okefenokee NWR. These kick-off meetings sought to bring together scientists, managers, and others to collaborate and share information and data about the river, refuge, management issues. The overall objectives were to achieve a greater understanding of existing refuge water resources; identify data needs, concerns, and threats to those resources at multiple spatial and temporal scales; and provide a basis for refuge management actions and operational recommendations. A summary of the meeting, attendees, and meeting products from the Okefenokee NWR WRIA kick-off meeting is provided in Appendix A. Additional information about the WRIA for Lower Suwannee can be found in Thom et al. 2015.

6.1 Water Resource Issues of Concern

For many freshwater aquatic systems like those protected by both Okefenokee NWR and Lower Suwannee NWR, water quality and water quantity are the two most critical factors influencing the ability of managers to meet the primary purposes of refuge establishment. A primary concern of the Okefenokee NWR is to maintain the quantity and quality of surface water flows and the rich biological diversity within the basin (USFWS 2006). Related to water quantity, water withdrawals for municipal, industrial, and agricultural use are a primary concern. Within the Suwannee Basin, the State Water Management Districts, as required by the Florida legislature, have developed minimum flow requirements for the Suwannee River and the Santa Fe Rivers. An identified issue is to evaluate the effectiveness of these minimum flows for ecological function and biological community protection under various hydrologic regimes and seasonality for the Suwannee River, delta, and estuary. The effects of groundwater withdrawals on minimum flows and levels in surface waterbodies, and the resulting impacts of groundwater withdrawals on ecosystem integrity on the refuge and in the surrounding landscape, are also primary concerns.

The Comprehensive Conservation Planning (CCP) document for the Okefenokee NWR highlighted many threats to the refuge, the contributing watersheds, and the greater Okefenokee Ecosystem including mining and oil and gas development, impacts to wetland habitat from changing land use, silvicultural practices, urbanization, altered hydrology, climate change, groundwater use, the influence of authorized recreational activities, and air pollution (USFWS 2006). Because Okefenokee Swamp is primarily maintained by precipitation and surface runoff, air quality and land use greatly influence water quality within the refuge and wetlands.

Predicted climate-related impacts are of concern, including the conversion of freshwater wetlands and forested riverine wetlands to estuarine and saltwater marsh due to factors including sea-level rise, altered hydrologic regimes, and increased water withdrawals (Buell et al. 2009). Climate effects, acting in concert with increased water withdrawal and lower yields, could increase hydrologic stress on the Suwannee Basin, especially the Lower Suwannee River. Floods, droughts, natural disasters, climate change, changing timber management practices, industrial and commercial development, air pollution, authorized public use, and urbanization are all identified as threats in the Okefenokee NWR CCP (USFWS 2006).

Finally, limitations in staff and funding at the refuge highlight the need for leveraging various data and staffing needs through partnerships across the St. Marys River and Suwannee River Basins. Identified partners include USGS, the University of Georgia, Valdosta State University, the University of South Carolina, the Suwannee River Water Management District, the University of Florida, Florida State University, Georgia Department of Natural Resources (including the Environmental Protection Division), Florida Department of Environmental Protection, and other federal, state, and non-governmental organizations.

6.1.1 Urgent/Immediate Issues

6.1.1.1 Water Quantity

Both the St. Marys River and the Suwannee River are unaffected by any major dams, flow diversions, or navigation projects, with the exception of one privately owned dam on Sweetwater Creek in Clinch County, Georgia (Farrell et al. 2005; Loftin et al. 2000). Impacts to both surface water and groundwater quantity are mainly due to water withdrawals and consumptive use. Urgent issues related to water quantity derive from the need to maintain sufficient water levels and flows to sustain aquatic biota and habitat and include the following:

- Within the RHI and immediately adjacent to Okefenokee NWR, surface hydrology has been altered through silvicultural practices. Ditching of the wetlands has shortened the hydroperiod (decreased the duration of seasonal inundation) by increasing drainage rates. Ditching and draining also connects isolated wetlands and exposes amphibians to threats from fish invasions and diminished seasonal water availability. Several threats to water resources (both quantity and quality) for Okefenokee NWR involve impacts from proposed strip mining activities for titanium (proposed for 22,000 acres within the refuge along Trail Ridge, which directly influences hydrology in portions of the swamp), as well as oil and gas extraction (USFWS 2006).
- It is known that the surface water flows (especially in the Suwannee Basin) in both rivers and spring systems are inextricably linked to groundwater (Farrell et al. 2005), and that river flow is intimately connected with spring flows throughout the year (Pittman et al. 1997). Springs maintain river flow during the low flow periods, providing relatively stable flows year-round, while during high flow periods river water flows back into the springs, recharging the groundwater. However, there is insufficient information on the details of these interactions to inform water management strategies to maintain adequate water levels and flows to protect the Okefenokee Swamp ecosystem.
- Groundwater contributions to the Okefenokee Swamp's water budget are not well known (USFWS 2006), but could be important. Holes in the bed of the swamp were located during construction of logging railroads (Hopkins 1947), so there is a remote possibility of seepage through the Hawthorn formation to or from the aquifers below, although most available studies indicate that the Hawthorn formation effectively separates the water table aquifer from the principal artesian aquifer (Rykiel 1977).
- Within the St. Marys Basin, the influence that groundwater seepage has on decreasing (or sometimes increasing) dissolved oxygen levels in the river due to physical mixing of groundwater and surface water with differing levels of dissolved oxygen is not well understood.

6.1.1.2 Water Quality

Although studies within RHI indicate overall good water quality in most areas, there are several urgent issues related to water quality in the Okefenokee Swamp, and within the St. Marys and Suwannee River Basins that threaten the ability to maintain water quality within ranges that would promote a healthy ecosystem.

- Large nitrogen inputs to the land surface from fertilizers, animal waste, sewage effluent (septic tanks, land application and deep well injection of treated sewage effluent) are raising concerns regarding human and ecosystem health. Nitrate concentrations in groundwater and spring waters have increased substantially from near background concentrations of less than 0.1 mg/L in the 1960s and 1970s (Rosenau et al. 1977) to more than 5 mg/L in the late 1990s at some first-magnitude springs (Hornsby and Ceryak 1998; Katz et al. 1999). In some areas, nitrate-N concentrations in the Upper Floridan aquifer (the source of water supply) exceed the maximum contaminant level of 10 mg/L for drinking water. Within the Suwannee Basin, groundwater and surface water are intimately connected, with groundwater quality directly influencing surface water quality. Effects from high nitrate concentrations in the Suwannee River estuaries, including contamination of the local shellfish industry and impacts to coastal fisheries, are also of concern.
- Atmospheric deposition of mercury and the subsequent bioaccumulation of mercury in certain fish species is an important water-quality issue in the Okefenokee Swamp and within the Suwannee River Basin. Mercury levels in crayfish, sunfish, and largemouth bass increased significantly in the Suwannee River with increasing distance upstream from the estuary (Chasar

et al. 2004). Fish-consumption advisories for mercury have been issued for the Santa Fe River and for stream segments in the Alapaha, Withlacoochee, and Upper Suwannee subbasins in Georgia (Katz and Raabe 2005).

- Land use, especially habitat conversion, concentrated animal-feeding operations (CAFOs), cropland farming, silvicultural practices, and other land-surface/land-cover alterations can alter water quality parameters, leading to decreased dissolved oxygen, increased water temperatures, and eutrophic conditions in general. Both point source and non-point source pollution related to changing land use introduce contaminants including: sediments, wastewater treatment plant (WWTP) effluents, pesticides, fertilizers, toxic compounds, pathogens, xenobiotic contaminants (e.g., pharmaceuticals), ammonia, and nitrates; all of which contribute to water quality degradation and human health concerns.
- Stochastic events (such as releases from WWTPs caused by flooding) increase nutrients and pathogens, and decrease dissolved oxygen, thereby causing water quality issues. Both point source and non-point source inputs are threats to the St. Marys River and Suwannee River systems.

