Effects of the Suwannee River Sill on the Hydrology of the Okefenokee Swamp: Application of Research Results in the Environmental Assessment Process

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Abstract—The Okefenokee Swamp is a 200,000 ha palustrine, freshwater wetland in the southeastern United States managed as a National Wildlife Refuge and a National Wilderness Area. Wildfires frequently occur, modifying vegetation structure and creating the swamp landscape mosaic. Following extensive wildfires in 1954-1955, the Suwannee River was impounded by a dam (Suwannee River Sill) built outside the Wilderness Area but within the Refuge to exclude fire reoccurrence. By the late 1980s indications were that fire was not being excluded, although the swamp hydrology and vegetation suggested changes due to extended hydroperiod. The dam's effects were delineated with a spatial hydrology model and studies of species' hydrological sensitivities, and an Environmental Assessment considered the multiple uses and management goals to determine the best sill management alternative.

The Okefenokee Swamp is a 200,000 ha palustrine, freshwater wetland in southeast Georgia and northeast Florida. Two coastal plain rivers, the Suwannee and the St. Marys, originate within its landscape. The swamp was relatively undisturbed by explorers and settlers until the end of the 19th century, when it was subjected to draining, timber harvest and peat mining. Protection and preservation of the landscape and remaining resources were goals in 1937, when the swamp became part of the National Wildlife Refuge System. The Suwannee River sill, a low earthen dam constructed in 1960 across the main outflow channel of the Suwannee River where it exited the swamp, was also intended to protect and preserve the swamp. Built in response to fires that burned across the swamp and into the surrounding properties during 1954-1955, the sill was to impound water in the Okefenokee Swamp to keep similar fires from igniting and burning in the swamp. Further protection of the swamp was intended in 1974 when most of the Refuge (excluding the sill structure and adjacent area, and perimeter fire management compartments) was designated as a National Wilderness Area. During the 30 years following construction of the sill concern about the health of the swamp ecosystem began to emerge. Was the Suwannee River sill responsible for altering swamp vegetation, or were the perceived changes artifacts of the observers' temporal and spatial scales? Rather than "protecting" the swamp, was the sill damaging the wetland by disrupting the natural hydrologic environment and, subsequently, the vegetation community dynamics? During 1989, the sill structure was examined and found to be in need of extensive repair. Should the sill be repaired, modified or removed?

Addressing these questions required examination of the Okefenokee Swamp landscape composition and structure and the processes that create and maintain this structure. Hydrology is a primary driving function of all wetlands, and the hydrologic regime, principally hydroperiod (duration of flooding), determines wetland type (Mitsch and Gosselink 1986). Many wetlands are also shaped by fire, and fire suppression may compromise wetland integrity (Mitsch and Gosselink 1986). In these systems, fire and the hydrologic regime are intricately linked; periodic droughts create conditions favorable for burning. Fires occur, potentially altering site environments (soil composition, site elevation and hydrologic features) and subsequent species composition. Alterations of frequencies, intensities and extent of these processes (fire and the hydrologic regime) can modify landscape composition and structure (DeAngelis and White 1994). Human activity has disrupted Okefenokee Swamp hydrology and fire regimes. Hierarchy theory (Allen and Starr 1982; Allen and Wyleto 1983) suggests that the extent of these disruptions depends both on the organizational level of the ecosystem normally affected by these processes and the relative importance of the affected driving function (e.g., hydrology) in maintenance of the system hierarchy.

Upon completion of the study of the sill's effects on the swamp hydrology and vegetation composition and distribution, an Environmental Assessment (EA) of the sill's effects was formally implemented by the U.S. Fish and Wildlife Service and Okefenokee National Wildlife Refuge staff to aid in decision-making for sill management. In compliance with the provisions of the National Environmental Policy Act (NEPA), the EA was prepared to evaluate sill management alternatives and their environmental consequences. Determination of the need for an Environmental Impact Statement (EIS) could also be achieved in this process. This

In: McCool, Stephen F.; Cole, David N.; Borrie, William T.; O'Loughlin, Jennifer, comps. 2000. Wilderness science in a time of change conference—Volume 3: Wilderness as a place for scientific inquiry; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-3. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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assessment also provided an opportunity to examine the appropriateness of the sill and its management in a designated Wilderness Area. The process provided opportunity for public education in workshops, press releases and public comment periods on the proposed management alternatives. A summary document and proposed plan of action concluded the EA.

Study Area Description

The Okefenokee Swamp is a complex of forested uplands and freshwater wetlands covering approximately 1670 km^2 of the lower Atlantic Coastal Plain in southeast Georgia and northeast Florida (fig. 1). Approximately 80% of the swamp is within the Okefenokee National Wildlife Refuge. Formation of the wetland landscape began at least 6,500 years ago, as plant decay was delayed by continuous flooding, which created anaerobic, acidic conditions favorable for peat production (Cohen 1973a). Peat accumulation continues today and is punctuated by periods of extreme drought, when peat is removed by fire and oxidation.

The swamp's watershed (3,702 km^2) includes three drainage basins (Rykiel 1977; Hyatt 1984; Brook and Hyatt 1985). The Suwannee River carries 85% of the exiting flow from the western swamp; the St. Marys River (11%) and Cypress and Sweetwater Creeks account for the remainder (4%) exiting the southern third of the swamp (Rykiel 1977). Groundwater exchange is minimal (Brook and Hyatt 1985; Hyatt and Brook 1984). Water enters the swamp as precipitation (70%) and surface drainage of uplands along the western and eastern boundaries (Rykiel 1977). Water levels are generally lowest during April-May, when evapotranspiration (ET) demands are high and seasonal precipitation is low, and October-November due to low precipitation (Loftin 1998). Most rainfall occurs during June-September.

