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Assessing Geographically Isolated Wetlands in North and South Carolina – the Southeast Isolated Wetlands Assessment (SEIWA)

Final Report

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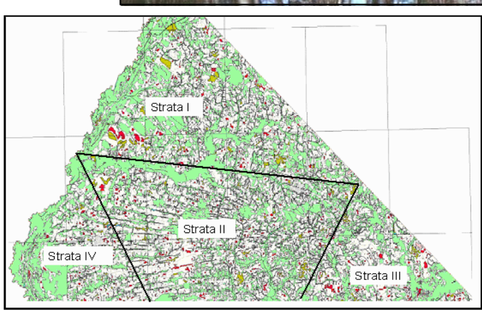

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Assessing Geographically Isolated Wetlands in North and South Carolina –

Technical Report for the Southeast Isolated Wetlands Assessment (SEIWA)

The use of probabilistic methods to answer questions about the condition and fate of geographically isolated wetlands in southeast coastal plain of Region 4

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Abstract

Wetlands provide significant benefits to habitats and the surrounding environment. Geographically isolated wetlands (IWs) can provide the same environmental benefits but are subject to being lost due to the encroachment of human infrastructure and agriculture. The Southeast Isolated Wetland Assessment (SEIWA) explored the condition and fate of geographically isolated wetlands (IWs) in an 8-county portion of the coastal plain of North and South Carolina under a grant from the U.S. EPA's Regional Environmental Monitoring and Assessment Program (REMAP). The SEIWA project was conducted by a partnership of wetland scientists and statistician from RTI International (RTI), the North Carolina Center for Geographic Information and Analysis (NC CGIA), the North Carolina Division of Water Quality (NC DWQ), the University of South Carolina (USC), and the South Carolina Department of Health and Environmental Control (SC DEHC). SEIWA employed a phased approach based on three levels of wetland assessment described by EPA (U.S. EPA, 2006): Level 1, which uses geographical information systems (GIS) to identify IWs in the study area; Level 2 to rapidly assess the type and condition of a random sample of the Level 1 sites; and Level 3, detailed assessments to measure the hydrologic, water quality, and habitat functions of selected IW wetland sites.

The SEIWA Level 1 geographical information systems (GIS) approach modeled physical, hydrologic and biological characteristics relevant to the conditions of geographically IWs. The Level 1 method produced polygon datasets that represent the candidate locations of geographically IWs for eight counties along the coast of North and South Carolina. Level 2 field assessments were then done on randomly selected candidate IW sites to determine the accuracy of the maps for depicting wetlands and isolated wetlands, as well as to develop a statistically extensible estimate of the characteristics, condition, and relative level of functioning of the target population. In terms of accuracy, 69% of the candidate IW polygons in the study area were wetlands and 22% were isolated wetlands. These accuracy data, along with field

results from the Level 2 rapid assessments conducted at the randomly sampled IW sites, were used to estimate the number, size, and condition of isolated wetlands in the entire study area. We estimate that there are over 50,000 IWs in the 8-county study area occupying about 30,000 acreas of land, or 2% of the total wetland area. The IWs are mostly forested depressions; we estimate they can hold over 4,000 acre-feet of water in NC, and sequester around 5 million metric tons of carbon in wetland soils. Detailed (Level 3) wetland assessments conducted on two wetland clusters demonstrate assessment methods and techniques and evaluate how IWs in good condition perform in terms of their hydrologic, water quality, and habitat functions in the landscape of the study area.

Problem Statement

It is widely recognized that wetlands provide significant environmental benefits, including assimilation of pollutants, flood water storage, ground water recharge, carbon sequestration, and fish and wildlife habitat. Unfortunately, this recognition has come late. Tiner (1984) and Dahl (1990) estimated that 50% to 55% of the original wetland area in the conterminous United States has been lost since pre-settlement times. This loss has not ceased. In the mid-90's some 15% of current wetlands are estimated to be in a state of transition to other land uses (Moorhead and Cook, 1992). More recent status and trends reports for the United States shows a net gain of wetland acreage although a large portion of that is due to increases in ponds (Dahl. 2006). In addition a more recent study showed that losses of wetlands continue in coastal watersheds of the eastern US (Stedman and Dahl. 2008).