6.1.1.3 Invasive Species

Aquatic invasive species (AIS) (i.e., those species that have been introduced and are not native) and aquatic nuisance species (ANS) (i.e., those species that may be native to an area but cause detrimental alterations to an ecosystems) may be impacting the distribution of native species and altering aquatic, marine and estuarine ecosystem function; these potential impacts are of great concern for the refuge. Currently 12 AIS/ANS are listed as occurring within the St. Marys Basin (HUC 8), and 26 AIS/ANS are listed as occurring within the Lower Suwannee (HUC 8), including several species of fishes, reptiles, frogs, mollusks, and two mammals associated with aquatic environments (nutria and capybara) (USGS 2014b). Recent surveys conducted by USGS documented several species of South American suckermouth armored catfishes (*Loricariidae*, *Pterygoplichthys spp*.) in the Santa Fe River drainage (Nico et al. 2012). These specimens represent the first confirmed records of *Pterygoplichthys* in the Suwannee River Basin, and the *P. gibbiceps* specimen represents the first documented record of an adult or near adult of this species in open waters of North America. *Pterygoplichthys disjunctivus* or its hybrids are already abundant and widespread in other parts of peninsular Florida, but the Santa Fe River represents a northern range extension. *Pterygoplichthys* are still relatively uncommon in the Santa Fe drainage and successful reproduction is not yet documented. These South American catfish apparently use artesian springs as thermal refugia. In the Santa Fe River, eradication might be possible during cold periods when catfish congregate in spring habitats.

The present small population of *Pterygoplichthys* in the Santa Fe River drainage may not have much of an impact on the environment. However, if these non-native catfishes increase in number, they may have a negative effect on ecosystem condition. Currently, it is not known whether the population in the Santa Fe drainage is selectively feeding on the nuisance algae or if their feeding is contributing to the loss of desirable plants and benthic invertebrates. Research on invasive *Pterygoplichthys* in Mexico has revealed that their grazing reduces the quality and quantity of benthic resources and also causes marked changes in the nutrient dynamics of the impacted river systems (Capps 2012). Adverse impacts have also been associated with their burrowing activities, contributing to bank instability and erosion, shoreline loss, safety concerns and economic loss (Nico et al. 2009a). Interactions between introduced *Pterygoplichthys* and certain native species are a concern. For example, in the St. Johns basin, *Pterygoplichthys* and native Florida manatees *(Trichechus manatus latirostris*) both congregate in spring habitats during winter months, and large numbers of catfish commonly attach to the manatees and graze the biofilm on the large mammal's skin (Nico et al. 2009b; Gibbs et al. 2010; Nico 2010). The Florida manatee is a federally endangered species and populations are especially vulnerable during the winter, but it is still unclear if the presence of *Pterygoplichthys* is a substantial threat.

6.1.2 Long-Term Issues

6.1.2.1 Potential Impacts Related to Climate Change

- Many factors related to climate change may influence the Okefenokee Swamp, and the St. Marys and Suwannee Basins, including changing rainfall amounts and precipitation intensity, as well as changes in the frequency, timing, magnitude, and duration of tropical storms and hurricanes. Future climate projections have large uncertainties associated with the magnitude and the direction of some of these changes. Water use and other land use may exacerbate impacts related to altered hydrologic regimes resulting from a changing climate.
- Palmer Drought Severity Index values are increasing and becoming more severe at the same time that water withdrawals (both surface water and groundwater) are increasing for agriculture and other human demands due to growing population in both Georgia and Florida for both the Suwannee and St. Marys Basins (USFWS 2006). This is especially evident along the Coastal Plain in Florida and Georgia, where water withdrawals from the Floridan aquifer and other aquifer systems along the coast have increased. These issues are likely to intensify in the future with continuing climate change and growth-driven increases in water demand.
- Rare fish and aquatic species near the edge of their range, such as the blackbanded sunfish (a state endangered species in Georgia; Bechler and Salter 2014), could be threatened by continued climate change.
- With climate change and continued introductions from human activities, yet unknown introduced species may pose future risks to the refuge and the Suwannee River Basin.

6.1.2.2 Recreation and Management

- Given increasing population trends and future development scenarios, future interbasin water transfers pose a potential threat to maintaining adequate water levels and flows to protect the Okefenokee Swamp ecosystem.
- Potential threats and impacts to both terrestrial and aquatic species as a result of recreation are unknown. Impacts could be both direct and indirect to species and habitats. Examples include impacts to habitat from increased boat traffic/personal watercraft, and introduction of invasive or nuisance aquatic and terrestrial species.

6.2 Needs and Recommendations

This section presents recommendations related to water resources for Okefenokee NWR, based on a review of the information collected in the WRIA process.

6.2.1 Partnerships, Research, and Planning Coordination

Many agencies (including multiple programs within USFWS) and citizen groups are active partners in conservation and management of the Okefenokee Swamp, the St. Marys River Basin, and the Suwannee River Basin. In order to most effectively manage and protect these complex wetland and river systems and the public lands within, continued and expanded future support of these and other partnerships is critical. Capitalizing on funding opportunities such as Restore Act funding or through other avenues to support research projects should be pursued. Every effort should be made to maintain and improve coordination and communication within and between agencies. Especially within USFWS, coordination among Okefenokee NWR, Lower Suwannee NWR, and Cedar Key NWR is essential. For example, a potential local government partnership would include planning and coordinating with the St. Marys River Management Committee to integrate the St. Marys River management plan into other natural resource management plans, comprehensive plans, and conservation programs (SMRMC 2003; SMRMC 2015; CRC 2014).

Along with improved coordination among agencies, ensuring that monitoring and data collection needed to support conservation planning and management activities occurs throughout these basins is essential, as is developing and applying consistent and comparable data collection methods and protocols. Facilitating data sharing and knowledge transfer among agencies is also important. In respect to establishing and expanding partnerships, and in developing research and planning coordination, key specific recommendations include the following:

- Resurrect the Suwannee Basin Interagency Alliance (SBIA). This organization was formed in 1995 with a primary goal to promote coordination among agencies in the basin and estuary (Webster and Winn 1997). Many of the issues and research needs identified by SBIA in 2005 (Katz and Raabe 2005) are still relevant ten years later. Unfortunately, due to lack of funding and other reasons this alliance is no longer active despite great need.
- Evaluate the effectiveness of minimum flow levels (MFLs) developed by the Suwannee Water Management District for ecological function and biological community protection under various hydrologic regimes and seasonality for the Suwannee River, delta, and estuary.
- There is a significant amount of information on water quality and quantity in the Suwannee River and Okefenokee Swamp, including modeling studies. However, this information is fragmentary and has not yet been examined holistically. A comprehensive exploration and discussion of these issues with a forum of experts is needed to move forward with collaborative, transparent, watershed management and action.
- There is a need to better communicate the work of the refuge and its research, conservation, and recreation partners to the public. Potential strategies include engaging political, opinion, policy and natural resources leaders; adding a link to the refuge website on the Paddle Florida website; seeking National Blueways designation for the Suwannee River; making greater use of USFWS avenues for public involvement; developing a smart phone application for the refuge; and coordinating with Georgia and Florida state parks about media/advertising. In addition, it would be beneficial to the refuge to evaluate the human dimensions involved with watershed planning (Decker et al. 2012).

Additional research and monitoring needs and opportunities within the Suwannee watershed have been identified by multiple universities, State, and Federal agencies:

- Identify and characterize critical linkages between changing land use and water quantity and water quality degradation by monitoring environmental response to rapid land use change and increased urbanization, nutrient loading, and increased water use. Efforts need to be coordinated across state boundaries.
- Initiate and expand water flow and water quantity impact studies on the refuge and in adjacent habitat(s) including the river, riverine wetlands, and the estuary. Estuarine research on production

and contaminants in relation to surface and groundwater is needed. Hydrologic models should include climate-change scenarios.

- Basic water use data is critically needed related to permitting and tracking use (current and predicted future use) of groundwater and surface water withdrawal (especially acreage of irrigation, and consumptive use permits for intensive agriculture). Evaluating the extent of aquifer use and trends over time across Georgia and Florida is needed.
- Support efforts related to USFWS Region 4 Species-at-Risk, including the Suwannee Moccasinshell, Southern Lance, Freemouth Hydrobe Snail, Santa Fe Cave Crayfish, American Eel, and others as warranted. Data needs include basic inventories, life history work, flow needs, and habitat requirements.