Several vegetation communities occur in the Okefenokee Swamp. Shallow prairies of emergent and floating aquatic macrophytes are found where peat layers are thick over depressions in the basement topography (Cohen 1973a, 1973b, 1974; Cohen and others 1984) and cover approximately 8% of the swamp (Loftin 1998). Forested areas of pond cypress (*Taxodium acsendens*), loblolly bay (*Gordonia lasianthus*) and dahoon holly (*Ilex cassine*) cover 57% of the swamp (Loftin 1998). Slash pine (*Pinus elliottii*) and longleaf pine (*P. palustris*) occur on the remaining area of sandy islands and ridges (5%) (Loftin 1998). Dense shrub thickets fill the remaining swamp interior (29%) (Loftin 1998). Much of the western portion of the swamp, where mixed forests of pond cypress, loblolly bay and blackgum (*Nyssa sylvatica* v. *biflora*) historically predominated, was logged during 1900-1930 (Izlar 1984). This area currently supports stands of shrubs and hardwoods, with little cypress regeneration (Hamilton 1984, 1982; Loftin 1998).

The classic model of hydrarch succession (development of a terrestrial forest climax community from an open water body) directed by autogenic processes (Mitsch and Gosselink 1986) is only partially applicable to the swamp. The regional topography facilitates collection of surface water in the swamp, and periodic droughts expose the accumulated peat, allowing oxidation and decline in the surface elevation. Site

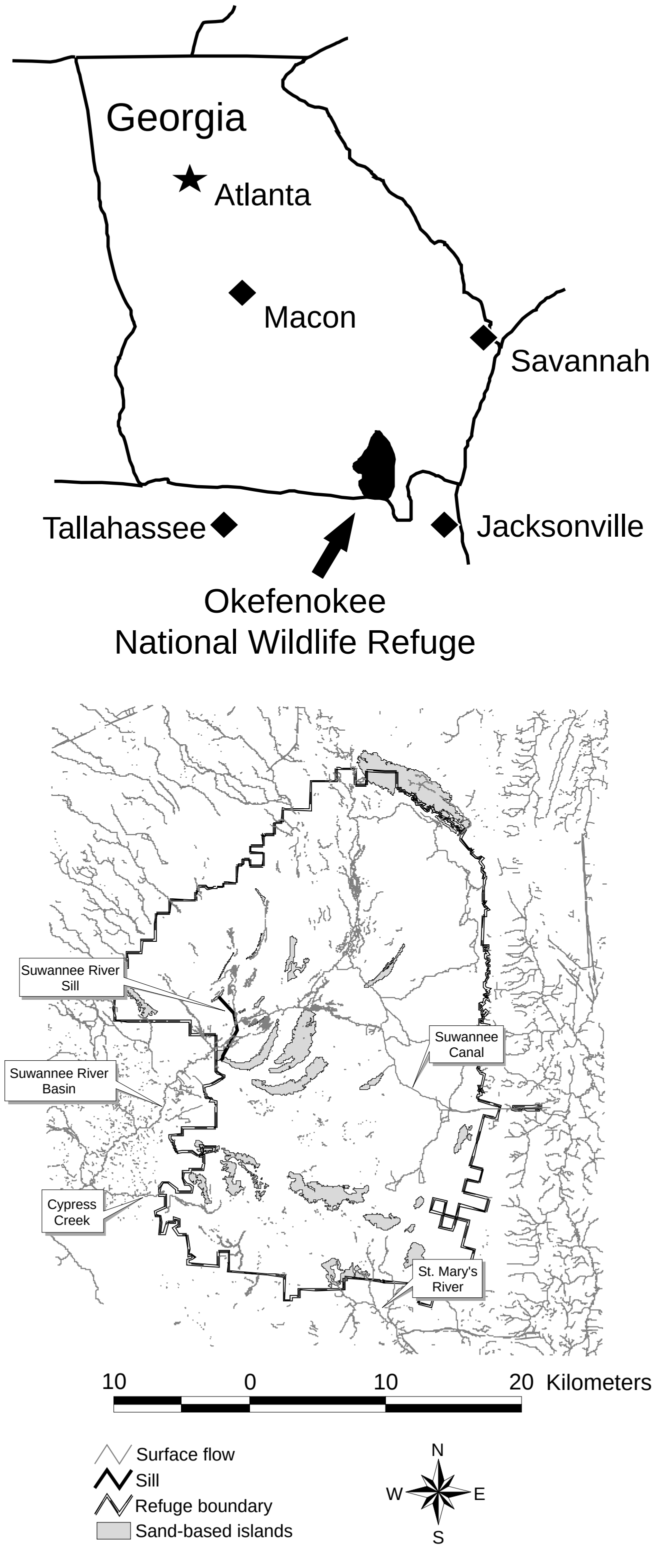


Figure 1—Location of the Okefenokee National Wildlife Refuge in Georgia.

elevations are raised as plant debris accumulates, creating more favorable conditions for species less tolerant of flooding. A progression from prairie to cypress swamp to broadleaved evergreen or mixed cypress swamp occurs in the absence of fire as peat accumulates (Hamilton 1982, 1984). However, in the swamp's history, this sequence has frequently been disrupted when drought, fire and subsequent species changes occur, and the wetland landscape mosaic is maintained (Hopkins 1947). Manipulations of the swamp vegetation composition (through logging) and hydrology (through trail, canal and sill construction and maintenance) during the past two centuries, as well as current fire management (suppression, control and prescribed burning), have affected fire frequency and occurrence across the swamp (Loftin 1998).

Purpose of the Suwannee River Sill

During 1954-1955, nearly 80% of the swamp was burned by wildfires during a severe drought (Hamilton 1982, 1984). Many of these fires began in the surrounding uplands, spread into the swamp where the peat slowly burned and returned to the perimeter uplands. Neighboring landowners sustained significant property loss from these fires. There was great interest in protecting the swamp and surrounding lands from future fires; a law was enacted by the United States Congress in 1956 to require construction of a dam, the Suwannee River sill,

> ...to protect the natural features and the very substantial public values represented in the Okefenokee National Wildlife Refuge, Georgia, from disastrous fires..., and for the purpose of safeguarding the forest resources on more than four hundred thousand acres of adjoining lands recently damaged by wildfires originating in or sustained by the desiccated peat deposits in the Okefenokee Swamp. (Chapter 742, Public Law 81-810, 70 Statute 668, pages 781-782).