It appears that geographically isolated wetlands[1] can provide the same environmental benefits as wetlands in general, and are particularly vulnerable to losses from urbanization and agriculture precisely because they are geographically isolated and have varying amounts of regulatory protection. However significant gaps in our understanding of key aspects of their occurrence and ecological characteristics make it difficult to manage isolated wetlands in both landscape and regulatory contexts. Although much is known about these systems, recent reviews of the functions and values of isolated wetlands, including those on the U.S. southeastern coastal plain, articulate a clear need for additional research to increase our understanding of these wetlands (e.g., Kirkman et al., 1999; Leibowitz, 2003). This is particularly so in the context of the rapid development and human migration that is transforming the coastal areas of North and South Carolina.

The first requirement for proper assessment of the functions and values of isolated wetlands is a tool to predict their geographic location and extent. Before this project, there was not a dependable method to accurately map isolated wetlands without sending field scientists into the field to perform surveys or requiring that image technicians perform heads-up digitizing from vast archives of aerial photography. Both of these methods would require considerable time and cost for large coastal areas. Existing GIS data and mapping methods also present some challenges to accurately map isolated wetlands for large project areas.

[1] The term "geographically isolated wetland' refers to those wetlands that have no surface connection to downstream waters. This definition is consistent with that used by the US Army Corps of Engineers for the 404 Permitting Program. This is in contrast to other wetlands identified and regulated by the 404 Permit Program as delineated by the US Army Corps of Engineers Wetland Delineation Manual (Environmental Laboratory, 1987).

- Most satellite imagery used in previous land cover classification projects do not have the resolution needed to capture the small areas covered by isolated wetlands.
- High-resolution imagery, such as aerial photography, contains far too much detail to use traditional land cover classification methods. In addition, remotely sensed imagery is often several years old and may be inaccurate especially in areas with significant development.
- Existing wetland coverages, such as the National Wetland Inventory (NWI) or county soil survey maps, are not reliable and accurate for locating isolated wetlands for several reasons: (1) they are dated (in North Carolina, the NWI maps date from the mid-1980's); (2) they are not sensitive enough to detect small scale features; and (3) they do not separately identify wetlands into isolated and non-isolated categories.

Given the benefits of isolated wetlands, a cost-effective mapping tool was needed to predict their geographic location and extent. The output data generated by a mapping tool should be verified against truth data collected in the field.

The southeast coastal plain has many types of isolated wetlands; forested depression isolated wetlands present particular challenges for resource managers and they occur in large numbers, especially on the outer coastal plain. Forested depression isolated wetlands occur in hydrologic sinks that have small watersheds and are generally hydrologically isolated from surface flows. They may be seasonally or permanently ponded, depending on local conditions. Typically there is a shallow groundwater connection to other wetlands and streams (e.g., Pyzoha et al., 2008). These wetlands can be sinks for nutrients; thus, alterations (e.g., ditching) have negative effects on downstream water quality (Amatya et al., 1998; Blann et al., 2009). Adjacent land use has important implications for both diversity and richness of sensitive taxa such as salamanders and frogs (Russell et al., 2002a; Russell et al., 2002b). Adjacent land management activities, even in rural settings, also have measurable effects on hydrology (Sun et al., 2001). Isolated forested depressions are frequently small (Tiner et al., 2002), making them difficult to detect and inventory, as mentioned above. Problems with detection and less scientific attention focused on these problems contribute to greater vulnerability to degradation and destruction.

The combination of these and related issues have led to inconsistent resource protection strategies in both natural resource management and regulatory agencies. SEIWA is a probability based study designed to provide information that can be used to help regulatory agencies identify and locate isolated wetlands, assess their water quality and hydrologic benefits, and make inferences (e.g. projections of the number and extent) to a region of interest. By applying these tools and techniques, regulatory agencies can quantify the benefits of isolated wetlands, determine their current extent and condition, estimate the rate of loss, and better recognize, protect, and manage these valuable resources.