6.2.2 Water Quantity

To enhance water quantity information for refuge management, some baseline data for the Suwannee River Basin are needed, including:

- Develop basin-wide water budgets for surface water and groundwater, as well as basin-wide hydrologic modeling. Tied to this is the need to better understand flood storage and groundwater recharge, and interaction between groundwater and surface water within the Okefenokee Swamp, the St. Marys River, and within the Suwannee River Basin. Incorporate and evaluate developed current and future water budgets and recommended minimum flows in relation to climate change and sea-level rise (SLR) scenarios.
- Develop, model, and map future agriculture water use projections showing the distribution, composition (surface water vs. groundwater), and water needs throughout the entire river basin (both Florida and Georgia). Include information related to various agricultural and silvicultural practices and groundwater/surface water availability. Strategic implementation of the Rural and Family Lands Act program to advance water management needs/goals (e.g. to preserve forestry operations, promote proper implementation of best practices for row crop planting and irrigation, etc.) may provide unique collaborations and water conservation opportunities.
- Evaluate the existing network of stream gages and monitoring wells measuring aspects of both surface water and groundwater flow levels. Strategically enhance the existing network by adding additional parameters measured on existing gages and wells and/or adding or moving gages or wells within the basin.
- Quantify flow requirements of trust resources (including species and strategic habitat) for multiple life history stages. This includes riverine, wetland, marsh habitats and species. Information needs to include timing and frequency in addition to magnitude, rate, and duration.
- Define past climatic conditions through analysis of tree core, peat records, pollen, plant fragments and C14 dating, also considering lightning patterns, hurricane history and their effects on the Okefenokee Swamp. Evaluate past drought events to provide a baseline for assessing current and potential future droughts under future climate projections.

6.2.3 Water Quality

Water quality within the St. Marys and Suwannee River Basins, the river floodplains, river channels, tributary streams, springs, wetlands, and estuaries is essential for both human and ecosystem health.

Management of water quality in the St. Marys and Suwannee River Basins will require consistent basin-wide monitoring networks, accessible basin-wide databases, hydrologic models, and the monitoring of areas where BMPs have been implemented to evaluate their effectiveness in reducing nutrient loading and nonpoint source impacts. Water quality information in relation to spring (groundwater) resources, as well as the ability to directly correlate water quality conditions and parameters to minimum flow level (MFL) development and nitrogen impacts to groundwater are needed, primarily in the Suwannee River basin. Specific high-priority needs with respect to water quality include the following:

- Continue to monitor pH, conductivity, water temperature and dissolved oxygen at selected water monitoring stations and further develop the monitoring program to address water chemistry dynamics related to fire, water levels, weather events, plant composition, public use activities and land use adjacent to the refuge.
- Additional monitoring is needed to more accurately assess seasonal and diurnal dissolved oxygen (DO) variations, particularly in the St. Marys River and its tributaries. These efforts are needed in order to better assess whether observed low DO levels are due to natural factors such as seasonal temperature and flow variation, or are attributable to impairment from anthropogenic causes. Blackwater streams often have low DO levels during warm summer months when water flows are lower, and DO levels also naturally fluctuate over a 24-hour period. (DO is lower at night when photosynthesis ceases and can vary up to 1 to 3 mg/l from dawn to dusk.) None of the data collected thus far has included an hourly time profile to assess natural fluctuations of DO within a 24-hour period.
- Develop and encourage the use and evaluation of Best Management Practices (BMPs), mainly by agriculture and silvicultural industries in the St. Marys and Suwannee Basins, to reduce nonpoint source contamination and nitrification of both surface and groundwater resources. This includes new BMPs with best available (and new) technologies, BMP cost-share programs, and monitoring and research to evaluate the occurrence of agricultural chemicals in groundwater, springs, the river and estuaries. There are many management measures currently identified within existing planning documents/programs for Coastal Georgia that may be used to help reduce and/or maintain ultimate oxygen demand (UOD) loads. These include compliance with the requirements of the NPDES permit program and application of BMPs appropriate to nonpoint sources (GAEPD 2002b,c; CRC 2014).
- Study groundwater availability under various forestry management regimes to improve BMPs (use USDA and NRCS partnerships).
- Seek funding opportunities and research partnerships to evaluate how mercury sources, transport processes, and local biogeochemical processes affect mercury concentrations in water and biota.
- Evaluate natural reduction of elevated nitrate via surface water/groundwater interactions, including the role of wetlands in the denitrification process, the effects of mixing of organic-carbon-rich river water with groundwater, and reduction of nitrate due to denitrification in the aquifer during high flow conditions.
- Evaluate the interactions between water quantity and water quality; assess whether or not the current minimum flow recommendations preserve water quality and protect ecosystem and human health.
- Investigate relationships and interactions between nutrient-enriched freshwater and the health, productivity, and sustainability of the downstream and estuarine ecosystems.

6.2.4 Habitat and Biological Communities

The St. Marys and Suwannee River Basins including the Okefenokee Swamp support unique water resources and biota within relatively undeveloped watersheds. The timing, duration, and distribution of water flow are essential to sustain natural ecosystem function. Additional needs and recommendations for the habitats and biota include:

- Establishment of a statistically robust and systematic monitoring program to evaluate ecosystem health and impacts on the Swamp as a result of climate change.
- Identify factors that would trigger consideration of interbasin water transfers and evaluate the risks to the St. Marys Basin and the Suwannee Basin, including the introduction of nonnative species, contaminants, and disease.
- Conduct detailed mapping of in-stream, floodplain, wetland, and other aquatic habitats and associate these habitats with critical flow levels (e.g. flows needed to maintain these habitats, and associated obligate species or life stages). Associate known threats with specific habitats.
- Assess the impacts of past and present hydrologic alteration due to silvicultural practices (e.g., ditching and draining) in areas adjacent to the refuge on aquatic habitats and species of management interest. Potentially include decreased duration of seasonal flooding and increased risk of invasive species due to more rapid drainage and increased connectivity of previously isolated wetlands resulting from ditching and draining.
- Hydrological and ecological impacts of Swamp Edge Break have not been characterized. First steps to address this issue would be to accurately map the Swamp Edge Break, monitor impacts, and evaluate potential solutions and mitigation for actions associated with maintaining this fire management related feature.
- Evaluate impacts from historic logging trails, past silvicultural practices, and canoe trails and remote Wilderness access into the Okefenokee Swamp through permitted public use activities including canoe trails, chemical toilets, and camping platforms.
- Monitor diversity and abundance of aquatic fauna (including USFWS Species-At-Risk species). Leverage partnerships and funding to most effectively and strategically monitor aquatic fauna.
- Develop an invasive species management plan for terrestrial and aquatic invasive animals and plants. A management plan would be beneficial for the refuge, especially if tied to risk management, early detection, and rapid response. All long-term planning should incorporate climate mitigation, resiliency, and adaptation strategies.

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8 Appendices

Appendix A

August 26, 2014 Okefenokee NWR WRIA Kick-Off Meeting Agenda, Summary and Participant List

Draft Region of Hydrologic Influence (RHI)

Threats, Needs and Recommendations (summary from kick-off meeting)

MEETING SUMMARY

Water Resources Inventory and Assessment (WRIA) for Okefenokee National Wildlife Refuge

Meeting Date: Tuesday, August 26, 2014 (8:30 AM – 5:00 PM) Eastern
Meeting Location: Okefenokee National Wildlife Refuge
2700 Suwannee Canal Road, Folkston, GA 31537-7906

Meeting Purpose:

1. Provide an overview of the WRIA process including outcomes, and timelines for completion
2. Identify expertise, data, information, contacts, etc. for various sections within the WRIA process
3. Begin the WRIA process at Okefenokee NWR
4. Collaborate and share information/data about the river, refuge, management issues and other related work happening in the watershed including public education/outreach.