A perimeter road that would permit access to remote areas for fire control and serve as a fire break to spreading fires was also required by the law. In 1962, construction of the sill berm and closure of the two spillway gates were completed. The berm spans 7.2 km and averages 35.5 m above mean sea level and 3-4 m above the surrounding Suwannee River floodplain; a ditch borders its entire length to the east. The berm does not intercept the entire river floodplain in the swamp; significant flow bypasses and exits west of the sill. The original south gate collapsed in 1979 and was replaced; the north gate is the original structure. Although the gates are maneuverable, they remain closed to maximize impoundment. The 1974 Wilderness Area designation excluded the sill and adjacent area from protection.

Prolonged flooding by impounding runoff and stream flow may reduce water level variation that normally occurs with precipitation (Finn and Rykiel 1979). Yin (1990) and Yin and Brook (1992) estimated an increase in average storage and a decrease in discharge throughout the swamp after sill construction. If the sill is extending periods of high water, it may be altering the landscape by affecting vegetation succession. Decreased fire frequency and extent may be encouraging woody vegetation to invade prairies during the occasional drier periods, hastening succession to cypress or bay swamp, and eliminating the mosaic of vegetation and the associated biodiversity in a landscape historically perpetuated by periodic disturbances (Hamilton 1982, 1984).

Problem Statement

Apparent changes in vegetation composition of the Okefenokee Swamp during 1960-1990 precipitated concern that the Suwannee River sill and the Okefenokee National Wildlife Refuge fire management policy were permanently altering the swamp's ecology (Roelle and Hamilton 1990). The Suwannee River sill was constructed to prevent recurrence of fires during periodic drawdowns. During 1962-1990, extensive fires did not occur in the swamp. However, this may have been the result of the Refuge's fire management policy rather than the impoundment effects of the sill. In fact, scattered fires during 1990 and 1993 suggest that the sill had not eliminated fire. Thus, the sill was performing as it was intended (to suppress fires) only in its localized area during periods of average hydrologic conditions; this temporally and spatially extended hydroperiod beyond the local area during intervening years when water levels were generally higher (Roelle and Hamilton 1990) but did not retain a substantial amount of water during extended periods of below average rainfall (Loftin 1998).

When the study of the processes that shape the swamp landscape was initiated in late 1991, the uncertainty of the sill's effects on the hydrology and vegetation of the swamp raised questions of whether it should be opened, repaired as a fixed height weir or replaced with a controllable structure. The swamp's Wilderness designation also had to be considered; although the sill was in place when this designation was made and the Wilderness-protected area excludes the sill structure, the extent of the sill's effects into the Wilderness Area was unknown. Effects of the sill on vegetation communities within the landscape needed to be documented and predicted effects of future hydrologic management alternatives analyzed so that the swamp hydrology could be appropriately managed to meet Refuge and Wilderness Area goals. To address these needs, it was necessary to analyze the swamp vegetation and shaping functions from several spatial and temporal scales. Hydrologic monitoring and topographic surveying at locations throughout and surrounding the swamp provided data for describing the swamp hydrology. Wildfire and prescribed burning records provided a spatial history of fire to compare with hydrologic and vegetation distribution information. Pre-logging surveys and post-logging aerial photography and satellite imagery classification indicated vegetation distributions resulting from natural successions, wildfire management and logging. A spatial hydrology model was developed and used to estimate the spatial extent of the sill's influence on the swamp hydrologic environment. A geographical information system (GIS) was used to identify the spatial relationships of these components to the sill and to current vegetation community distributions and hydrologic features, elucidating the sill's effects on the swamp ecosystem. The research findings addressed many of the issues raised in the subsequent EA process that was initiated after the research had concluded.

Methods

The Suwannee River Sill Environmental Assessment (EA)

The EA Process—Management of the Okefenokee National Wildlife Refuge is governed by the established purposes, as well as the recently passed National Wildlife Refuge System Improvement Act. In addition to these general guidelines, the U.S. Fish and Wildlife Service (FWS) was directed to construct the Suwannee River sill as a result of congressional action embodied in Public Law 84-810 (70 Stat. 668). The FWS is required to carry out this law unless otherwise instructed by Congress.

Deterioration of the Suwannee River sill and potential safety hazards identified periodically since 1982 made repairs necessary. In 1990, a workshop was held addressing the FWS's concern that the sill and the current fire management policy might be altering the floristic composition and wildlife use of the Okefenokee Swamp (Roelle and Hamilton 1990). Although the Suwannee River sill was constructed prior to the establishment of the National Environmental Policy Act (NEPA), the process of preparing environmental documents (such as EAs) to aid in decision-making and assist in informing and involving the public was recommended. This process was initiated in April 1997, when Georgia Representative Saxby Chambliss requested that an EA be conducted to assess future sill management (fig. 2). Immediate remedial action to the structure was recommended following an October 1997 report giving the sill an overall safety classification of "unsatisfactory".

An environmental assessment is prepared to evaluate alternatives and environmental consequences to determine if the environmental impacts are significant enough to warrant preparation of an Environmental Impact Statement (EIS). If the impacts are not significant enough for such a document, the proposed action can be implemented without further documentation. Although the EA process does not require an official scoping meeting, the FWS sponsored workshops at two locations near the Okefenokee Swamp to disseminate general information about the sill. Notices and articles announcing the workshop and introducing the issues were presented in the local newspapers. Comment packets were mailed to interested parties. Results from recently completed comprehensive investigations of the sill's effects on the swamp hydrology and associated landscape alterations (see discussion in next section) were presented at the workshops, giving the public a chance to learn about the subject and correct misunderstandings about the sill. Following the presentation, representatives from the Refuge and the Georgia Department of Natural Resources Fisheries Division listened to the public's concerns and answered questions. Public comments at these meetings were recorded, and written or verbal comments were accepted for 30 days following the workshops. All concerns raised during these workshops and in the comment packages, as well as applicable technical issues, were reviewed and used to develop management alternatives.

In the process of identifying the issues, alternatives and preferred alternatives, meetings and consultations were held with various state and federal agencies, adjacent landowners and civic and environmental organizations.