The Level 2 and Level 3 portions of this study were used to help quantify the environmental benefits of isolated wetlands, both on a landscape scale (Levels 1, 2 and 3) and individually (Levels 2 and 3). Few studies have been done on the condition, relative level of functioning, storage and pollution absorption capacity, and hydrological connection of existing isolated wetlands to groundwater and surface water resources in the coastal plain of the Carolinas. This type of information will be valuable for resource management and policy planning in regards to isolated wetlands in the southeast.

Project Description

The SEIWA project (1) estimated the number and spatial extent of isolated wetlands in a selected study area using GIS mapping tools developed for the project and probability based estimators; (2) developed probability design-based estimates and corresponding standard errors of the number and extent of isolated wetlands and the general level of characteristics and condition in the study area; and (3) estimated the assimilative capacity of selected isolated wetlands for key pollutants, hydrologic connectivity, and biotic communities (amphibians, aquatic macroinvertebrates, and plants). Other outputs of this research included statistic and GIS methodologies and data for developing a GIS isolated wetland–predictive mapping tool and a probability sampling design. These project outputs will lead to the more general environmental outcomes of improved knowledge of and management of these isolated wetland resources within the study area, a blueprint for performing similar analyses in other areas, and an extensive GIS dataset that can be used in future isolated wetland protection and management activities in the study area by the participating regulatory agencies (NC DENR and SC DHEC).

The definition for isolated wetland status were based on the concepts and principles established in the Solid Waste Agency of Northern Cook County vs. United States Army Corps of Engineers (SWANCC) legal decision[2], which are vital to federal regulatory approaches to wetlands and are also of concern to both North Carolina and South Carolina as they pursue their own state-based programs to address isolated wetland issues.

Methodologically, SEIWA employed a phased approach that is consistent with the three levels of wetland assessments recently described by the U.S. Environmental Protection Agency (U.S. EPA, 2006a), as illustrated in **Figure 1**. For **Level 1** assessments, we evaluated existing geospatial and remote sensing imagery and developed GIS mapping tool that defined a population frame of candidate polygons likely to contain, be contained within, or intersect isolated wetlands in the SEIWA study area. Using this population frame, we developed a probability sampling design that was used to select a random set of candidate polygons in the study area for the **Level 2** field work. In Level 2, we conducted rapid assessments to collect data to evaluate the accuracy of the initial population frame (mapping tool) and determine the number, extent, relative level of function, condition, storage capacity (volume), and soil carbon pool of the isolated wetlands in the study area. In the **Level 3** field work, we conducted intensive assessments of selected IWs in the study area. Data from Level 3 include the pollutant absorption capacity, biological characteristics, water quality, hydrologic connectivity, and cumulative hydrologic

[2] The term "geographically isolated wetland' are those wetlands that have no surface connection to downstream waters since this definition is consistent with that used by the US Army Corps of Engineers for the 404 Permitting Program. This is in contrast to other wetlands identified and regulated by the 404 Permit Program as delineated by the 1987 US Army Corps of Engineers Wetland Delineation Manual.