Goals and Objectives:

WRIA - The goal of the National Wildlife Refuge System (NWRS) Water Resources Inventory and Assessment (WRIA) effort is to provide up-to-date, accurate data on Refuge System water quantity and quality in order to acquire, manage, and protect adequate supplies of clean and fresh water.

a. Achieve a greater understanding of existing refuge water resources
b. Identify data needs, concerns, and threats to those resources at multiple spatial and temporal scales
c. Provide a basis for refuge management actions and operational recommendations

Meeting Agenda:

TUESDAY – August 26, 2014

8:30 AM – 10:30 AM – Welcome, Meeting Logistics, and Introductions

- Welcome / Housekeeping – lunch order (FWS)
- Introductions (all)
- Brief introduction to the refuge and its management history
- Overview of the river basin, including biological resources, past disturbance, future threats, personal experience, long-term view of the area – both surface water and groundwater (FWS; all participants)

10:30 AM – 10:45 AM (BREAK)

10:45 AM – 12:00 PM – Water Resources Inventory and Assessment (WRIA) Process

- Introduction, goals, timeline and data needs for WRIA process (John Faustini); (Atkins presentation)
- WRIA components, data sources and initial data collected for Okefenokee NWR
  - Discussion: Region of Hydrologic Influence (RHI) to incorporate for WRIA process
  - Discussion: data, data gaps, potential sources, contacts, management issues, timeline, etc.

12:00 PM – 1:00 PM – (LUNCH) – on-site (order form to follow soon)

1:00 PM – 5:00 PM – Water Resource Inventory and Assessment (WRIA) Process (continued)

- Discussion of water resource issues of concern, recommendations, potential solutions (all)
  - **Urgent/immediate** issues, recommendations, solutions, data needs
  - **Long term** issues, recommendations, solutions, data needs
- Discussion and populating of the WRIA spreadsheet data items (group contributions)
  - Identify data gaps, potential sources, contacts, management issues, timeline, etc.
  - Assignments for data needs, milestones, etc.
- Dates for future meetings/follow-up for WRIA
- Other action items

5:00 PM – Adjourn

Meeting Attendees:

Last Name	First Name	Affiliation	E-mail
Aicher	Sara	FWS	sara_aicher@fws.gov
Bechler	David L.	Valdosta State University	dbechler@valdosta.edu
Boyle	Forbes	FWS	maxwell_boyle@fws.gov
Calhoun	Dan L.	USGS - Georgia Water Science Center	dcalhoun@usgs.gov
Cohen	Art	University of South Carolina (retired)	cohen@geol.sc.edu
Dalton	Melinda	USGS - Georgia Water Science Center	msdalton@usgs.gov
Faustini	John	USFWS - Regional Hydrologist	john_faustini@fws.gov
Harrison	Don	GA DNR	don.harrison@dnr.state.ga.us
Lusk	Michael	USFWS - Okefenokee NWR	michael_lusk@fws.gov
Marsh	Pamela	University of Mississippi	paelma@excite.com
Thom	Theresa	USFWS - Inventory & Monitoring	theresa_thom@fws.gov

Additional Comments / Recommendations Received from:

Albanese	Brett	Georgia DNR	brett.albanese@dnr.state.ga.us
Barichivich	Jaime	USGS	wbarichivich@usgs.gov
Buell	Gary R.	USGS	grbuell@usgs.gov
Duncan	Will	USFWS	will_duncan@fws.gov
Gude	Andrew	USFWS - Lower Suwannee NWR	andrew_gude@fws.gov
Herod	Jeffrey	USFWS	jeffrey_herod@fws.gov
Loftin	Cynthia	USGS (in Maine) / Co-op unit	cynthia.loftin@maine.edu
Patten	Bernie	University of Georgia (retired)	
Waters	Matt	Valdosta State University	mwaters@valdosta.edu

Meeting Summary:

(Part 1- Theresa Thom): Brief overview of Goals And Objectives of WRIA process

The goal of the National Wildlife Refuge System (NWRS) Water Resources Inventory and Assessment (WRIA) effort is to provide up-to-date, accurate data on Refuge System water quantity and quality in order to acquire, manage, and protect adequate supplies of clean and fresh water.

- Achieve a greater understanding of existing refuge water resources
- Identify data needs, concerns, and threats to those resources at multiple spatial & temporal scales
- Provide a basis for refuge management actions and operational recommendations

Comment: Dan Calhoun and Mindy Dalton (USGS GA Water Science Center) mentioned the “soon to happen” (expected October 1, 2014) merger of the USGS water science centers in NC SC GA to form the Atlantic Water Science Center.

(Part 2 - Sara Aicher): Okefenokee NWR History

Okefenokee NWR encompasses 403,119 acres; 353,981 acres of Wilderness

- Much of refuge is designated Wilderness Area; most of wetlands are within Wilderness Area.

- Not pristine---Suwannee Canal dug early 1900's to drain the swamp (13 miles into the St. Marys)
- Timber harvest of cypress within swamp (431 million board feet removed using trams)
- Suwannee River Sill dug (year: 1960) to slow down devastating wetland fires (response to big fires in mid-1950s.) Sill altered hydrology within western side of swamp but flow structures are open and allow drainage to Suwanee River; restoration work occurred in 2004 – breached sill in 3 places.

Natural processes still govern the landscape
- Main known input to swamp is rainfall
- 5 main basins within the swamp (described by Loftin – two river outflows [St. Marys and Suwannee Rivers]; Northwest basin is primary location of terrestrial runoff and flow "into" swamp from Trail Ridge.
- Fire (mainly from lightning strikes); Extreme dry conditions provide big wildfire potential. Natural cycle probably 10-50 (>50) years. Water levels and moisture content of peat determine where fire burns and how deep fire burns into the peat.

Relevant Monitoring:
- 3 Weather Stations on refuge
- 10 water monitoring stations (water level and precipitation).

Recent Threats:
DEVELOPMENT/URBANIZATION: airport proposal on Trail Ridge (highest point in Charlton Co., so always threat to development); amphitheater proposal; motorcross track; Landfill; Herbicides and Fertilizers used rather than prescribed fire (timber owners/mgrs.) Development (dense homes change fire suppression in lands around swamp.

MINING: DuPont put in a proposal (in 1990s) to mine titanium and other minerals; they have been doing this around Starke FL, which is further south along Trail Ridge (see photos of mining in Starke, FL). Want to mine up to 50 feet (below elevation of Oke Swamp). Some DuPont land was donated to Conservation Fund. Mineral rights are owned by GA Wildlife Fed. Mining is still possible on Toledo property next to Oke Swamp. Two small mining companies (Iluka Mining Co. and Southern Ionics) started shallow mining in Charlton County (not next to swamp); they claim shallow mining not detrimental to gopher tortoise or geomorphology – potential positioning to retry titanium mining near Oke swamp.

SILVICULTURE: Timber productions in surrounding landscape threaten Okefenokee, especially slash pine production since little prescribed fire is used, but heavy use of herbicide/fertilize. Refuge and partners (Greater Okefenokee Association of Landowners) trying to maintain buffer(s) between swamp and uplands to create a "fire resistant" landscape to protect timber and dwellings. In 2007, fires resulted in significant loss on timberlands from wildfire escaping the swamp. Besides silviculture, there are lots of blueberry farms popping up around refuge.

RECREATION: impact of trail maintenance (esp. canoe trails) on hydrology and ecology of Oke Swamp unknown.

WATER WITHDRAWAL: Proposal from the St. John's Water Management District (FL) to pull water out of St Mary's River to supply water to northeast Florida.

QUESTION: John Faustini (**What was the intent behind the Suwannee Sill?**):

RESPONSE: The sill was built in 1960 due to pressure after mid-1950's fires to stop fire; Congress approved 5-mile earthen dam with two water control structures with the idea to back water up during dry conditions. But the sill didn't really work, as there are several series of natural terraces in the swamp, and water flow is from NE to West toward headwaters of Suwannee River. When the Suwannee Sill was built, it only really affected drainage around the general area of Sill – (basically didn't have much effect on the whole wetland system b/c of placement of natural terraces). The Suwannee Sill was in disrepair, and an EA was completed to either fix or remove the Sill. It was cost prohibitive to remove the sill completely (especially the fill).