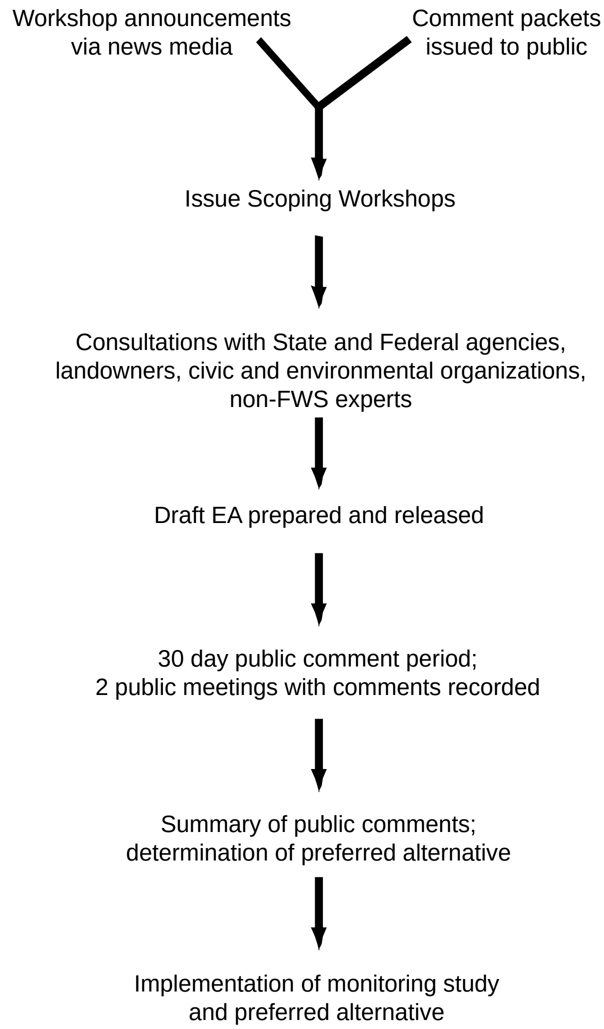


Figure 2—Approach of the Suwannee River sill Environmental Assessment

Okefenokee National Wildlife Refuge and Regional Office staff coordinated preparation of the EA, consulting non-FWS experts and information sources to ensure adequate coverage of each impact topic. After the draft EA was released, comments on the proposed action were gathered during a 30-day public comment period and two formal public meetings. A public outreach plan was also developed to address questions and concerns arising during the preferred alternative implementation.

Determination of the Preferred Alternative—The four alternatives addressed in the EA are outlined in table 1. Implementing regulations for NEPA provide for the elimination of some alternatives from detailed study, following a brief discussion of the reasons for doing so. After evaluation, a fifth alternative of expanding the sill structure and constructing additional structures within the Refuge was not considered a reasonable alternative and was not evaluated further. The environmental impacts of each alternative on hydrology, water quality, vegetation, fire, forestry, fisheries, wildlife, archeological and historical resources, public use and the local economy were addressed and

Table 1—Alternatives addressed in the Suwannee River sill environmental assessment.

Alternative	Action
A	No action (continue minimal maintenance/ monitoring)
B	Phased removal of concrete water control structures and breaching of the sill in selected locations (Preferred Action).
C	Remove Suwannee River sill and water control structures completely.
D	Repair and maintain the original structure.

evaluated in relation to the mission and goals of the Refuge. The preferred alternative was selected on the basis of reestablishing the natural processes within the swamp and restoring the link between the swamp and the Suwannee River. Public interest in the future recreational use of the area was considered, as well as public safety. A cost-benefit analysis was conducted in the final step.

Research Applied in the Ecological Assessment Process

An extensive analysis on effects of the Suwannee River sill on the Okefenokee Swamp landscape (Loftin 1998) preceded the EA. A brief review of these data is presented here.

Hydrology Studies—A spatial hydrology model (HYDRO-MODEL) was developed using ArcInfo and ARC GRID (version 7.3) to describe the swamp hydrologic environment, identify local- and system-level sensitivities to potential alterations in the Suwannee River sill structure, and compare type, location and extent of hydrologic and vegetation changes. Model development is detailed in Loftin (1998). The model was calibrated with weather and vegetation data representing conditions in the Okefenokee National Wildlife Refuge during 1980-1993 and topographic information collected during 1991-1994. The model is intended to represent the swamp hydrology cycling in twice-monthly time steps during 1980-1993. Independent data sets for 1941-1979 were used to assess model performance and system response to various manipulations. The "with-" and "pre-sill" conditions (1960-1993 and 1941-1959, respectively) were represented by topographic surfaces with and without the sill in place. The no-sill topographic surface was also modeled with hydrology data from 1980-1993 to demonstrate water surface elevations that might have occurred during that period had the sill been absent. Output data include water depth, water surface elevation and amount of water moved in each time step.

Wildfires in the Suwannee River Sill-Affected Area—Refuge records contain information primarily on wildfires that were suppressed and not on those that were naturally extinguished before detection. Therefore, it is not possible to determine if the sill affected total fire occurrence. However, it is possible to determine if the sill was elevating water levels during seasons of high fire frequency, if fires were arrested in the sill impact area due to elevated water levels, and if reported incidences of wildfires decreased following sill construction. These questions were addressed by comparing maps of wildfire ignition location and burn extent with a delineation of the sill-affected area and information on general hydrologic conditions at the time of the wildfires, summarized from the water level recorder database and model output surfaces. Comparisons were made using IMAGINE (version 8.2) summaries and overlays and ArcView map inquiries.