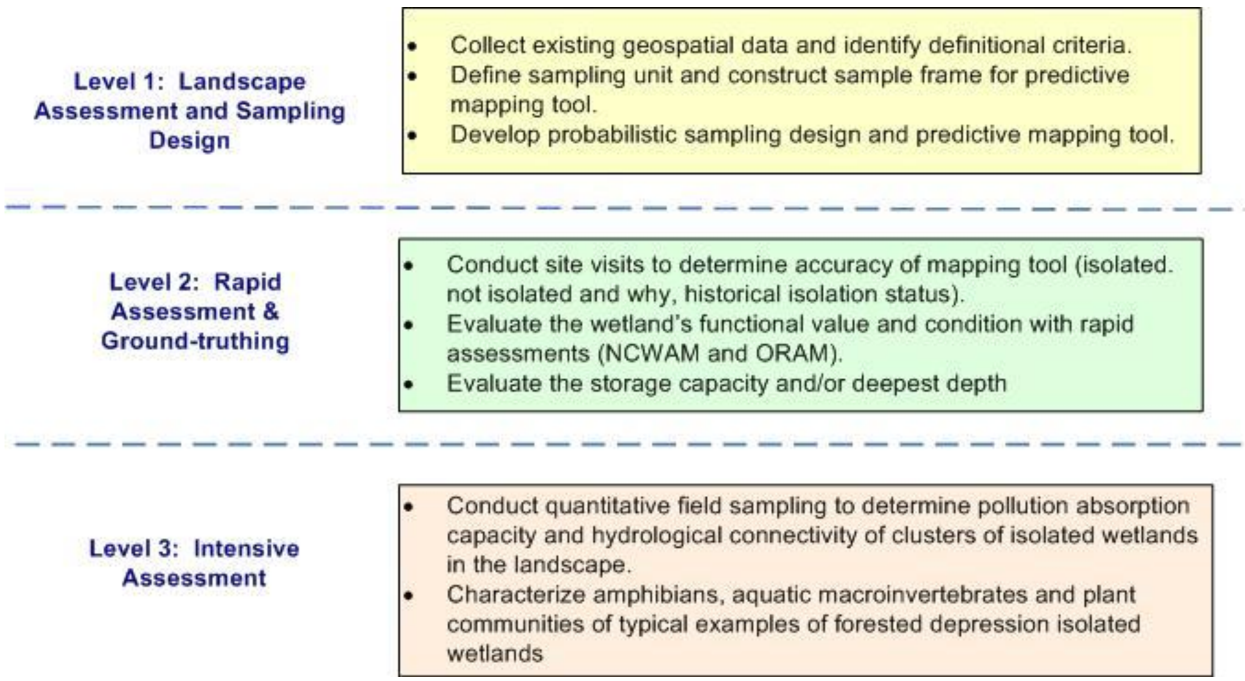

Figure 1. The SEIWA project employed a three-level wetland assessment approach.

effects of isolated wetland clusters, and create an approach and a base dataset that can be built upon through additional Level 3 investigations in the study area.

The Level 1 assessment began by using digital elevation models (DEMs) and a GIS "sink" algorithm to create candidate polygon sinks representing low spots in the landscape that could be isolated wetlands. These polygons were then overlaid with existing hydrography, soils, floodplains, and land use GIS layers to mask (remove) obviously connected features and soils, wetlands, infrared imagery, and land cover layers to score the remaining features as to their likelihood to be isolated wetlands. These candidate isolated wetland polygon were then randomly selected for the Level 2 assessment.

The Level 2 analysis involves field observations of wetland type and condition in NC and SC using the NC Rapid Assessment Method (NC WAM) (NC Wetland Functional Assessment Team, 2008)) and Ohio Rapid Assessment Method (ORAM) (Ohio EPA, 2001)).The NC WAM ratings allowed a relative determination of hydrology, water quality and habitat functions, and evaluate the various stressors that are present in these wetlands. In addition the Level 2 assessment measured the volume of each isolated wetland in the sample and collected, analyzed, and compared soil samples taken from the wetland and from the surrounding uplands.

For the Level 2 field study, producing estimates with a reasonable precision level required a sample size of around 150 randomly selected sites in the two-state study area. For Level 3, 20 sites would be required statistically. Our selected sample size produced statistically valid results for Level 2 of this project, but budget constraints limited the sample size for Level 3 to two clusters of isolated wetlands.

To ensure the success of the intensive fieldwork, the Level 3 sites were selected based on several criteria that include accessibility (landowner permission), security (safety of deployed equipment), and the occurrence of relatively intact isolated wetlands that are typical of the isolated wetland types of interest. Also, the Level 3 sites were selected to contain clusters of isolated wetlands because initial Level 1 and 2 results suggested that many isolated wetlands occur in close proximity to other isolated wetlands, and studying clusters of wetlands offered the opportunity to see how they function in groups in the coastal plain landscape.

In terms of wetland types for the Level 3 study, the SEIWA team considered focusing on the more common IW types observed in Level 2: flats or forested depression isolated wetlands such as cypress or tupelo ponds. Water levels for these features are normally lowest in autumn and highest in early spring. Some are wet all year; while others fill with water, then dry up, depending on the season. Forested depressions (seasonally or semi-permanently flooded forests of depressional features in broad interstream flats) are smaller isolated wetlands, ranging in size from 0.1 to 10 acres. Both of these types of wetlands are classified as "small basin wetlands" by NC WAM but are very distinct wetlands using the "Third Approximation" (Schafele and Weakley 1990).