At same time Sill was built, Swamp Perimeter Road was put in to help fight fires off of, including placement on areas outside refuge boundary. In early 1990's there was a big push to build a larger fire break (i.e., Swamp's Edge Break); a 20ft buffer put in between uplands and swamp. The original intent of the Swamp's Edge Break was meant to be a defensible space from which to more easily work on suppressing wildfires and prevent them from escaping off the refuge into the community. In 2007 Wildfire Teams wanted to widen Swamp's Edge Break to stop fire (did this in place, widen from 20 ft to 200ft in places, and it didn't work anyway as the break was widened and there was still loss of timber on adjacent landowners property during the 2007 fires). The current Swamps Edge Break is major influence on hydrology of swamp. The original Swamps Edge Break was critical in gaining support for letting wildfires burn in interior of swamp, but there are other ways to prevent neighbor property loss from wildfire (e.g. Firewise, encouraging neighbors to plant longleaf and fire resistant buffers) rather than maintaining a very large break that is impacting swamp hydrology and impacting species inhabiting the ecotone between wetlands and uplands.

FWS owns a strip of land along Trail Ridge, but Forest Investments Associates own the timber and recreation rights thru 2081. Currently it is cost-prohibitive for FWS to purchase these rights (too expensive). This area has gopher tortoises and indigo snakes, also many cultural resources so some prohibitions for land management activities by Forest Investment Associates right now. The property ownership has changed over the years – Union Camp, International Paper, now Forest Investments Associates. Much of this eastern edge of Swamp has been drained (along Trail Ridge) for timber management, including isolated wetlands.

QUESTION: Dan Calhoun (**What is the herbicides use around the swamp and where, if known?**)

RESPONSE: Lots of herbicides in use around edge of swamp by all timber companies, although major areas include Southwest and Northwest corners, and along the Swamp Perimeter Road. The main herbicides are Garlon 4 and ESCORT – this has been a shift in management practices (using herbicides rather than fire management in LLP). A benefit of planting LLP around the refuge as a fire resilient tree, and to better protect the community from wildfire would be reduced herbicide use using fire to keep understory/midstory clear.

DISCUSSION: Art Cohen: Toledo inholdings wanted to 'mine peat' back when he worked here in the 1970's. Other threats to refuge include the landfill – how many acres? Impact from runoff is probably into the St. Marys Drainage, although there are impacts to the refuge from light pollution and to animals.

(Part 3) All Participants / Discussion: Overview of the river basin, including biological resources, past disturbance, future threats, personal experience, long-term view of the area – both surface water and groundwater

(Dr. Art Cohen -University of South Carolina):
Had NSF grant to examine the effects of fires on peat (esp. 2007 fires); although there were extensive fires across OKE, the fires were surface fires and did not burn into the peat - the fires did not burn all peat due to unique properties of peat and water runoff (runoff is largely controlled by peat). The thickness of the peat across the OKE is not uniform. Dr. Cohen used a grid to cover swamp and collected peat cores using a McCauley Peat Sampler throughout the swamp in these grids, from which he developed isopleth maps of peat formations across the Swamp. Although on average the peat is a few feet thick, some areas have deep peat areas 15-20 ft. deep.

Peat at Okefenokee is typically below the water table. Peat is constantly going up and down ("land of trembling earth.") The various layers of peat will move either up or down, typically move down when it's dry. Peat islands are different thicknesses and can also pop up or breaks loose> Fred J. Rich did PhD on origin of tree islands (Penn State Univ.[The Origin and Development of Tree Islands in the Okefenokee Swamp, as determined by peat petrography and pollen stratigraphy – 1978, 602 pp. http://www.jstor.org/stable/3687521]) Dr. Cohen also has research papers on hydrologic connectivity of peat and water holding capacity of peat as well as other papers that don't mention Okefenokee but use peat examples from Okefenokee/ (in Cohen's library);[see Paleoecological history of west-central Okefenokee Swamp based on palynologic and petrographic analysis Stable URL: http://www.jstor.org/stable/3687496].

The thickness of the peat layers control the surface vegetation. Peat in OKE is multi-layered. Dr. Cohen completed radio-carbon dates of cores throughout the Swamp – from 500 to 5000 yrs ago and developed maps of different peats in the Swamp. It would be interesting to know the hydrologic connectivity and influence of groundwater flow on peat in the Okefenokee Swamp.

(Dr. David Bechler; Valdosta State University):
Prof. Matt Waters (Valdosta State U.): worked around Valdosta and found peat layers and Everglades -he thinks peat system was vast across FL and S. GA. His work included cores in Lake Louise (near Valdosta): cored peat going back 47,000 years. Sink hole lakes that feed FL aquifer.

(A. Cohen): **CRITICAL TO DISCUSS WATER CONDUCTIVITY and PEATS FUNCTION FOR ANY WATER RELATED DISCUSSION**.

DISCUSSION: (Dan Calhoun) 7,000-10,000 years ago, end of Pleistocene, streams would have been higher, 3-5 x's water flow – potential changes to peat formations. ; Sink holes are more continuous peat.

(D. Belcher): University of Tennessee – Knoxville (professor) Henri Grissino-Mayer did some peat work in Lake Louise in Valdosta and correlated peat cores to tree cores; estimated frequency of hurricanes based on tree rings and isotope ratio in peat.

DISCUSSION: What is the recurrence interval of deep peat burns? (A. Cohen): 1930-32 and 1950s and 1980's fires show up in cores although consider fires are also patchy across the landscape, as is peat (Cohen paper on charcoal layer; microscopic techniques using microbial indicators (a result of oxidation) to determine when dry period, but maybe no fire); Peat can be used as an indicator of dry periods, not just fire (typically fire used to show dry periods) – but peat can be used to indicate drought; Peat cells don't re-expand immediately following drought. Once the cells dry, they never reinflate/expand the way they were before when rewetted, dried peat does not retain the same water holding capacity like it had during extended 'normal' wet years (water holding capacity different than in "fresh" peat).

DISCUSSION: Based on long-term fish sampling in OKE, noticed changes in fish community overtime?

(D. Belcher): Important to look at select sites within OKE and look at changes of aquatic flora and invertebrates and fish over a period of 50 years, ever 4-5 years. During periods of extensive drought, monitor every year. In field work, noticed consistent fish fauna in canals, but more variable fish community in swamp. Consider how fish fauna recovers after drought, and consider influence of canals for recovery of fish community in swamp post-drought. [Need to also consider success of amphibian production in swamp following drought – fishless/reduced fish predation]. Also look at Palmer Drought Index (the index has been calculated back to 1900, gives estimates on rainfall and drought events). Compare fish populations and/or core information to Drought Index. For example, Blackbanded sunfish and when caught in SE GA always caught after 3-4 year heavy rain events and never caught after extensive drought. Canals might represent refugia for invertebrate and vertebrate/ ichthyofauna due to lack of water depth (increased droughts) throughout other areas of swamp. Graduate student (Valdosta State) showed that bridge sites along creeks actually serve as refuge for species during drought years (compared bridge sites to up and down river); ?are these impaired or poorly designed bridge sites that have altered hydrology around the bridge/stream crossing? [grad student contact/paper(s)]. – **POPULATION ADAPTATION TO HYDROLOGY**

(Group) Noted that after fires, much better fishing (old-timers say this around Swamp); maybe because of nutrients released into the water following fire event.

(Don Harrison): discuss invasive species / some work being done to keep eye out for aquatic invasive species (fish, but also aquatic macrophytes); some discussion with Sara Aicher regarding water hyacinth introduction at Steven Foster state park – introduced during fire suppression efforts.

(Part 4) John Faustini: Introduction, goals, timeline and data needs for WRIA process

- WRIA components, data sources and initial data collected for Okefenokee NWR
- Discussion: Region of Hydrologic Influence (RHI) to incorporate for WRIA process
- Discussion: data, data gaps, potential sources, contacts, management issues, timeline, etc.

(John Faustini): Goals of process (see above); inventory of what are the issues with water resources for refuge. Assessment of those issues, condition. To identify potential threats to water resources. And develop a centralized database for water resources information. What is an WRIA: First, it's an inventory: what is there: water features, water rights, regulatory issues, water-related infrastructure, water monitoring information, climate, historical data (e.g. temp increasing with climate change, evapotranspiration will increase, water demands will increase).