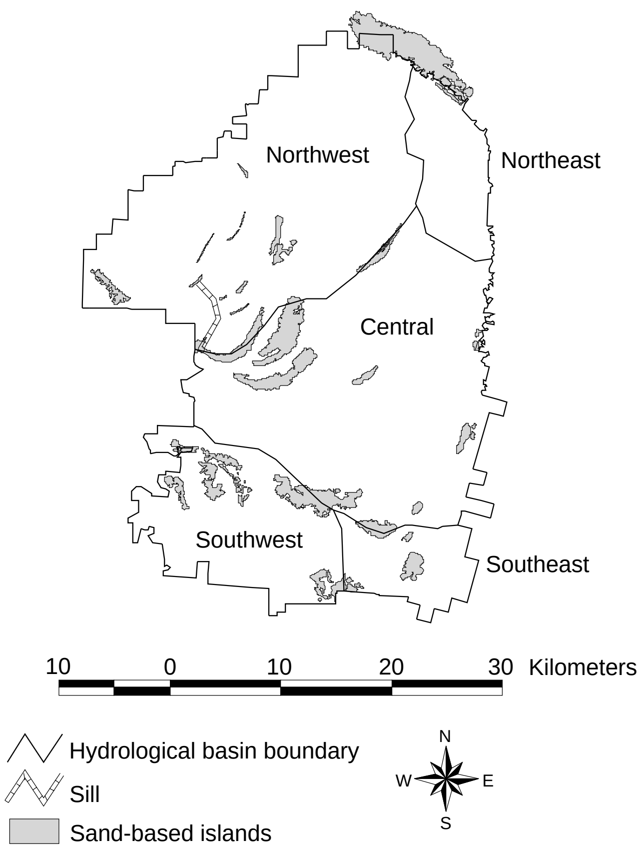
Vegetation Change in the Suwannee River Sill-Affected Area—Areas of vegetation change attributed to hydrologic modifications of the Suwannee River sill were determined with ERDAS-IMAGINE summary overlays of the estimated sill impact area and interpretations of pre-sill aerial photography and with-sill aerial photography and satellite imagery. Proportions of vegetation types inside and outside of the affected area were estimated and compared between the areas with these overlays. Comparisons of vegetation distributions relative to logging and wildfire histories are detailed in Loftin (1998).

Results and Discussion

The Sill's Effects on Swamp Hydrology

The complexity of the swamp hydrological environment was illustrated with swamp water level data and spatial hydrology model analysis. Water level data indicate that the Okefenokee Swamp contains sub-basins with similar seasonal trends but different water level variability and amplitudes (fig. 3). HYDRO-MODEL manipulations indicate that sensitivities to model parameters (ET, inflow volumes, outflow volumes) reflect differences in the hydrodynamics of these sub-basins (fig. 4). Although water depths did not change significantly in the northeastern basin with simulated sill removal, lower water depths were measured at stations in the western and southwestern basins. Responses in the Suwannee River floodplain in the western basin reflect the sill's absence from the topographic surface; however, responses in the southwestern creeks reflect the connectivity between the river and creek basins (particularly Sweetwater and Cypress Creeks) outside the Refuge boundary. Drainage of this region is affected by the topography of the river basin outside of the Refuge boundary. Peaks and troughs in the river channel slow drainage of the area, creating pooling in the Suwannee River above the topographic rise or berm, until water surface elevations exceed the crest, and overflow occurs. This condition is repeated throughout the Suwannee River floodplain in the Refuge interior, as well (fig. 5).

The central and southeastern basins behaved independently of the sill's presence in all but high water levels. Under low water level conditions, the Suwannee River floodplain drains rapidly as inflow is reduced, and water levels in the central and southeastern basins drop through evaporation. Under average conditions, flow in the central basin is limited to the western terminus of the Suwannee Canal. Under high water conditions, drainage from the central basin via the canal is delayed, as impoundment by the sill and the natural berms in the river floodplain delay de-watering.



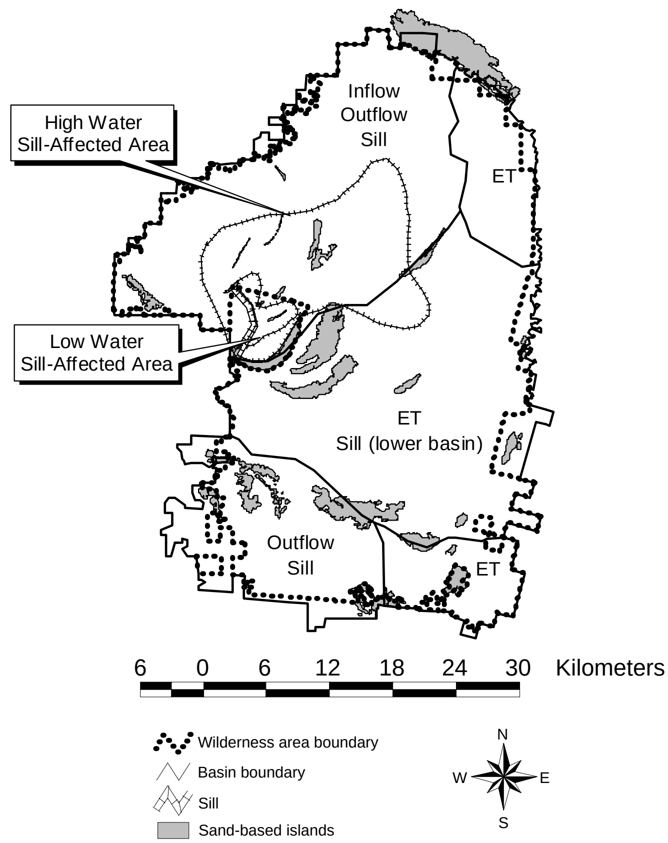


Figure 4—Regional differences in sensitivities to parameter manipulations in HYDRO-MODEL simulations.