Level 3 sampling focused on measuring IW hydrologic and water quality responses and measuring the diversity of the IW biotic communities (amphibians, aquatic macro-invertebrates, plants). The limited number of Level 3 locations was used to develop, test, and define a methodology that can be applied to produce reliable estimates in similar studies when appropriate sample size is available. Part of the project team (USC and NC DWQ) has expanded the Level 3 sample size and analyses, including the Level 3 sites, to investigate longer term and geographically broader results than was possible within the SEIWA project.

Study Area

The SEIWA study area is an eight-county coastal and inter-coastal area (approximately 6,500 mi^2) of North and South Carolina (**Figure 2**). This area was selected because: (1) it has known, significant wetland resources, many of which may be presently unidentified isolated wetlands (Tiner et al., 2002; Comer et al., 2005; Dahl, 2000); (2) the issues expected to be encountered and methodologies used in estimating isolated wetlands in this area should be representative of similar issues/methodologies for the larger Region 4 coastal area as well as elsewhere; (3) because the study area includes subregions of both North and South Carolina, the results will be useful to regulatory programs in both states; (4) the study counties encompass a sharp development gradient: coastal counties with significant growth and development pressure and inland counties with little or no growth; and (5) the study area is large enough to contain a significant number of isolated wetlands, yet small and accessible enough to be doable under the project resources and schedule. The area of interest consists of all regions in these eight counties where the SEIWA wetlands specialists anticipated that isolated wetlands exist.

Table 1 provides basic size and demographic data for the eight selected counties, including area, population density, and population change from 2000 to 2009. The NC counties are very similar in size (around 900 square miles) while the SC counties range in size from 405 to 1,134. The eight counties represent a general development gradient from the coast inland. The two coastal counties (Brunswick,