Second, an <u>assessment of station's water resources</u>. (water needs [when and how much do we need], water threats).

***Compiling existing resource information, in an effort to prioritize and streamline future data needs or data collection – avoid duplication of effort; maximize gain to refuge, FWS, partners.

***(Okefenokee Refuge Staff): Understanding Water Rights related issues are critical for Okefenokee NWR.

*** Understand what are the KEY threats.

<u>WRIA process is a national level effort</u>. First iteration of WRIA, questionnaire poling refuges. Now a national water team, looking at what we need to assess (national coordination). Also an on-line database application being created in Fort Collins CO. (on ECOS platform); WRIA database application. Not just another database – streamline connection with other information(ServCat, PRIMR, etc.). The WRIA application allows user to input and view data; generate reports, view geo-spatial enabled data, etc. Application does not store data, but links to data repositories so data is always most current. Separately, there is also an effort to develop a regional water quality database to collect and store collect store water resource information from all refuges and hatcheries (currently under development).

<u>WRIA Expected benefits</u>: for field stations (baseline assessment, of water resource assets, conditions threats, needs) support water resource planning, db to track water assets., ID monitoring needs. For RO: regionally consistent info on water resources, baseline WR assessments to guide I*M planning, easily respond to data calls from Washington.

<u>Coordinates with other NWRS efforts</u>: CCP, Contaminant Assessment Process (CAP), HGM, HMPs, Climate Change Vulnerability Assessments.

Showed cover page (table of Contents) of Cahaba River NWR WRIA. (dec 2013).

Hydrologic Database (Gary Buell sent)—location of USGS gaging stations with most complete long records from 1927 thru present surrounding swamp. Seasonality flows of Suwanee River (high flows--Feb-Apr and Nov-Dec; low flows--May-Jul).

- Gage information includes Fargo, MacClenny, FL (St. Marys gage), also White Springs, FL

DISCUSSION: Springs / Discharge zone for the Floridan aquifer – farming, agricultural practices in GA and FL—aquifers feeding ag. FL or GA. Depleting discharge areas. Low flow rates in springs due to agricultural pumping; tributaries in the Flint River are showing decreases in flow.

DISCUSSION: WRIA provides compilation and assessment. Immediate next step is data gathering, and looking at where things haven't been sampled. Where are data gaps? Work with partners to see where there is additive delivery.

QUESTION: What are plans for WRIA Database Application (on ECOS) to go public? Uncertain.

RECOMMENDATION: Get STORet data = EPA involved….plan to get them involved? YES -

RECOMMENDATION: GA State Water Plans: within resource demands/River Basin Management Plans publication reports (http://www.georgiawaterplanning.org/pages/regional_water_planning/water_planning_councils/); also FL Water Management District water budgets http://www.dep.state.fl.us/secretary/watman/

REQUEST: PLEASE Share PowerPoints from meeting? YES - powerpoints will be made available

(Part 5) Theresa Thom - Details for data compilation and the WRIA process

- Goal of presentation: highlight what data are going into WRIA

Atkins (contract firm to do this work): Kirsten Hunt is contact with Atkins located in Raleigh, NC

2 main contracts with USFWS—USFWS in Southeast and also DOI (contract with Div of Planning): other work--NWI Mapping, SET Station Project, Burn assessment and restoration at Alligator R NWR; also in R5 for WRIA as well. WRIA have been completed at 5 refuges in R5 and R4 (several are near completion). Very different habitat, some refuges with lots of water control structures, and everywhere in between in terms of water management but lots of similarities with water resource threats.

Inventory of existing water resources: trying to SUMMARIZE what has already gone on and assessing that work relative to threats and future needs.

Target audience—refuge staff, RO, and PARTNERS!!!

Work with Atkins to compile information (Track down GIS info); compiled whole list of dams (e.g.); helping with report preparation.

WORK TO DATE FOR OKE NWR WRIA:

* Facility info (CCP), * Hydroclimate data, * HCDN streamflow data, * SSURGO, * geology and hydrogeology

DISCUSSION: Region of Hydrologic Influence (HUC 8 and HUC 10 map units) (RHI) – note: different scales for sections of WRIA (inventory OR monitoring). RHI: 1,136,846 acres (using existing Approved Acquisition Boundary); still some property that could be added beyond that boundary scale.

(D. Belcher): Homerville GA: break of rivers/streams that flow to east and those that flow west. Blackbanded sunfish data from creeks west of refuge towards Homerville, although inaccessible

(M. Dalton): Add polygon NE of refuge, connecting Gum sloughs from Little Okefenokee; water moving into the basin from the North. NOTE: groundwater doesn't necessarily follow a HUC (HUC assumes alluvial flow);

(D. Calhoun): What about areas north (HUC) for contaminant concerns, esp. from road, or railroad?

RECOMMENDATION: Go back and revisit RHI boundary, potentially adding areas around Gum Slough and areas north and west in the adjacent HUC 8.

DISCUSSION: Main Driver is RAIN, but need to know more about the interaction with groundwater.

Flood year vs. drought year and water levels in the swamp/important to evaluate

Limestone features // surface expression of the Florida aquifer in the Okefenokee Swamp? Potential to evaluate groundwater upwelling using conductance and pH sampling across OKE Swamp.

(S. Aicher): Hydrologic Budget done for Oke Watershed, ground water represents 1.3% of input. (connection with aquifer is not well none; better understanding of ground versus surface water); Suwannee Creek is an important tributary creek to the Okefenokee Swamp.

(J. Faustini): Wants to see map of existing water management structures on the refuge (currently only water level monitoring sites ~10 around refuge since 1999. Water monitoring units (YSI sondes: Temp/pH/Conductivity) are not currently deployed at water level monitoring stations – but they will be once everything is working again. YSI sondes are connected to the FTS system and can be downloaded remotely; data stored locally. Weather Stations (N=3) around refuge as well.

Hydrologic Characterizations (USGS)—only one done was Suwannee Sill Study.

(M. Dalton): --National Water Census—goal is to provide water budget data at HUC8 scale across country. Test Pilot in SE, streamflow at ungauged locations at HUC12; data portal is available. Some publications out which models are best for which conditions (site and hydro). She can forward this info. Data portal is being developed and in 3-5 years will be useful. Highly focused in areas out west, but current focus area includes ACF basin, also basins in Delaware and Colorado.

(T. Thom): Was a Contaminant Report or contaminants study ever completed at the refuge? BEST was completed, also contaminants study for Suwannee Creek and Gum Slough [when were they completed?].

RECOMMENDATION: Make sure to include NADP site**:** make sure we tie into this (Site GA09). Long-term atmospheric data- refuge planning (pesticides, herbicides, other –'cides; the NADP does have expanded network where they're trying to sample for this- example showing change of rainwater pH from 4.5 to 5.0). Refuge does have air quality station (contaminants' study off of boardwalk, isolated study). Another study, inflows from major tributaries (Suwannee Creek and Gum Slough) coming into refuge, 5 different points, where researchers looked at contaminants. (need to pull those out, to see if we have these documents already; BEST documentation).

USGS publication and maps of karst areas in the U.S. Could be useful for karst ecosystem conservation and management. http://pubs.usgs.gov/of/2014/1156/ (Karst in the United States: A Digital Map Compilation and Database. – potentially useful for GA/FL connections with groundwater?)

Task List for data (spreadsheet population assignment) = SEE SPREADSHEET

- Discussion and populating of the WRIA spreadsheet data items (group contributions)
  - Identify data gaps, potential sources, contacts, management issues, timeline, etc.
  - Assignments for data needs, milestones, etc.