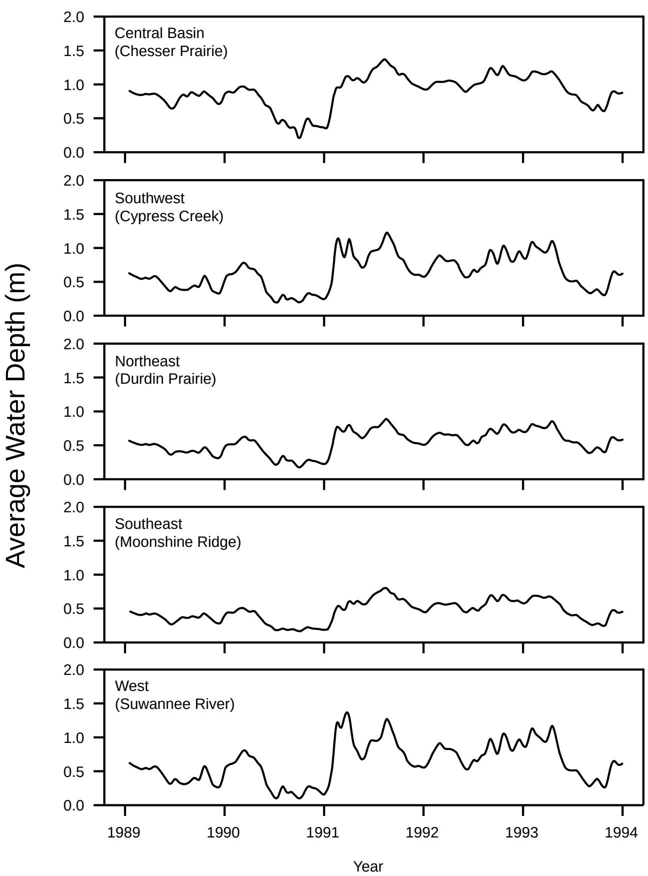


Figure 3—Hydrographs from Okefenokee Swamp sub-basins.

Changes in water depths do not necessarily mean changes in inundation duration (hydroperiod). The significance of these hydrologic changes to swamp vegetation communities depends on species' sensitivities to the degree and timing of change (Loftin 1998). The western swamp experienced longer periods of slightly deeper water depths during 1960-1993 (with-sill) than during 1941-1959 (no-sill). Inundation depths and frequencies in the northeastern, central and southeastern swamp did not change during 1941-1993 with the addition of the sill during 1960-1993. Also, no changes in hydroperiod were indicated at northeastern, central and southeastern swamp when the sill was added to the 1941-1959 model runs or removed from the 1961-1993 iterations. Slightly lower water depths and shorter hydroperiods occurred in the western and southwestern swamp when the sill was removed from the 1960-1993 model iterations; longer flooding periods were recorded in these areas when the sill was added to the 1941-1959 simulations.

HYDRO-MODEL was also manipulated to increase the volume of water impounded by the sill. With this manipulation water depths in the area immediately surrounding the sill increased 1-1.5 m due to the reduced outflow; depths in the western swamp increased roughly 0.40 m, and no change occurred in the remainder of the swamp. Hydroperiods were also prolonged where the increased depths occurred.

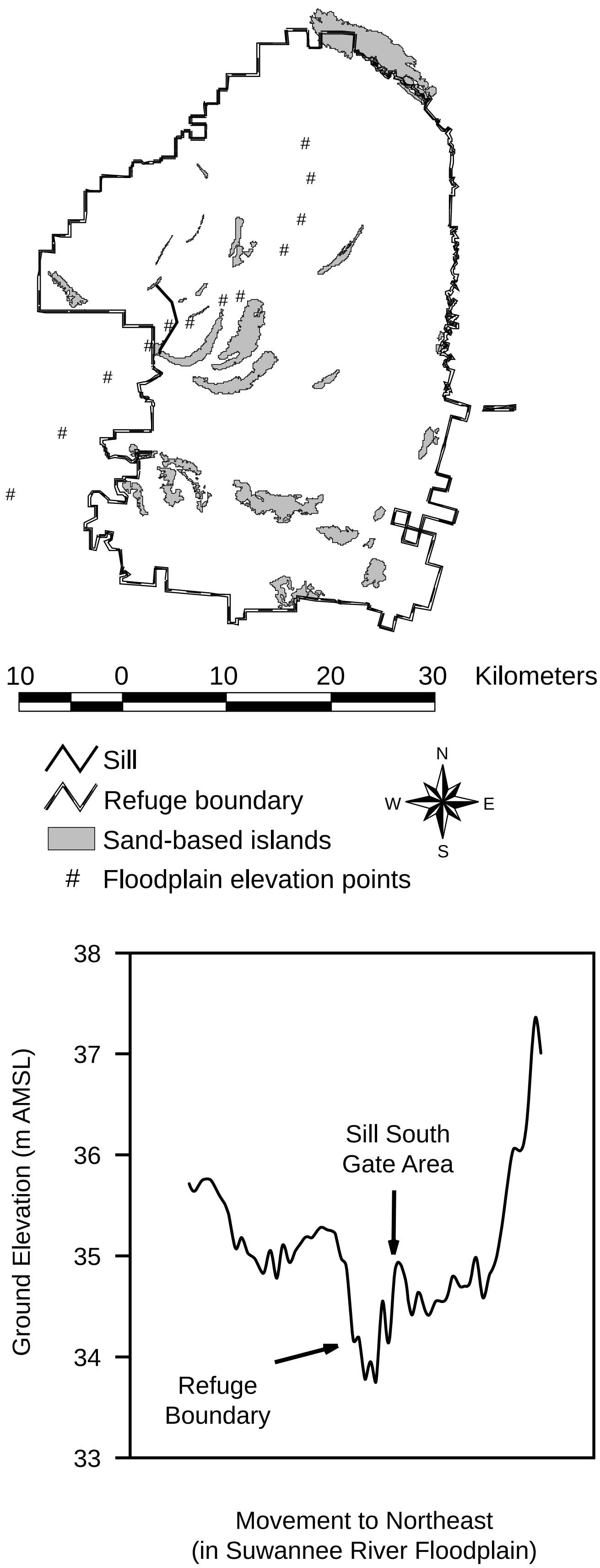


Figure 5—Elevation changes in the Suwannee River channel and floodplain in the Okefenokee National Wildlife Refuge and southwest of the Suwannee River sill.

Manipulations of evapotranspiration (ET) rates to examine potential effects of vegetation change on swamp water levels indicate that regional differences exist in the influence of this process on the swamp hydrology (fig. 4). Changes in ET volumes had significant effect throughout the swamp, particularly in basins outside the Suwannee River floodplain. Regional differences in vegetation distributions and topographic relief drive these responses. The higher topographic gradient in the river floodplain emphasizes changes in outflow volumes in the western swamp, whereas the prevalence of open water, aquatic and herbaceous prairie and the low topographic gradient are probably responsible for the importance of ET in the water budget in the remainder of the swamp.