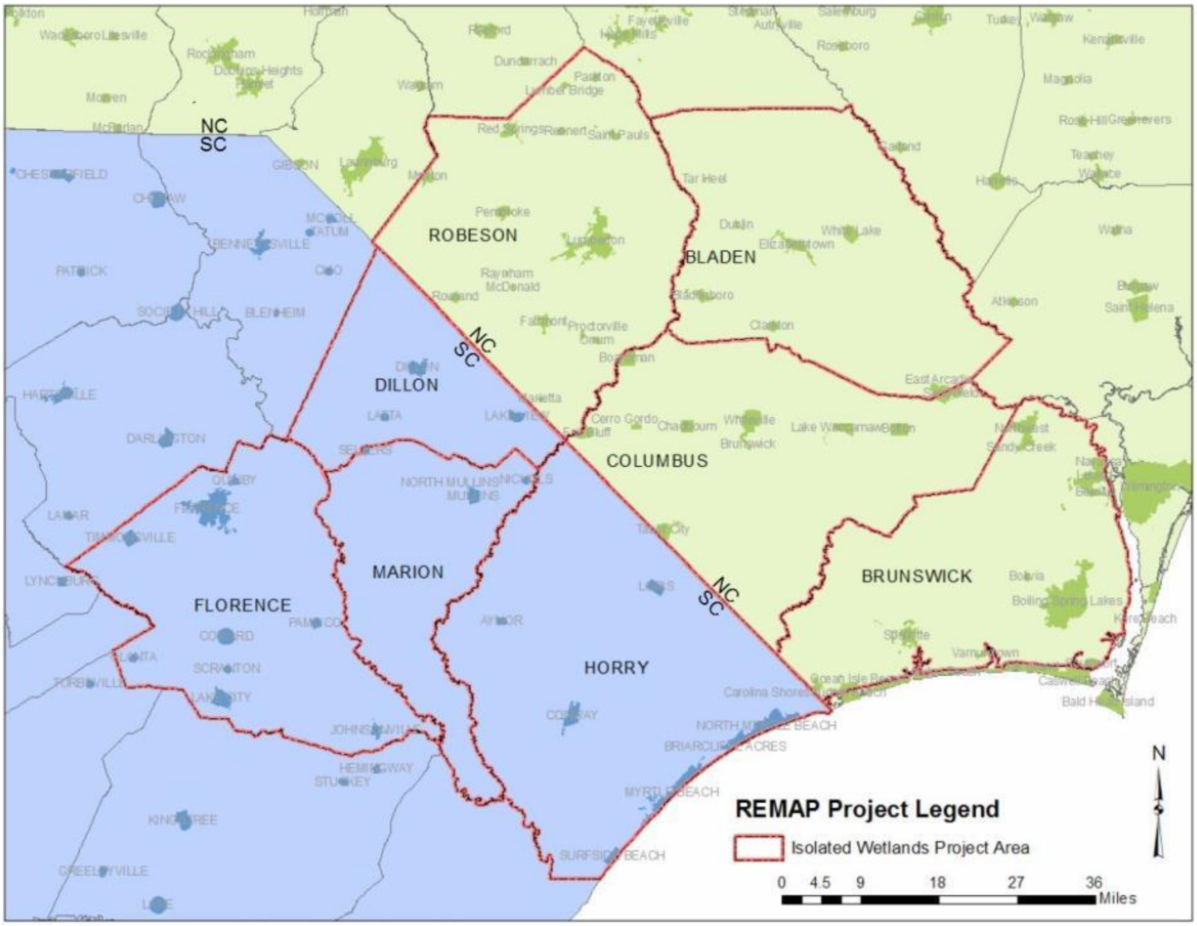

Figure 2. SEIWA study area, showing eight selected counties and population centers.

Table 1. North Carolina and South Carolina Counties Selected for the Southeast Isolated Wetlands Assessment (SEIWA)

County	Area (square miles)	Population (2000)	Population (2009 estimate)	2000 Population Density (per square mile)	2009 Population Density (per square mile)	Percent Change (2000-2009)
North Carolina (165.2 persons per square mile, 16.6% 2000-2009 growth)						
Bladen	874.9	32,280	32,343	37	37	0.2%
Brunswick	854.8	73,107	107,062	86	125	46%
Columbus	936.8	54,751	54,221	58	58	-1.0%
Robeson	948.8	123,241	129,559	130	137	5.1%
South Carolina (133.2 persons per square mile, 13.7% 2000 - 2009 growth)						
Dillon	404.8	30,722	30,912	76	76	0.6%
Florence	799.8	125,761	134,208	157	168	6.7%
Horry	1,133.7	196,660	263,868	174	233	34%
Marion	489.1	35,466	33,468	73	68	-5.6%

Source: U.S. Census State and County Quick Facts (http://quickfacts.census.gov/qfd/index.html; September 2010)

NC, and Horry, SC) have had a very high population growth (46% and 34% respectively), about 2.5 times the state average, which is consistent with the very high rate of coastal development that has occurred over the past decades. The other counties showed small growth (about 1/3 to 1/2 of the state average) only in the counties with population centers (Florence in Florence County and Lumberton in Robeson County). The remaining four rural counties showed no significant growth (Bladen and Dillon) or population loss (Columbus and Marion) over the past decade and have low population densities.

Geologically the SEIWA study area occurs on a feature known as the Cape Fear Arch, an uplifted area of the southeast coastal plain that contains a series of marine terraces with higher elevations as one moves away from the coast. These terraces are composed of marine sediments and limestone that were laid down during former high stands of sea level ranging from Quaternary to Cretaceous in age. The marine terraces have been dissected by river and stream erosion during low sea levels. Within these river valleys alluvial terraces have been formed during subsequent sea level rise in the most recent geologic periods (the Holocene and Pleistocene).

Riggs et al. (2005) observed that historic ditching activities to drain lands for agriculture and forestry have proceeded from the higher (and more easily drained) marine terraces to the lower alluvial terraces, the younger of which have not been drained as extensively as the others. This is significant for isolated wetlands in the study area as ditching has destroyed many wetlands and connected many of the wetland features that would otherwise be isolated.