GIS coverage of roads in refuge, topo maps, orthoquad maps for Okefenokee,

Threats Needs and Recommendations (open discussion) = SEE NEEDS/THREATS/Document

- Discussion of water resource issues of concern, recommendations, potential solutions (all)
  - **Urgent/immediate** issues, recommendations, solutions, data needs
  - **Long term** issues, recommendations, solutions, data needs

Water Related

- St. Johns Water Management District– pumping water out of the St. Marys
- How are water withdrawals from the Lower Suwannee affecting Okefenokee Swamp?
- How much water (surface water) is flowing through the Swamp? How long does it take (average retention rate(s)?
- Satilla River connected to Okefenokee during high flows? NO – Although Okefenokee is connected to the St. Marys through the St. Marys cut –during high flows.
- Water level data – upload to ServCat? Capture and make available – need to analyze water level data and synthesize. // potential for Landis Corporation to analyze water level data?

Human Use/ Management Activities

- C.T. Trowell – extensive history of human use /Cultural Resource investigations of Okefenokee Swamp area. His work would show the nutrient changes in the swamp as a result of increasing urbanization/changing land use of area/swamp.
- Fire// manage landscape for fuel; what has been done over time/understand influence on Oke habitat; FireWise community, other fire-related outreach
- Use of drones for monitoring in OKE?// potential , but Wilderness considerations. NPS has banned the use of drones on NPS lands. Not sure what FWS policy is on drones [follow-up]. USGS in Reston, VA has remote data flight lab/data platforms to attach to equipment. Potential contact w/NPS is Jolene Williams, Acting Chief of Science and Resource Mgmt. at Gulf Islands National Seashore.
- Recreation/Trail clearing activities impact on Swamp (need backcountry ranger(s)); impact from composting toilets on Swamp, Signage in Wilderness;
- Use of airboats
- http://alabamamaps.ua.edu/historicalmaps/us_states/georgia/topos/15mintopos.html
  - 1918 maps for both Moniac and Folkston

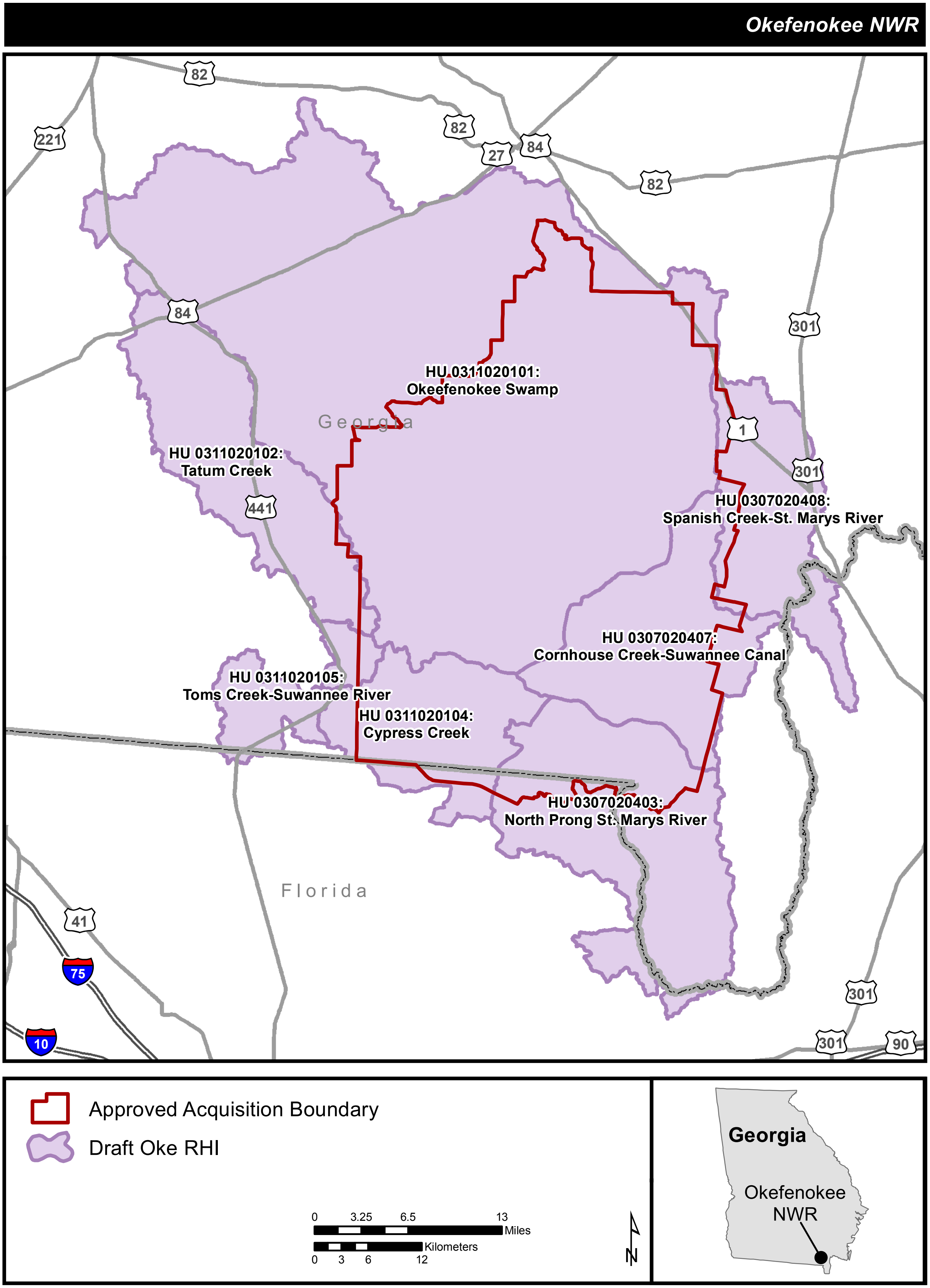
Contacts/Follow-up

- Dr. Art Cohen – see the Okefenokee book (and map), and guidebook – he will be re-writing/updating
- Coordination with Lower Suwannee NWR
- Dr. Can Denizman (Valdosta State Univ./Dept. Geosciences); hydrology, karst geomorphology, groundwater, geochemistry
- USGS groundwater monitoring network // Gary Buell
- Mike Peck [context?}

- Dr. Gretchen K. Bielmyer-Fraser (Valdosta State Univ/Dept. of Biology)// ecotoxicology of St. Johns River
- Amphibian surveys/Laura Smith @ Jones Center, also John Jensen (GA State Herpetologist) have conducted work on amphibians in the Swamp
- See water related issues/threats compiled by refuge staff from CCP, Biological Review, others…

Remember—Wilderness Character of Refuge

3:30 PM – Adjourn



Map Date: 7/22/2014 File: Draft Oke_RHI.mxd Data Sources: USFWS 2013 Approved Acquisition Boundary; National WBD HU-10 units; ESRI Map Service.

THREAT	NEED	RECOMMENDATION
AQUATIC BIOTA		
THREAT: water flow needs for amphibians	NEED: Monitor amphibian populations in refuge/surrounding basin (ARMI protocol – USGS)	RECOMMENDATION: Using ARMI – standardized protocols / VES and automated recording Species at edge of range very important to monitor Potential to use eDNA for certain species.
THREAT: Rare native fish populations threatened by water quality and water quantity issues; species at edge of range threatened by climate change.	NEED: surveys for state listed species of concern NEED: conservation of native fishes. Okefenokee Swamp has a really important population of Blackbanded Sunfish. This is a state endangered species but Okefenokee NWR is also important regionally as a relative stronghold for the species on the southern portion of its range. The species occasionally shows up in monitoring by Georgia DNR Fisheries and it has been captured sporadically by other groups in the past. It's a very difficult species to monitor in a quantitative sense, but I still think it is important that existing monitoring is continued for this species.	(GA DNR – Brett Albanese) RECOMMENDATION: Continue existing monitoring for this species and other rare fish species eDNA techniques appropriate for rare fish survey ▪ Contact Tanya Darden (Charleston College) re: Blackbanded sunfish / eDNA work
THREAT: Native, rare and T&E species threatened by water quality and water quantity issues; climate change and other threats to aquatic species	NEED: Conservation of native invertebrate species – and relevant species distribution and abundance data.	(USGS/FWCC – Gary Warren, et al.) (Gary Warren, Jim Williams, Matt Rowe, Jordan Holcomb) currently conducting mussel surveys throughout the basin, focusing not only on imperiled species but also whole community distribution and abundance. Surveys in 2014
THREAT: Invertebrate species threatened by water quality and water quantity issues	NEED: Conservation of native invertebrate species – and relevant species distribution and abundance data.	(USGS/FWCC – Gary Warren, et al.) Currently monitoring distribution of snails, segmented worms, mayflies, stoneflies, dragonflies, caddisflies, and midges throughout the basin.
THREAT: Invertebrate species threatened by water quality and water quantity issues	NEED: distribution and genetics of hydrobiid snails	(USGS/FWCC – Gary Warren, et al.) – currently conducting this work in the basin.
THREAT: Invasive species	NEED: Early detection / rapid response; life history research (increased levels of fecundity – key factors (# eggs produced, etc.) for emerging or increasing threats, growth rates) indicating more success	RECOMMENDATION: Early detection, rapid response surveys using standardized protocols, and develop list of emerging invasive species (esp. aquatic) for Okefenokee