The Sill's Effects on Wildfire Occurrence

More fires were reported in the Okefenokee Swamp during the with-sill period (151) than during the century prior (98) to its construction. Burned area decreased after sill construction, although this decrease was probably not due to the sill since water levels were low or at drought levels when most of the fires were ignited, and the fires occurred outside of the low-water and drought impoundment areas. The decrease was more likely due to fire suppression efforts and the absence of severe drought during 1960-1993 (Loftin 1998). Since 1855, 37 fires were reported in the area affected by the sill impoundment; 18 of these fires were prior to sill construction, and 11 were in the watersheds of the southwestern creeks (Loftin 1998). Most of the wildfires (25) in the sill-affected area ignited during June-October, when lightning strikes are most common and water levels rapidly decline in the absence of precipitation (Loftin 1998). Greatest impoundment usually occurs during winter months, when thunderstorms and lightning activity are infrequent, and water level accumulation occurs with reduced levels of evapotranspiration. The sill increases water levels during dry periods only in the immediate river floodplain of the southwestern swamp (fig. 4). Fire exclusion throughout the swamp will never be achieved with the present sill due to the limited affected area (18% of the swamp at high water levels) and seasonality of impoundment. Because the swamp hydrologic system is so tightly linked with area rainfall and evapotranspiration, the sill cannot impound enough water during the period when its impoundment effects are most needed to counteract drought and arrest wildfire spread.

The Sill's Effects on Swamp Vegetation

Types of vegetation changes occurring in the sill impoundment area mirror those in the remainder of the swamp, although change rates differ (Loftin 1998). Wet forest initially increased in the river floodplain affected area during 1952-1977 and was persistent during the next 13 years, whereas shrub, prairie and upland pine coverages were nearly halved during 1952-1990 (Loftin 1998). These changes occurred at rates slower than the surrounding swamp during 1952-1977 and then greater than the surrounding swamp during 1977-1990 (Loftin 1998). Shrubs flooded during the initial impoundment did not survive unless located on elevated surfaces. The apparent increase in proportion of forested area was probably due to this relative decline in shrub coverage. Recruitment of trees and shrubs has been eliminated during the extended flooding; only periods of drought provide exposed surfaces for germination, and survival of seedlings is jeopardized by re-flooding before they achieve sufficient stature to survive impoundment. As in the remainder of the swamp, vegetation in the impounded area is succeeding in the absence of severe fire (Loftin 1998).

Applying Results from Scientific Research in the Environmental Assessment Process

HYDRO-MODEL simulations included manipulations of the sill and hydrological environment, and analysis of swamp hydrological sensitivity. Model predictions indicated the extent and intensity of hydrological changes expected with sill modification. Observed changes in vegetation distributions and wildfire occurrences and distributions were compared with HYDRO-MODEL predictions to establish relationships. This information was used extensively throughout the EA process. Questions arising during the scientific review and public comment period were addressed by referencing the research findings. This information contributed to the selection of the preferred alternative.

The hydrology study was concentrated within the Refuge perimeter. Information about the Suwannee River hydrology outside of the Refuge boundary was lacking. The FWS had an opportunity to proceed in a phased (defined in the preferred alternative) removal of the water control structures and earthen dike. Incorporated into the preferred alternative was a proposal to collect two years of baseline data downstream from the sill and verify HYDRO-MODEL predictions of downstream changes. Two years of monitoring with the water control structures opened will follow. A supplemental report summarizing the monitoring will be attached to the original EA upon conclusion of the supplemental study. Barring any documented negative impacts to public use or private landowners that cannot be mitigated through additional management actions or accepted as factors in the system restoration, the alternative will be fully implemented. This phased approach to preferred alternative implementation was also taken to address concerns of flooding due to above-average rainfall along the Suwannee River; the FWS formed a partnership with the US Geological Survey-Water Resources Division to monitor Suwannee River water levels and examine those concerns.

Comments on the draft EA illustrated the public's comprehension of the issues. Only seven individuals made verbal comments at the two public meetings. Eighty-five individuals responded in 67 written comments, and one person provided verbal comments by phone during the 30-day comment period. Eighty-five supported the preferred alternative, three supported Alternative C, and five supported Alternative D. Providing current, credible information to the public, agencies, and special interest organizations guided the EA process. This was an issue originally expected to be highly controversial, yet the use of recent technology and expanded analysis capabilities to study alterations in this large landscape guided the NEPA process to successful conclusion.

Conclusions

The Suwannee River sill was constructed to protect the swamp from drought and wildfires, processes once considered damaging to the swamp landscape. In the years immediately following sill construction, rainfall maintained swamp water levels and wildfires were infrequent. Wilderness designation occurred during this period of high water levels and low fire occurrence. Although the sill and its immediate surroundings were not included in the Wilderness Area protection, impounded areas further from the sill were in the designated Wilderness Area. By the early 1980s drought and wildfires were again occurring throughout the swamp, and the role of the sill in vegetation and hydrological changes was questioned. Research suggested that cycles of drought and fire were necessary to maintain the swamp landscape mosaic. The palustrine environment of the sill impoundment was in contrast to the naturally dynamic riparian hydrology existing prior to sill construction. Although limited in extent, the static hydrology created by the sill during years of normal rainfall was leading to changes in vegetation community composition and distributions.