The basic geomorphic units (GMUs) resulting from the depositional and erosional processes are described in **Appendix A**, moving from lower to higher elevations and generally away from the coast. The marine terrace GMUs are the deposits where most of the isolated wetlands in this study were found, as surface depressions formed mainly by erosional processes during deposition or, in portions of Horry and Brunswick counties, by sinkhole collapse from dissolution of deeper limestone layers. All marine terraces in the area are generally characterized by sandy soils with occasional silts and clays. The alluvial terraces tend to be sands interbedded with silts and clays.

In the Cape Fear Arch region, the surficial Cenozoic alluvial and marine deposits are underlain by Cretaceous aquifers that are used as the primary source of water supply in the area. The uplift along the crest of the Arch (which is aligned to the northwest and centered in the Wilmington, NC, area), has brought these aquifers close enough to the surface that rivers (such as the Waccamaw in Brunswick, Columbus, and Horry counties) have eroded through the overlying Cenozoic system into the Cretaceous aquifers, which discharge groundwater, often at a relatively high pH, into the river systems (Riggs et al., 2005).

As a result, the geologic literature (e.g., Riggs et al., 2005; Harden et al., 2003; Pyzoha et al., 2008) has found that the hydrologic system in the study area (aka “Cape Fear Arch”) is a groundwater dominated system. In other words, because of the flat terrain, permeable (sandy) soil, and the underlying upwelling Cretaceous aquifers, surface water and groundwater are intricately and always linked. For example, in Brunswick County, Harden et al. (2003) found that up to 62 percent of the flow in the Waccamaw River is from groundwater seepage, where the stream is incised into underlying Cretaceous aquifers, or from flows from upland banks on more modern flood plains, and the conceptual hydrologic model developed by Pyhoza et al. (2008) showed strong groundwater/surface water connections in a Carolina Bay wetland in the South Carolina coastal plain. Soil descriptions for the hydric soils that are characteristic of isolated wetlands in the study area are consistent with this hypothesis as they indicate that the hydric soils are formed when the water table rises and stays near the surface during the wet months of the year and creates the saturated conditions needed to form hydric soils. In other words, the isolated wetlands we studied in this project are filled both by rainfall falling directly on the wetlands and the small local watersheds they occupy and by water that infiltrates the surrounding land and raises the water table across the landscape, which in turn wets these depressional wetlands from below. In our Level 3 study sites we have sited lines of piezometers within and between wetlands and the nearest downgradient waterbody so we can measure and quantify this interconnectivity.

Project Objectives

To meet the objectives of this project, the Level 1 GIS/remote sensing data, Level 2 rapid assessment data, and Level 3 wetland intensive monitoring data were developed and applied to answer these key project questions.

1. How accurate are existing geospatial datasets in identifying and delineating U.S. Southeastern Coastal Plain isolated wetlands of varying sizes, wetland types, and in differing landscape matrices, and how can that accuracy be improved using existing high resolution remote sensing datasets derived from LIDAR? What is the accurate extent of the isolated wetland resource, what is its condition, and what are its basic characteristics?
2. What is the rate of destruction or extent of modification for these wetland systems? How many and at what rate have these systems been converted, modified, or destroyed?
3. What is the pollutant absorption capacity of isolated wetlands? What are their sizes, condition and relative level of functioning? What is the hydrologic connectivity and function of clusters of isolated wetlands in the coastal plain landscape?
4. What are the characteristic biotic features (amphibians, aquatic macroinvertebrates, and plant communities) of clusters of forested depression isolated wetlands?
5. What tools can be used by regulators and wetland practitioners to reliably locate and assess isolated wetland resources and protect, preserve, and restore these features so they can provide these ecological functions in the study area and other regions where isolated wetlands are a significant portion of the wetland resource?

This report addresses these questions in three Parts describing methods and results for each phase of the SEIWA project: Part 1 for Level 1 (GIS methods), Part 2 for Level 2 (rapid assessment), and Part 3 for Level 3 (intensive assessment). Part 4 summarizes the methods developed, discusses of the overall results, and describes how the study results and methods can be used by wetland regulators and managers in North and South Carolina.