WATER QUALITY		
THREAT: Nutrient inputs to the ecosystem (especially historic nutrient inputs (C,N, P)/ algal response)	NEED: paleolimnology research to examine sediment cores and see how ecosystems have changed over the past 100 years to the late Holocene. Sediment cores from the swamp were collected previously, but the dating record was not satisfactory for publication. Potential to take cores from the more permanent lake areas (Gannet, Buzzard's Roost, Coward Lake) and reconstruct historic inputs of nutrients (C, N, P), metals, and algal and cyanobacterial response. Focus would be ecological changes over the past 150 years.	(Matt Waters – Valdosta State University) RECOMMENDATION: • work w/ Matt Waters, other partners • work w/ Will Trowell (human use of area) • NADP site shows long-term water quality and air quality trends (changing pH of rain) • Long-term ecosystem work (Art Cohen)
THREAT: human waste	NEED: understand potential impact (+ and -) of septic tanks in surrounding community, WWTP, composting toilets on platforms (canoe trails)	
THREAT: Water quality contamination due to industry, mining, development	NEED: examine NPDES permits; evaluate historic patterns of urbanization, growth, incentives for industry in area (especially Georgia)	RECOMMENDATION: • Contact Gretchen Belvever (Valdosta State) ecotoxicologist working in St. John's River
THREAT: Fertilizers and herbicides (forestry practices)	NEED: detect, quantify, impact to refuge from surrounding land use / use of chemicals Spatial analysis of land uses - timber industries, agricultural use (both current & future projections)	RECOMMENDATION: GAP data Potential to work with local hunt clubs/
THREAT: Water quality of canals	NEED: Understand influence of canals on peat; canals as source of contamination; effect on hydrology , ecosystem	
THREAT: Lead toxicity from hunt clubs / bullets, sinkers	NEED: potential issue for hunting areas	
THREAT: overflights / fuel dumping (contaminants); current overflights and potential for more overflights w/ proposed airport	NEED: soundscape monitoring, evaluation baseline information on soundscape, night sky ; ensure no water quality degradation from overflights (monitoring)	RECOMMENDATION: Periodic monitoring of water to include jet fuel and related contaminants potentially resulting from airport, or overflights
THREAT: groundwater contamination	NEED: understand interaction w/groundwater	RECOMMENDATION: USGS network, also researchers at Valdosta State Univ. (Dr. Denismen; Mike Peck; Gretchen Belmever)
WATER QUANTITY		
THREAT: water levels – decreasing? Increasing?	NEED: Synthesize and evaluate water level data • Make water level data available	RECOMMENDATION: automate data capture
THREAT: Threats to peat deposits (oxidation / loss of peat due to reduced flows)	NEED: Understand historic changes in peat deposits	RECOMMENDATION: Art Cohen's research

THREAT: increase of development; both water quality and water quantity impacts	NEED: long-term modeling to examine past and future land use trends; data to inform conservation strategies; mitigation of urbanization	RECOMMENDATION: see River Basin Plans (modeling for various basins) – state partners • Work with Water Management Districts • Karst research • use USGS National Water Census work • Southeast Climate Science Center(s)
THREAT: contamination of OKE from surrounding watershed or groundwater contamination	NEED: better understanding of surface water and groundwater interaction/ springs in the swamp?	RECOMMENDATION: USGS network, also researchers at Valdosta State Univ. (Dr. Denismen; Mike Peck; Gretchen Belmever)
LAND USE / LOCAL, REGIONAL		
THREAT: FIRE	NEED: evaluate impacts of fire and fire suppression Swamp Edge Break (hydrological /ecological impacts purpose to support surrounding landowners (prevent fire escape) fire break to work on fires, not to stop fires Evaluate threats to resource as a result of fire suppression work (invasive spp. intro.)	RECOMMENDATION:
THREAT: Mining	NEED: mitigate threat from future mining of trail ridge	
THREAT: silviculture practices	NEED: private lands allowed to do ditching/clearing and breaks as "standard silvicultural practices" not allowed on federal lands – NEED: consistent standards; also better BMPs	RECOMMENDATION: Evaluate Impact of silvicultural practices on sedimentation, groundwater, water quality • NRCS / FWS Partners program
THREAT: increase of development; both water quality and water quantity impacts	NEED: evaluate current land use trends; model /predict future land use patterns	RECOMMENDATION: see River Basin Plans (modeling for various basins) • (USGS) Gary Buell database; other data • Water management districts info (FL)
THREAT: contamination of OKE from surrounding watershed or groundwater contamination	NEED: better understanding of surface water and groundwater interaction/ springs in the swamp?	
RECREATION		
THREAT: human waste	NEED: understand potential impact (+ and -) of composting toilets associated with canoe trail	
THREAT: use of motors (boats)	NEED: monitoring / water quality impacts; introduction of invasive species	
THREAT: cutting of water ways / trail cutting through vegetation and peat, removal of trees; herbicide use to open canoe trails	NEED: new/creative ways to do this with adequate water levels (building berm on one side of the trail); evaluate different ways to do this, that are protective of	RECOMMENDATION: Other sites – how do they do this? (NPS? Big Cypress NP; Congaree, etc.)

	ecosystem but still allow recreation	
WATER RIGHTS / LEGAL AUTHORITIES		
THREAT: Legal challenge to water rights	NEED: Understand legal authority; water rights for Okefenokee NWR to ensure long-term protection and ability of refuge to meet legal obligations; Clarify legal standing regarding water rights for OKE	RECOMMENDATION: consult with FWS legal Consider water needs / GA, FL – coordination with Lower Suwannee NWR, work with both Suwannee River and St. Mary's Water Mgmt. Districts
THREAT: Threats to the Wilderness Character including soundscape, darkness, etc.	NEED: Clarify legal authority for Wilderness ▪ Soundscape monitoring ▪ Wilderness Stewardship for all staff ▪ Ensure Wilderness Act compliance ▪ Monitoring tied to Wilderness Character *Night sky quality (urbanization impacts) *Soundscape quality	RECOMMENDATION: Wilderness training for staff; volunteers; Dedicated staff to manage Wilderness for Okefenokee including trail maintenance/ especially canoe related Visitor Services work Evaluate various activities in Wilderness: • Overflights (soundscape) • Canoe trail clearing • Airboat use • Research
THREAT: Drone Technology	NEED: Evaluate drone technology; potential benefits related to sampling/safety/search and rescue vs. negative impacts; impact to Wilderness and Wilderness experience for visitors	RECOMMENDATION: Ensure compliance with DOI policy, FAA policies, Regional policy, Refuge
THREAT: Cultural resources protection		
PERSONNEL / WORKFORCE / CAPACITY		
THREAT: lack of personnel to complete necessary monitoring; meet refuge obligations (legal, etc.)	NEED: technicians / needed Collect the data, shared position between agencies, programs (Clemson University – 5 yr. techs) Baruch – CO-op programs//	
THREAT:		

Other Sources:

- Water Issues are identified in the CCP for Okefenokee NWR (2003)
- Critical Needs were identified in the Bio-Pulse Check for Okefenokee NWR (2009)
- Research needs have been brainstormed, related to hydrology, wetlands, contaminants, climatological issues, geology,

NOTE: A summary of these items is provided in a separate document – attached –(AUTHOR? DATE?)