Providing habitat for wildlife, arresting wildfire movement into surrounding privately-owned land, and ensuring access to the swamp for recreational users are issues directing management of the Okefenokee National Wildlife Refuge. Protecting the Okefenokee Swamp's naturalness, which is a goal in the designated Wilderness Area, requires recognition of the complexity of the driving processes that have shaped this landscape at multiple spatial and temporal scales. Humans have locally manipulated the swamp landscape with logging, peat dredging, trail maintenance, fire management, and the sill. The regional hydrological cycle, however, also shapes the swamp landscape. Droughts create conditions for landscape-altering fires to occur at decades to century intervals. These drought-fire cycles have occurred since swamp formation began thousands of years ago, and the effects are somewhat predictable. However, human-caused changes in the swamp landscape during the past century have affected this predictability by altering plant species compositions and peat and fuel accumulation rates. Coupled with these changes is the need for swamp management to achieve multiple goals, including producing and protecting of wildlife habitat, providing public recreation opportunities, and ensuring wilderness protection. The EA process presented a framework to recognize the various roles of the sill in this area managed with different objectives, as a National Wildlife Refuge and a National Wilderness Area. Results from scientific study of the sill's effects guided formulation of the management alternatives while recognizing the area's many uses, and public participation in the EA process provided an opportunity to build consensus necessary between refuge managers and the interested public for successful implementation of the preferred alternative.

Acknowledgments

This paper represents Florida Agricultural Experiment Station Journal Series No. R-07131. This study was funded in part by the U.S. Fish and Wildlife Service Okefenokee National Wildlife Refuge under Cooperative Agreement #14-45-009-1544. J. Aufmuth, C. Depkin, J. Kitchens, J. Loftin, D. O'Neill, L. Pearlstine, B. Rasberry, K. Williges, J. Andrews, and the staff of the Okefenokee National Wildlife Refuge contributed to various phases of this study. Their assistance is appreciated.

References

Allen, T. F. H.; Starr, T. 1982. Hierarchy: perspectives for ecological complexity. Chicago, IL: University of Chicago Press. 261 p.

Allen, T. F. H.; Wyleto, E. P. 1983. A hierarchical model for the complexity of plant communities. Journal of Theoretical Biology. 101:529-540.

Brook, G. A.; Hyatt, R. A. 1985. A hydrological budget for the Okefenokee Swamp watershed, 1981-82. Physical Geography. 5(2):127-141.

Cohen, A. D. 1973a. Possible influences of subpeat topography and sediment type upon the development of the Okefenokee Swamp-marsh complex of Georgia. Southeastern Geology. 15:141-151.

Cohen, A. D. 1973b. Petrology of some holocene peat sediments from the Okefenokee Swamp-marsh complex of southern Georgia. Bulletin of the Ecological Society of America. 84:3867-3878.

Cohen, A.D. 1974. Petrography and Paleoecology of Holocene Peats from the Okefenokee Swamp-Marsh Complex of Georgia. Journal of Sedimentary Petrology 44(3):716-726.

Cohen, A. D.; Andrejko, M. J.; Spackman, W.; Corvinus, D. 1984. Peat deposits in the Okefenokee Swamp. In: Cohen, A. J.; Casagrande, D. J.; Andrejko, M. J.; Best, G. R., eds. The Okefenokee Swamp: its natural history, geology, and geochemistry. Los Alamos, NM: Wetlands Surveys: 493-553.

DeAngelis, D. L.; White, P. S. 1994. Ecosystems as products of spatially and temporally varying driving forces, ecological processes, and landscapes: a theoretical perspective. In: Davis, S. M.; Ogden, J. C., eds. Everglades: the ecosystem and its restoration. Delray Beach, FL: St. Lucie Press: 9-27.

Finn, J. T.; Rykiel, Jr., E. J. 1979. Effect of the Suwannee River sill on Okefenokee Swamp water level. Water Resources Research. 15(2):313-320.

Hamilton, D. B. 1982. Plant succession and the influence of disturbance in the Okefenokee Swamp, Georgia. Ph.D. Dissertation. Athens, GA: University of Georgia: 254 p.

Hamilton, D. B. 1984. Succession and the influence of disturbance in Okefenokee Swamp. In: Cohen, A. J.; Casagrande, D. J.; Andrejko, M. J.; Best, G. R., eds. The Okefenokee Swamp: its natural history, geology, and geochemistry. Los Alamos, NM: Wetlands Surveys: 86-111.

Hopkins, J. M. 1947. Forty-five years with the Okefenokee Swamp. Bulletin of the Georgia Society of Naturalists. (4):1-69.

Hyatt, R. A. 1984. Hydrology and geochemistry of the Okefenokee Swamp. Ph.D. Dissertation. Athens, GA: University Georgia: 361 p.

Hyatt, R. A.; Brook, G. A. 1984. Ground water flow in the Okefenokee Swamp and Hydrologic and nutrient budgets for the period August, 1981 through July, 1982. In: Cohen, A. J.; Casagrande, D. J.; Andrejko, M. J.; Best, G. R., eds. The Okefenokee Swamp: its natural history, geology, and geochemistry. Los Alamos, NM: Wetlands Surveys: 229-245.

Izlar, R. L. 1984. A history of Okefenokee logging operations: a bourbon and branch water success story. In: Cohen, A. J.; Casagrande, D. J.; Andrejko, M. J.; Best, G. R., eds. The Okefenokee Swamp: its natural history, geology, and geochemistry. Los Alamos, NM: Wetlands Surveys: 5-17.

Loftin, C. S. 1998. Assessing patterns and processes of landscape change in Okefenokee Swamp, Georgia. Ph.D. Dissertation. Gainesville, FL : University of Florida: 864 p.

Mitsch, W. J.; Gosselink, J. G. 1986. Wetlands. New York, NY: Van Nostrand Reinhold. 539 p.

Roelle, J. E.; Hamilton, D. B. 1990. Suwannee River sill and fire management alternatives at the Okefenokee National Wildlife Refuge. Fort Collins, CO: U.S. Fish and Wildlife Service, National Ecology Research Center. 39 p.

Rykiel, E. J. 1977. The Okefenokee Swamp watershed: water balance and nutrient budgets. Ph.D. Dissertation. Athens, GA: University of Georgia: 246 p.

Yin, Z. 1990. The impact of the Suwannee River sill on the surface hydrology of Okefenokee Swamp. Ph.D. Dissertation. Athens, GA: University of Georgia: 352 p.

Yin, Z.; Brook, G. A. 1992. The impact of the Suwannee River sill on the surface hydrology of Okefenokee Swamp, USA. Journal of Hydrology. 136:193-217.