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Appendix A. Geomorphic Units (GMUs) in the SEIWA Study Area

Holocene GMU (Qh, Recent). Alluvial valley deposits in active floodplains confined to major drainageways and small valleys, overlapping older sediments. Deposits are generally incised into or on top of the Wando or Socastee GMUs and are typically interbedded dark clays and light sands (Owens, 1989). For the most part, the Holocene floodplain deposits have not been drained for forestry or agriculture (Riggs et al., 20095)

Wando GMU (Qwa, late Pleistocene). Alluvial valley deposits in older floodplain deposited during last (Wisconsin) glacial maximum. Deposits generally are incised into or on top of Socastee GMU sediments and represent sediment from a larger river system than today. The Wando deposits for a terrace above the Holocene floodplain in the Waccamaw and Pee Dee river valleys, ranging in height from 3 to 34 m above mean sea level (AMSL) in the Pee Dee basin (Owens, 1989) and 6 to 9 m AMSL in the Waccamaw river basin (Riggs et al., 2005). According to Riggs et al. (2005), areas of the Wando terrace in the Waccamaw basin was ditched and drained for forestry operations in the late 1900's, after those on the Penholoway and Socastee terraces. This drainage and silvculture has destroyed many of the wetlands on the terrace.

Socastee GMU (Qs, late Pleistocene). Largely marine deposits deposited by past high sea level stand(s) during previous late-Pleistocene interglacials. The Socastee occurs primarily as a 30 km wide marine terrace in the outer coastal plain within Horry, Columbus, and Brunswick counties as well as alluvial terraces along the Cape Fear River valley in Bladen County and along the Pee Dee river in Marion, Robeson, and Dillon counties. In the outer coastal plain, the Socastee is characterized by a ridge-and-swale topography that represents the remnants of a barrier island system deposited during interglacial high stands of sea level. The surface of the coastal Socastee ranges from 9 m AMSL in the south and east to around 15 m AMSL in the north and west of its range (Owens, 1989; Riggs et al., 2005). The Socastee is composed of interbedded sands and clays. In the Waccamaw basin, wetlands on the Socastee GMU occur between 9 and 15 meters AMSL. As with the Penholoway GMU, the natural hydrology the Socastee terrace was dominated by sheet flow, with wetlands occurring in depressions and in areas of low permeability clay and humic (peat) soils. The Socastee wetlands were drained for agriculture and forestry after the Penholoway wetlands in the mid-1900's (Riggs, 2005).

Penholoway GMU (Qph, early Pleistocene). The Penholoway GMU is a marine terrace composed of barrier and back-barrier deposits and ranging from 15 to 21 m AMSL in the study area (Owens, 1989; Riggs et al., 2005). As with the Socastee GMU, the Penholoway is primarily composed of back-barrier deposits of interbedded sands and clay, with barrier deposits composed of coarser and cleaner sands. The Penholoway was likely formed during a high interglacial sea level stand during the early Pleistocene. According to Riggs (2005), in the Waccamaw basin wetlands occur in depressions on the surface of the Penholway formation and in areas where low permeability clay and humic (peat) soils impeded rainfall infiltration and originally resulted in sheet flow regime across the terrace. The Penholway wetlands were the first wetlands targeted for serious ditching for agriculture, beginning in the 1920's and continuing into the 1950's. Many of the wetlands were destroyed by the drainage process.

Waccamaw formation (Qw, early Pleistocene). The Wacccmaw is mainly composed of barrier and back-barrier deposit that form the basal (oldest) Pleistocene unit in the Cape Fear/Long Bay region, with maximum height ranging from 21 to 30 m AMSL (Owens, 1989).

Tb-Bear Bluff formation (late Pliocene). Another largely barrier/back-barrier unit, the Bear Bluff comprises the marine terrace between the Suffolk and Mechanicsville scarps at 30.5 and 41 m, respectively. As described by Owens (1989), the Bear Bluff includes all barrier and back-barrier facies between the Pee Dee and Cape Fear Rivers. In the Pee Dee valley, the Bear Bluff includes interfingered fluvial and back-barrier/barrier deposits (Owens, 1989).

Td-Duplin formation (early Pliocene). The highest marine terrace in the study region is the Duplin formation, from the Mechanicsville scarp to the Orangeburg scarp. The elevation of this broad, highly dissected plain ranges between 41 and 67 m AMSL. Fossil evidence and sedimentary facies suggest a continental shelf depositional environment (Owens, 1989).